卒業論文

日立 32 m 電波望遠鏡によるモニター観測データを用いた 12.2 GHz メタノールメーザーの周期変動導出 および 6.7 GHz メタノールメーザーとの比較

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1　導入

1.1　研究背景

大質量星形成領域では、若い大質量原始星の周囲においてメタノールメーザー放射がしばしば観測される。特に 6.7 GHz および 12.2 GHz のクラス II メタノールメーザーは、大質量星形成のごく初期段階を示す有効なトレーサーとして知られている。これらのメーザーは赤外線放射による放射励起を受けており、その強度は中心天体周辺の放射環境や降着活動の変動を敏感に反映する（Menten 1991）。そのため、メーザー強度の時間変動を詳細に追跡することは、若い大質量星の内部構造や連星系の存在、周期的な降着変動などの物理過程を探る上で重要である（Breen, et al. 2012）。

近年、一部のメタノールメーザー天体において周期的な強度変動が報告されており、連星系モデルや周期的な赤外線放射変調との関連が議論されている（Goedhart, et al. 2005）。しかし、周期変動の検出には長期かつ高頻度のモニター観測が不可欠であり、十分な観測データが蓄積されている天体は限られている。また、6.7 GHz と 12.2 GHz の両周波数で同時に周期性を比較した研究例はまだ多くない。

1.2　メーザーと大質量星

メーザー（MASER）とは、Microwave Amplification by Stimulated Emission of Radiation の略称であり、これは「誘導放射によるマイクロ波増幅」を意味する。

通常の熱平衡状態では下の準位の粒子の数の方が多い。ところが、粒子数密度の小さい宇宙空間では上の準位の方により多くの粒子が存在する場合があり、このような状態は**反転分布**と呼ばれる。ある 2 準位間の遷移においてそのような反転分布が起こっているとき、図 1 のようにその準位間のエネルギー差に相当する周波数 ν_{ul} の電波が入射すると、上の準位にある粒子 u が落ちてきて ν_{ul} の電波を誘導放射する。これが連続的に起きることにより、非常に強い放射が見られる。これがメーザー放射の原理である。特に宇宙空間で強いメーザー現象を起こす分子として、水やメタノールが挙げられる。

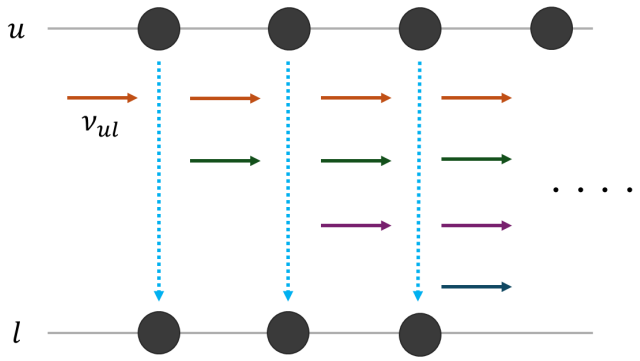


図 1　メーザー放射が起こるときの概略図

大質量星形成領域に見られるメタノールメーザーは、若い星の周囲環境を探る重要な手がかりとなる天体現象である。特に本研究で対象とする 6.7 GHz および 12.2 GHz のメタノールメーザーは、若い大質量星近傍の温かいダストから放射される赤外線によって励起されると考えられており、その発生機構は大質量星形成過

程と強く結びついている。このため、これらのメーザーは若い星の近傍における物理環境や進化段階を探る有効な指標として用いられている。

1.3 先行研究

本研究は平野（2020）を基盤とするものである。平野（2020）では、日立 32m 電波望遠鏡によって 2012 年 12 月 30 日〜2020 年 10 月 2 日に観測された 453 天体の 6.7 GHz メタノールメーザーの観測データに対して周期解析を行うことで長周期変動を示す天体を新たに検出することを目的としていた。

1. L-S Power の最大値が、誤警報確率 $\alpha < 0.0001$ を満たすこと。
2. 条件 1 で導出された周期が、解析期間に 3 周期以上含まれること。

上記の 2 つの条件を満たす天体は周期変動があると定義して周期解析を行った結果、452 天体のうち 196 天体が周期天体であるという結果が得られたと記述されている。その中でも、139 天体がこの解析によって新たに得られた長周期変動天体であると紹介されている。その天体に対して統計をとったところ、周期が 300 日〜400 日に多く分布していることが判明し、それは地球の公転周期 (=365 日) と関係した観測システムに起因した偽の周期である可能性を考慮し、周期が 300 日〜400 日である速度成分をもつ天体を除き、この研究で得られた真の長周期変動天体は 14 天体であると結論付けられた。

1.4 本研究の目的

本研究では、日立 32m 電波望遠鏡による長期モニター観測データを用い、先行研究の解析手法を踏襲して 6.7 GHz および 12.2 GHz メタノールメーザーの周期解析を行い、両周波数の比較を通じて周期変動の物理的解釈の深化を目指す。

まず、各速度成分ごとのライトカーブを作成し、強度変動の全体像を把握する。次に、不均一サンプリングデータに適した Lomb–Scargle 法を用いてピリオドグラムを計算し、有意な周期成分の有無を統計的に評価する。誤警報確率（FAP）を用いて有意性を判定し、さらに検出周期が解析条件（20 日以上 300 日以下）を満たすかを確認することで、周期変動天体を客観的に抽出する。さらに、周期変動が認められた天体については、極大日および極小日におけるスペクトルを比較し、強度変動が全速度成分に共通するのか、特定の成分に限定されるのかを検証する。これにより、変動の空間的・物理的起源について制約を与えることが可能となる。このように、本研究は長期モニター観測データを体系的に解析し、周波数間比較を通じてメタノールメーザー変動の物理的起源を探ることを目的とする。

2　観測・解析

2.1　観測概要

本研究では、日立 32 m 電波望遠鏡で観測している 422 天体を解析の対象とし、2023 年 2 月 26 日〜2025 年 9 月 16 日の 933 日間に行われた観測コード M23057S〜M25259S のデータを使用するものとする。6.7 GHz および 12.2 GHz メタノールメーザーでは観測開始時期がそれぞれ 異なるため、本研究における解析対象データは 6.7 GHz と 12.2 GHz で同じ期間になるようにした。したがって、本研究における解析対象データの観測期間は、開始日、終了日ともに先行研究とは異なっている。

観測諸元を表 1 に示す。

表 1　観測諸元

	6.7 GHz メタノールメーザー	12.2 GHz メタノールメーザー
観測周波数	6664 – 6672 MHz	12170 – 12186 MHz
積分時間	5 min	5 min
分光点数	8192 ch	8192 ch
速度分解能	0.044 km/s	0.048 km/s
3 σ ノイズレベル	〜0.9 Jy	〜1.0 Jy

2.2　解析手法

- Lomb-Scargle 法
  - **Lomb-Scargle 法**とは、不均一間隔サンプリングデータに対する離散フーリエ解析の拡張として提案された周期解析手法である。
  - 通常のフーリエ変換は等間隔データを前提とするが、天文学における観測データは天候や装置状況などの影響により不規則な時間間隔で取得されることが多く、日立 32 m 電波望遠鏡によるモニター観測もそのようなデータになる。Lomb-Scargle 法はこのような不均一間隔の観測データに対しても周期成分を適切に抽出できる点に特徴があり、天体の周期探索に広く用いられている。
  - 観測時刻 t_i における観測値 x_i に対し、角周波数 ω における正規化パワー $P(\omega)$ は次式で与えられる。

$$P(\omega) = \frac{1}{2}\left[\frac{\left(\sum_i x_i \cos\omega(t_i-\tau)\right)^2}{\sum_i \cos^2\omega(t_i-\tau)} + \frac{\left(\sum_i x_i \sin\omega(t_i-\tau)\right)^2}{\sum_i \sin^2\omega(t_i-\tau)}\right] \tag{1}$$

    この (1) 式を **Lomb–Scargle ピリオドグラム**という。ここで、τ は位相のずれを補正するための時間オフセットであり、

$$\tan(2\omega\tau) = \frac{\sum_i \sin 2\omega t_i}{\sum_i \cos 2\omega t_i} \tag{2}$$

    で定義される。
  - Lomb-Scargle ピリオドグラムからは、観測データに含まれる周期成分の有無およびその周期候補を読み取ることができる。ピリオドグラムにおけるピークは、対応する周期において変動成分が強いことを示している。

  - 本研究では各速度成分ごとのフラックス密度の時間変動（ライトカーブ）に対して Lomb-Scargle 解析を実施し、得られたパワースペクトルから周期候補を抽出した。

- 誤警報確率
  - Lomb-Scargle ピリオドグラムにおいて得られるピークが統計的に有意であるかを判断するため、**誤警報確率（False Alarm Probability : FAP）**が一般的に用いられる。
  - FAP とは、実際には周期成分が存在しないにもかかわらず、ノイズのゆらぎによって偶然ピークが生じる確率を表す指標である。FAP が小さいほどそのピークが偶然によるものである可能性は低く、周期成分が統計的に有意であると判断できる。
  - 先行研究では FAP = 0.01 % が用いられたが、本研究では誤検出を極力抑えるために FAP = 0.001 % を有意水準として採用した。すなわち、ピークが偶然に生じる確率が 0.001 % 以下である場合のみを有意な周期候補とした。この厳しい基準を設けることで、多数の周波数領域を探索する際に生じうる偶然ピークの影響を最小限に抑えた。
- スペクトル
  - 本研究では、ライトカーブから求めた極大日および極小日に対応するスペクトルを重ね合わせて比較した。
  - これにより、時間変動がスペクトルのどの速度成分に対応しているかを明らかにした。極大日と極小日のスペクトル差を調べることで、変動が特定の速度成分に限定されるのか、あるいは全体的な増減であるのかを判別することができる。

解析の流れは以下の通りである。

1. 全天体に対してライトカーブを作成
2. 全天体に対して周期解析 (Lomb-Scargle 法) を行い、ピリオドグラムを作成
3. 全天体に対してスペクトルを作成
4. 条件に合う周期天体を選出

以下のような条件を設定し、全天体を a,b,c の 3 種類に分類した。

a. 周期性のある天体
   (1) 1 つ以上の速度成分で LS-Power の最大値が誤警報確率 FAP(0.001 %) を超えている
   (2) (1) を満たす速度成分において、周期が 20 日以上 300 日以下である
b. 周期性のない天体
   - a,c 以外
c. メーザー放射が検出されなかった天体
   - 全ての速度成分で 3 σ 以上のメーザー放射が確認できない

周期の範囲に関して、波の形を sin 関数で再現するにあたって最低でも 1 周期に観測日が 4 回必要である。今回扱う天体の多くが 5 日に 1 回観測されているため、5 日× 4 = 20 日を下限とした。また、周期の信頼性を確保するためには、解析対象期間内に少なくとも 3 周期以上が含まれる必要がある。本研究の観測期間は 933 日であるため、933 日÷ 3 = 311 日となる。したがって、十分な周期数を確保できる範囲として、上限を 300 日に設定した。

先行研究では、ノイズレベル以下の観測点も含めて周期解析が行われていた。本研究では、周期解析の信頼

性向上を目的として、ノイズレベル未満のデータ点を除外したうえで Lomb-Scargle 解析を実施した。

ライトカーブにおける観測期間内で最大および最小のフラックス密度を示す日をそれぞれ極大日、極小日と定義した。これらの日のスペクトルを抽出し、同一図上に重ねて比較することで、時間変動に伴う強度およびスペクトル形状の変化を評価した。

3　結果

3.1　天体の分類

周期解析を行った結果は以下の表 2 の通りであり、周波数ごとの周期変動天体数および検出状況の違いを示している。

表 2　両メーザーの周期性

	a（周期性あり）	b（周期性なし）	c（メーザー検出なし）
6.7 GHz	141	281	0
12.2 GHz	82	282	58

6.7 GHz では全天体でメーザー放射が検出されたのに対し、12.2 GHz では一部天体でメーザー放射が検出されなかった。また、周期性ありに分類された割合は 6.7 GHz では 33.4 % であったのに対し、12.2 GHz では全天体の 19.4 % であった。

次に、両メーザーで周期性があった天体の周期を表 3 で比較する。6.7 GHz メタノールメーザーの周期を P_6、12.2 GHz メタノールメーザーの周期を P_{12} と表記することにする。

表 3　両メーザーの周期の比較

天体名	P_6	P_{12}
0.315-02	31.7	300
0.409-05	61.4	44.9
0.546-08	23.5	128.8
5.900-04	71.3	31.9
6.189-03	185.1	53.7
6.795-02	182.3	93.1
7.632-01	72.6	31.2
9.621+01	25.7	53.2
10.20-03	56.9	31.5
10.28-01	182.2	39.9
10.32-02	38.3	25.7
10.32-01	21.5	26
11.49-14	296.2	128.7
11.904-0	300	300
12.02-00	24.3	35.3
12.20-01	192	45.1
12.62-00	81	215.7
12.68-01	227.8	23
12.88+04	23.9	127.8
12.90-02	116.1	25.3
14.23-05	76.5	40.8
19.36-00	117.6	53.1
19.47+01	300	243.2
19.75-01	22	54.3
20.24+00	150.8	26.4
22.43-01	111.9	73.9
23.19-03	119	21.9
23.39+0B	300	30
24.14+00	184	180.6
24.33+01	23.7	225.9
24.64-03	47.5	76.2
24.93+00	300	75
25.27-04	36.2	32.1
25.65+10	24.3	27.4
28.28-0B	248.7	20.4
30.20-01	36.2	38.2
30.30+00	79.8	27.6
30.76-00	36.3	50.9
32.11+00	26.4	31.1
33.09-00	29.1	58.6
33.40+00	31.4	127.4
33.64-02	24.2	69.8
34.20-06	247.4	234.9
34.24+01	75.6	33.9
35.20-17	300	236.5
35.79-01	33.1	35.9
36.84-00	123	300
37.40+15	21.7	32.5
37.47-01	47.7	191
38.26-02	45.1	49.2
39.10+04	94.9	27.3
40.28-02	73.1	45.7
43.15+00	34.4	36.2
43.17-00	300	21.1
49.03-10	230.2	76.3
49.41+03	28.2	22.5
49.49-03	21.2	45.6
52.20+07	261.2	45.2
52.66-10	239.7	142.7
59.78+00	31	44.6
69.52-09	300	40.3
85.40-00	300	25.9
174.1-00	26	32
183.3-05	66.4	24.7
188.9+08	25.2	75.8
192.6-00	285.3	28.2
196.4-16	300	59.6
209.0-19	112.1	112.9
213.7-12	300	300
358.9-0B	142.8	21.6
359.6-02	300	23
G351.2+0	23.8	61.7
IRS22198	32.2	21.4

ここで、6.7 GHz と 12.2 GHz で周期が異なる天体が多いことに着目したい。

各周波数で独立に LS power 最大の速度成分を選択すると、異なる速度成分を比較してしまう可能性がある。同一天体であっても速度成分ごとに空間的位置や物理条件が異なるため、その場合に得られる周期の差は周波数依存性によるものか、速度成分によるものかを区別できない。そこで、各周波数で最も LS-Power が大きい周期を比較するのではなく、同一速度成分における周期を対応づけて比較する手法を試してみた。

2.2 で示した分類条件で周期性ありと判断された天体 (a) において、6.7 GHz および 12.2 GHz それぞれの LS 解析結果から両周波数で共通して検出される速度成分を抽出（速度の一致判定は ± 0.10 km/s 以内とした）し、それぞれの周波数で 20–300 日の範囲において LS-power が最大となる周期を採用した。その結果を以下の表 4 に示す。

v_6 と v_{12} はそれぞれ 6.7 GHz と 12.2 GHz における速度成分を表している。

表 4　速度成分ごとの周期

天体名	v_6	P_6	v_{12}	P_{12}
0.315-02	18.24	253.8	18.20	300.0
0.315-02	19.55	300.0	19.63	70.3
0.546-08	18.30	300.0	18.39	285.1
0.546-08	18.85	300.0	18.78	55.0
5.900-04	0.65	71.3	0.60	31.9
6.189-03	-34.08	178.7	-34.02	31.0
6.189-03	-30.14	186.6	-30.16	53.7
6.795-02	15.47	230.1	15.47	89.8
6.795-02	15.75	233.5	15.70	232.4
6.795-02	16.23	223.4	16.15	108.2
6.795-02	26.86	300.0	26.92	93.1
7.632-01	149.66	167.7	149.69	31.2
7.632-01	156.91	193.6	156.91	92.8
7.632-01	158.10	192.0	158.08	55.5
9.621+01	-3.13	300.0	-3.14	239.8
9.621+01	-1.83	241.0	-1.85	244.7
9.621+01	-0.83	116.4	-0.84	261.3
9.621+01	0.39	234.9	0.39	23.0
9.621+01	1.32	231.4	1.41	246.1
9.621+01	2.50	231.4	2.43	121.8
9.621+01	4.16	229.1	4.24	300.0
9.621+01	5.39	116.7	5.44	53.2
10.20-03	1.40	61.0	1.42	31.5
10.32-01	5.00	300.0	4.95	21.5
10.32-01	6.29	300.0	6.30	35.0
10.32-01	8.43	300.0	8.34	23.3
10.32-01	10.14	222.4	10.21	300.0
10.32-02	36.31	115.8	36.37	175.4
10.32-02	39.13	117.0	39.09	25.7
11.49-14	5.54	258.3	5.50	147.3
11.49-14	6.61	280.1	6.60	32.3
11.49-14	7.44	275.1	7.35	20.4
11.49-14	7.65	65.5	7.73	84.0
11.49-14	8.33	296.2	8.34	248.0
11.49-14	9.34	23.3	9.39	113.6
11.49-14	13.24	278.4	13.26	128.7
11.49-14	13.72	259.7	13.71	267.8
11.49-14	13.83	267.2	13.88	231.5
11.49-14	14.58	242.1	14.63	194.4
11.49-14	16.06	244.7	16.00	32.1
11.904-0	42.91	255.4	42.92	300.0
11.904-0	43.21	300.0	43.26	300.0
11.904-0	43.84	300.0	43.83	130.7
12.02-00	106.25	27.8	106.23	144.3
12.02-00	110.08	170.4	110.07	35.3
12.02-00	110.59	248.7	110.60	91.6
12.02-00	111.81	285.3	111.85	84.1
12.02-00	112.75	99.8	112.76	49.5
12.20-01	20.39	27.8	20.45	45.1
12.62-00	21.45	237.1	21.36	74.9
12.62-00	24.87	300.0	24.79	215.7
12.68-01	57.56	213.2	57.51	30.3
12.68-01	59.06	226.7	59.14	23.0
12.88+04	38.23	29.2	38.26	127.8
12.88+04	39.27	29.2	39.35	29.2
12.90-02	38.66	116.1	38.75	21.1
12.90-02	39.31	116.9	39.30	25.3
14.23-05	23.92	44.4	23.91	40.8
19.36-00	29.62	118.2	29.72	53.1
19.75-01	116.27	300.0	116.25	54.3
19.75-01	122.91	22.0	122.94	24.1
20.24+00	73.20	298.1	73.16	26.4
22.43-01	27.55	294.2	27.54	249.2
22.43-01	29.56	227.4	29.59	73.9
23.19-03	80.83	116.0	80.92	42.2
23.19-03	81.72	117.4	81.79	133.0
23.19-03	82.86	116.8	82.83	21.9
23.39+0B	75.23	233.5	75.30	30.0
23.39+0B	75.96	300.0	75.96	39.7
24.14+00	17.53	189.3	17.50	175.7
24.14+00	17.72	200.0	17.73	180.6
24.33+01	109.65	93.1	109.67	225.9

天体名	v_6	P_6	v_{12}	P_{12}
24.64-03	35.64	300.0	35.56	76.2
24.64-03	50.77	47.5	50.75	82.3
24.93+00	45.76	194.8	45.71	75.0
25.27-04	65.72	211.5	65.79	32.1
25.65+10	40.38	141.5	40.39	27.4
25.65+10	42.59	162.7	42.61	29.1
25.65+10	43.53	24.3	43.55	142.7
28.28-0B	41.47	248.7	41.45	20.1
28.28-0B	42.82	50.4	42.85	33.9
28.28-0B	79.87	150.0	79.85	101.7
28.28-0B	92.72	163.8	92.70	63.2
30.20-01	104.73	261.1	104.66	38.2
30.20-01	108.21	300.0	108.30	49.9
30.20-01	109.62	113.2	109.57	26.6
30.20-01	110.27	116.3	110.23	300.0
30.20-01	112.73	280.1	112.77	131.5
30.20-01	113.23	137.4	113.14	130.8
30.30+00	33.68	29.1	33.64	42.5
30.30+00	34.08	300.0	34.01	39.3
30.30+00	34.46	122.8	34.48	27.6
30.30+00	35.65	300.0	35.67	28.6
30.30+00	36.19	114.6	36.19	248.5
30.30+00	36.39	113.5	36.43	78.5
30.76-00	91.45	300.0	91.36	50.9
33.09-00	71.69	52.7	71.72	58.6
33.09-00	101.30	135.3	101.26	21.6
33.40+00	97.83	31.6	97.91	295.9
33.40+00	105.72	31.5	105.73	127.4
33.64-02	57.06	24.2	57.02	20.1
33.64-02	59.30	300.0	59.29	71.2
33.64-02	59.59	151.6	59.62	68.8
33.64-02	60.30	300.0	60.26	146.8
33.64-02	61.02	122.8	60.99	89.1
34.24+01	57.63	300.0	57.71	153.6
34.24+01	57.92	300.0	57.92	189.0

天体名	v_6	P_6	v_{12}	P_{12}
35.20-17	44.83	300.0	44.92	236.5
35.20-17	45.30	300.0	45.27	91.1
35.79-01	60.86	33.0	60.92	33.1
36.84-00	54.75	20.8	54.77	300.0
37.40+15	41.31	300.0	41.30	300.0
37.40+15	46.18	31.9	46.14	32.5
37.40+15	49.33	21.7	49.36	152.9
37.47-01	56.86	183.9	56.85	191.0
37.47-01	61.30	69.4	61.25	20.4
37.47-01	61.67	187.7	61.68	68.8
37.47-01	62.01	68.8	62.00	80.1
37.47-01	62.59	193.2	62.58	34.9
38.26-02	79.92	31.4	79.83	49.2
39.10+04	12.40	49.6	12.45	24.6
39.10+04	14.43	59.6	14.37	23.4
39.10+04	15.76	176.2	15.74	169.3
39.10+04	24.86	176.9	24.86	53.3
39.10+04	25.68	69.5	25.70	34.7
39.10+04	26.17	21.2	26.20	51.7
39.10+04	26.80	43.2	26.81	27.3
39.10+04	28.73	300.0	28.73	28.6
39.10+04	29.48	253.7	29.50	58.3
40.28-02	71.03	189.1	70.97	45.7
40.28-02	73.31	187.5	73.24	222.9
40.28-02	74.08	184.5	74.02	27.5
40.28-02	74.45	181.6	74.47	26.4
40.28-02	74.78	184.5	74.76	119.6
40.28-02	77.86	188.3	77.84	20.5
40.28-02	78.81	112.1	78.84	86.5
40.28-02	79.71	300.0	79.62	300.0
40.28-02	80.03	232.0	80.06	38.7
43.15+00	-1.06	22.0	-1.04	82.1
43.15+00	-0.63	91.6	-0.61	36.2
43.15+00	8.37	300.0	8.37	34.9
43.15+00	13.55	300.0	13.64	176.5

天体名	v_6	P_6	v_{12}	P_{12}
43.15+00	14.02	237.2	14.03	60.3
43.15+00	19.01	300.0	19.01	177.6
43.15+00	19.60	300.0	19.59	36.2
43.15+00	20.35	300.0	20.40	43.6
43.15+00	21.48	300.0	21.41	21.2
43.15+00	21.94	300.0	21.96	64.1
43.17-00	-1.05	118.1	-0.96	21.6
43.17-00	13.56	300.0	13.66	60.3
43.17-00	14.01	122.5	14.02	29.1
43.17-00	17.59	121.2	17.50	21.1
43.17-00	20.34	300.0	20.37	29.7
43.17-00	21.33	300.0	21.31	29.7
43.17-00	21.50	23.7	21.50	127.3
43.17-00	21.93	300.0	21.92	215.1
49.03-10	35.64	270.2	35.59	76.3
49.41+03	-10.87	115.9	-10.90	22.5
49.49-03	56.23	177.3	56.20	196.3
52.20+07	3.24	261.2	3.31	45.2
52.20+07	3.72	32.0	3.70	28.5
52.66-10	63.21	239.7	63.20	58.7
52.66-10	65.15	243.5	65.21	252.4
52.66-10	65.82	239.7	65.82	126.4
52.66-10	66.56	252.7	66.59	48.0
52.66-10	68.11	26.7	68.10	30.0
59.78+00	17.11	234.5	17.06	44.6
59.78+00	27.10	300.0	27.03	300.0
69.52-09	0.03	237.3	-0.01	54.5
69.52-09	1.18	300.0	1.12	40.3
69.52-09	1.36	78.8	1.45	59.1
69.52-09	2.34	24.5	2.35	45.5
85.40-00	-32.93	300.0	-32.95	33.4
85.40-00	-30.68	300.0	-30.76	142.7
85.40-00	-30.36	300.0	-30.35	25.9
85.40-00	-28.55	300.0	-28.55	38.6
174.1-00	0.37	26.0	0.37	37.4
174.1-00	3.81	300.0	3.82	42.8

天体名	v_6	P_6	v_{12}	P_{12}
174.1-00	4.57	300.0	4.53	57.4
183.3-05	-15.18	66.4	-15.21	41.5
183.3-05	-14.60	66.4	-14.54	24.7
183.3-05	-4.85	300.0	-4.80	53.1
188.9+08	-3.74	283.4	-3.75	75.8
188.9+08	9.69	116.3	9.73	244.4
188.9+08	10.51	116.3	10.51	300.0
192.6-00	0.42	24.8	0.40	21.6
192.6-00	1.13	22.9	1.13	189.4
192.6-00	2.30	225.3	2.34	43.3
192.6-00	3.39	236.9	3.42	47.9
192.6-00	3.97	300.0	3.91	166.7
192.6-00	4.77	228.7	4.82	155.5
192.6-00	5.45	227.6	5.46	164.4
192.6-00	5.88	159.3	5.87	169.8
196.4-16	14.71	159.4	14.62	59.6
196.4-16	15.15	300.0	15.14	181.4
213.7-12	12.88	300.0	12.98	300.0
213.7-12	13.06	300.0	13.08	300.0
358.9-0B	-21.21	251.4	-21.20	40.5
358.9-0B	-19.83	70.3	-19.84	24.1
358.9-0B	-18.64	300.0	-18.65	37.8
358.9-0B	-15.96	142.8	-15.90	26.9
359.6-02	22.85	300.0	22.82	238.2
359.6-02	24.62	300.0	24.62	51.0
G351.2+0	-10.40	300.0	-10.43	61.7
IRS22198	-16.07	110.1	-16.05	159.5
IRS22198	-15.50	26.4	-15.50	39.8
IRS22198	-9.18	34.1	-9.19	219.7
IRS22198	-8.51	34.0	-8.48	20.3
IRS22198	-7.30	34.2	-7.29	48.6

表 4 をもとに、縦軸が P_{12}、横軸が P_6 の散布図（図 2）を作成した。図 2 の直線は $P_6 = P_{12}$ を示す。

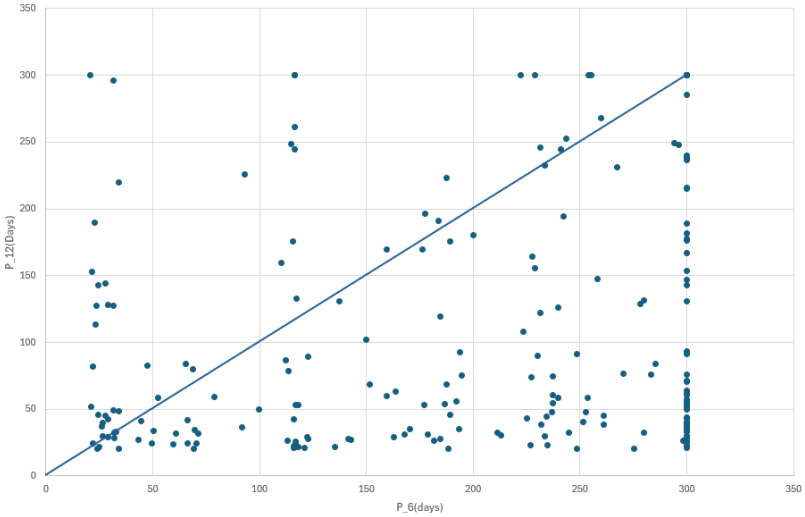


図 2　同一速度成分における周期の比較

この図と表から、

- $P_6 = P_{12}$ の線上に観測点が密集しているわけでははく、同一速度成分においても 6.7 GHz と 12.2 GHz の周期が一致しない例が多数見られることがわかる。
- 一方で、一部の天体・速度成分では両周波数でほぼ同一の周期が検出された（例：6.795-02 の v_6 で 233.5 日、v_{12} で 232.4 日）。
- 約 2 倍の差がある速度成分がみられ、倍周期を示している可能性がある（例：5.900-04 の v_6 で 71.3 日、v_{12} で 31.9 日）。

などの違いが読み取れる。

3.2　代表天体の詳細解析

ここからは前節での結果を踏まえ、代表的な天体を取り上げ、ライトカーブ・ピリオドグラム・スペクトルを用いて個別に詳細な解析を行う。これにより、周期変動の具体的な特徴や速度成分ごとの変動特性を明らかにする。

- 両遷移で a（周期性あり）： **IRS22198**
  - 両遷移において対応する速度成分が存在したが、同一速度成分においても導出された周期は一致しなかった。
  - 特に 6.7 GHz では複数の速度成分で約 34 日の周期が一貫して検出された一方、12.2 GHz では速度成分ごとに異なる周期が検出された。

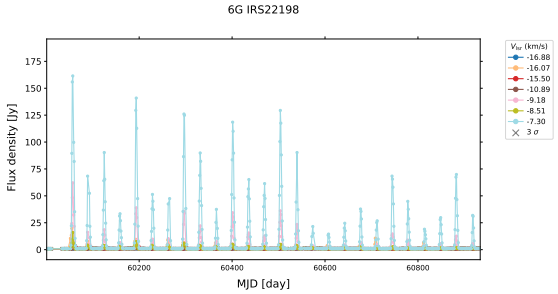


図 3　6.7 GHz における IRS22198 のライトカーブ

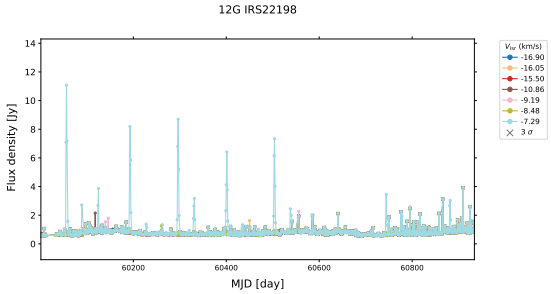


図 4　12.2 GHz における IRS22198 のライトカーブ

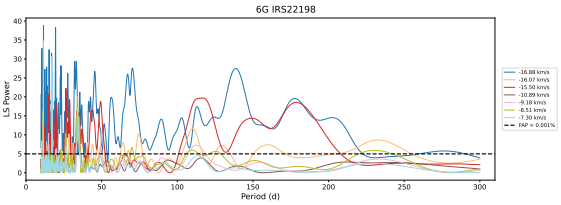


図 5　6.7 GHz における IRS22198 のピリオドグラム

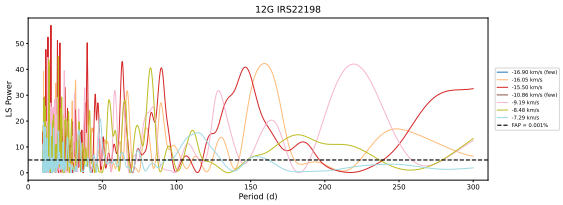


図 6　12.2 GHz における IRS22198 のピリオドグラム

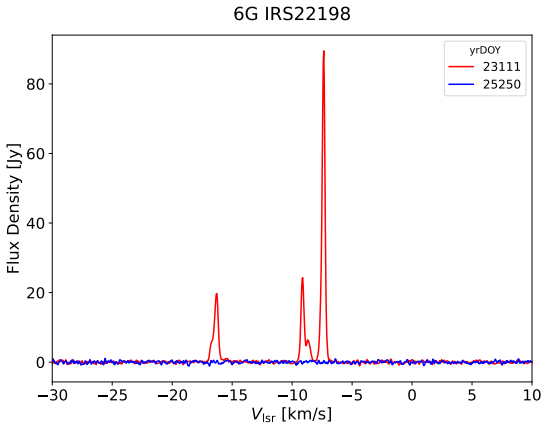


図 7　6.7 GHz における IRS22198 のスペクトル

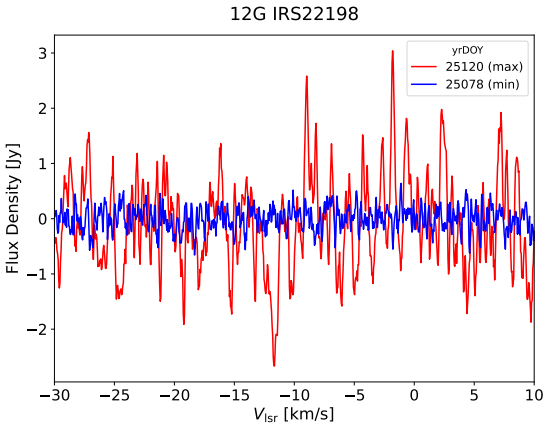


図 8　12.2 GHz における IRS22198 のスペクトル

- 両遷移で b（周期性なし） ： **35.20-07**
  - 観測点数は十分にあるが、最大の LS-Power が低く、有意な周期が出なかったと考えられる。



図 9　6.7 GHz における 35.20-07 のライトカーブ

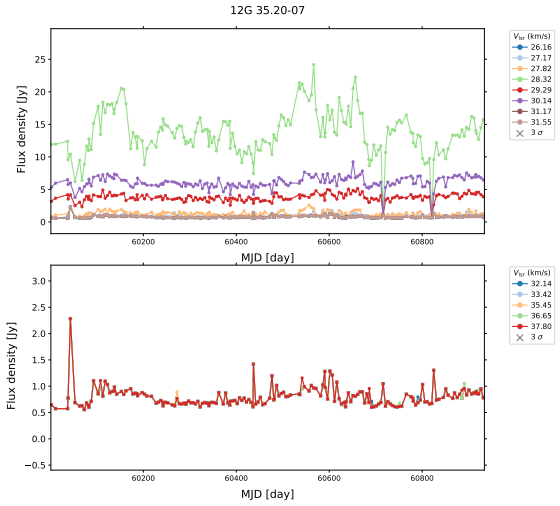


図 10　12.2 GHz における 35.20-07 のライトカーブ

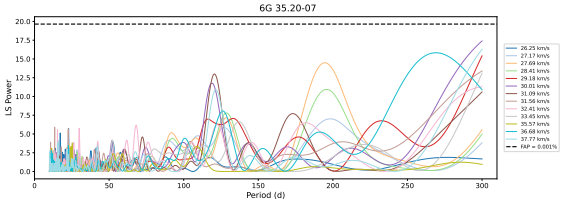


図 11　6.7 GHz における 35.20-07 のピリオドグラム

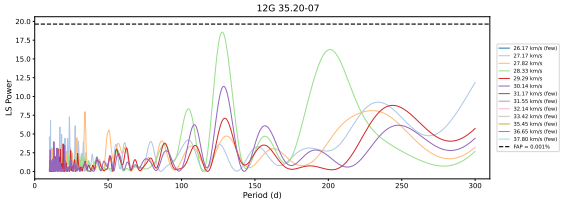


図 12　12.2 GHz における 35.20-07 のピリオドグラム

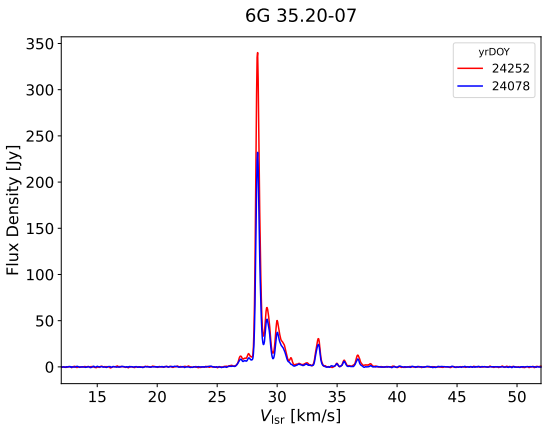


図 13　6.7 GHz における 35.20-07 のスペクトル

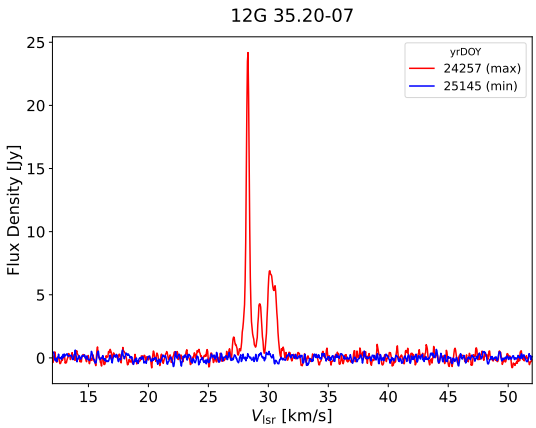


図 14　12.2 GHz における 35.20-07 のスペクトル

- 6.7 GHz では a（周期性あり）、12.2 GHz では b（周期性なし）： **25.82 – 01**
  - 6.7 GHz では周期が 100 日〜250 日帯に集中しており、複数の速度成分で似た周期スケールが示されている。
  - 12 GHz では約 170 個という十分なデータ点数があり観測不足の可能性が低いものの、LS-Power が 10 前後であり一貫した周期構造が見られない

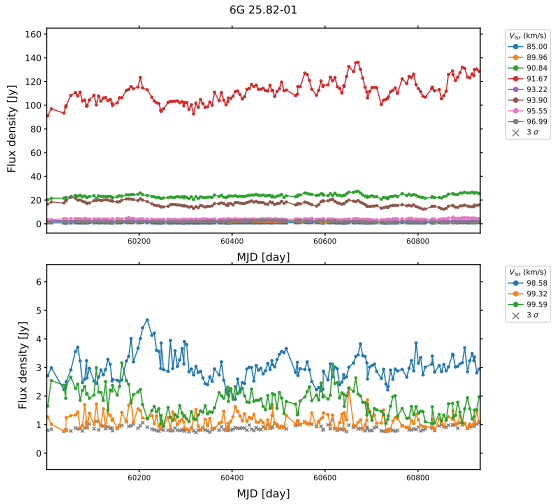


図 15　6.7 GHz における 25.82-01 のライトカーブ

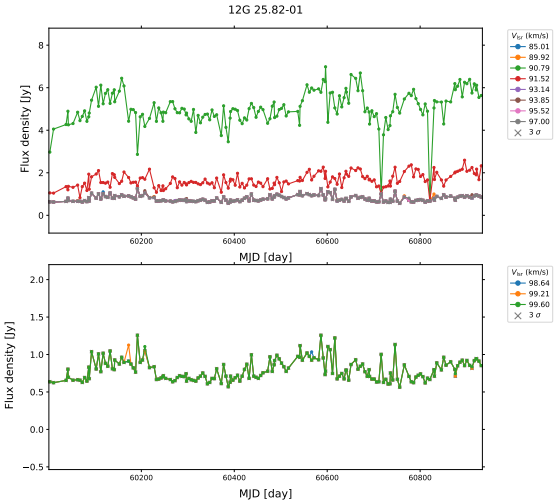


図 16　12.2 GHz における 25.82-01 のライトカーブ

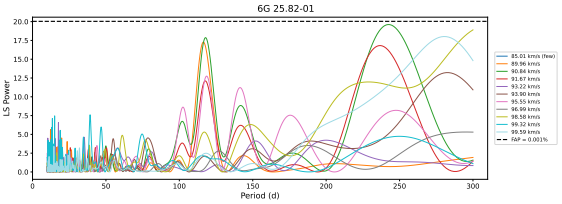


図 17　6.7 GHz における 25.82-01 のピリオドグラム

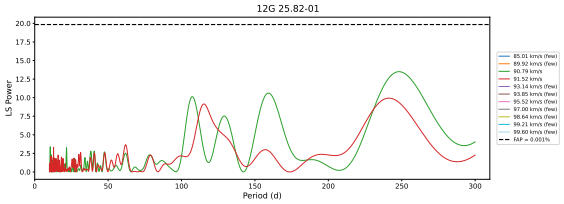


図 18　12.2 GHz における 25.82-01 のピリオドグラム

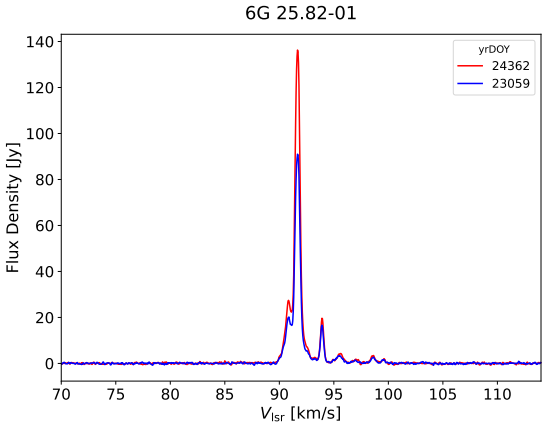


図 19　6.7 GHz における 25.82-01 のスペクトル

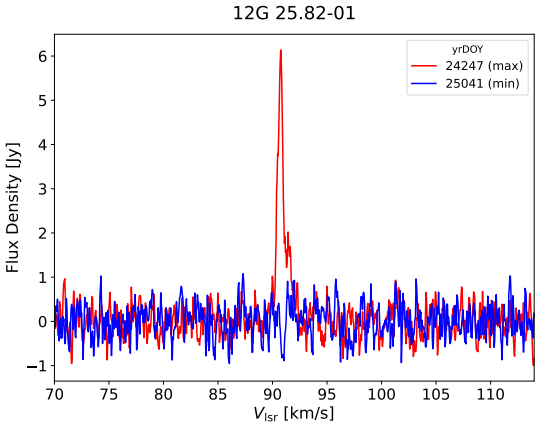


図 20　12.2 GHz における 25.82-01 のスペクトル

4　考察

本研究では、6.7 GHz および 12.2 GHz メタノールメーザーの長期モニター観測データに対し Lomb–Scargle 解析を適用し、周期性の有無を分類した。その結果、(1) 両周波数で周期が検出される天体、(2) 両周波数で周期が検出されない天体、(3) 6.7 GHz のみ周期が検出される天体、など複数のタイプが存在することが明らかとなった。特に、同一速度成分で比較しても周期が一致しない例が多く見られたことは重要である。これは、単なる速度成分の違いではなく、遷移依存の変動応答の差を示唆している。

4.1　6.7 GHz と 12.2 GHz メタノールメーザーにおける周期性の違い

本研究では、6.7 GHz と 12.2 GHz の間で周期性検出率に有意な差が見られた。6.7 GHz では 103/422（約 24.4 %）に周期性が検出されたのに対し、12.2 GHz では 24/422（約 5.7 %、検出天体に対しても約 16.3 %）と低率であった。この差の原因として少なくとも二つの可能性が考えられる。

第一に、観測的要因である。12.2 GHz メタノールメーザーは一般に 6.7 GHz に比べて強度が弱く、検出感度の影響を受けやすいことが知られている。Cragg,Sobolev,& Godfrey,（2005）による励起計算では、12.2 GHz 遷移はより限定された物理条件下でのみ強く励起されることが示されており、その結果実際の観測でも 6.7 GHz に比べ検出天体数が少ない（Breen, et al. 2012）。したがって、12.2 GHz に周期変動が存在していても、S/N 比が十分でない場合には LS 解析で有意なピークとして検出されない可能性がある。この点は、積分時間を延ばし感度を向上させた観測により検証可能である。

第二に、物理的要因である。6.7 GHz と 12.2 GHz はいずれも Class II メタノールメーザーであり赤外放射ポンピングにより励起される（Menten 1991）。しかし、両遷移は必ずしも同一の空間領域・物理条件をトレースするとは限らない。6.7 GHz は比較的広い温度・密度条件で励起される一方、12.2 GHz はより高密度・高温の狭い条件を必要とする（Cragg, Sobolev,& Godfrey 2005）。高分解能観測では、両遷移が空間的に近接しつつも完全には一致しないことが報告されている（Minier, Booth, & Conway 2000）。したがって、中心星の放射変調が存在しても、6.7 GHz は広域的に応答しやすいのに対し、12.2 GHz は局所的条件に依存し、周期的応答が弱まる可能性がある。本研究で同一速度成分においても周期が一致しない例が多く見られたことは、この遷移依存性を支持する結果といえる。

4.2　周期性を示す天体が少数である理由

本研究において周期変動が検出された天体は、全 422 天体中、6.7 GHz で約 24.4 %、12.2 GHz で約 5.7 % にとどまった。すなわち、大質量星形成領域におけるメタノールメーザーの大多数は周期的変動を示さない。この事実は、周期メーザーが特殊な物理条件の下でのみ発生する現象であることを示唆する。

周期的強度変動の発生機構としては、

- 連星系における準周期的質量降着変動によるポンピング赤外放射の変調（Araya, et al. 2010）
- 連星風衝突による自由-自由放射の周期変動（van der Walt 2011）
- 原始星の脈動変光によるポンピング変調（Inayoshi,et al. 2013）
- 連星円盤内のスパイラルショックによる増幅率変動（Parfenov, & Sobolev 2014）
- 連星による自由-自由放射の周期的遮蔽（Maswanganye, et al. 2015）

- 歳差運動する内円盤による遮蔽効果（Szymczak, et al. 2024）

などが提案されている。これらはいずれも時間的に安定した周期現象を駆動源とする構造を必要とする。

しかし、大質量星形成領域は一般に乱流的で、降着流やアウトフローが複雑に絡み合う非定常環境である。そのため、周期的に安定した変調構造を持つ系は全体の中では少数であると考えられる。すなわち、本研究で周期性が検出された天体は大質量星形成領域の中でも特に安定的な連星構造や規則的エネルギー供給機構を有する「特殊な系」である可能性が高い。

さらに、本研究で同一速度成分での比較を行った結果、周期の不一致や周波数依存性が多数確認されたことは、周期現象が単純な光度変動ではなくメーザー増幅過程そのものの非線形応答を伴う複雑な現象であることを示唆する。周期メーザーの物理的起源を明らかにするためには、VLBI など高空間分解能干渉計観測によりメーザー分布と中心天体構造を対応付ける研究が不可欠である。

4.3 解析の課題と展望

本研究では、6.7 GHz では比較的多くの周期候補が得られた一方、12.2 GHz では周期検出数が少ないという差異が確認された。この差は物理的要因に加えて観測的要因の影響も受けている可能性がある。一般に 12.2 GHz メタノールメーザーは 6.7 GHz に比べて強度が弱く、発現条件も限定的であるため、同程度の観測条件では S/N 比が低下しやすい。その結果、周期的変動が存在していても、LS 解析において有意なピークとして検出されない可能性がある。したがって、12.2 GHz において積分時間を延長し感度を向上させる観測を行うことで、現在は検出されていない周期成分が明らかになる可能性がある。また、観測期間をさらに長期化することにより、長周期（数百日規模）の変動や準周期的変動の検出精度も向上すると期待される。特に観測点数の増加は誤警報確率の低減に直接寄与し、周期判定の信頼性を高める。

さらに、6.7 GHz と 12.2 GHz の両方で周期性が検出された天体については、周期値や位相の詳細な比較が重要である。もし両遷移で周期および位相が一致するならば、共通の駆動源（例えば連星系に伴う放射変調）が両メーザーを同時に変調している可能性が高い。一方、周期は類似していても位相差が存在する場合には、空間的に異なる増幅経路や励起条件の違いが影響している可能性が示唆される。このような比較は、両遷移の発生領域の相対的位置関係や物理環境の違いを理解する上で重要な手がかりとなる。将来的には高空間分解能観測と時間変動解析を組み合わせることで、周期メーザー現象の発生機構により踏み込んだ理解が期待される。

5　まとめ

本研究では、日立 32 m 電波望遠鏡による長期モニター観測データを用いて、6.7 GHz および 12.2 GHz メタノールメーザーの強度変動を解析し、Lomb–Scargle 法により周期性の有無を体系的に調べた。その結果、6.7 GHz では比較的多くの周期候補が得られた一方、12.2 GHz では周期性が検出される天体は限られており、両遷移間で周期検出傾向に明確な違いが見られた。また、同一天体内の同一速度成分で比較しても、周期が一致しない例や、片方の遷移でのみ周期性が現れる例が確認された。

これらの結果は、メタノールメーザーの周期変動が単純な中心天体の光度変動の反映ではなく、遷移ごとの励起条件や増幅経路の違いに強く影響される現象であることを示唆している。特に、6.7 GHz のみで周期性が検出される天体の存在は、両遷移が必ずしも同一の物理環境をトレースしていない可能性を支持する。一方で、十分な観測点数を有しながら周期性が確認されない天体も存在し、周期メーザーは大質量星形成領域に普遍的に見られる現象ではなく、特定の安定的構造やエネルギー供給機構を持つ系において発現する可能性が高い。

今回の結果は、周期メーザーが一部の天体に限られること、さらに遷移依存性が存在する可能性を示唆したが、その物理的背景については依然として不明な点が多い。今後、より高感度・長期間のモニター観測を継続するとともに、干渉計による高空間分解能観測と組み合わせることで、メーザーの空間構造と時間変動の対応関係を明らかにすることが期待される。メタノールメーザーの時間変動研究は発展途上の分野であり、今後の観測技術の向上とともに、大質量星形成過程の理解を深める重要な手がかりを提供すると考えられる。

謝辞

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皆様のご支援なくして本研究を完成させることはできませんでした。改めて、深く御礼申し上げます。

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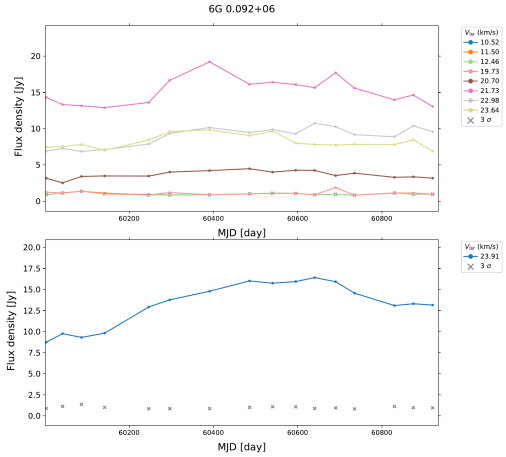
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付録　全天体のライトカーブ・ピリオドグラムおよびスペクトル

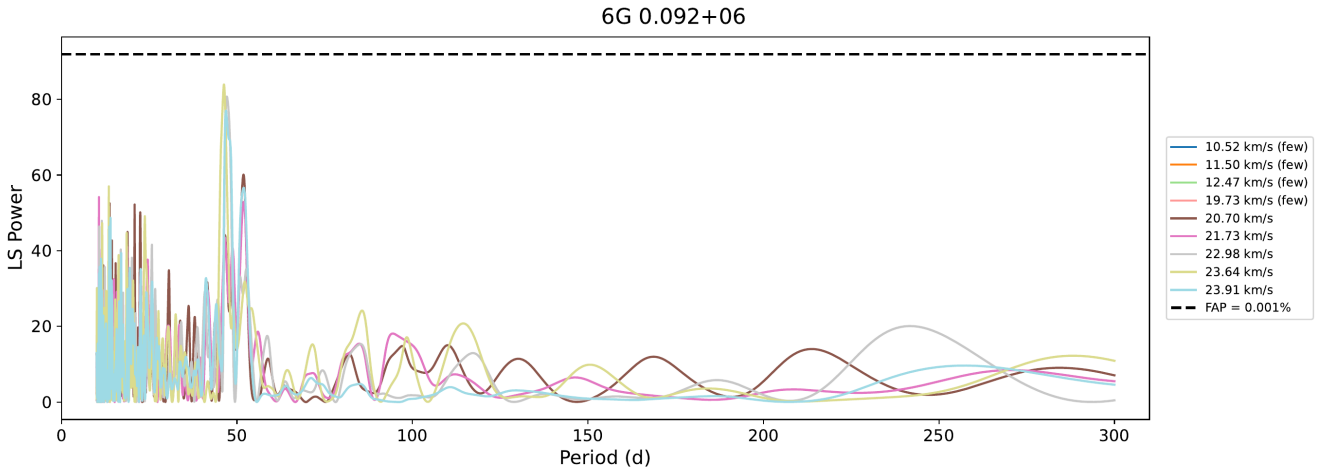
次ページから、全 422 天体の 6.7 GHz と 12.2 GHz メタノールメーザーのライトカーブ、ピリオドグラム、スペクトルを付録として示す。

6G 0.092+06

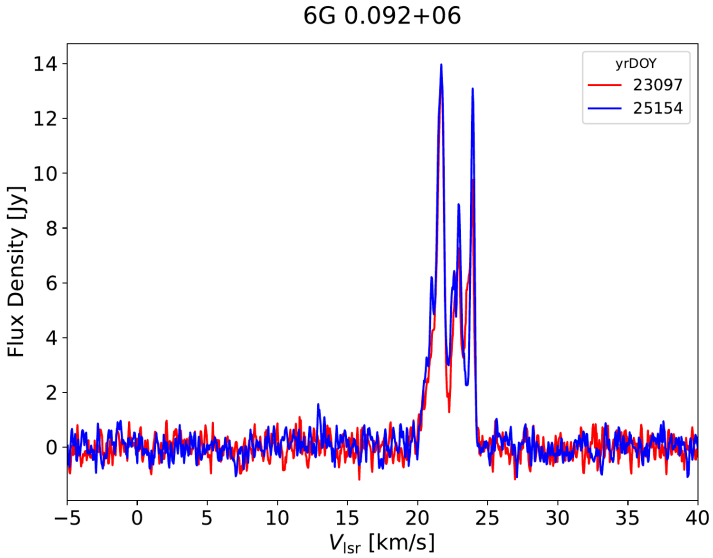
Light curve



Periodogram

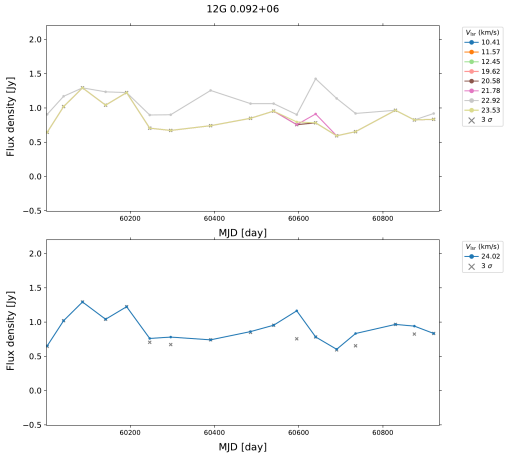


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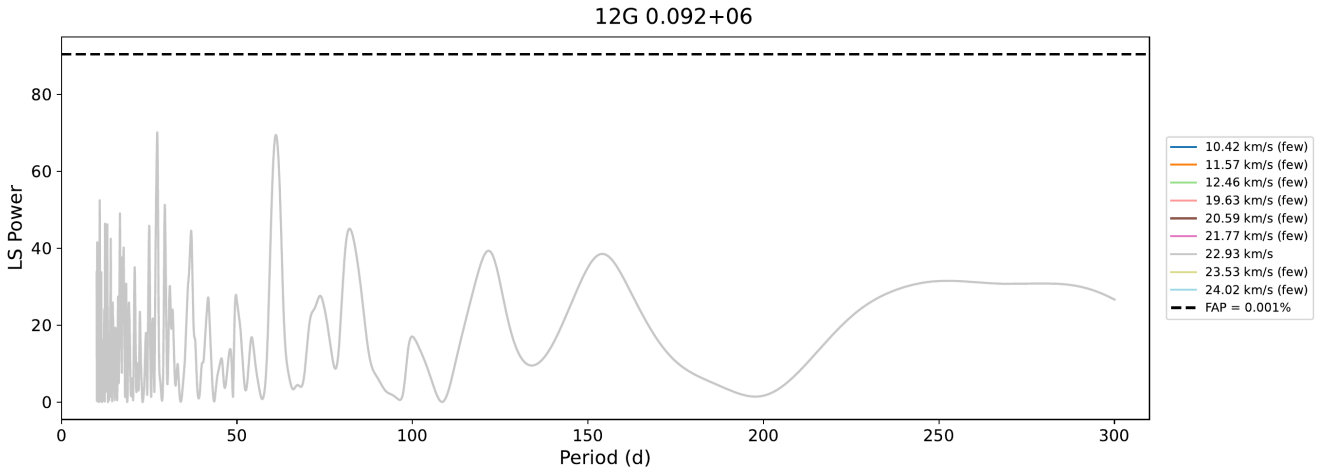


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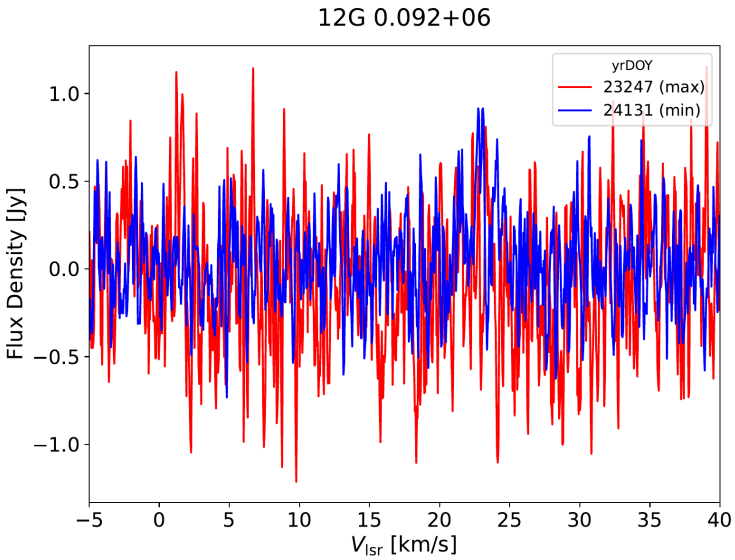
Light curve



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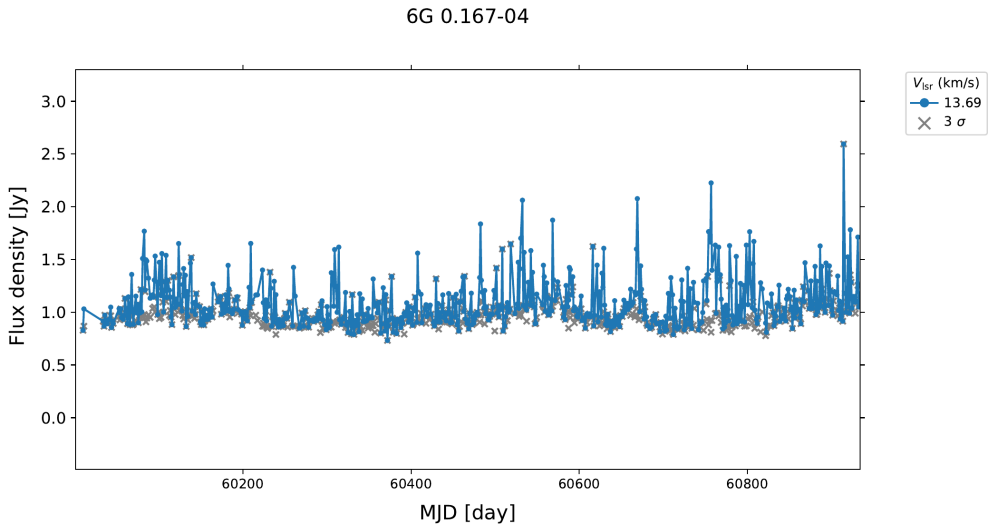


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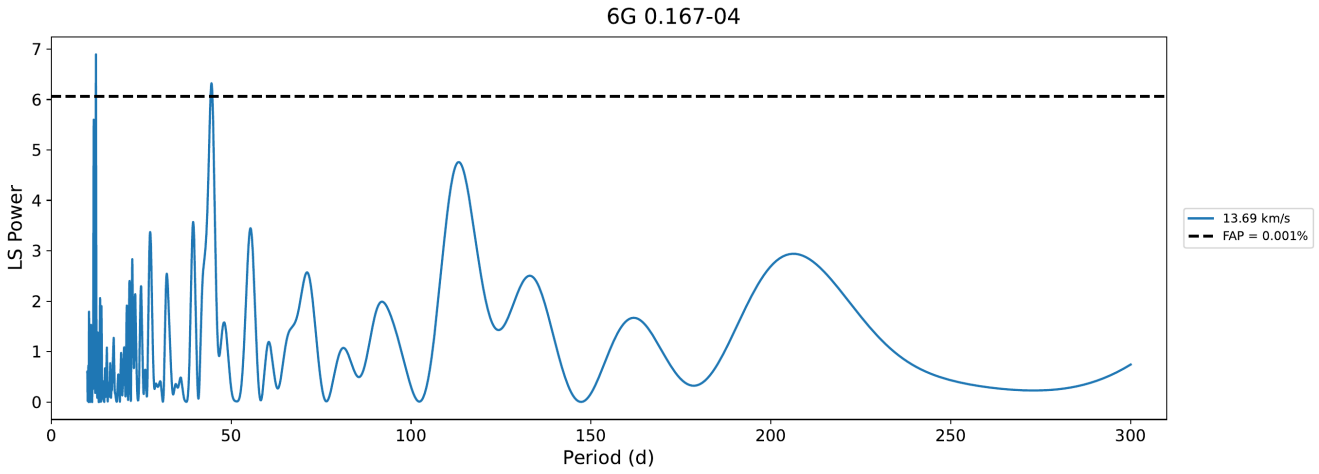


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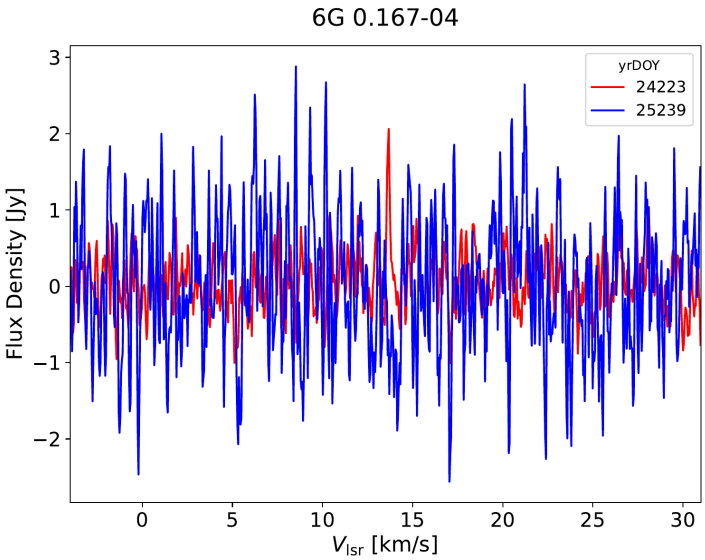
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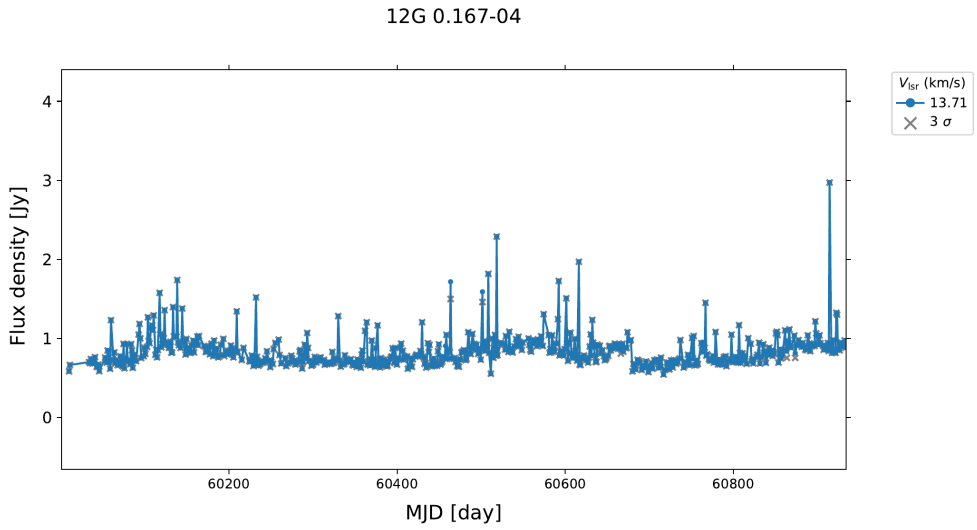


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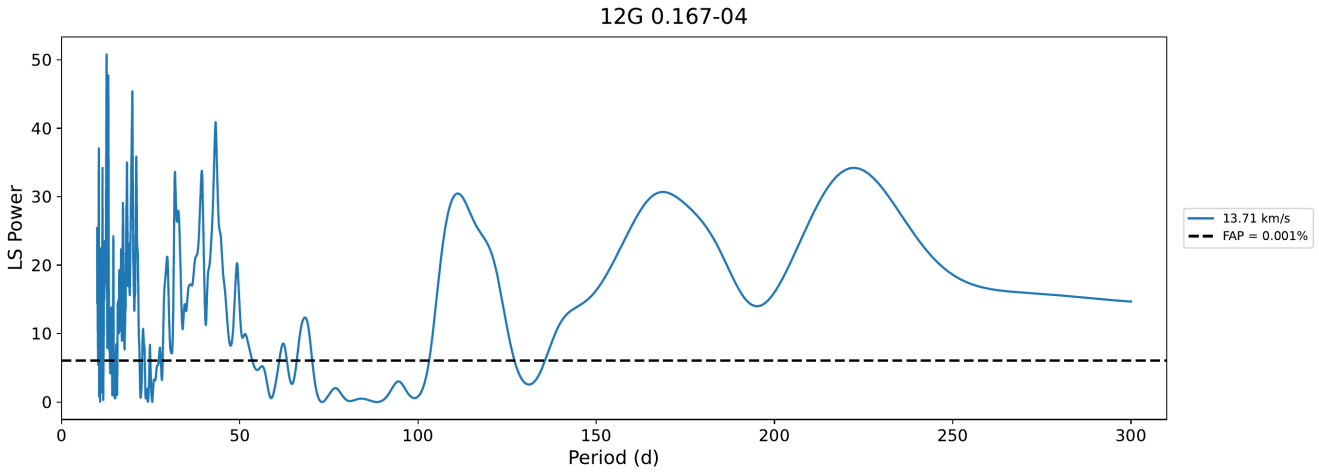


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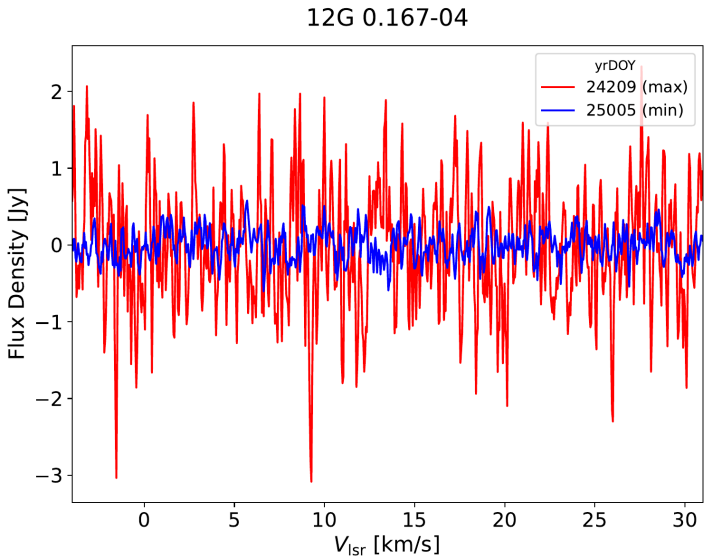
Light curve



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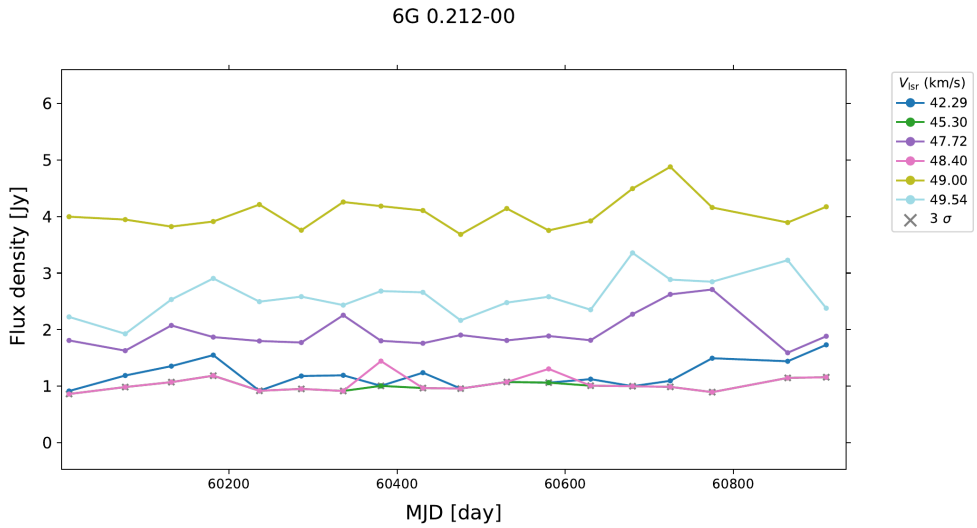


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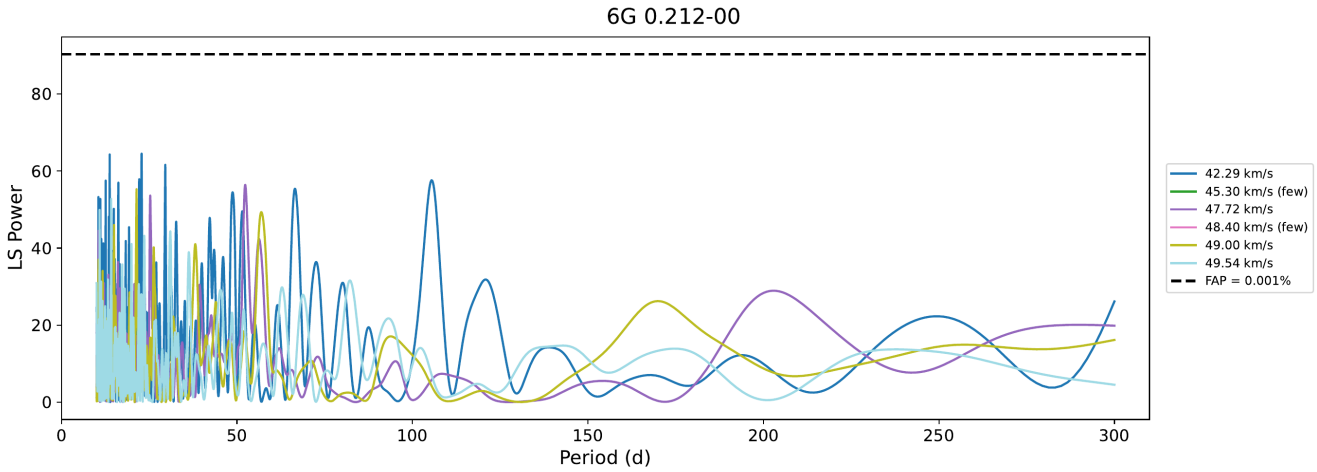


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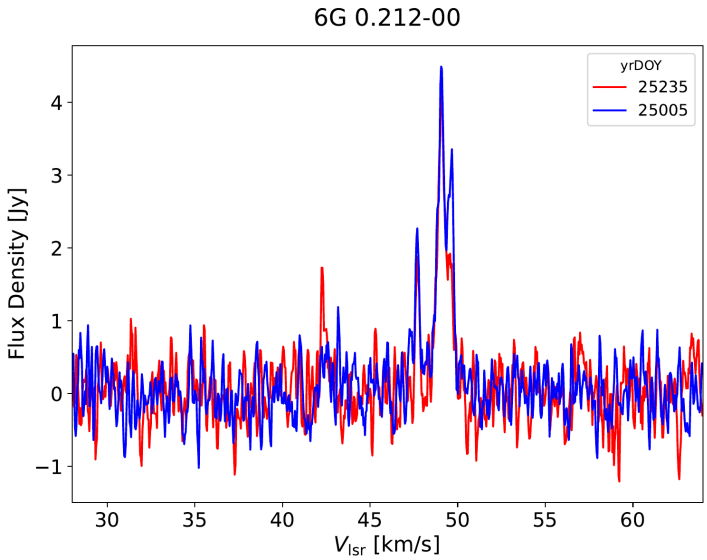
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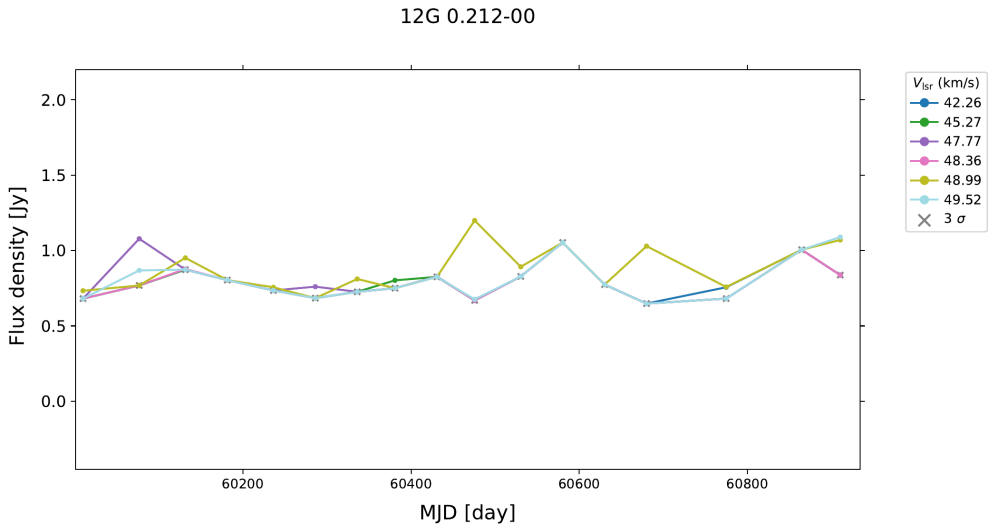


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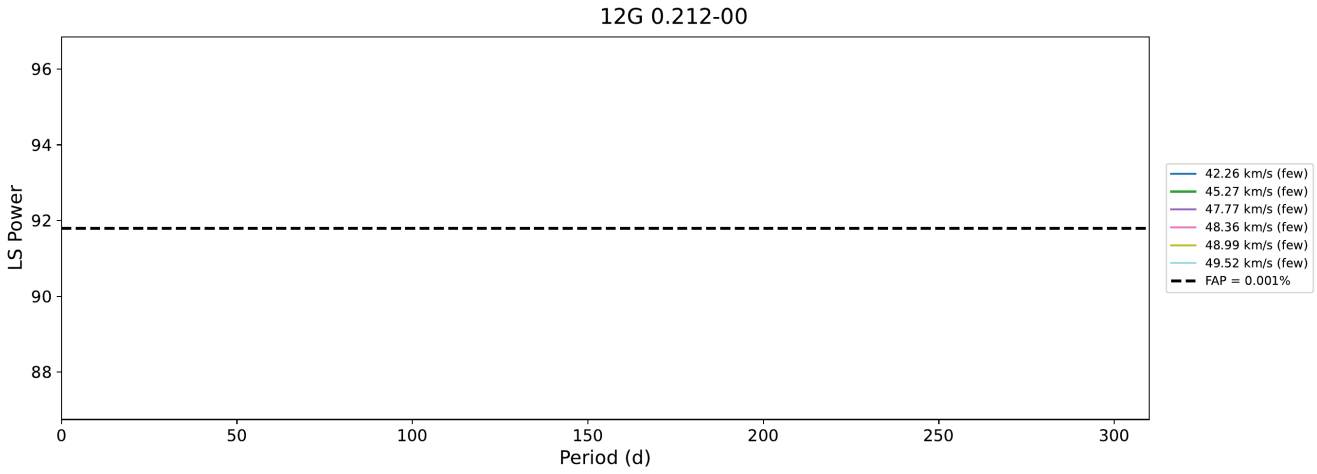


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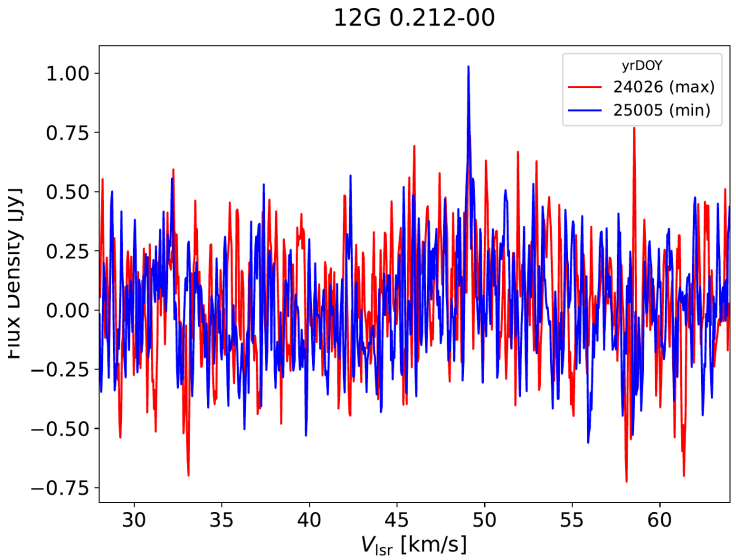
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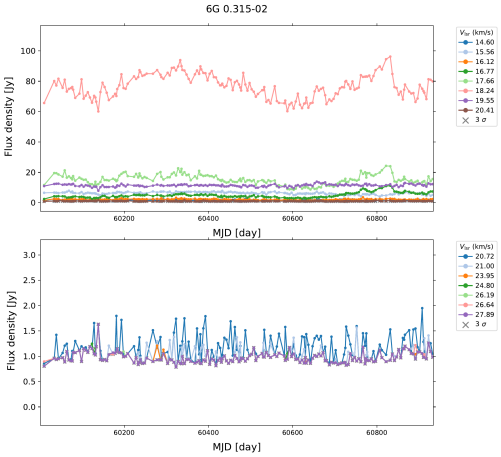


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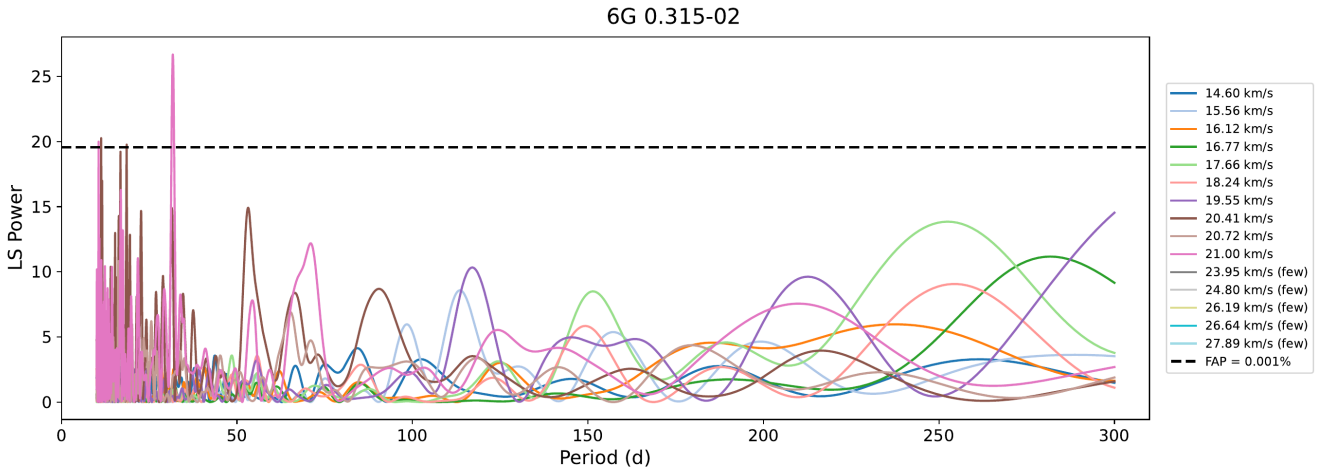


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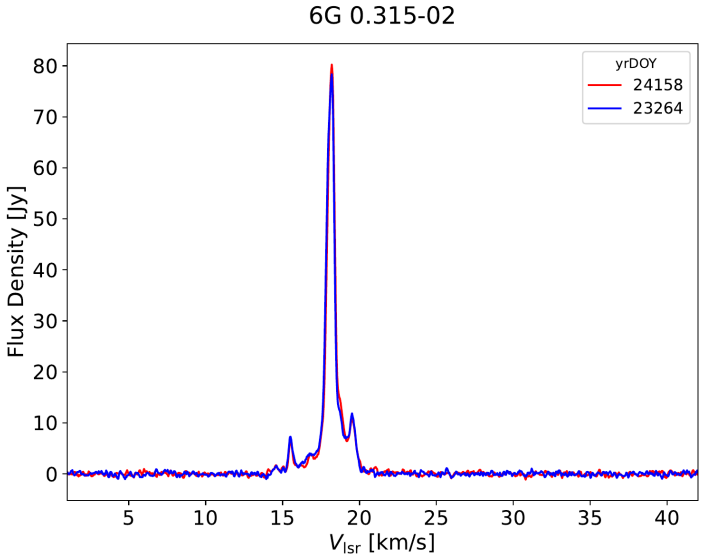
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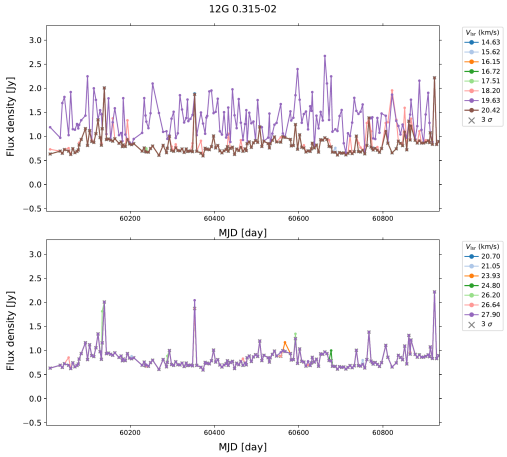


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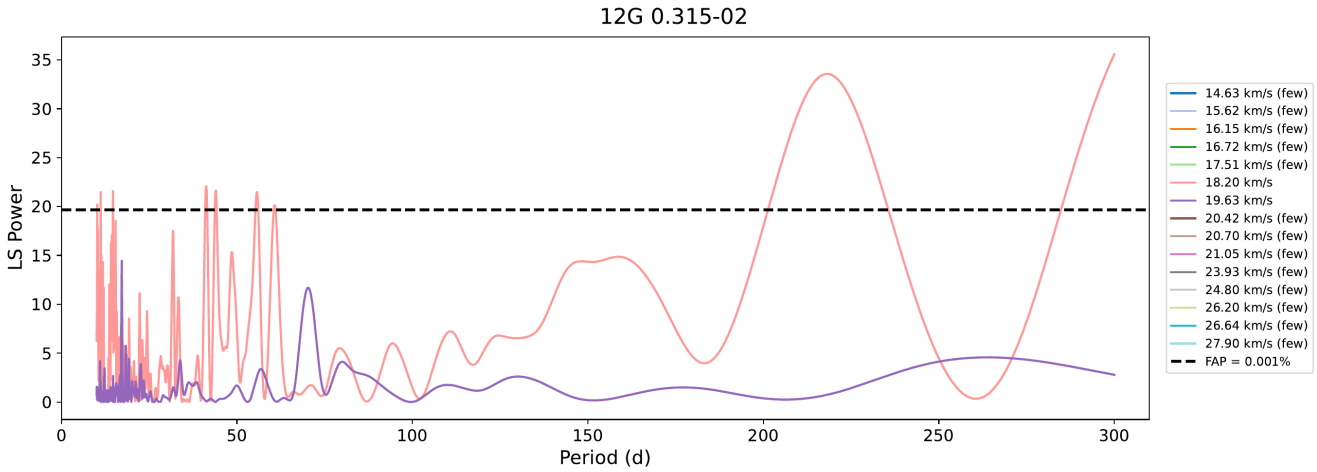


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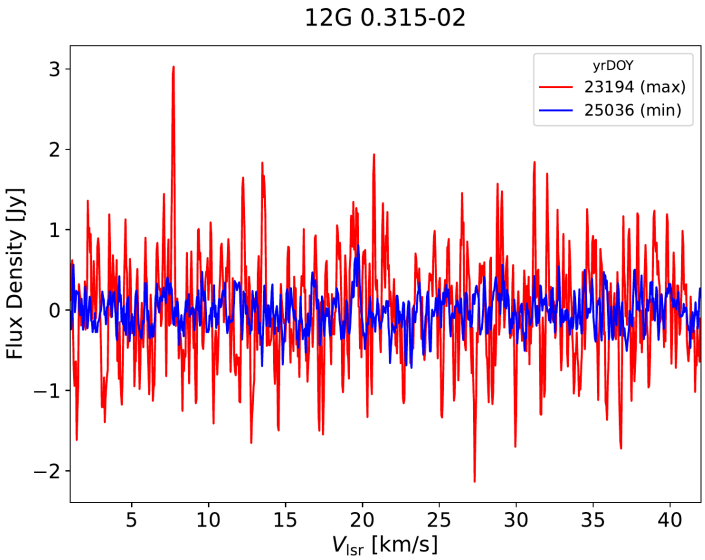
Light curve



Periodogram

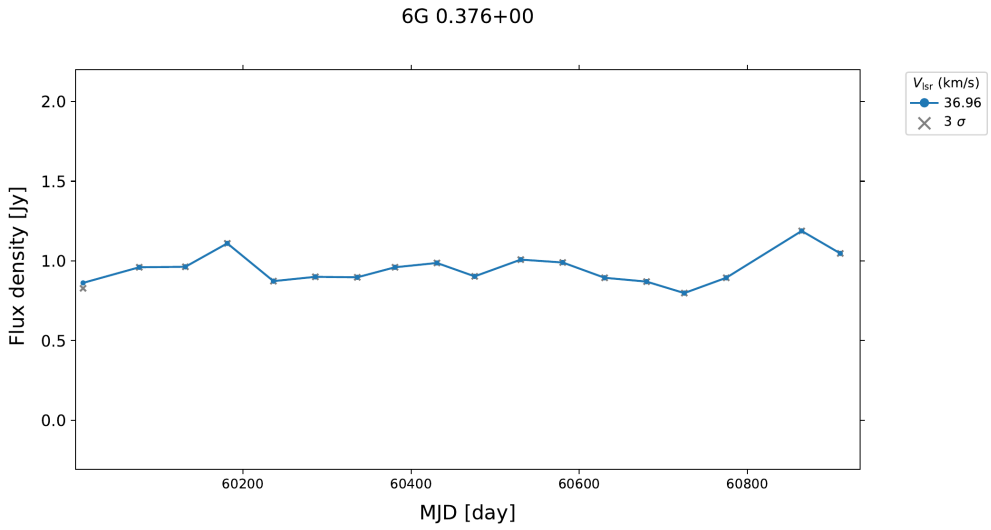


Spectrum

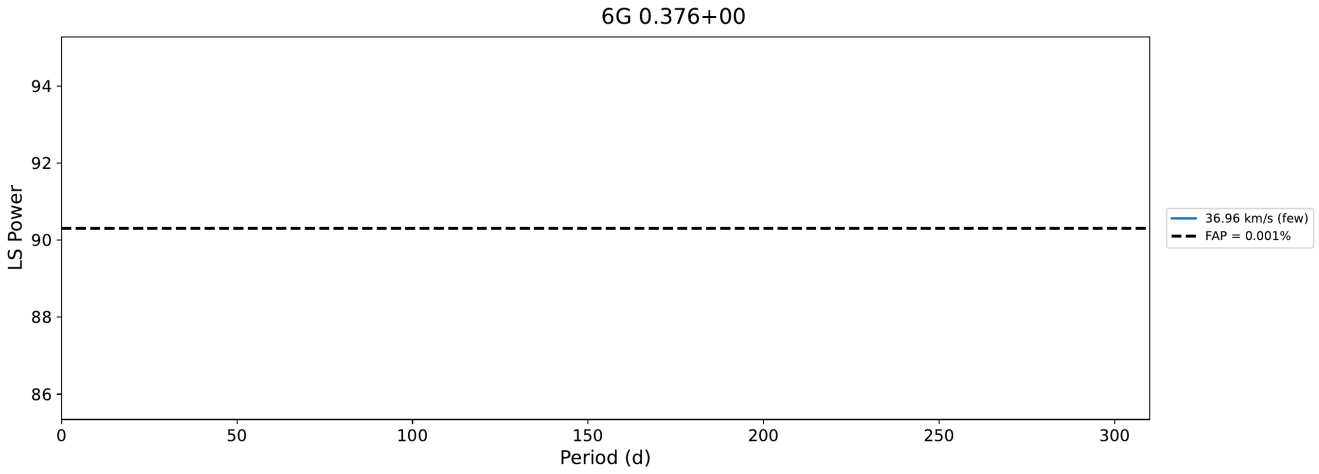


6G 0.376+00

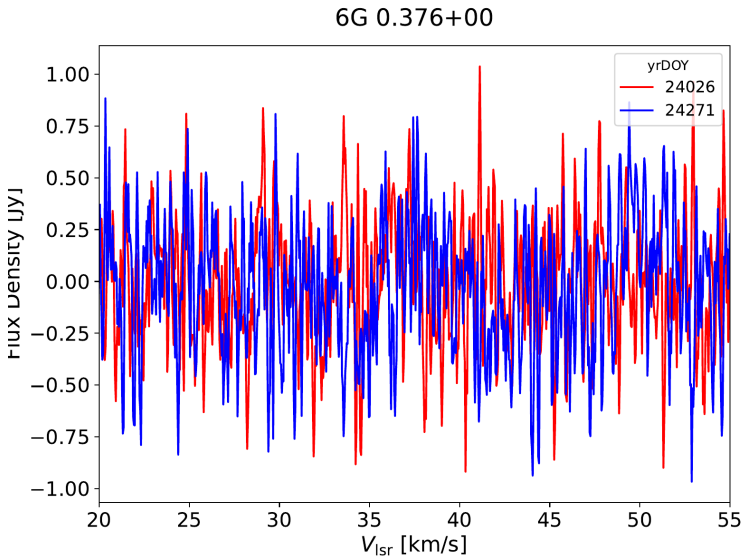
Light curve



Periodogram

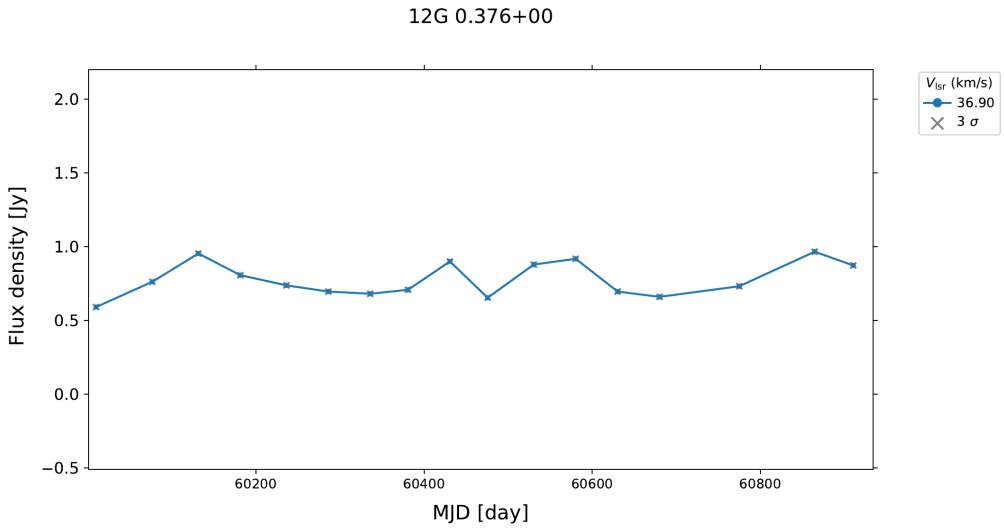


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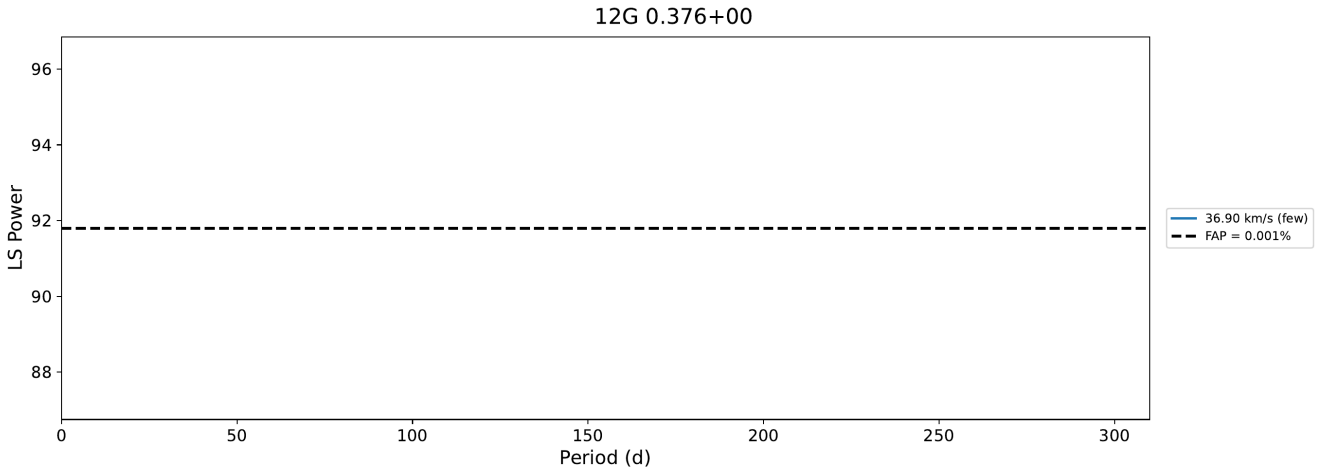


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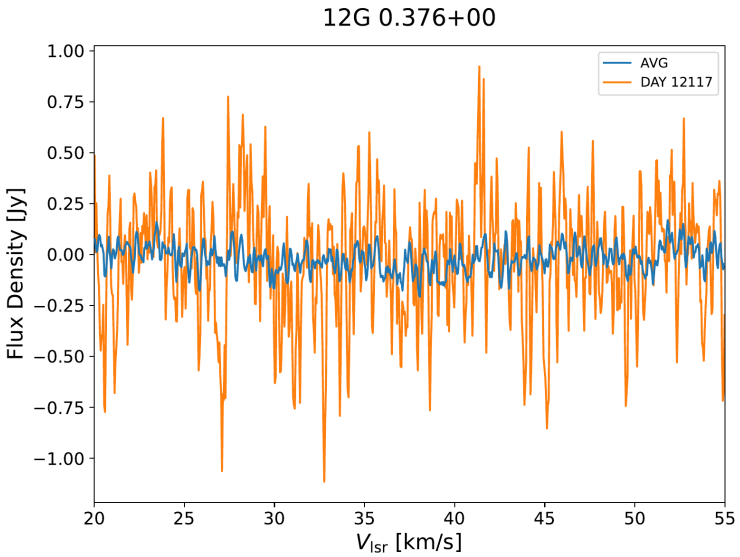
Light curve



Periodogram

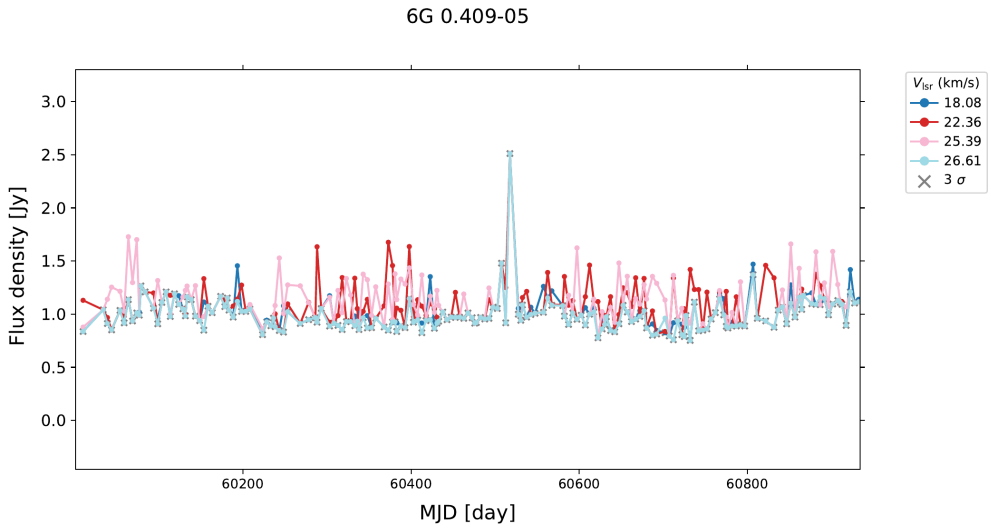


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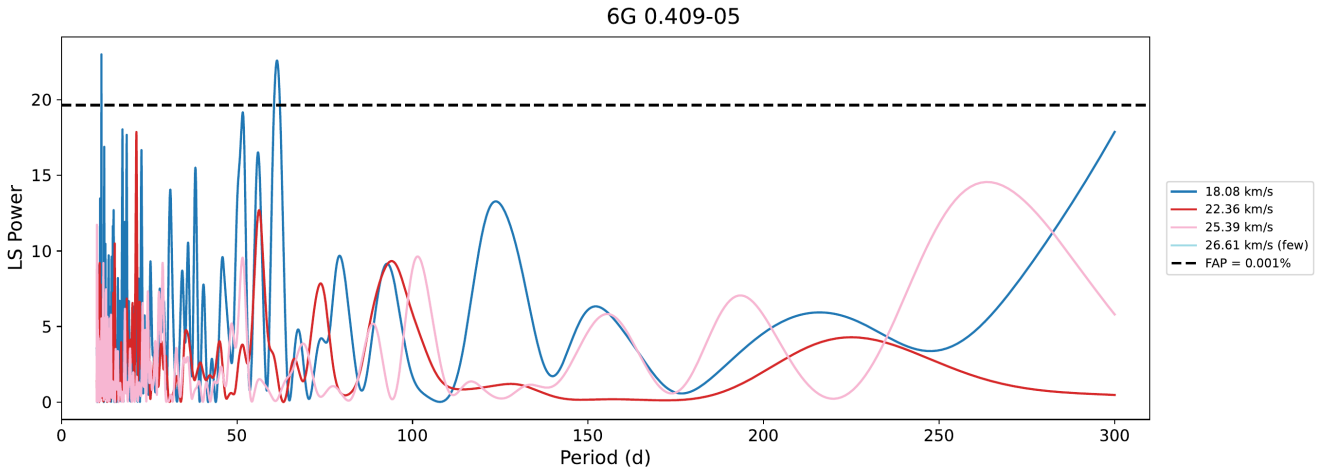


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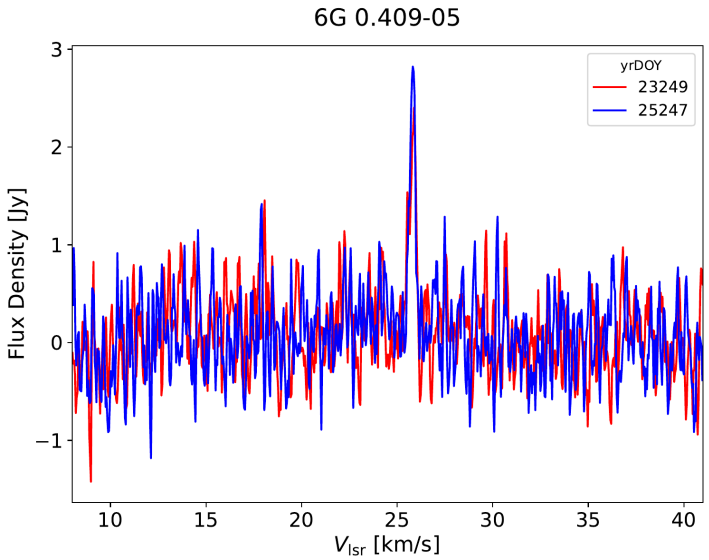
Light curve



Periodogram

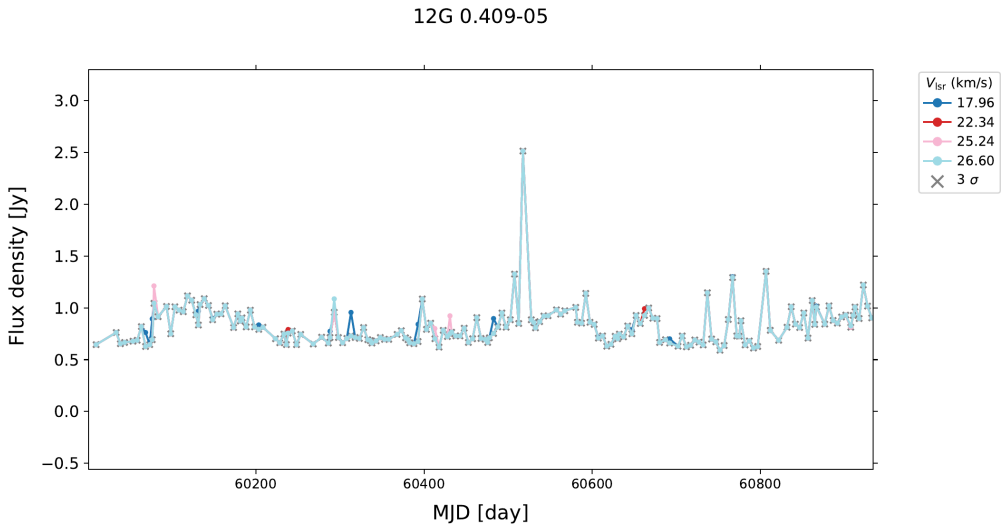


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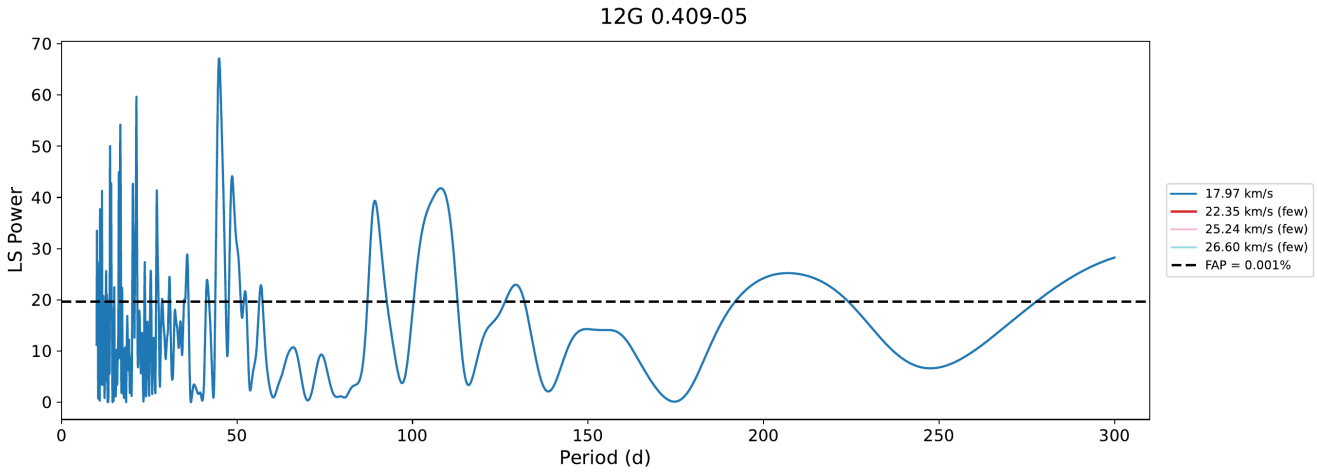


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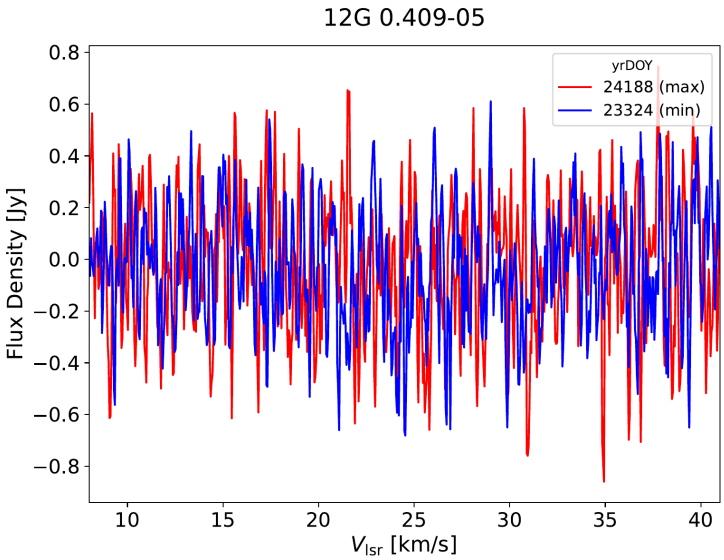
Light curve



Periodogram

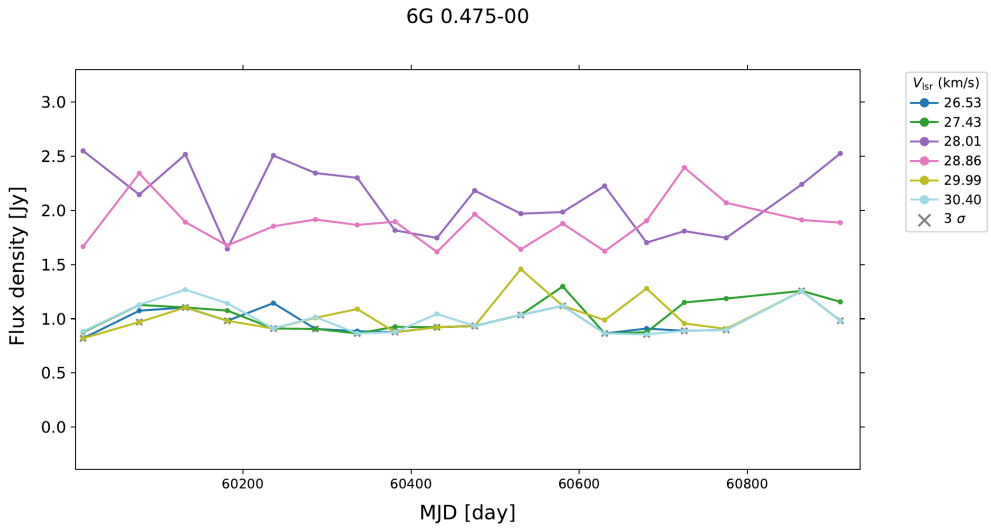


Spectrum

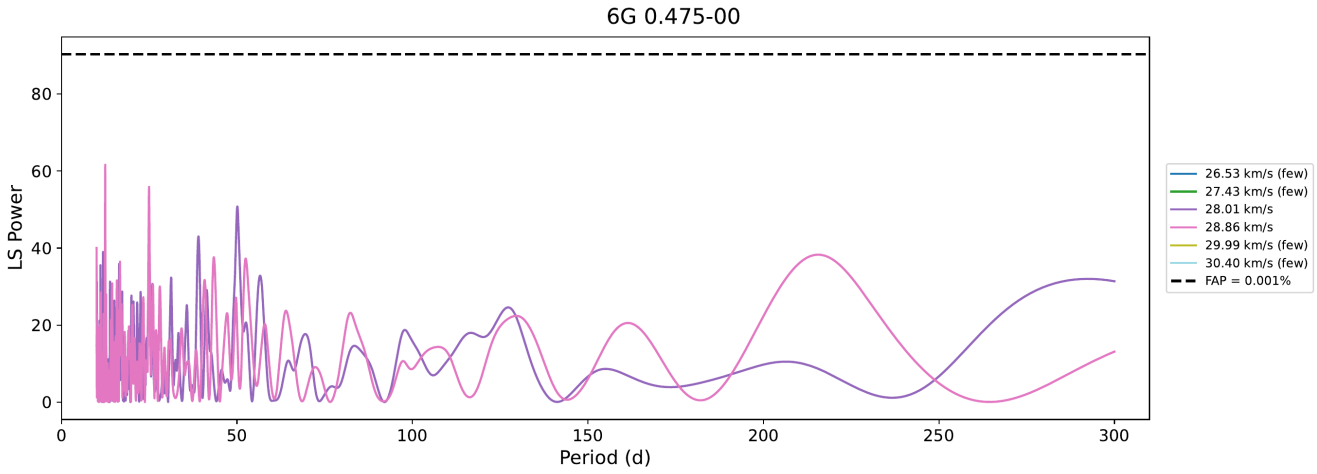


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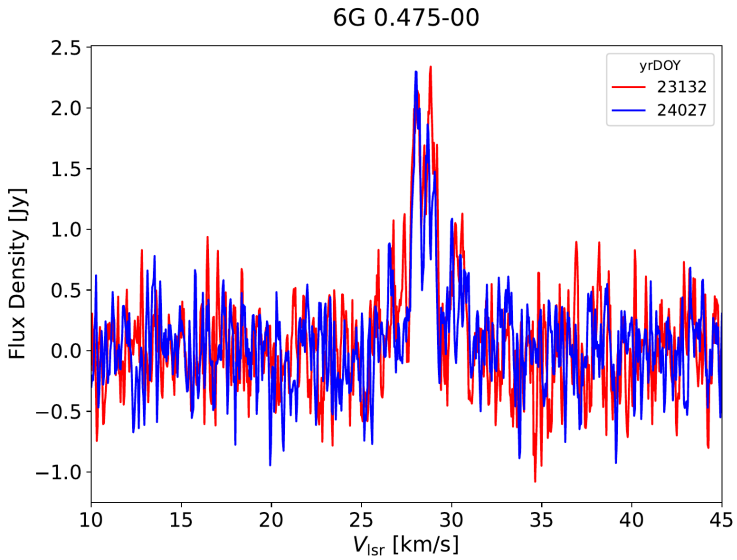
Light curve



Periodogram

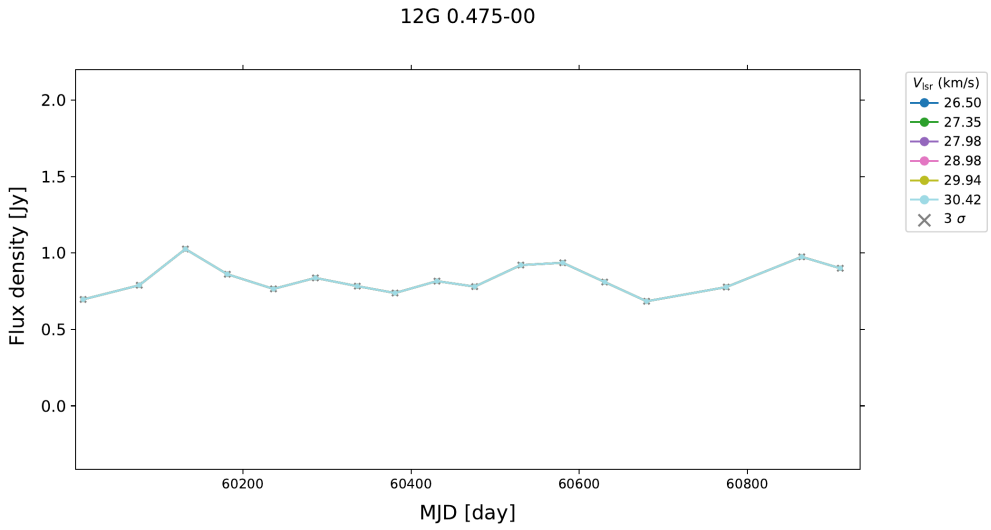


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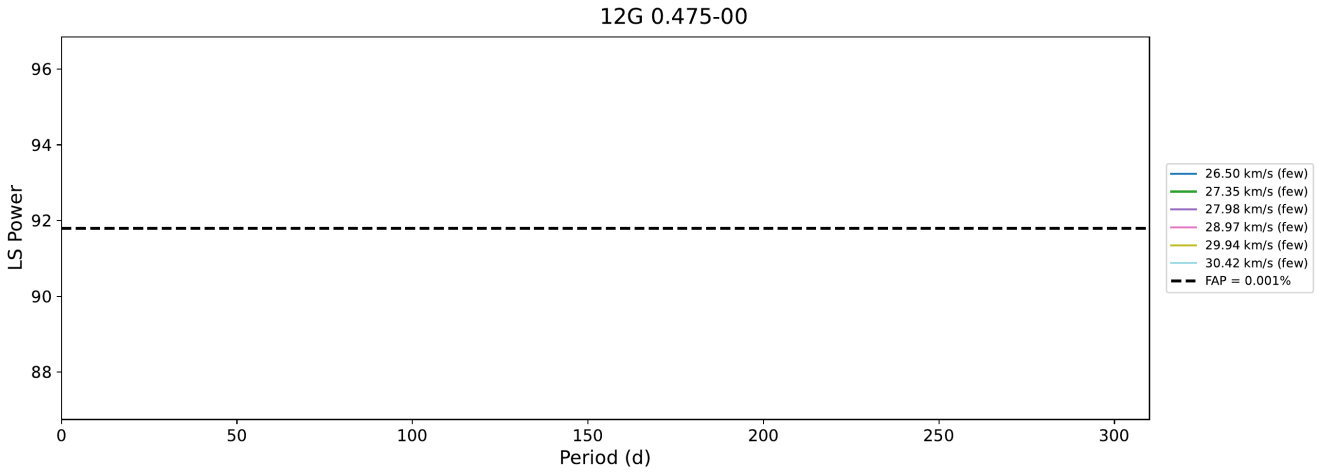


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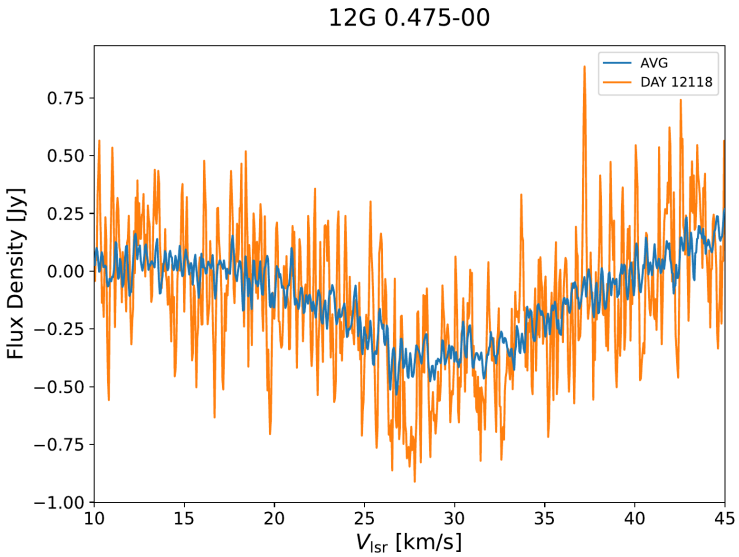
Light curve



Periodogram

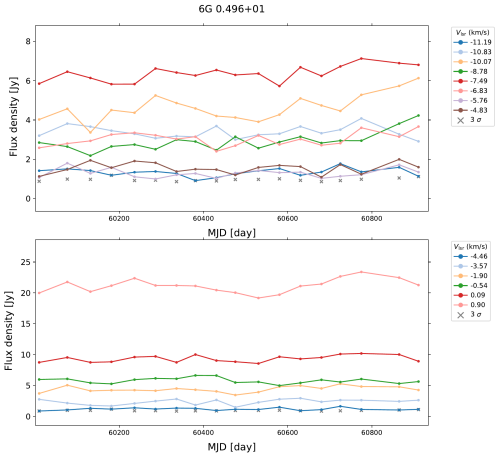


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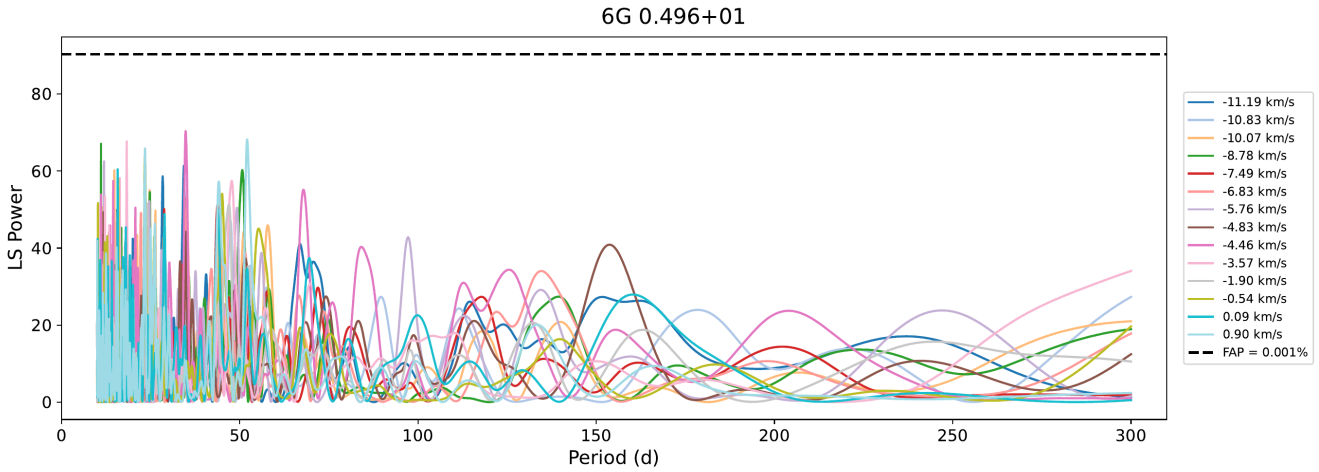


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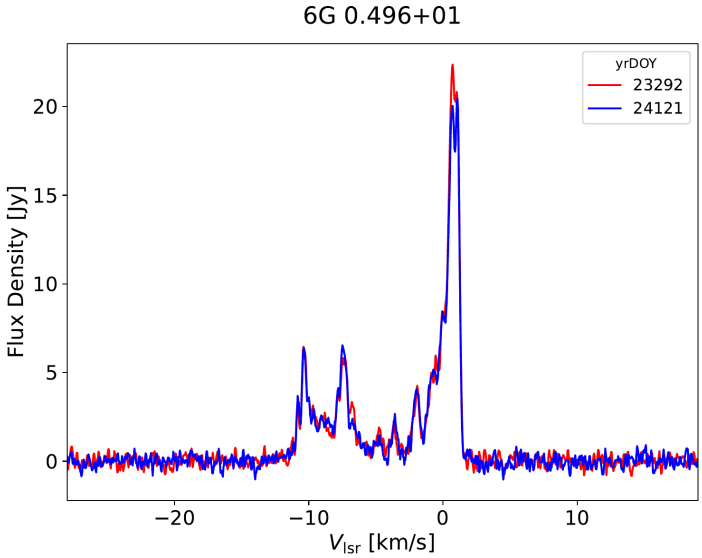
Light curve



Periodogram

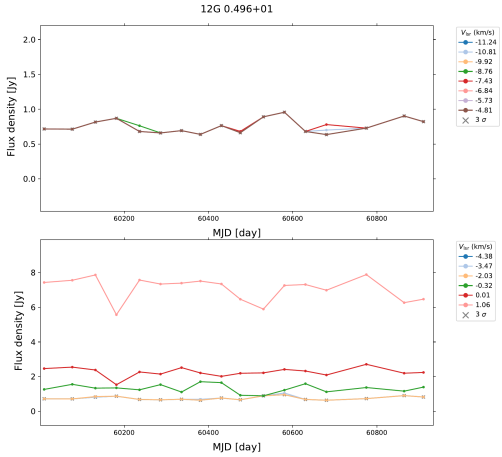


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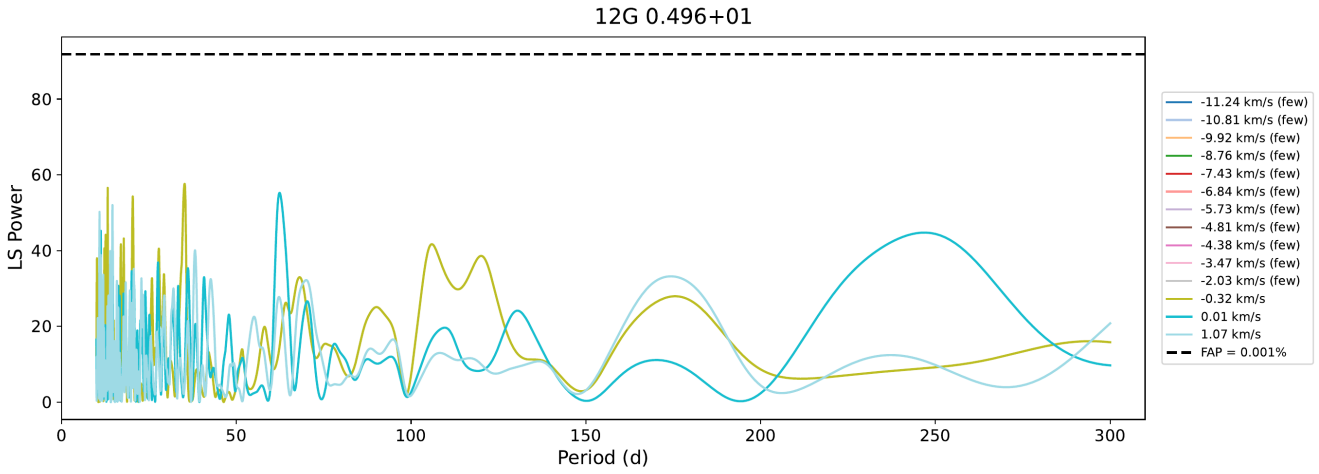


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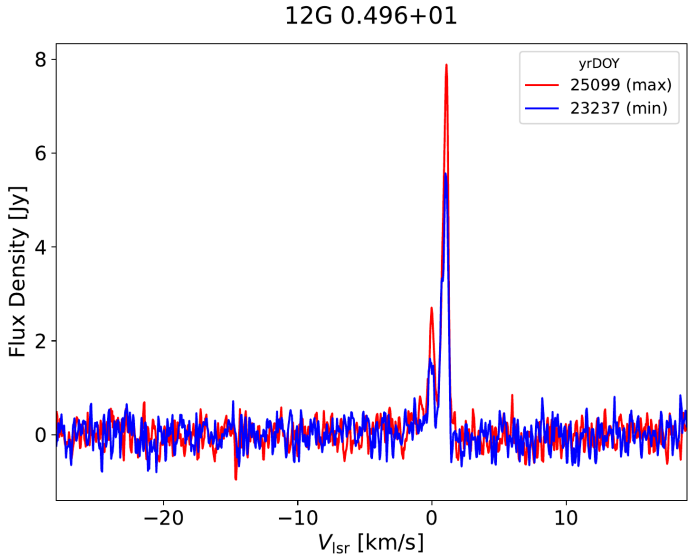
Light curve



Periodogram

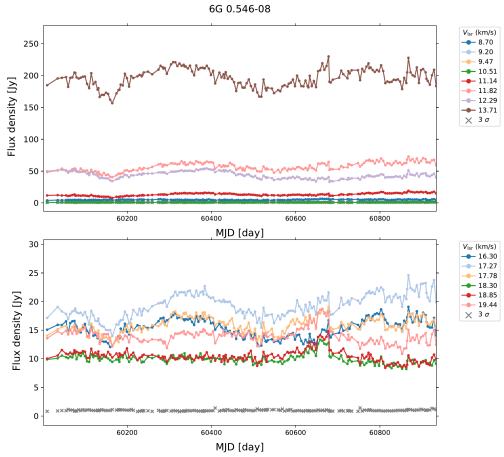


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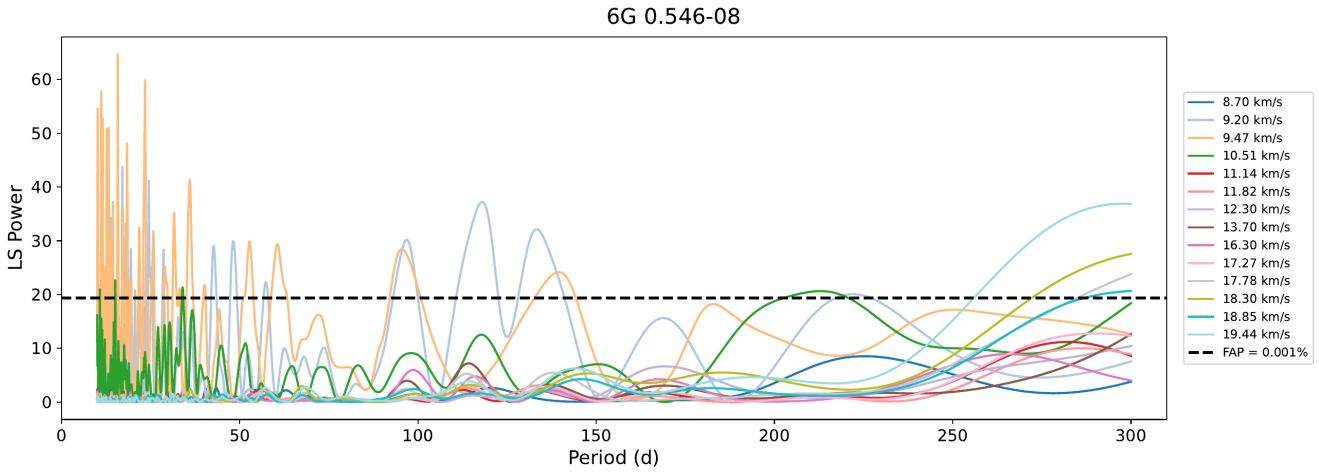


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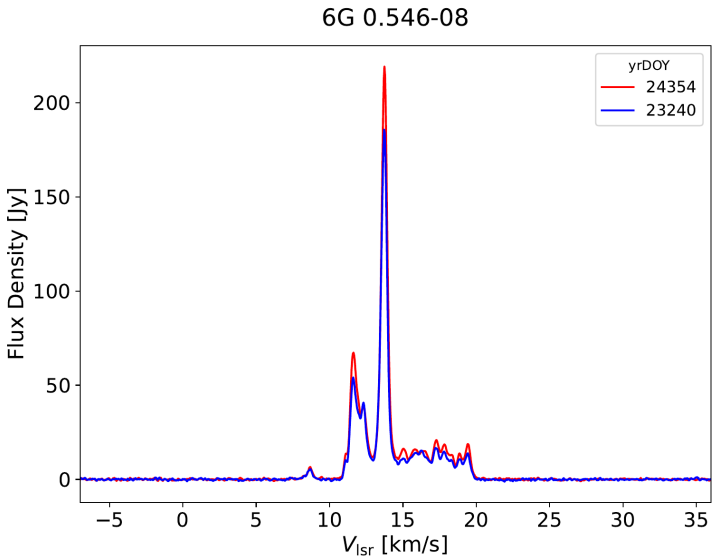
Light curve



Periodogram

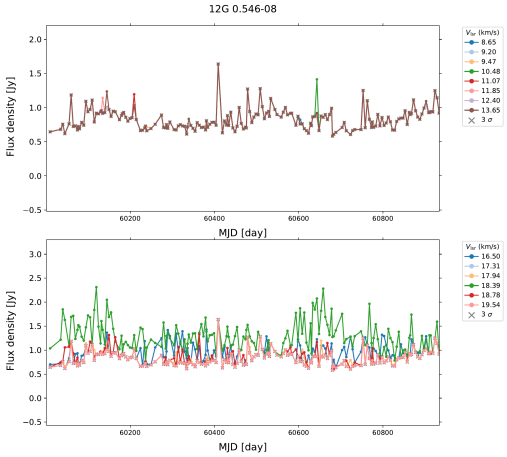


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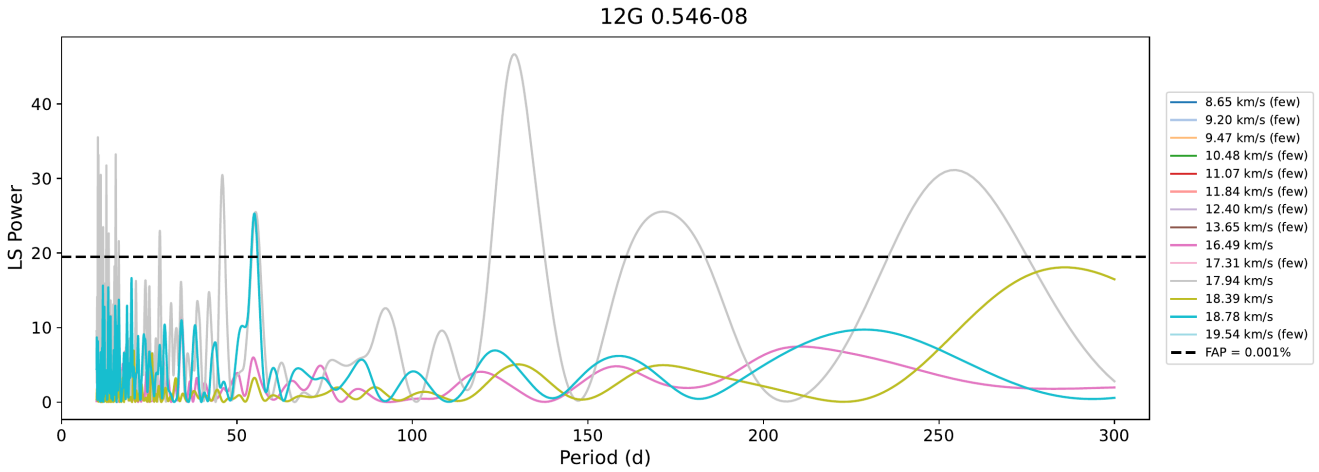


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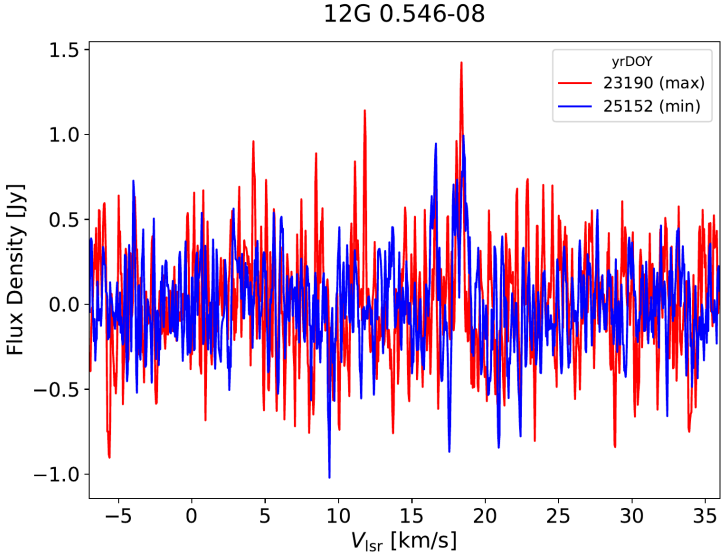
Light curve



Periodogram

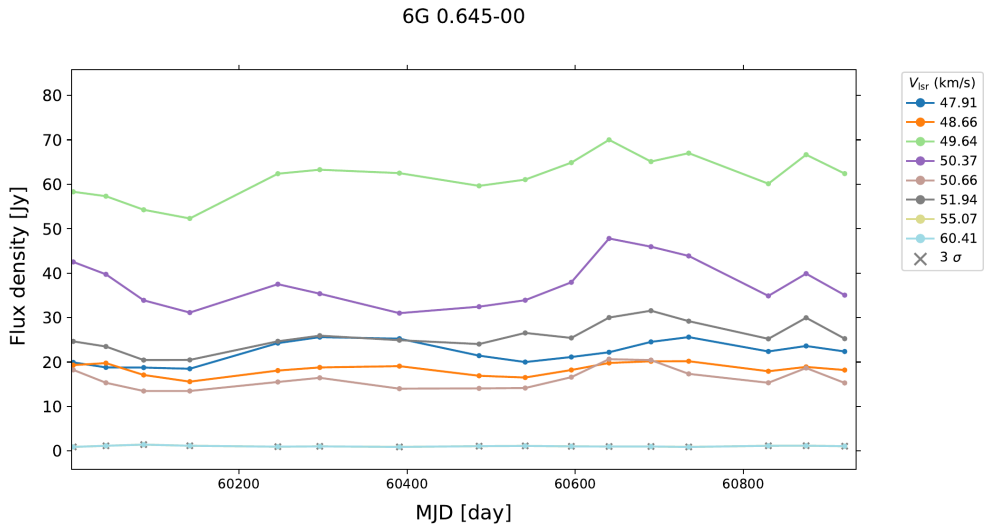


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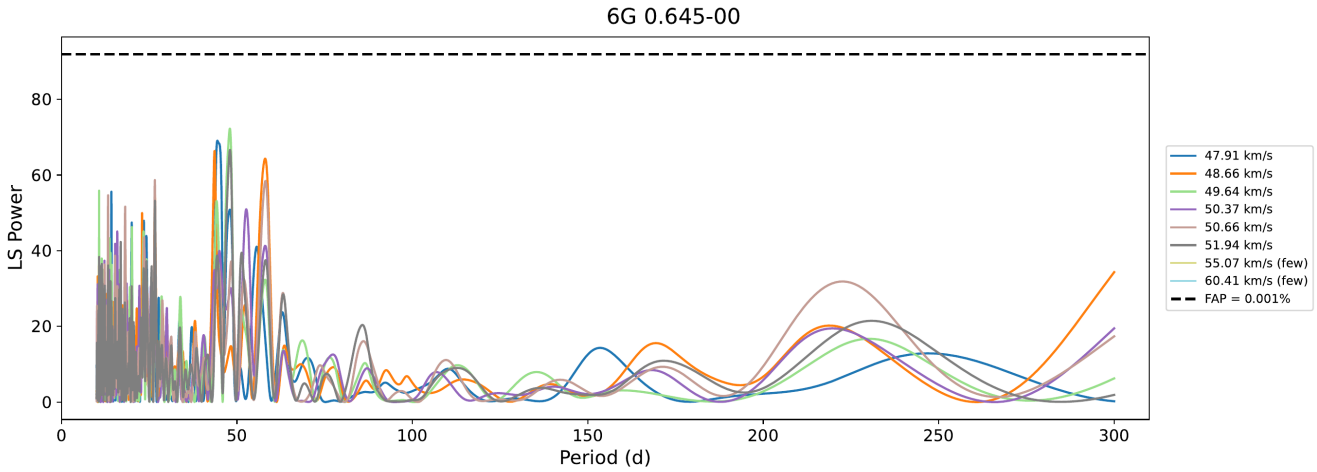


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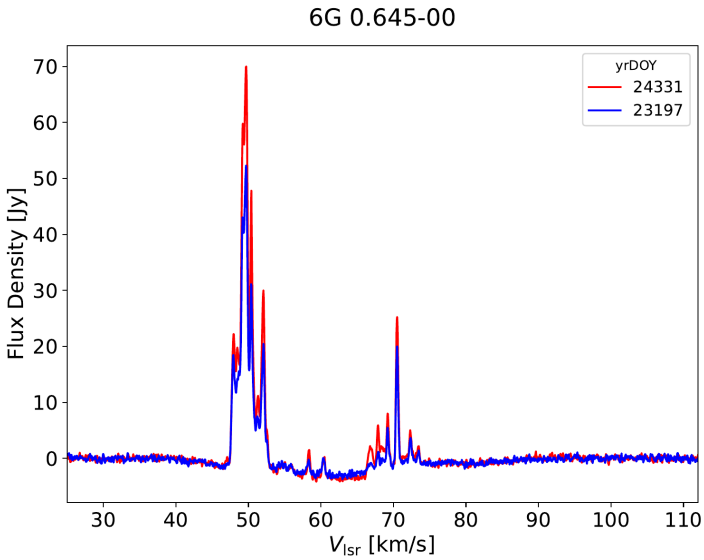
Light curve



Periodogram

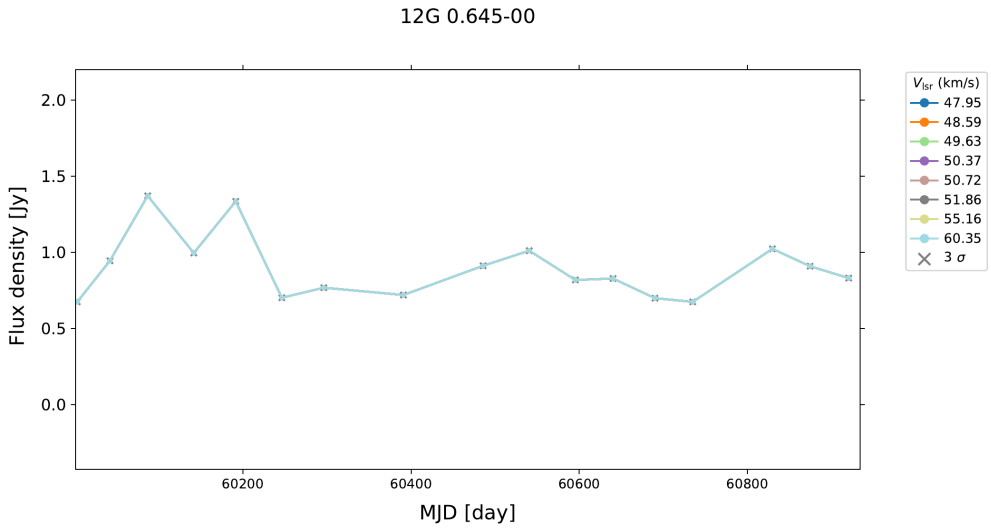


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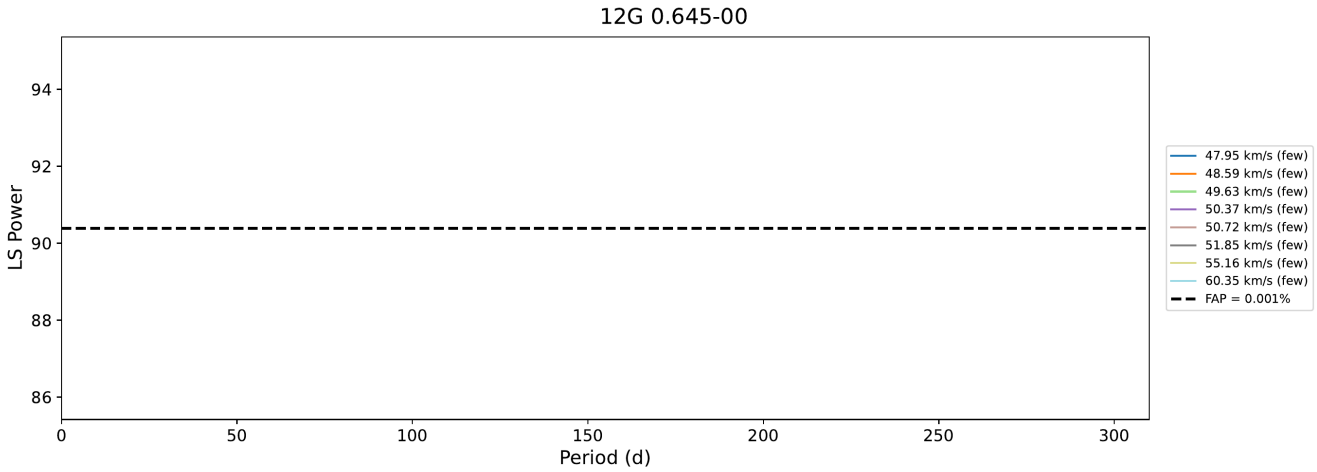


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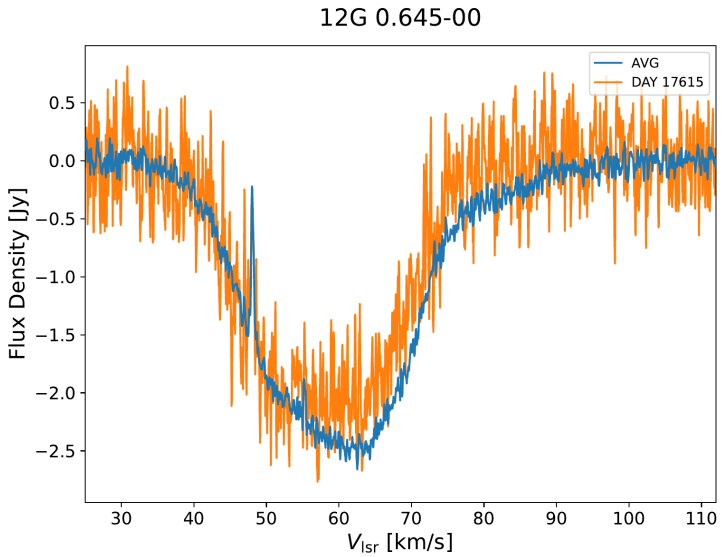
Light curve



Periodogram

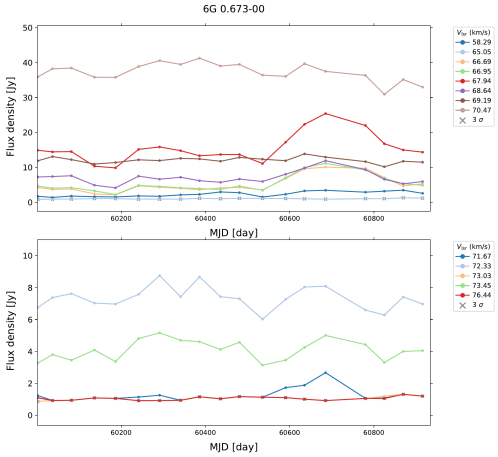


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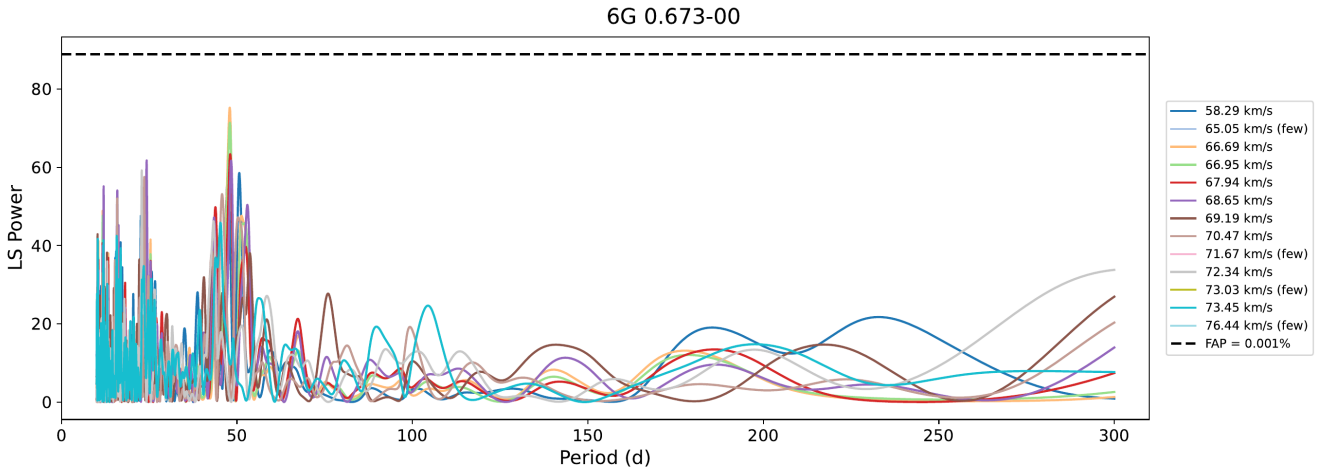


6G 0.673-00

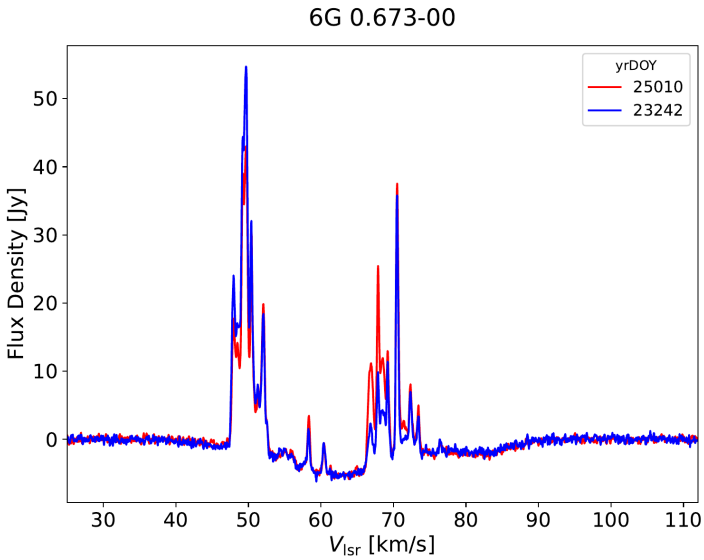
Light curve



Periodogram

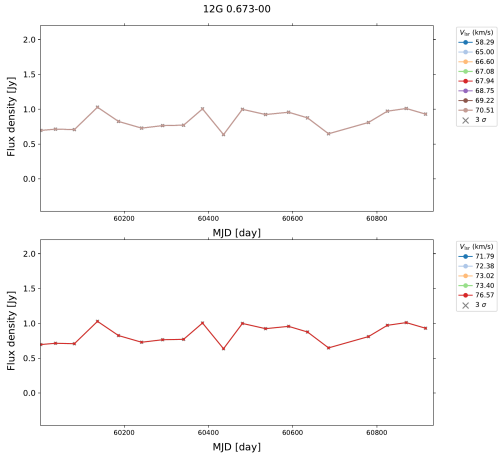


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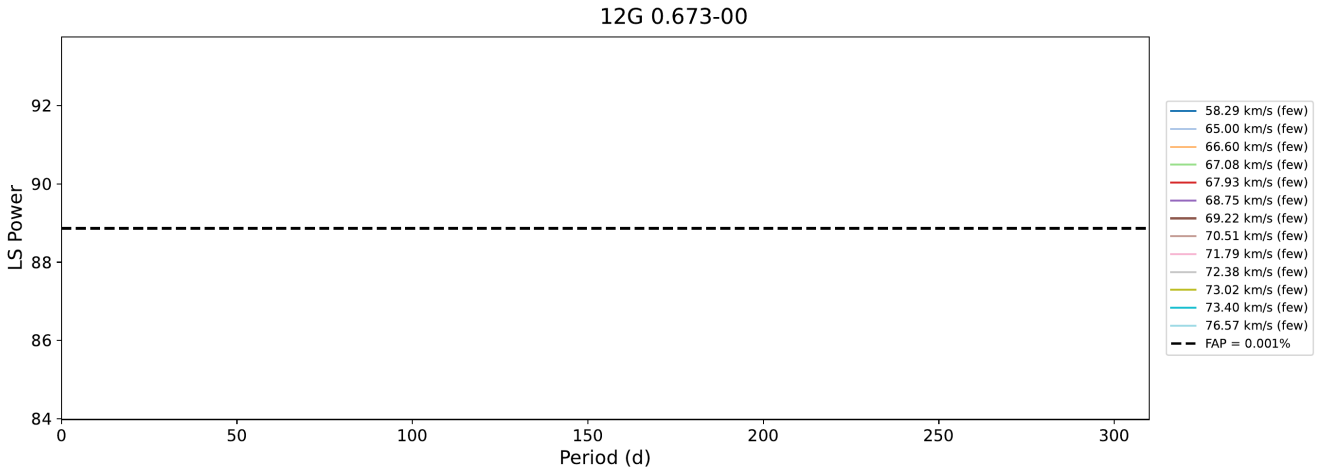


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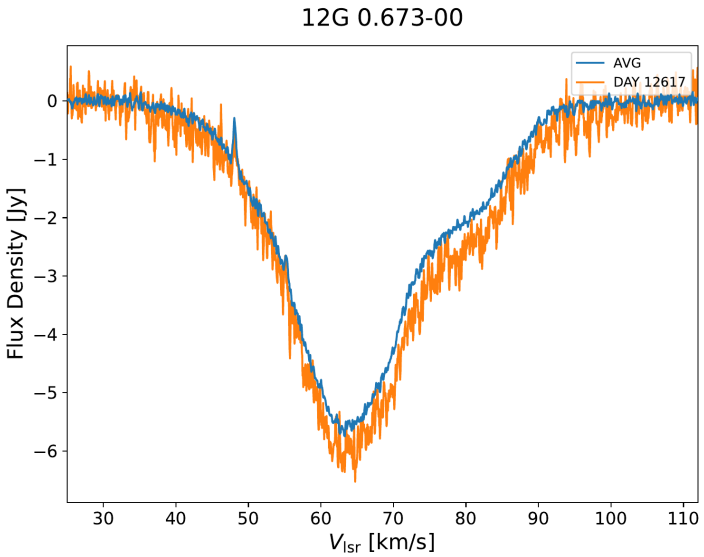
Light curve



Periodogram

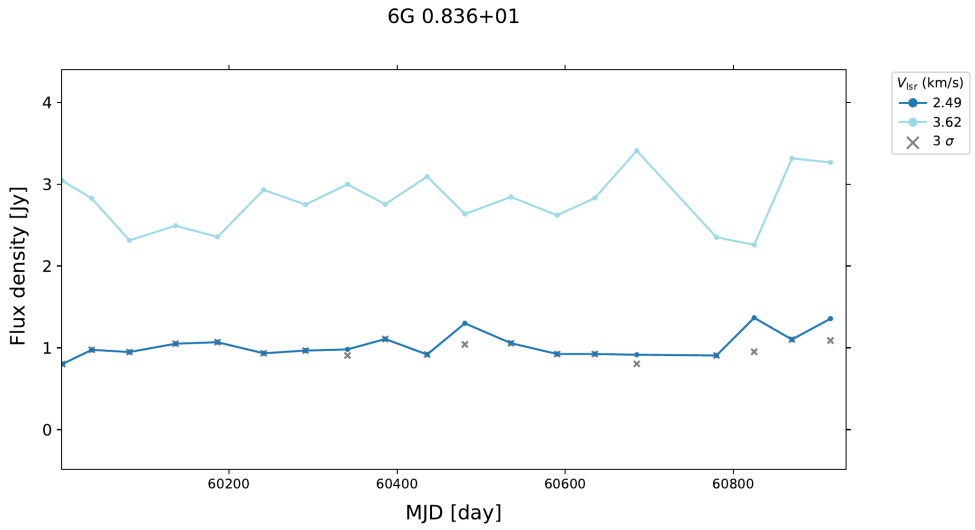


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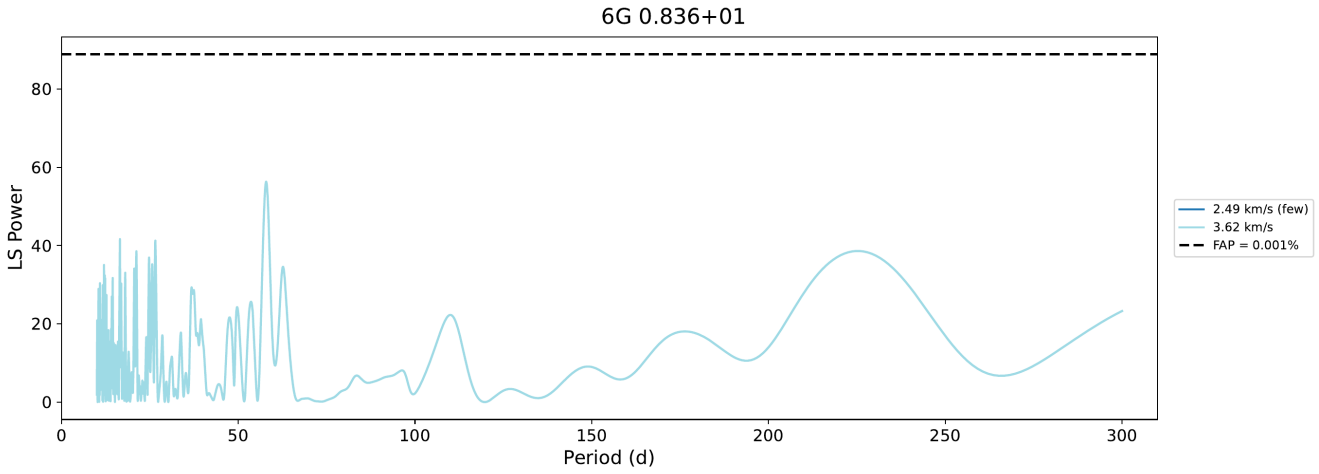


6G 0.836+01

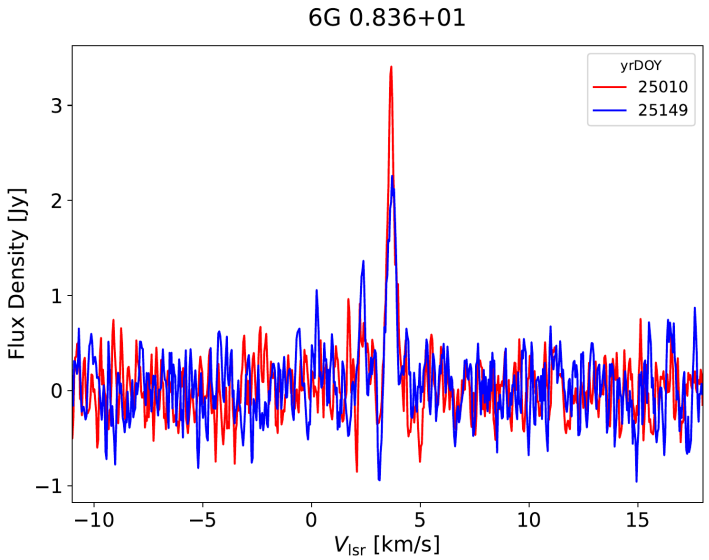
Light curve



Periodogram

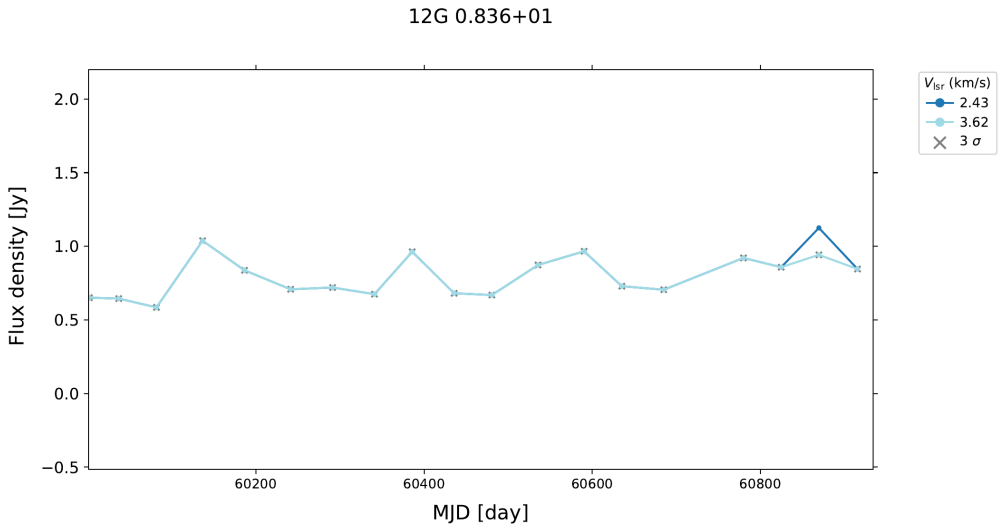


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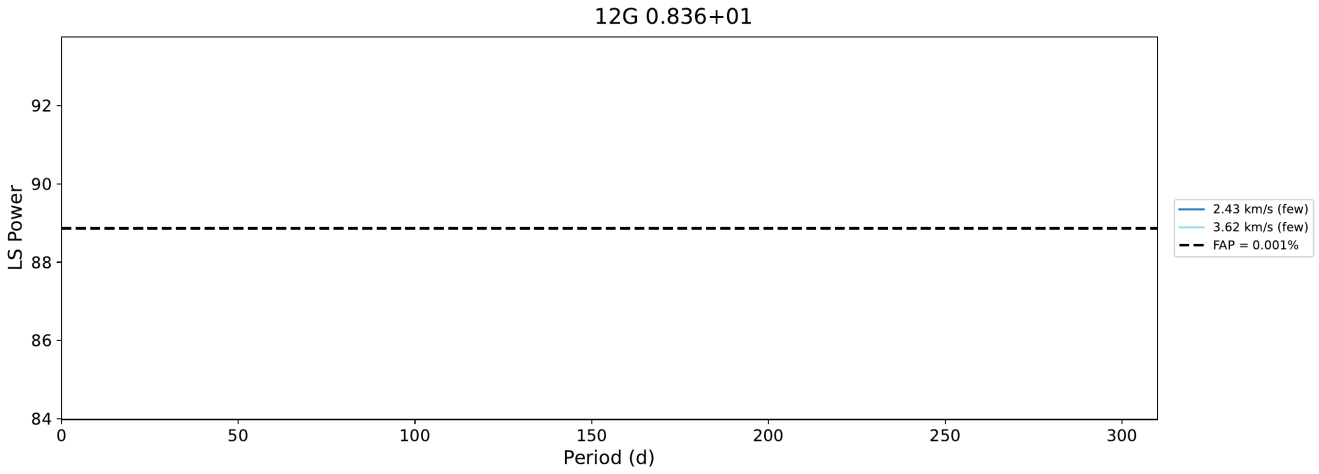


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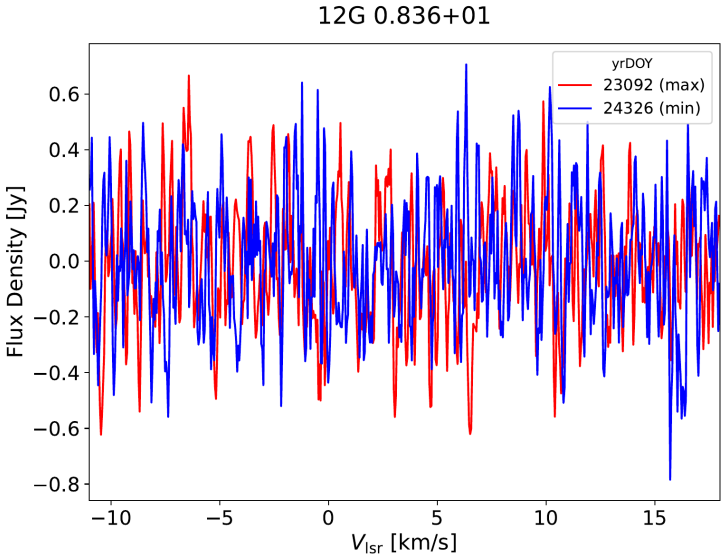
Light curve



Periodogram

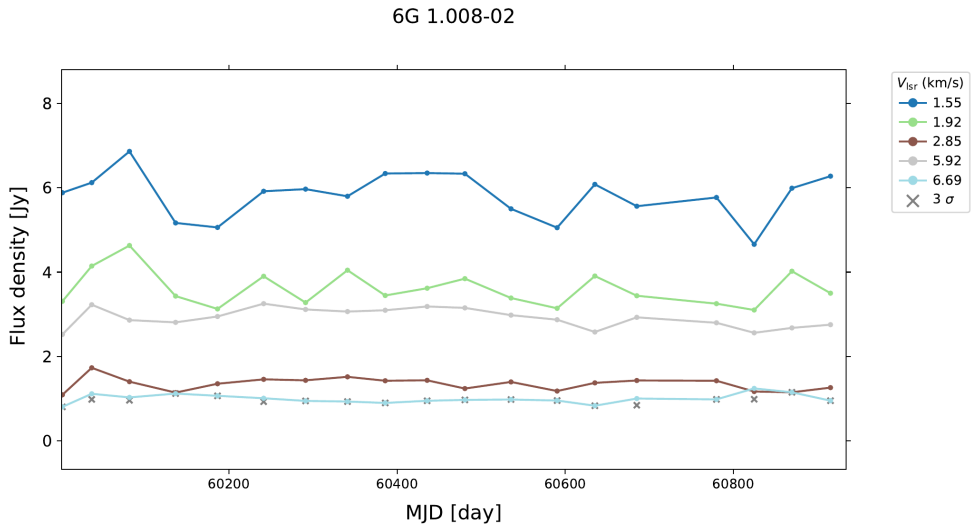


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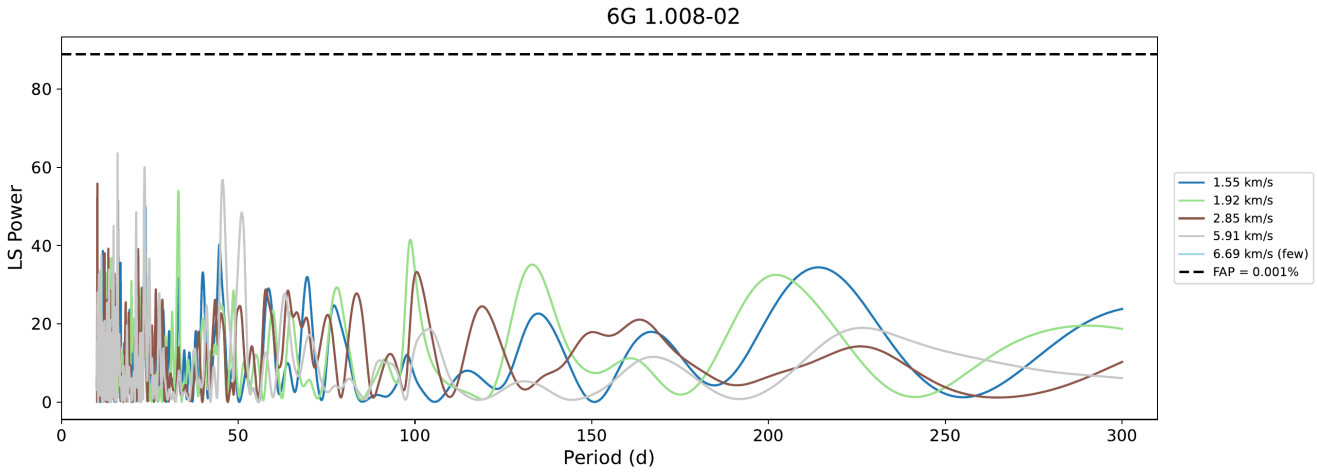


6G 1.008-02

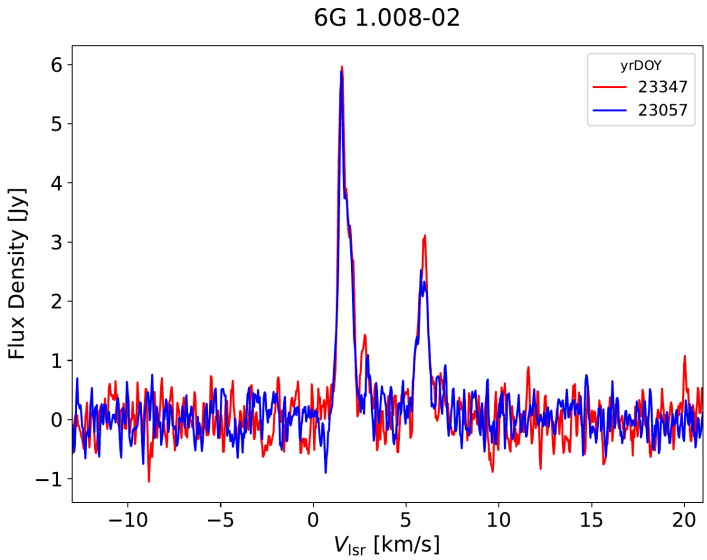
Light curve



Periodogram

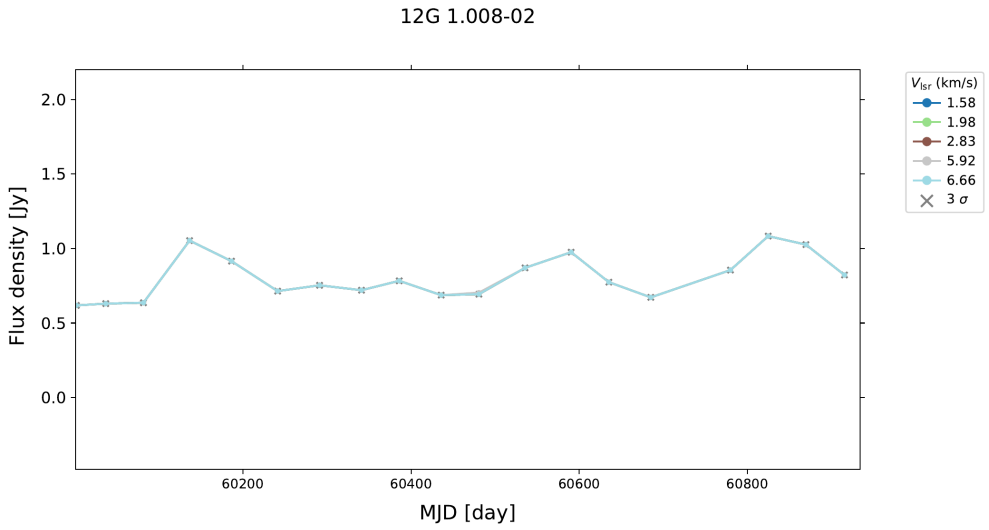


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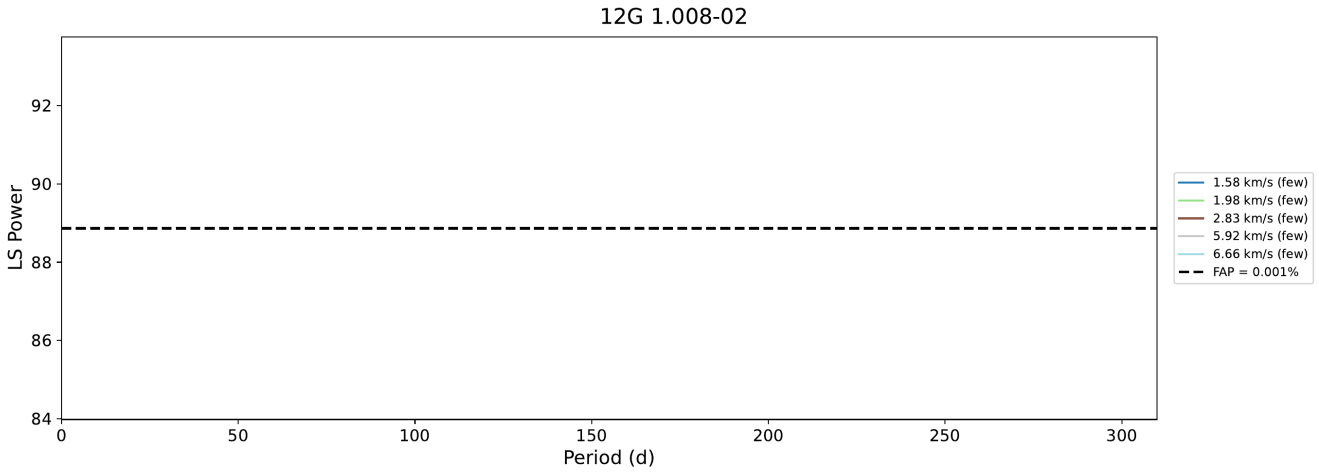


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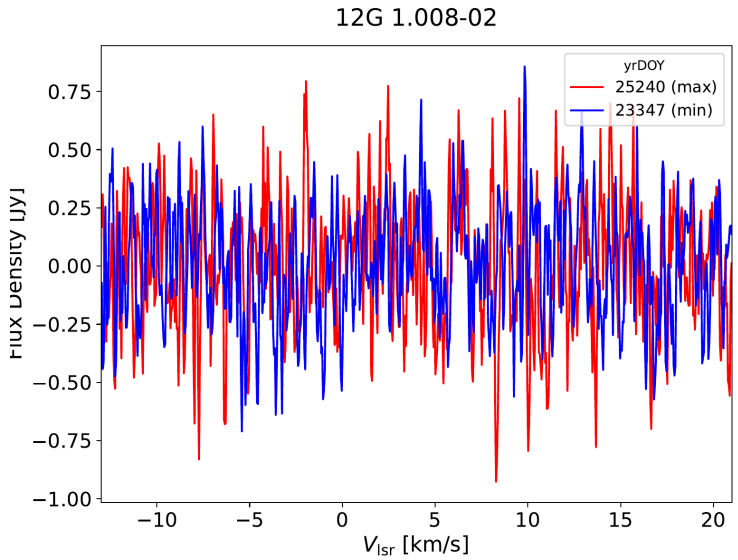
Light curve



Periodogram

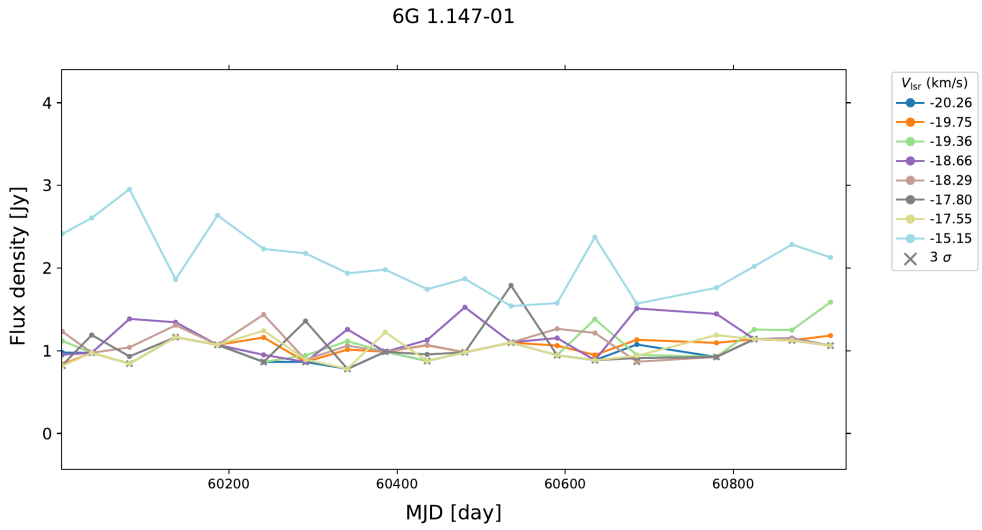


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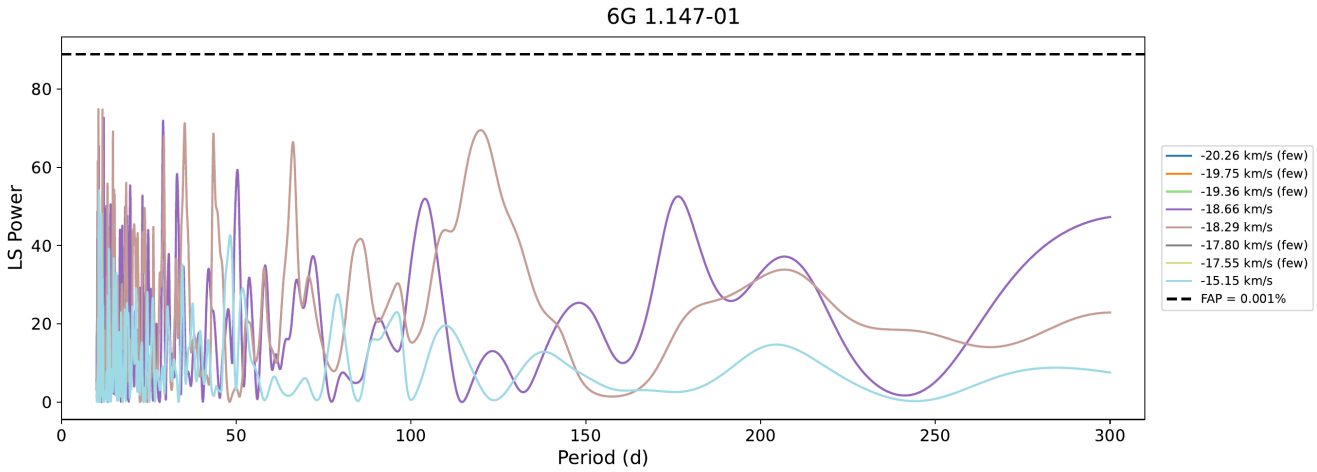


6G 1.147-01

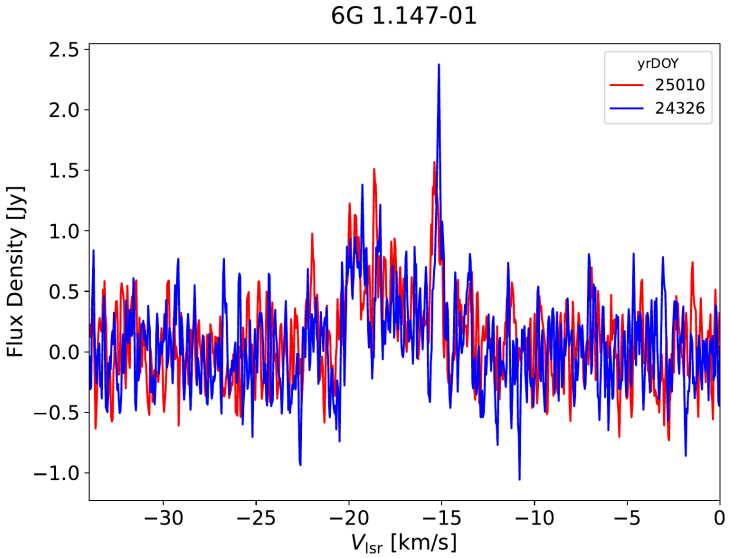
Light curve



Periodogram

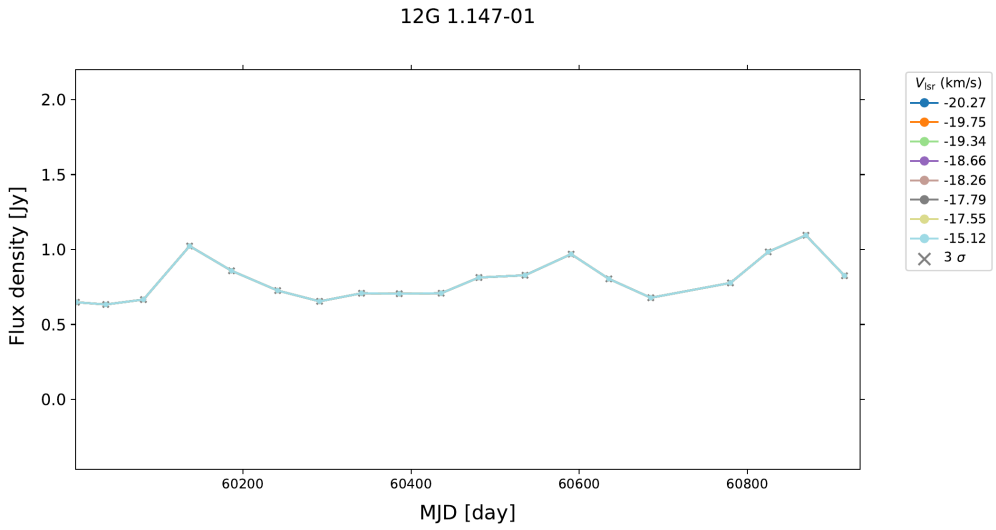


Spectrum

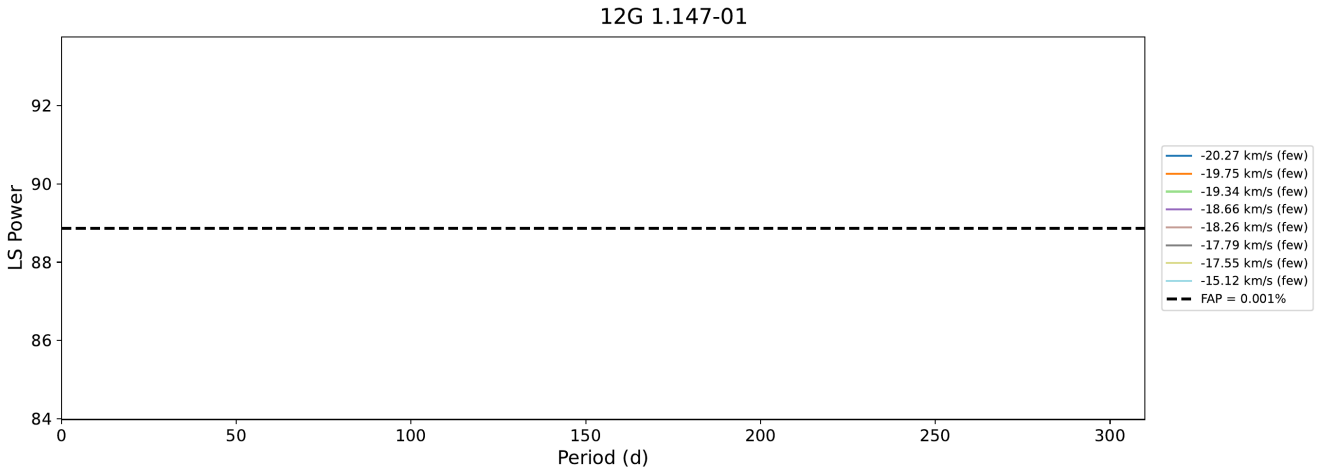


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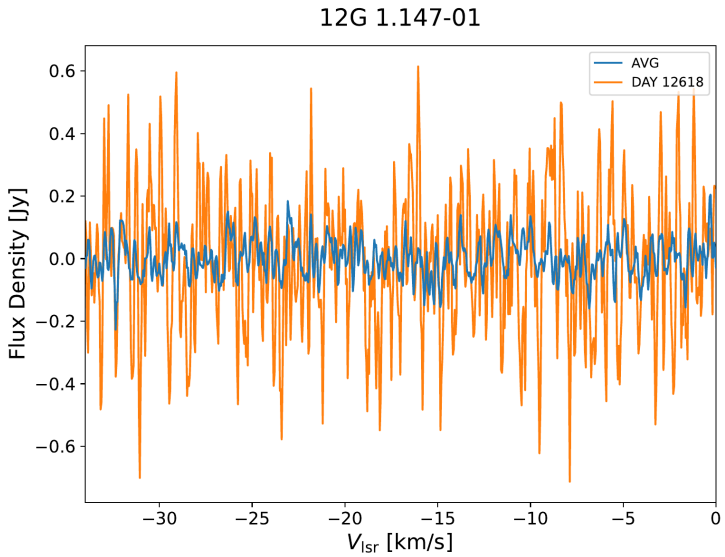
Light curve



Periodogram

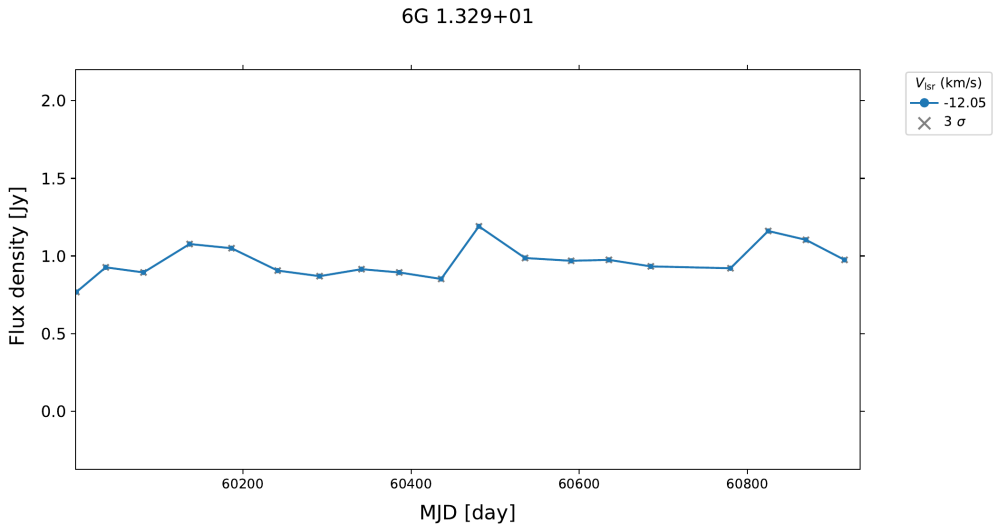


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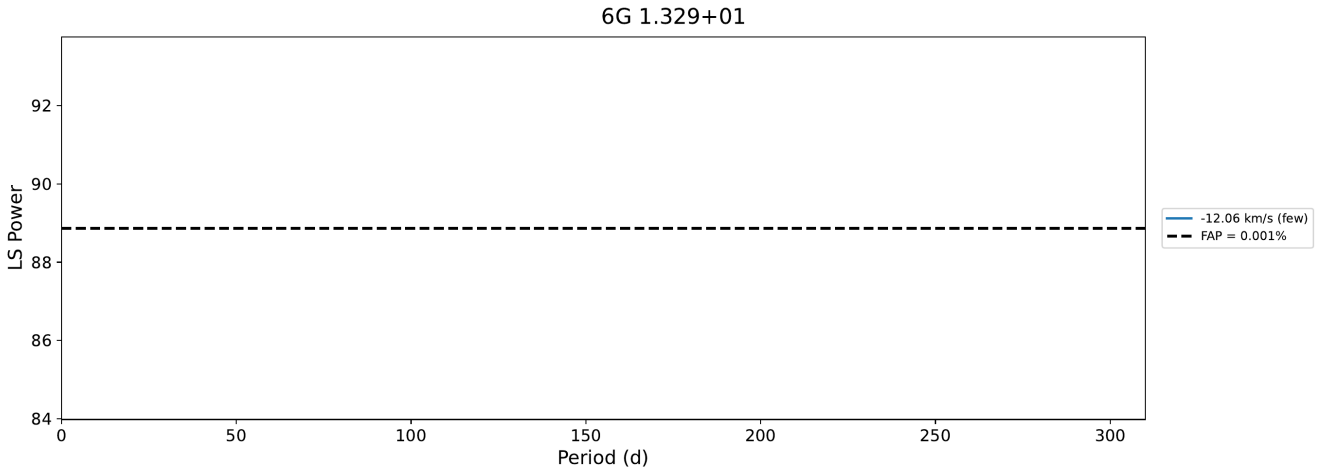


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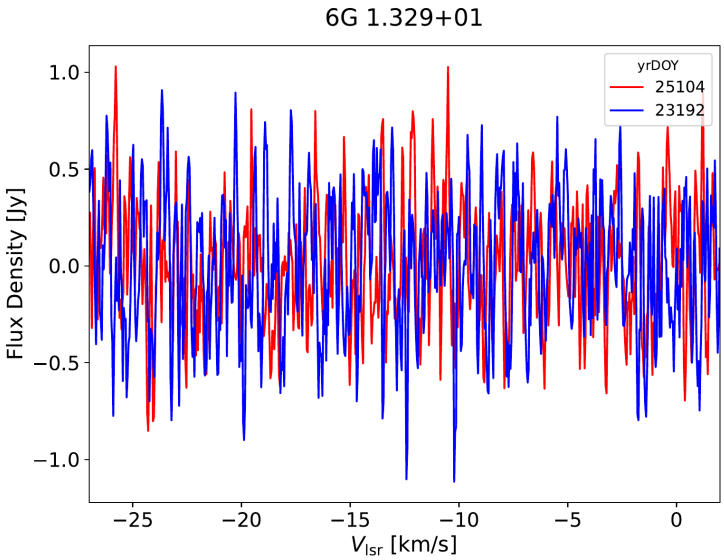
Light curve



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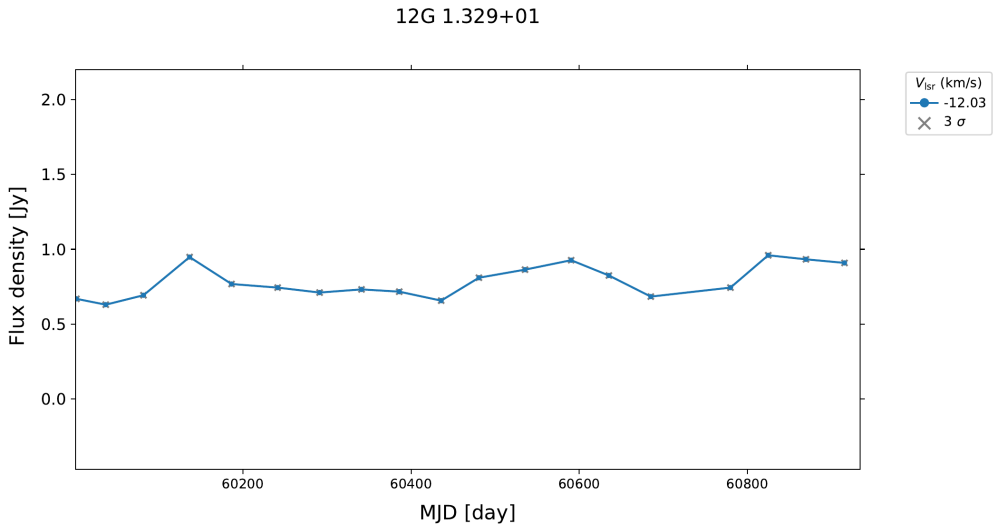


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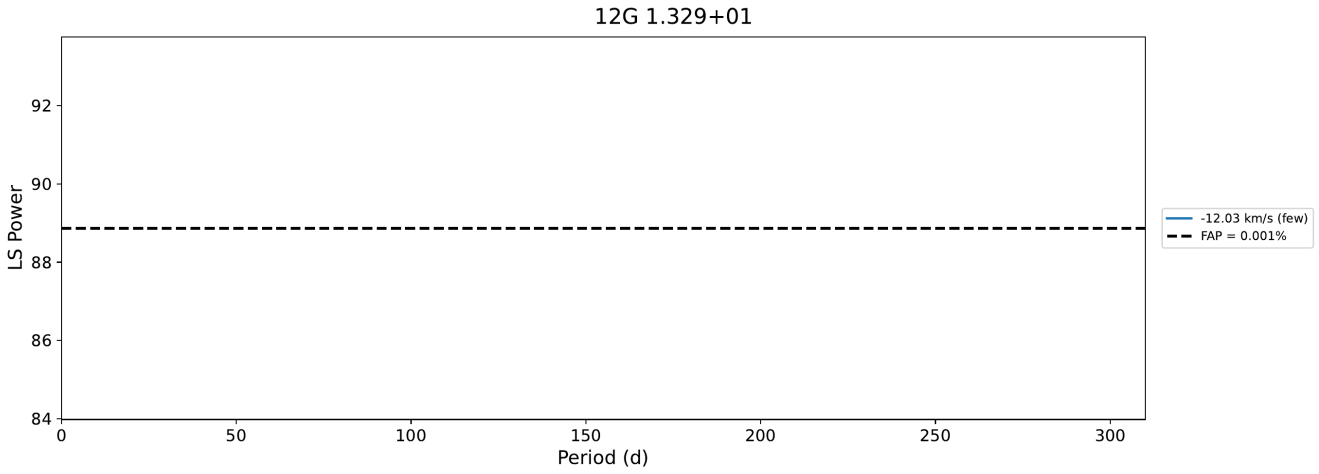


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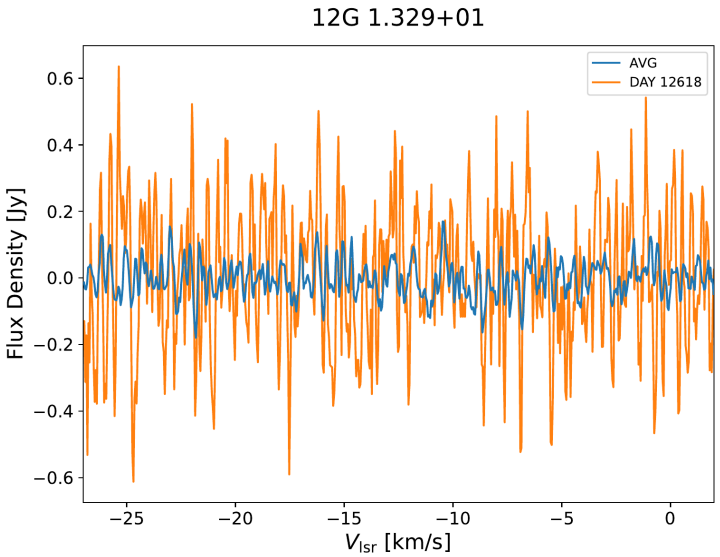
Light curve



Periodogram

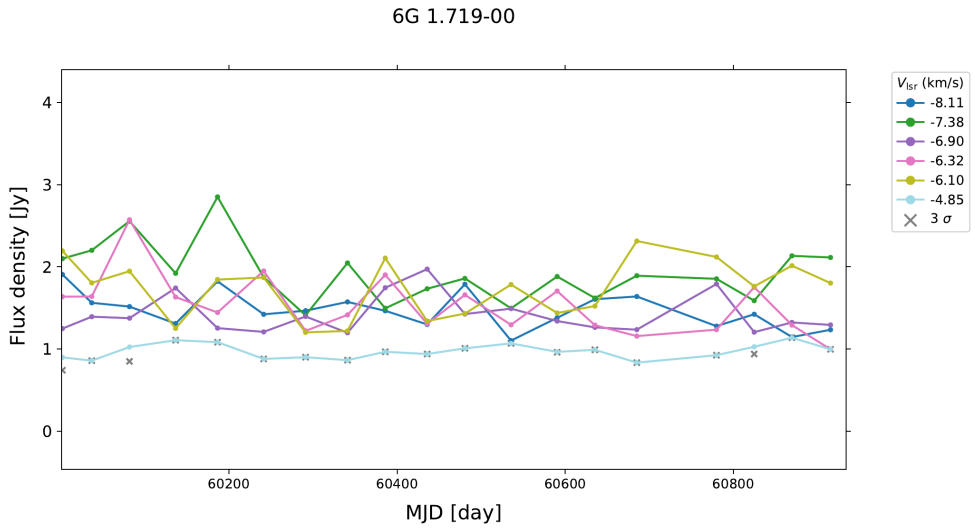


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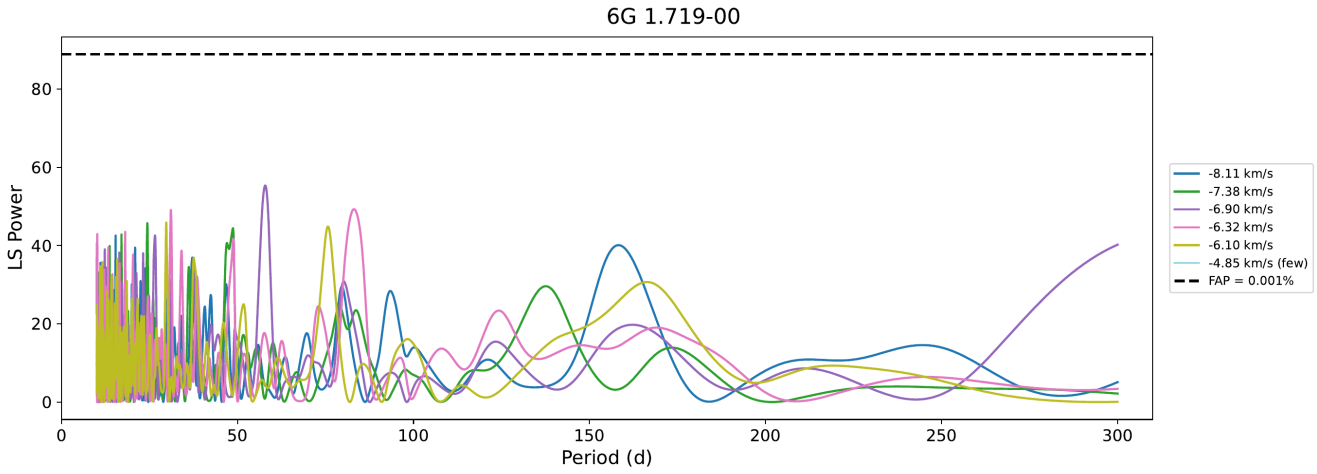


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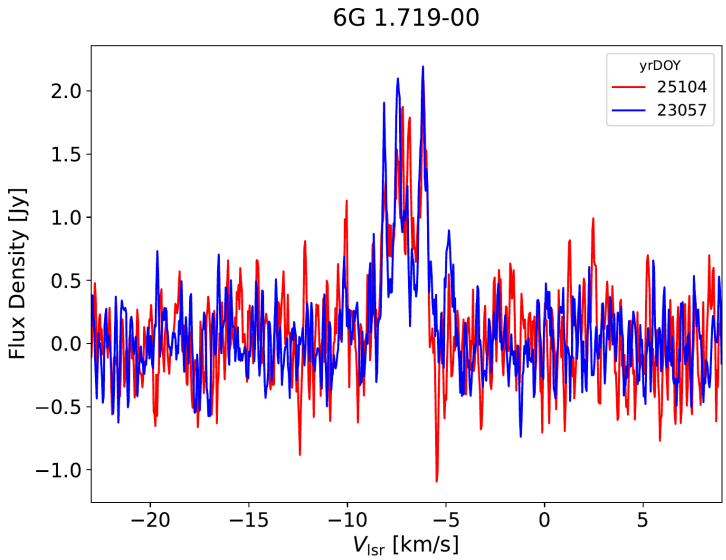
Light curve



Periodogram

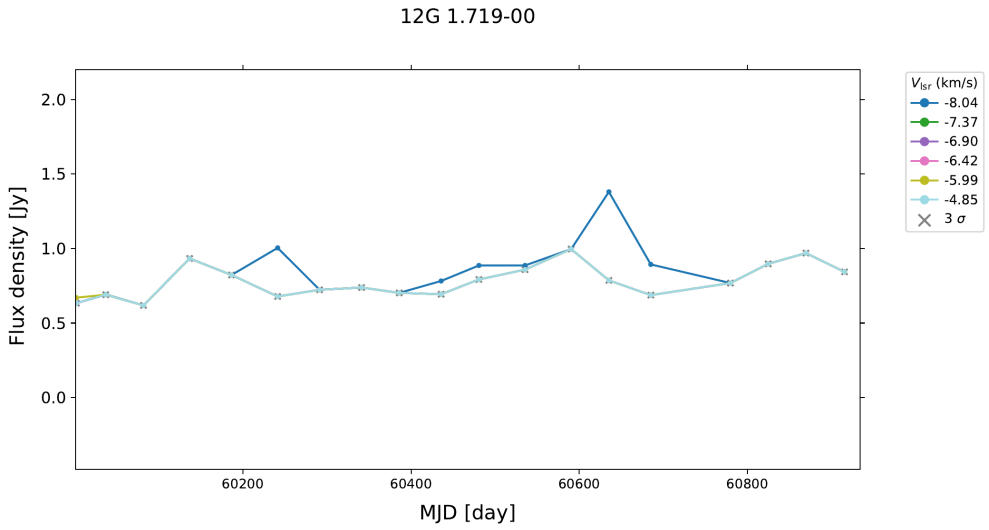


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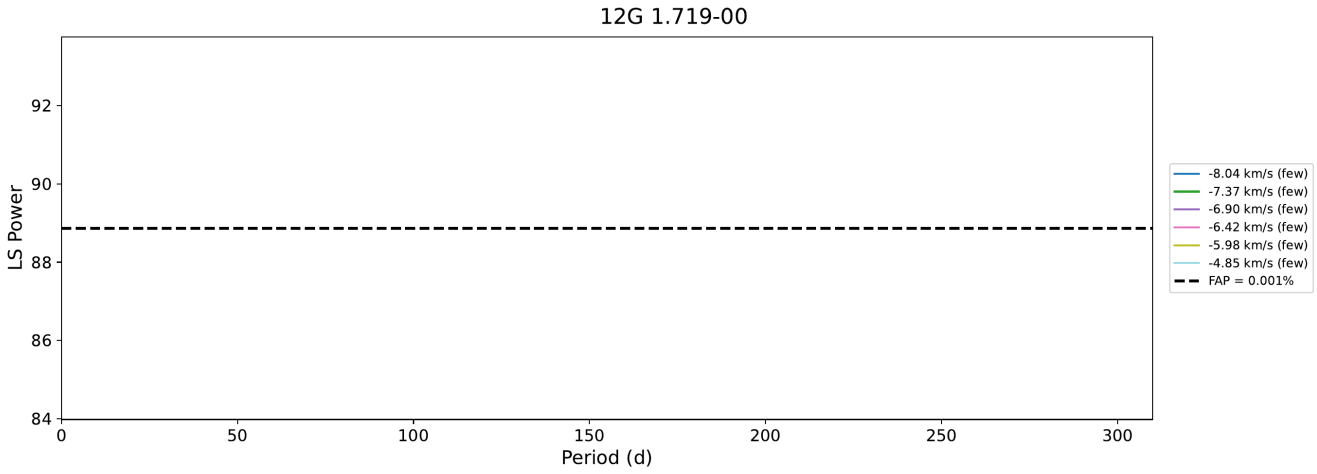


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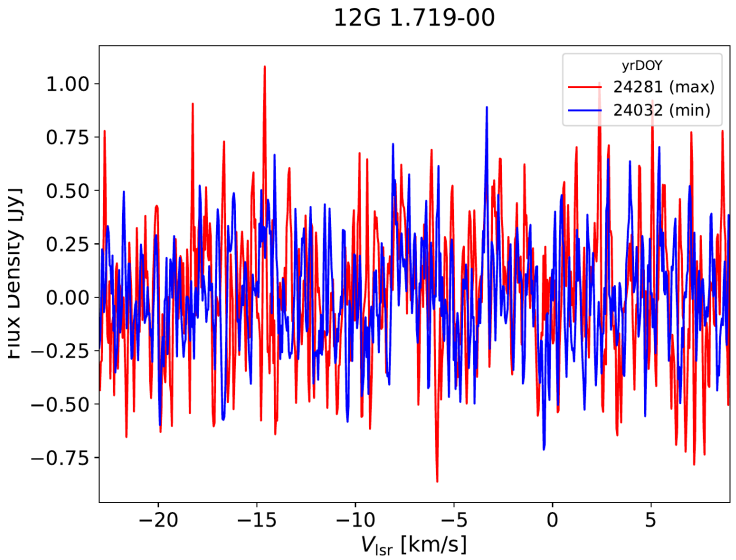
Light curve



Periodogram

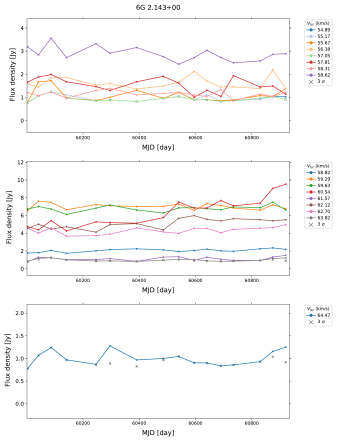


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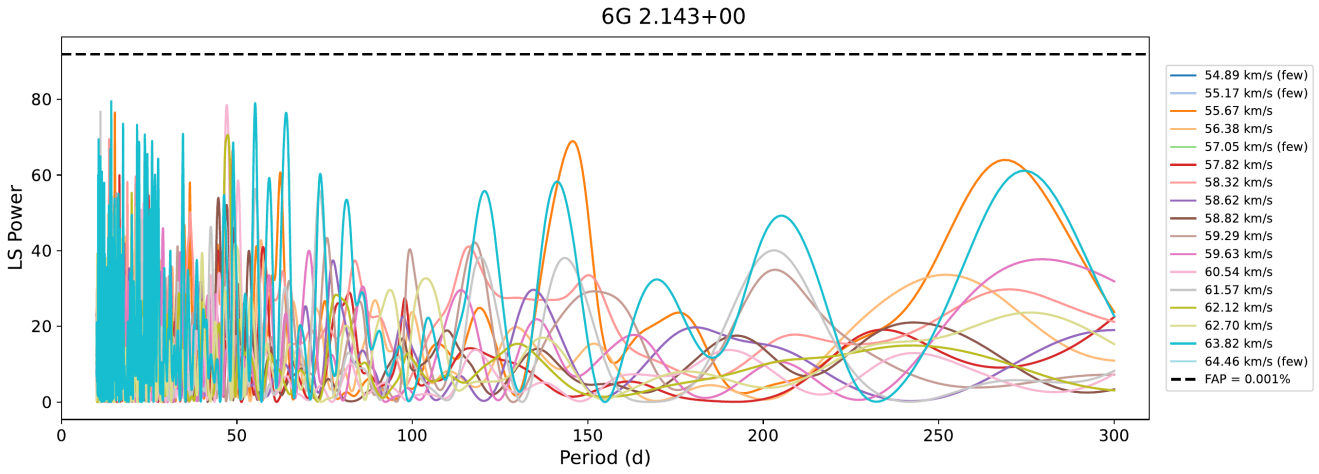


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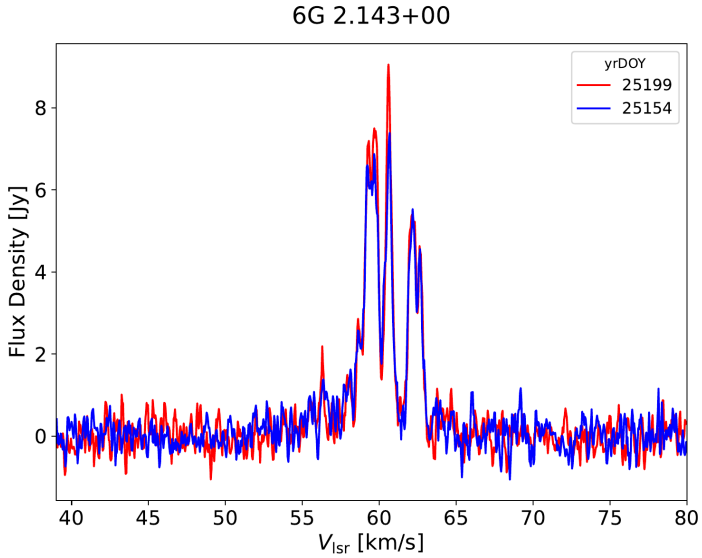
Light curve



Periodogram

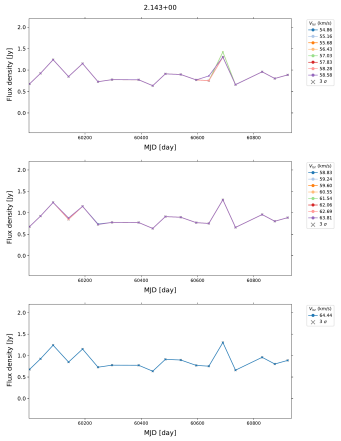


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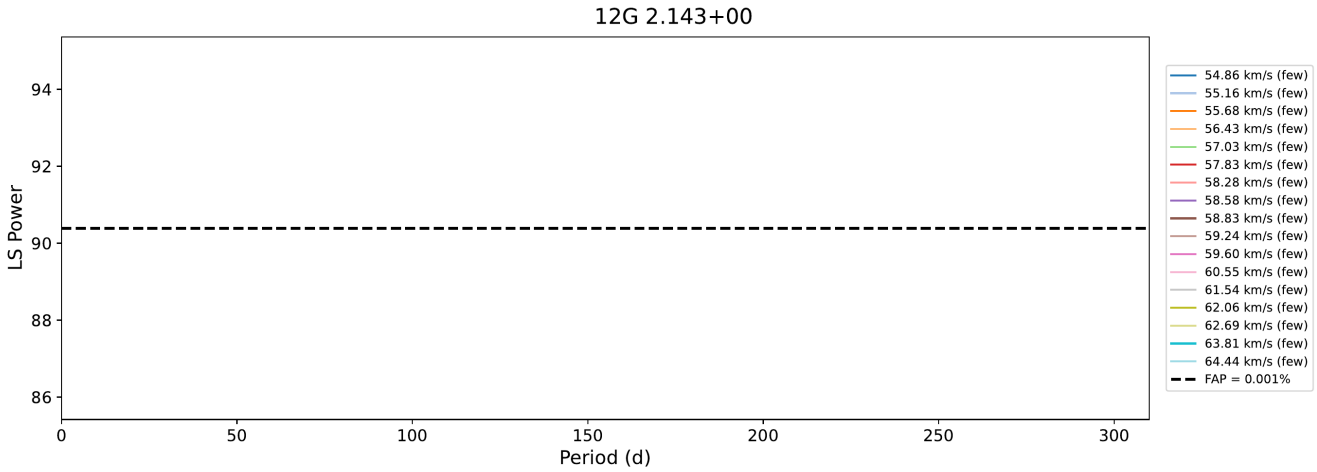


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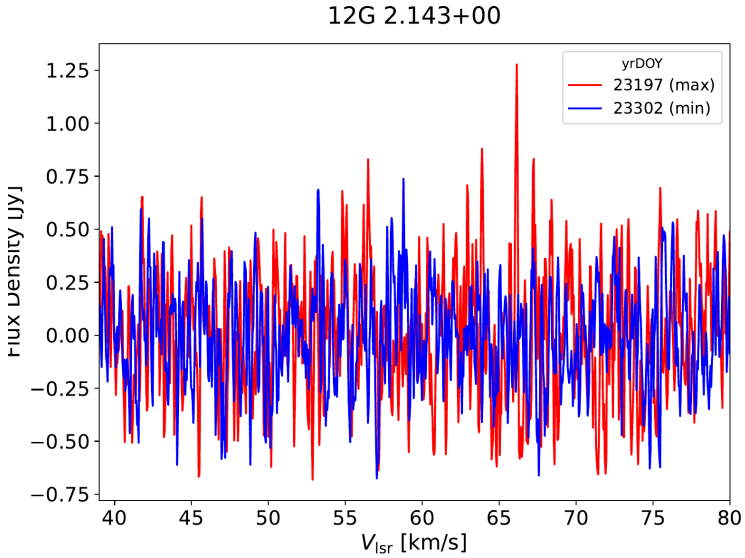
Light curve



Periodogram

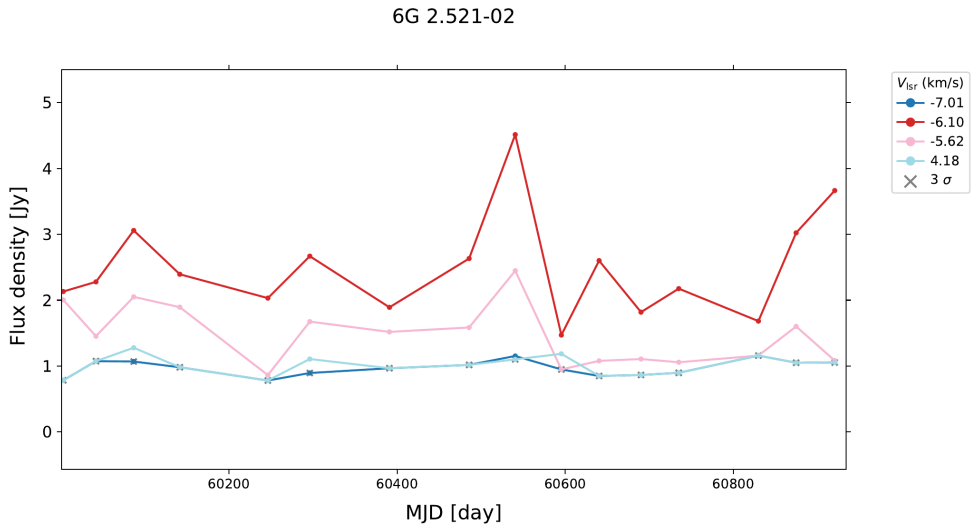


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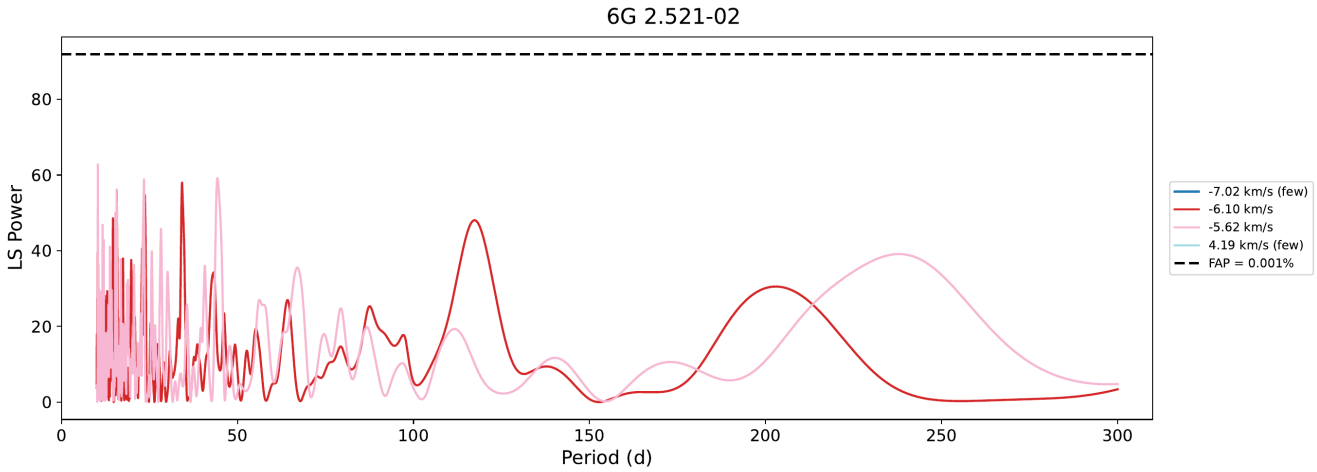


6G 2.521-02

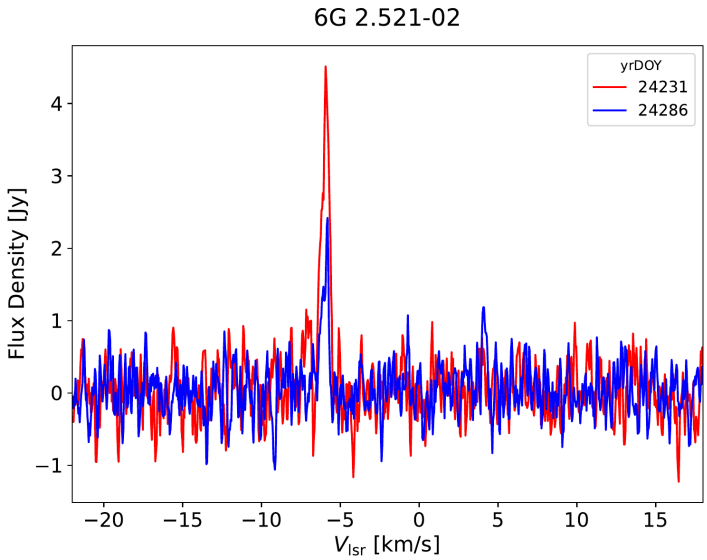
Light curve



Periodogram

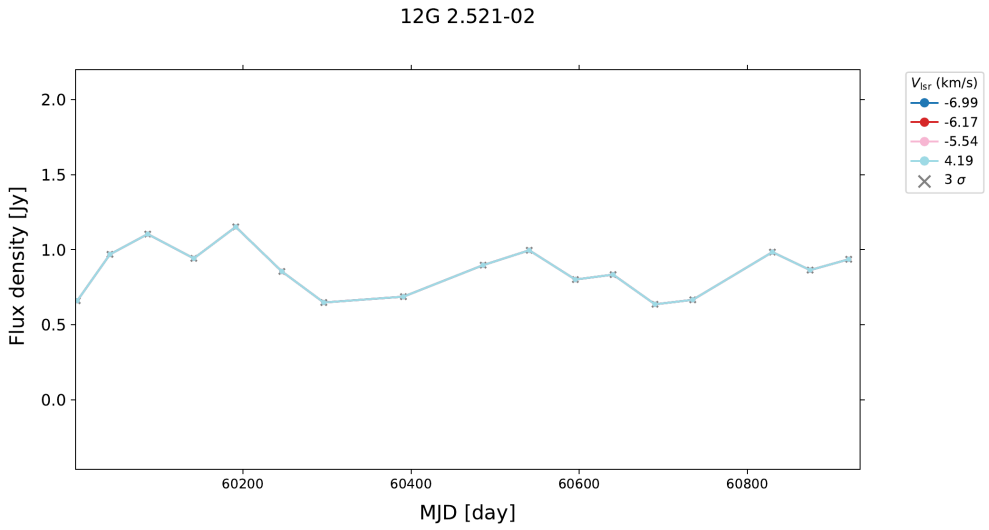


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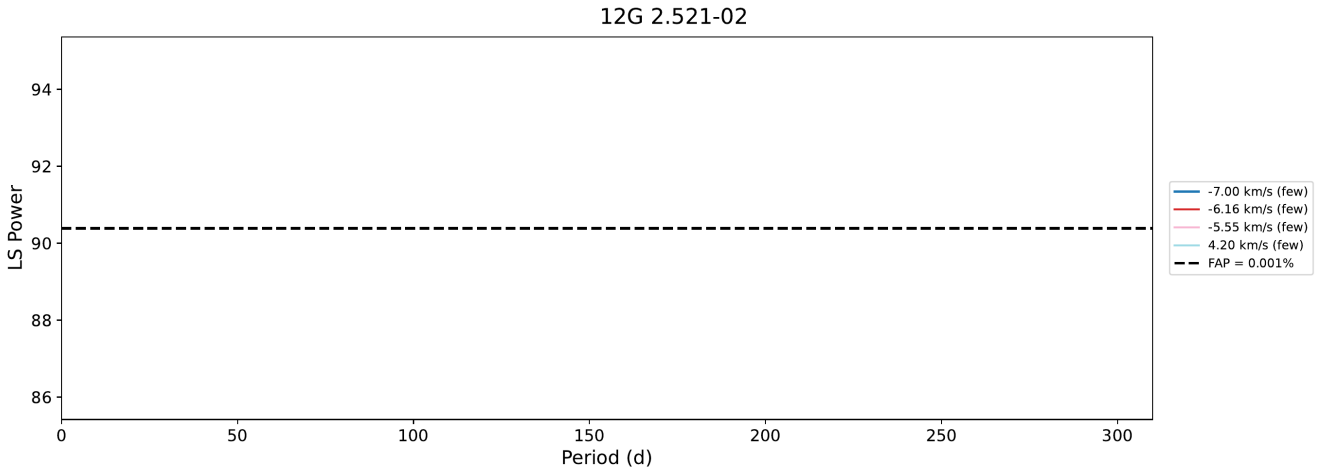


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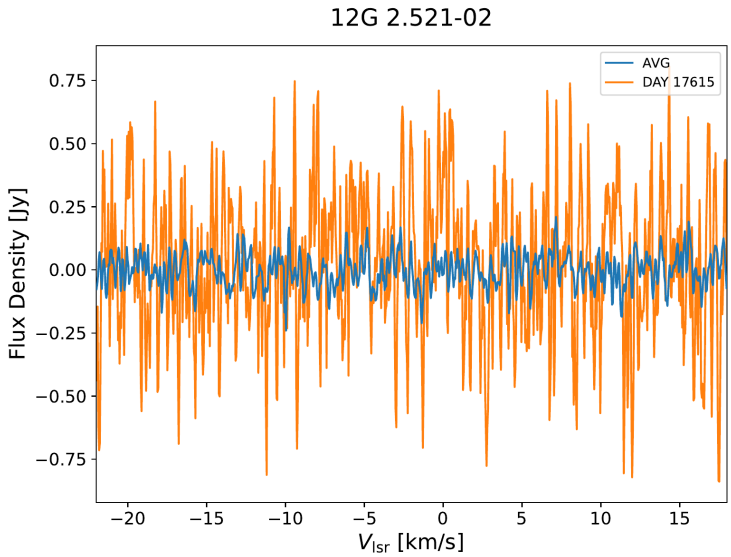
Light curve



Periodogram

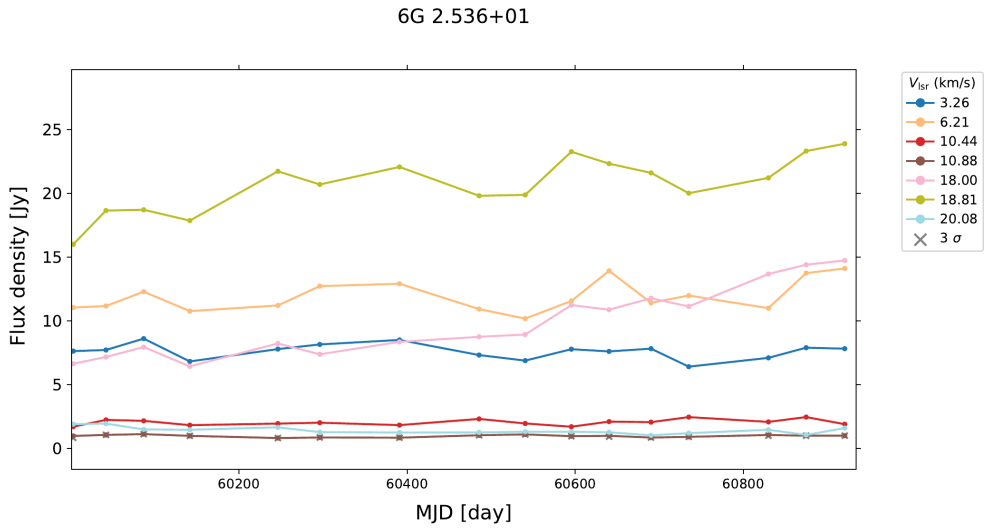


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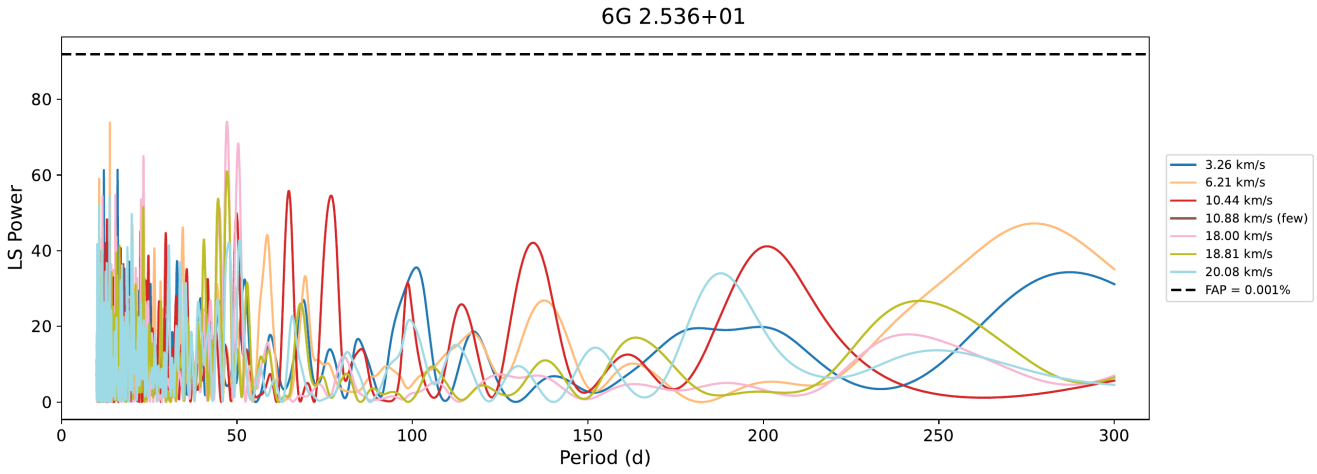


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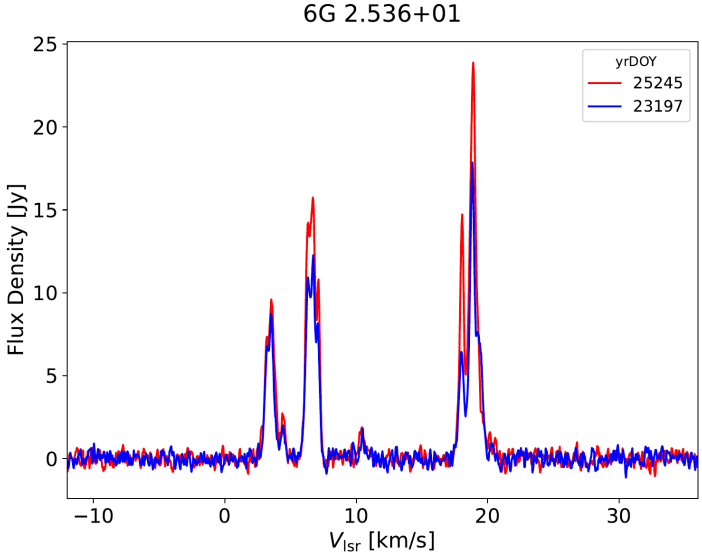
Light curve



Periodogram

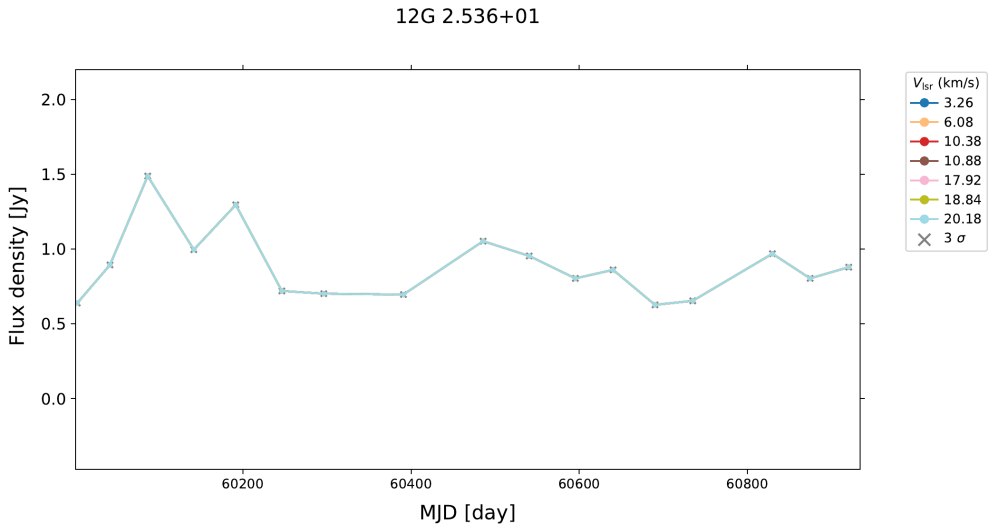


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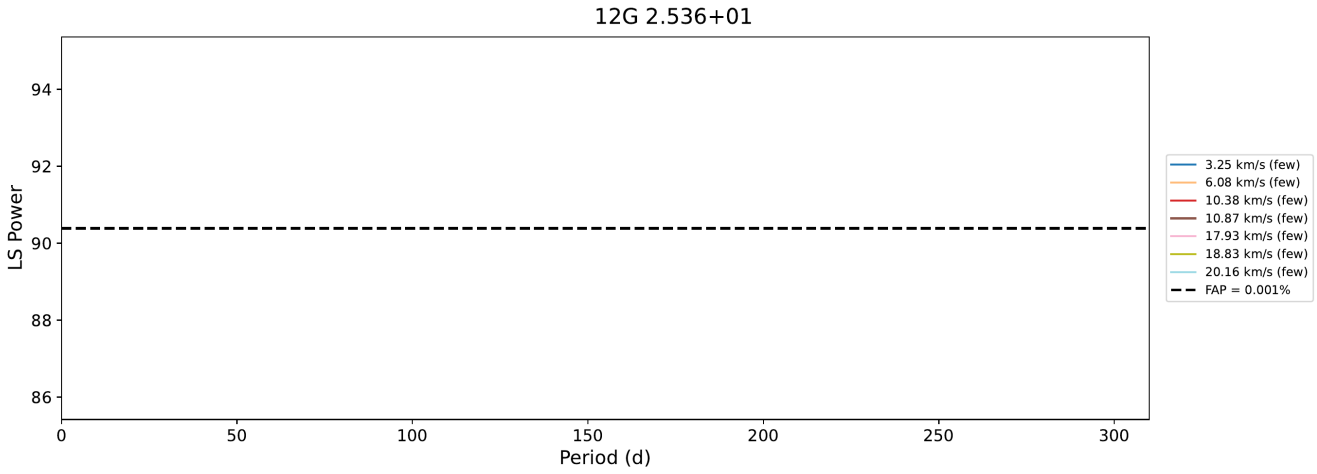


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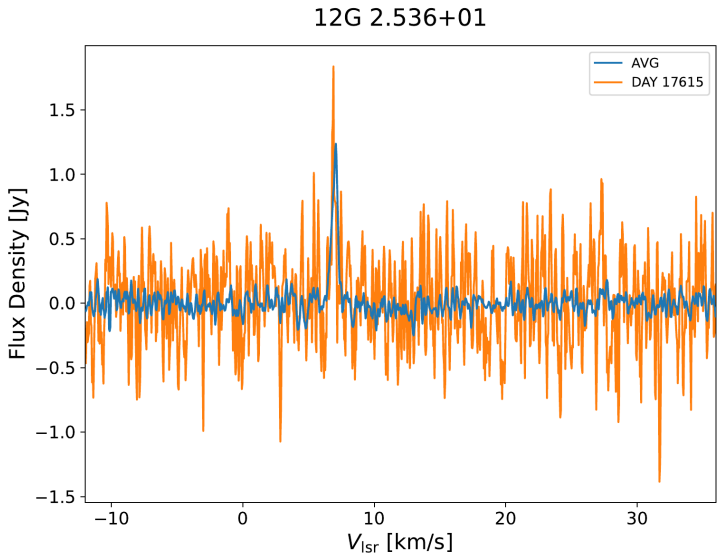
Light curve



Periodogram

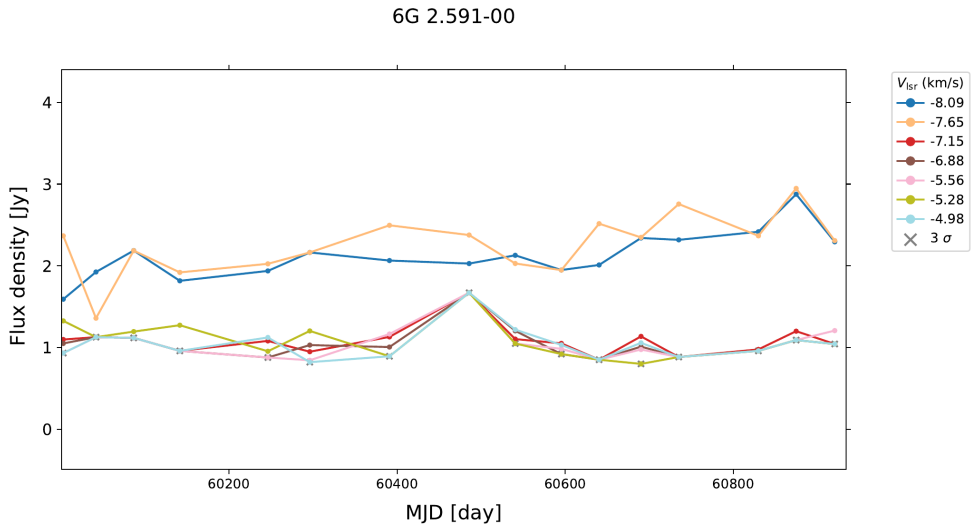


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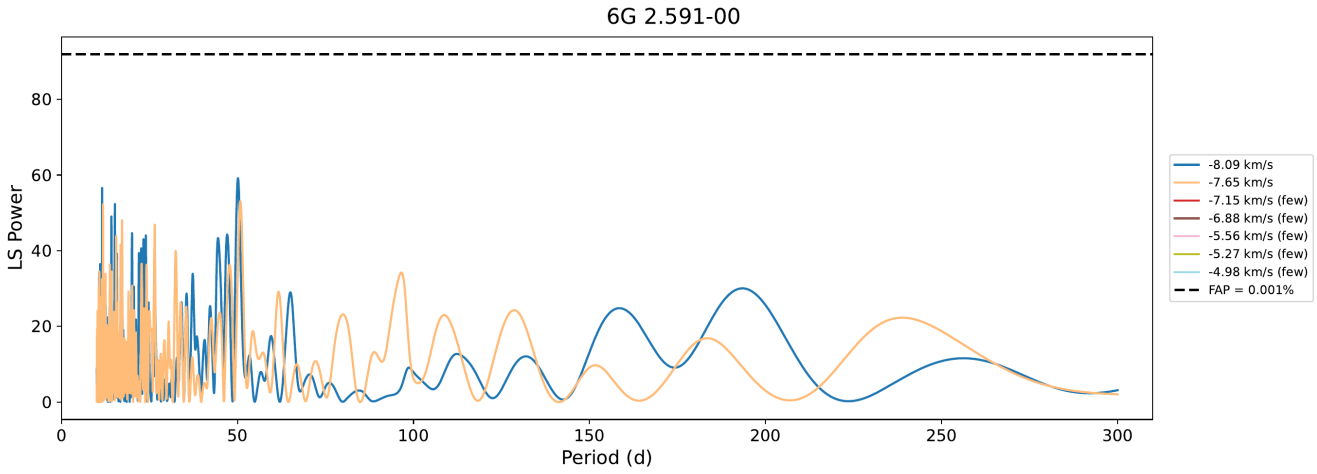


6G 2.591-00

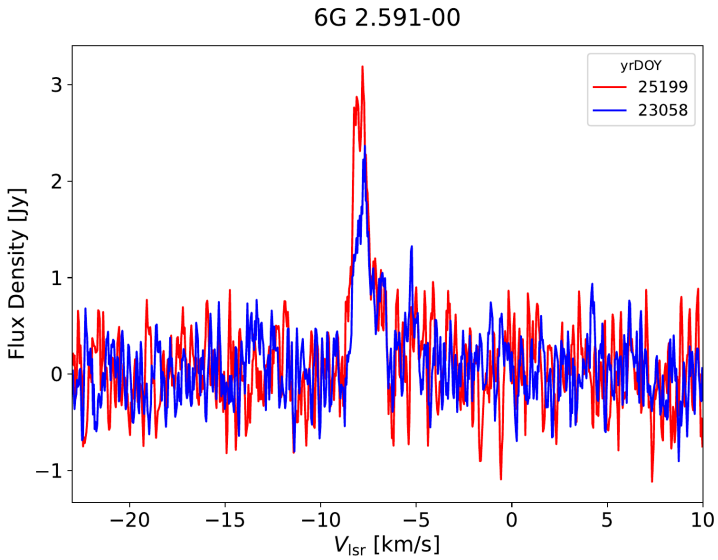
Light curve



Periodogram

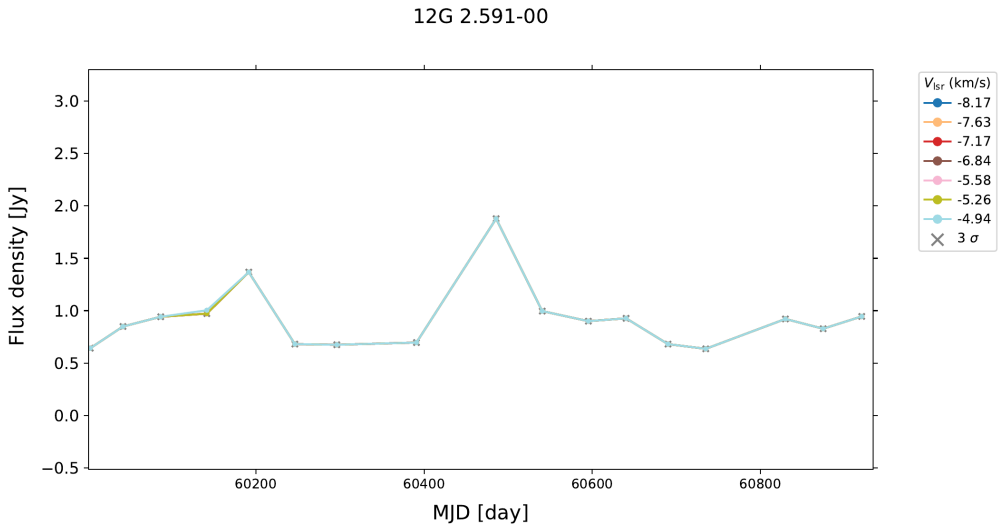


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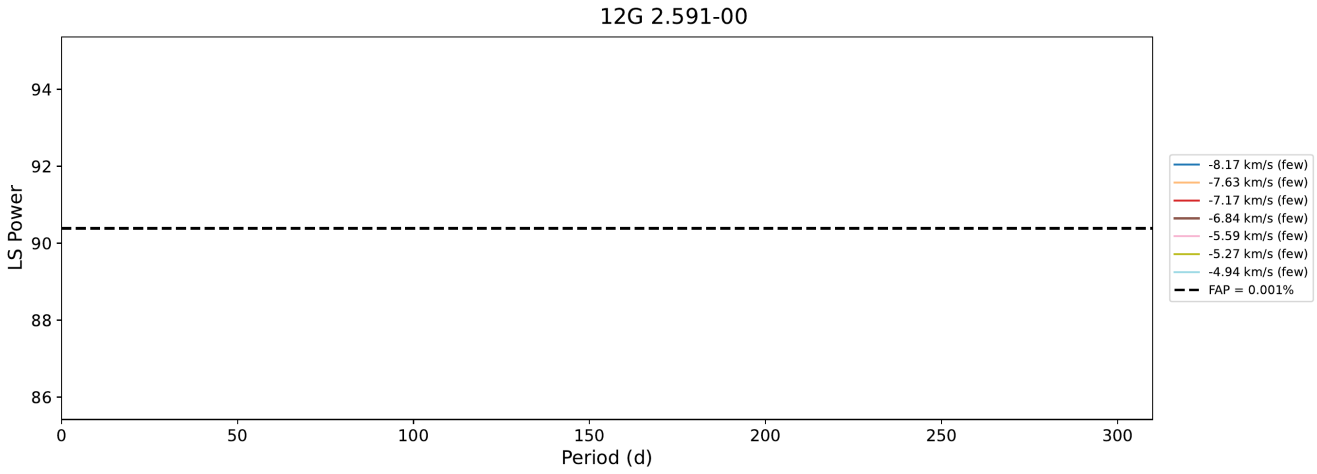


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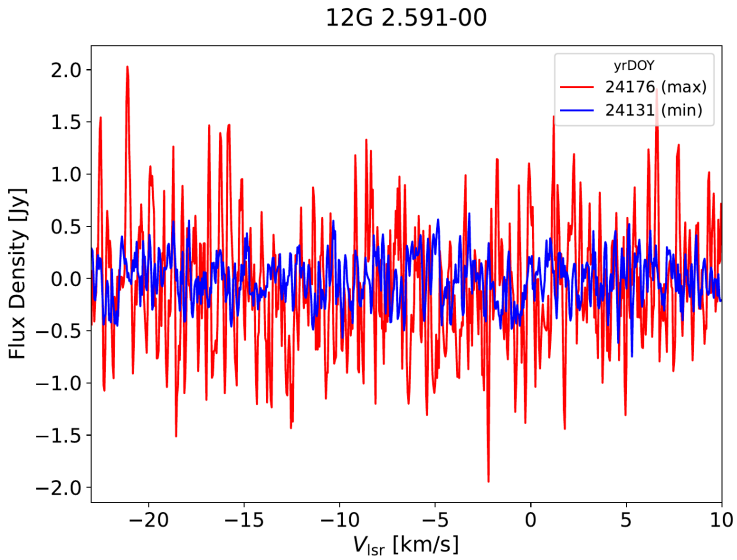
Light curve



Periodogram

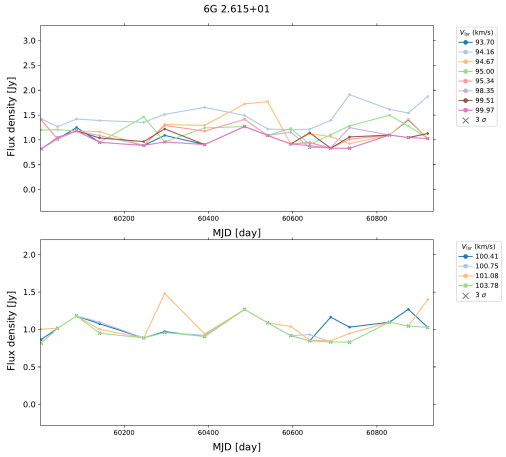


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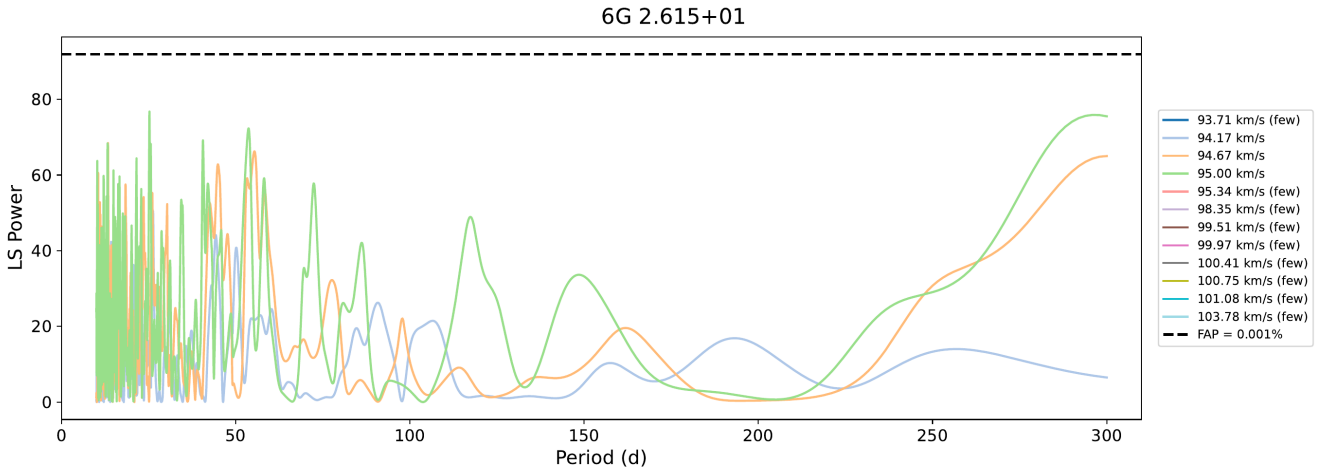


6G 2.615+01

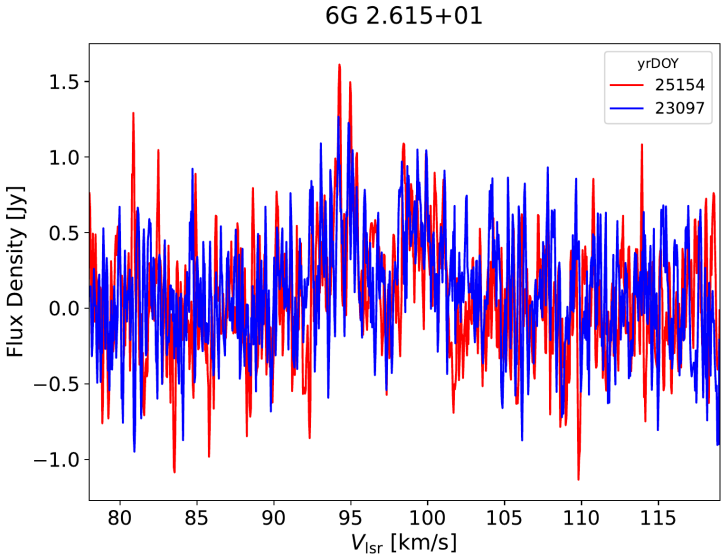
Light curve



Periodogram

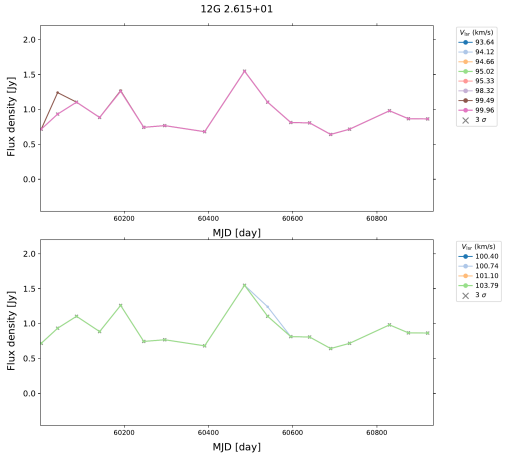


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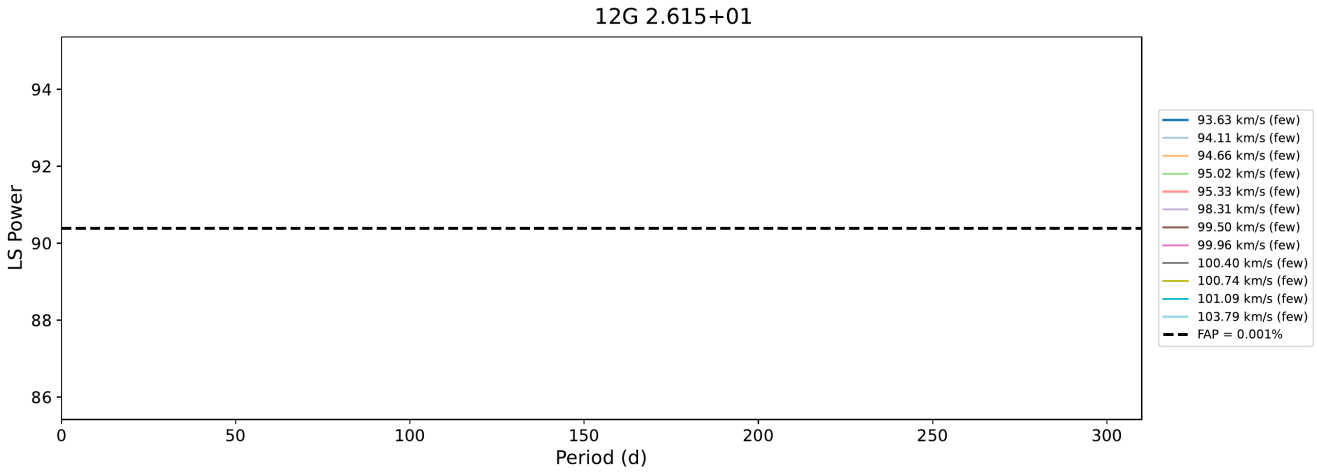


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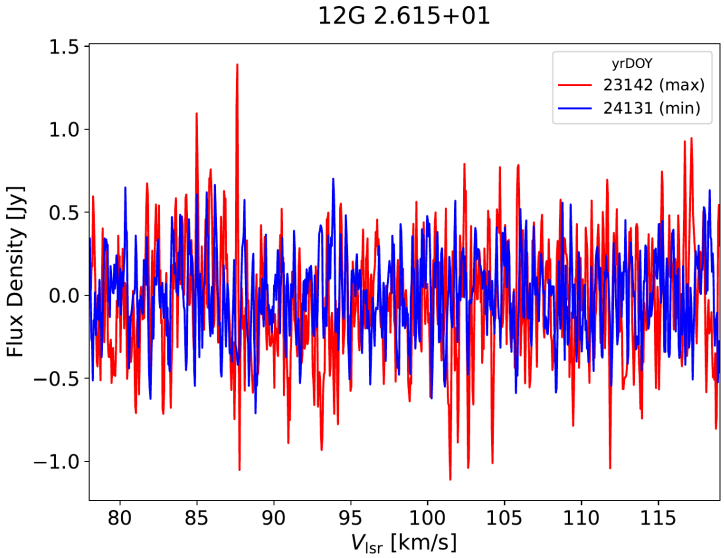
Light curve



Periodogram

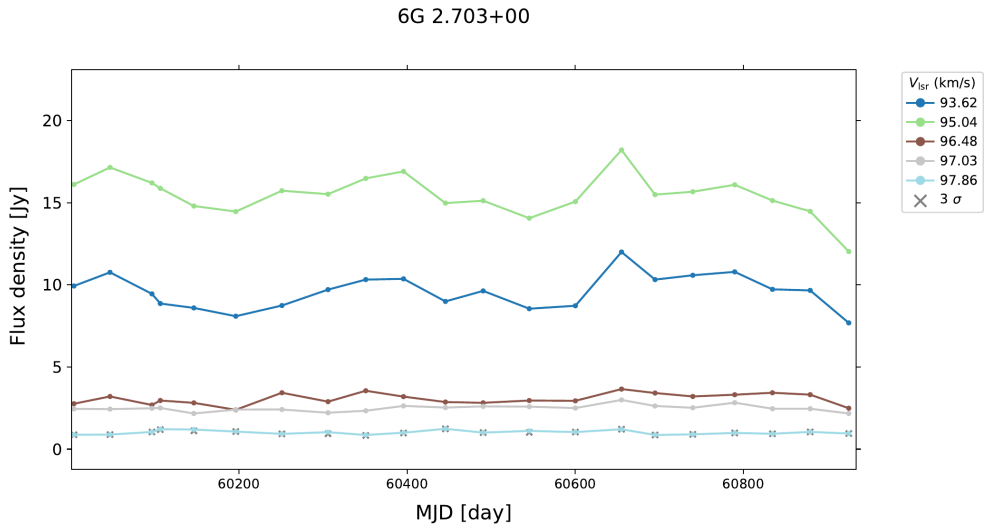


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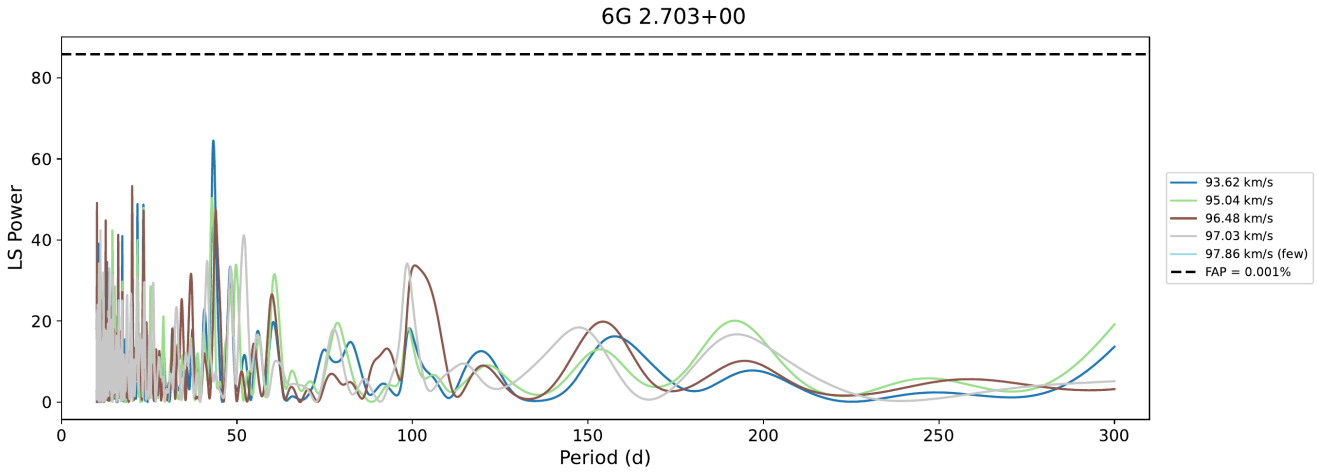


6G 2.703+00

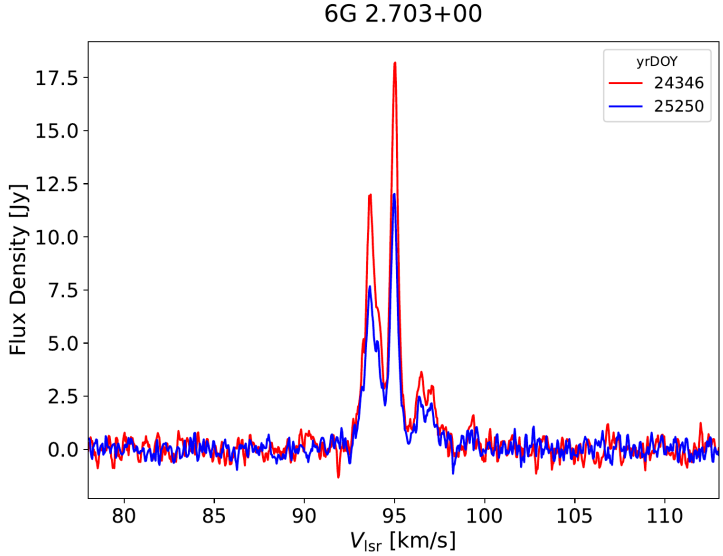
Light curve



Periodogram

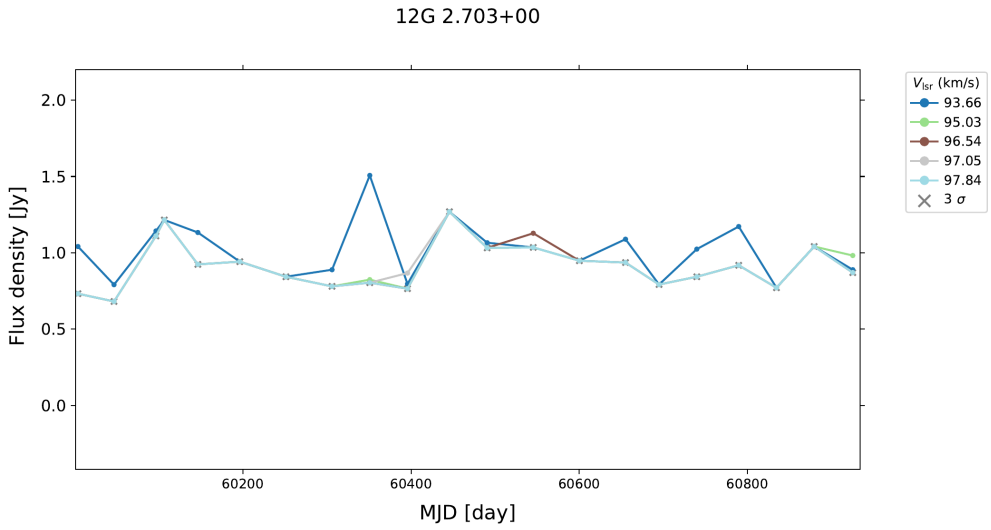


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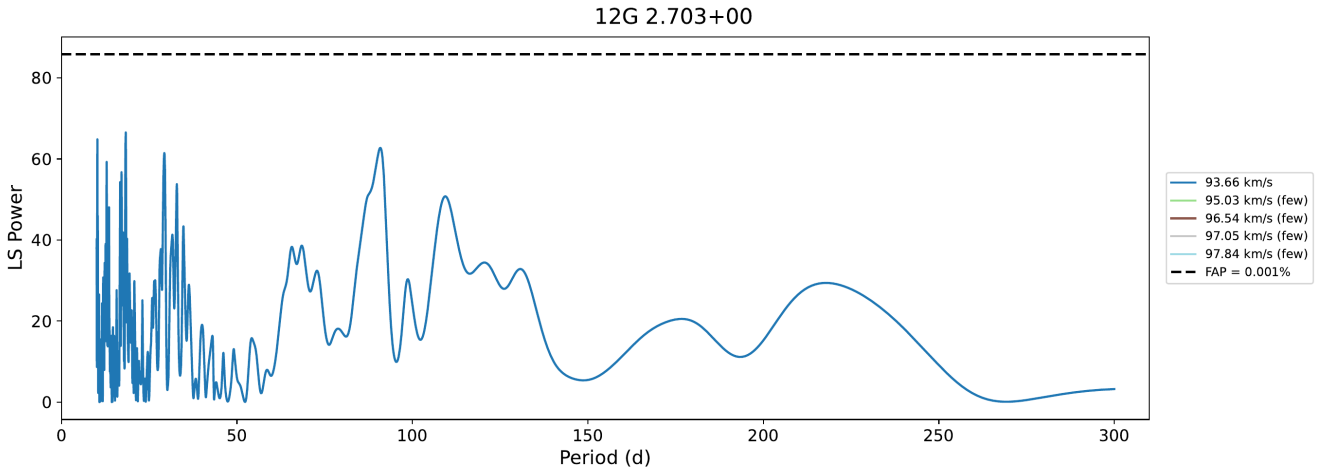


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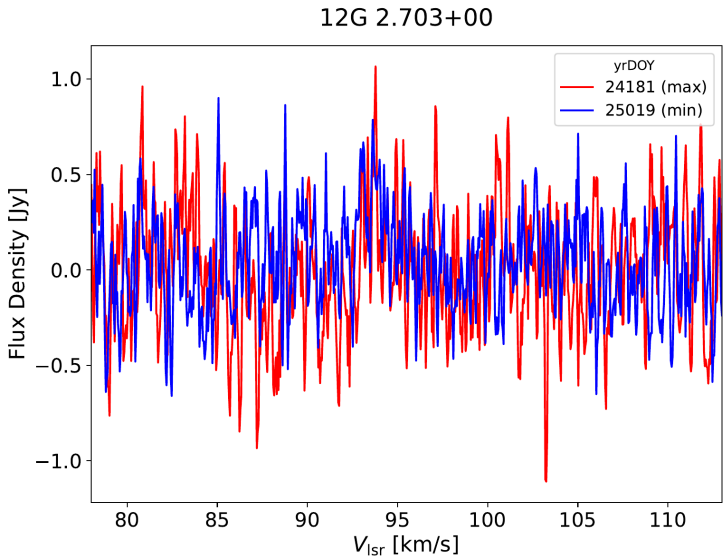
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Periodogram

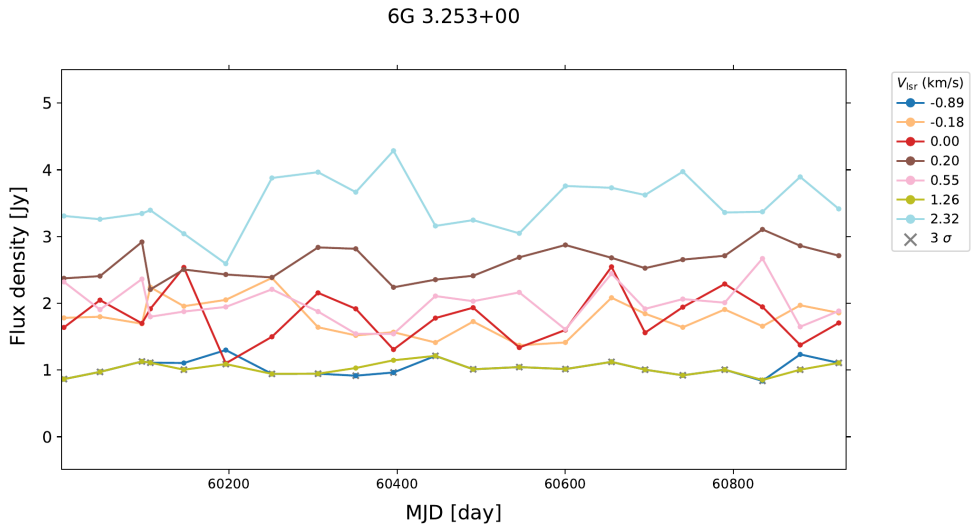


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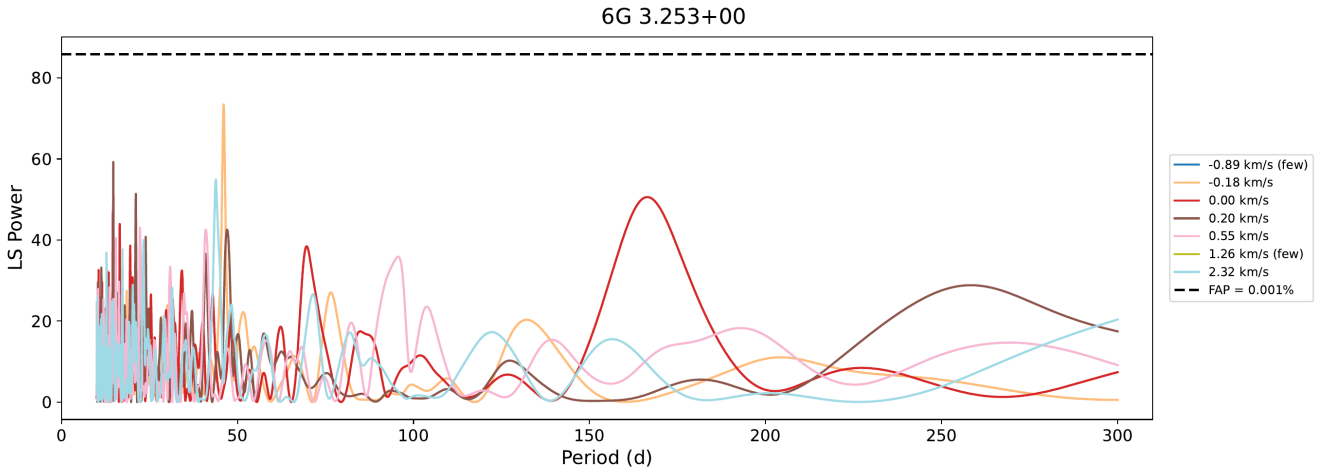


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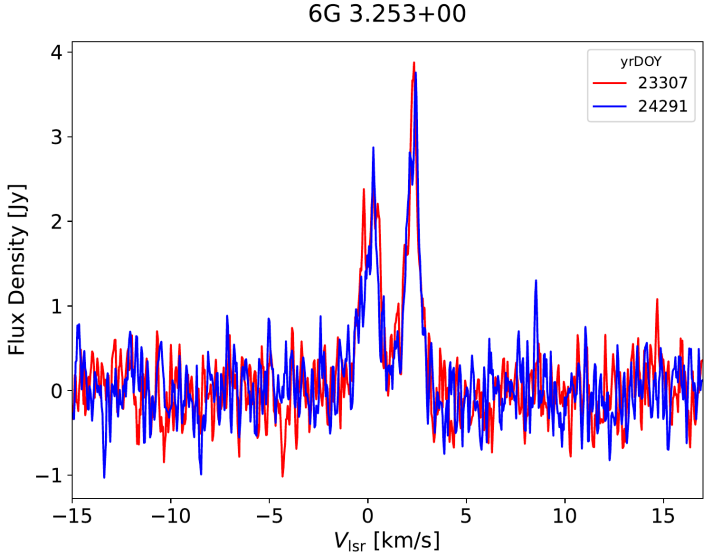
Light curve



Periodogram

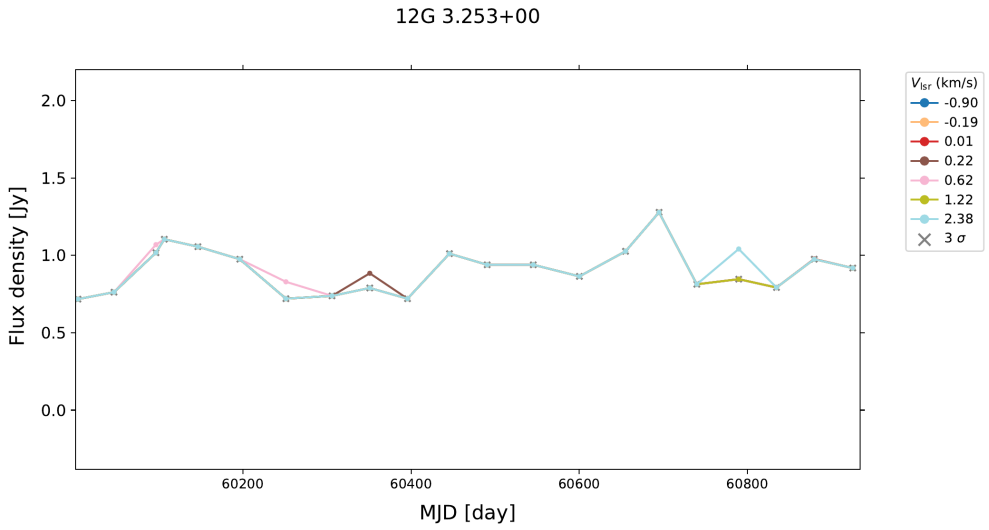


Spectrum

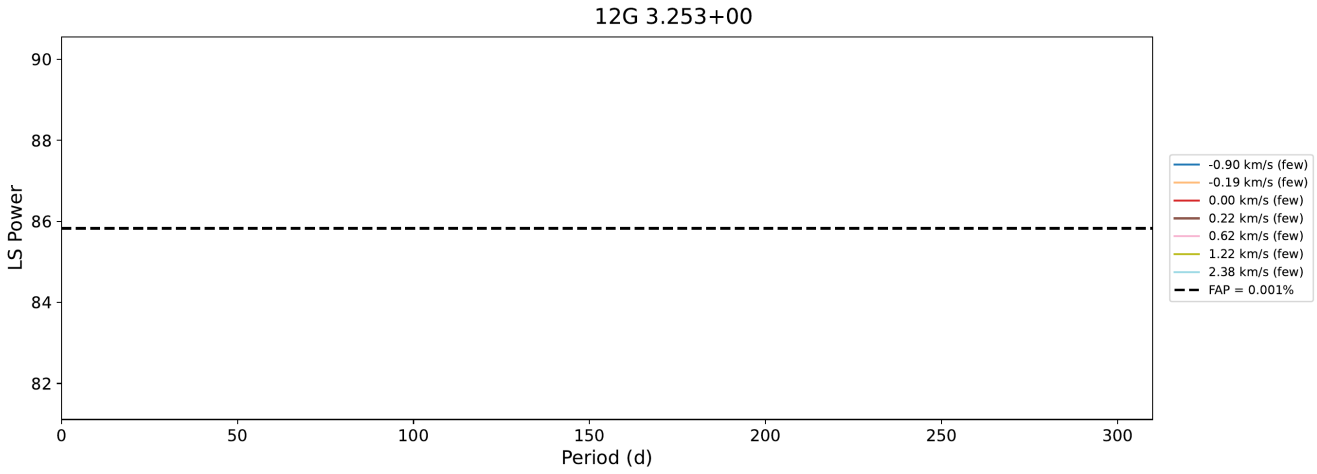


12G 3.253+00

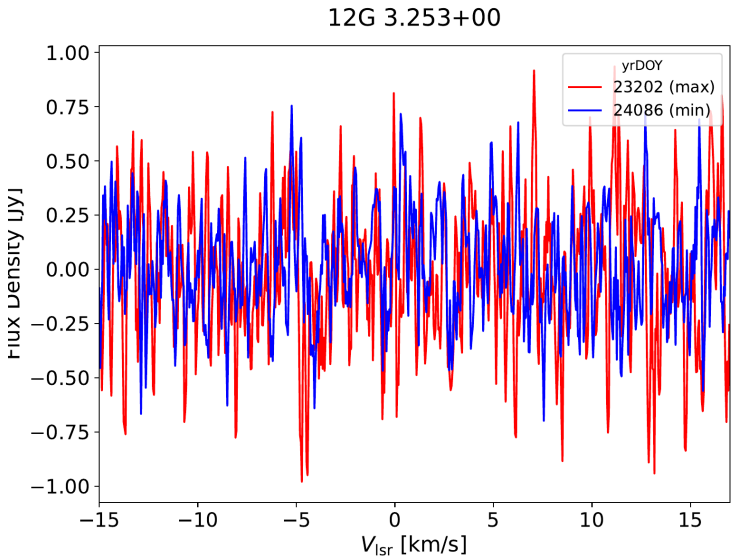
Light curve



Periodogram

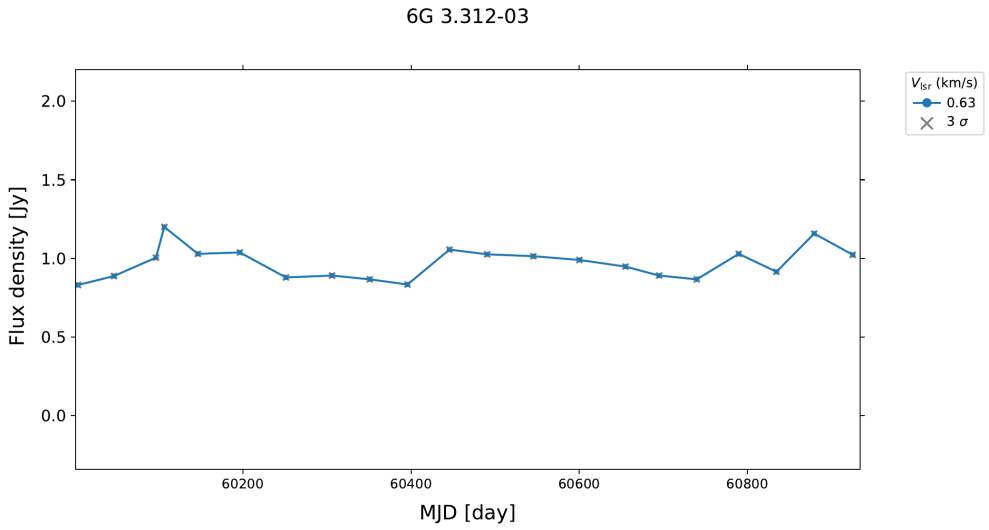


Spectrum

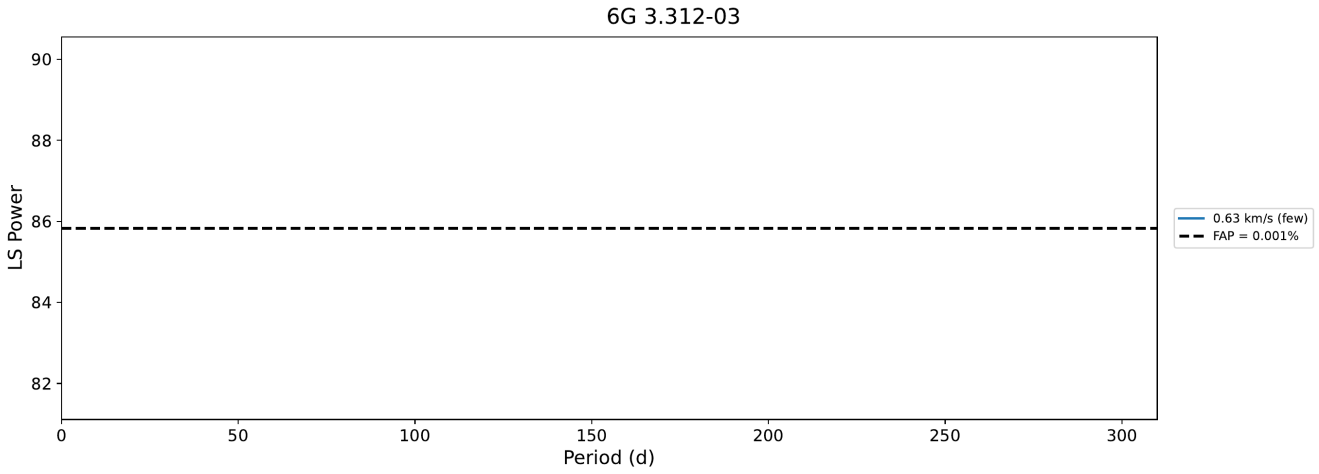


6G 3.312-03

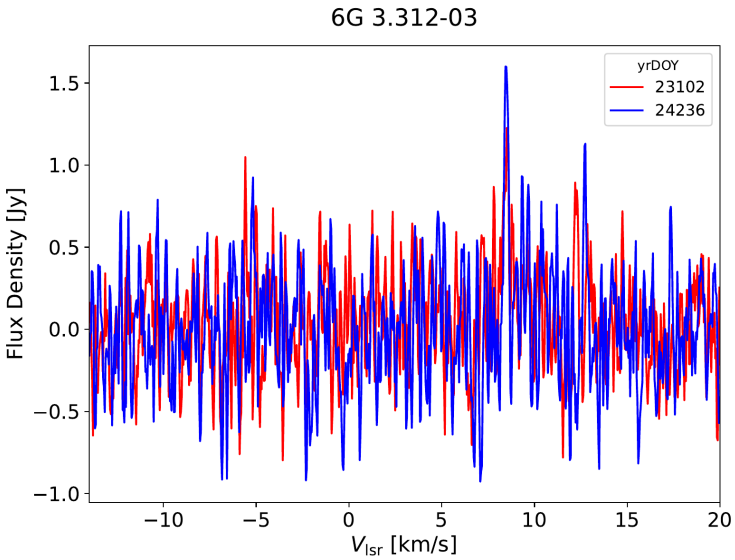
Light curve



Periodogram

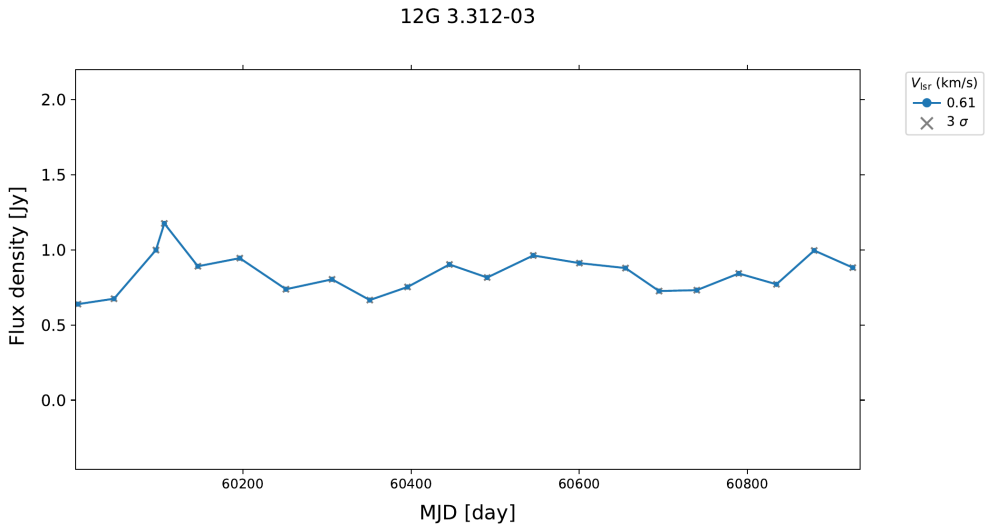


Spectrum

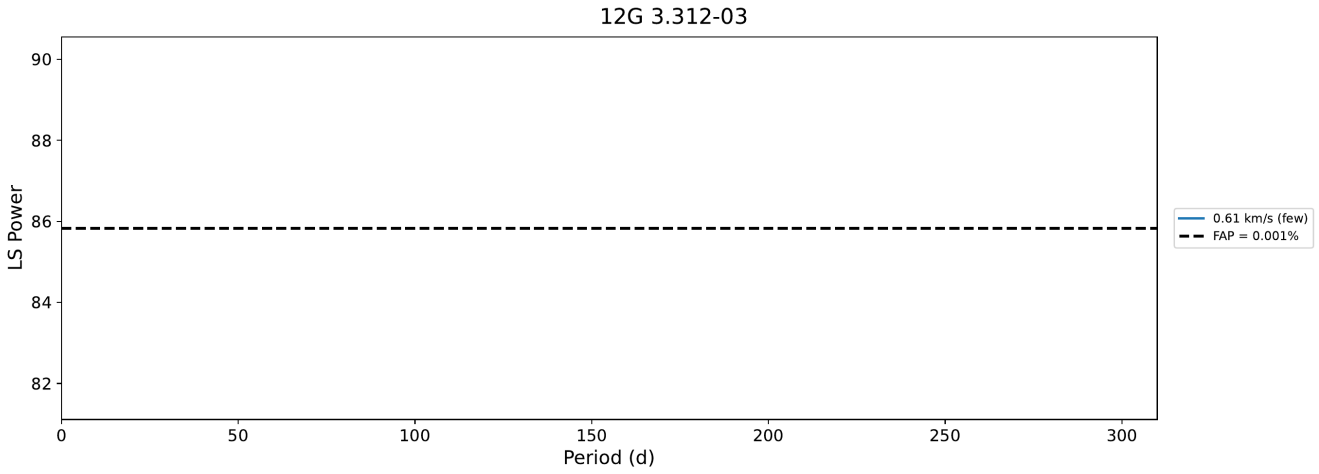


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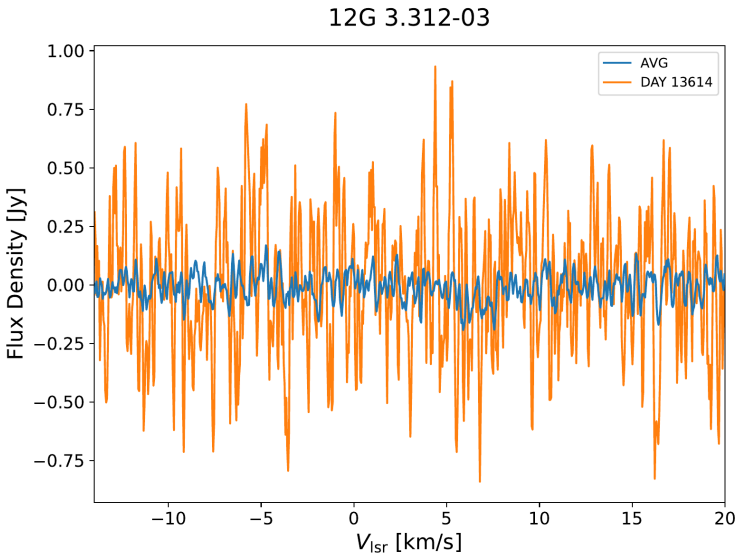
Light curve



Periodogram

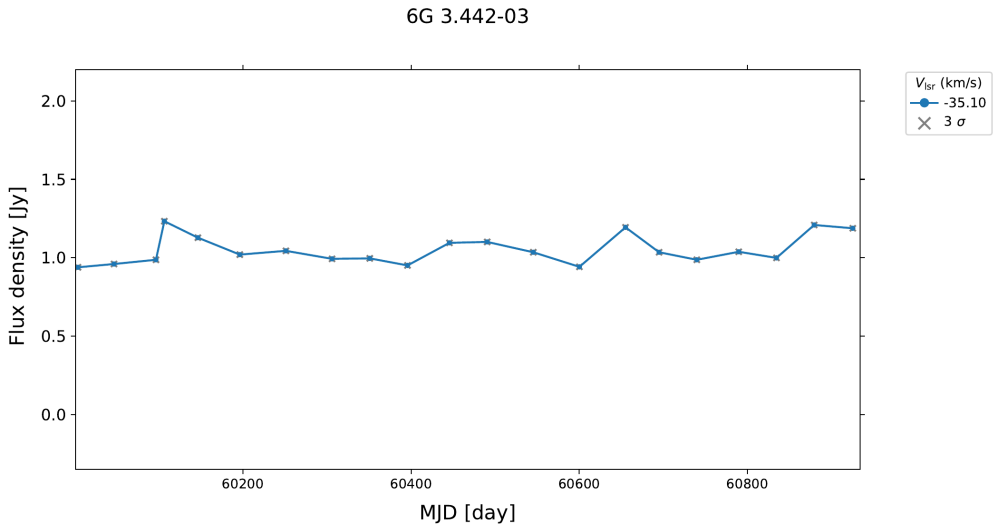


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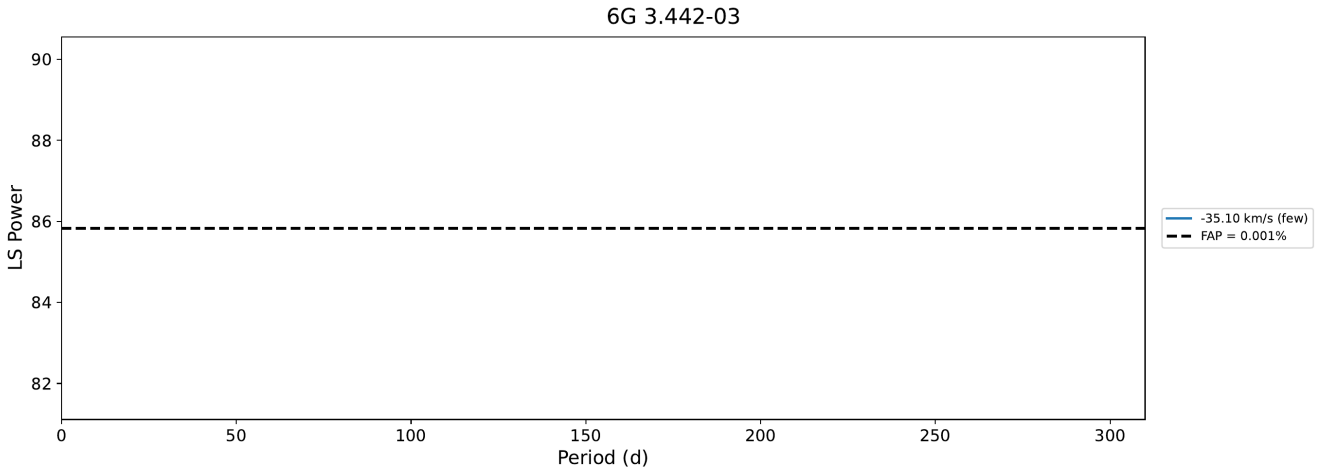


6G 3.442-03

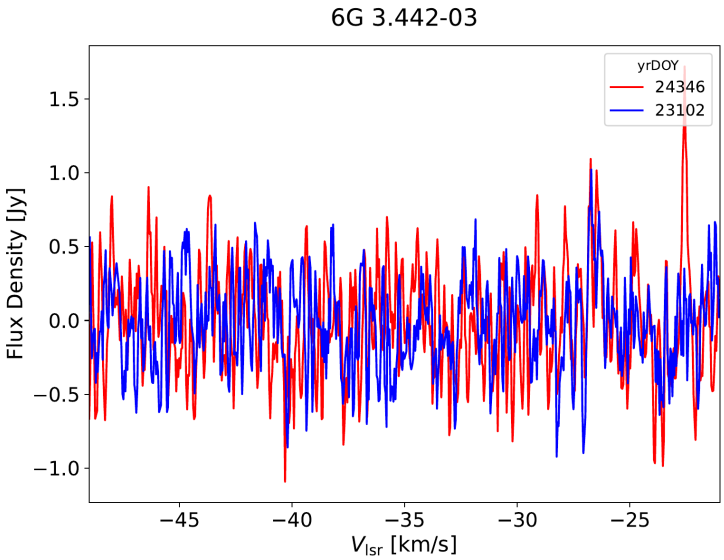
Light curve



Periodogram

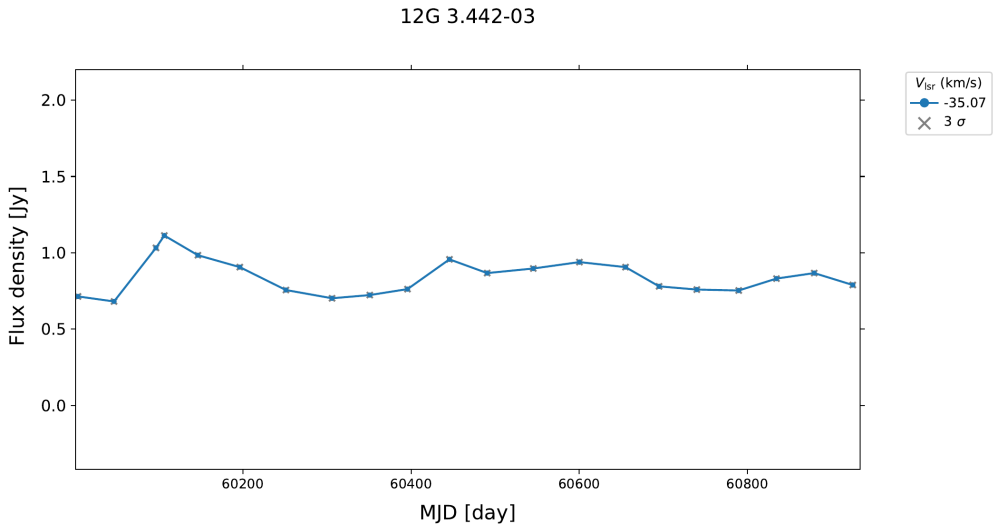


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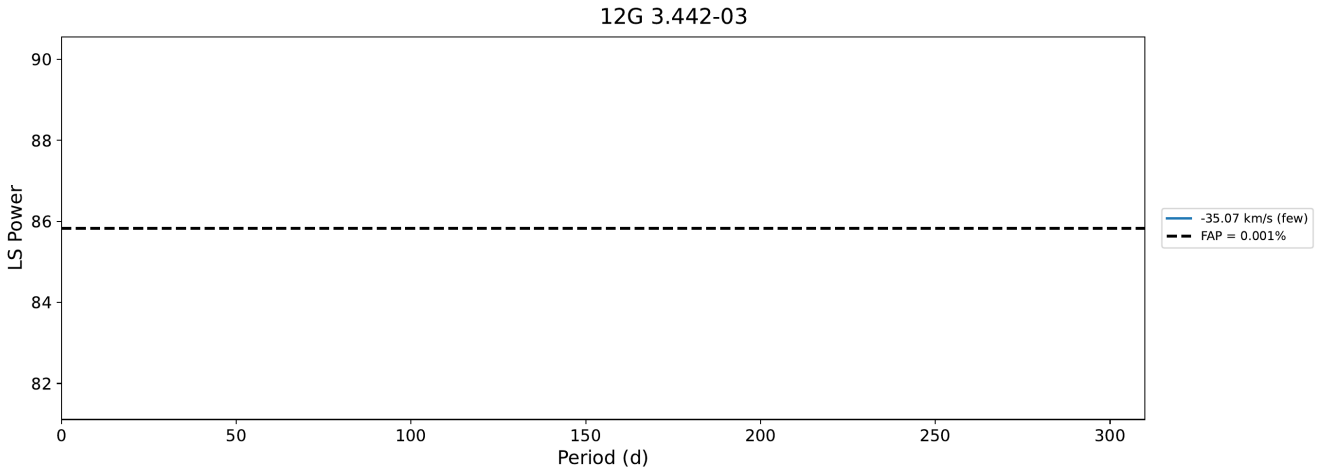


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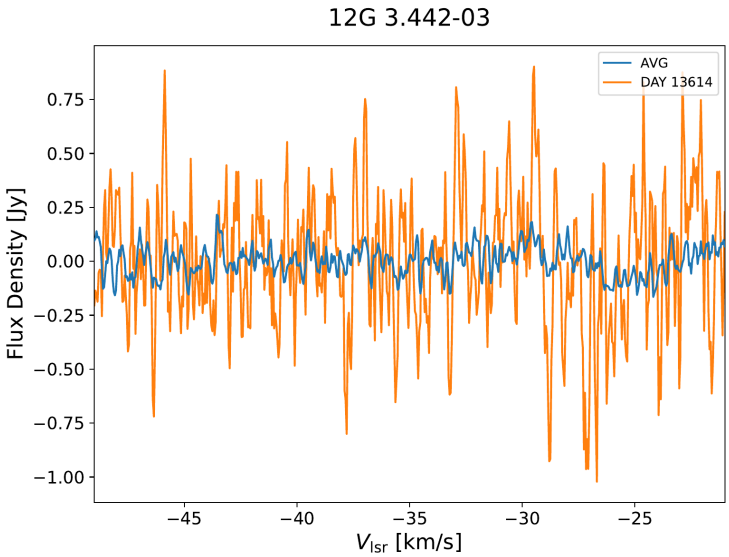
Light curve



Periodogram

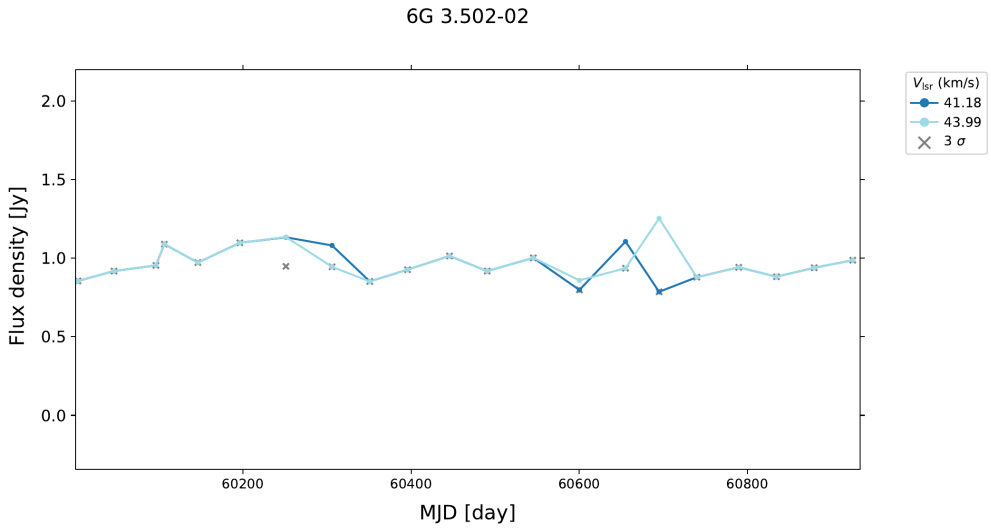


Spectrum

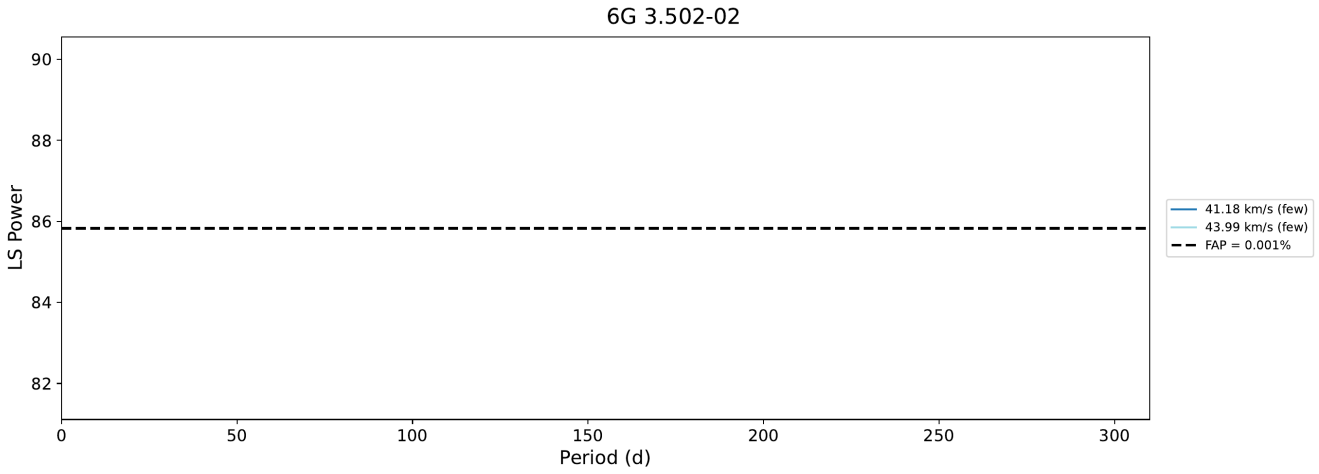


6G 3.502-02

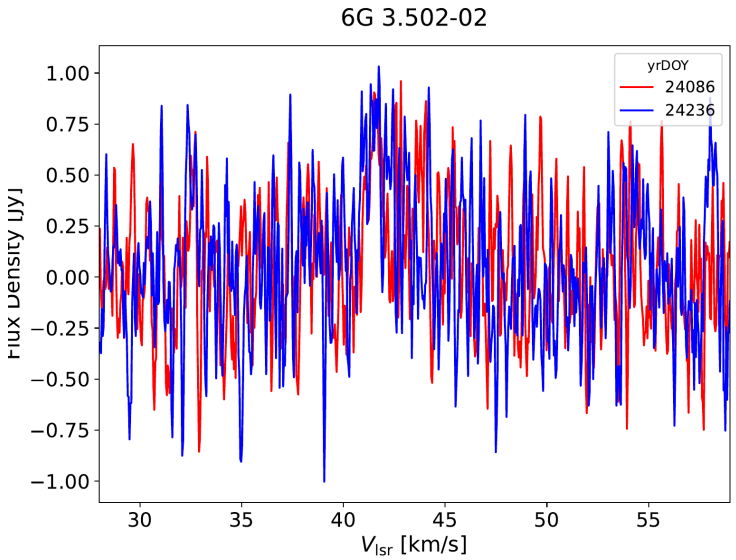
Light curve



Periodogram

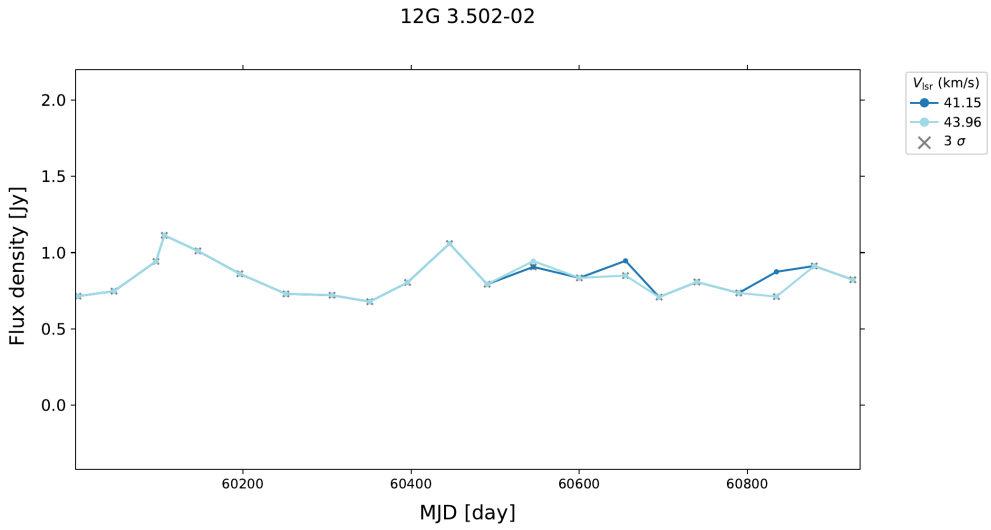


Spectrum

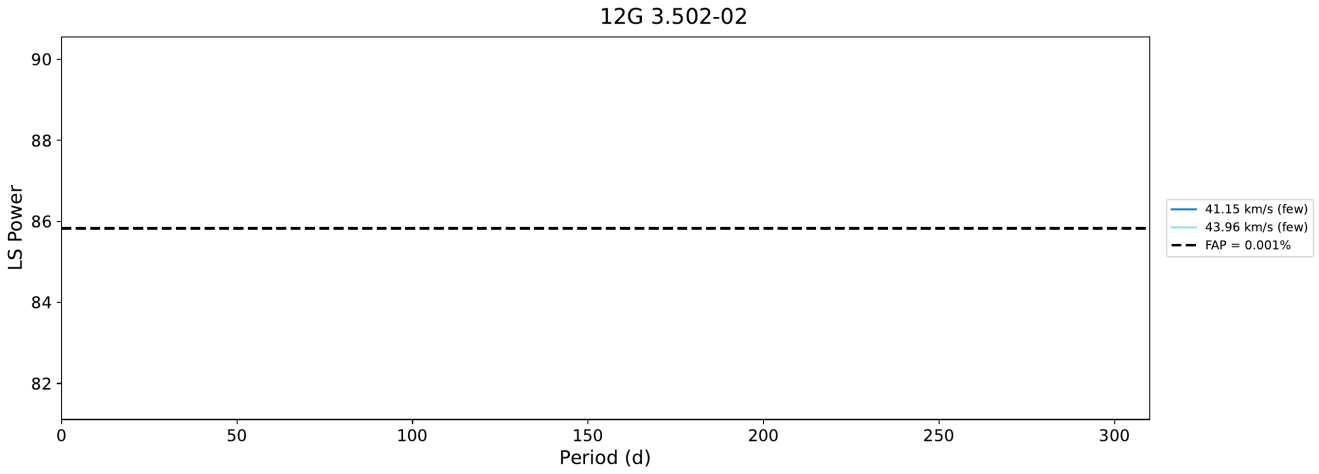


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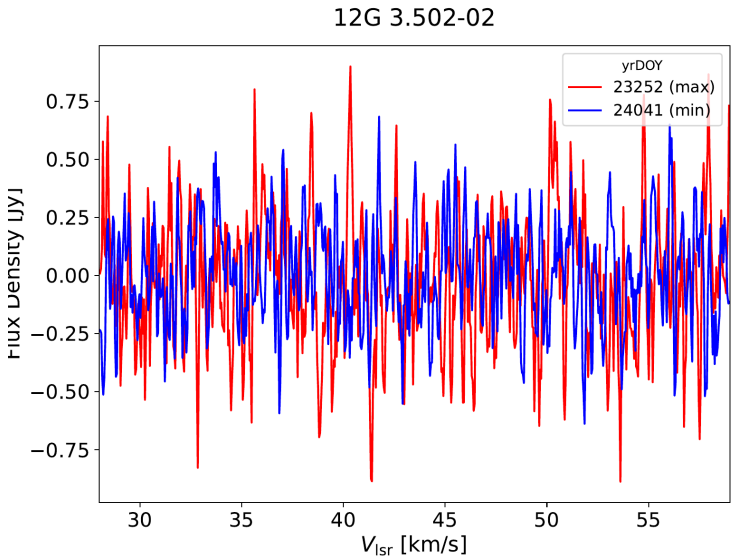
Light curve



Periodogram

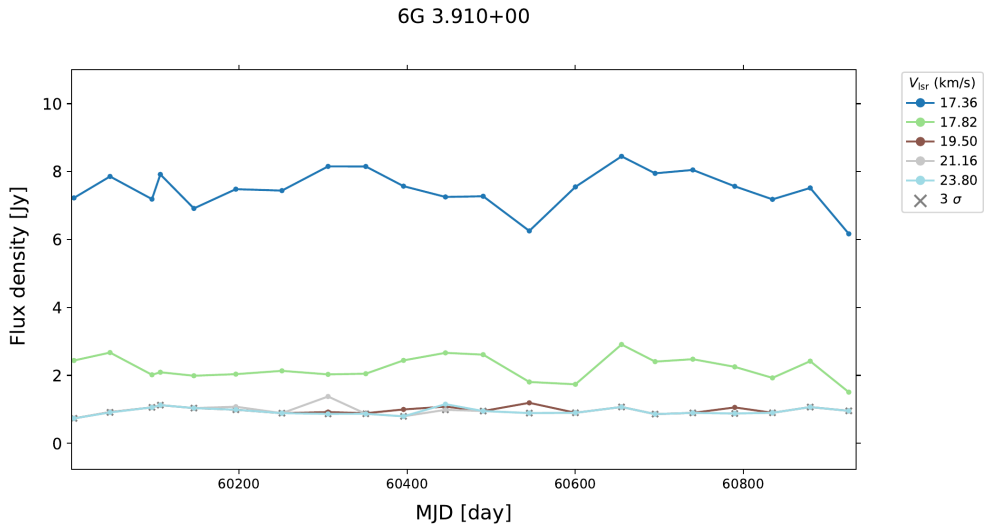


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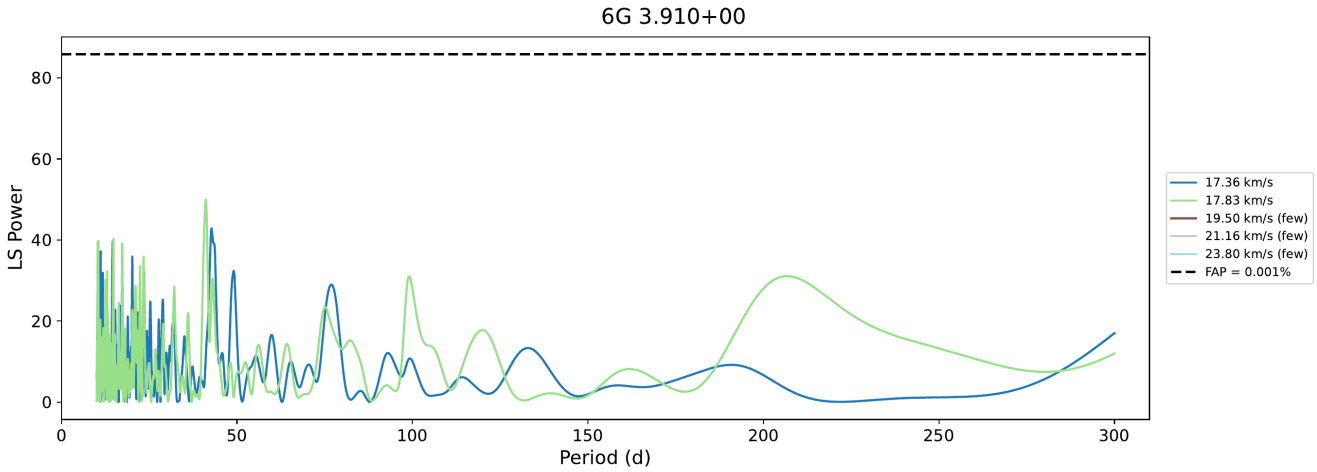


6G 3.910+00

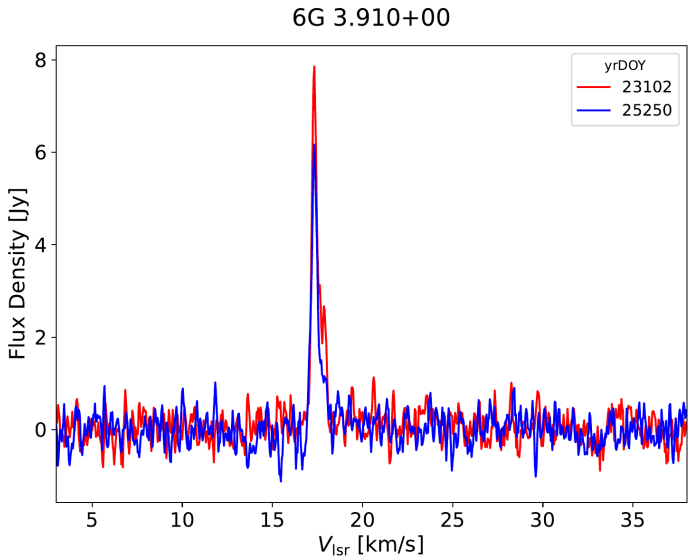
Light curve



Periodogram

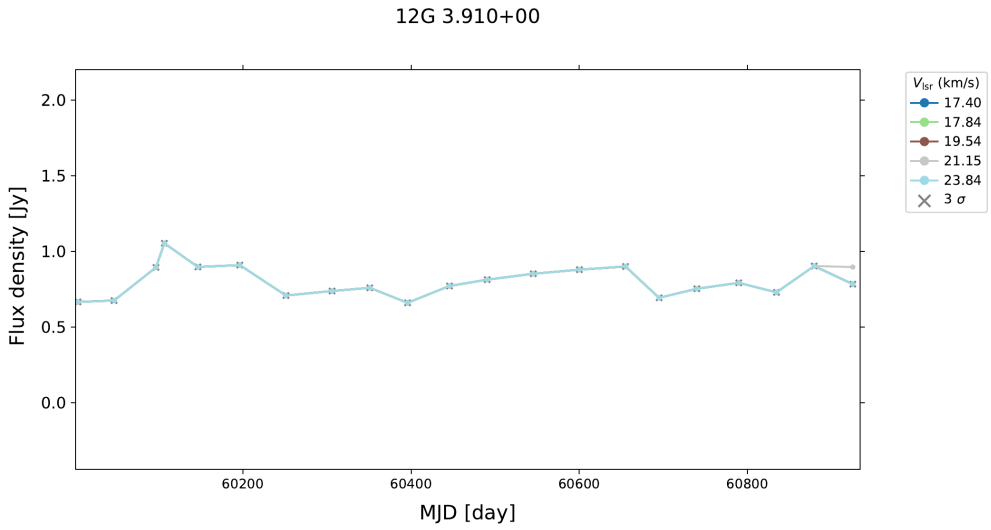


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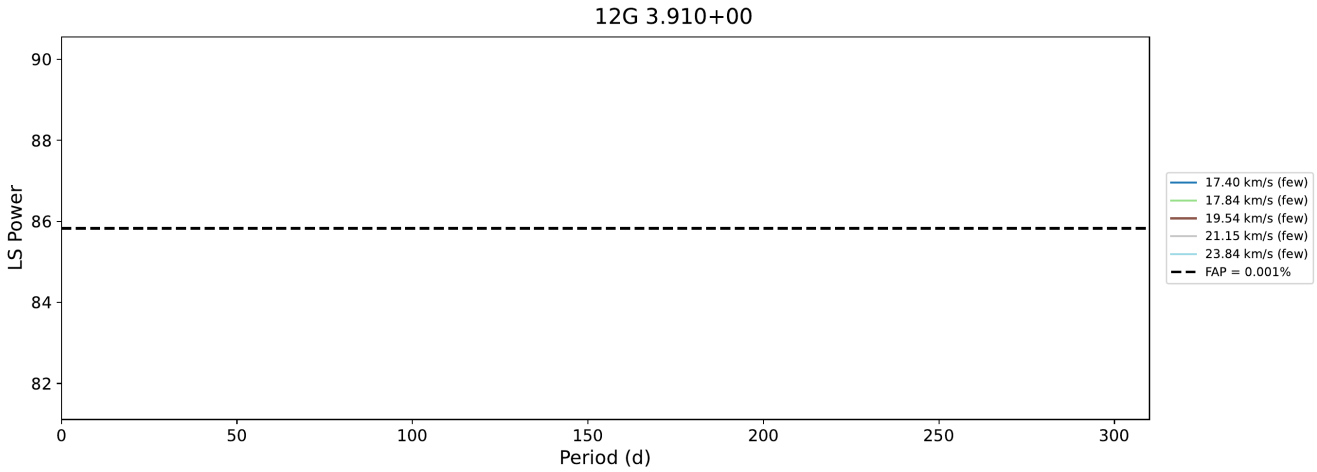


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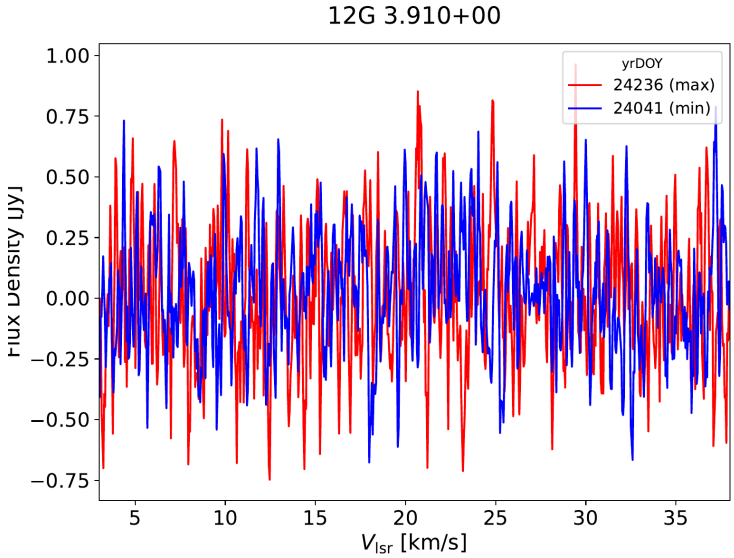
Light curve



Periodogram

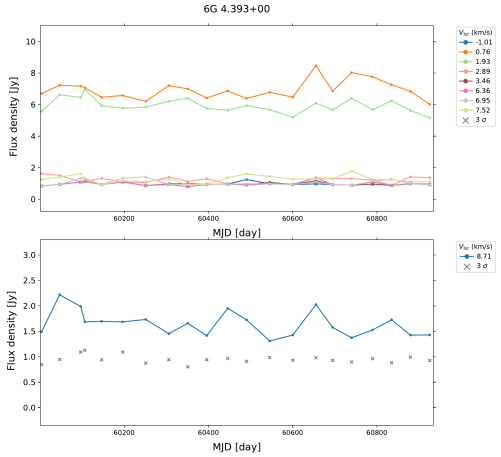


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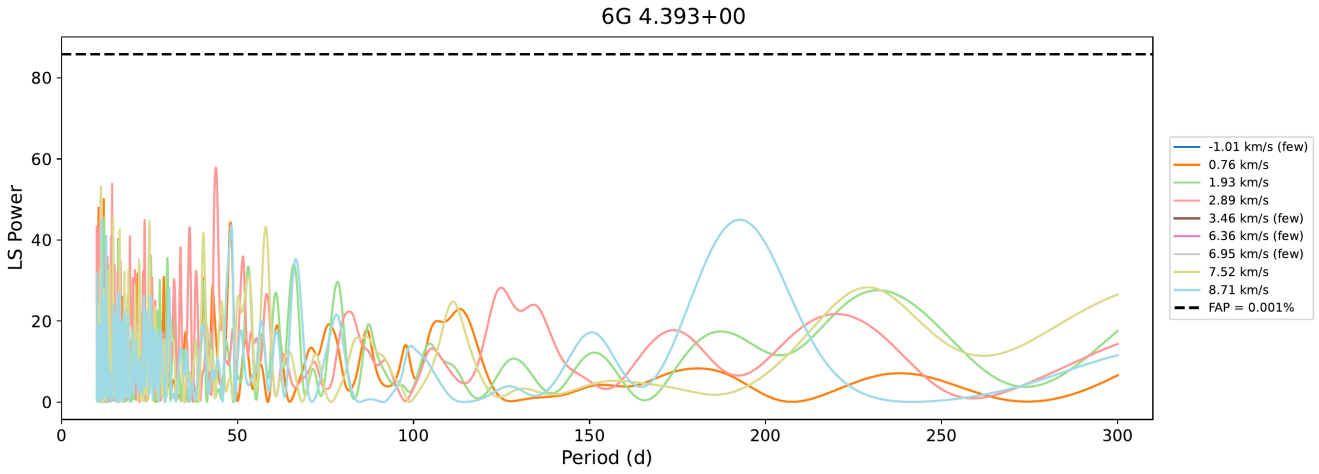


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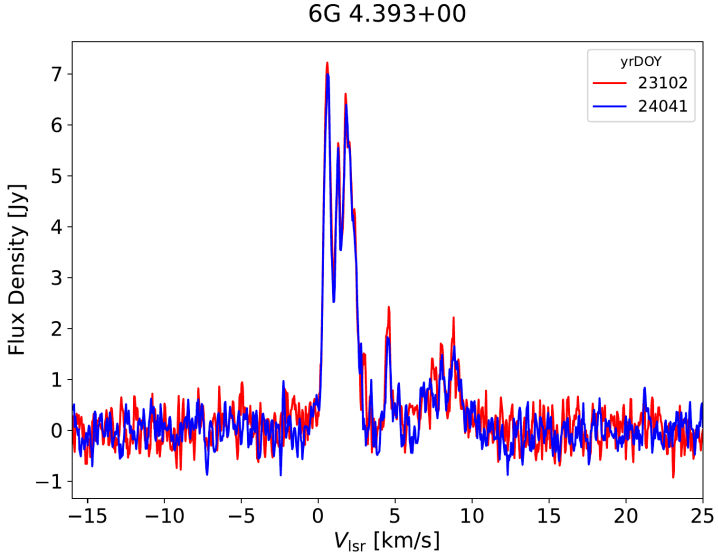
Light curve



Periodogram

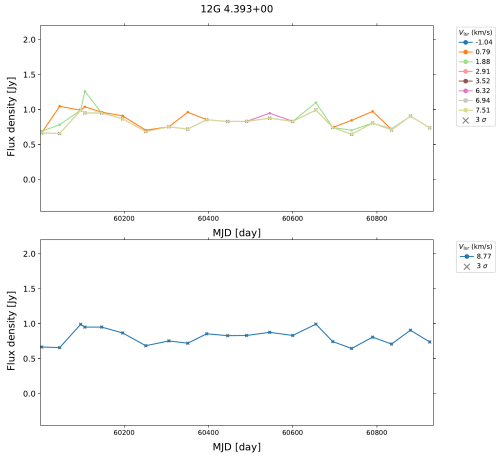


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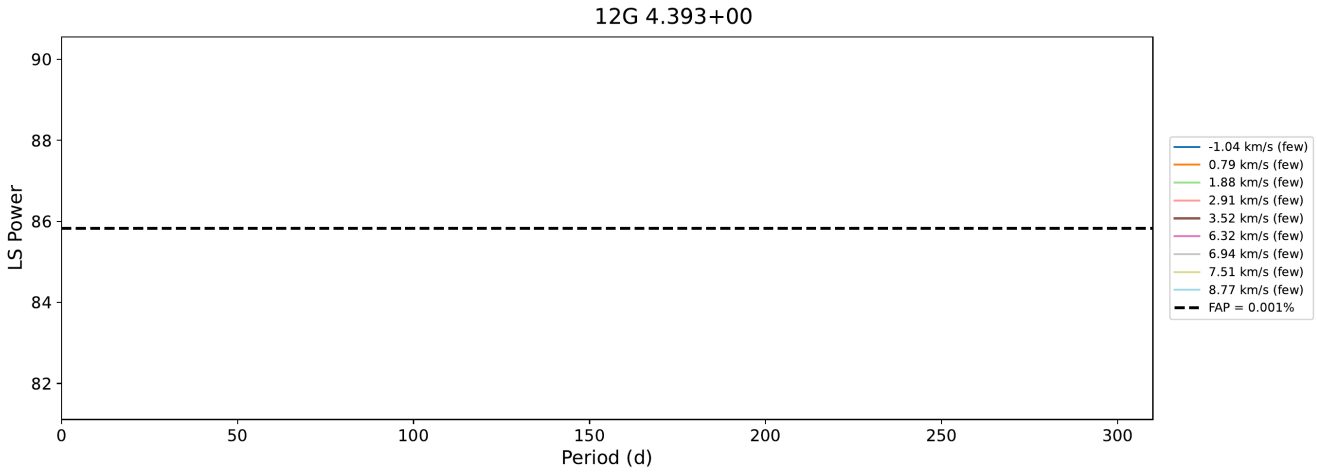


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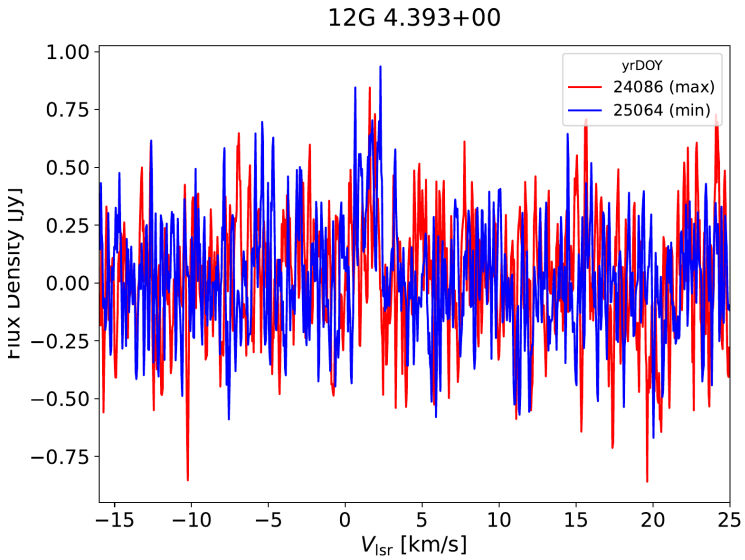
Light curve



Periodogram

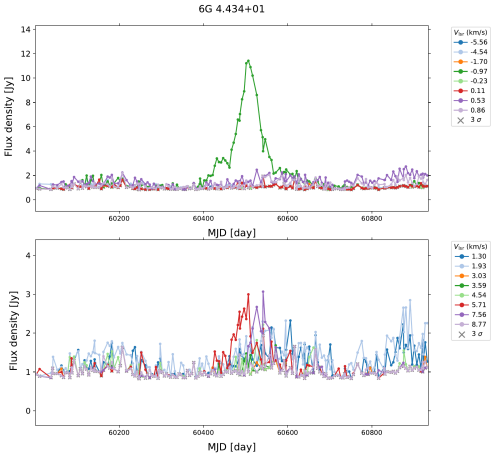


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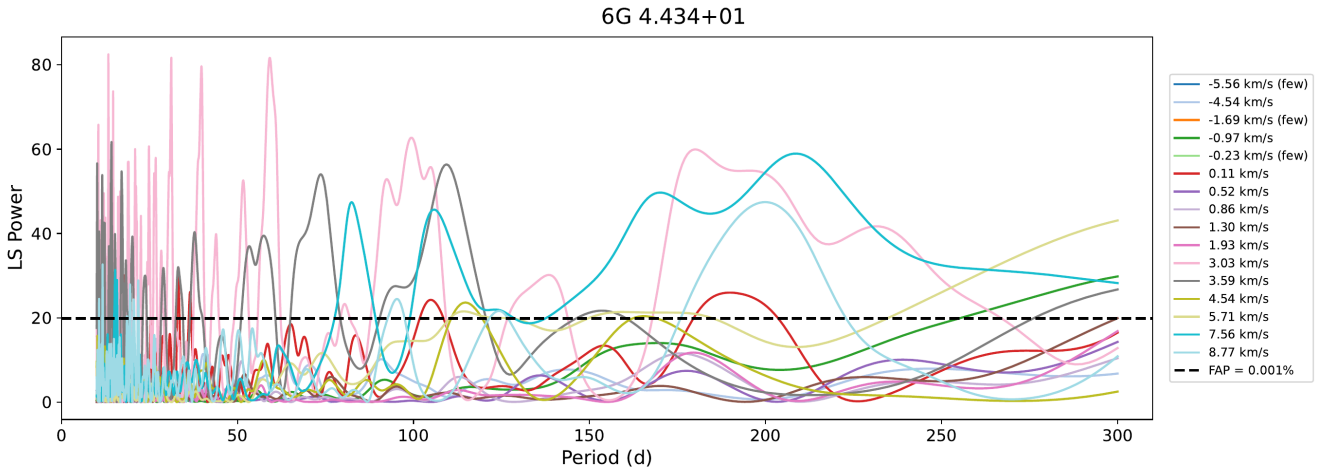


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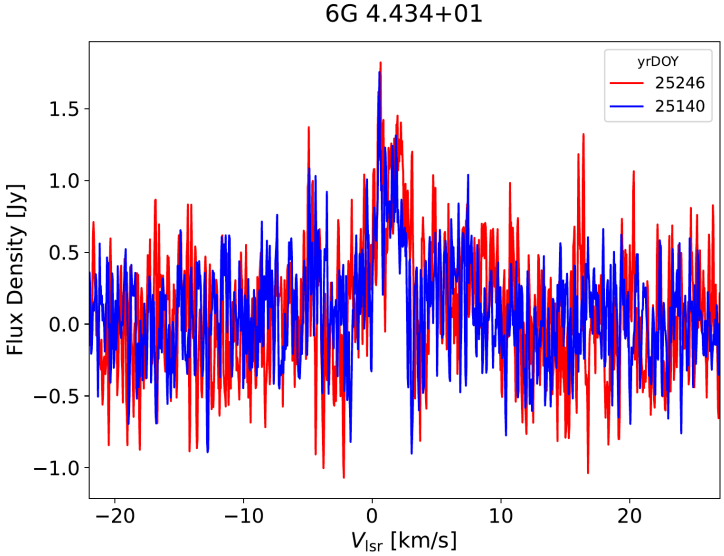
Light curve



Periodogram

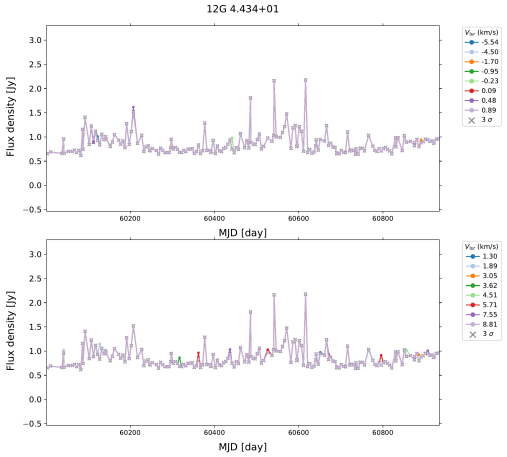


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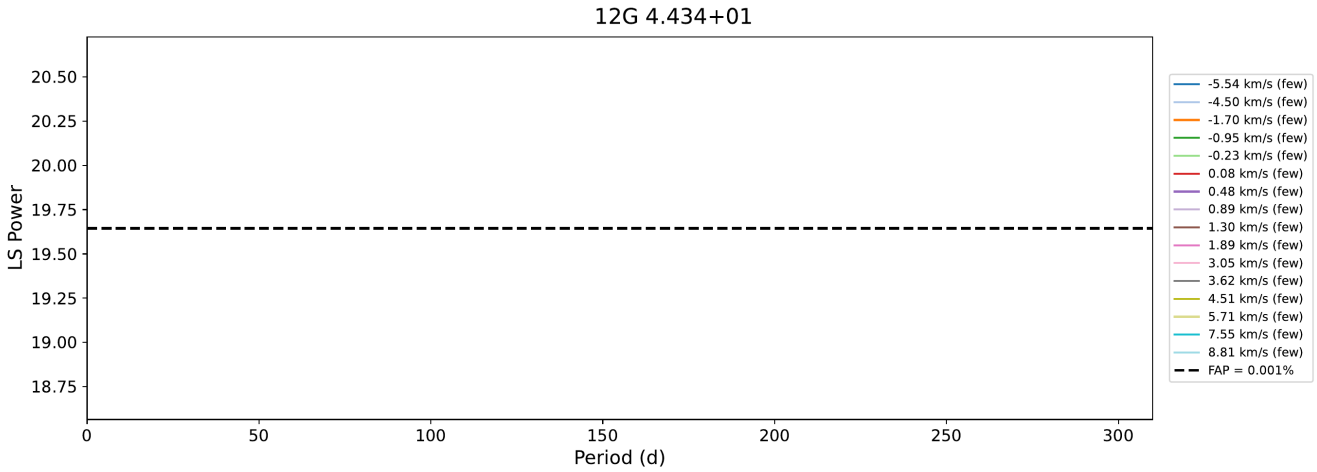


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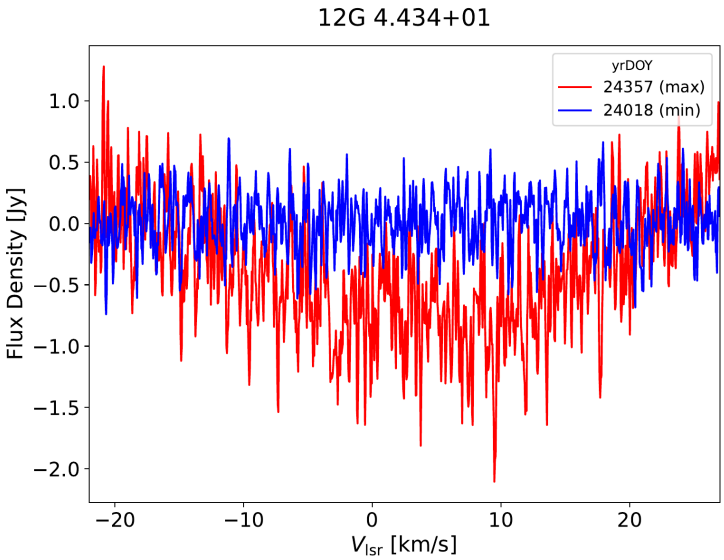
Light curve



Periodogram

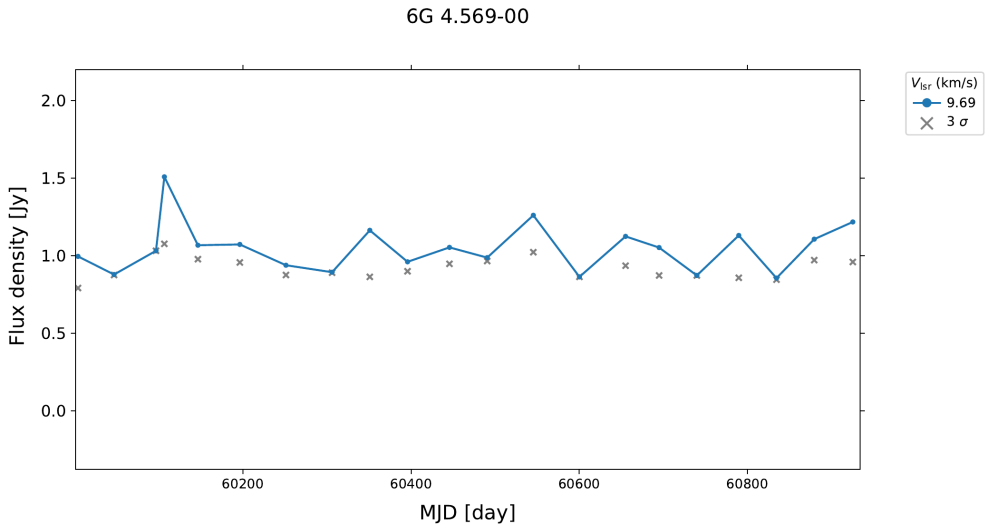


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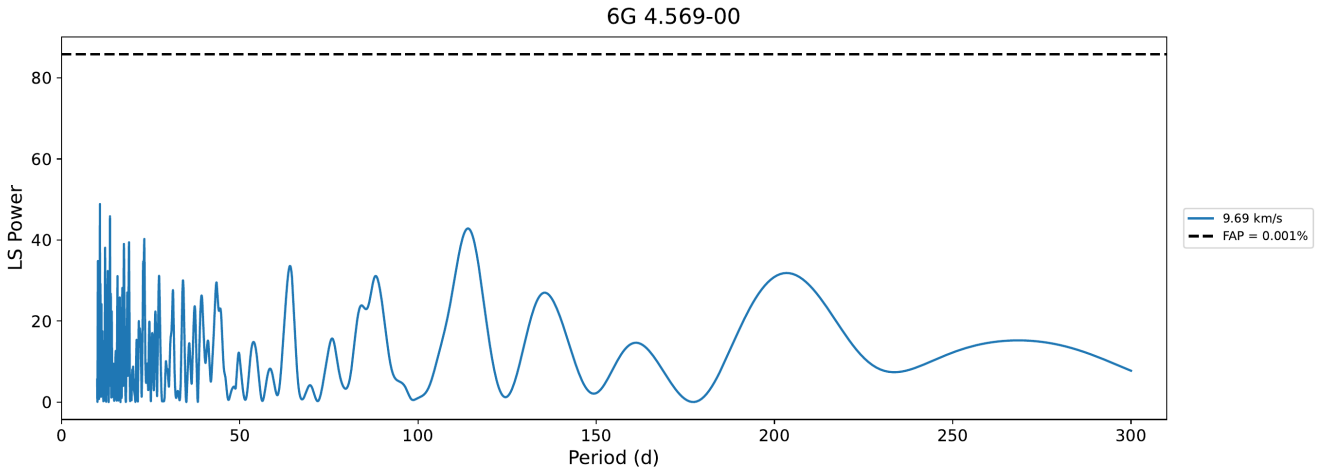


6G 4.569-00

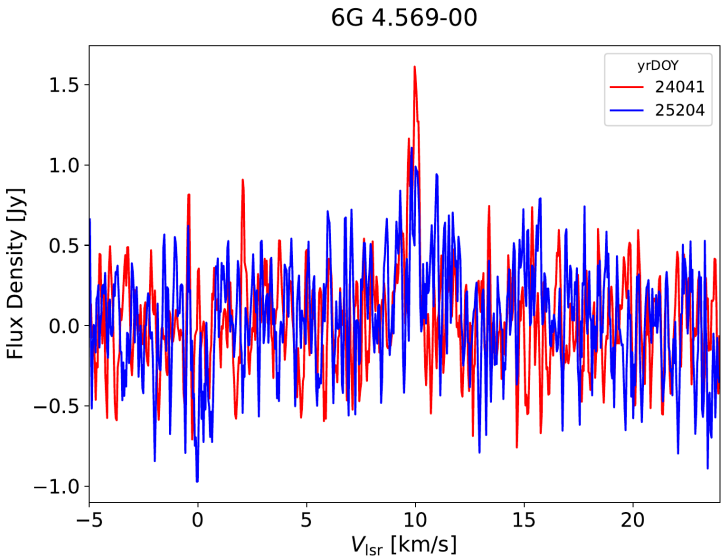
Light curve



Periodogram

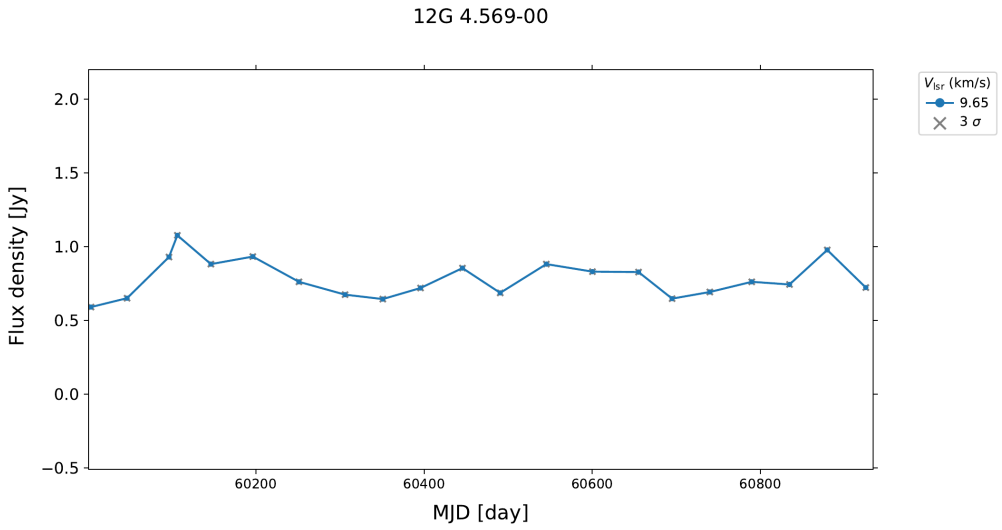


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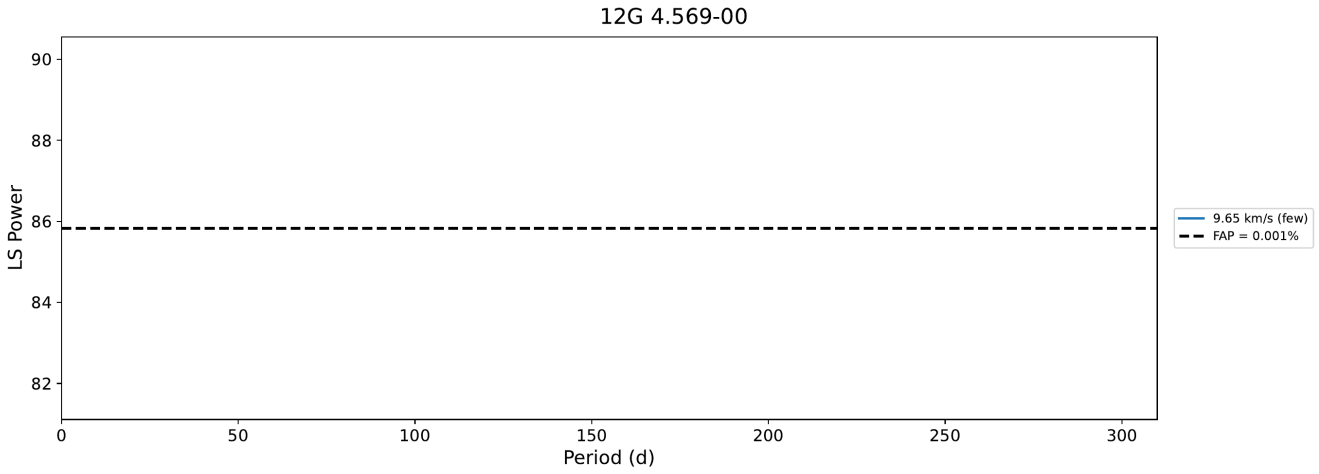


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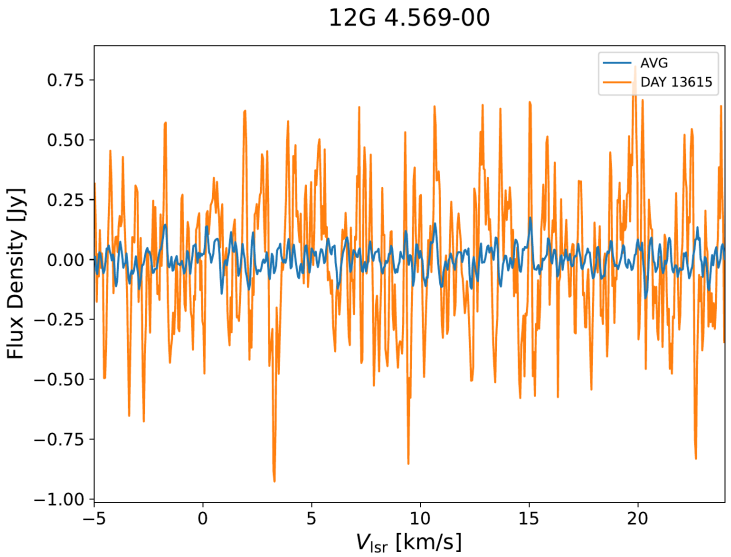
Light curve



Periodogram

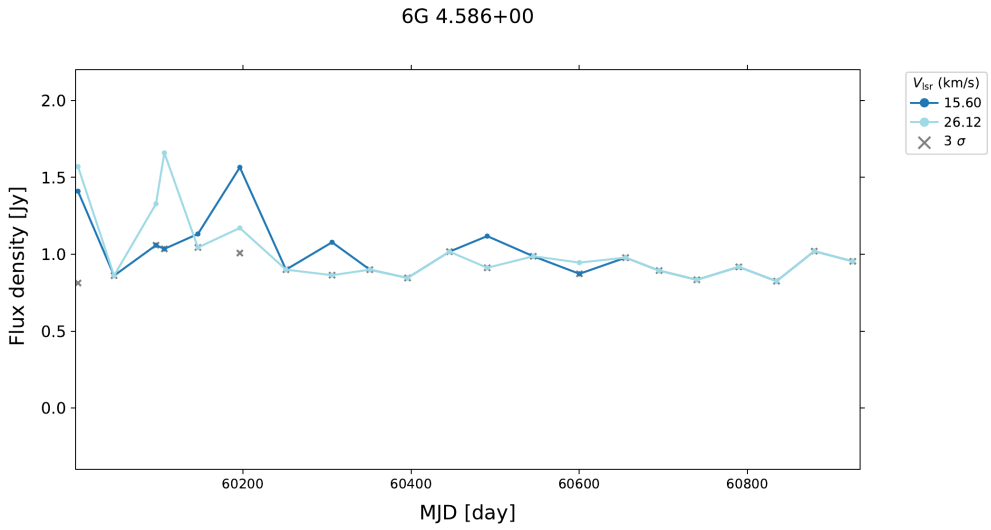


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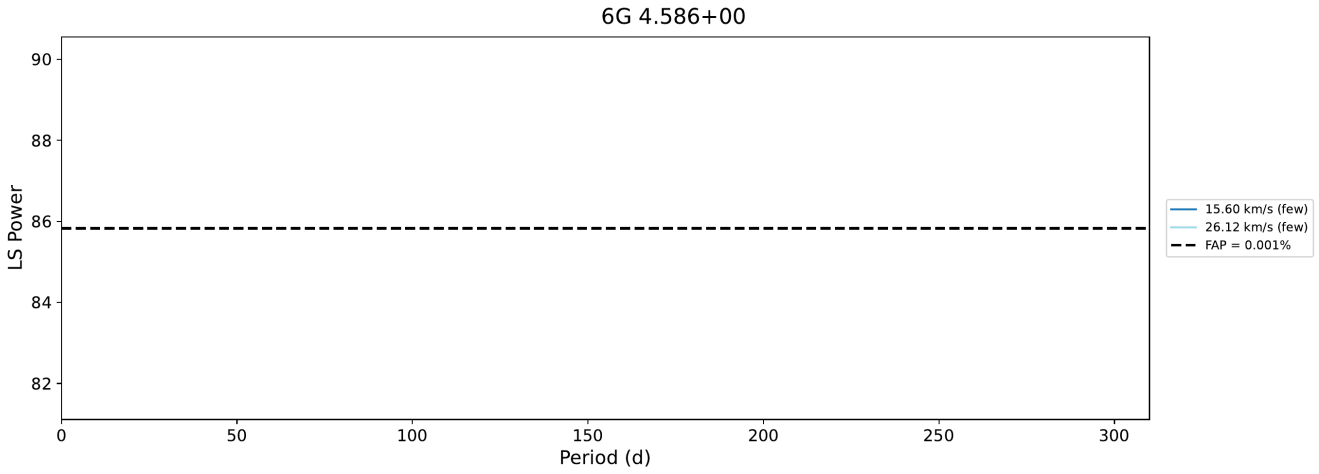


6G 4.586+00

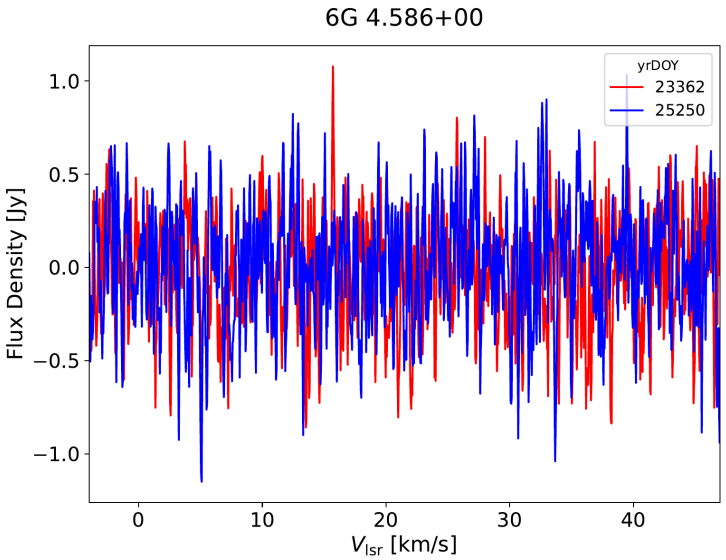
Light curve



Periodogram

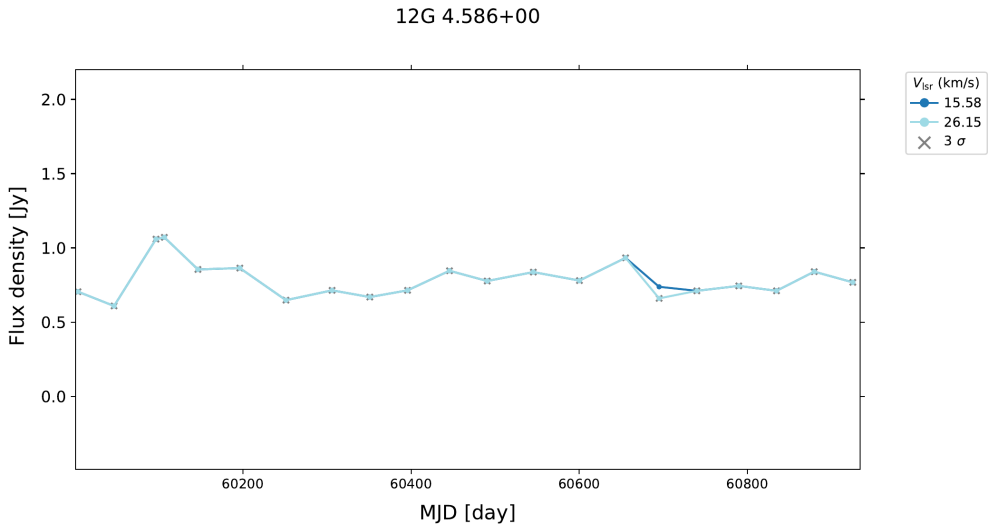


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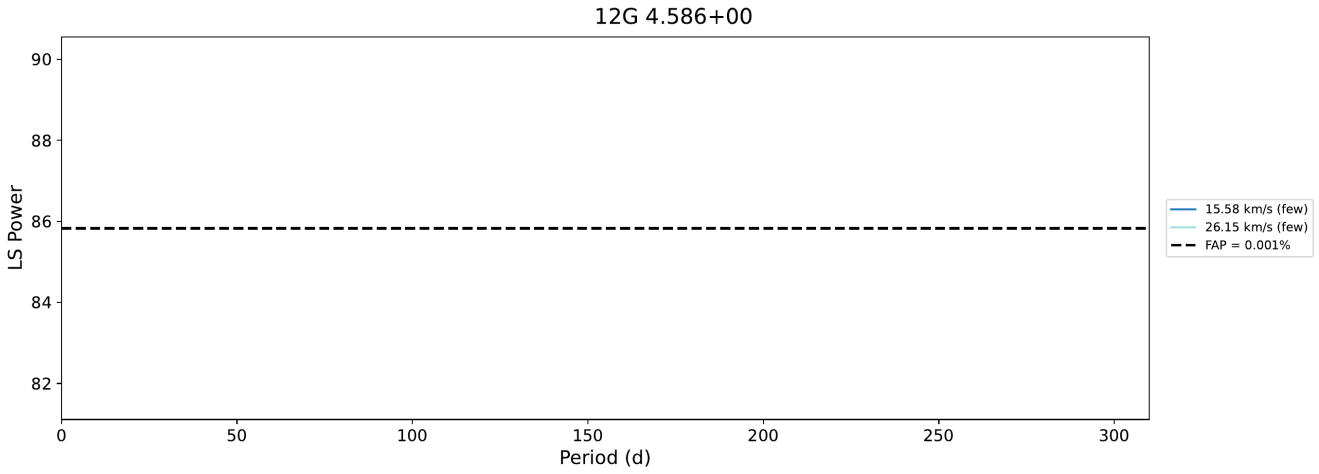


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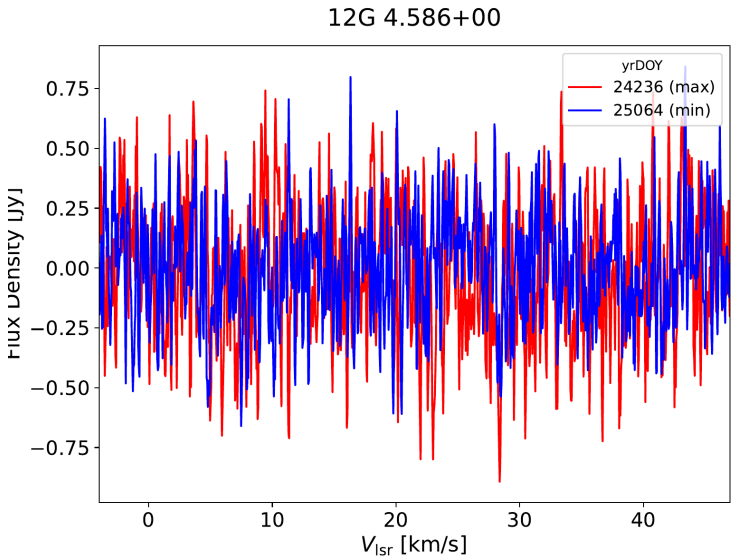
Light curve



Periodogram

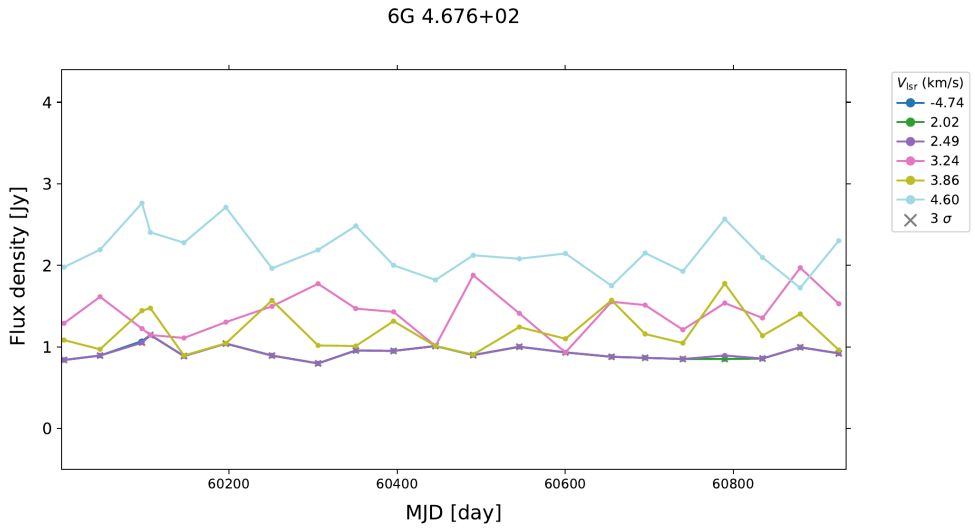


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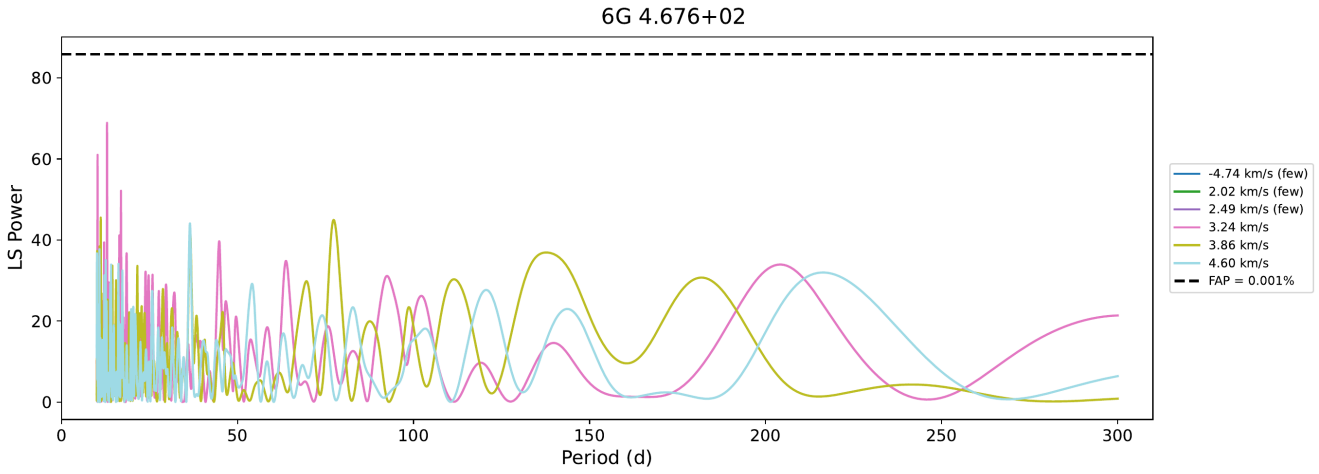


6G 4.676+02

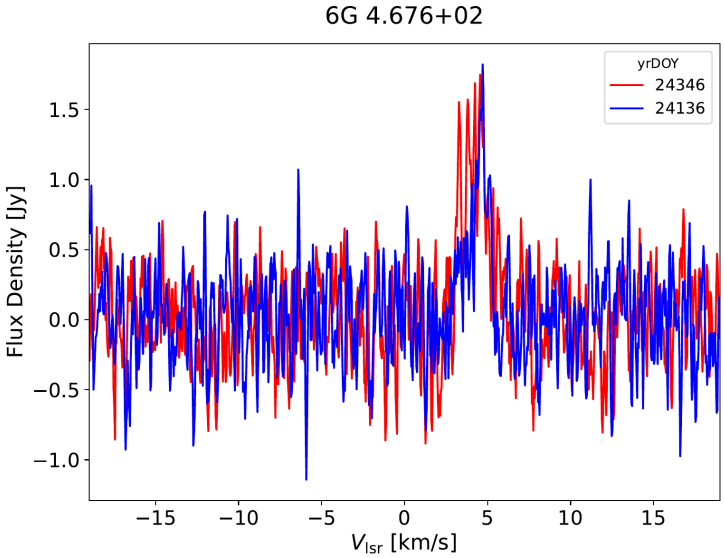
Light curve



Periodogram

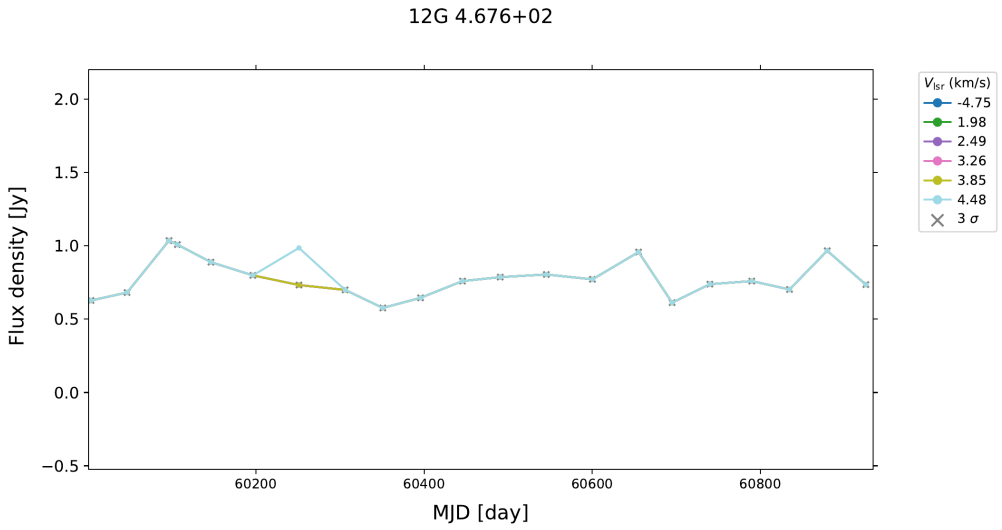


Spectrum

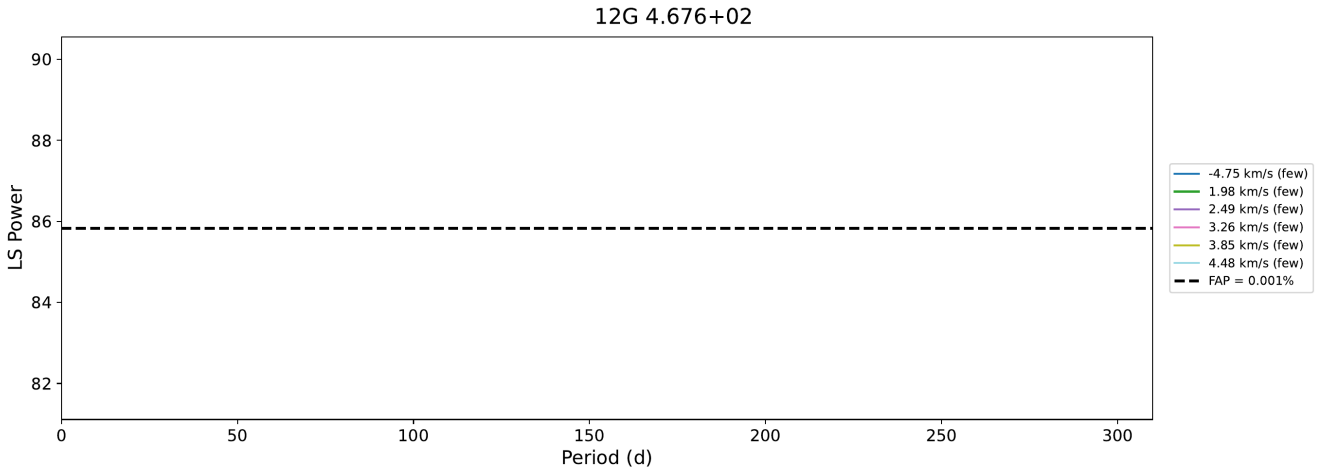


12G 4.676+02

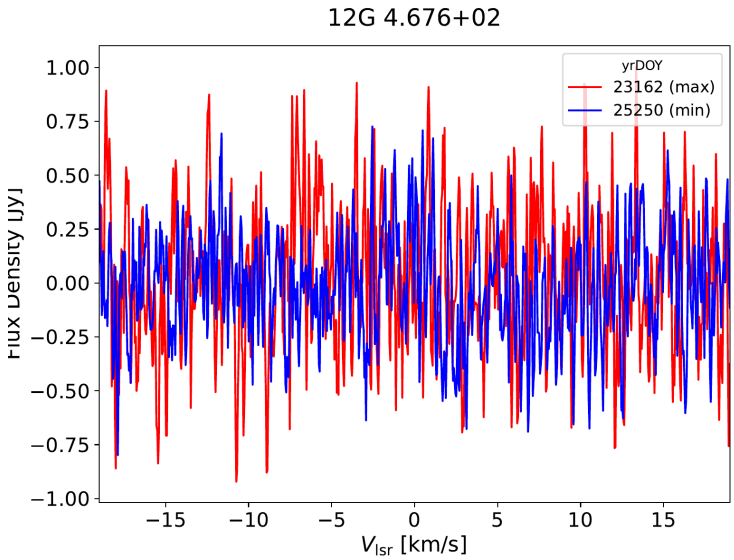
Light curve



Periodogram

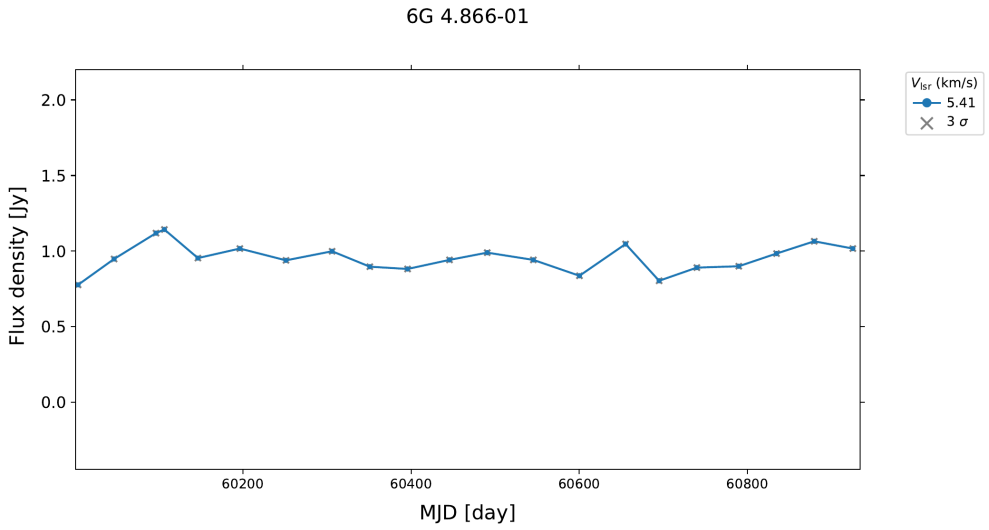


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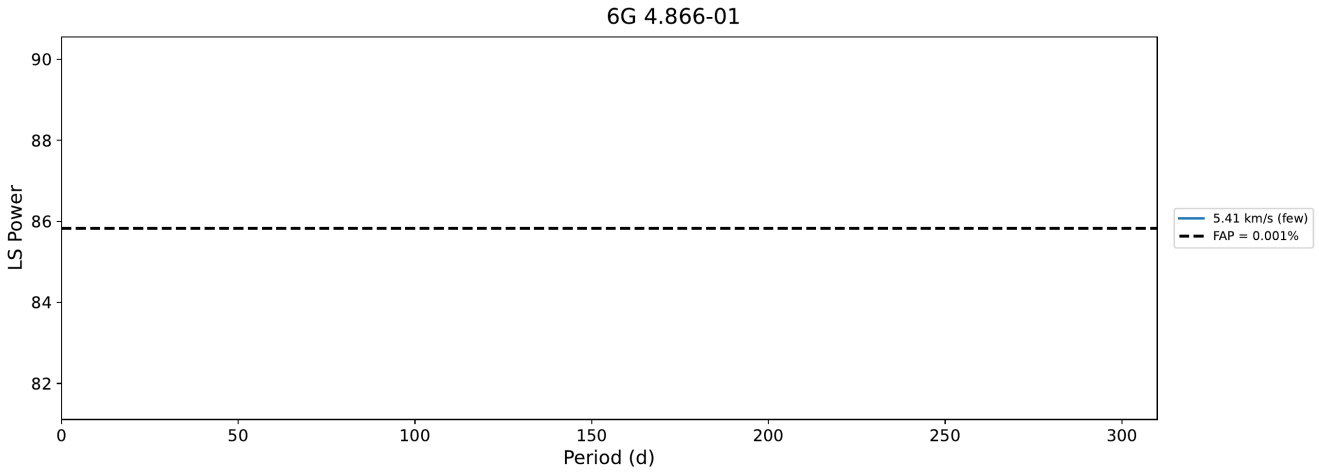


6G 4.866-01

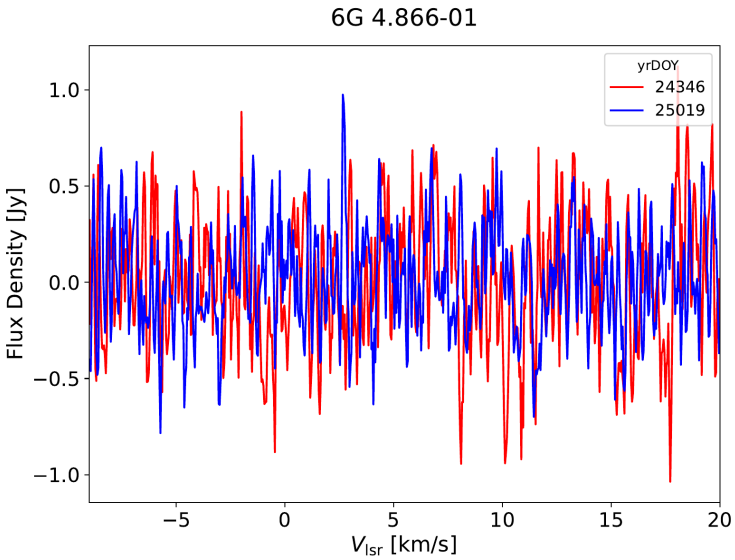
Light curve



Periodogram

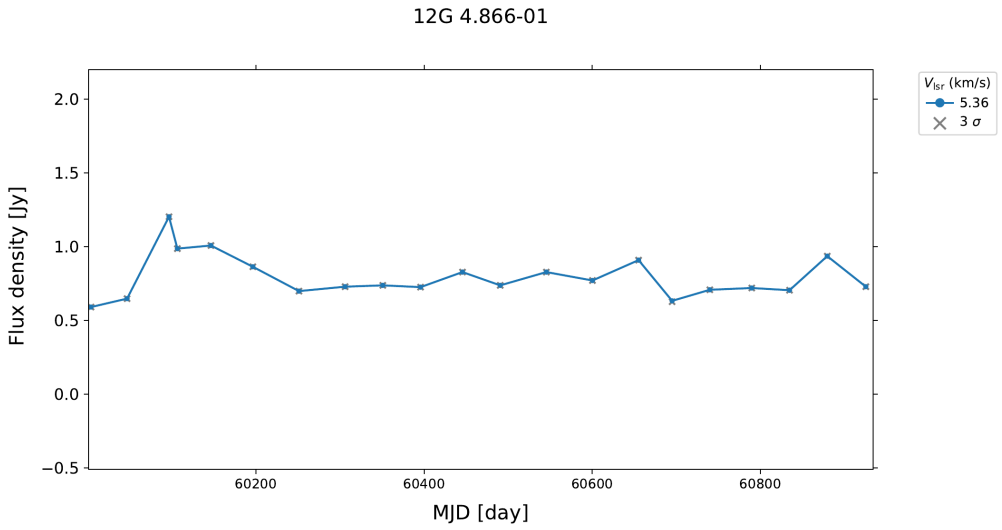


Spectrum

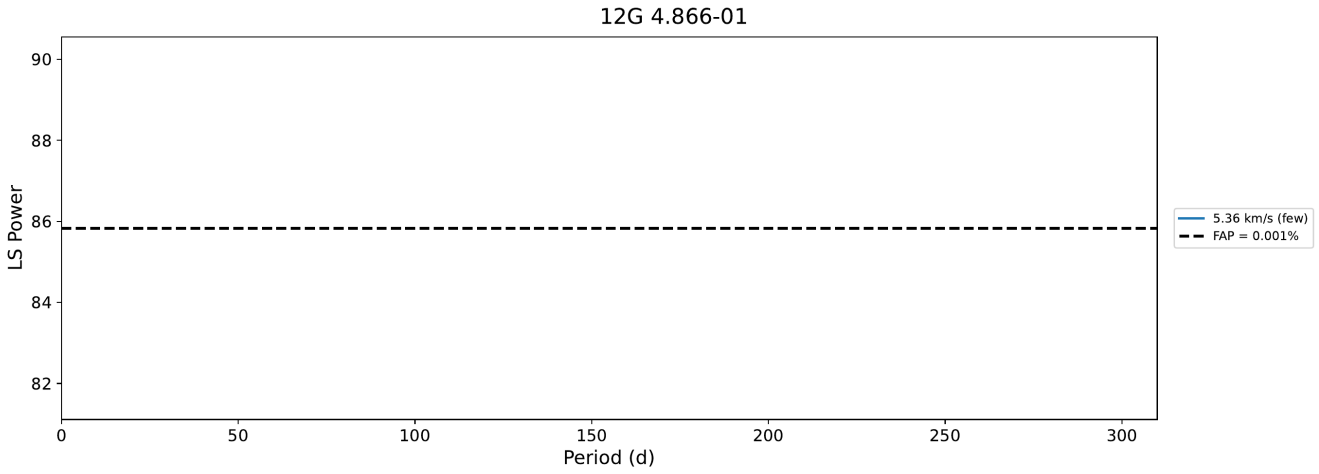


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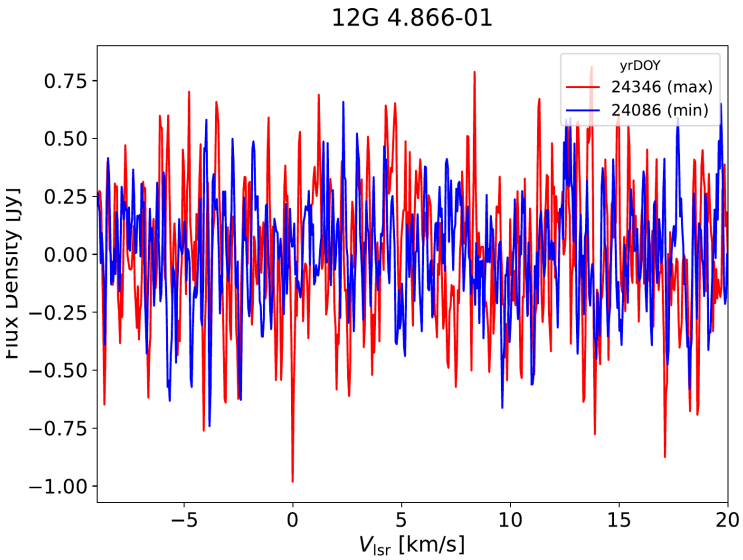
Light curve



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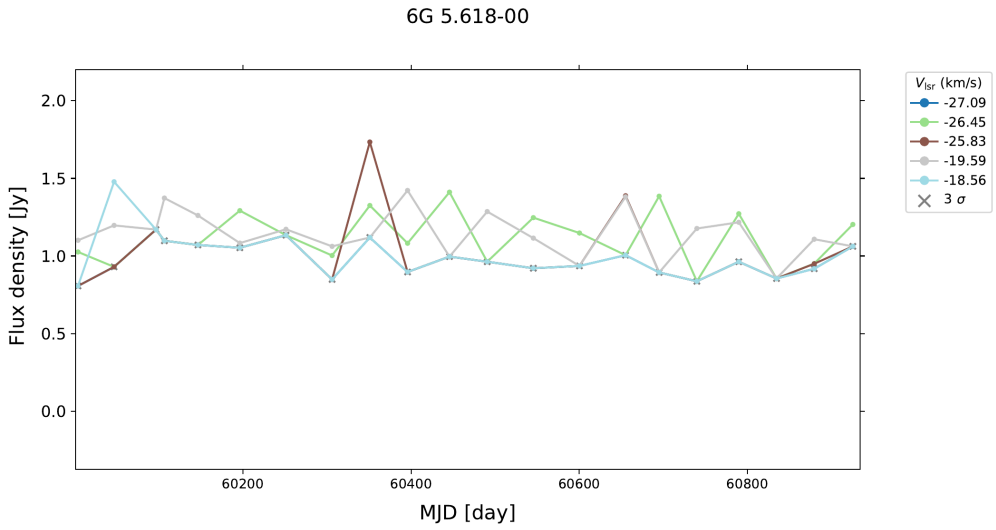


Spectrum

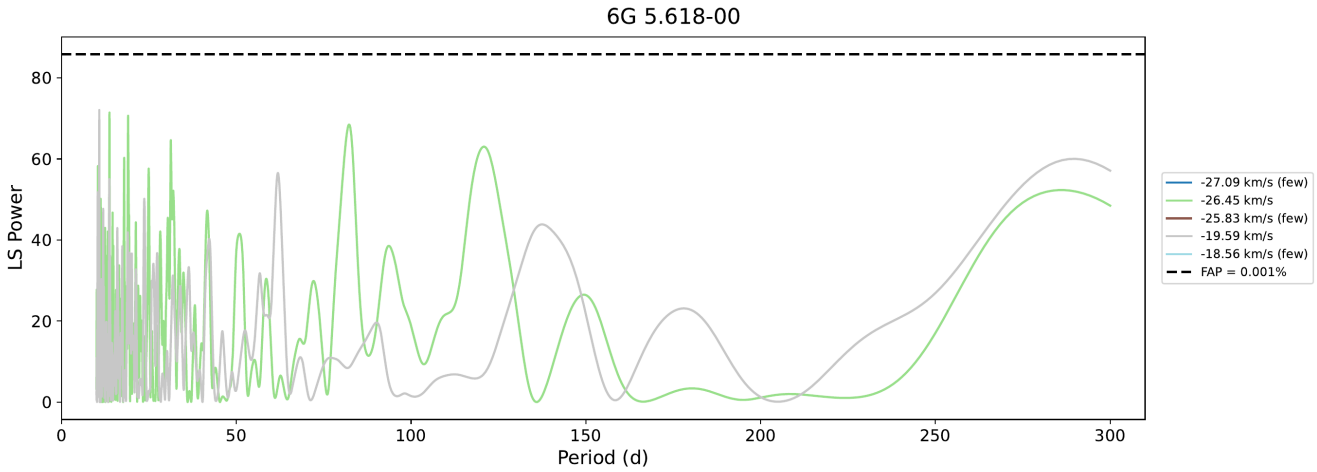


6G 5.618-00

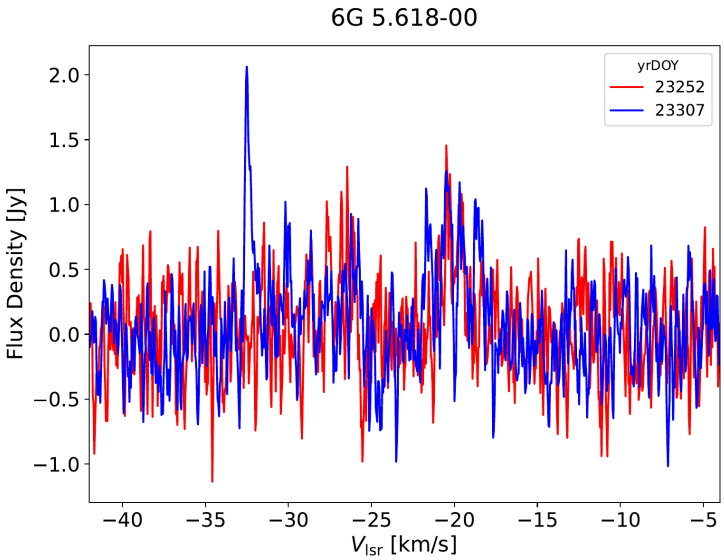
Light curve



Periodogram

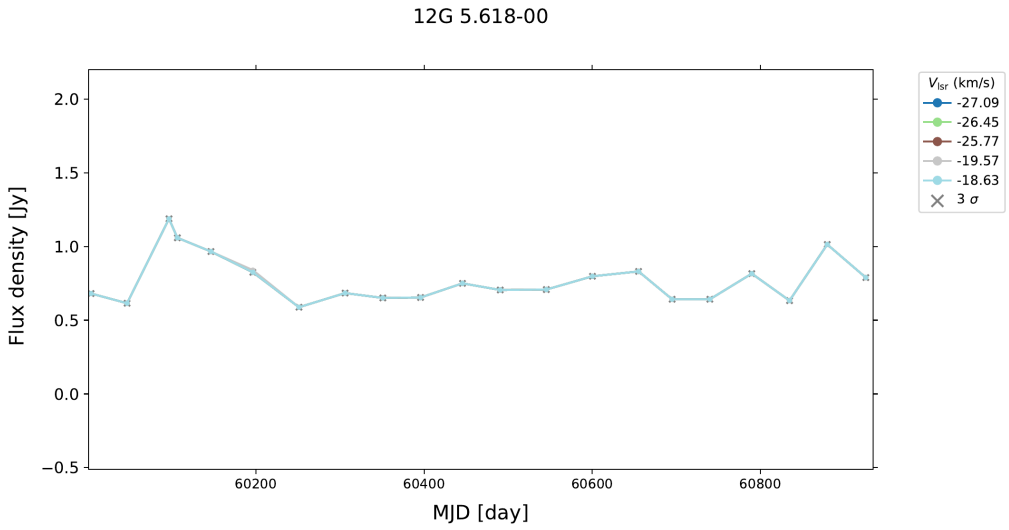


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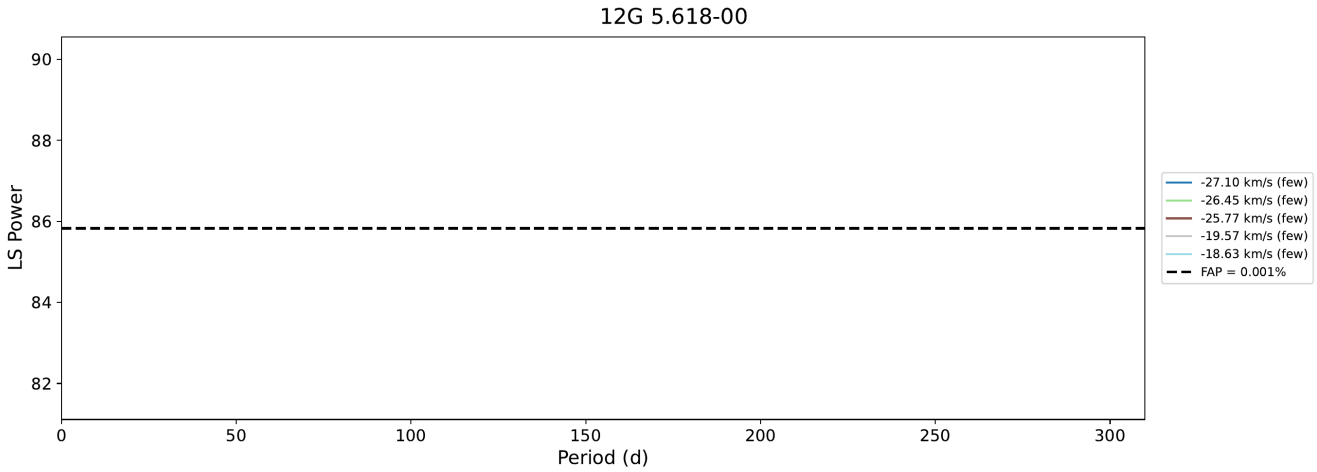


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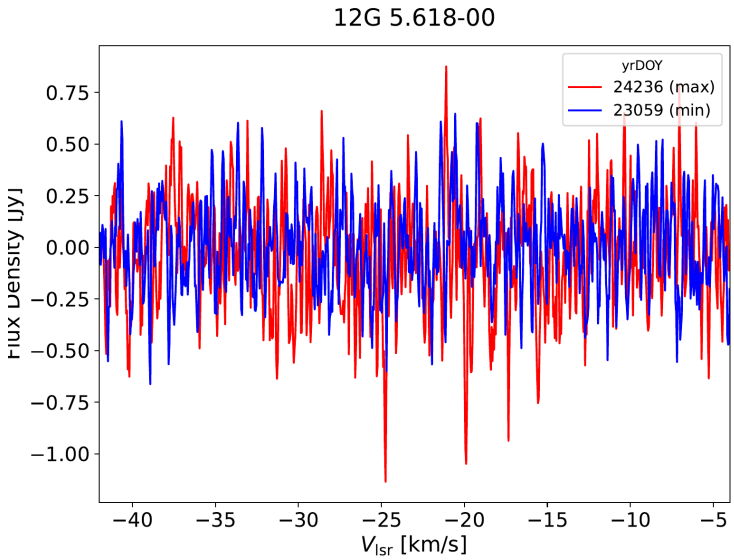
Light curve



Periodogram

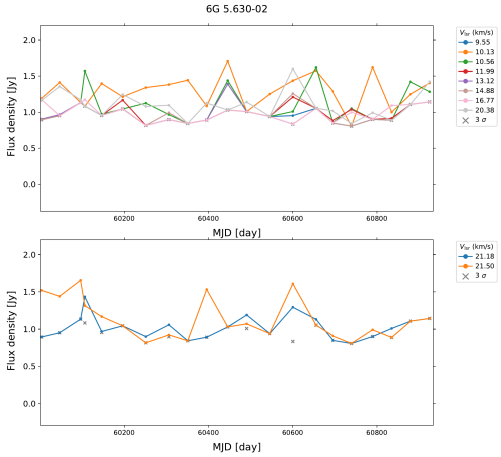


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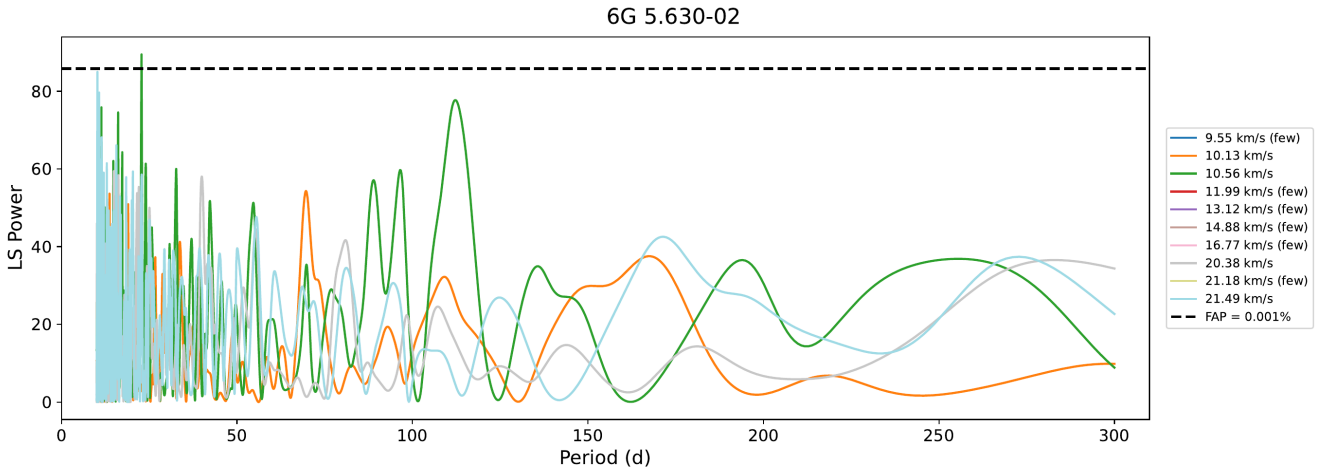


6G 5.630-02

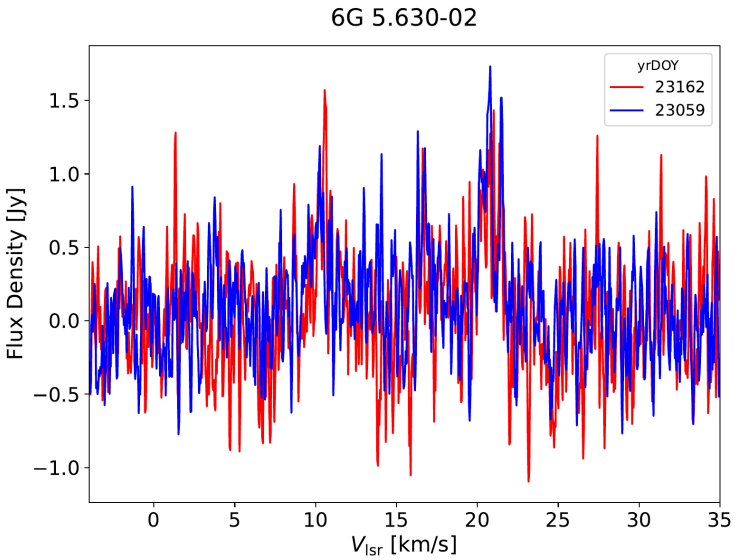
Light curve



Periodogram

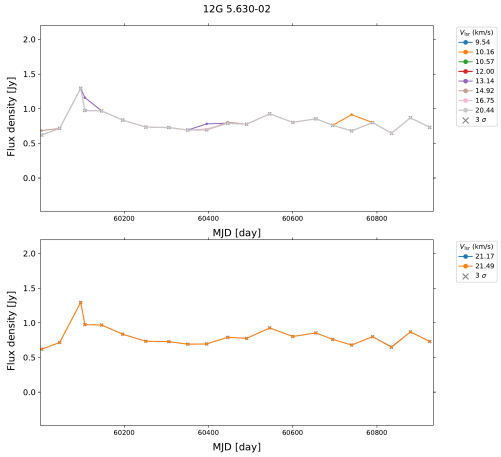


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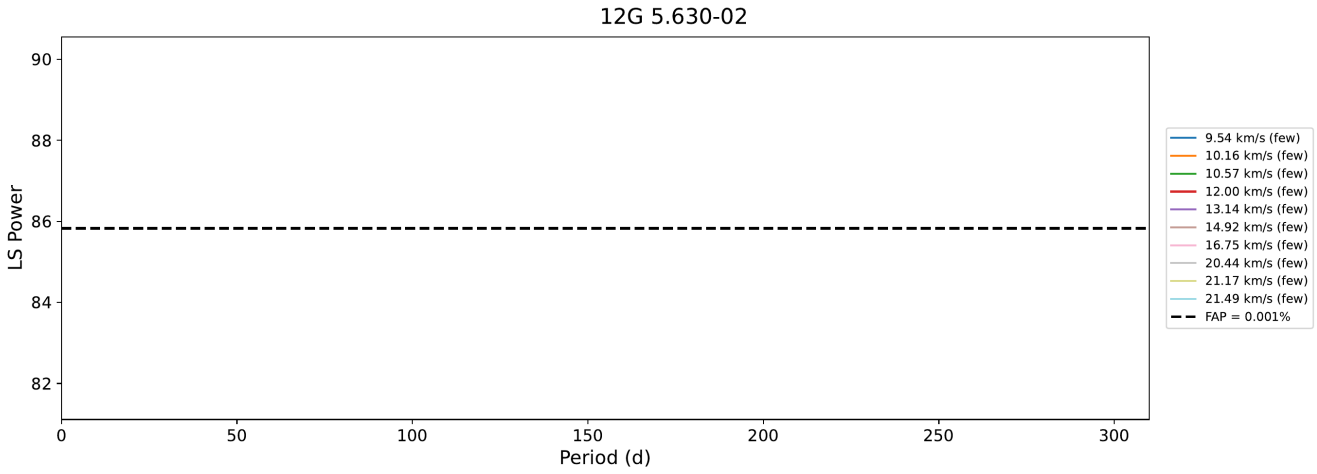


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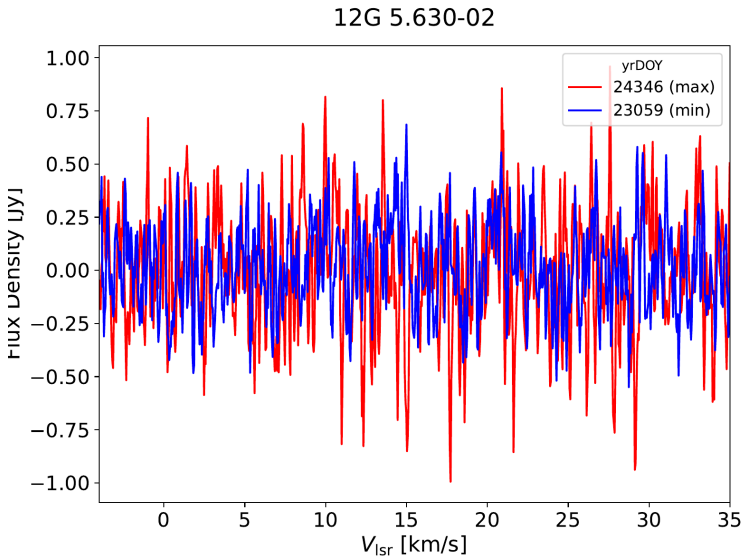
Light curve



Periodogram

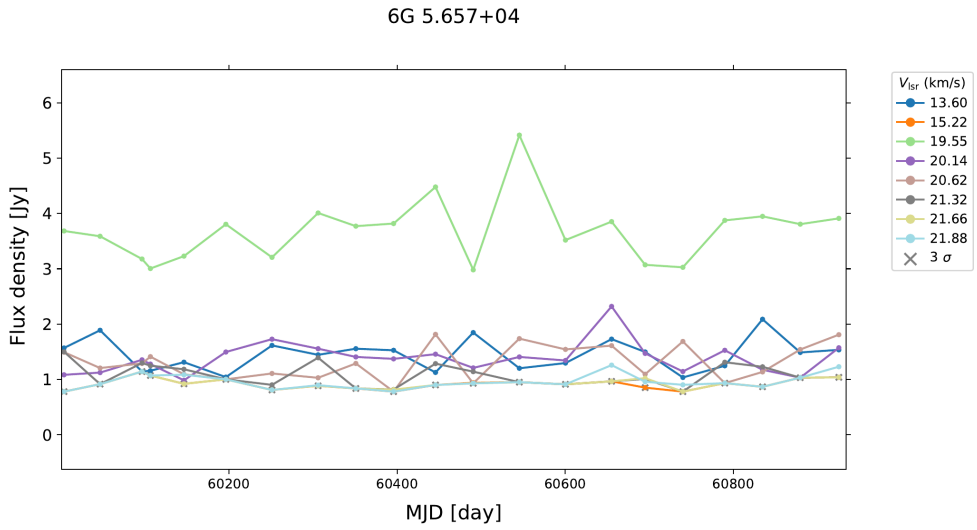


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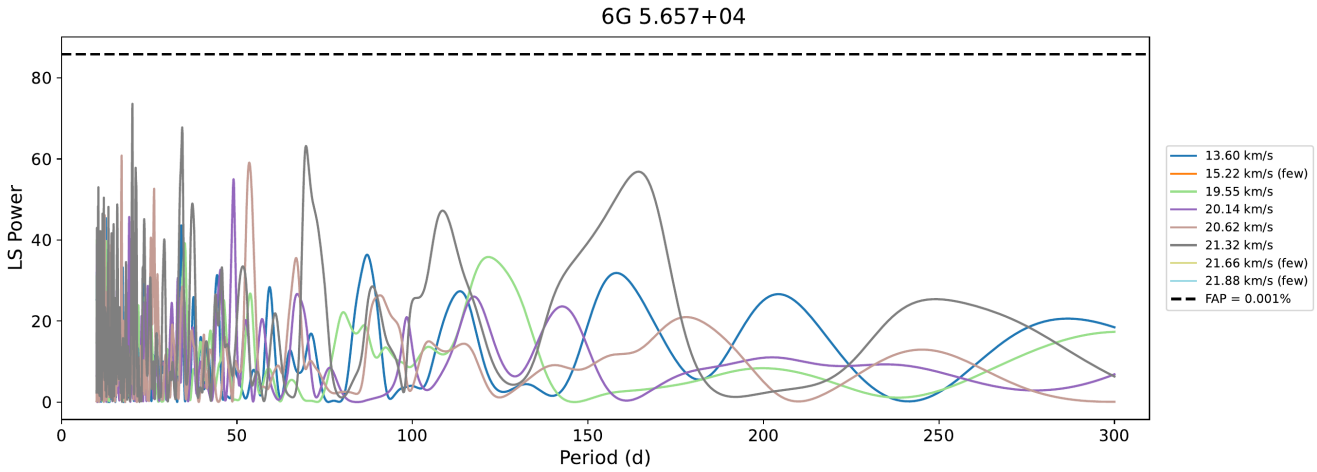


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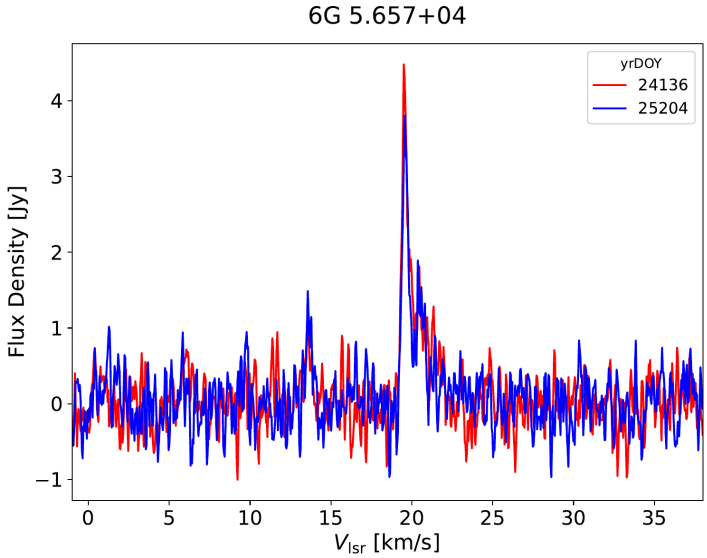
Light curve



Periodogram

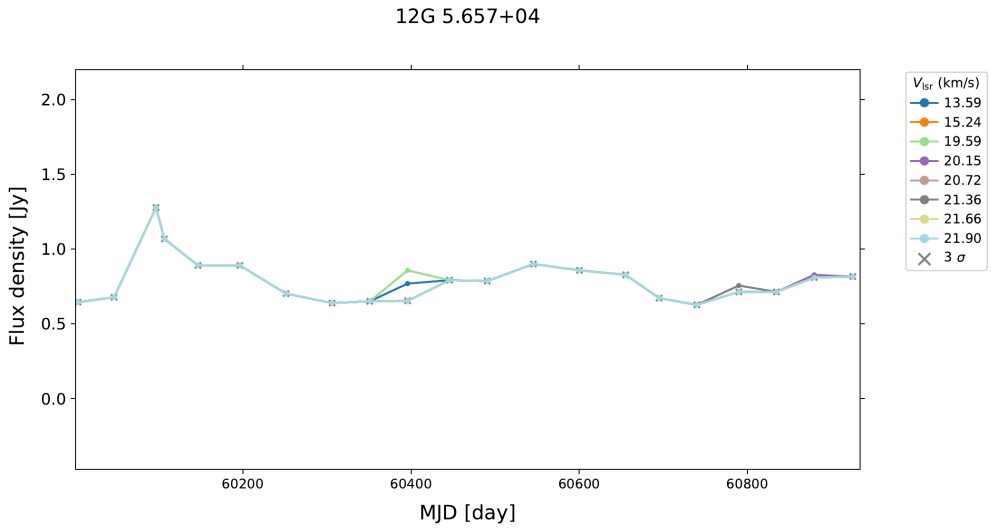


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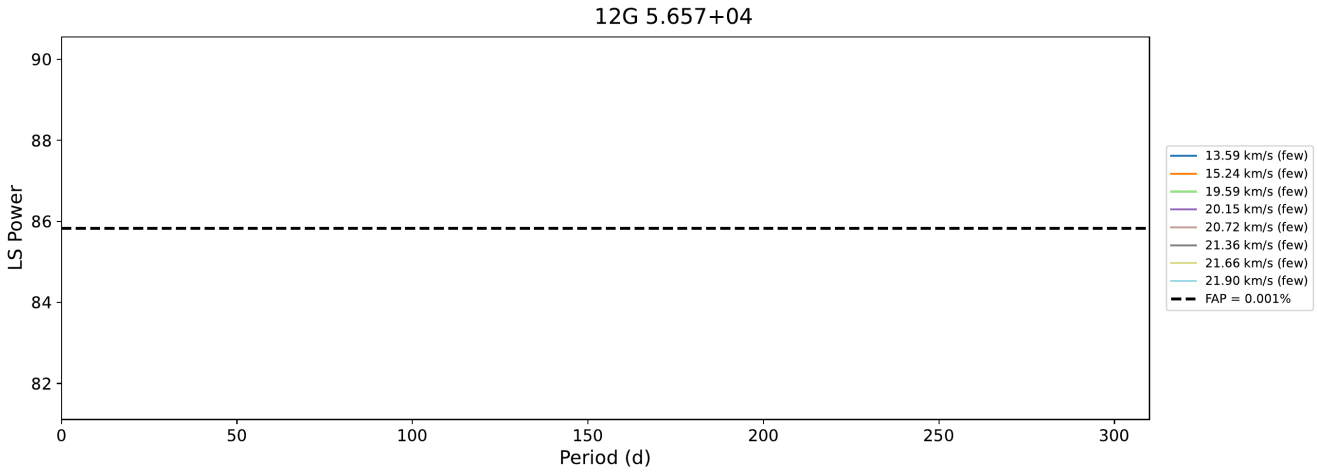


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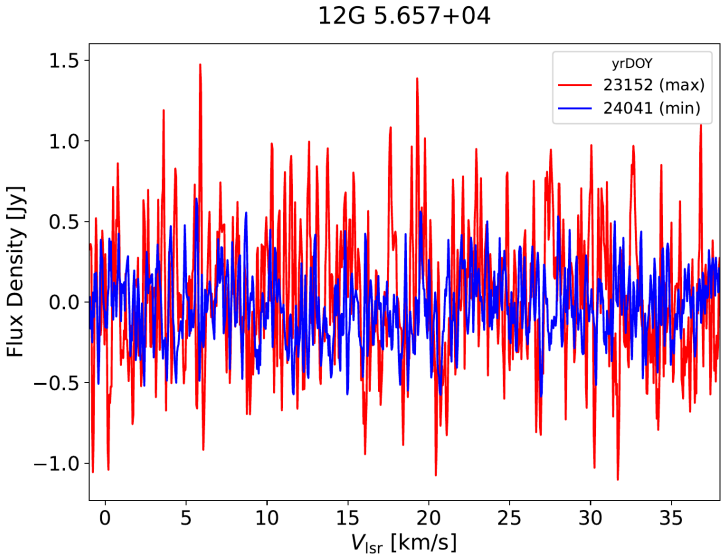
Light curve



Periodogram

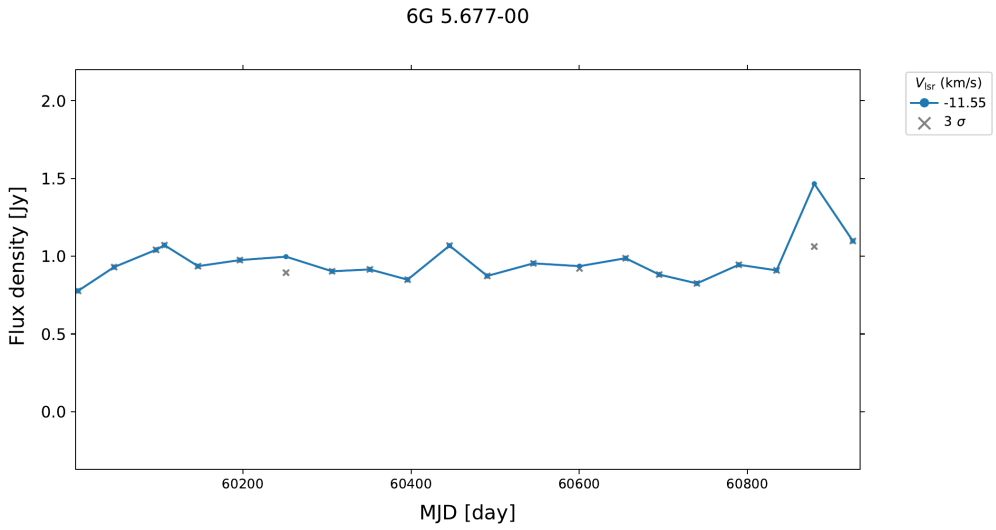


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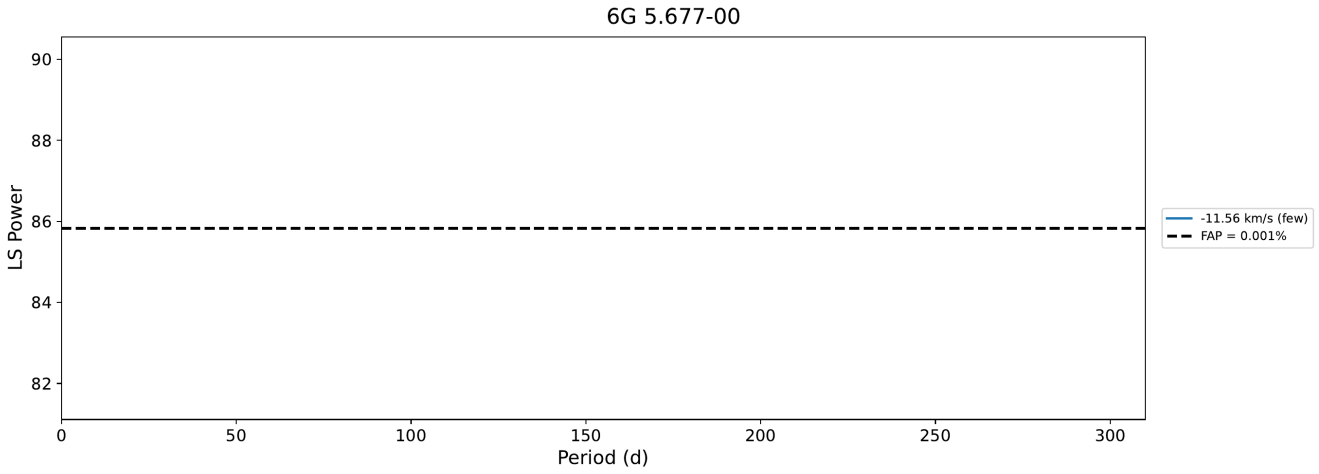


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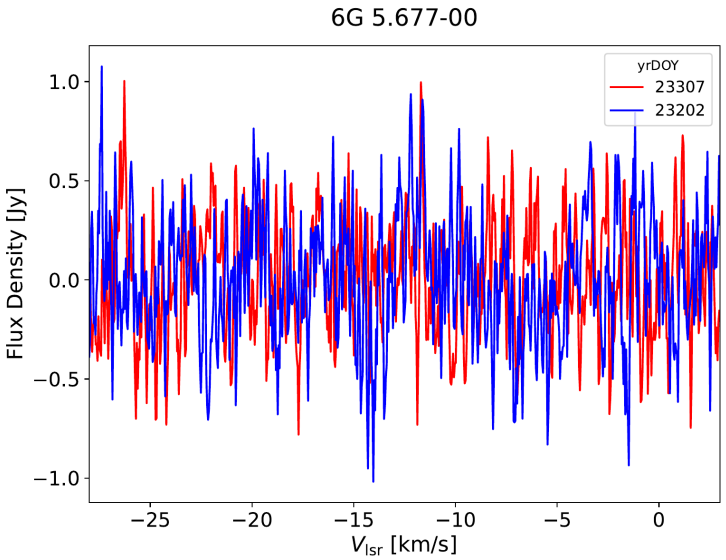
Light curve



Periodogram

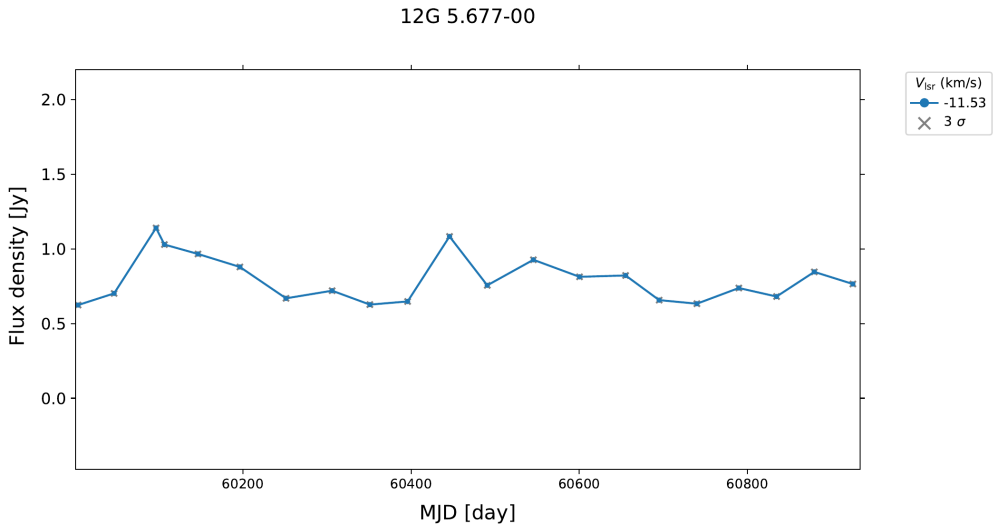


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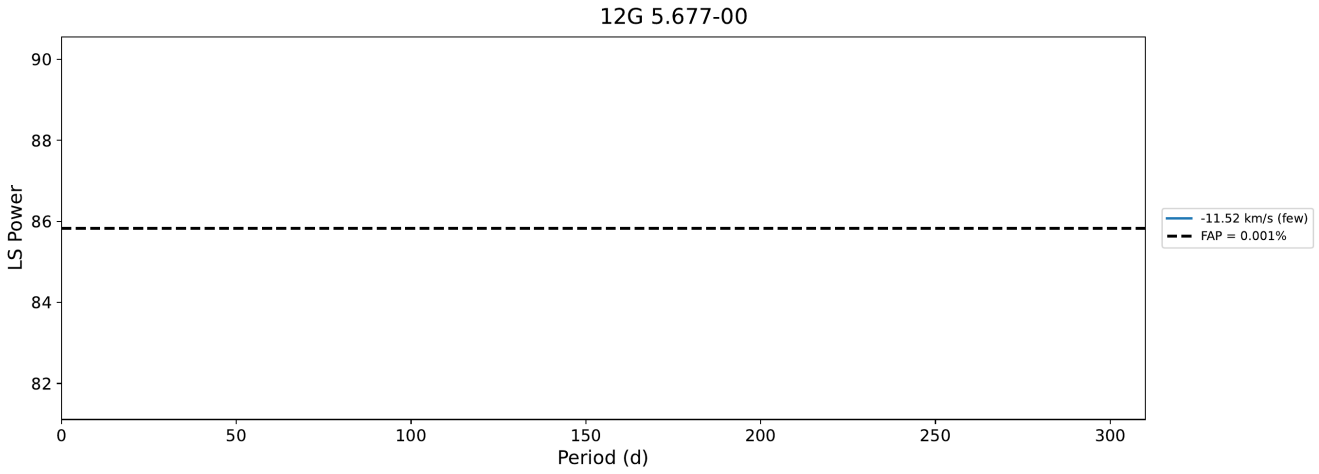


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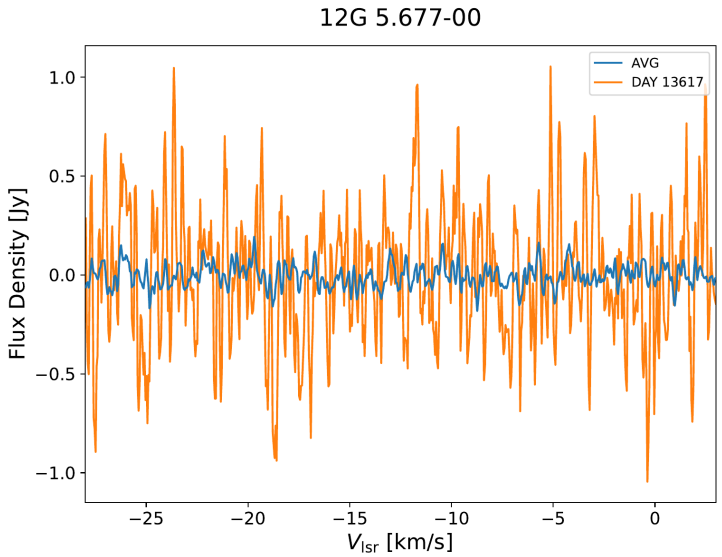
Light curve



Periodogram

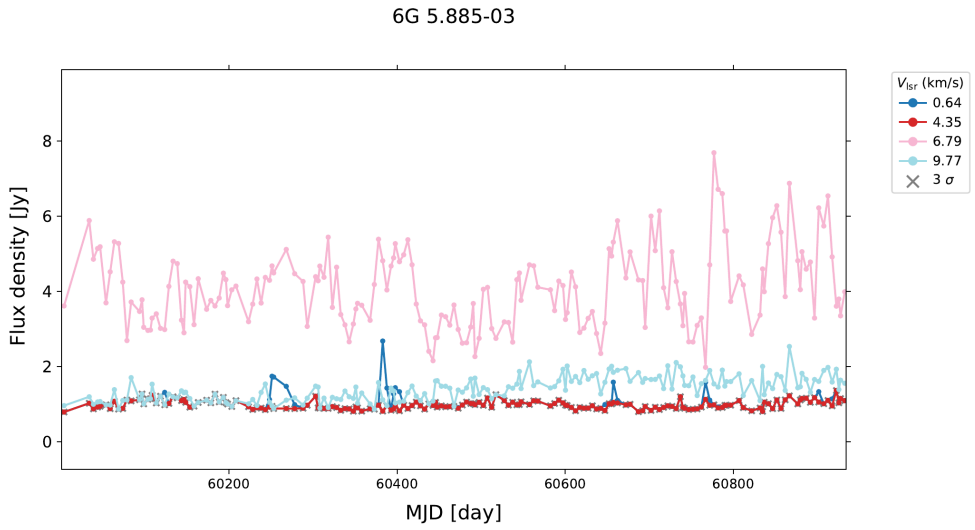


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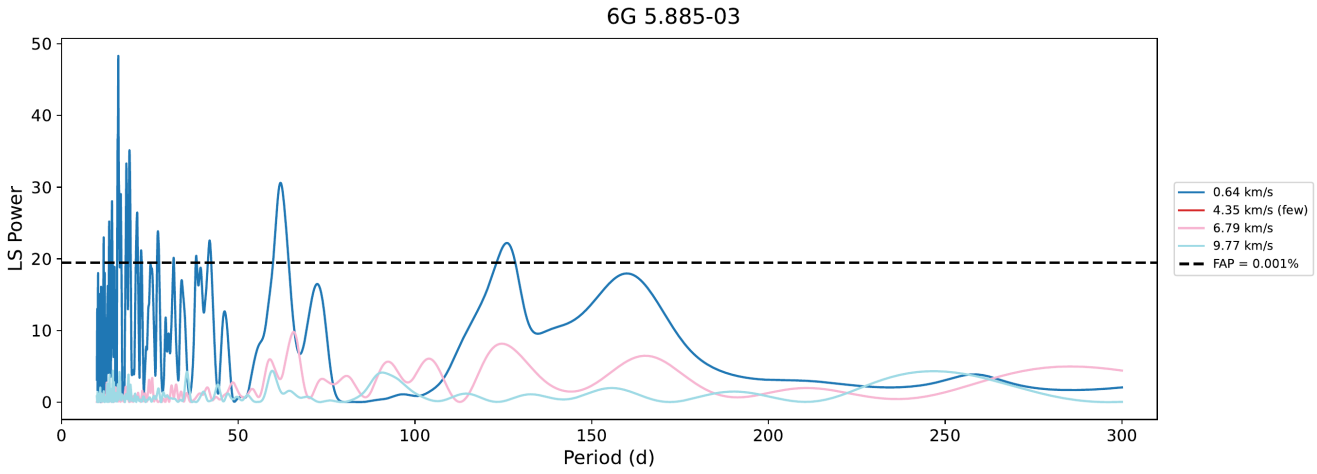


6G 5.885-03

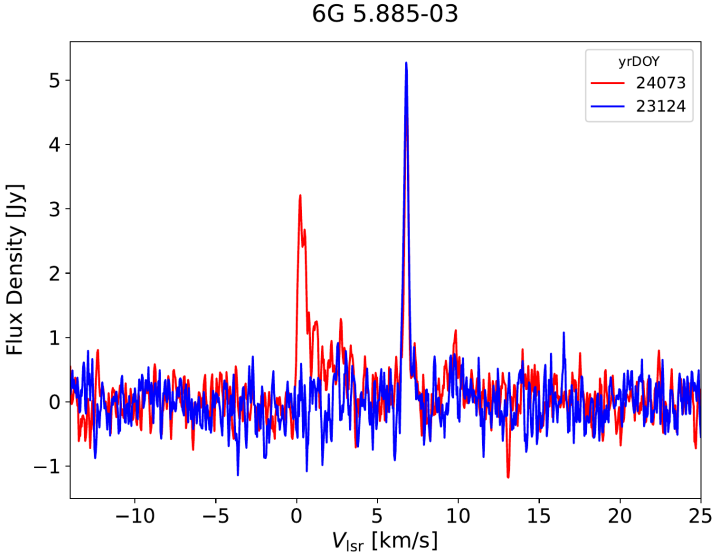
Light curve



Periodogram

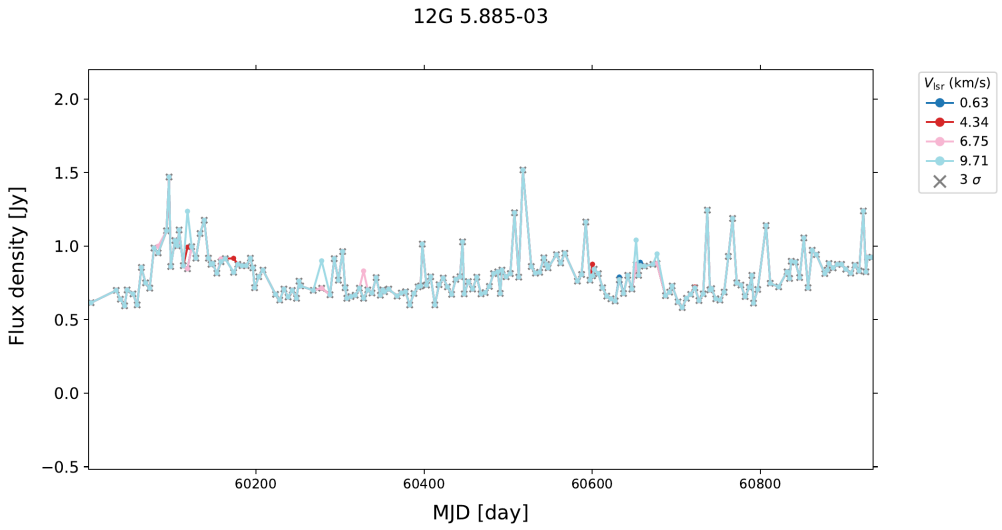


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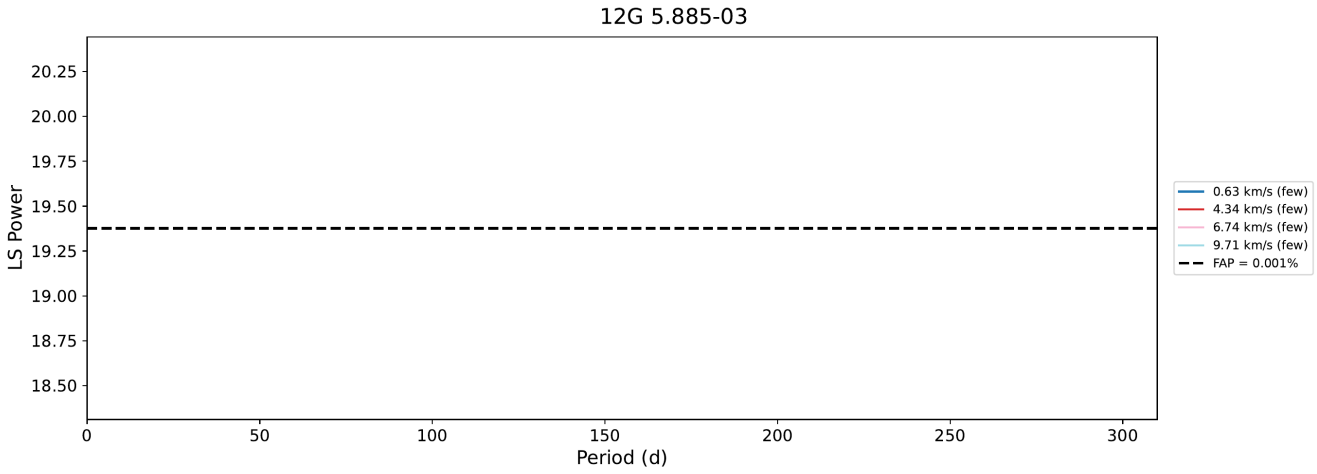


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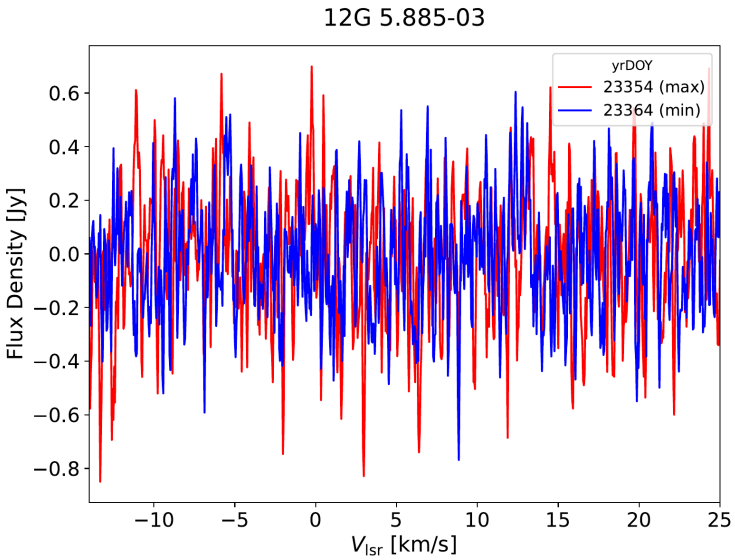
Light curve



Periodogram

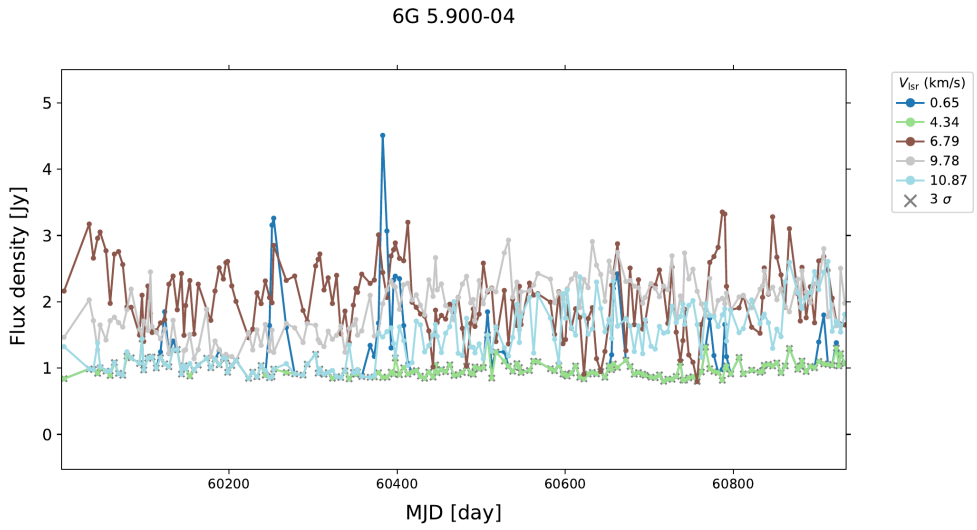


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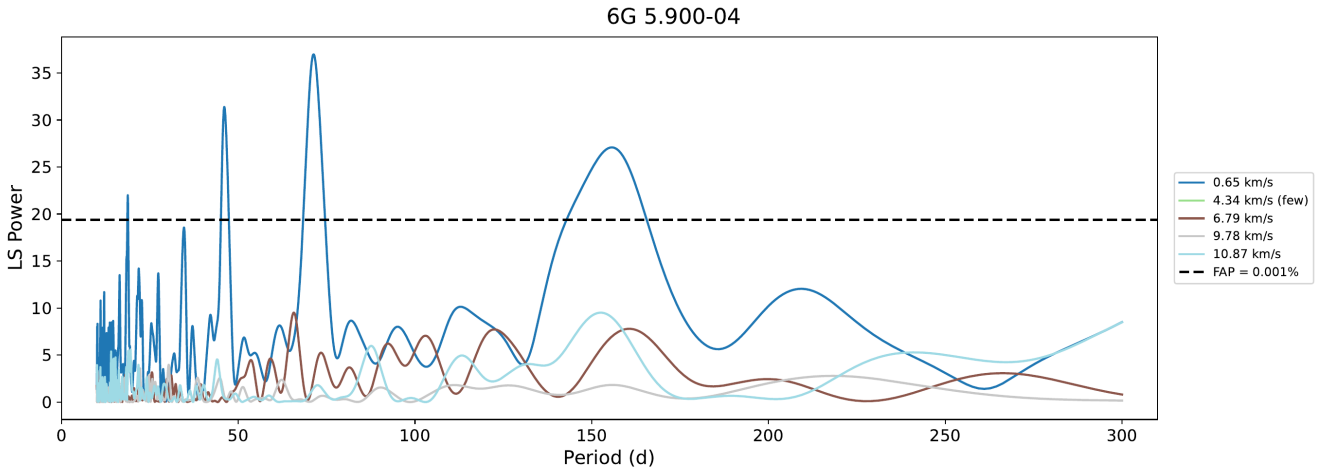


6G 5.900-04

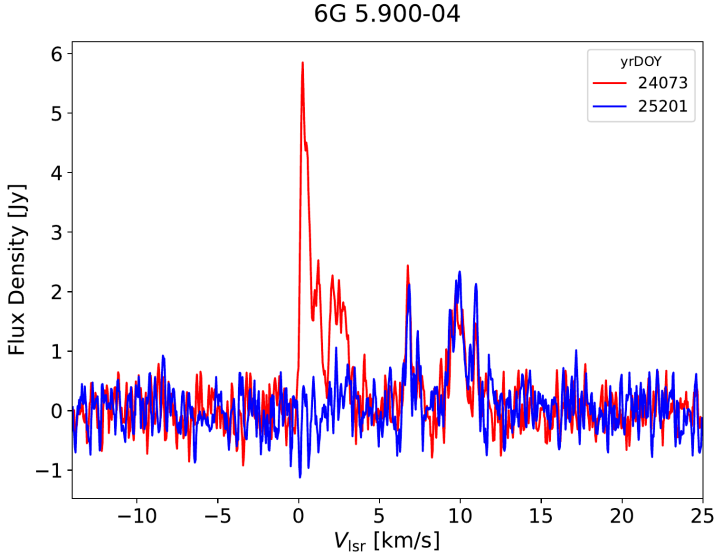
Light curve



Periodogram

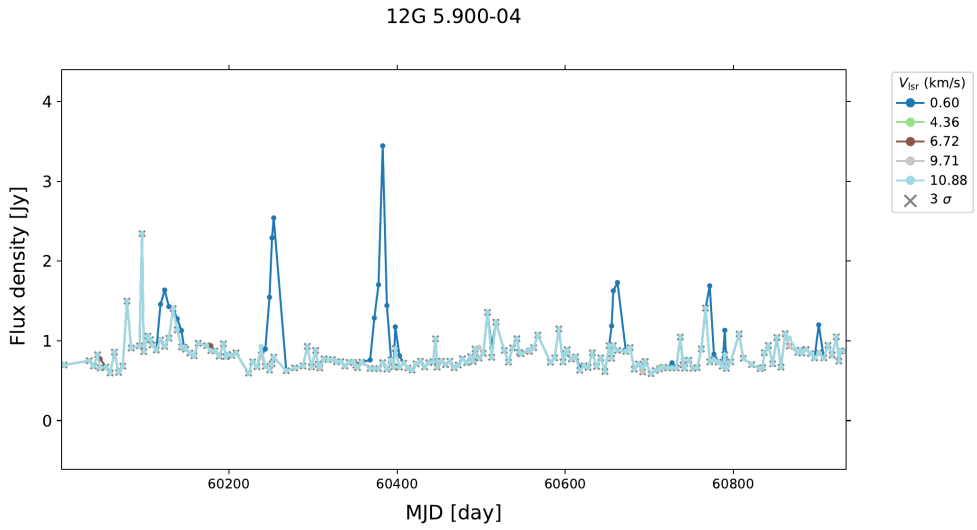


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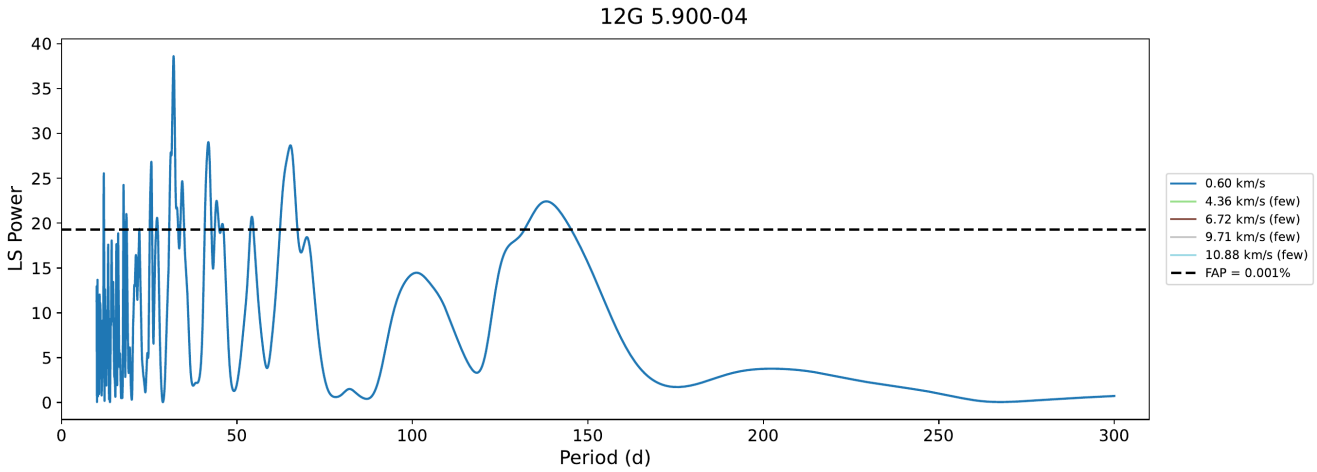


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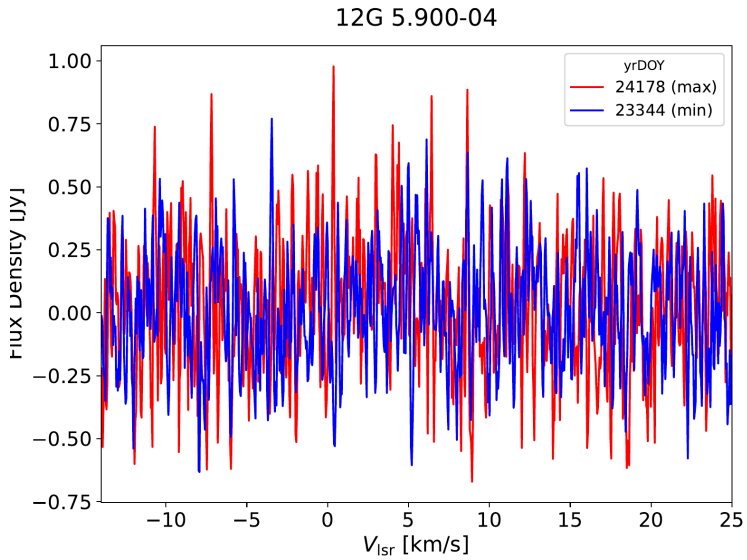
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Periodogram



Spectrum

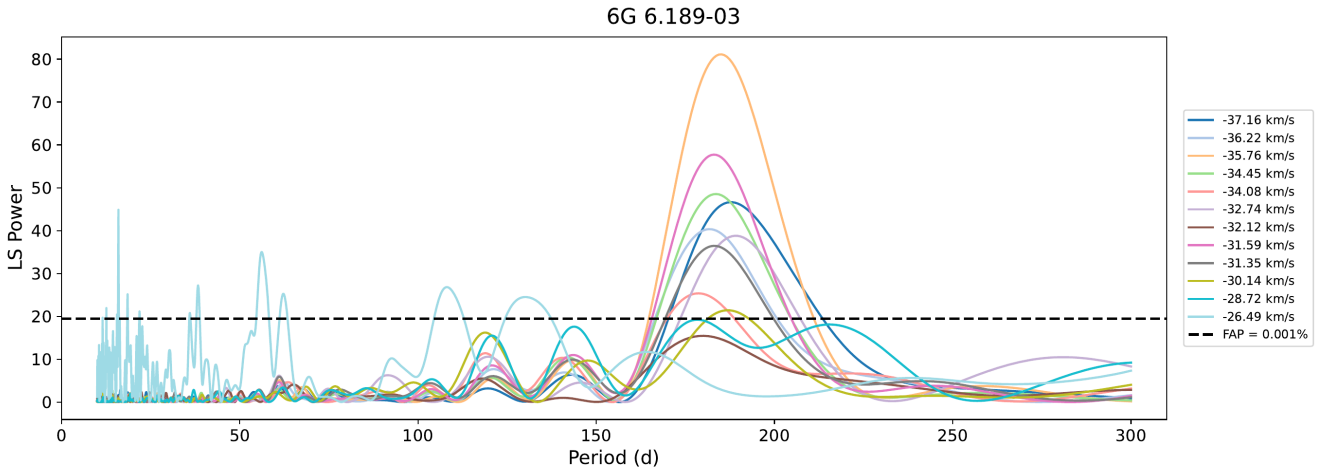


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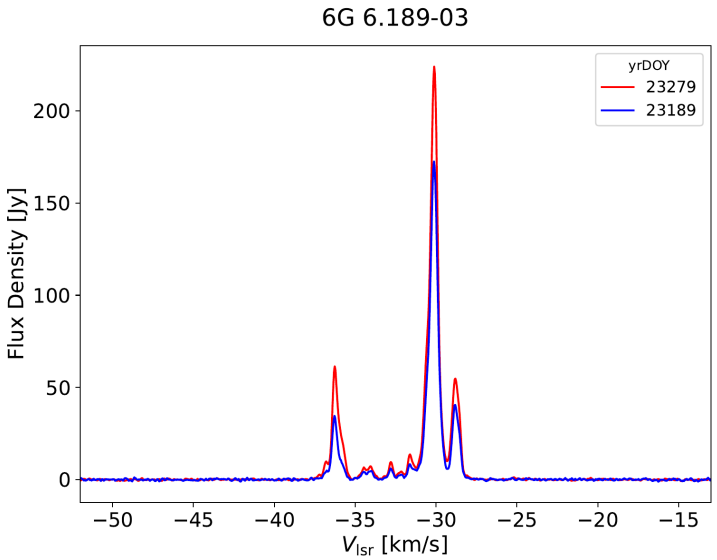
Light curve



Periodogram

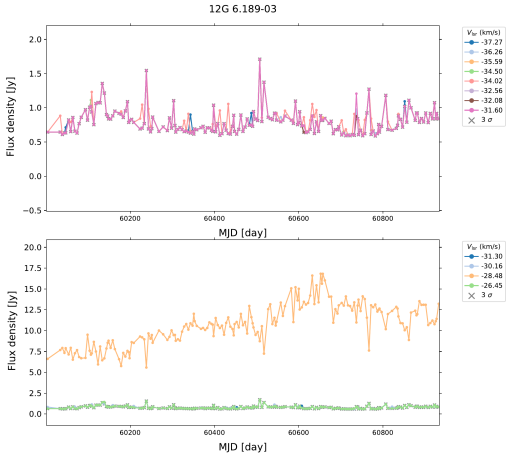


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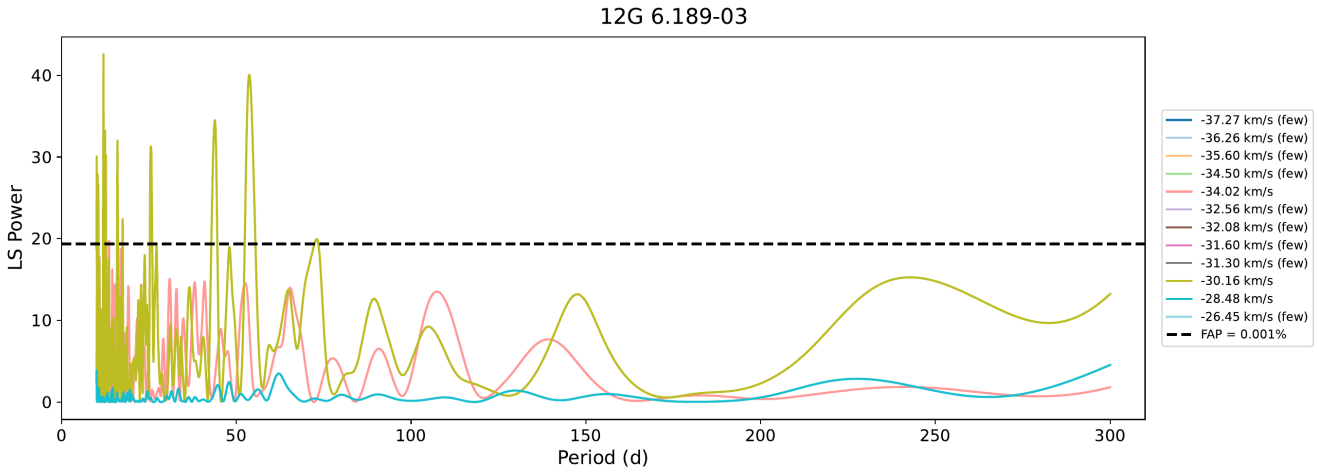


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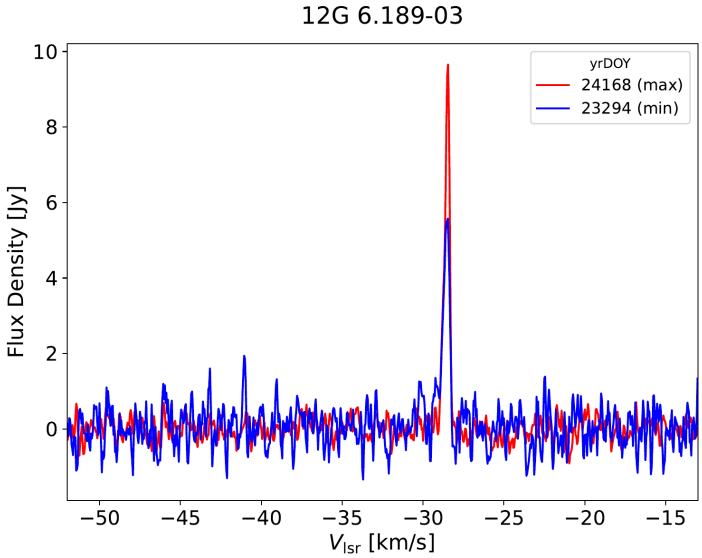
Light curve



Periodogram

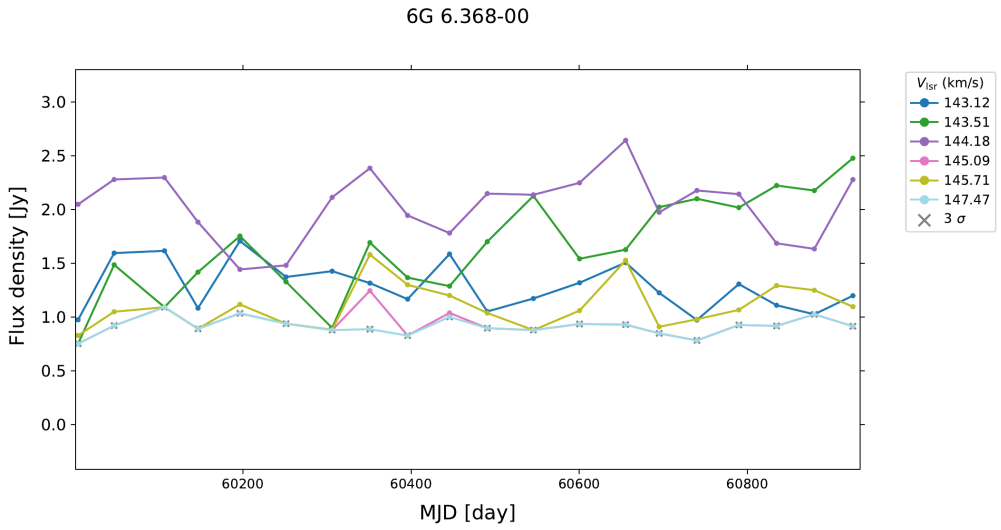


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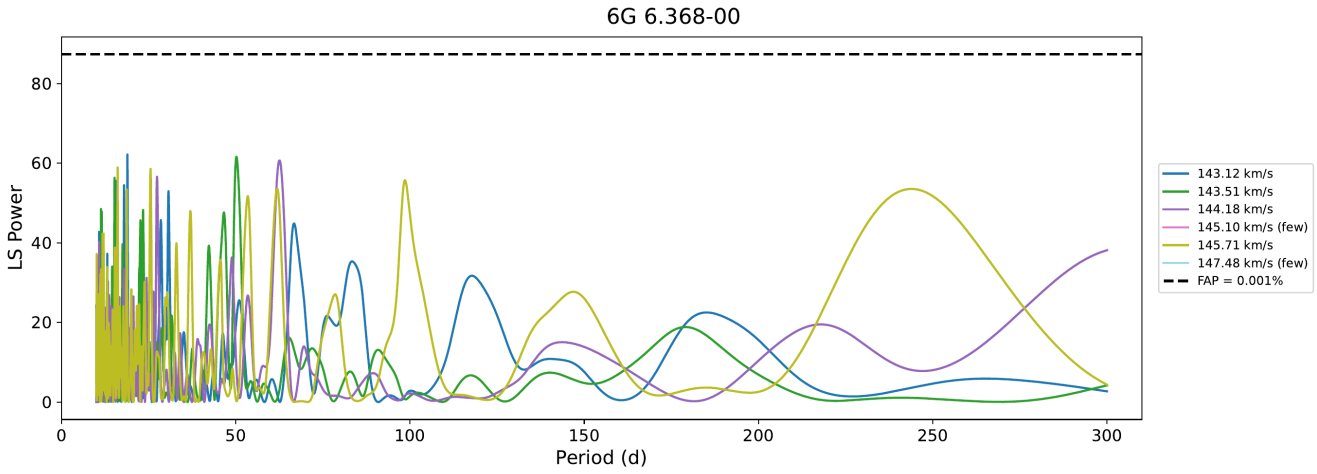


6G 6.368-00

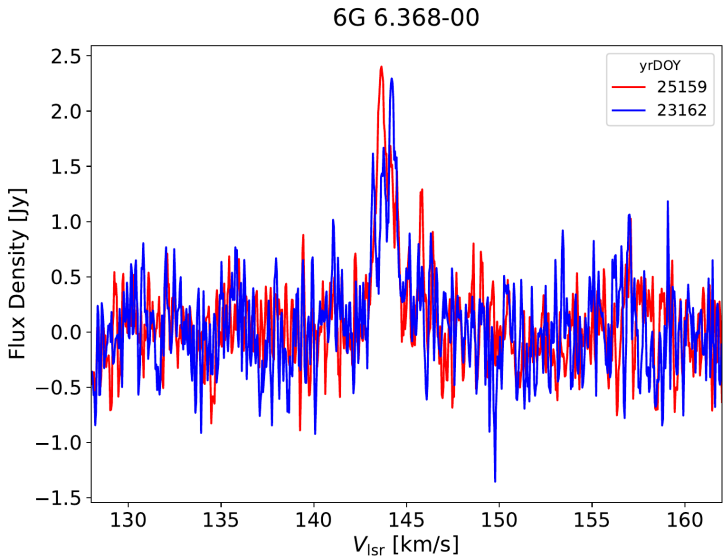
Light curve



Periodogram

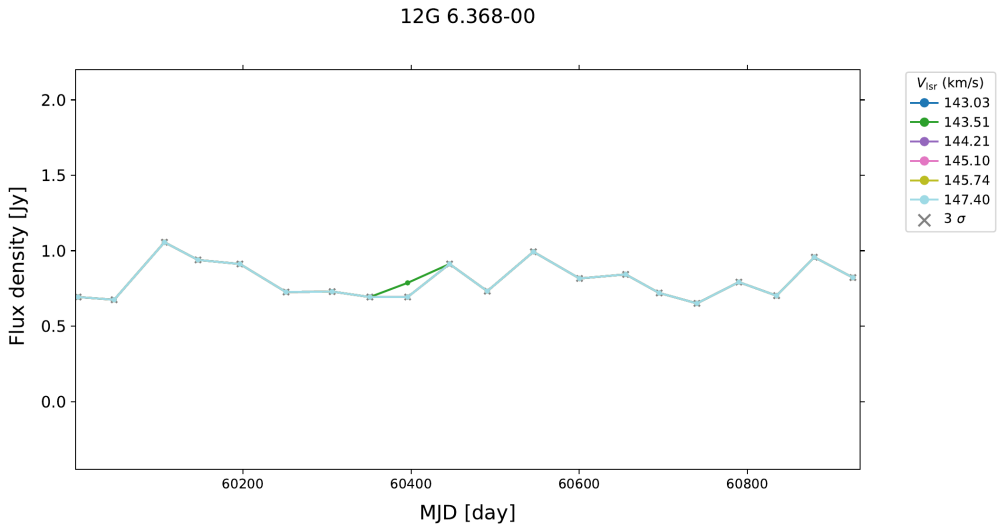


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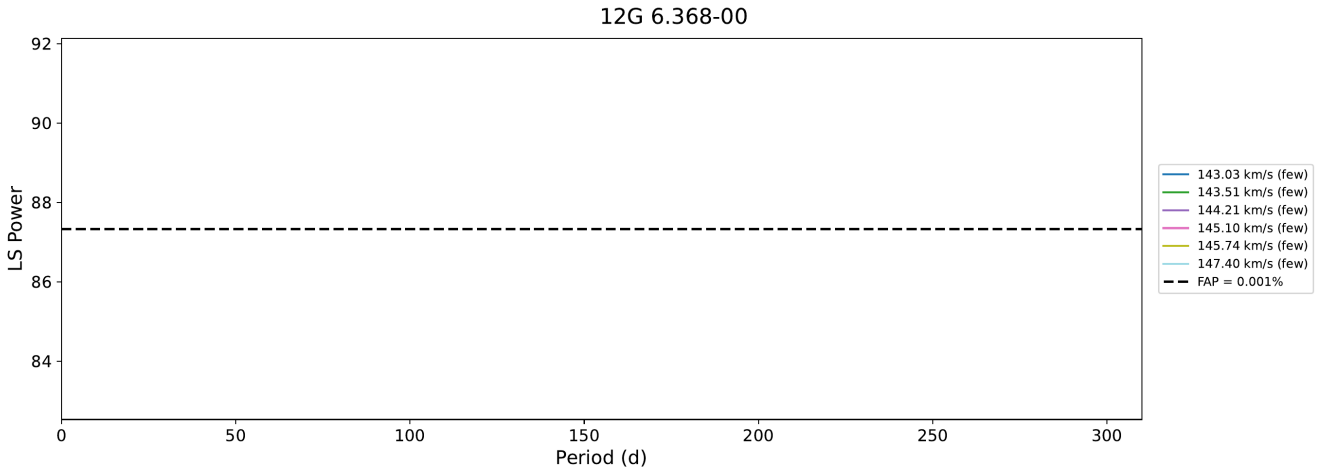


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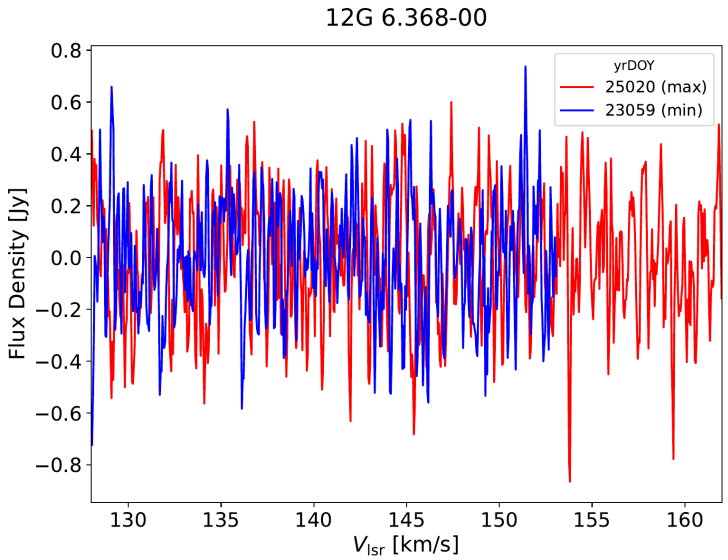
Light curve



Periodogram

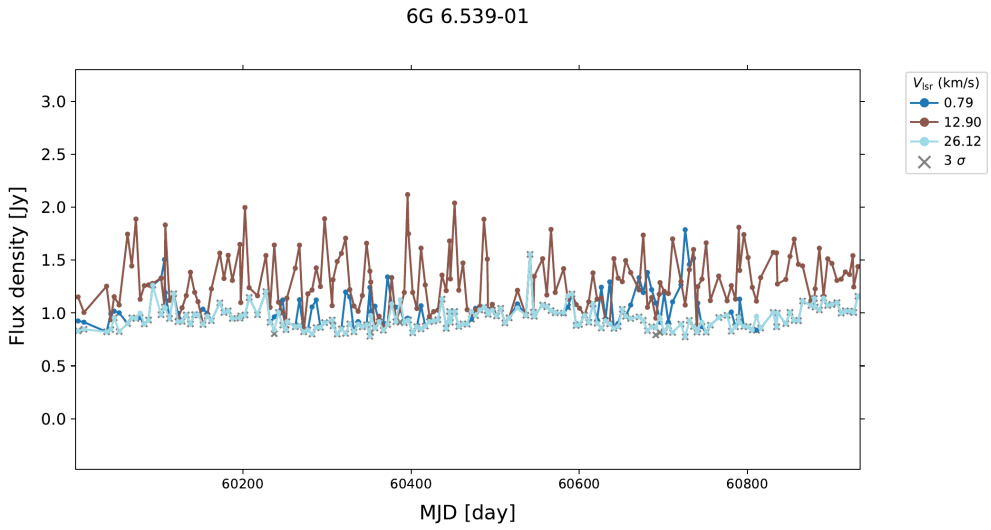


Spectrum

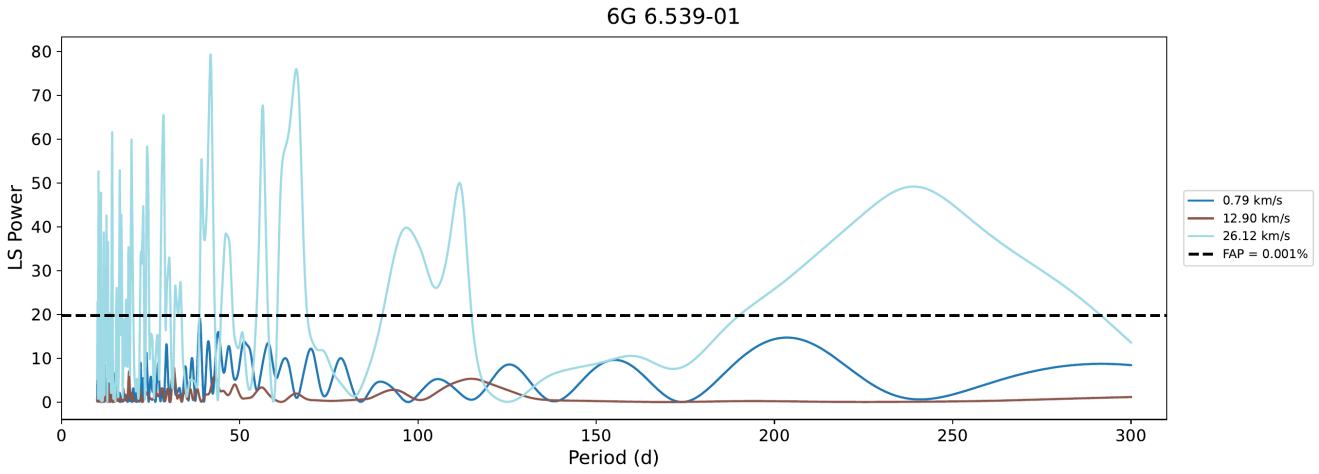


6G 6.539-01

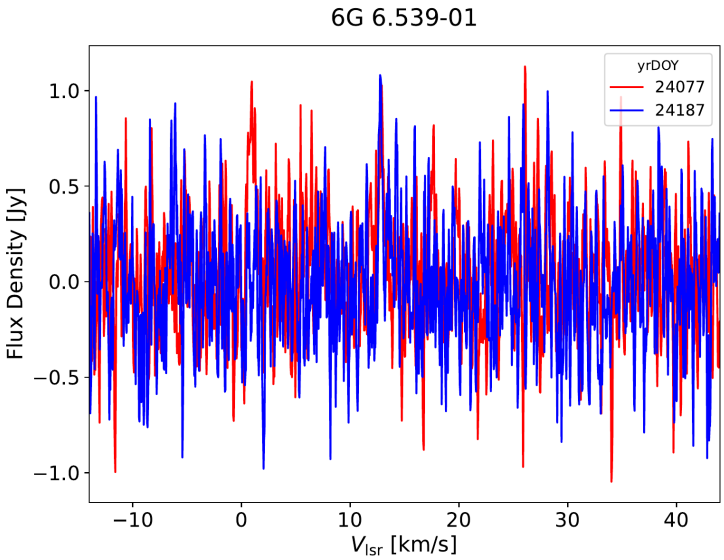
Light curve



Periodogram

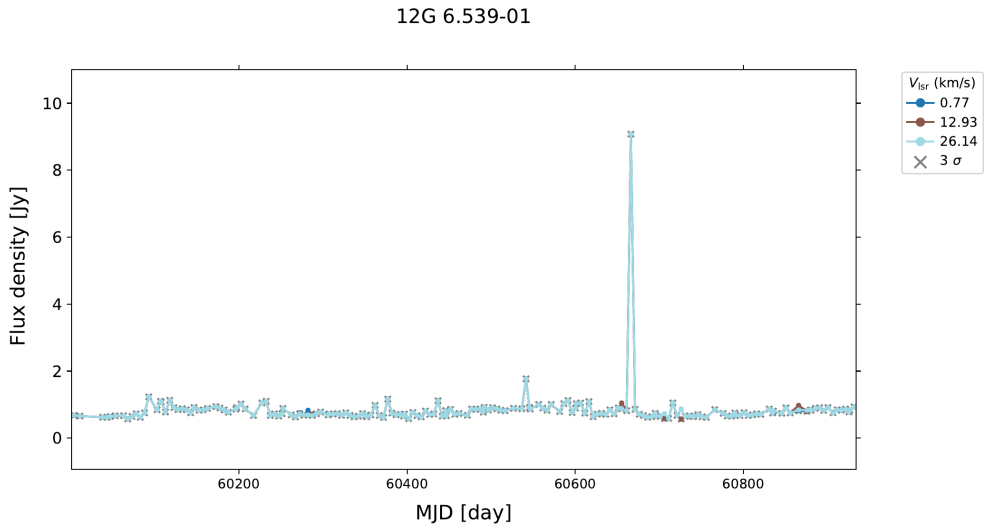


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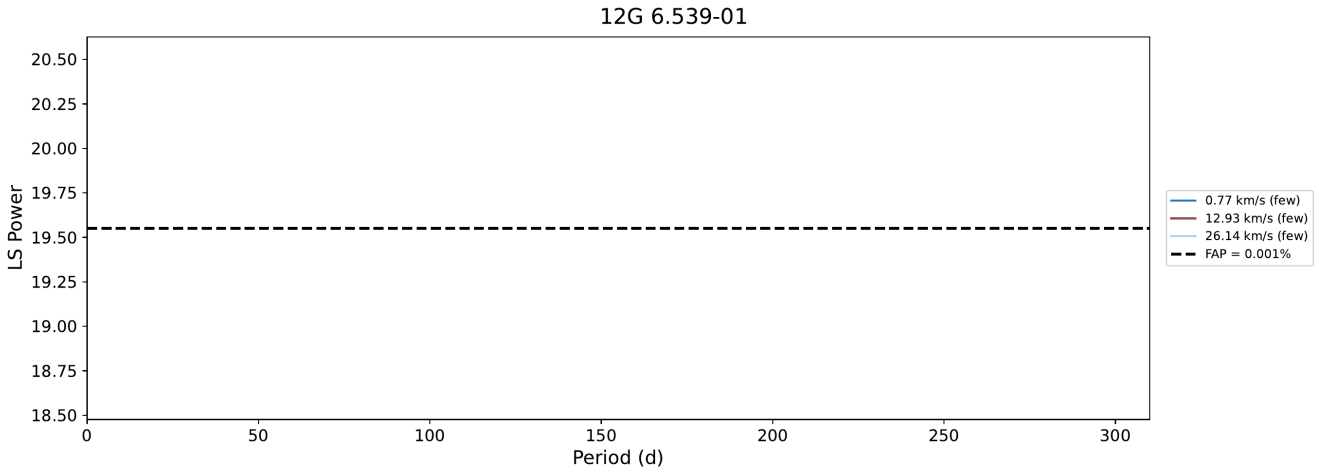


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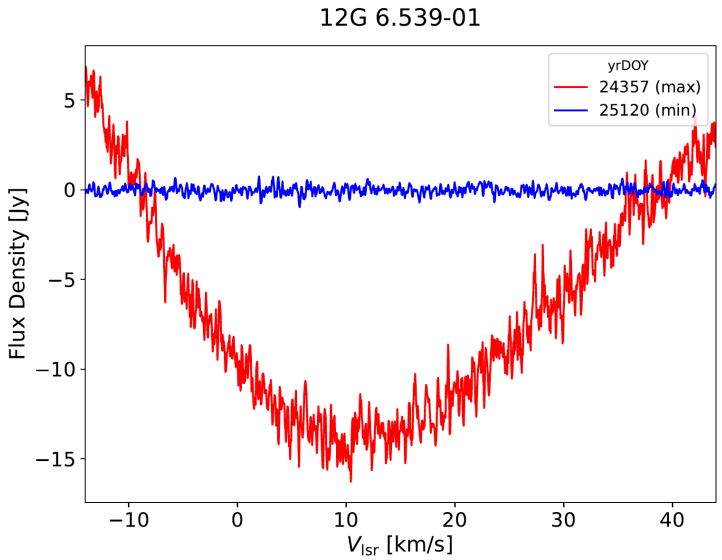
Light curve



Periodogram

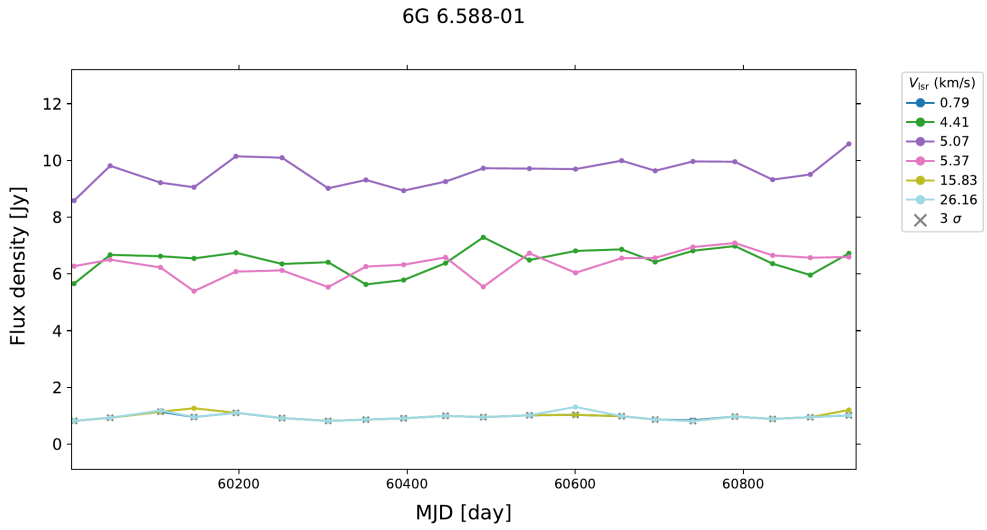


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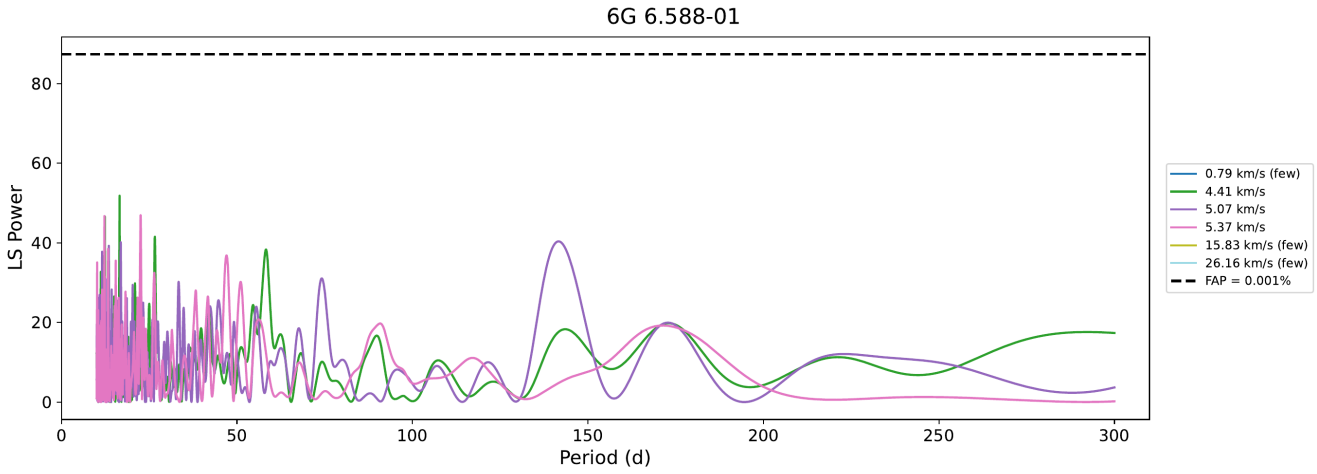


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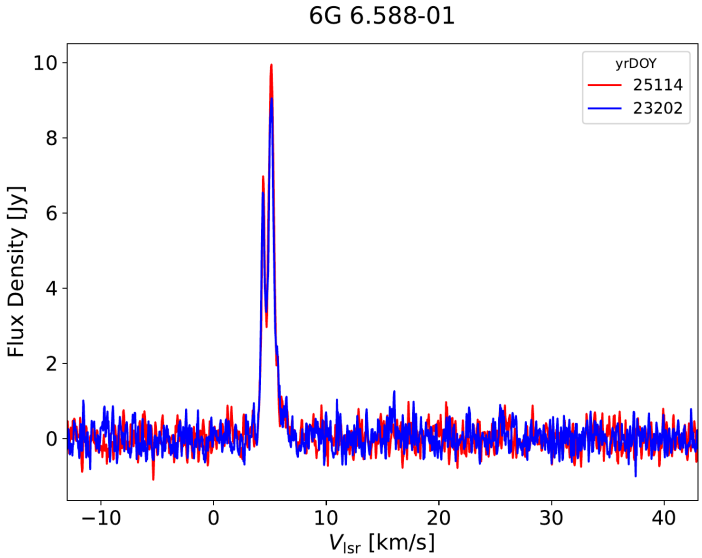
Light curve



Periodogram

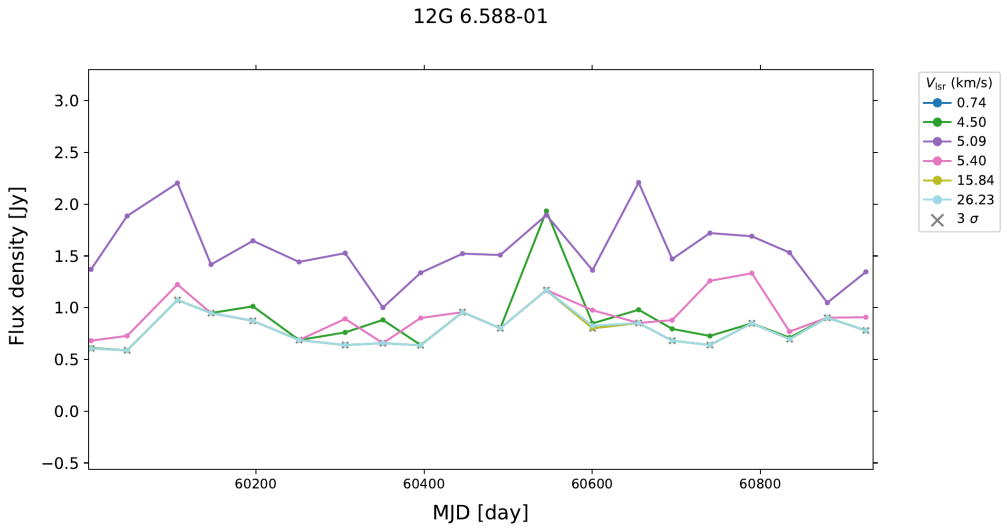


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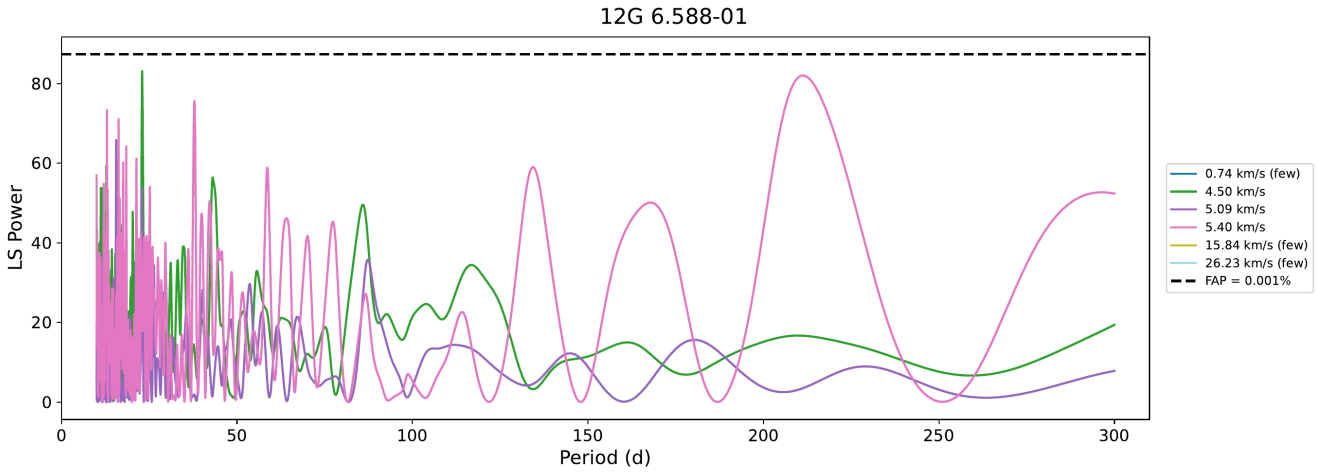


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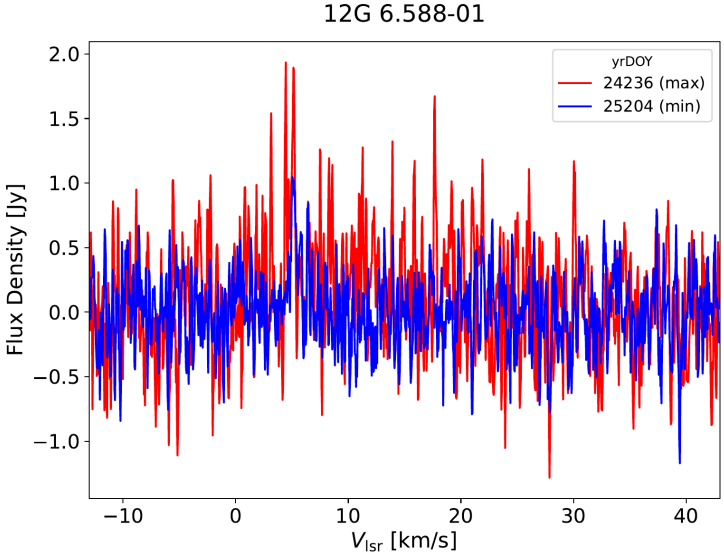
Light curve



Periodogram

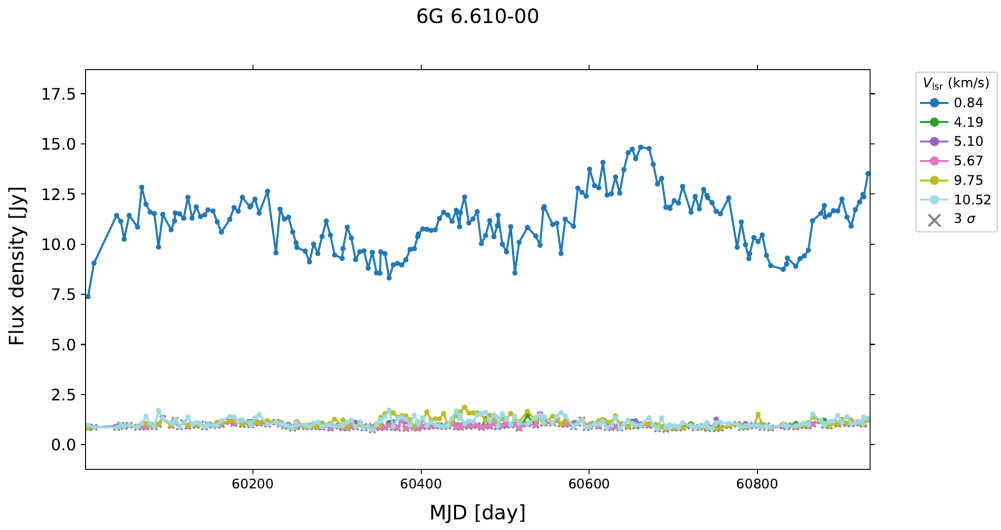


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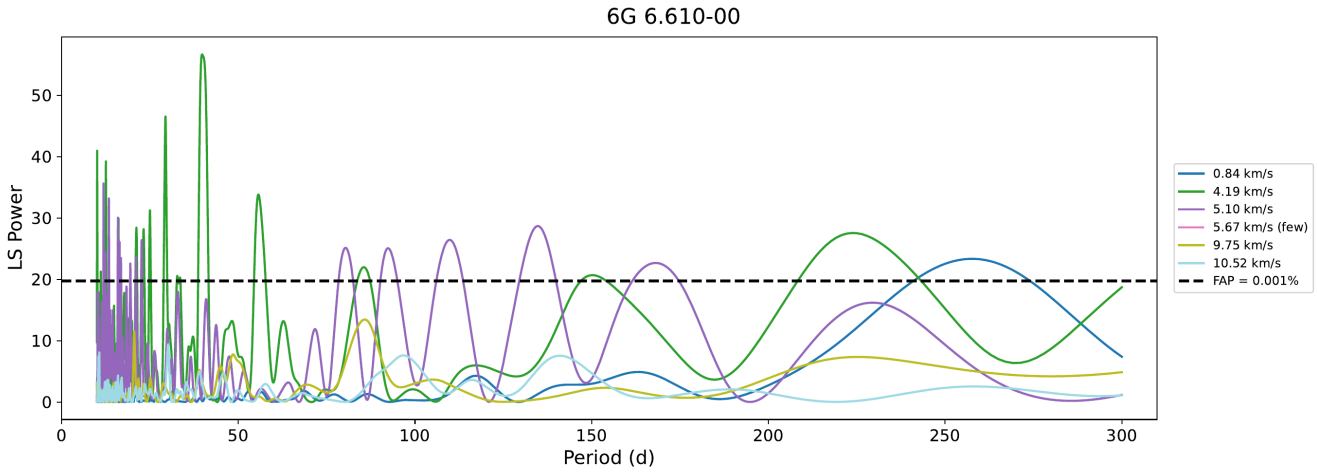


6G 6.610-00

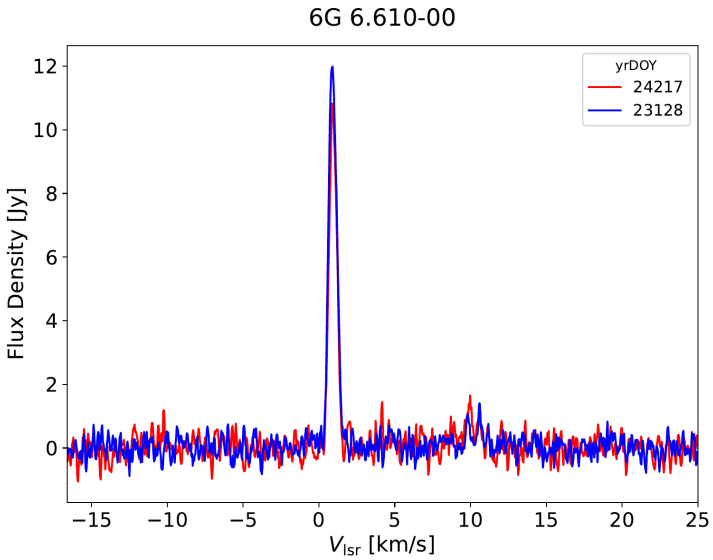
Light curve



Periodogram

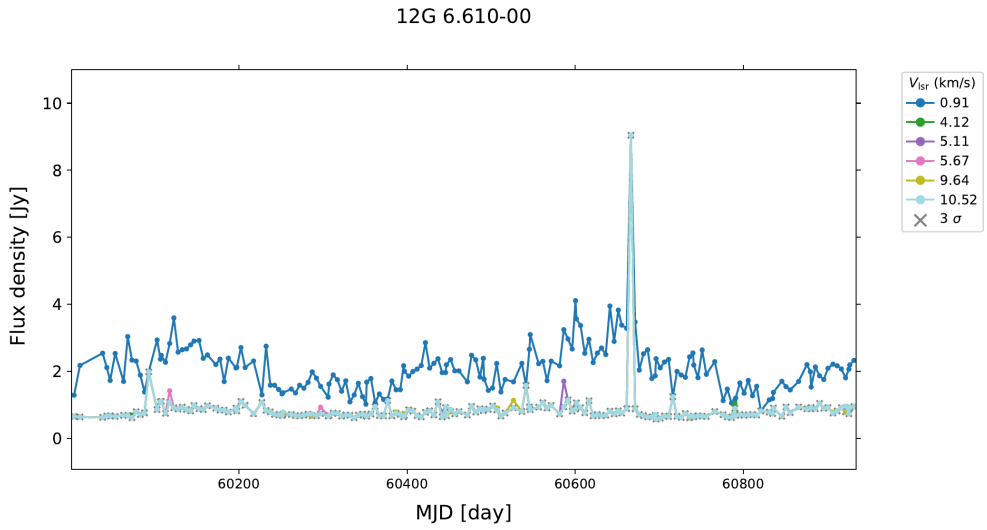


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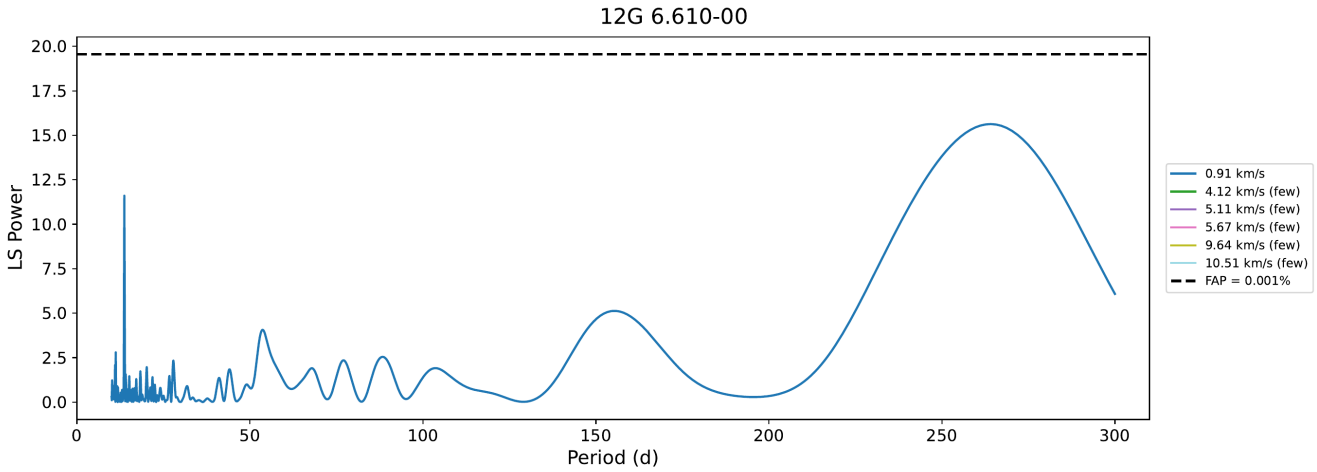


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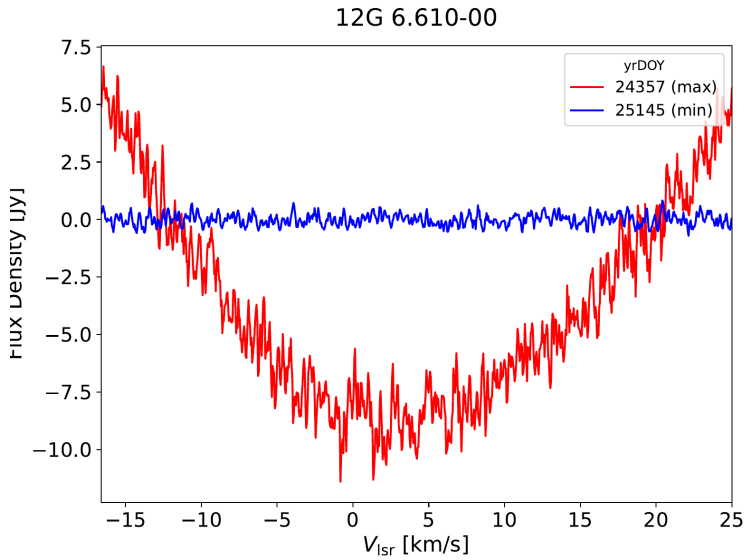
Light curve



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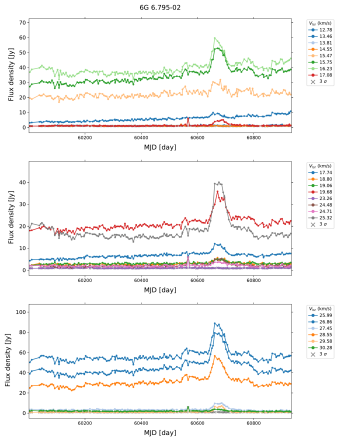


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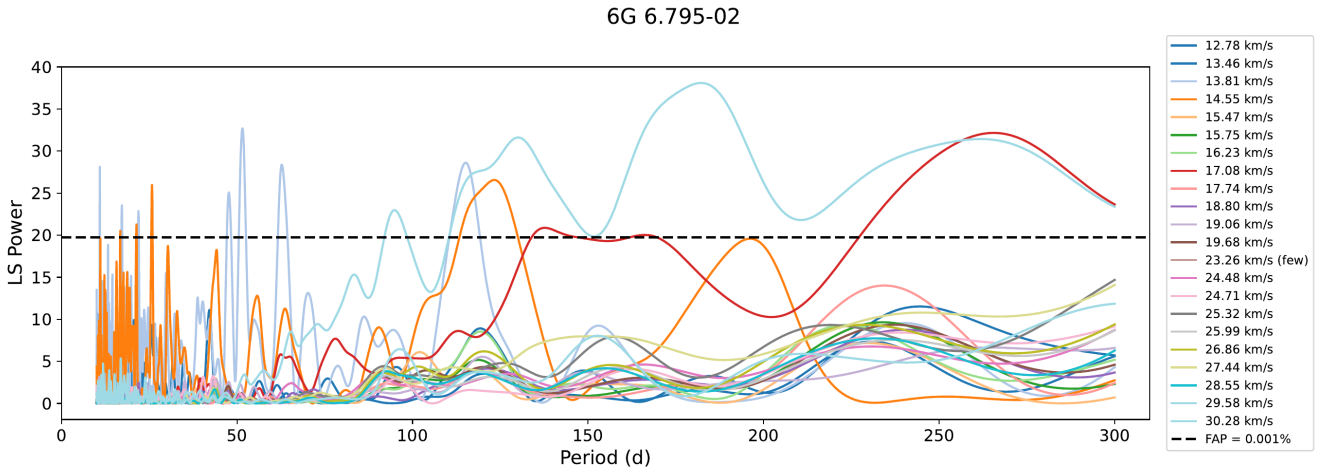


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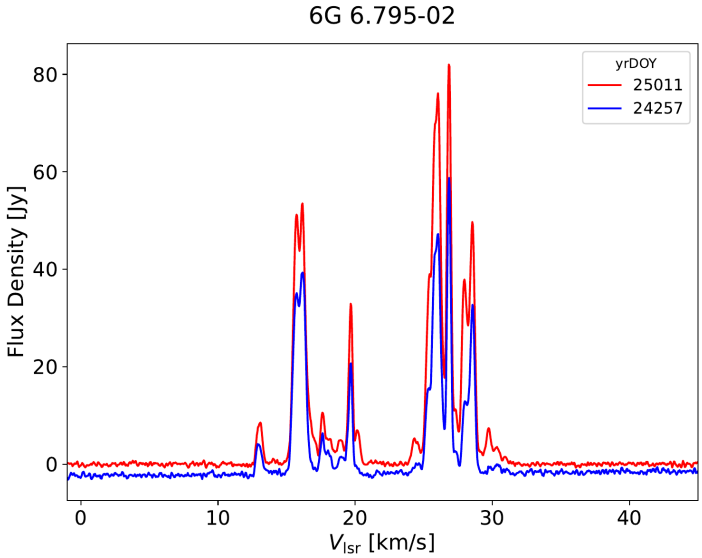
Light curve



Periodogram

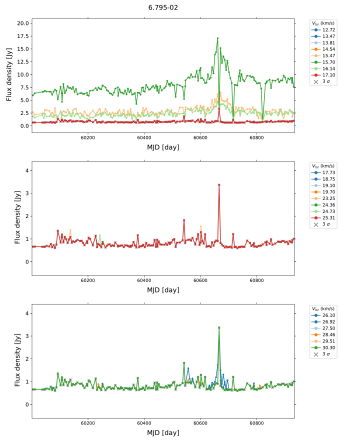


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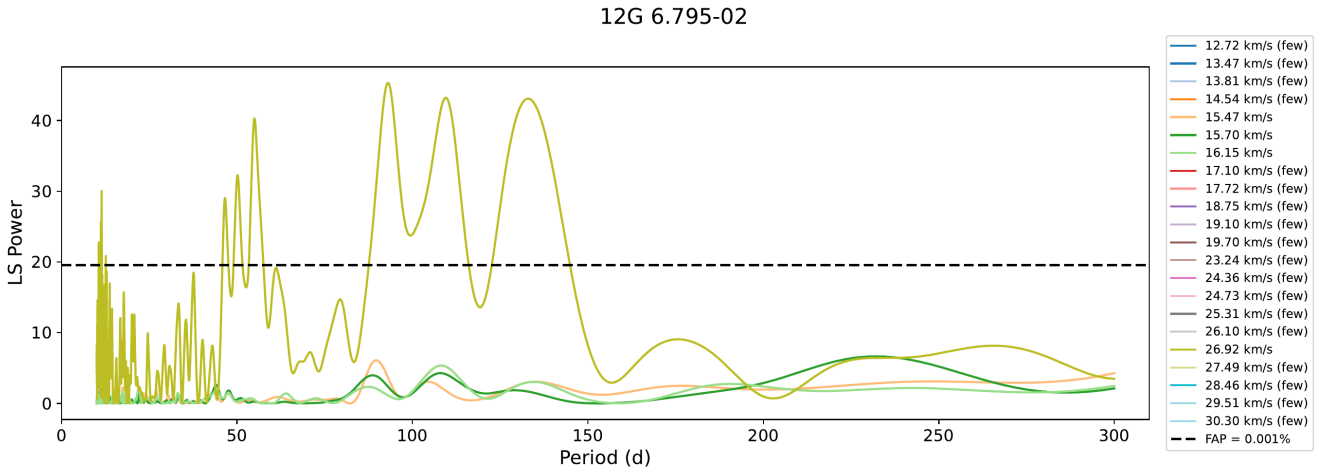


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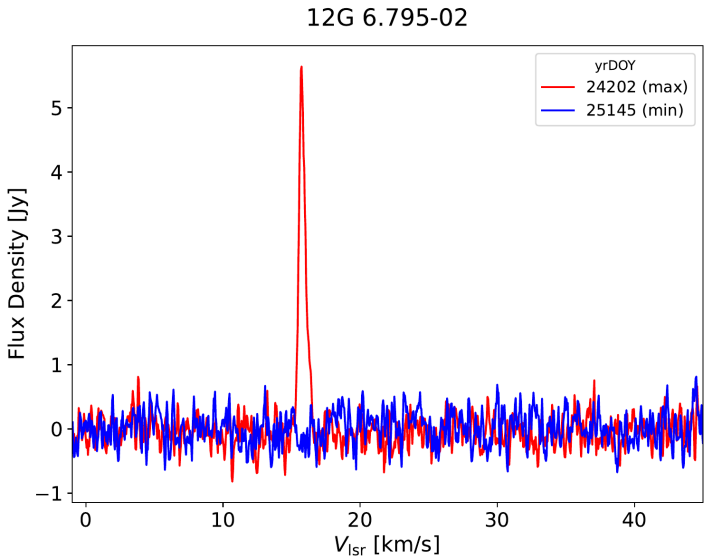
Light curve



Periodogram

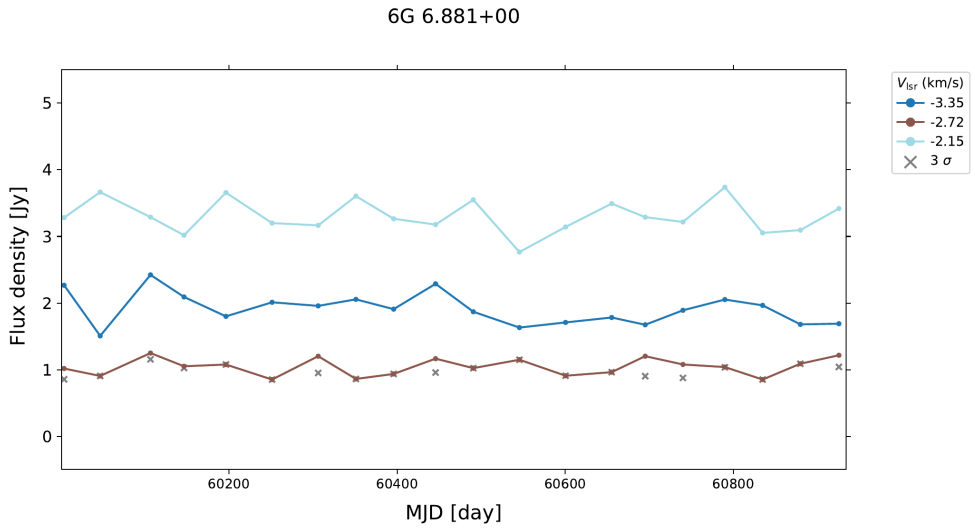


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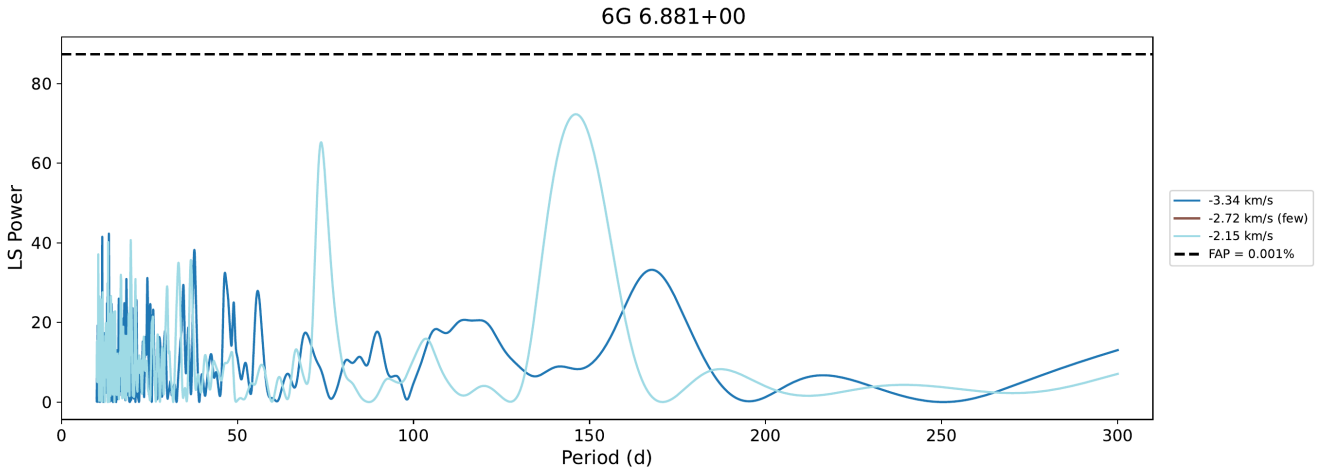


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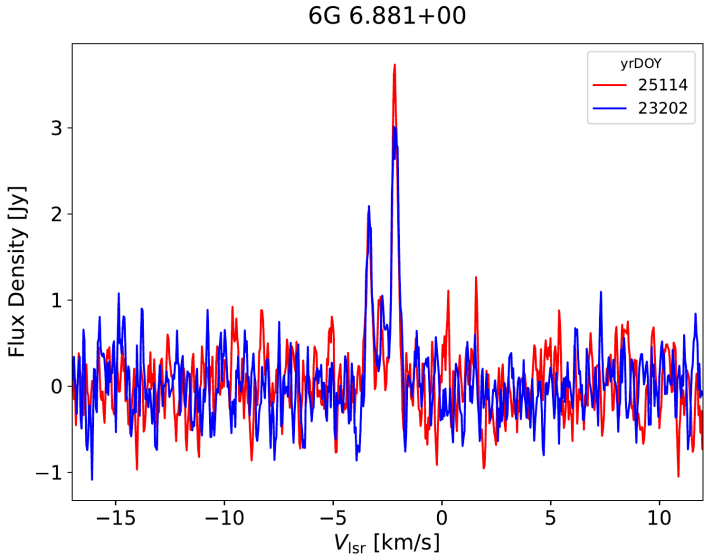
Light curve



Periodogram

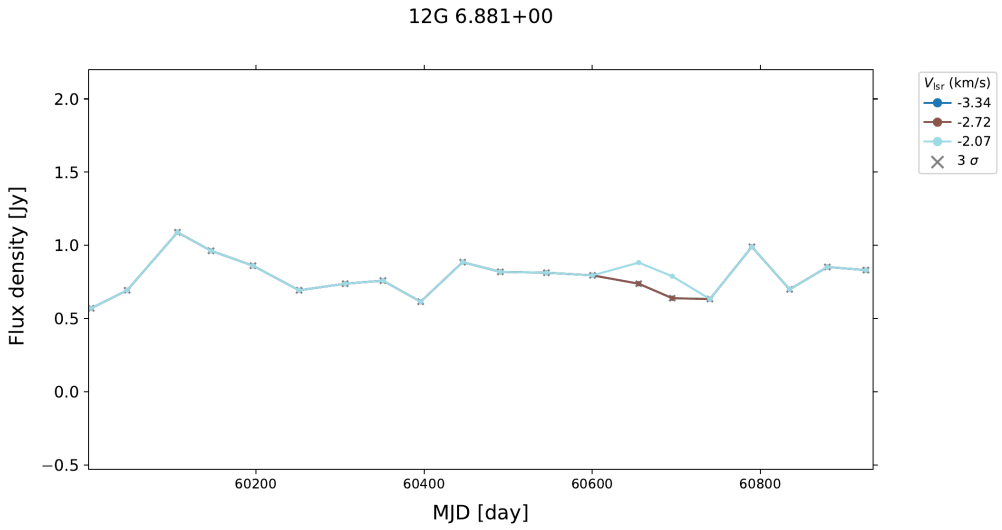


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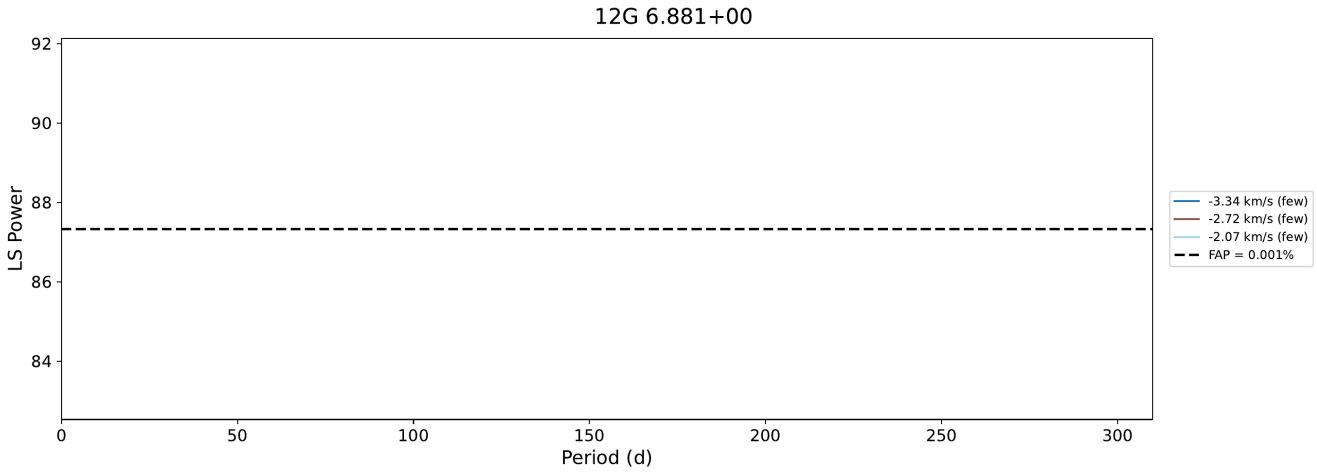


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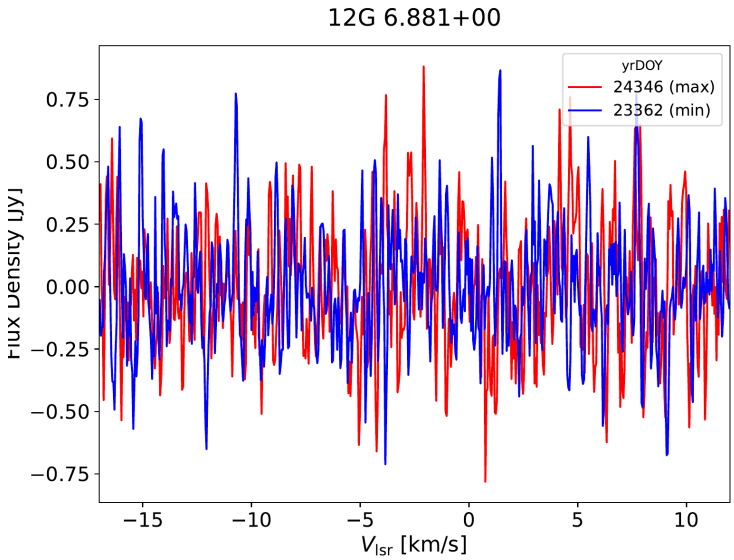
Light curve



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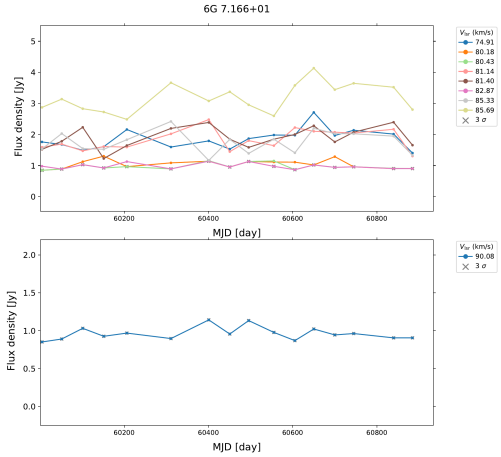


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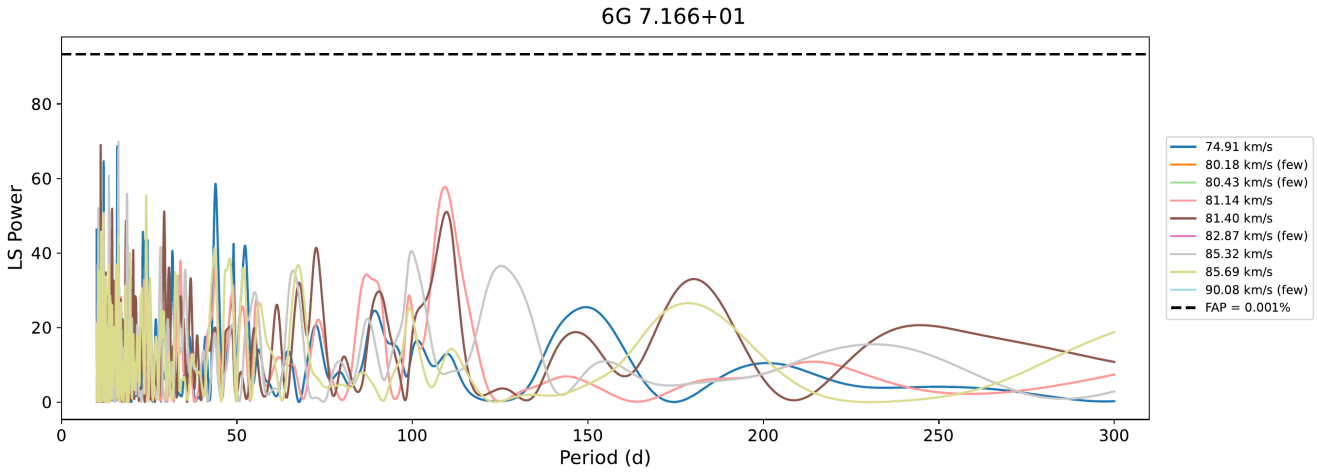


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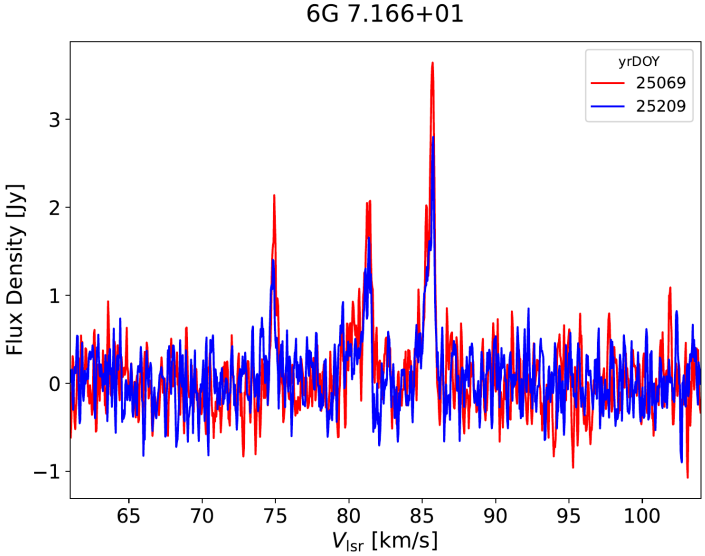
Light curve



Periodogram

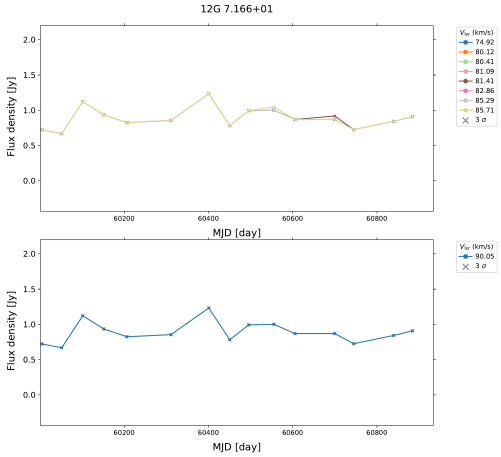


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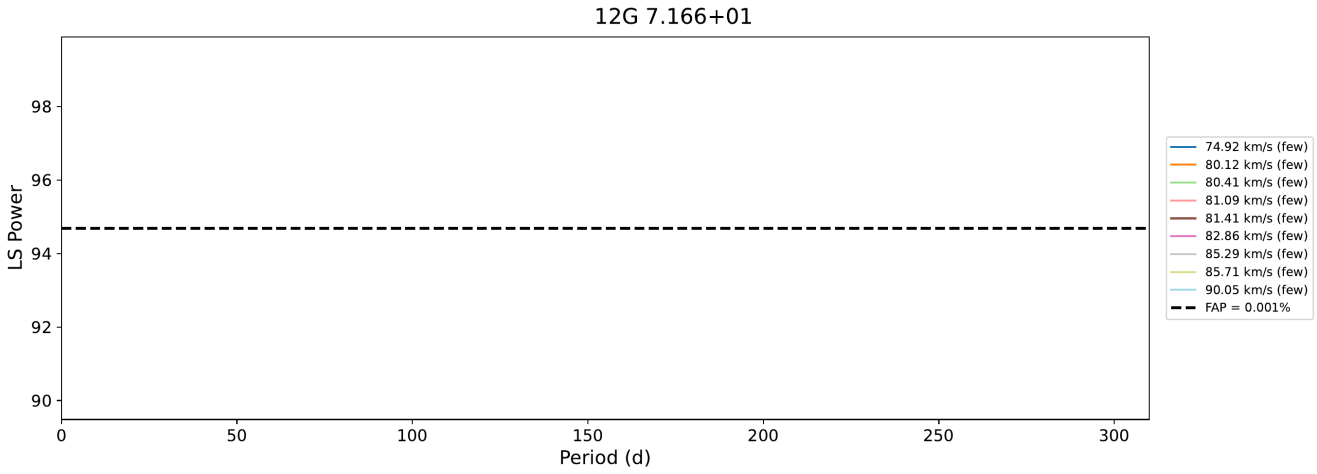


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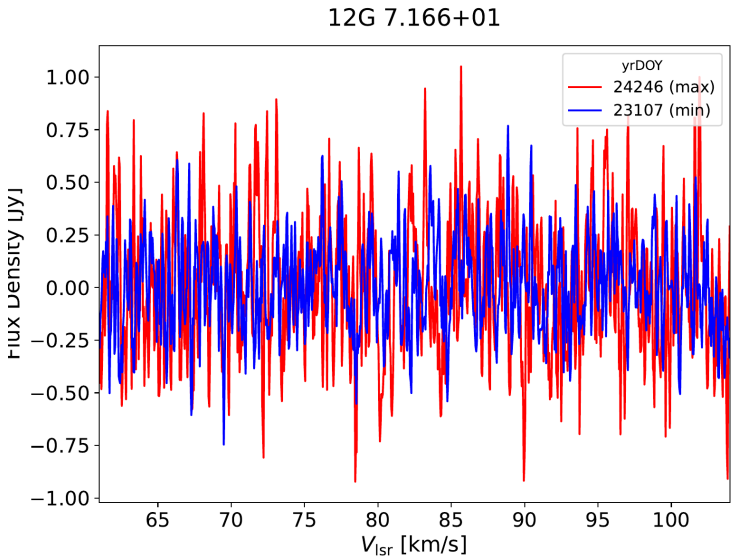
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Periodogram

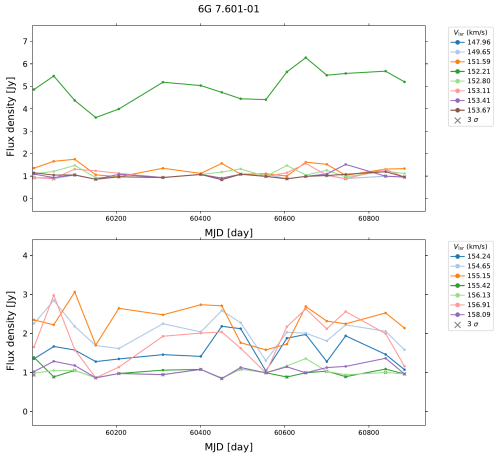


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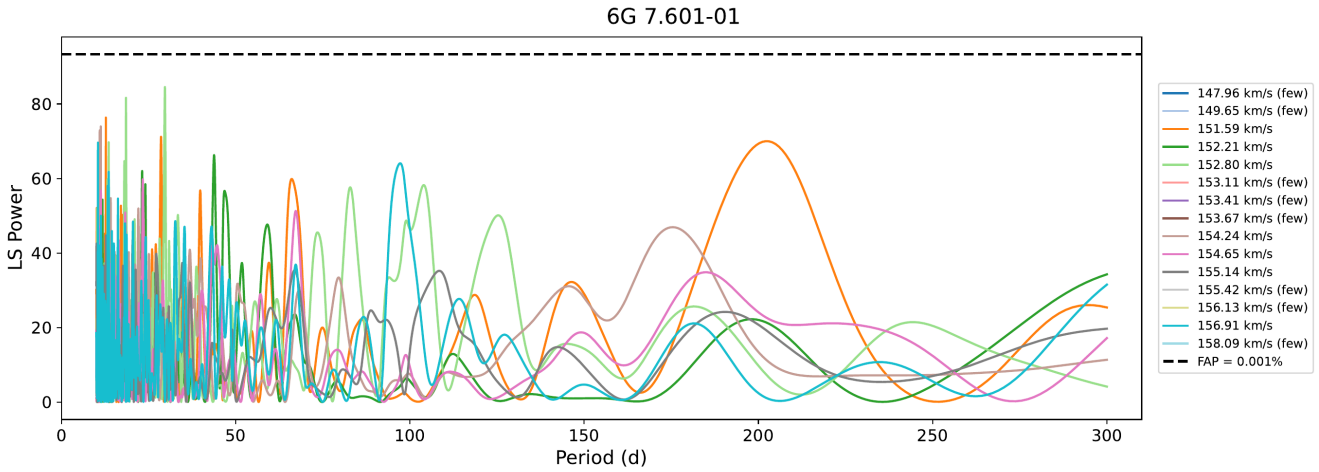


6G 7.601-01

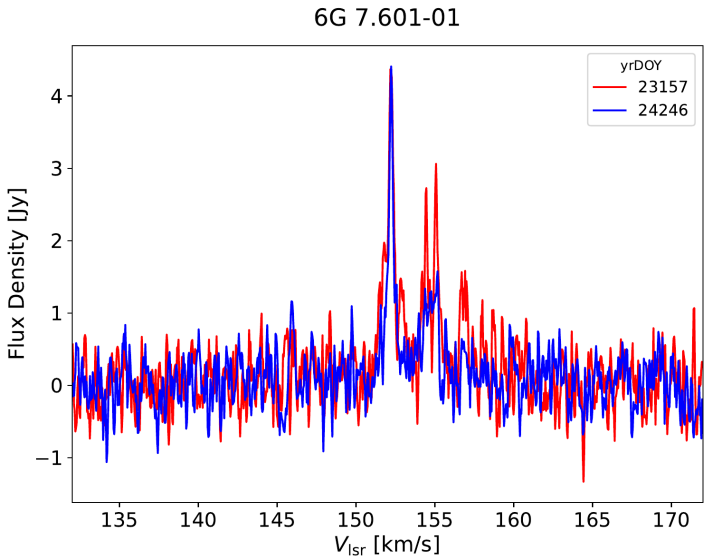
Light curve



Periodogram

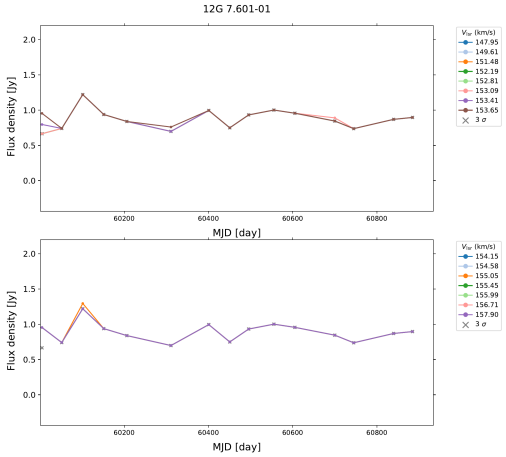


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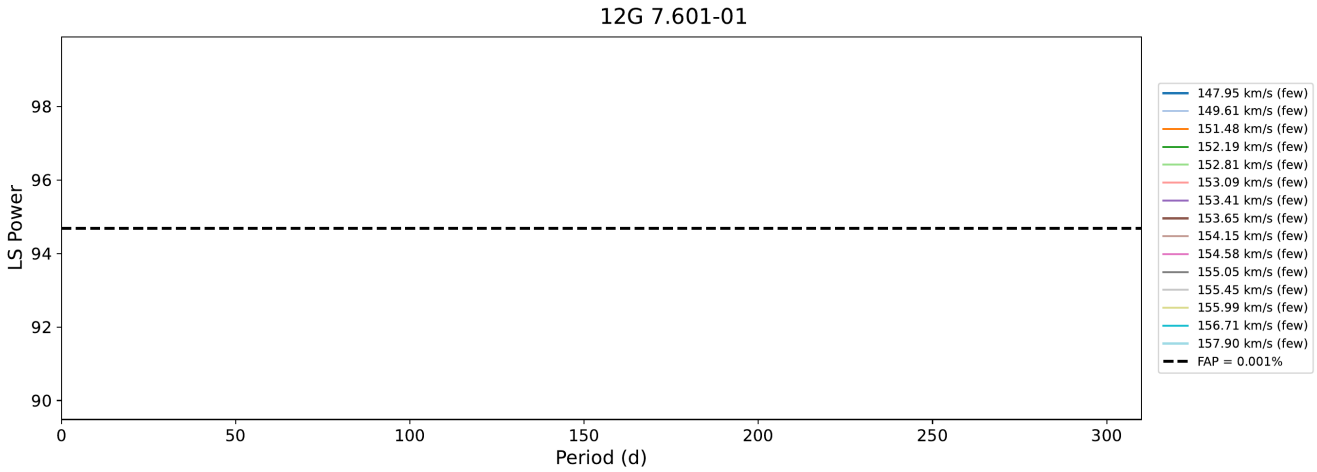


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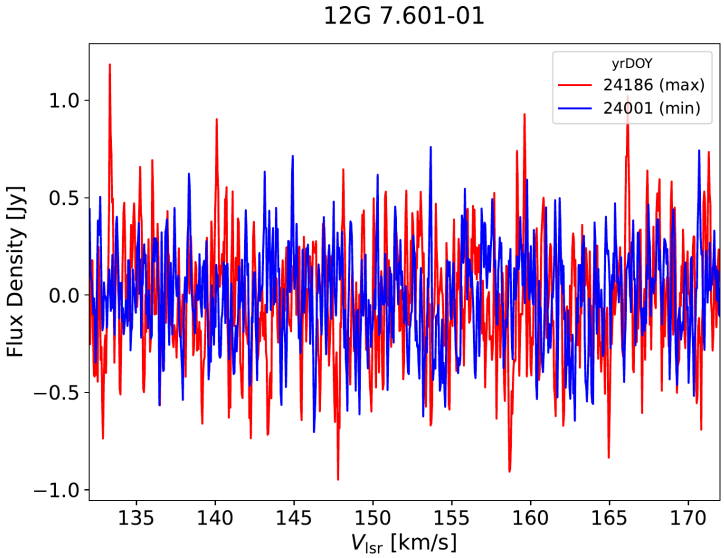
Light curve



Periodogram

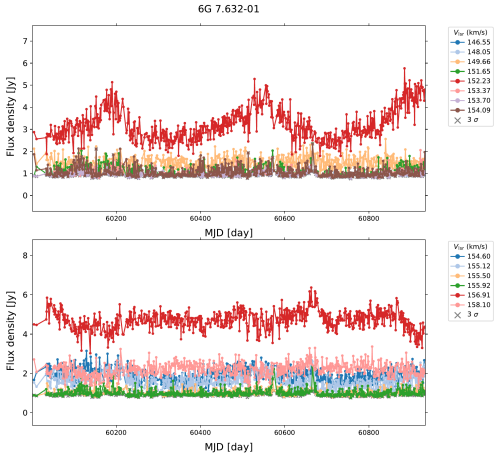


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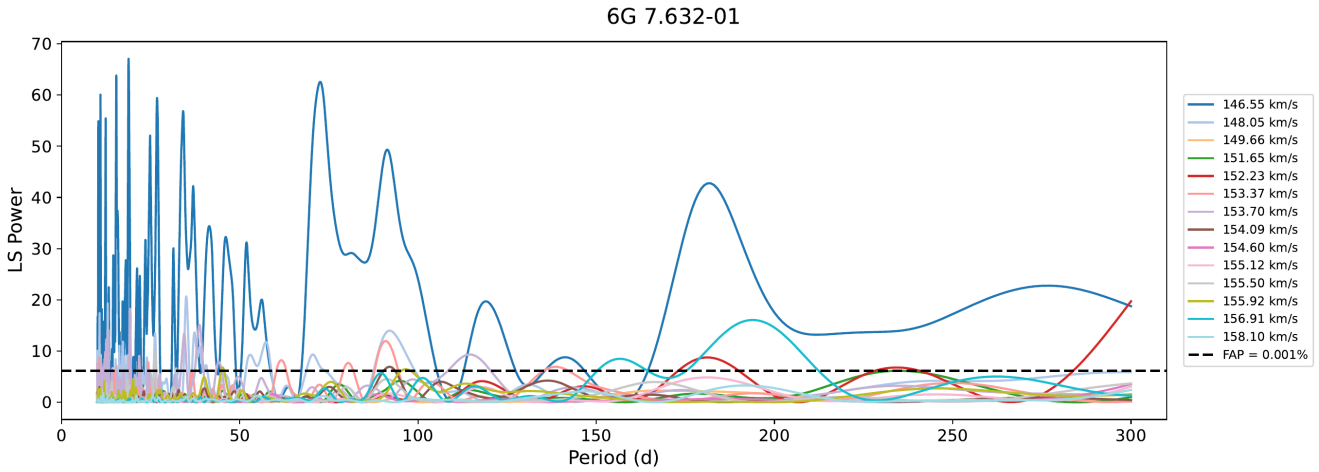


6G 7.632-01

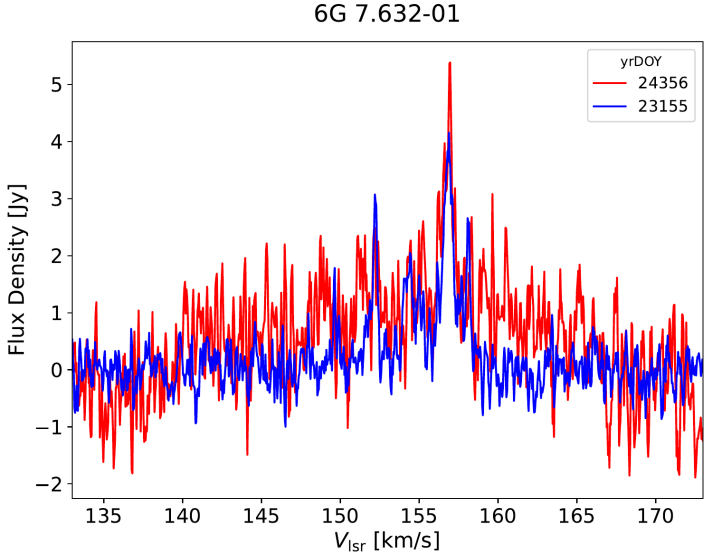
Light curve



Periodogram

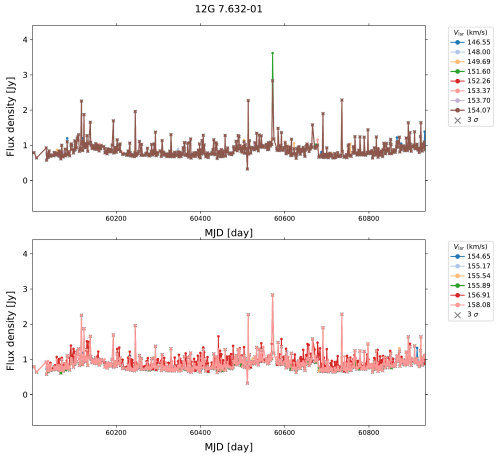


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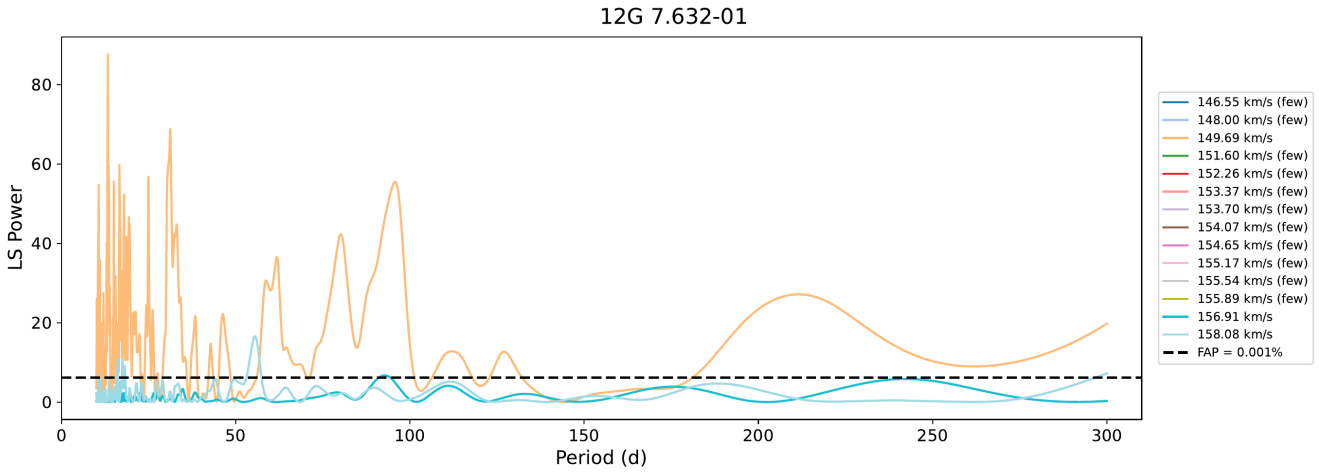


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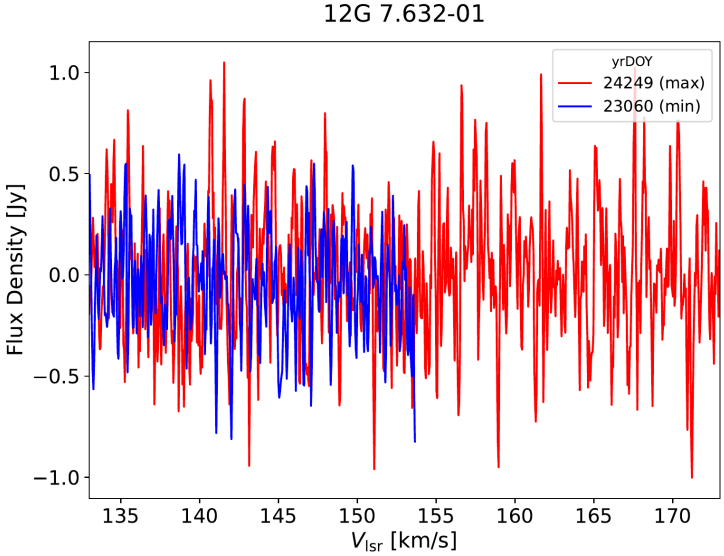
Light curve



Periodogram

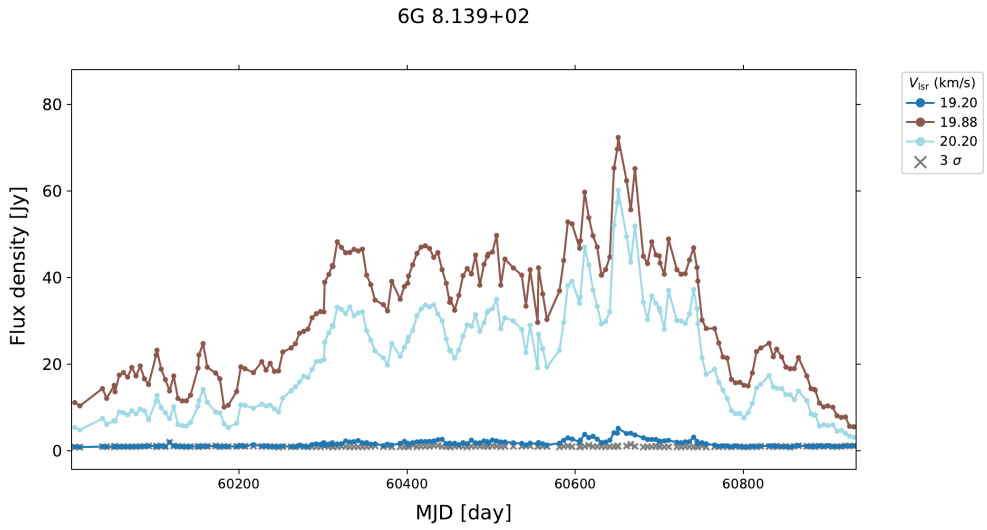


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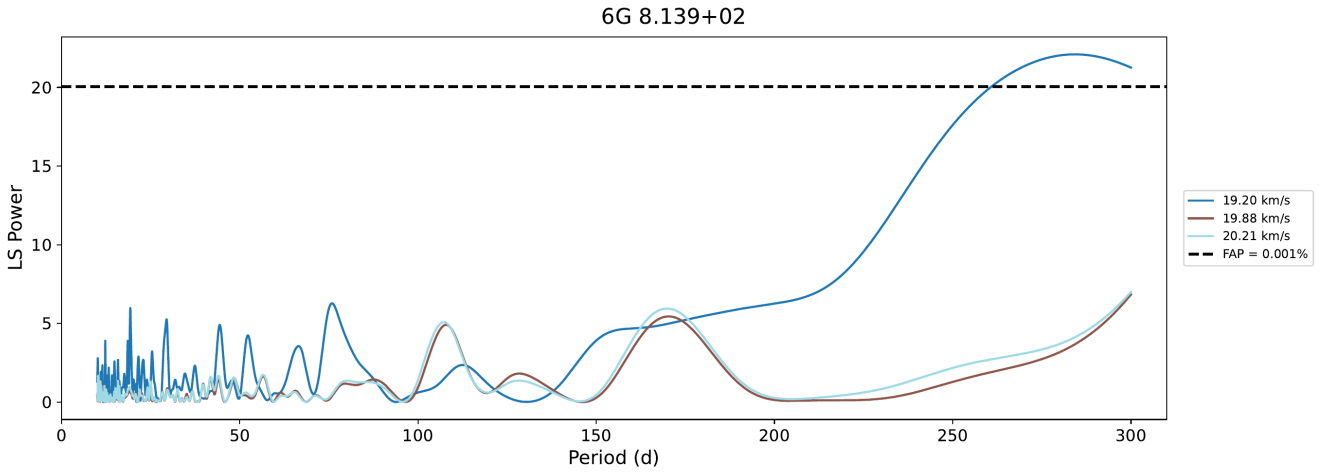


6G 8.139+02

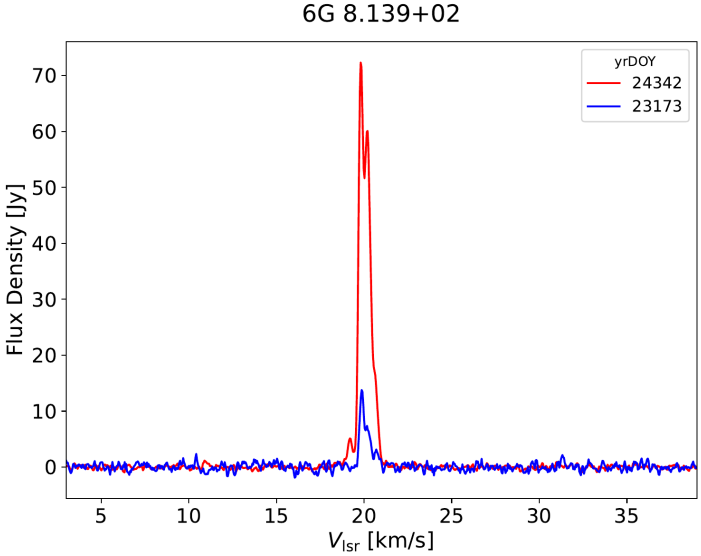
Light curve



Periodogram

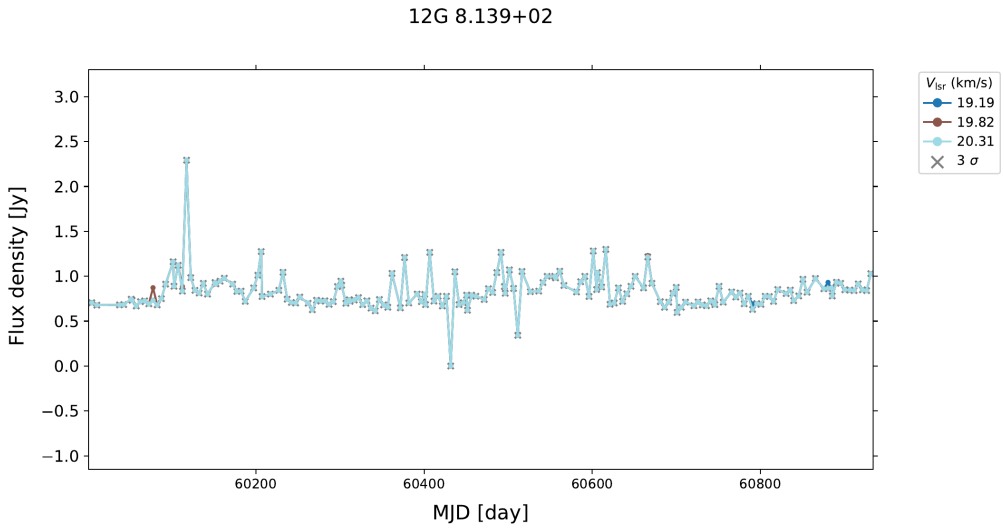


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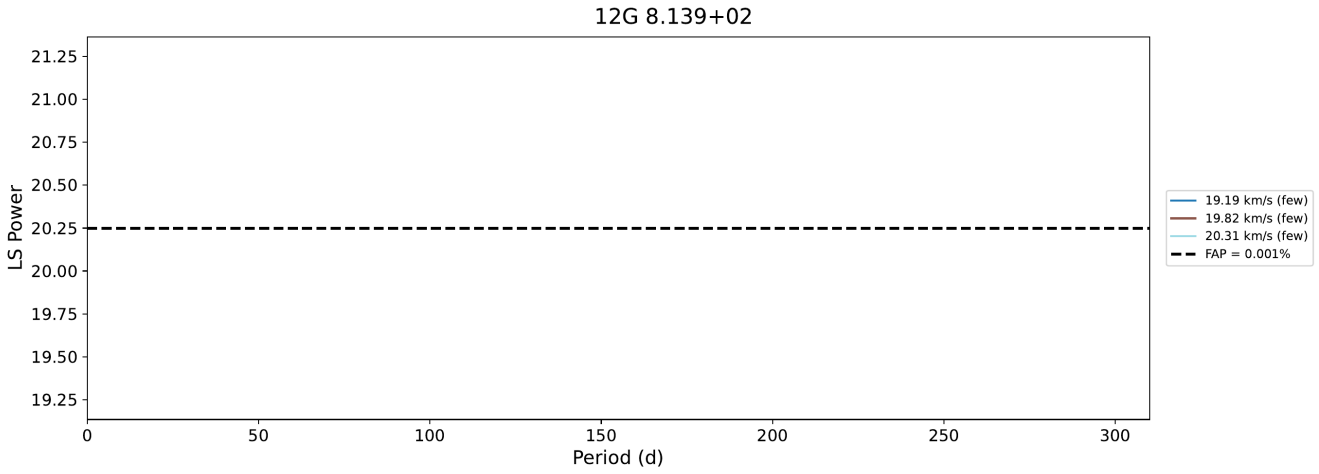


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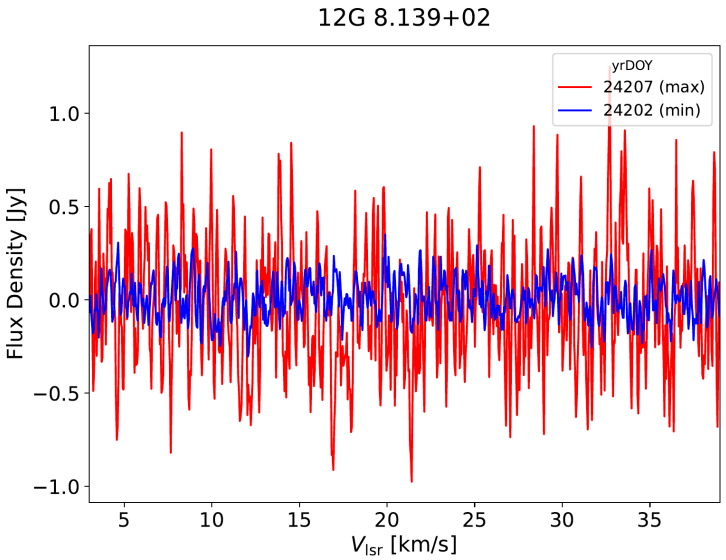
Light curve



Periodogram

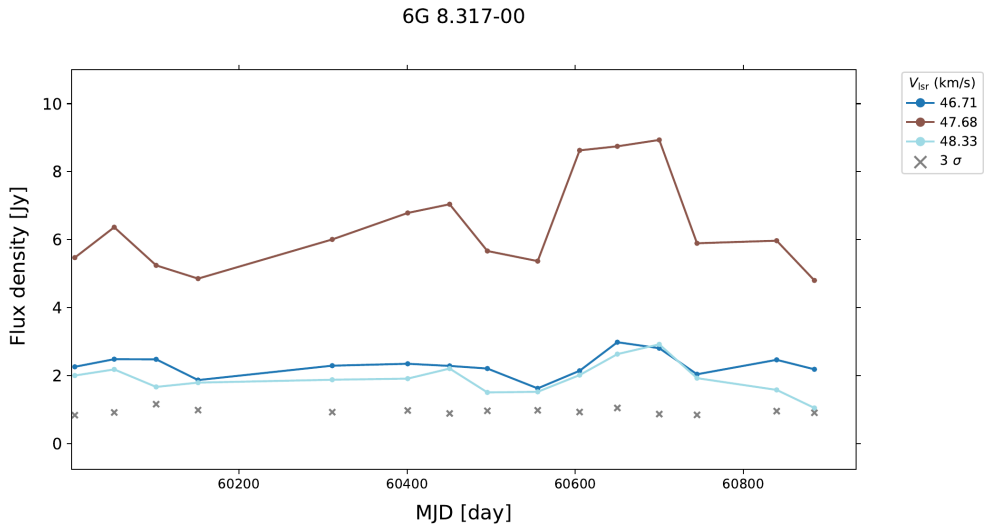


Spectrum

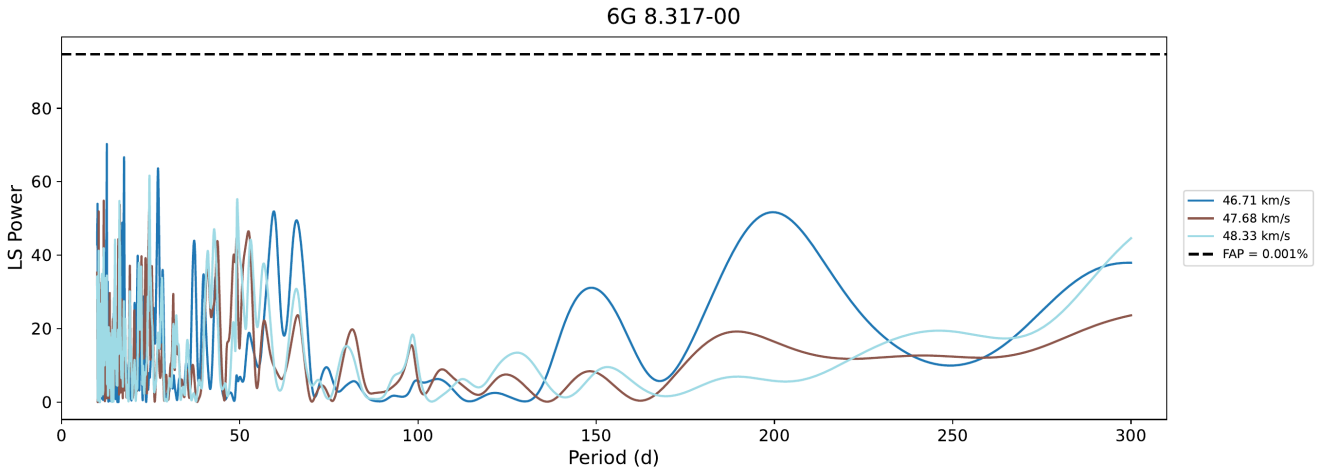


6G 8.317-00

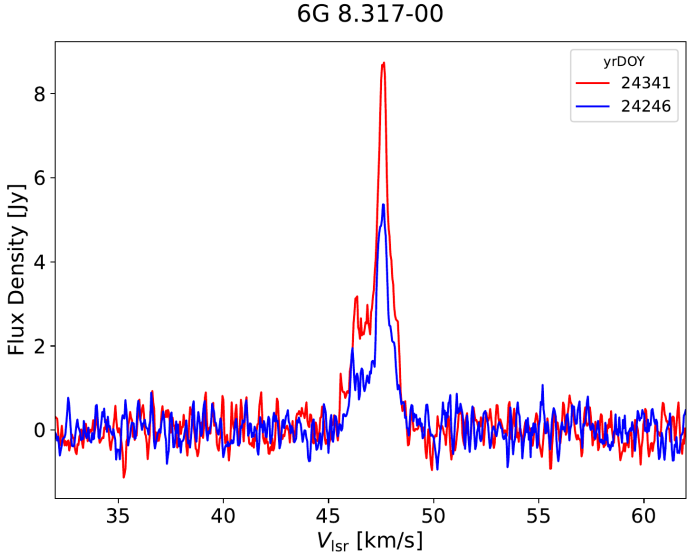
Light curve



Periodogram

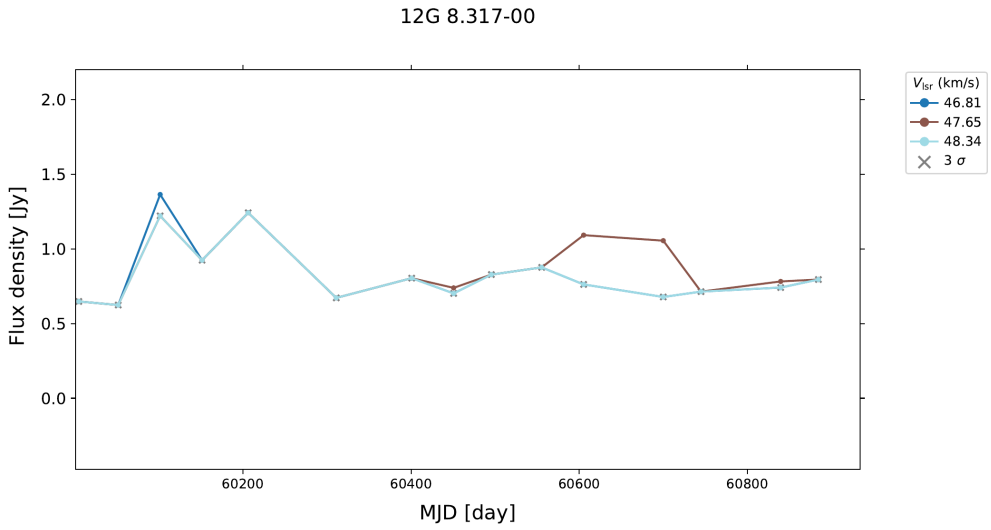


Spectrum

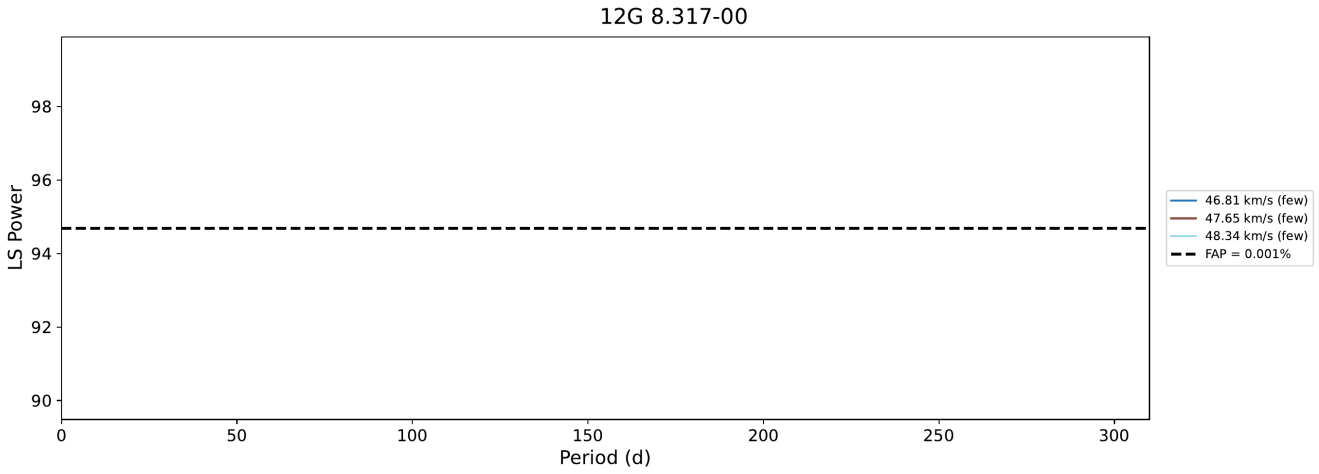


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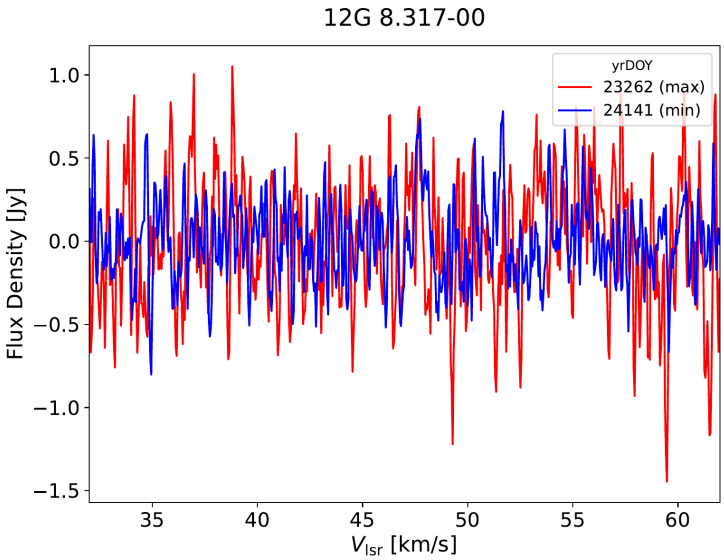
Light curve



Periodogram

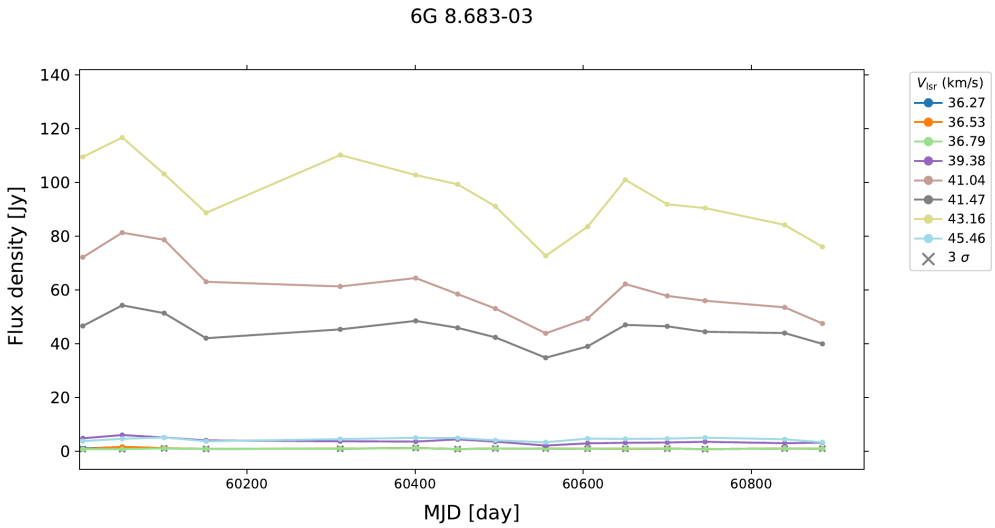


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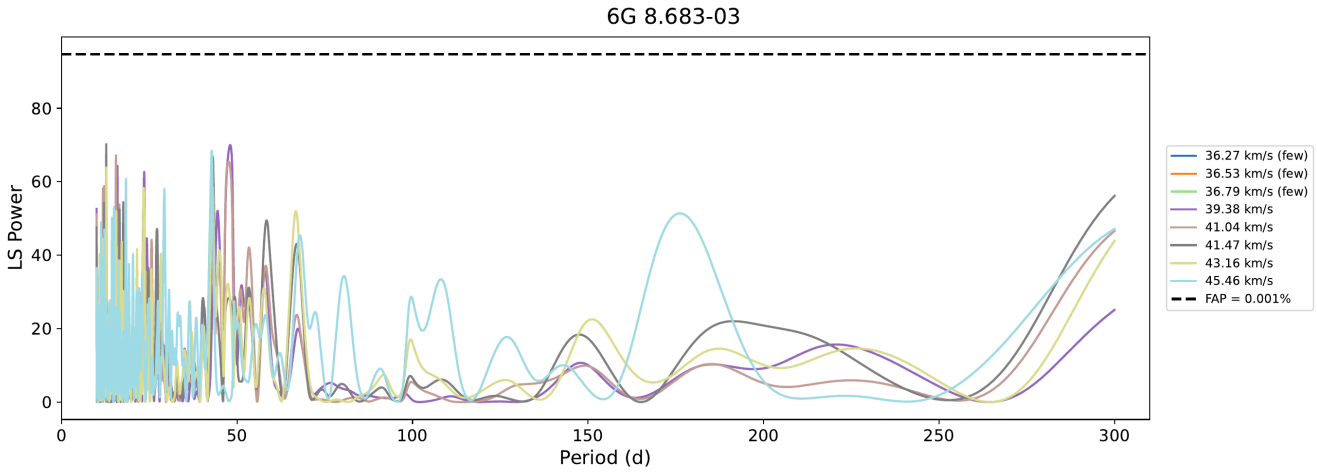


6G 8.683-03

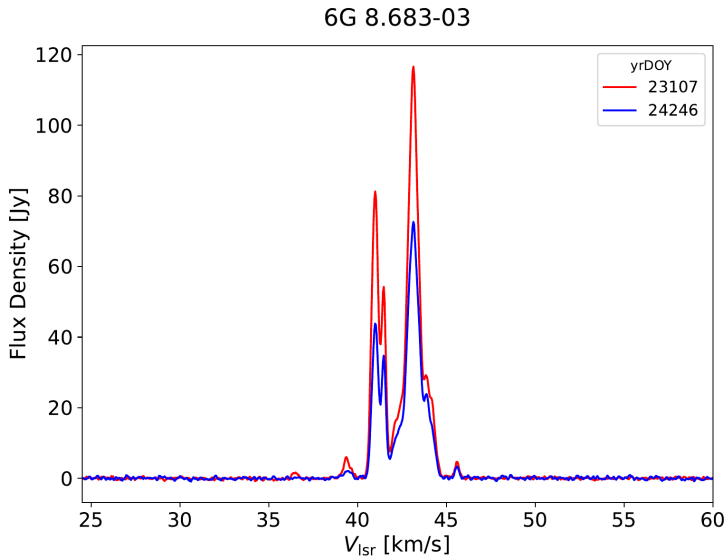
Light curve



Periodogram

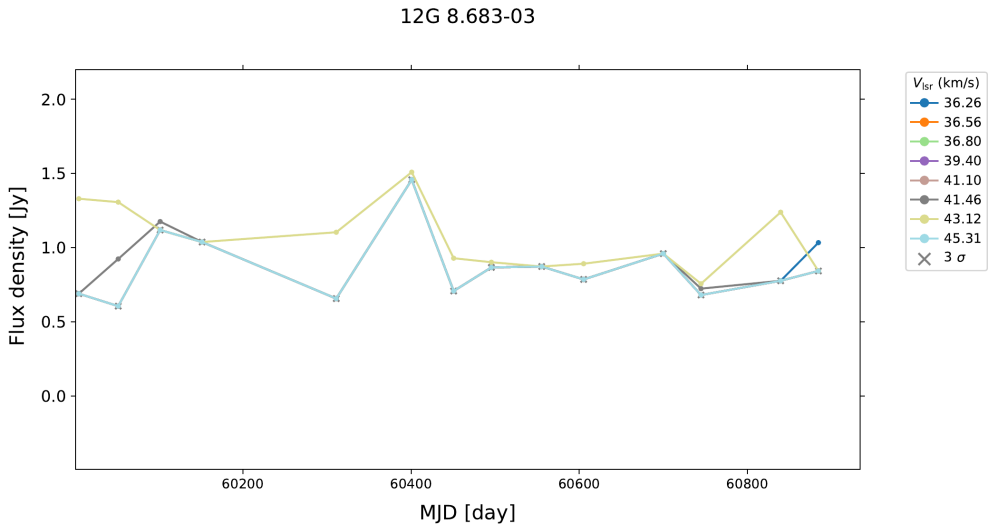


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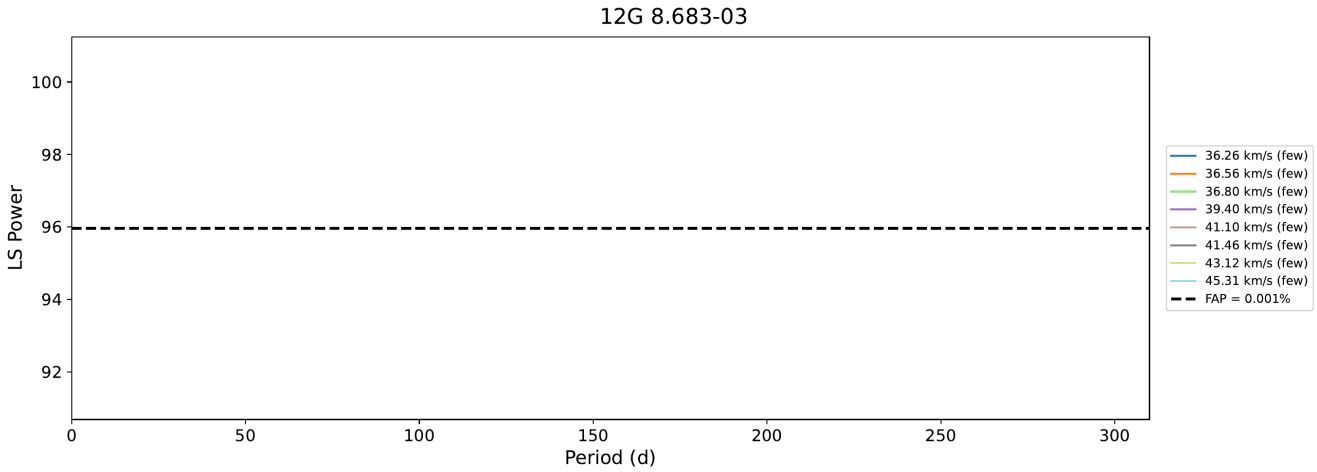


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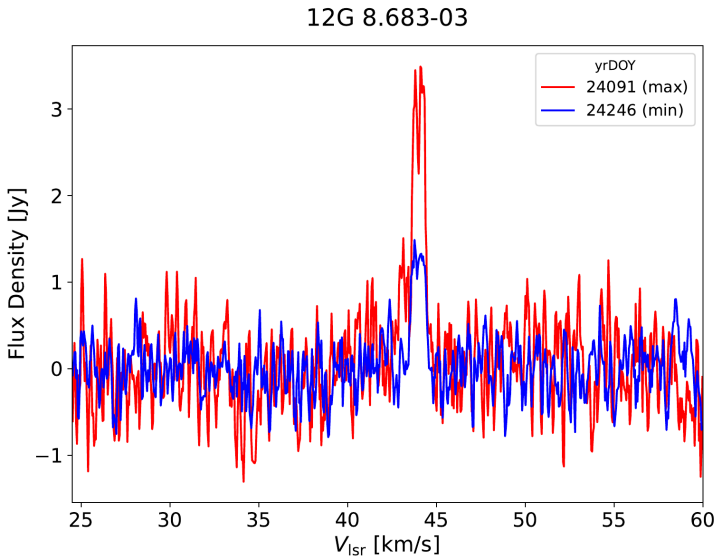
Light curve



Periodogram

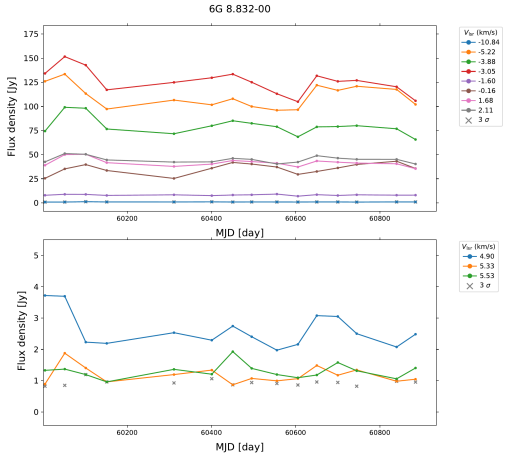


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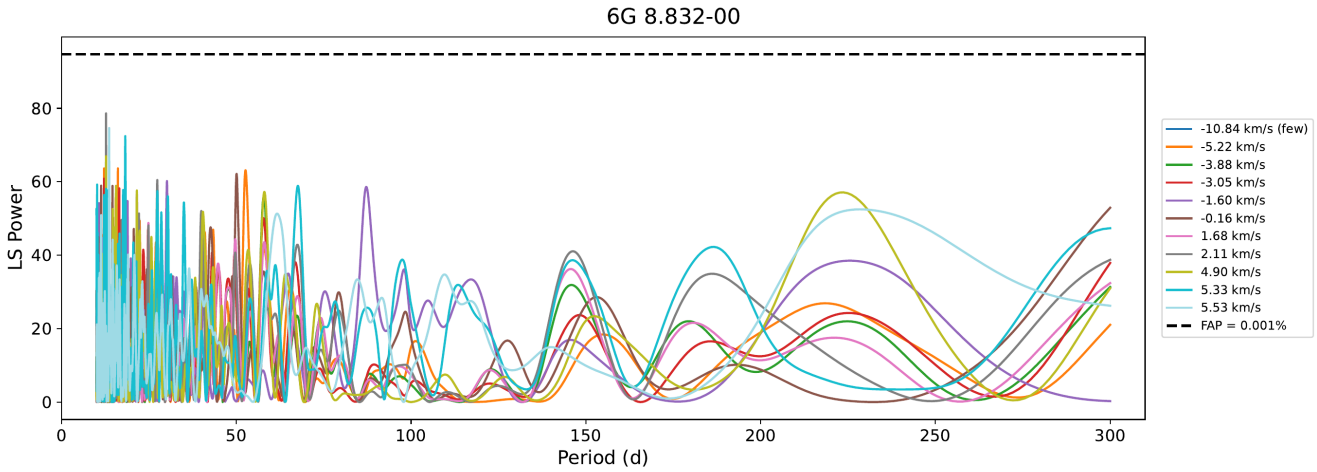


6G 8.832-00

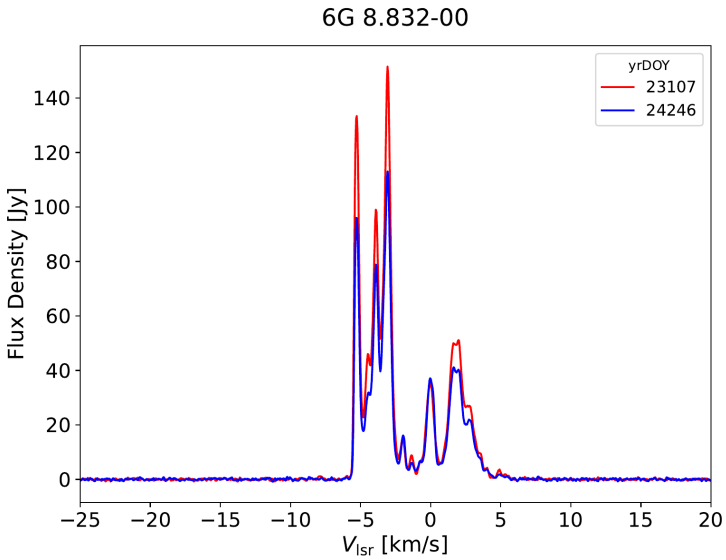
Light curve



Periodogram

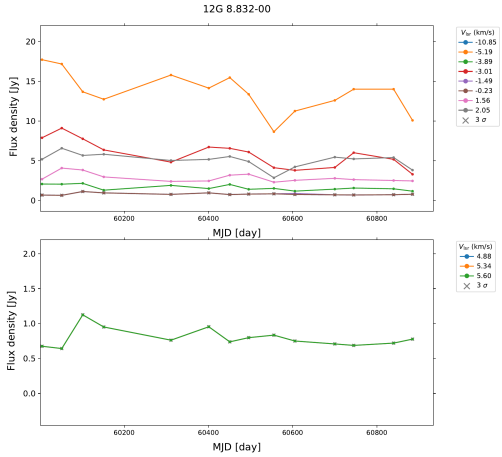


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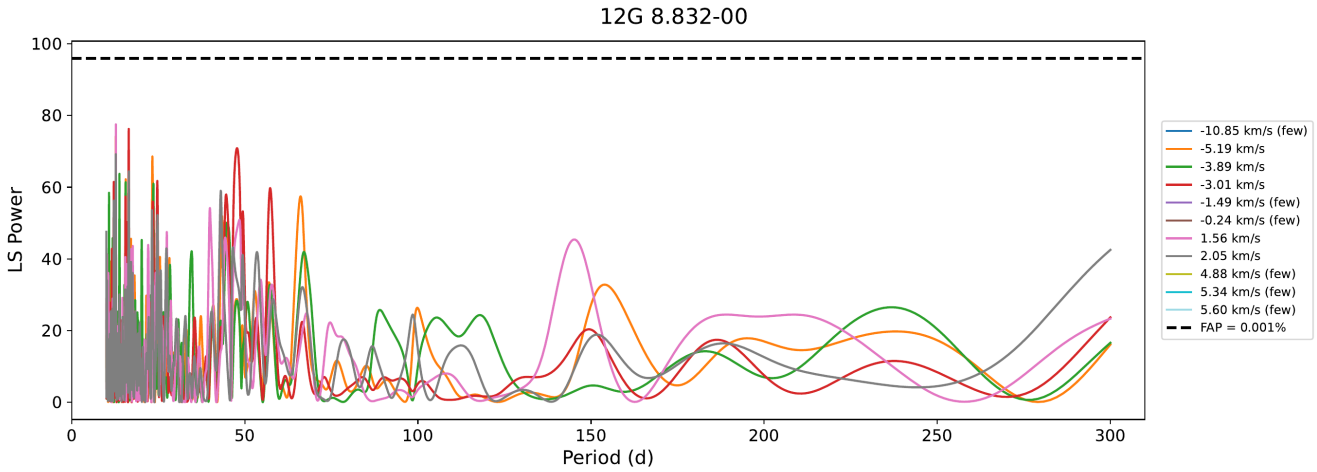


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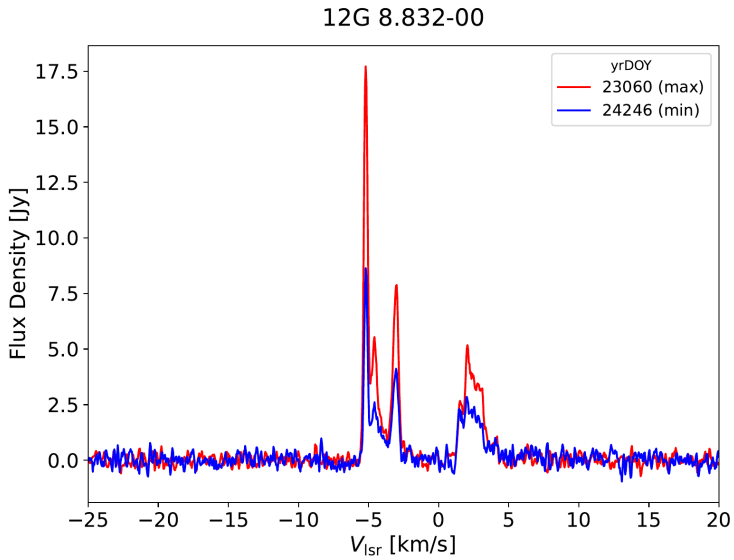
Light curve



Periodogram

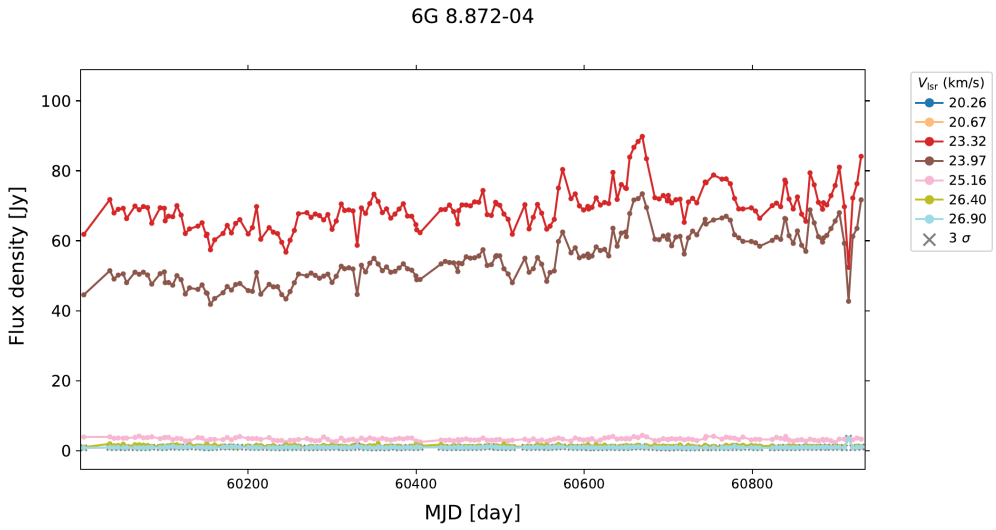


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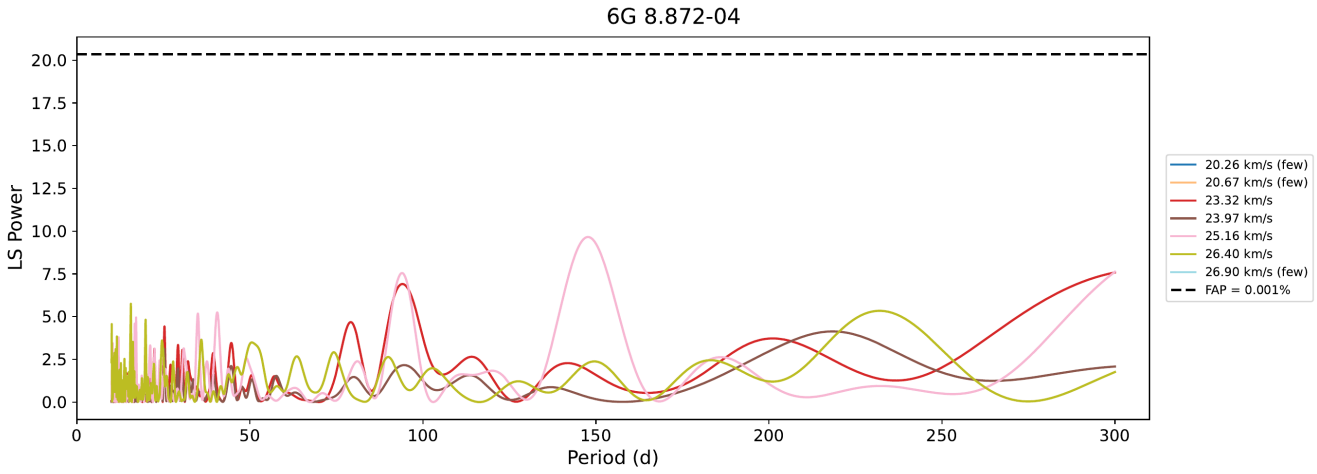


6G 8.872-04

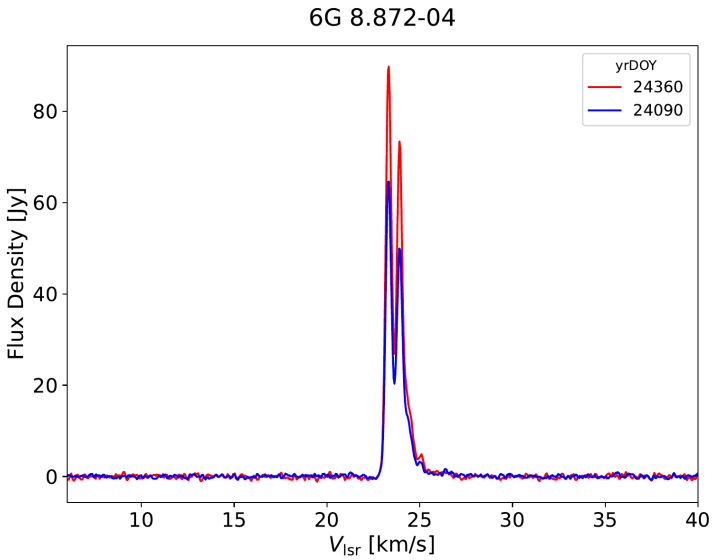
Light curve



Periodogram

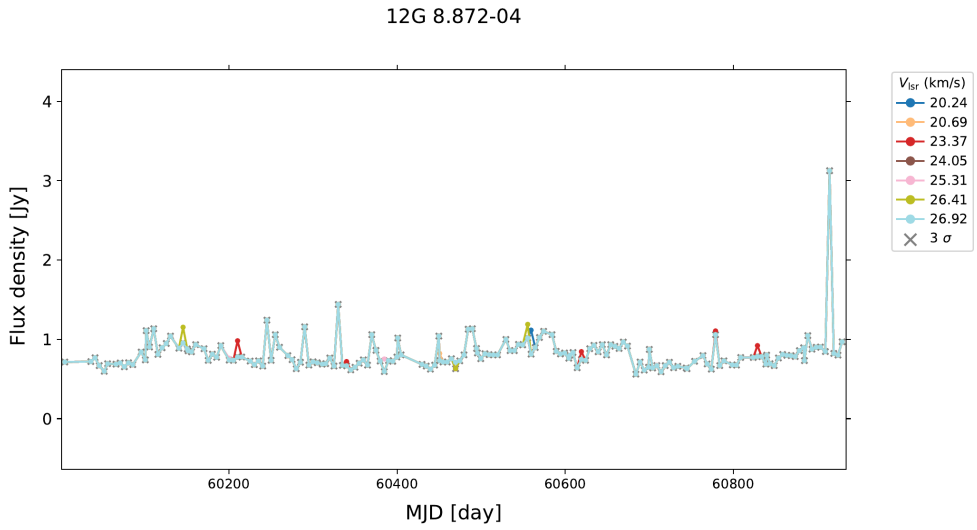


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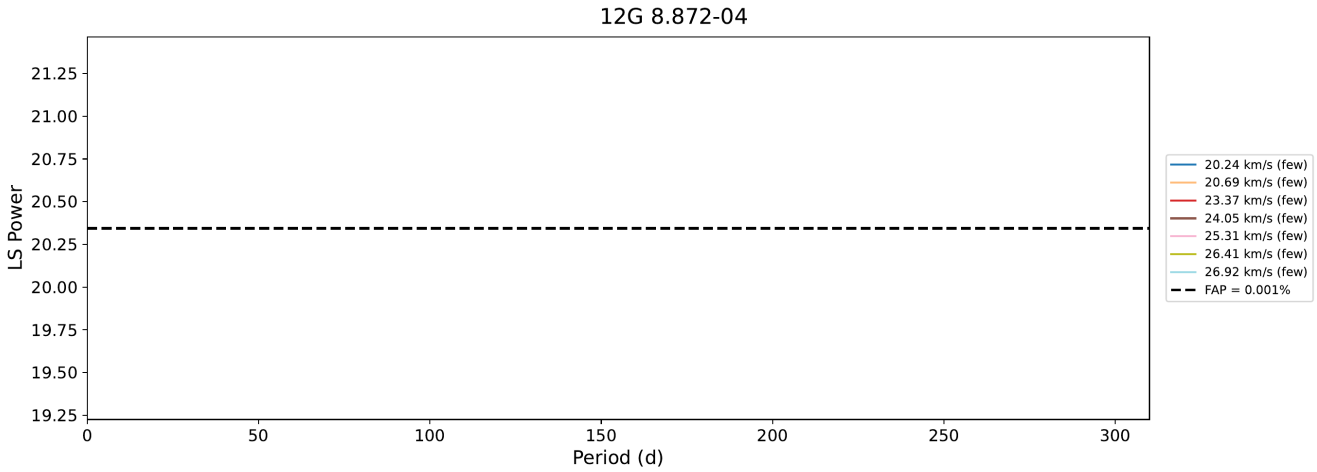


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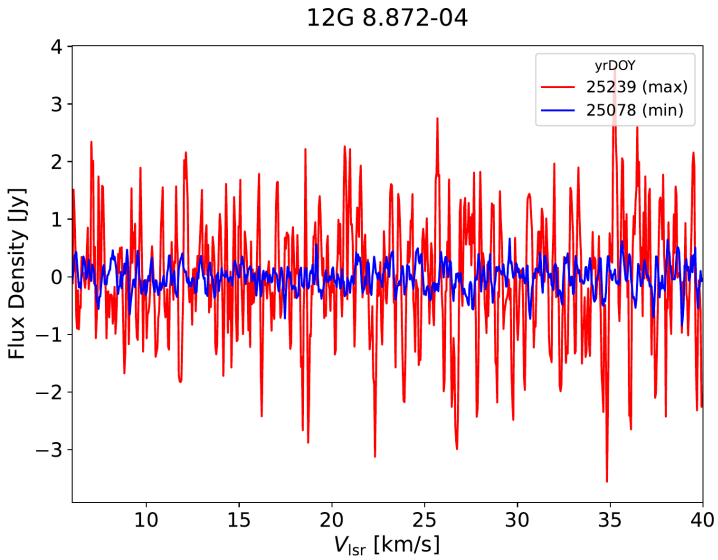
Light curve



Periodogram

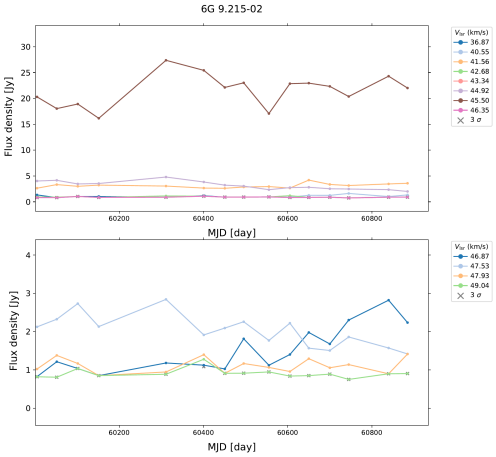


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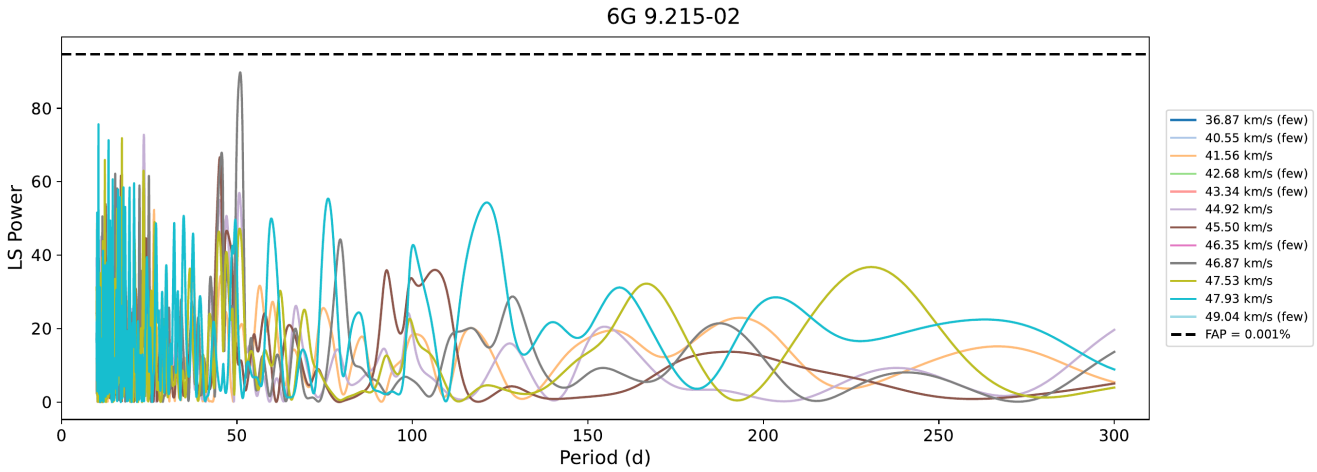


6G 9.215-02

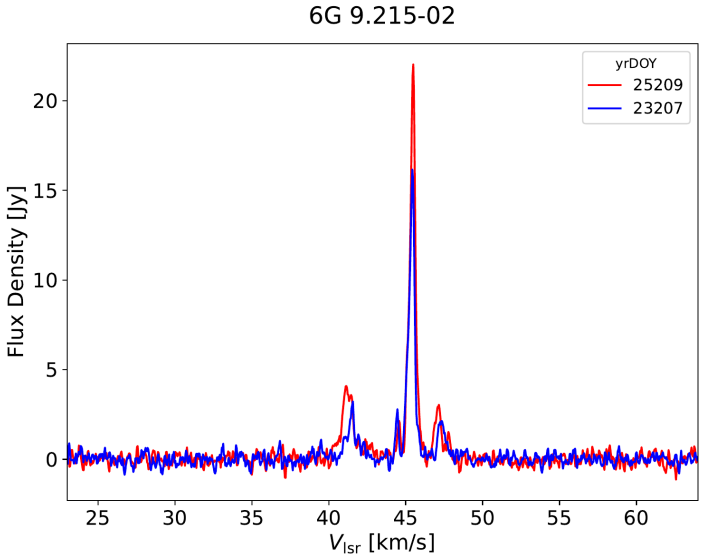
Light curve



Periodogram

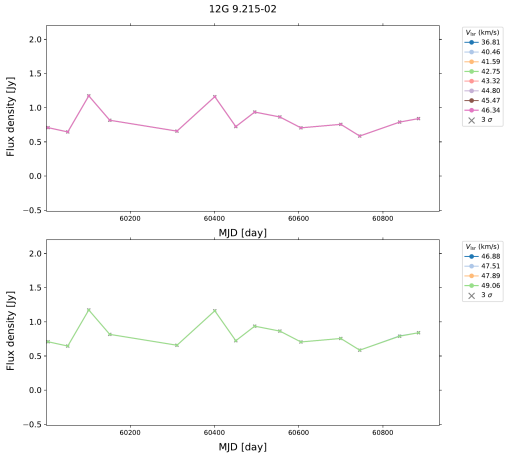


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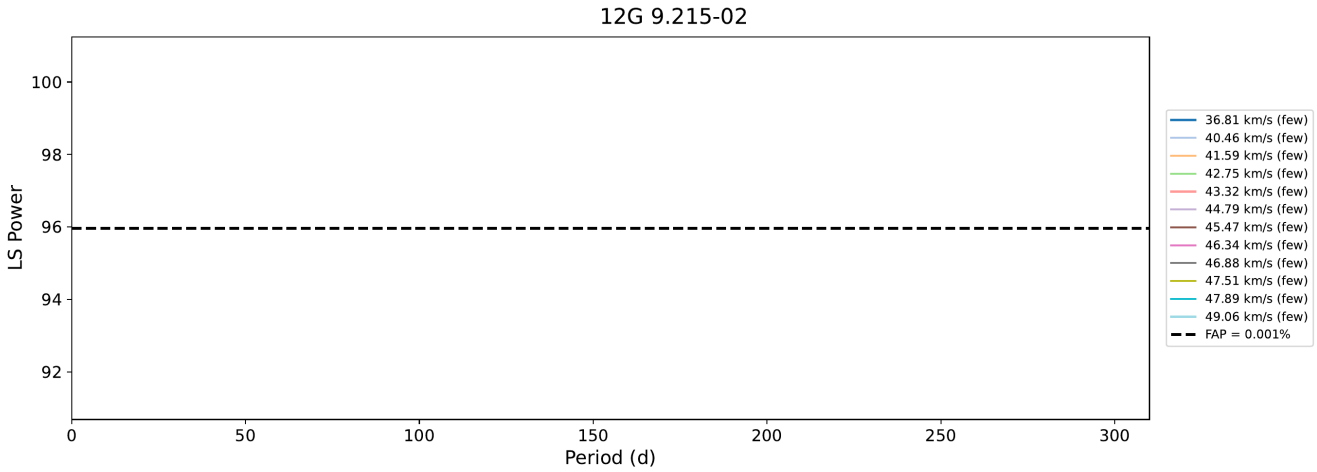


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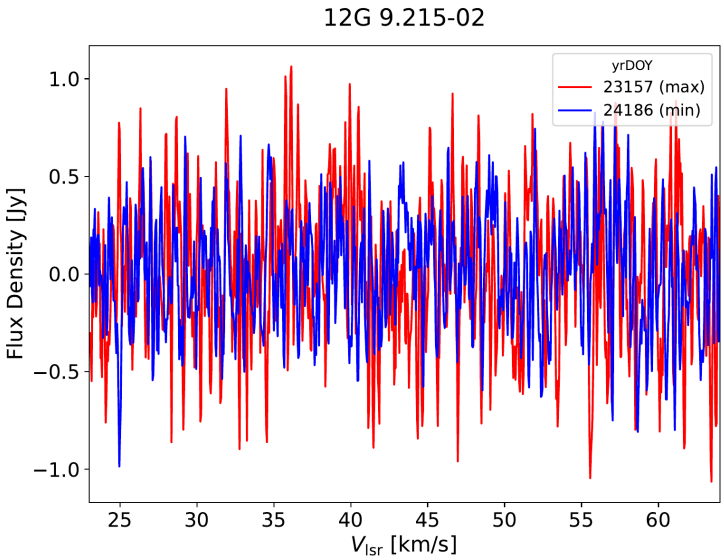
Light curve



Periodogram

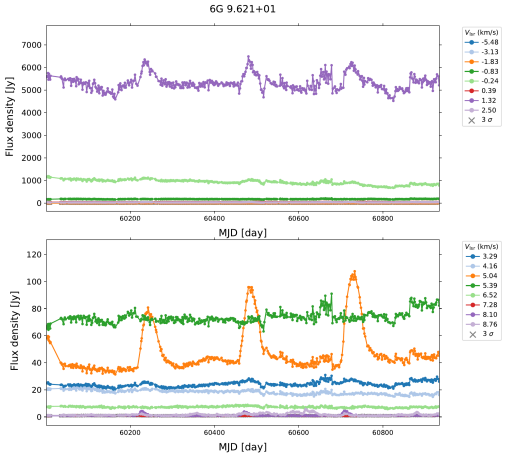


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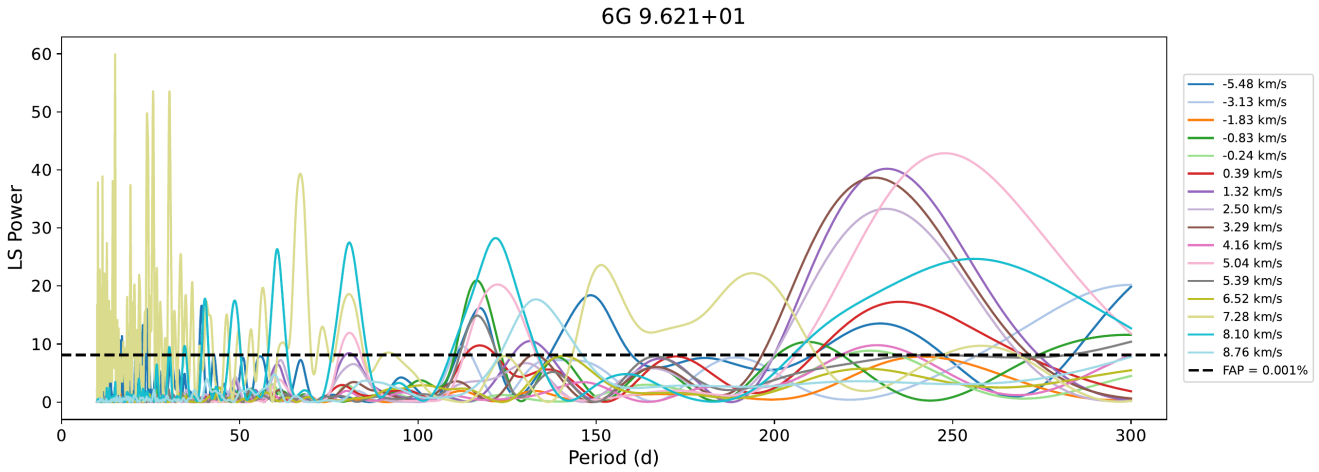


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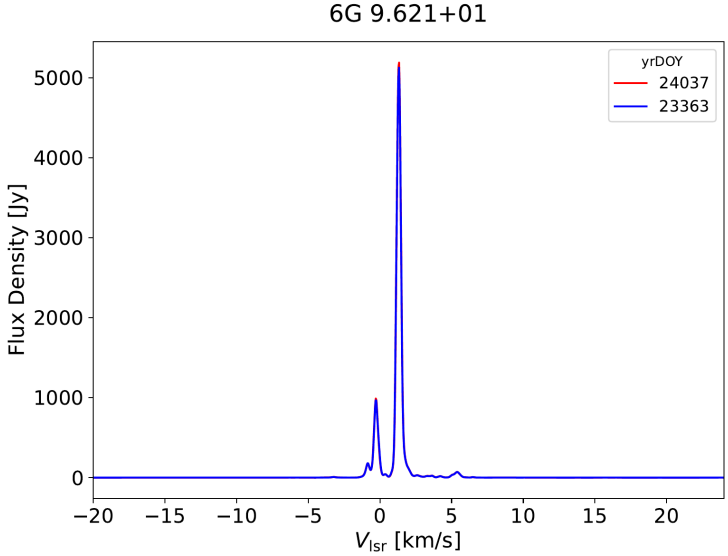
Light curve



Periodogram

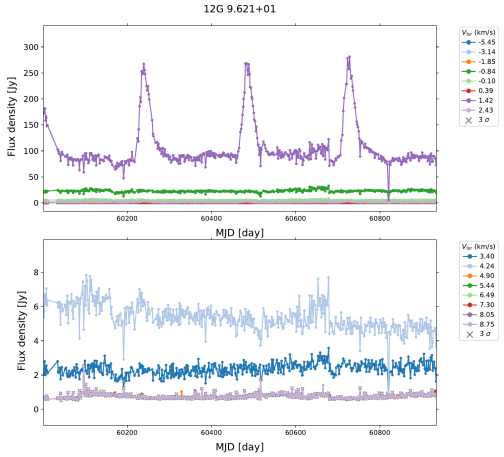


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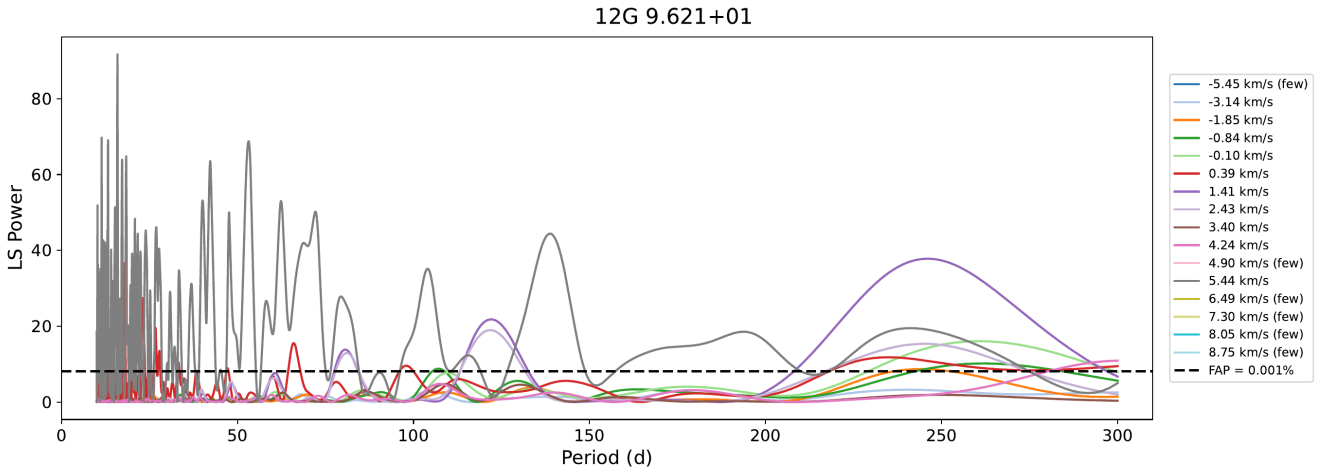


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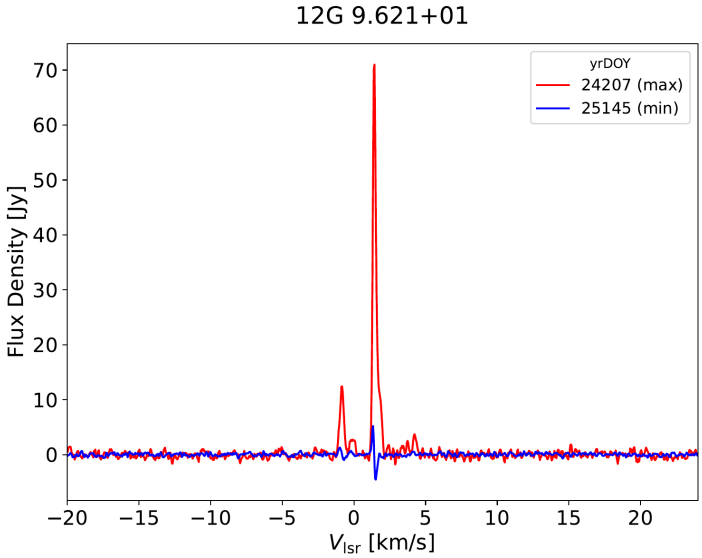
Light curve



Periodogram

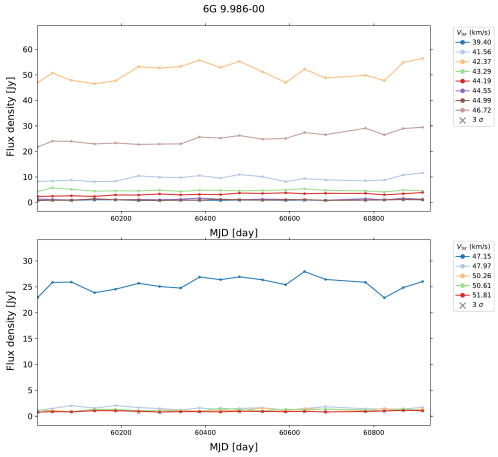


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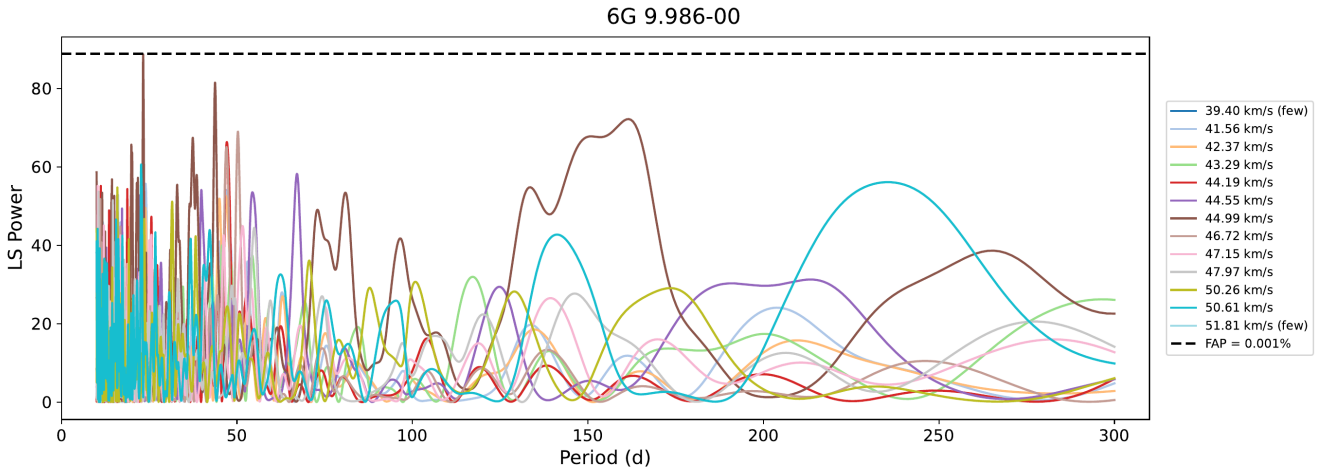


6G 9.986-00

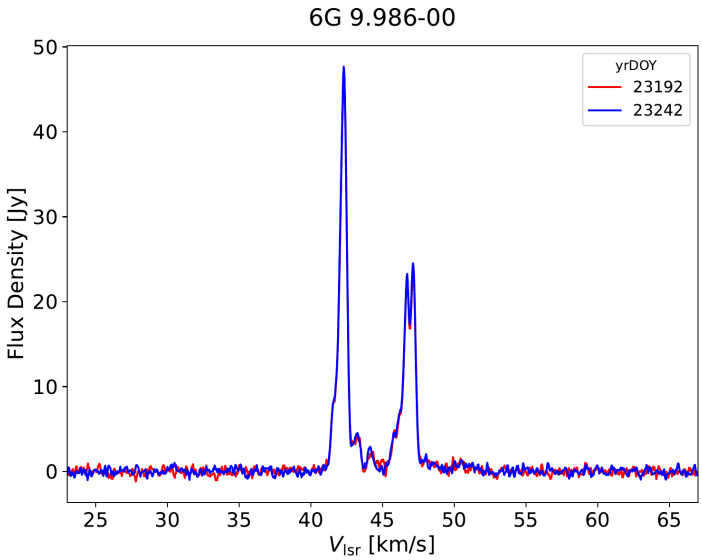
Light curve



Periodogram

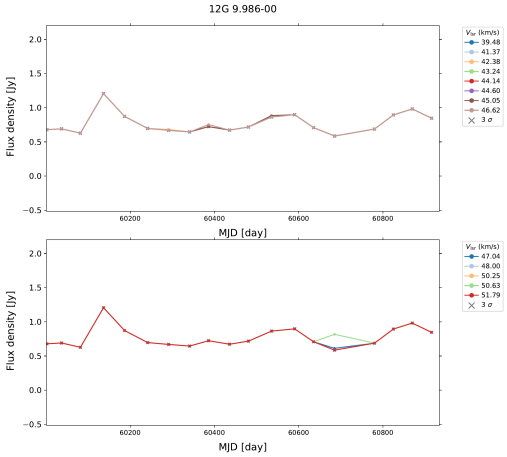


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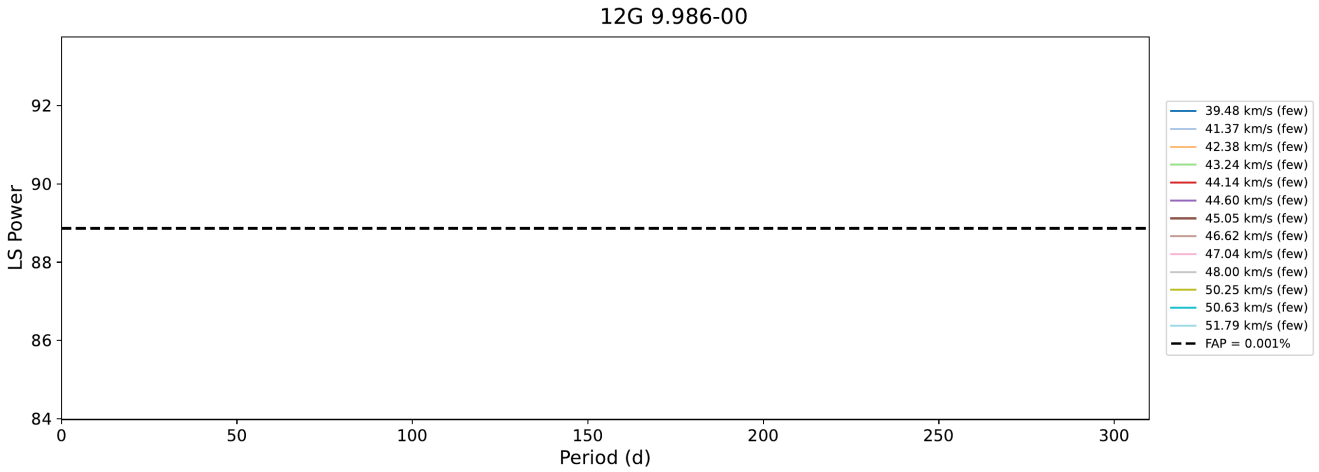


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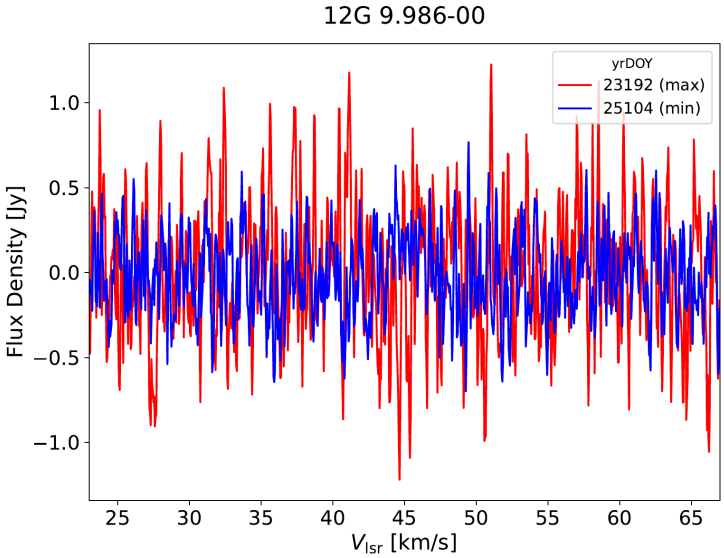
Light curve



Periodogram

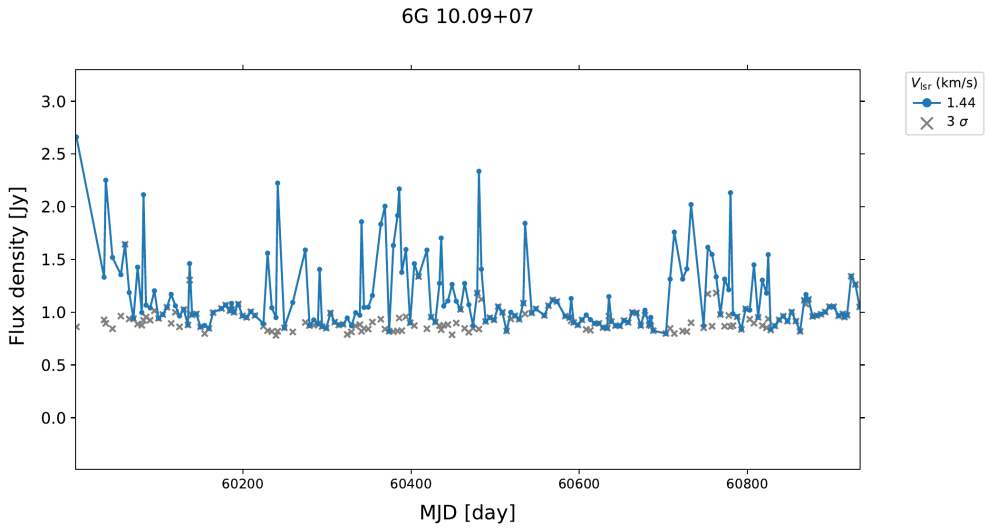


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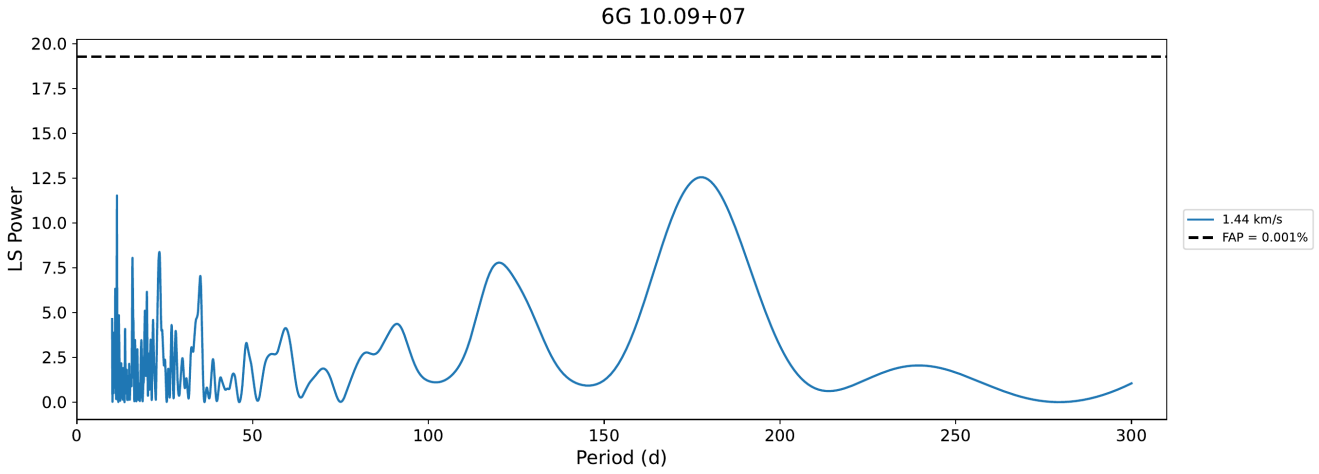


6G 10.09+07

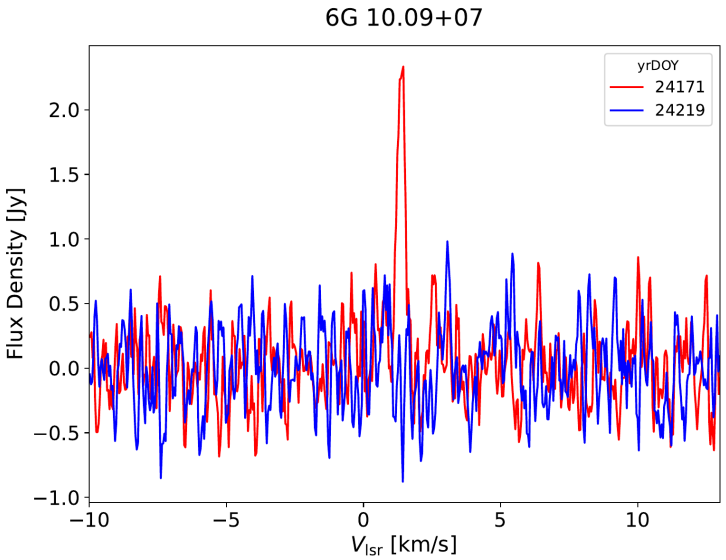
Light curve



Periodogram

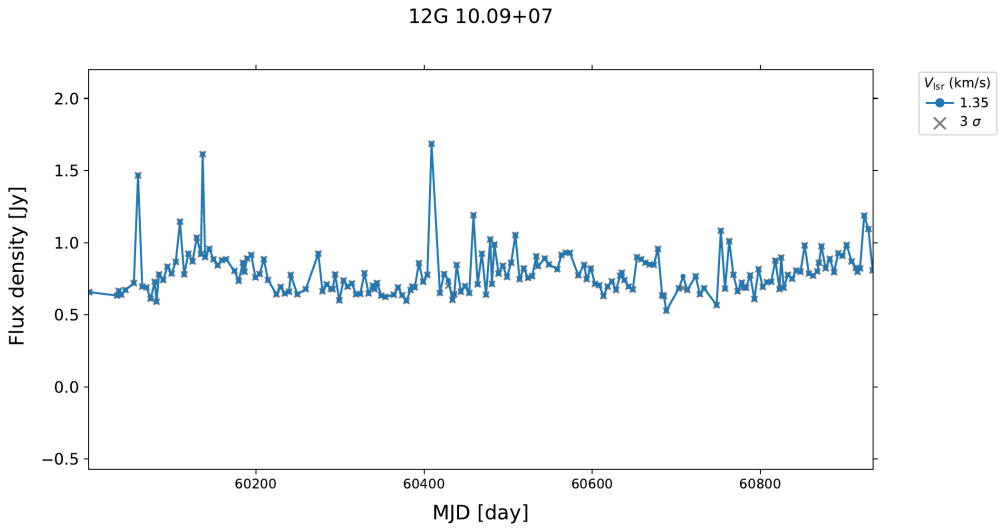


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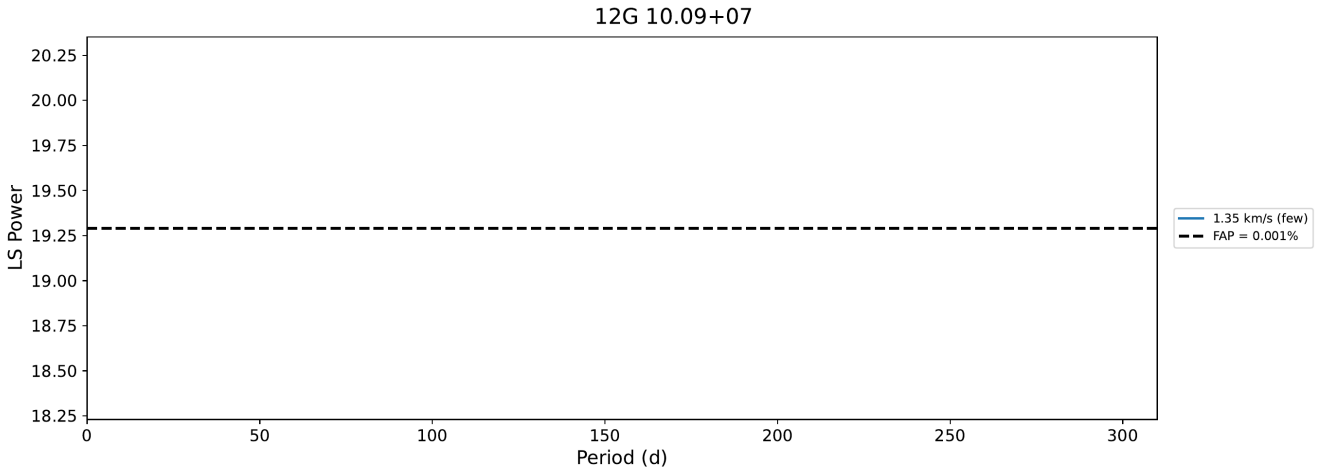


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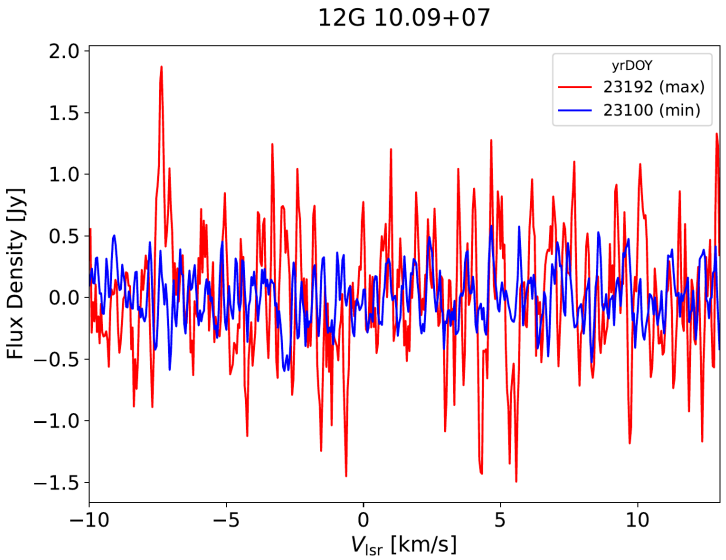
Light curve



Periodogram

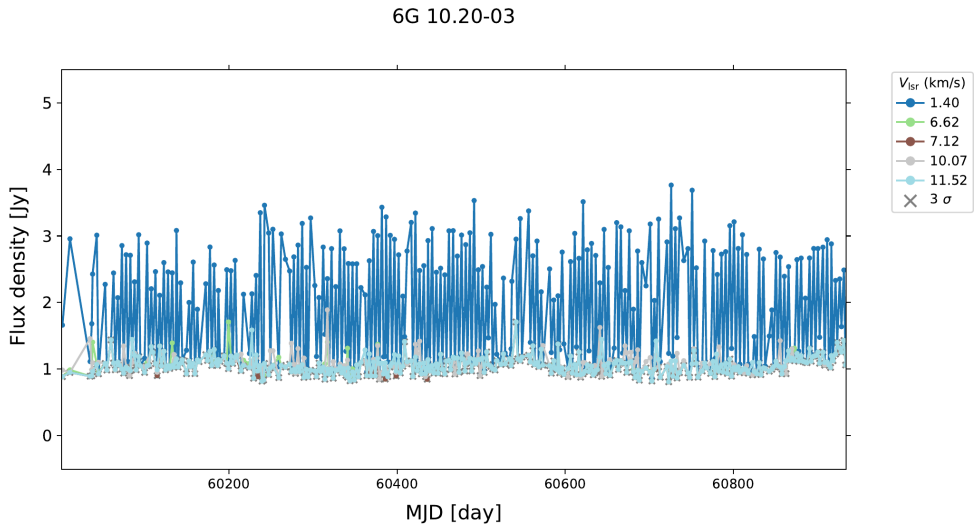


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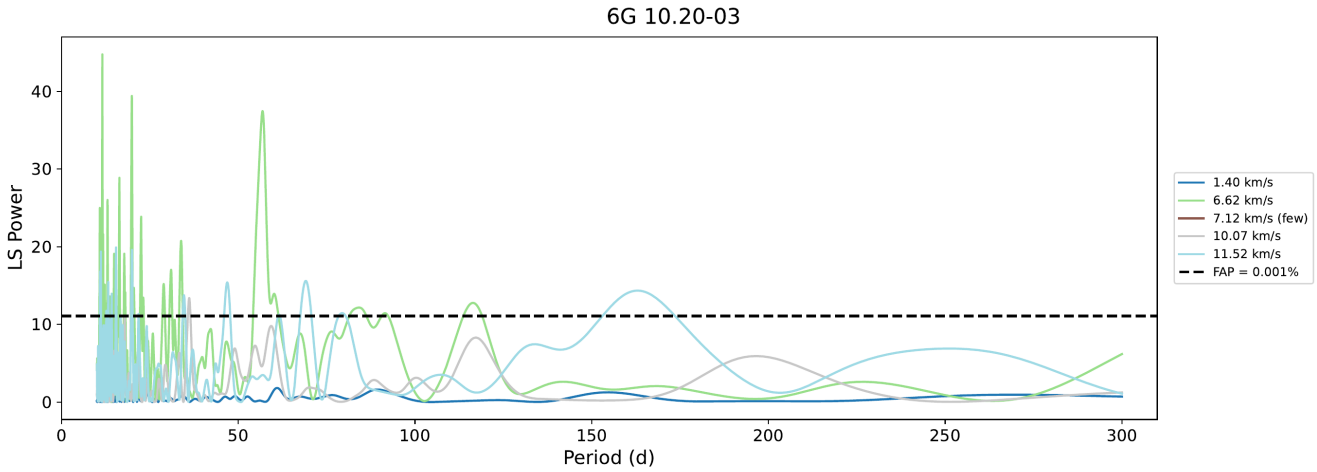


6G 10.20-03

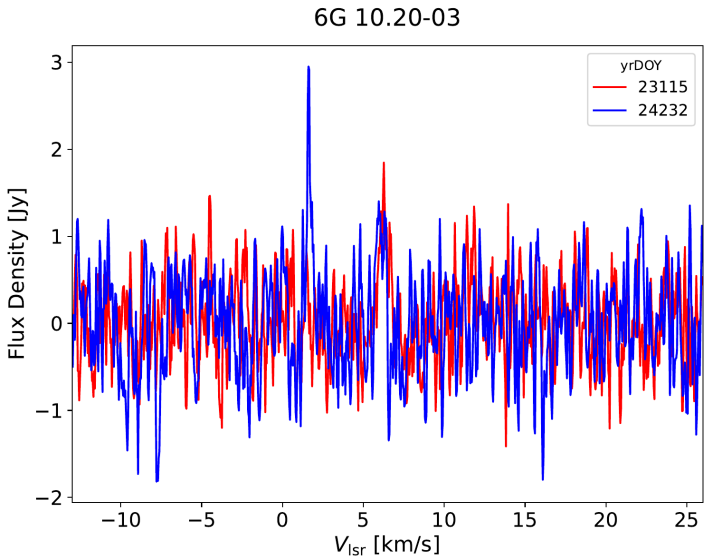
Light curve



Periodogram

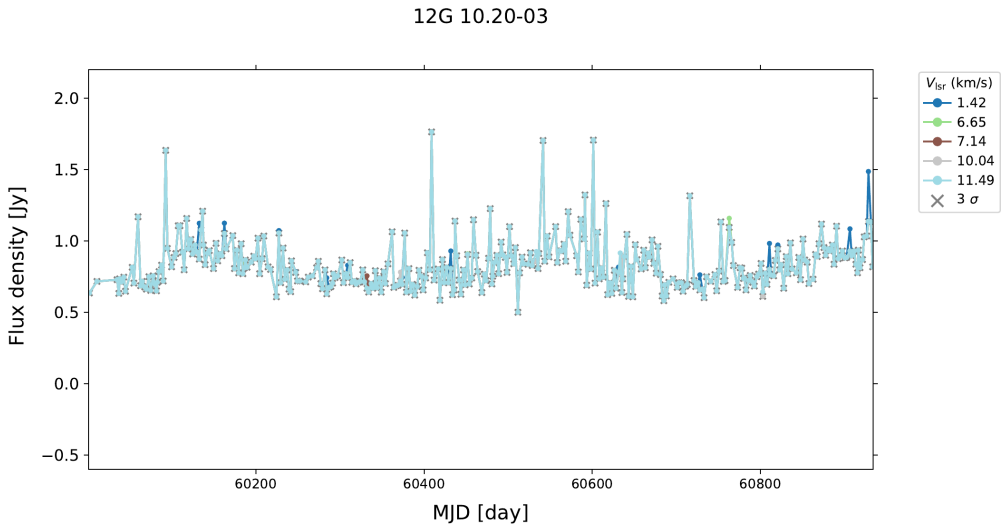


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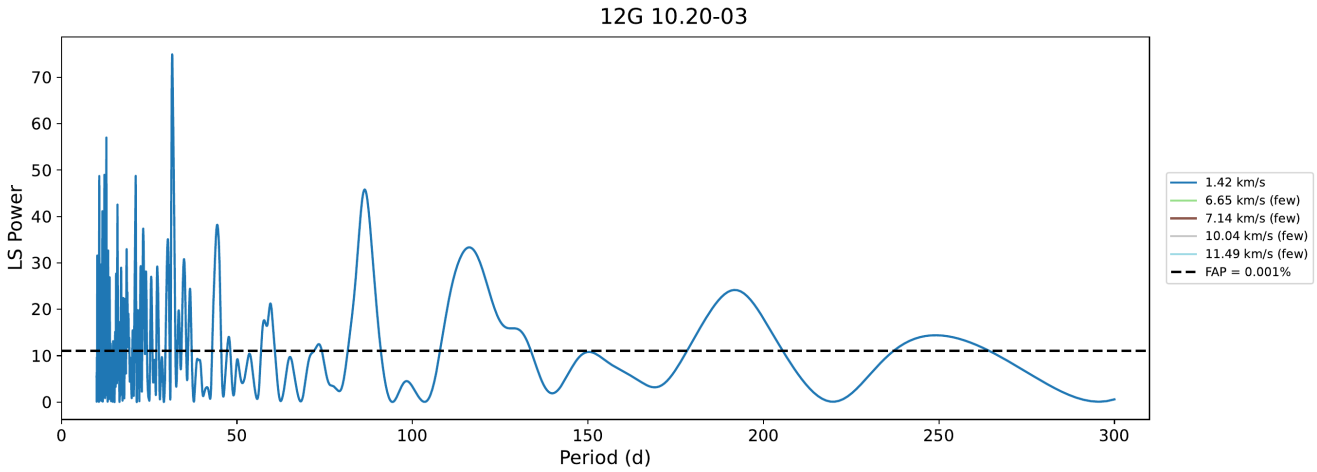


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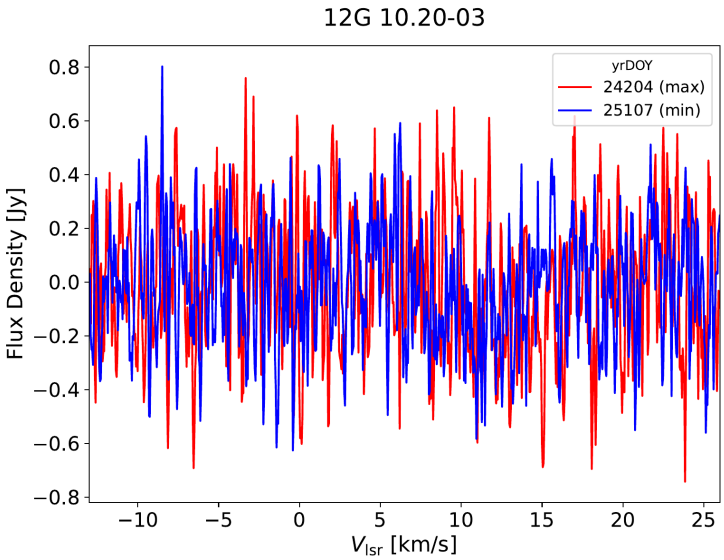
Light curve



Periodogram

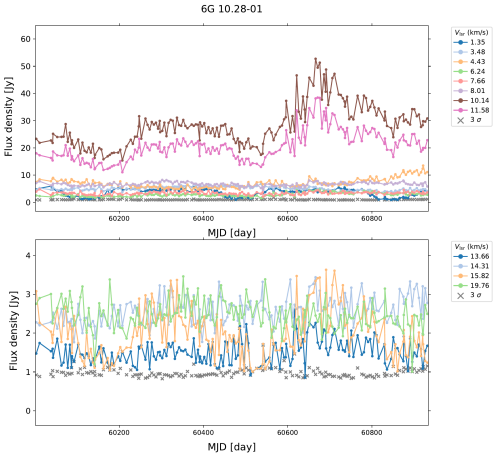


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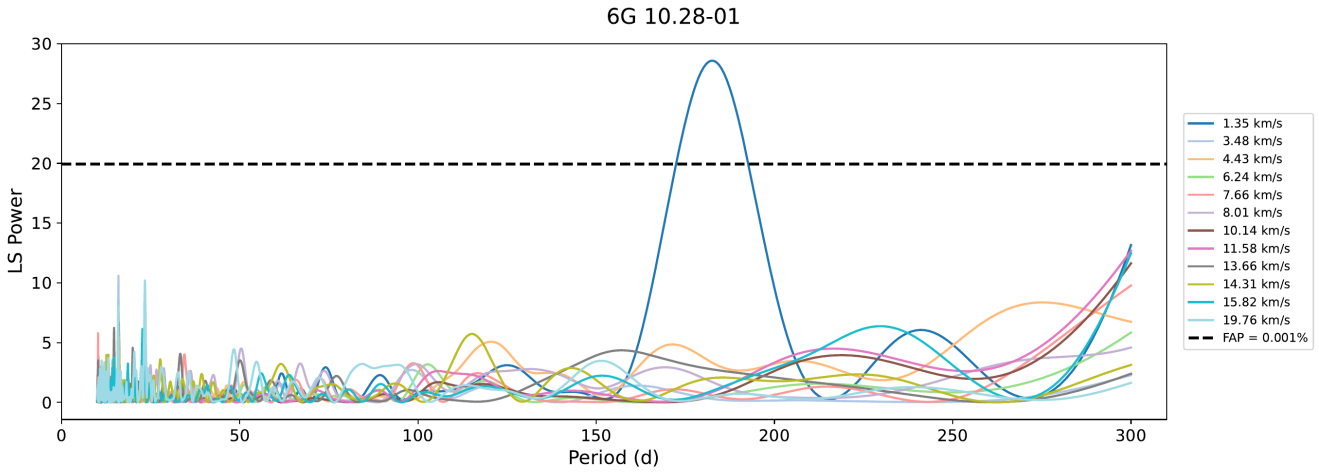


6G 10.28-01

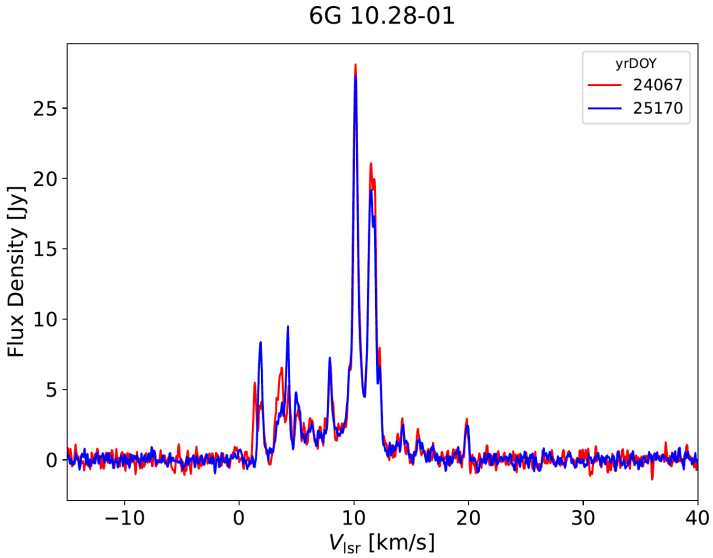
Light curve



Periodogram

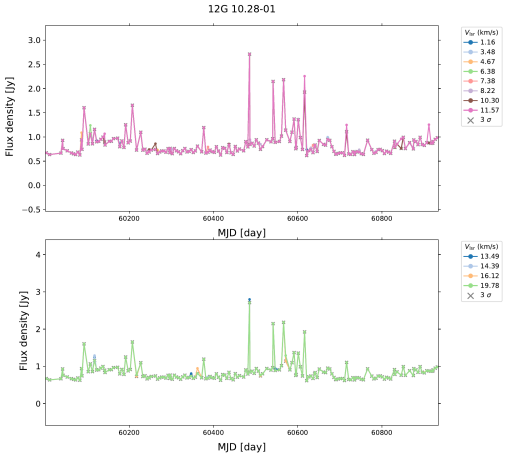


Spectrum

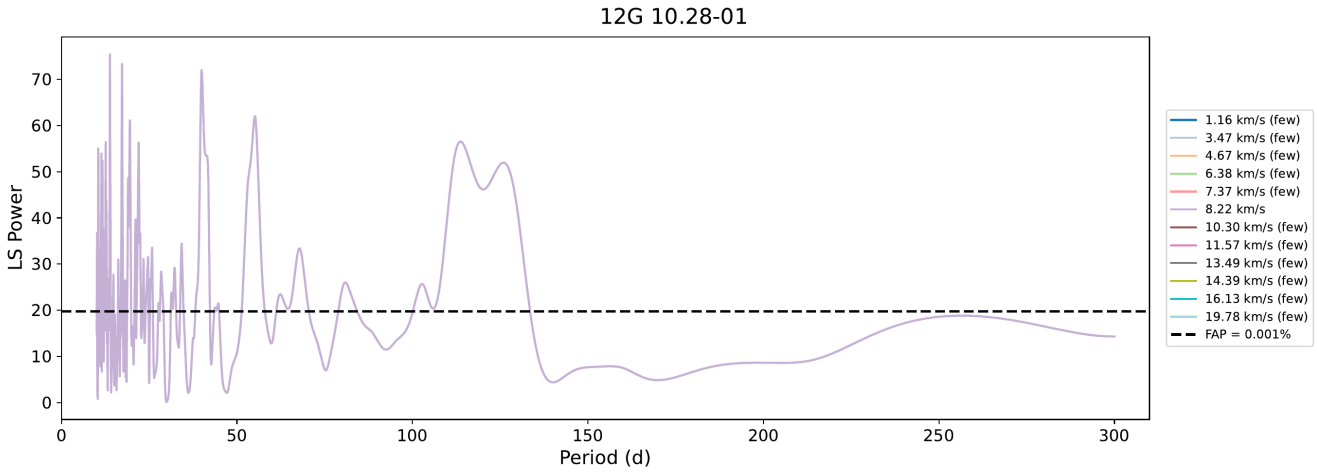


12G 10.28-01

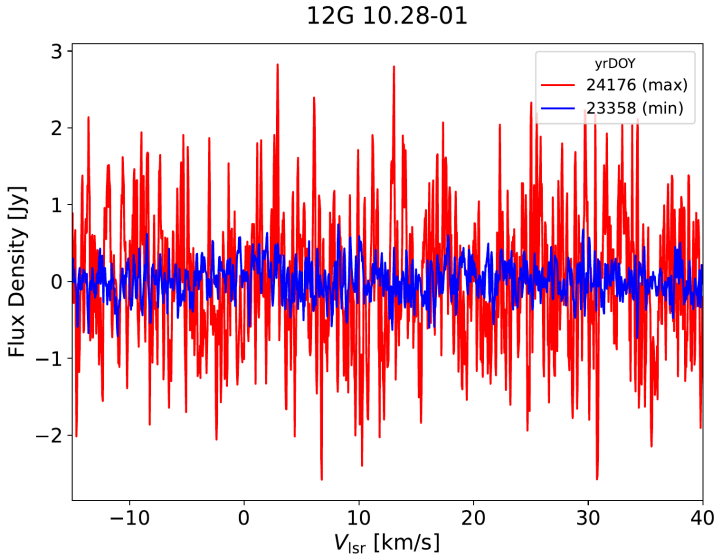
Light curve



Periodogram

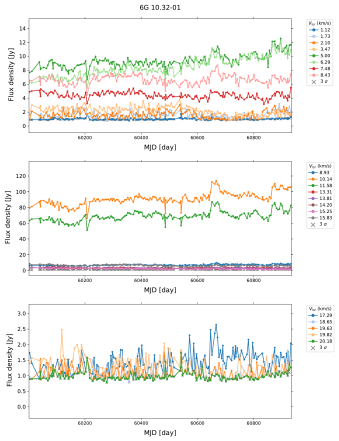


Spectrum

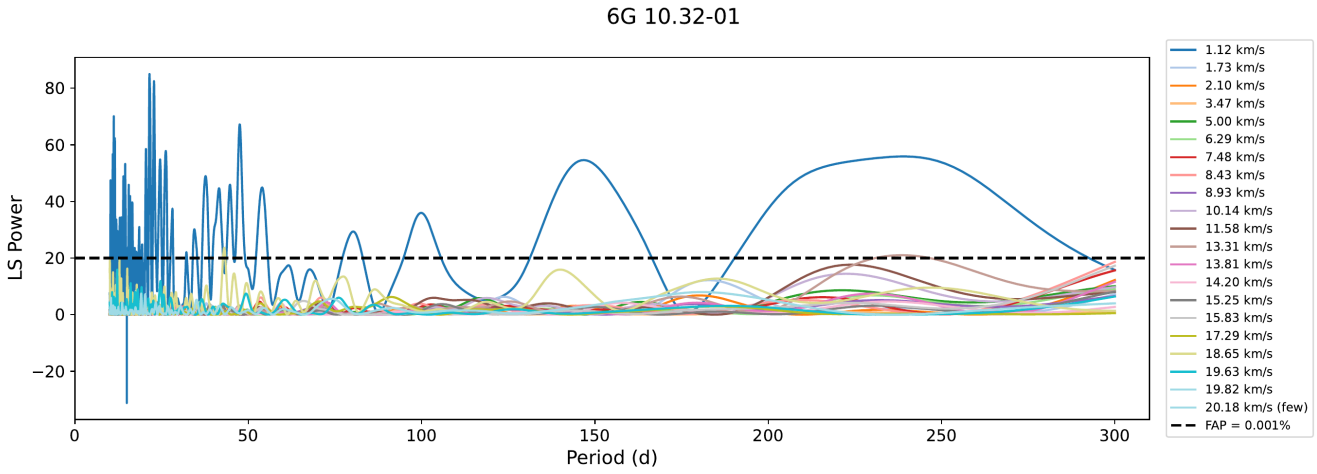


6G 10.32-01

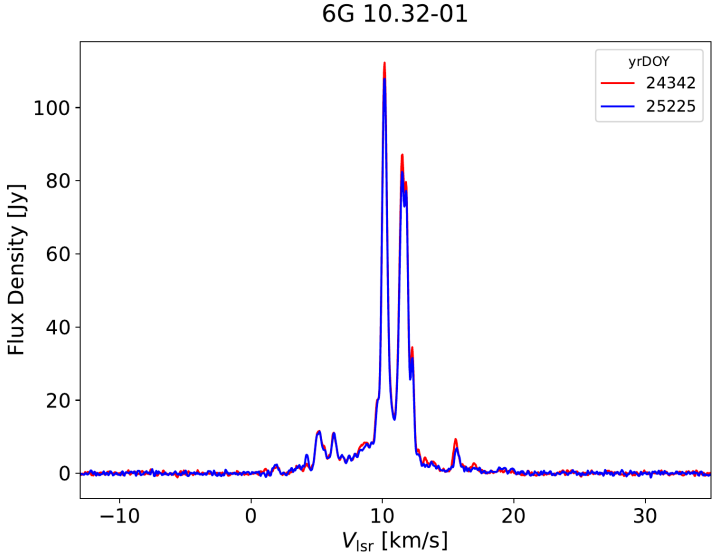
Light curve



Periodogram

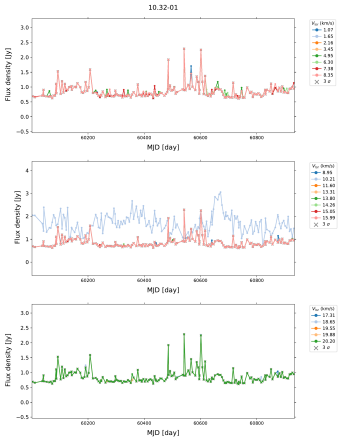


Spectrum

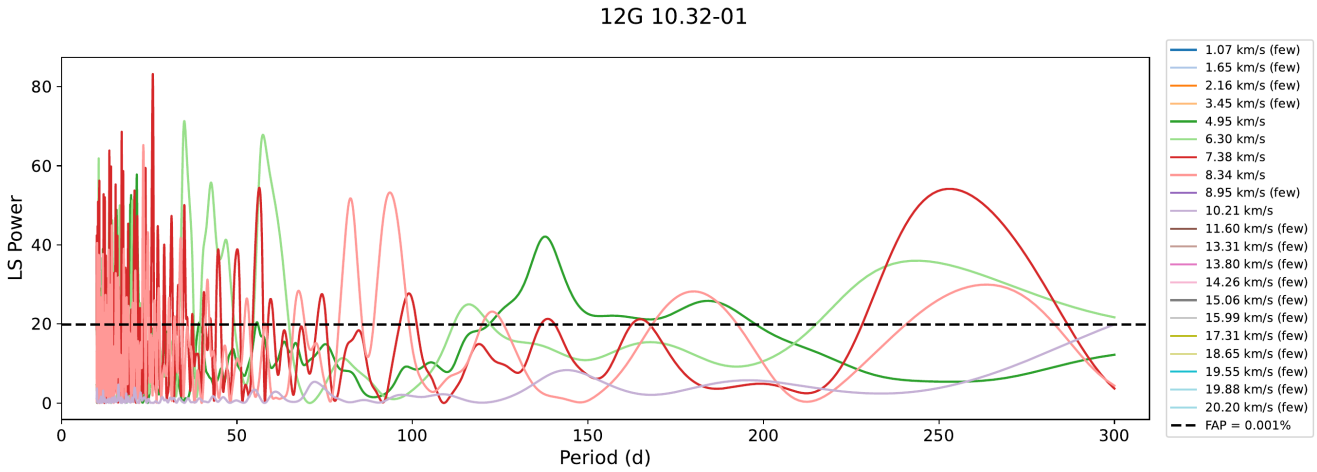


12G 10.32-01

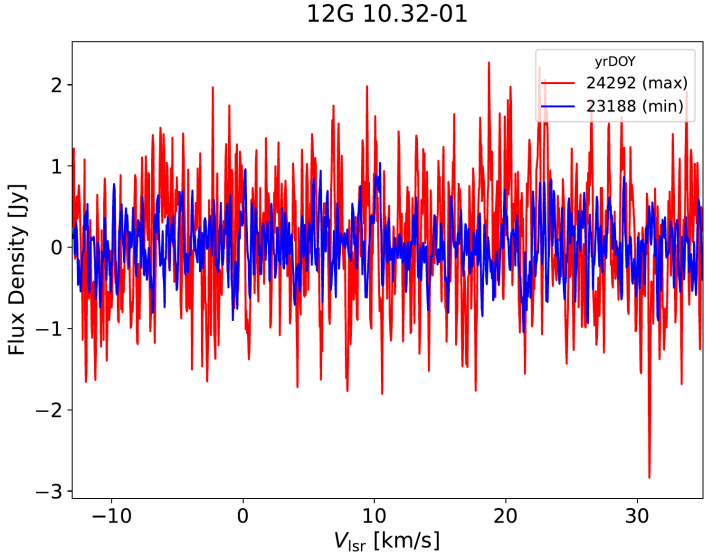
Light curve



Periodogram

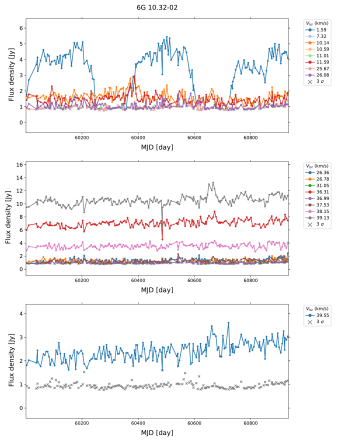


Spectrum

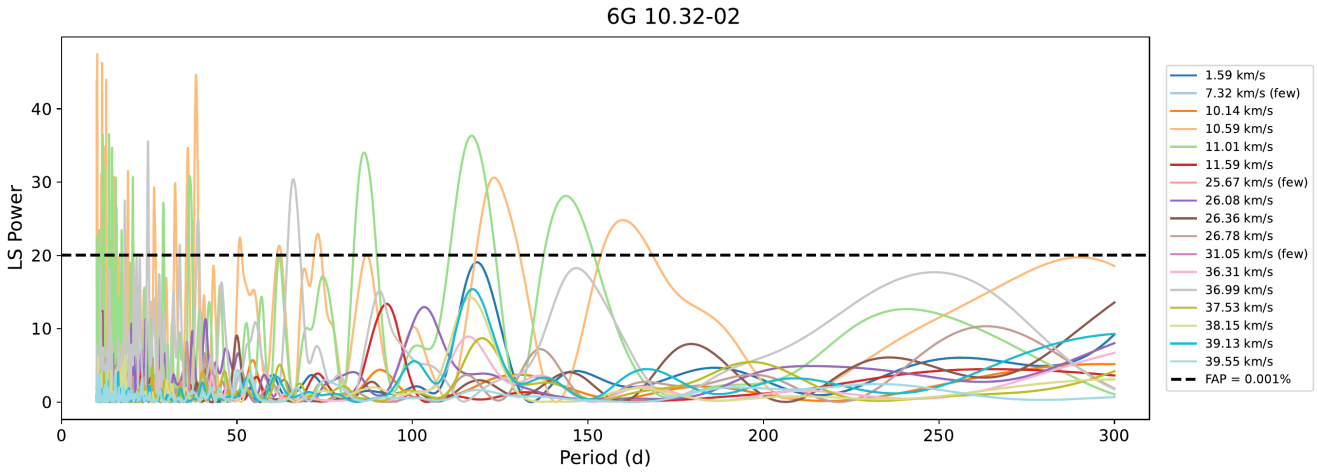


6G 10.32-02

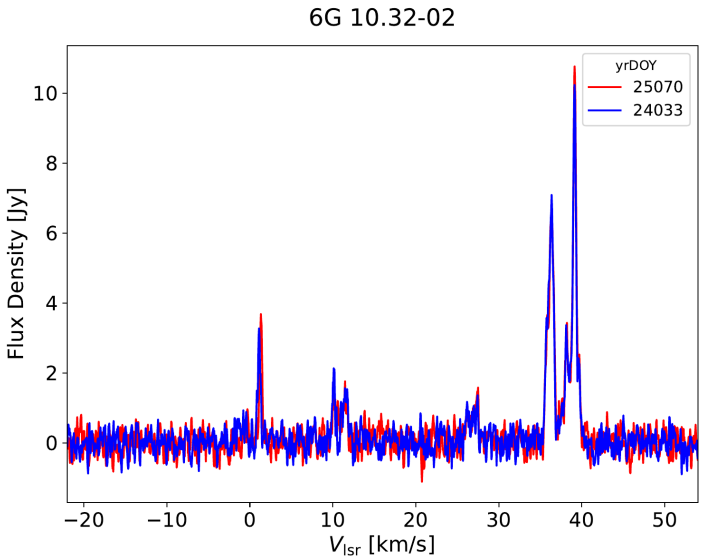
Light curve



Periodogram

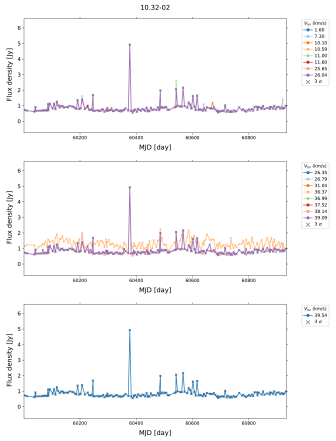


Spectrum

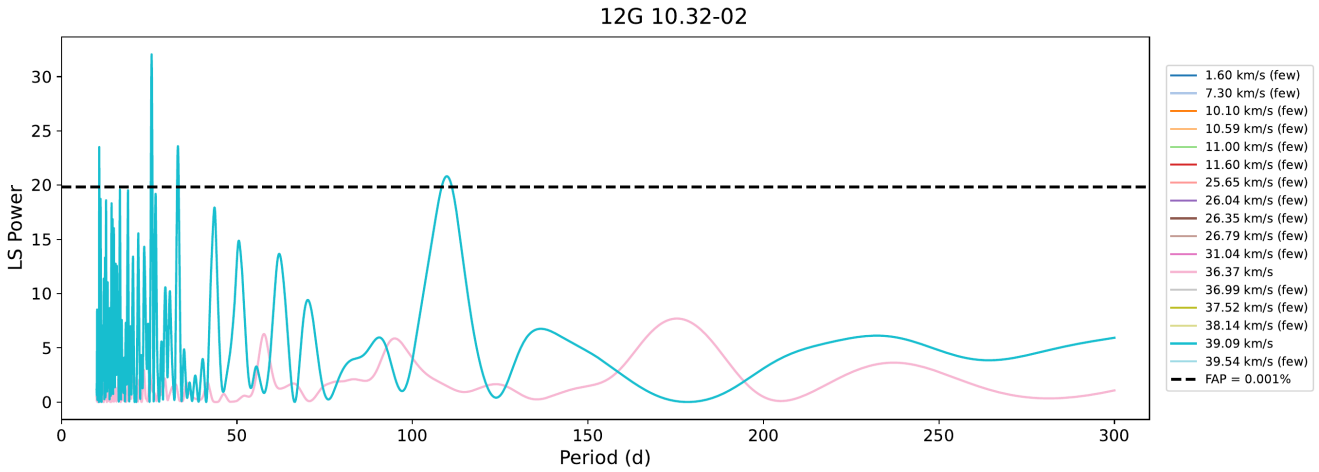


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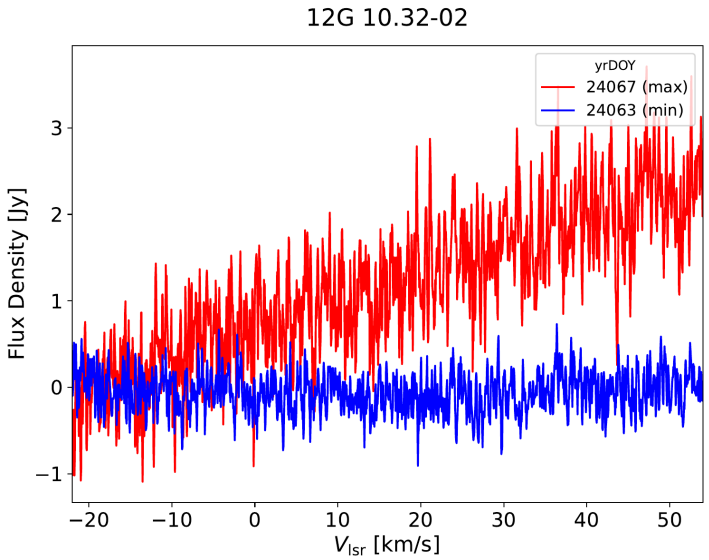
Light curve



Periodogram

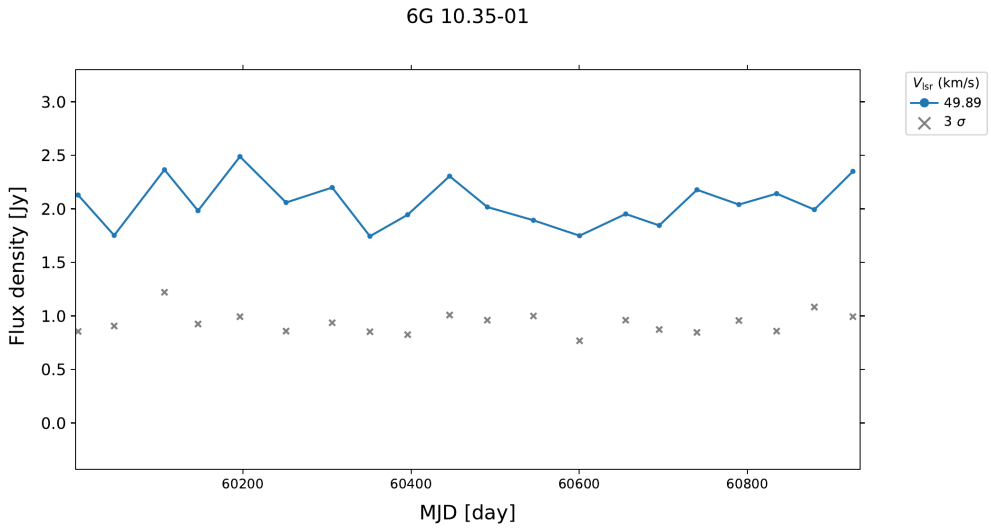


Spectrum

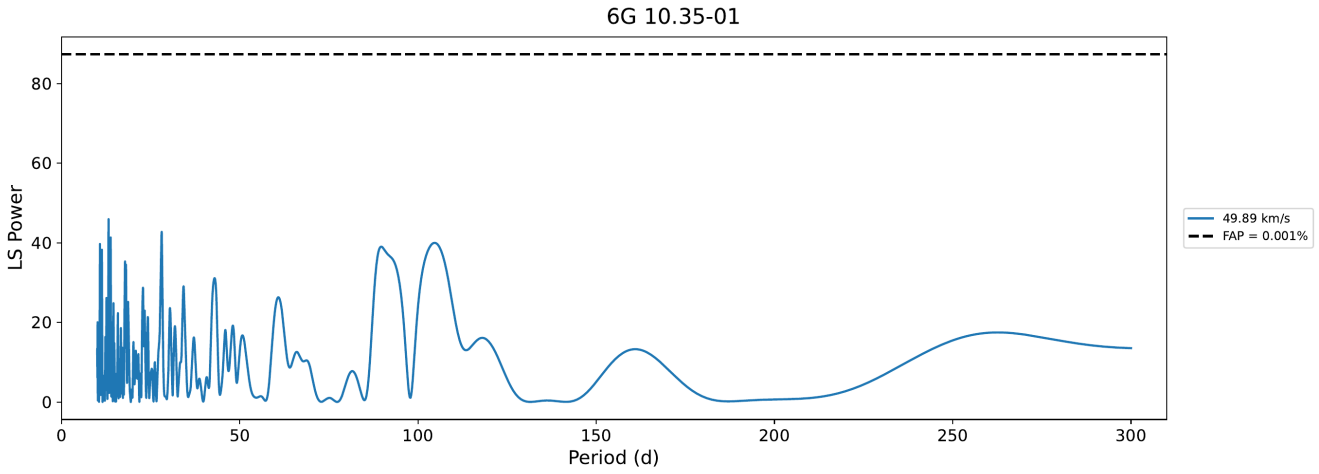


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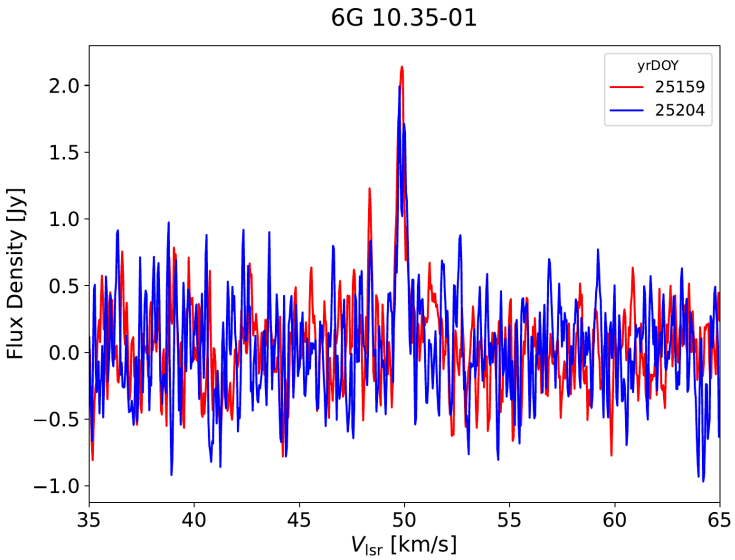
Light curve



Periodogram

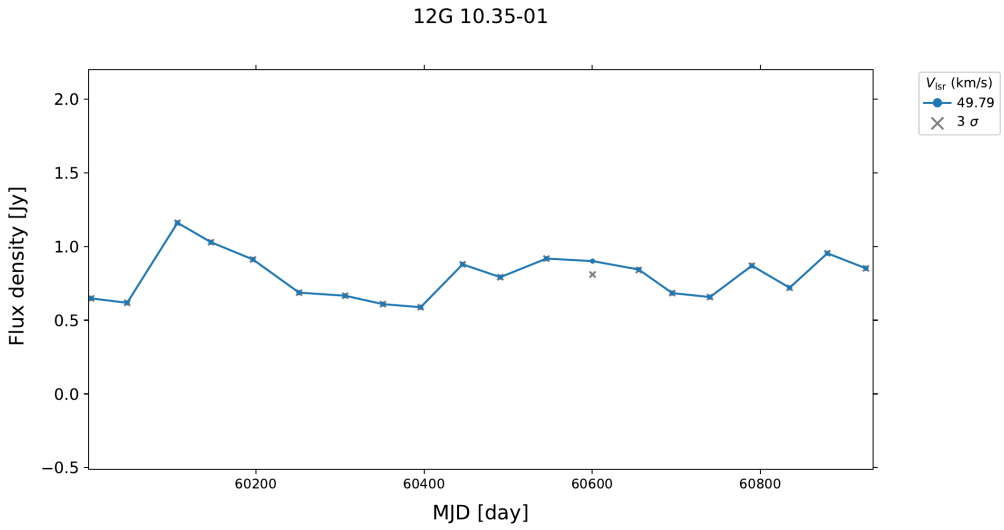


Spectrum

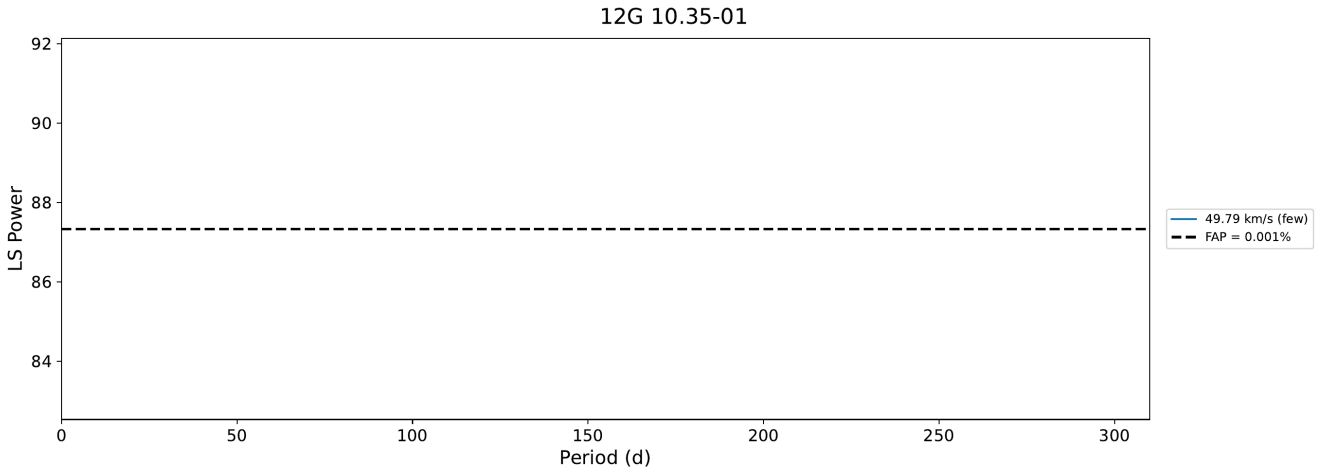


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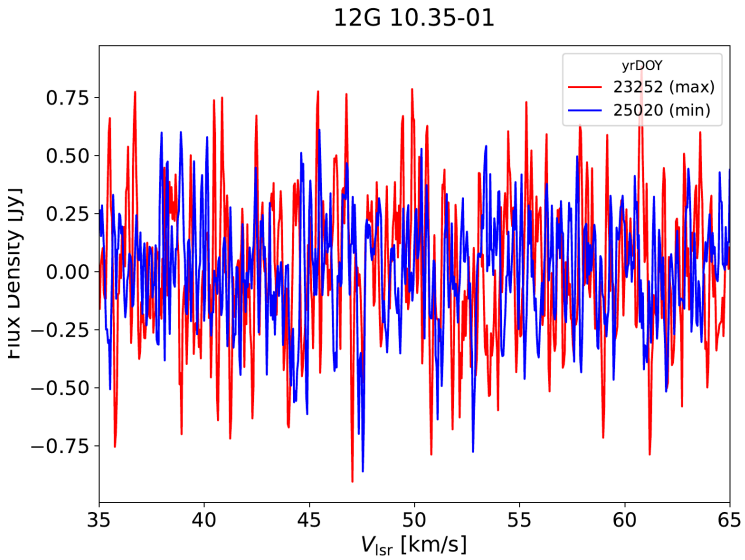
Light curve



Periodogram

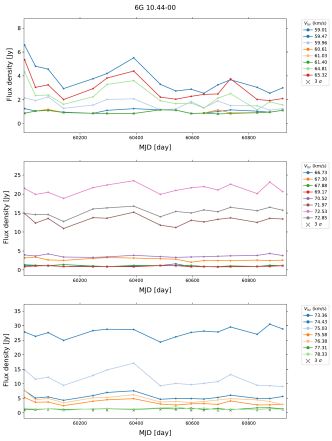


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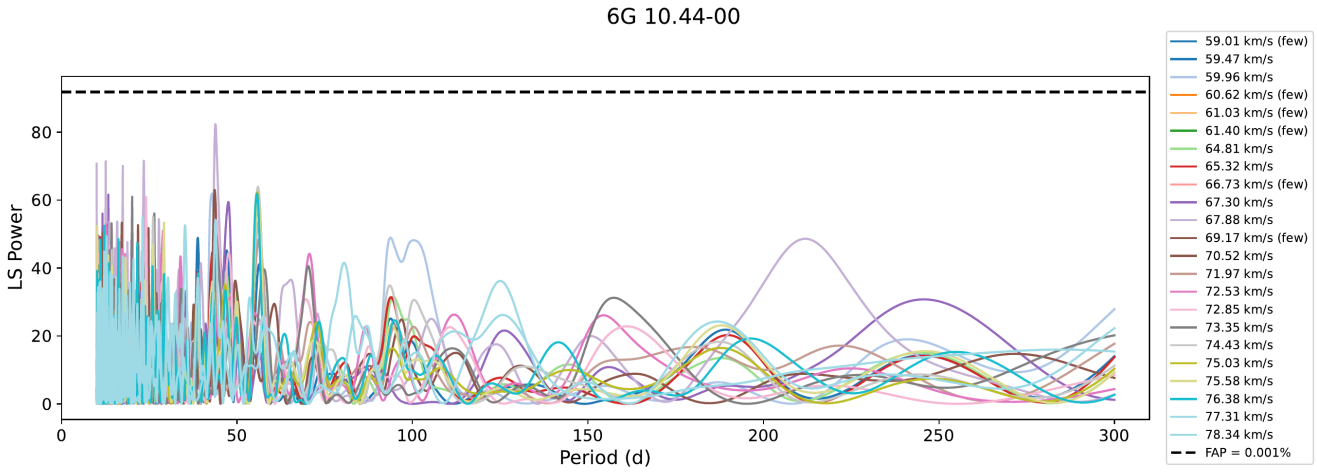


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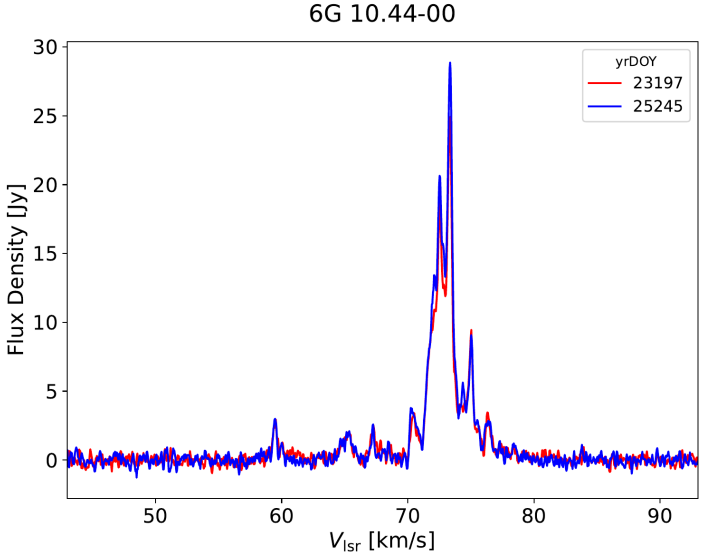
Light curve



Periodogram

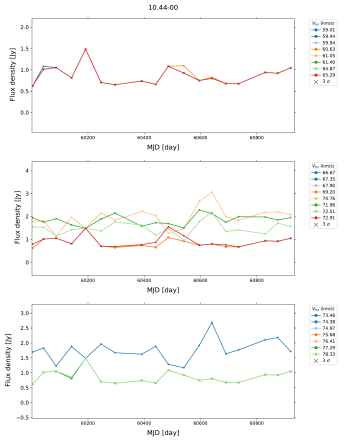


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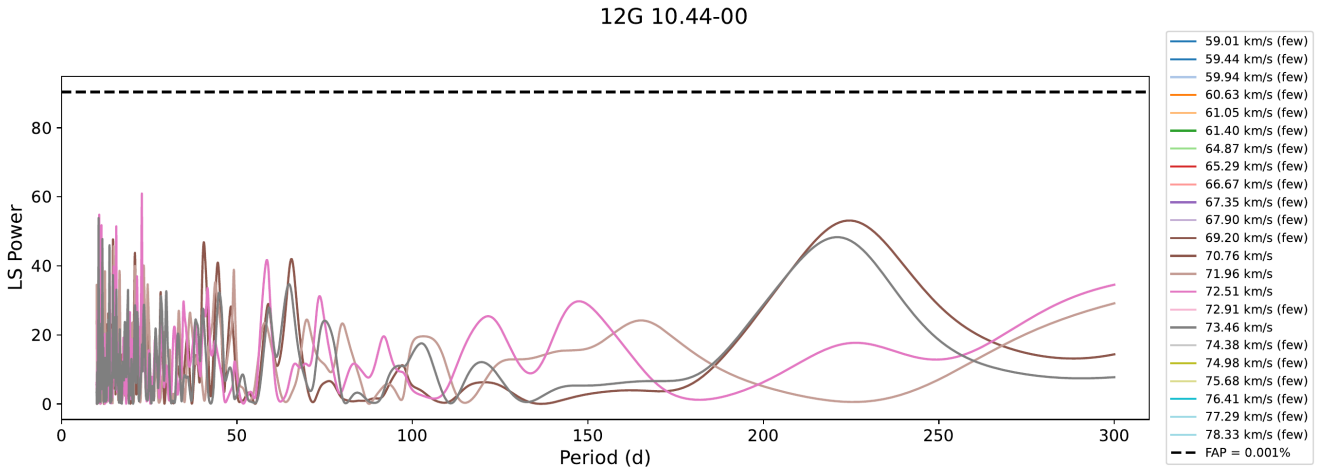


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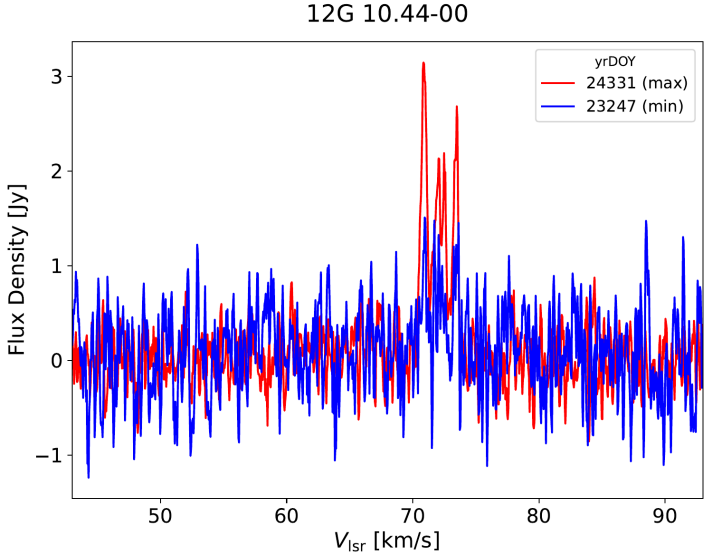
Light curve



Periodogram

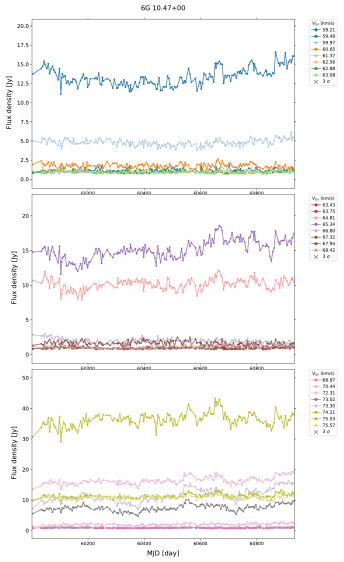


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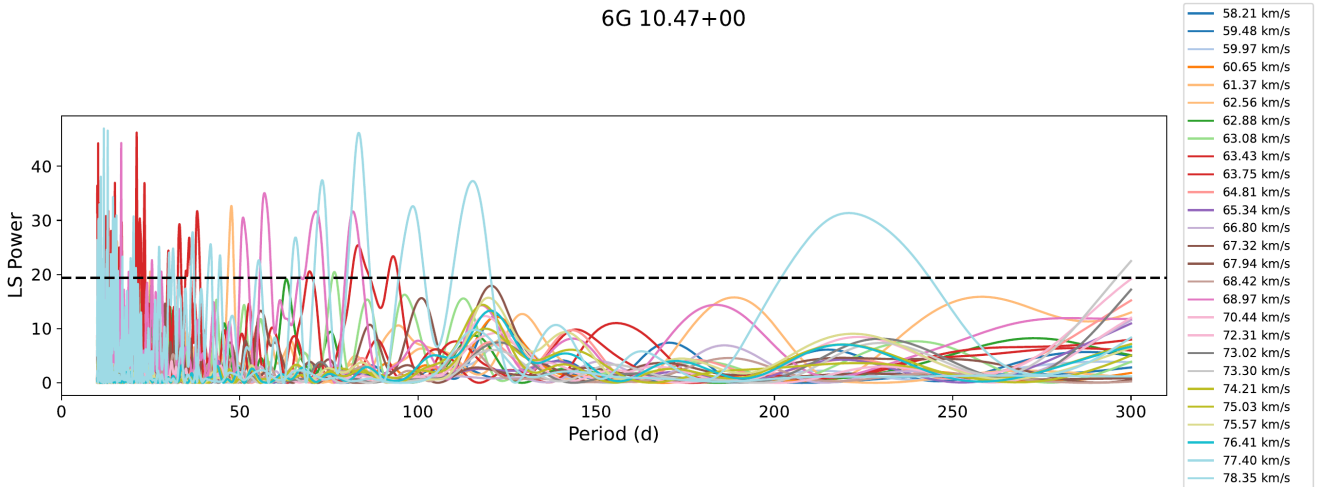


6G 10.47+00

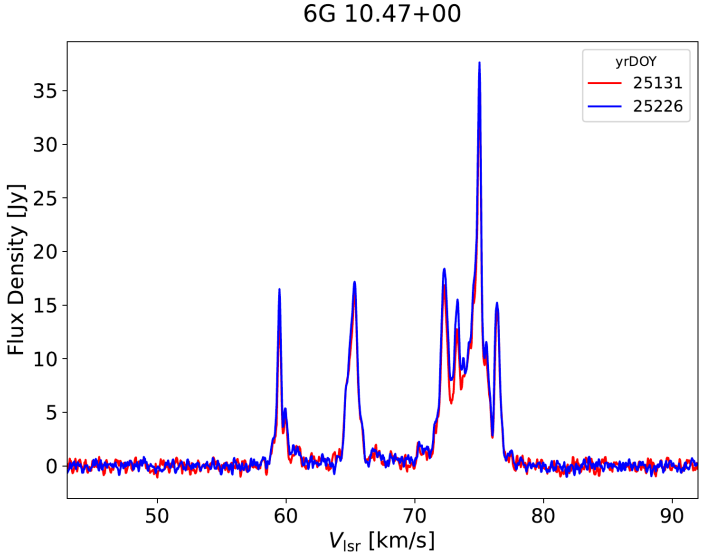
Light curve



Periodogram

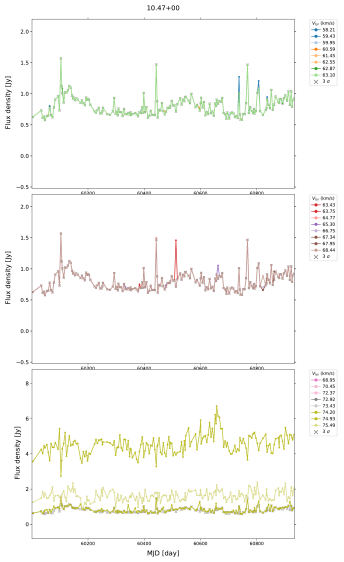


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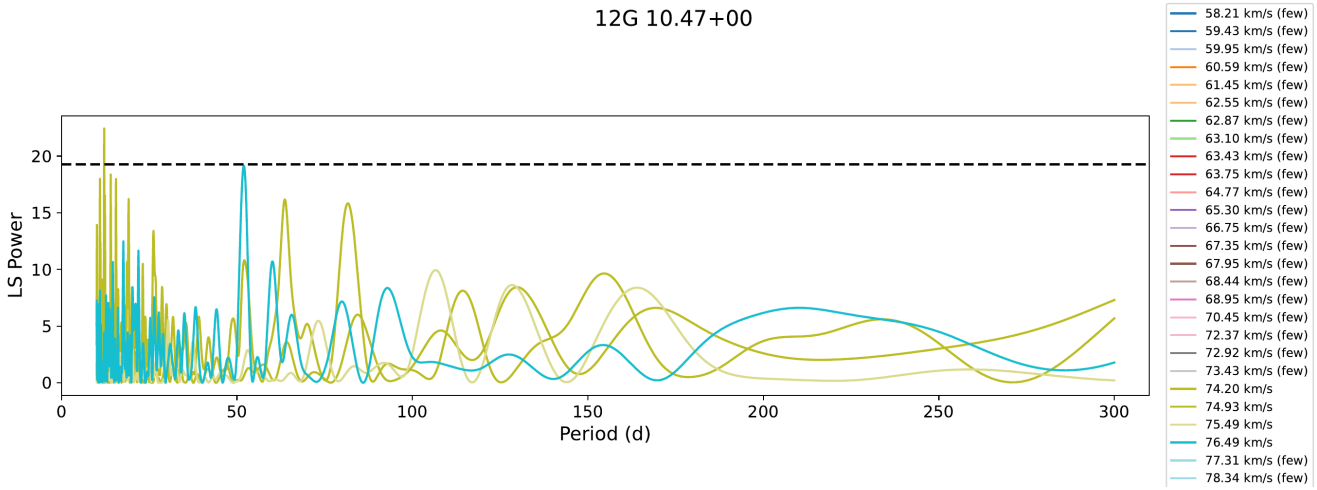


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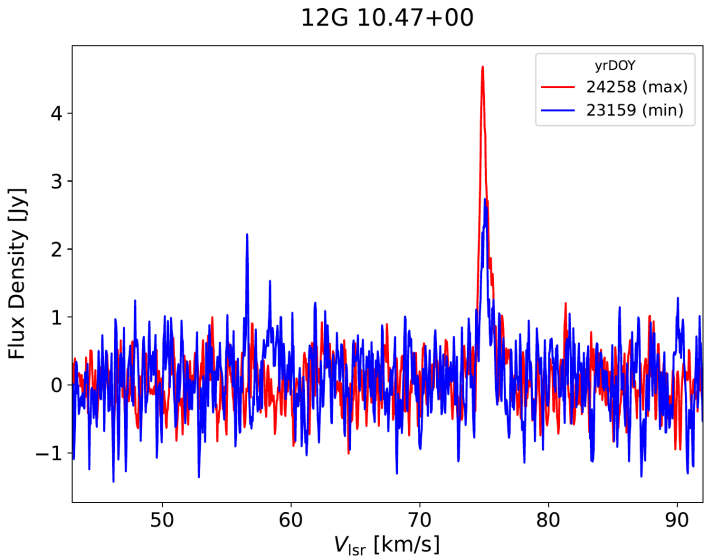
Light curve



Periodogram

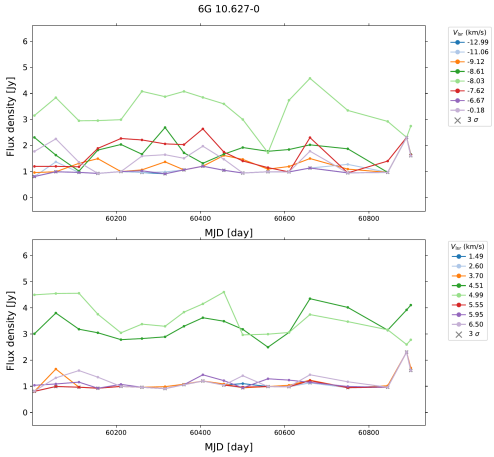


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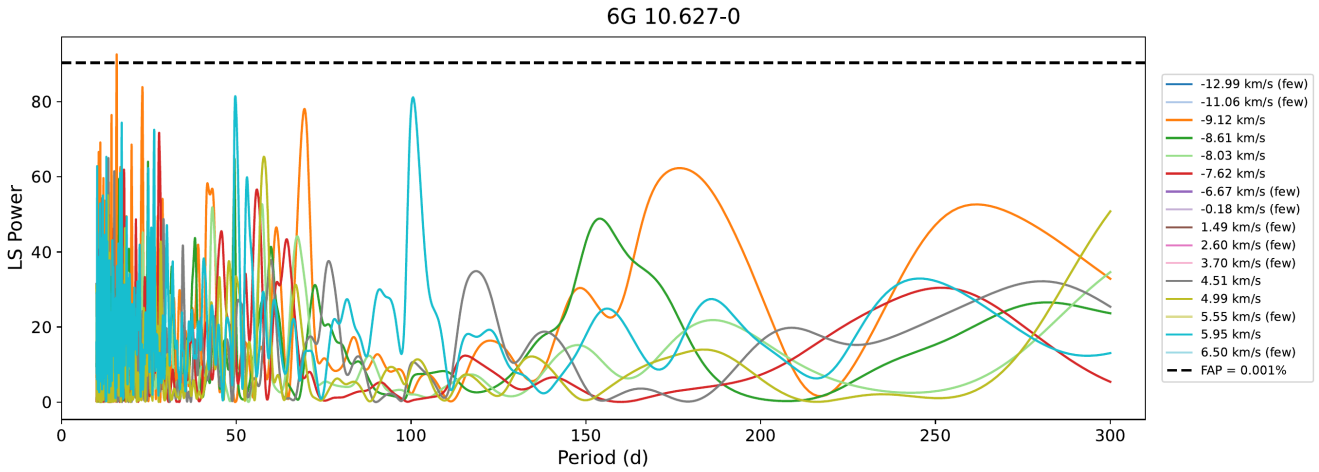


6G 10.627-0

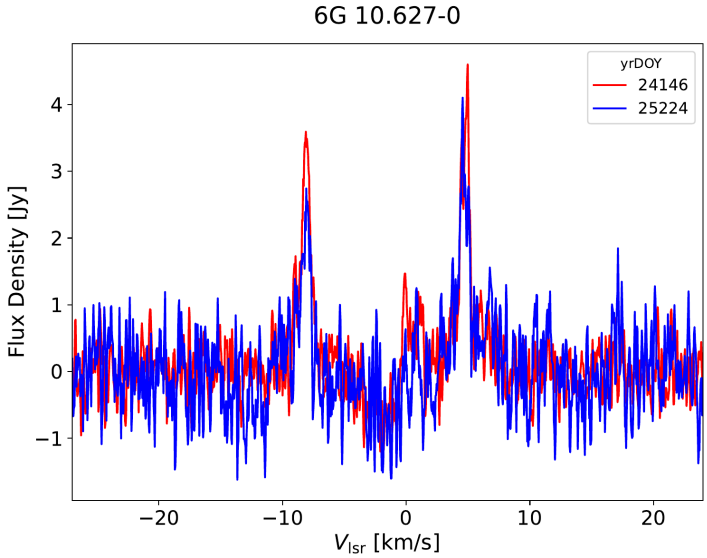
Light curve



Periodogram

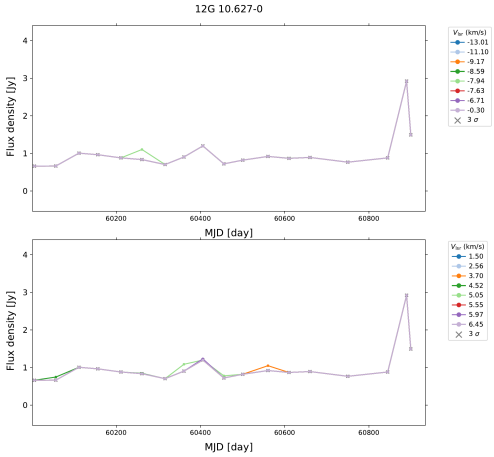


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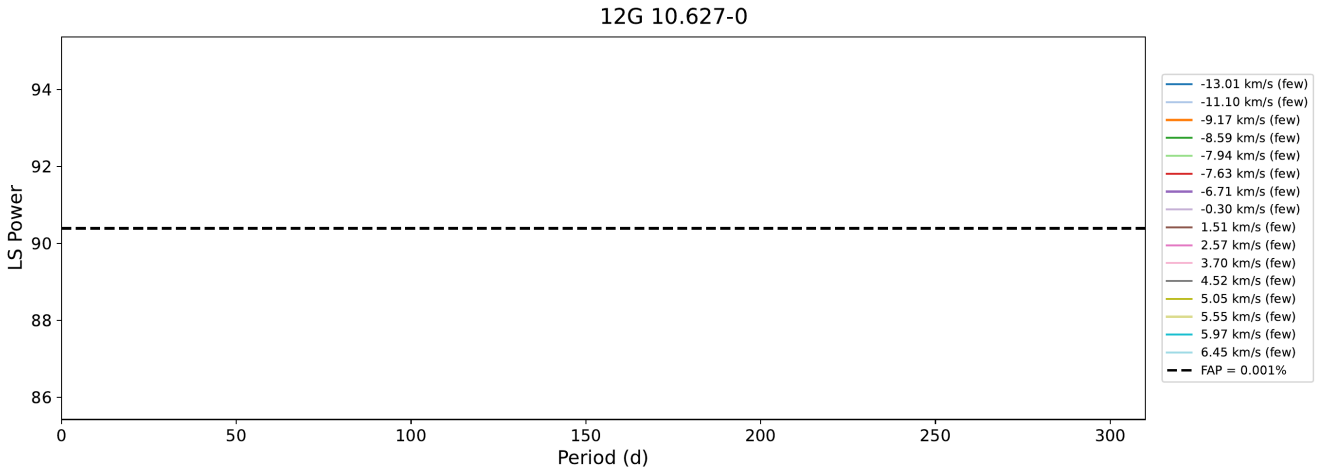


12G 10.627-0

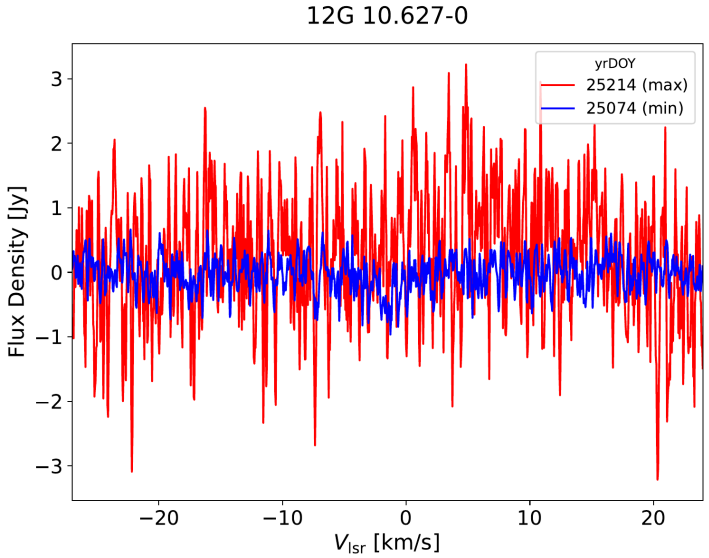
Light curve



Periodogram

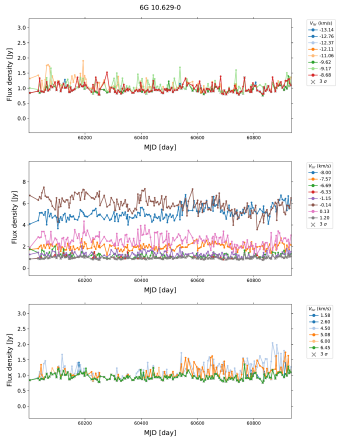


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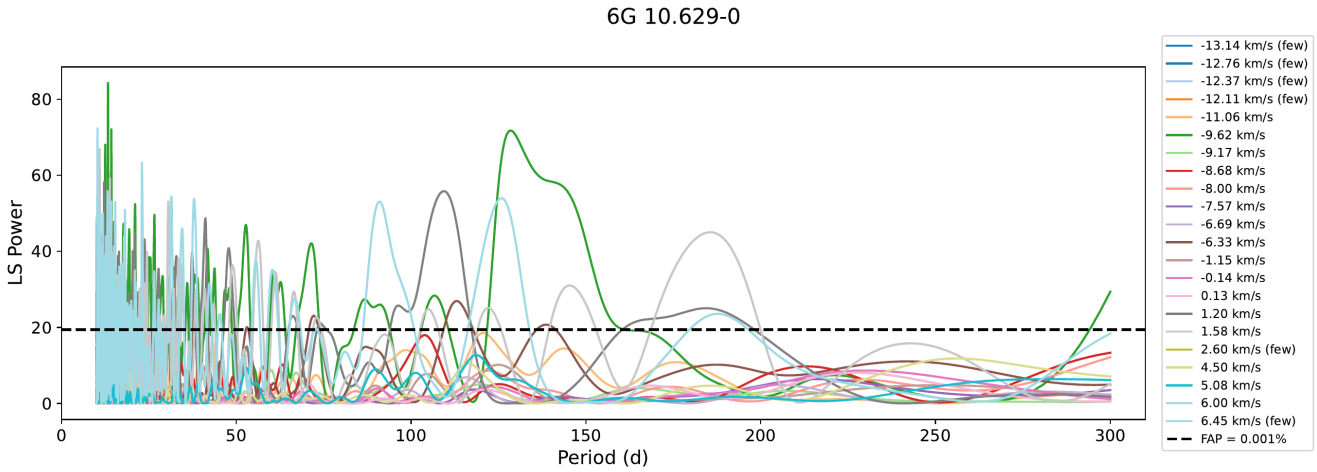


6G 10.629-0

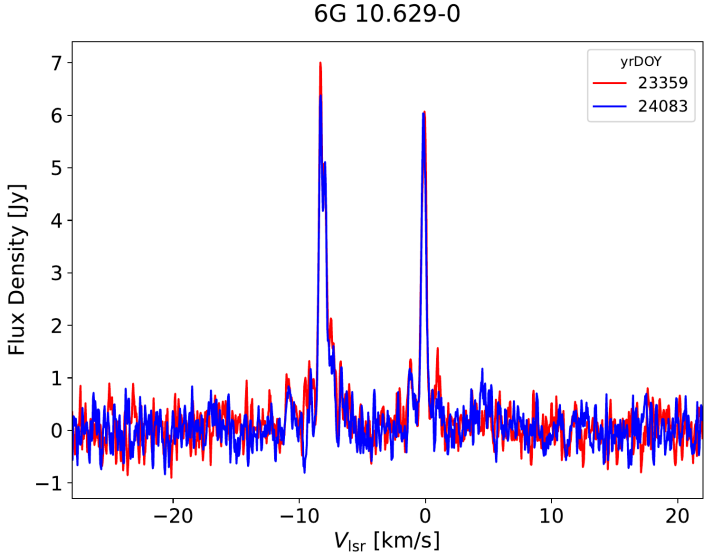
Light curve



Periodogram

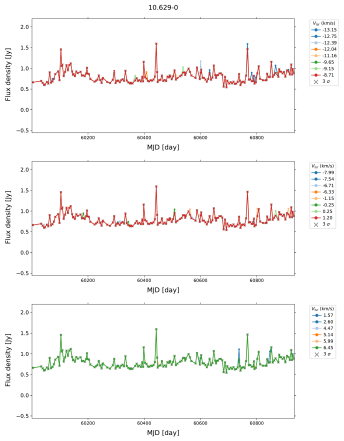


Spectrum

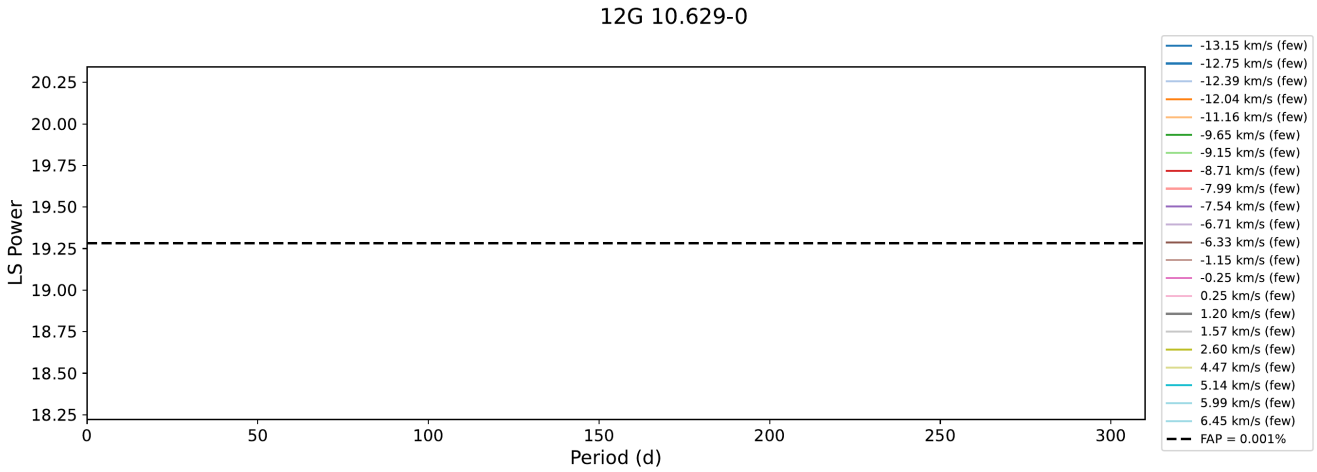


12G 10.629-0

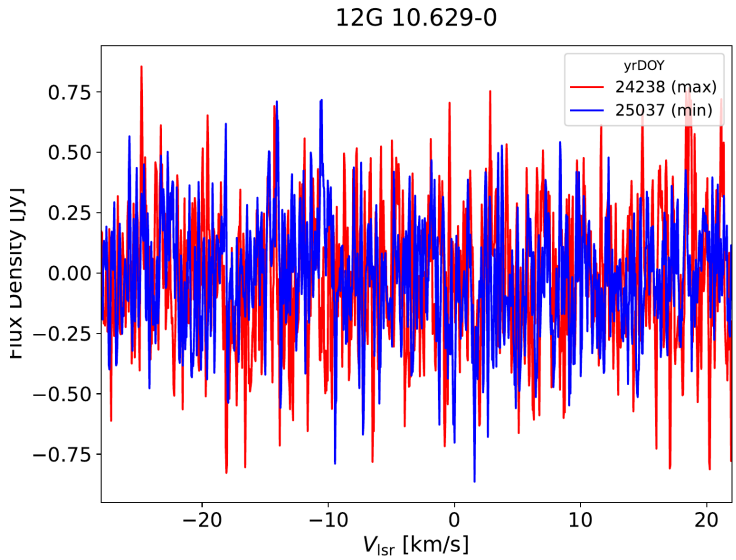
Light curve



Periodogram

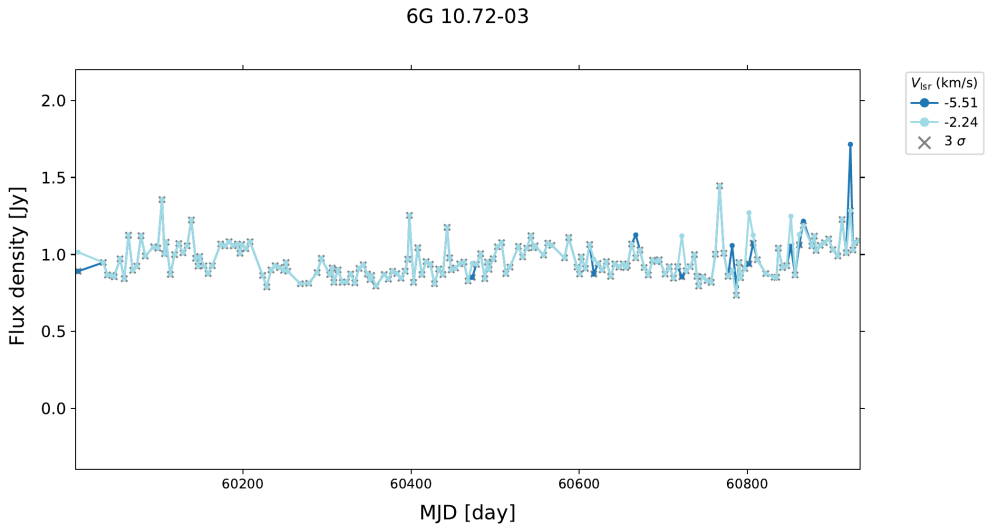


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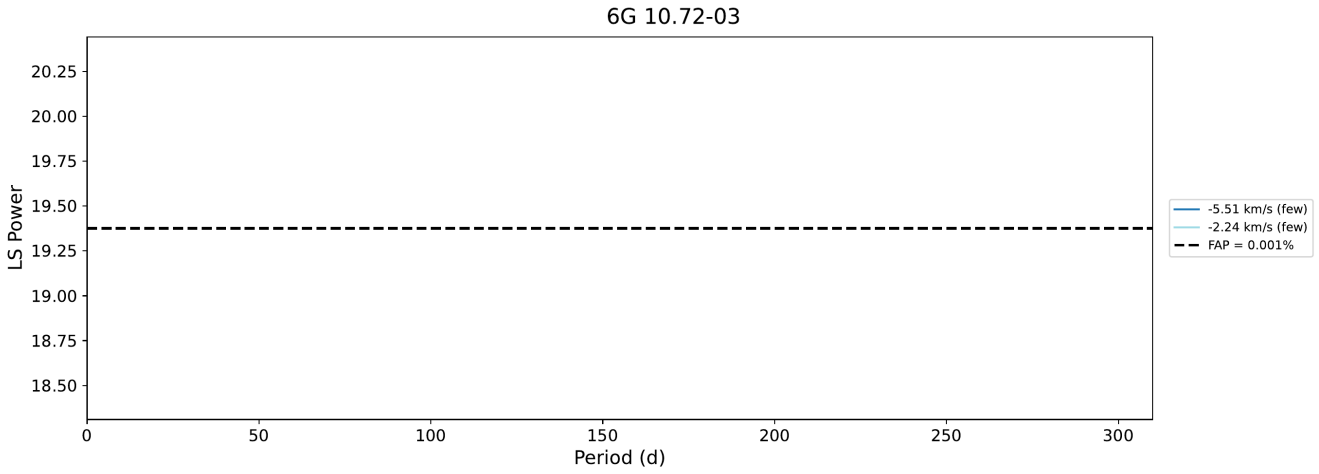


6G 10.72-03

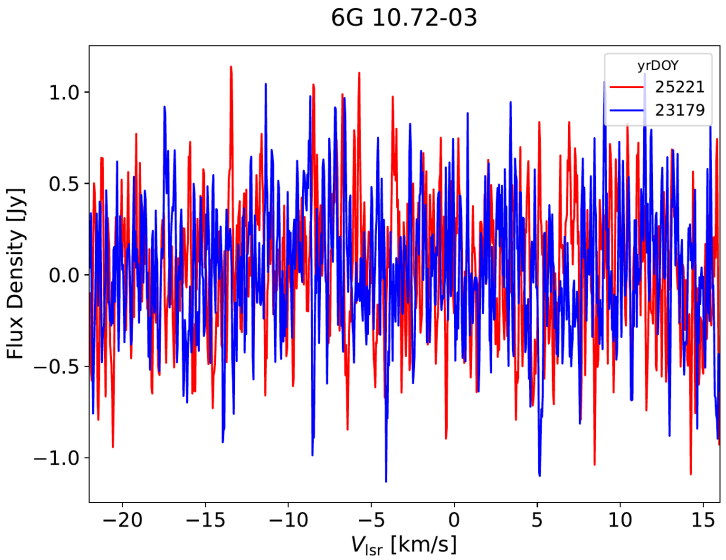
Light curve



Periodogram

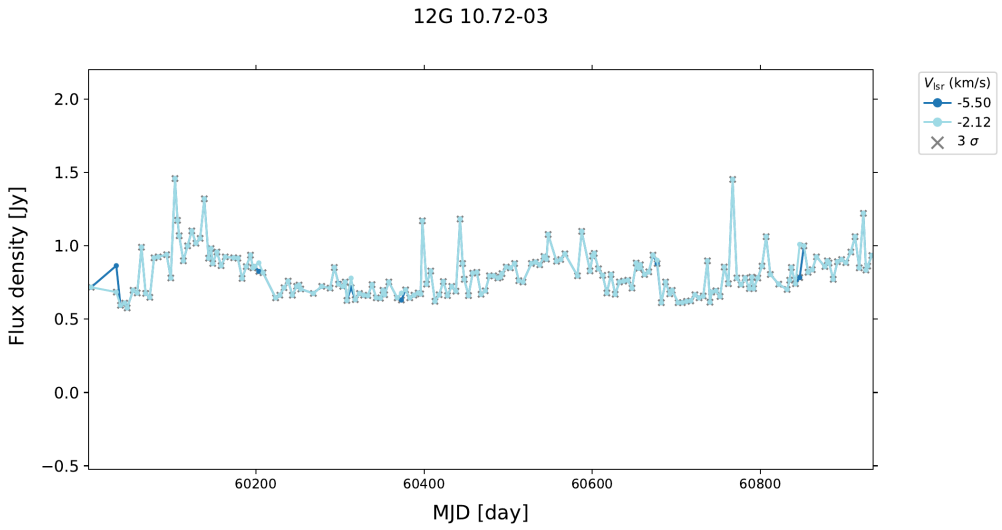


Spectrum

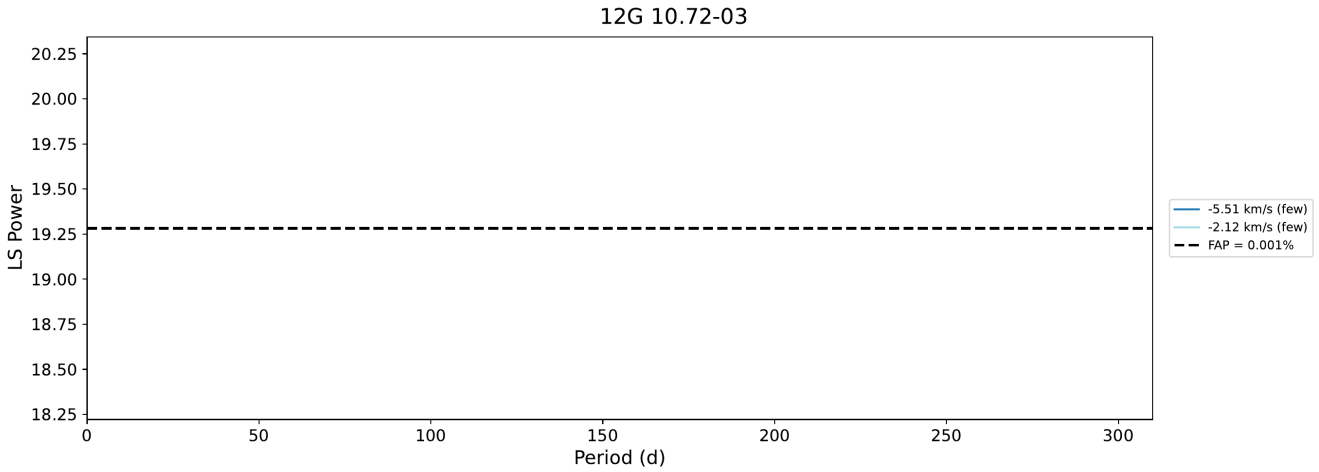


12G 10.72-03

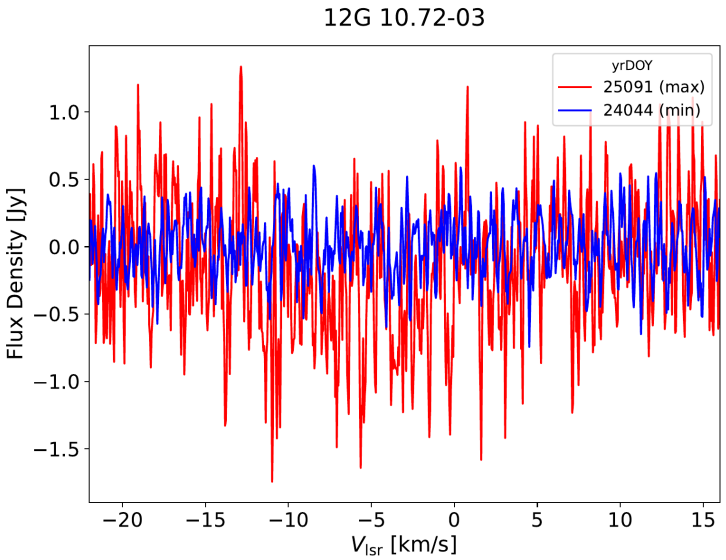
Light curve



Periodogram

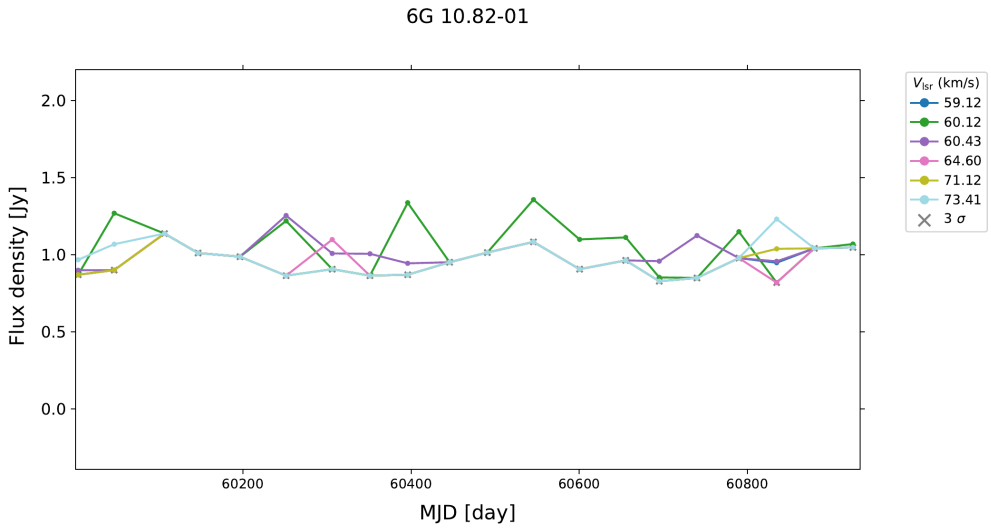


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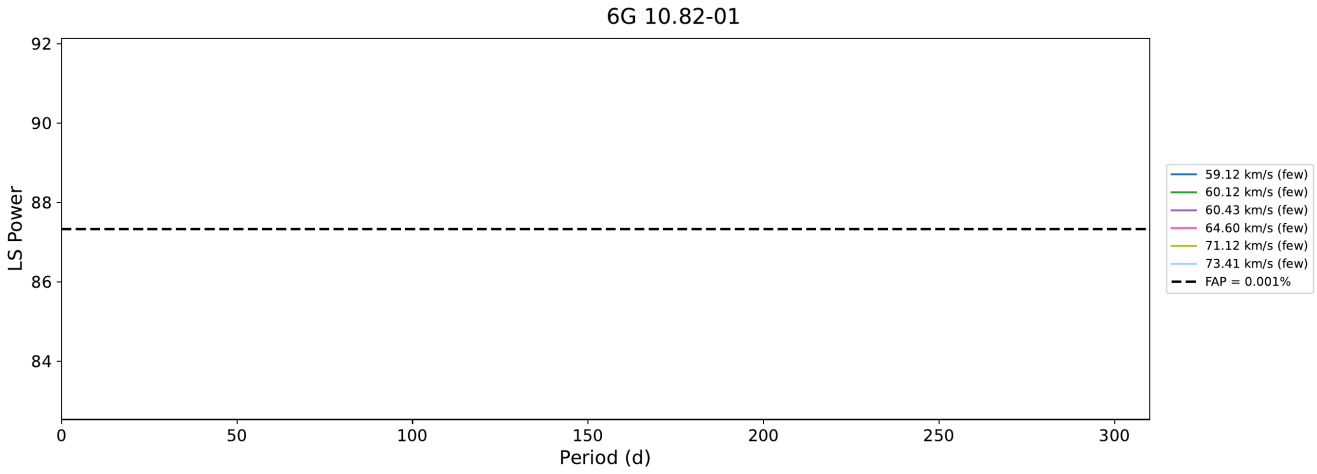


6G 10.82-01

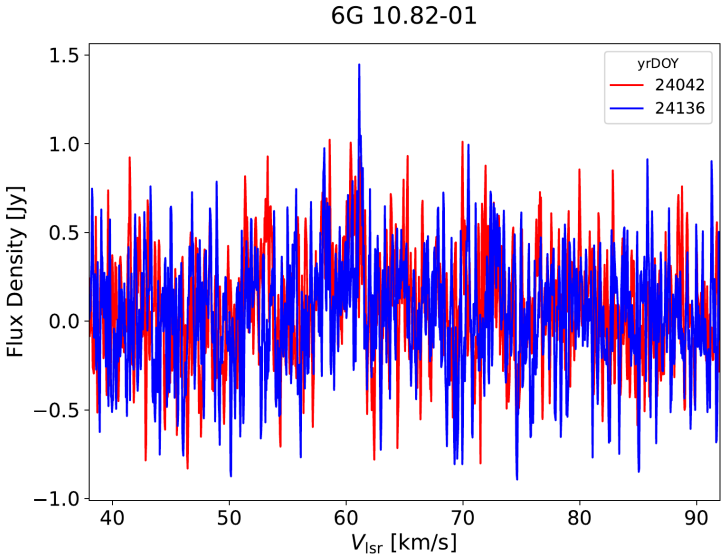
Light curve



Periodogram

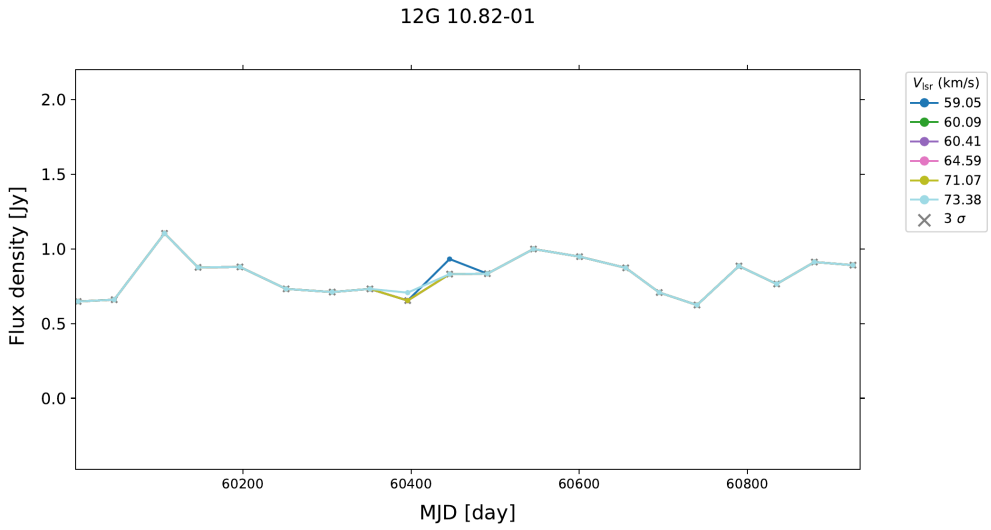


Spectrum

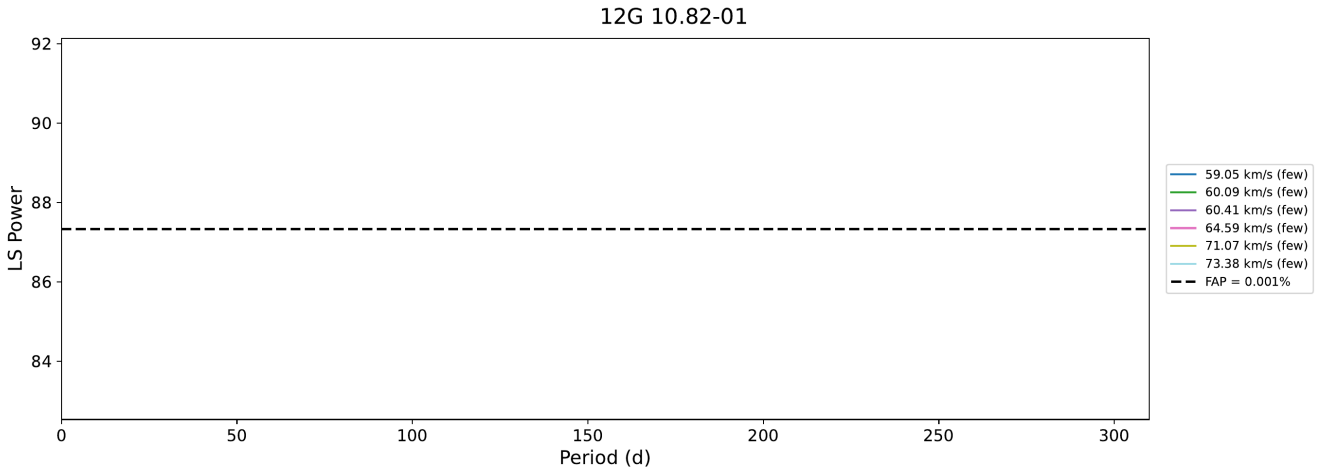


12G 10.82-01

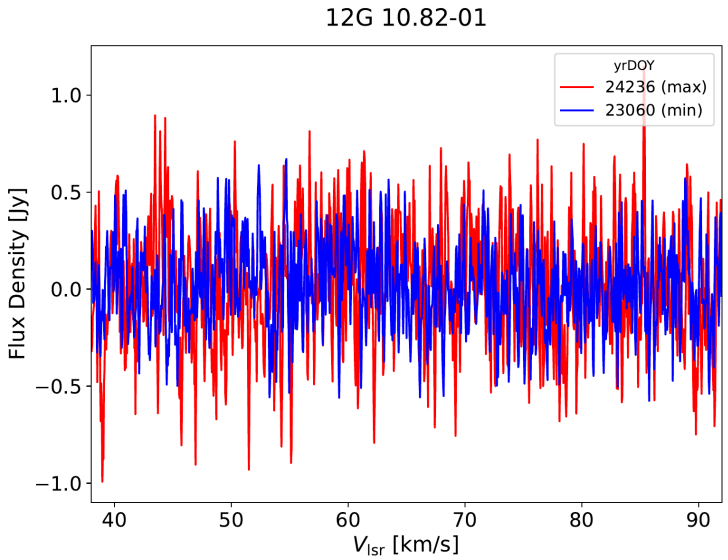
Light curve



Periodogram

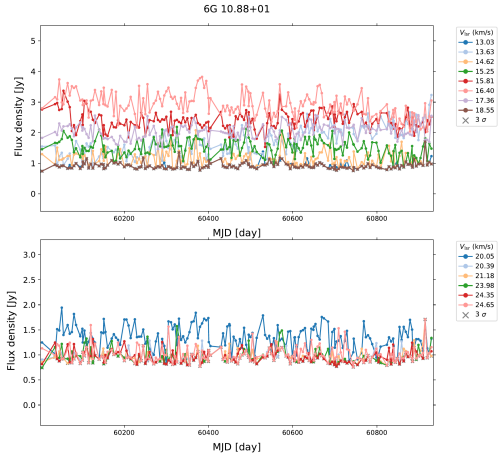


Spectrum

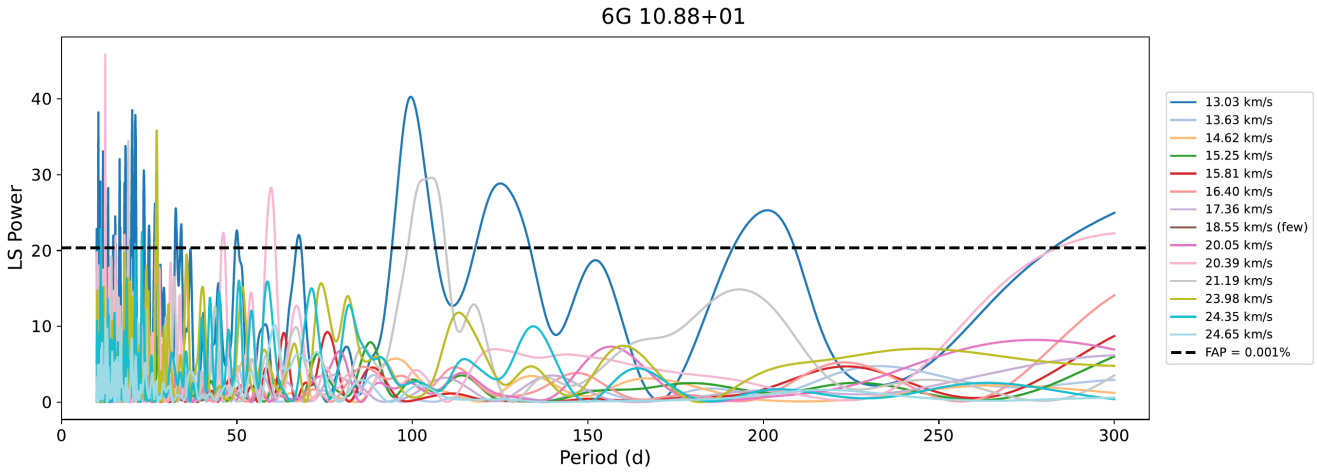


6G 10.88+01

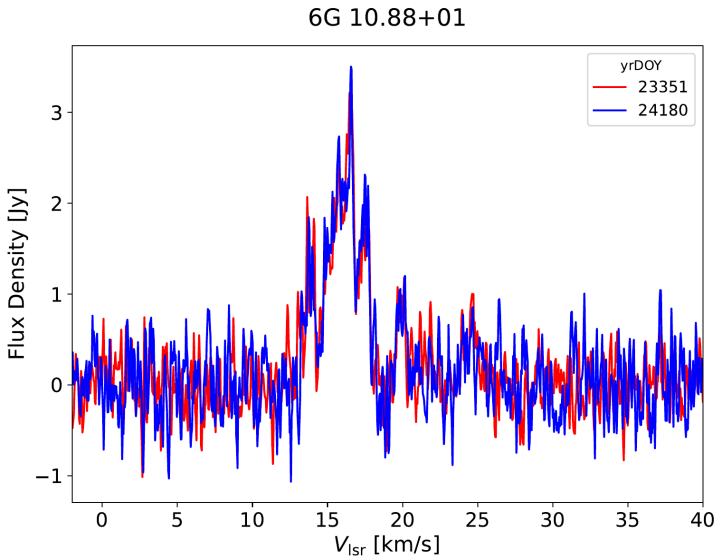
Light curve



Periodogram

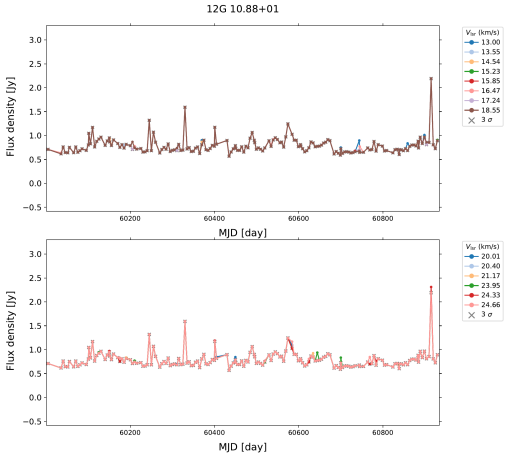


Spectrum

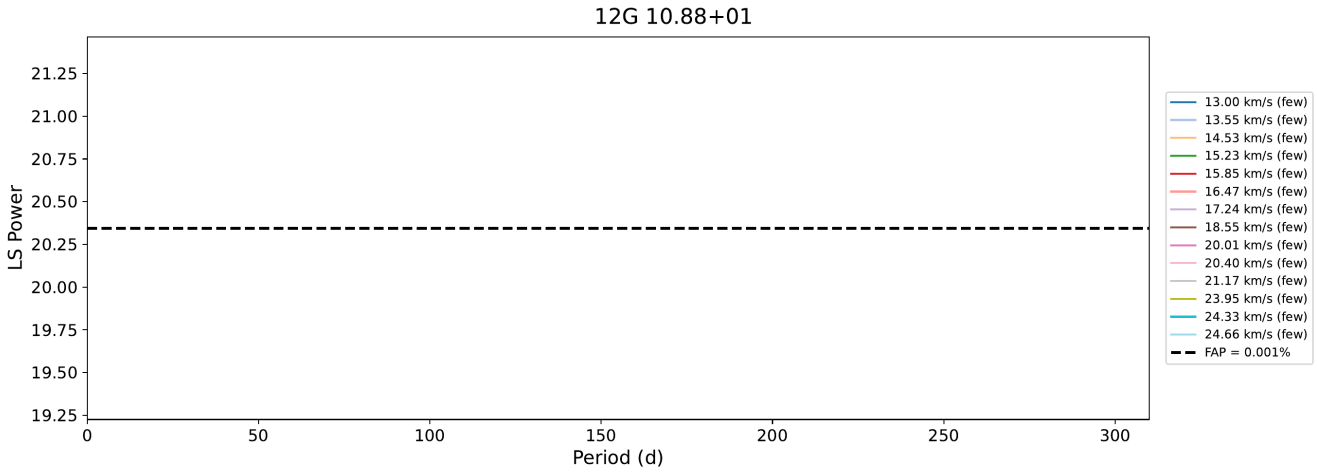


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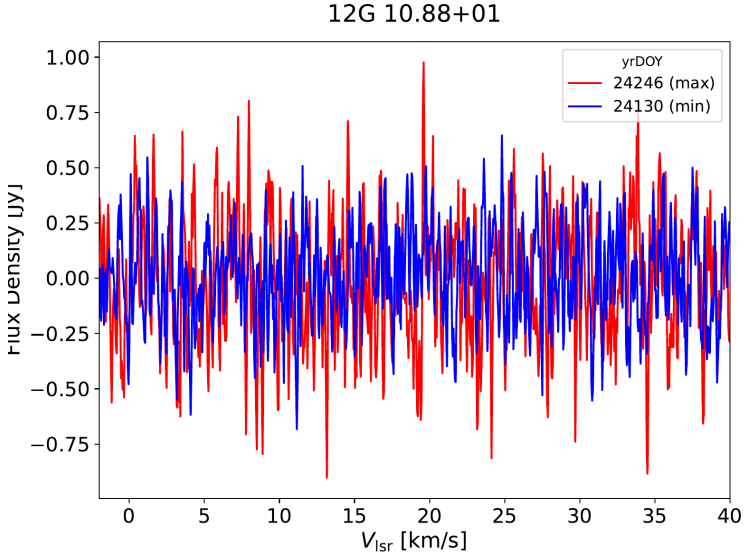
Light curve



Periodogram

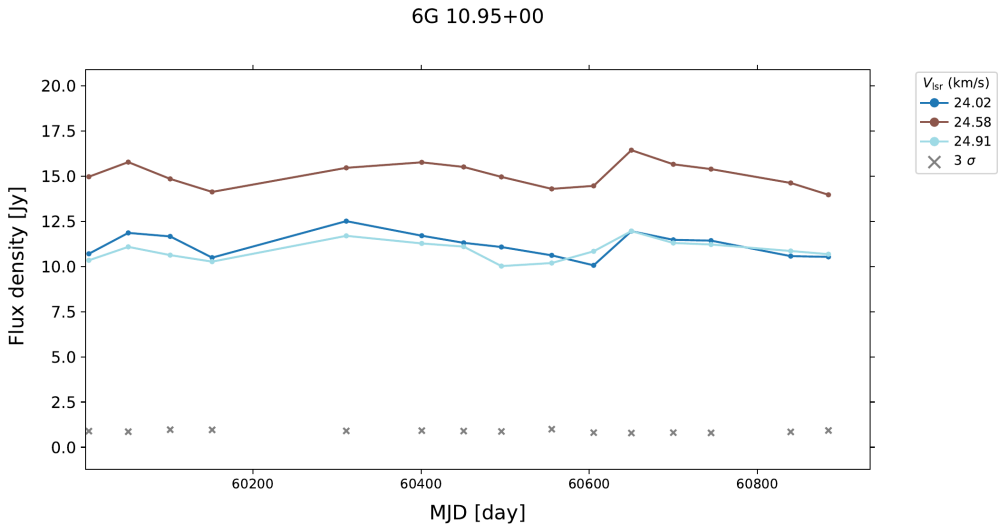


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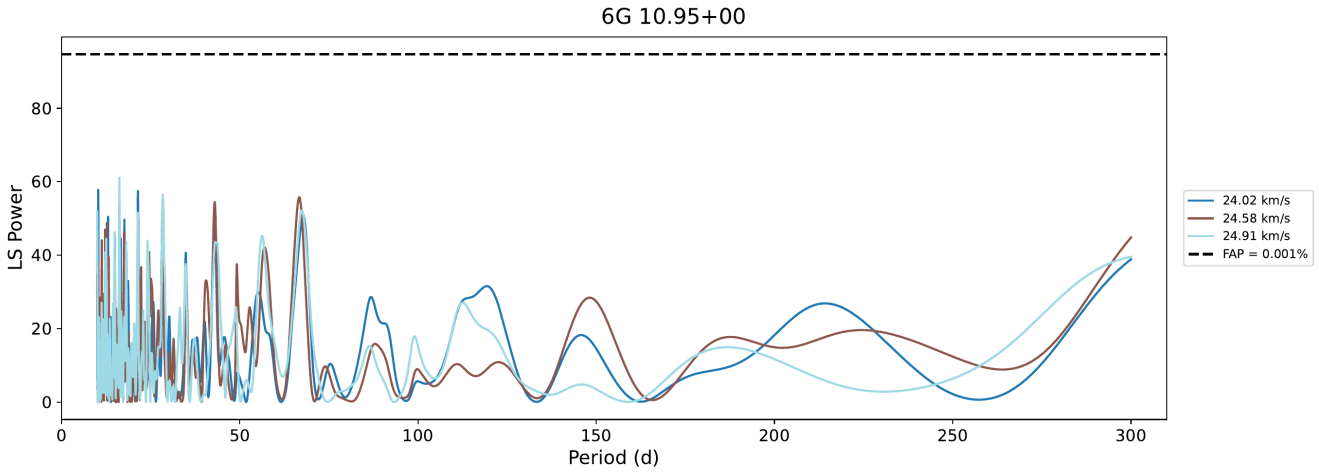


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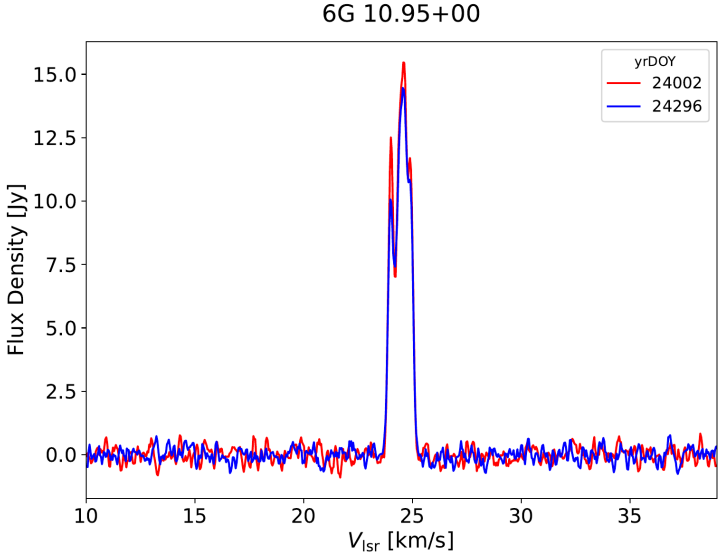
Light curve



Periodogram

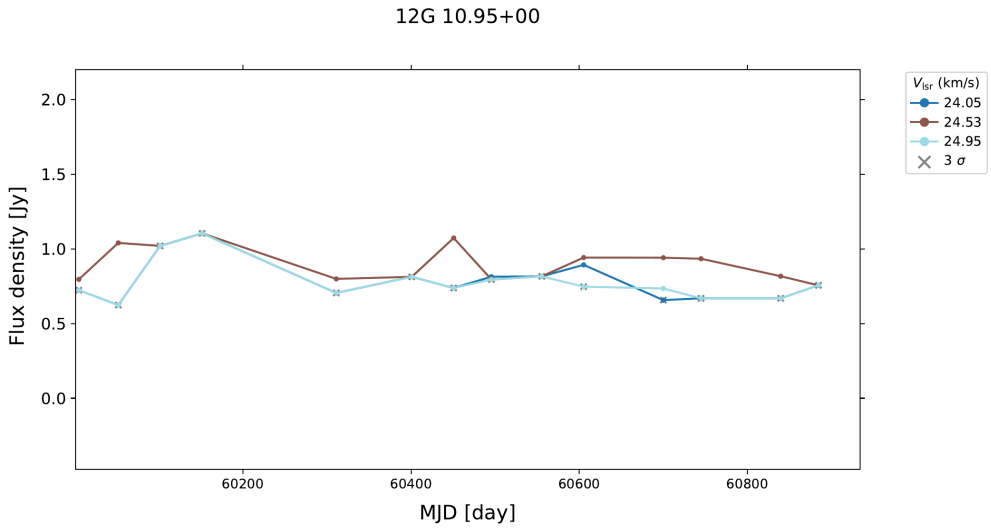


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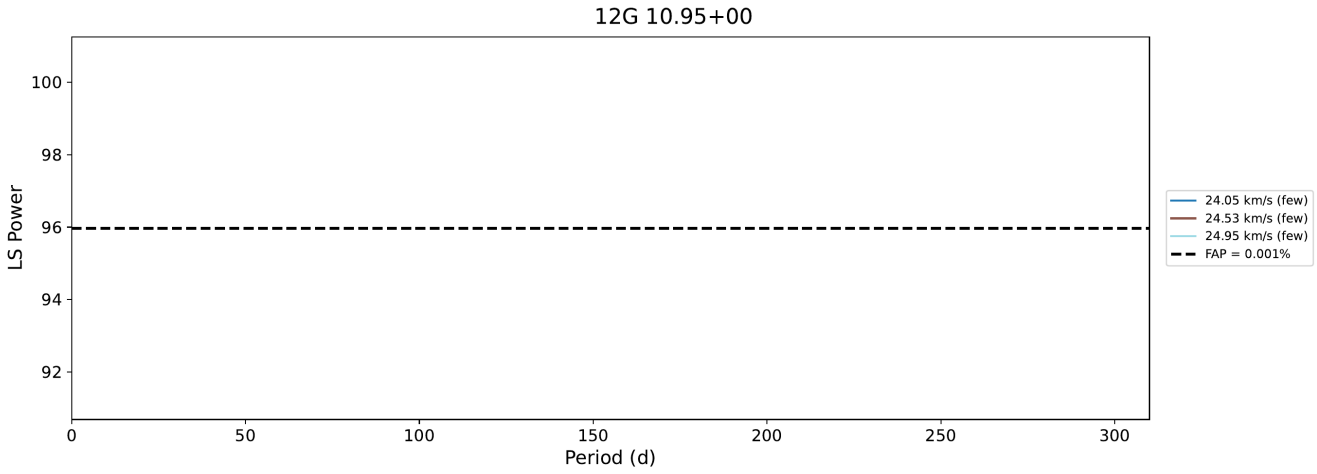


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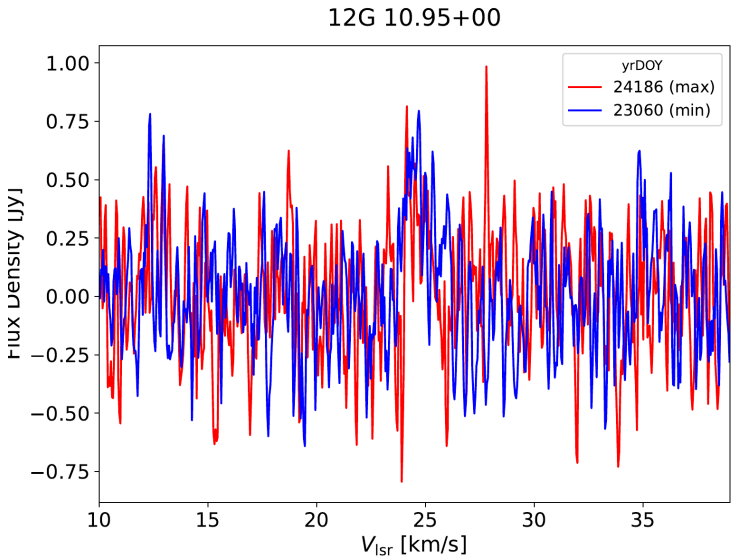
Light curve



Periodogram

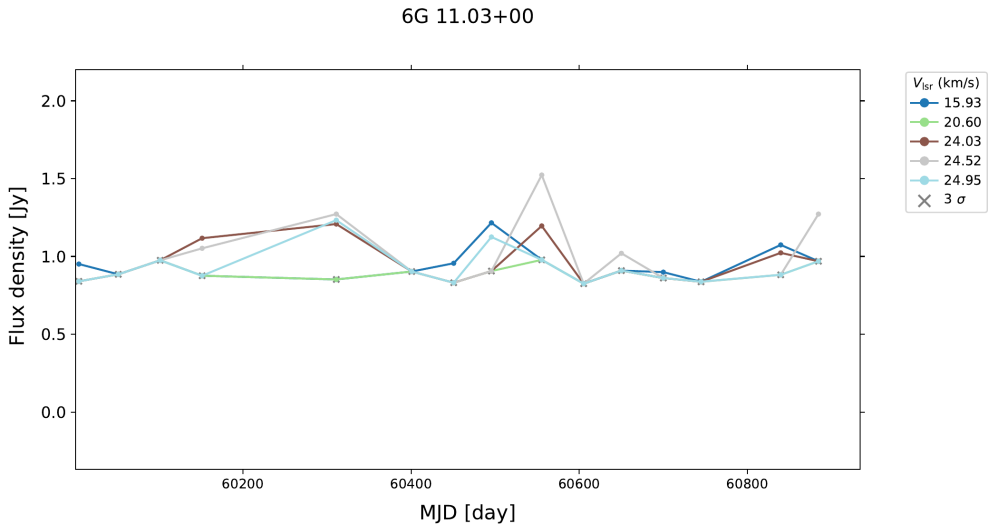


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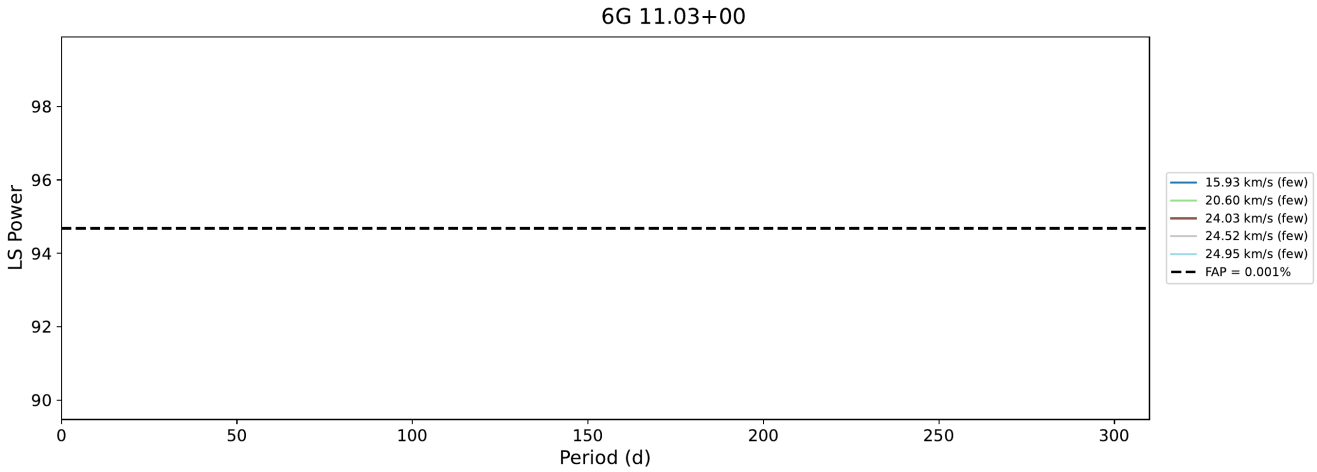


6G 11.03+00

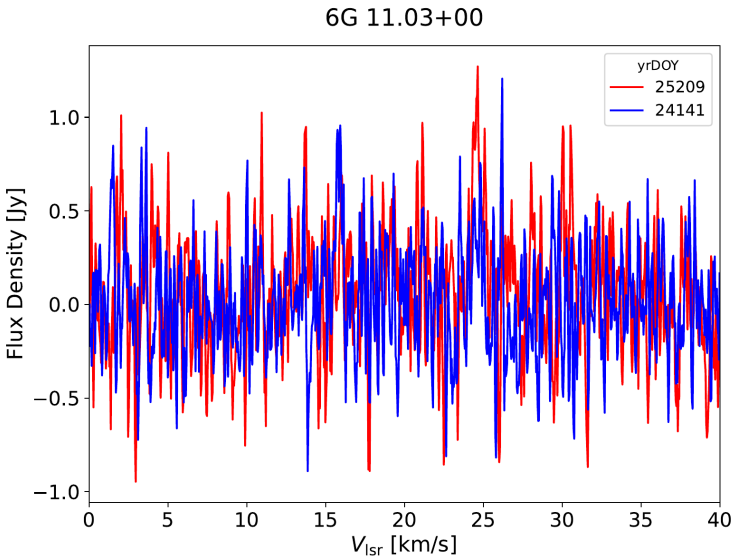
Light curve



Periodogram

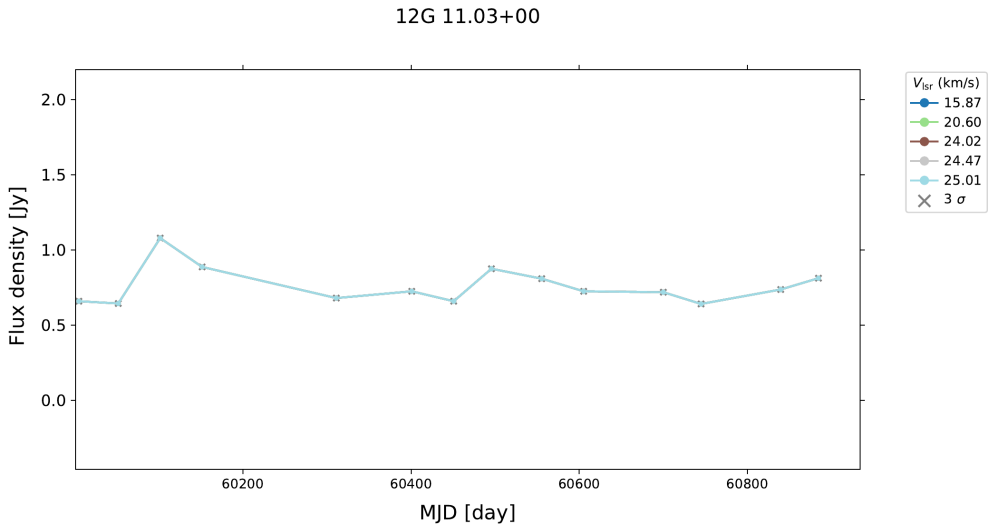


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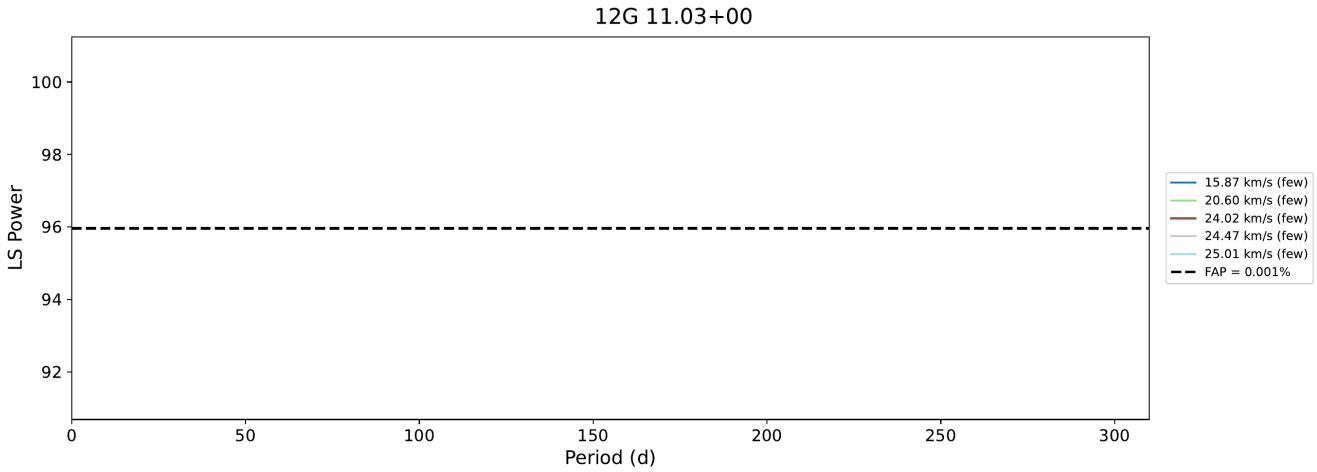


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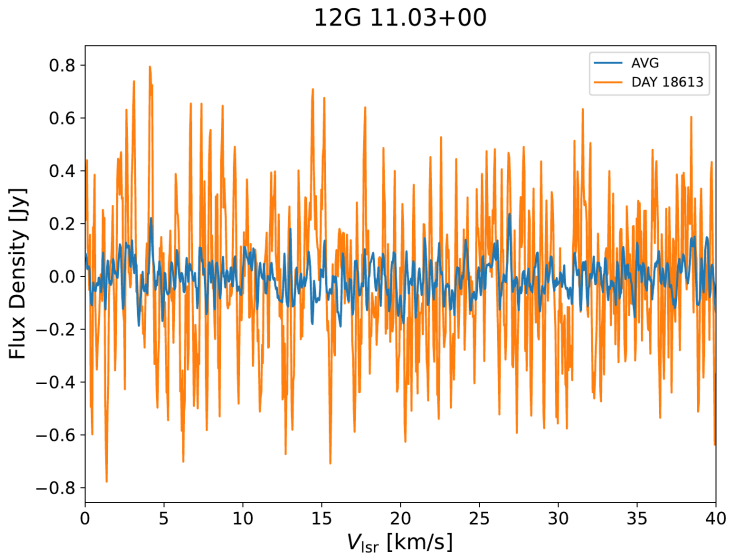
Light curve



Periodogram

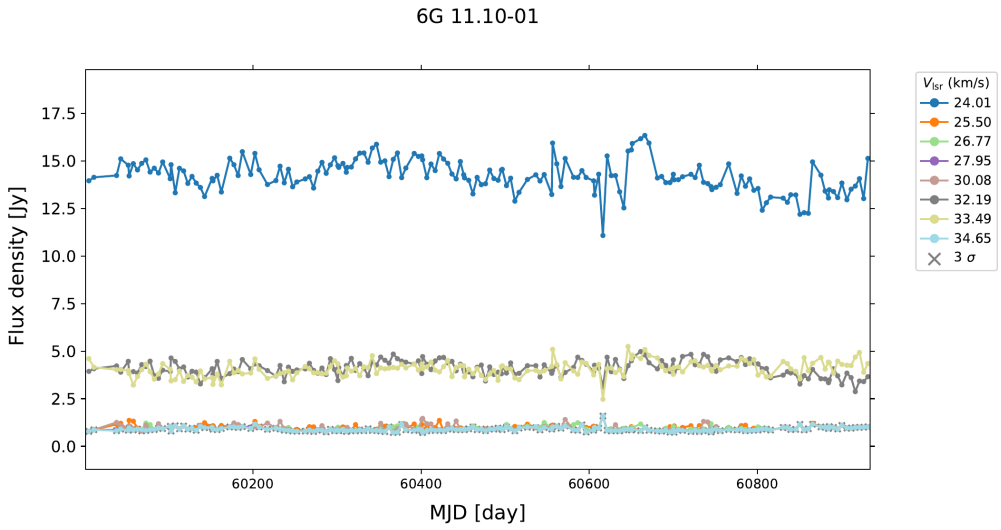


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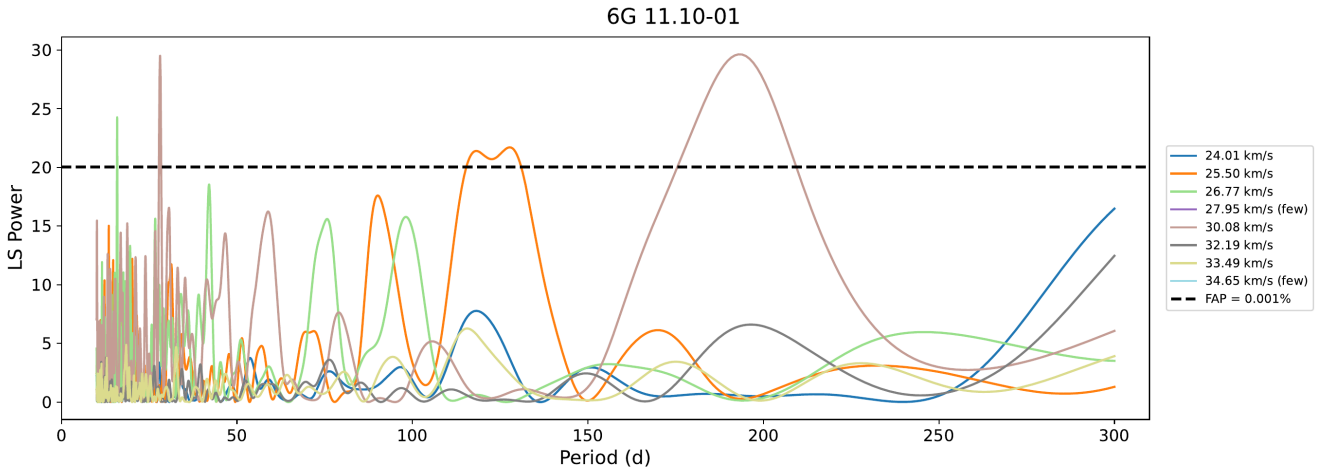


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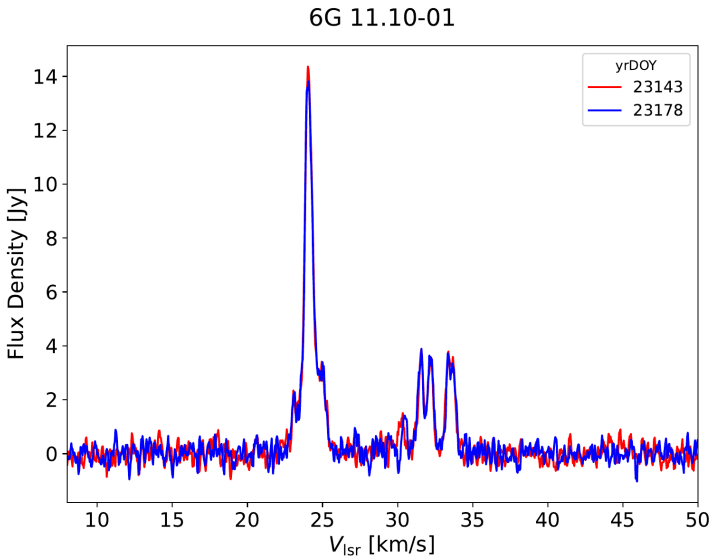
Light curve



Periodogram

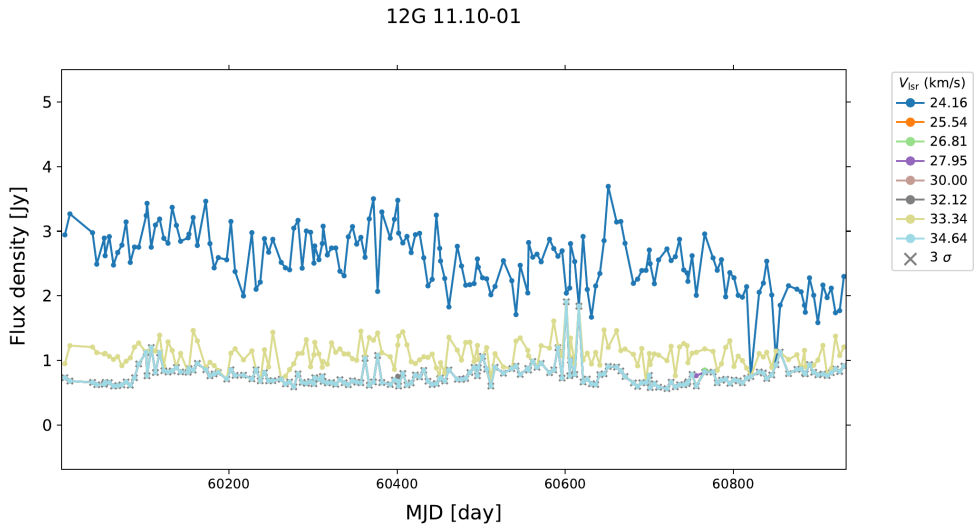


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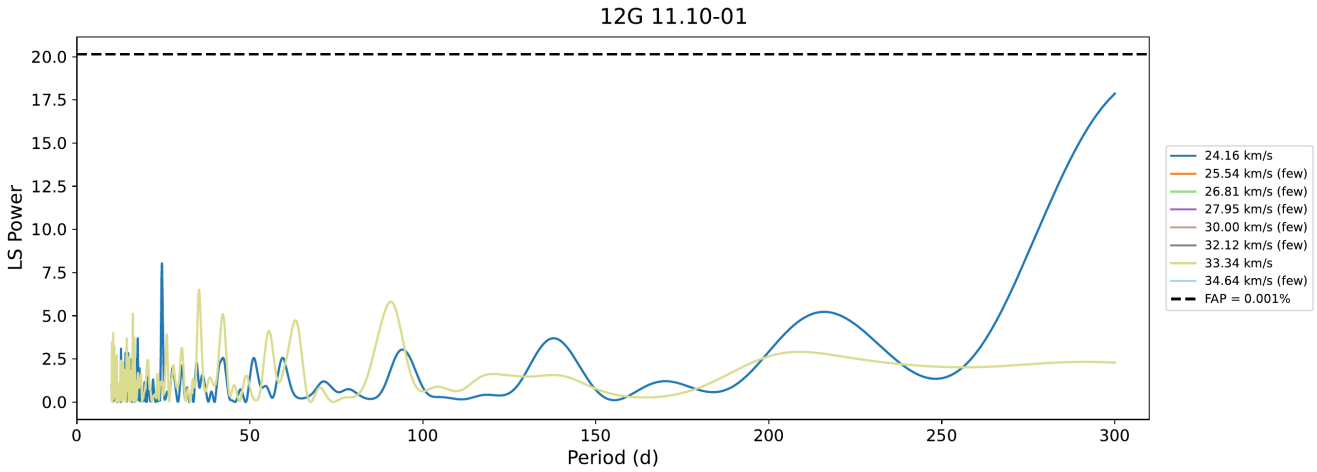


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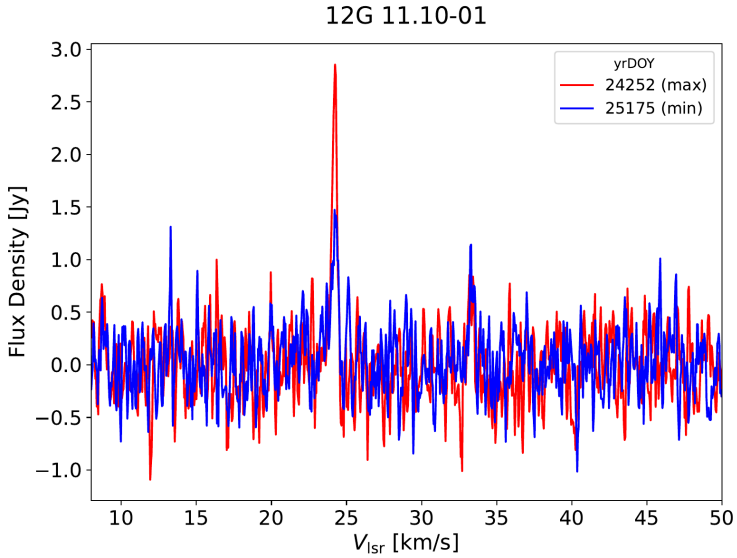
Light curve



Periodogram

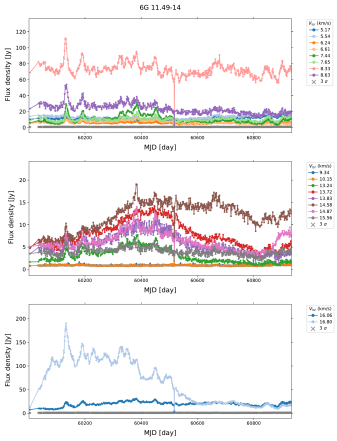


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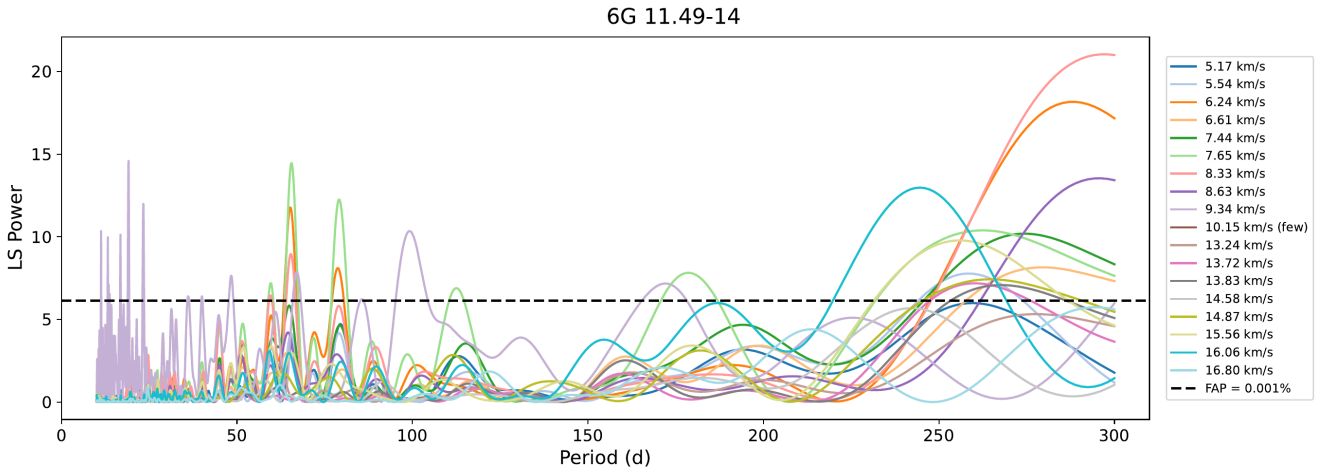


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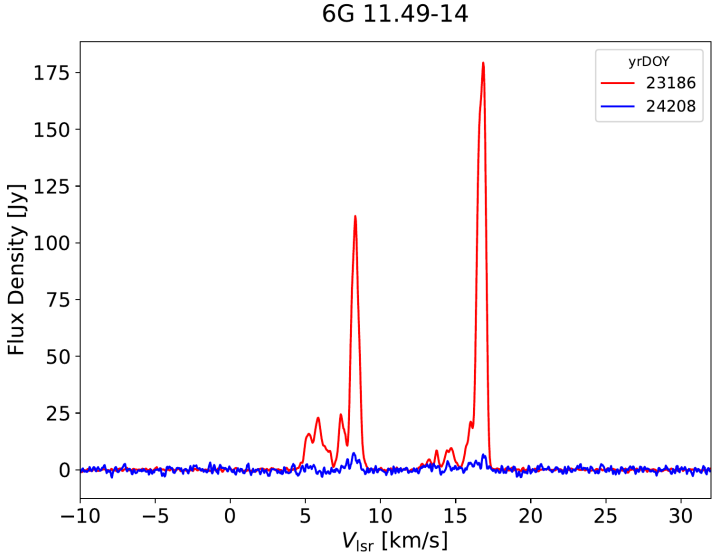
Light curve



Periodogram

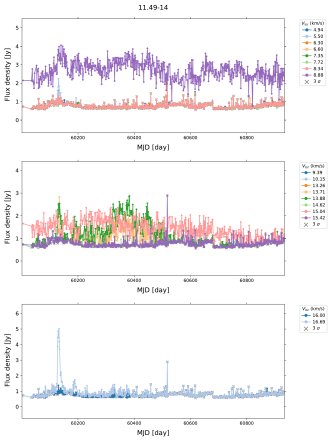


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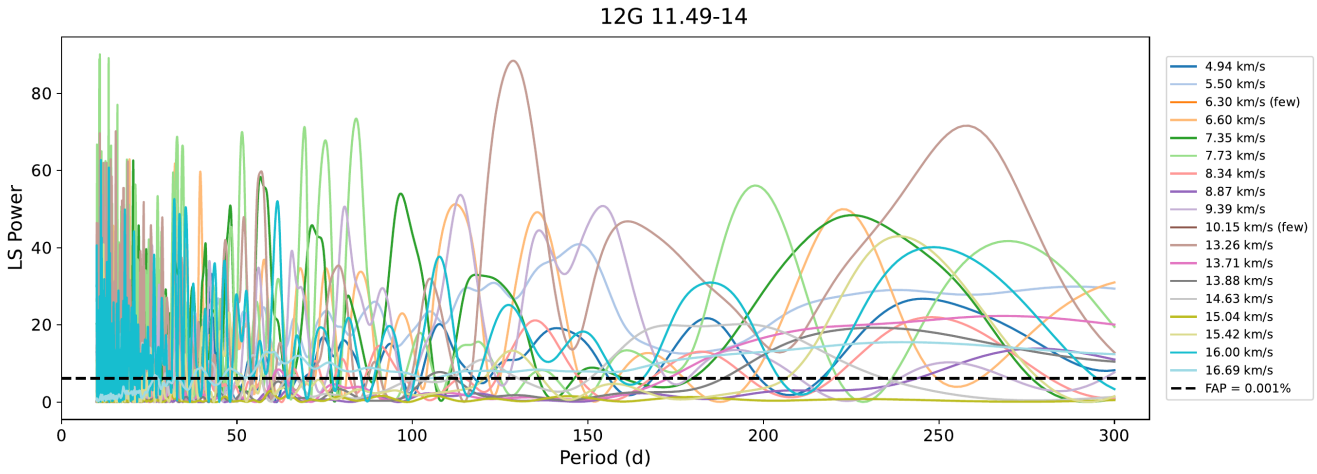


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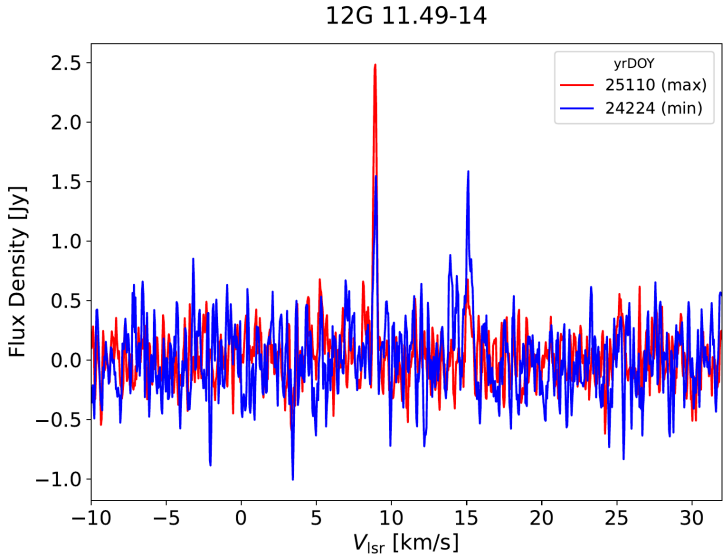
Light curve



Periodogram

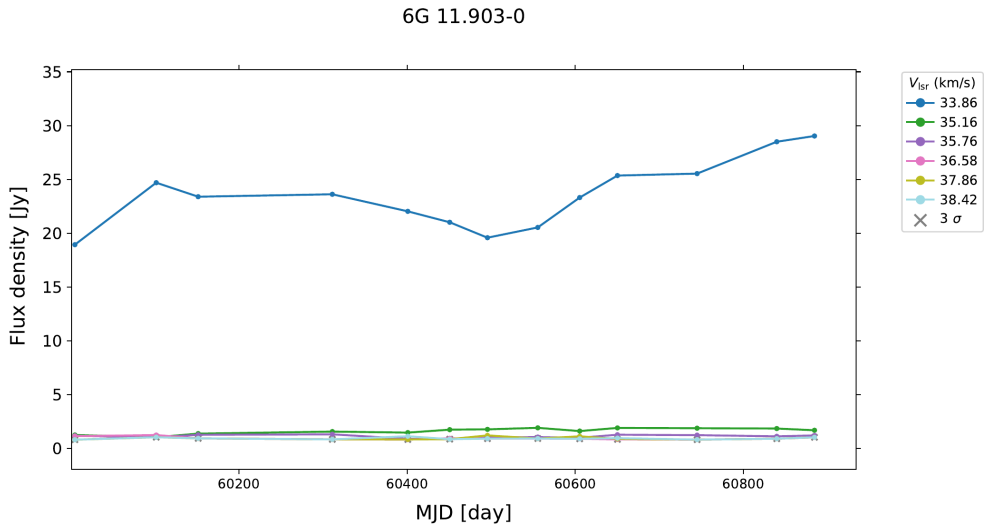


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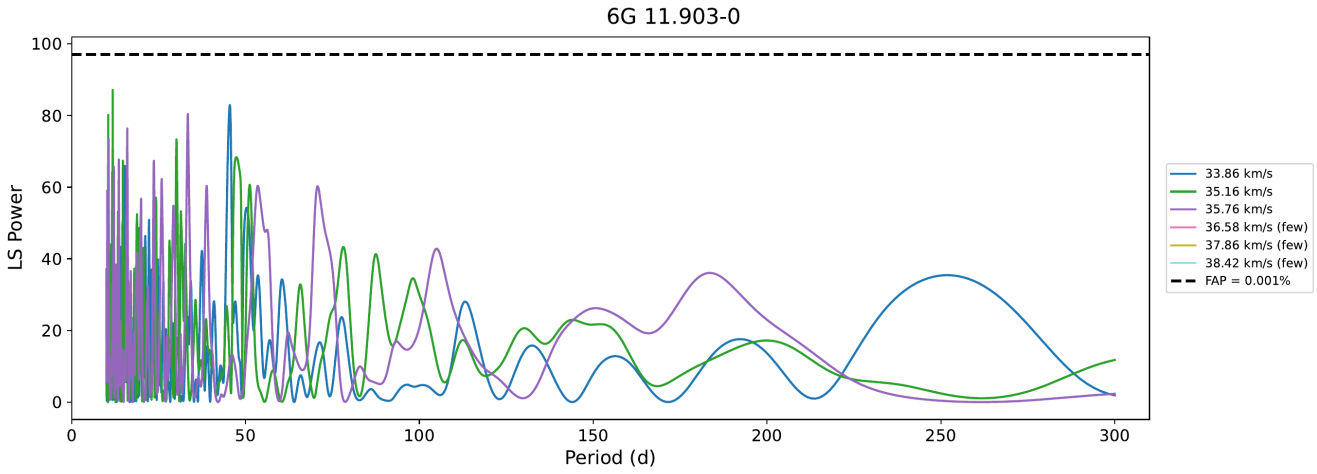


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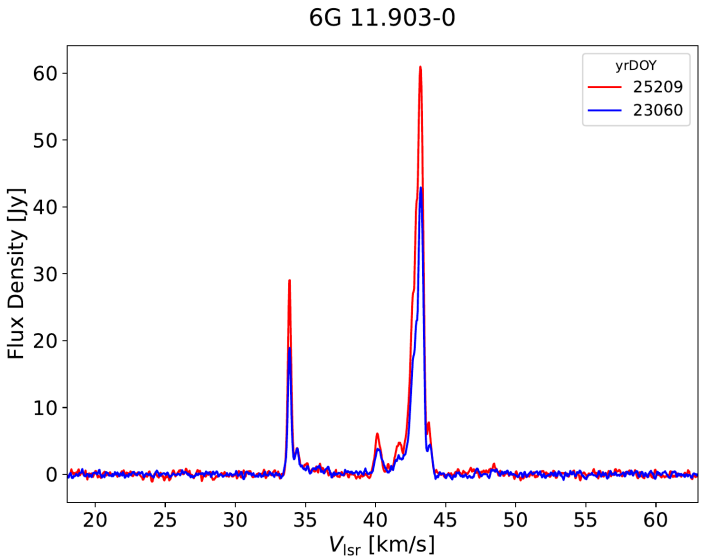
Light curve



Periodogram

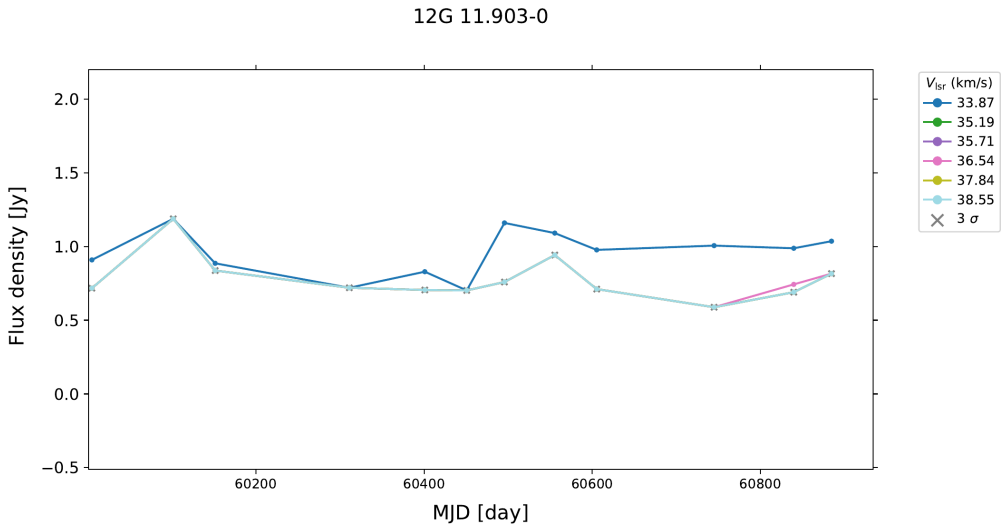


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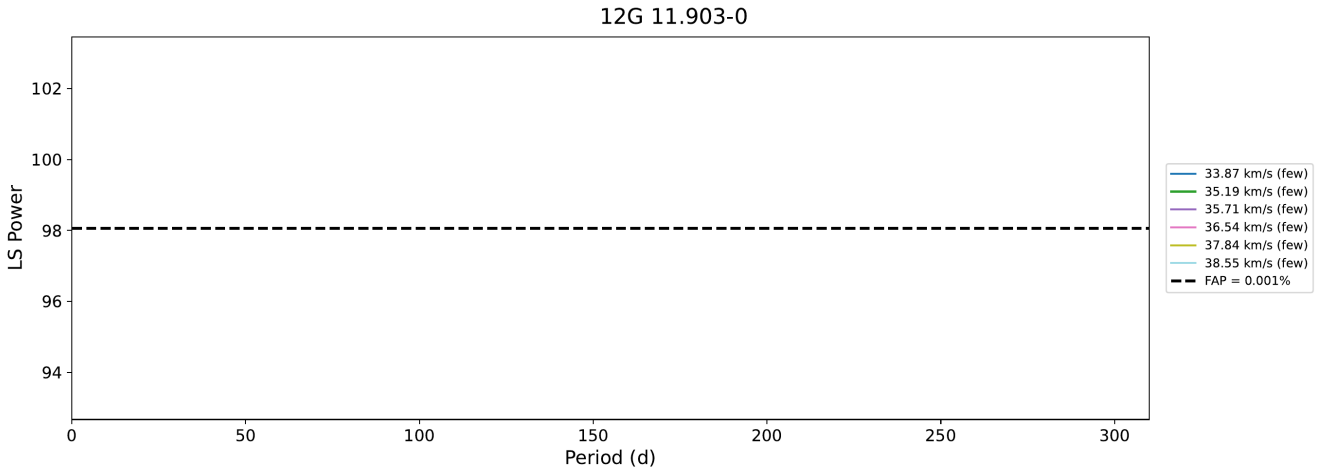


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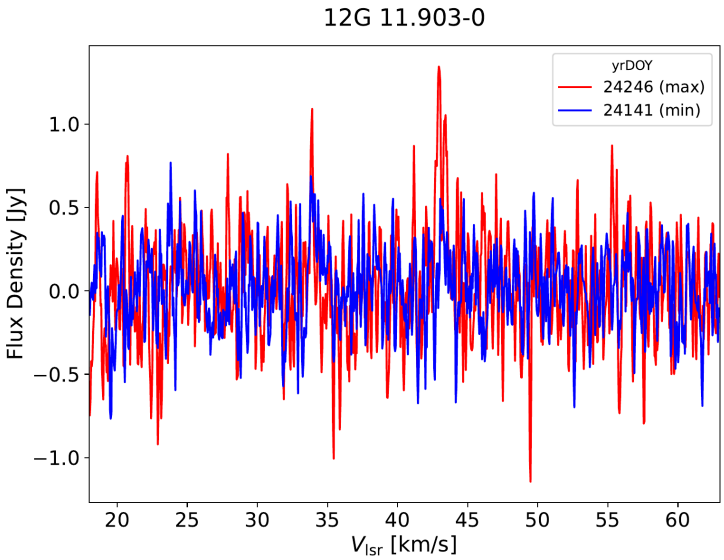
Light curve



Periodogram

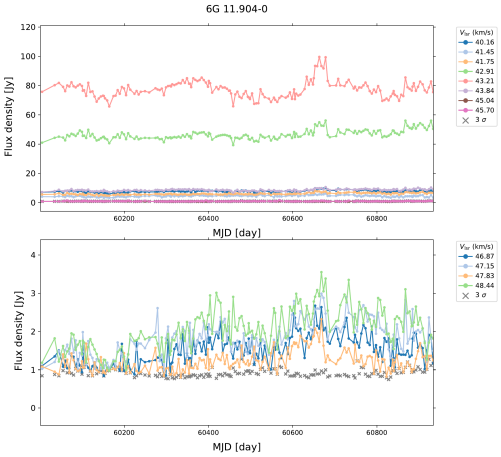


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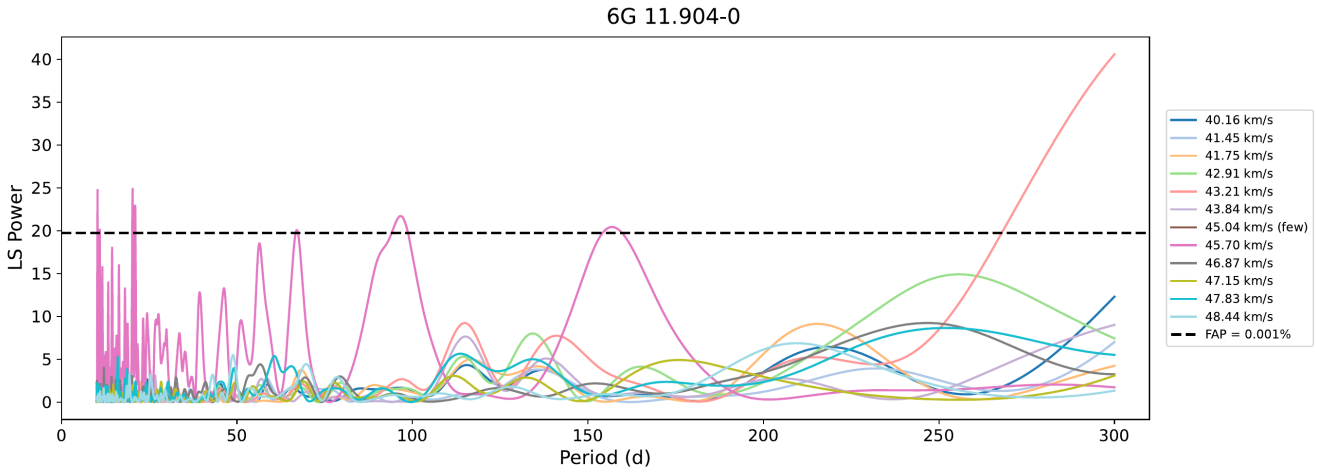


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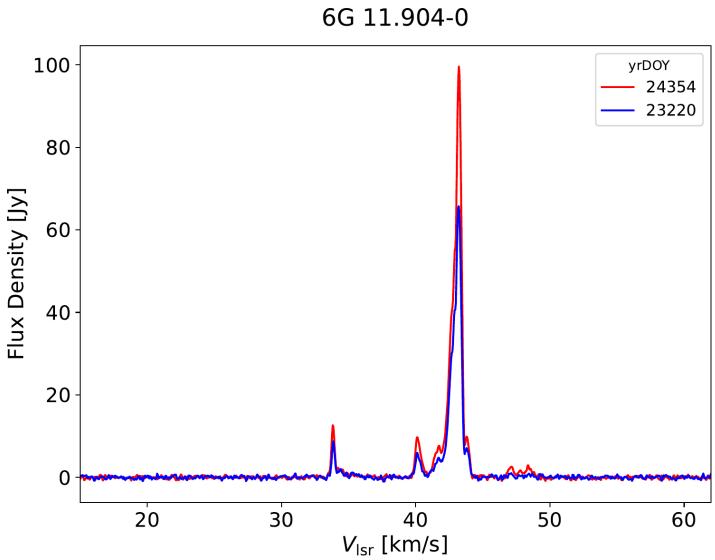
Light curve



Periodogram

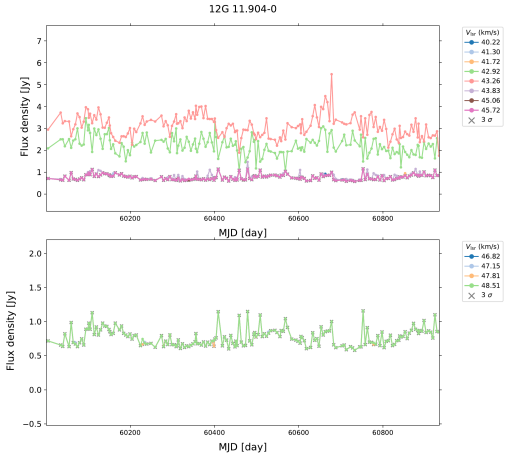


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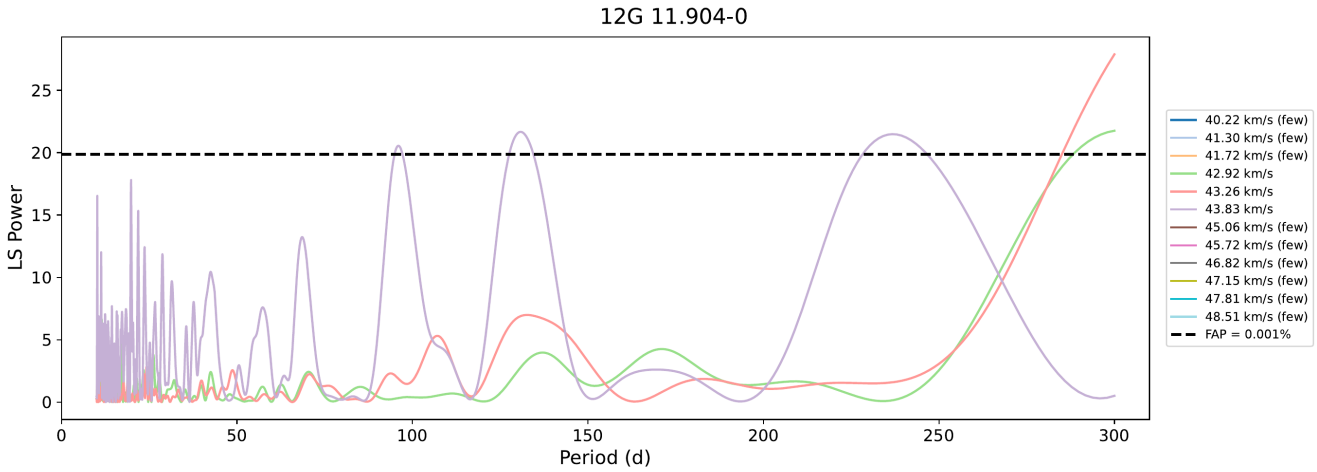


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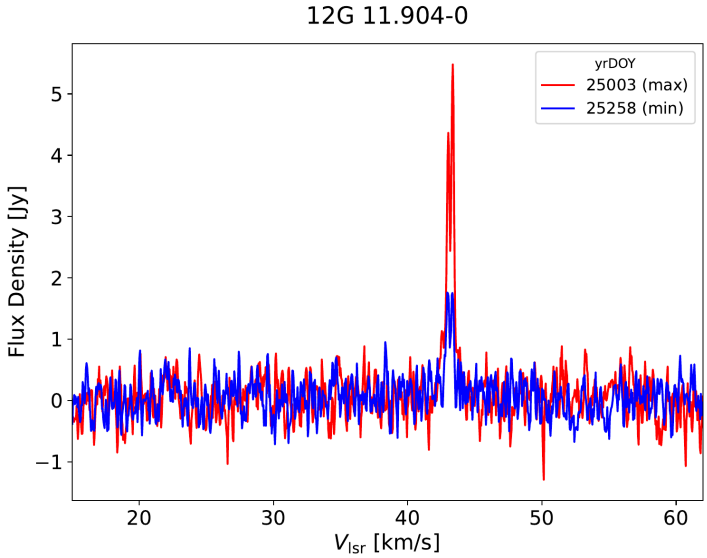
Light curve



Periodogram

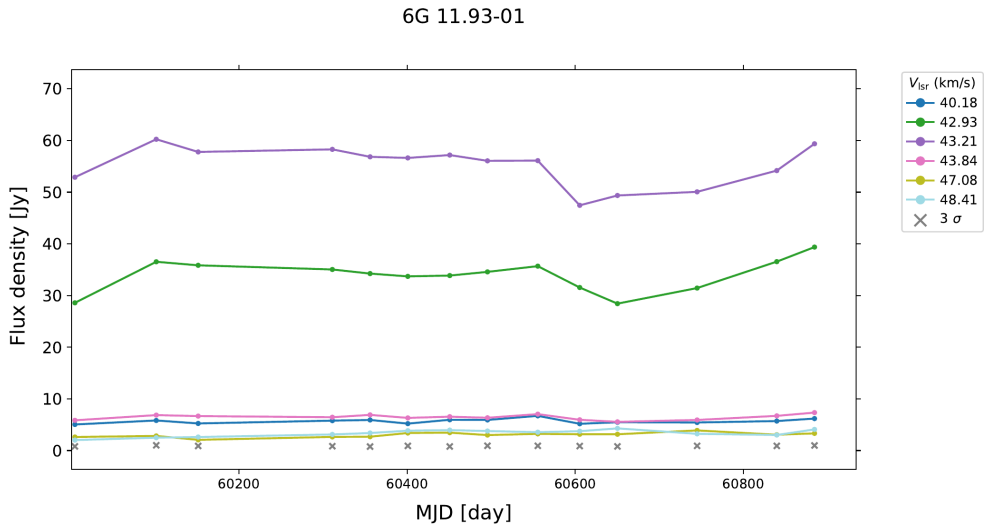


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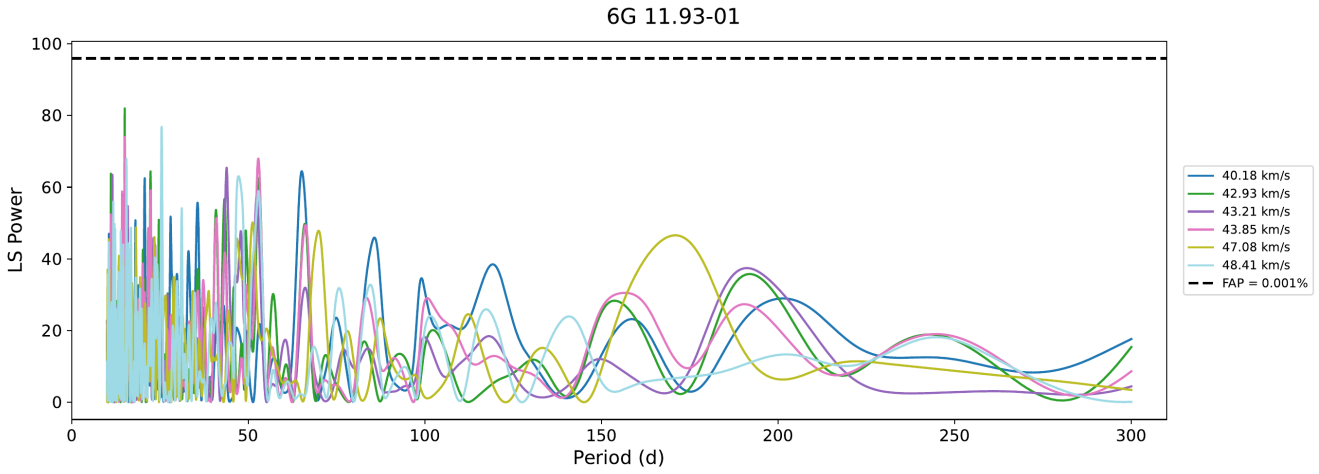


6G 11.93-01

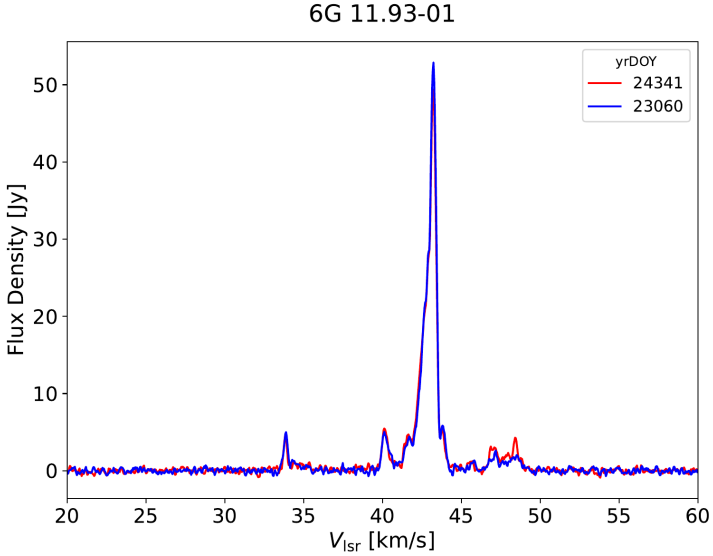
Light curve



Periodogram

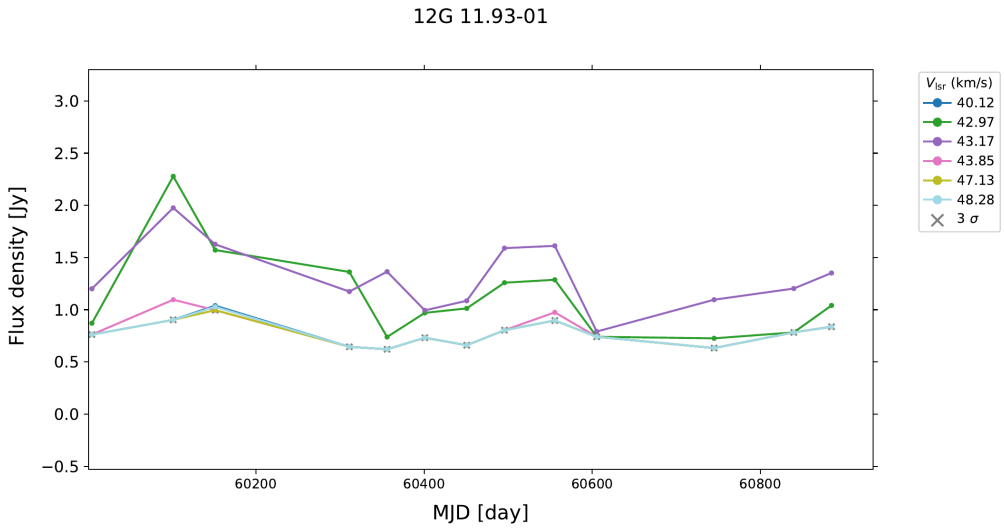


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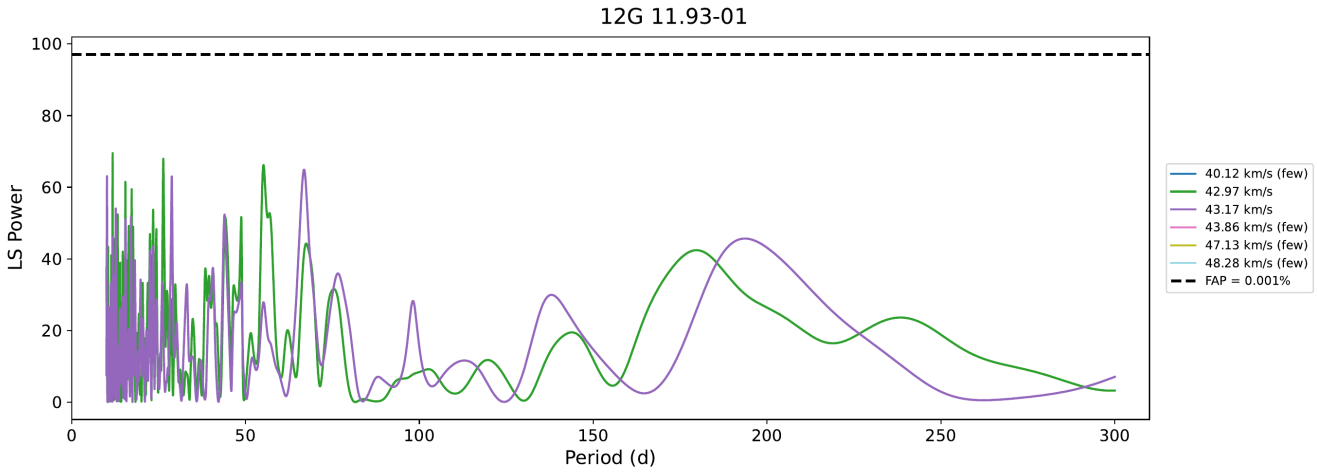


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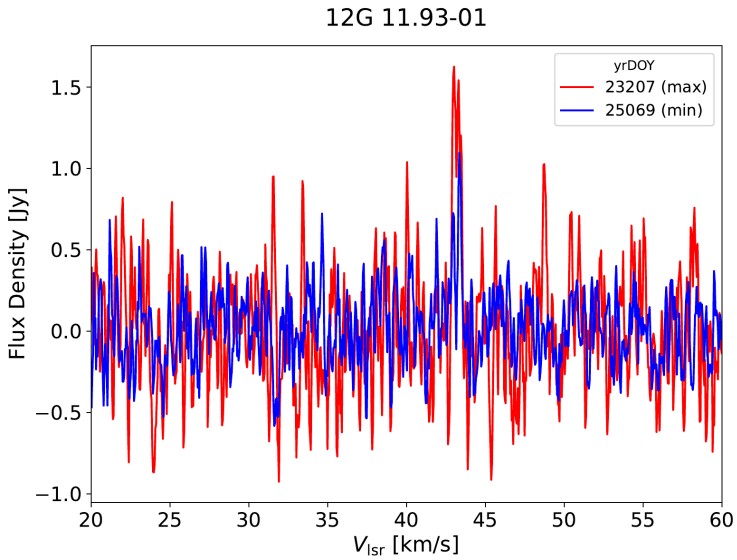
Light curve



Periodogram

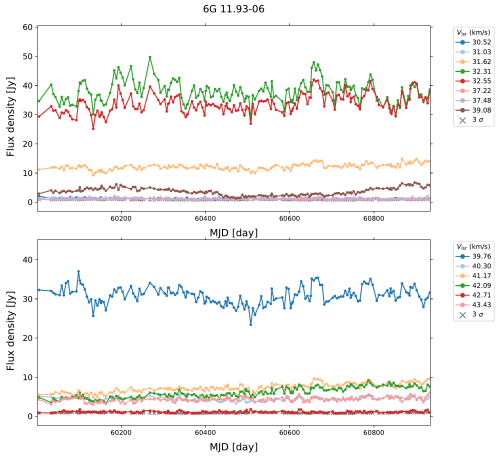


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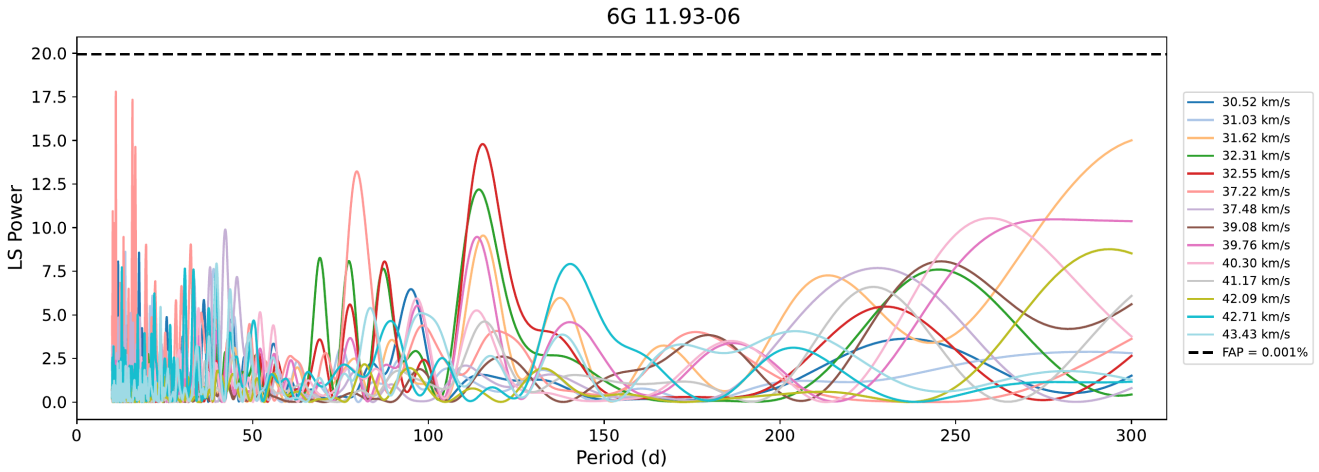


6G 11.93-06

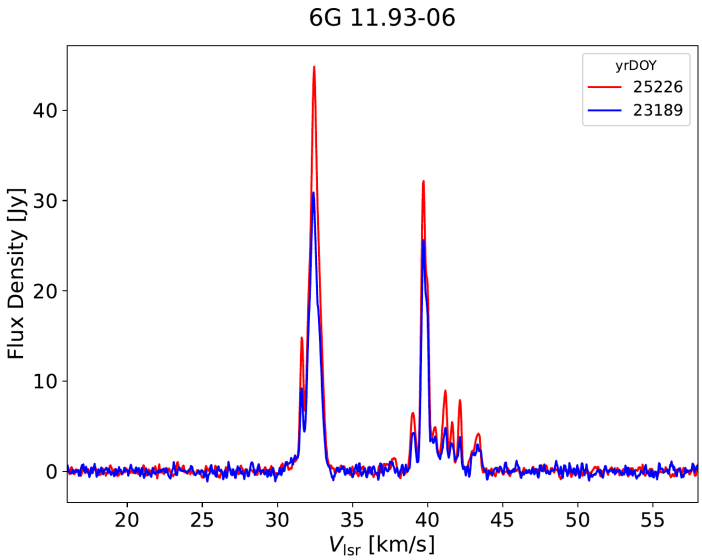
Light curve



Periodogram

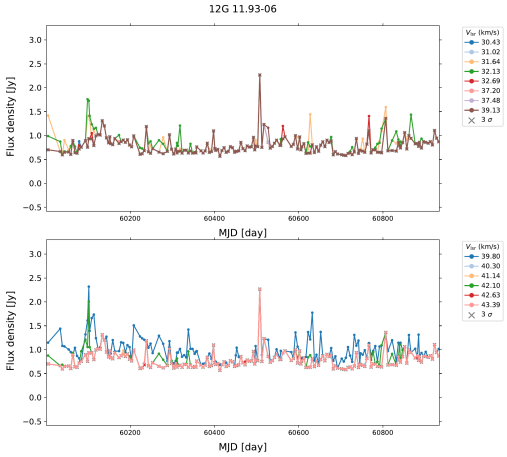


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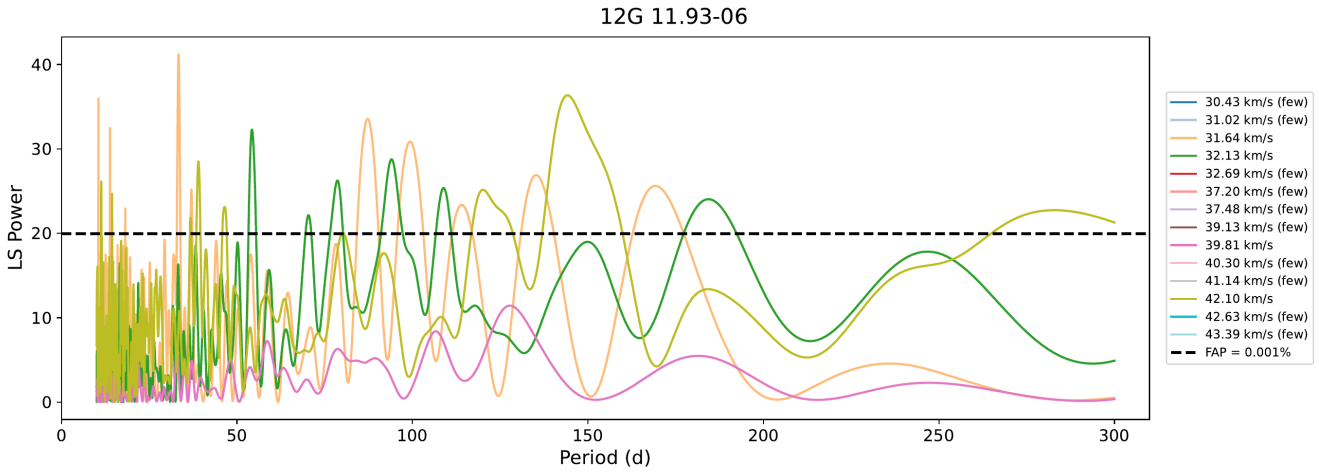


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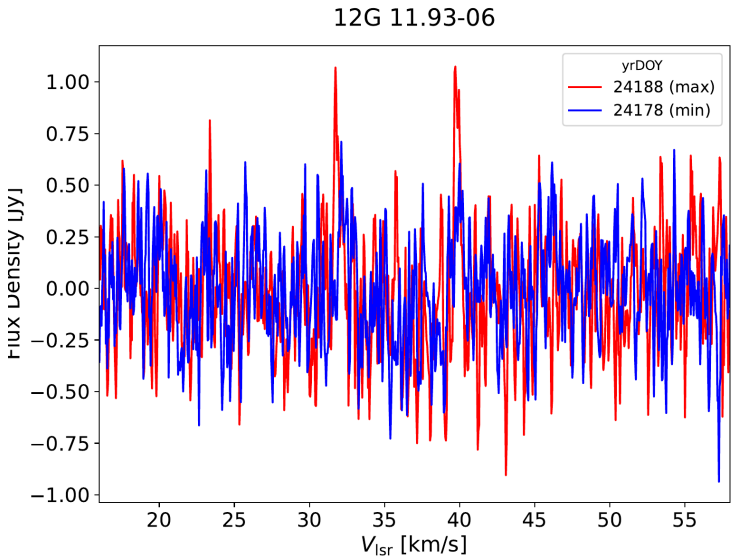
Light curve



Periodogram

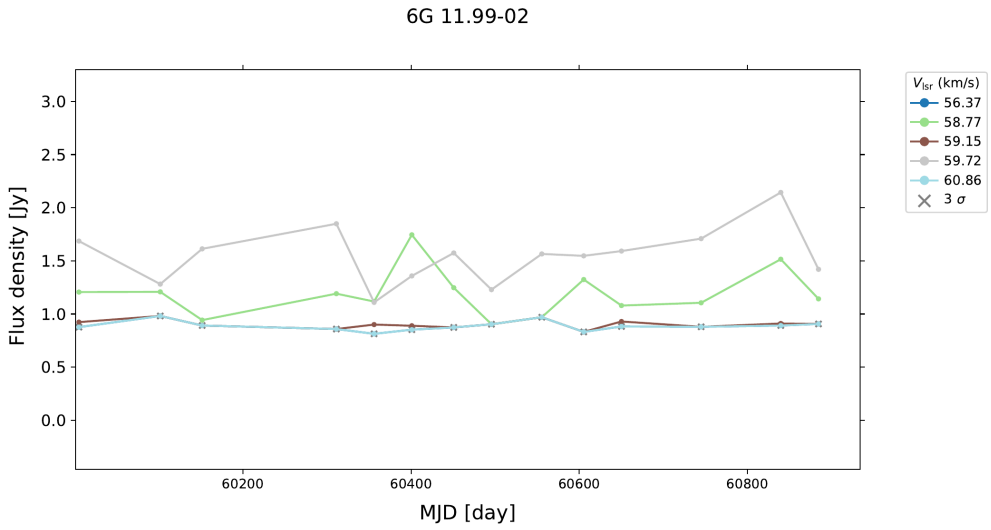


Spectrum

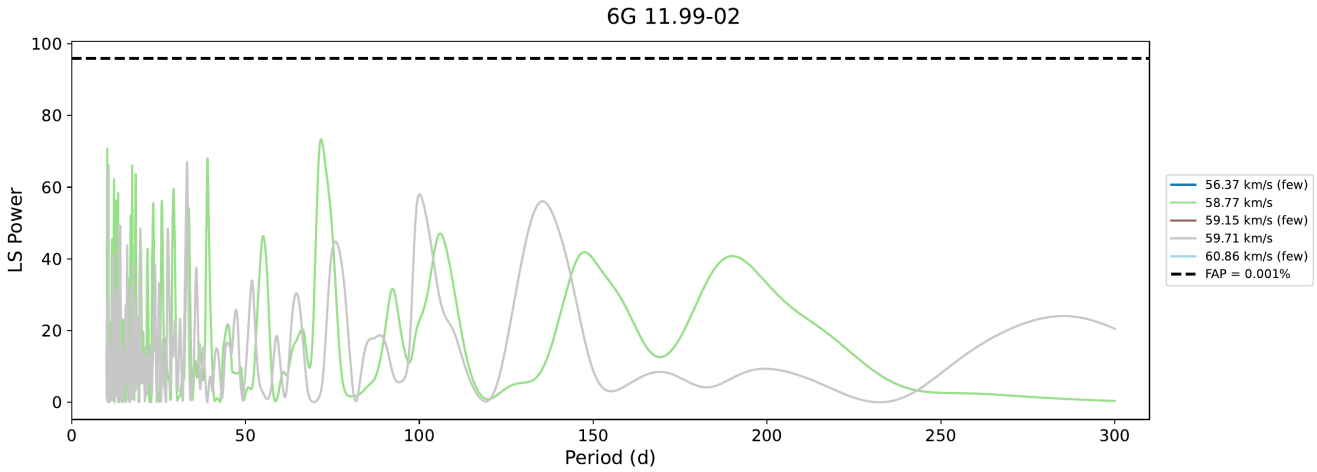


6G 11.99-02

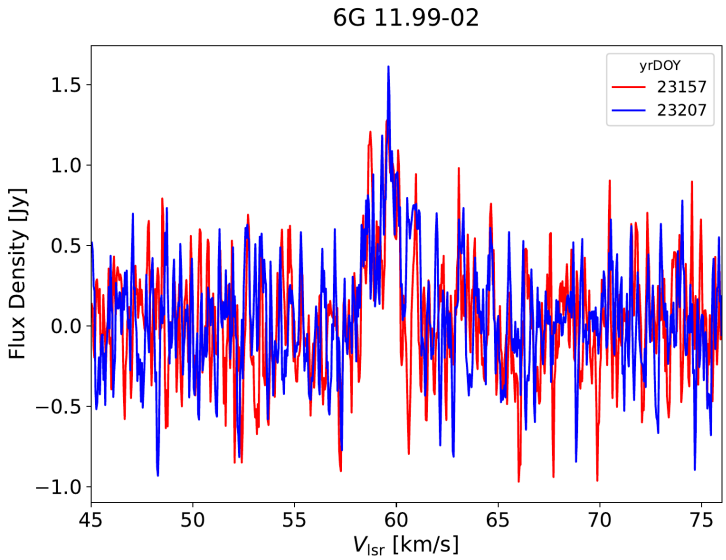
Light curve



Periodogram

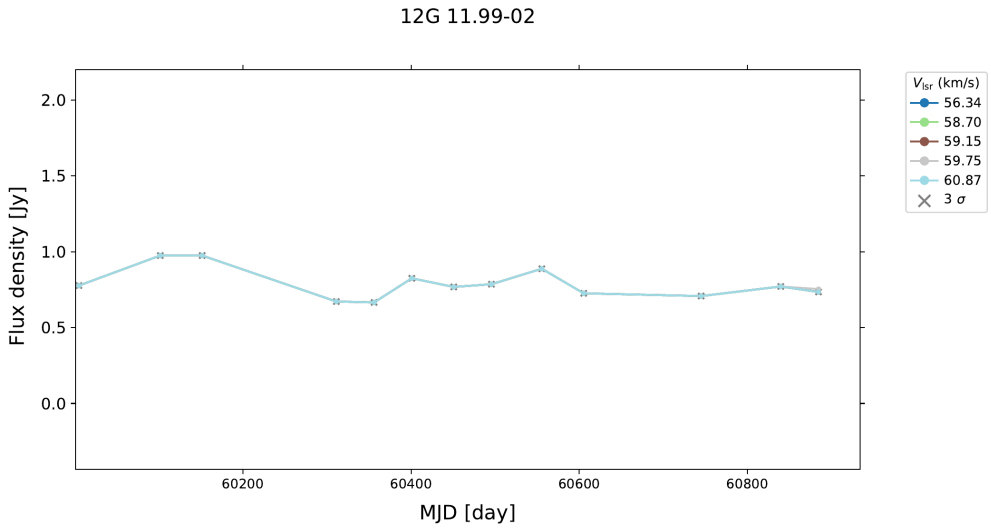


Spectrum

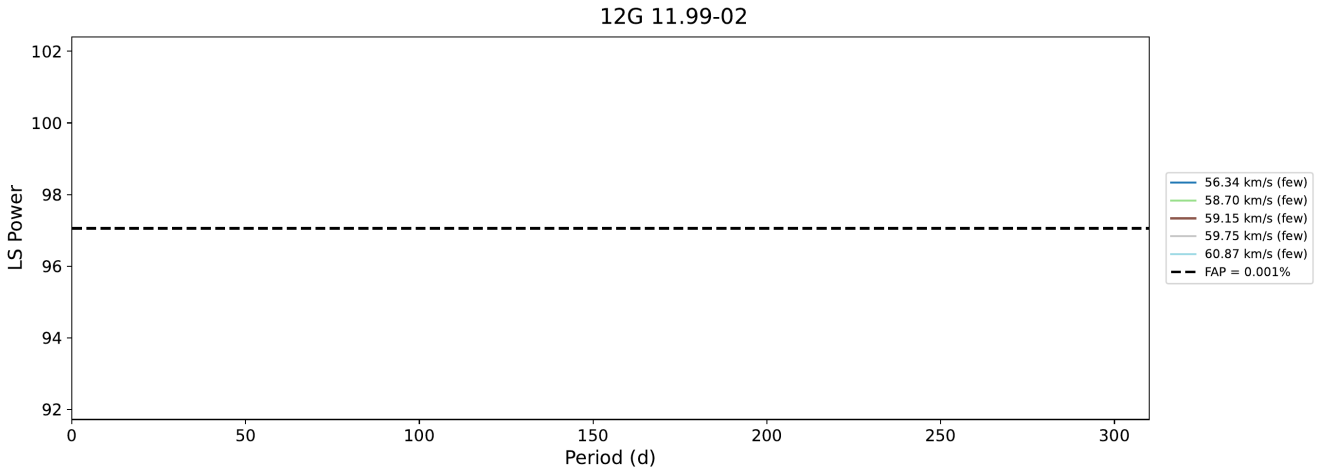


12G 11.99-02

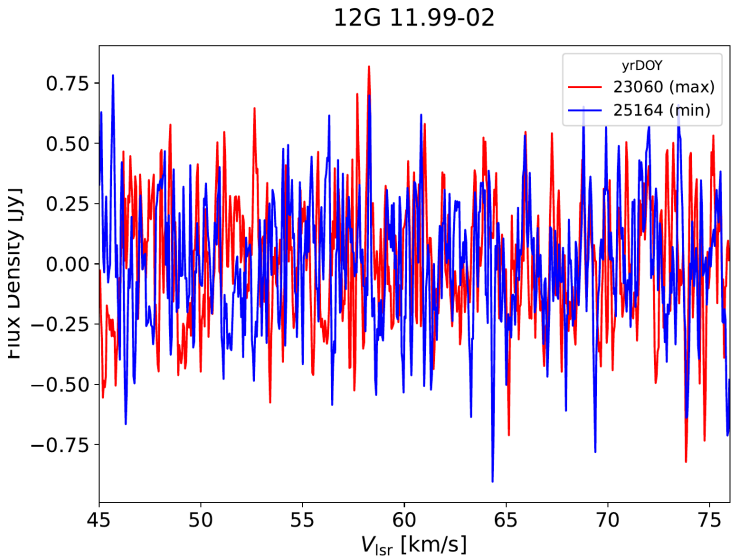
Light curve



Periodogram

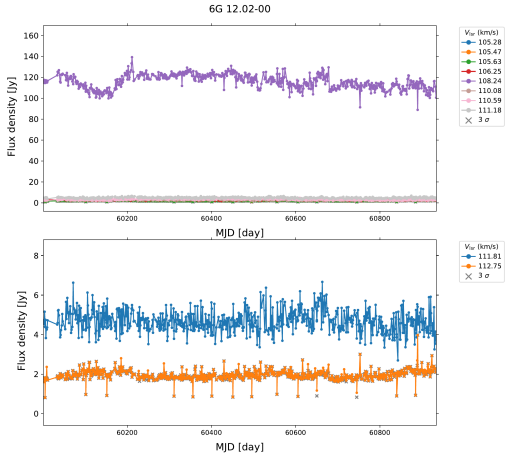


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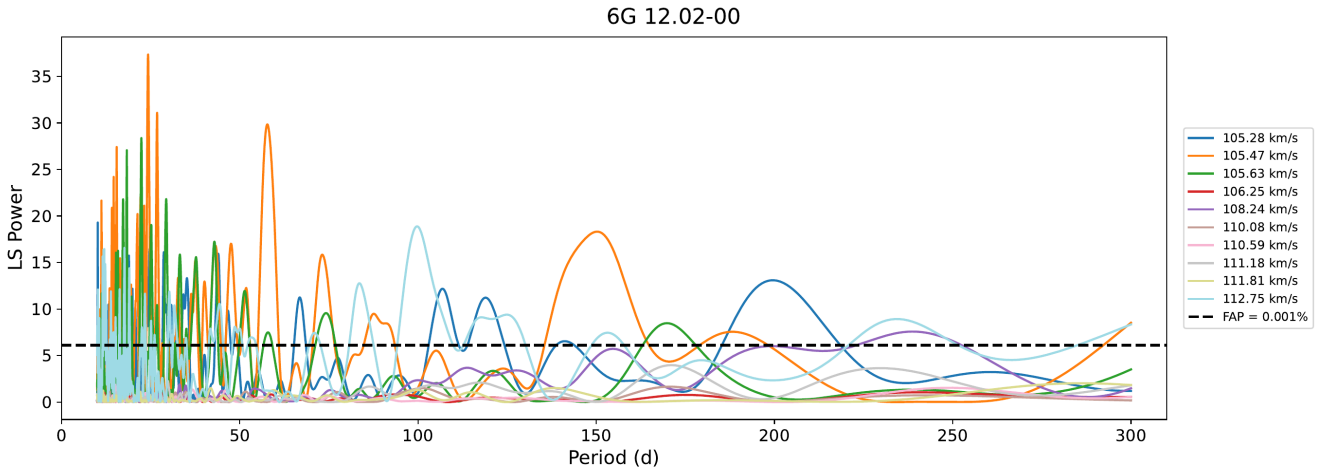


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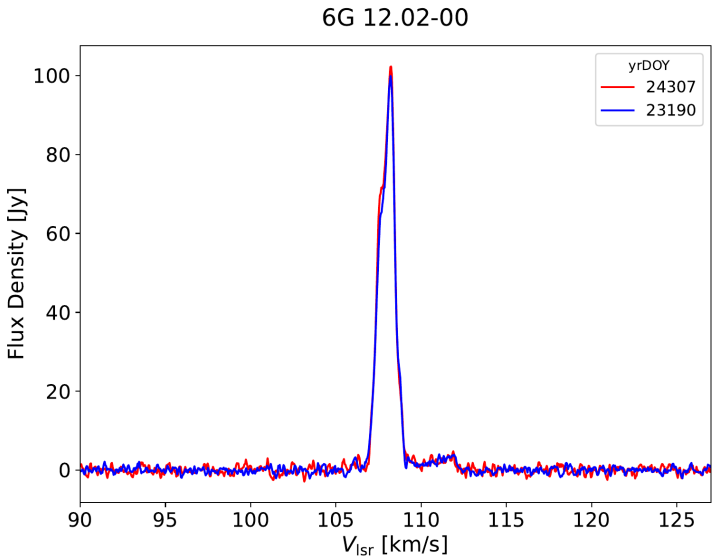
Light curve



Periodogram

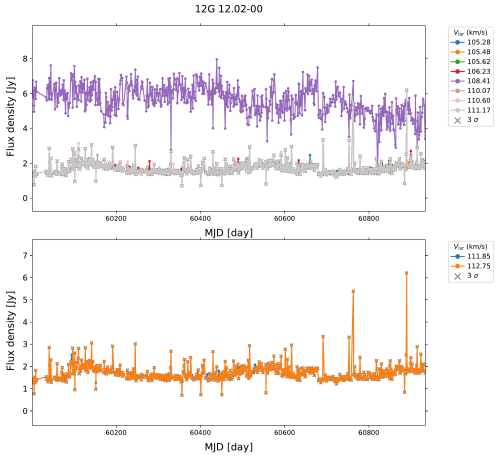


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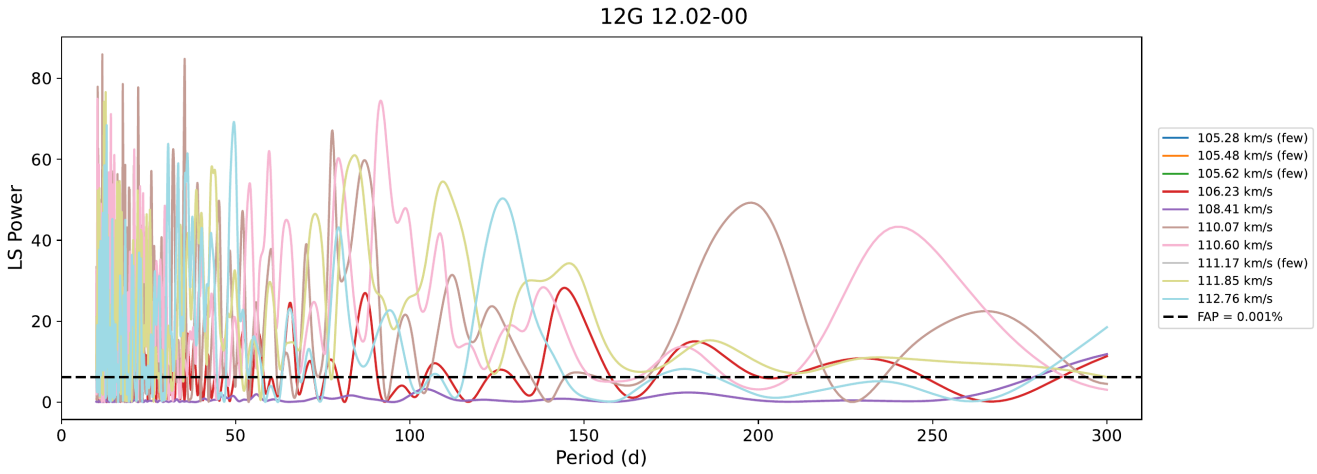


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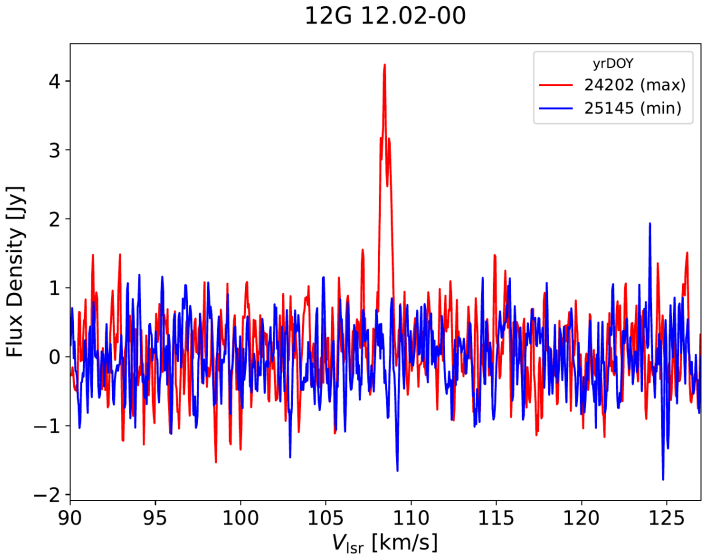
Light curve



Periodogram

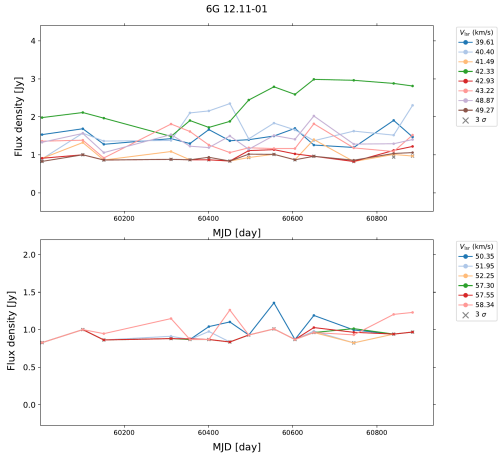


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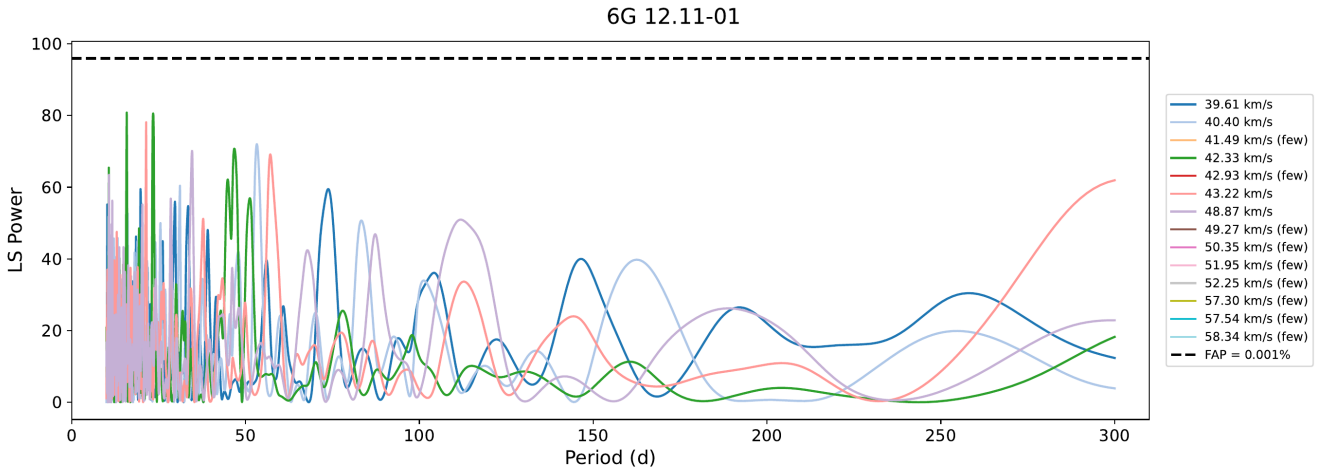


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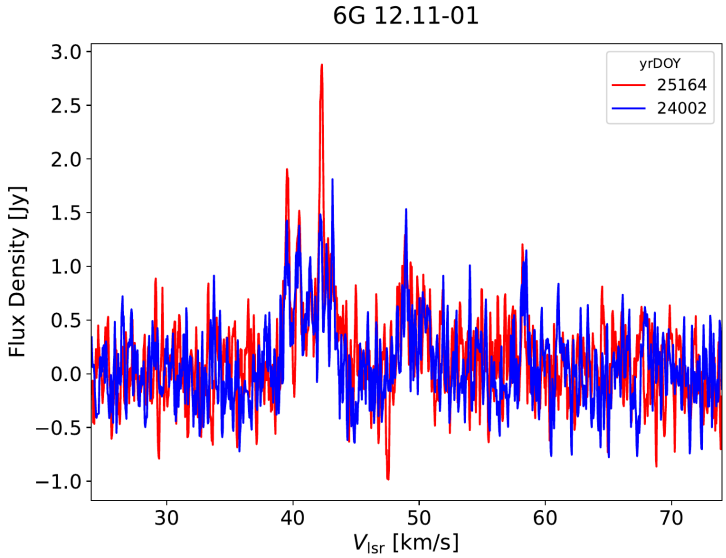
Light curve



Periodogram

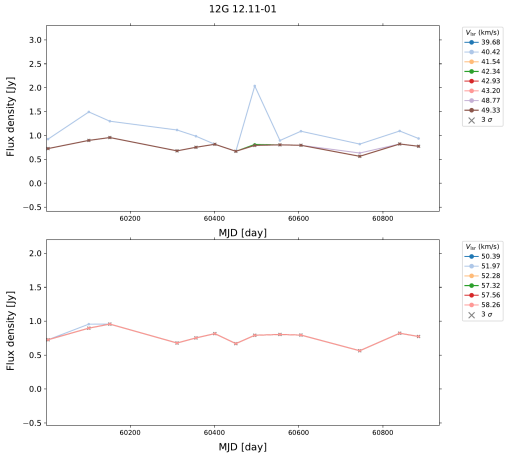


Spectrum

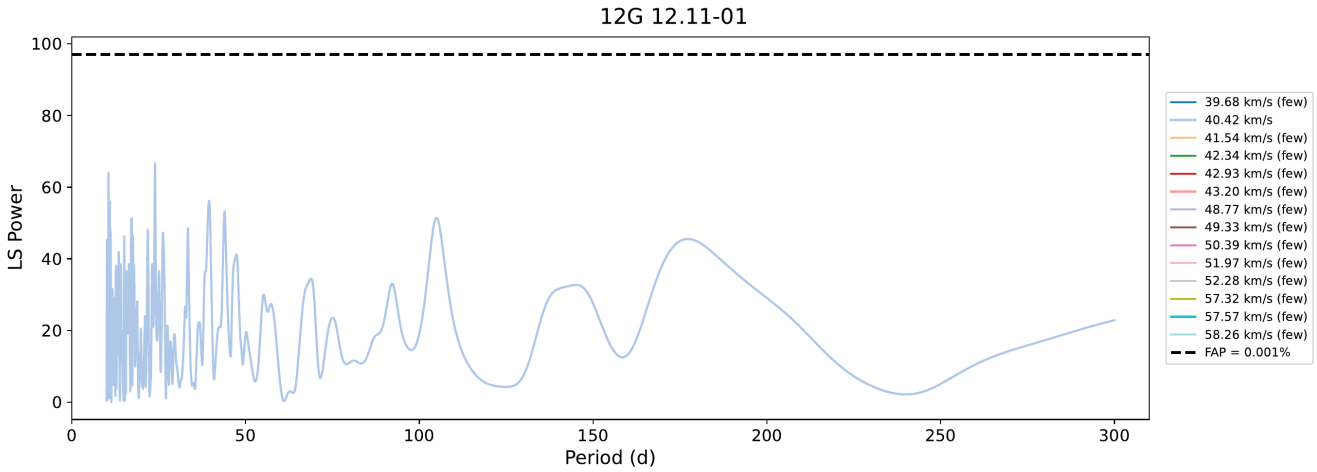


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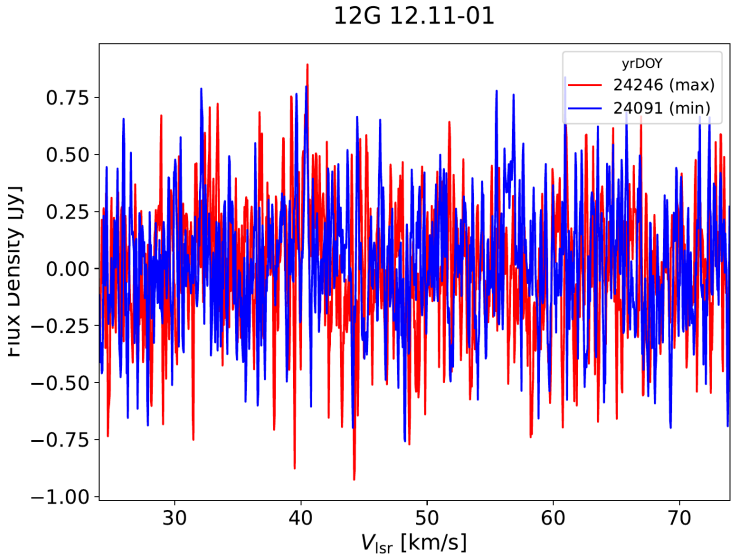
Light curve



Periodogram



Spectrum

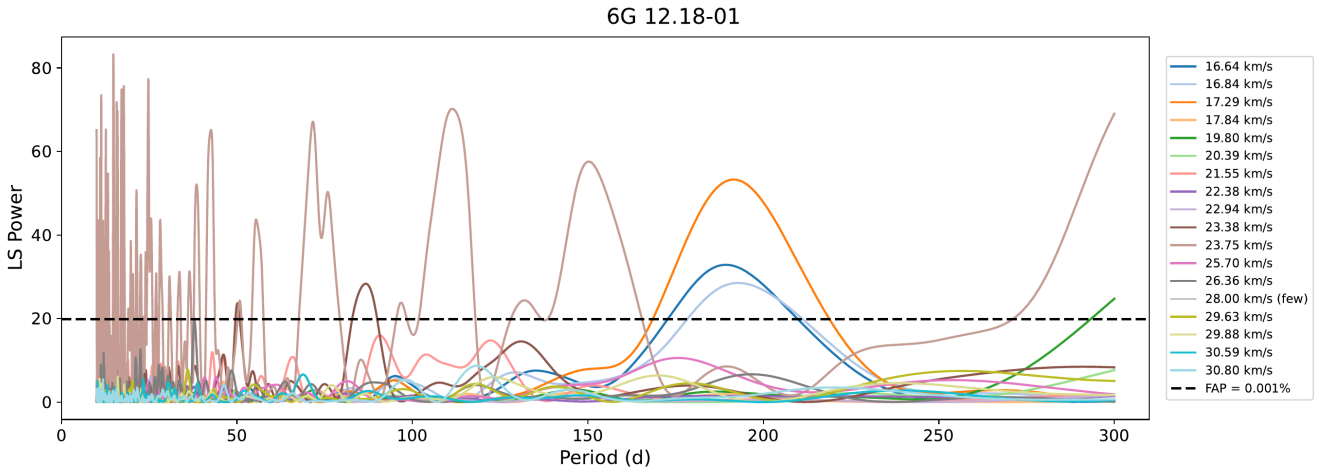


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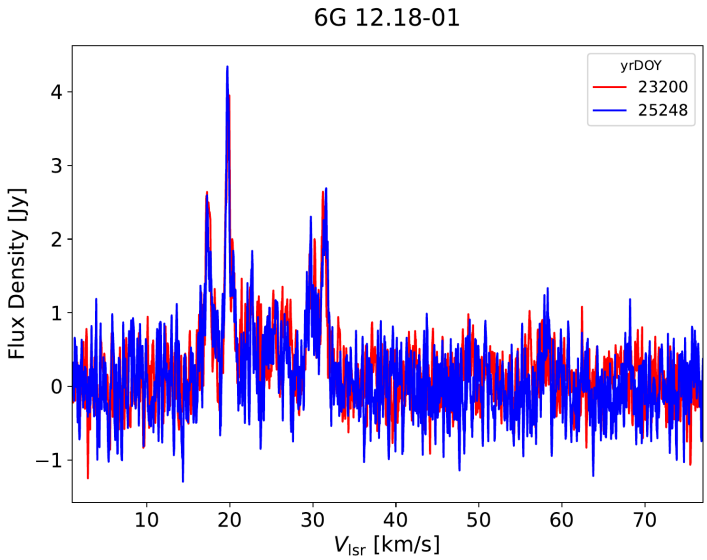
Light curve



Periodogram

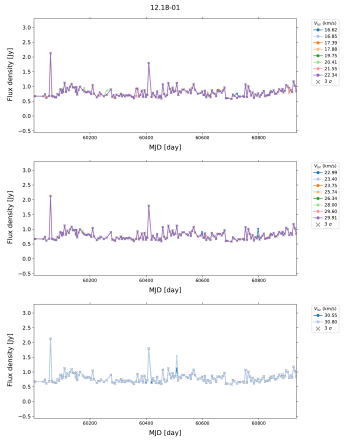


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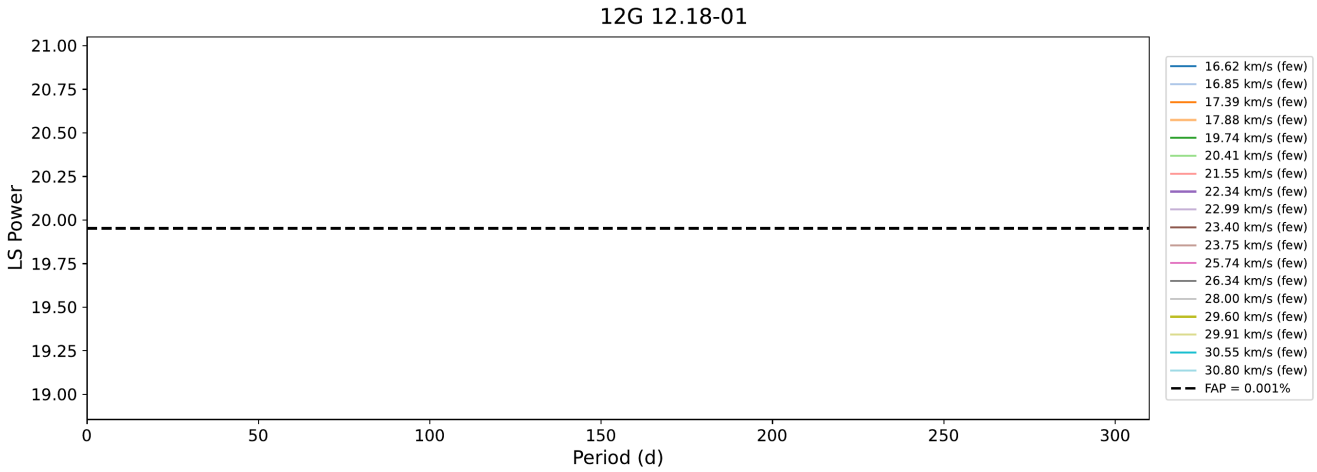


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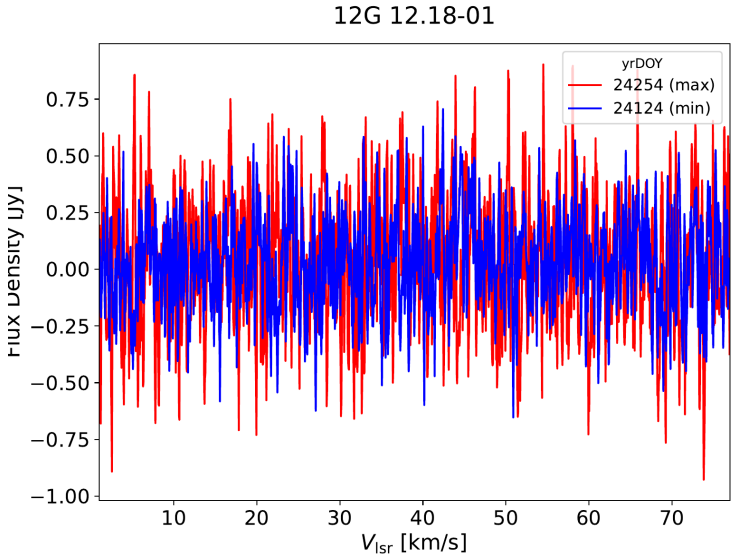
Light curve



Periodogram

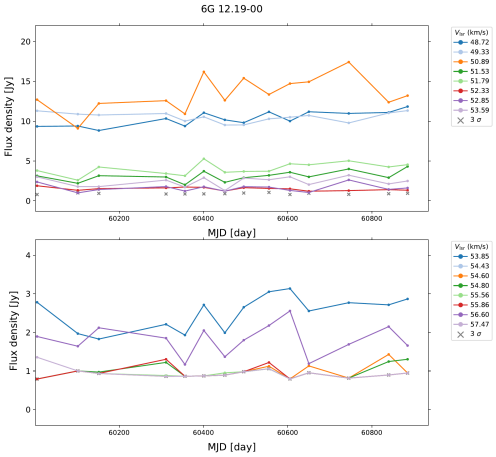


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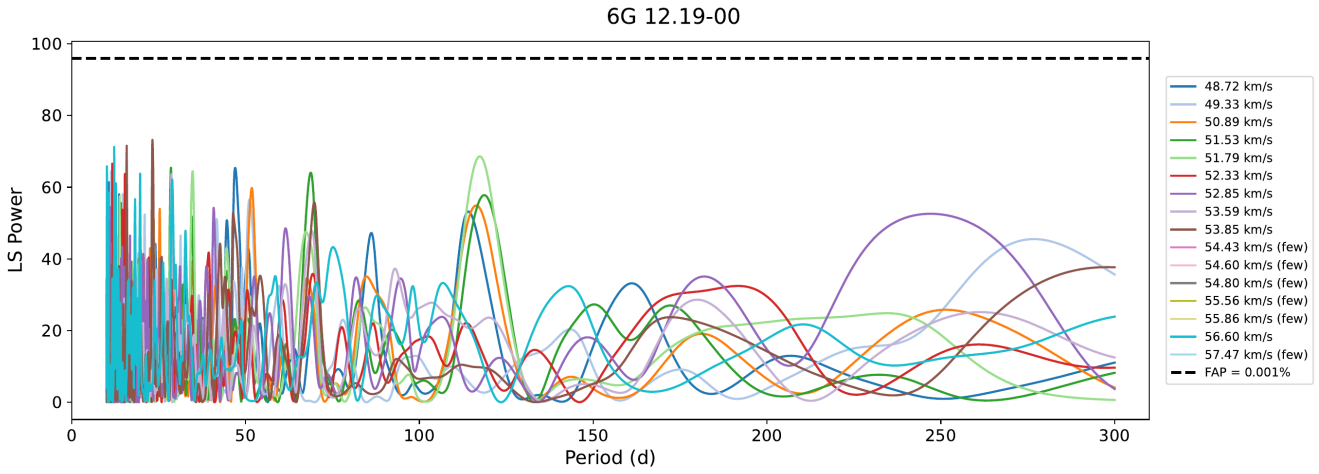


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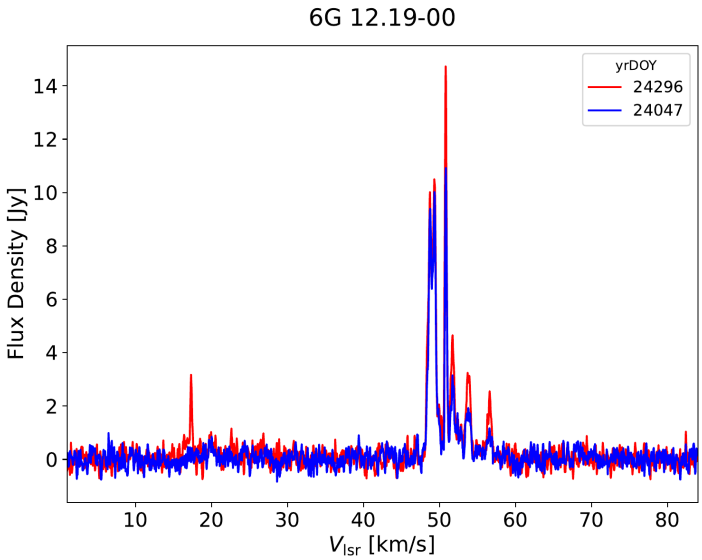
Light curve



Periodogram

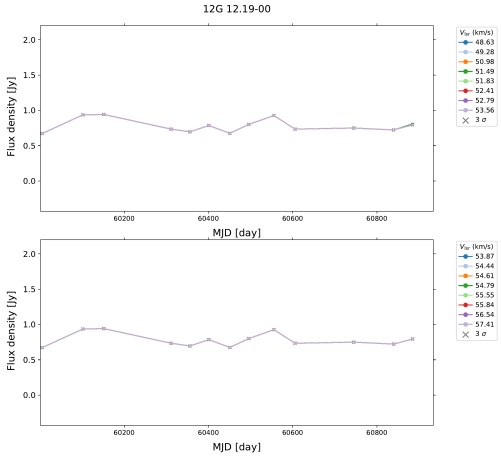


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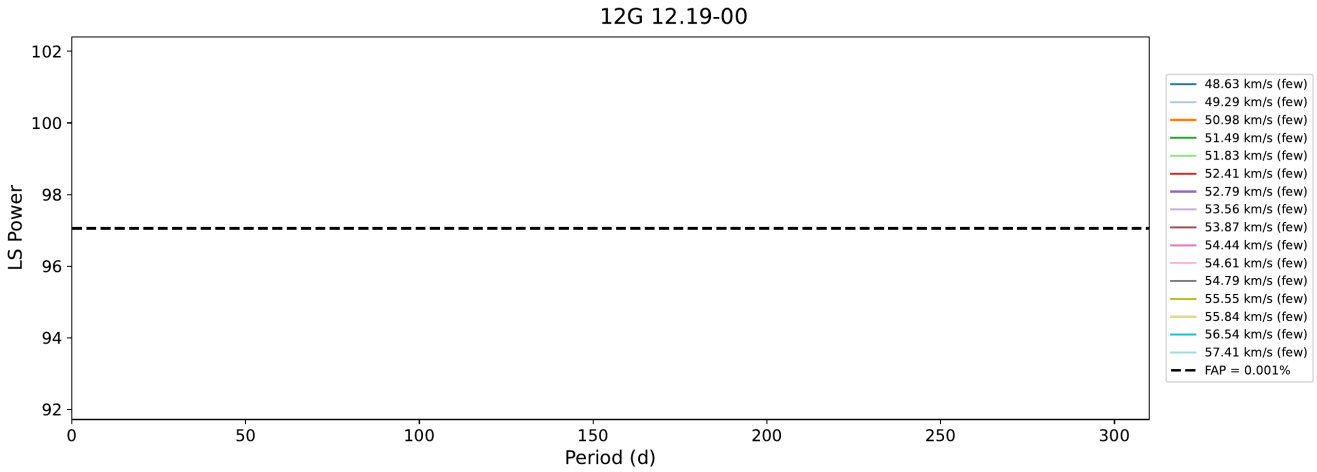


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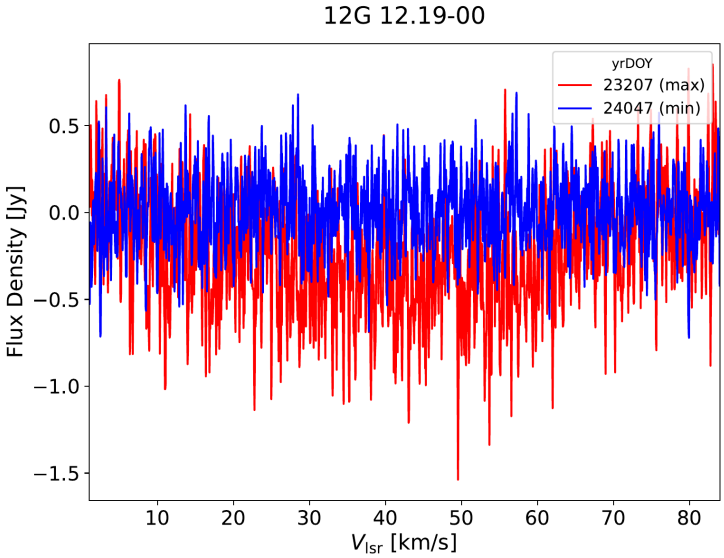
Light curve



Periodogram

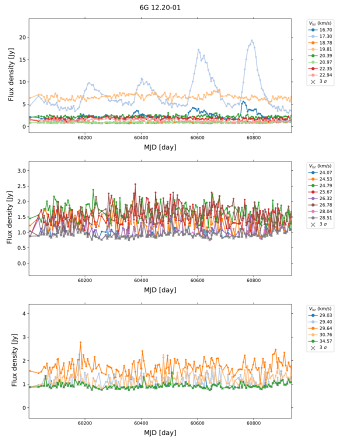


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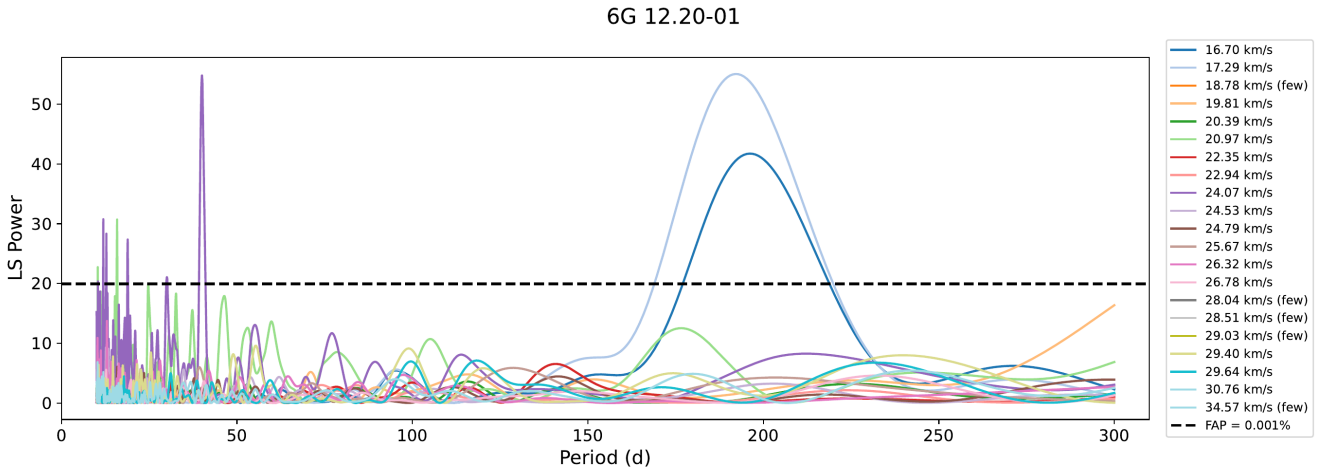


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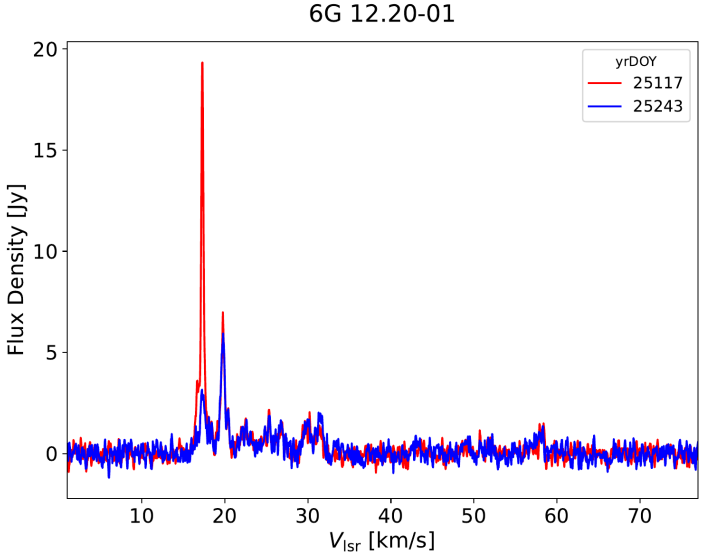
Light curve



Periodogram

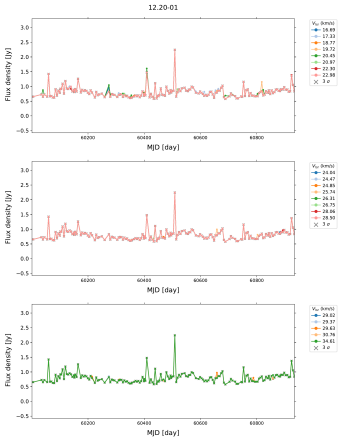


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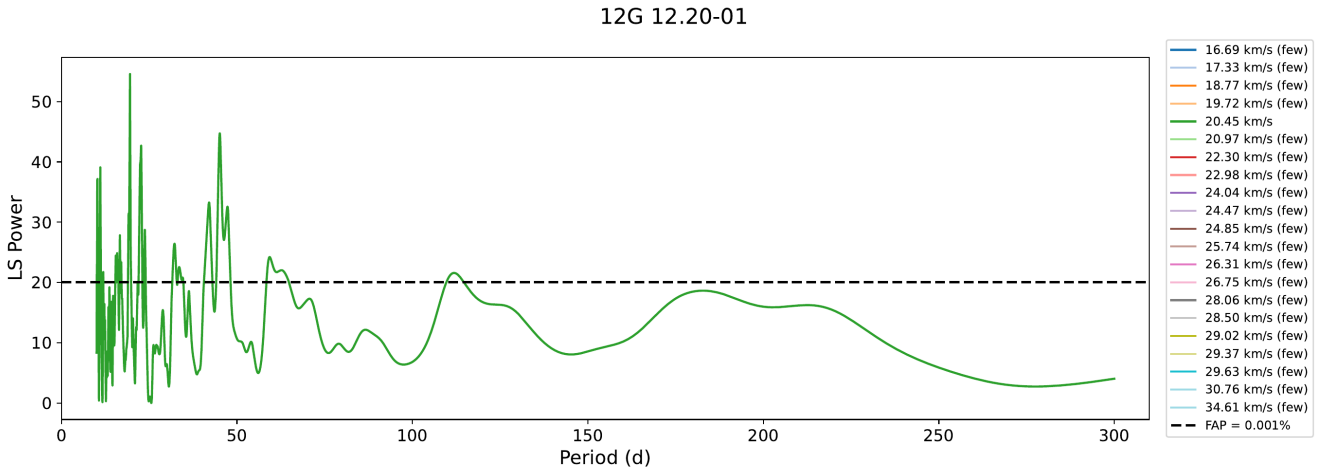


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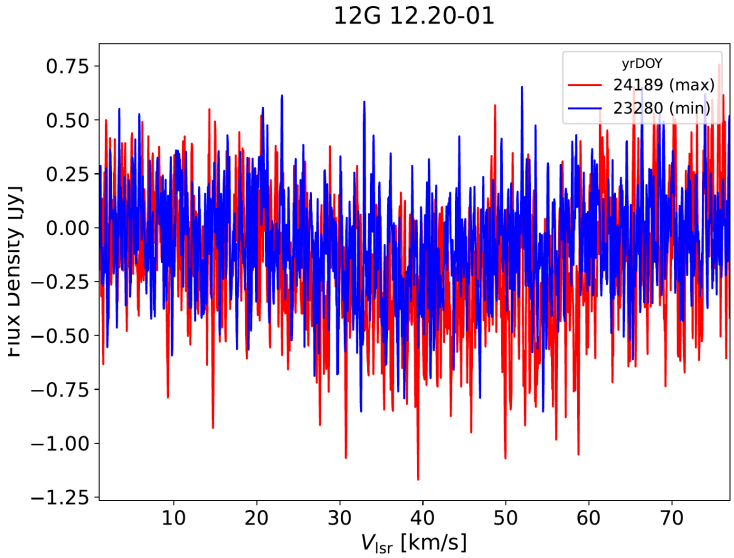
Light curve



Periodogram

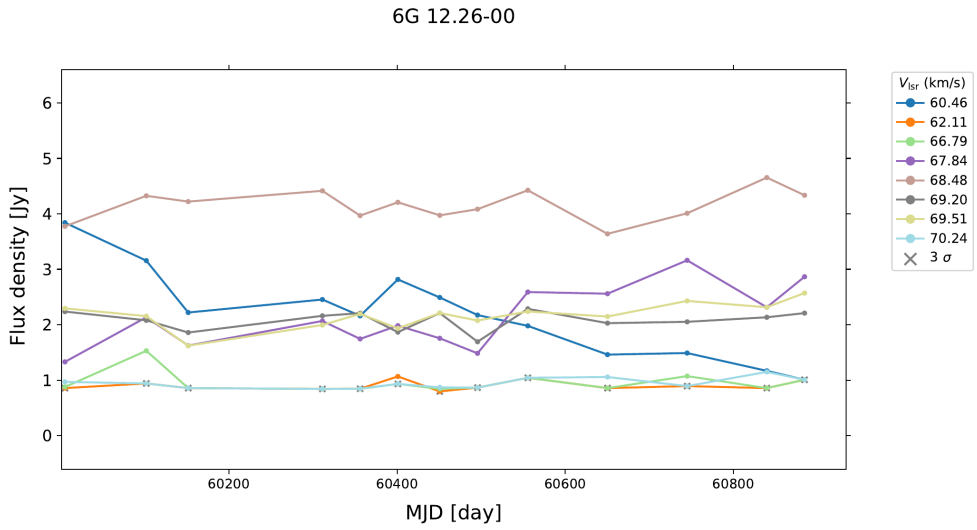


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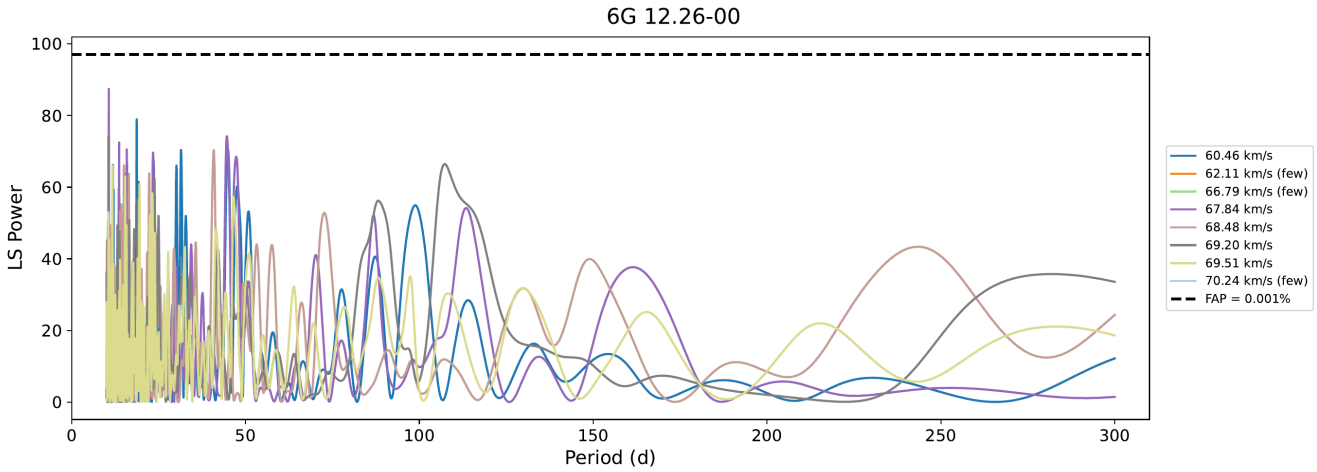


6G 12.26-00

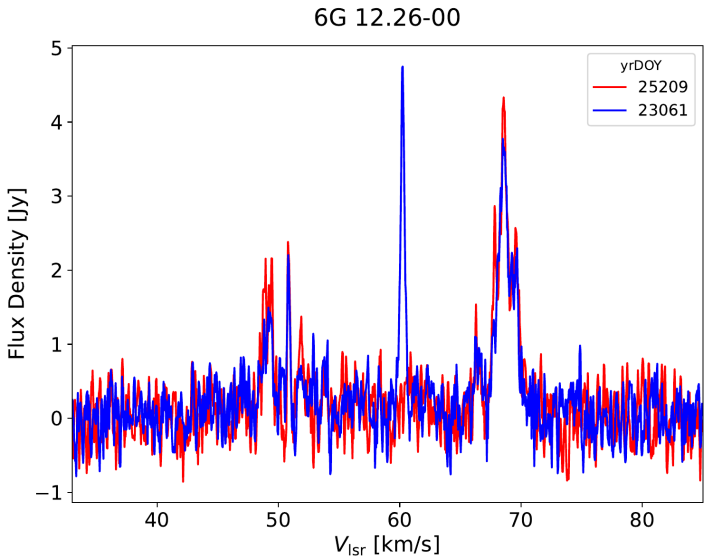
Light curve



Periodogram

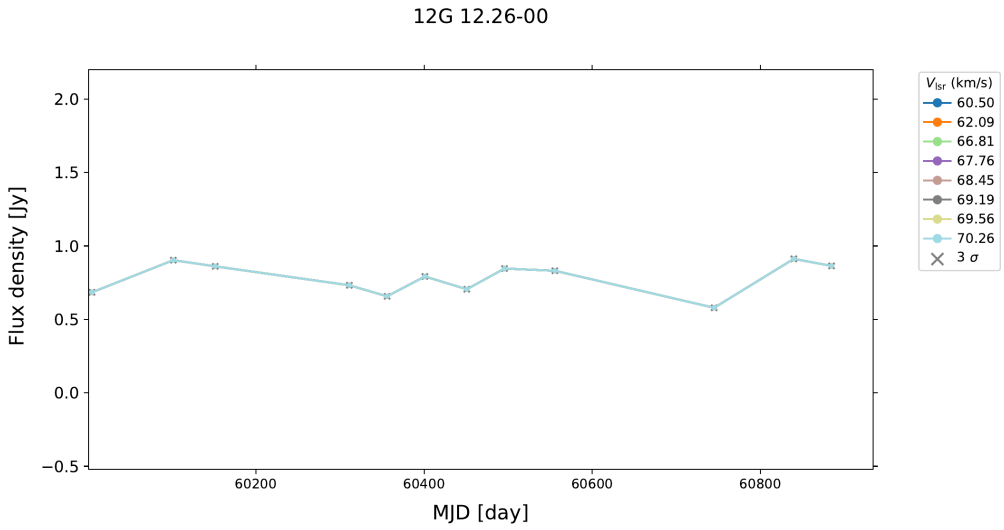


Spectrum

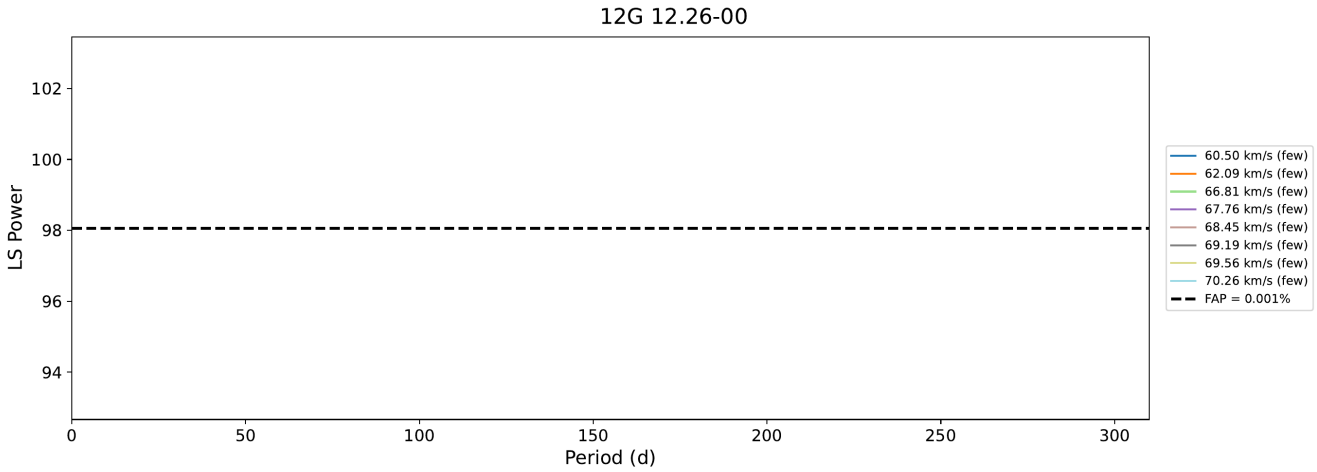


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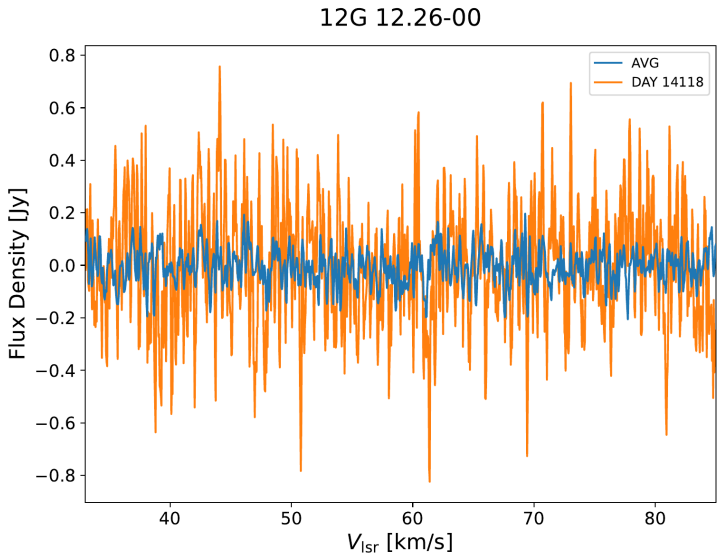
Light curve



Periodogram

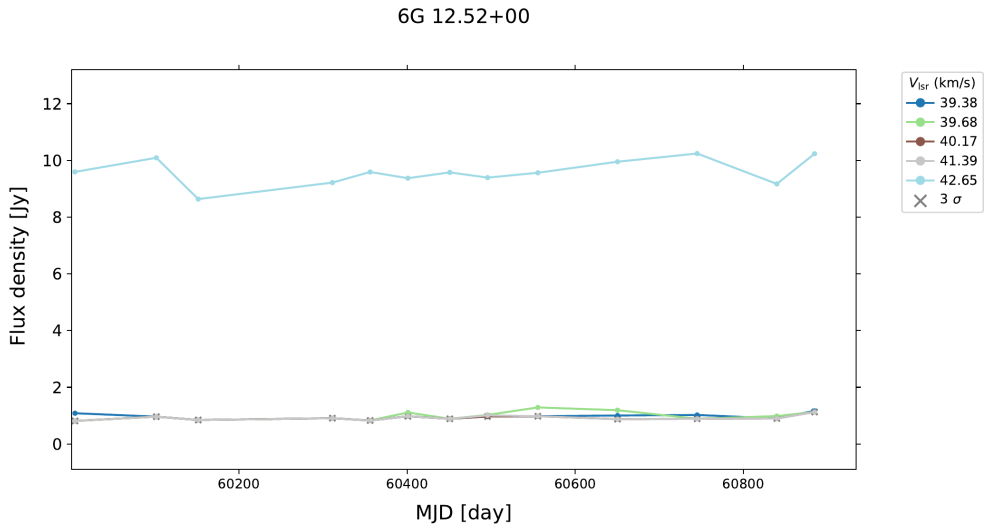


Spectrum

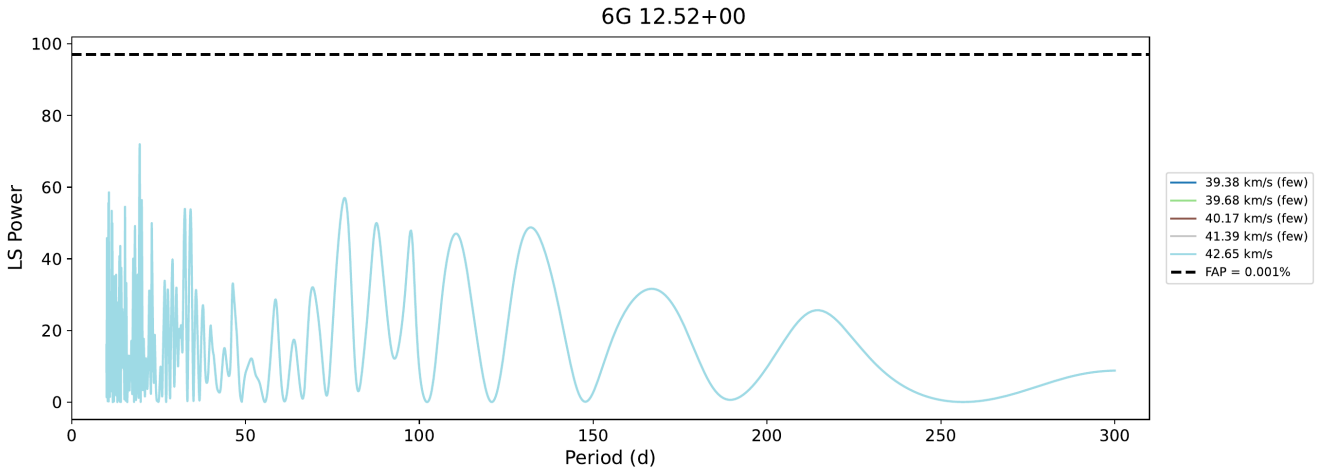


6G 12.52+00

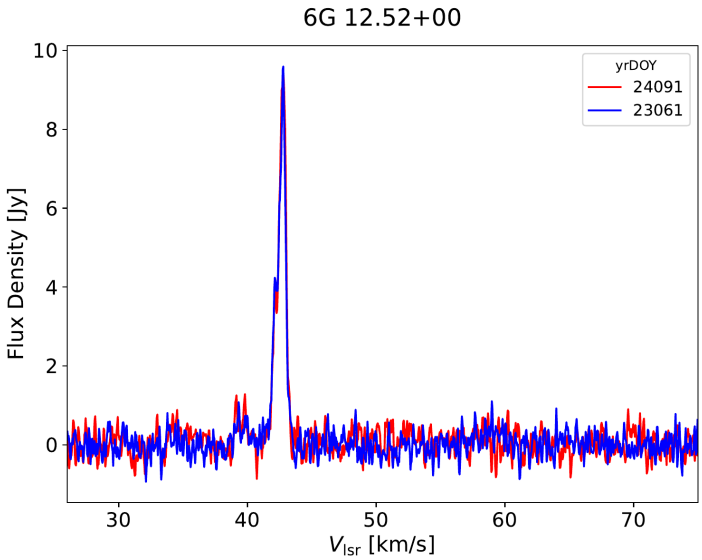
Light curve



Periodogram

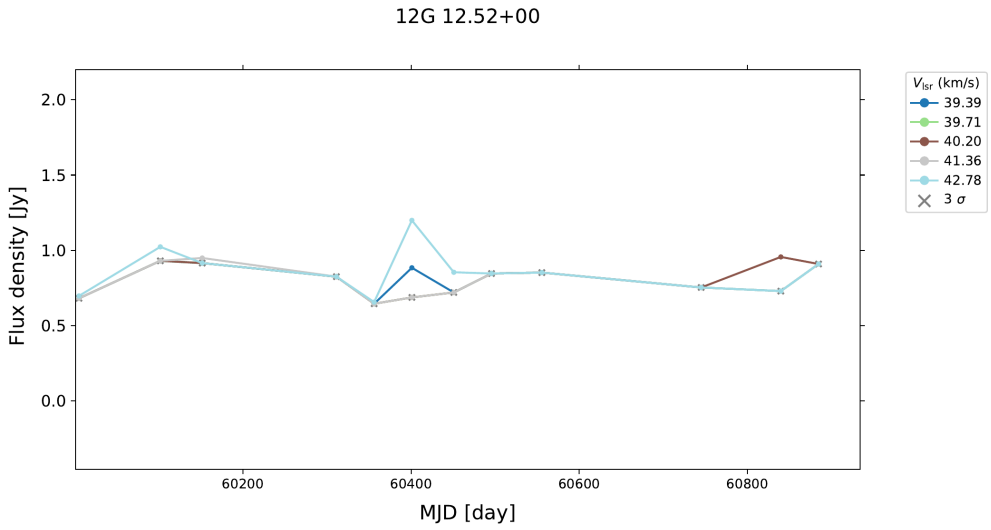


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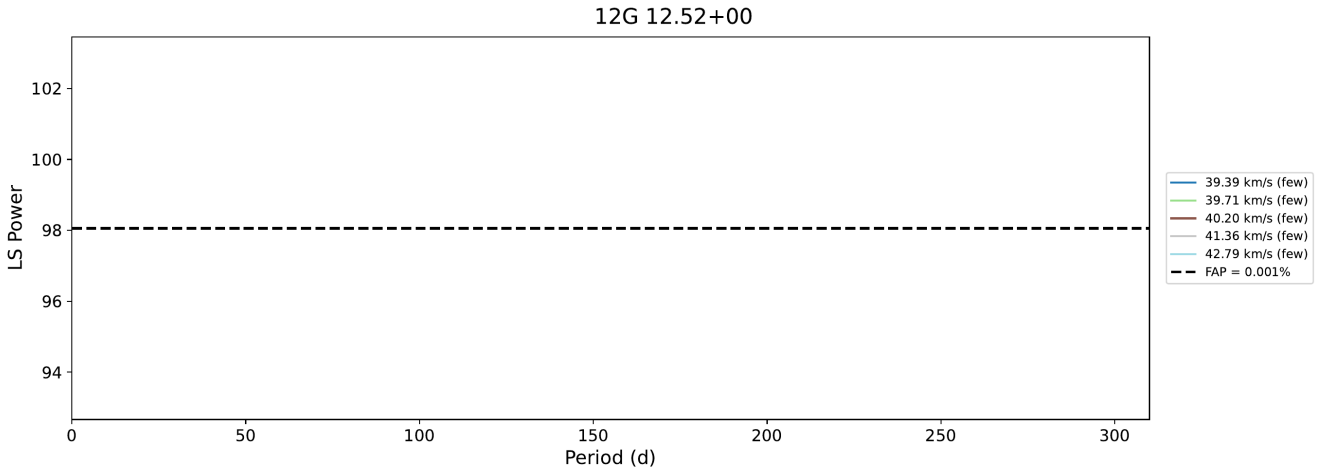


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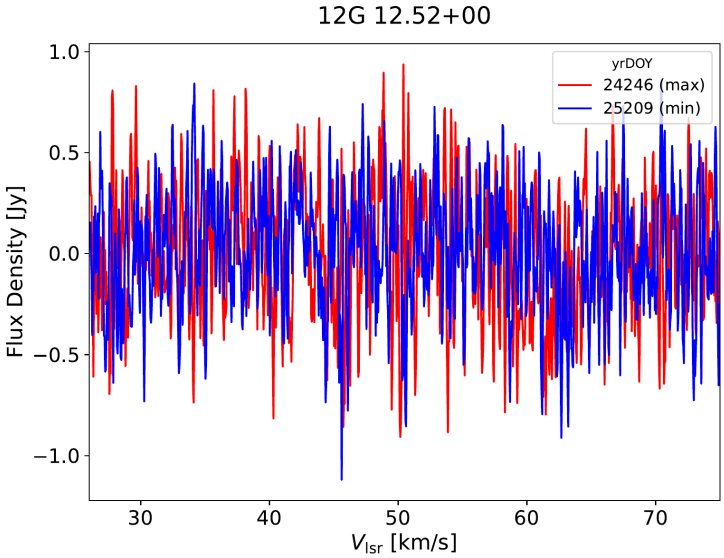
Light curve



Periodogram

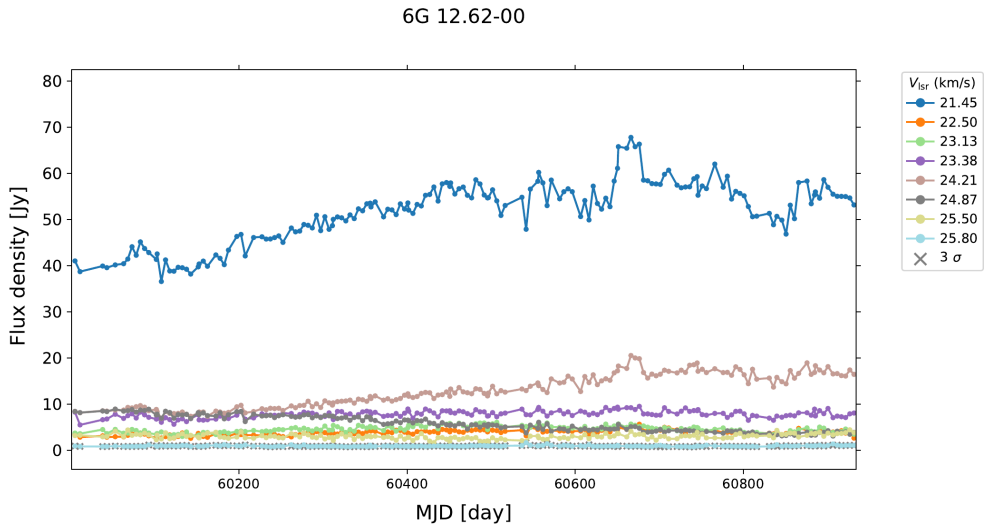


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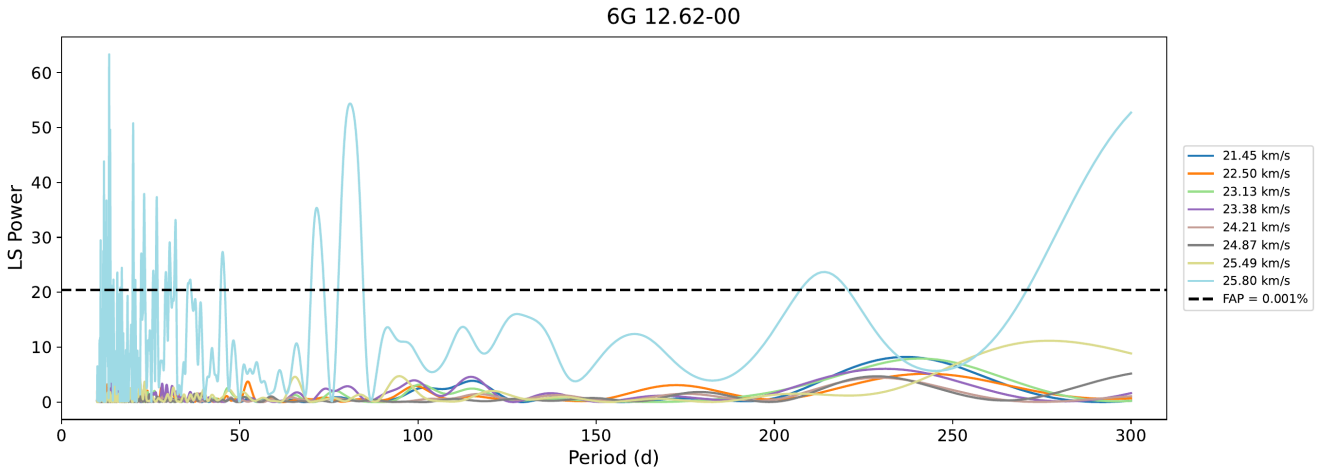


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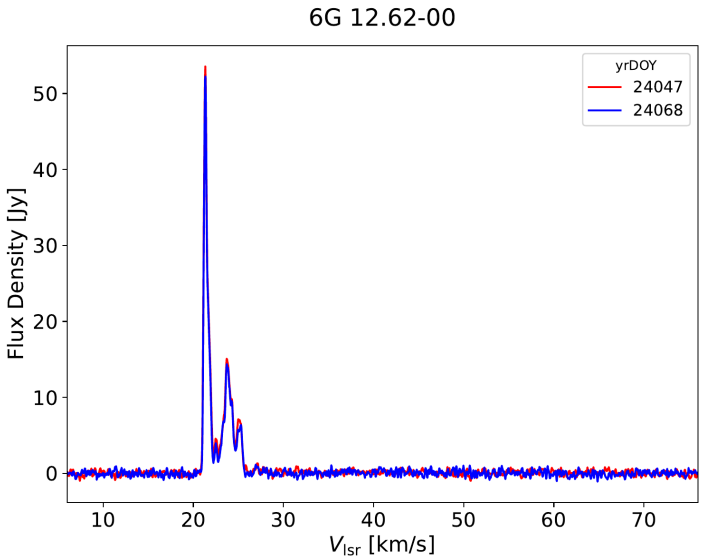
Light curve



Periodogram

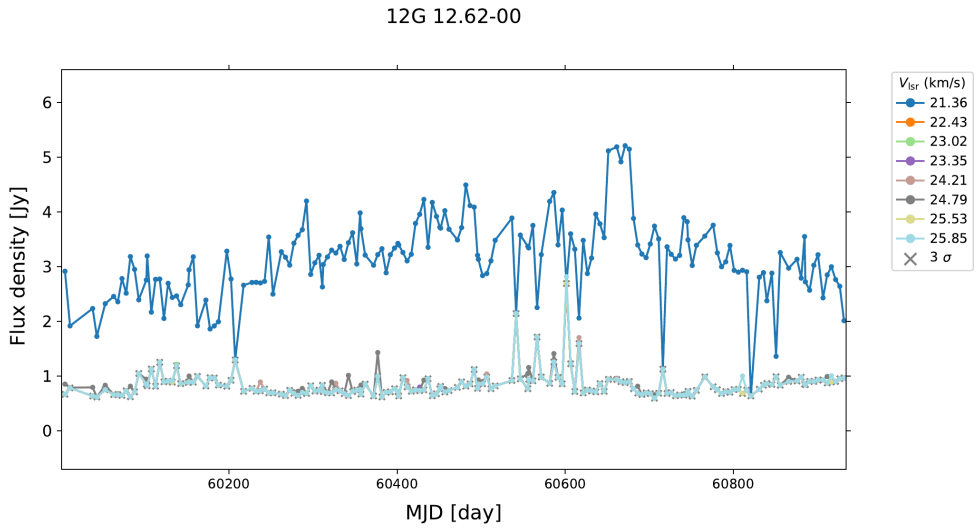


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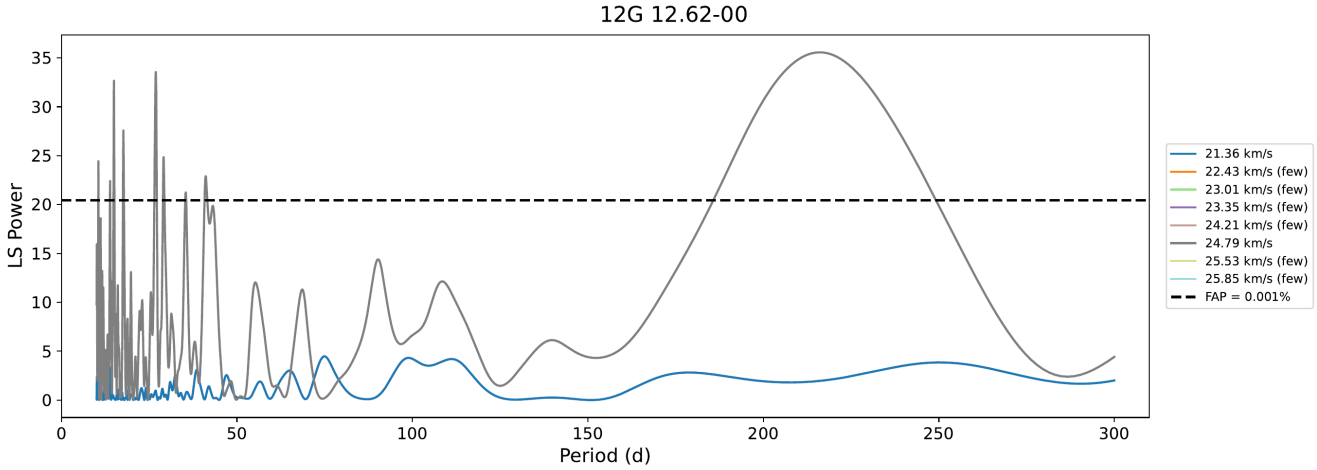


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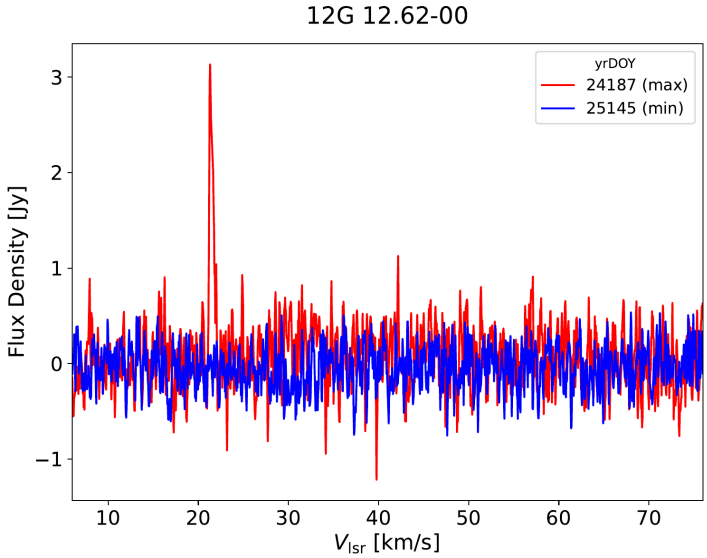
Light curve



Periodogram

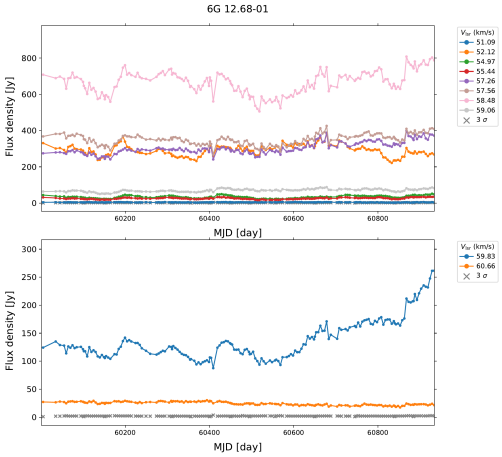


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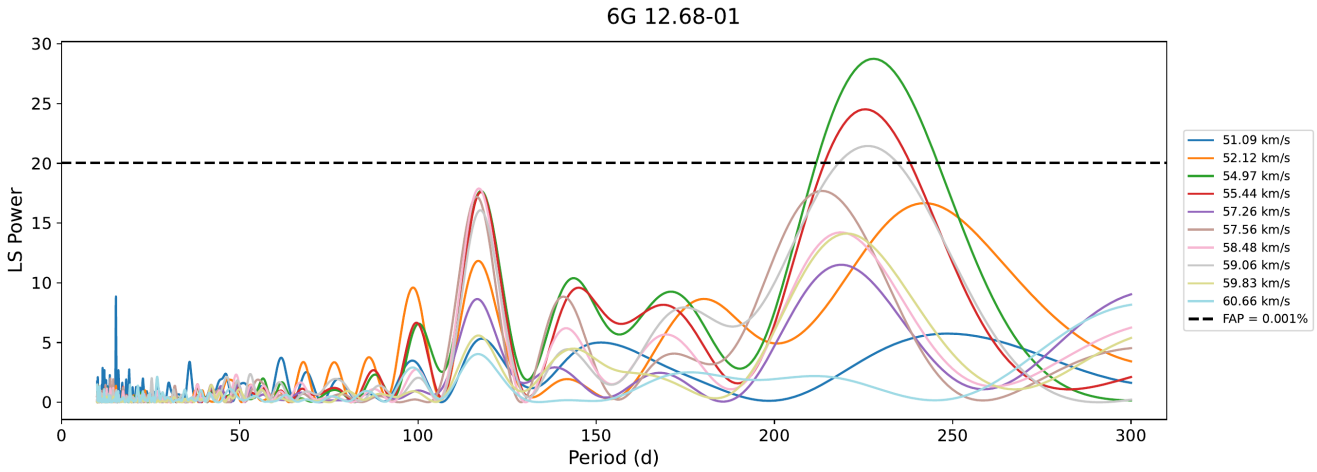


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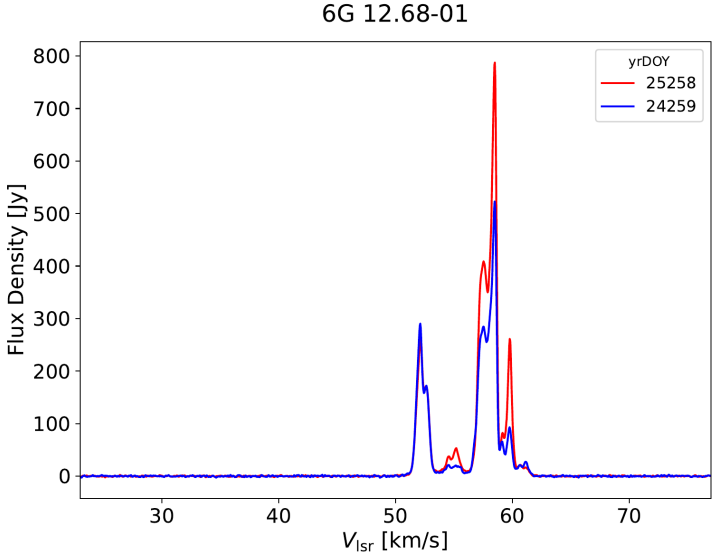
Light curve



Periodogram

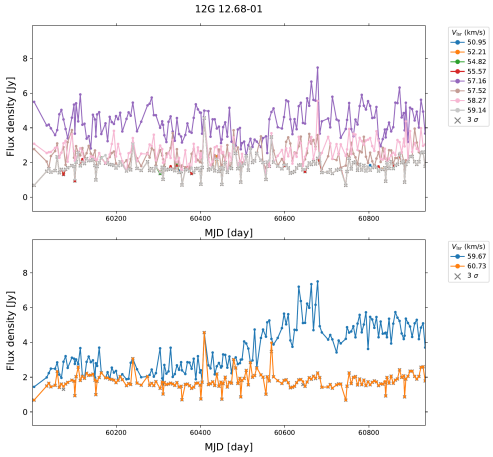


Spectrum

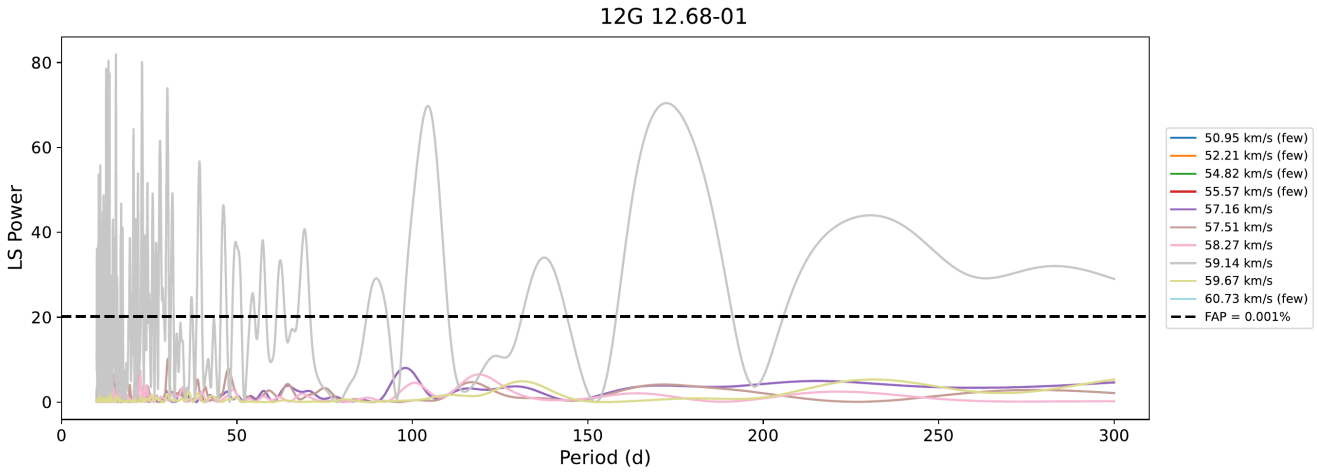


12G 12.68-01

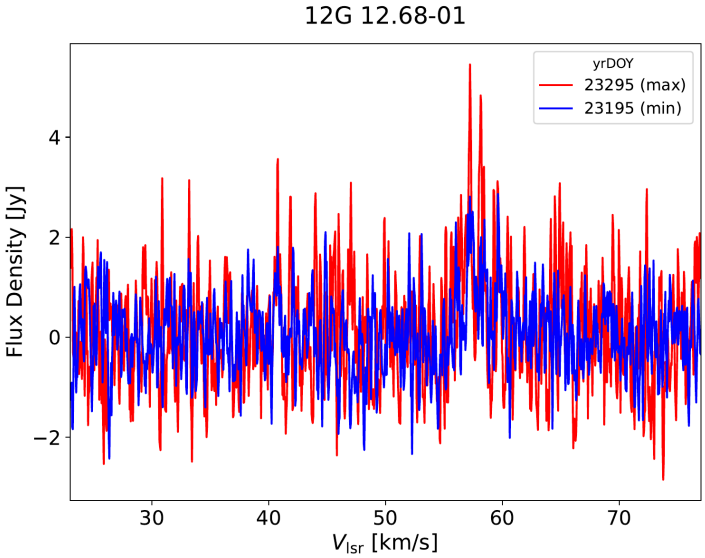
Light curve



Periodogram

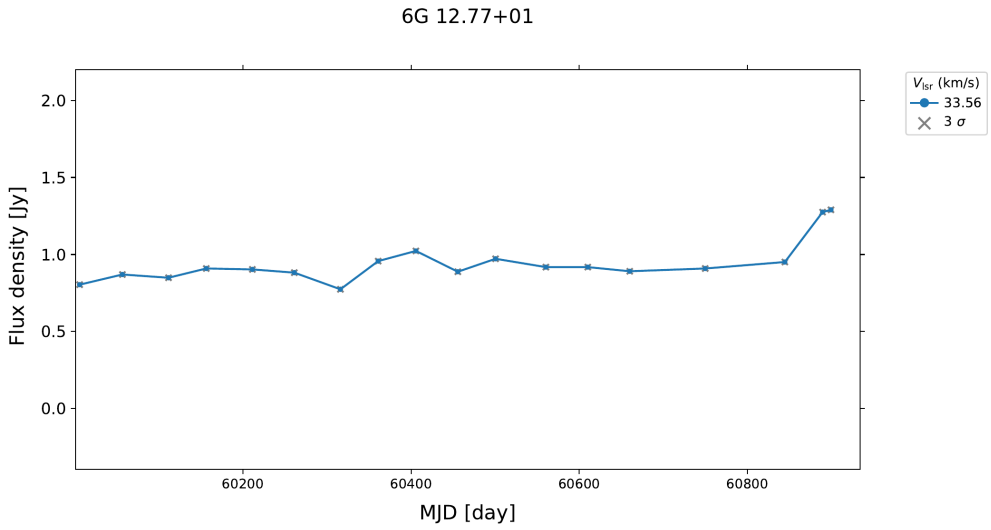


Spectrum

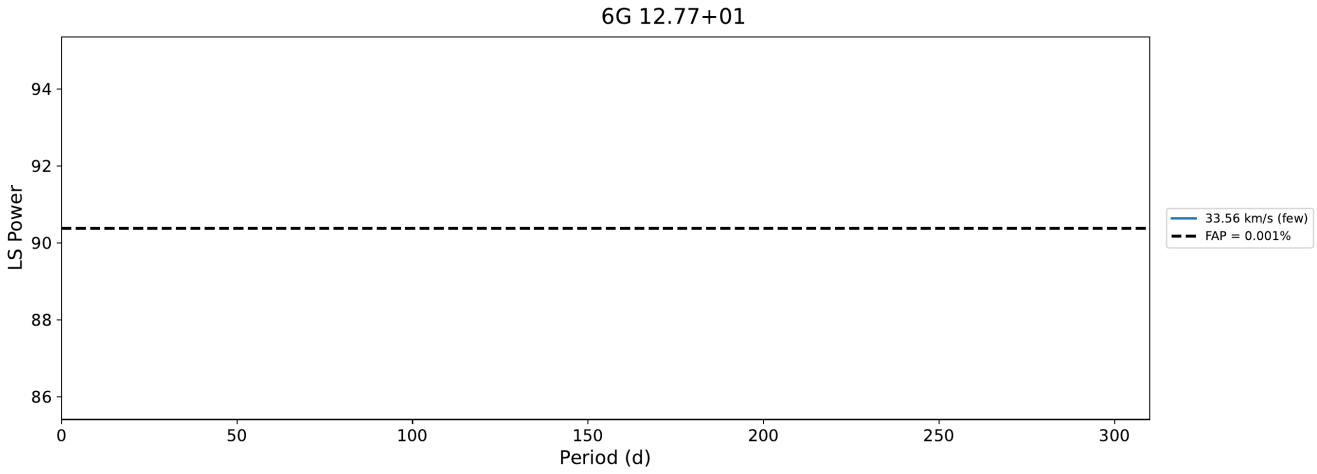


6G 12.77+01

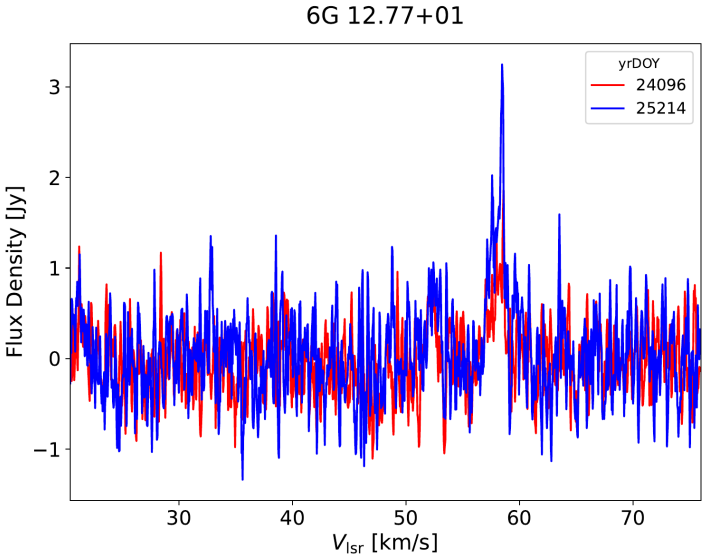
Light curve



Periodogram

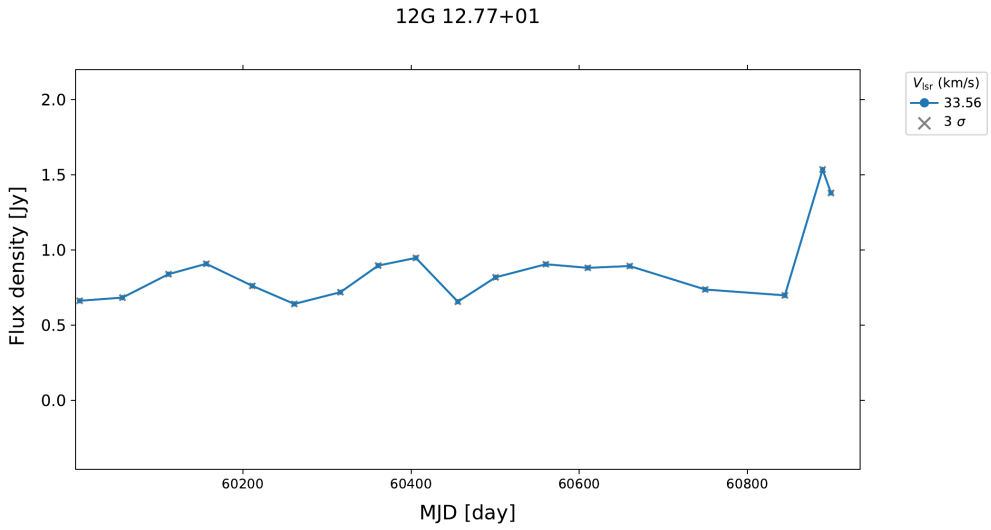


Spectrum

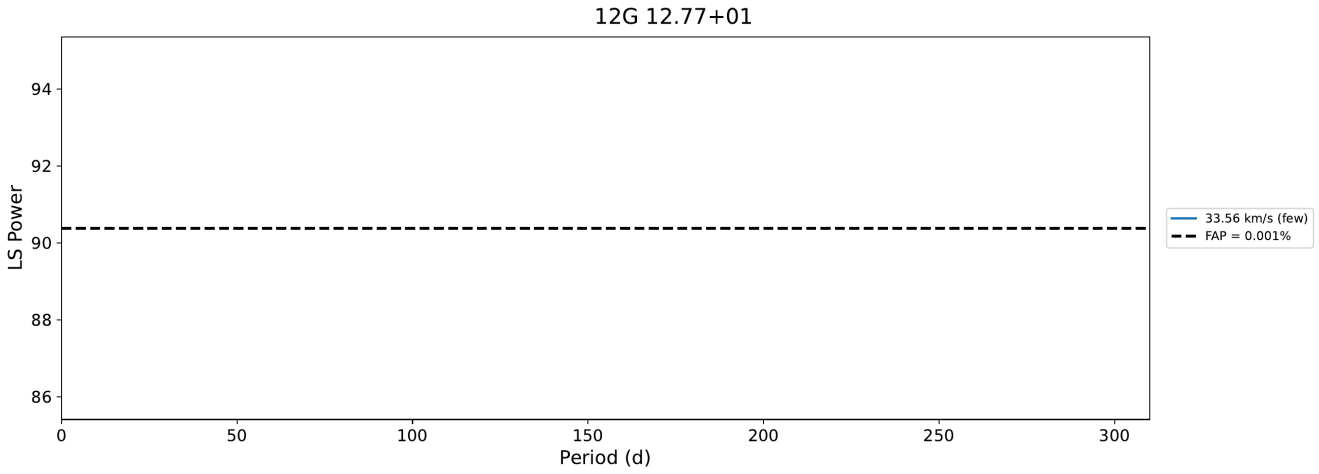


12G 12.77+01

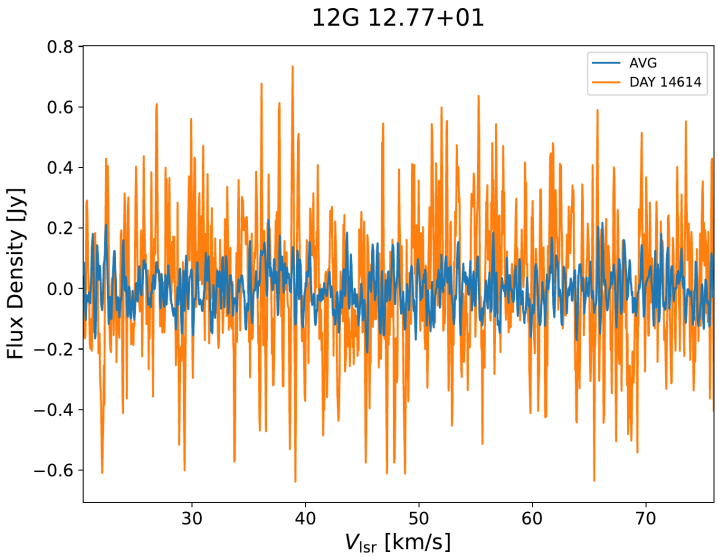
Light curve



Periodogram

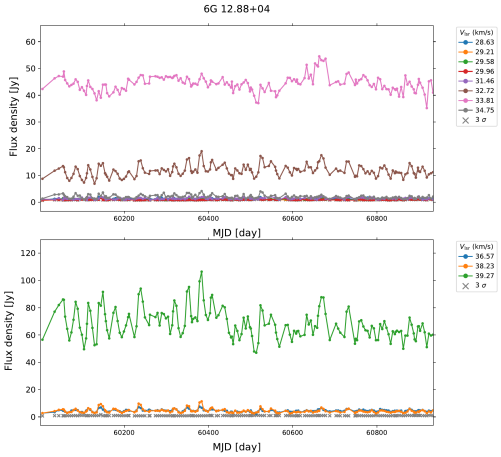


Spectrum

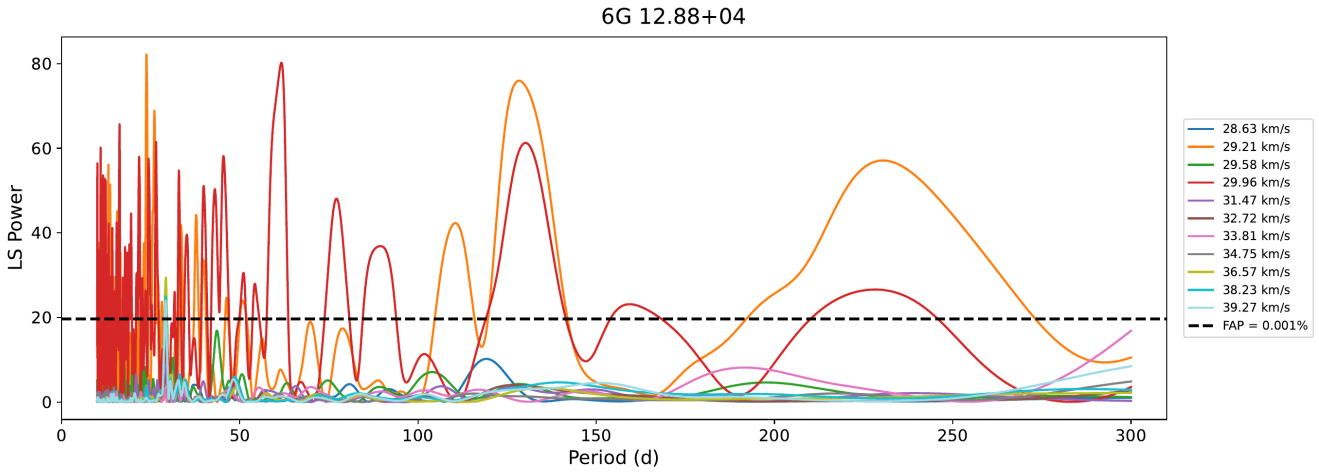


6G 12.88+04

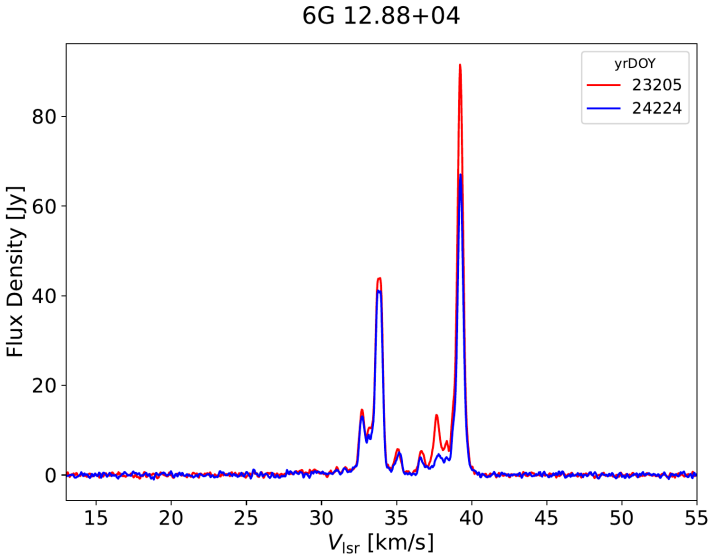
Light curve



Periodogram

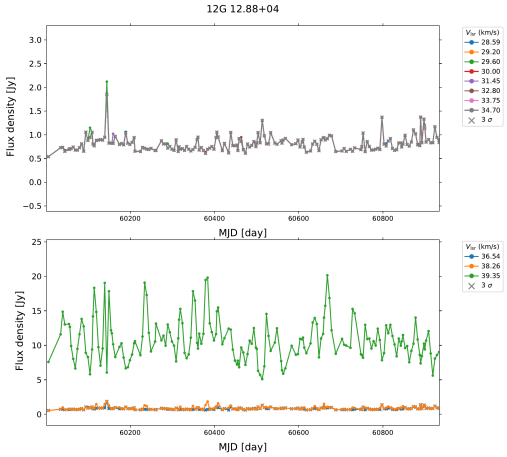


Spectrum

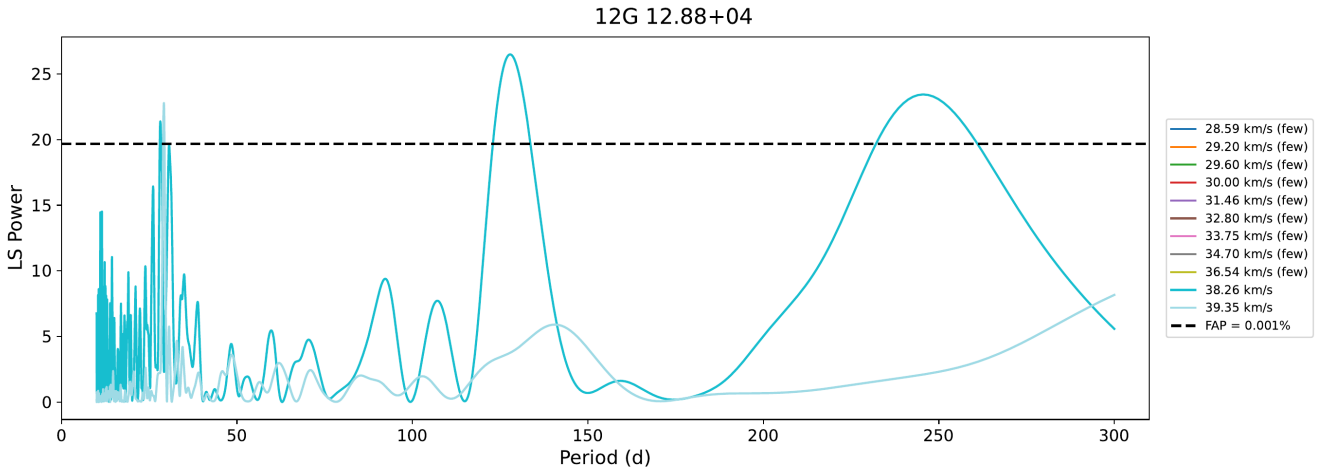


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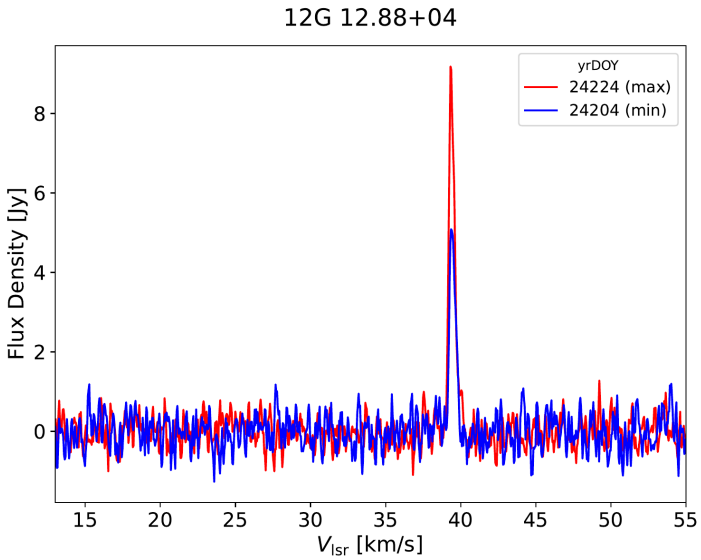
Light curve



Periodogram

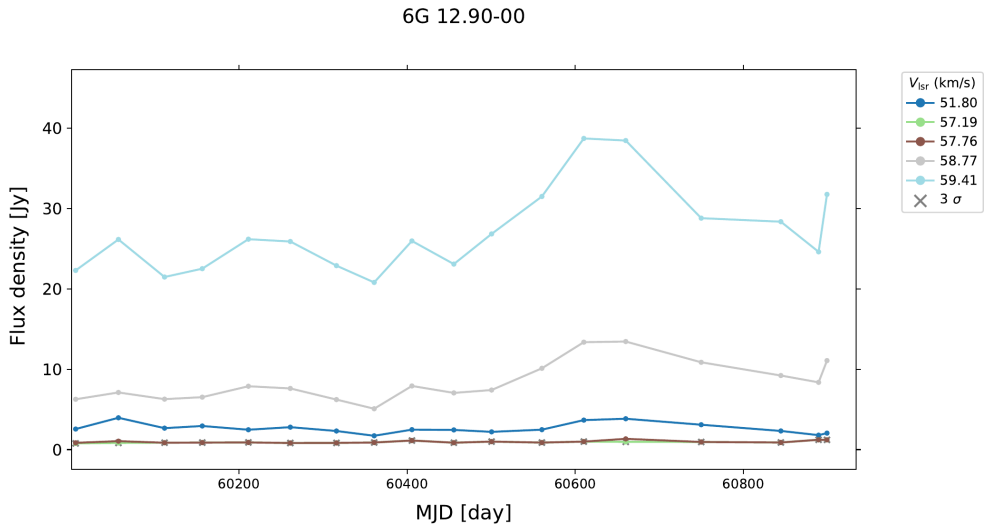


Spectrum

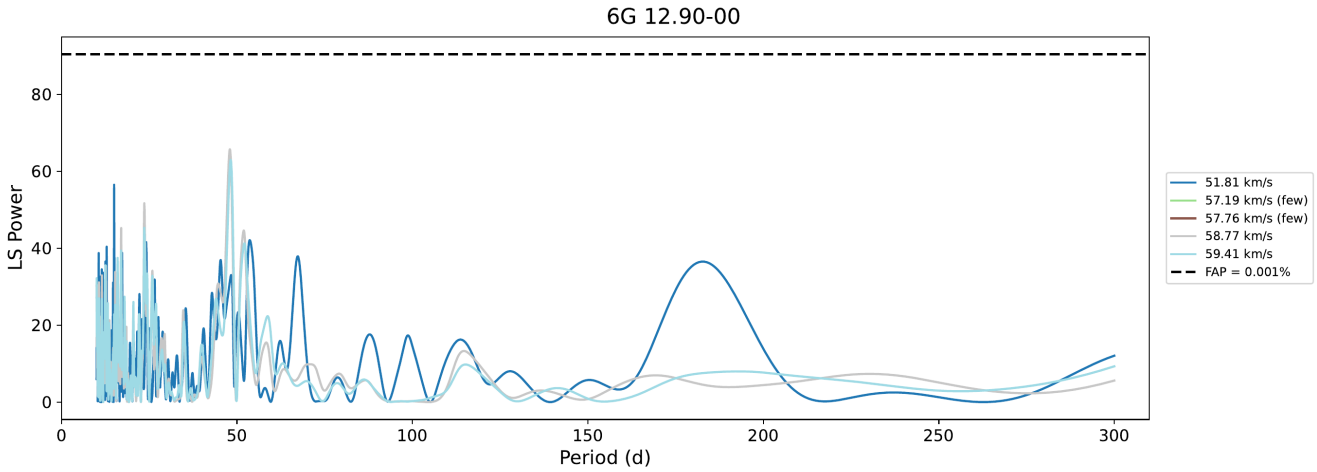


6G 12.90-00

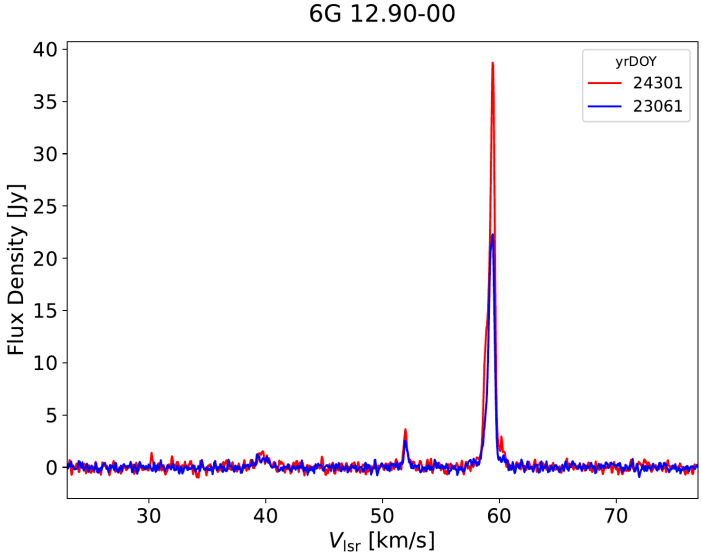
Light curve



Periodogram

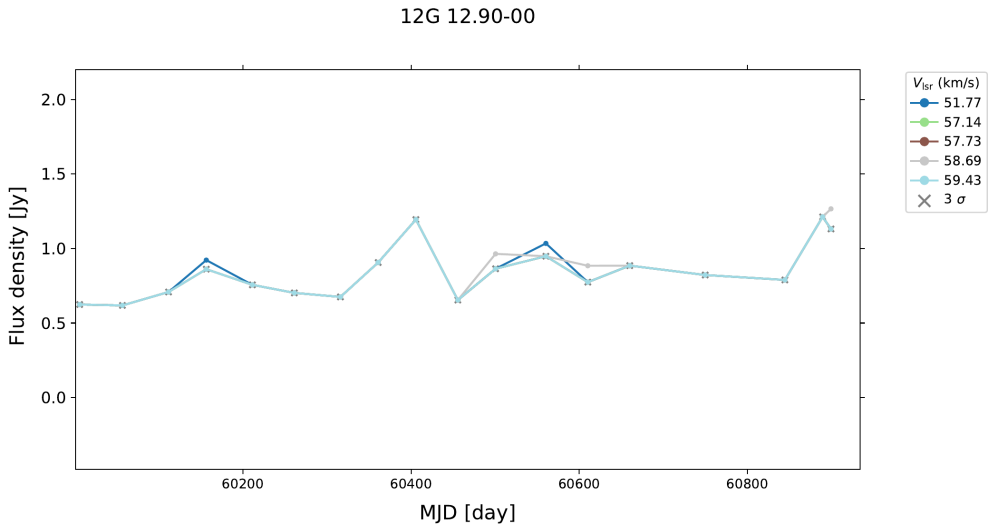


Spectrum

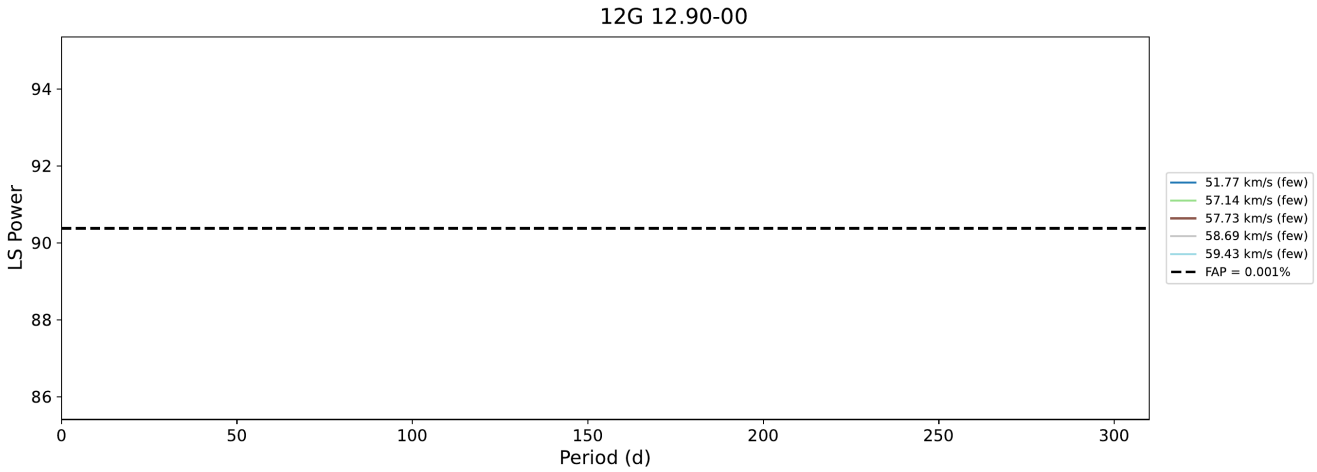


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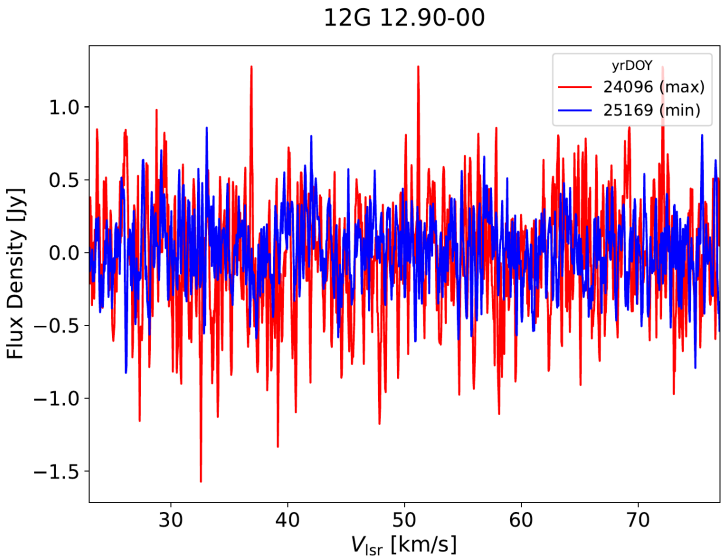
Light curve



Periodogram

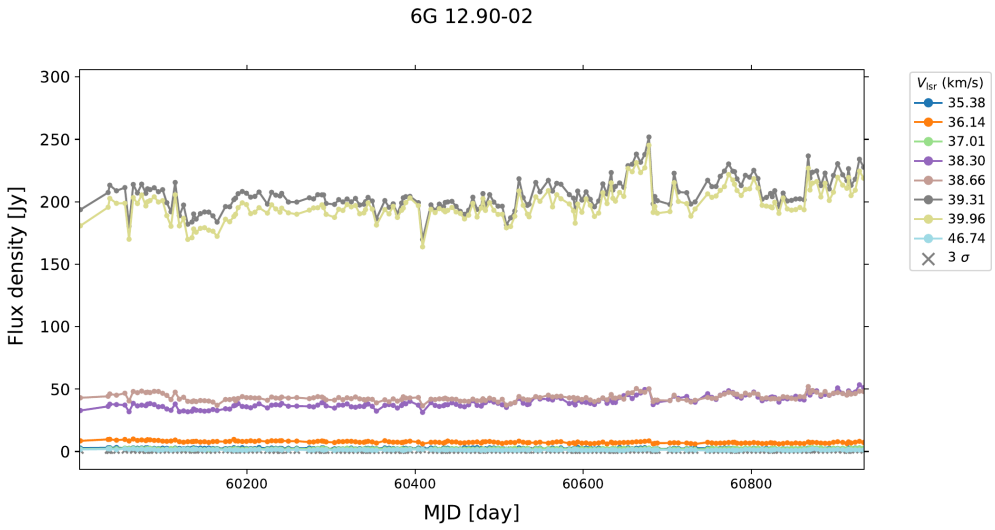


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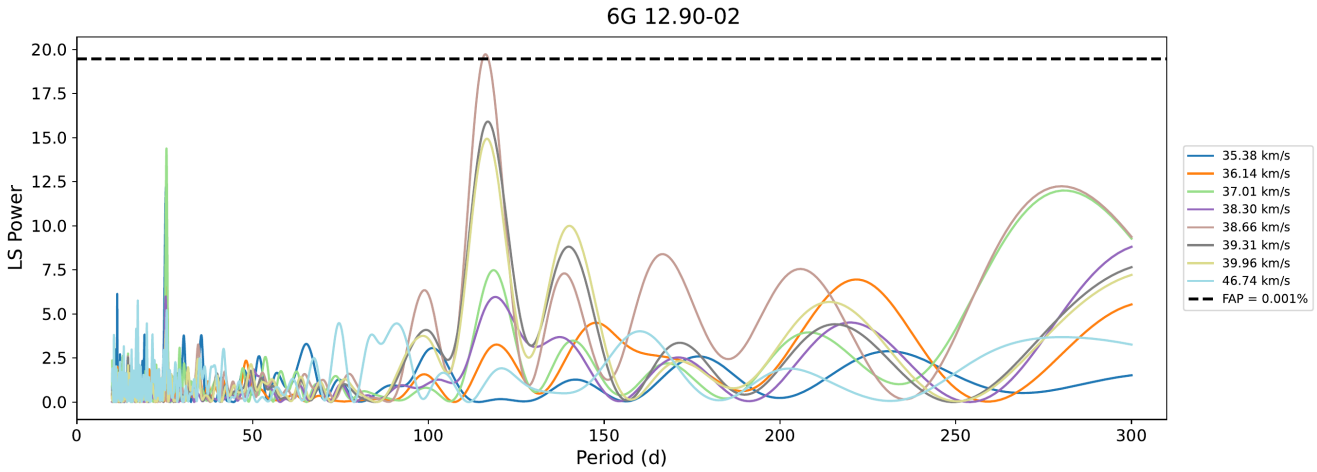


6G 12.90-02

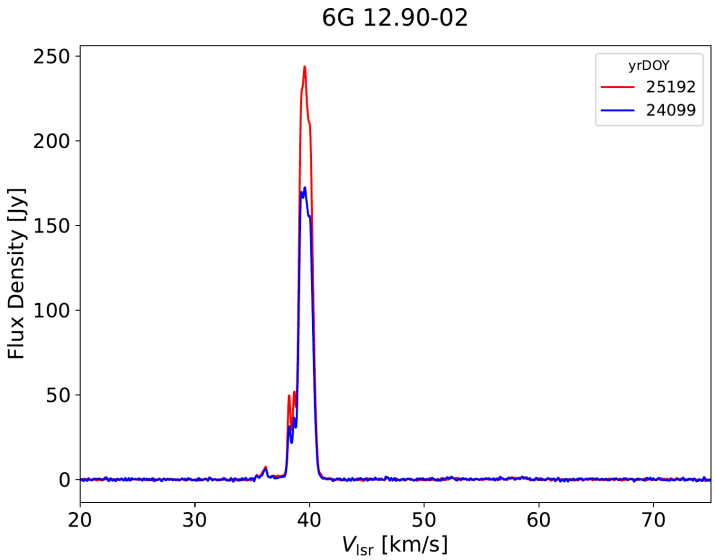
Light curve



Periodogram

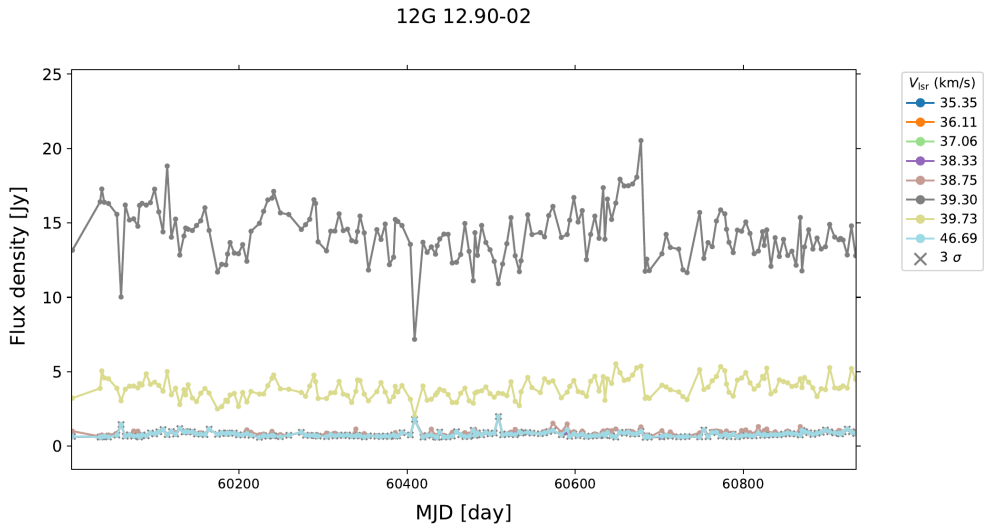


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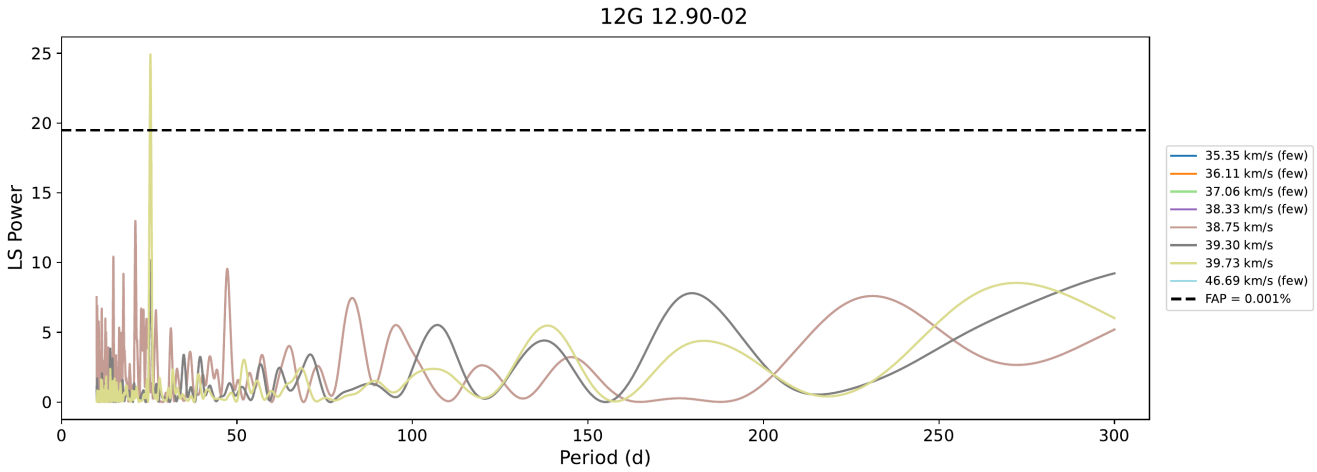


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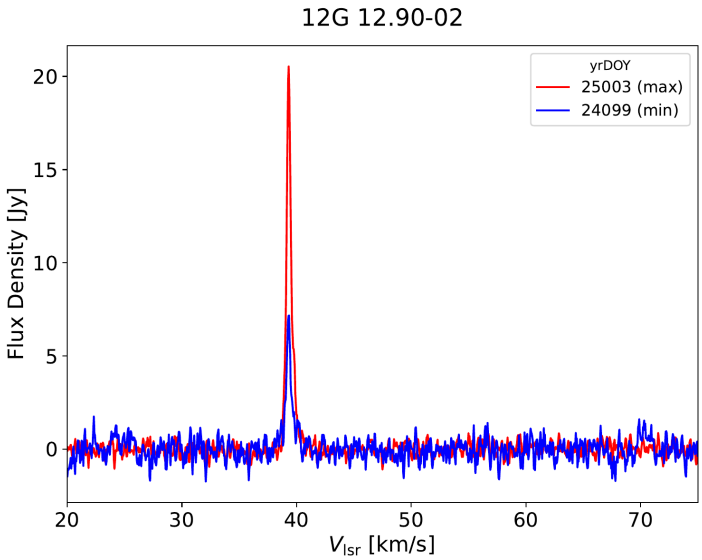
Light curve



Periodogram

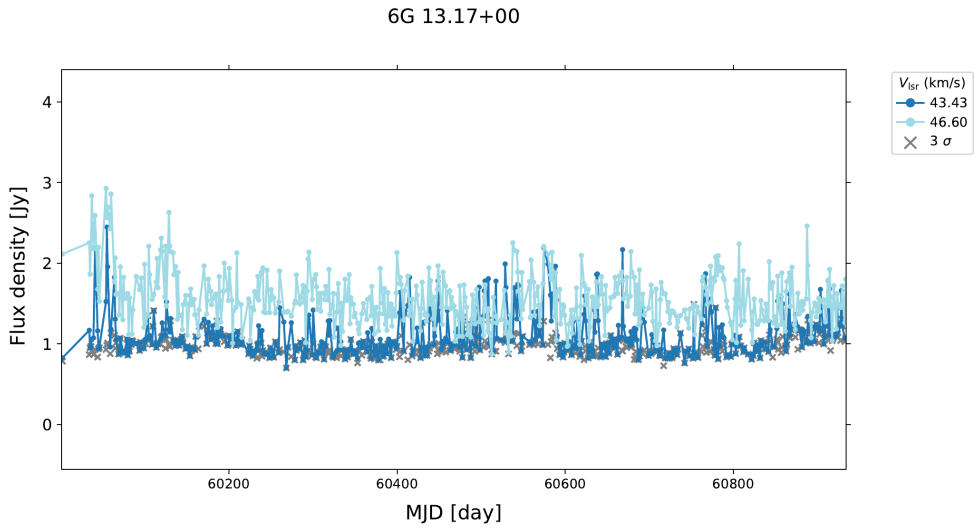


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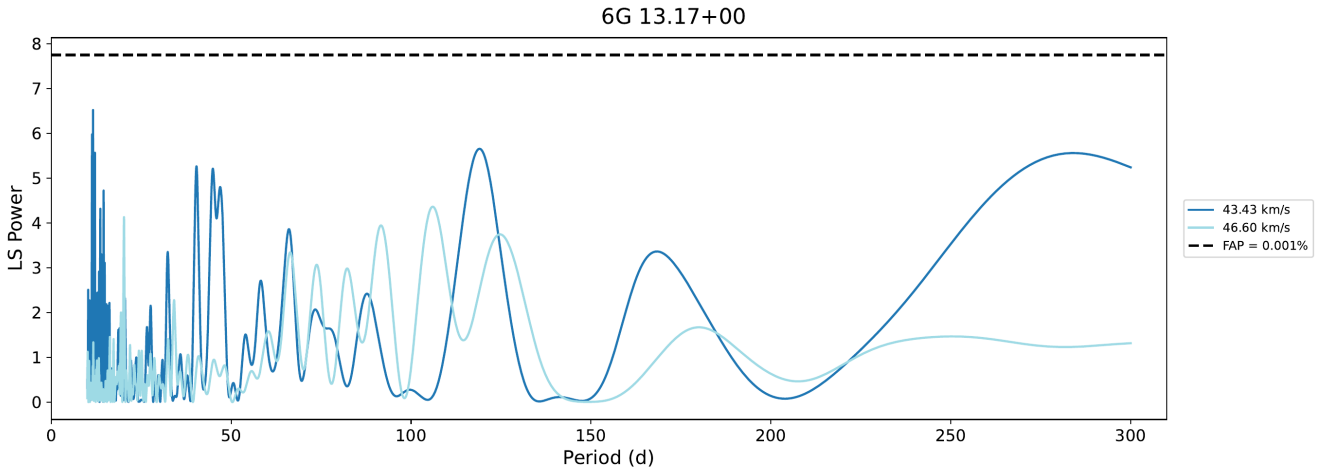


6G 13.17+00

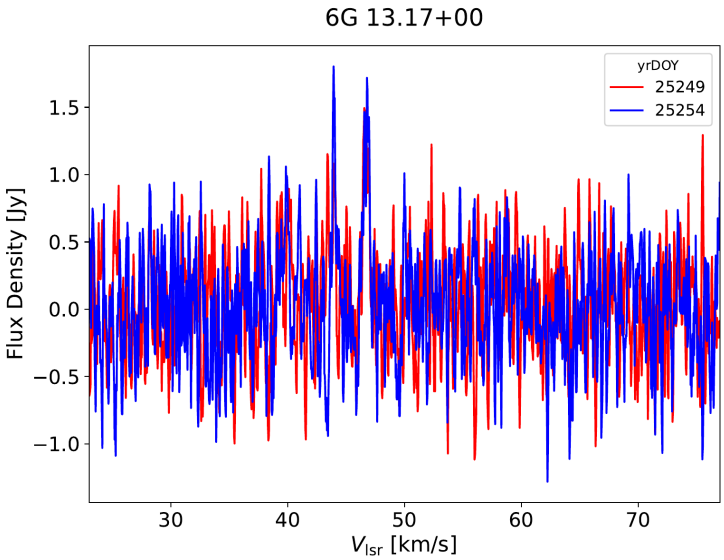
Light curve



Periodogram

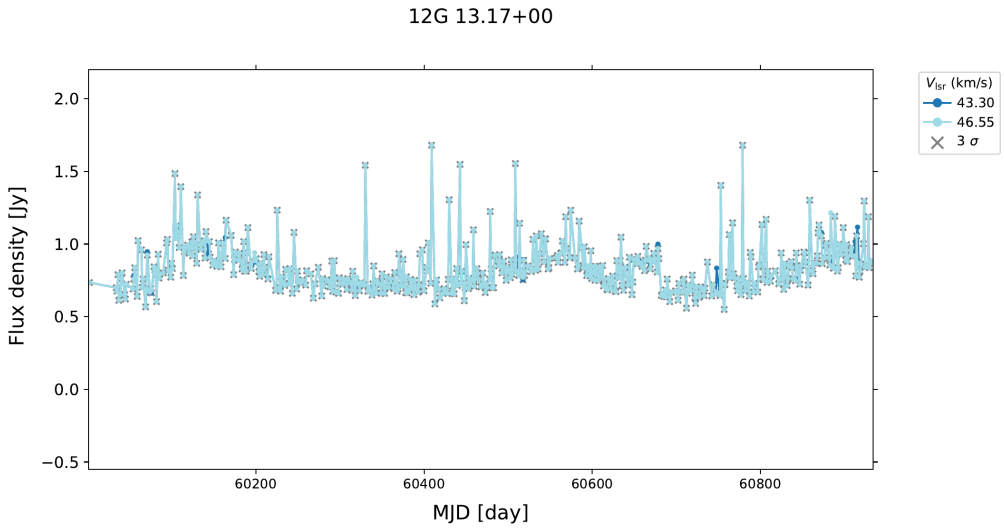


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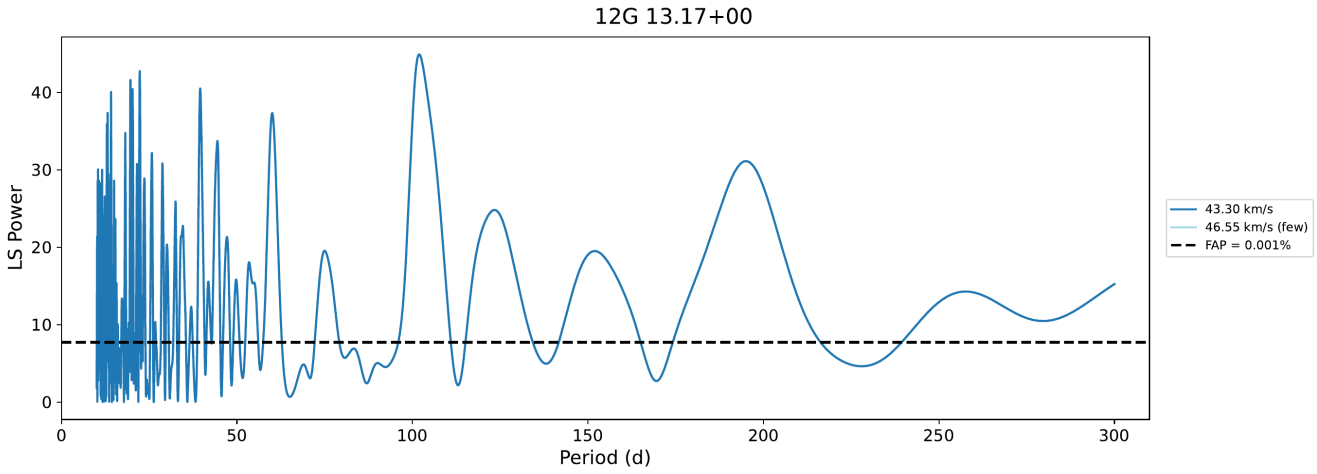


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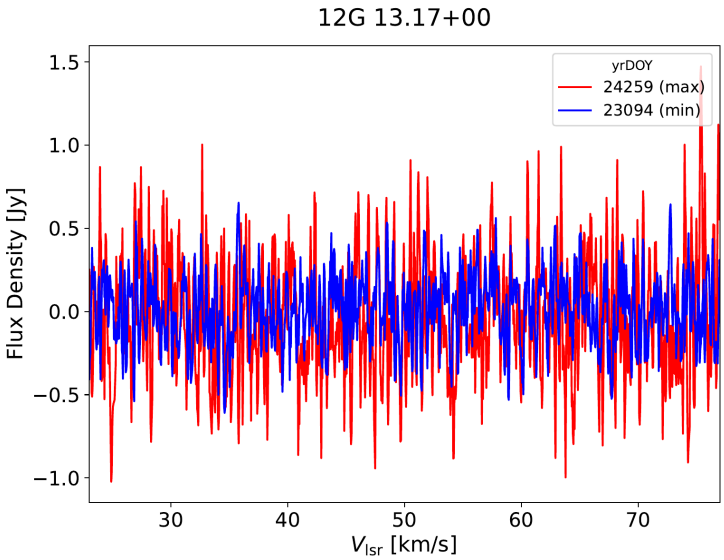
Light curve



Periodogram

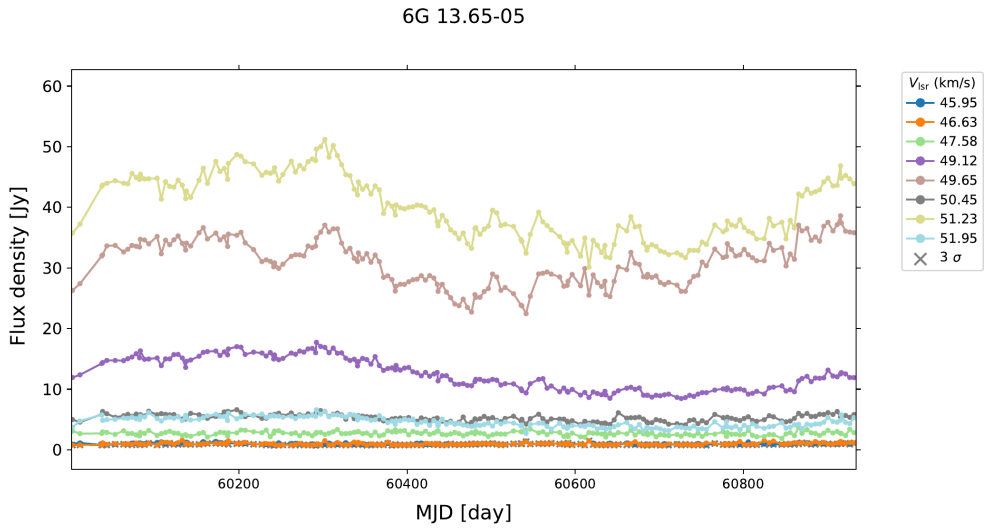


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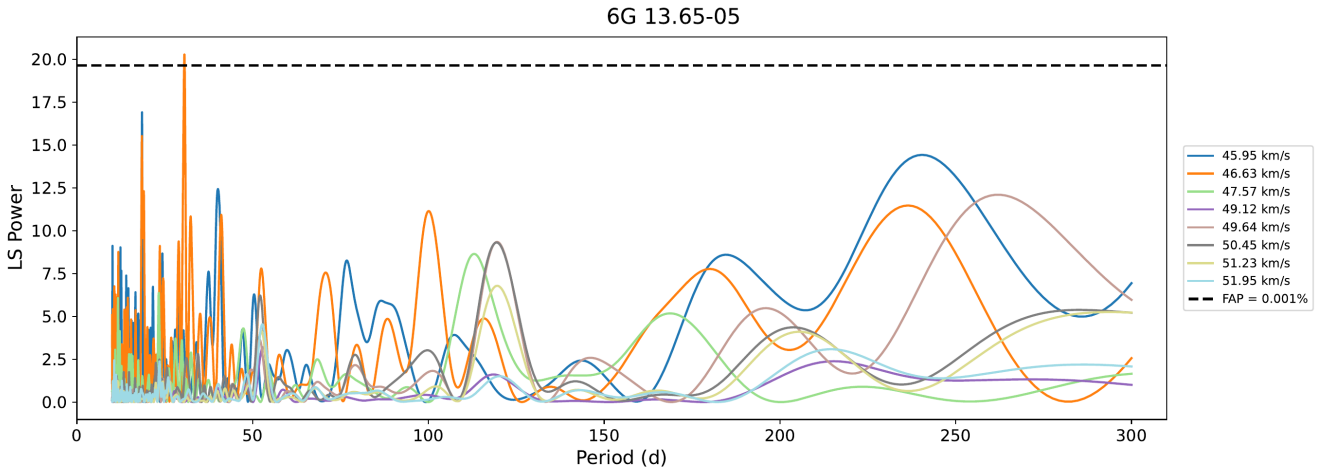


6G 13.65-05

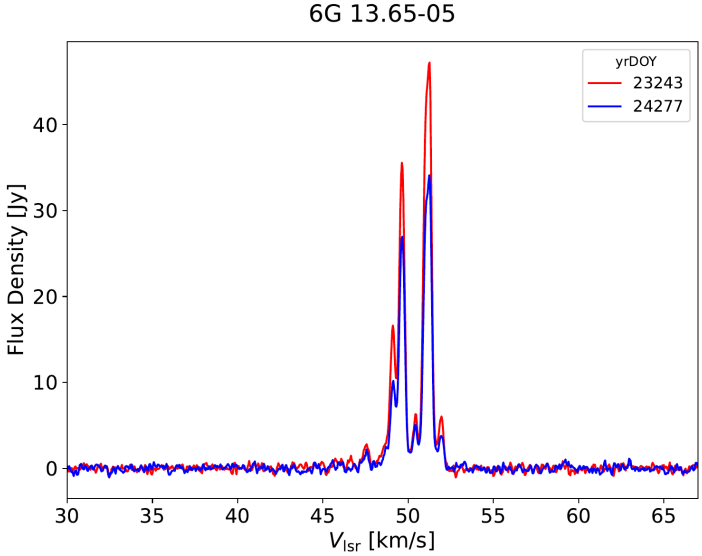
Light curve



Periodogram

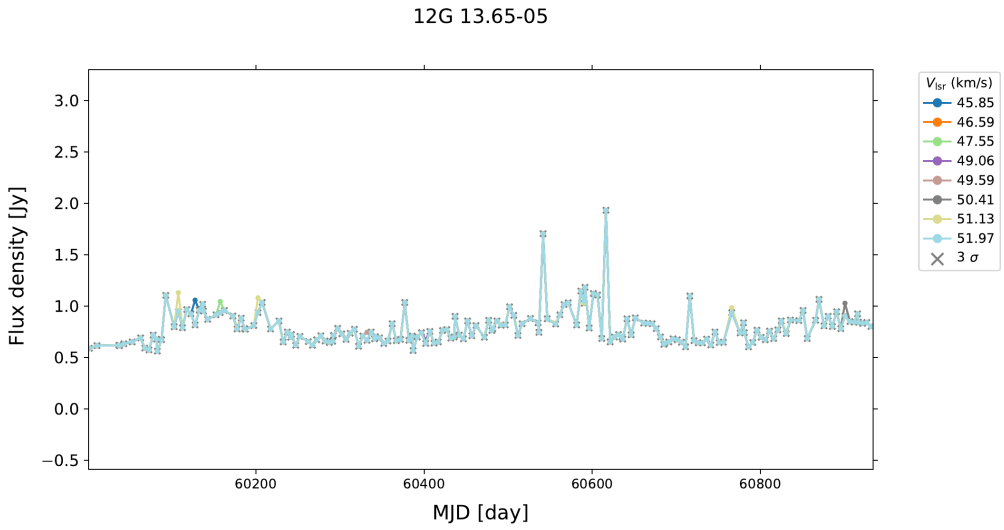


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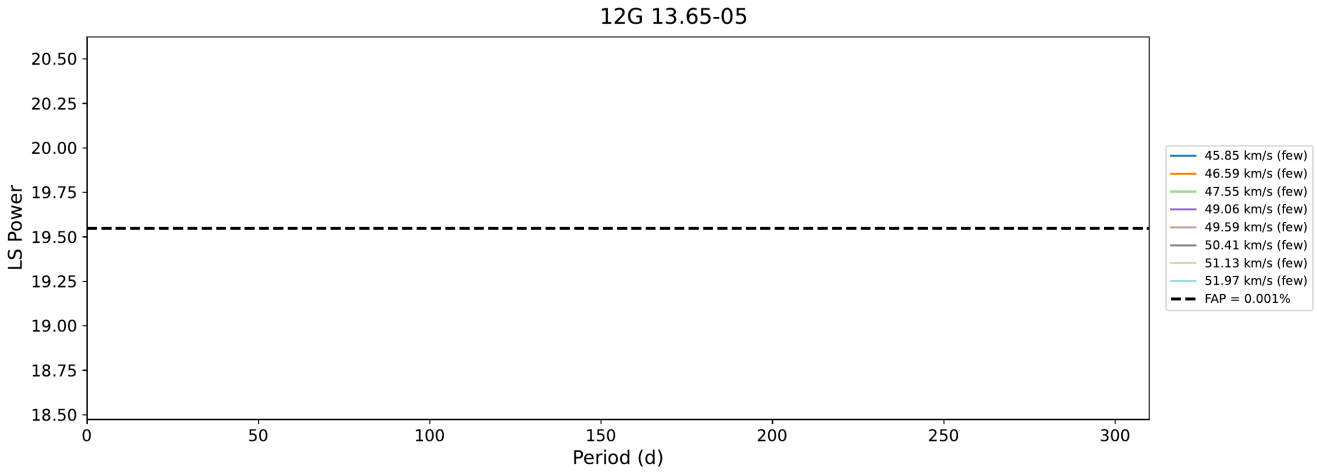


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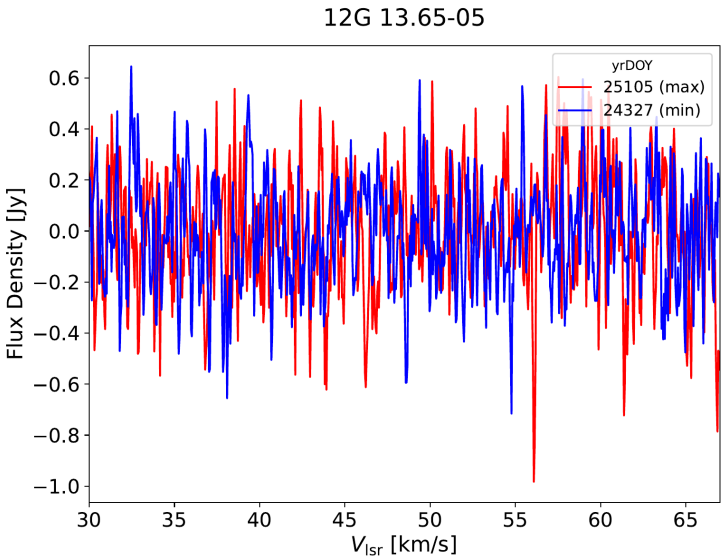
Light curve



Periodogram

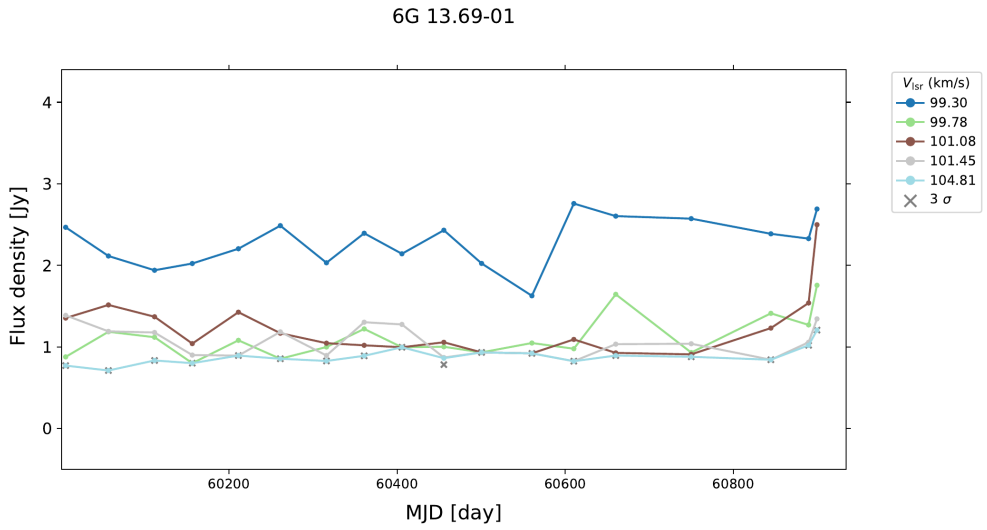


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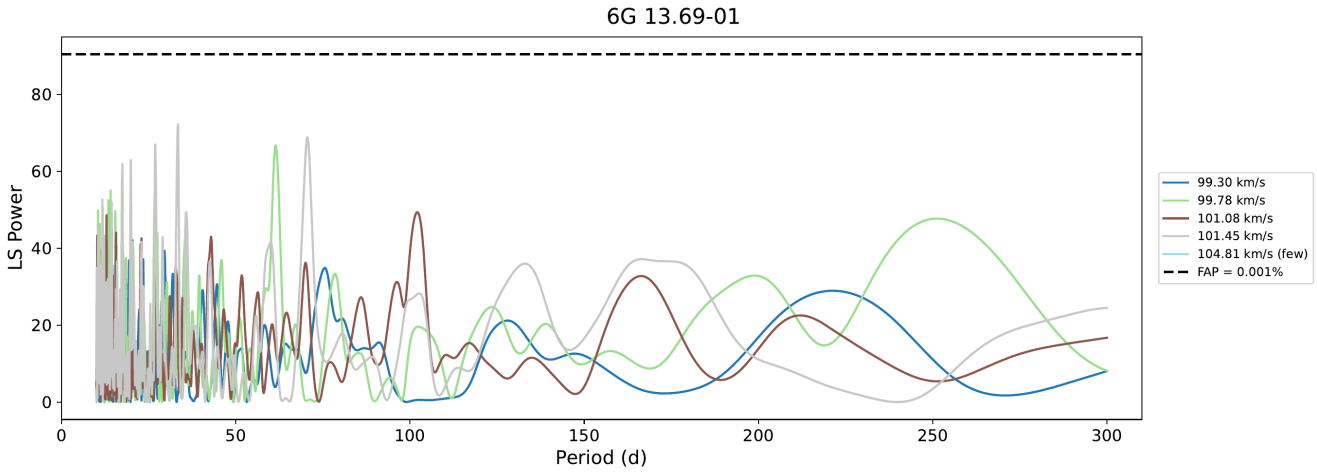


6G 13.69-01

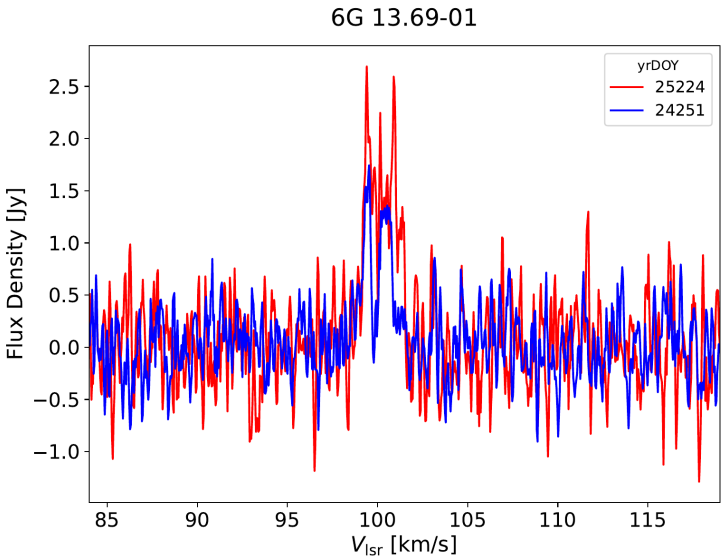
Light curve



Periodogram

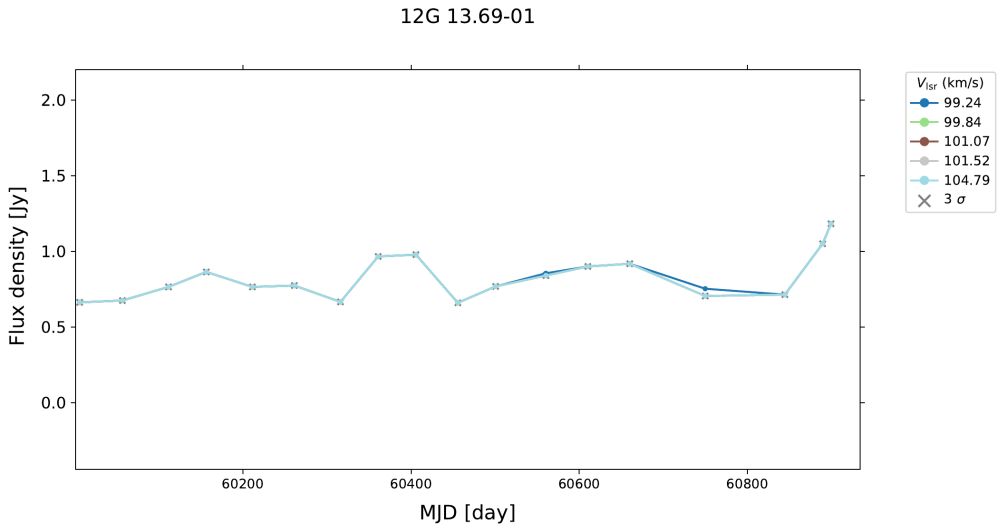


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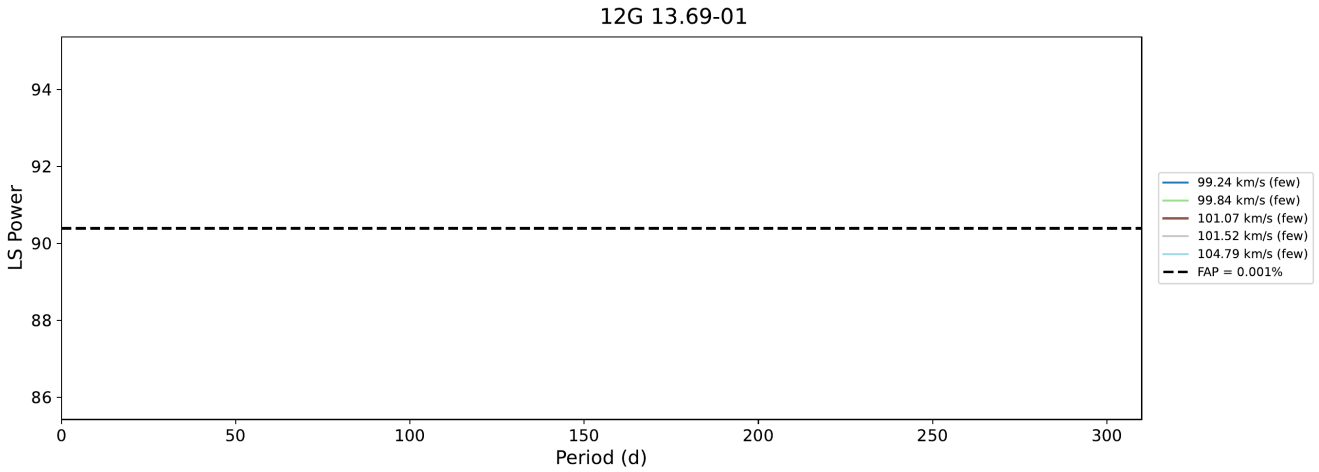


12G 13.69-01

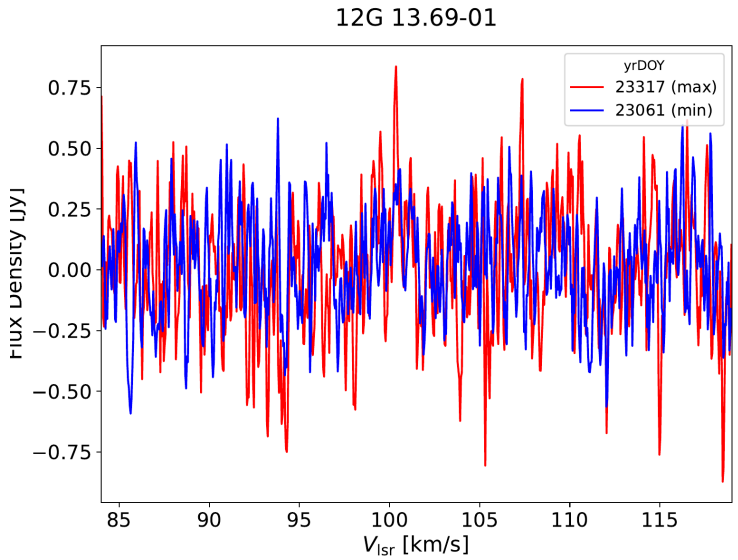
Light curve



Periodogram

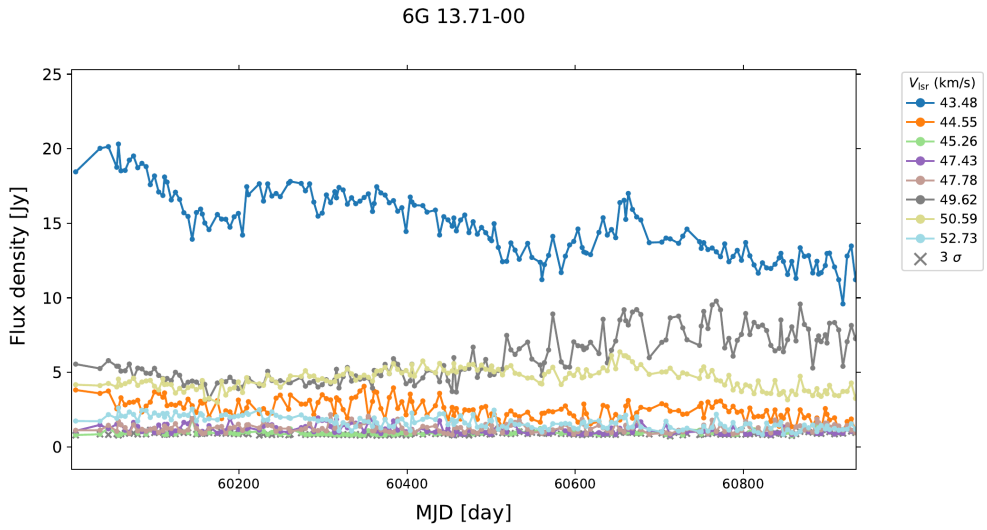


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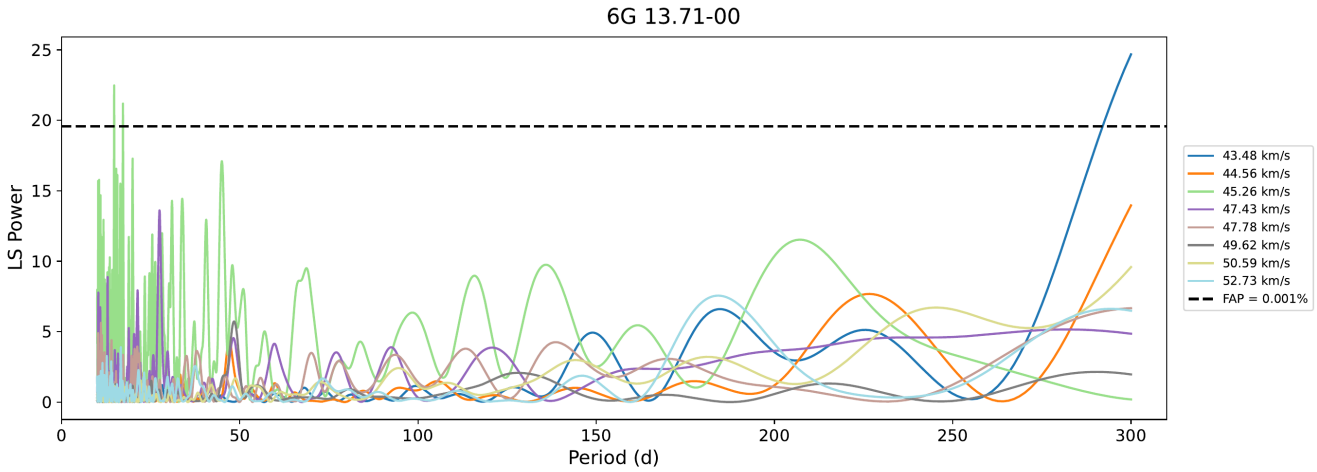


6G 13.71-00

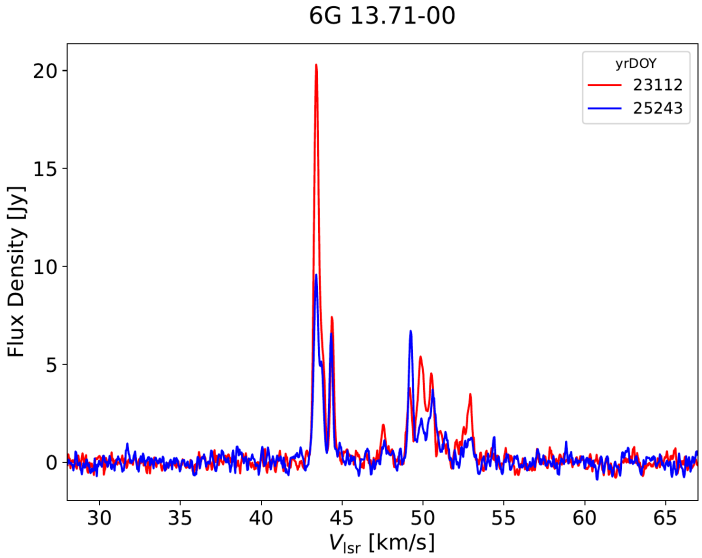
Light curve



Periodogram

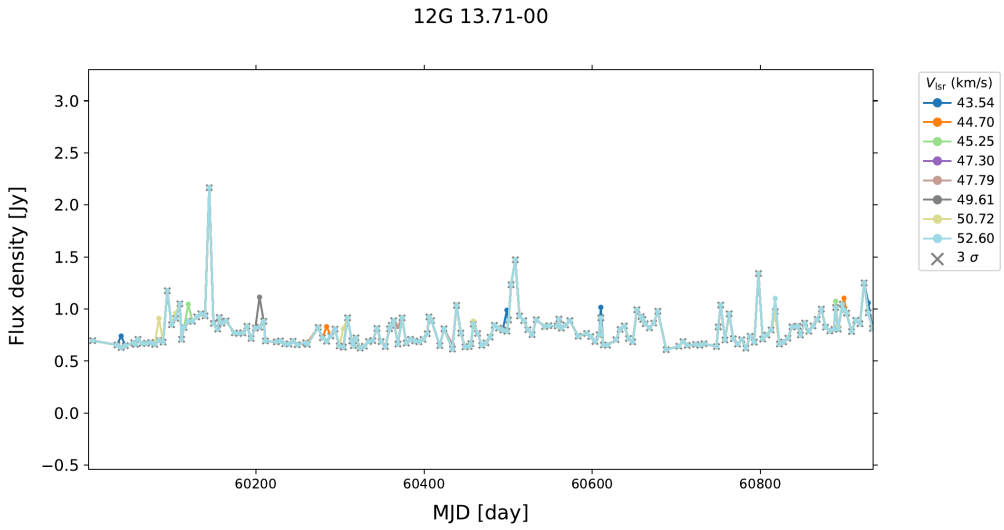


Spectrum

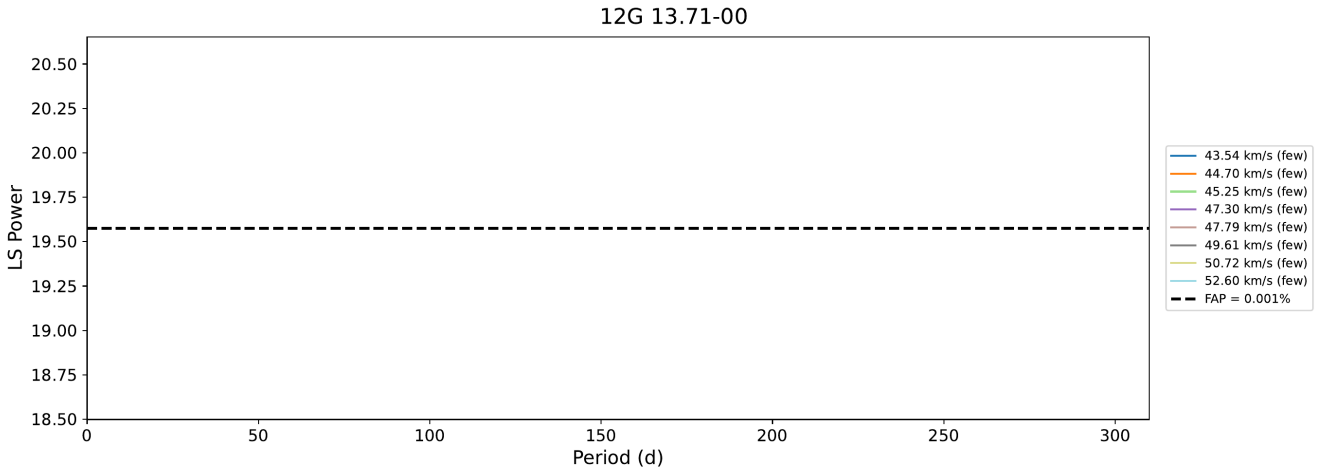


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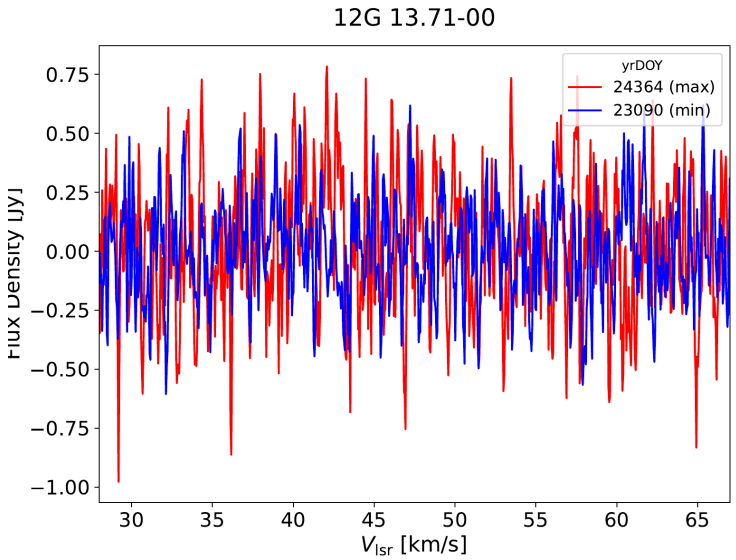
Light curve



Periodogram

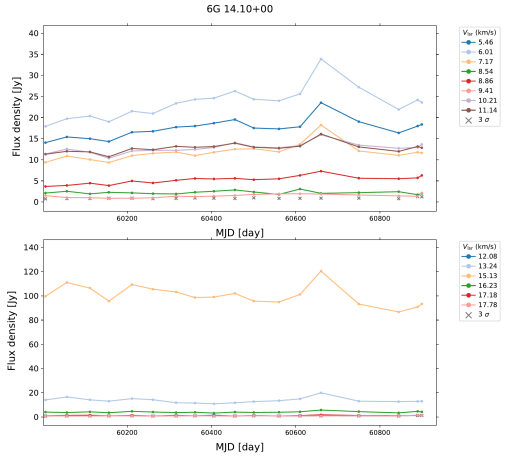


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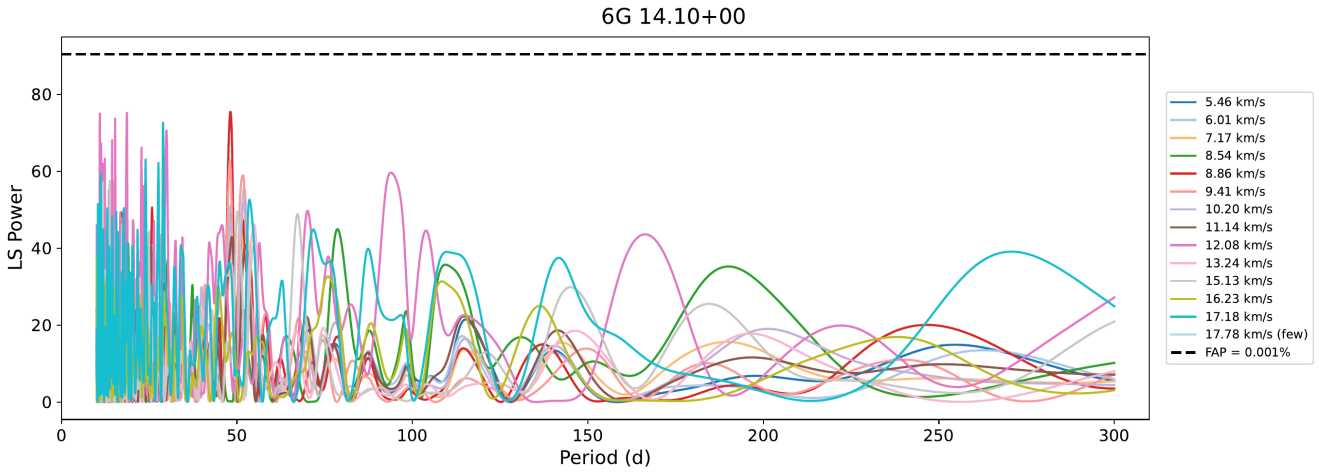


6G 14.10+00

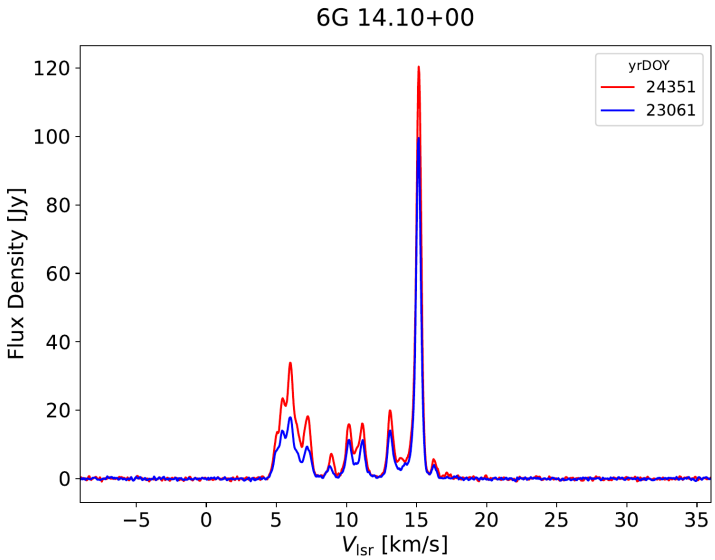
Light curve



Periodogram

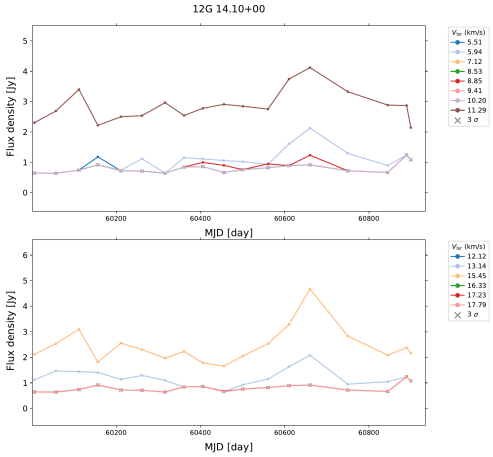


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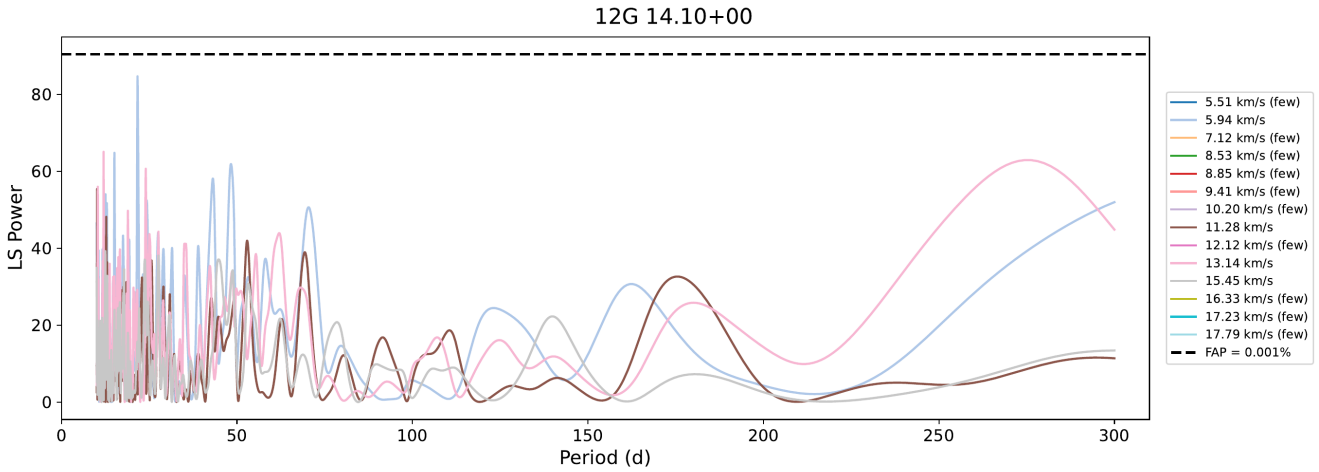


12G 14.10+00

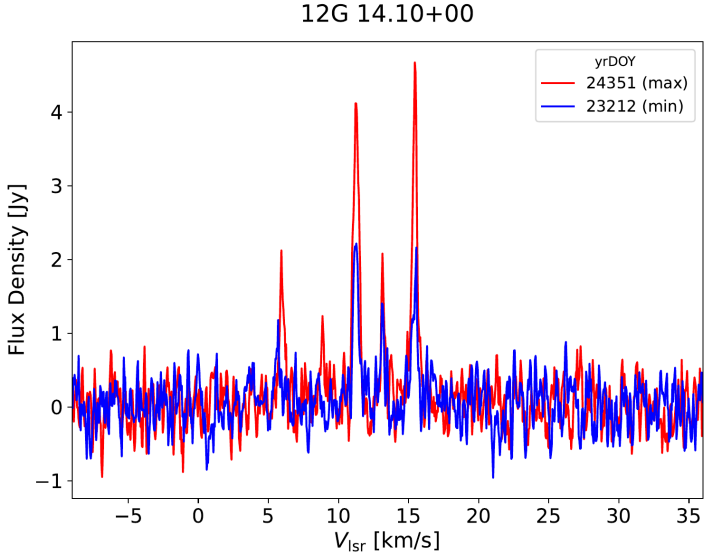
Light curve



Periodogram

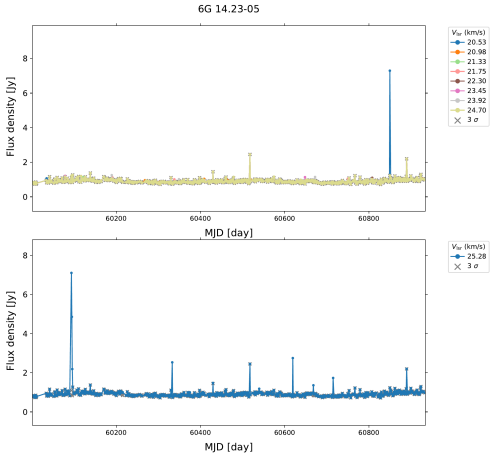


Spectrum

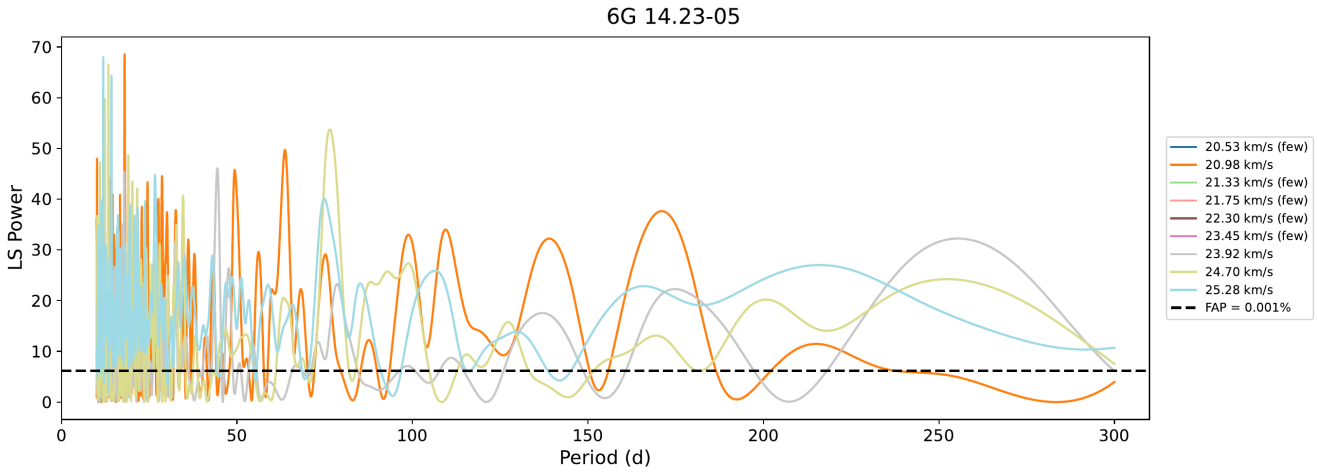


6G 14.23-05

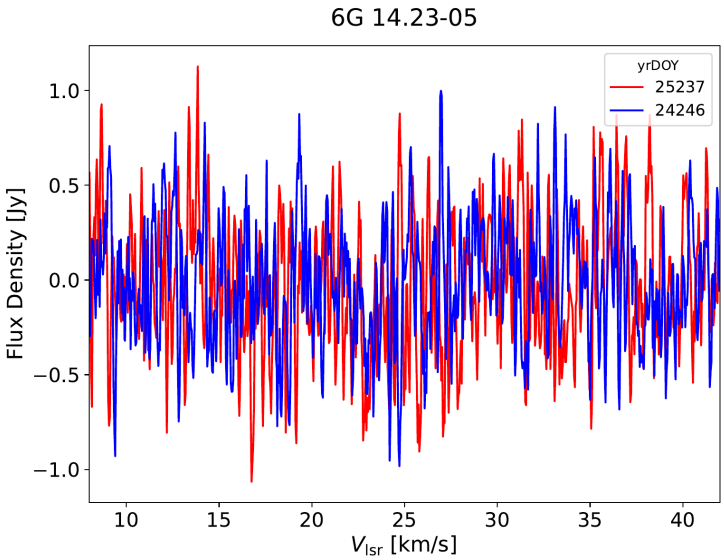
Light curve



Periodogram

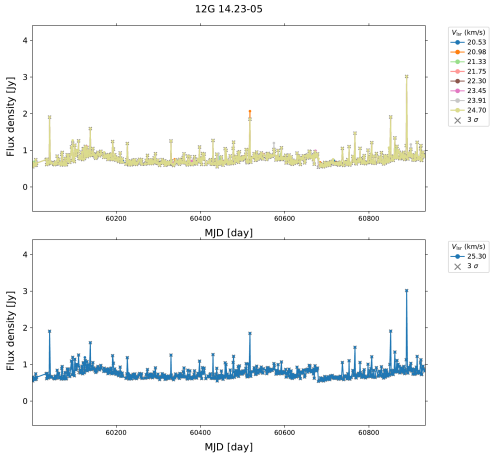


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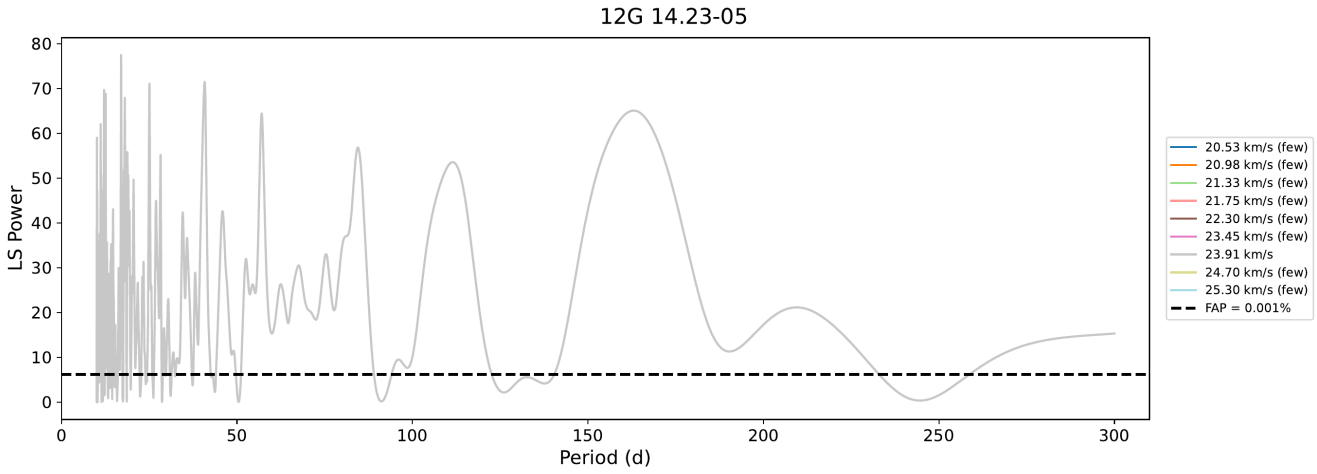


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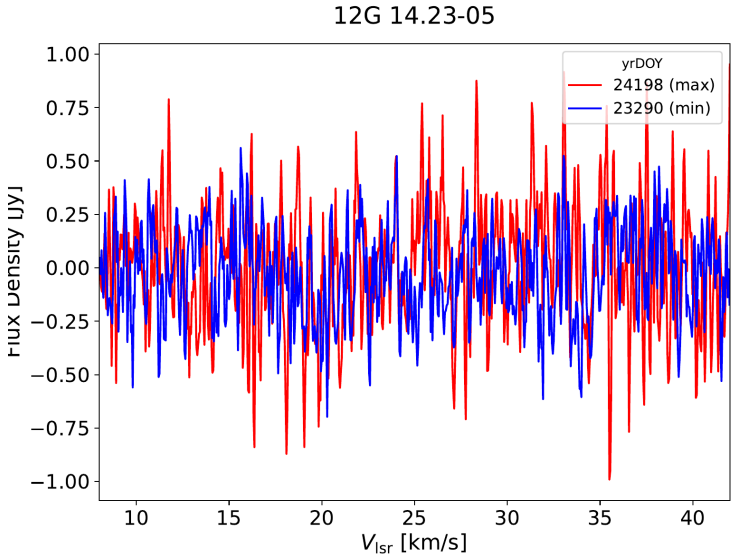
Light curve



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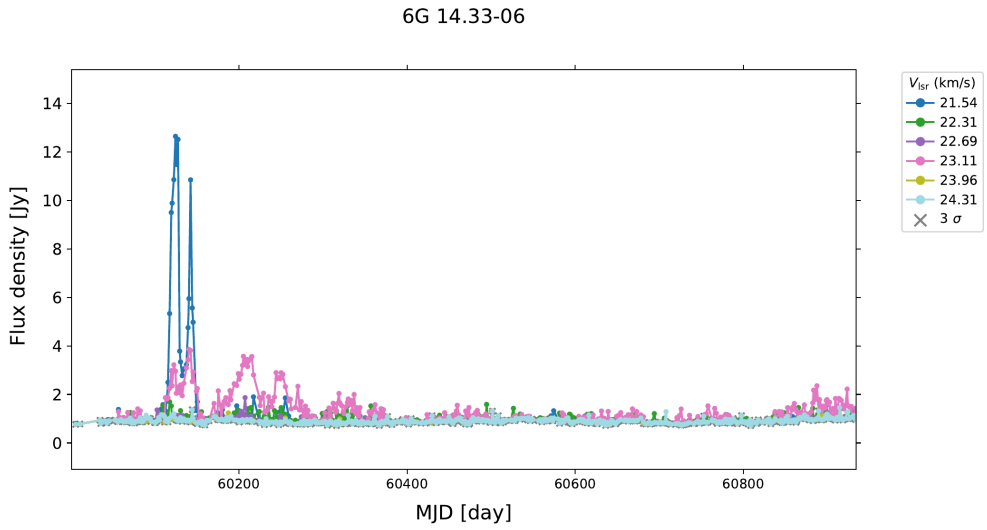


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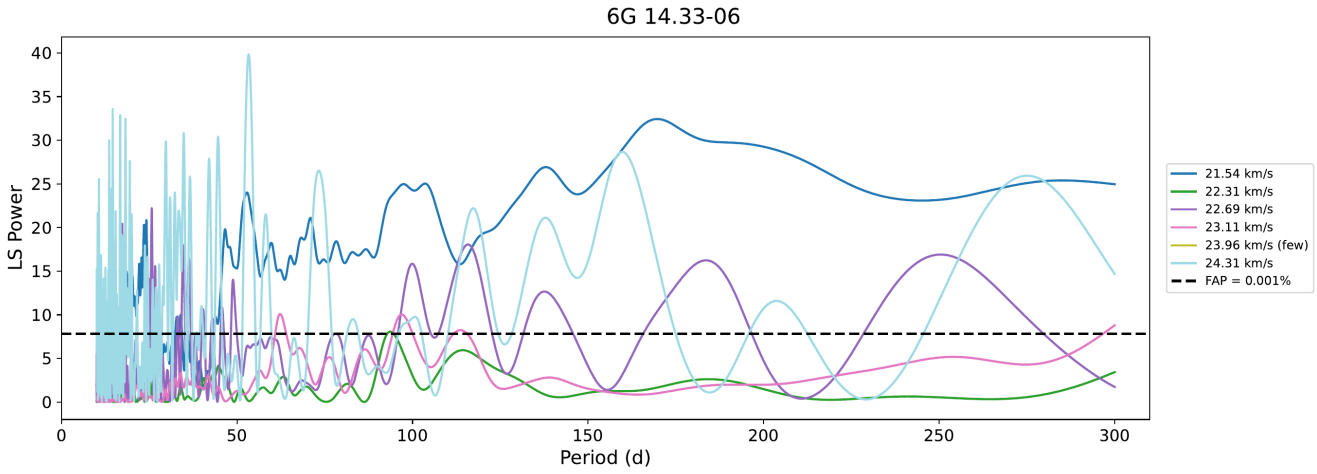


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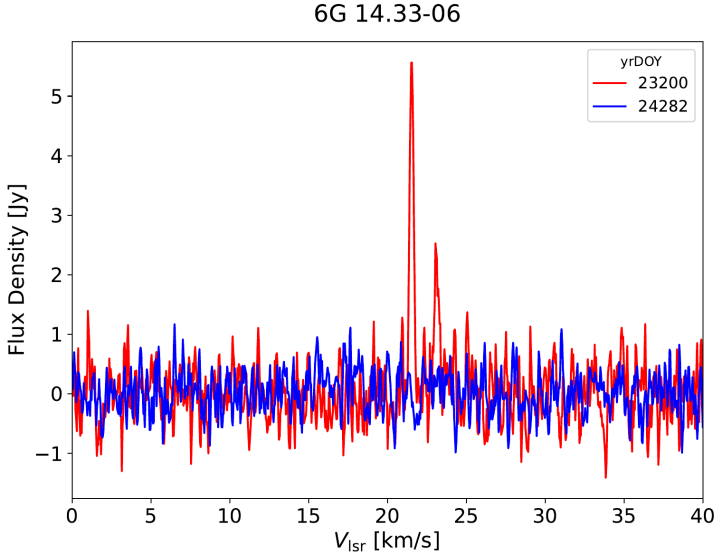
Light curve



Periodogram

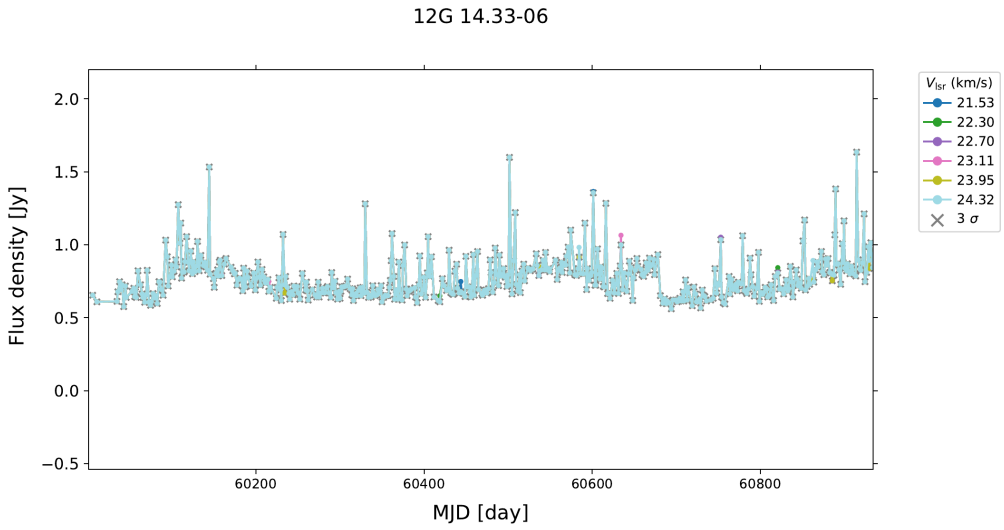


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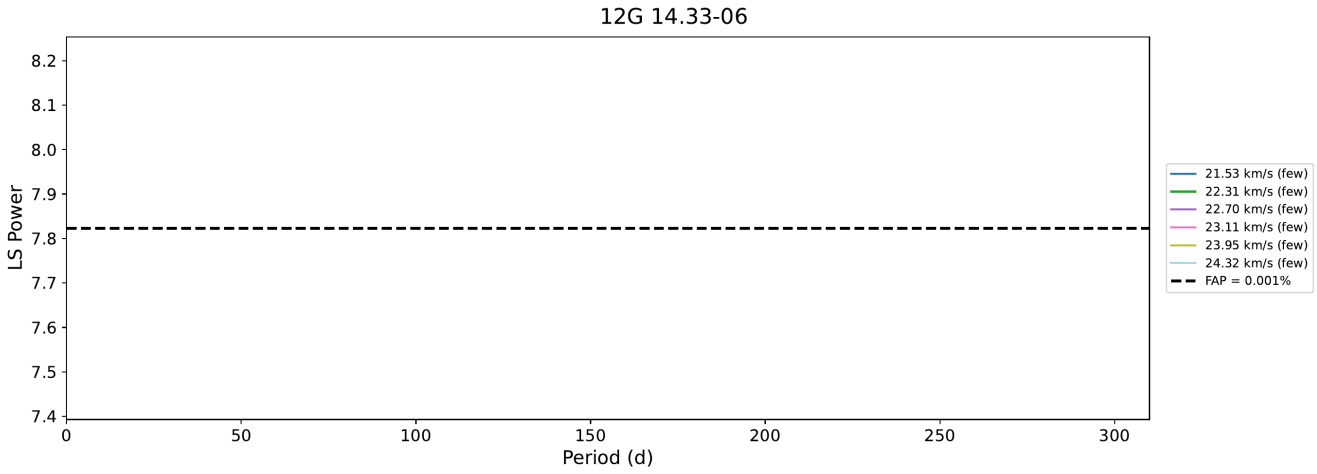


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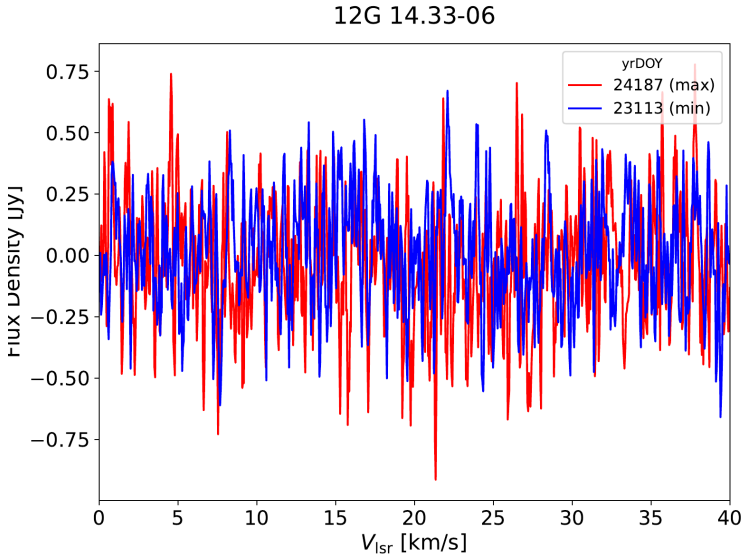
Light curve



Periodogram

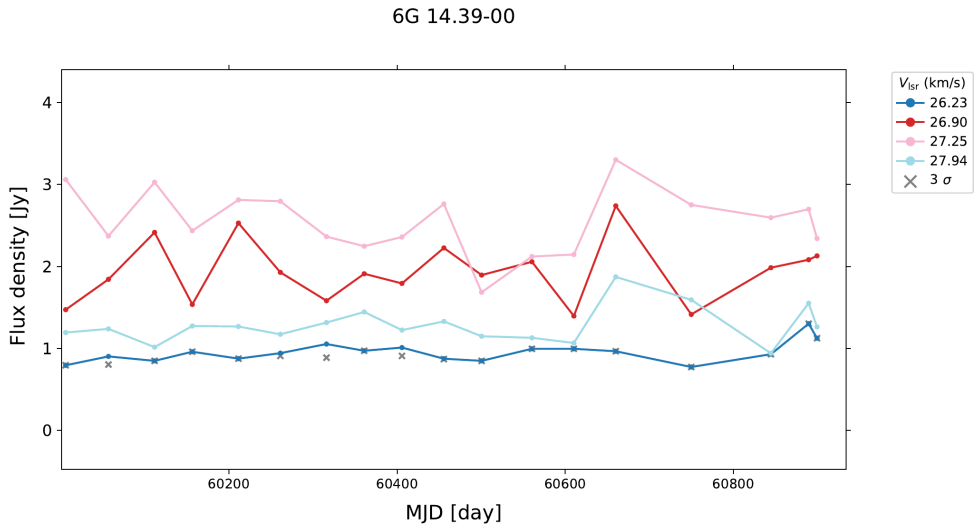


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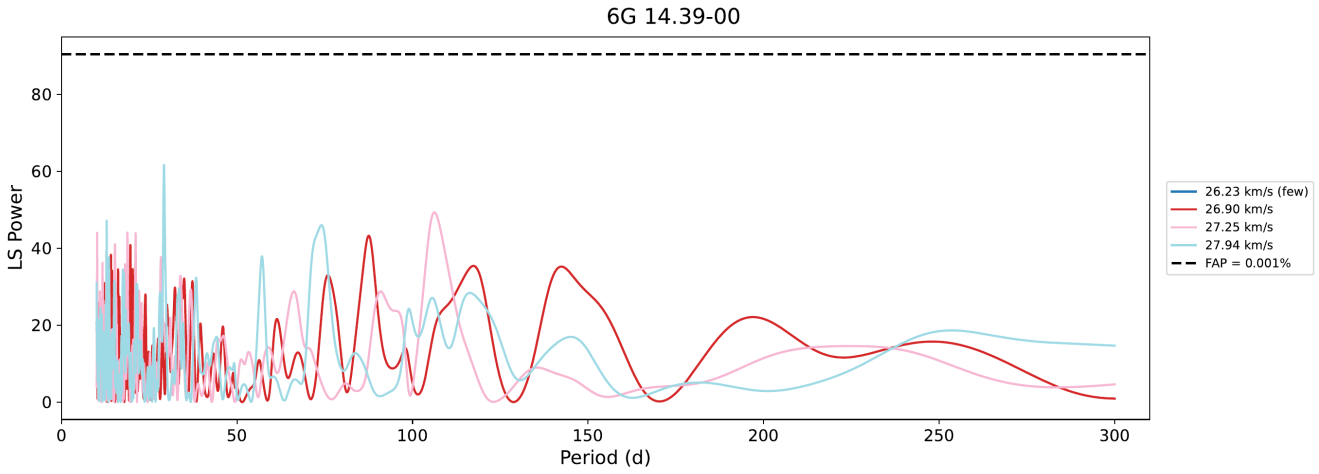


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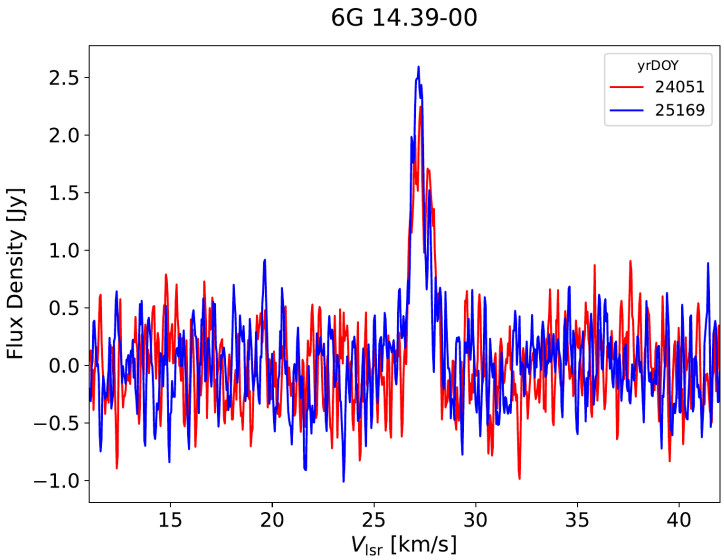
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Periodogram

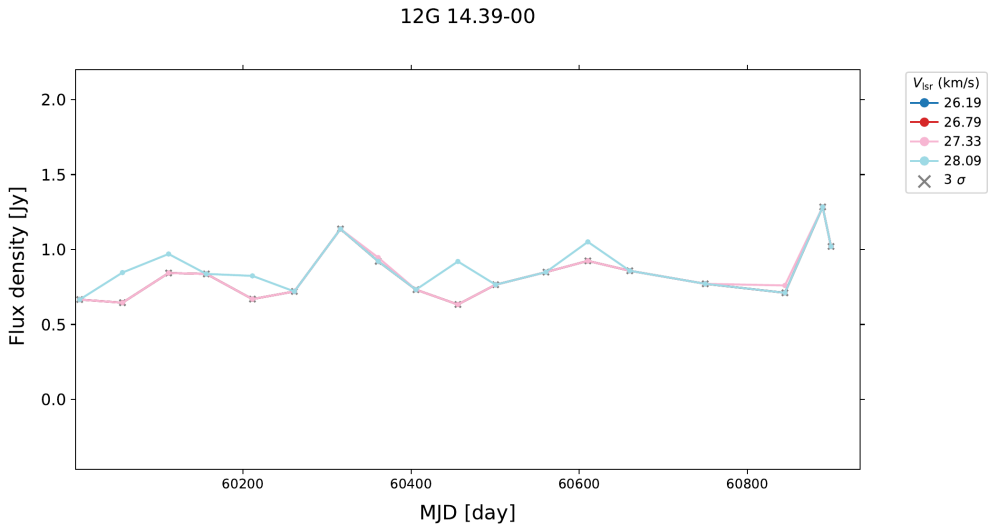


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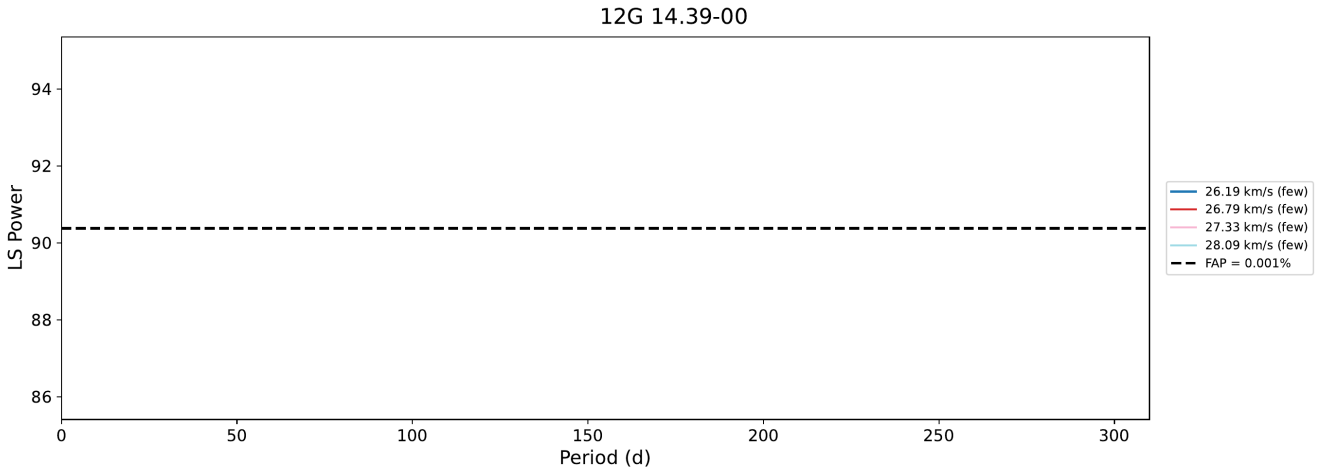


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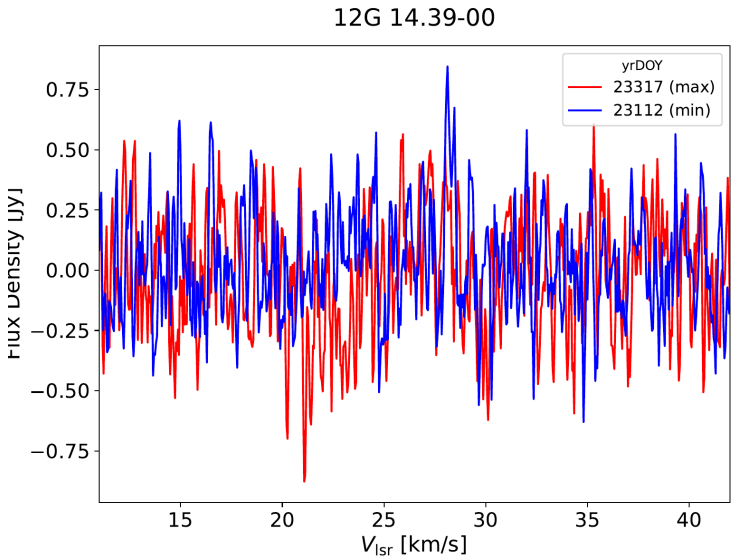
Light curve



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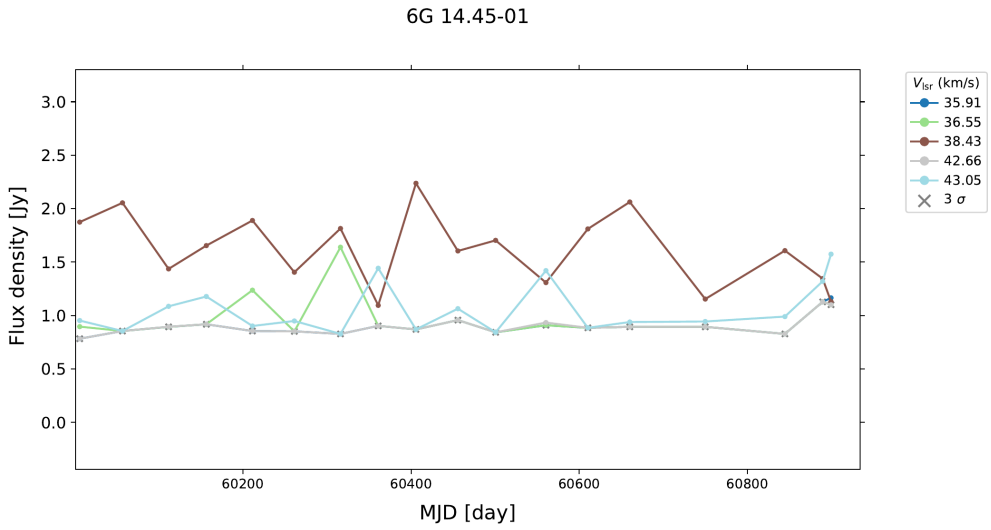


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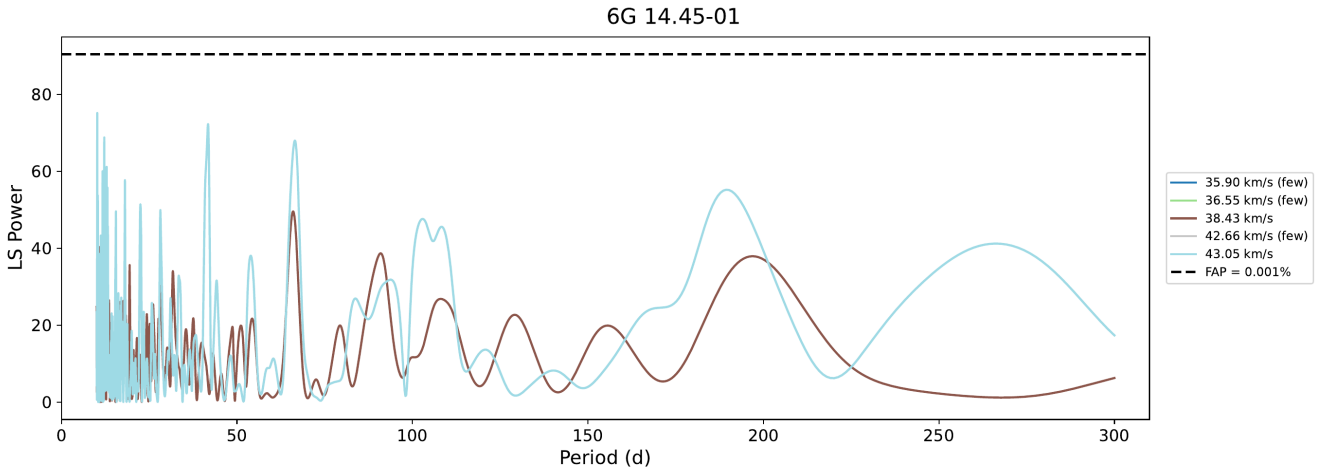


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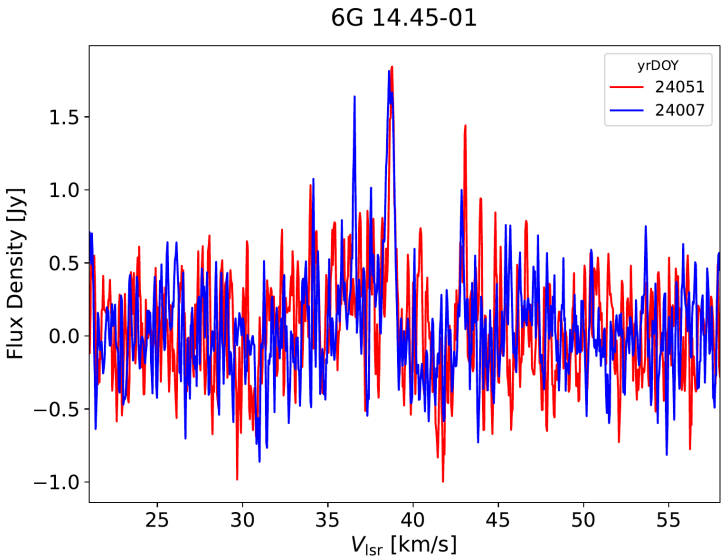
Light curve



Periodogram

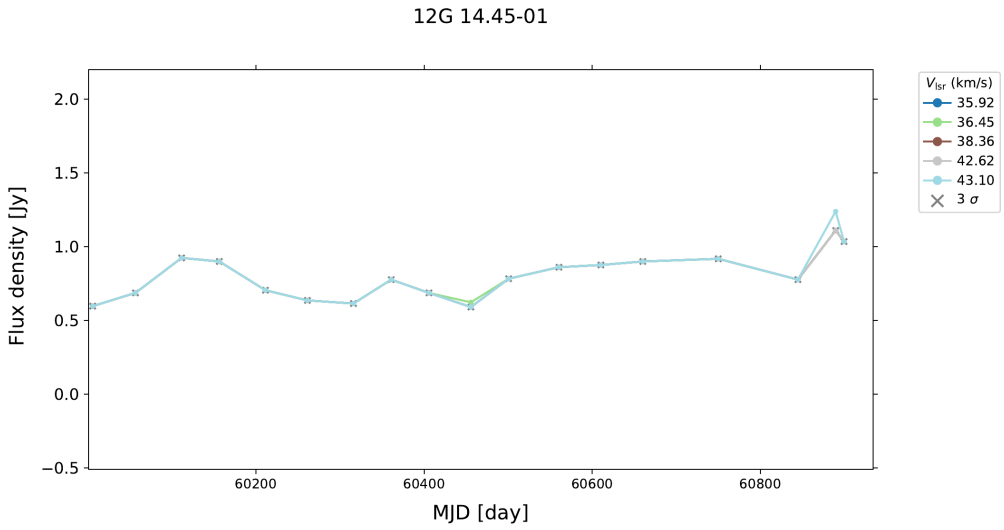


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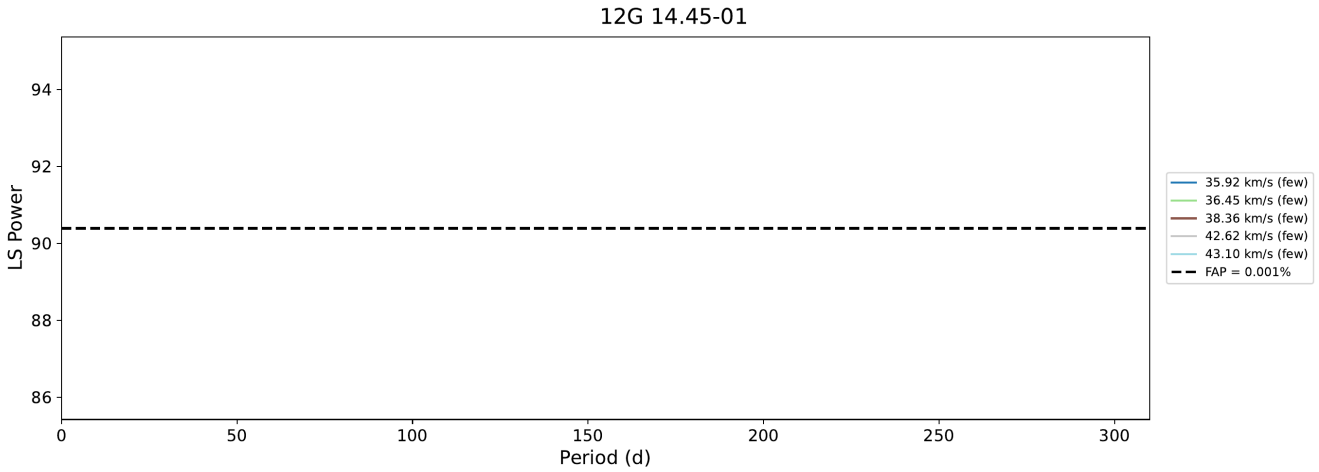


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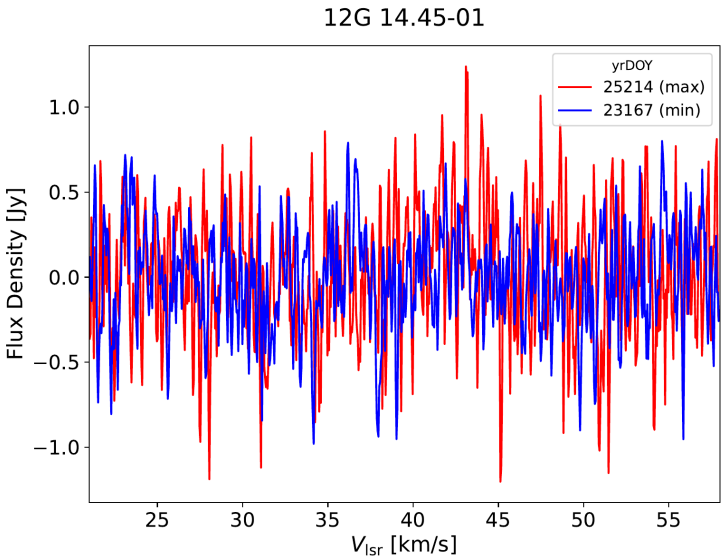
Light curve



Periodogram

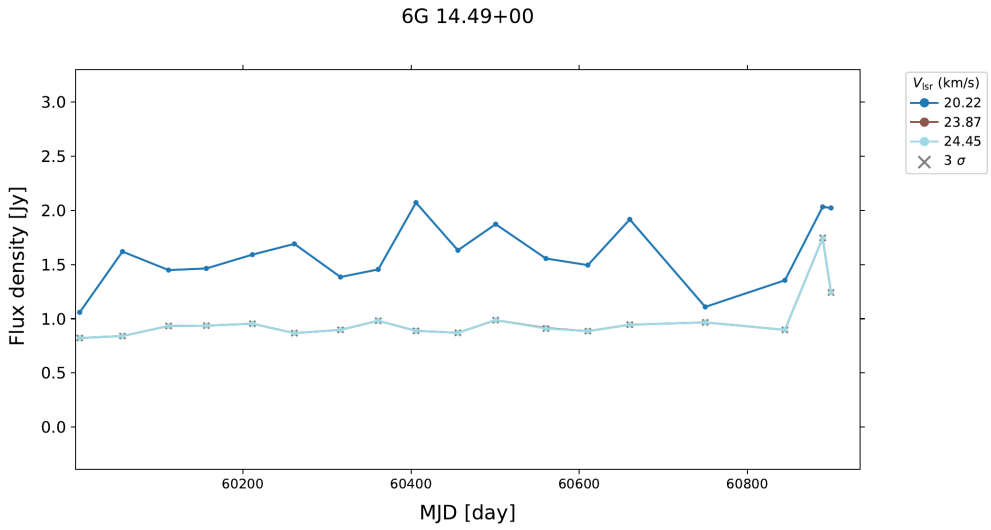


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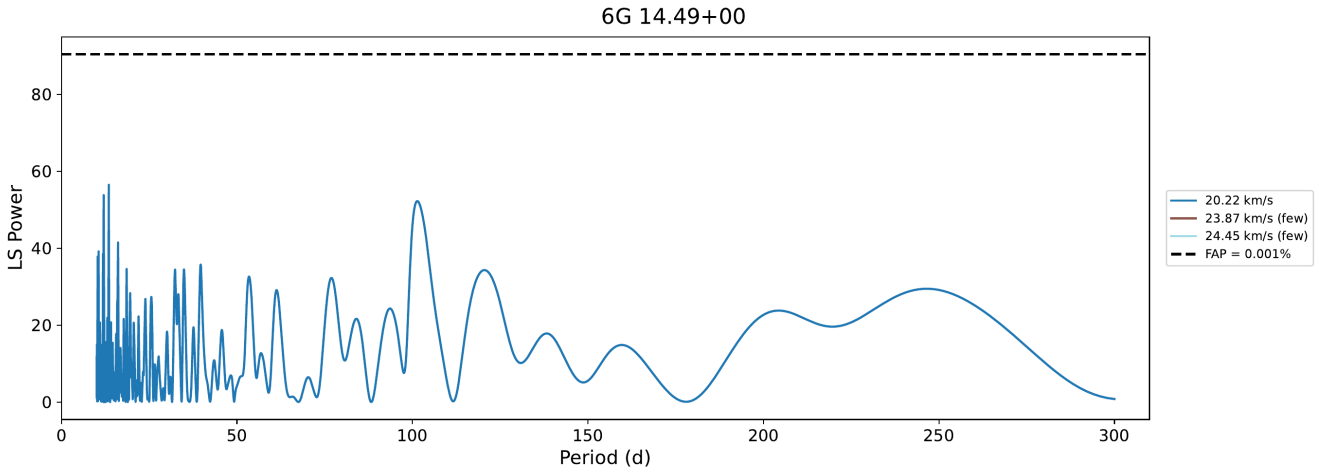


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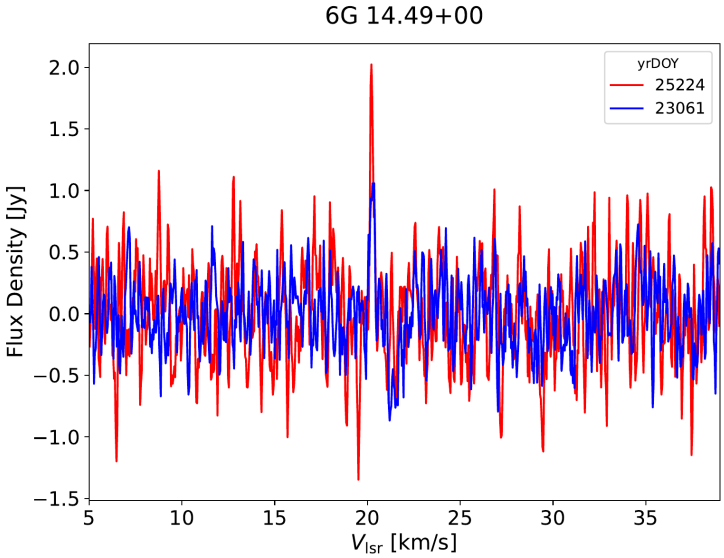
Light curve



Periodogram

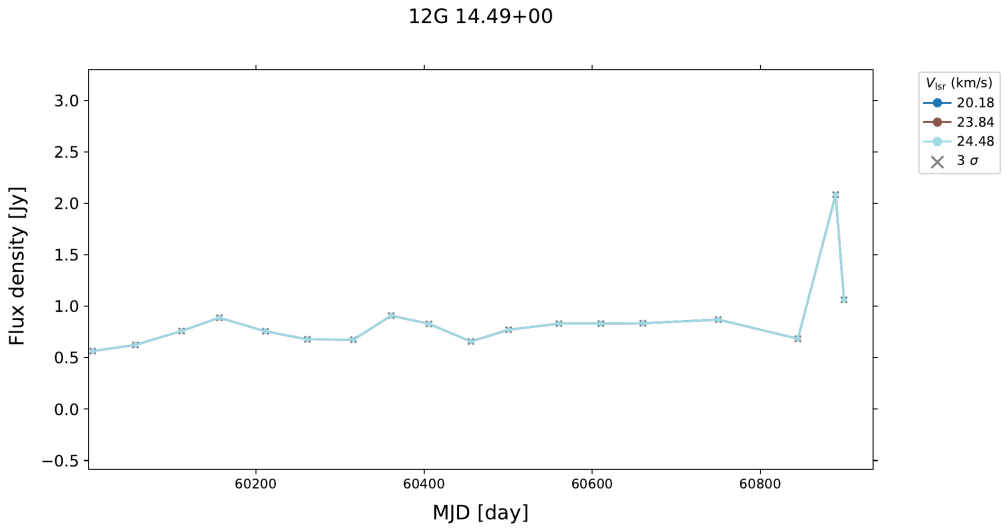


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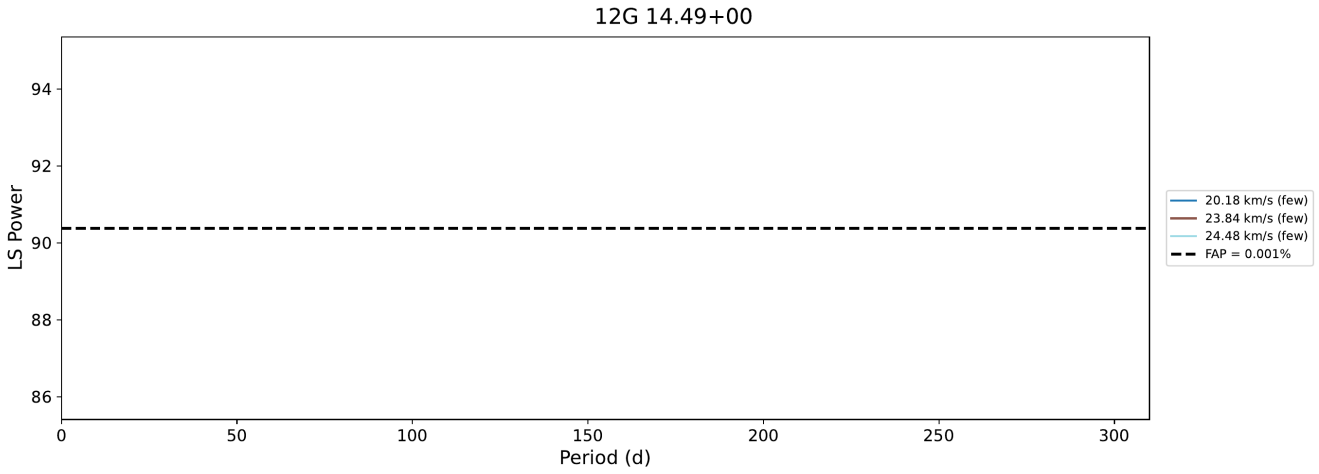


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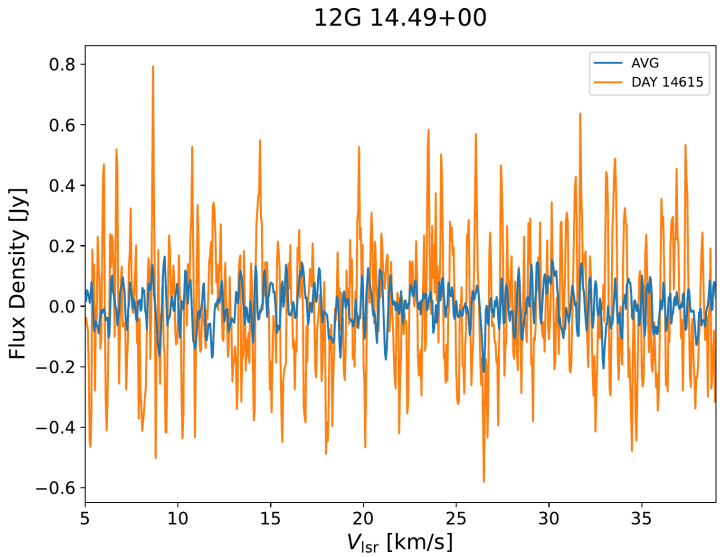
Light curve



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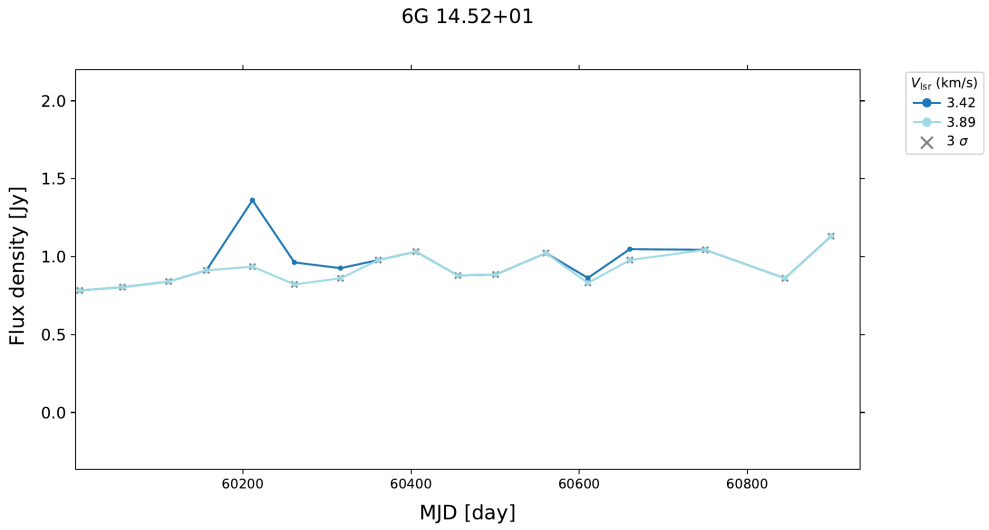


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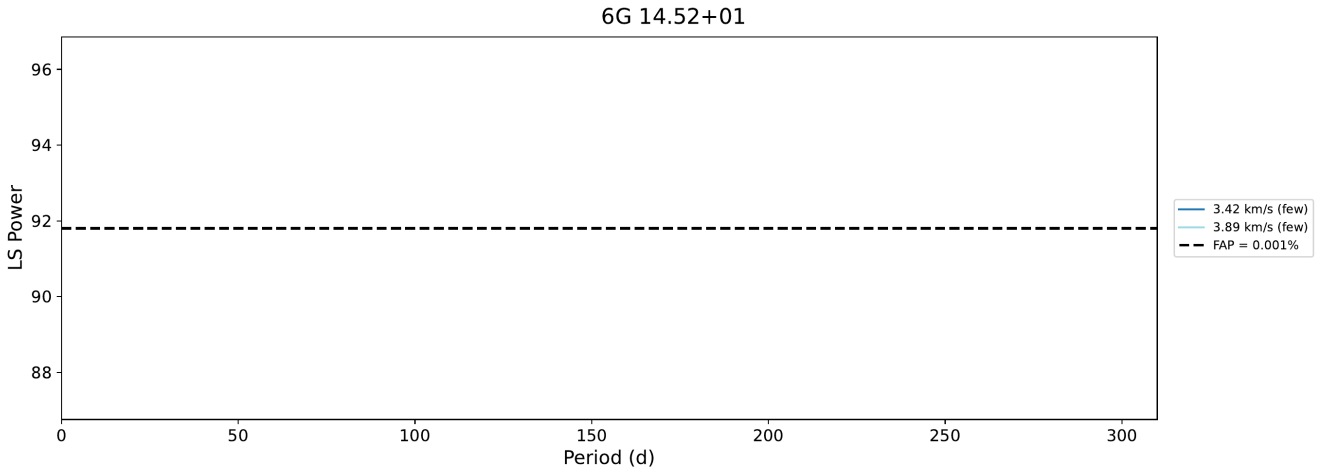


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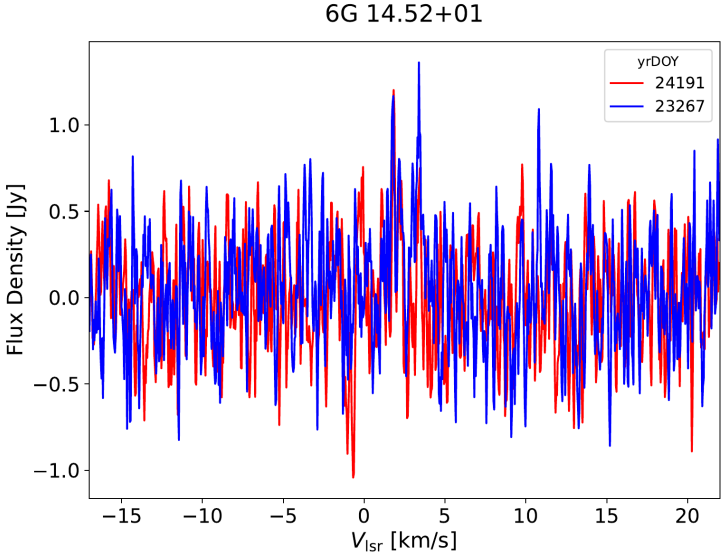
Light curve



Periodogram

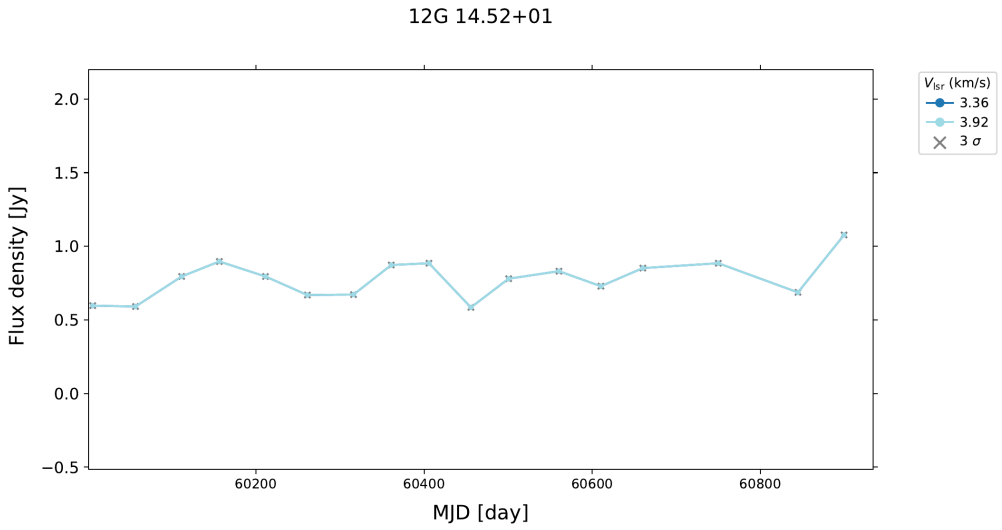


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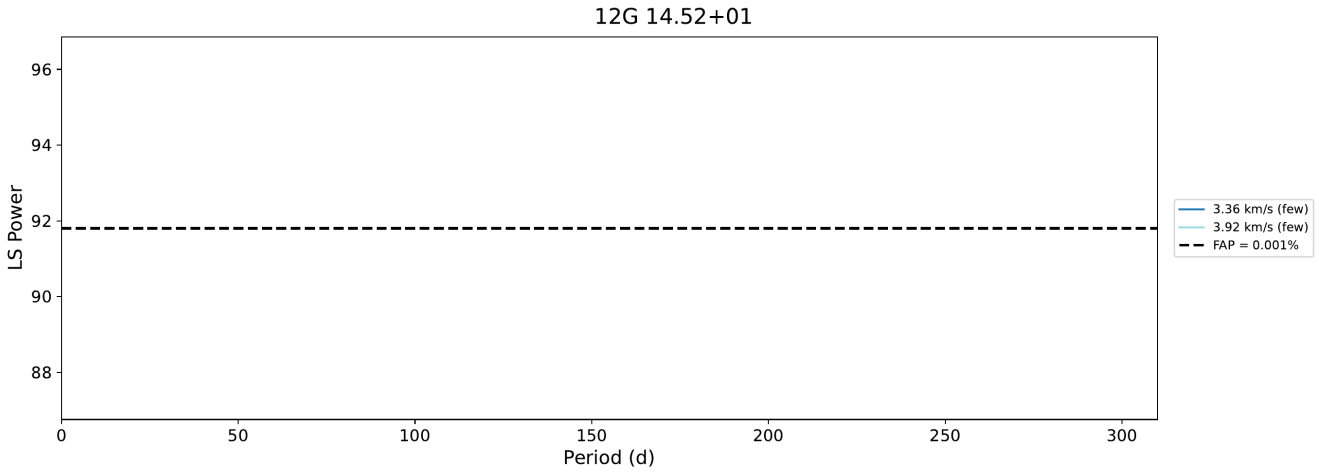


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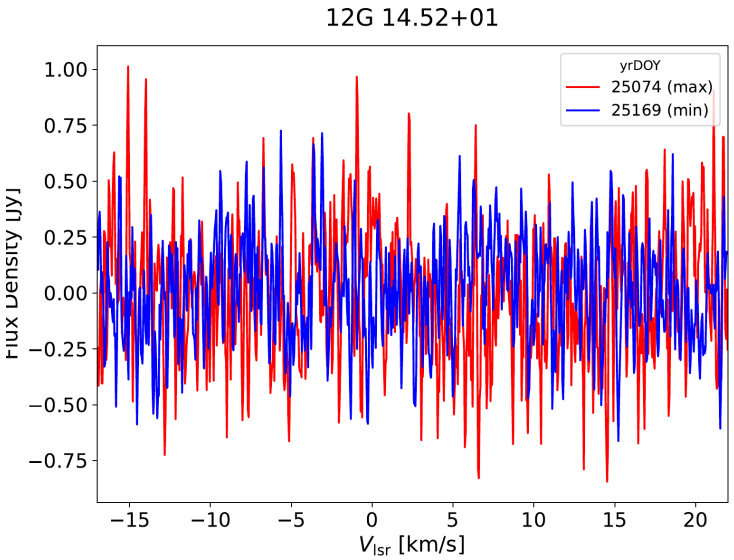
Light curve



Periodogram

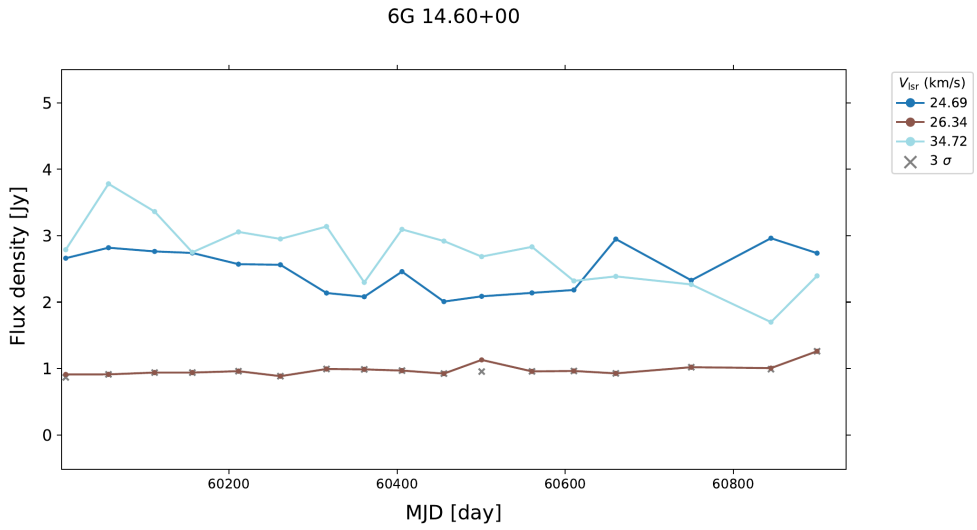


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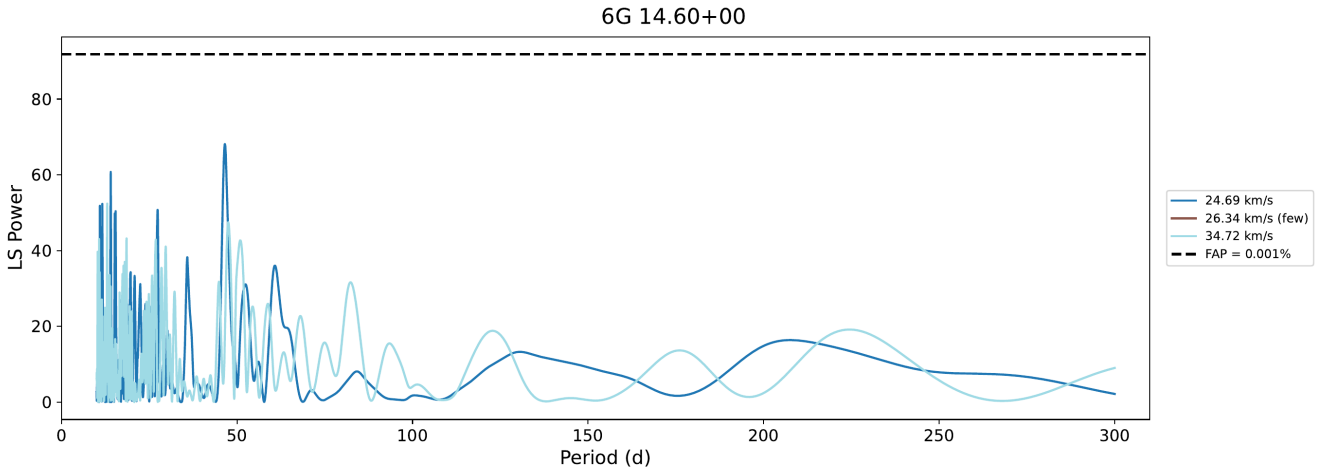


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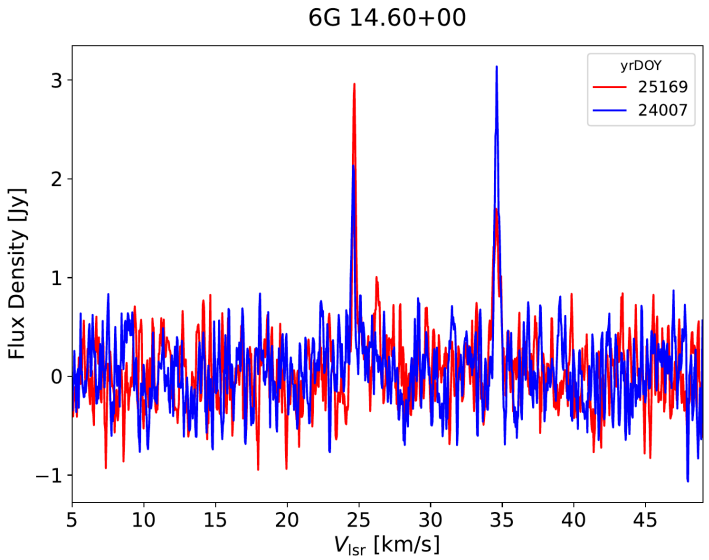
Light curve



Periodogram

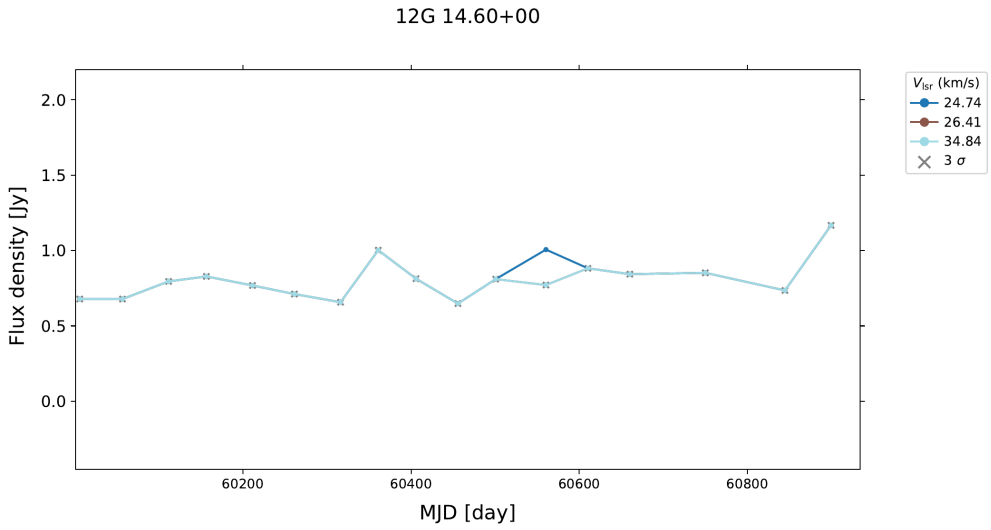


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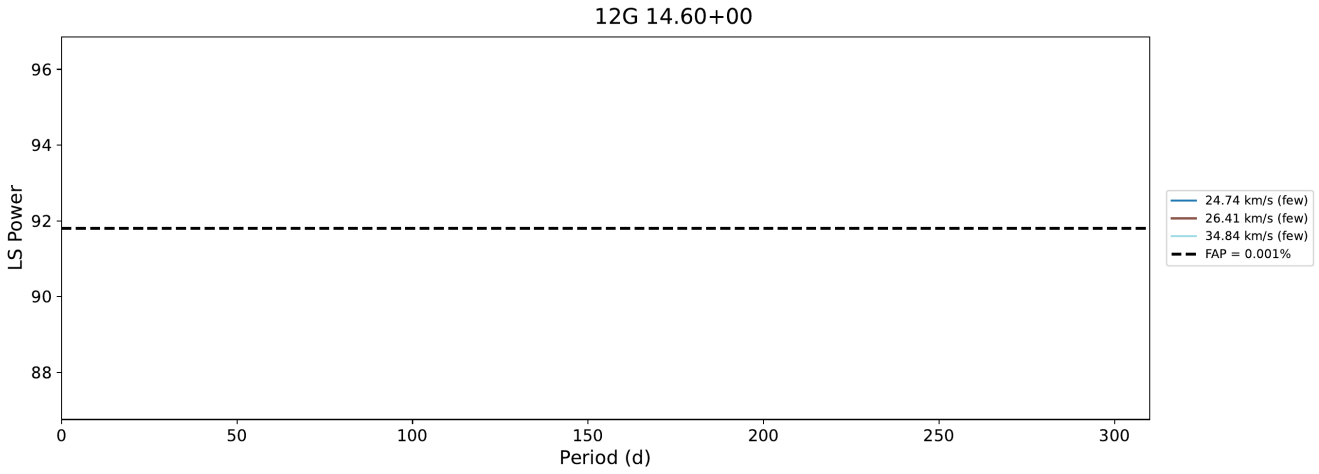


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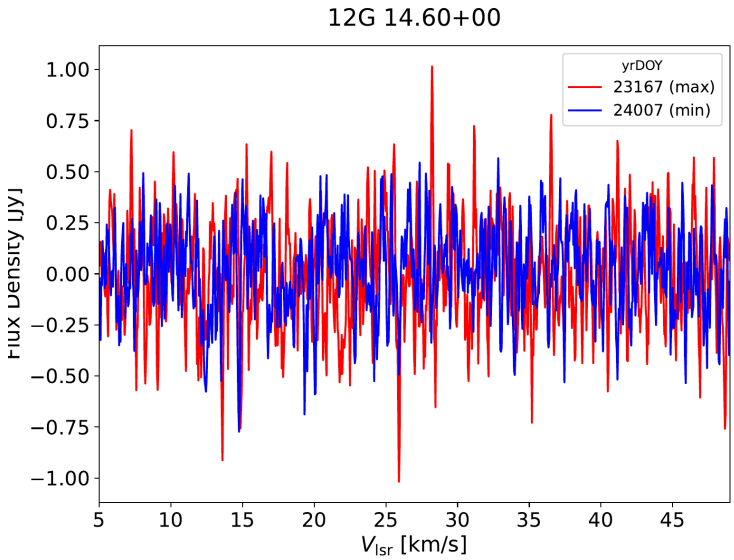
Light curve



Periodogram

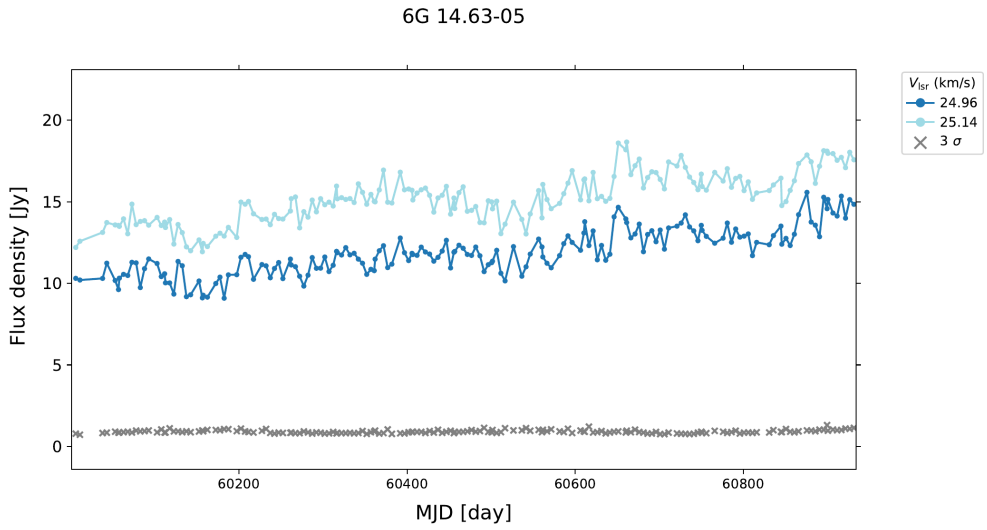


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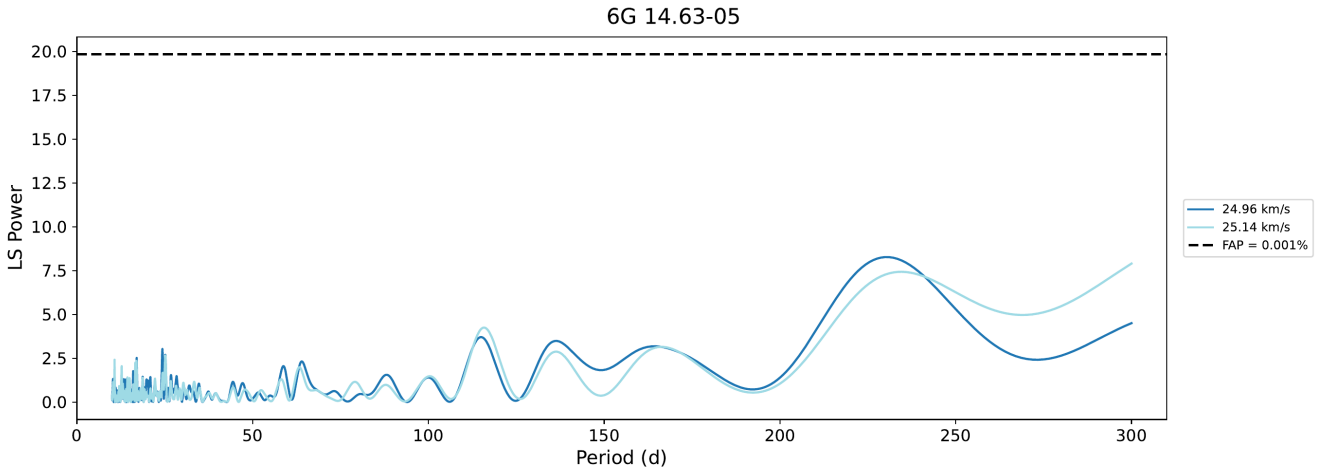


6G 14.63-05

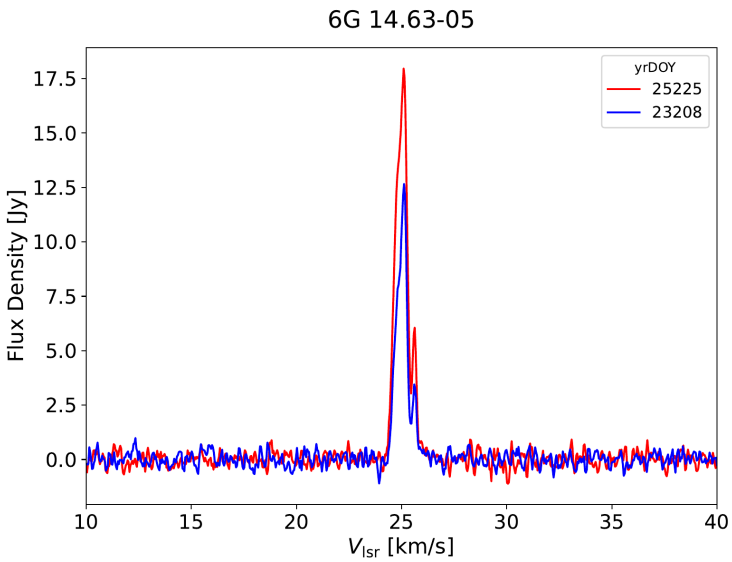
Light curve



Periodogram

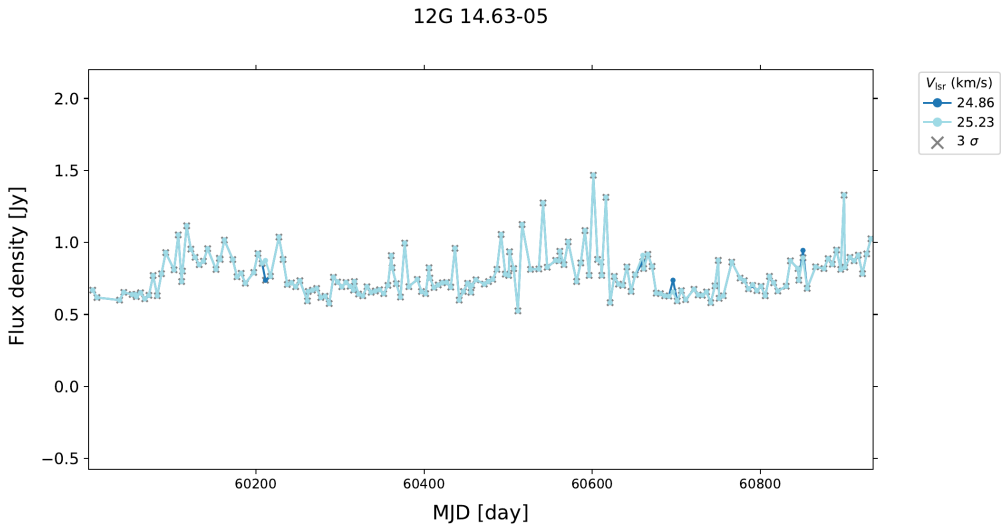


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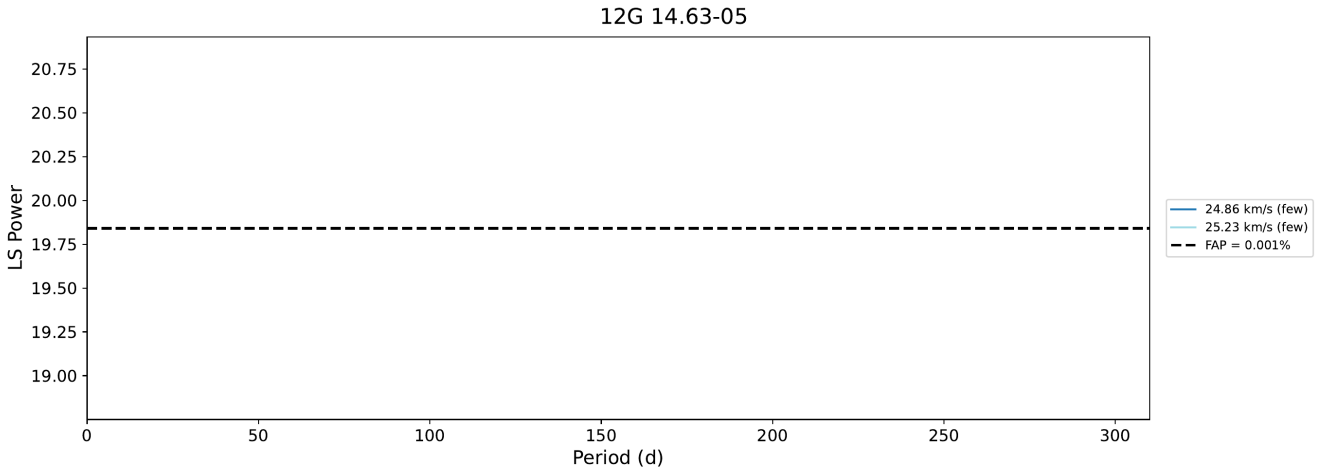


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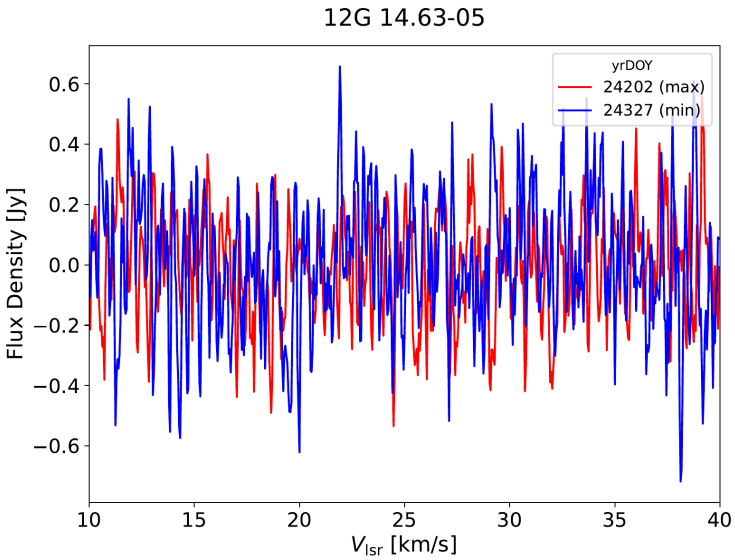
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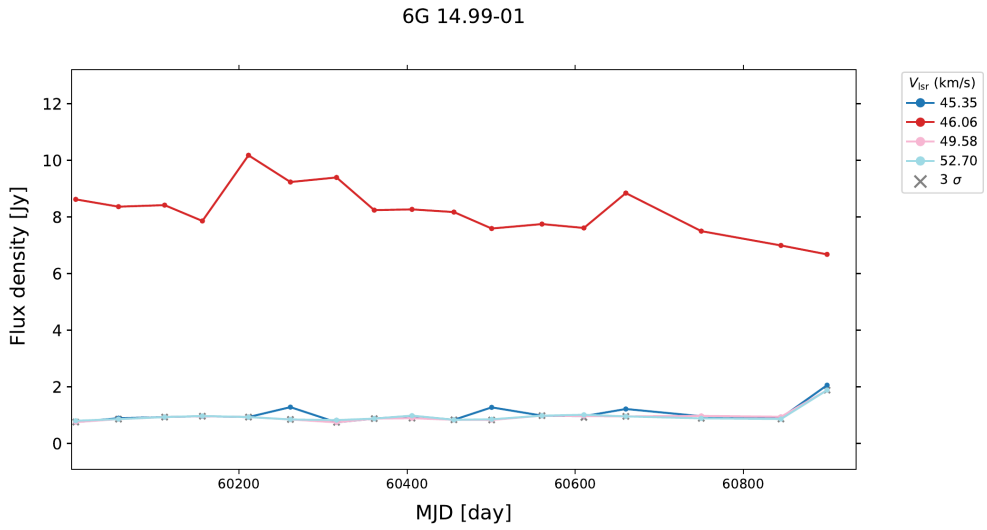


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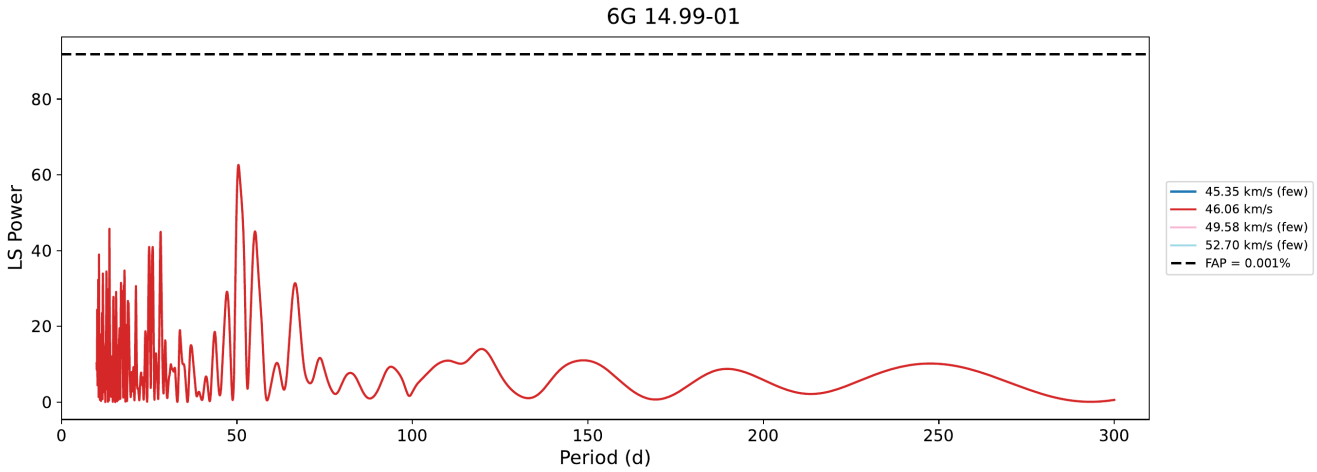


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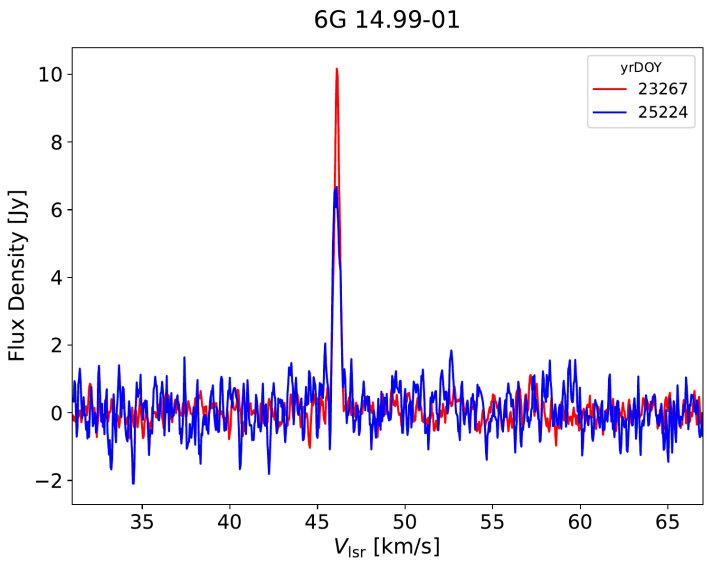
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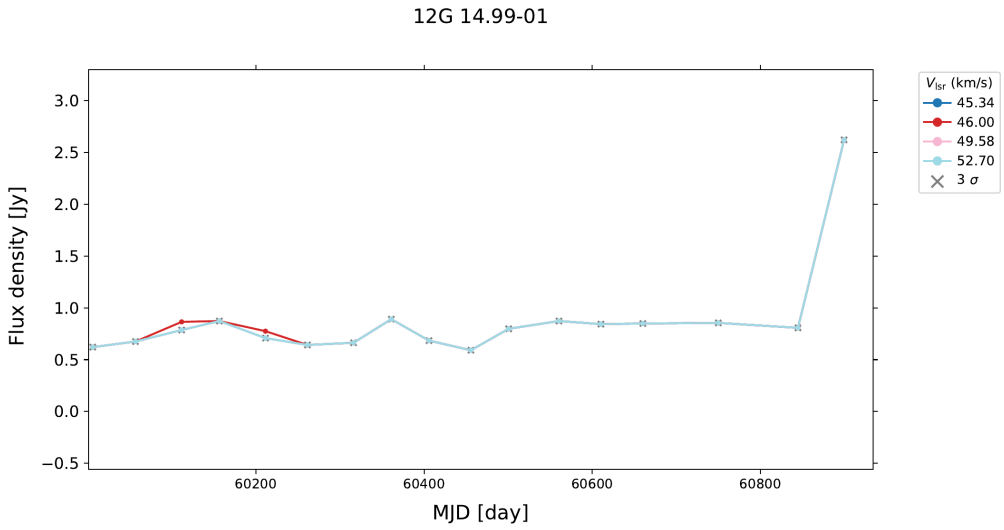


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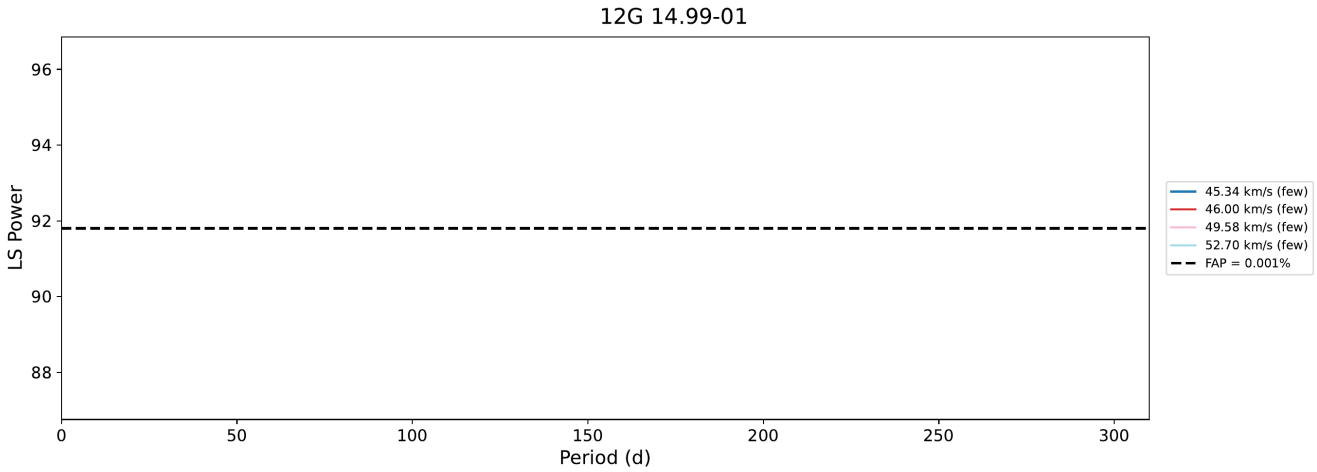


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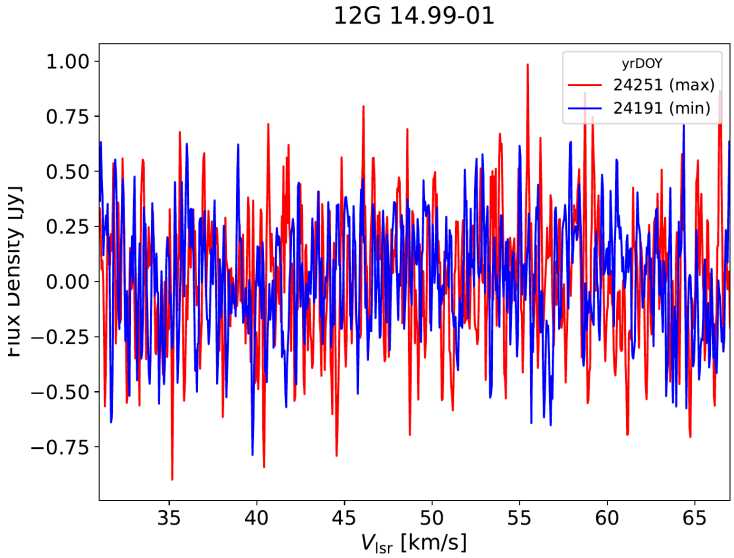
Light curve



Periodogram

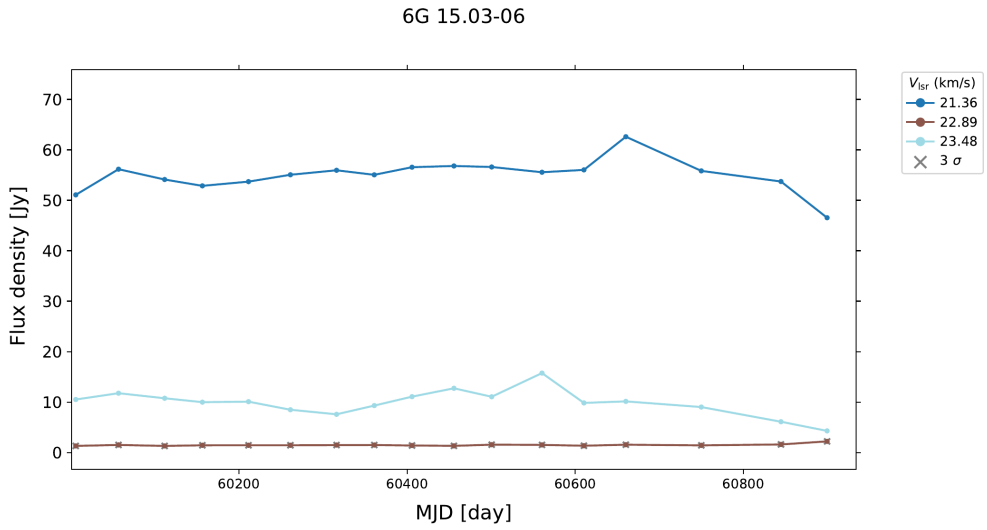


Spectrum

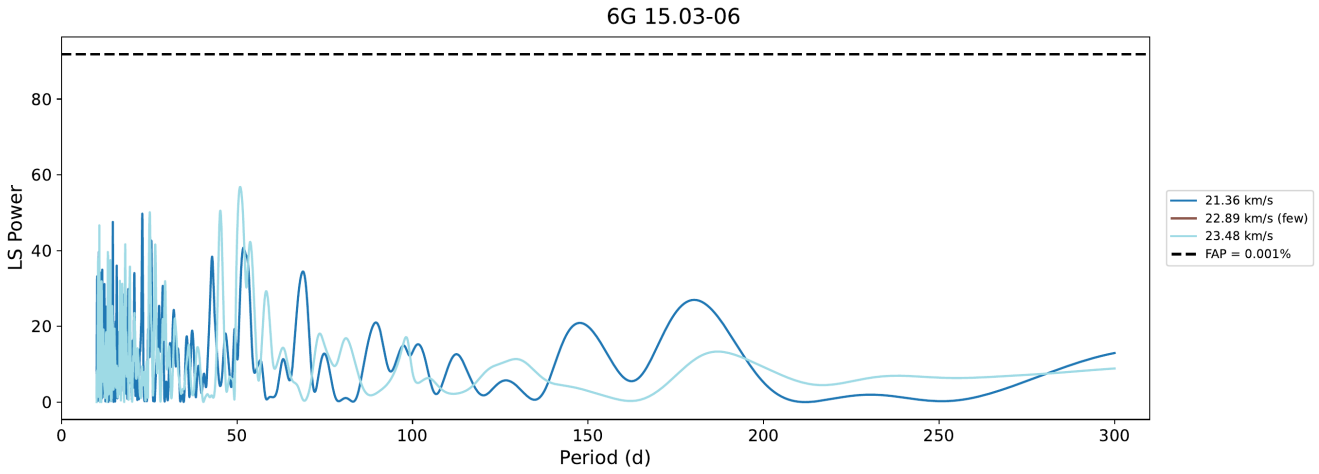


6G 15.03-06

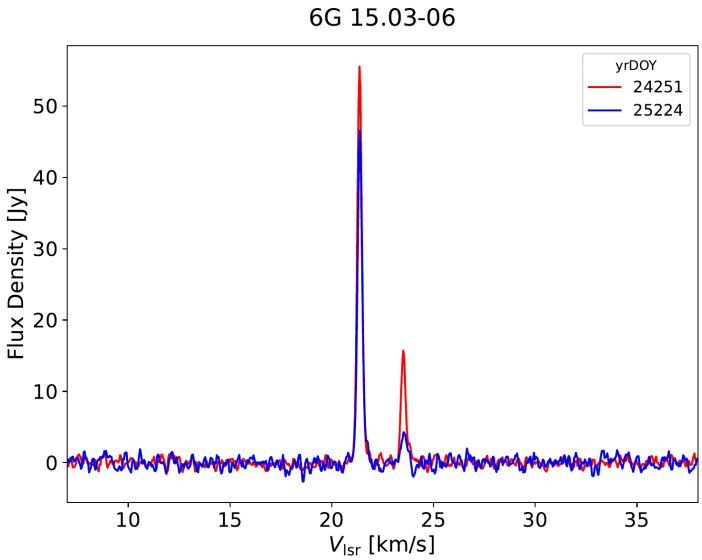
Light curve



Periodogram

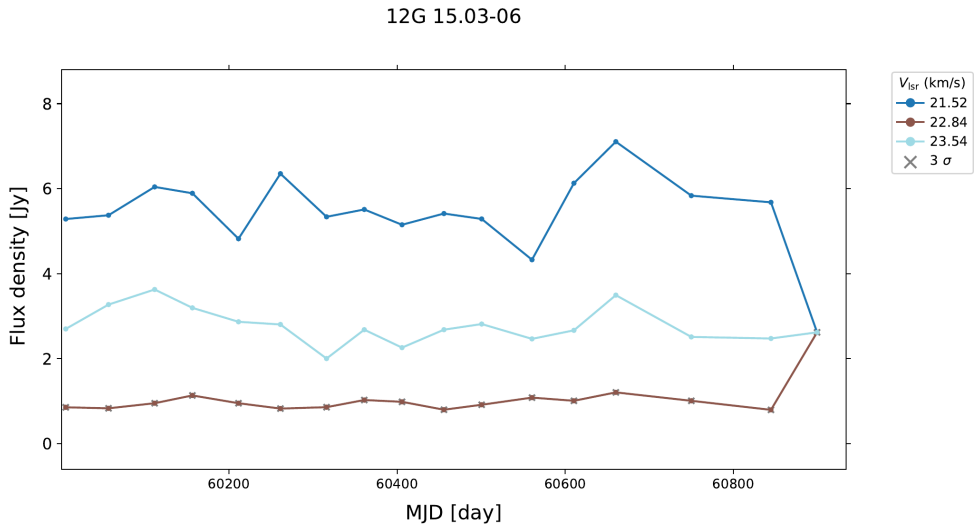


Spectrum

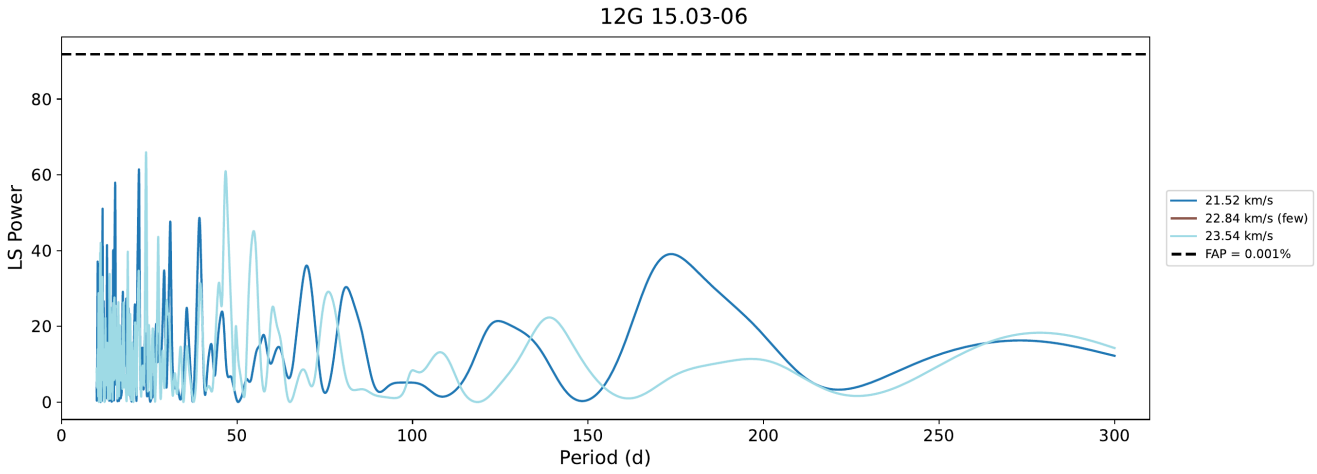


12G 15.03-06

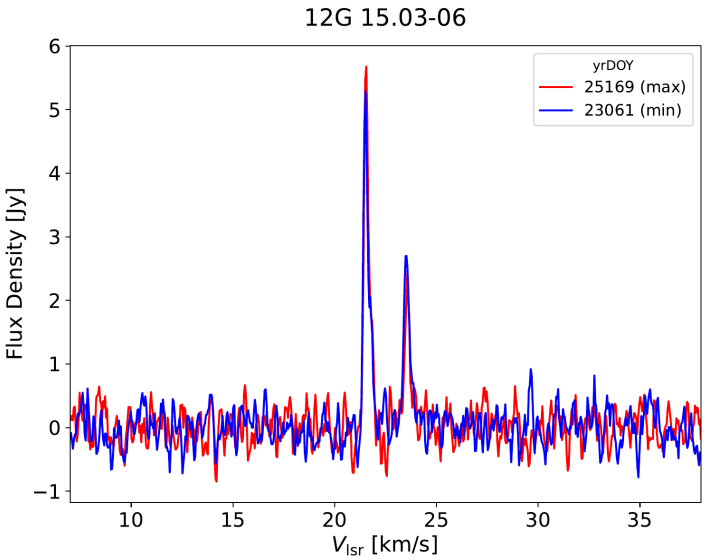
Light curve



Periodogram

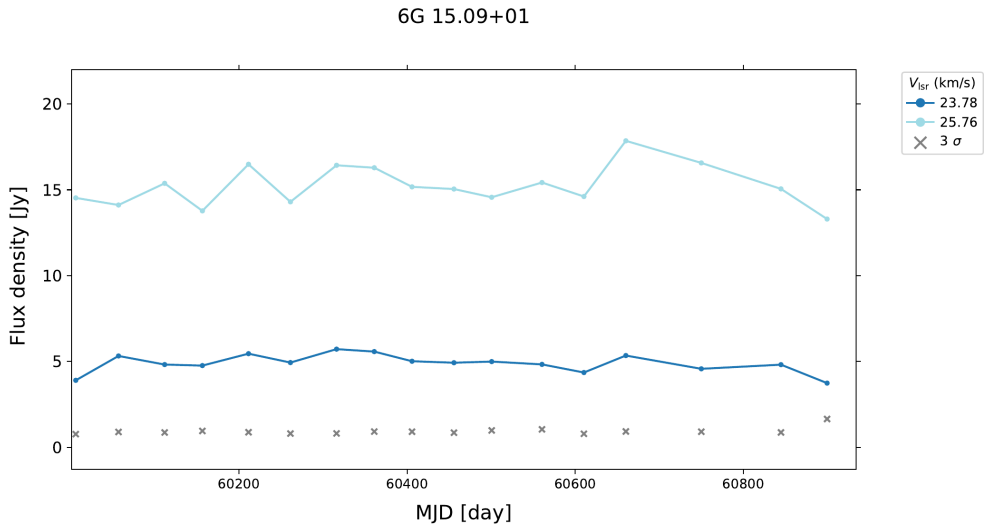


Spectrum

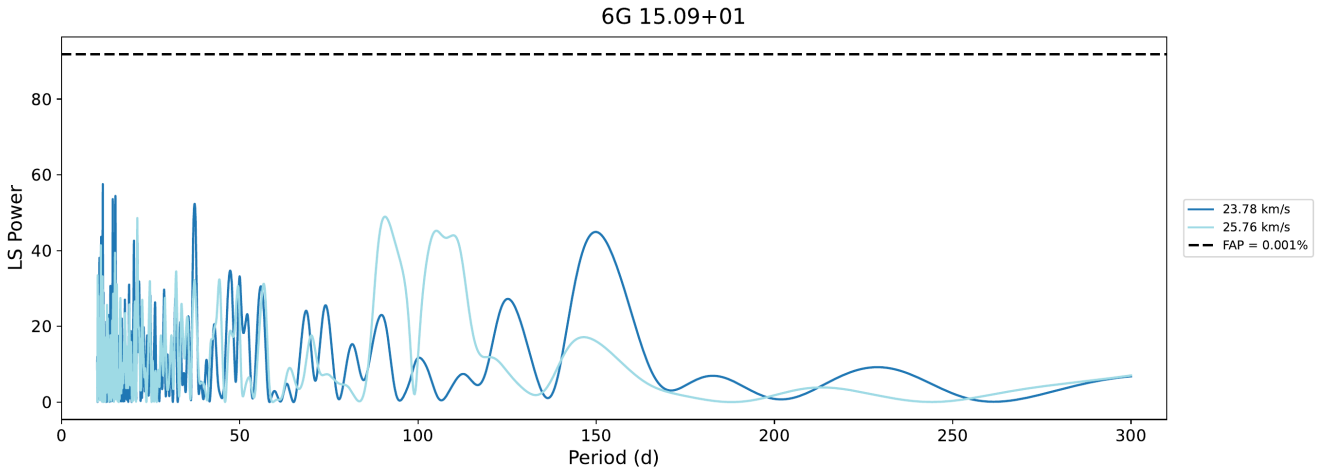


6G 15.09+01

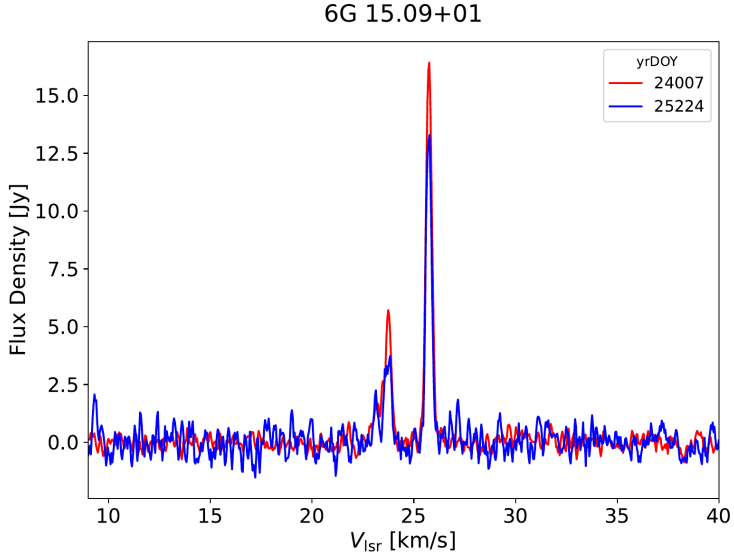
Light curve



Periodogram

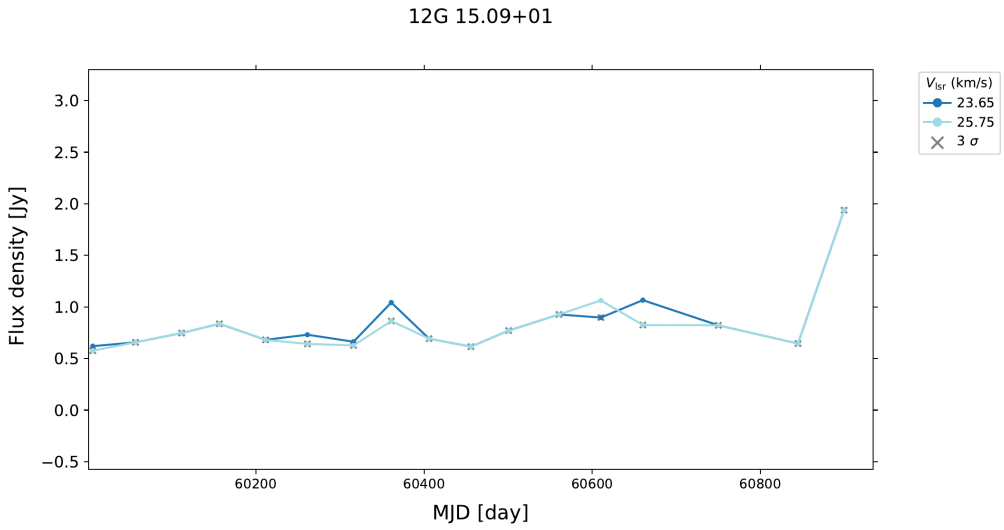


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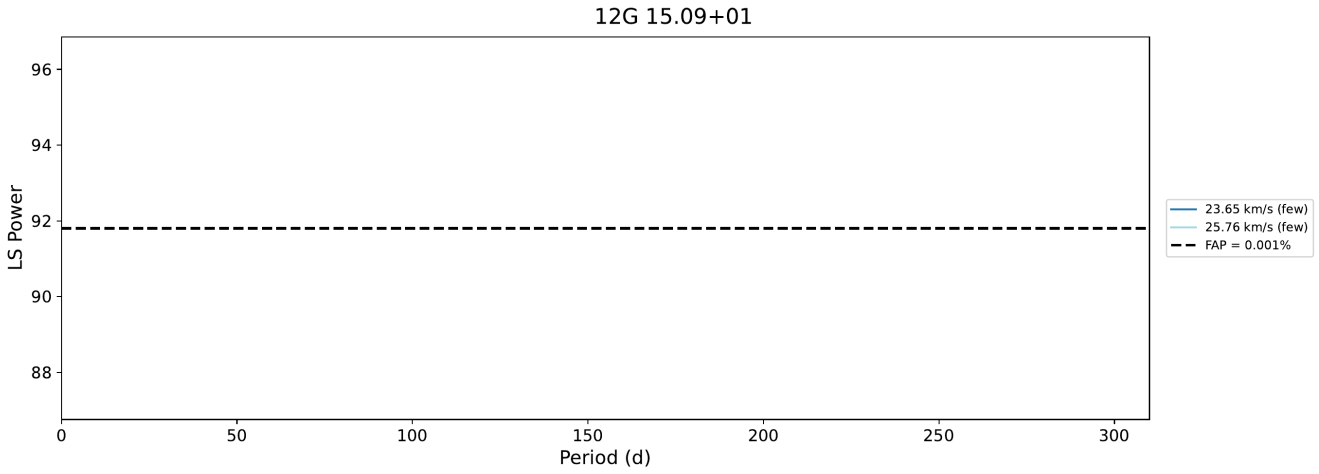


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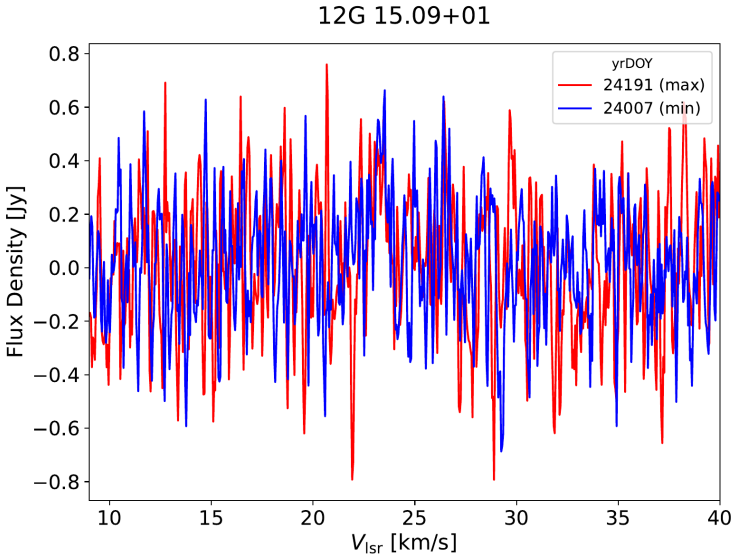
Light curve



Periodogram

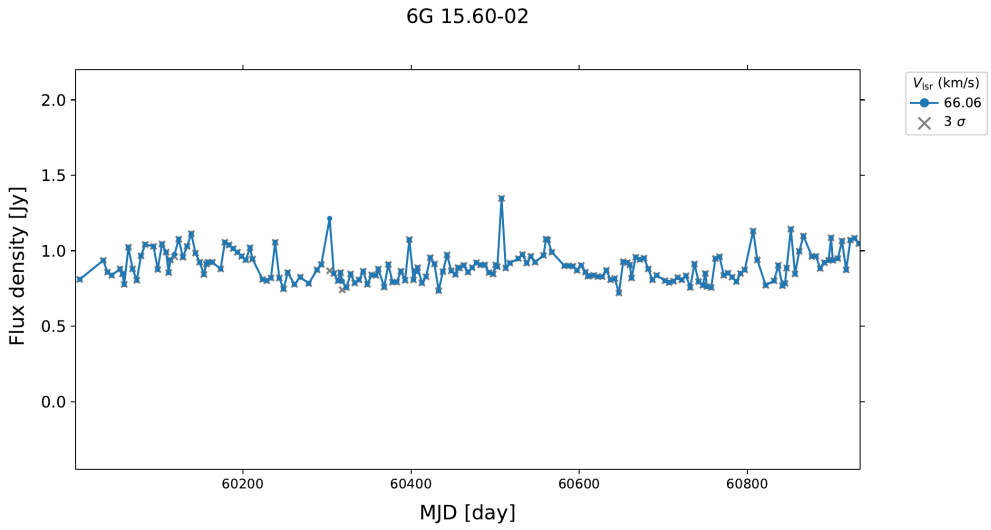


Spectrum

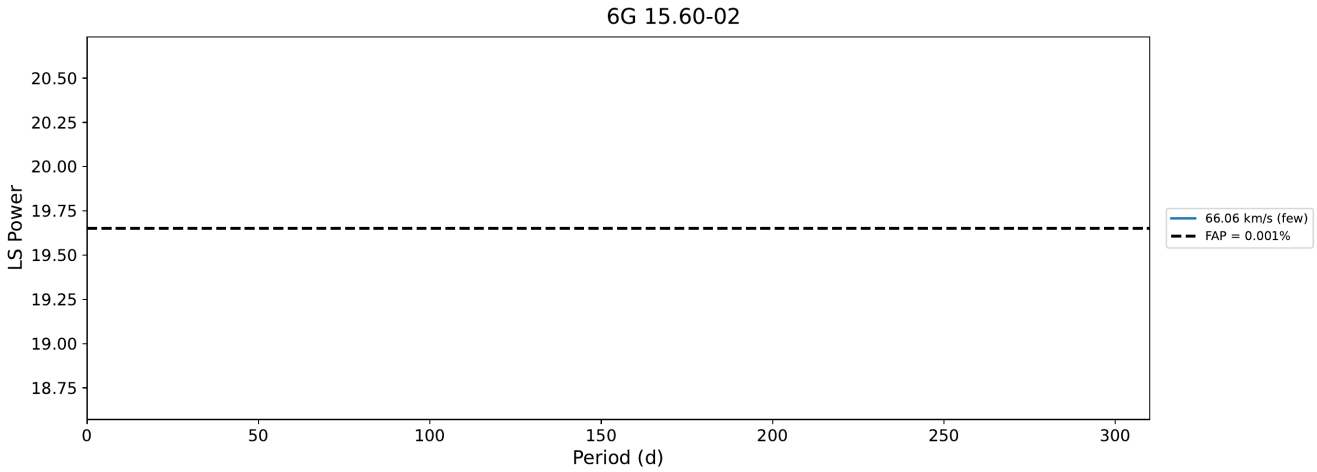


6G 15.60-02

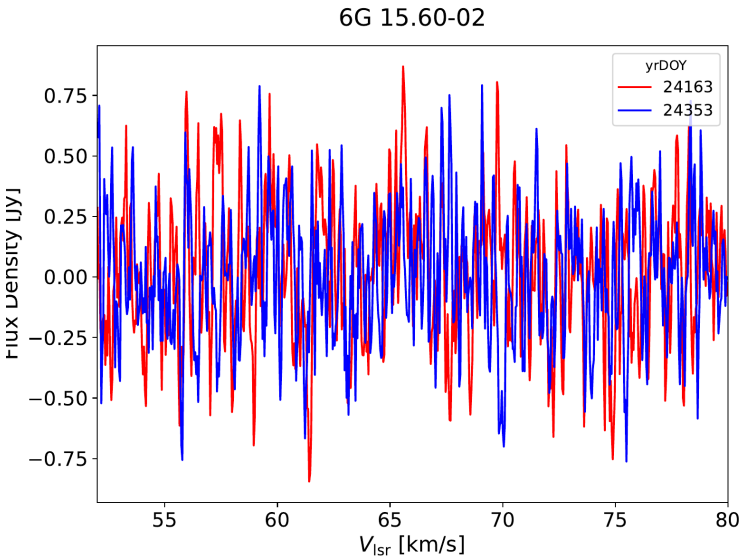
Light curve



Periodogram

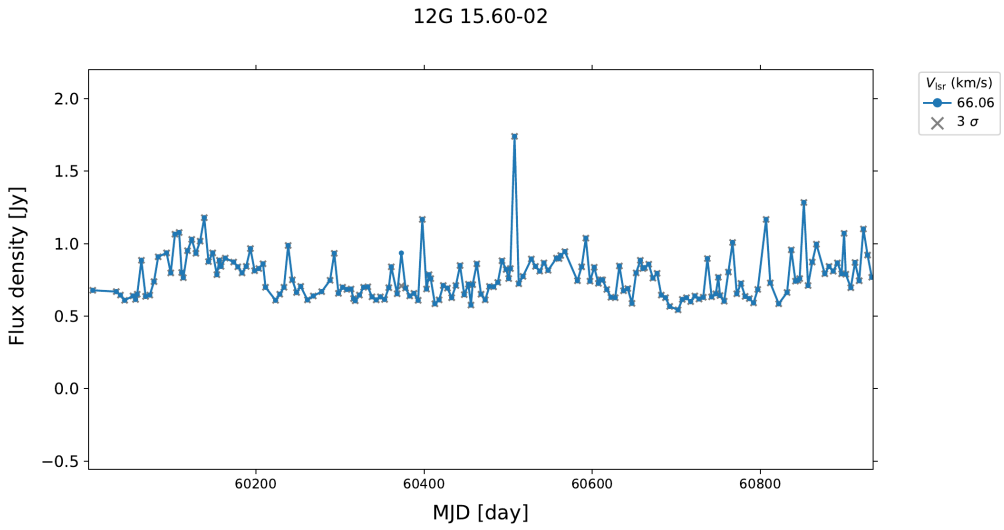


Spectrum

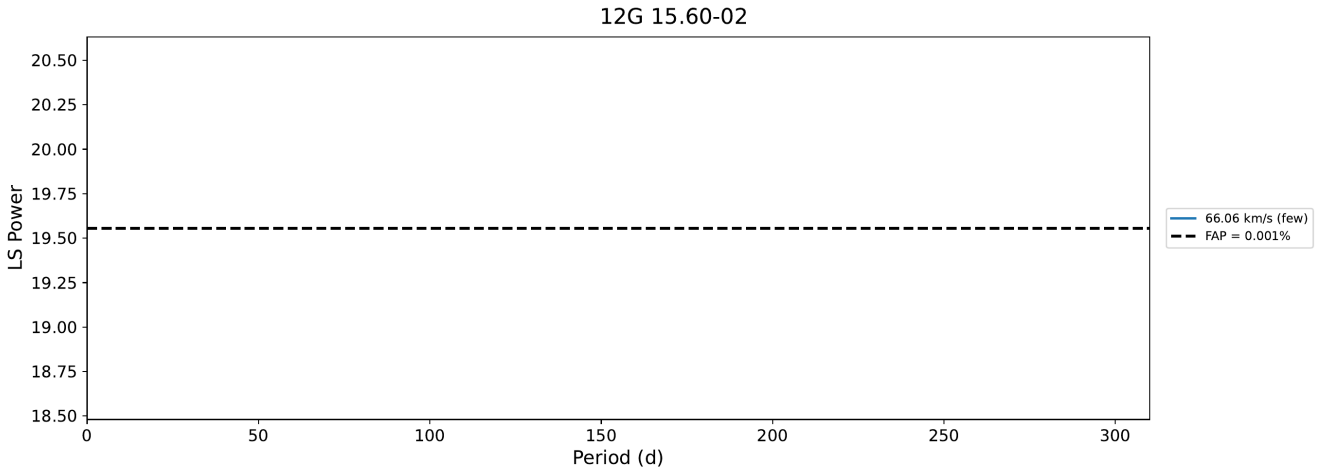


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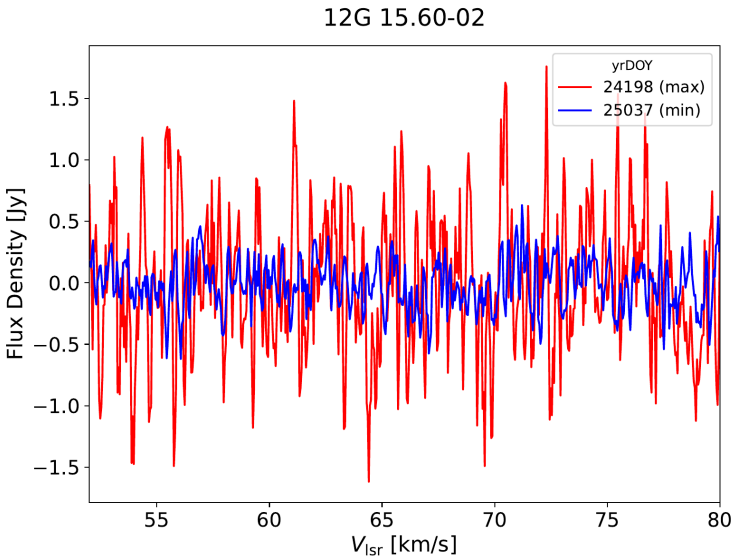
Light curve



Periodogram

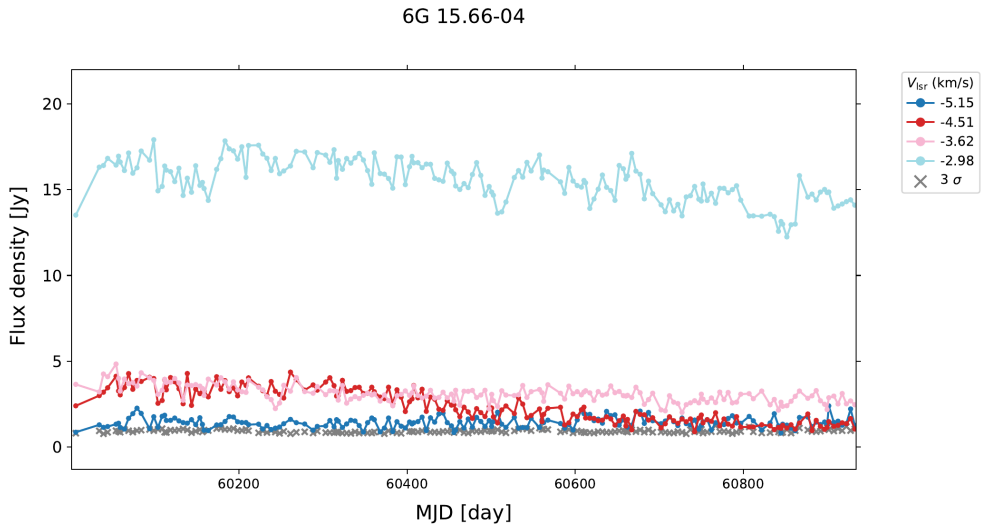


Spectrum

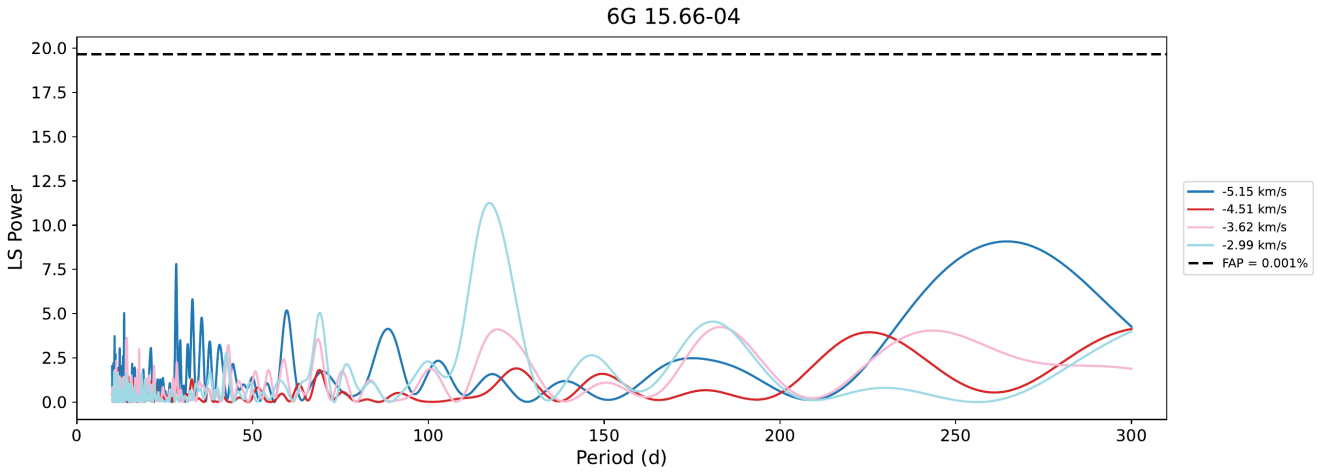


6G 15.66-04

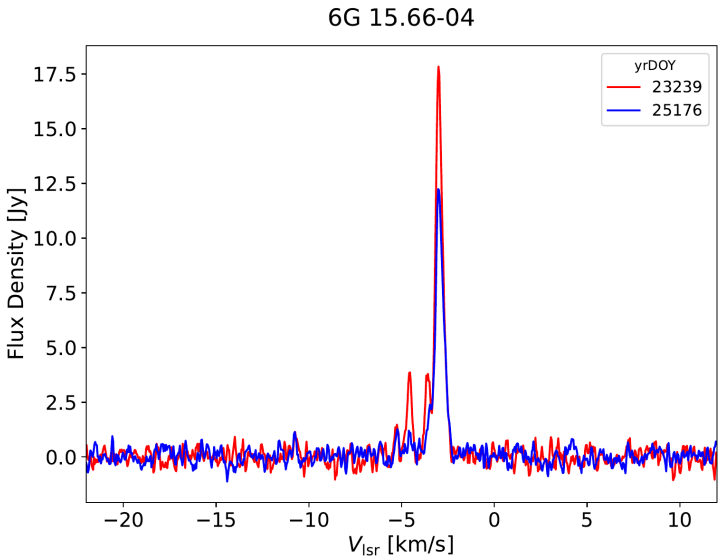
Light curve



Periodogram

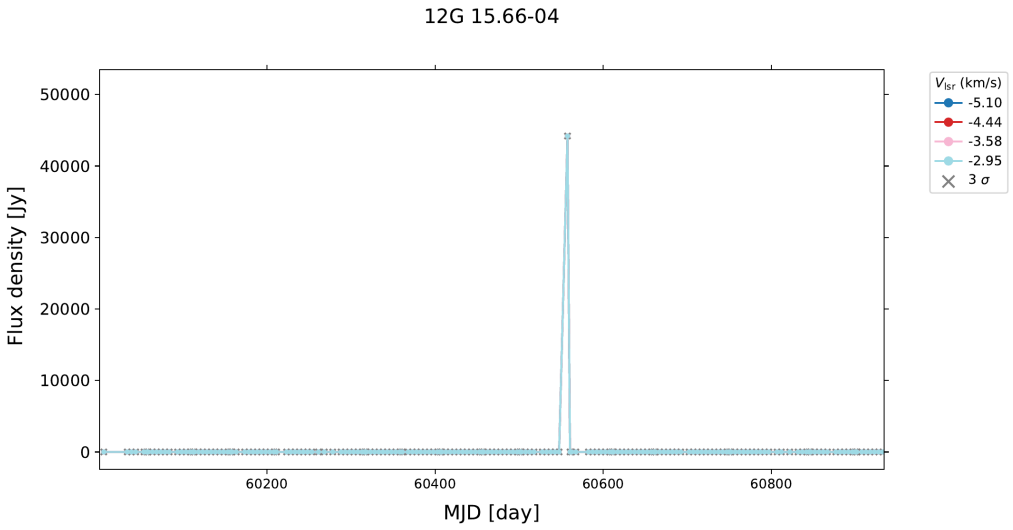


Spectrum

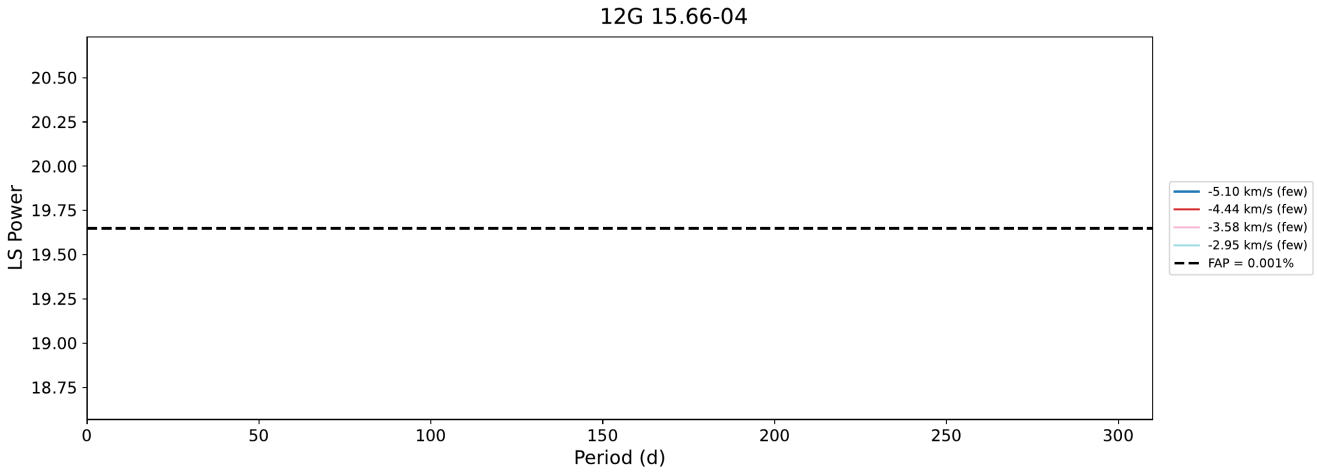


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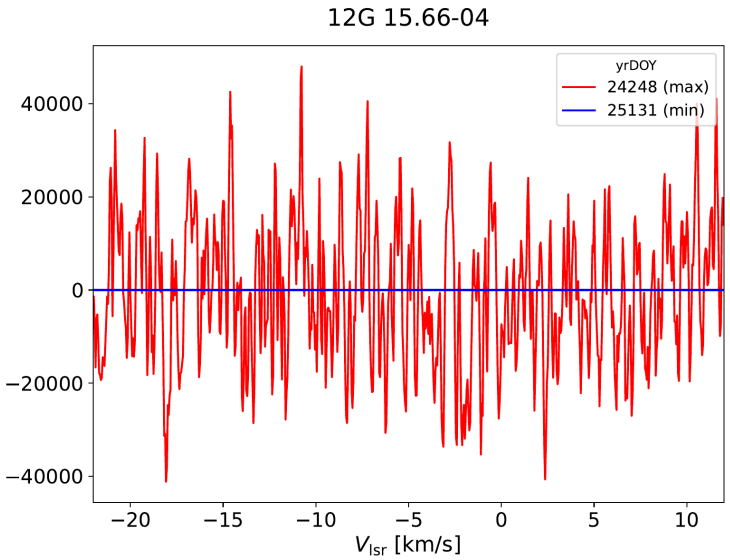
Light curve



Periodogram

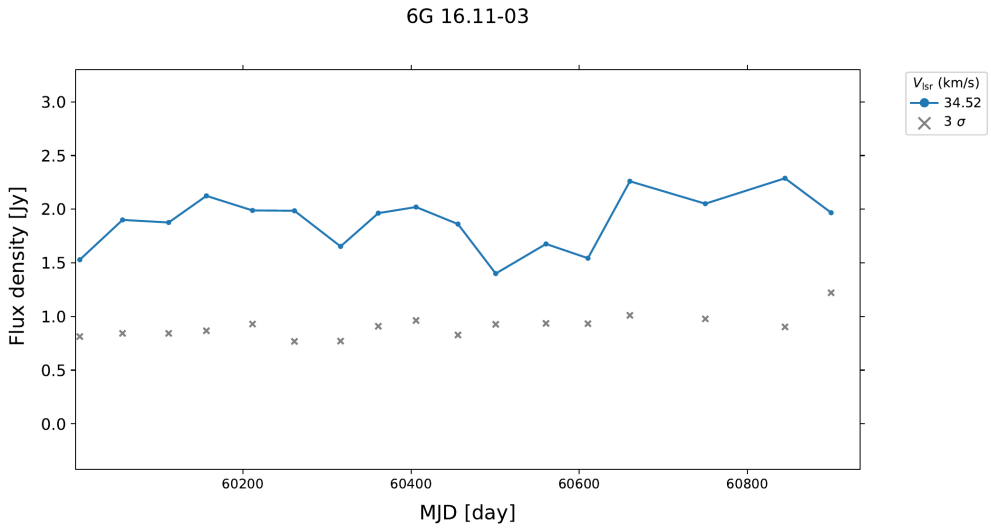


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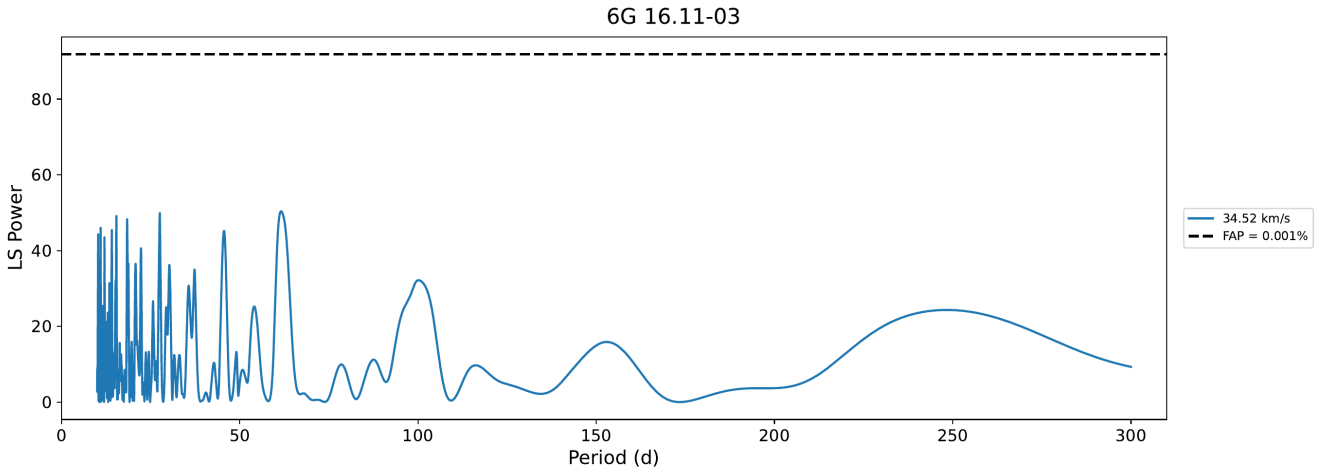


6G 16.11-03

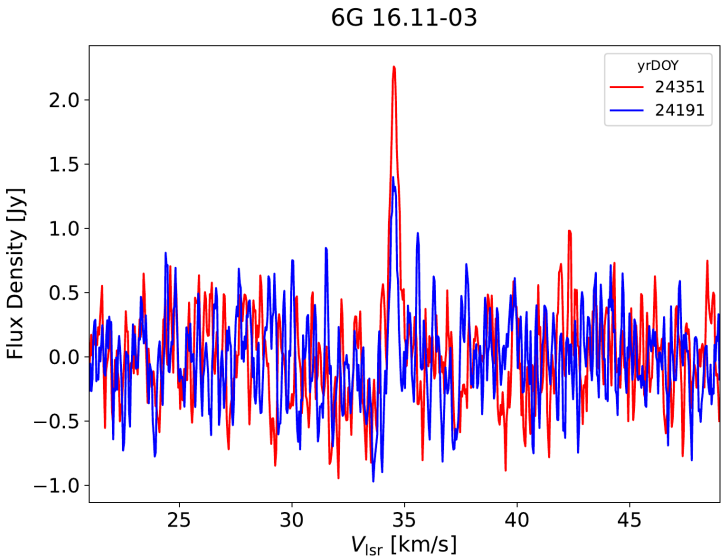
Light curve



Periodogram

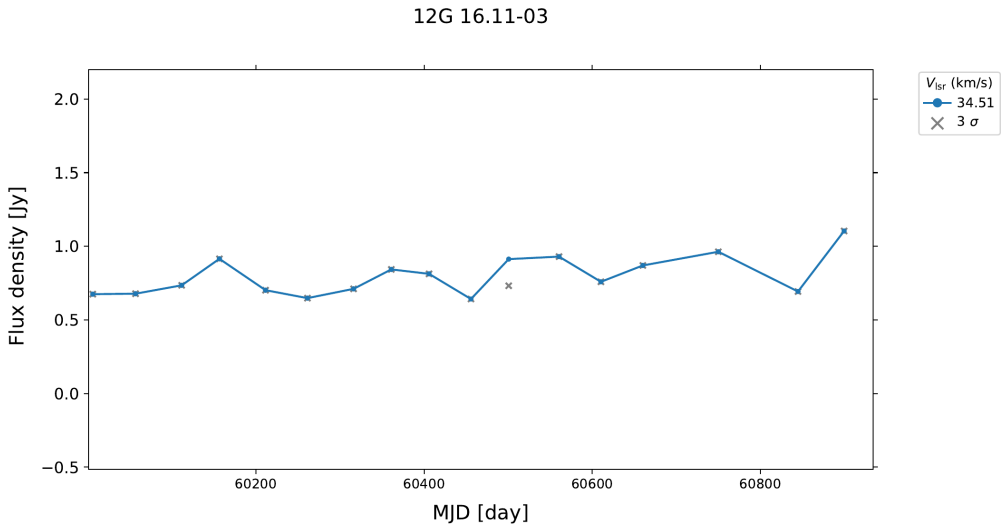


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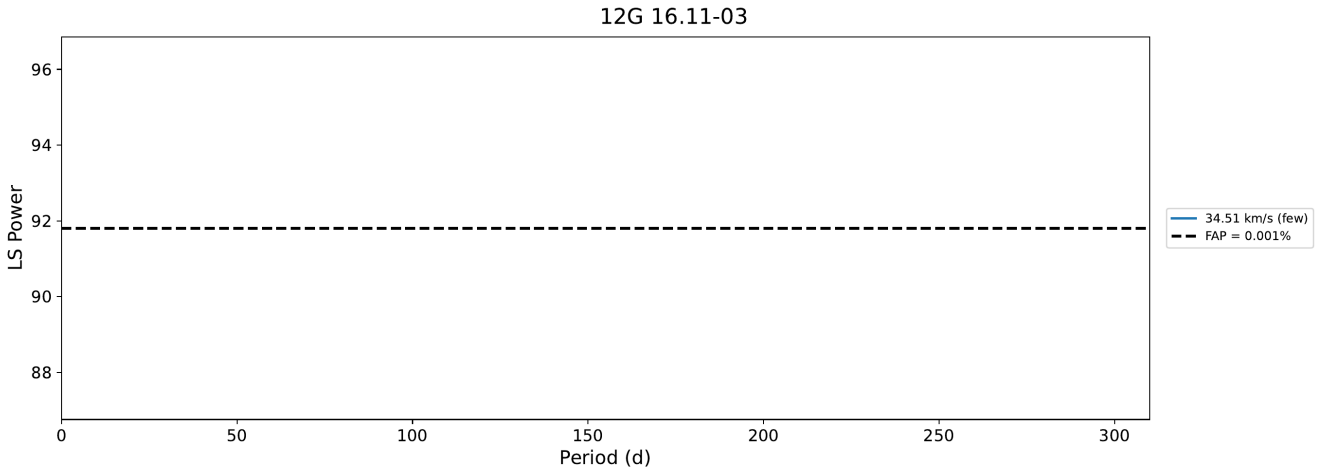


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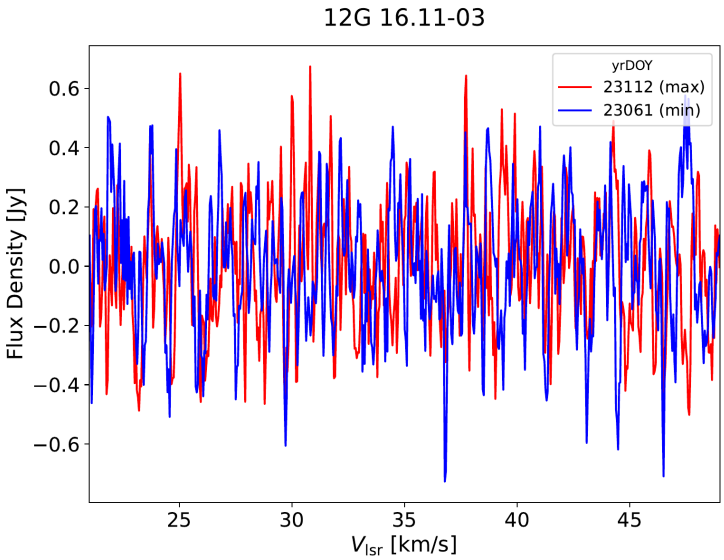
Light curve



Periodogram

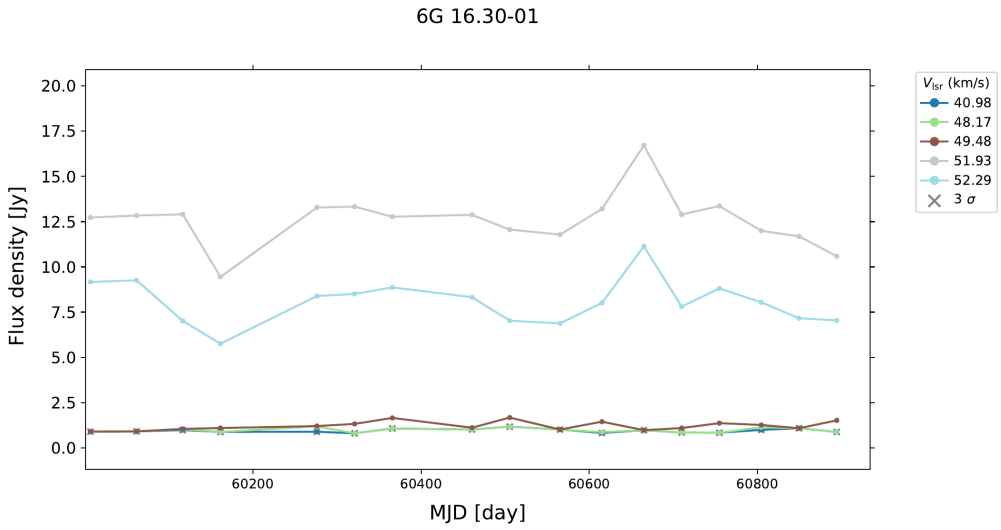


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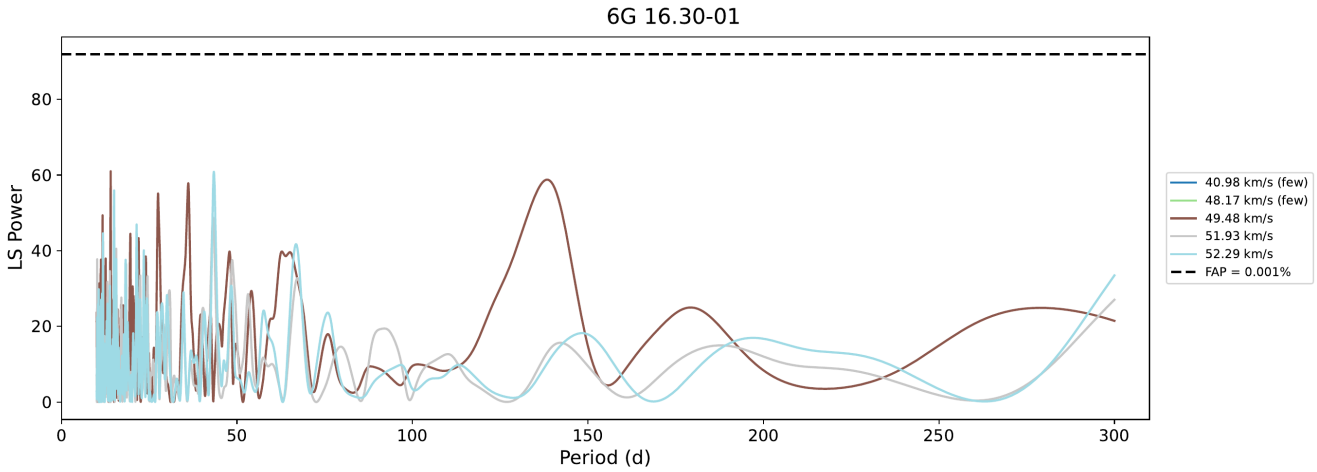


6G 16.30-01

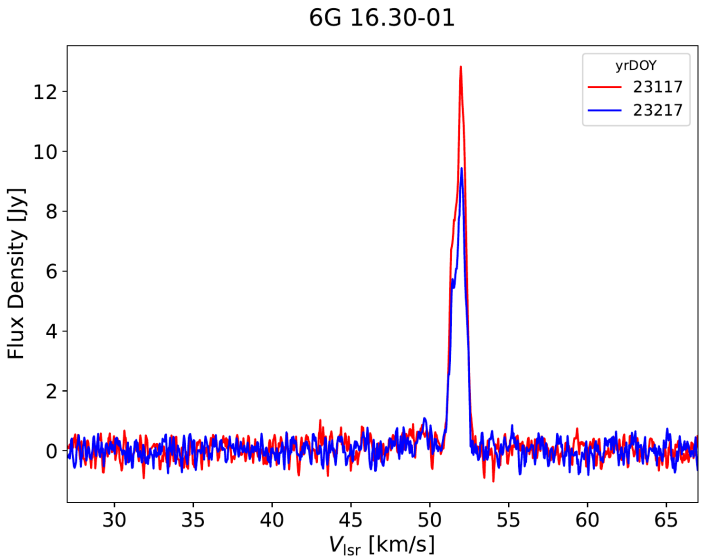
Light curve



Periodogram

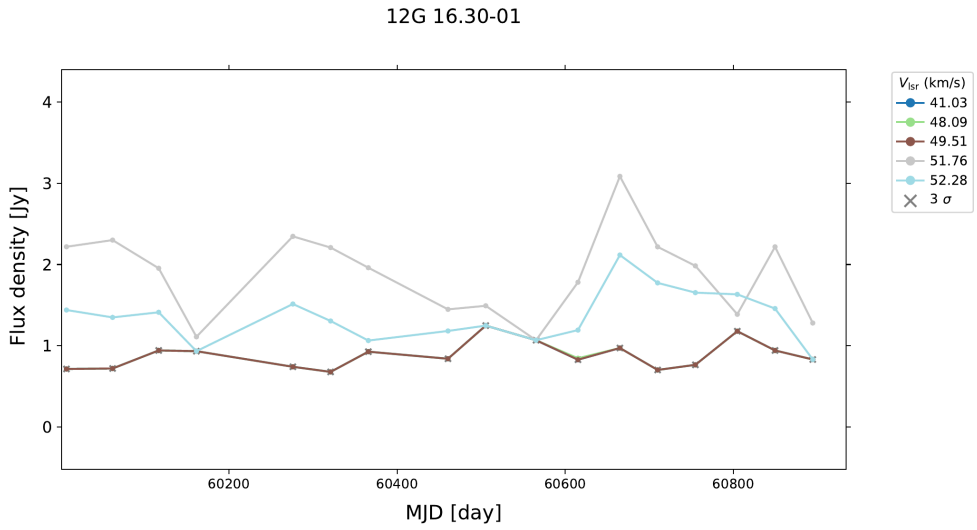


Spectrum

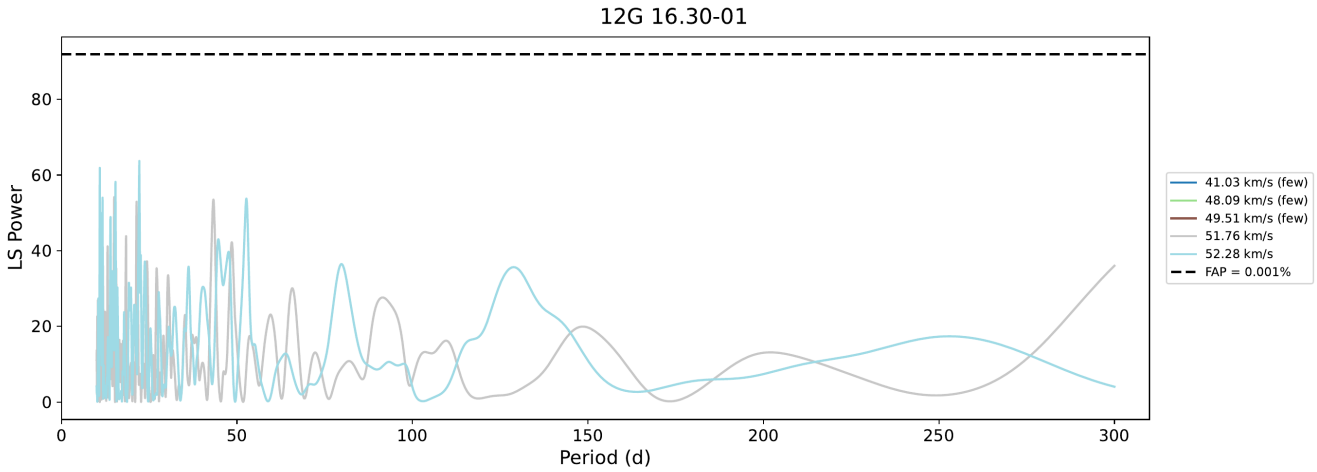


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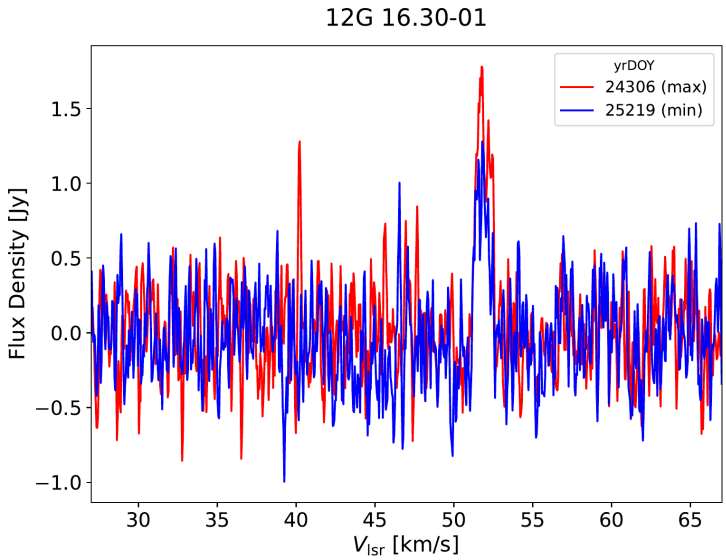
Light curve



Periodogram

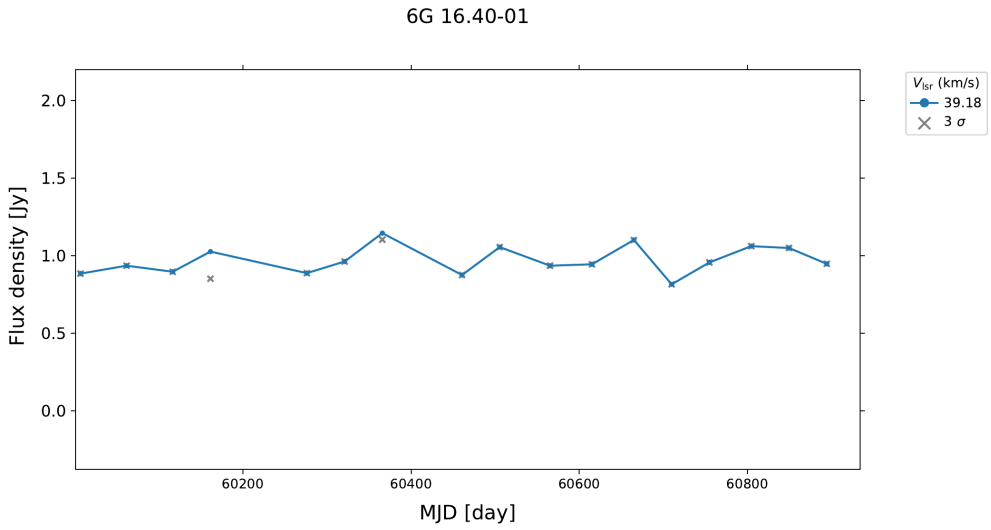


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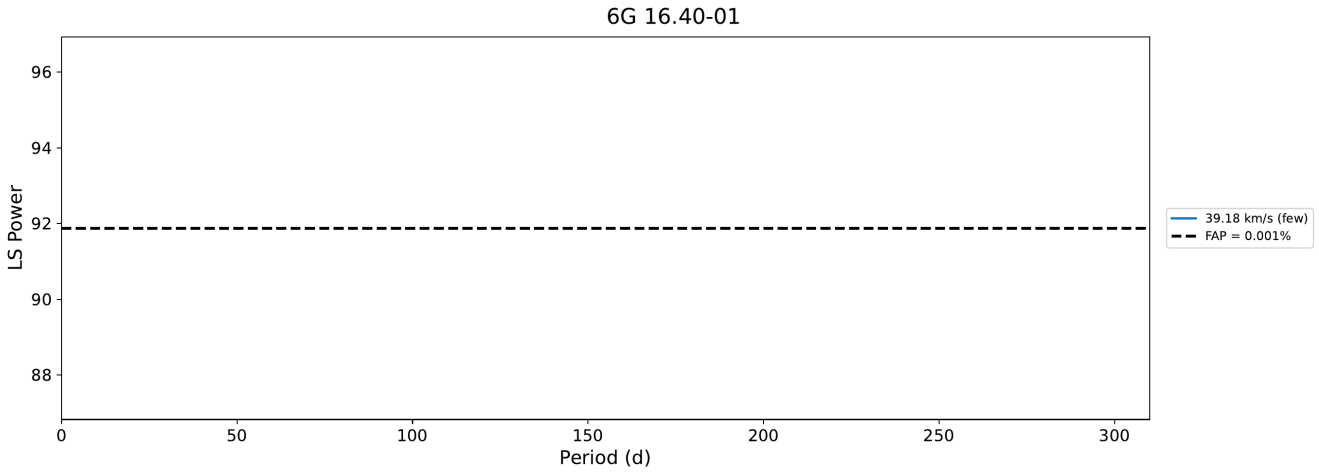


6G 16.40-01

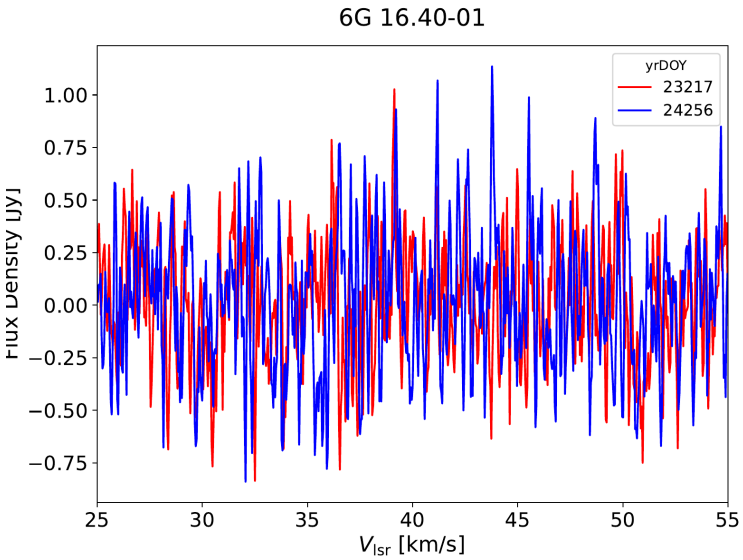
Light curve



Periodogram

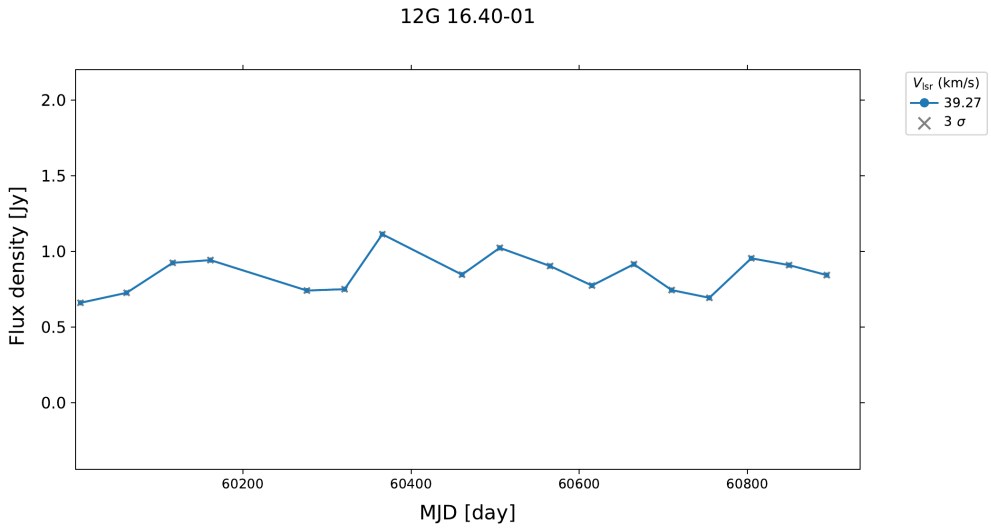


Spectrum

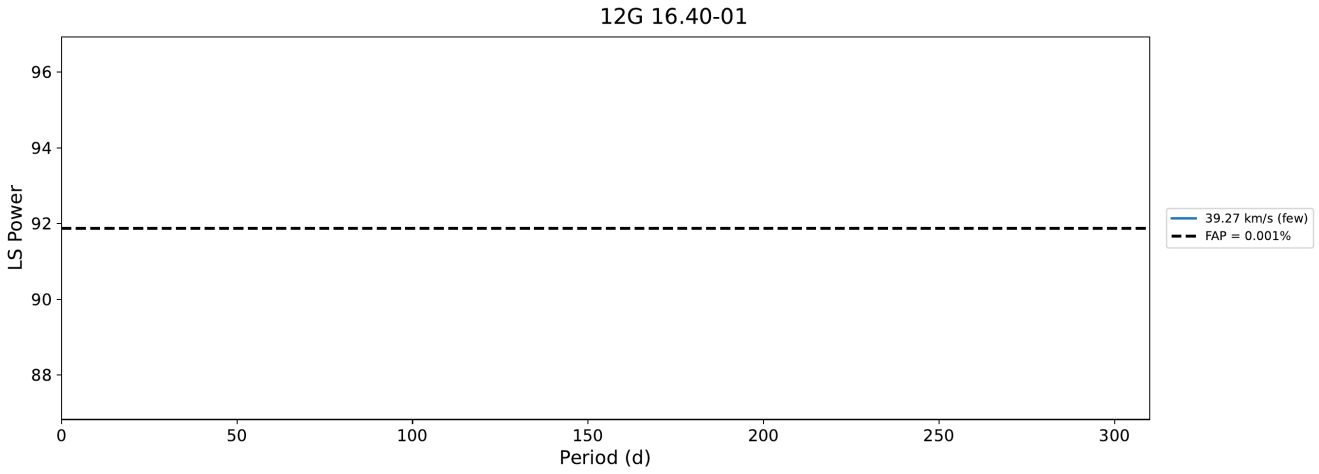


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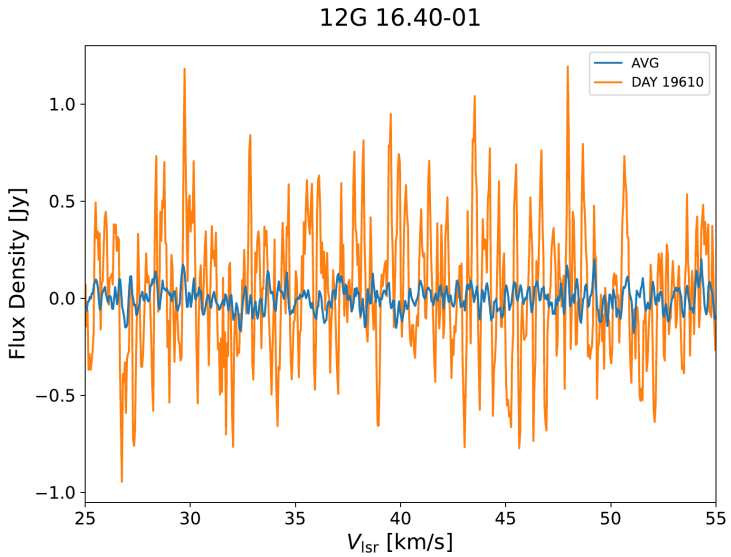
Light curve



Periodogram

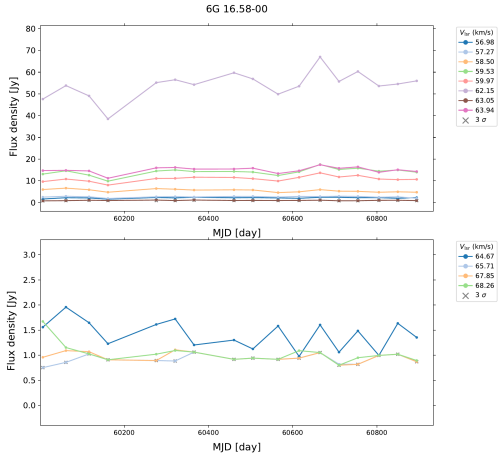


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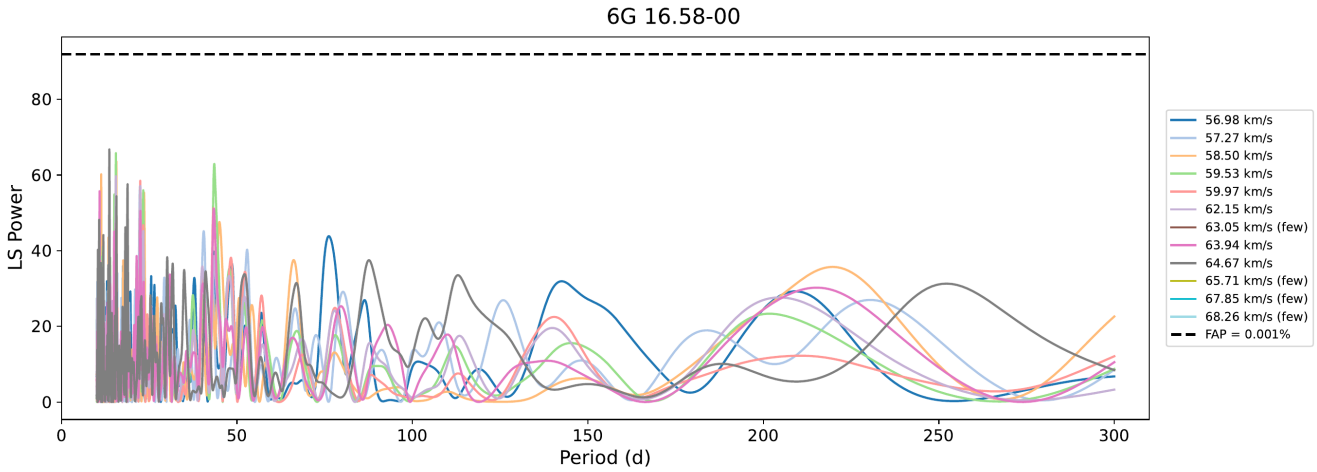


6G 16.58-00

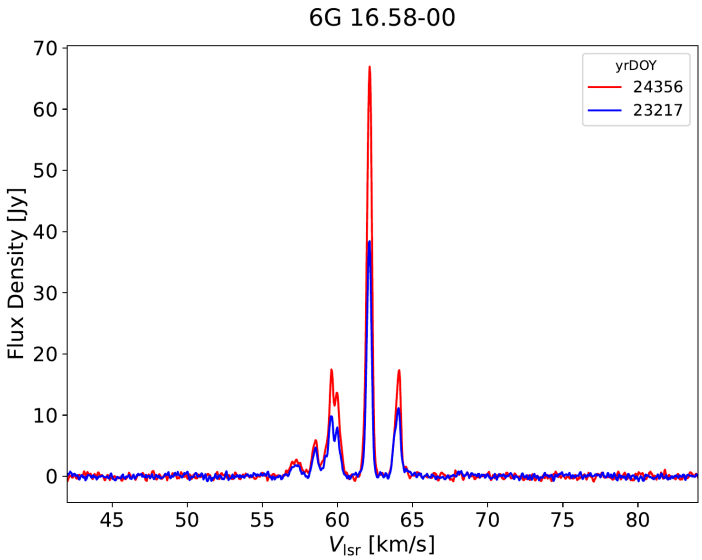
Light curve



Periodogram

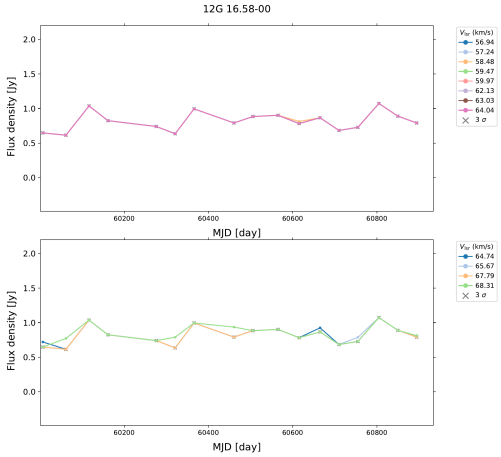


Spectrum

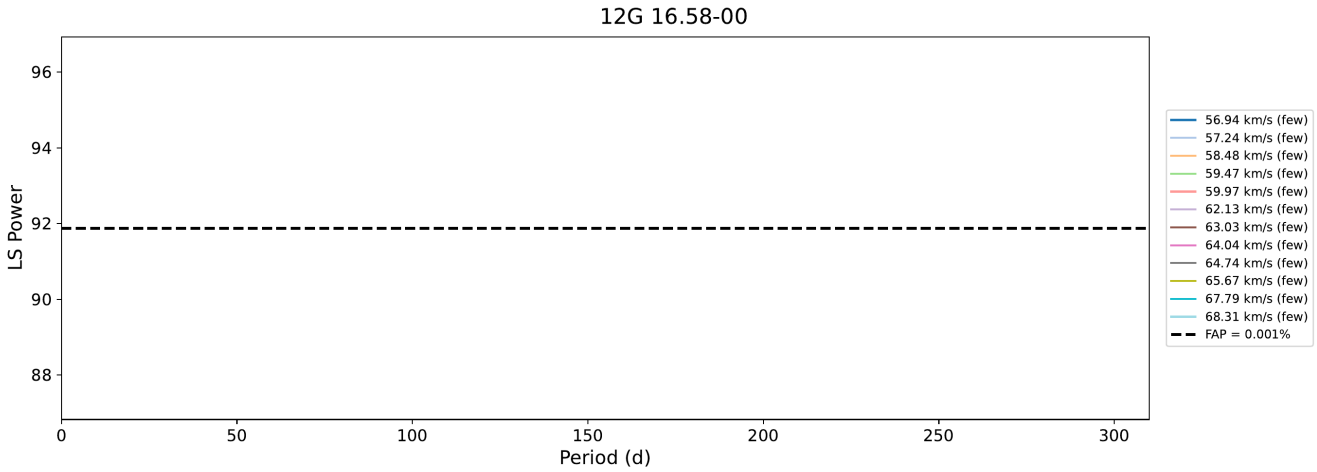


12G 16.58-00

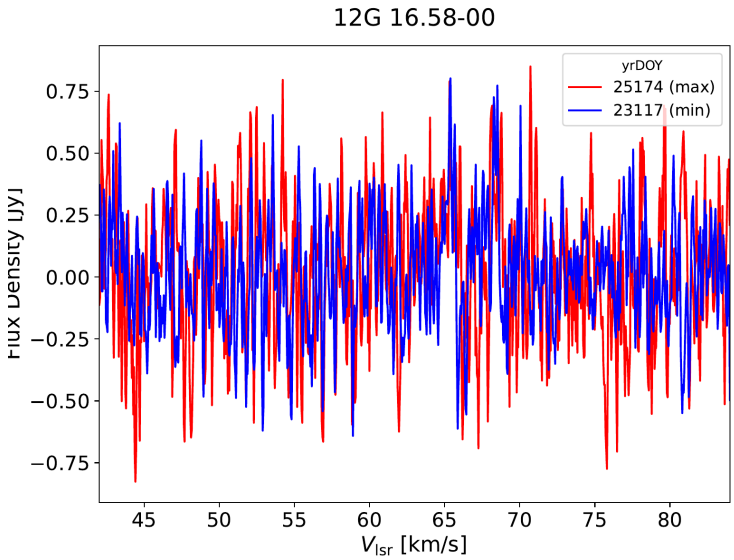
Light curve



Periodogram

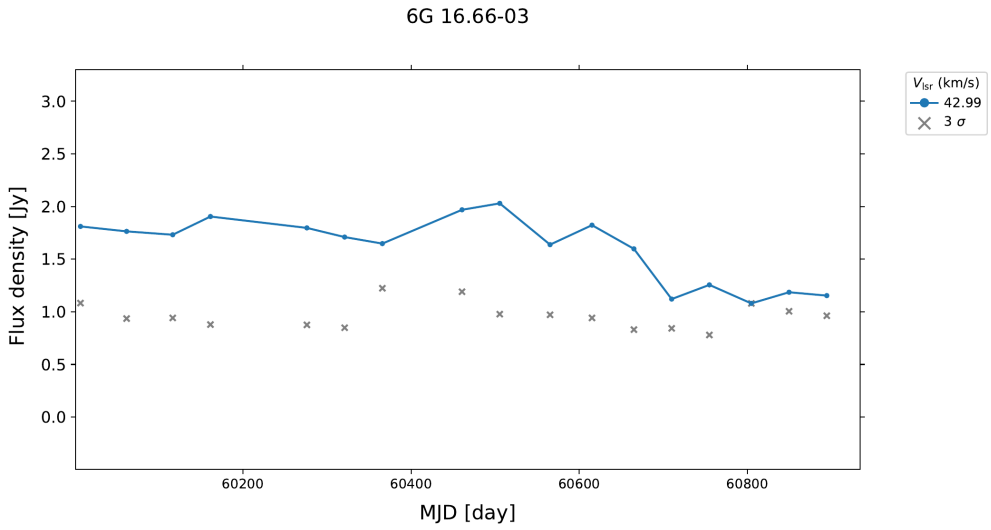


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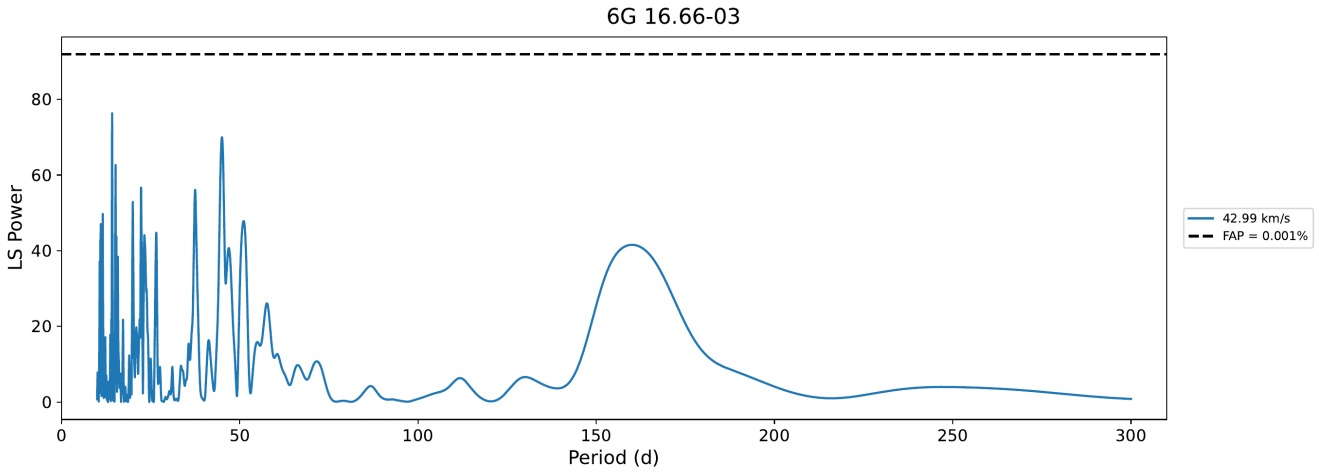


6G 16.66-03

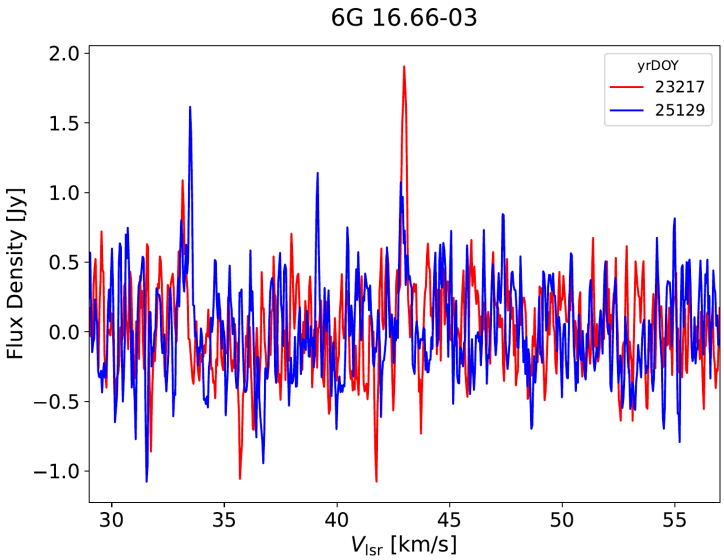
Light curve



Periodogram

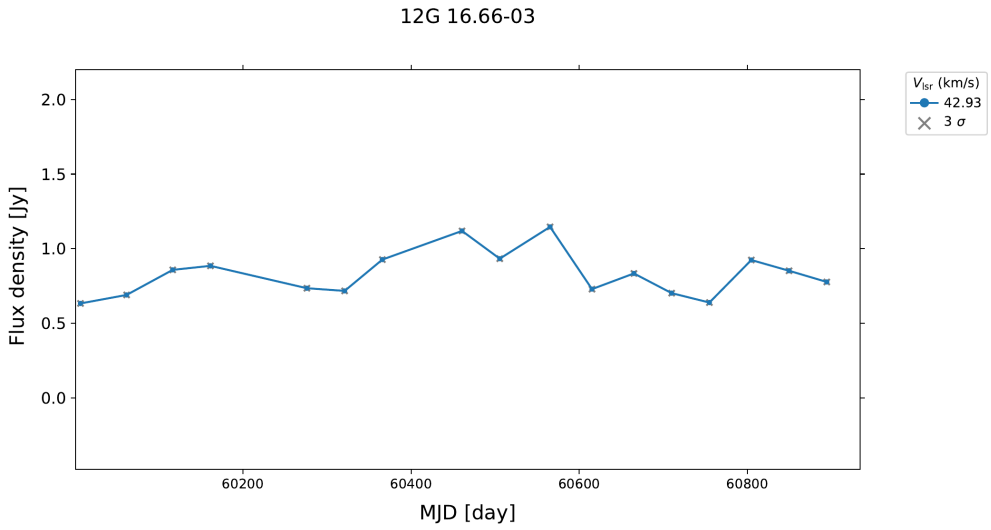


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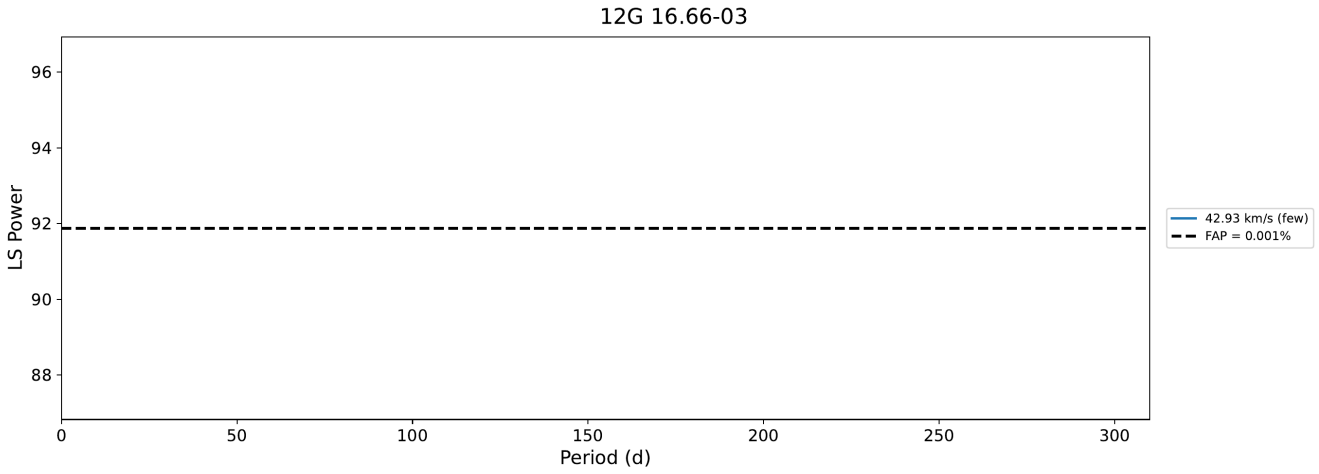


12G 16.66-03

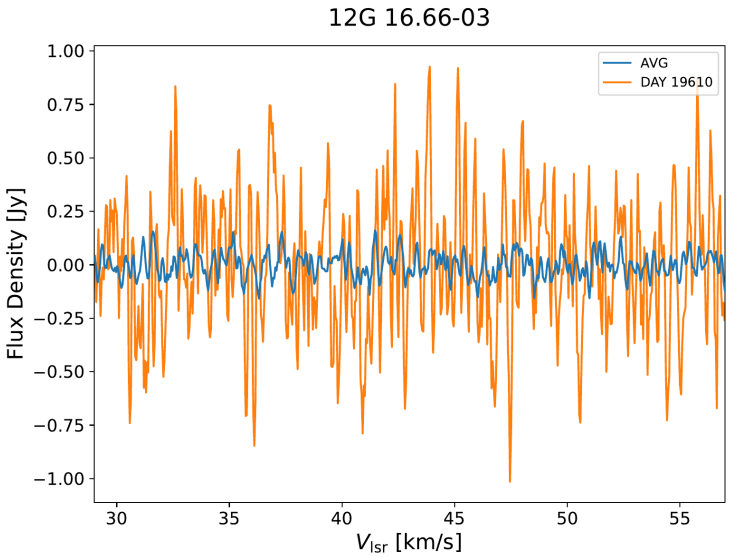
Light curve



Periodogram

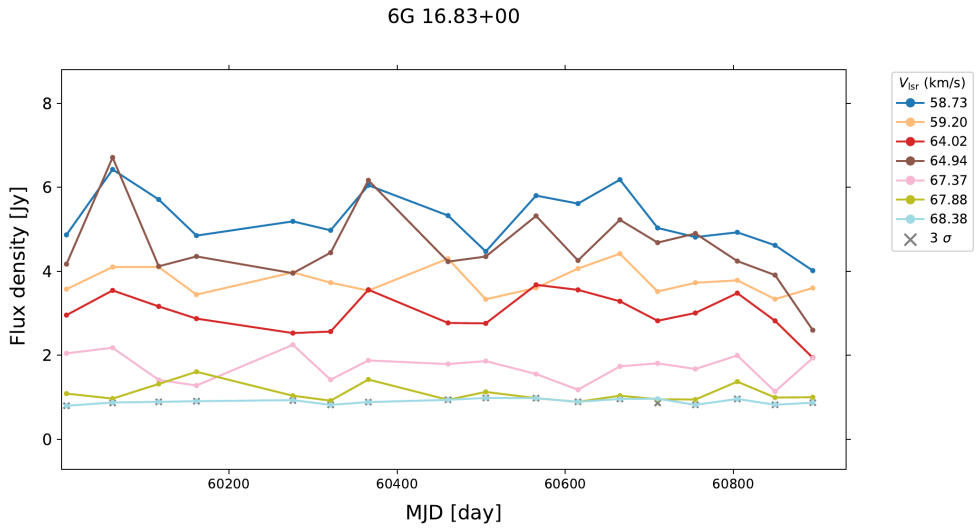


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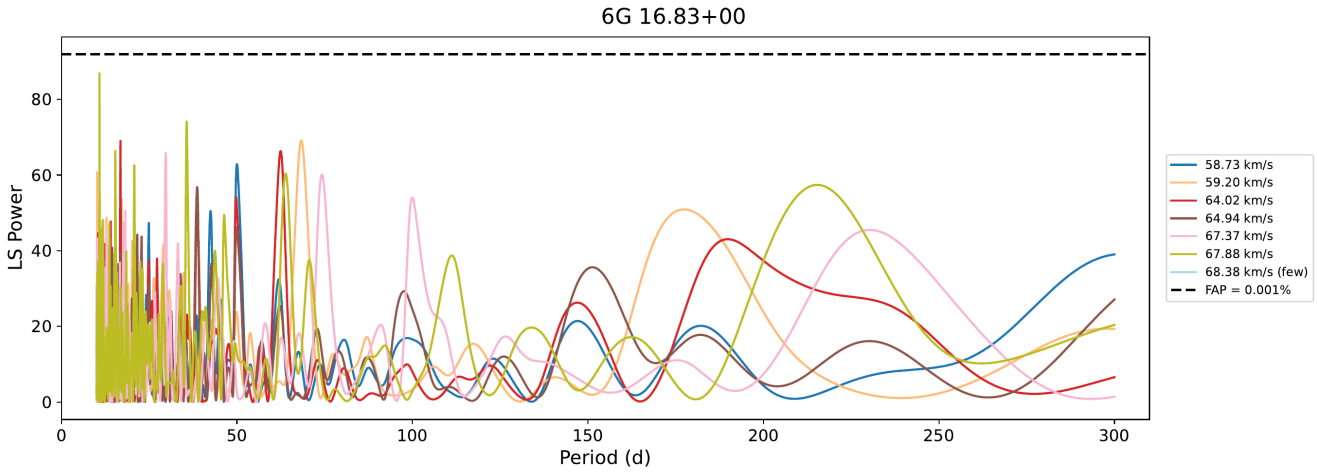


6G 16.83+00

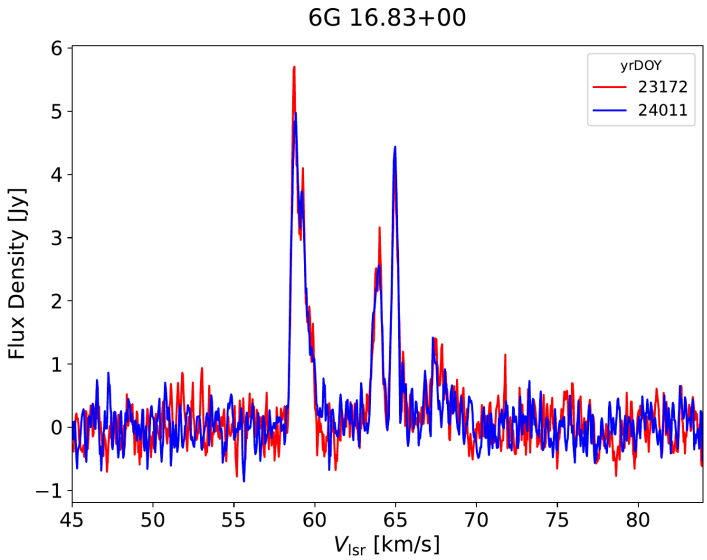
Light curve



Periodogram

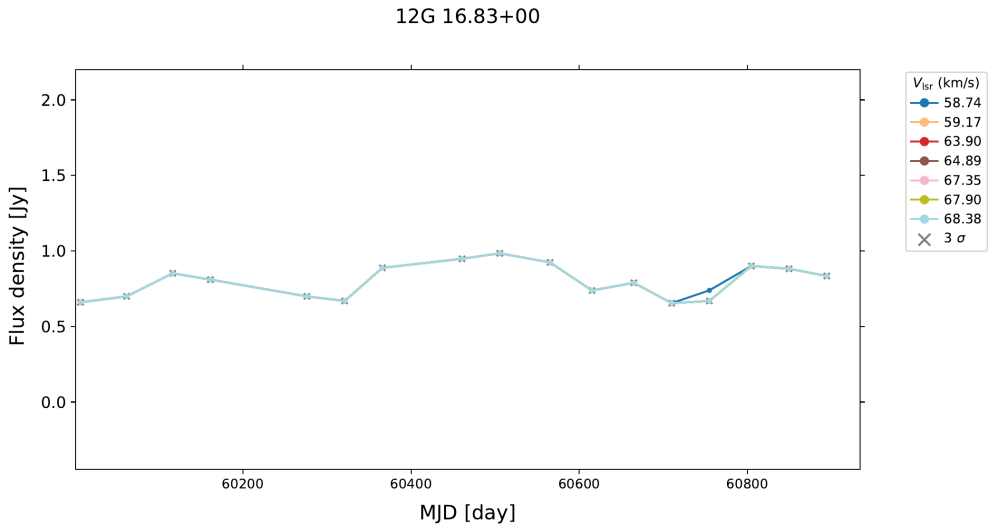


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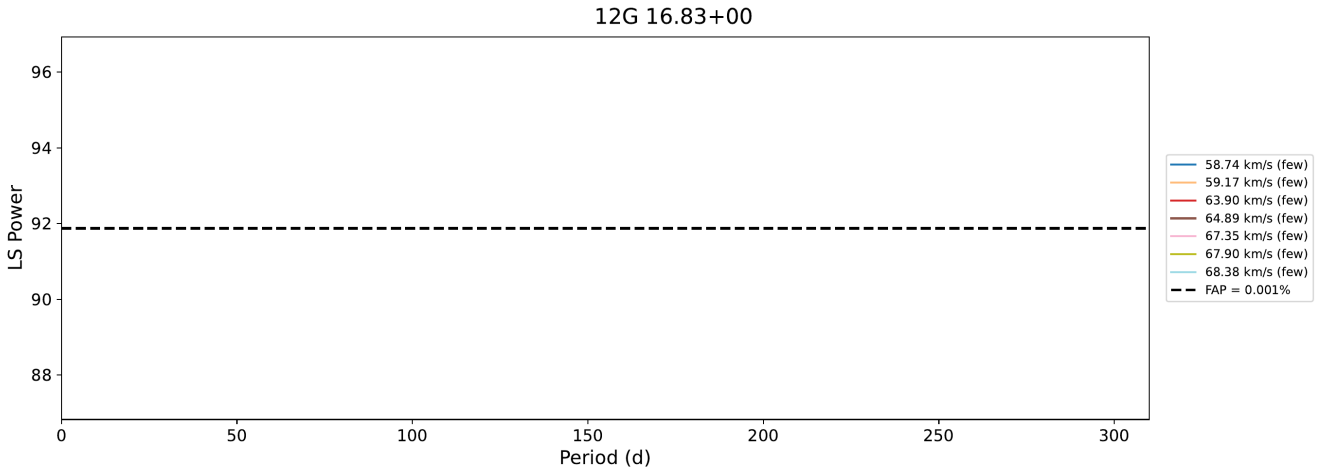


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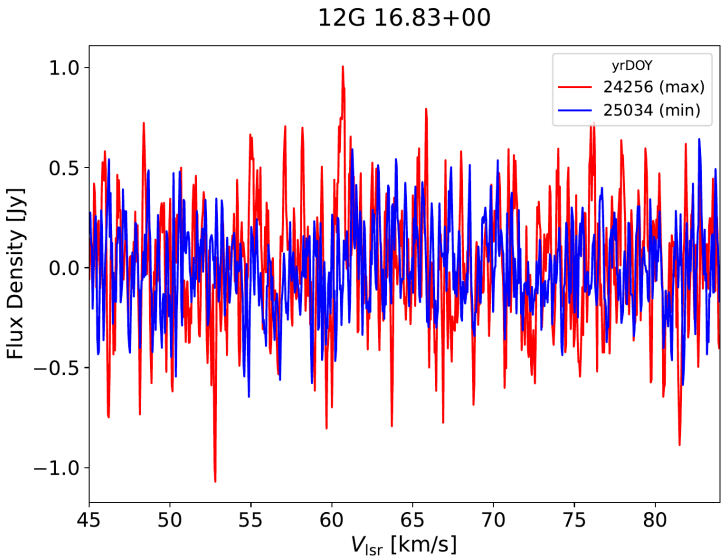
Light curve



Periodogram

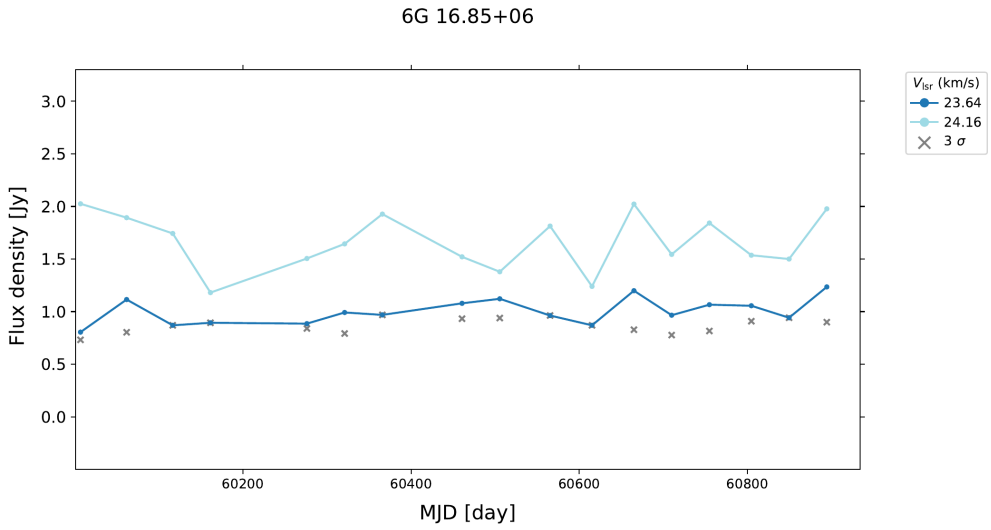


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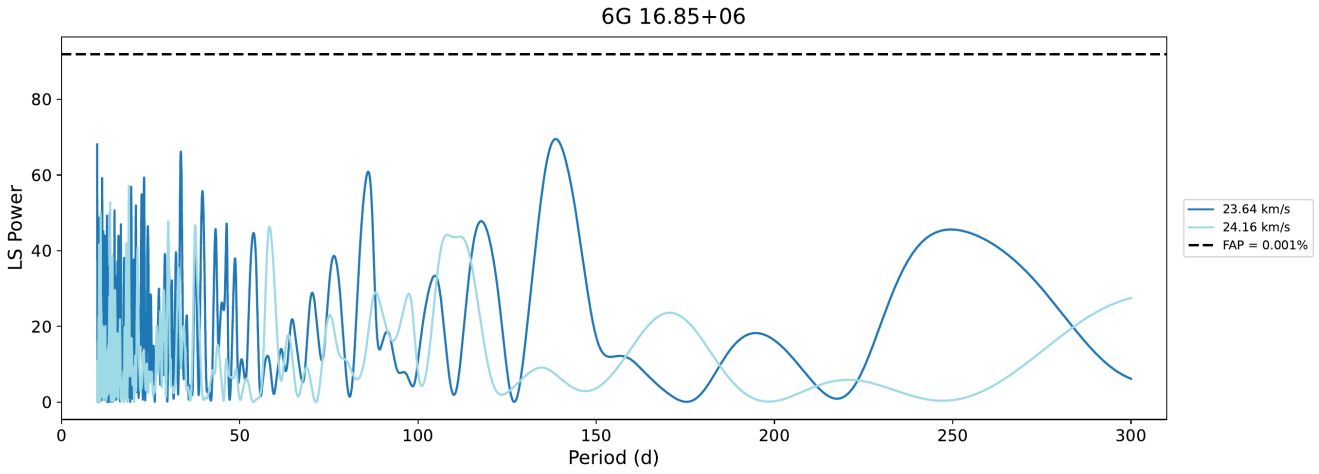


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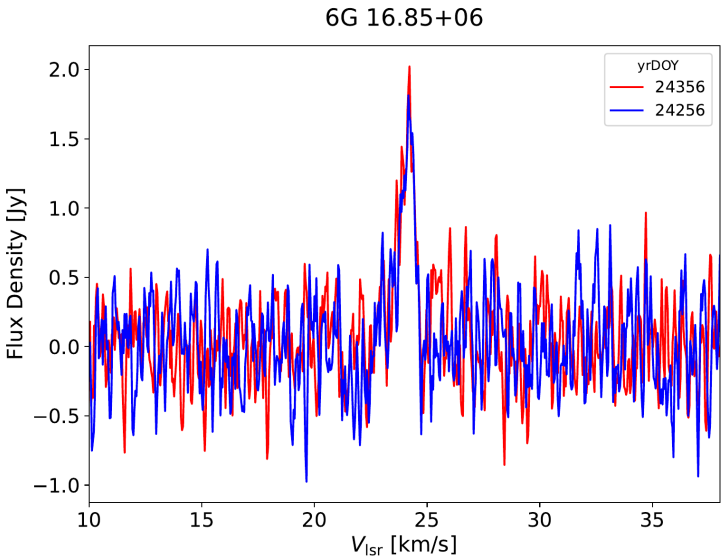
Light curve



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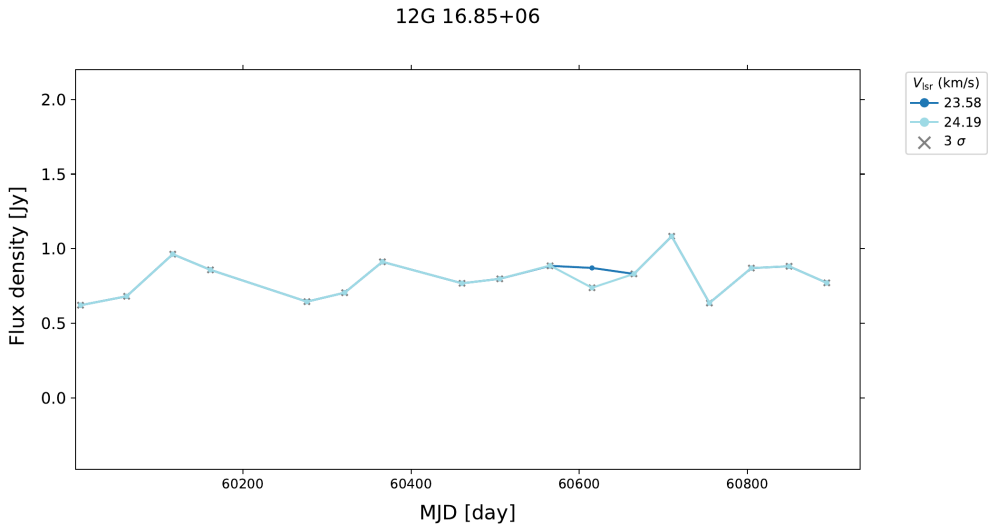


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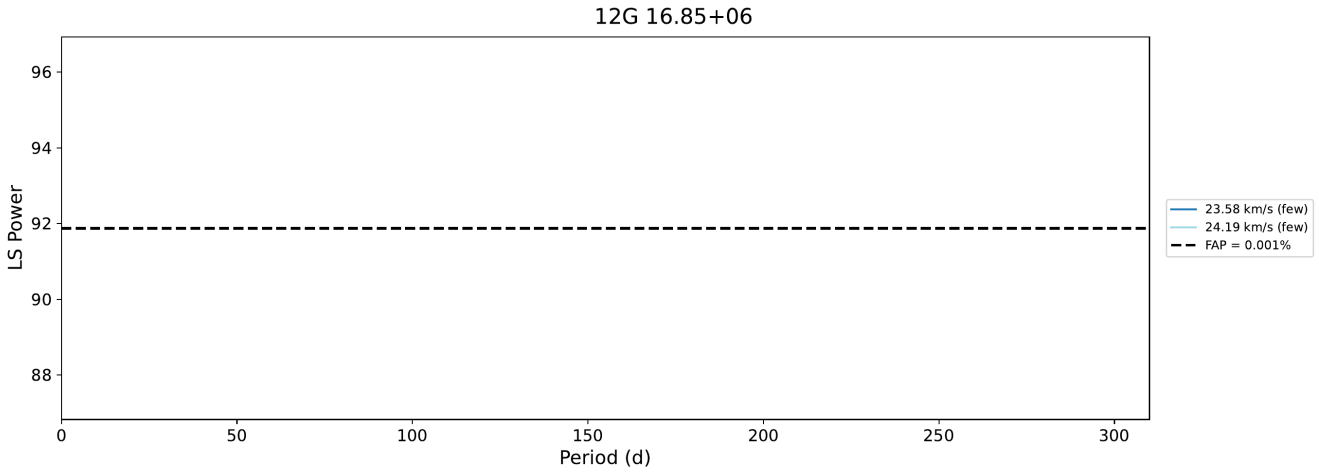


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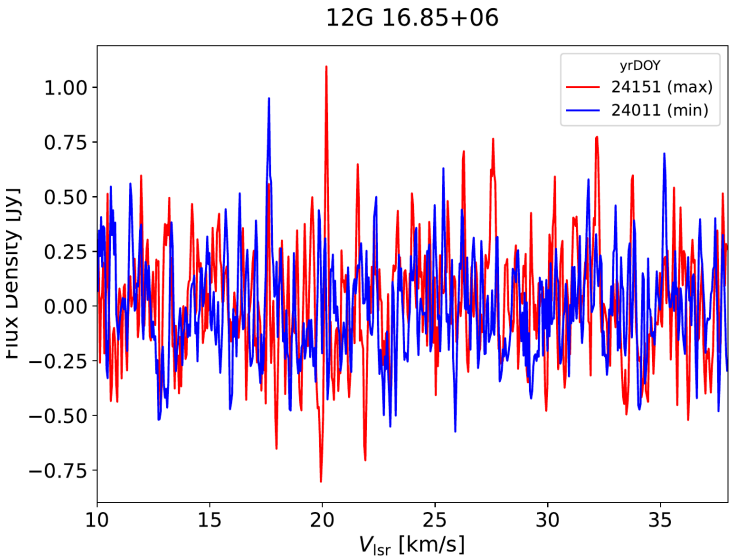
Light curve



Periodogram

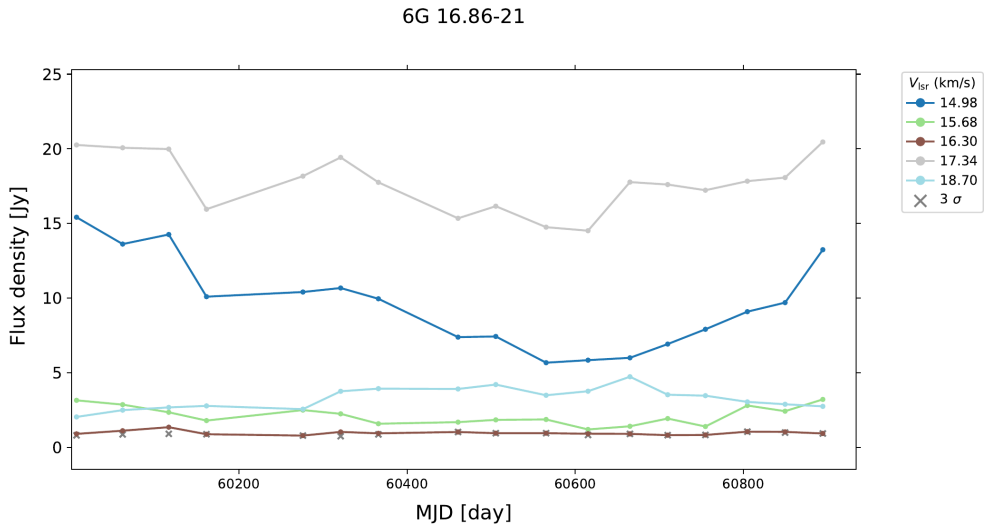


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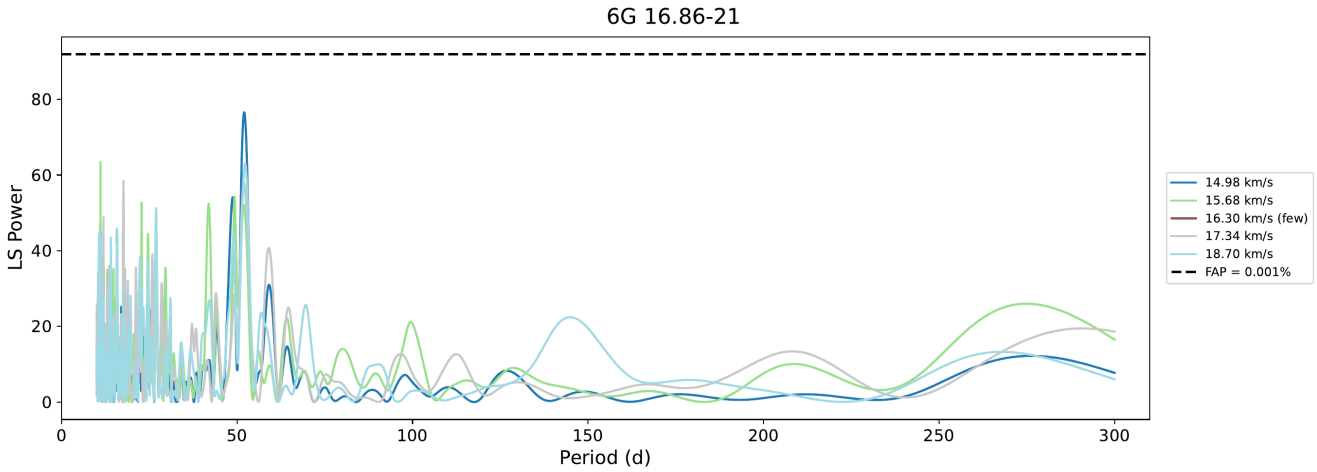


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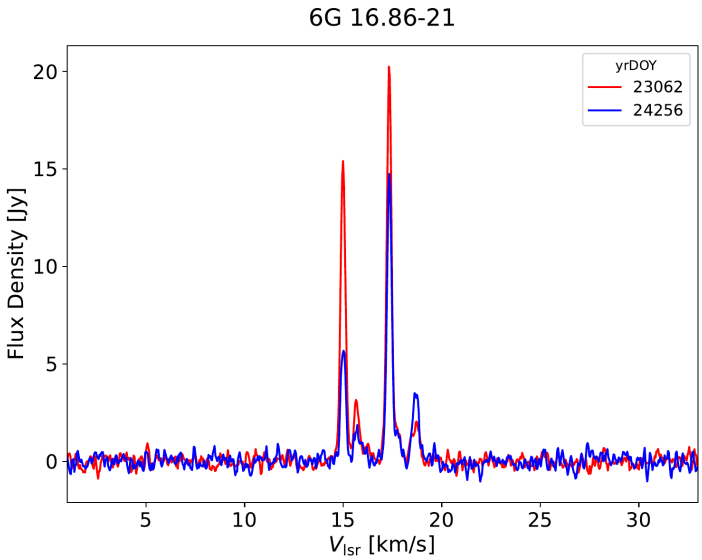
Light curve



Periodogram

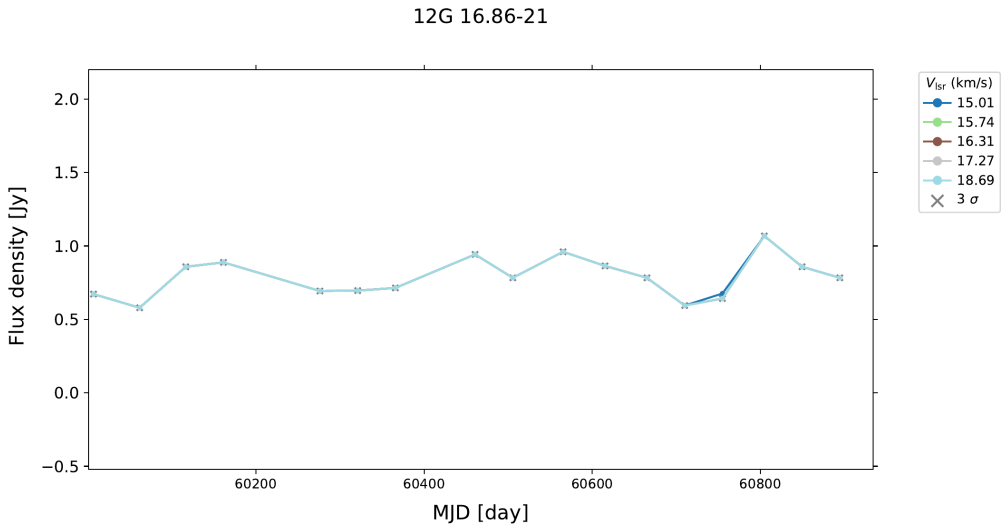


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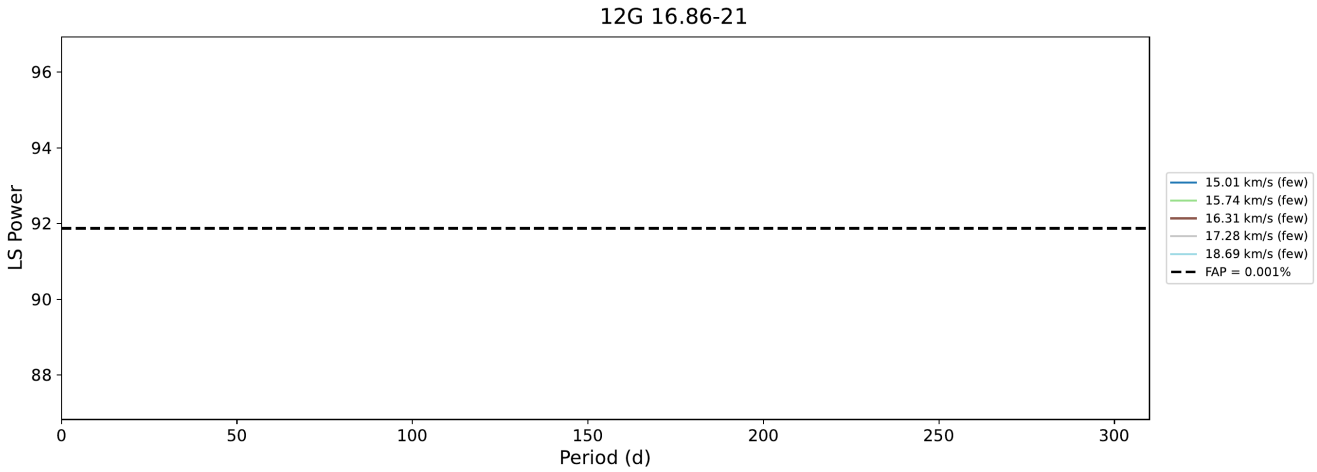


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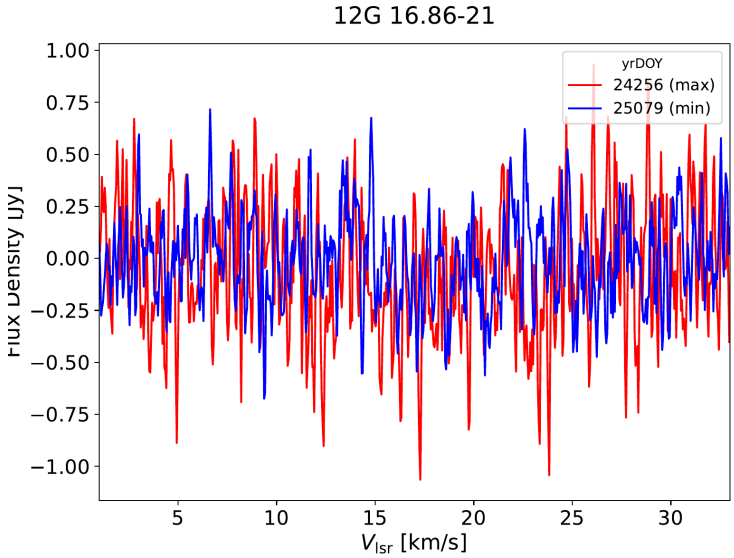
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Periodogram

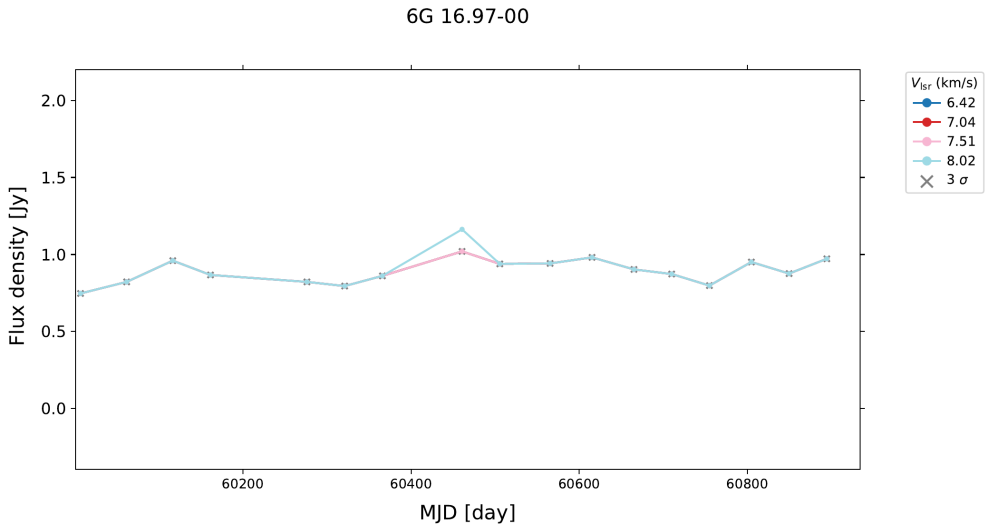


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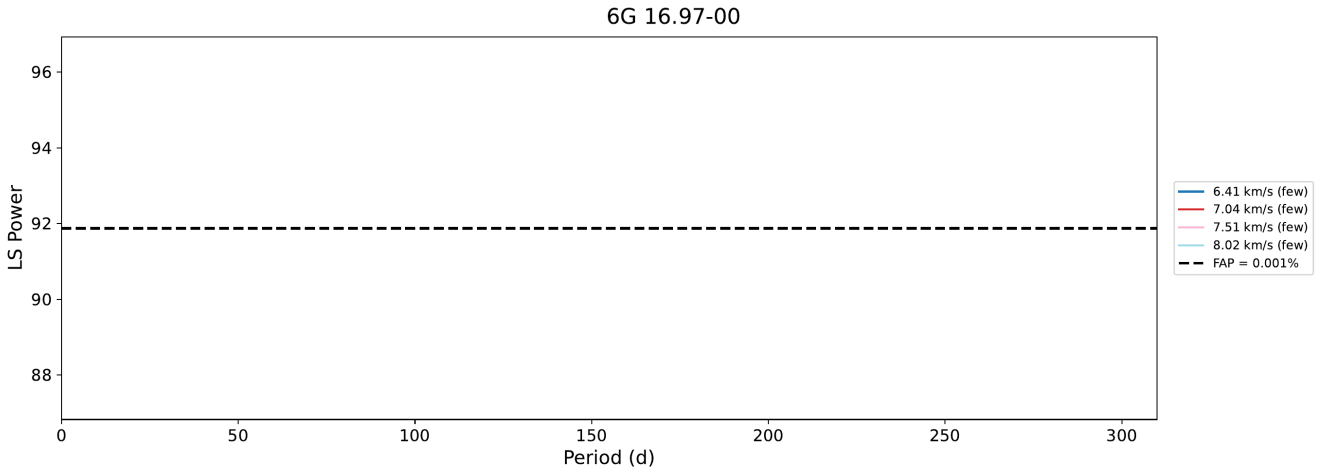


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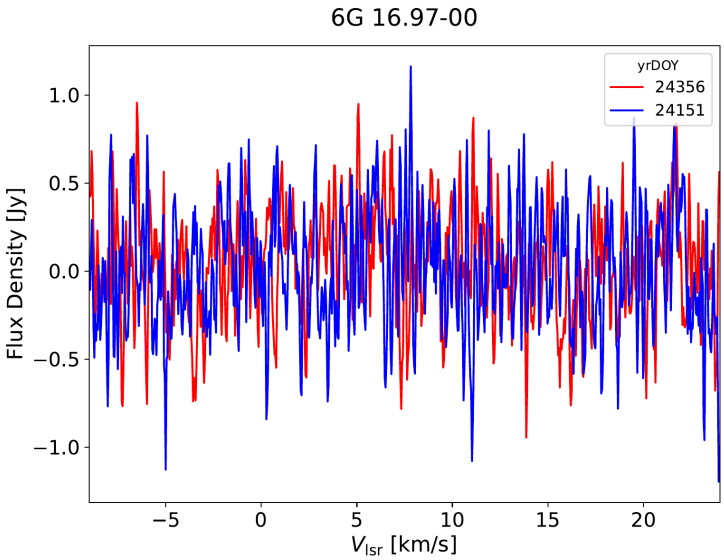
Light curve



Periodogram

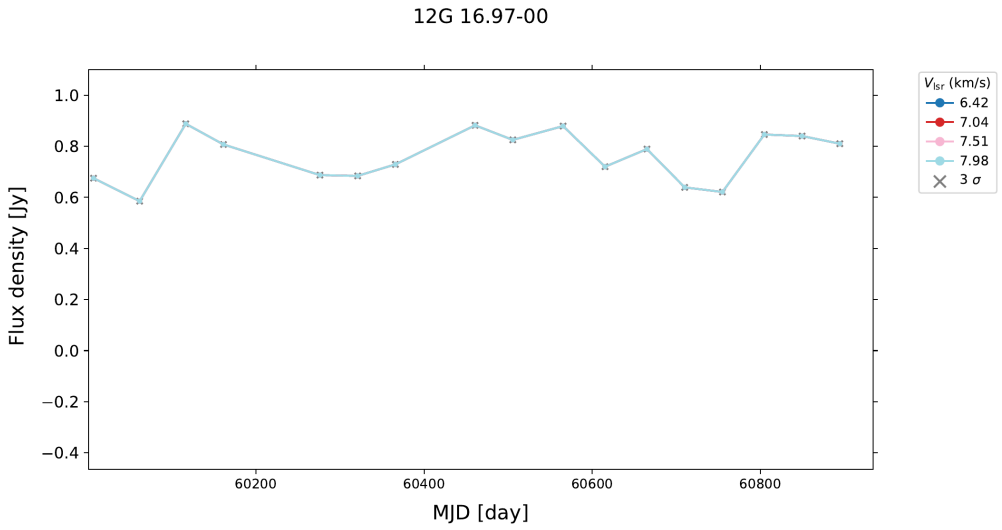


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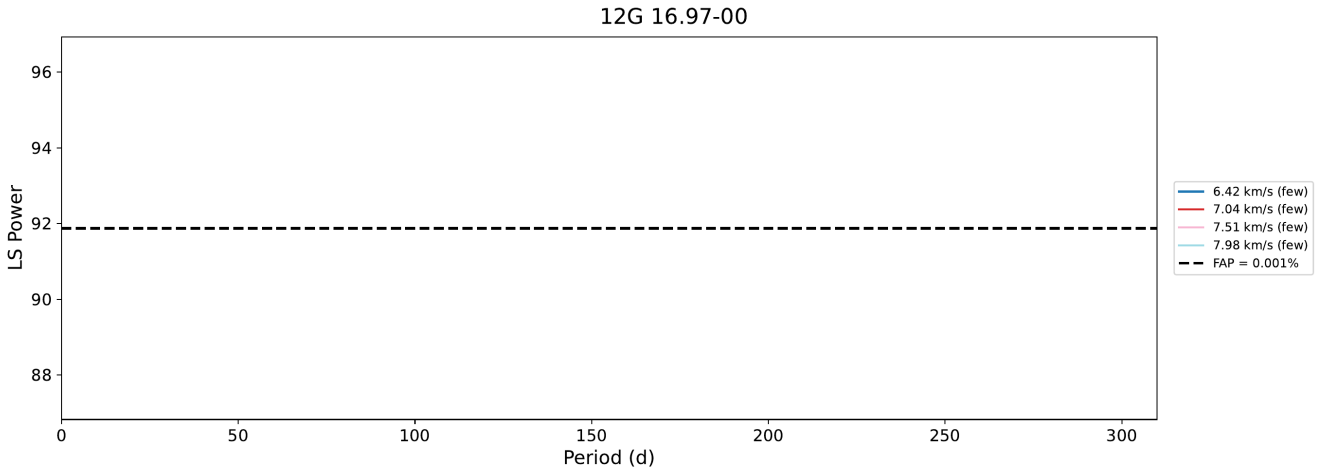


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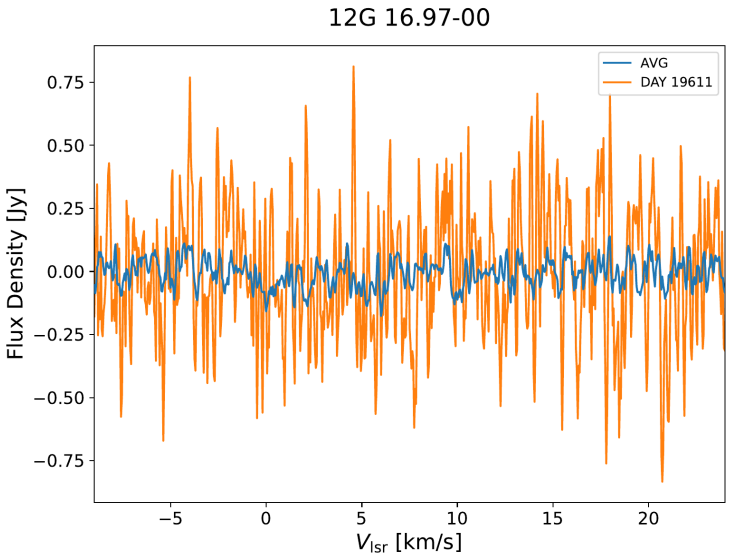
Light curve



Periodogram

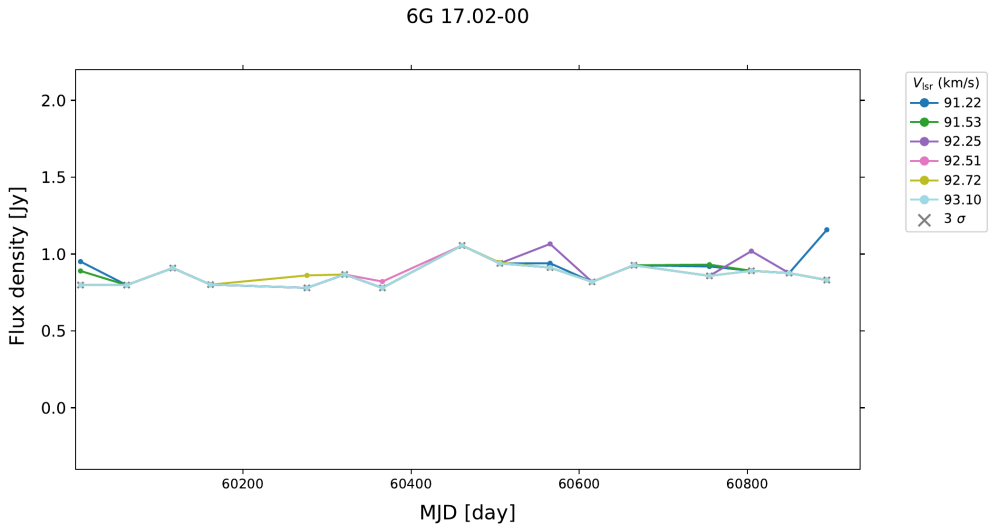


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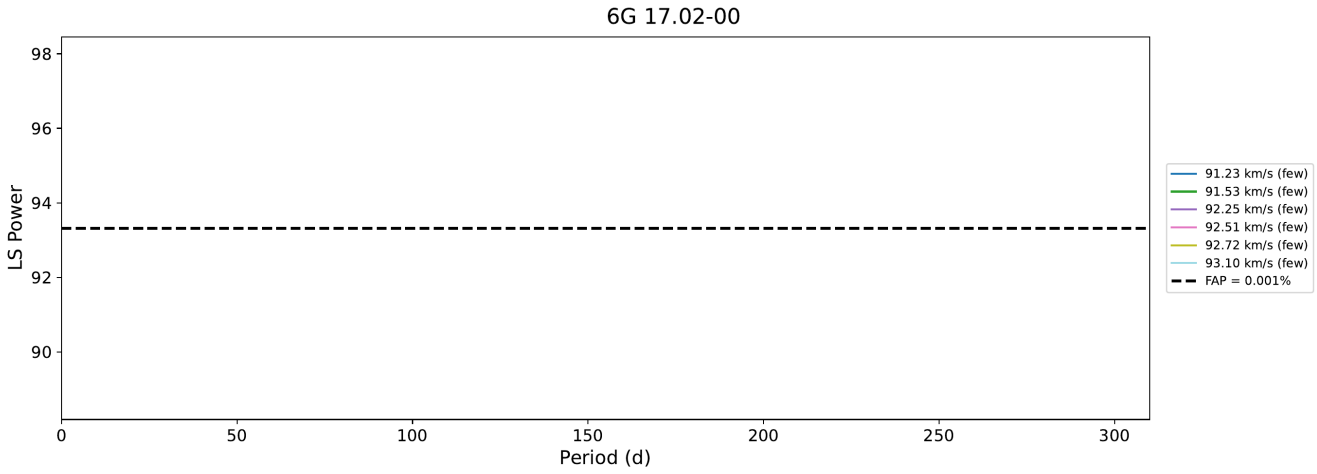


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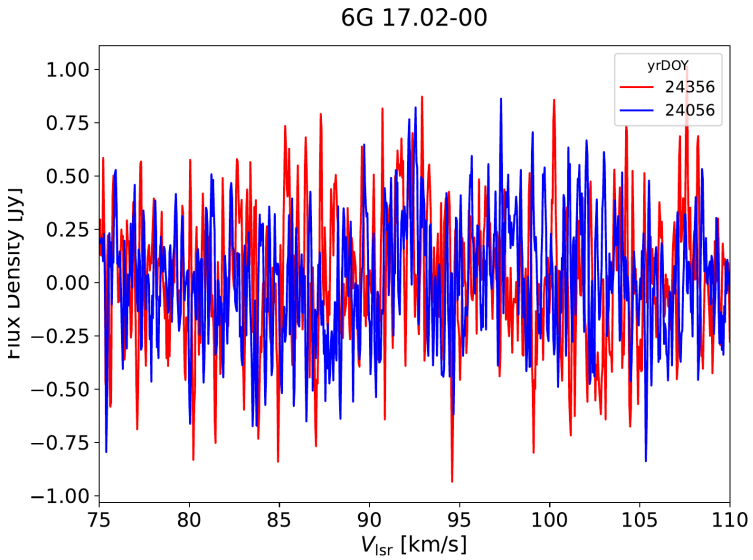
Light curve



Periodogram

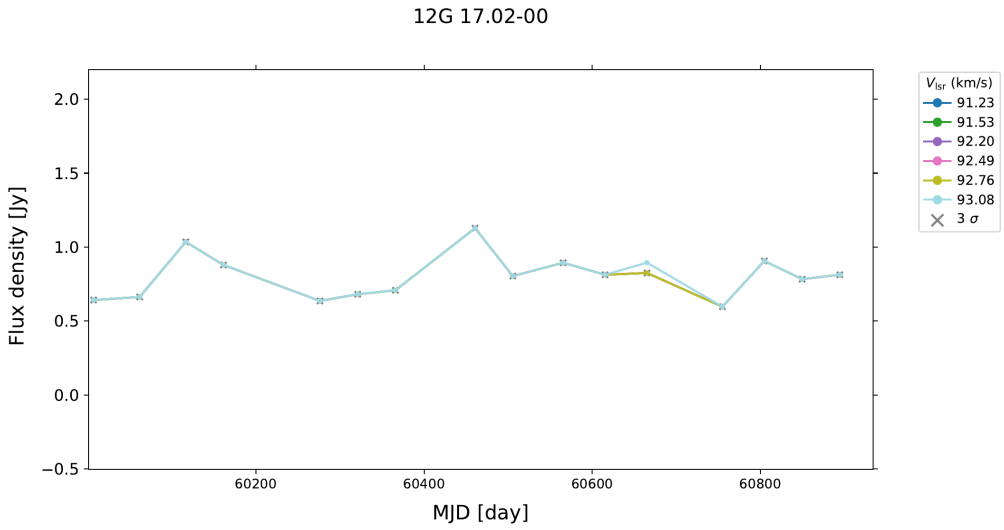


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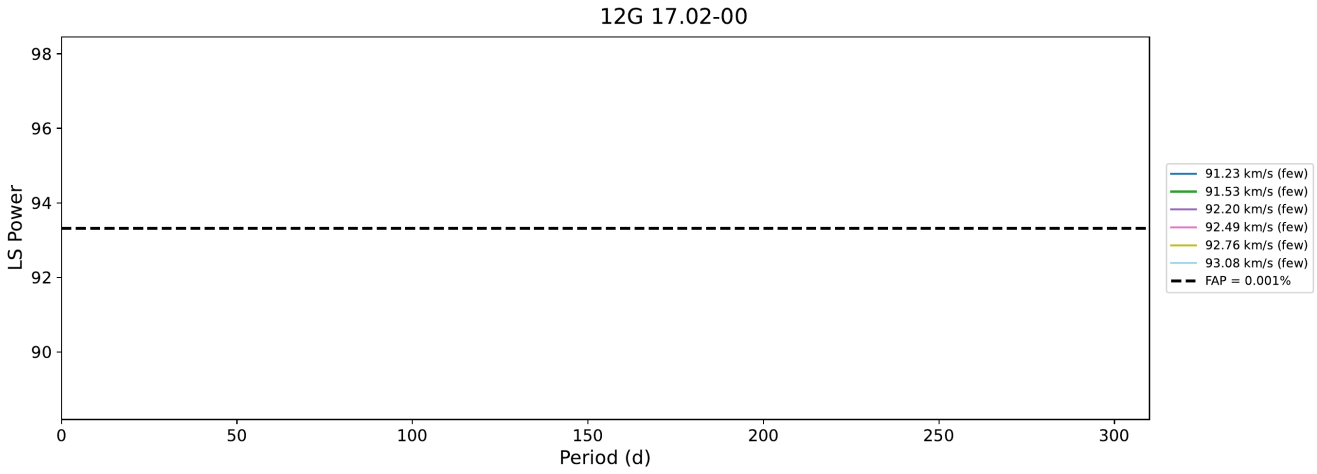


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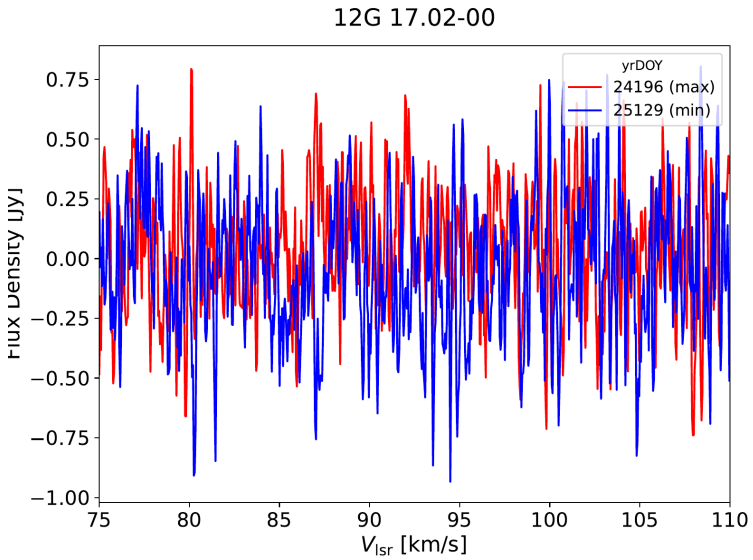
Light curve



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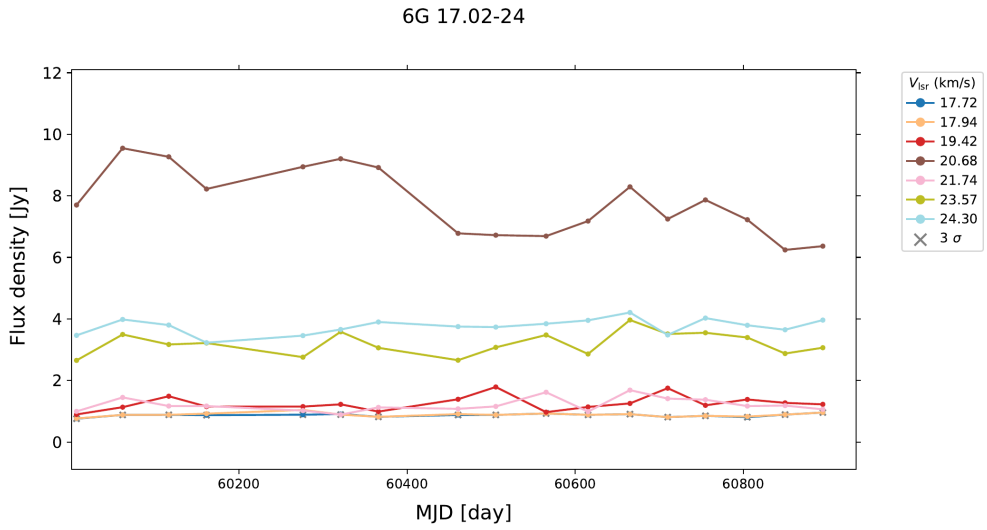


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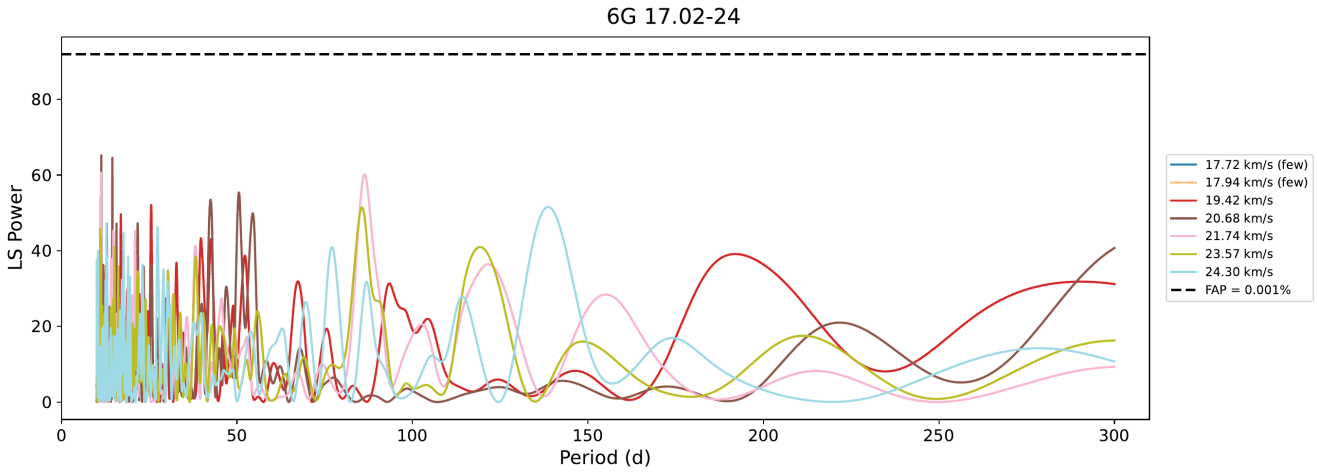


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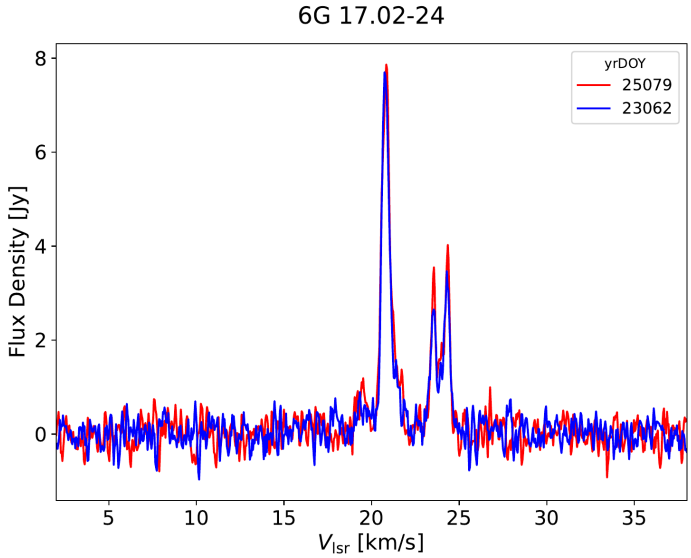
Light curve



Periodogram

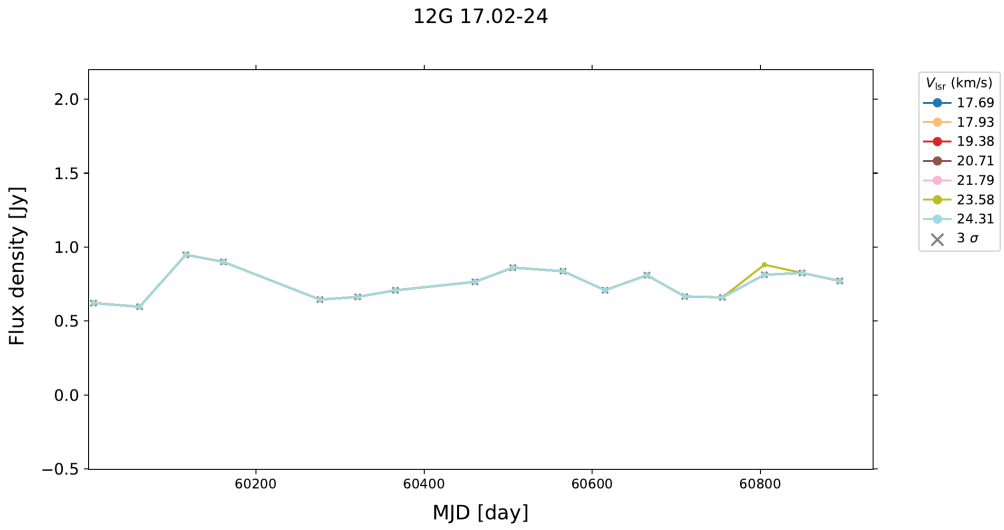


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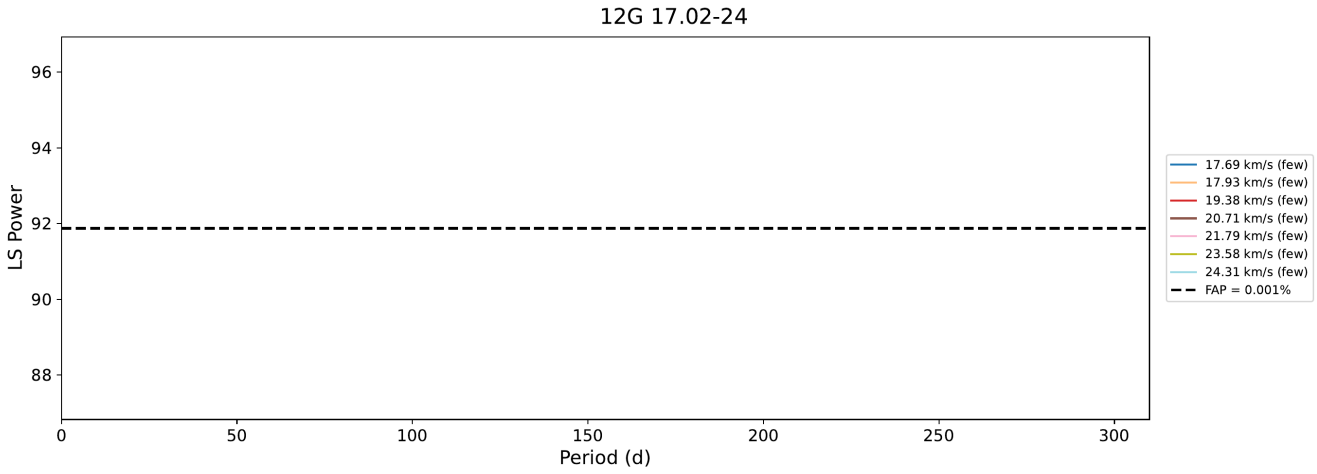


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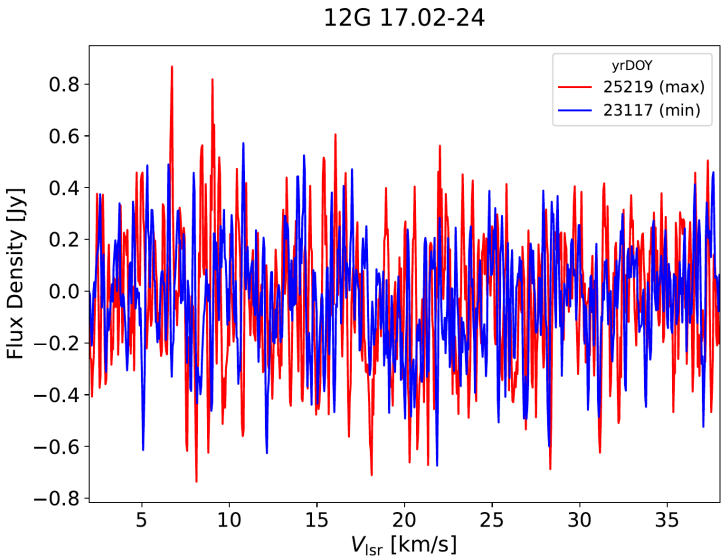
Light curve



Periodogram

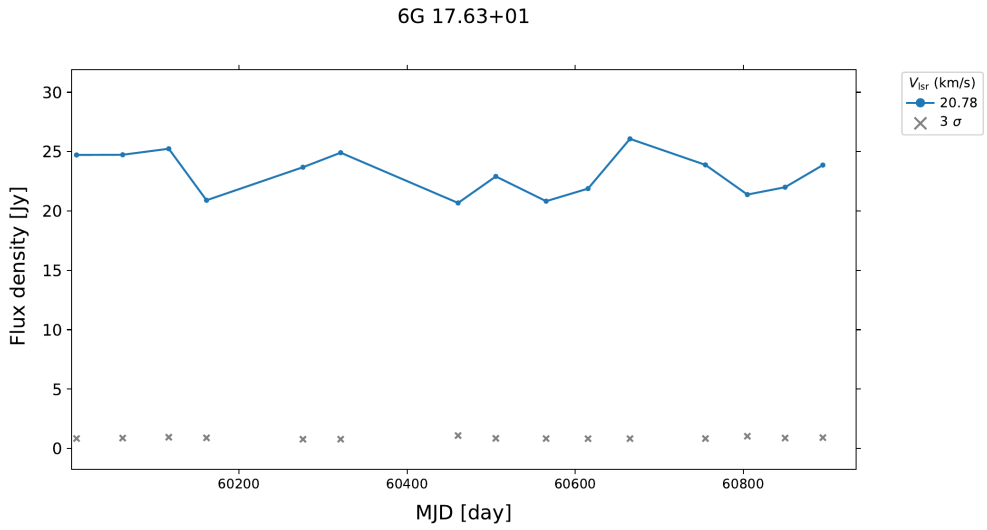


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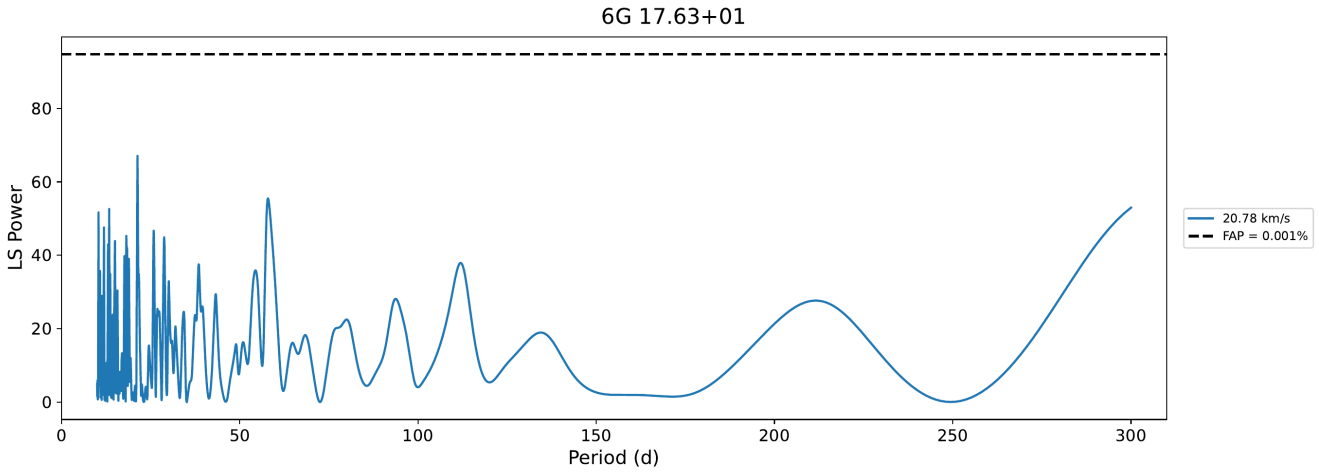


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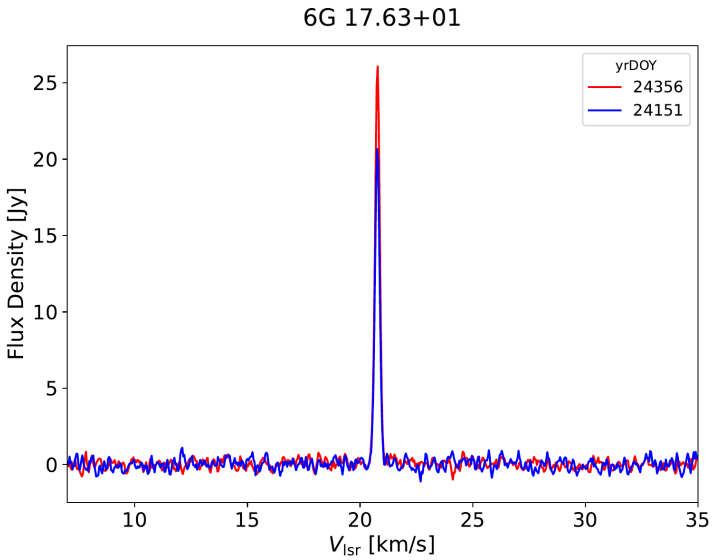
Light curve



Periodogram

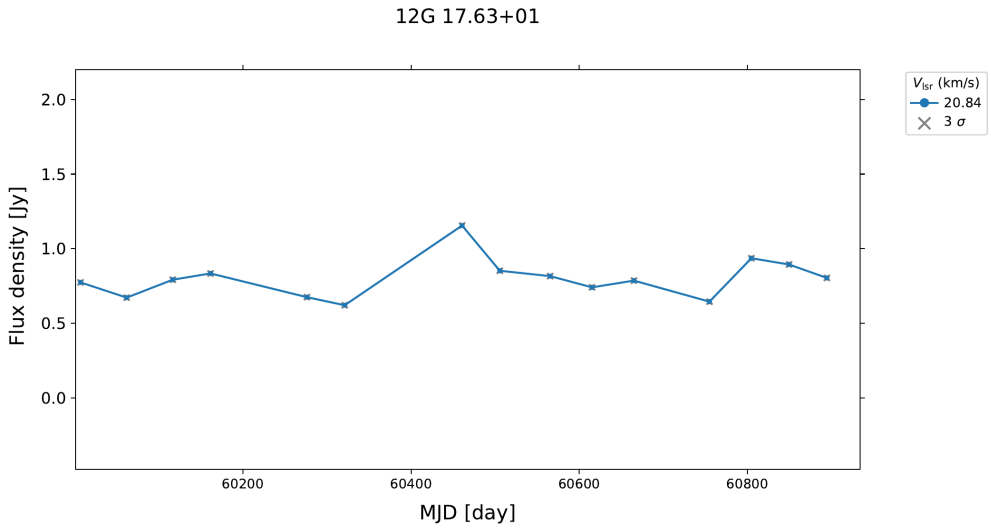


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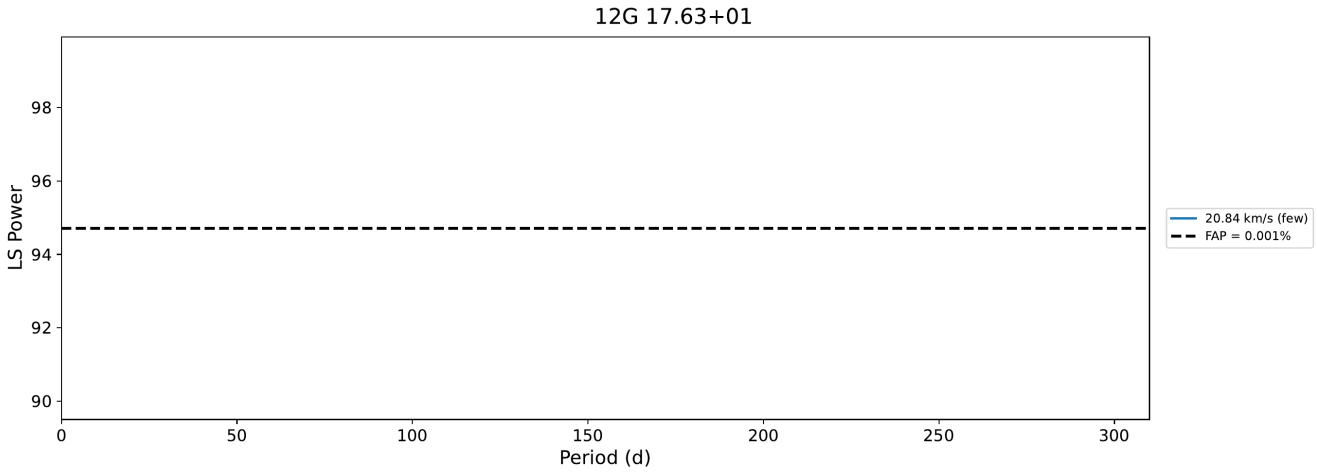


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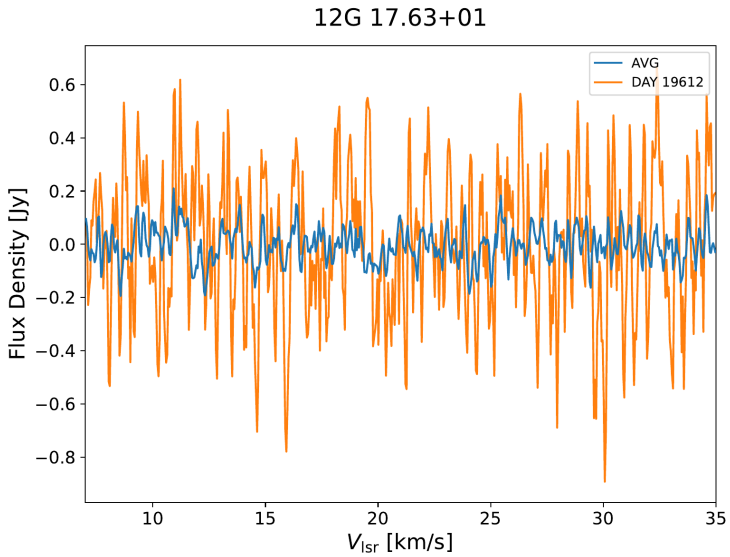
Light curve



Periodogram

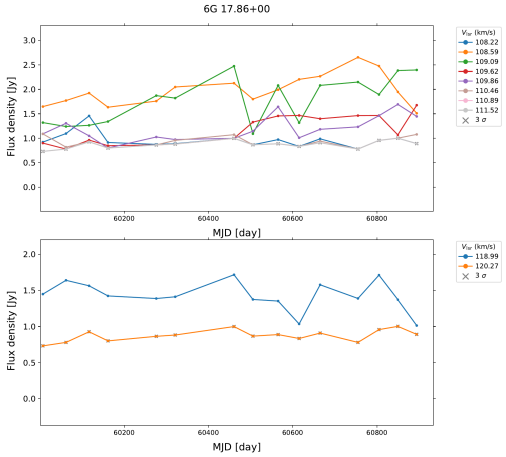


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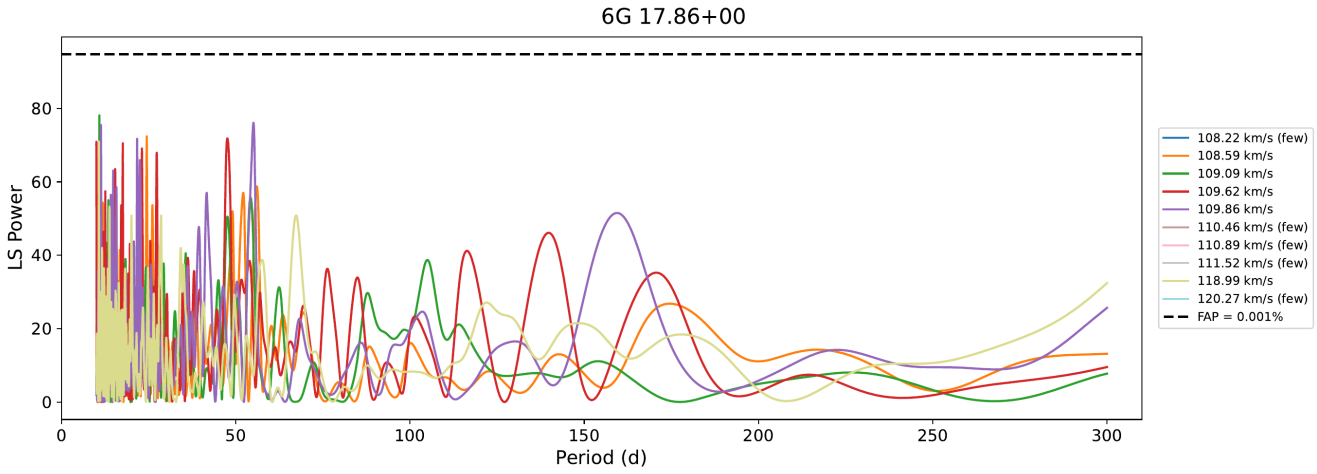


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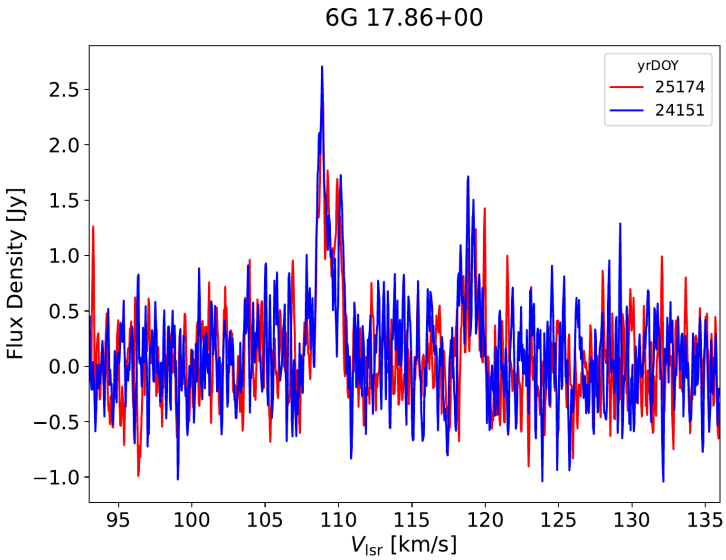
Light curve



Periodogram

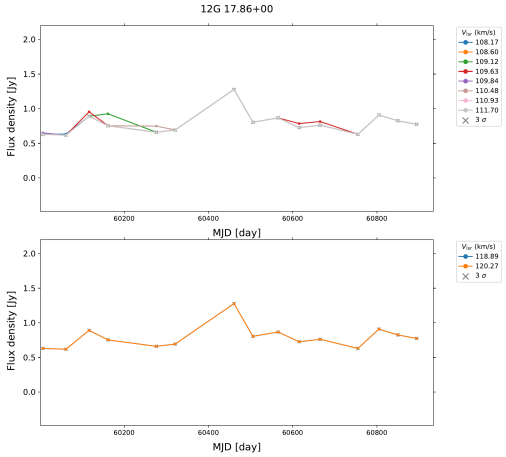


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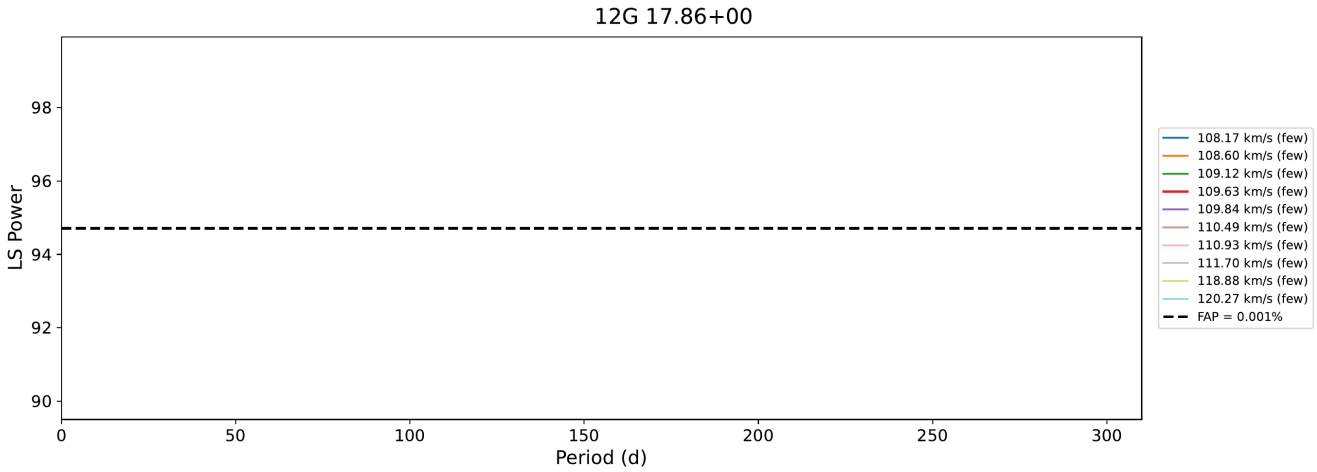


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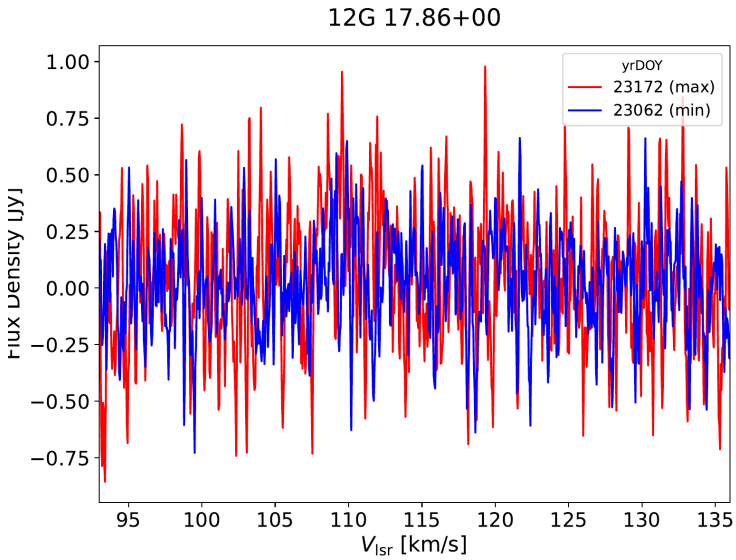
Light curve



Periodogram

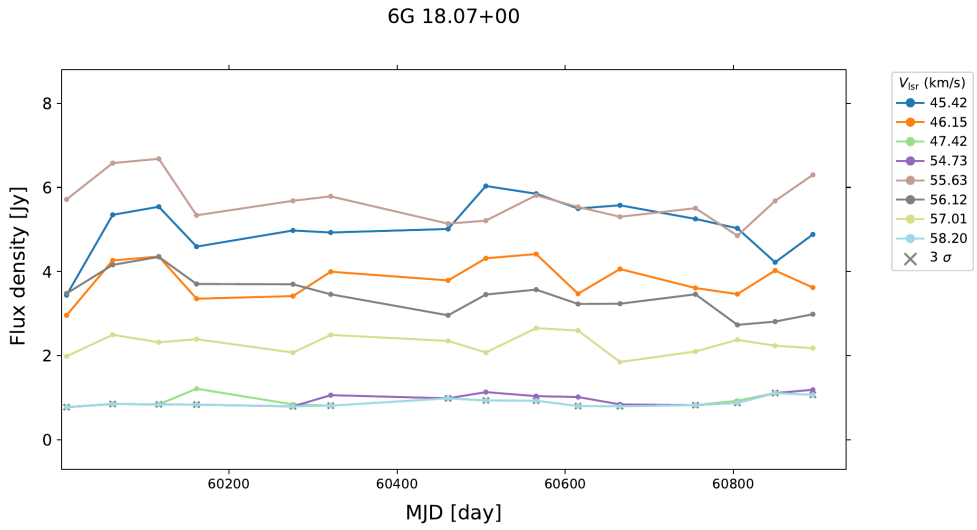


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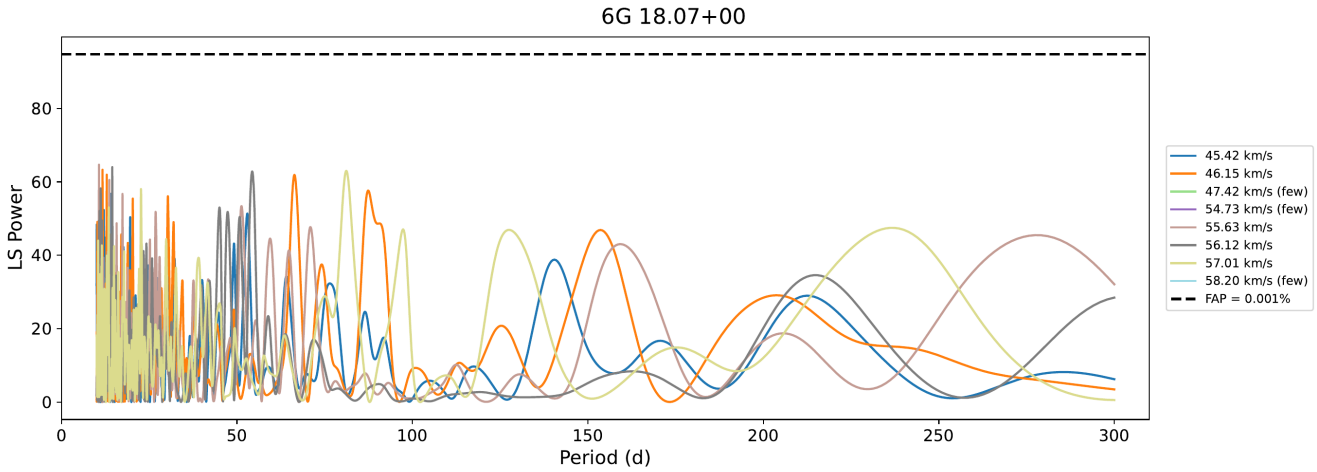


6G 18.07+00

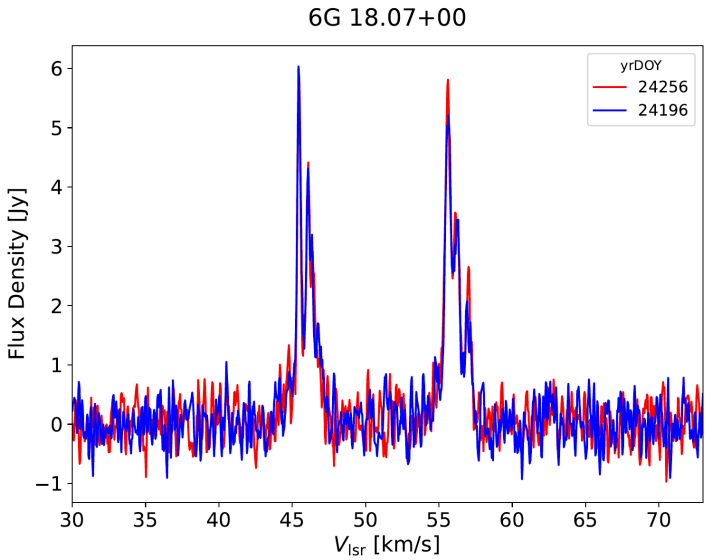
Light curve



Periodogram

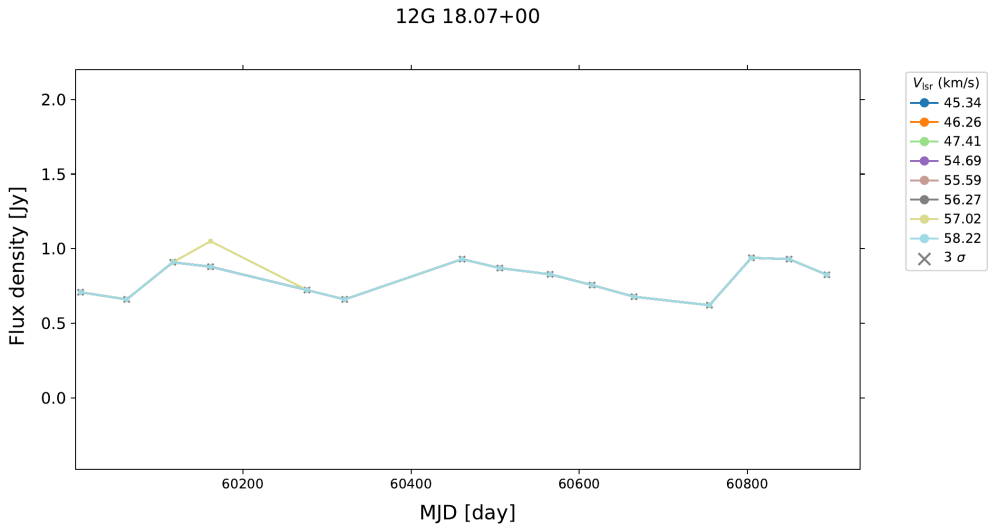


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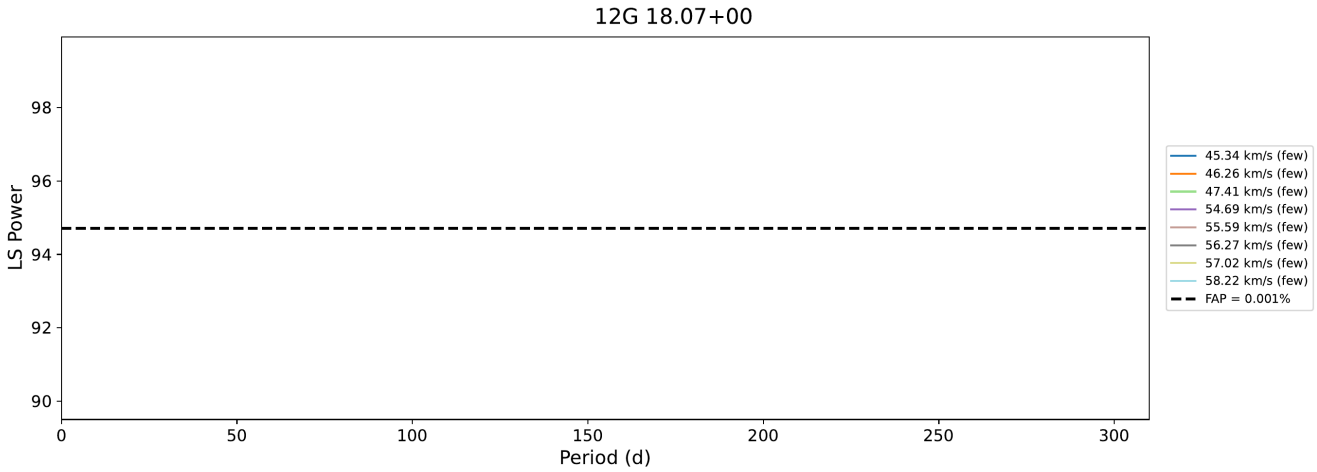


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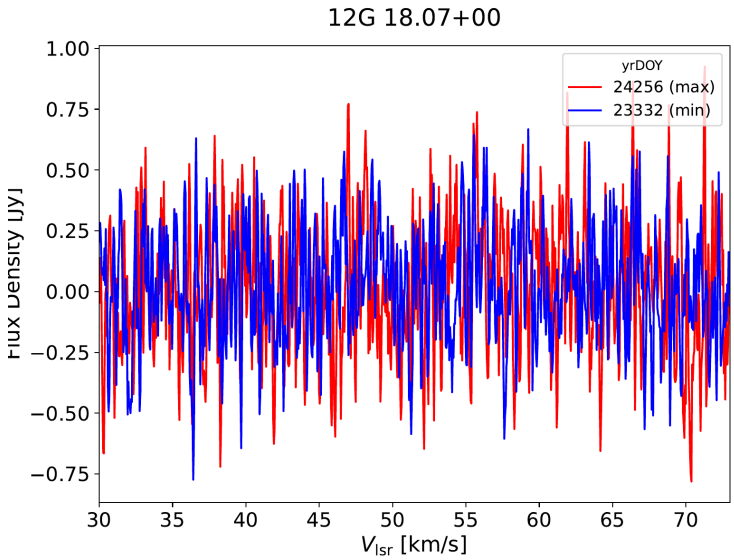
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Periodogram

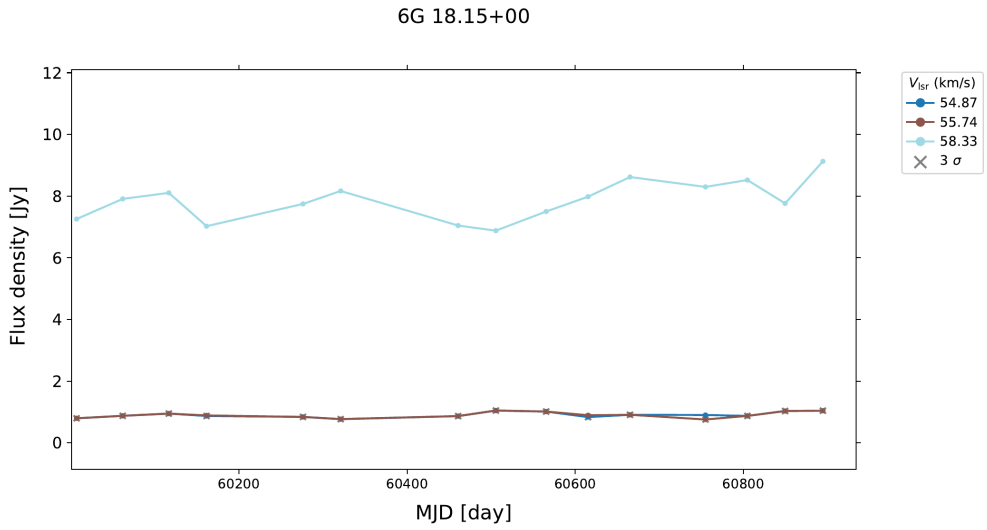


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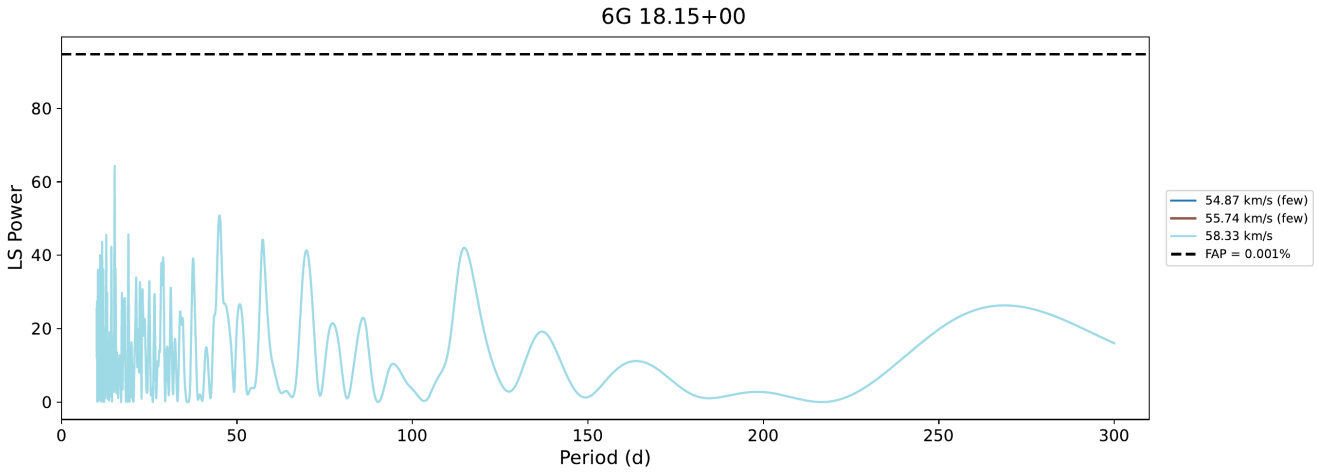


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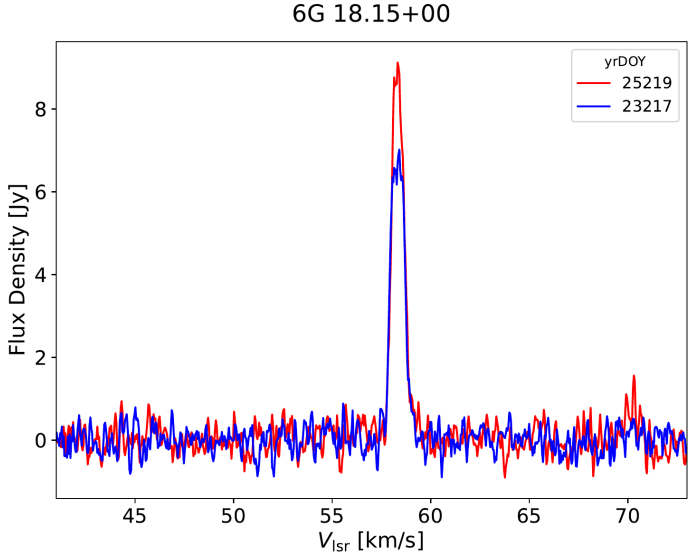
Light curve



Periodogram

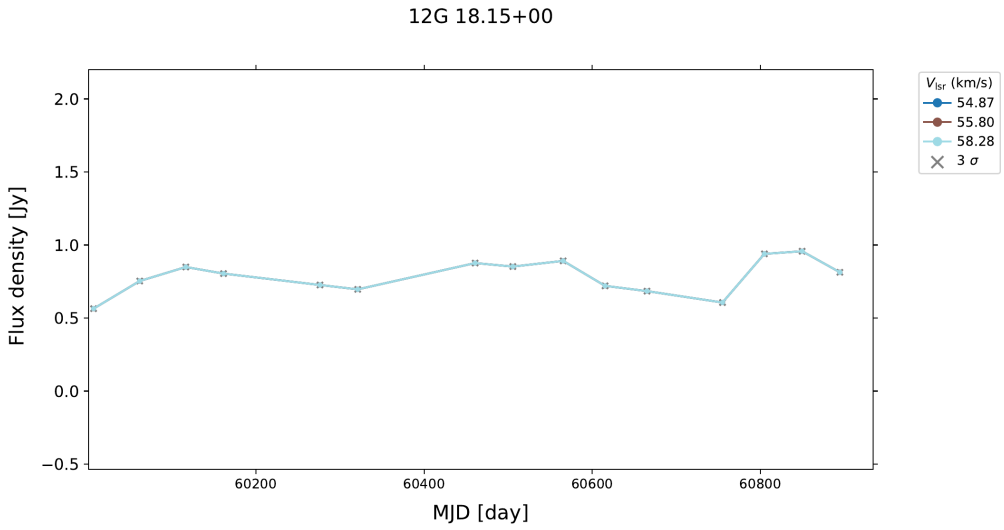


Spectrum

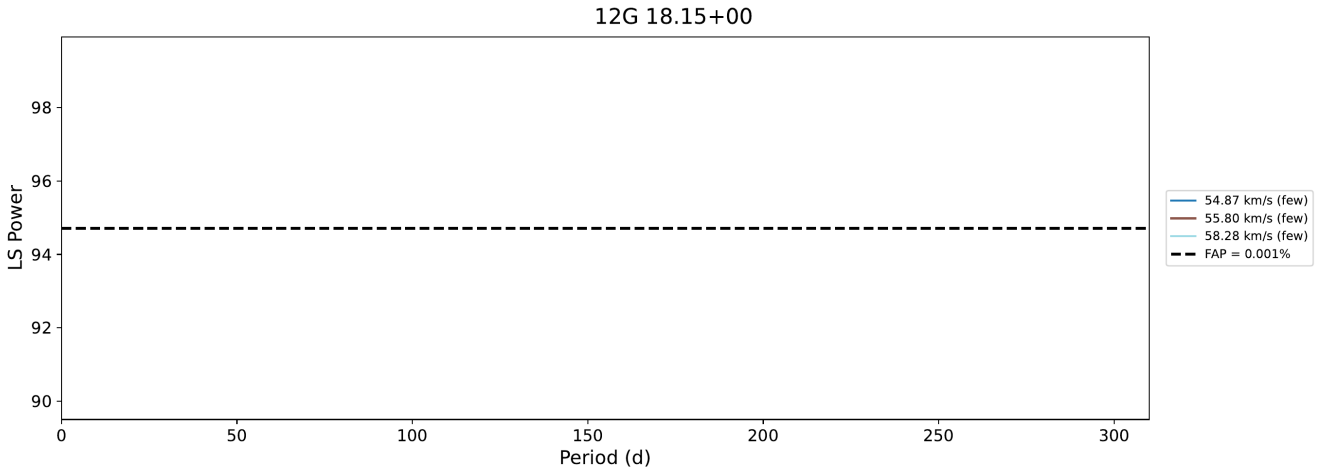


12G 18.15+00

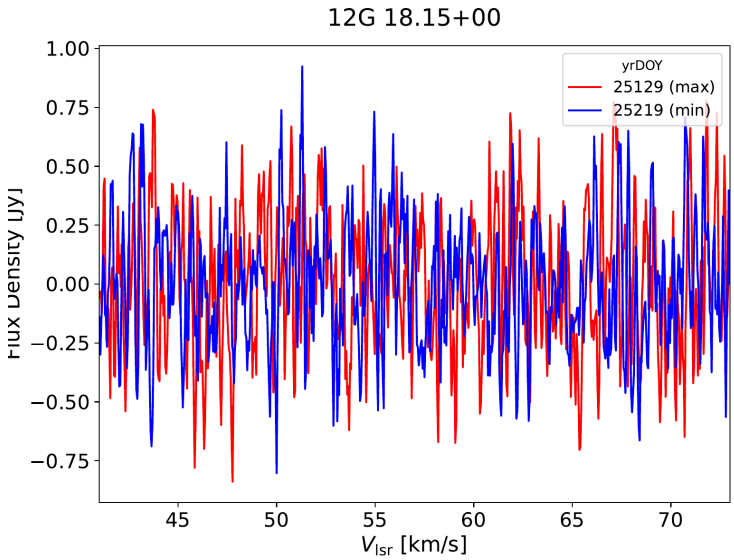
Light curve



Periodogram

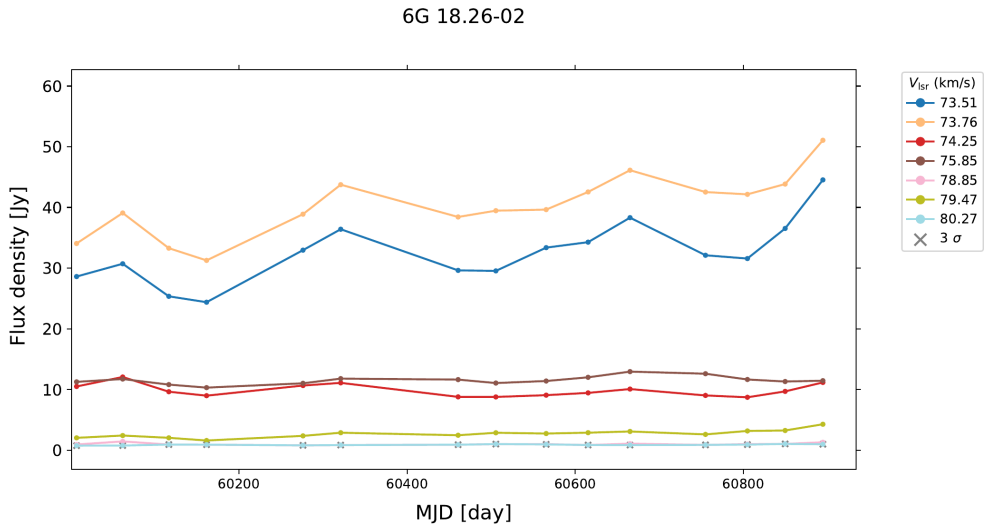


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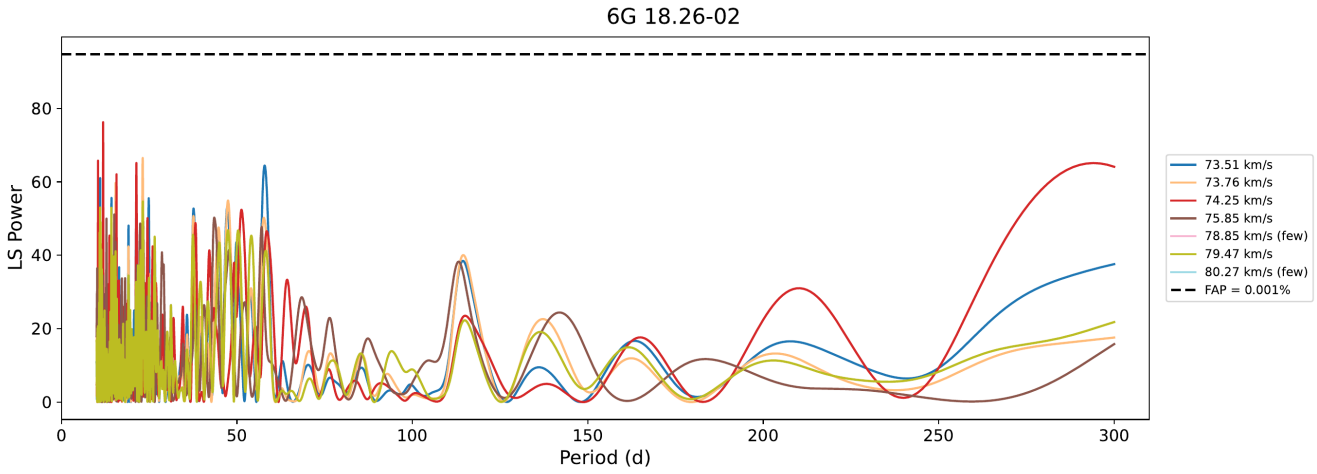


6G 18.26-02

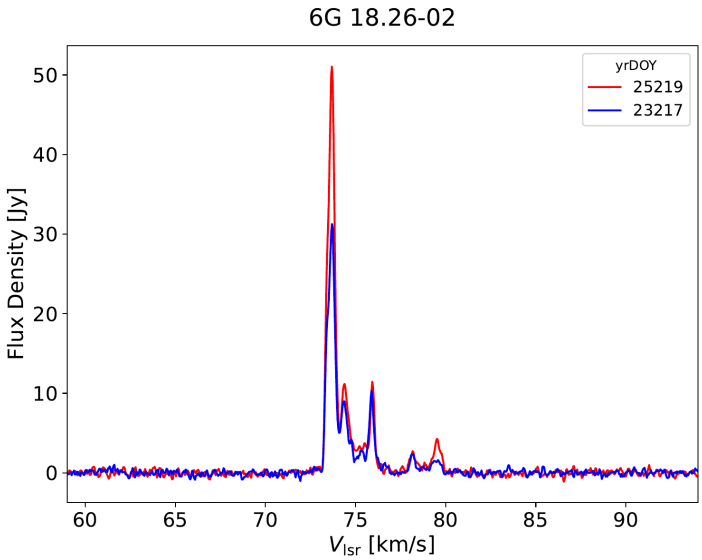
Light curve



Periodogram

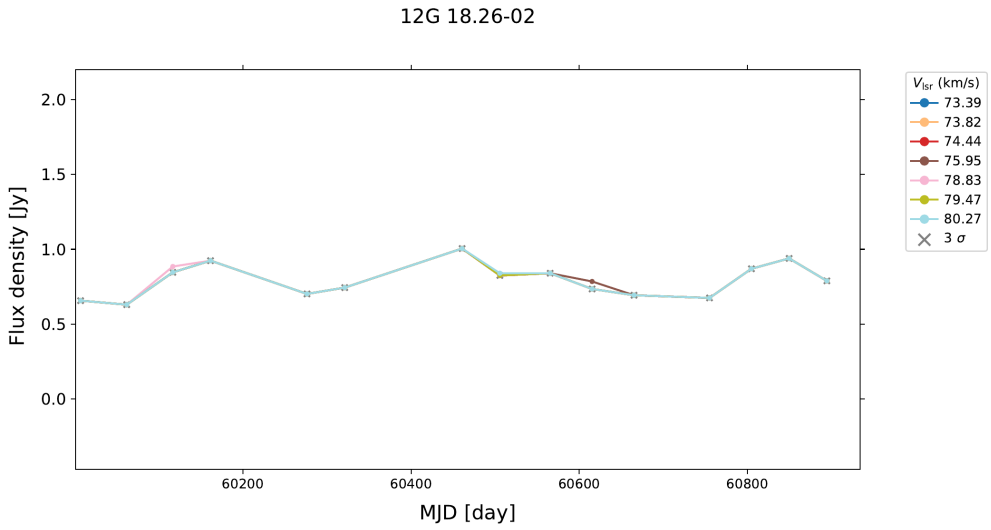


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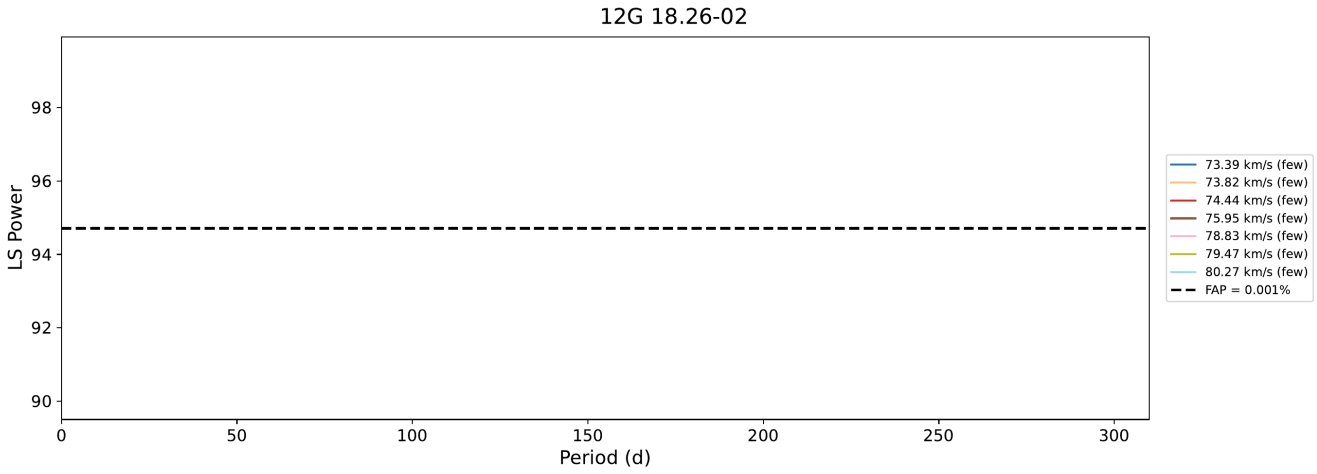


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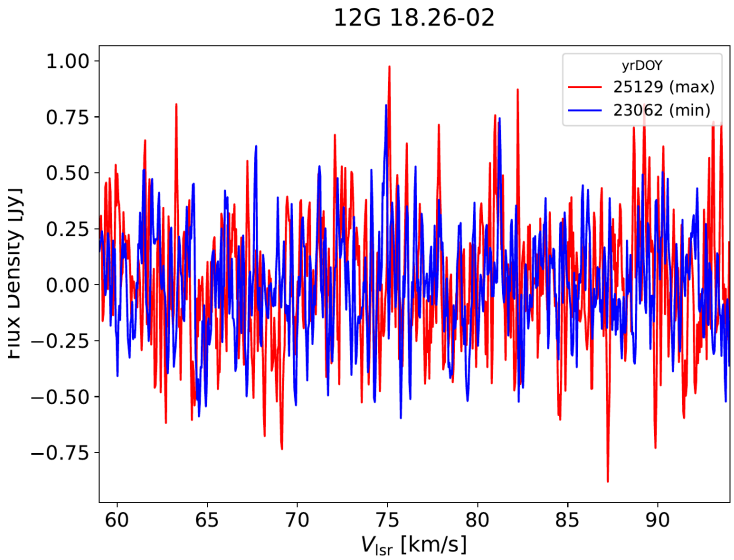
Light curve



Periodogram

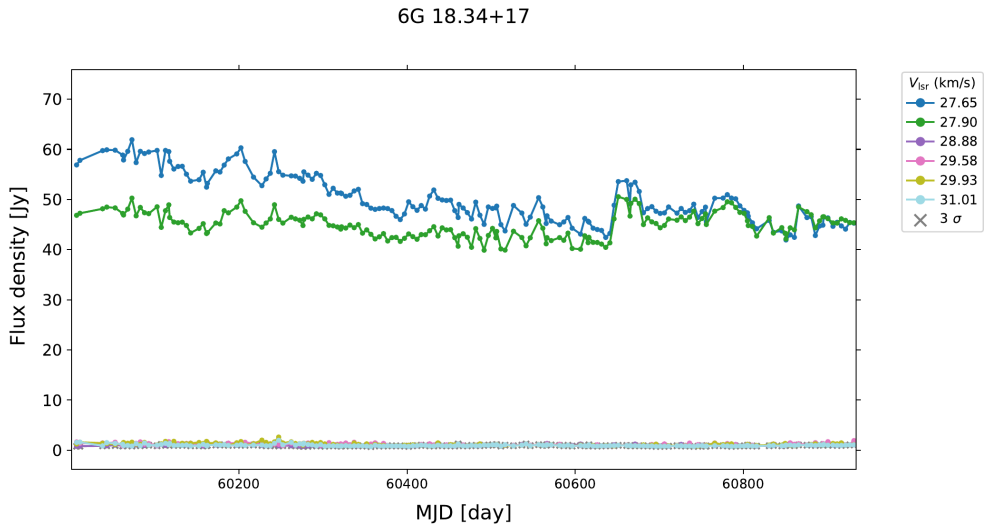


Spectrum

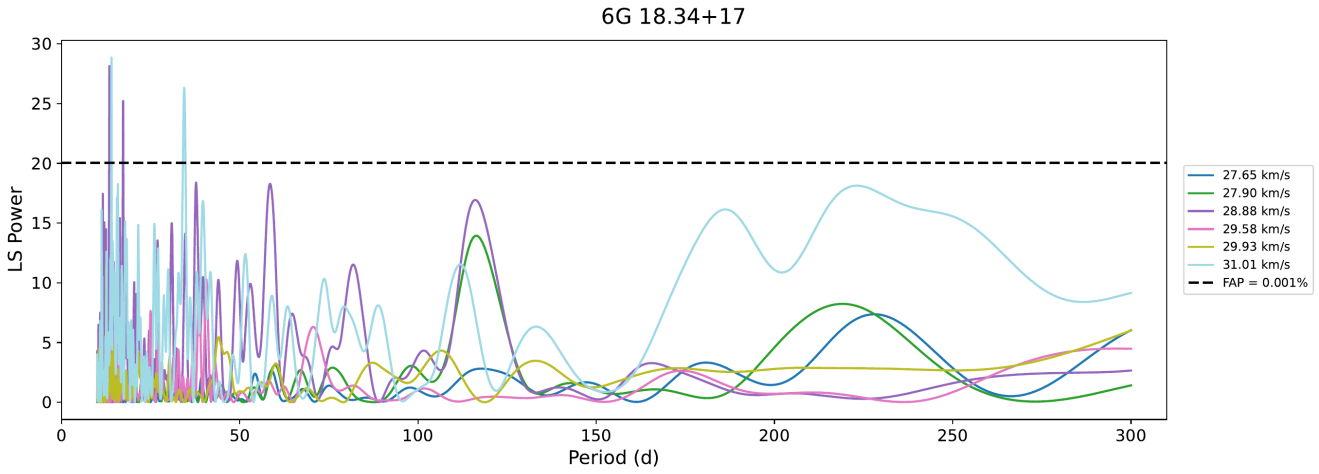


6G 18.34+17

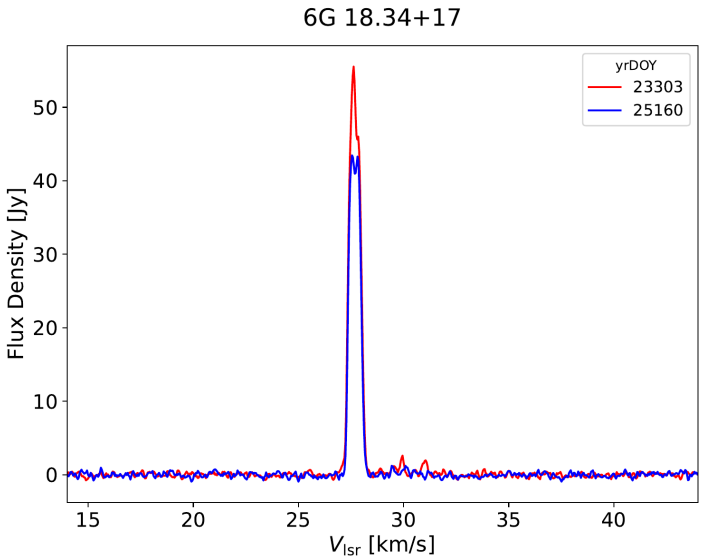
Light curve



Periodogram

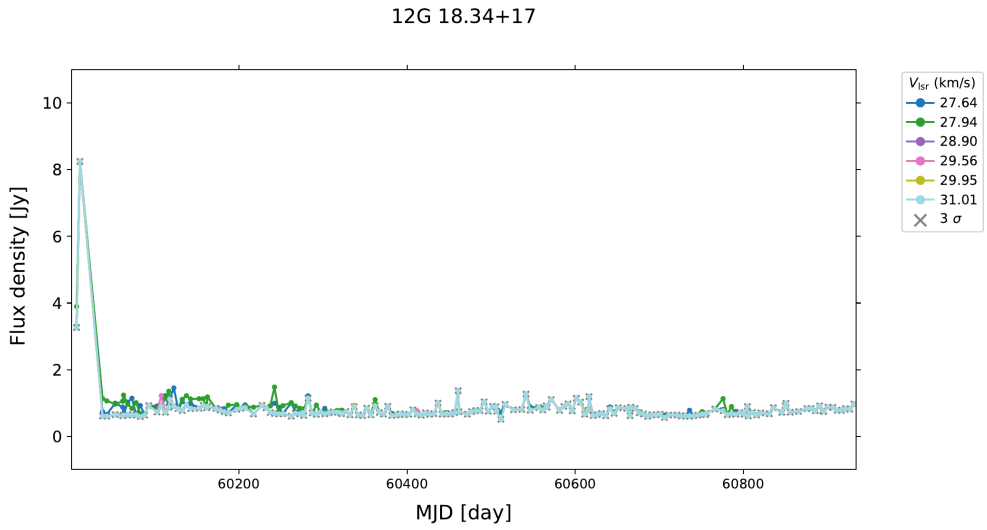


Spectrum

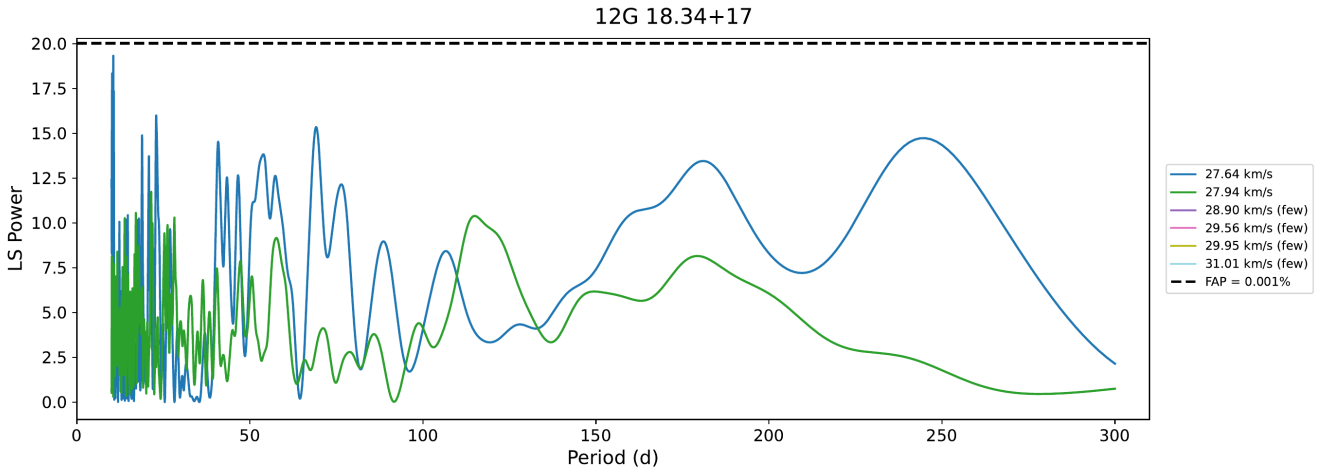


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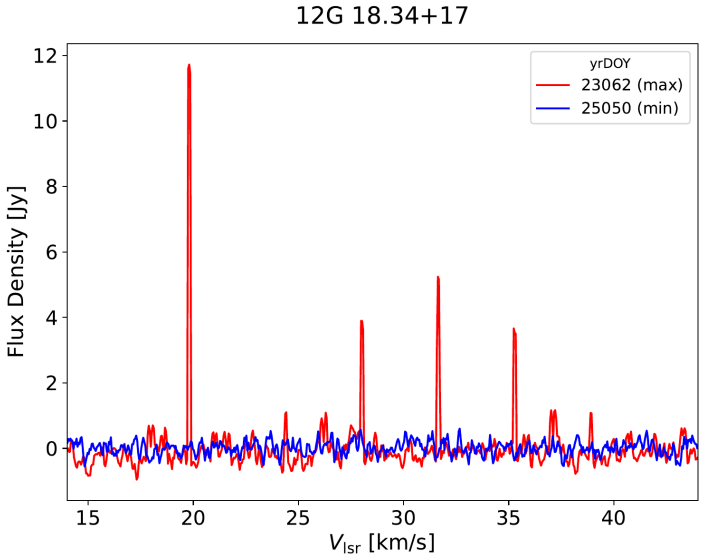
Light curve



Periodogram

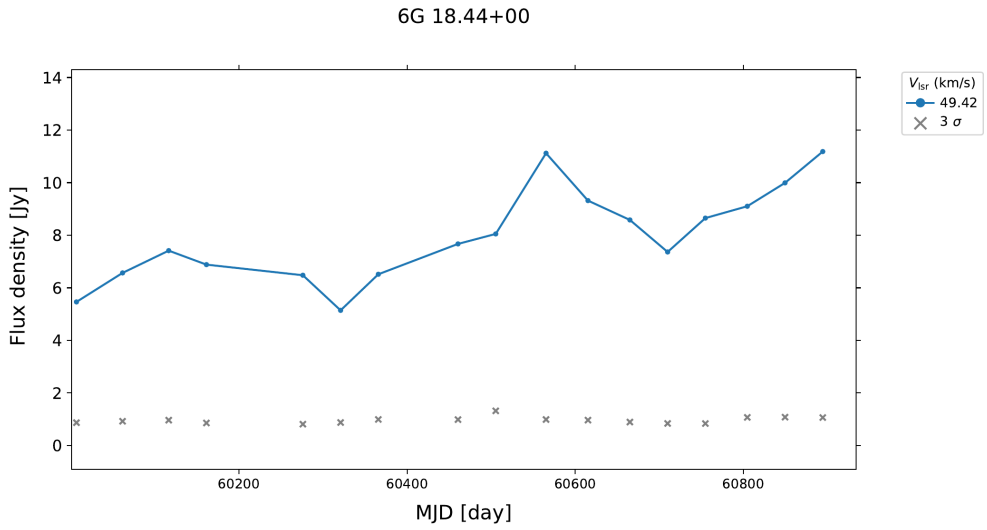


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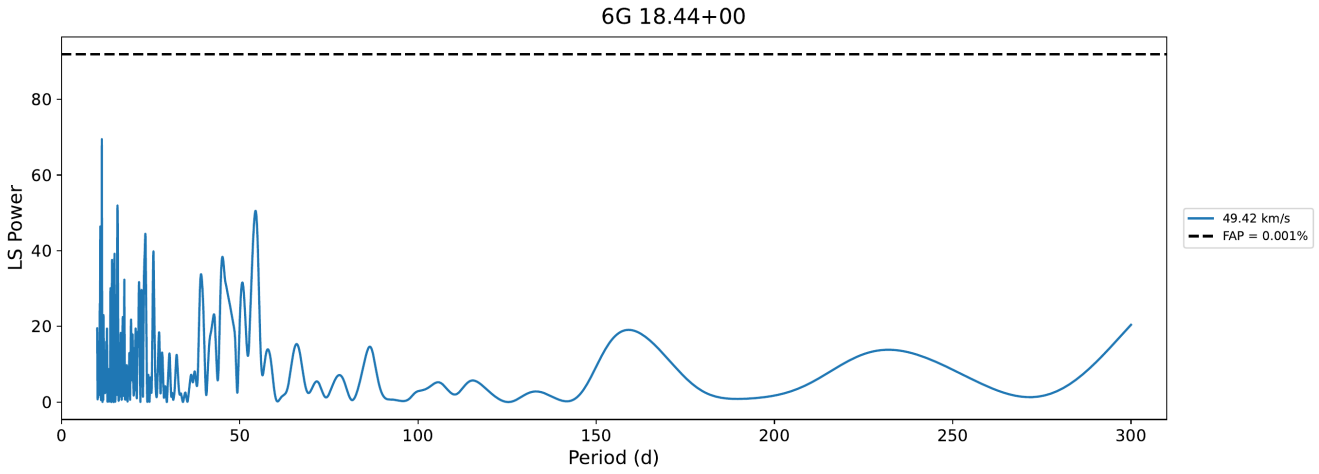


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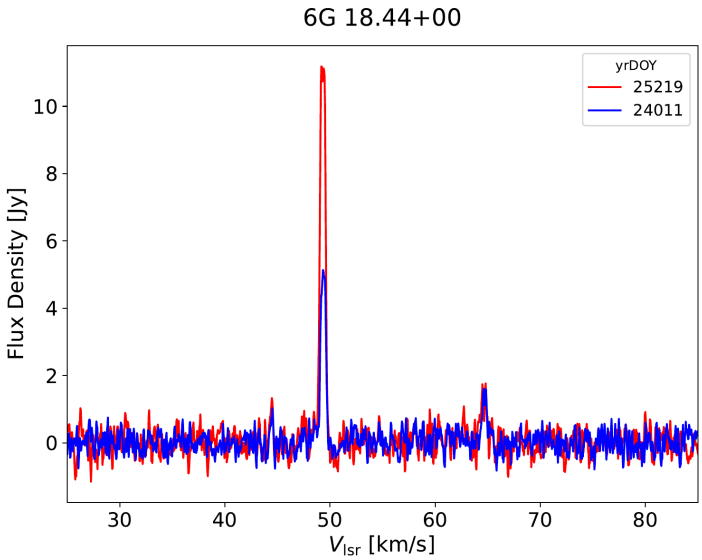
Light curve



Periodogram

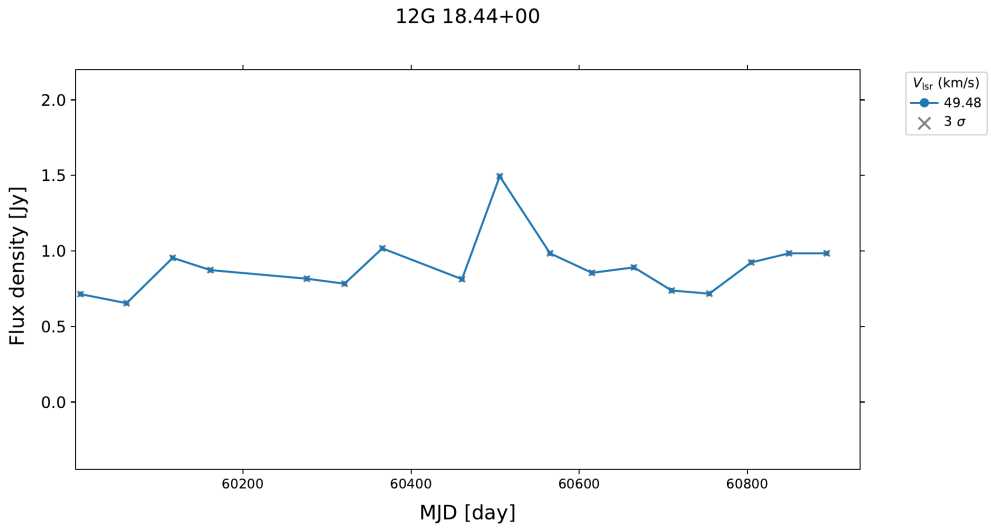


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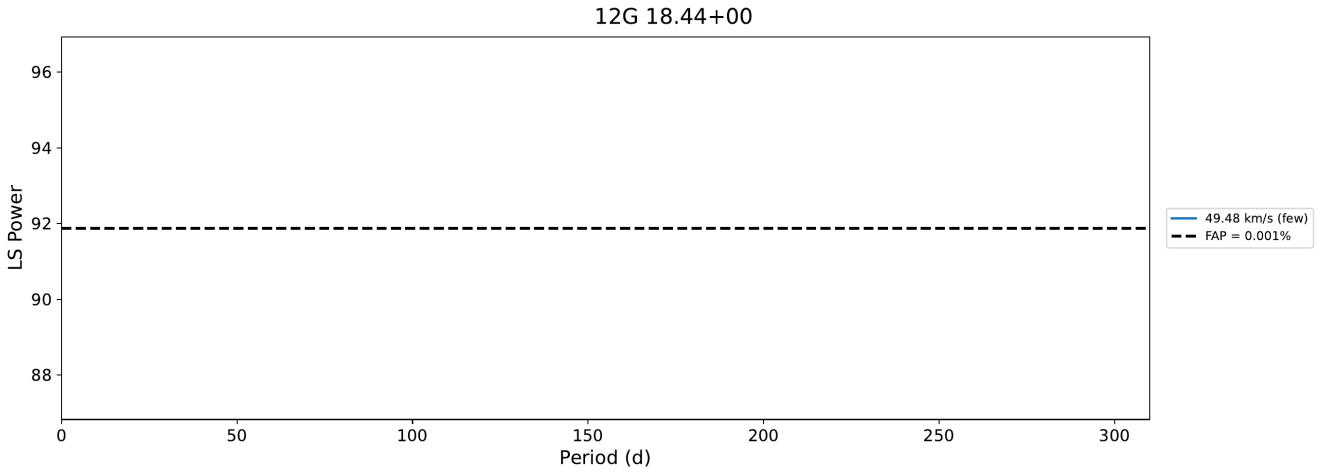


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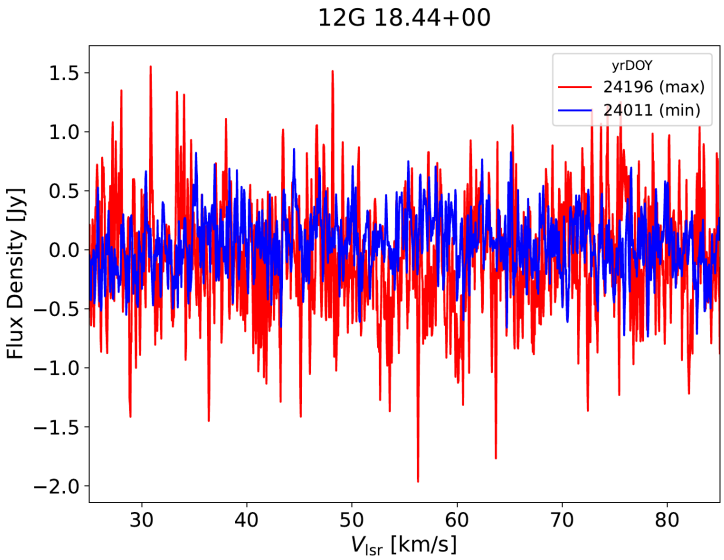
Light curve



Periodogram

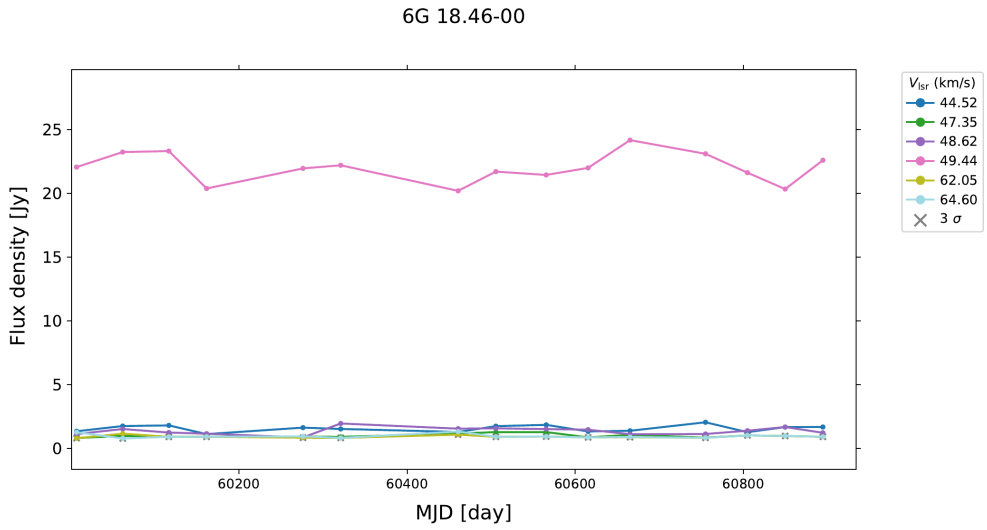


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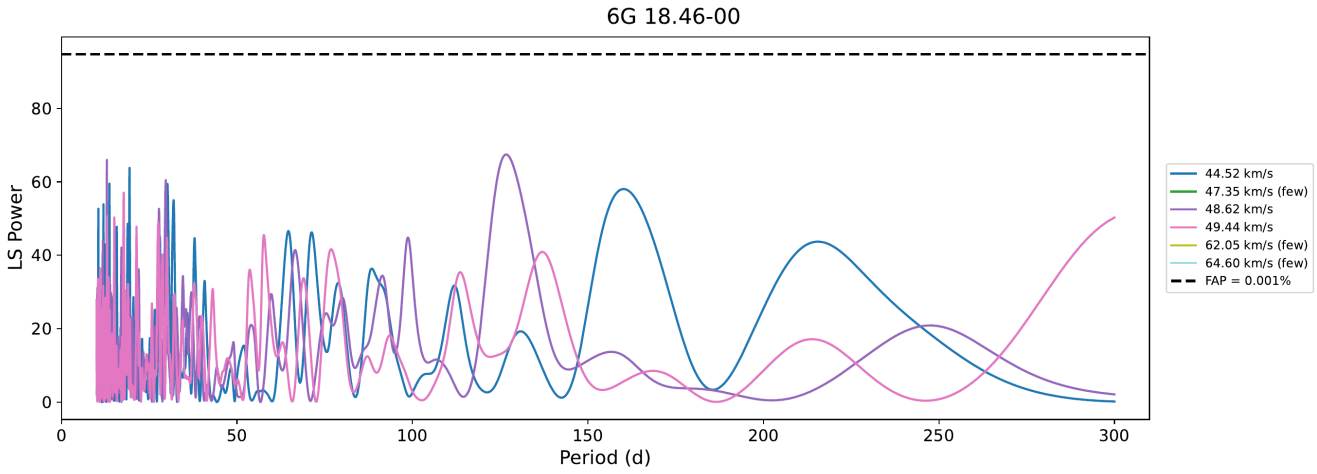


6G 18.46-00

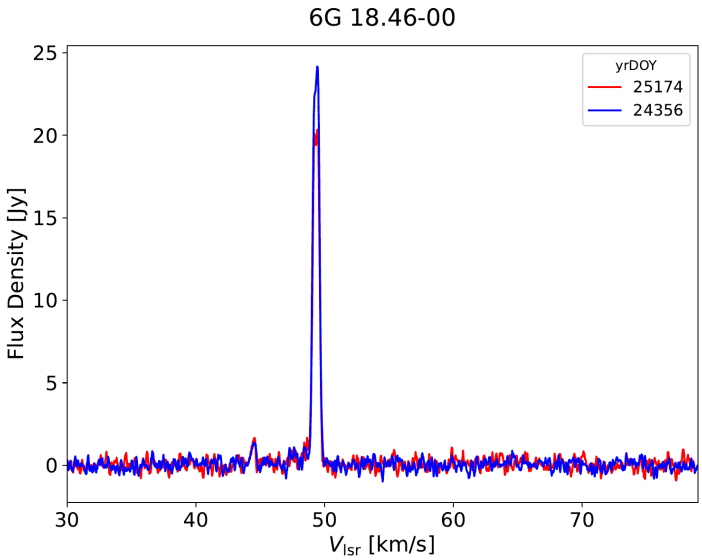
Light curve



Periodogram

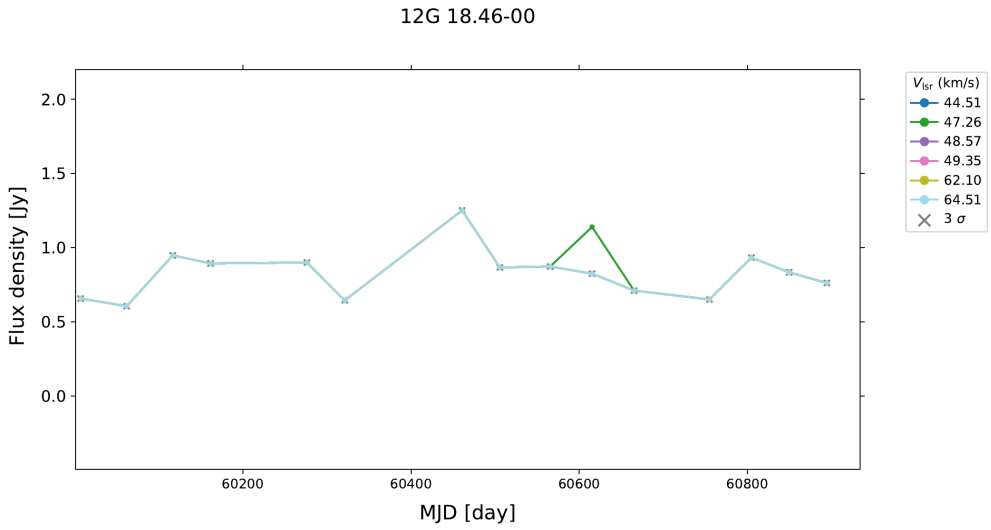


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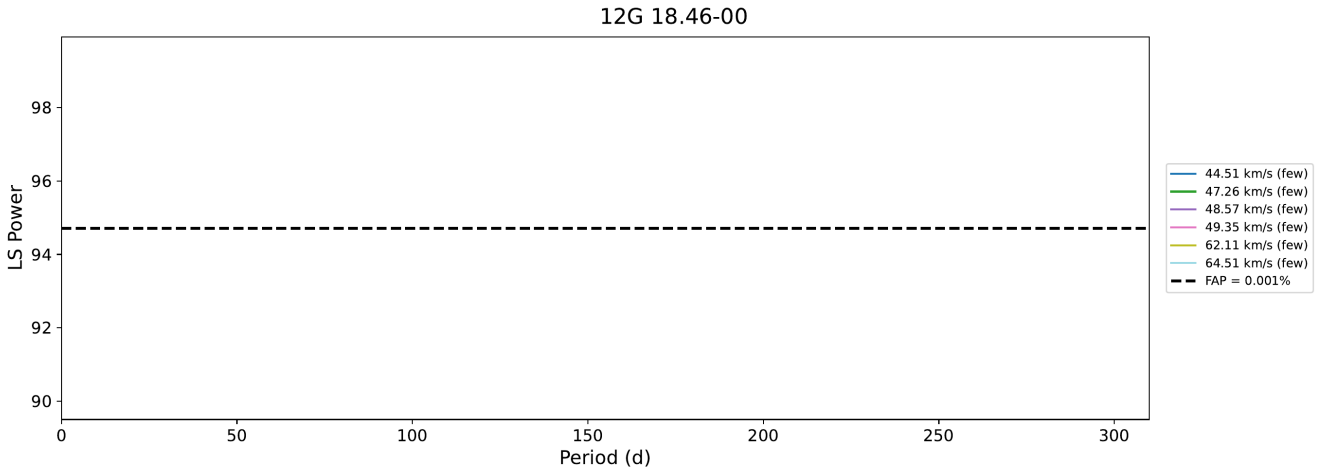


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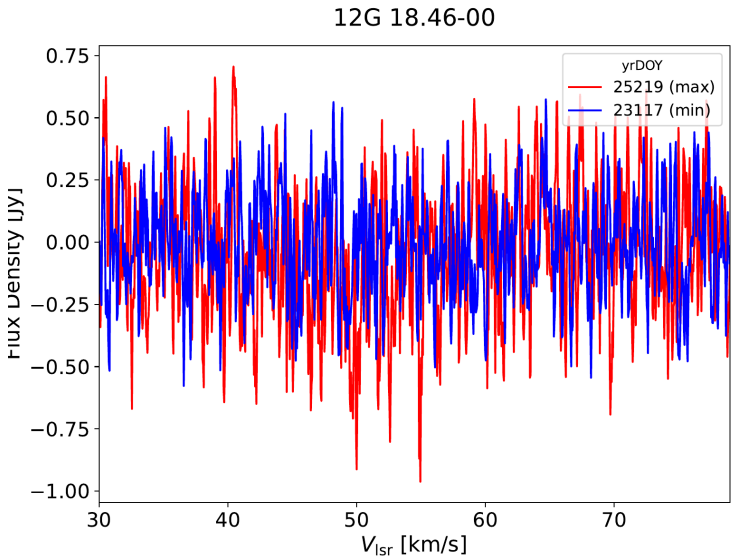
Light curve



Periodogram

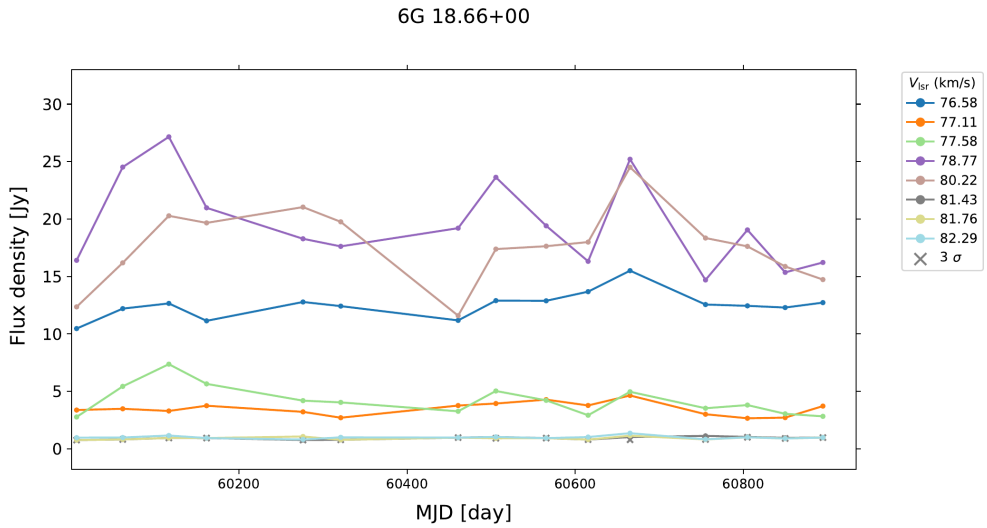


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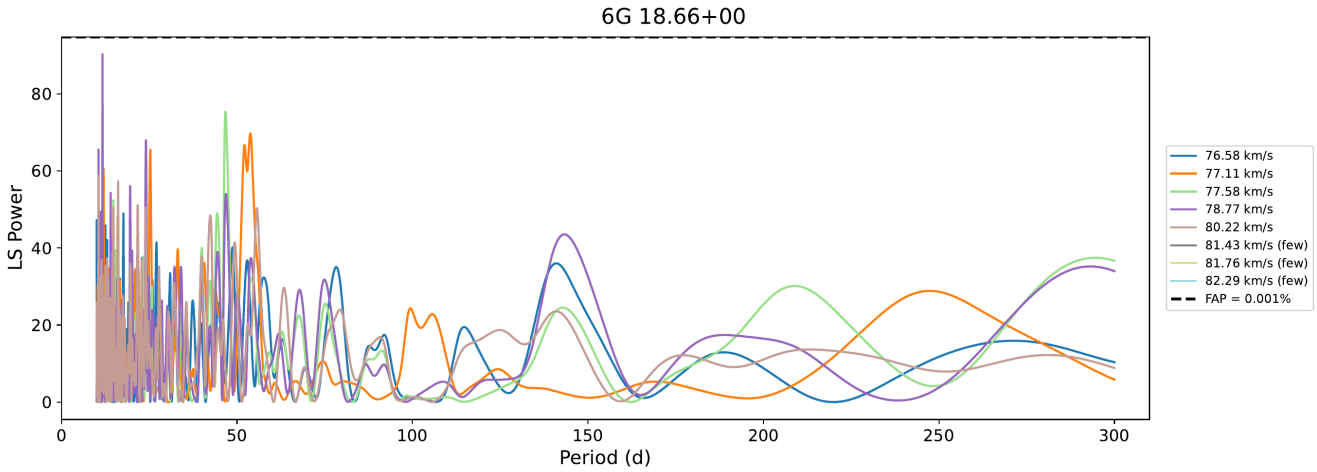


6G 18.66+00

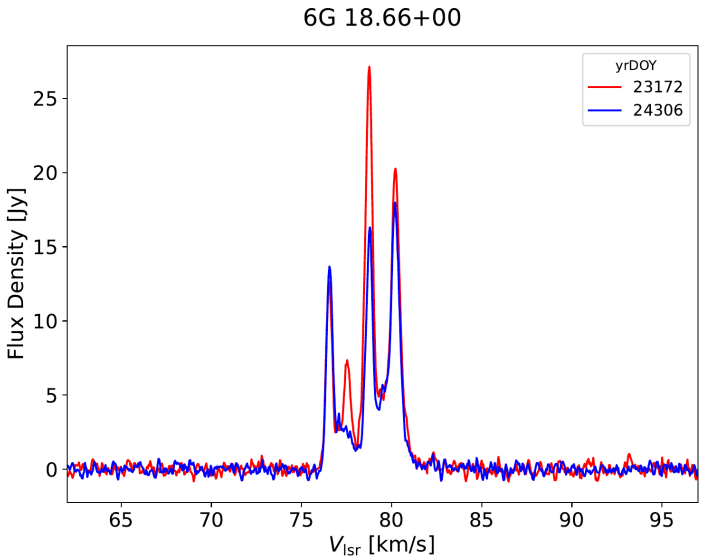
Light curve



Periodogram

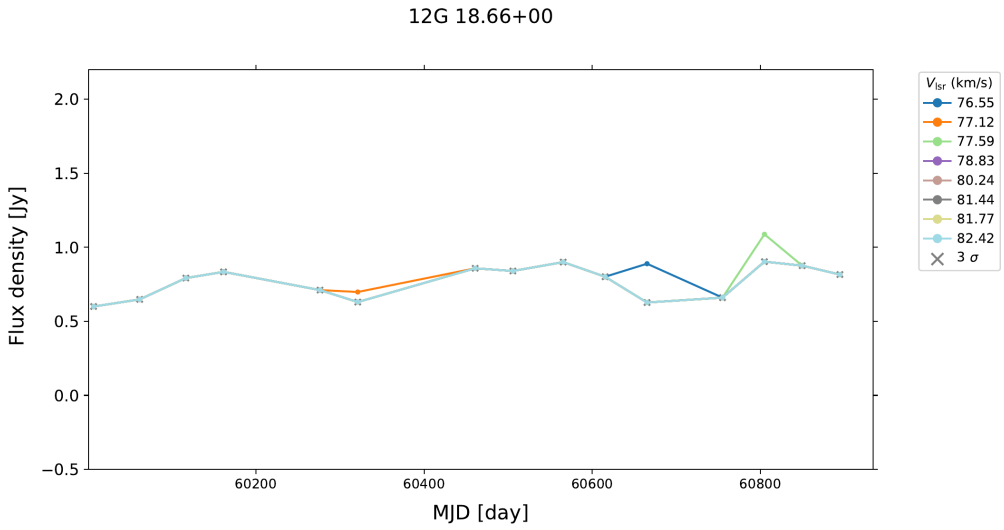


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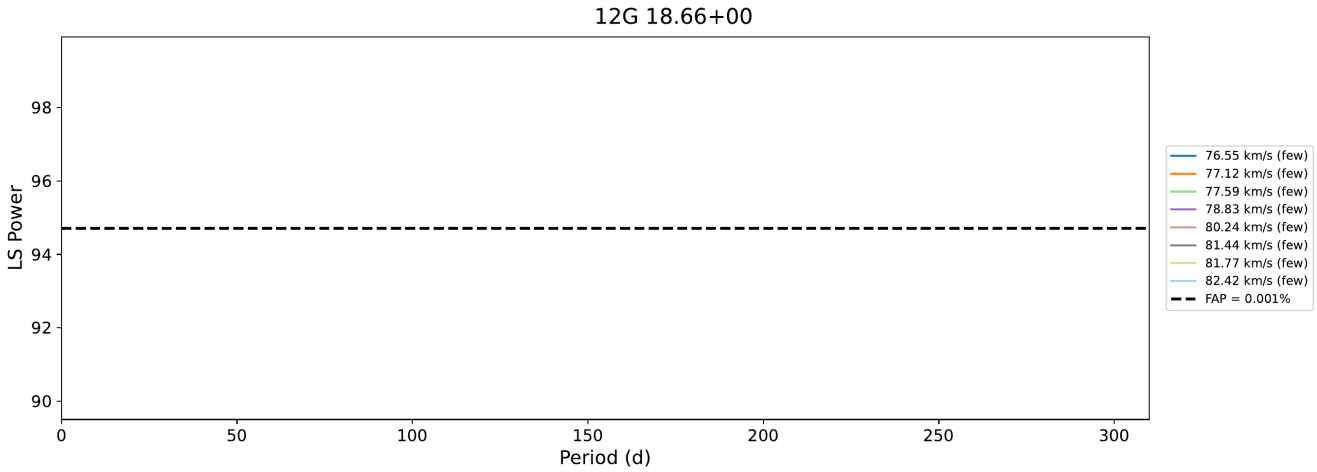


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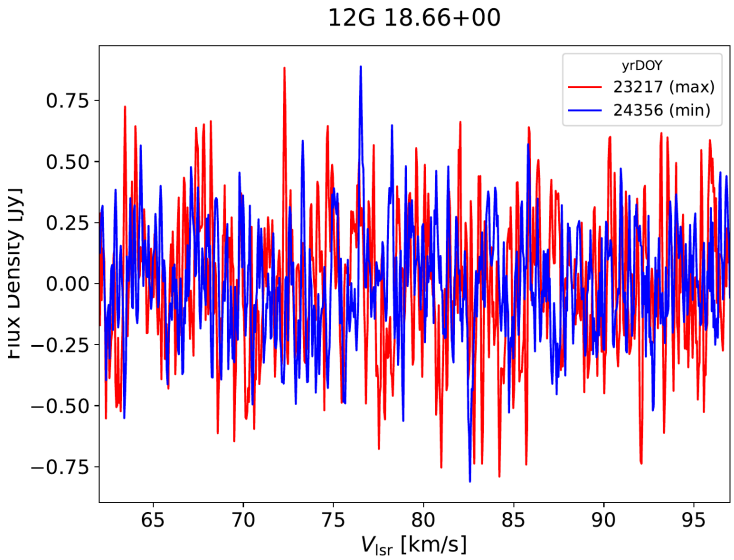
Light curve



Periodogram

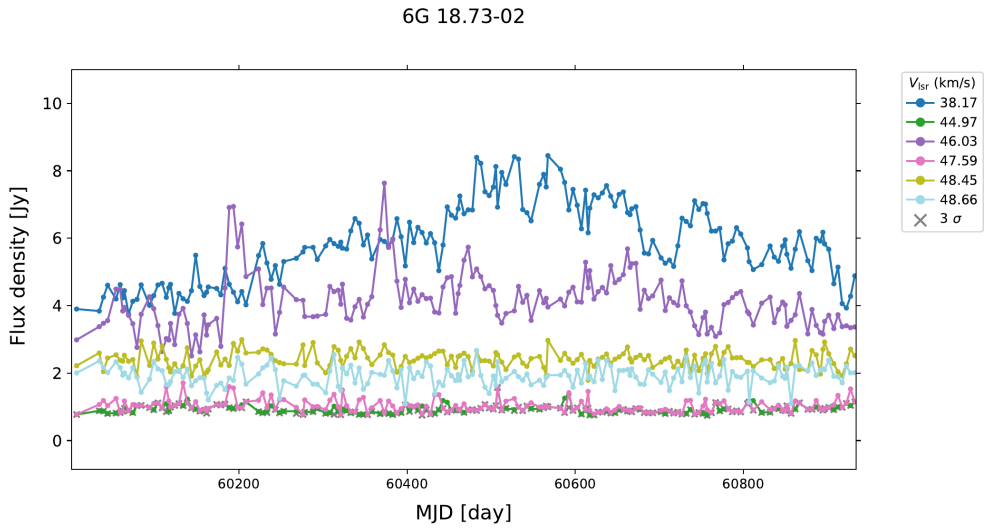


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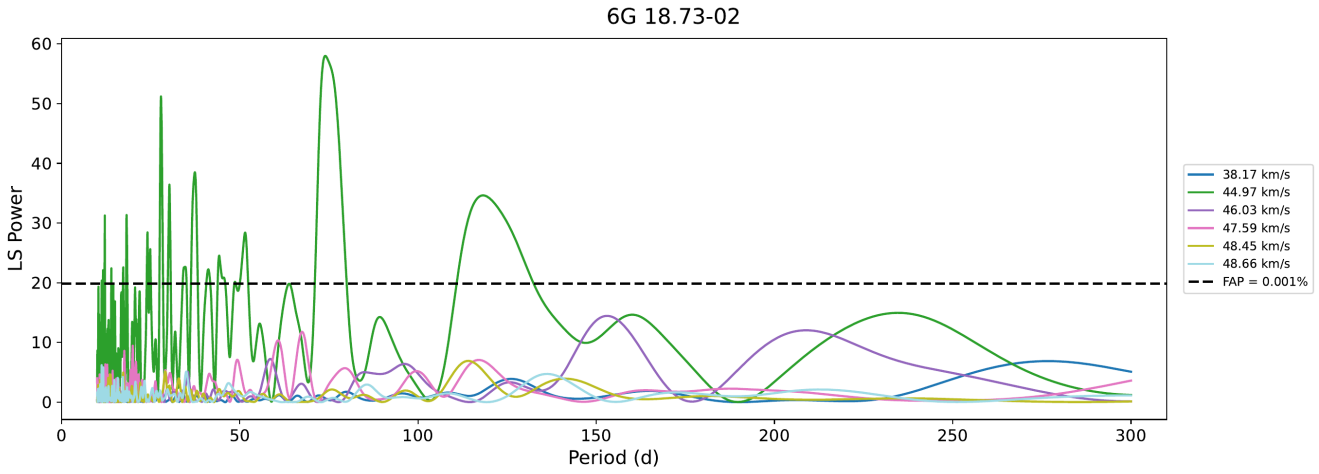


6G 18.73-02

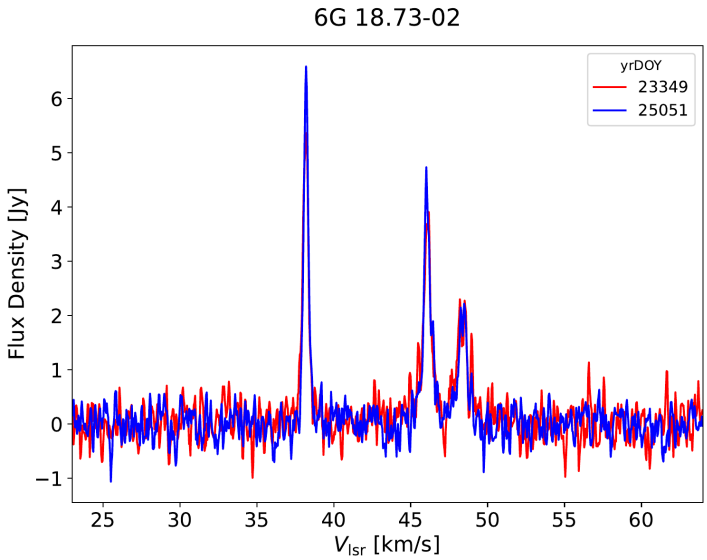
Light curve



Periodogram

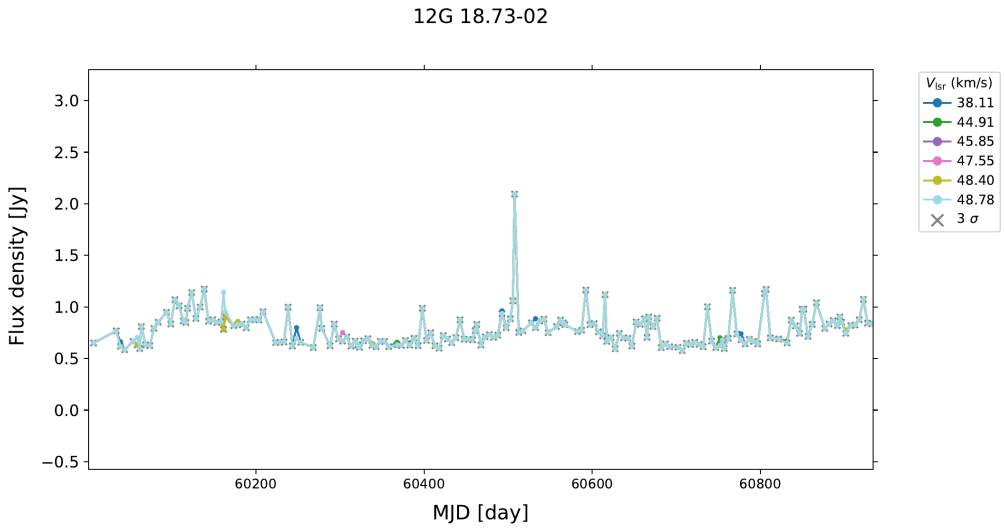


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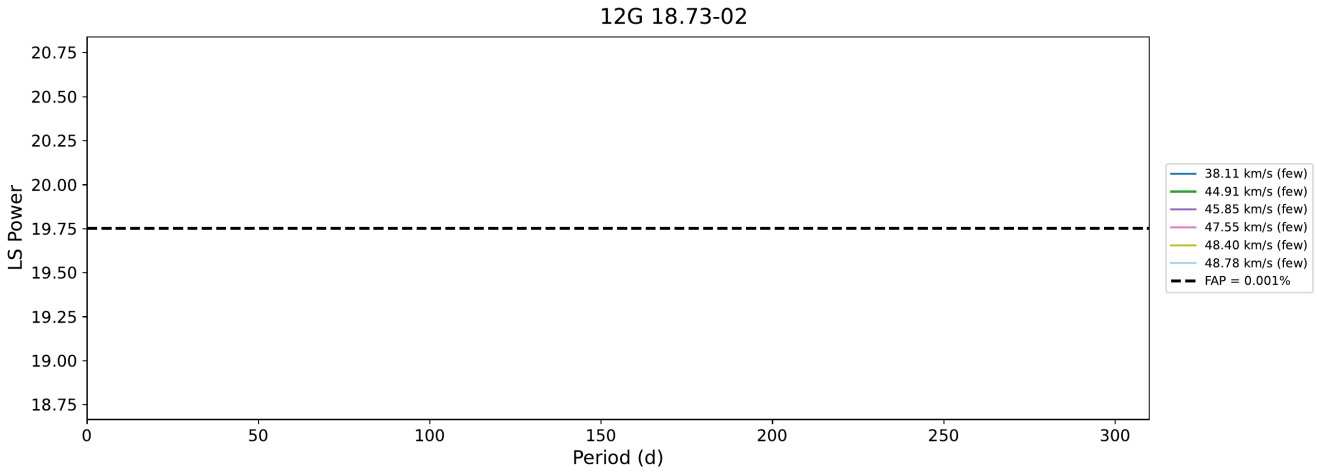


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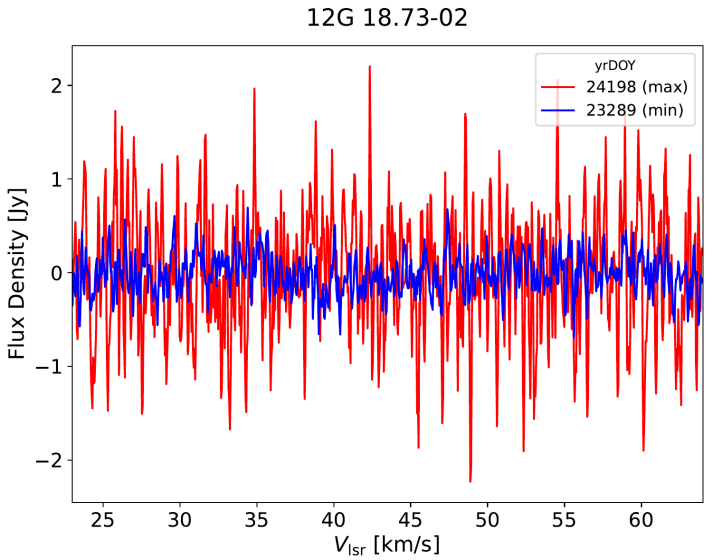
Light curve



Periodogram

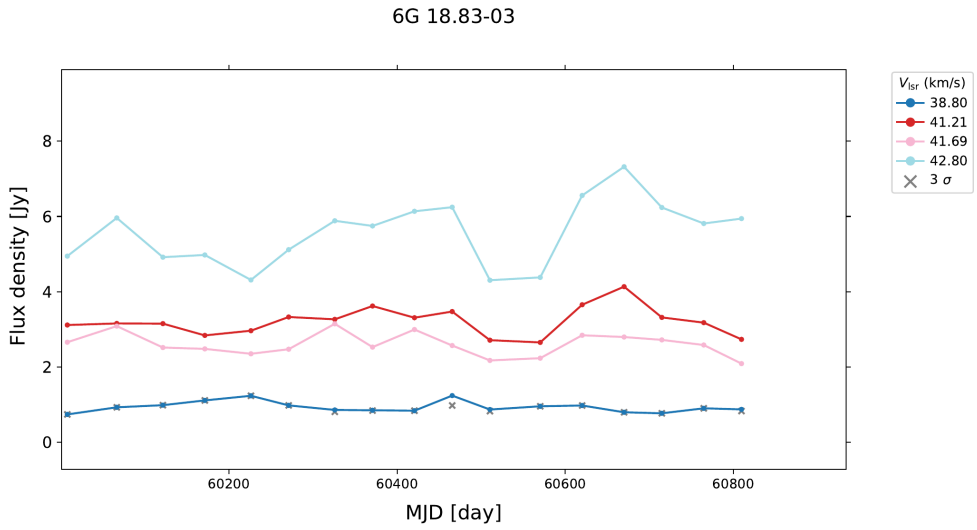


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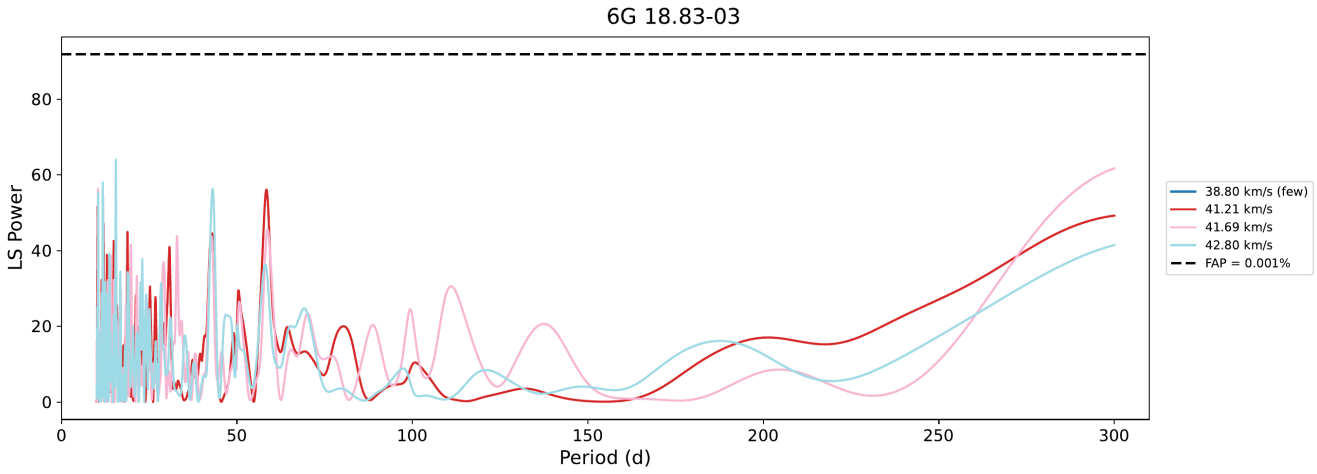


6G 18.83-03

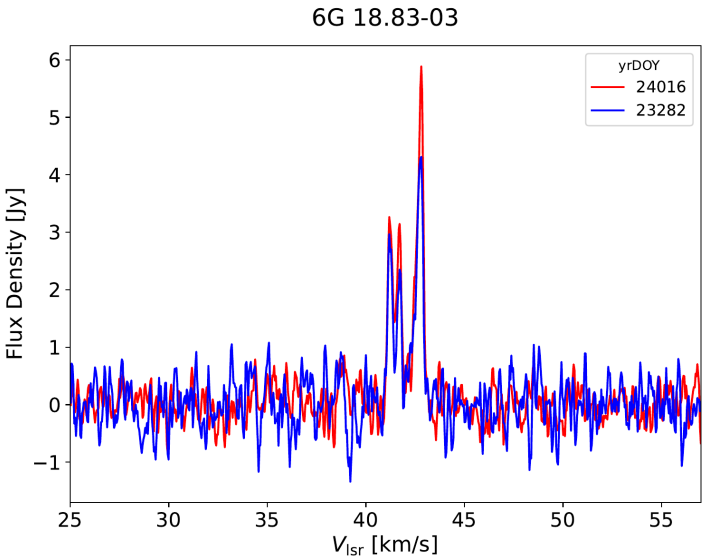
Light curve



Periodogram

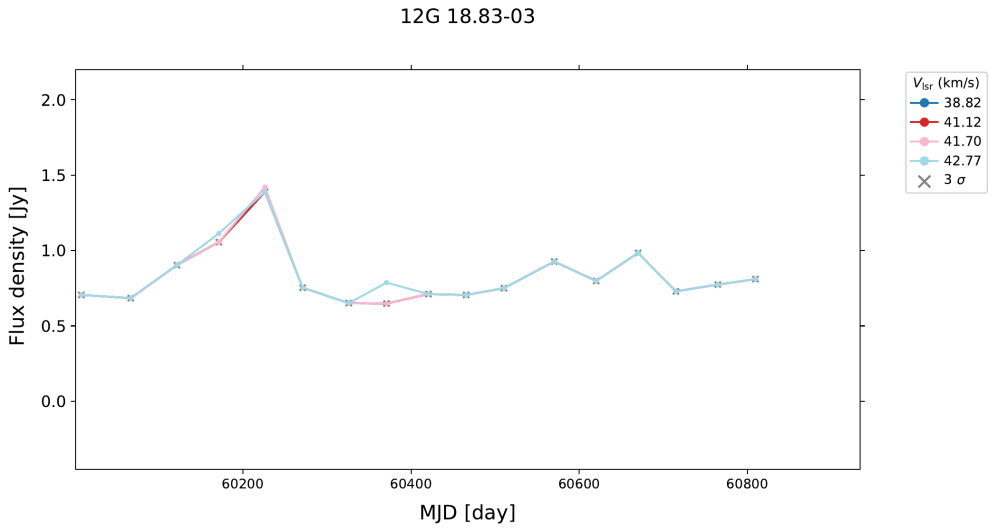


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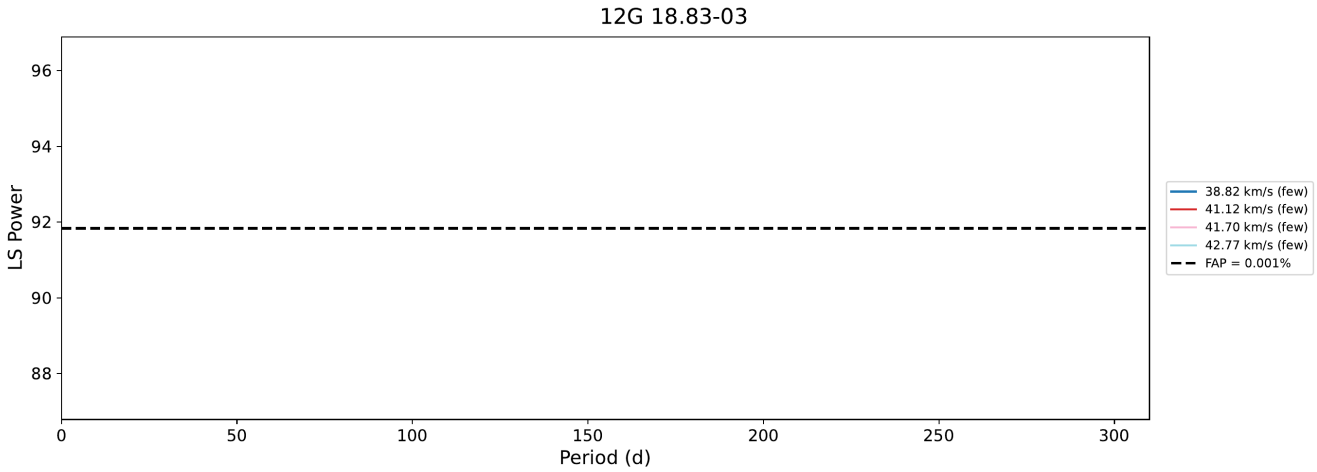


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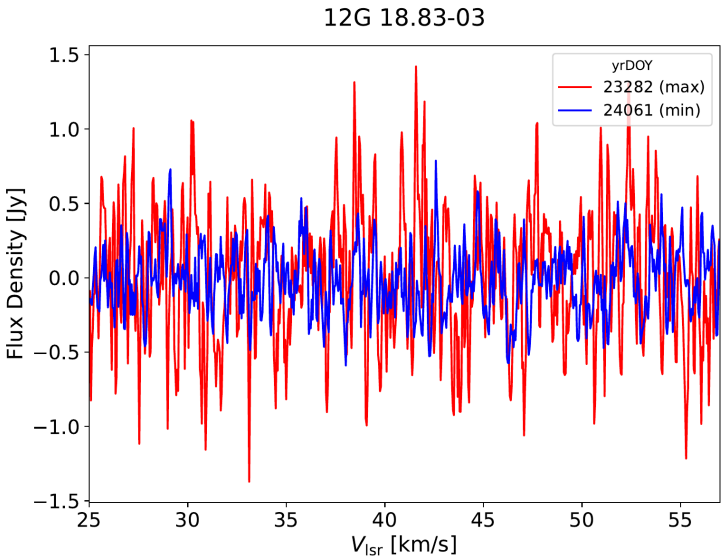
Light curve



Periodogram

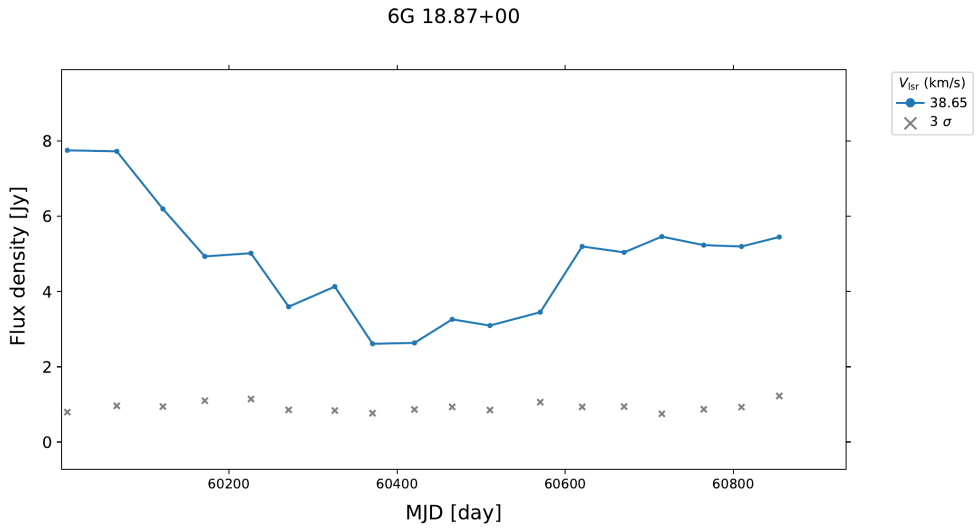


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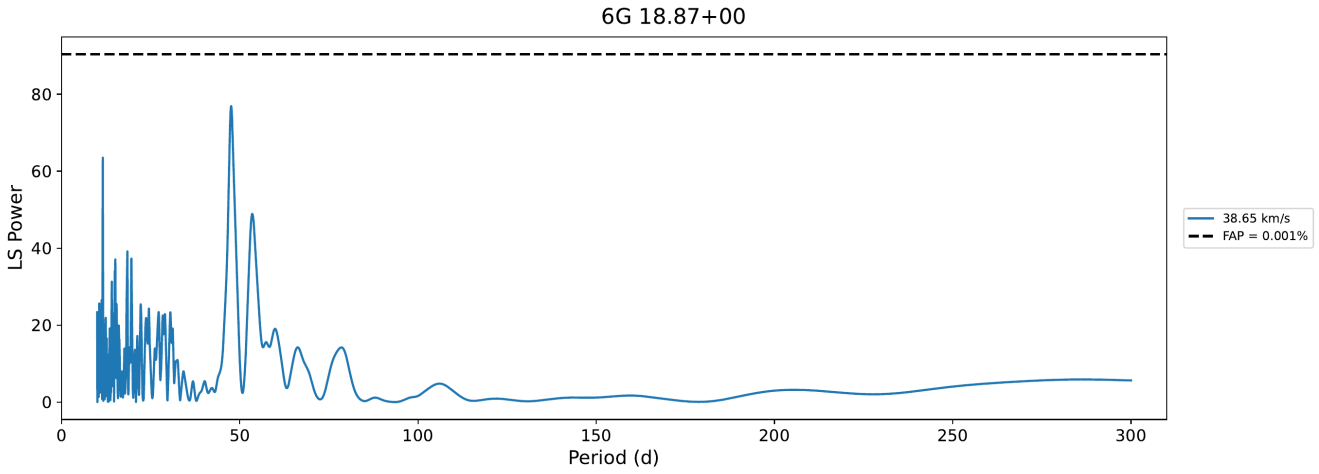


6G 18.87+00

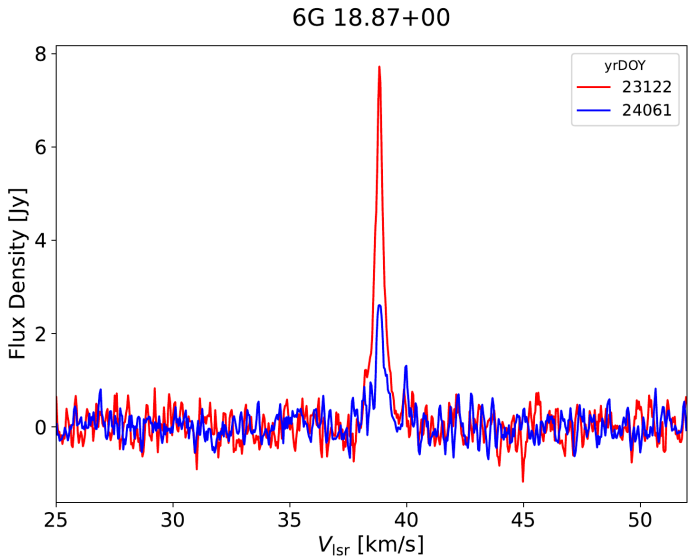
Light curve



Periodogram

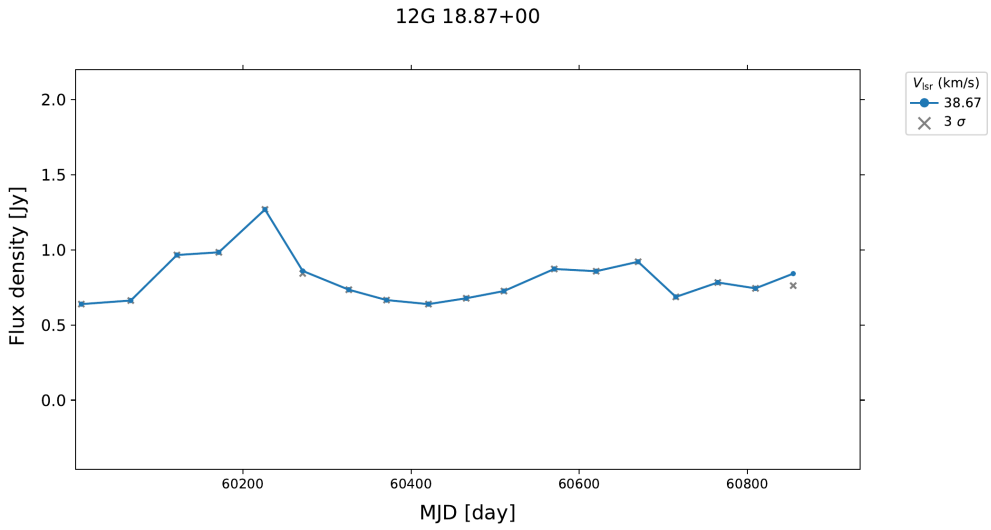


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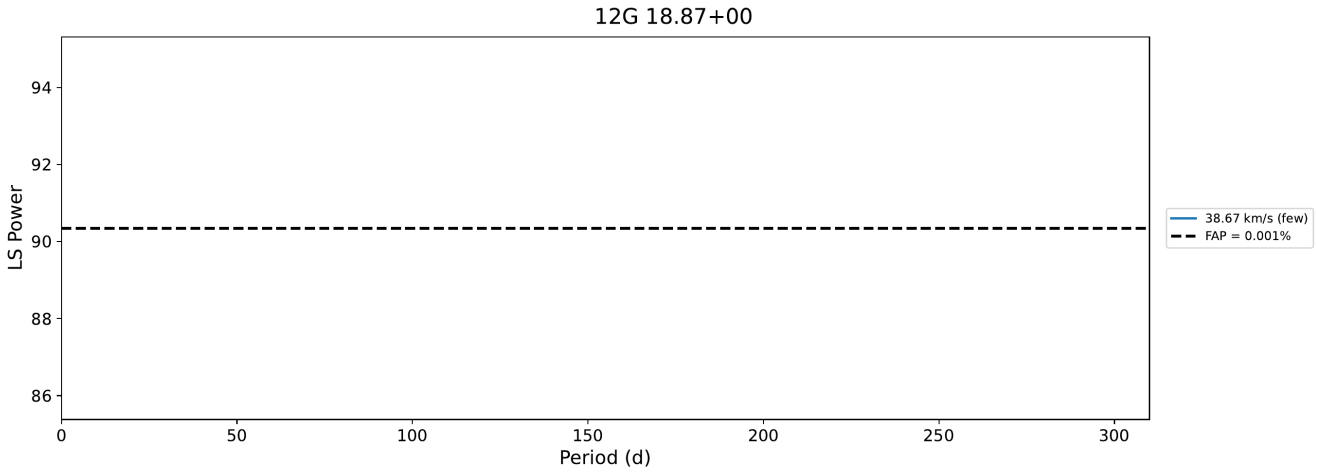


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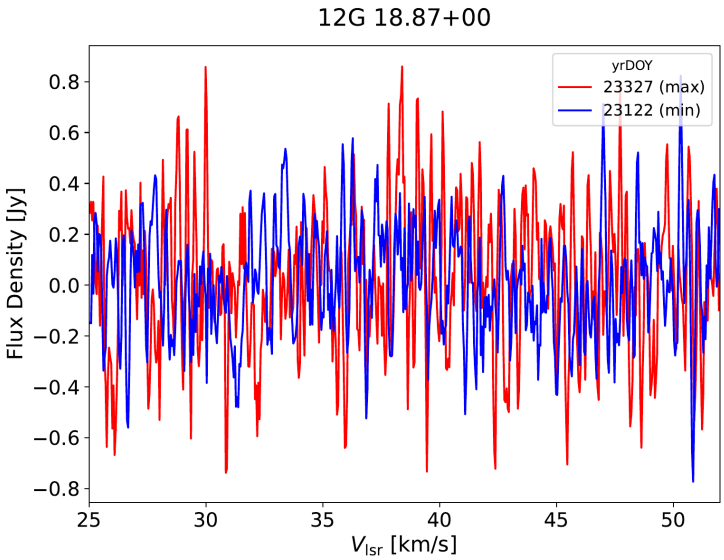
Light curve



Periodogram

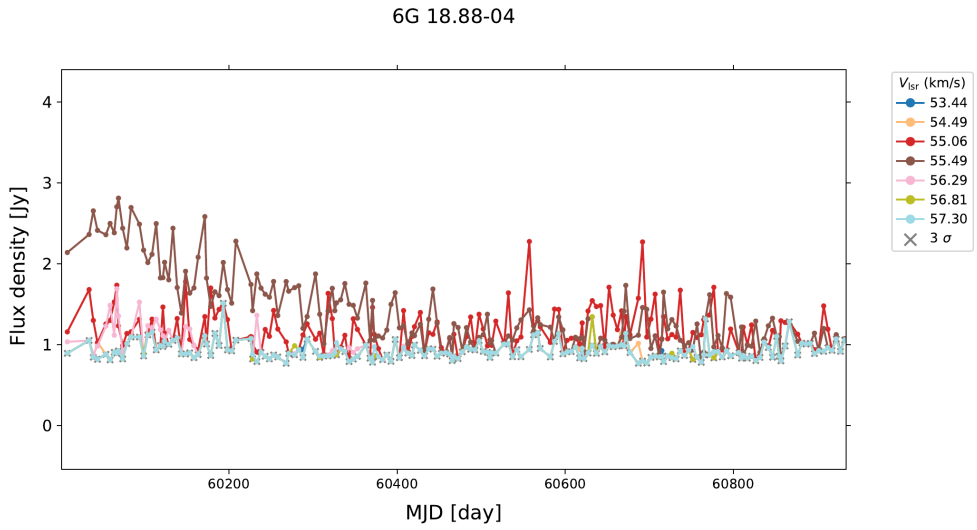


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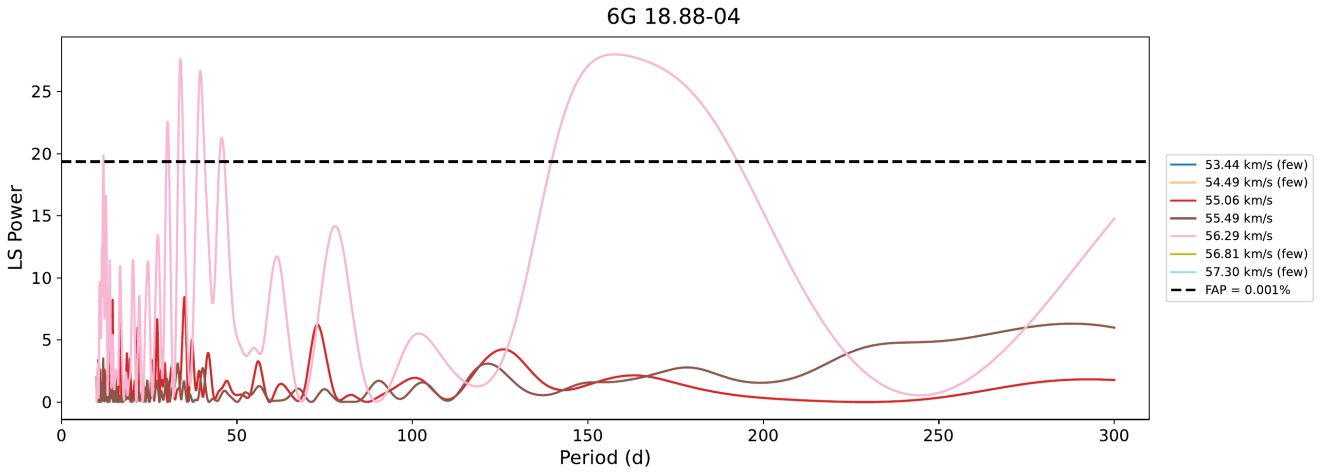


6G 18.88-04

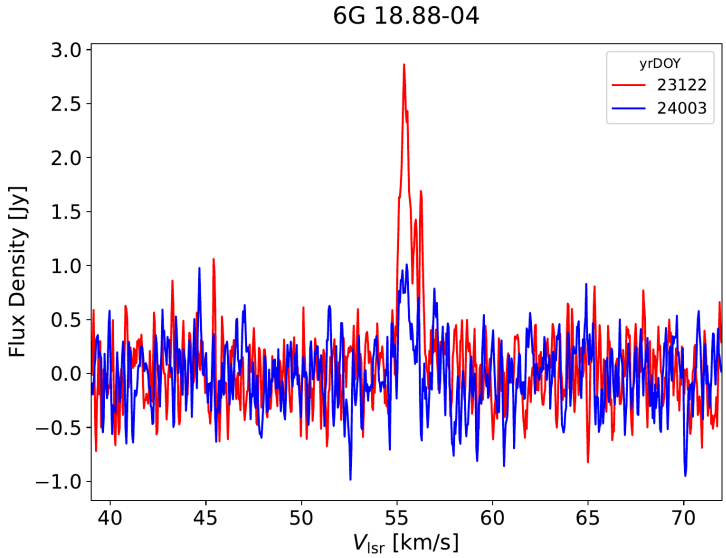
Light curve



Periodogram

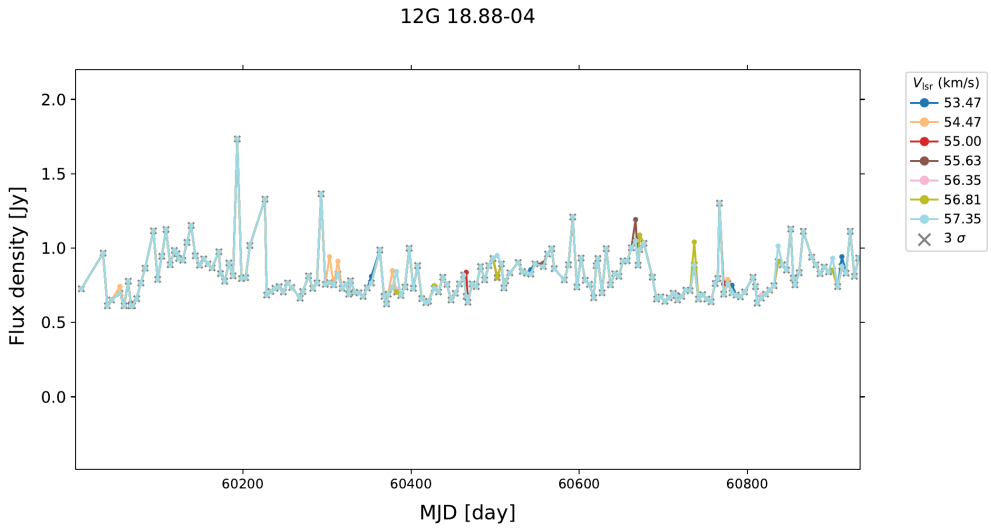


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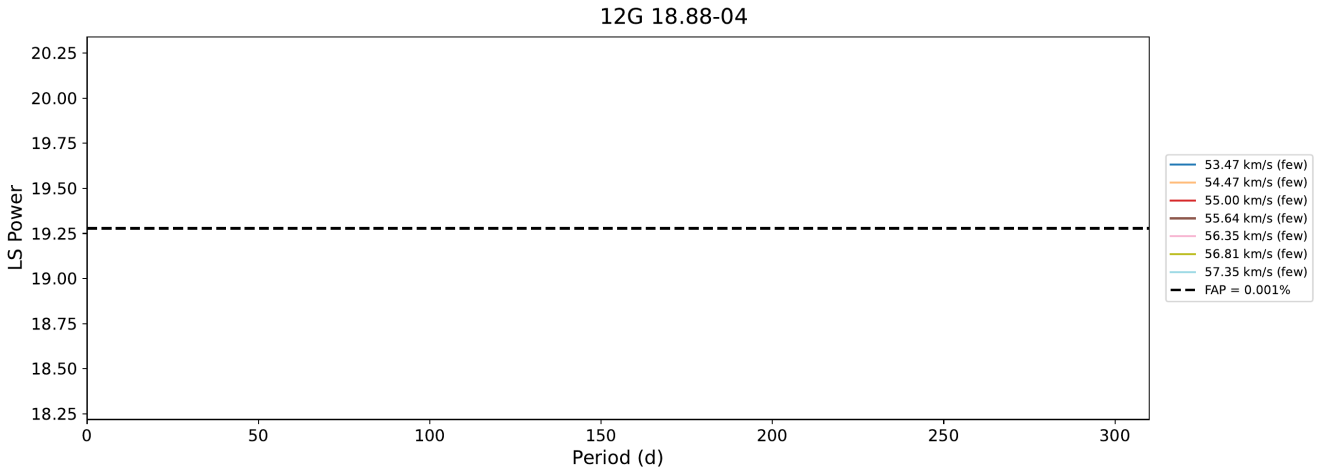


12G 18.88-04

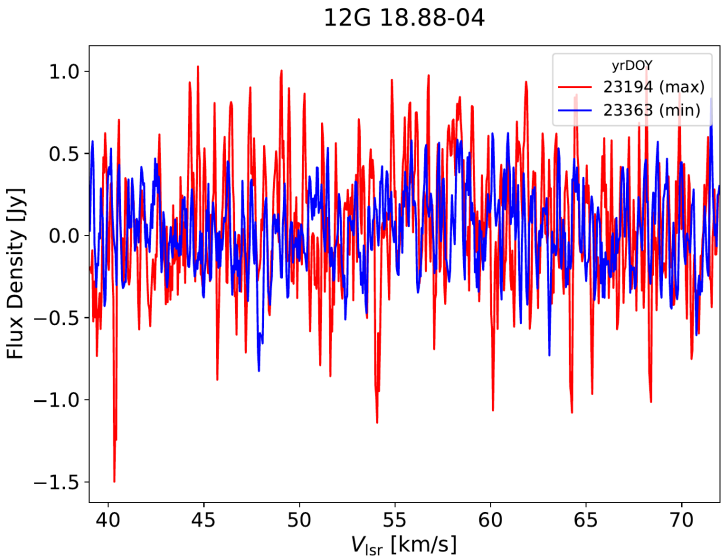
Light curve



Periodogram

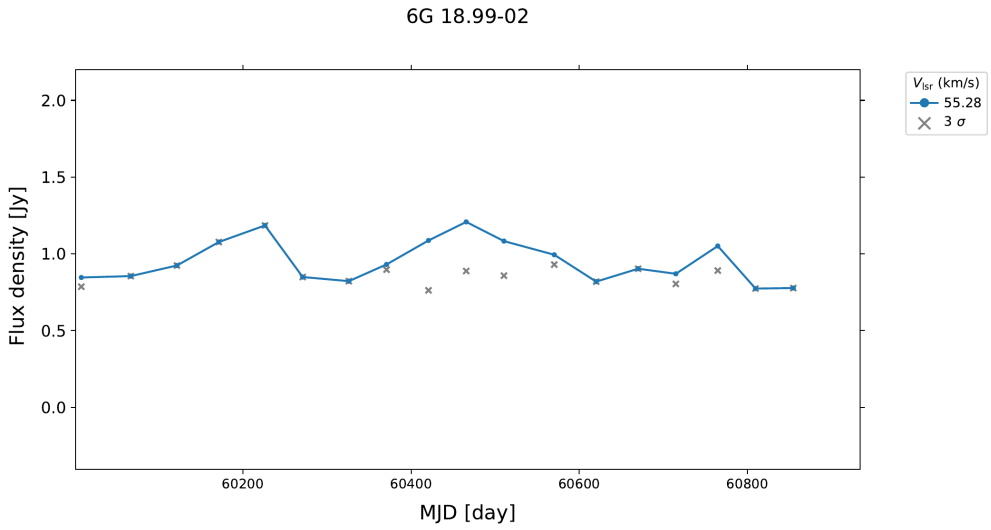


Spectrum

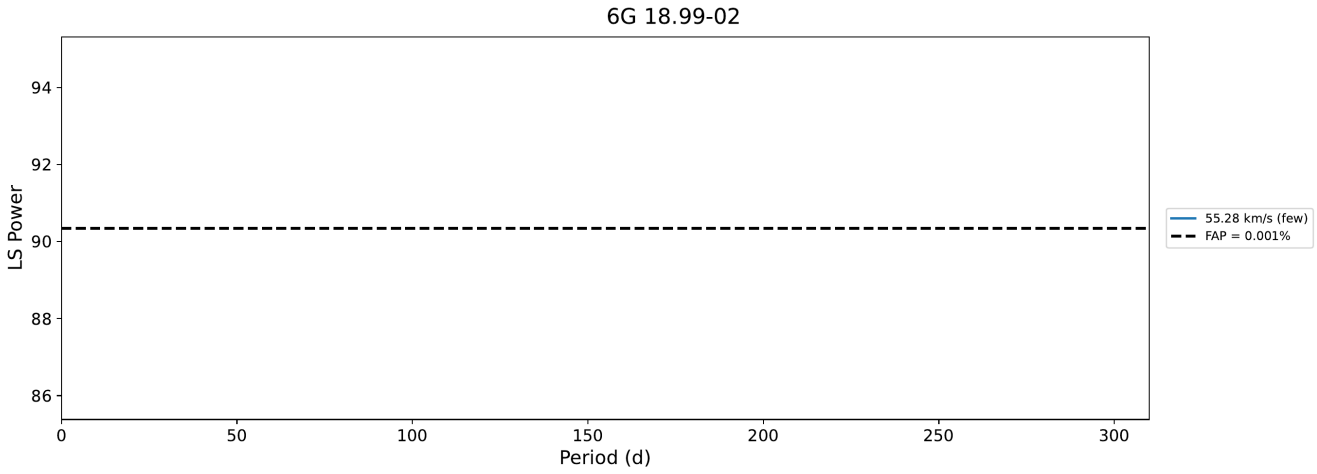


6G 18.99-02

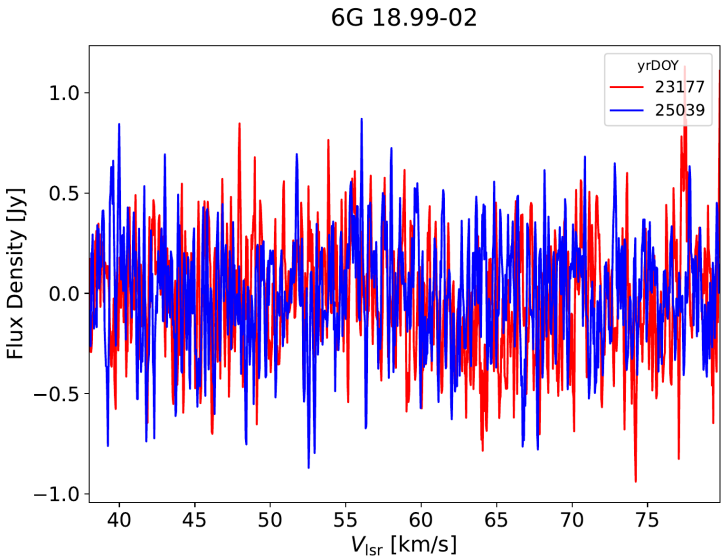
Light curve



Periodogram

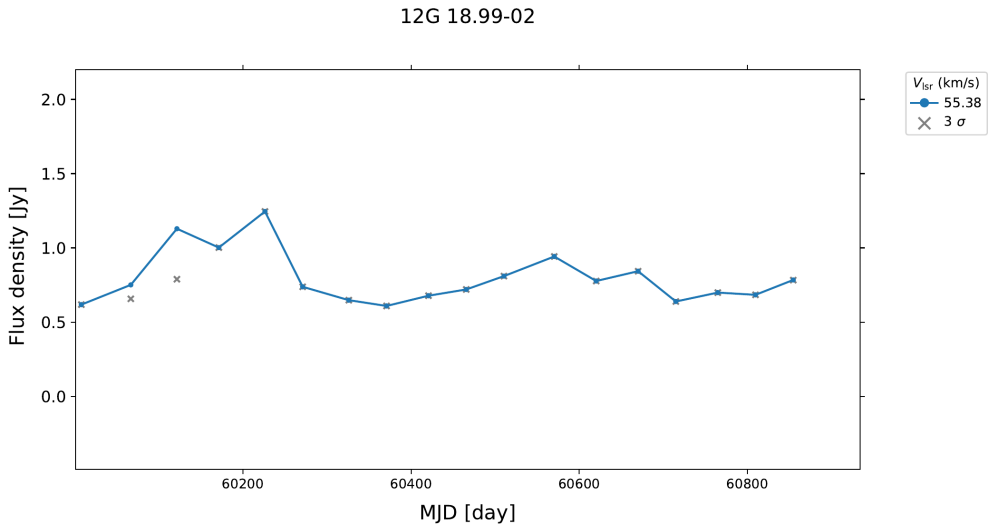


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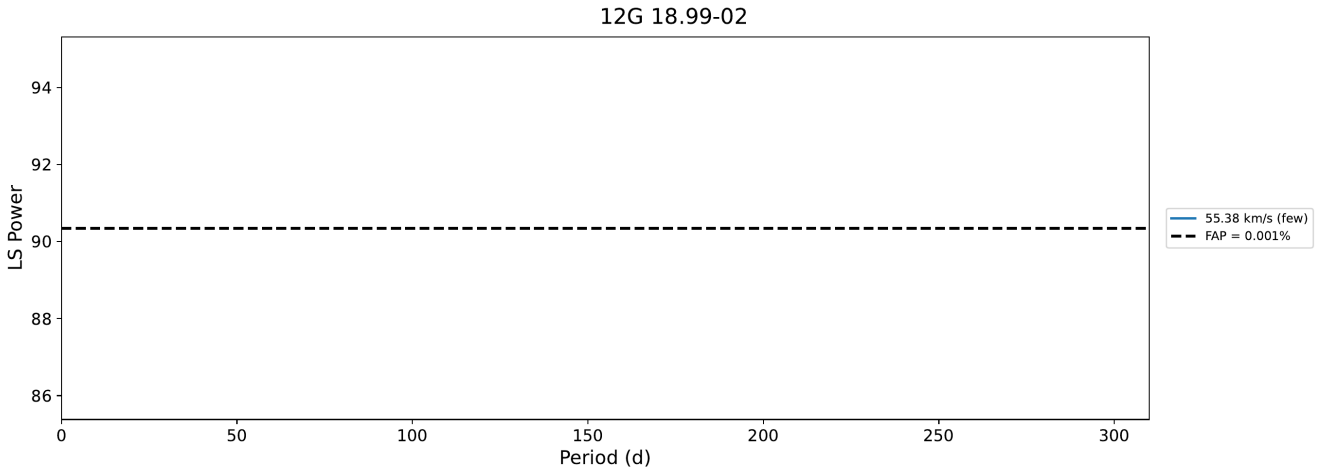


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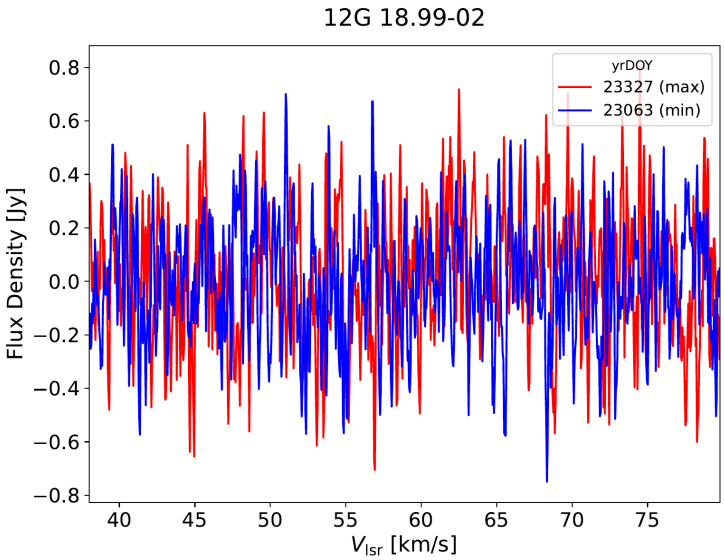
Light curve



Periodogram

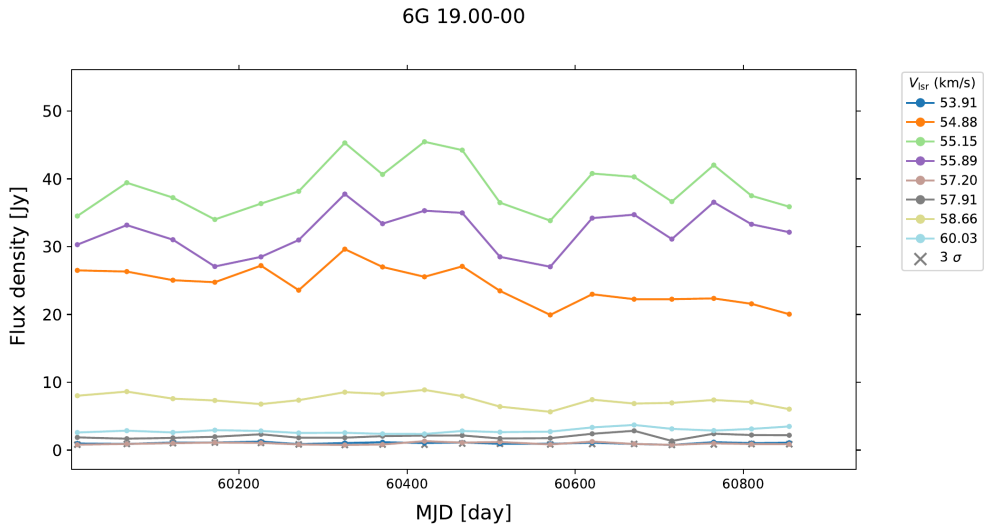


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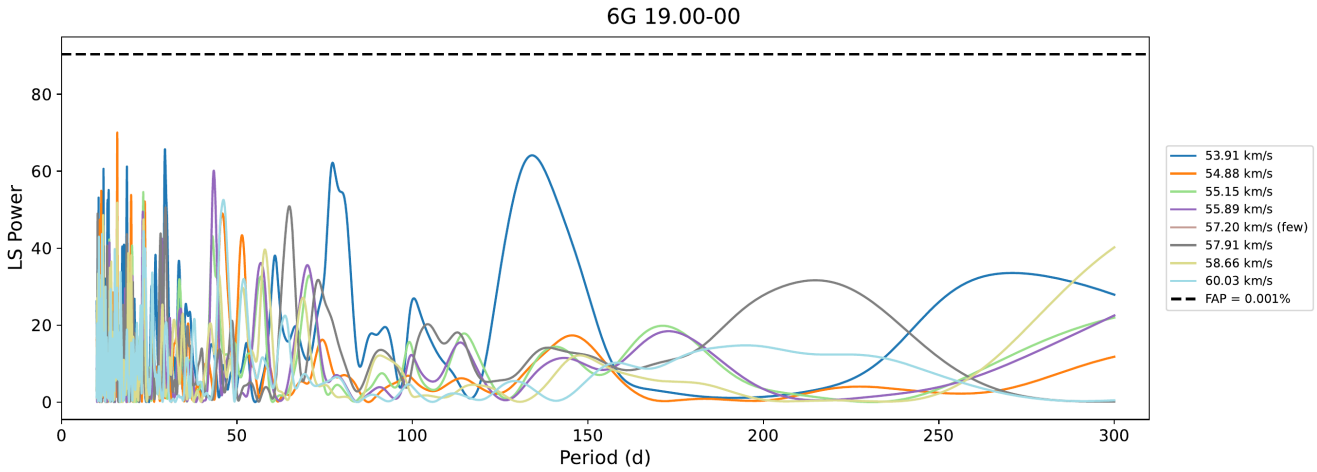


6G 19.00-00

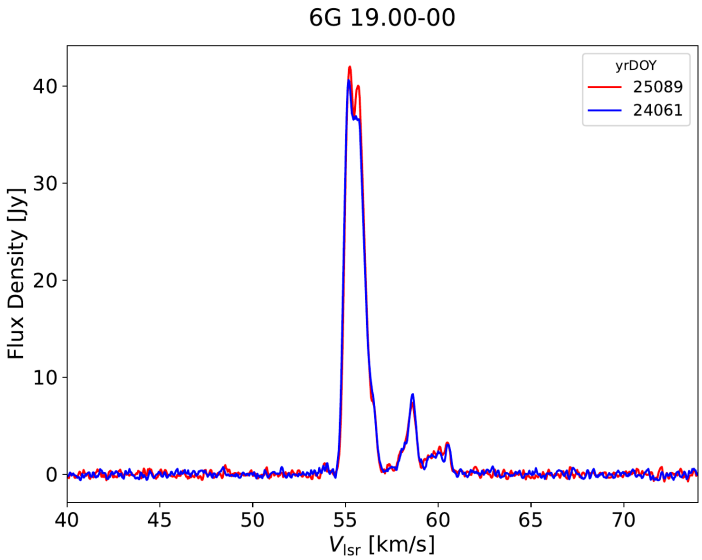
Light curve



Periodogram

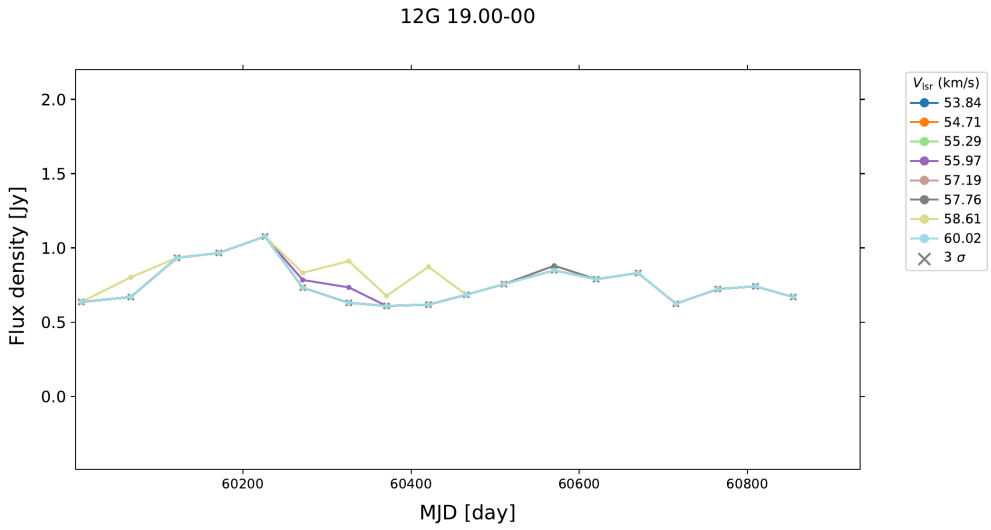


Spectrum

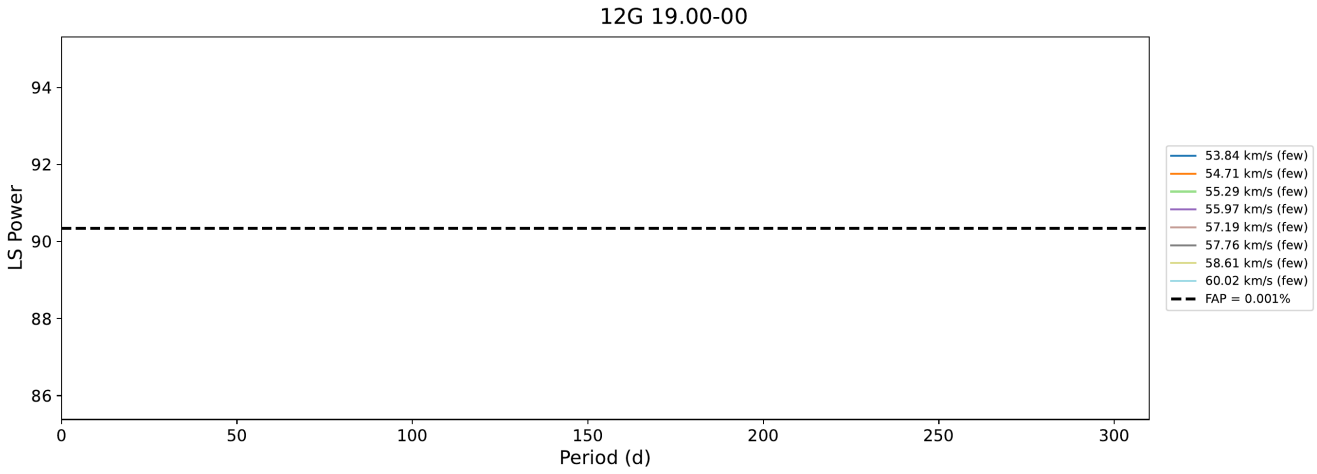


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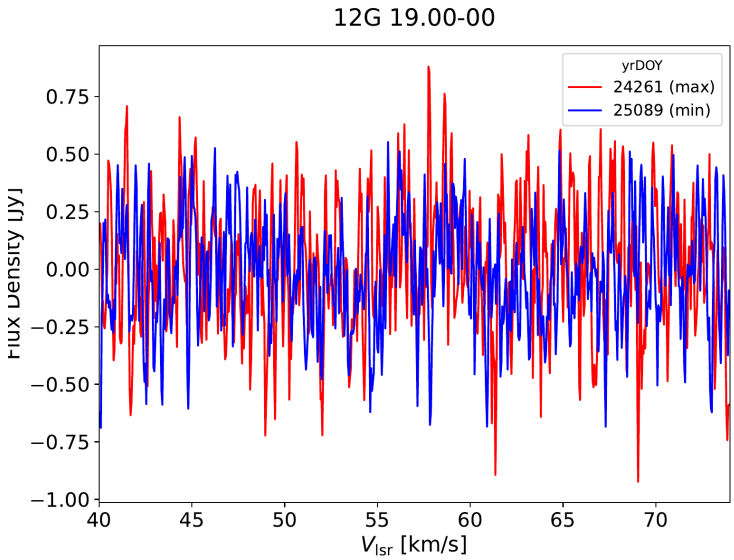
Light curve



Periodogram

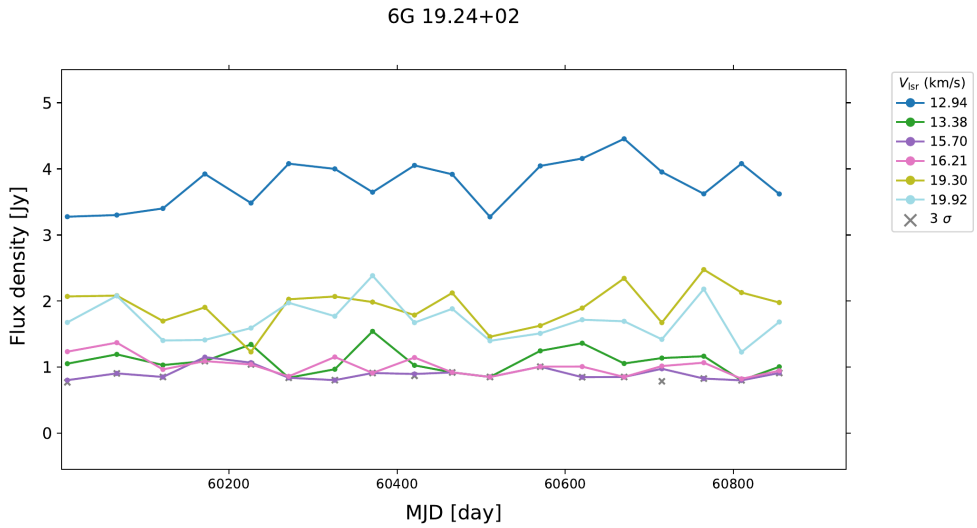


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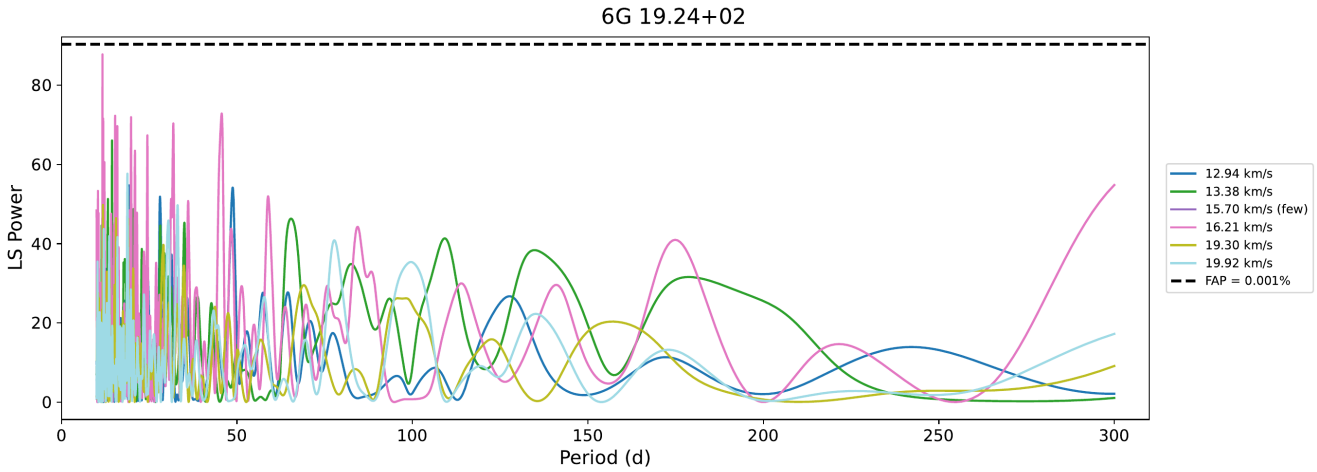


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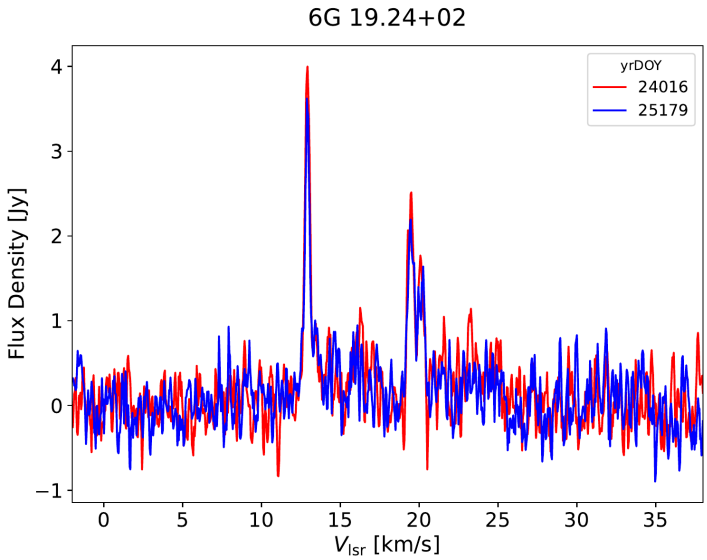
Light curve



Periodogram

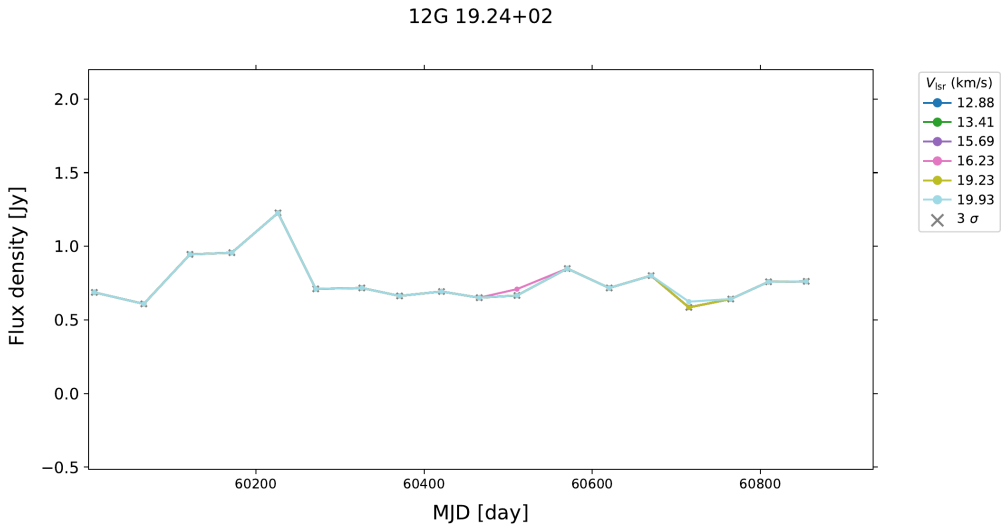


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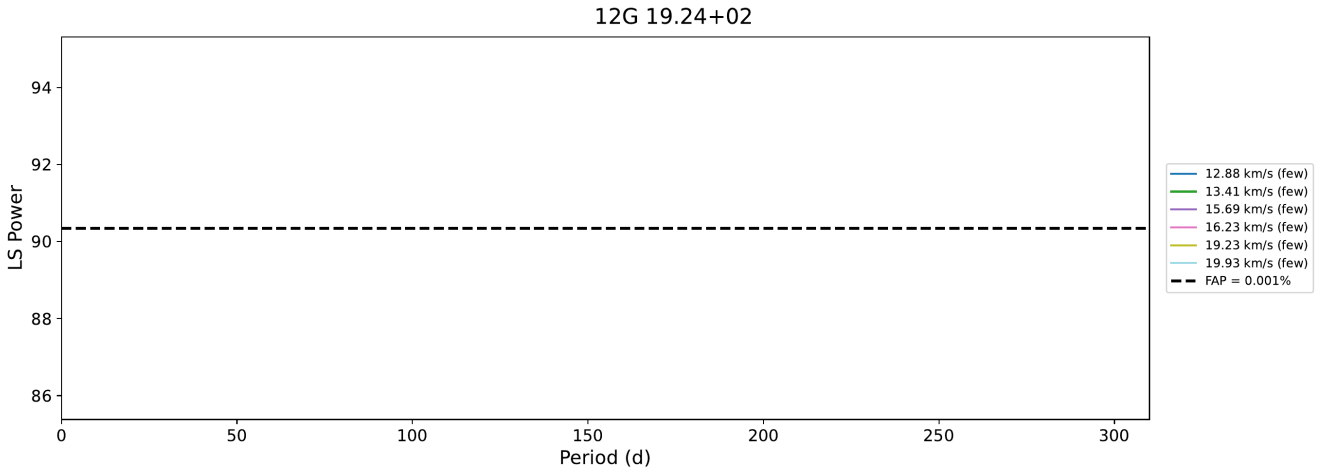


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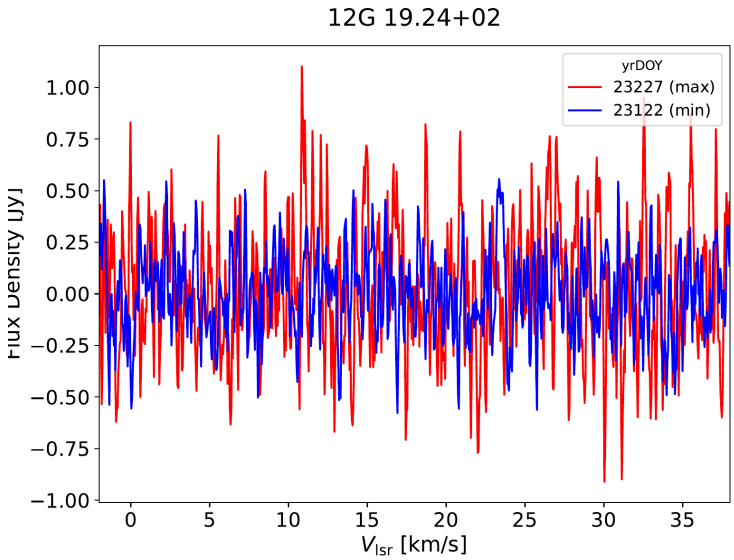
Light curve



Periodogram

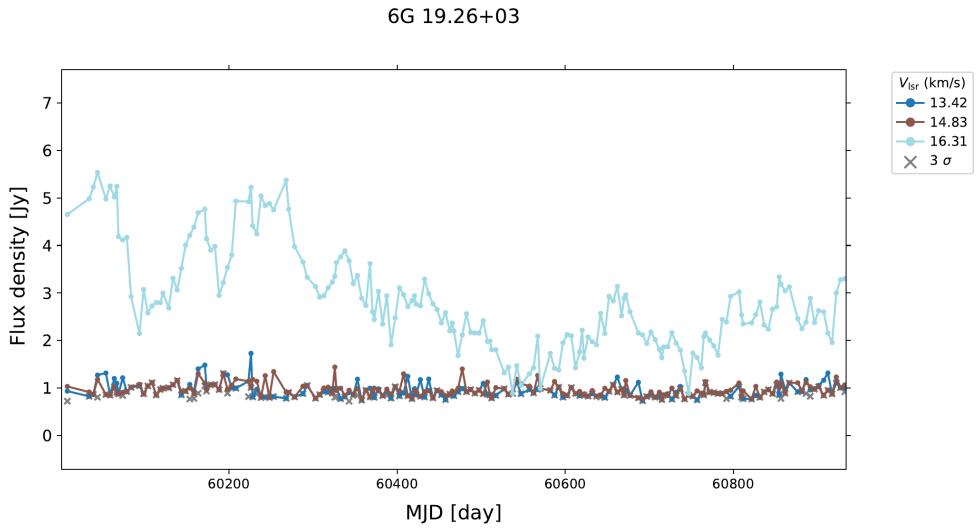


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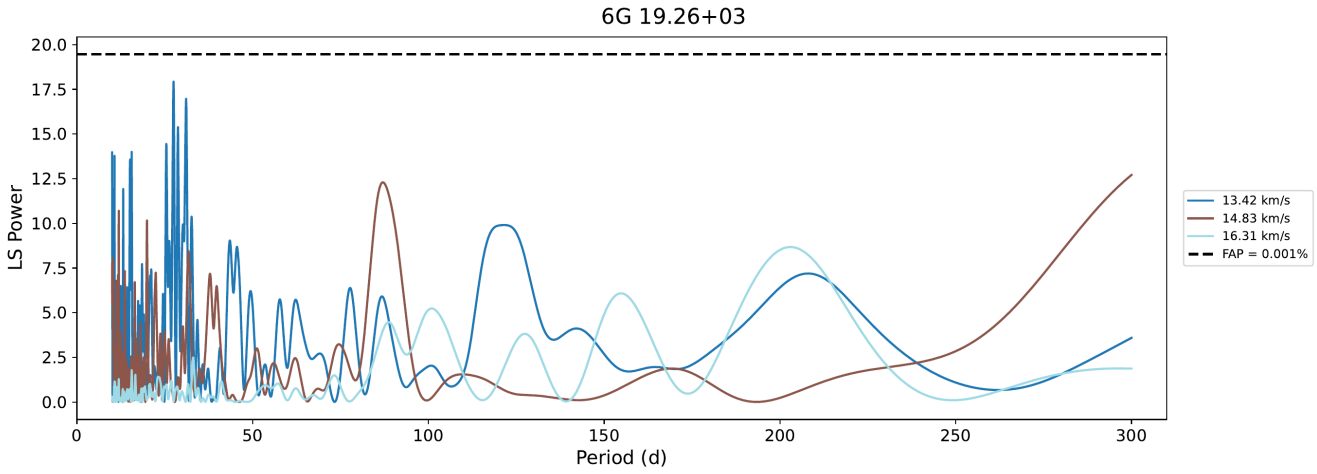


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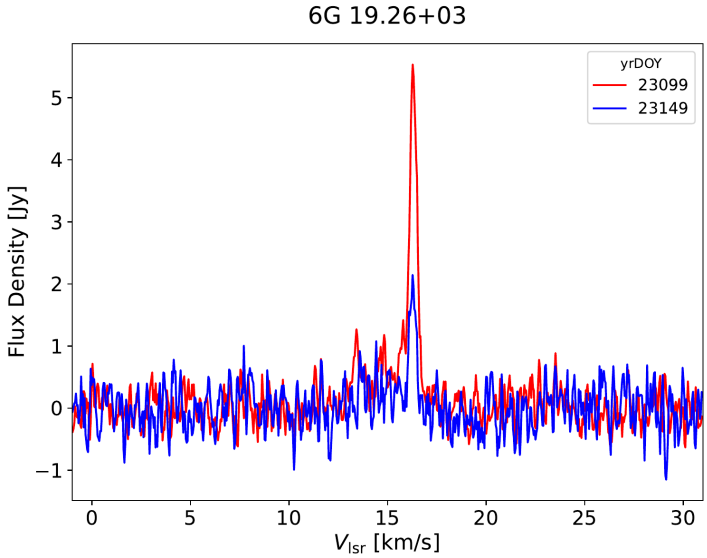
Light curve



Periodogram

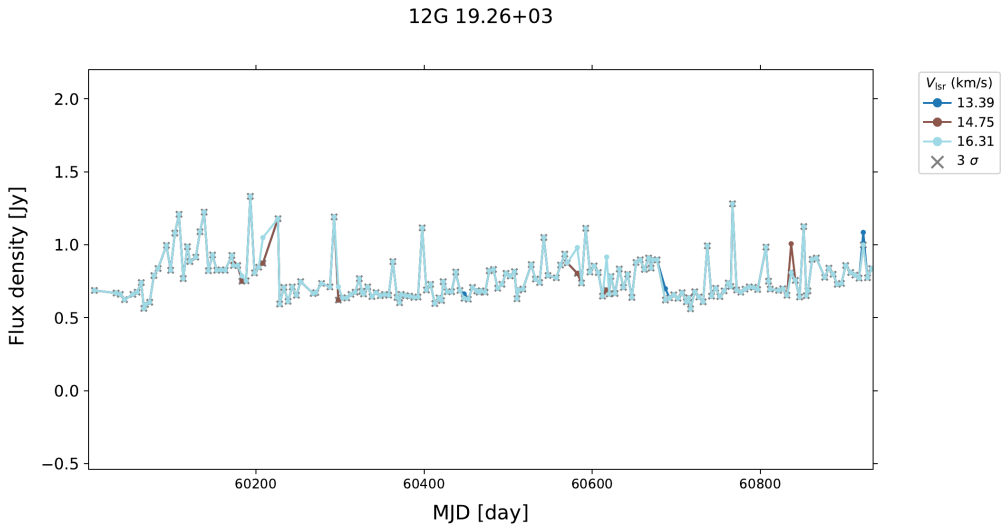


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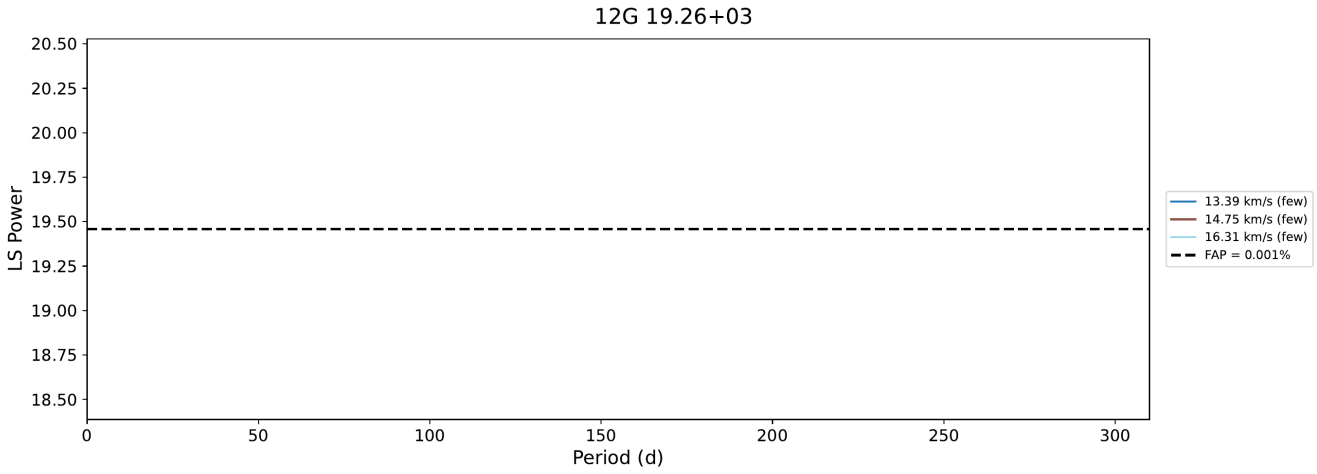


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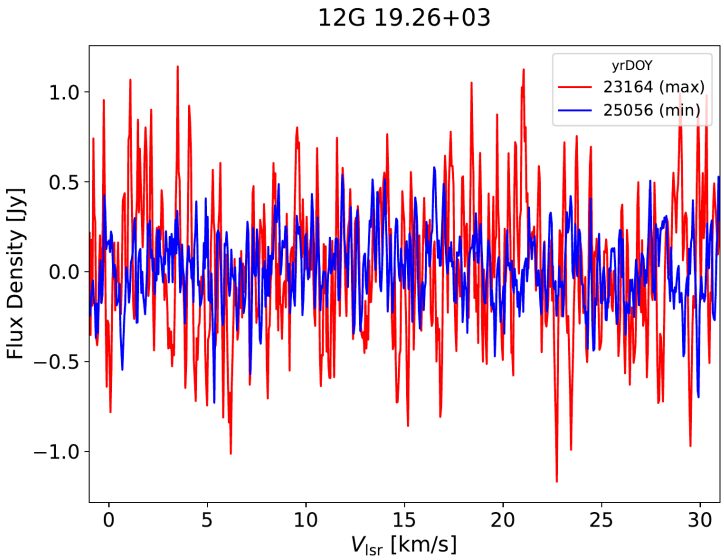
Light curve



Periodogram

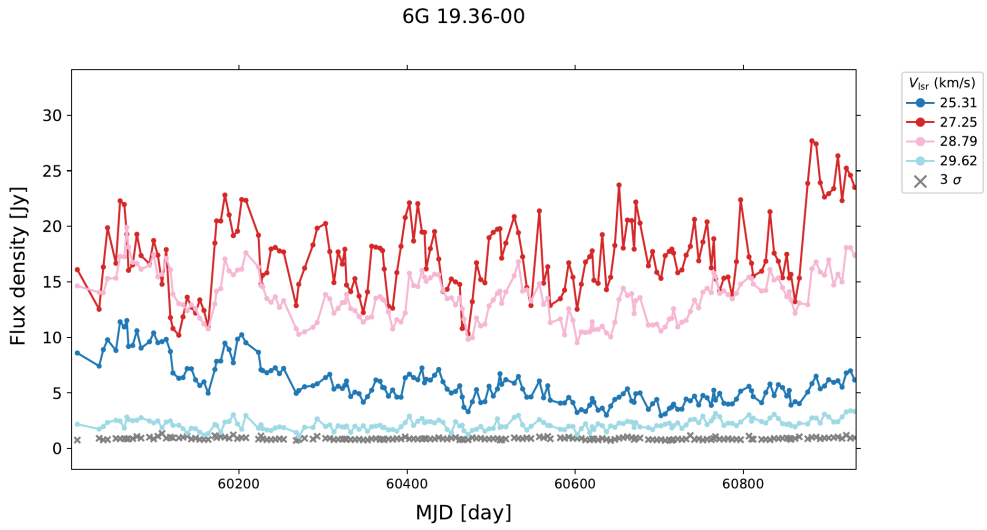


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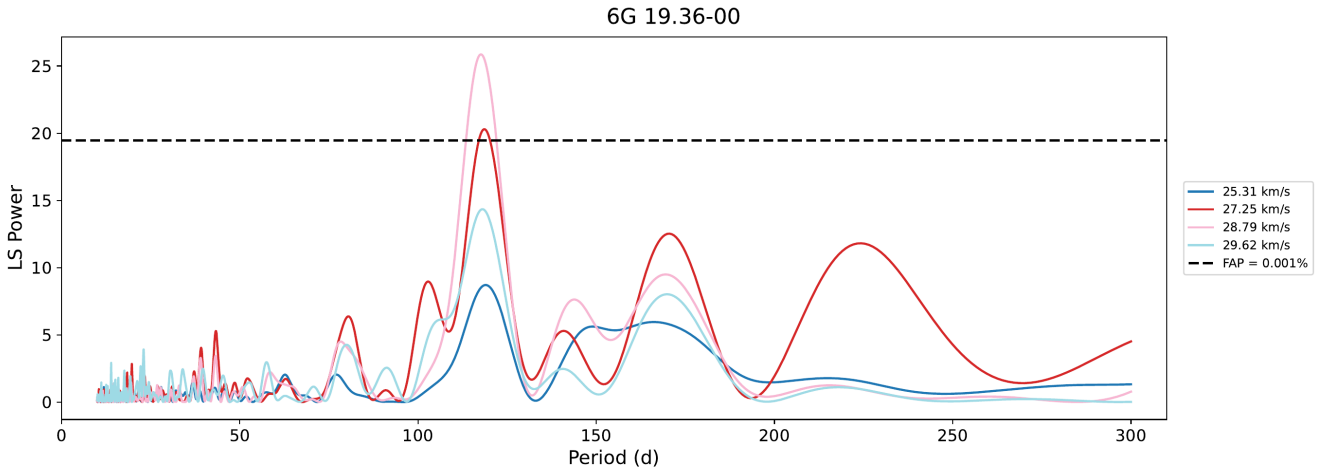


6G 19.36-00

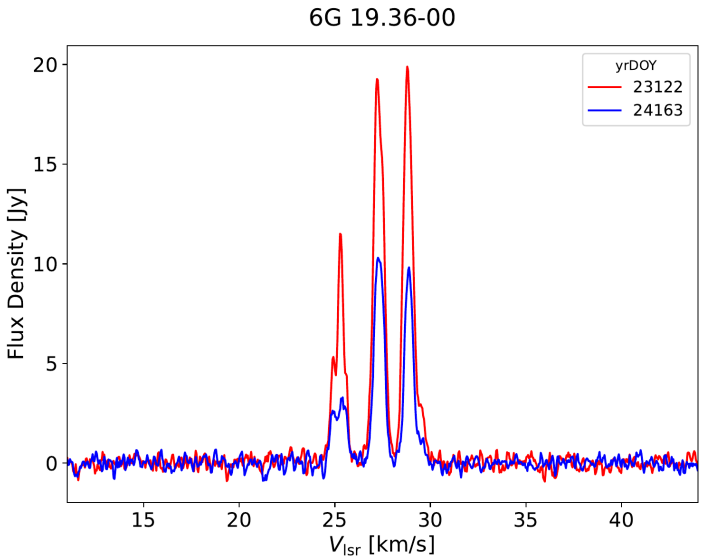
Light curve



Periodogram

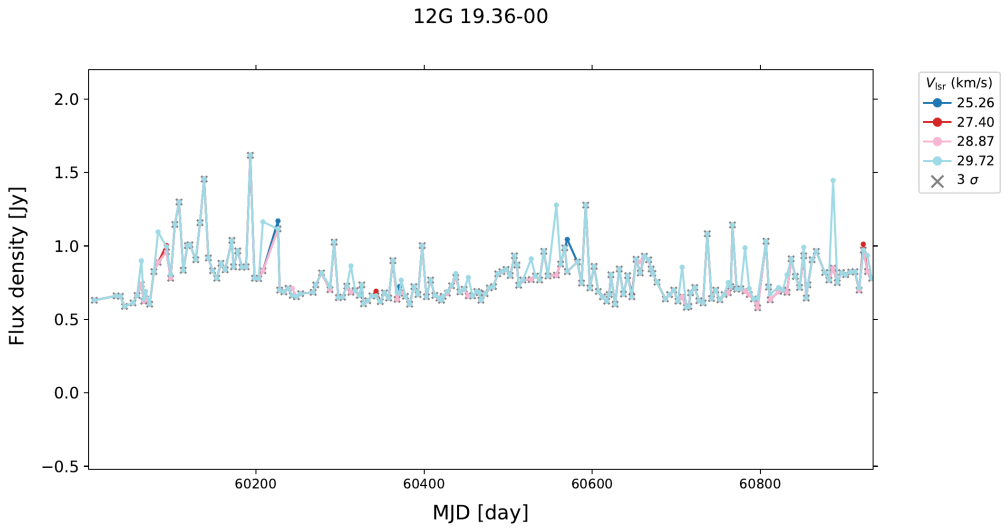


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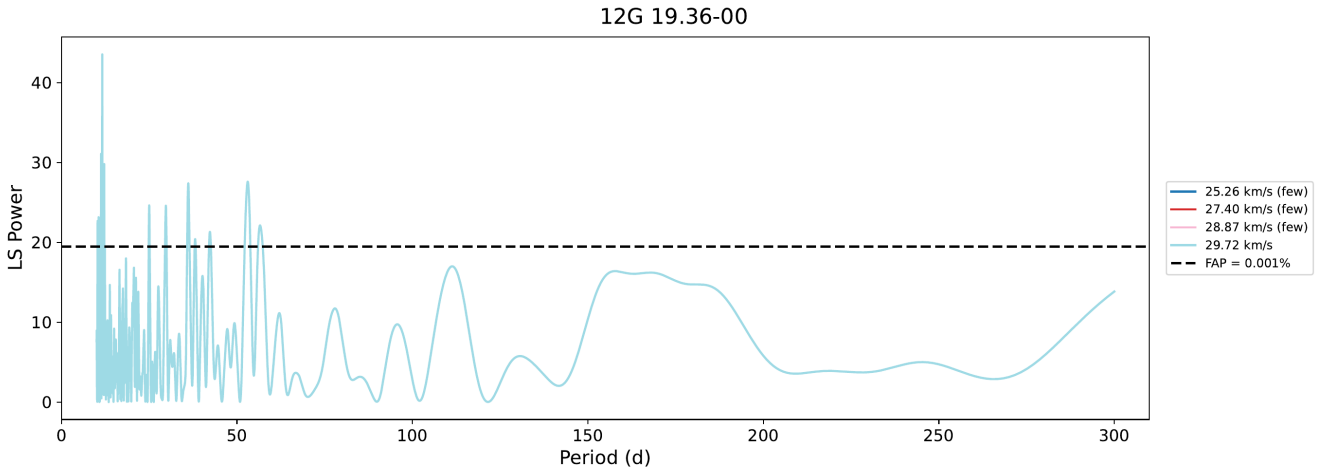


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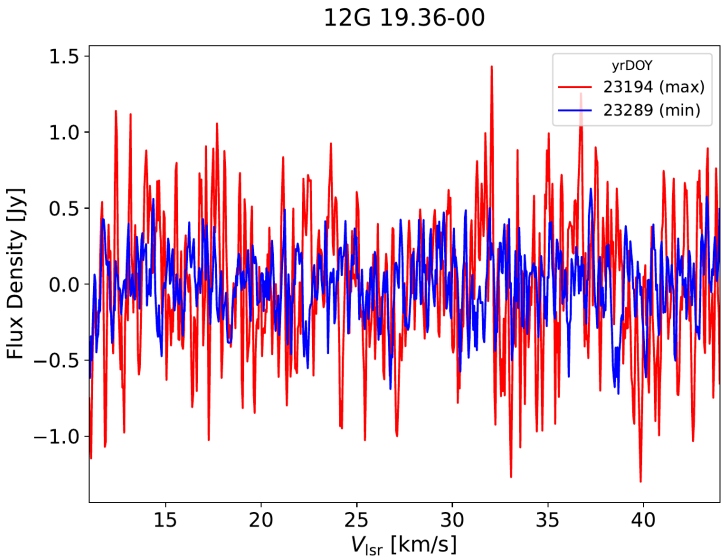
Light curve



Periodogram

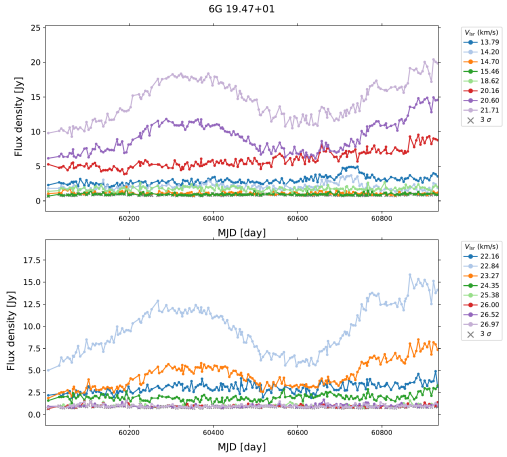


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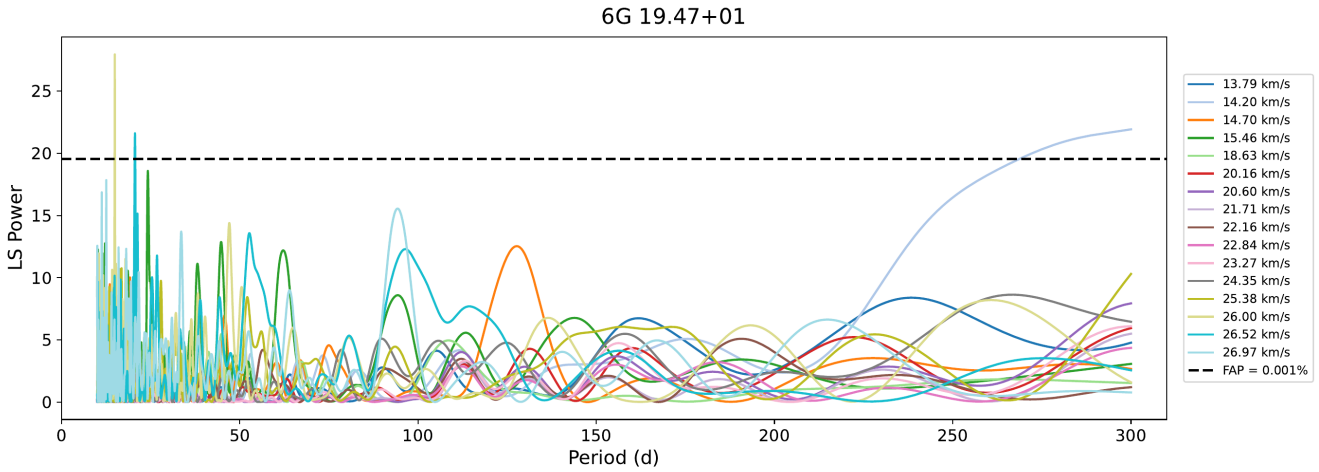


6G 19.47+01

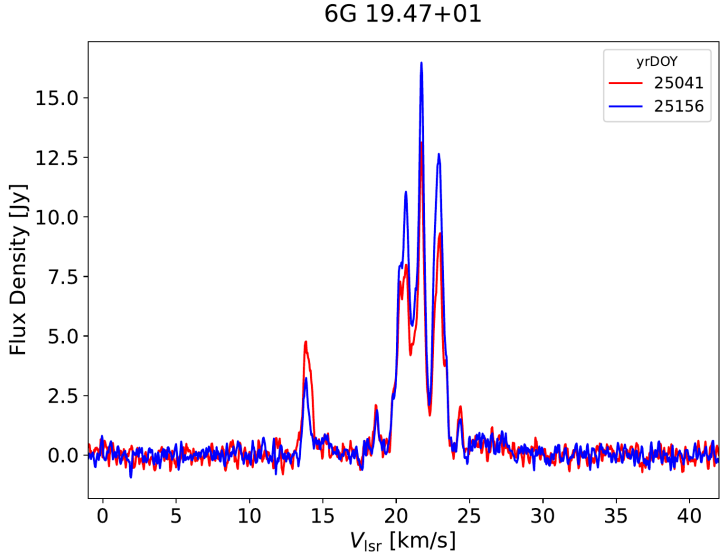
Light curve



Periodogram

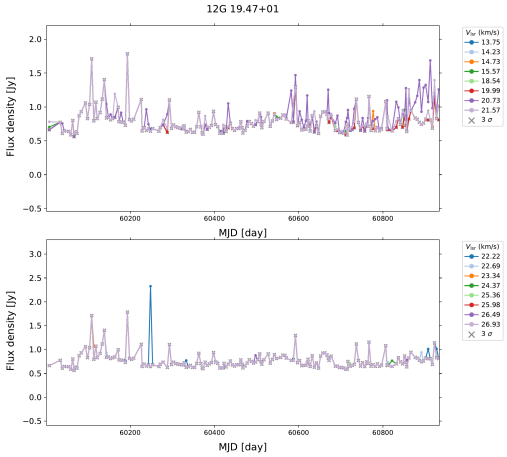


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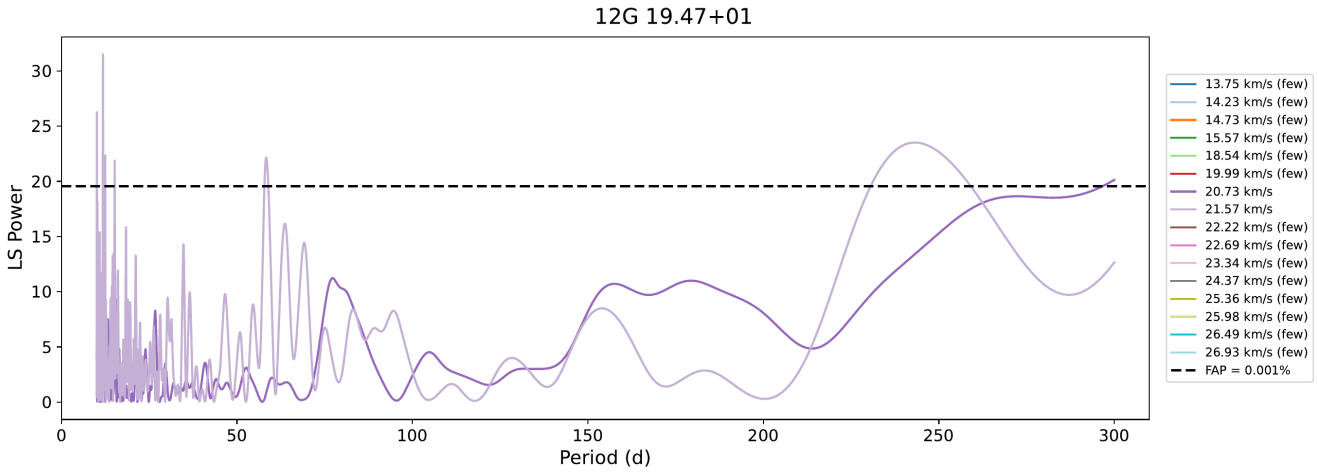


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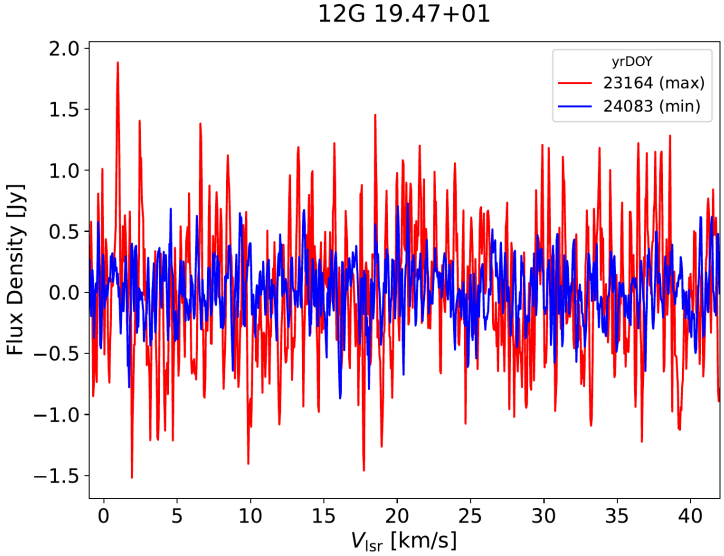
Light curve



Periodogram

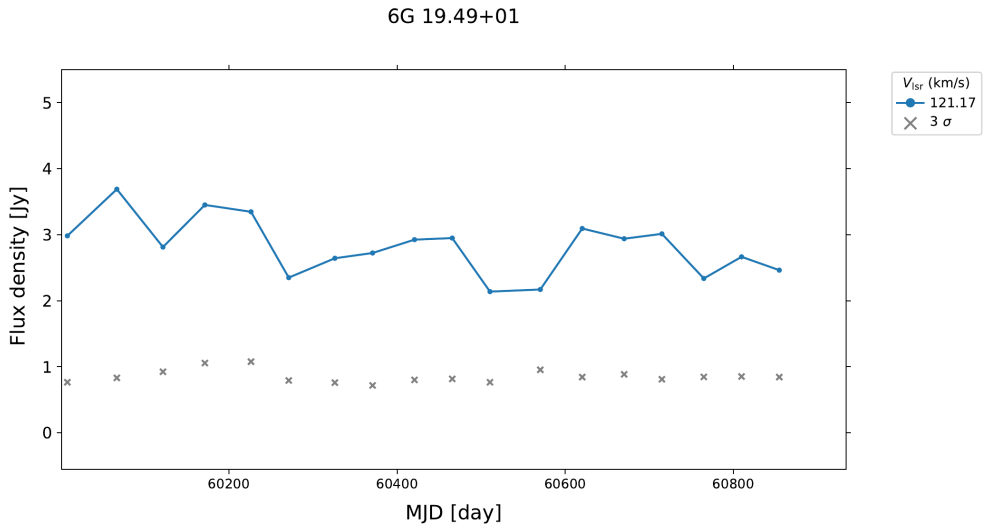


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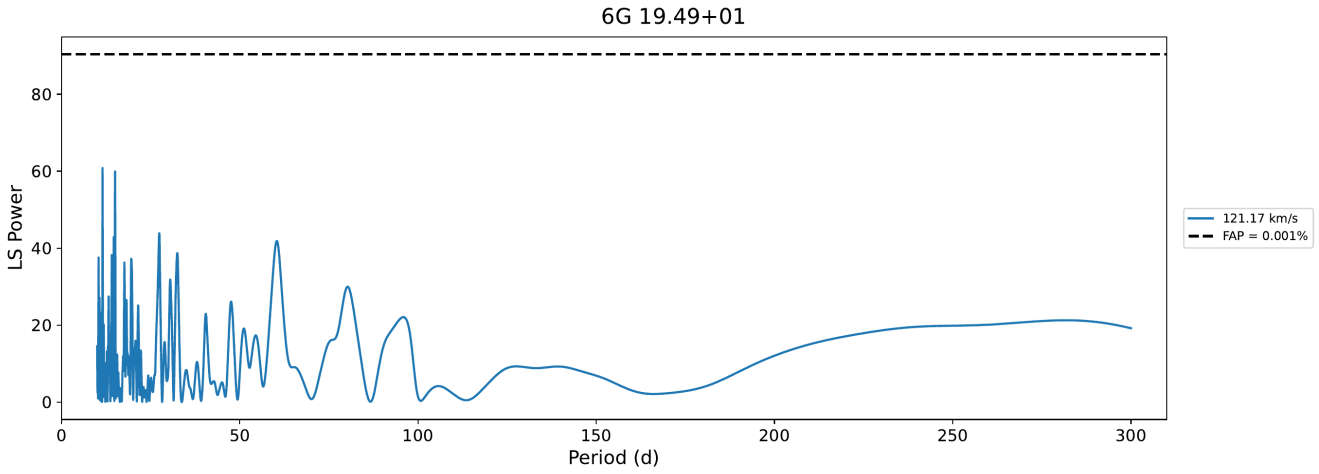


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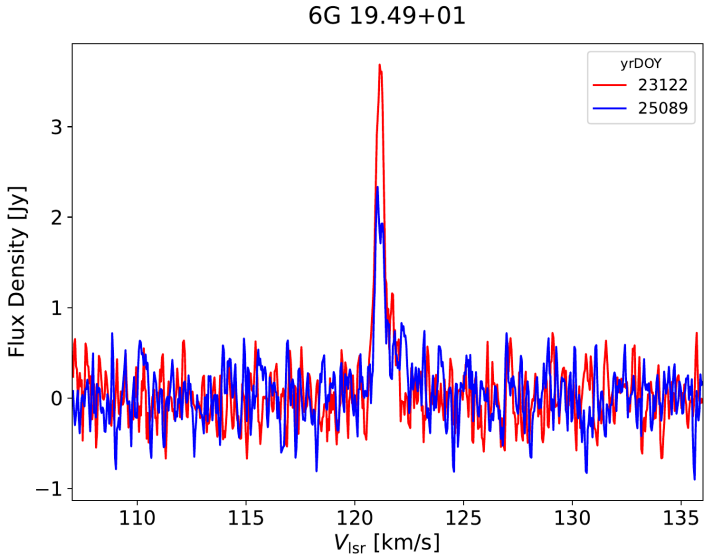
Light curve



Periodogram

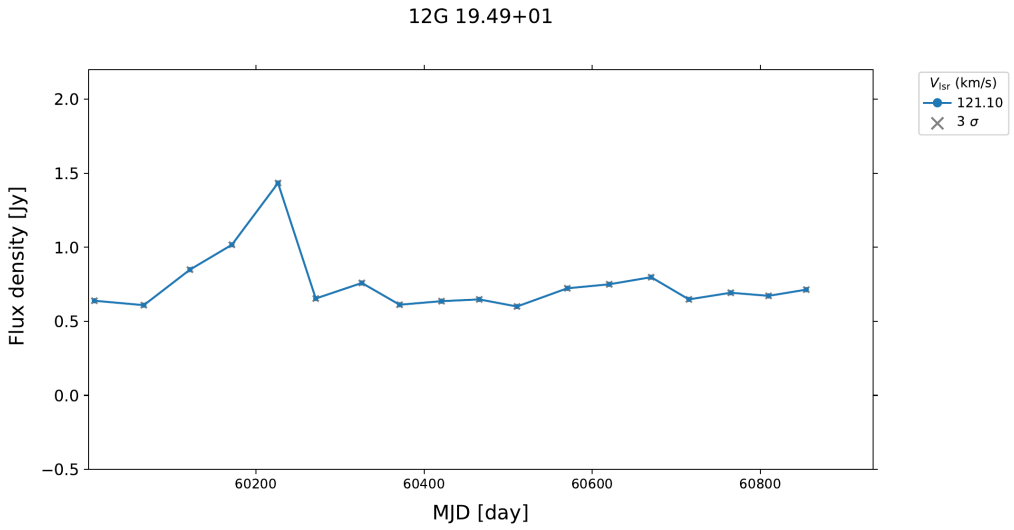


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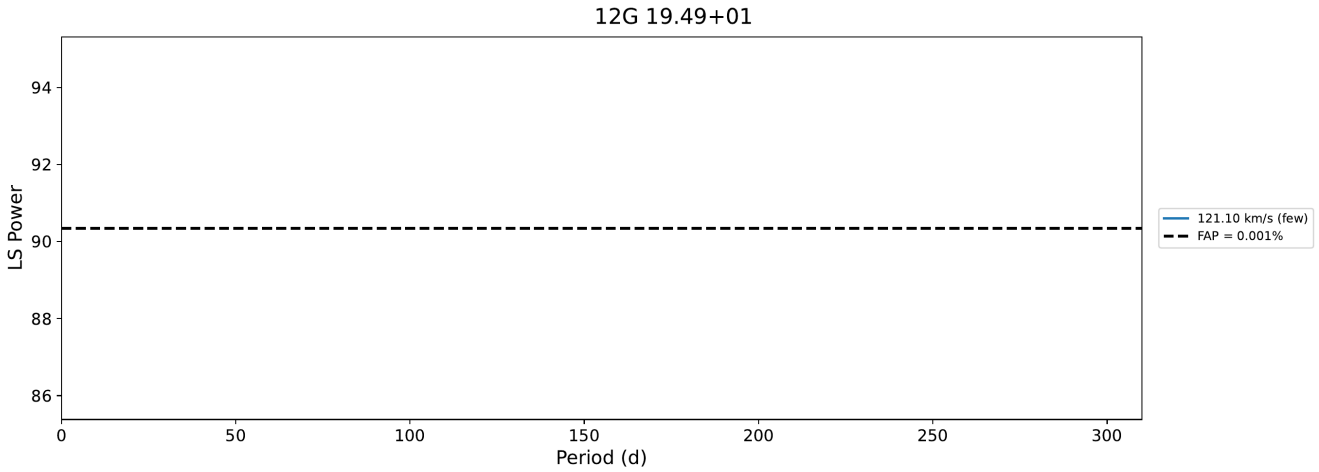


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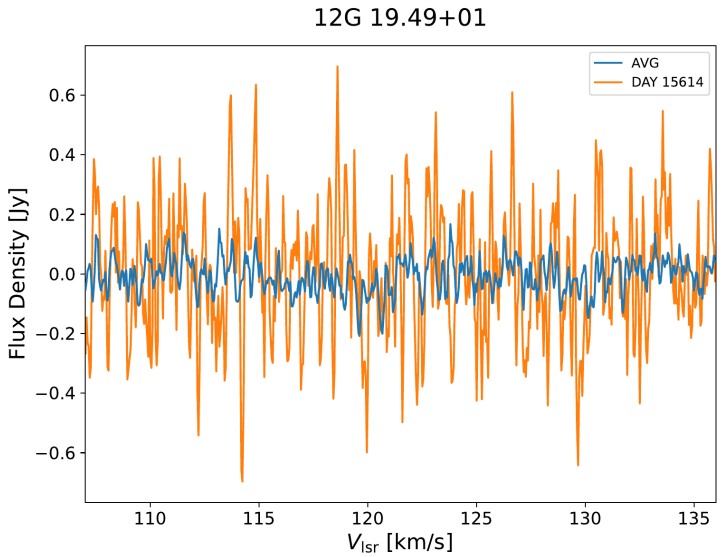
Light curve



Periodogram

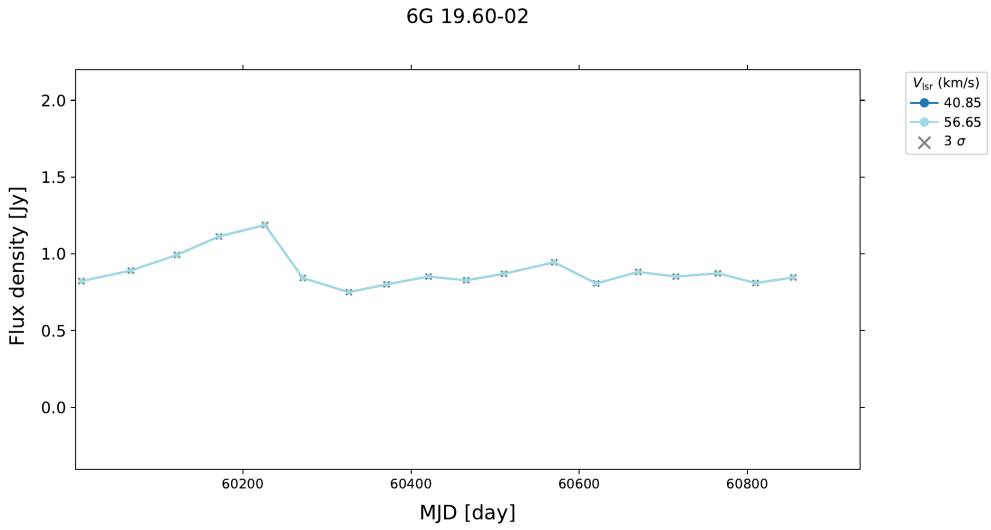


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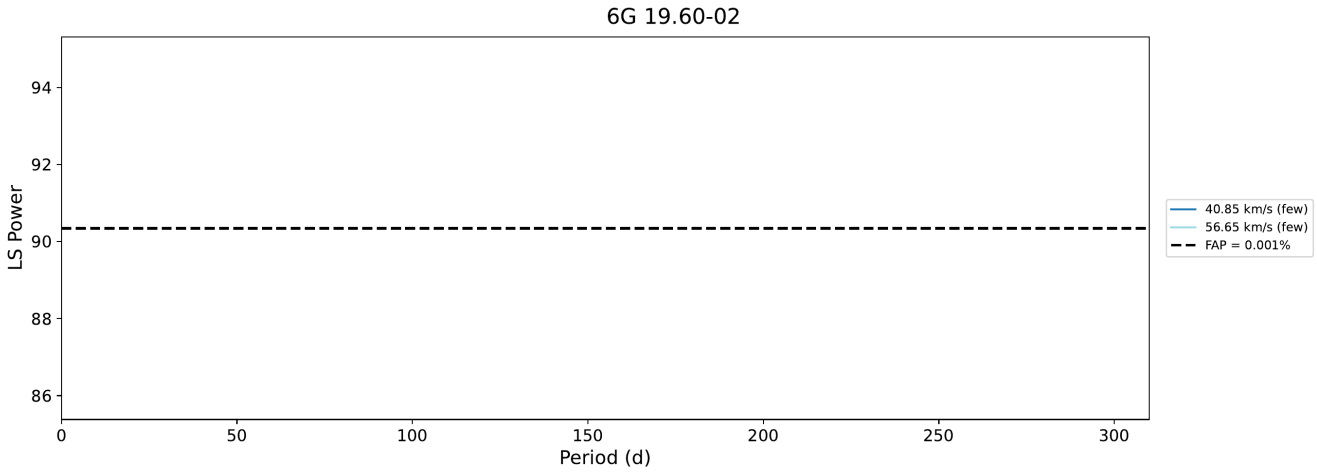


6G 19.60-02

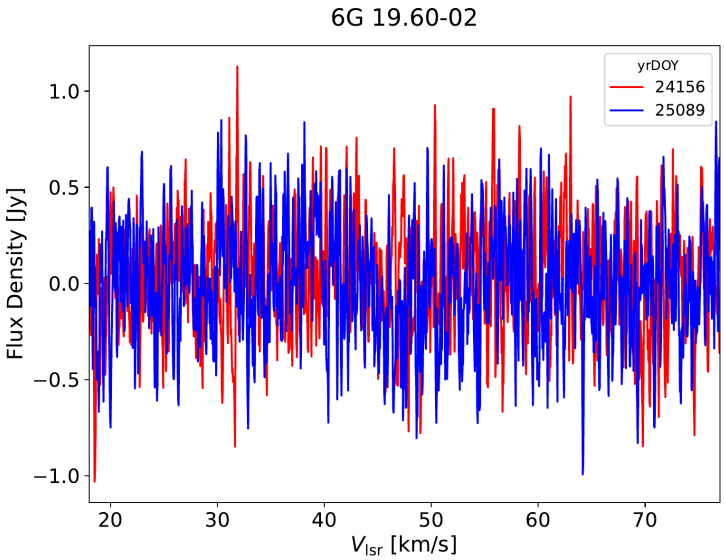
Light curve



Periodogram

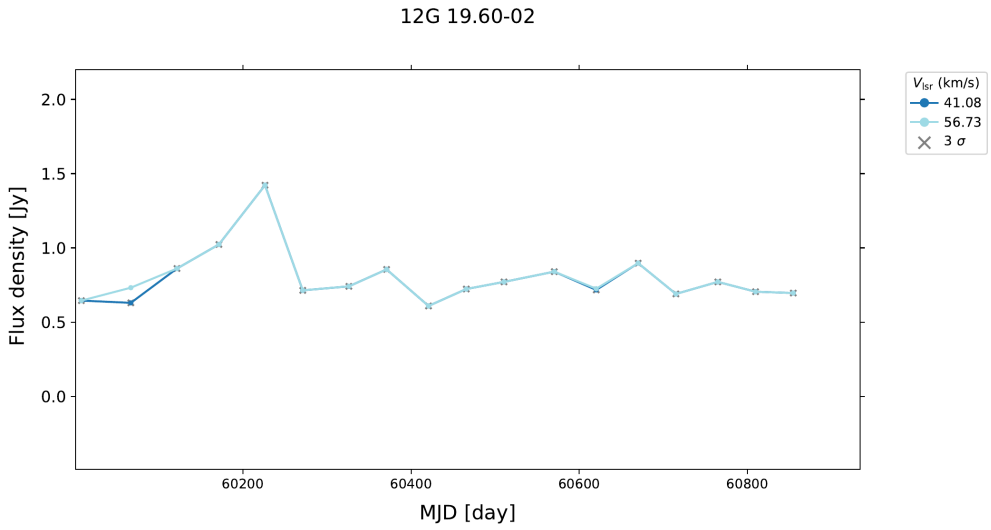


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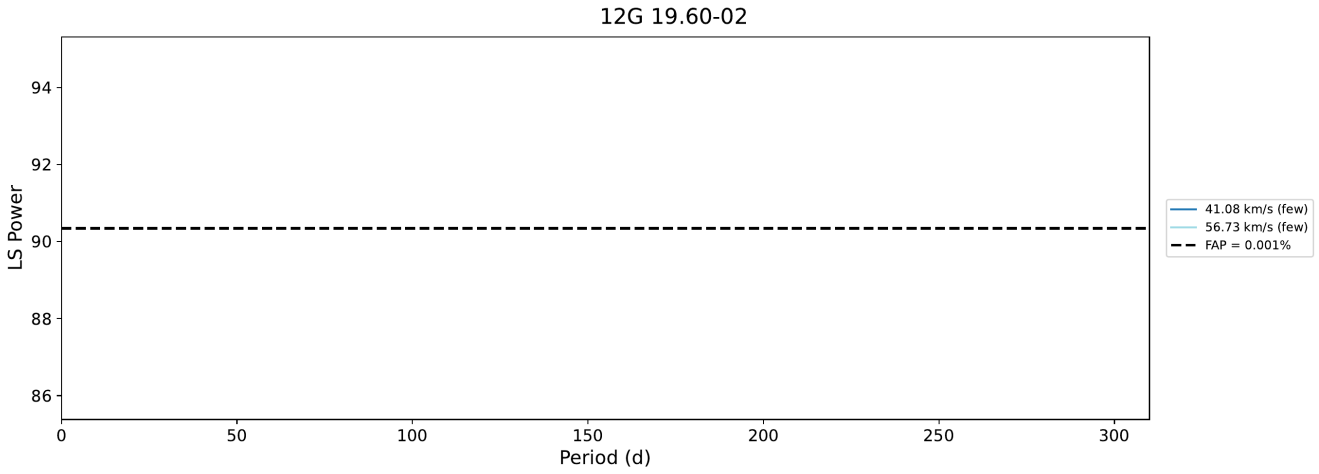


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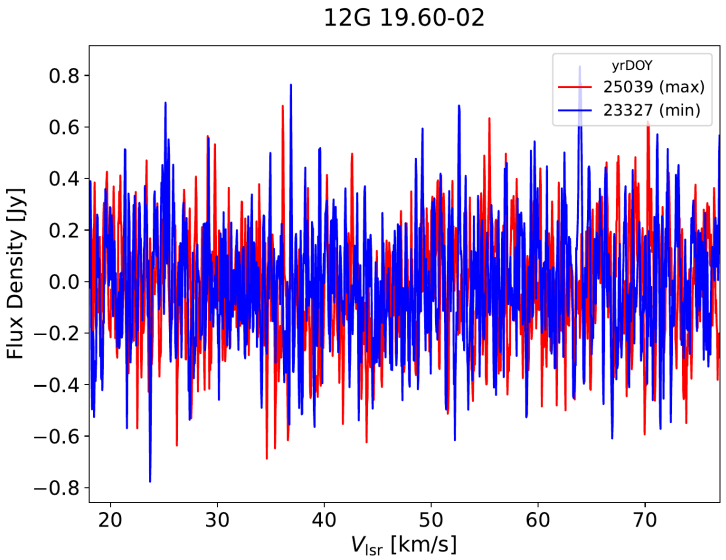
Light curve



Periodogram

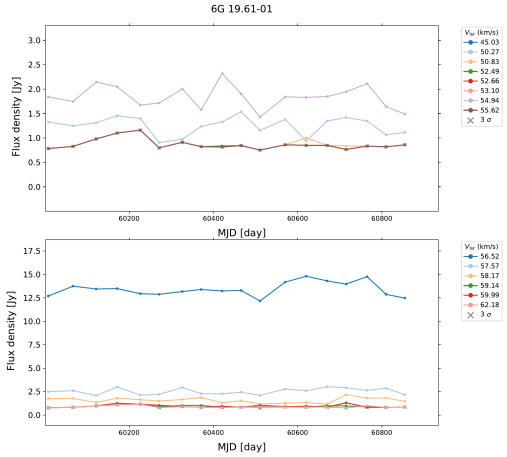


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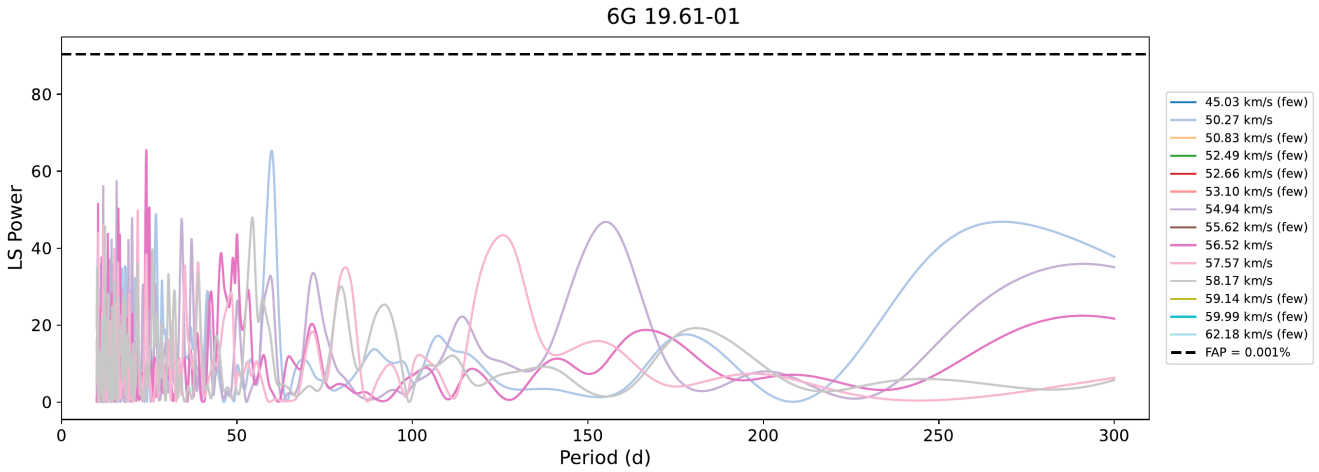


6G 19.61-01

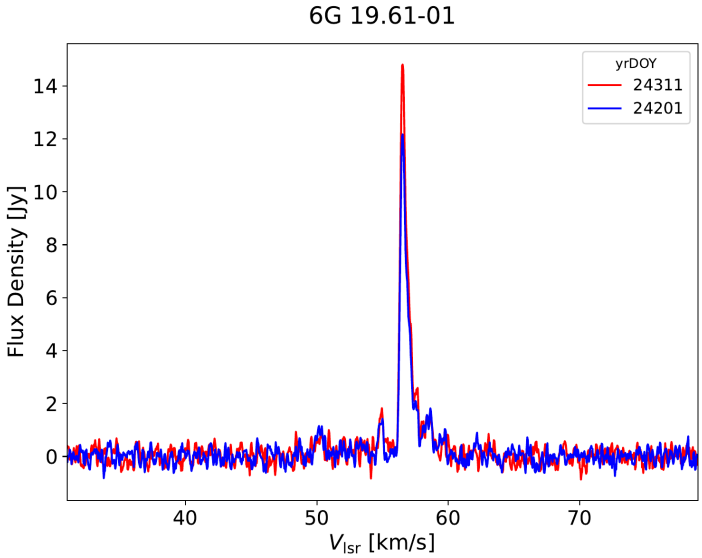
Light curve



Periodogram

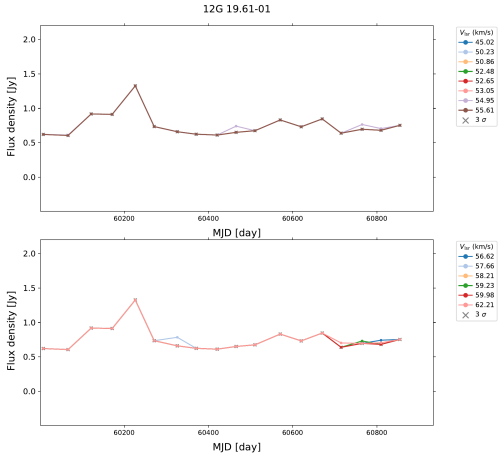


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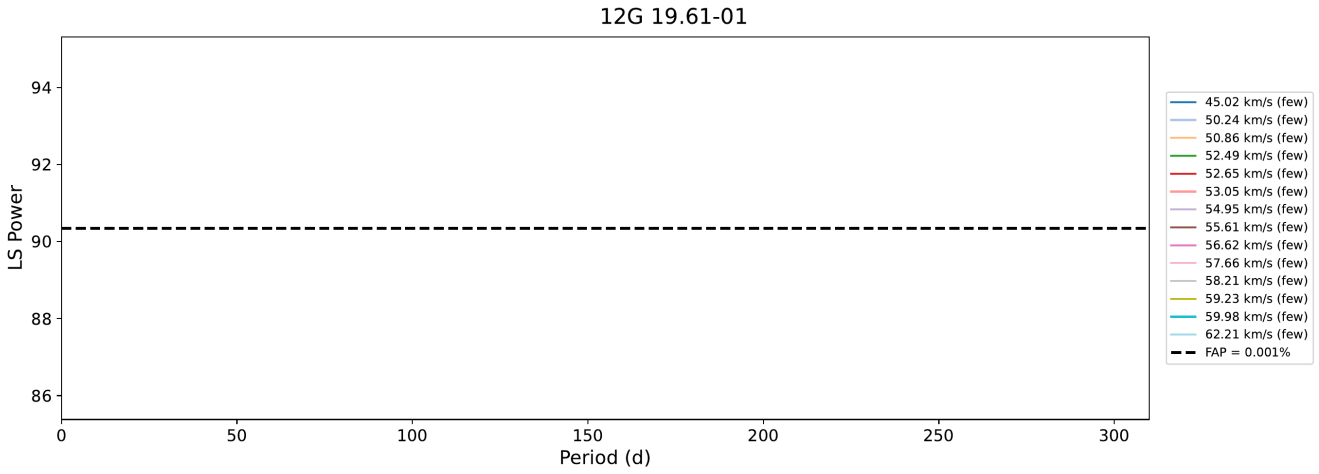


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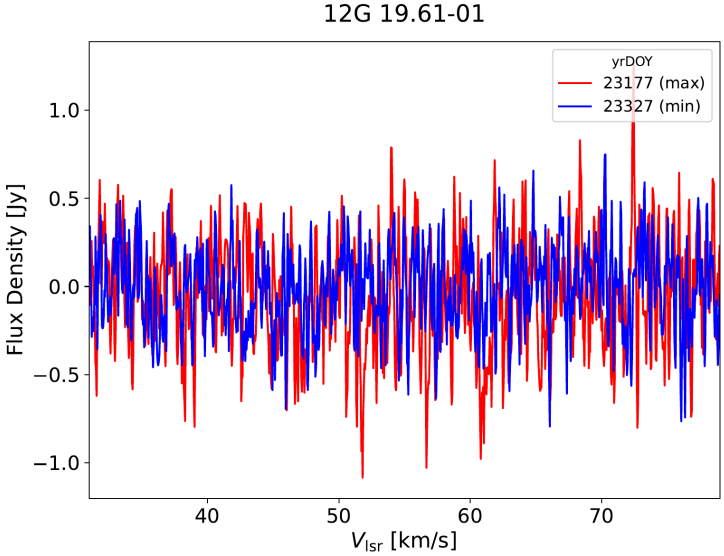
Light curve



Periodogram

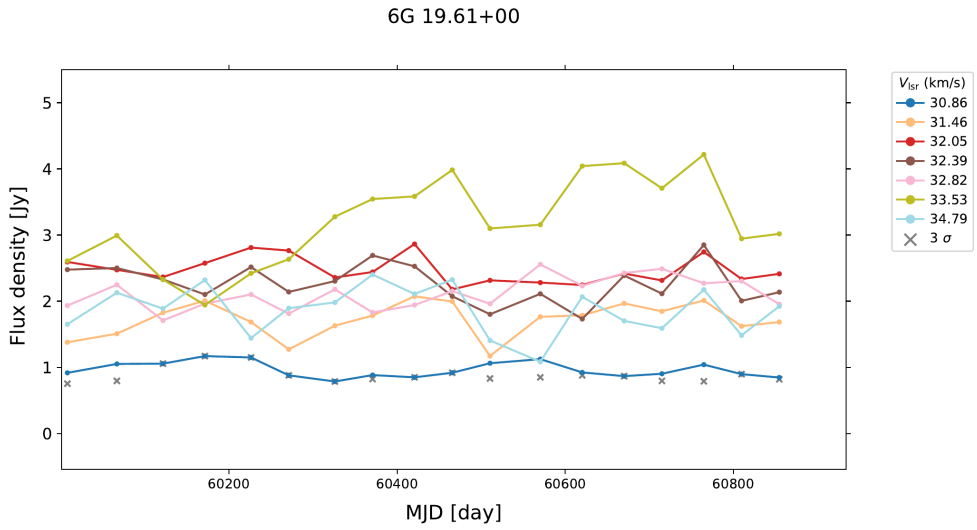


Spectrum

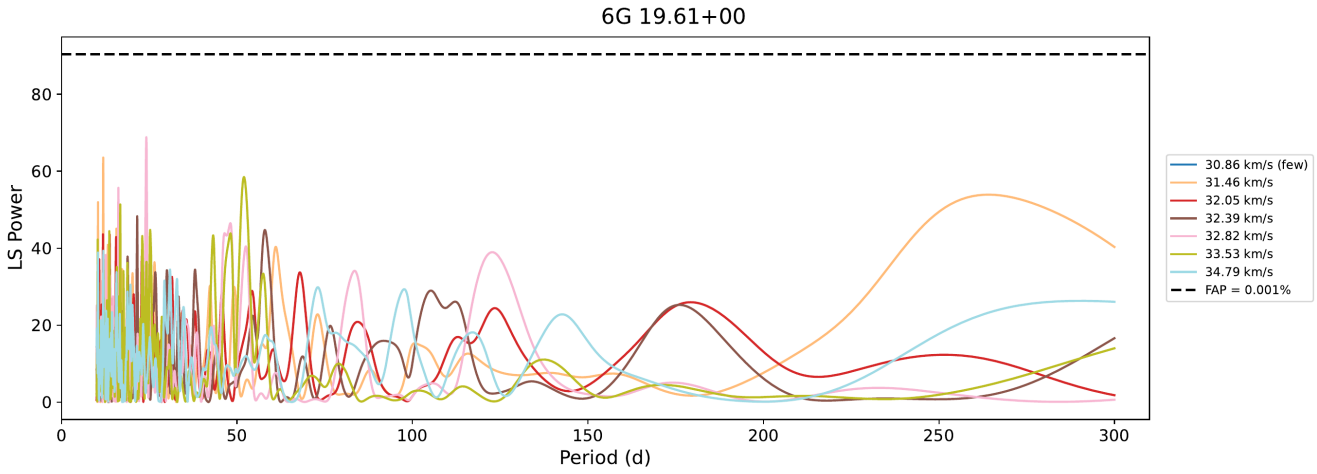


6G 19.61+00

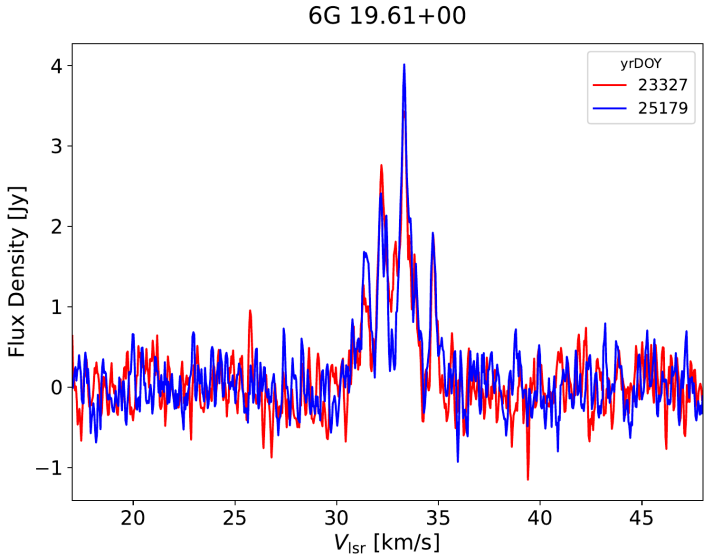
Light curve



Periodogram

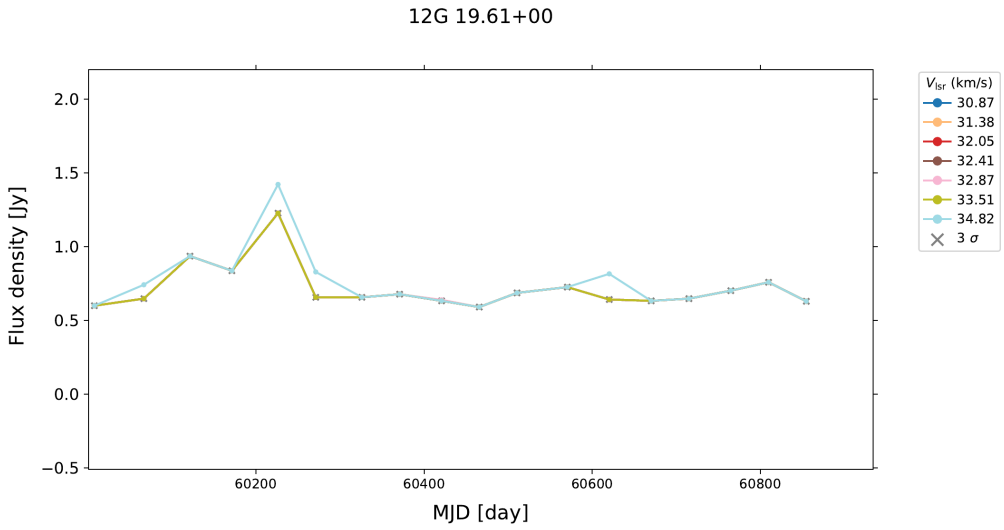


Spectrum

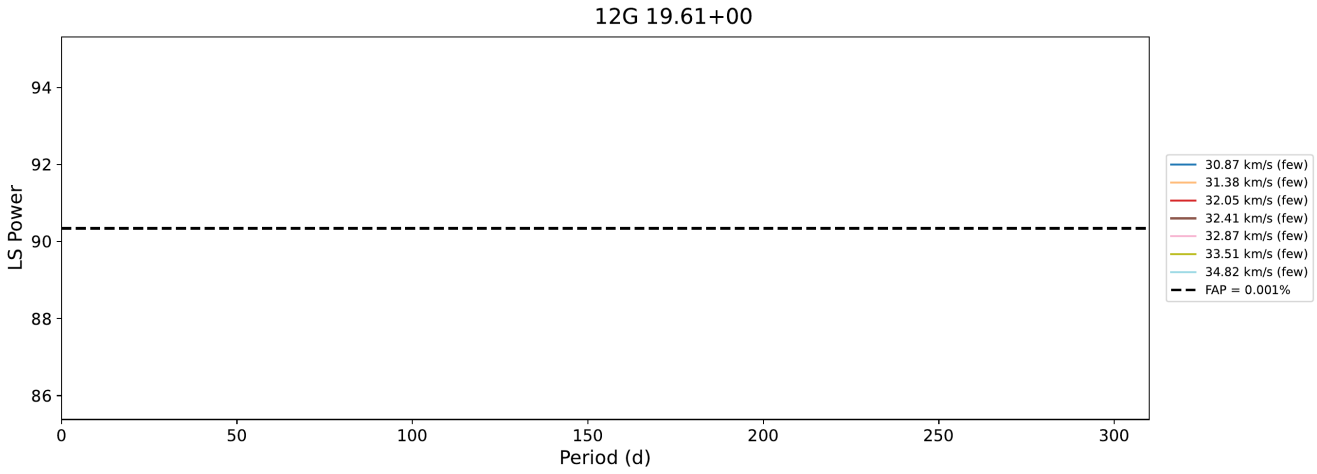


12G 19.61+00

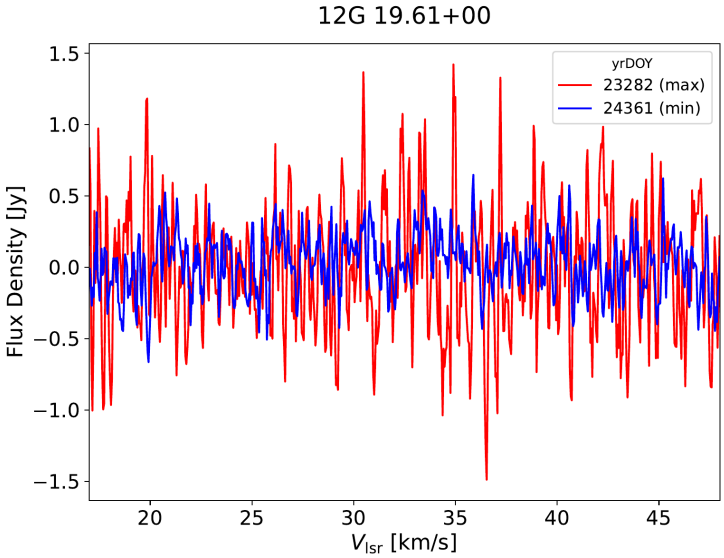
Light curve



Periodogram

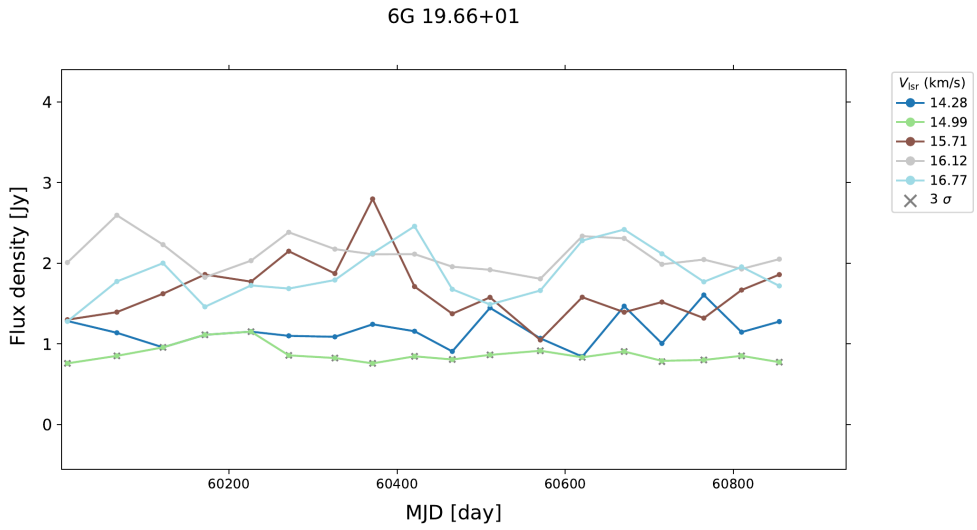


Spectrum

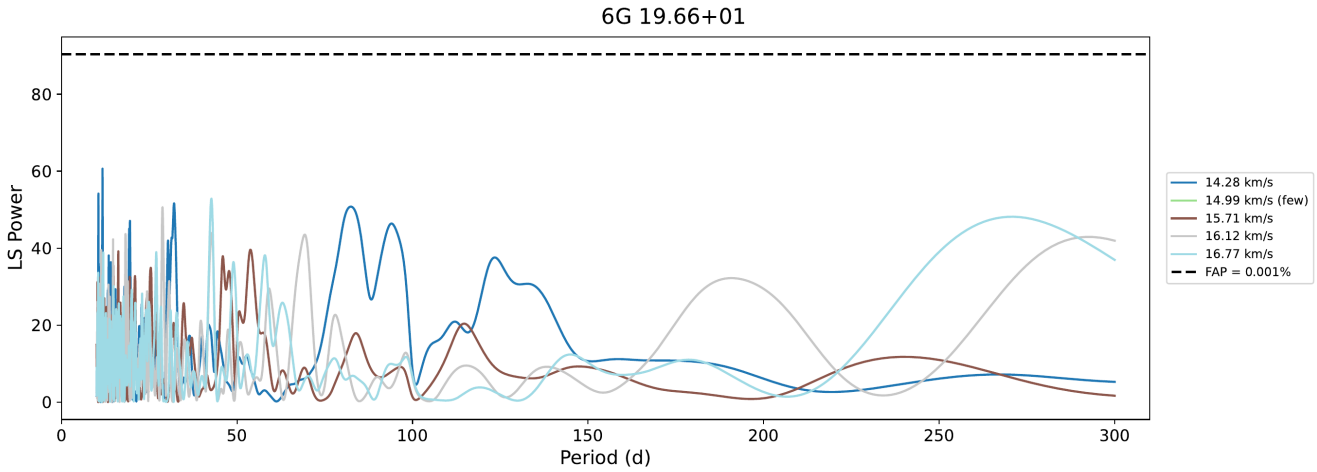


6G 19.66+01

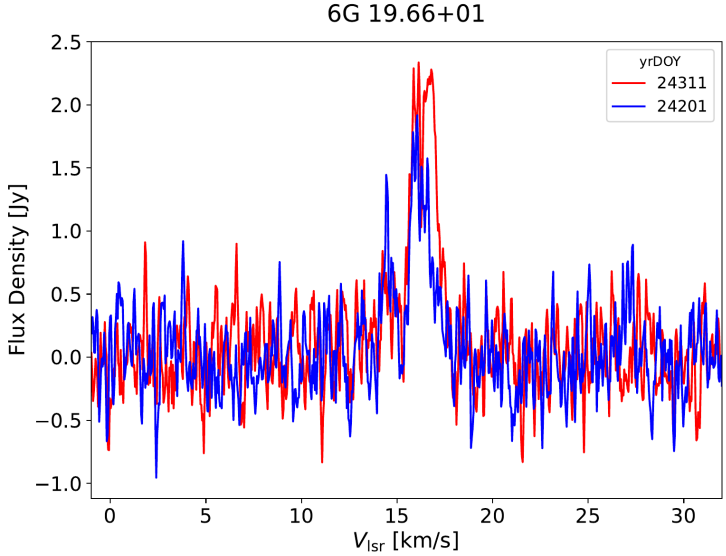
Light curve



Periodogram

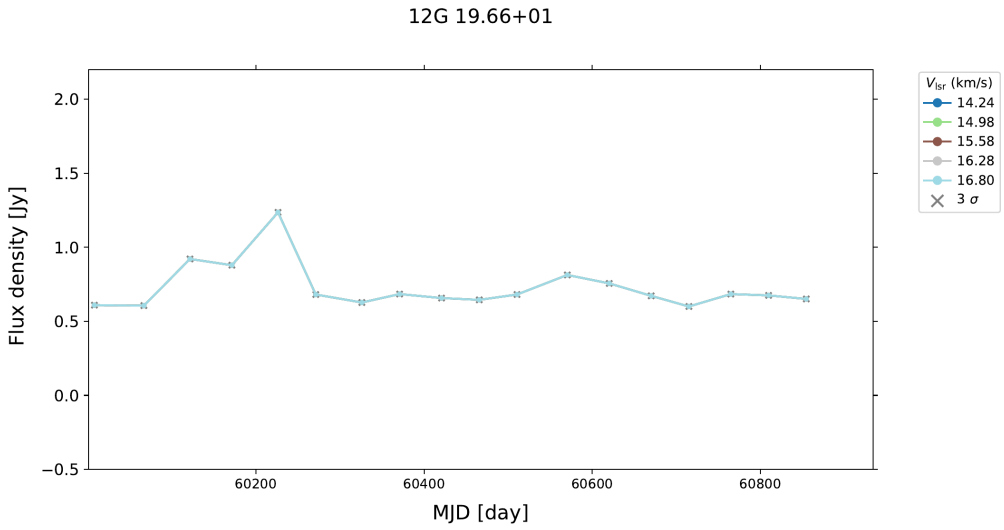


Spectrum

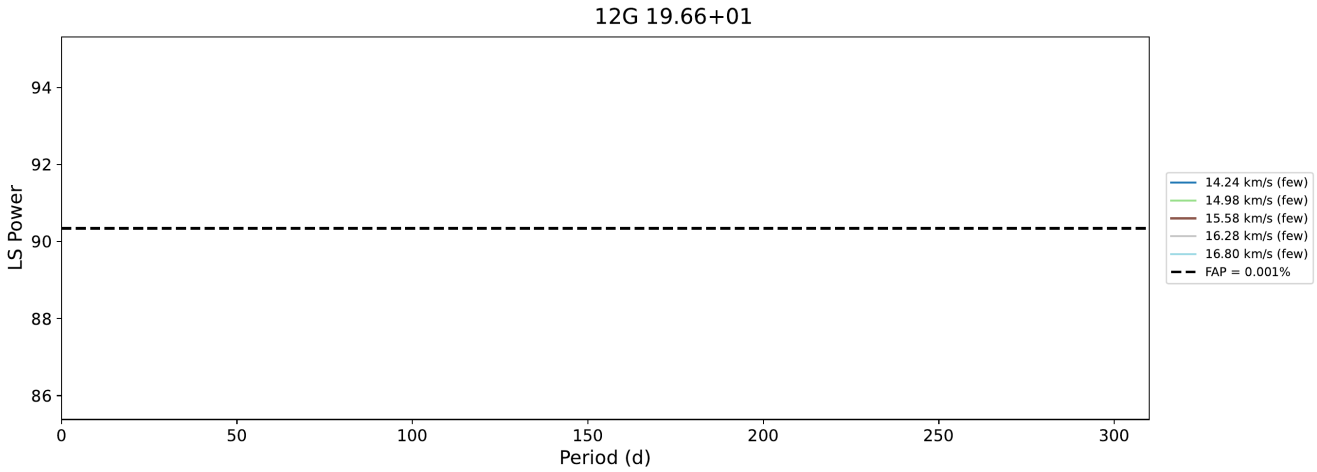


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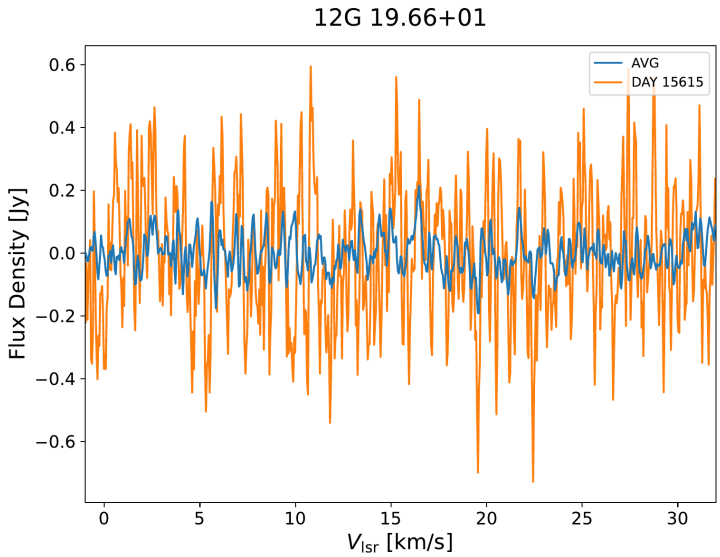
Light curve



Periodogram

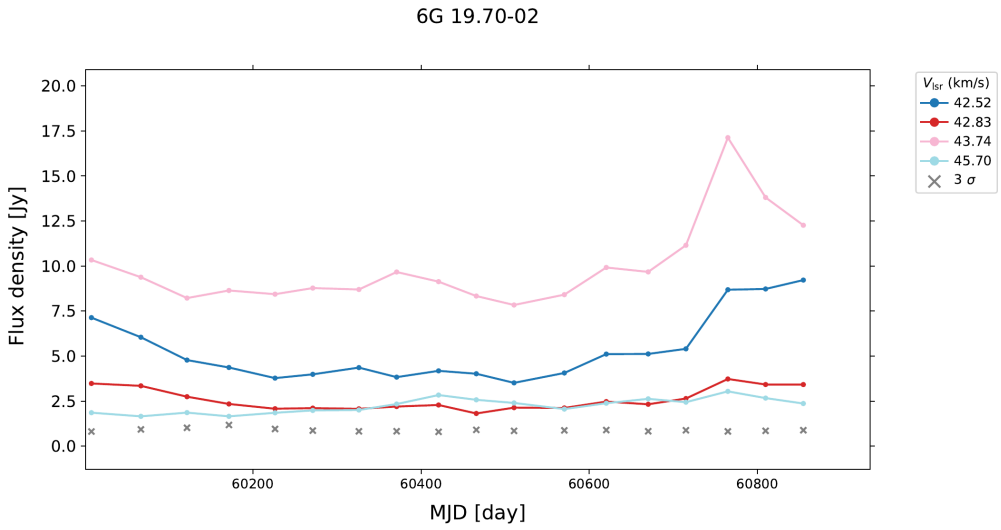


Spectrum

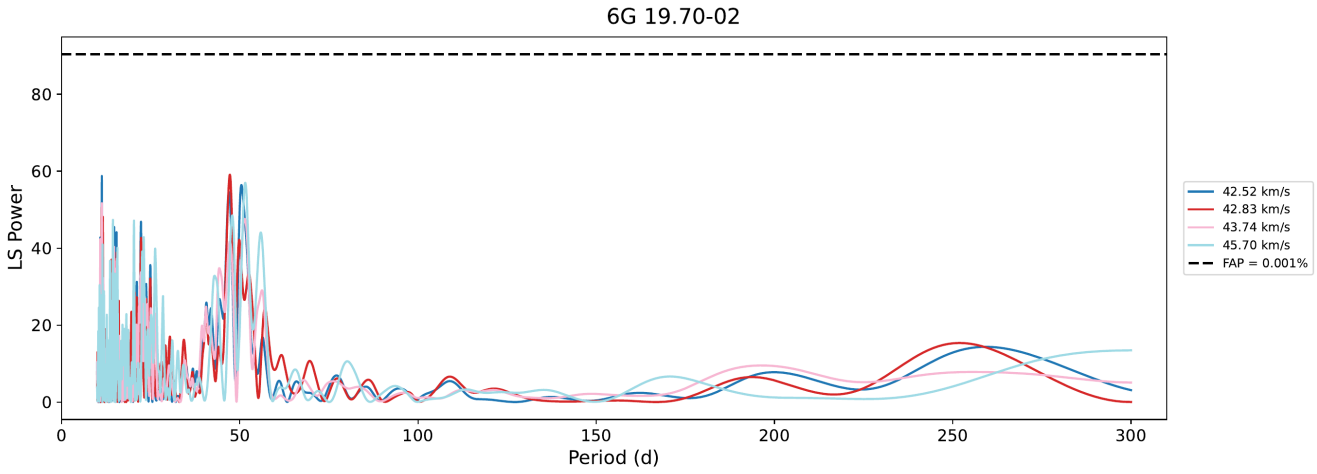


6G 19.70-02

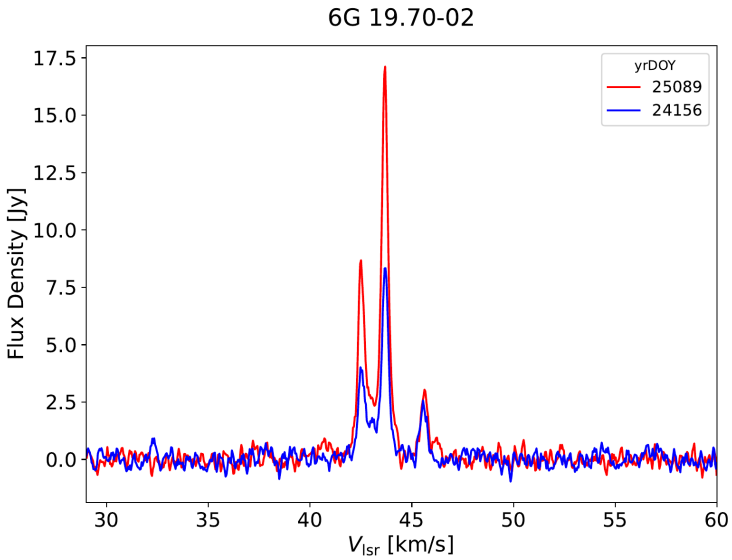
Light curve



Periodogram

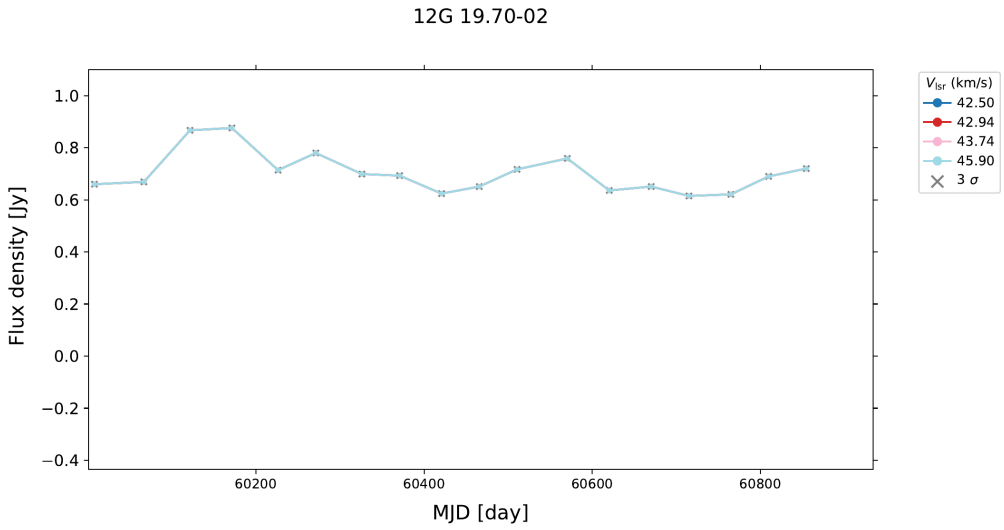


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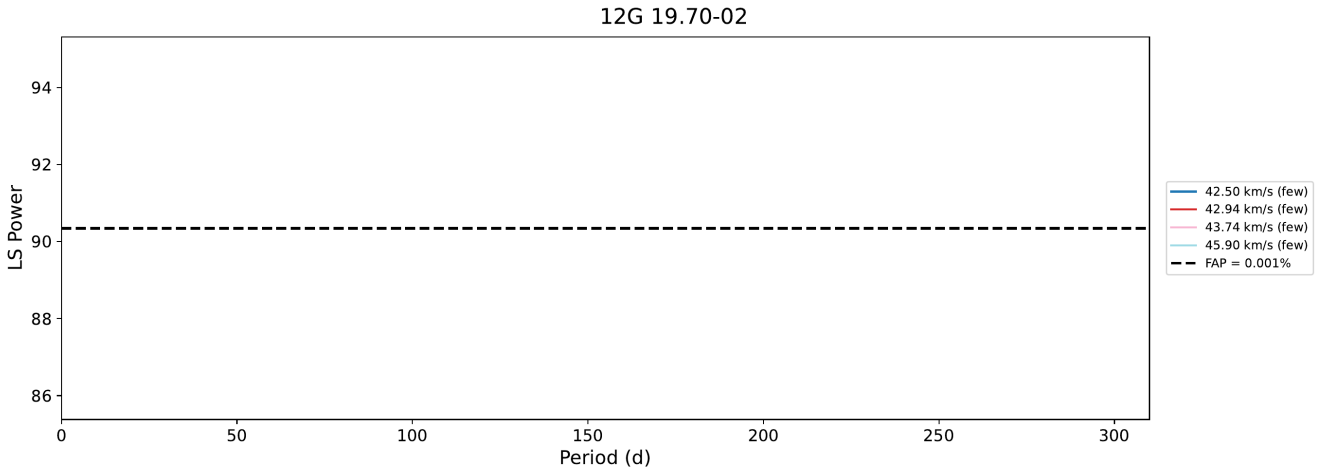


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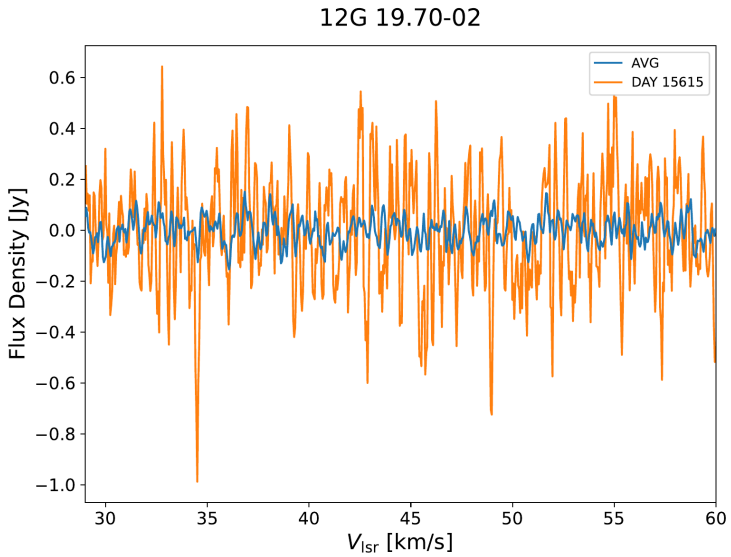
Light curve



Periodogram

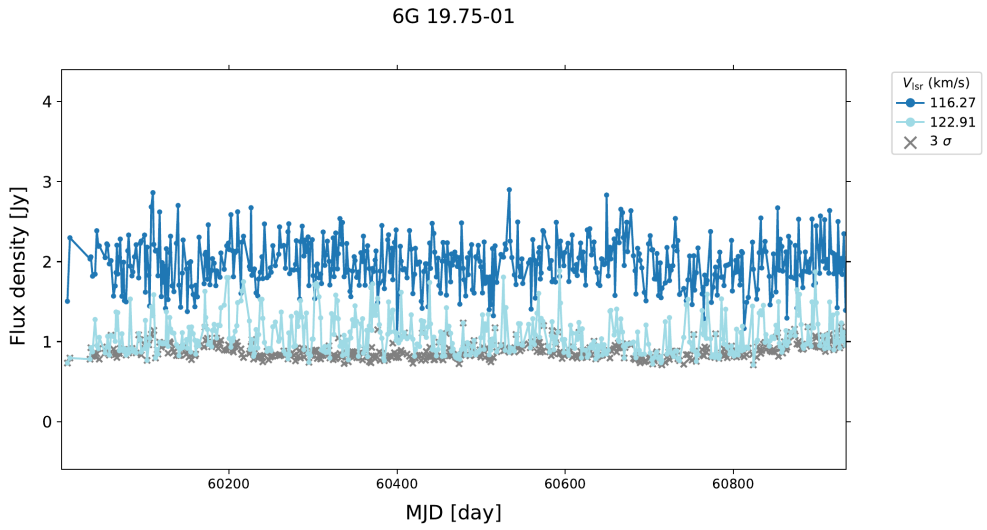


Spectrum

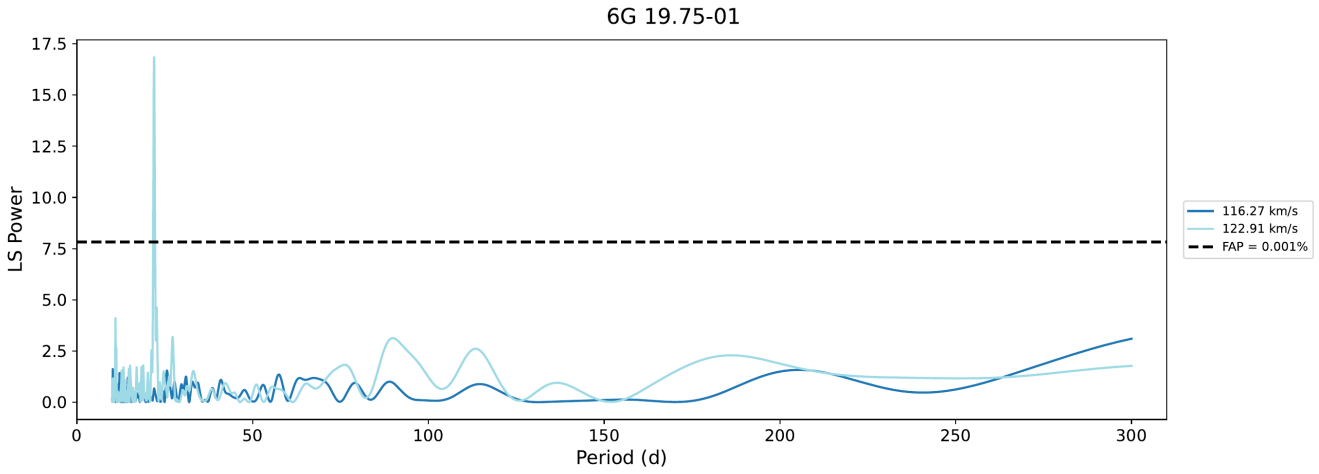


6G 19.75-01

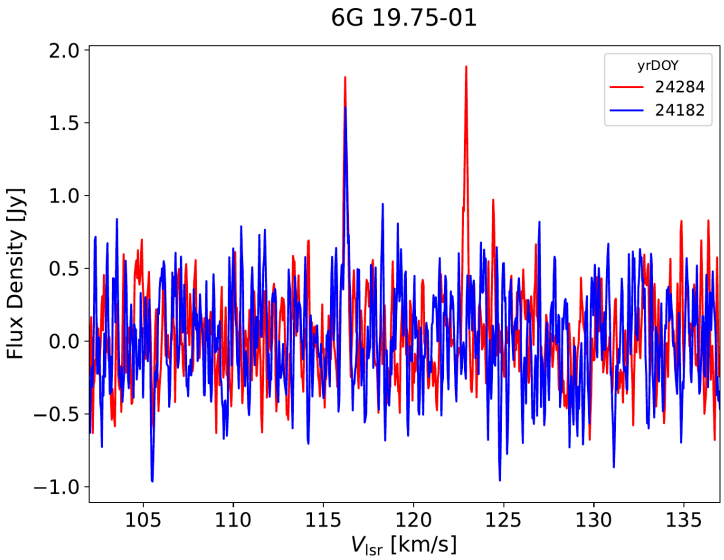
Light curve



Periodogram

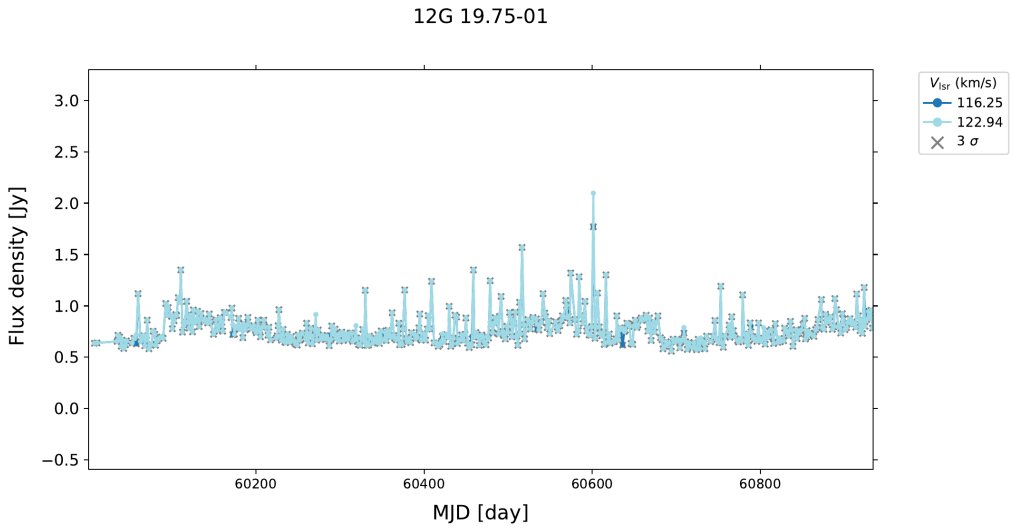


Spectrum

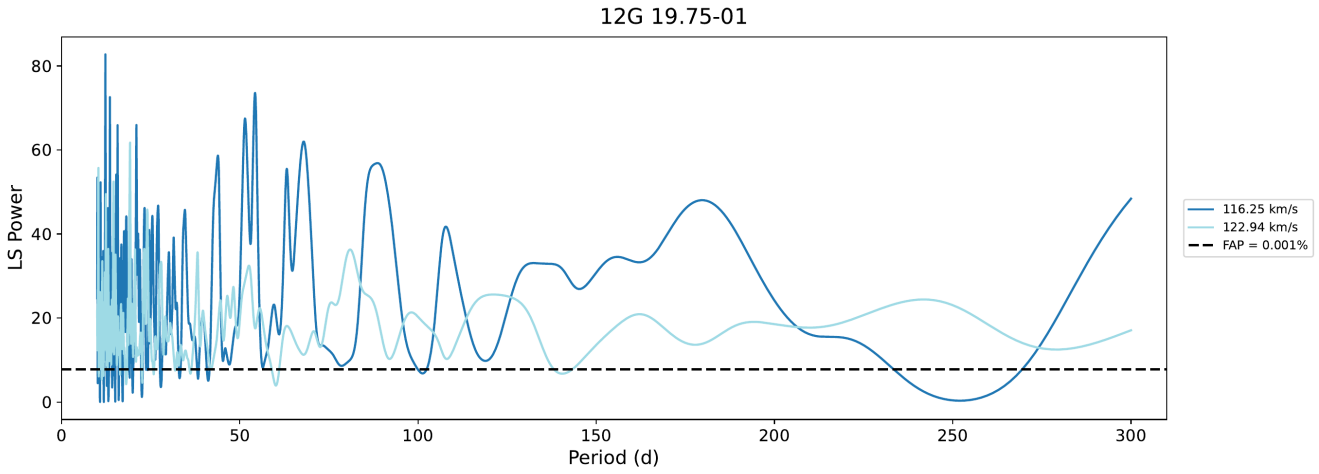


12G 19.75-01

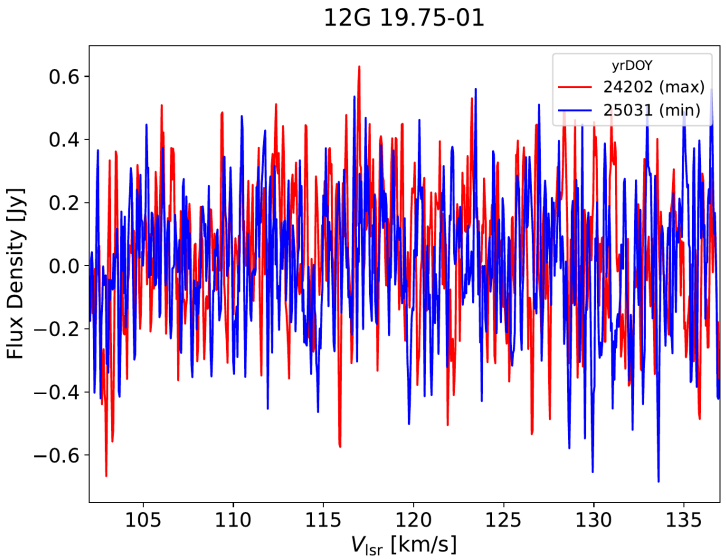
Light curve



Periodogram

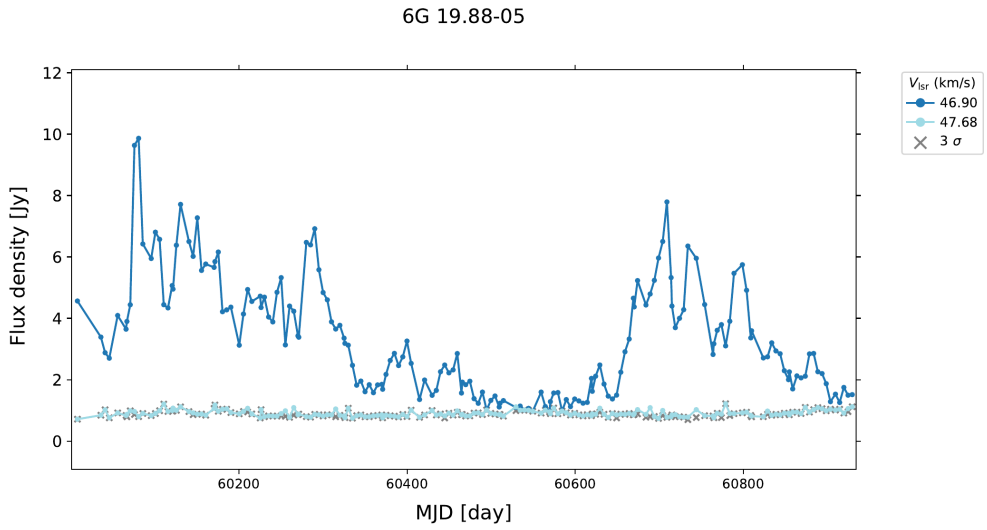


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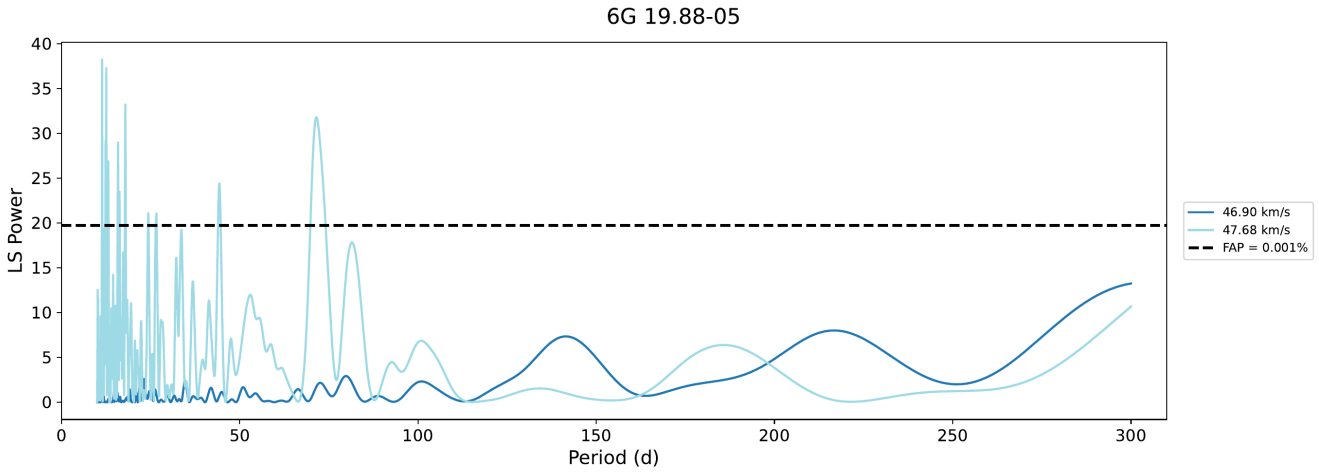


6G 19.88-05

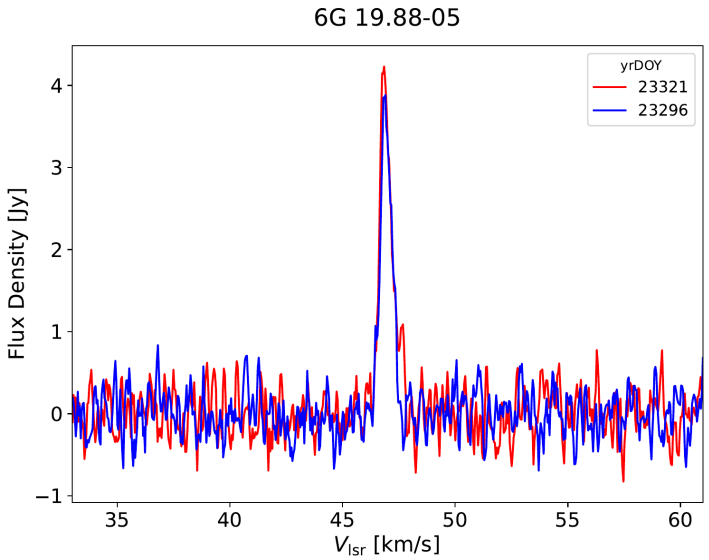
Light curve



Periodogram

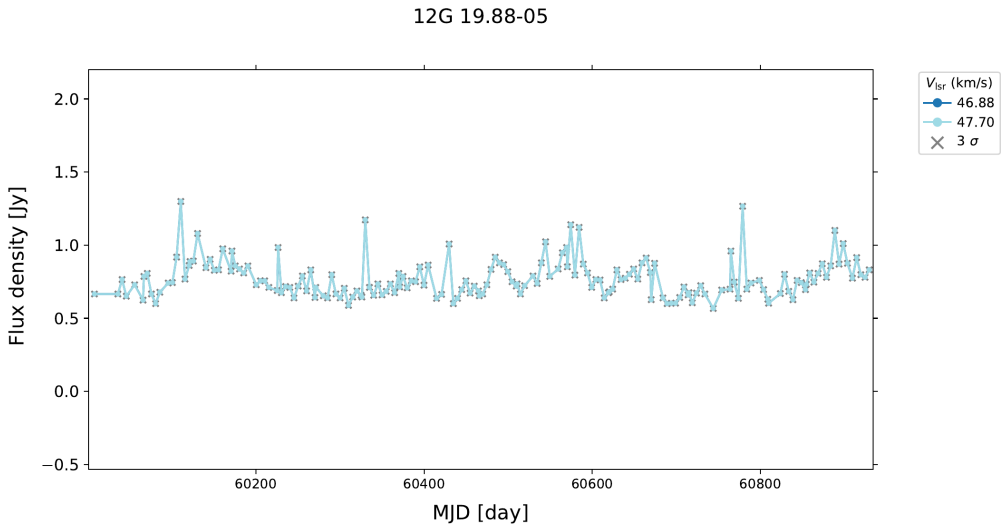


Spectrum

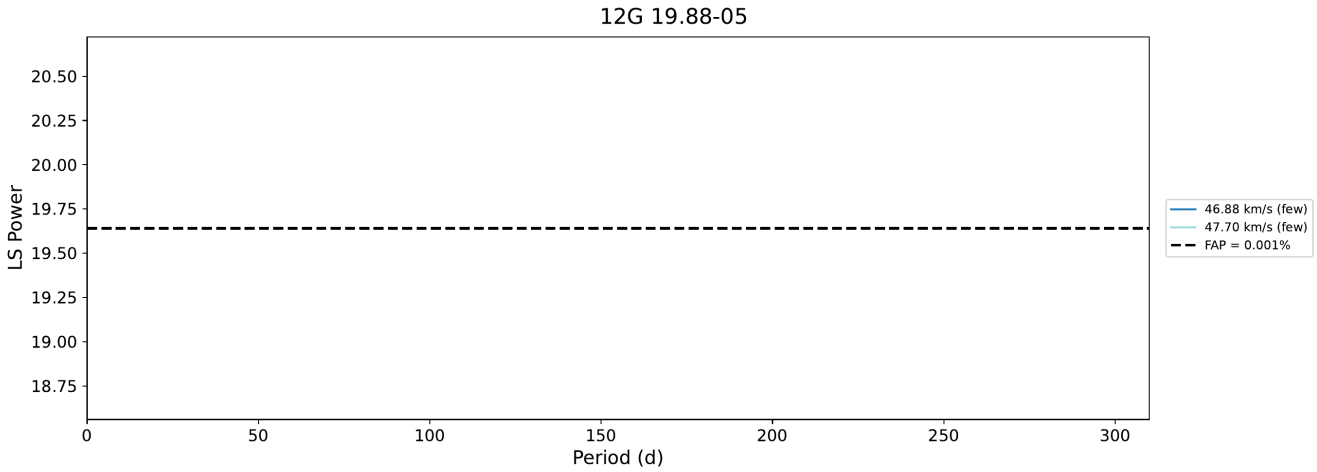


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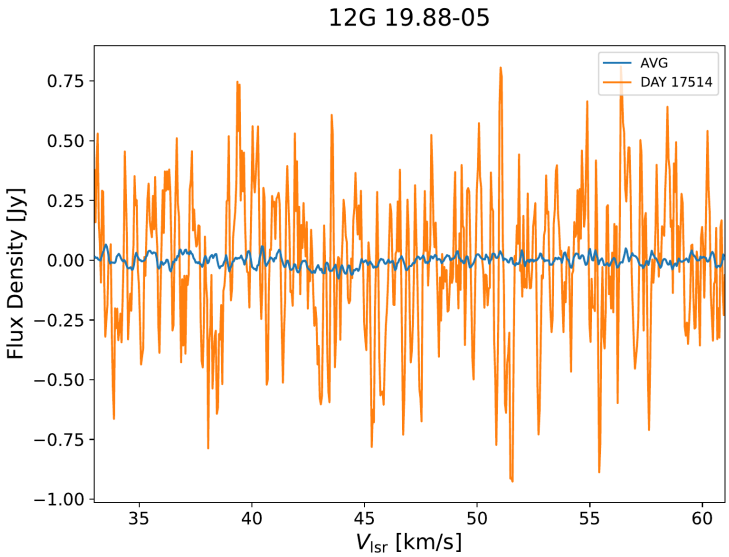
Light curve



Periodogram

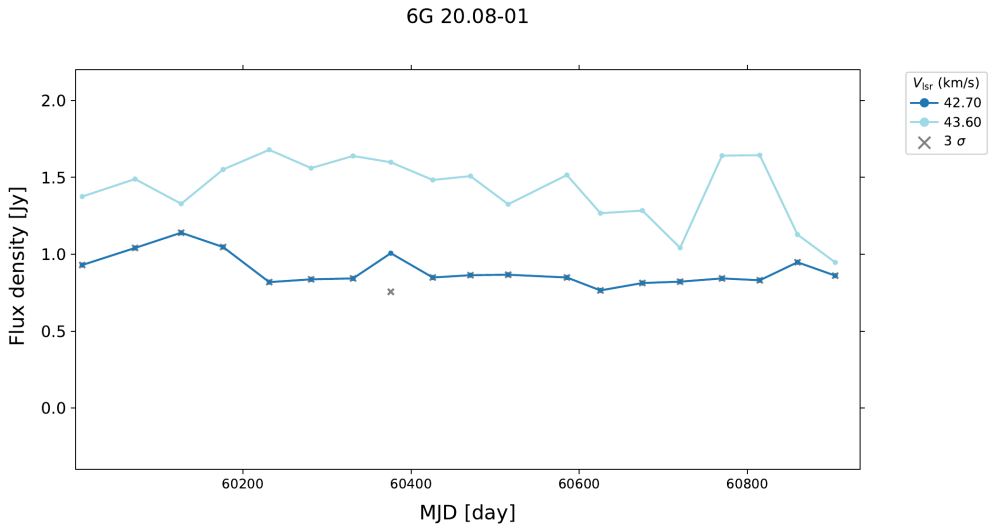


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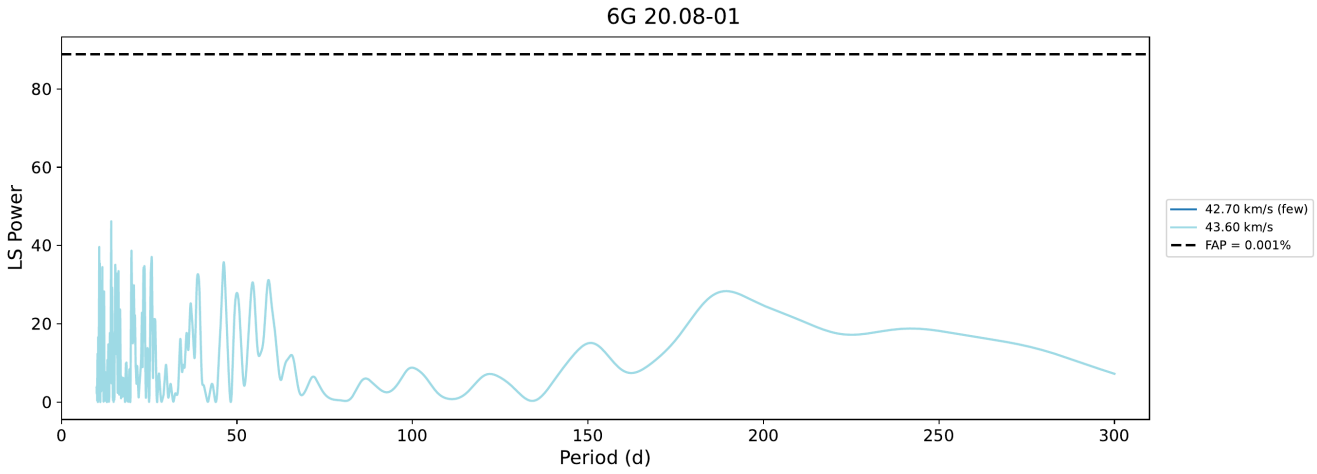


6G 20.08-01

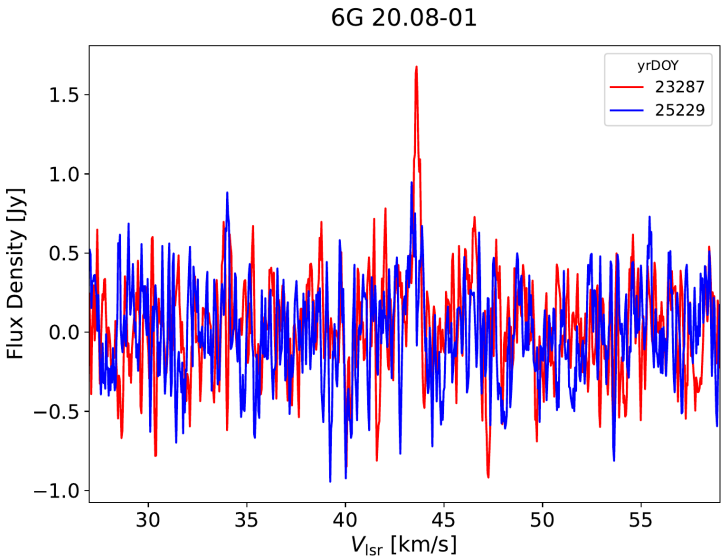
Light curve



Periodogram

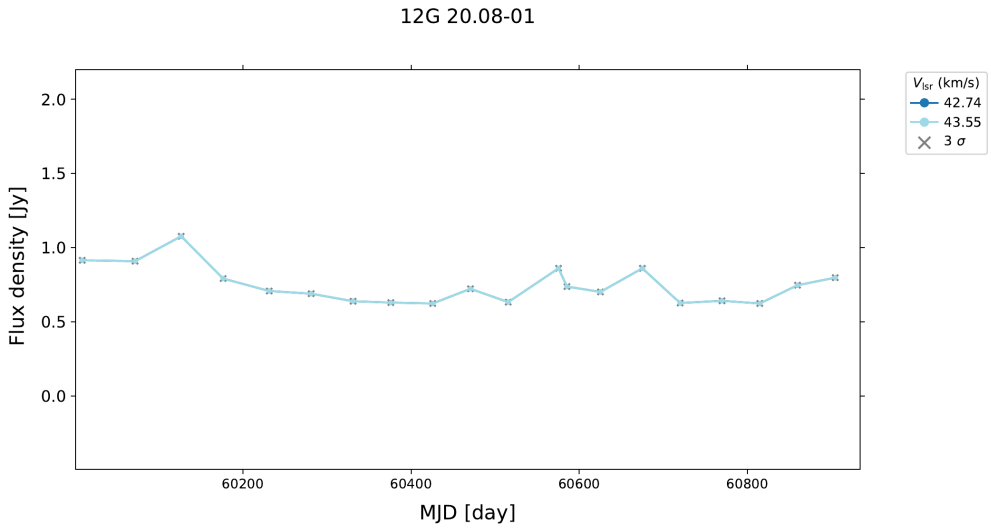


Spectrum

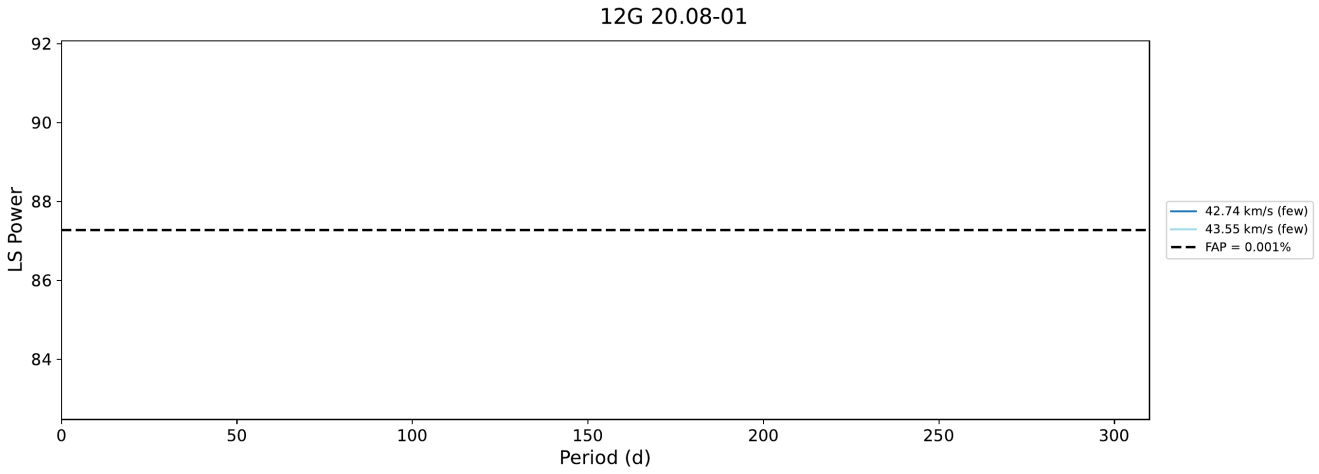


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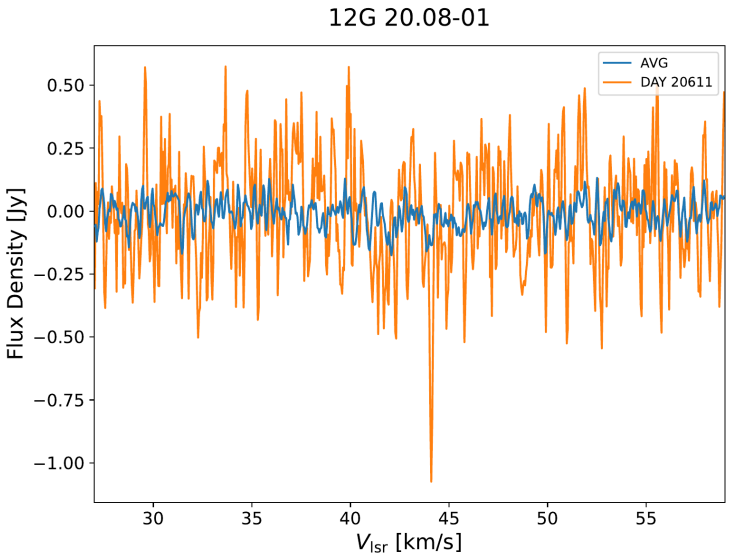
Light curve



Periodogram

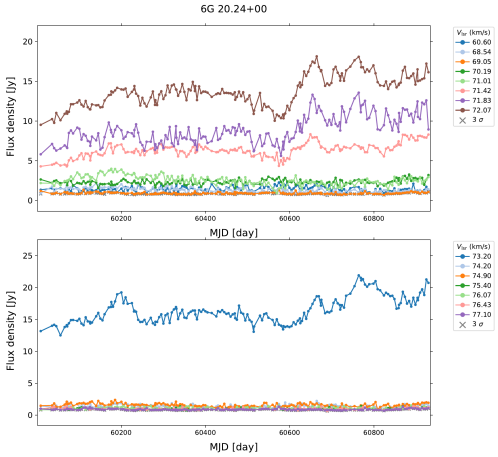


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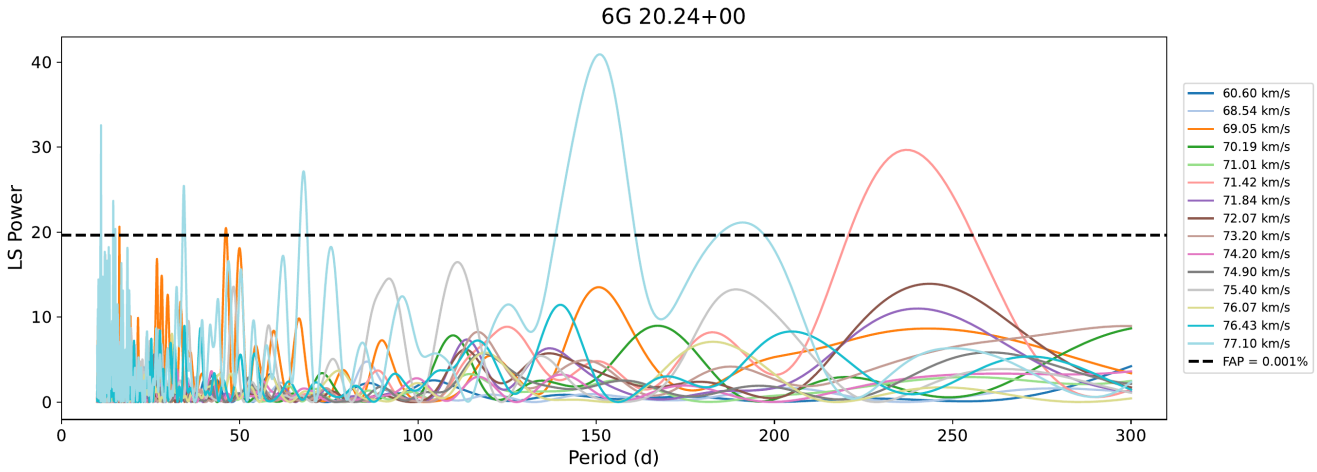


6G 20.24+00

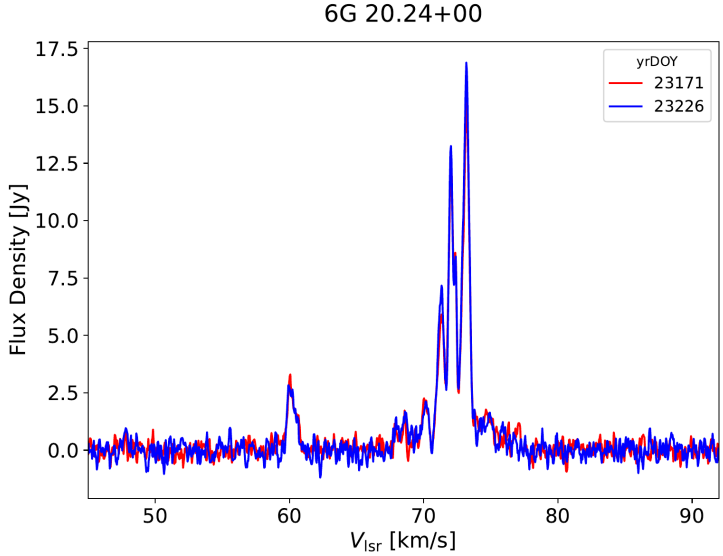
Light curve



Periodogram

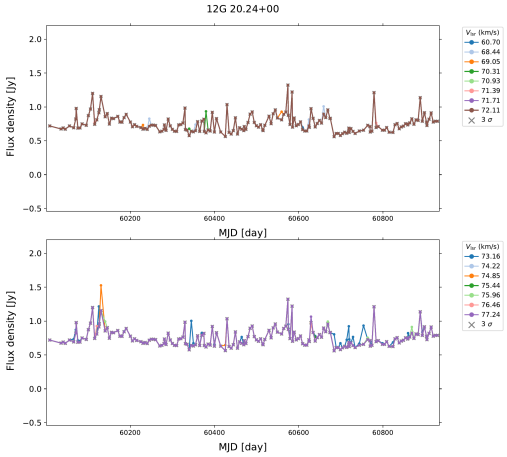


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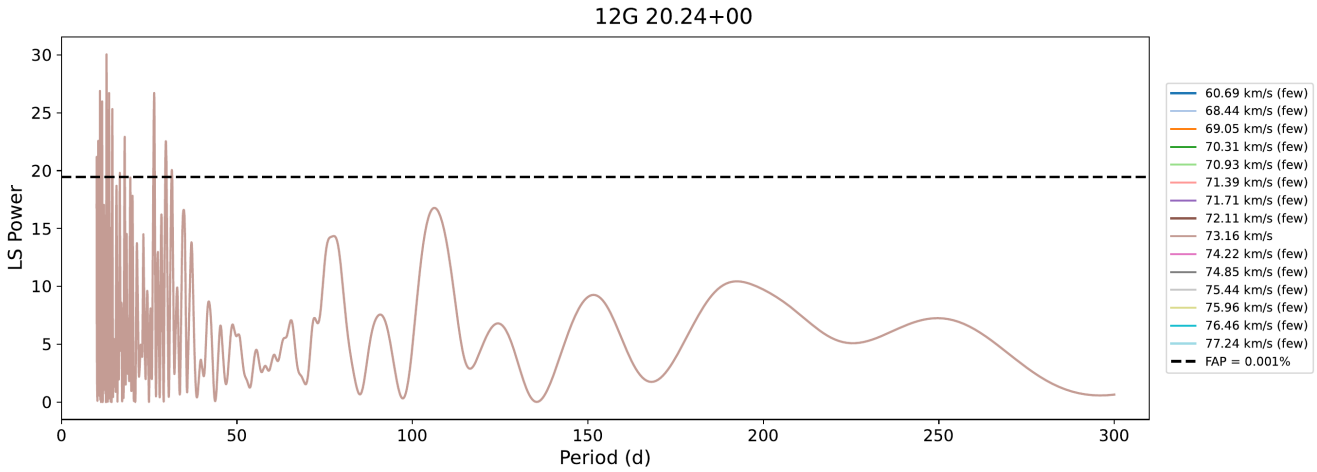


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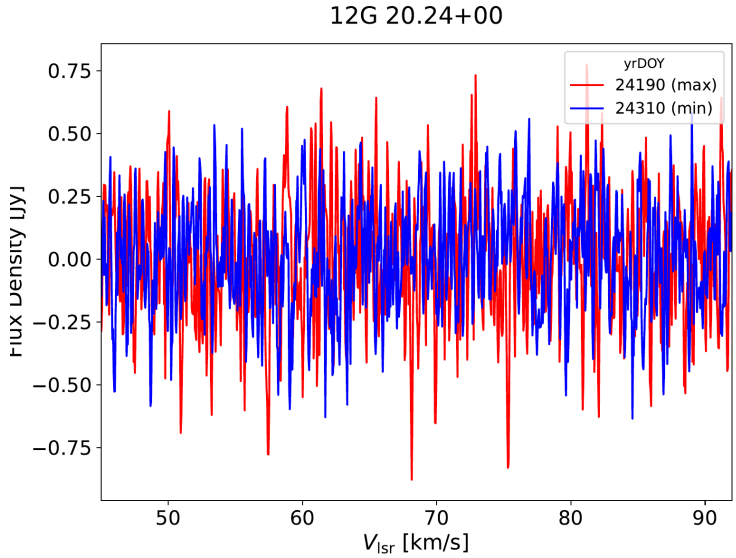
Light curve



Periodogram

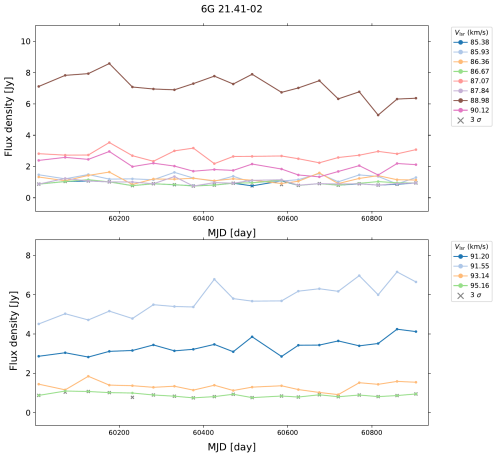


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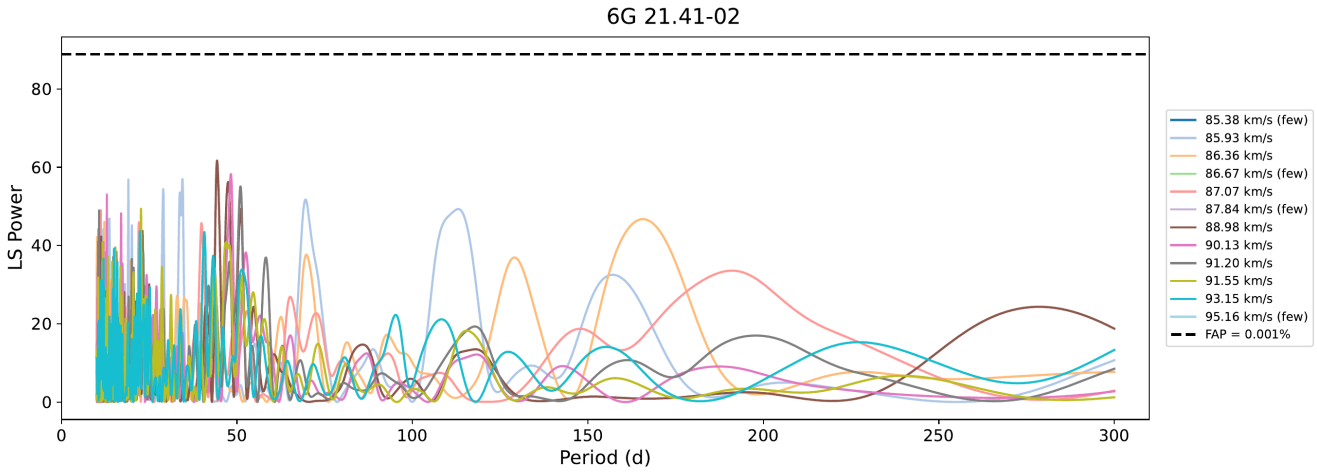


6G 21.41-02

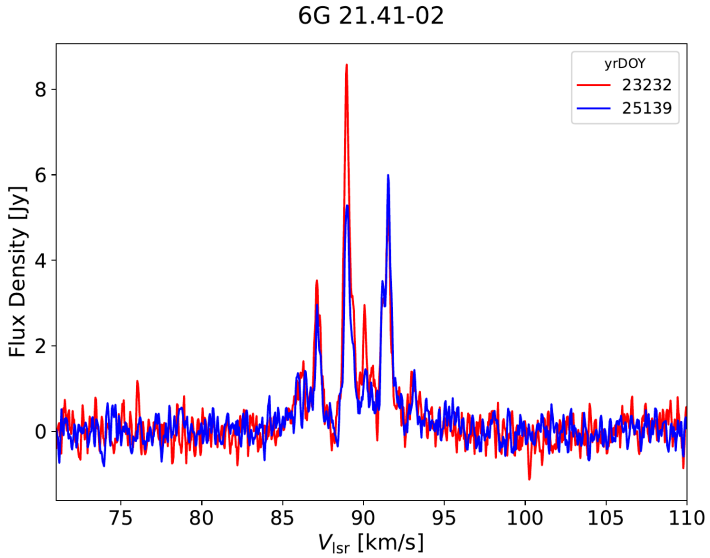
Light curve



Periodogram

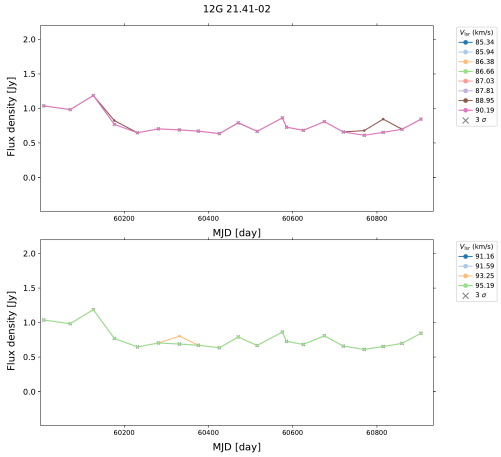


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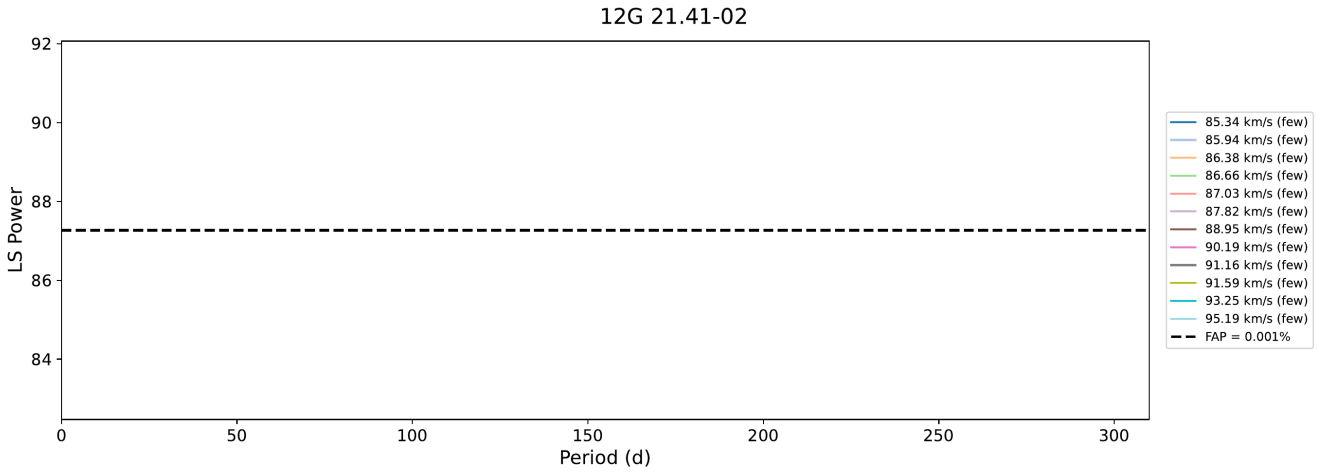


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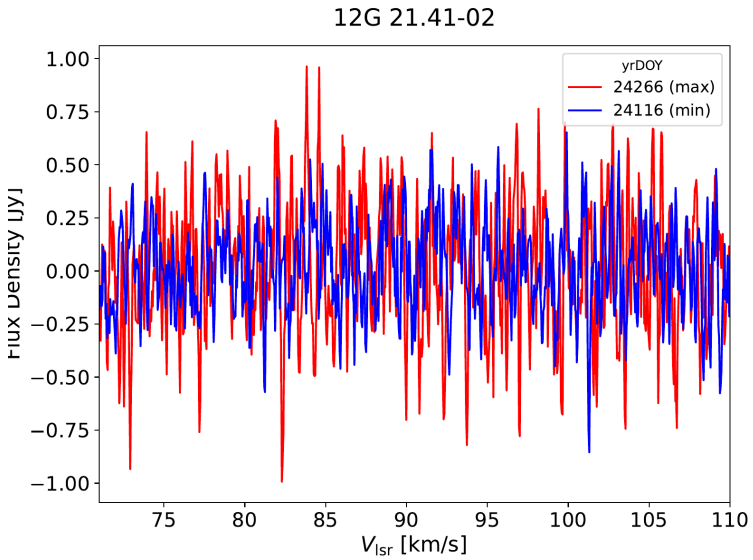
Light curve



Periodogram

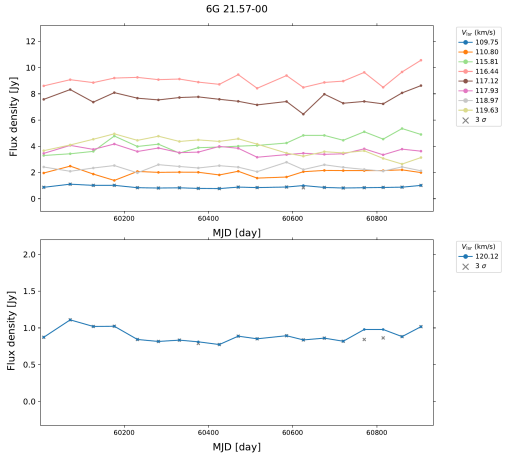


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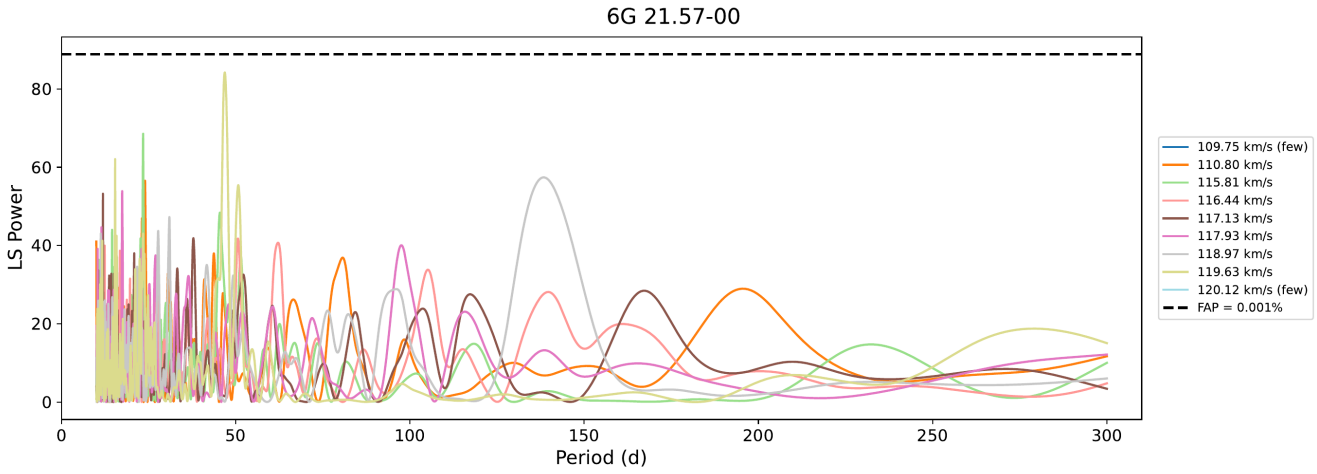


6G 21.57-00

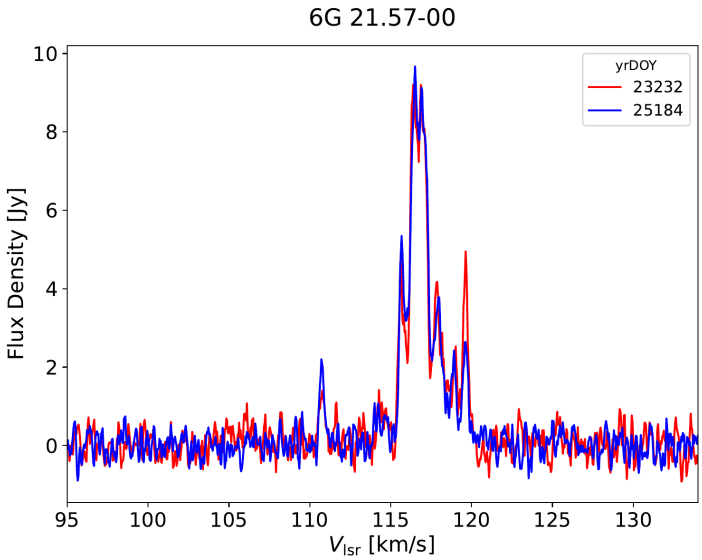
Light curve



Periodogram

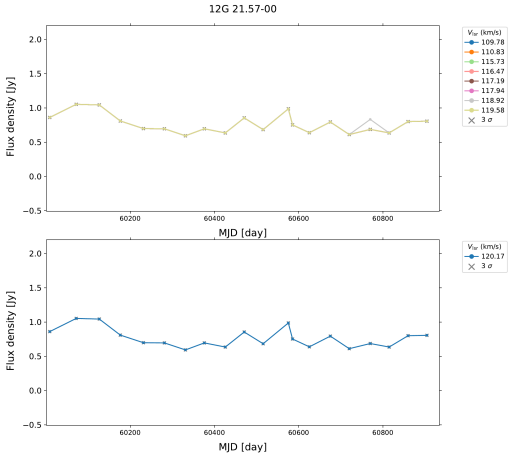


Spectrum

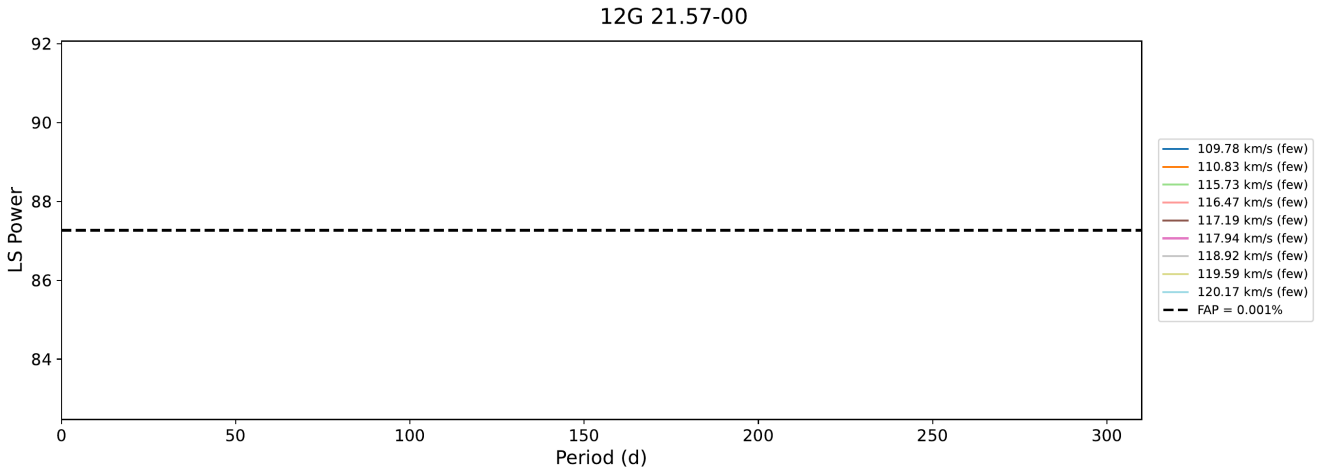


12G 21.57-00

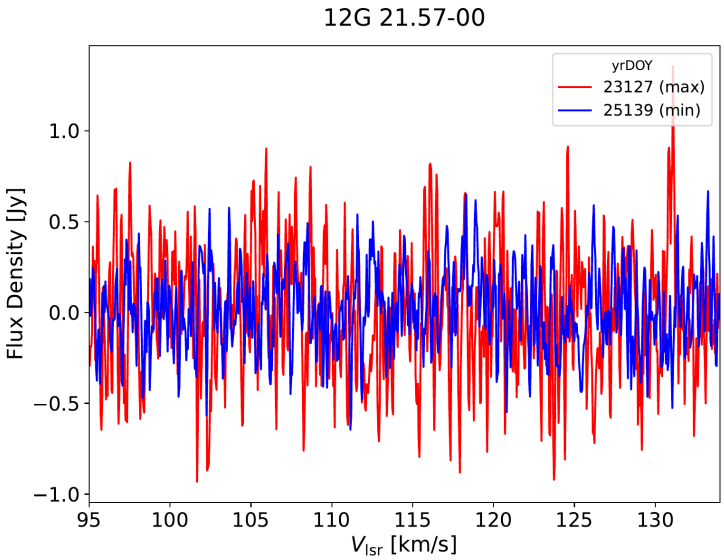
Light curve



Periodogram

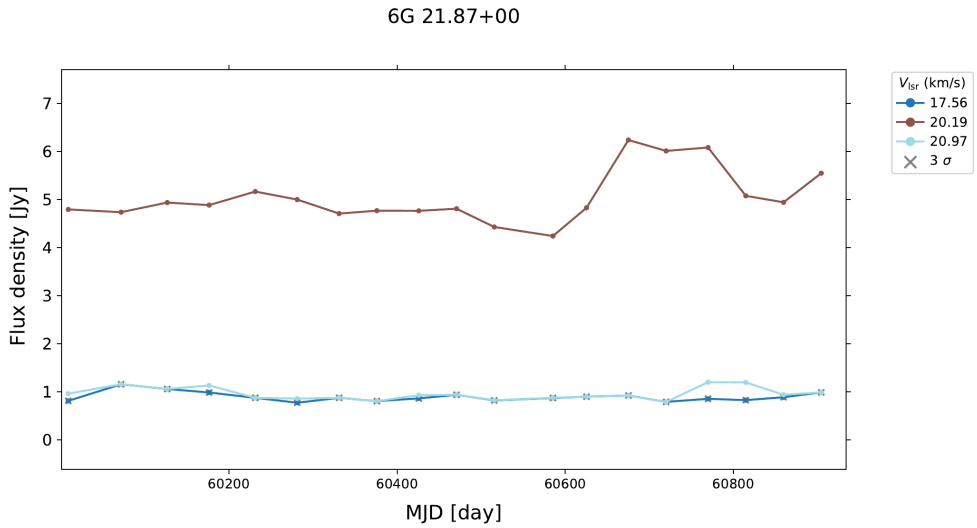


Spectrum

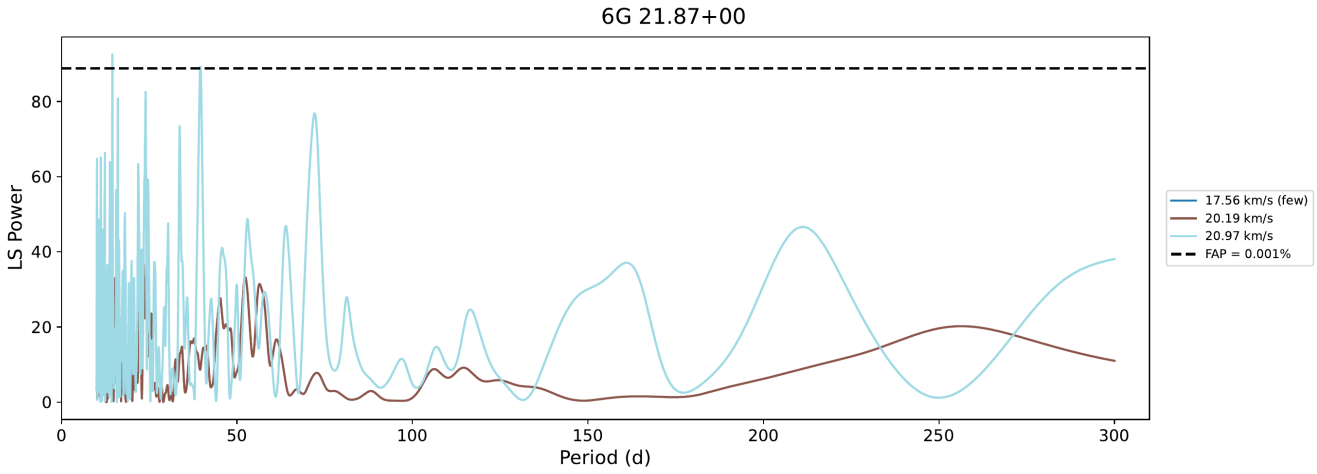


6G 21.87+00

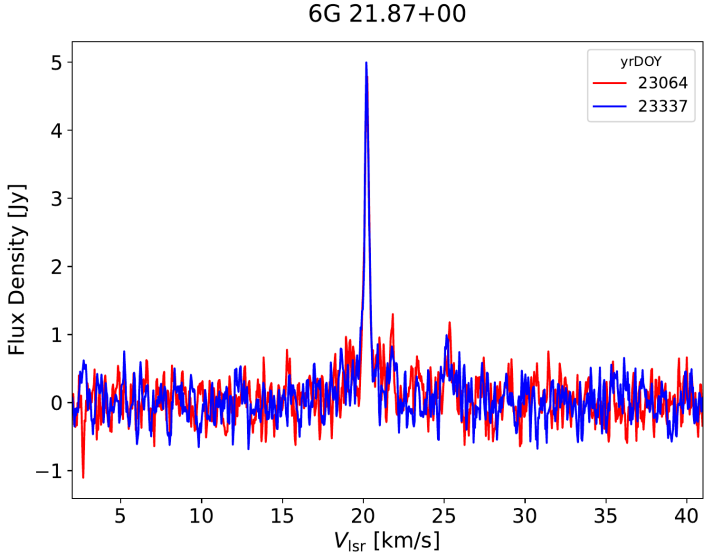
Light curve



Periodogram

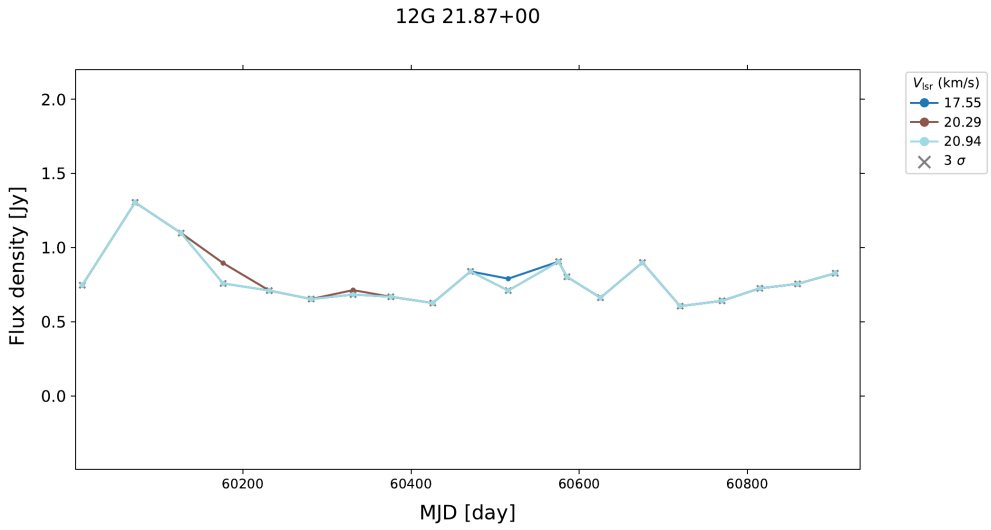


Spectrum

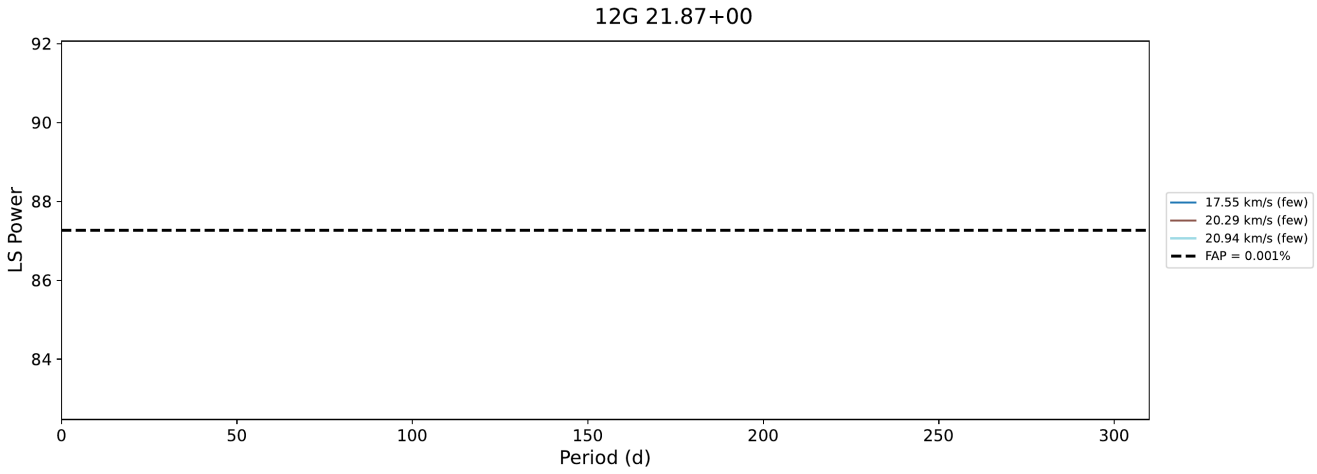


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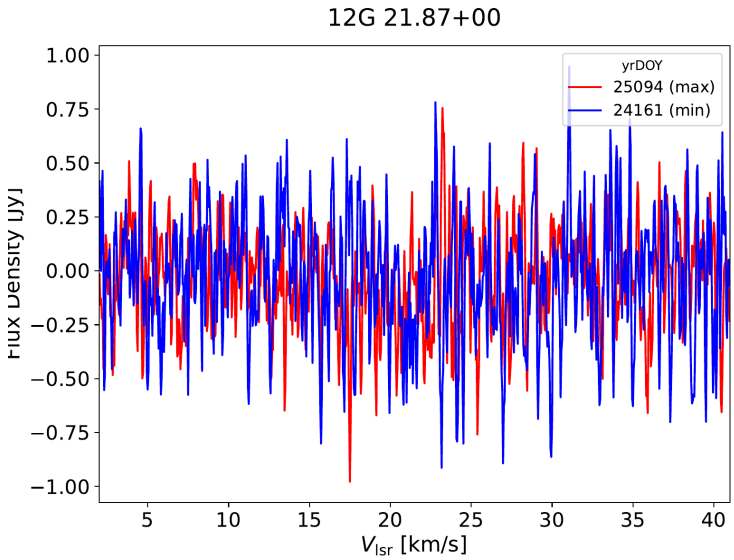
Light curve



Periodogram

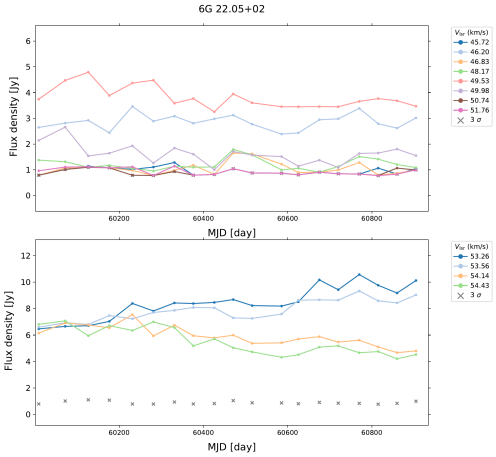


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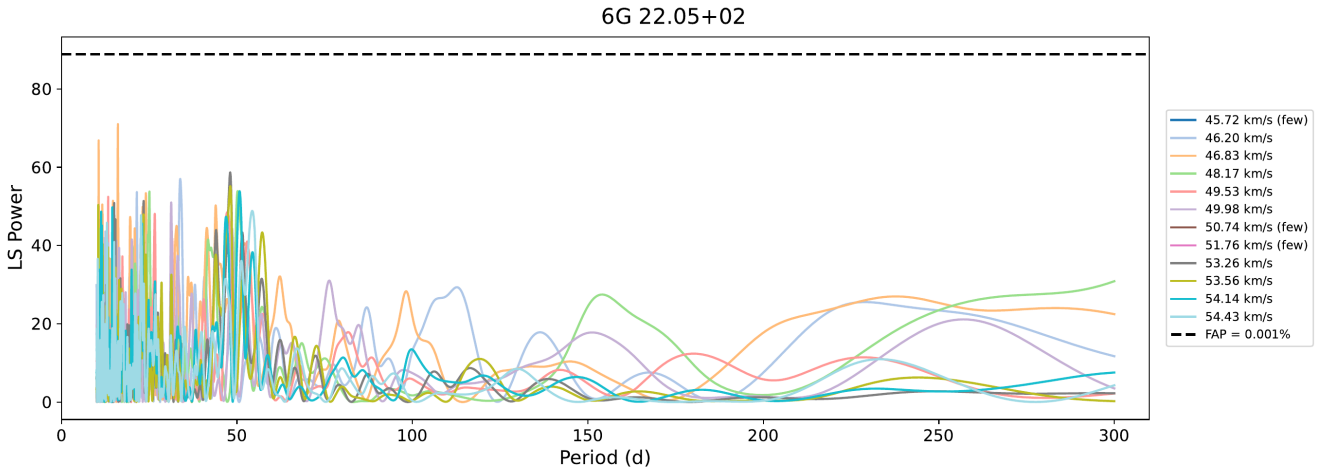


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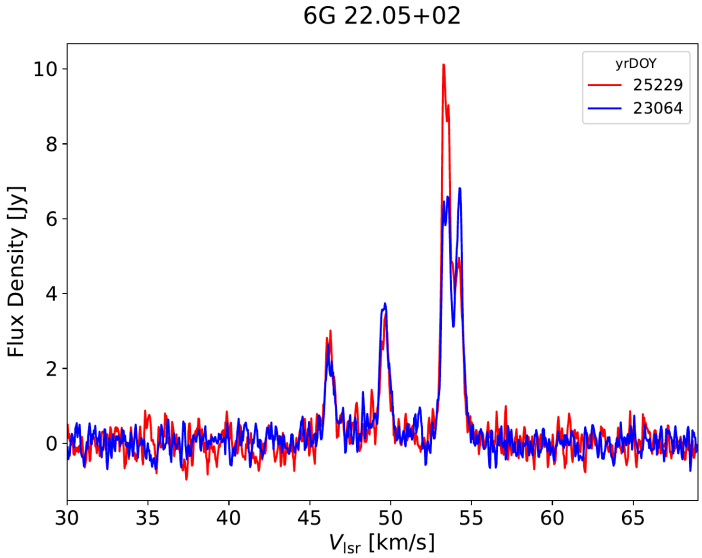
Light curve



Periodogram

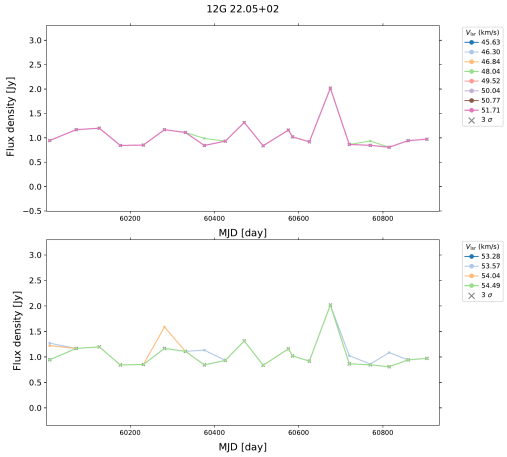


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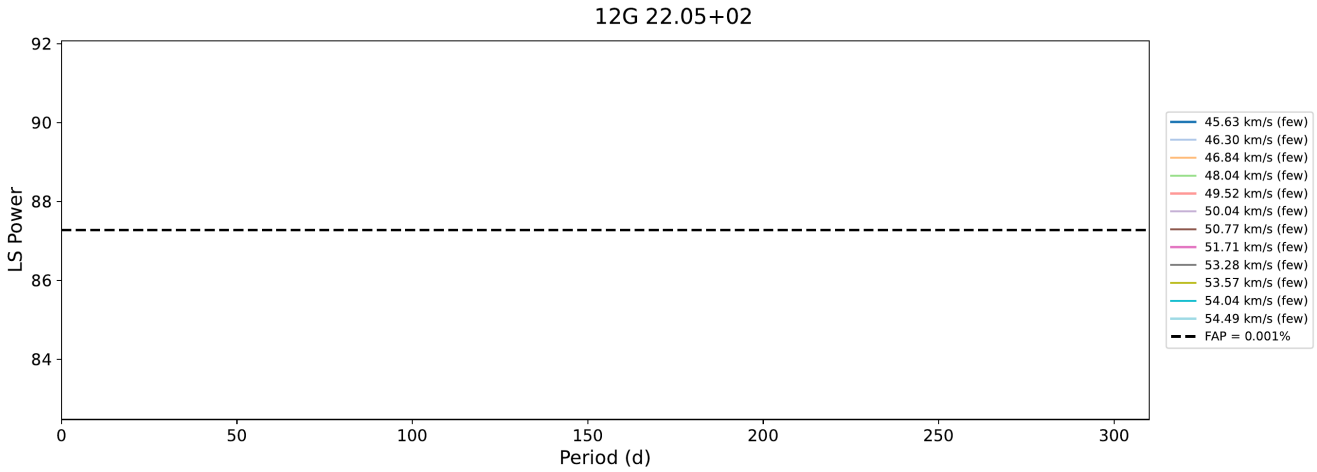


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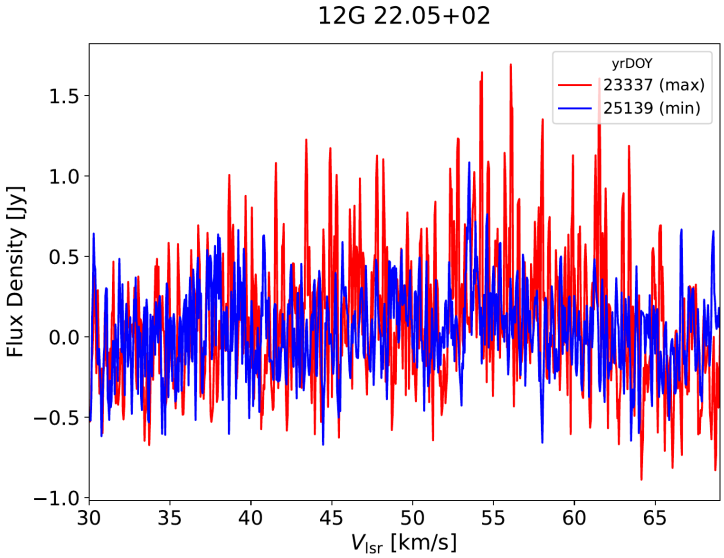
Light curve



Periodogram

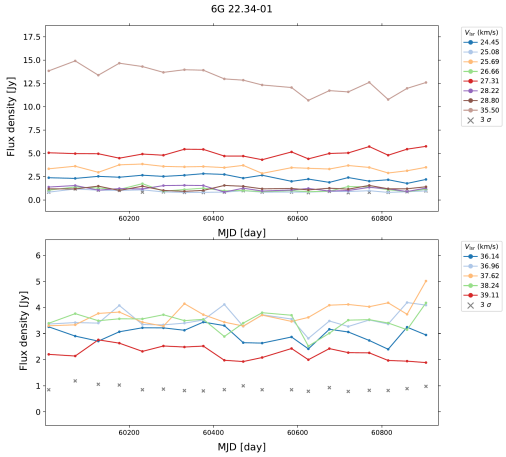


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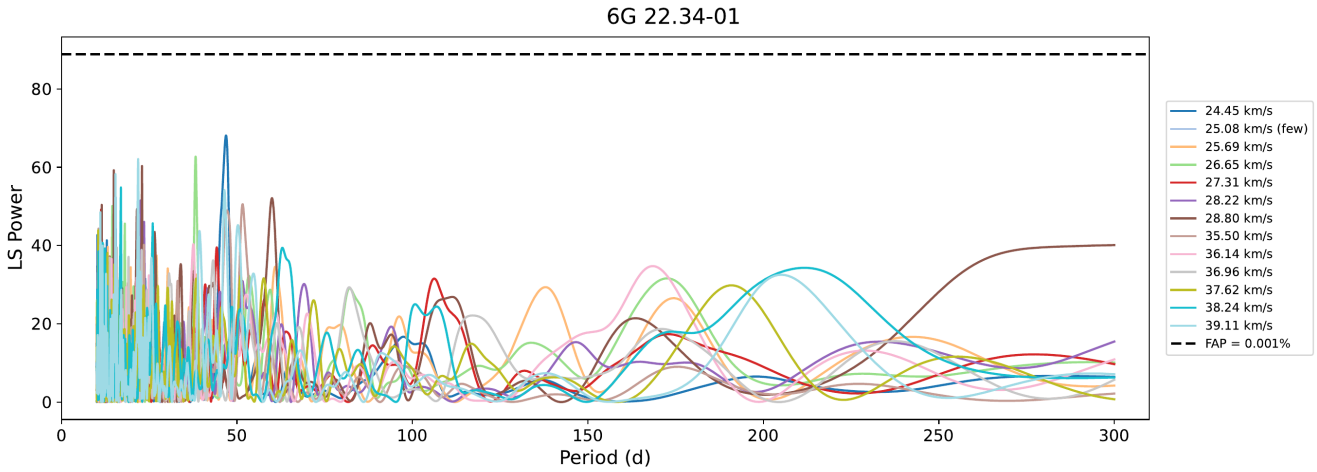


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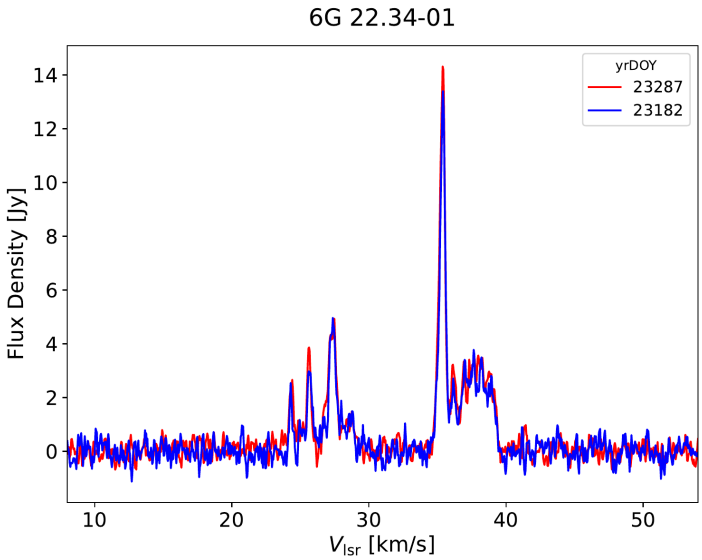
Light curve



Periodogram

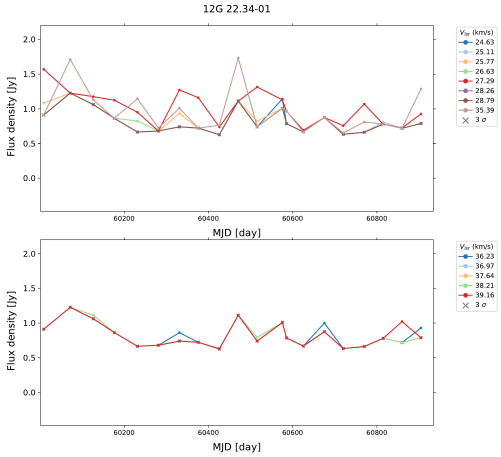


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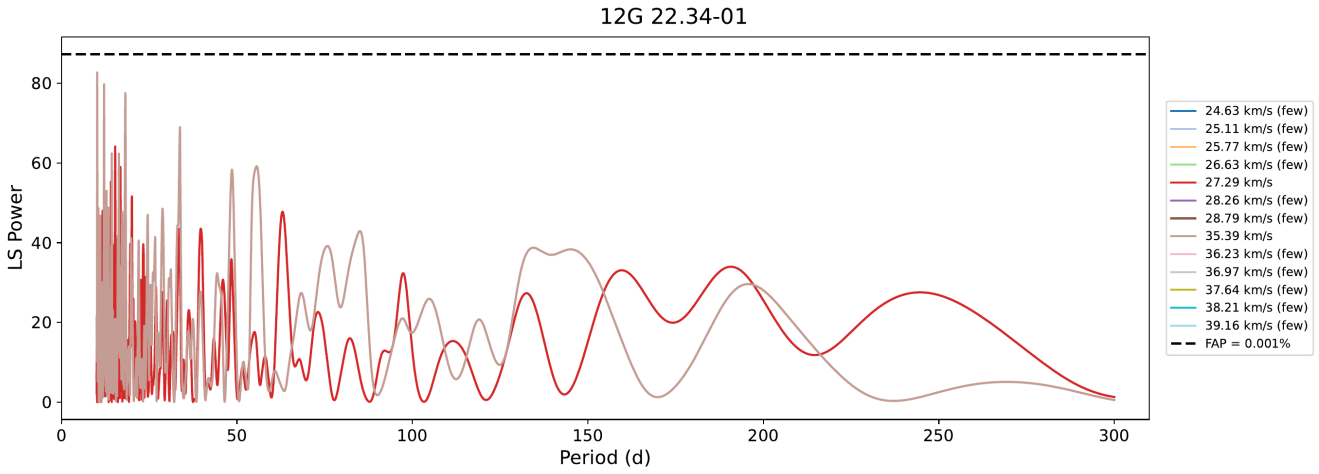


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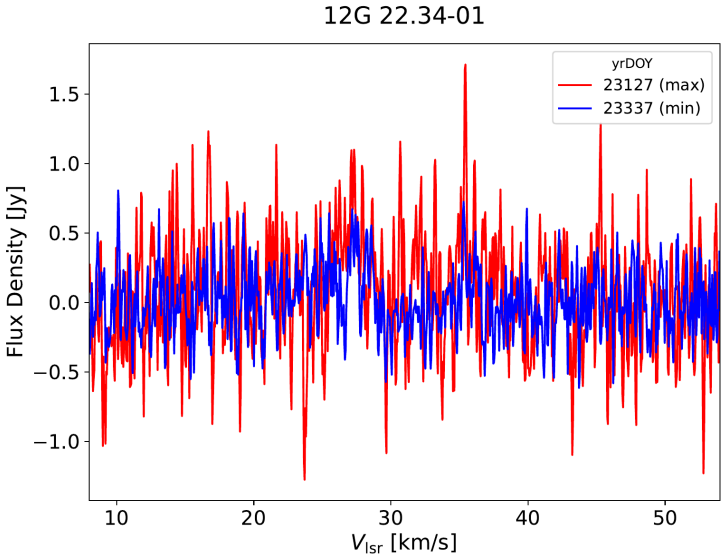
Light curve



Periodogram

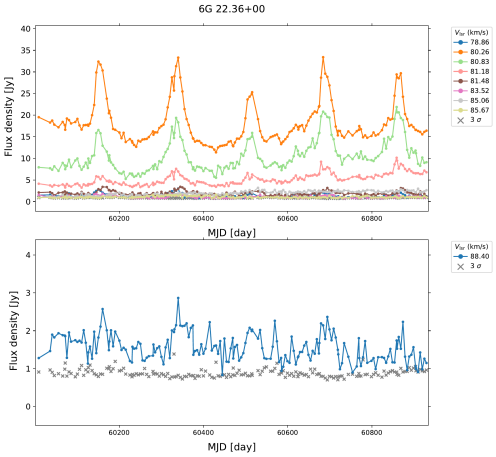


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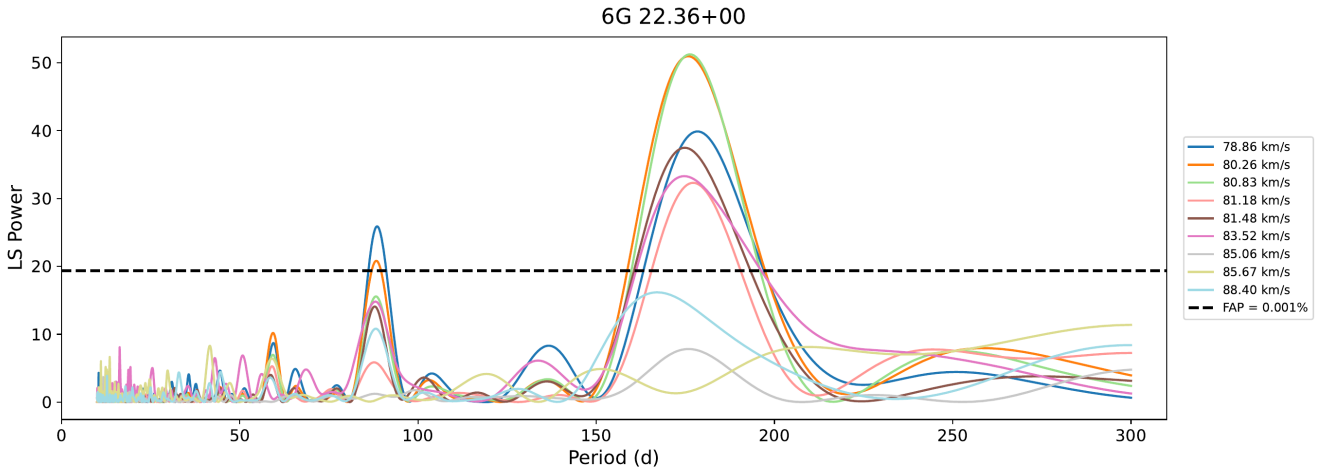


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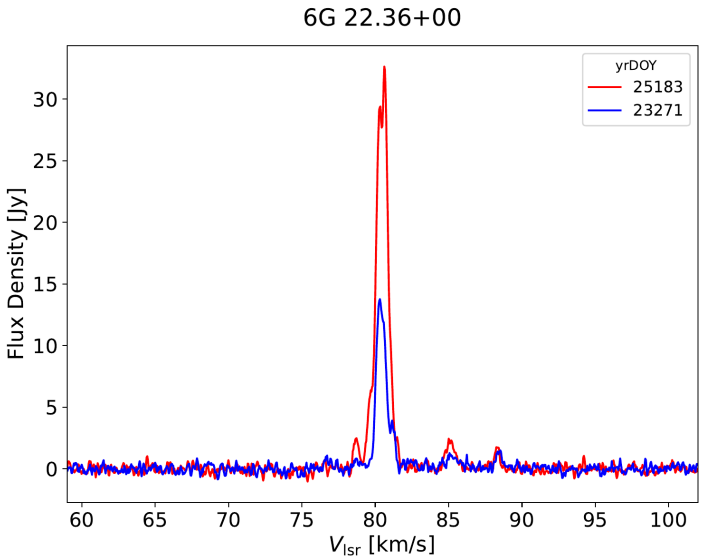
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Periodogram

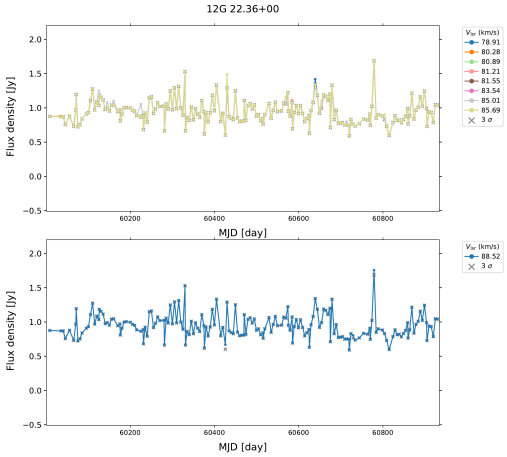


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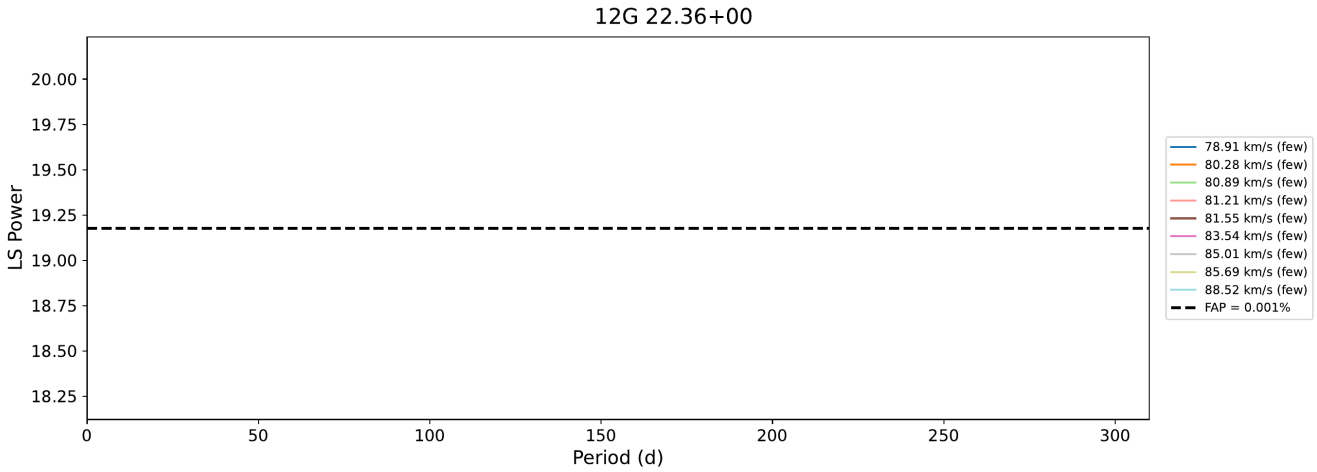


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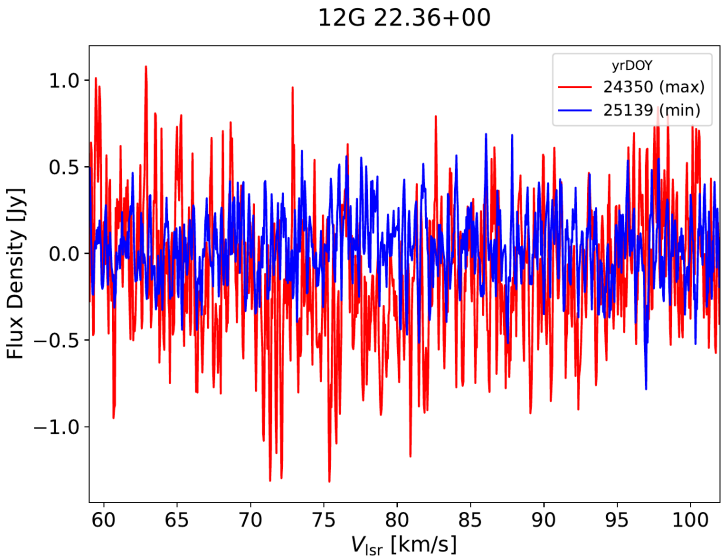
Light curve



Periodogram



Spectrum

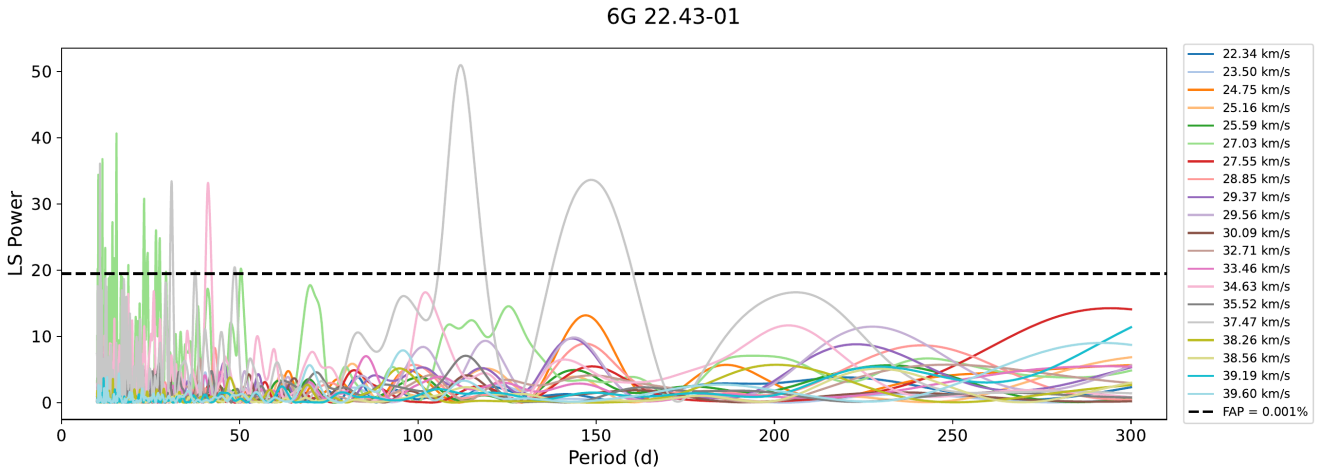


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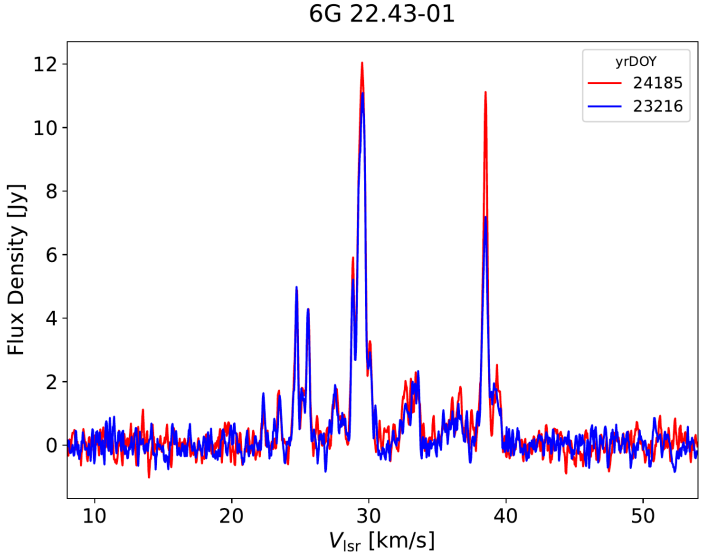
Light curve



Periodogram

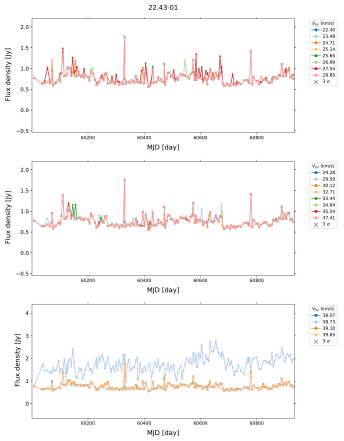


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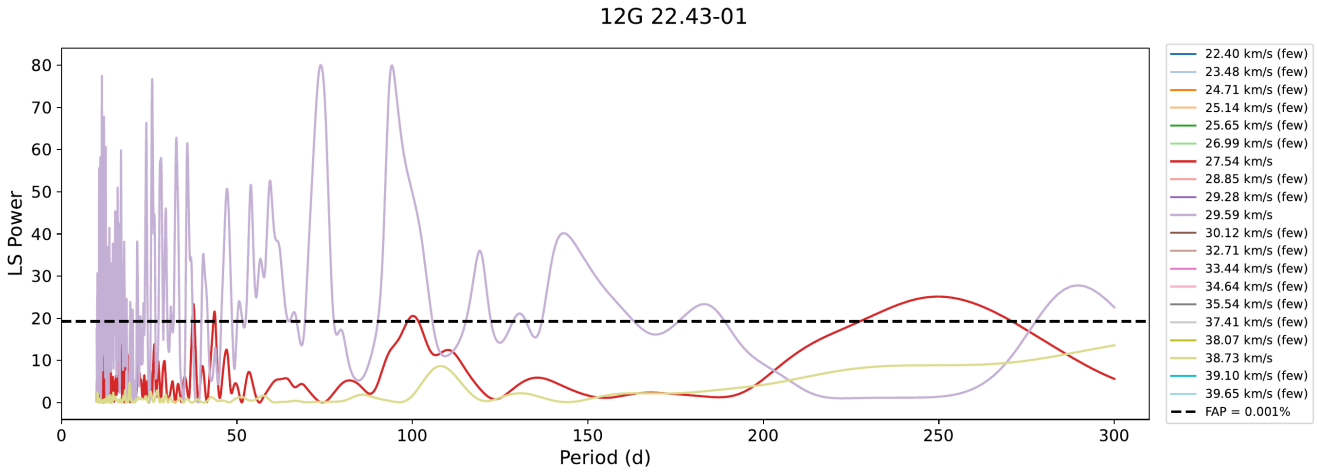


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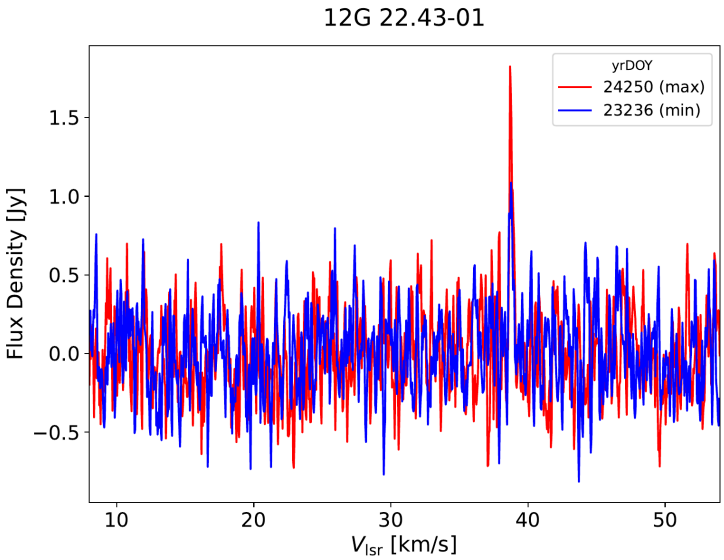
Light curve



Periodogram

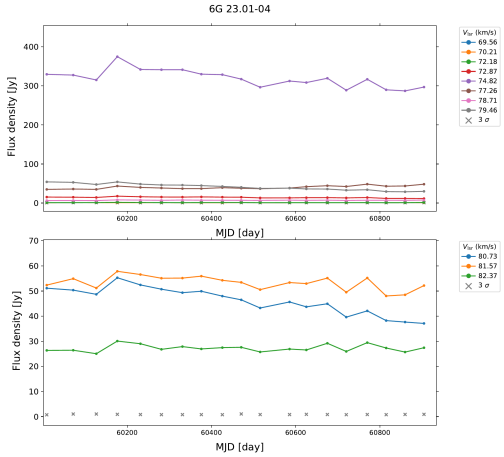


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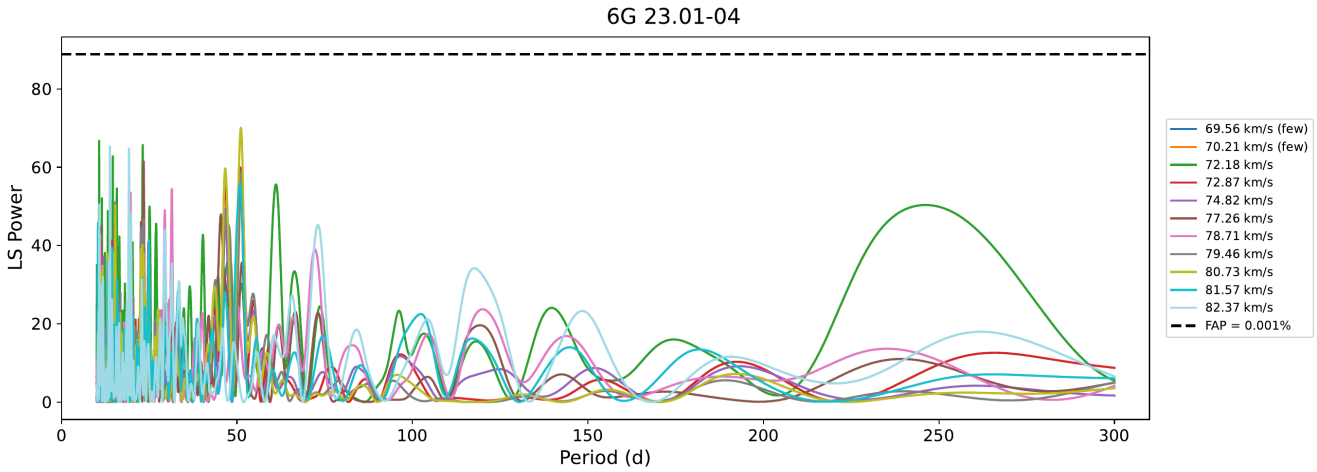


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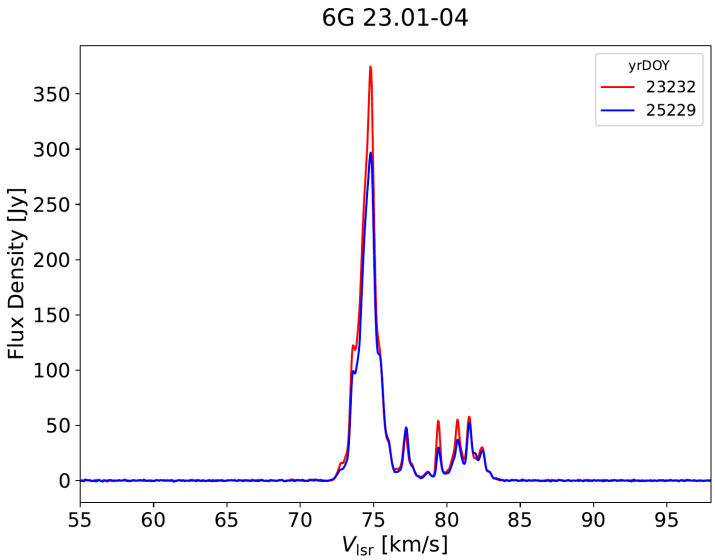
Light curve



Periodogram

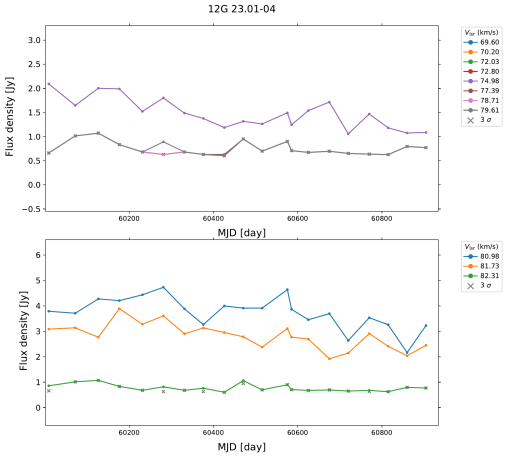


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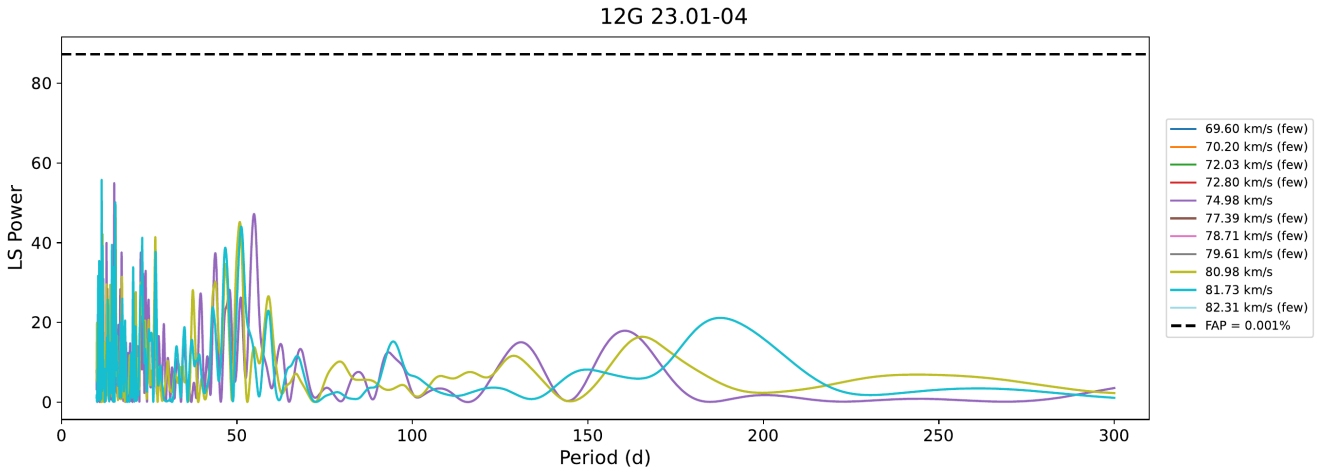


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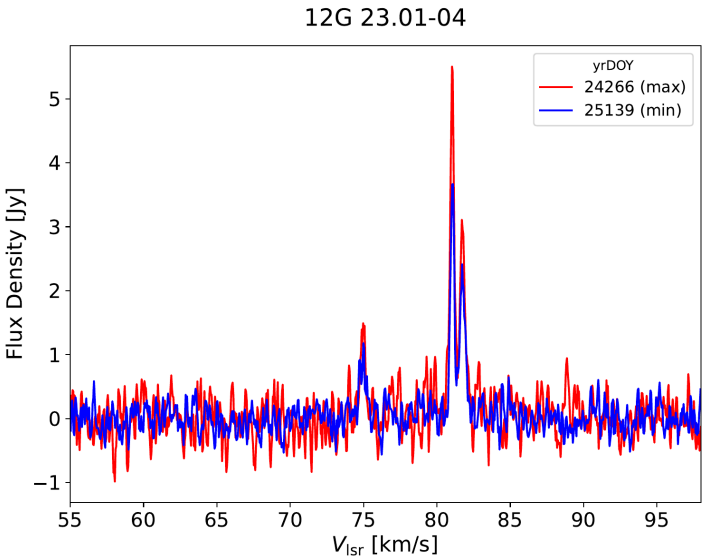
Light curve



Periodogram

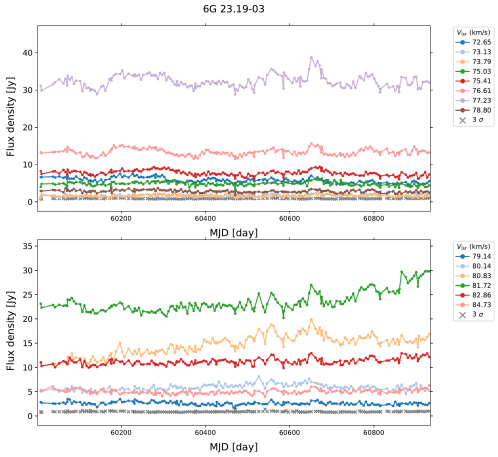


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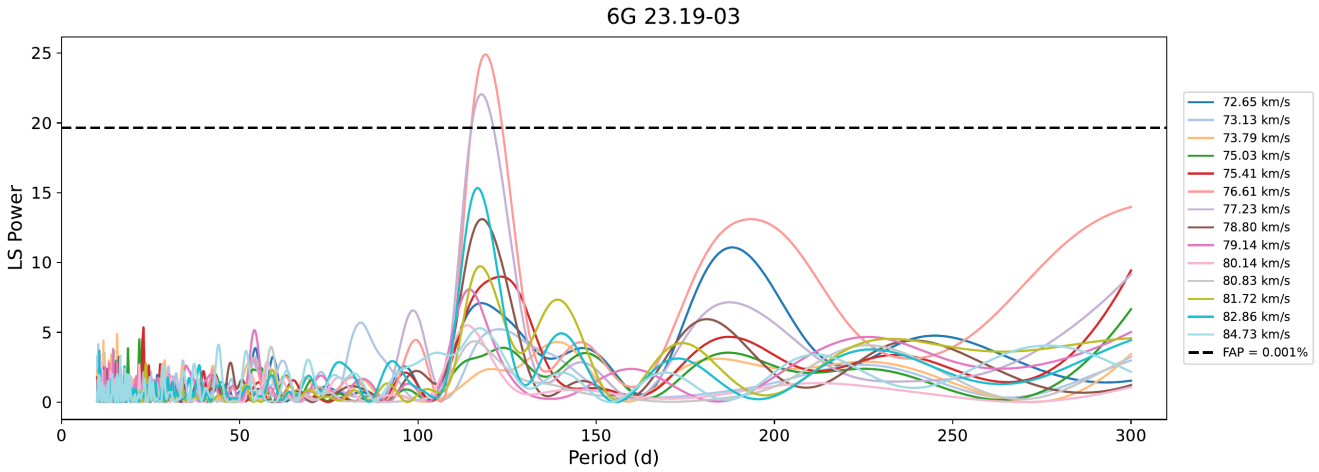


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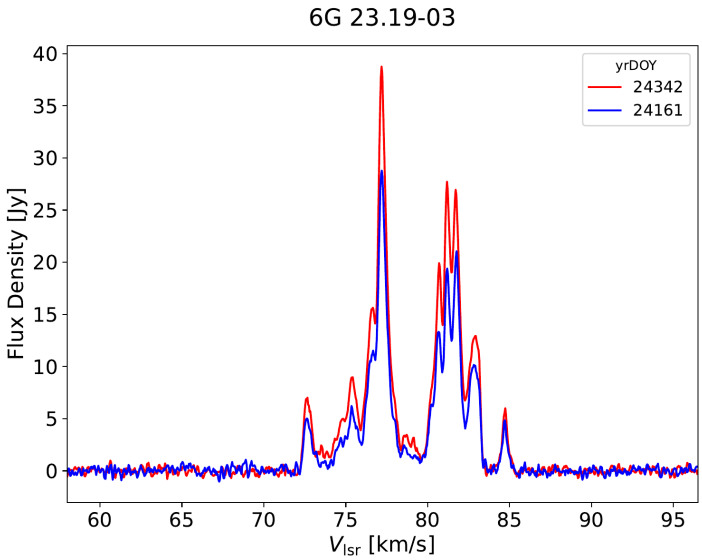
Light curve



Periodogram

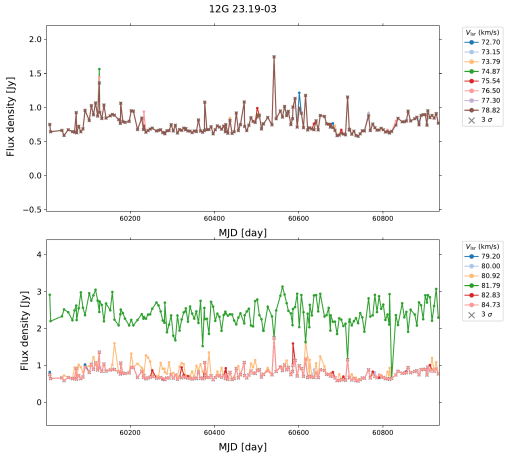


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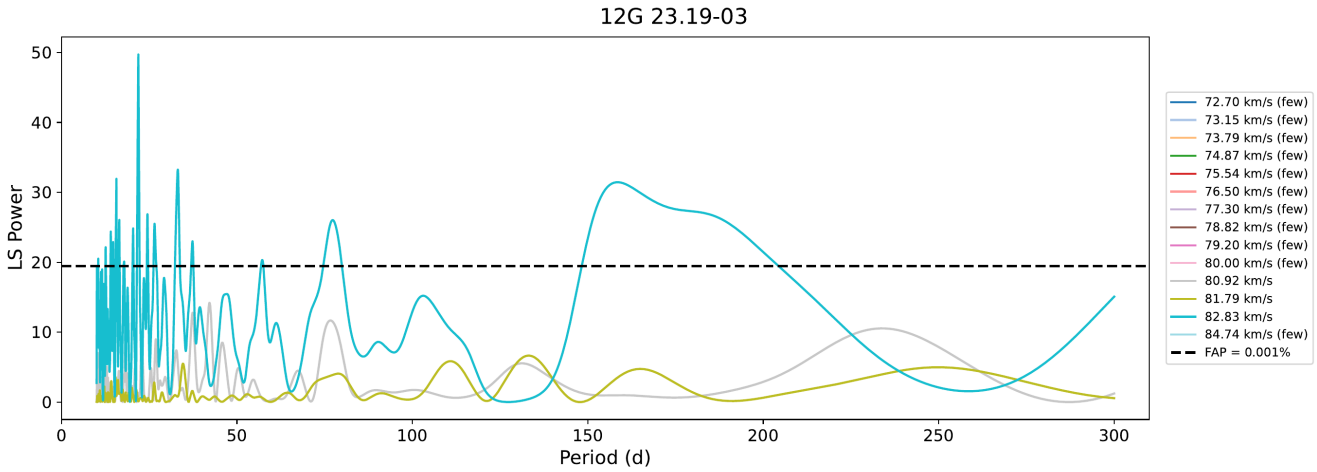


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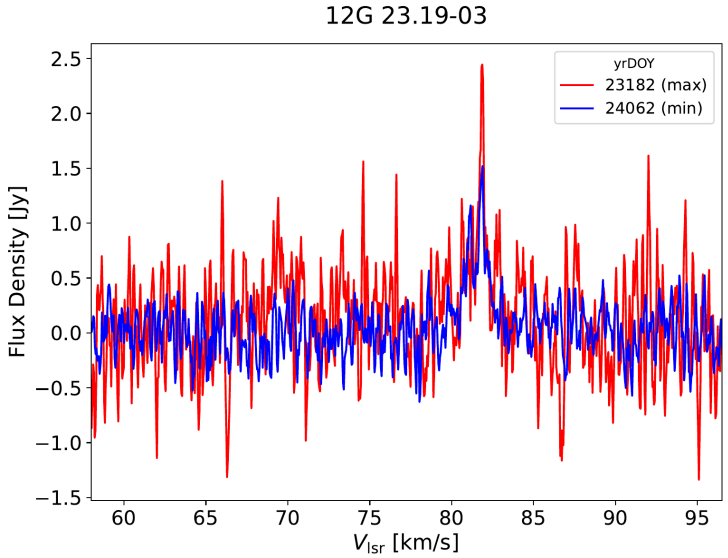
Light curve



Periodogram

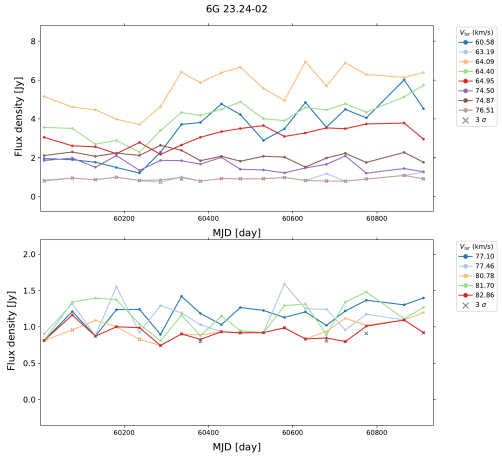


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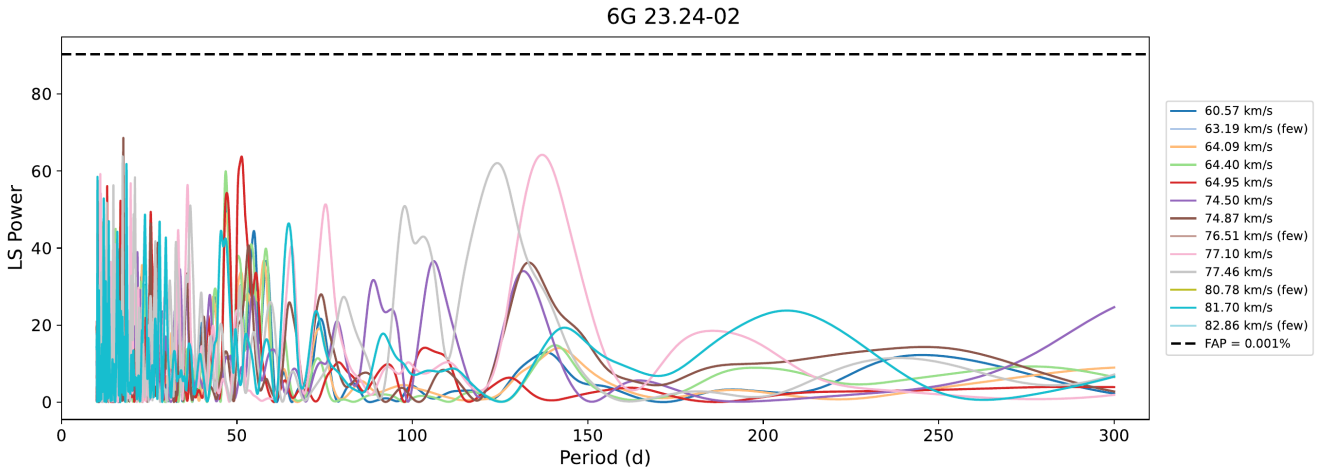


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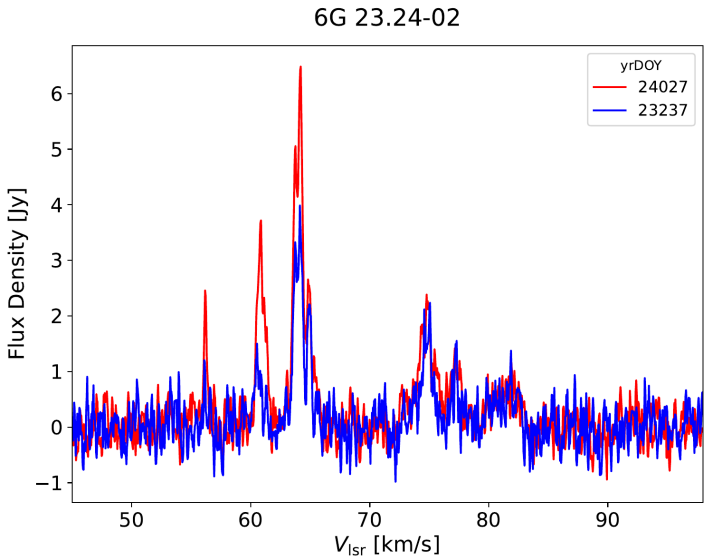
Light curve



Periodogram

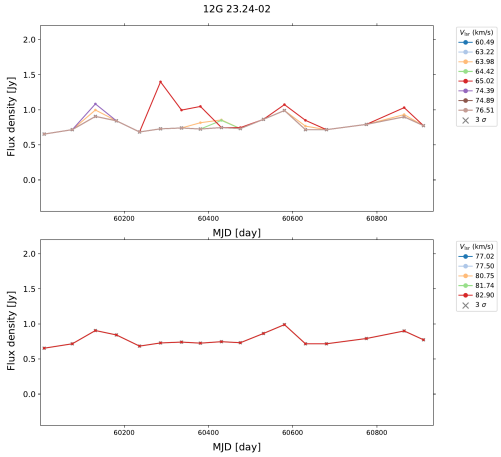


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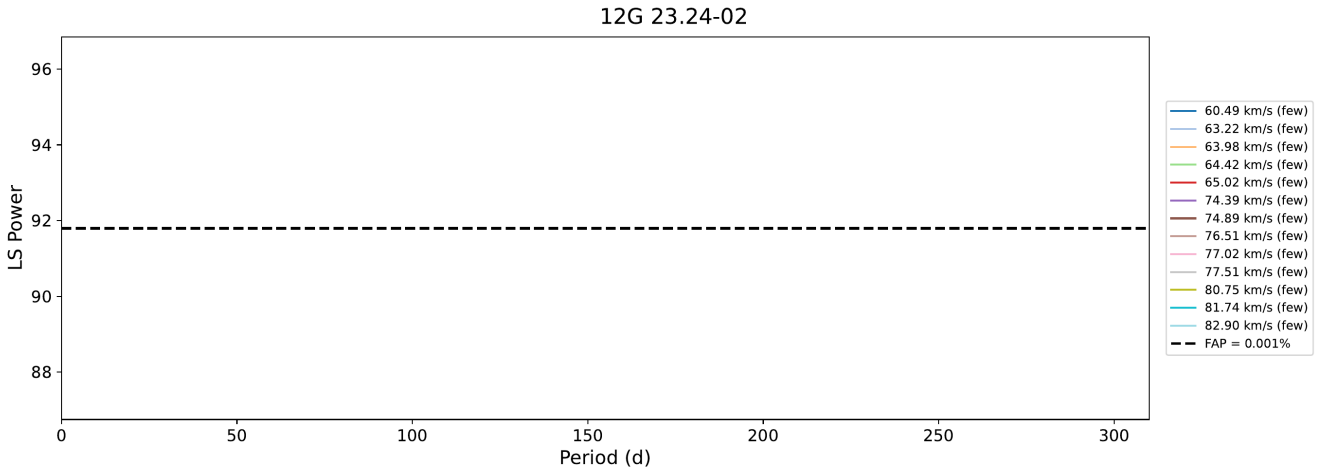


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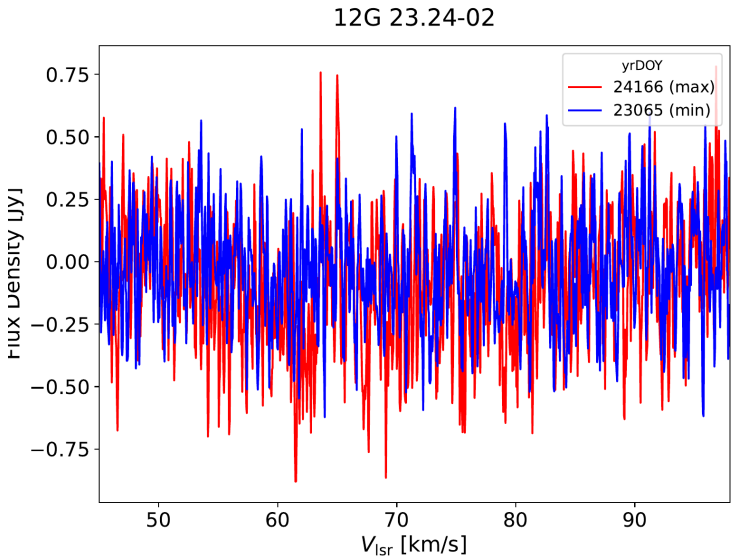
Light curve



Periodogram

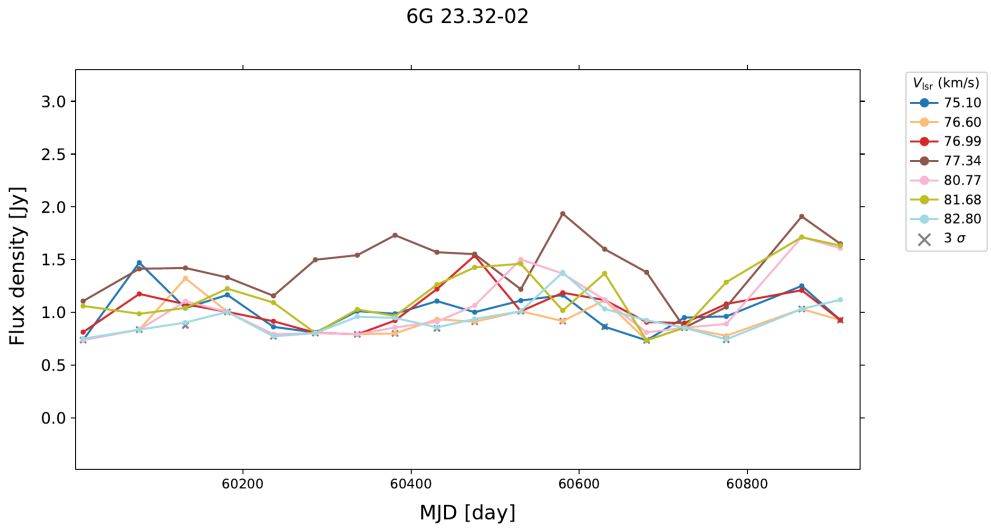


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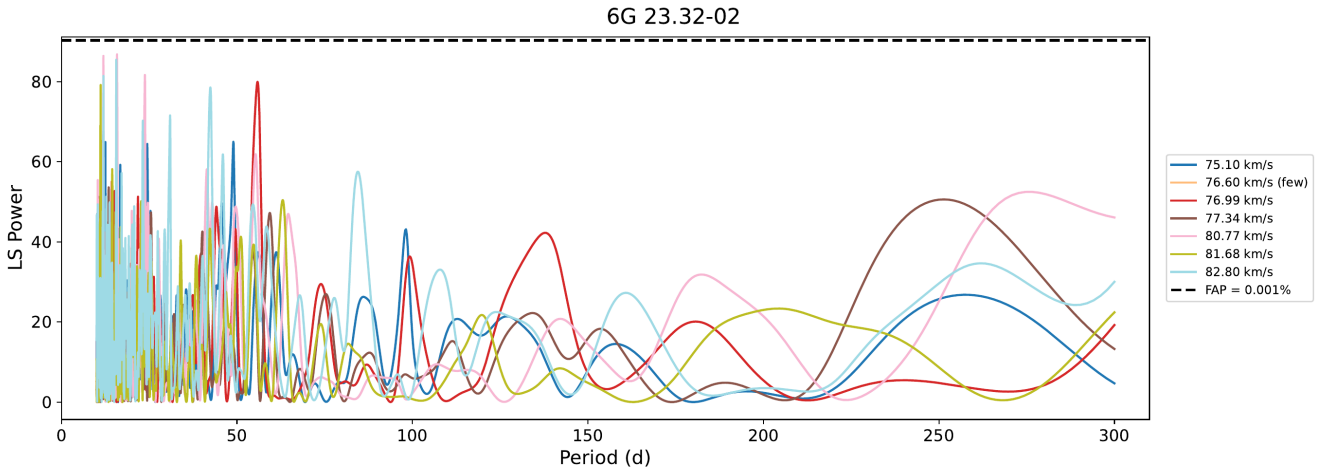


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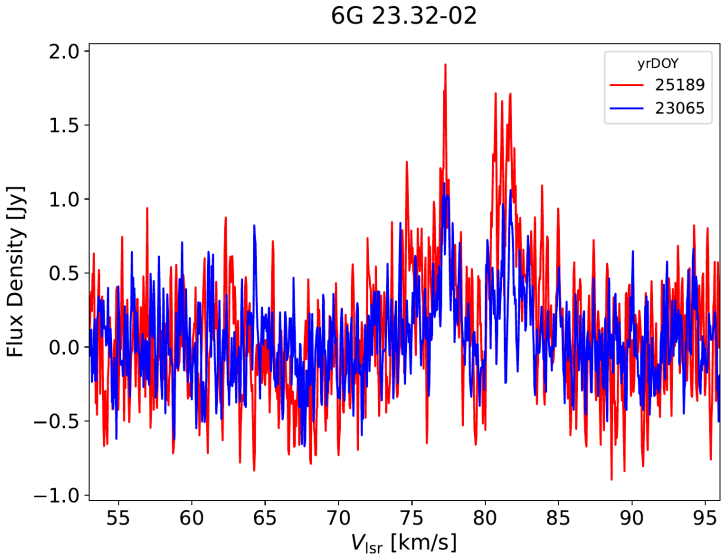
Light curve



Periodogram

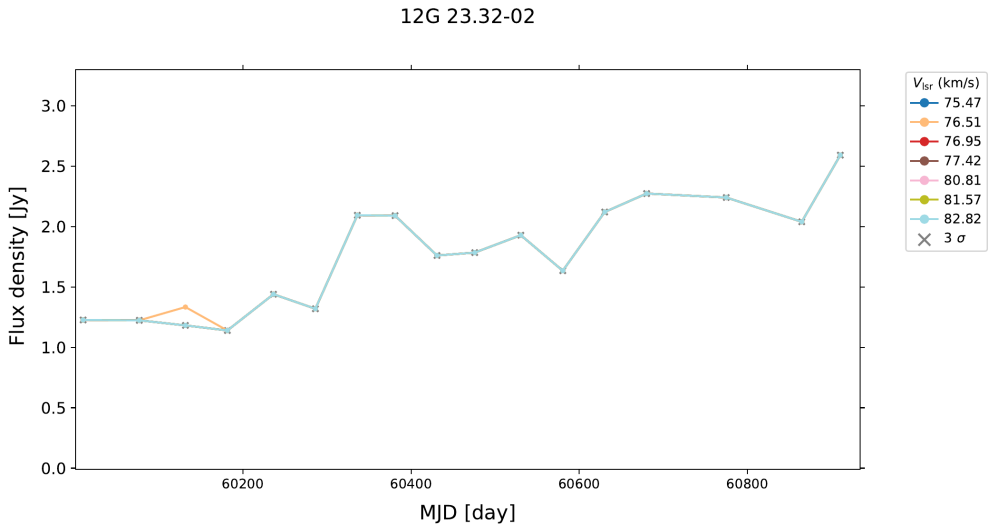


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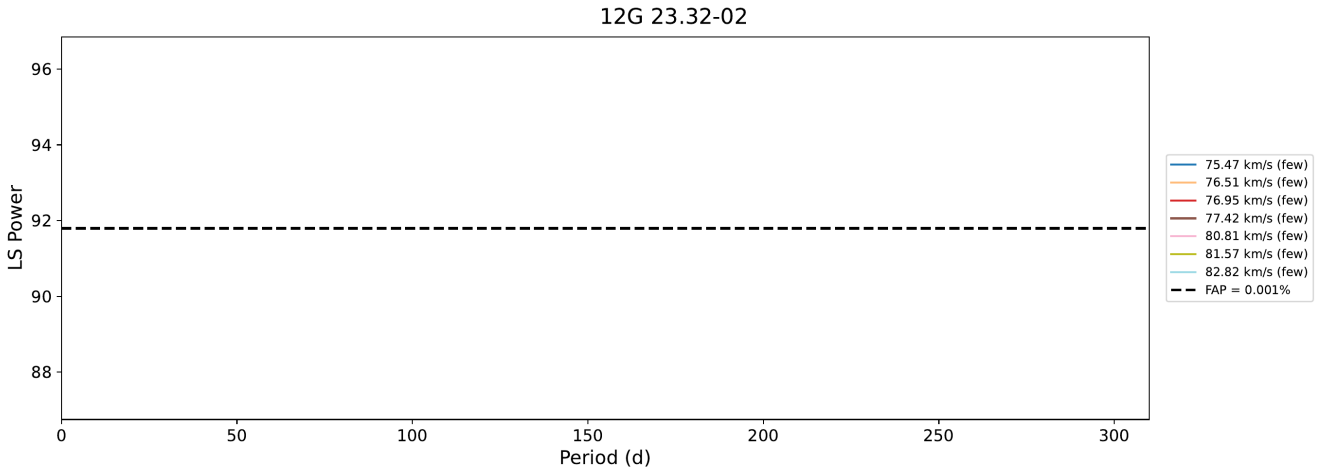


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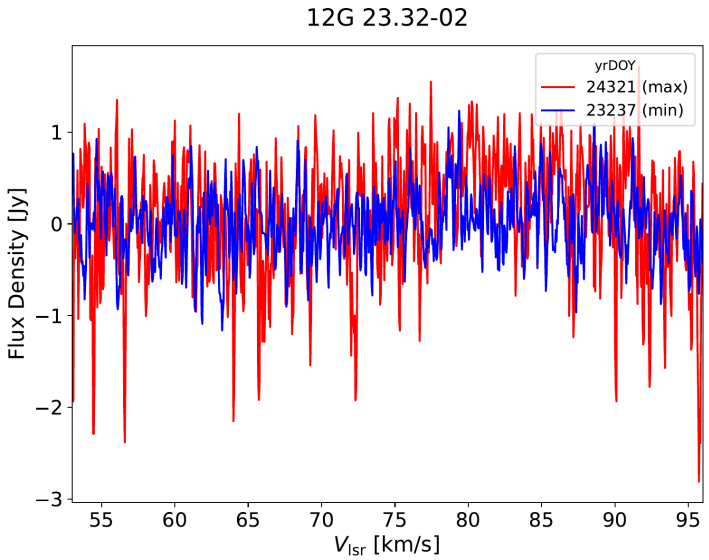
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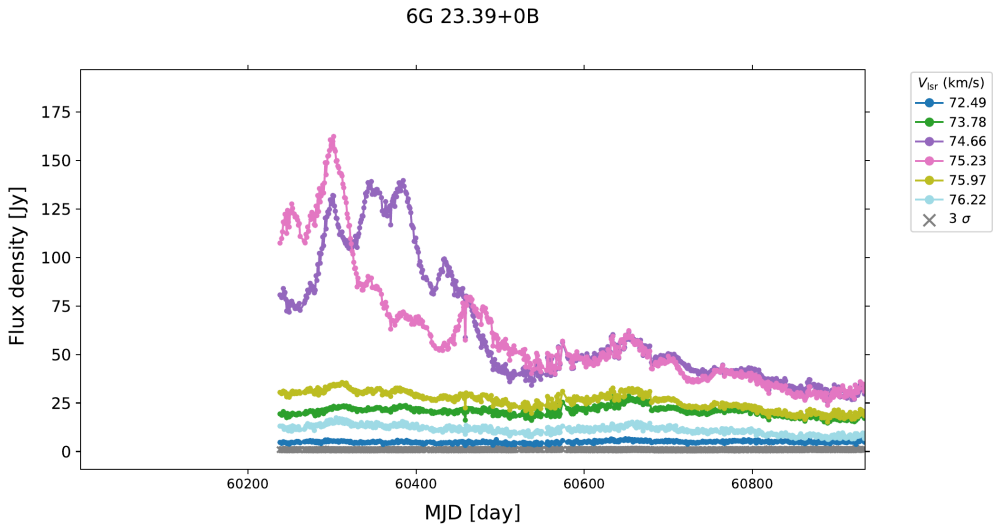


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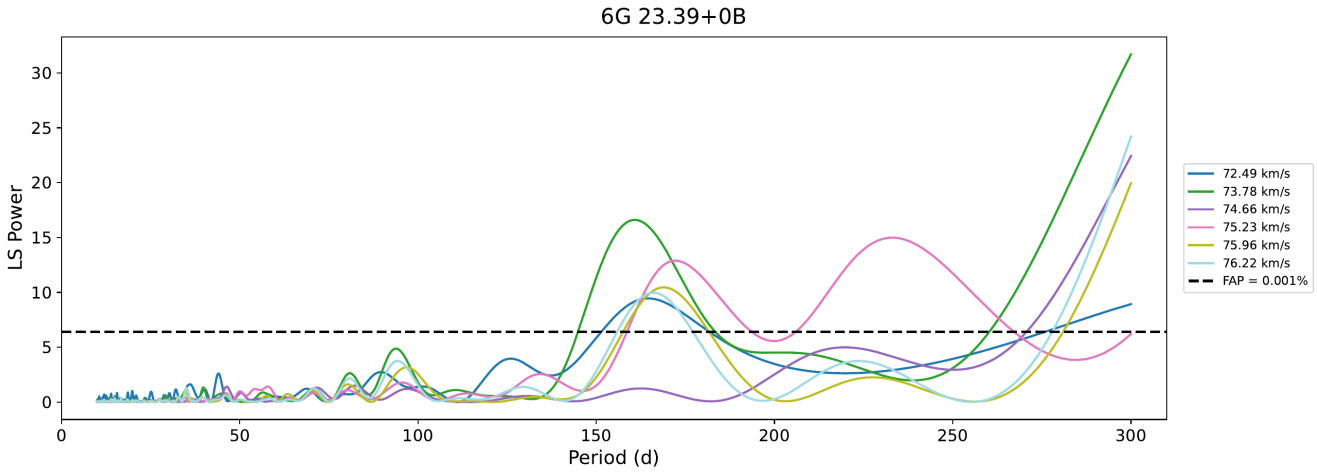


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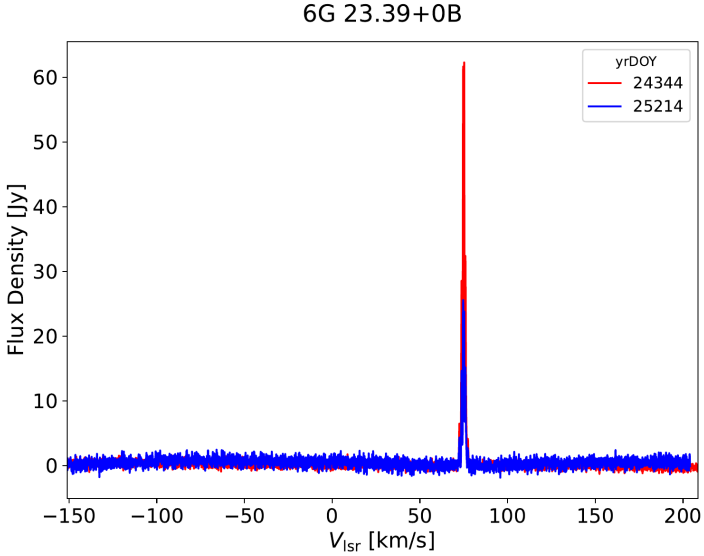
Light curve



Periodogram

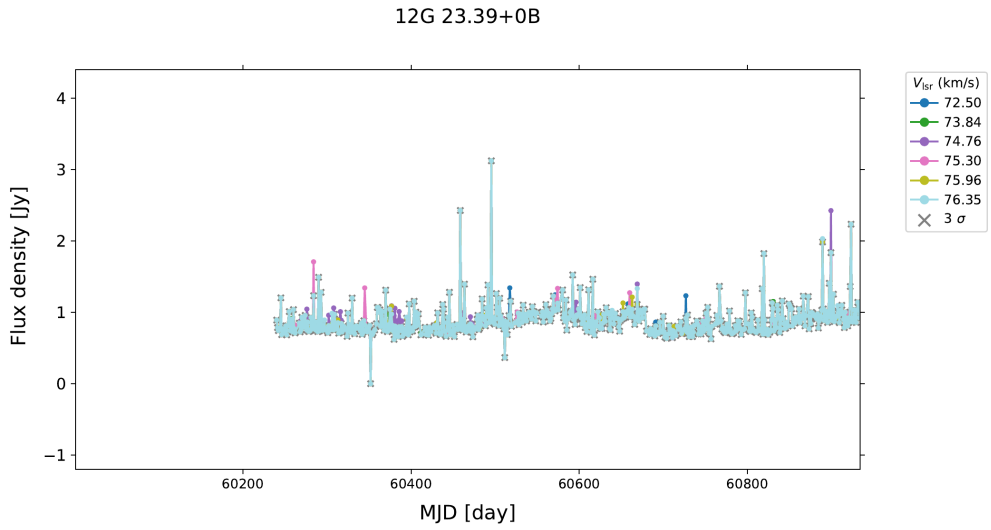


Spectrum

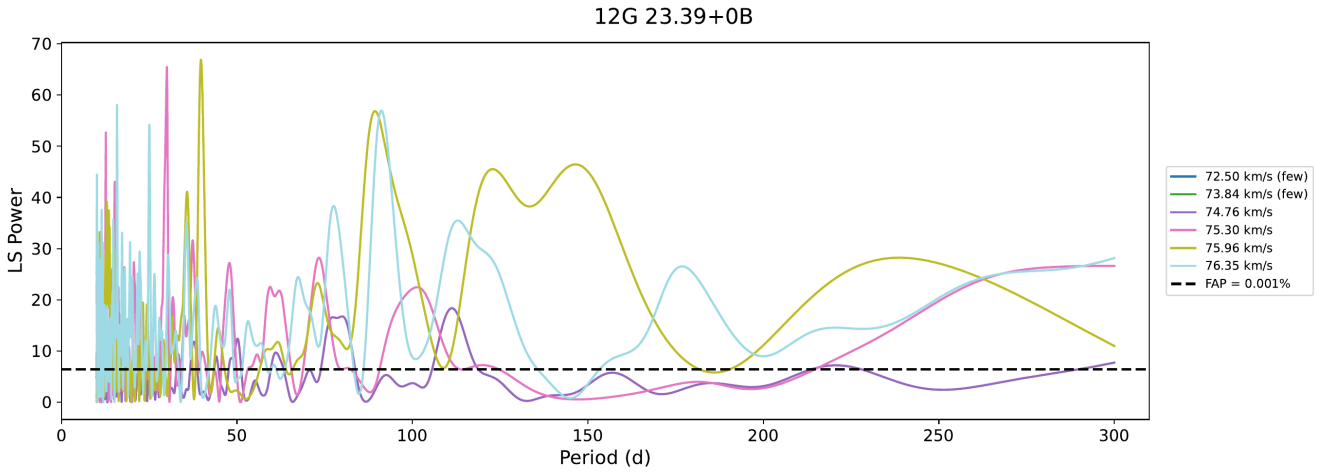


12G 23.39+0B

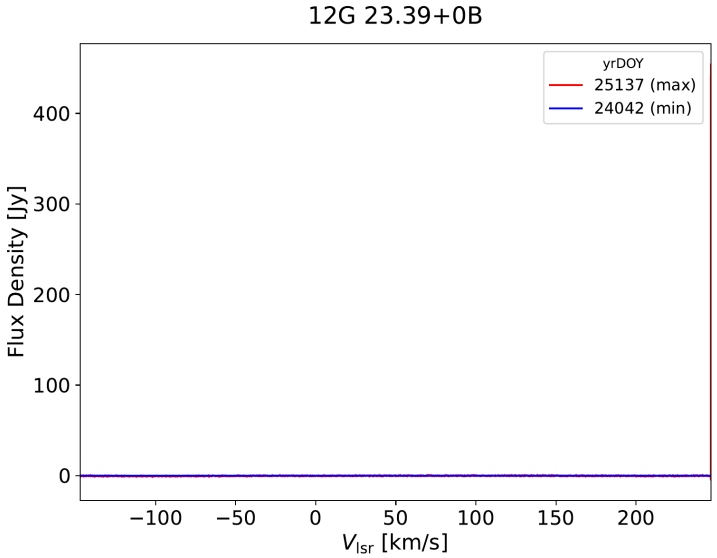
Light curve



Periodogram

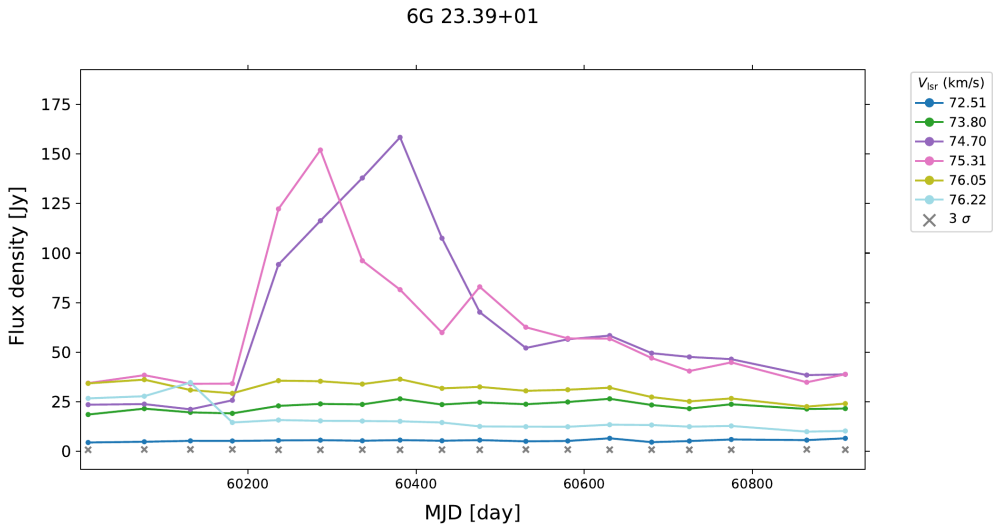


Spectrum

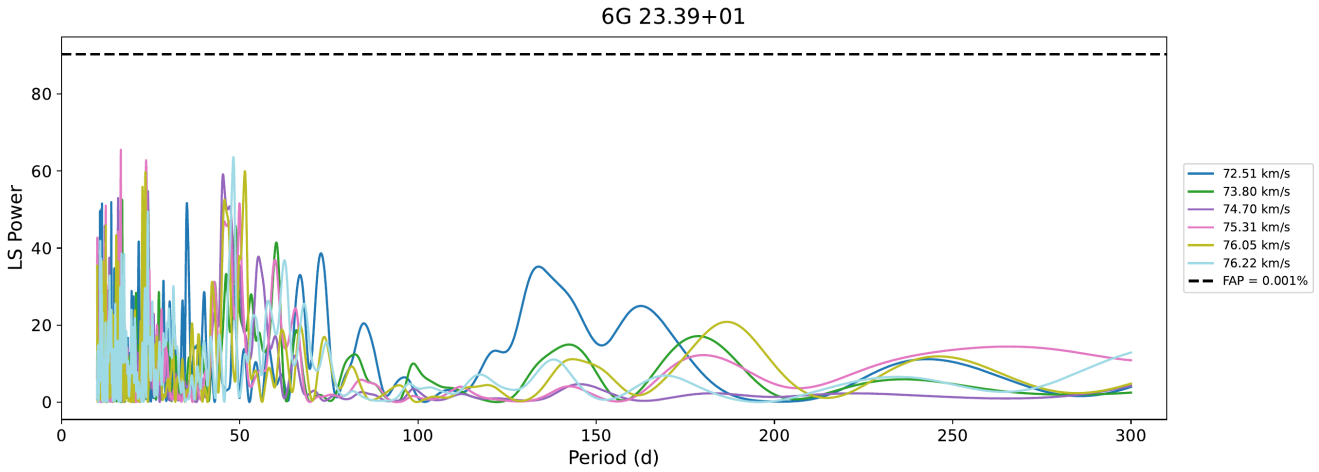


6G 23.39+01

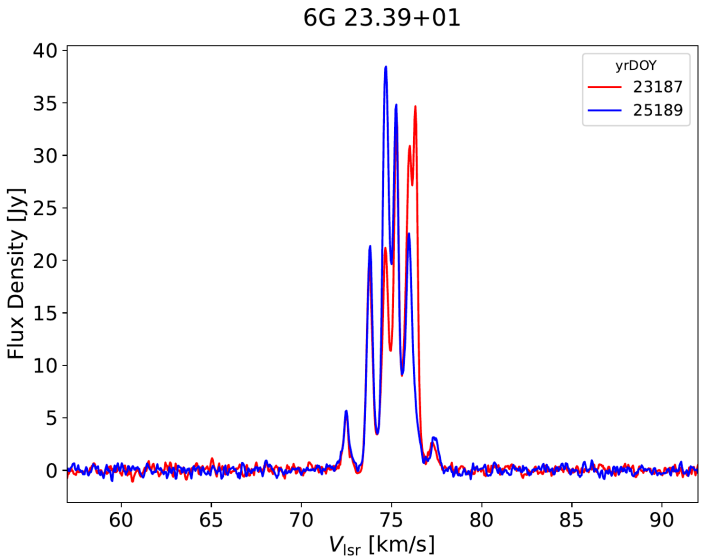
Light curve



Periodogram

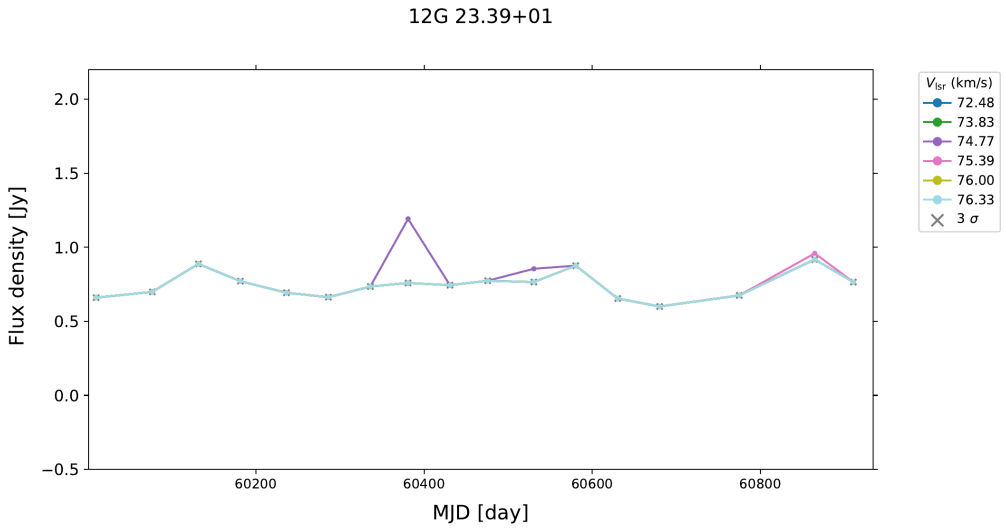


Spectrum

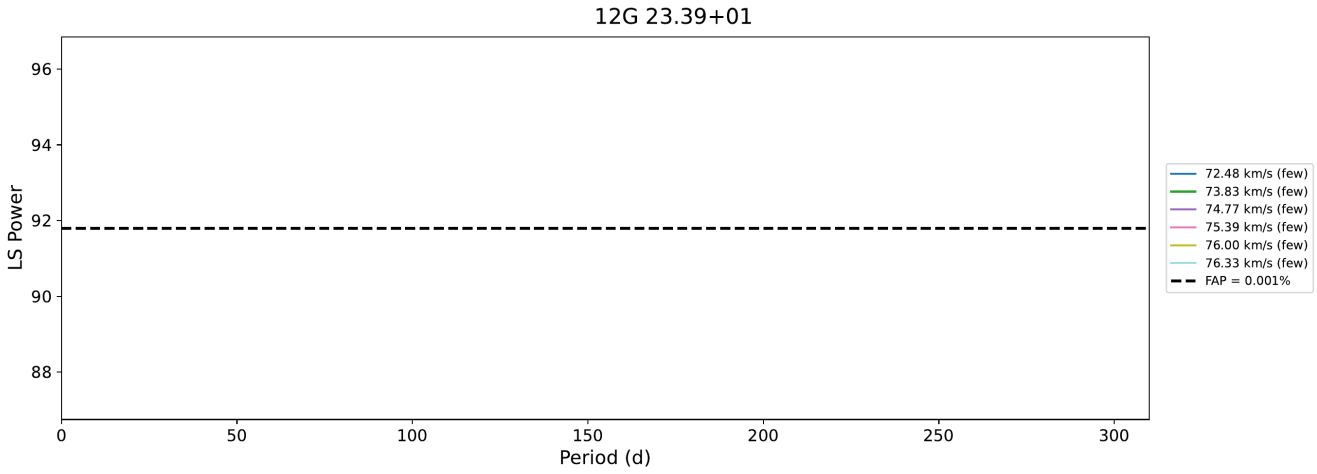


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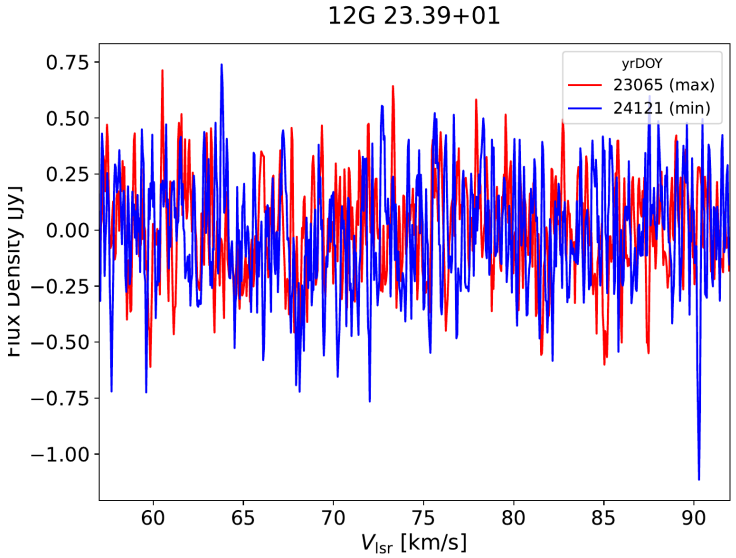
Light curve



Periodogram

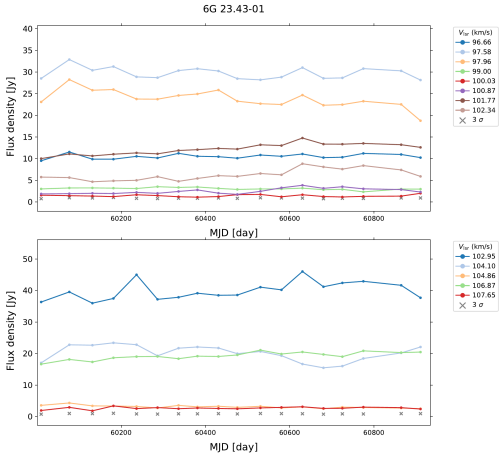


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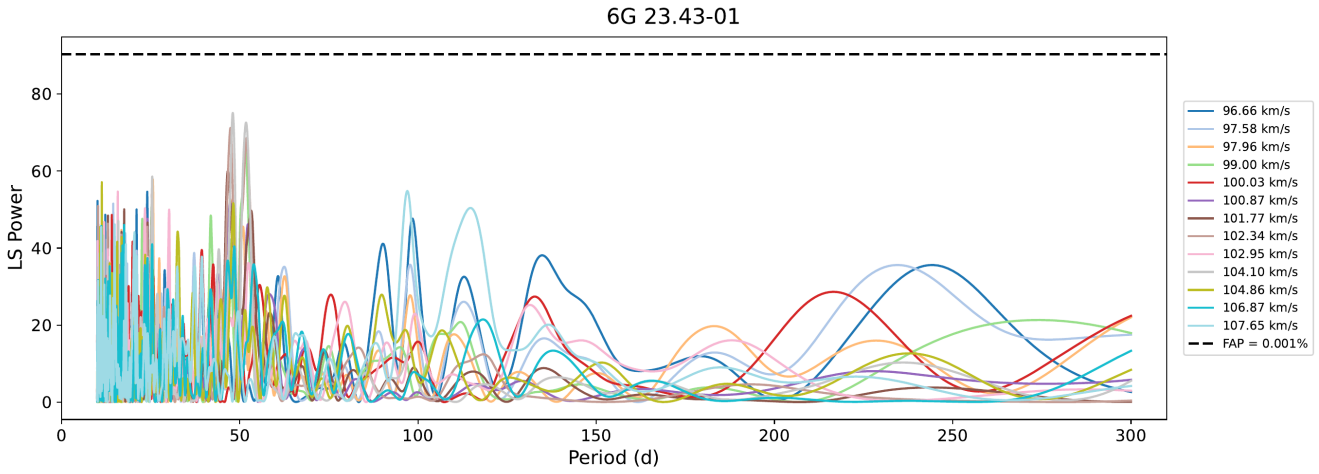


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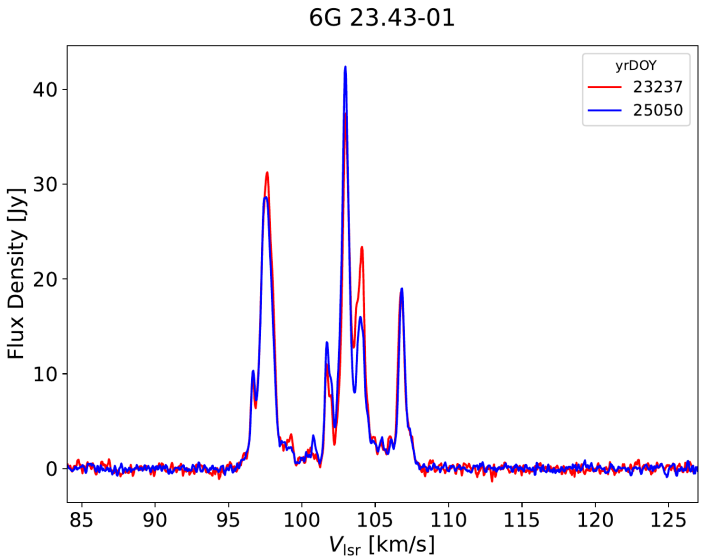
Light curve



Periodogram

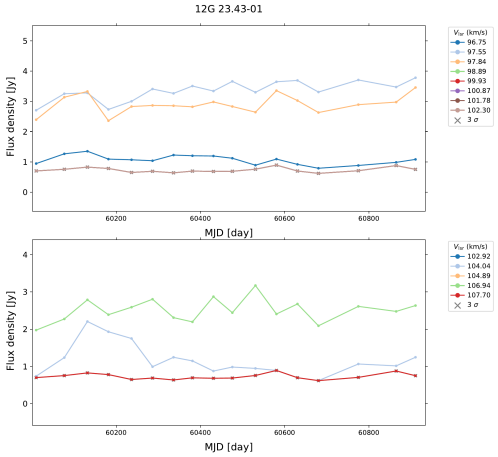


Spectrum

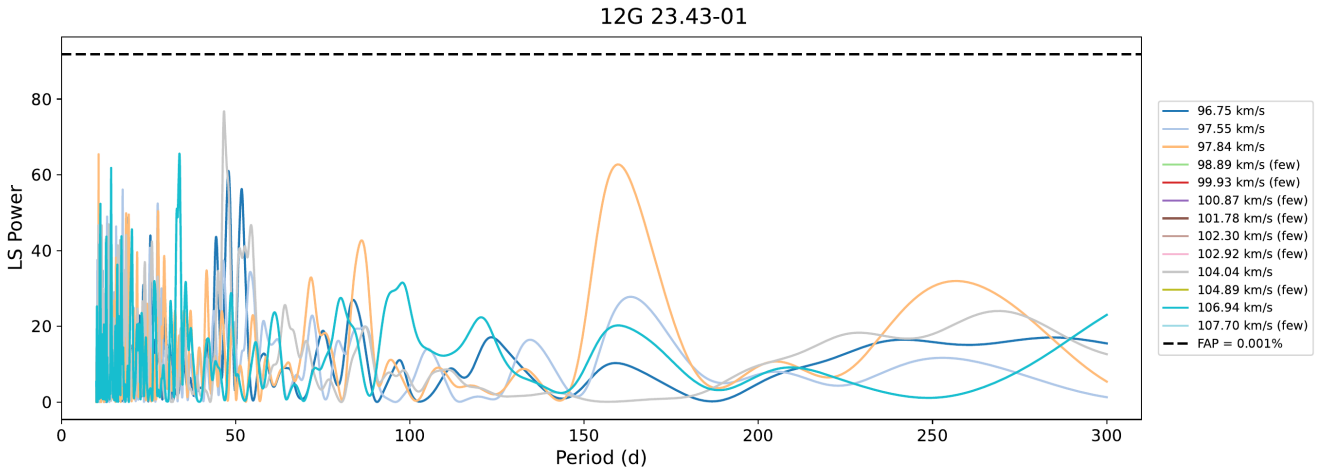


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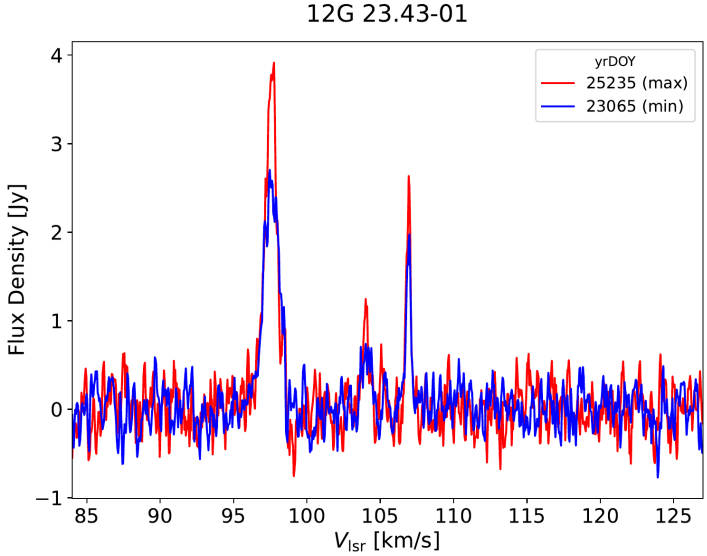
Light curve



Periodogram

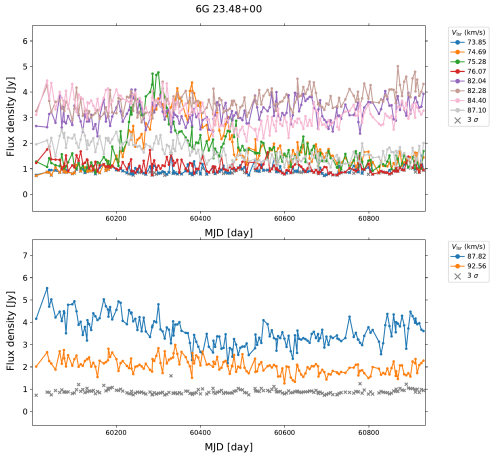


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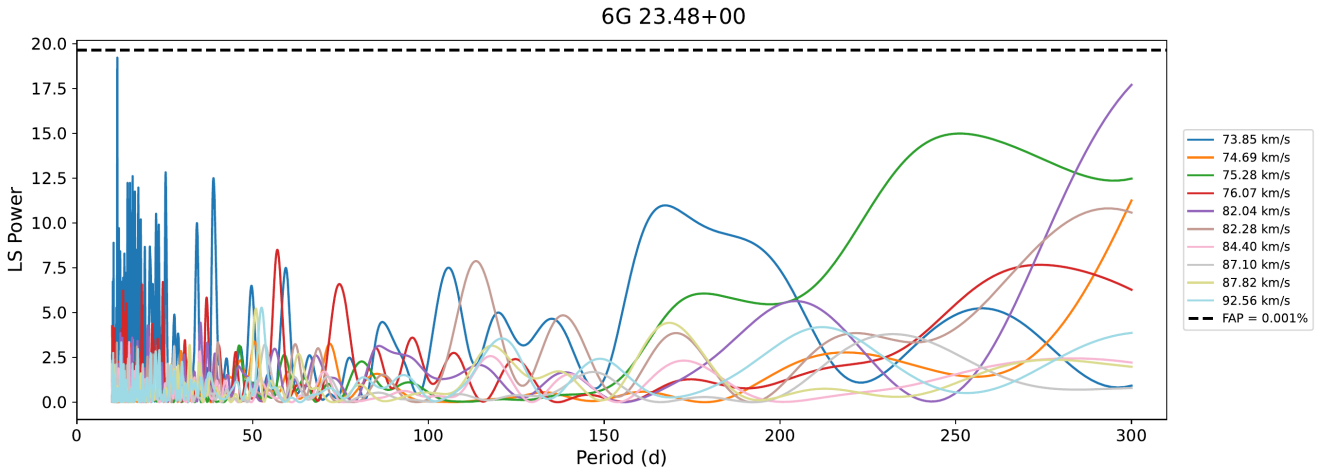


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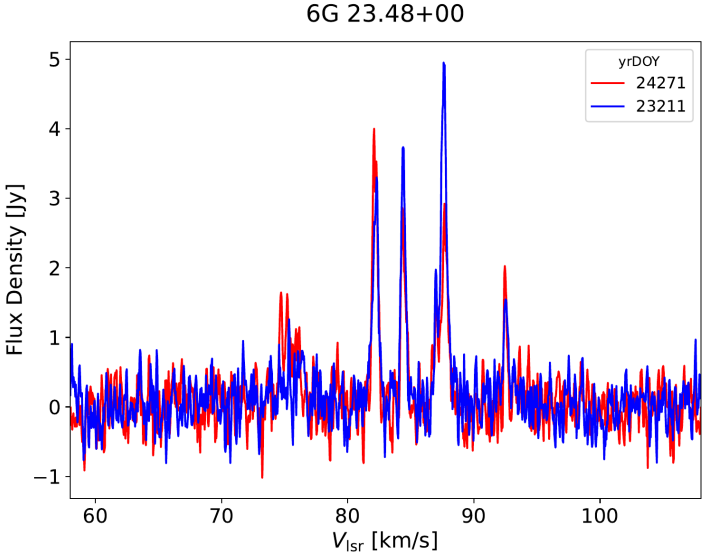
Light curve



Periodogram

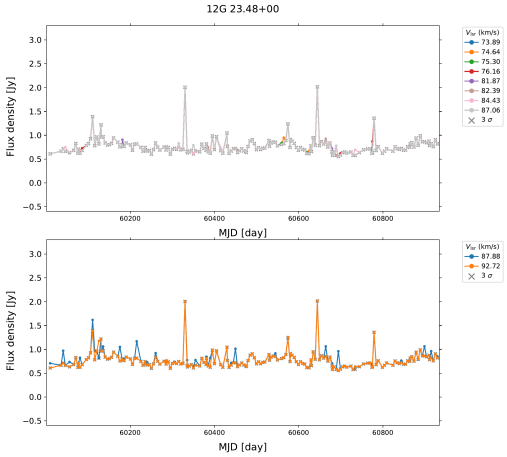


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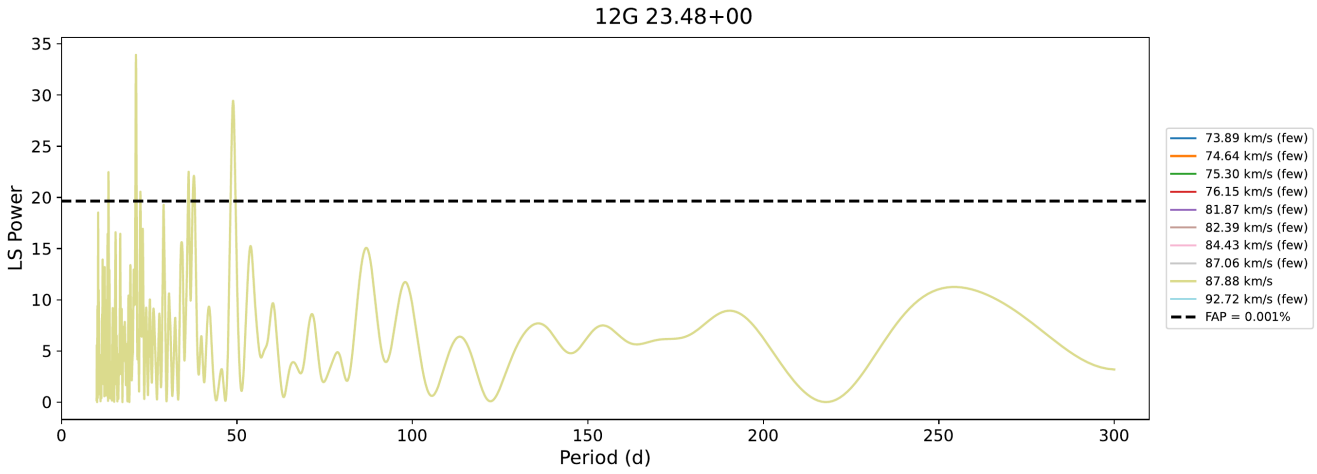


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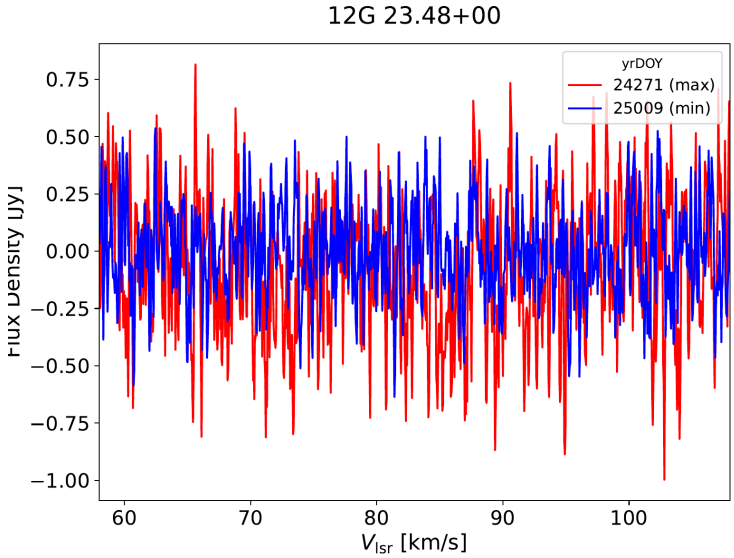
Light curve



Periodogram

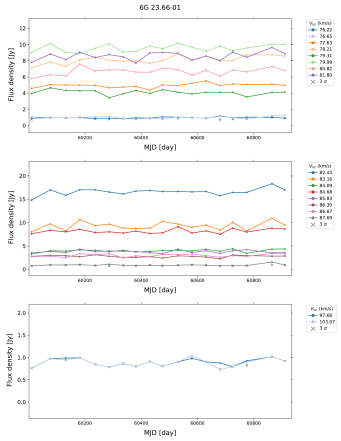


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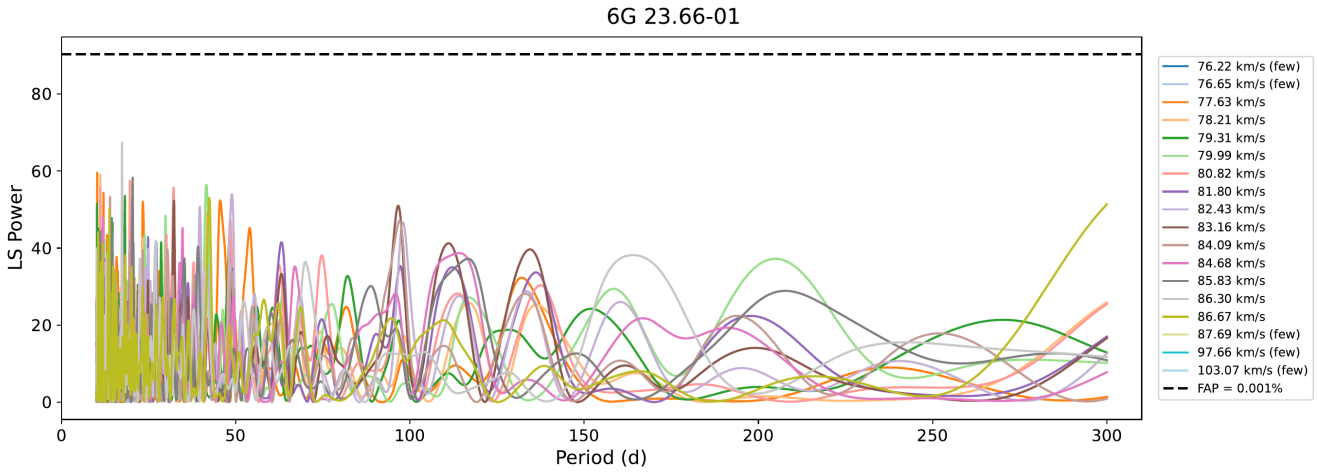


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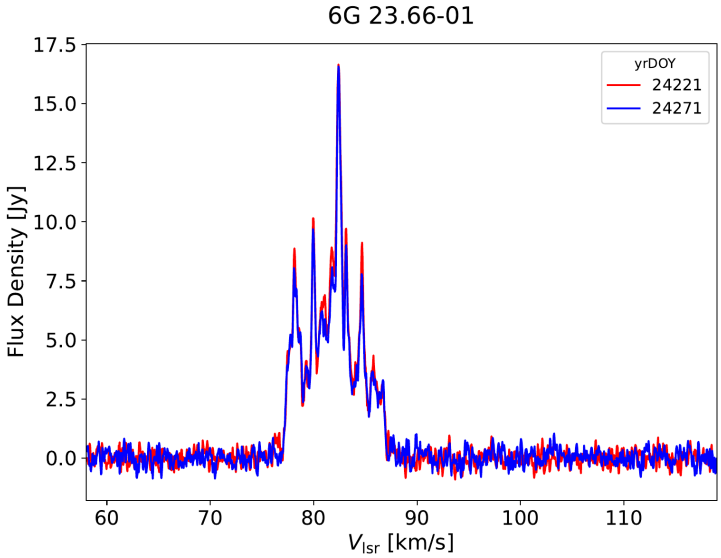
Light curve



Periodogram

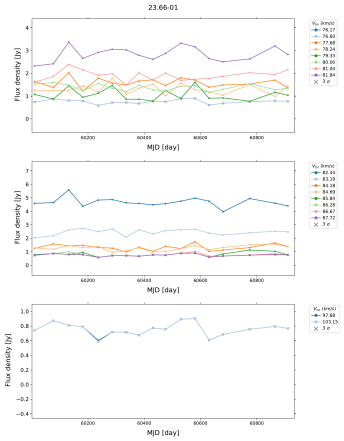


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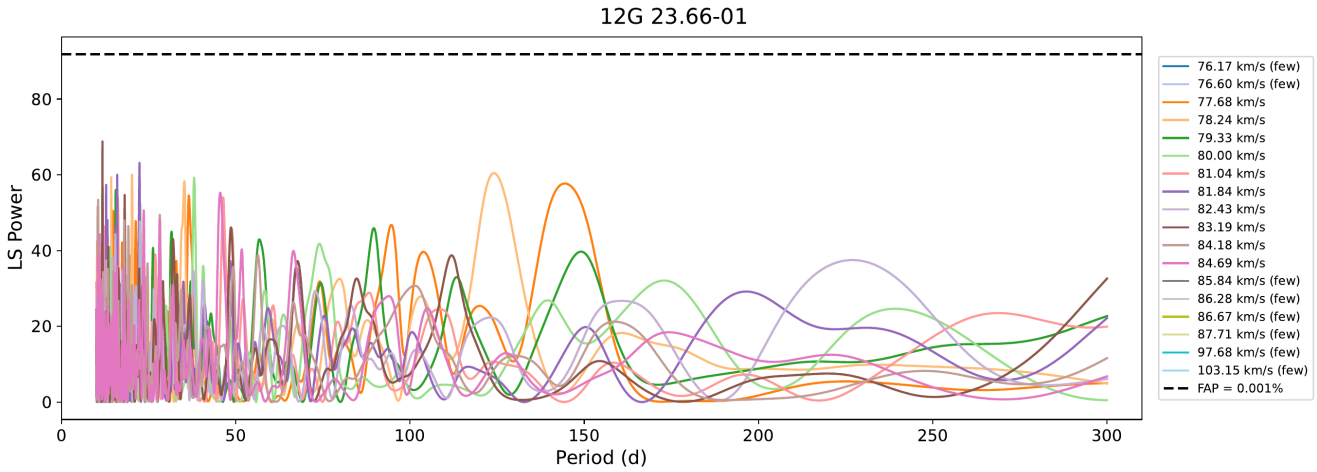


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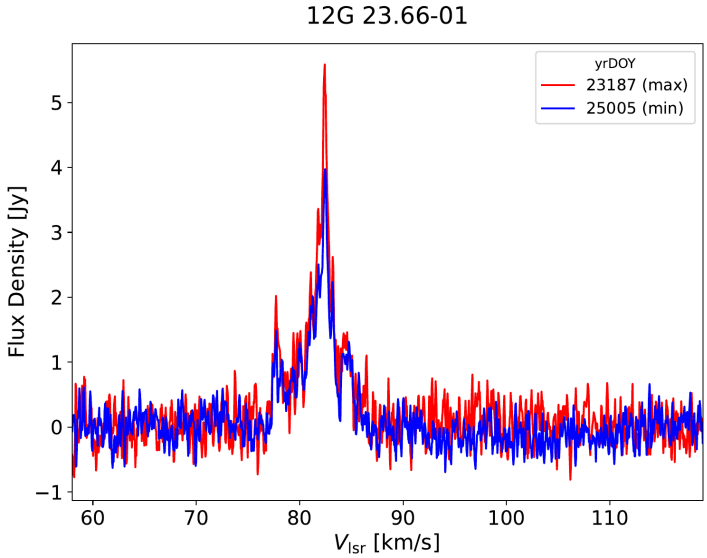
Light curve



Periodogram

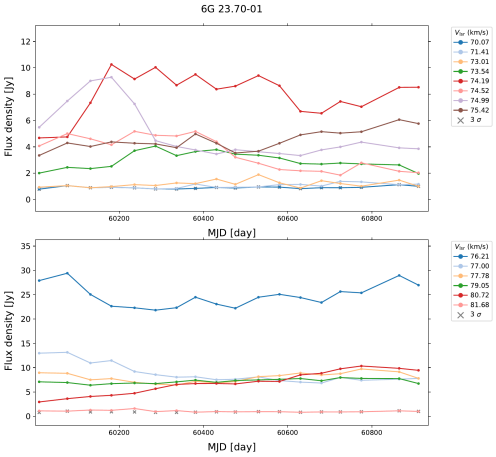


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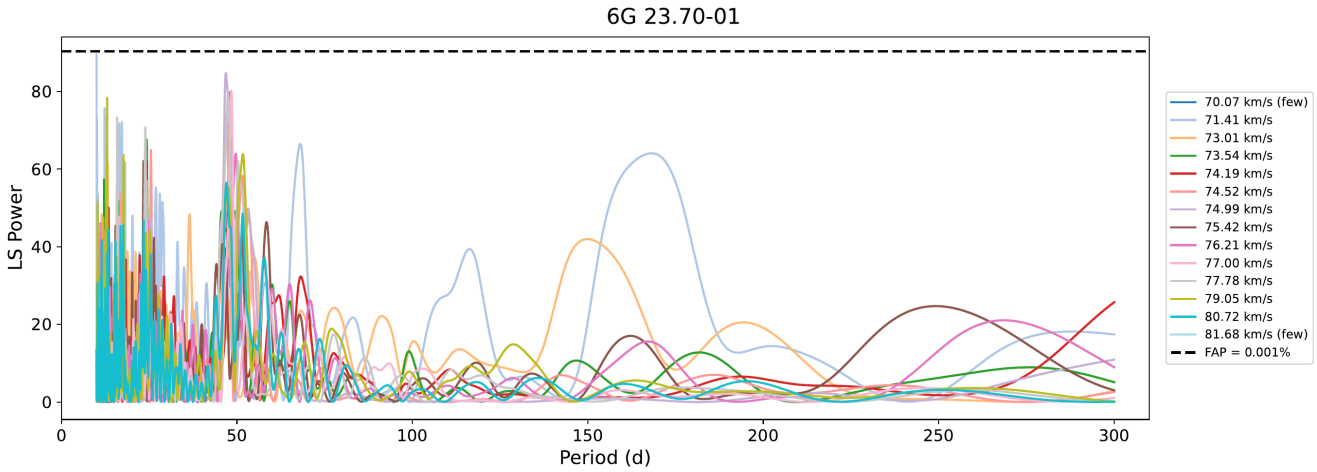


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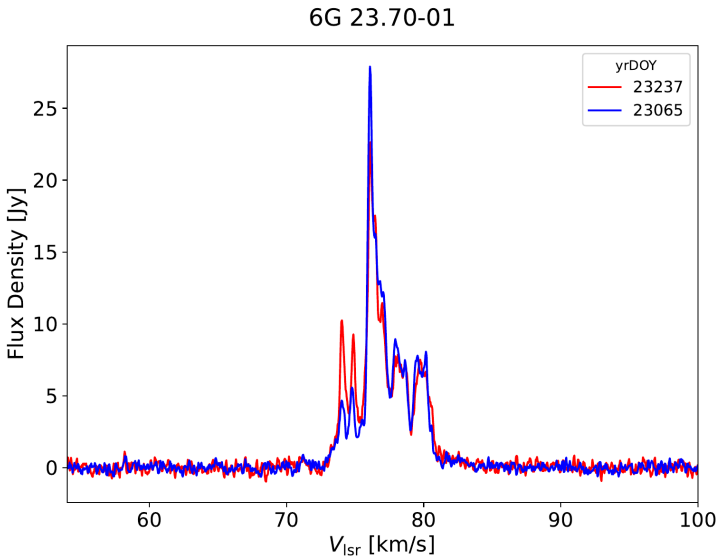
Light curve



Periodogram

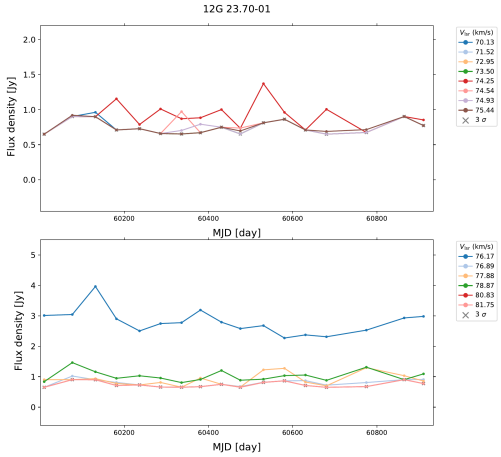


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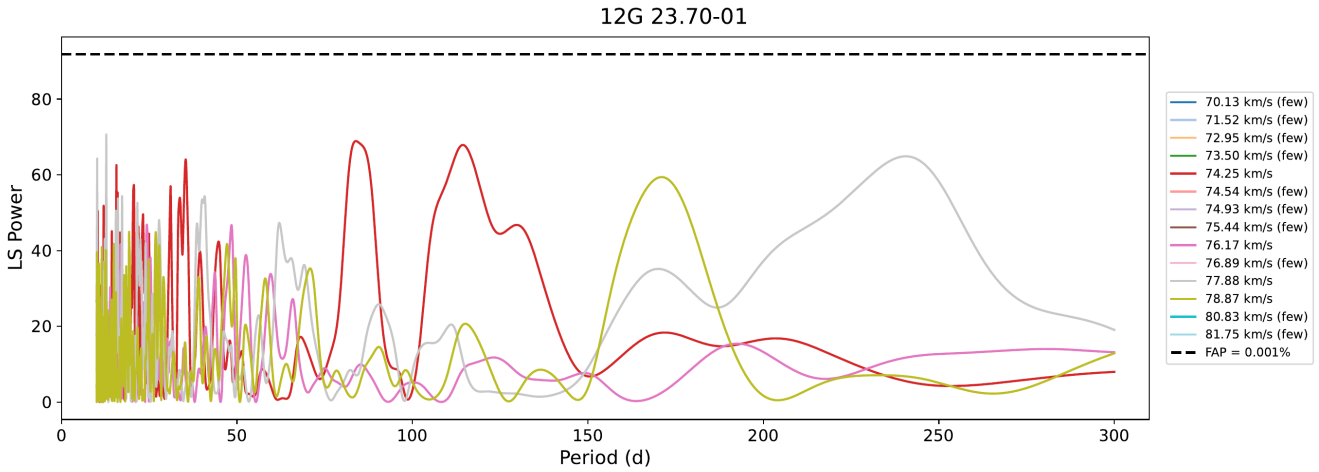


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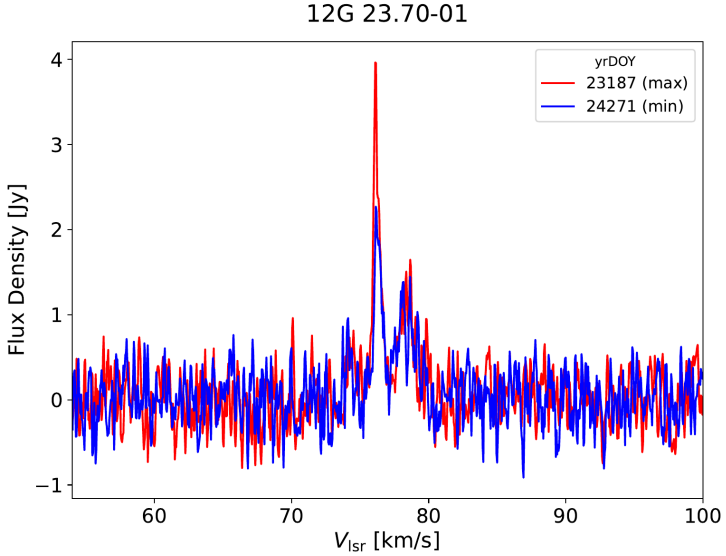
Light curve



Periodogram

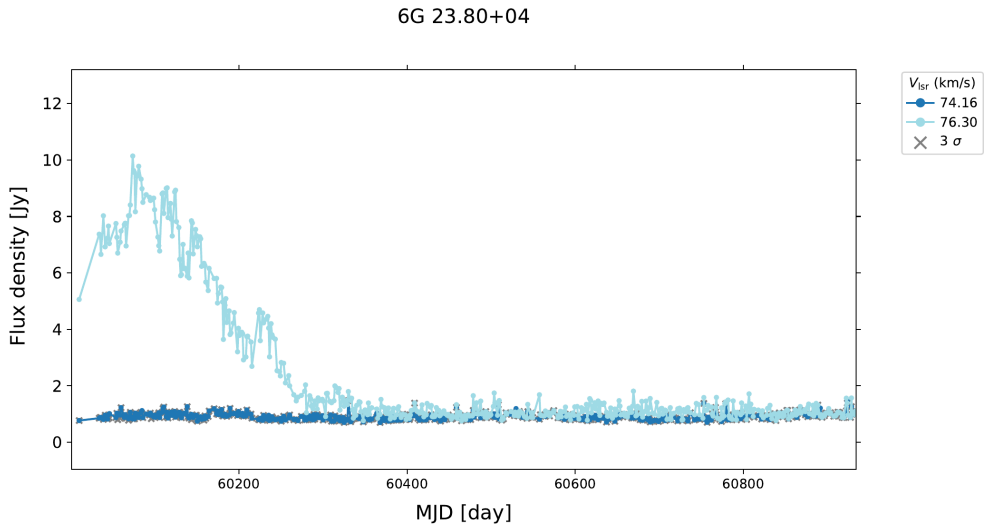


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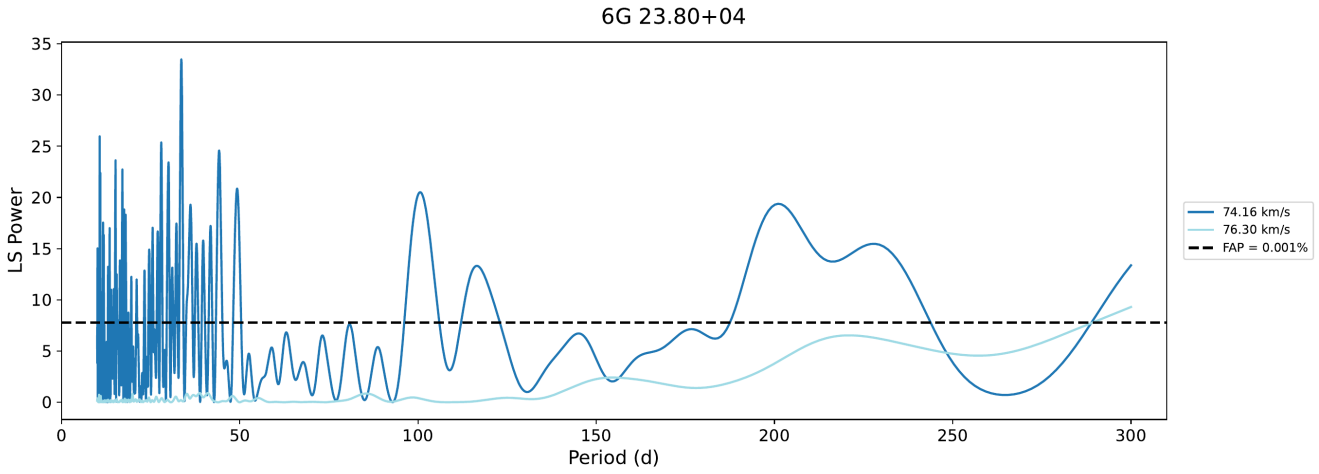


6G 23.80+04

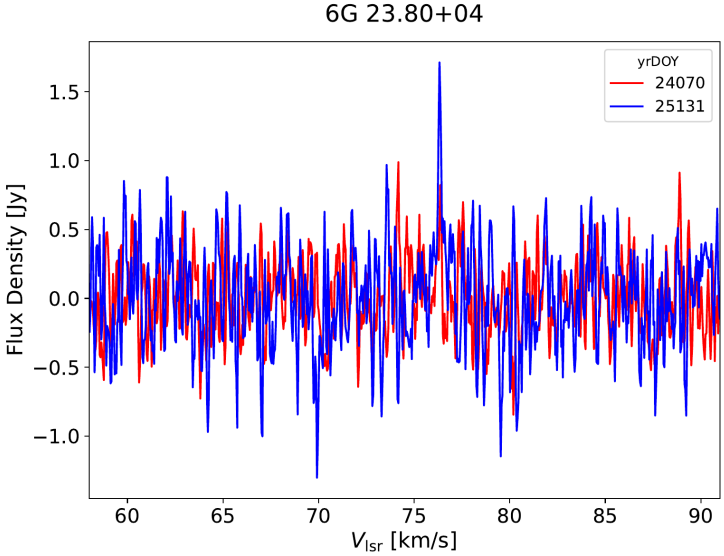
Light curve



Periodogram

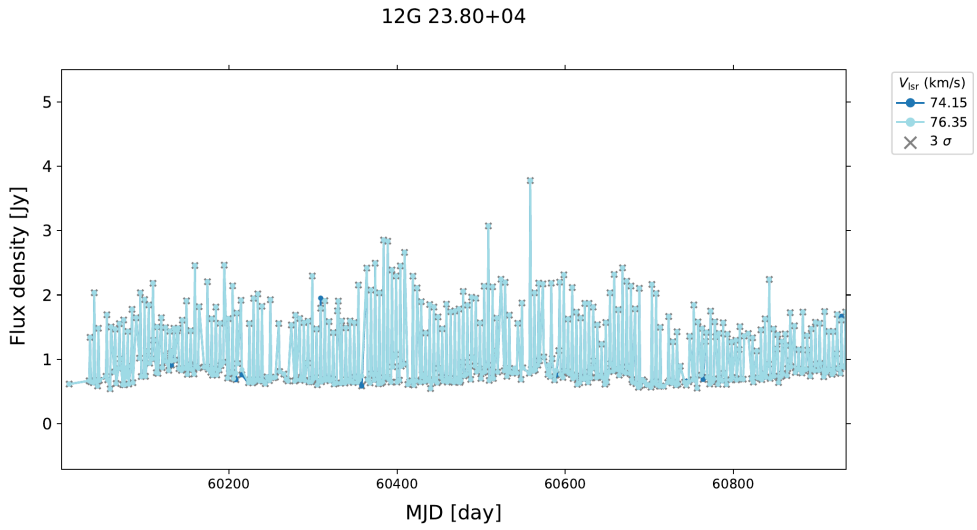


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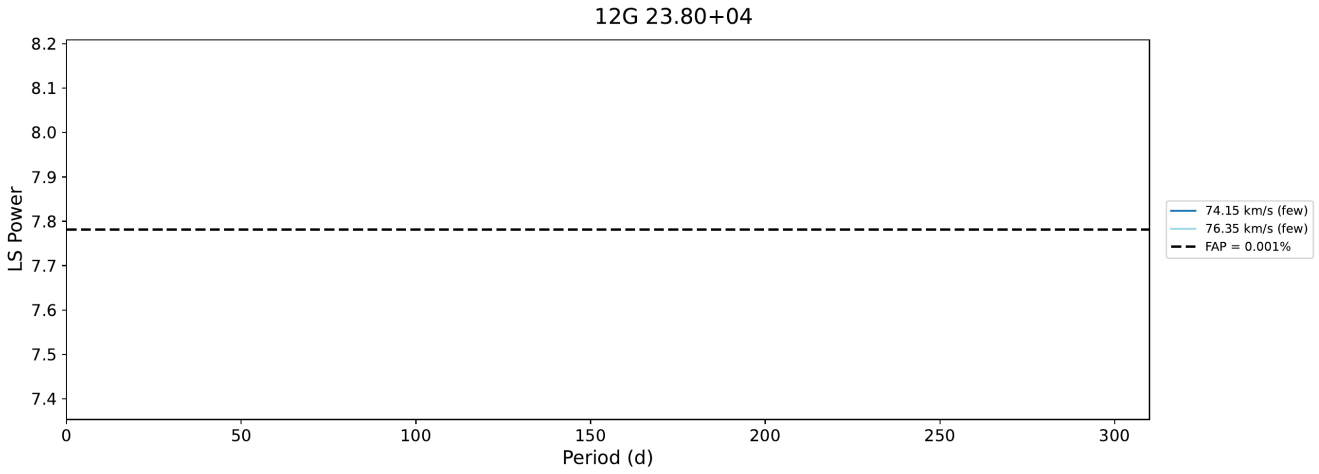


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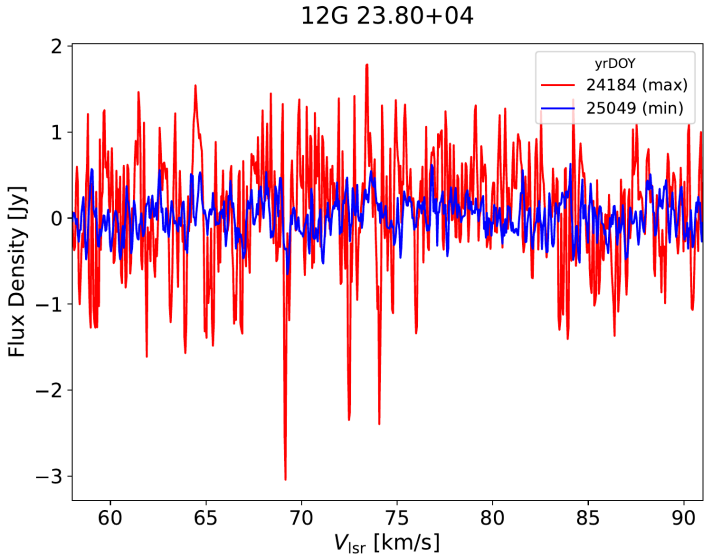
Light curve



Periodogram

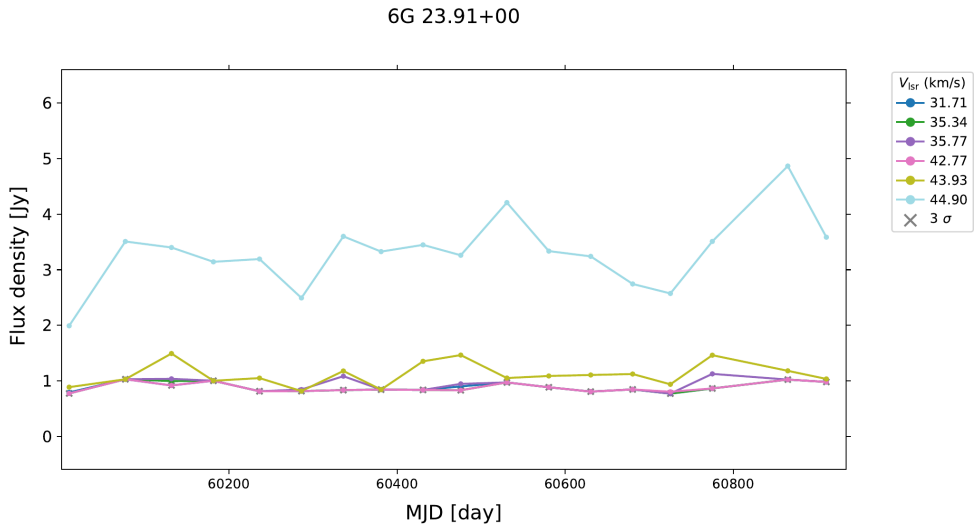


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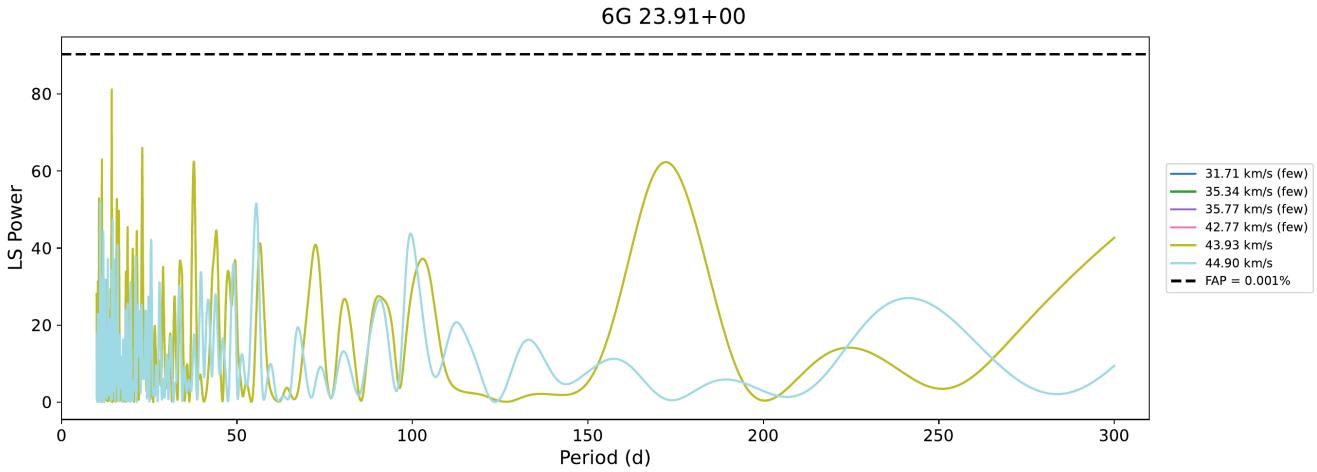


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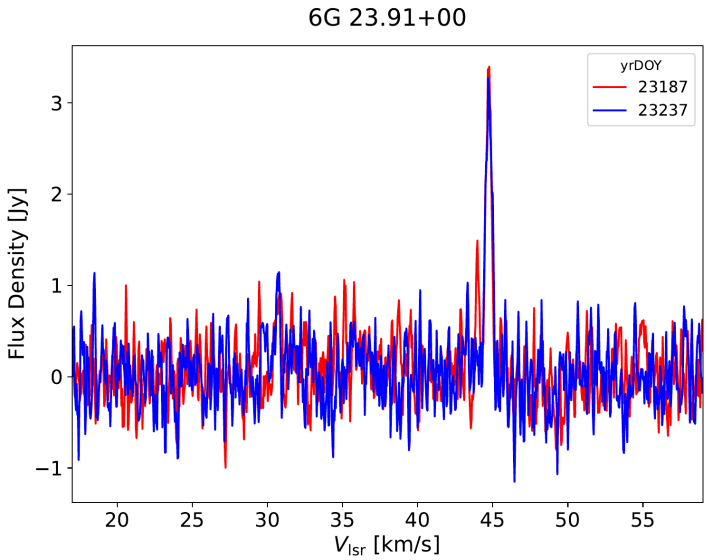
Light curve



Periodogram

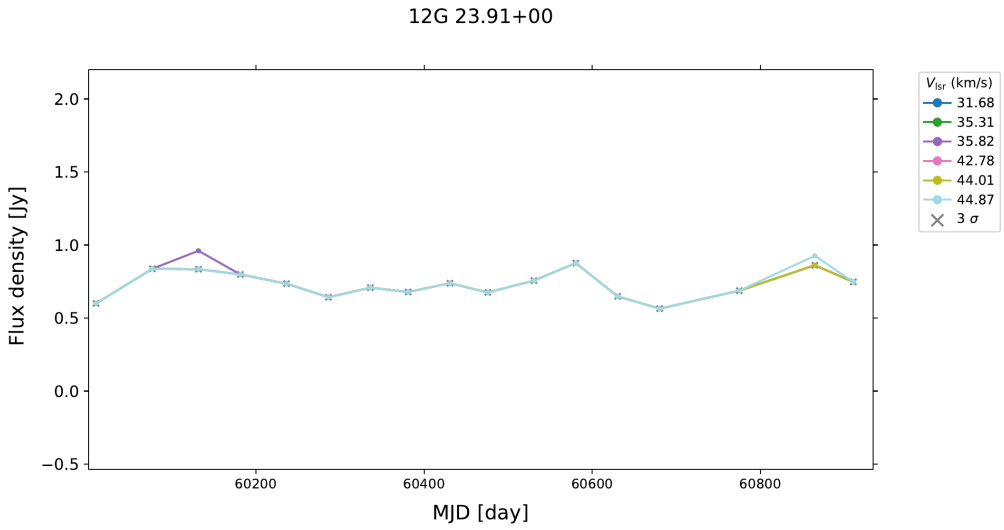


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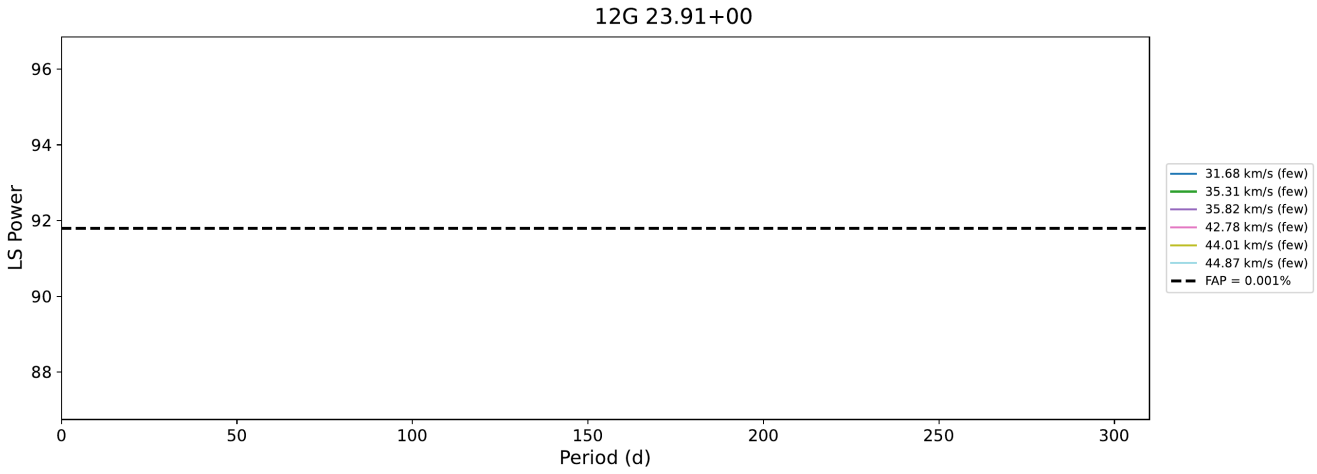


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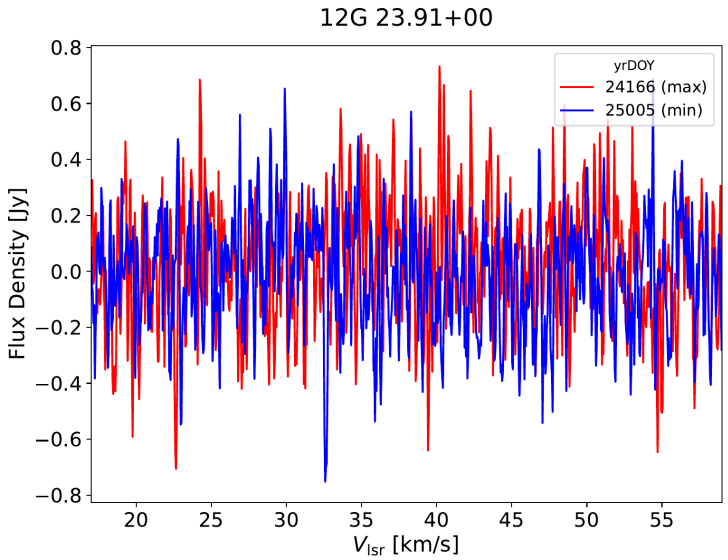
Light curve



Periodogram

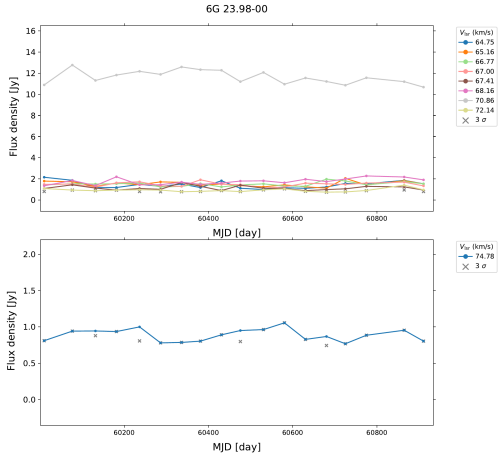


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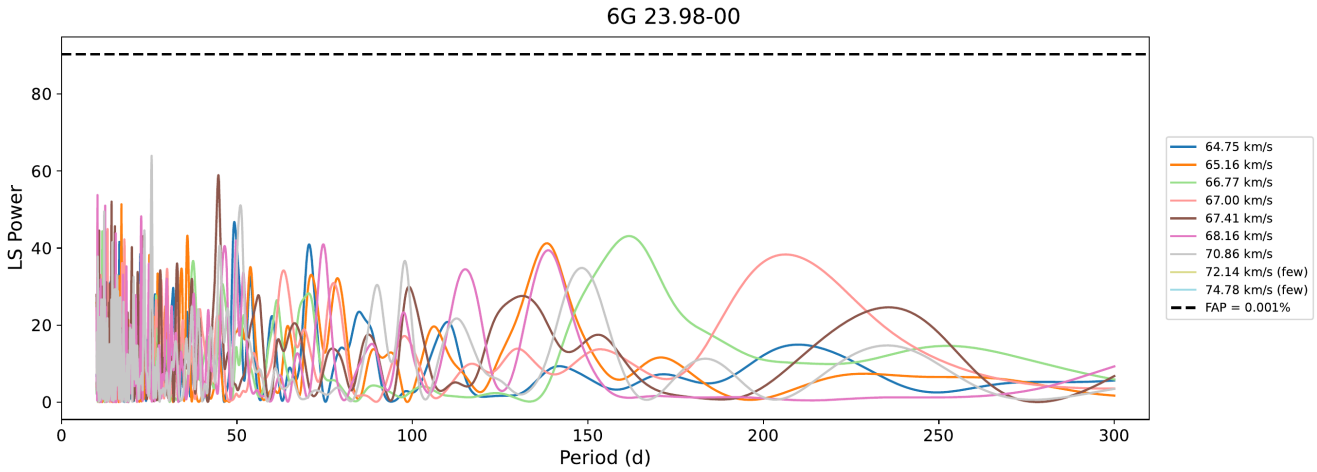


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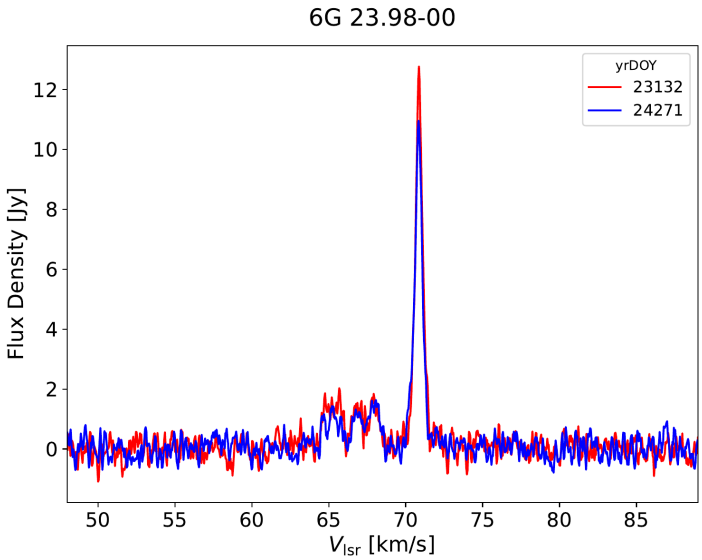
Light curve



Periodogram

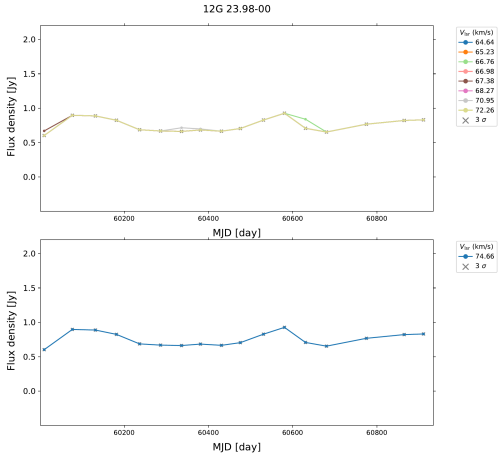


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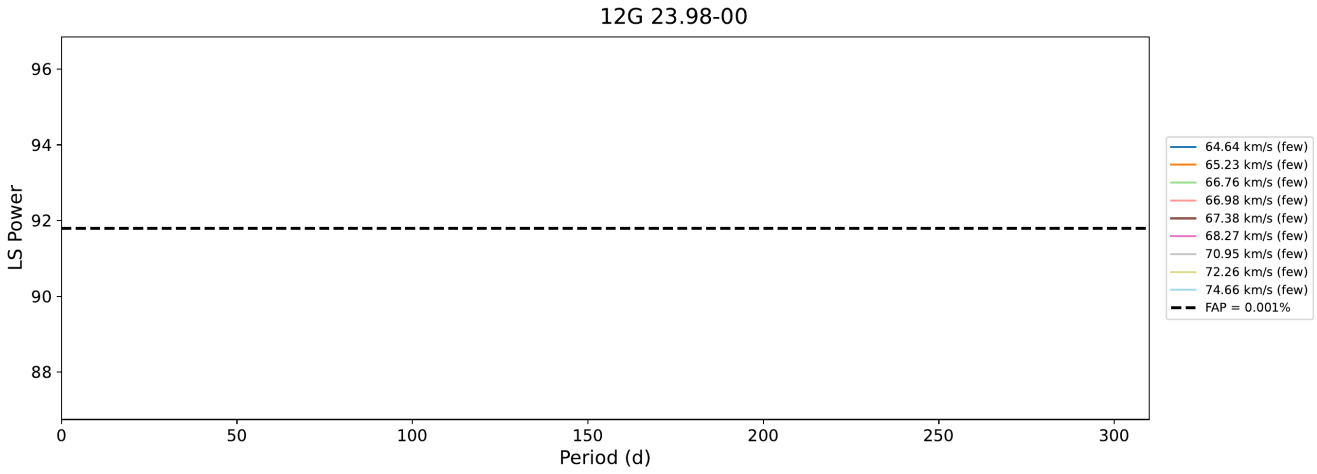


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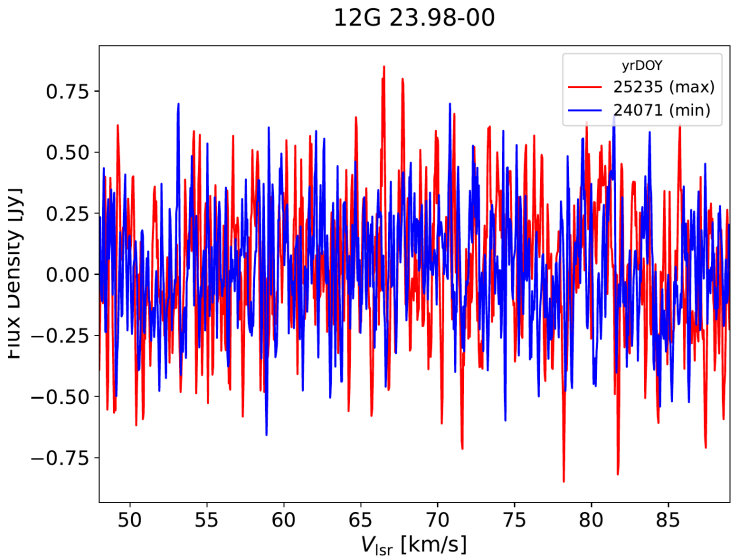
Light curve



Periodogram

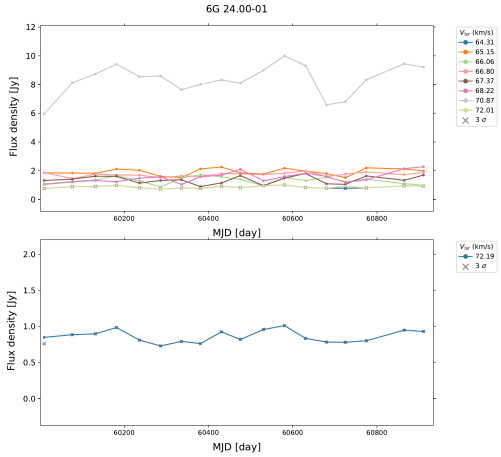


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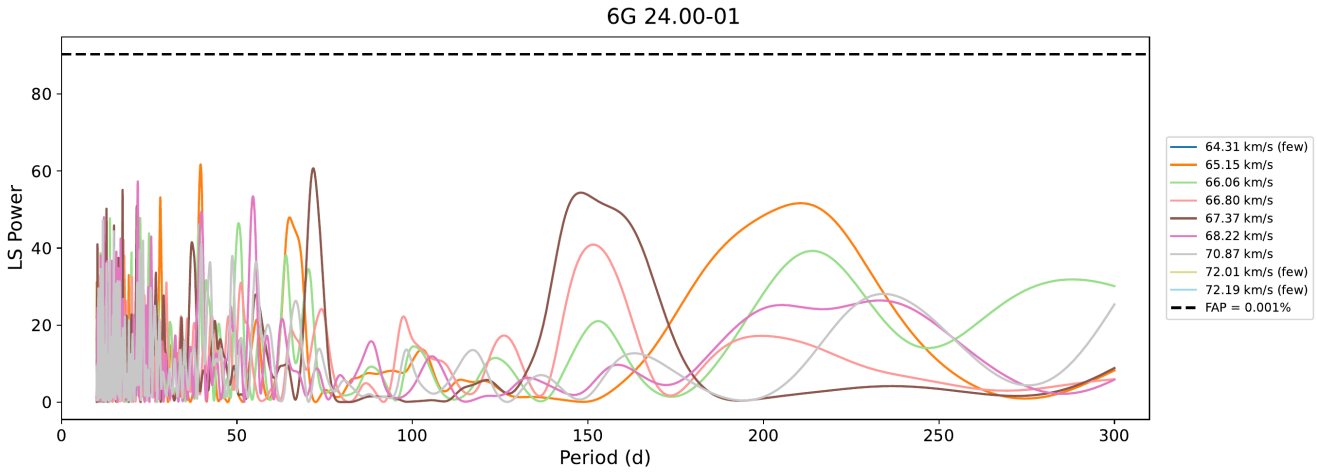


6G 24.00-01

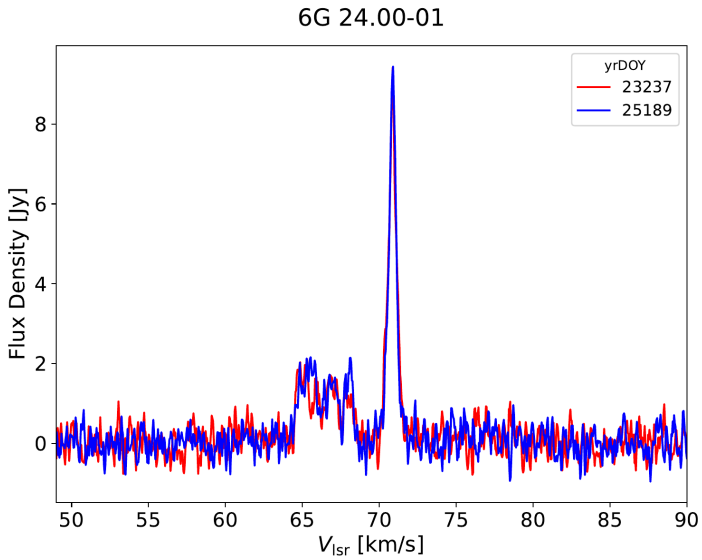
Light curve



Periodogram

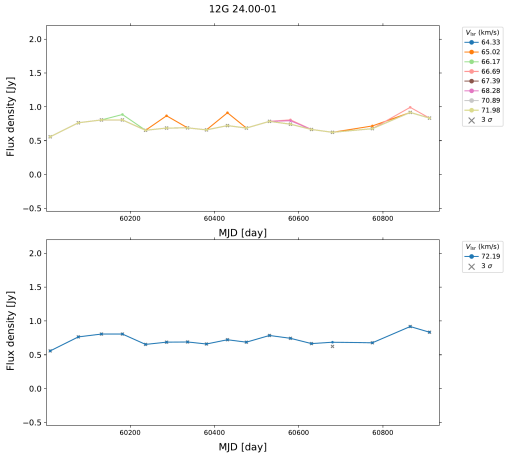


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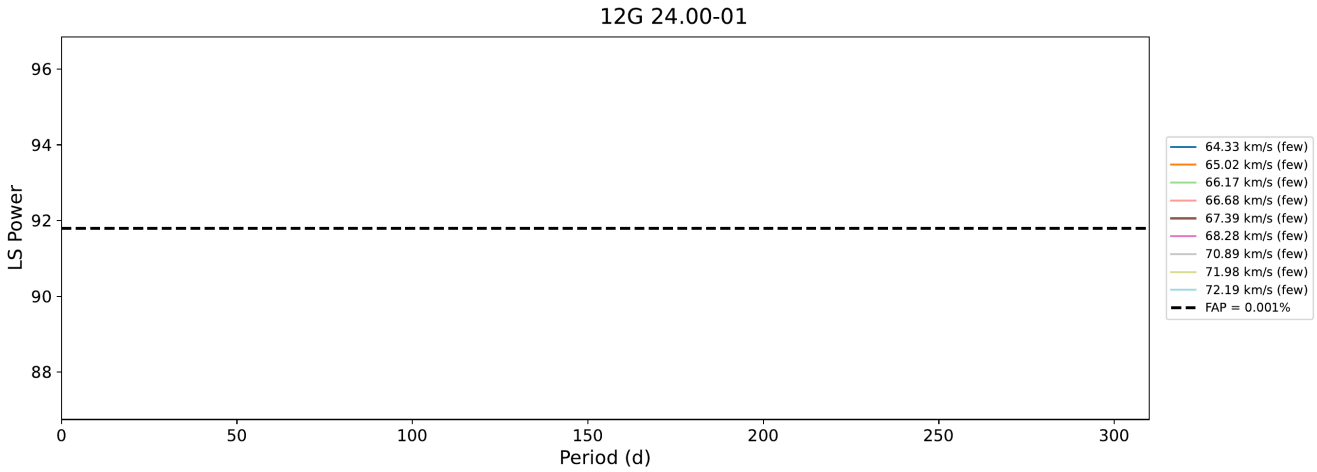


12G 24.00-01

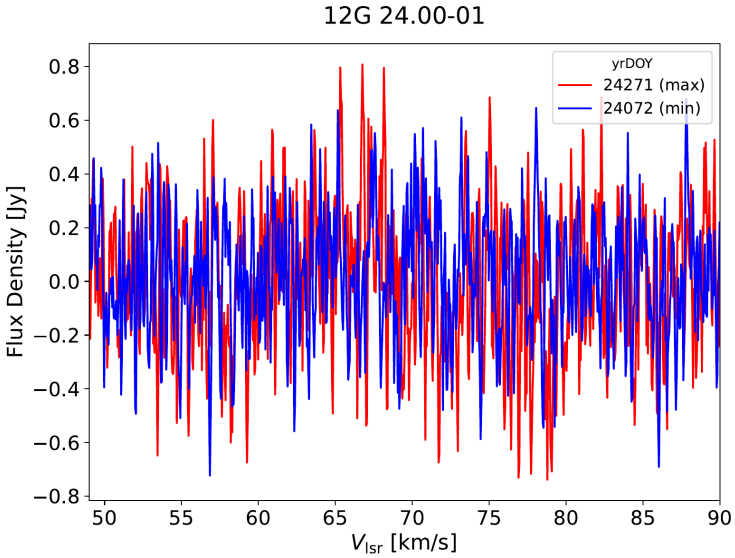
Light curve



Periodogram

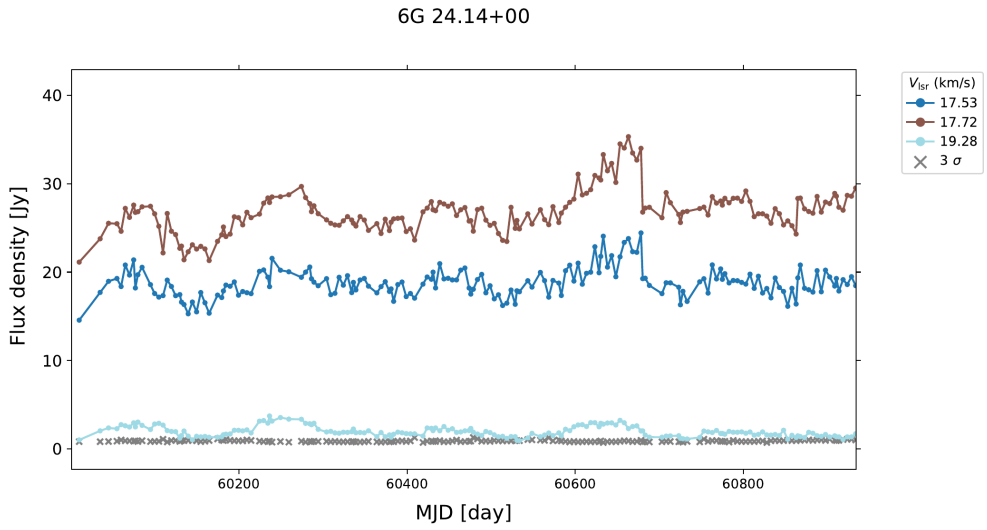


Spectrum

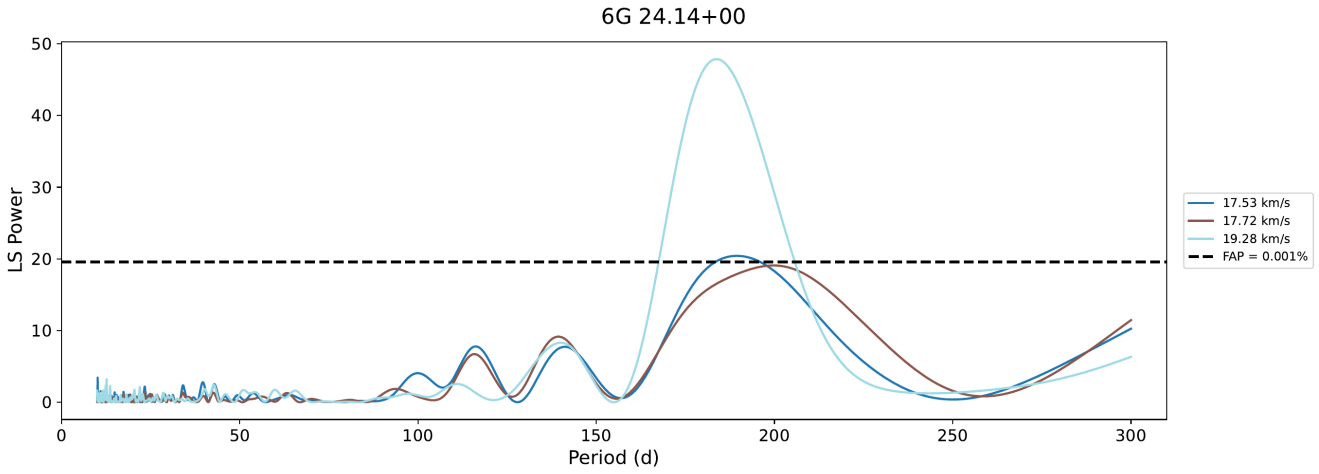


6G 24.14+00

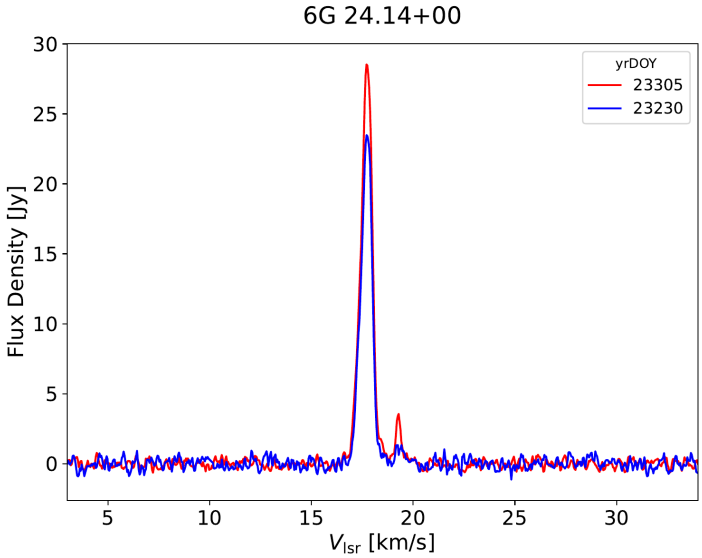
Light curve



Periodogram

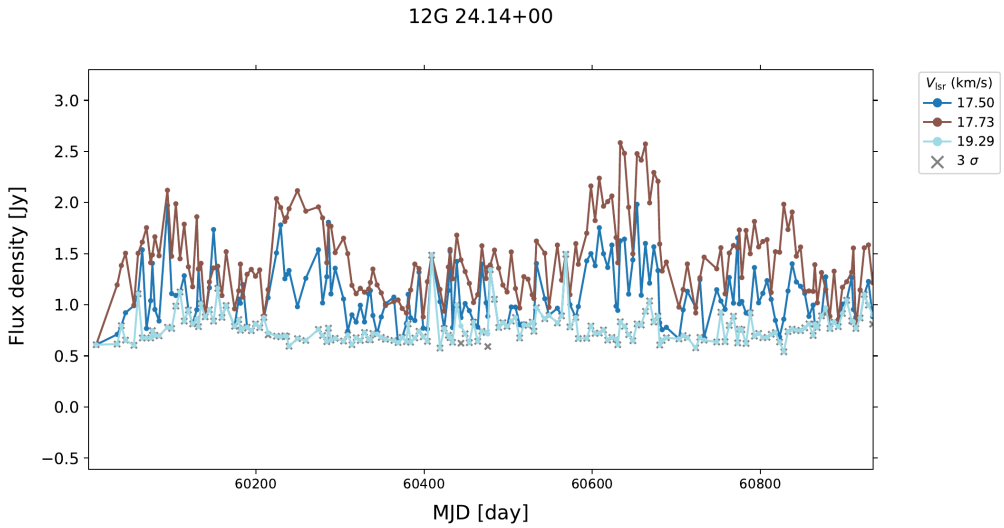


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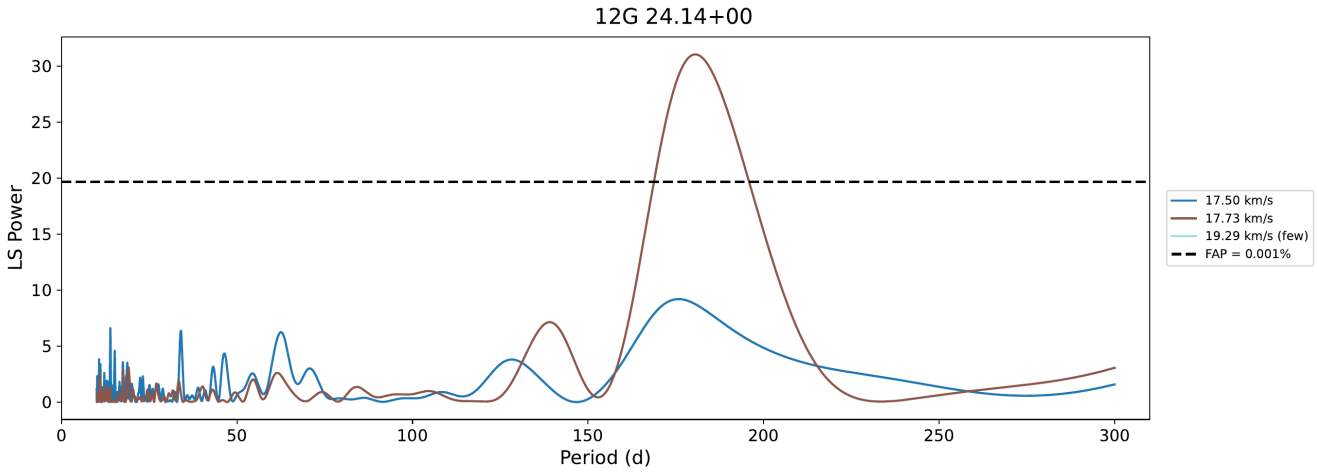


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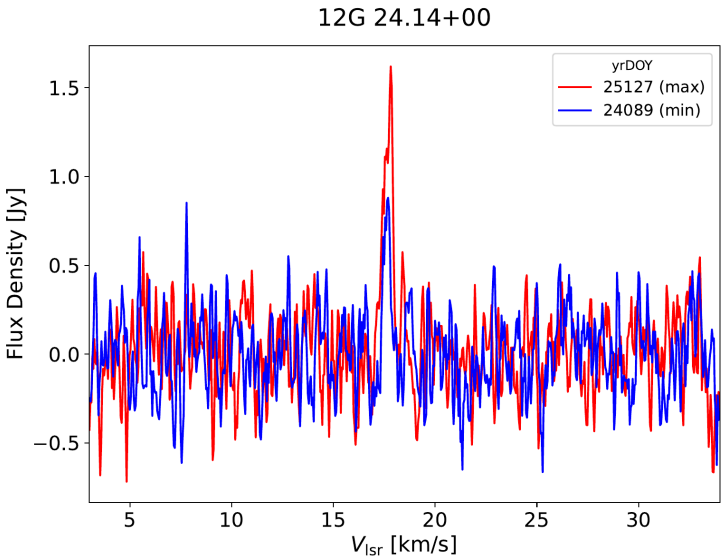
Light curve



Periodogram

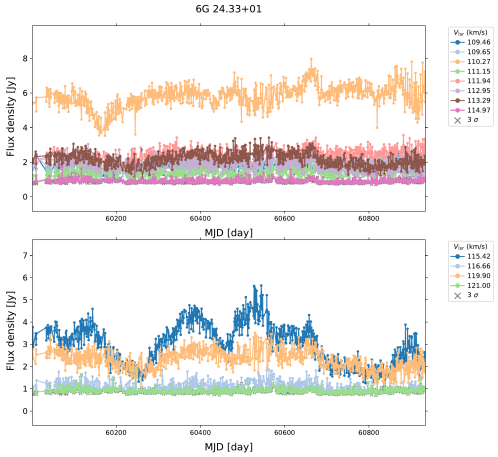


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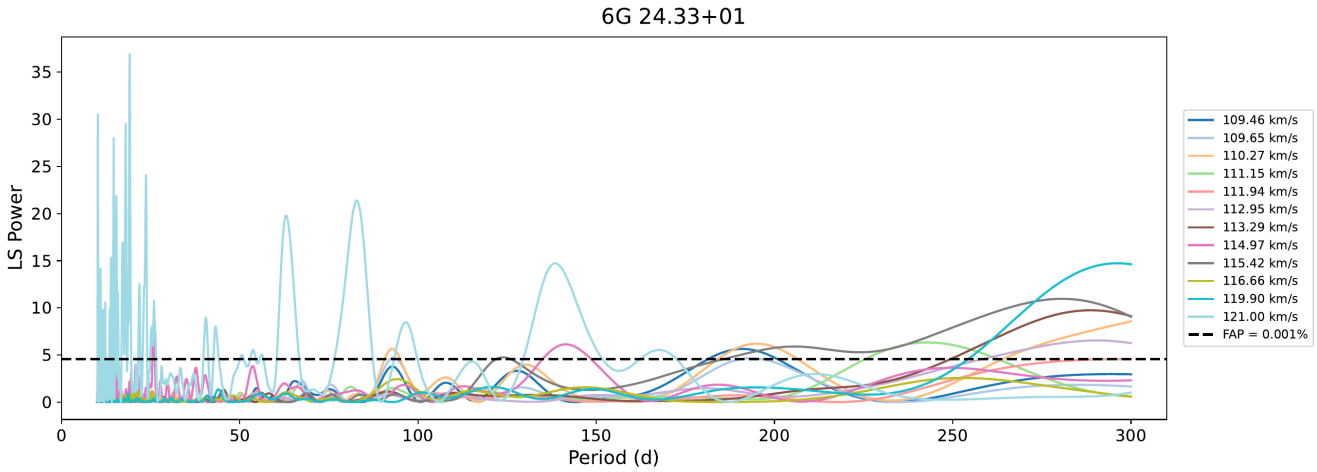


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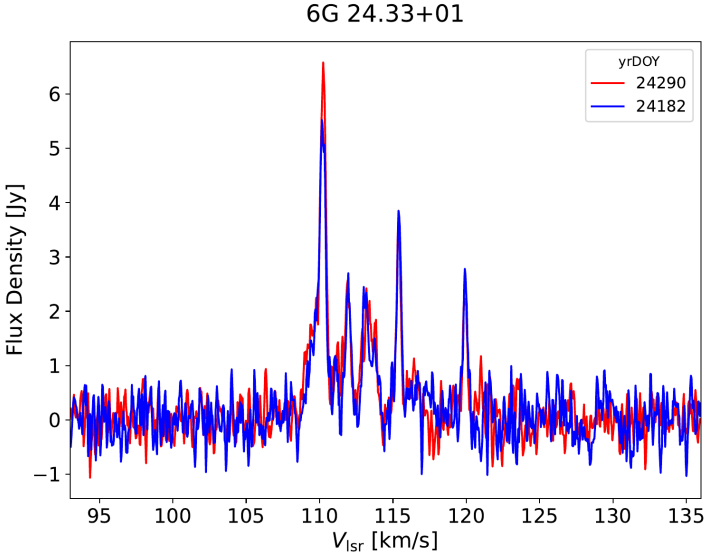
Light curve



Periodogram

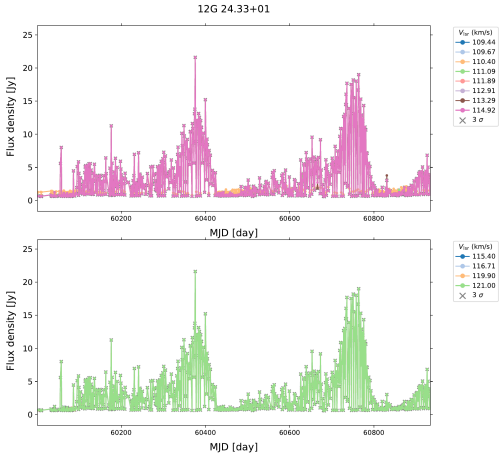


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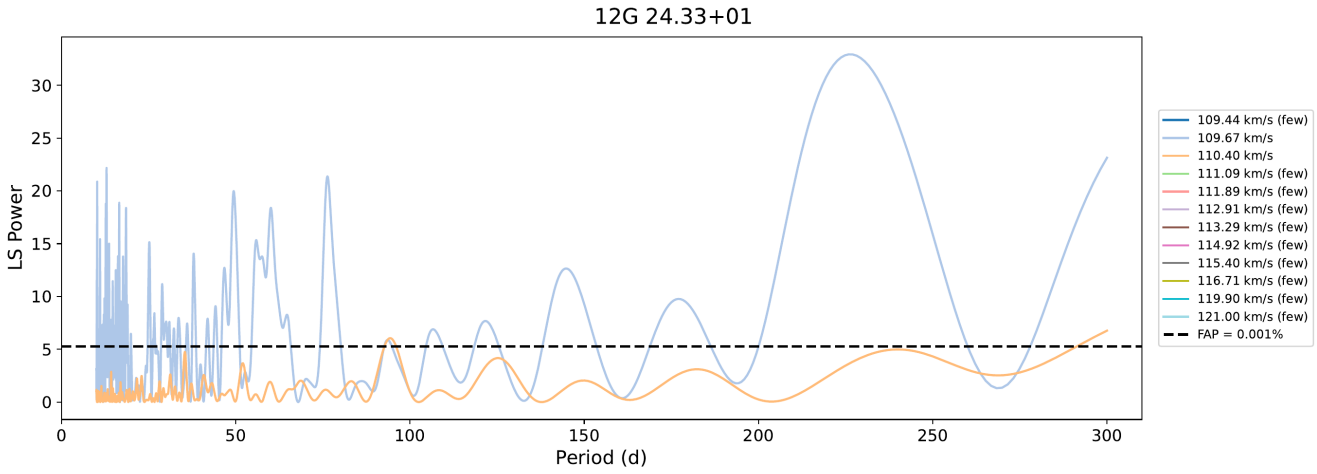


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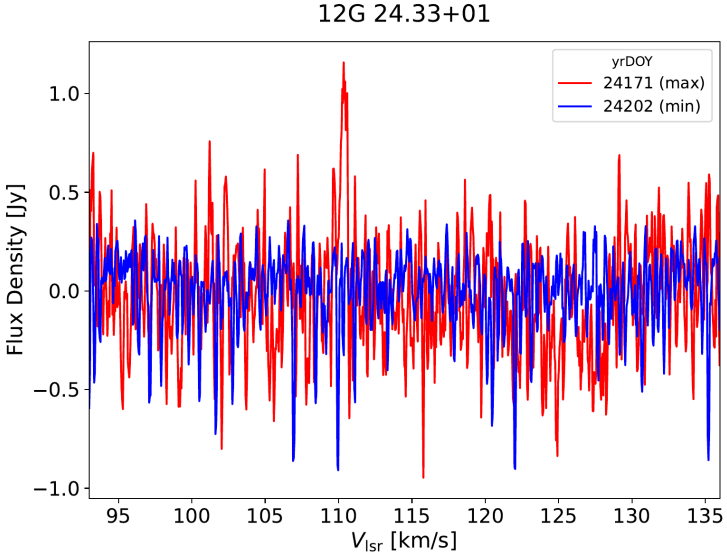
Light curve



Periodogram

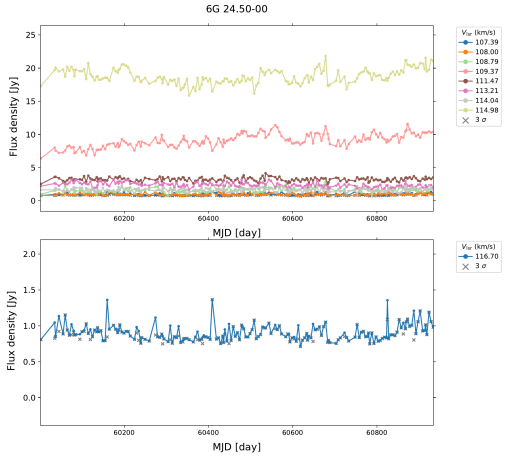


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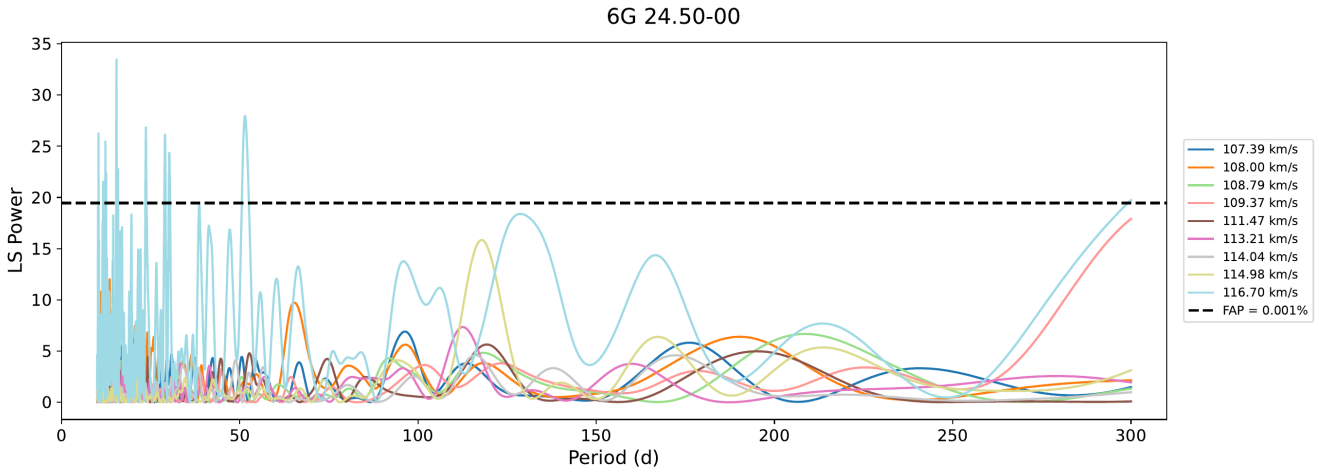


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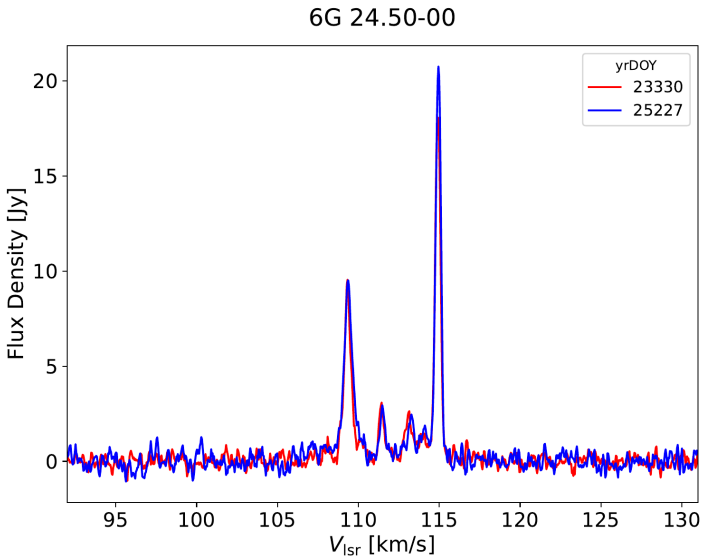
Light curve



Periodogram

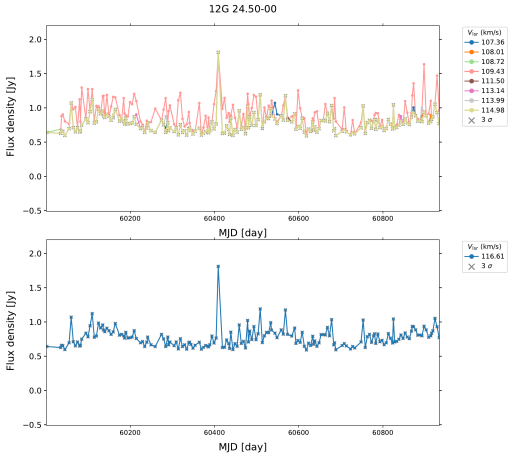


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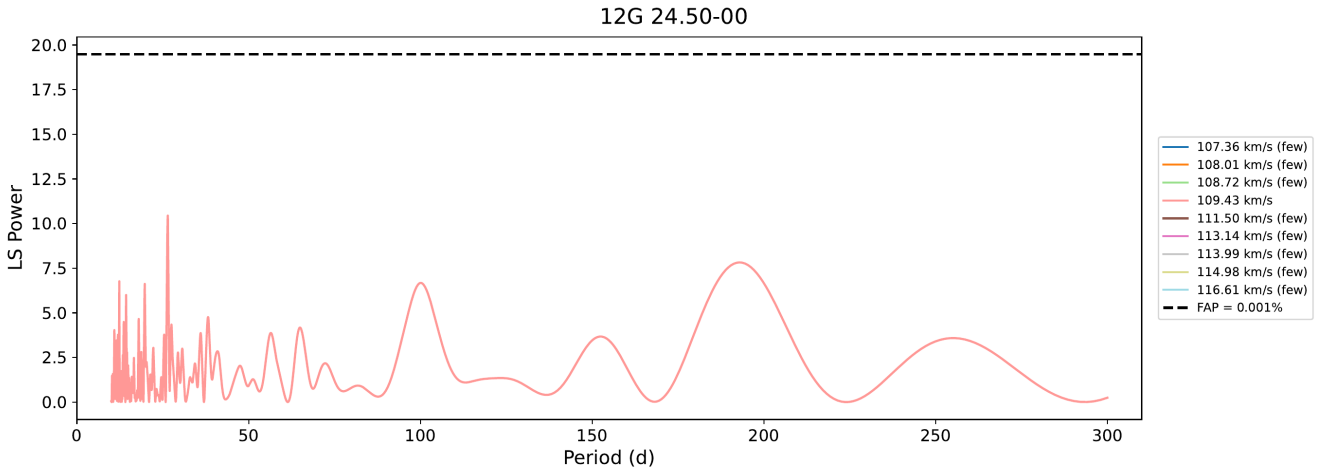


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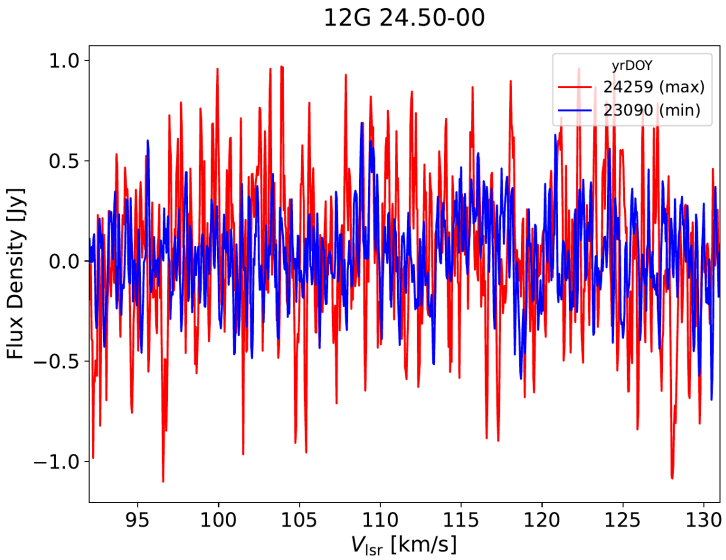
Light curve



Periodogram

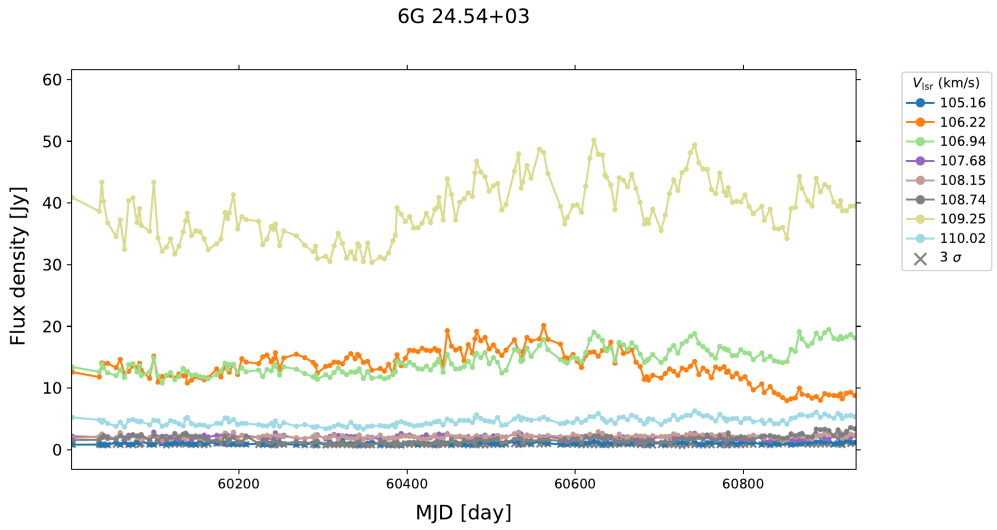


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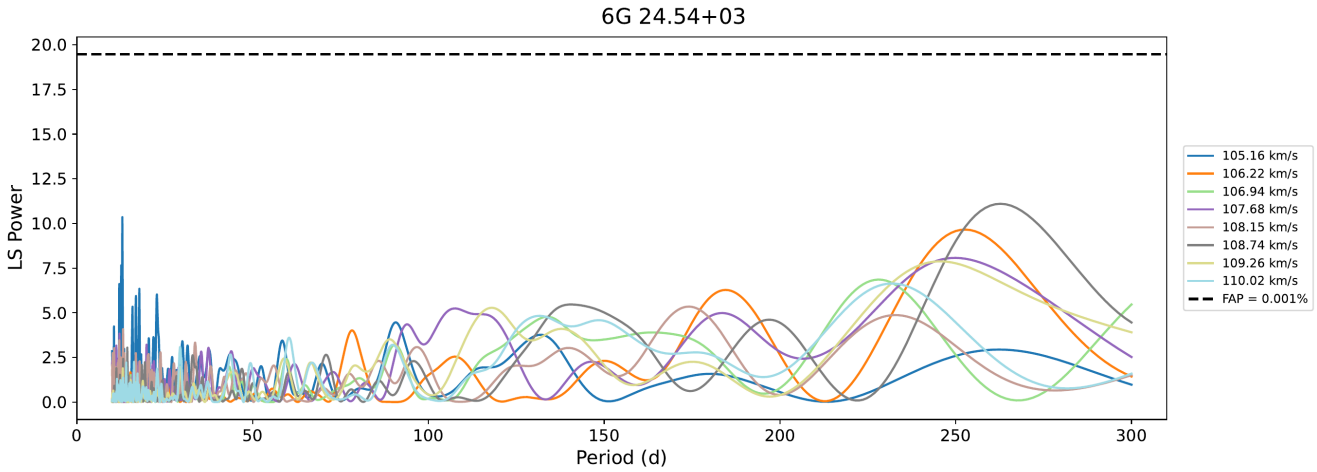


6G 24.54+03

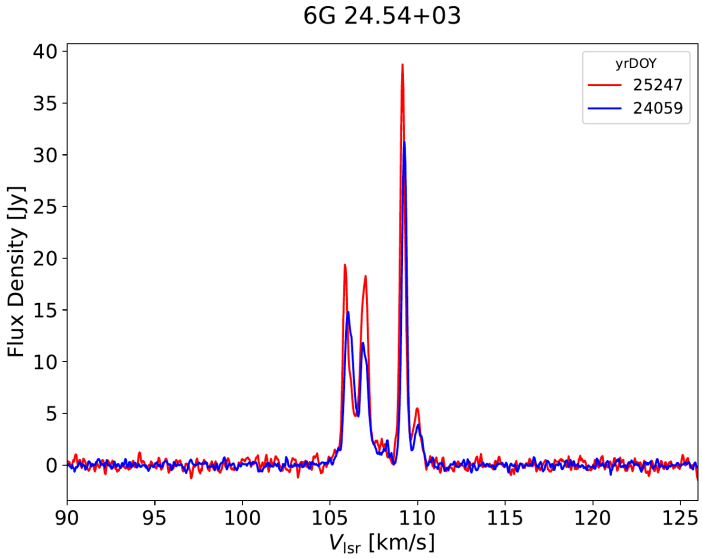
Light curve



Periodogram

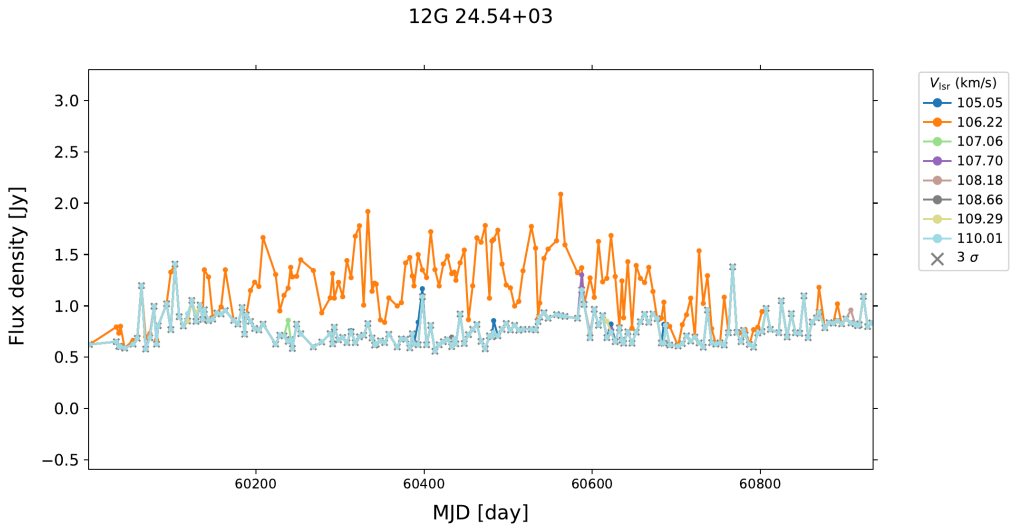


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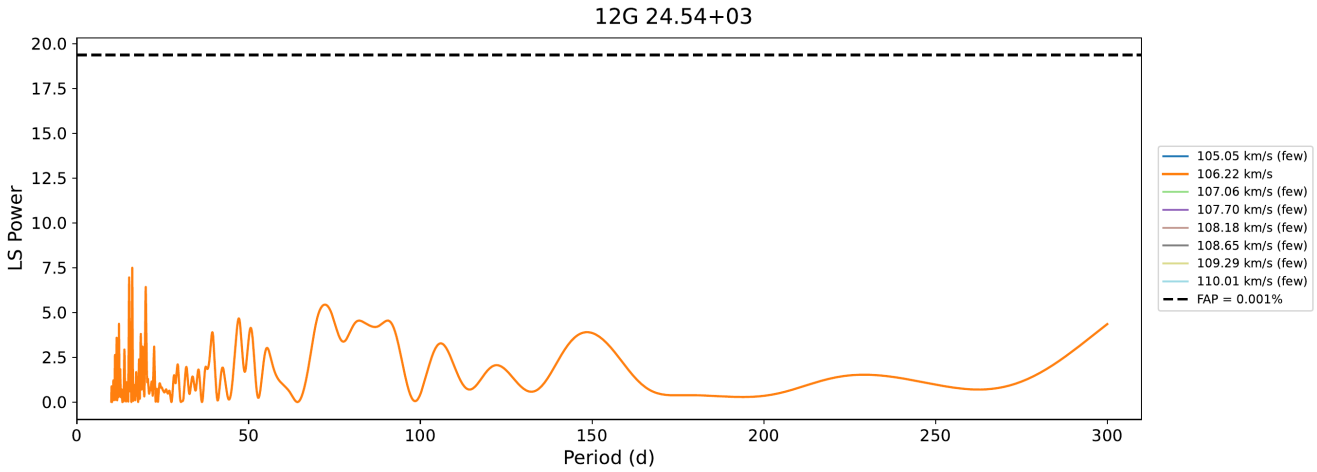


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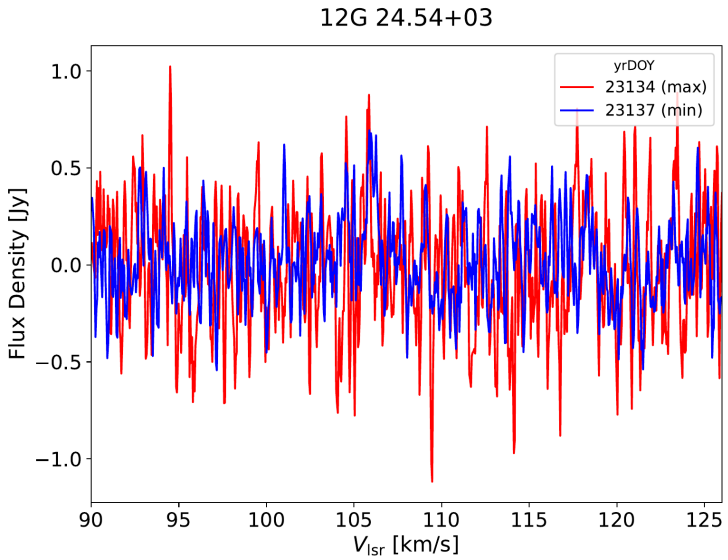
Light curve



Periodogram

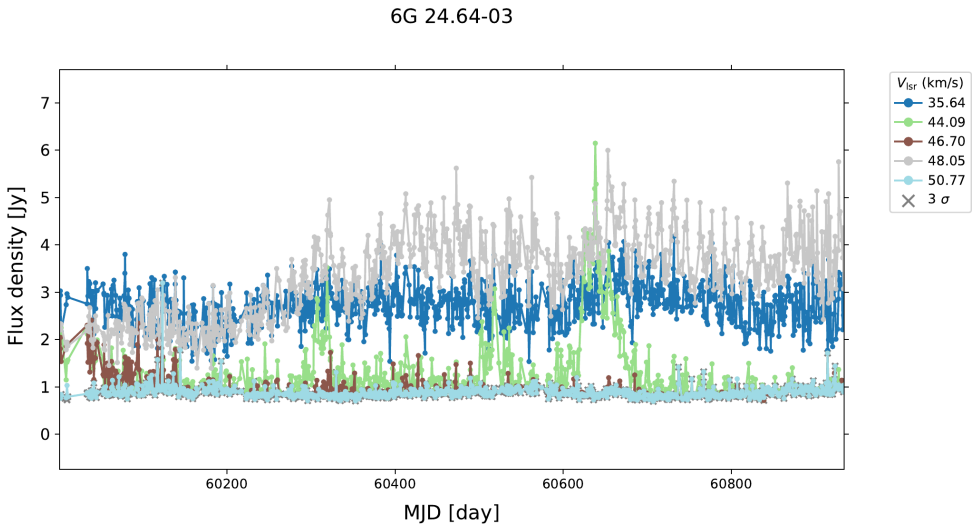


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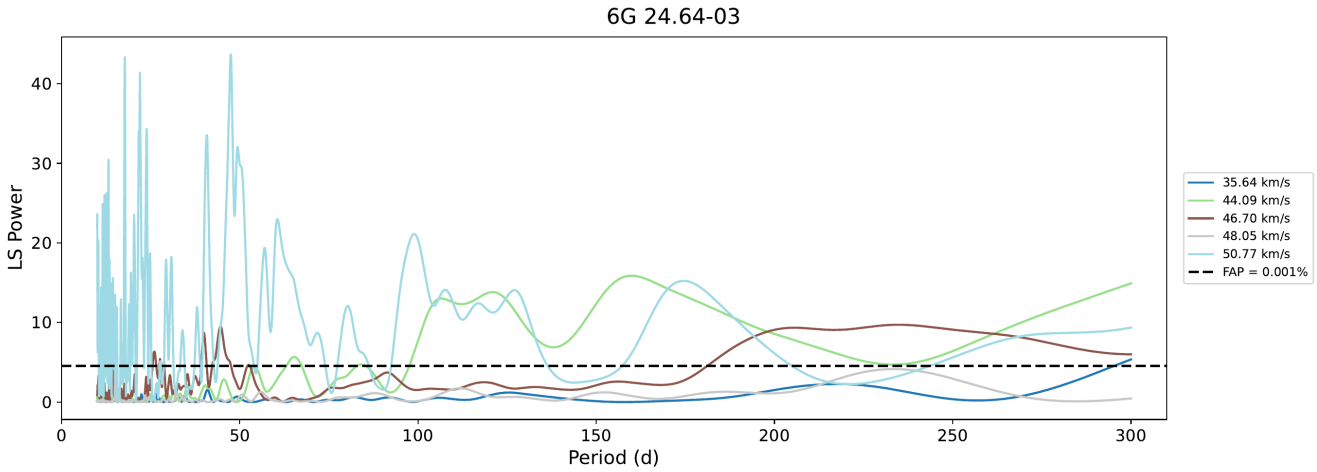


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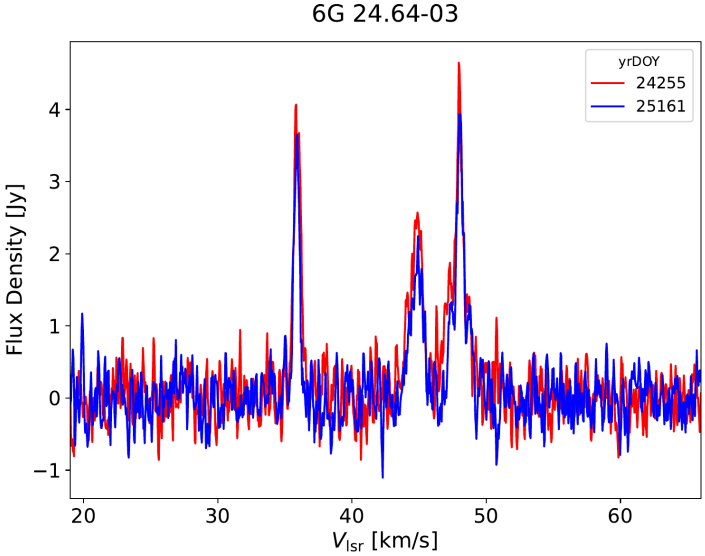
Light curve



Periodogram

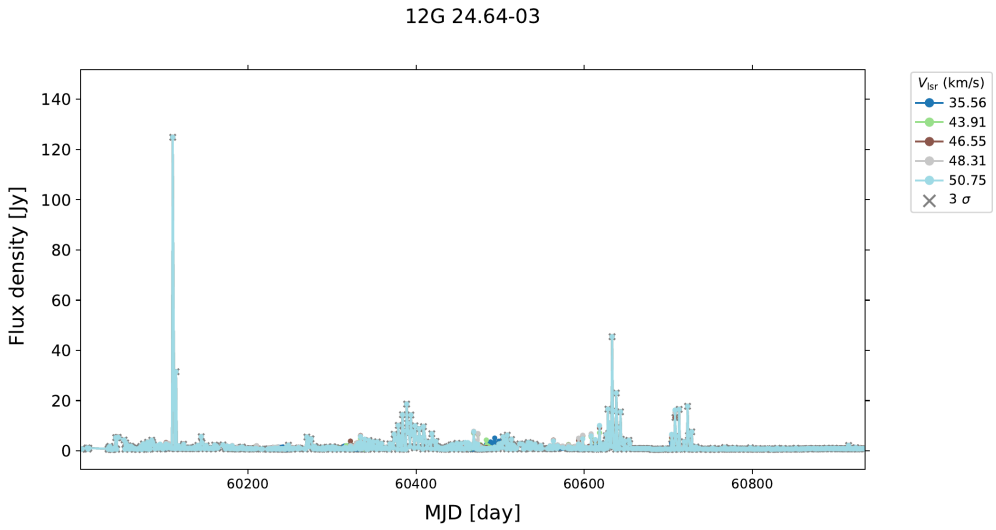


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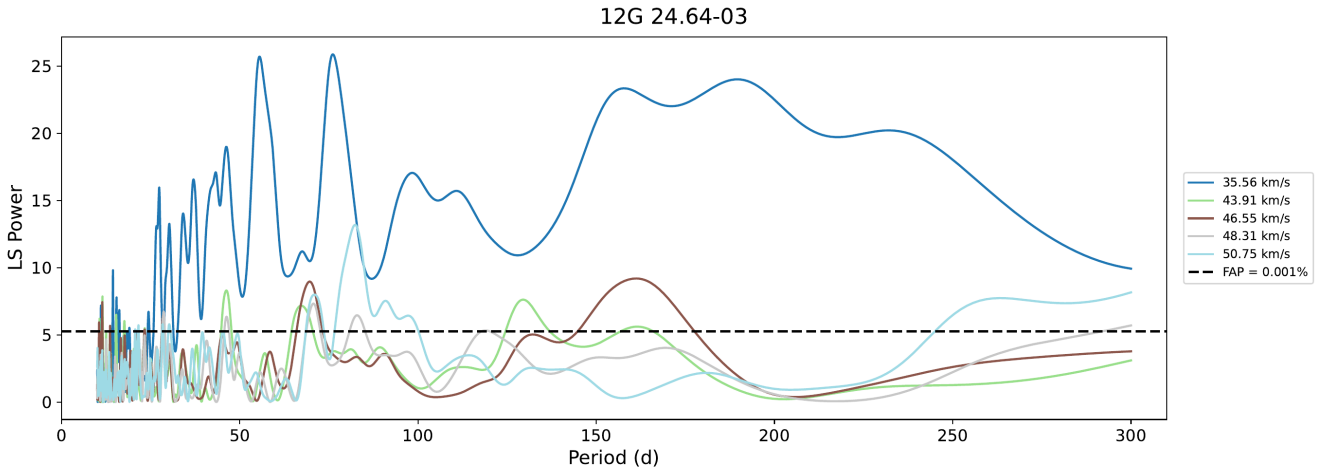


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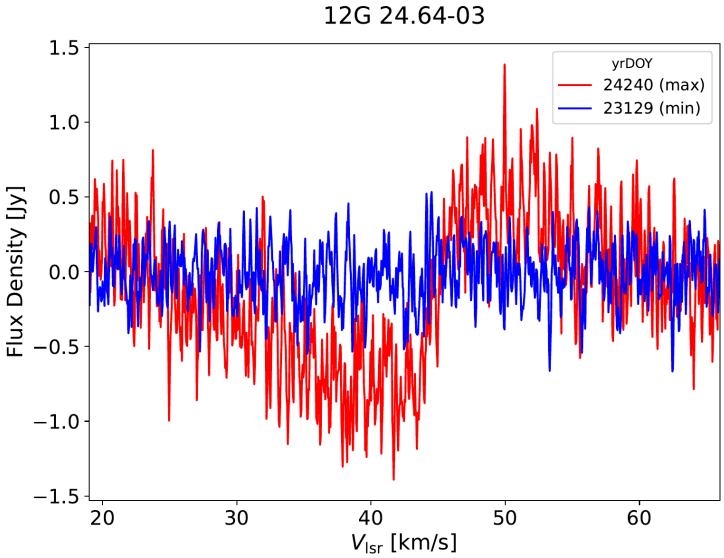
Light curve



Periodogram

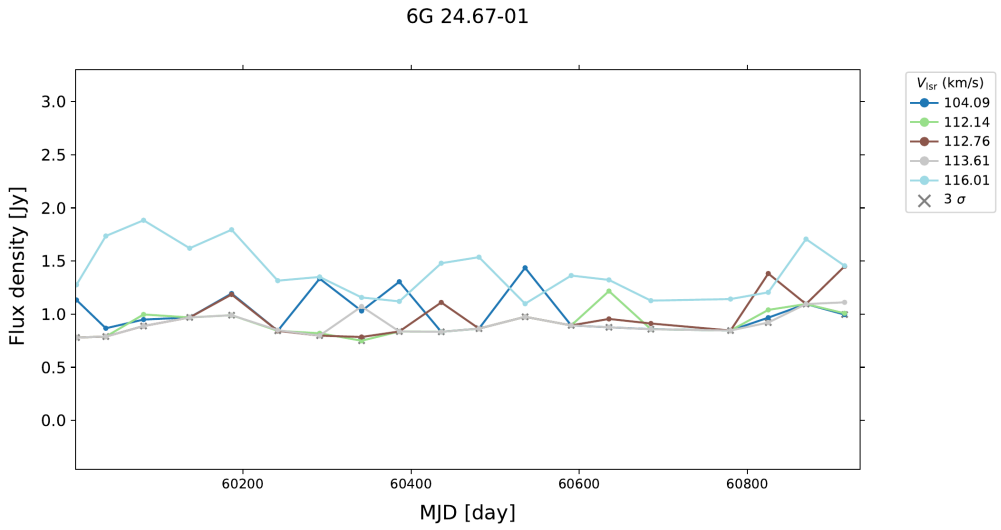


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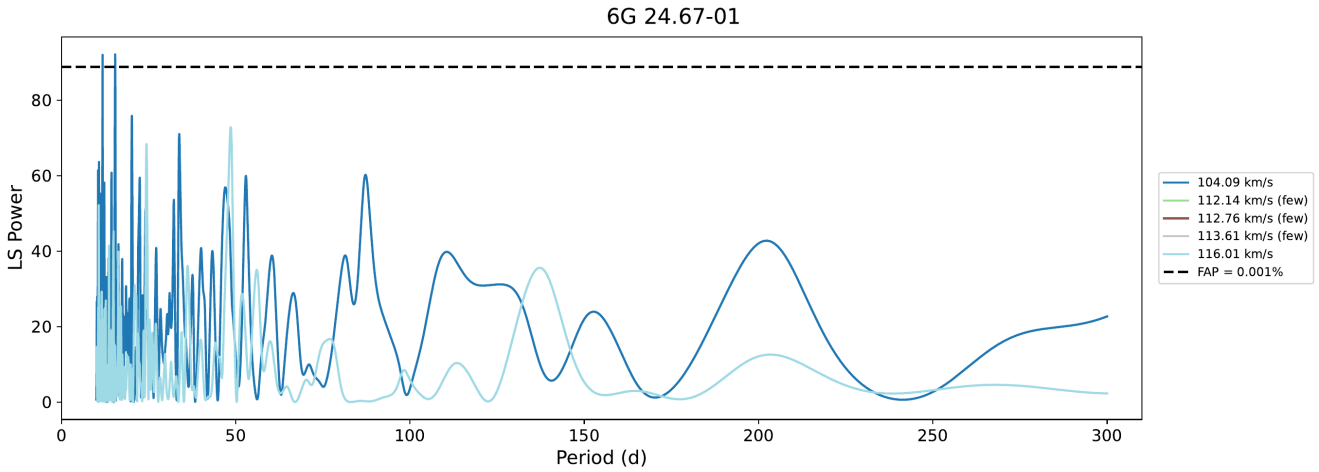


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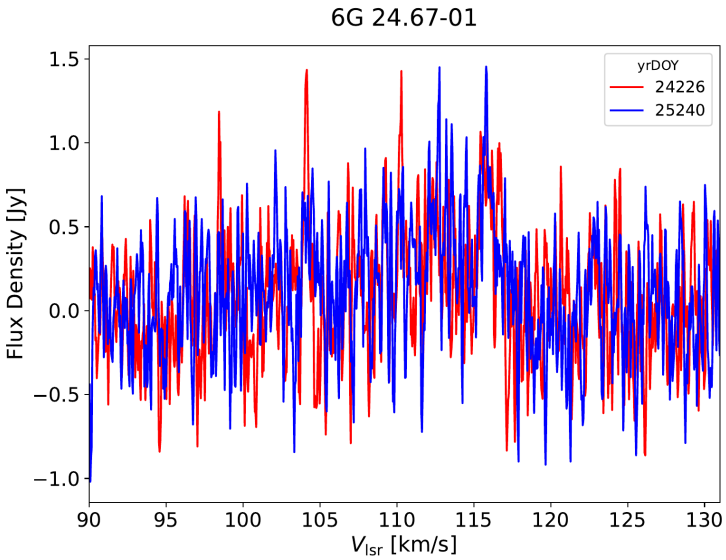
Light curve



Periodogram

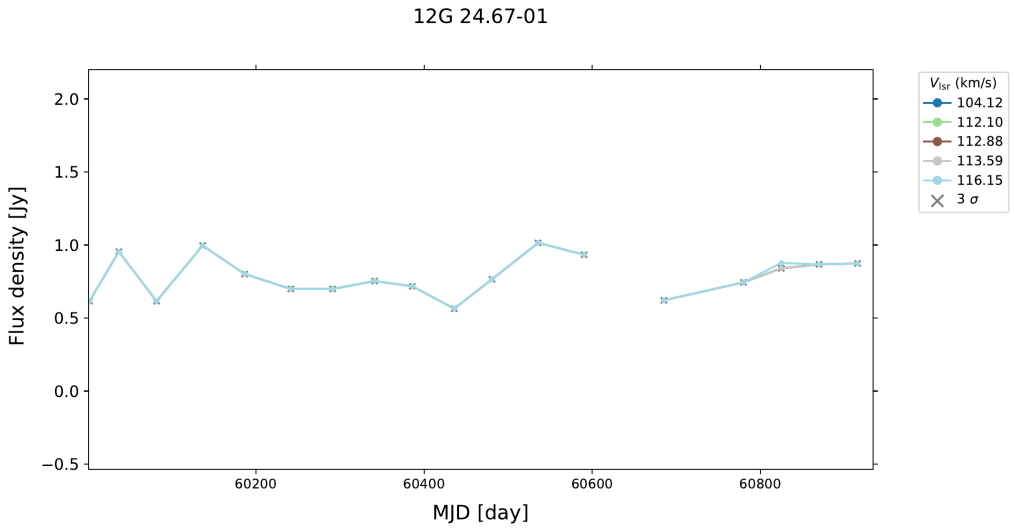


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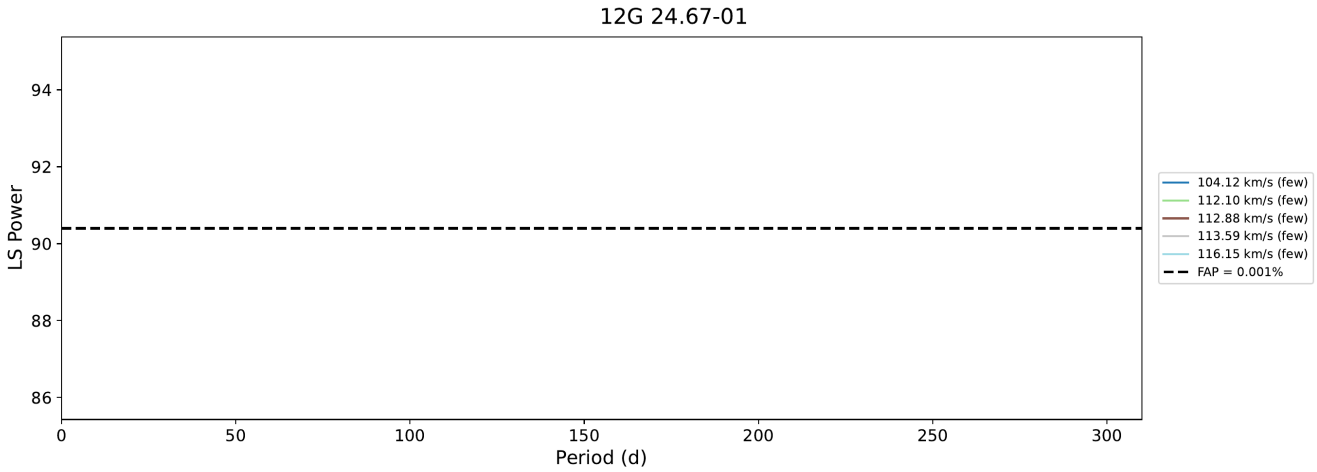


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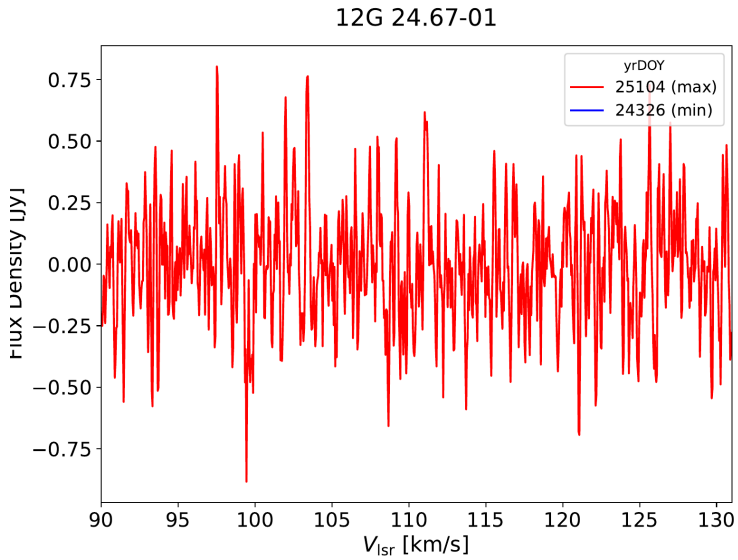
Light curve



Periodogram

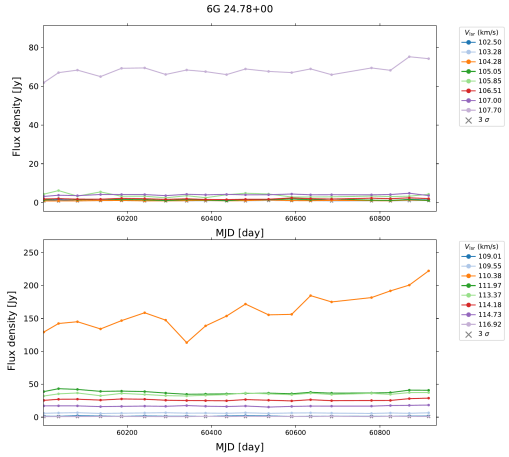


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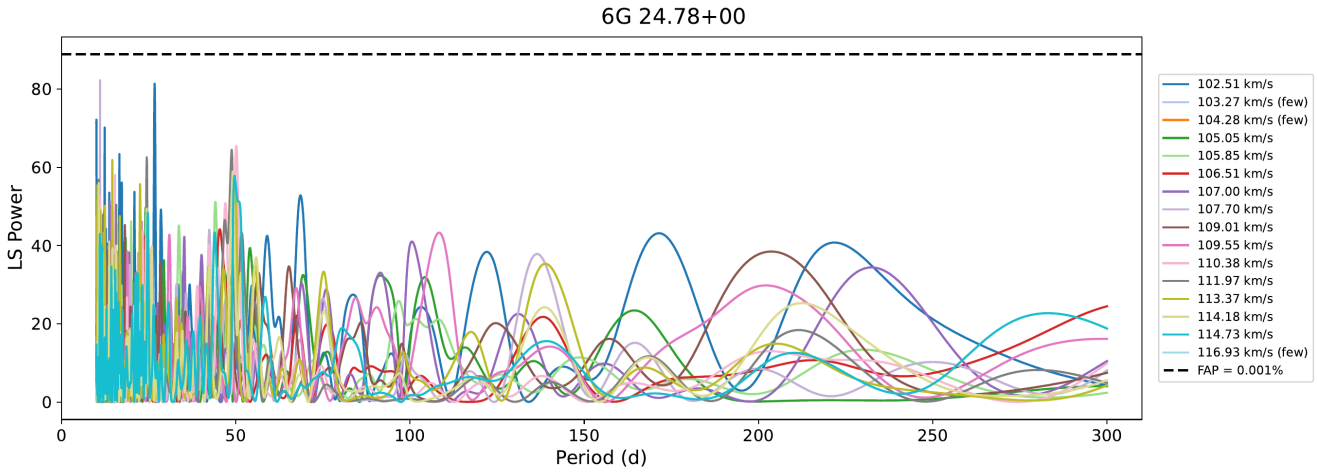


6G 24.78+00

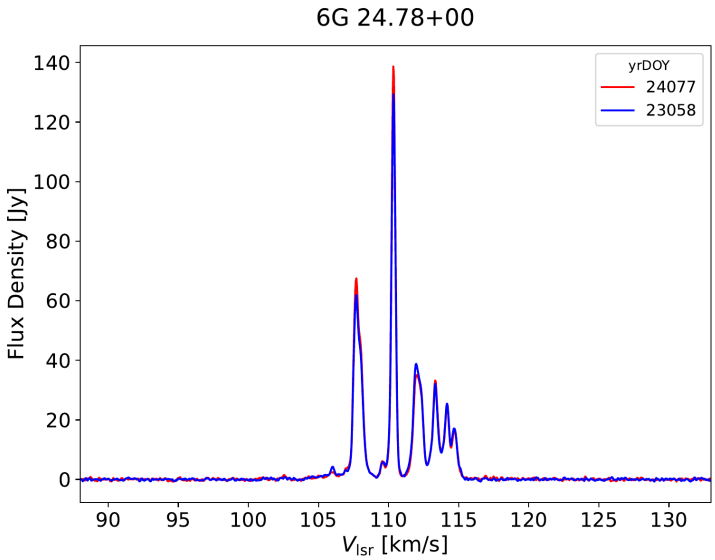
Light curve



Periodogram

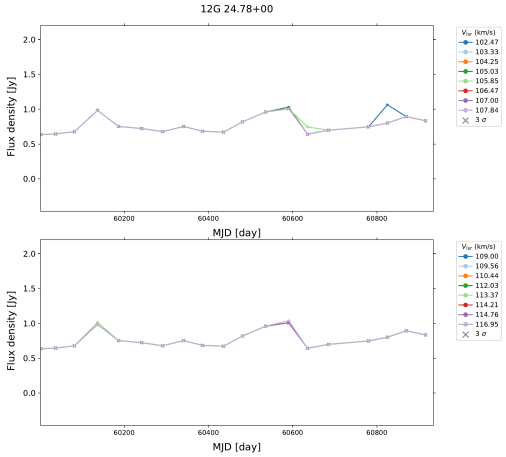


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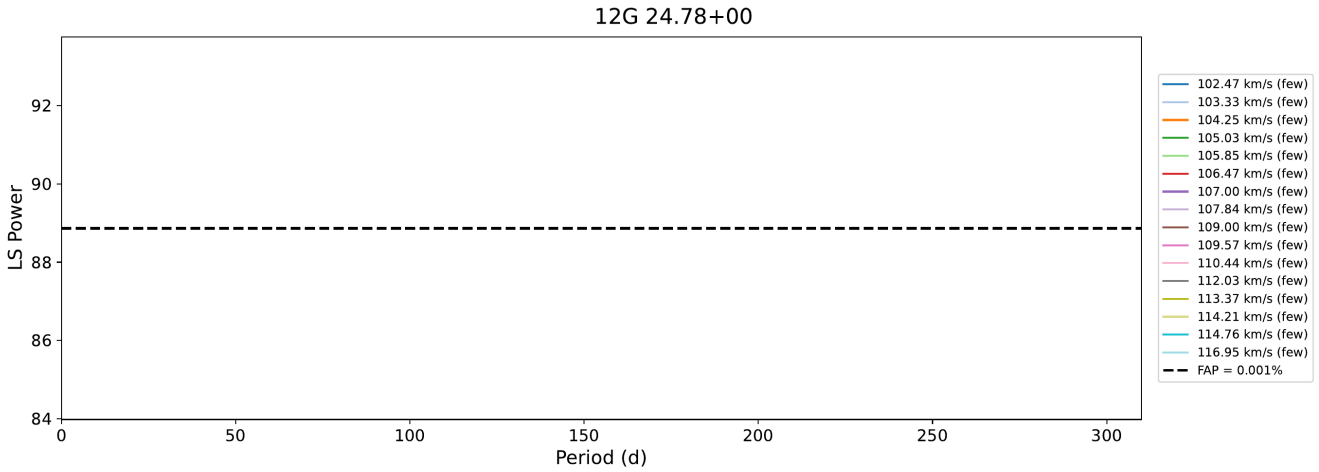


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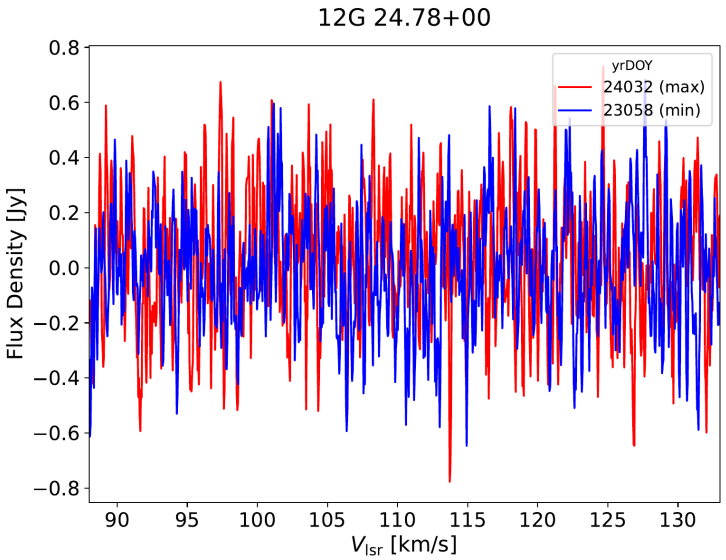
Light curve



Periodogram

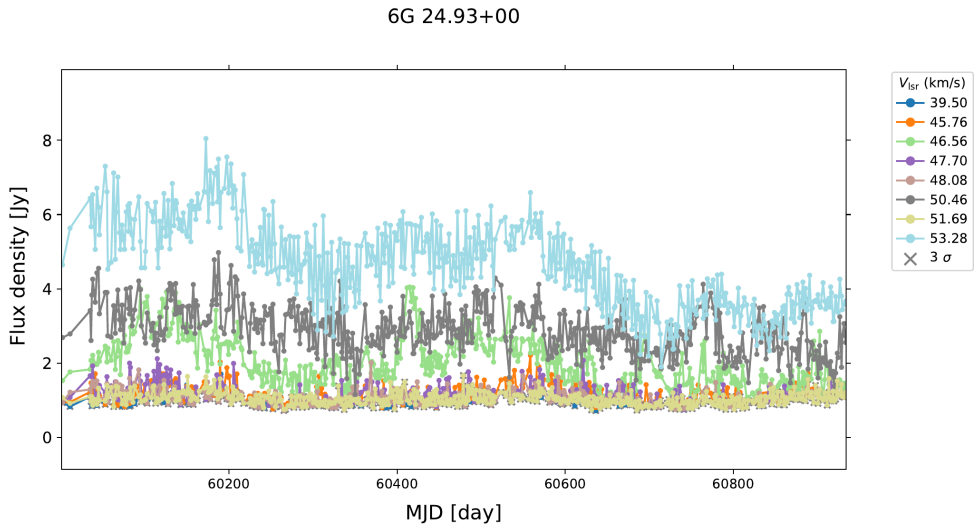


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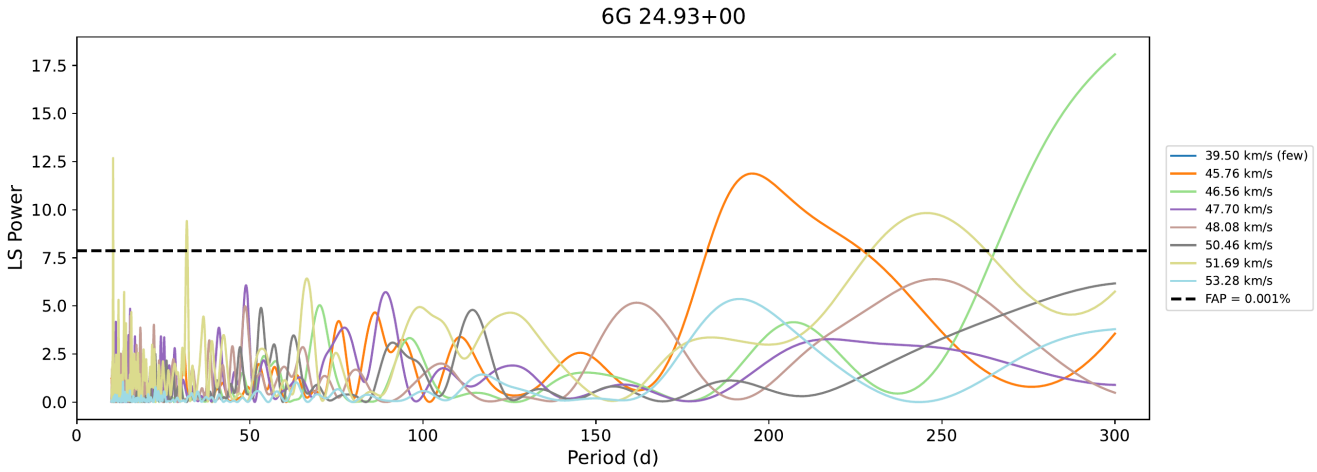


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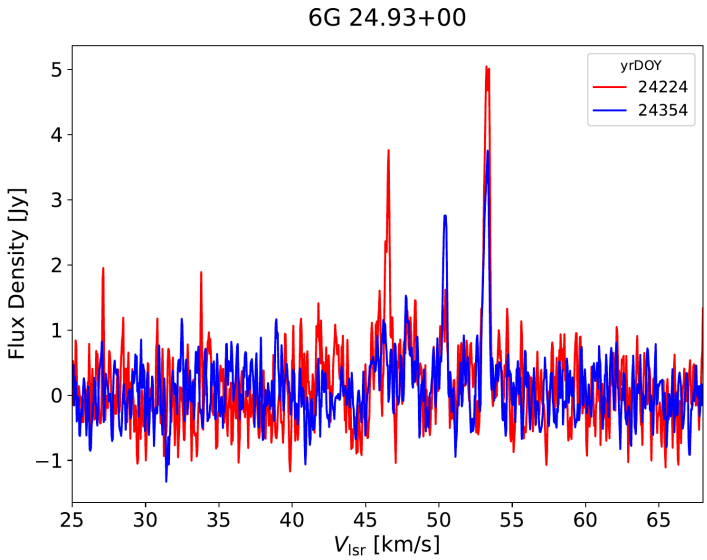
Light curve



Periodogram

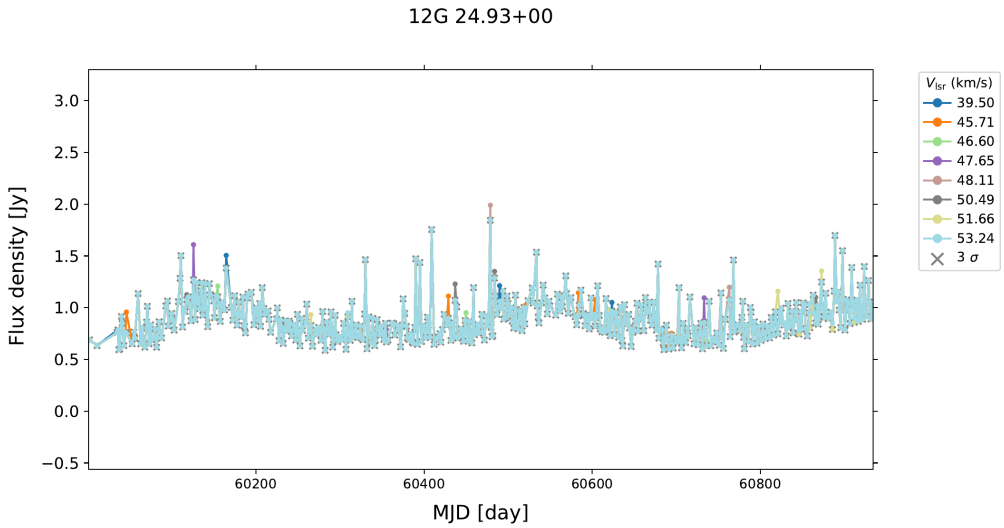


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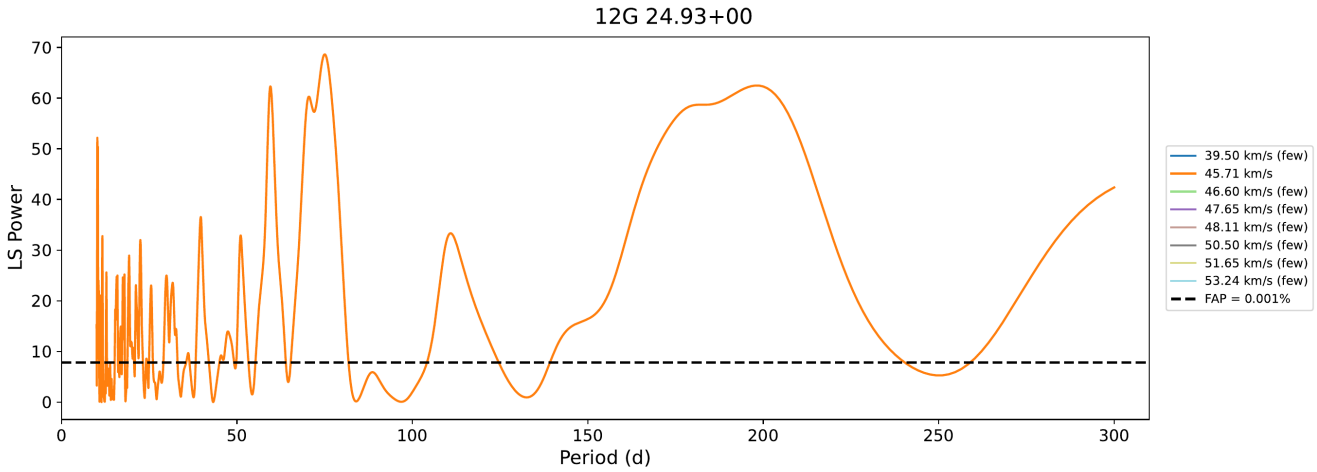


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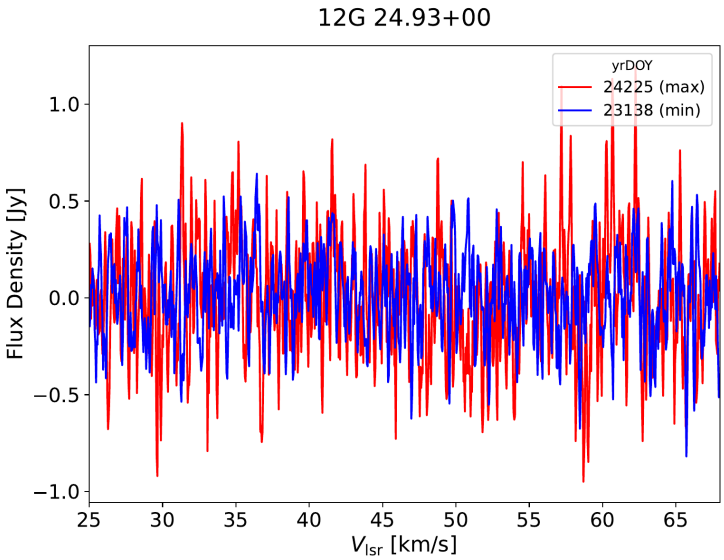
Light curve



Periodogram

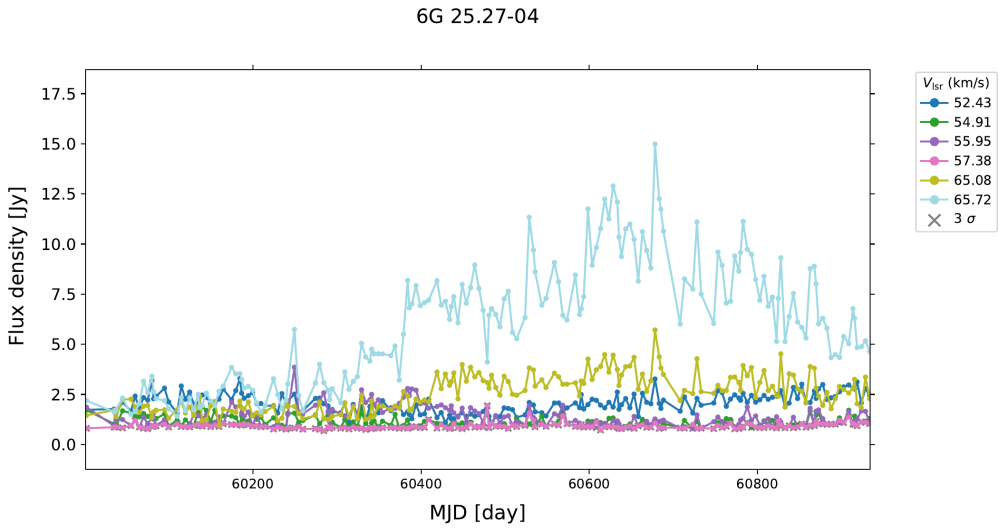


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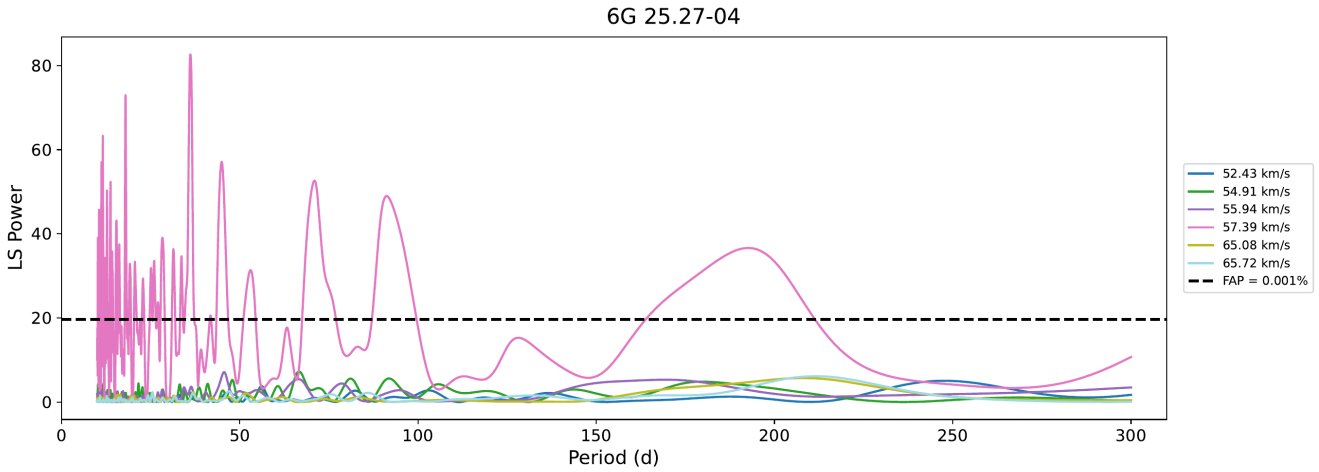


6G 25.27-04

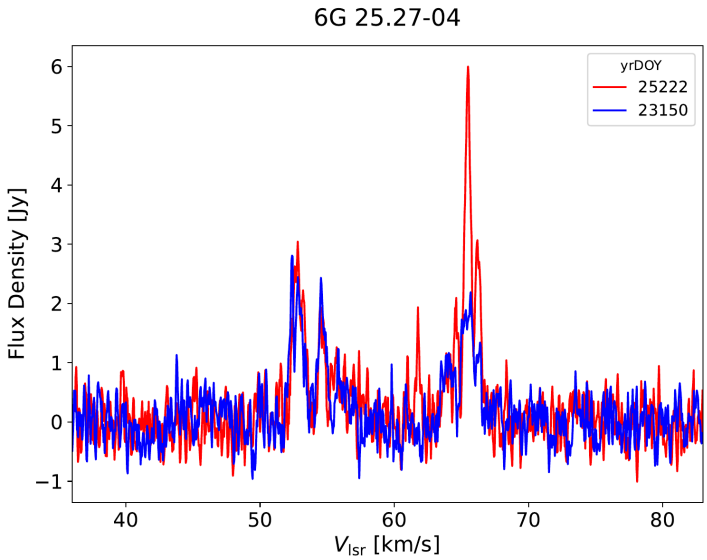
Light curve



Periodogram

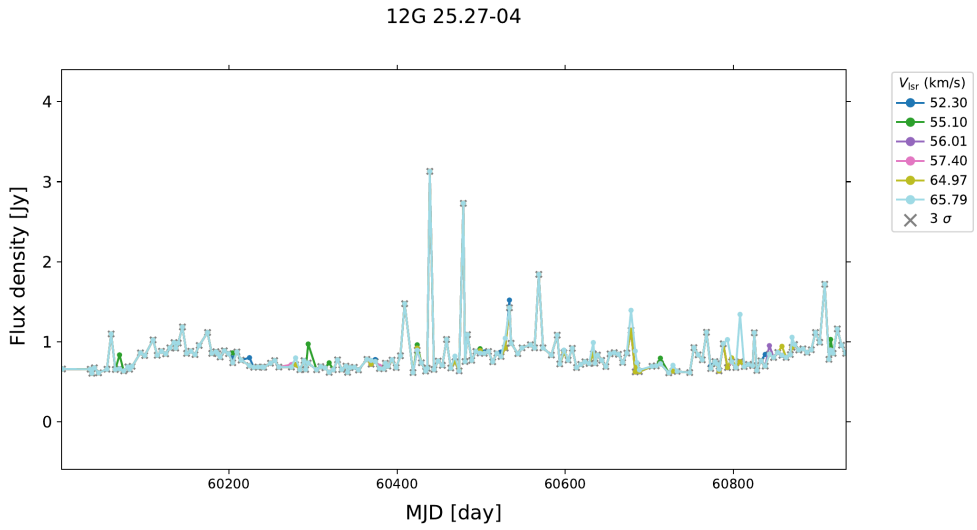


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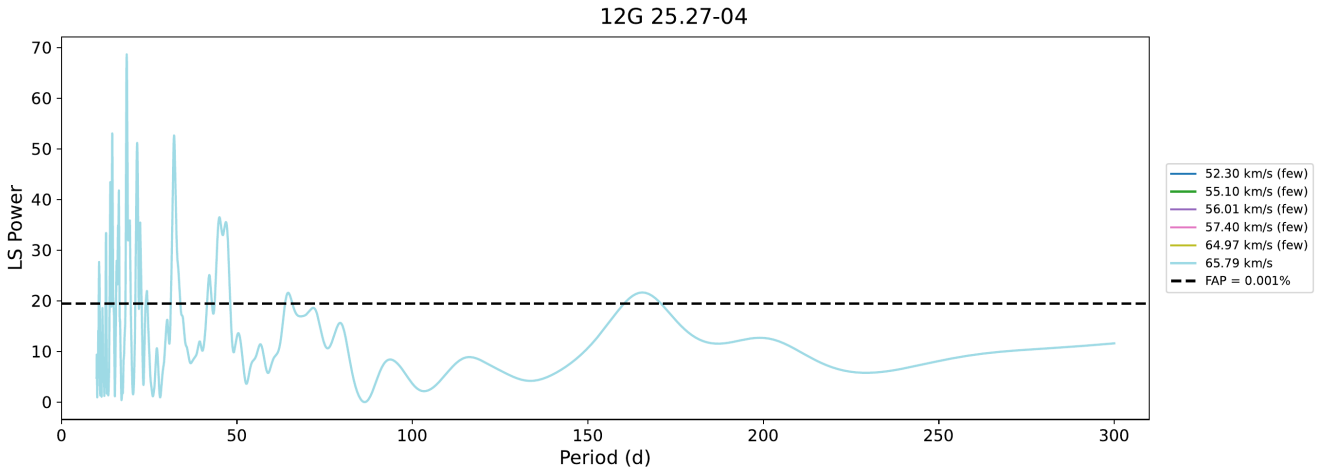


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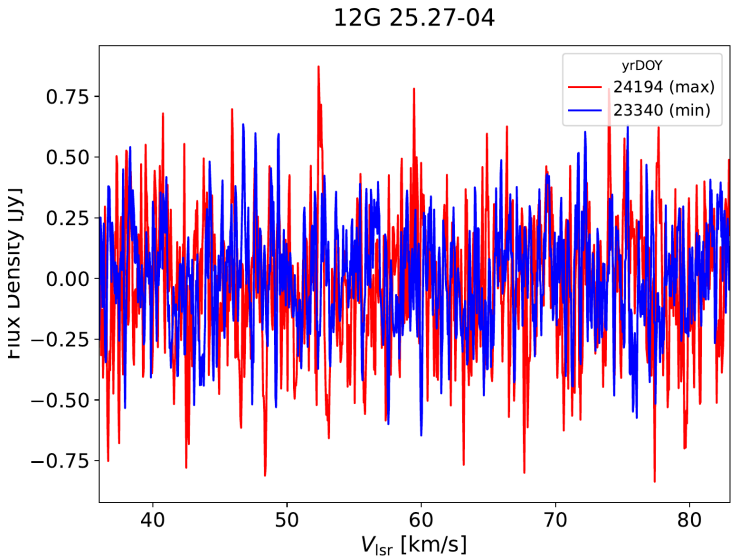
Light curve



Periodogram

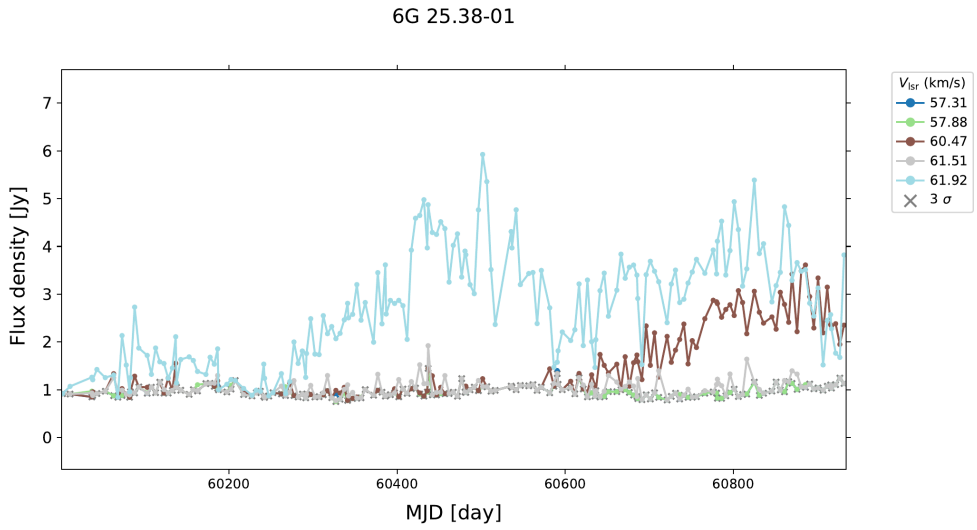


Spectrum

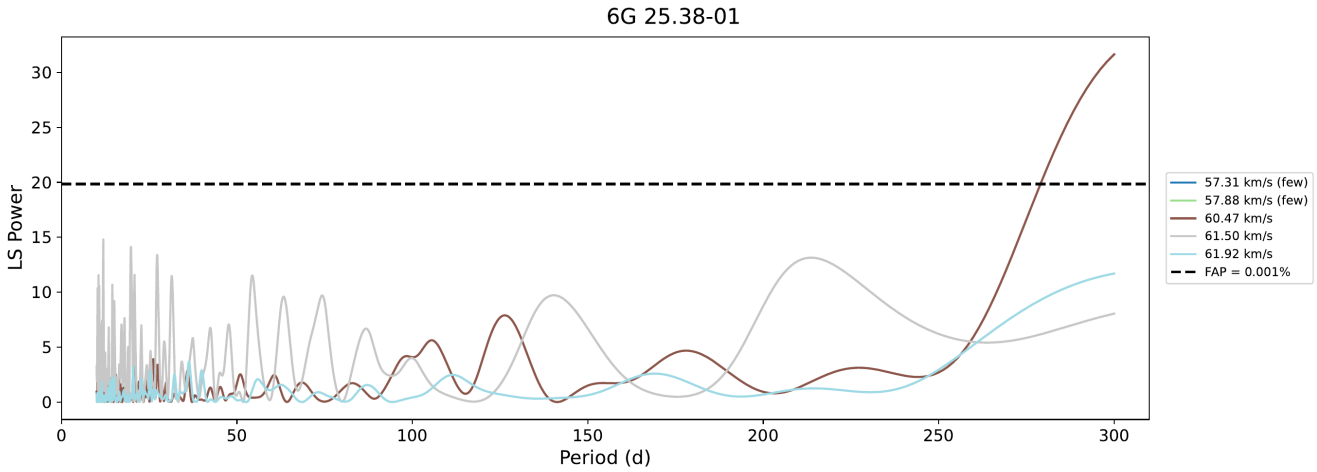


6G 25.38-01

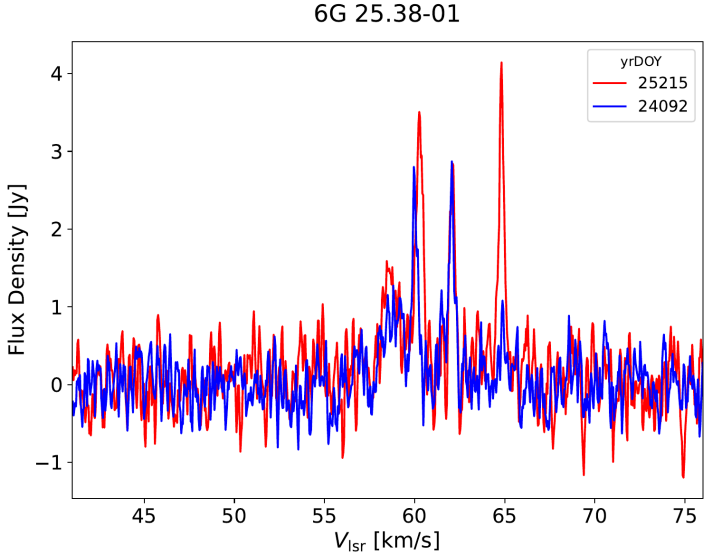
Light curve



Periodogram

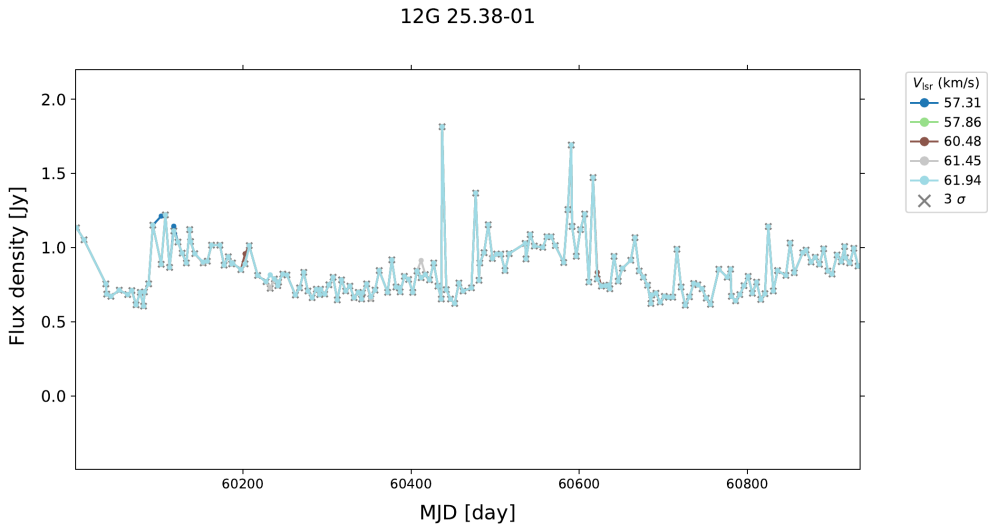


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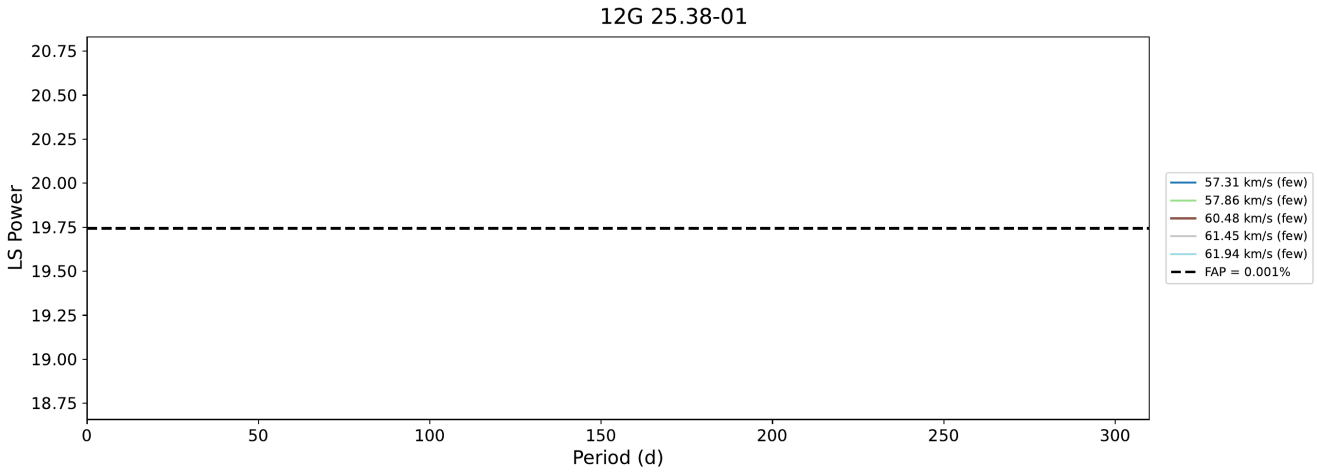


12G 25.38-01

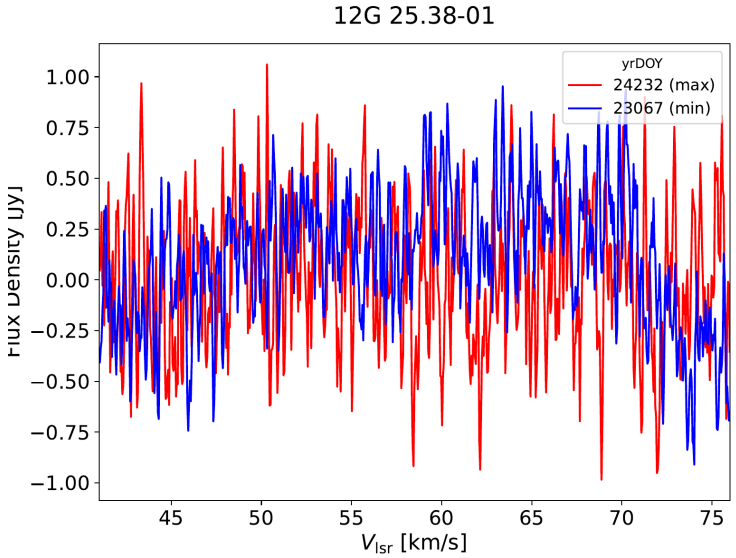
Light curve



Periodogram

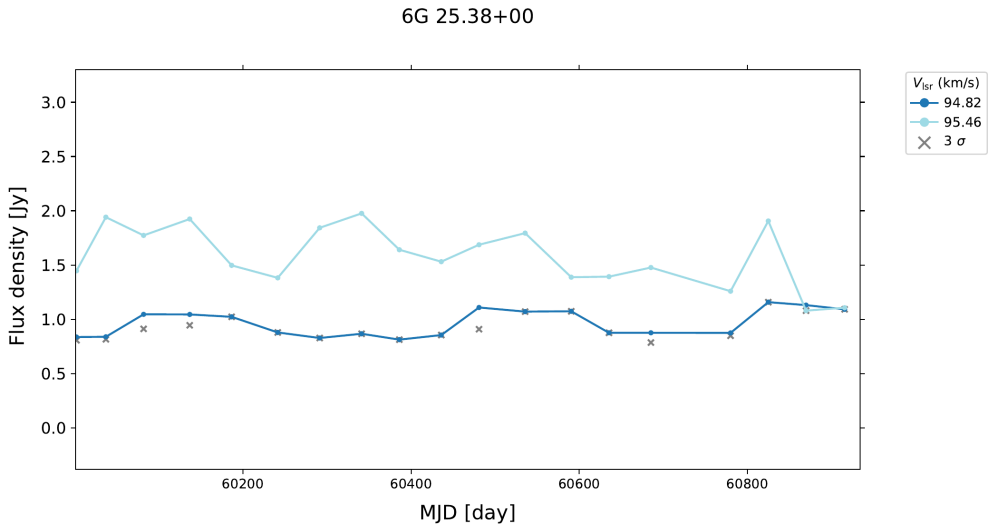


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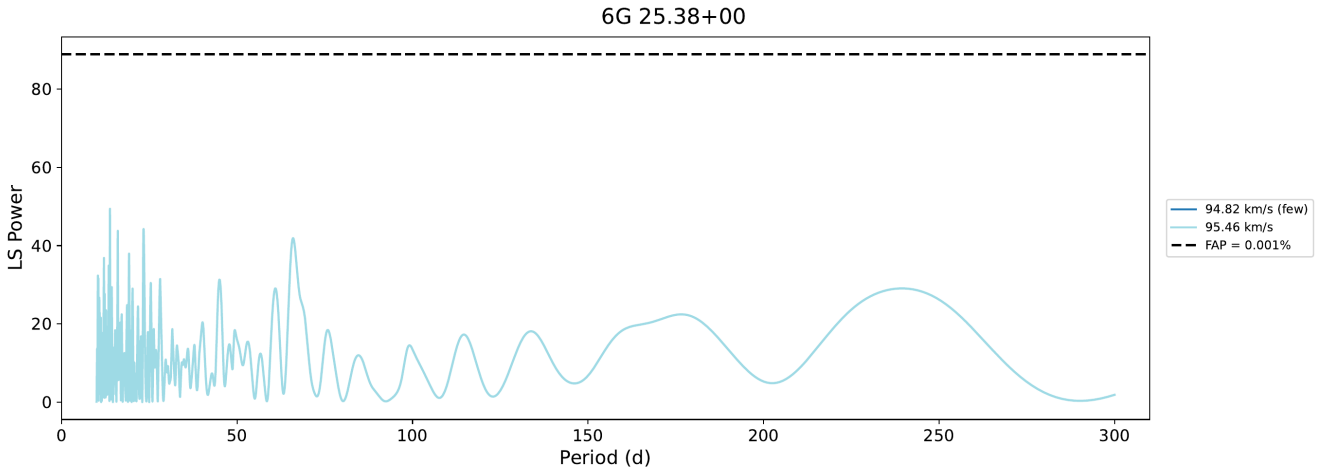


6G 25.38+00

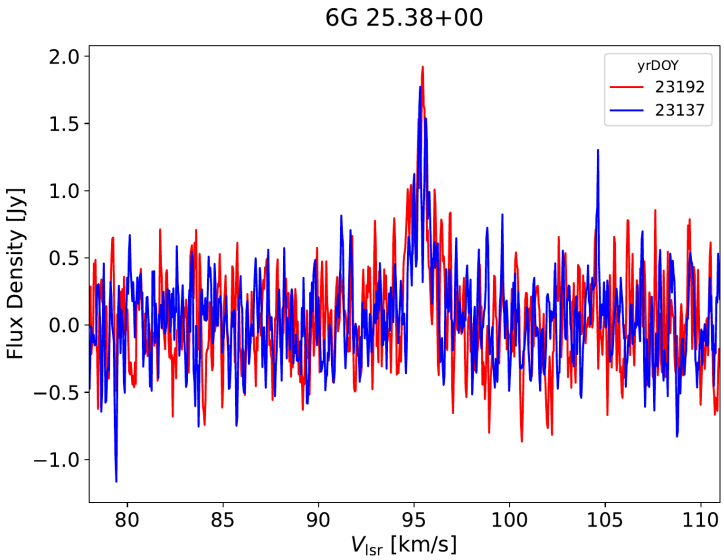
Light curve



Periodogram

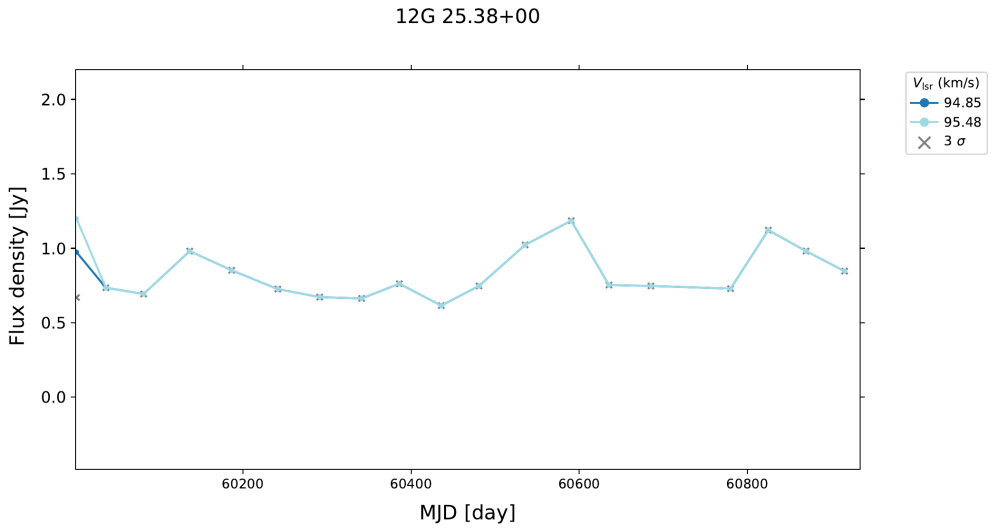


Spectrum

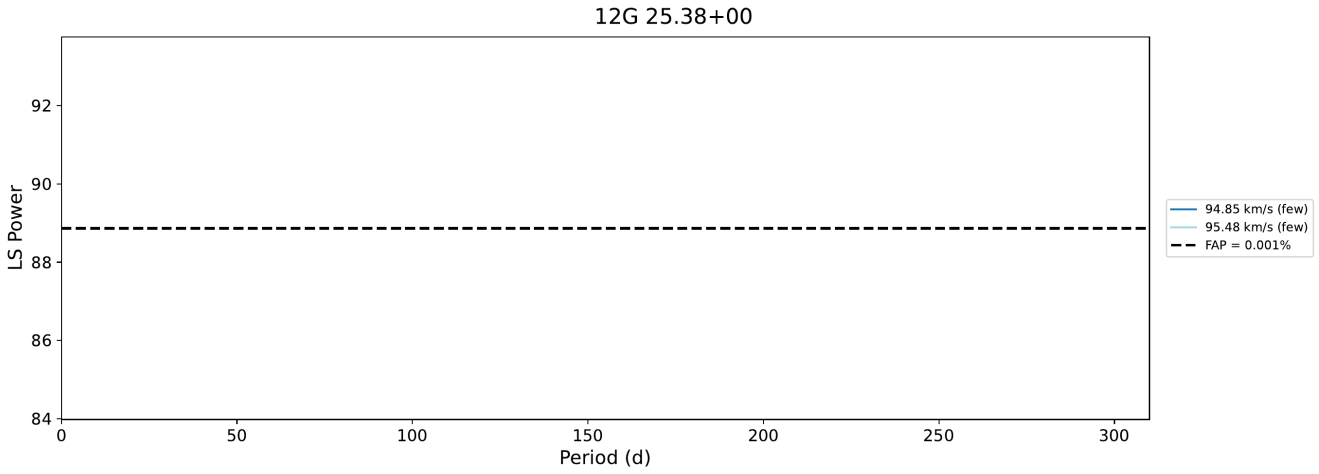


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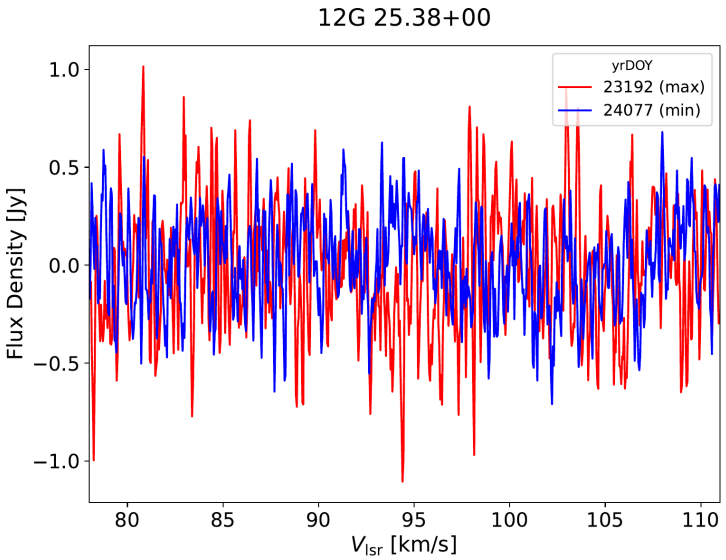
Light curve



Periodogram

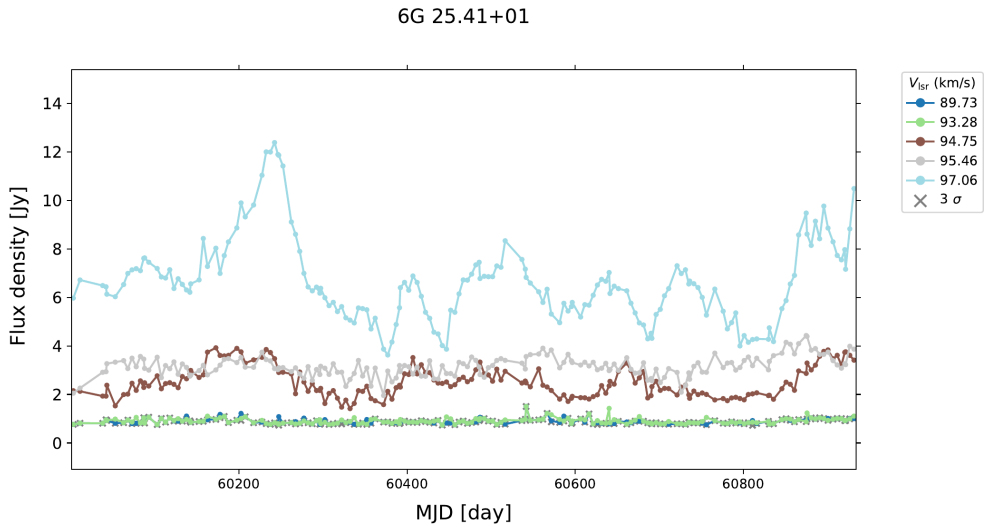


Spectrum

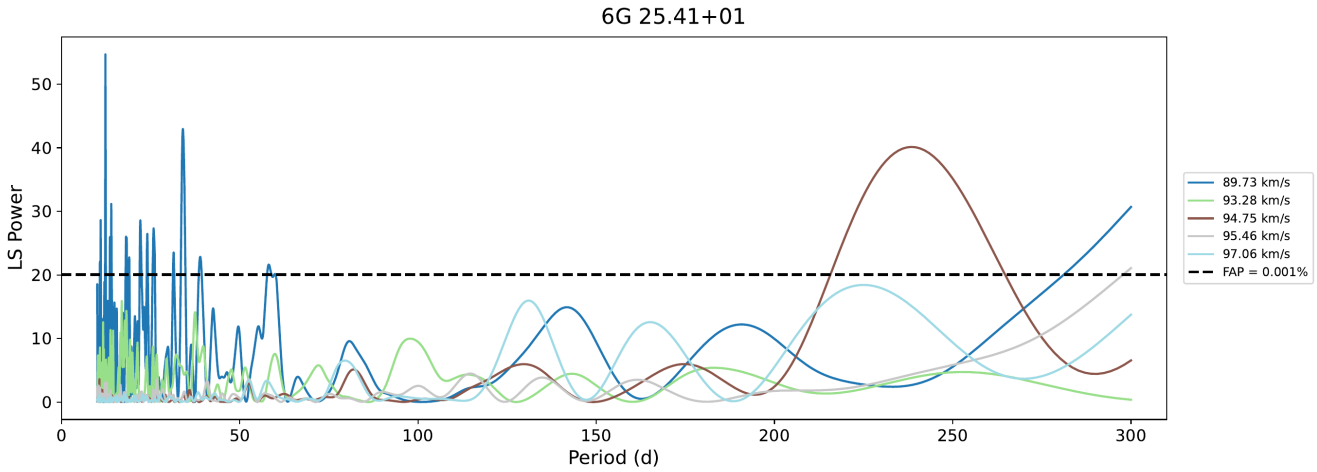


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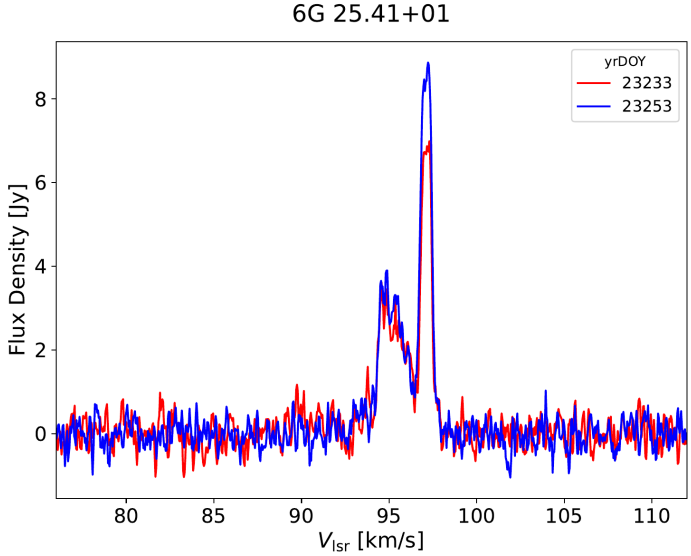
Light curve



Periodogram

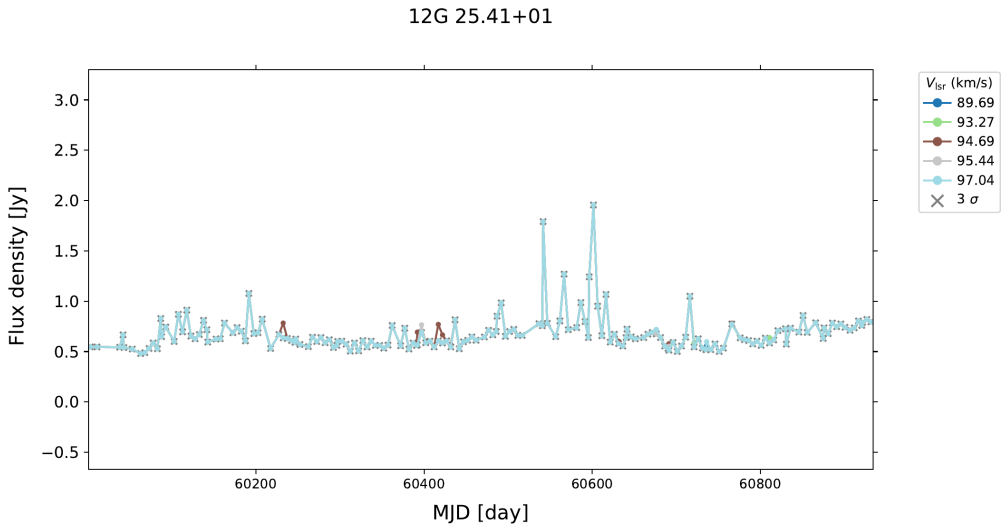


Spectrum

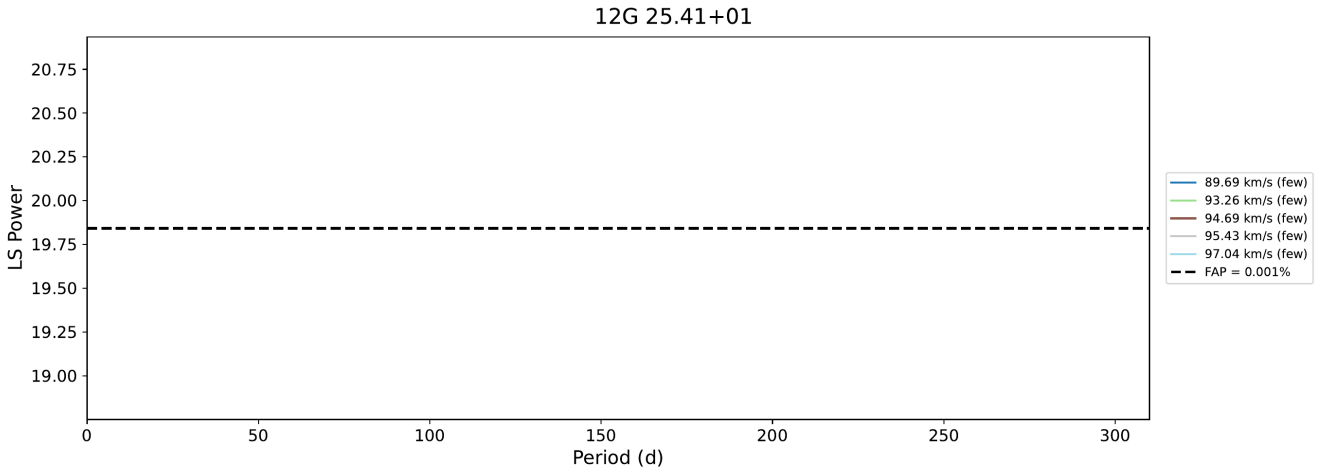


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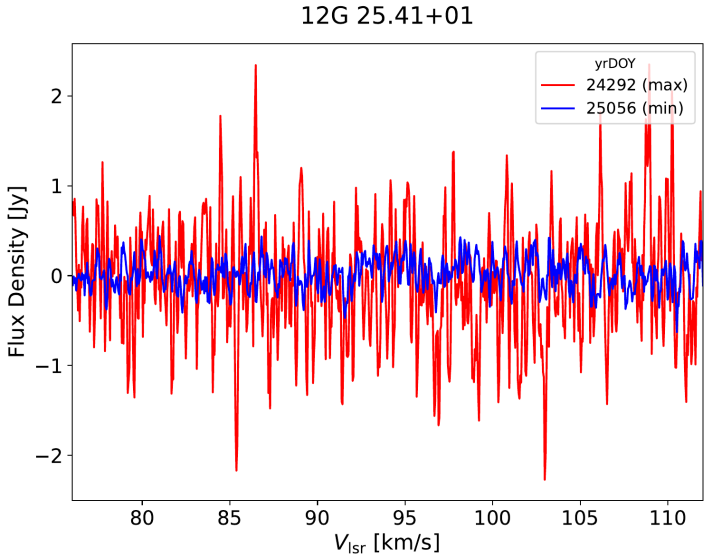
Light curve



Periodogram

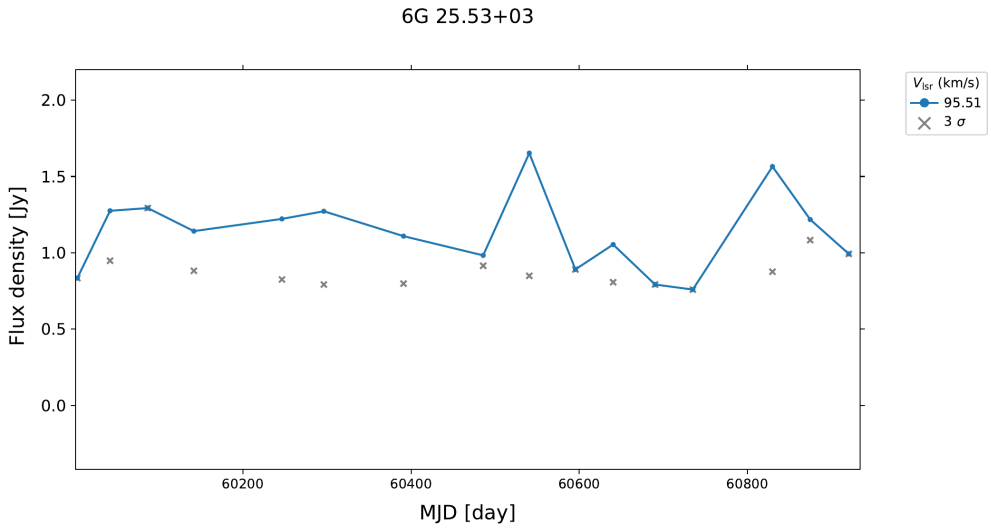


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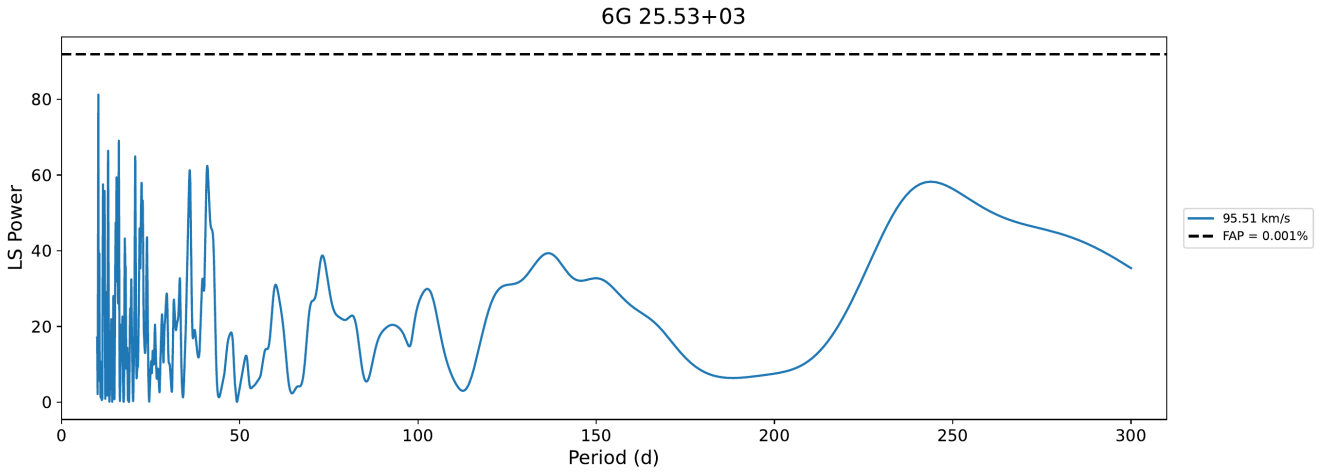


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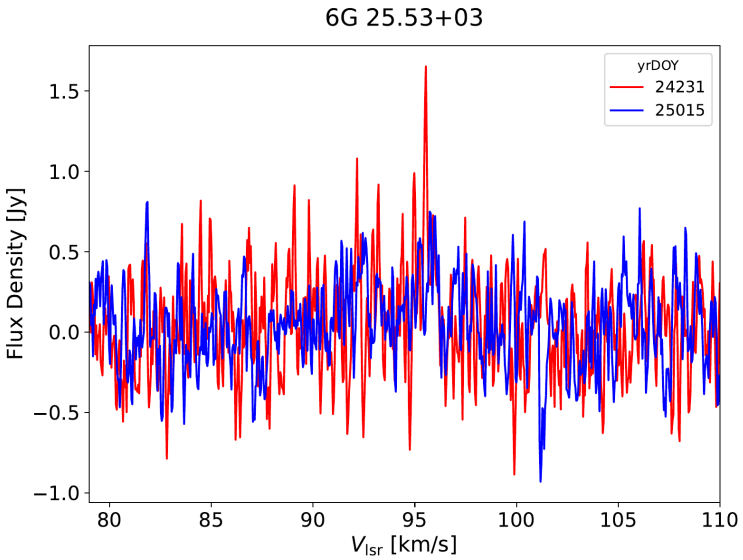
Light curve



Periodogram

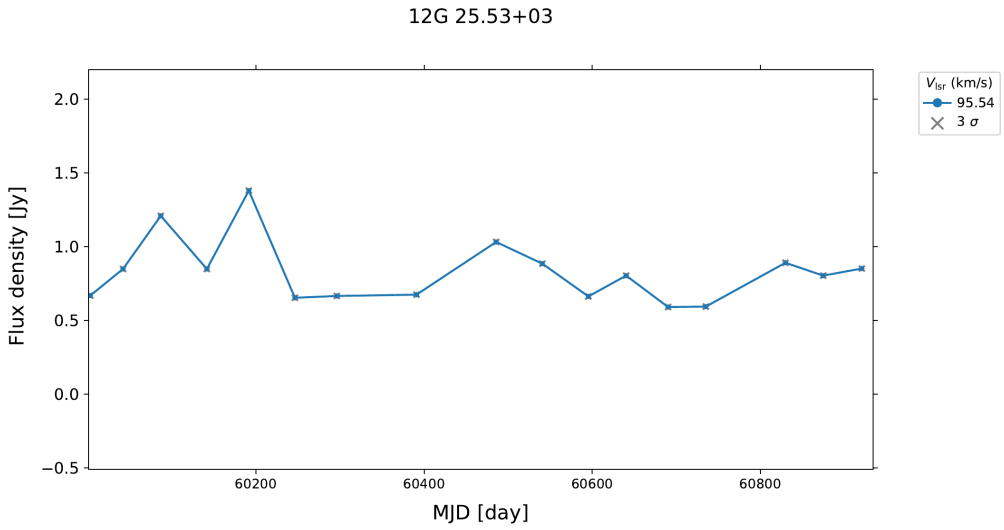


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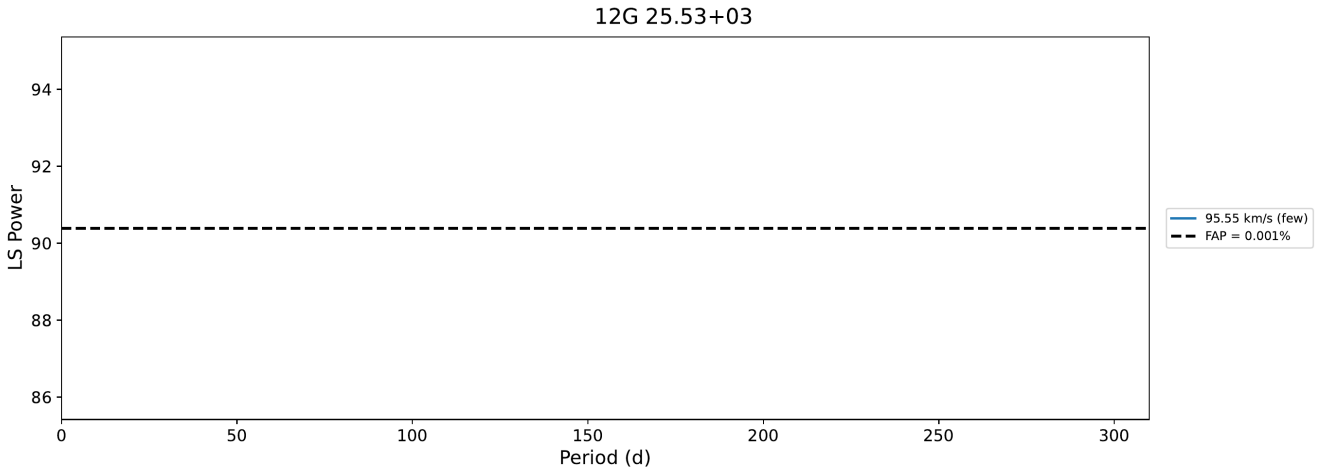


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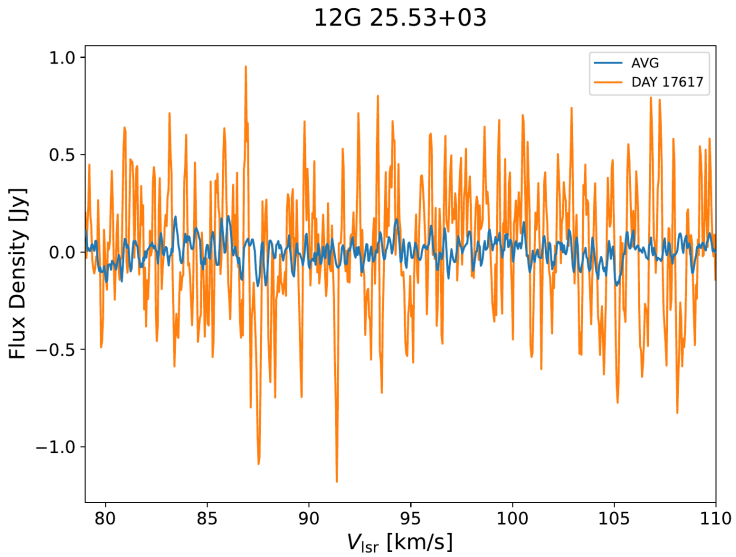
Light curve



Periodogram

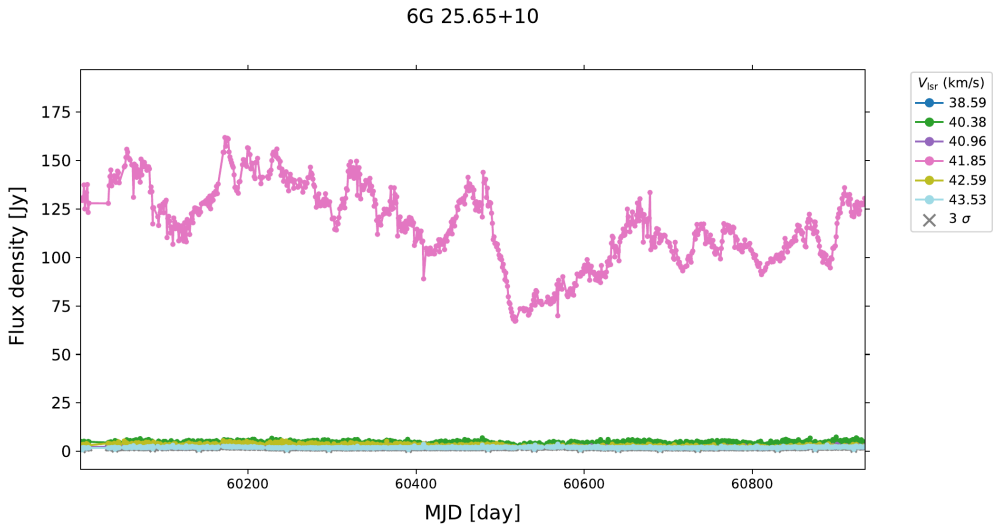


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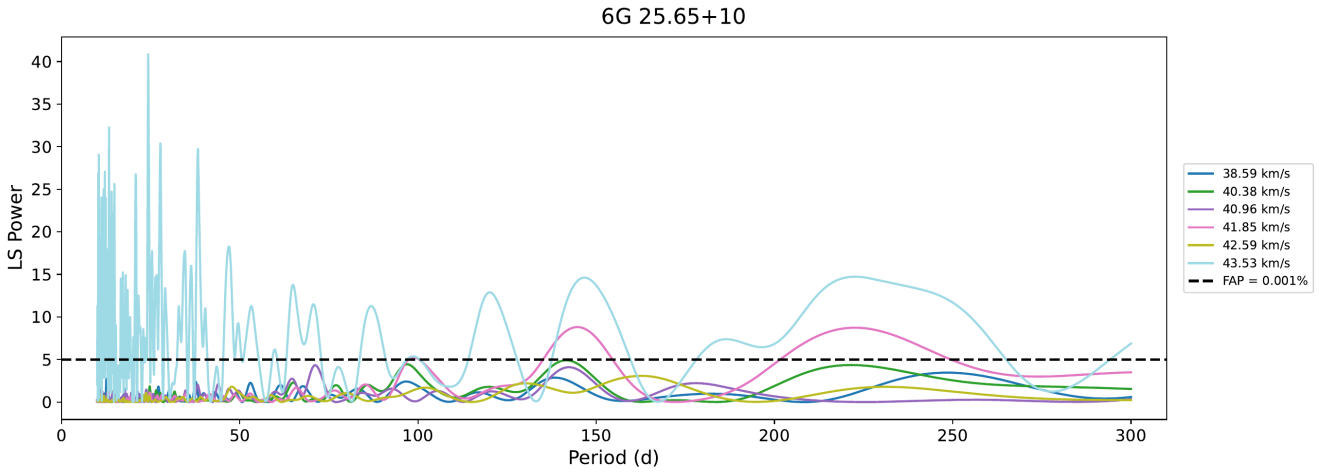


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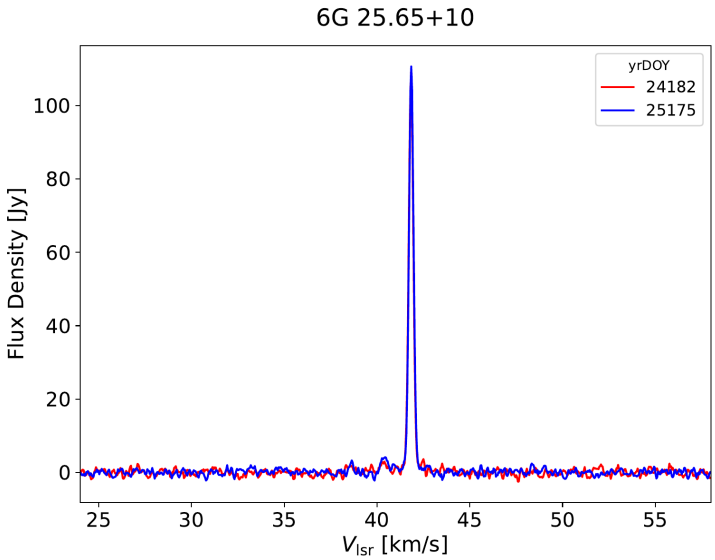
Light curve



Periodogram

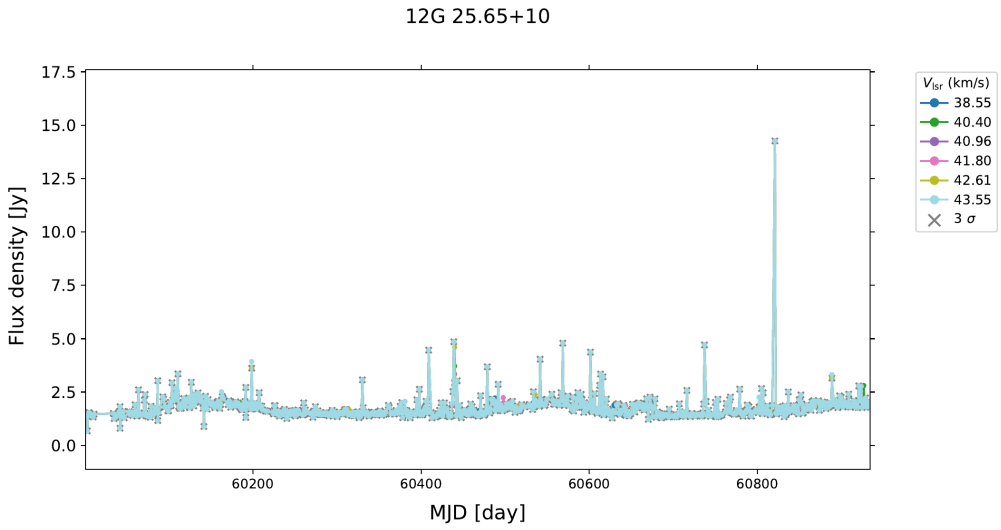


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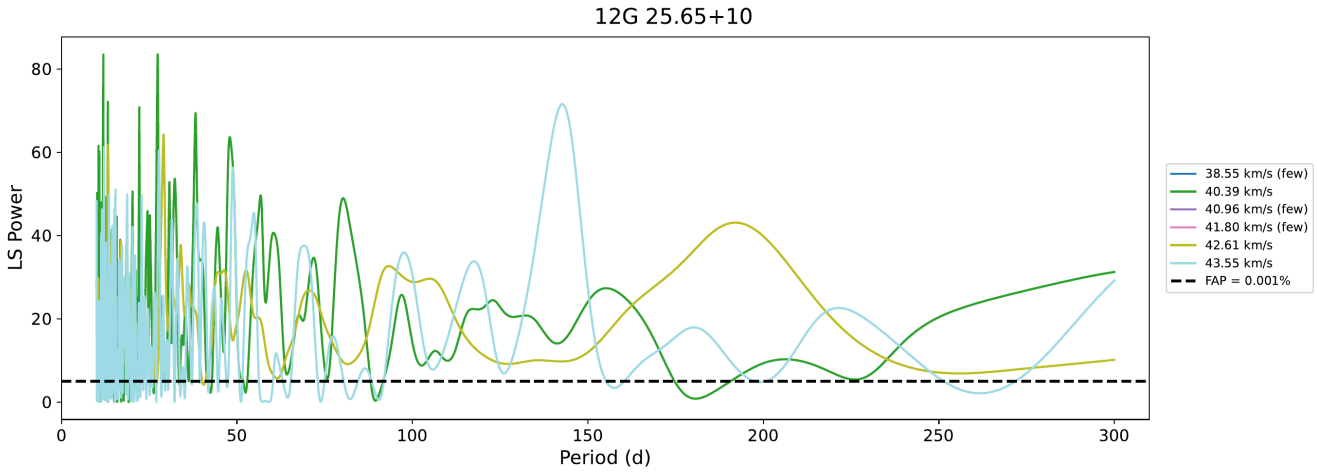


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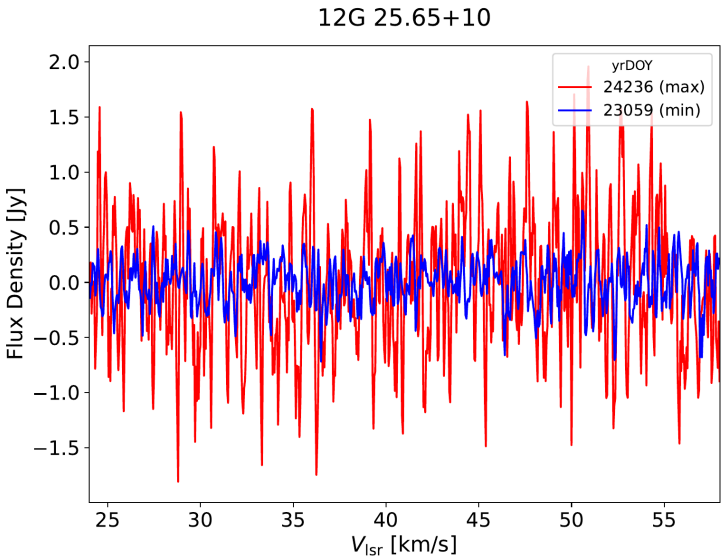
Light curve



Periodogram

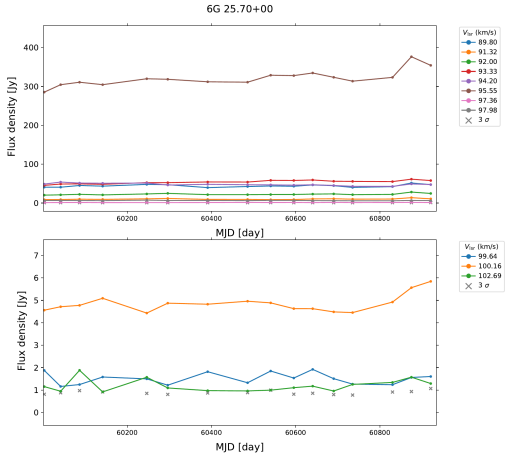


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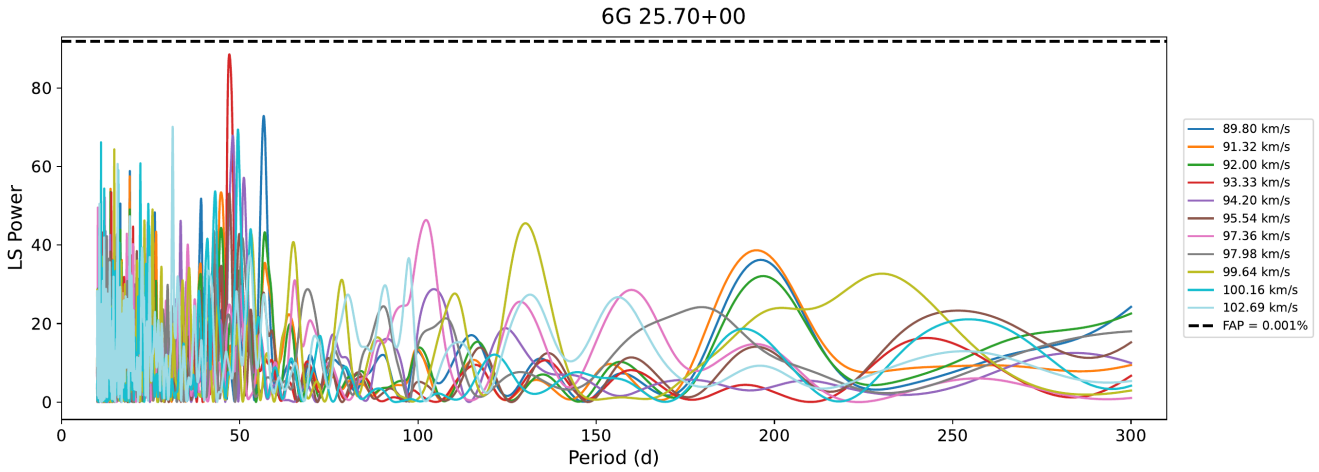


6G 25.70+00

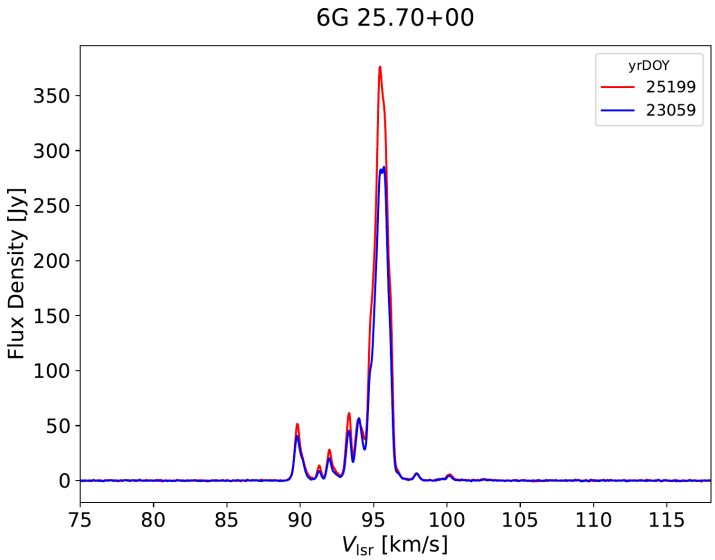
Light curve



Periodogram

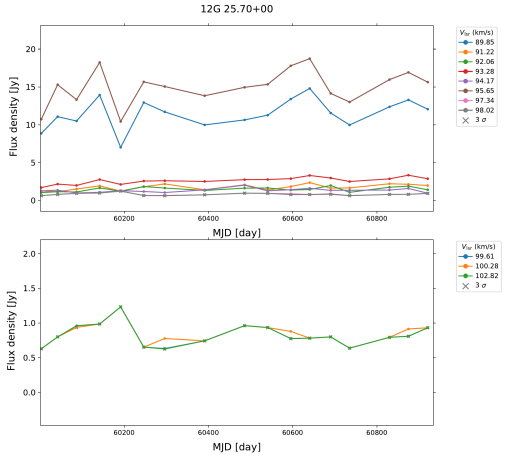


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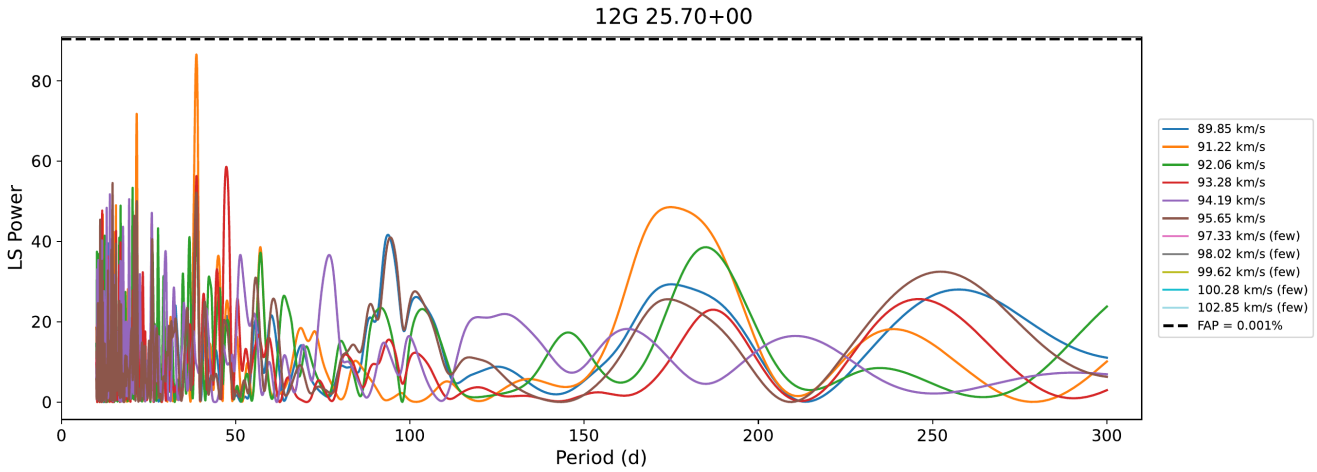


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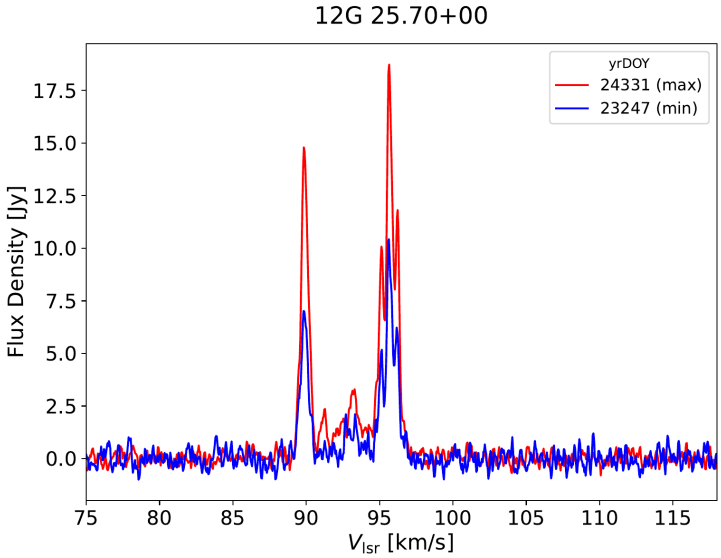
Light curve



Periodogram

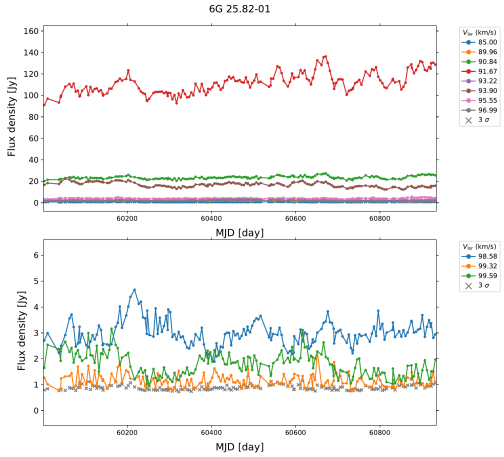


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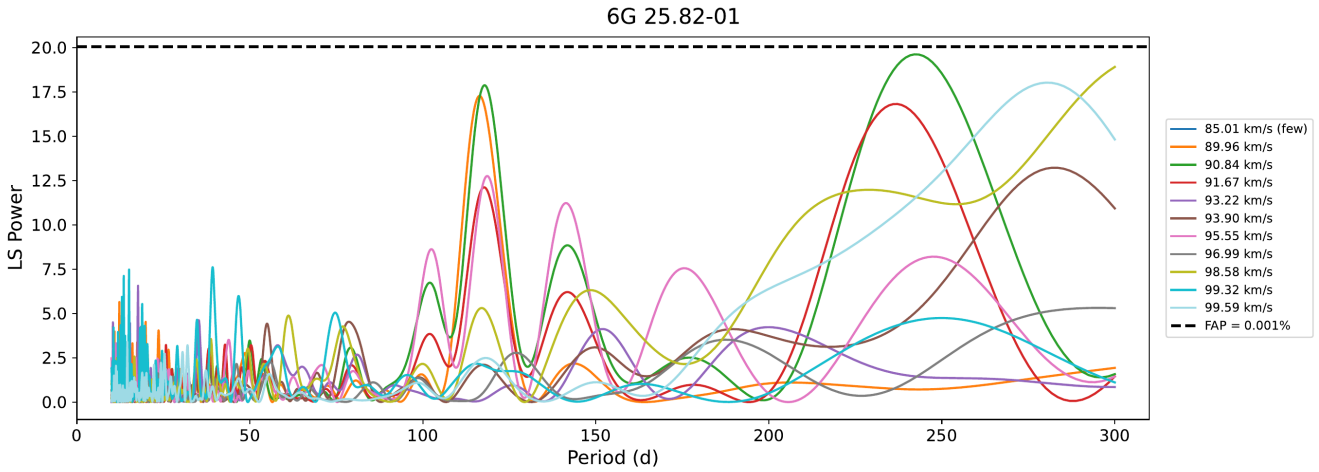


6G 25.82-01

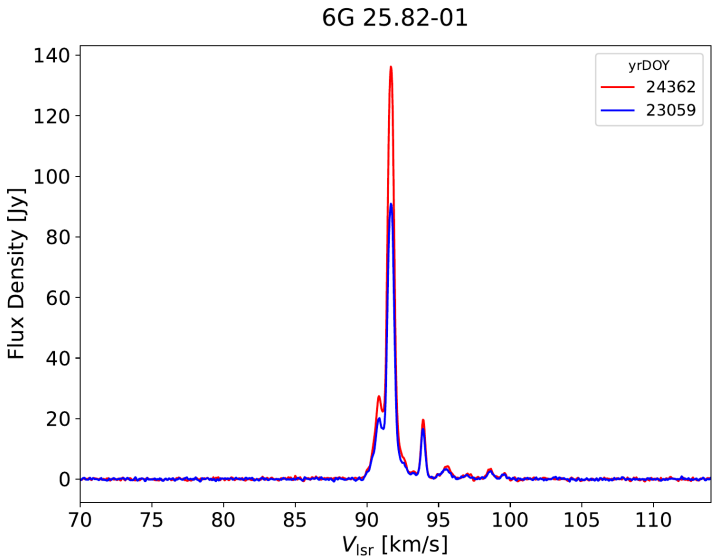
Light curve



Periodogram

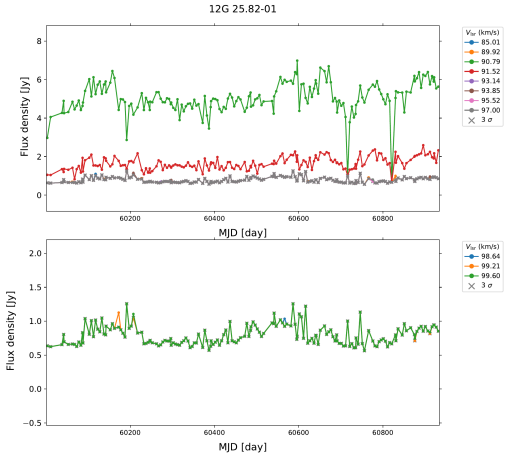


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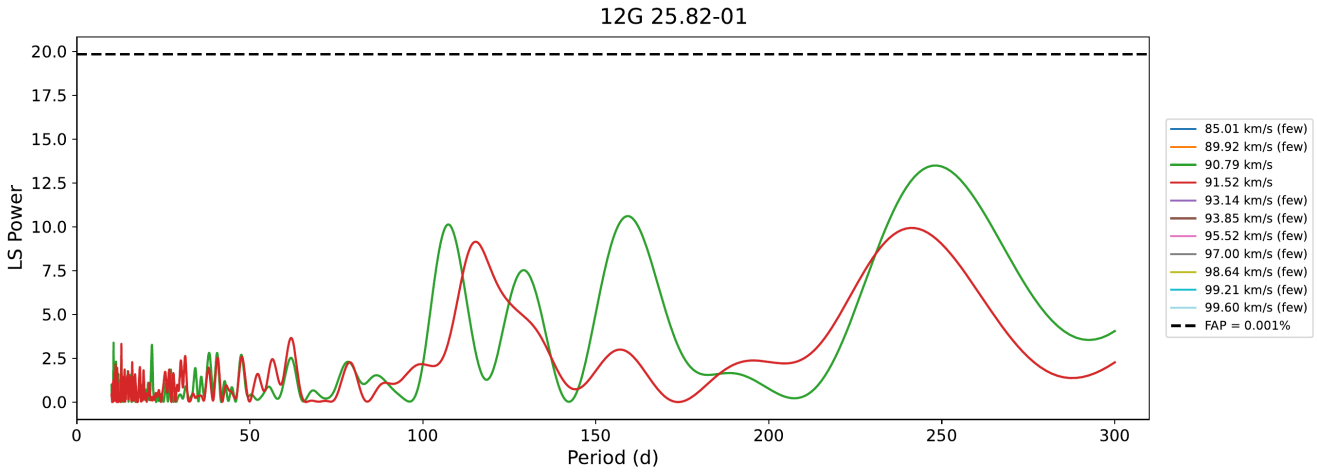


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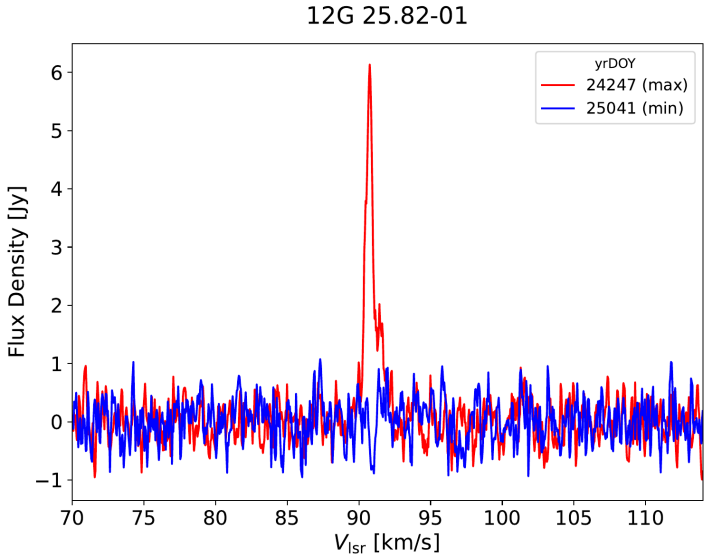
Light curve



Periodogram

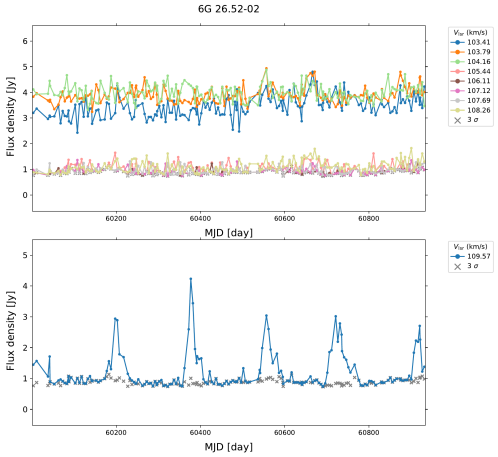


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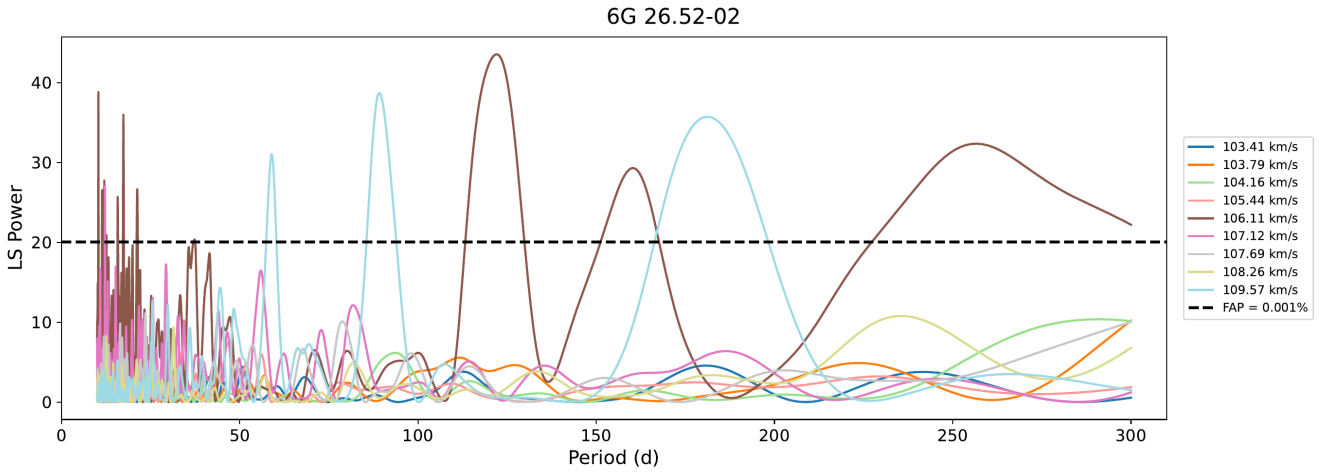


6G 26.52-02

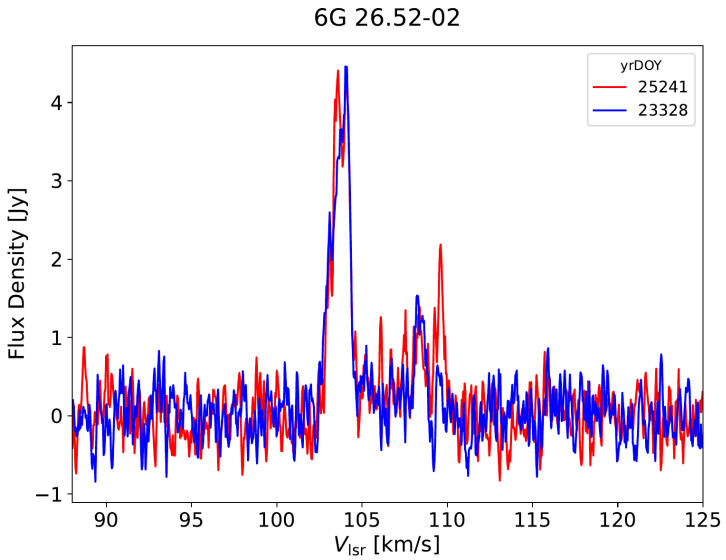
Light curve



Periodogram

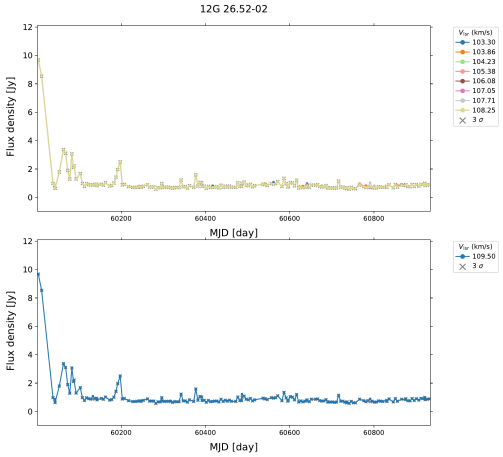


Spectrum

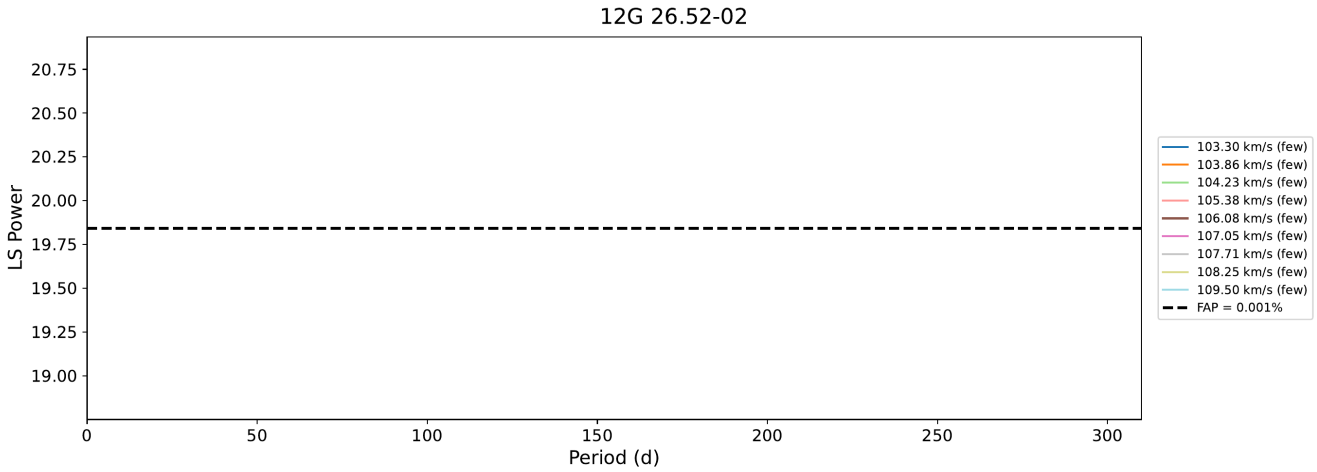


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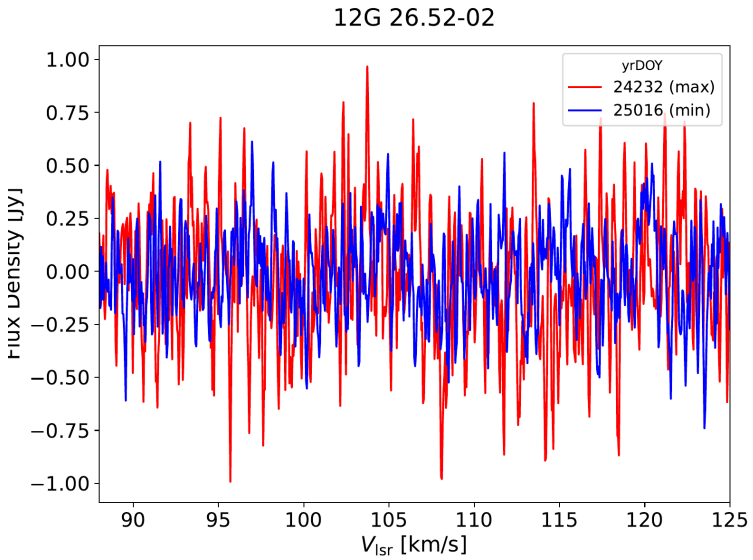
Light curve



Periodogram

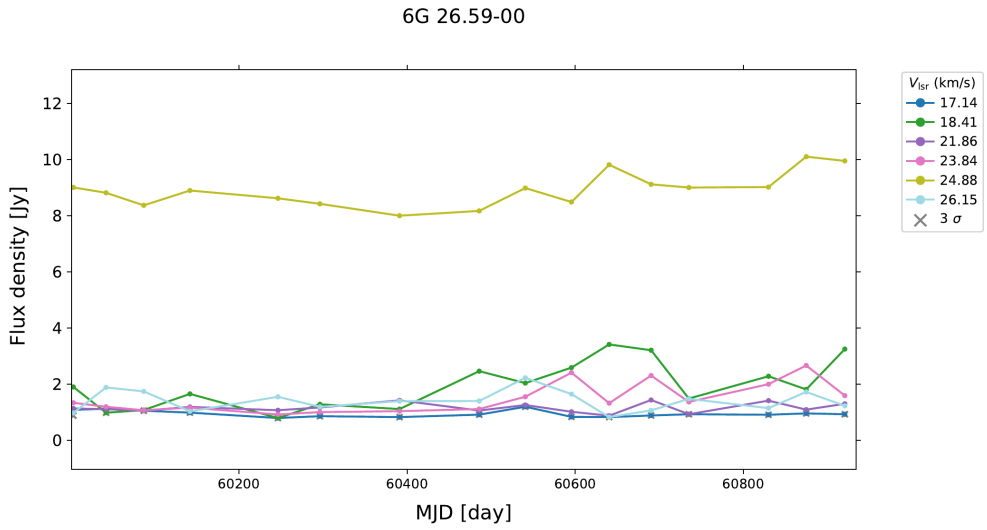


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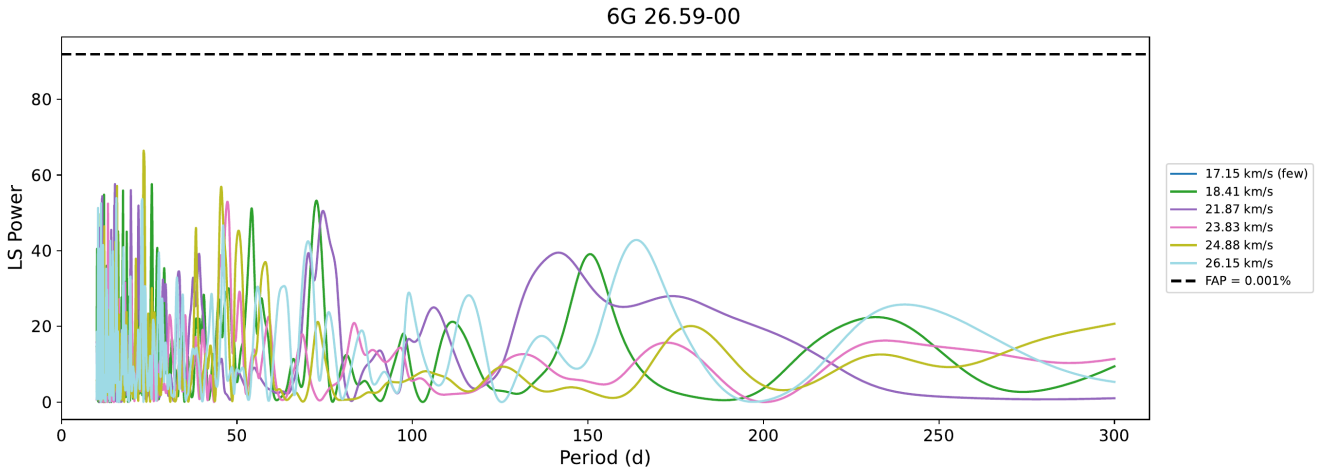


6G 26.59-00

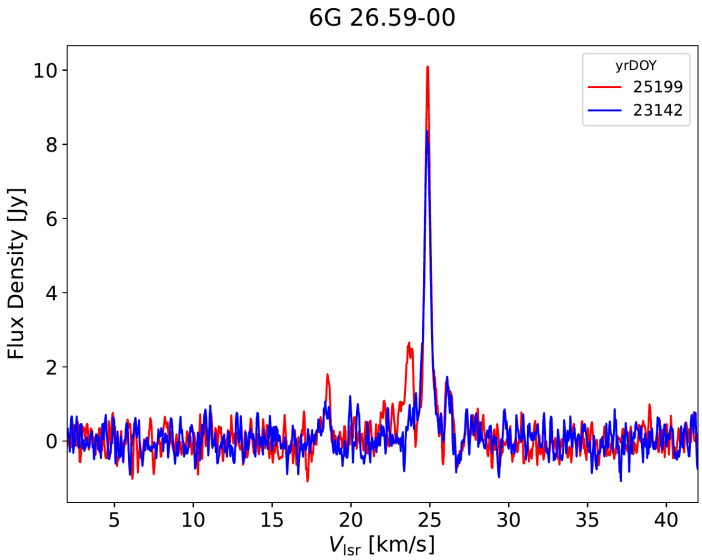
Light curve



Periodogram

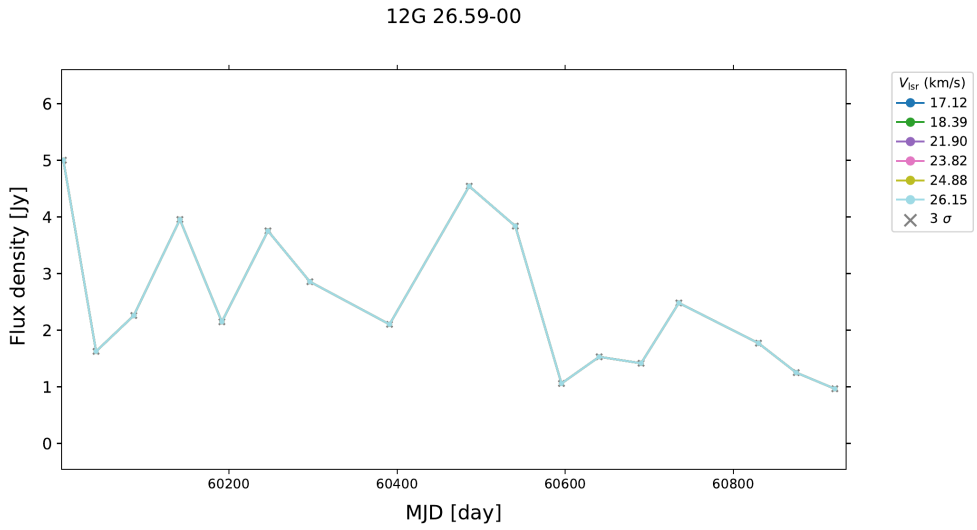


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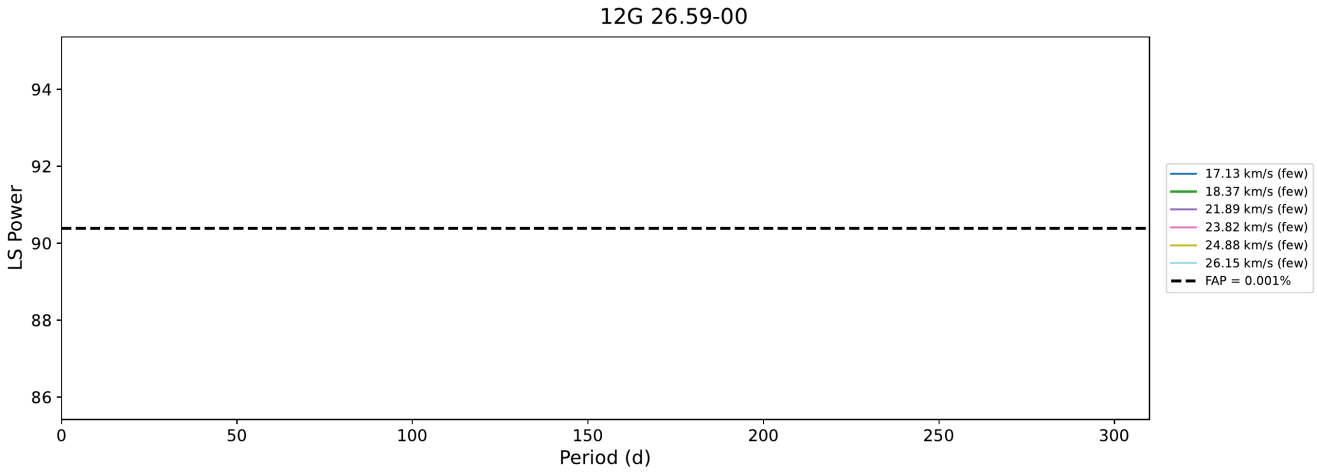


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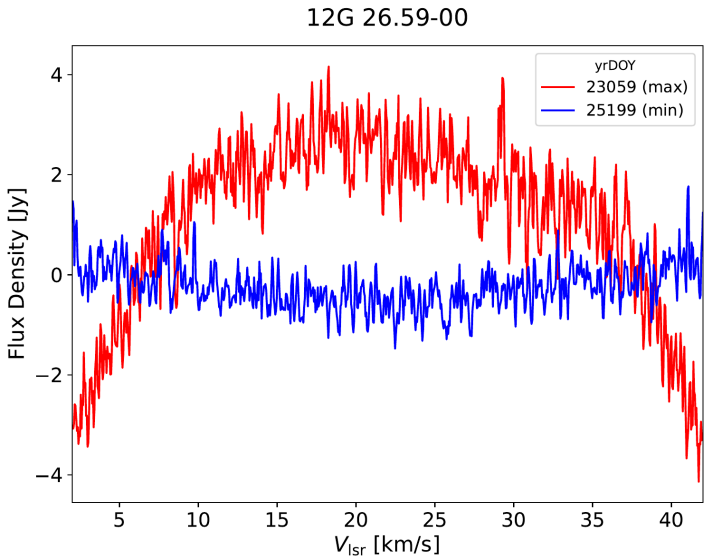
Light curve



Periodogram

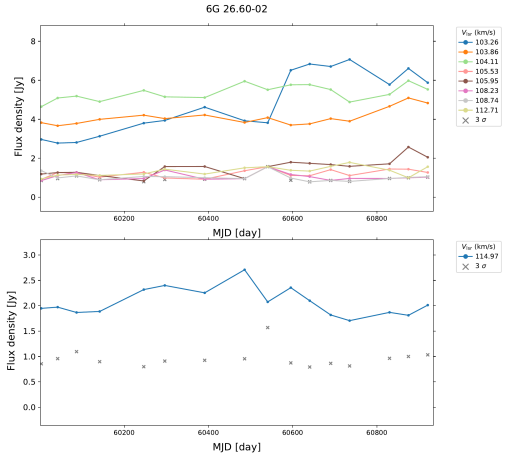


Spectrum

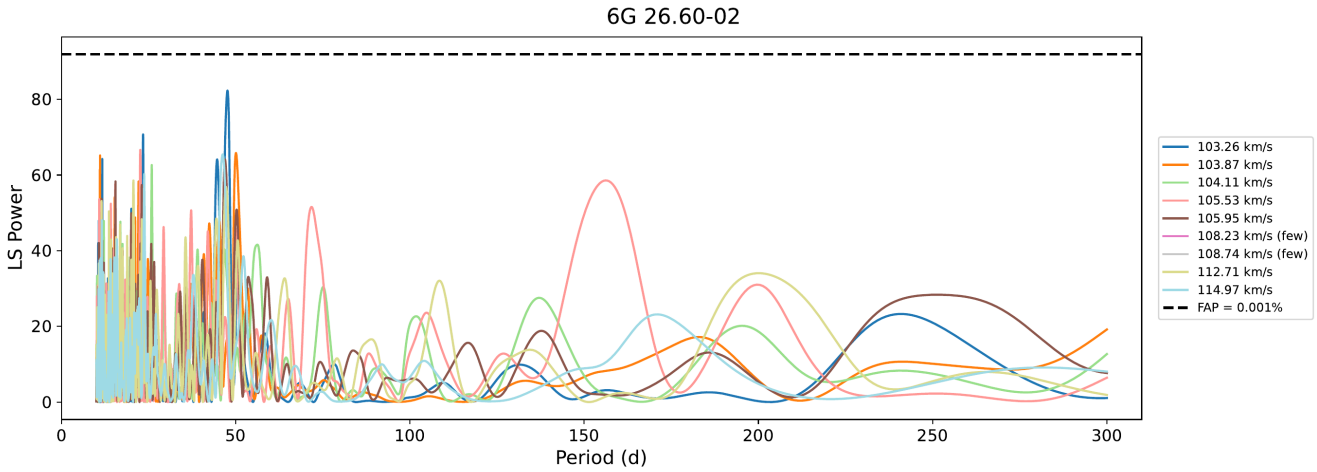


6G 26.60-02

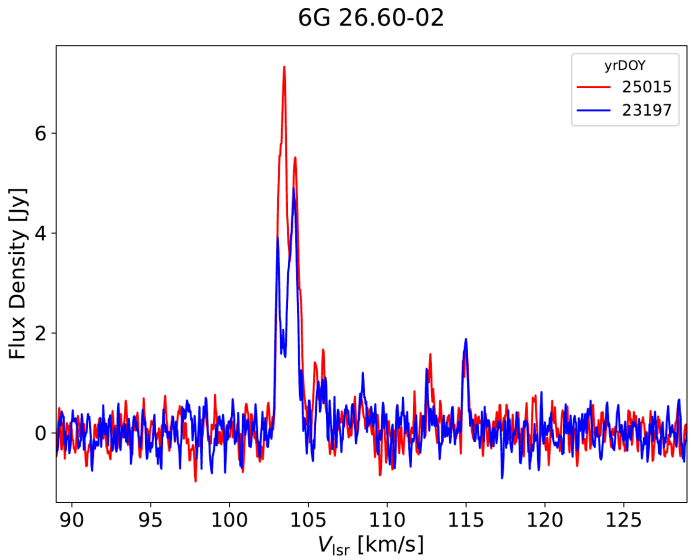
Light curve



Periodogram

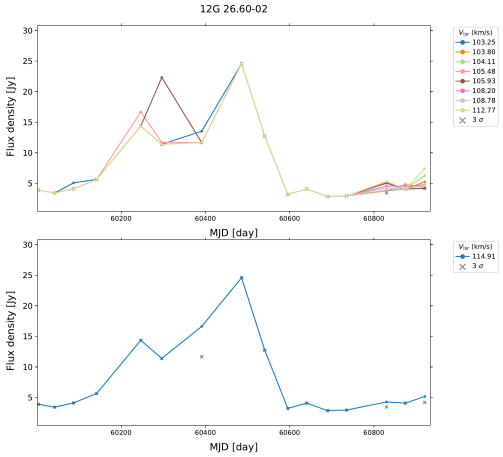


Spectrum

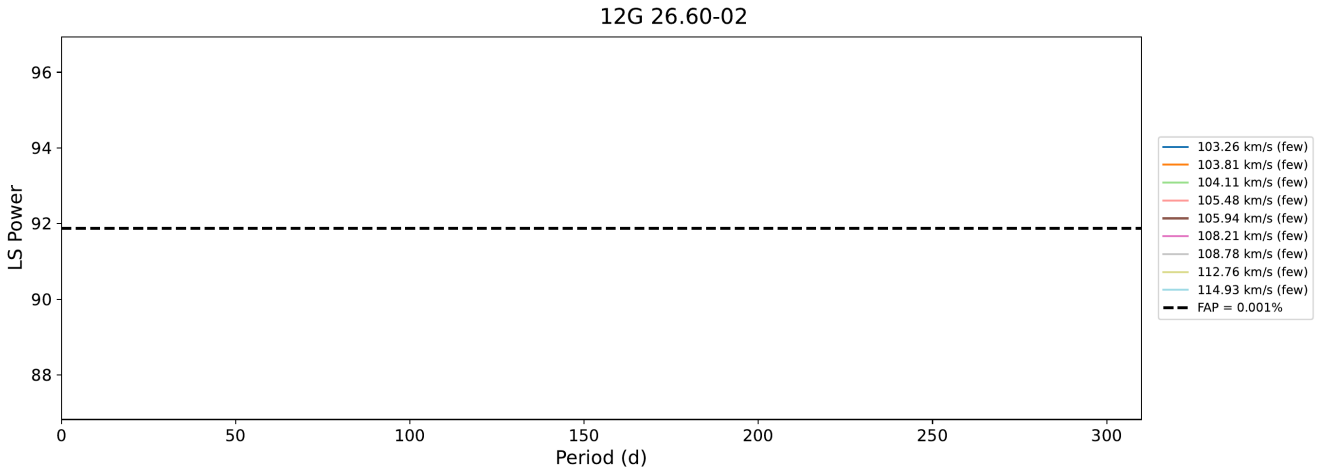


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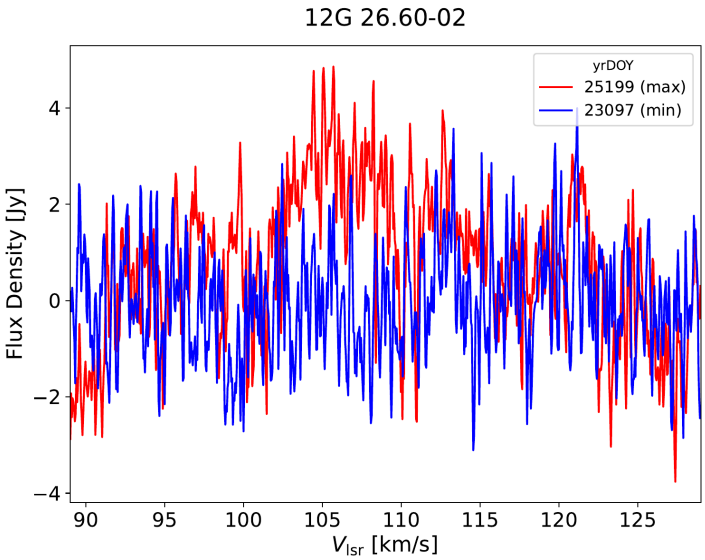
Light curve



Periodogram

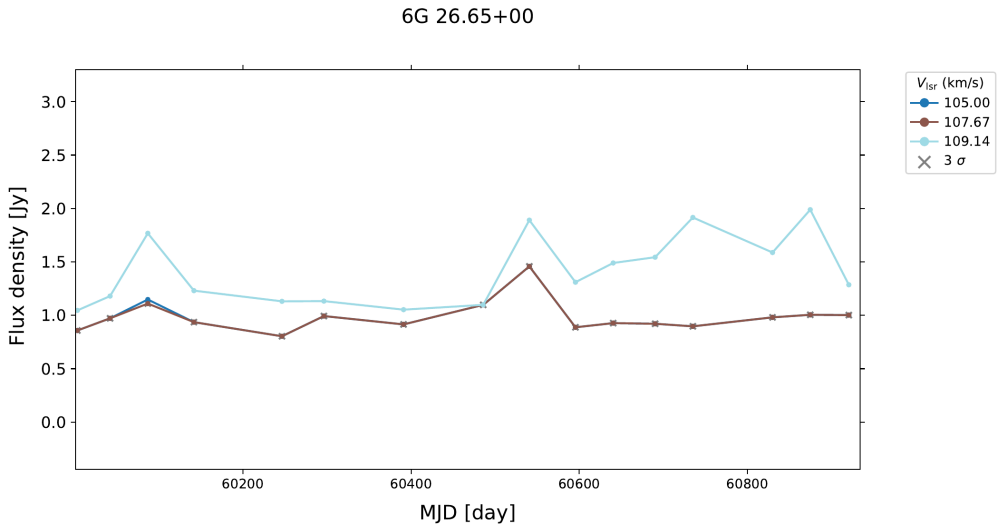


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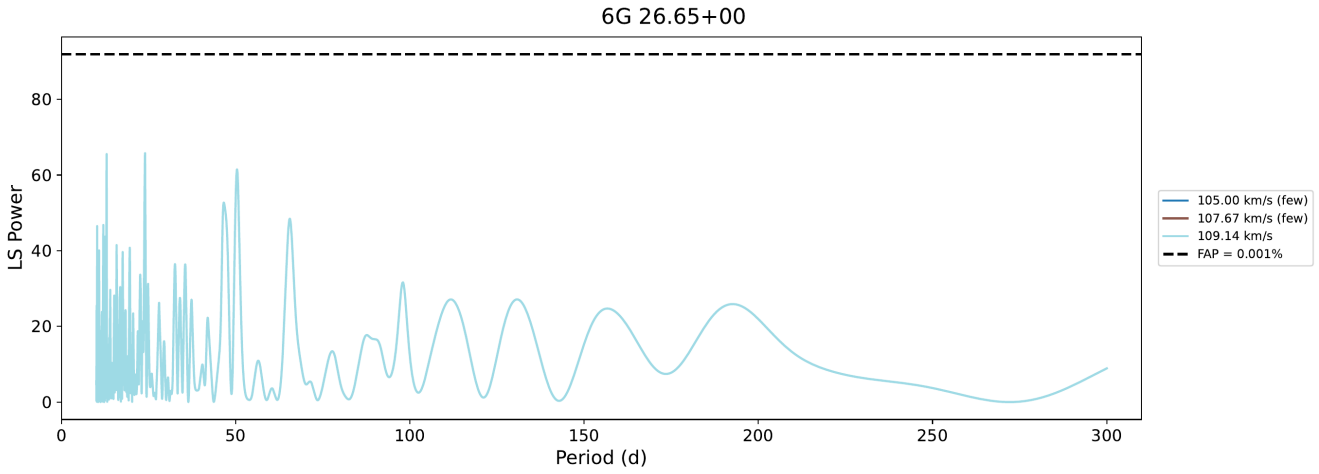


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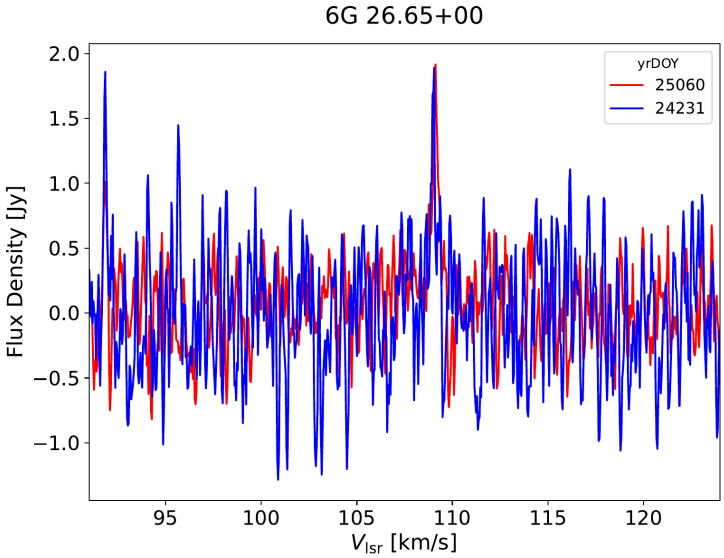
Light curve



Periodogram

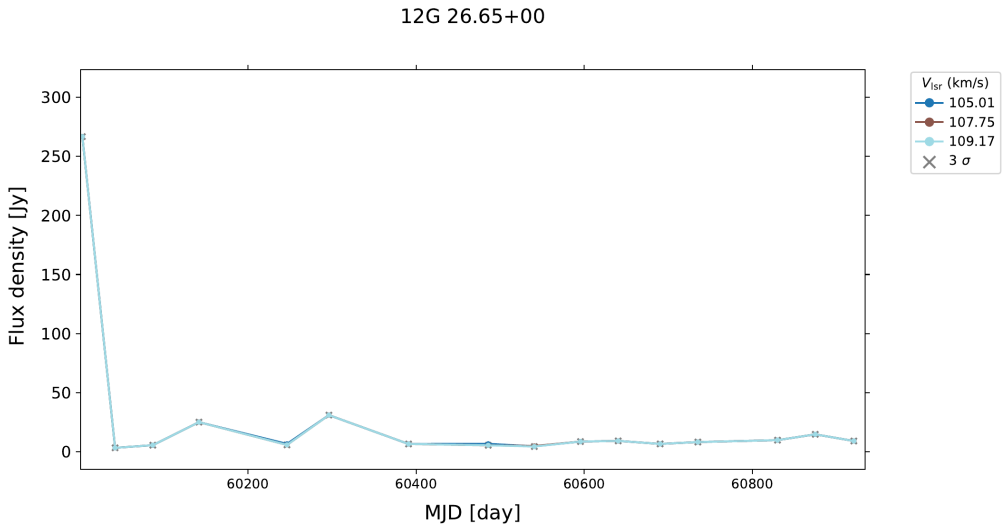


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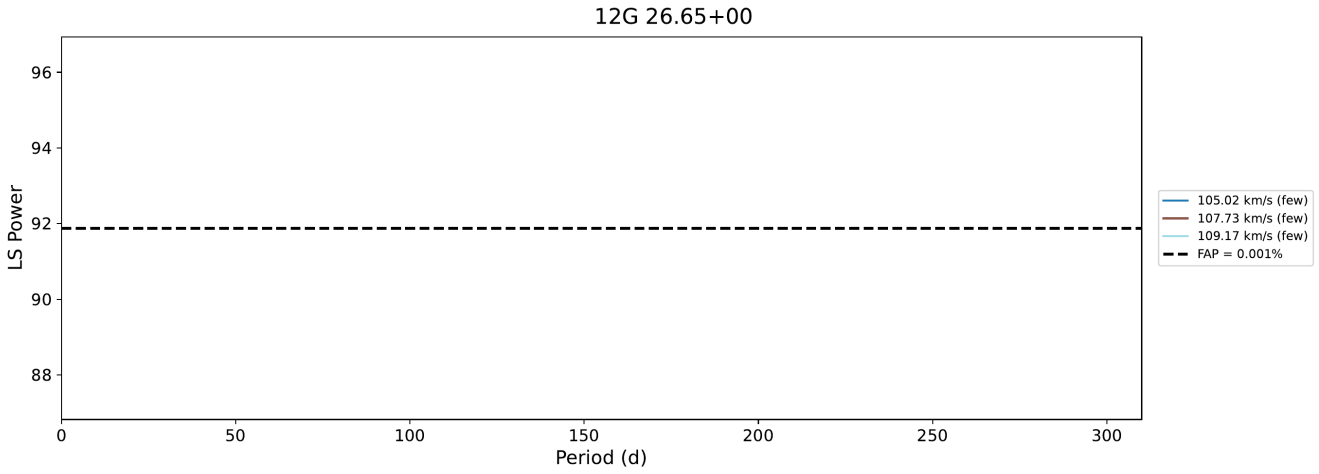


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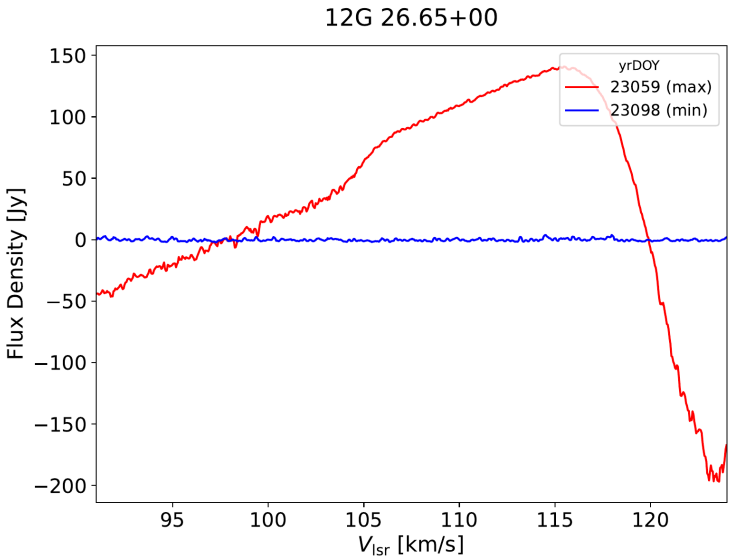
Light curve



Periodogram

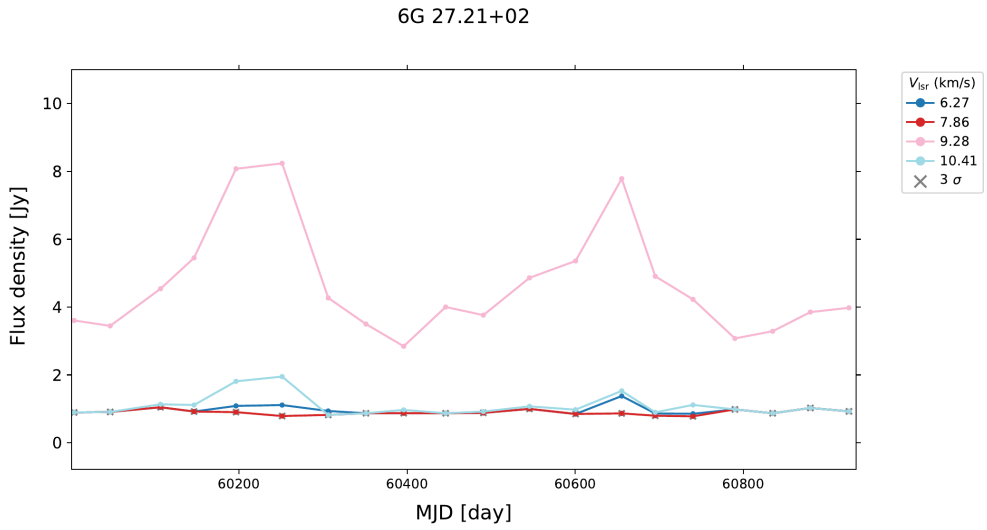


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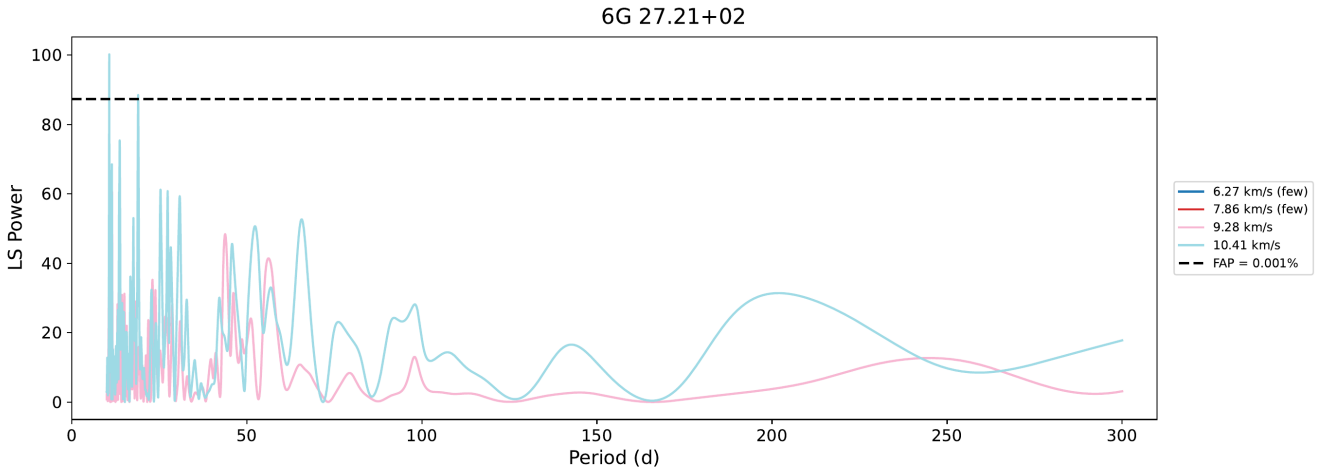


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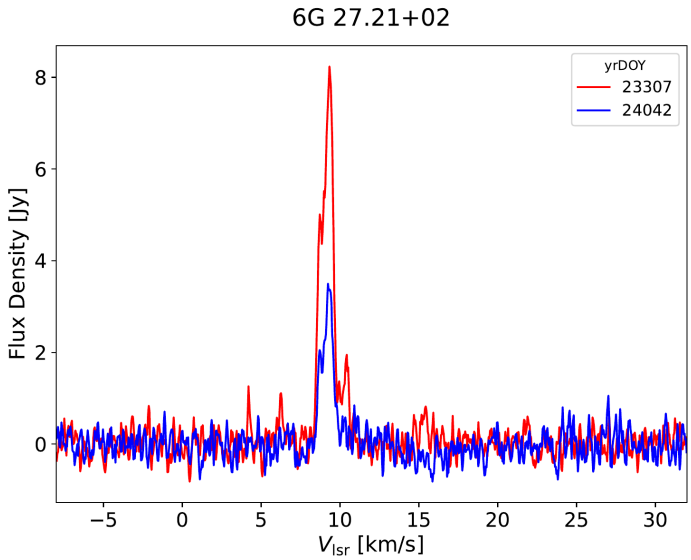
Light curve



Periodogram

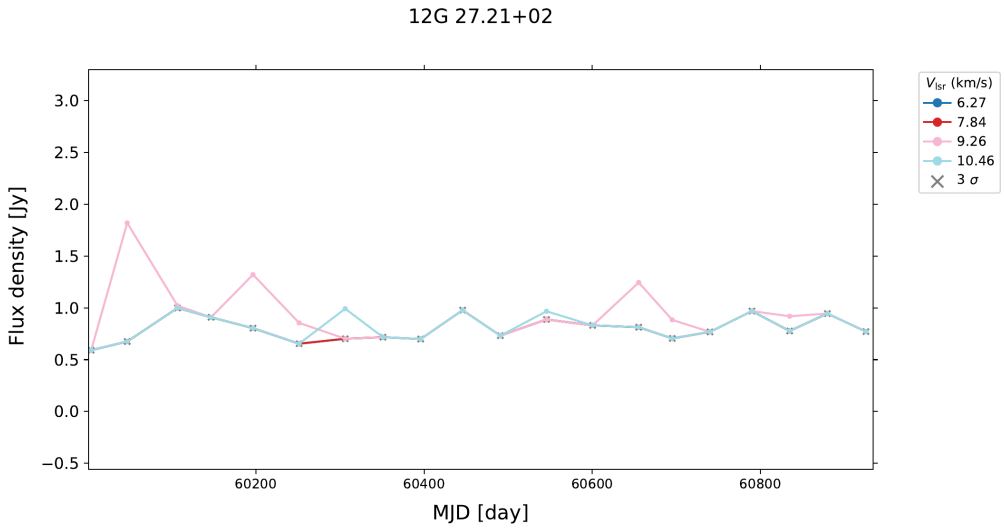


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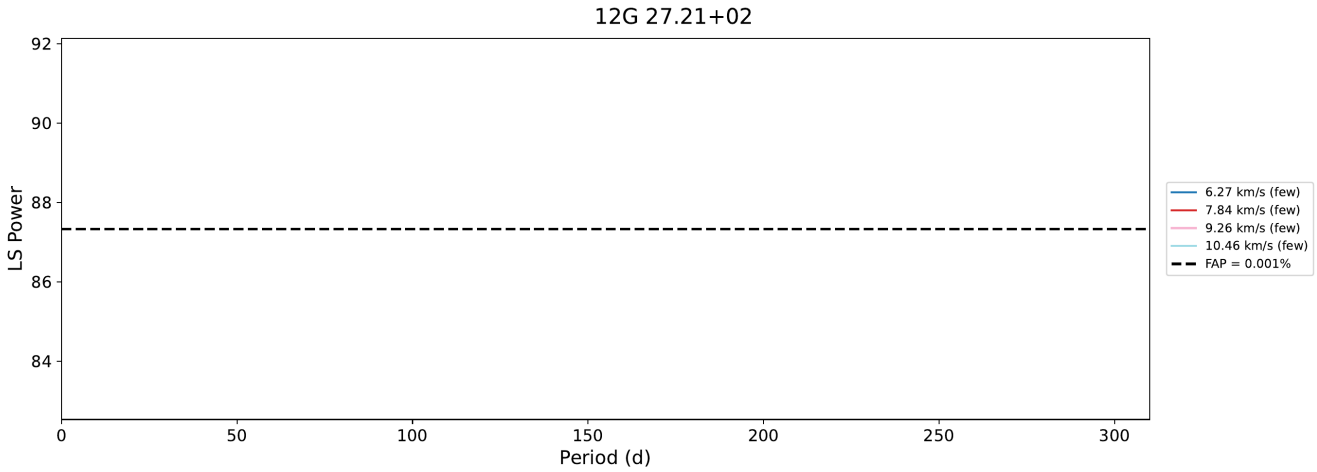


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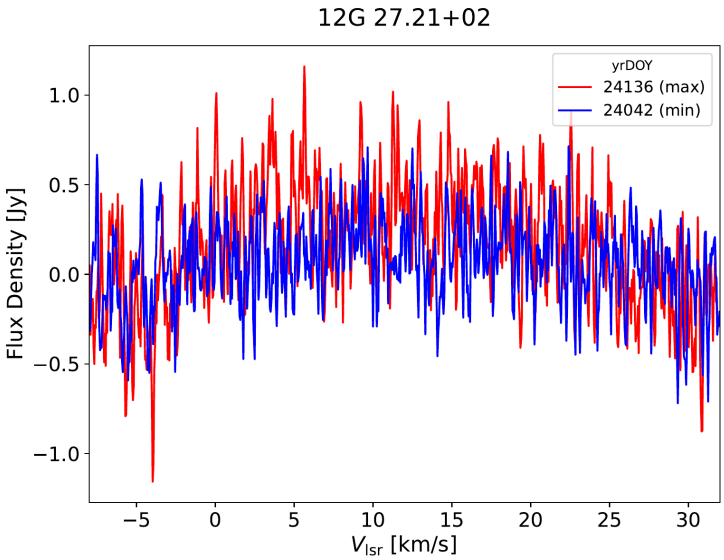
Light curve



Periodogram

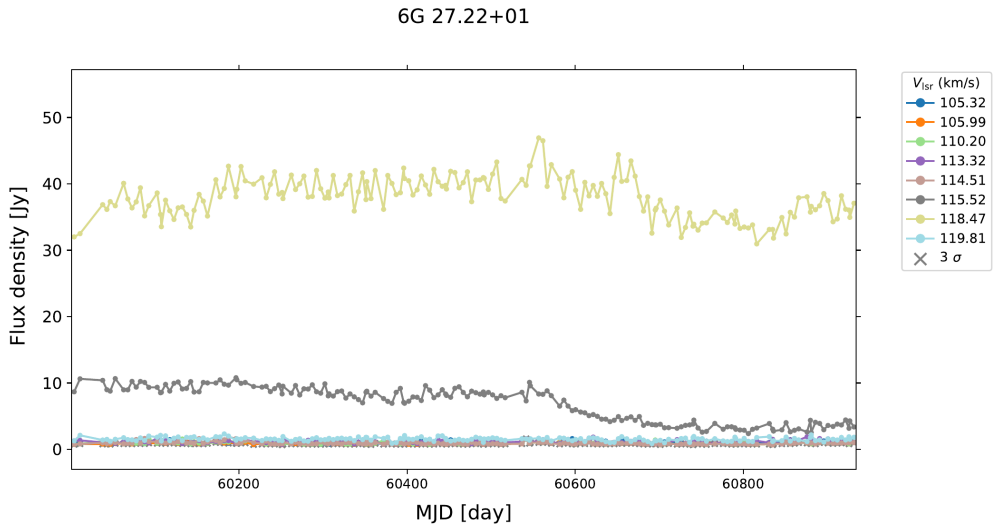


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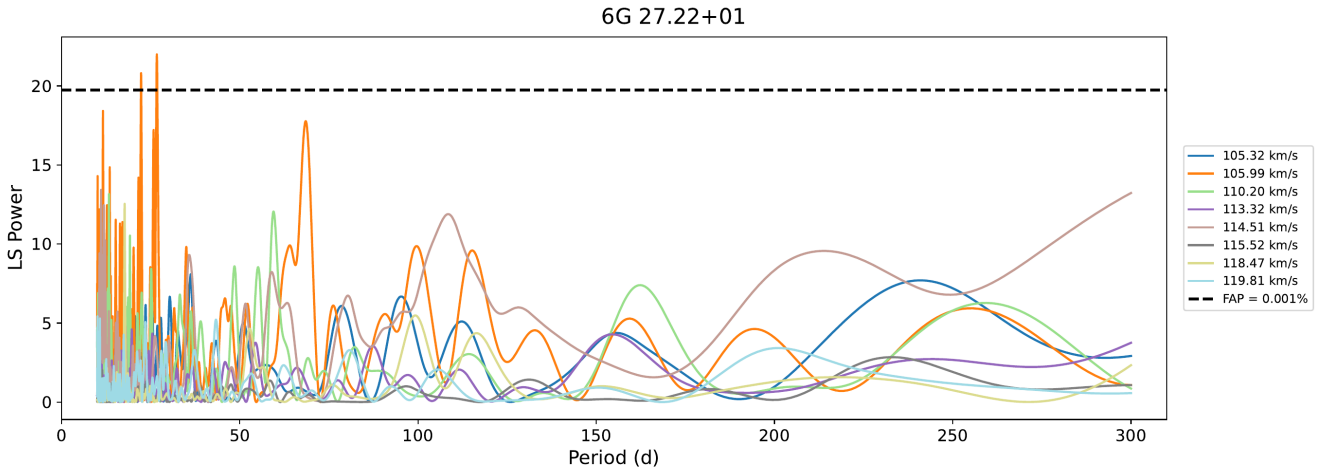


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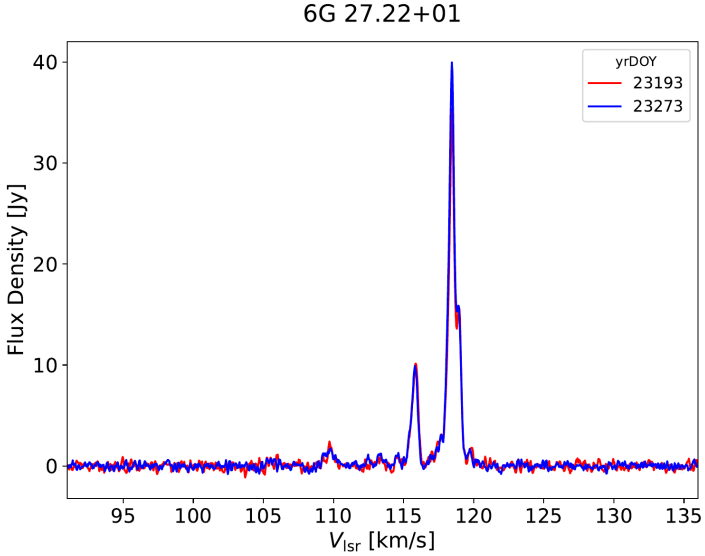
Light curve



Periodogram

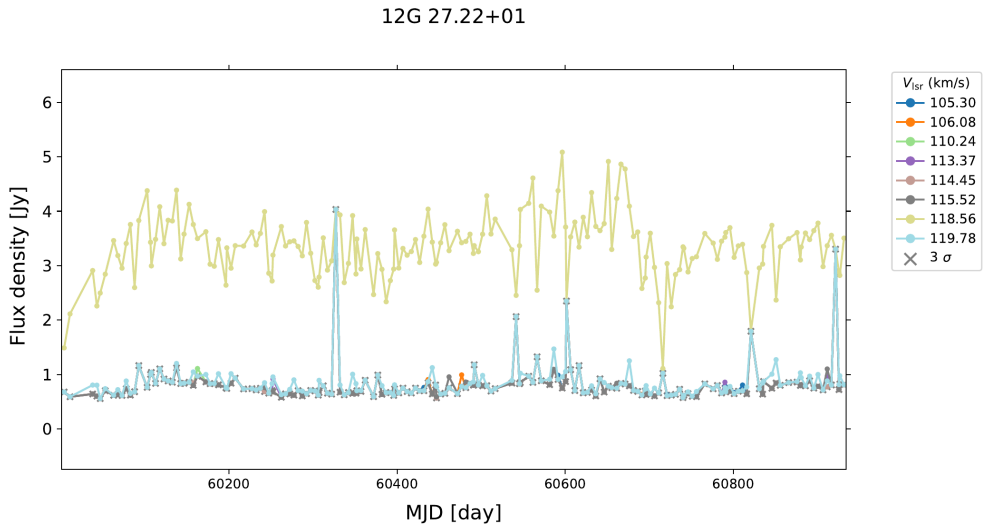


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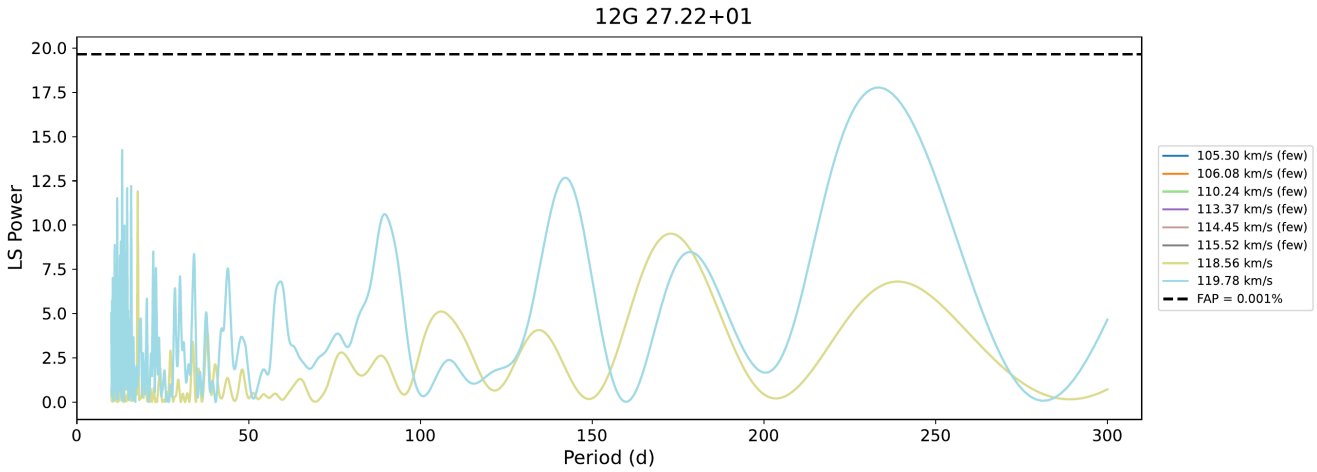


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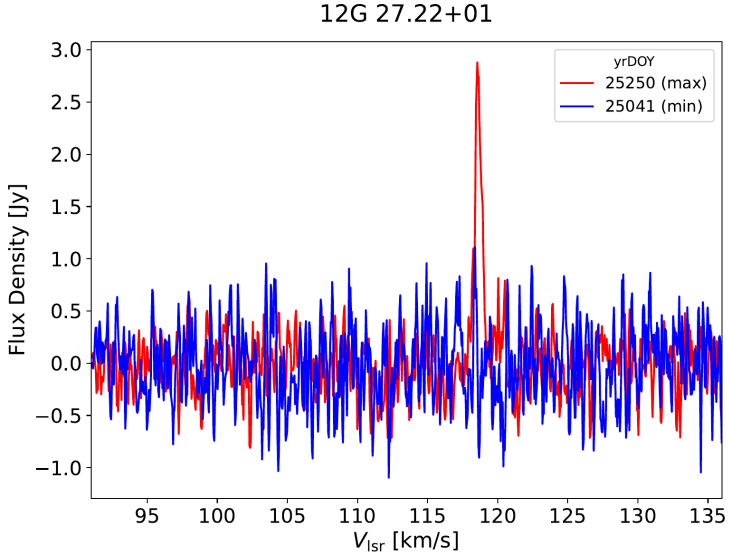
Light curve



Periodogram

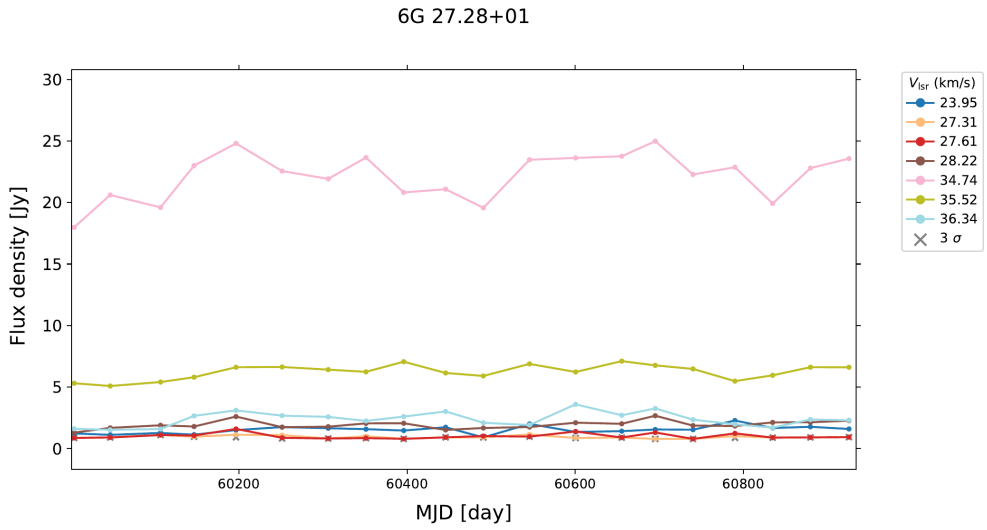


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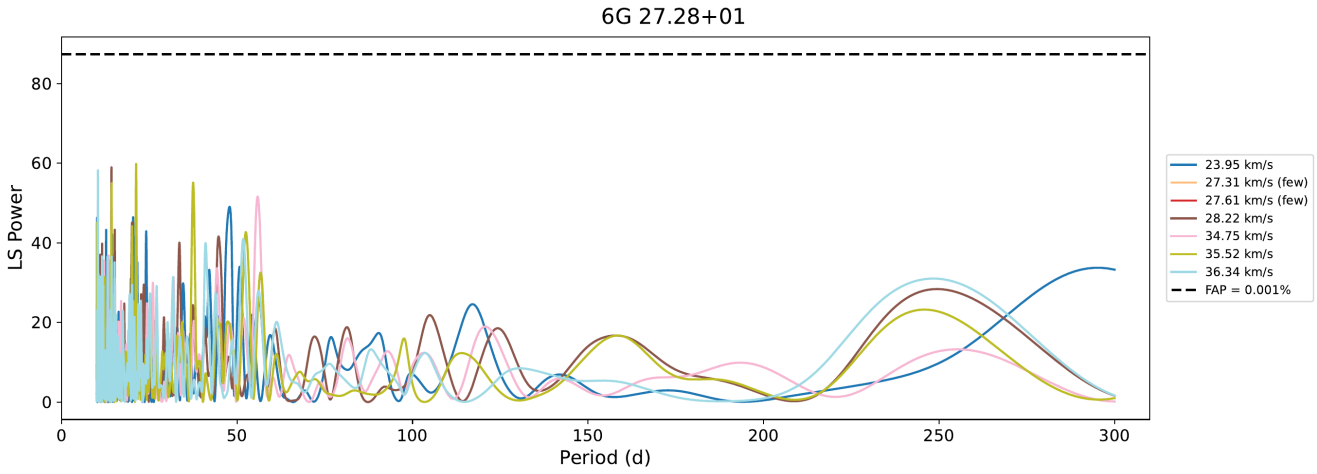


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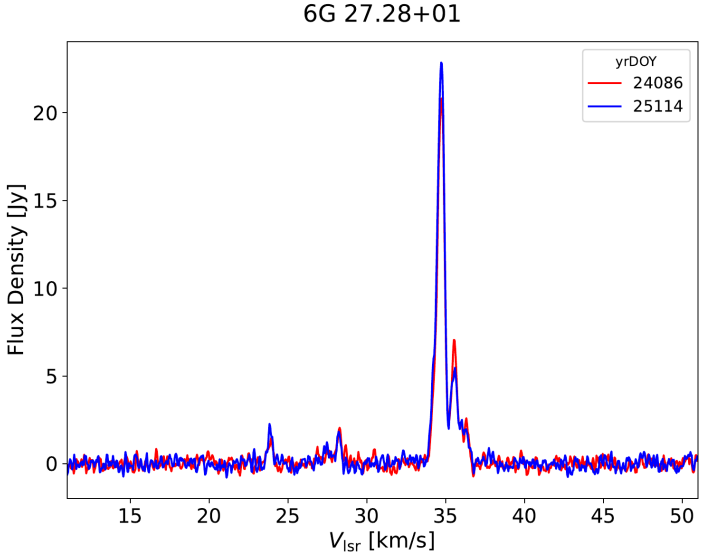
Light curve



Periodogram

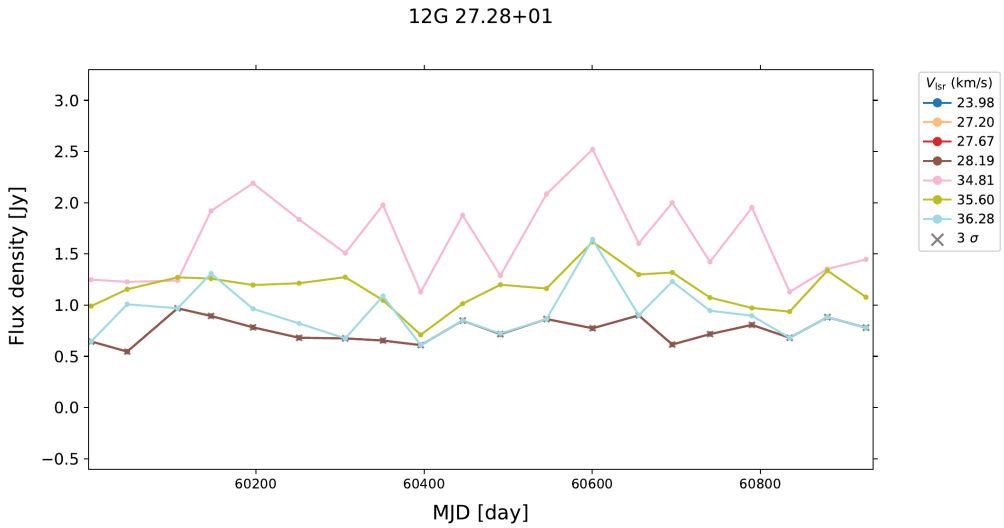


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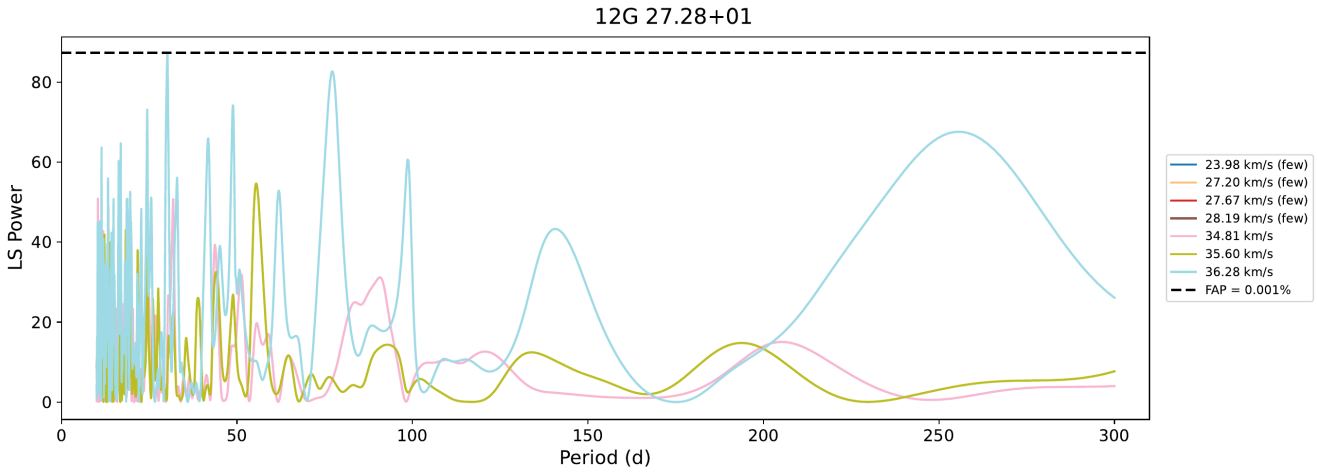


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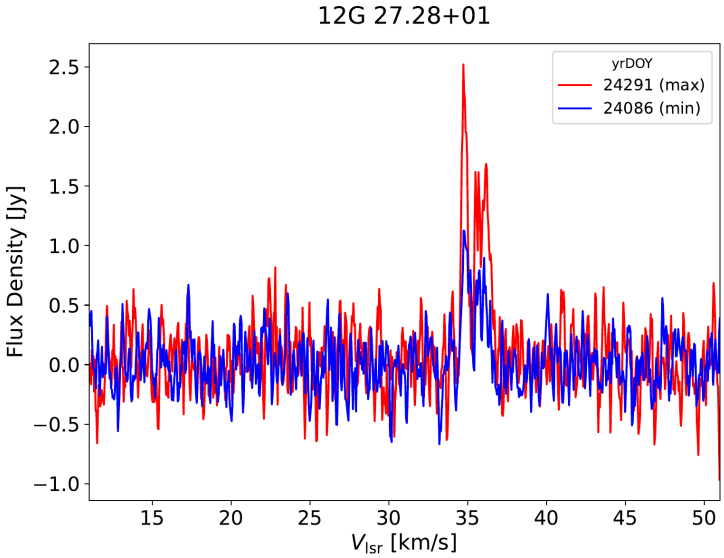
Light curve



Periodogram

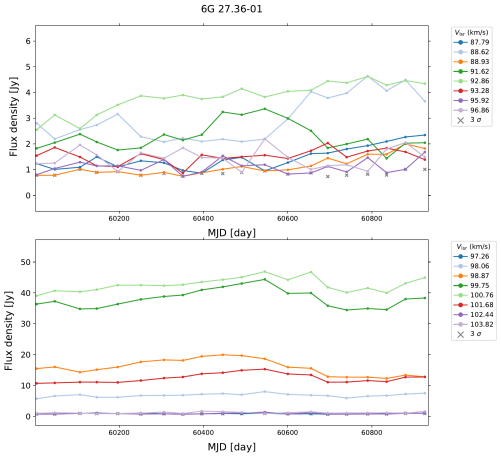


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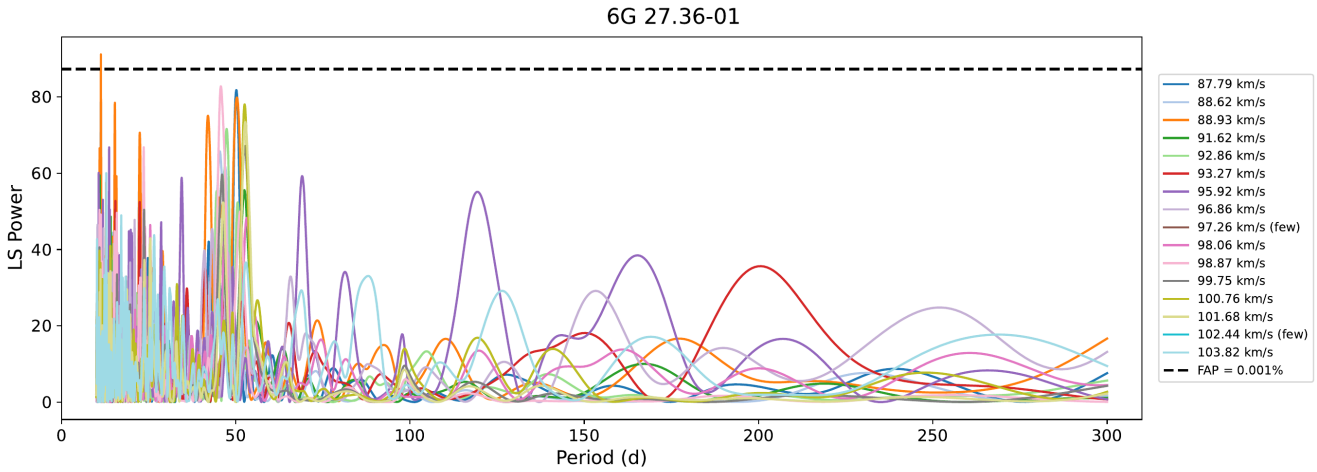


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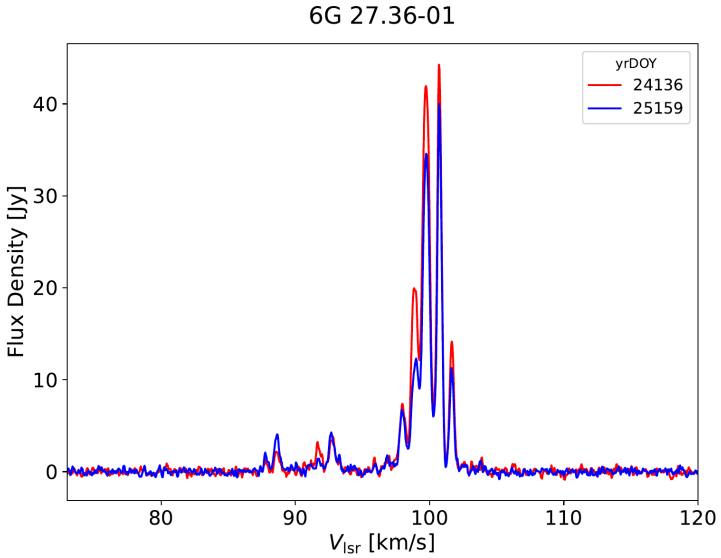
Light curve



Periodogram

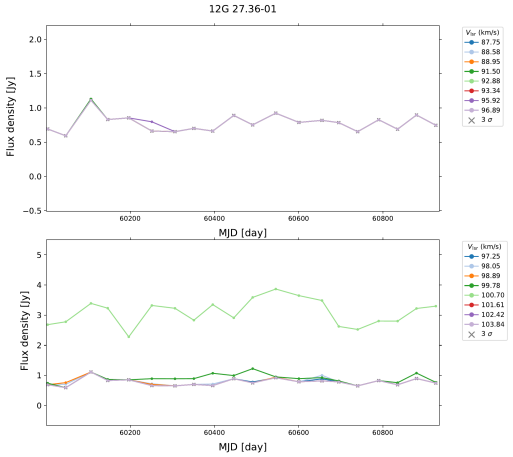


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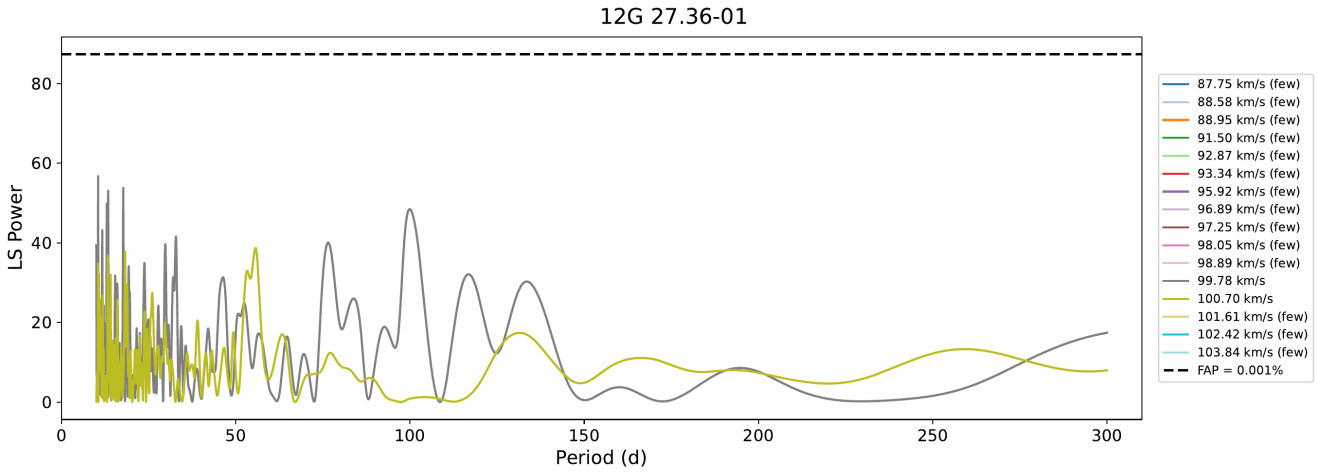


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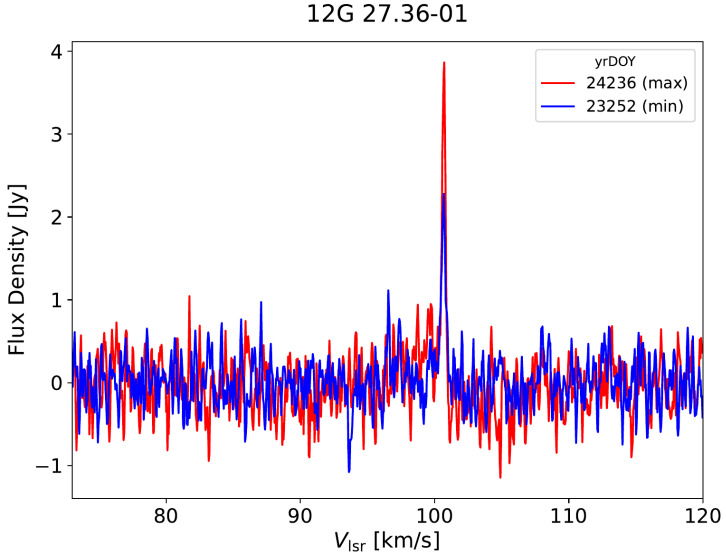
Light curve



Periodogram

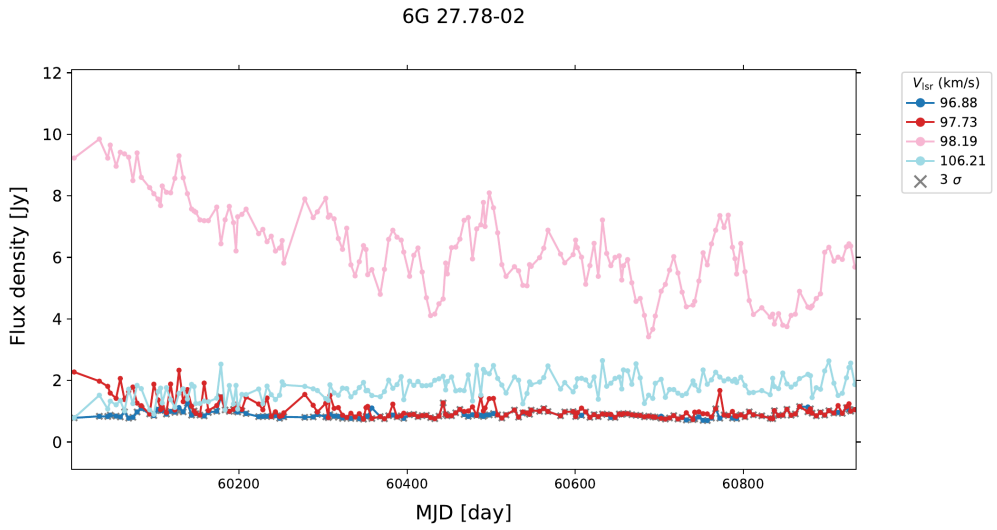


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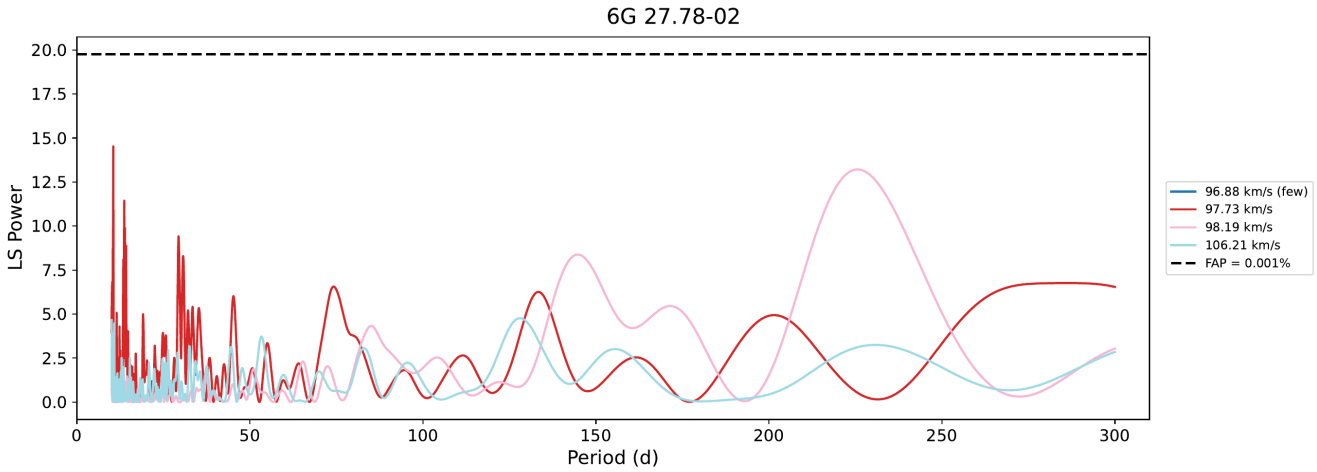


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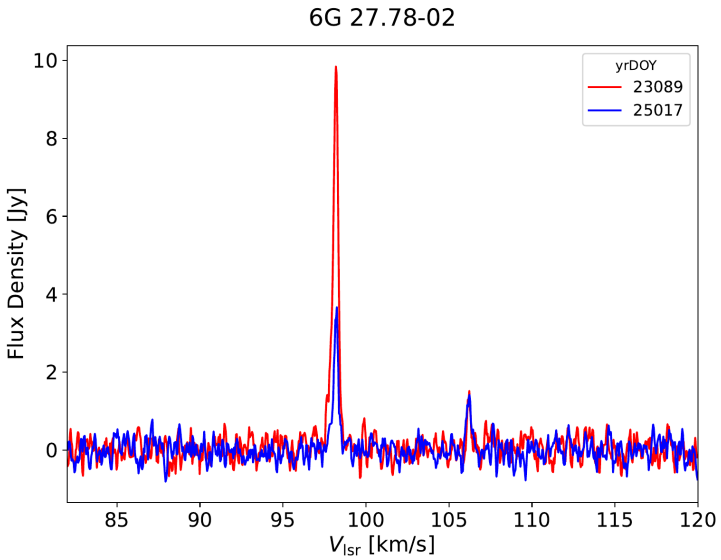
Light curve



Periodogram

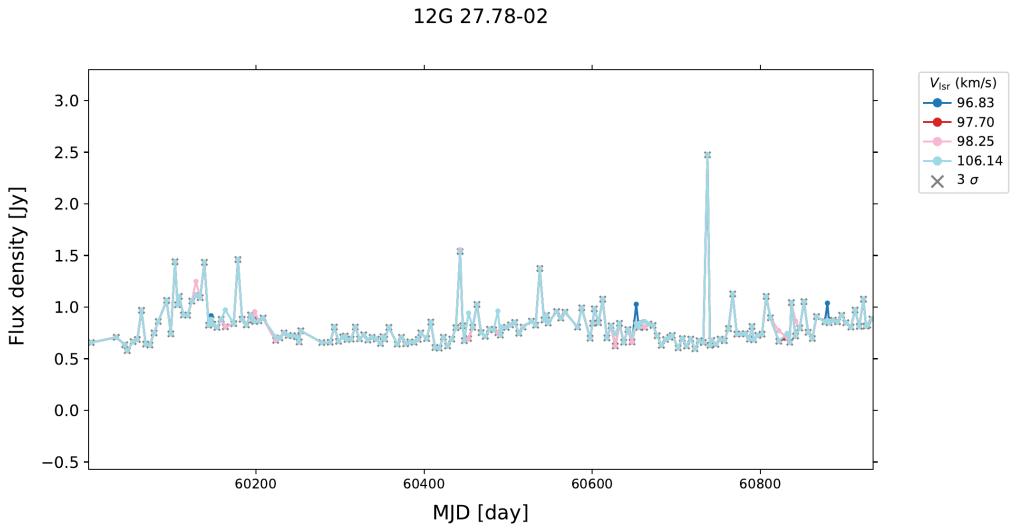


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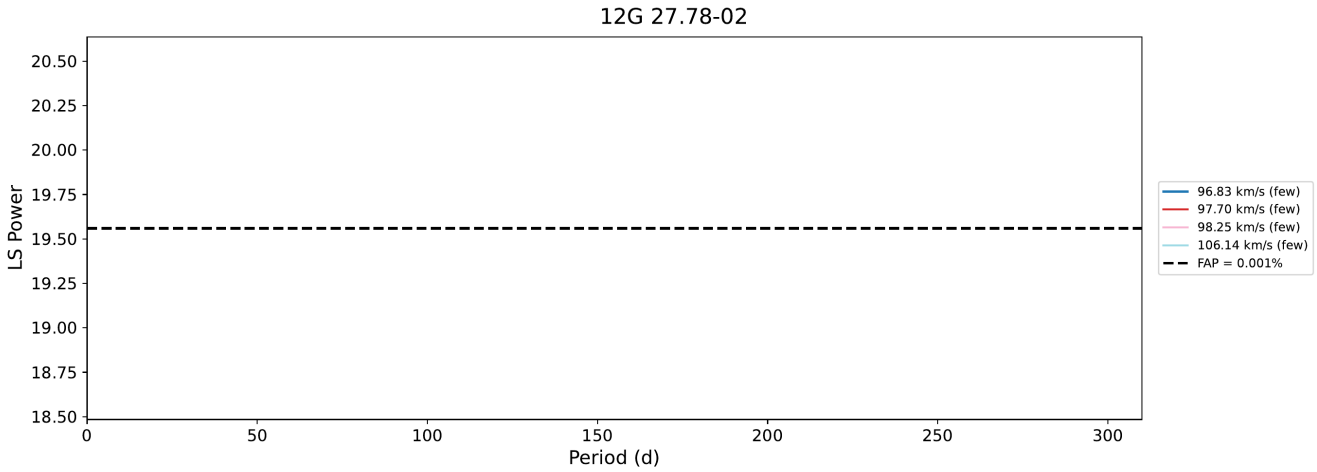


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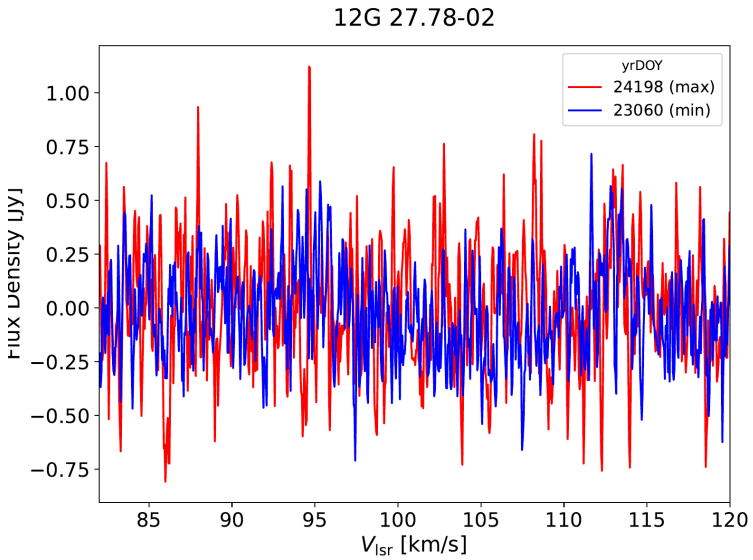
Light curve



Periodogram

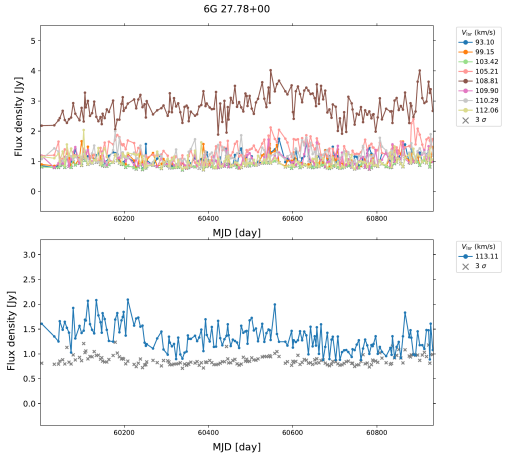


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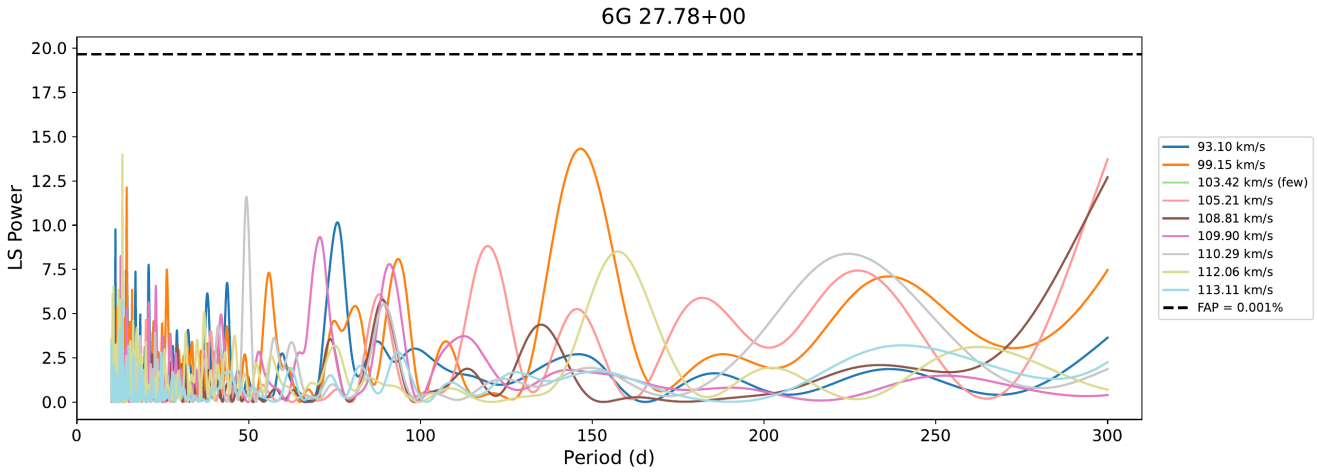


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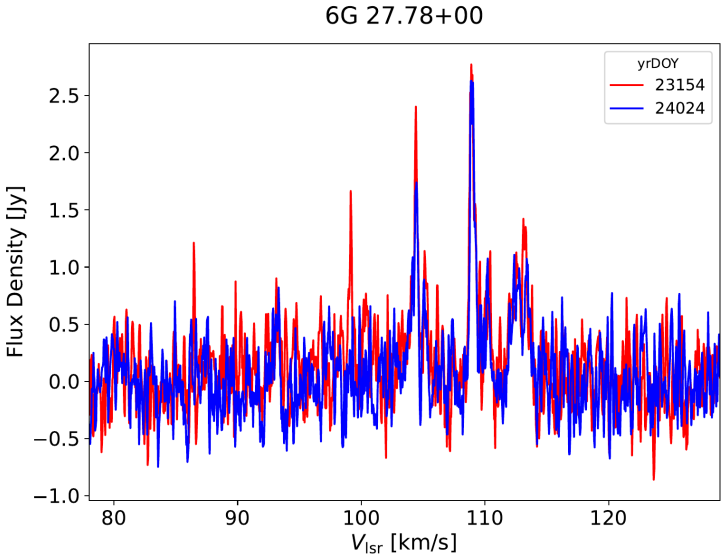
Light curve



Periodogram

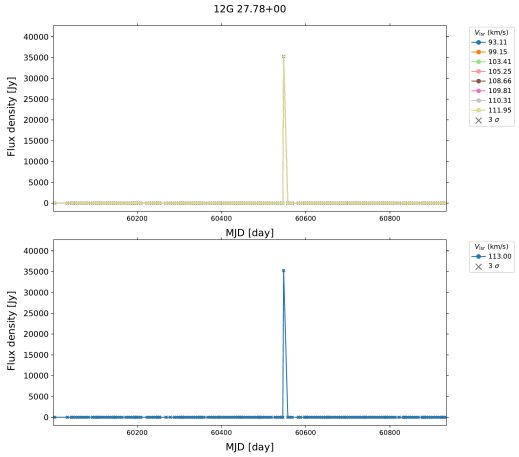


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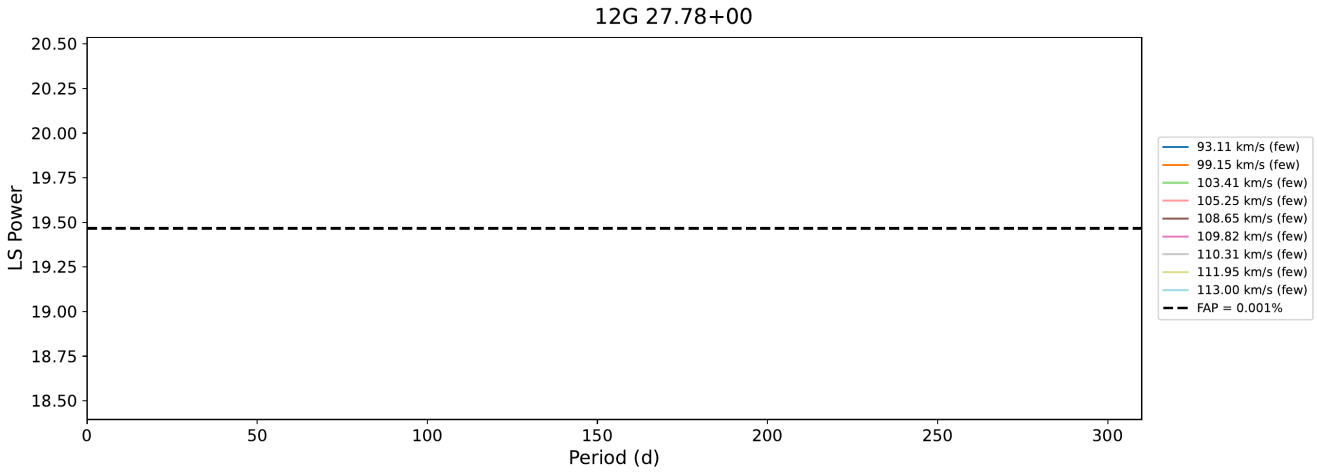


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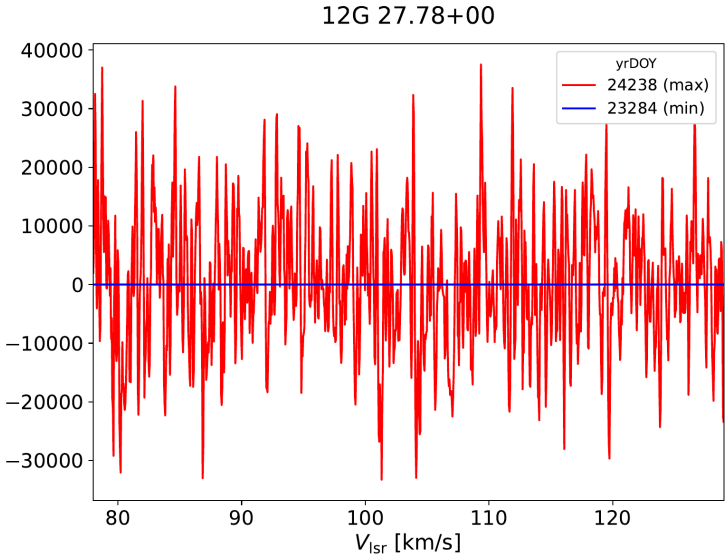
Light curve



Periodogram

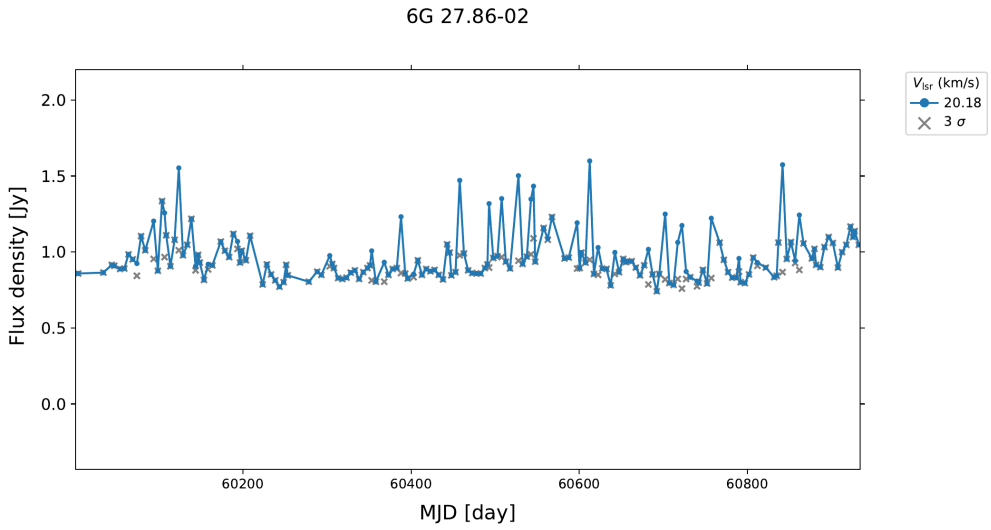


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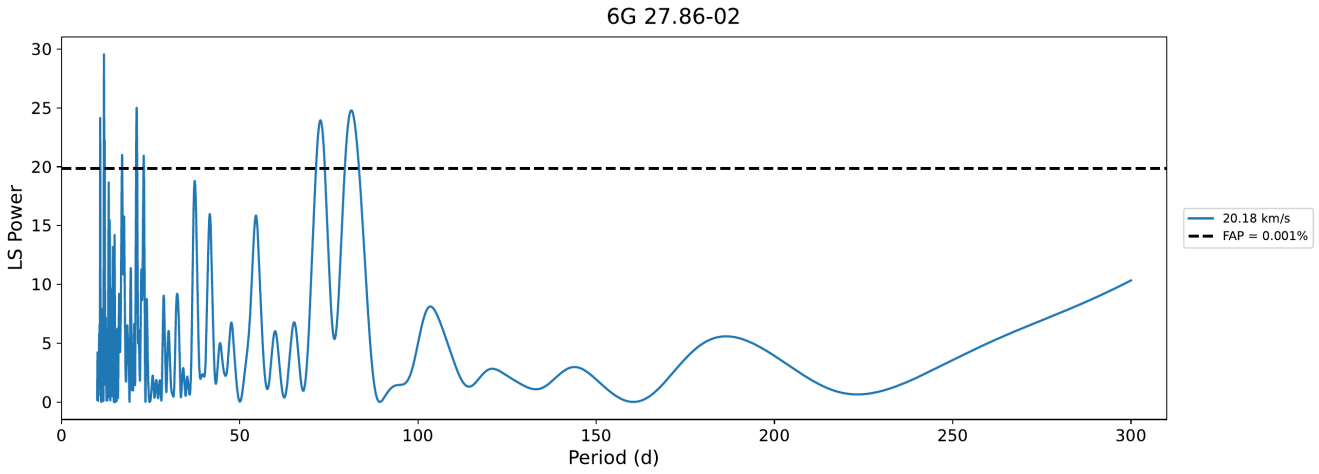


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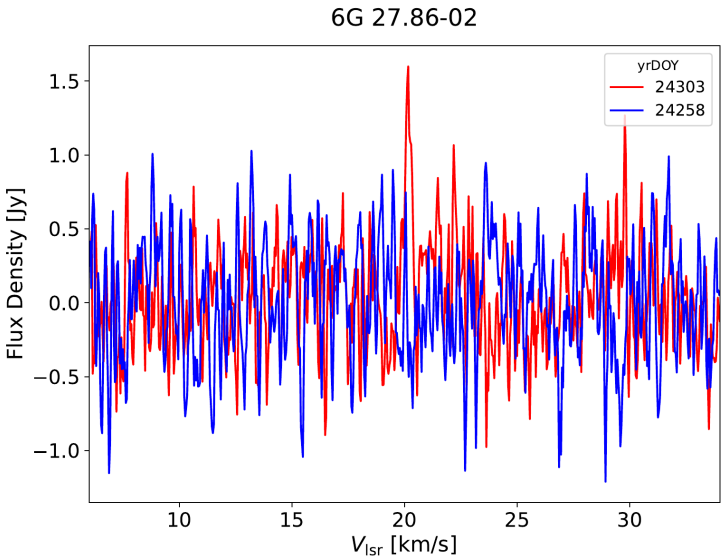
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Periodogram

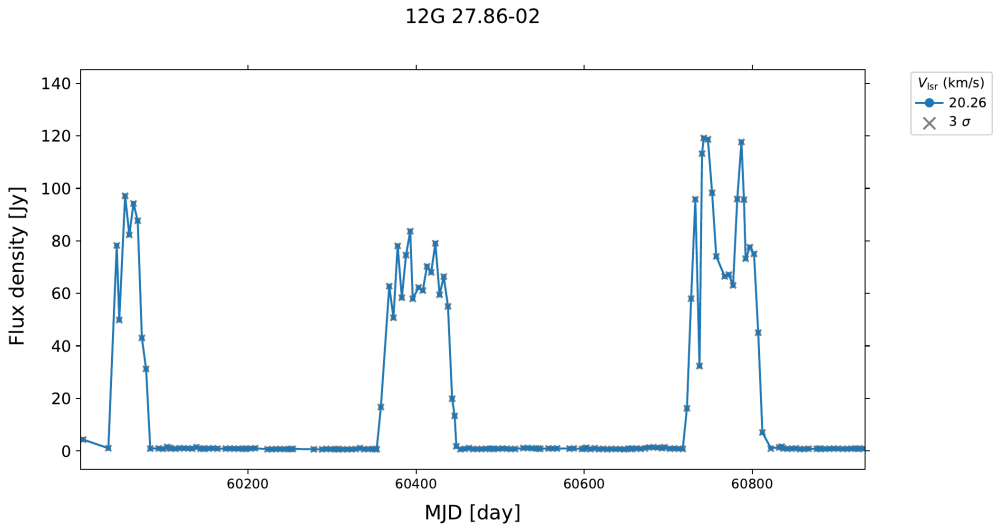


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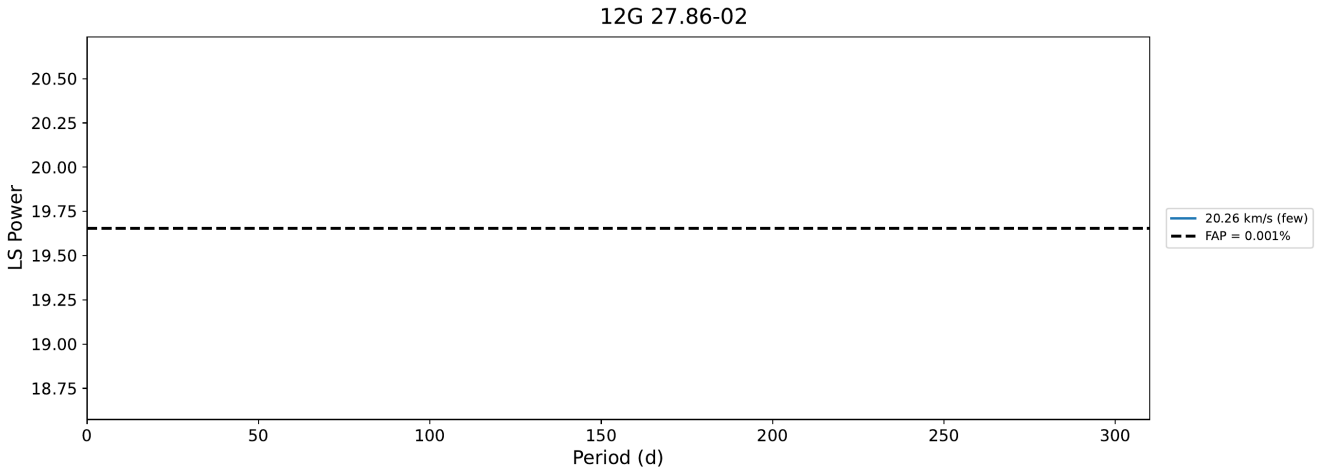


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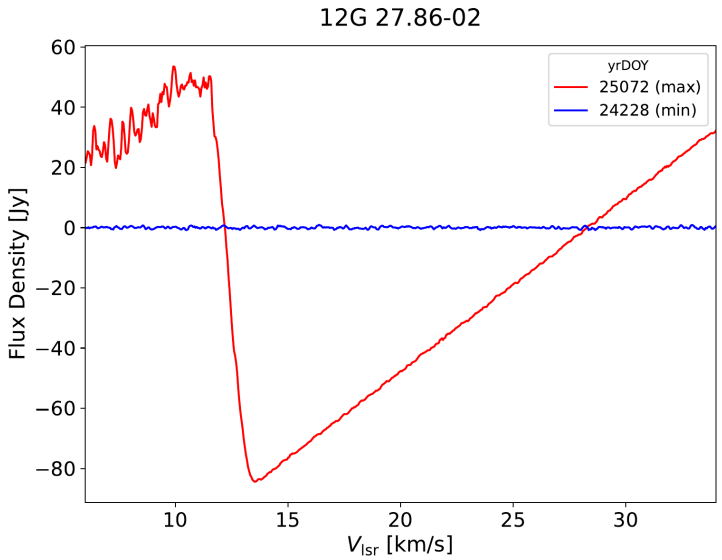
Light curve



Periodogram

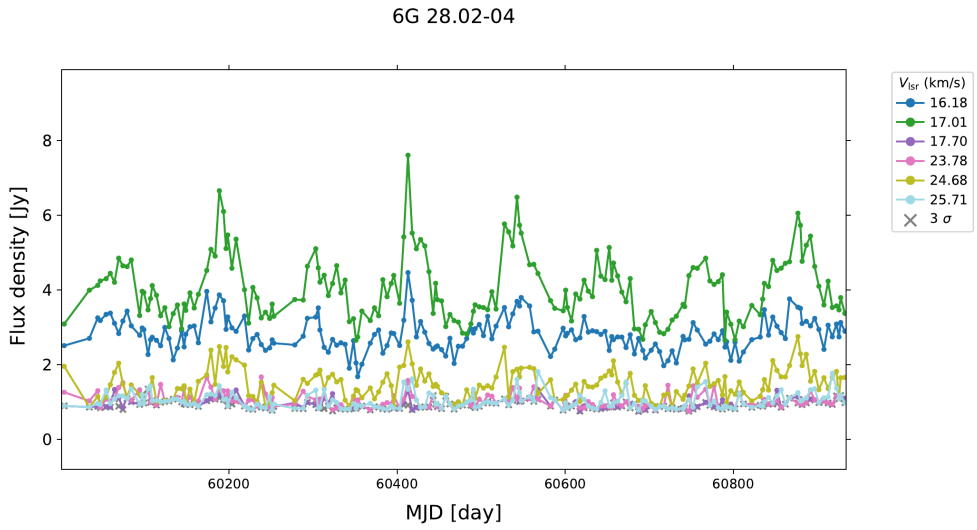


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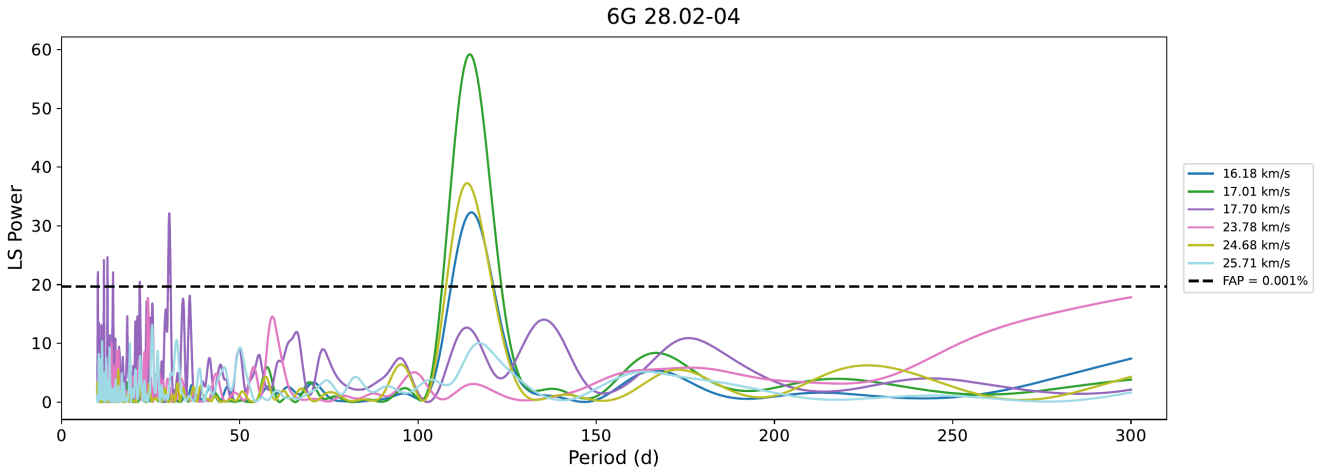


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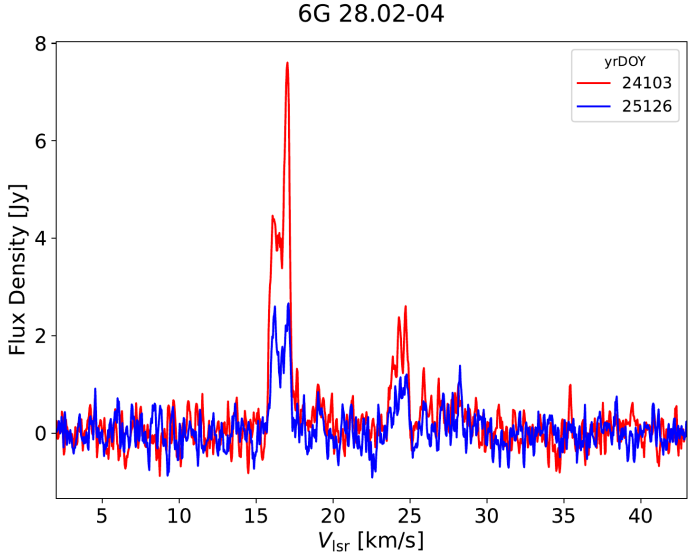
Light curve



Periodogram

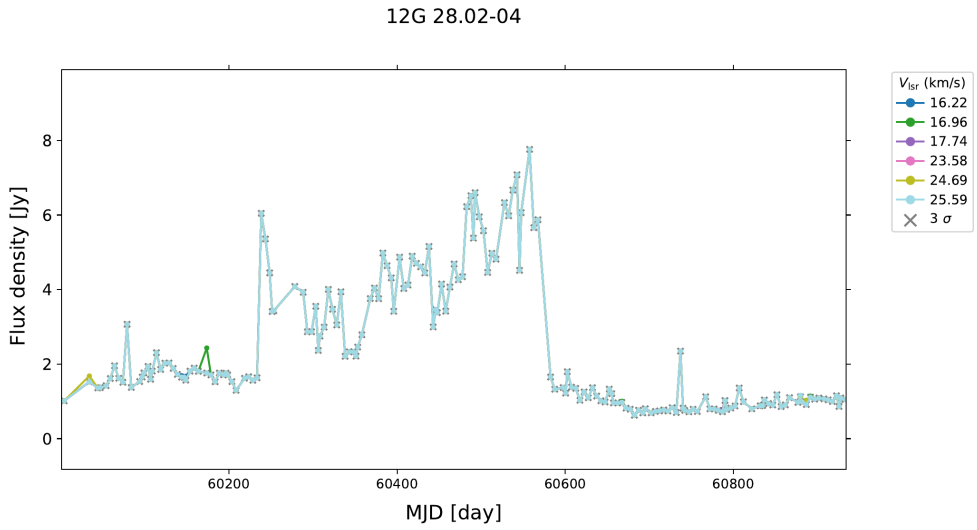


Spectrum

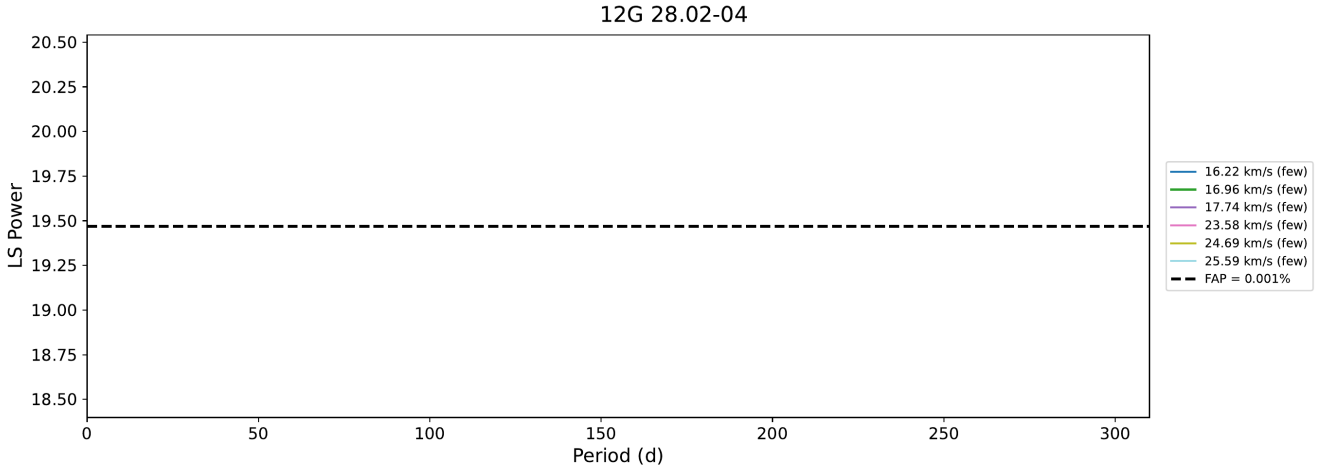


12G 28.02-04

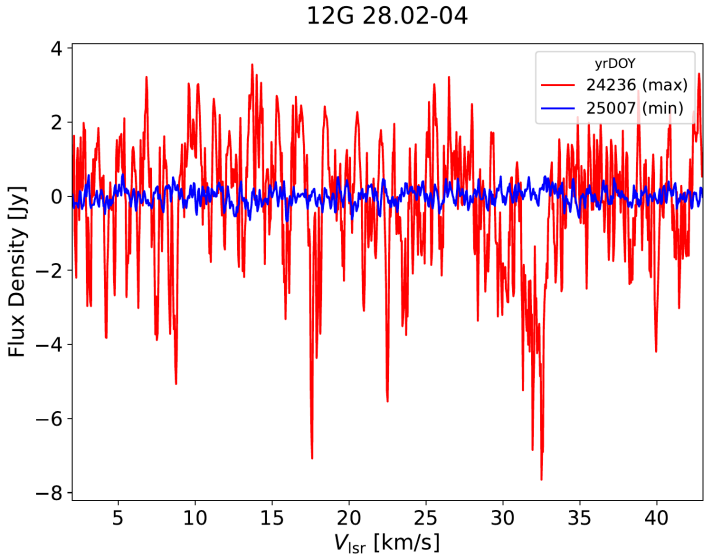
Light curve



Periodogram

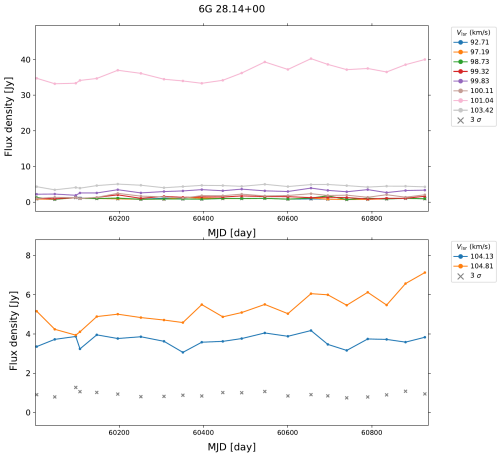


Spectrum

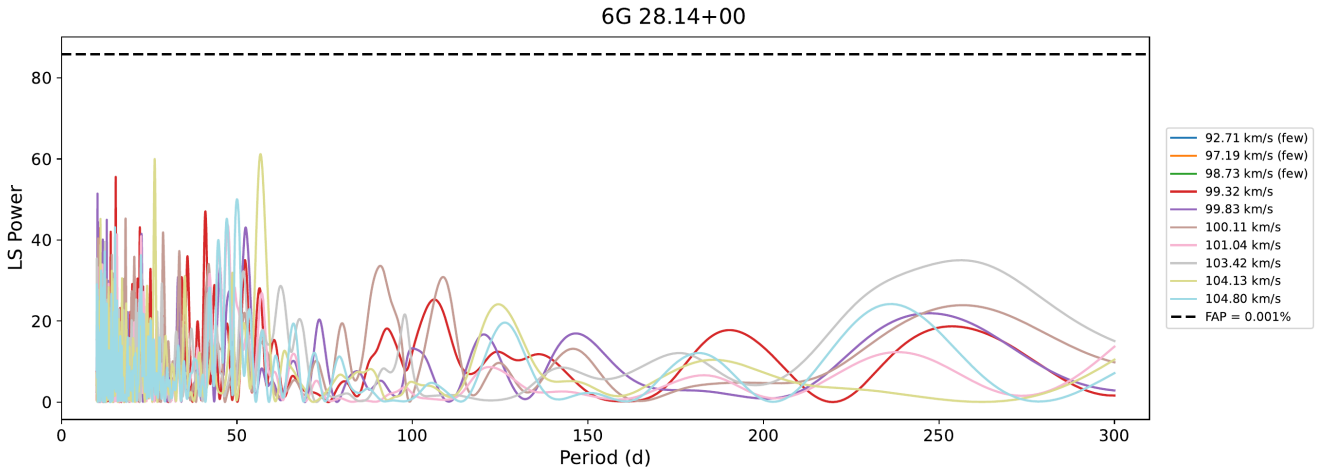


6G 28.14+00

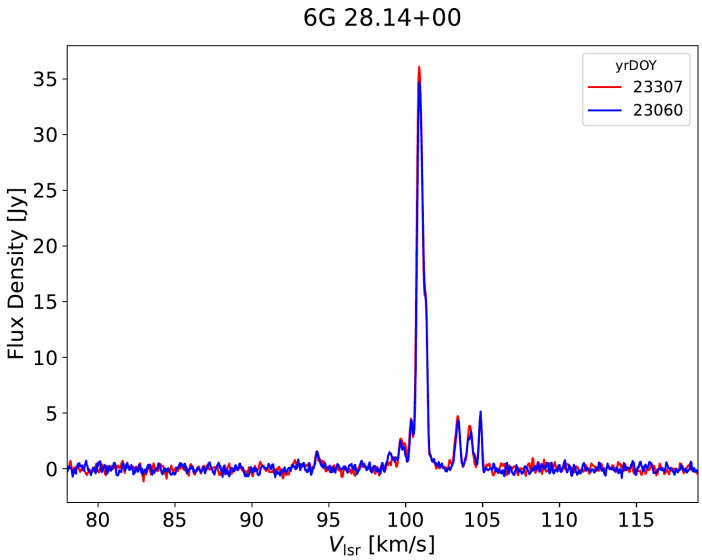
Light curve



Periodogram

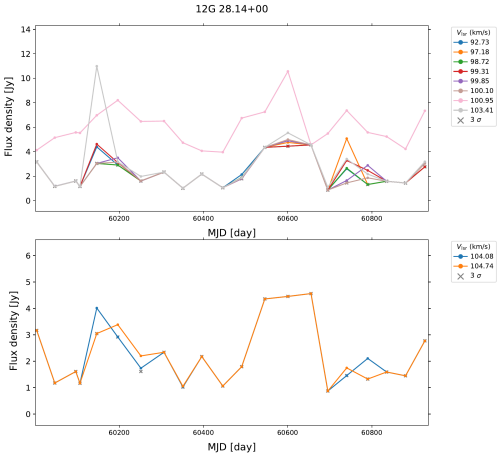


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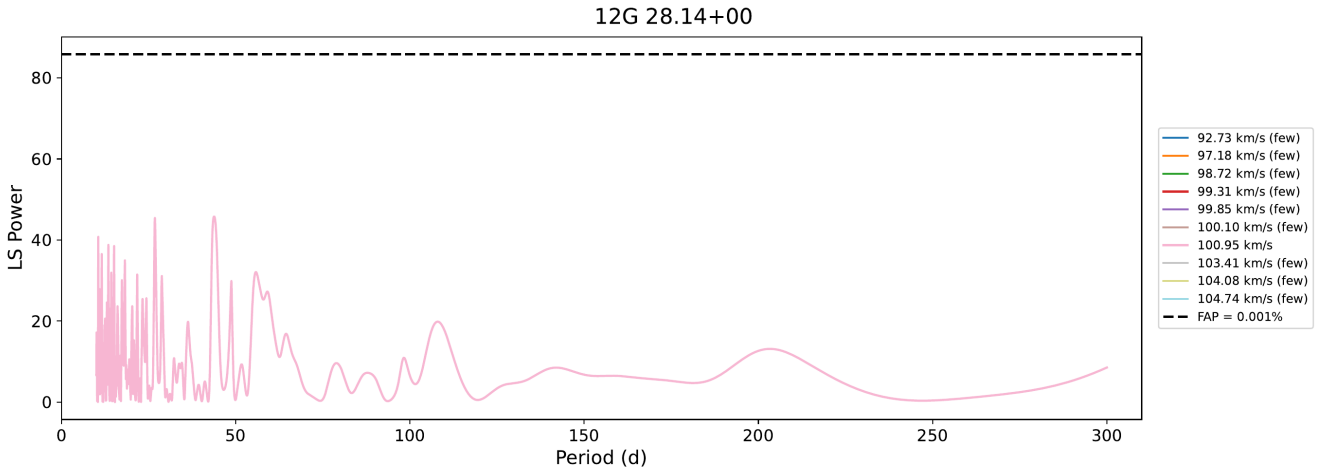


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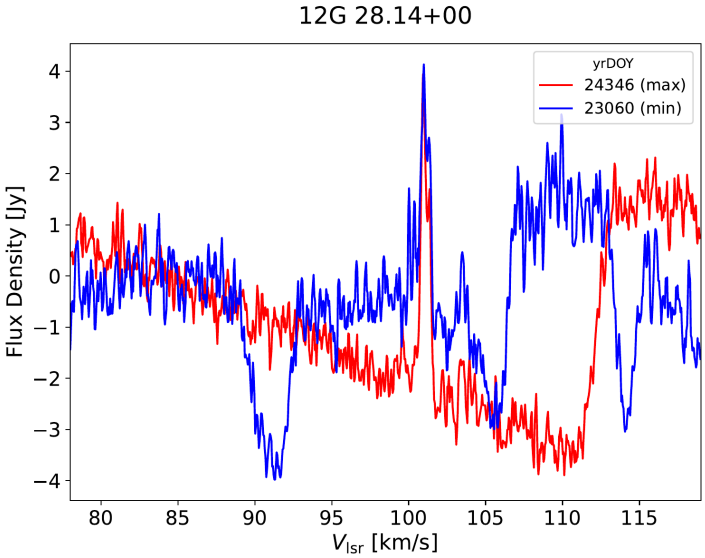
Light curve



Periodogram

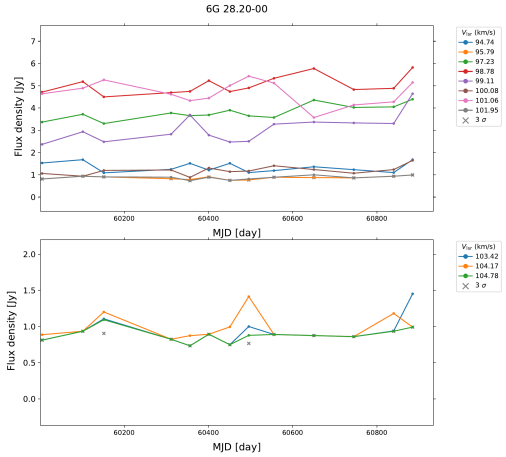


Spectrum

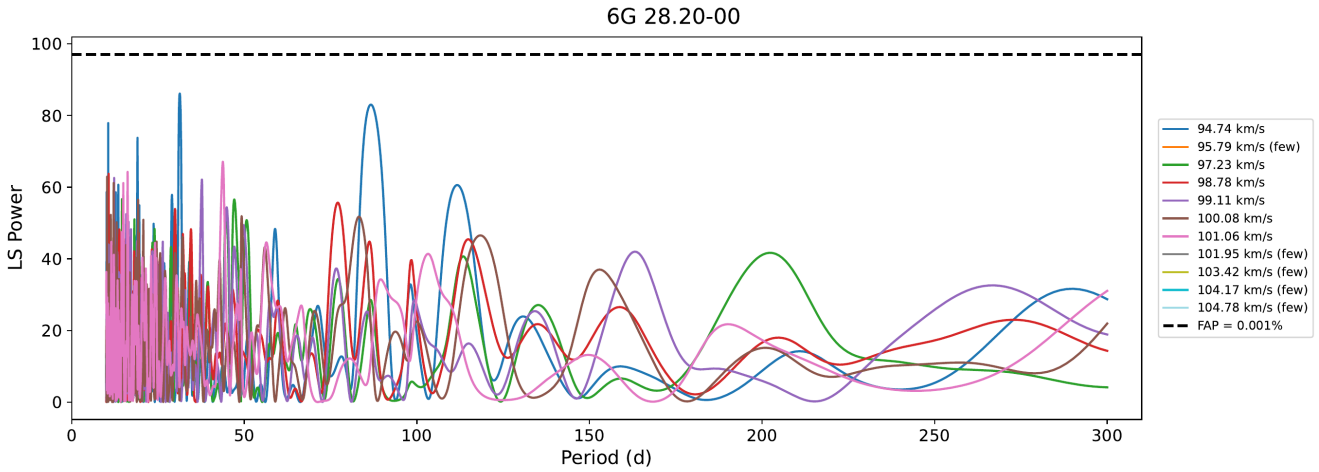


6G 28.20-00

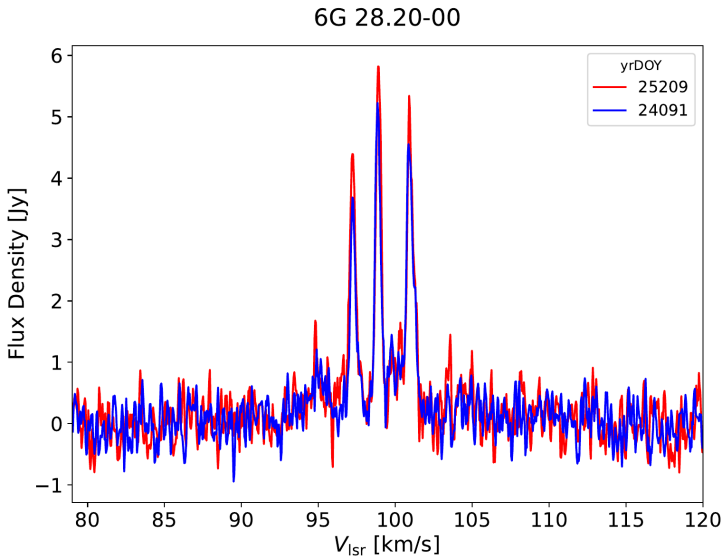
Light curve



Periodogram

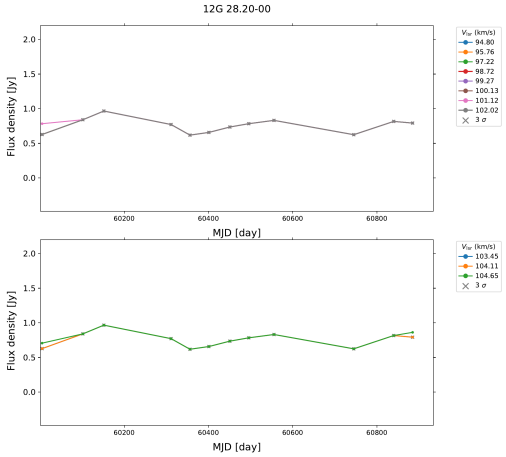


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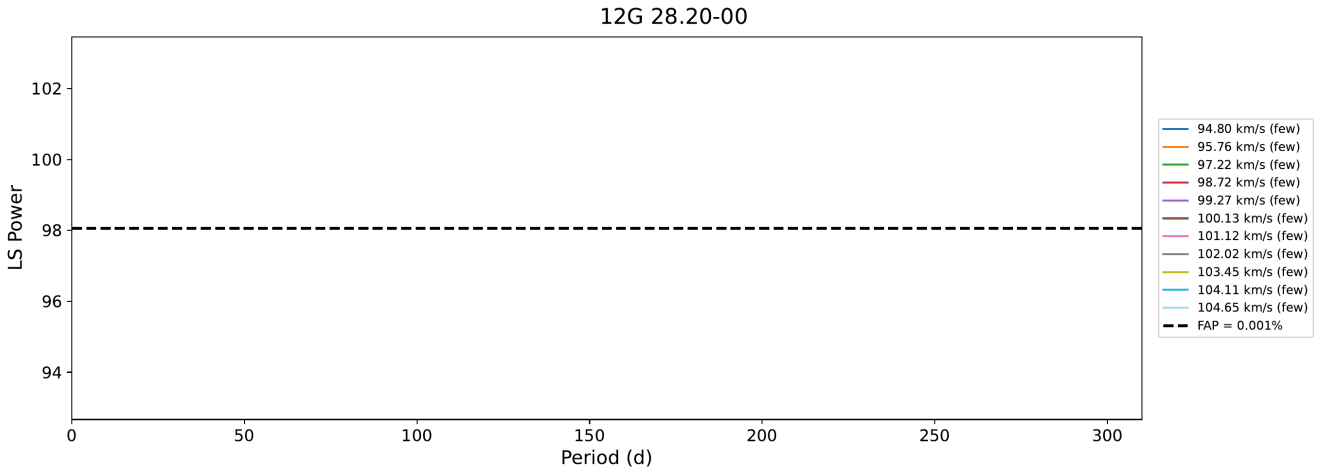


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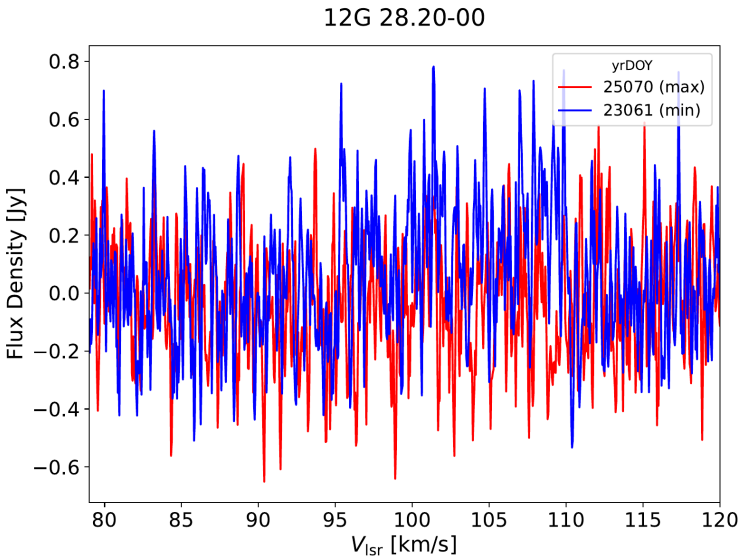
Light curve



Periodogram

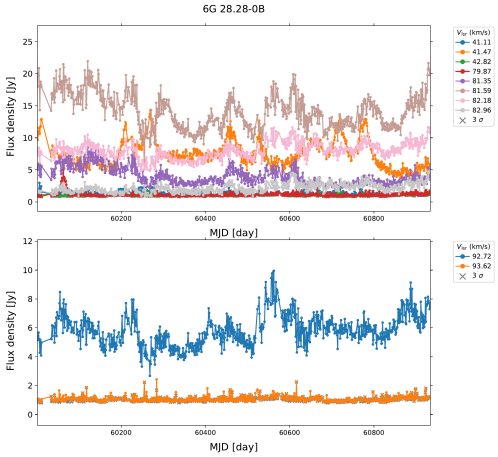


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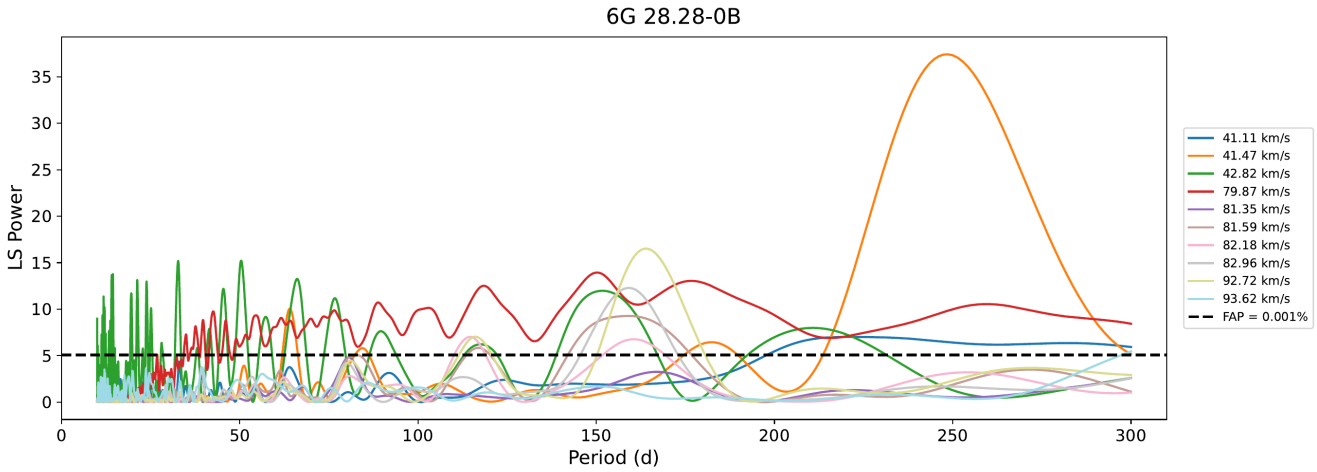


6G 28.28-0B

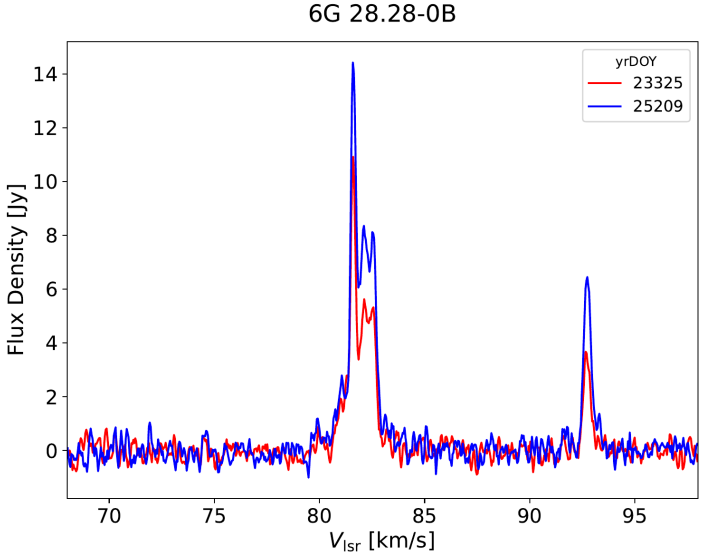
Light curve



Periodogram

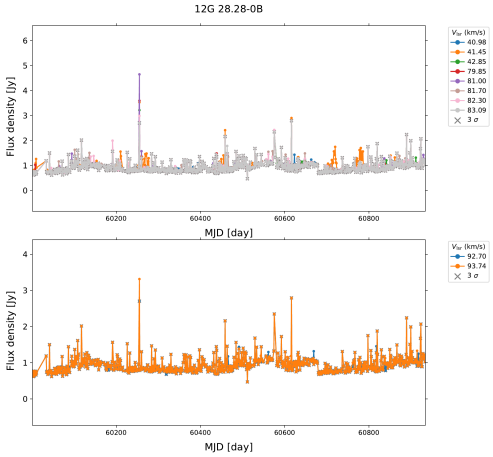


Spectrum

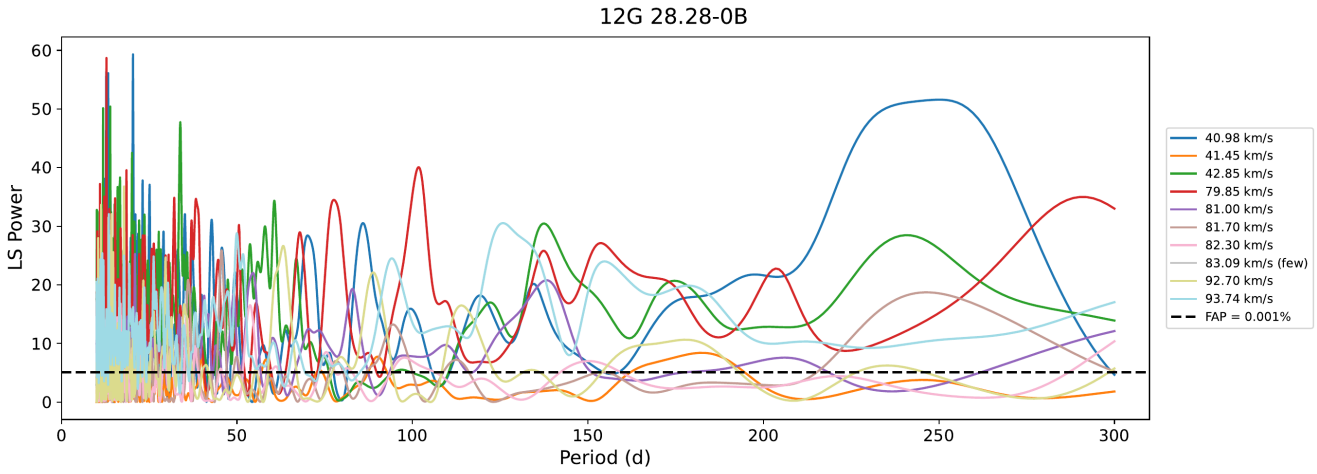


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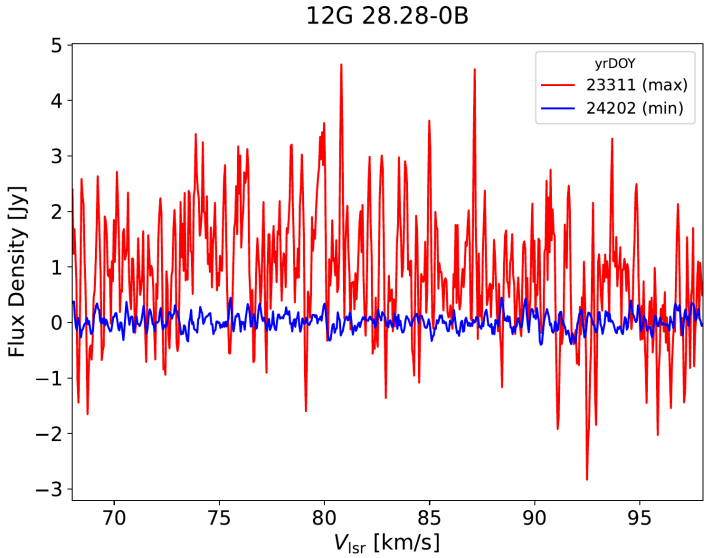
Light curve



Periodogram

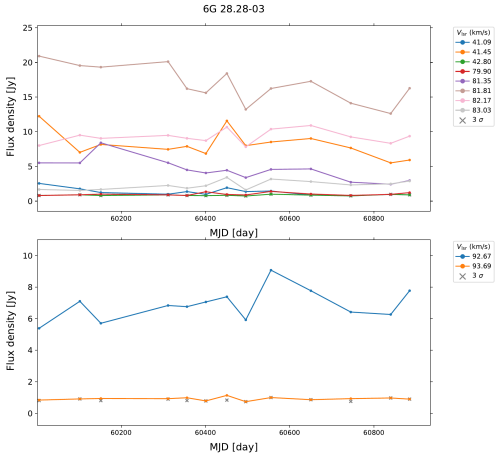


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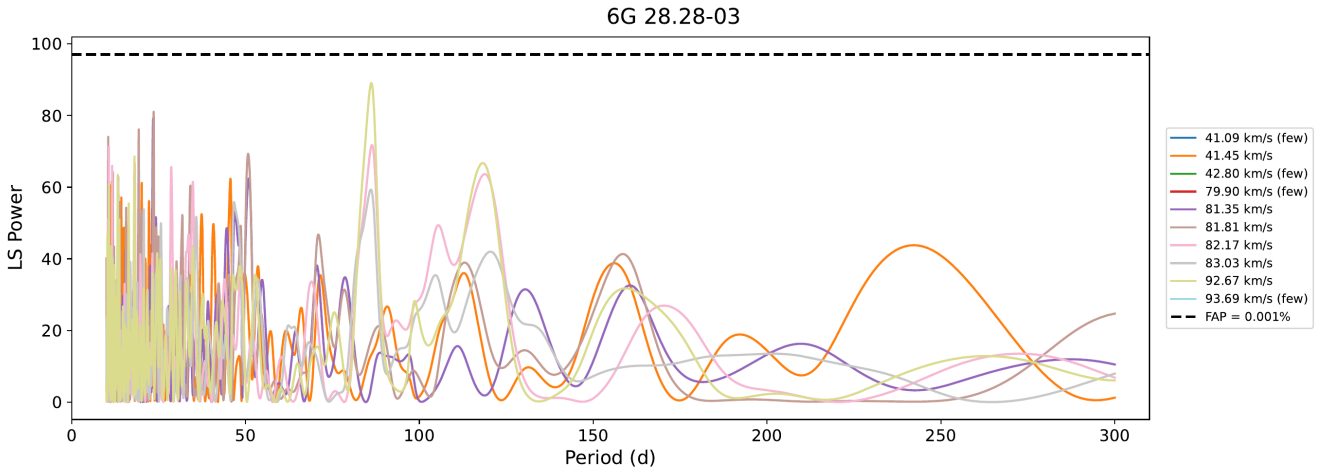


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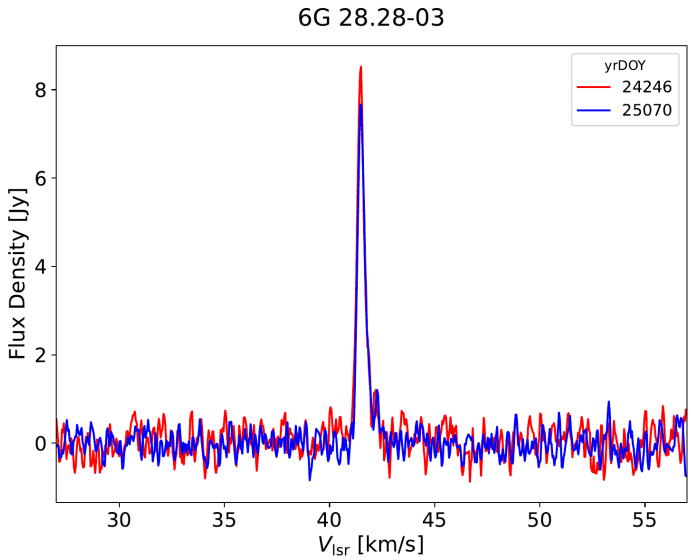
Light curve



Periodogram

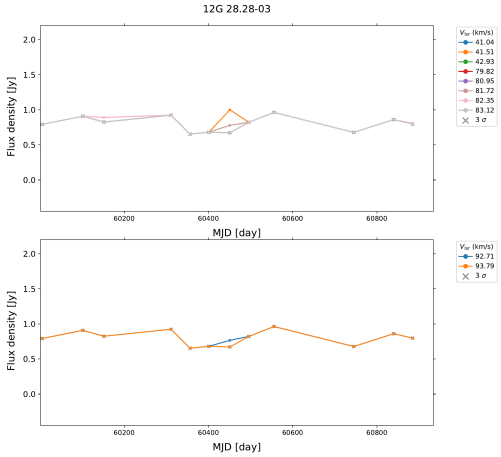


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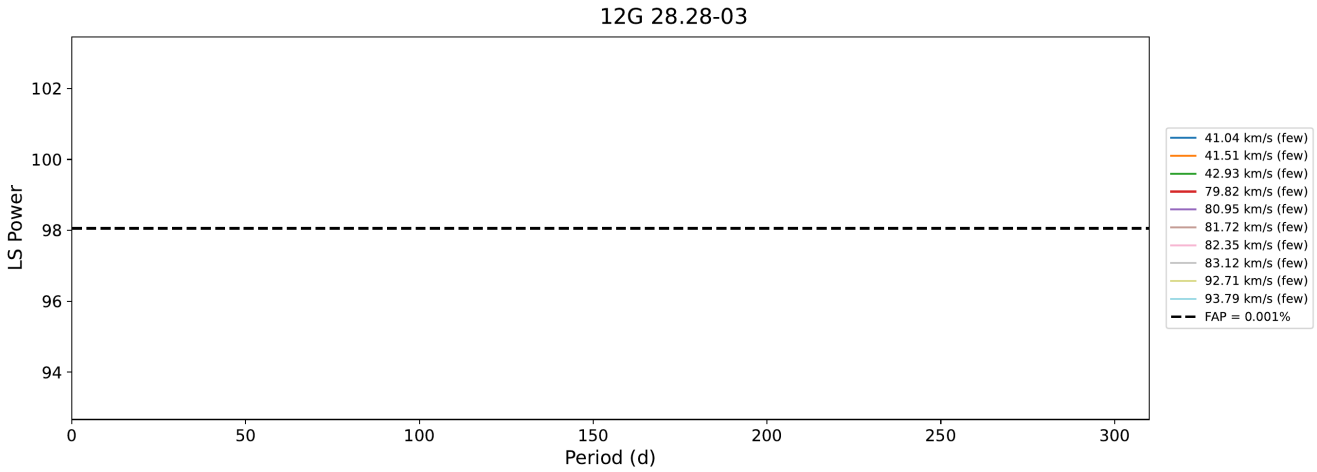


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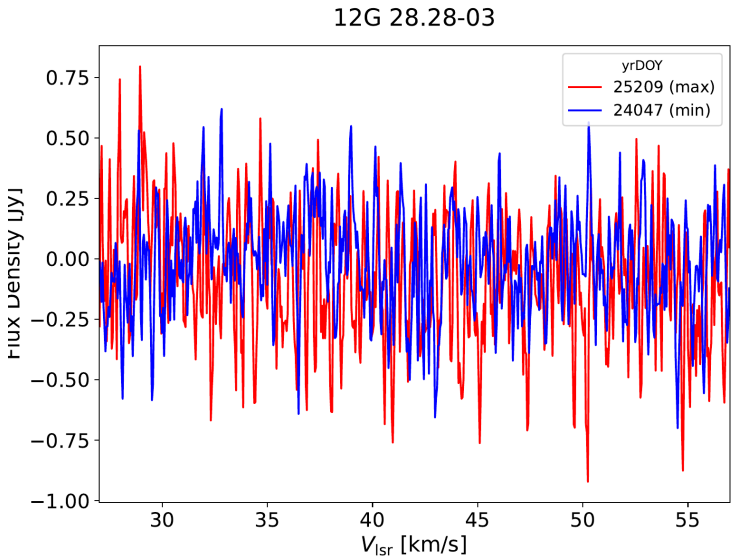
Light curve



Periodogram

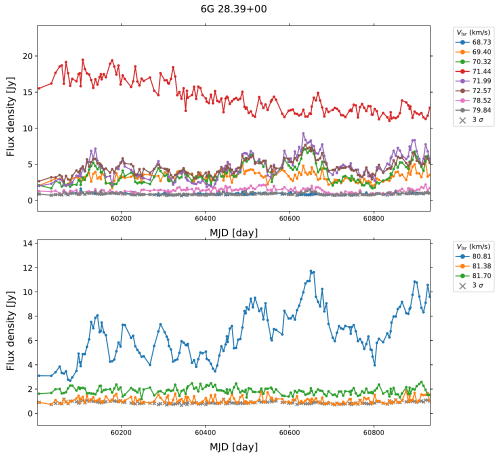


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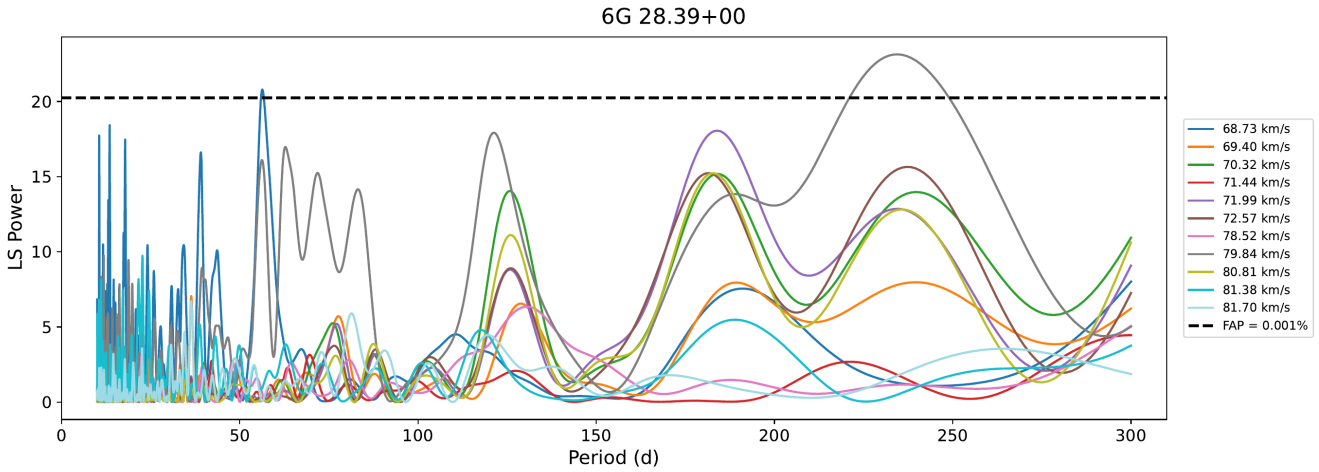


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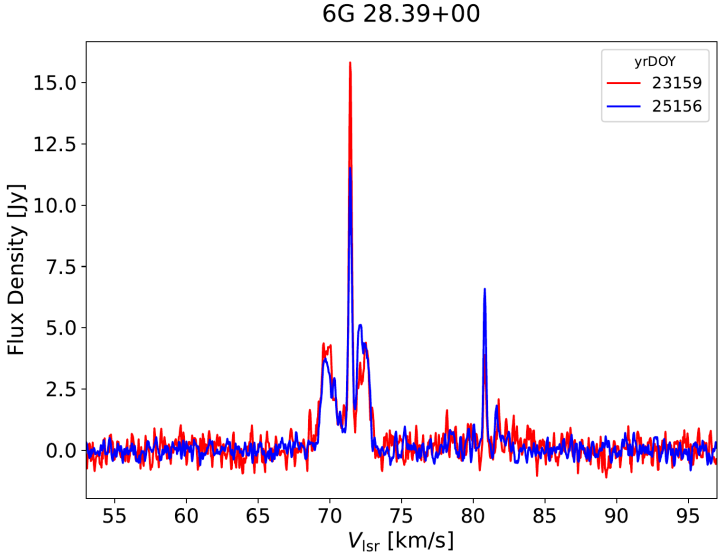
Light curve



Periodogram

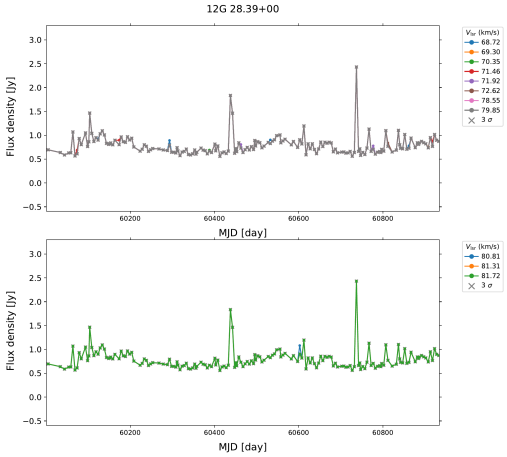


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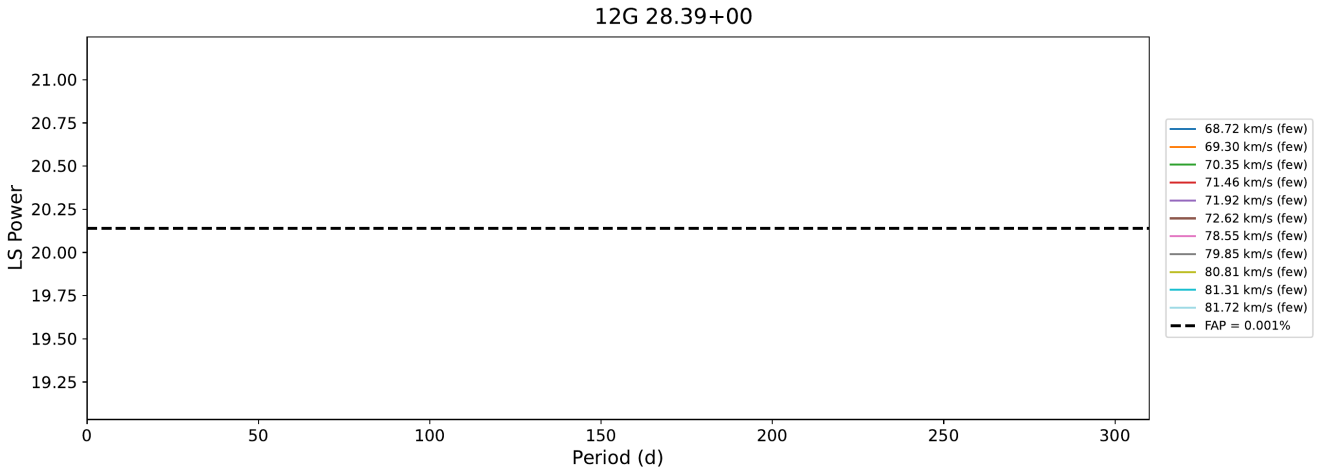


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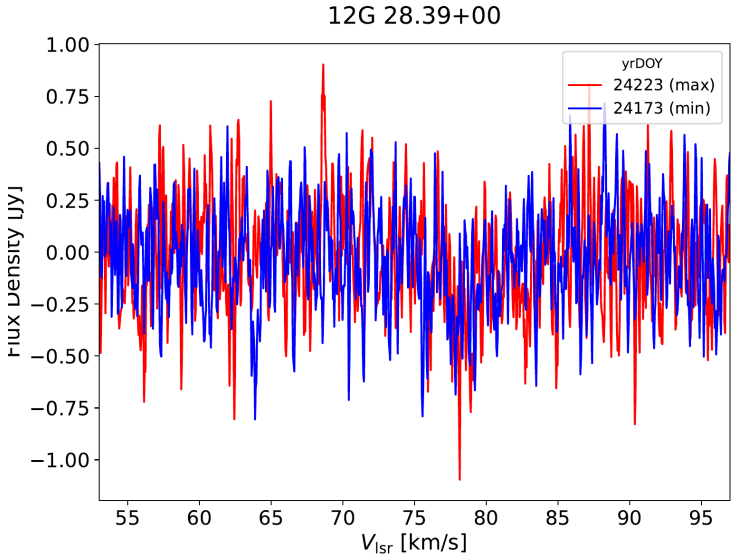
Light curve



Periodogram

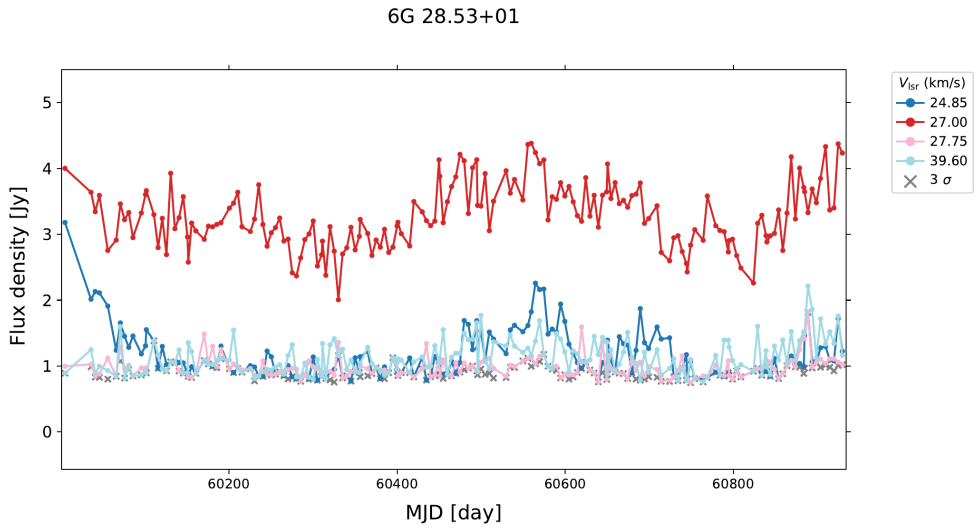


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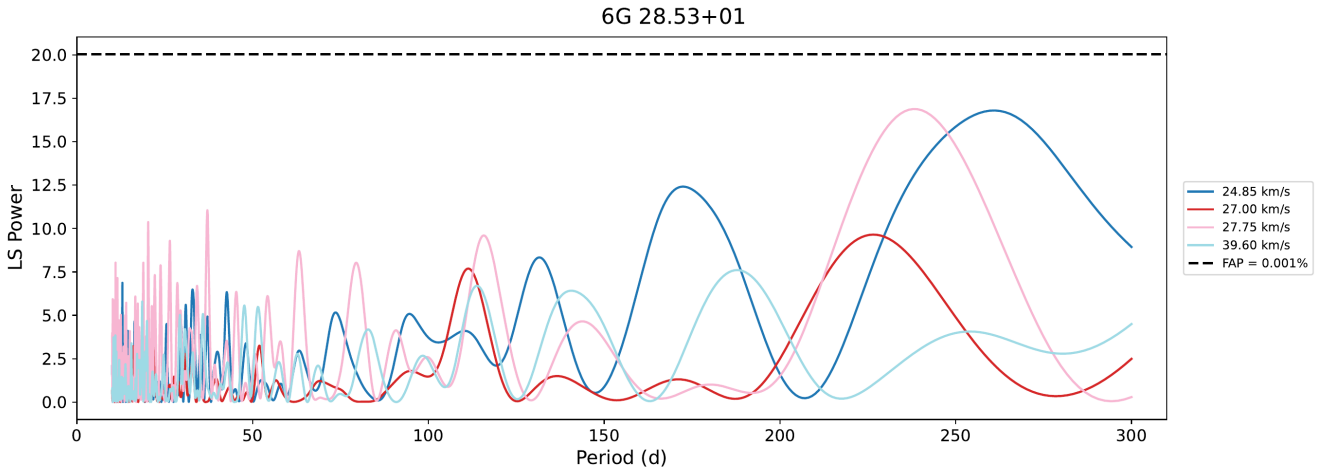


6G 28.53+01

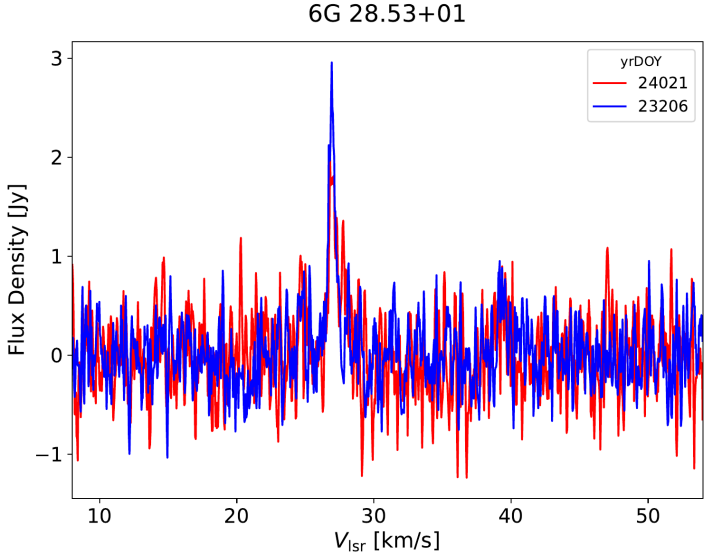
Light curve



Periodogram

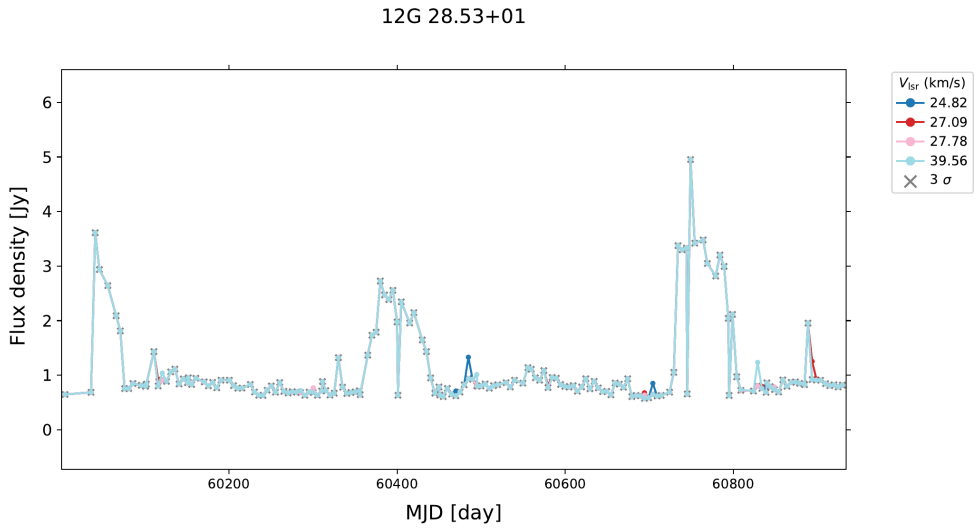


Spectrum

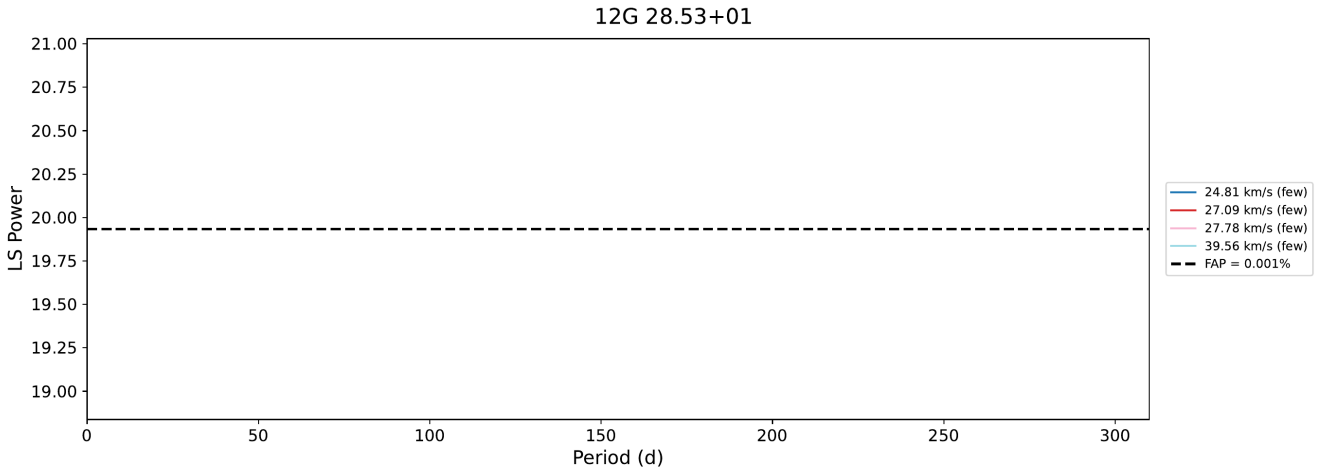


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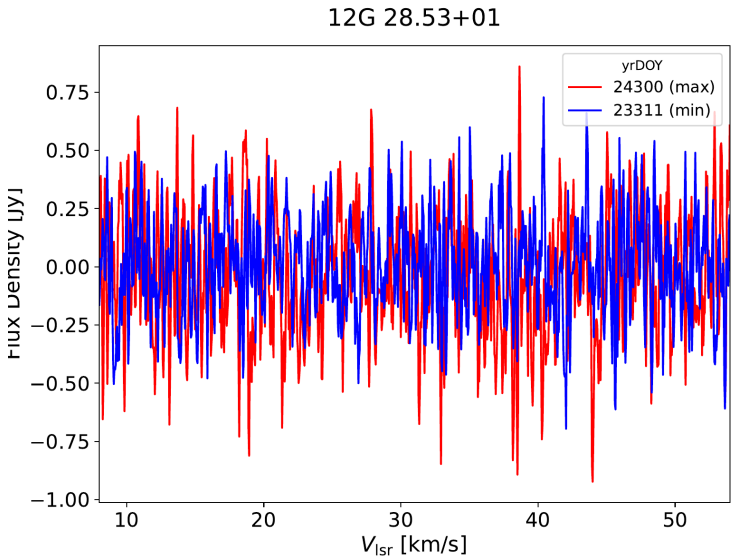
Light curve



Periodogram

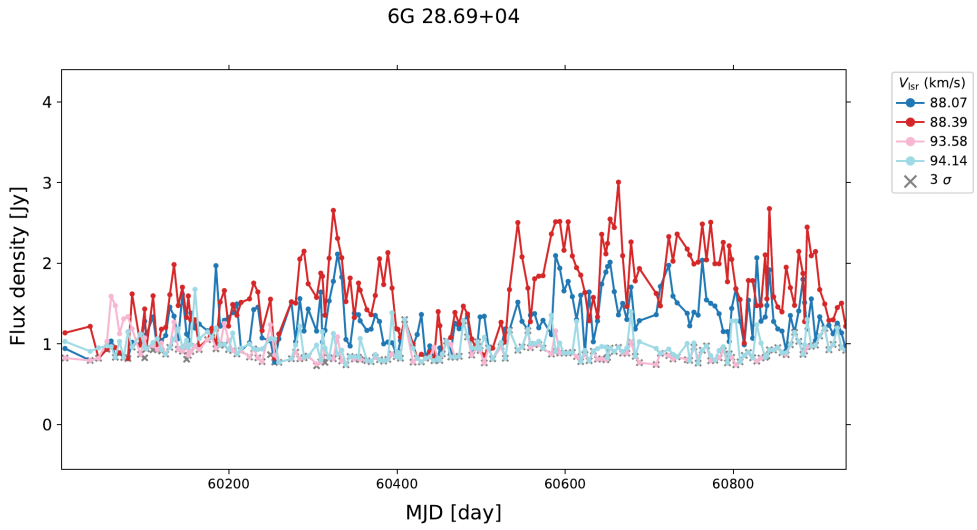


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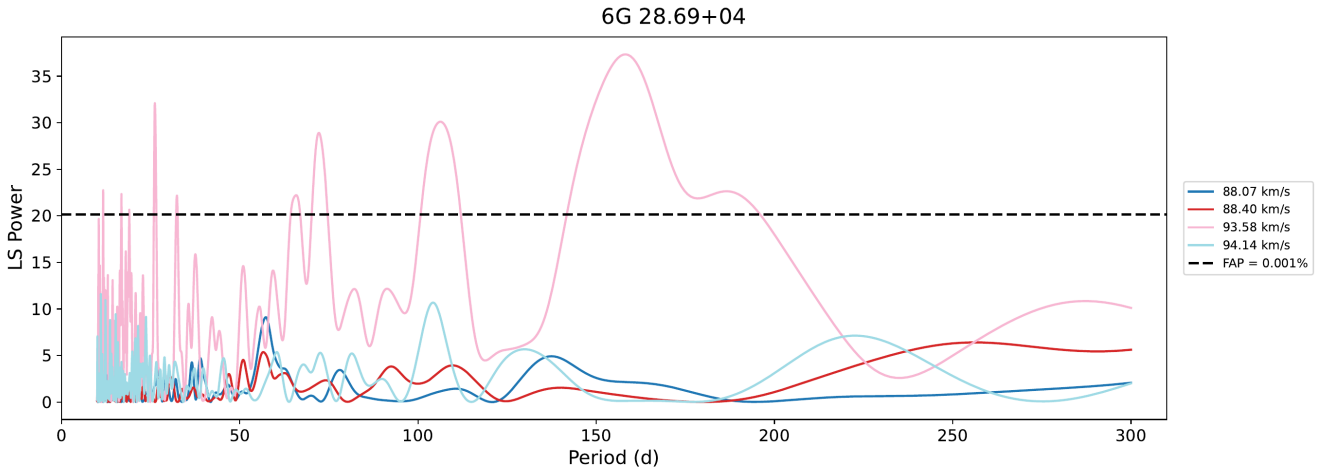


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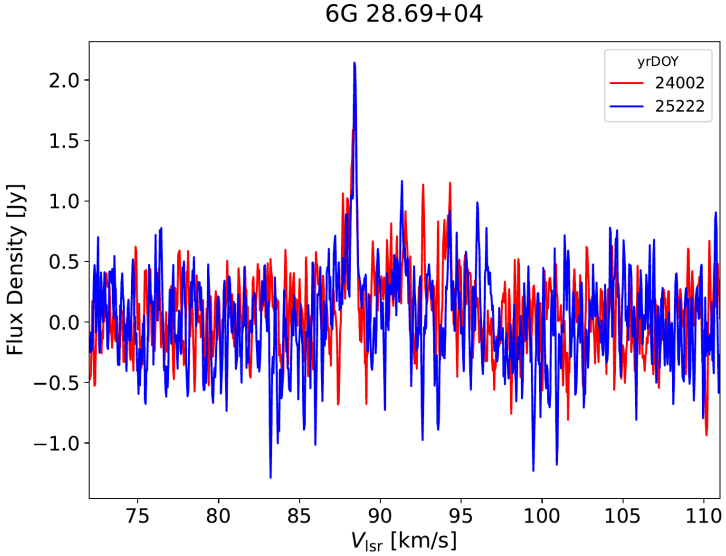
Light curve



Periodogram

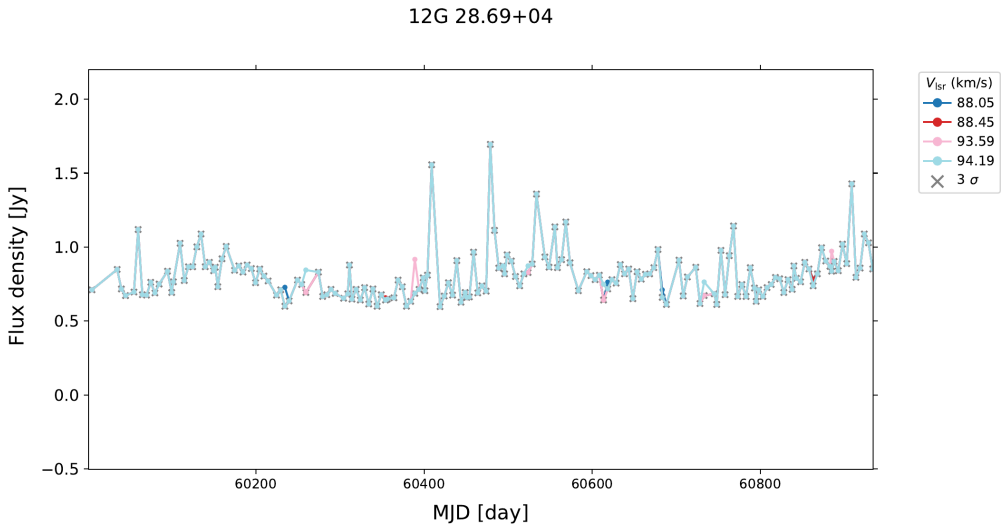


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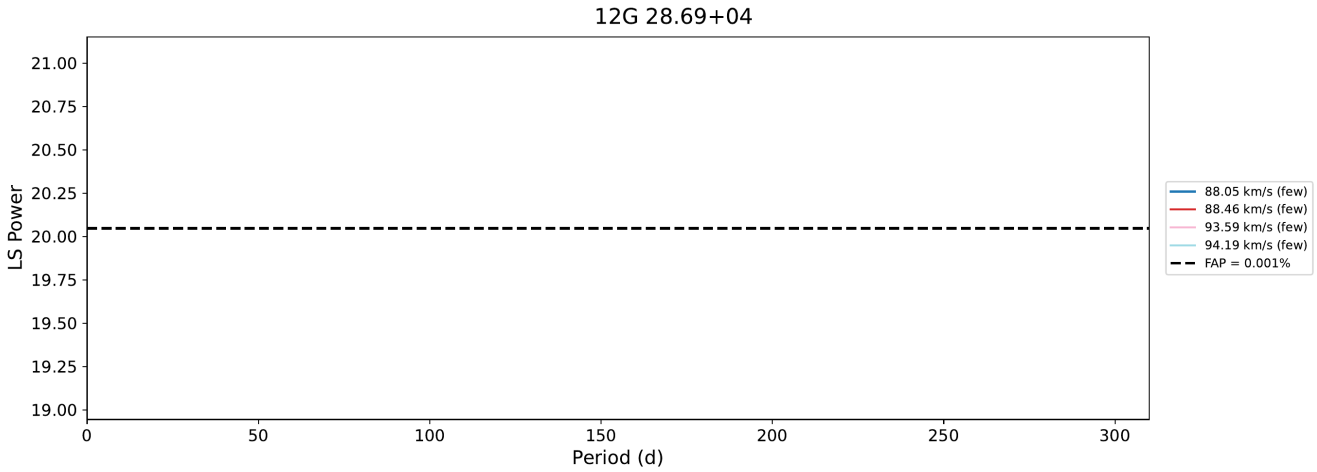


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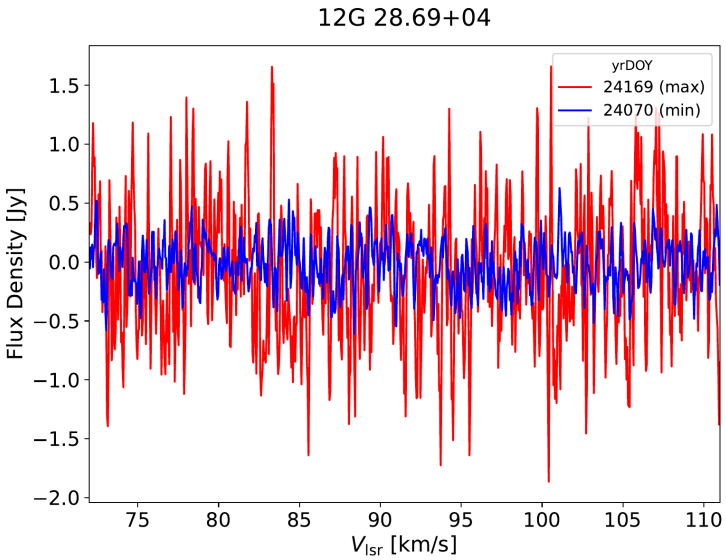
Light curve



Periodogram

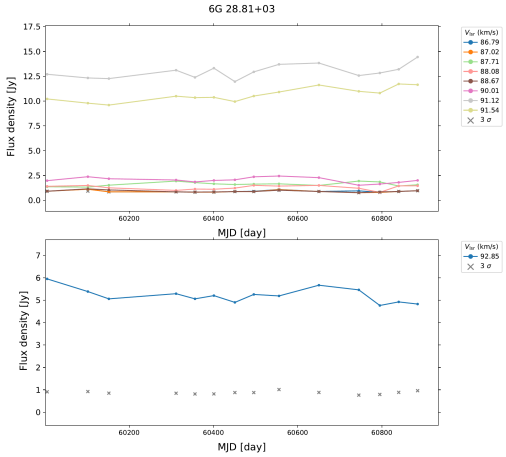


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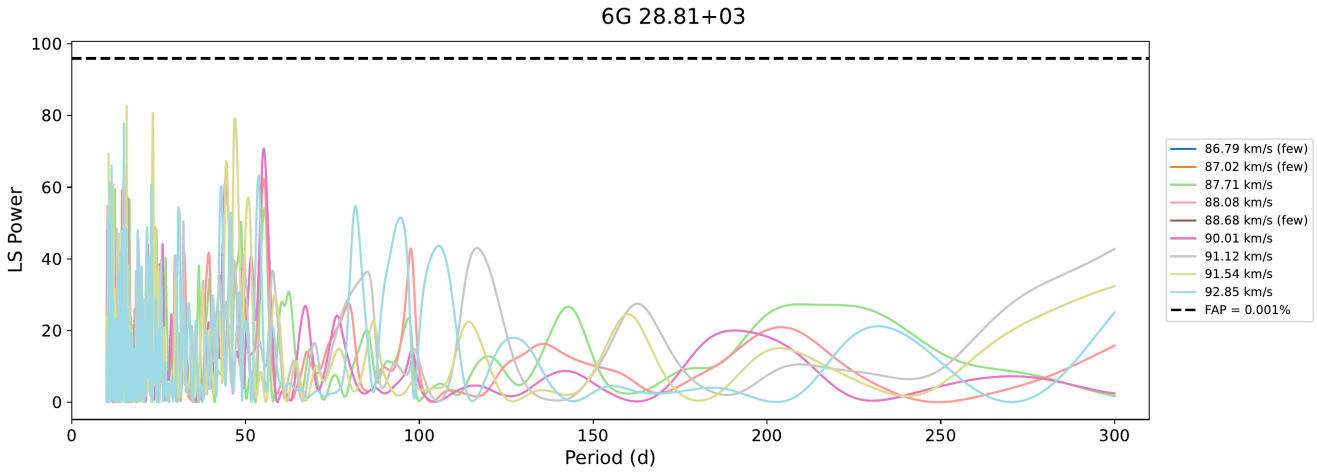


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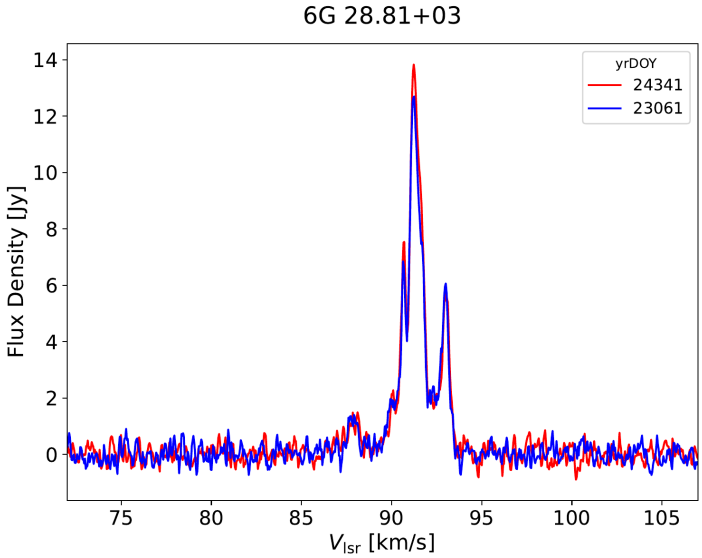
Light curve



Periodogram

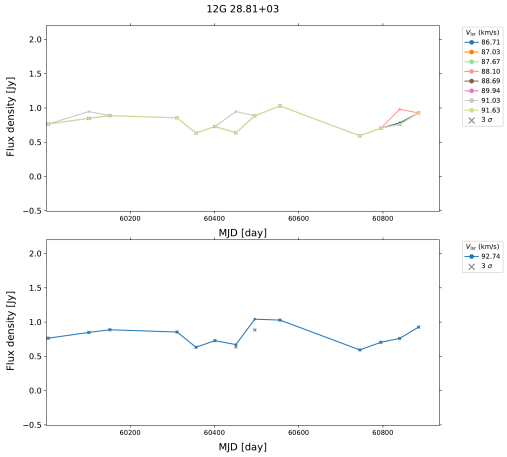


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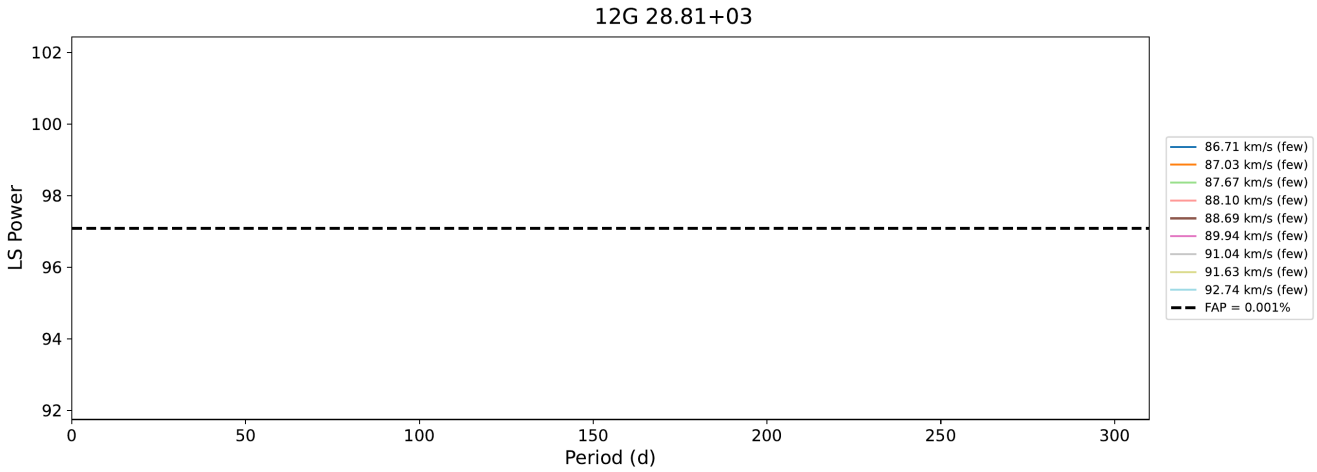


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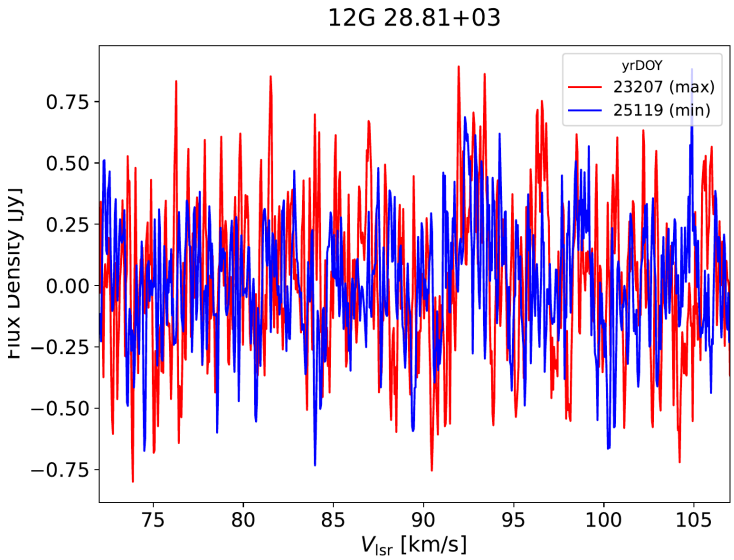
Light curve



Periodogram

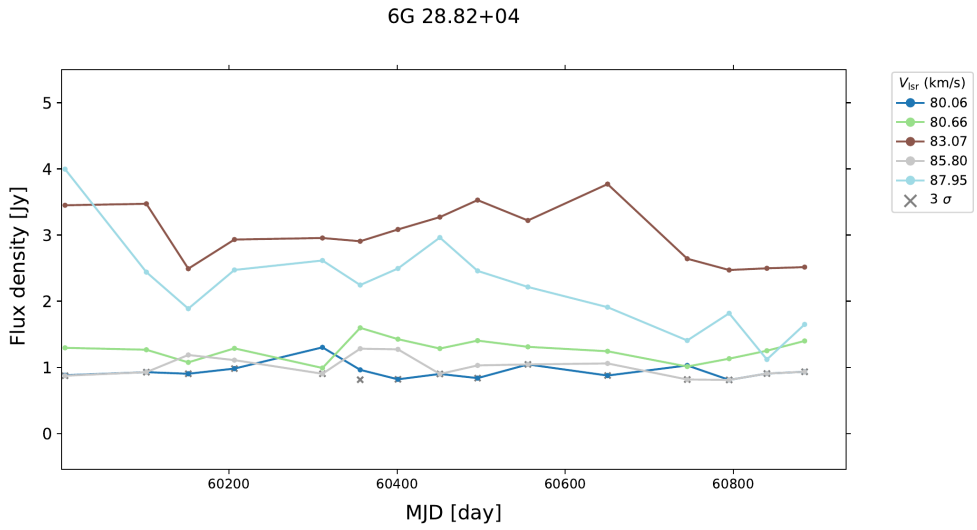


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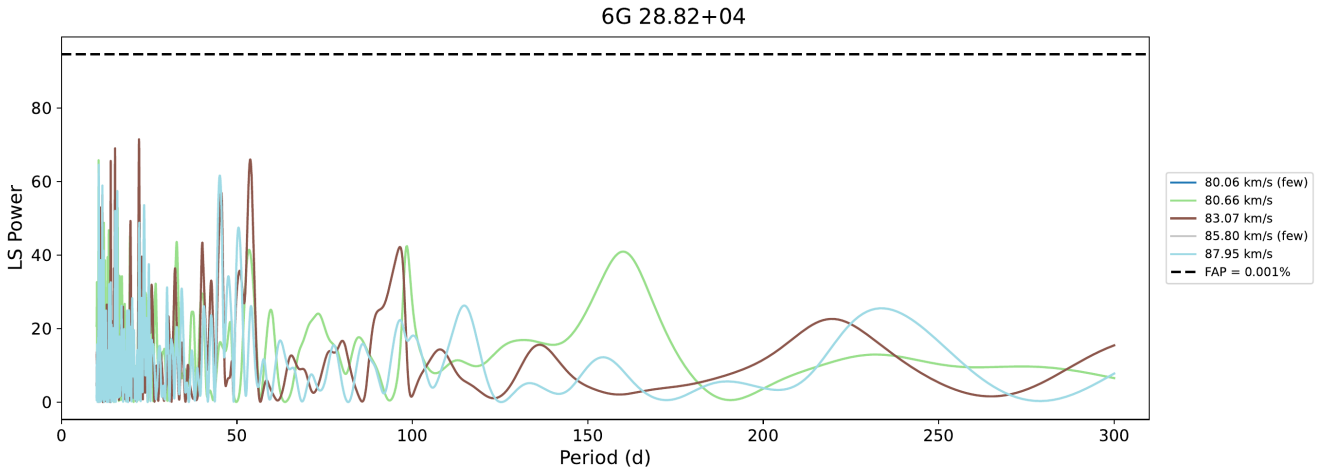


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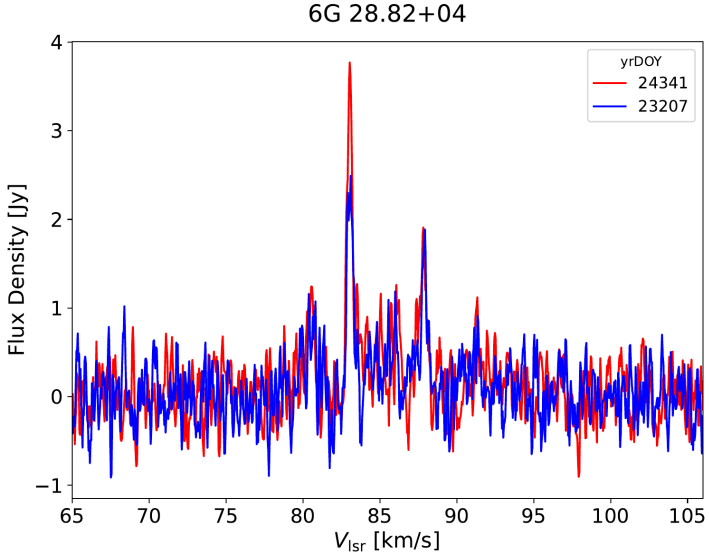
Light curve



Periodogram

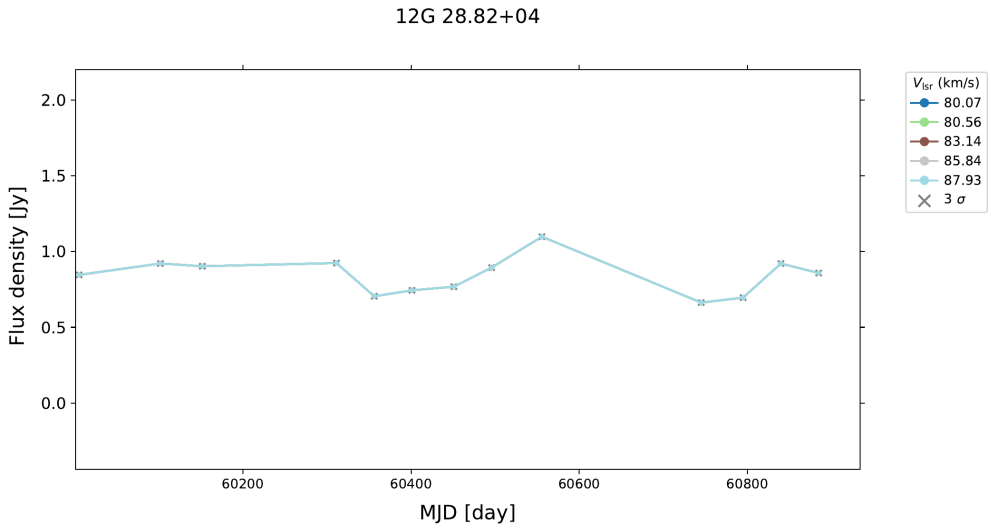


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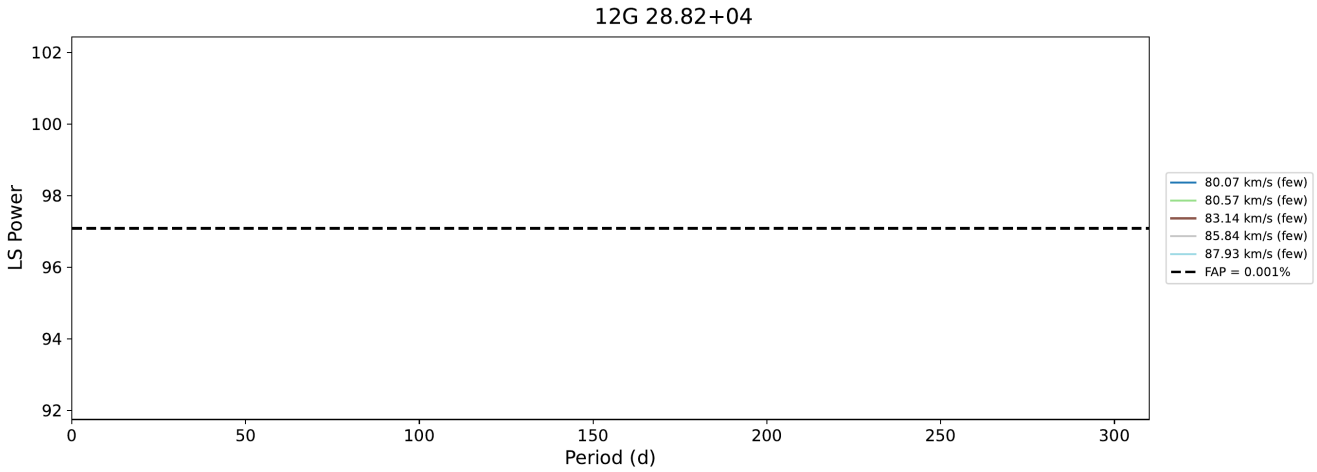


12G 28.82+04

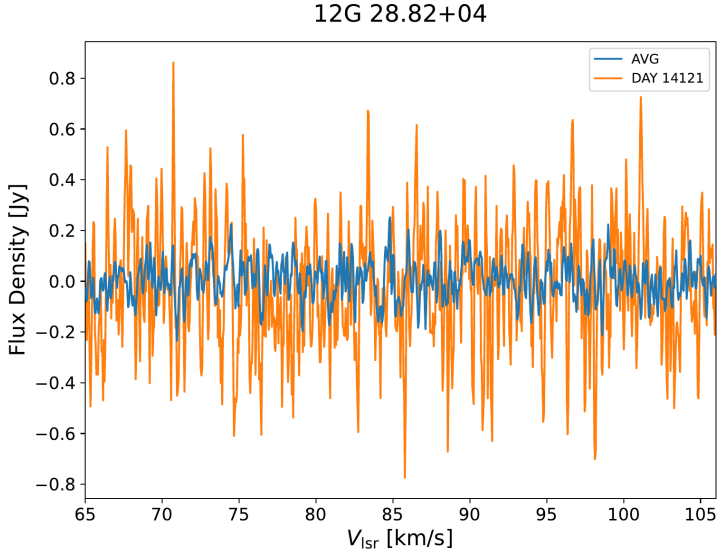
Light curve



Periodogram

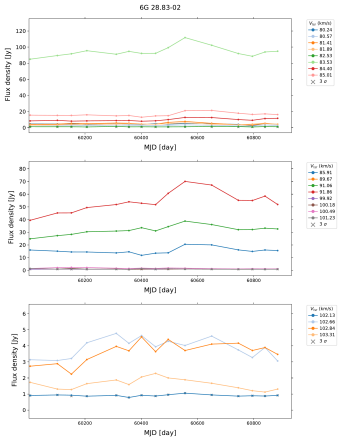


Spectrum

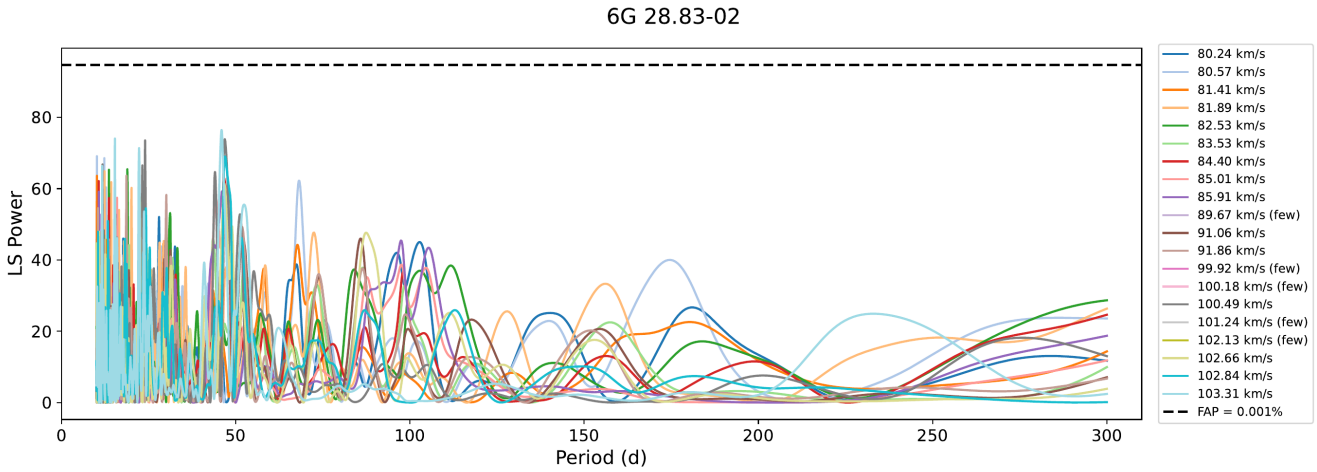


6G 28.83-02

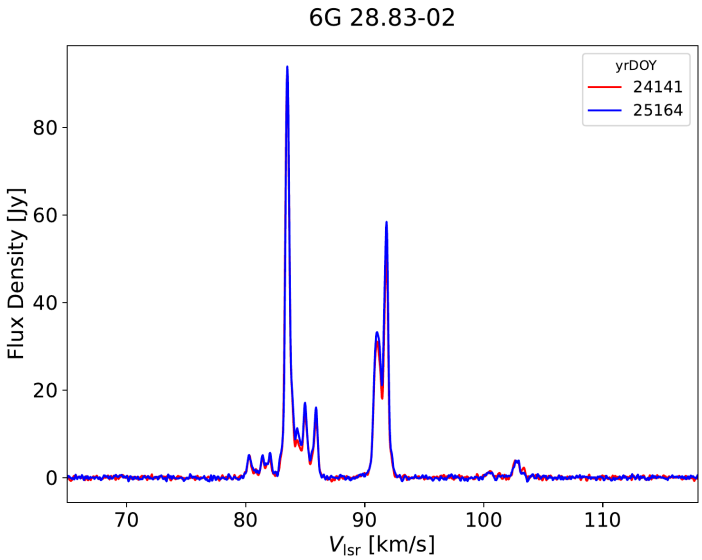
Light curve



Periodogram

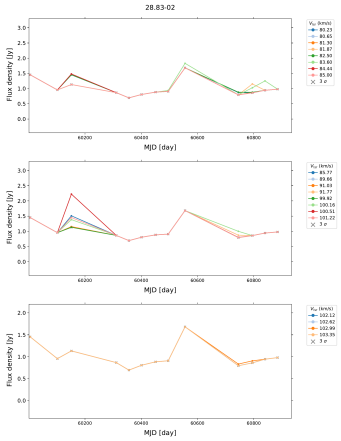


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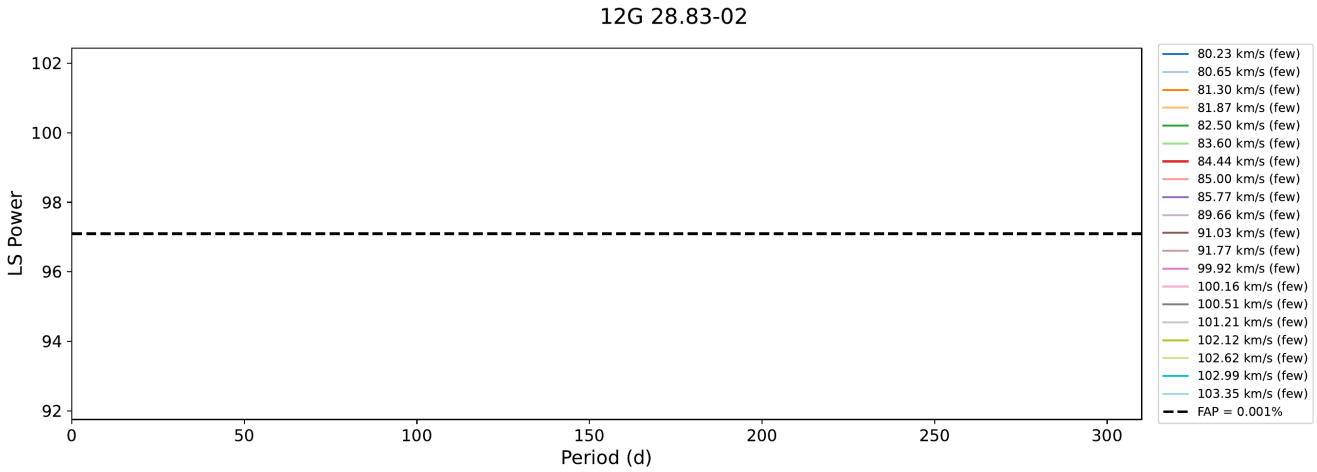


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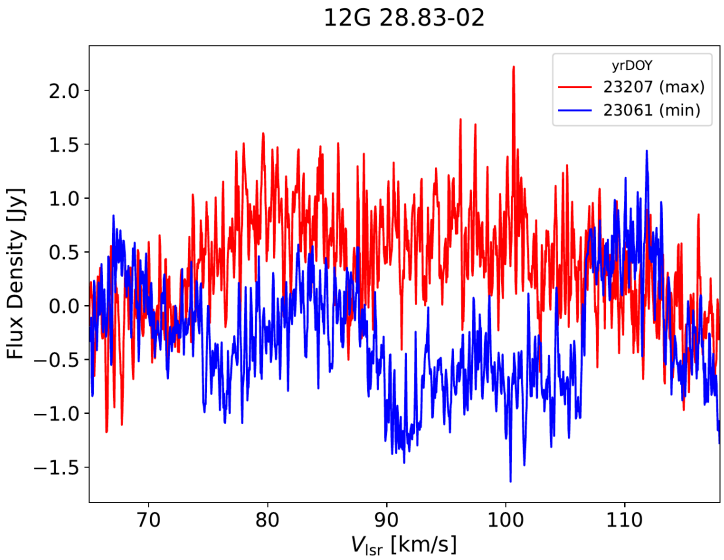
Light curve



Periodogram

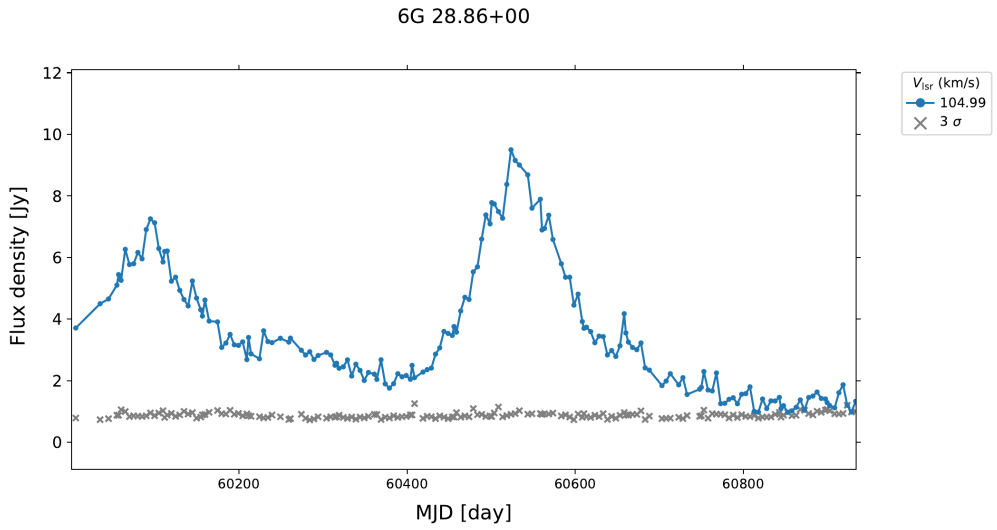


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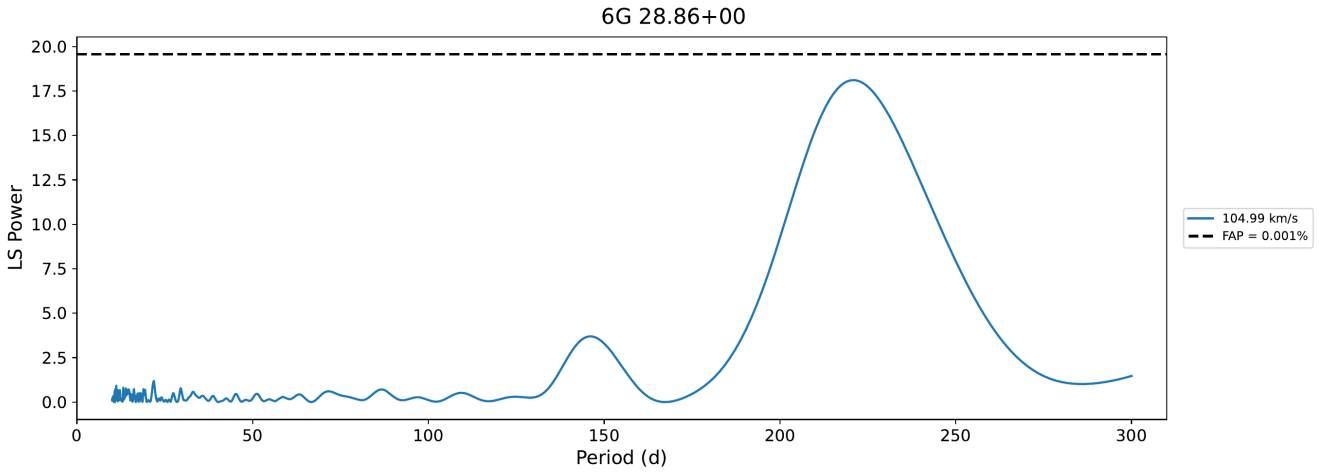


6G 28.86+00

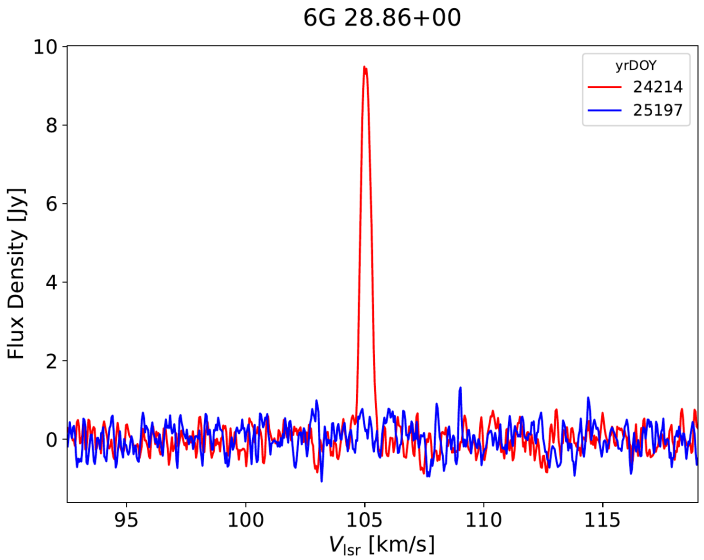
Light curve



Periodogram

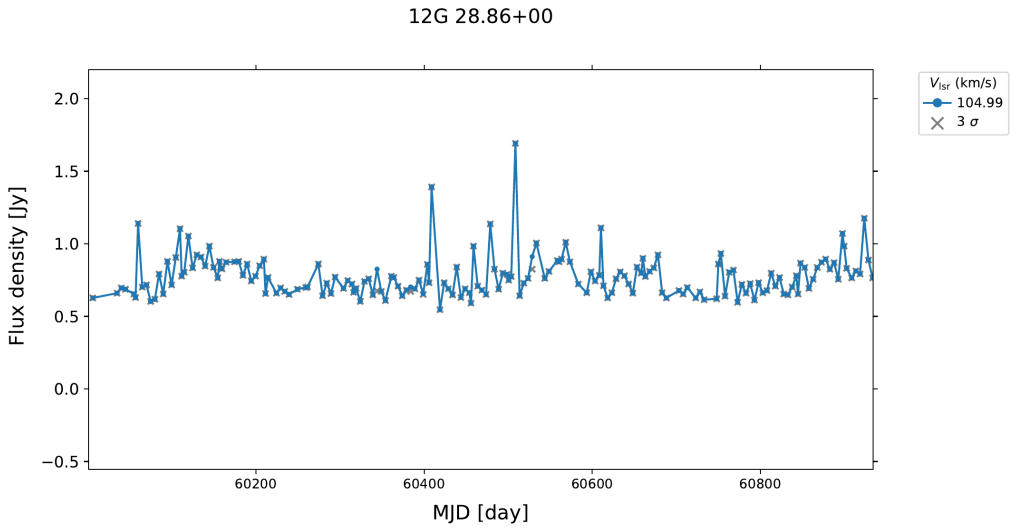


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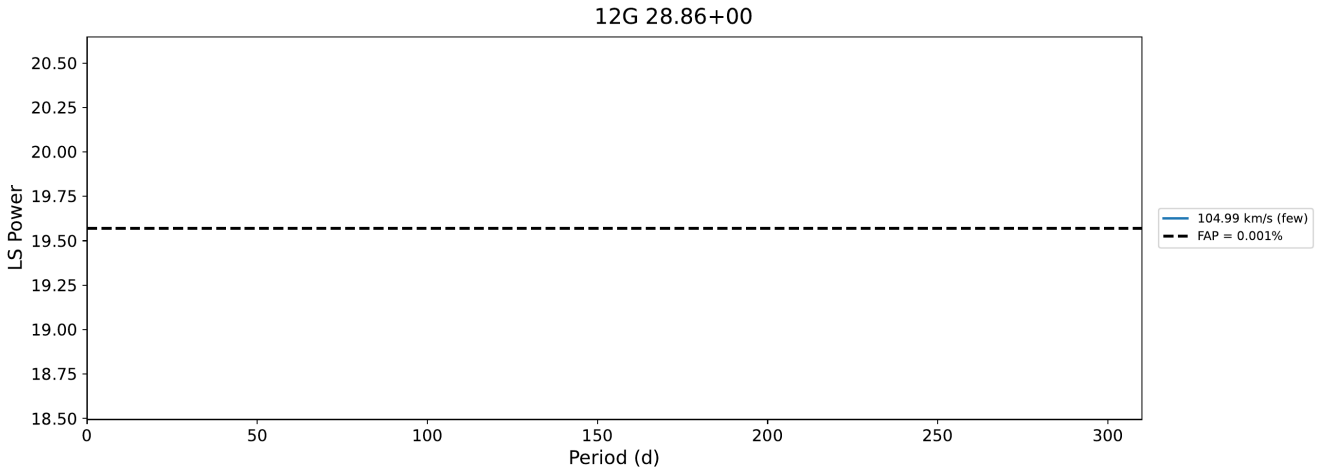


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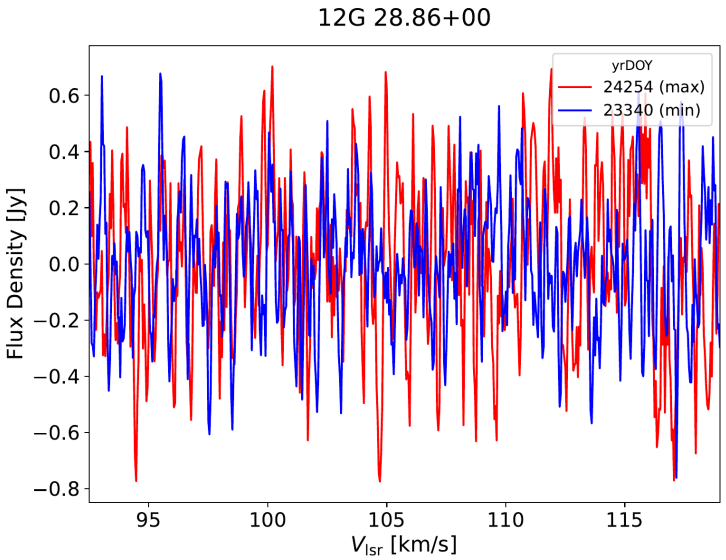
Light curve



Periodogram

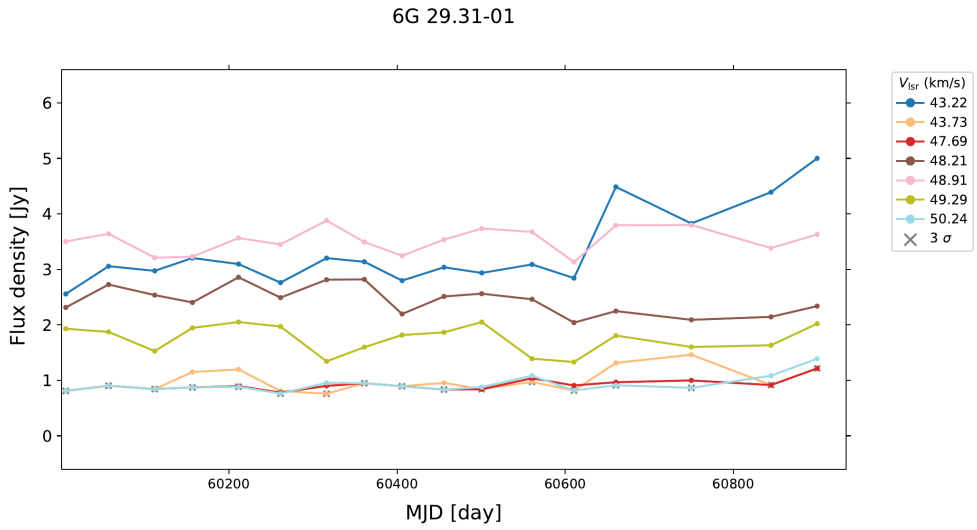


Spectrum

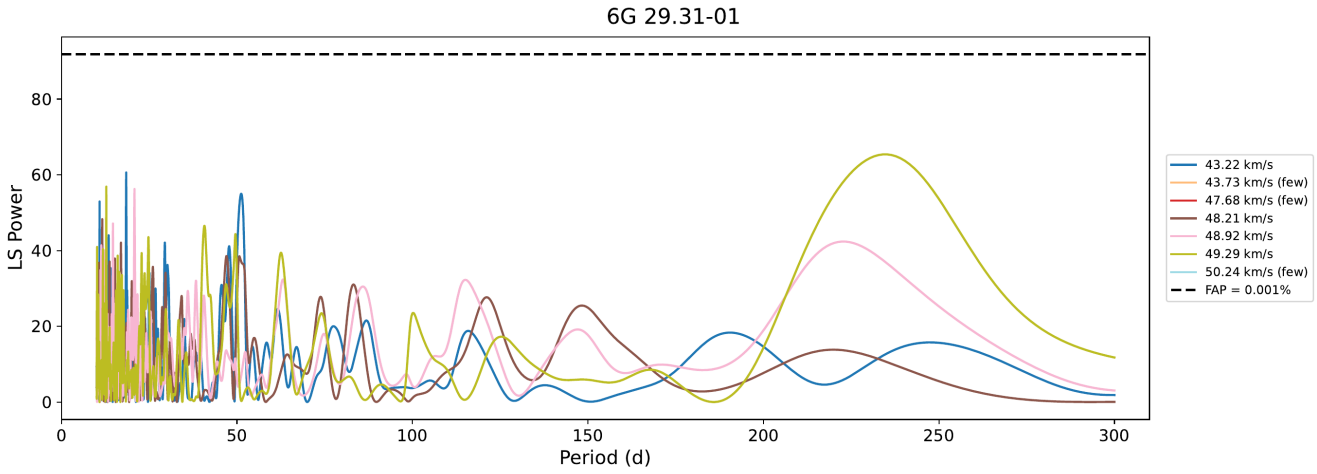


6G 29.31-01

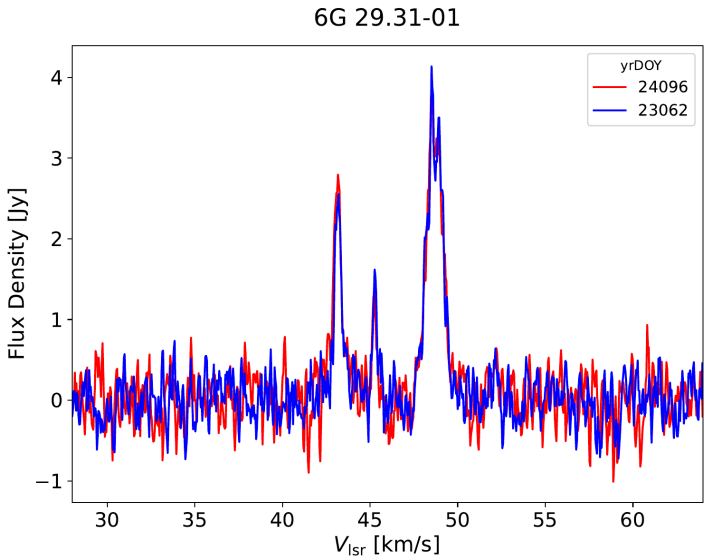
Light curve



Periodogram

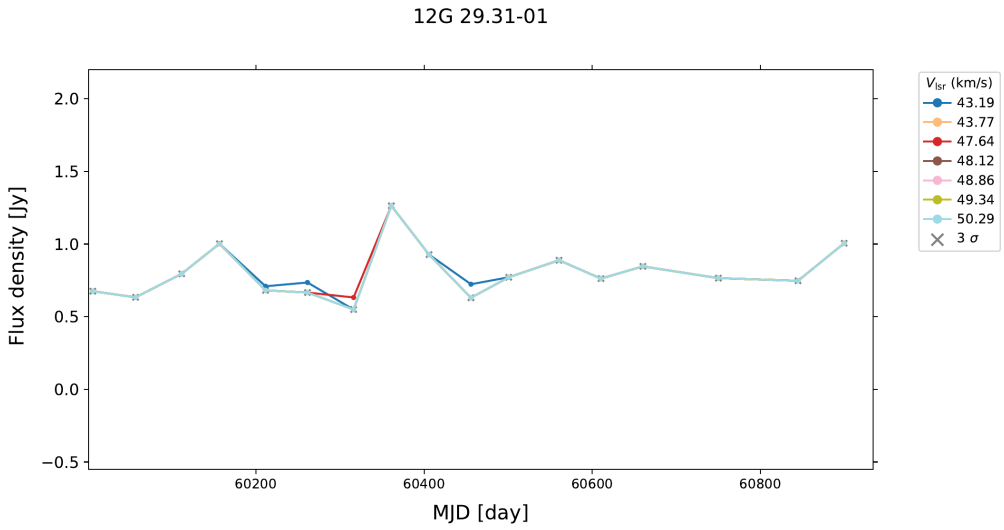


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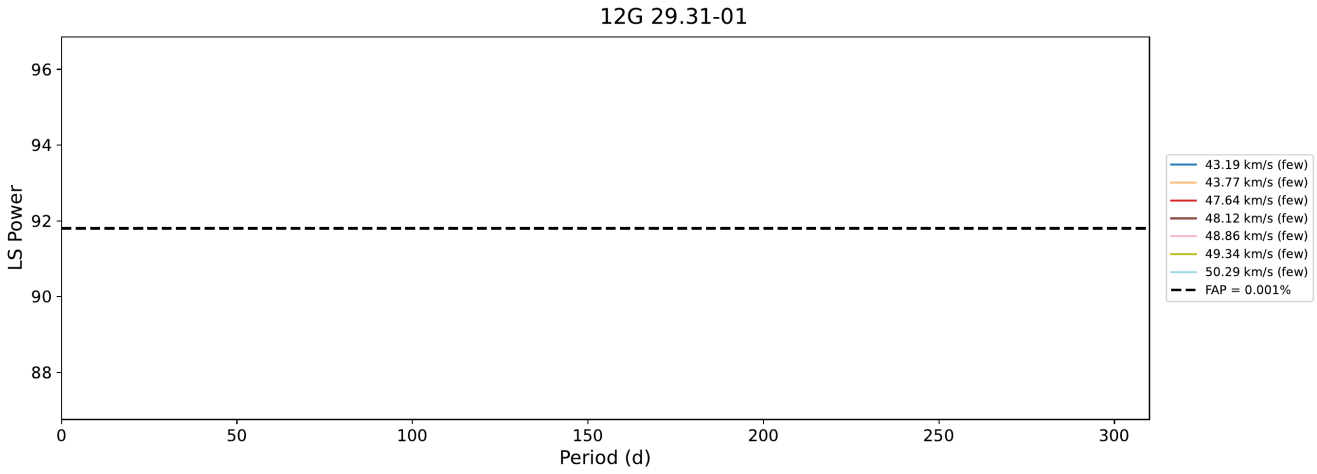


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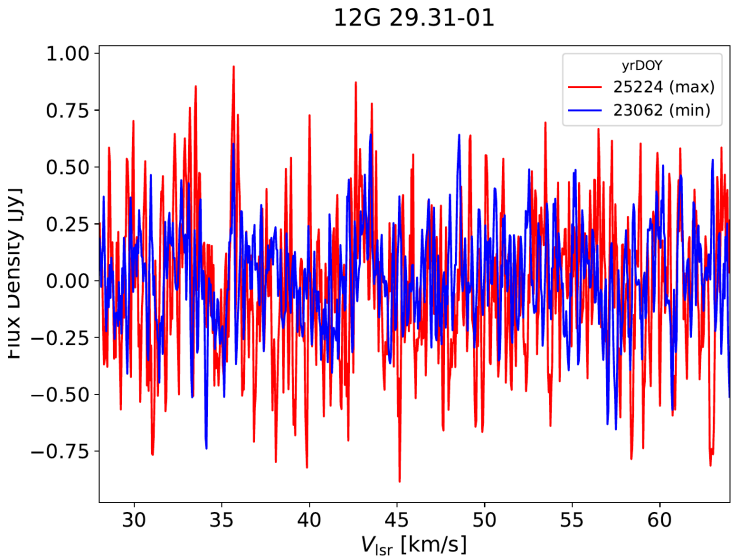
Light curve



Periodogram

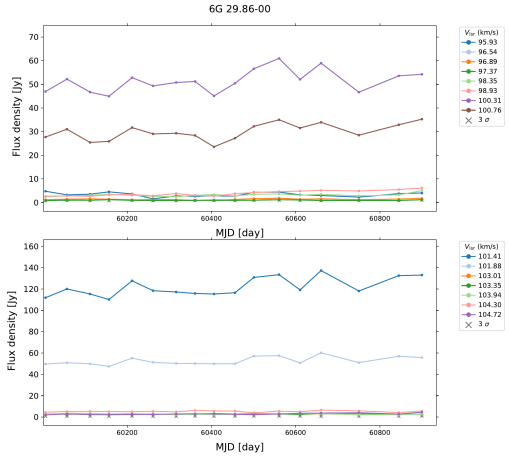


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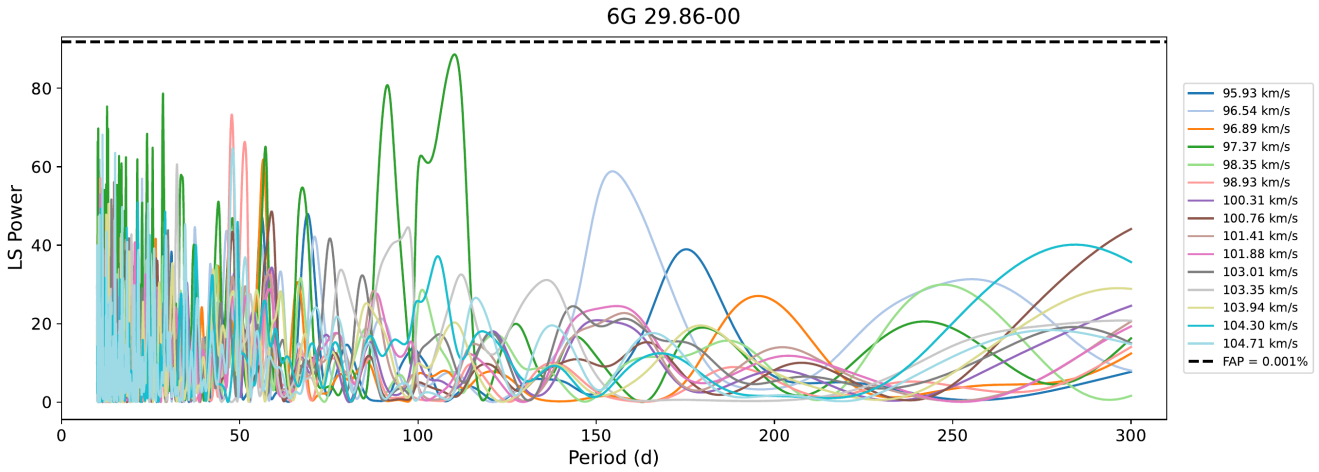


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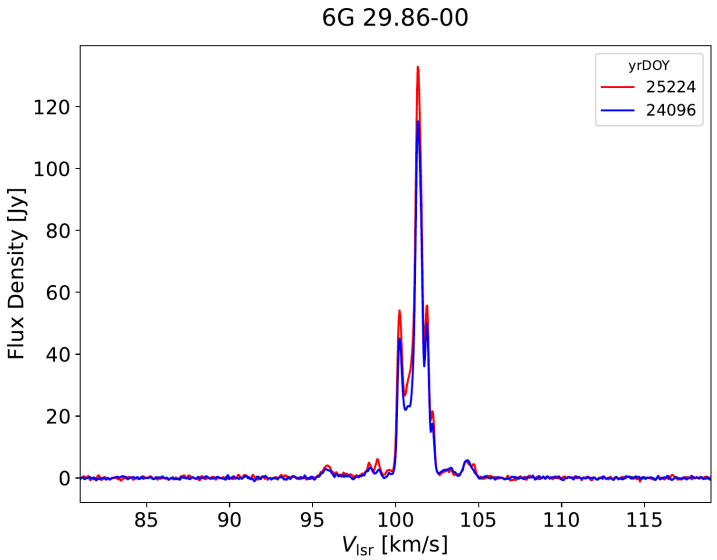
Light curve



Periodogram

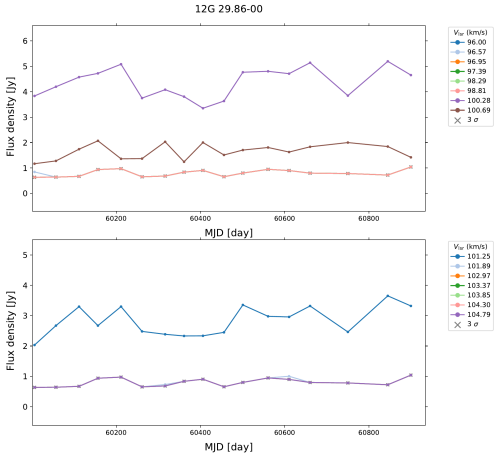


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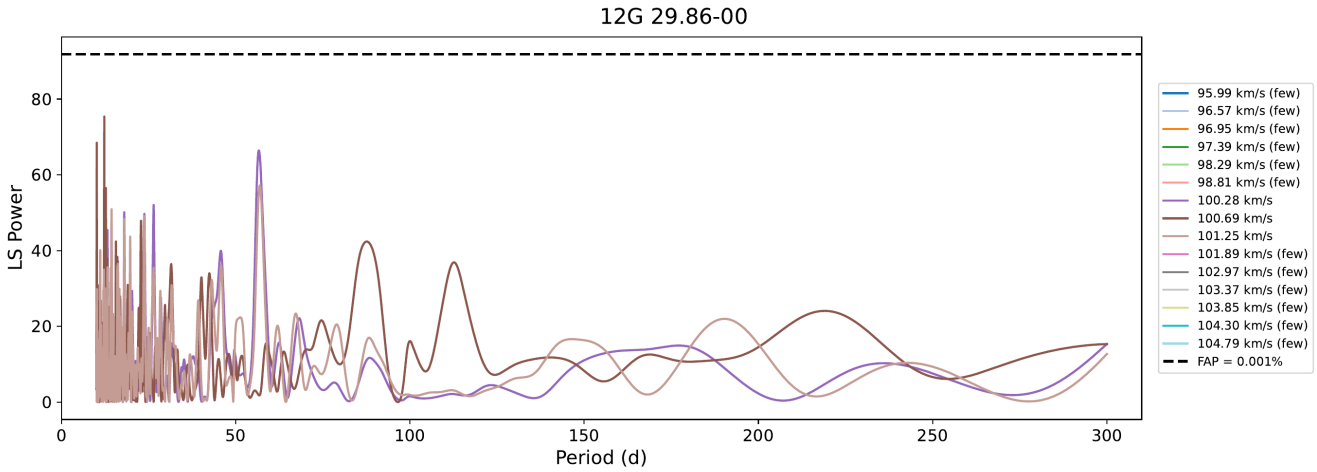


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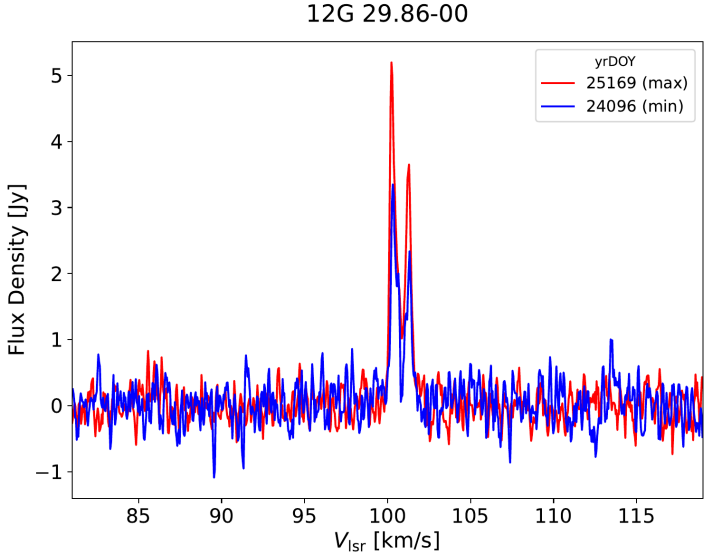
Light curve



Periodogram

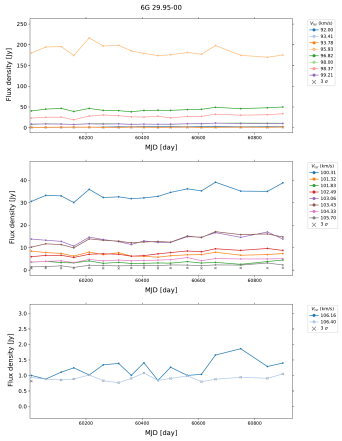


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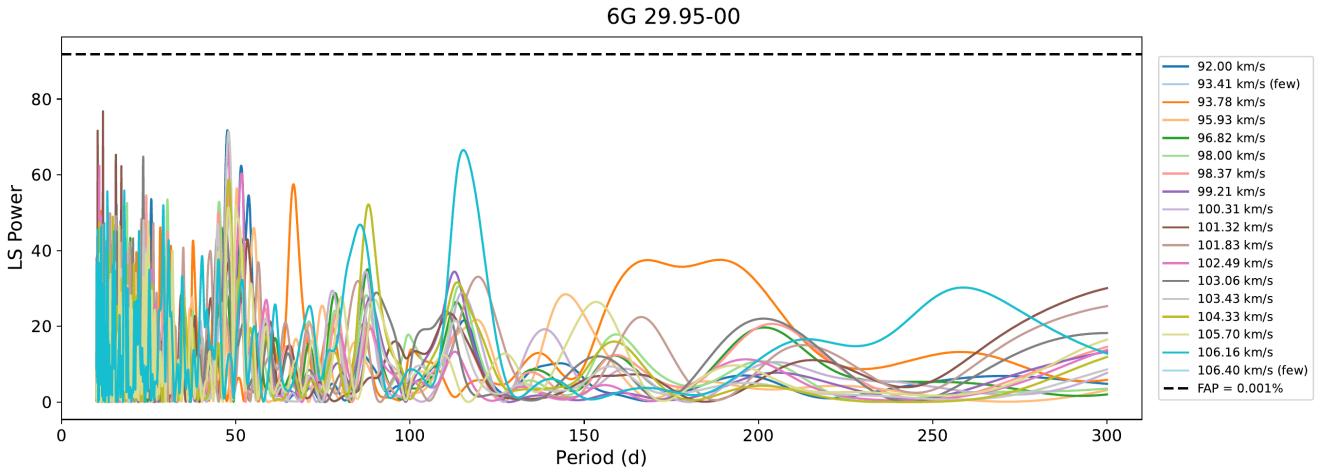


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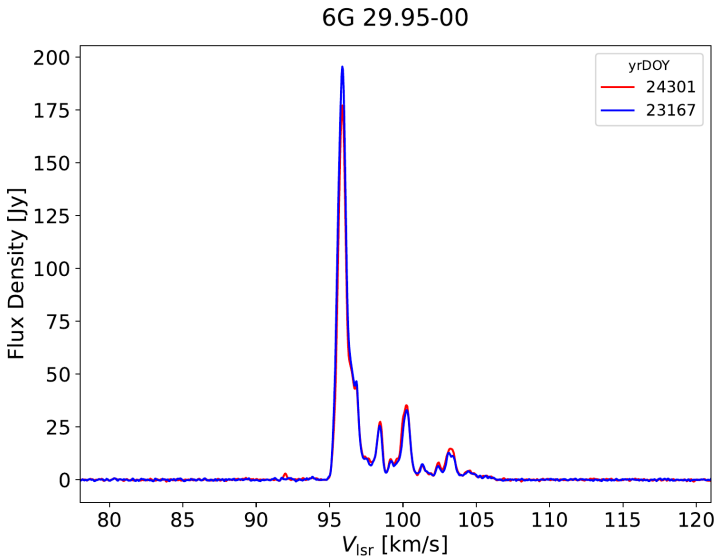
Light curve



Periodogram

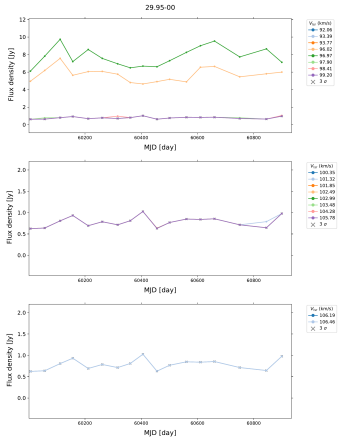


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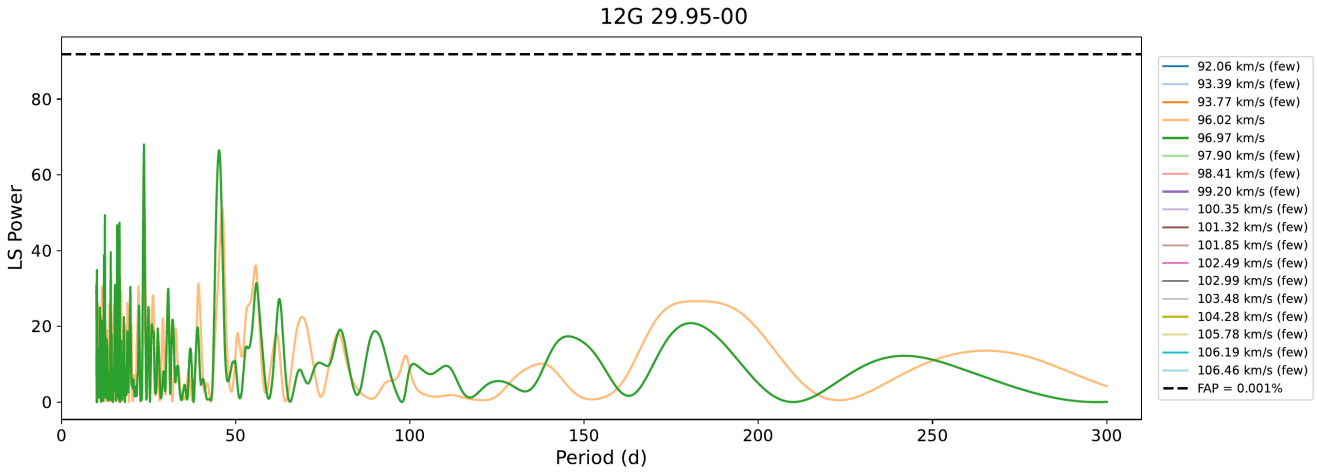


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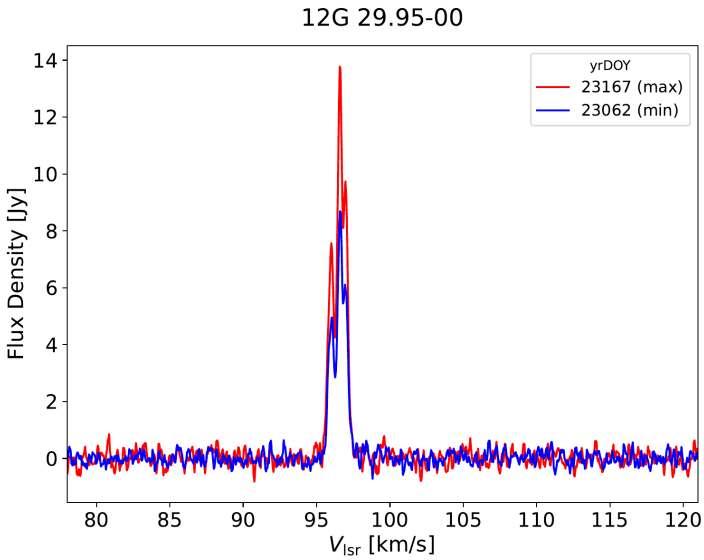
Light curve



Periodogram

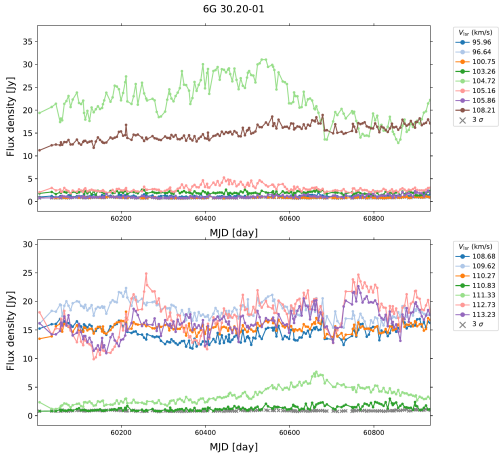


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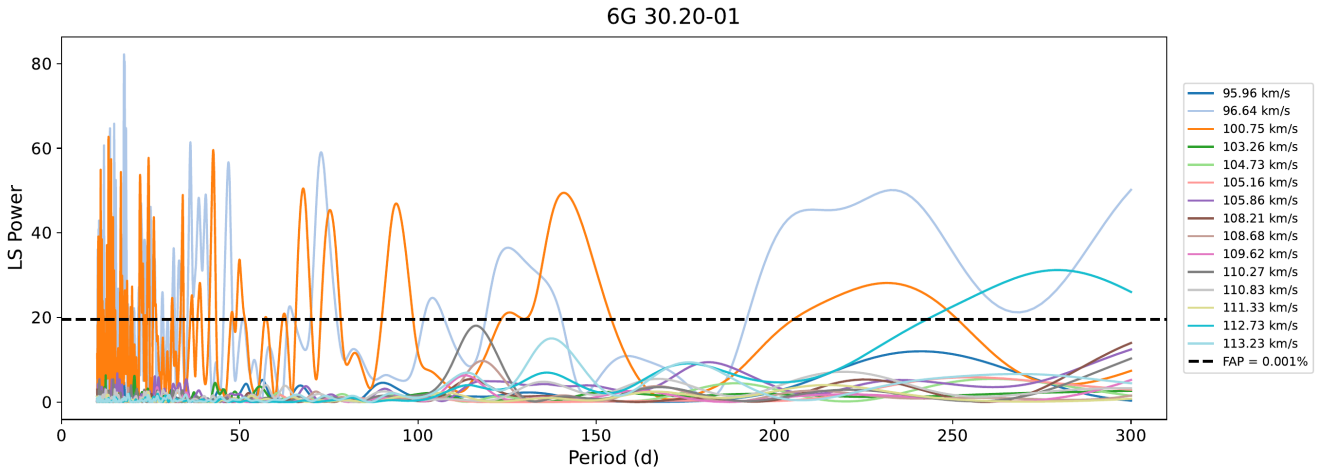


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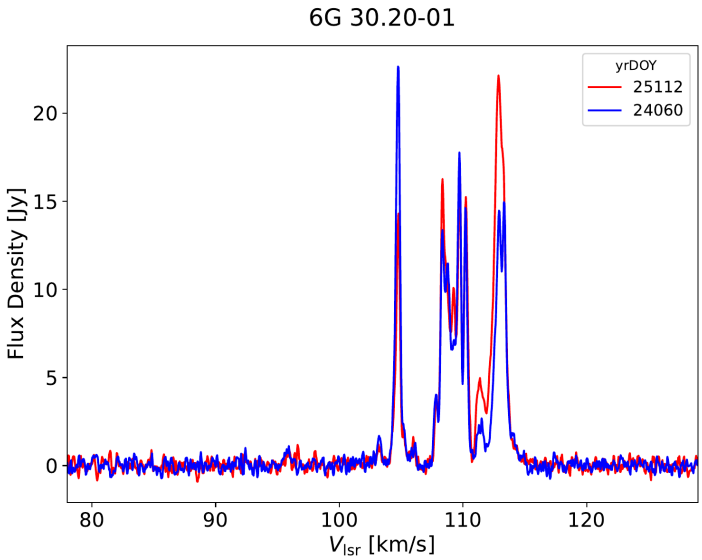
Light curve



Periodogram

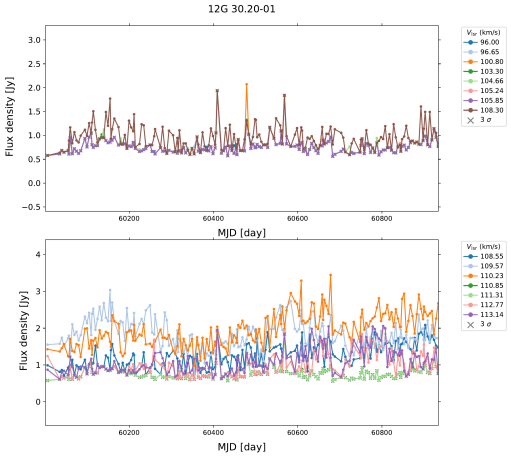


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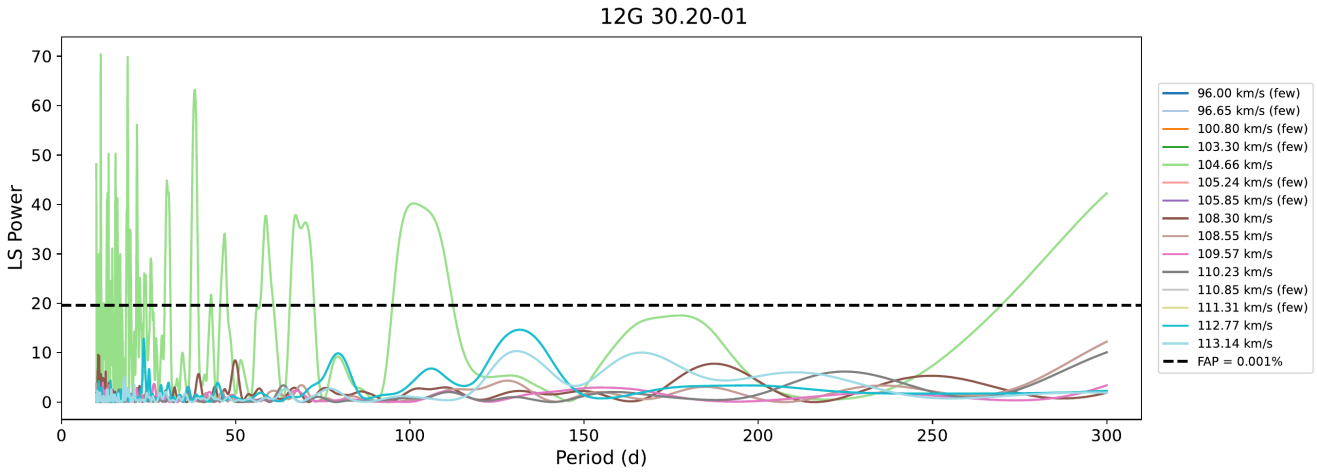


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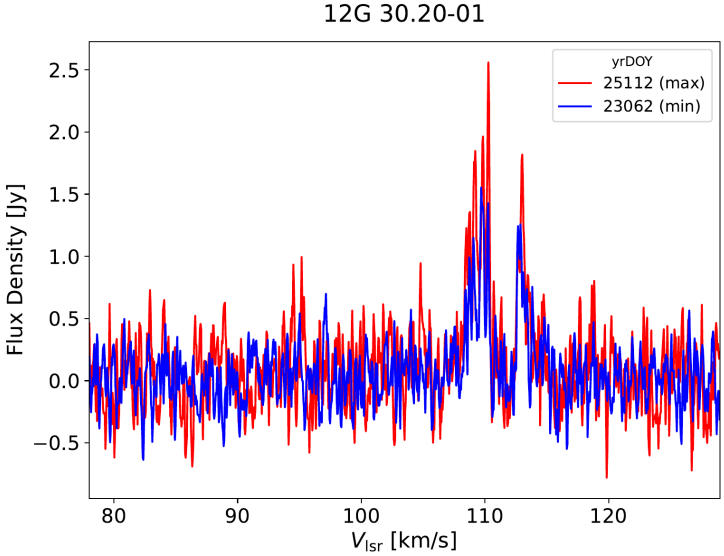
Light curve



Periodogram

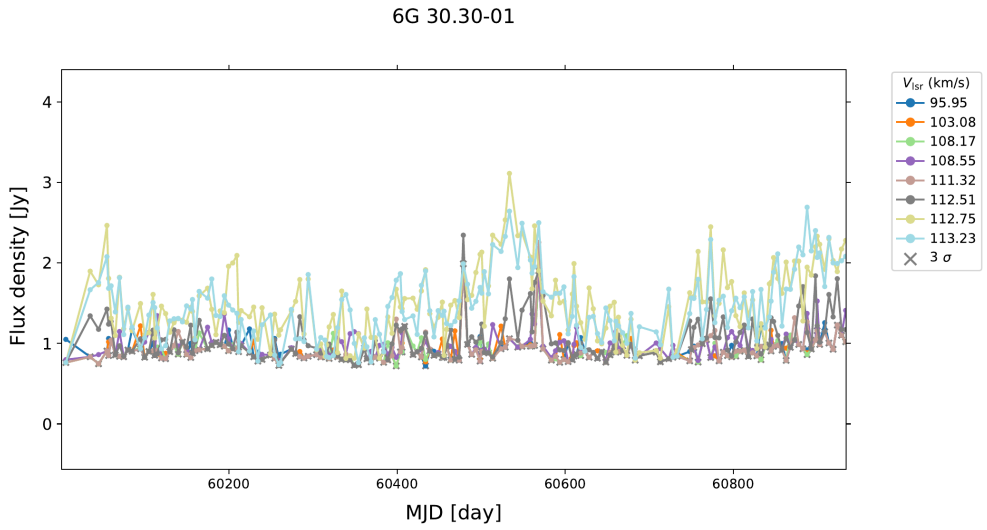


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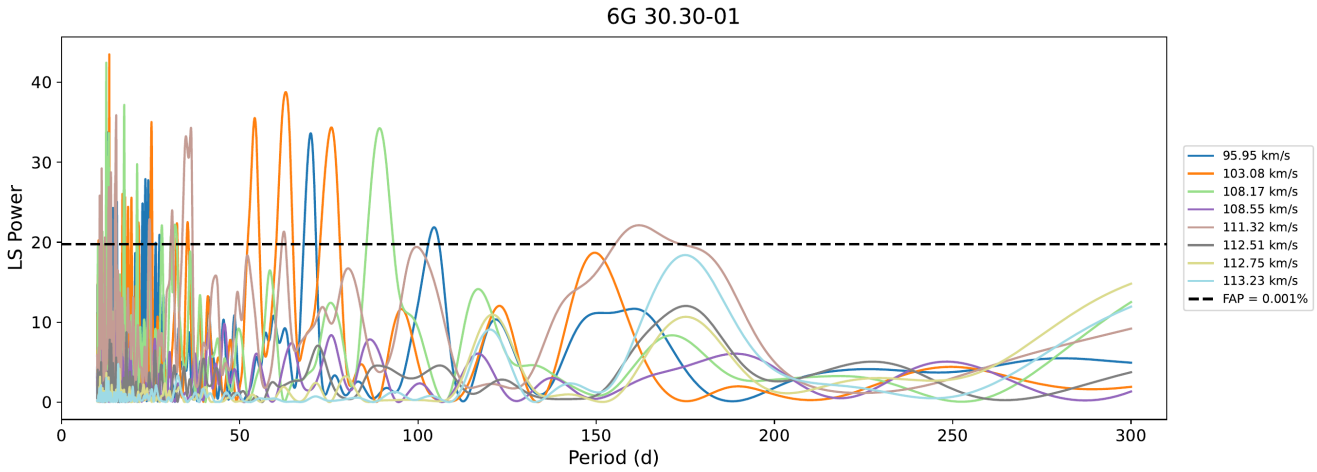


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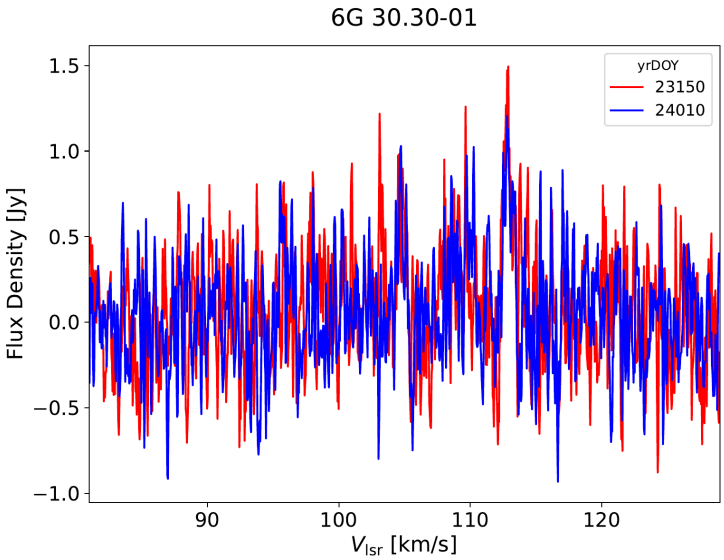
Light curve



Periodogram

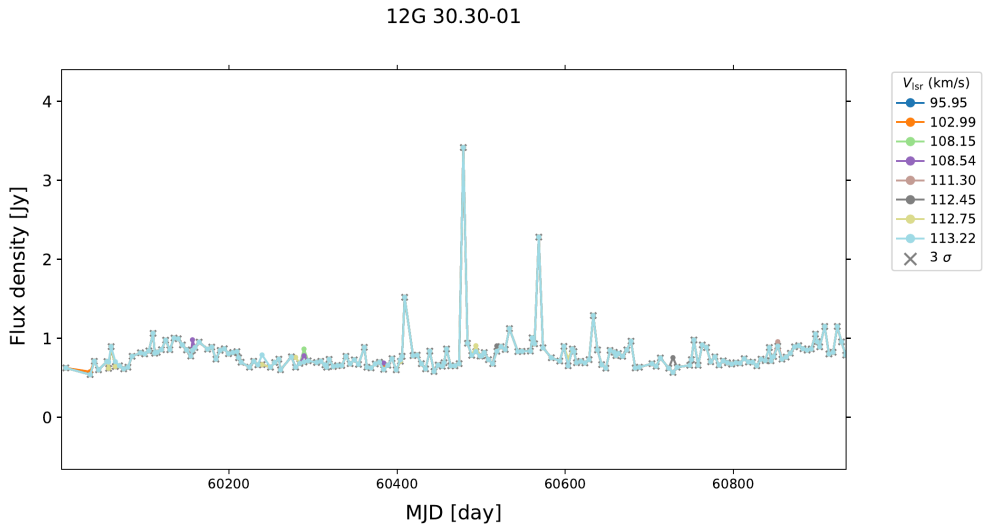


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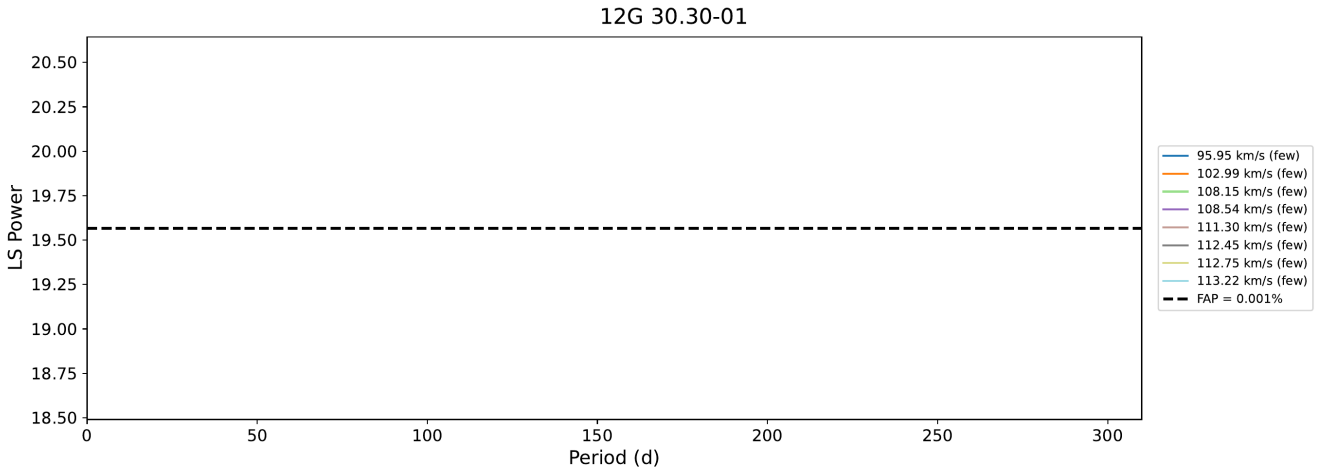


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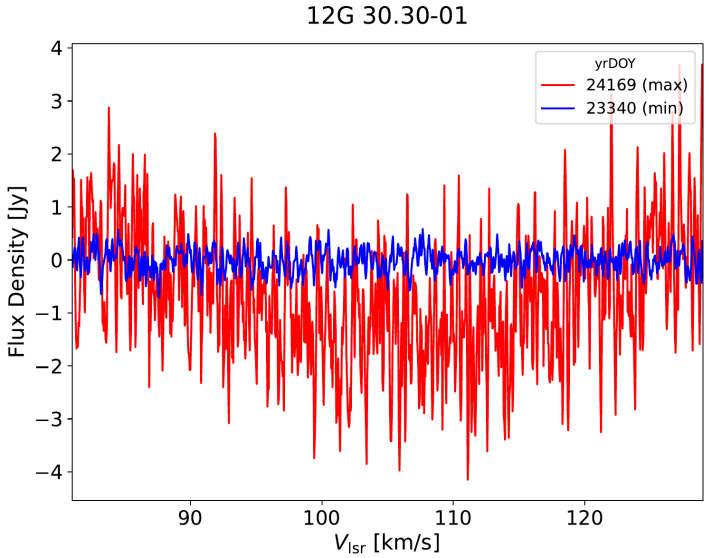
Light curve



Periodogram

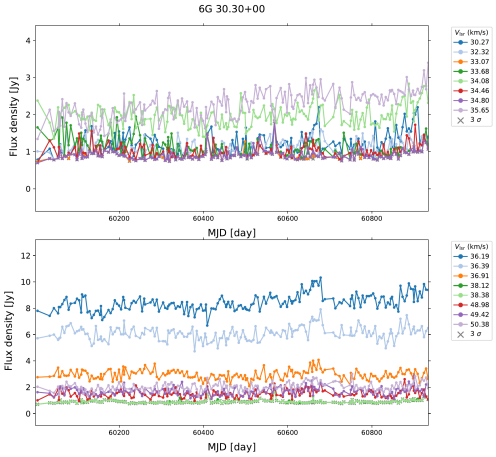


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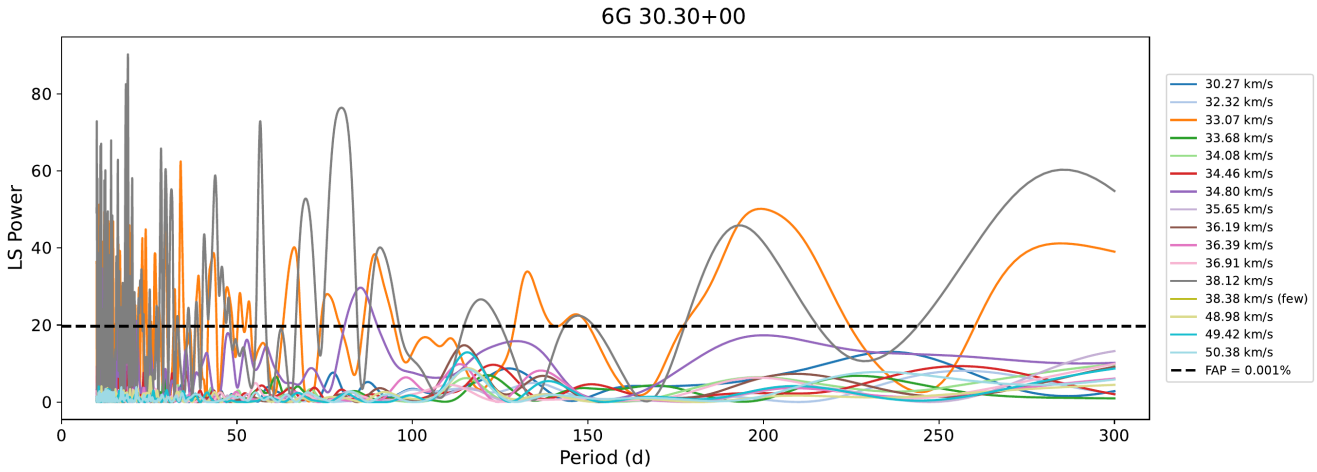


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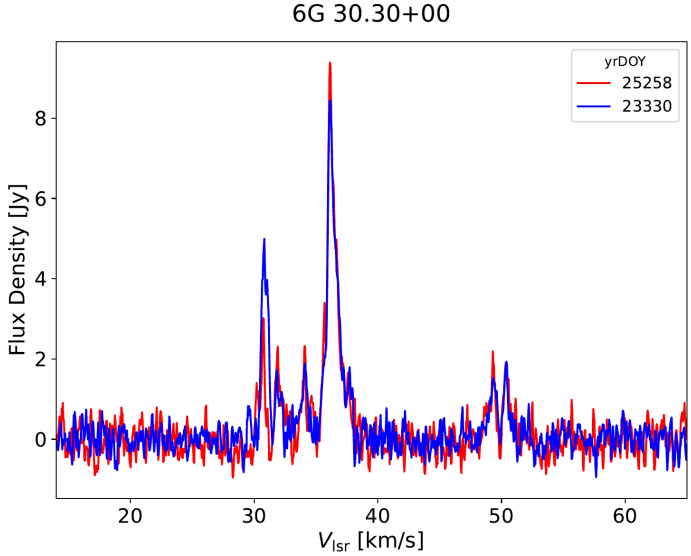
Light curve



Periodogram

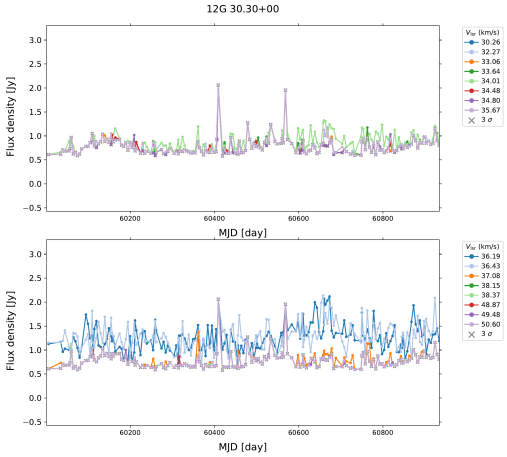


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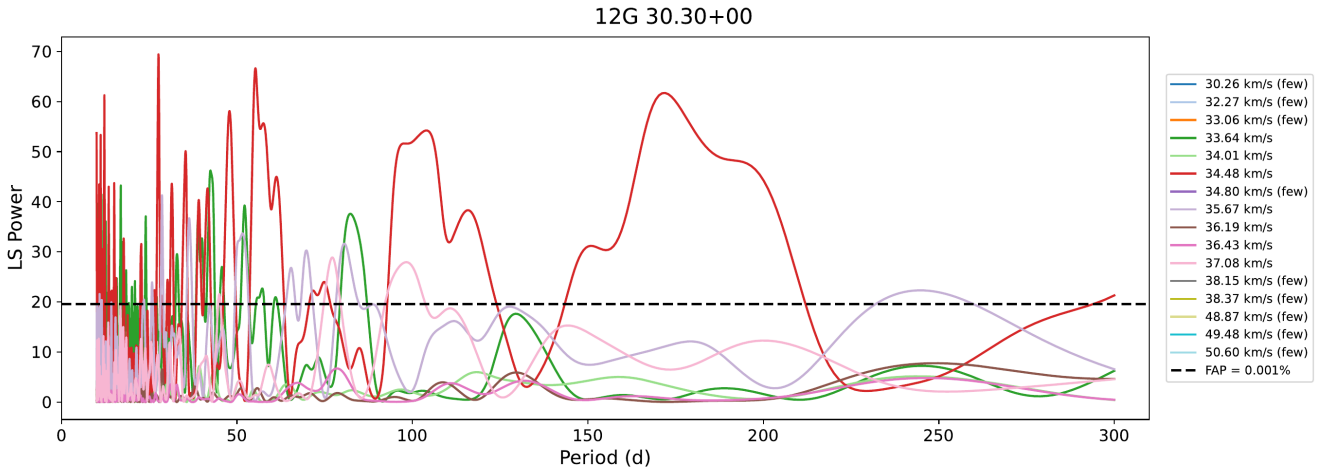


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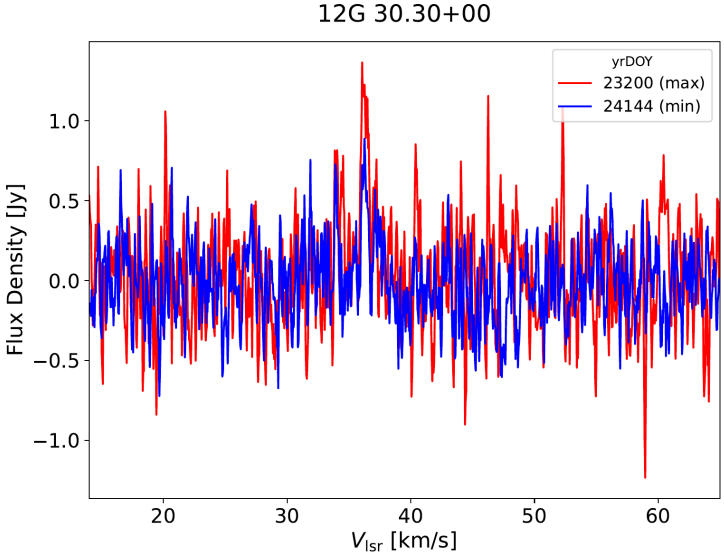
Light curve



Periodogram

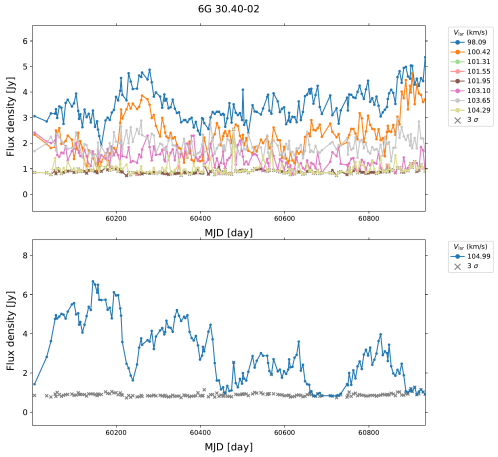


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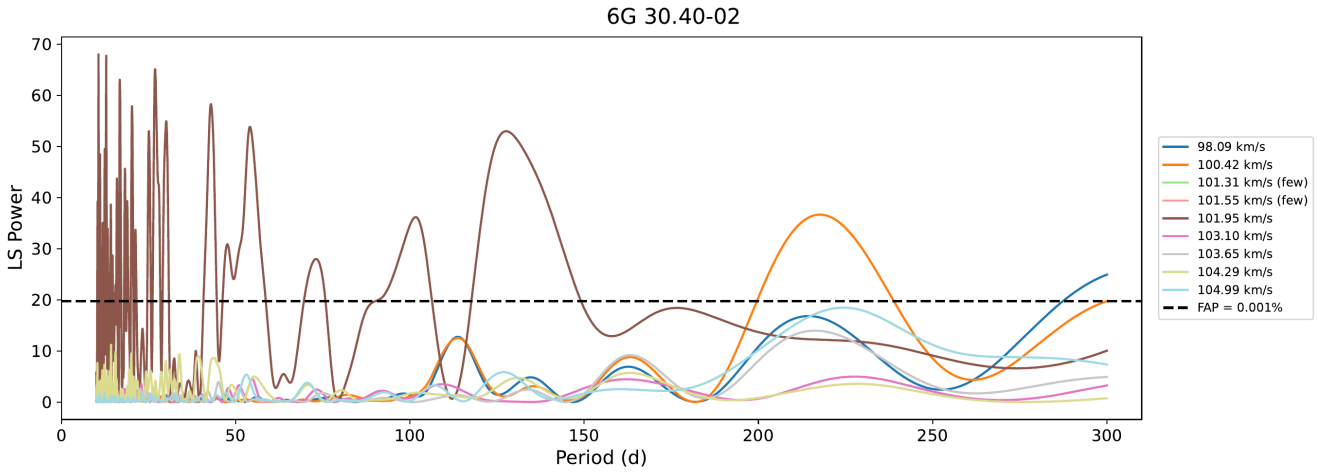


6G 30.40-02

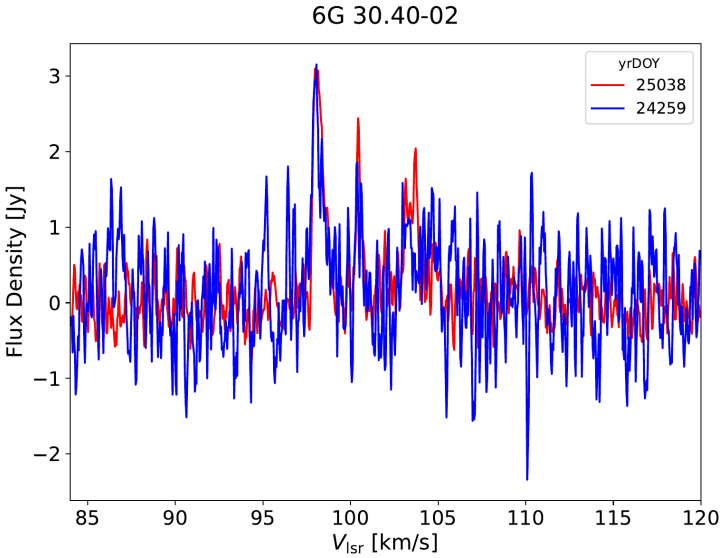
Light curve



Periodogram

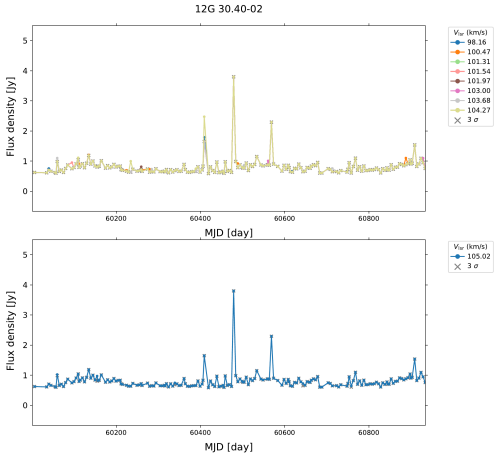


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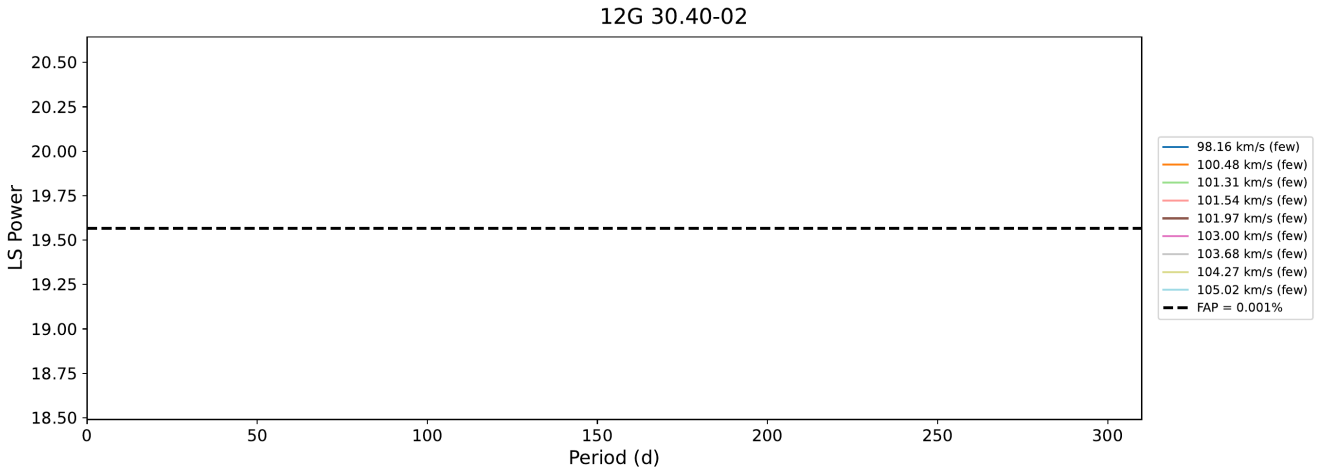


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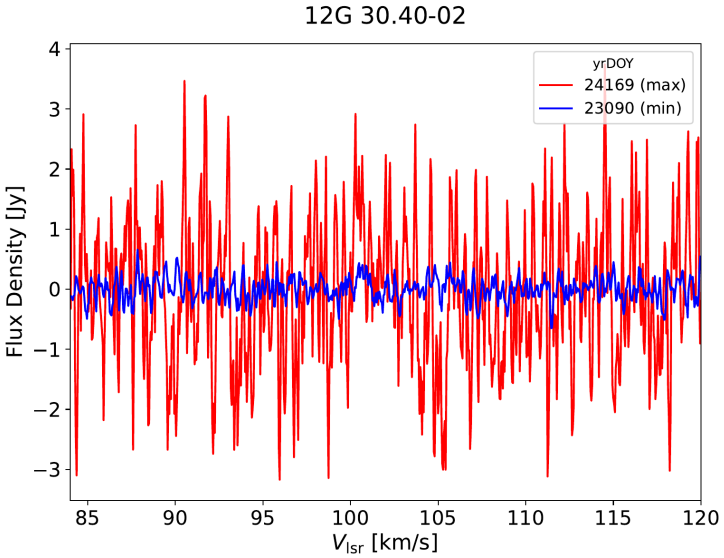
Light curve



Periodogram

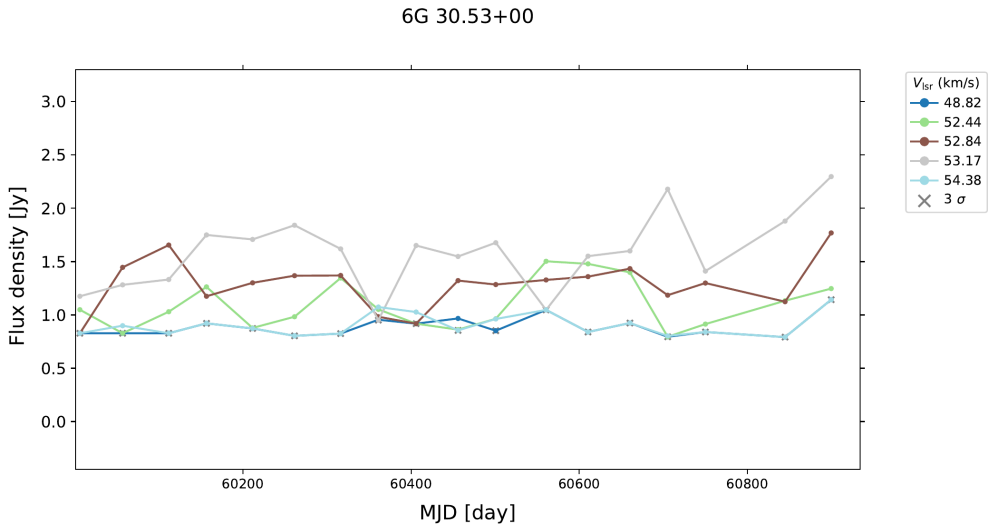


Spectrum

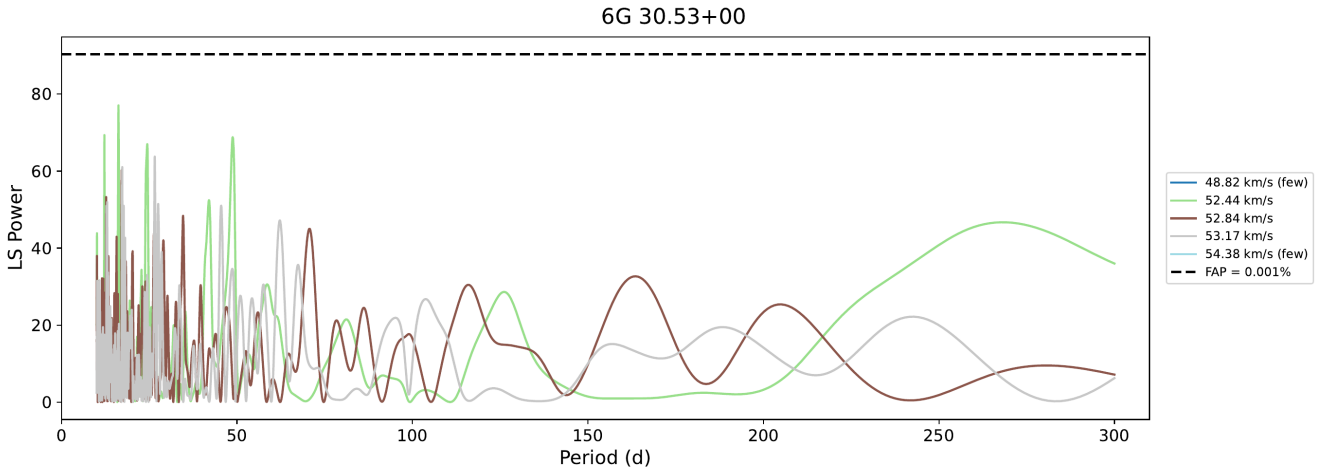


6G 30.53+00

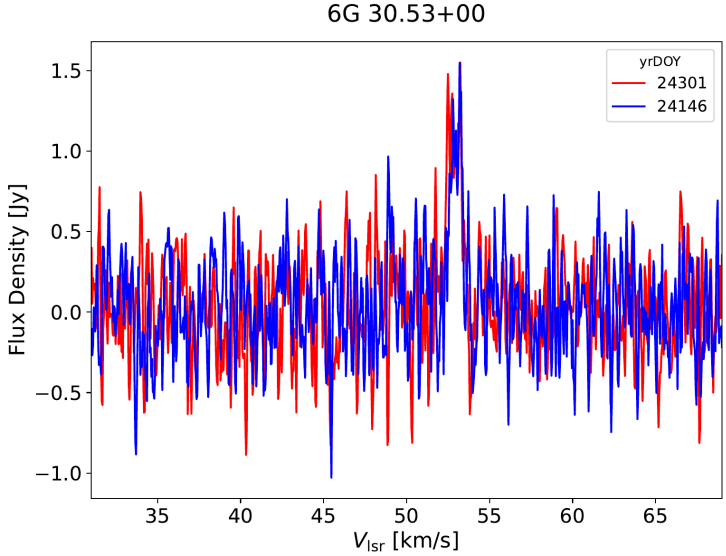
Light curve



Periodogram

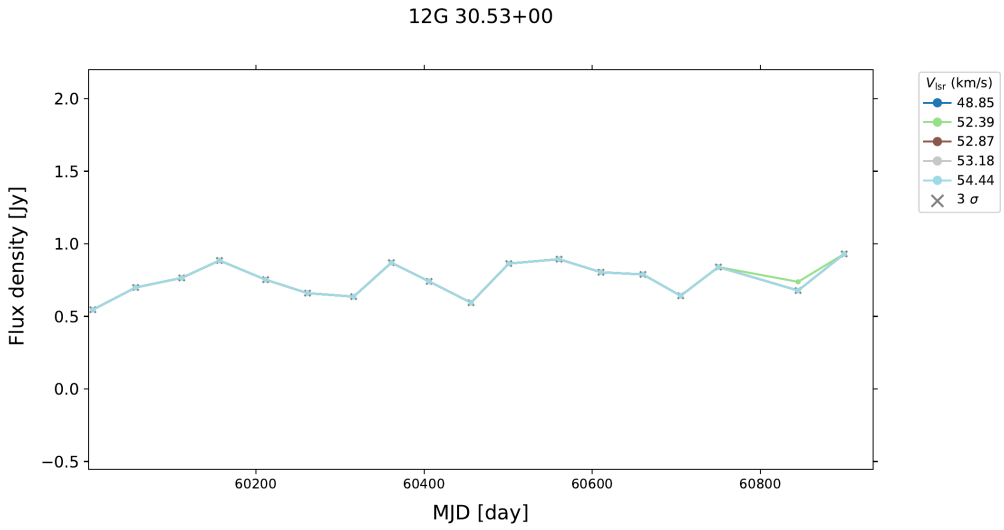


Spectrum

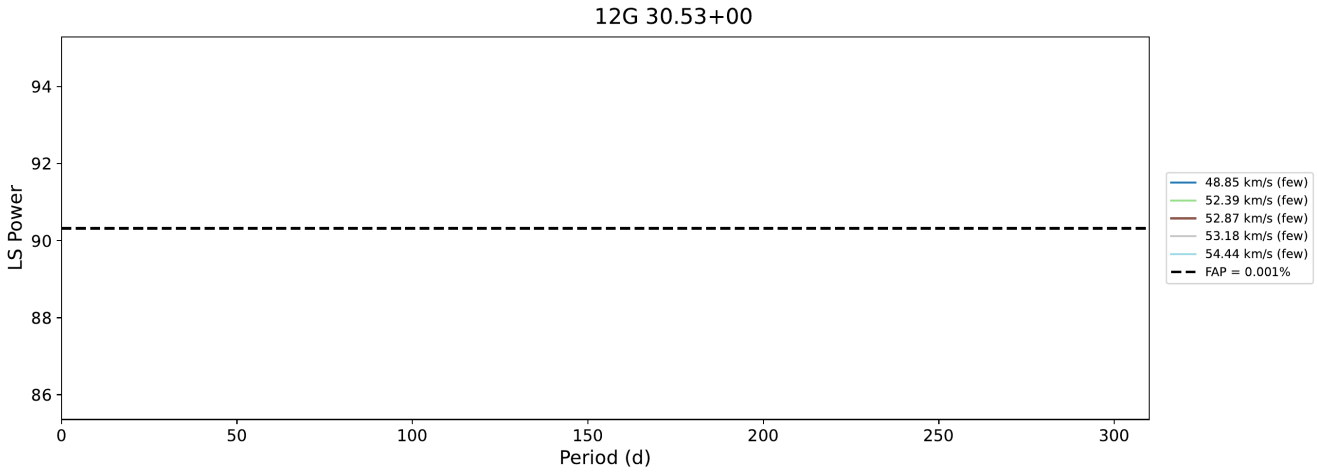


12G 30.53+00

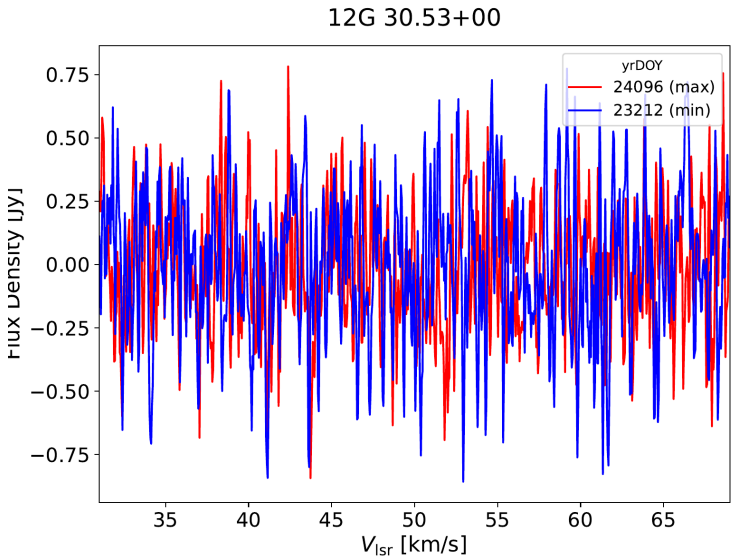
Light curve



Periodogram

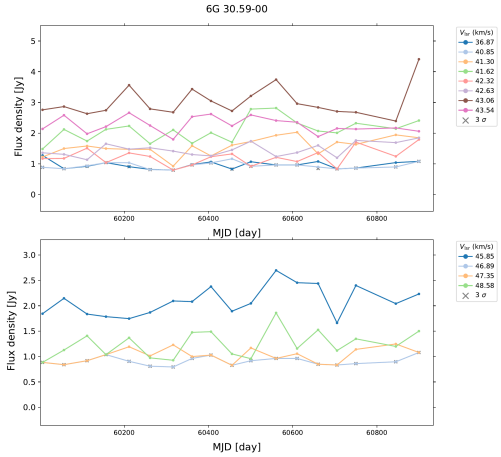


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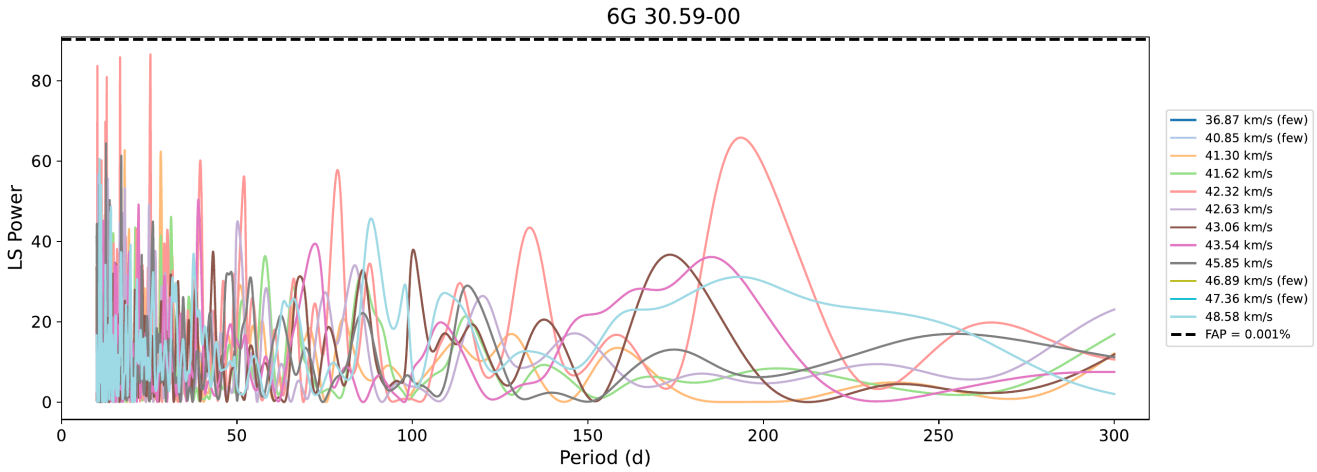


6G 30.59-00

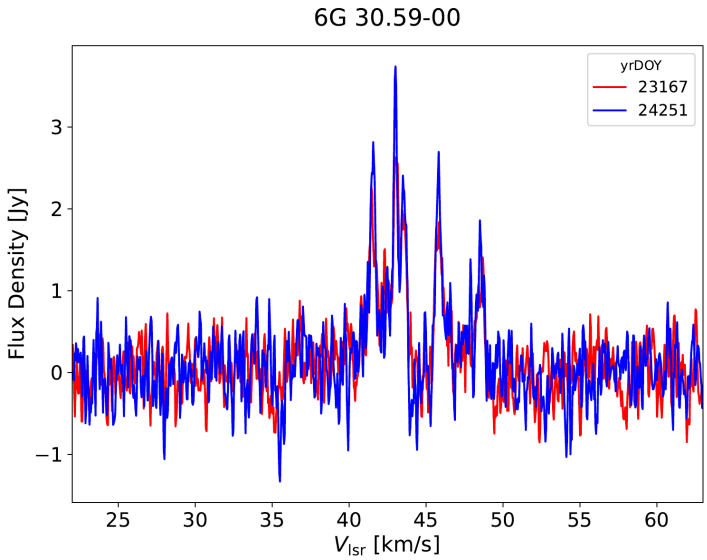
Light curve



Periodogram

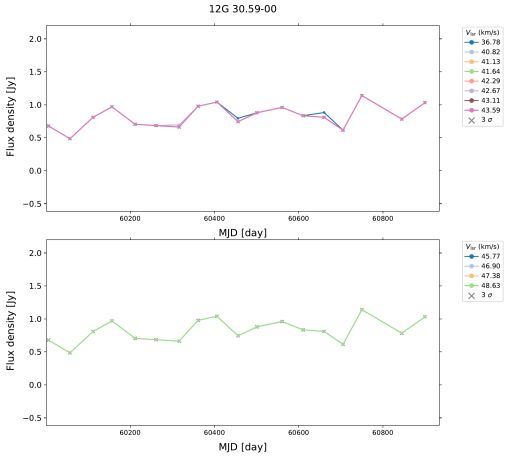


Spectrum

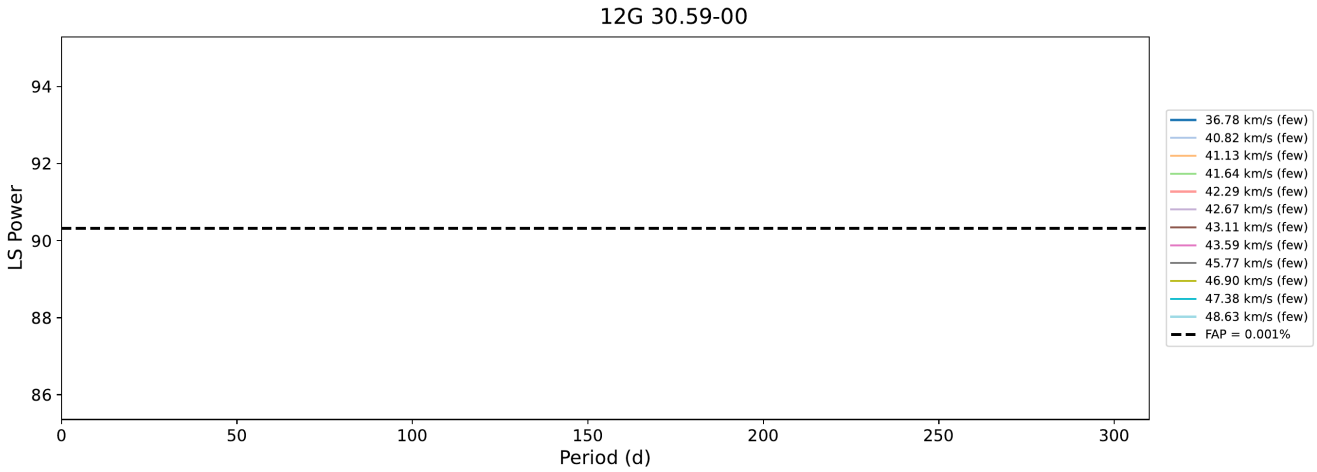


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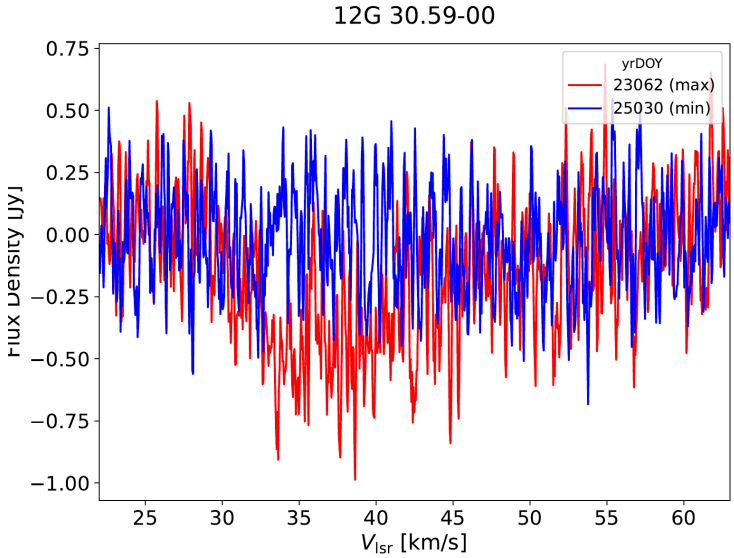
Light curve



Periodogram

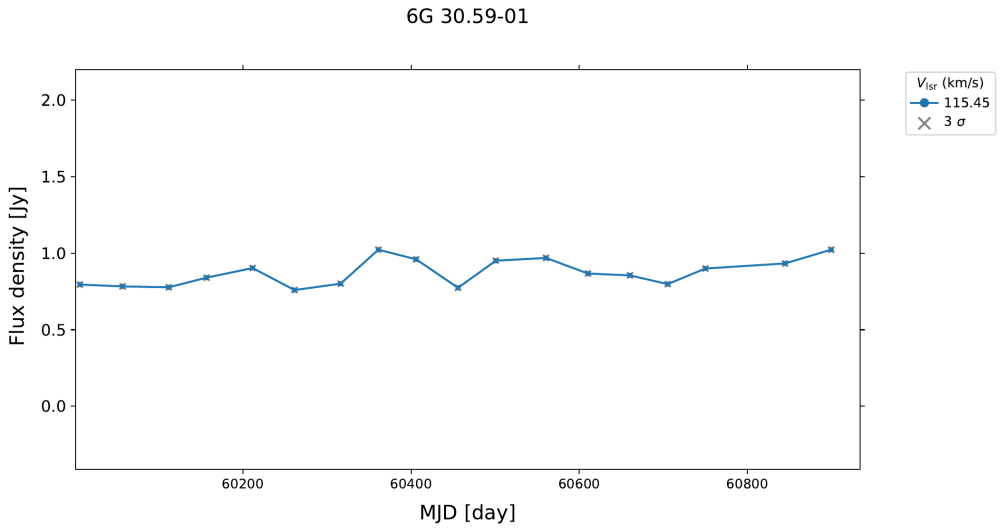


Spectrum

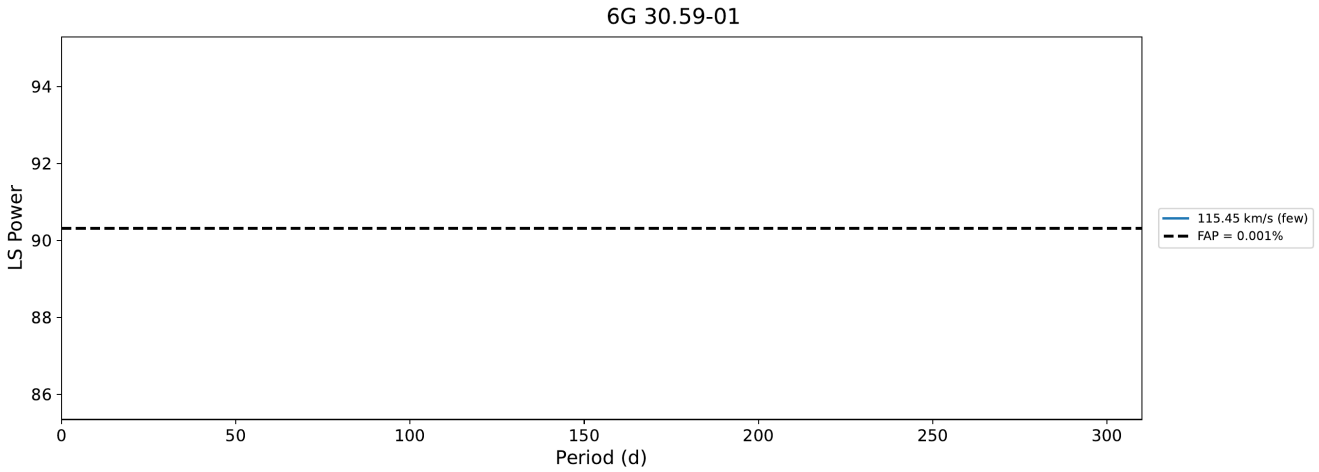


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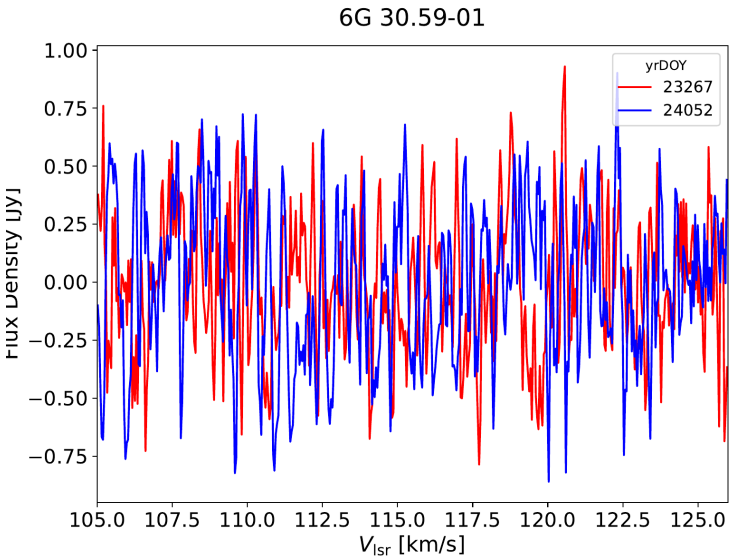
Light curve



Periodogram

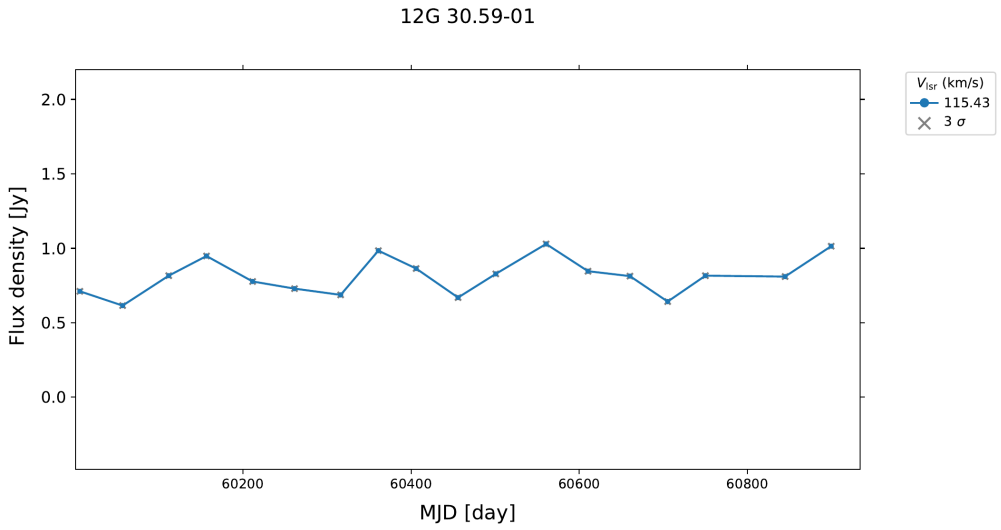


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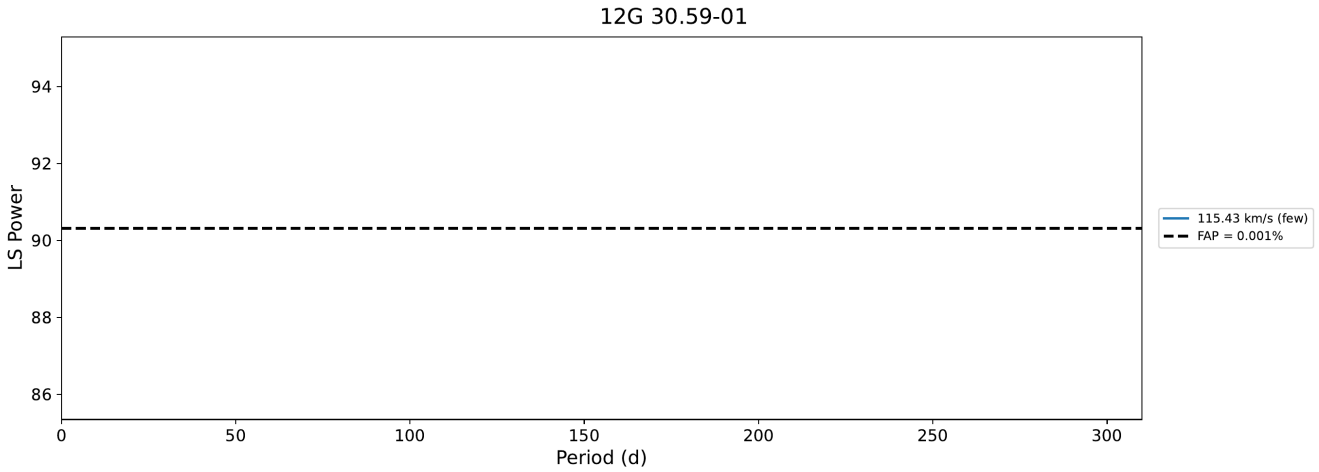


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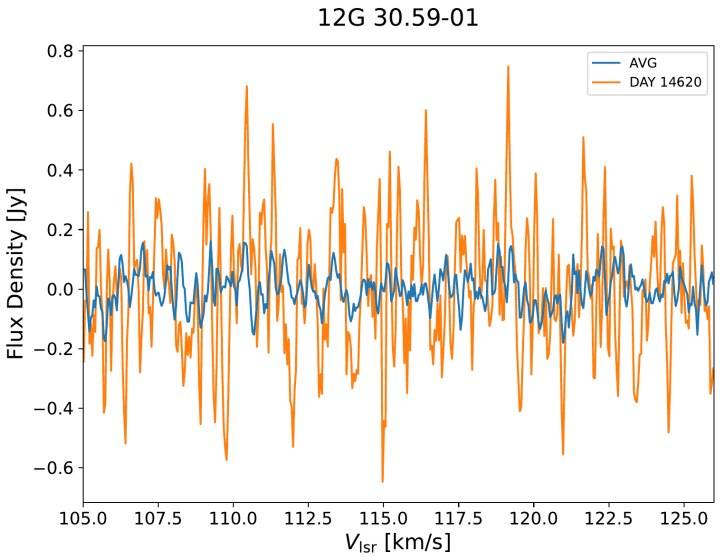
Light curve



Periodogram

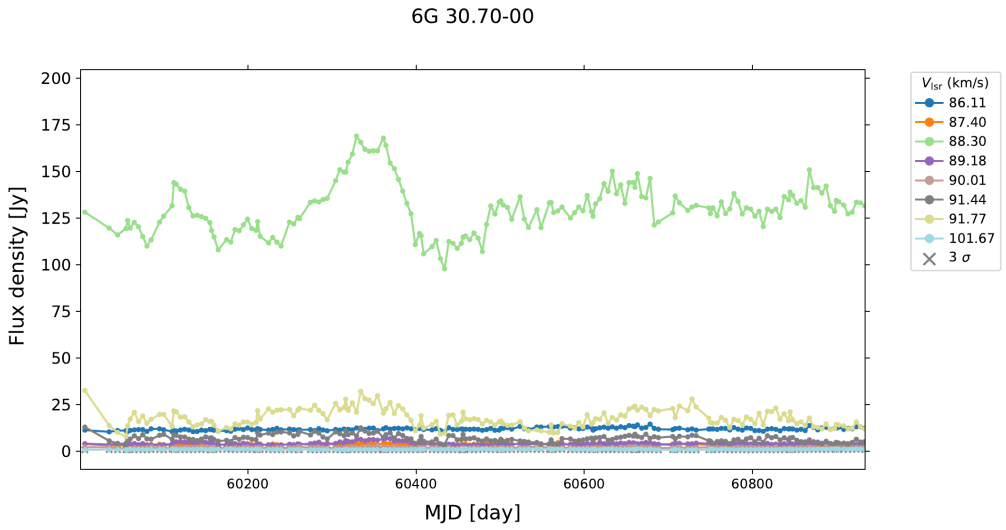


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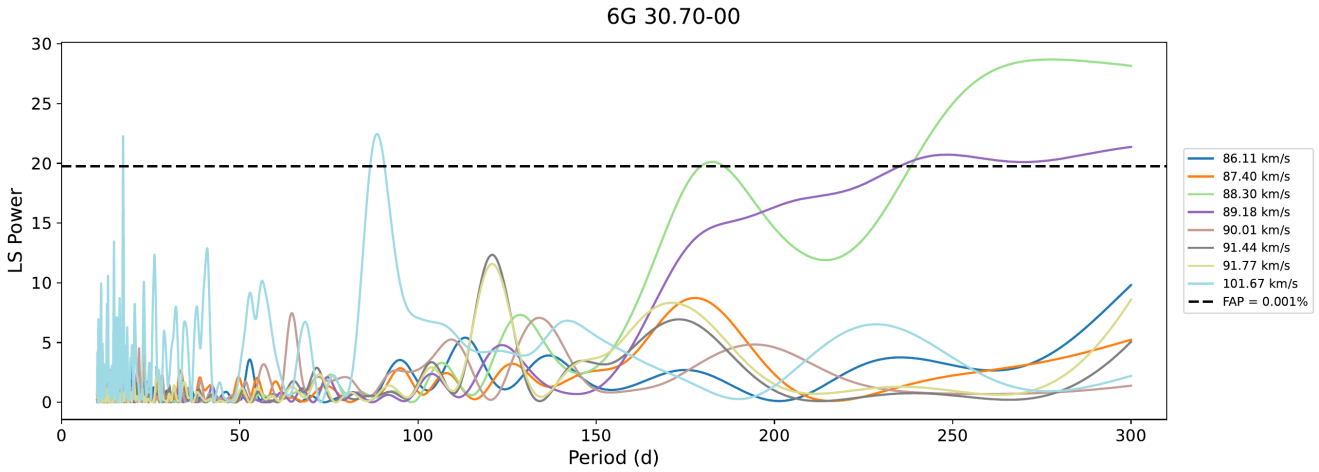


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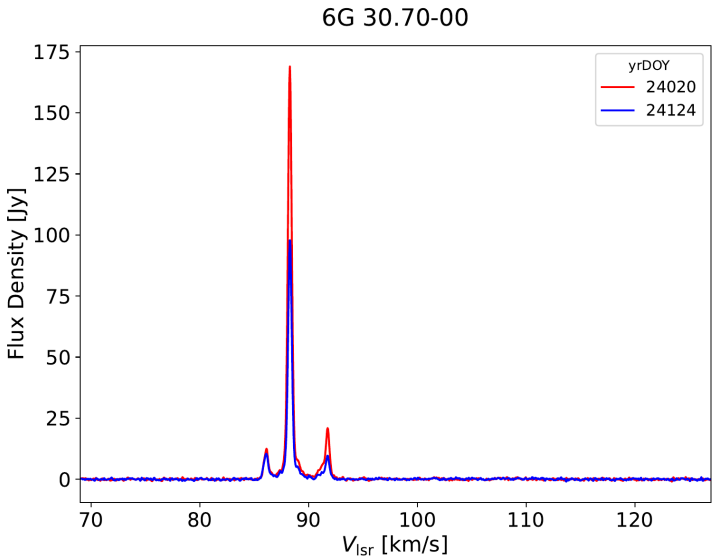
Light curve



Periodogram

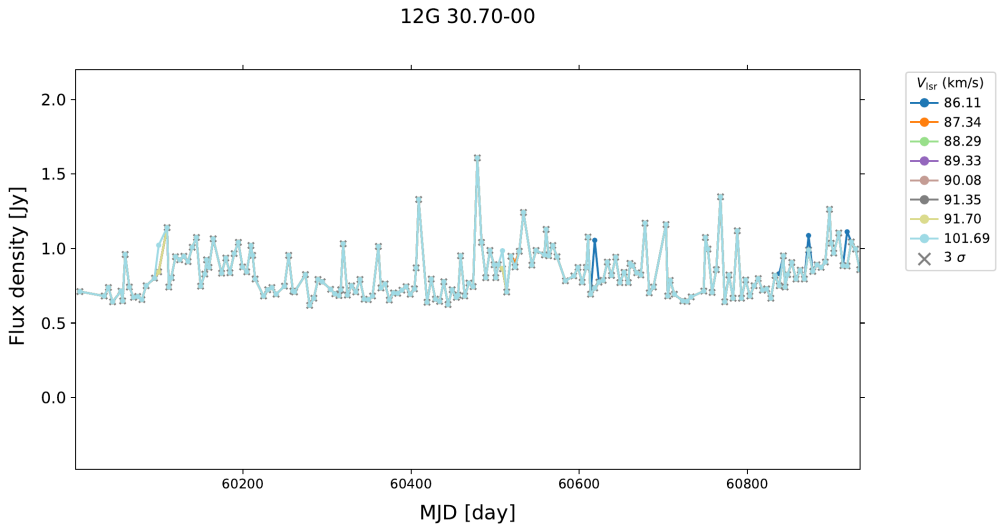


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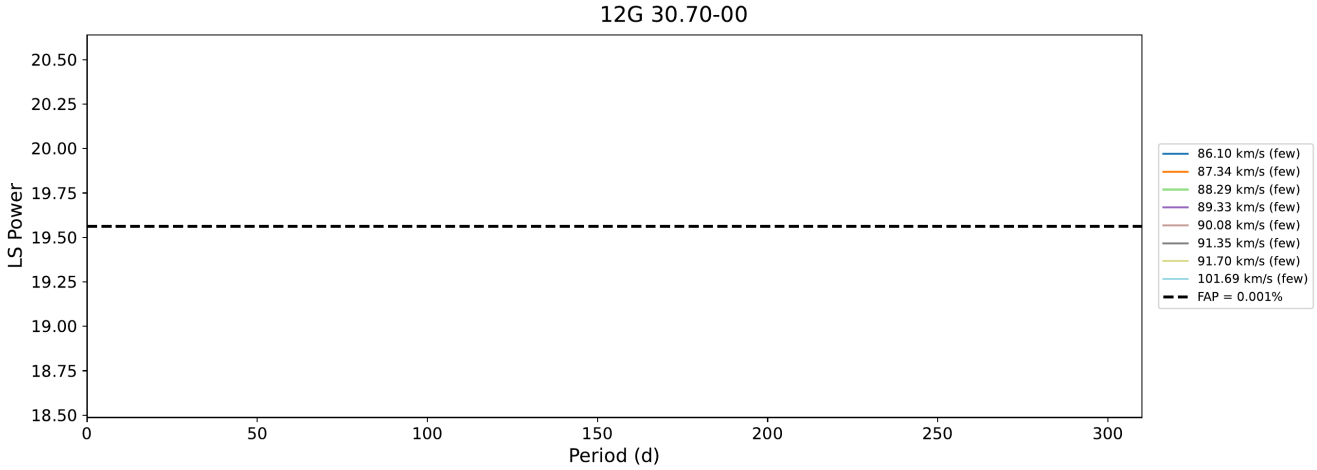


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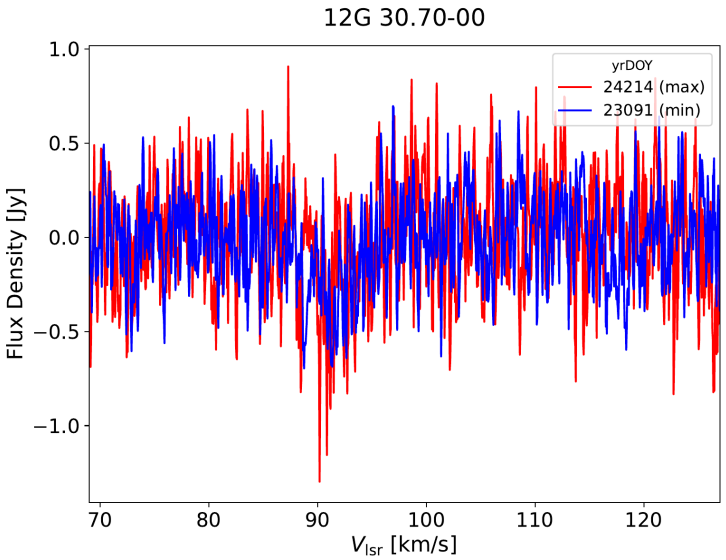
Light curve



Periodogram

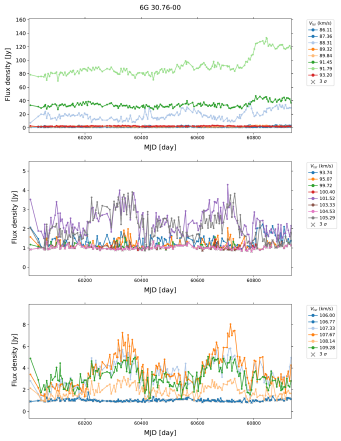


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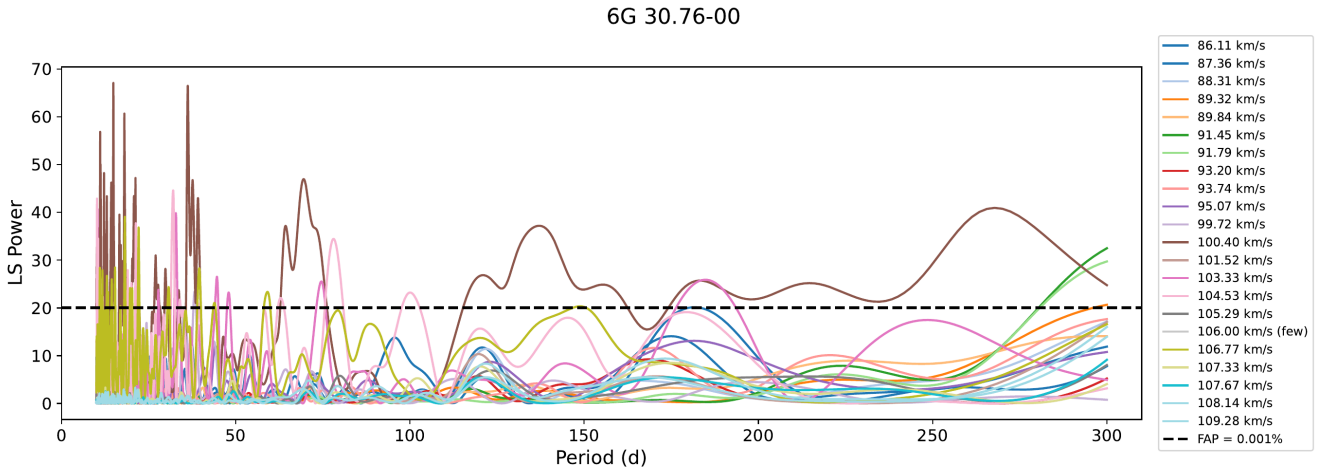


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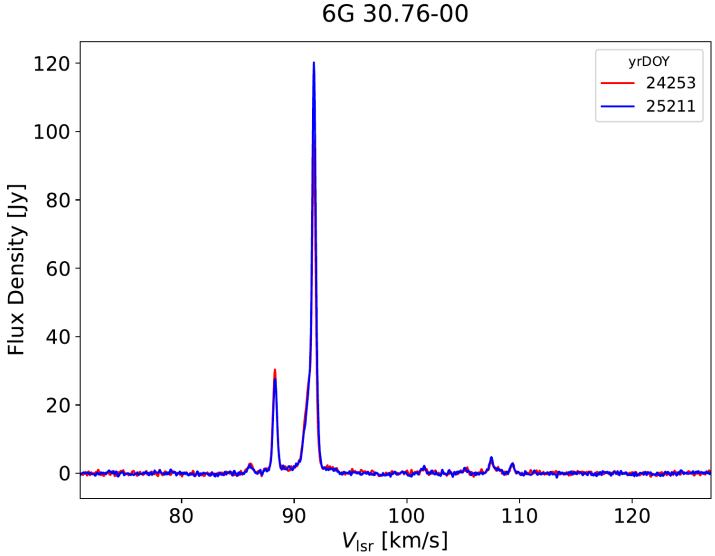
Light curve



Periodogram

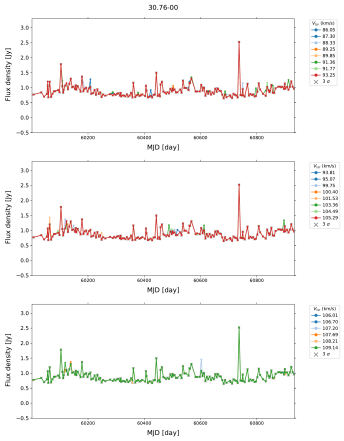


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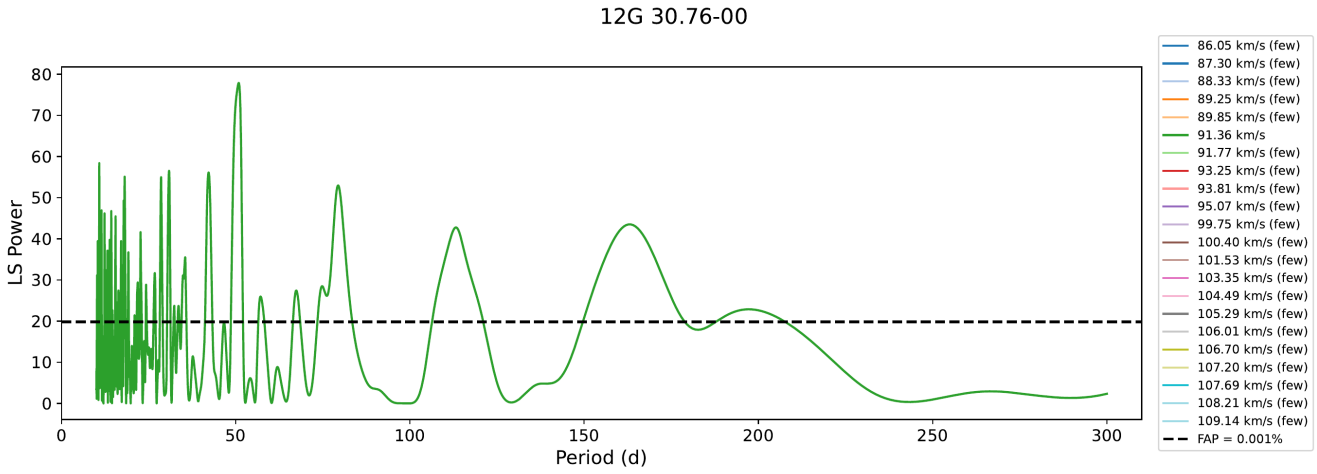


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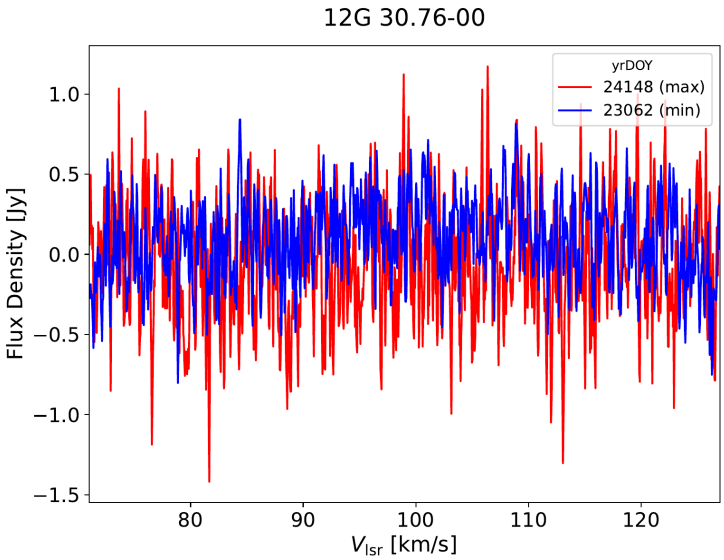
Light curve



Periodogram

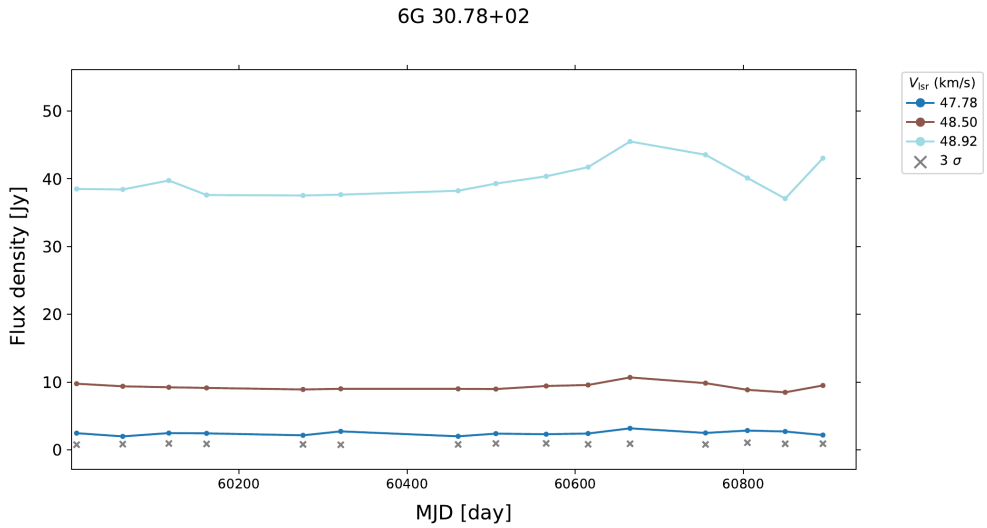


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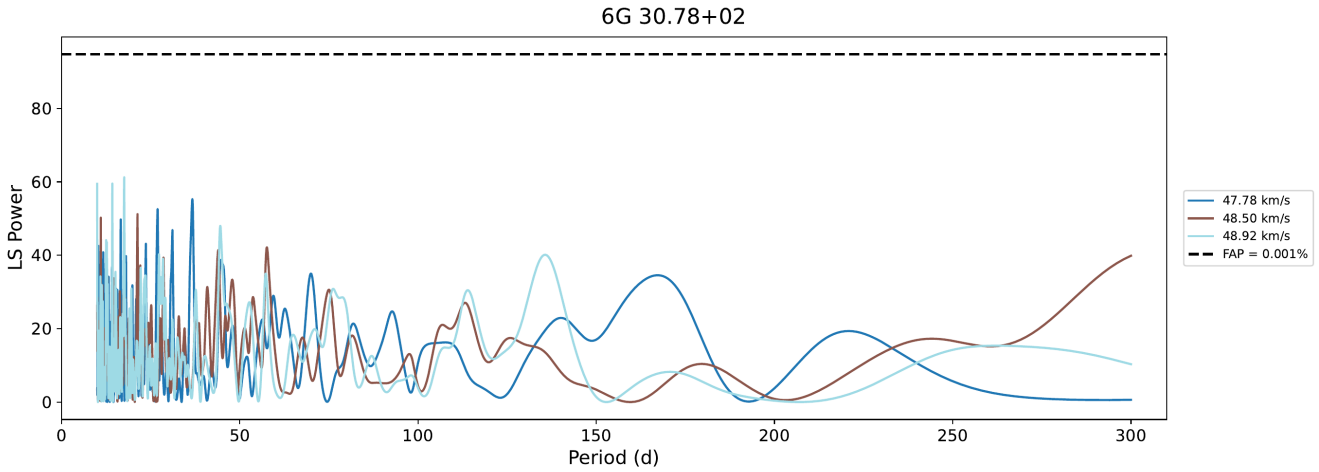


6G 30.78+02

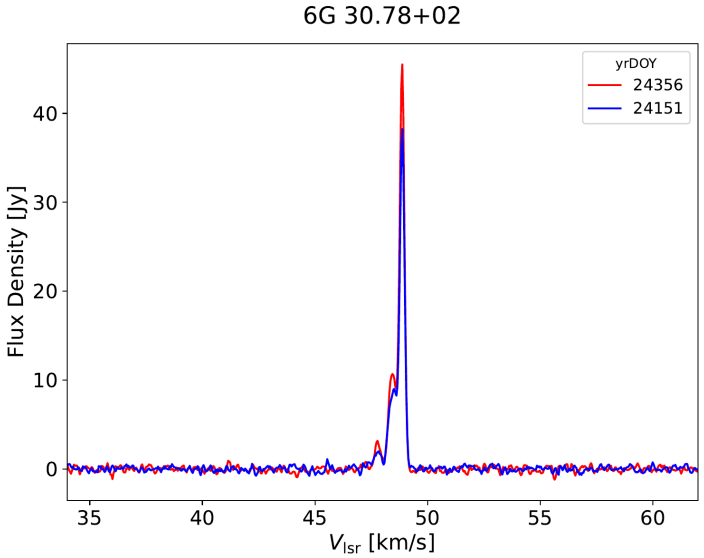
Light curve



Periodogram

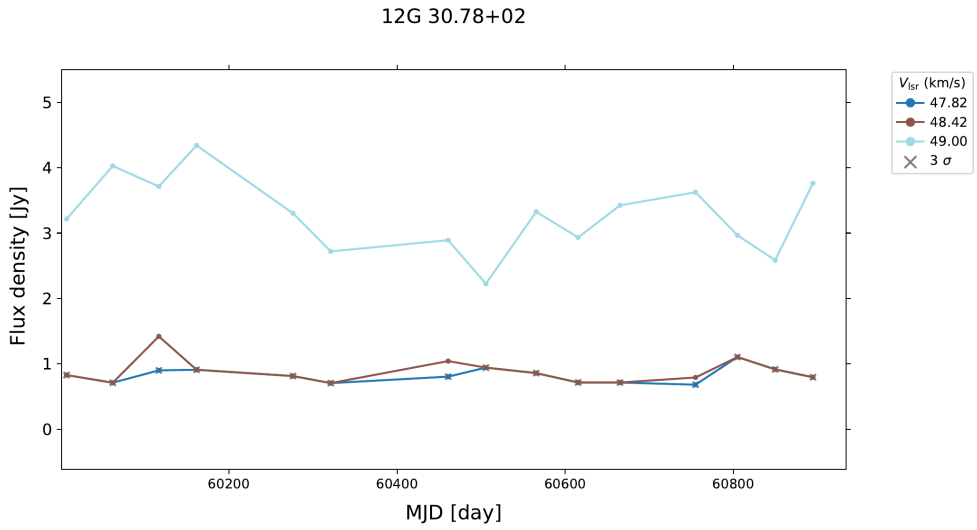


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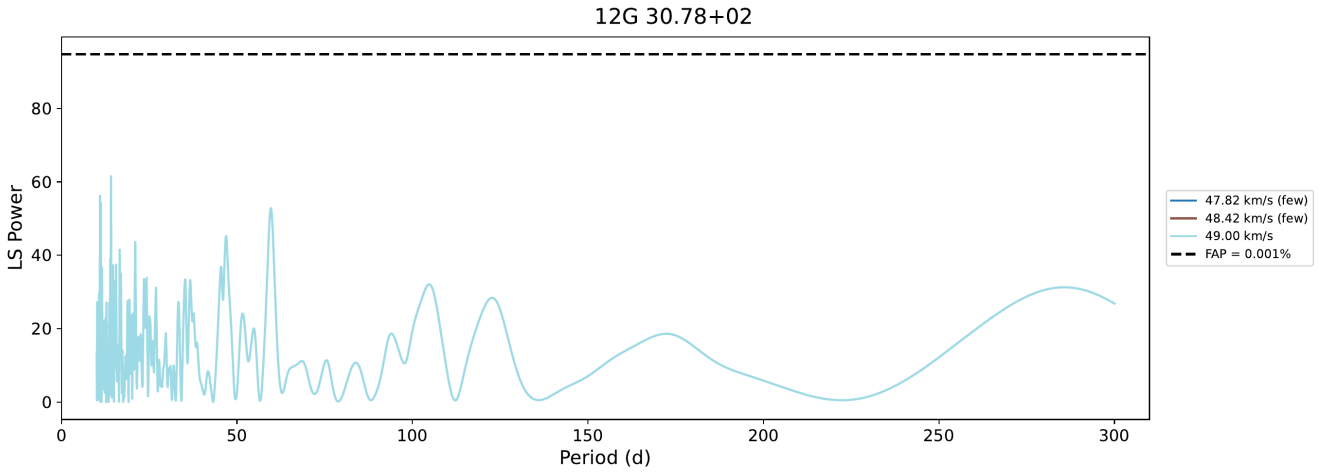


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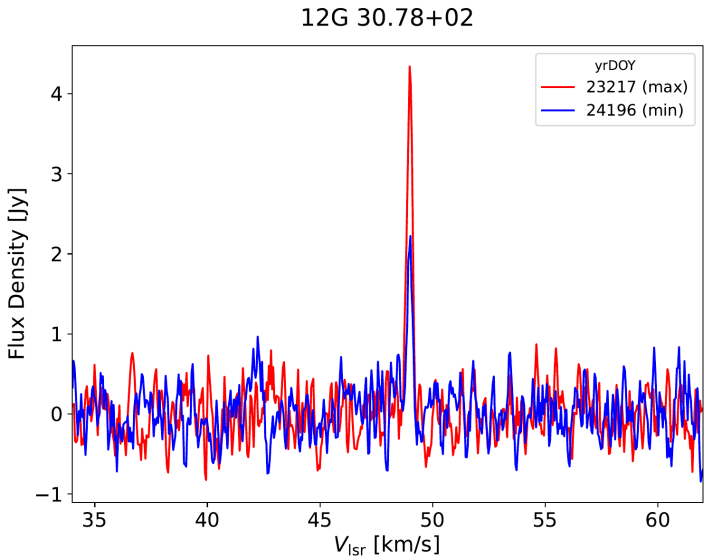
Light curve



Periodogram

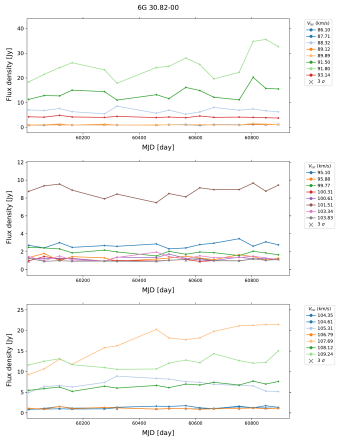


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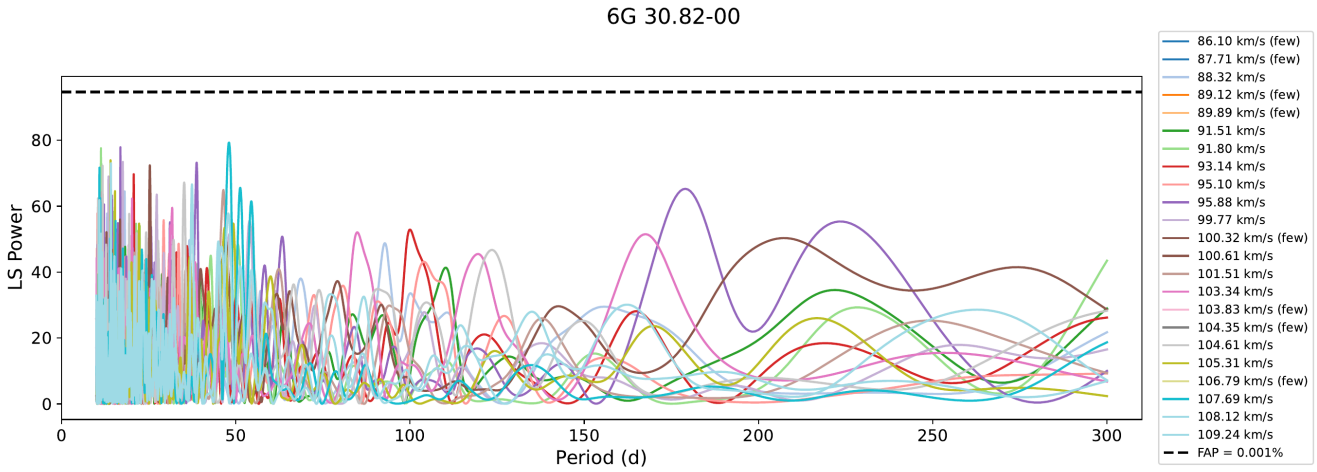


6G 30.82-00

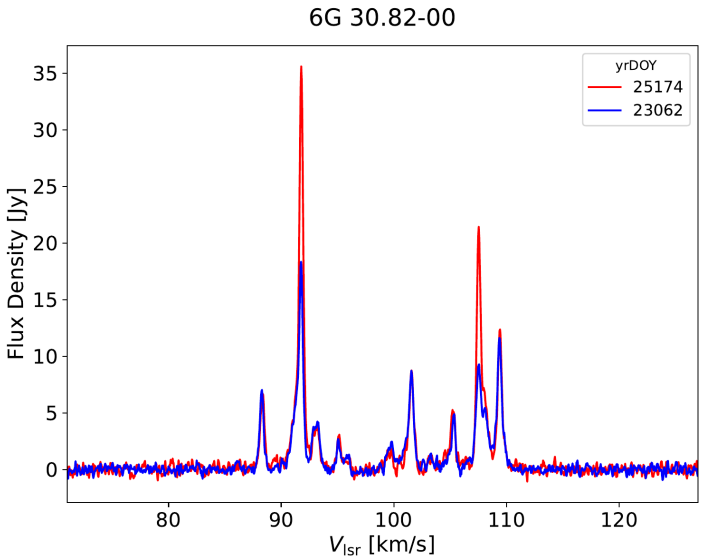
Light curve



Periodogram

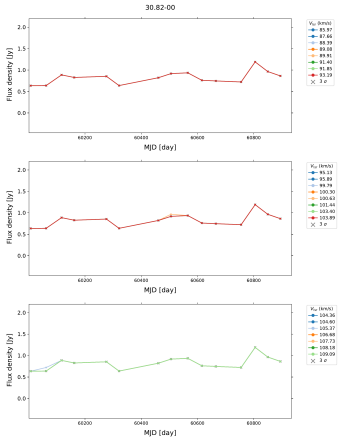


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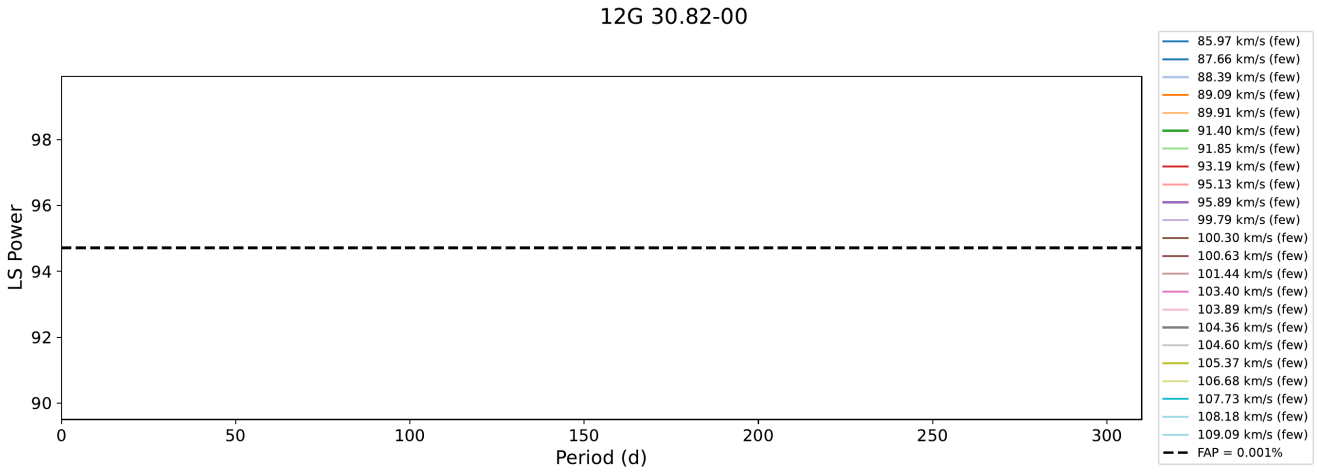


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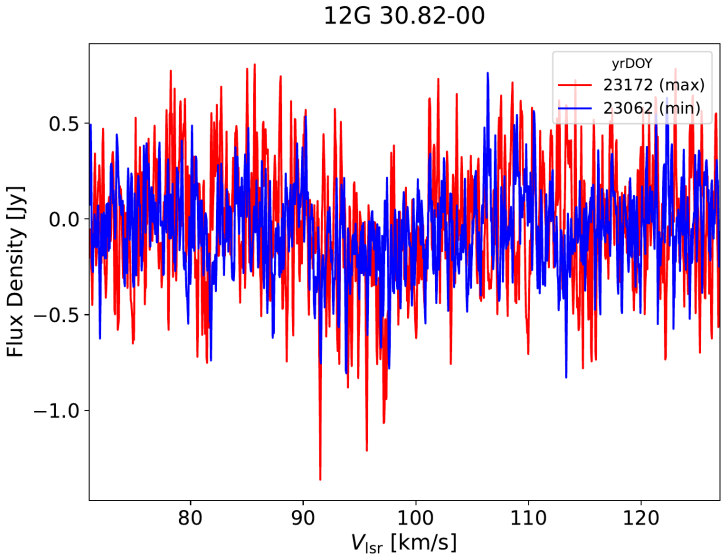
Light curve



Periodogram

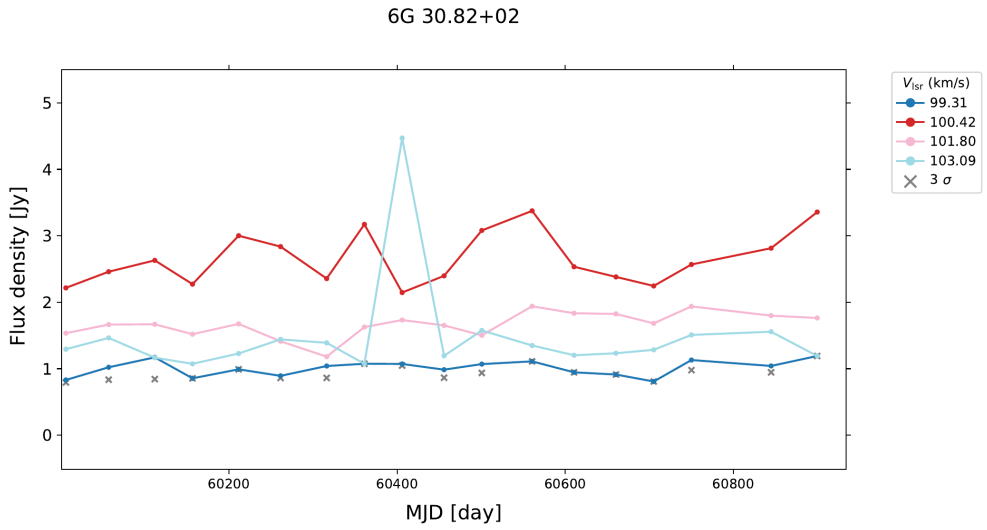


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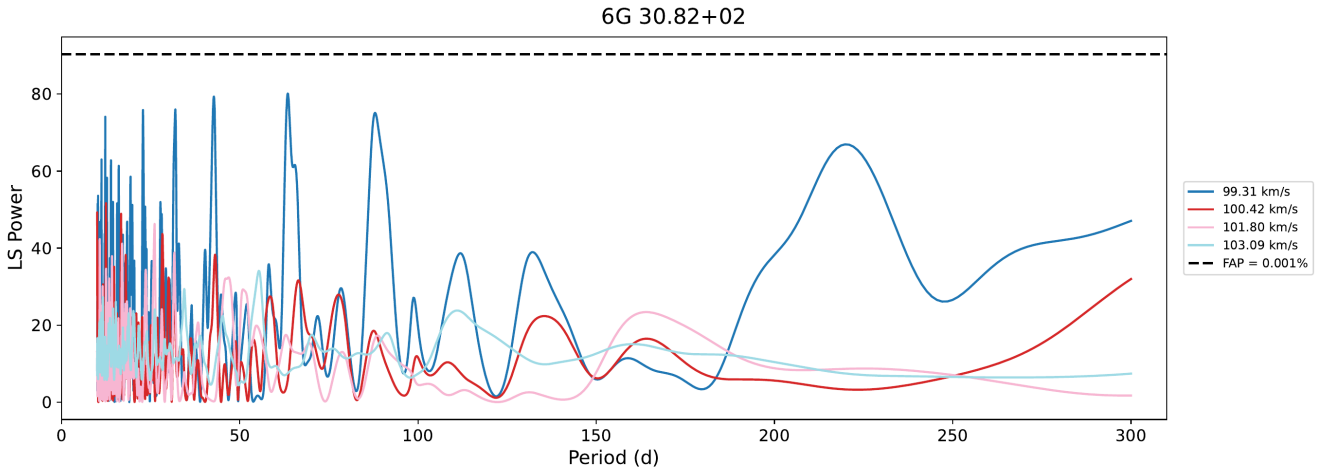


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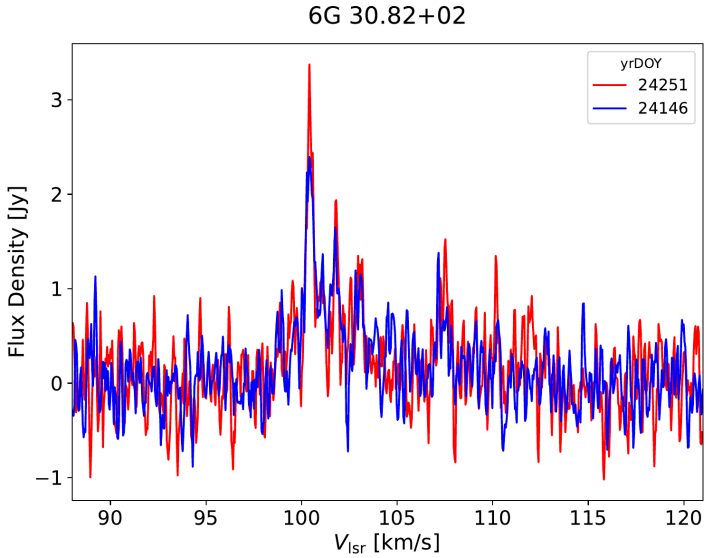
Light curve



Periodogram

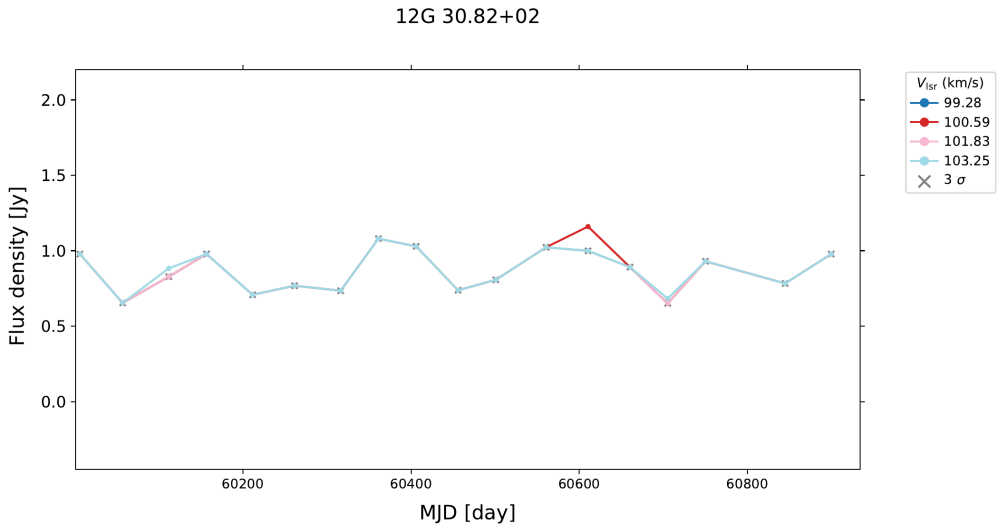


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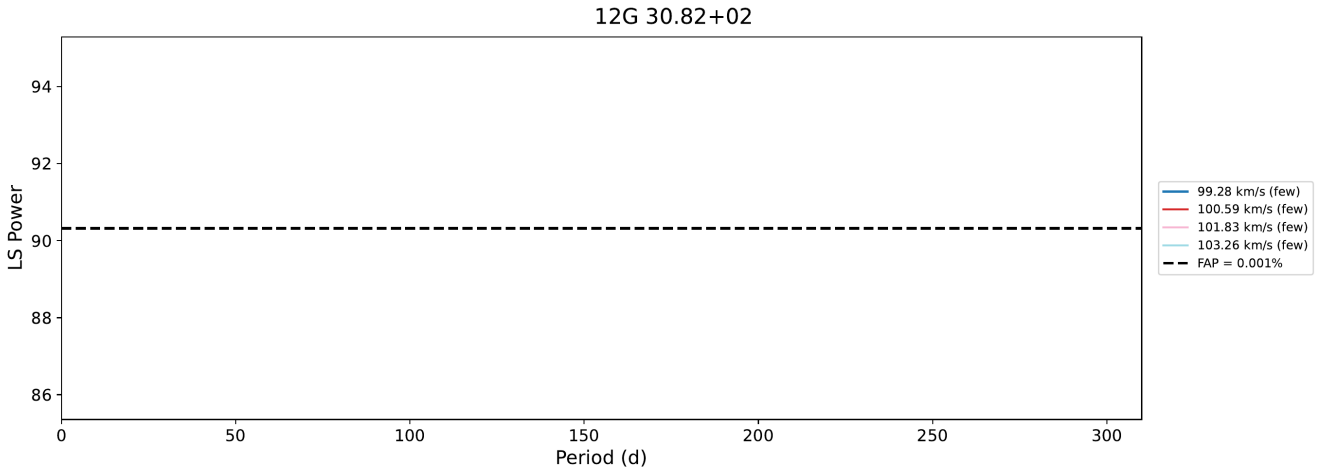


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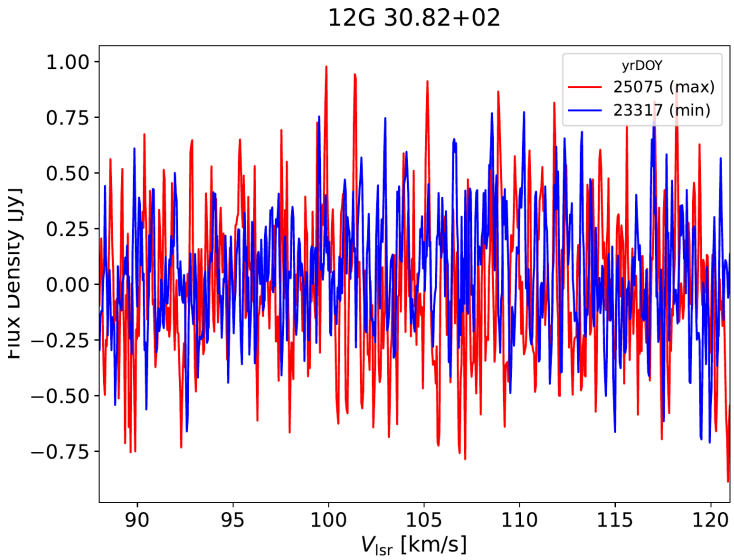
Light curve



Periodogram

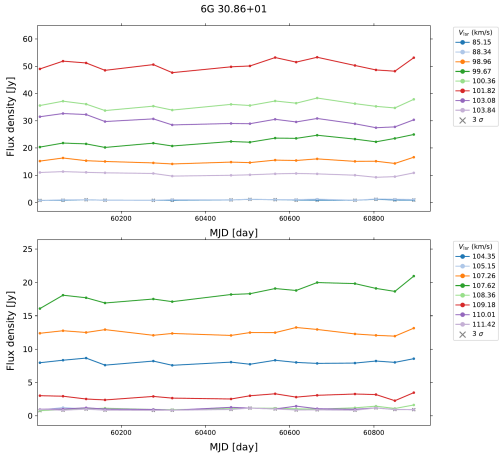


Spectrum

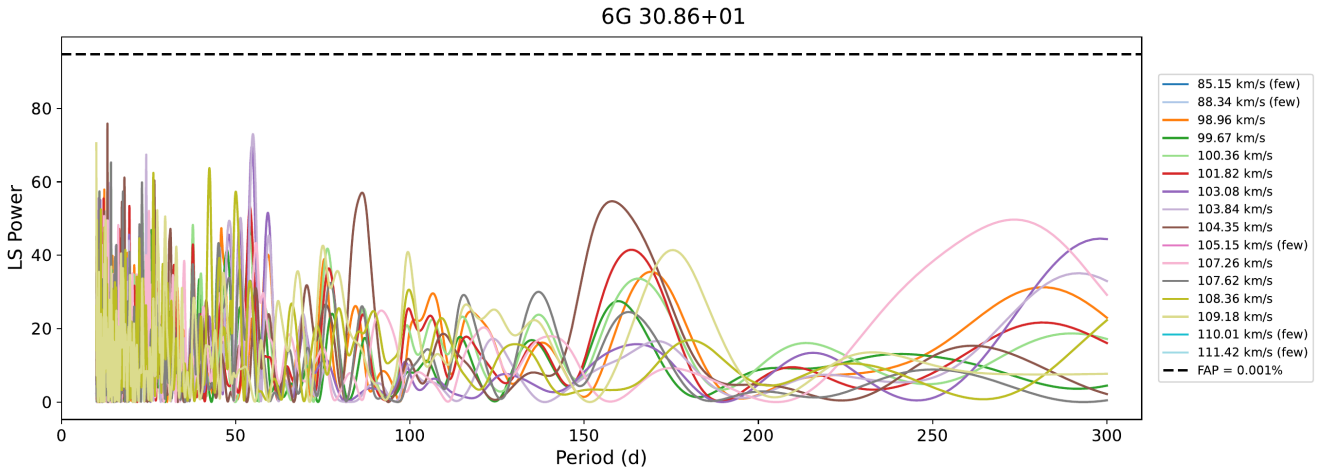


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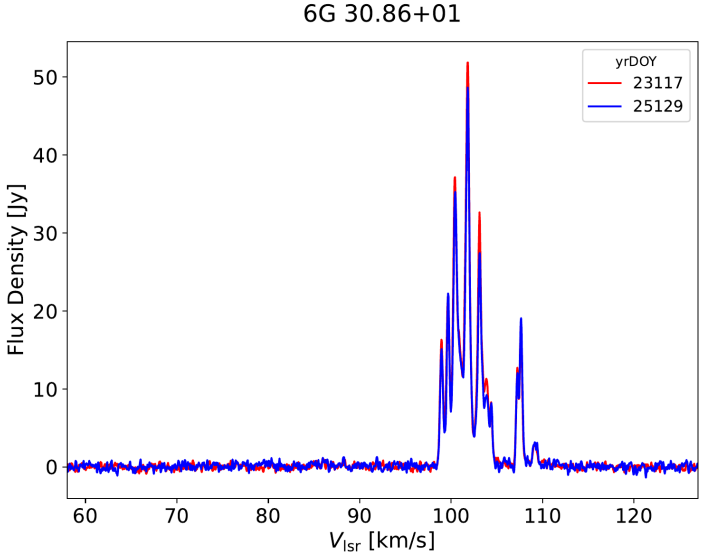
Light curve



Periodogram

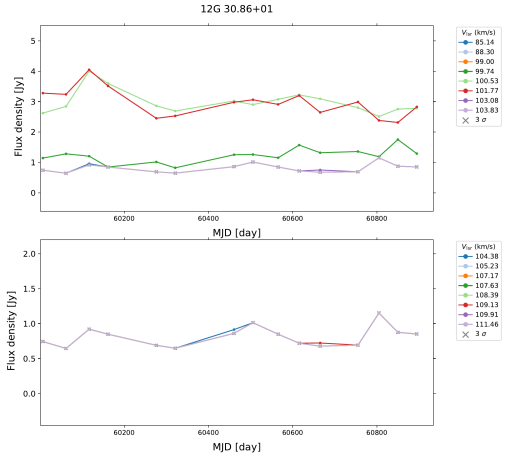


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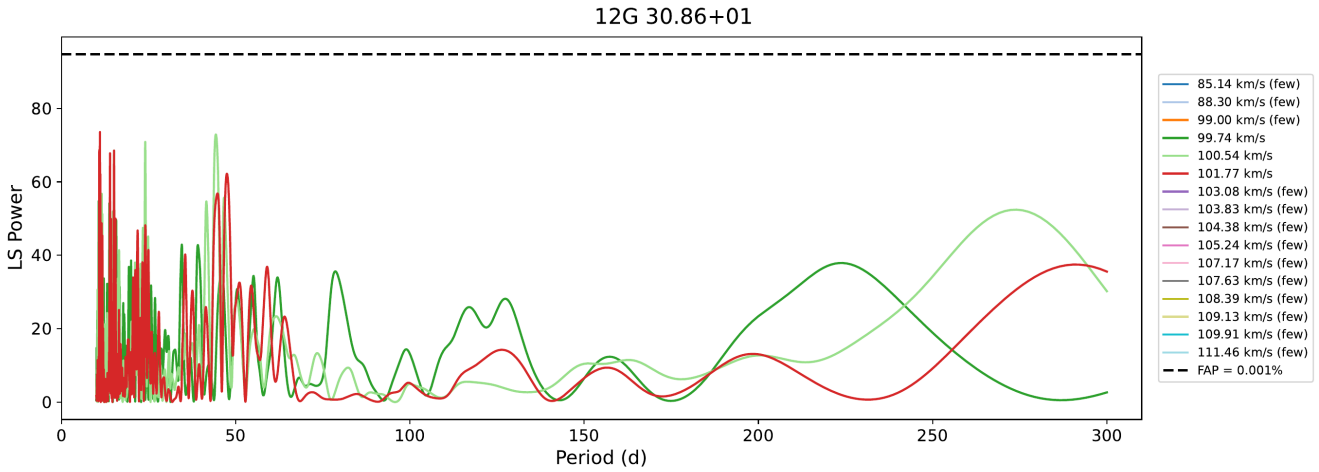


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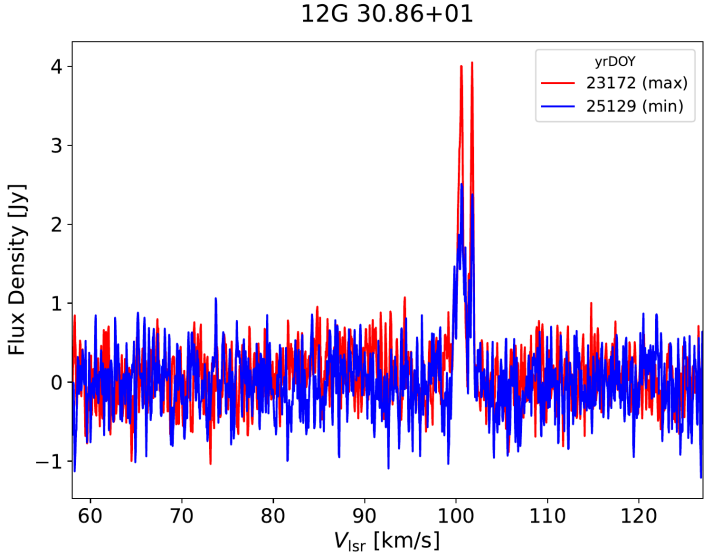
Light curve



Periodogram

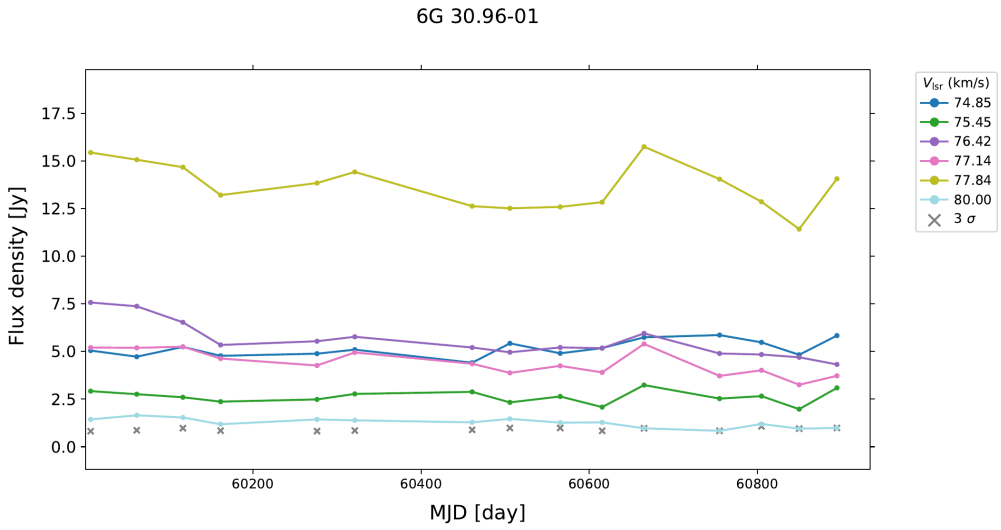


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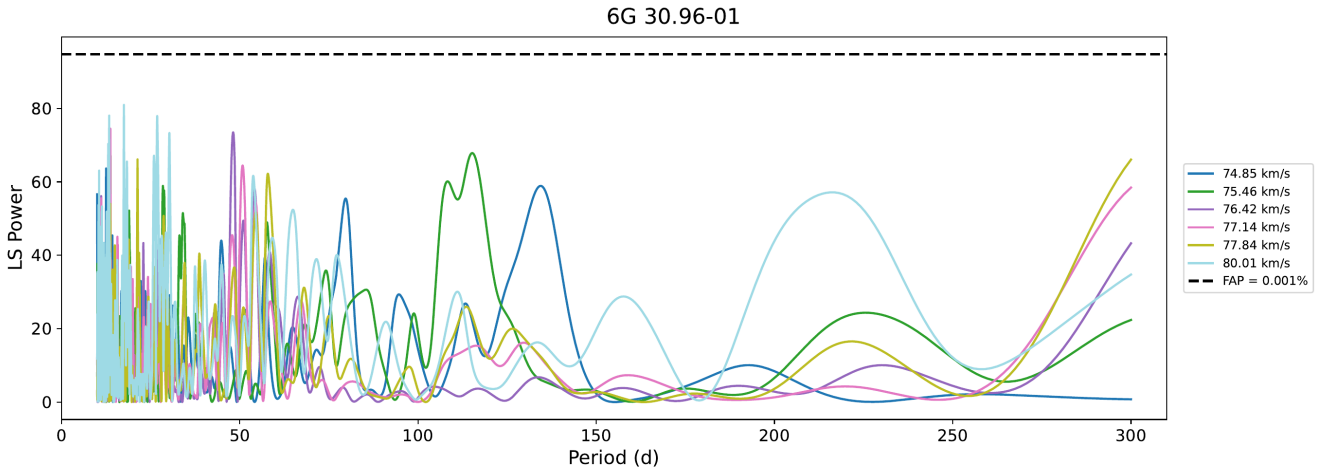


6G 30.96-01

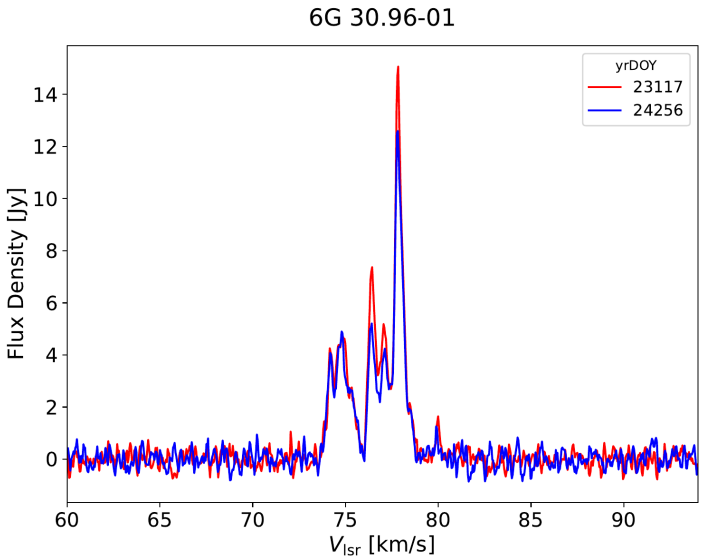
Light curve



Periodogram

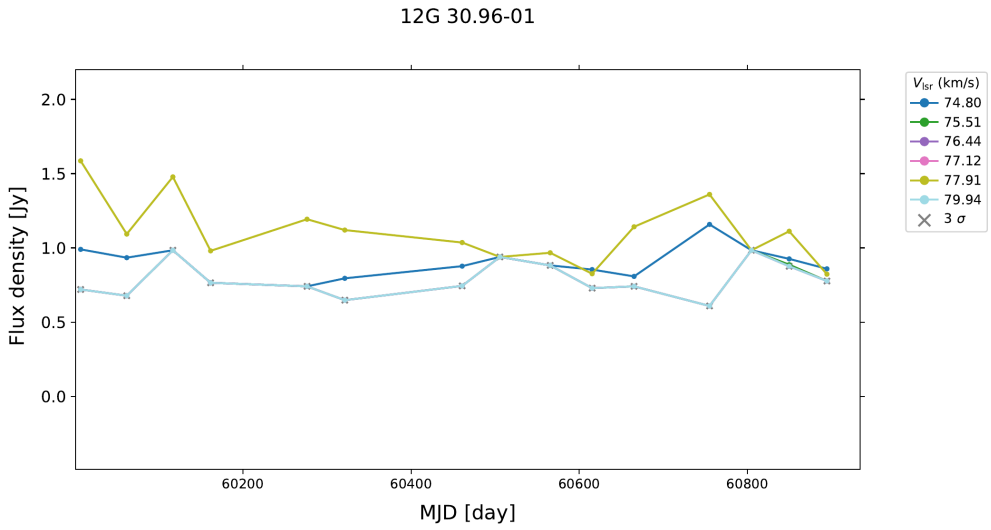


Spectrum

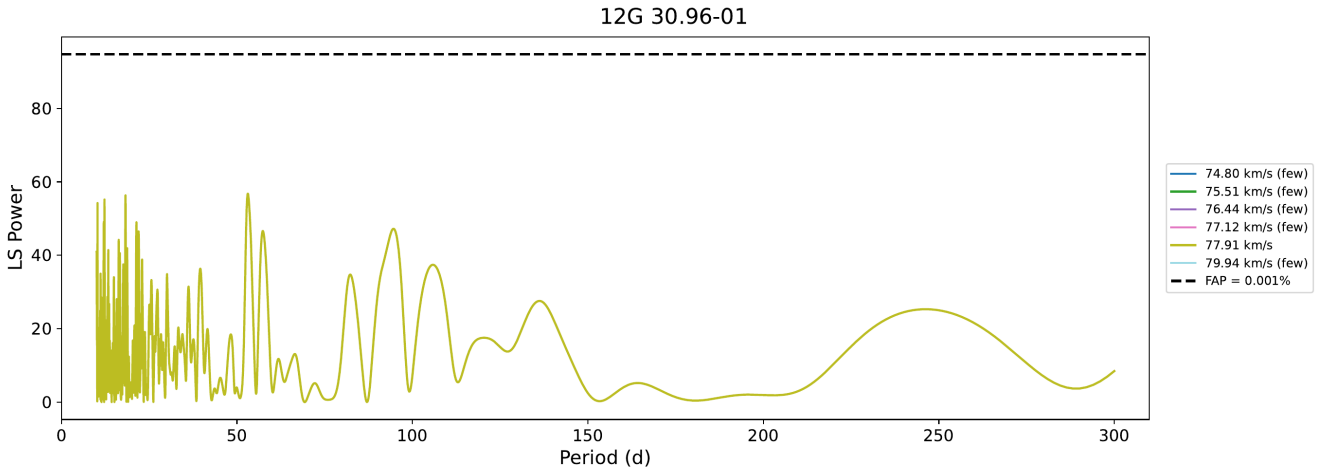


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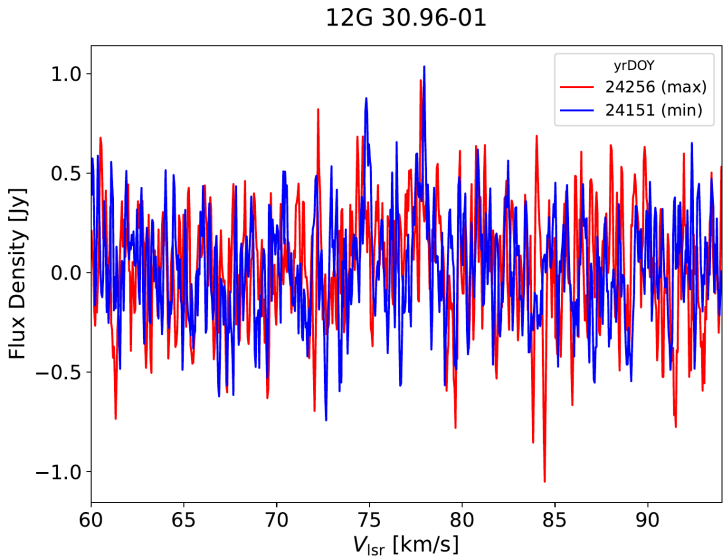
Light curve



Periodogram

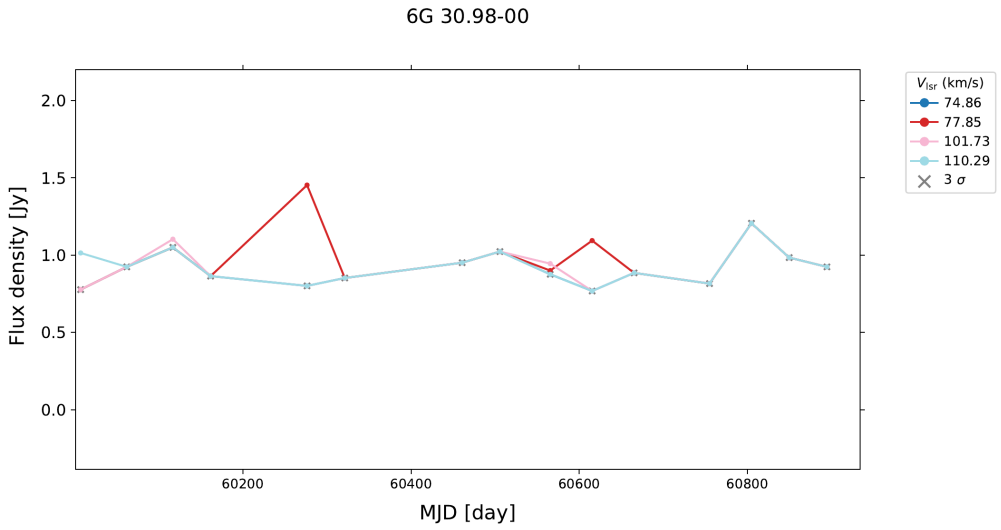


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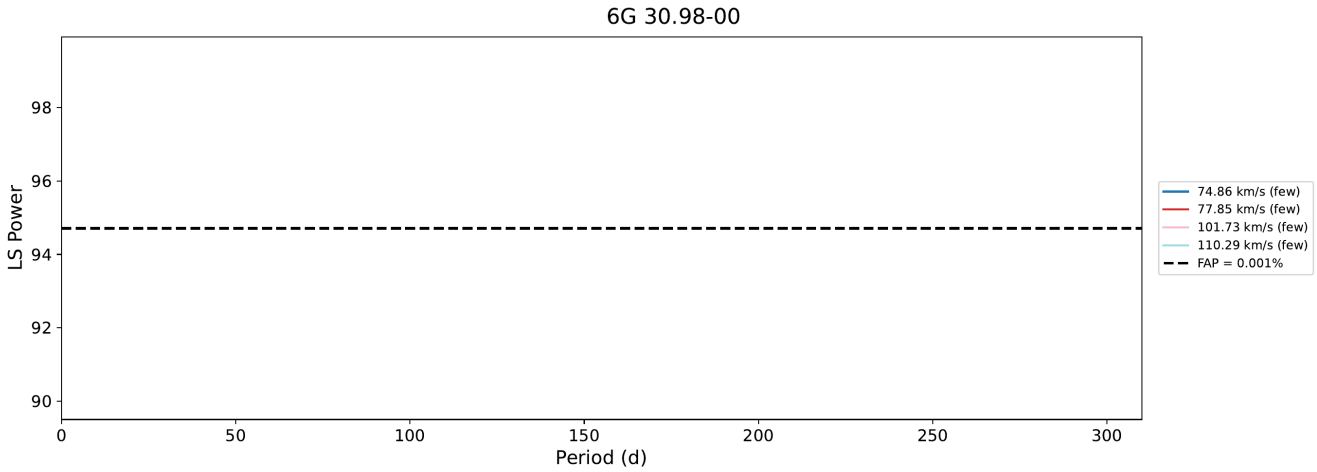


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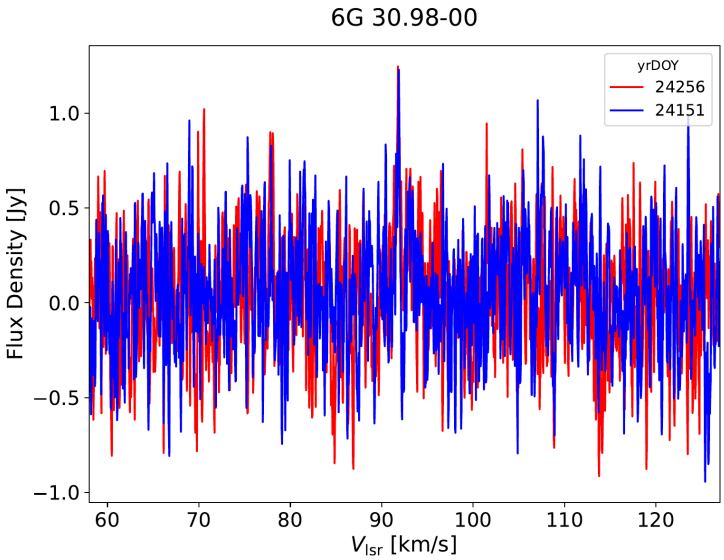
Light curve



Periodogram

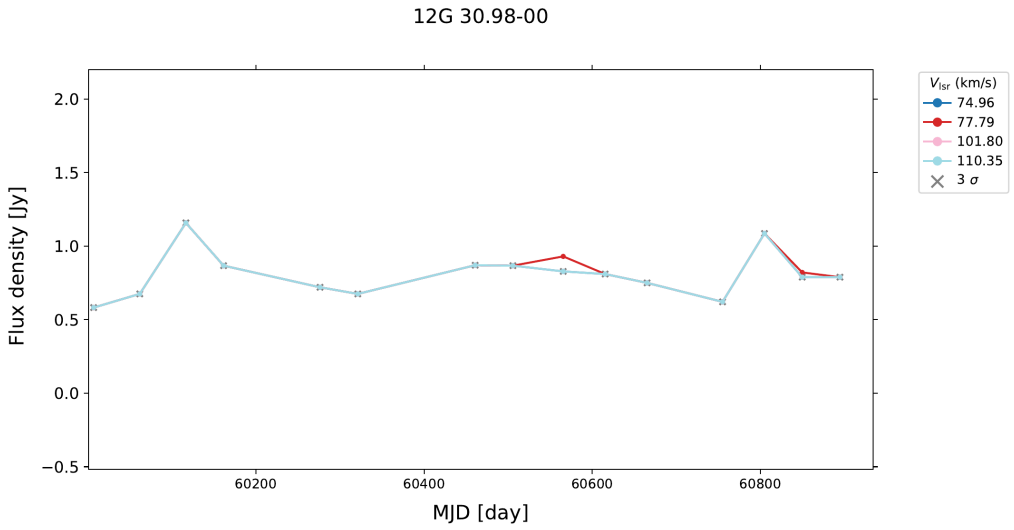


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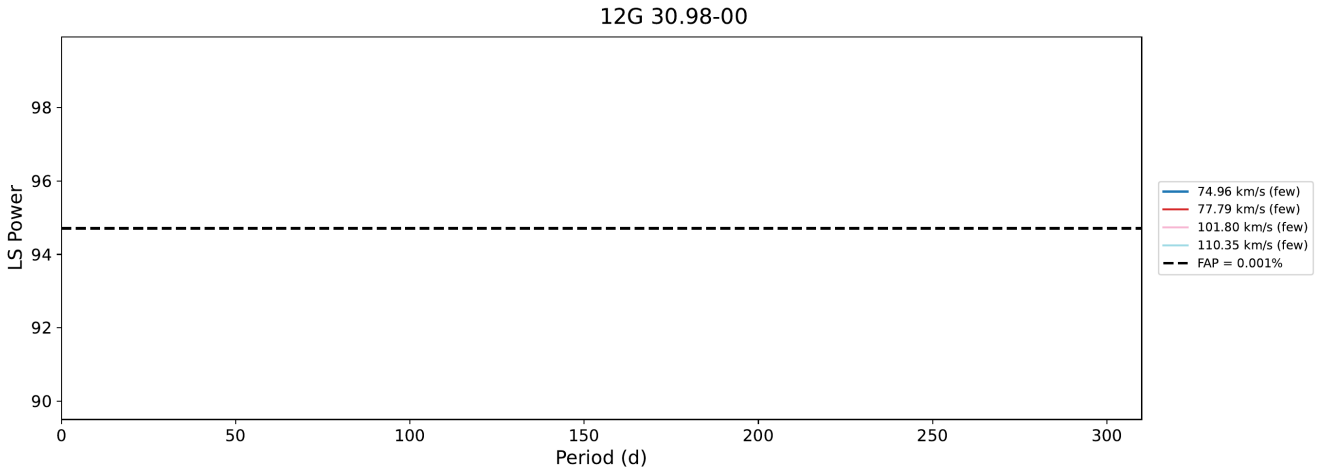


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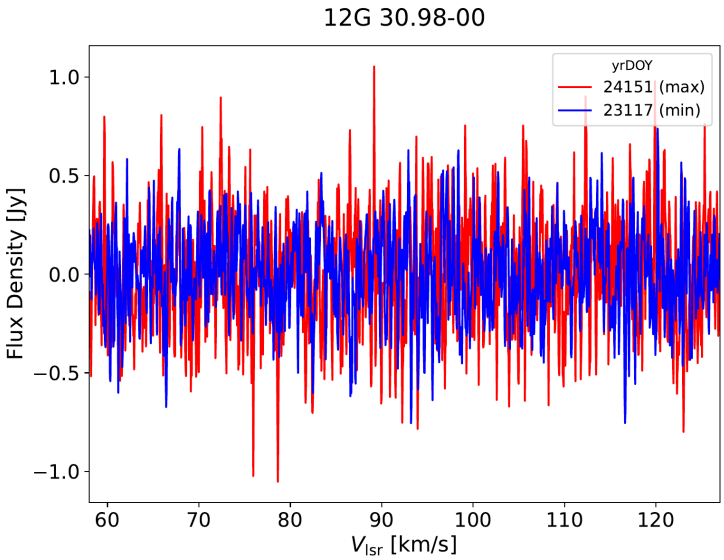
Light curve



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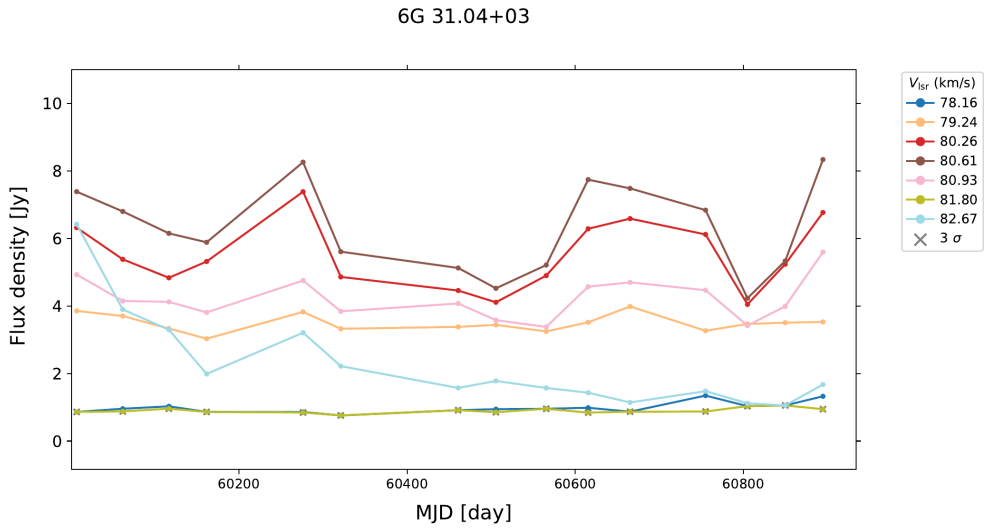


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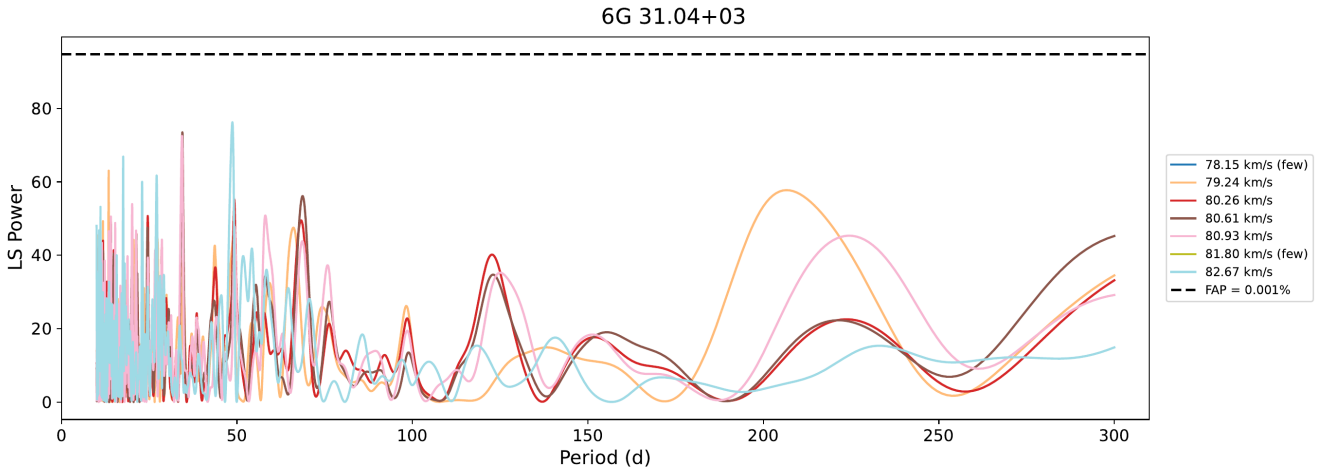


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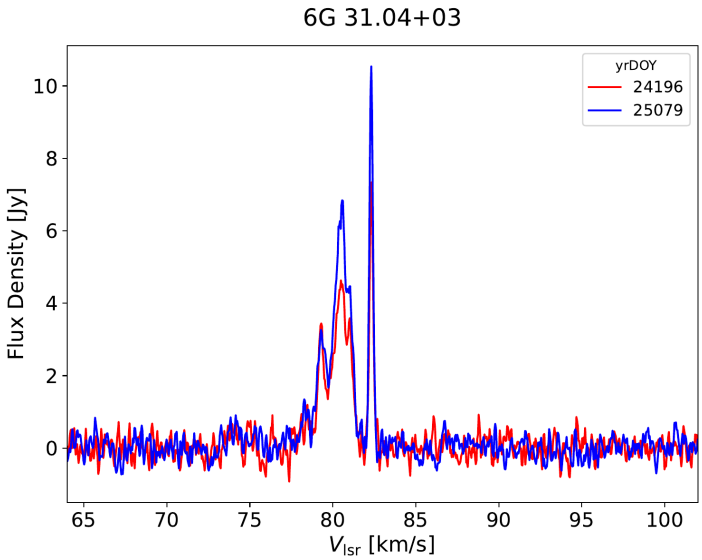
Light curve



Periodogram

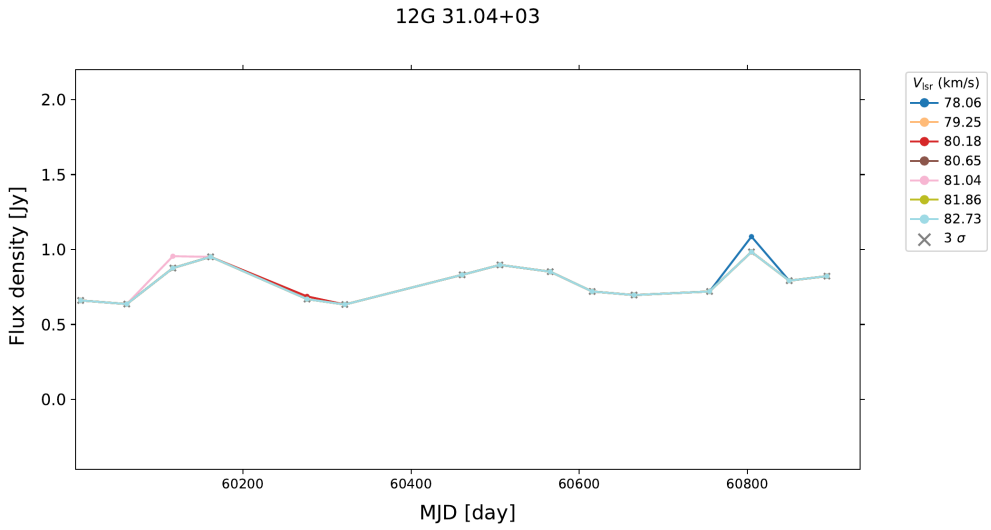


Spectrum

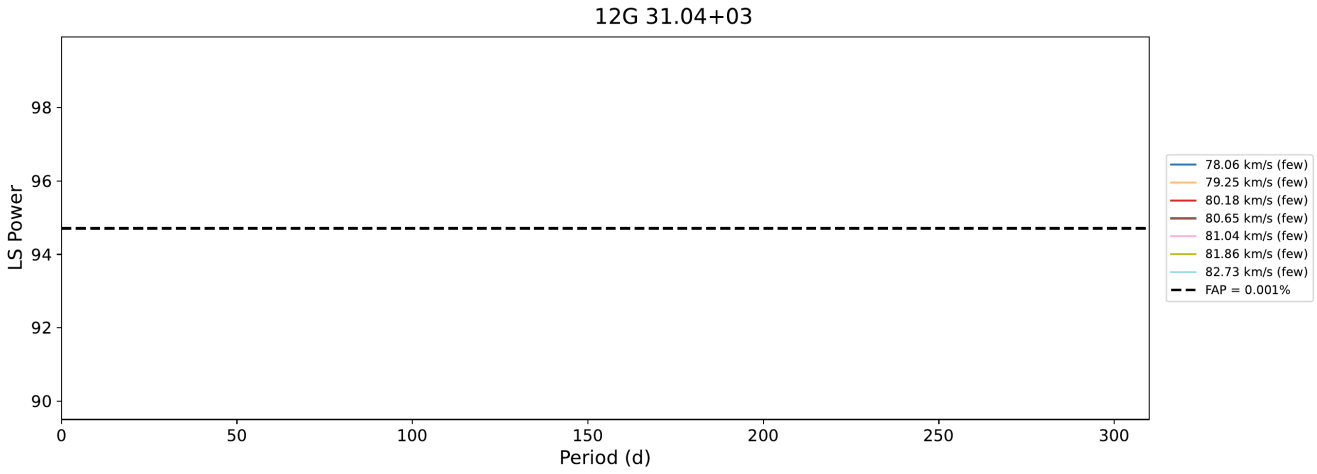


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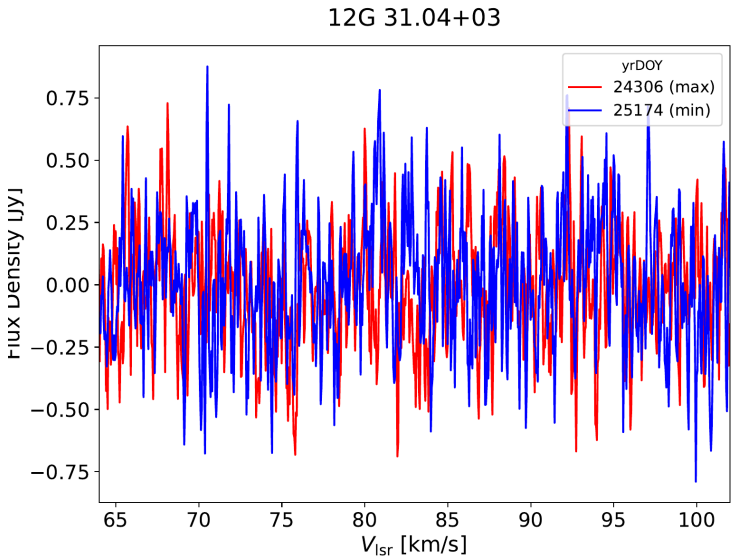
Light curve



Periodogram

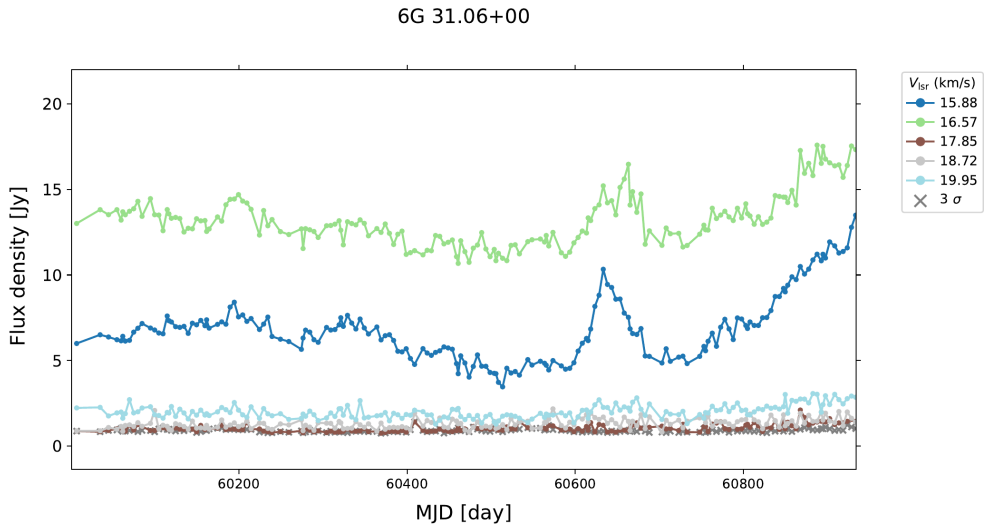


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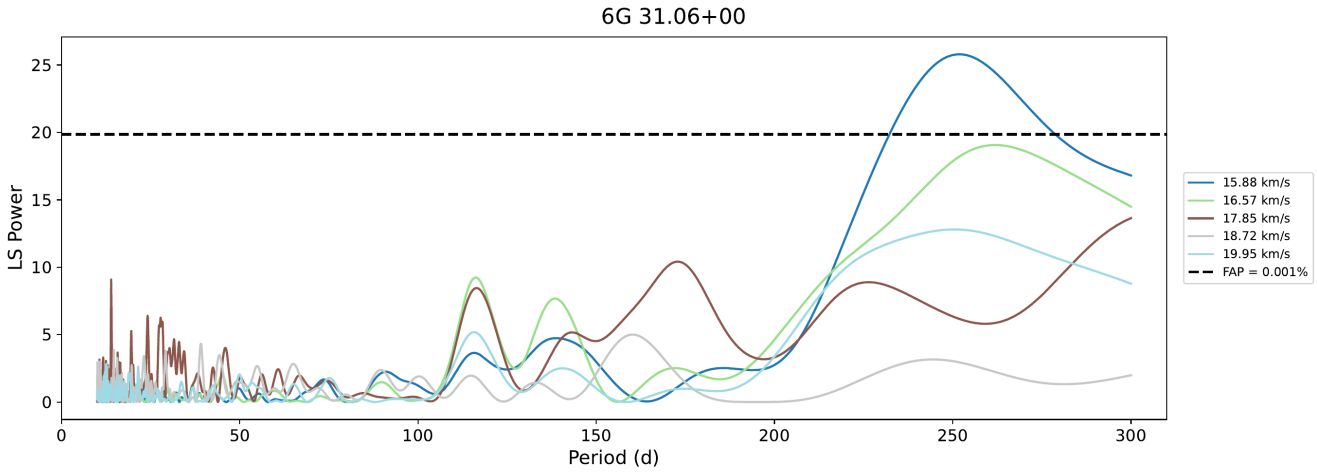


6G 31.06+00

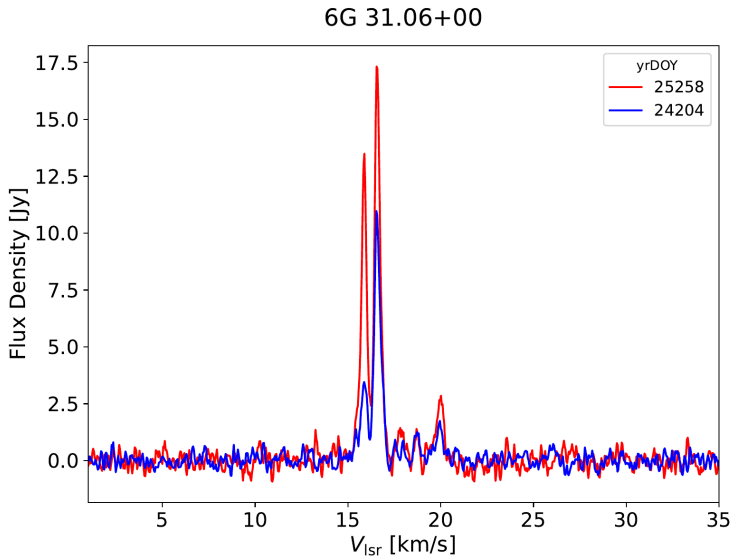
Light curve



Periodogram

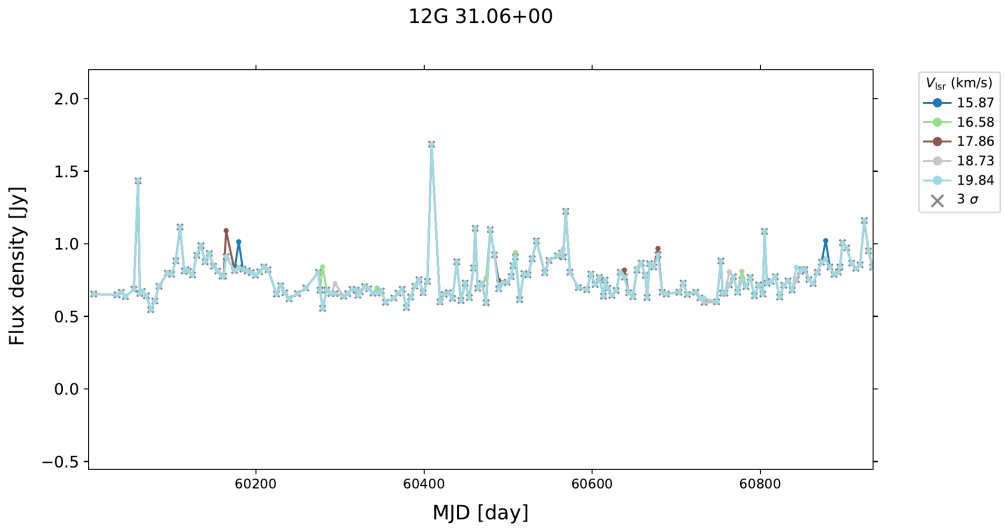


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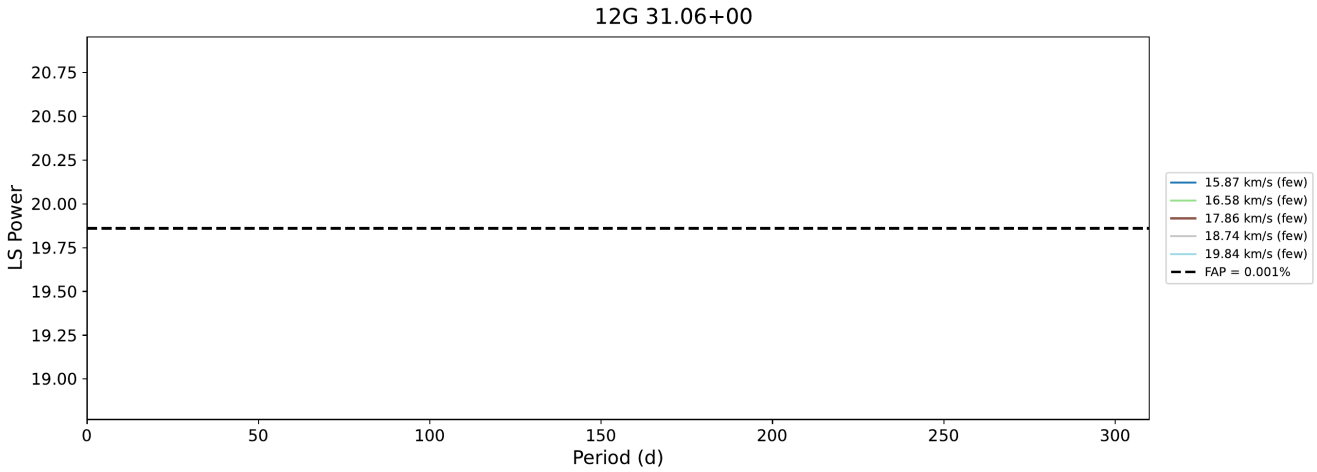


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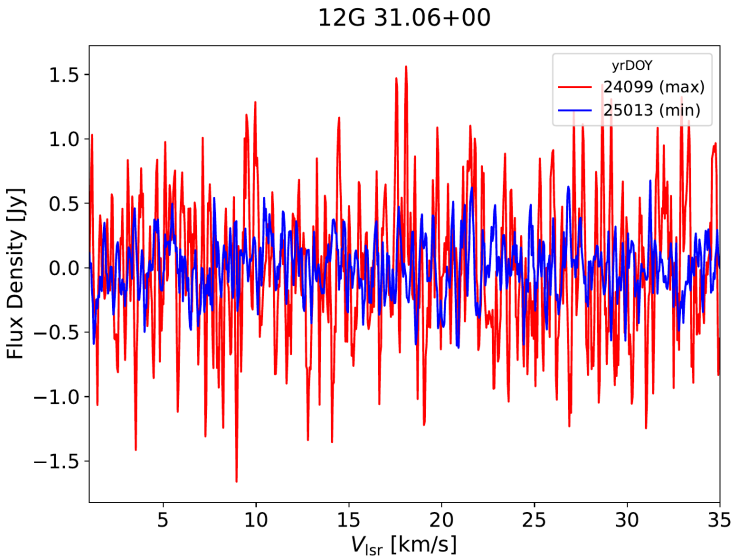
Light curve



Periodogram

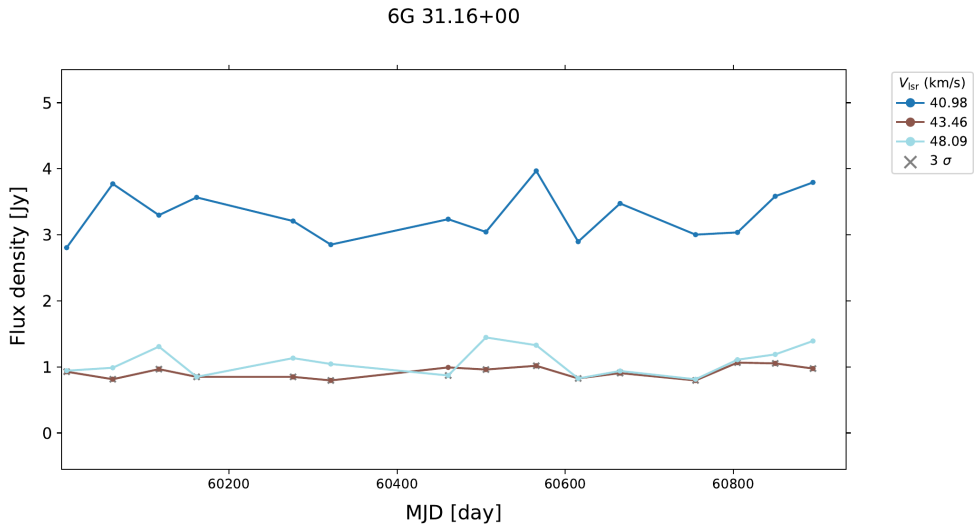


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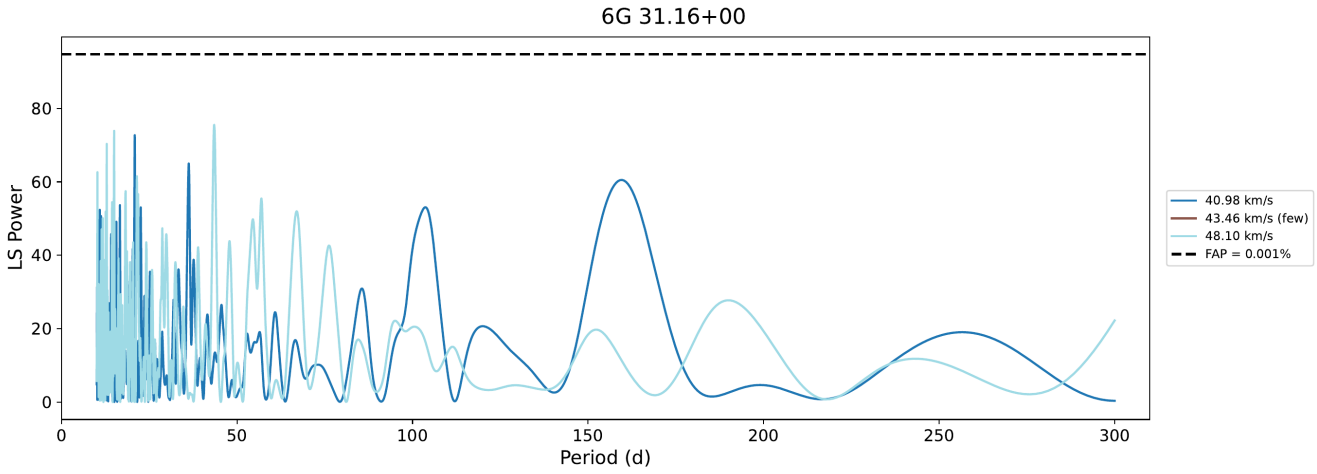


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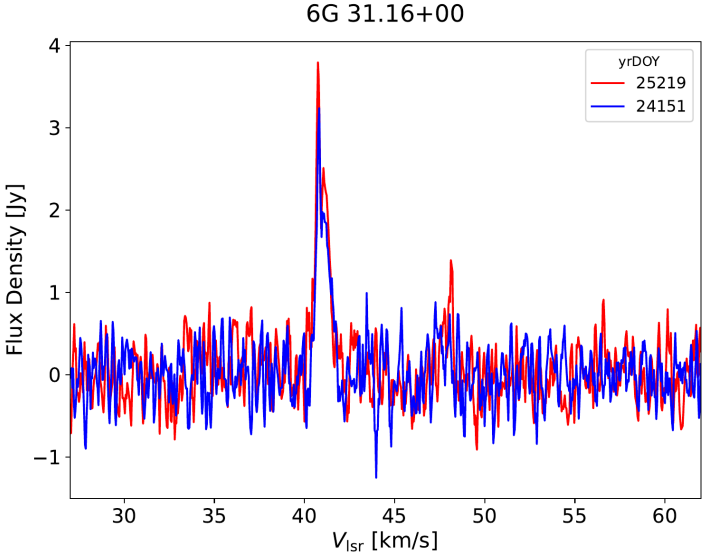
Light curve



Periodogram

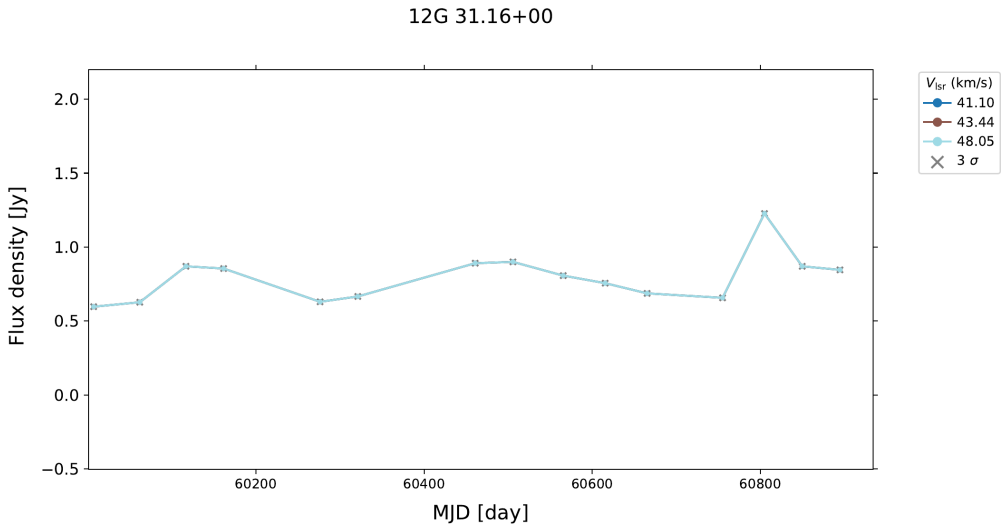


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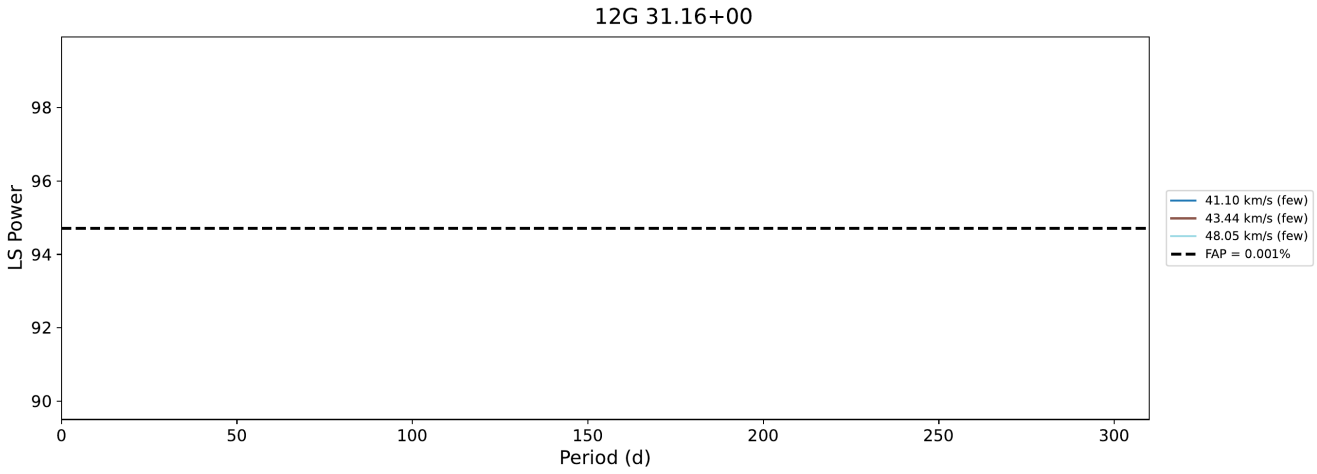


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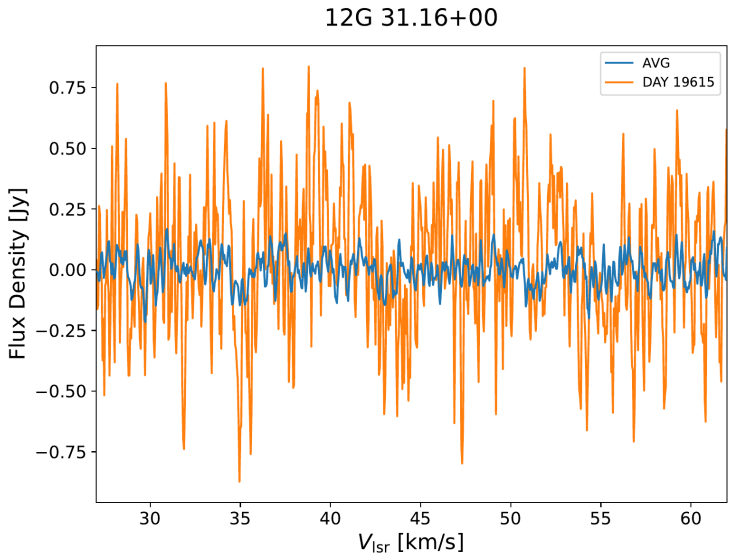
Light curve



Periodogram

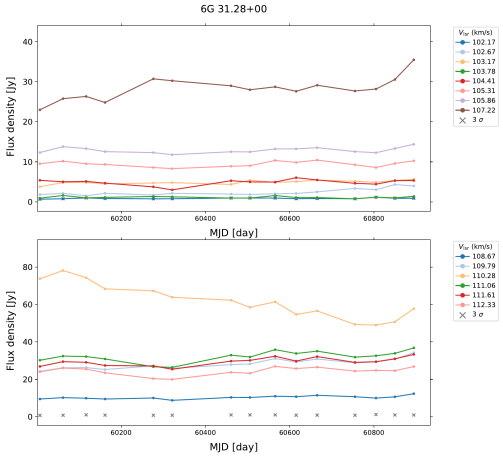


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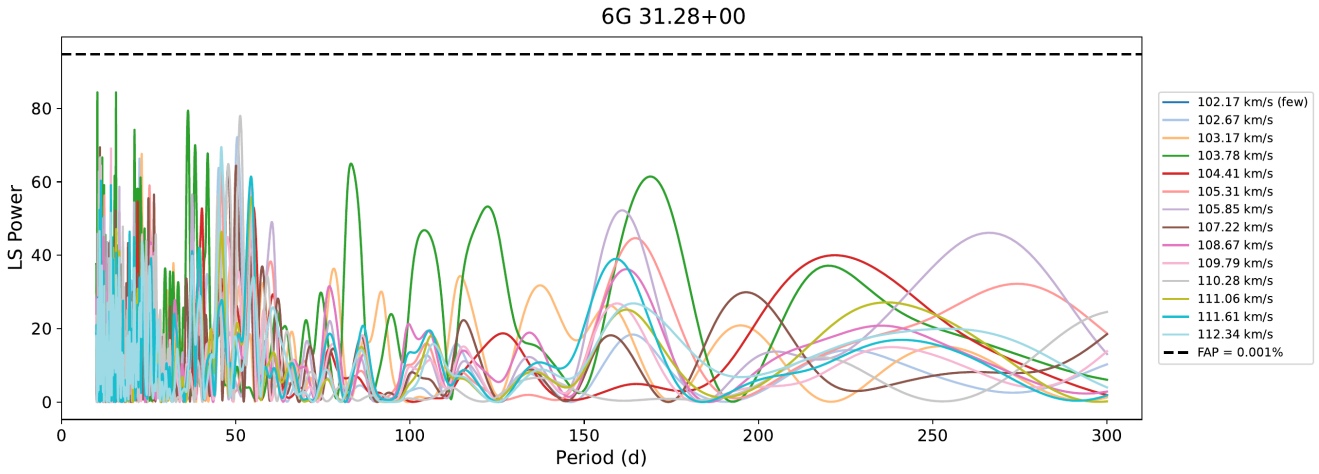


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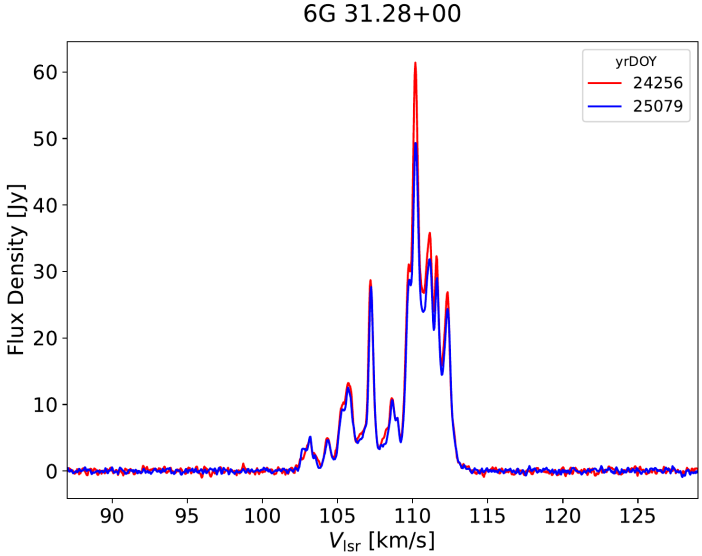
Light curve



Periodogram

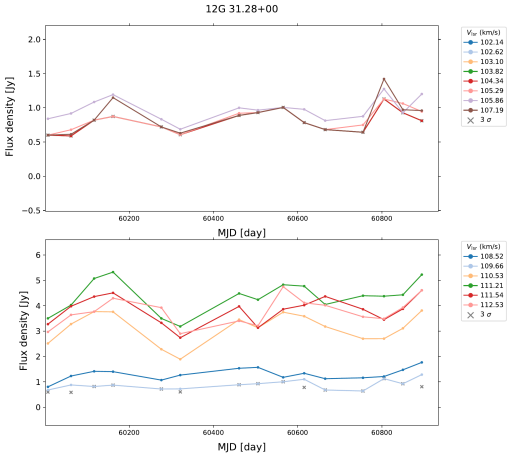


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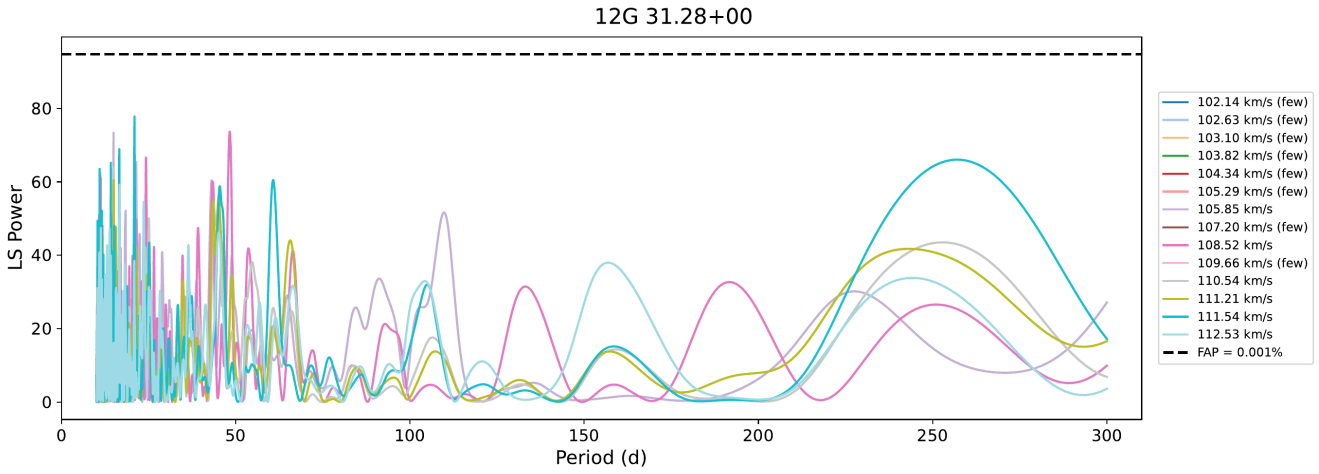


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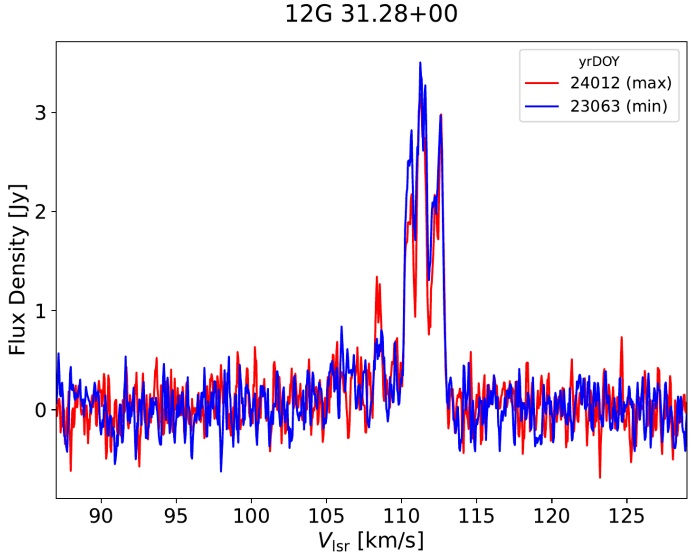
Light curve



Periodogram

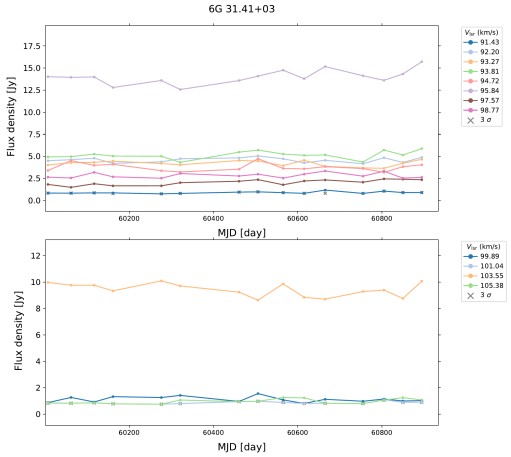


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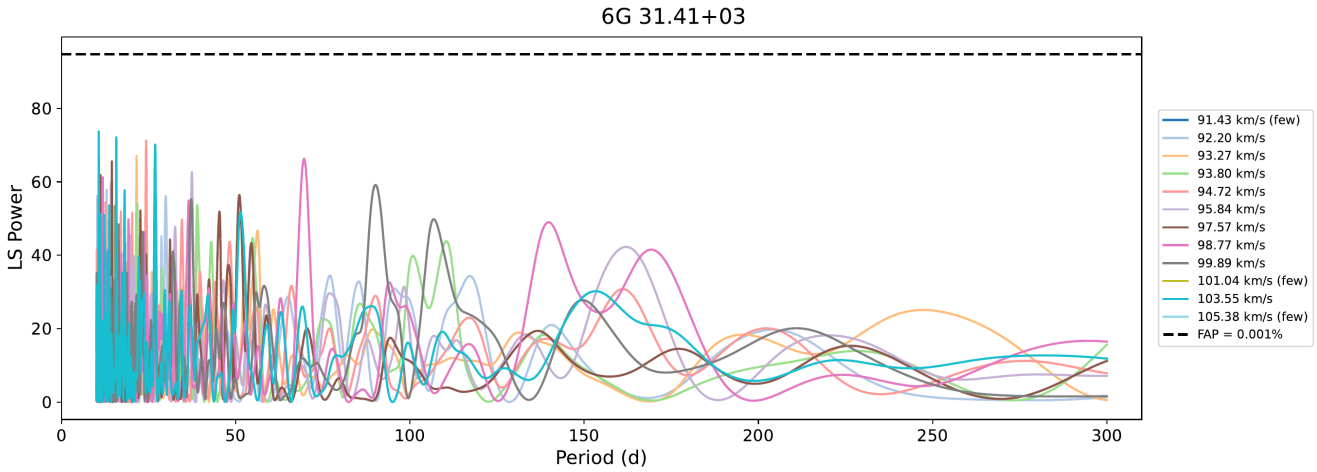


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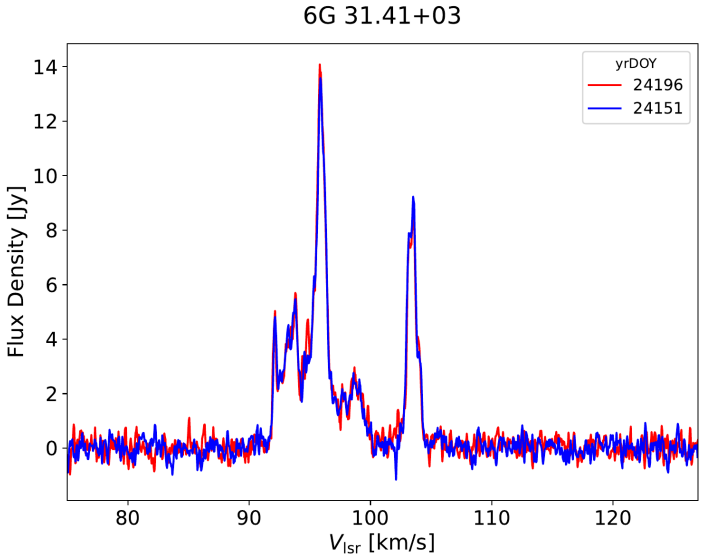
Light curve



Periodogram

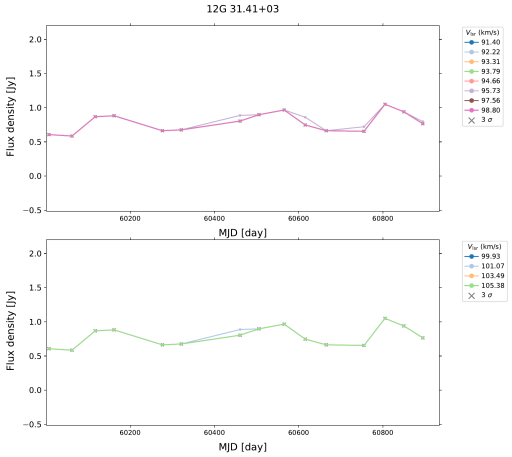


Spectrum

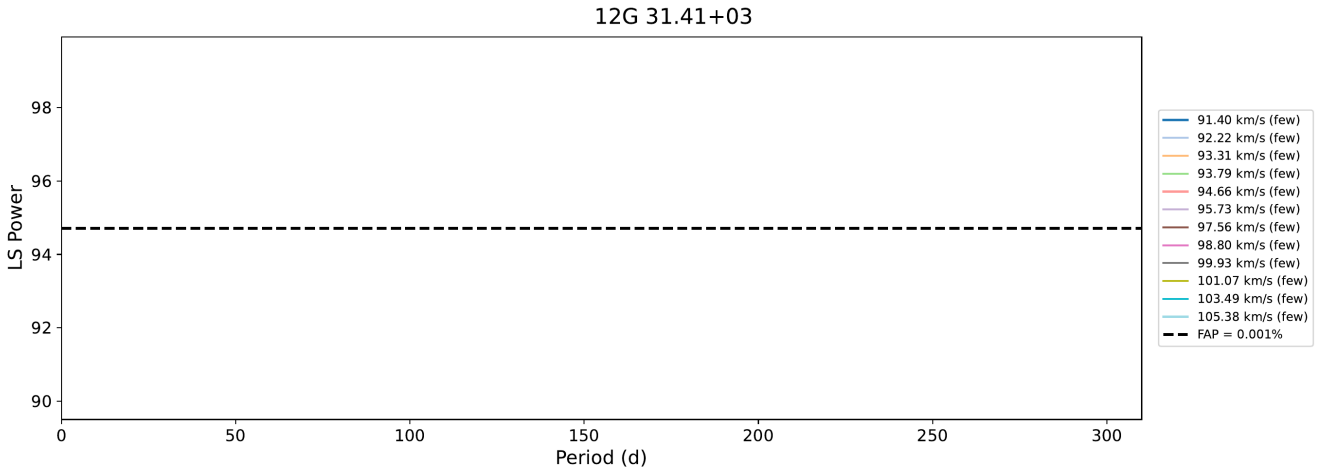


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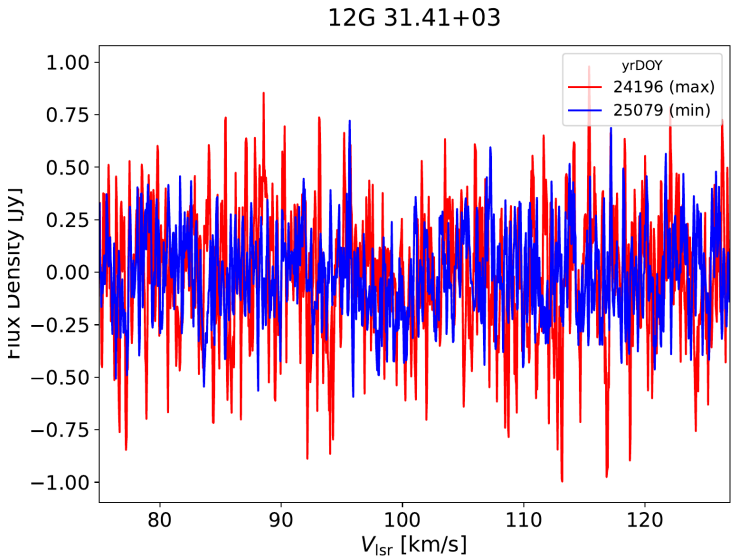
Light curve



Periodogram

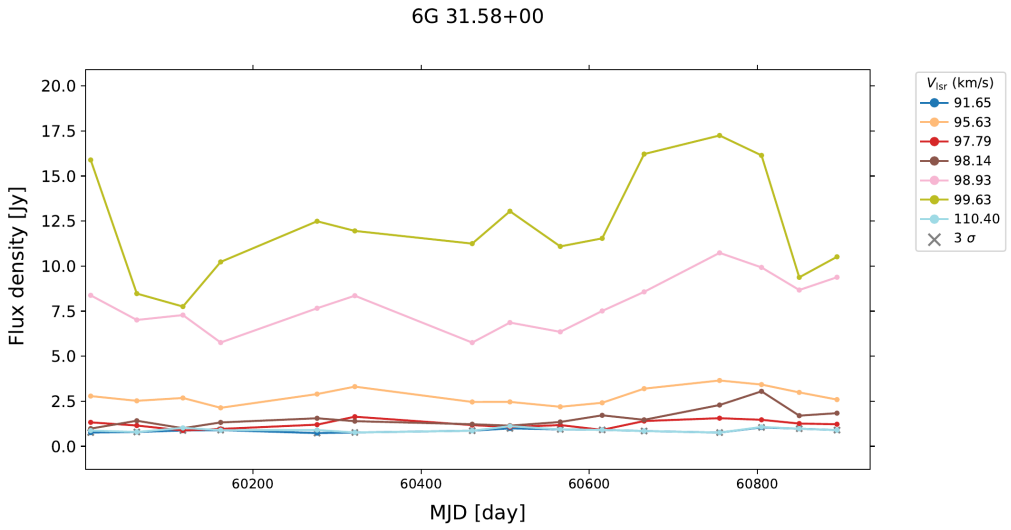


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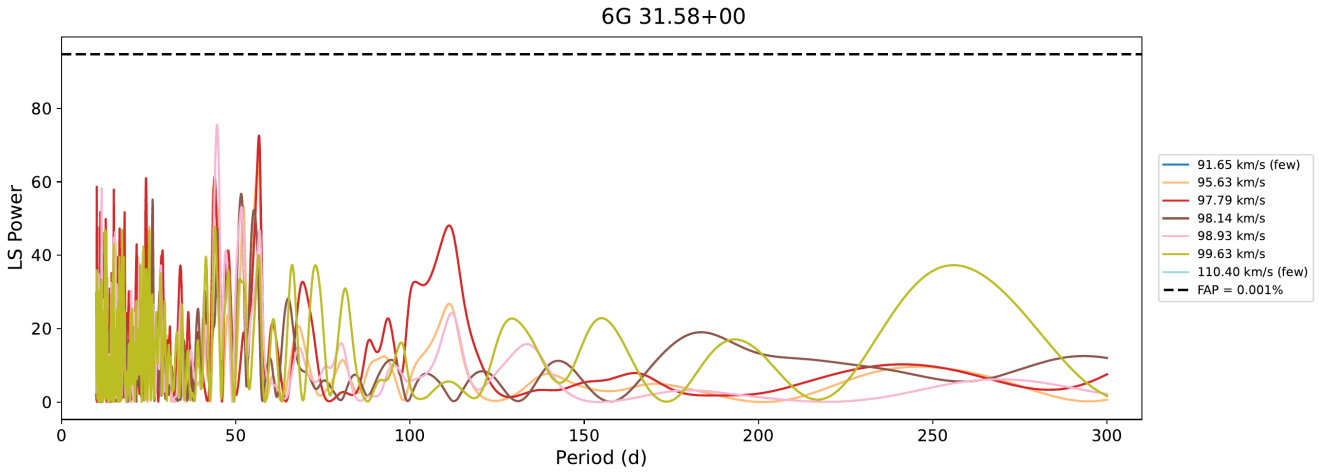


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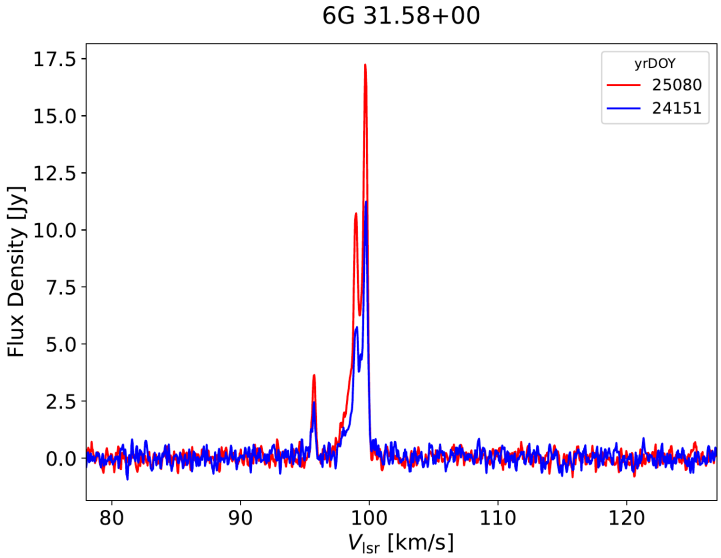
Light curve



Periodogram

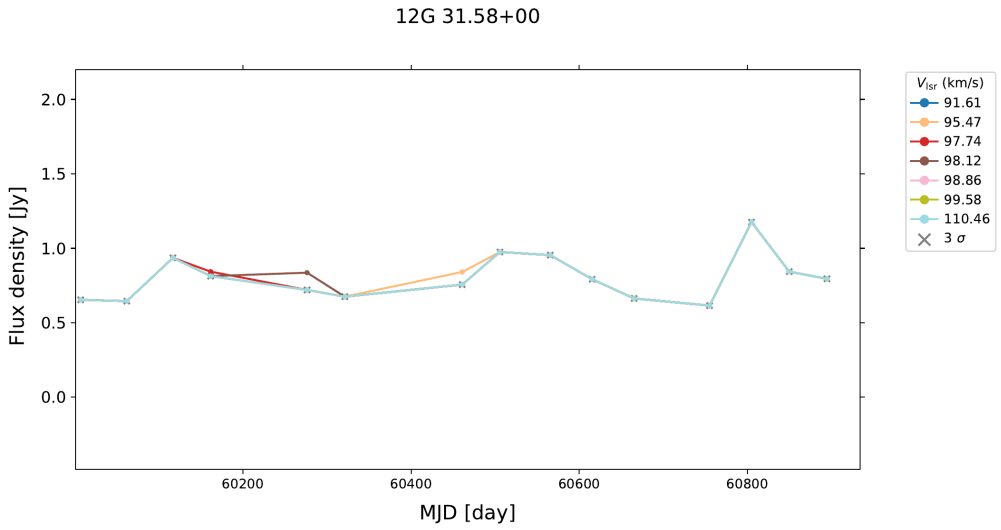


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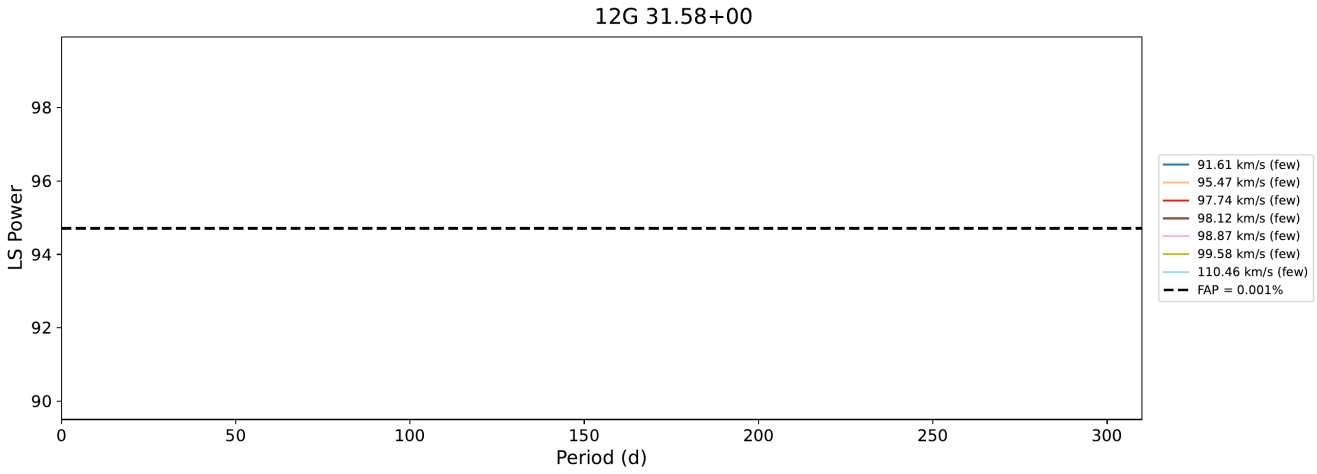


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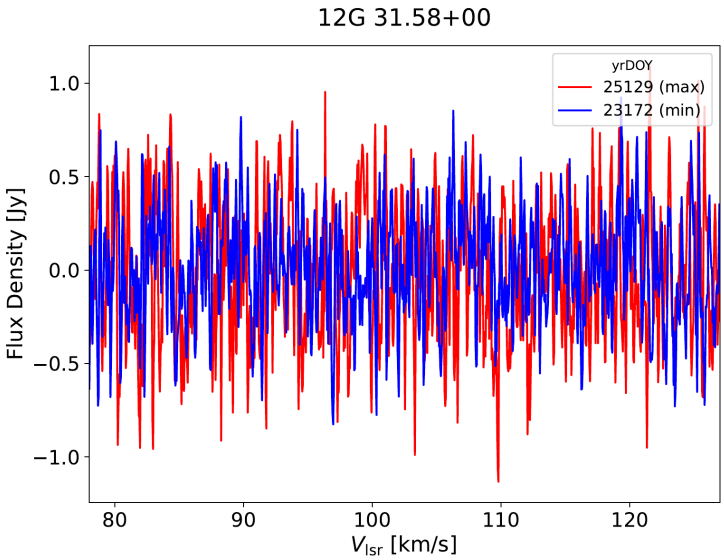
Light curve



Periodogram

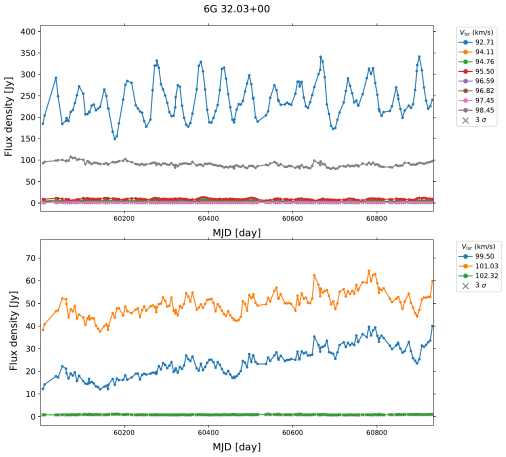


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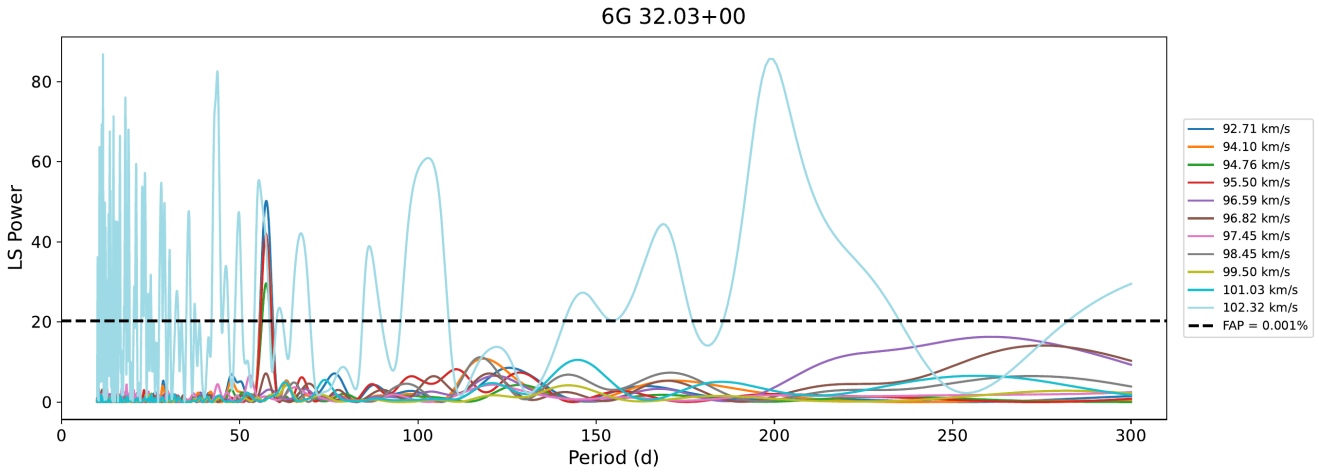


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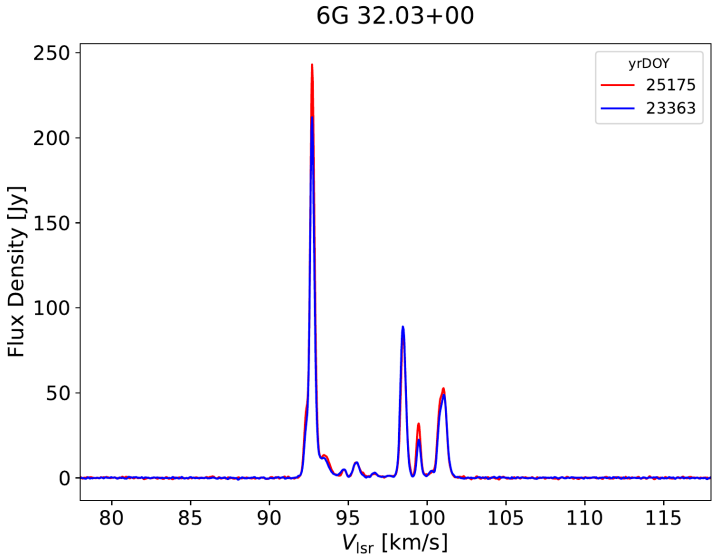
Light curve



Periodogram

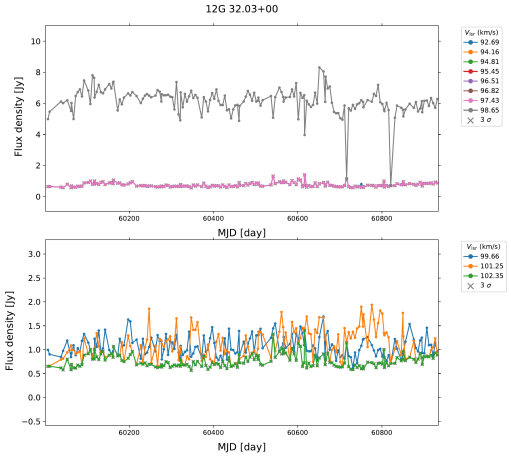


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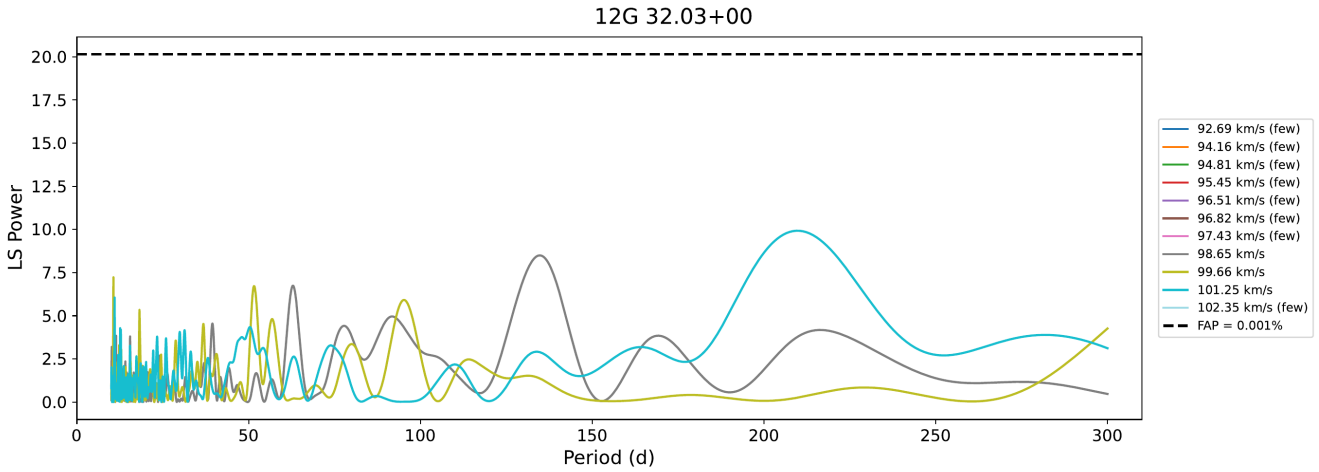


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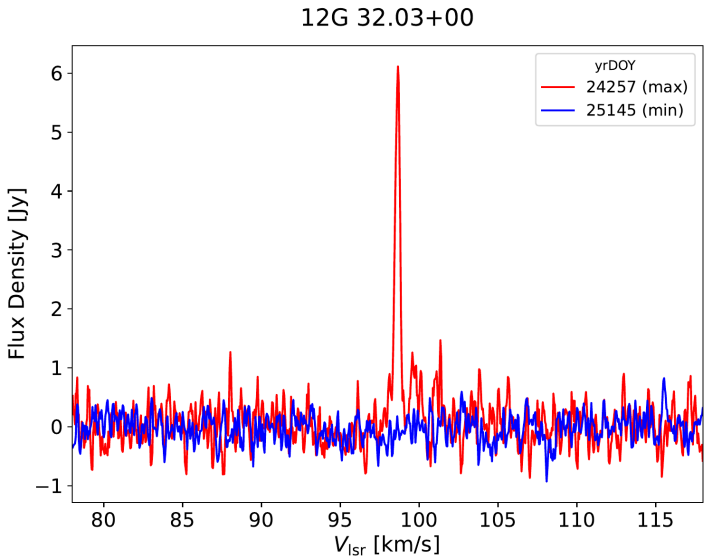
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Periodogram



Spectrum

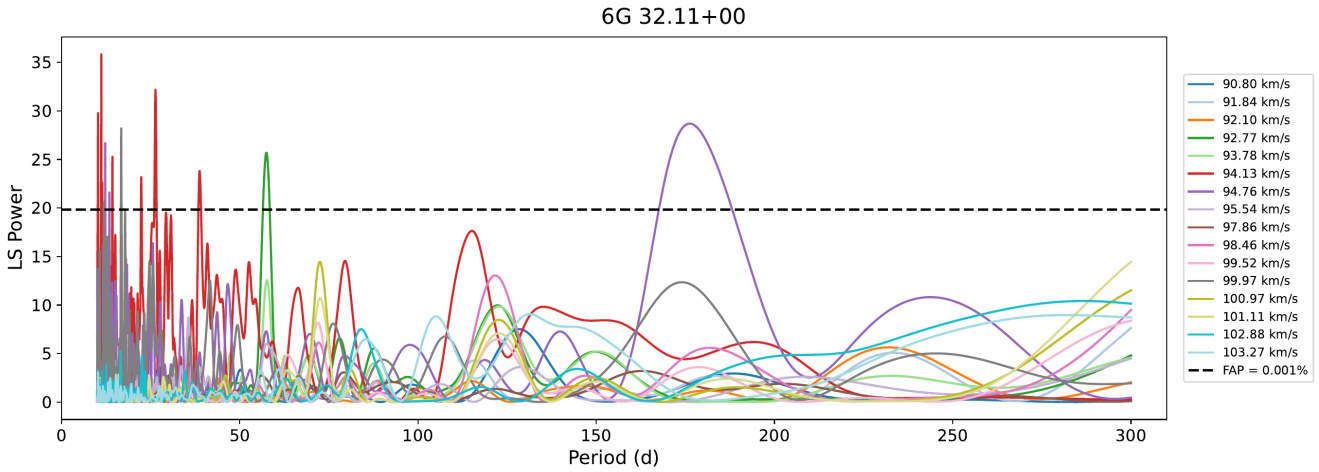


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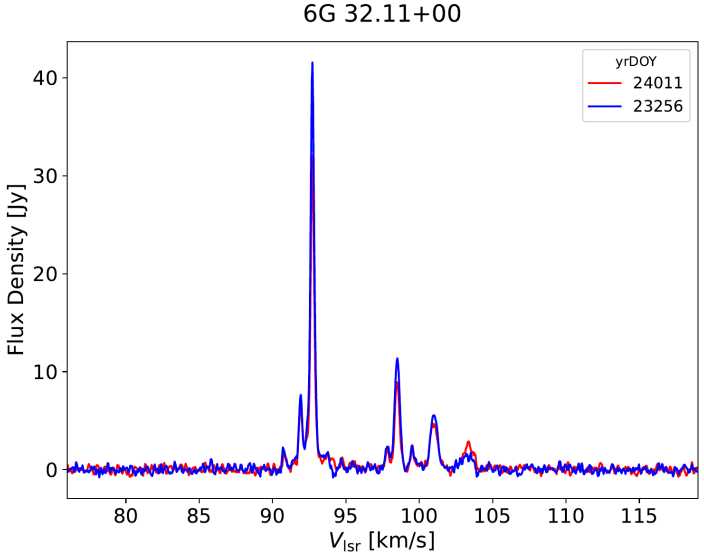
Light curve



Periodogram

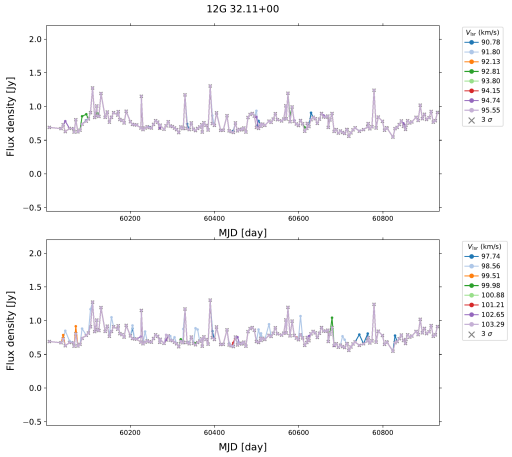


Spectrum

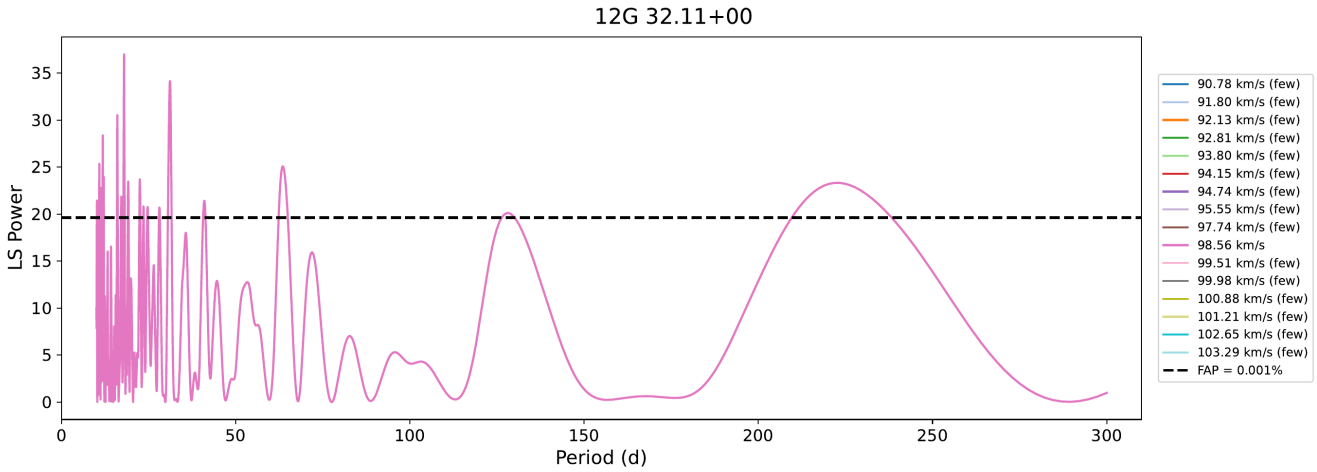


12G 32.11+00

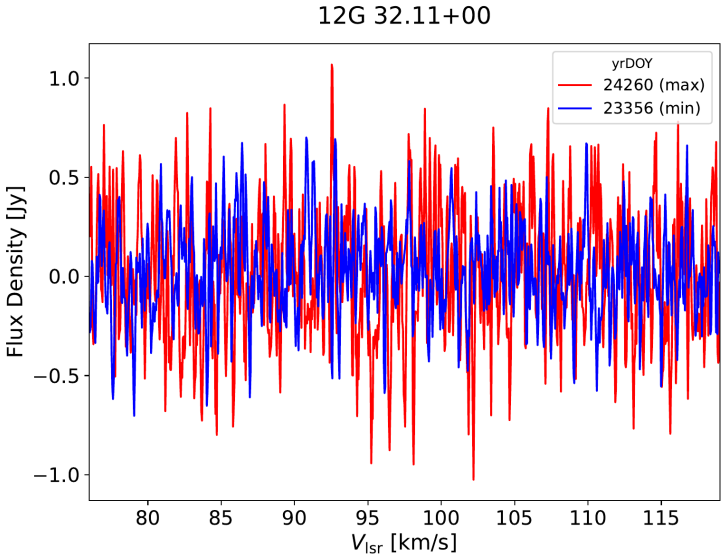
Light curve



Periodogram

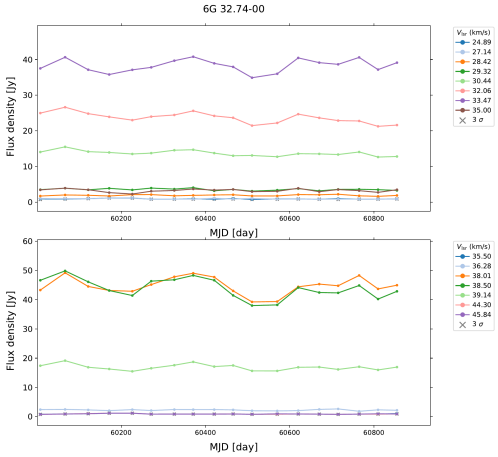


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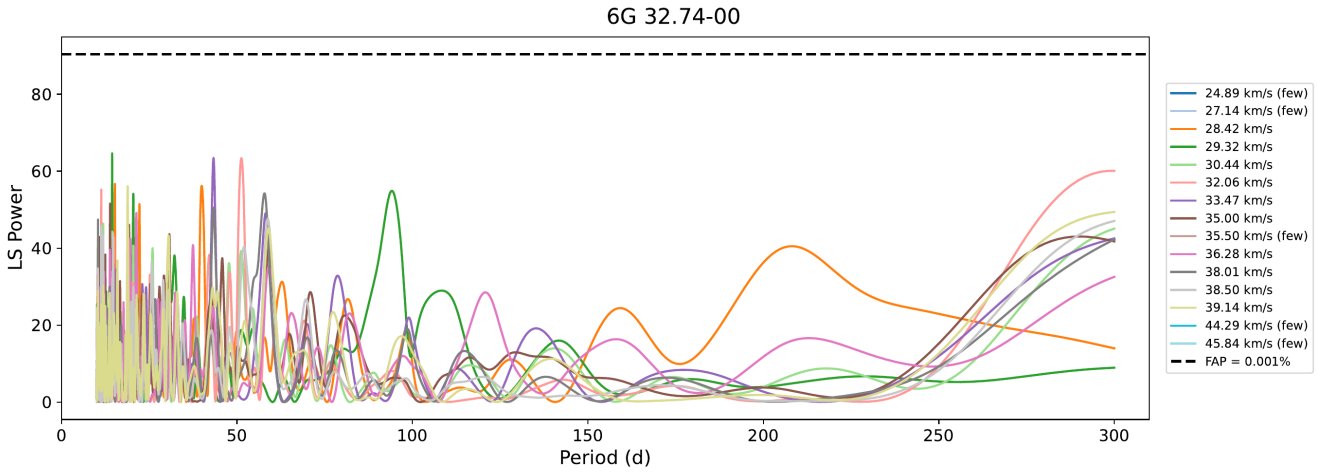


6G 32.74-00

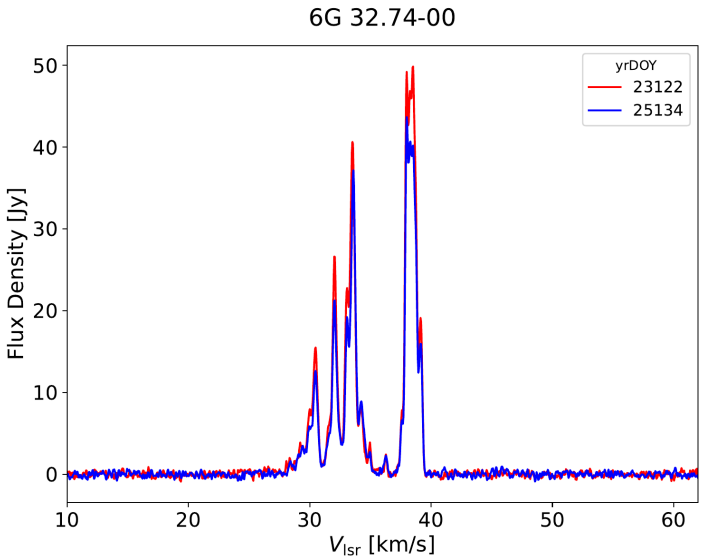
Light curve



Periodogram

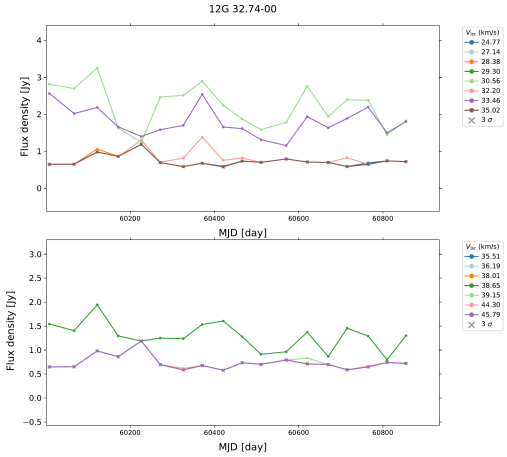


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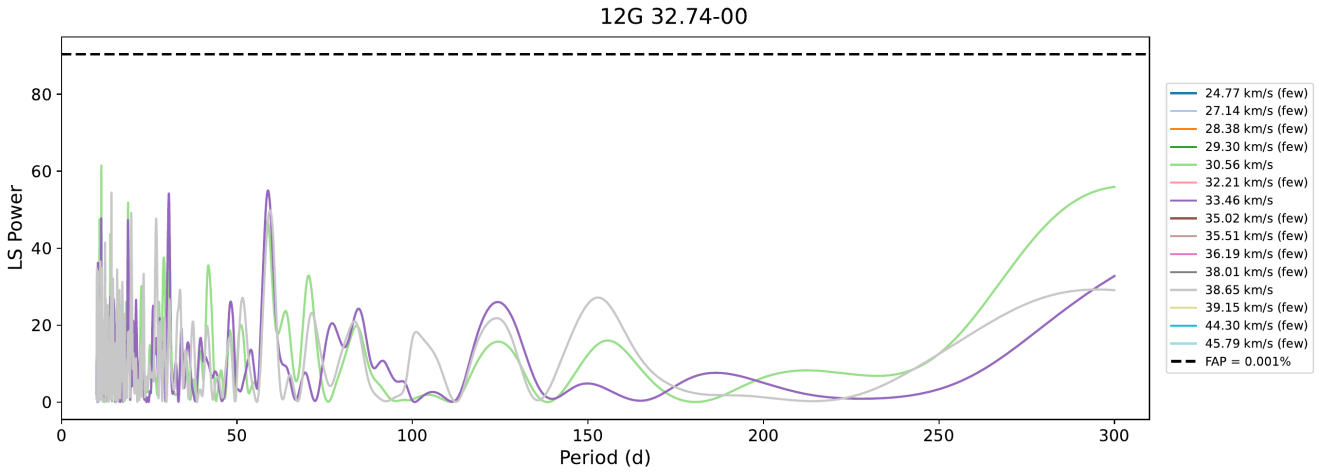


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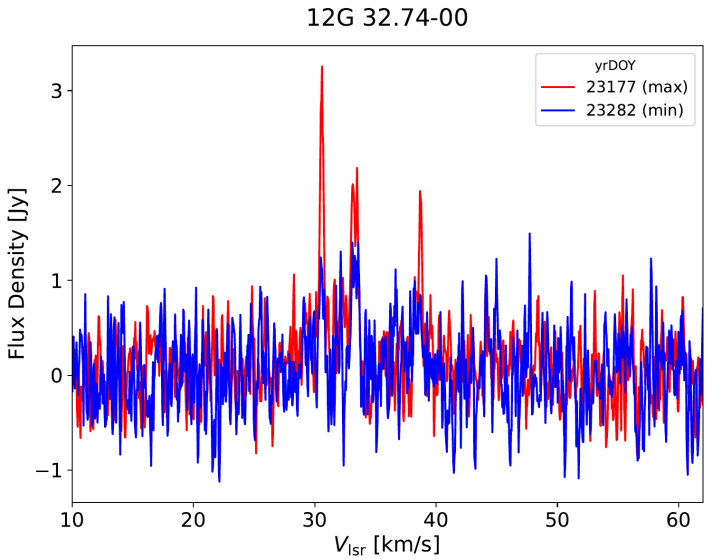
Light curve



Periodogram

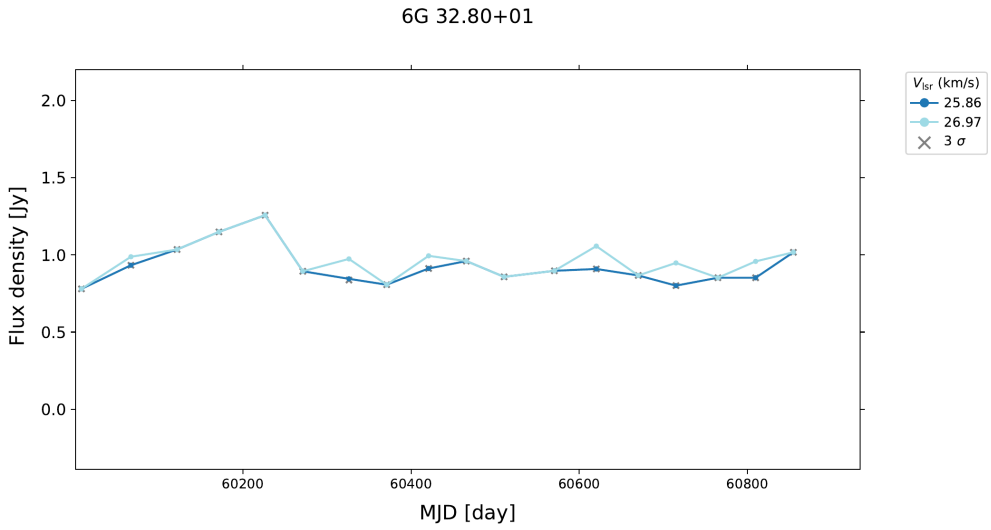


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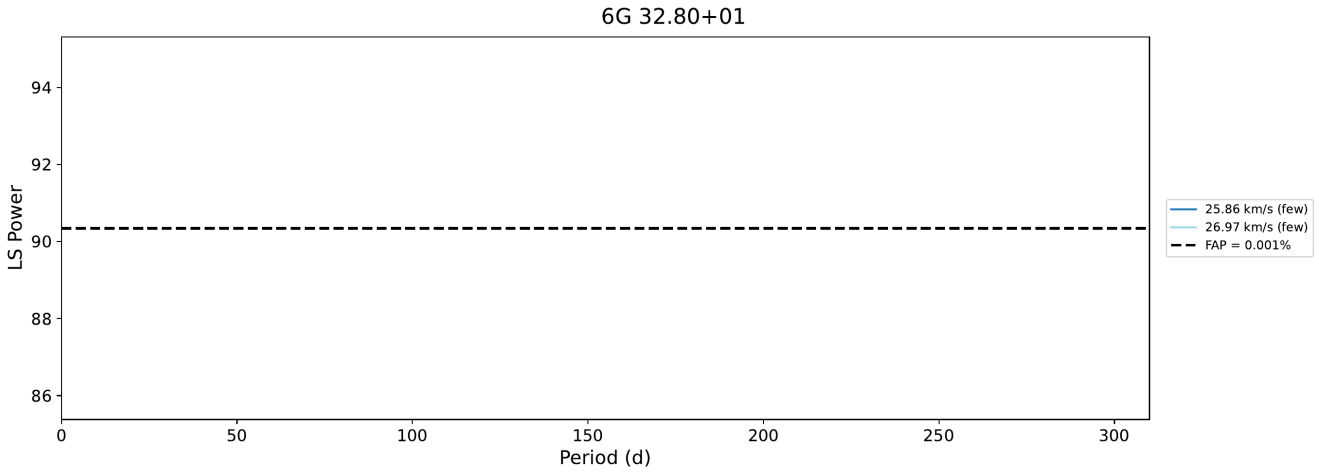


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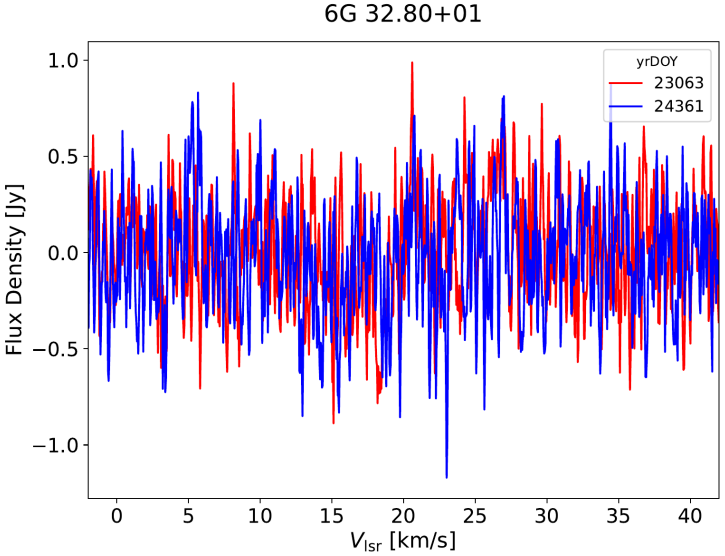
Light curve



Periodogram

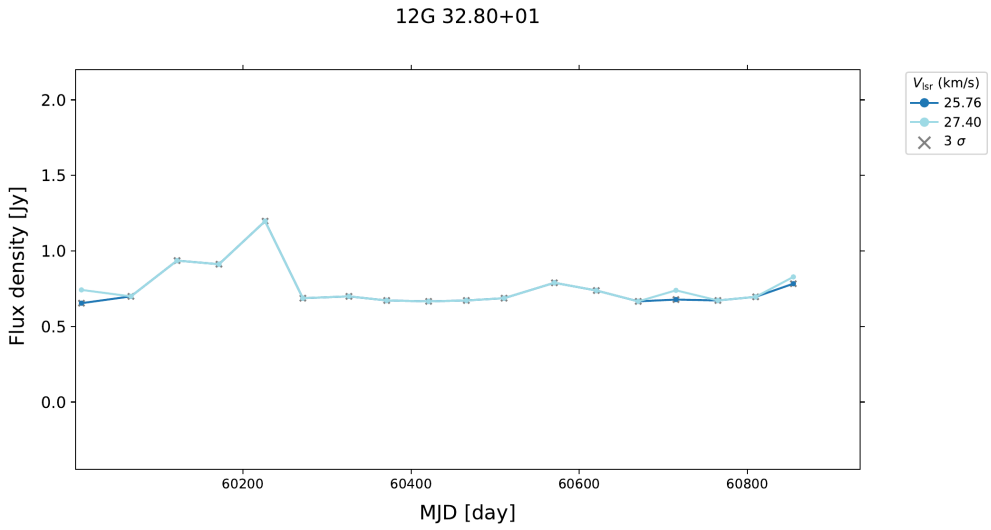


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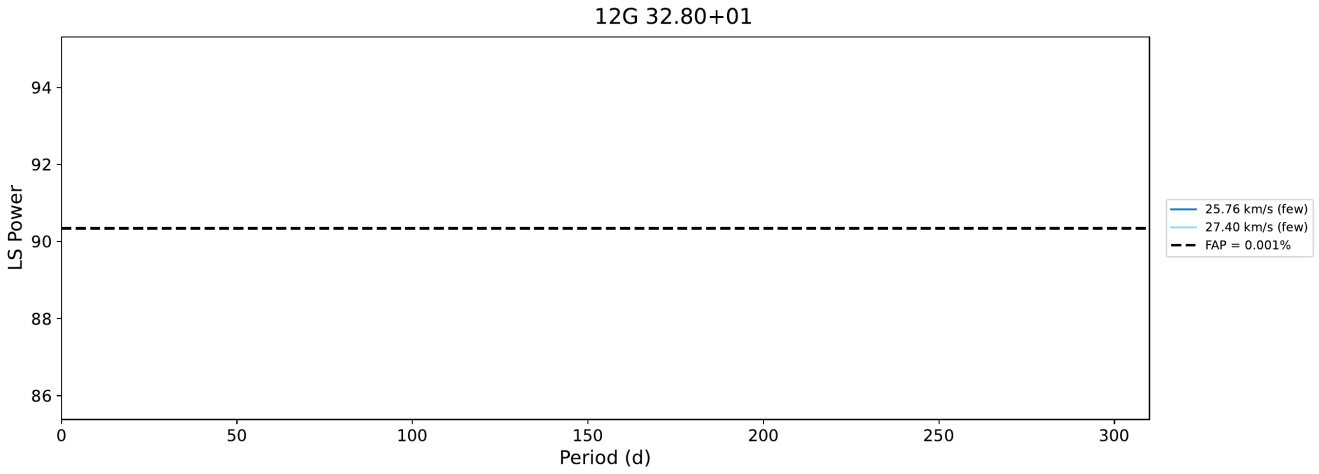


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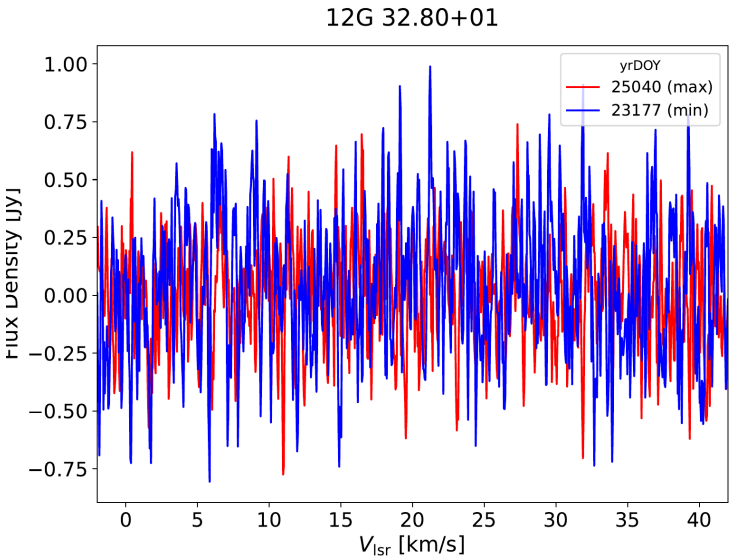
Light curve



Periodogram

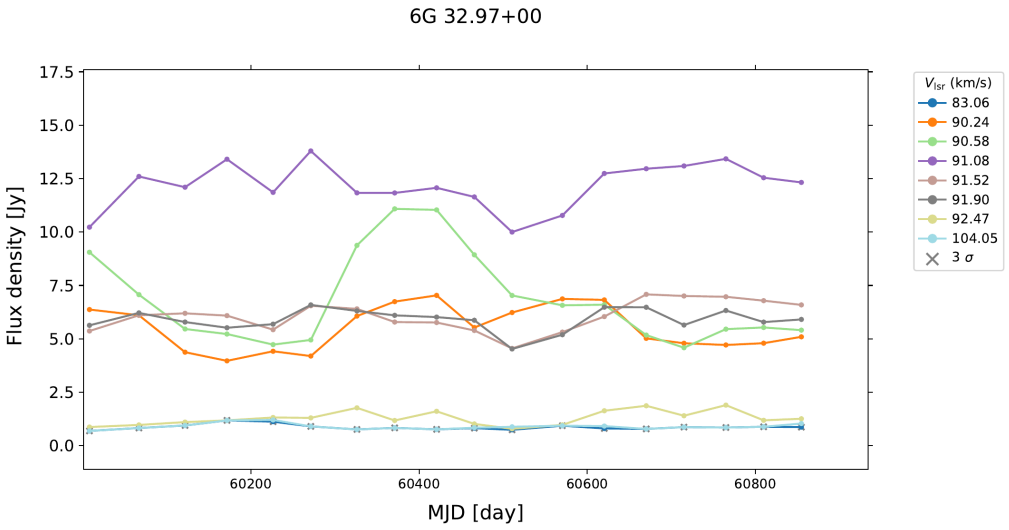


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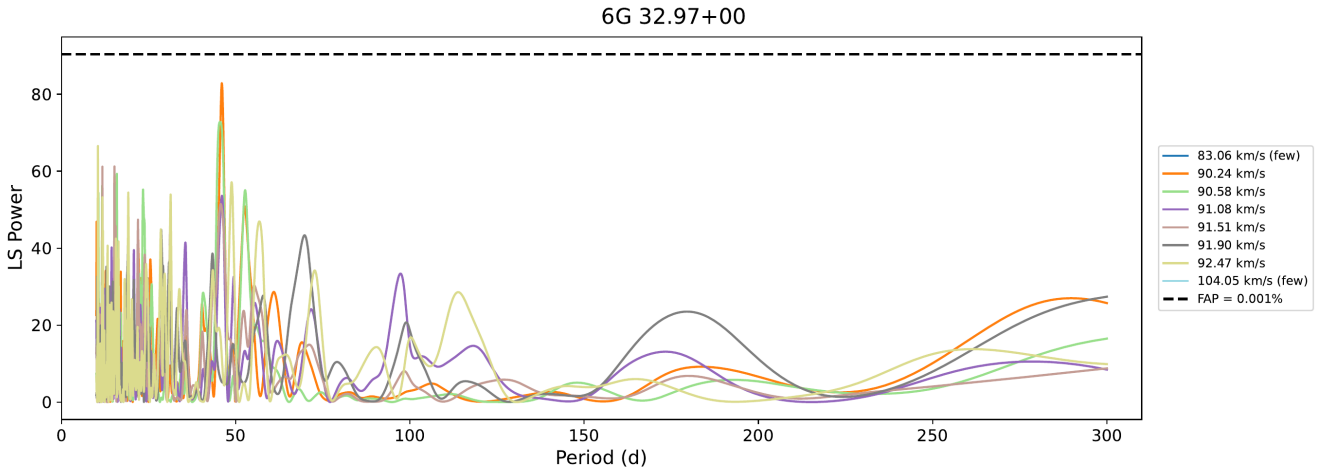


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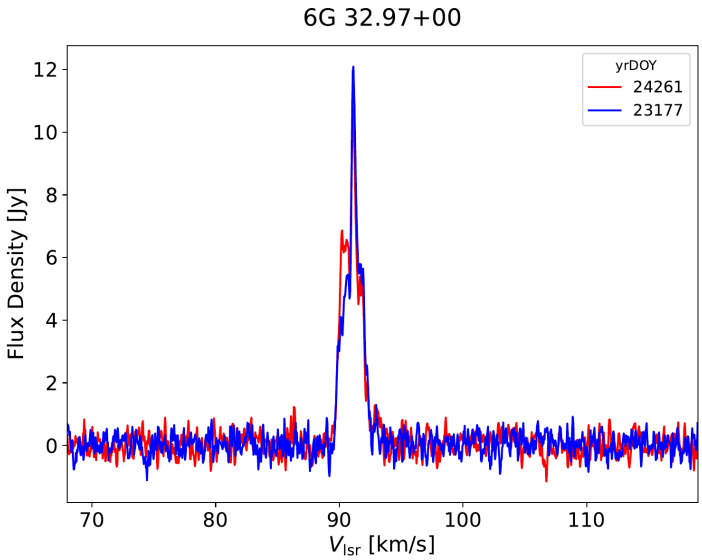
Light curve



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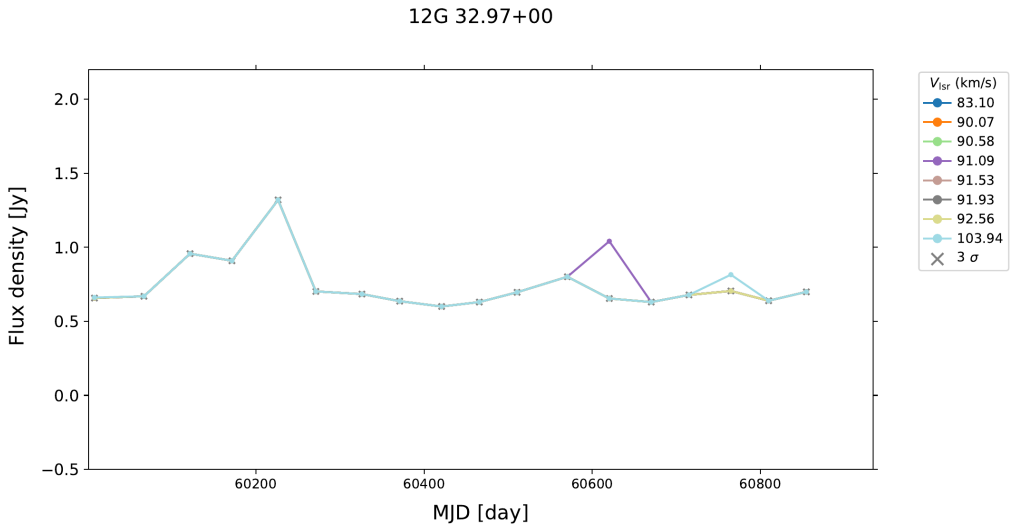


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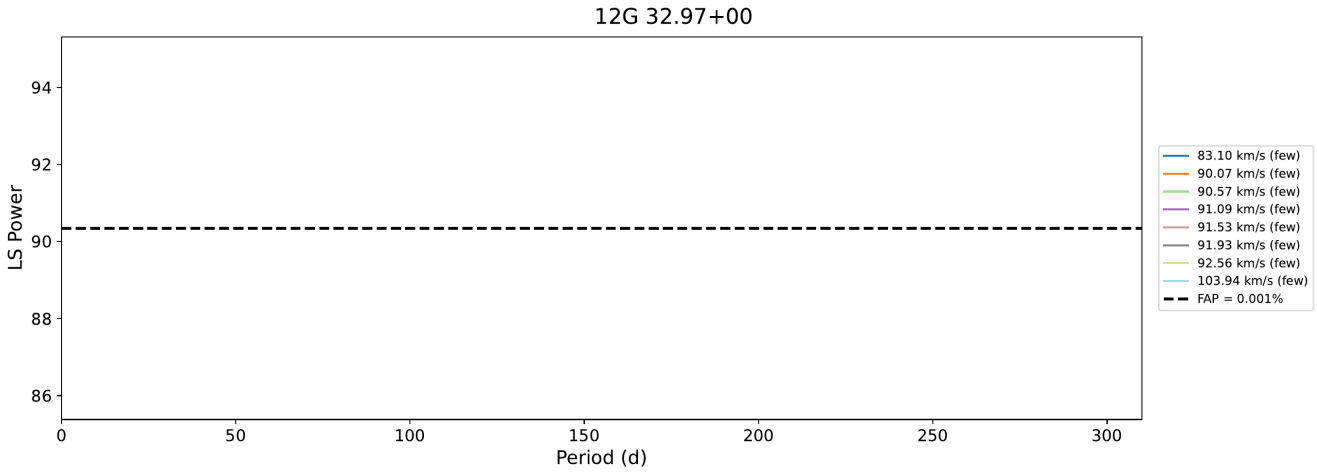


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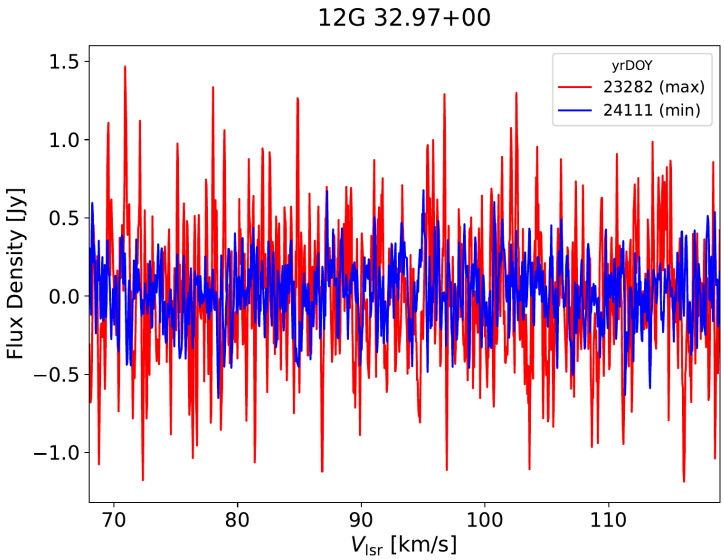
Light curve



Periodogram

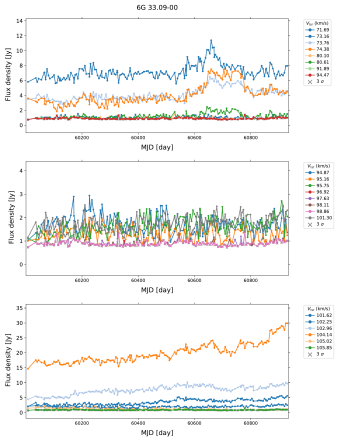


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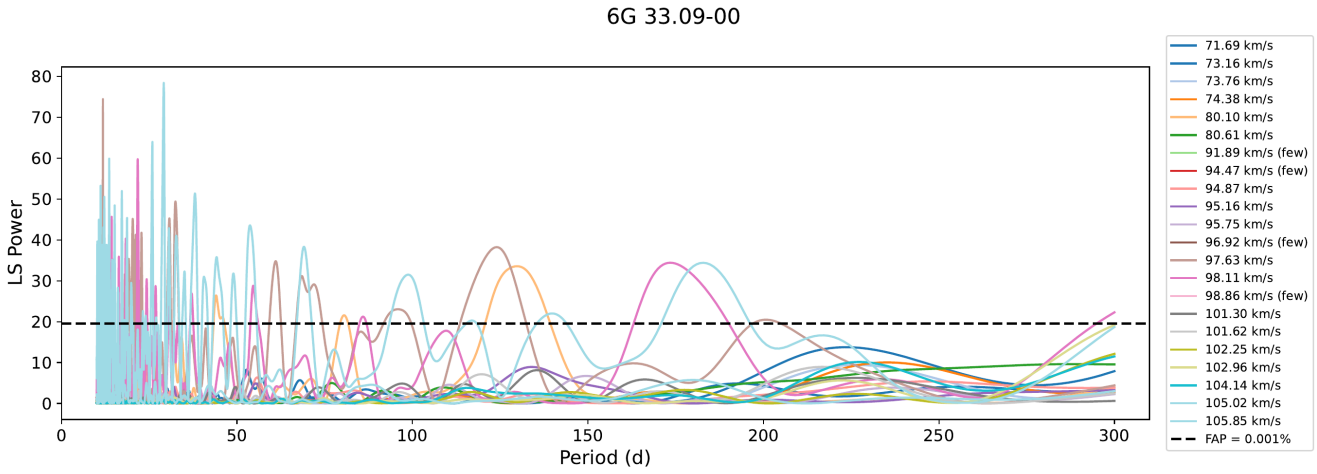


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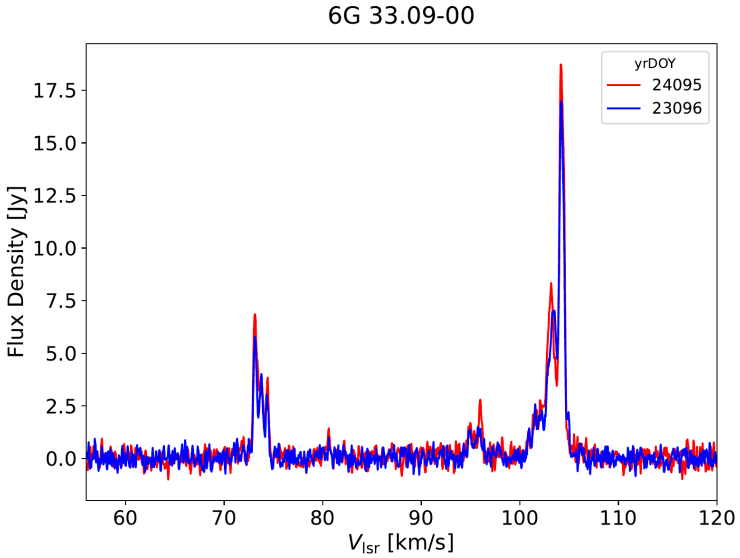
Light curve



Periodogram

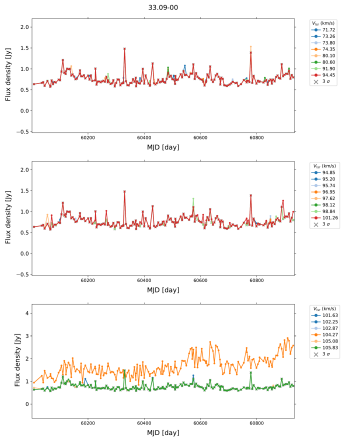


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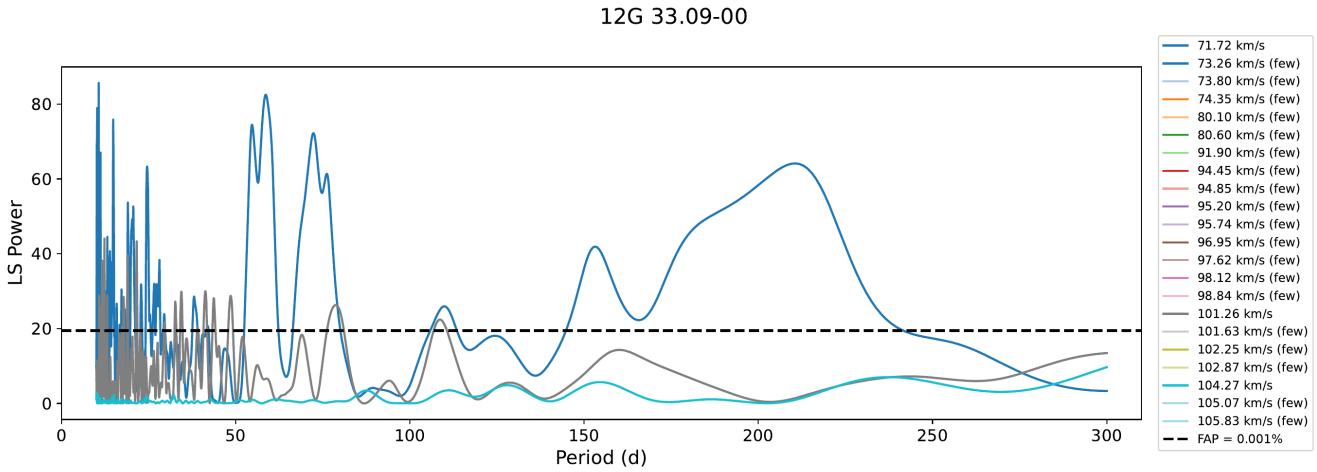


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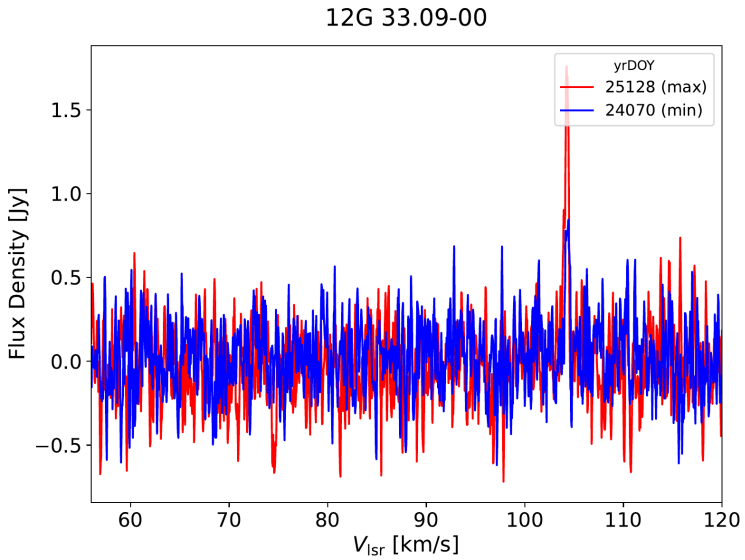
Light curve



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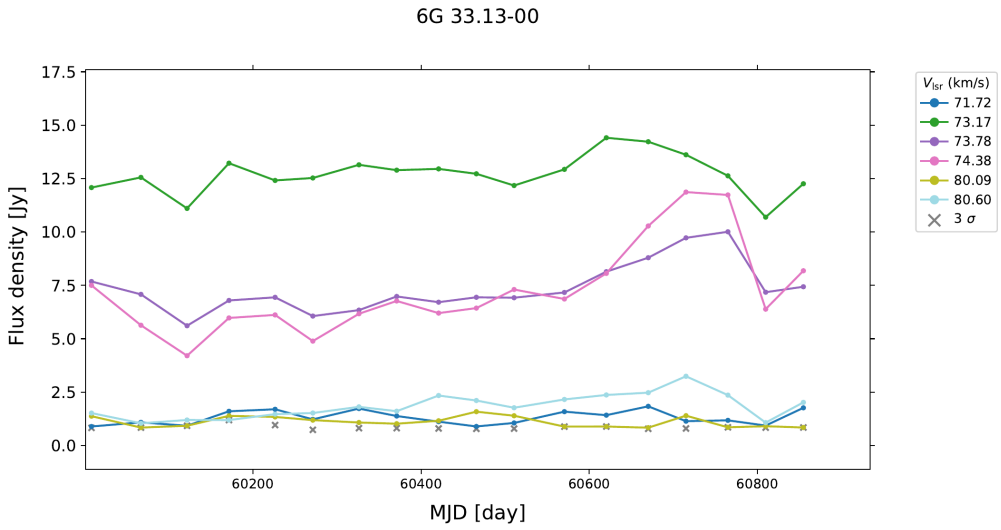


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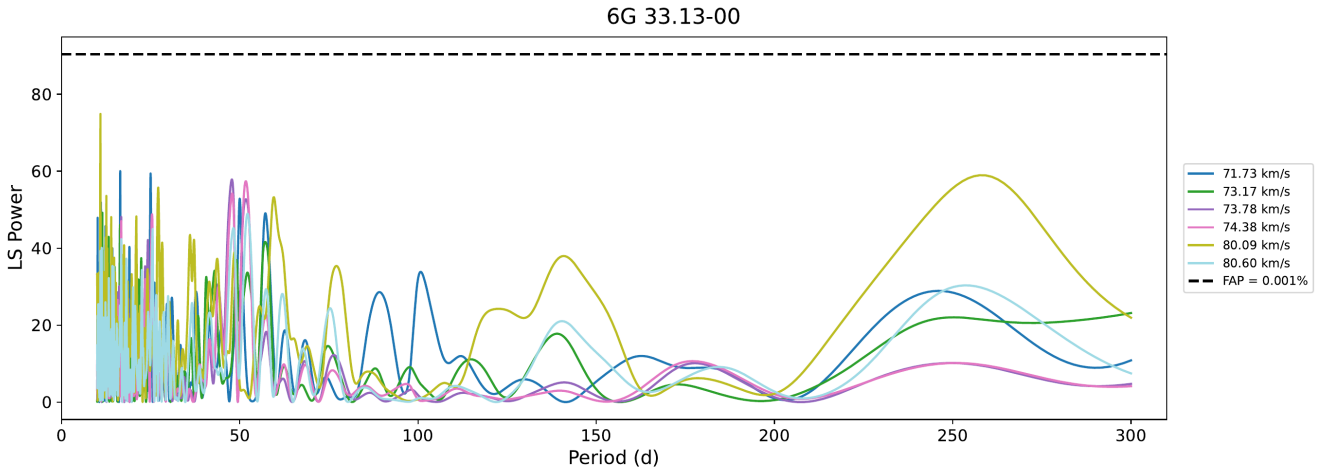


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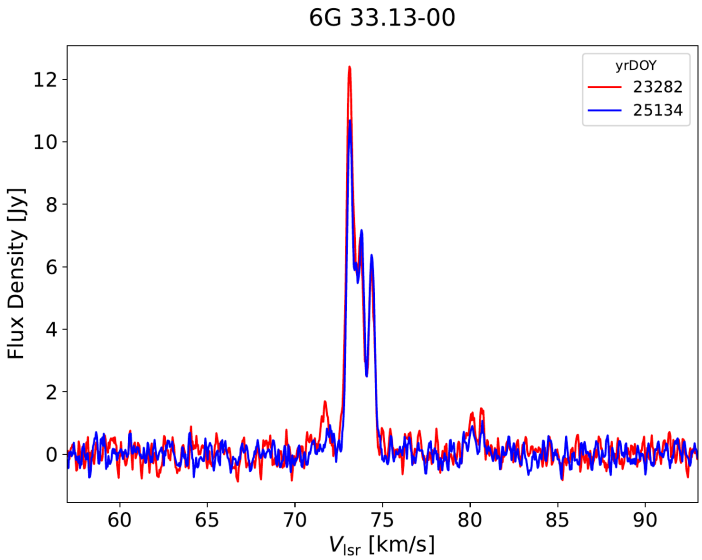
Light curve



Periodogram

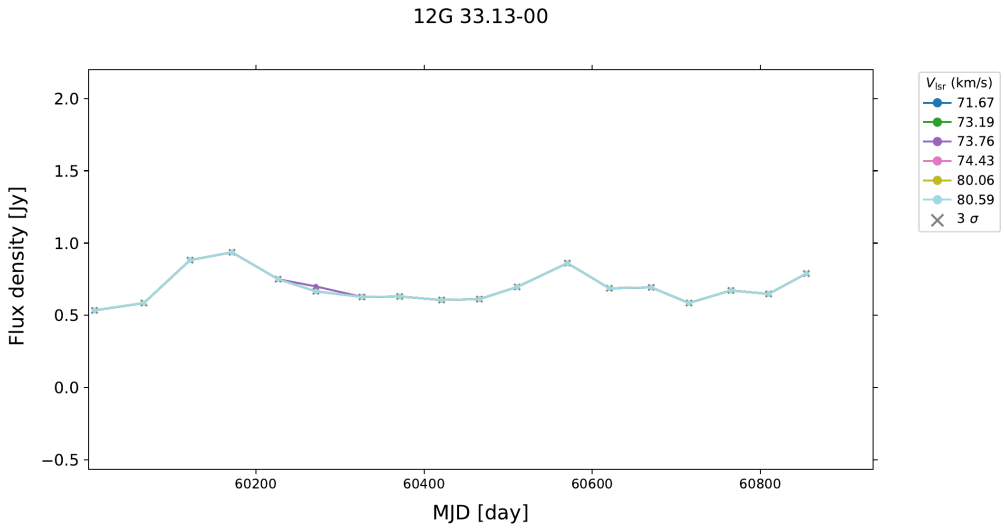


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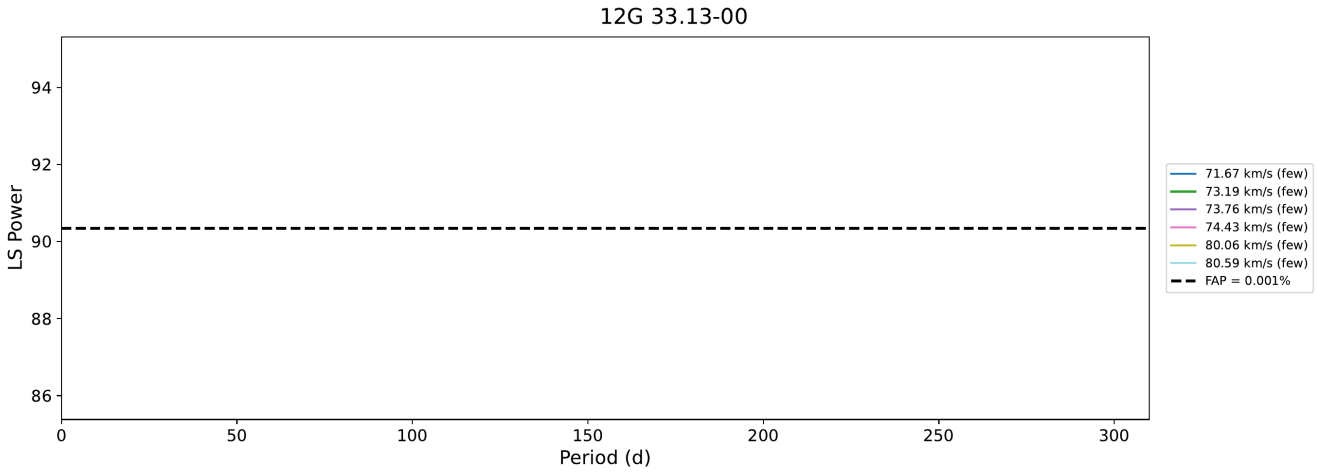


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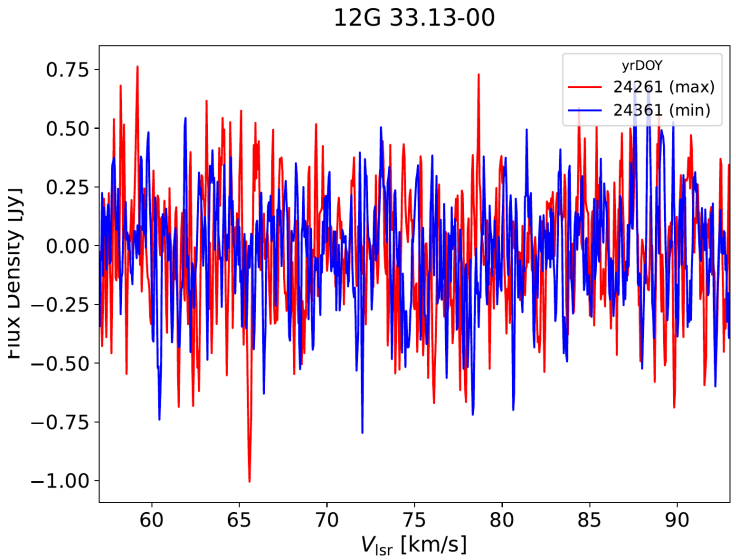
Light curve



Periodogram

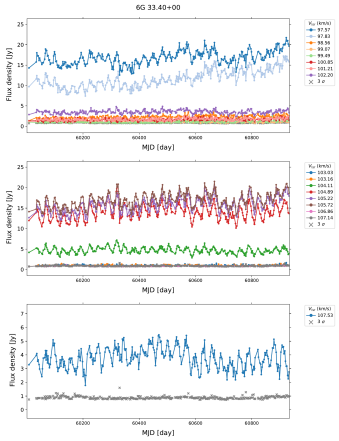


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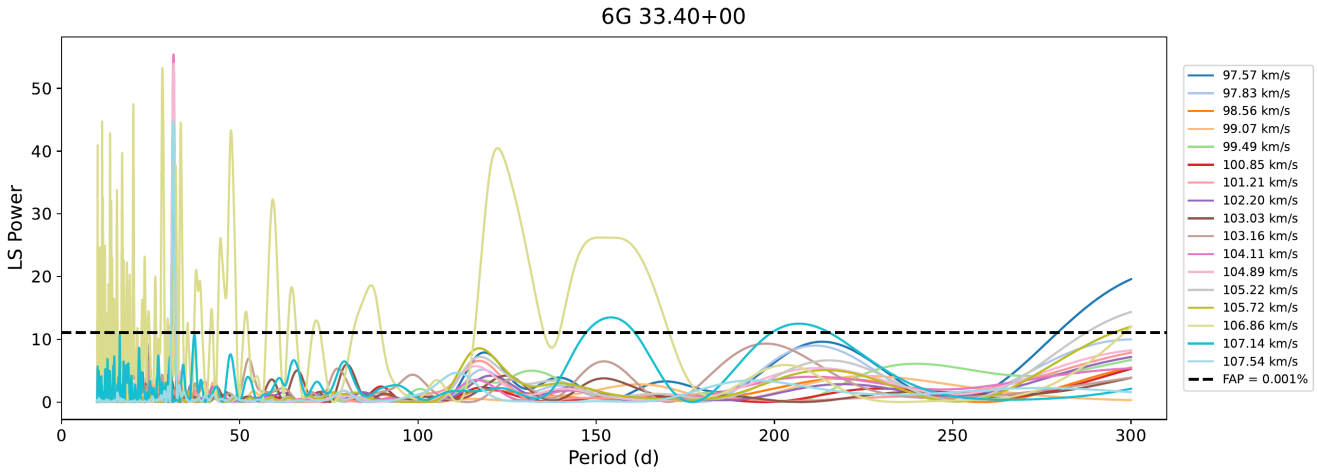


6G 33.40+00

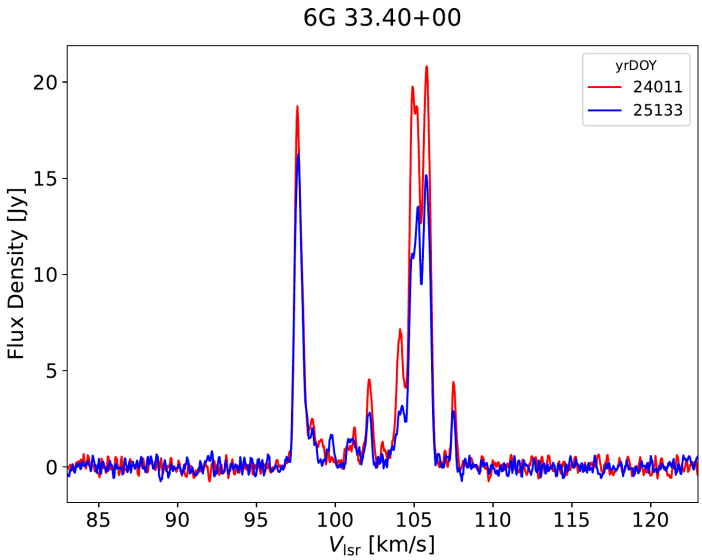
Light curve



Periodogram

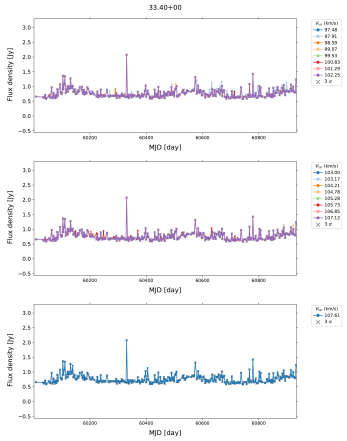


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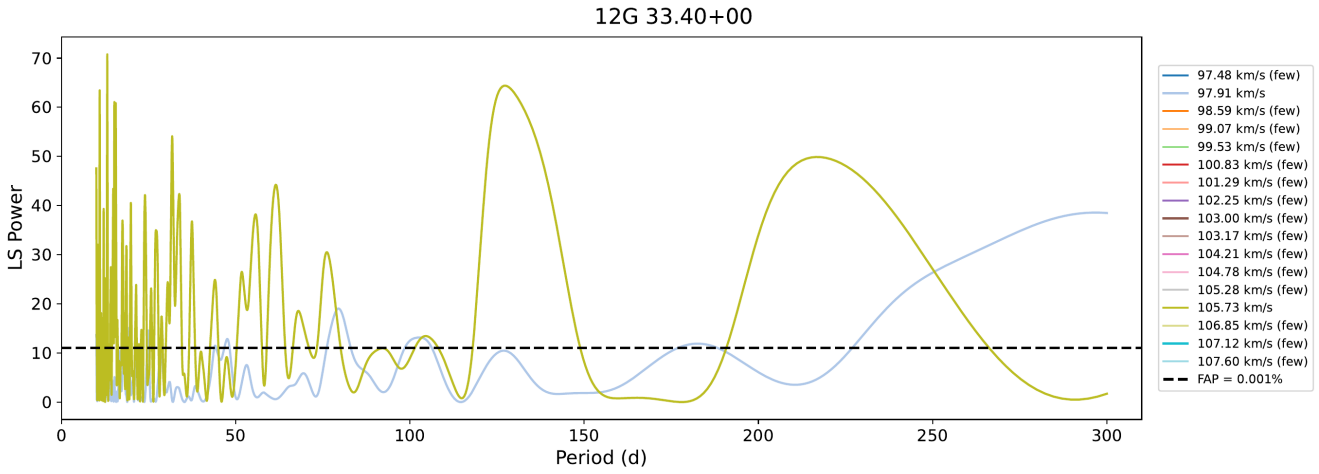


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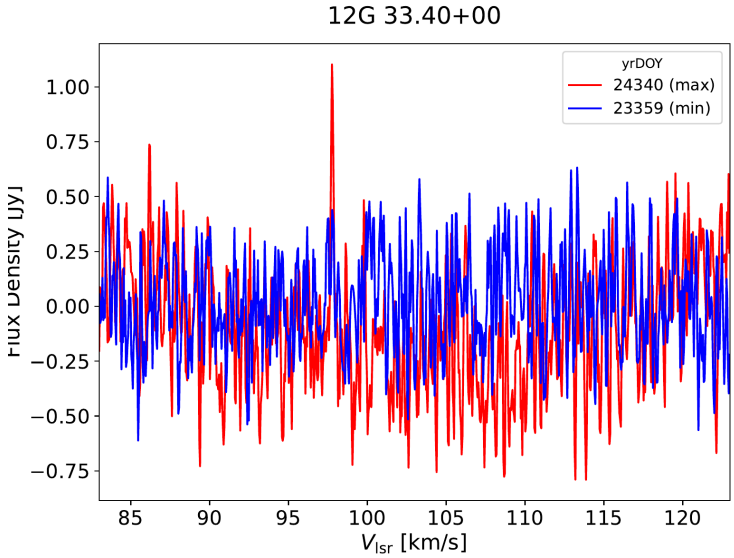
Light curve



Periodogram

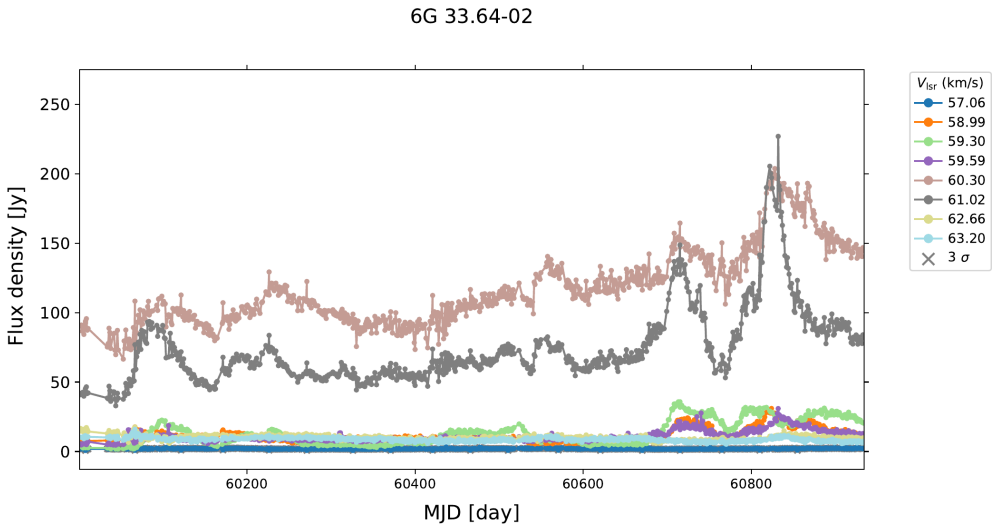


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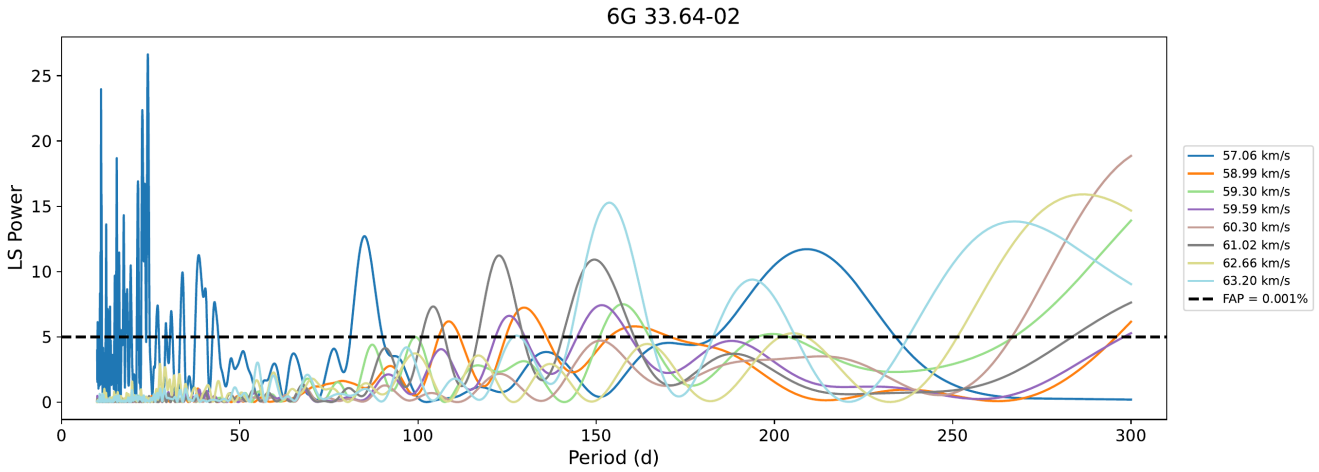


6G 33.64-02

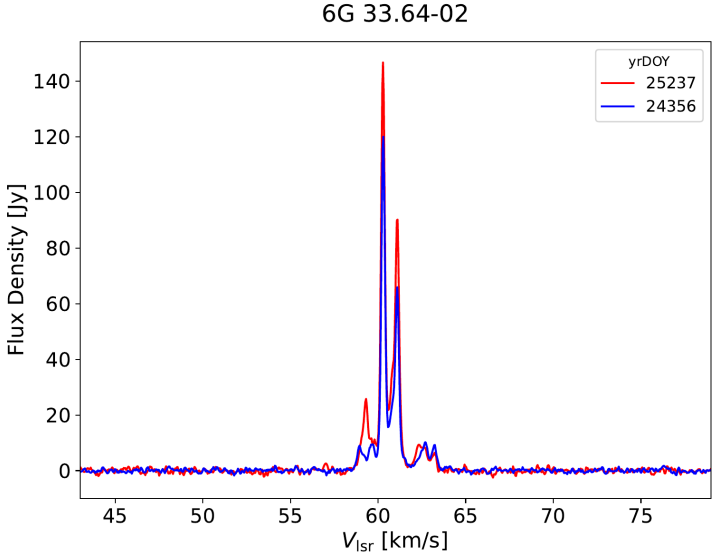
Light curve



Periodogram

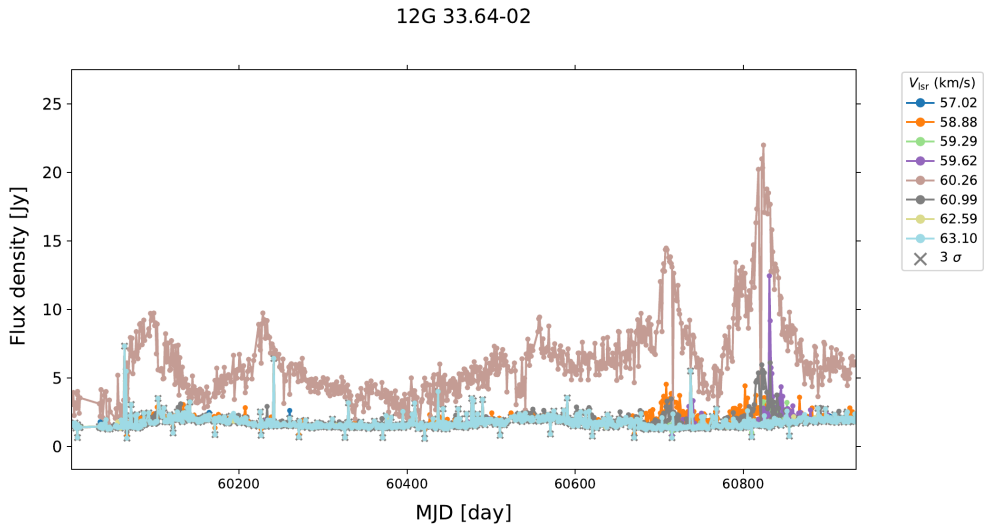


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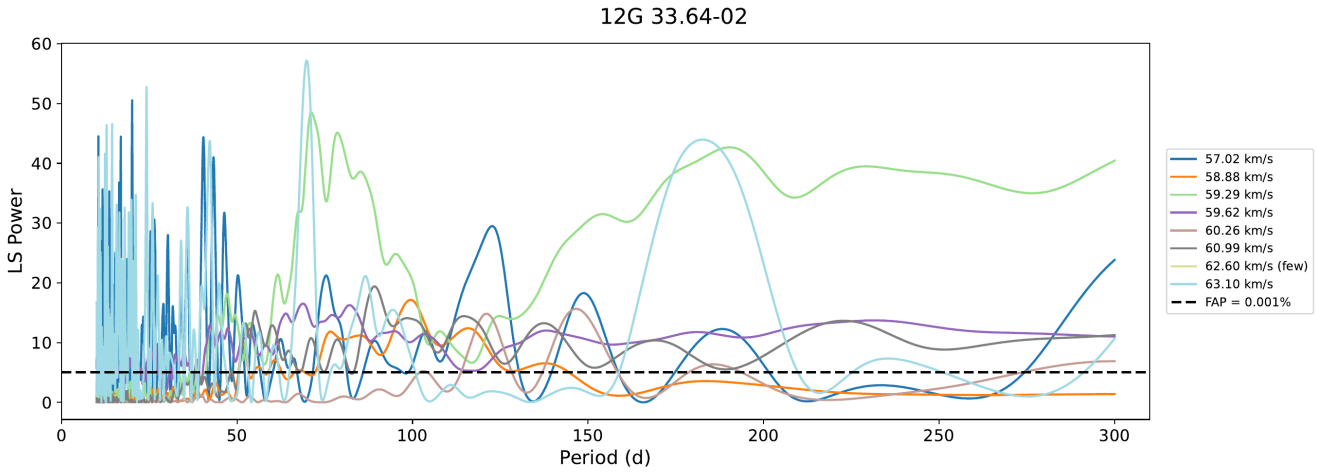


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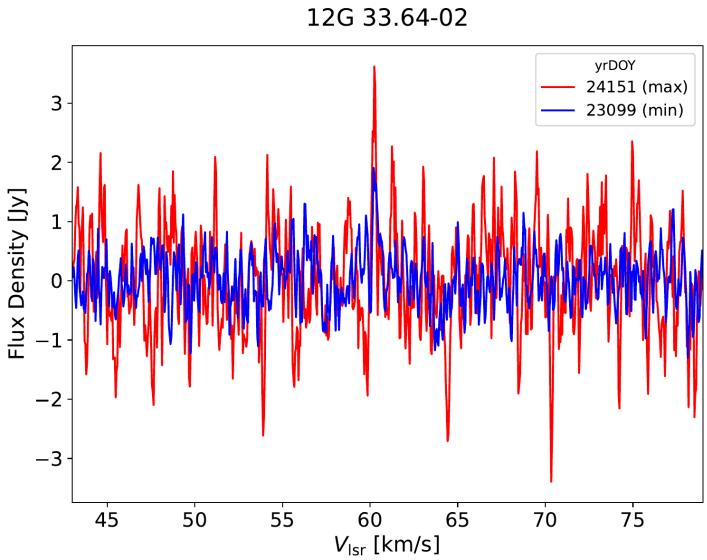
Light curve



Periodogram

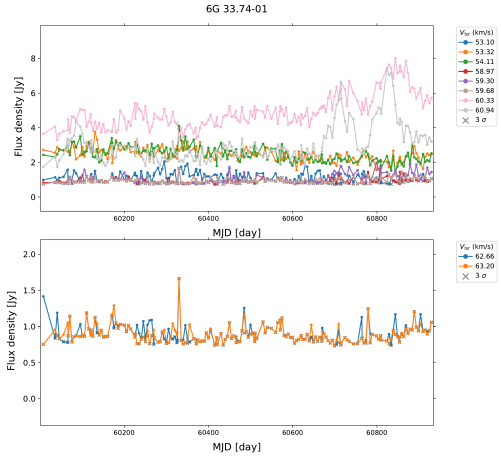


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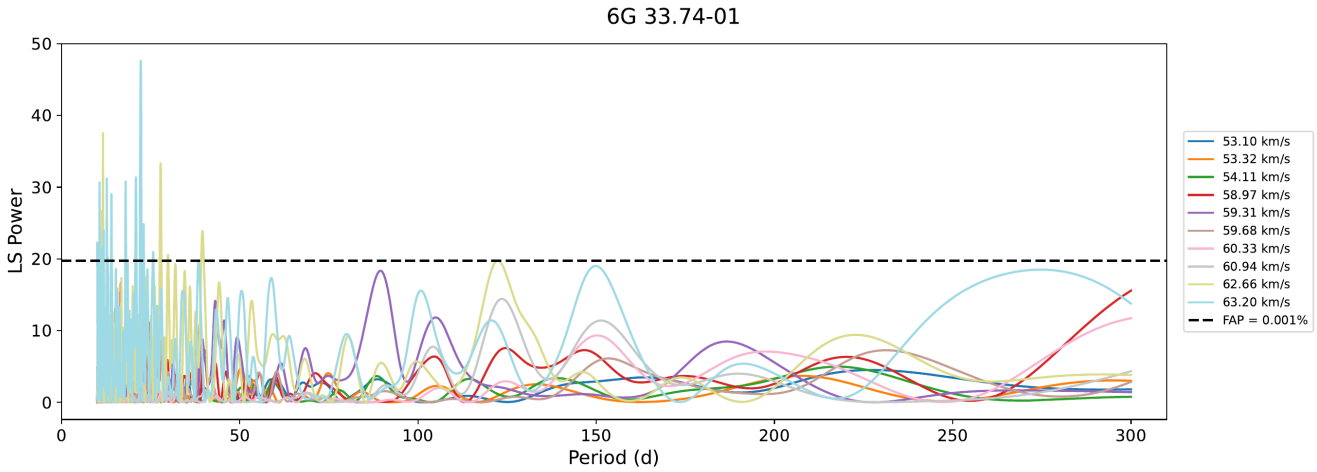


6G 33.74-01

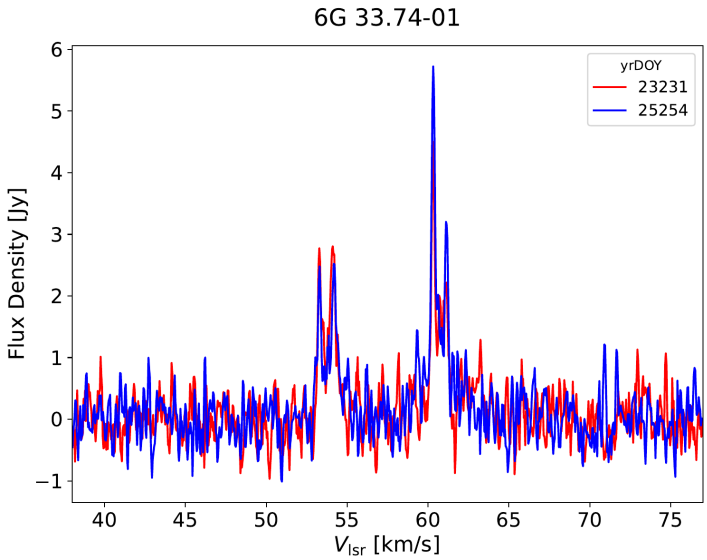
Light curve



Periodogram

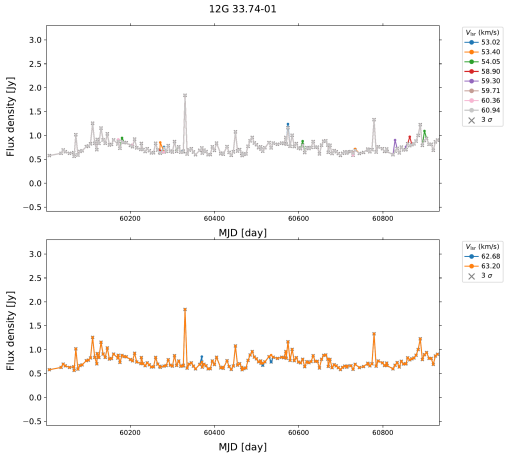


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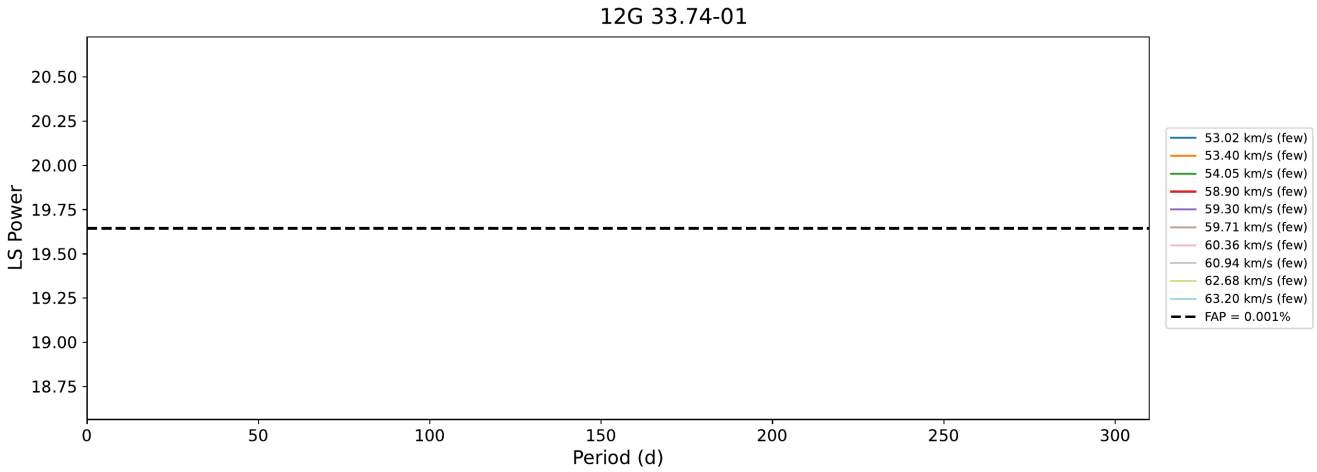


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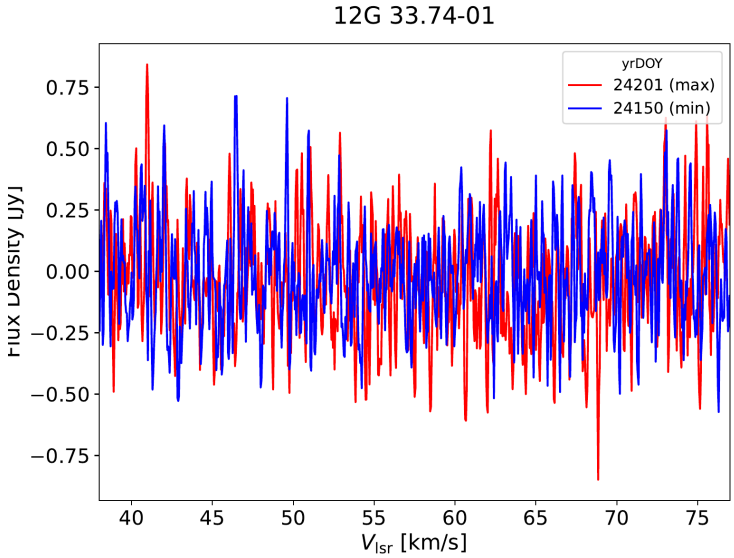
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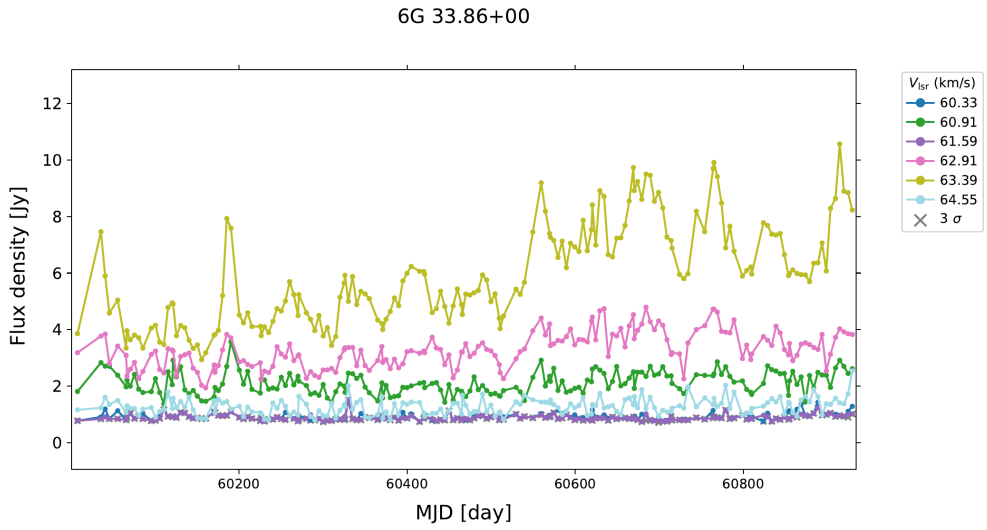


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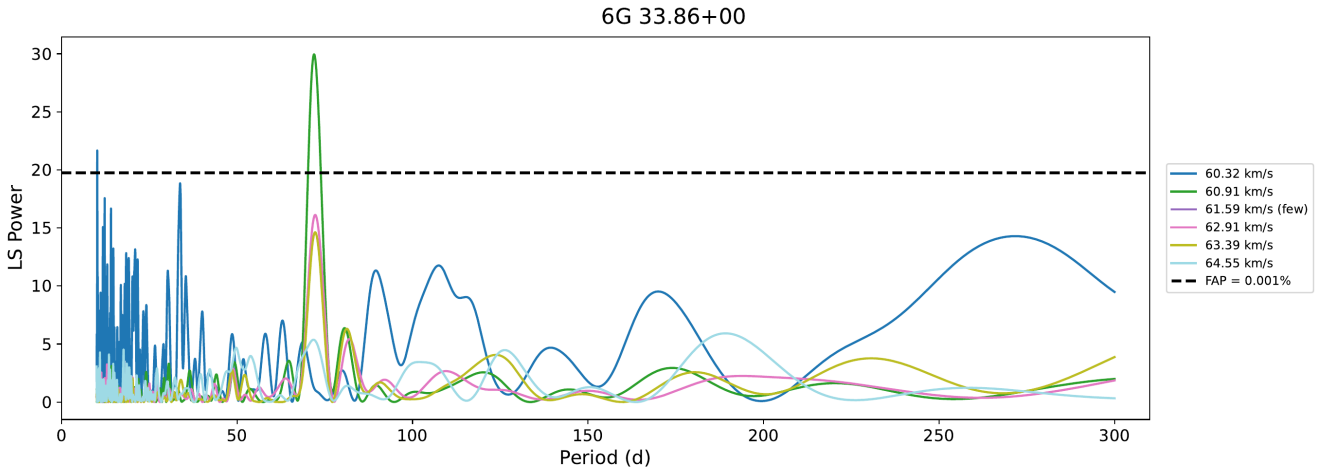


6G 33.86+00

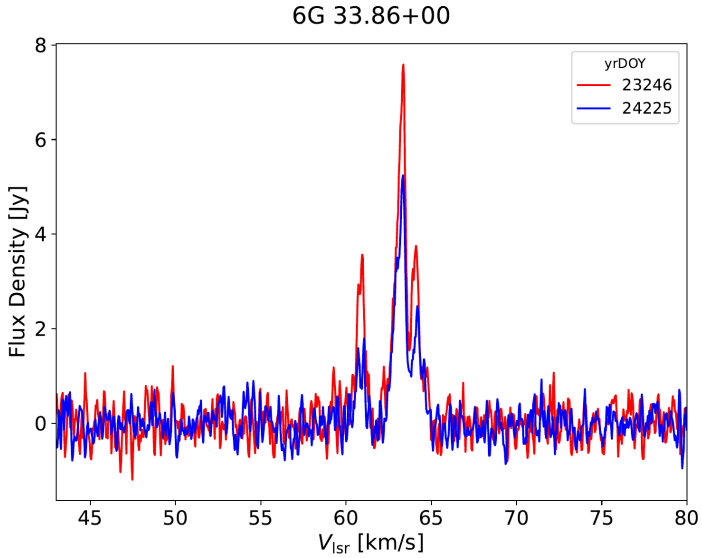
Light curve



Periodogram

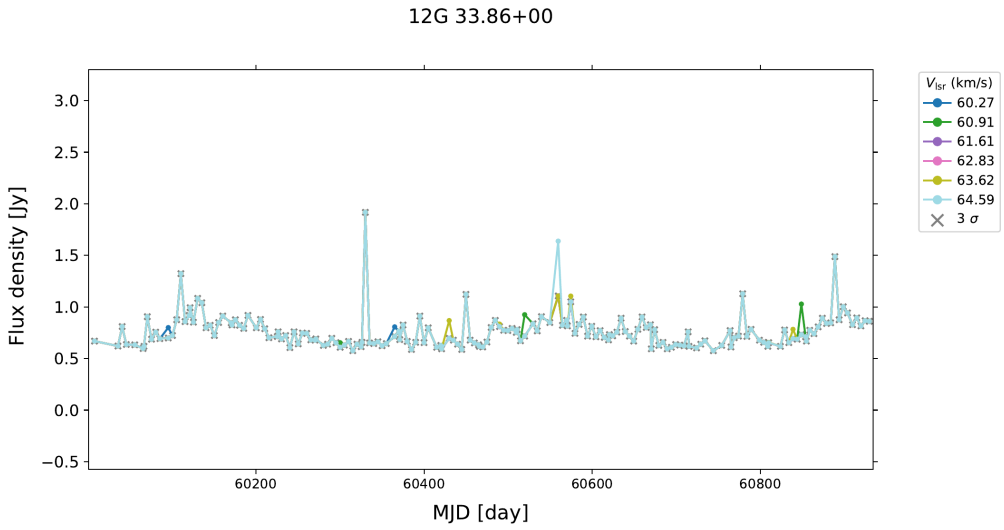


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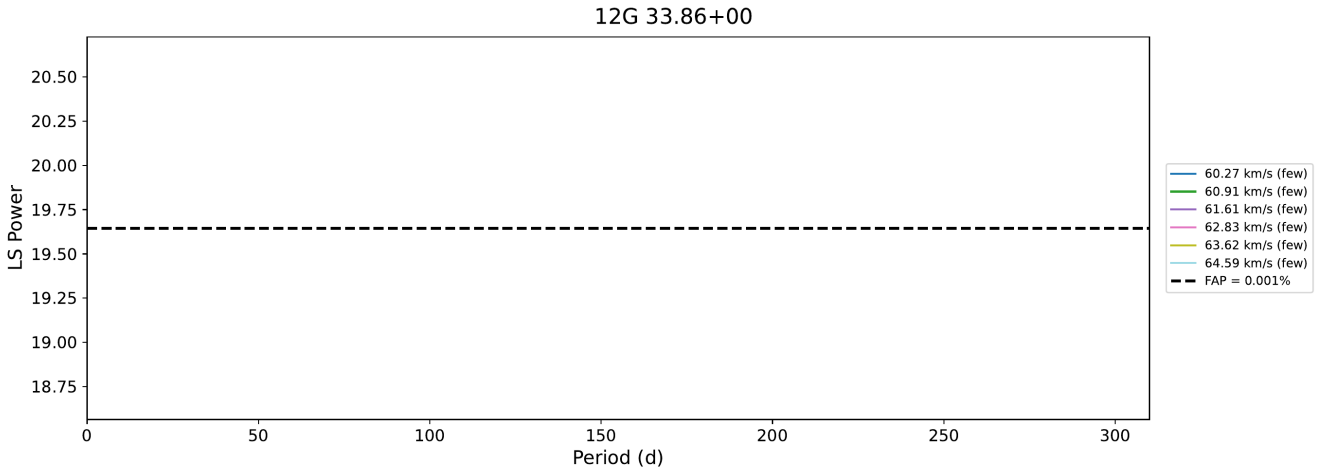


12G 33.86+00

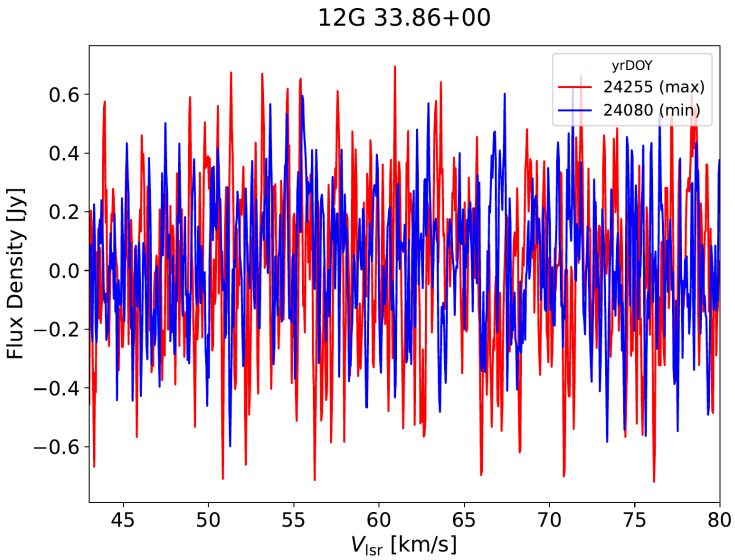
Light curve



Periodogram

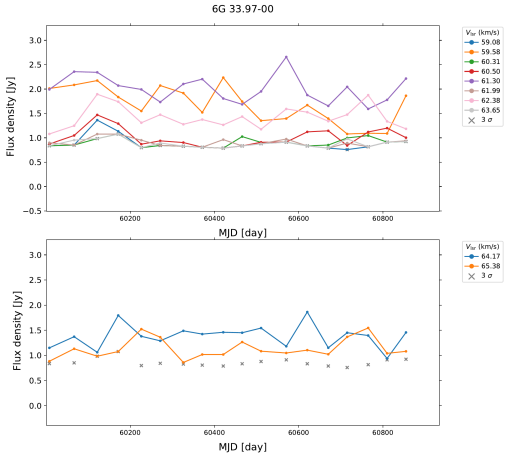


Spectrum

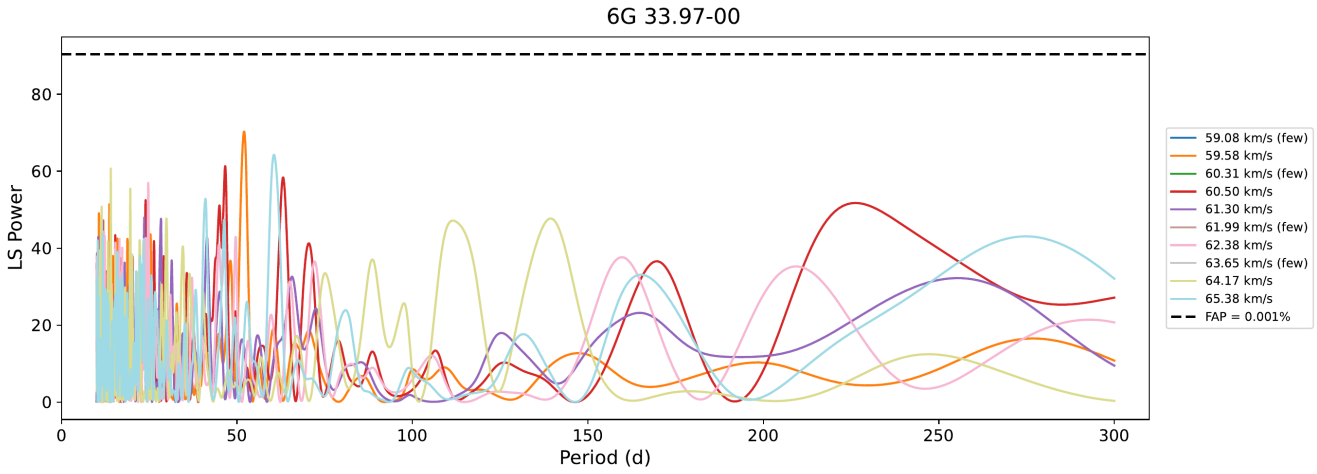


6G 33.97-00

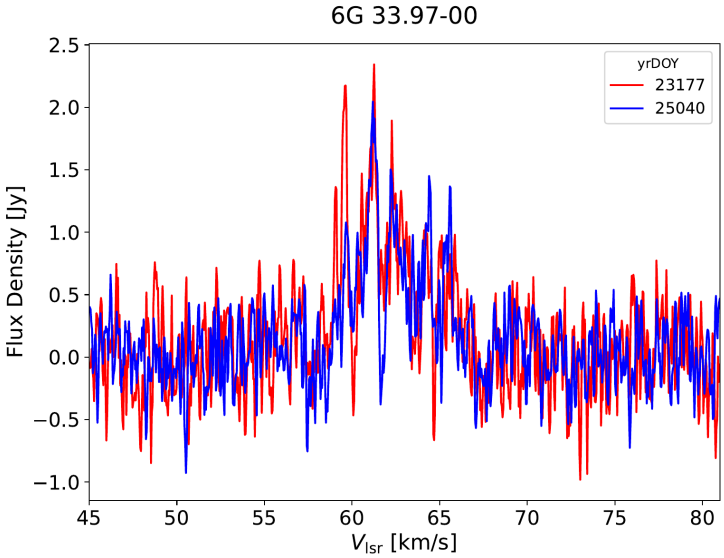
Light curve



Periodogram

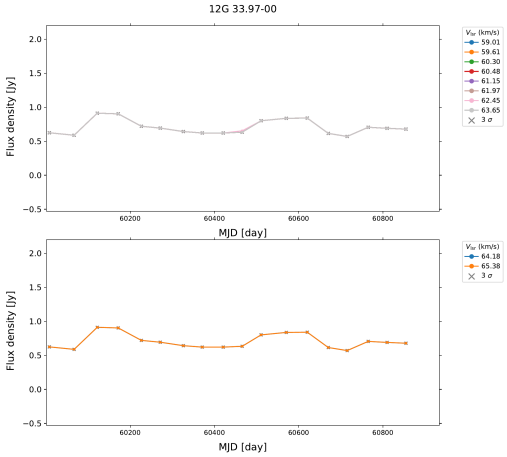


Spectrum

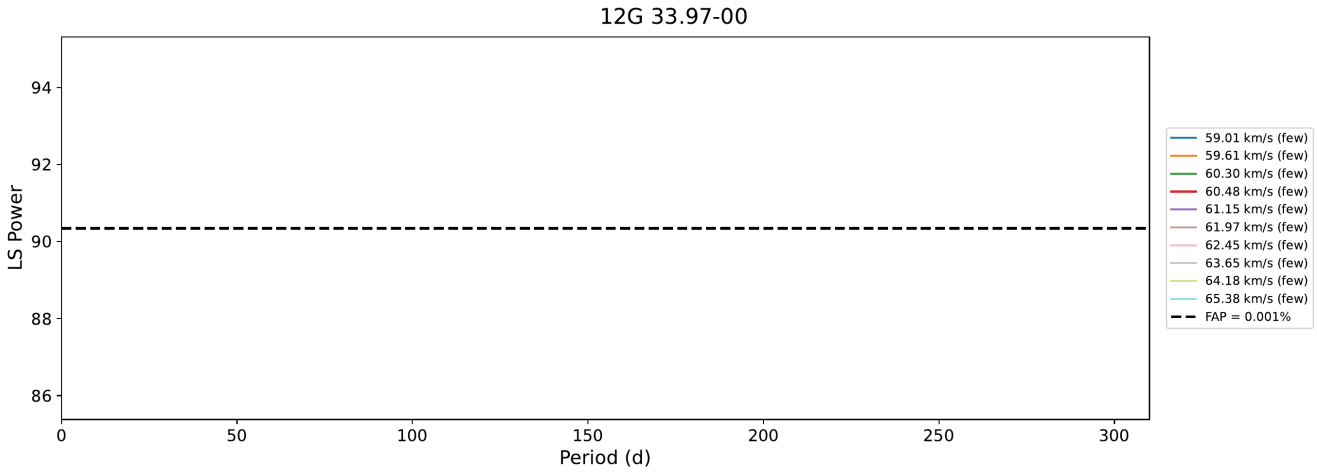


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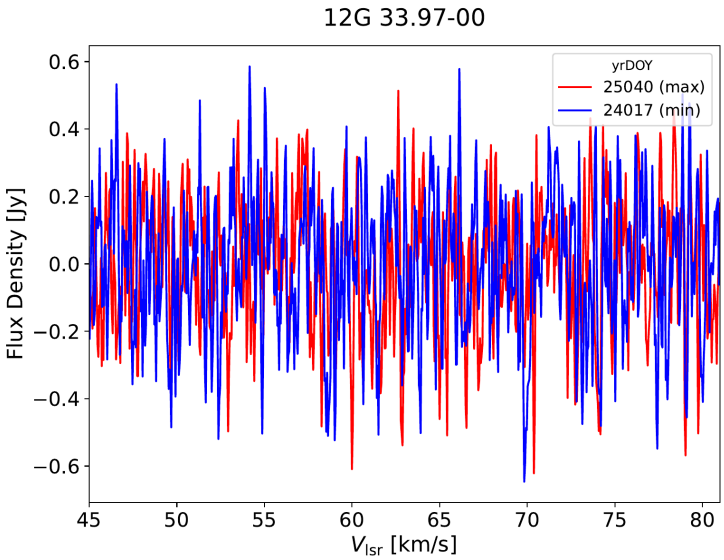
Light curve



Periodogram

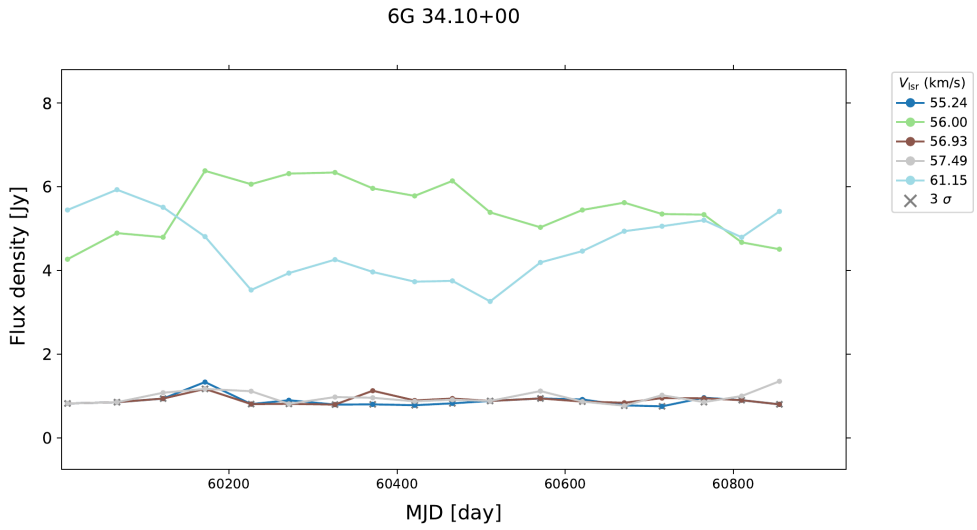


Spectrum

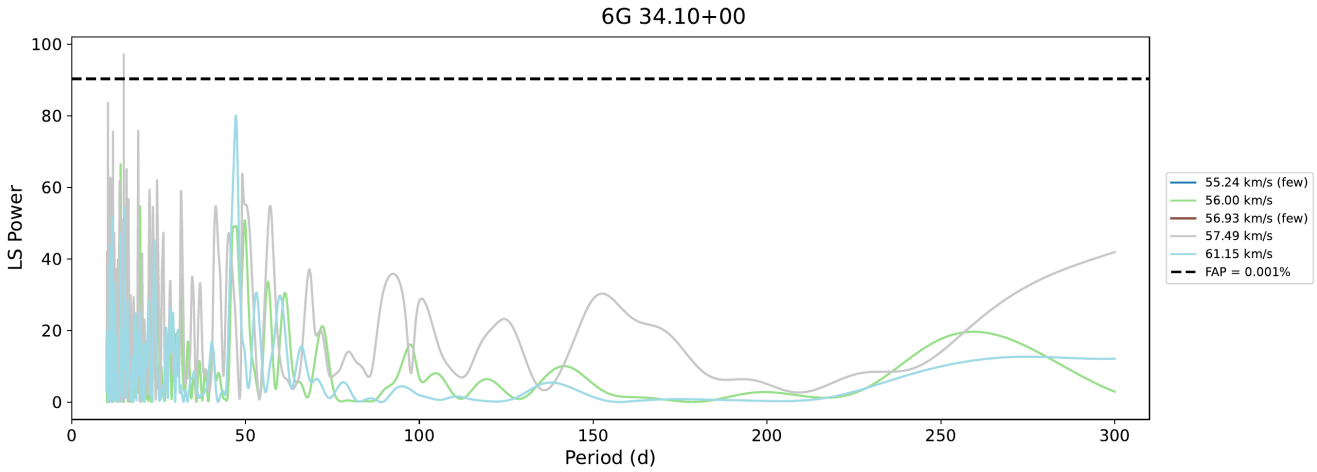


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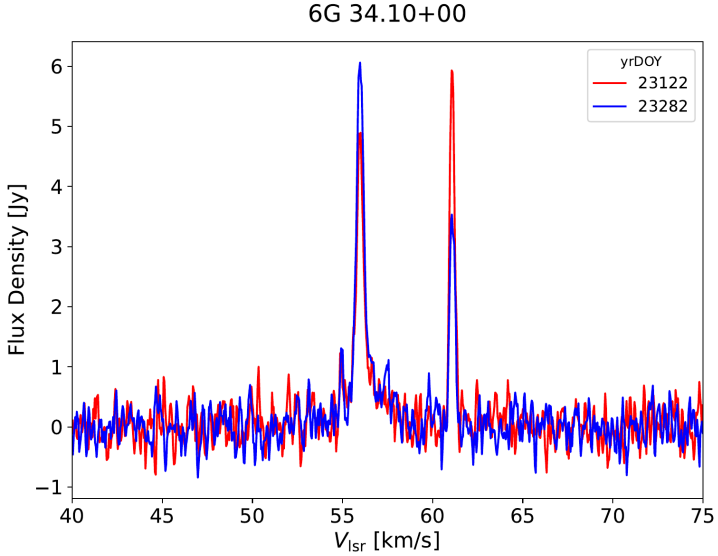
Light curve



Periodogram

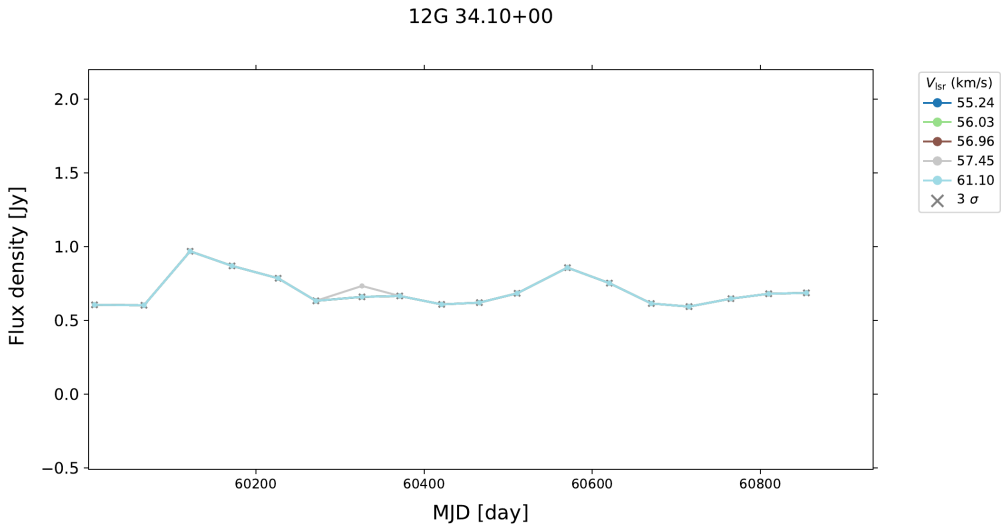


Spectrum

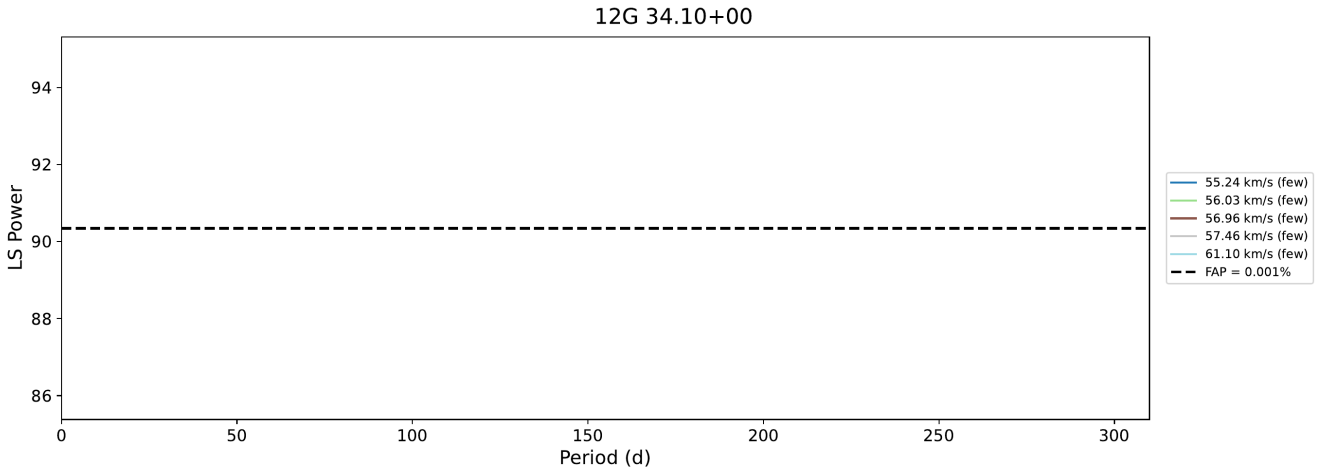


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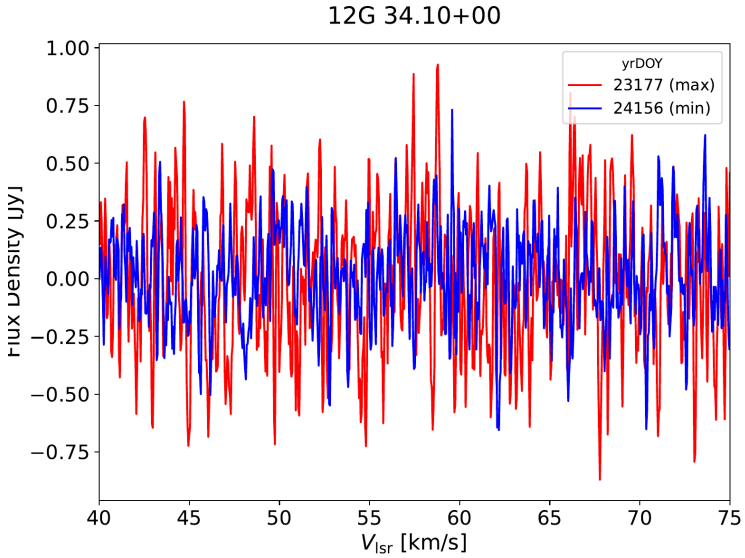
Light curve



Periodogram

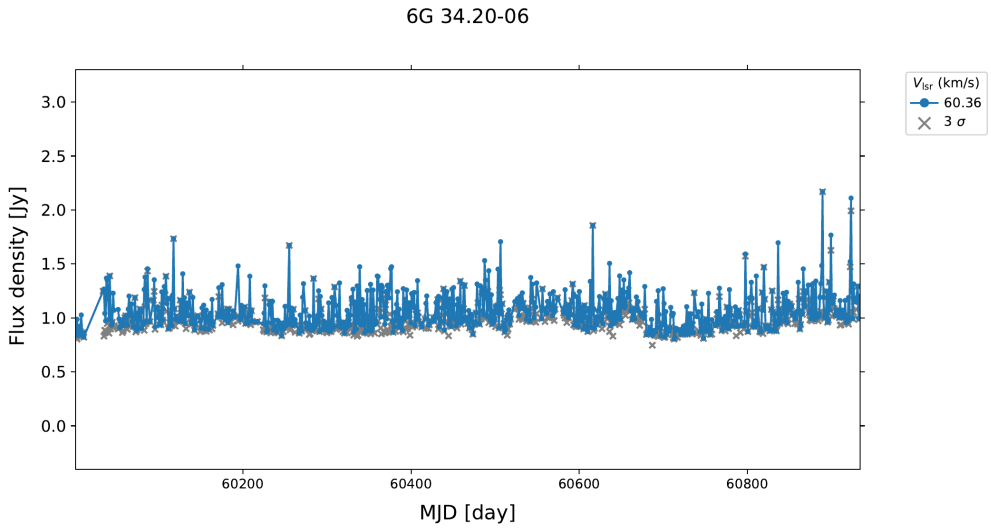


Spectrum

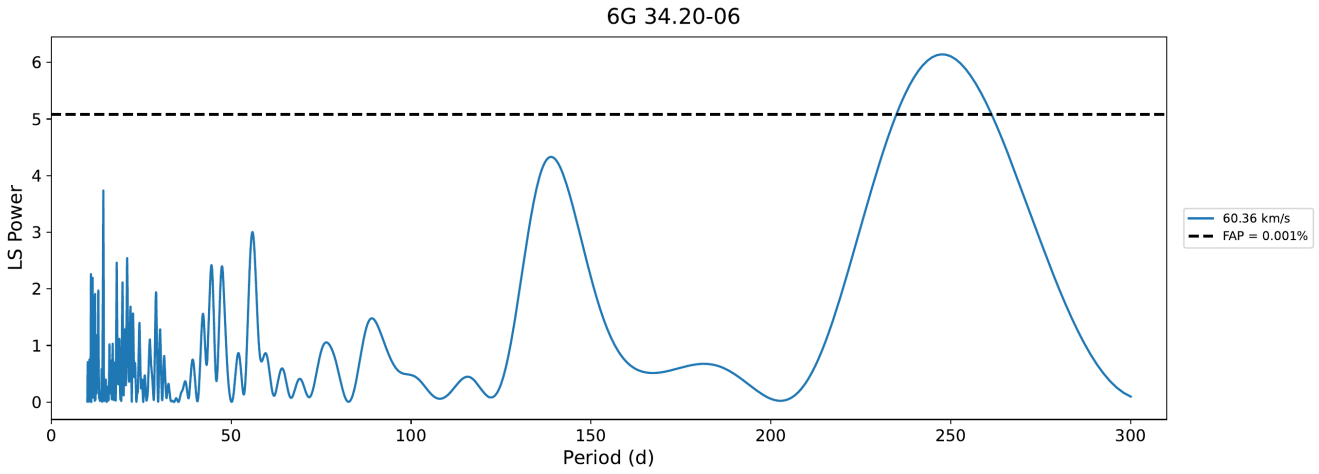


6G 34.20-06

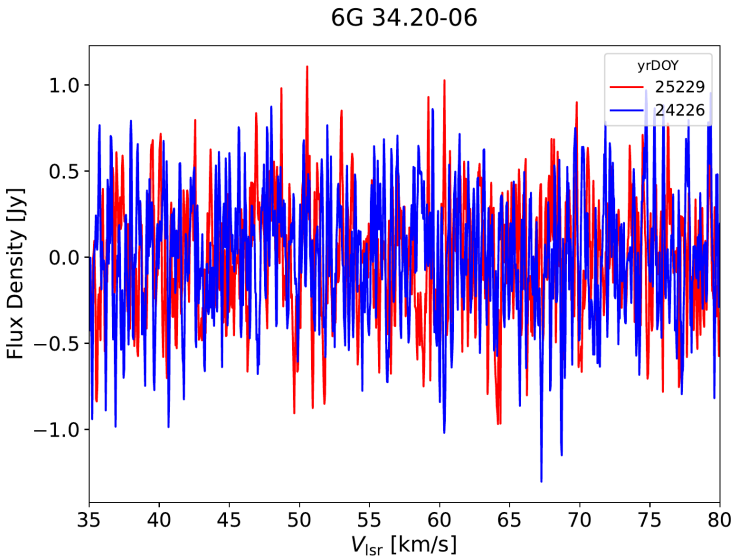
Light curve



Periodogram

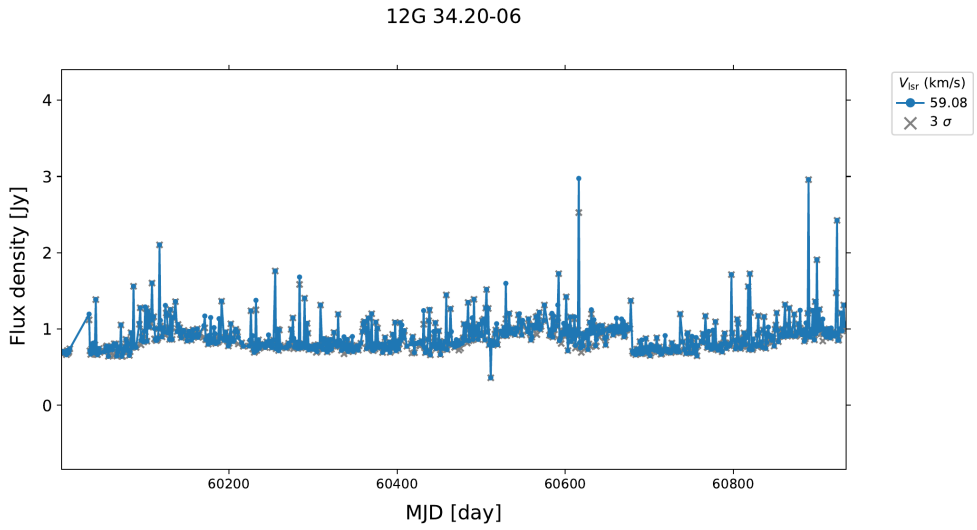


Spectrum

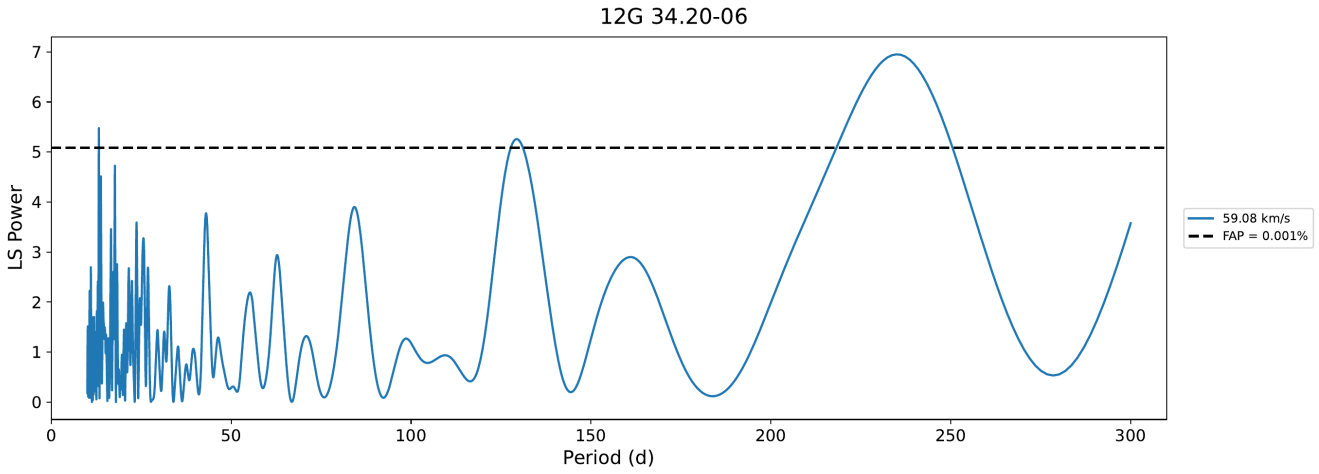


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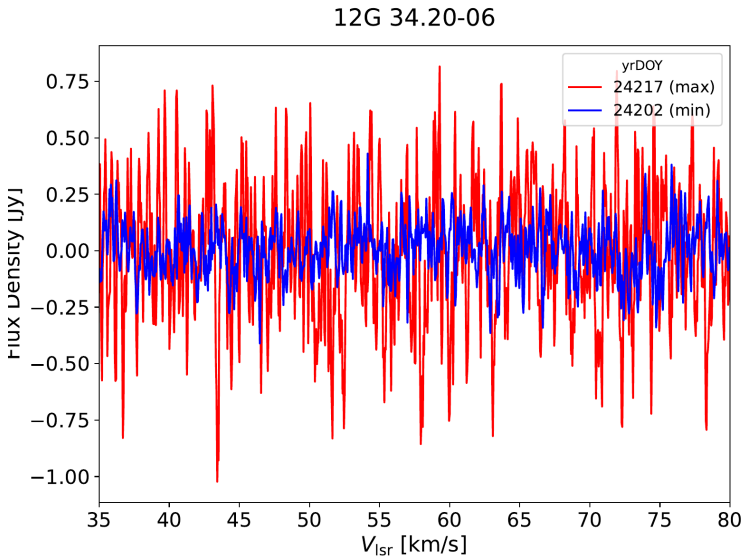
Light curve



Periodogram

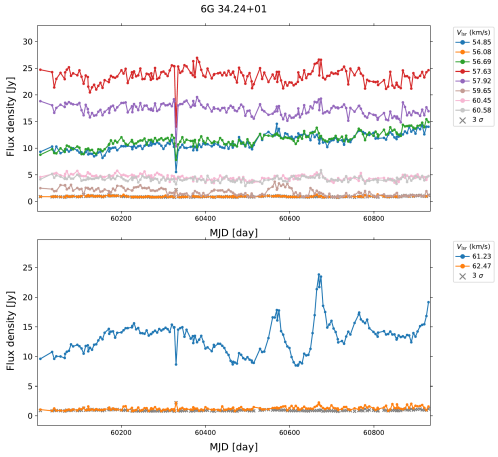


Spectrum

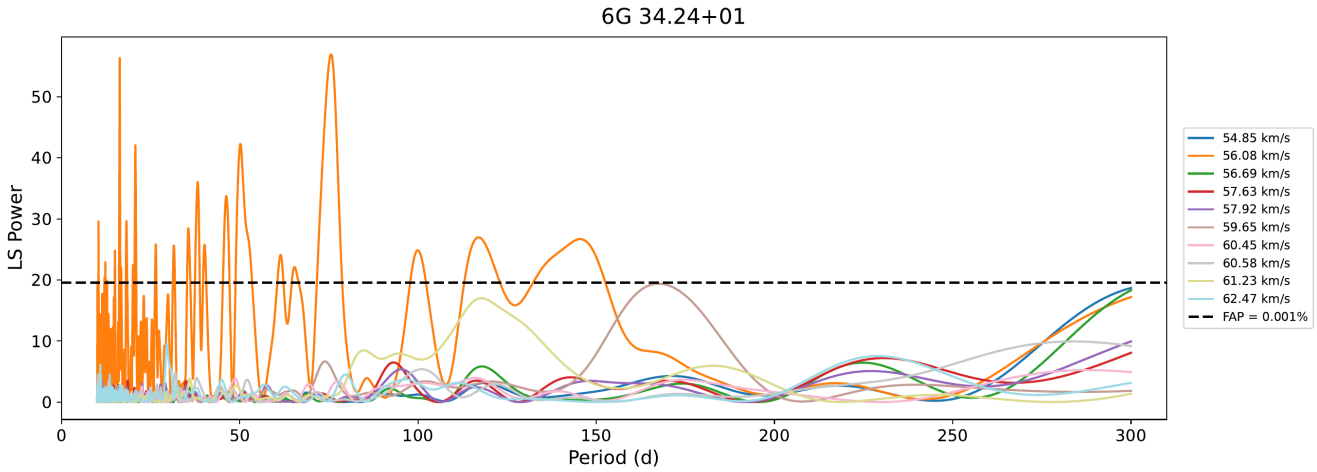


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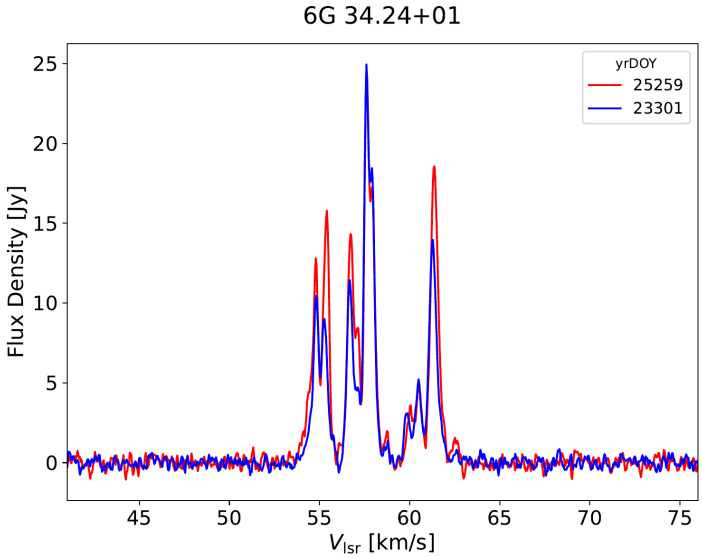
Light curve



Periodogram

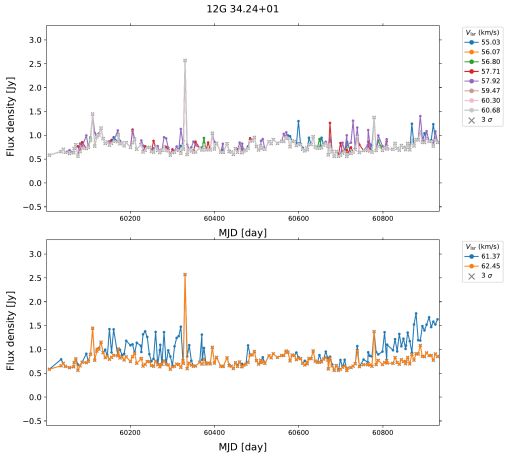


Spectrum

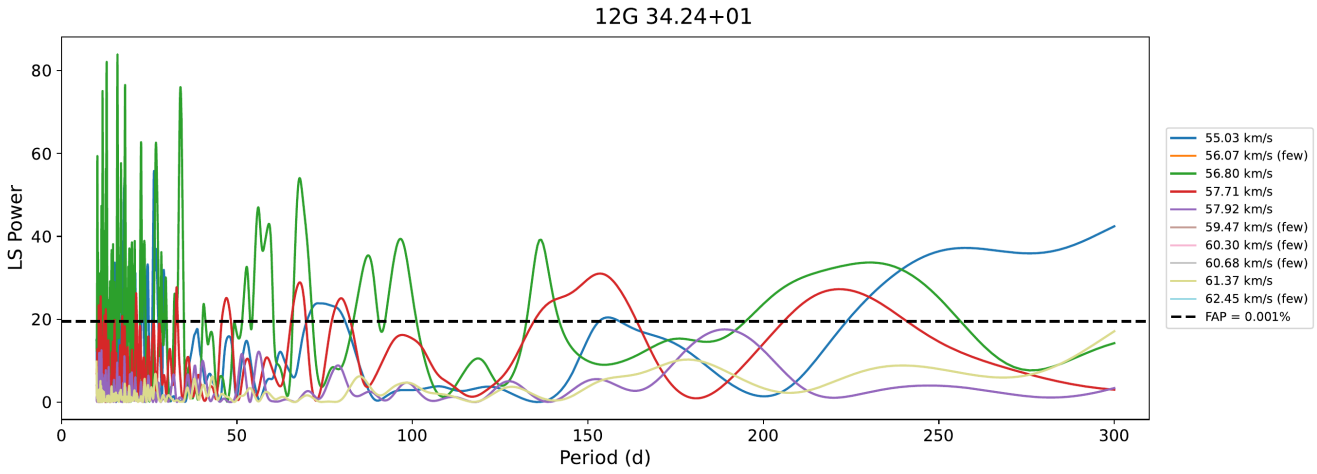


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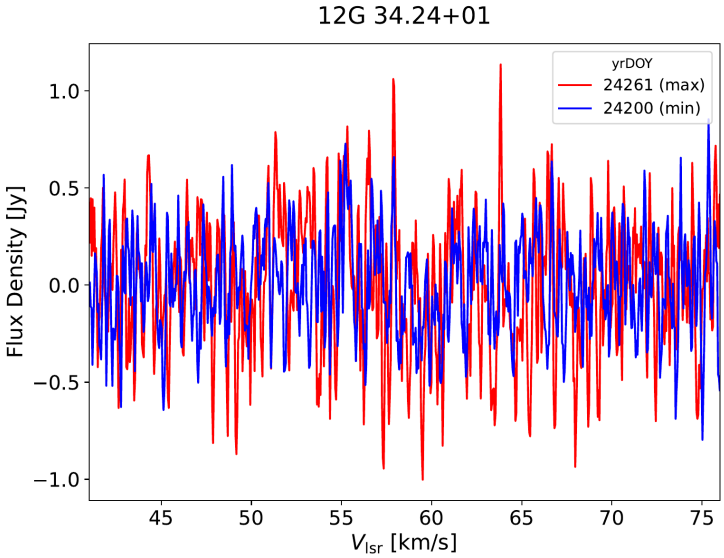
Light curve



Periodogram

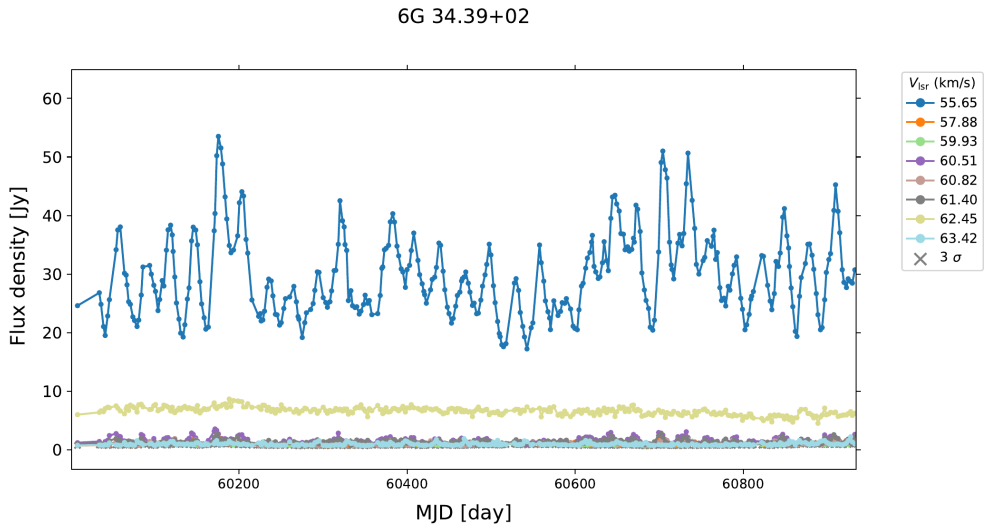


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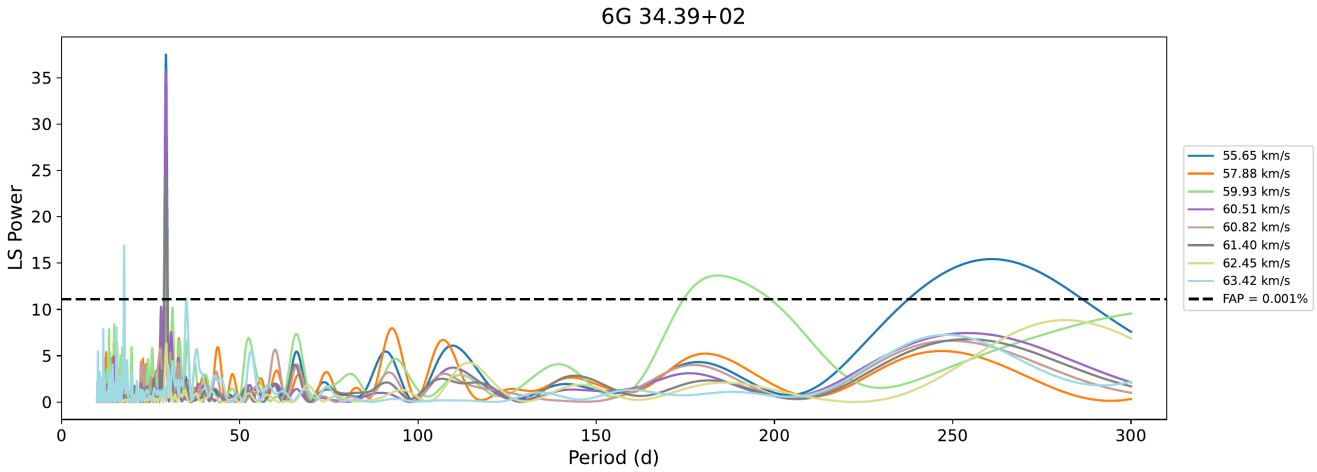


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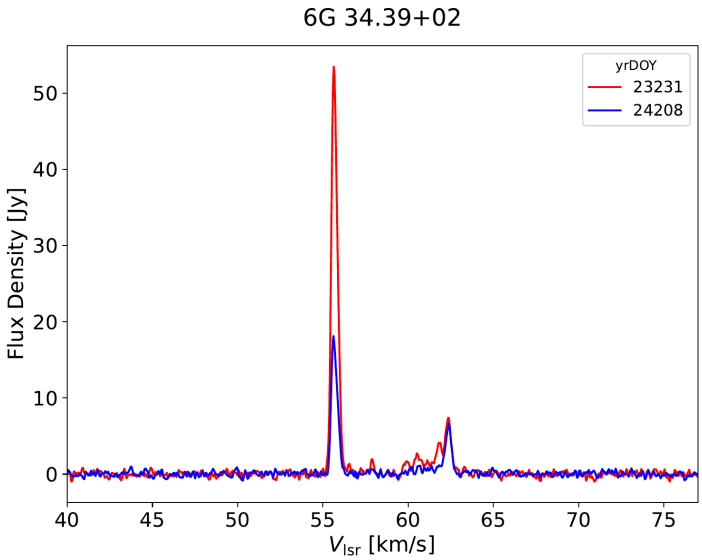
Light curve



Periodogram

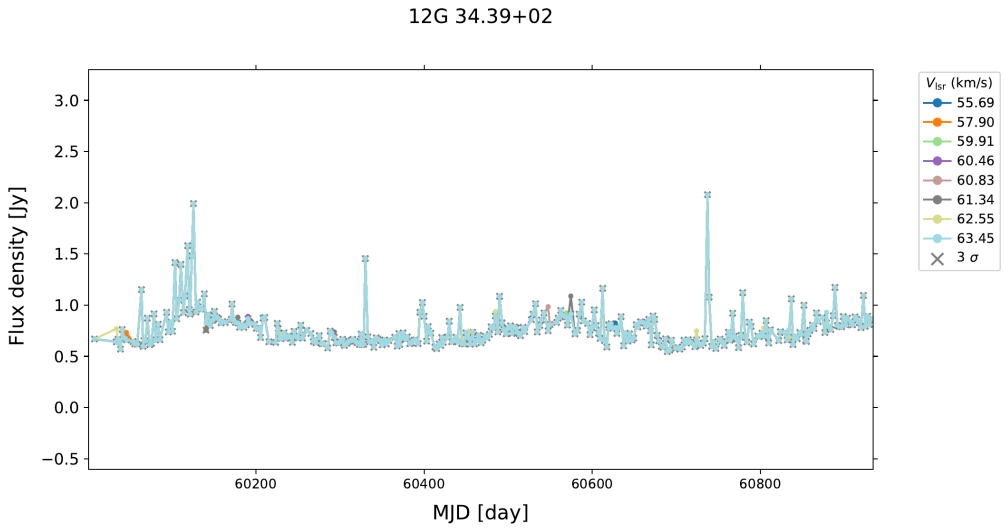


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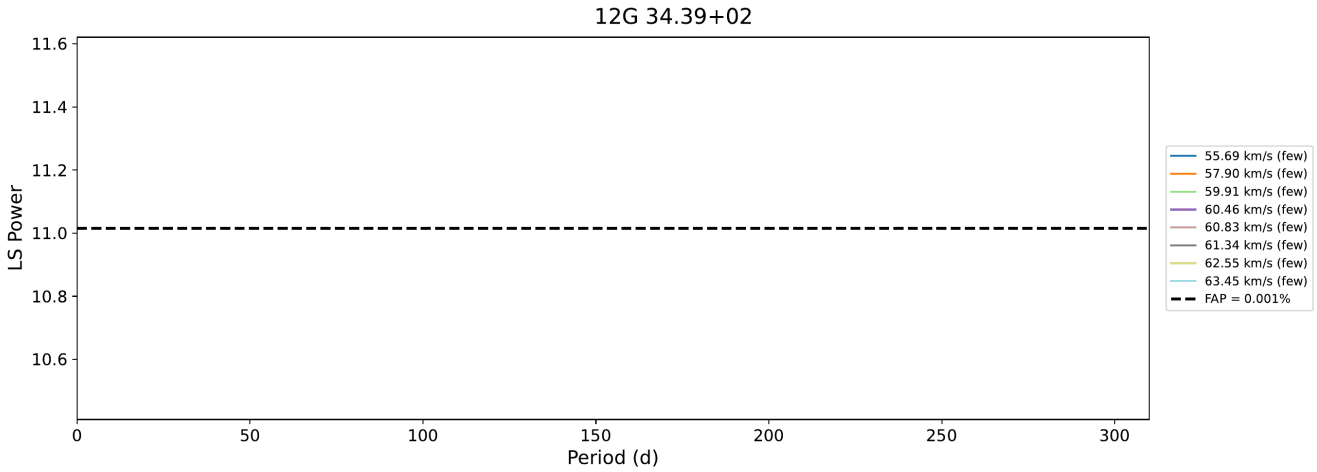


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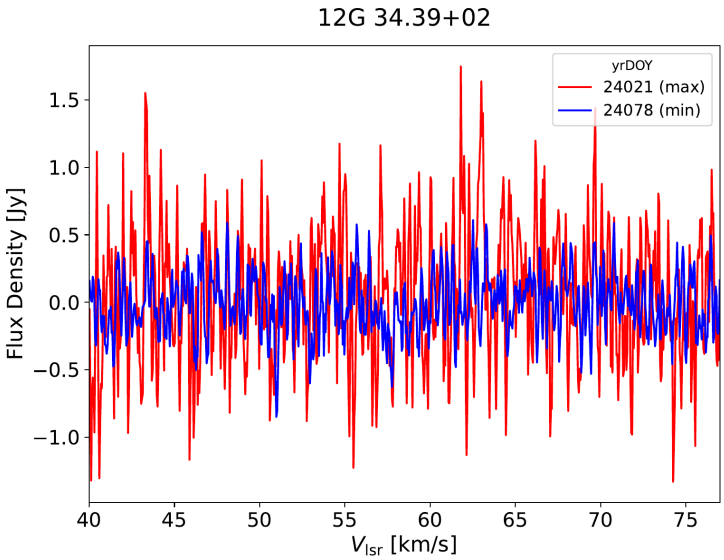
Light curve



Periodogram

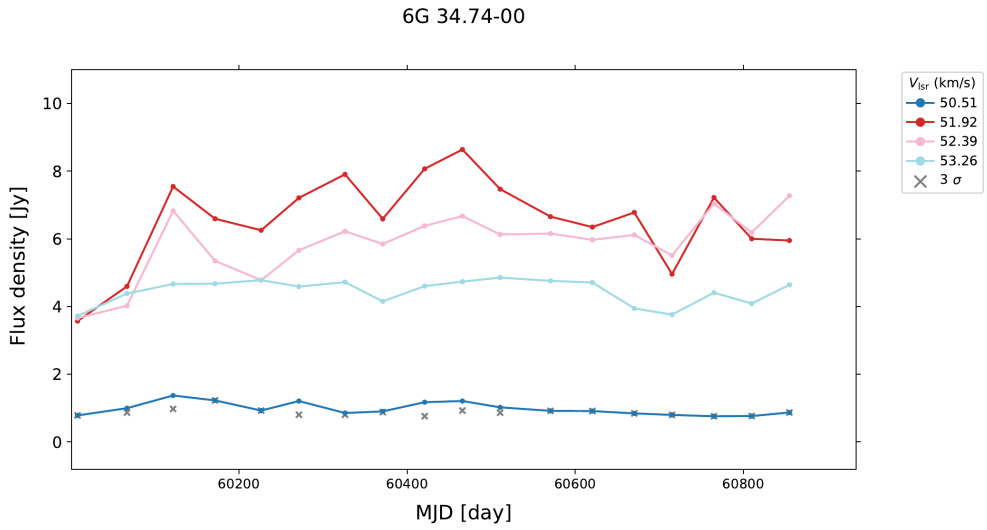


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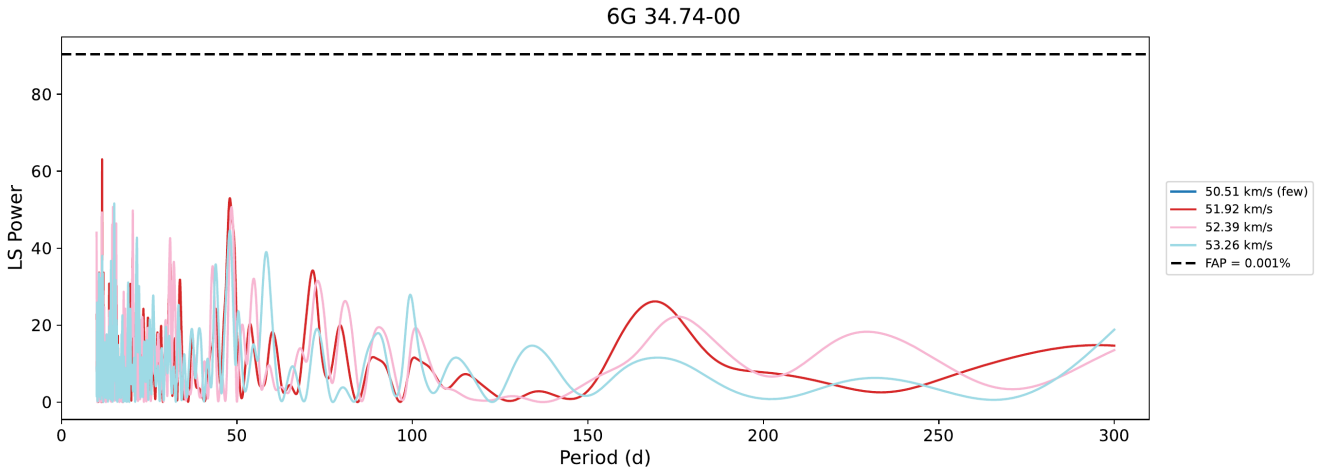


6G 34.74-00

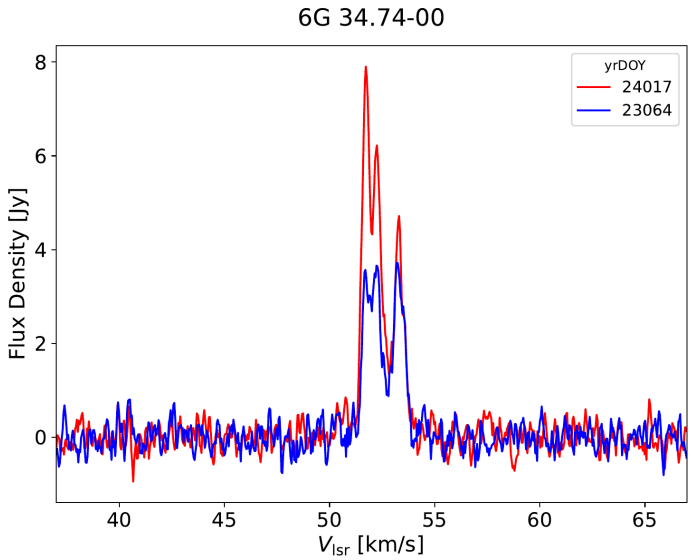
Light curve



Periodogram

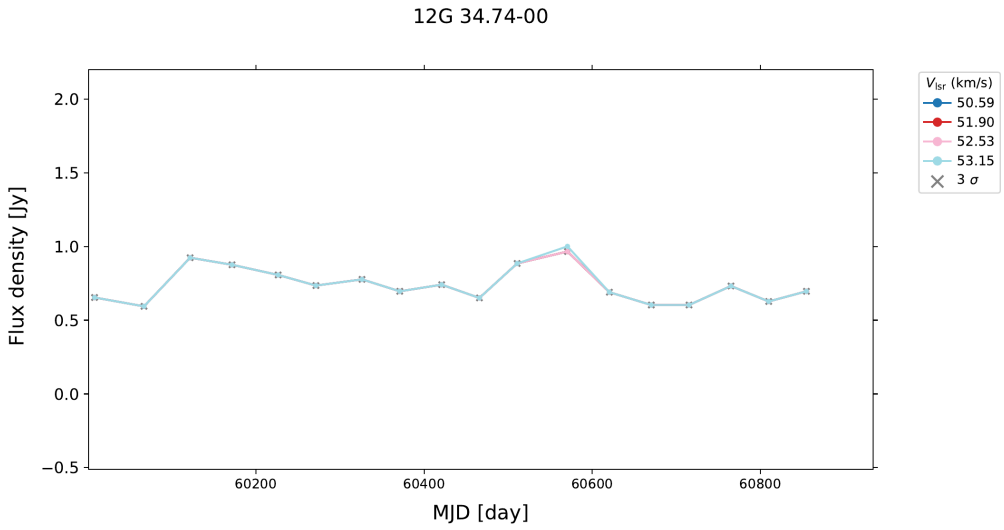


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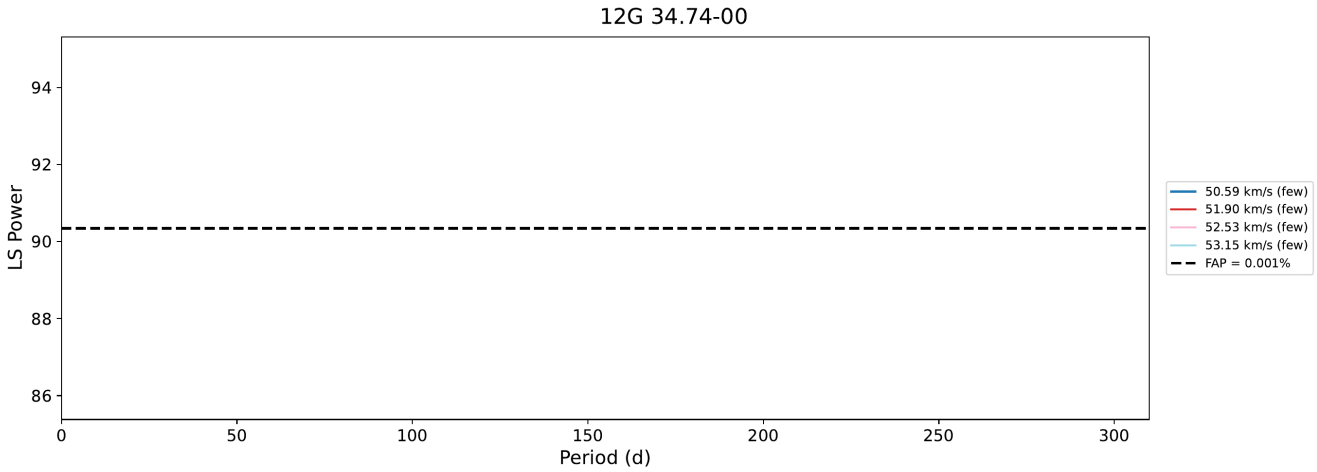


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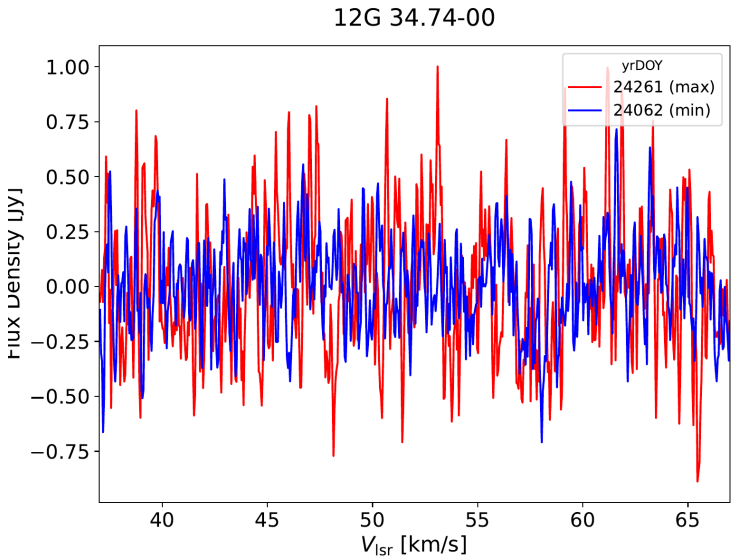
Light curve



Periodogram

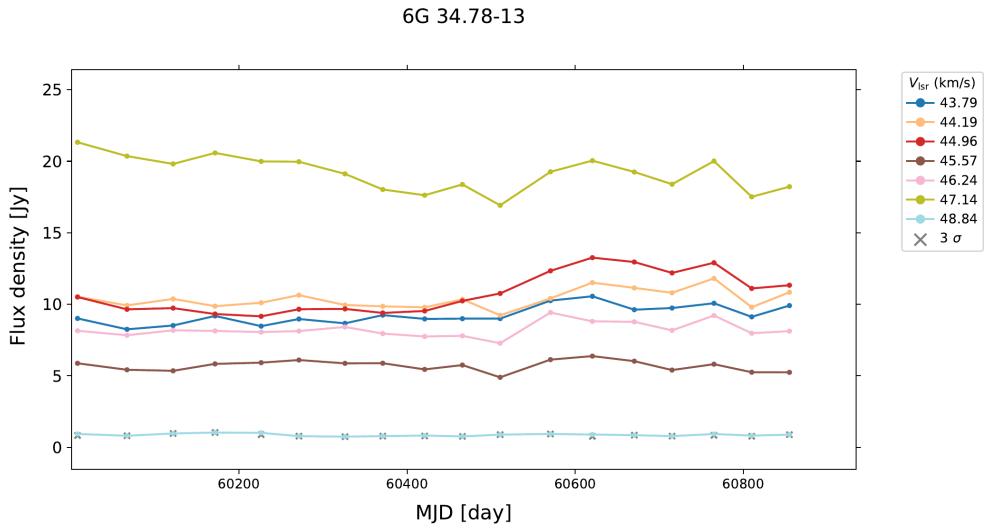


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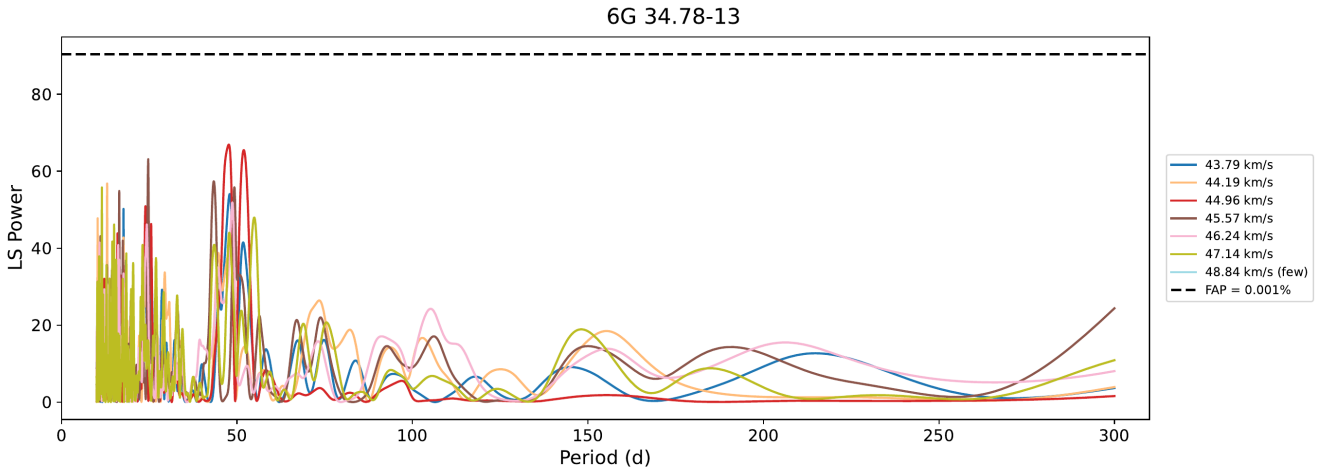


6G 34.78-13

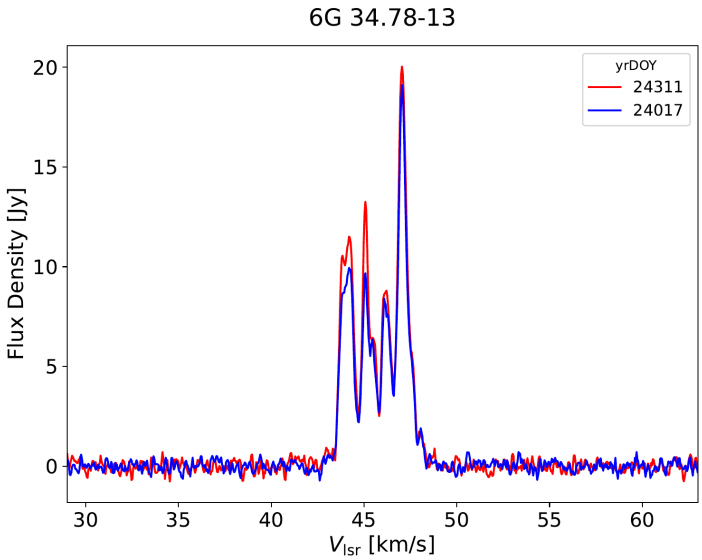
Light curve



Periodogram

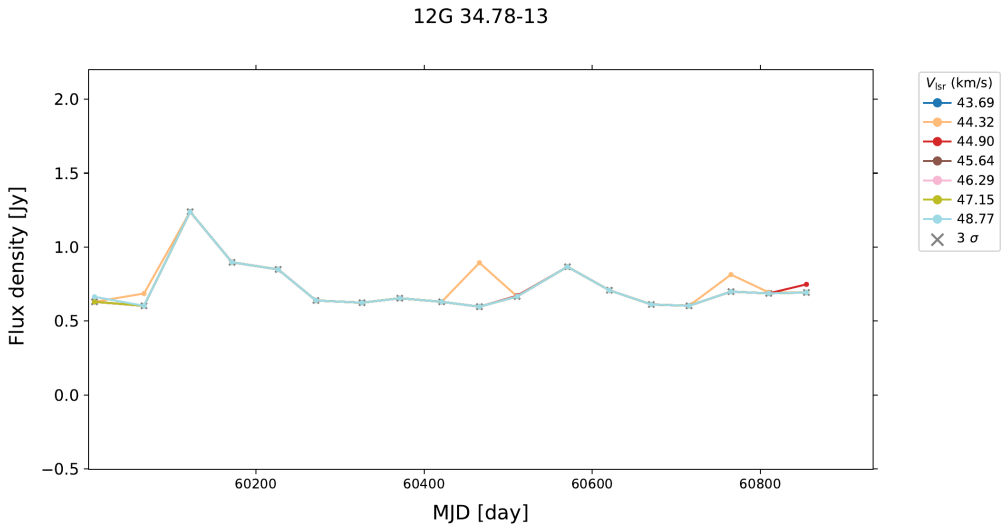


Spectrum

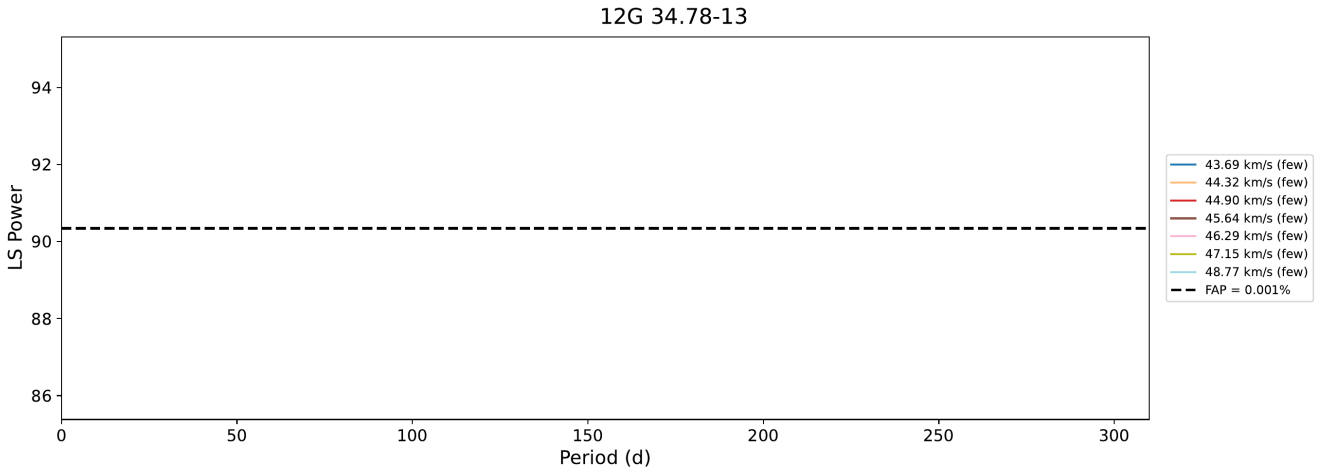


12G 34.78-13

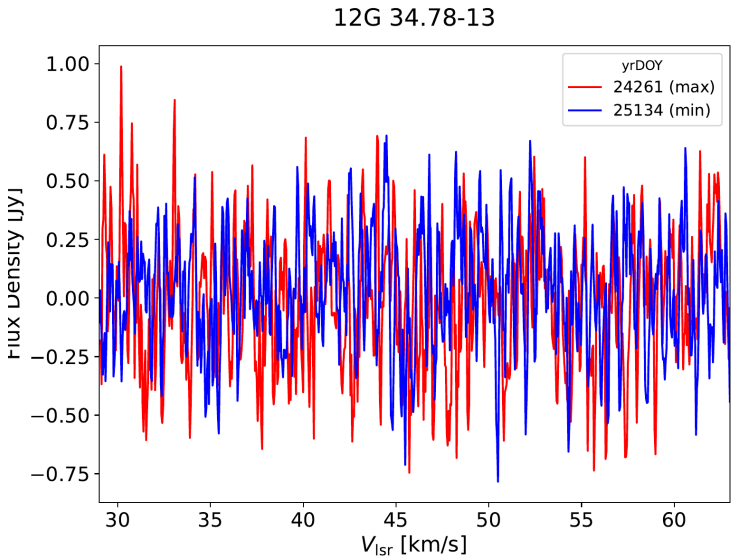
Light curve



Periodogram

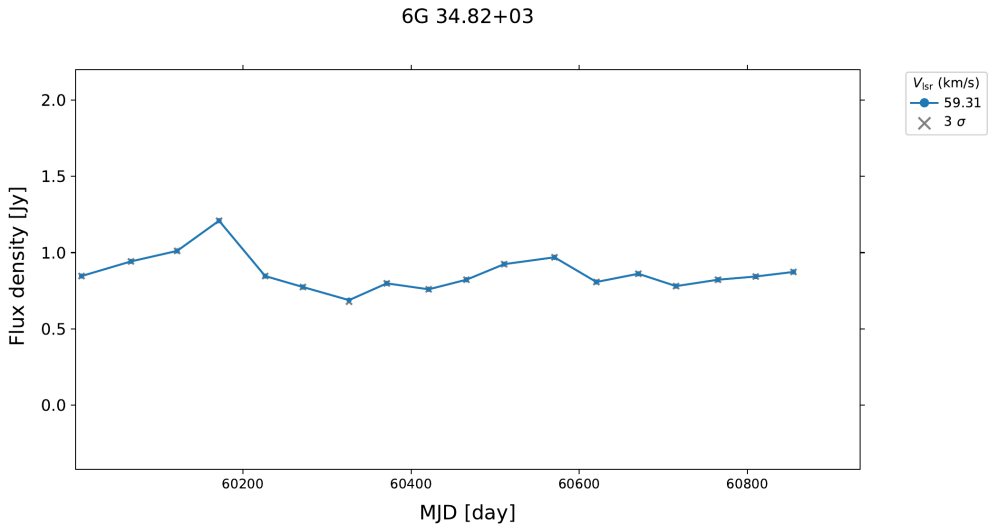


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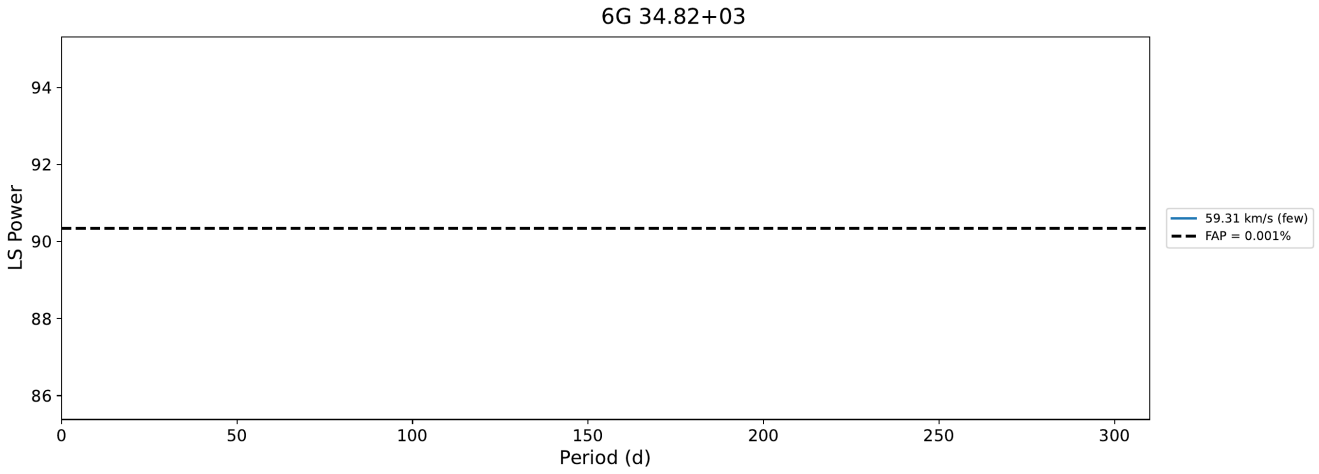


6G 34.82+03

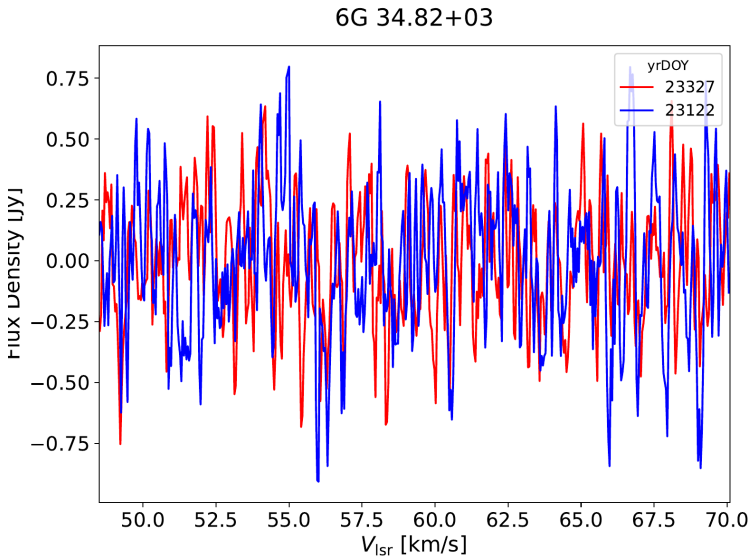
Light curve



Periodogram

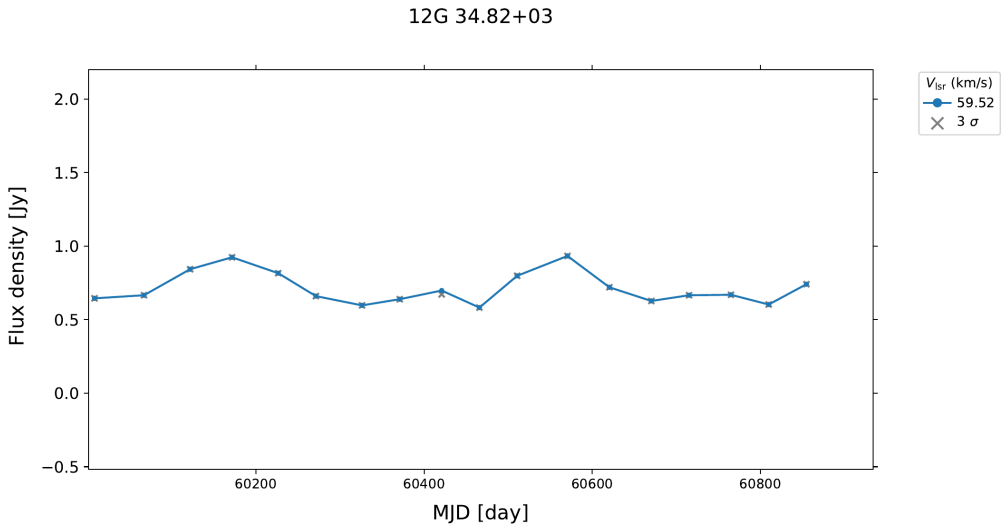


Spectrum

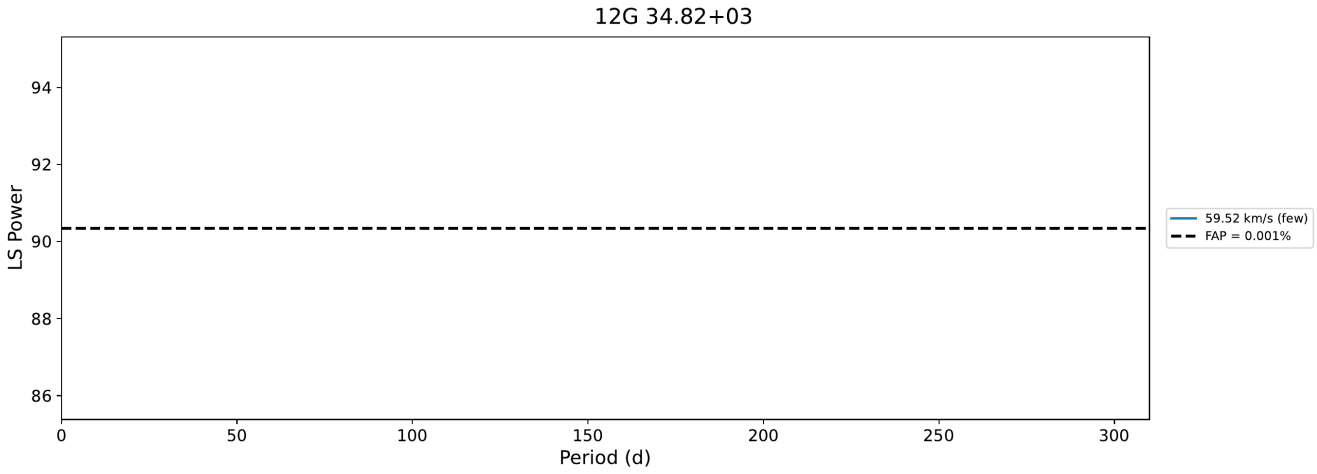


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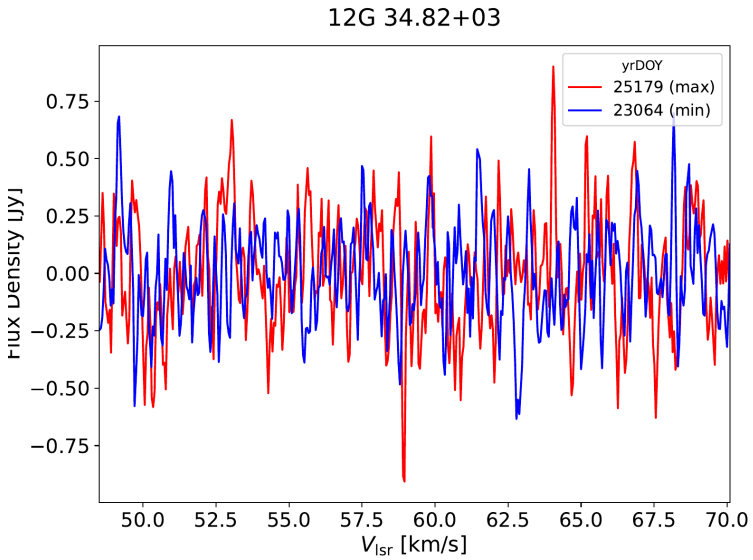
Light curve



Periodogram

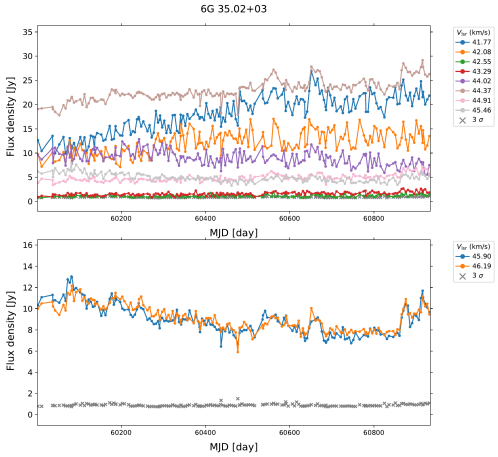


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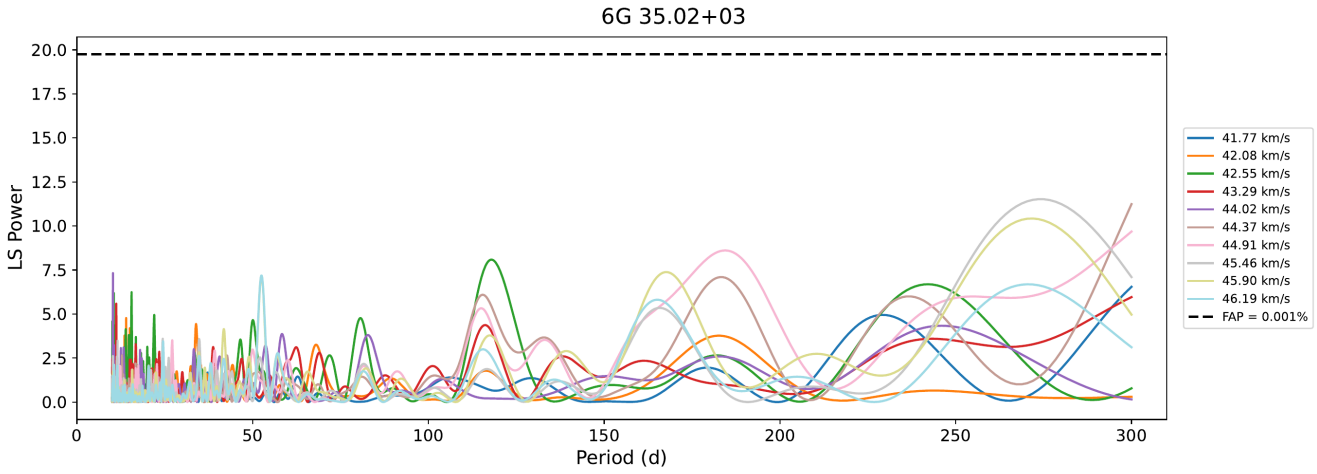


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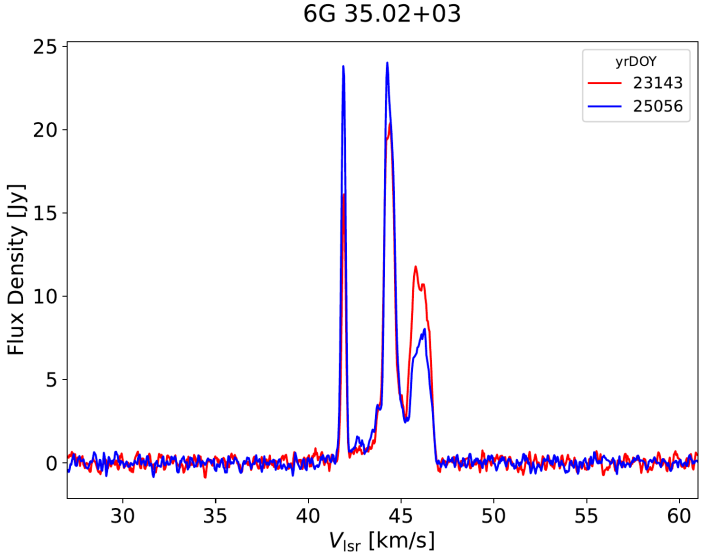
Light curve



Periodogram

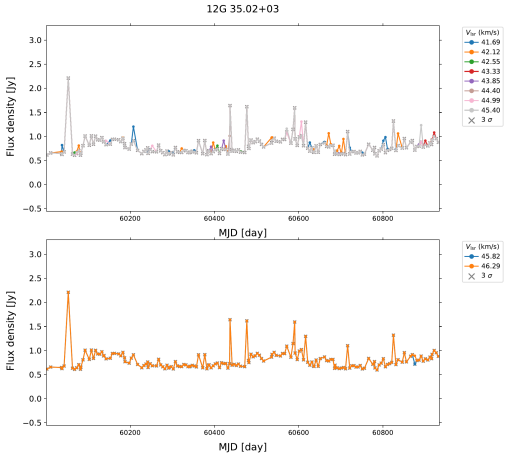


Spectrum

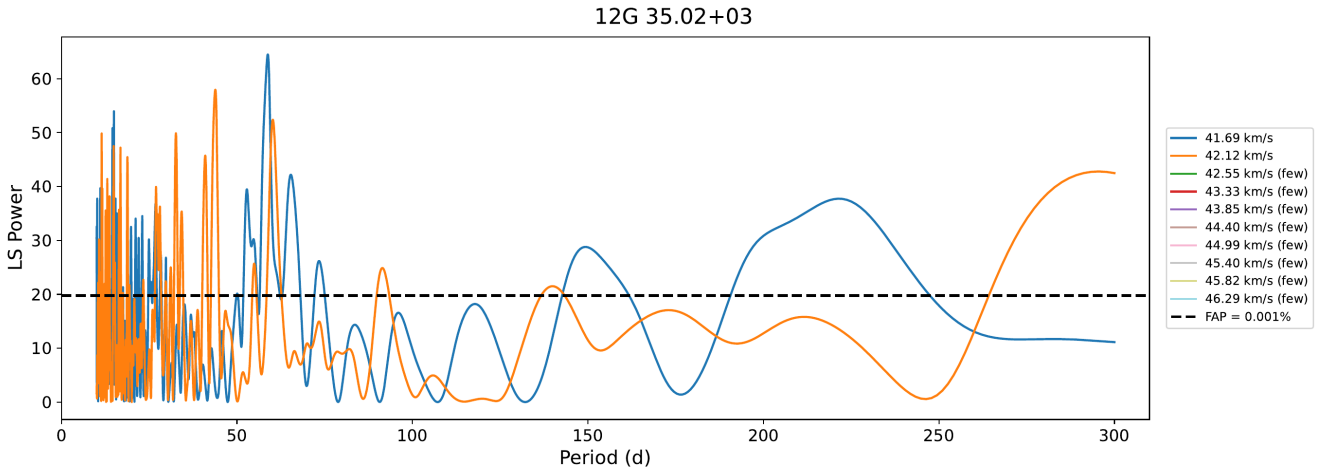


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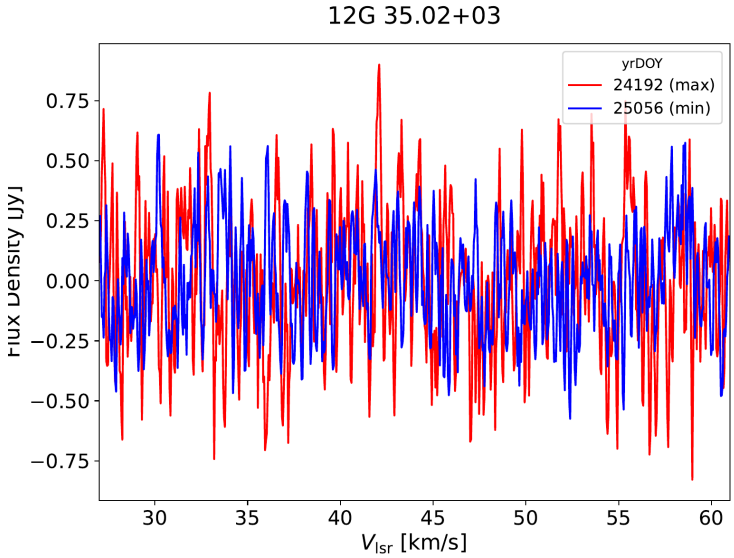
Light curve



Periodogram

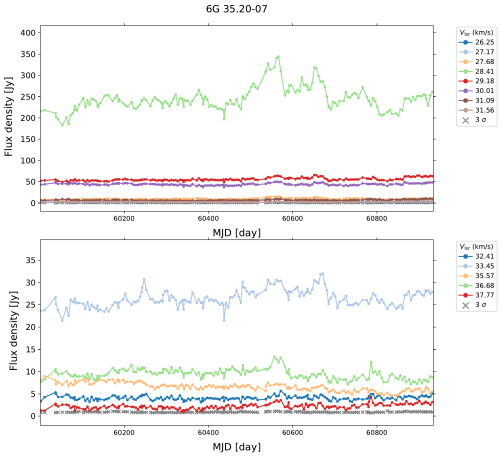


Spectrum

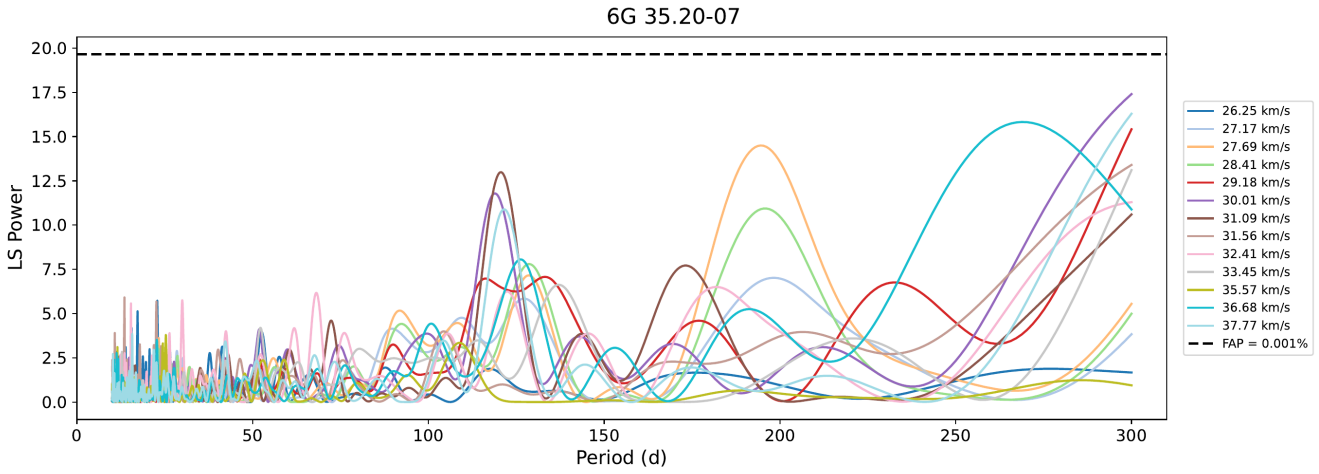


6G 35.20-07

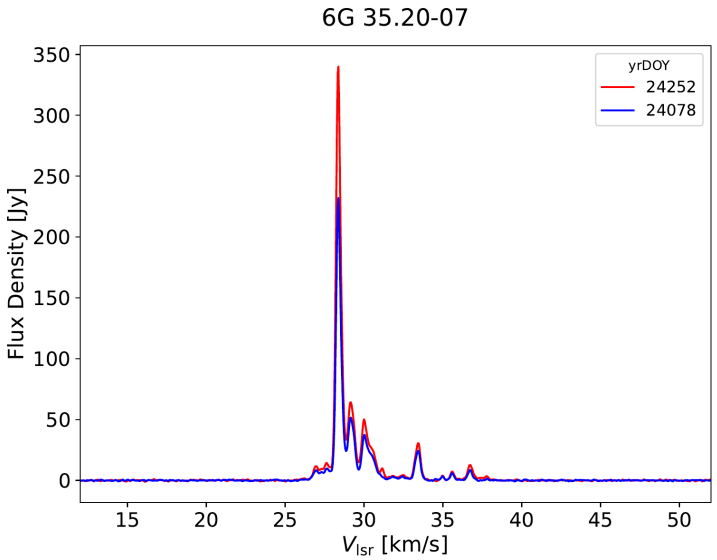
Light curve



Periodogram

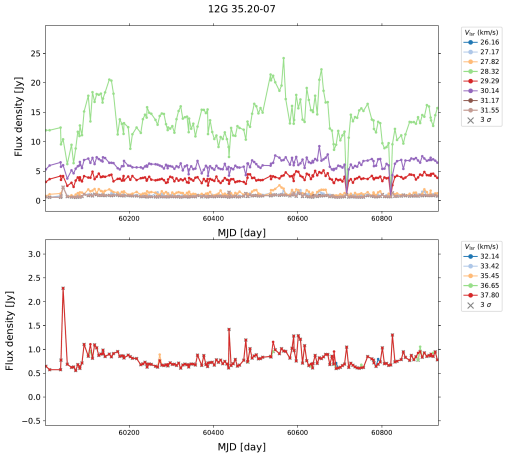


Spectrum

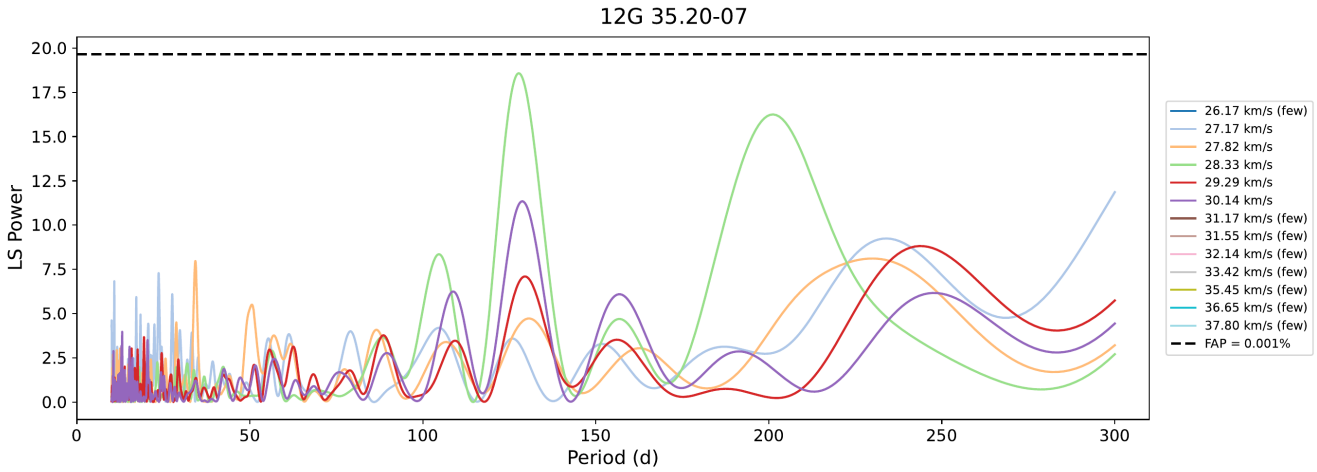


12G 35.20-07

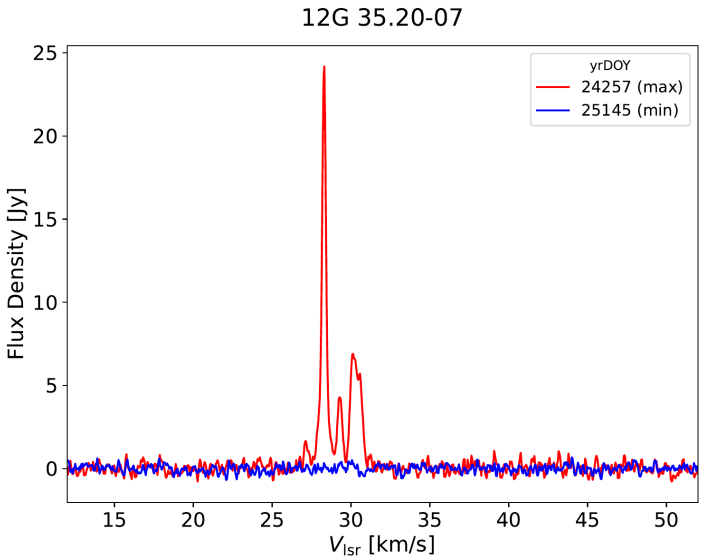
Light curve



Periodogram

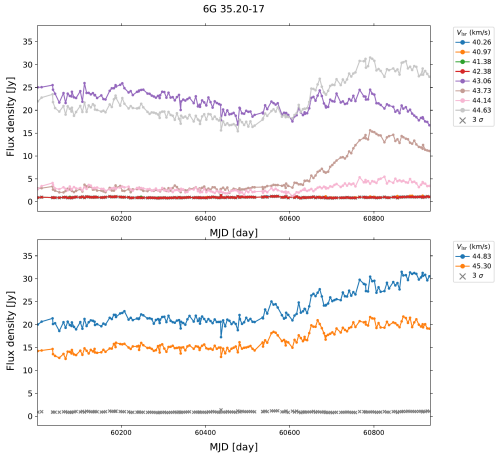


Spectrum

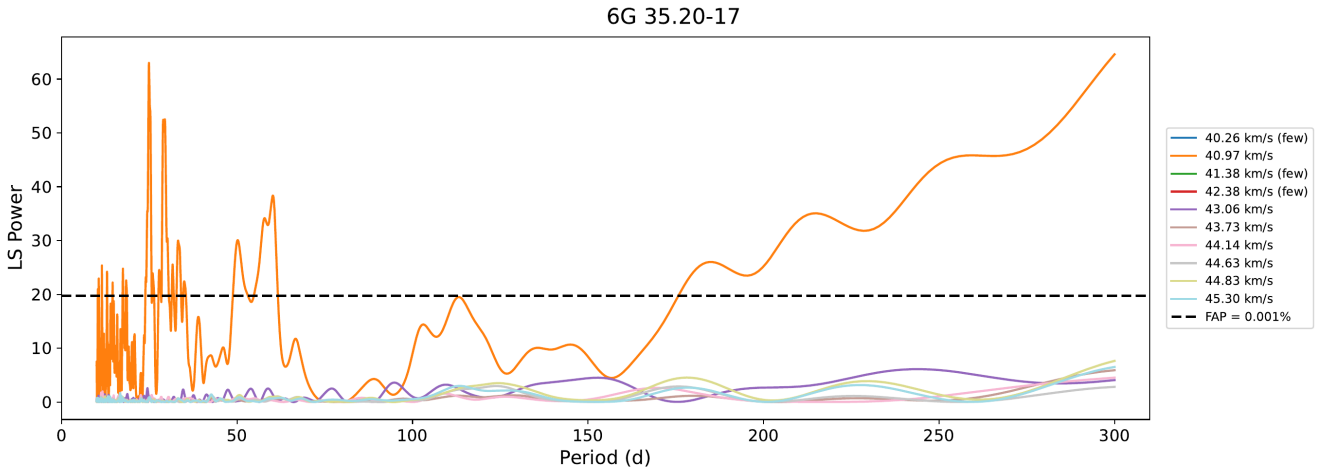


6G 35.20-17

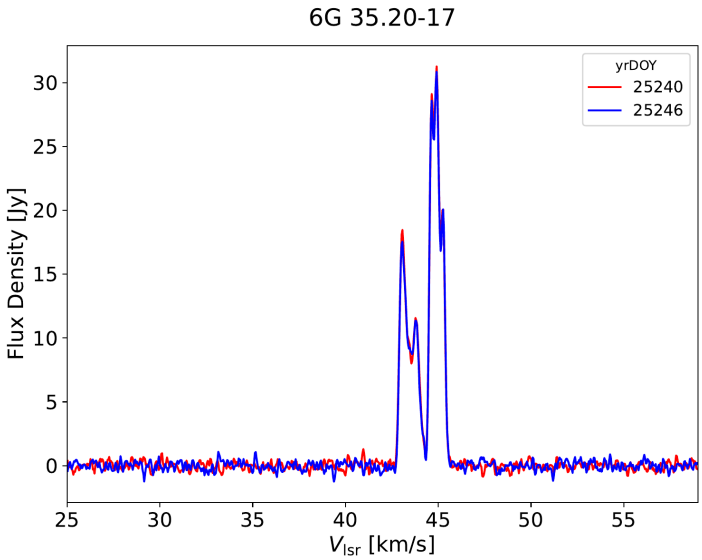
Light curve



Periodogram

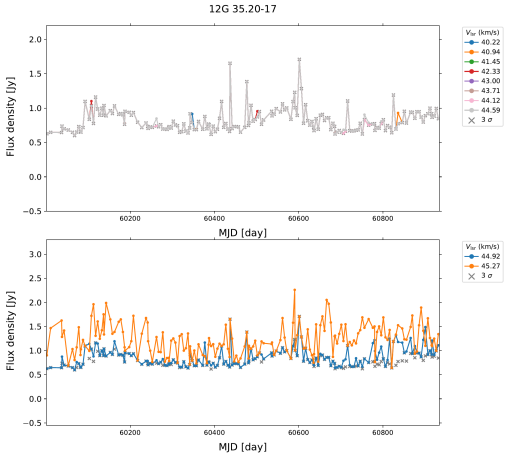


Spectrum

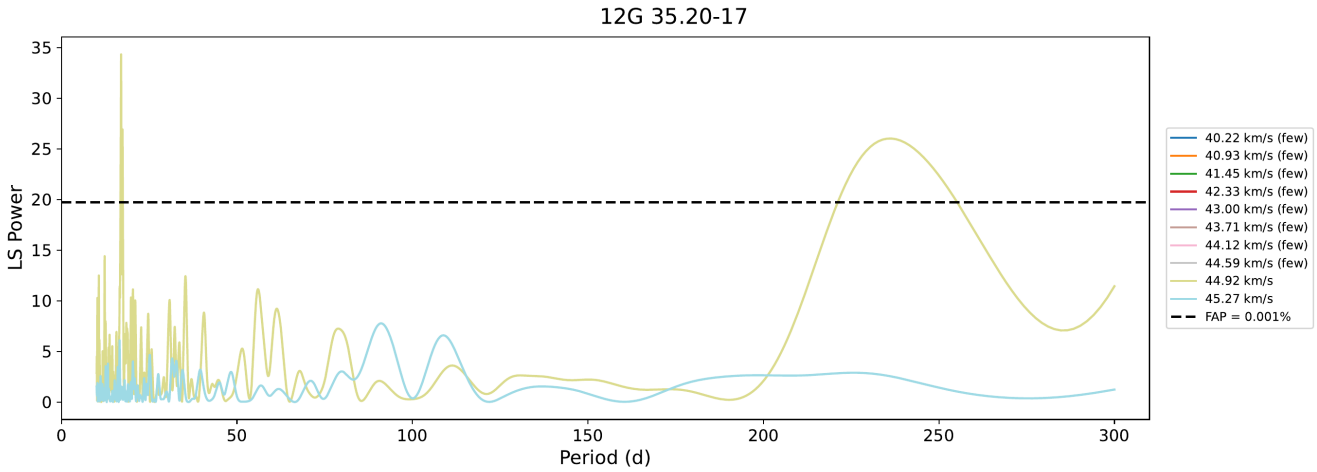


12G 35.20-17

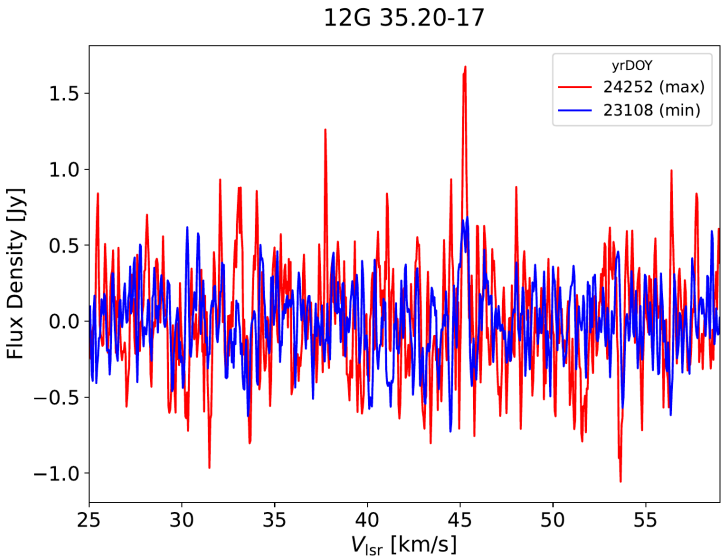
Light curve



Periodogram

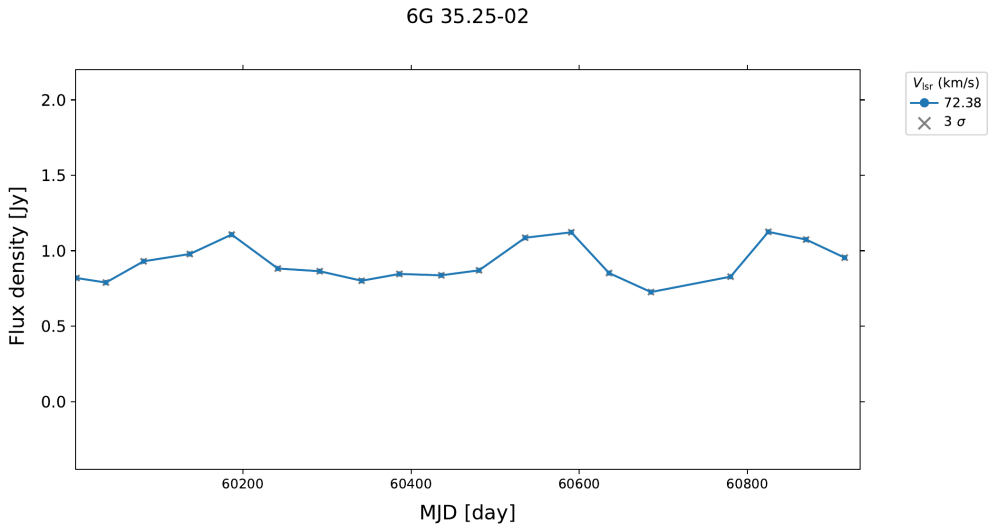


Spectrum

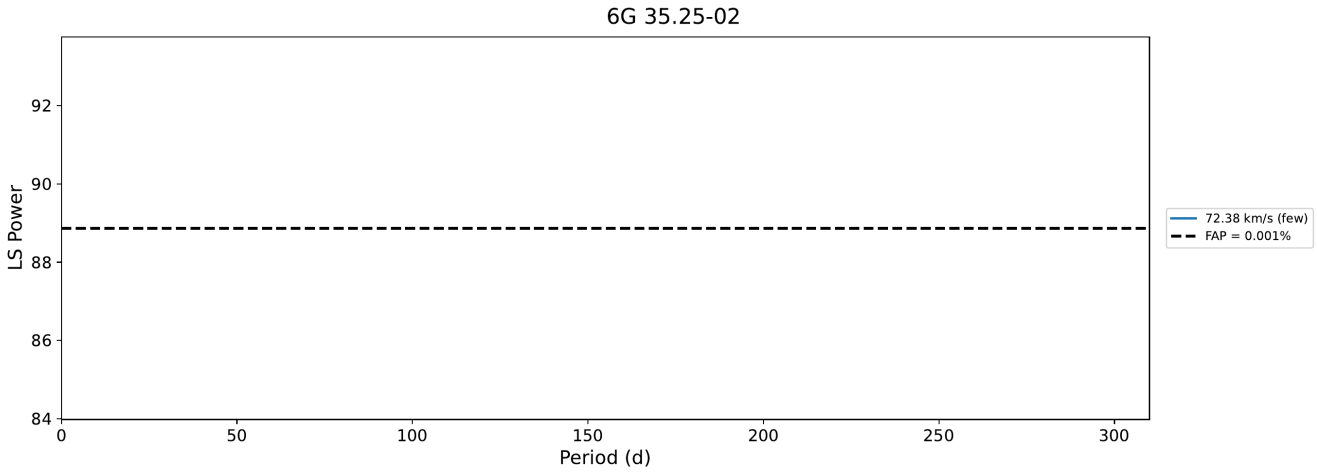


6G 35.25-02

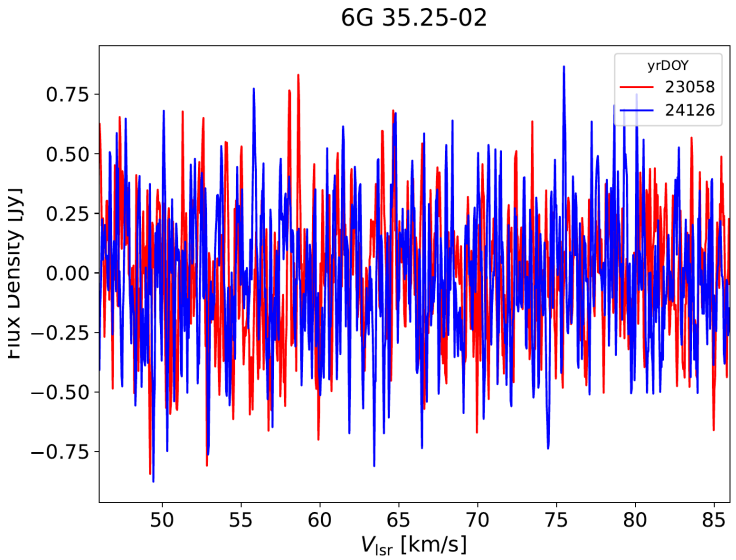
Light curve



Periodogram

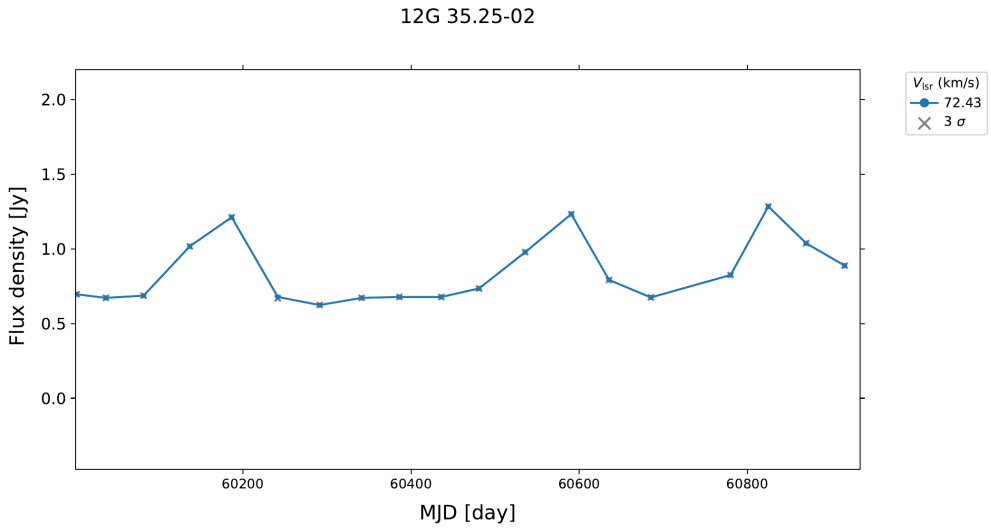


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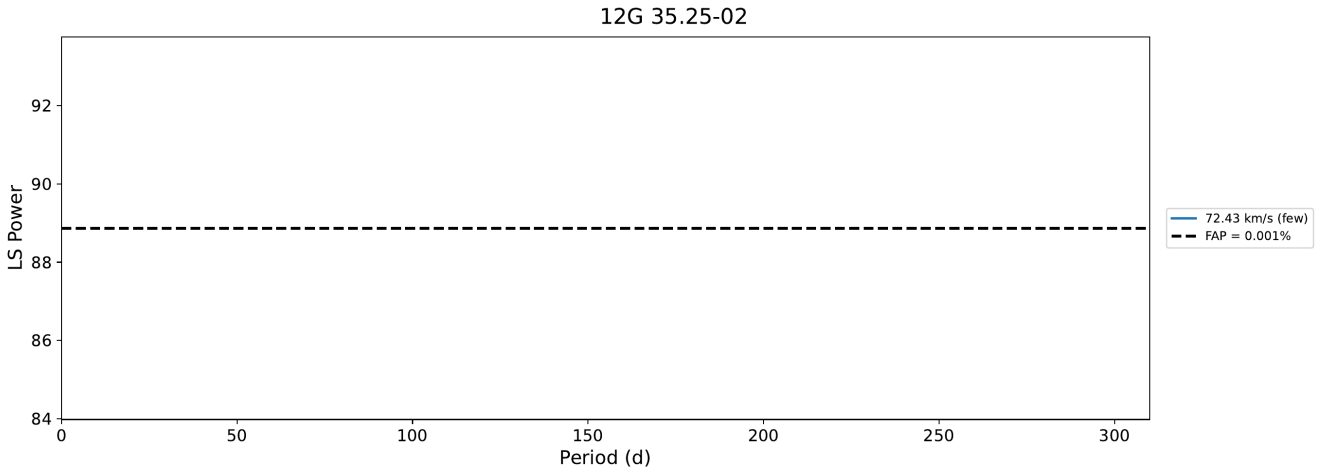


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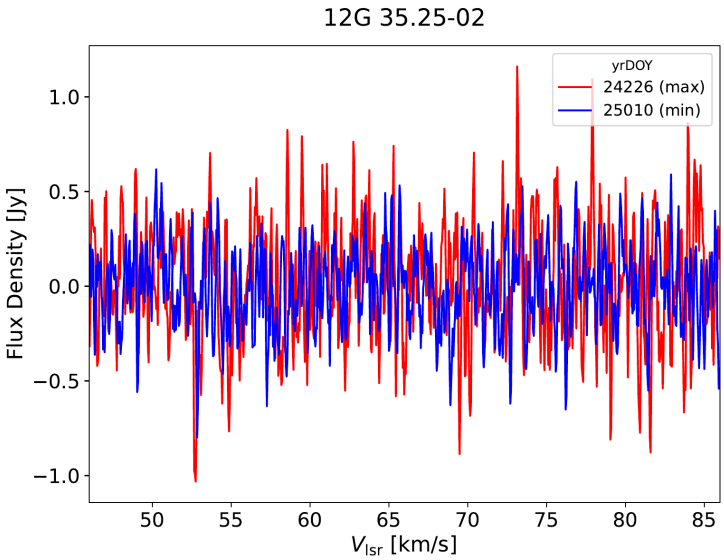
Light curve



Periodogram

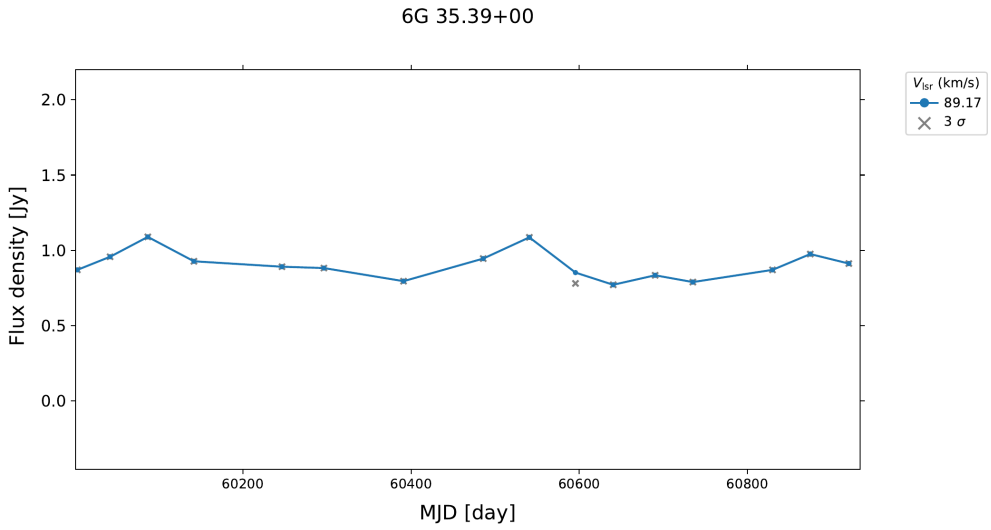


Spectrum

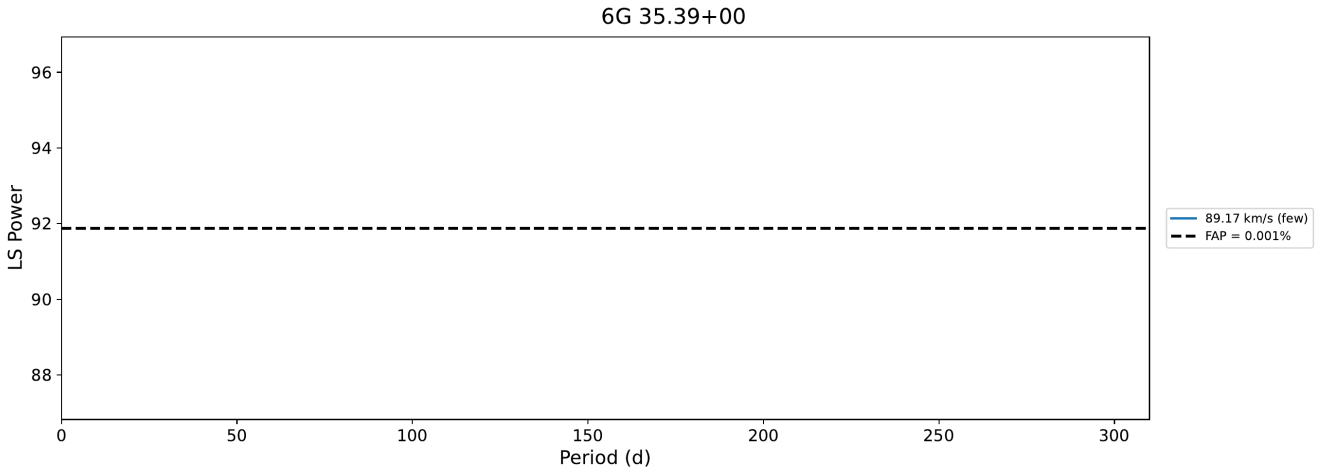


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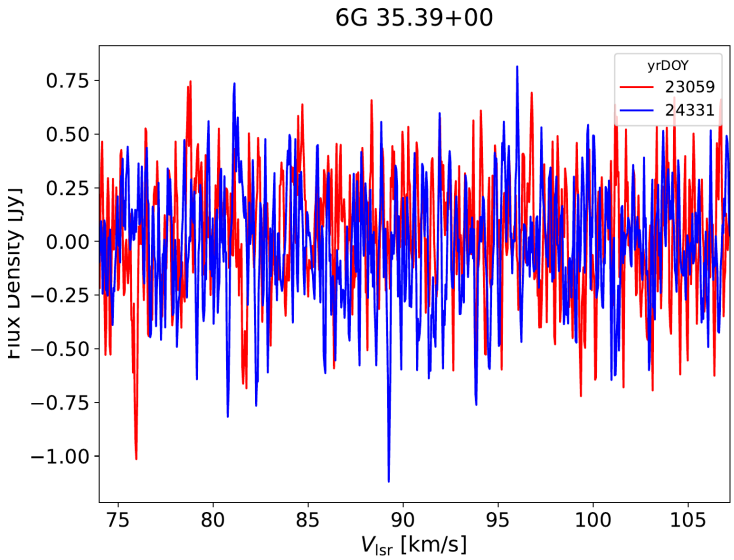
Light curve



Periodogram

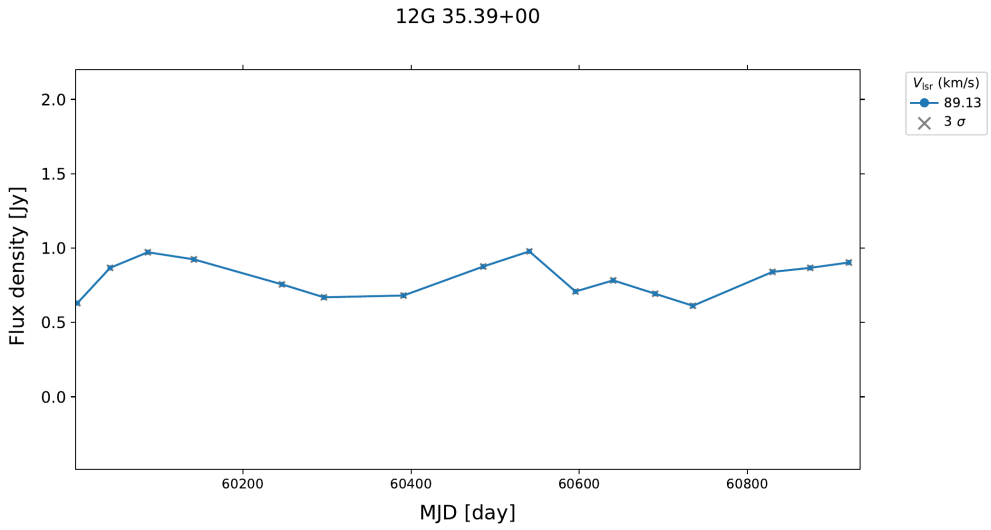


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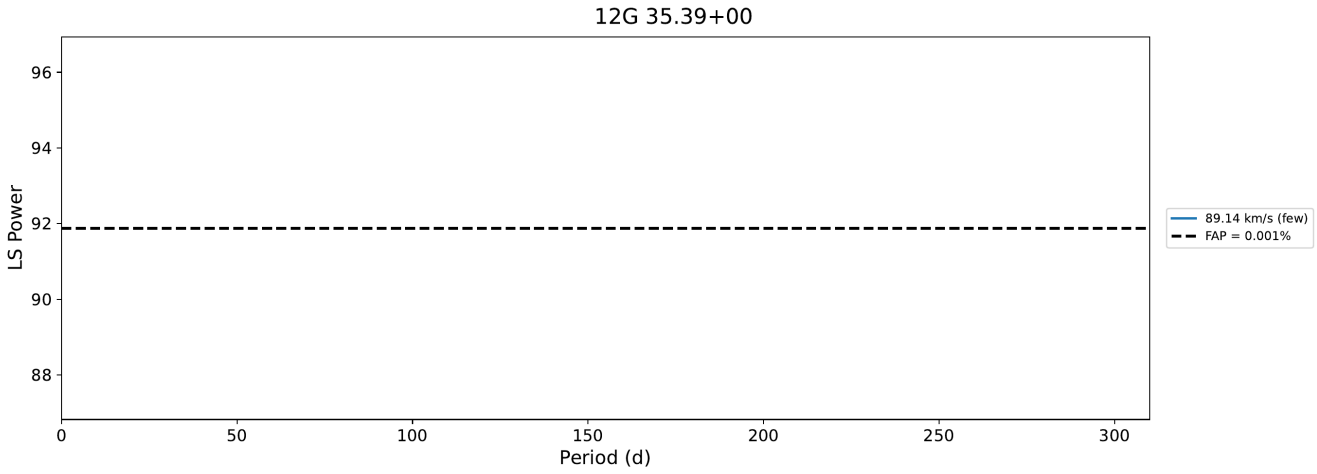


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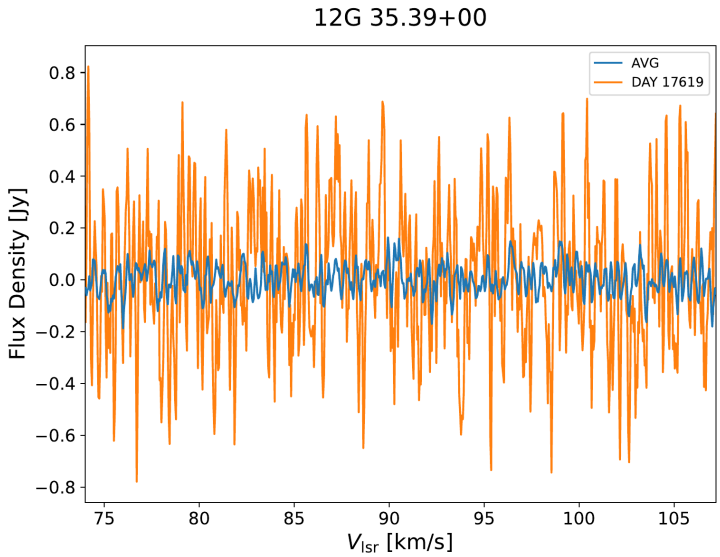
Light curve



Periodogram

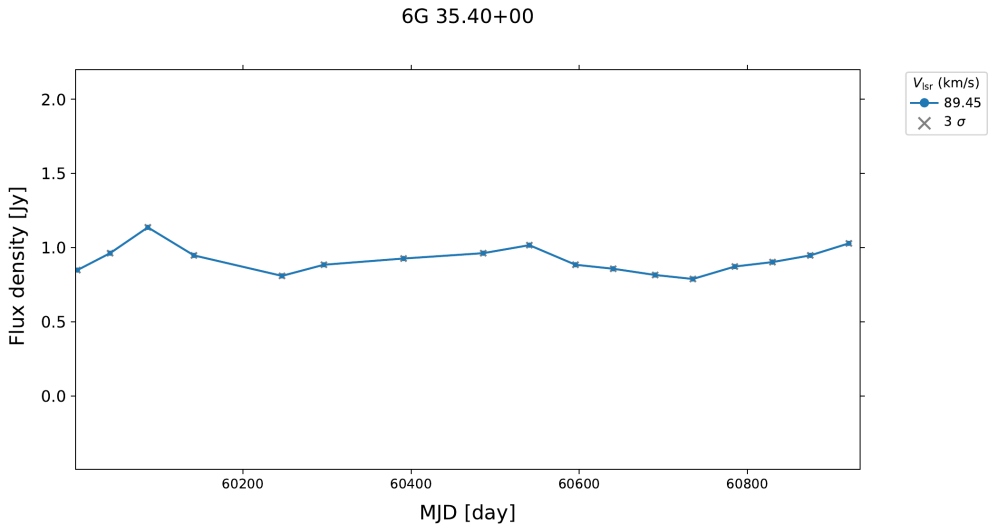


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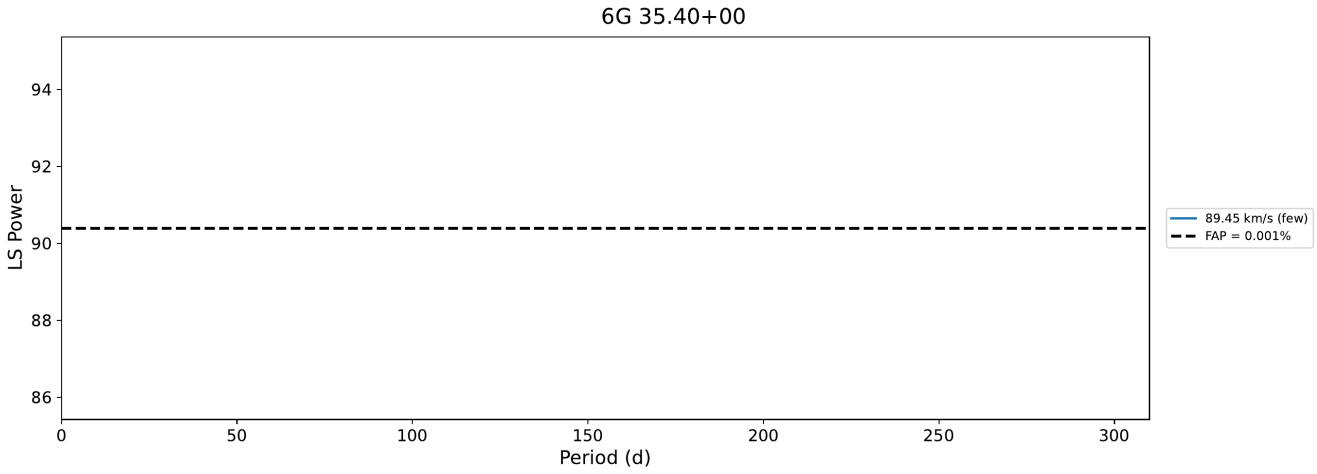


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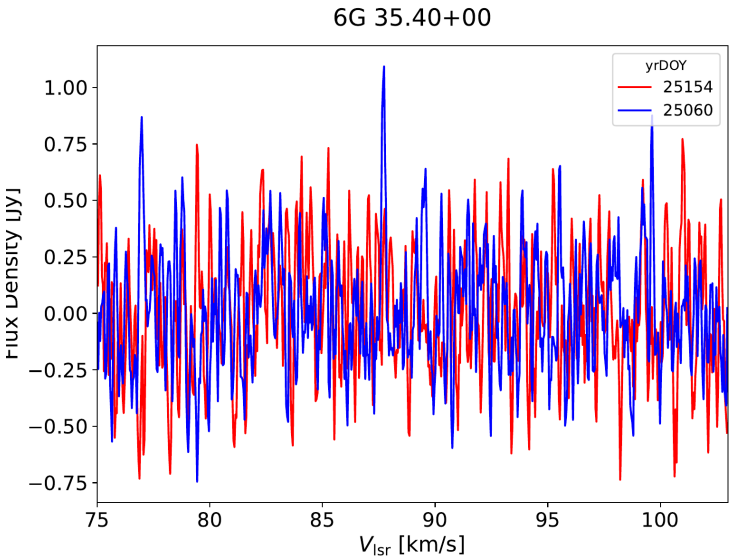
Light curve



Periodogram

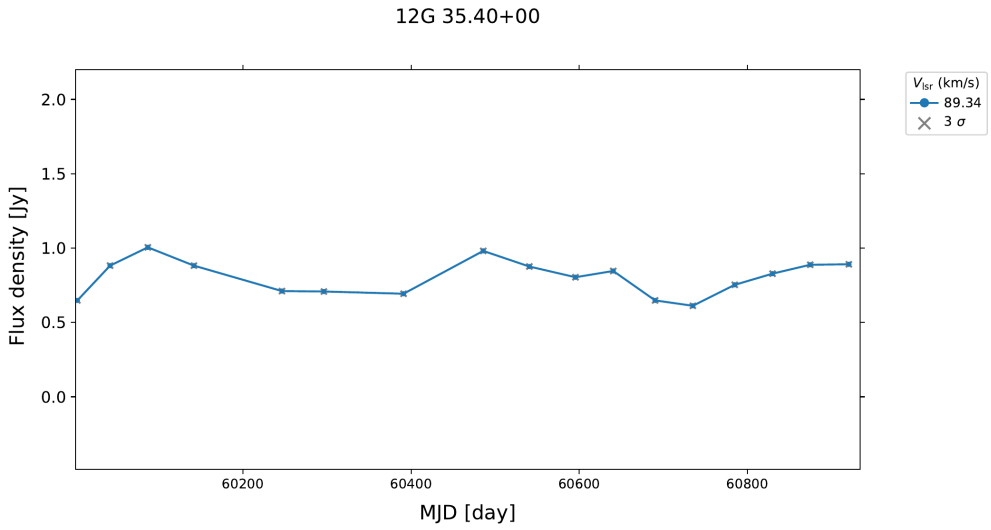


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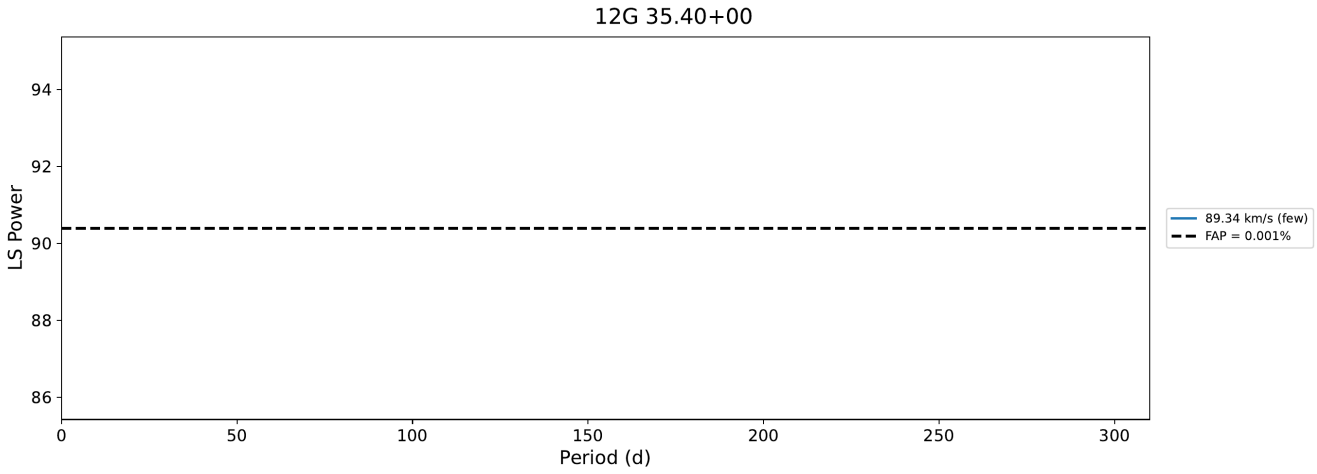


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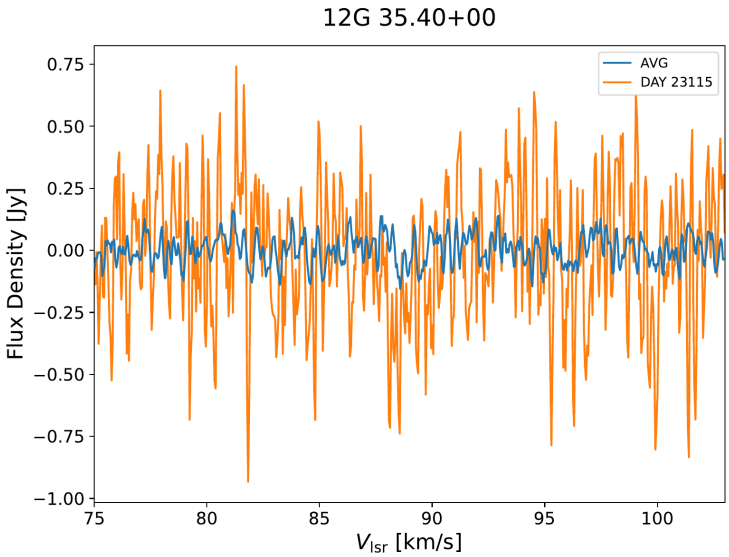
Light curve



Periodogram

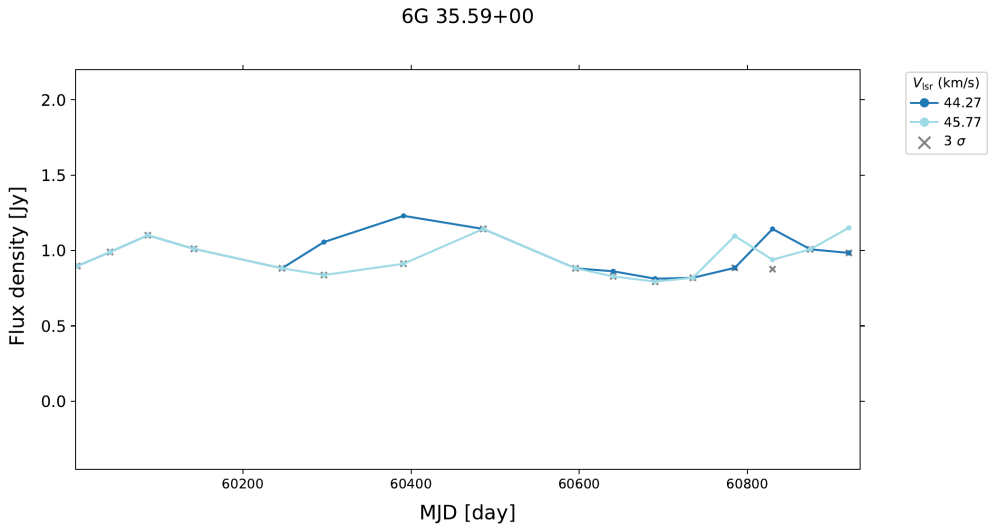


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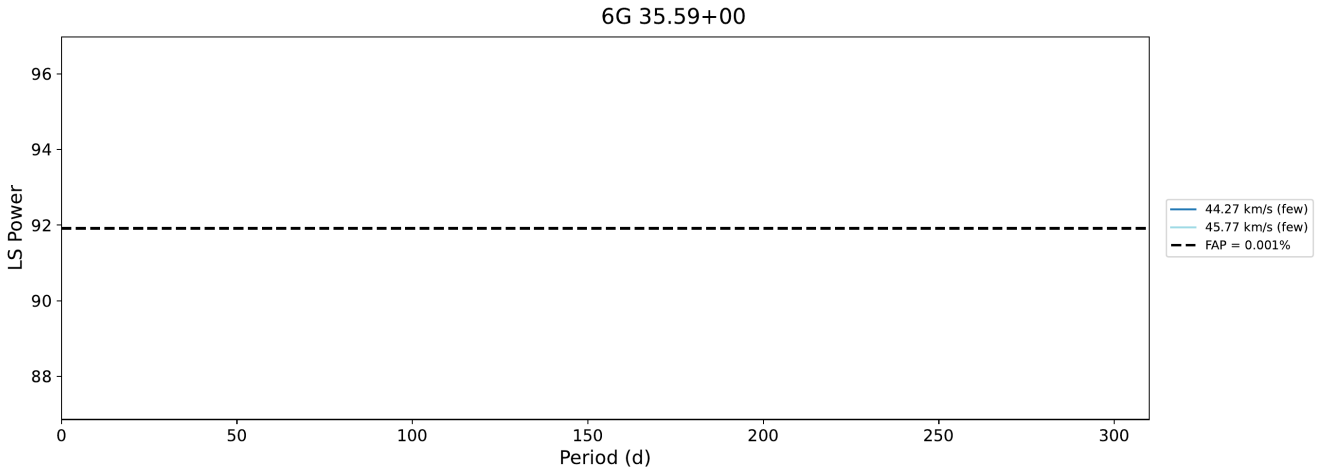


6G 35.59+00

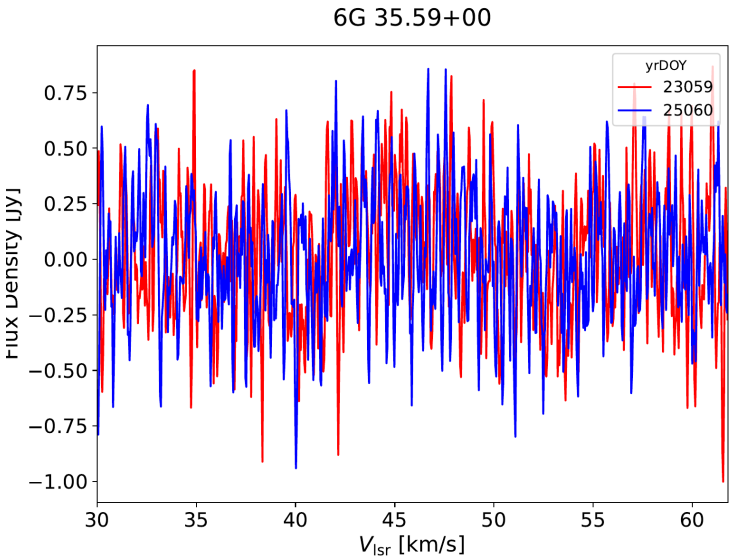
Light curve



Periodogram

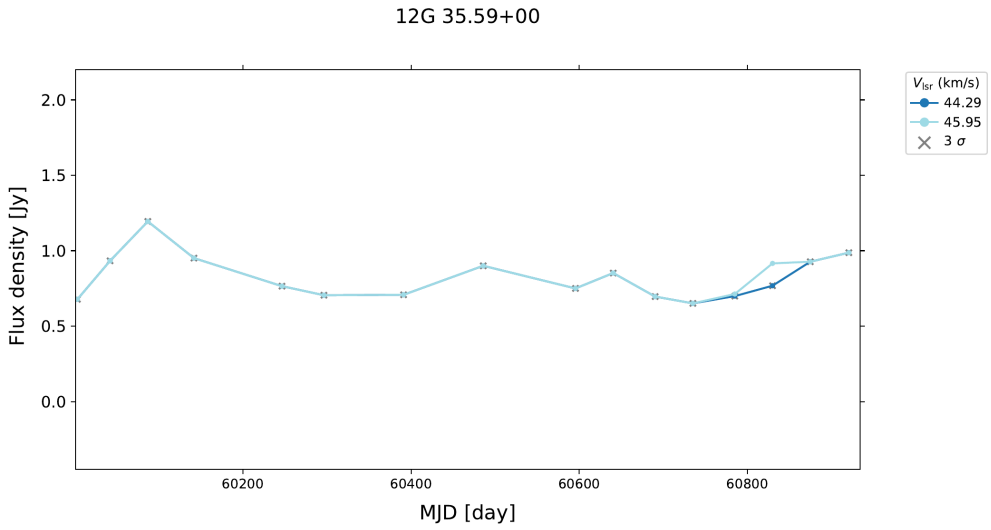


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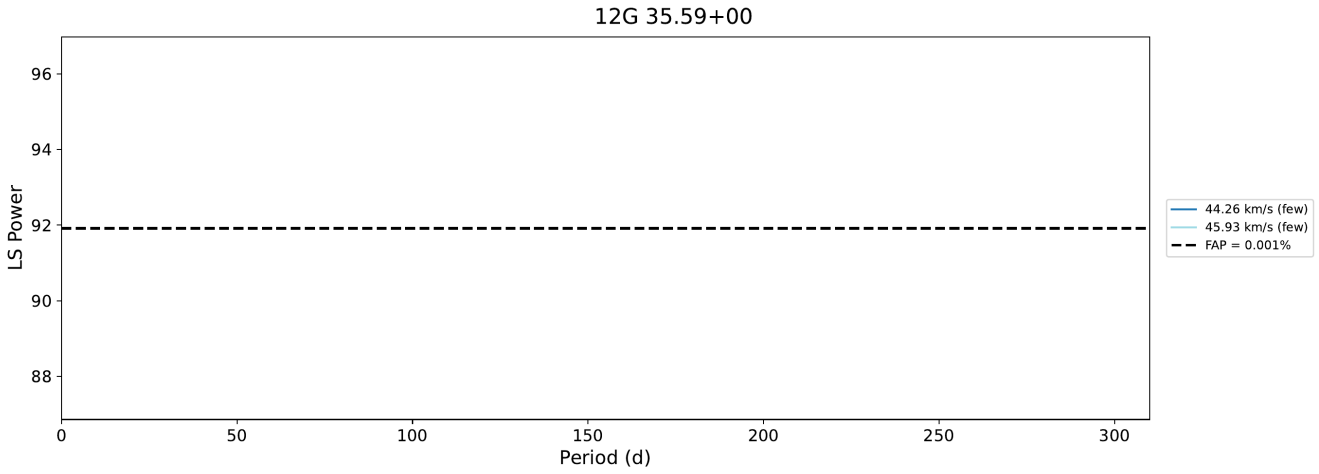


12G 35.59+00

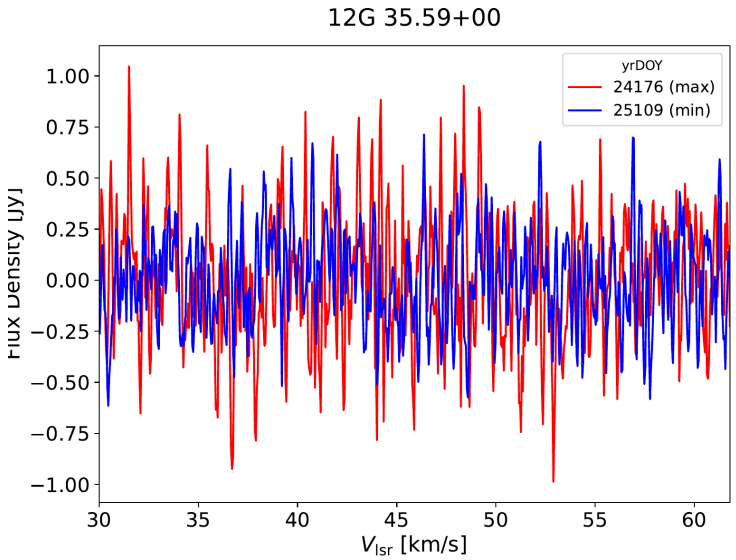
Light curve



Periodogram

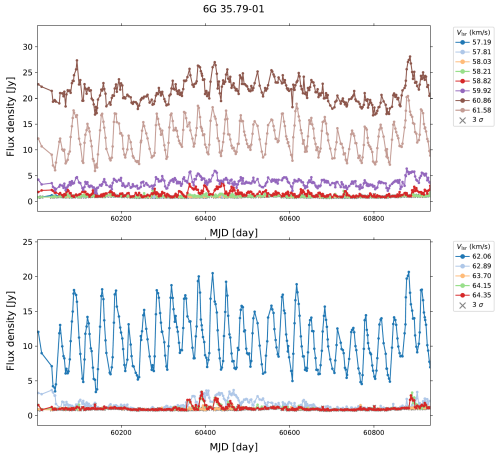


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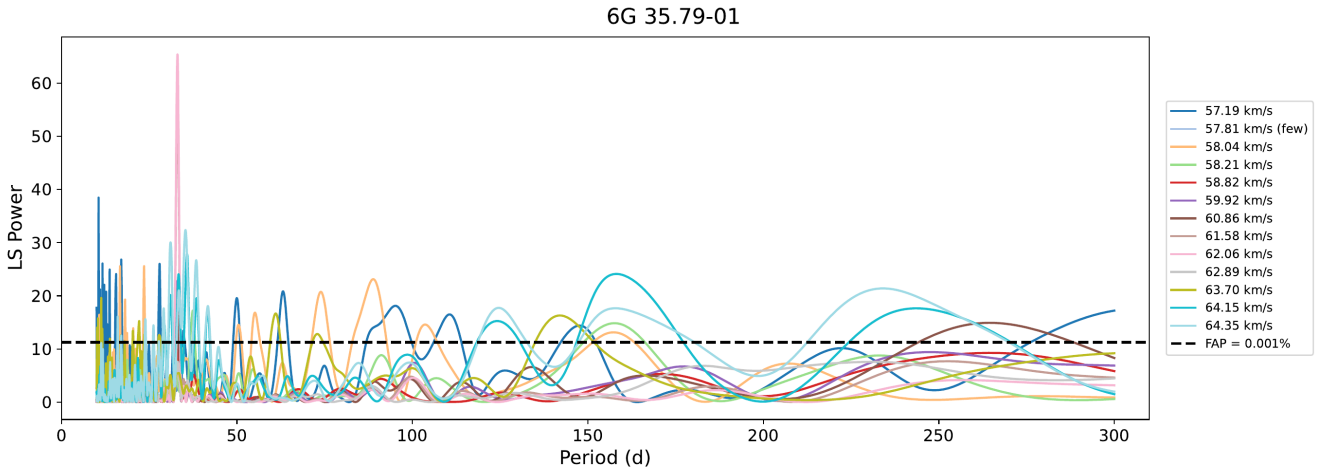


6G 35.79-01

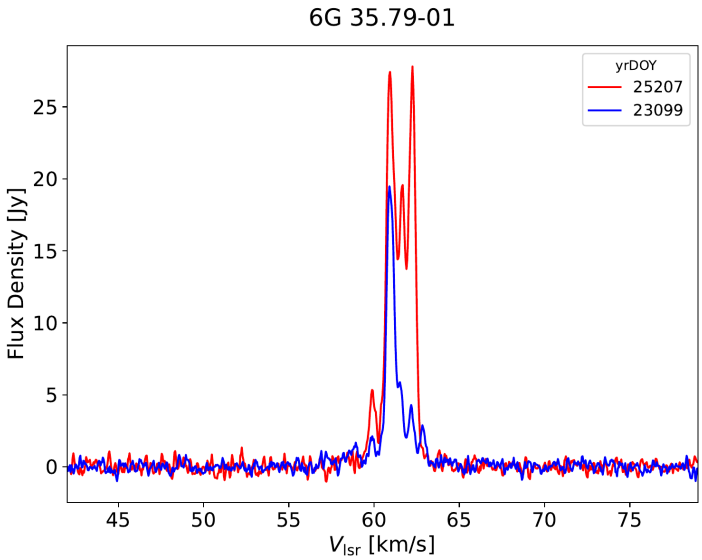
Light curve



Periodogram

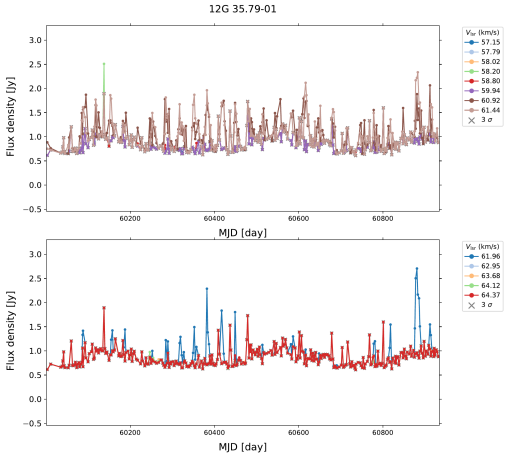


Spectrum

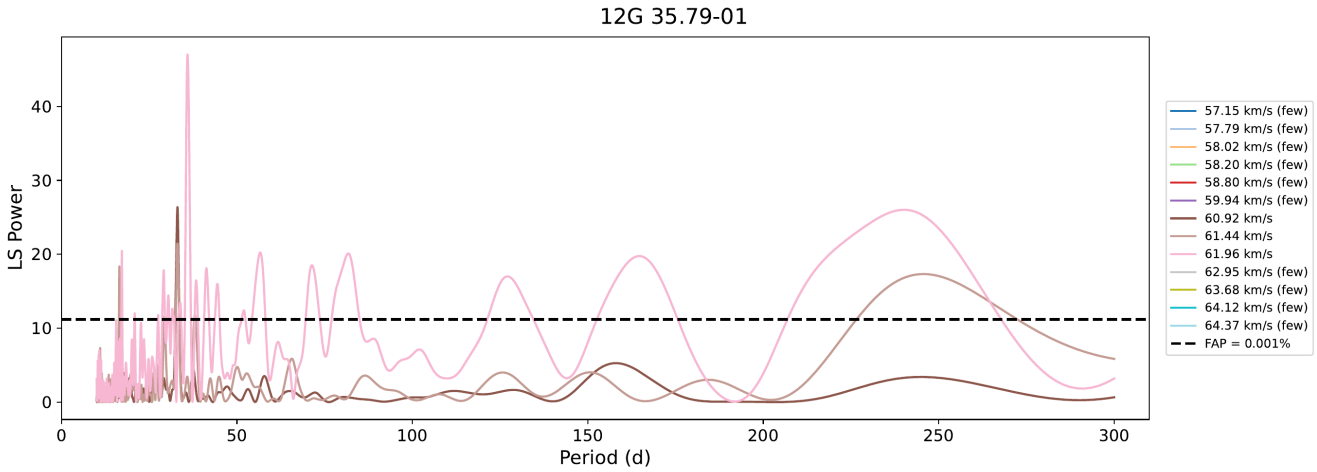


12G 35.79-01

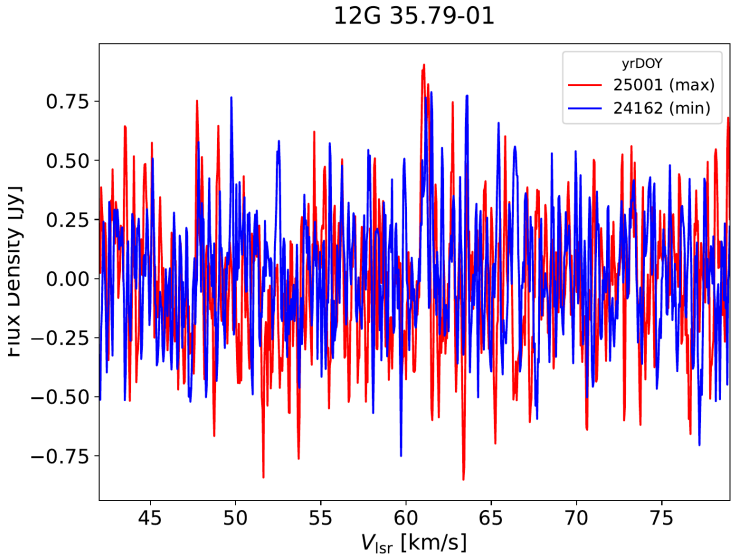
Light curve



Periodogram

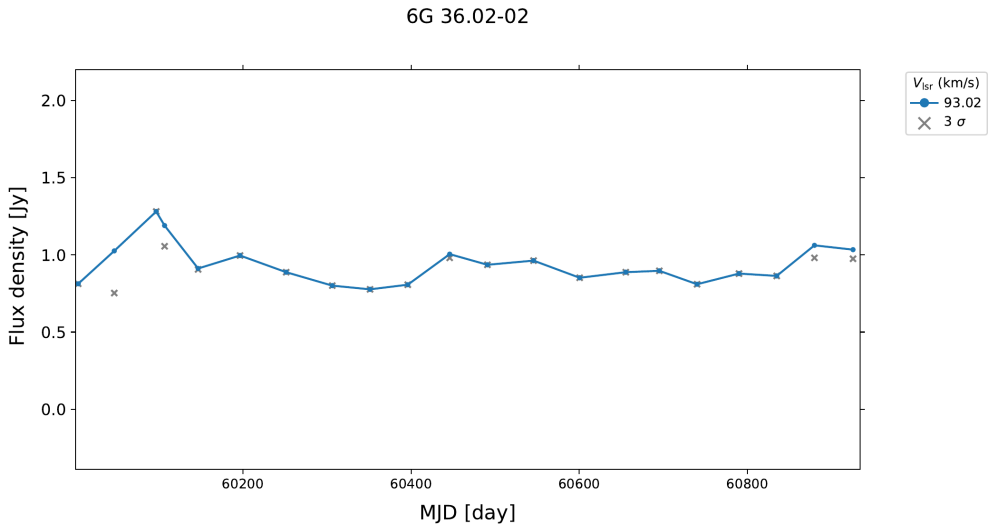


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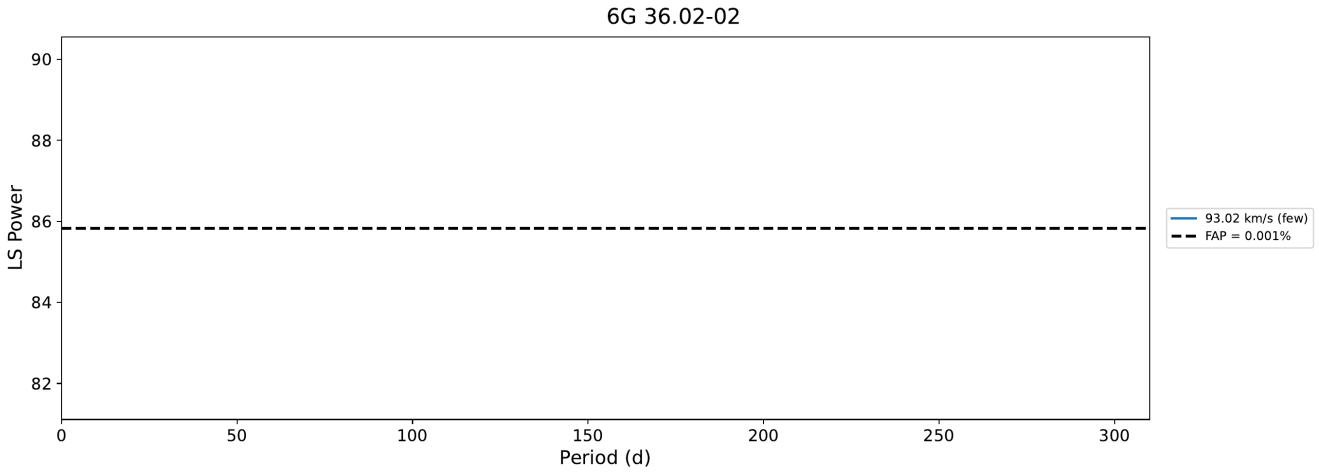


6G 36.02-02

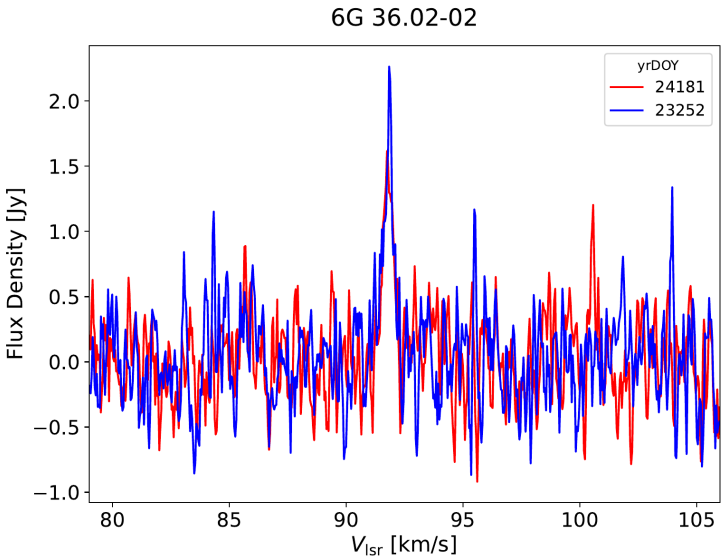
Light curve



Periodogram

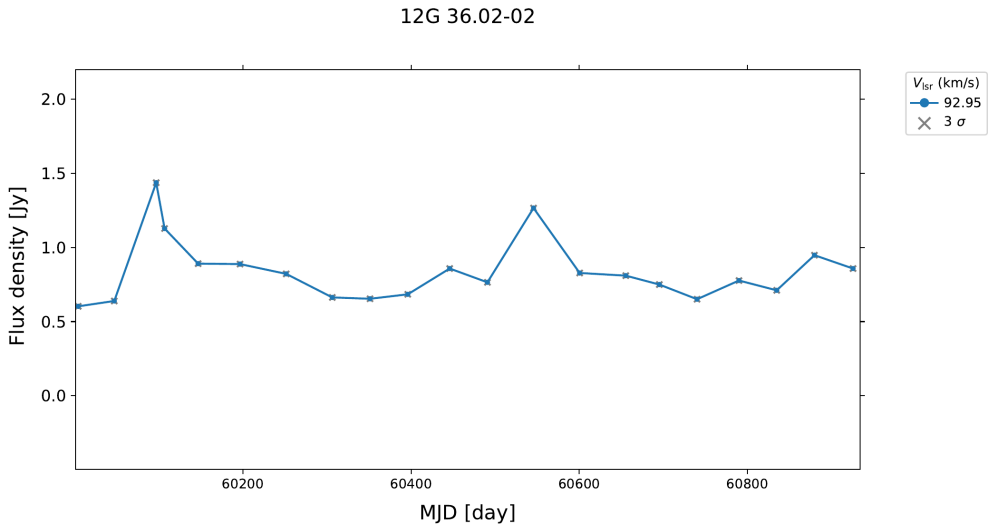


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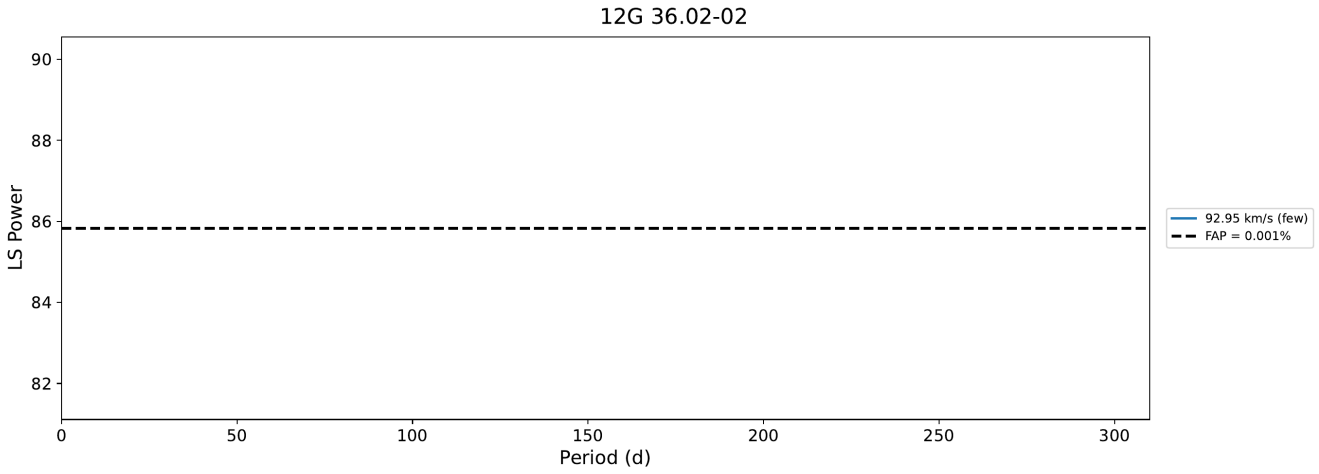


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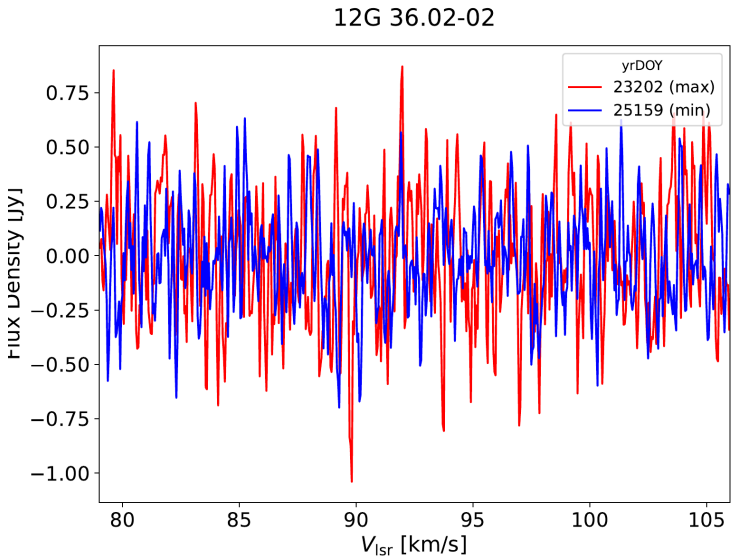
Light curve



Periodogram

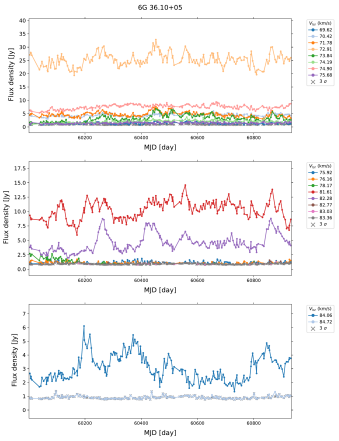


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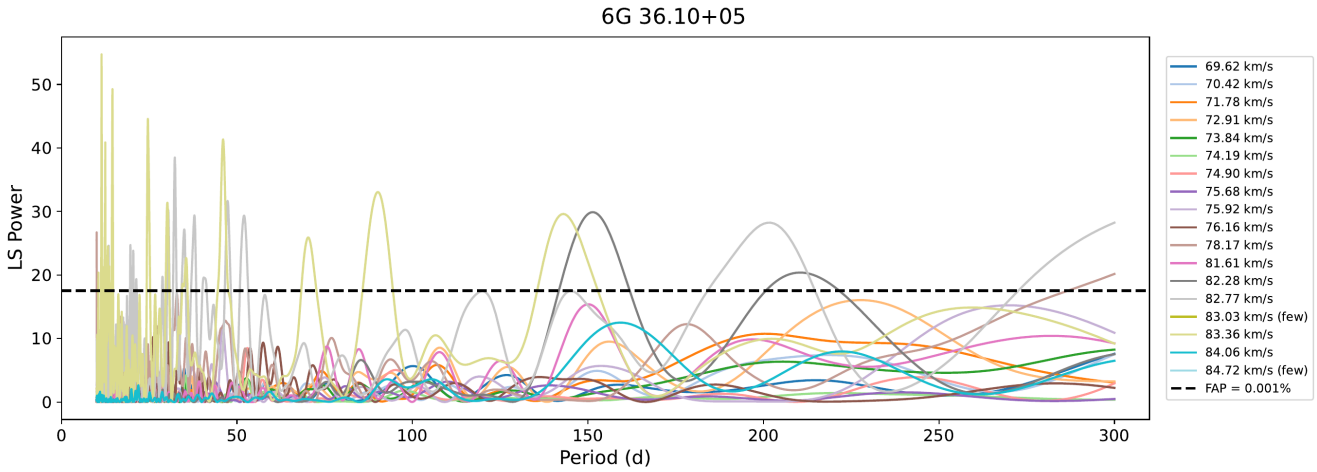


6G 36.10+05

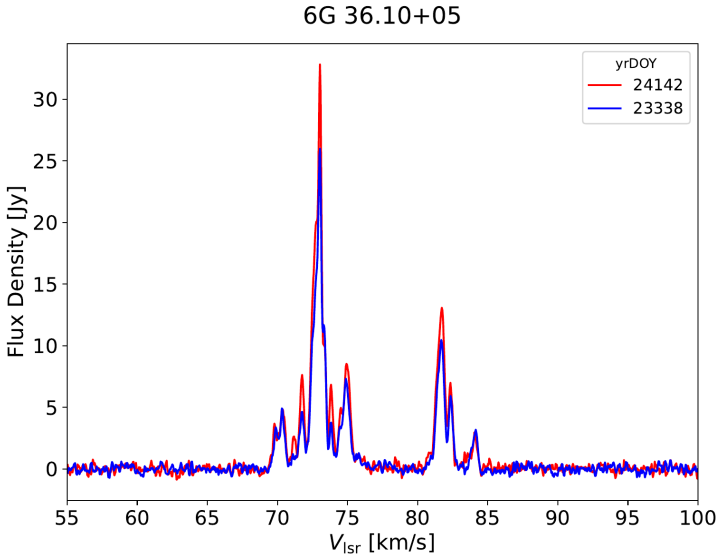
Light curve



Periodogram

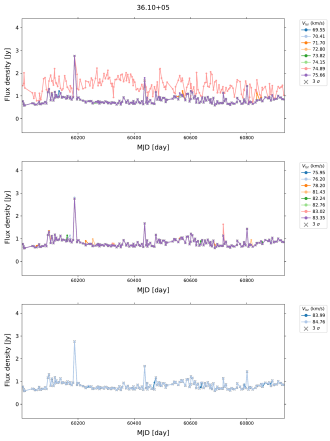


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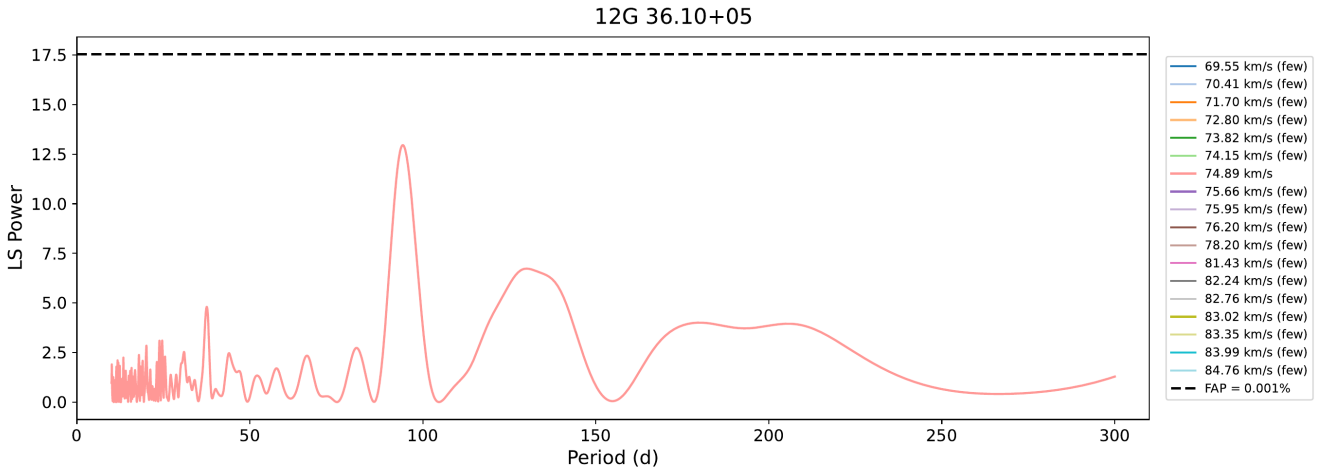


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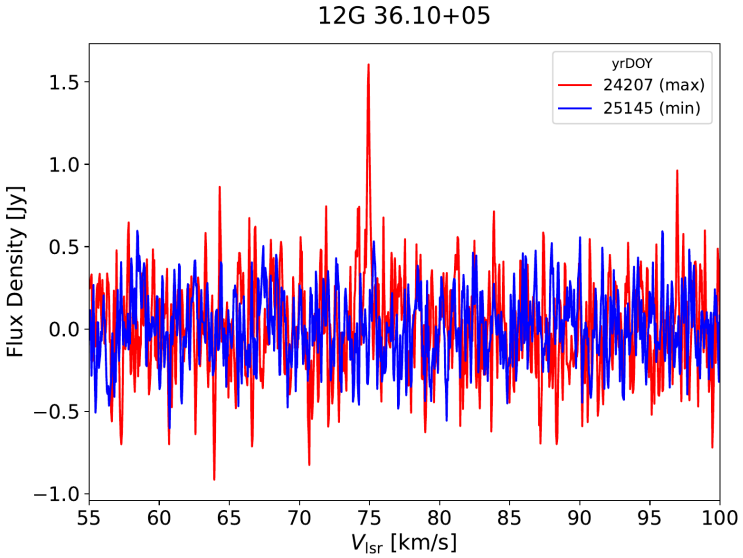
Light curve



Periodogram

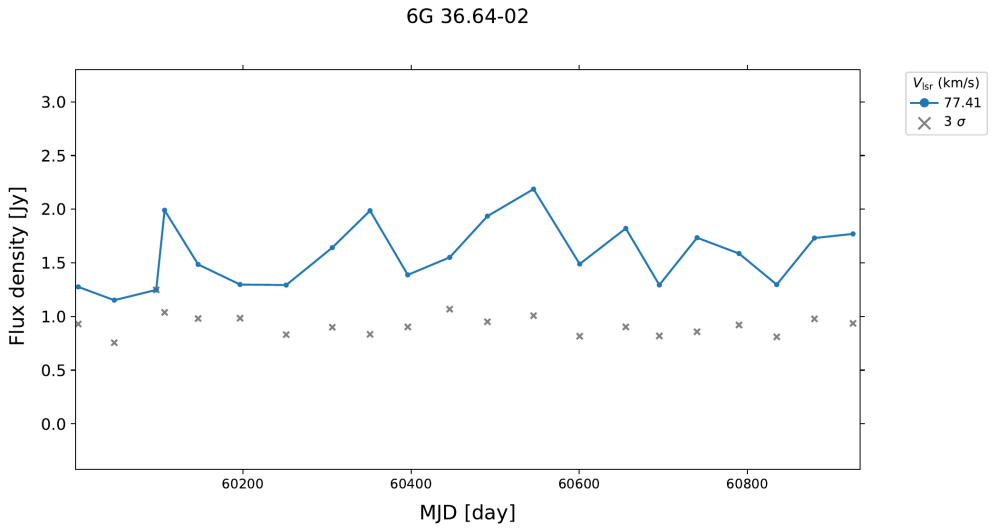


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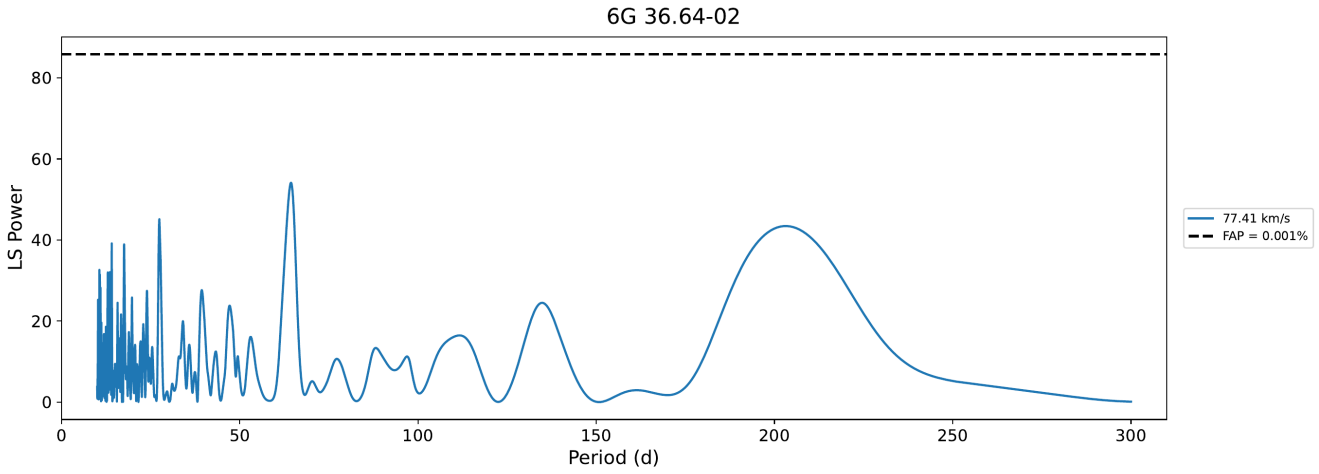


6G 36.64-02

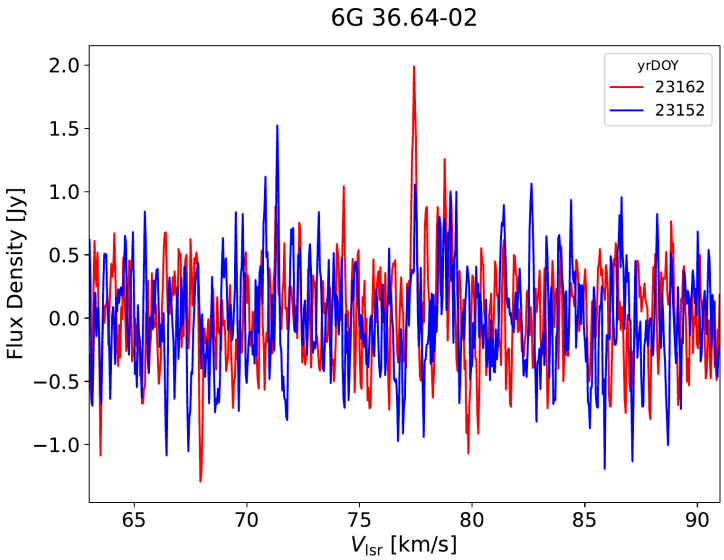
Light curve



Periodogram

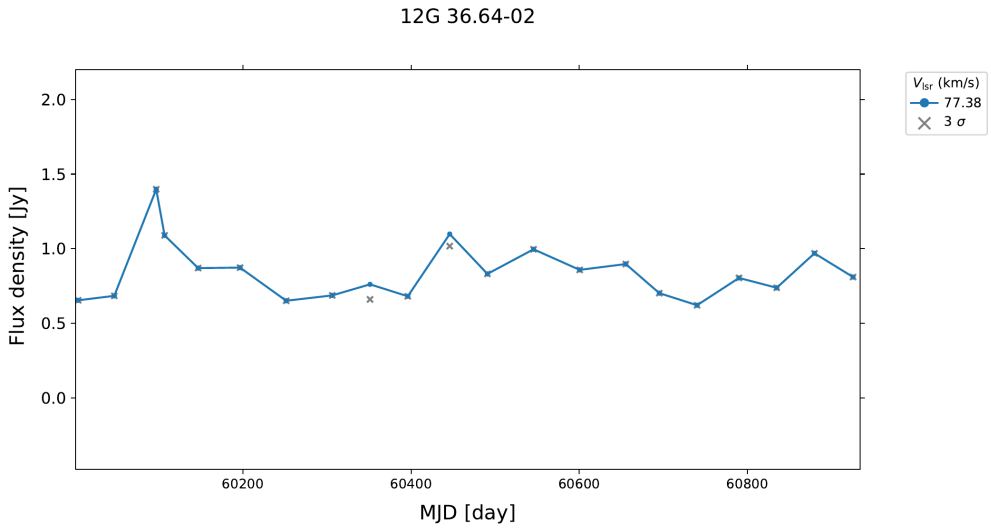


Spectrum

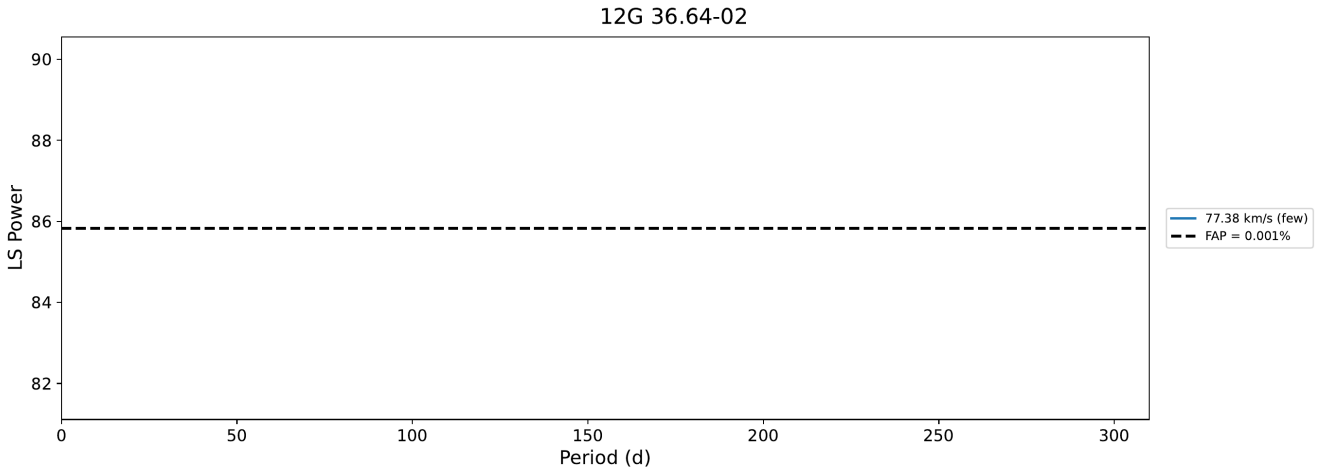


12G 36.64-02

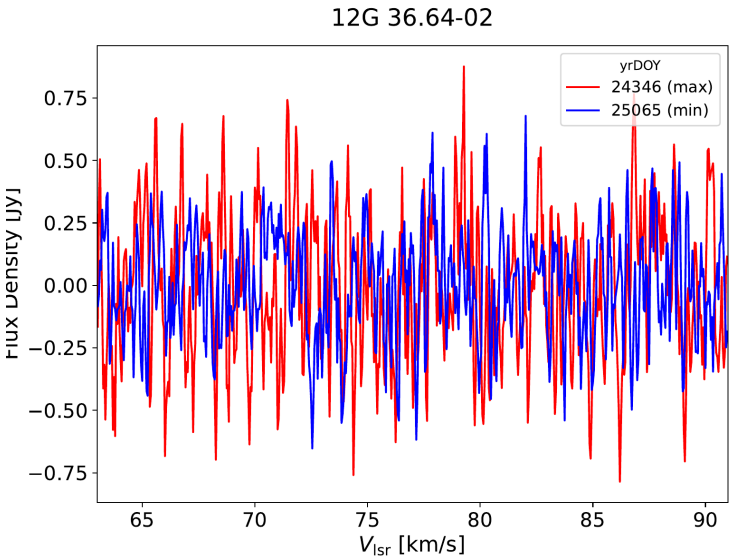
Light curve



Periodogram

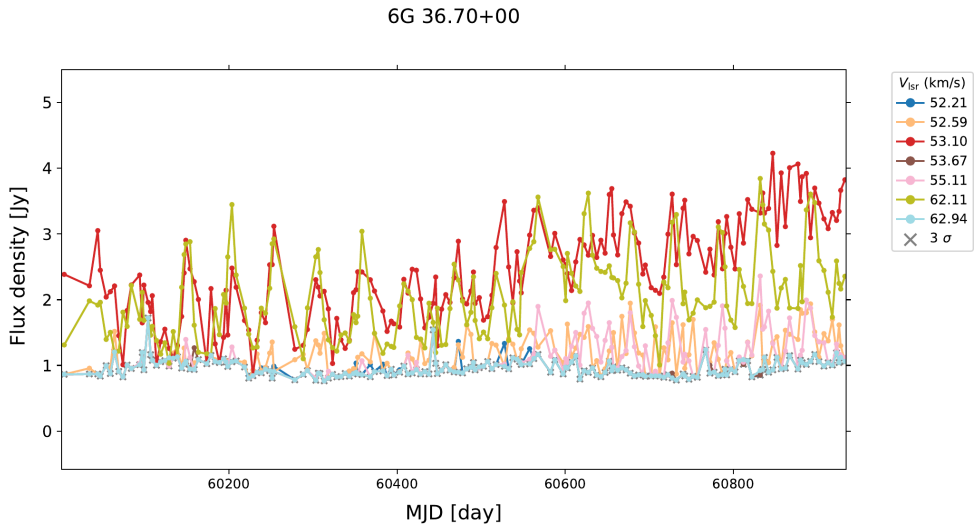


Spectrum

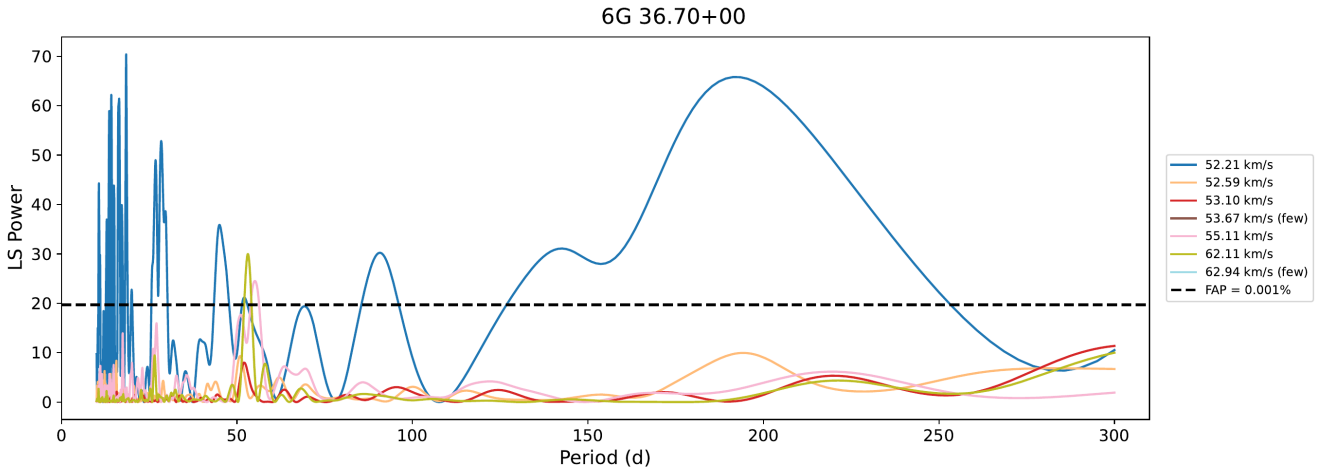


6G 36.70+00

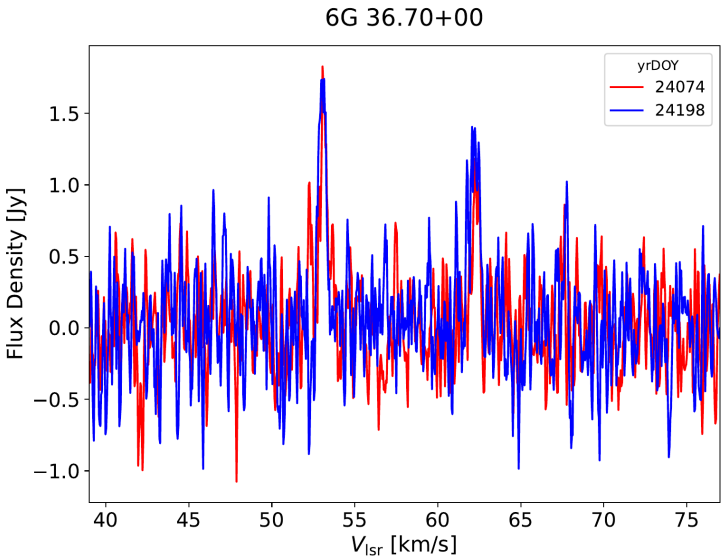
Light curve



Periodogram

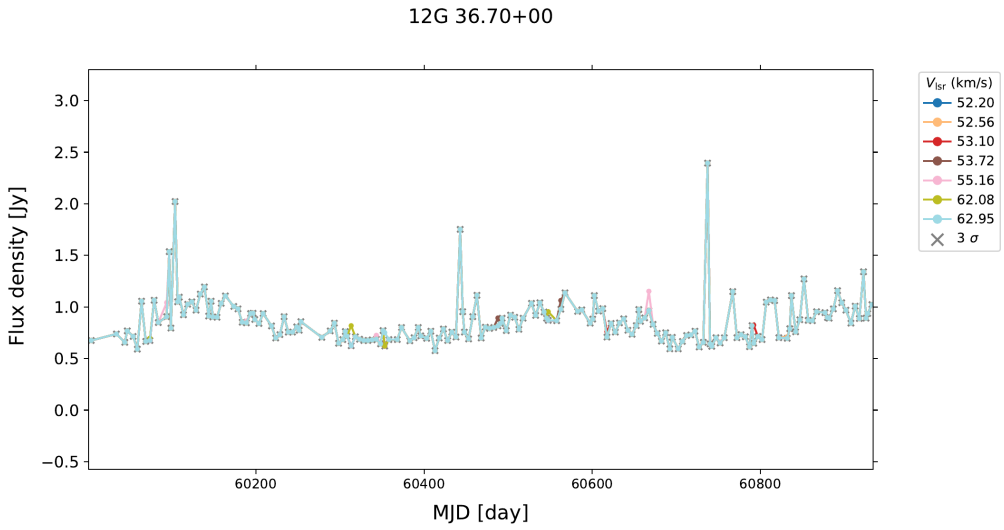


Spectrum

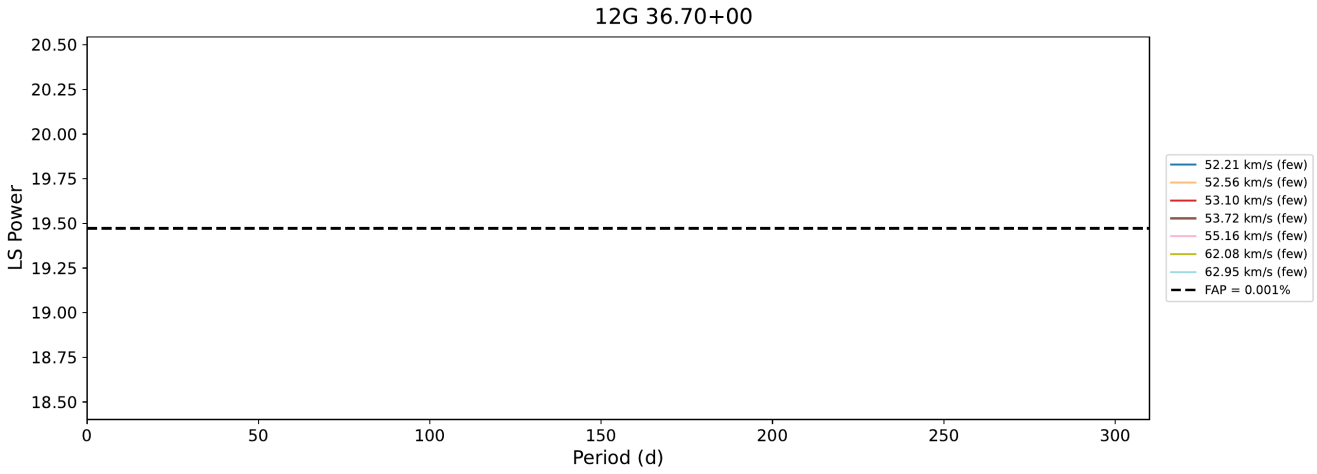


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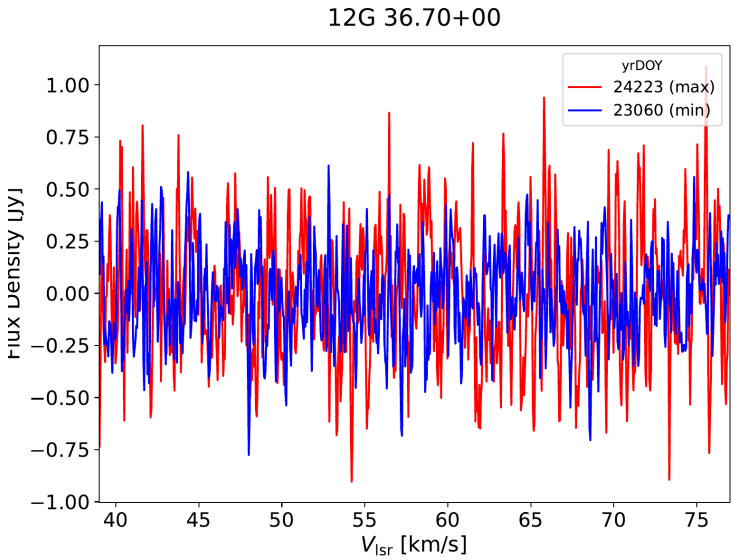
Light curve



Periodogram

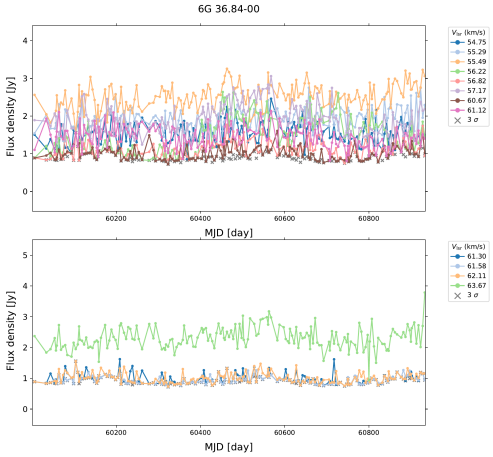


Spectrum

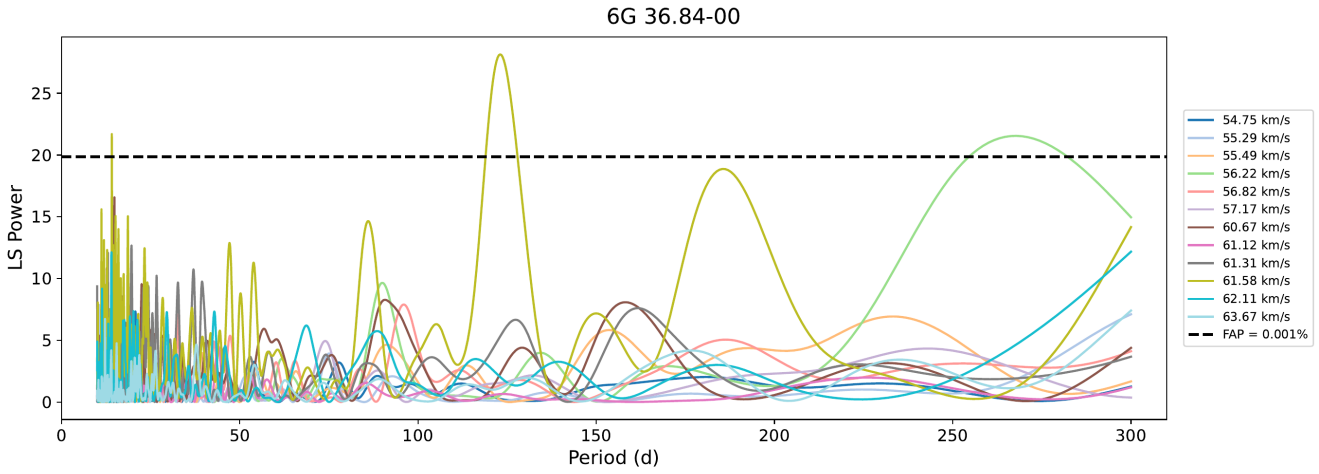


6G 36.84-00

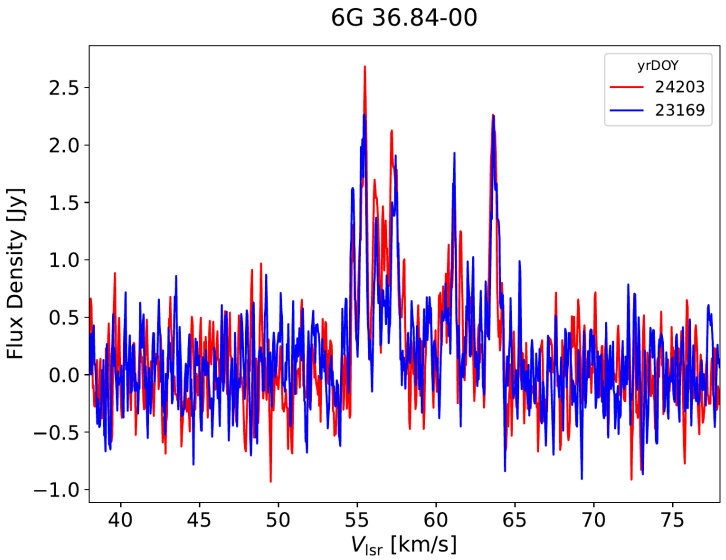
Light curve



Periodogram

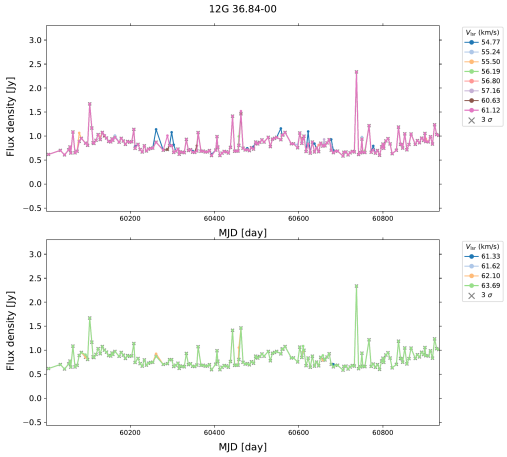


Spectrum

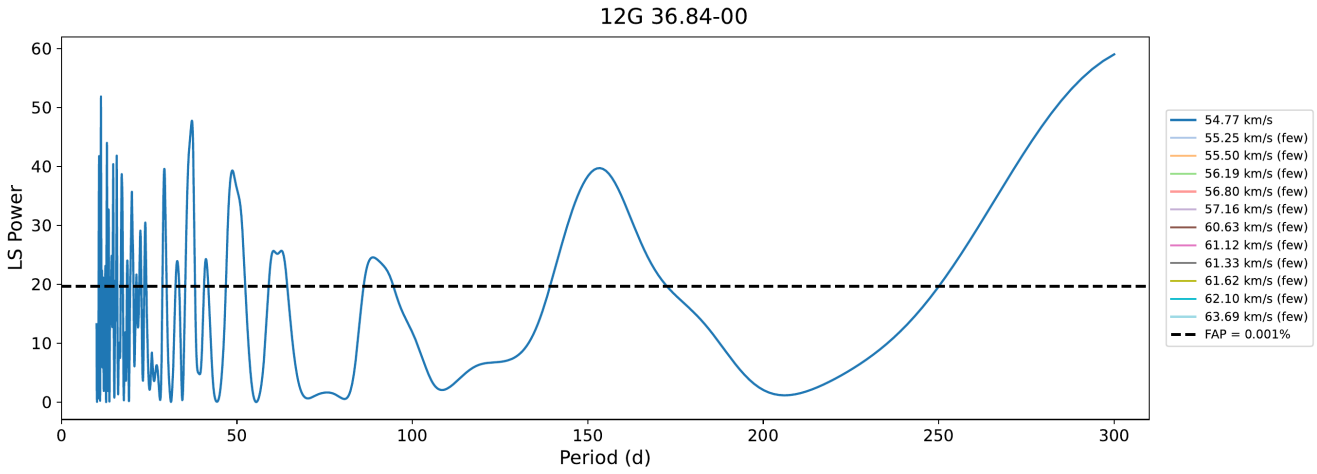


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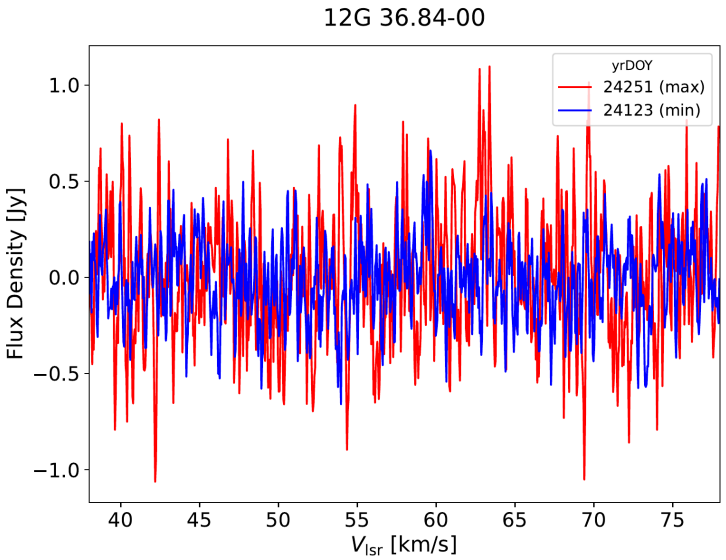
Light curve



Periodogram

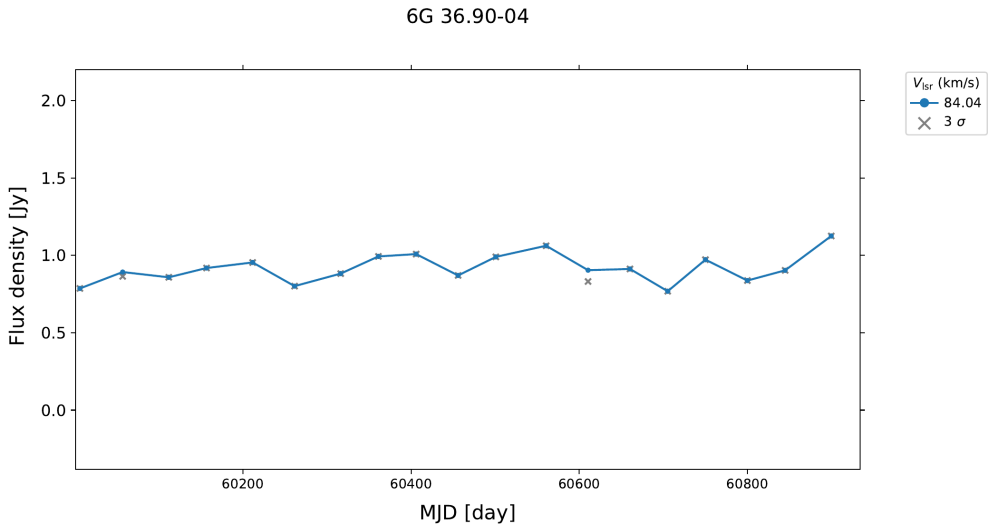


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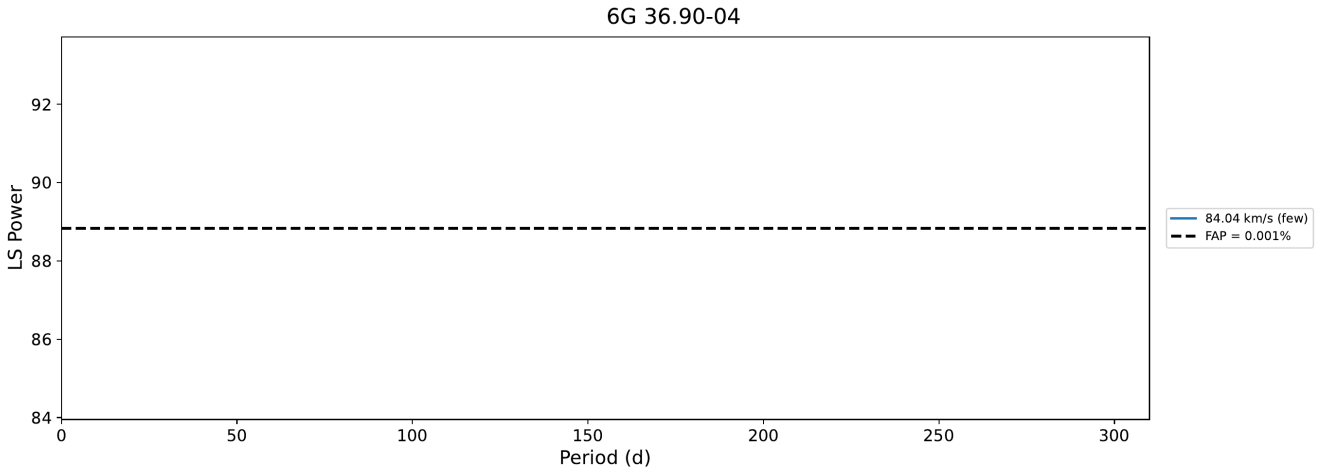


6G 36.90-04

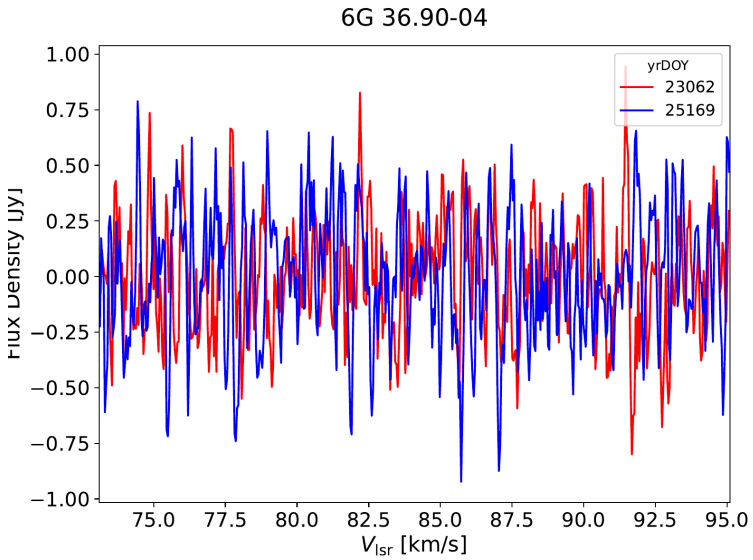
Light curve



Periodogram

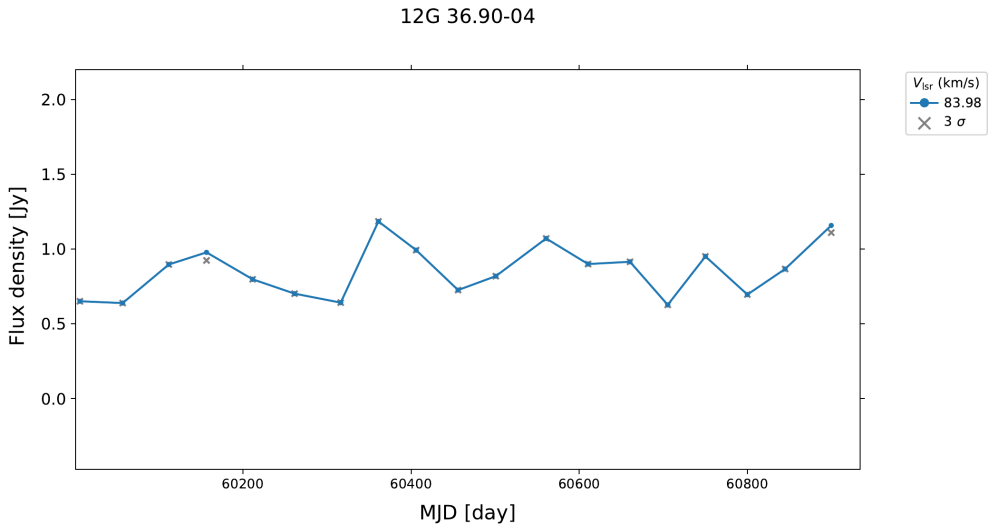


Spectrum

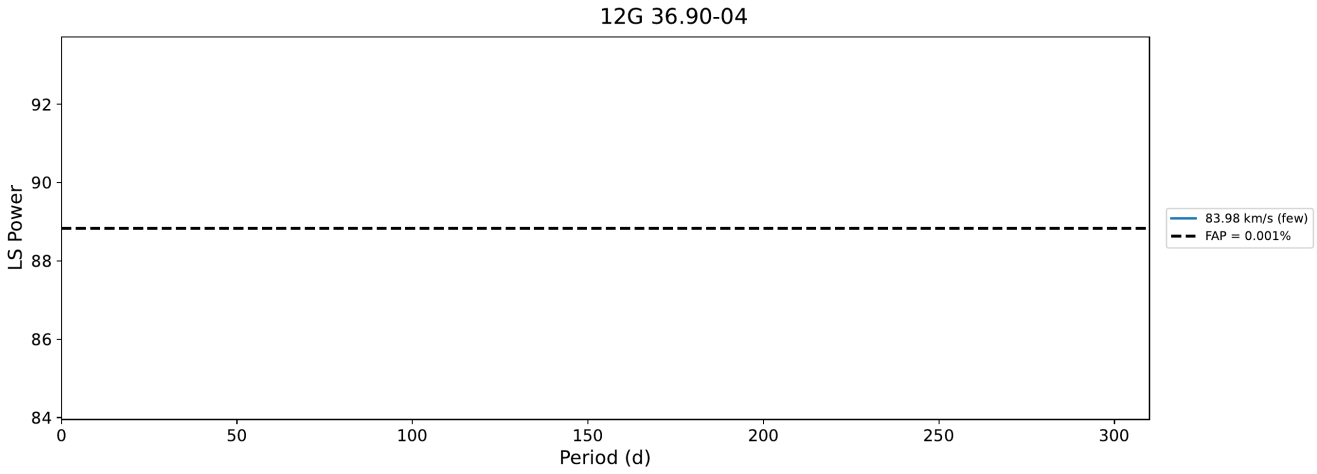


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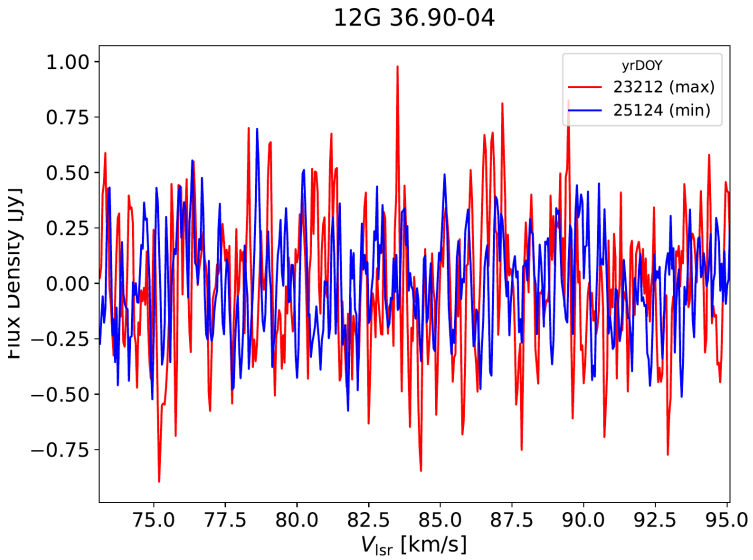
Light curve



Periodogram

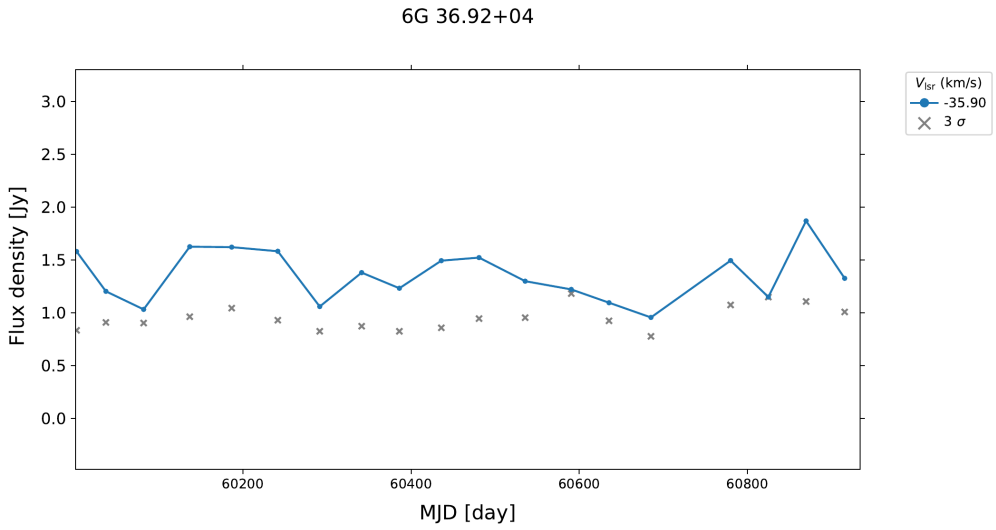


Spectrum

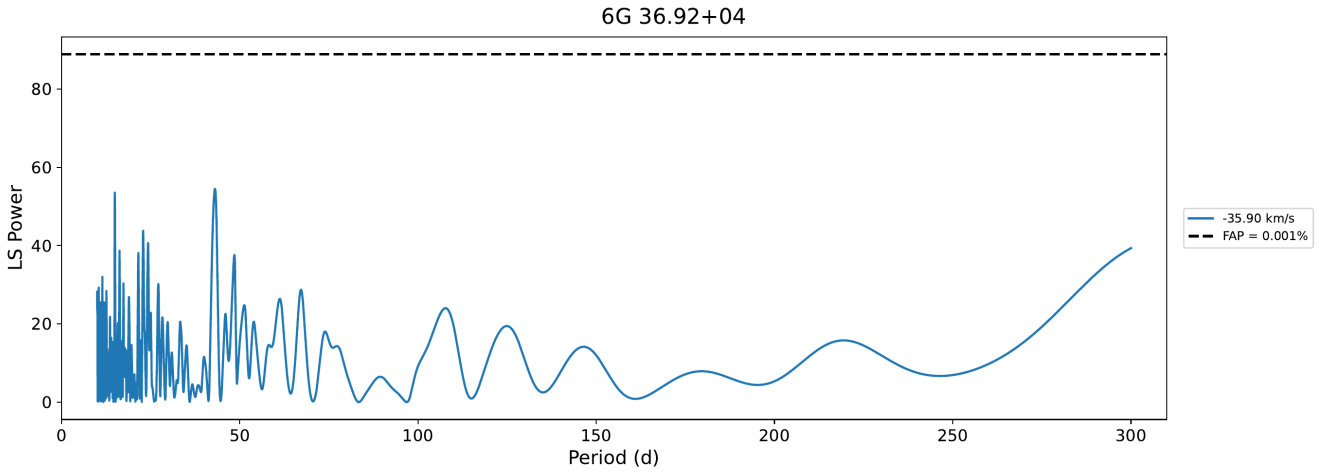


6G 36.92+04

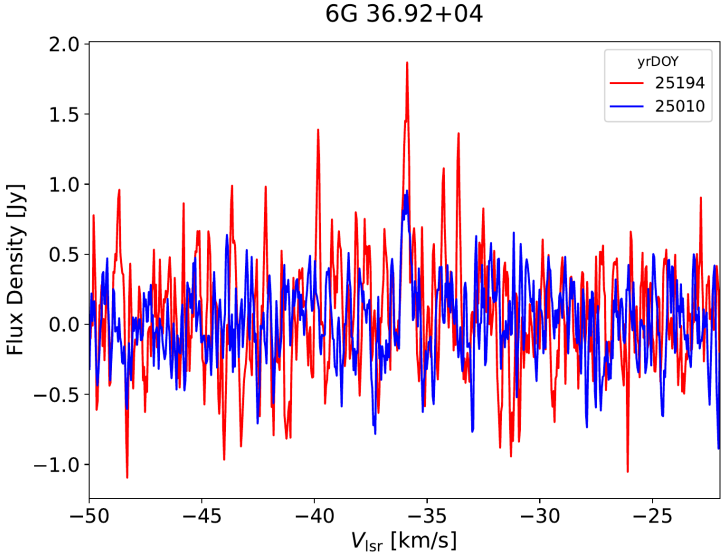
Light curve



Periodogram

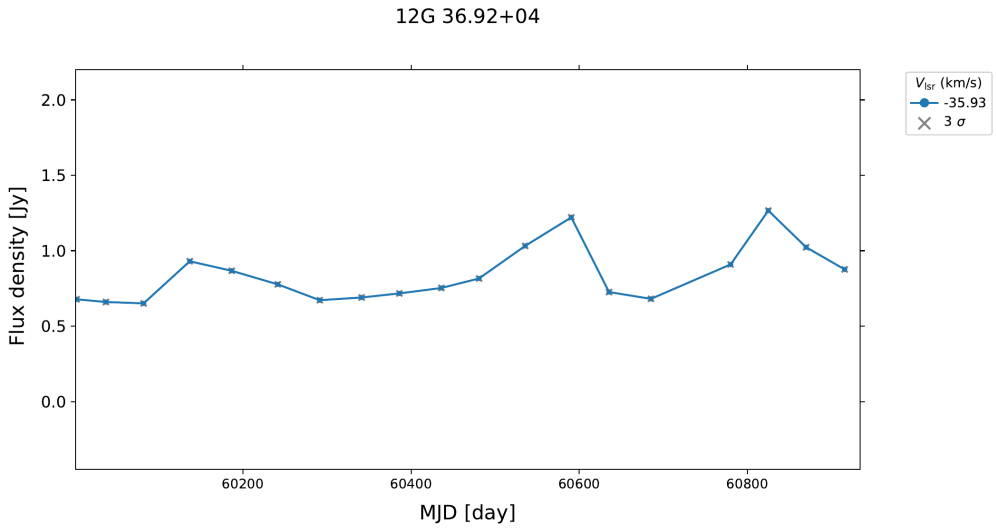


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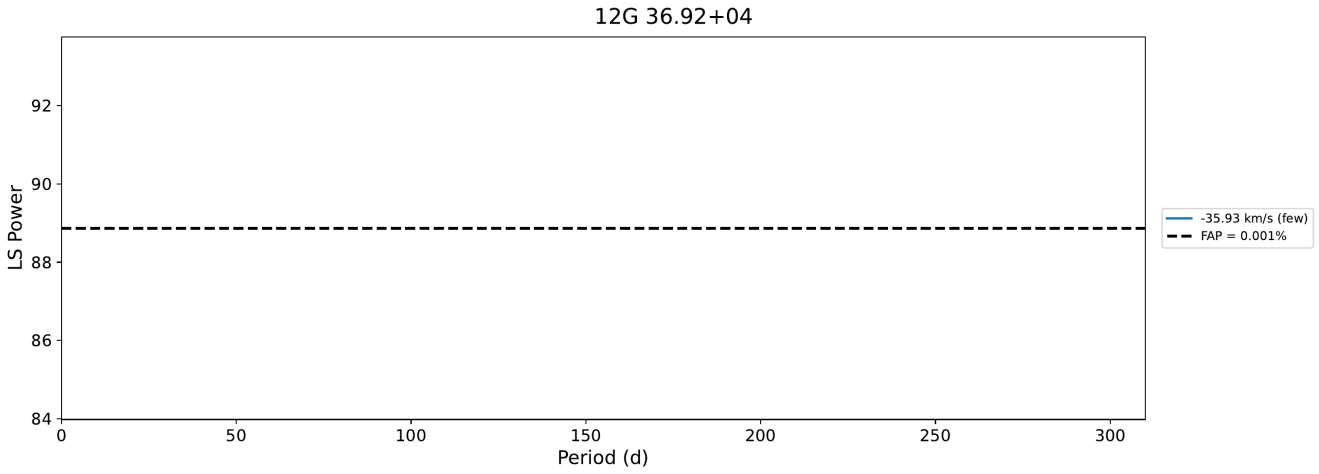


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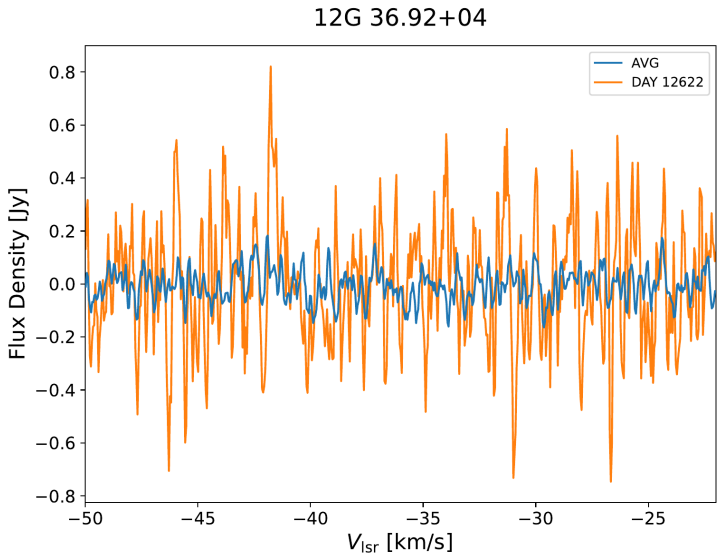
Light curve



Periodogram

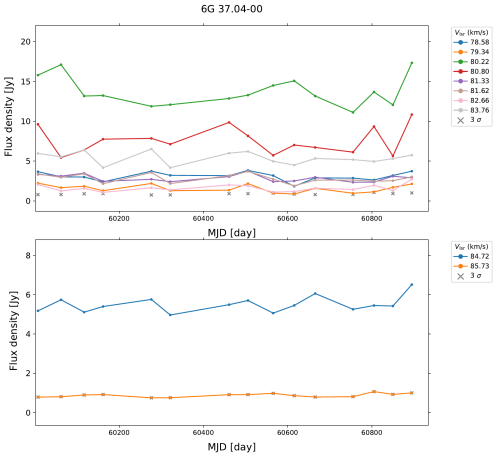


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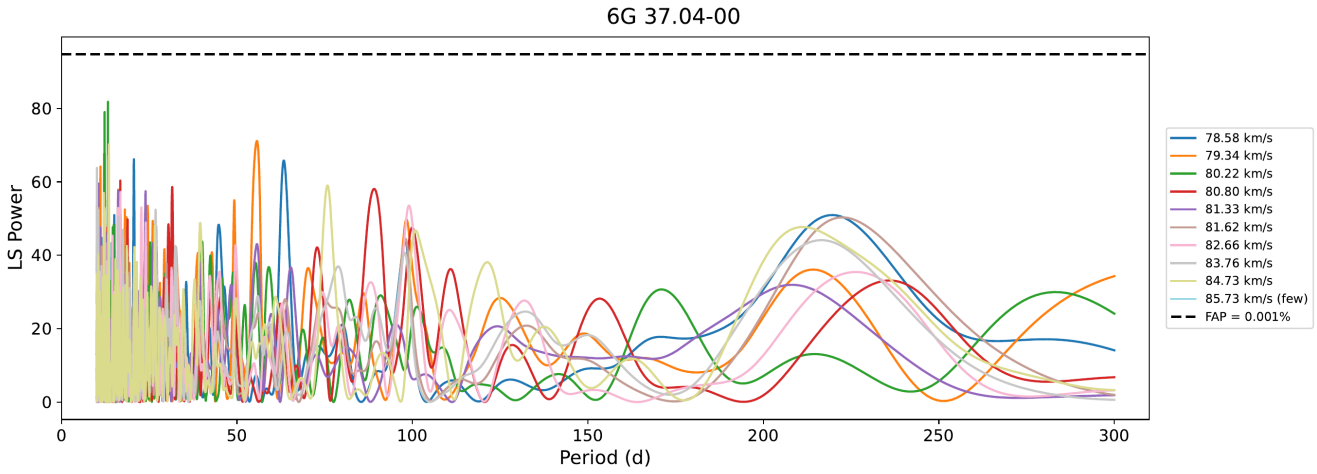


6G 37.04-00

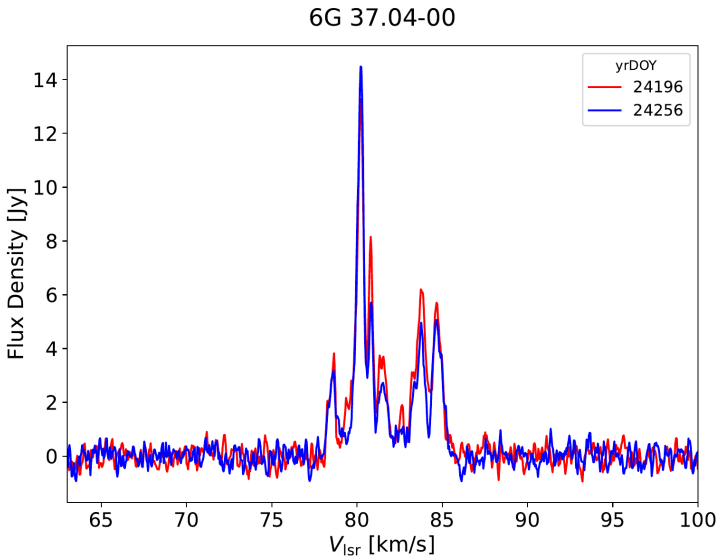
Light curve



Periodogram

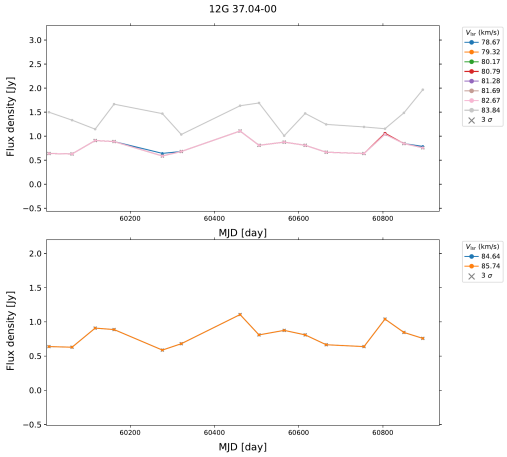


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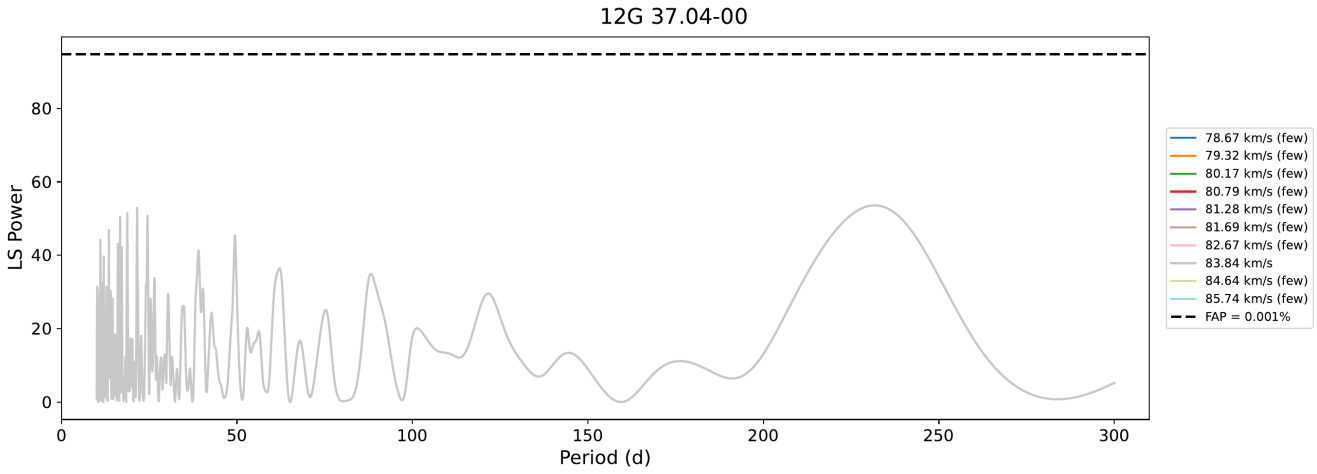


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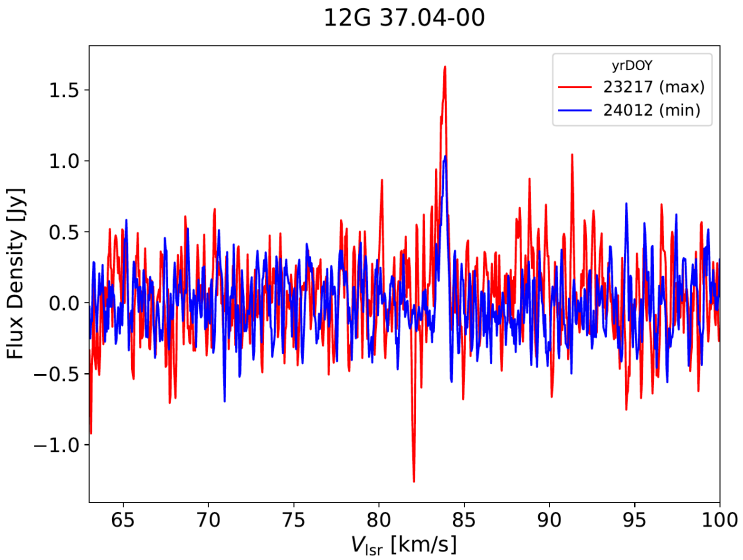
Light curve



Periodogram

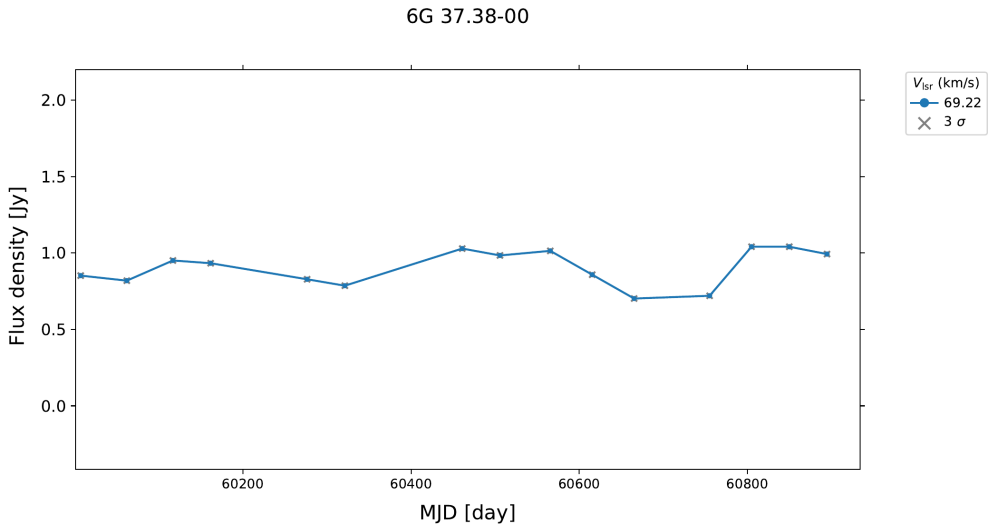


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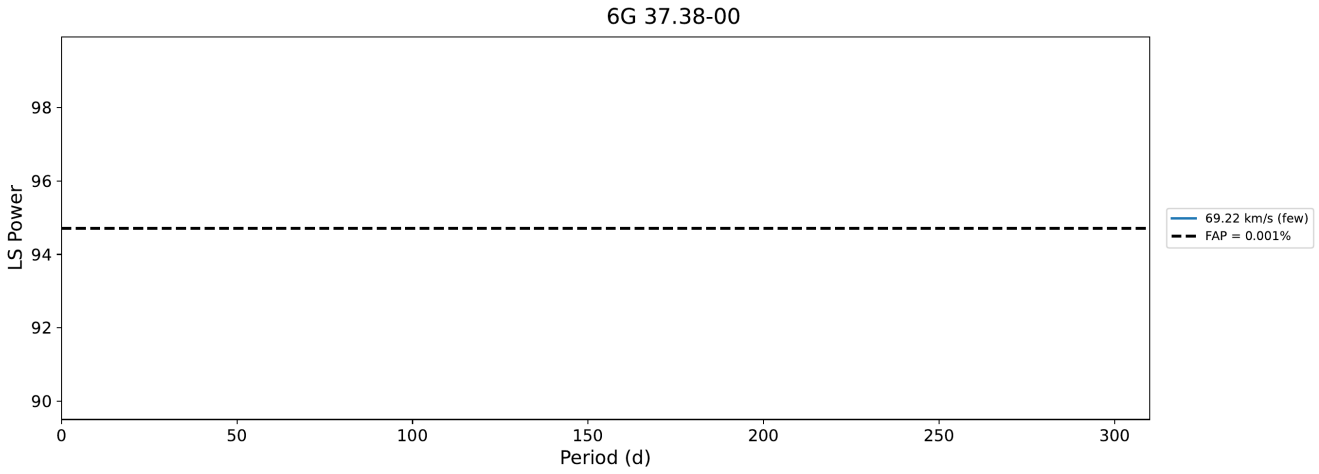


6G 37.38-00

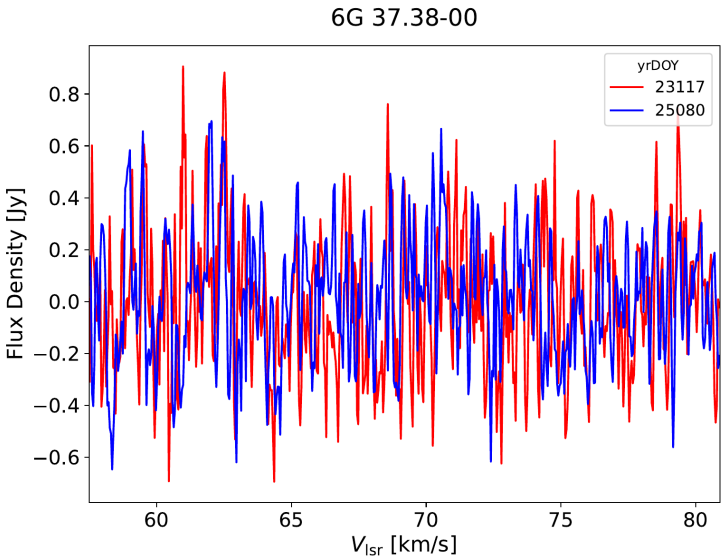
Light curve



Periodogram

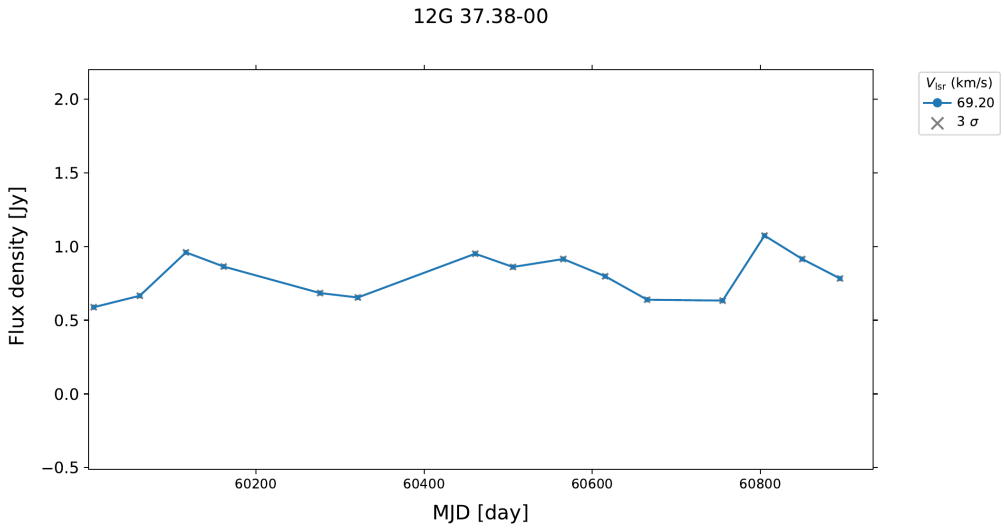


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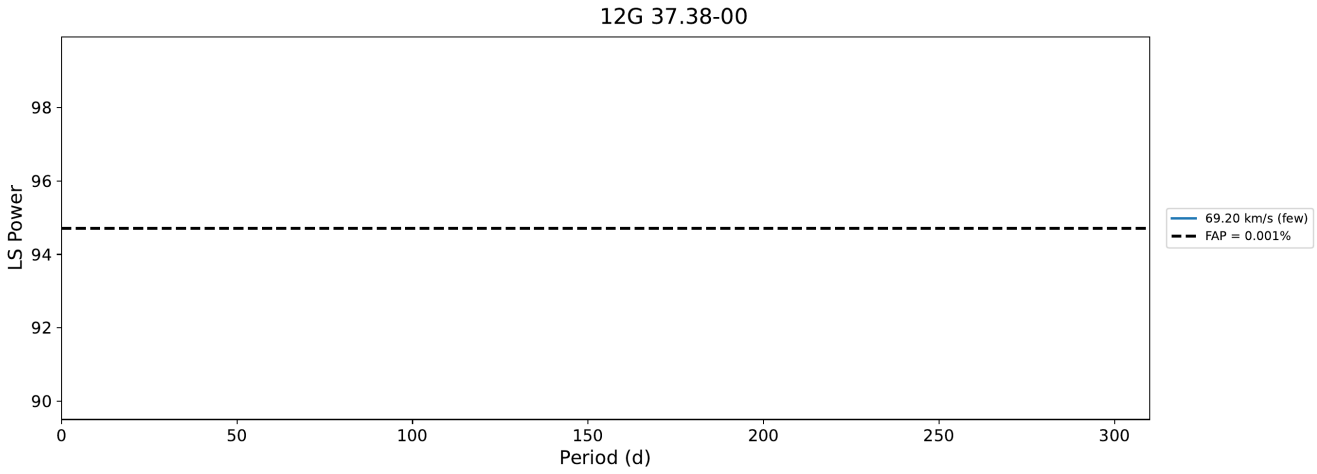


12G 37.38-00

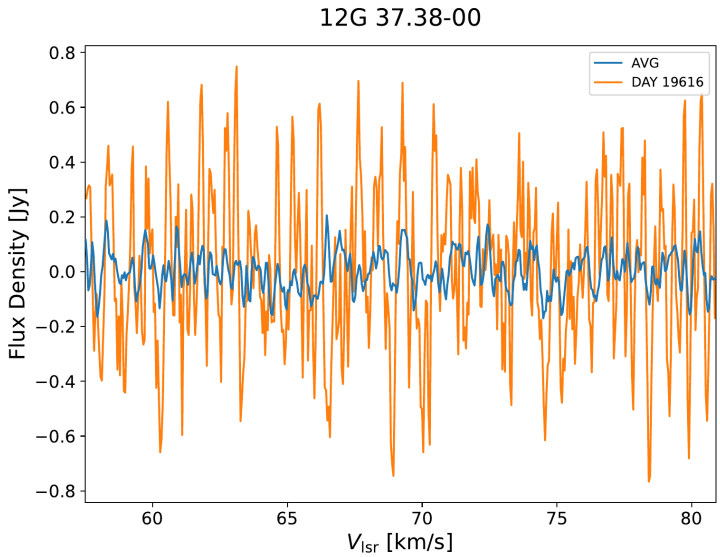
Light curve



Periodogram

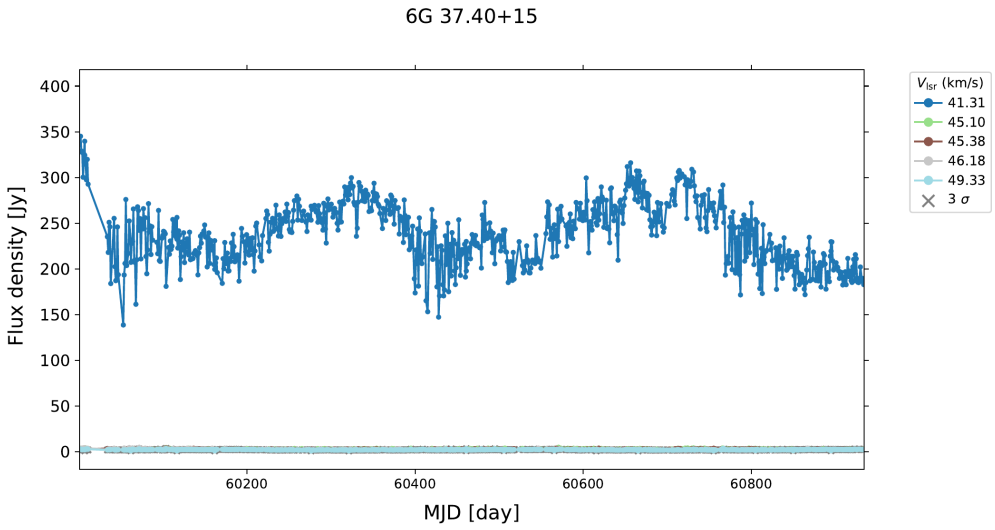


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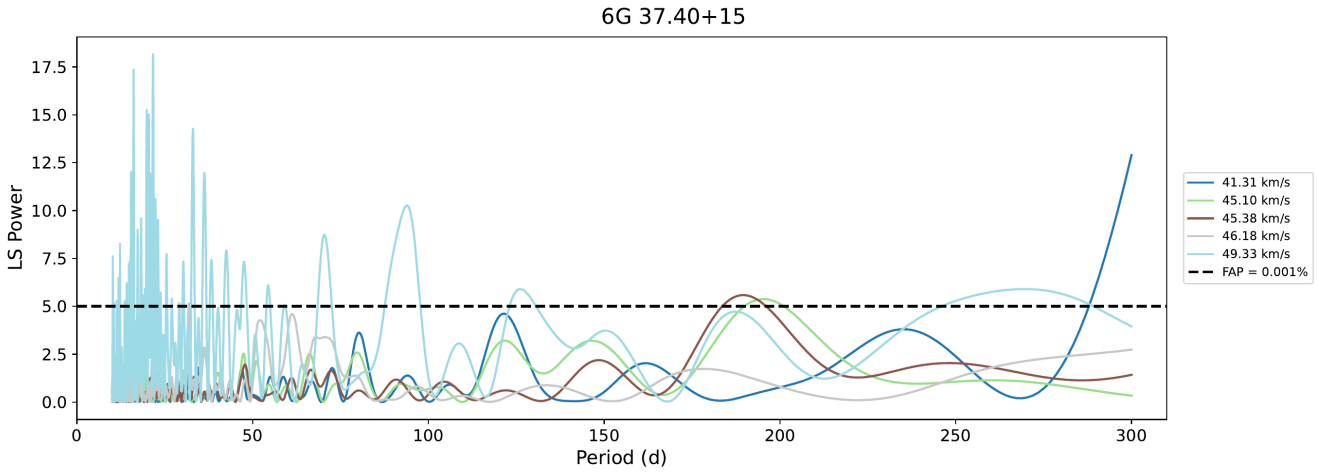


6G 37.40+15

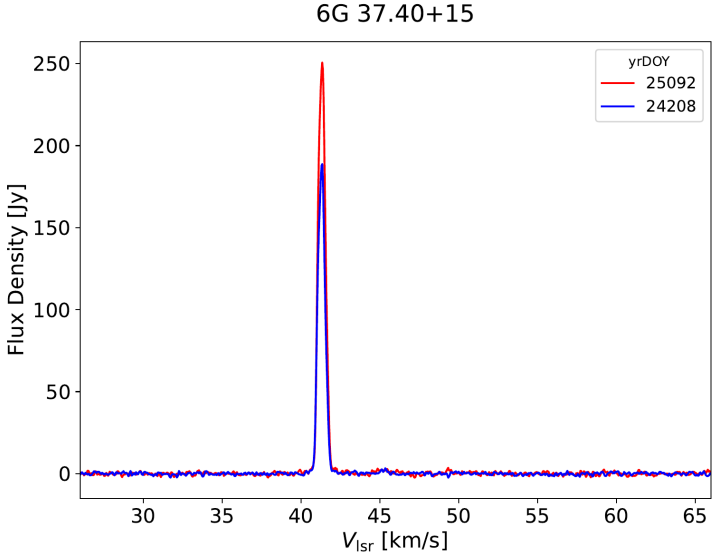
Light curve



Periodogram

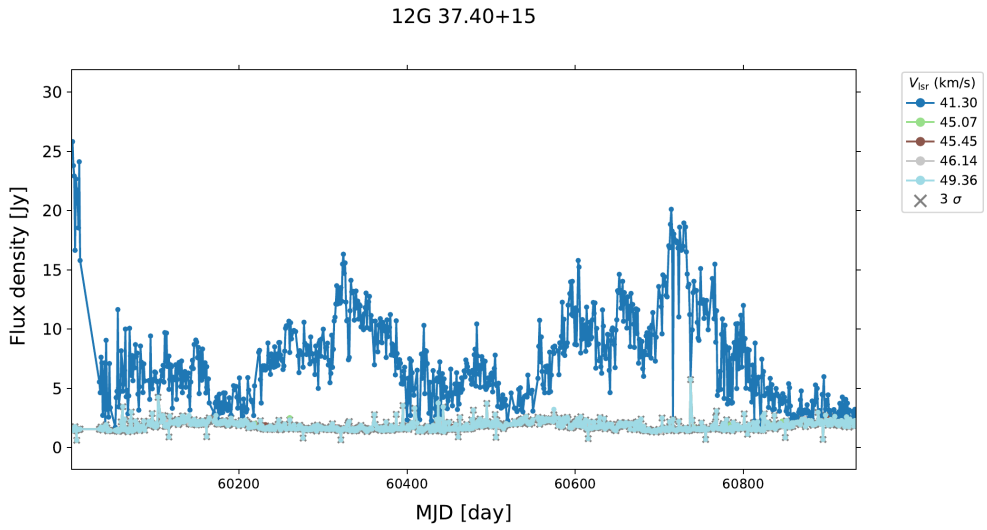


Spectrum

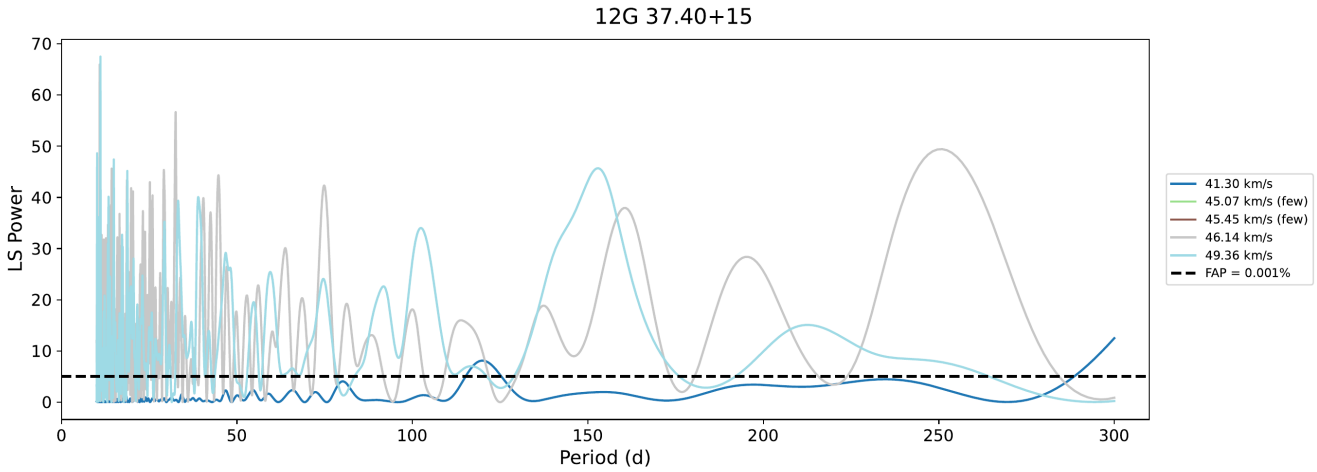


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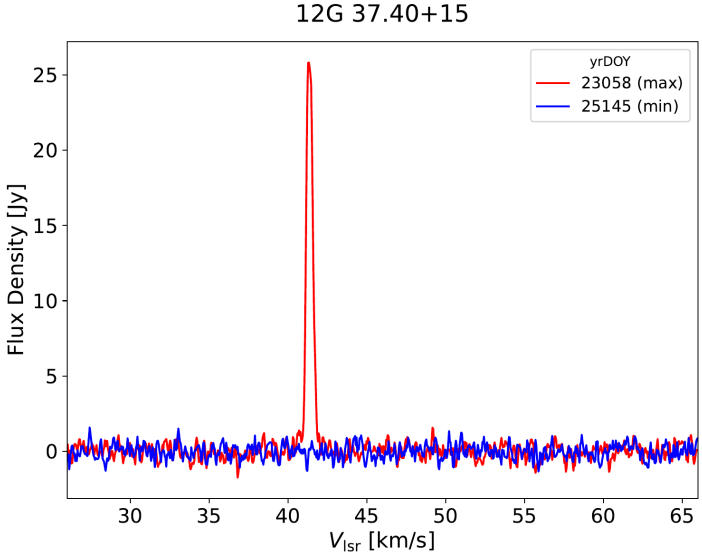
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Periodogram

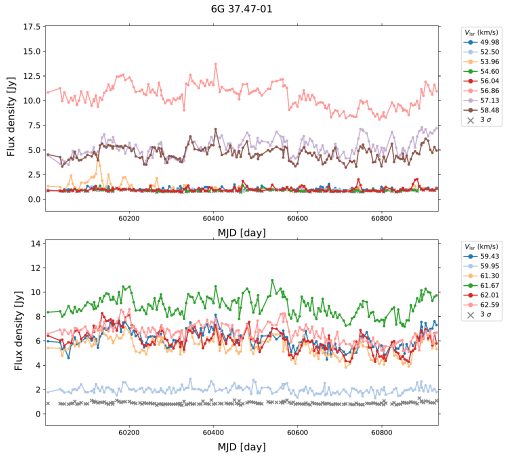


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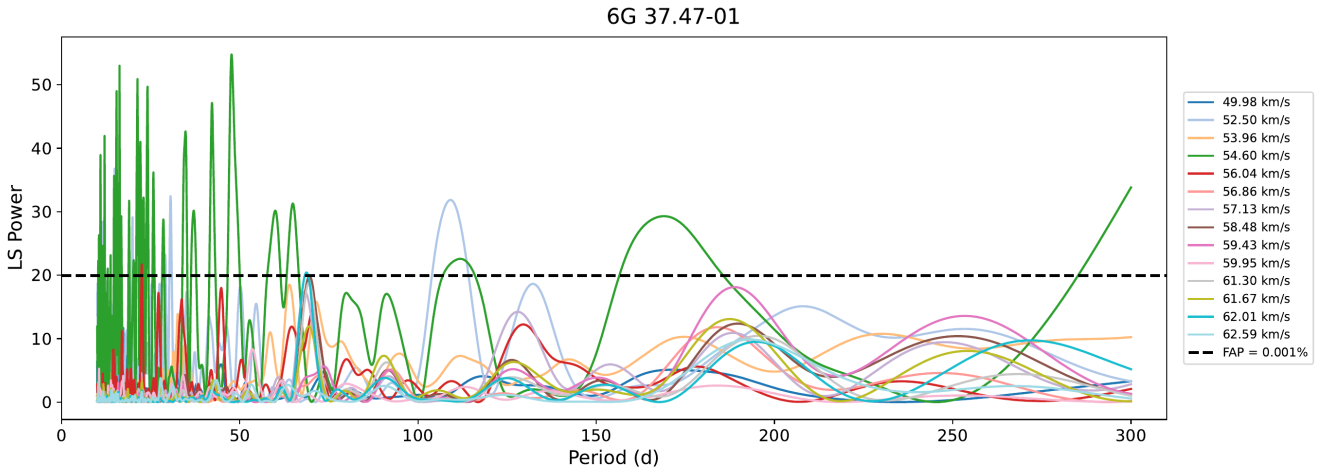


6G 37.47-01

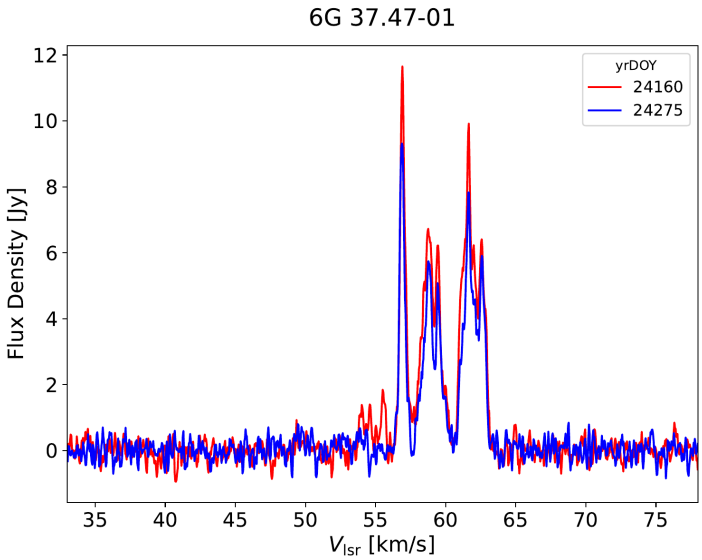
Light curve



Periodogram

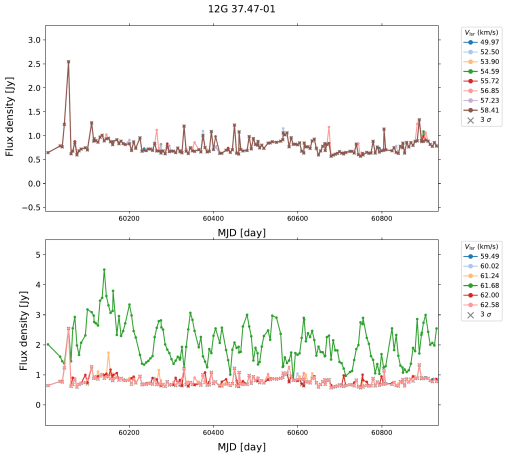


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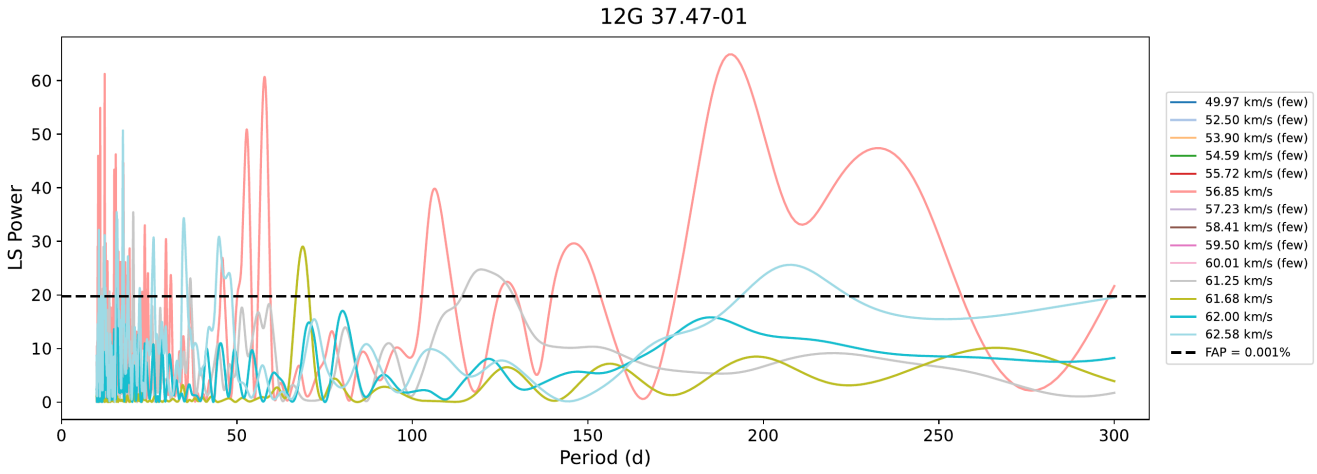


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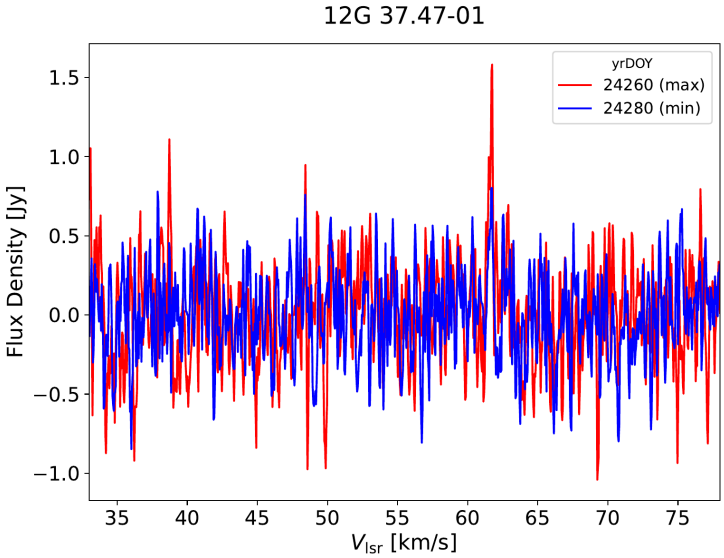
Light curve



Periodogram

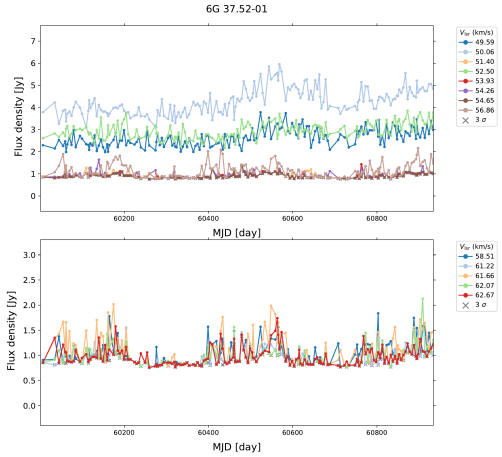


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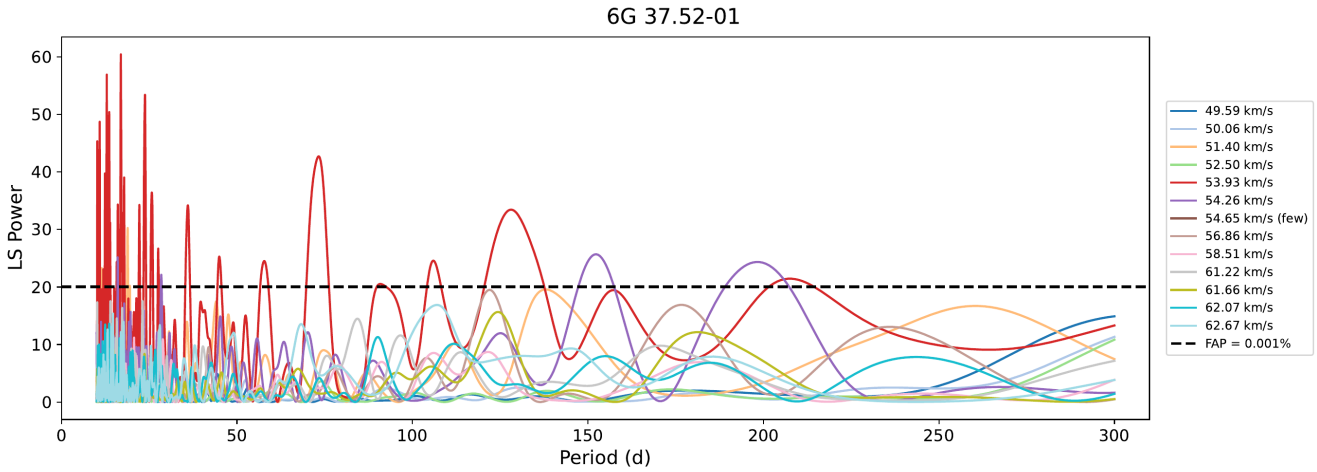


6G 37.52-01

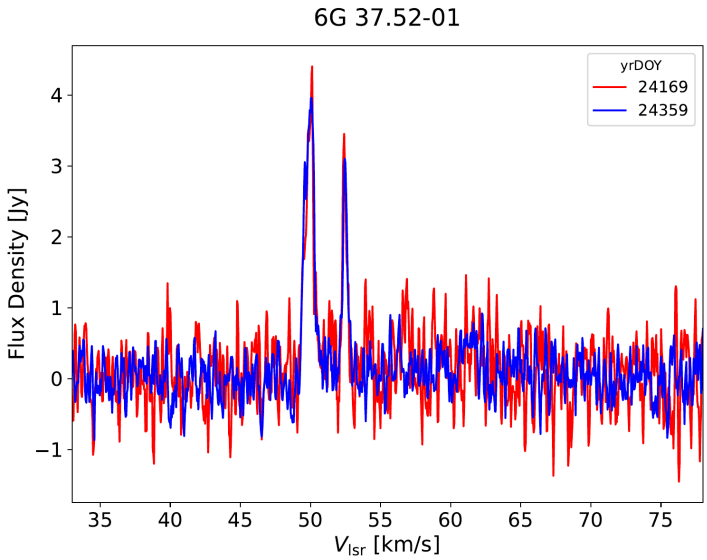
Light curve



Periodogram

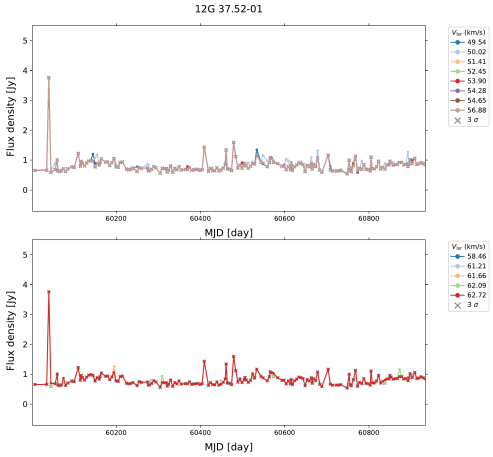


Spectrum

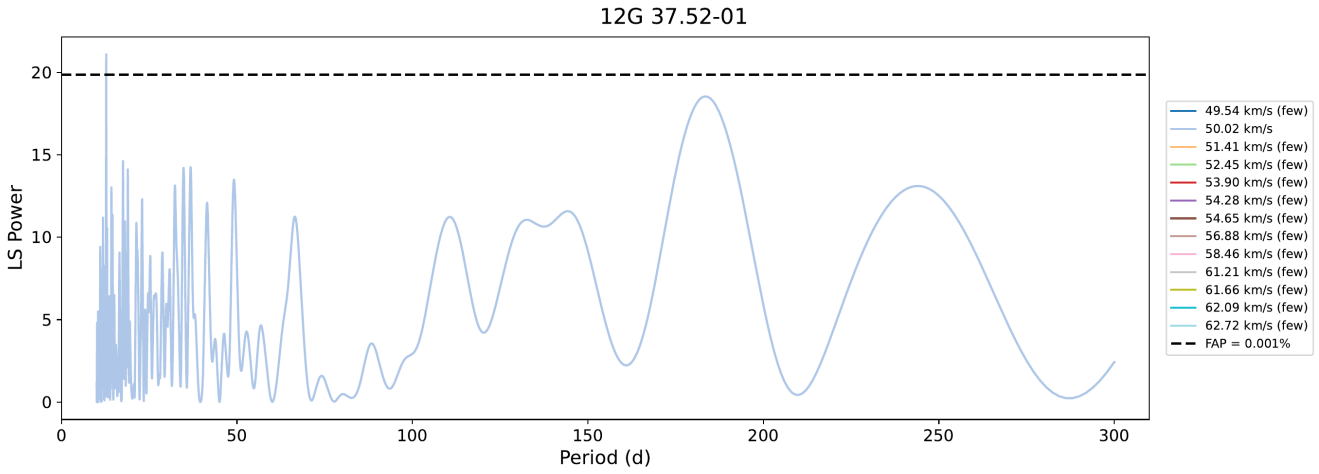


12G 37.52-01

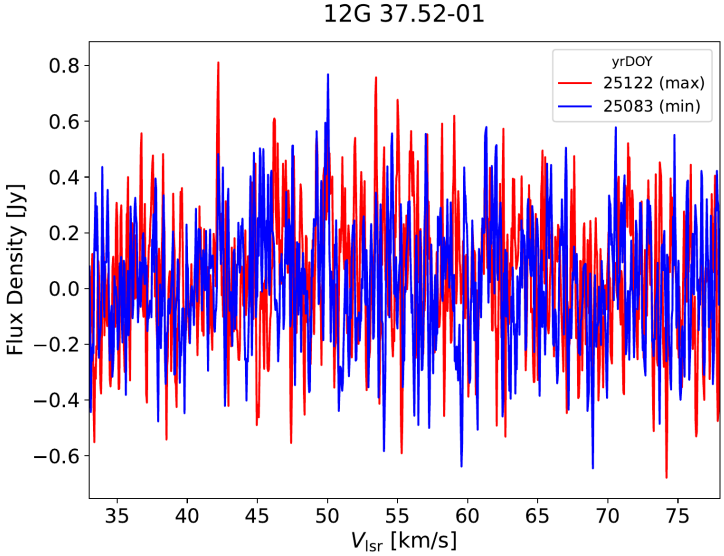
Light curve



Periodogram

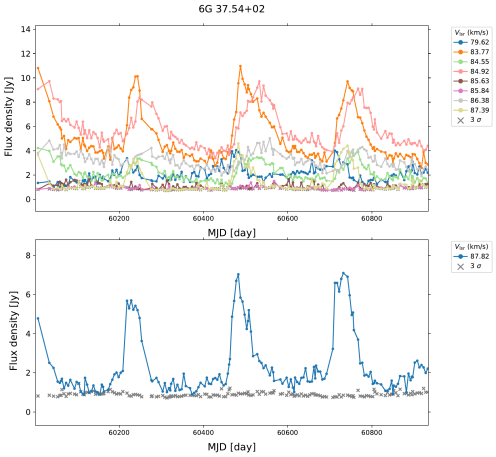


Spectrum

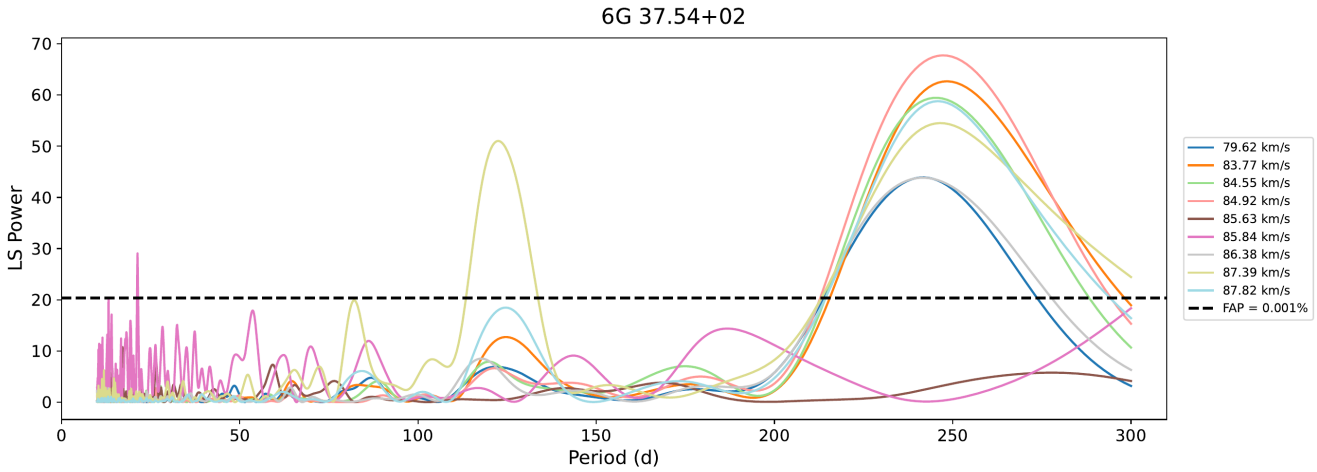


6G 37.54+02

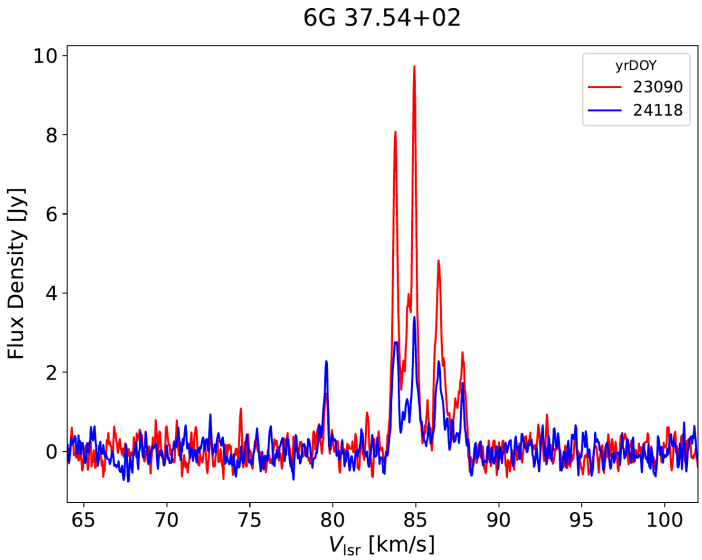
Light curve



Periodogram

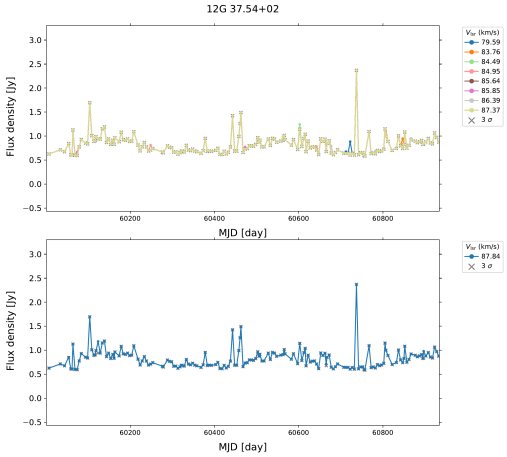


Spectrum

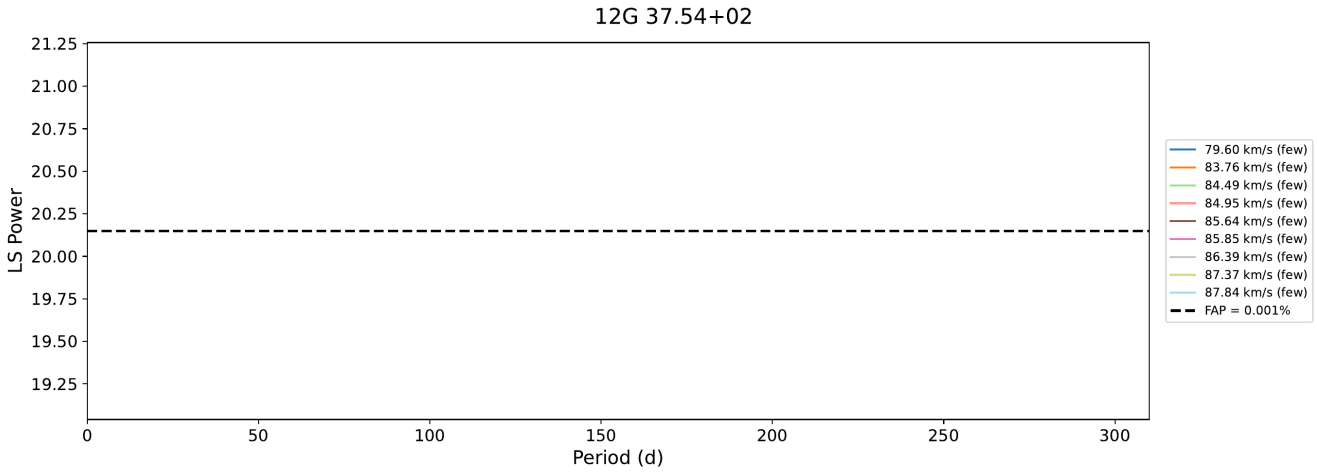


12G 37.54+02

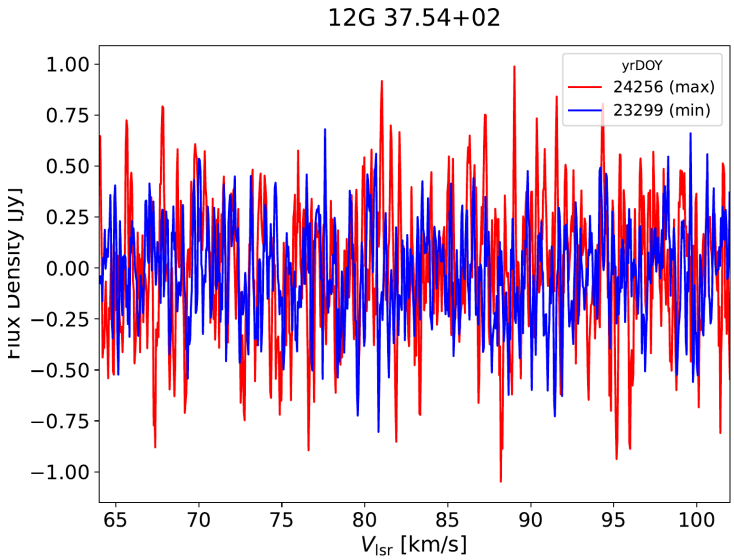
Light curve



Periodogram

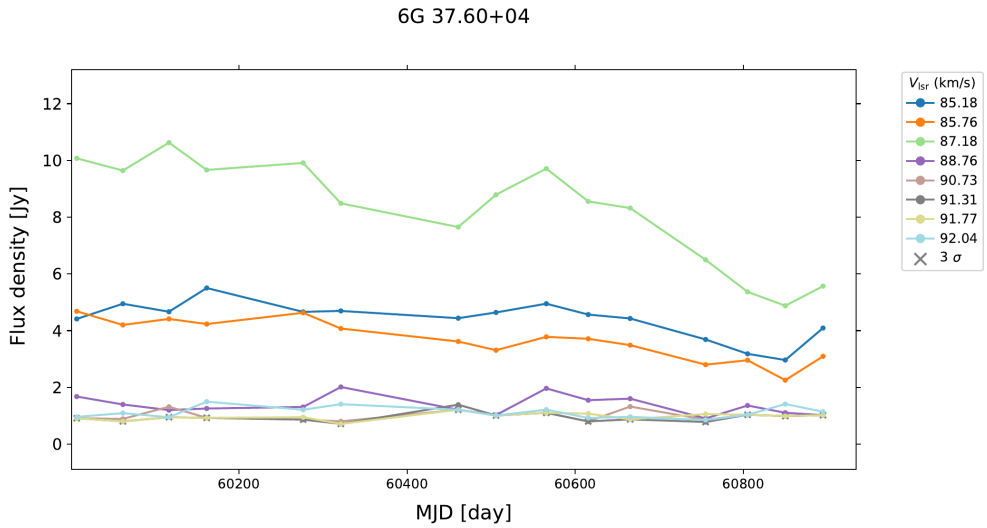


Spectrum

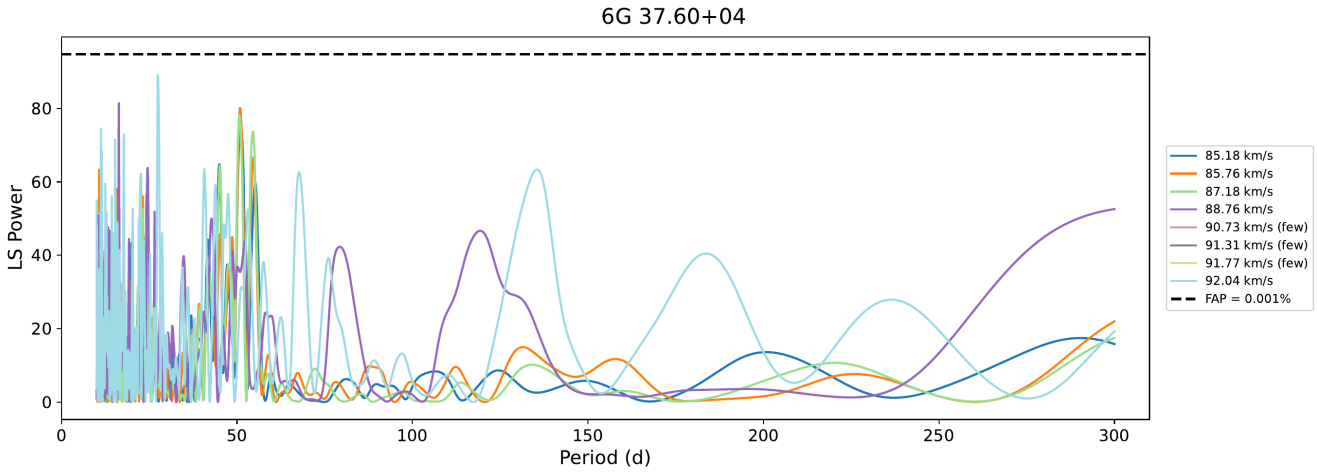


6G 37.60+04

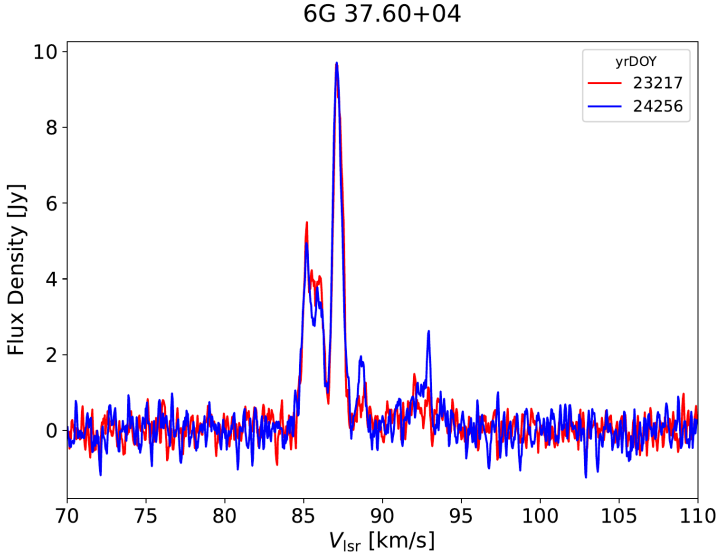
Light curve



Periodogram

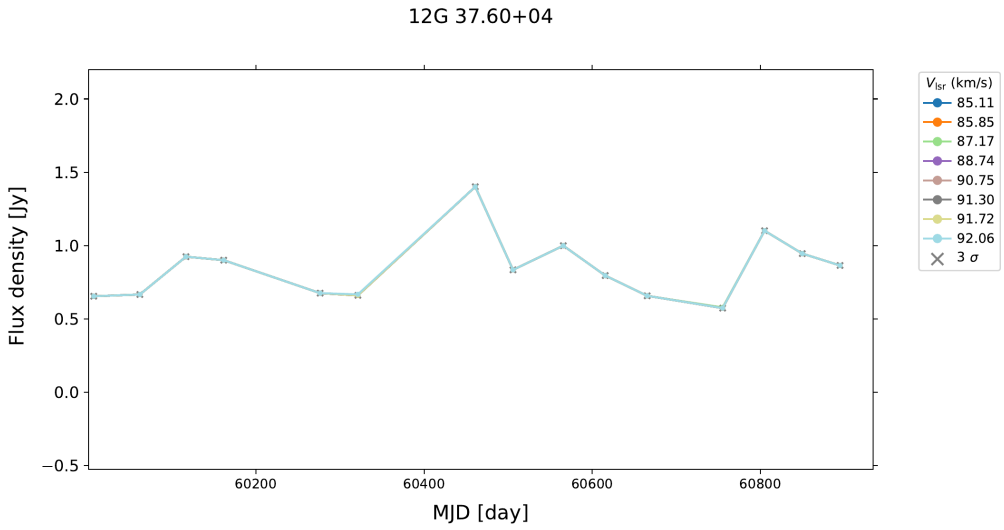


Spectrum

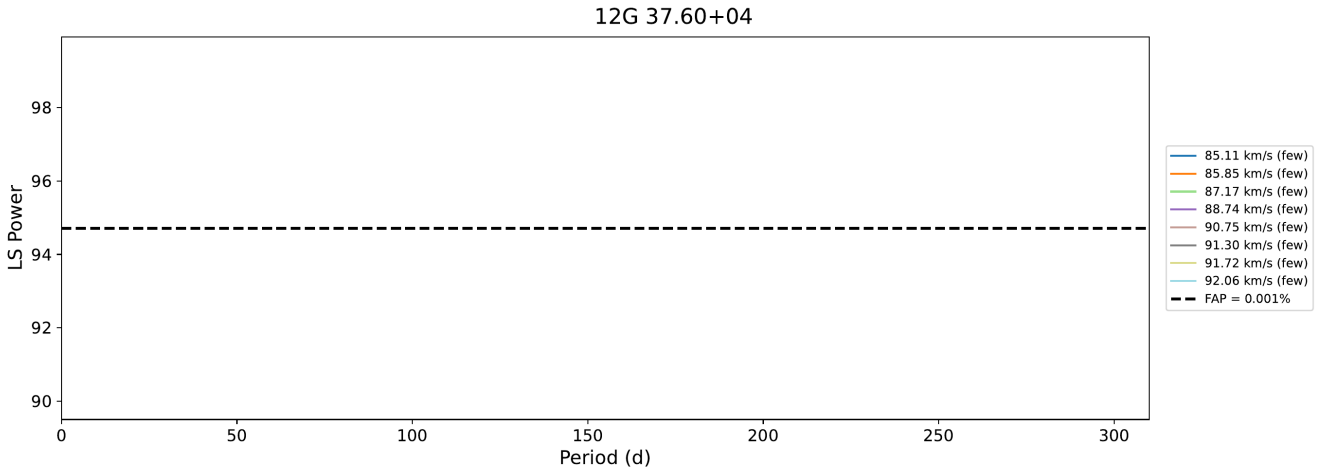


12G 37.60+04

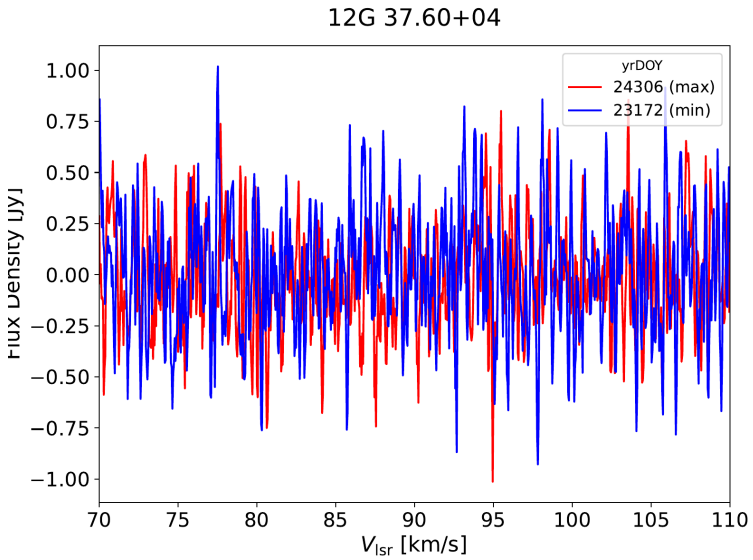
Light curve



Periodogram

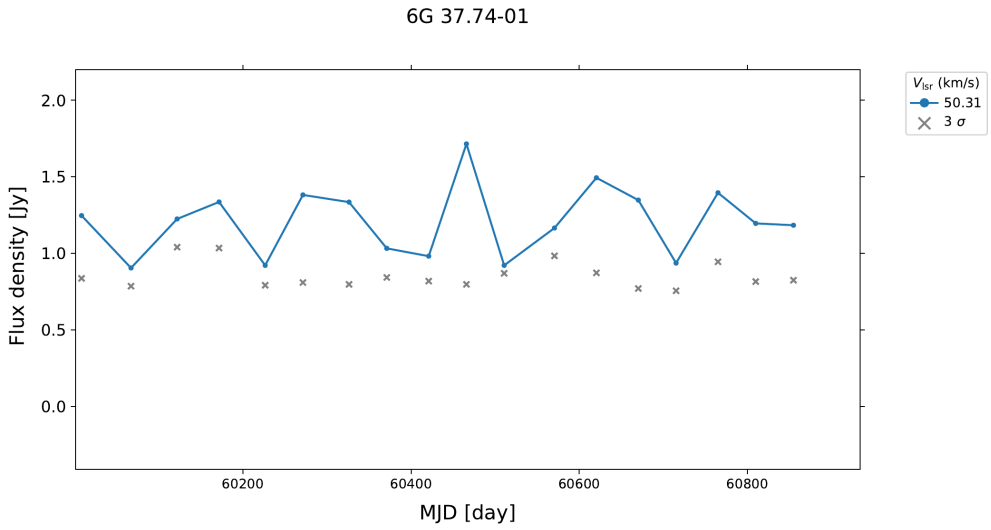


Spectrum

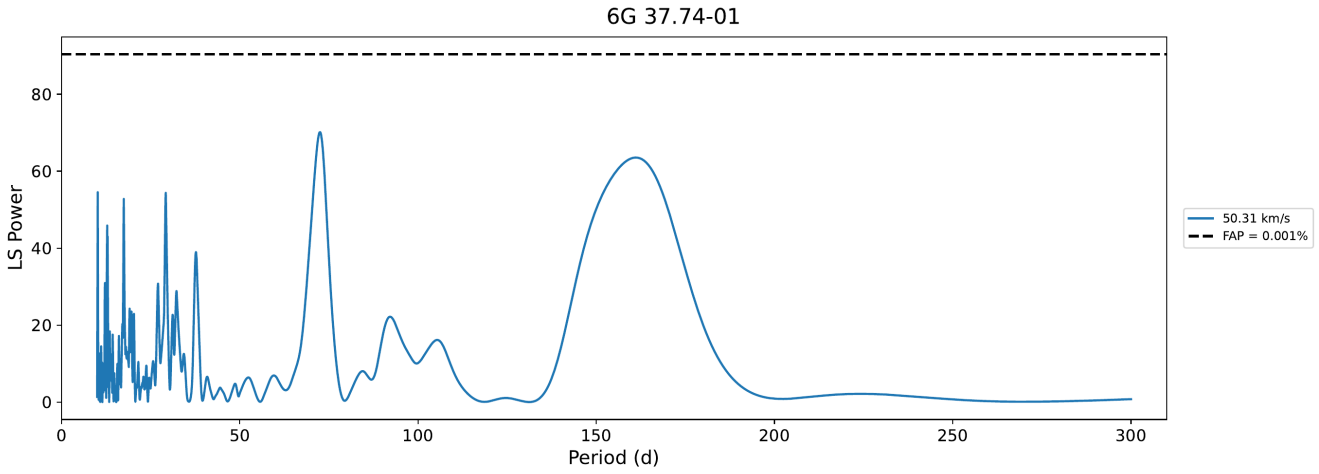


6G 37.74-01

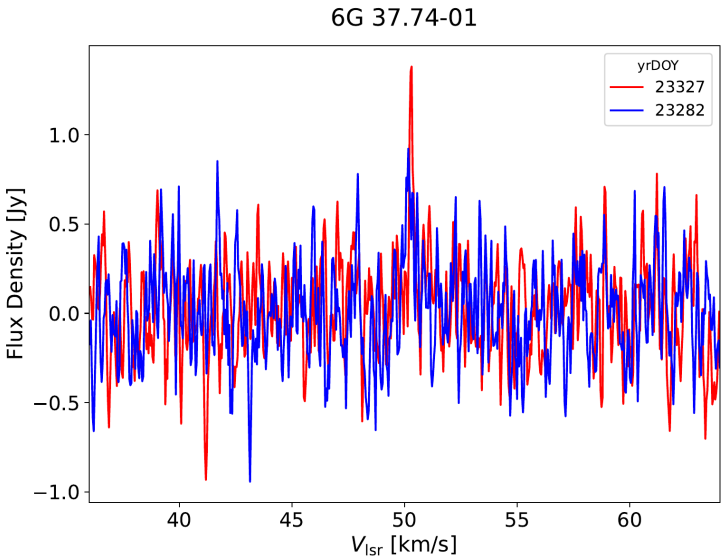
Light curve



Periodogram

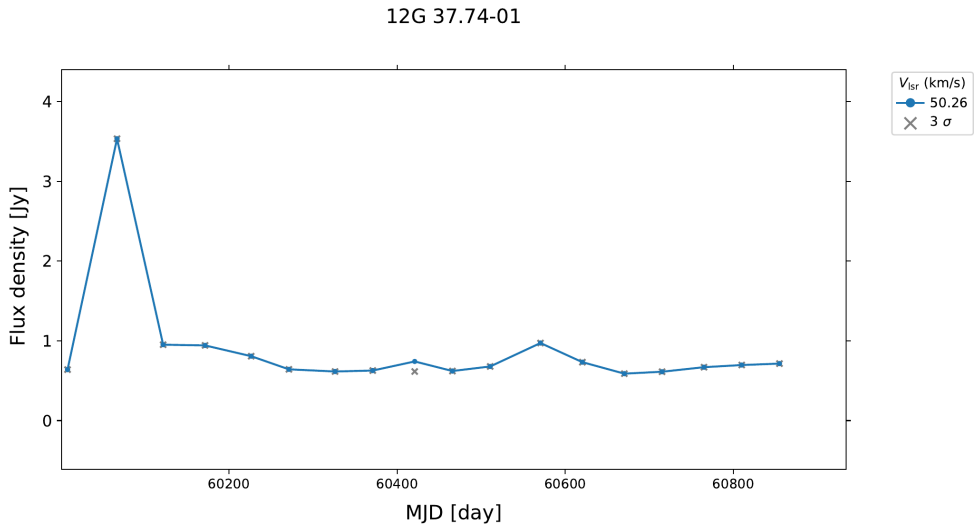


Spectrum

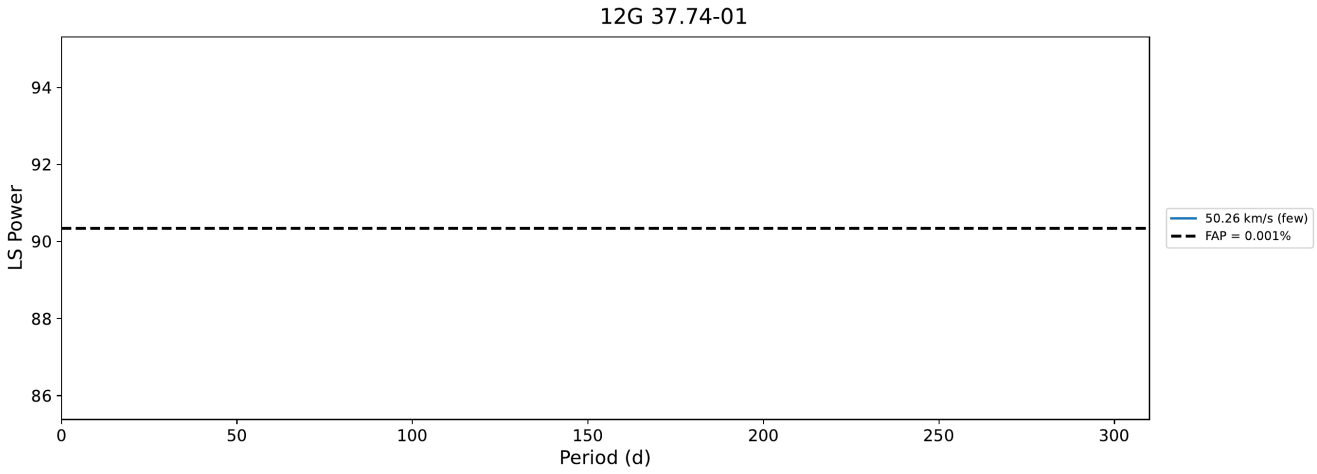


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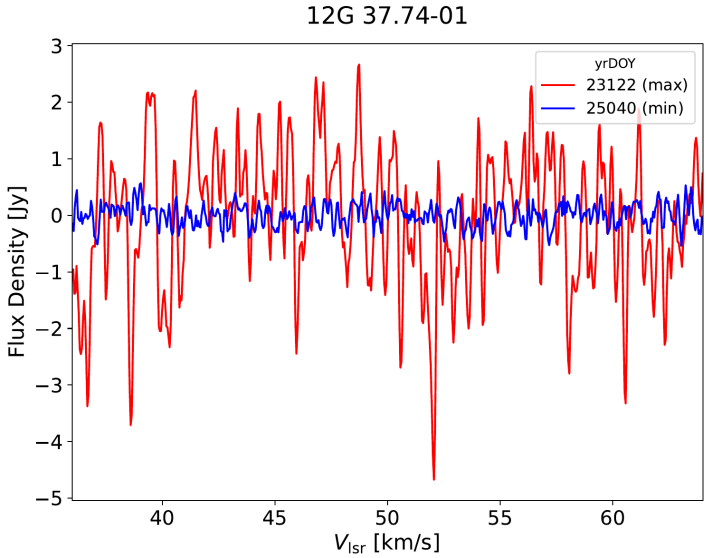
Light curve



Periodogram

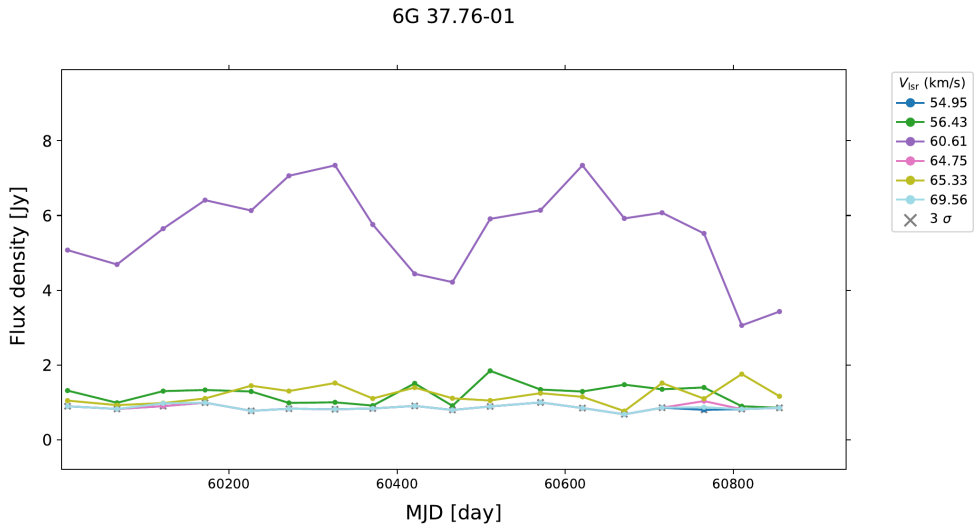


Spectrum

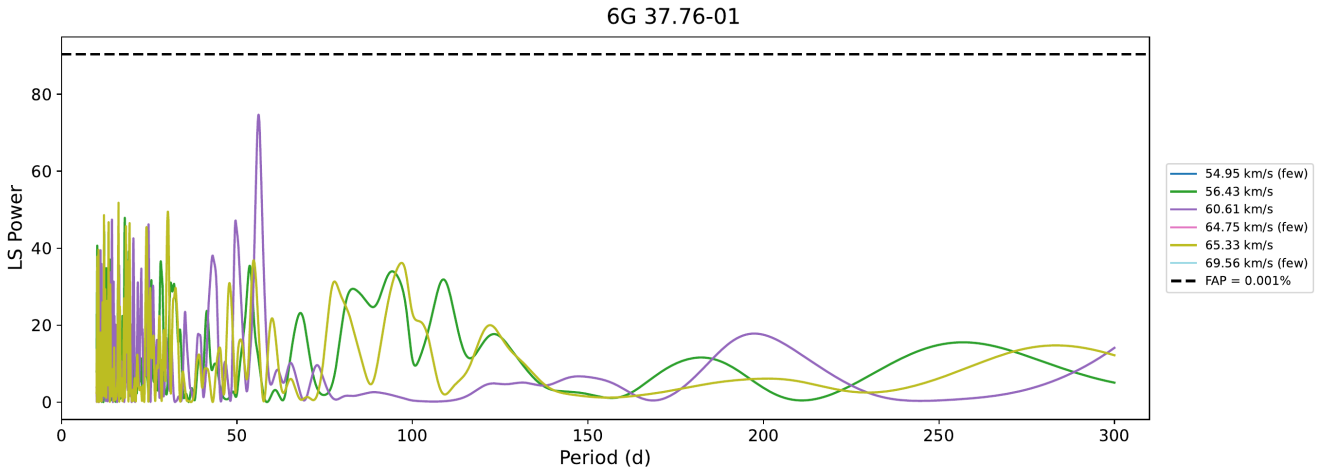


6G 37.76-01

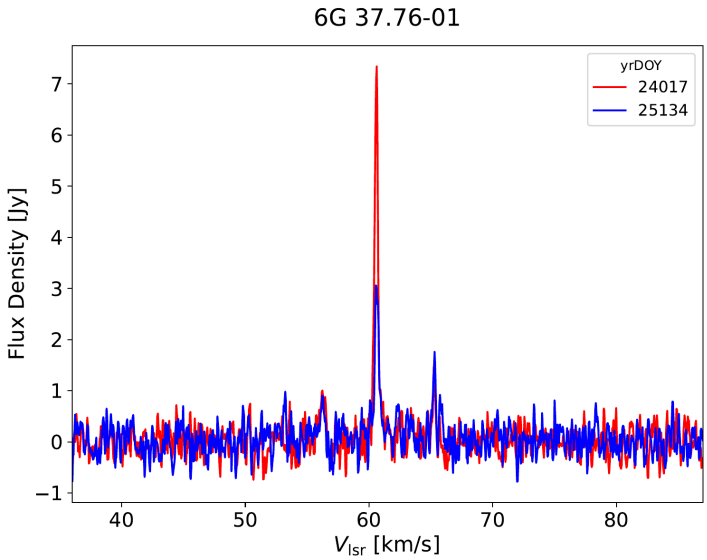
Light curve



Periodogram

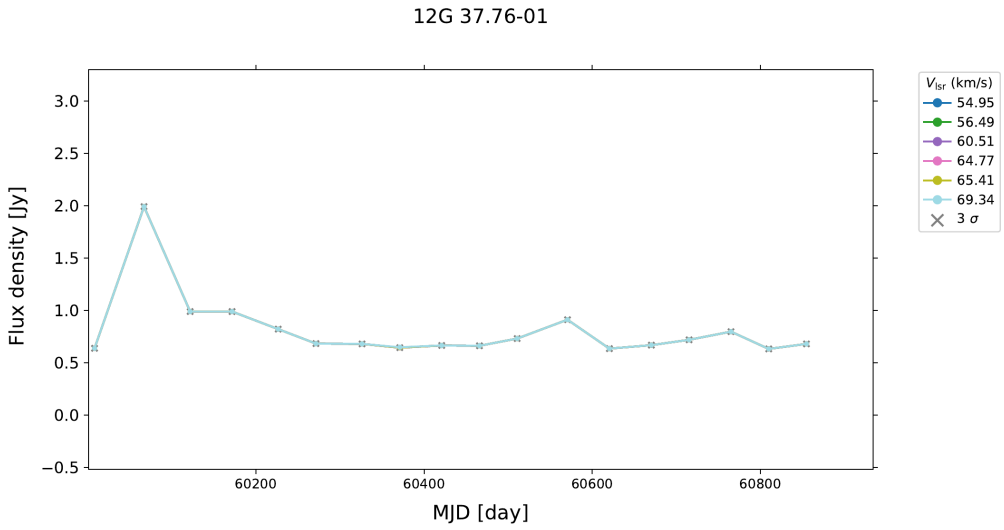


Spectrum

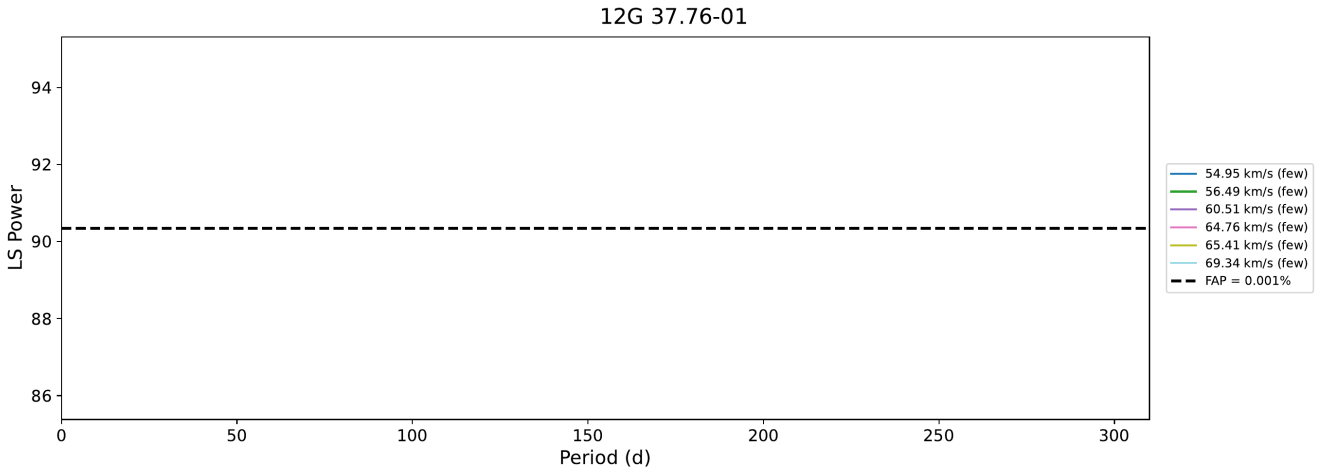


12G 37.76-01

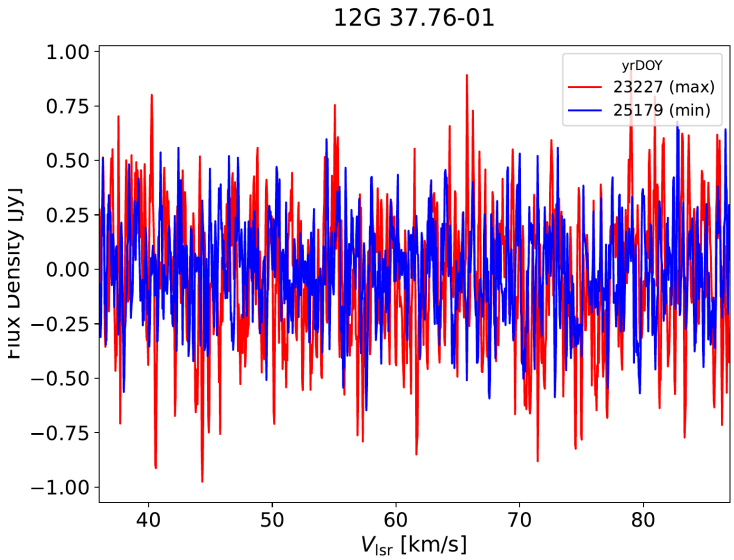
Light curve



Periodogram

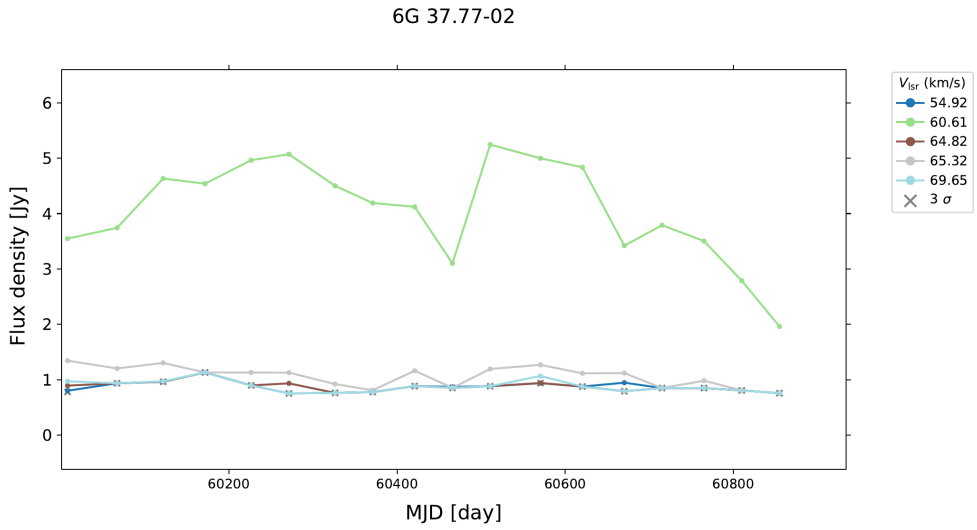


Spectrum

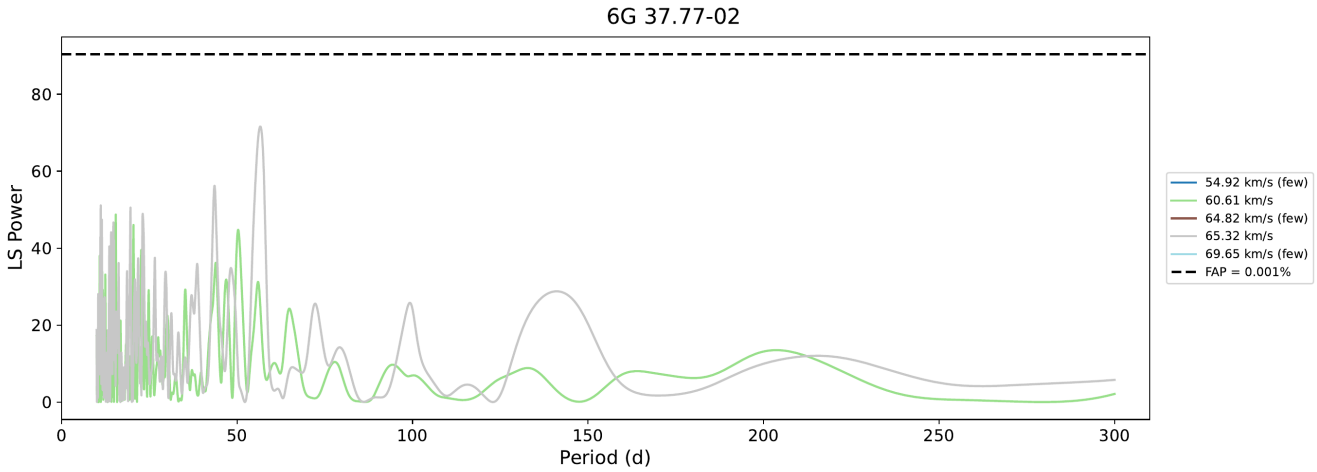


6G 37.77-02

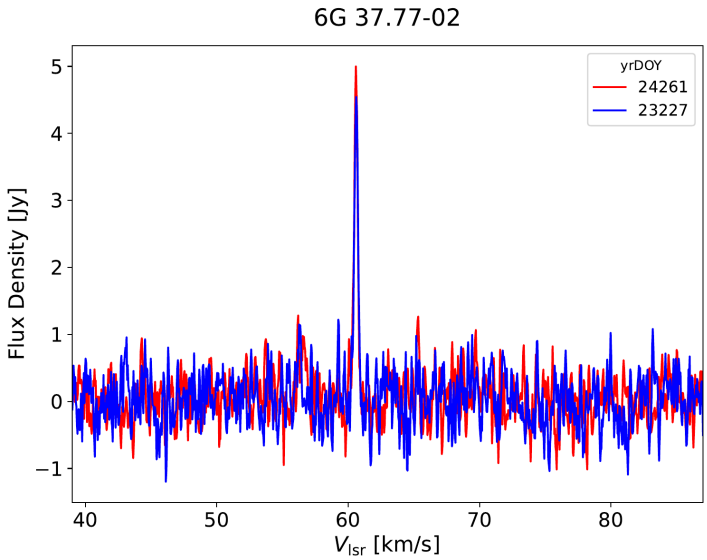
Light curve



Periodogram

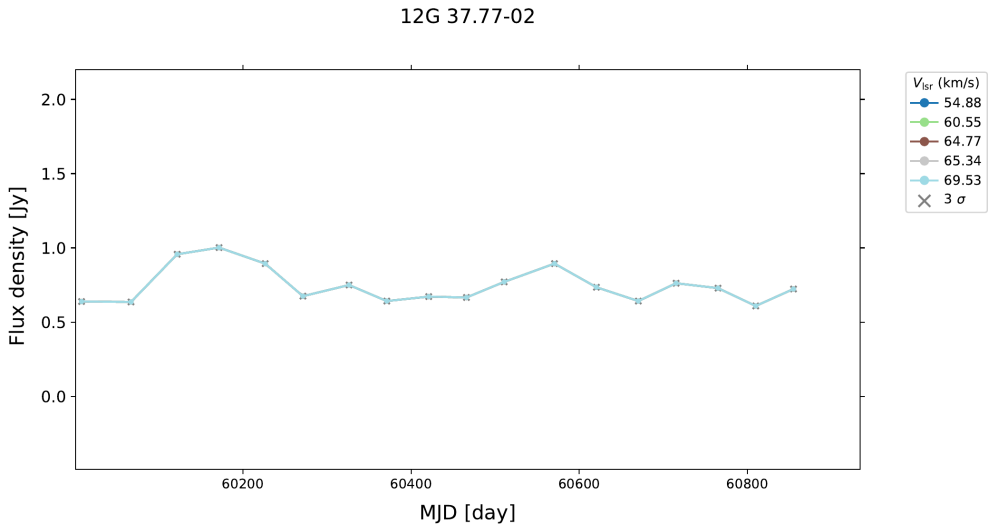


Spectrum

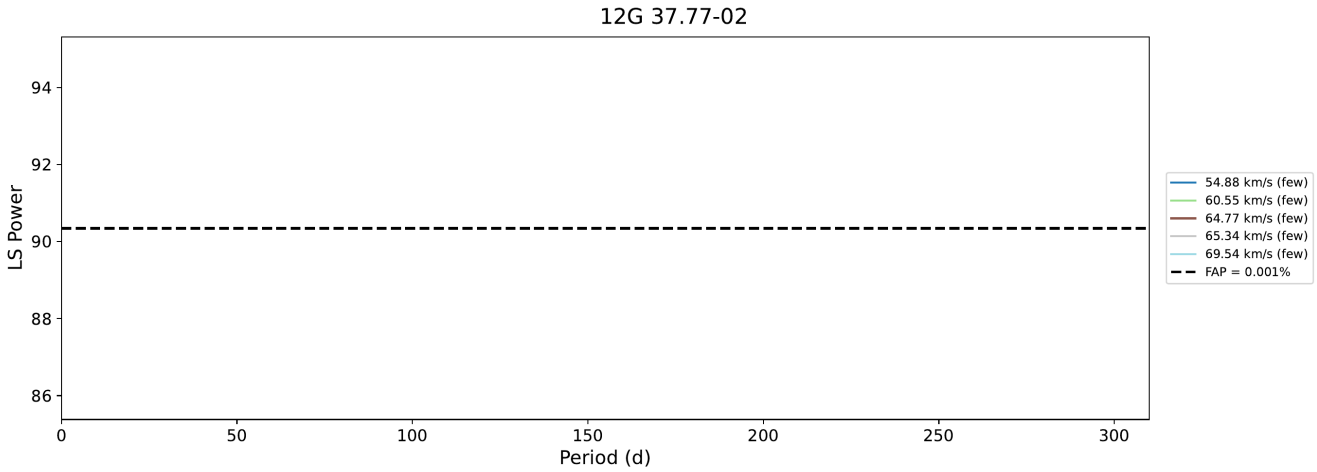


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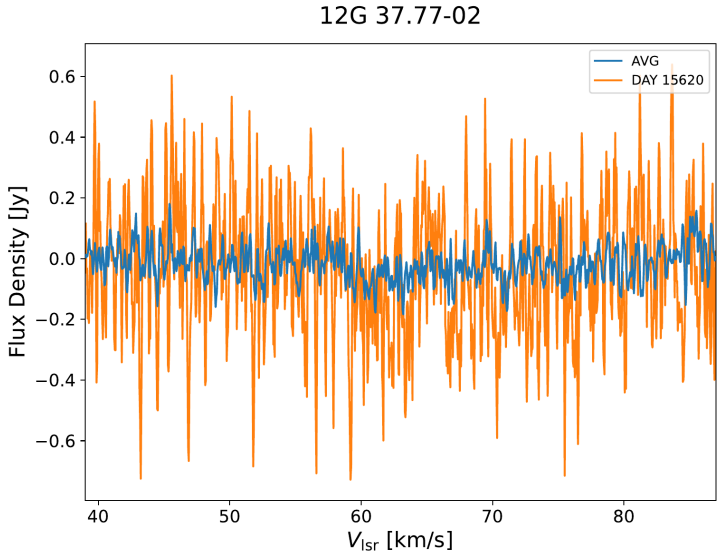
Light curve



Periodogram

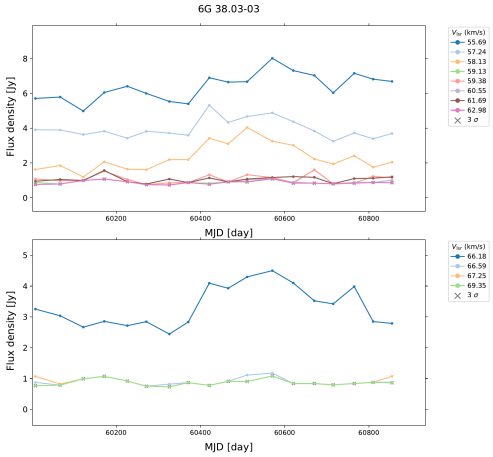


Spectrum

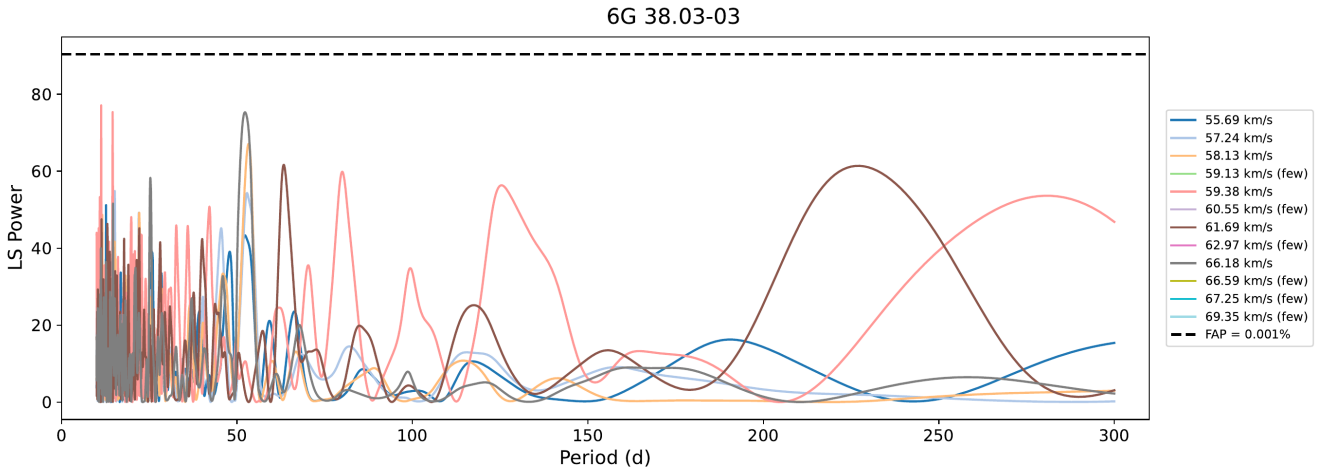


6G 38.03-03

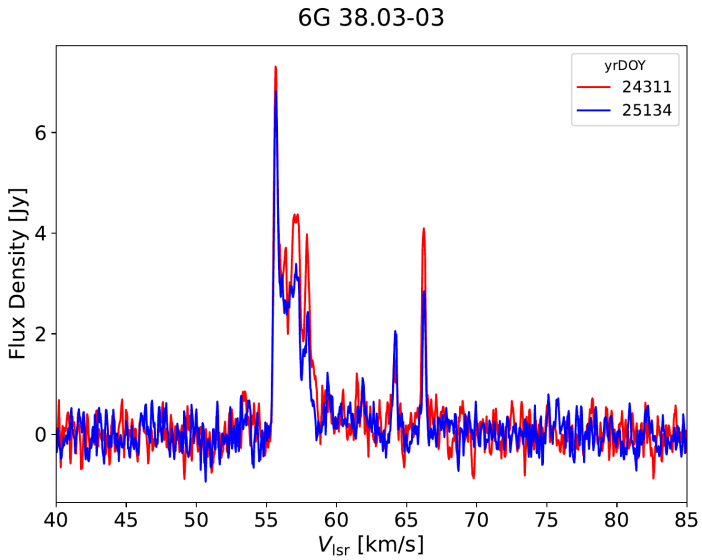
Light curve



Periodogram

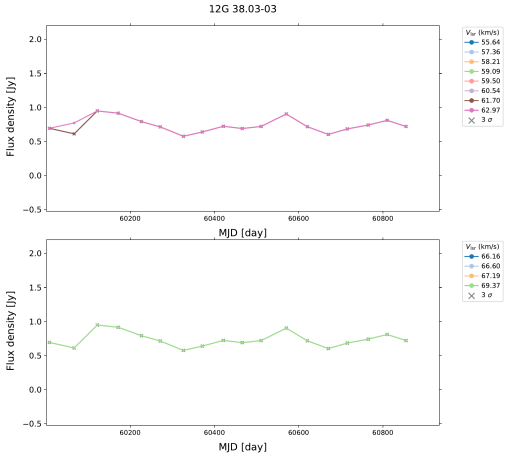


Spectrum

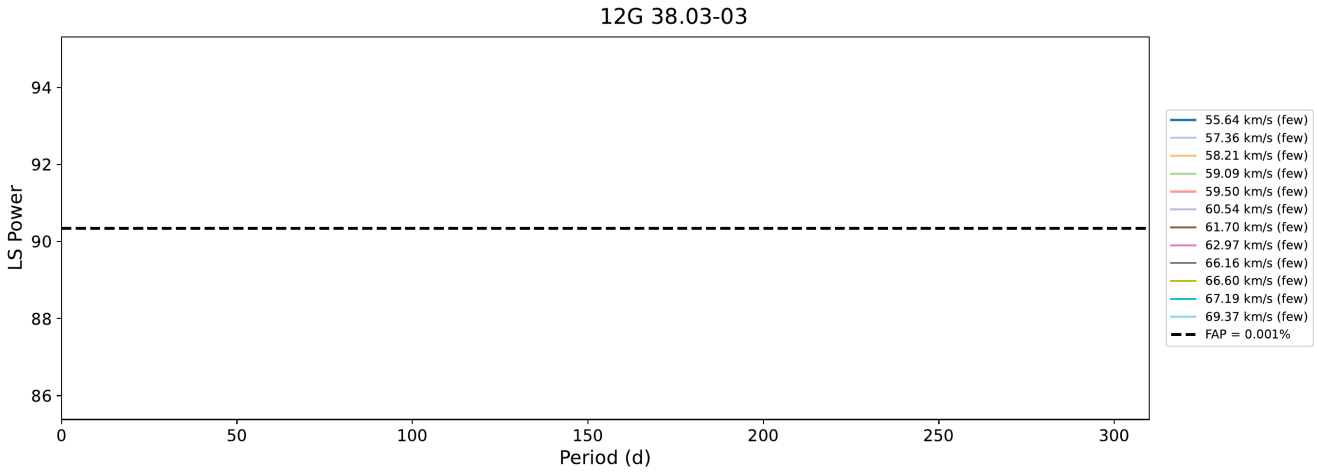


12G 38.03-03

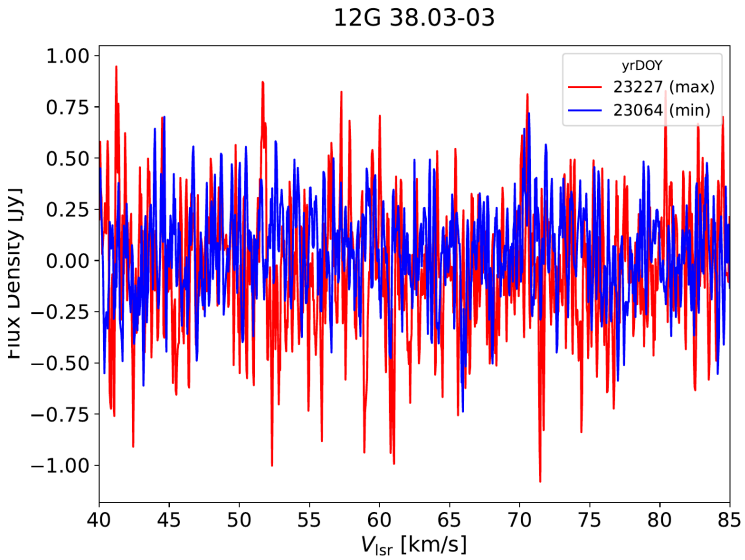
Light curve



Periodogram

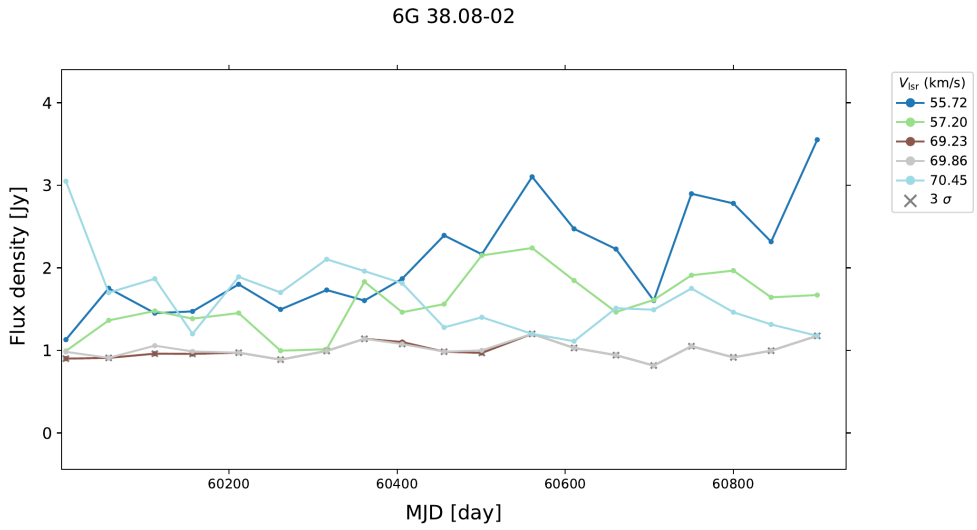


Spectrum

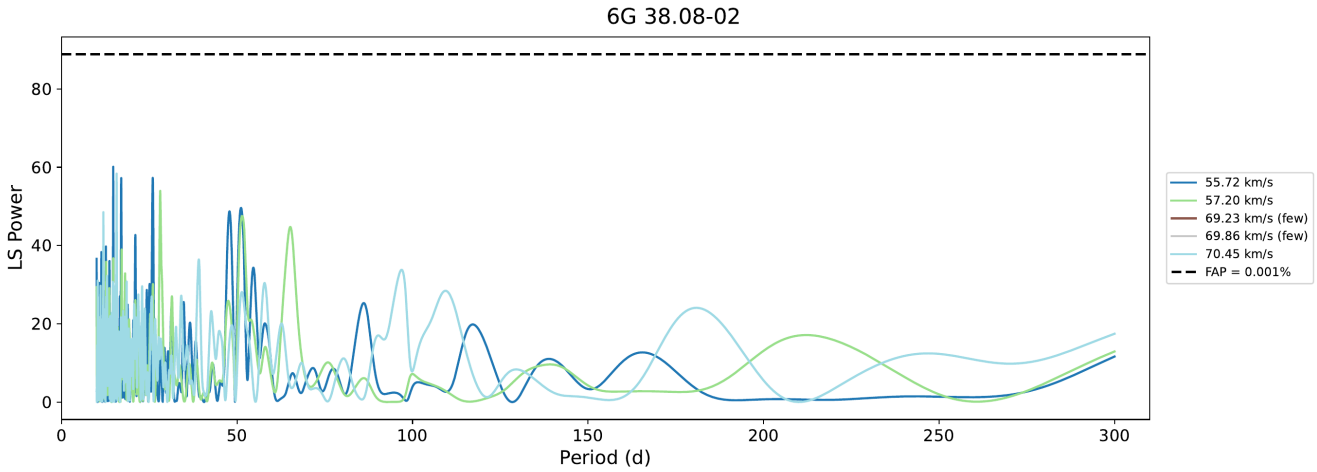


6G 38.08-02

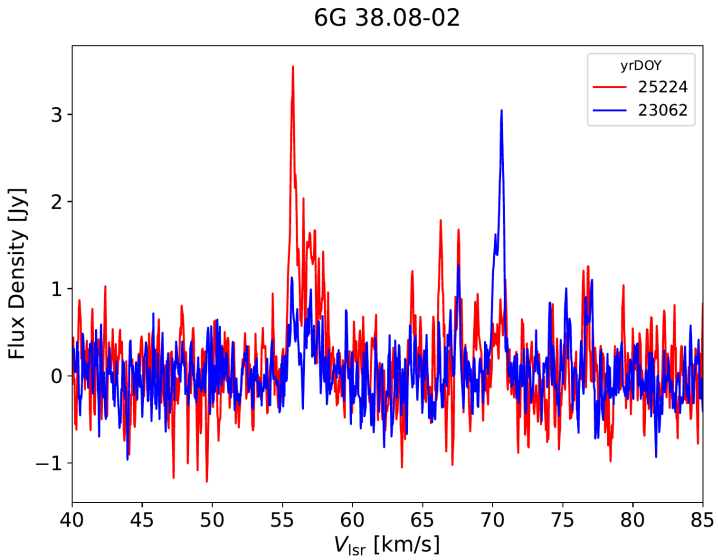
Light curve



Periodogram

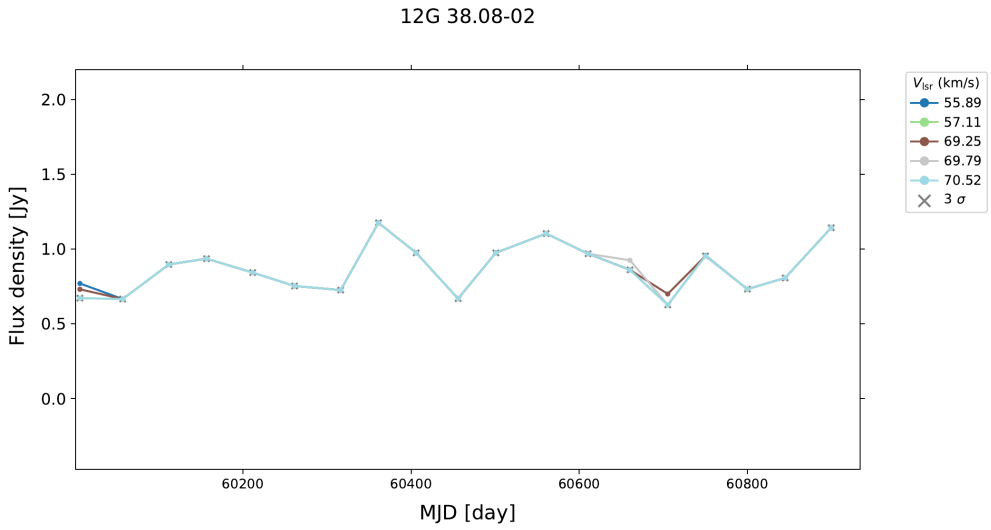


Spectrum

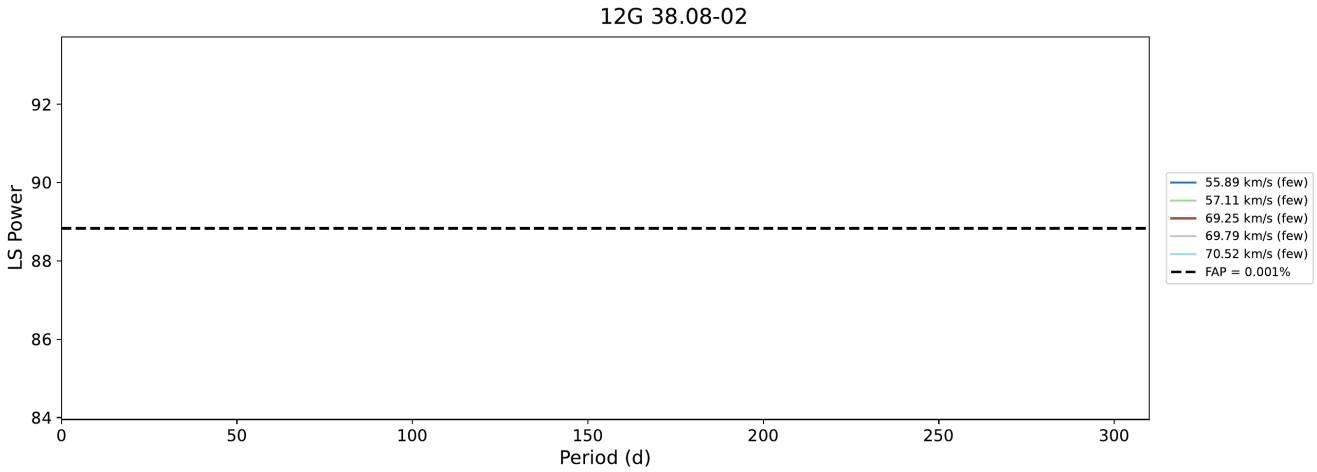


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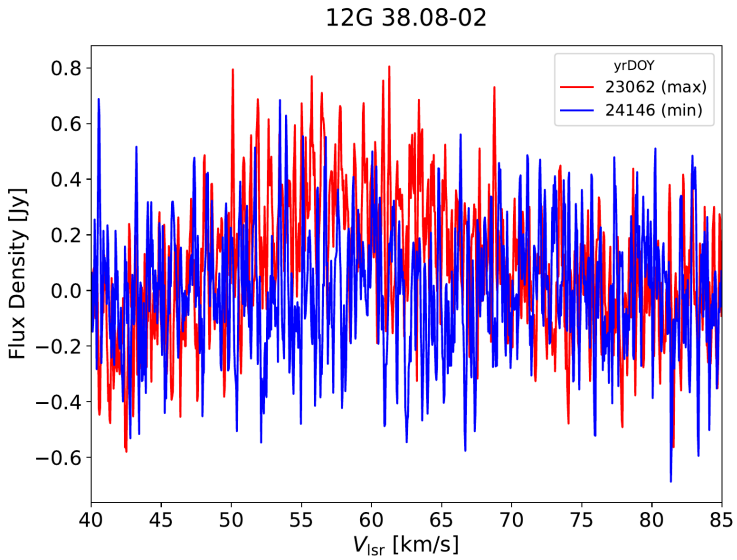
Light curve



Periodogram

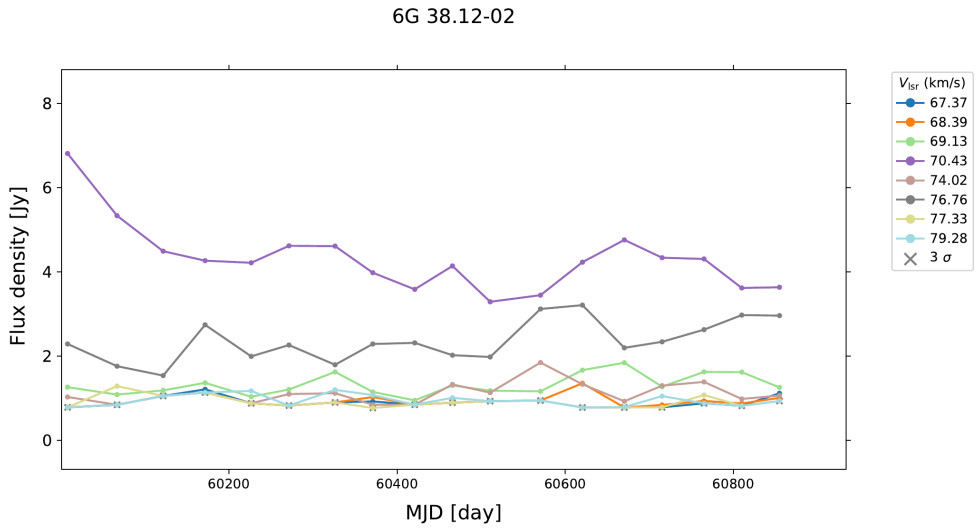


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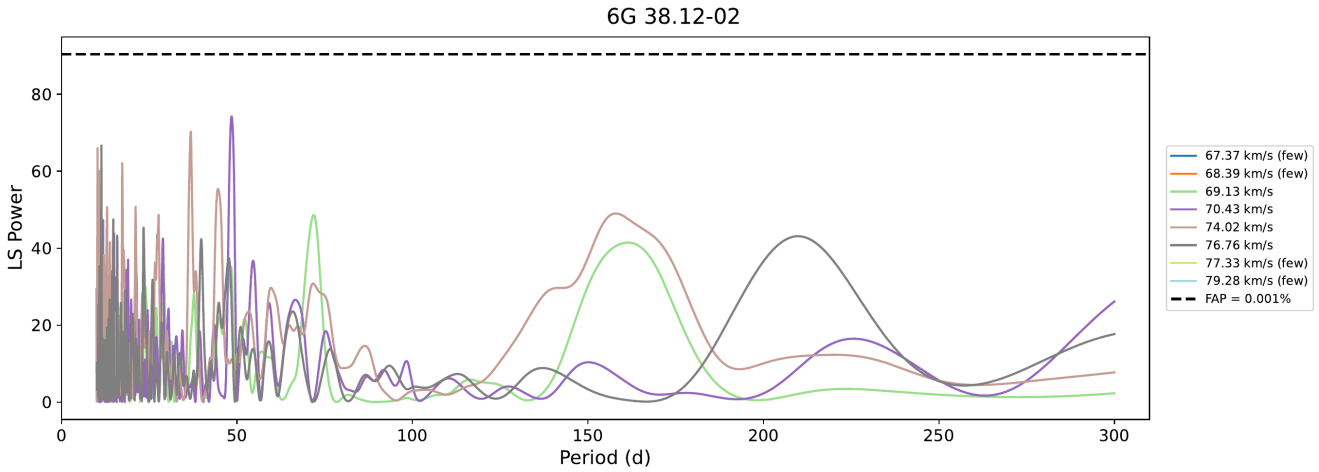


6G 38.12-02

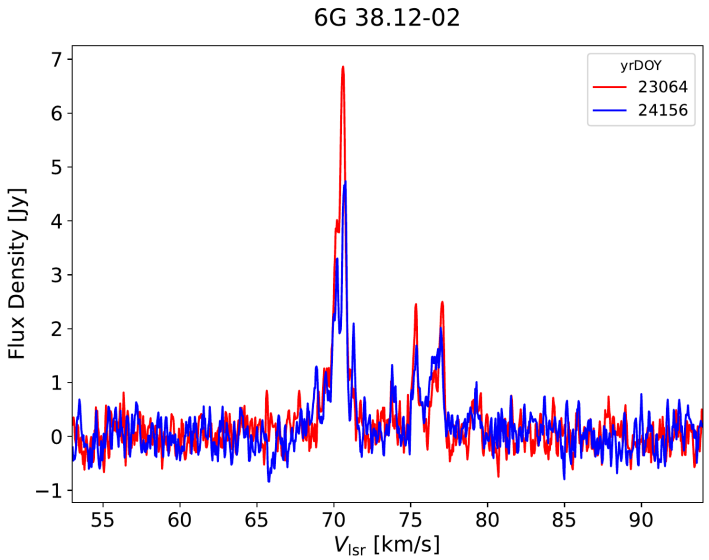
Light curve



Periodogram

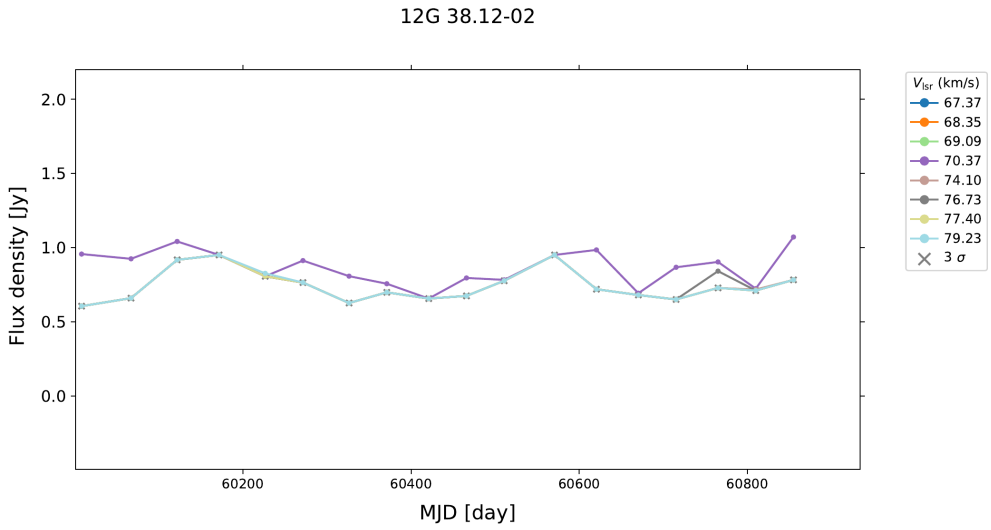


Spectrum

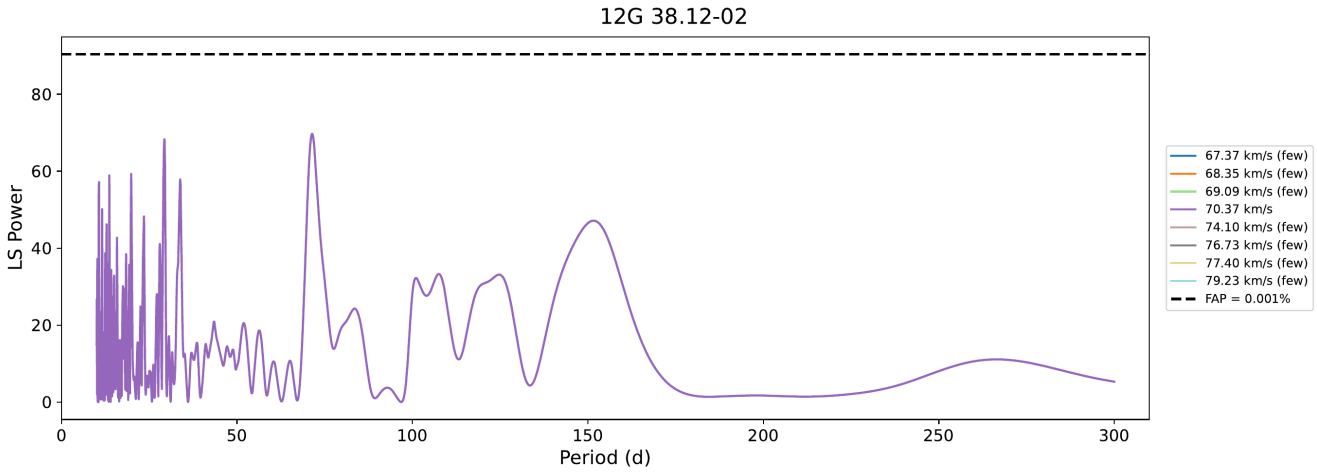


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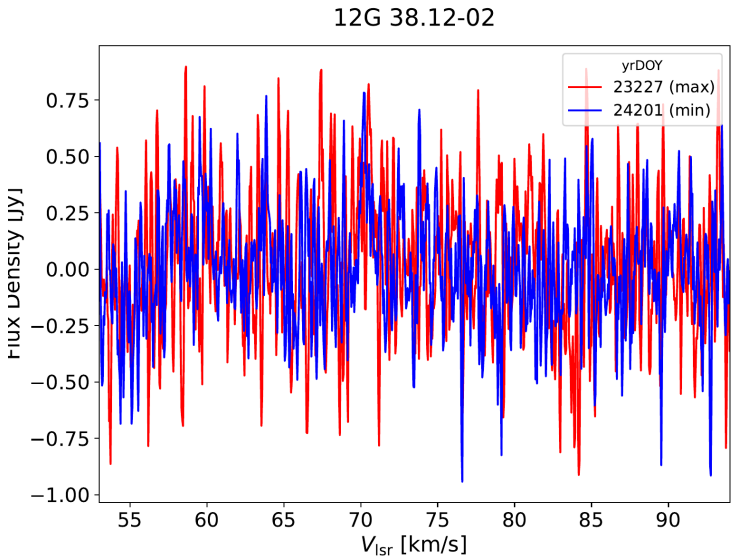
Light curve



Periodogram

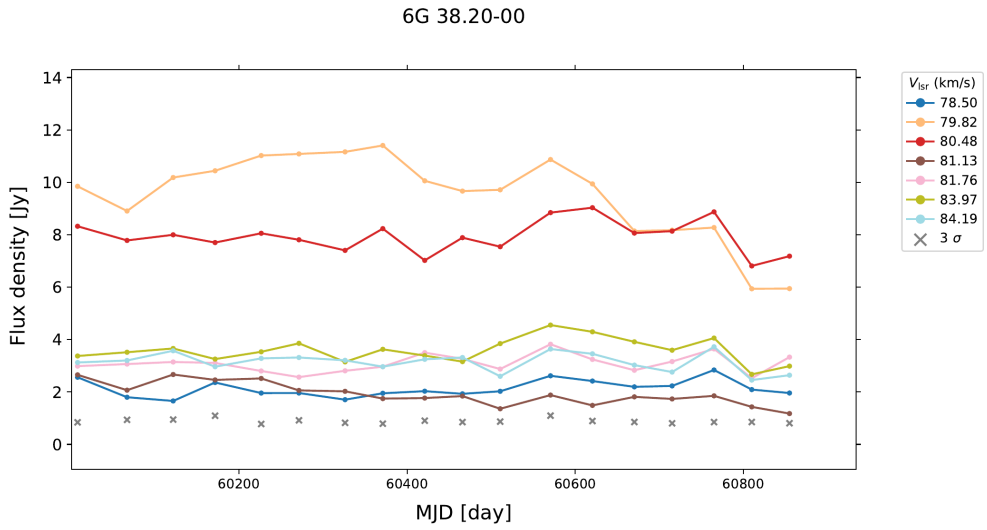


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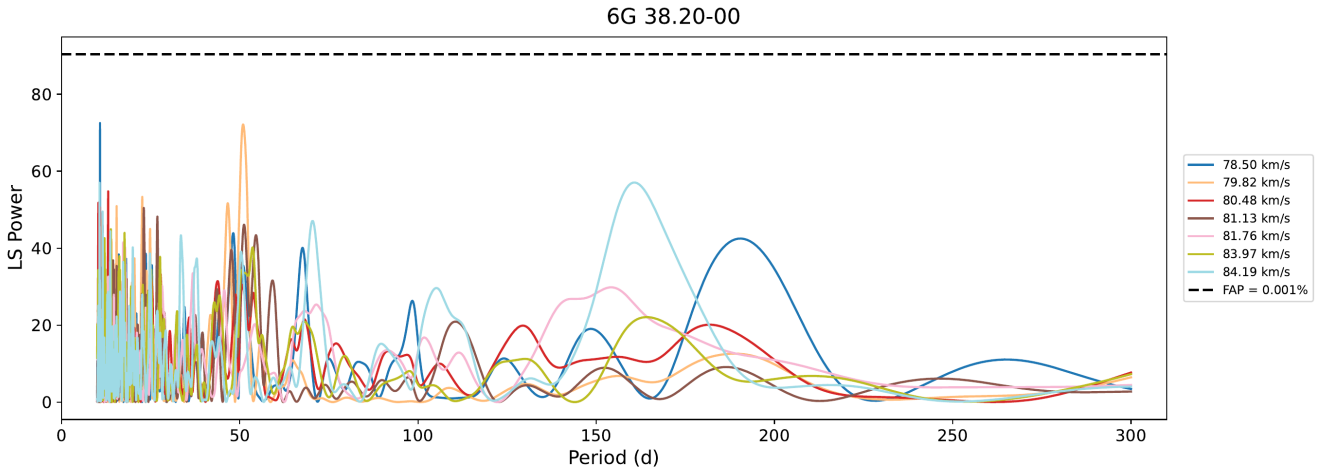


6G 38.20-00

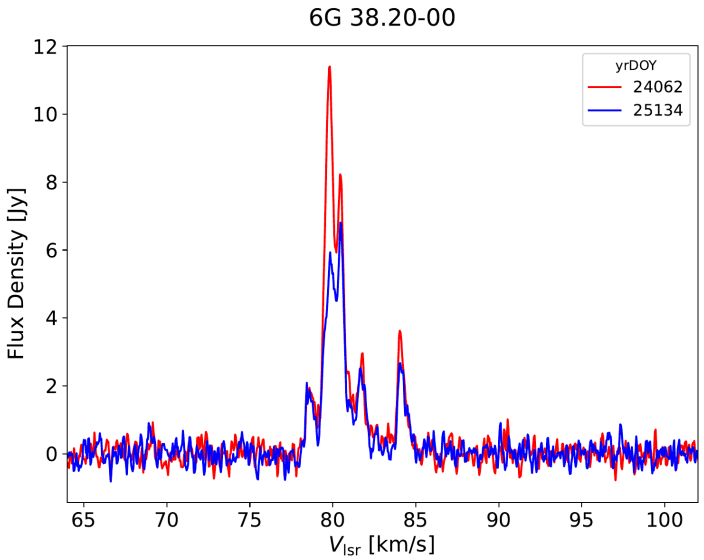
Light curve



Periodogram

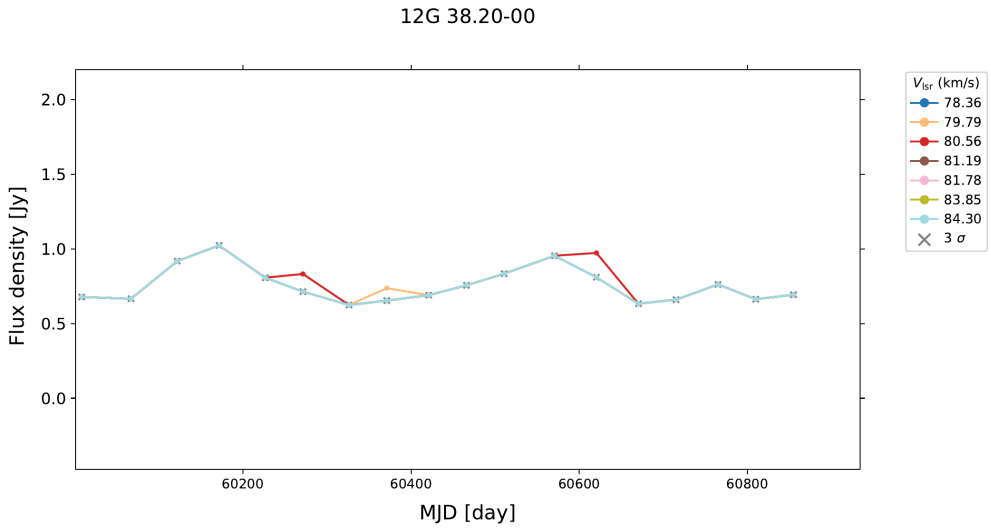


Spectrum

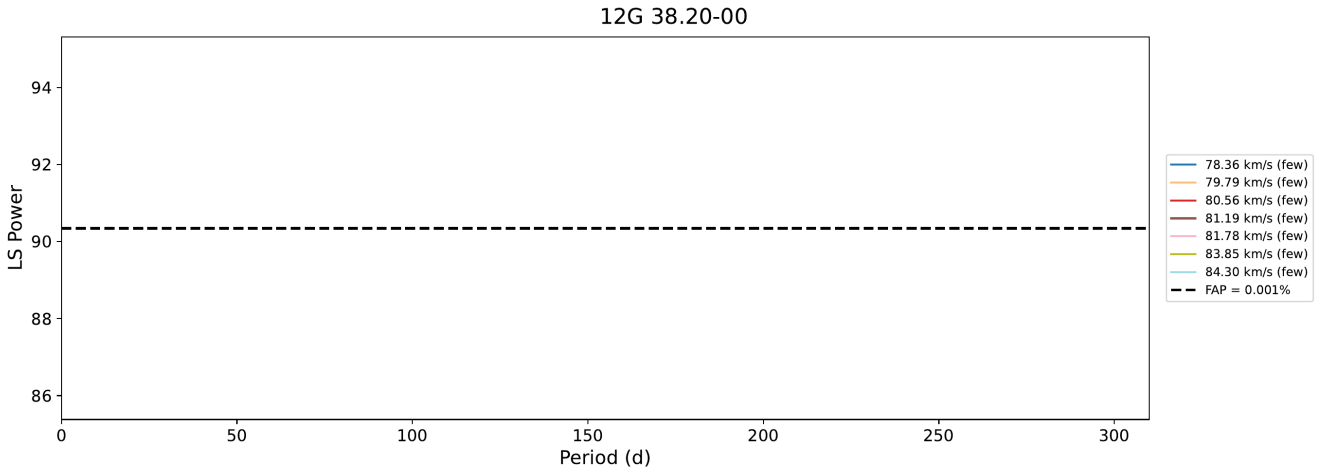


12G 38.20-00

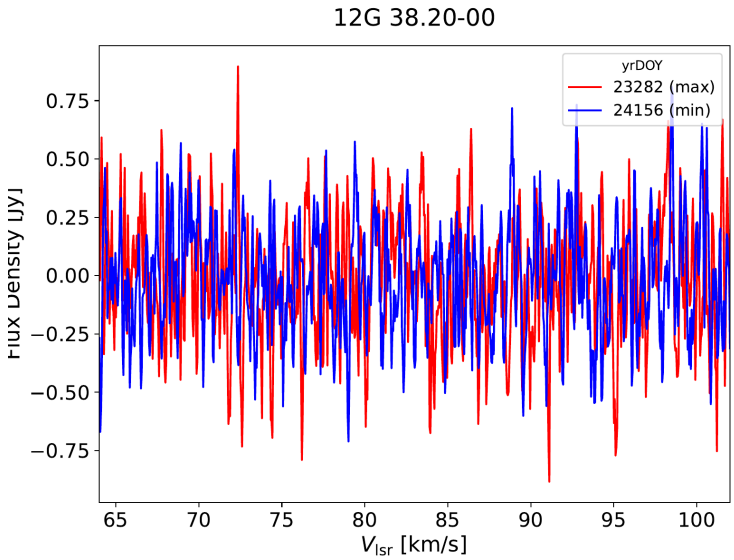
Light curve



Periodogram

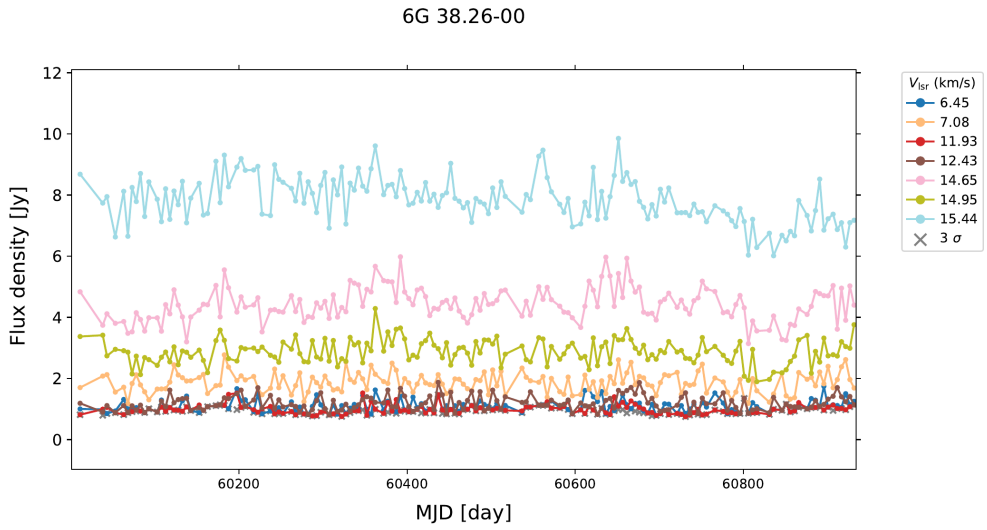


Spectrum

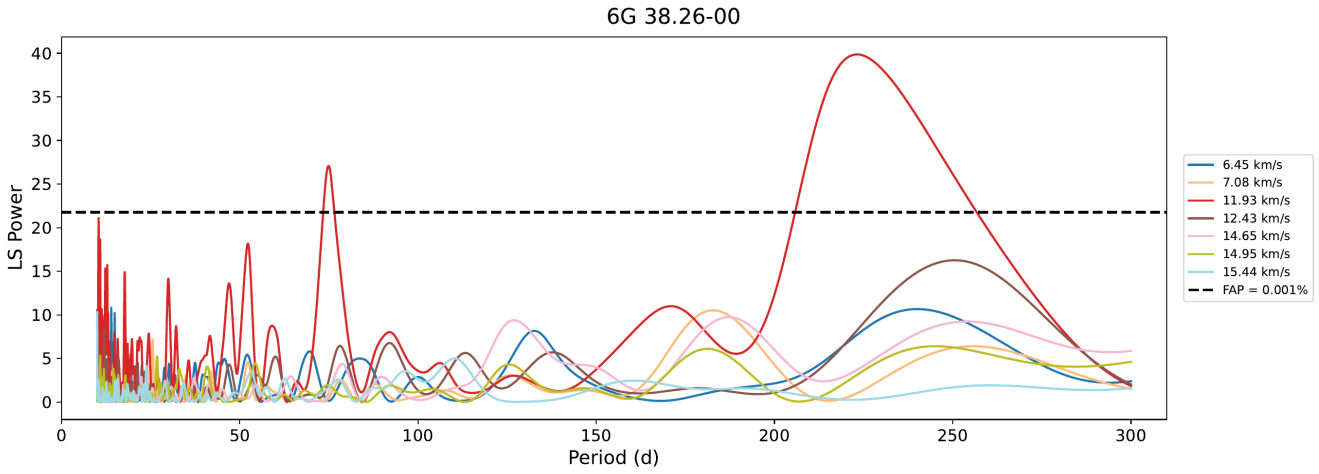


6G 38.26-00

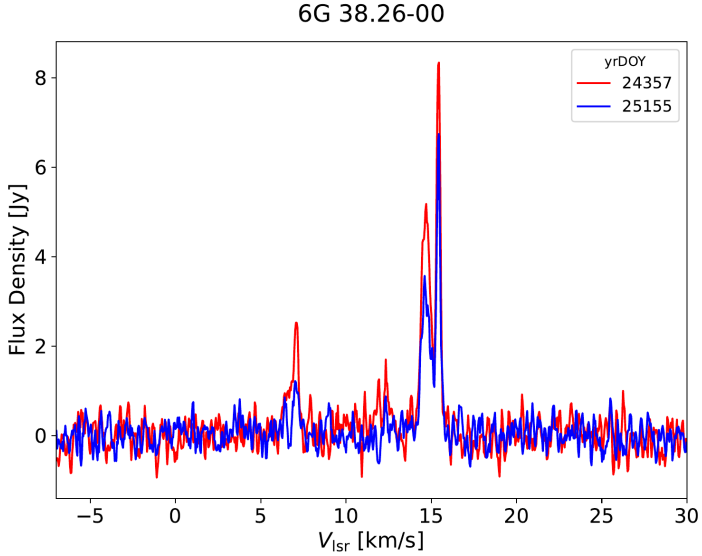
Light curve



Periodogram

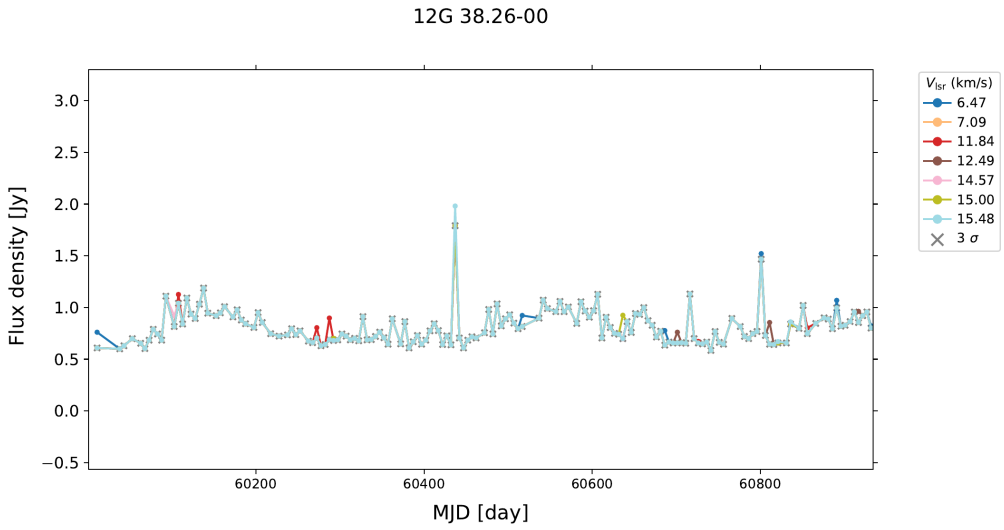


Spectrum

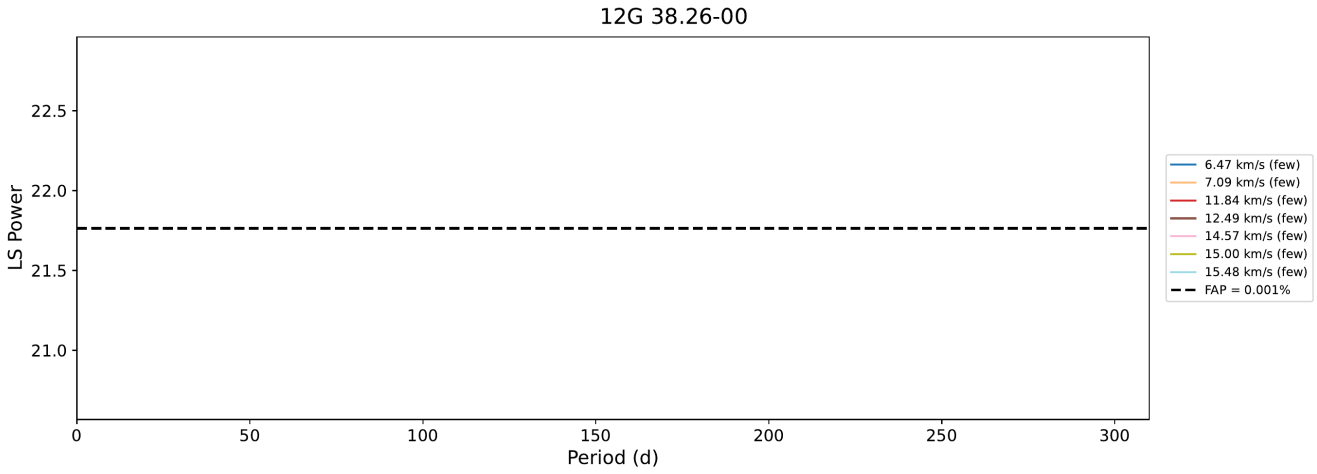


12G 38.26-00

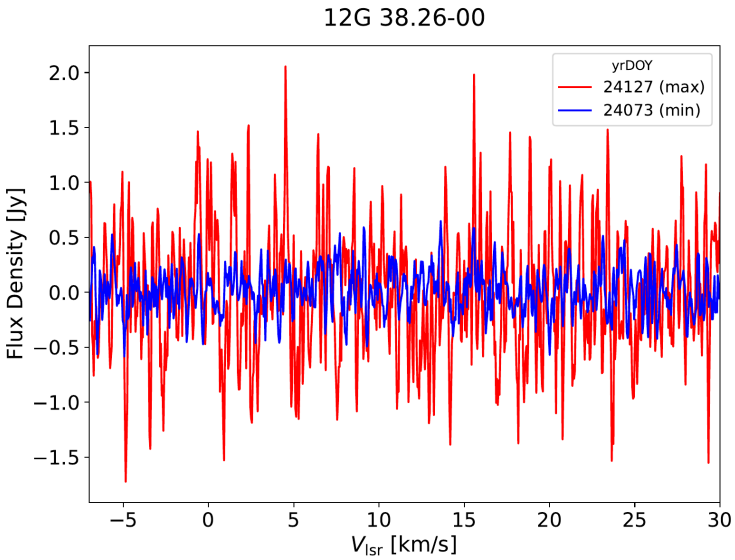
Light curve



Periodogram

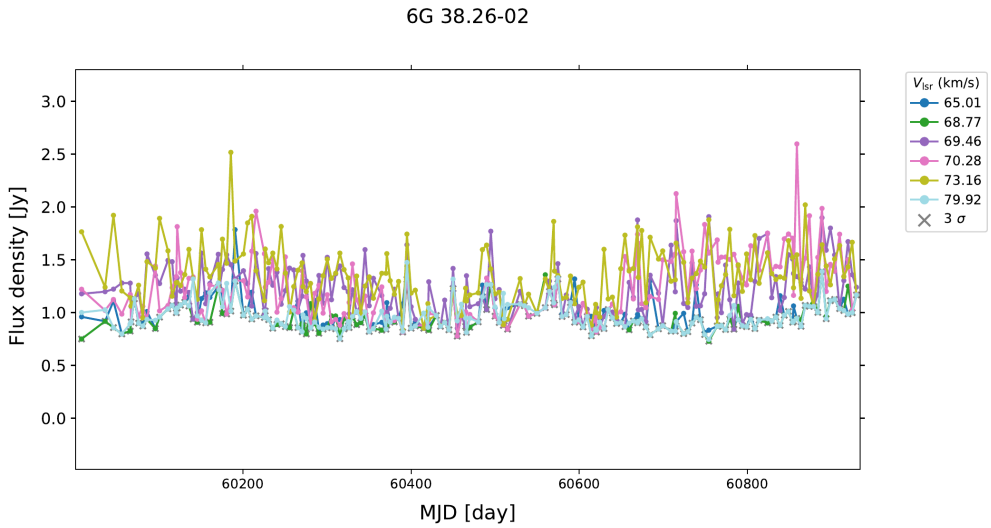


Spectrum

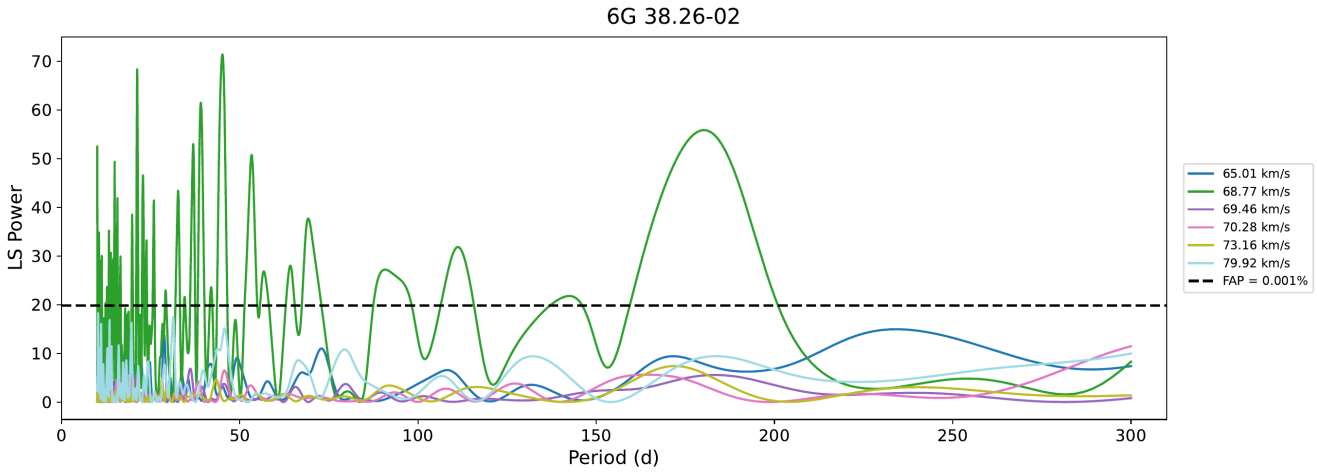


6G 38.26-02

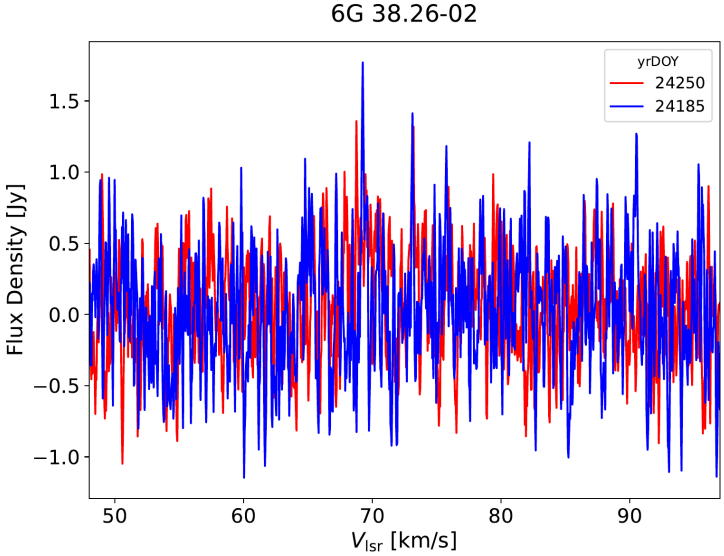
Light curve



Periodogram

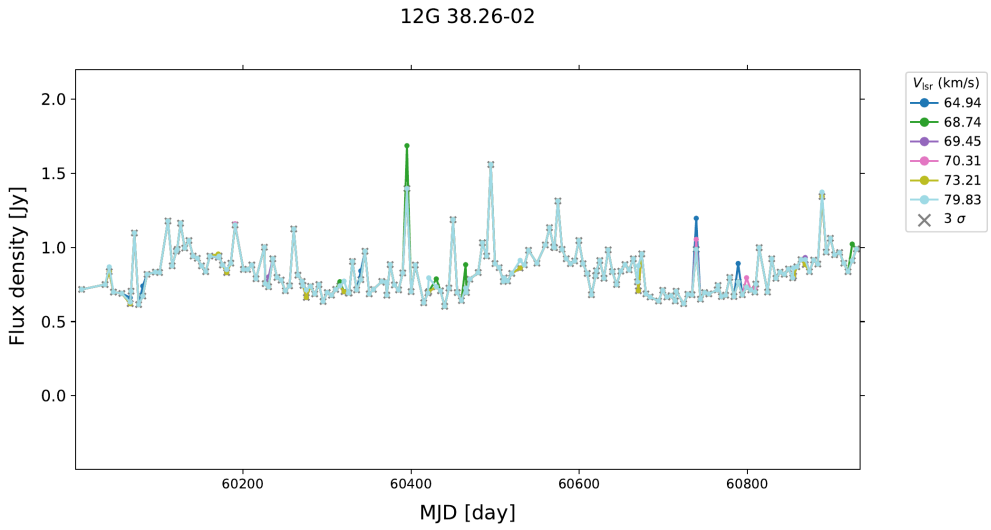


Spectrum

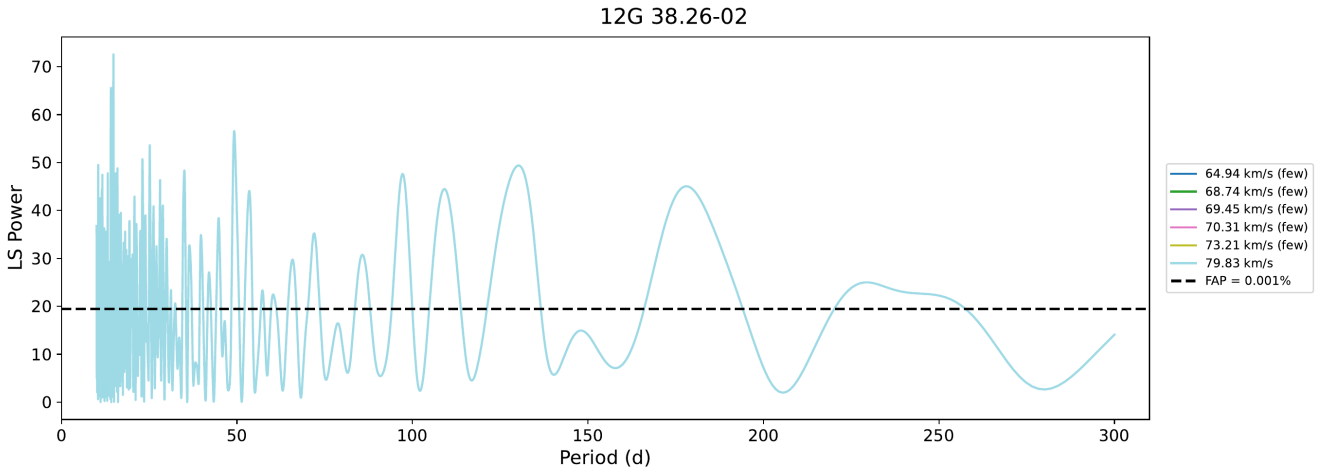


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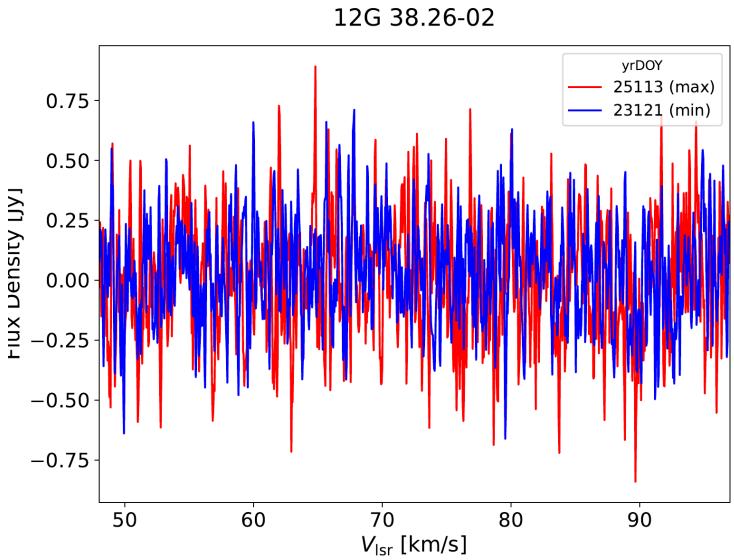
Light curve



Periodogram

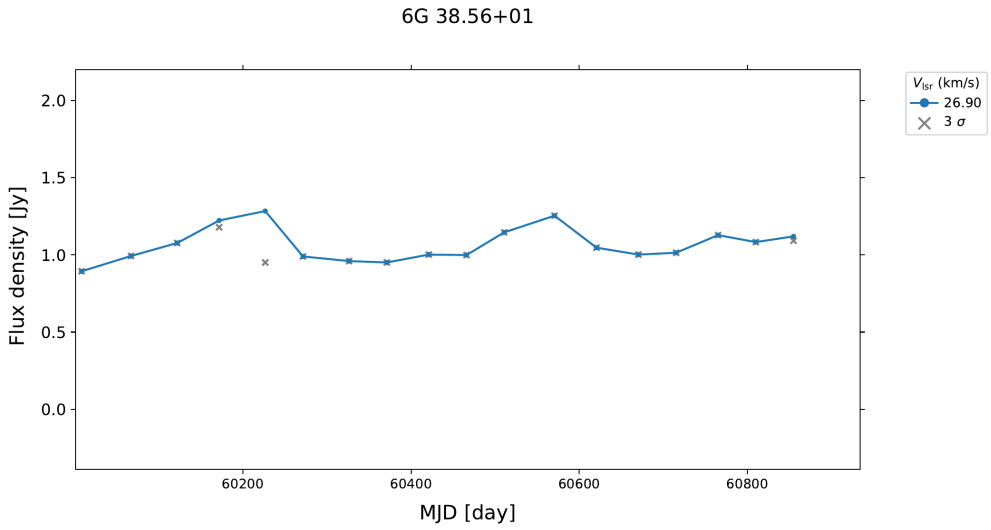


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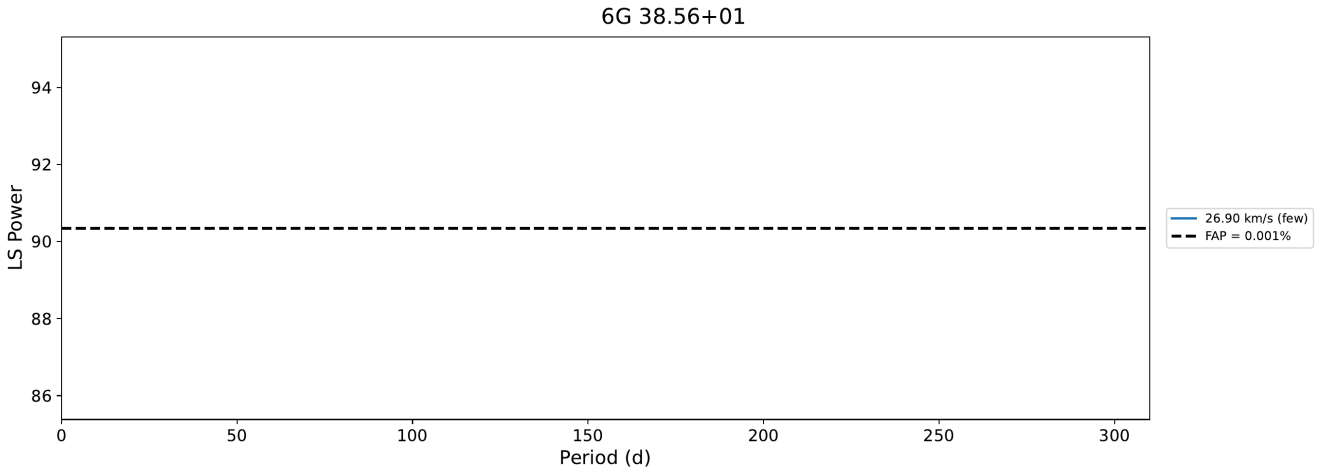


6G 38.56+01

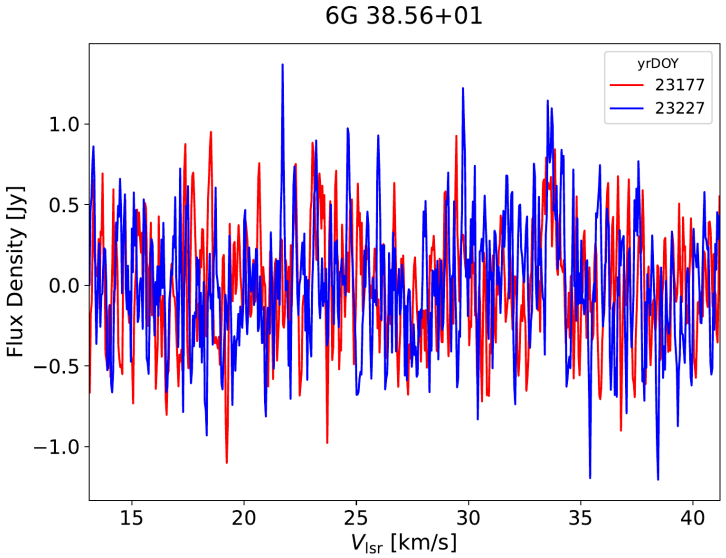
Light curve



Periodogram

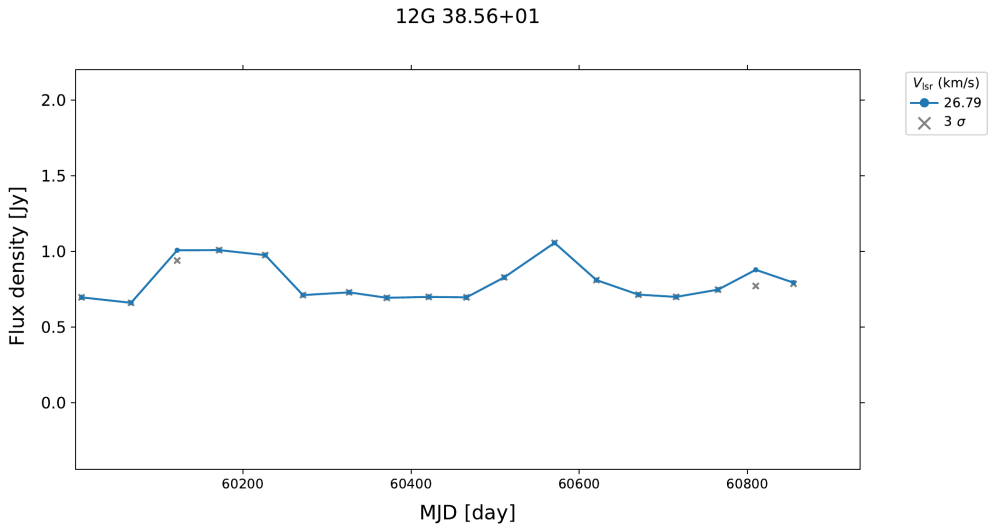


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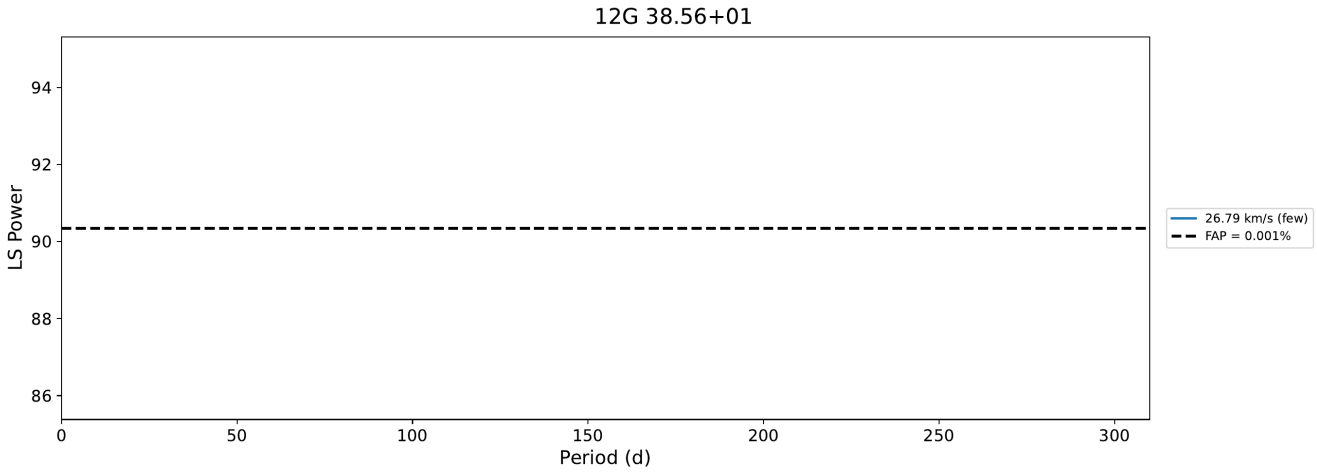


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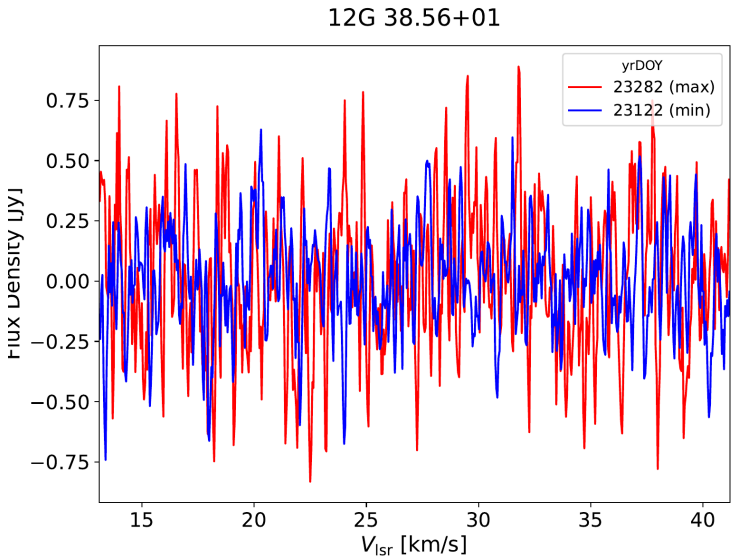
Light curve



Periodogram

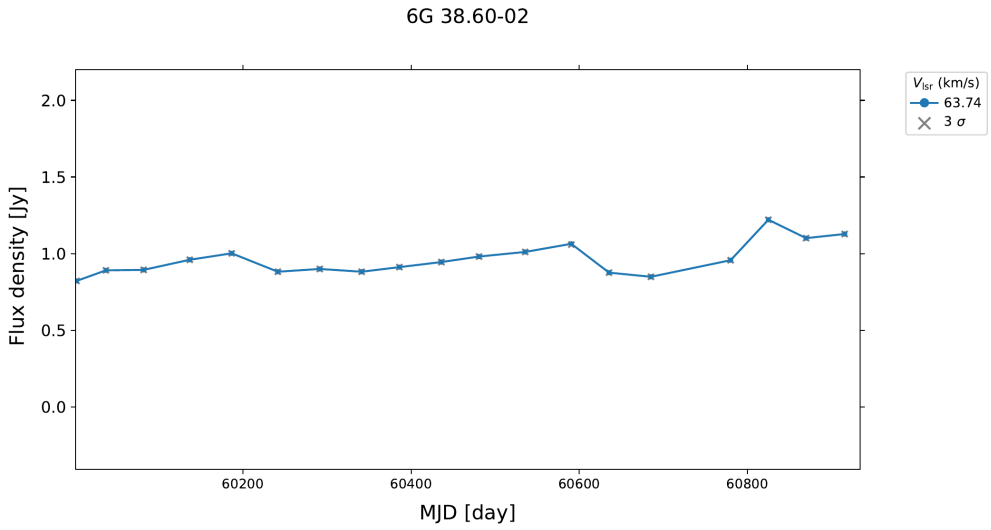


Spectrum

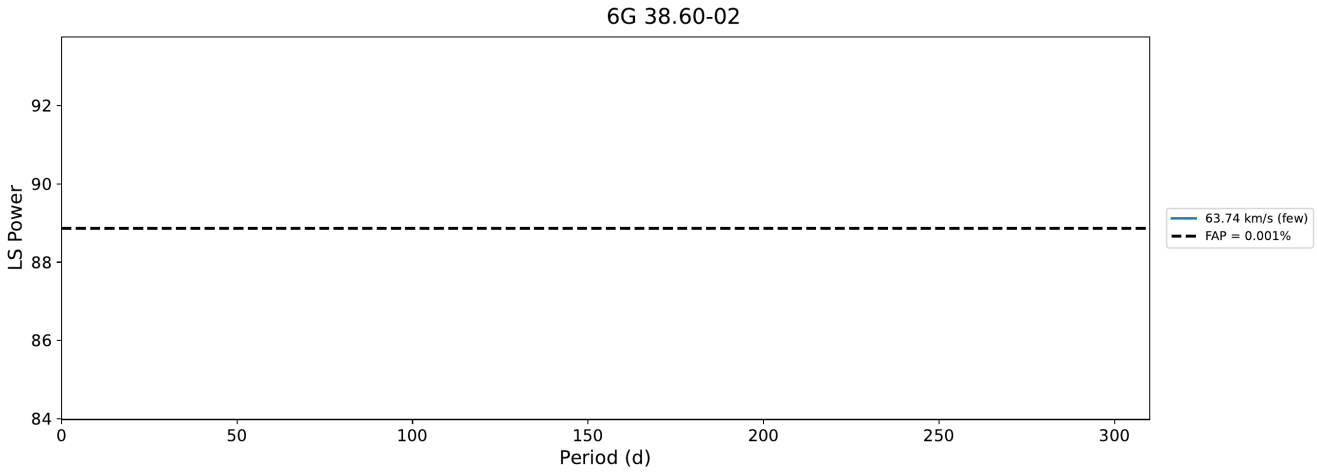


6G 38.60-02

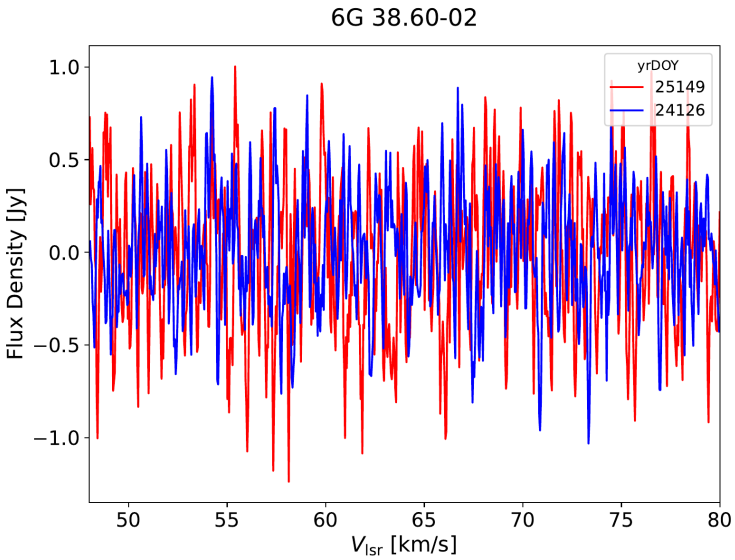
Light curve



Periodogram

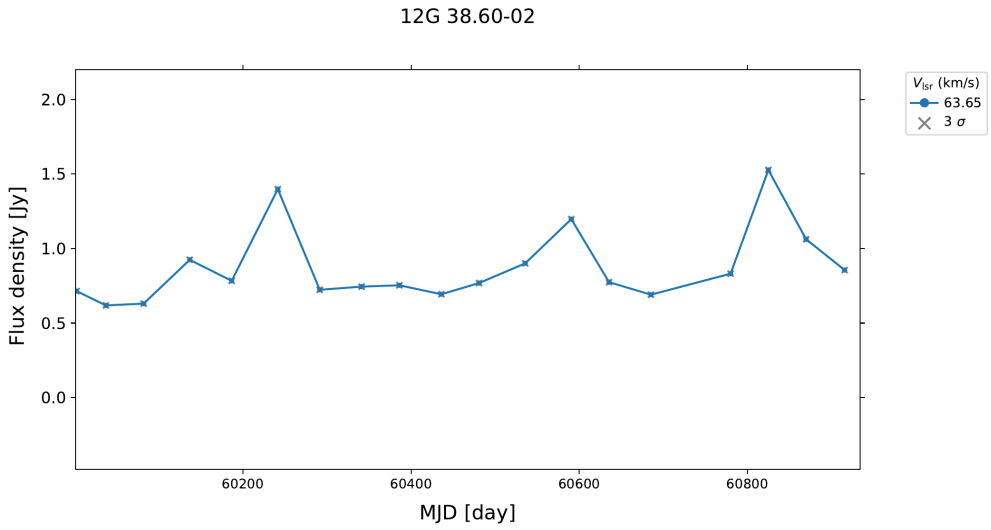


Spectrum

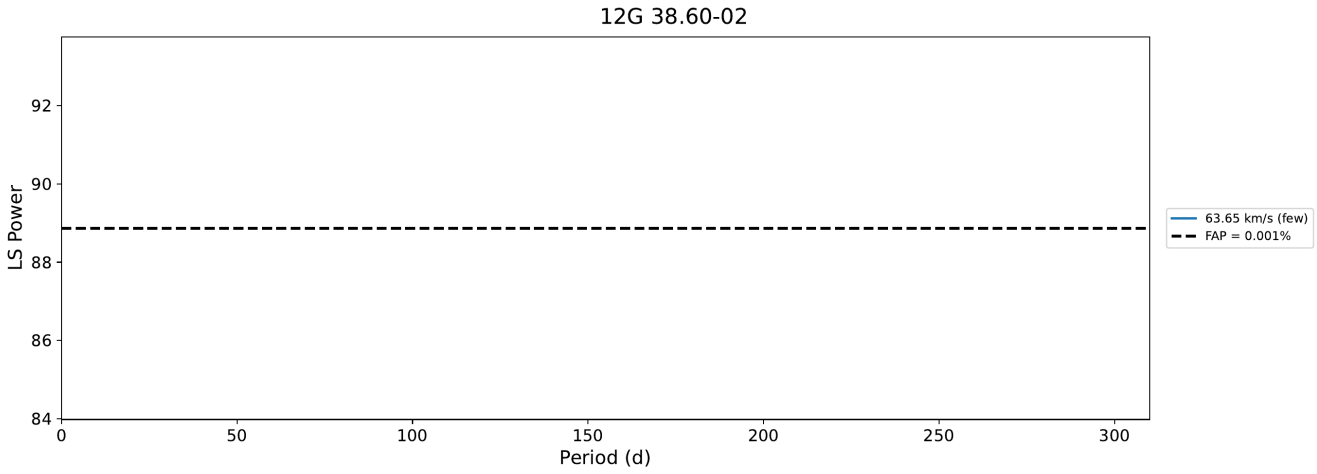


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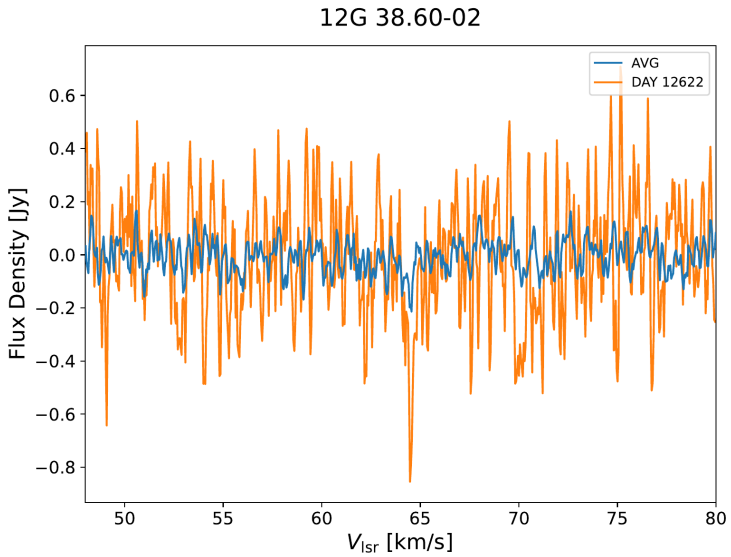
Light curve



Periodogram

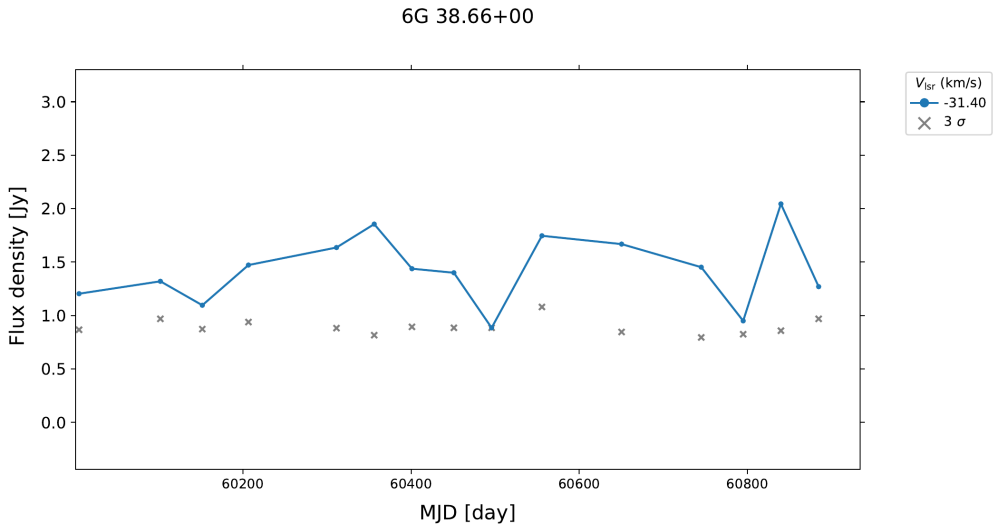


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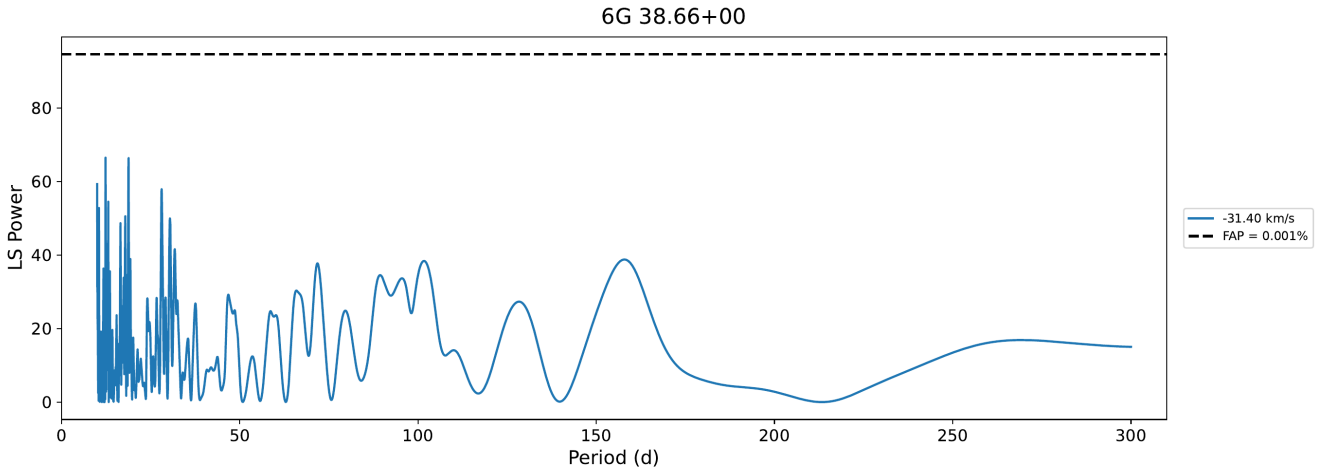


6G 38.66+00

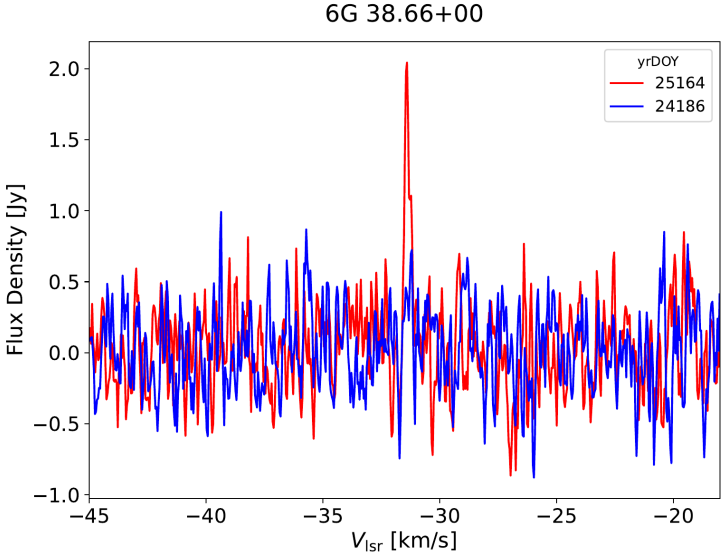
Light curve



Periodogram

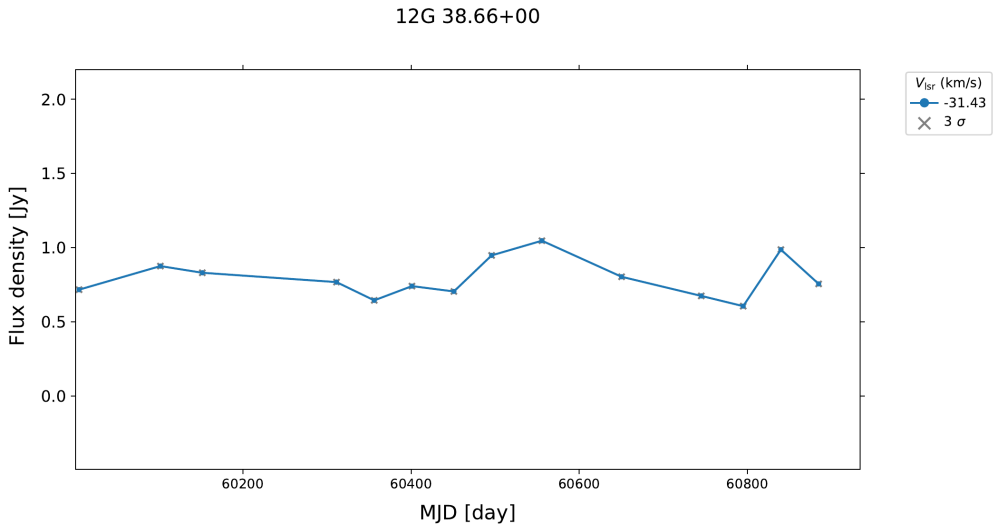


Spectrum

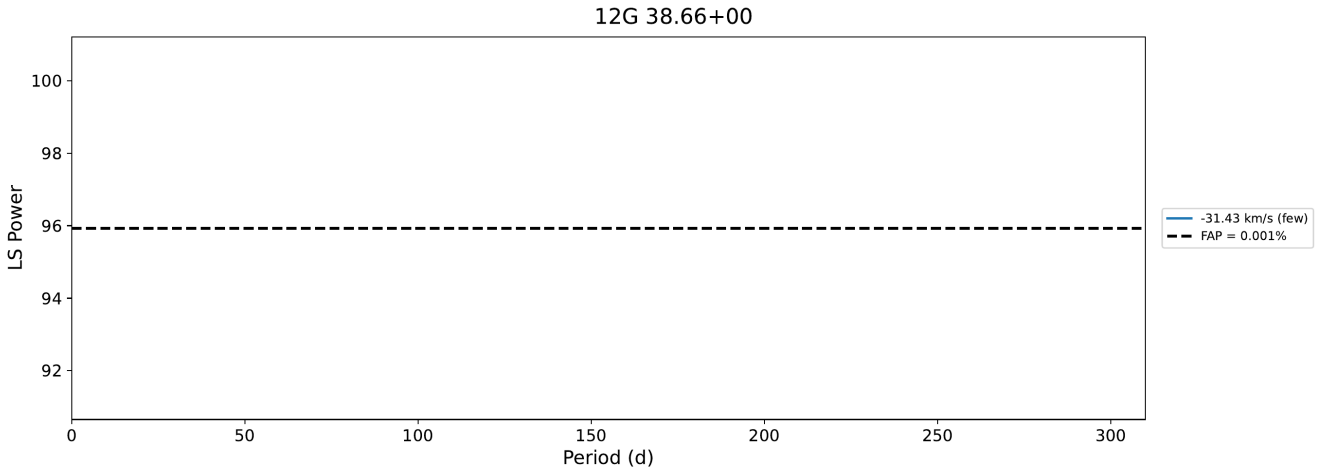


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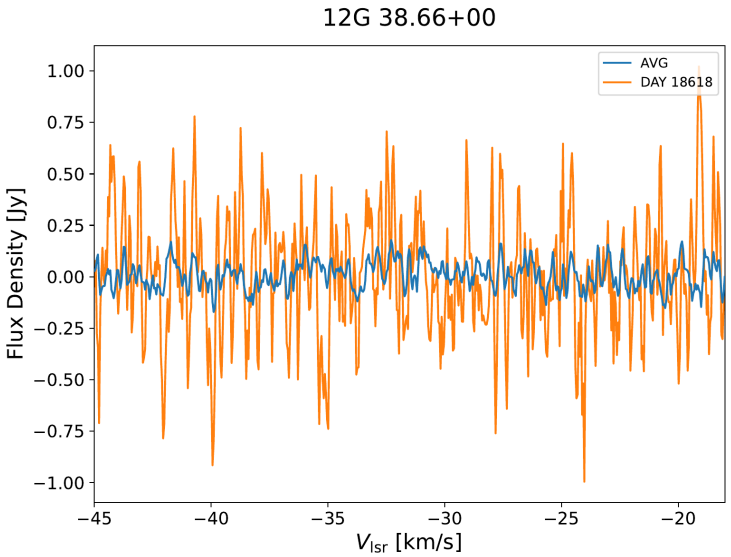
Light curve



Periodogram

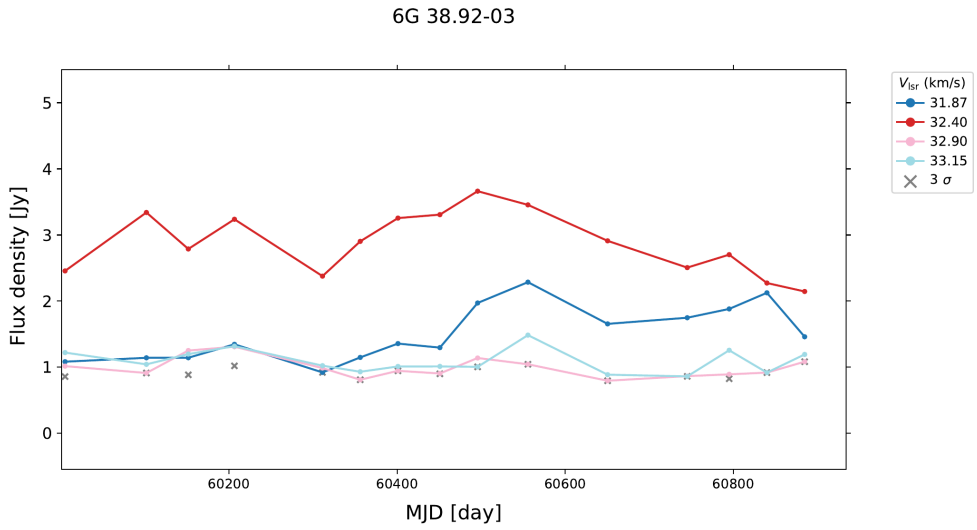


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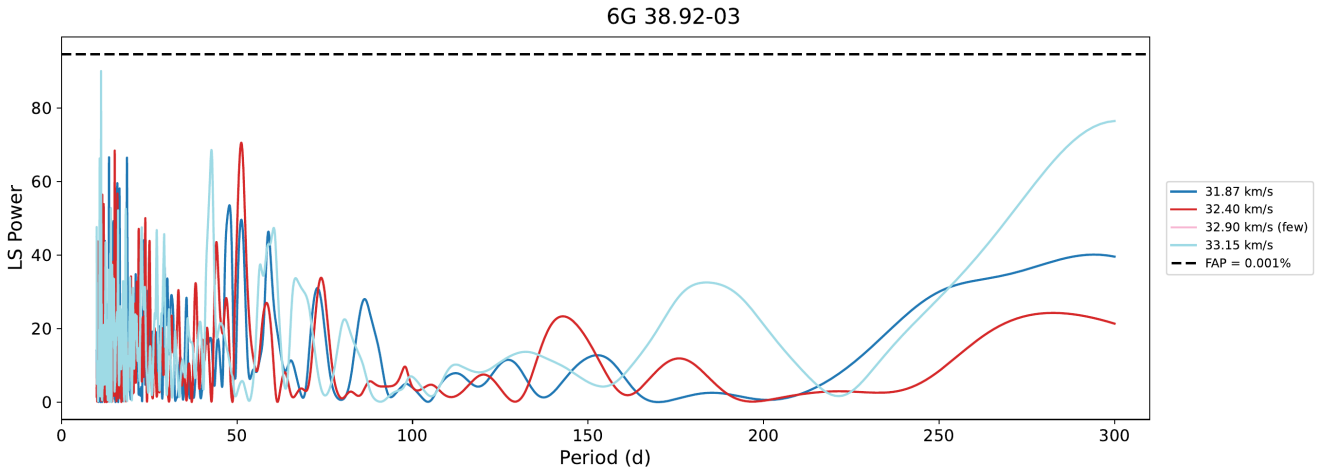


6G 38.92-03

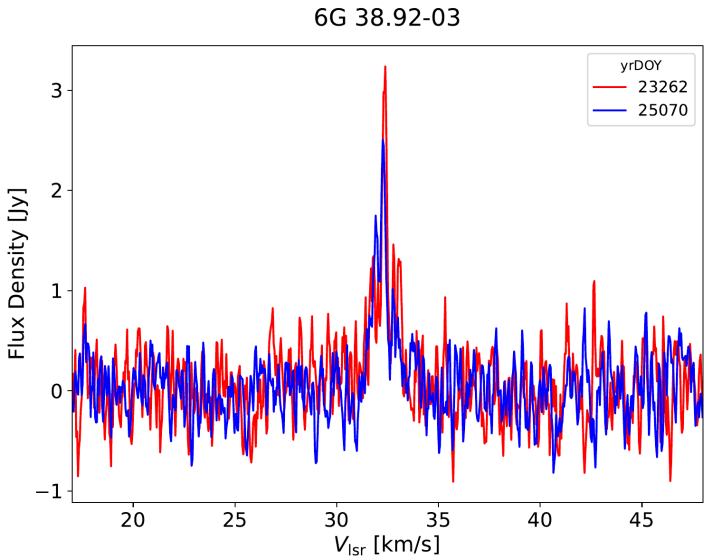
Light curve



Periodogram

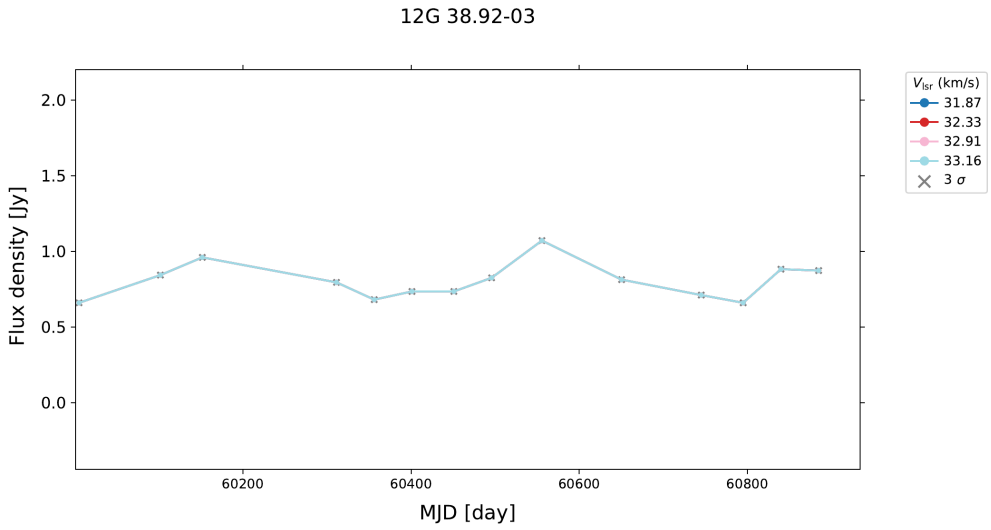


Spectrum

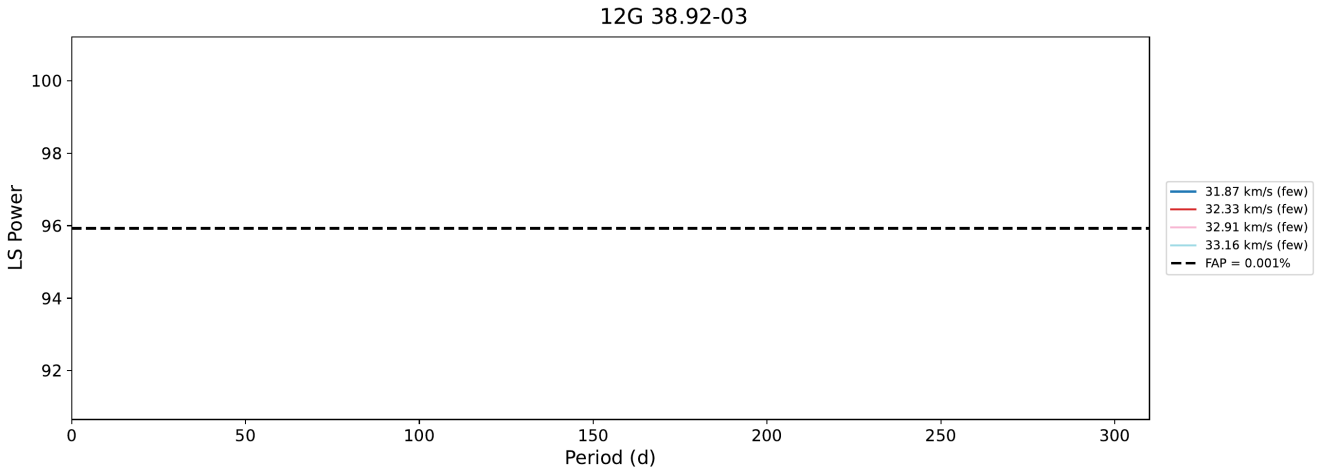


12G 38.92-03

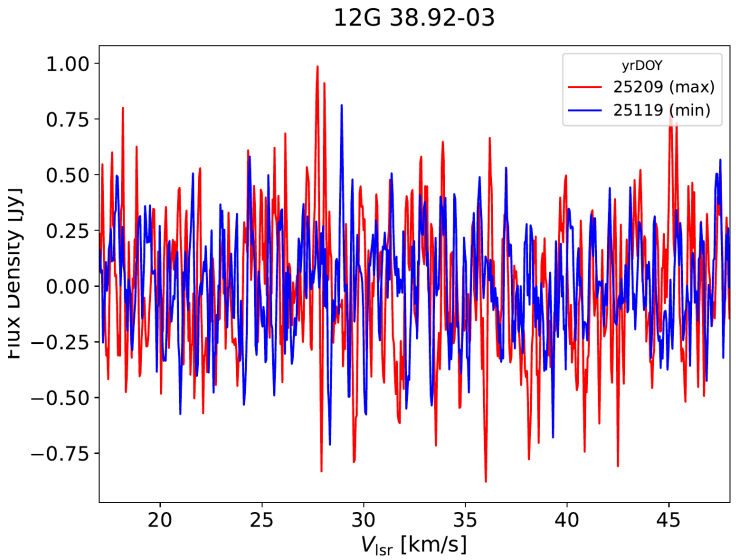
Light curve



Periodogram

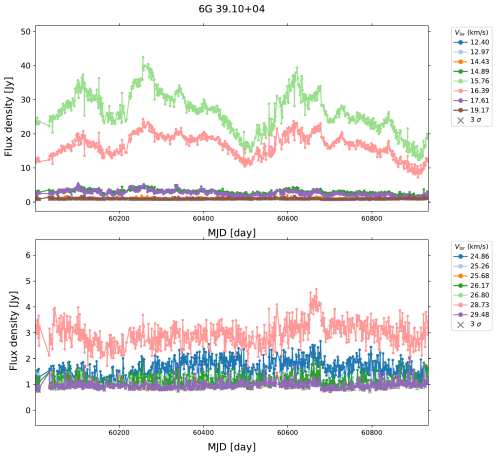


Spectrum

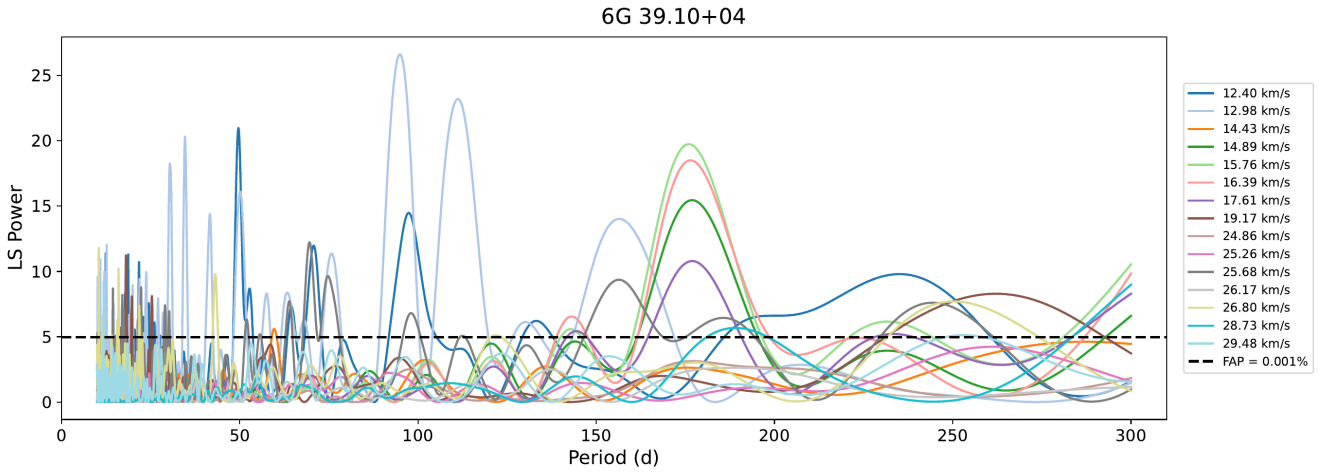


6G 39.10+04

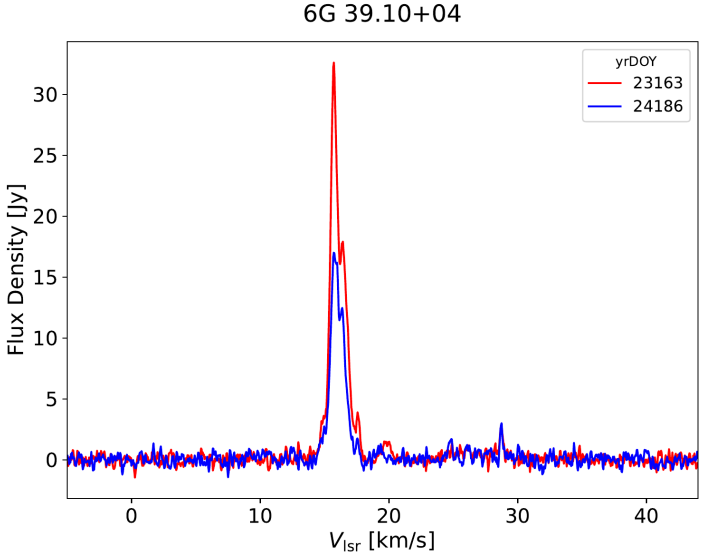
Light curve



Periodogram

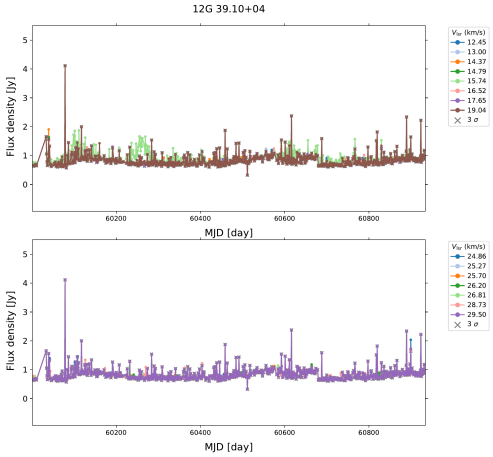


Spectrum

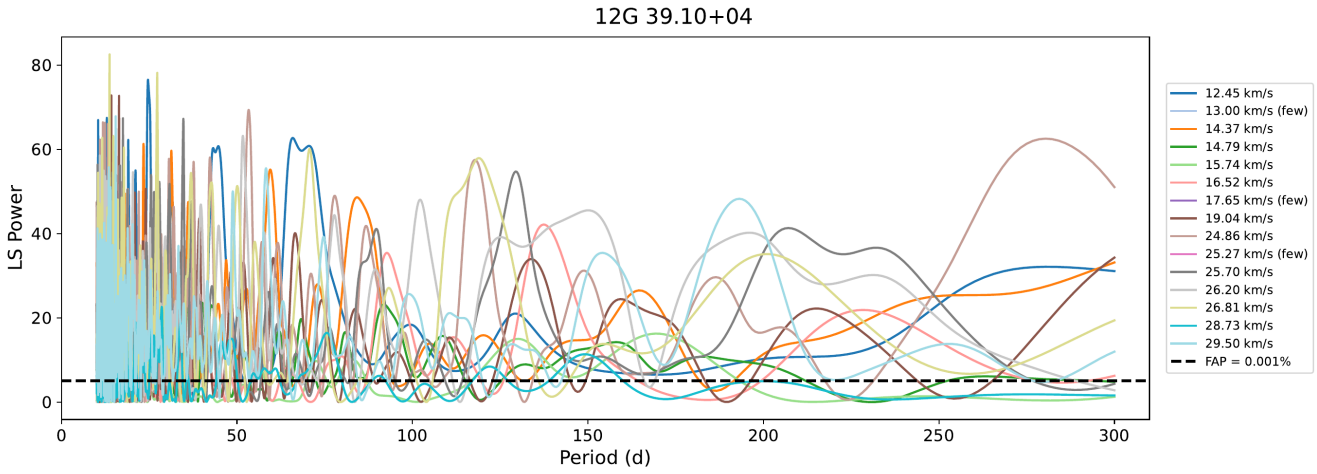


12G 39.10+04

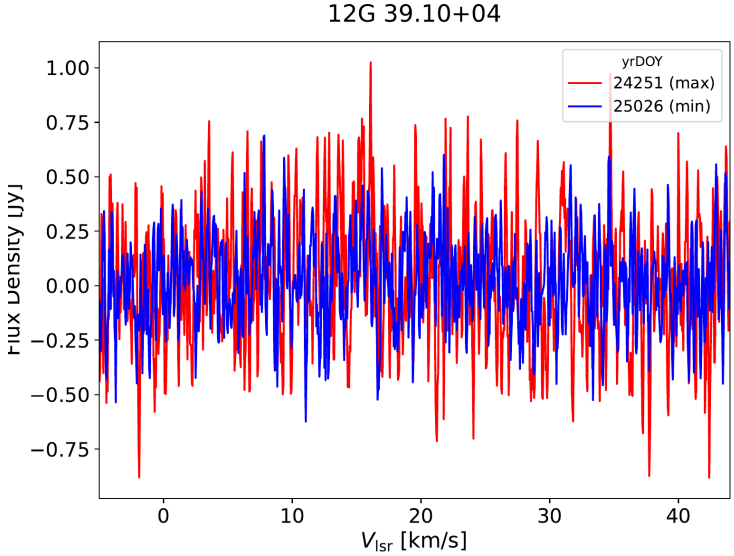
Light curve



Periodogram

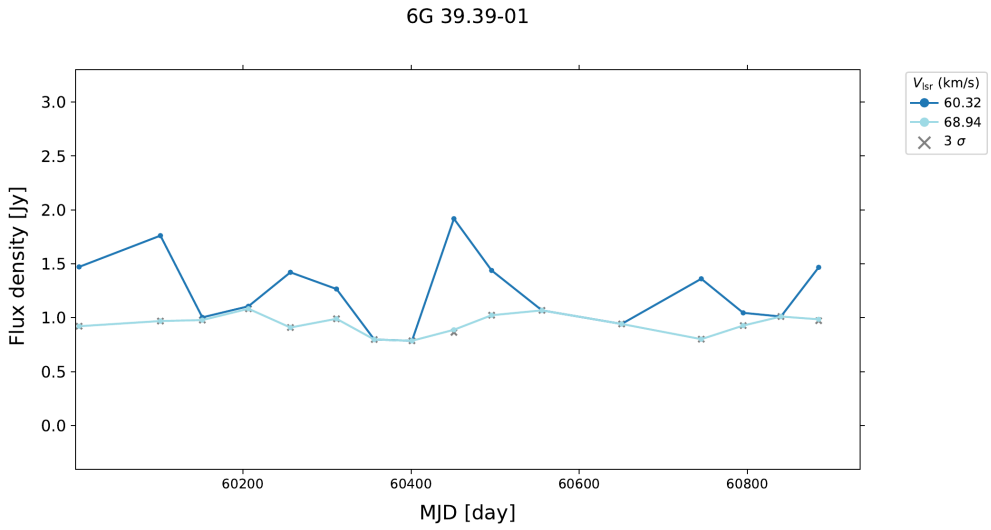


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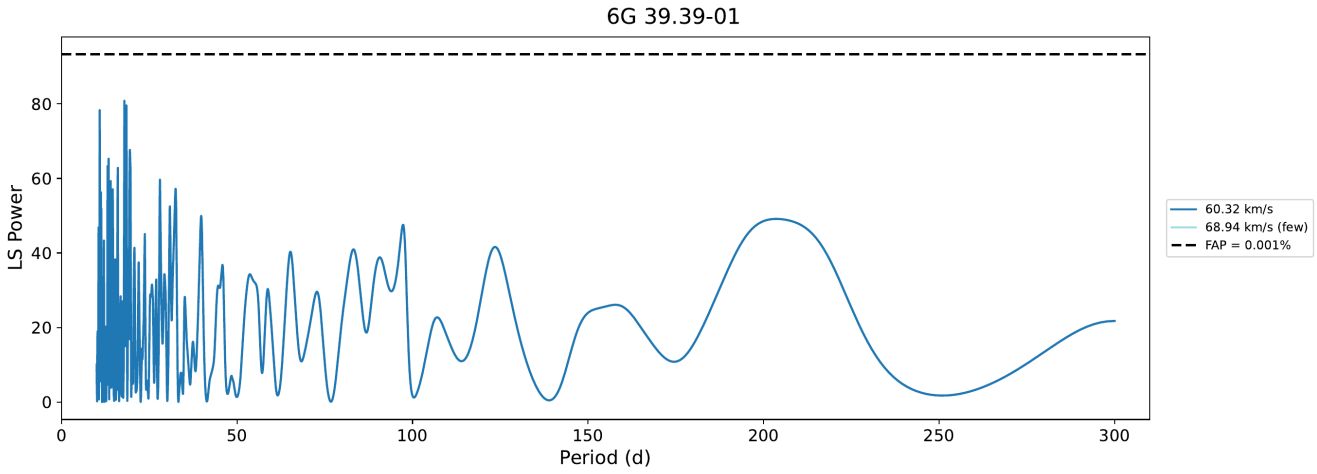


6G 39.39-01

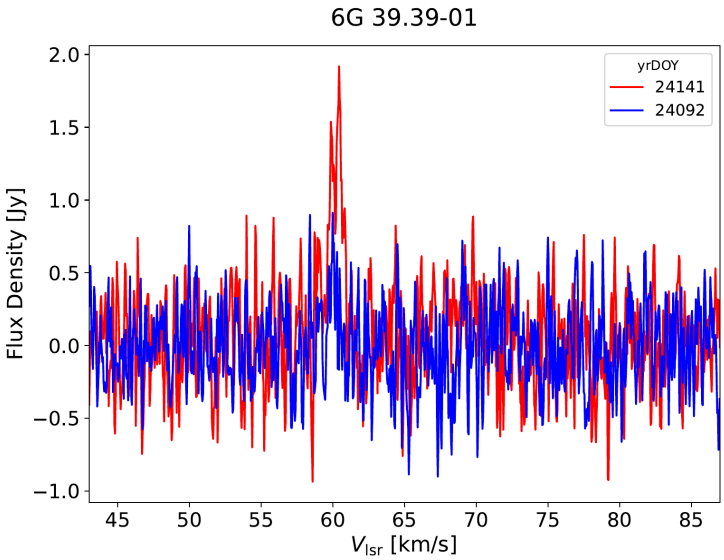
Light curve



Periodogram

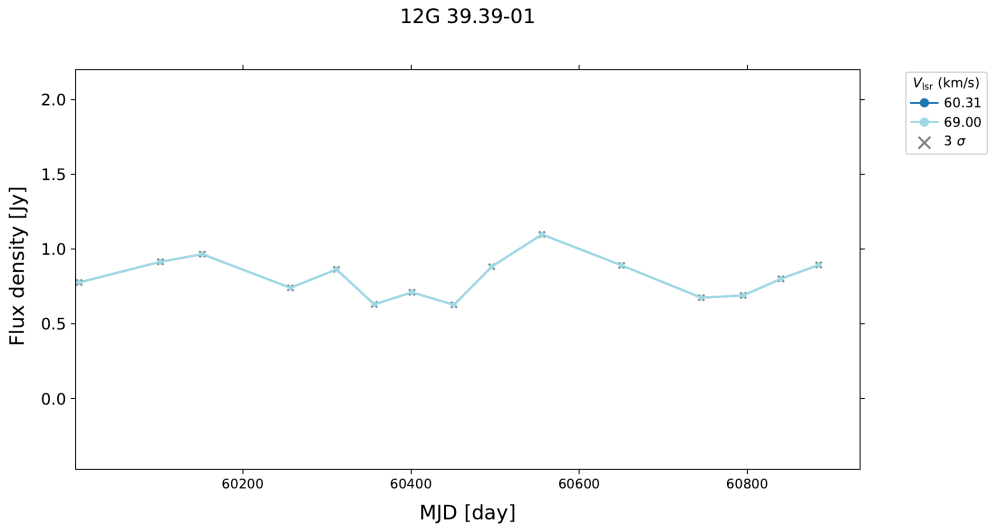


Spectrum

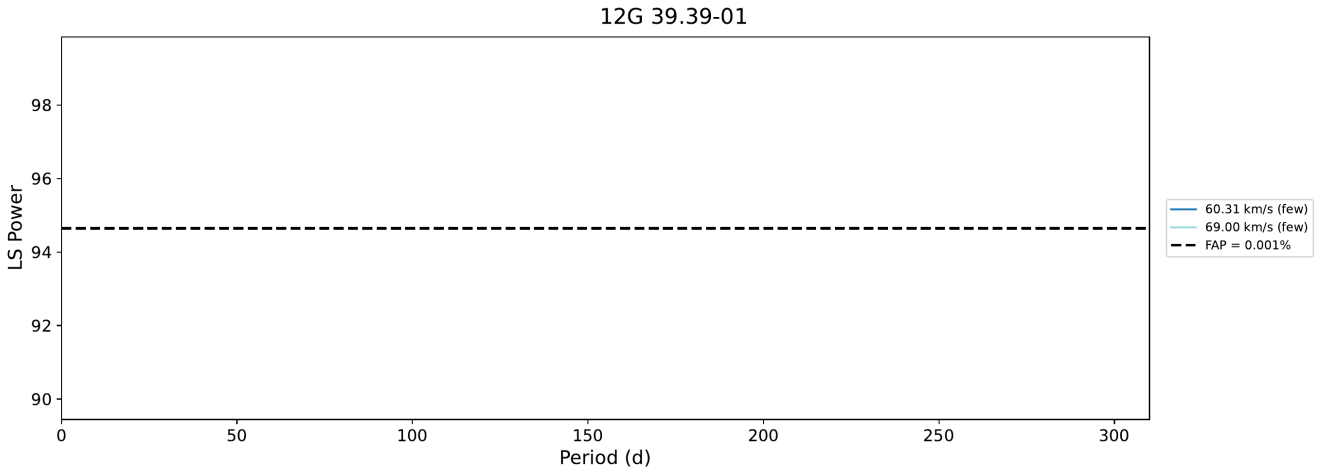


12G 39.39-01

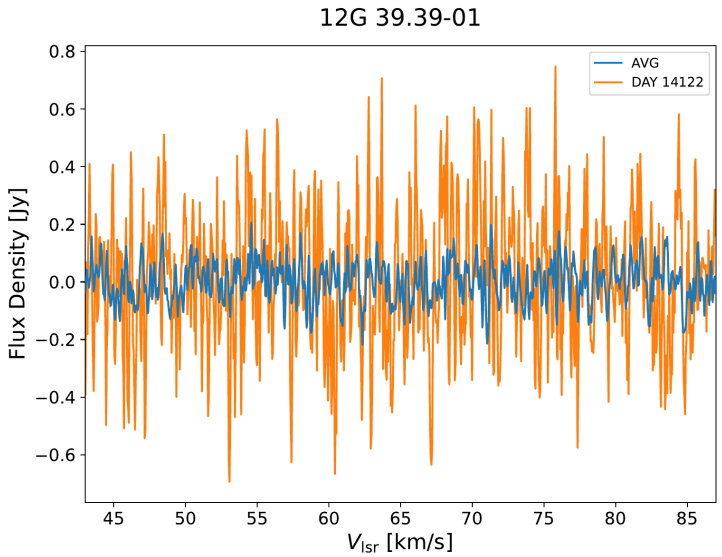
Light curve



Periodogram

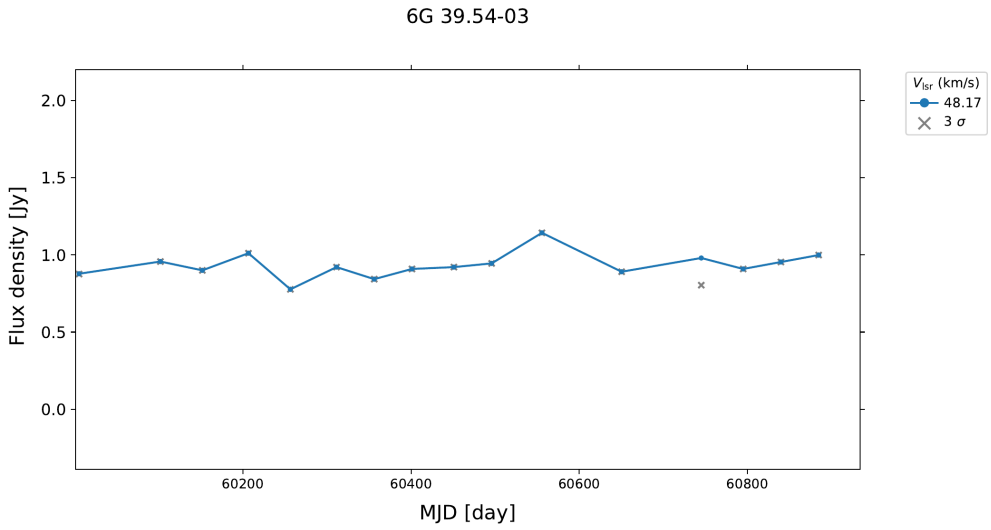


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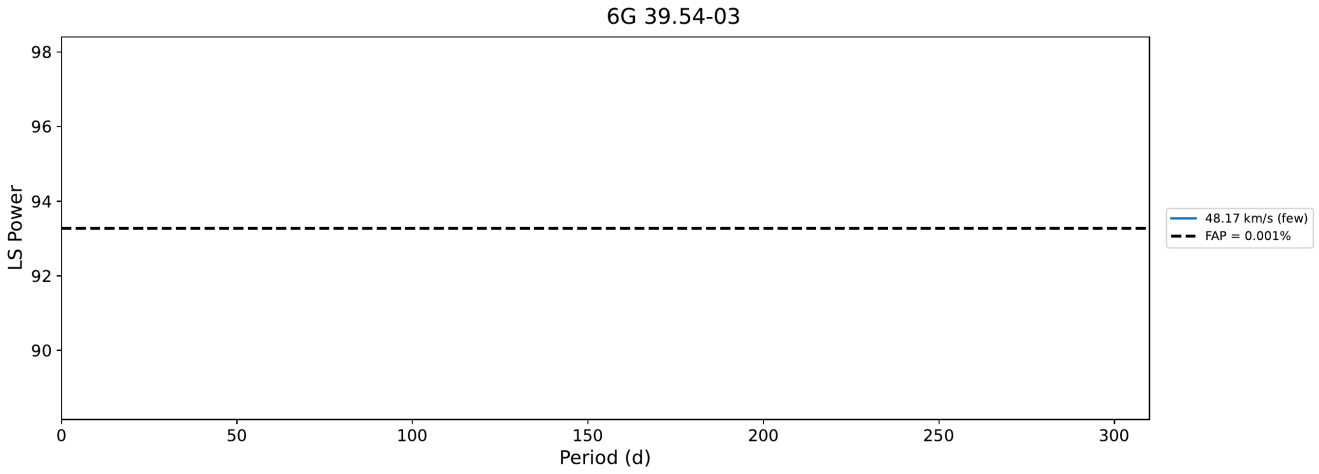


6G 39.54-03

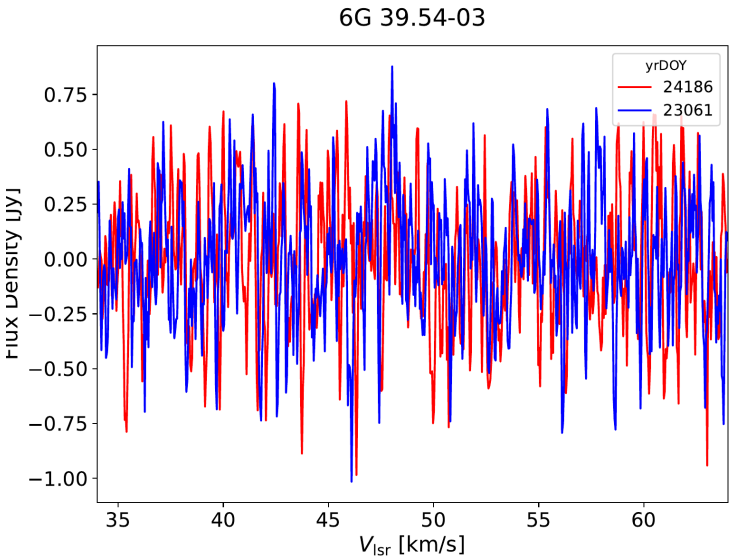
Light curve



Periodogram

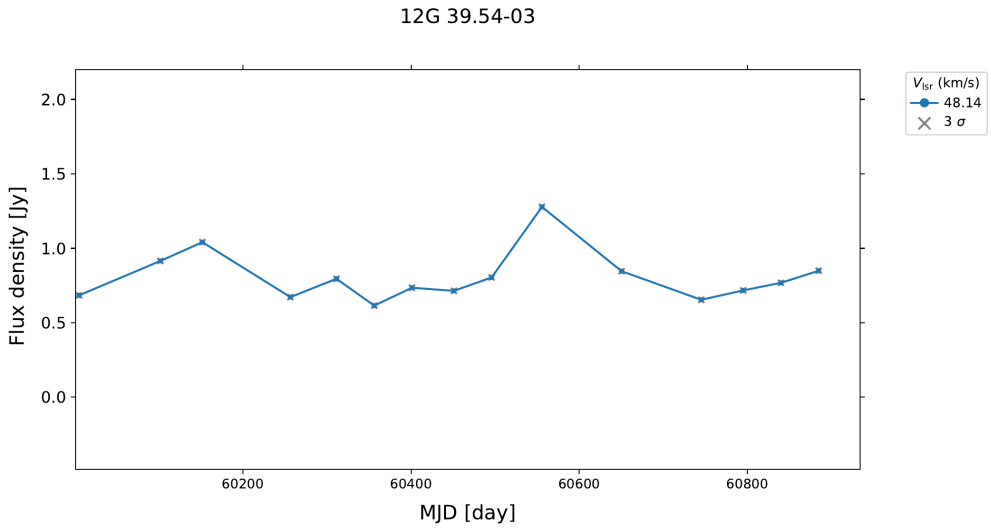


Spectrum

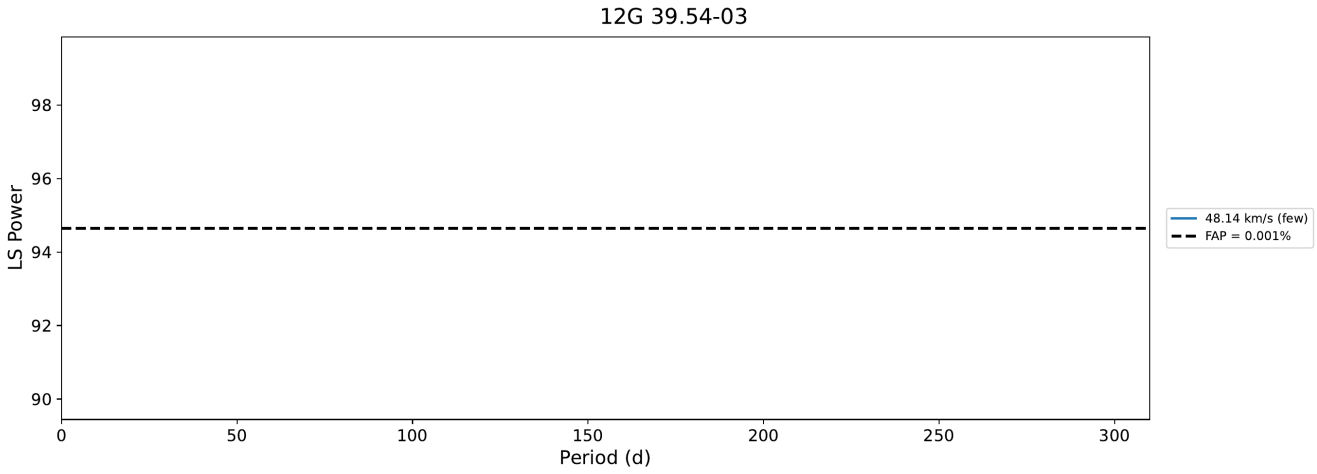


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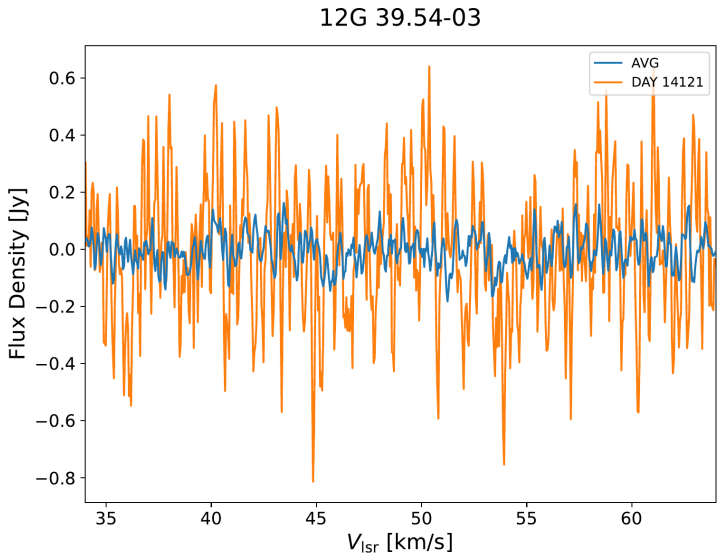
Light curve



Periodogram



Spectrum

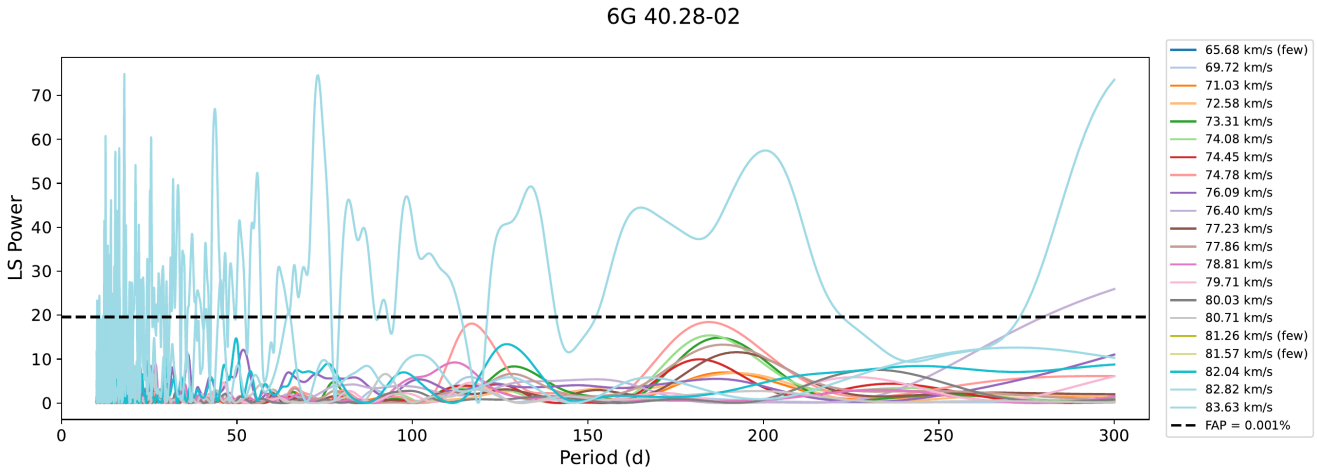


6G 40.28-02

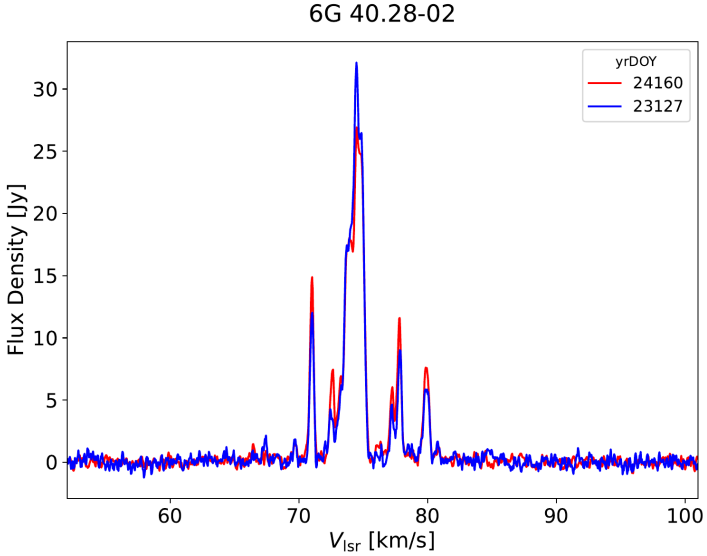
Light curve



Periodogram

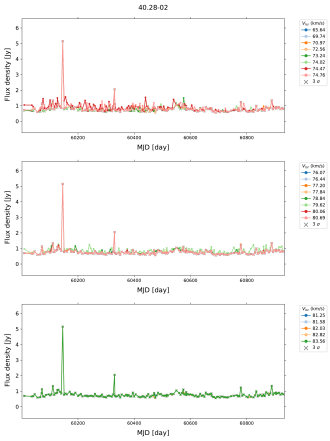


Spectrum

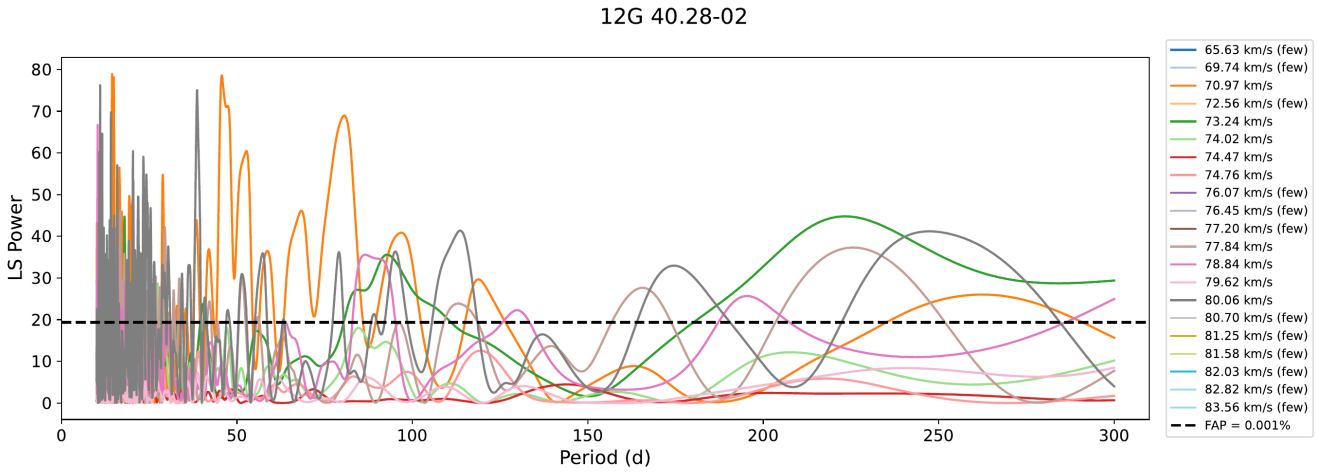


12G 40.28-02

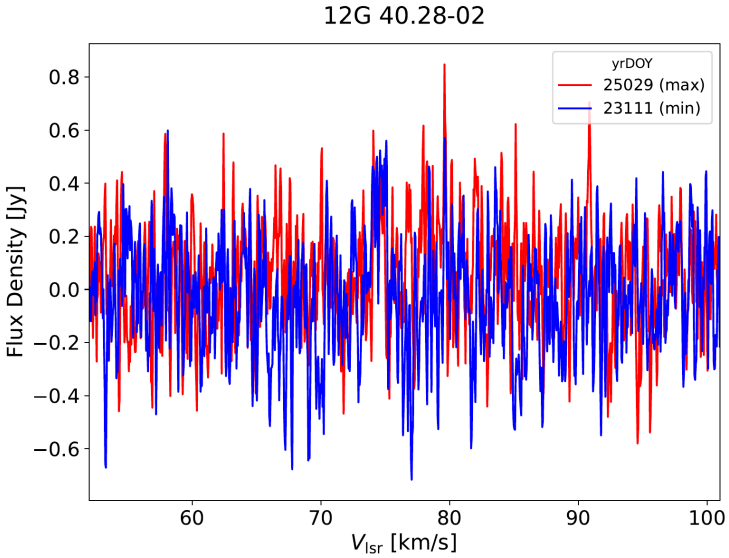
Light curve



Periodogram

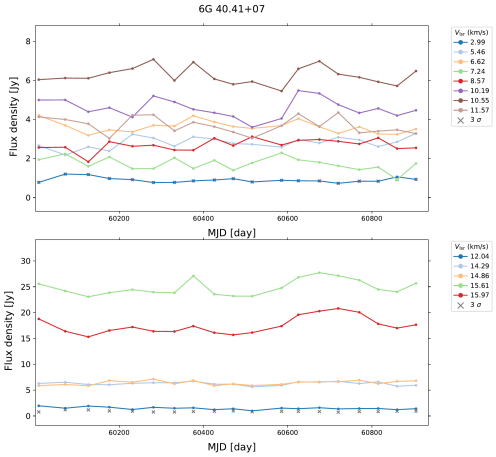


Spectrum

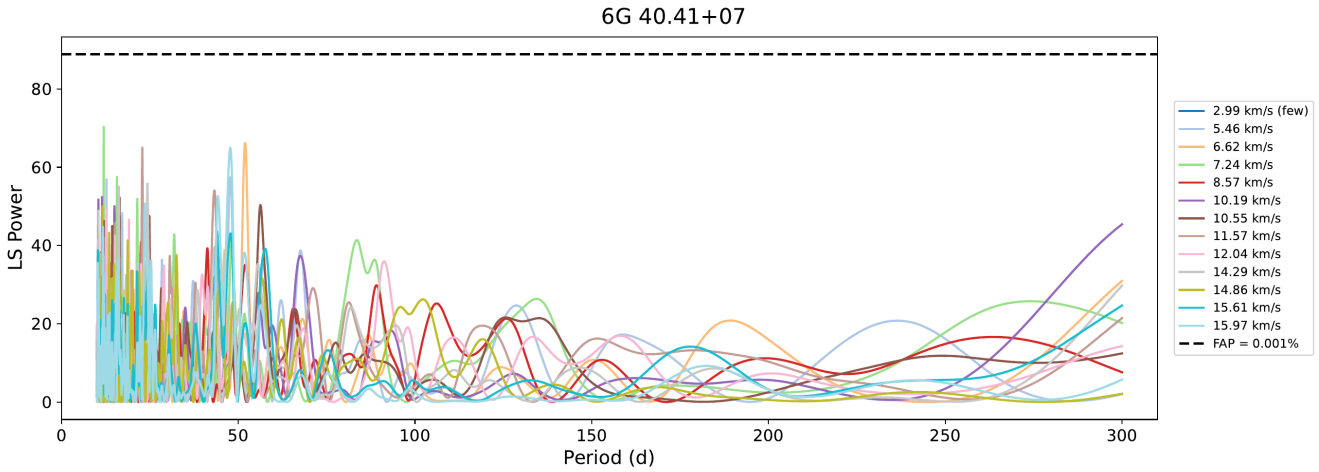


6G 40.41+07

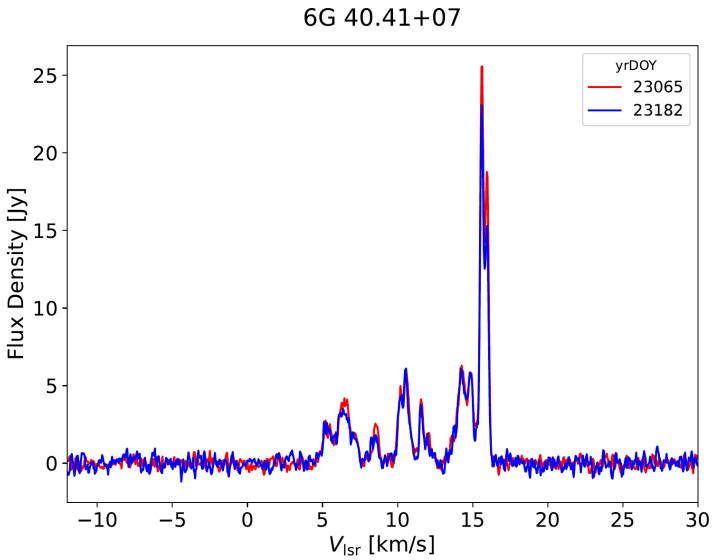
Light curve



Periodogram

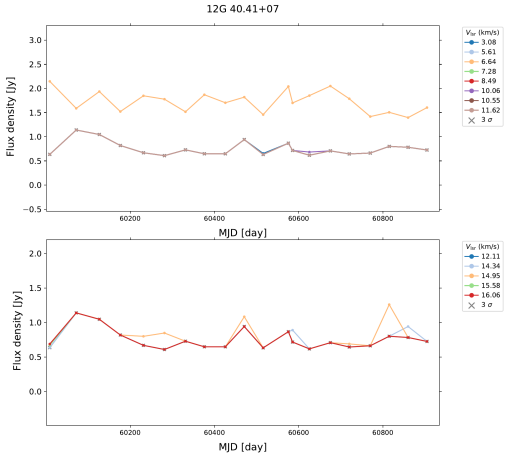


Spectrum

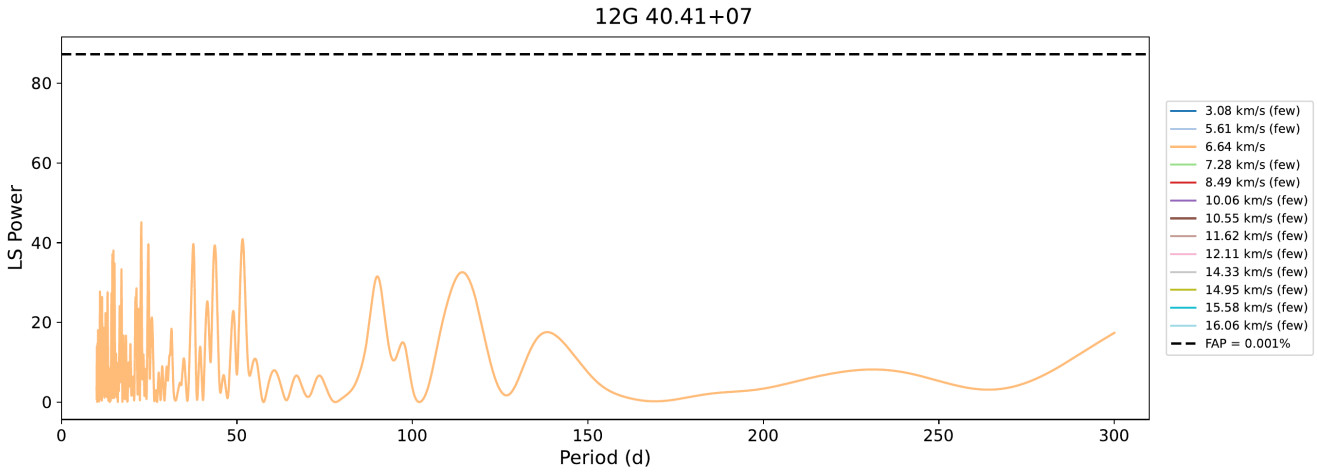


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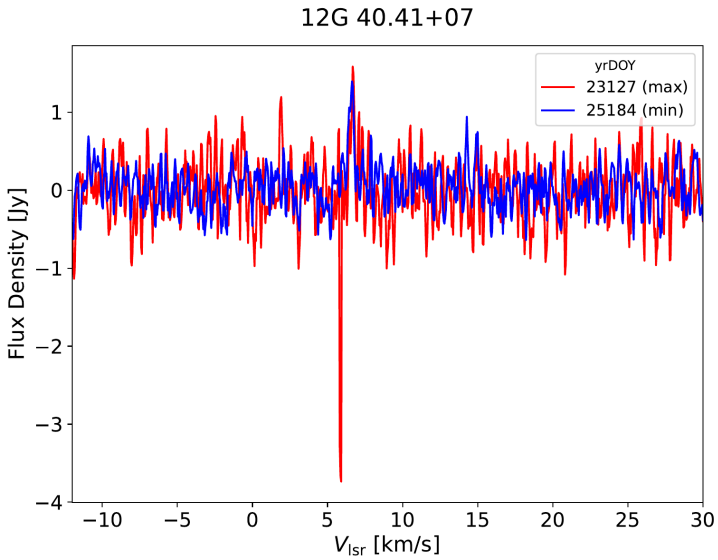
Light curve



Periodogram

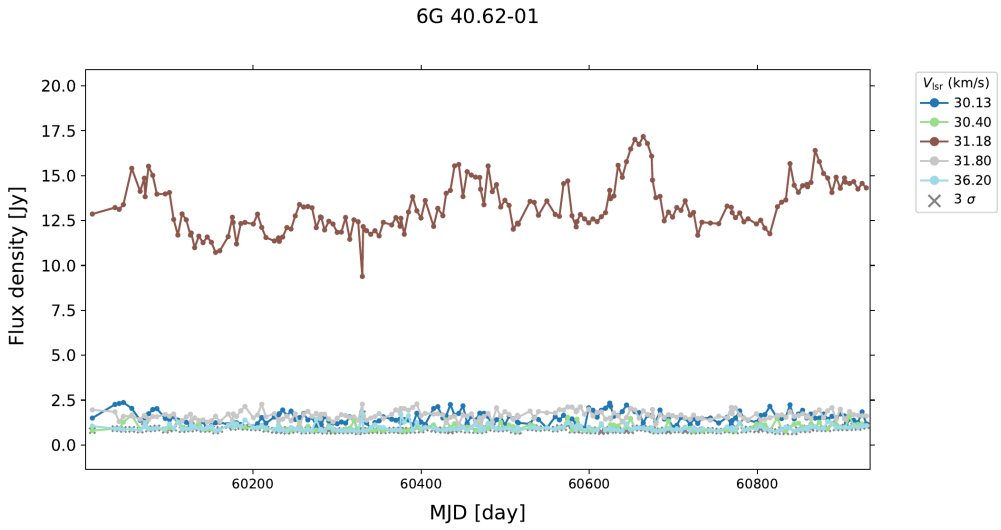


Spectrum

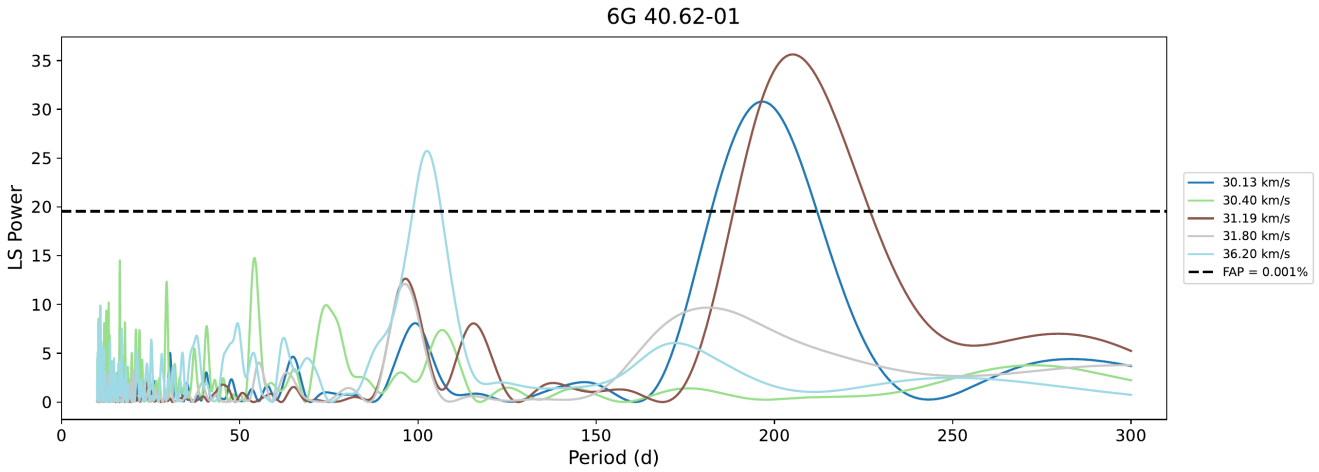


6G 40.62-01

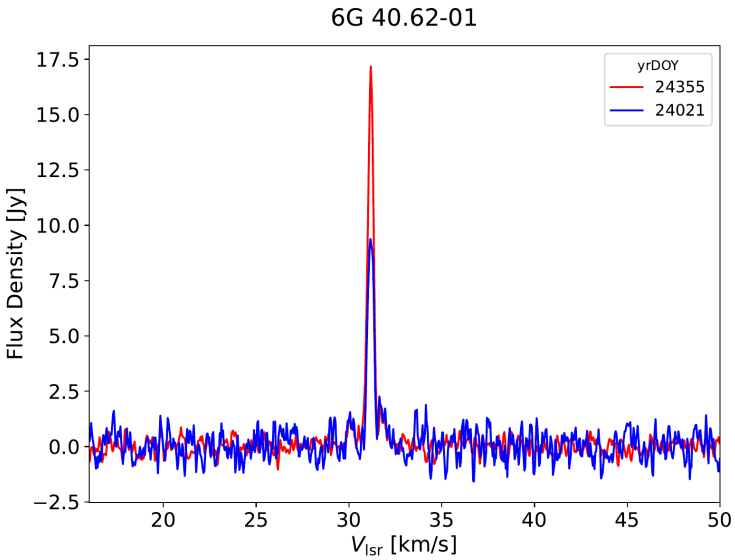
Light curve



Periodogram

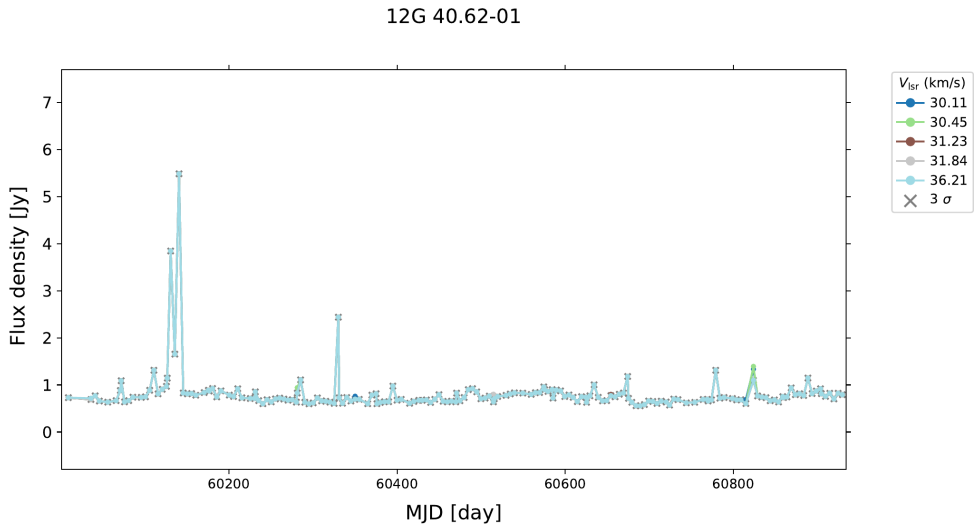


Spectrum

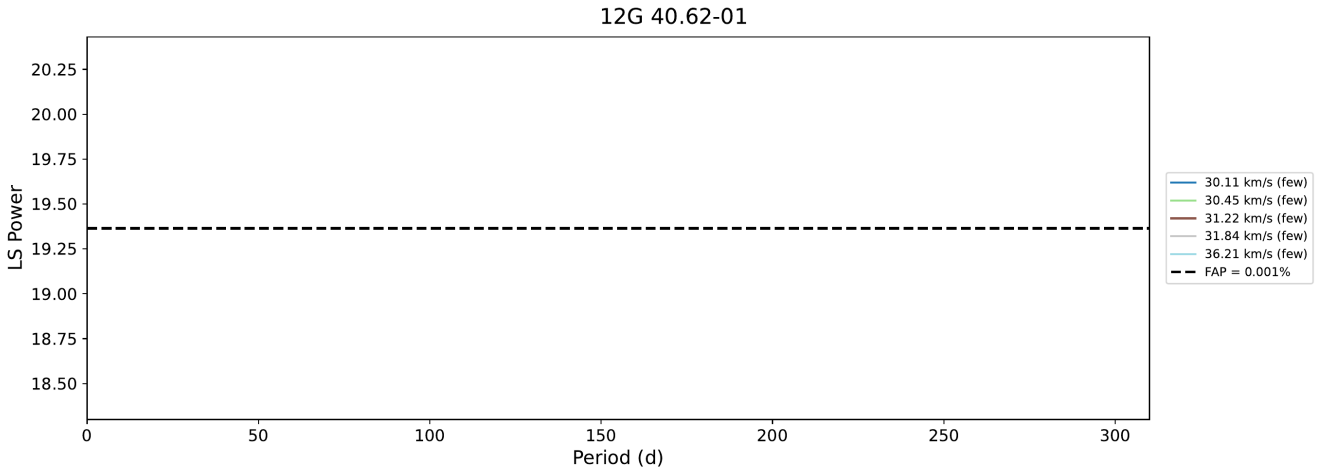


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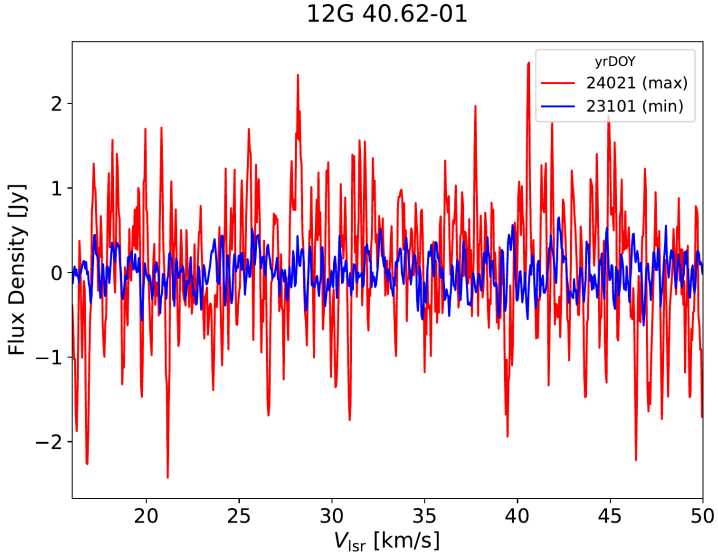
Light curve



Periodogram

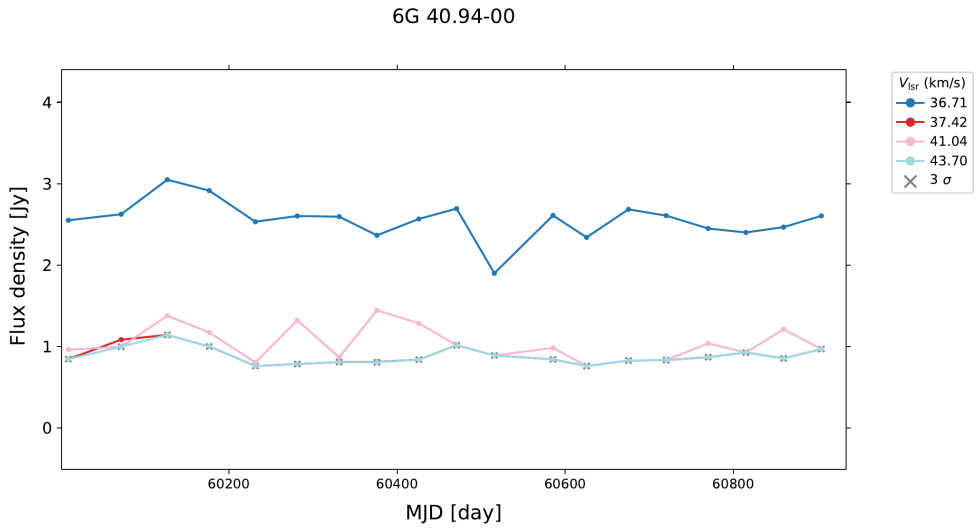


Spectrum

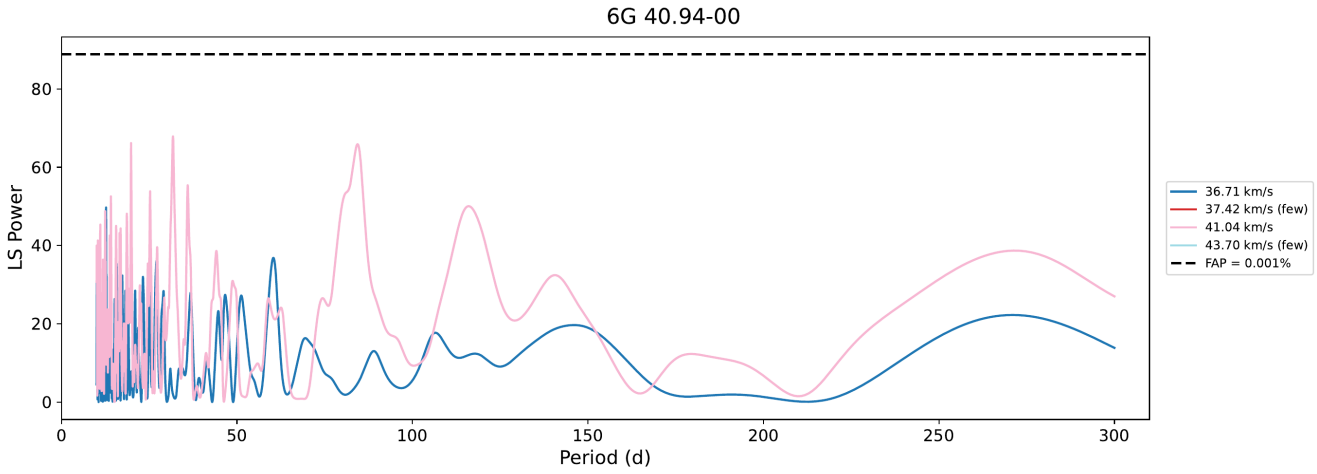


6G 40.94-00

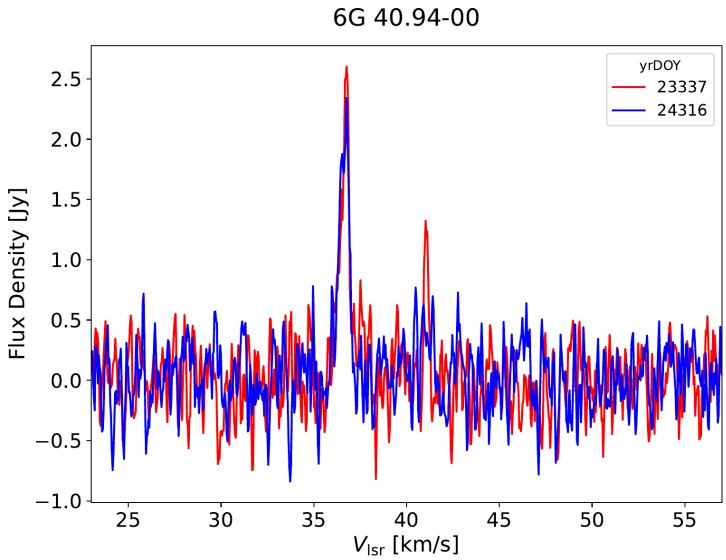
Light curve



Periodogram

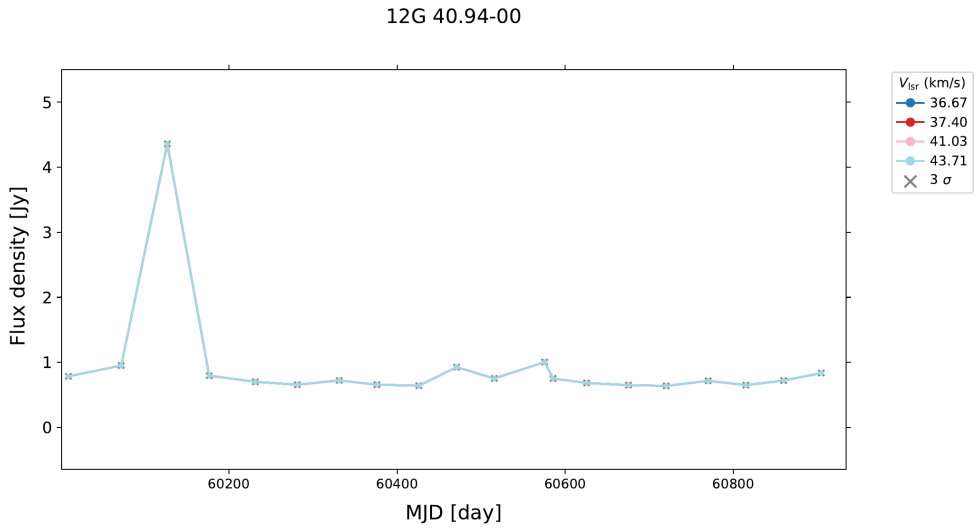


Spectrum

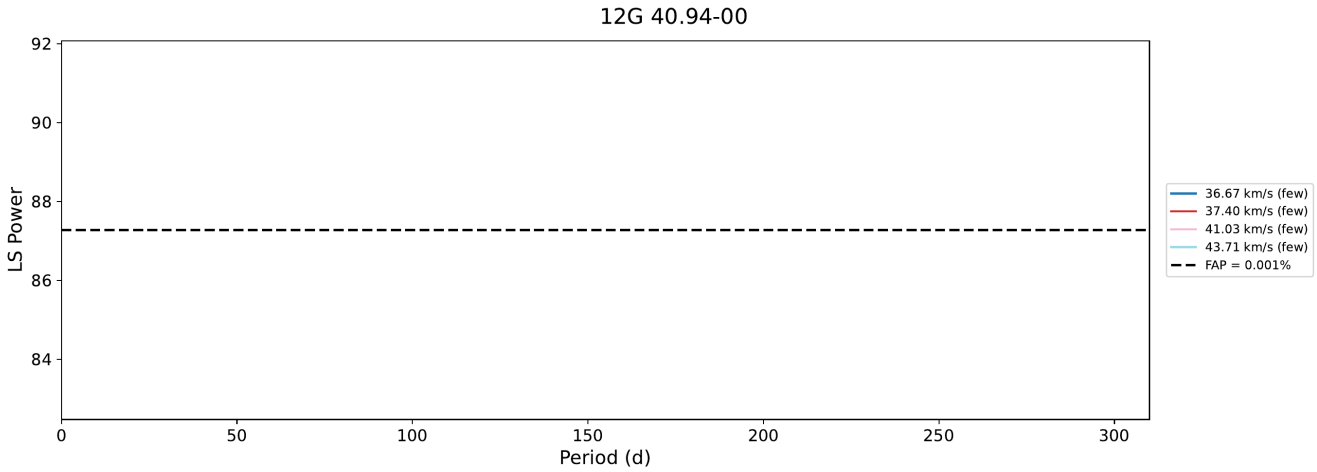


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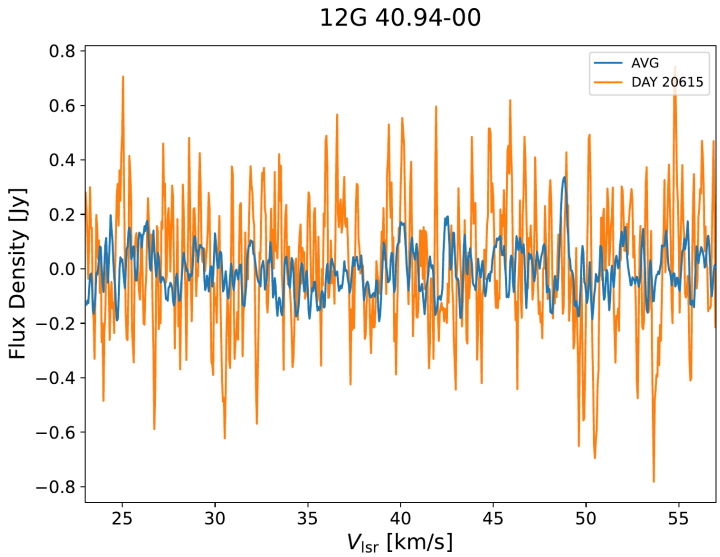
Light curve



Periodogram

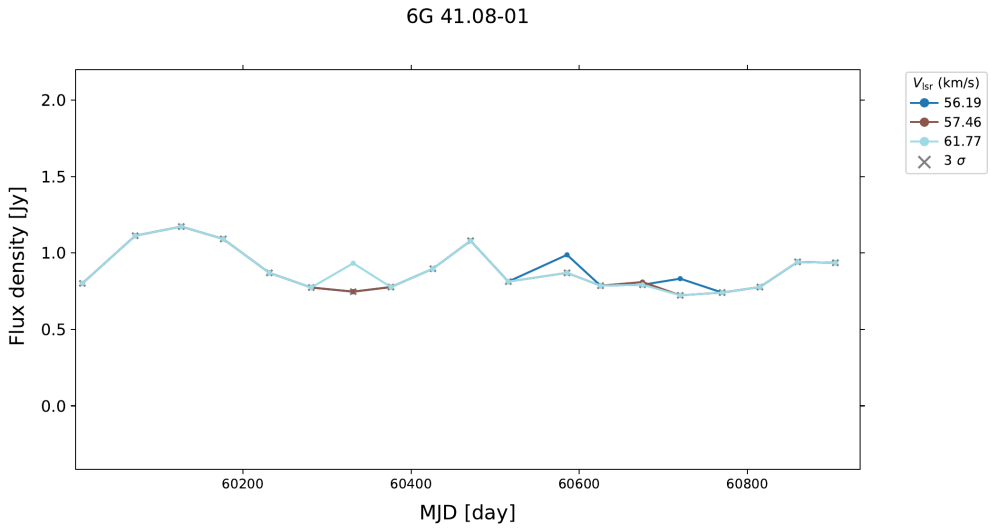


Spectrum

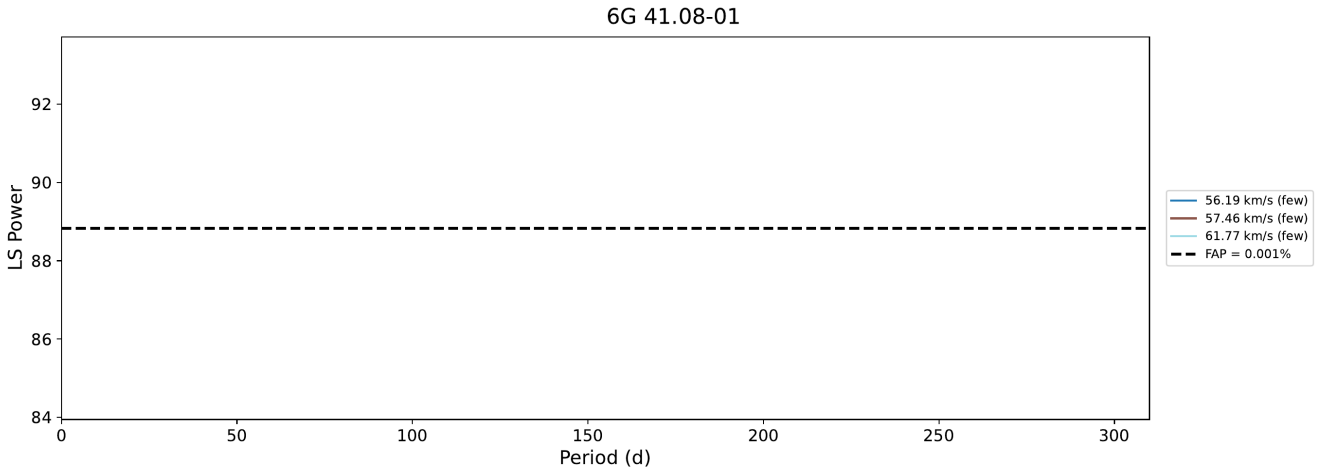


6G 41.08-01

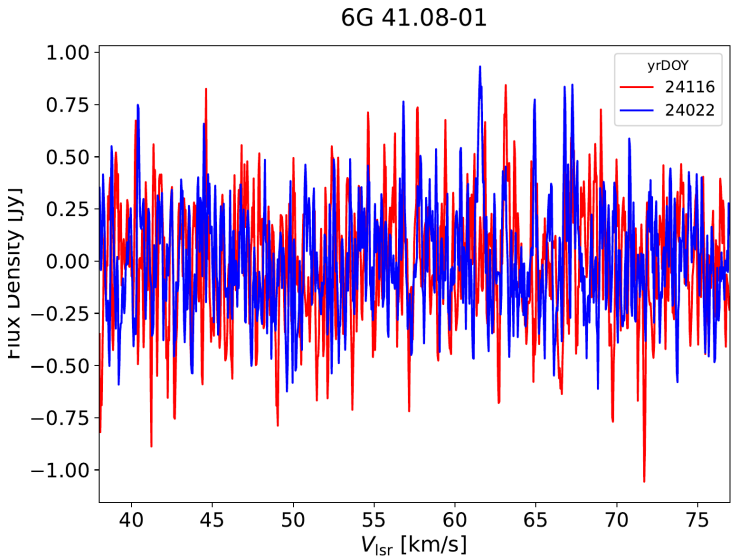
Light curve



Periodogram

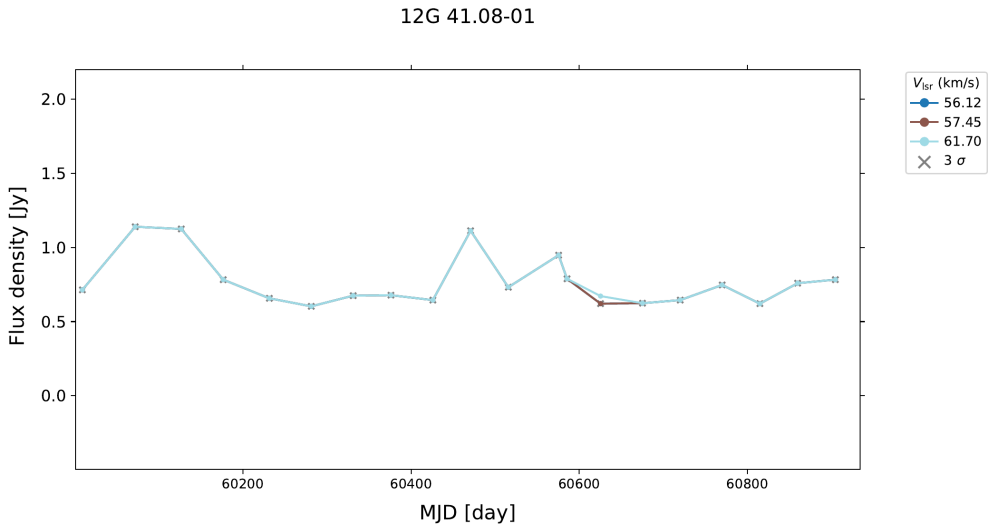


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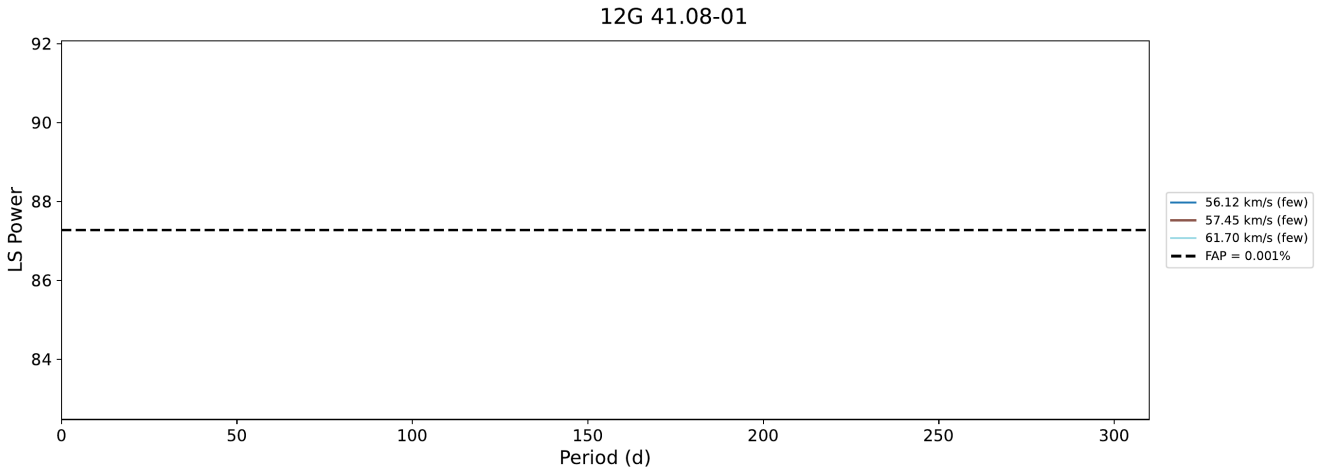


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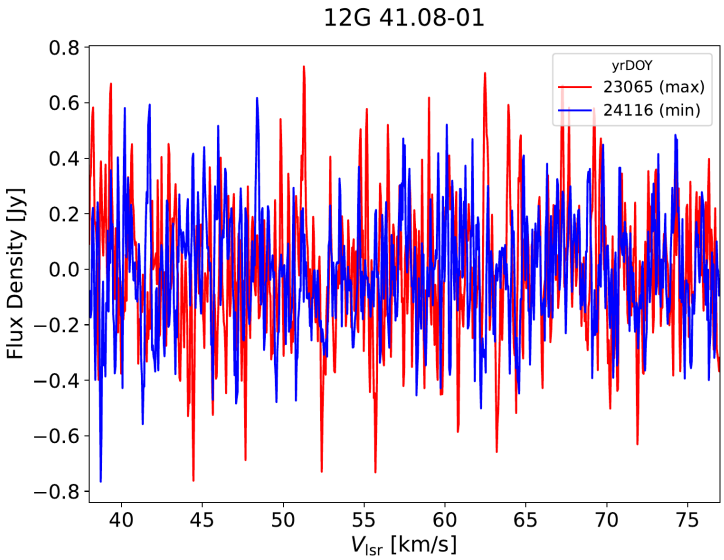
Light curve



Periodogram

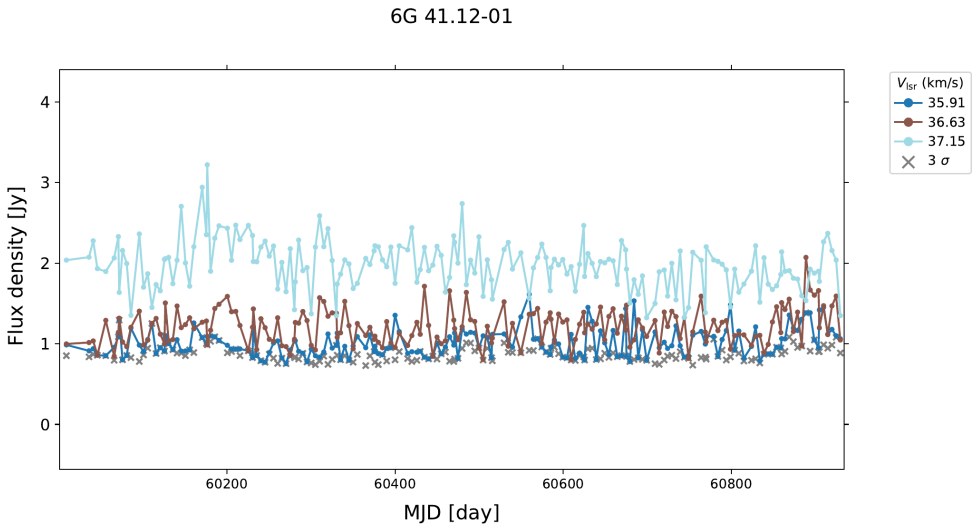


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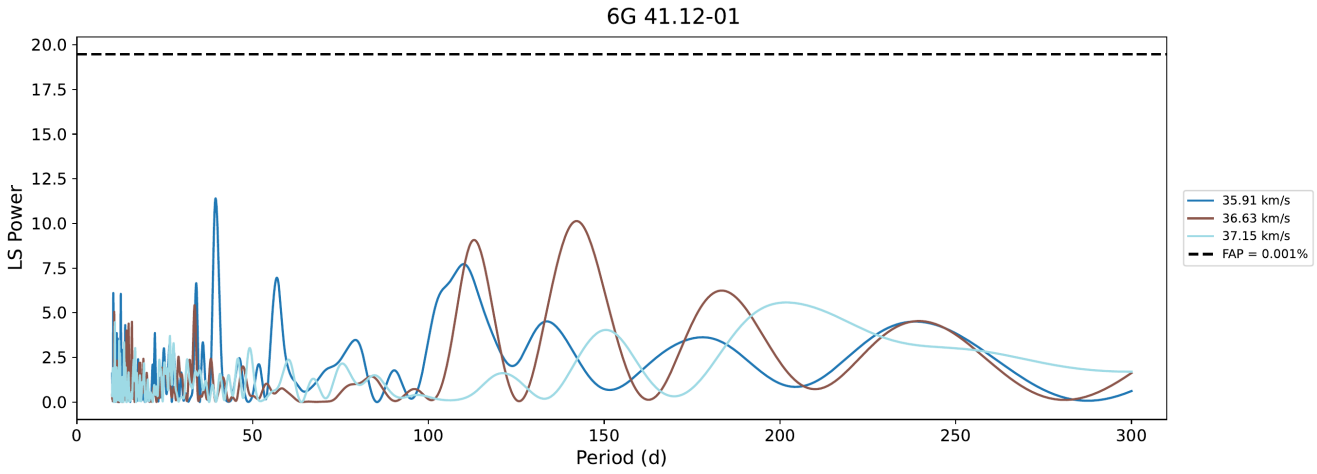


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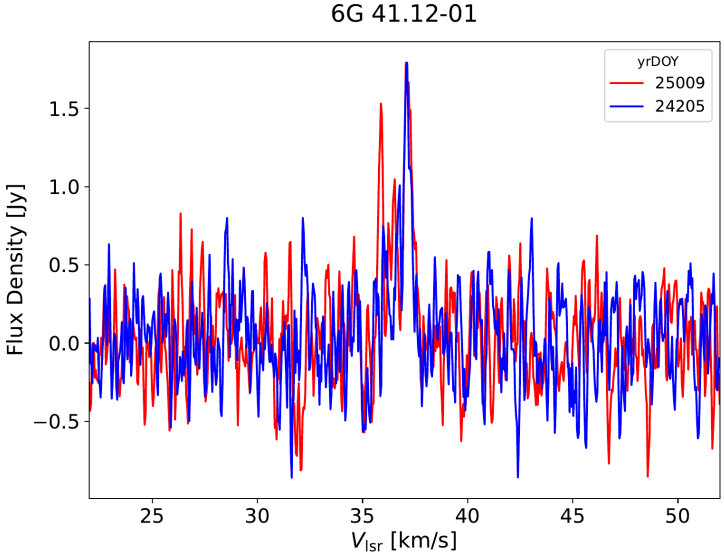
Light curve



Periodogram

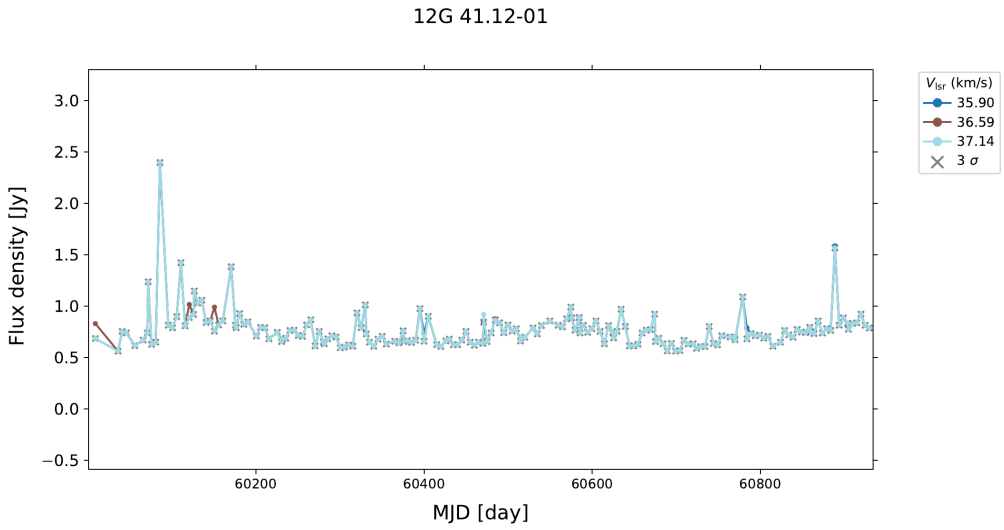


Spectrum

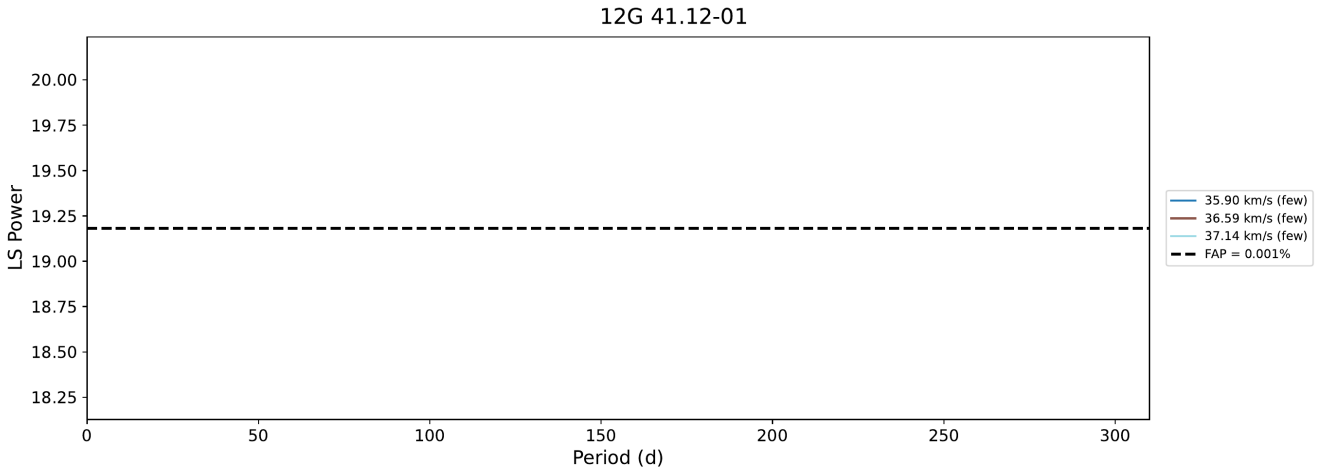


12G 41.12-01

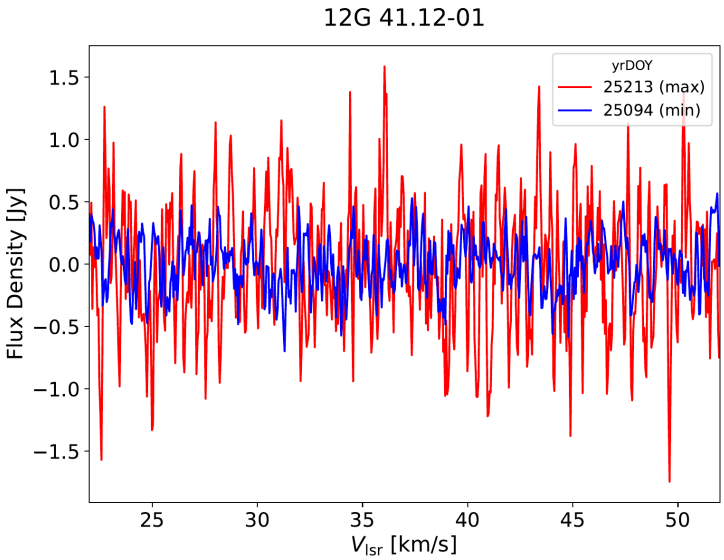
Light curve



Periodogram

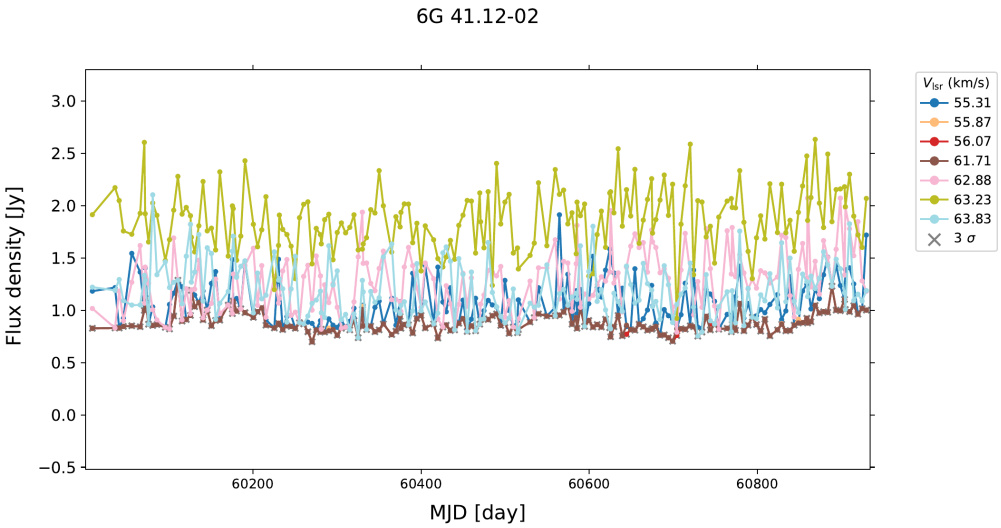


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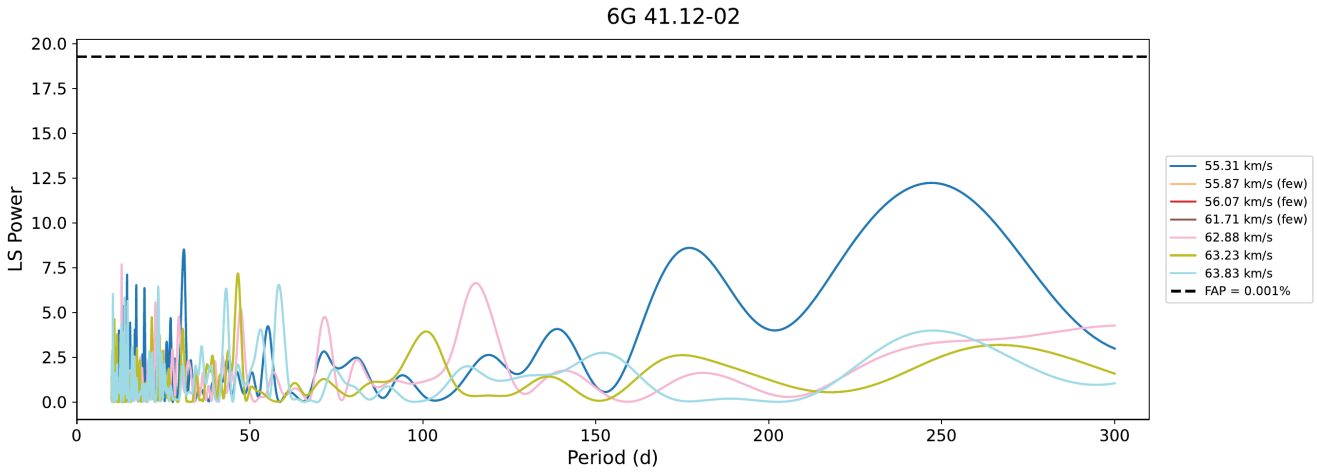


6G 41.12-02

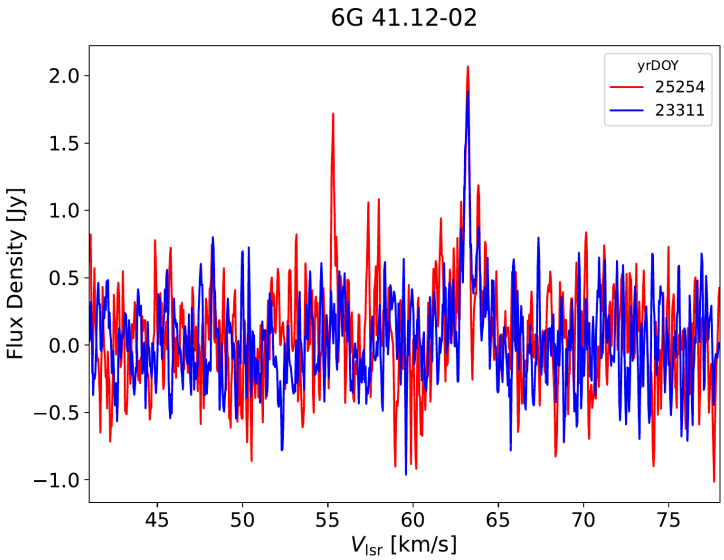
Light curve



Periodogram

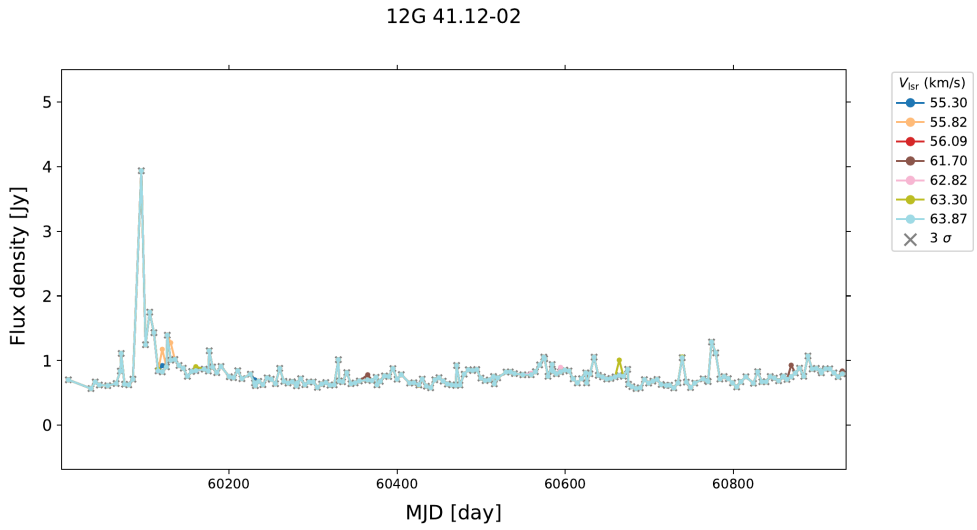


Spectrum

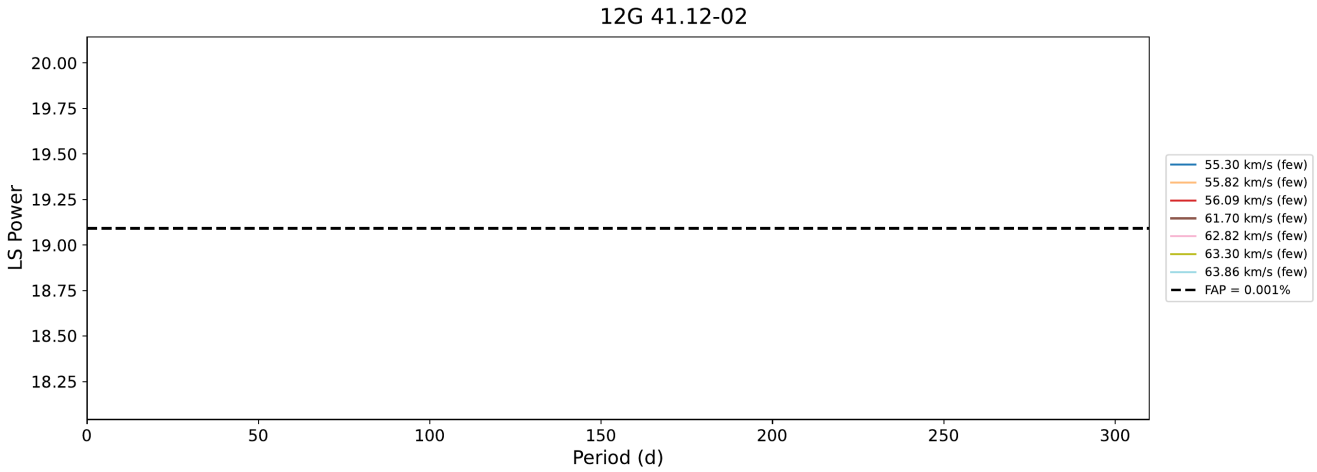


12G 41.12-02

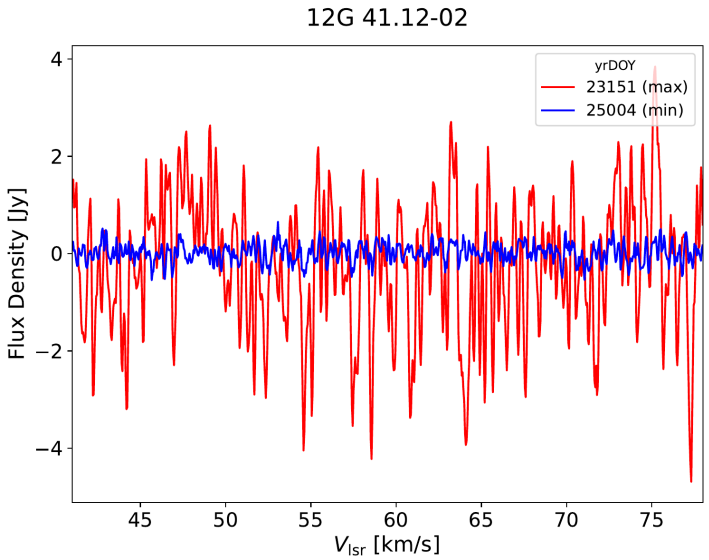
Light curve



Periodogram

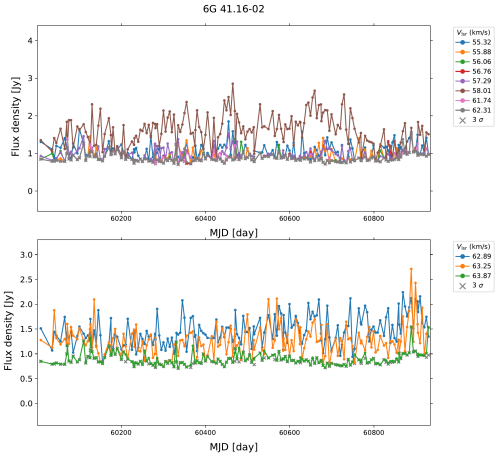


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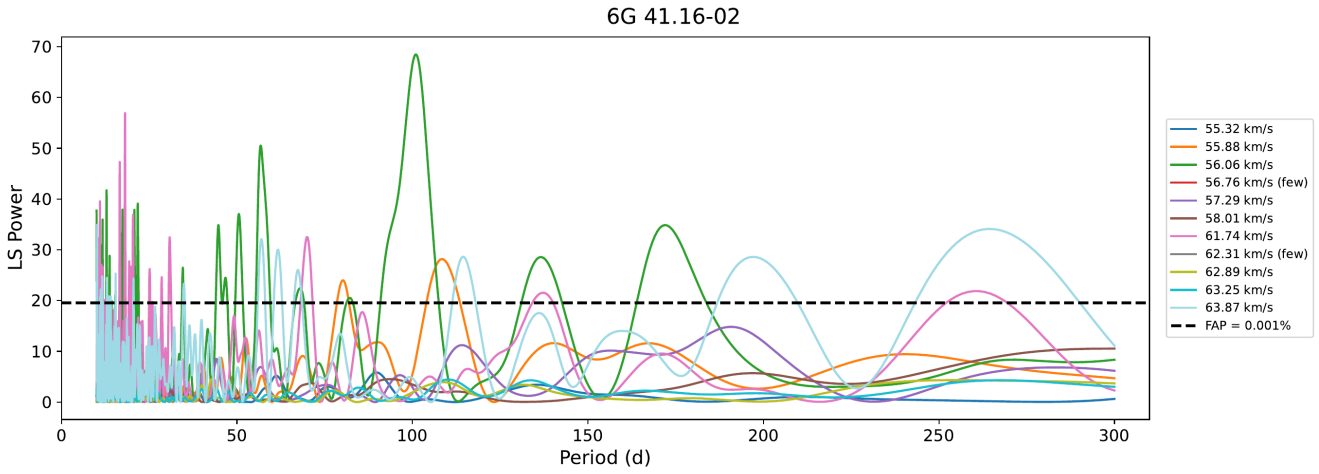


6G 41.16-02

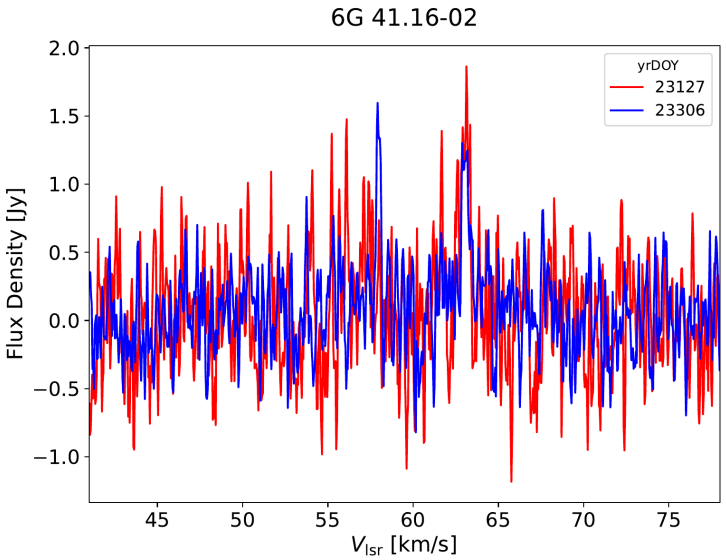
Light curve



Periodogram

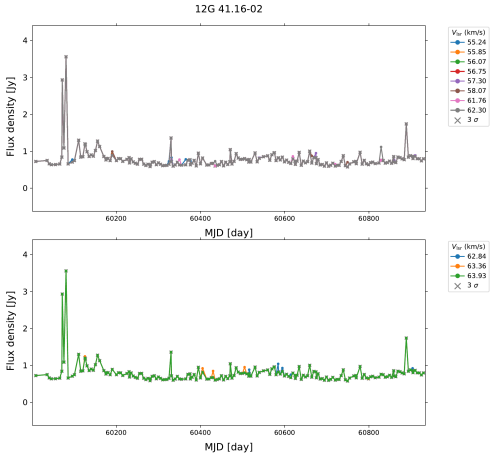


Spectrum

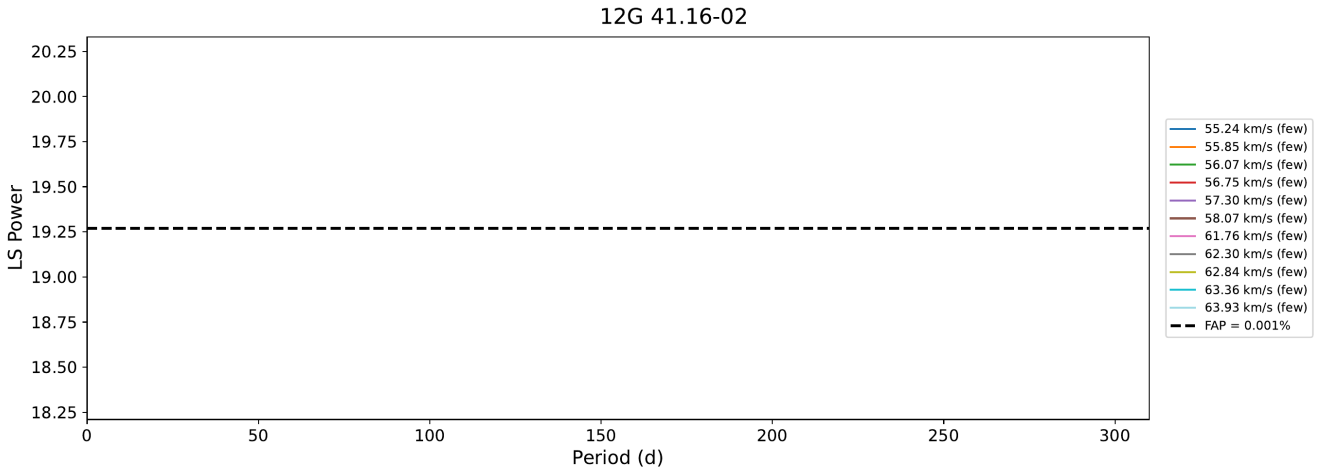


12G 41.16-02

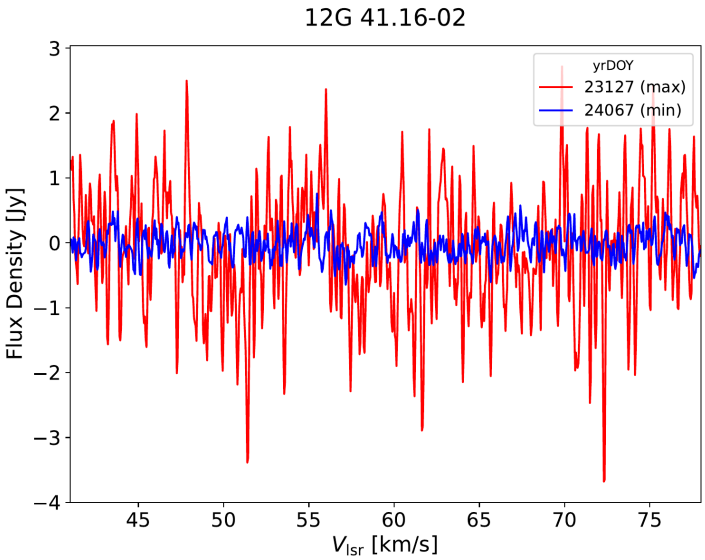
Light curve



Periodogram

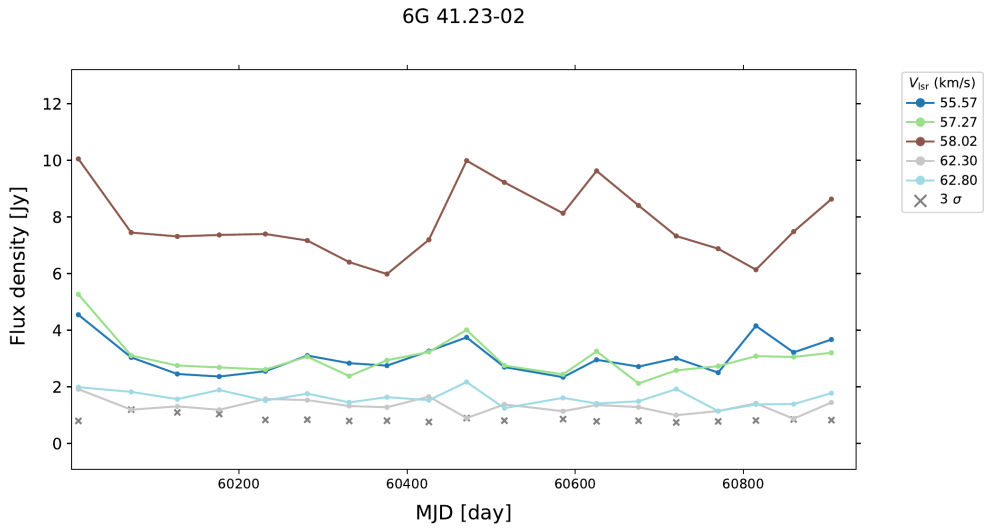


Spectrum

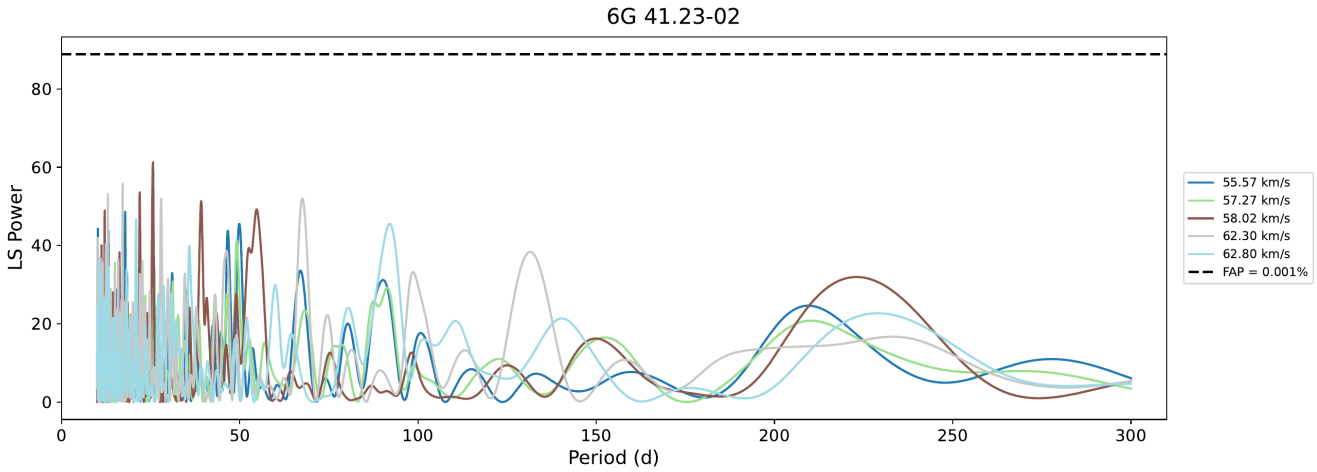


6G 41.23-02

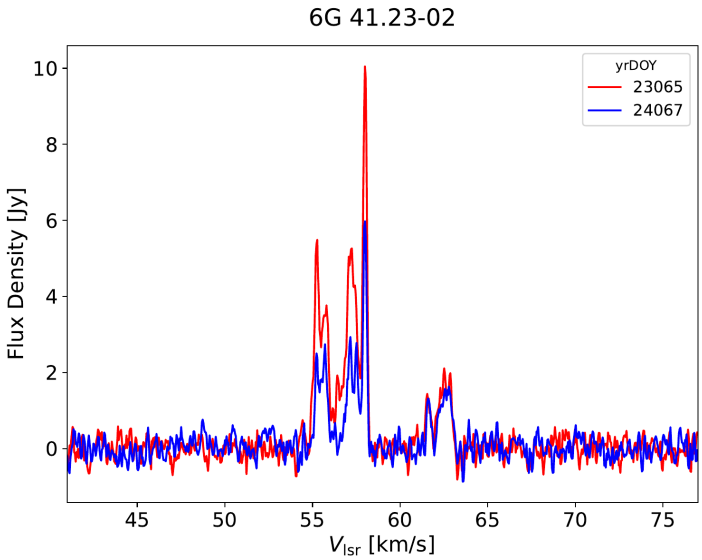
Light curve



Periodogram

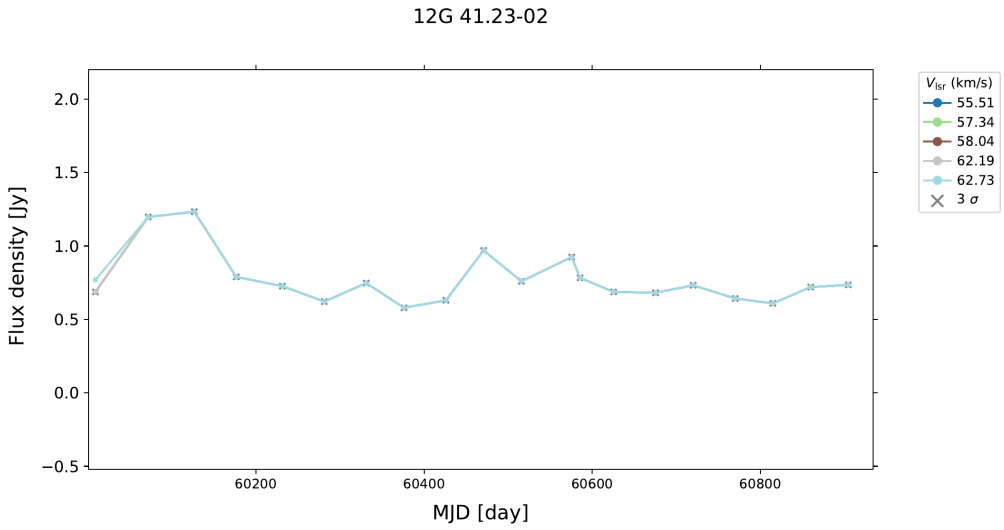


Spectrum

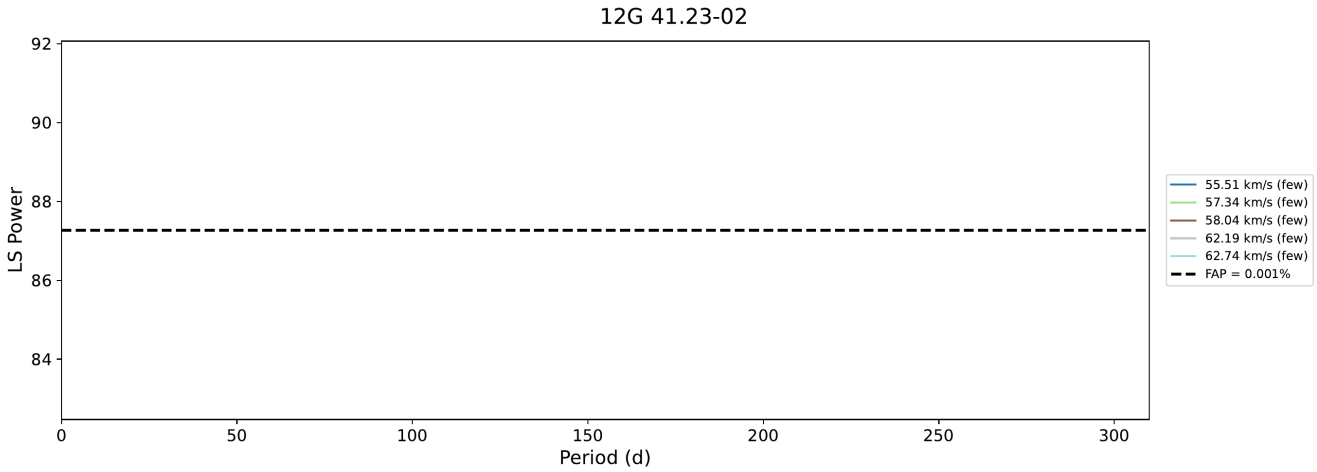


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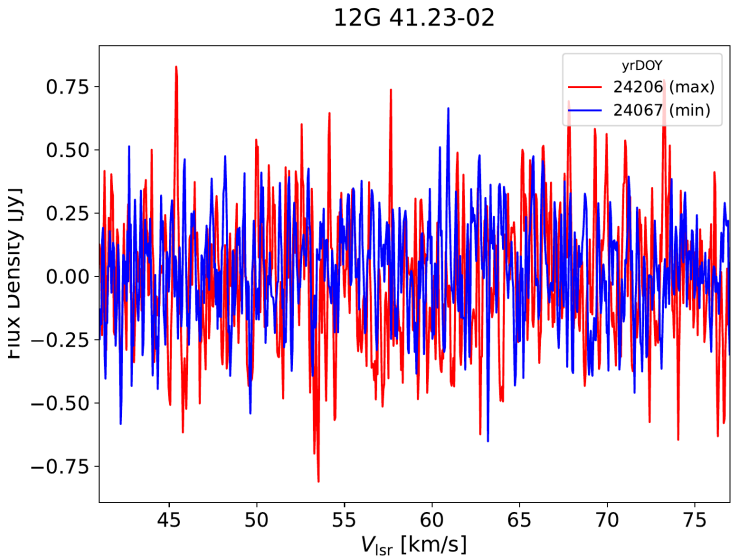
Light curve



Periodogram

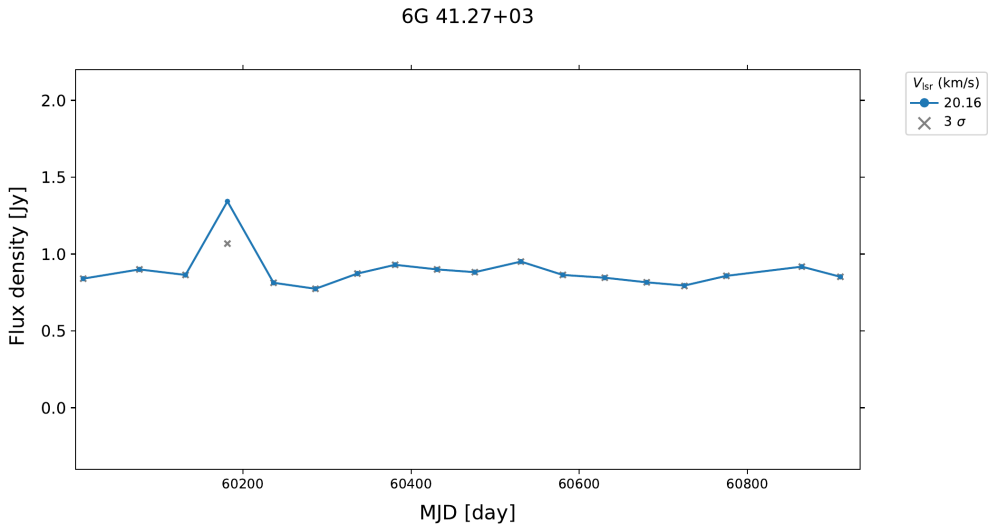


Spectrum

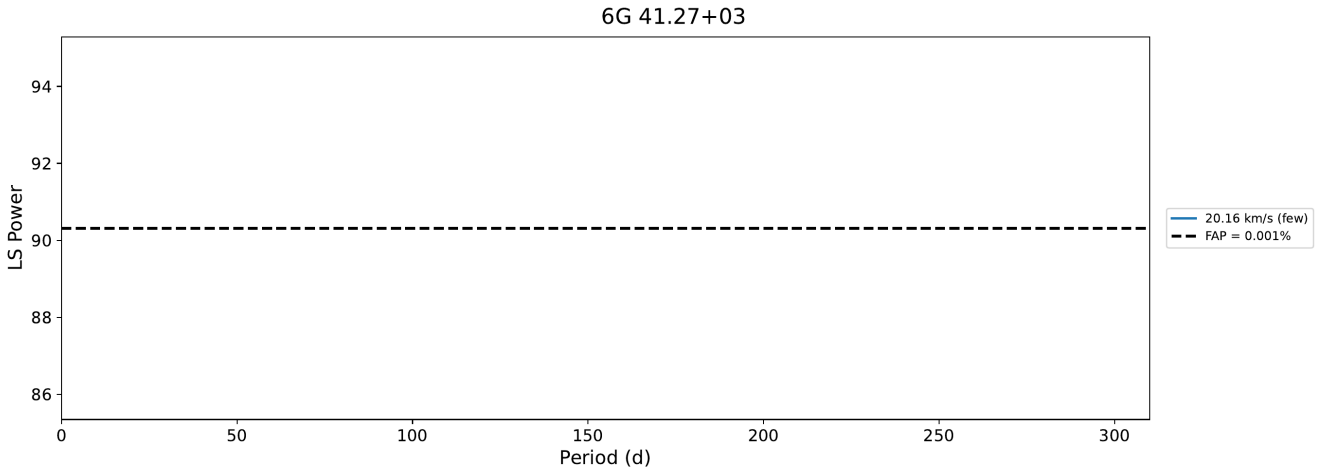


6G 41.27+03

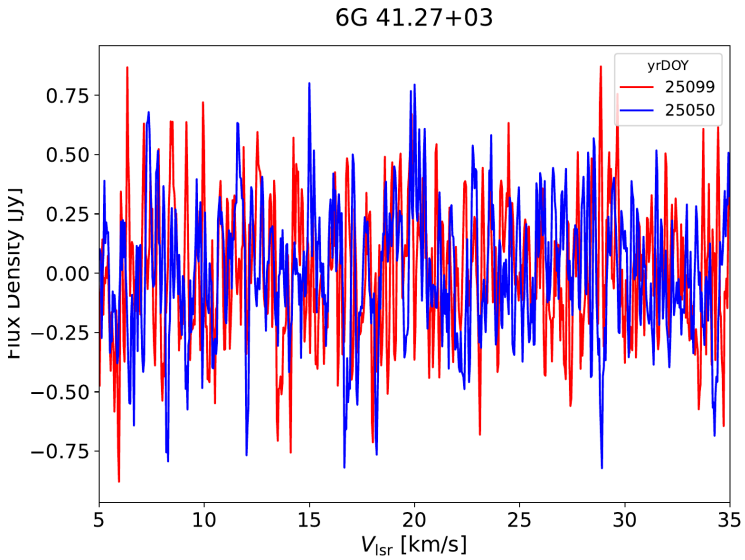
Light curve



Periodogram

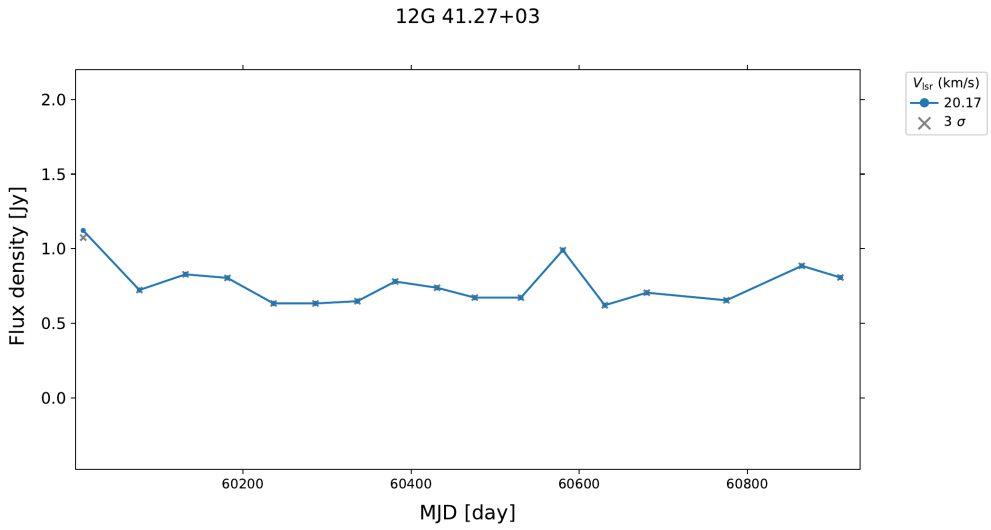


Spectrum

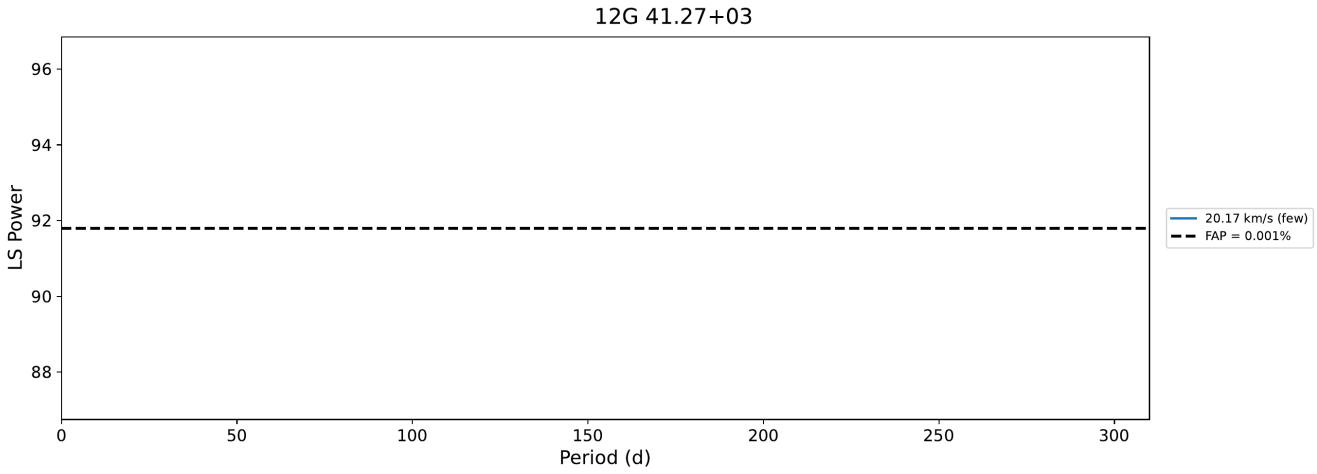


12G 41.27+03

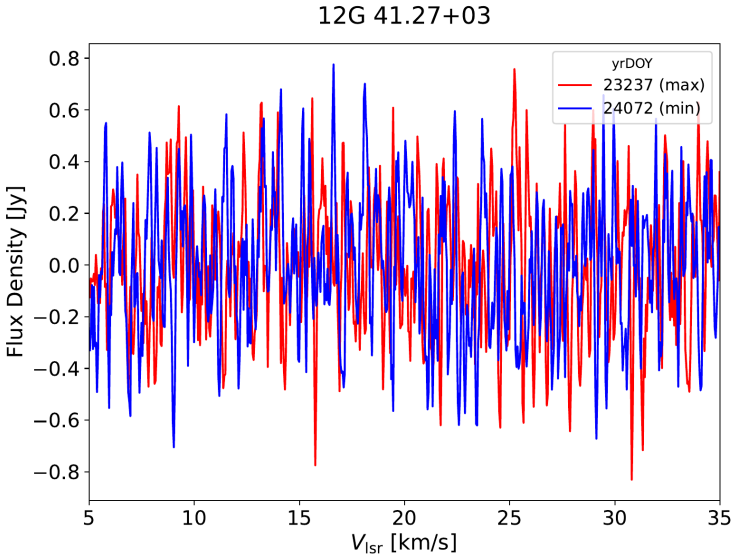
Light curve



Periodogram

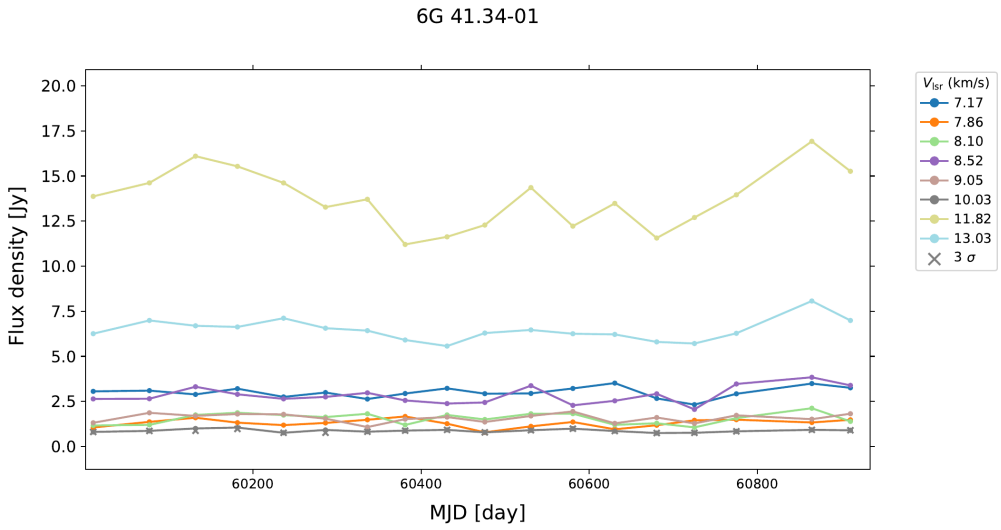


Spectrum

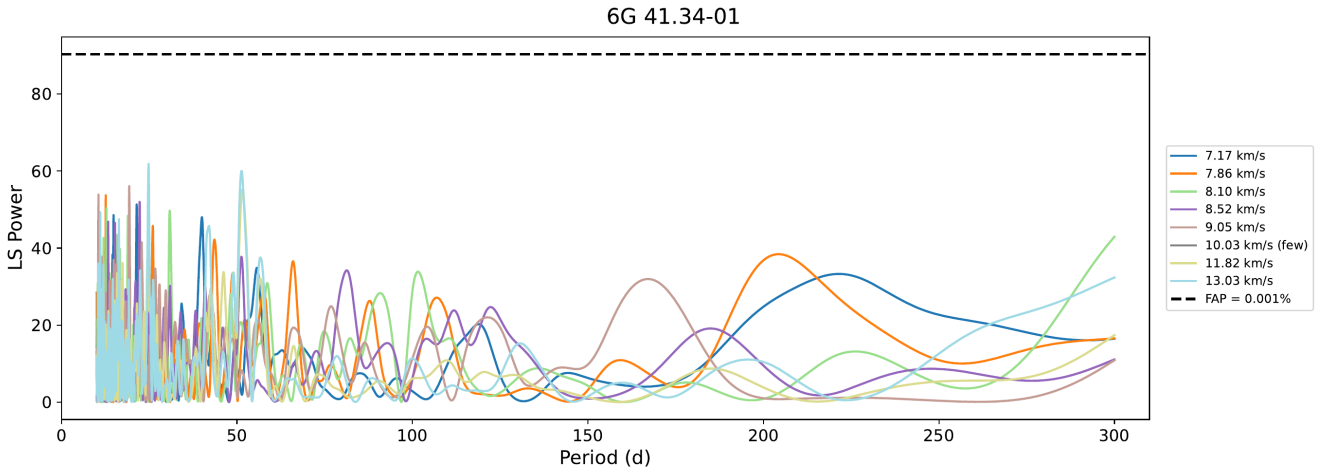


6G 41.34-01

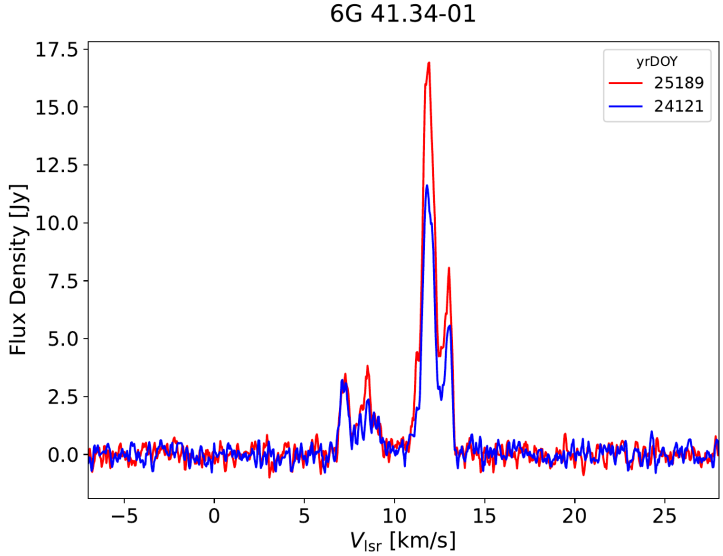
Light curve



Periodogram

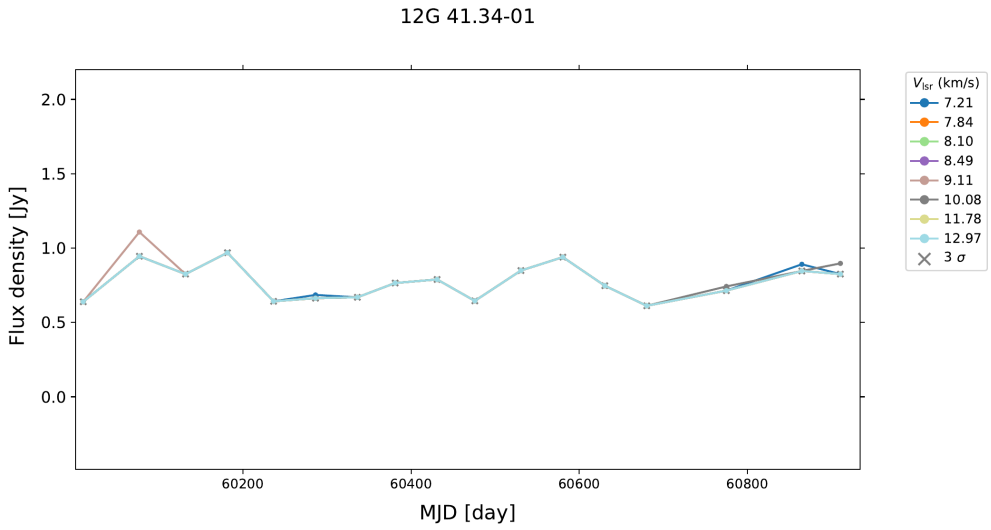


Spectrum

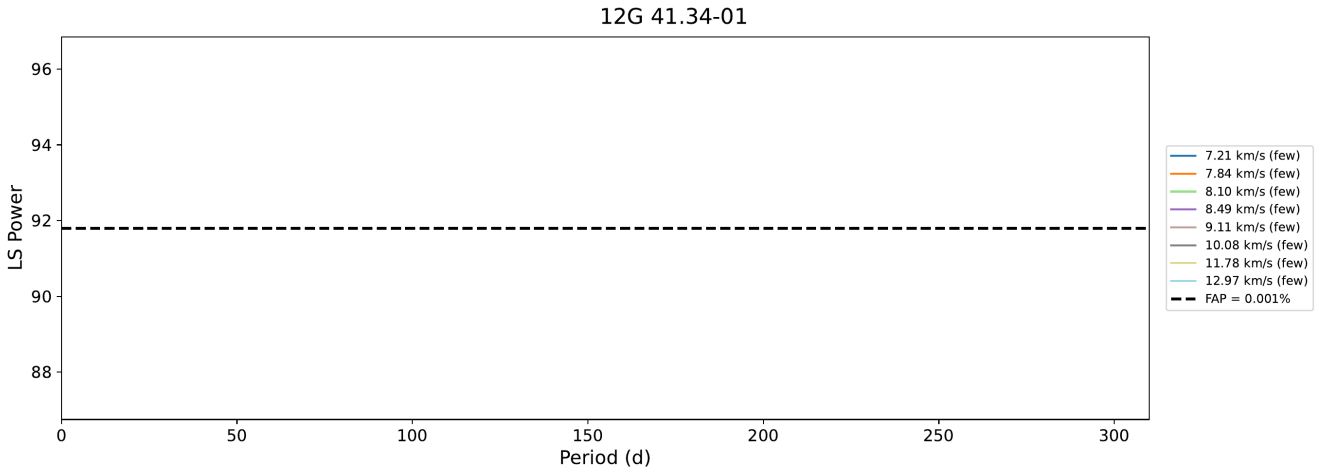


12G 41.34-01

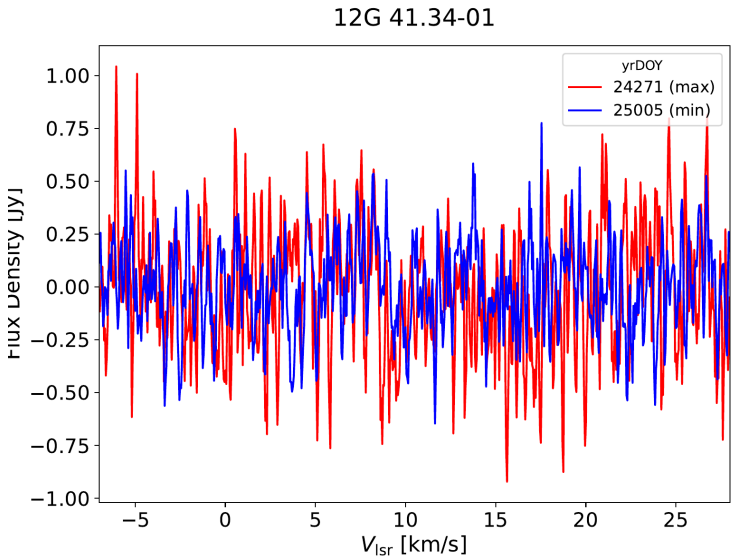
Light curve



Periodogram

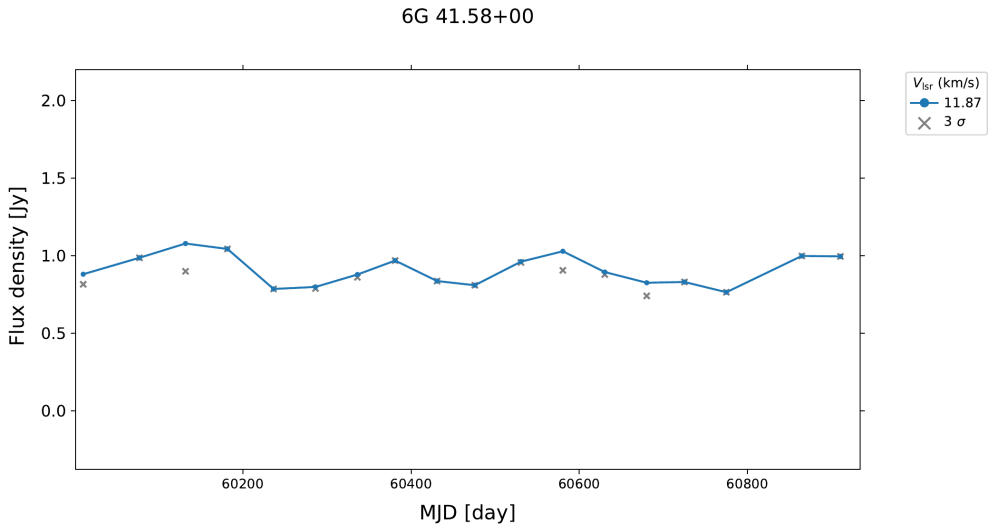


Spectrum

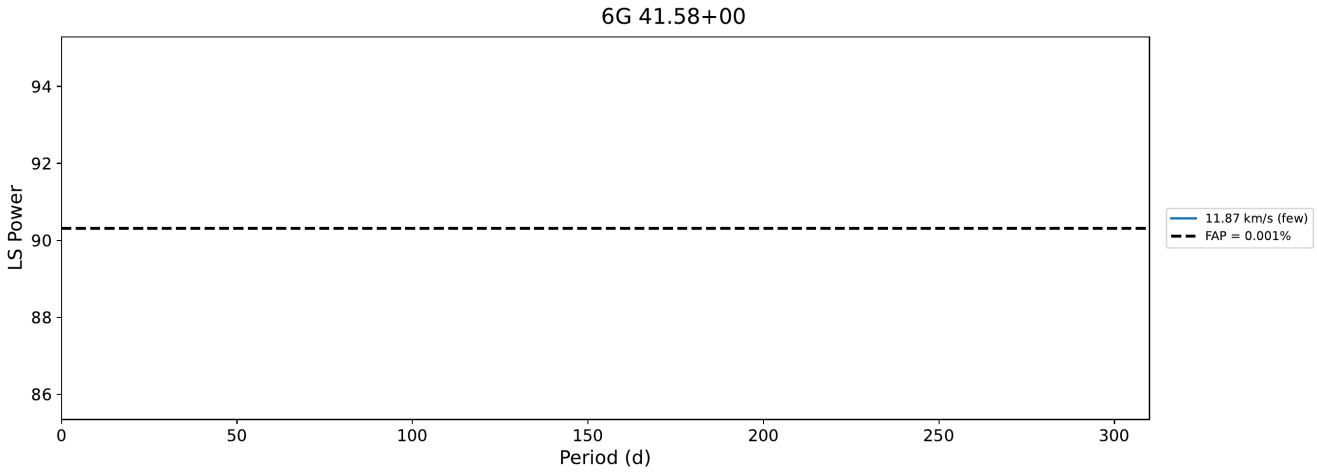


6G 41.58+00

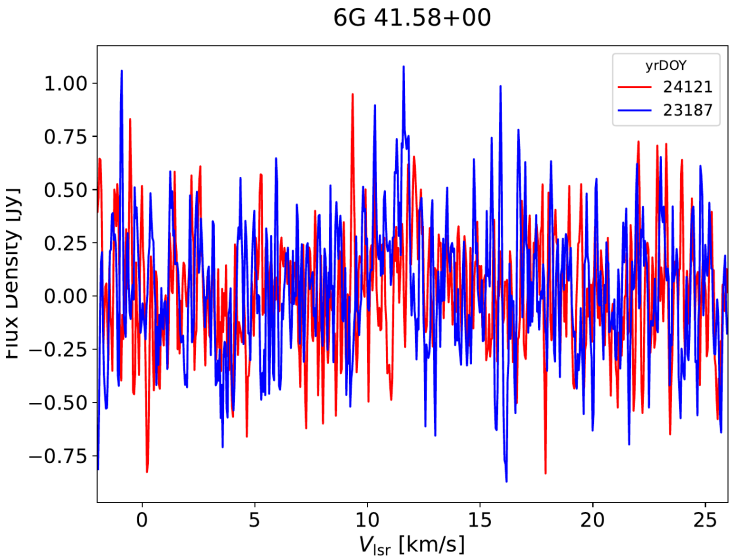
Light curve



Periodogram

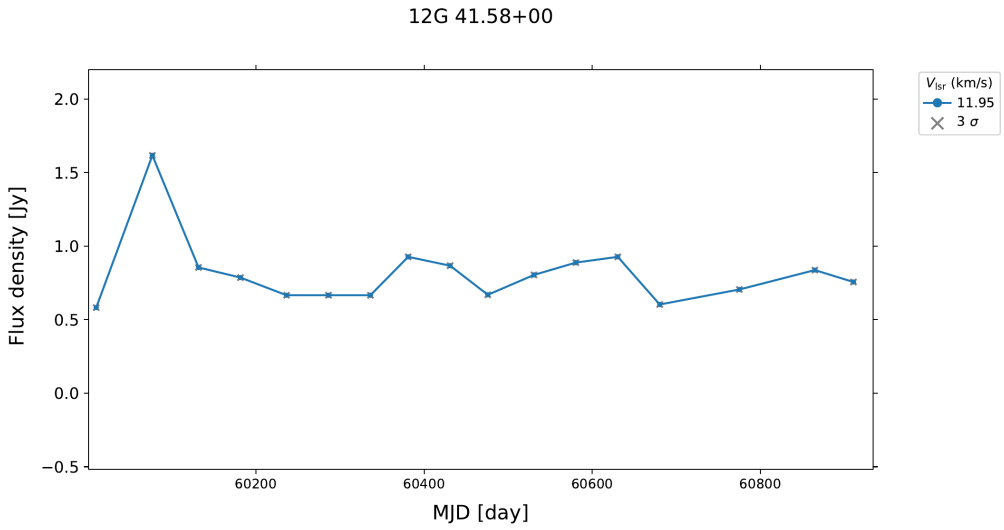


Spectrum

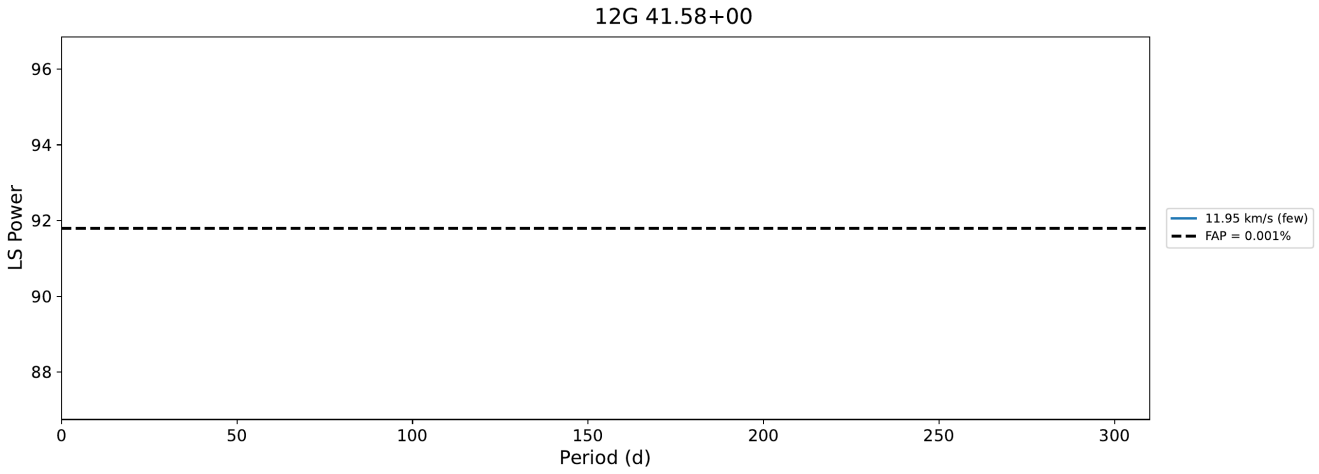


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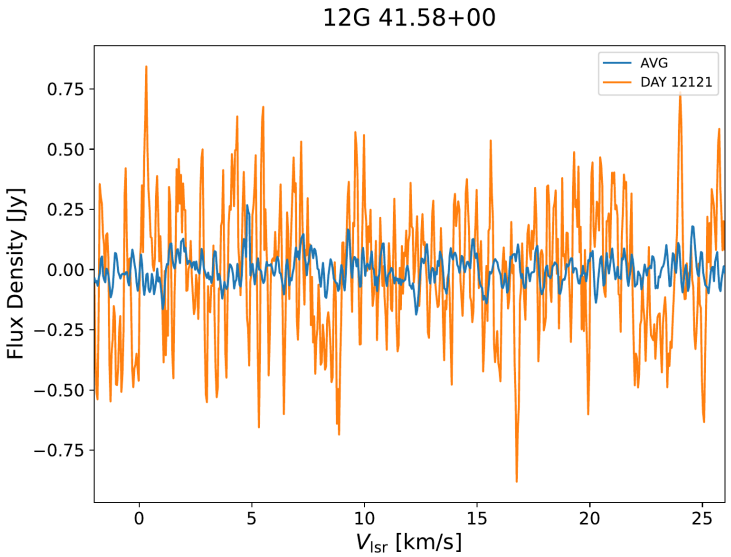
Light curve



Periodogram

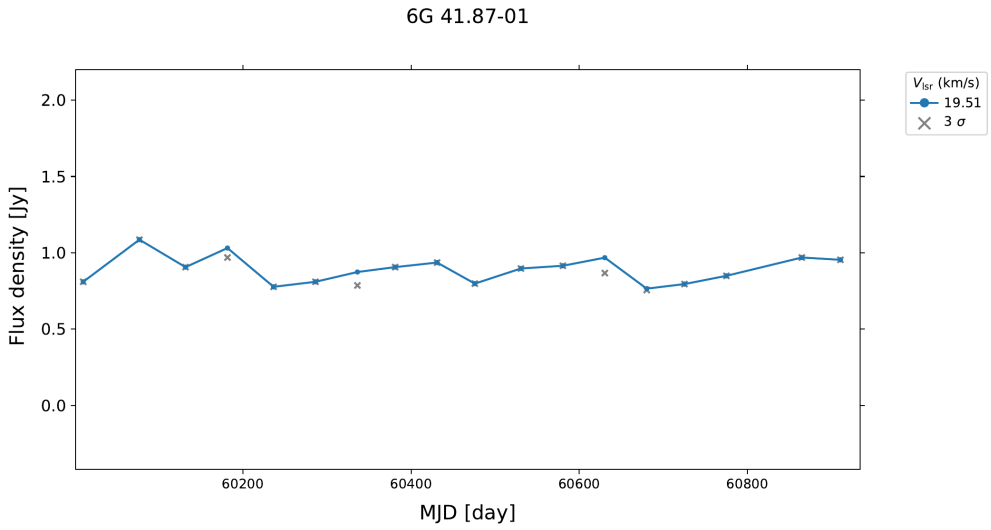


Spectrum

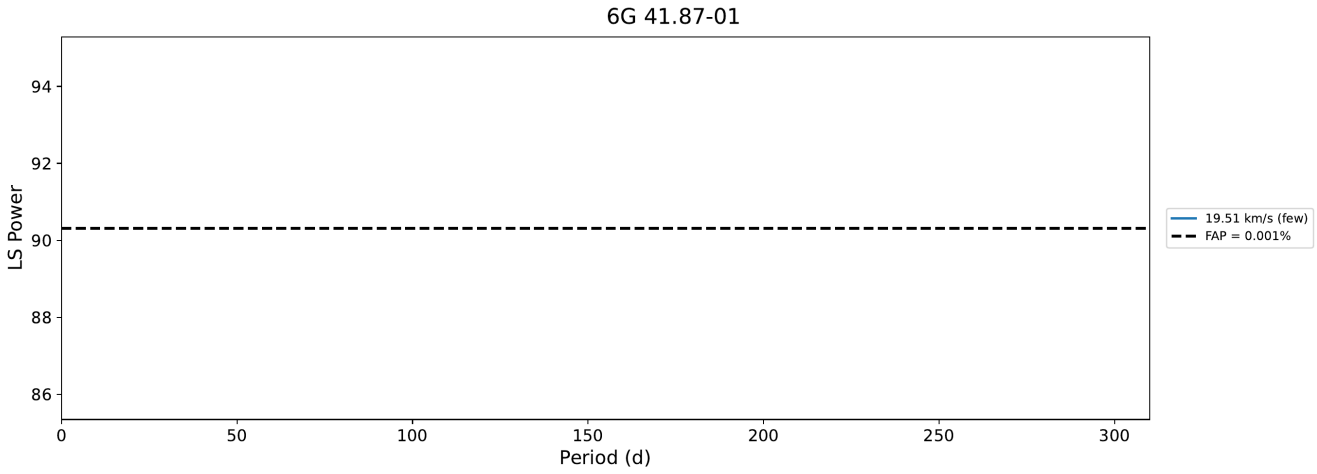


6G 41.87-01

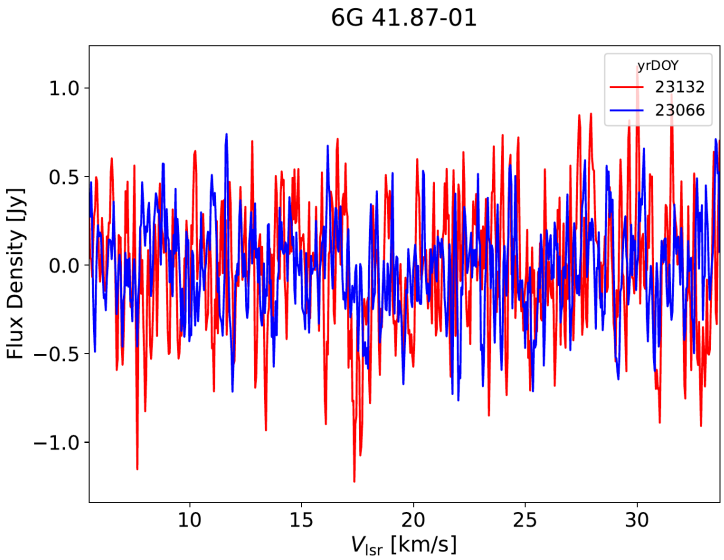
Light curve



Periodogram

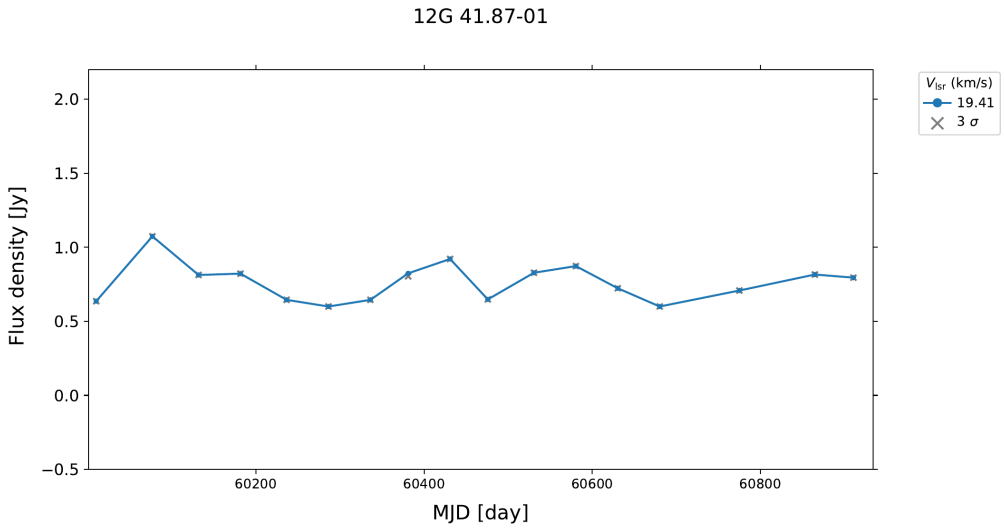


Spectrum

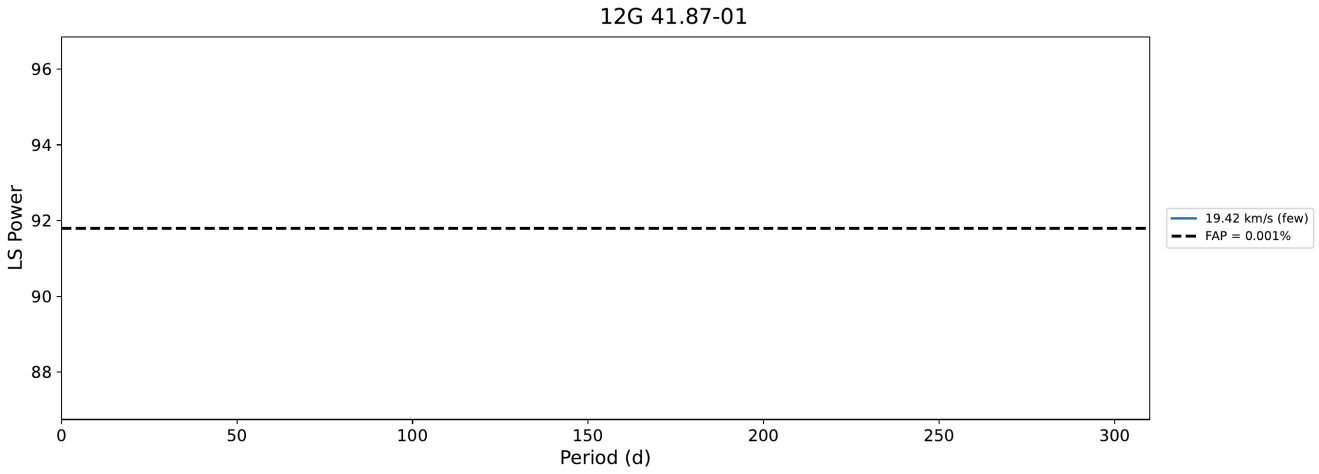


12G 41.87-01

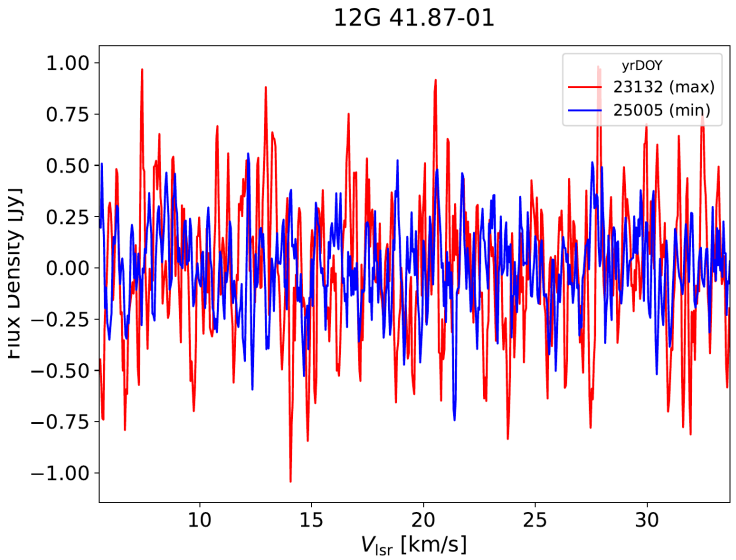
Light curve



Periodogram

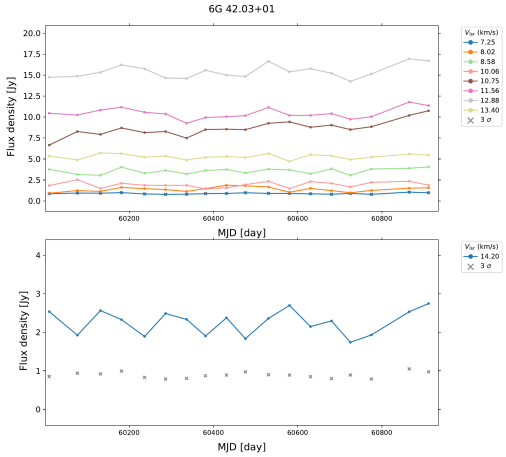


Spectrum

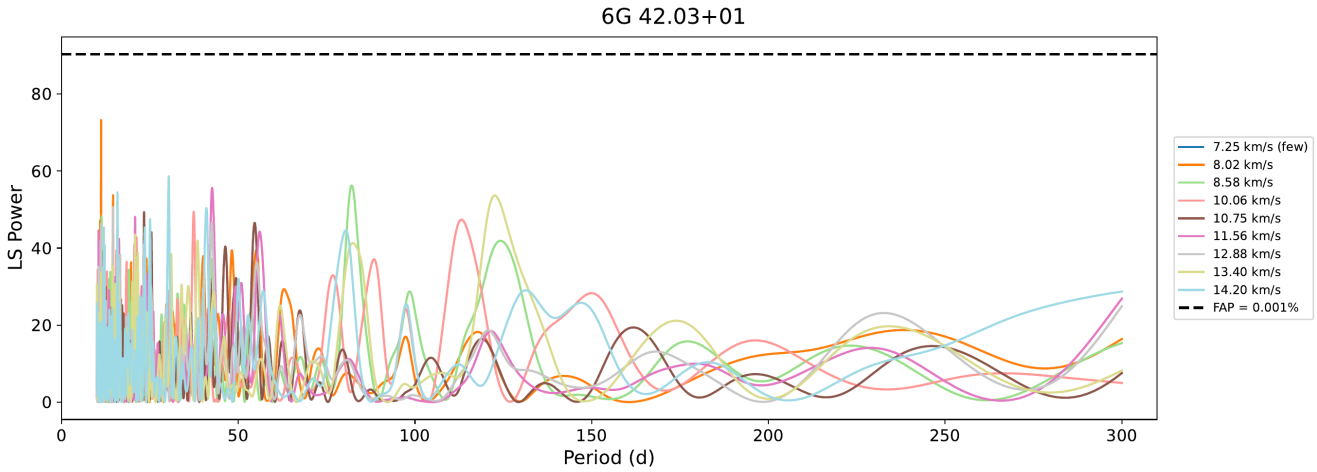


6G 42.03+01

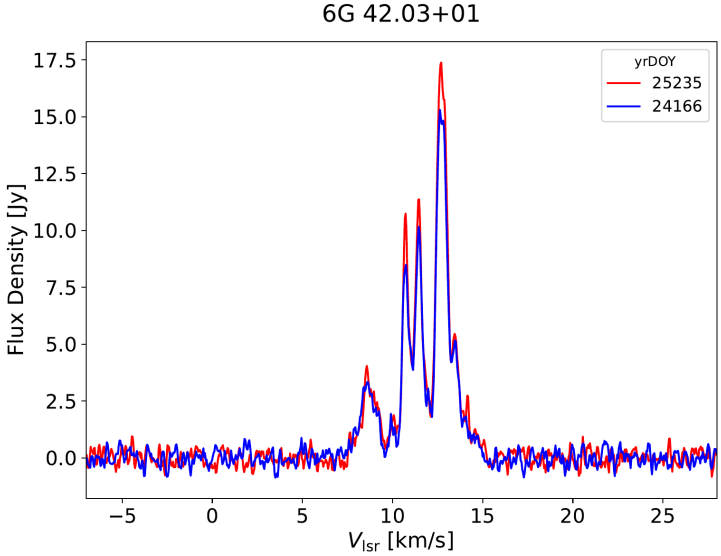
Light curve



Periodogram

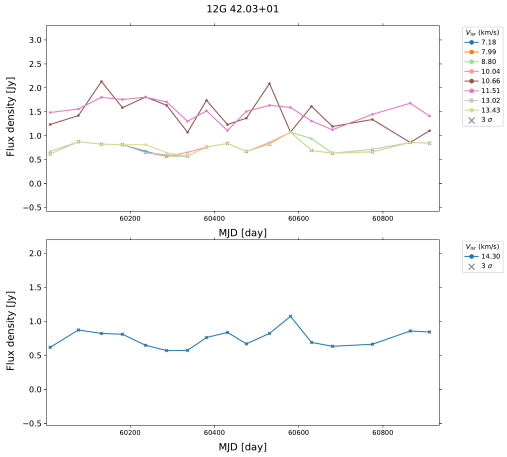


Spectrum

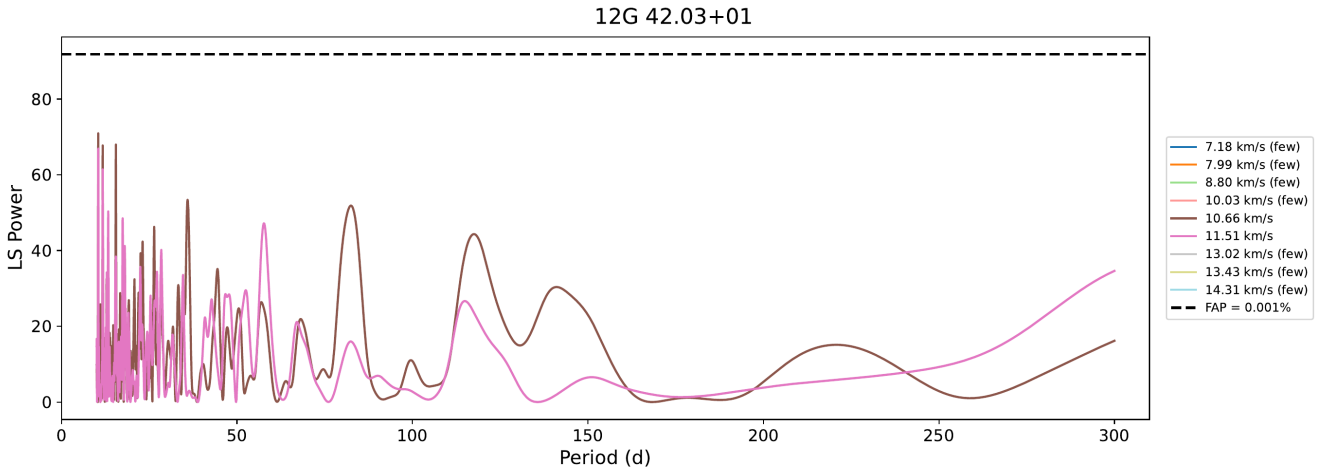


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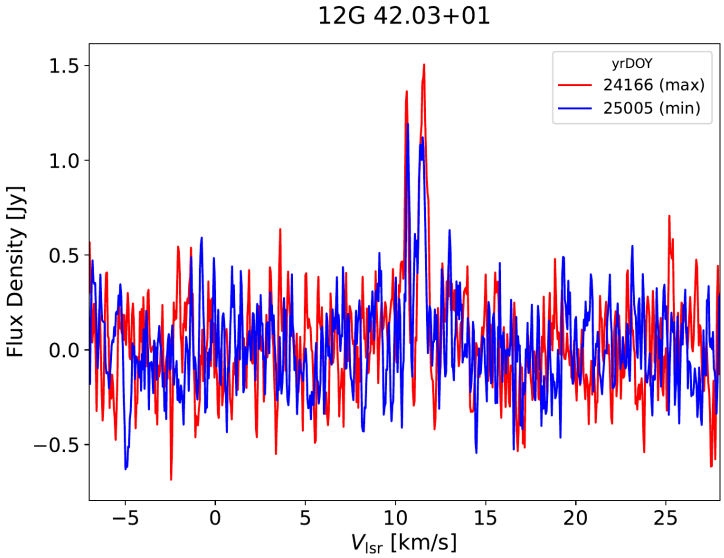
Light curve



Periodogram

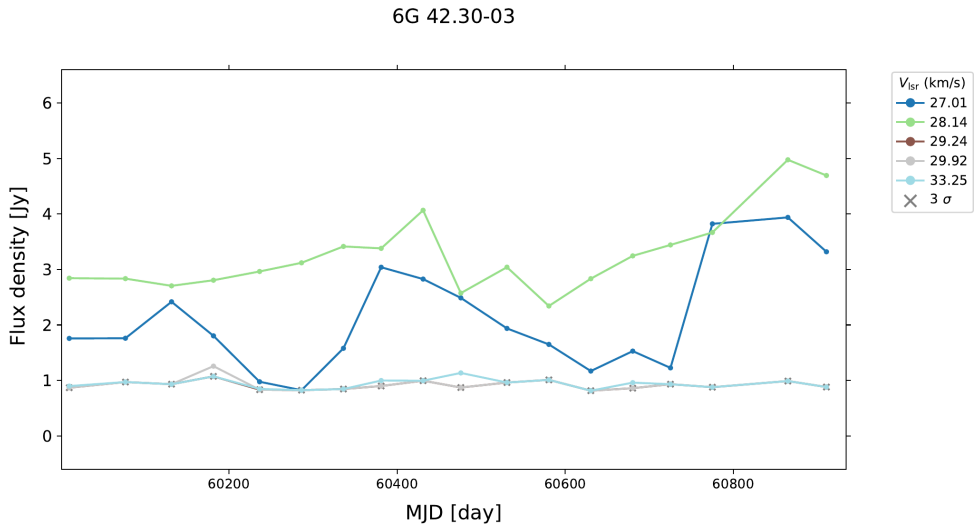


Spectrum

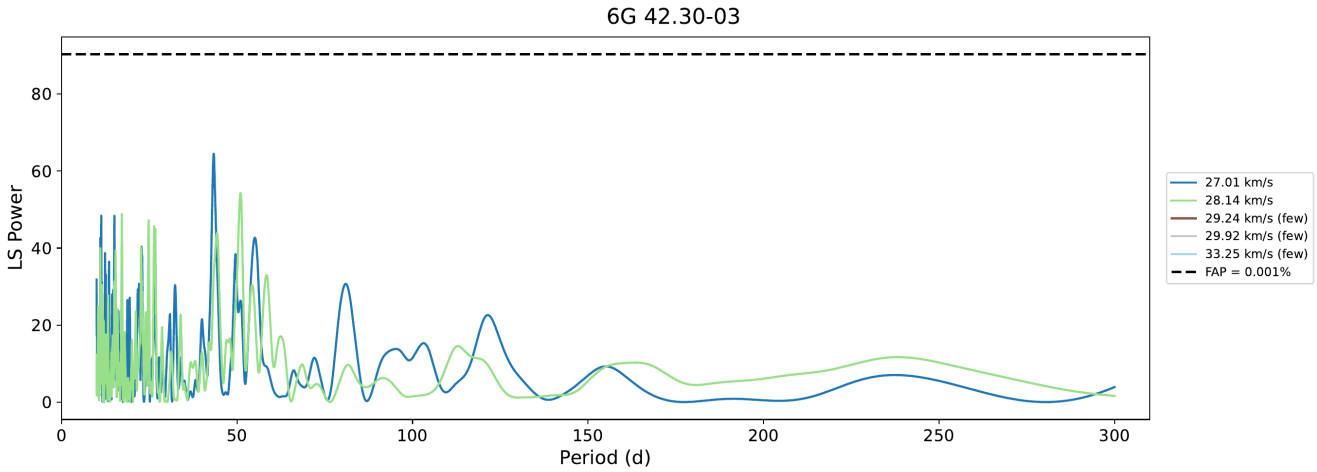


6G 42.30-03

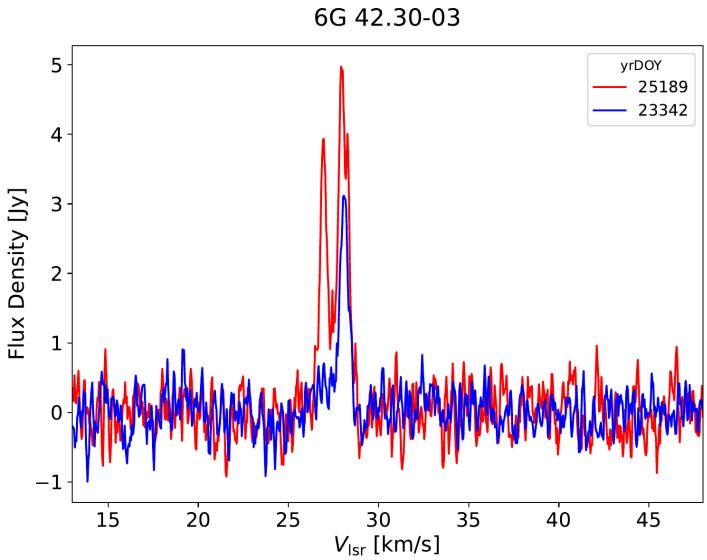
Light curve



Periodogram

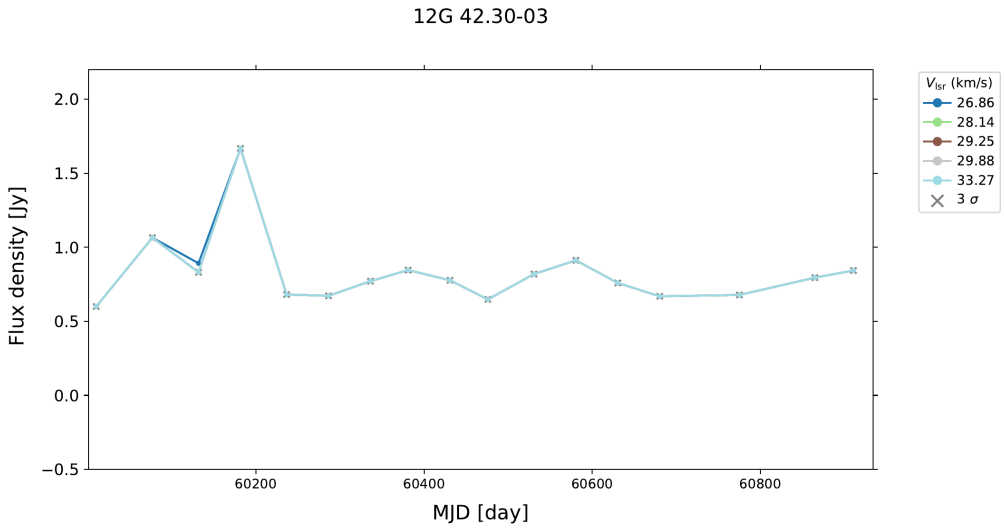


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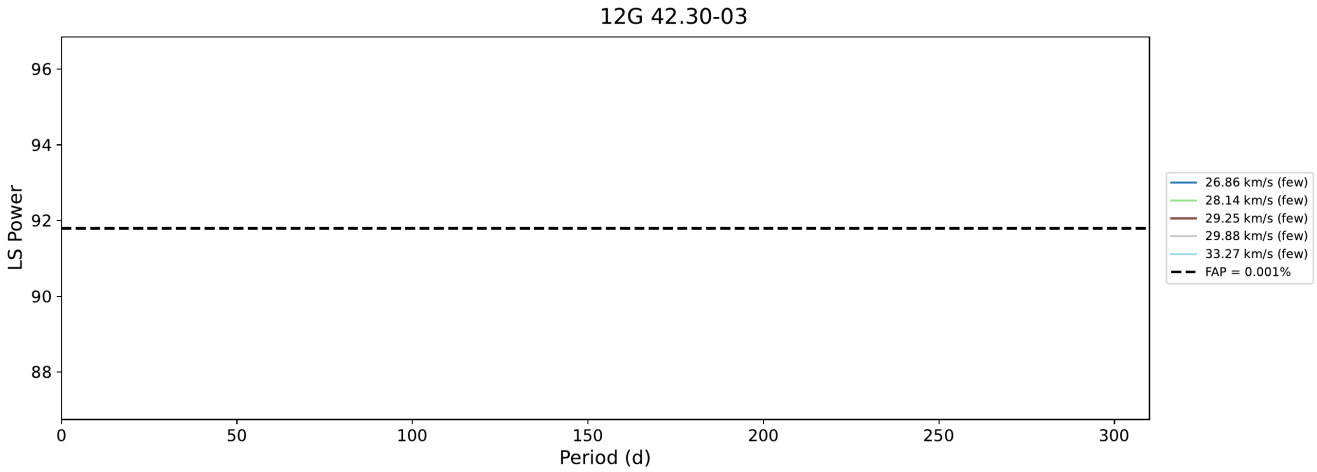


12G 42.30-03

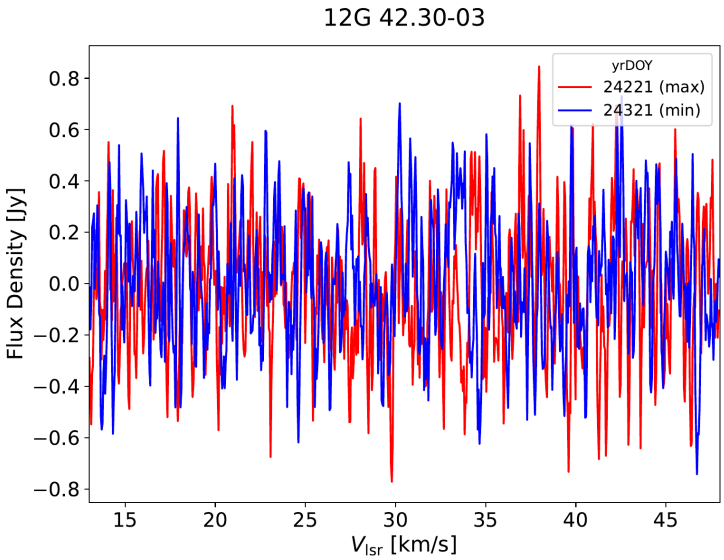
Light curve



Periodogram

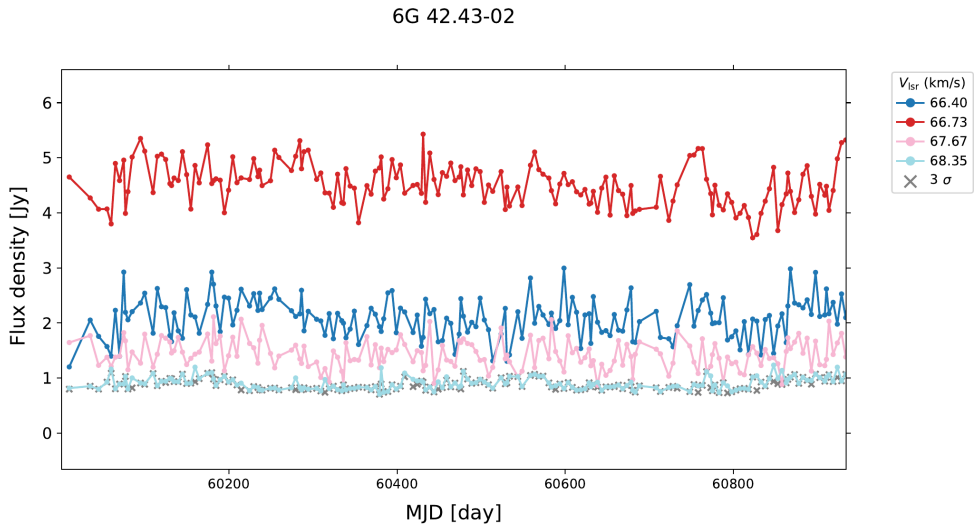


Spectrum

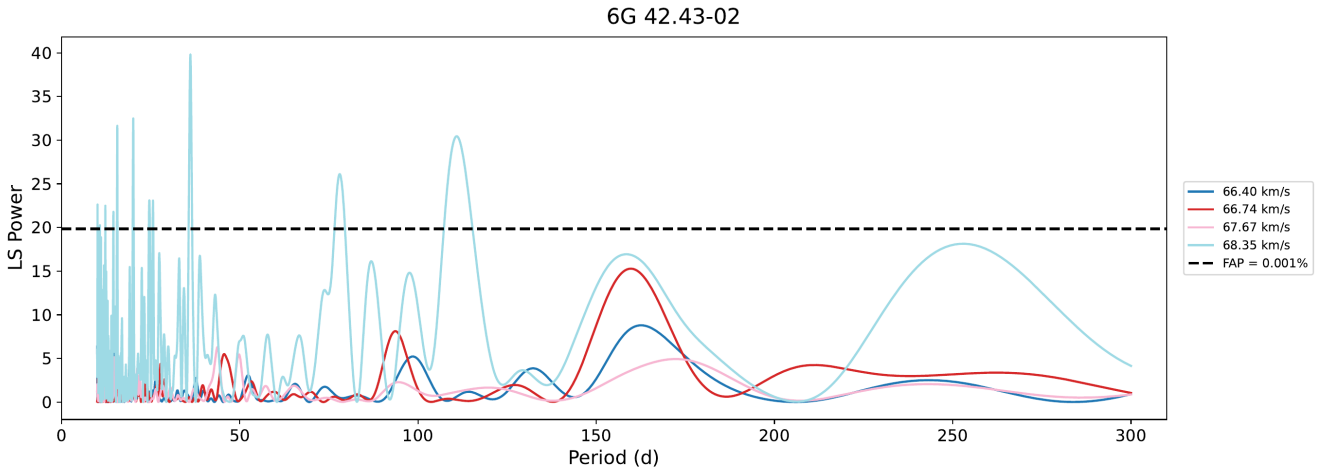


6G 42.43-02

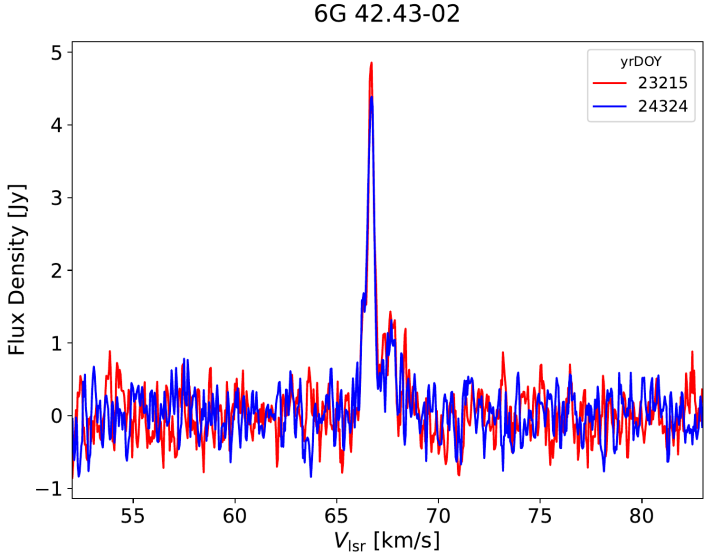
Light curve



Periodogram

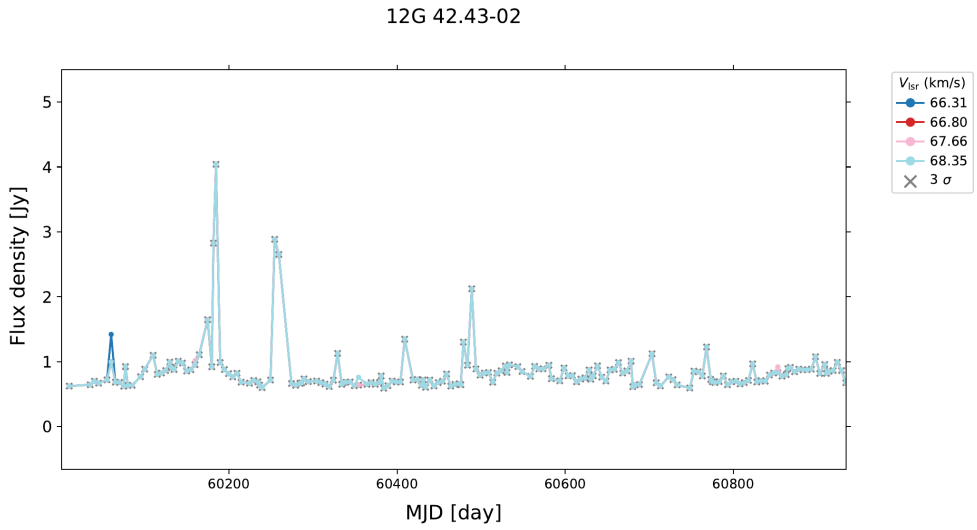


Spectrum

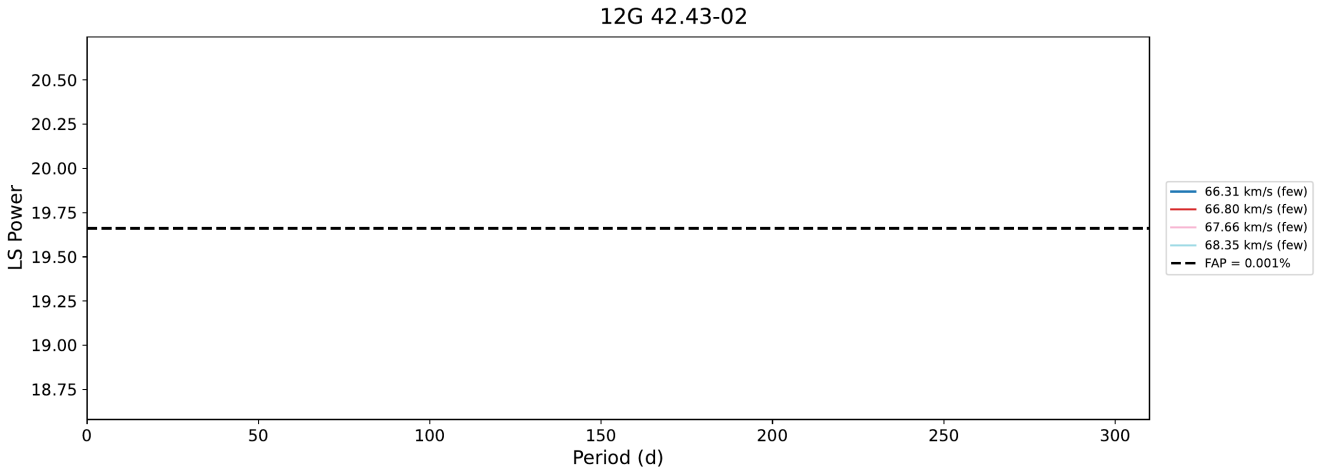


12G 42.43-02

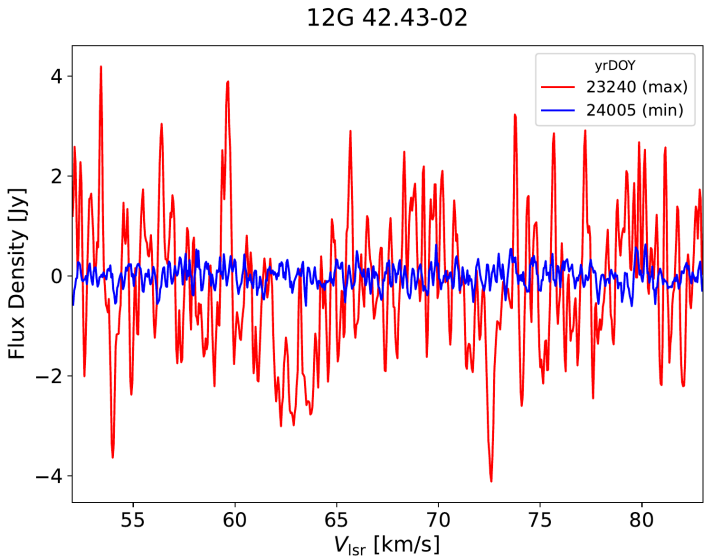
Light curve



Periodogram

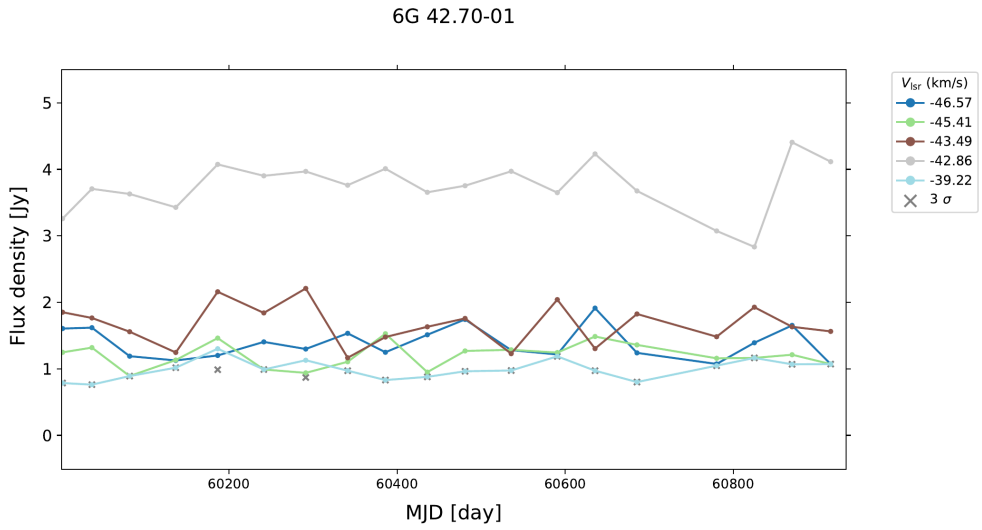


Spectrum

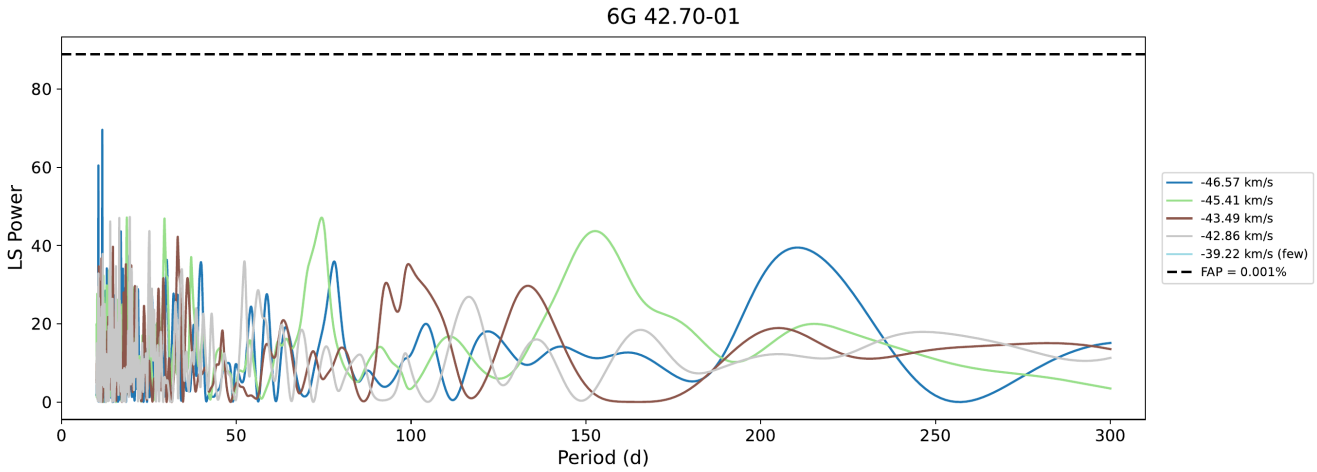


6G 42.70-01

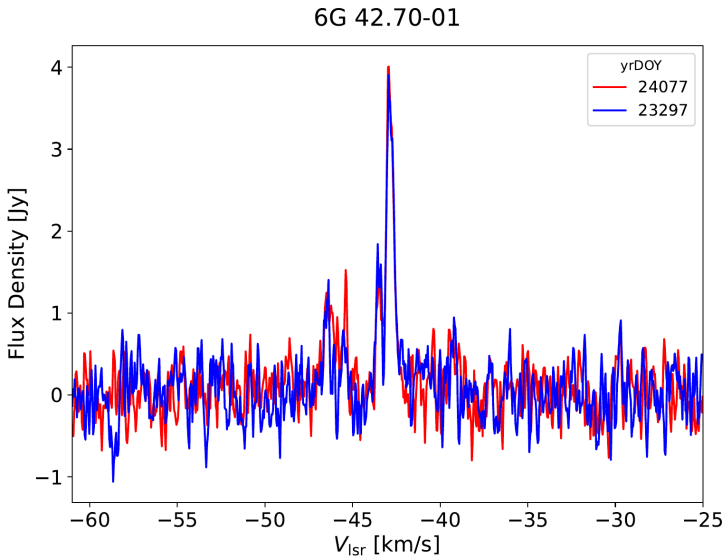
Light curve



Periodogram

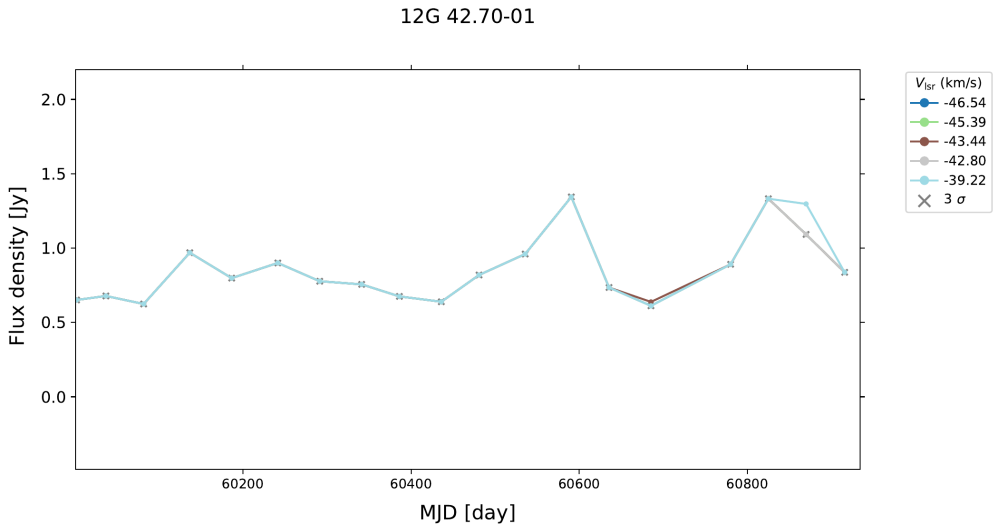


Spectrum

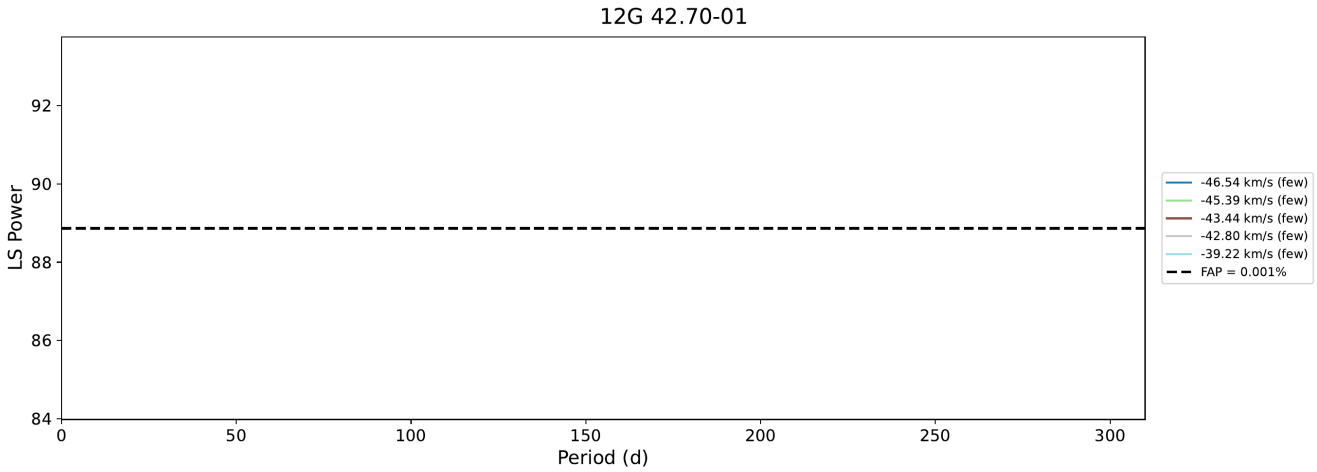


12G 42.70-01

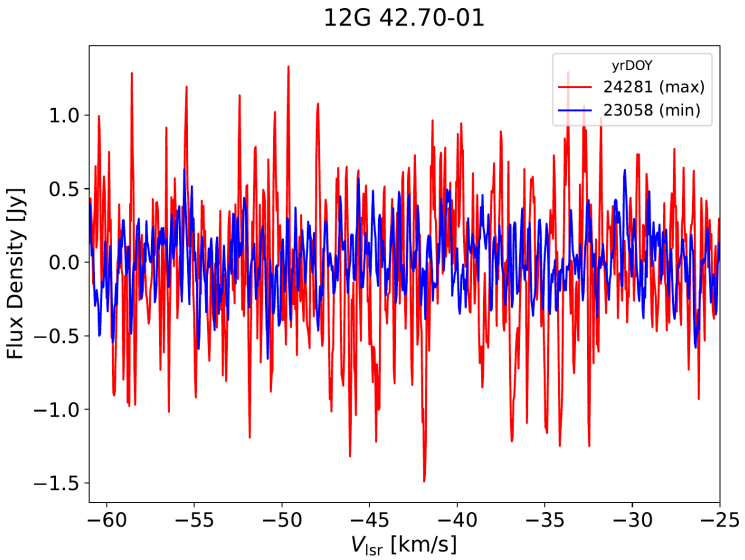
Light curve



Periodogram

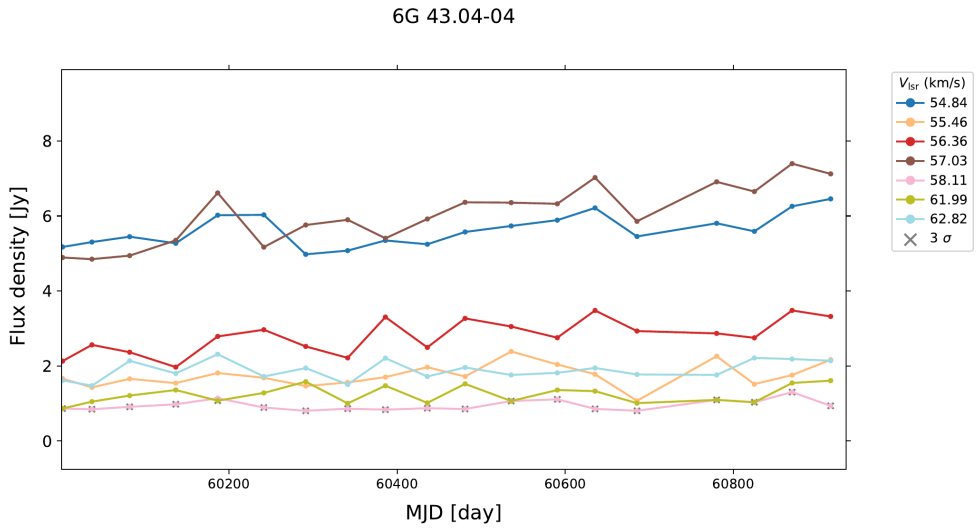


Spectrum

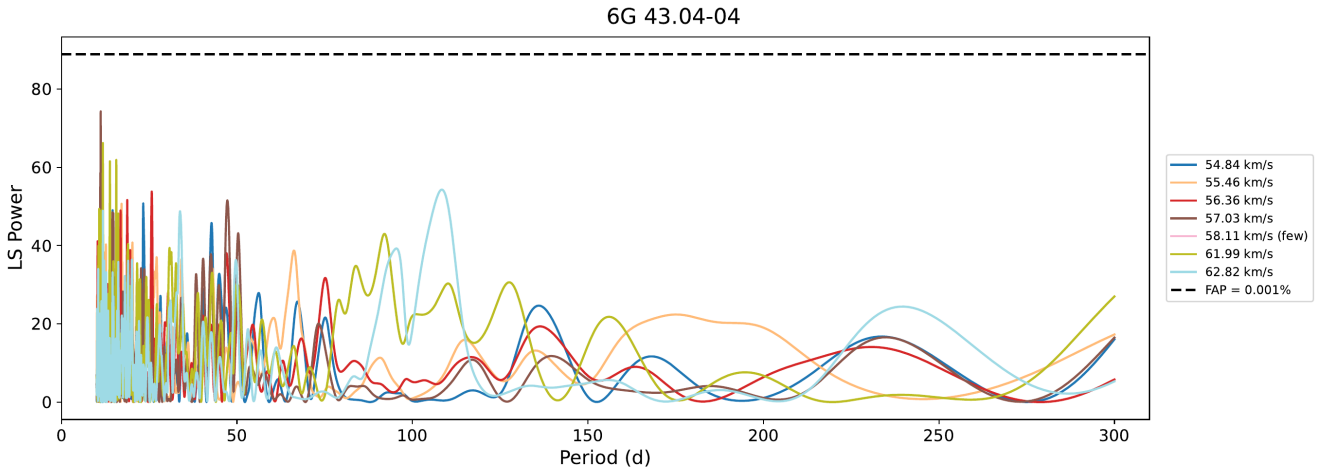


6G 43.04-04

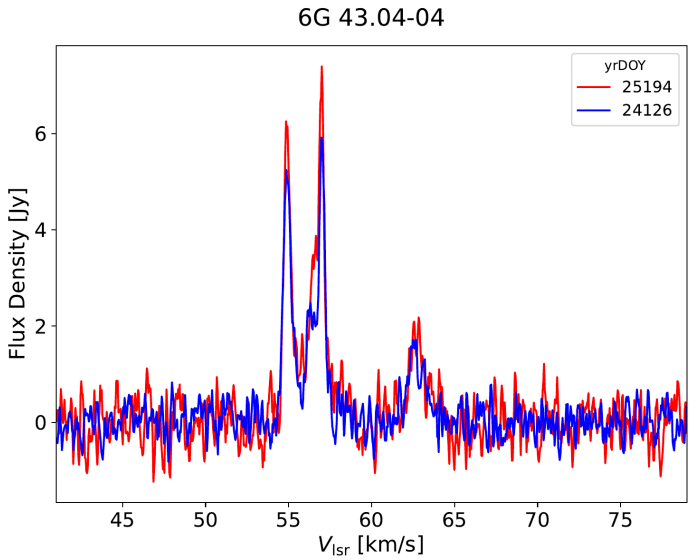
Light curve



Periodogram

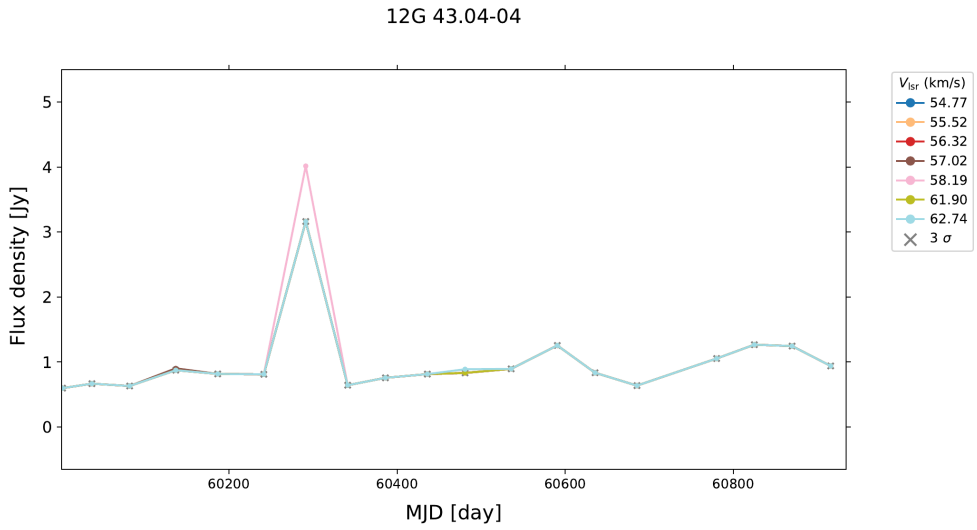


Spectrum

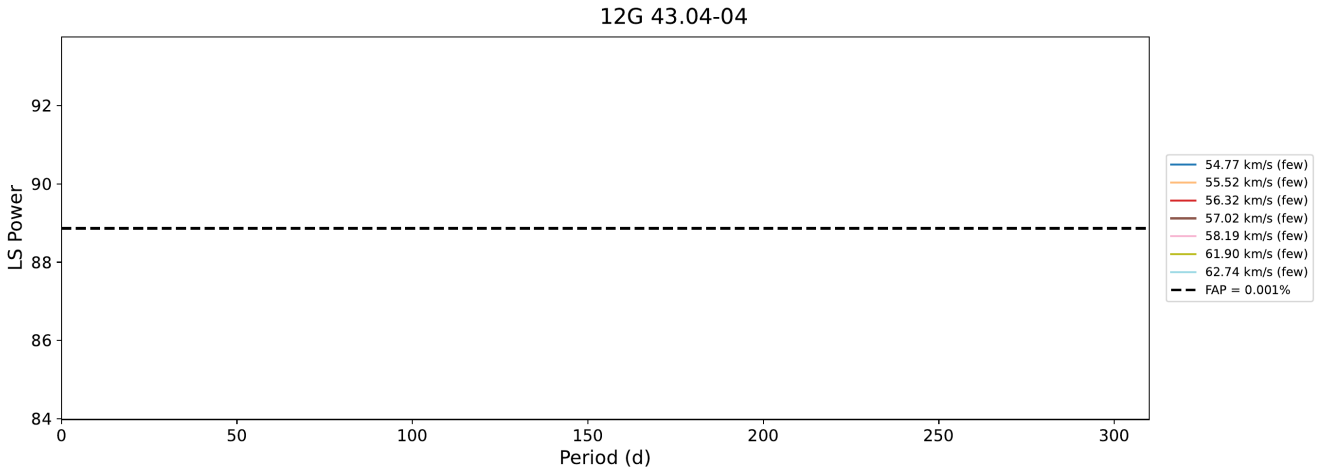


12G 43.04-04

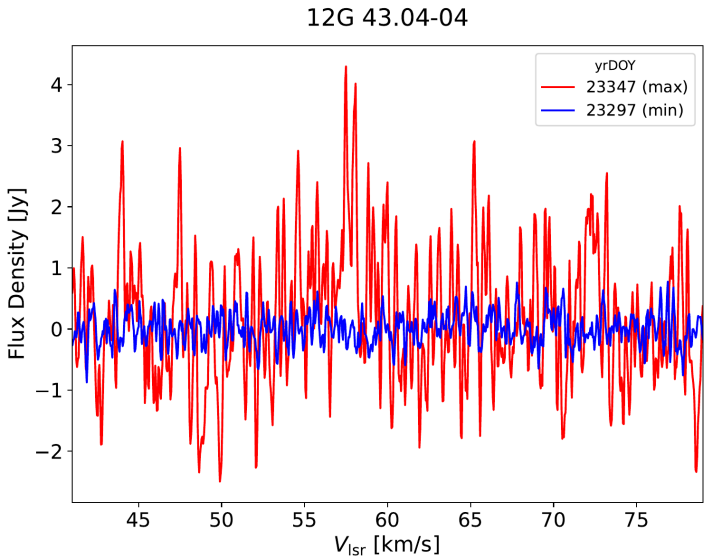
Light curve



Periodogram

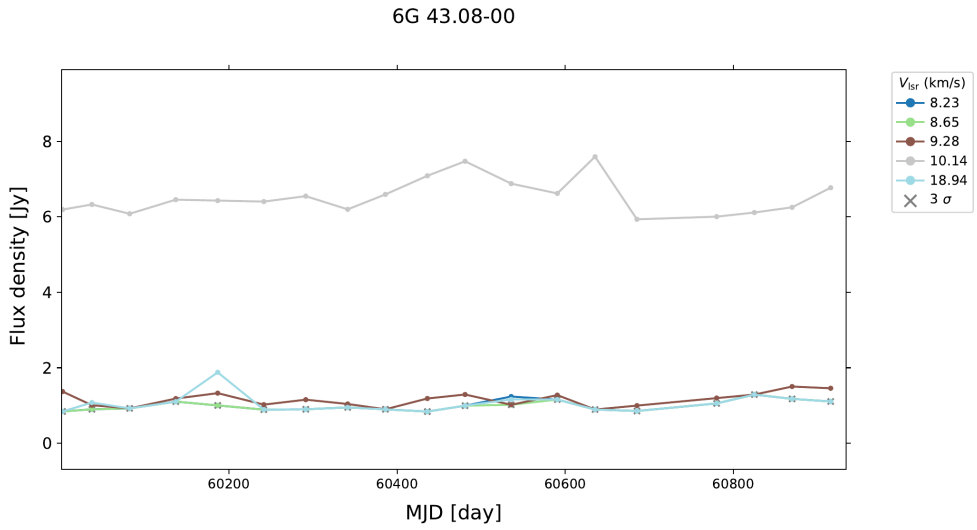


Spectrum

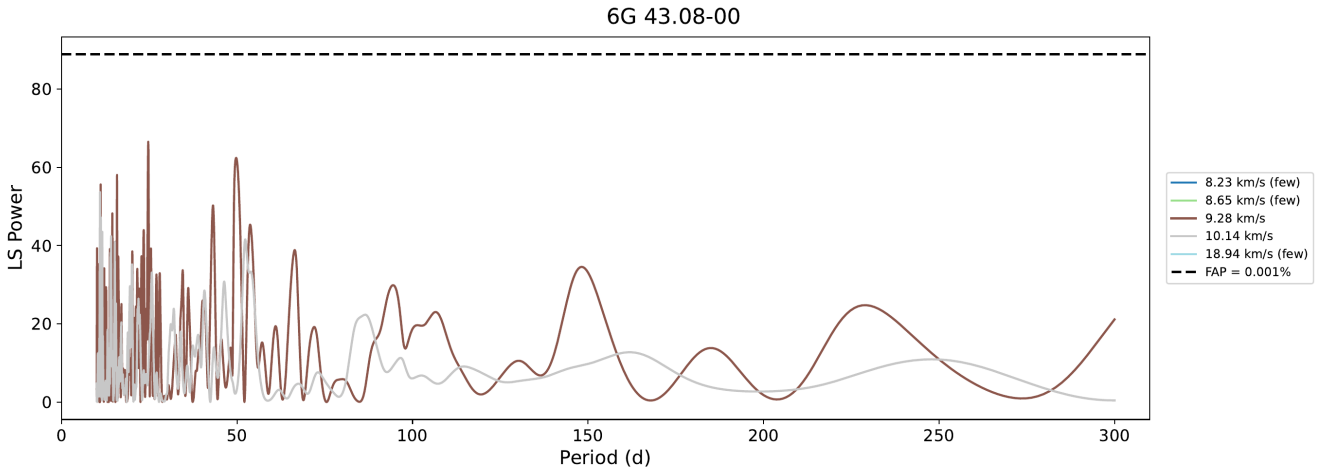


6G 43.08-00

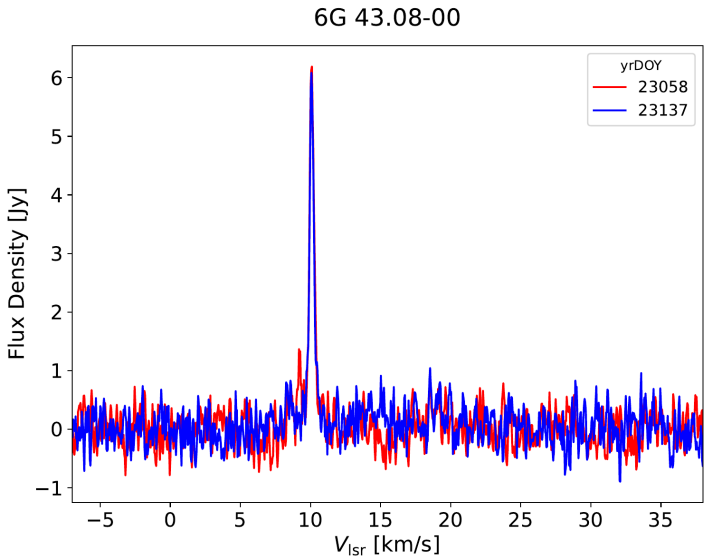
Light curve



Periodogram

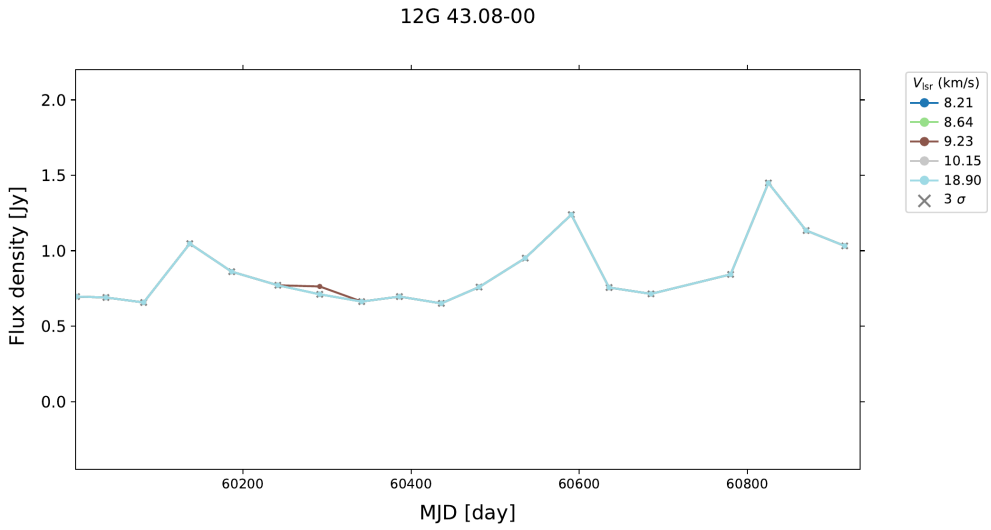


Spectrum

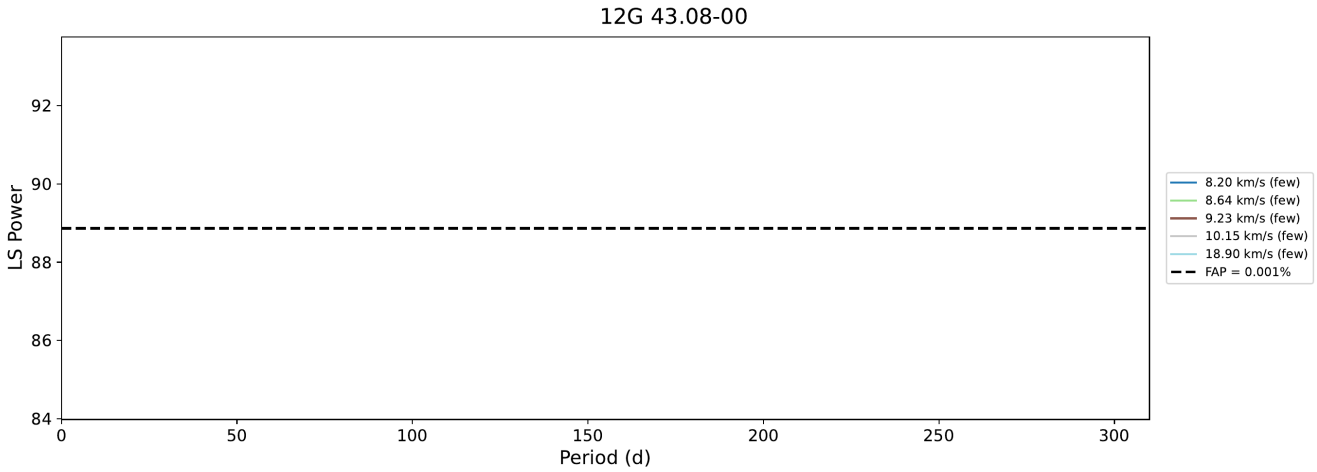


12G 43.08-00

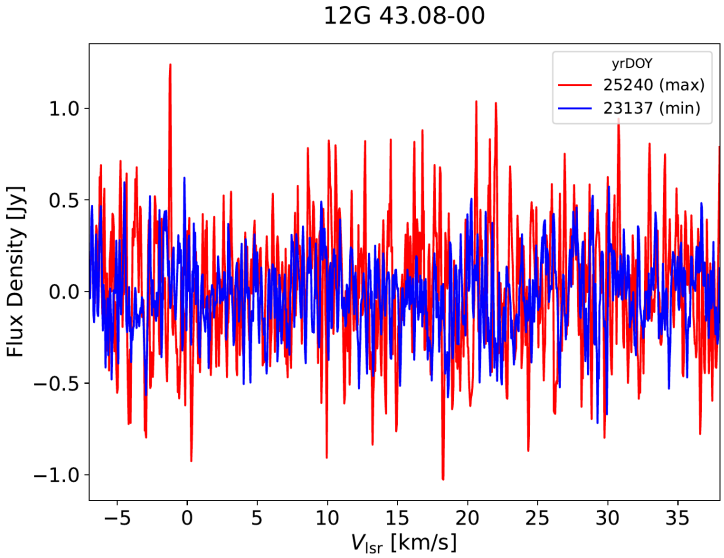
Light curve



Periodogram

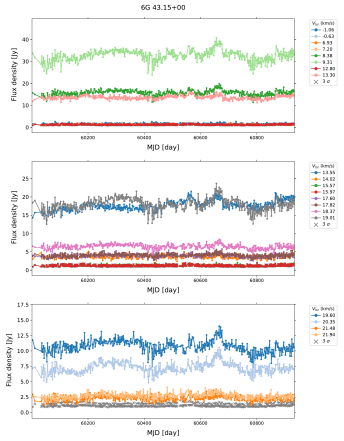


Spectrum

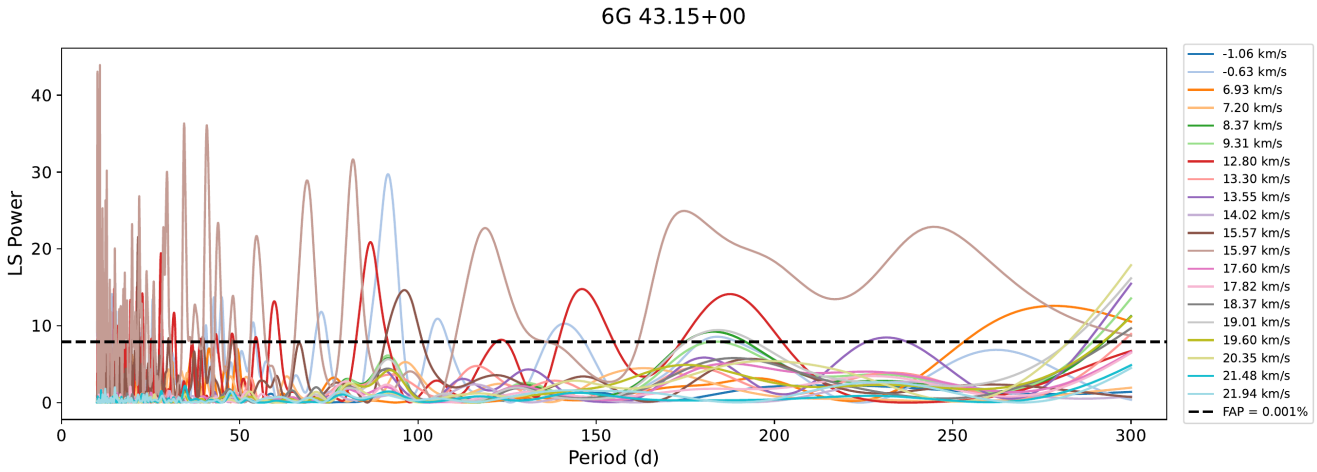


6G 43.15+00

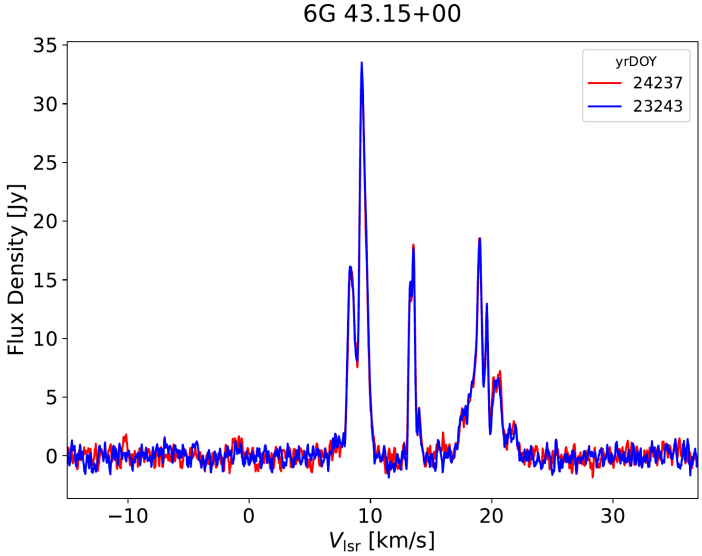
Light curve



Periodogram

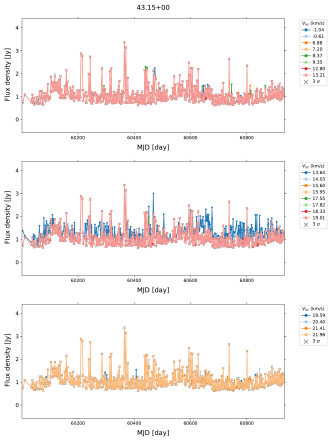


Spectrum

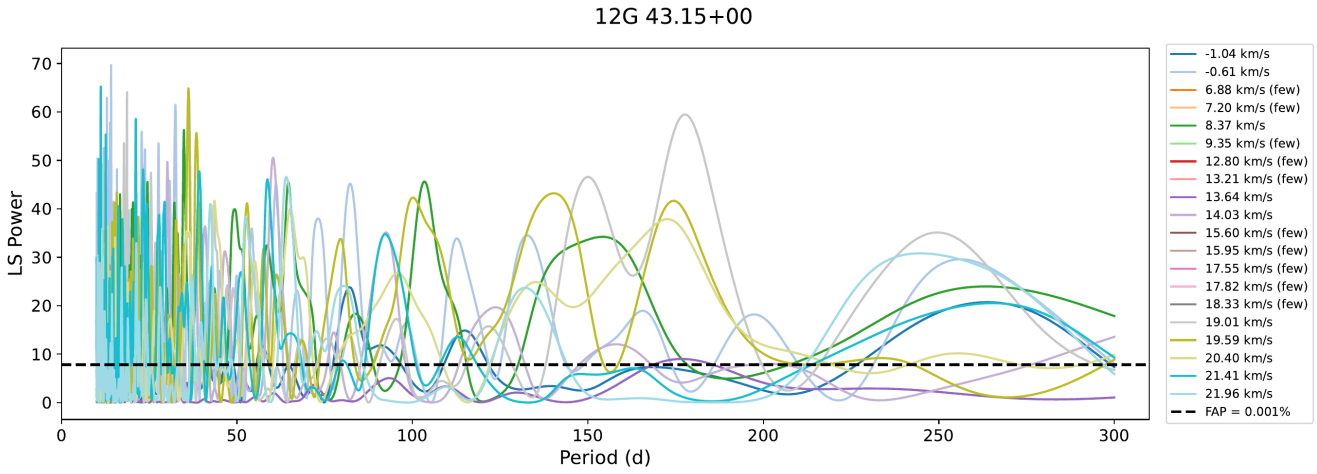


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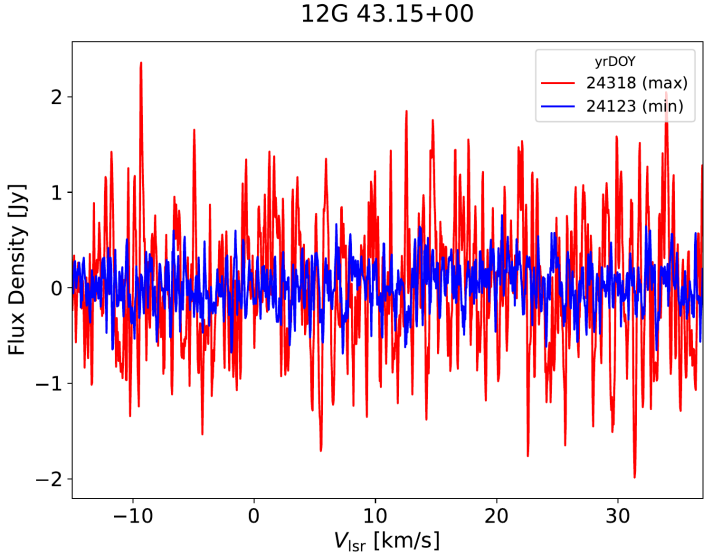
Light curve



Periodogram

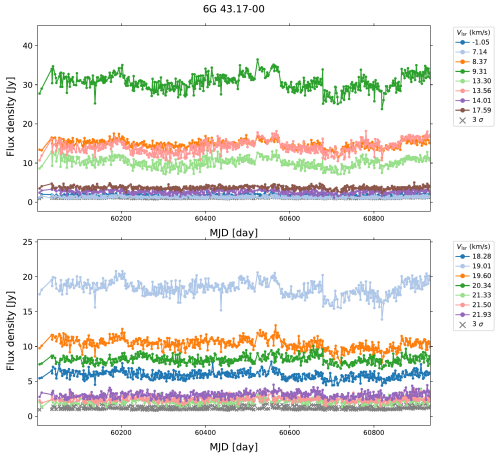


Spectrum

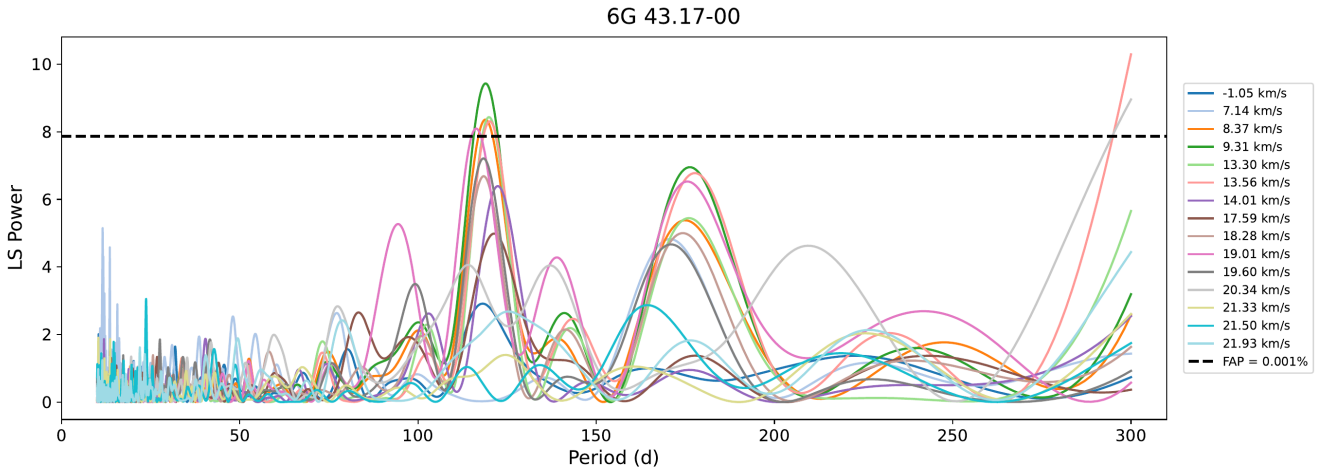


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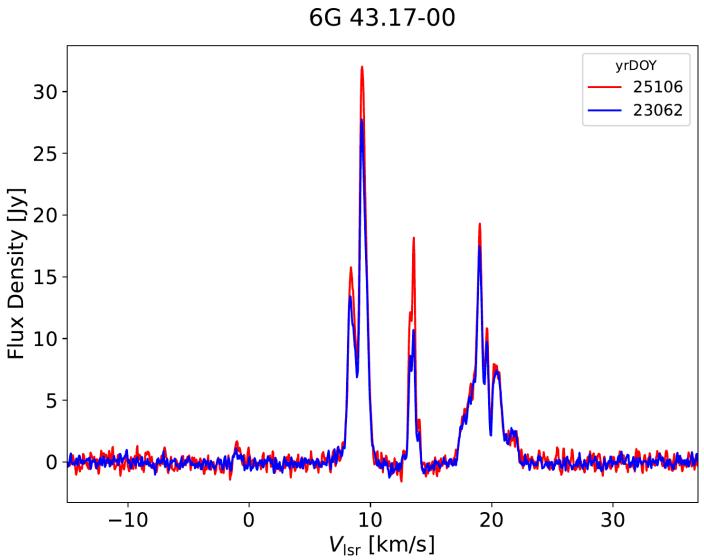
Light curve



Periodogram

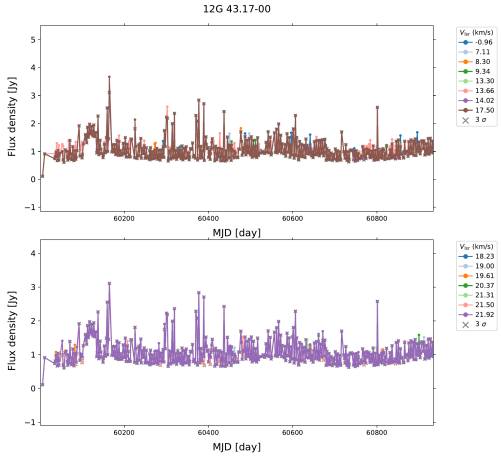


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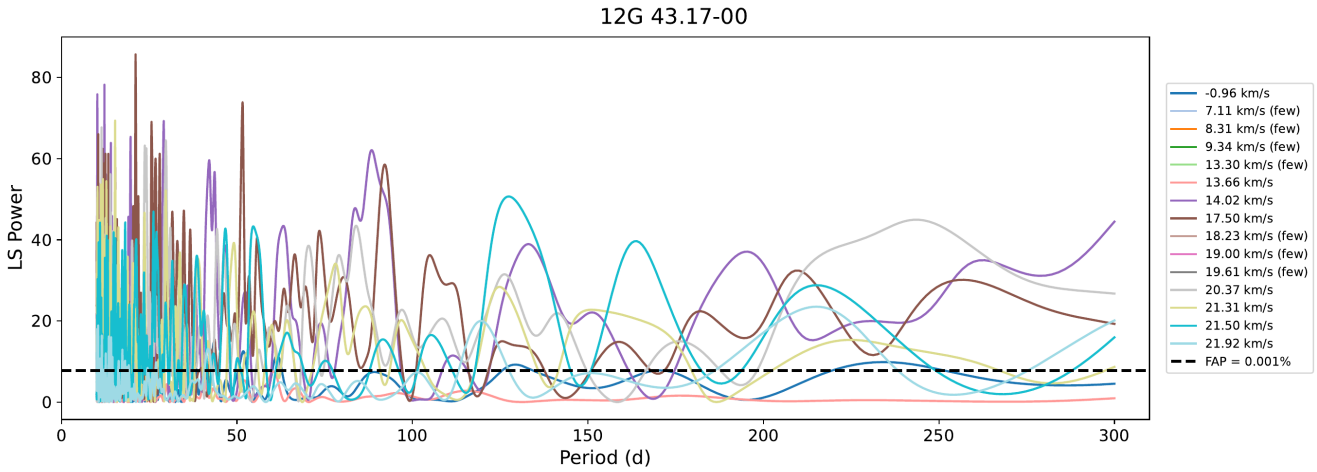


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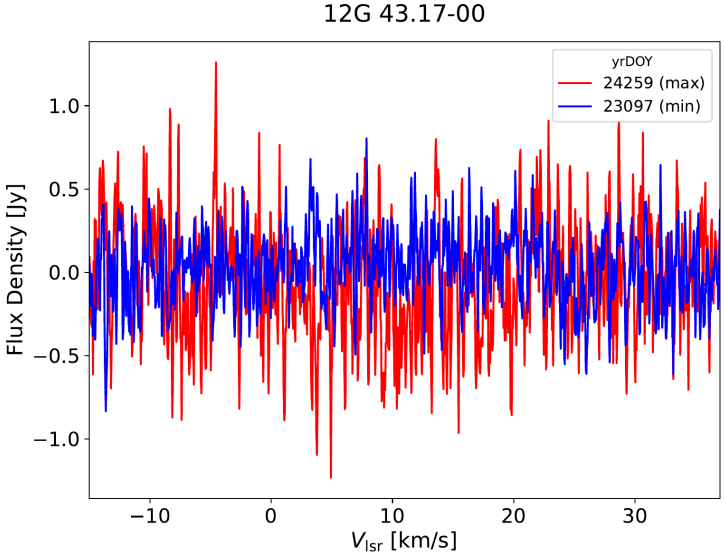
Light curve



Periodogram

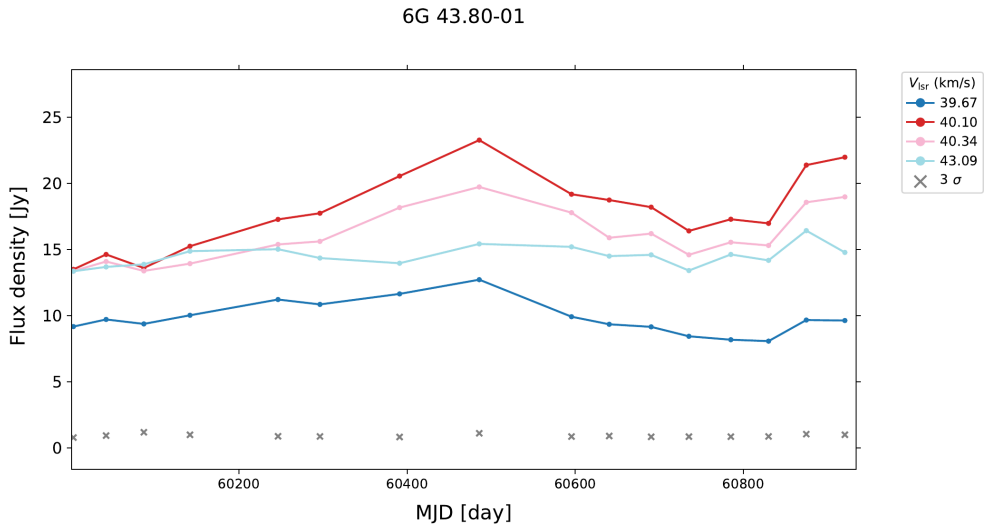


Spectrum

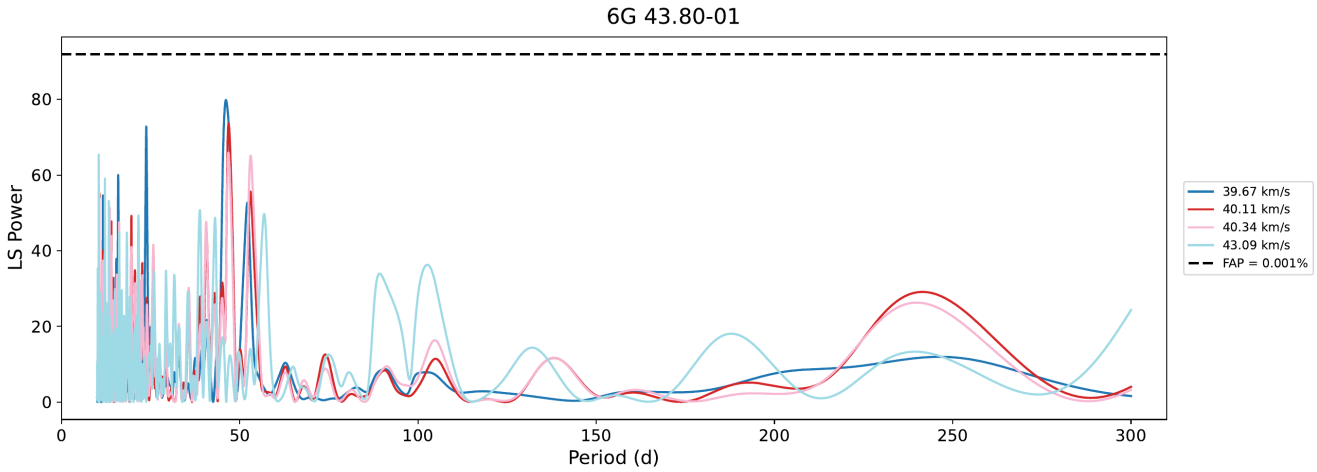


6G 43.80-01

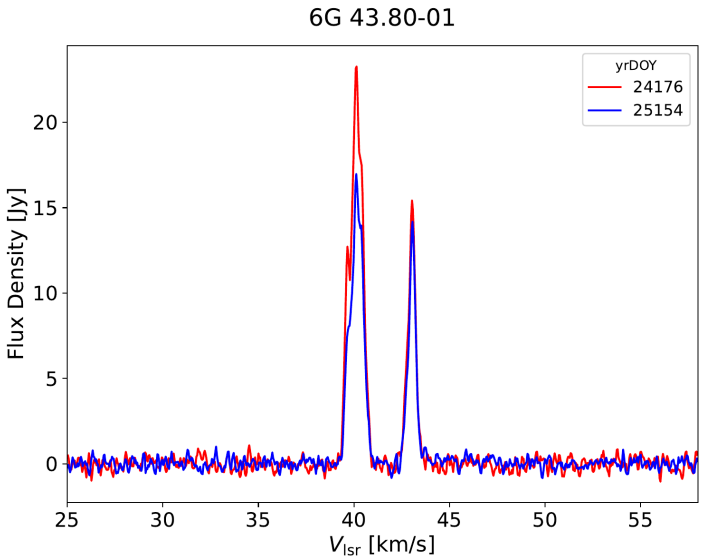
Light curve



Periodogram

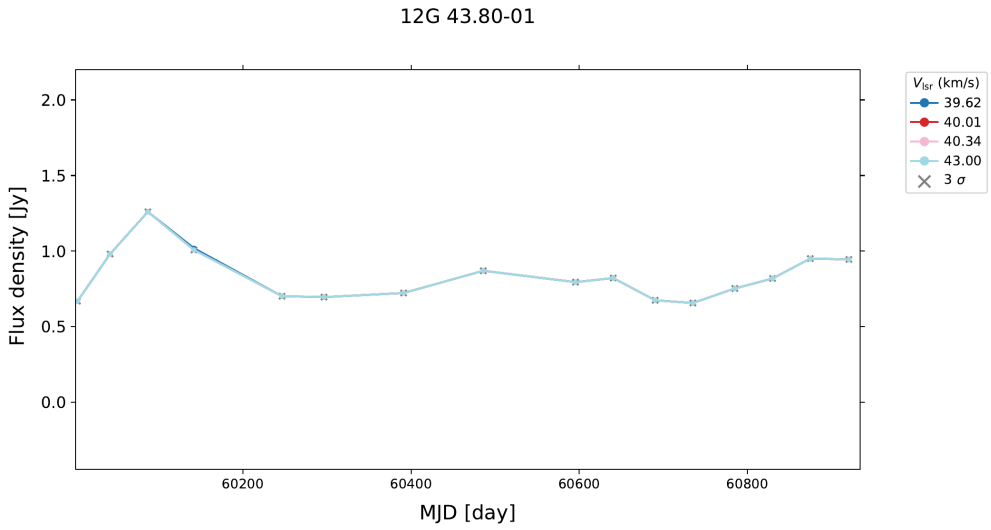


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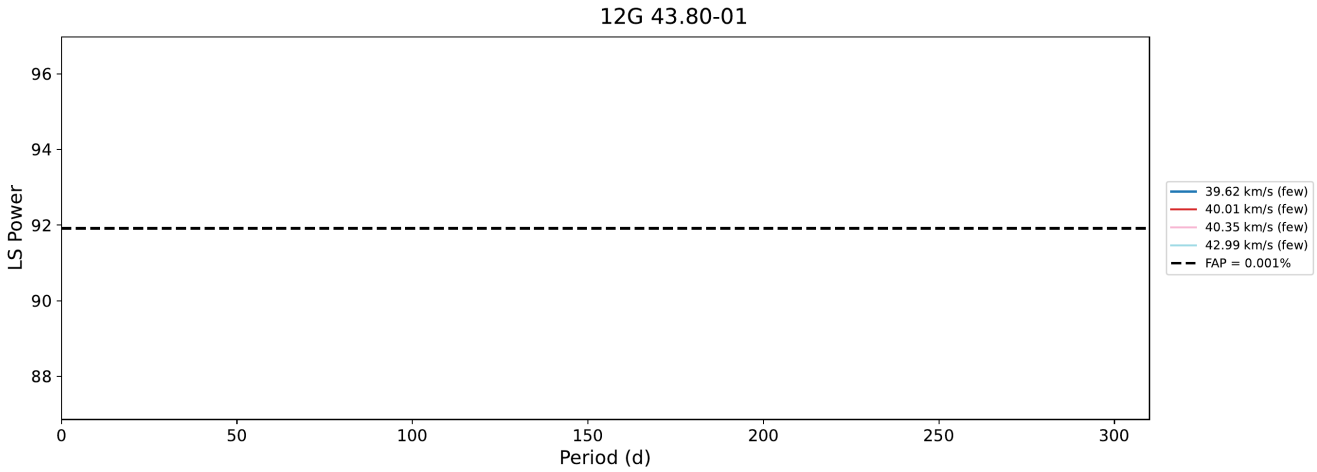


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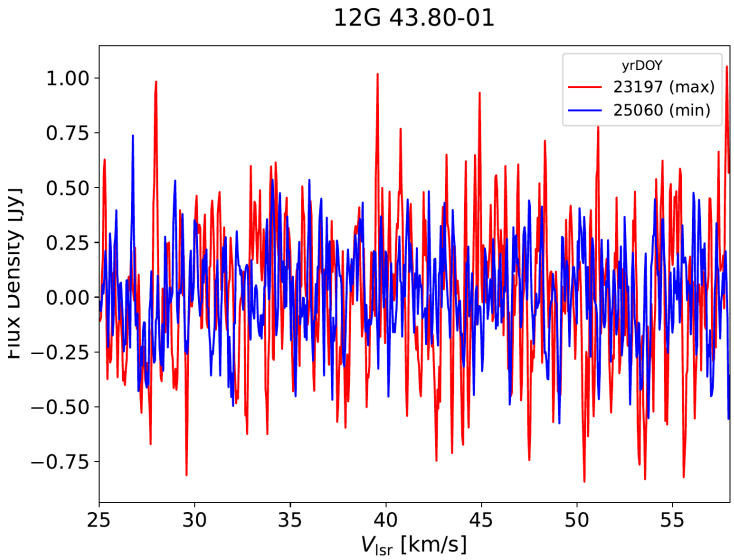
Light curve



Periodogram

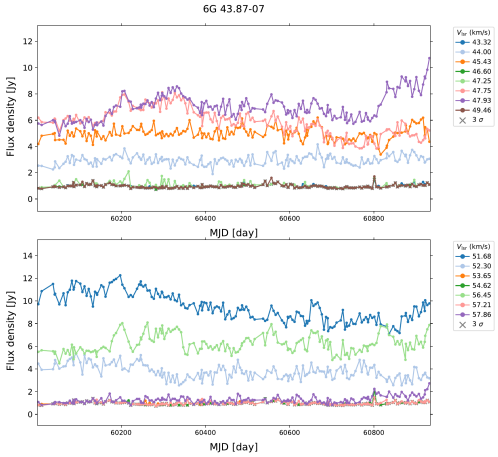


Spectrum

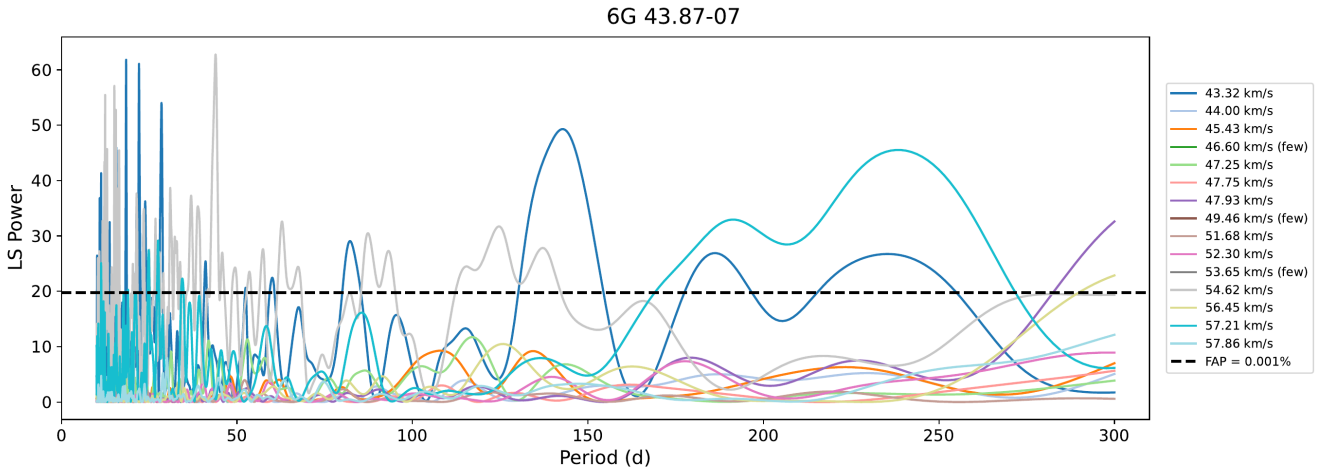


6G 43.87-07

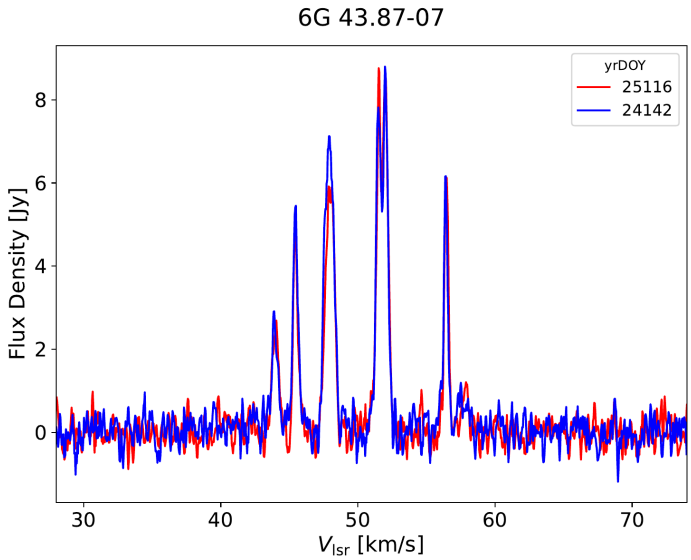
Light curve



Periodogram

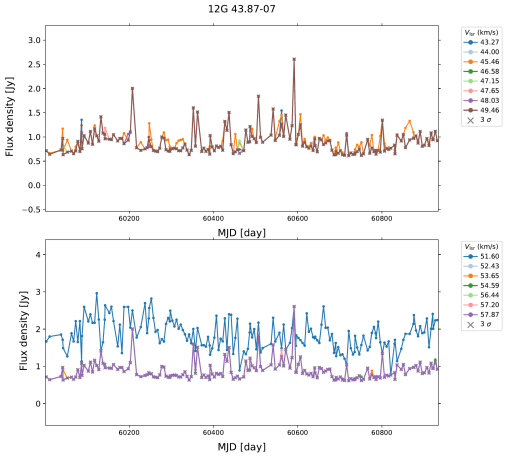


Spectrum

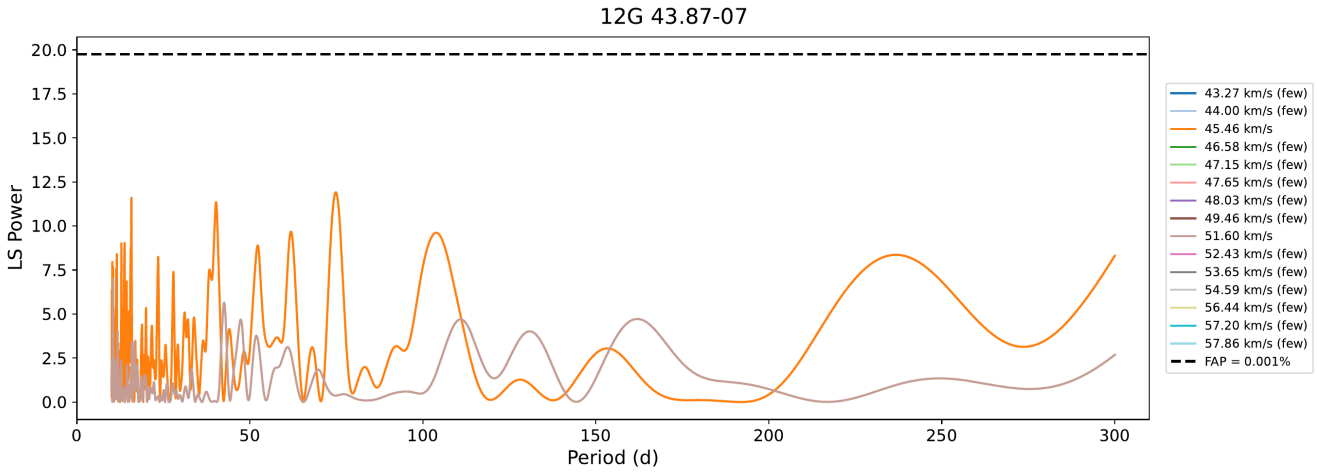


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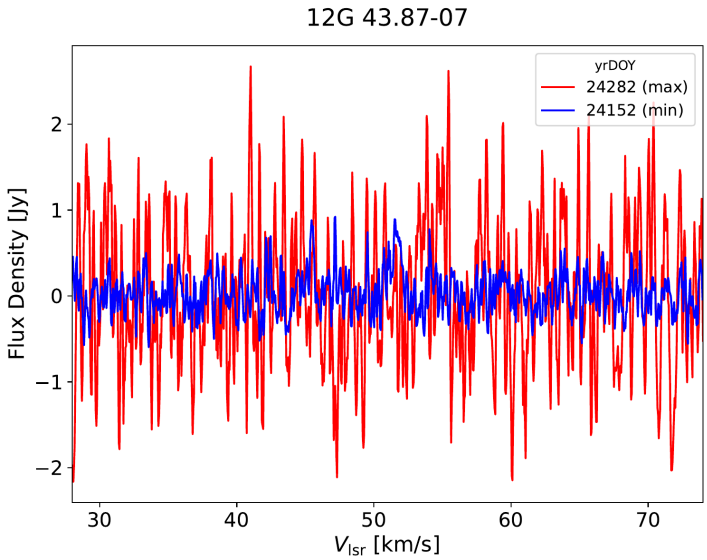
Light curve



Periodogram

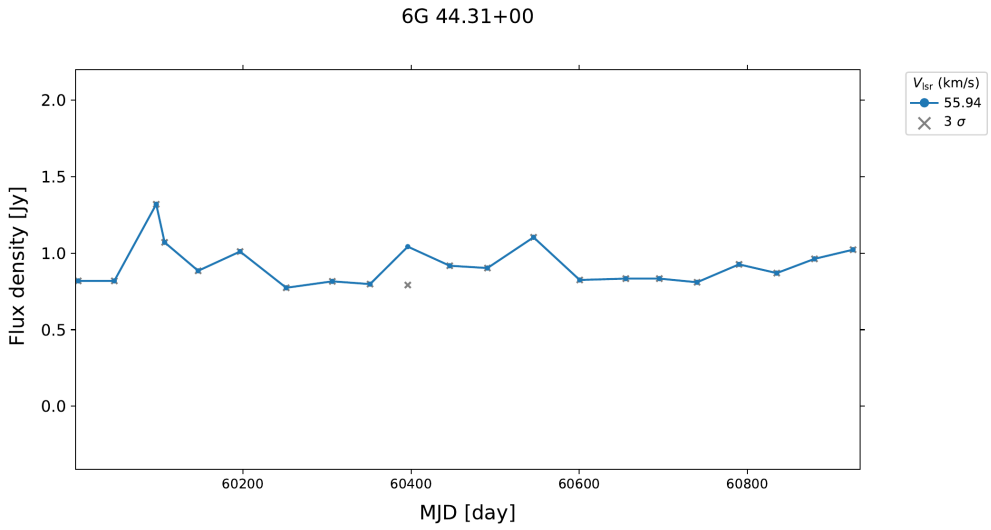


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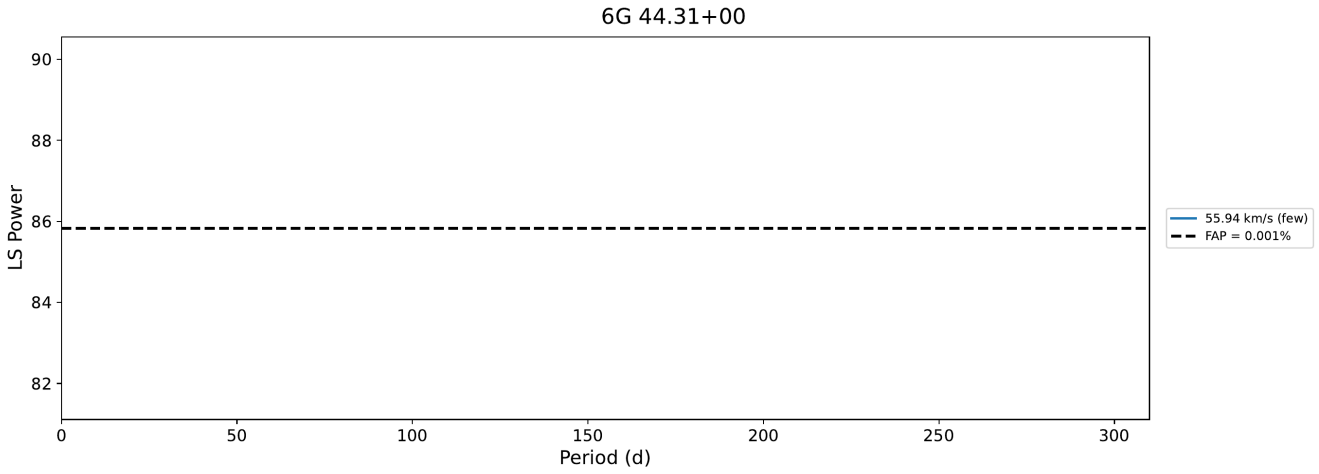


6G 44.31+00

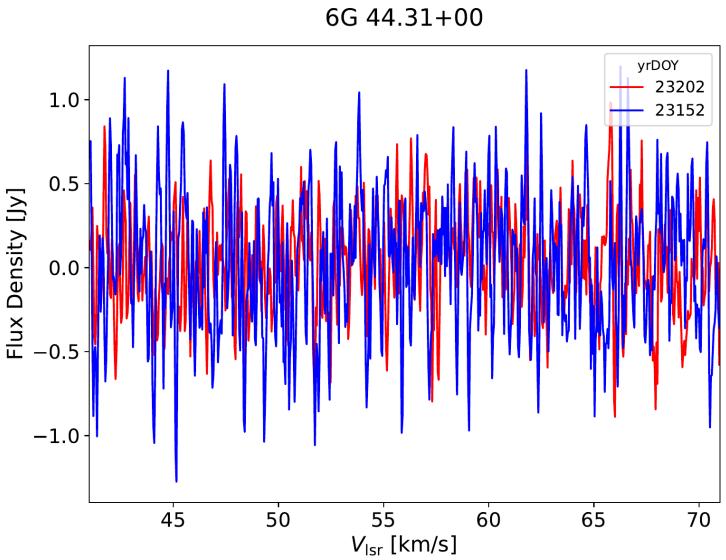
Light curve



Periodogram

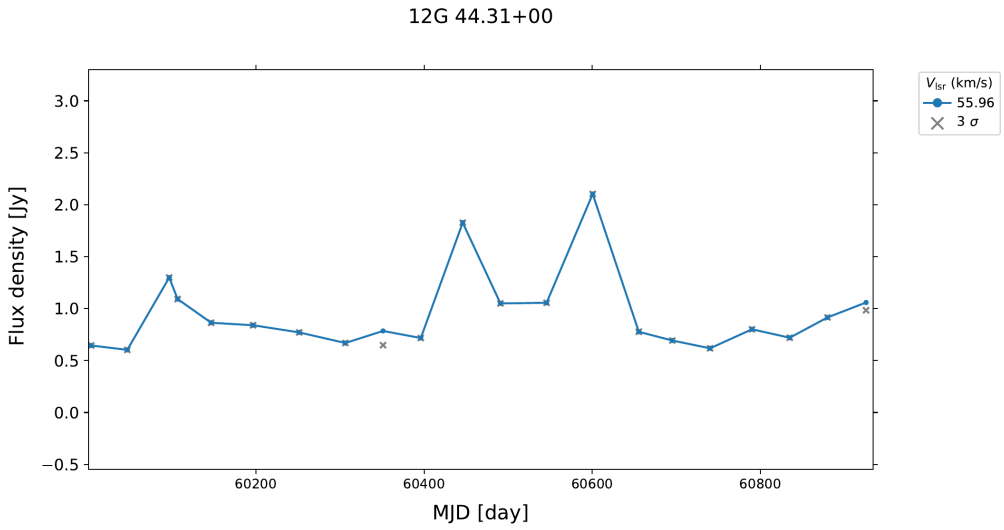


Spectrum

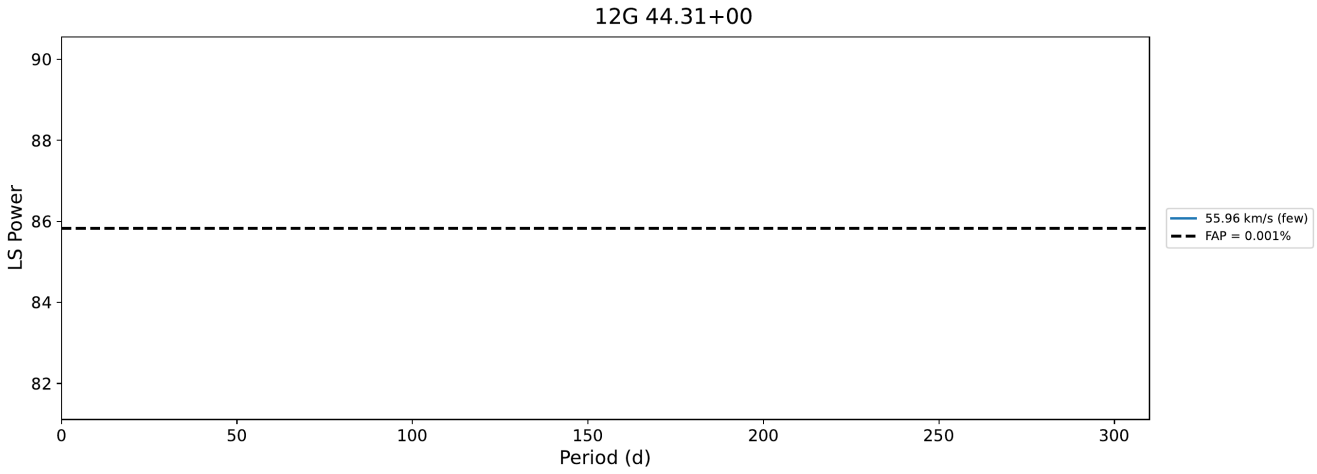


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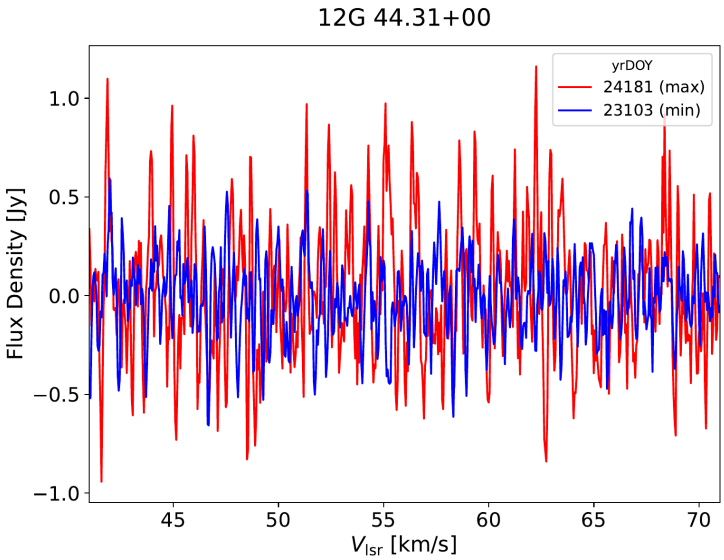
Light curve



Periodogram

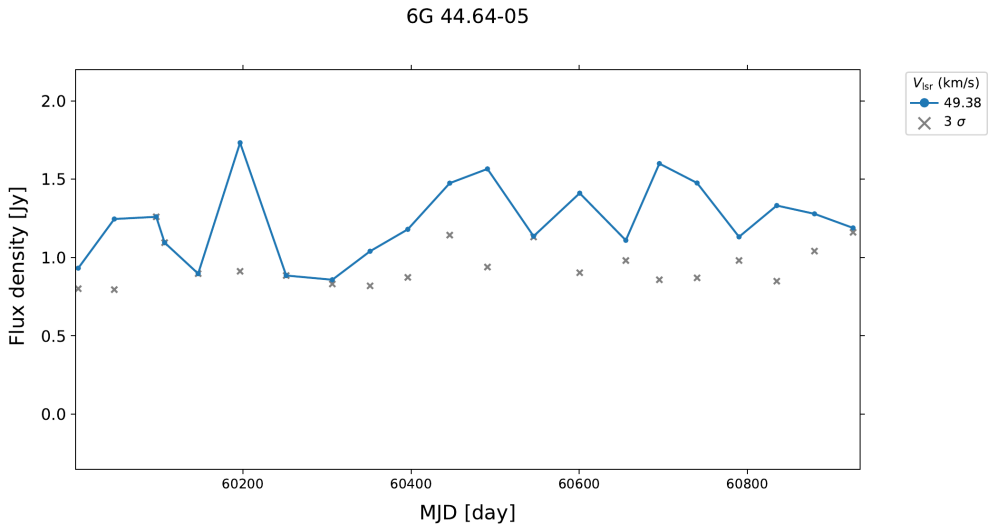


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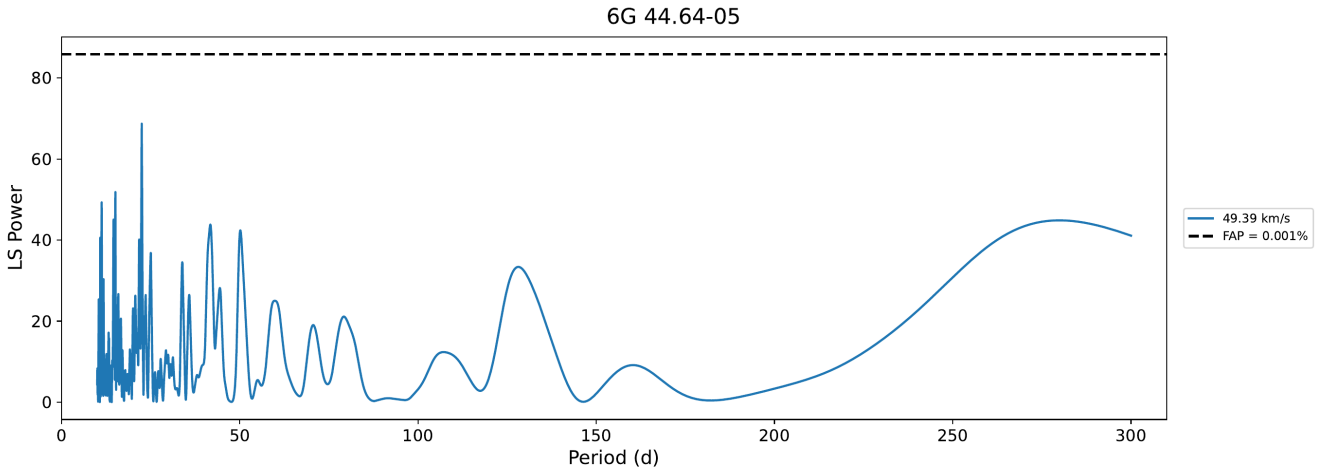


6G 44.64-05

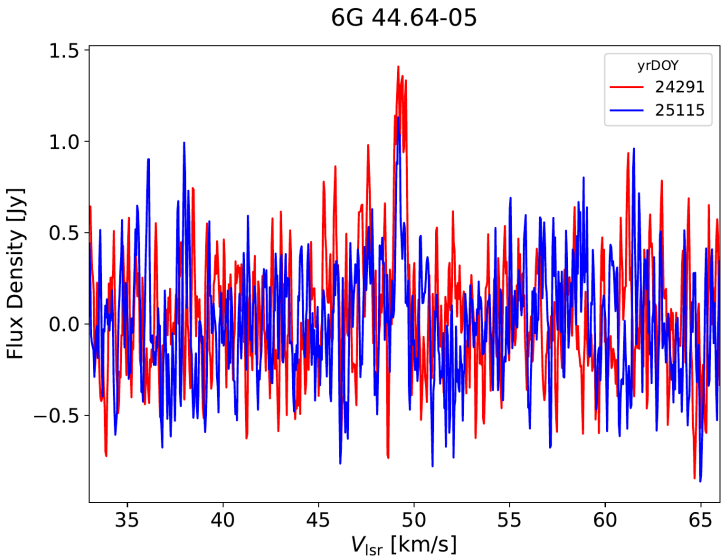
Light curve



Periodogram

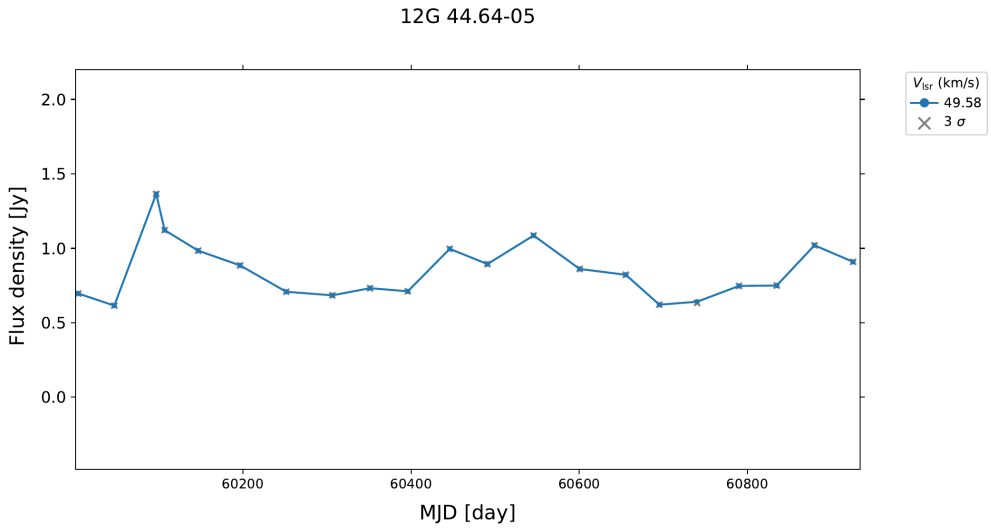


Spectrum

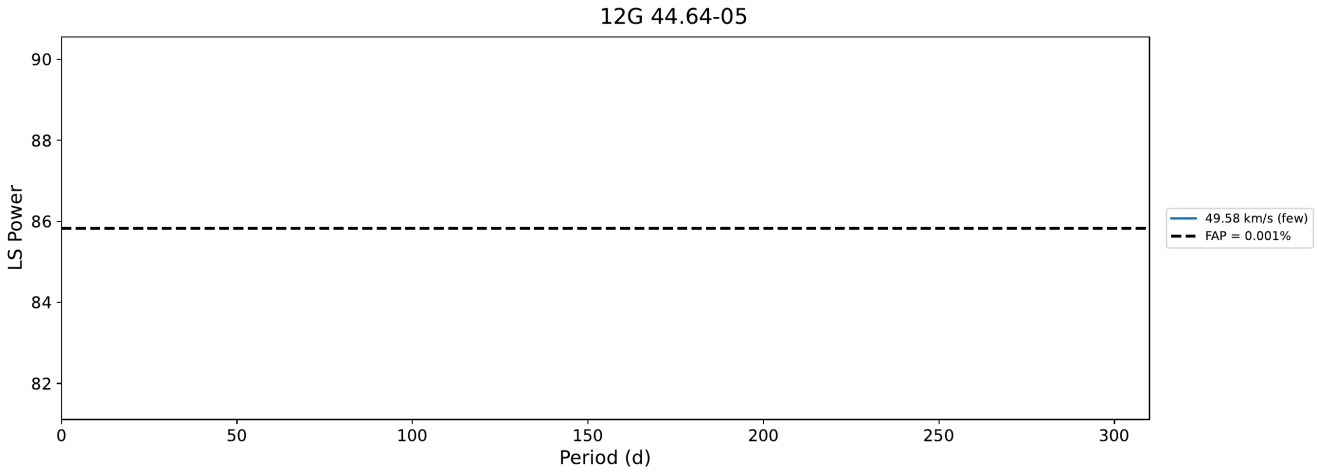


12G 44.64-05

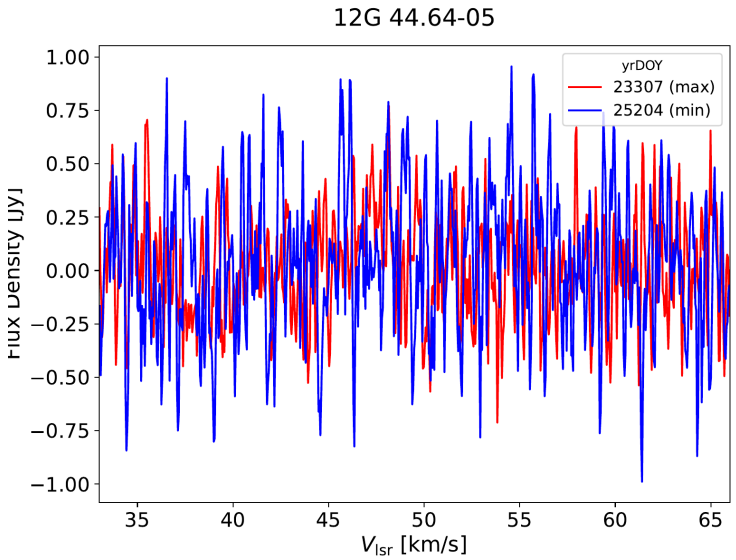
Light curve



Periodogram

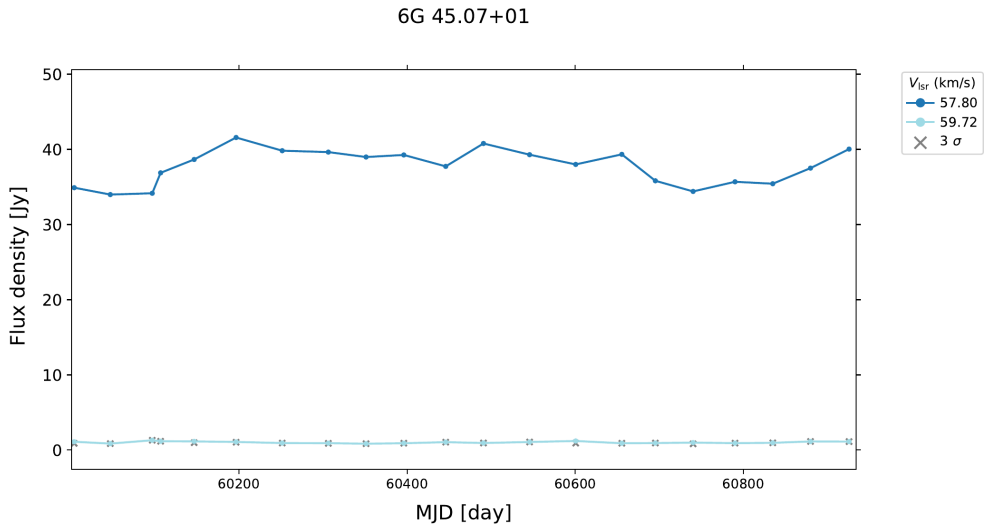


Spectrum

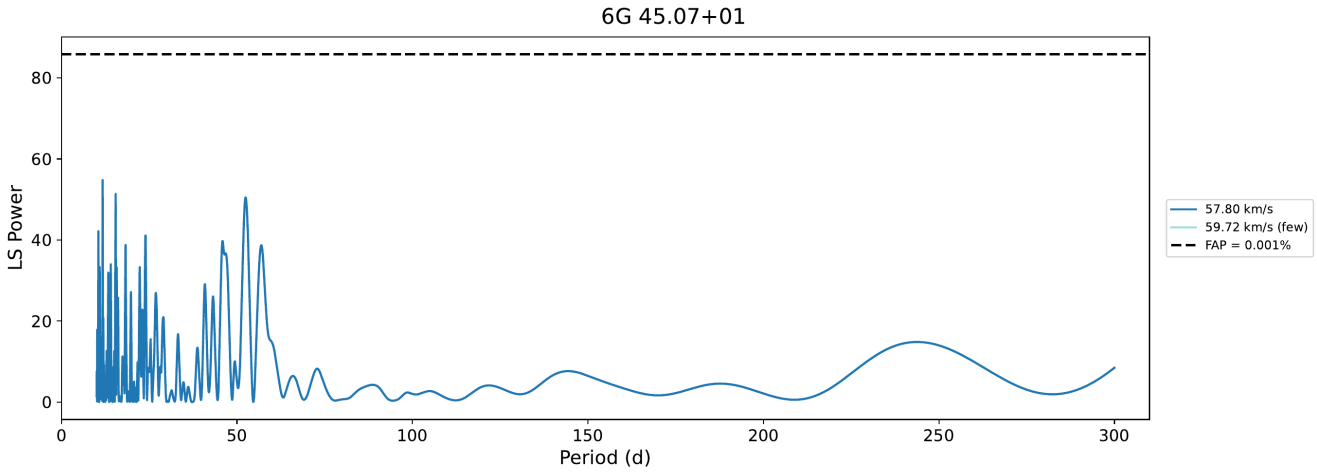


6G 45.07+01

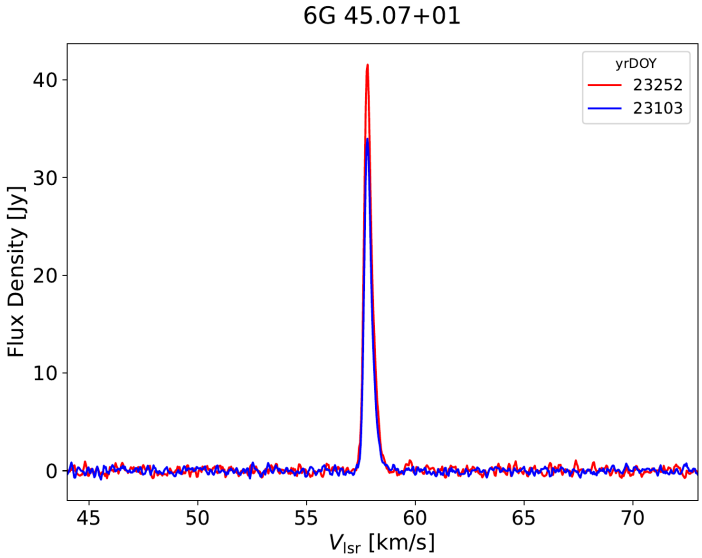
Light curve



Periodogram

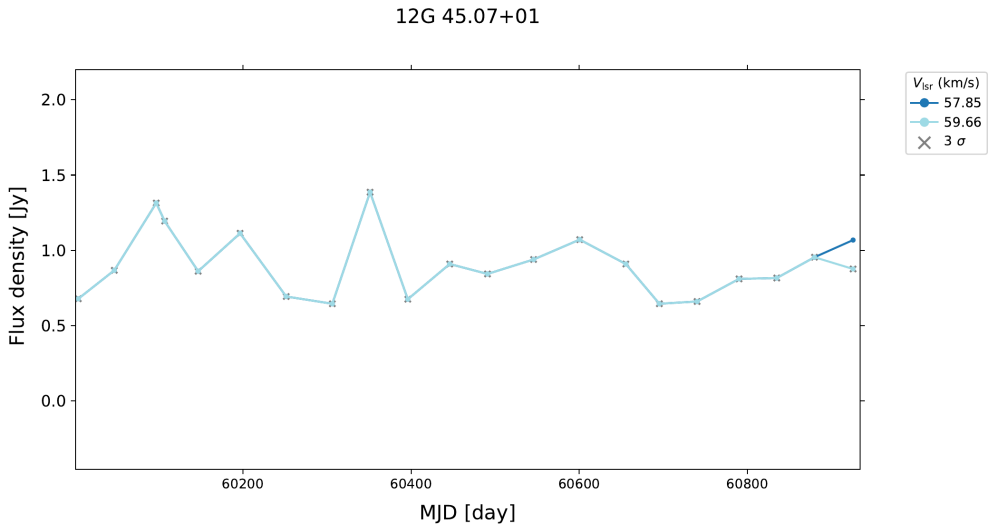


Spectrum

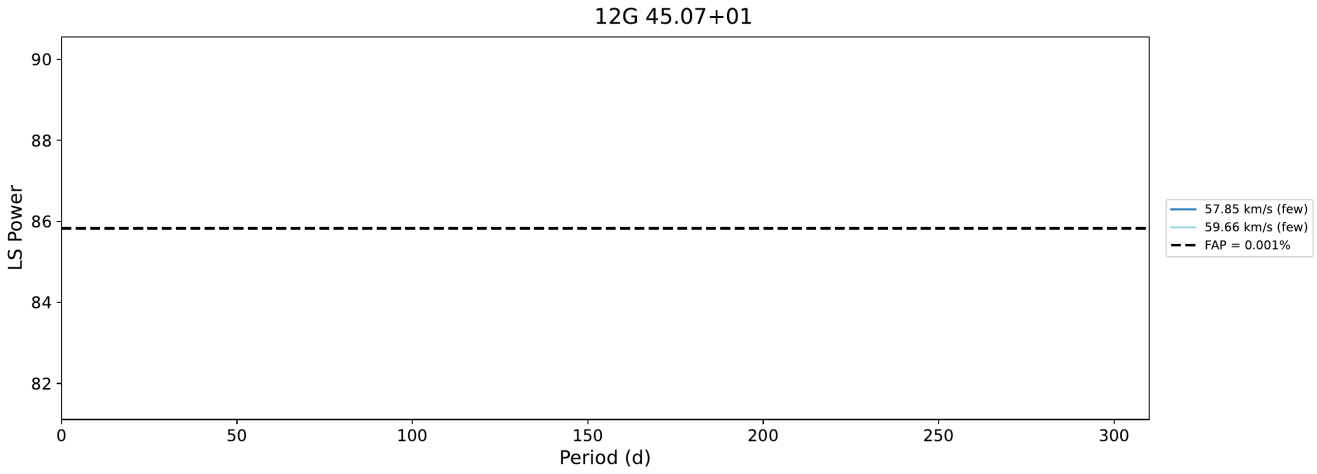


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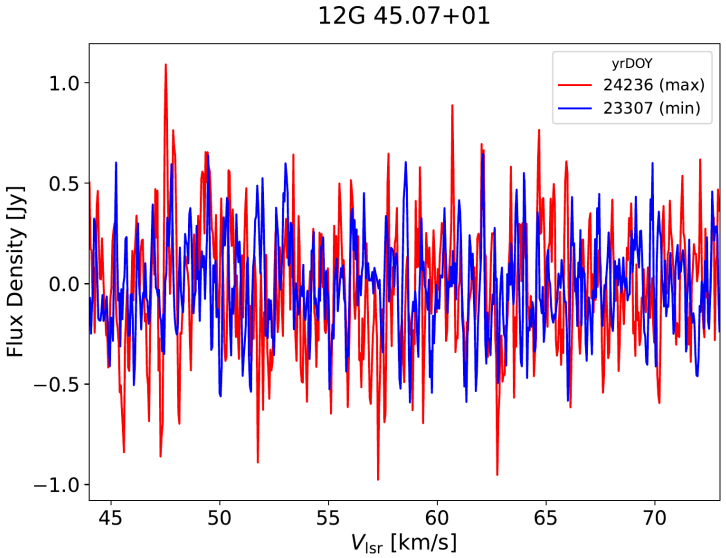
Light curve



Periodogram

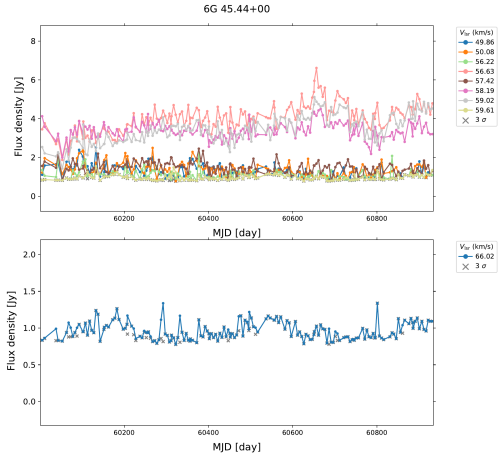


Spectrum

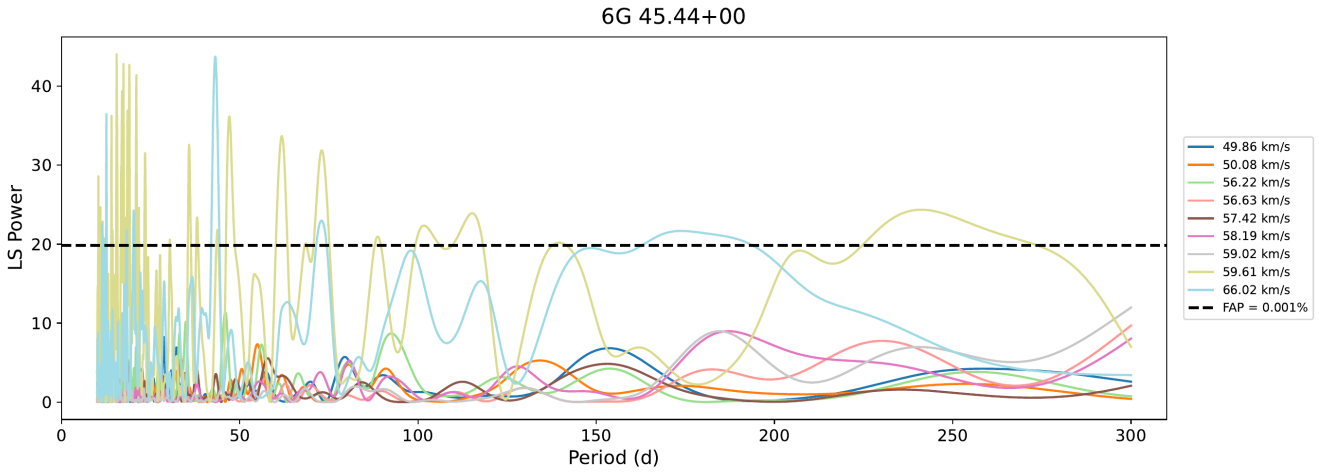


6G 45.44+00

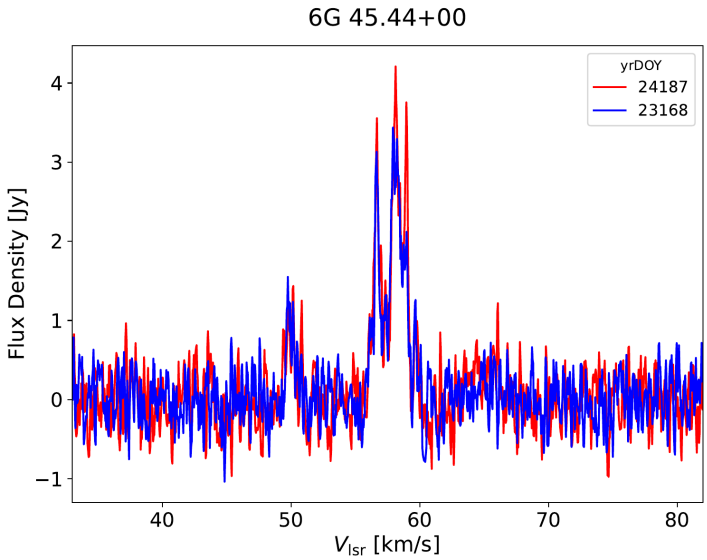
Light curve



Periodogram

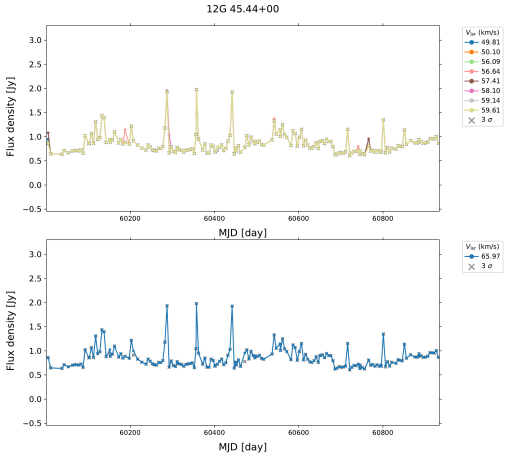


Spectrum

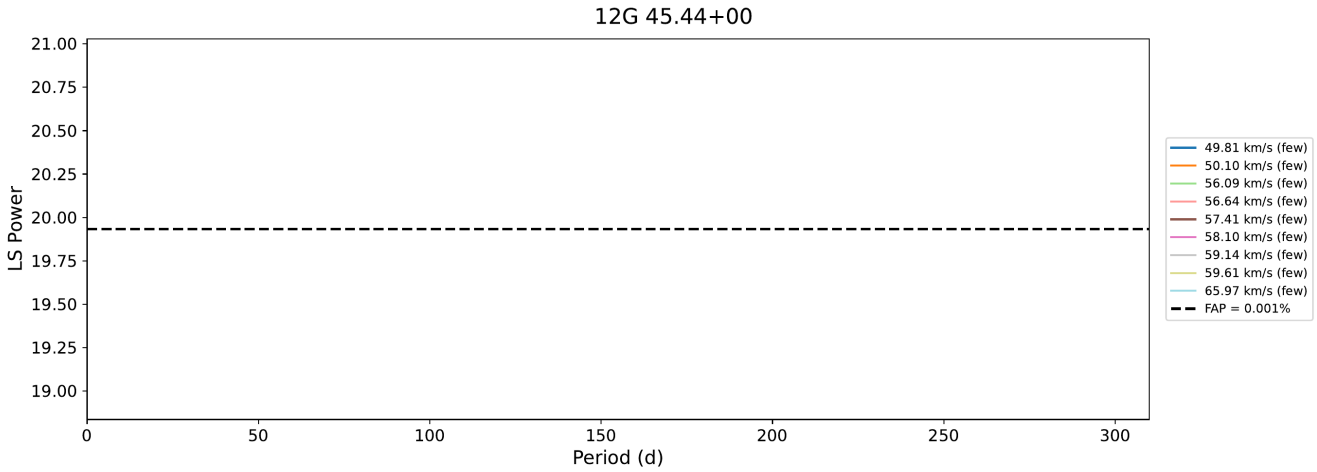


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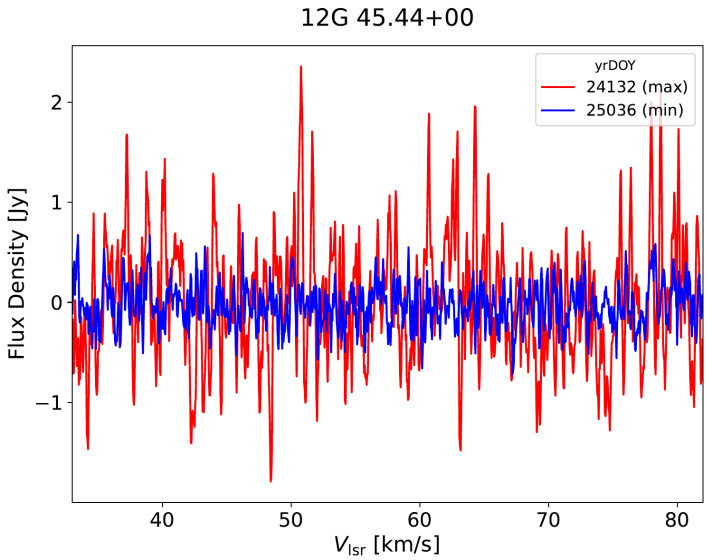
Light curve



Periodogram

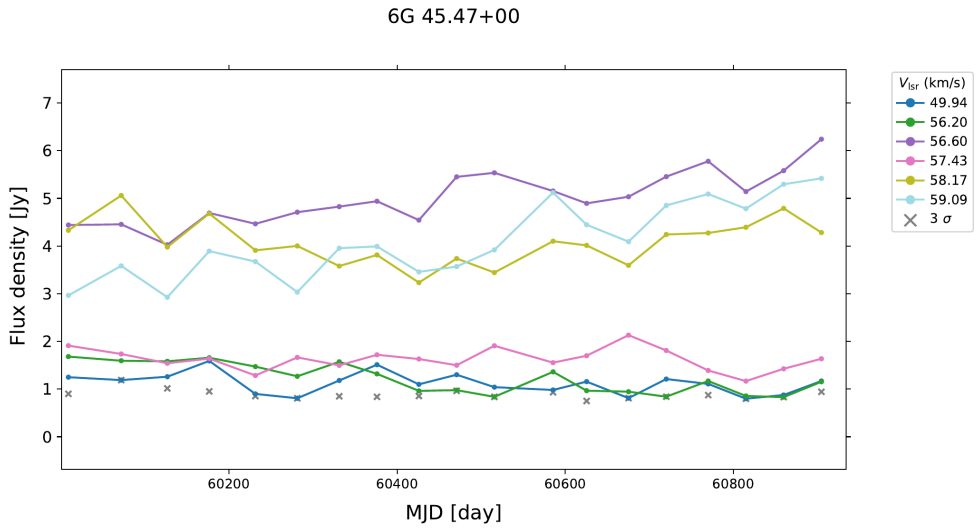


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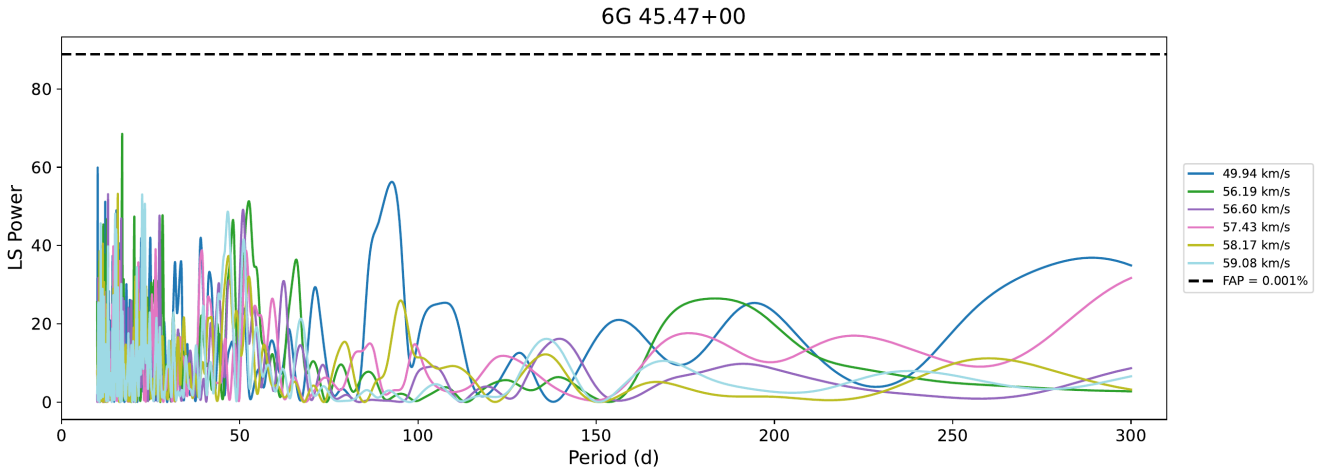


6G 45.47+00

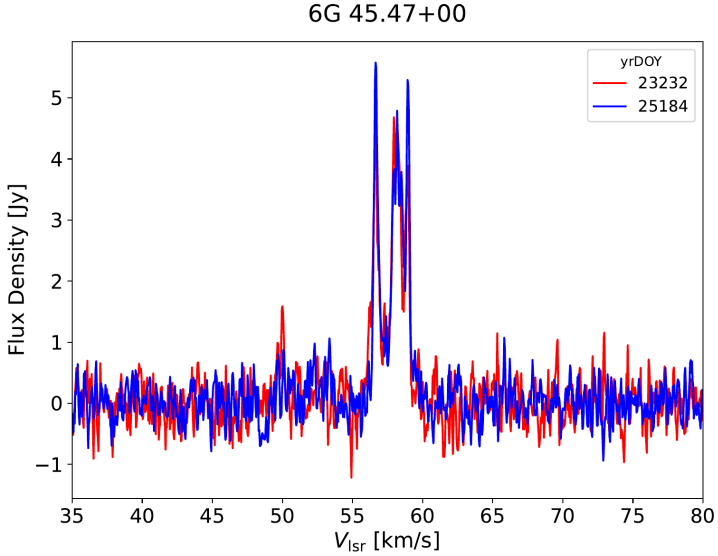
Light curve



Periodogram

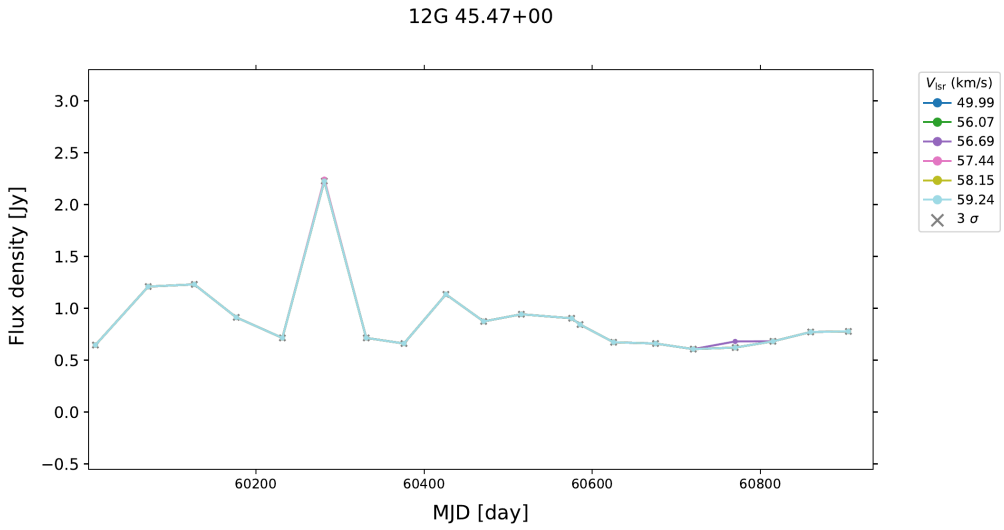


Spectrum

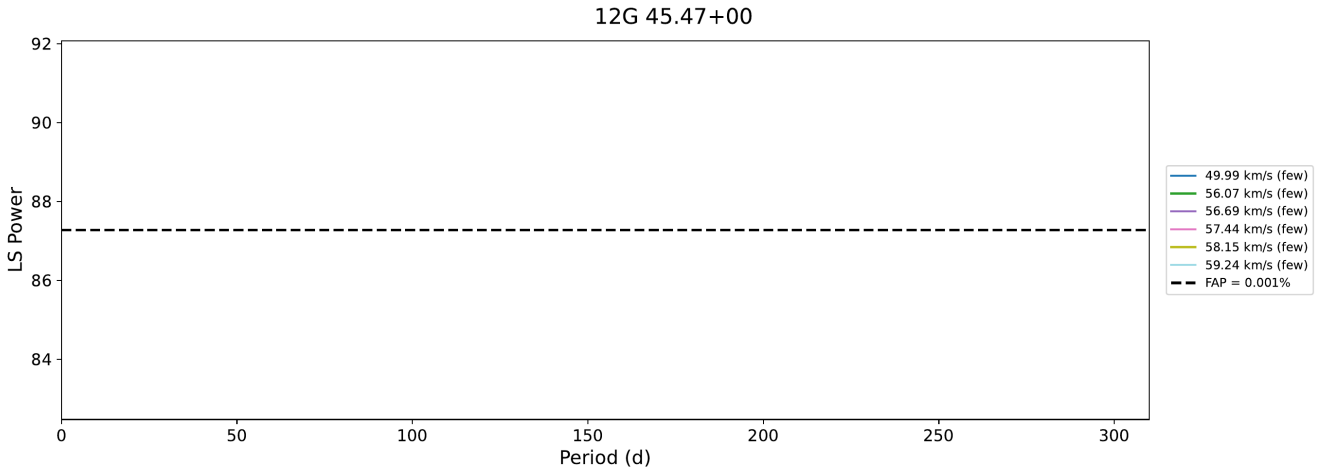


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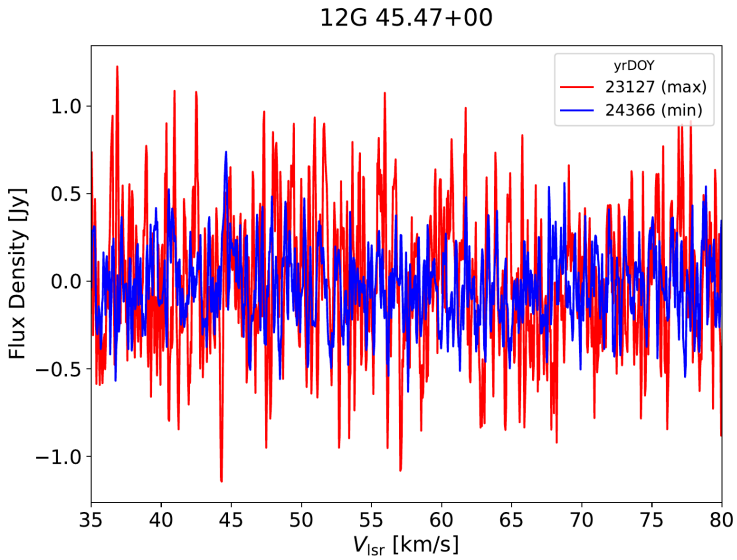
Light curve



Periodogram

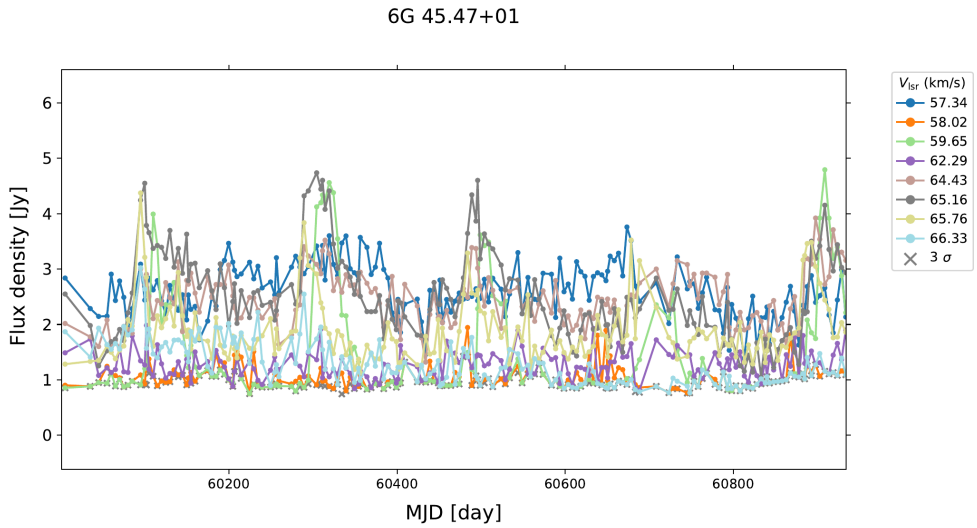


Spectrum

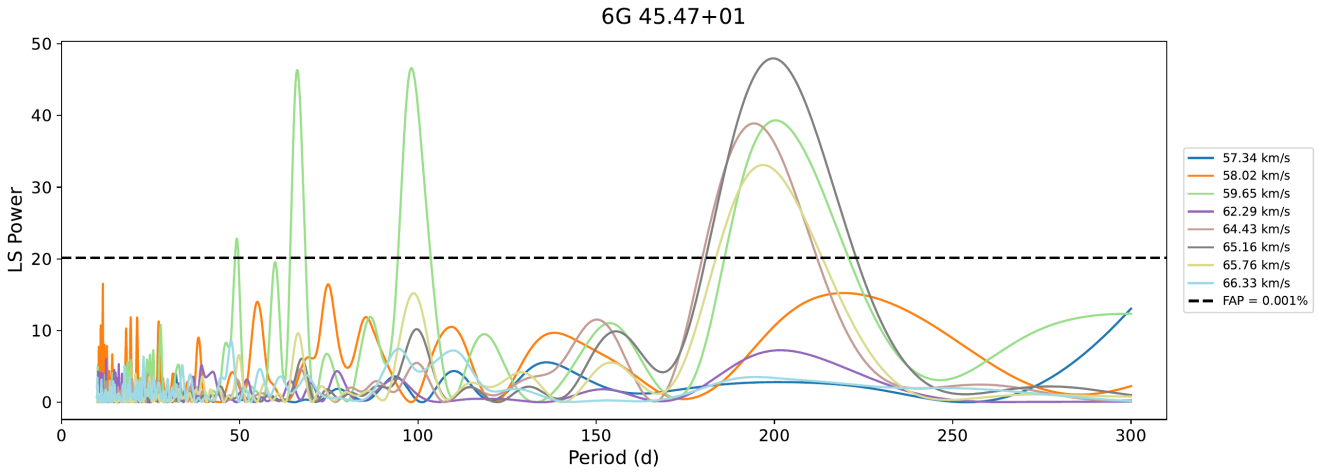


6G 45.47+01

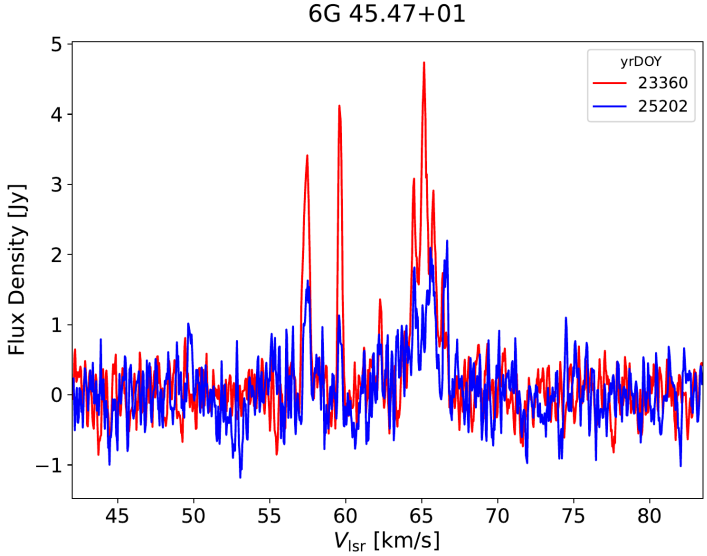
Light curve



Periodogram

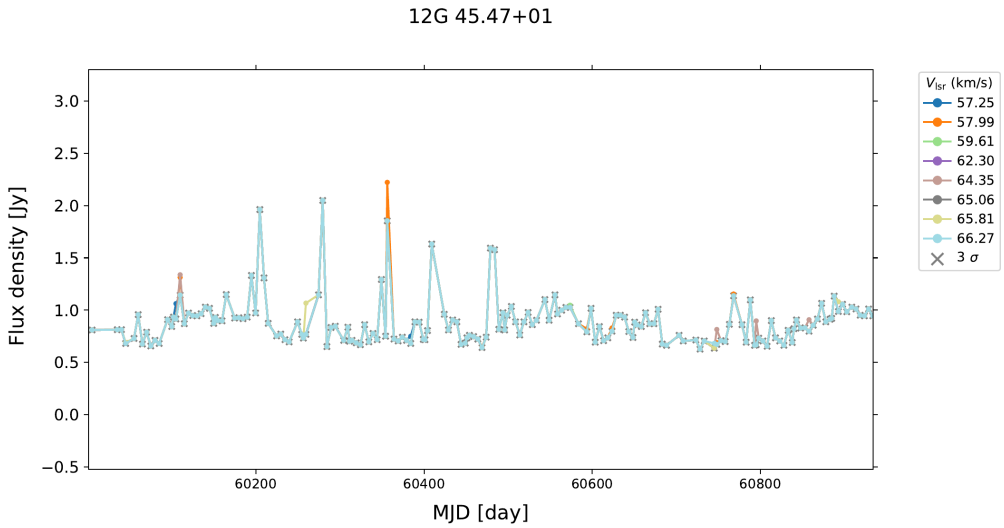


Spectrum

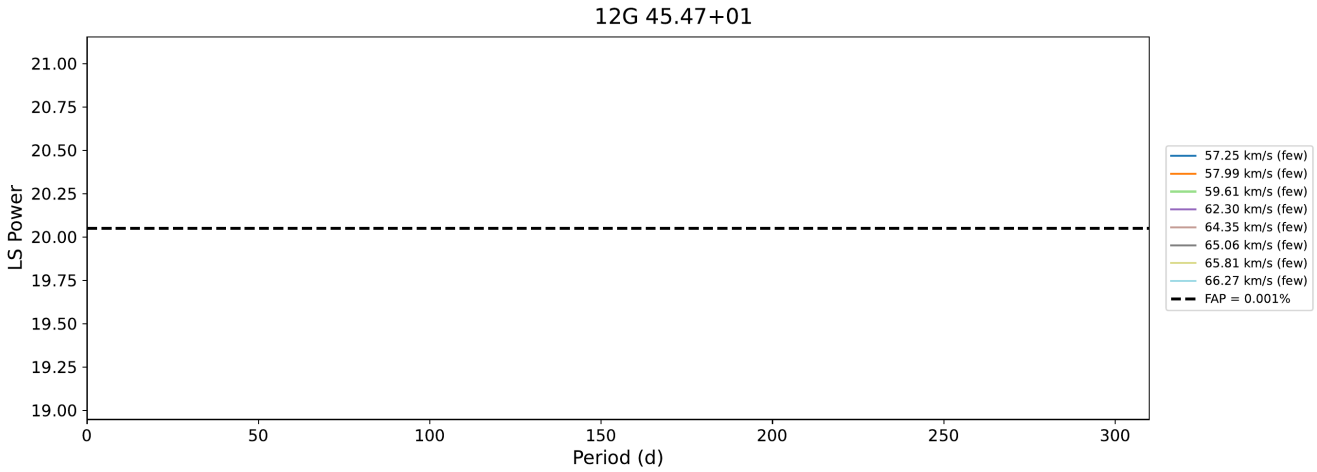


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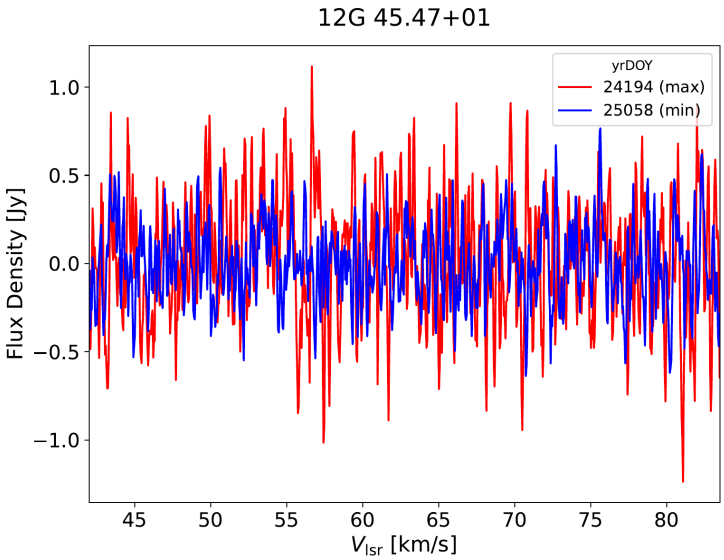
Light curve



Periodogram

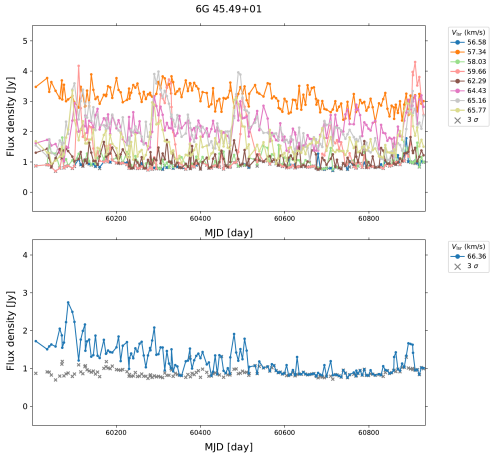


Spectrum

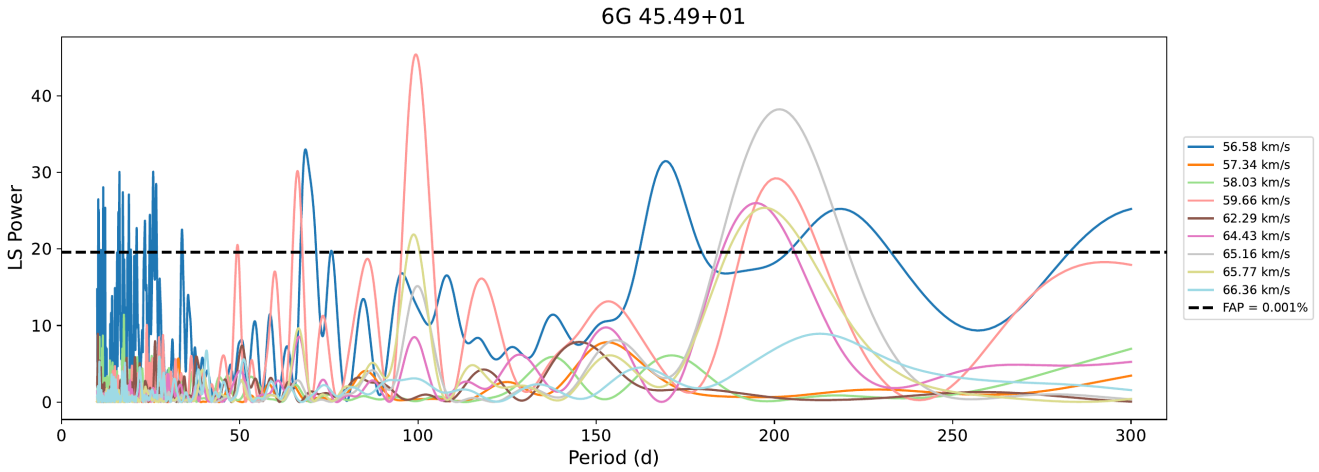


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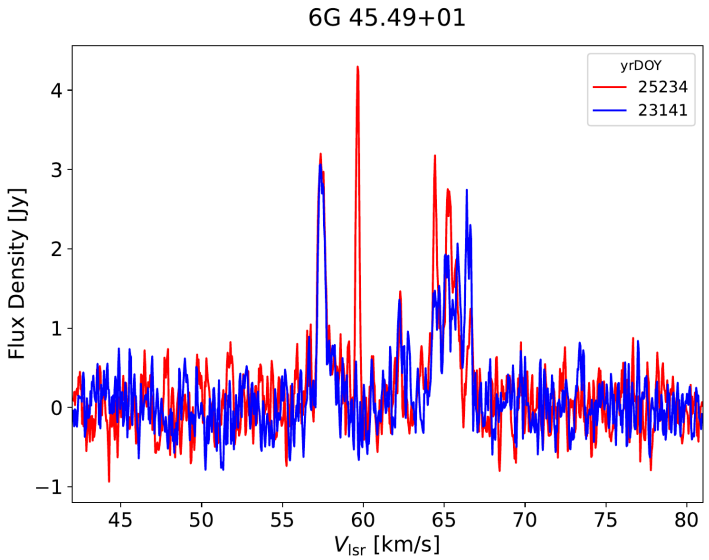
Light curve



Periodogram

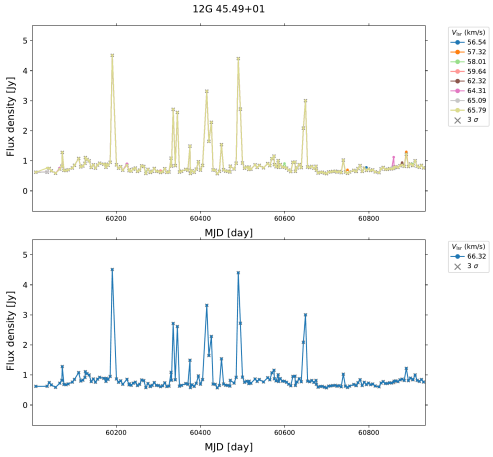


Spectrum

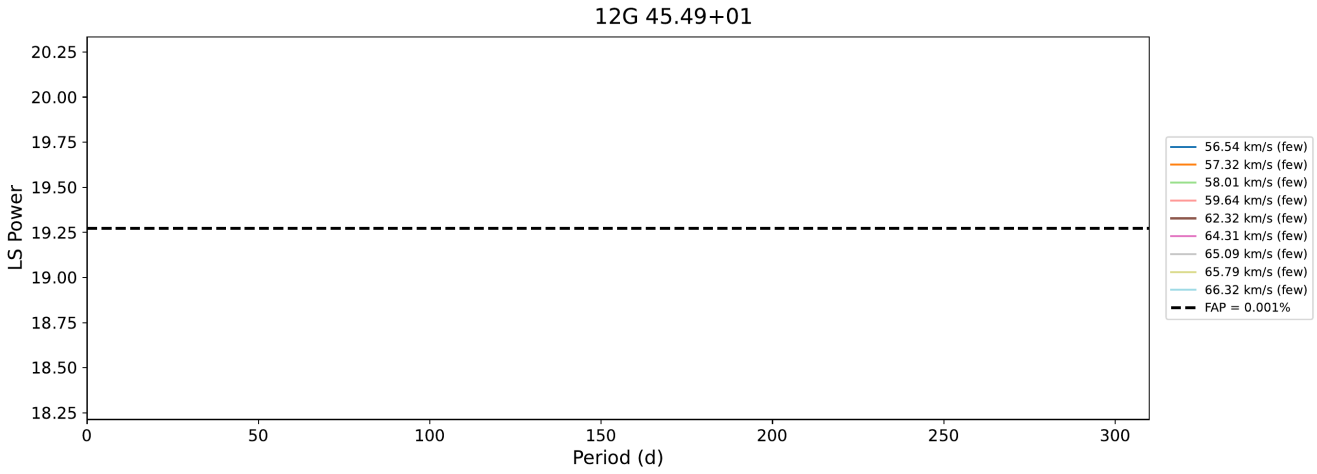


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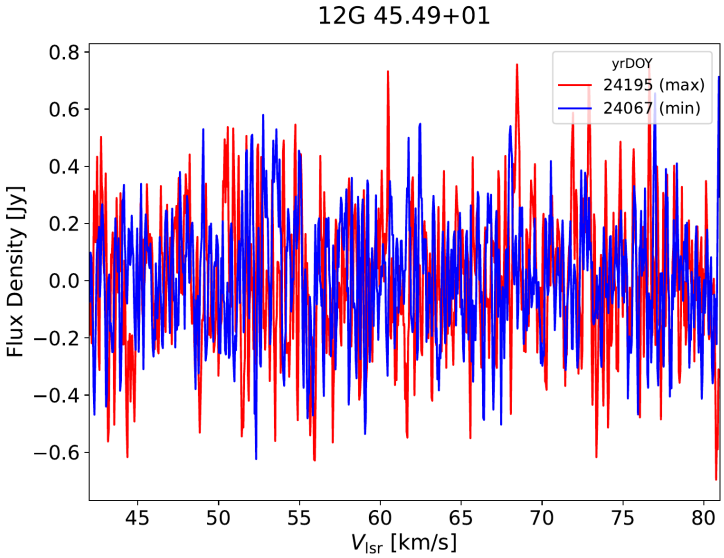
Light curve



Periodogram

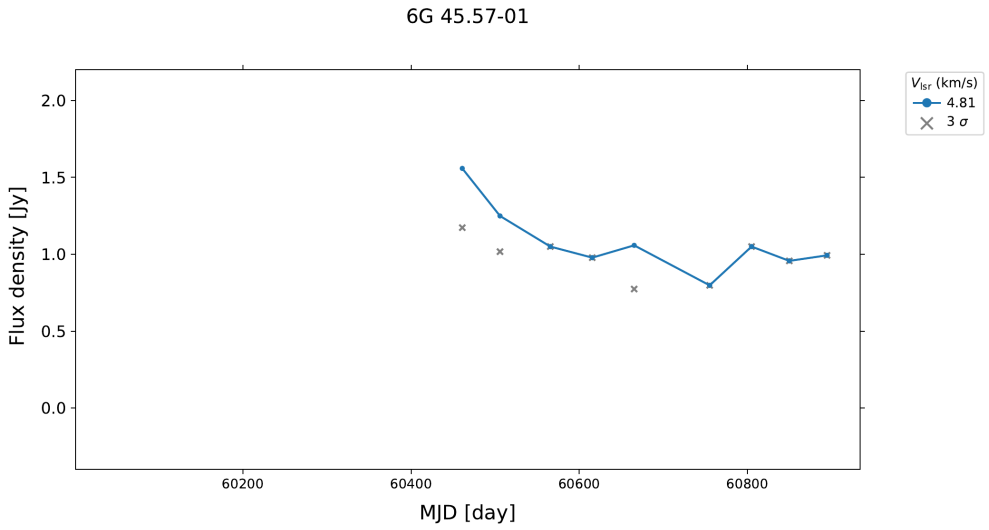


Spectrum

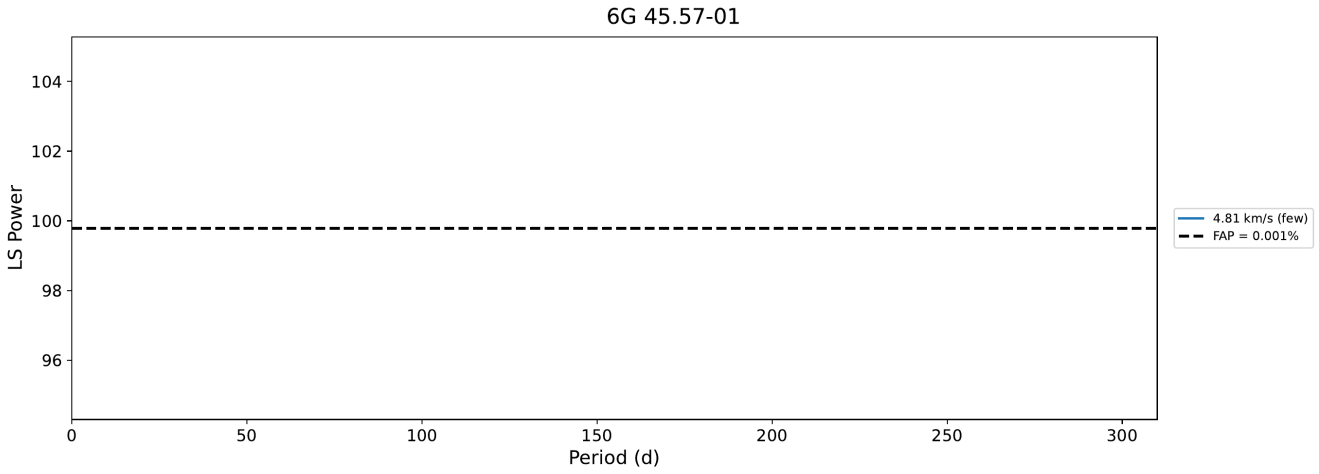


6G 45.57-01

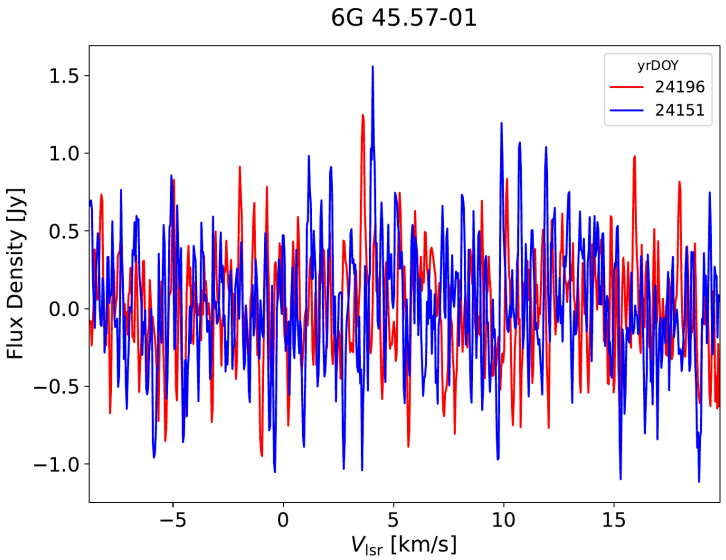
Light curve



Periodogram

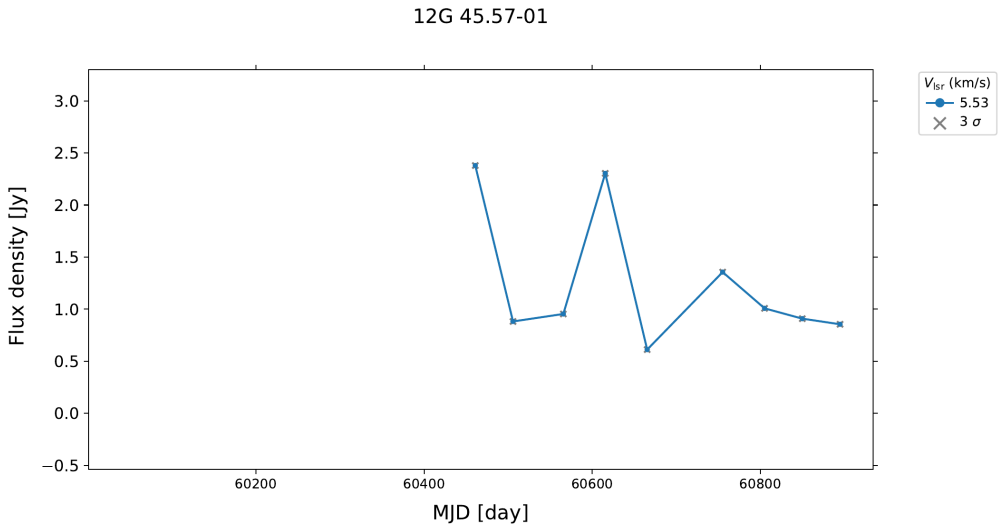


Spectrum

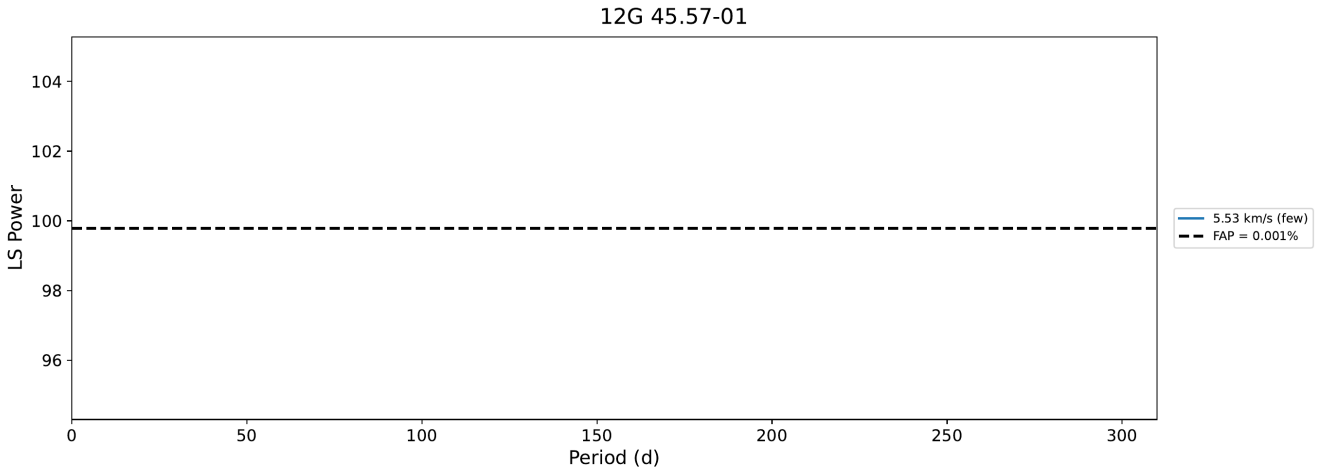


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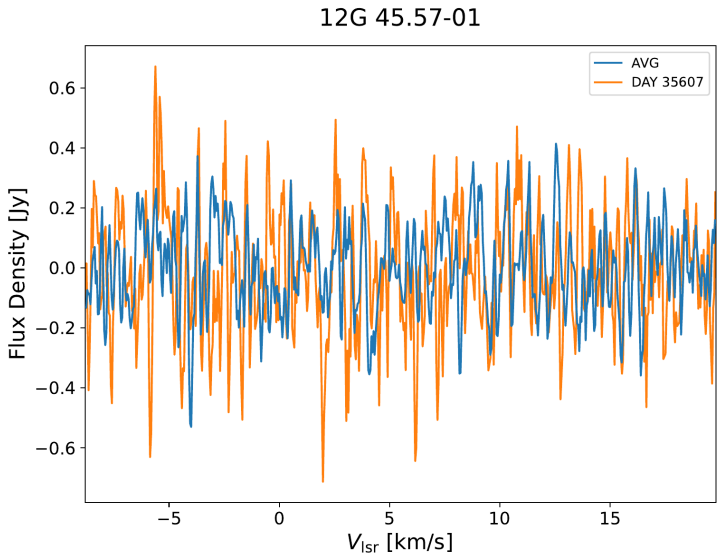
Light curve



Periodogram

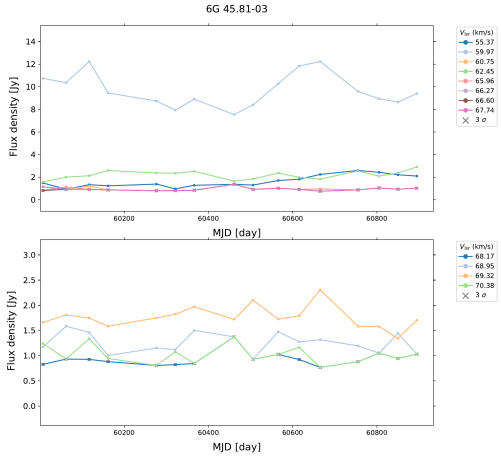


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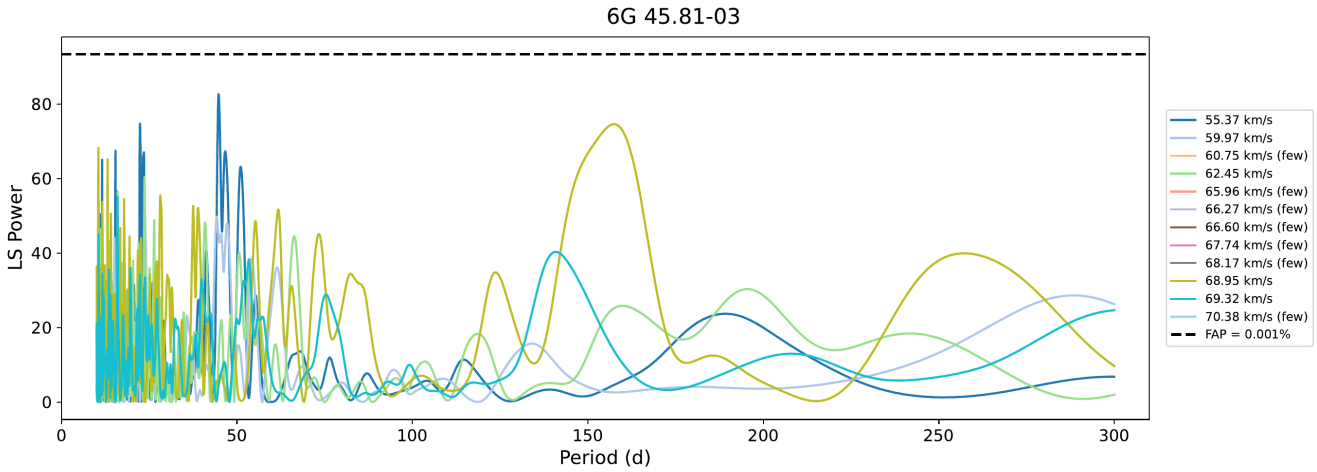


6G 45.81-03

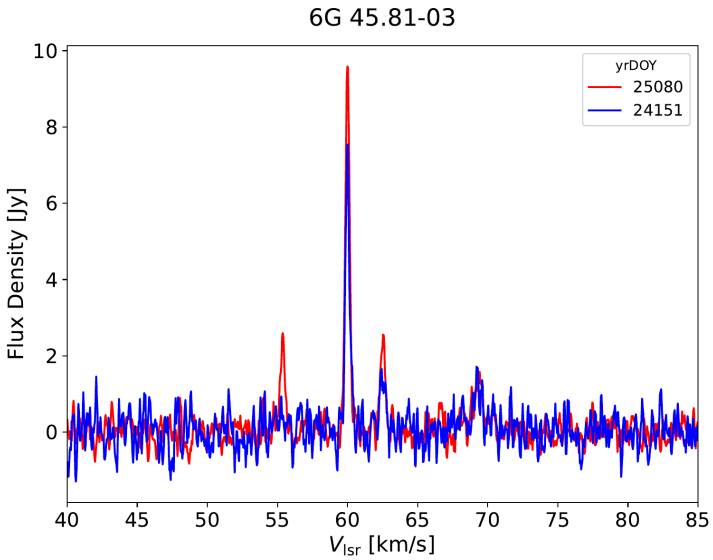
Light curve



Periodogram

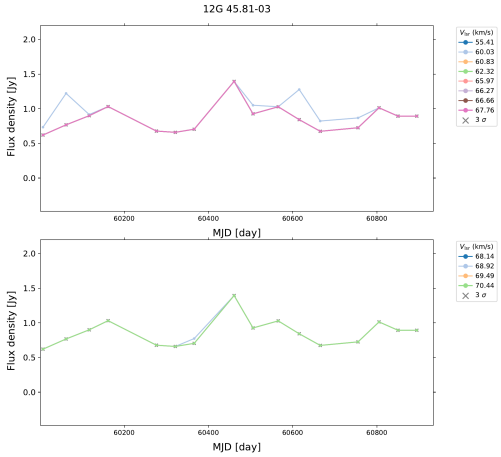


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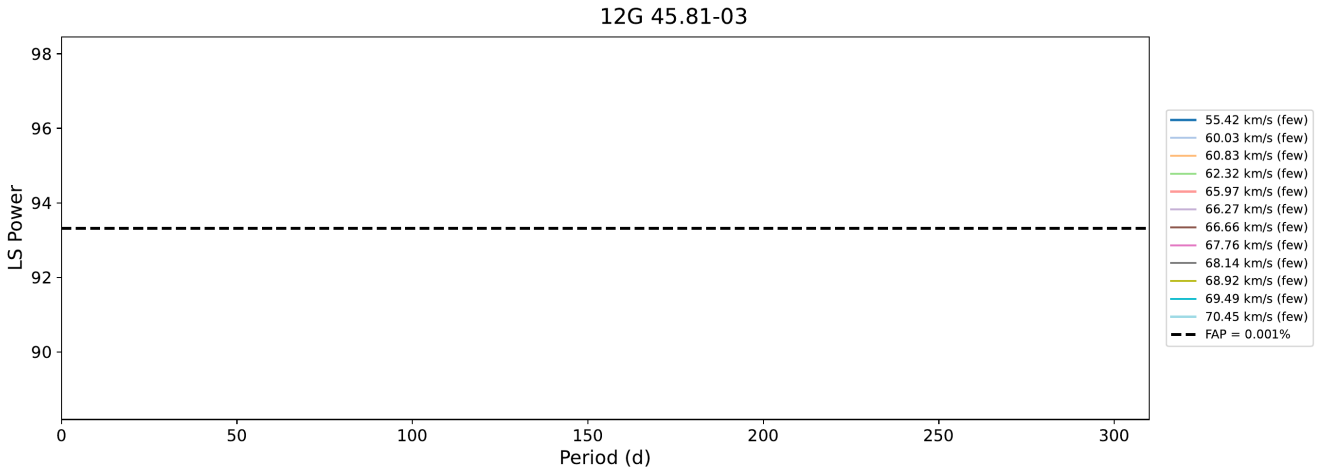


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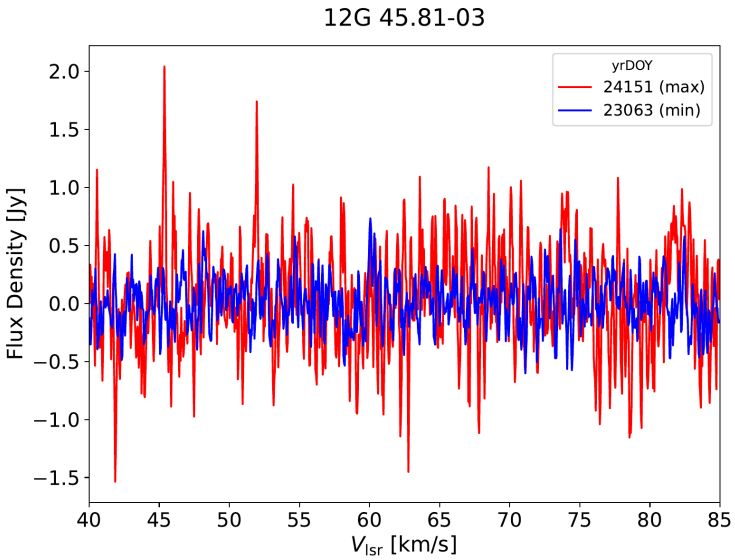
Light curve



Periodogram

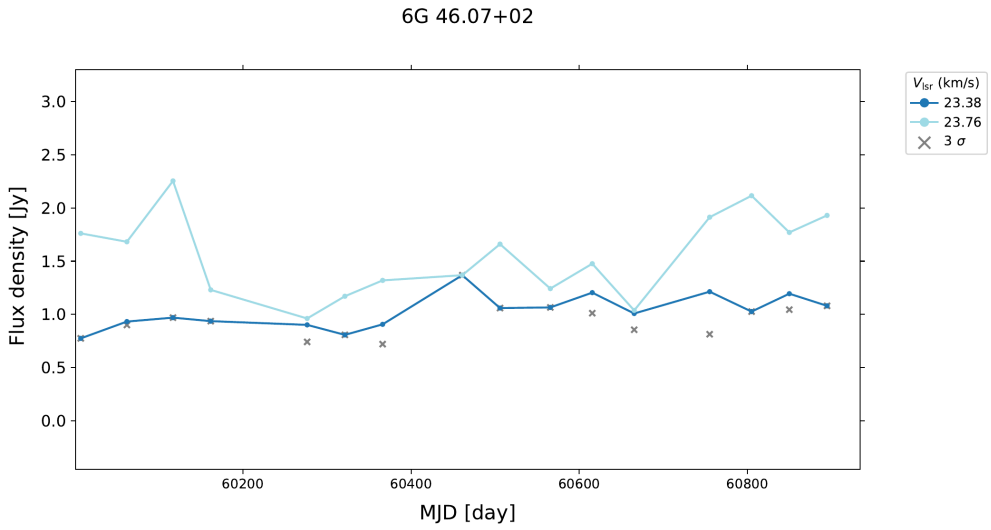


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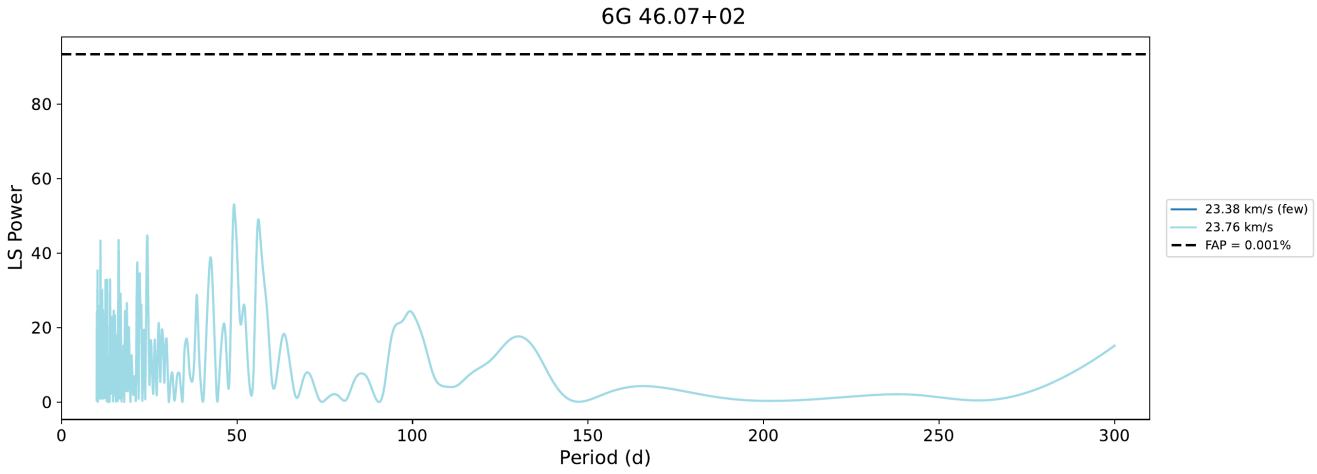


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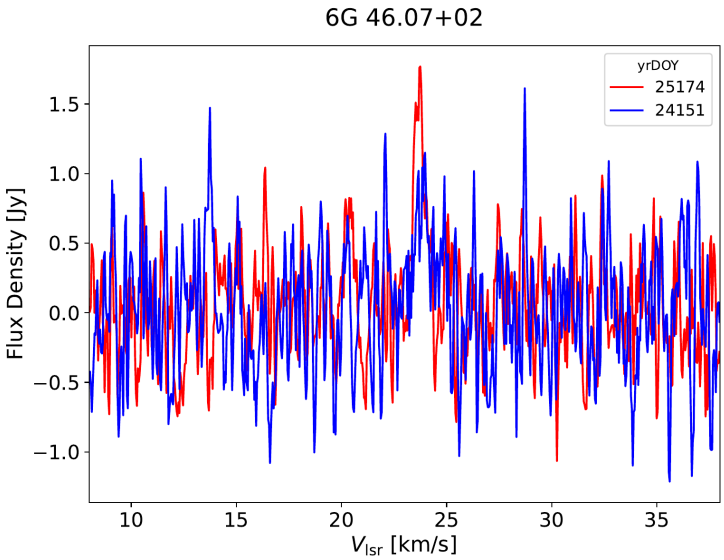
Light curve



Periodogram

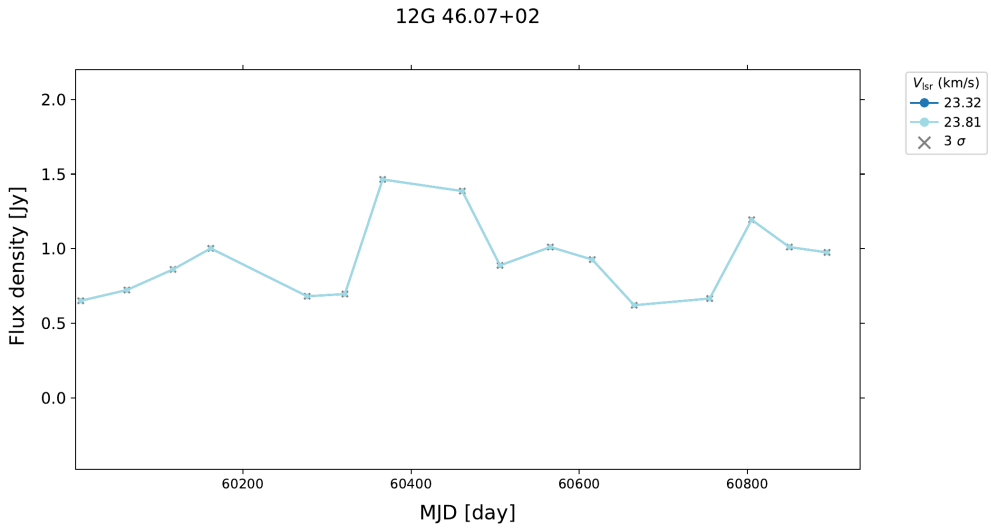


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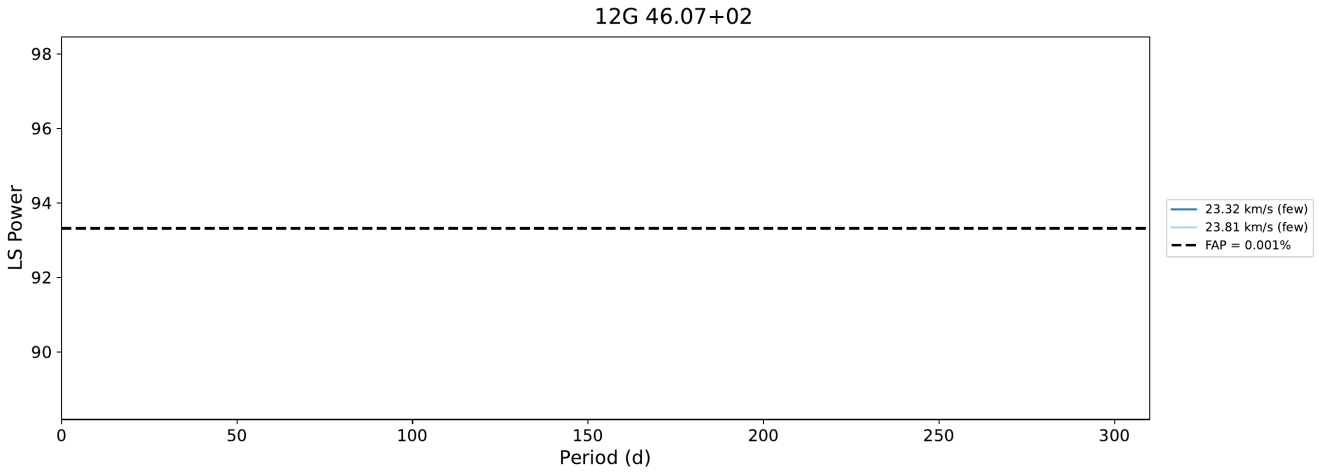


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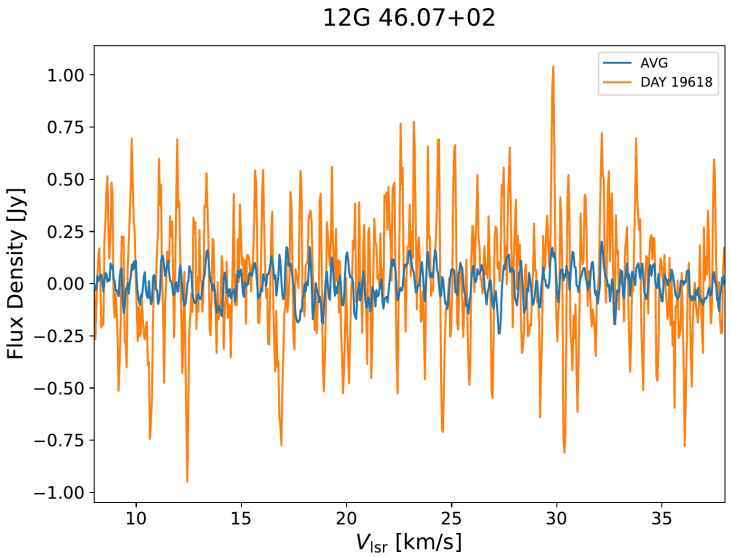
Light curve



Periodogram

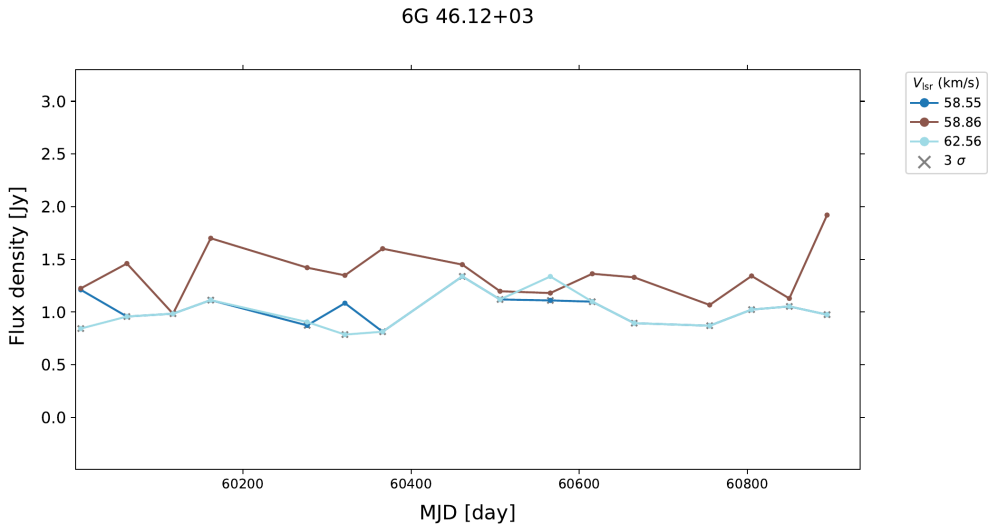


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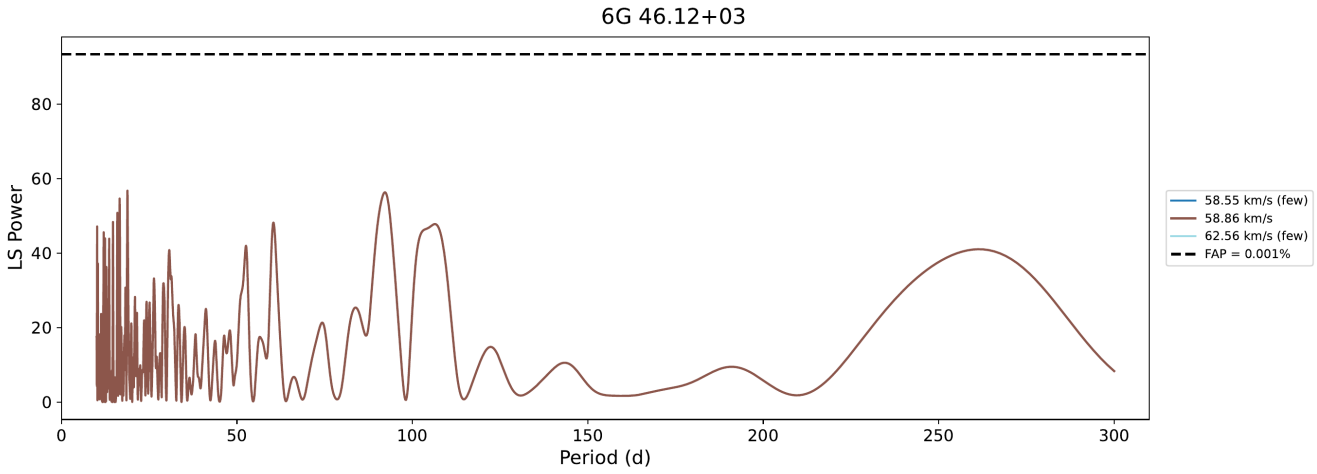


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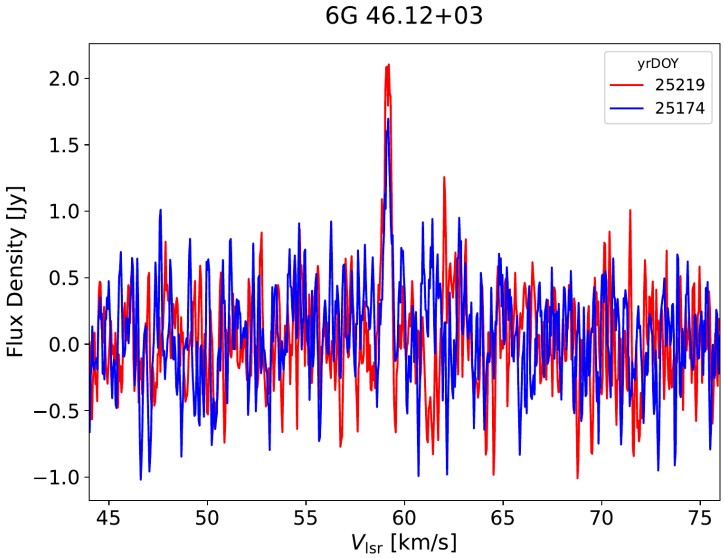
Light curve



Periodogram

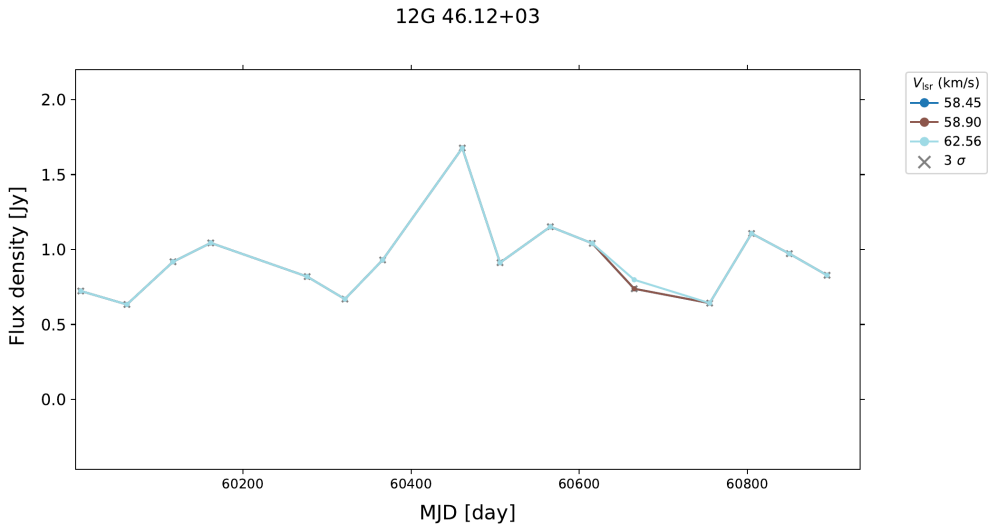


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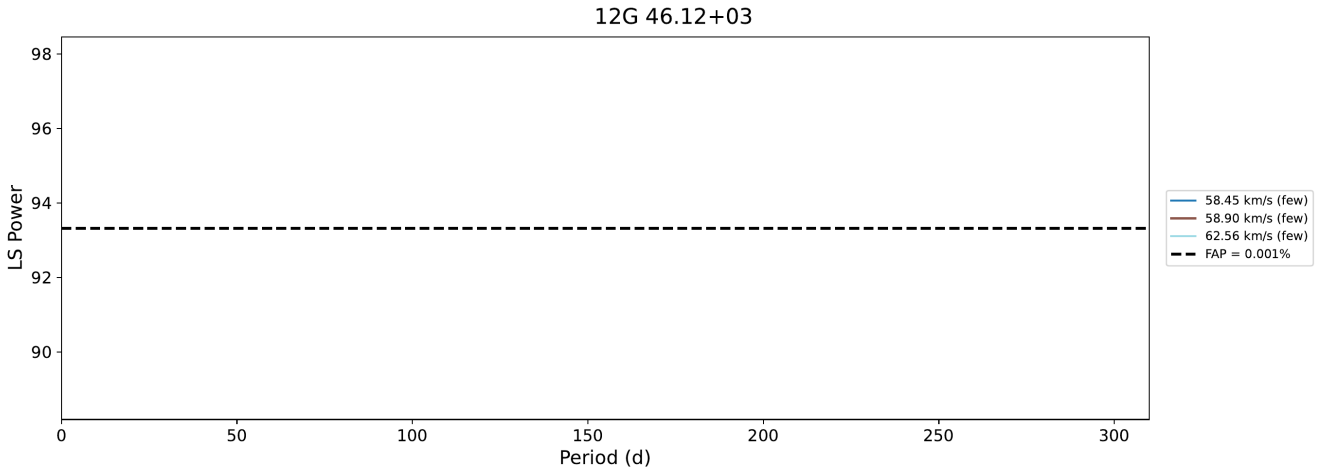


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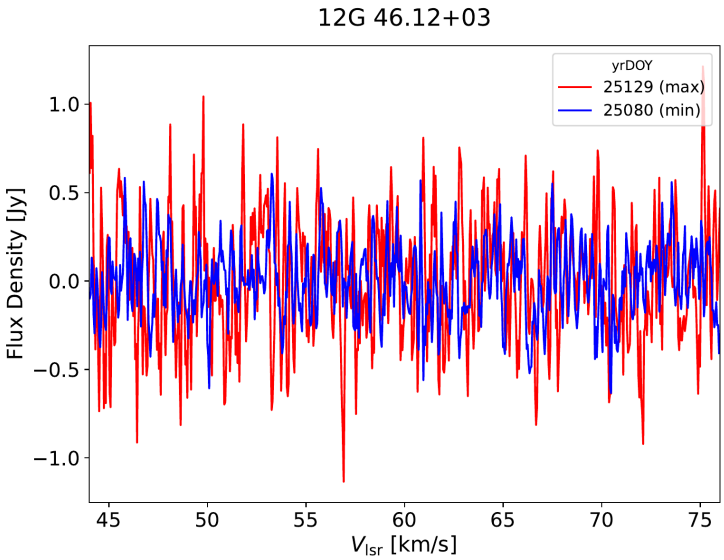
Light curve



Periodogram

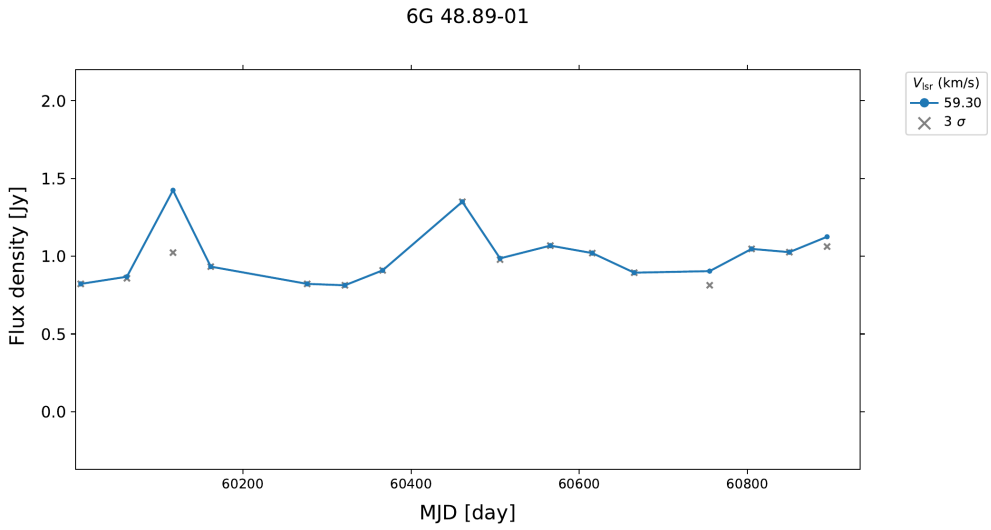


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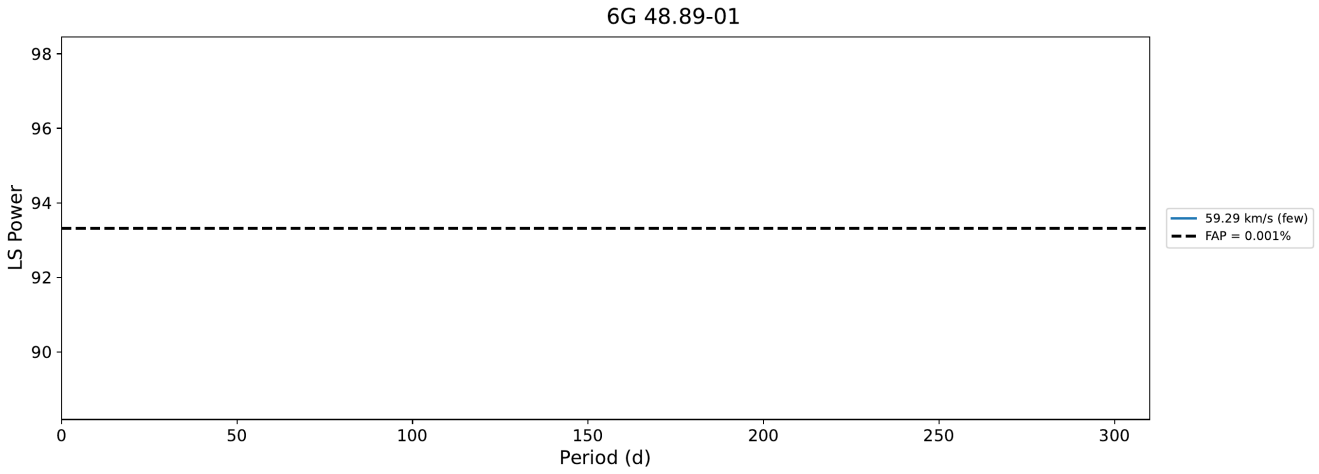


6G 48.89-01

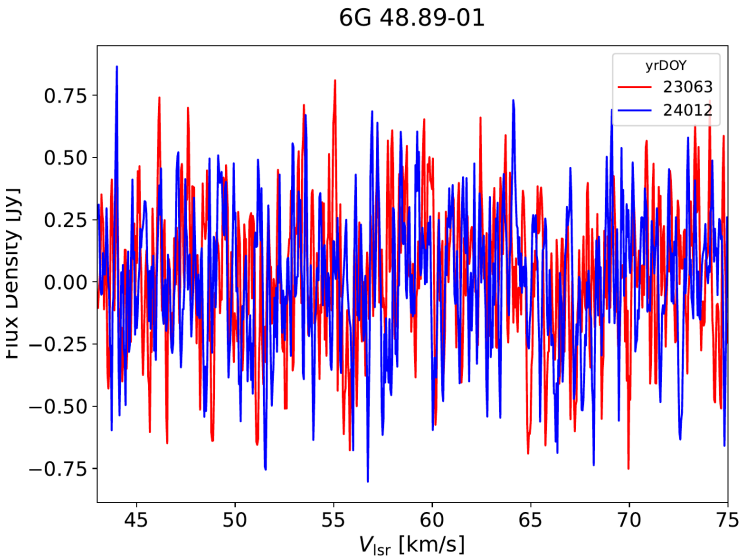
Light curve



Periodogram

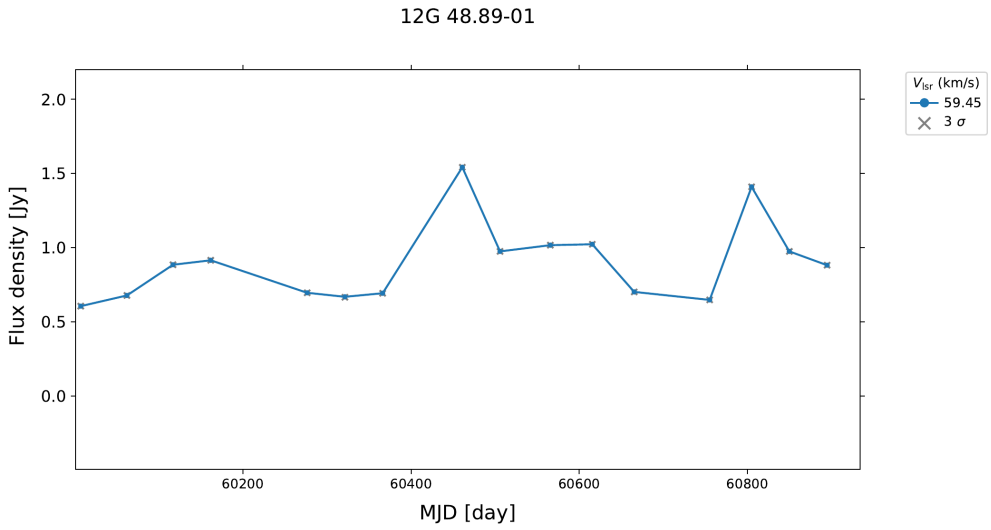


Spectrum

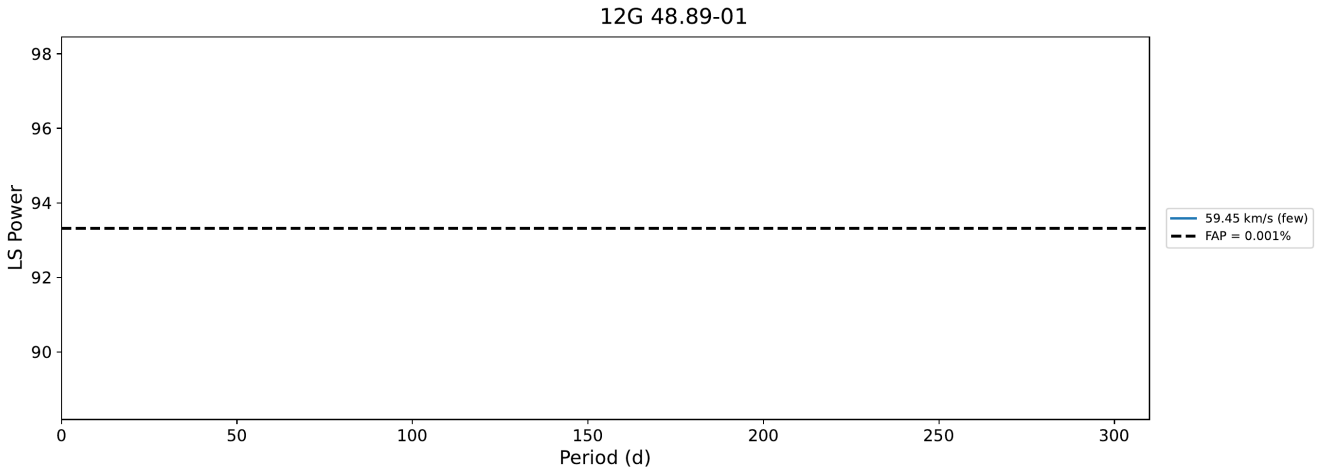


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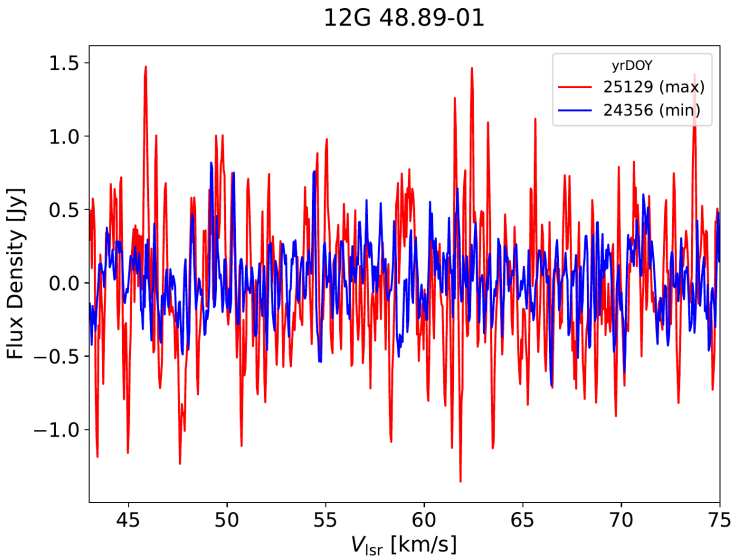
Light curve



Periodogram

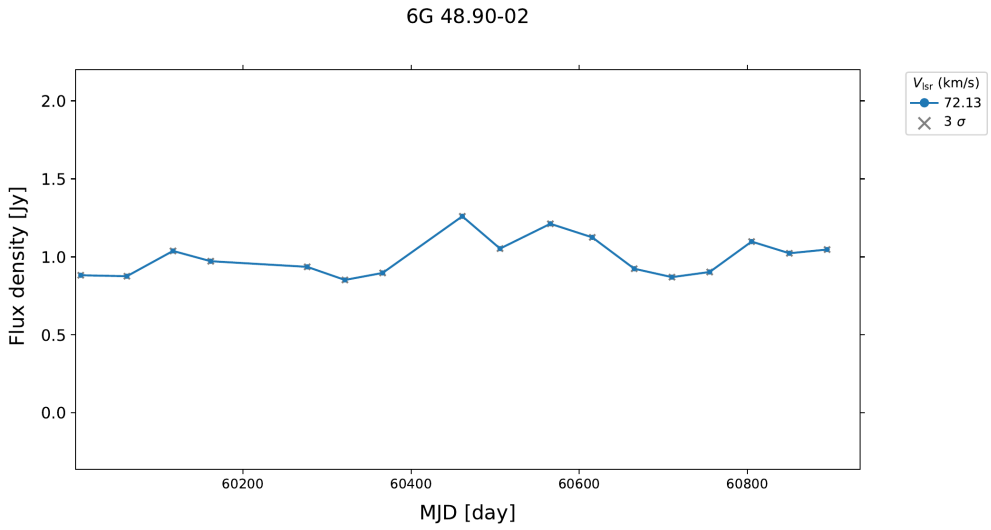


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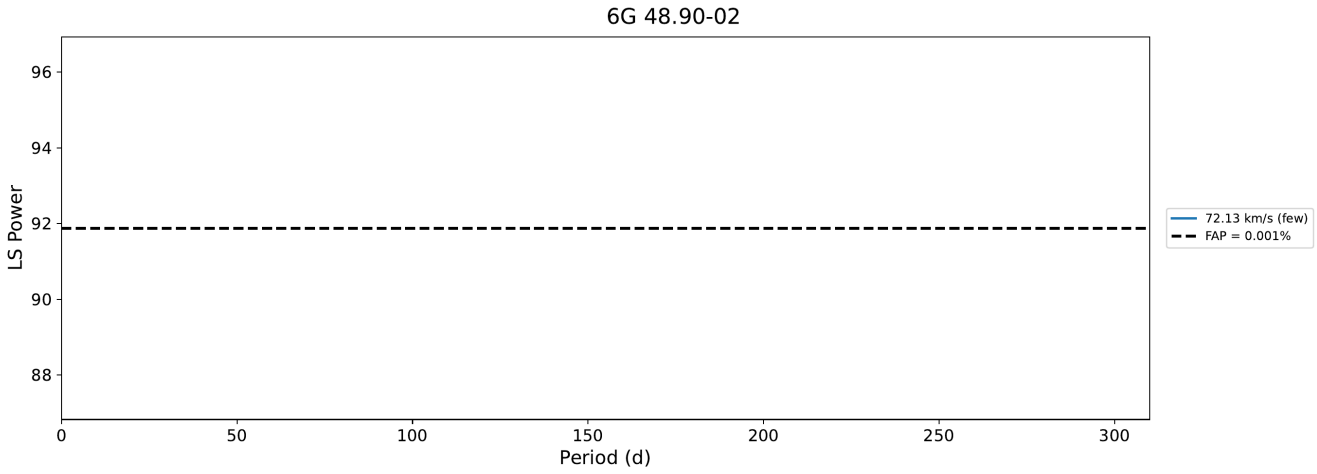


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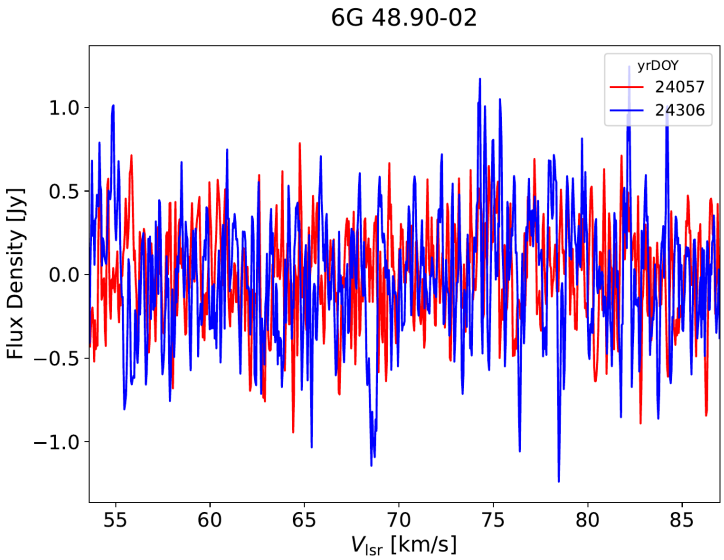
Light curve



Periodogram

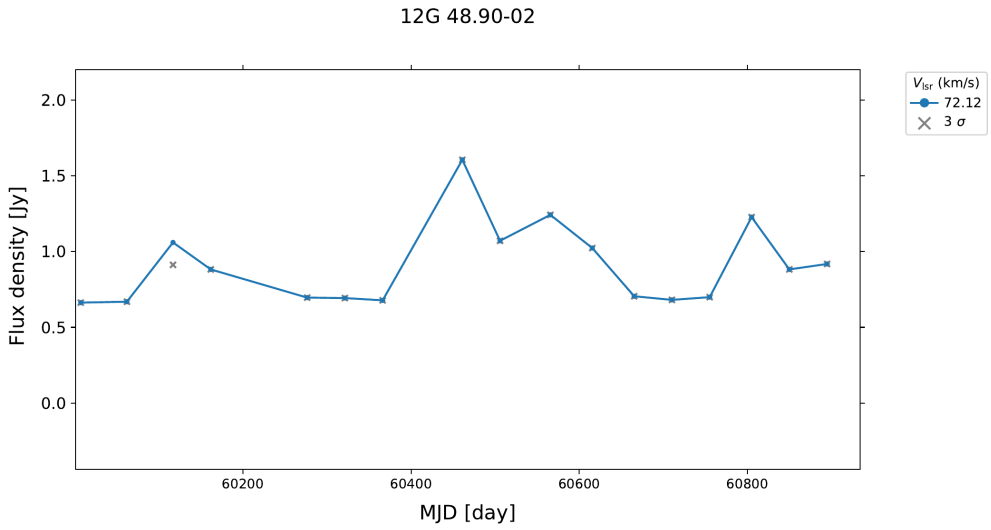


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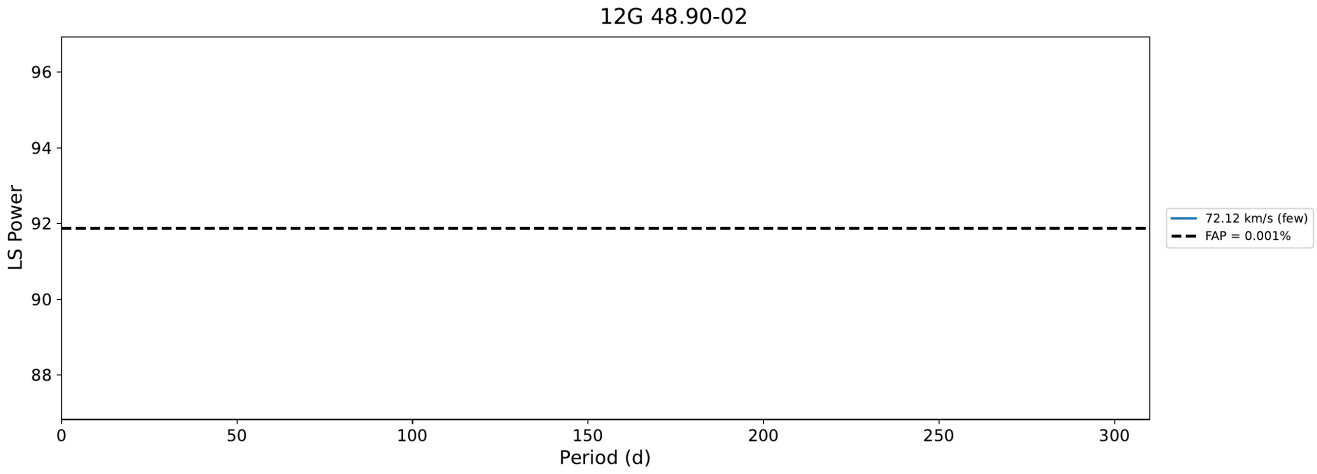


12G 48.90-02

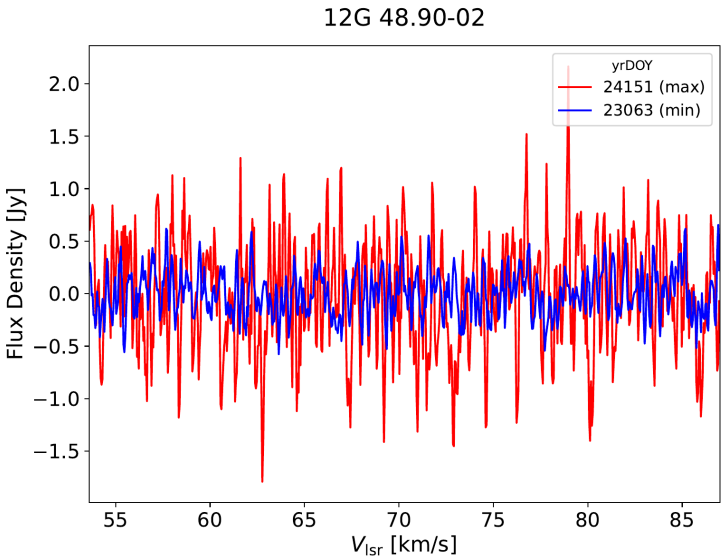
Light curve



Periodogram

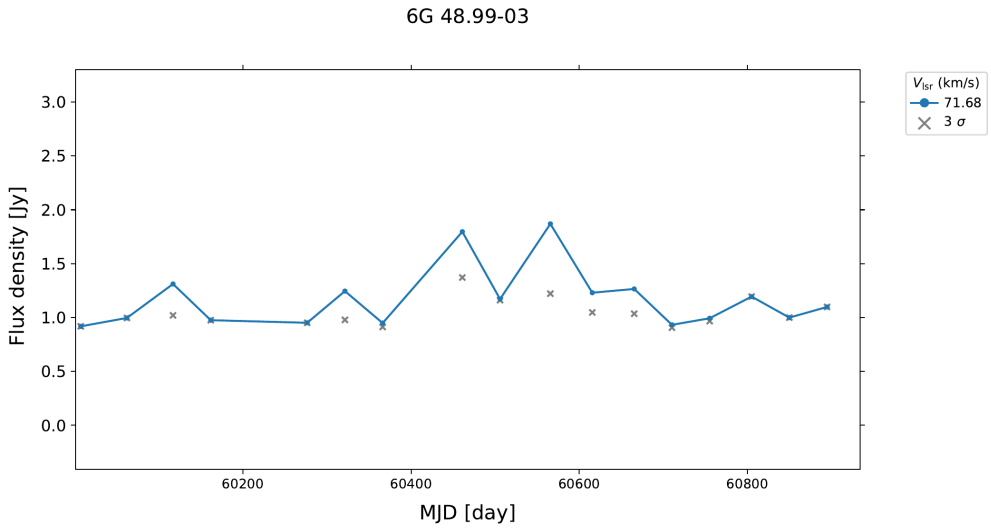


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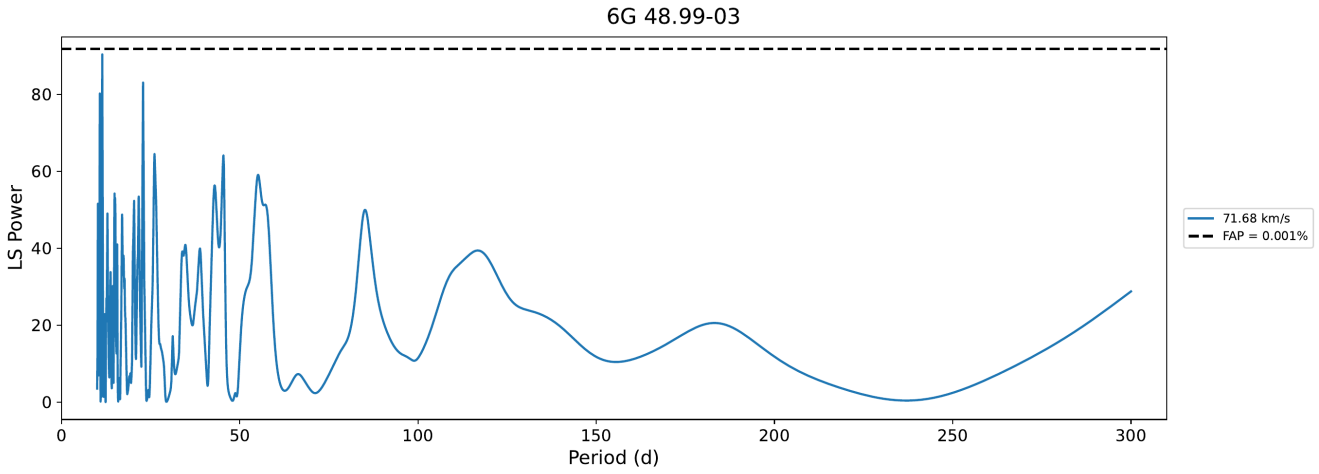


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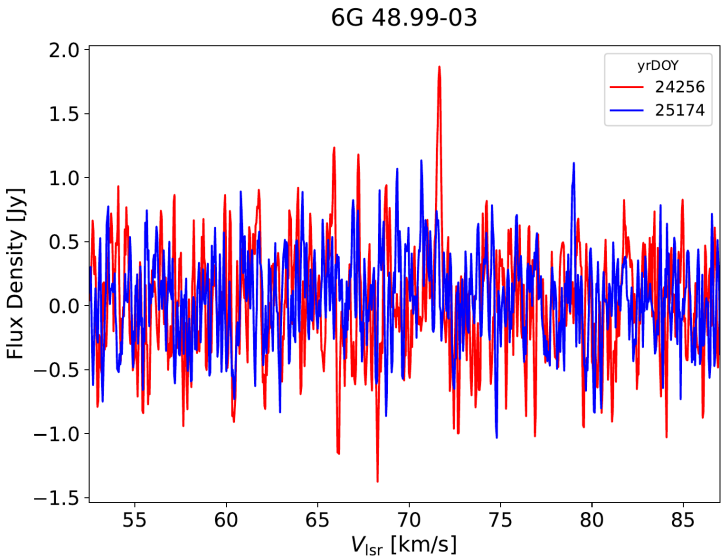
Light curve



Periodogram

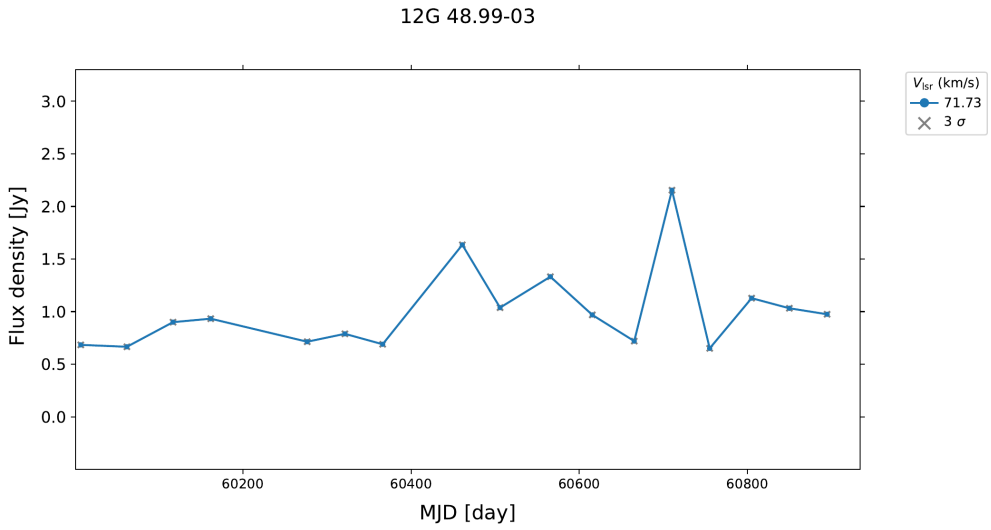


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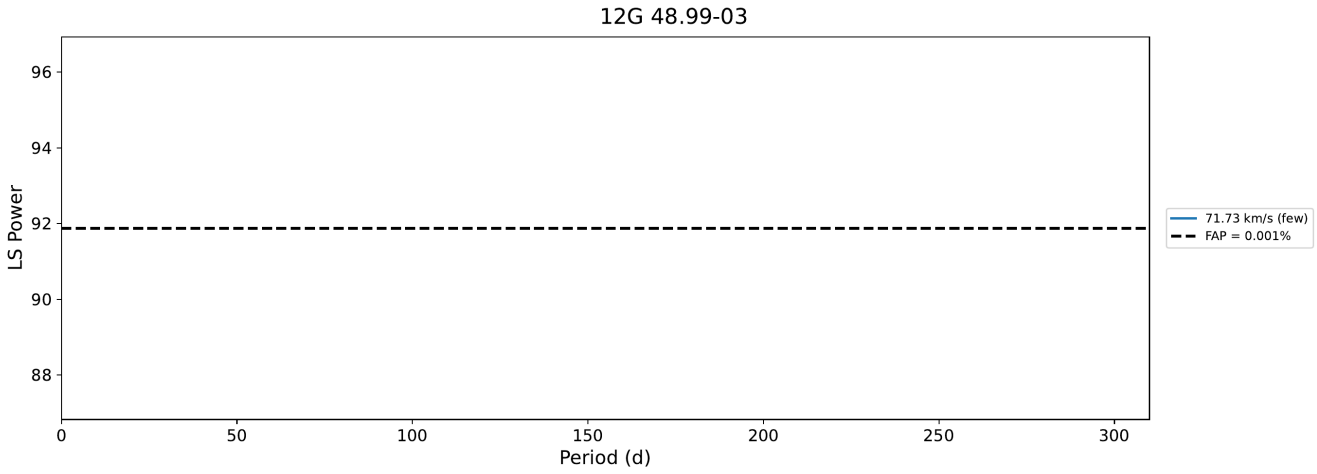


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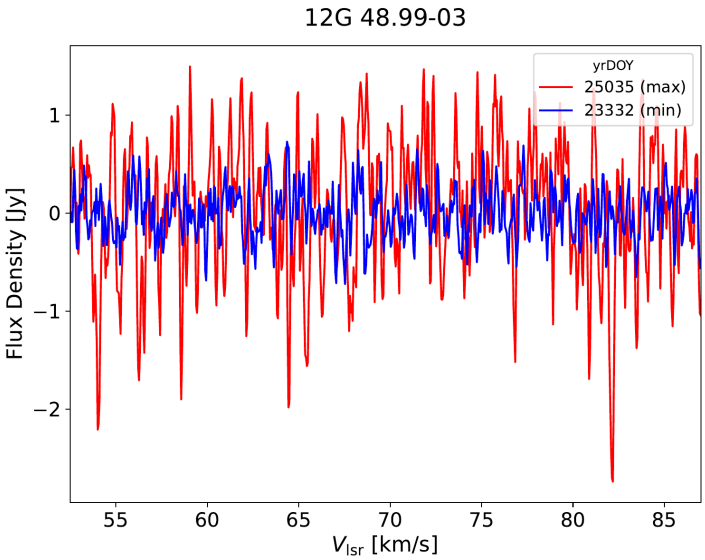
Light curve



Periodogram

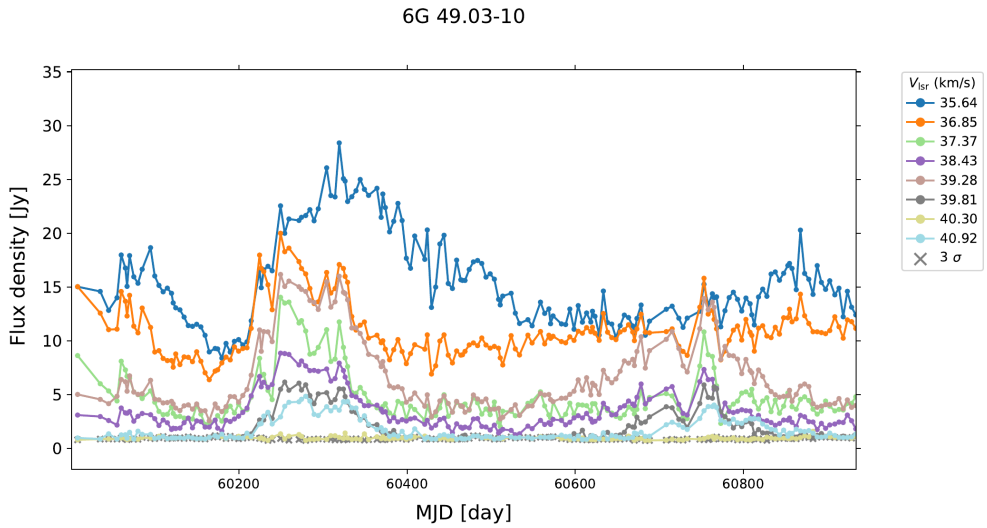


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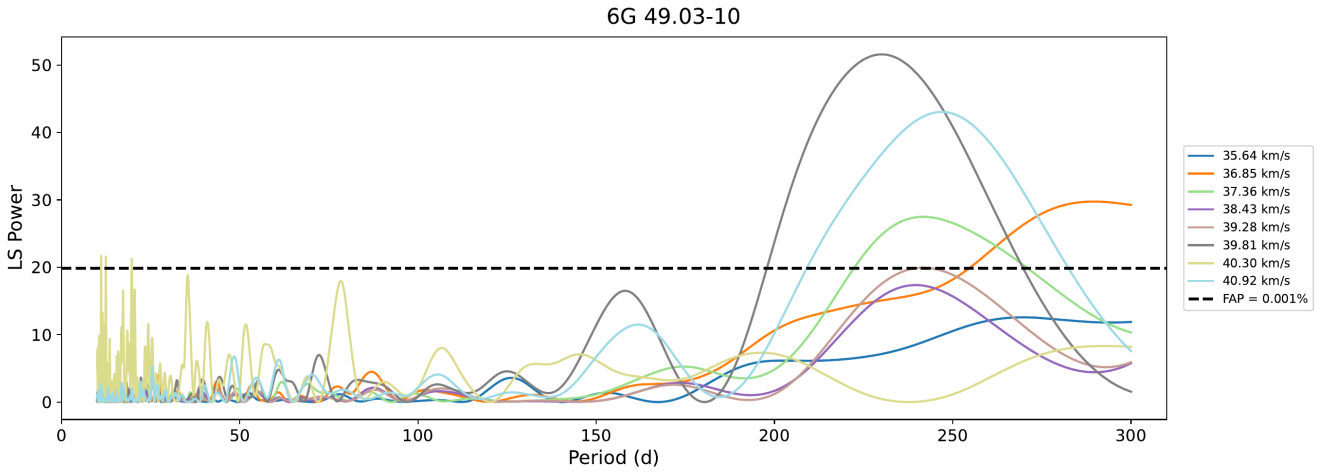


6G 49.03-10

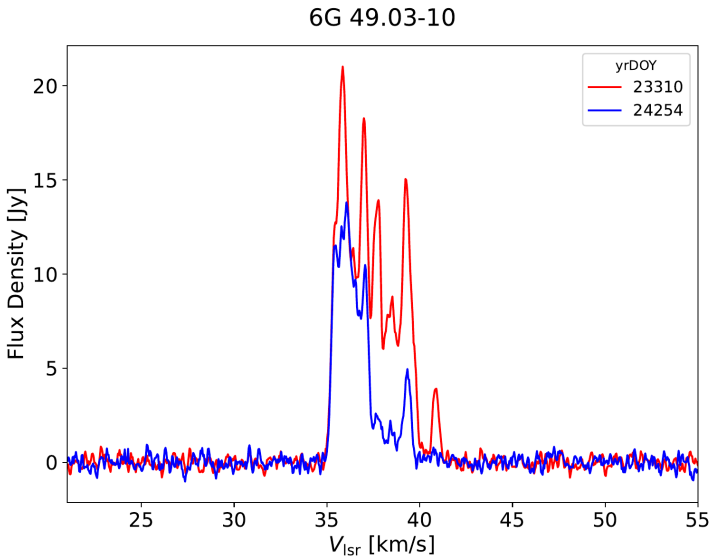
Light curve



Periodogram

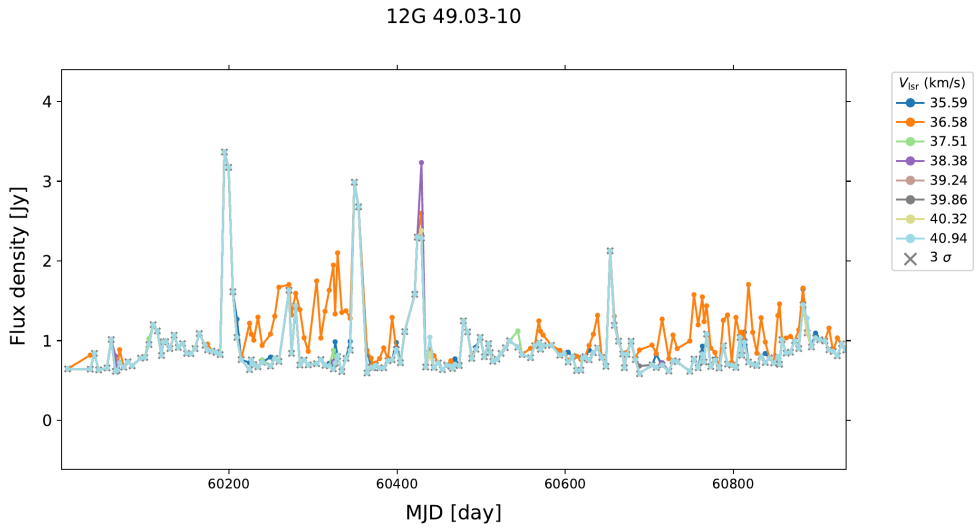


Spectrum

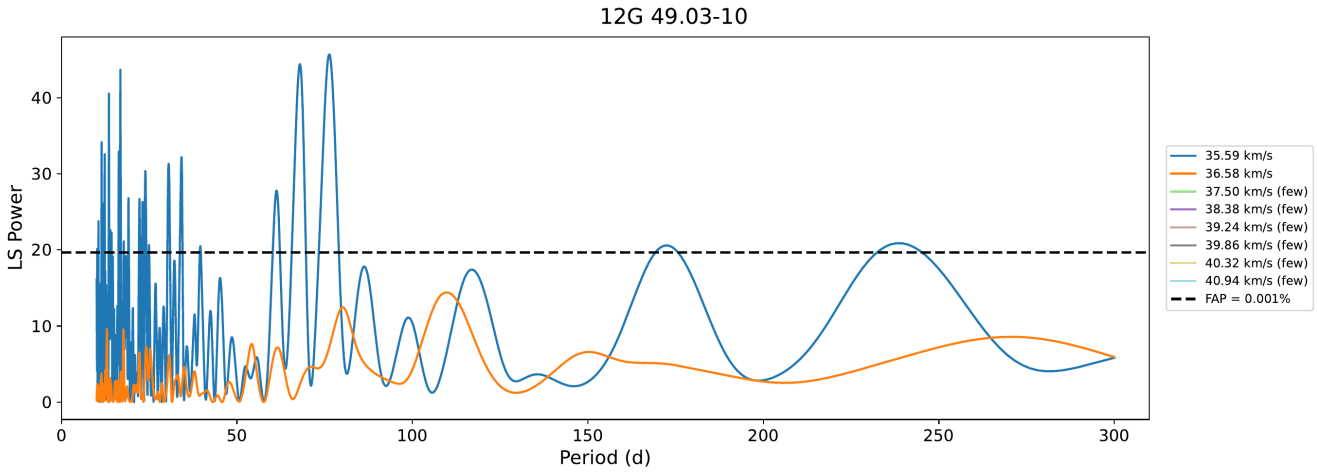


12G 49.03-10

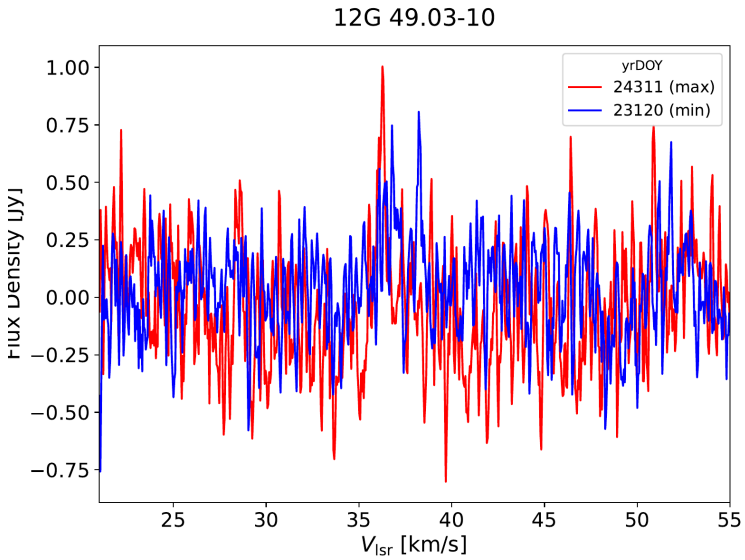
Light curve



Periodogram

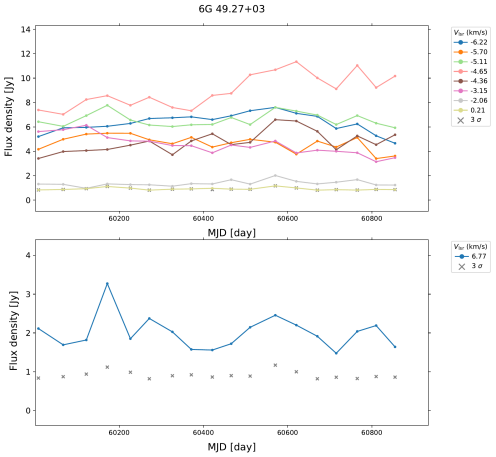


Spectrum

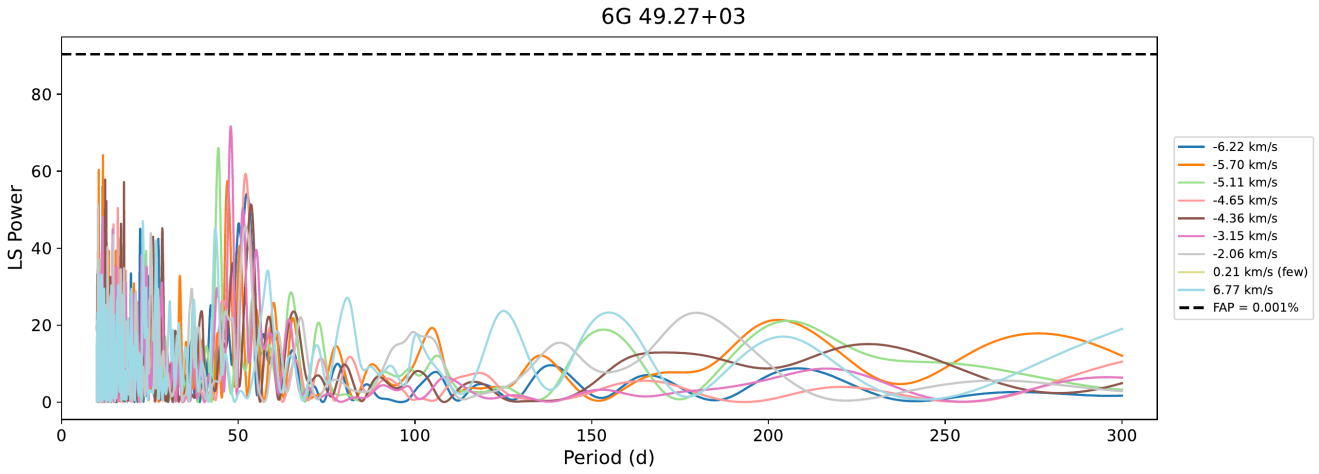


6G 49.27+03

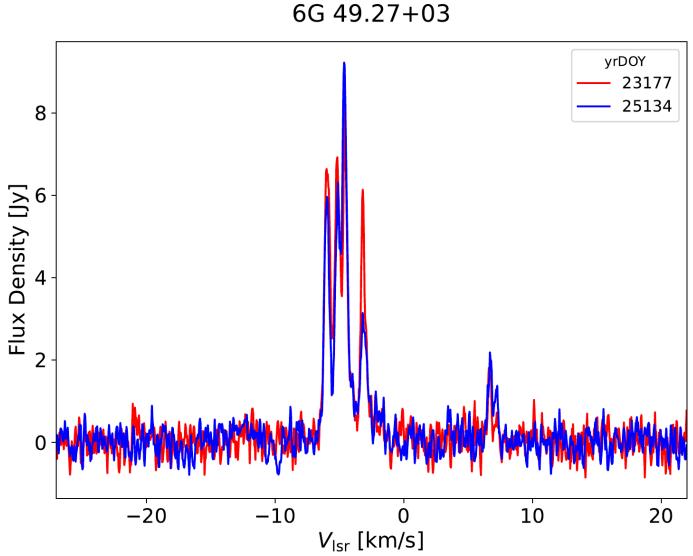
Light curve



Periodogram

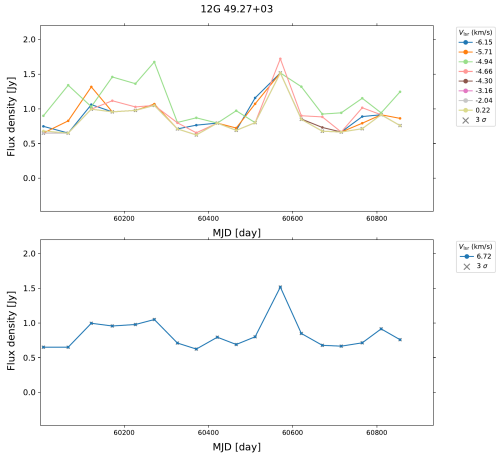


Spectrum

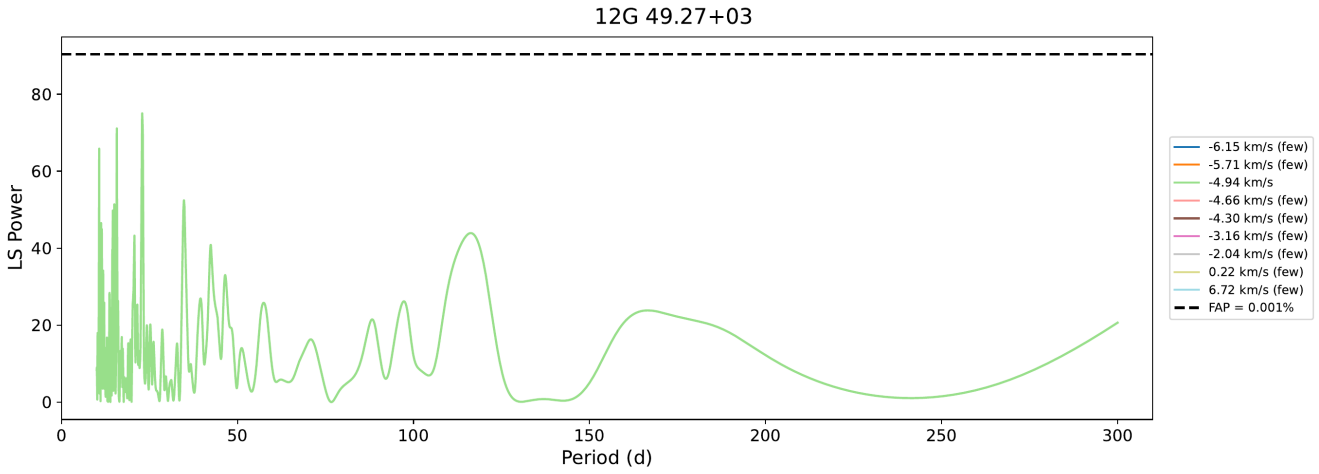


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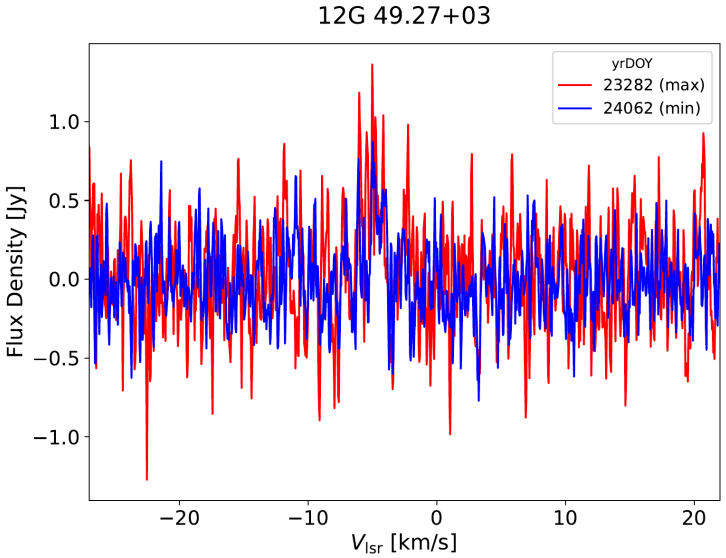
Light curve



Periodogram

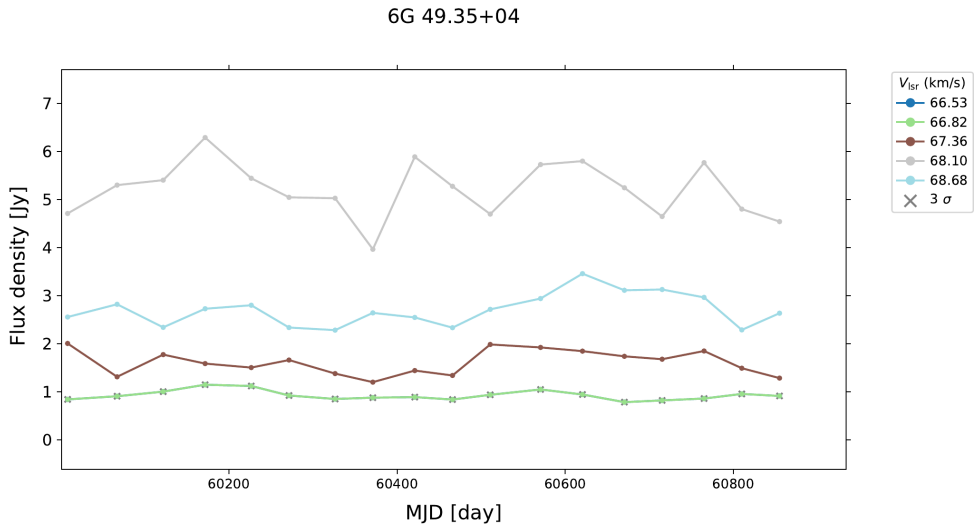


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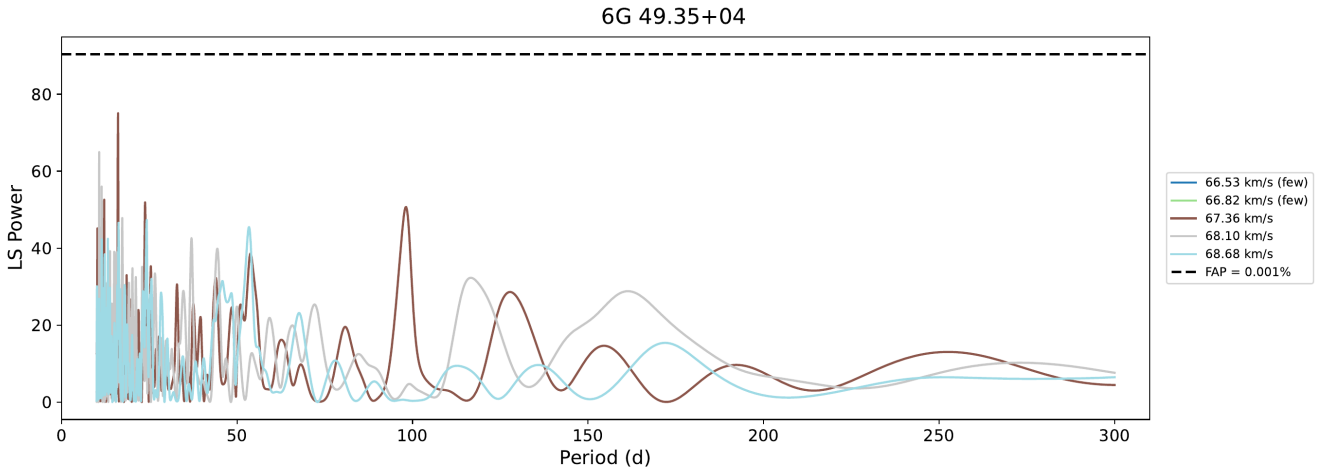


6G 49.35+04

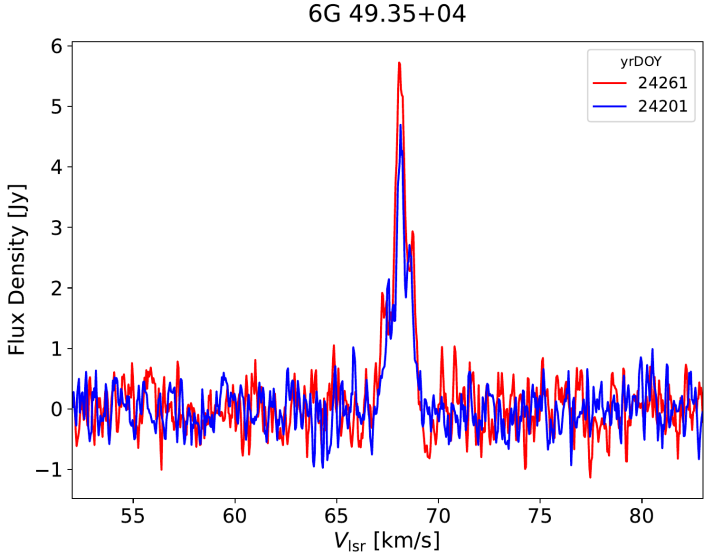
Light curve



Periodogram

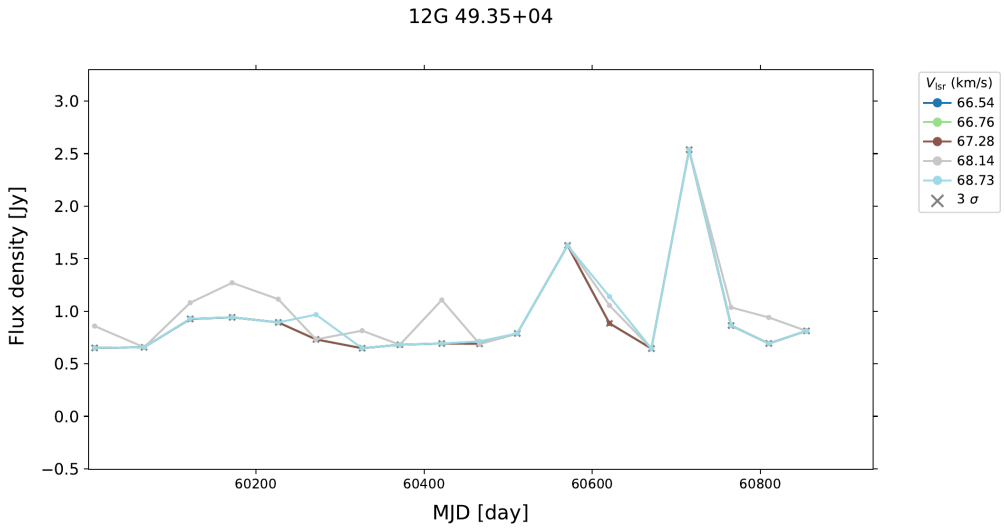


Spectrum

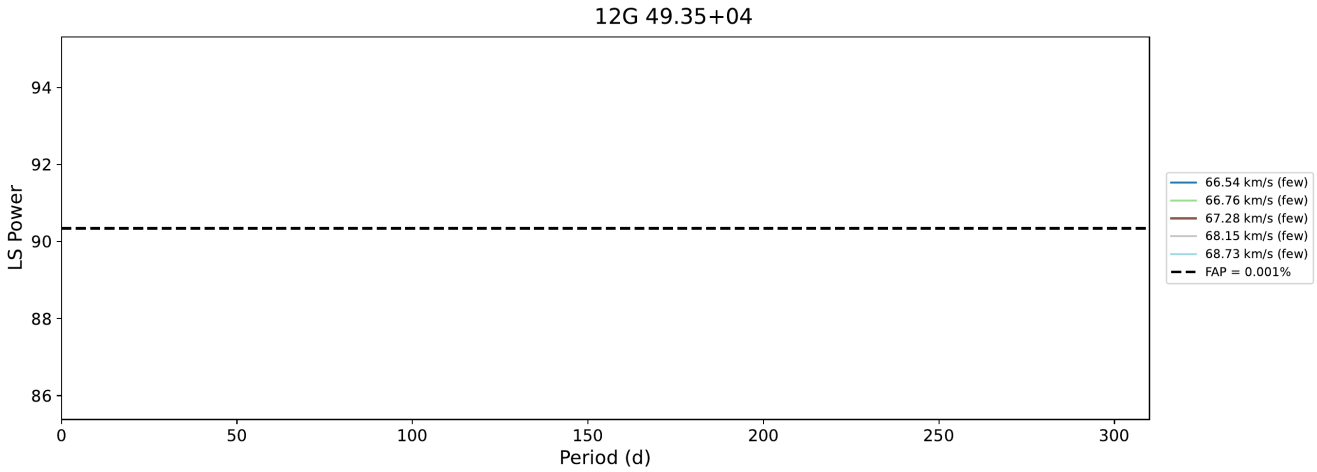


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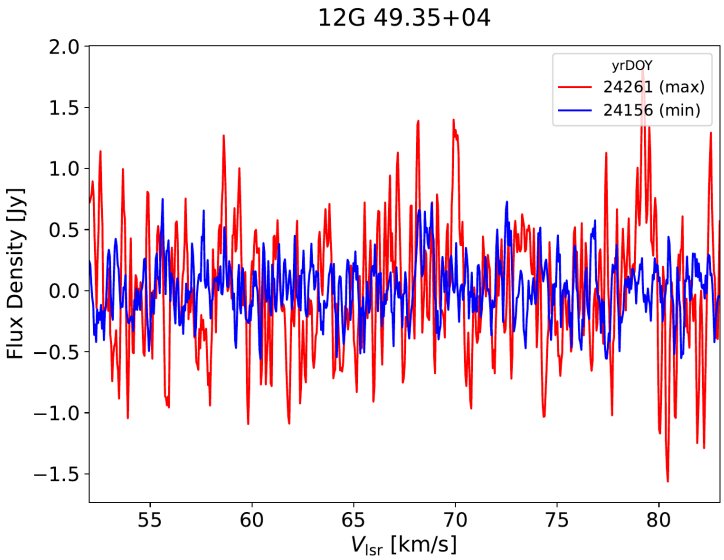
Light curve



Periodogram

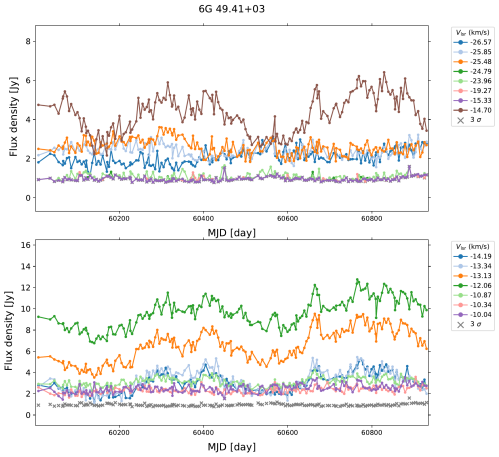


Spectrum

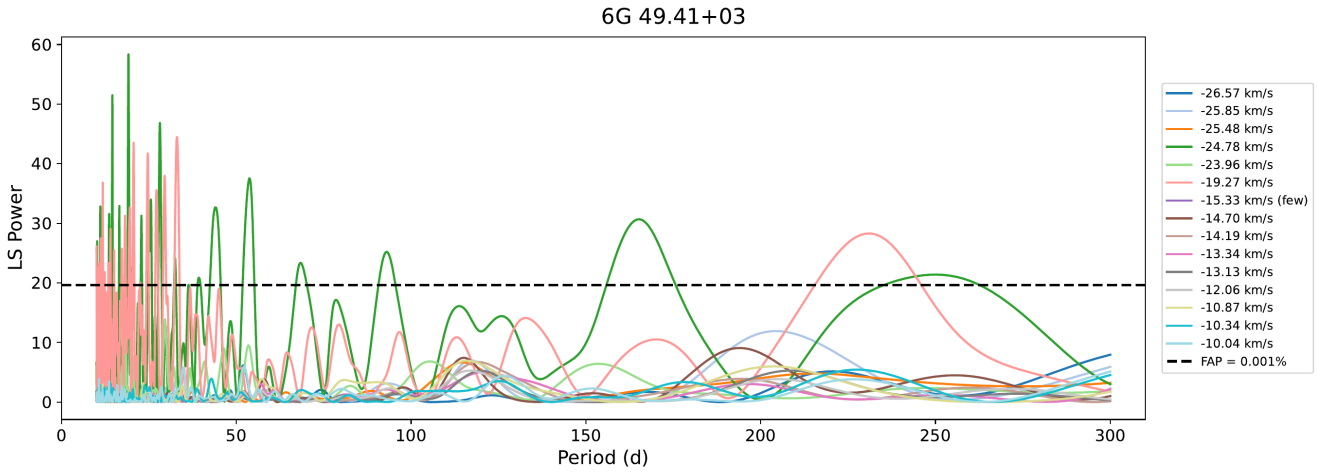


6G 49.41+03

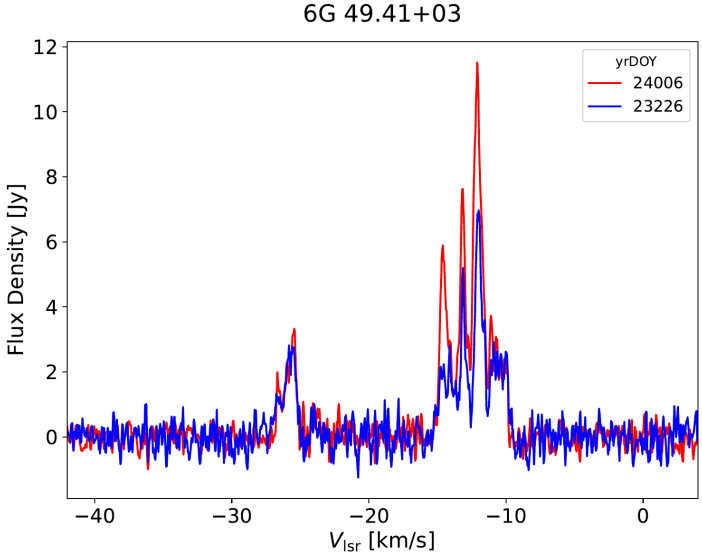
Light curve



Periodogram

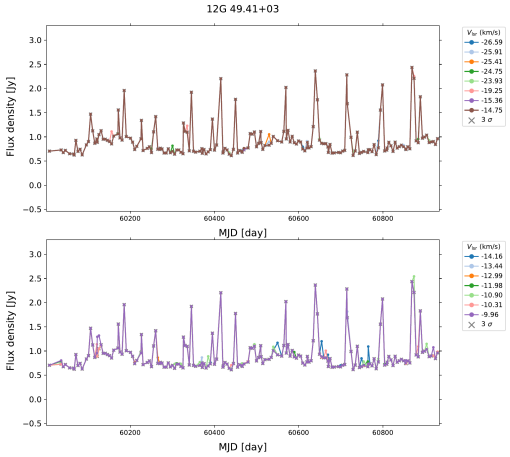


Spectrum

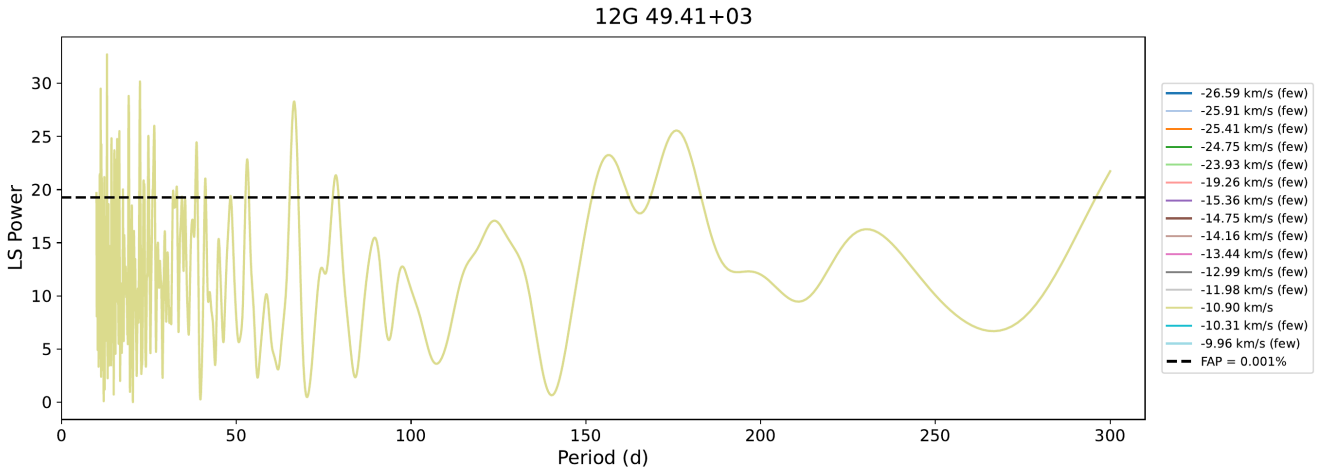


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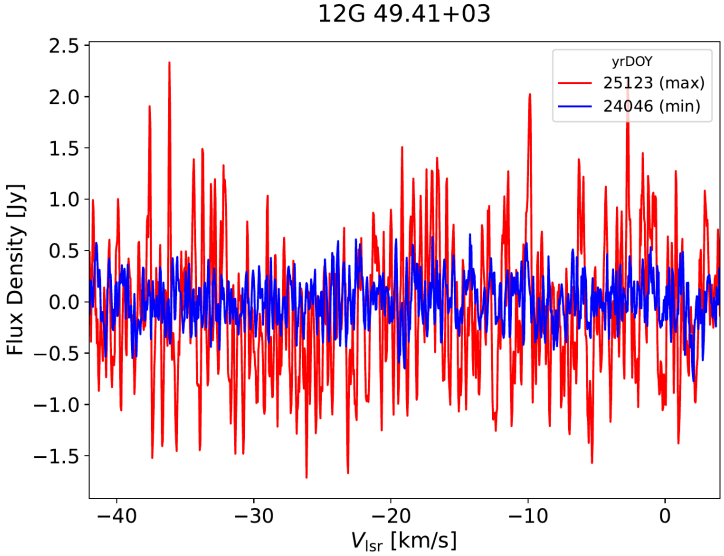
Light curve



Periodogram

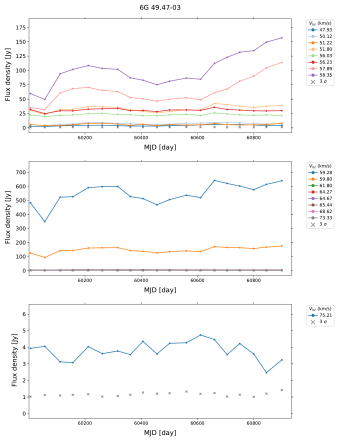


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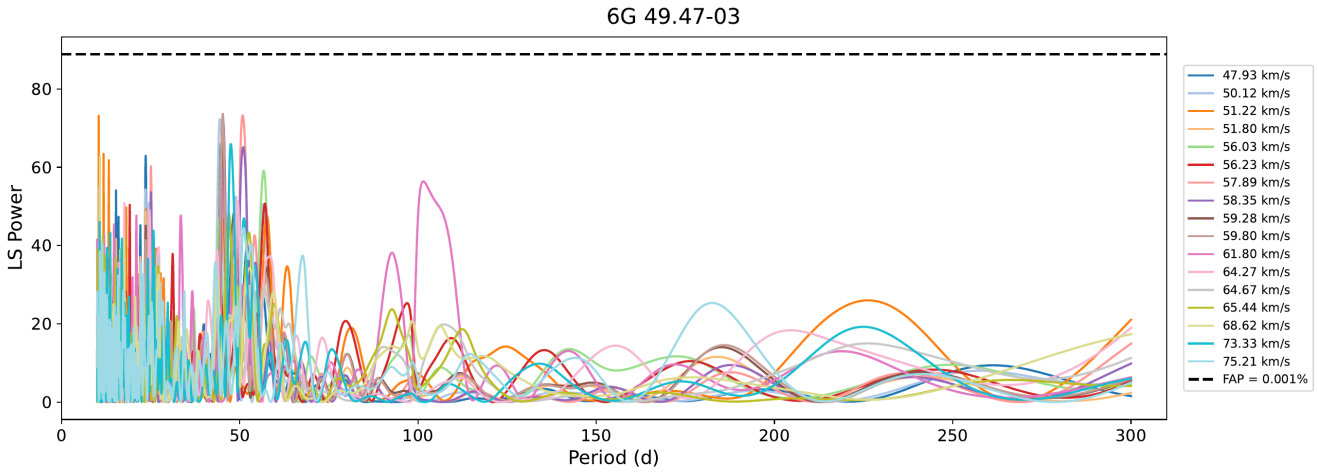


6G 49.47-03

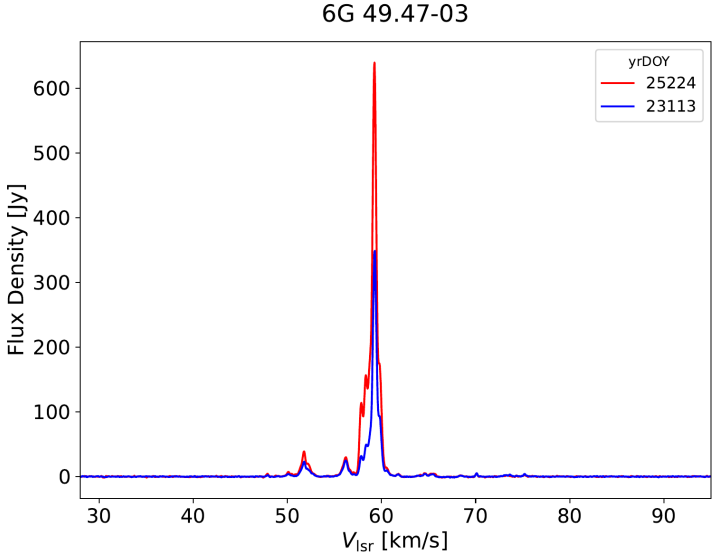
Light curve



Periodogram

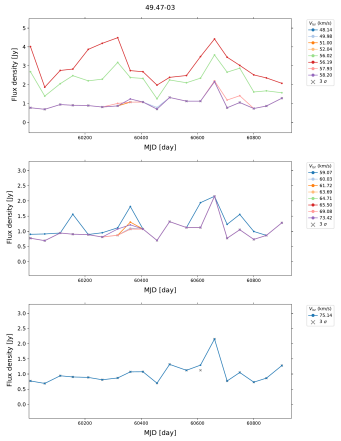


Spectrum

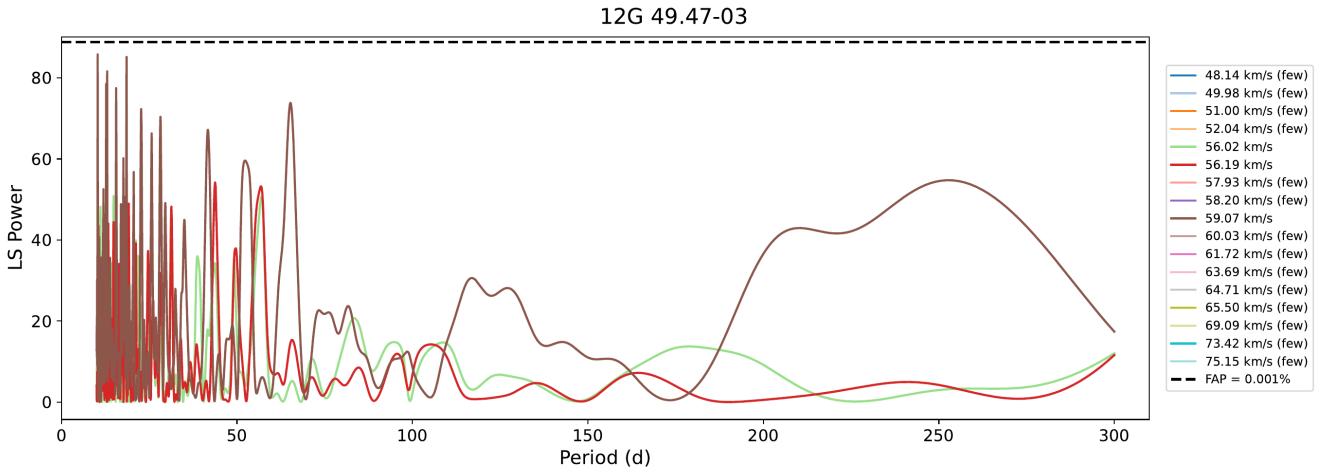


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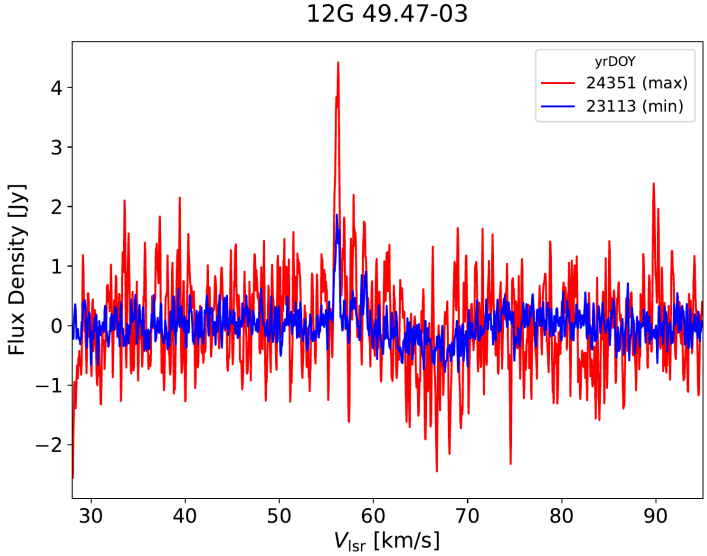
Light curve



Periodogram

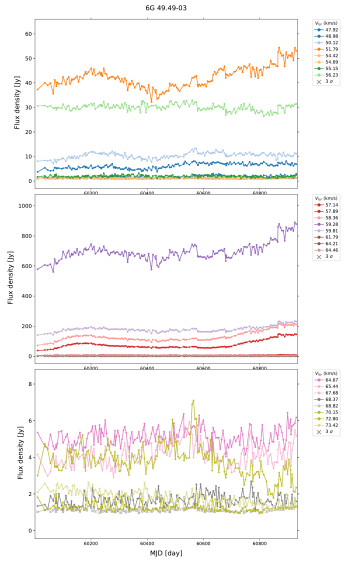


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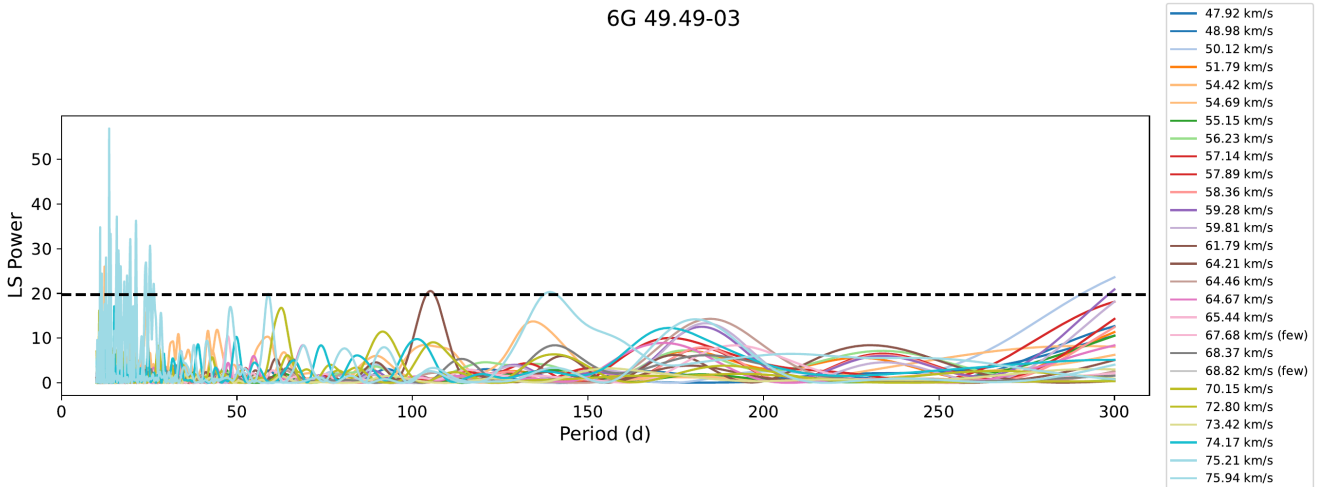


6G 49.49-03

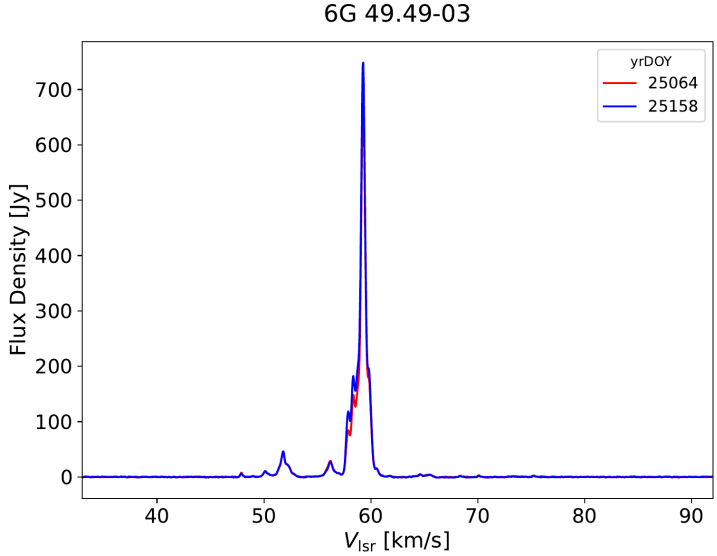
Light curve



Periodogram

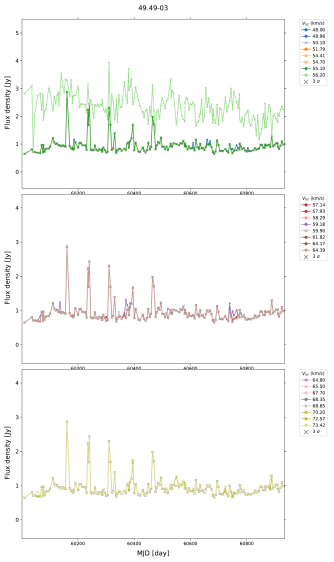


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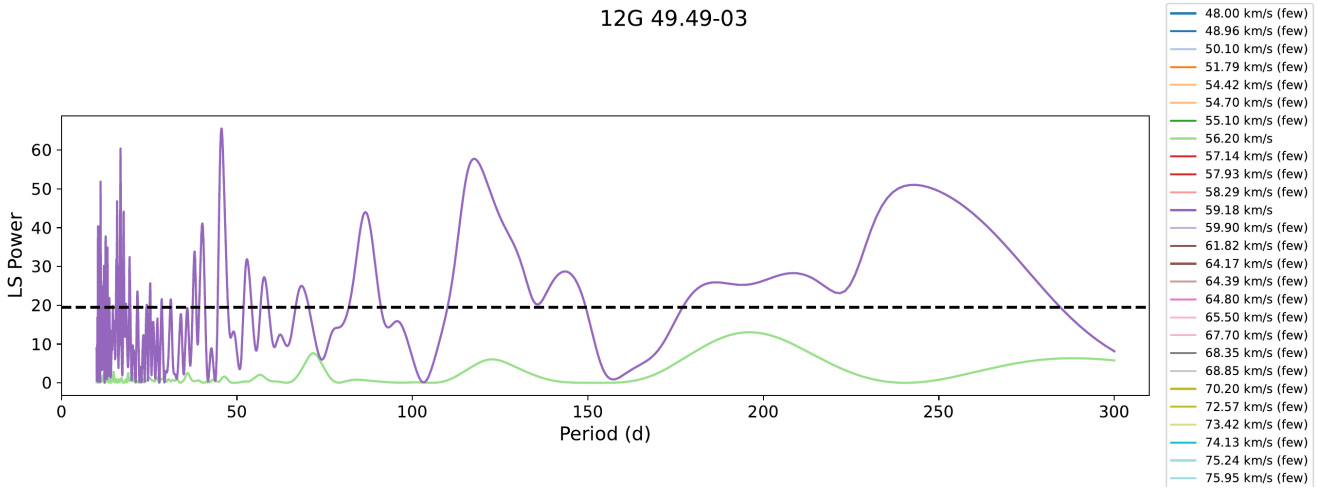


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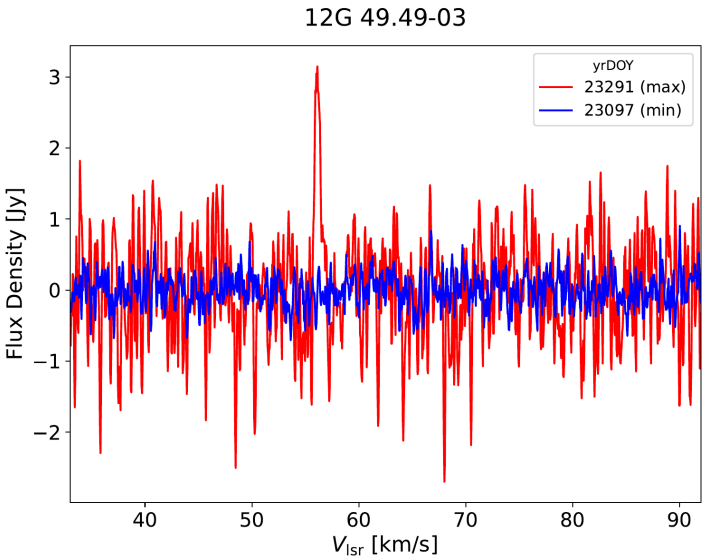
Light curve



Periodogram

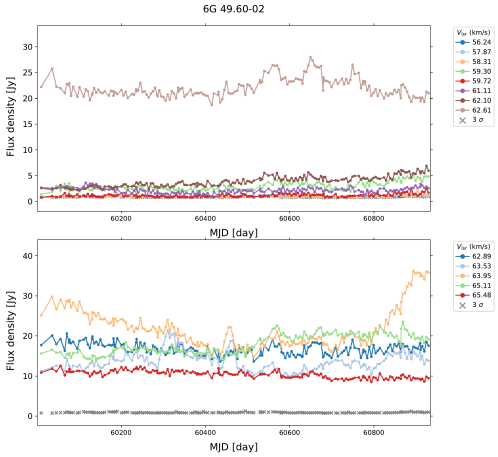


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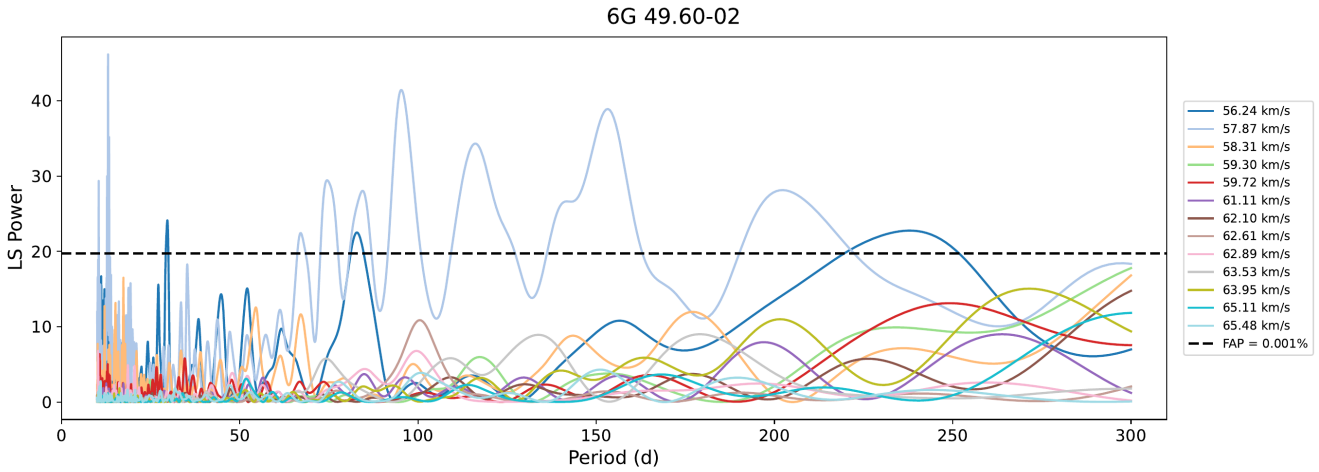


6G 49.60-02

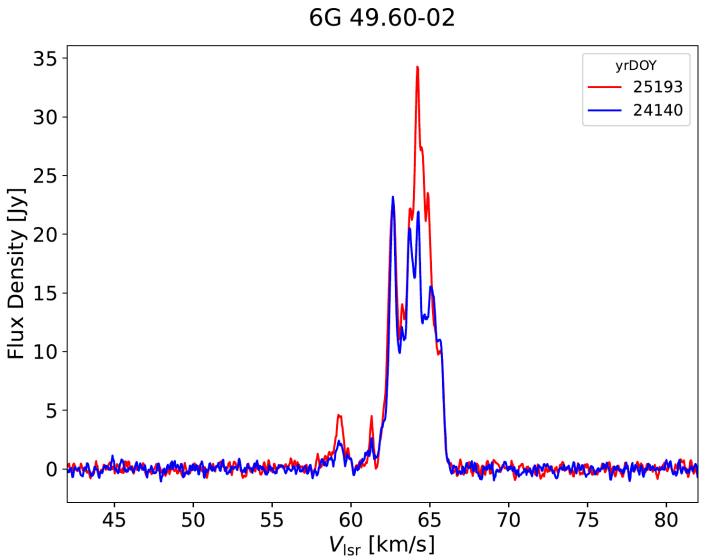
Light curve



Periodogram

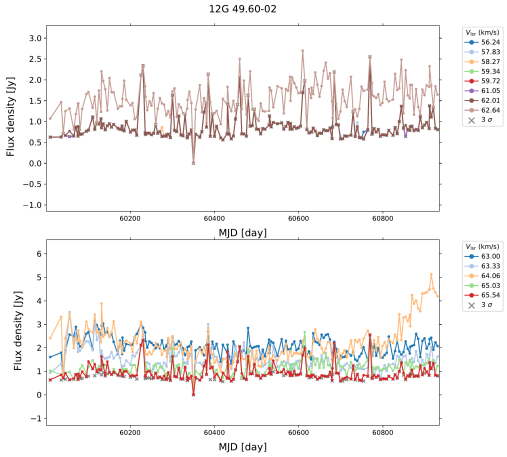


Spectrum

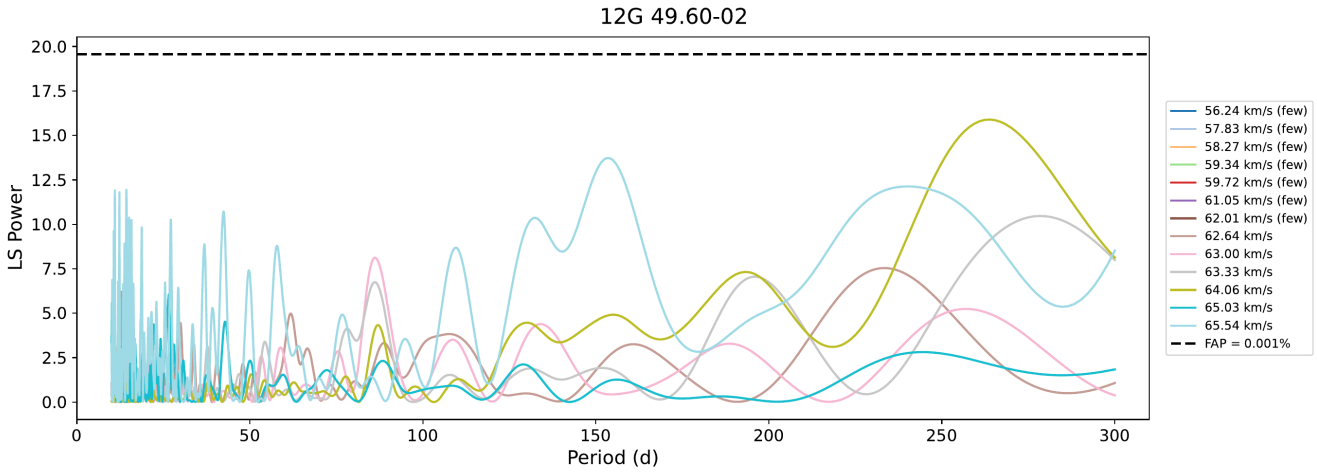


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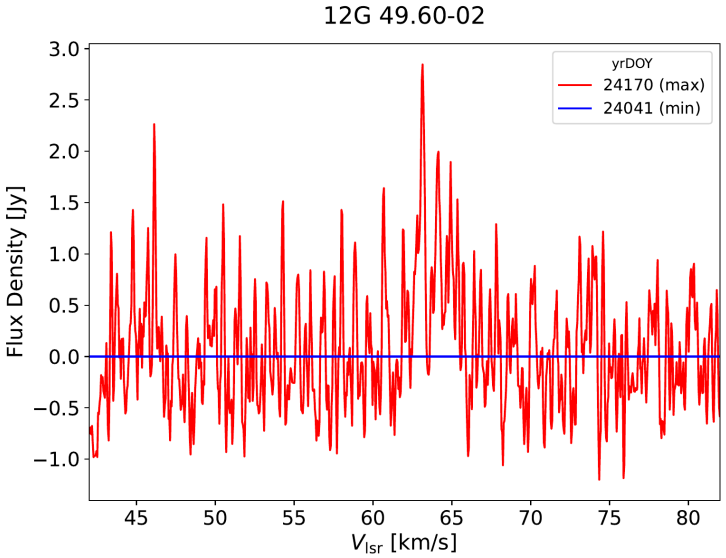
Light curve



Periodogram

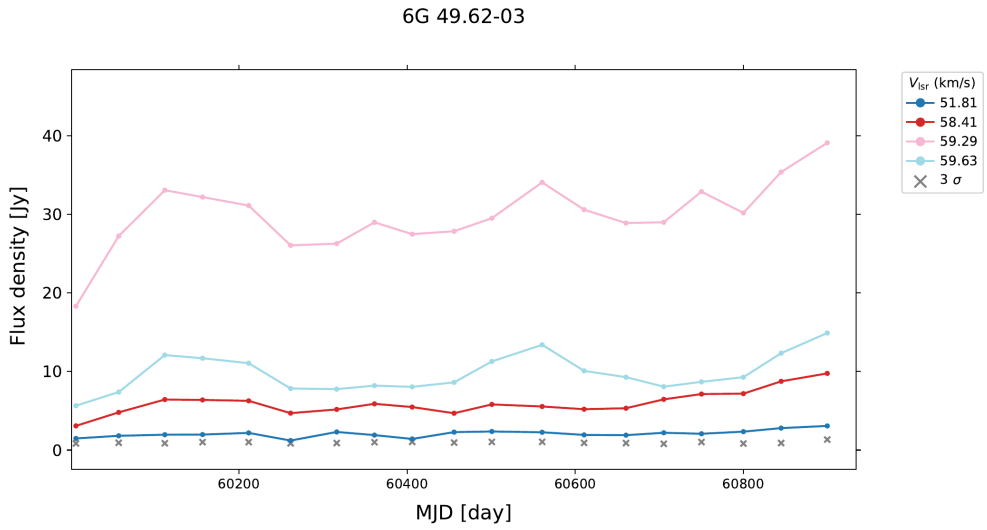


Spectrum

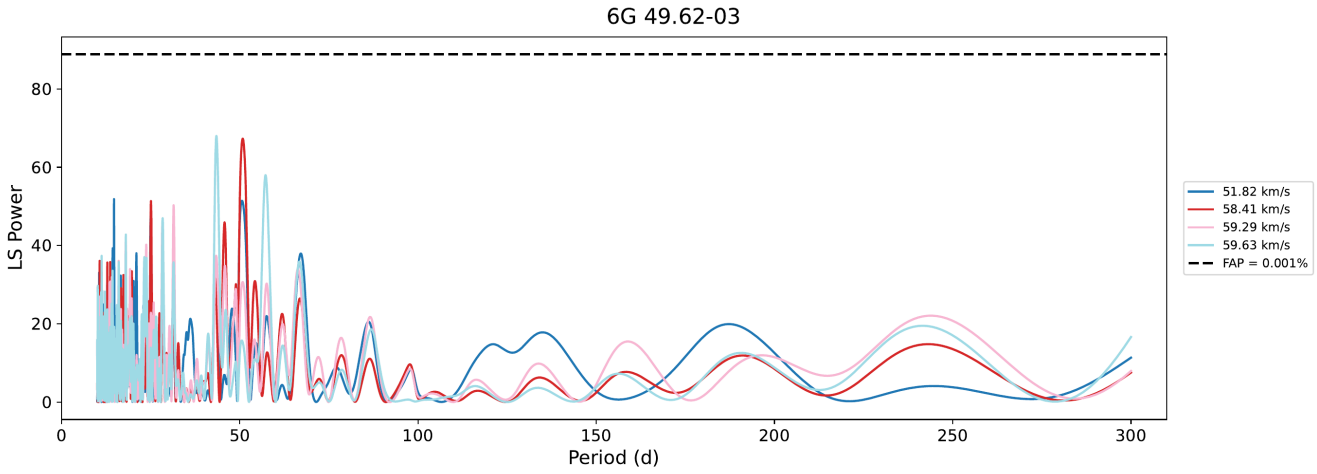


6G 49.62-03

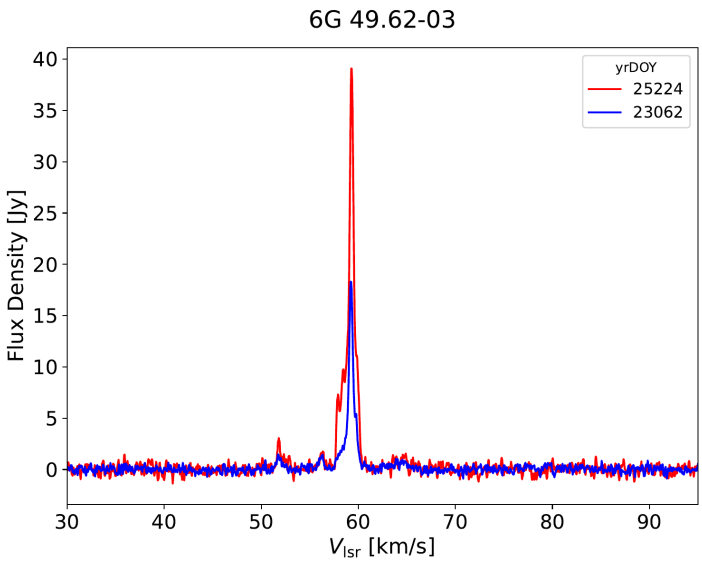
Light curve



Periodogram

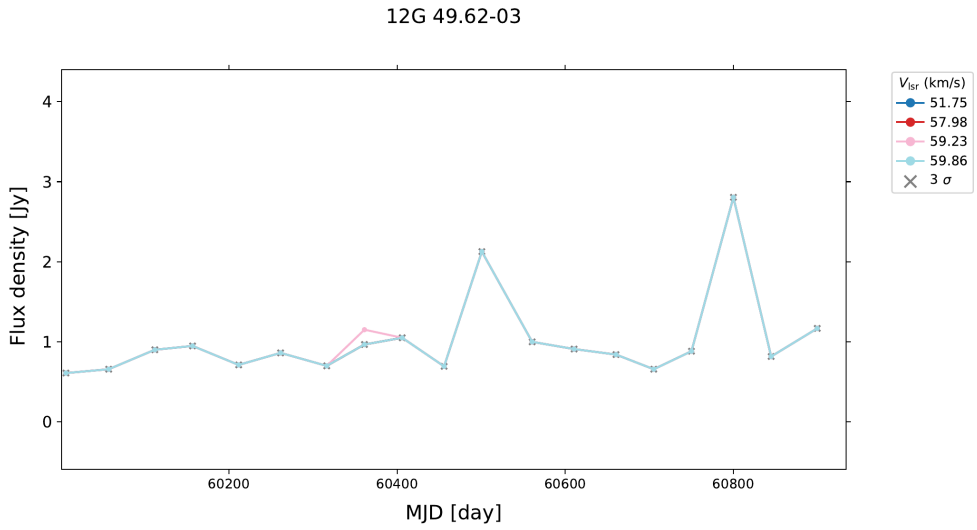


Spectrum

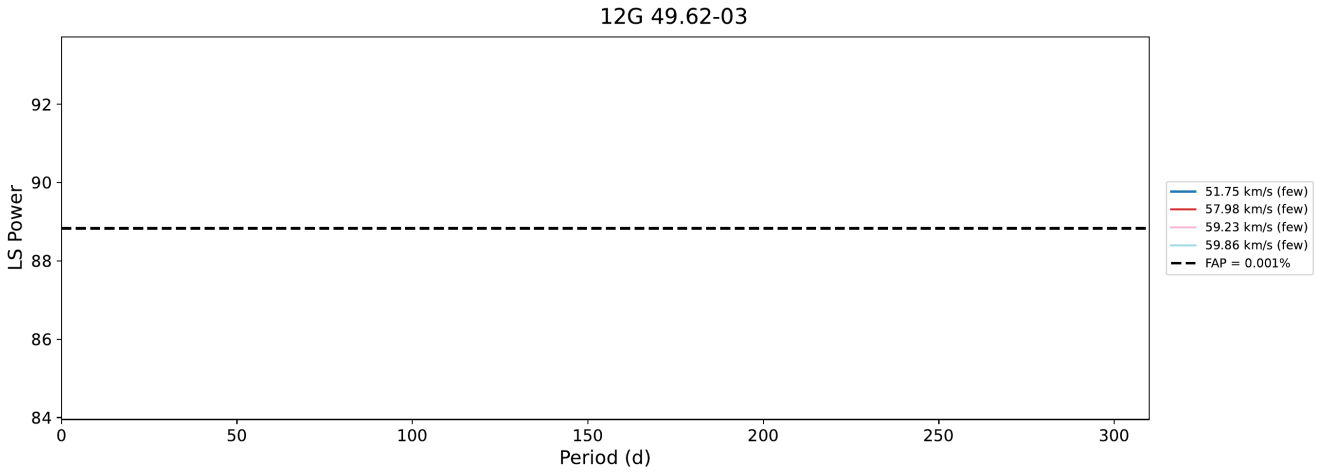


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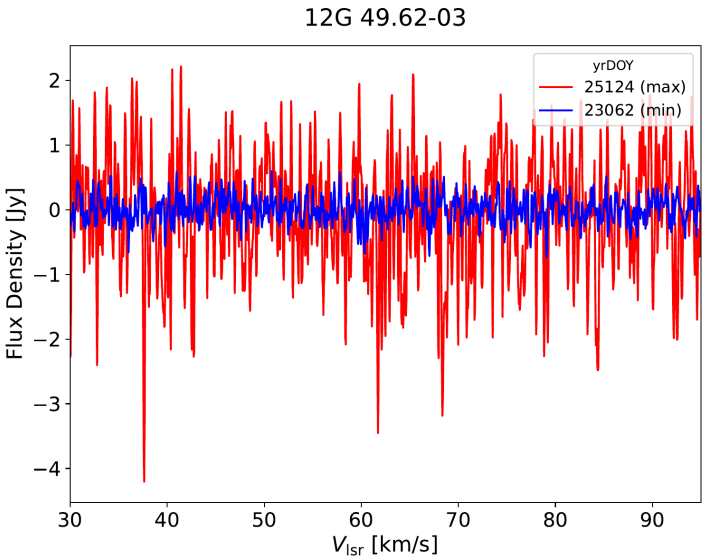
Light curve



Periodogram

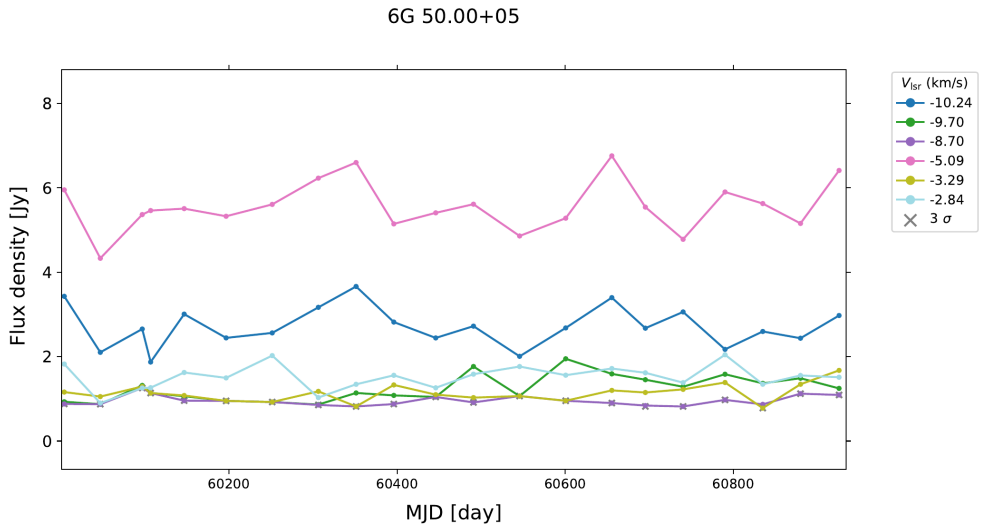


Spectrum

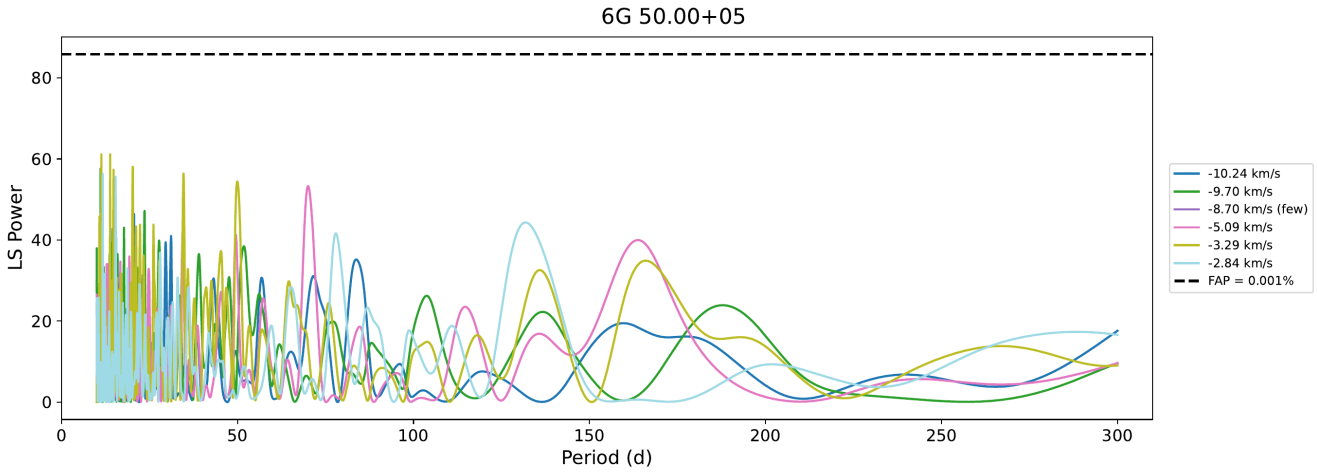


6G 50.00+05

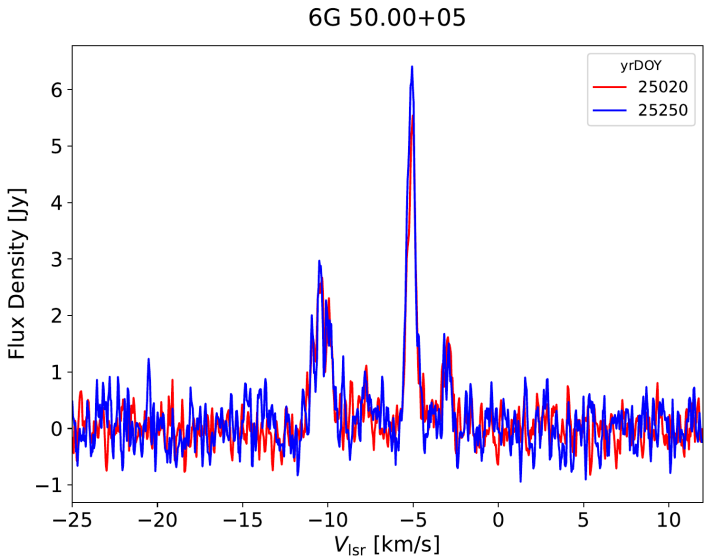
Light curve



Periodogram

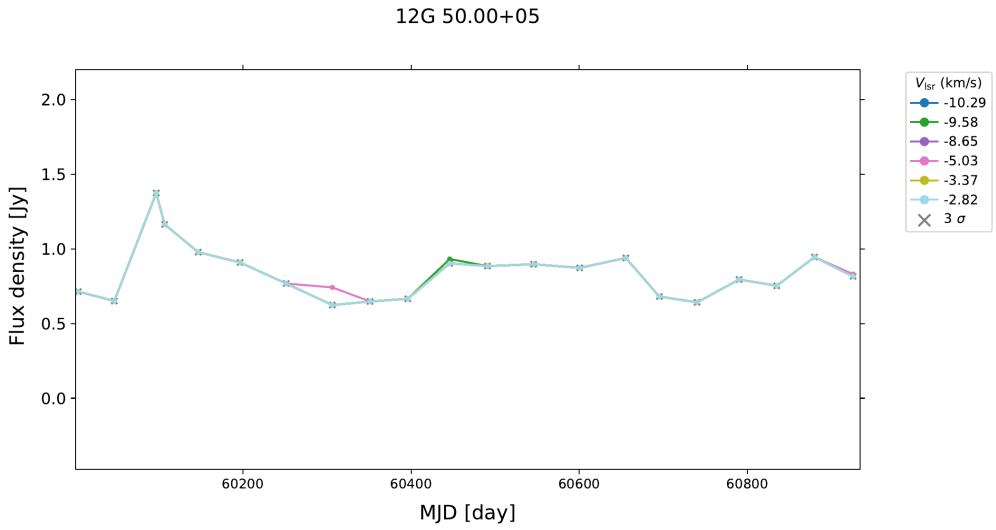


Spectrum

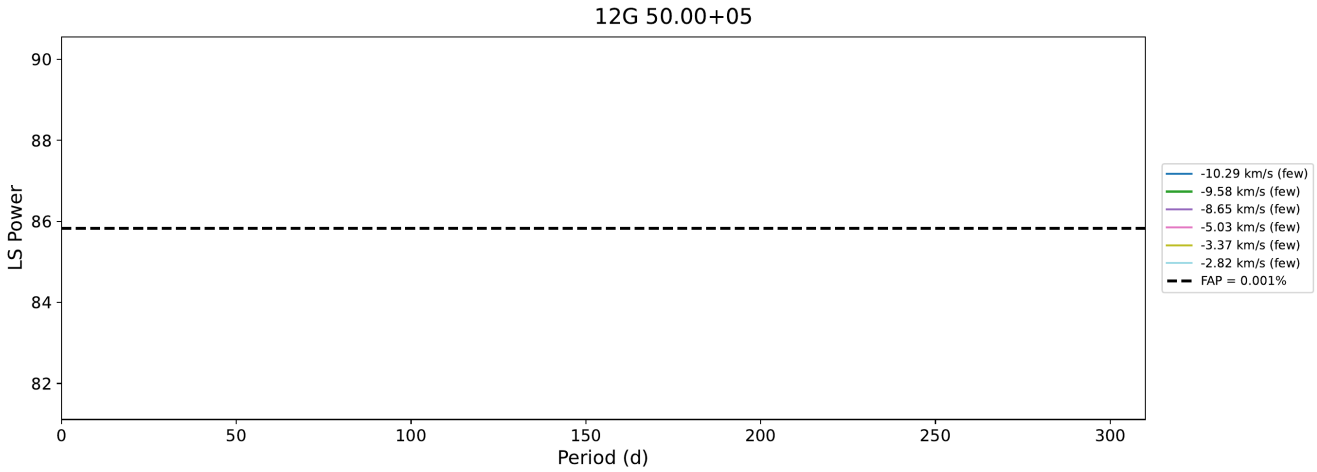


12G 50.00+05

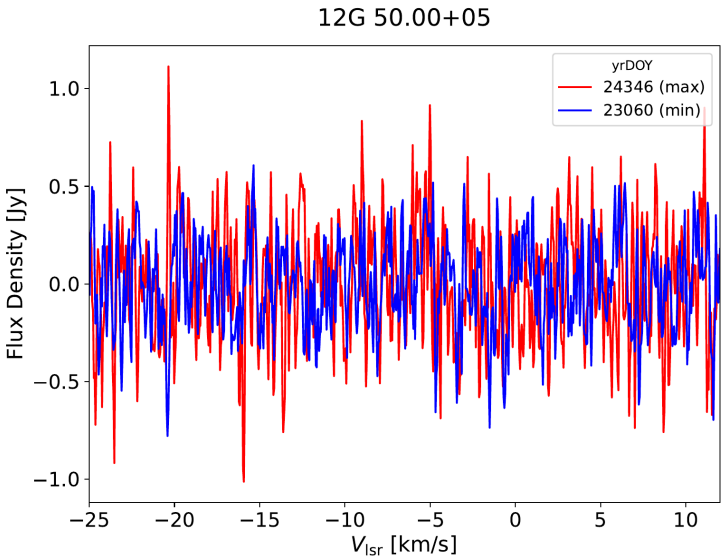
Light curve



Periodogram

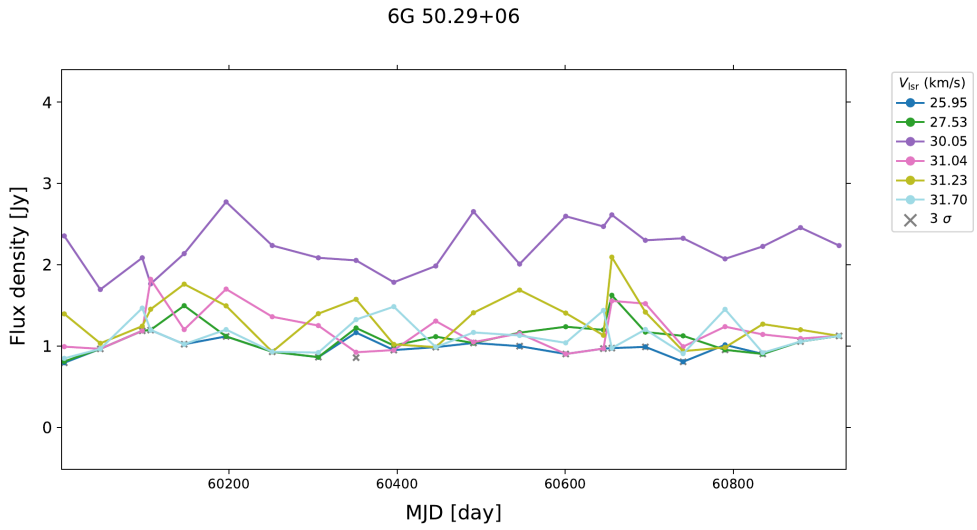


Spectrum

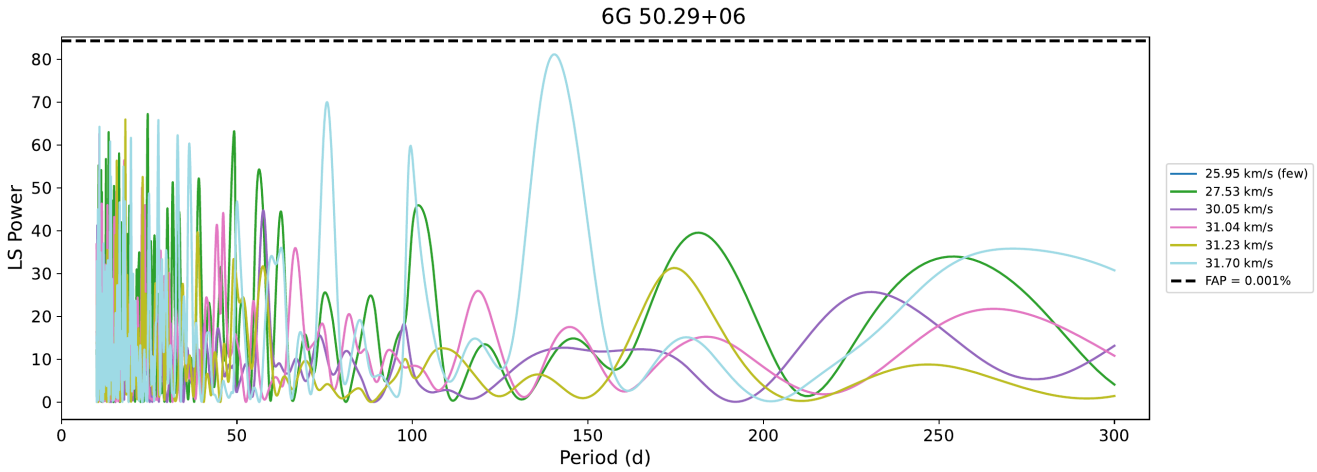


6G 50.29+06

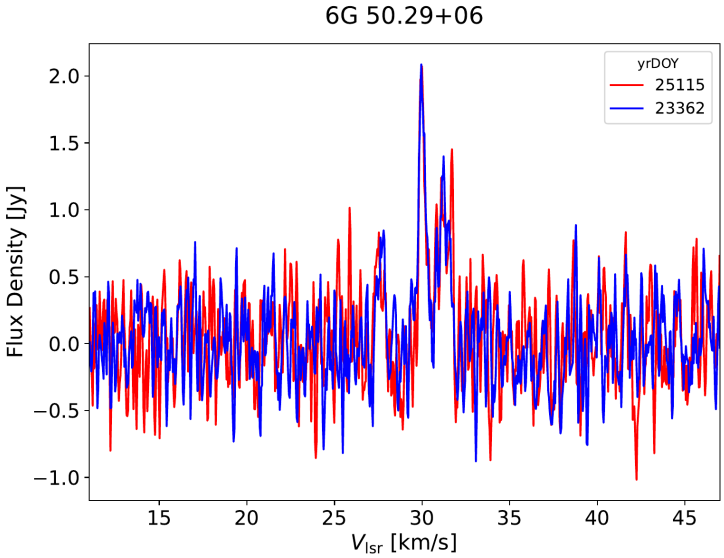
Light curve



Periodogram

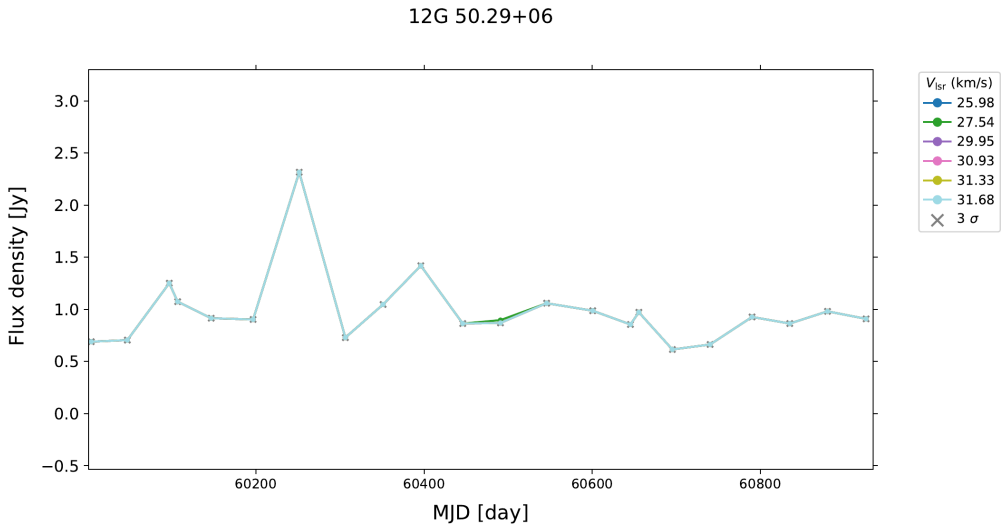


Spectrum

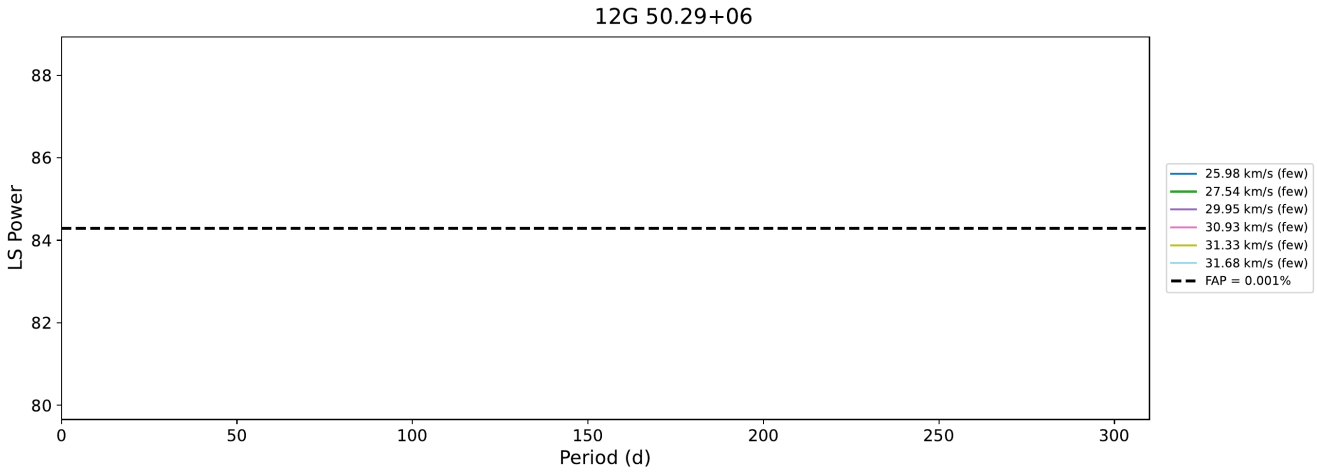


12G 50.29+06

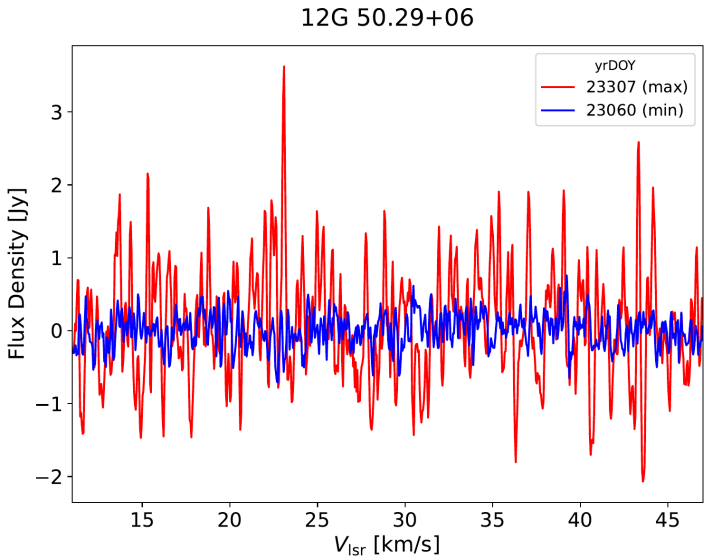
Light curve



Periodogram

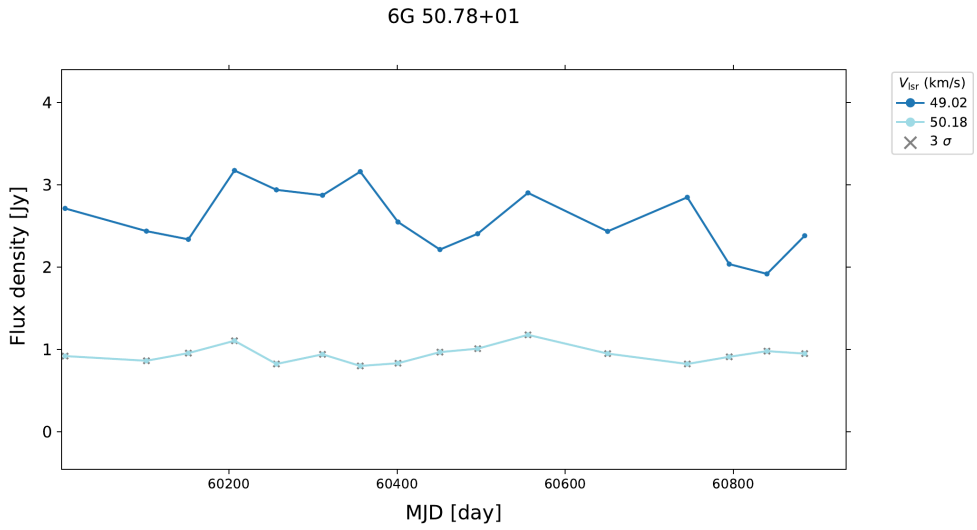


Spectrum

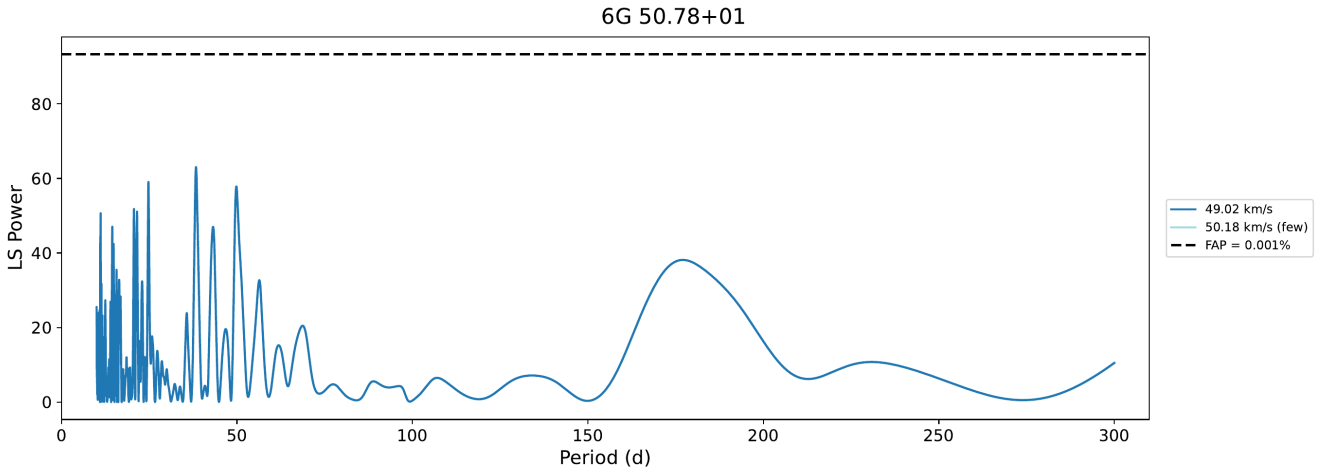


6G 50.78+01

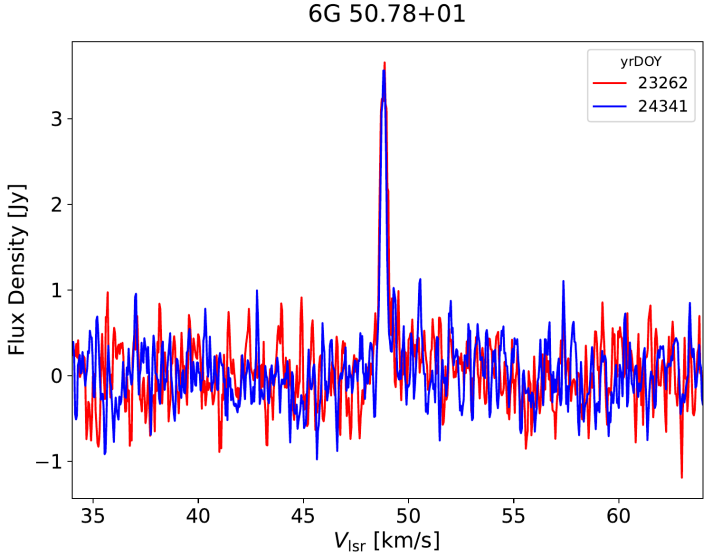
Light curve



Periodogram

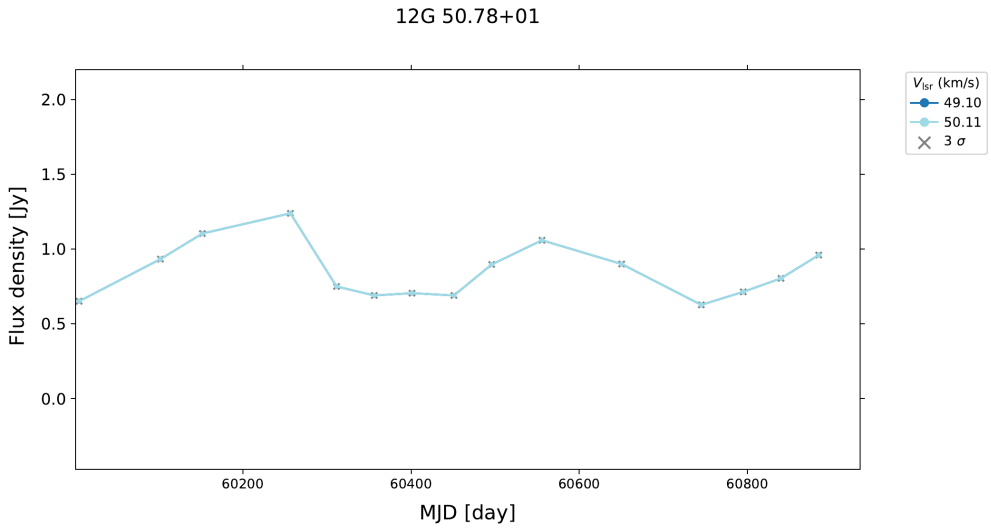


Spectrum

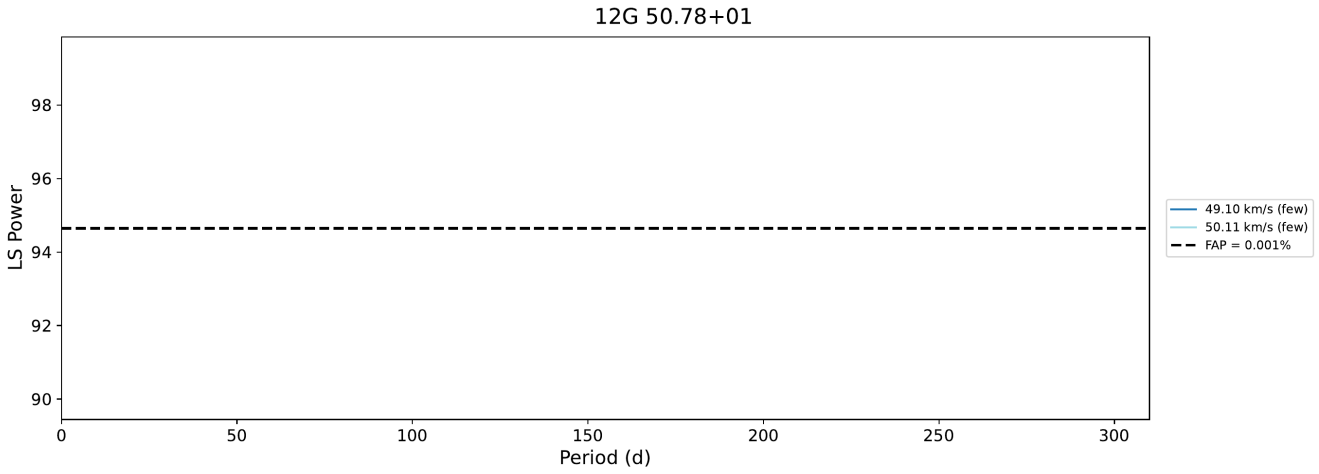


12G 50.78+01

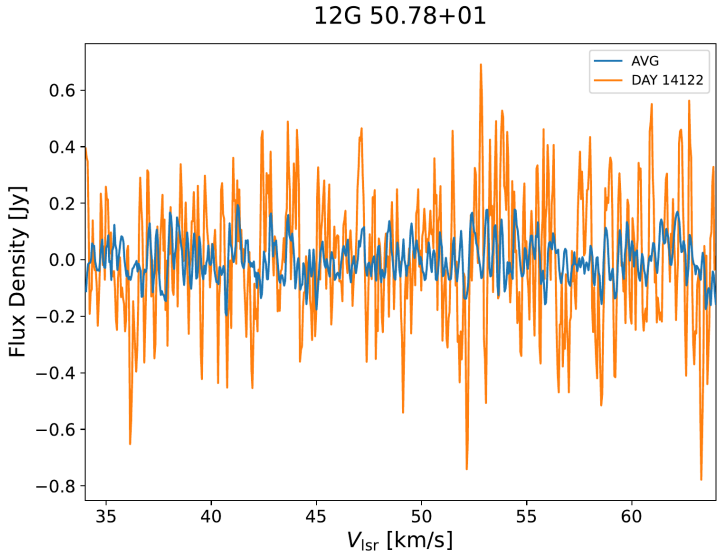
Light curve



Periodogram

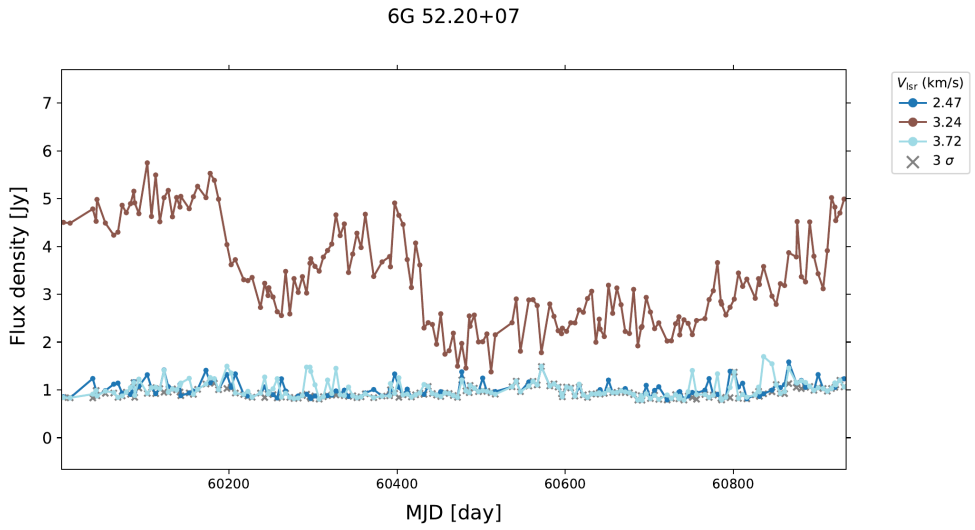


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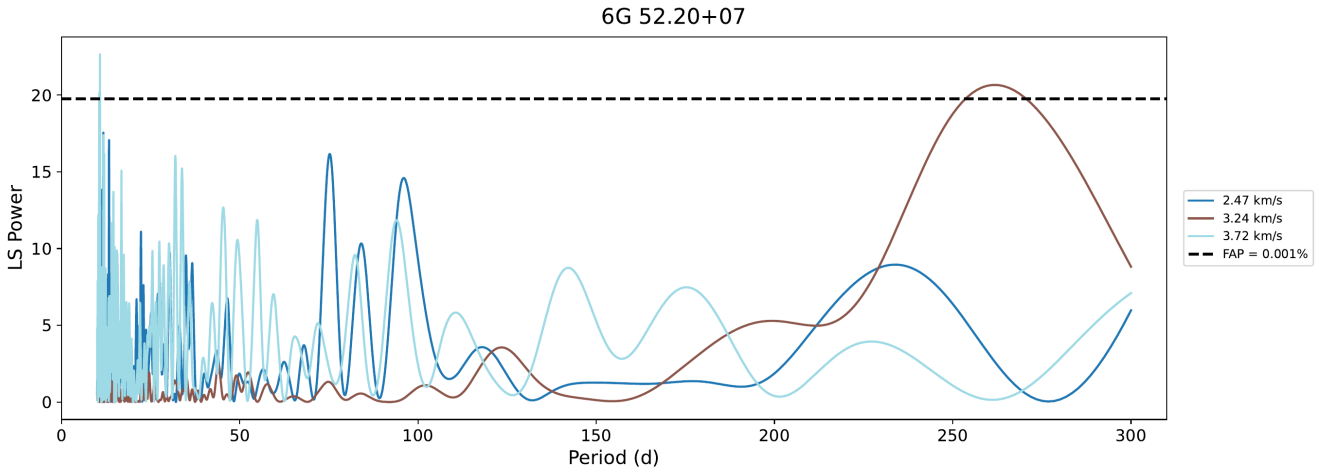


6G 52.20+07

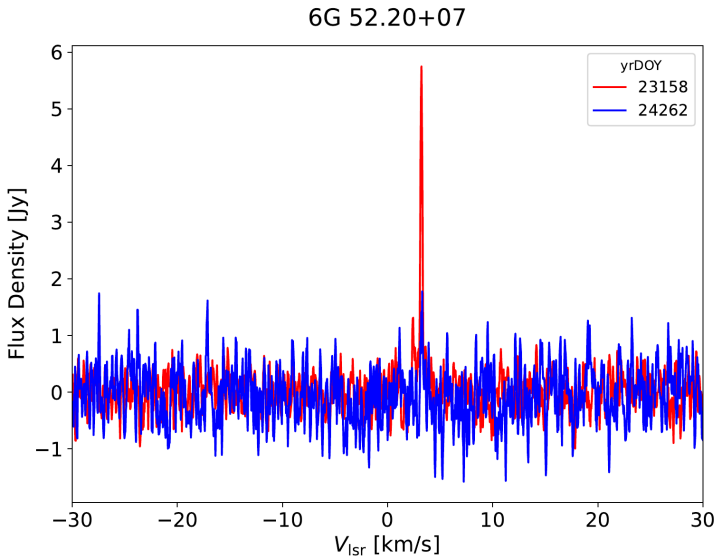
Light curve



Periodogram

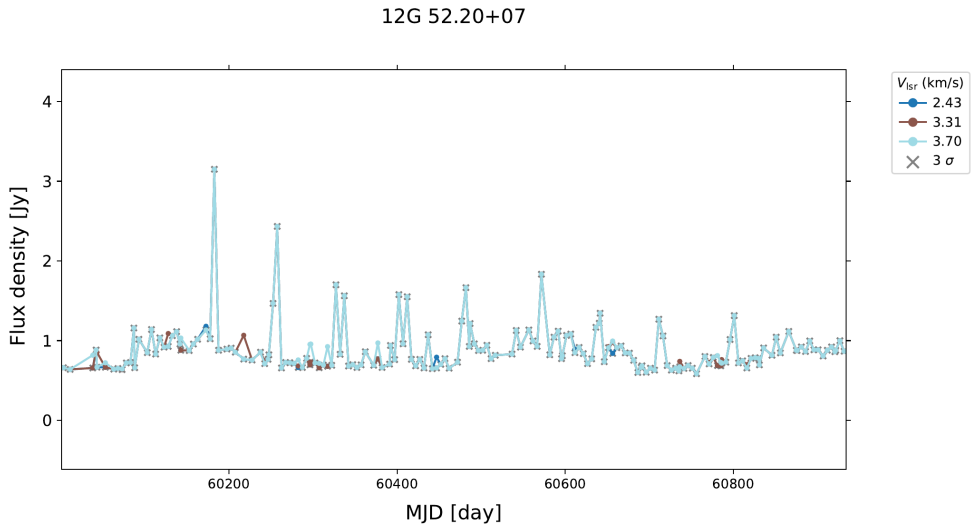


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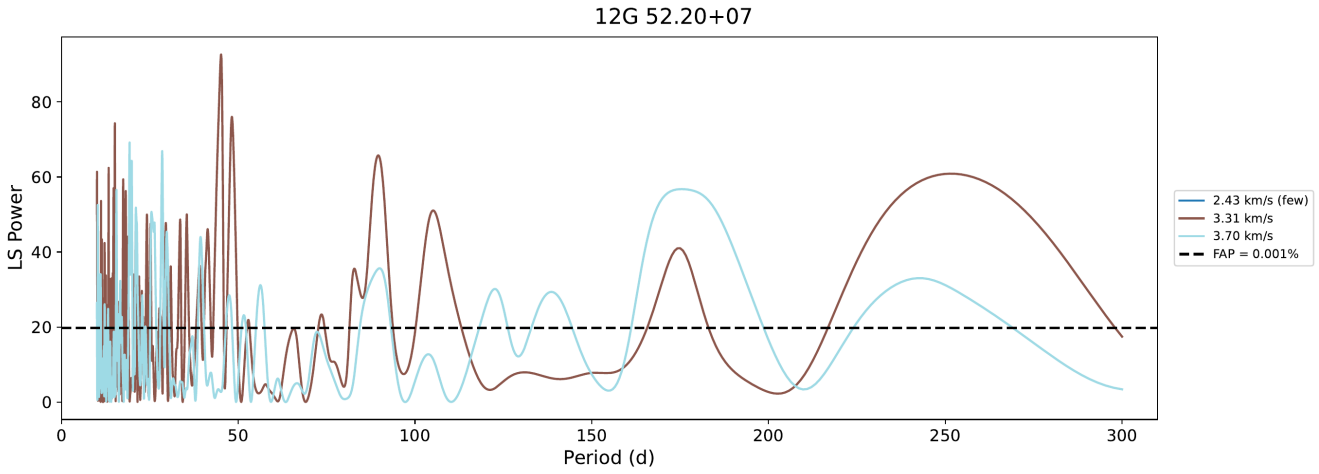


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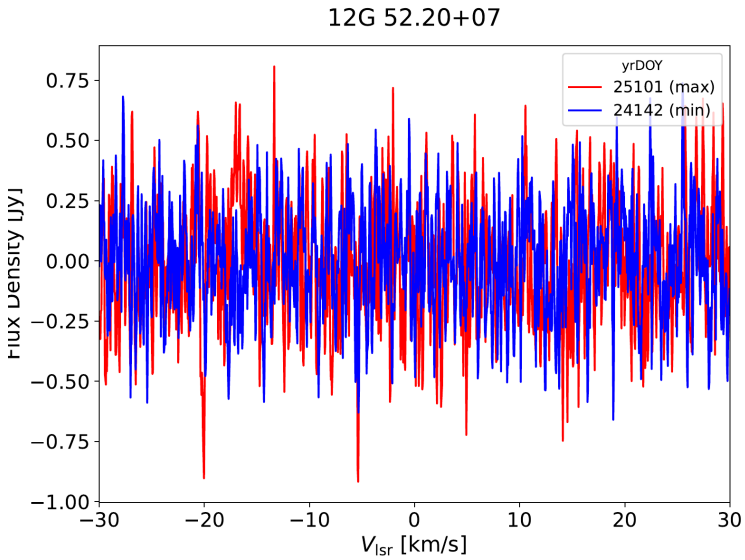
Light curve



Periodogram

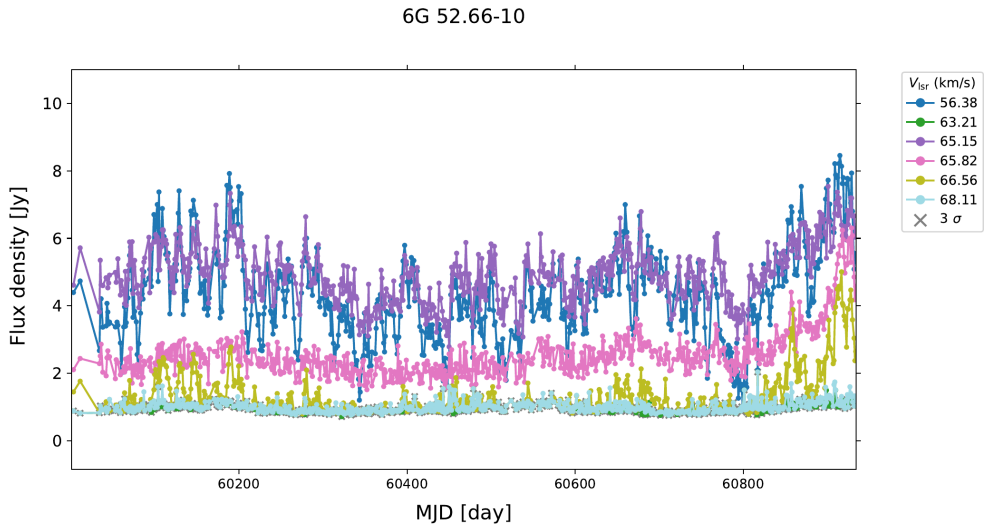


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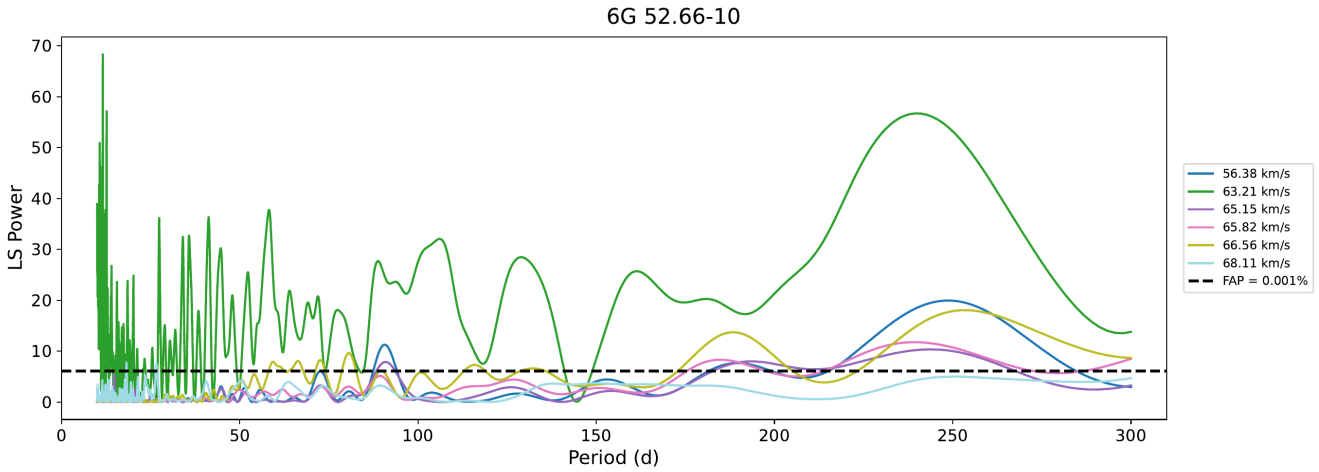


6G 52.66-10

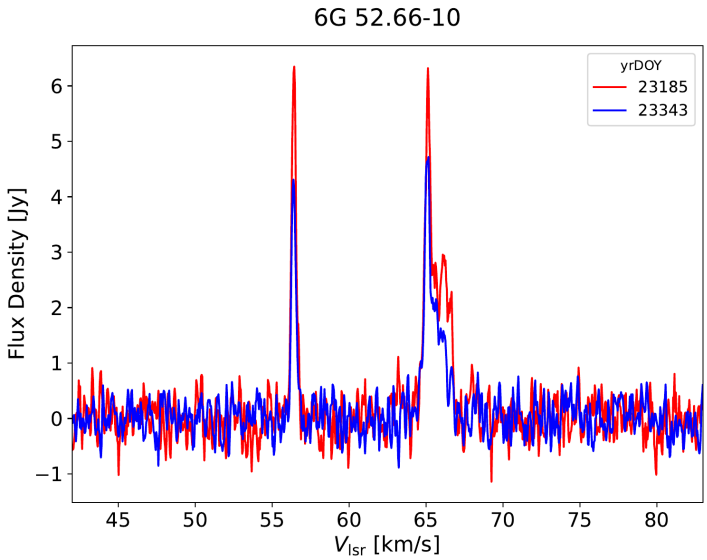
Light curve



Periodogram

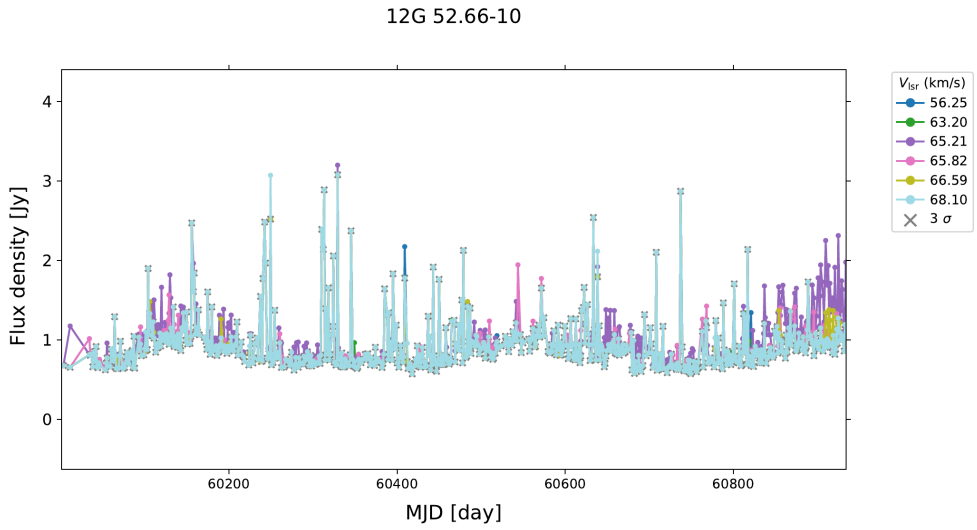


Spectrum

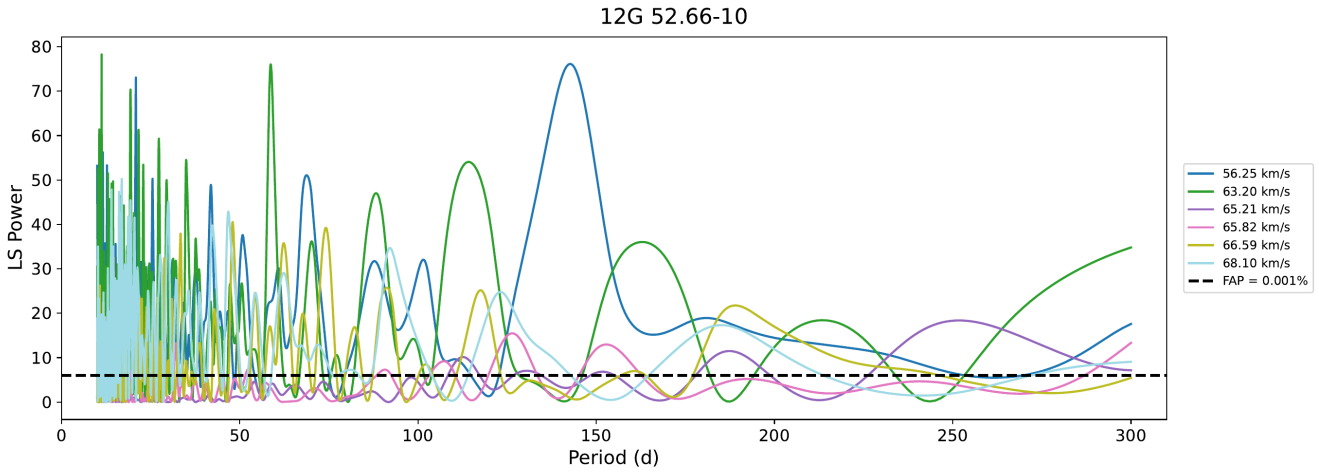


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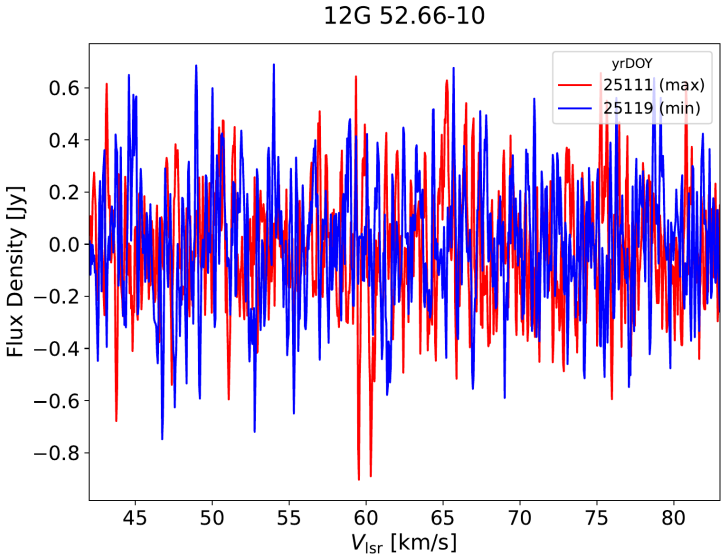
Light curve



Periodogram

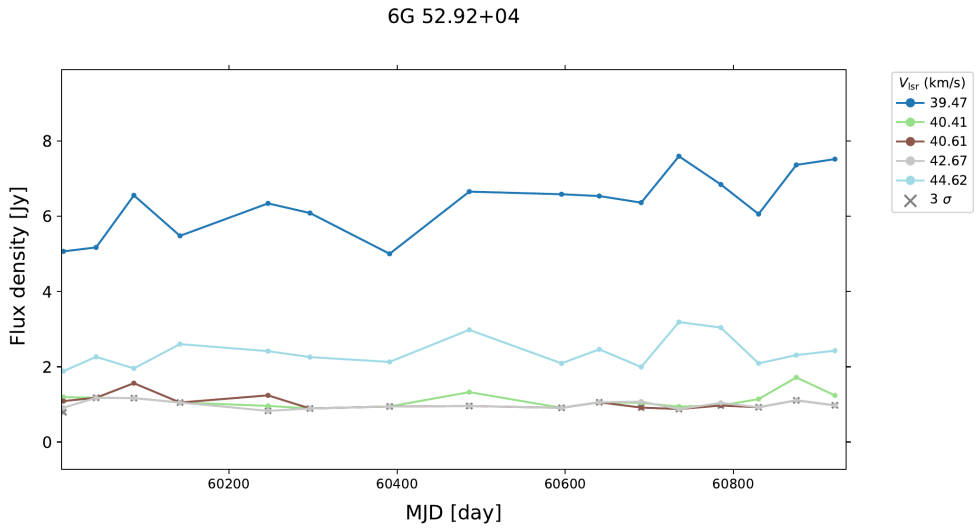


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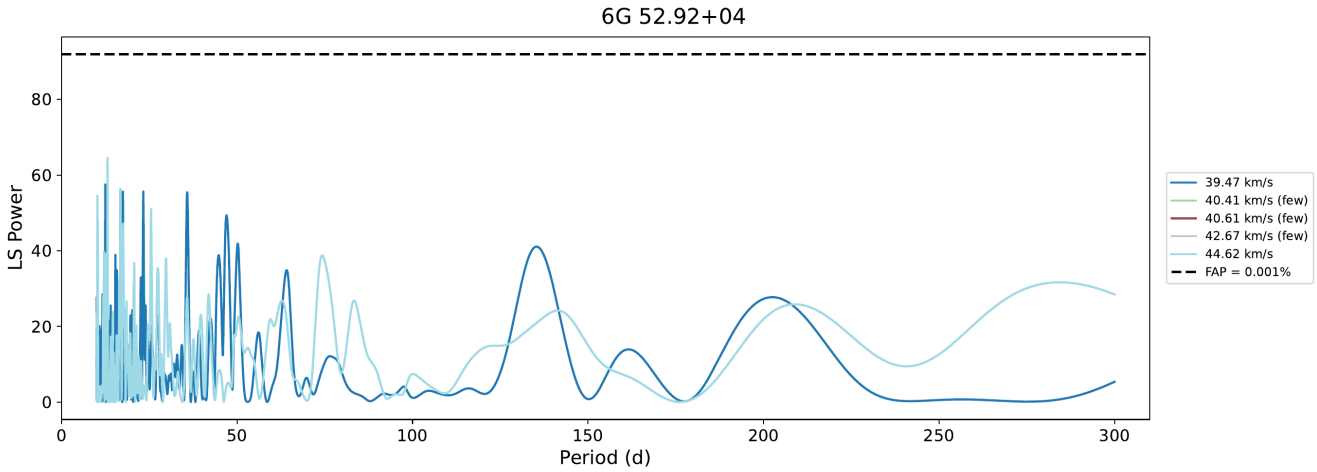


6G 52.92+04

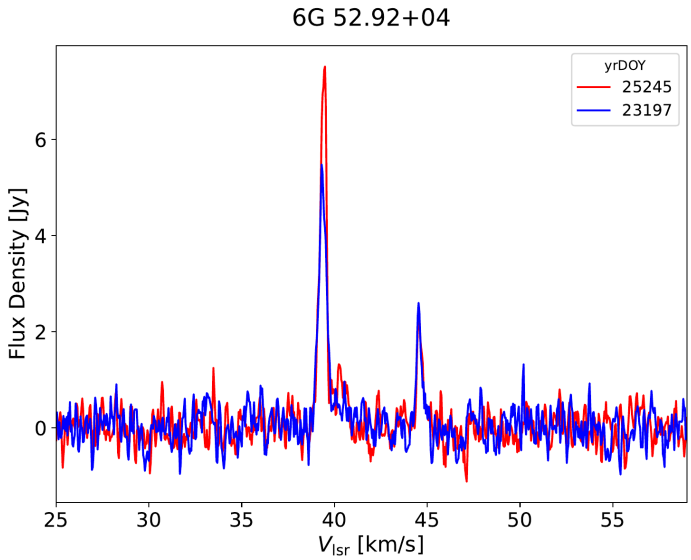
Light curve



Periodogram

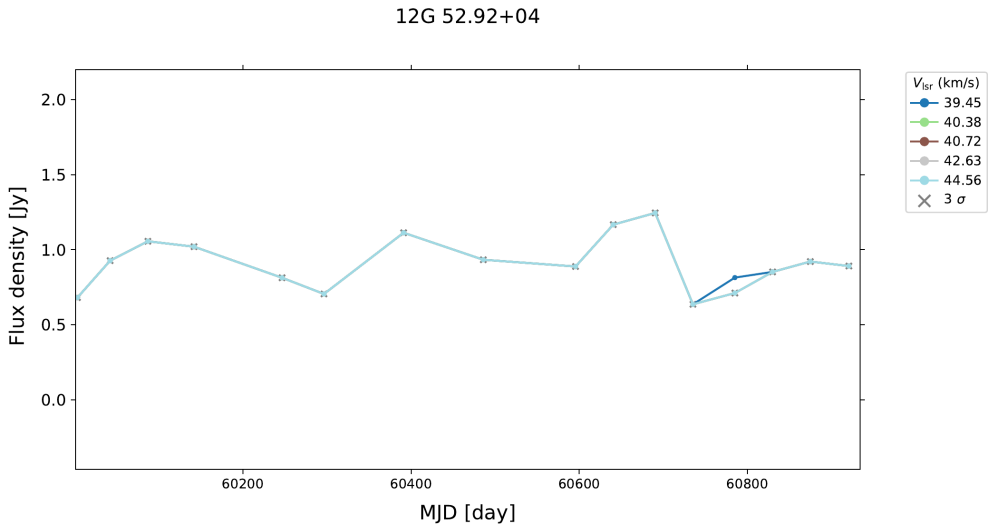


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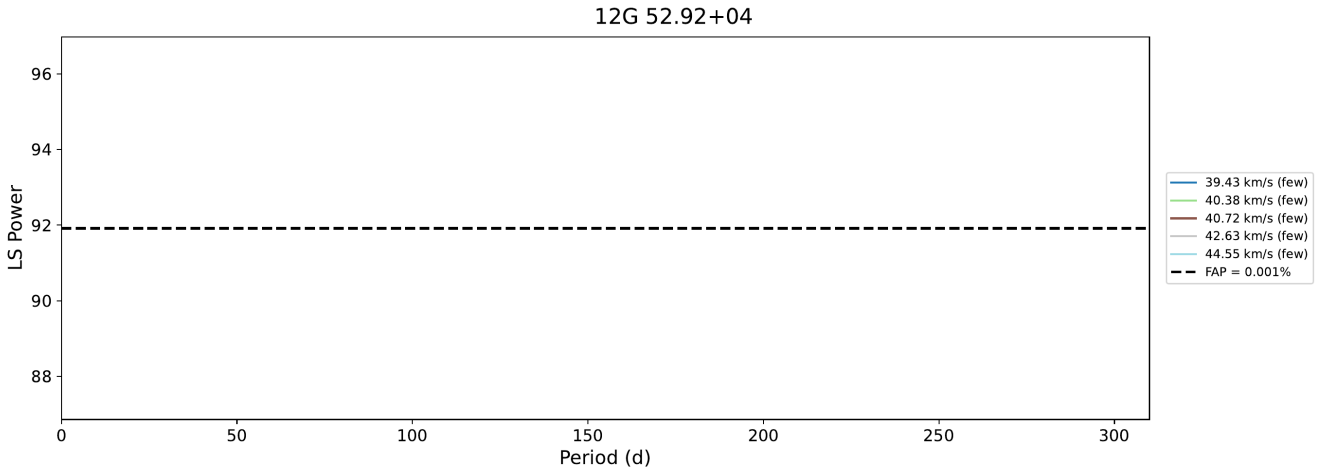


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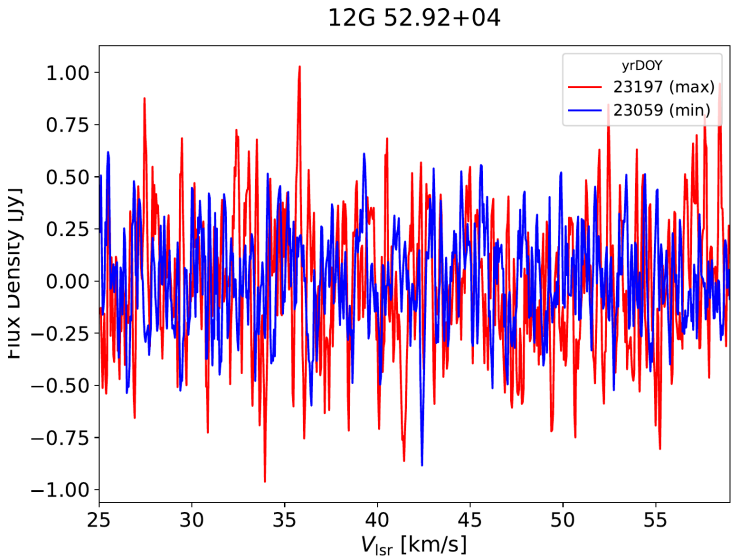
Light curve



Periodogram

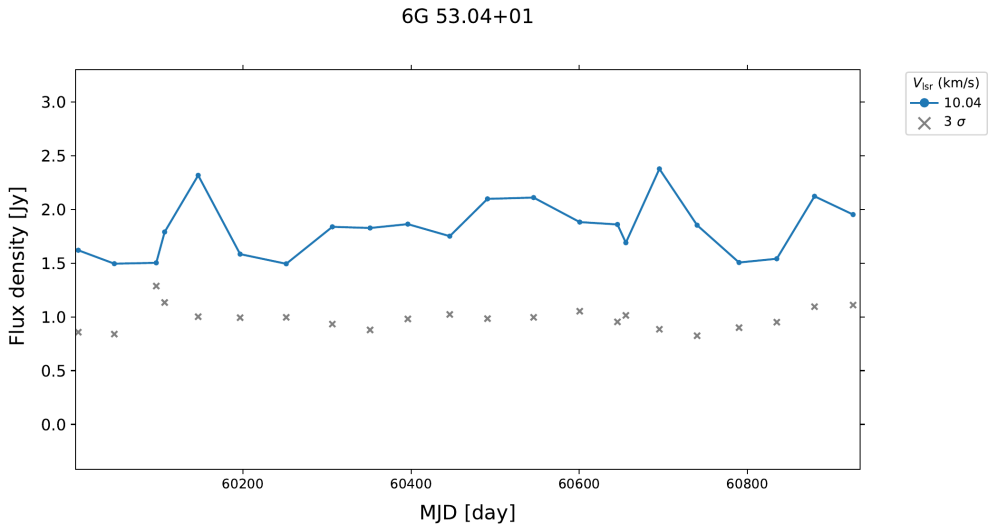


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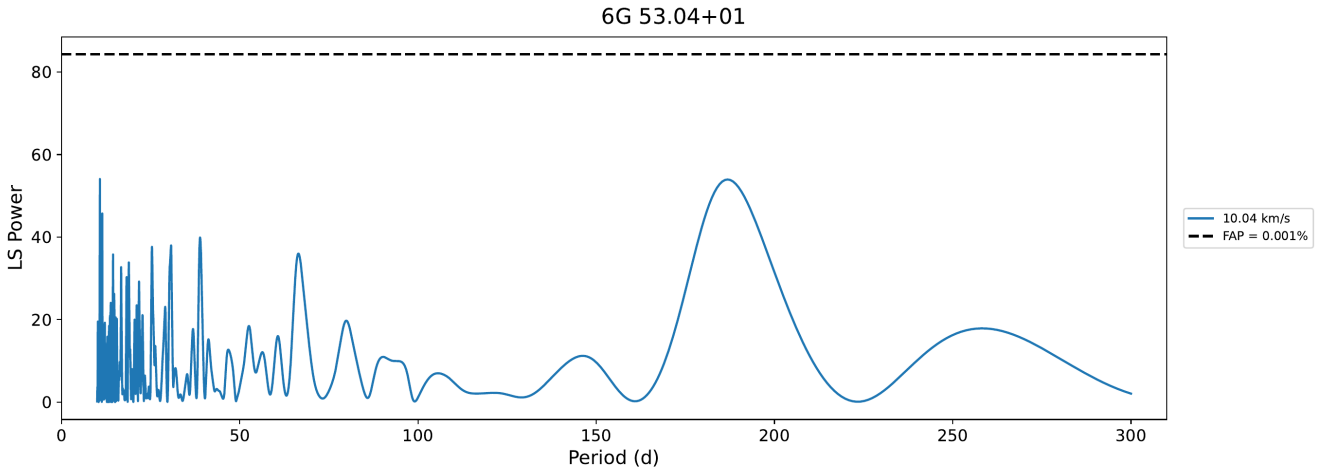


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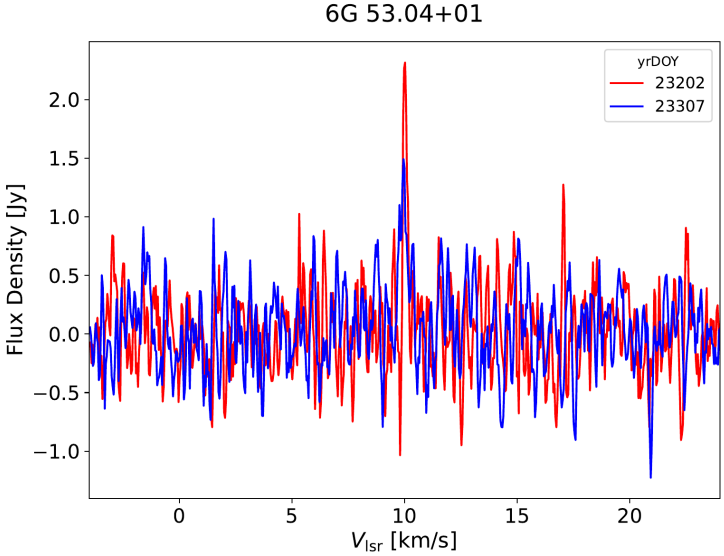
Light curve



Periodogram

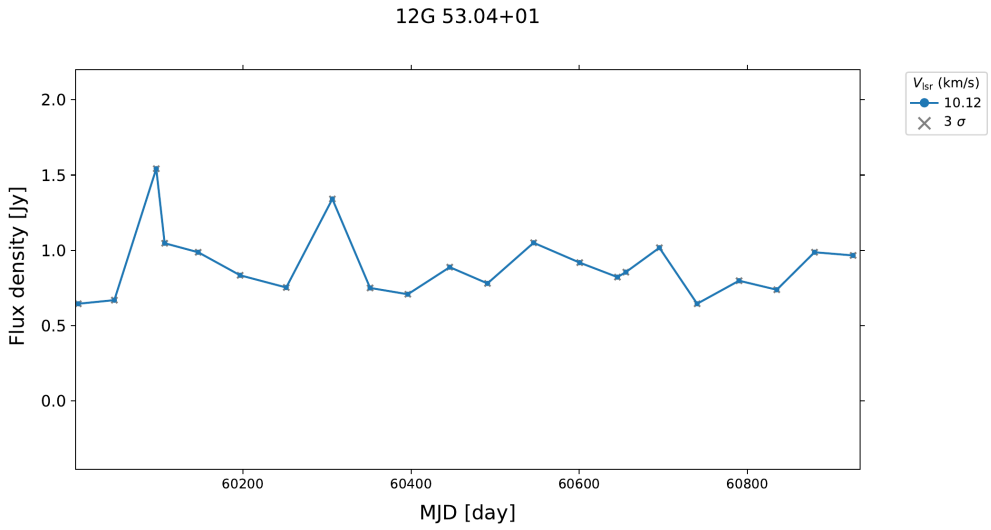


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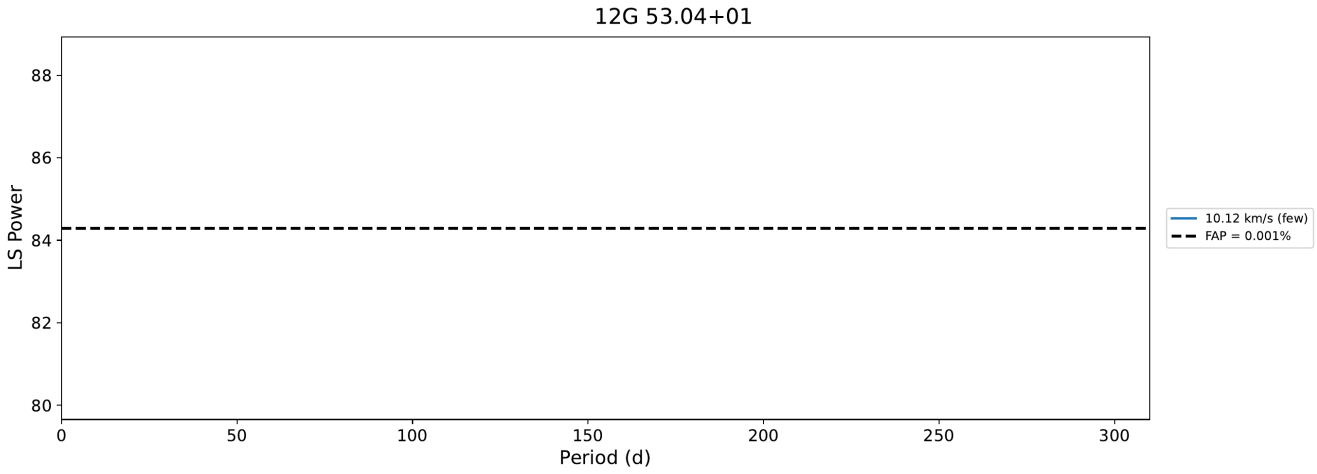


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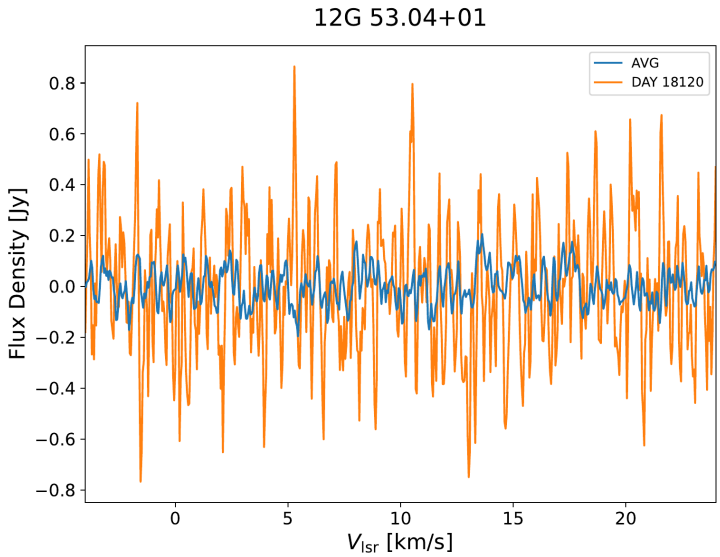
Light curve



Periodogram

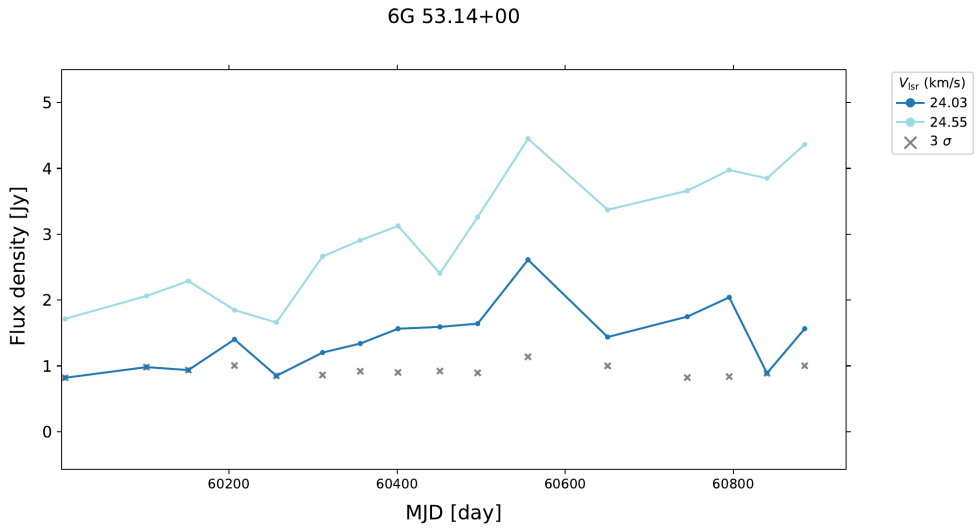


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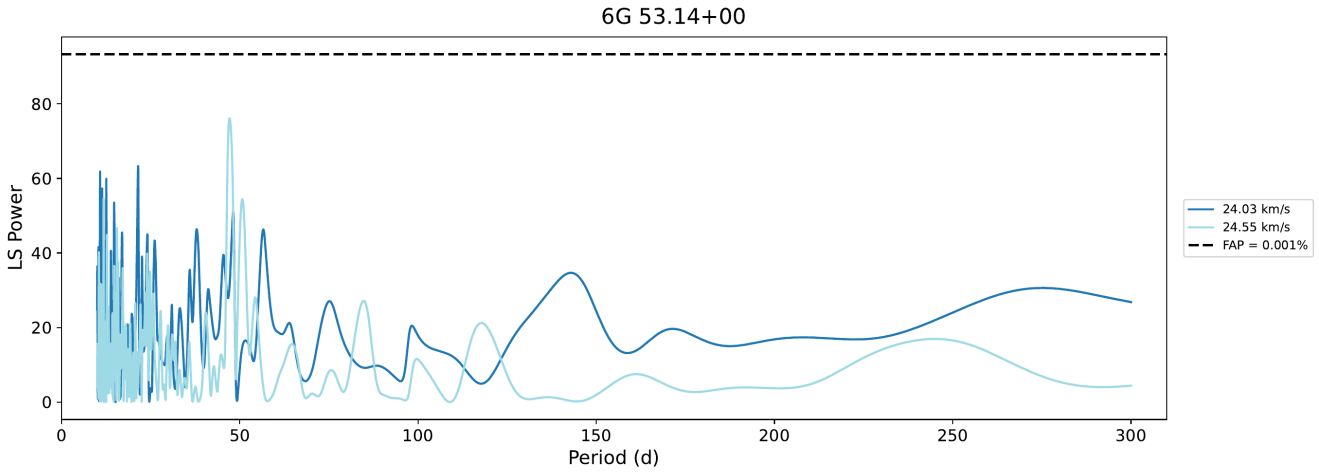


6G 53.14+00

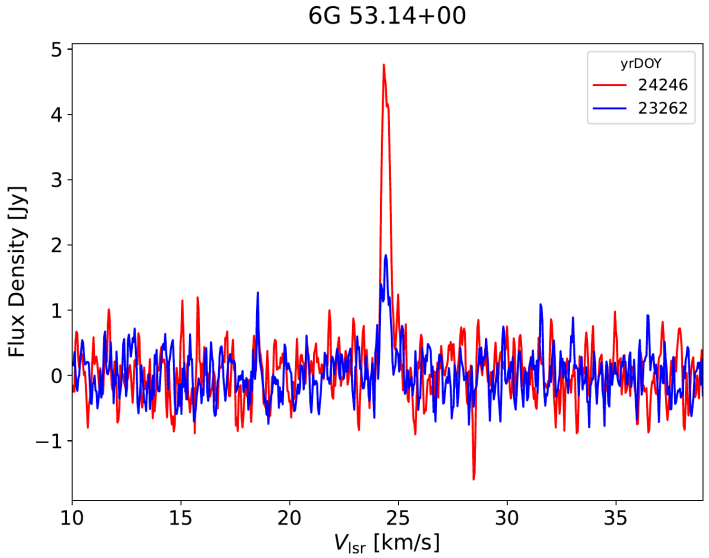
Light curve



Periodogram

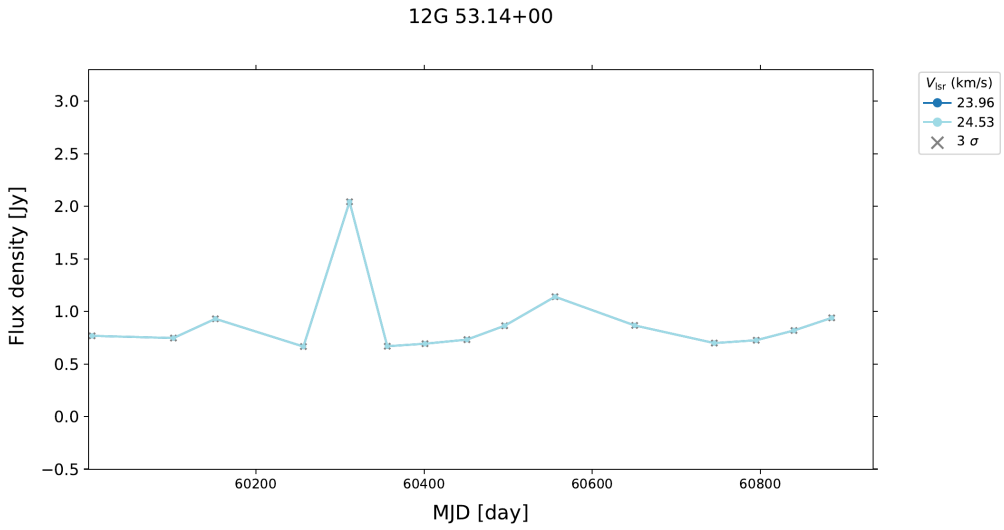


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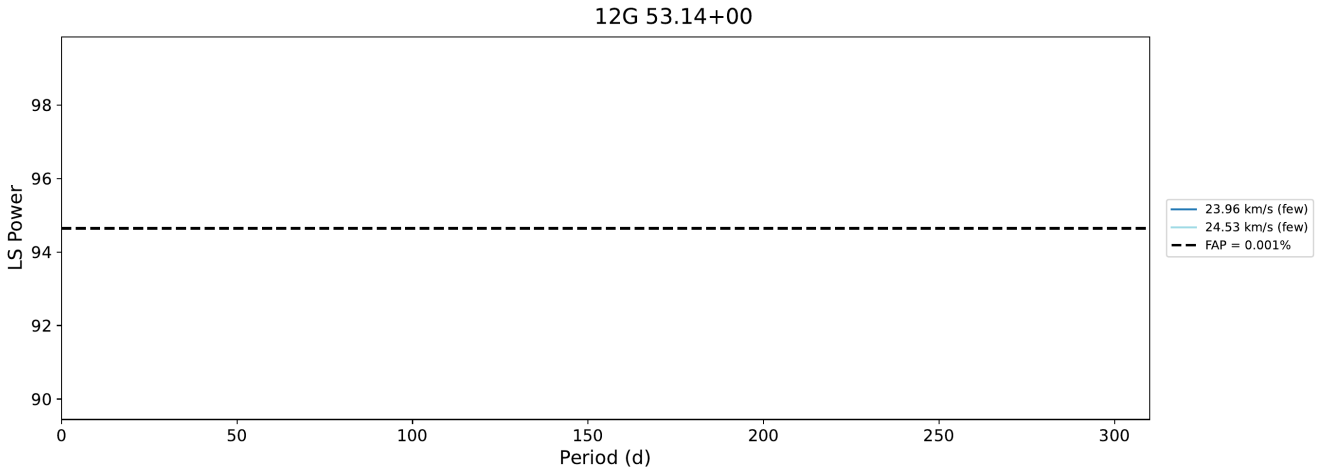


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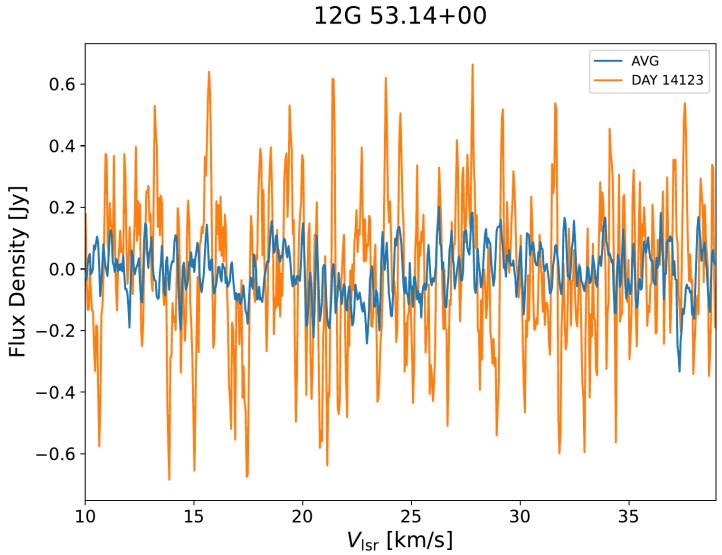
Light curve



Periodogram

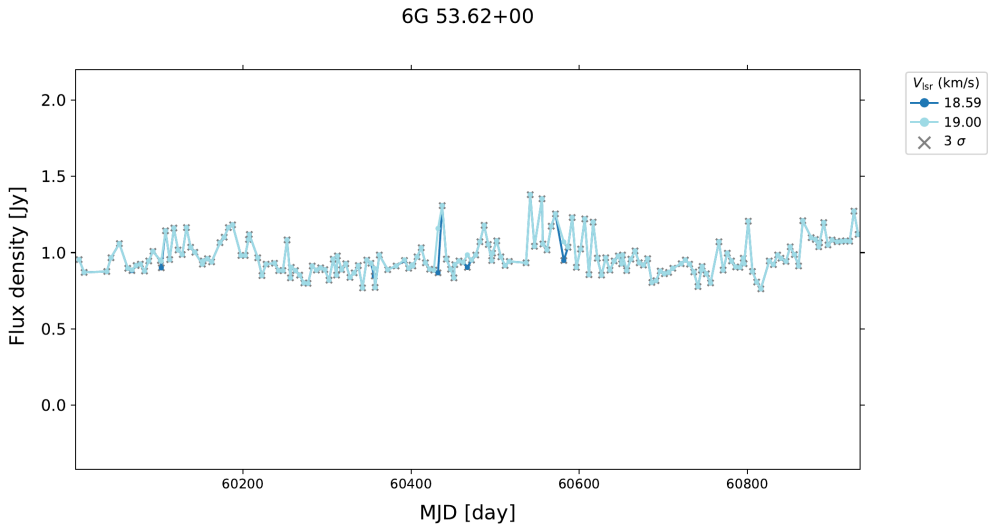


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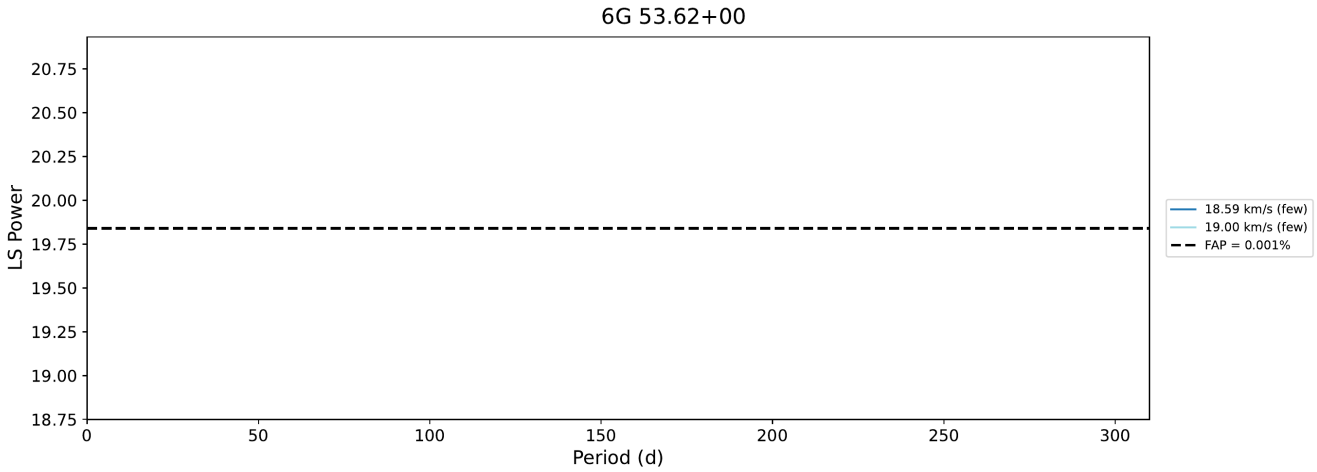


6G 53.62+00

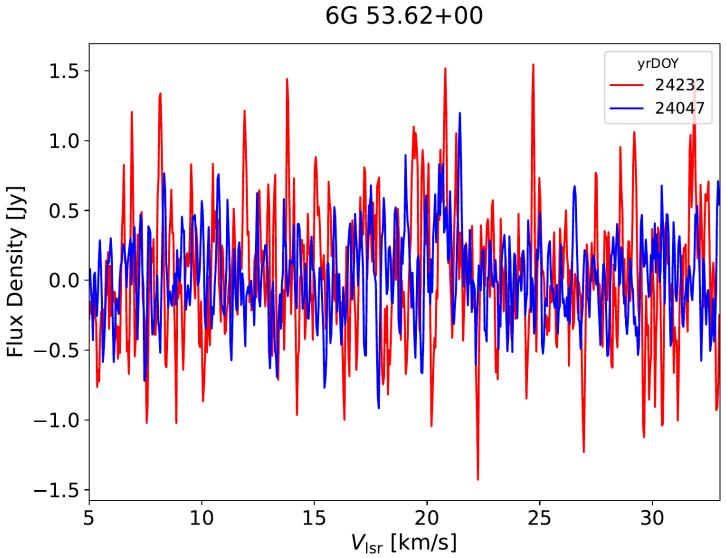
Light curve



Periodogram

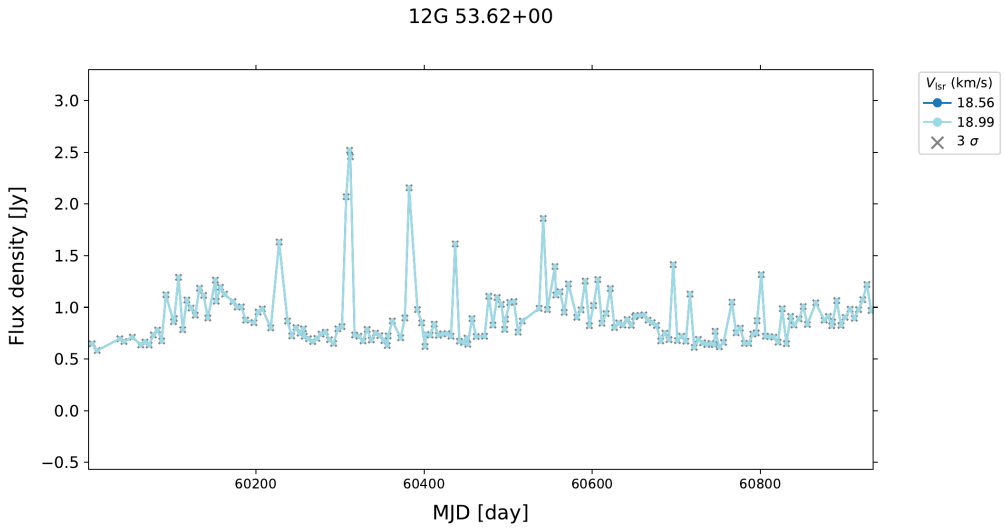


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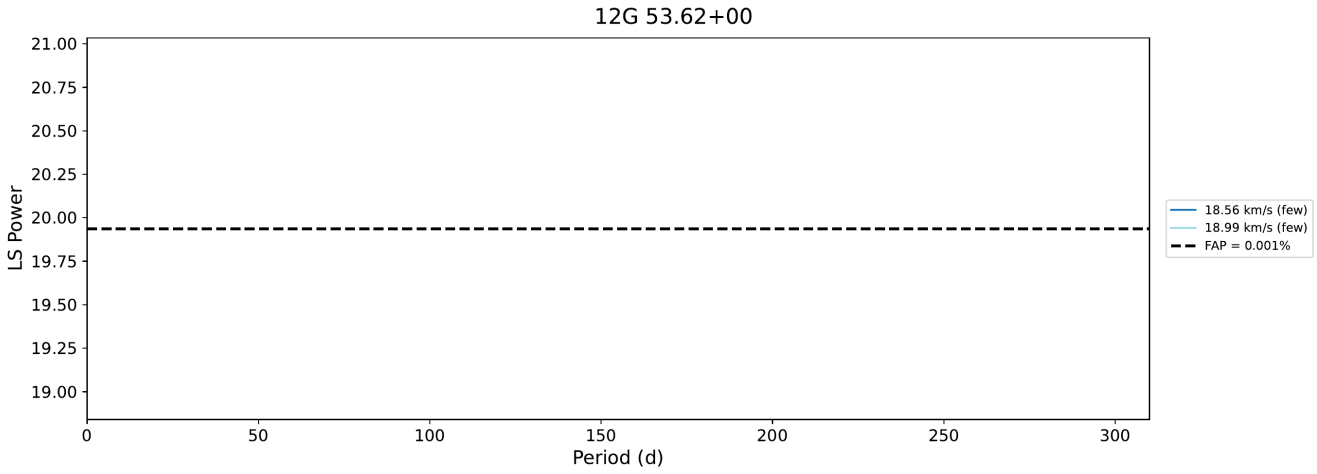


12G 53.62+00

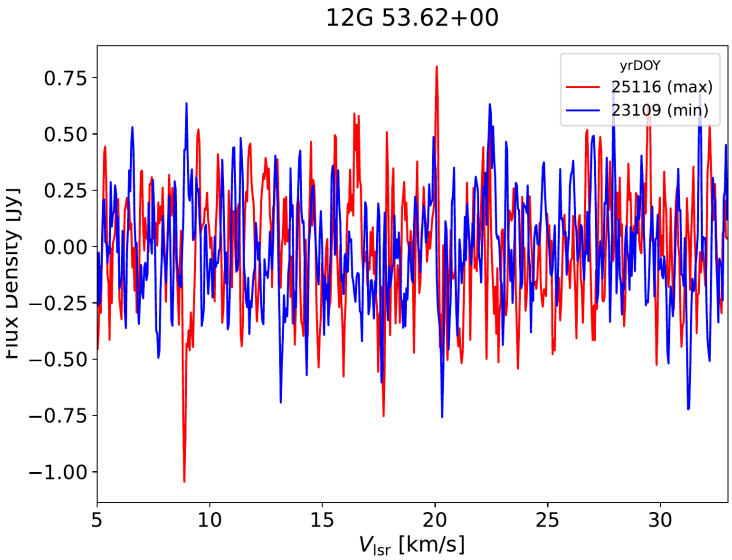
Light curve



Periodogram

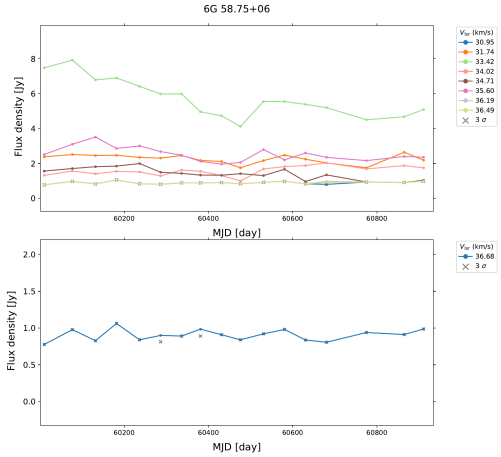


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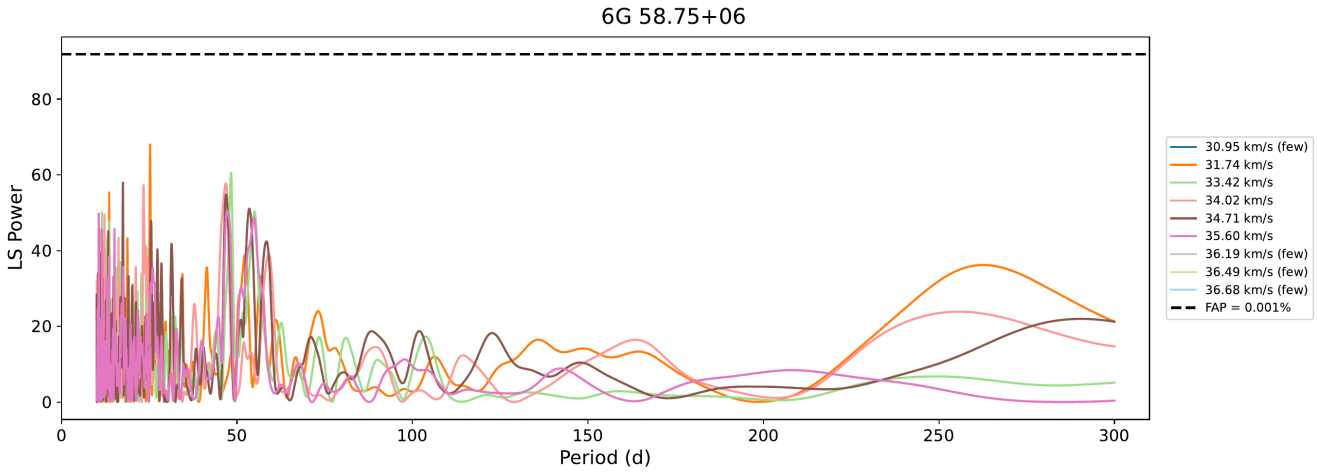


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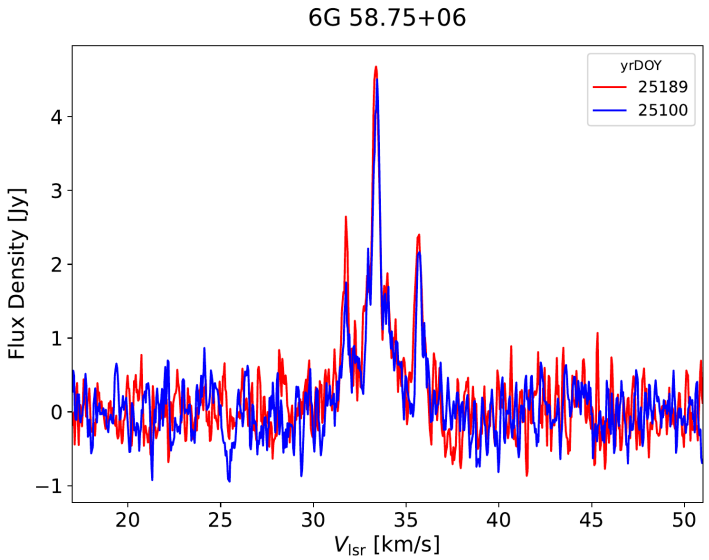
Light curve



Periodogram

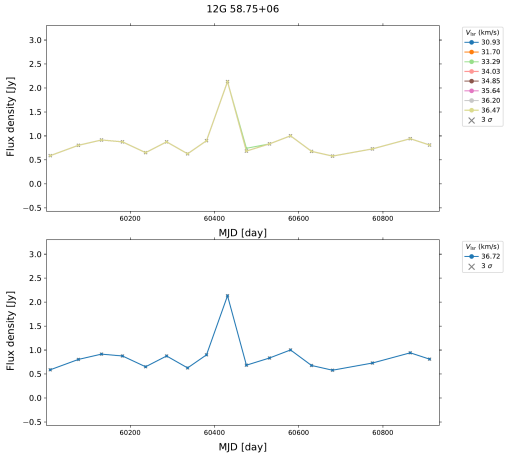


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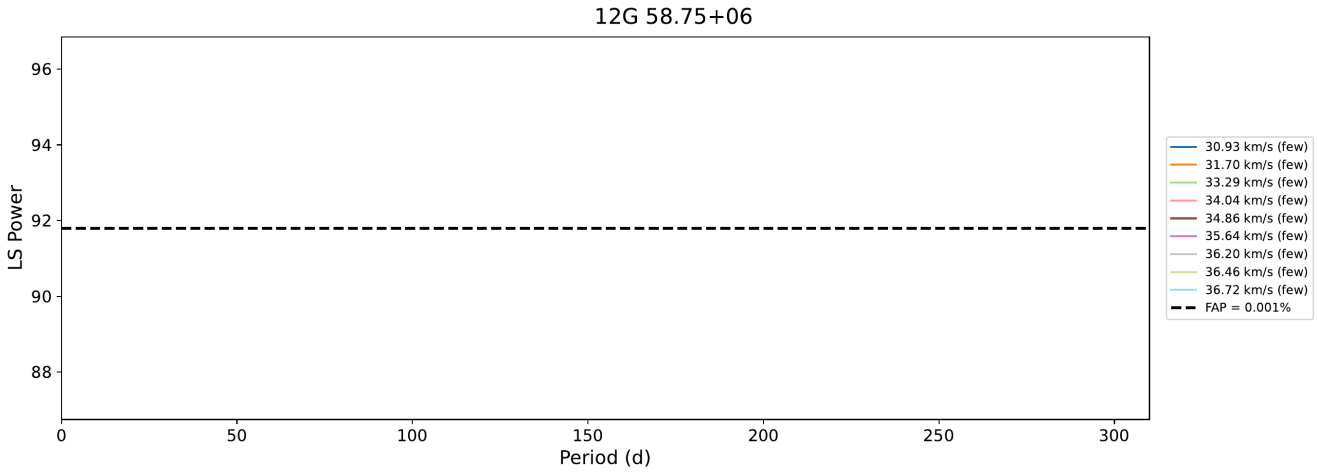


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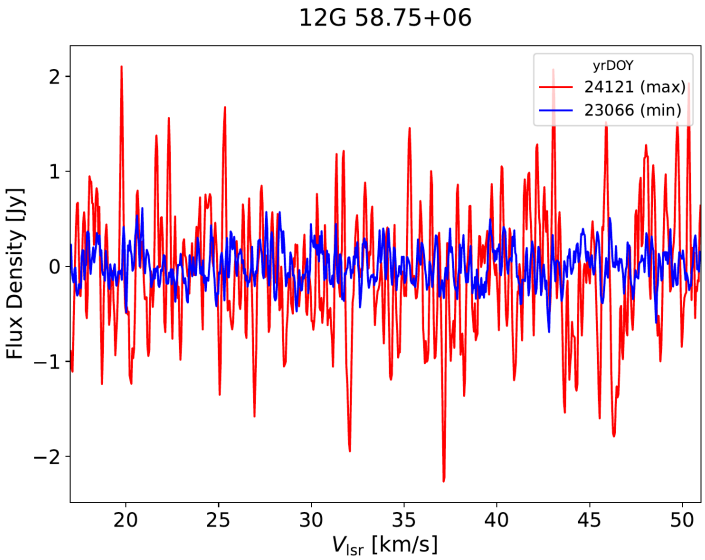
Light curve



Periodogram

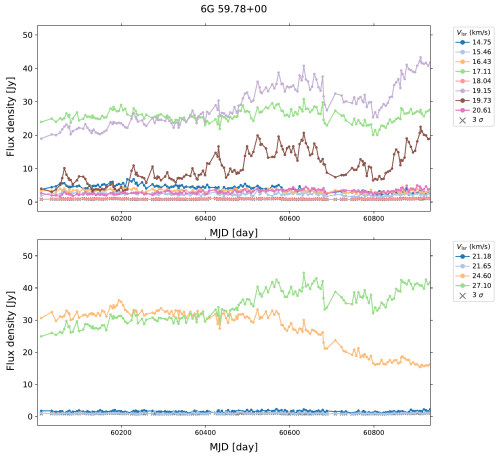


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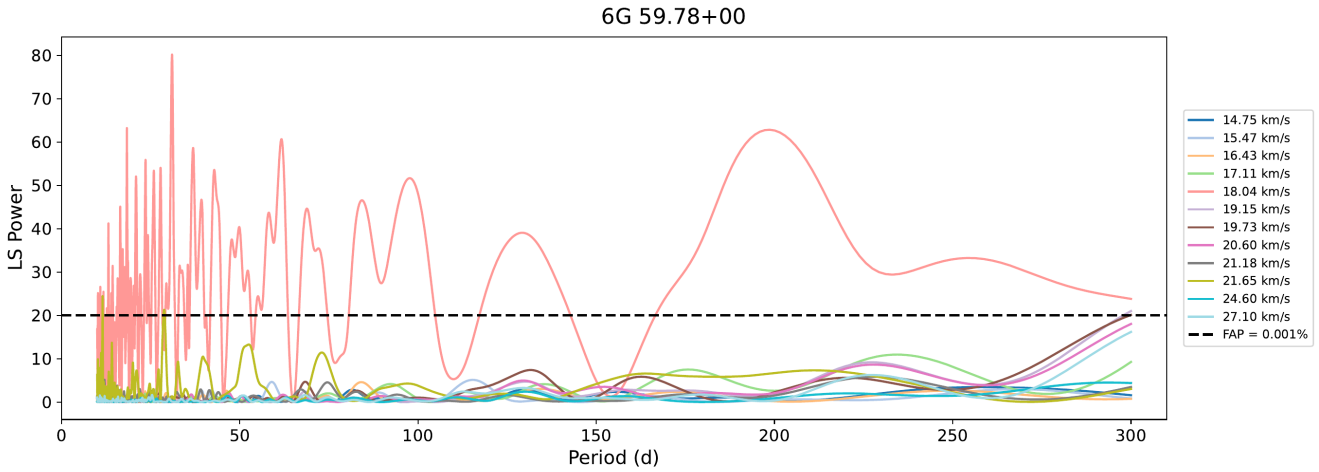


6G 59.78+00

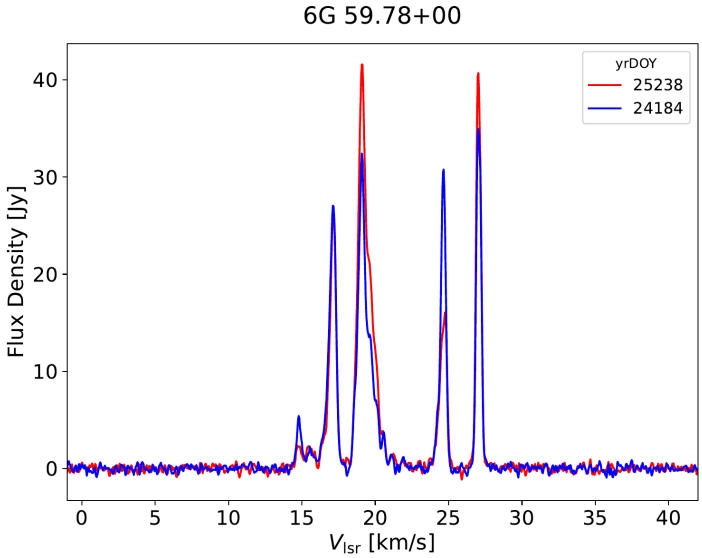
Light curve



Periodogram

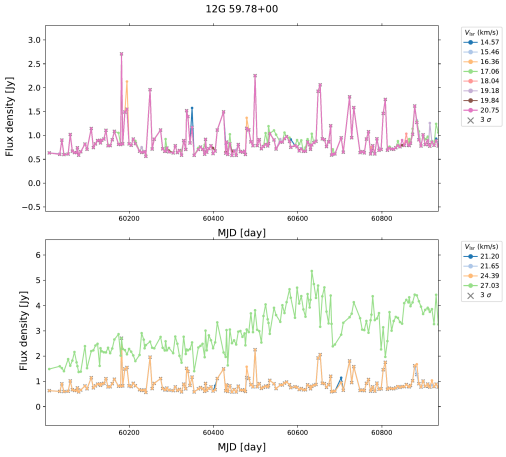


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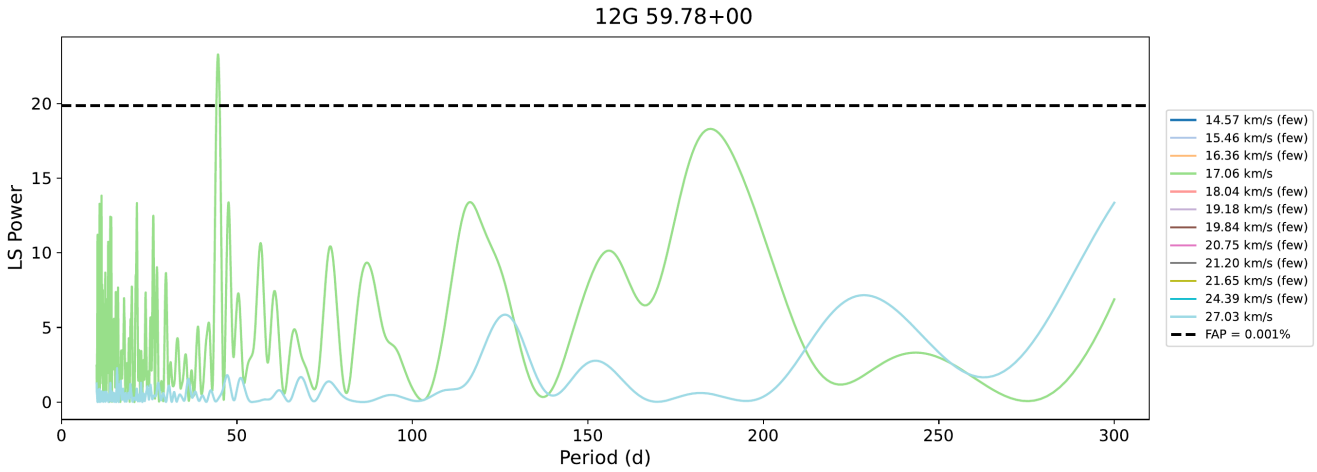


12G 59.78+00

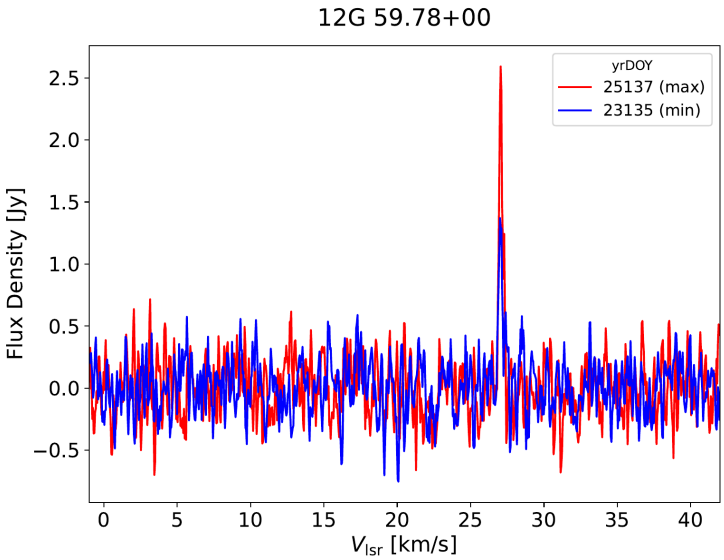
Light curve



Periodogram

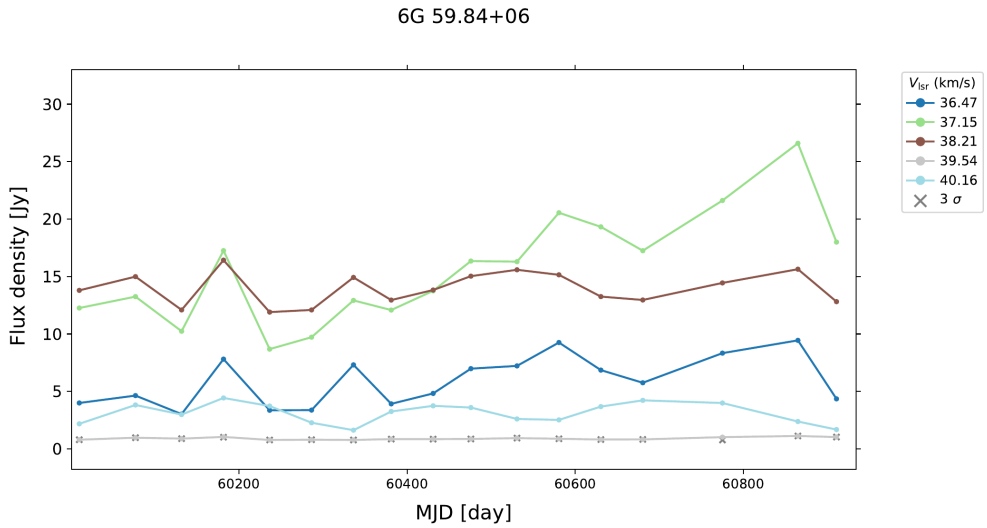


Spectrum

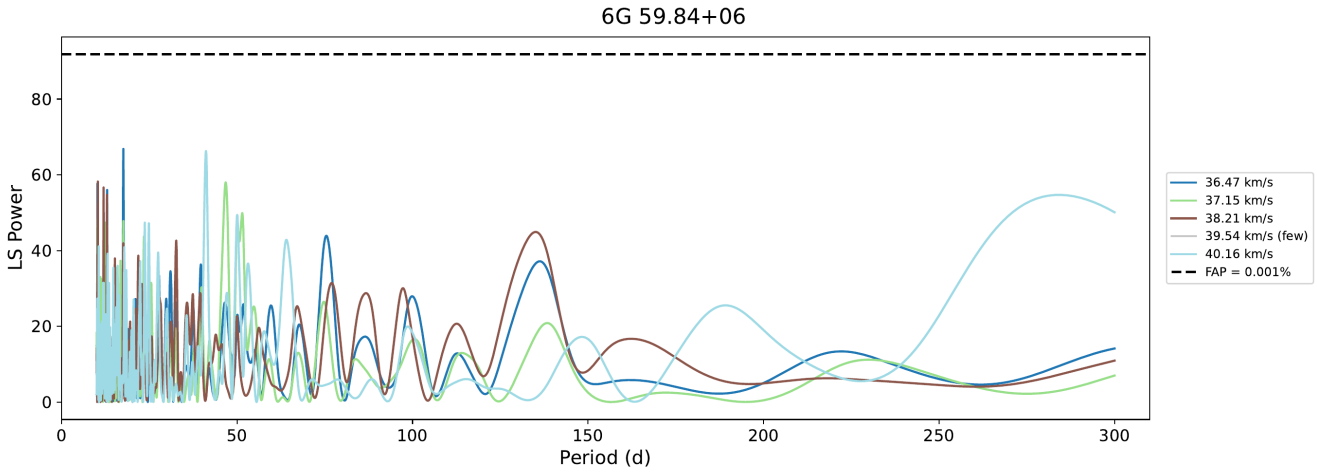


6G 59.84+06

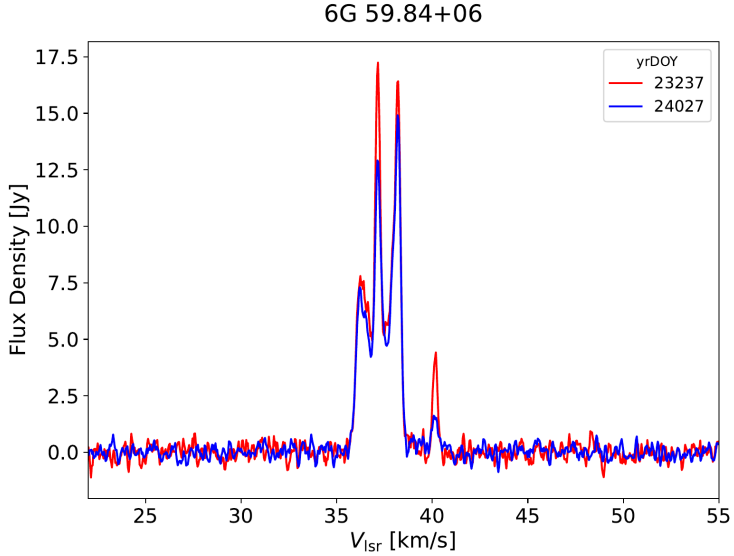
Light curve



Periodogram

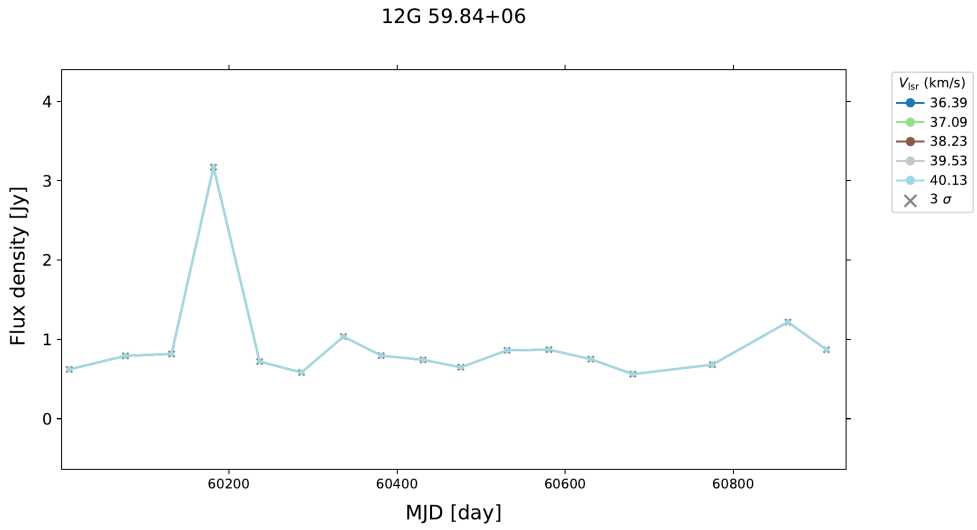


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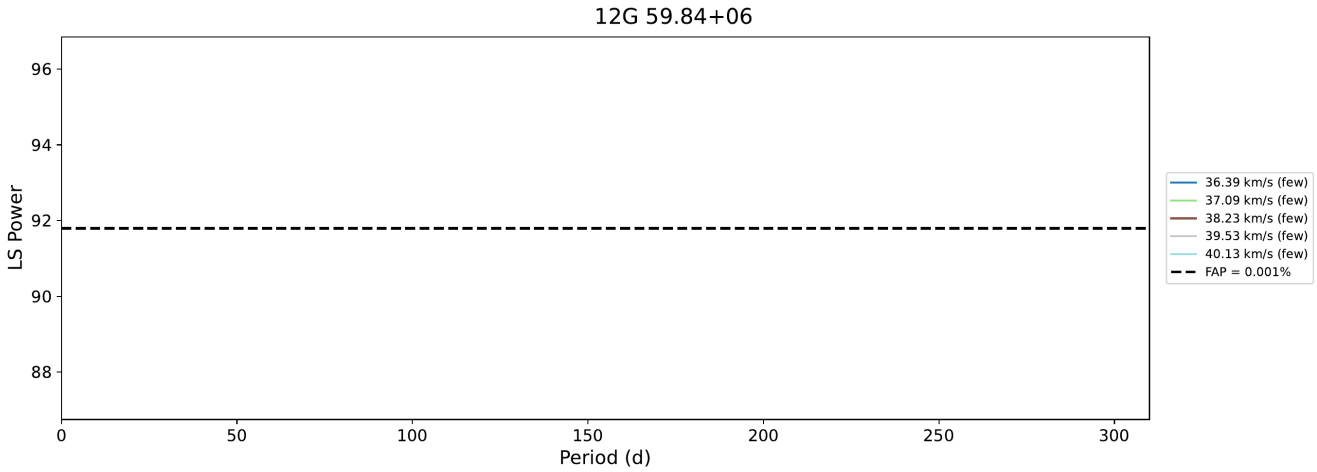


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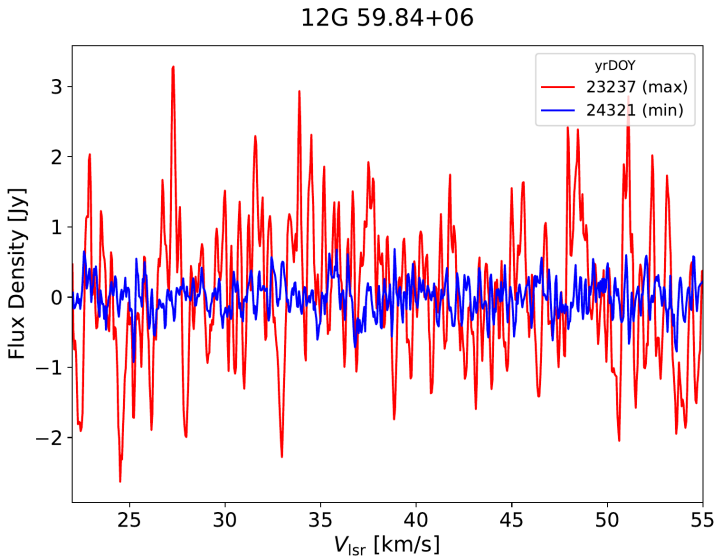
Light curve



Periodogram

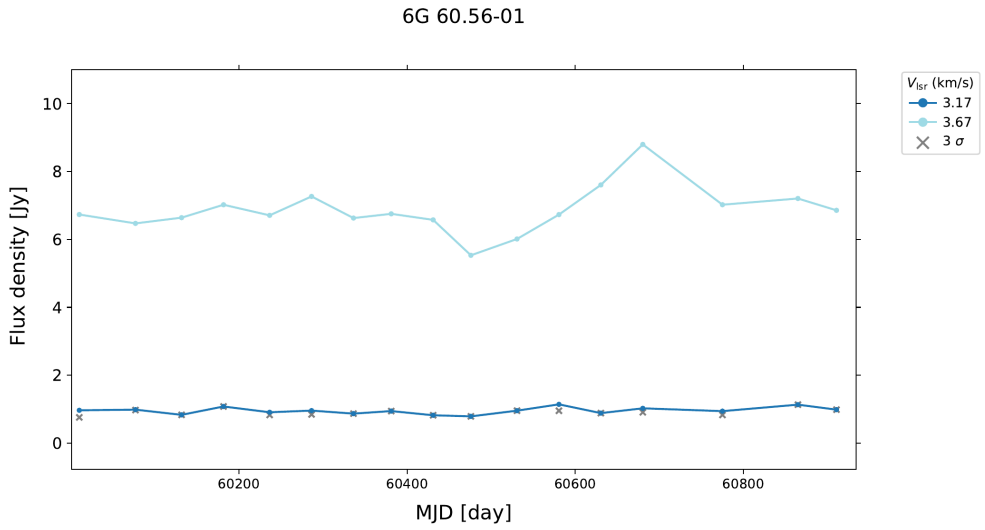


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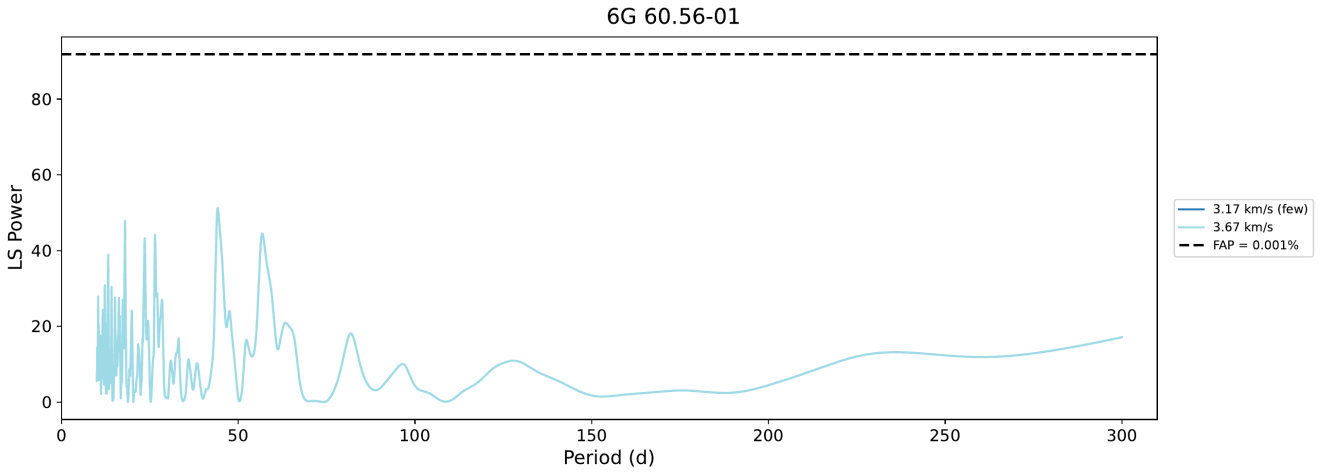


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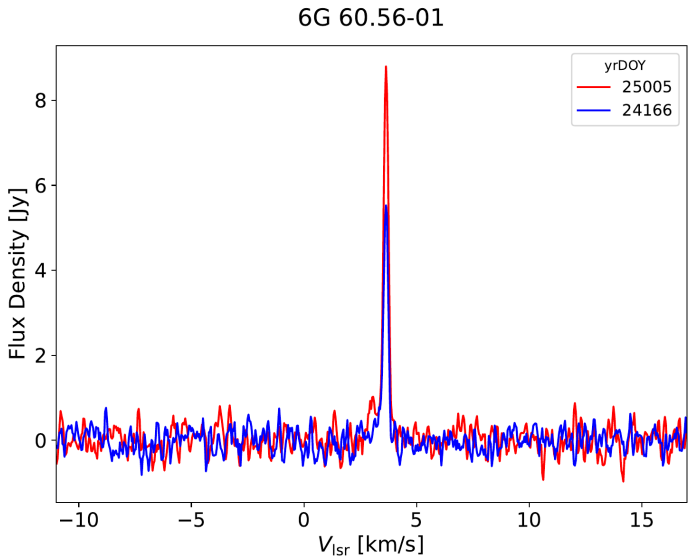
Light curve



Periodogram

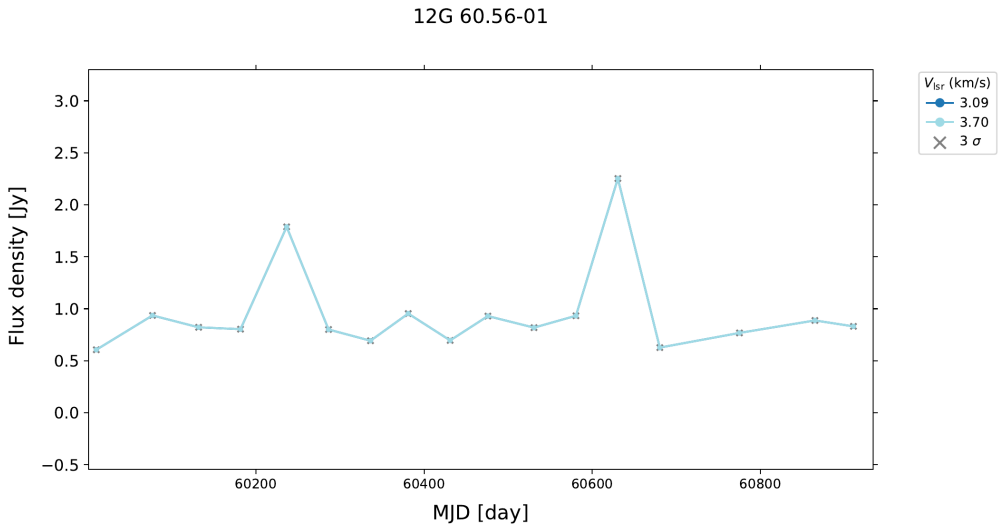


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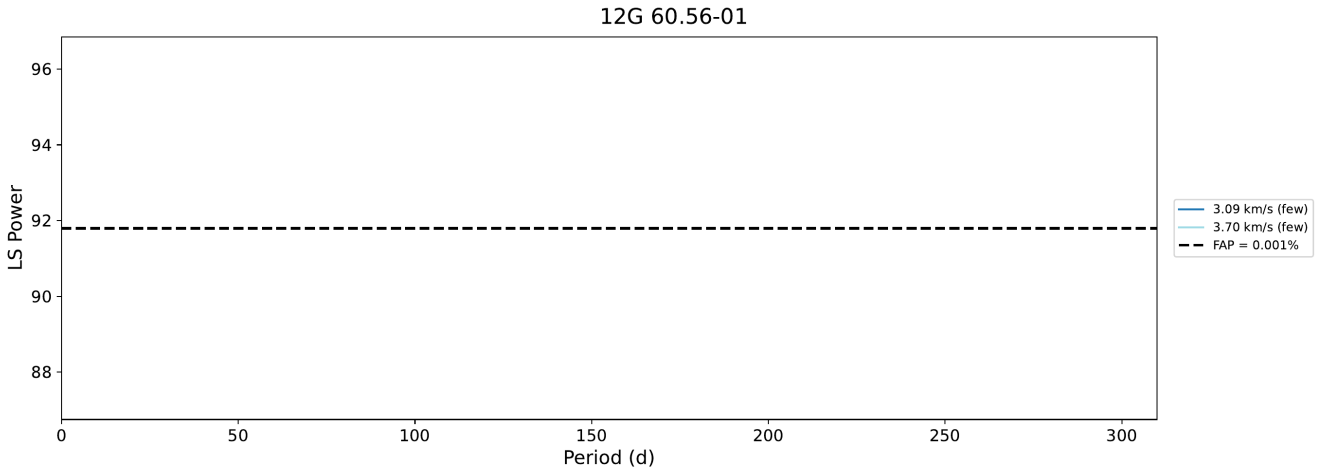


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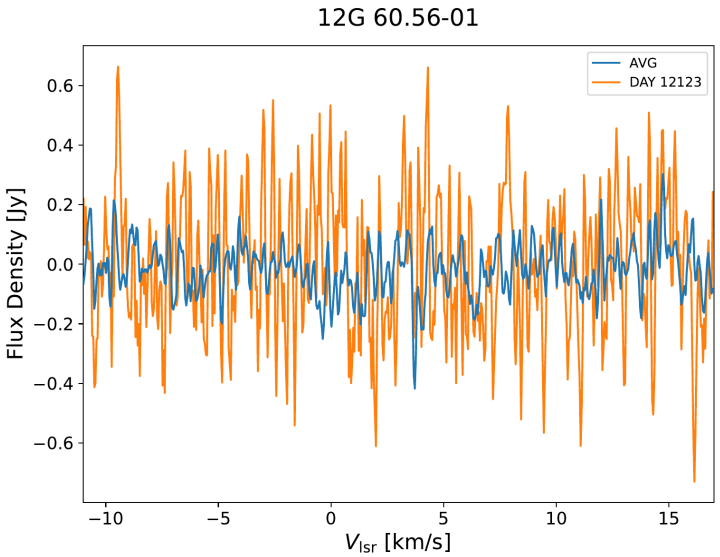
Light curve



Periodogram

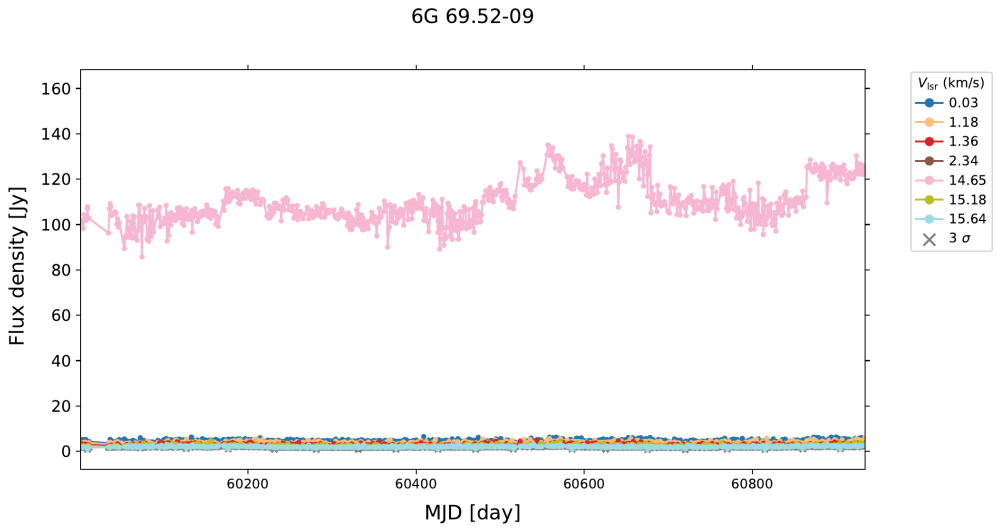


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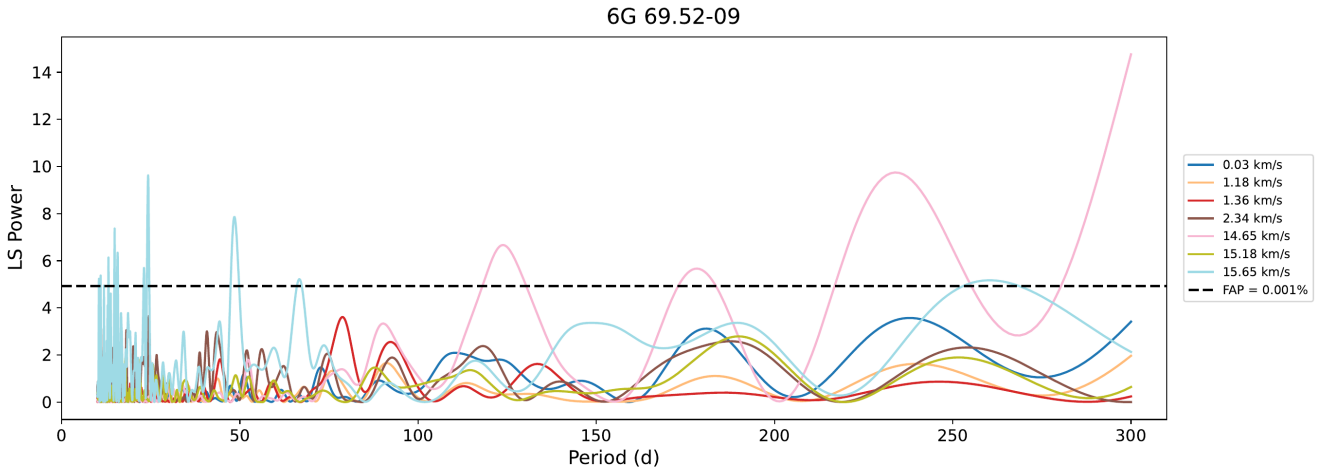


6G 69.52-09

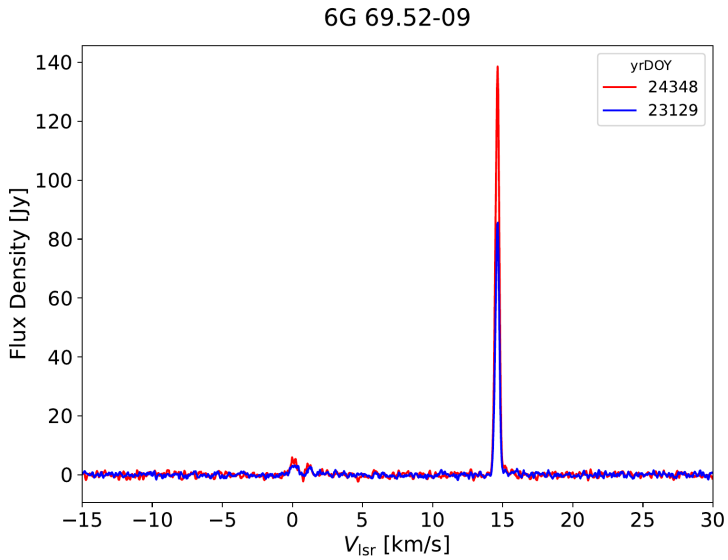
Light curve



Periodogram

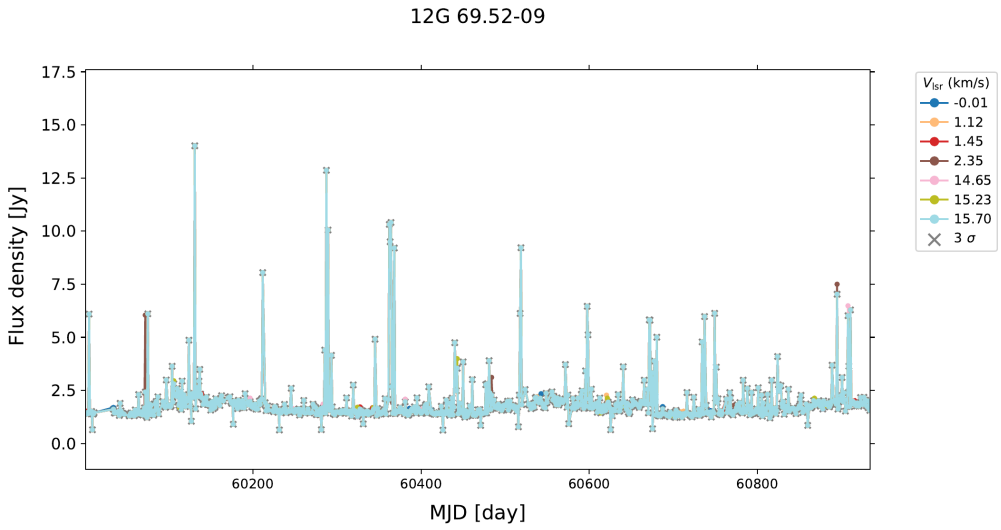


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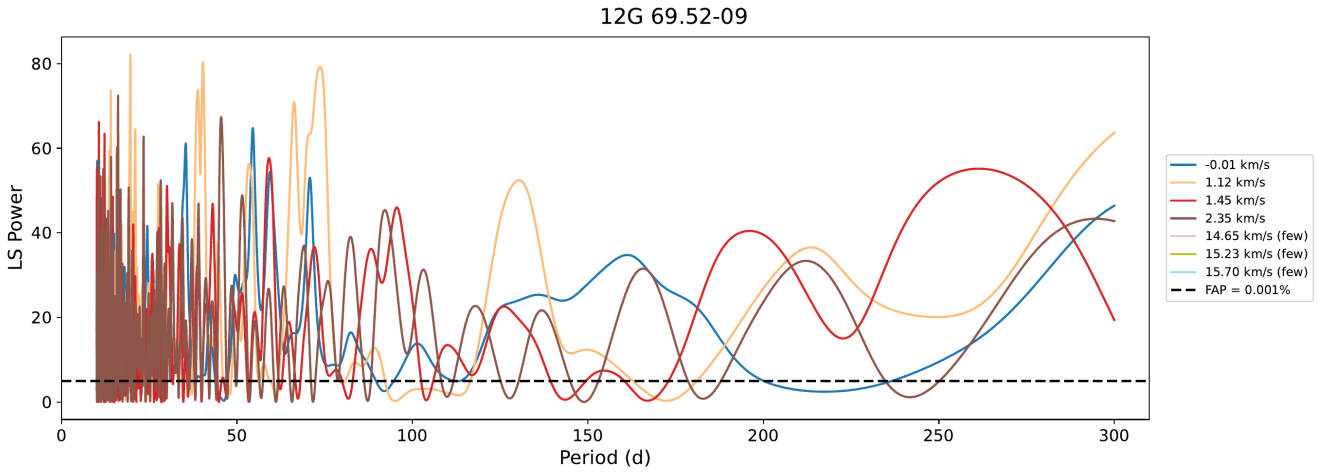


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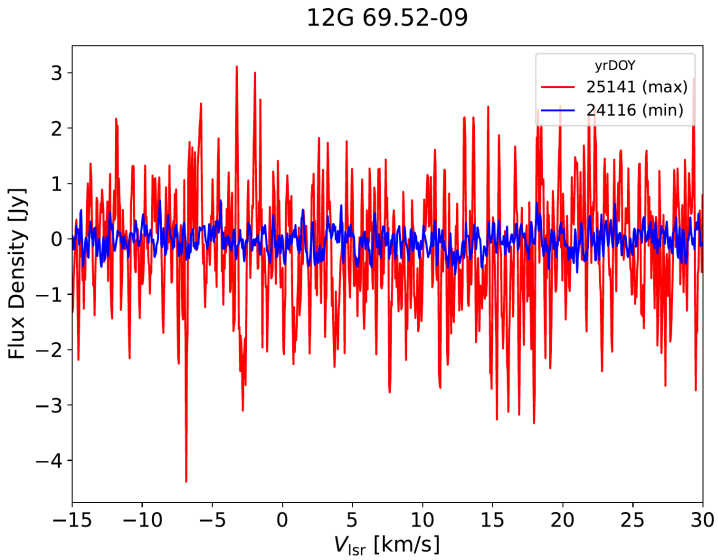
Light curve



Periodogram

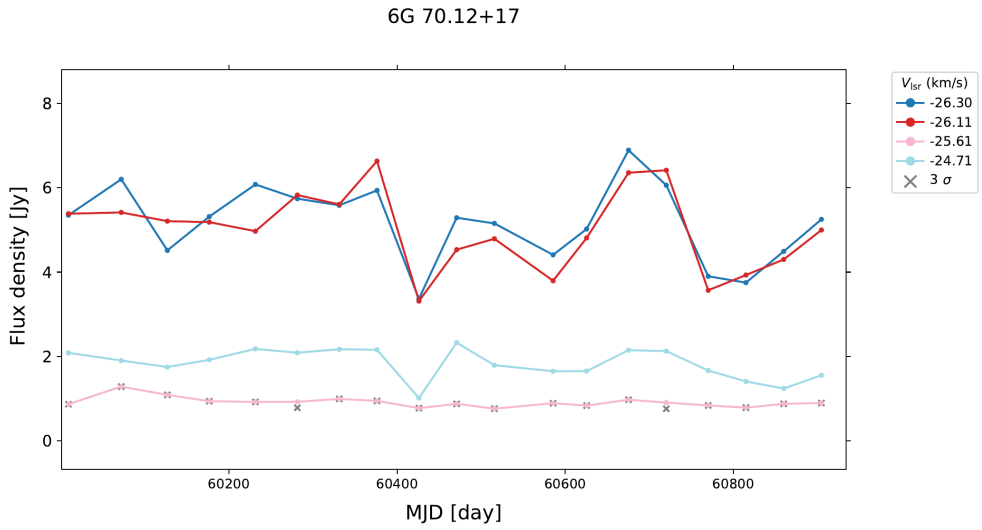


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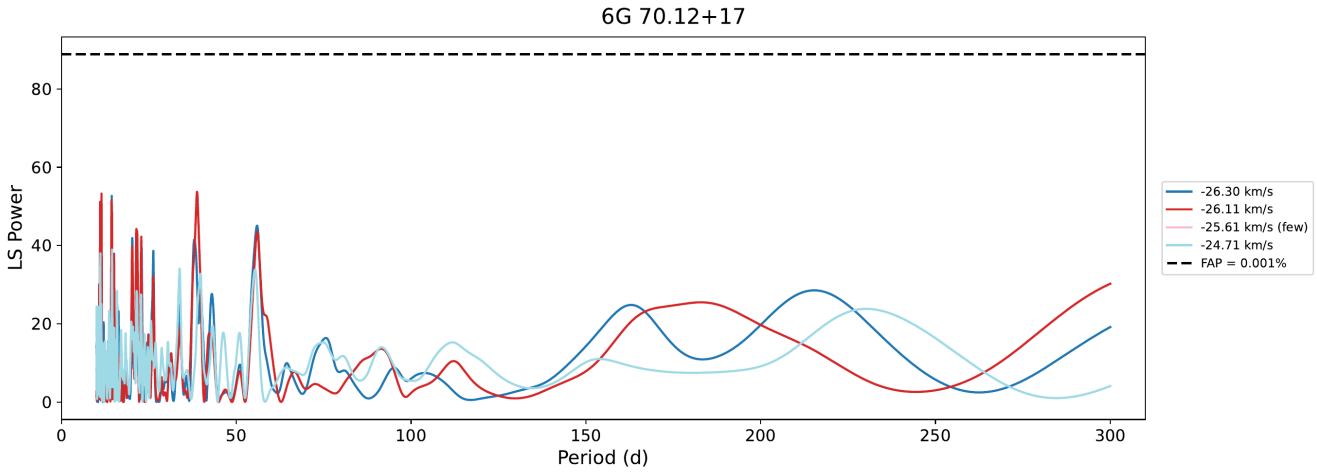


6G 70.12+17

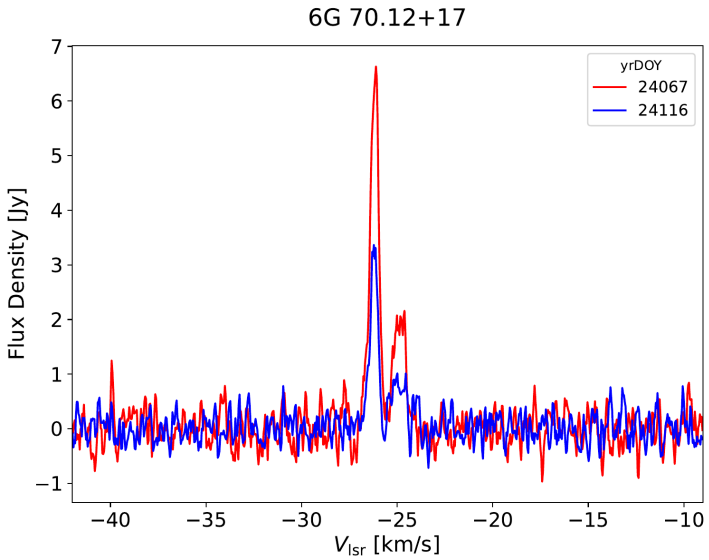
Light curve



Periodogram

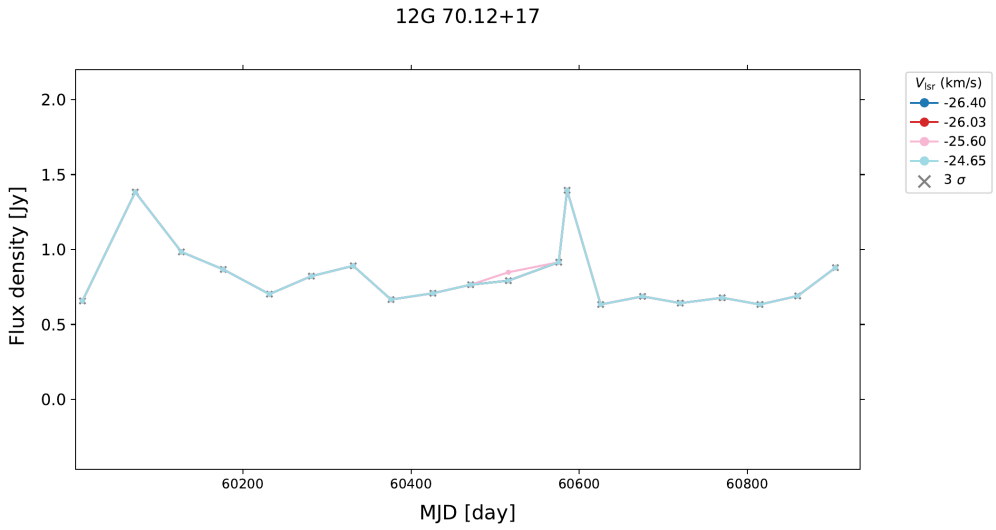


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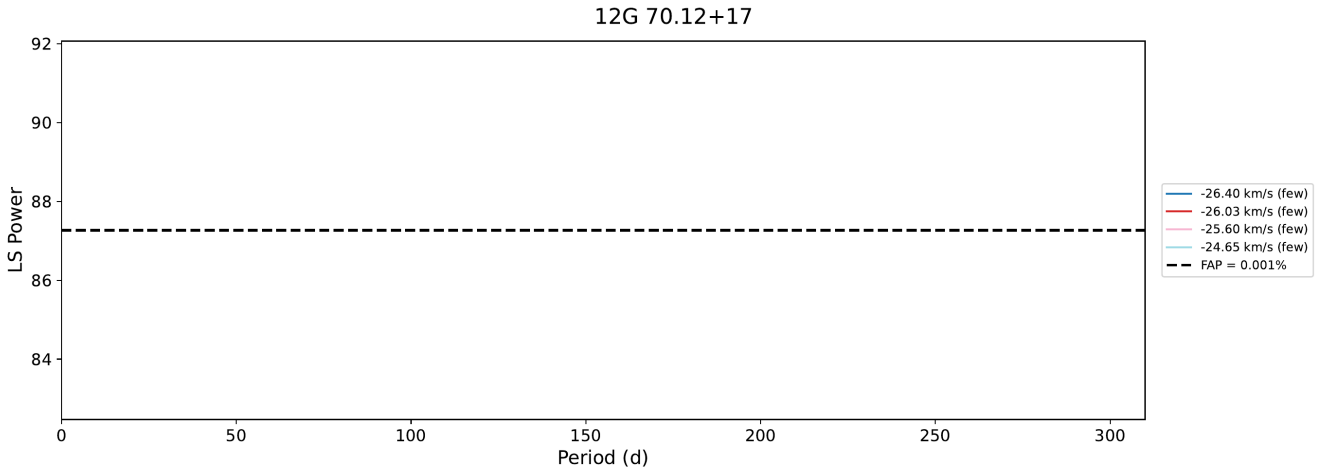


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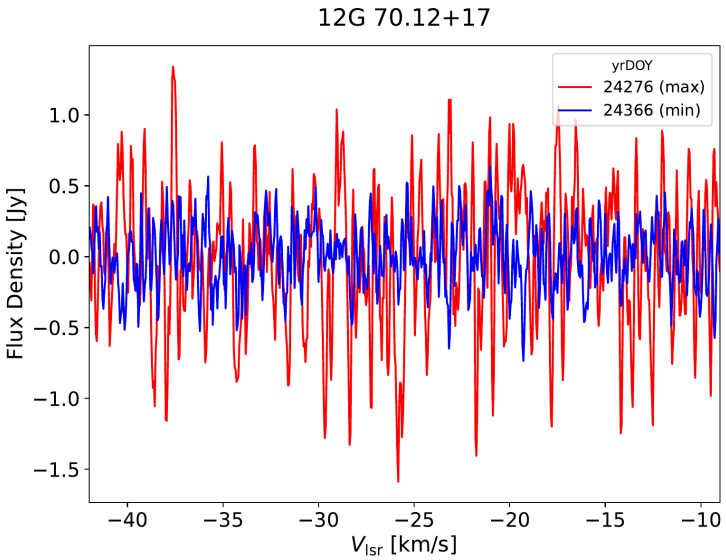
Light curve



Periodogram

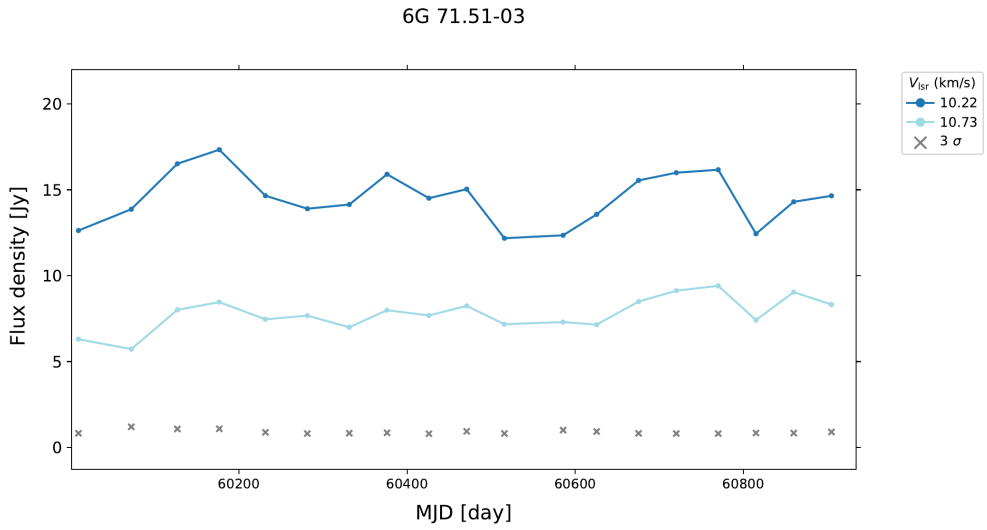


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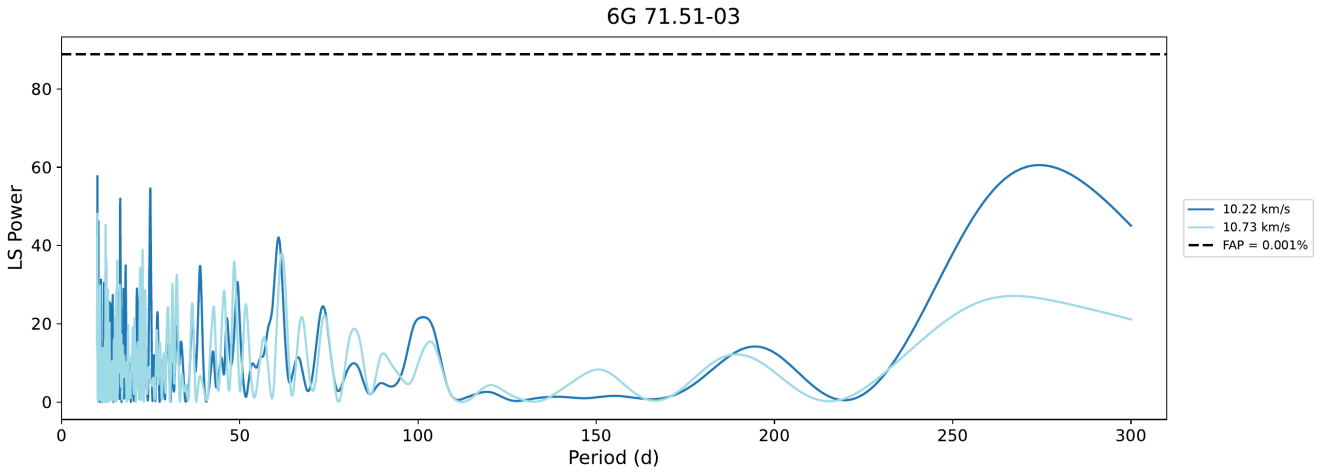


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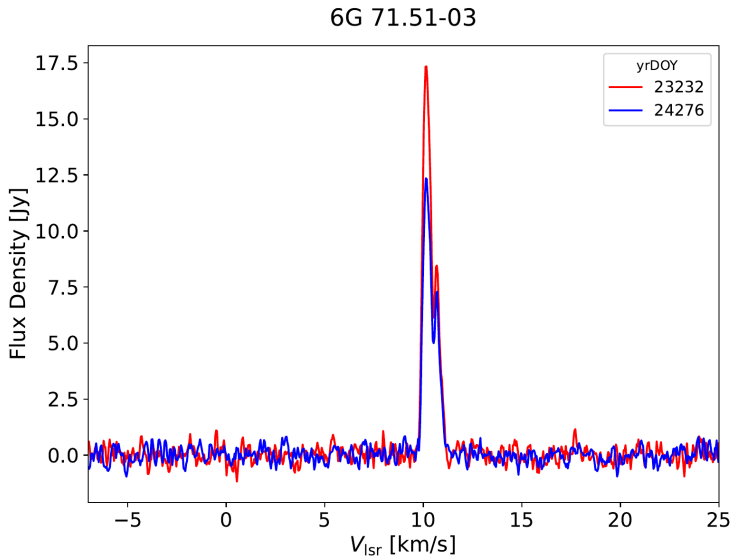
Light curve



Periodogram

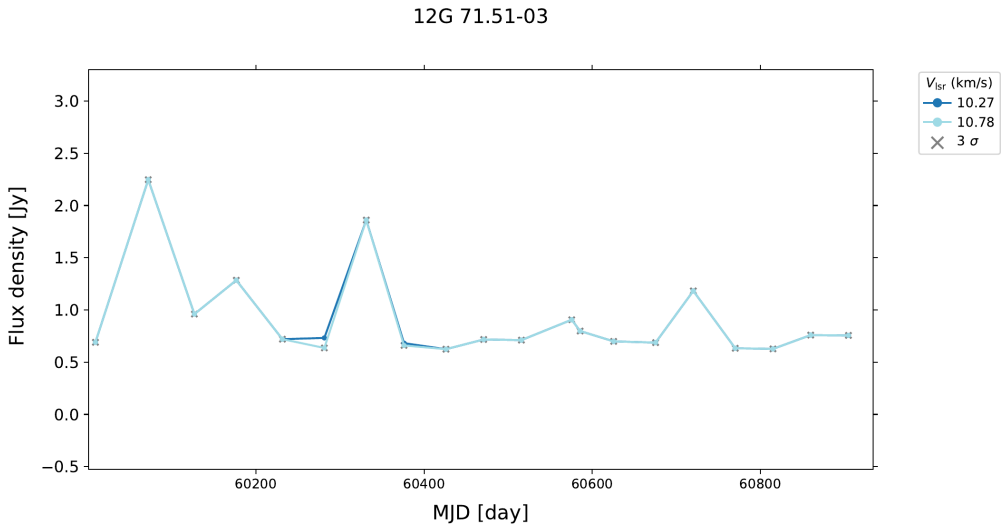


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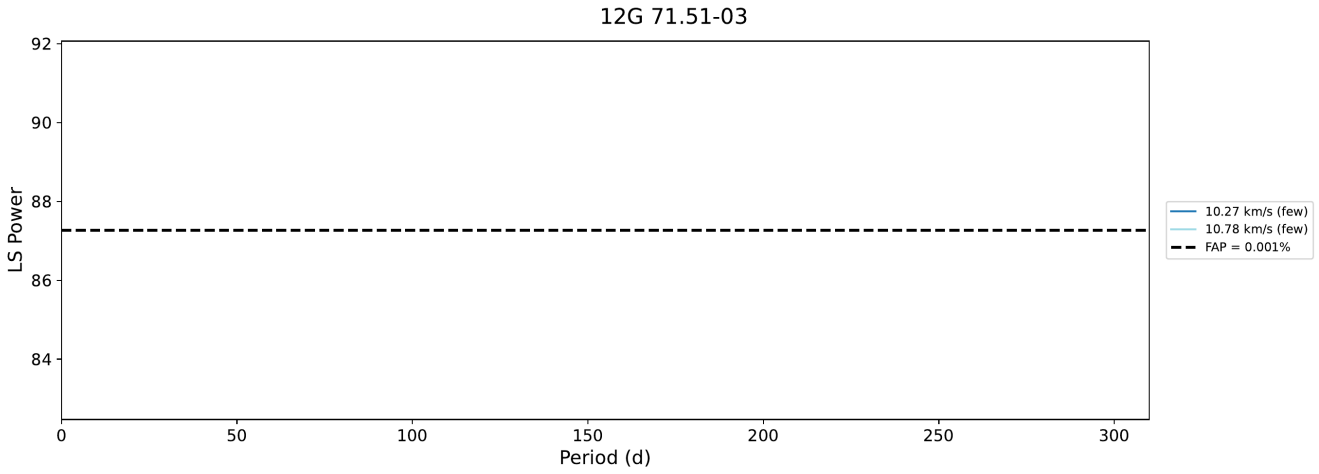


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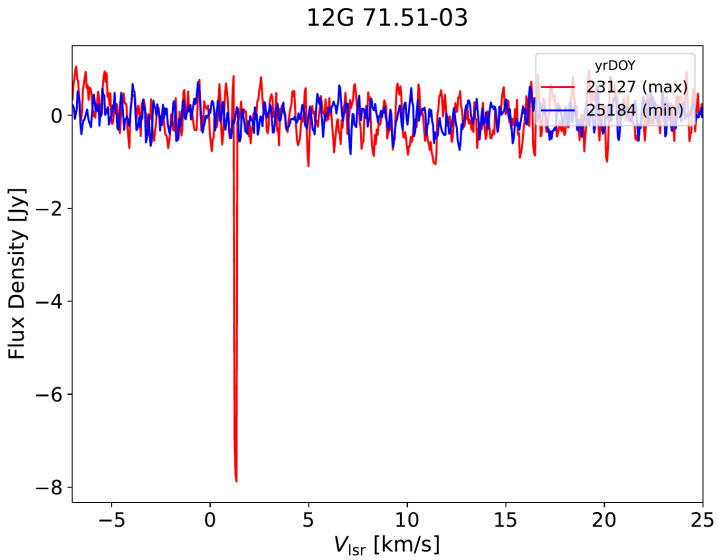
Light curve



Periodogram

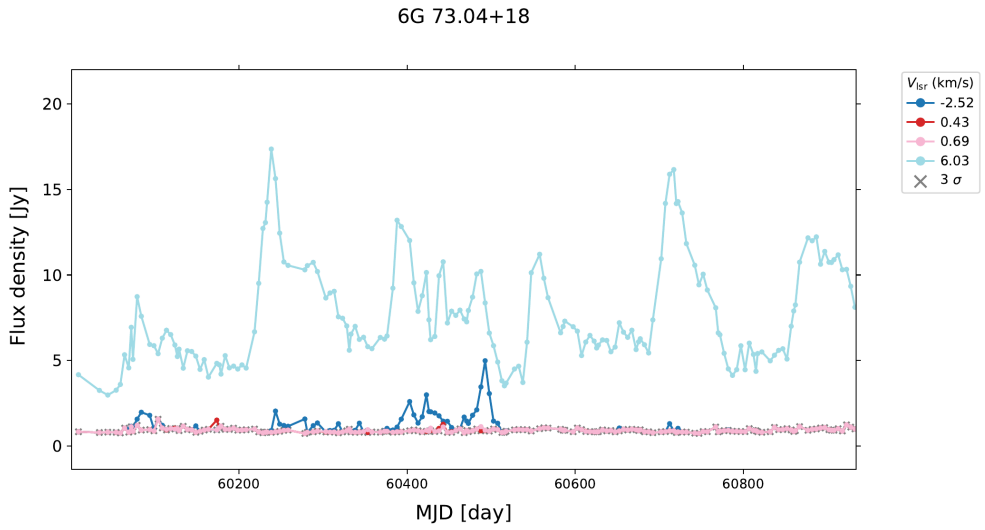


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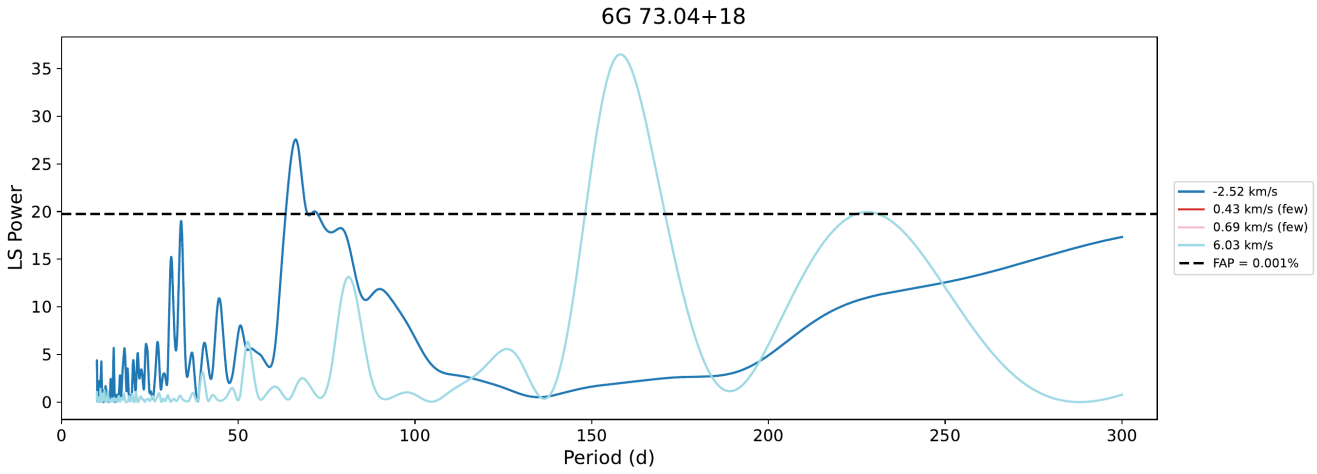


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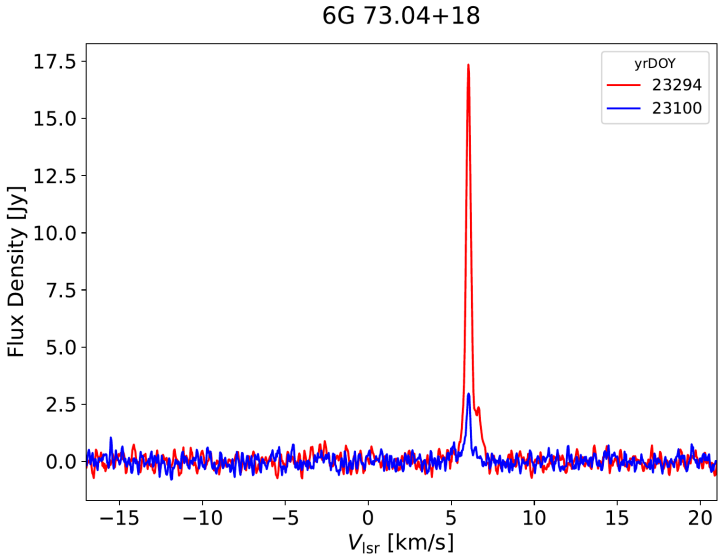
Light curve



Periodogram

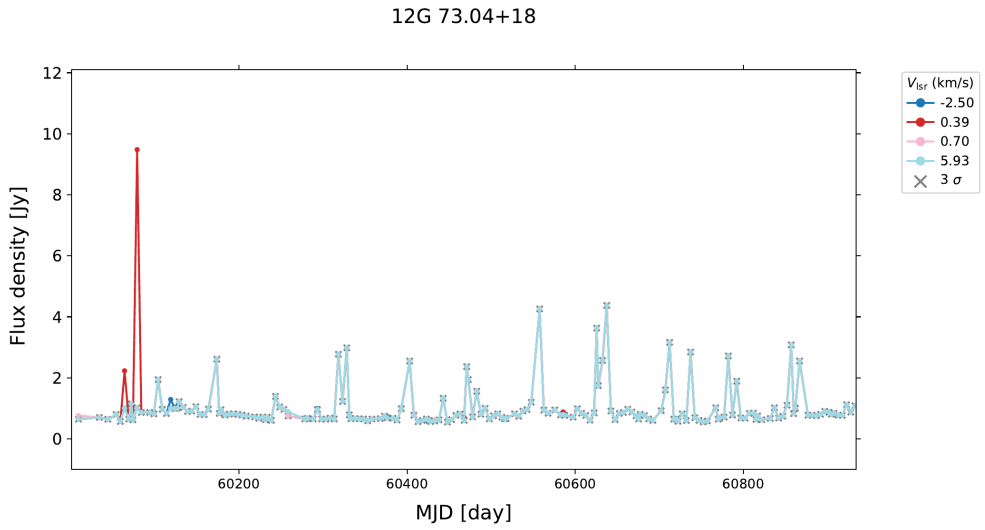


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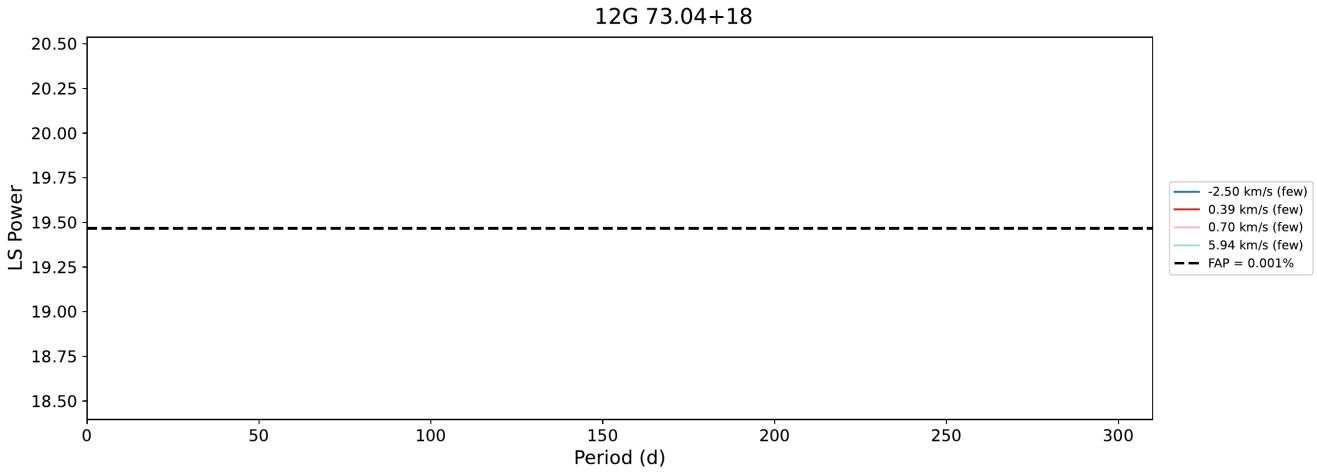


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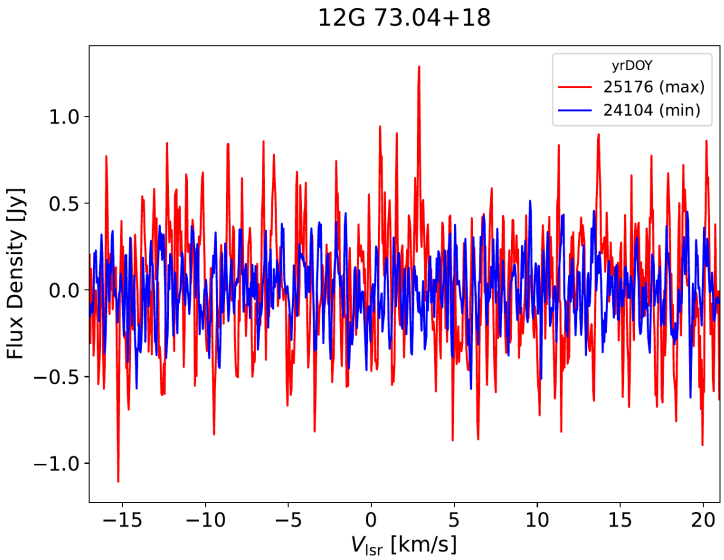
Light curve



Periodogram

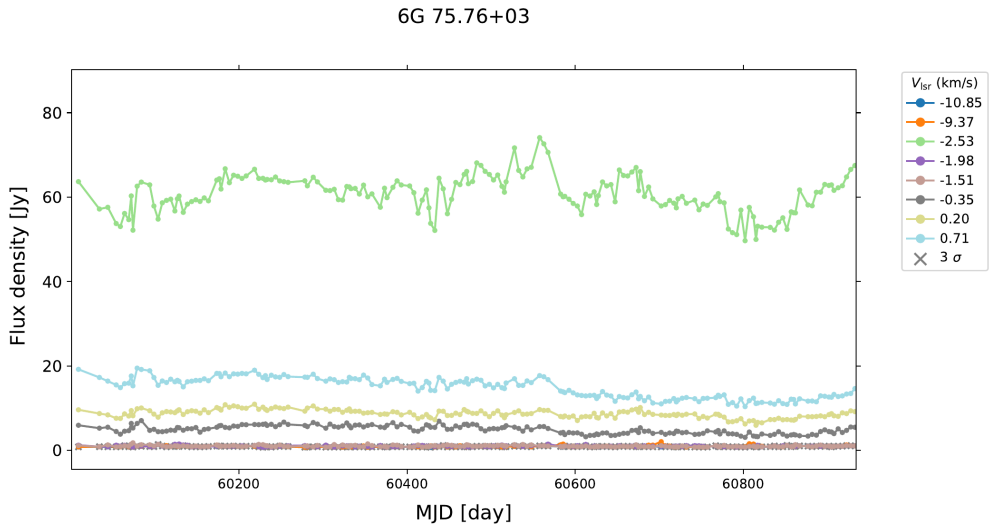


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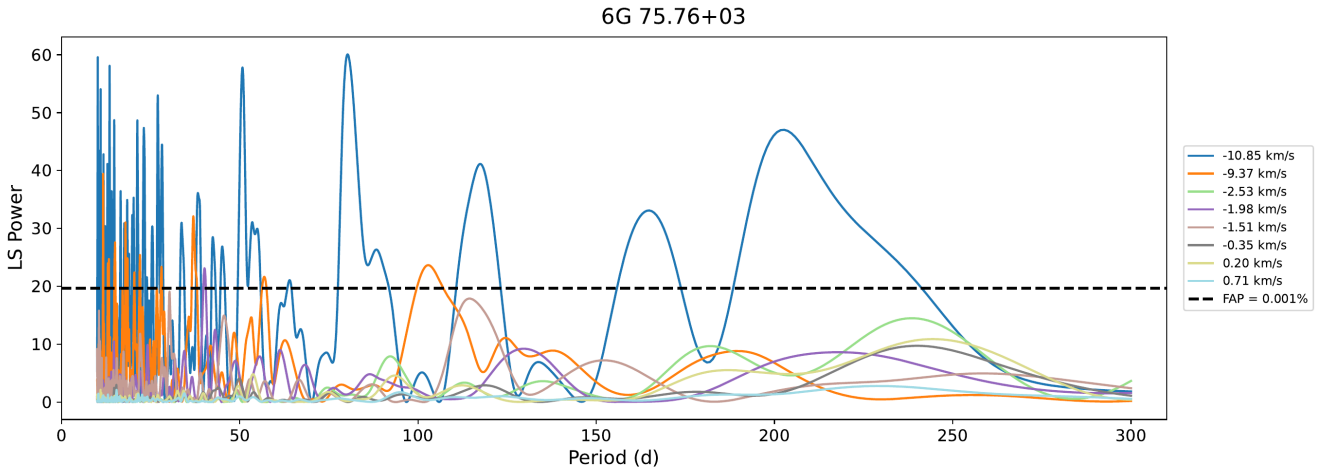


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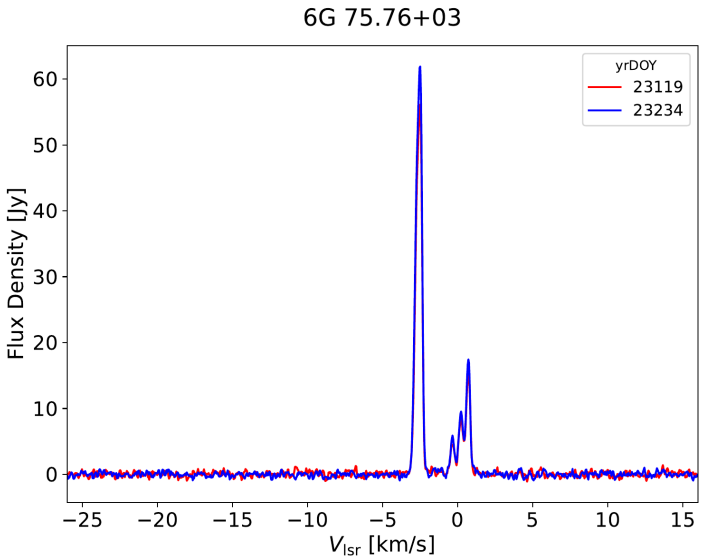
Light curve



Periodogram

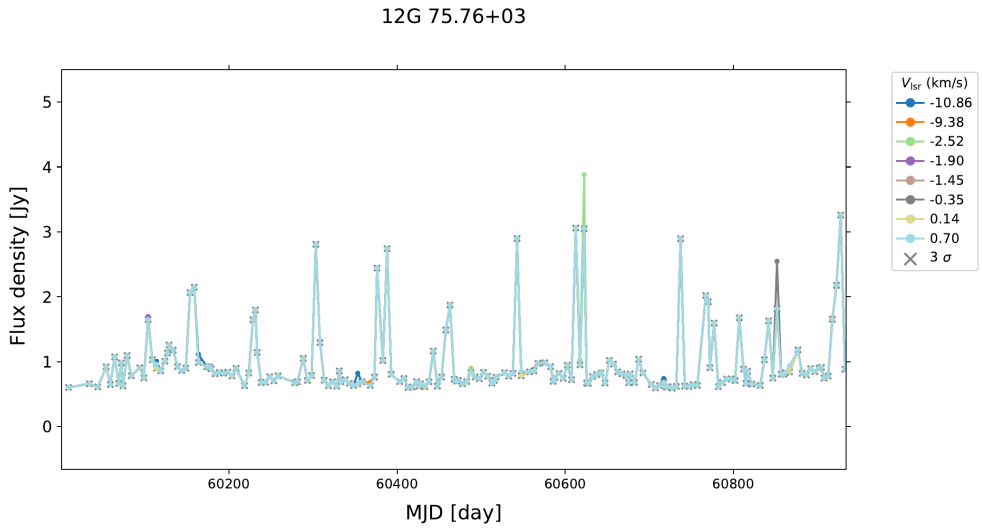


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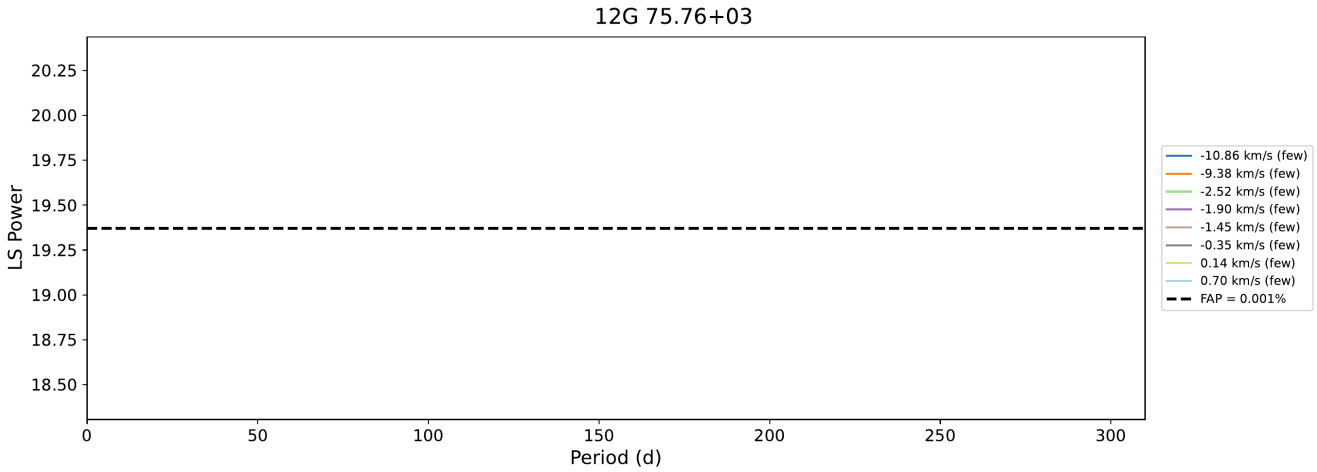


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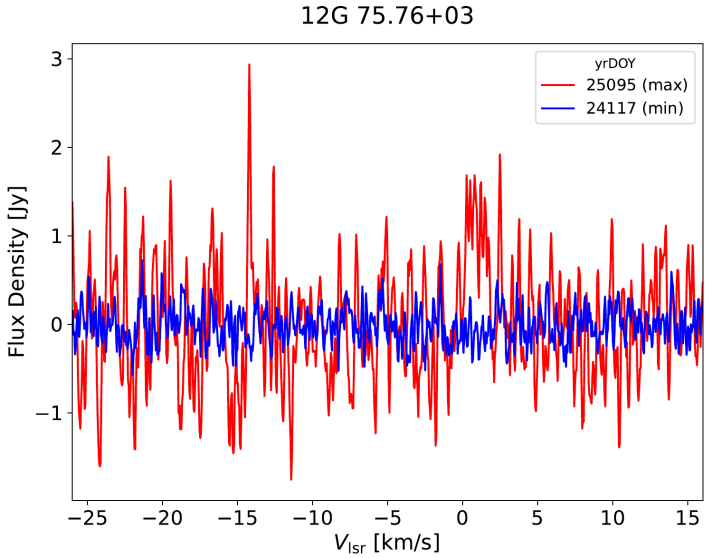
Light curve



Periodogram

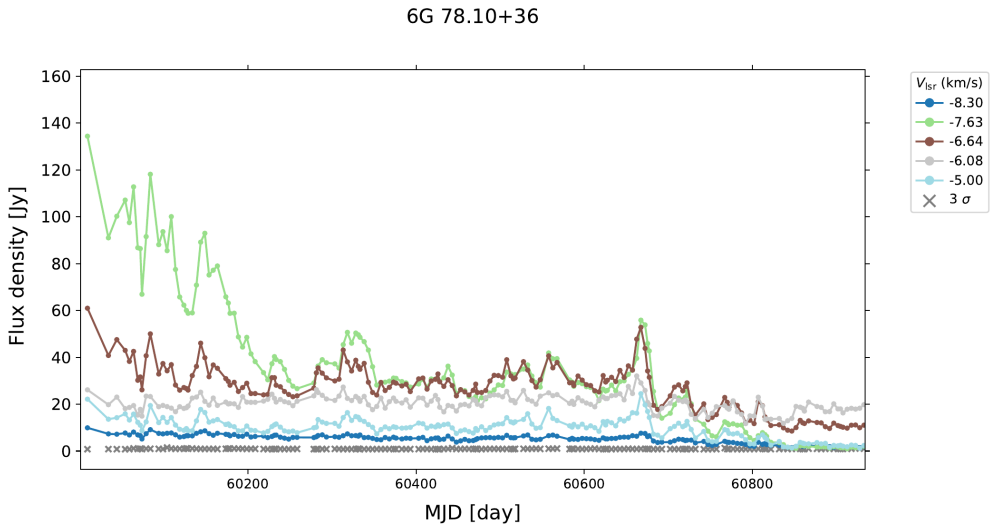


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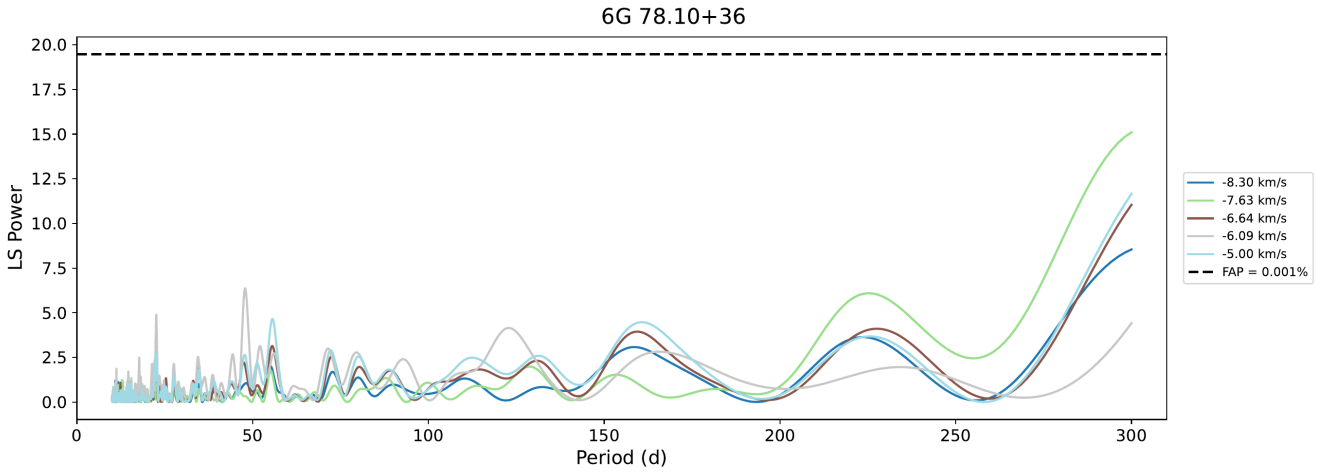


6G 78.10+36

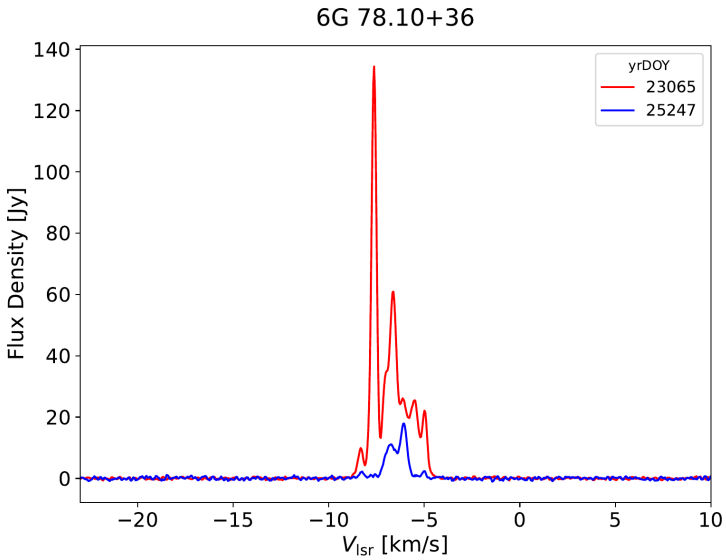
Light curve



Periodogram

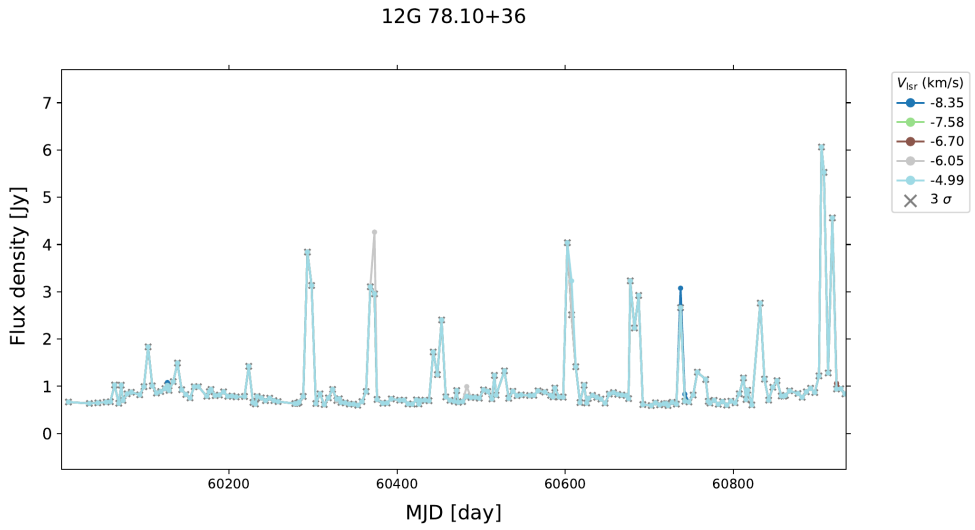


Spectrum

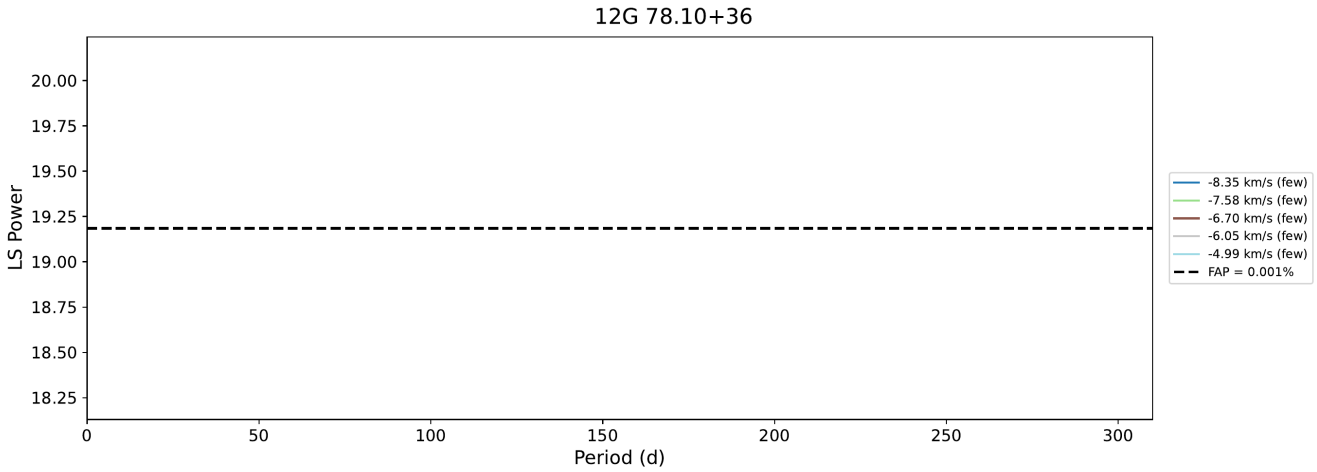


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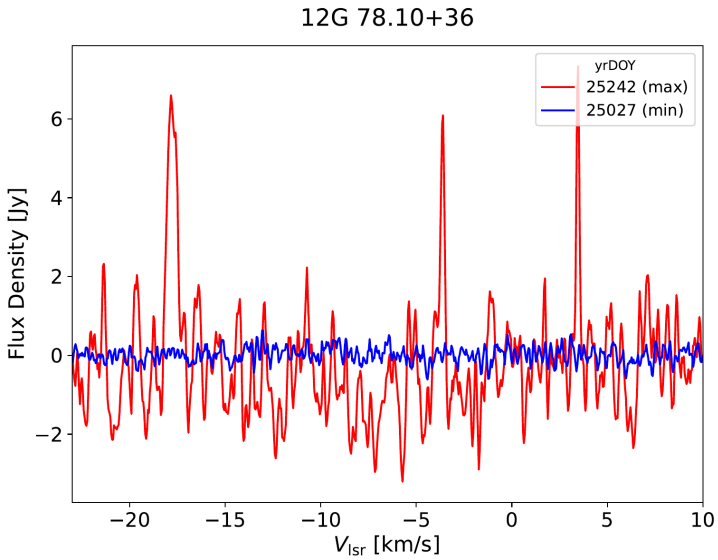
Light curve



Periodogram

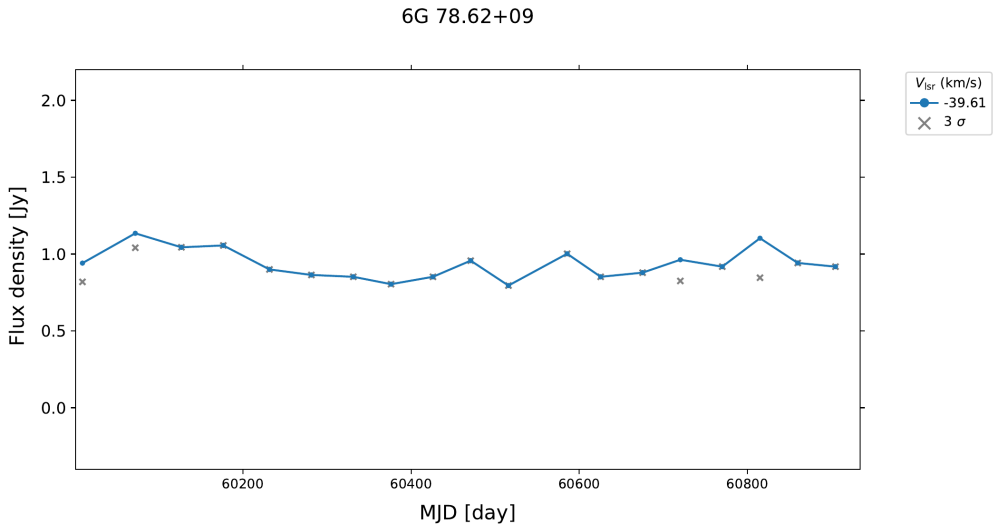


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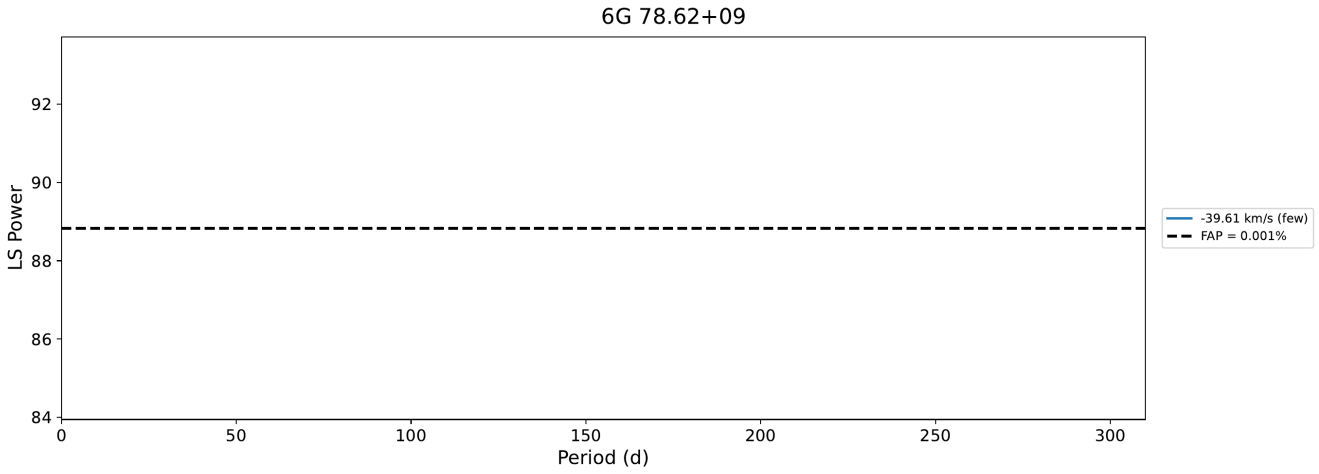


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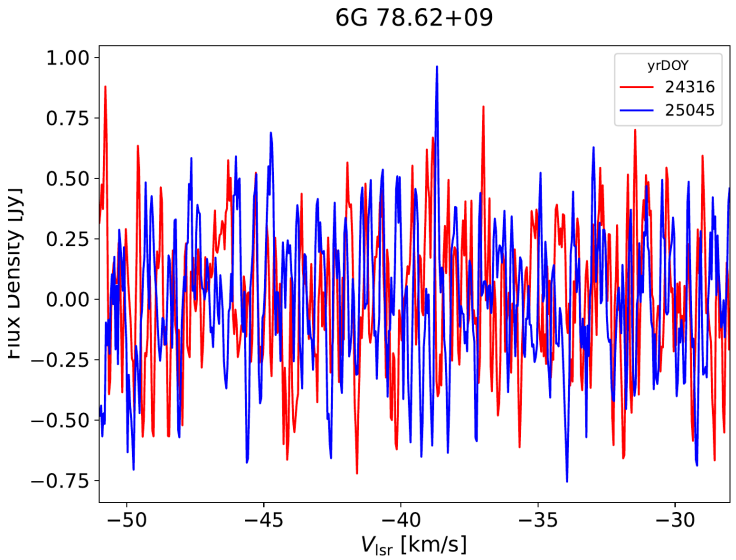
Light curve



Periodogram

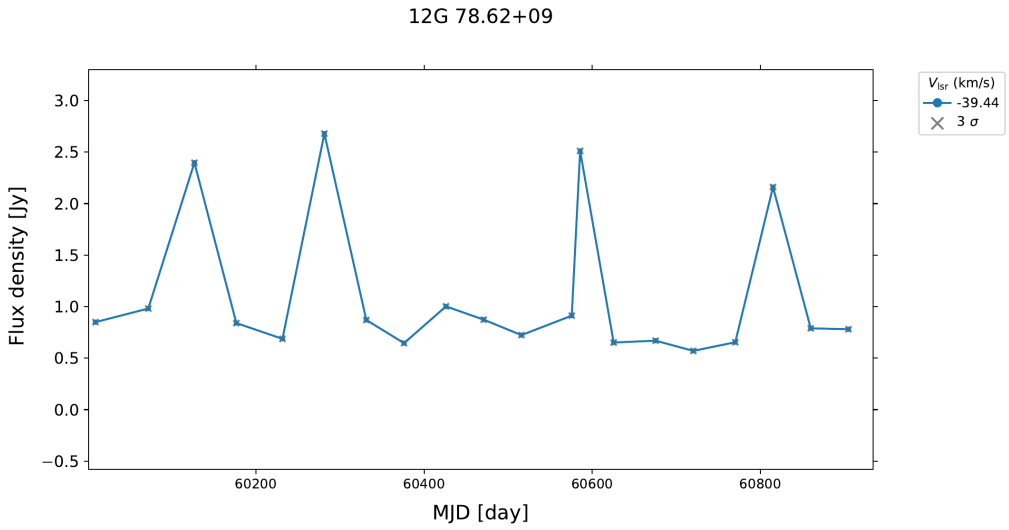


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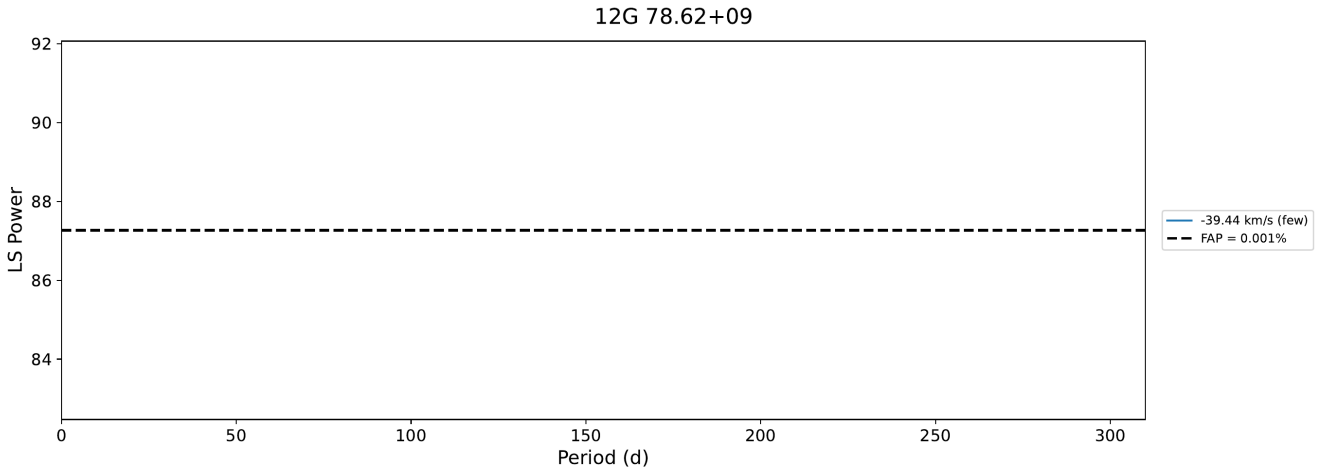


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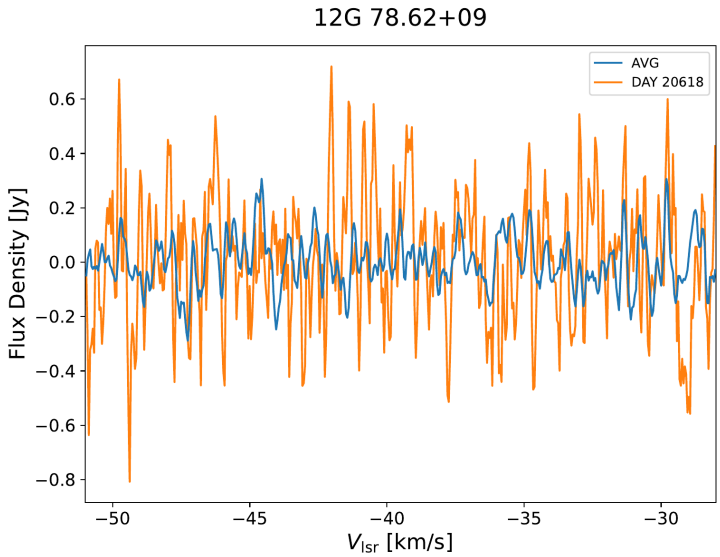
Light curve



Periodogram

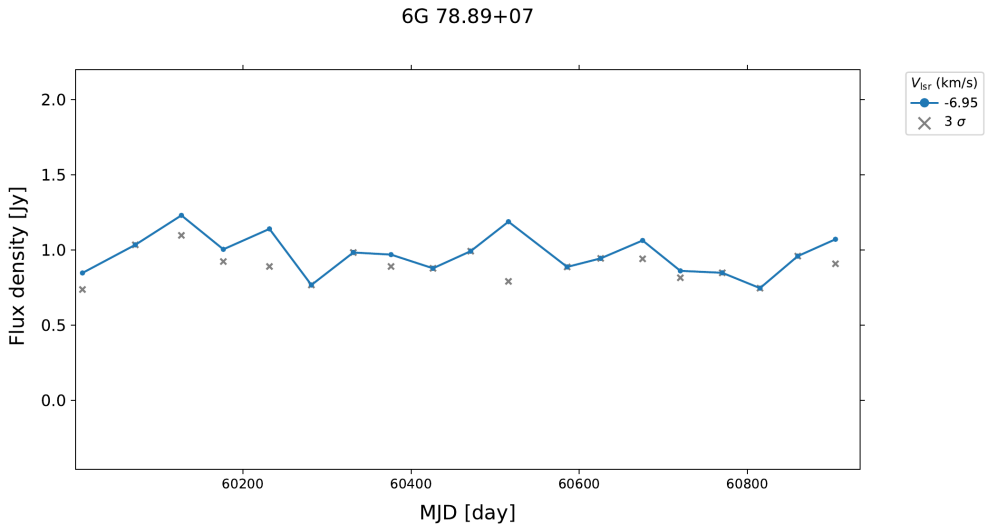


Spectrum

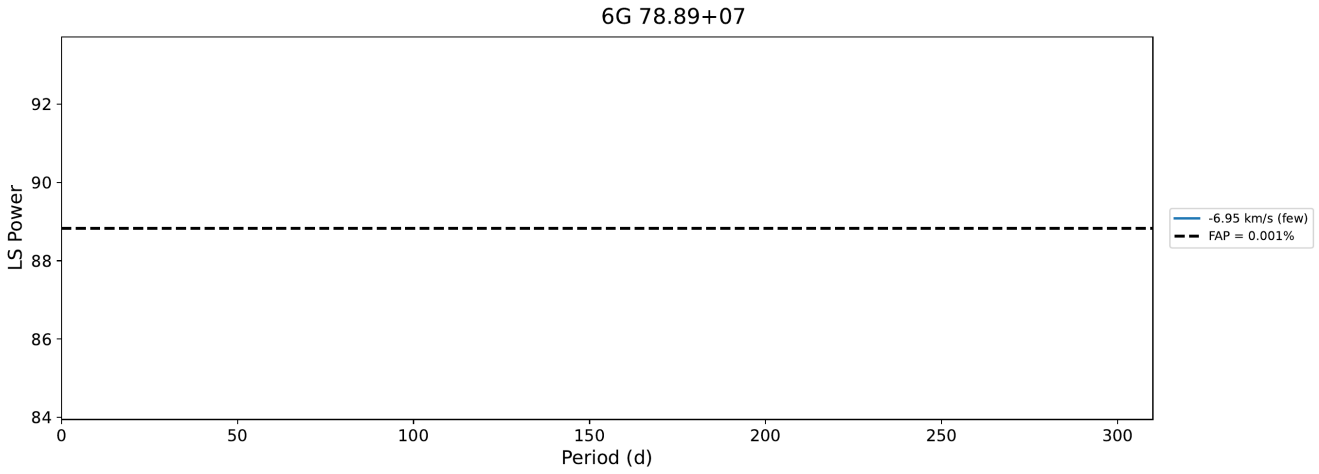


6G 78.89+07

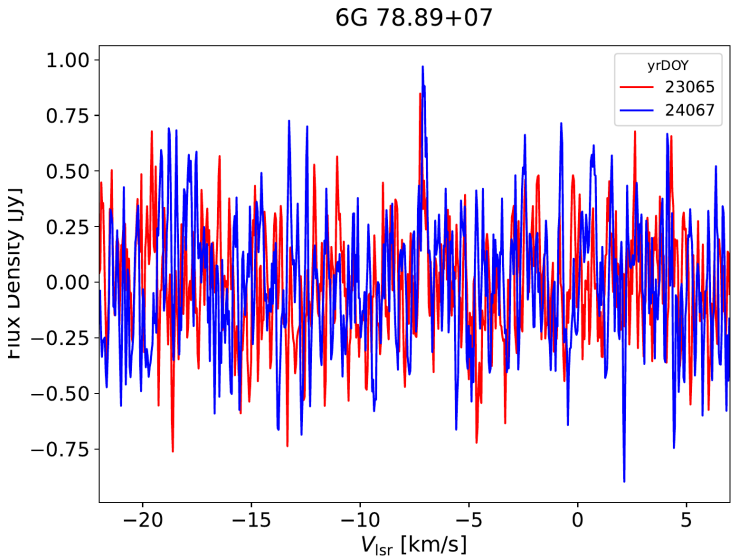
Light curve



Periodogram

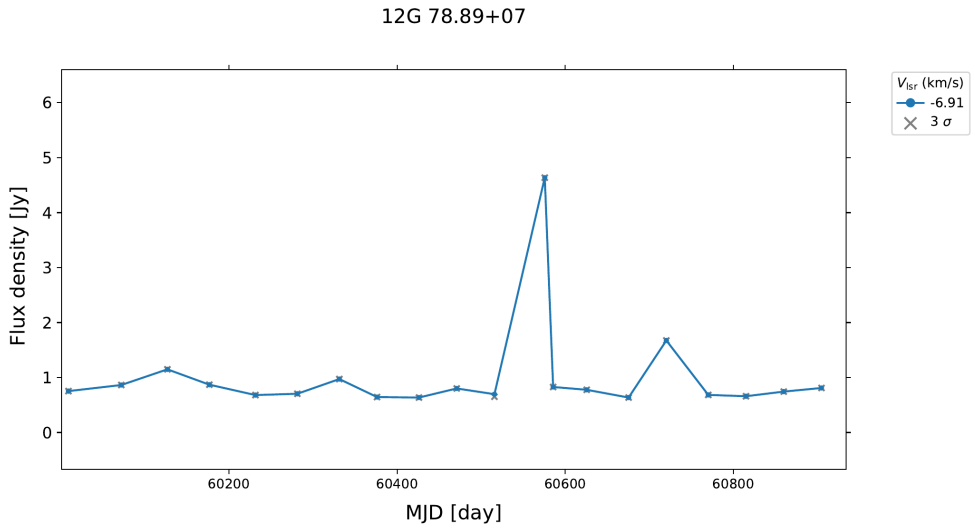


Spectrum

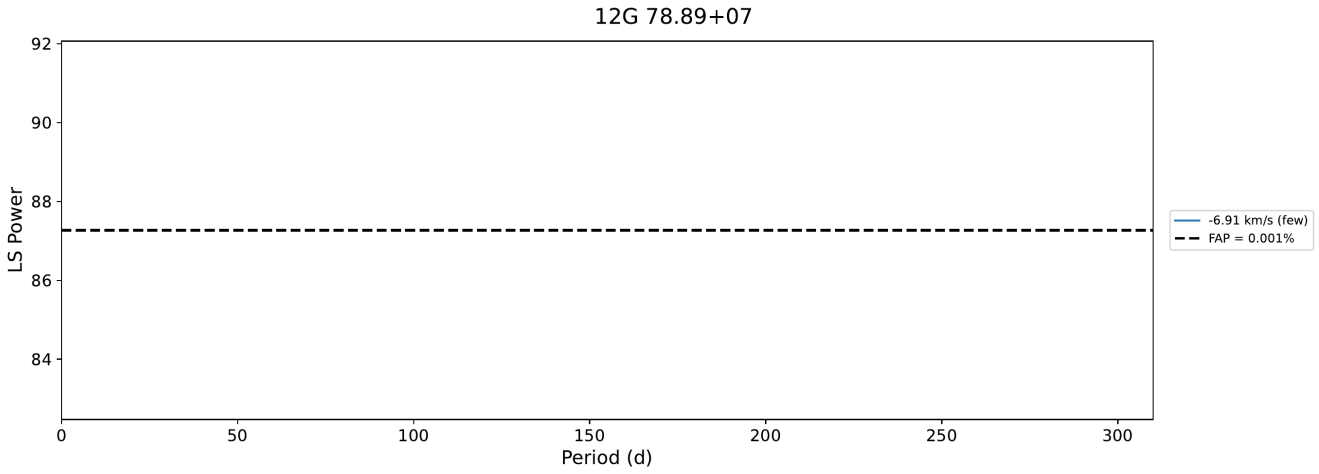


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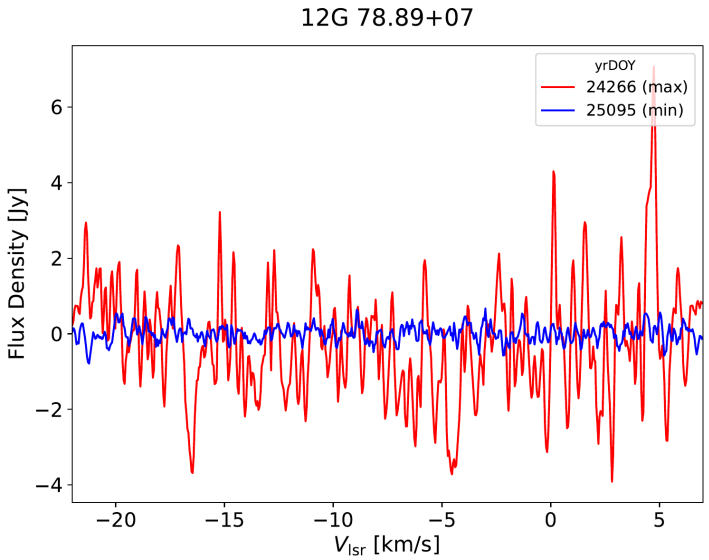
Light curve



Periodogram

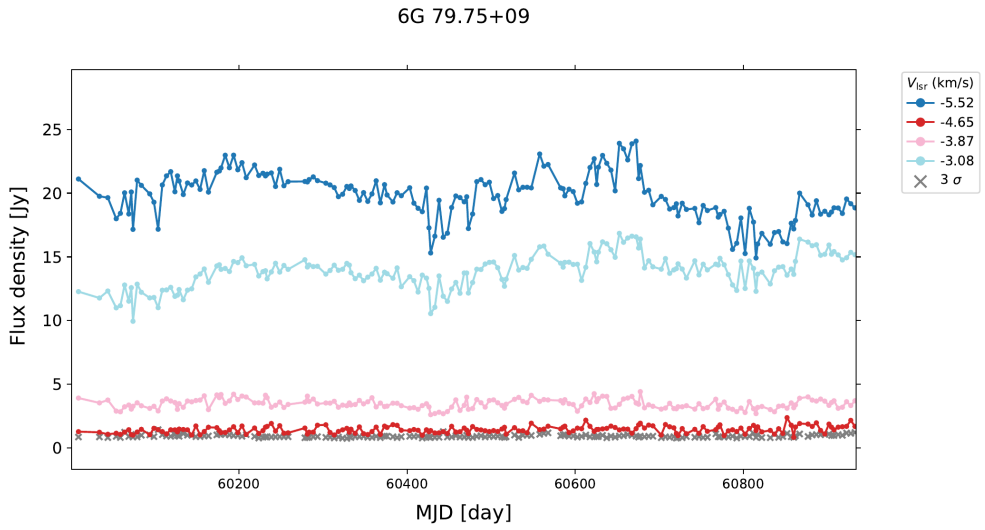


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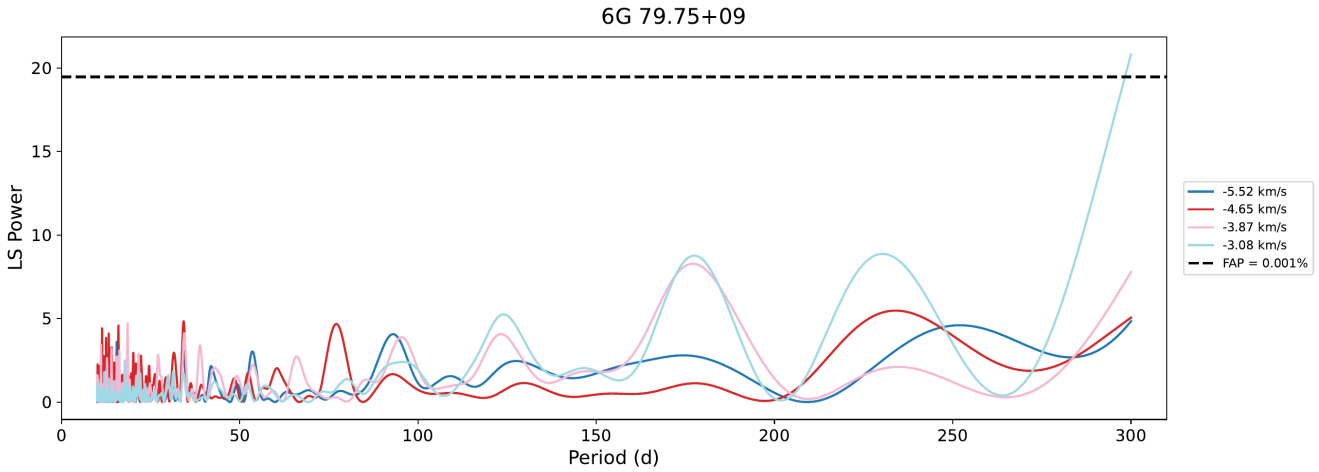


6G 79.75+09

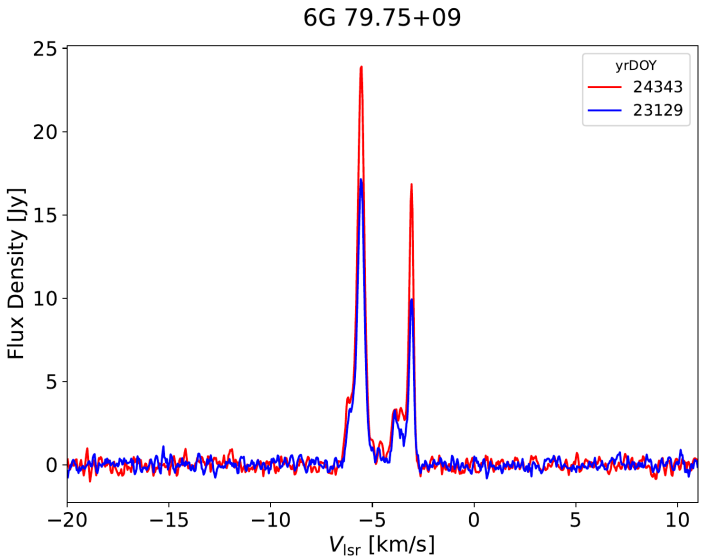
Light curve



Periodogram

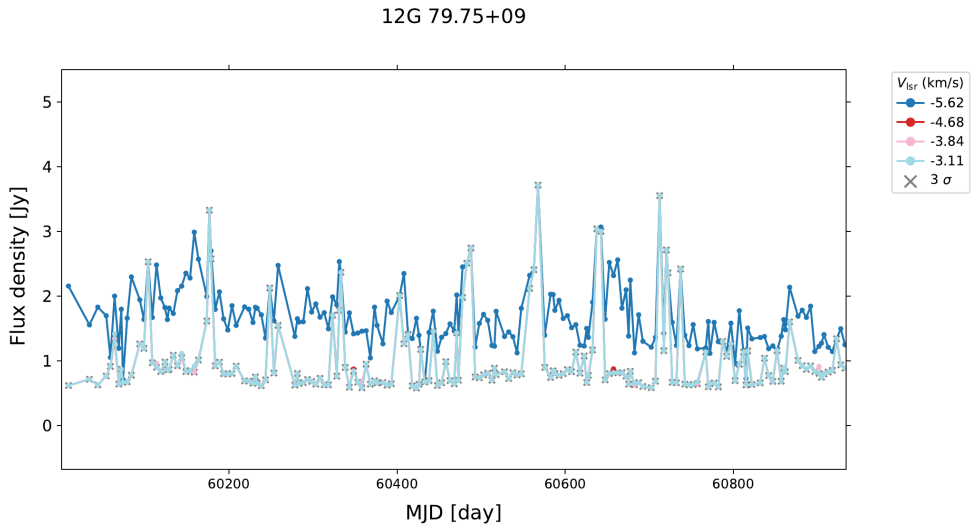


Spectrum

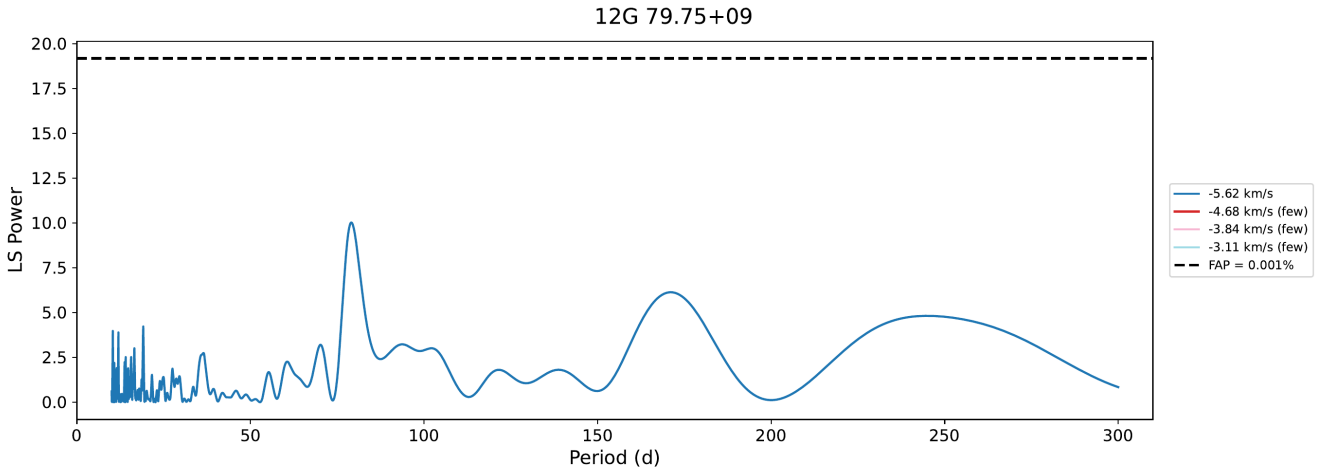


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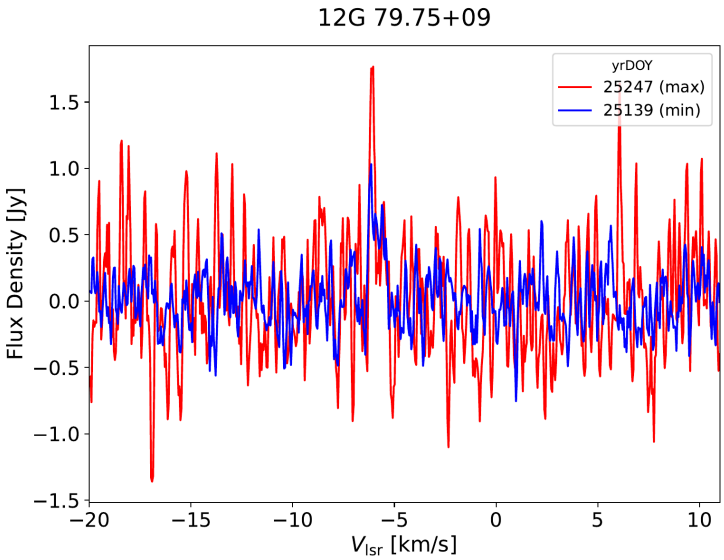
Light curve



Periodogram

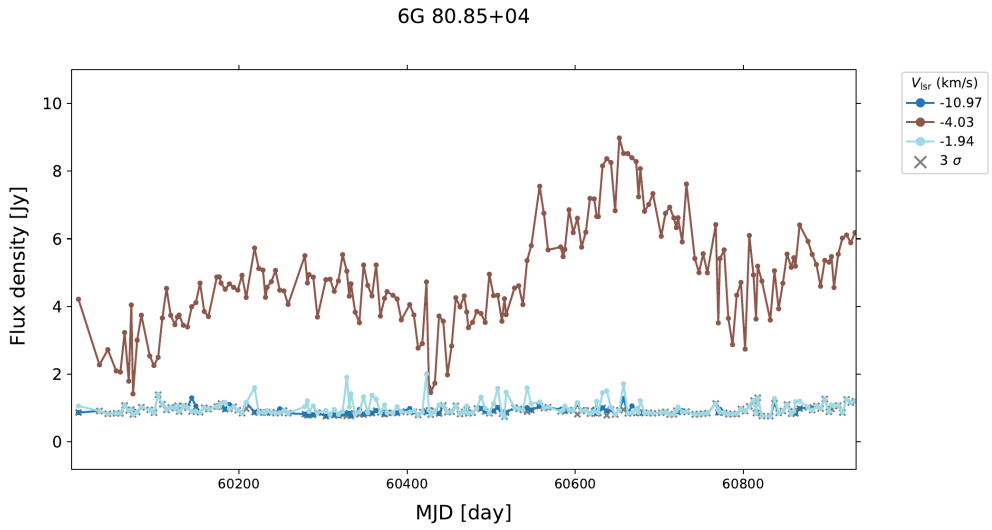


Spectrum

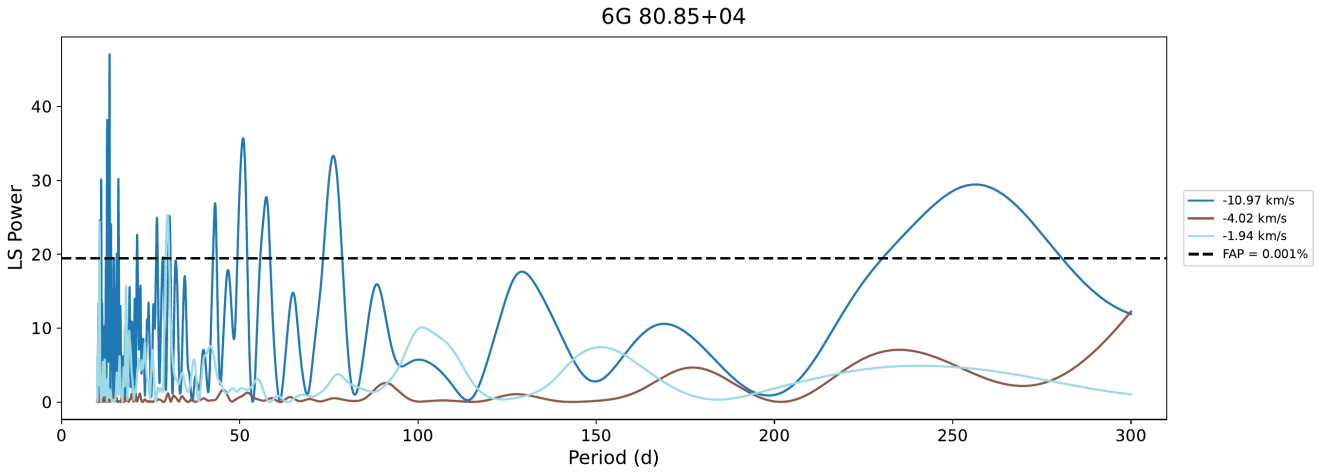


6G 80.85+04

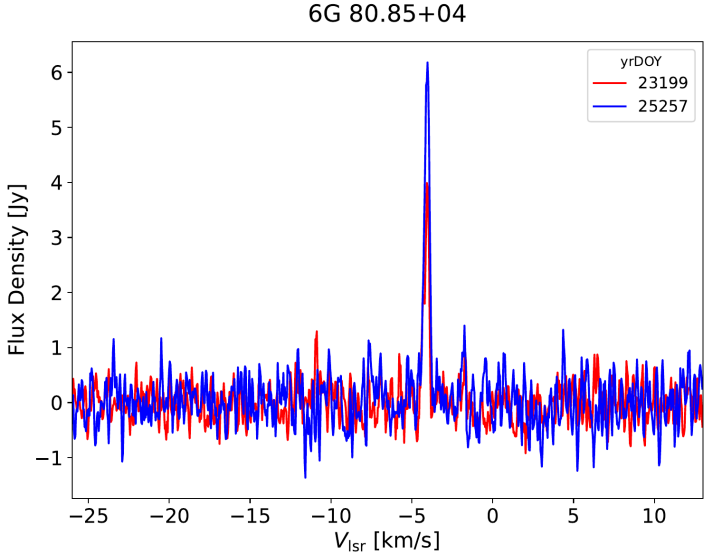
Light curve



Periodogram

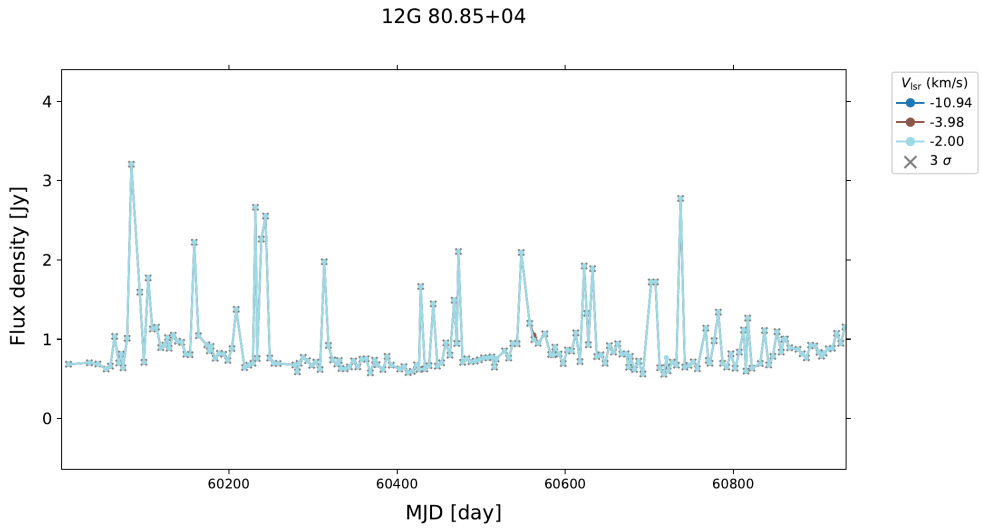


Spectrum

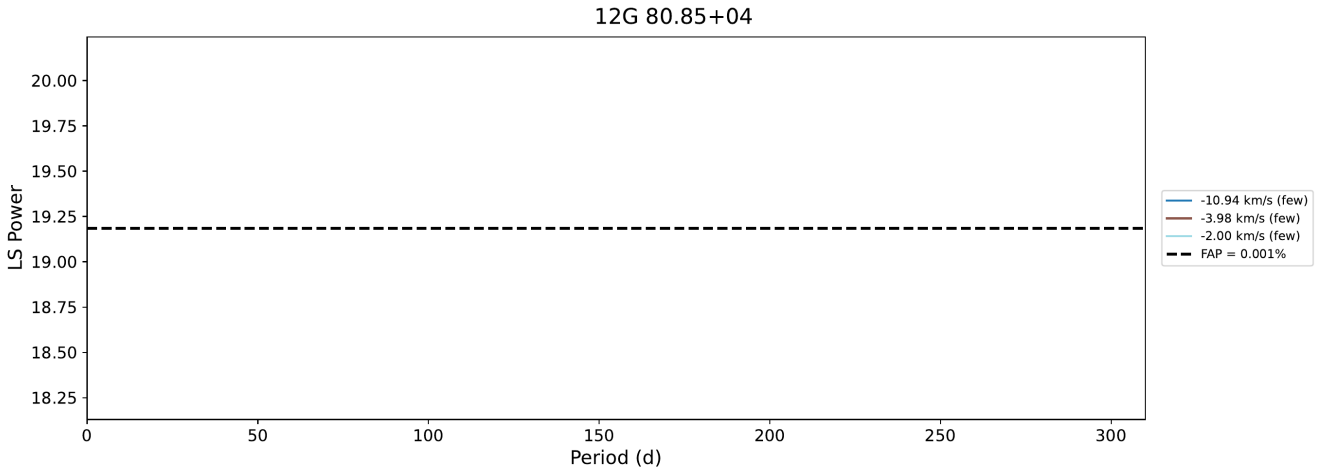


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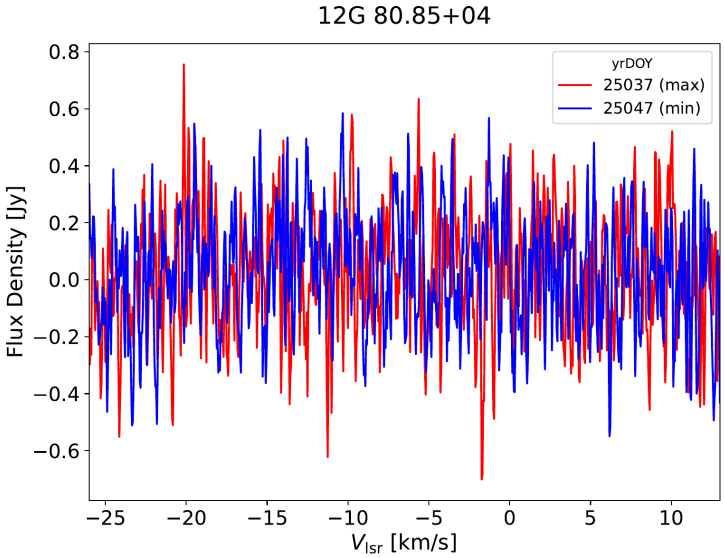
Light curve



Periodogram

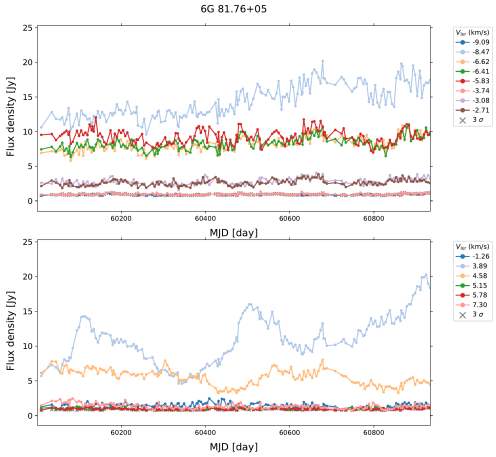


Spectrum

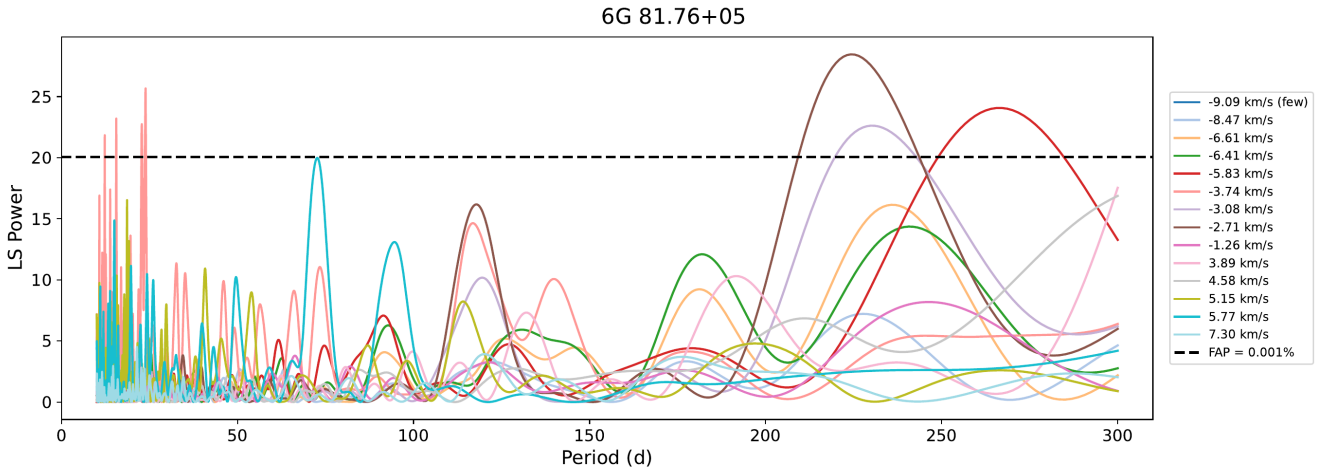


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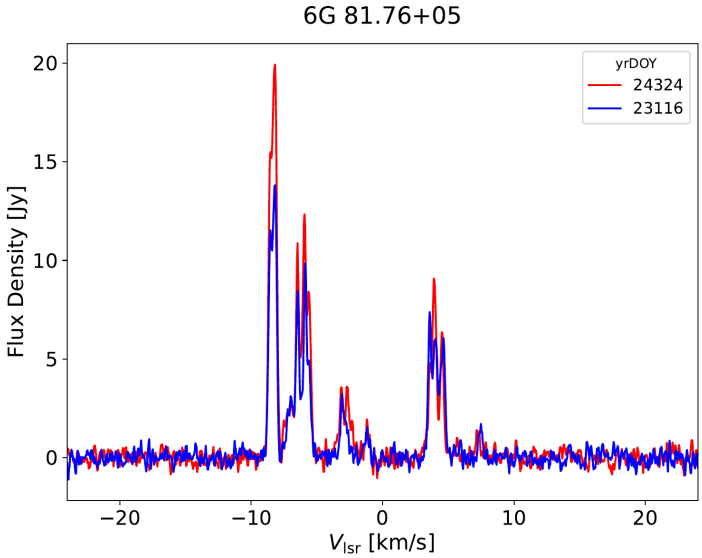
Light curve



Periodogram

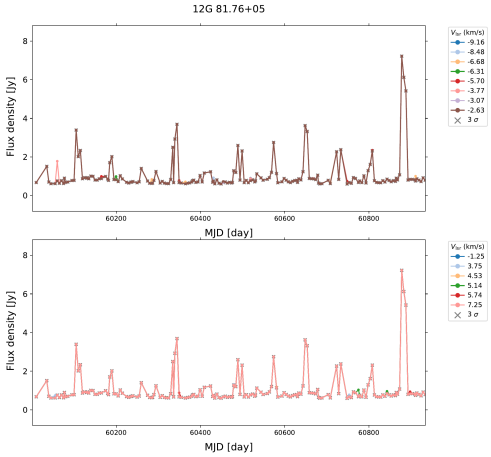


Spectrum

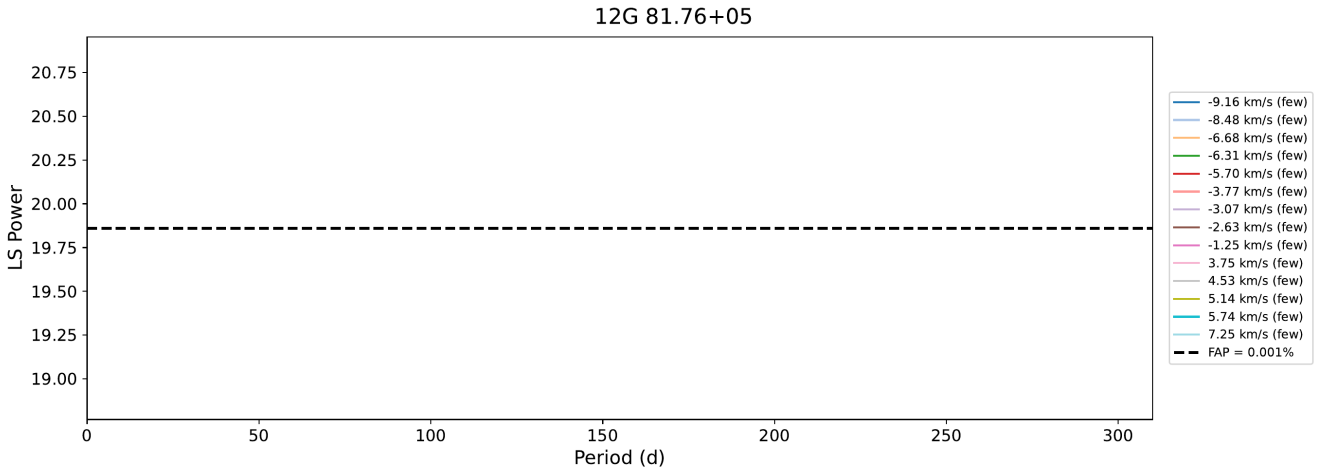


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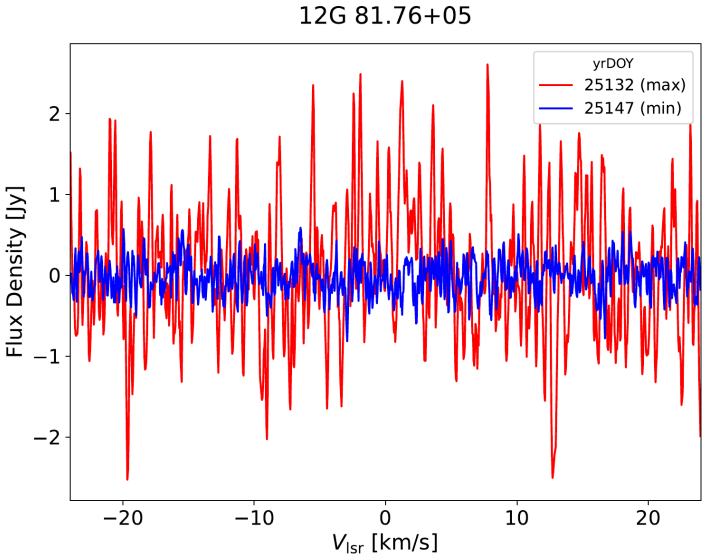
Light curve



Periodogram

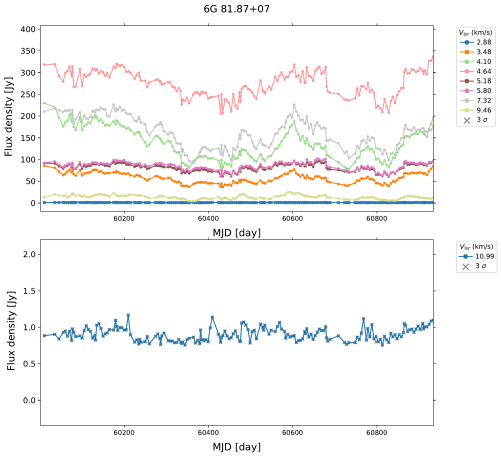


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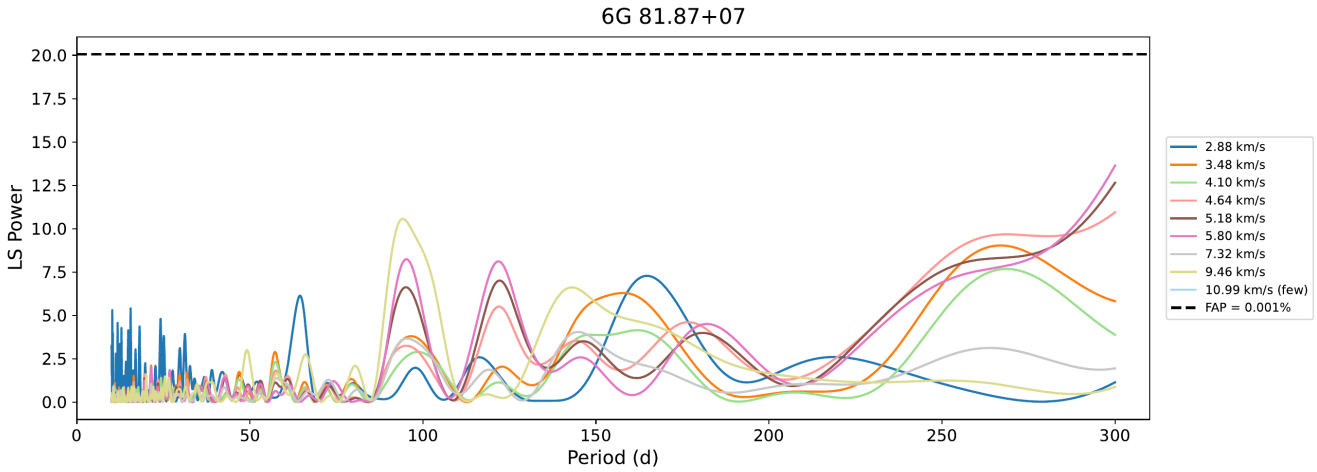


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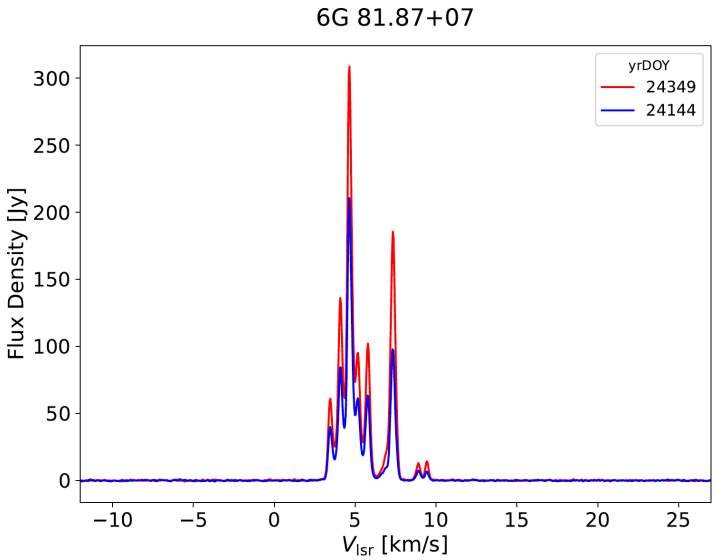
Light curve



Periodogram

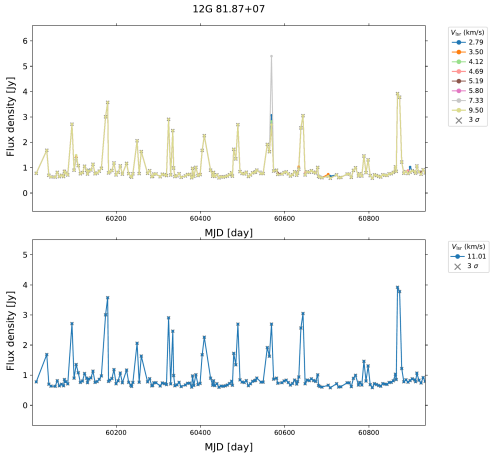


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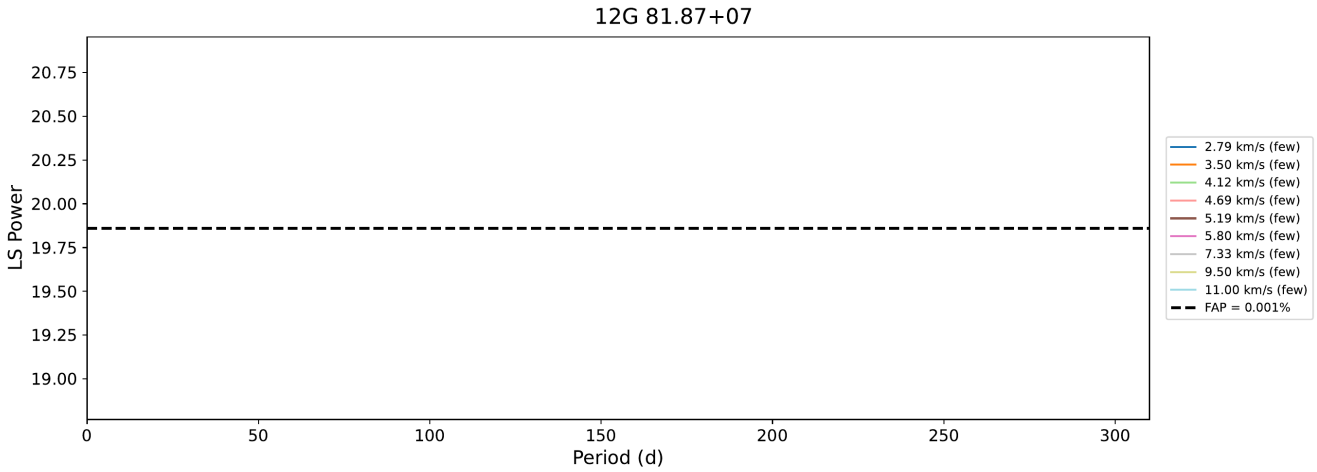


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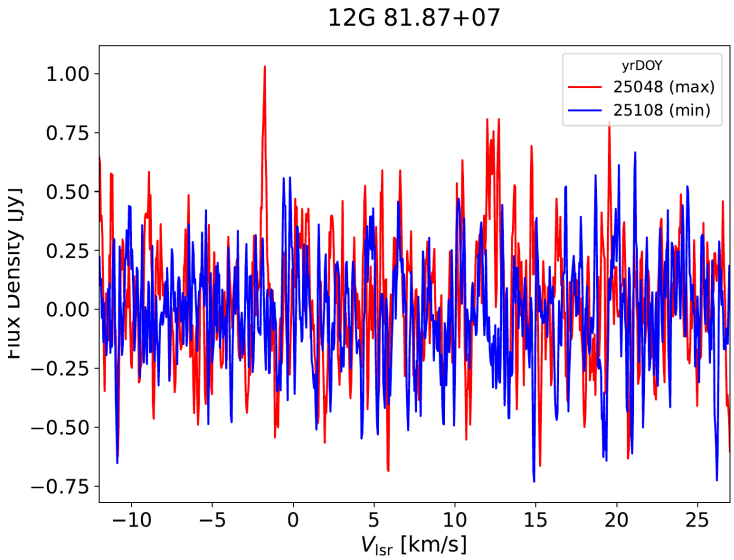
Light curve



Periodogram

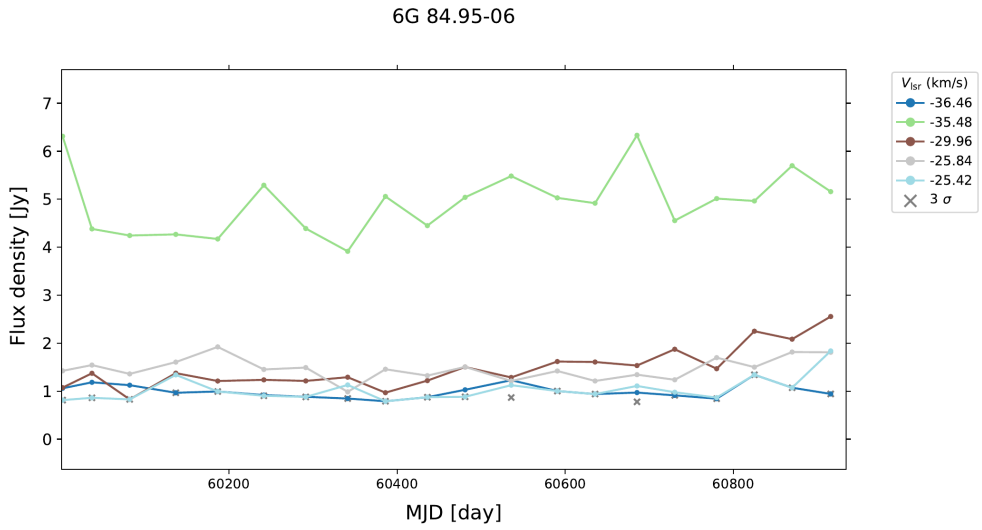


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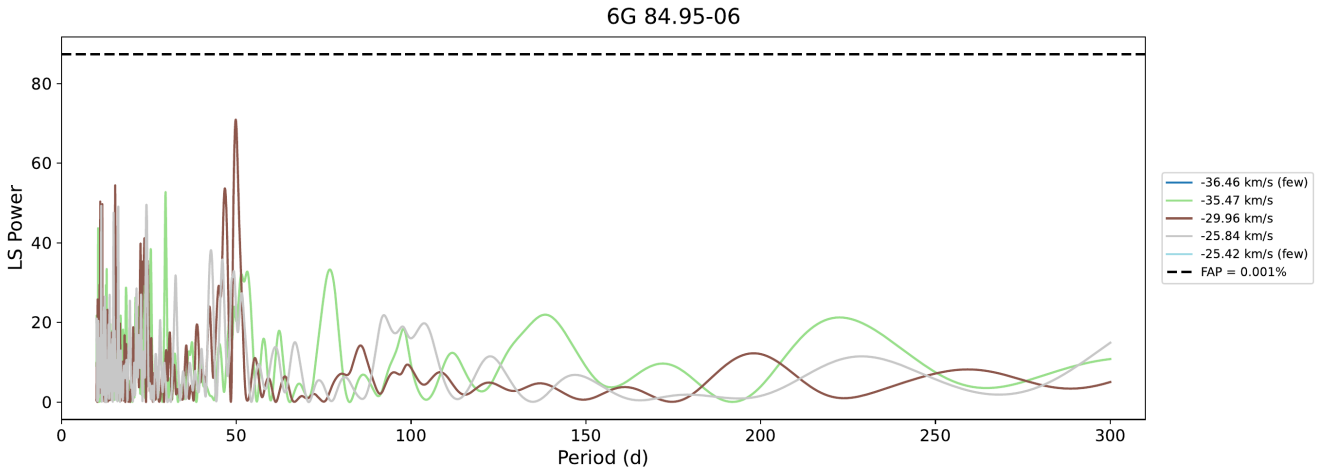


6G 84.95-06

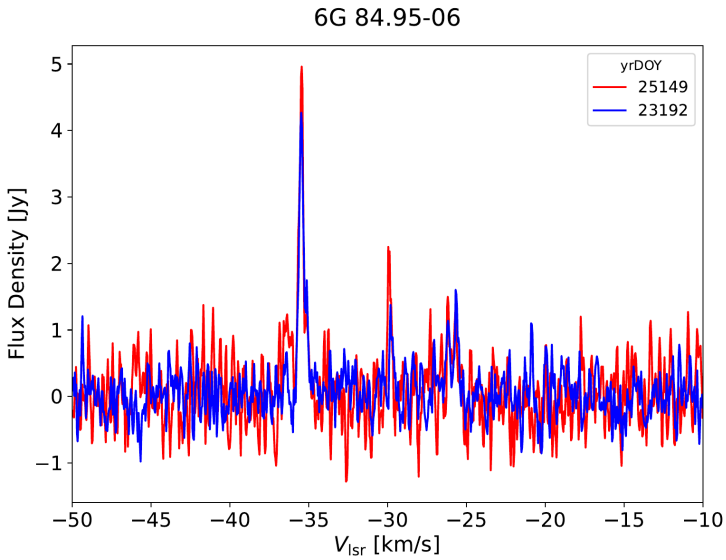
Light curve



Periodogram

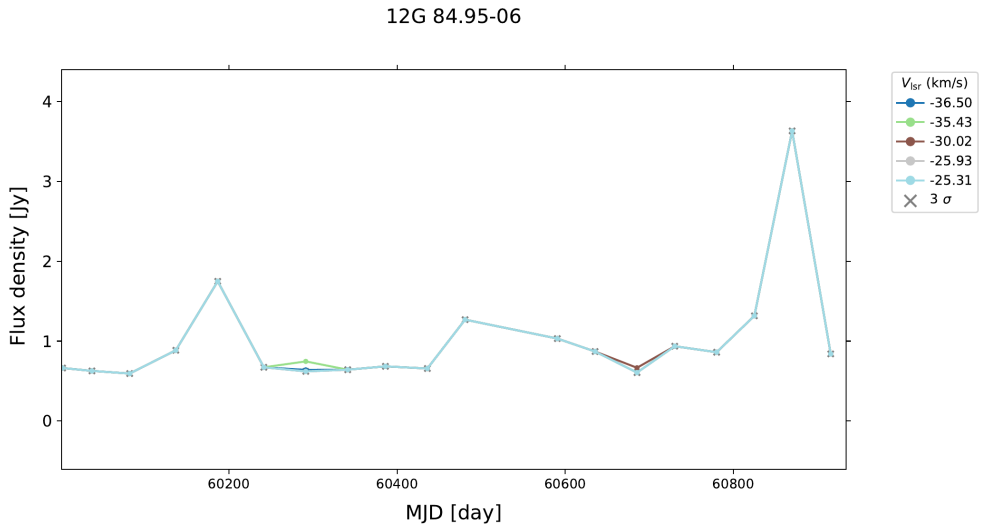


Spectrum

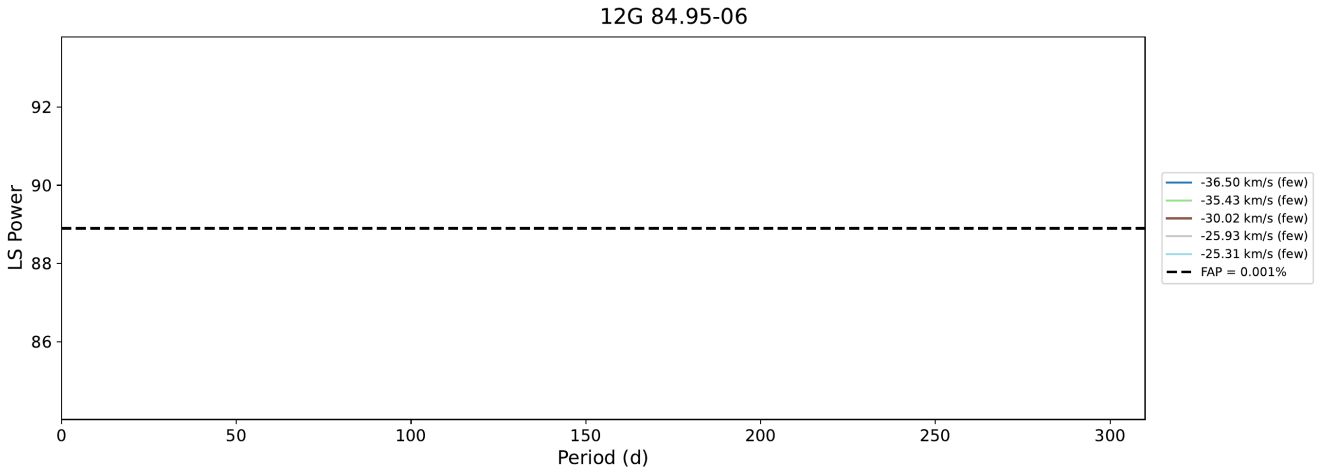


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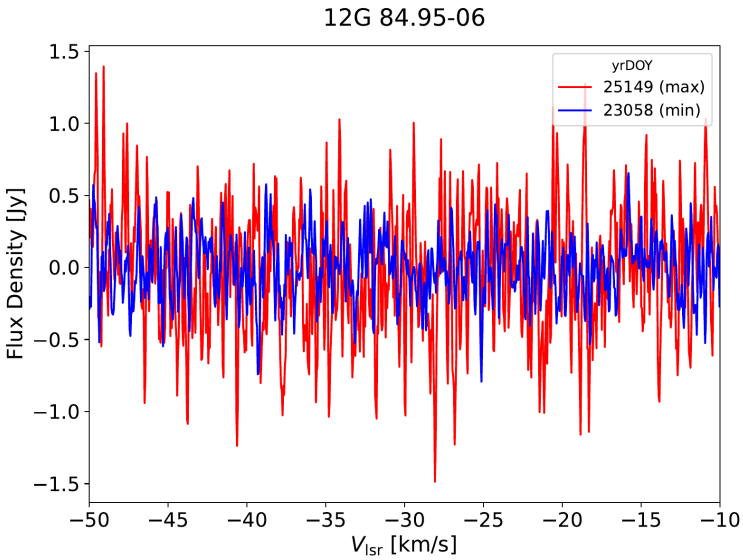
Light curve



Periodogram

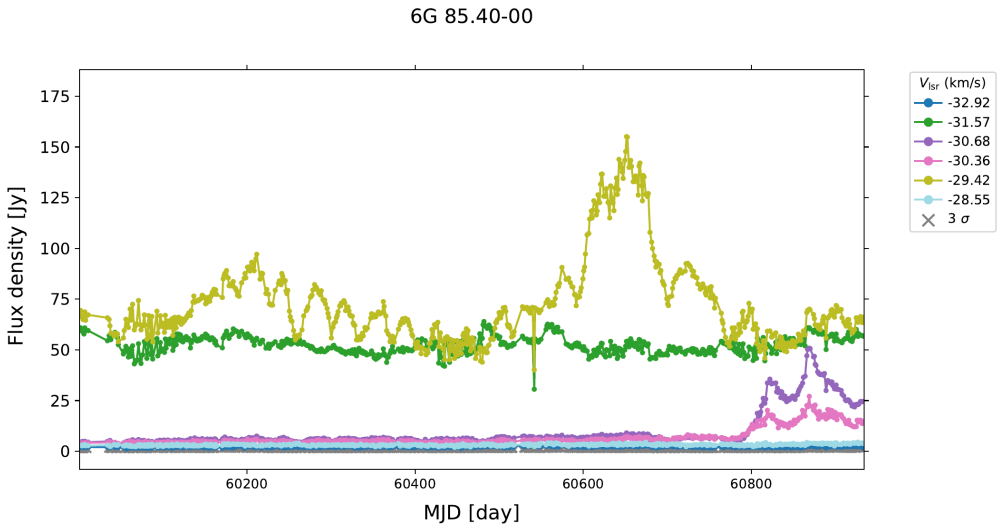


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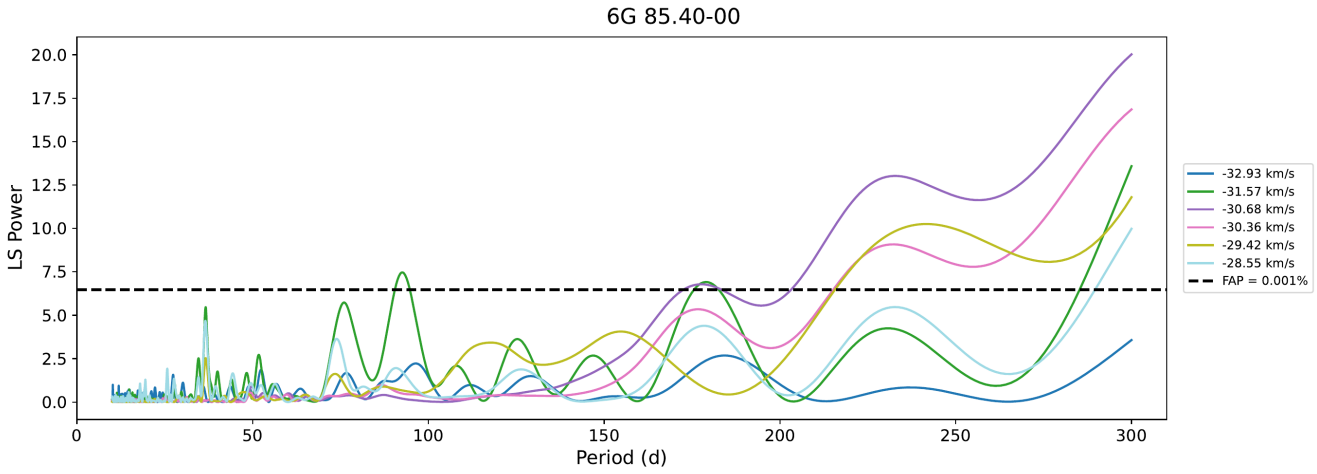


6G 85.40-00

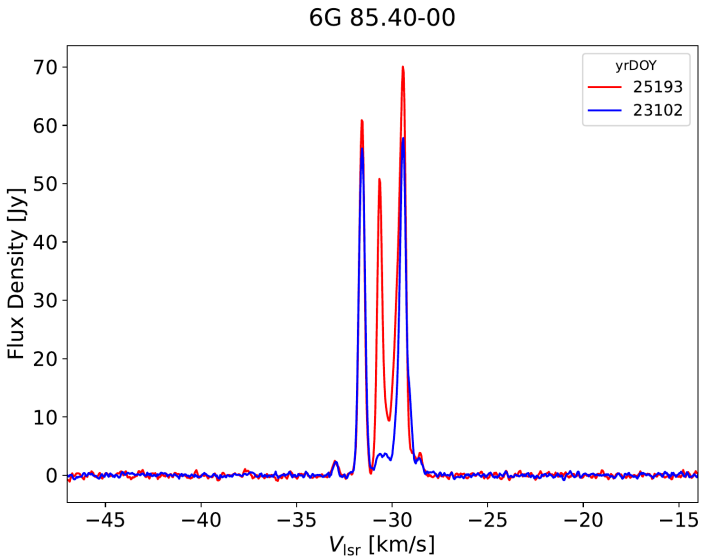
Light curve



Periodogram

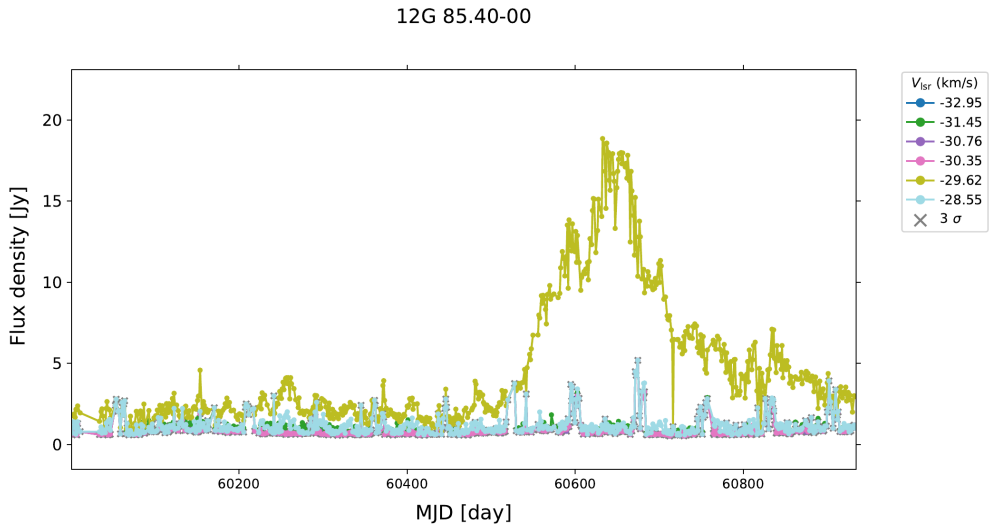


Spectrum

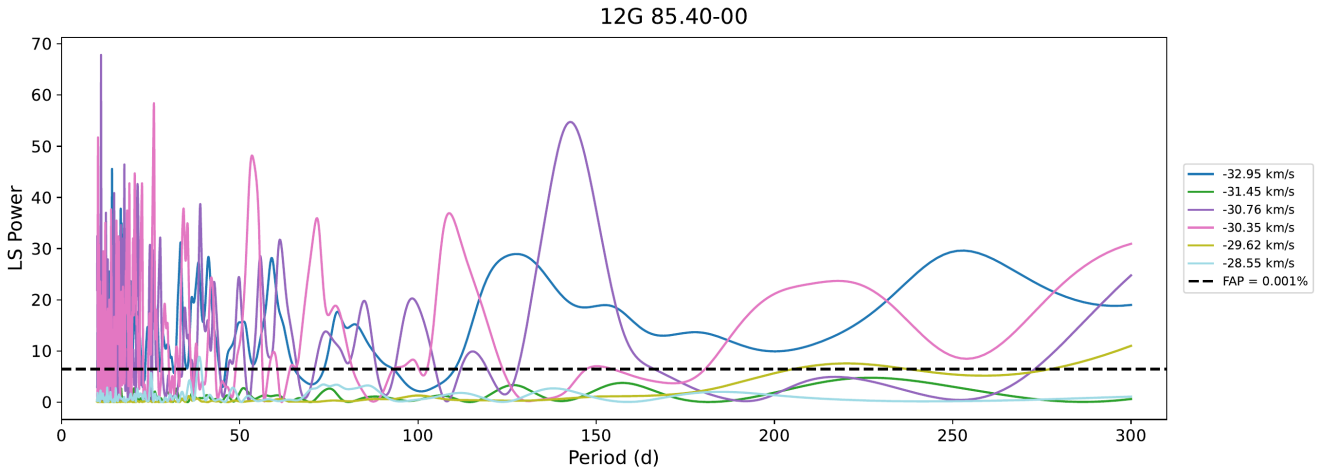


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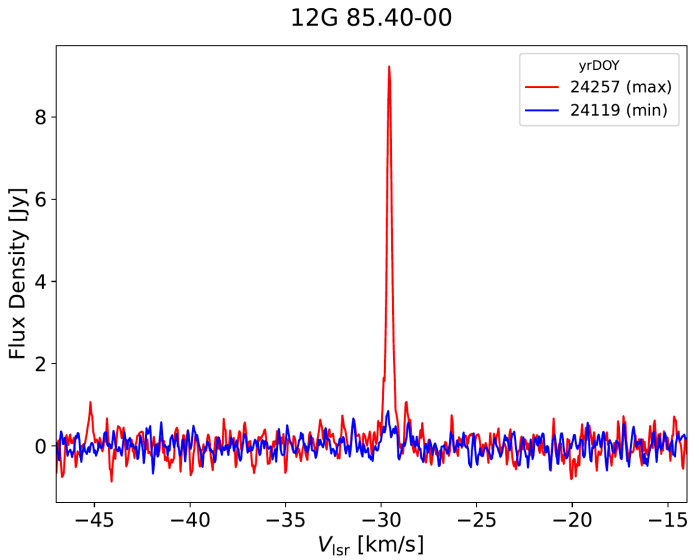
Light curve



Periodogram

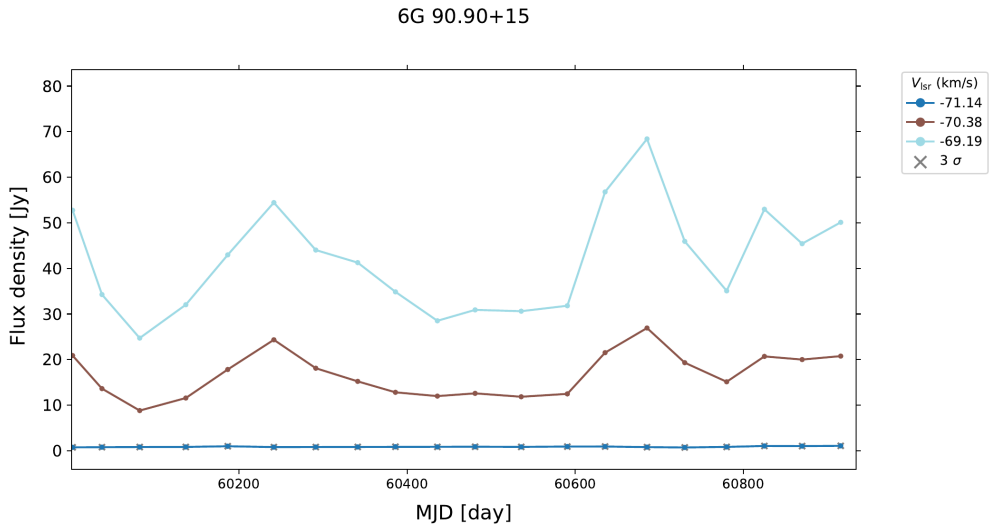


Spectrum

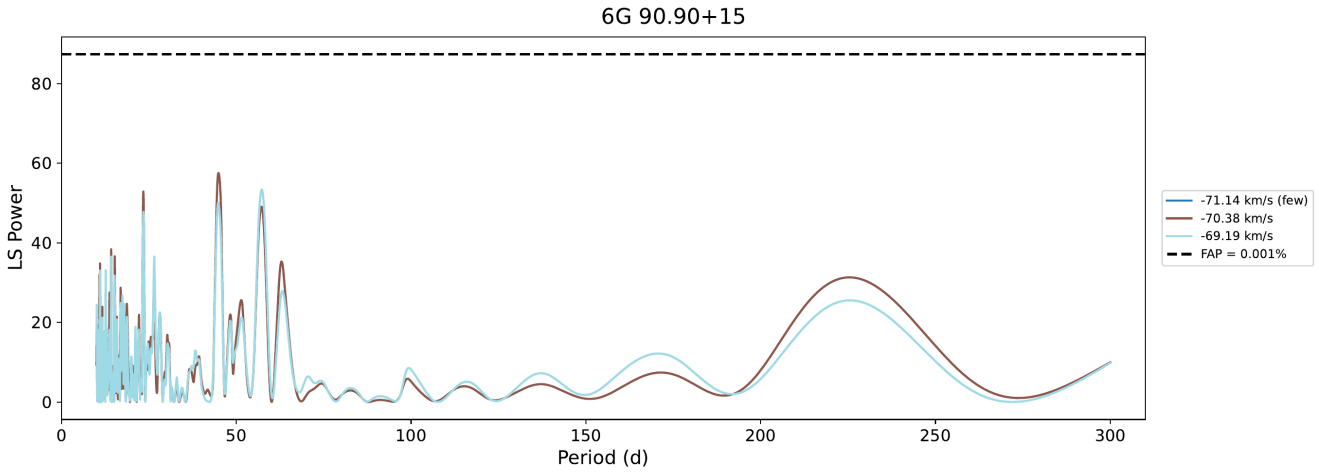


6G 90.90+15

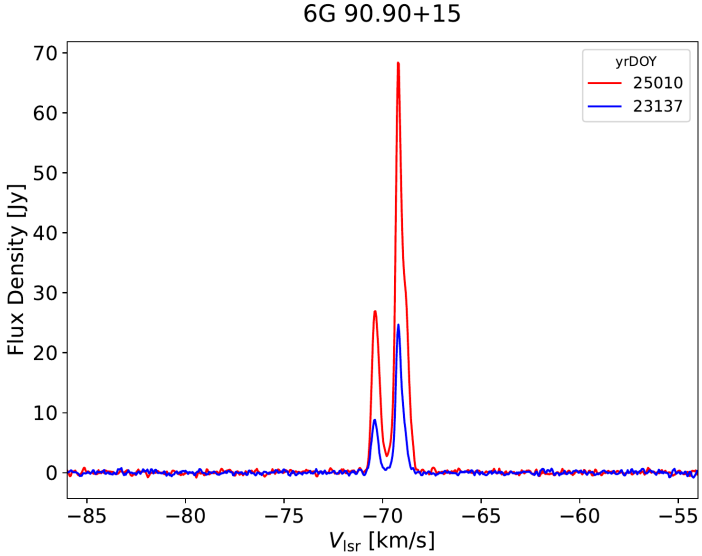
Light curve



Periodogram

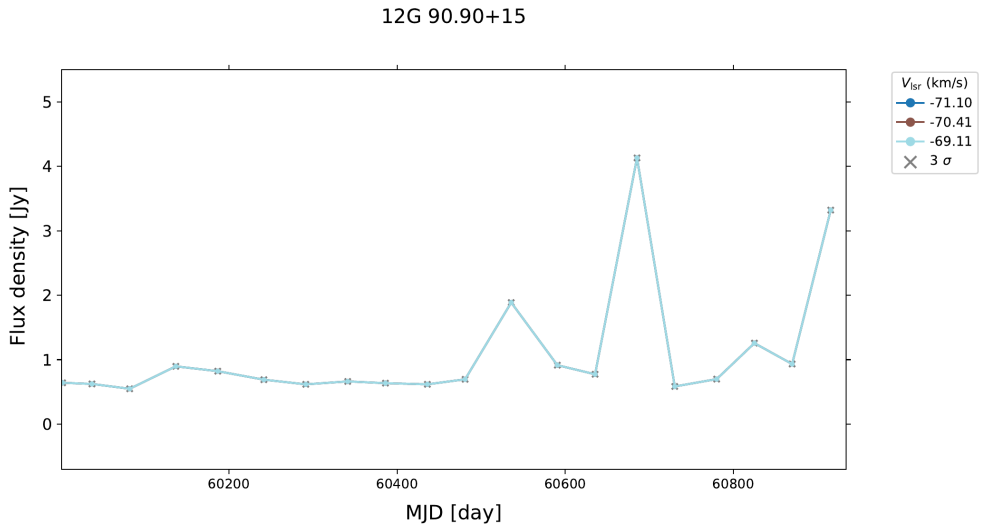


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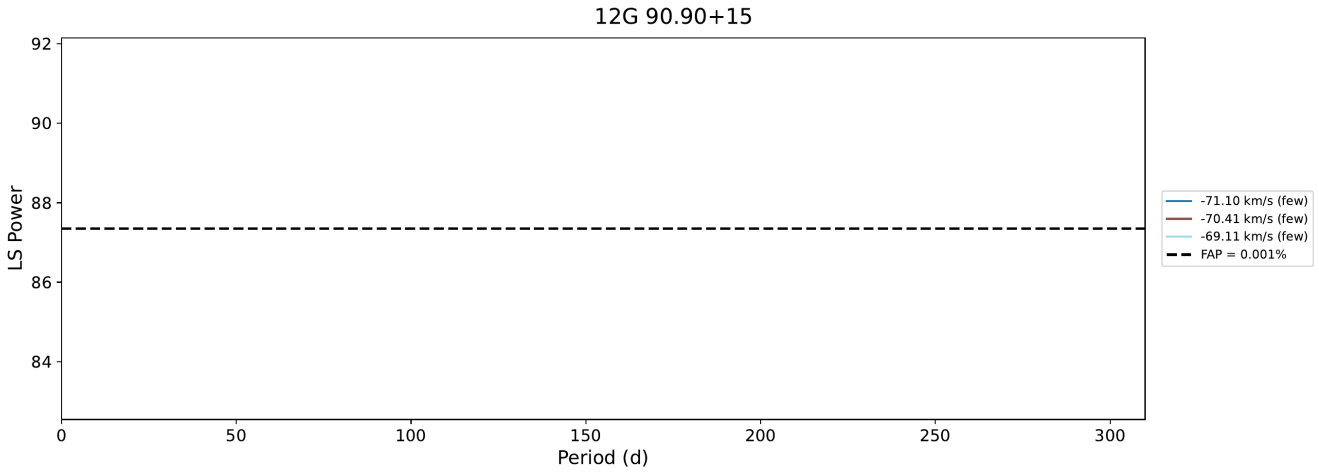


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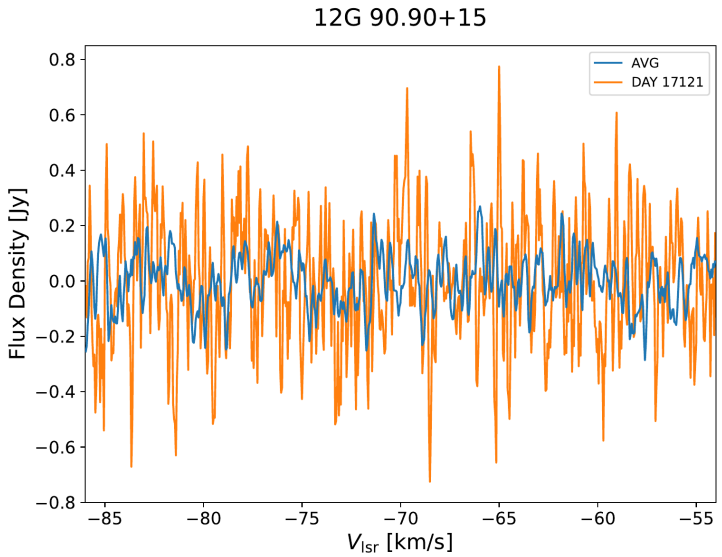
Light curve



Periodogram

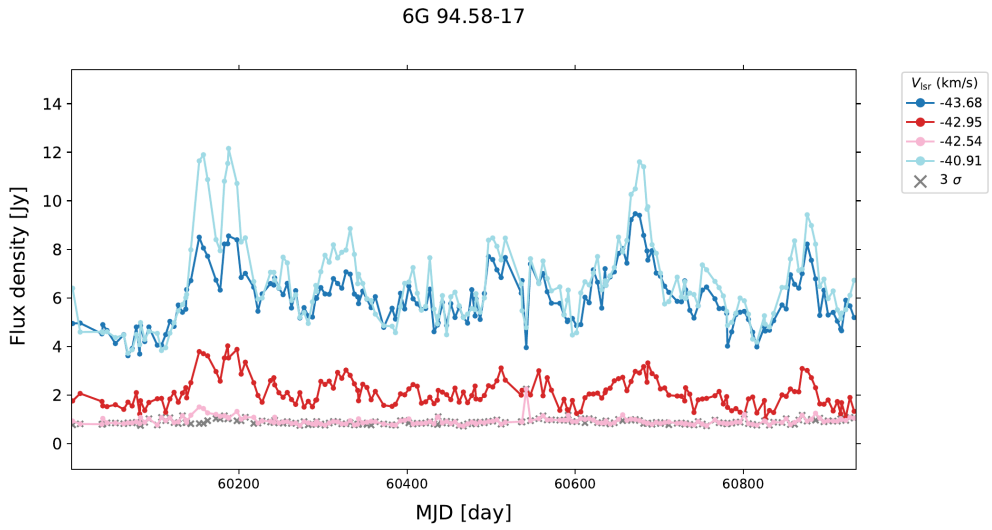


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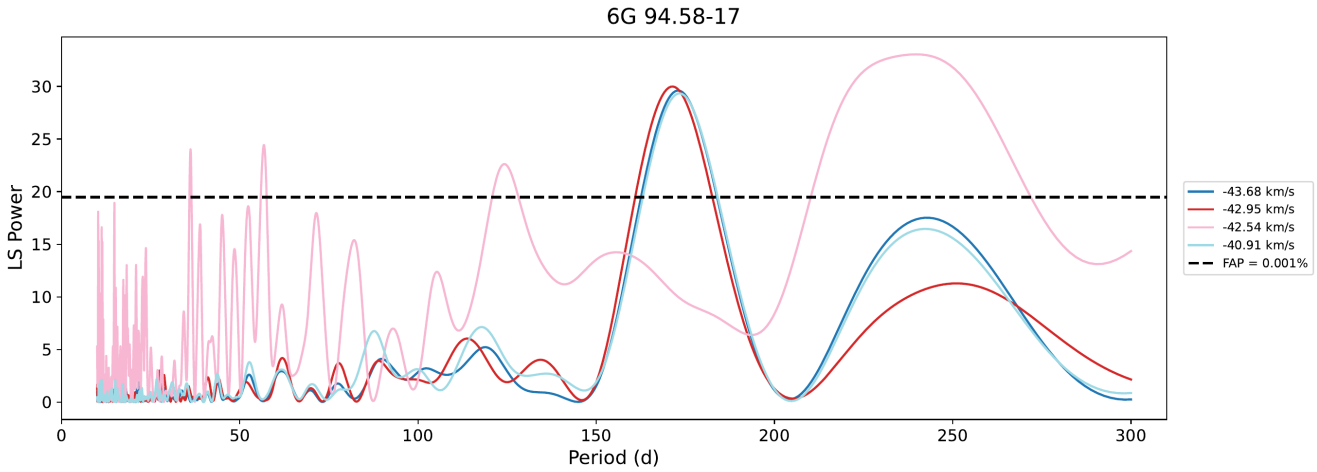


6G 94.58-17

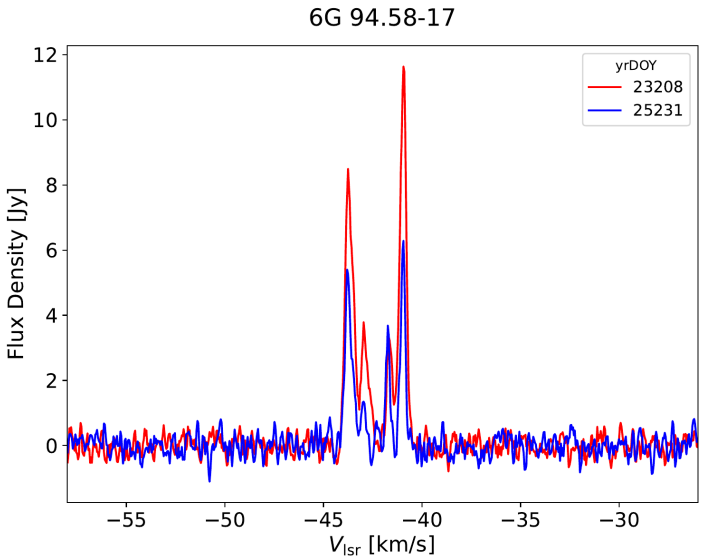
Light curve



Periodogram

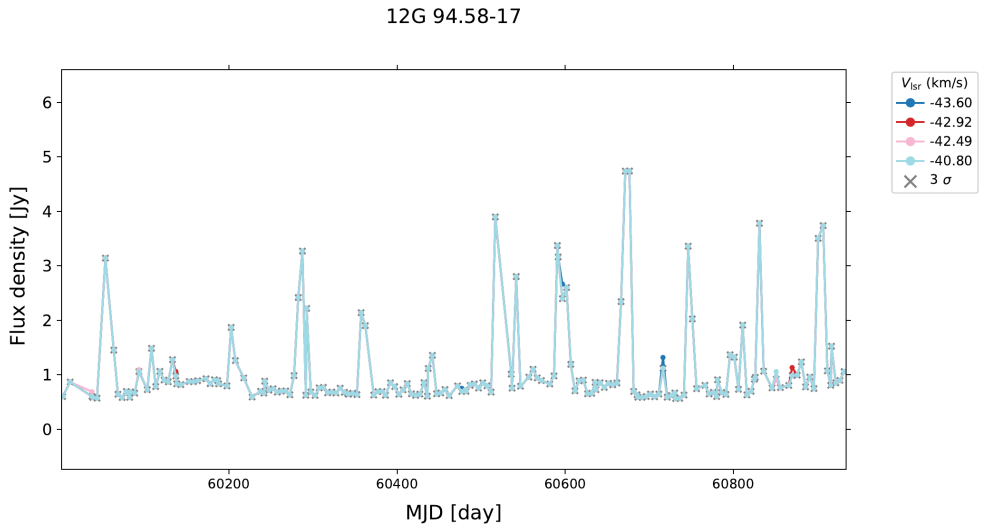


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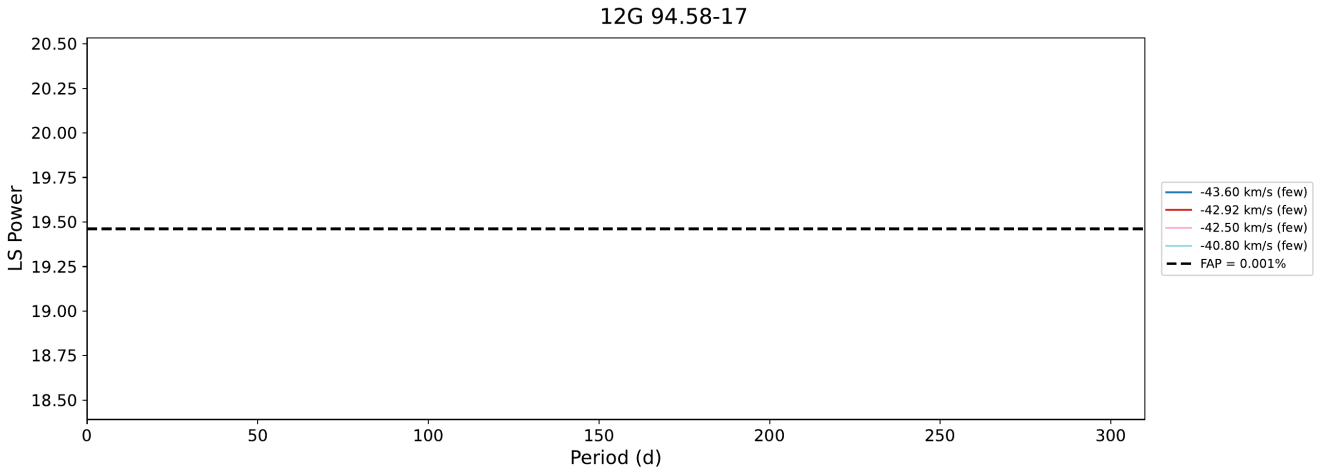


12G 94.58-17

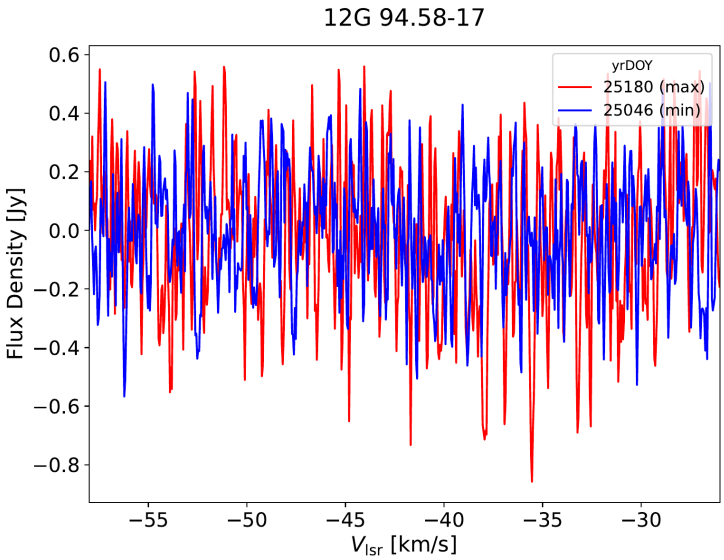
Light curve



Periodogram

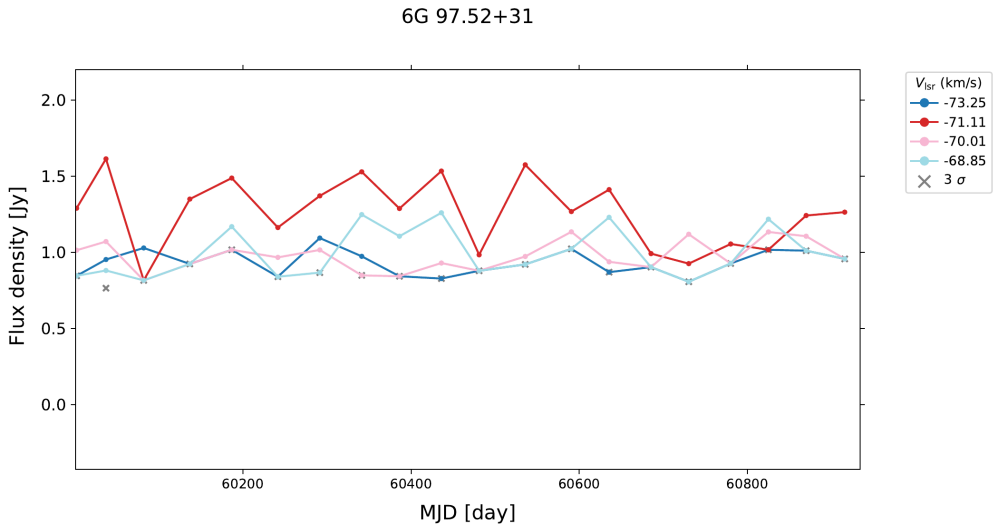


Spectrum

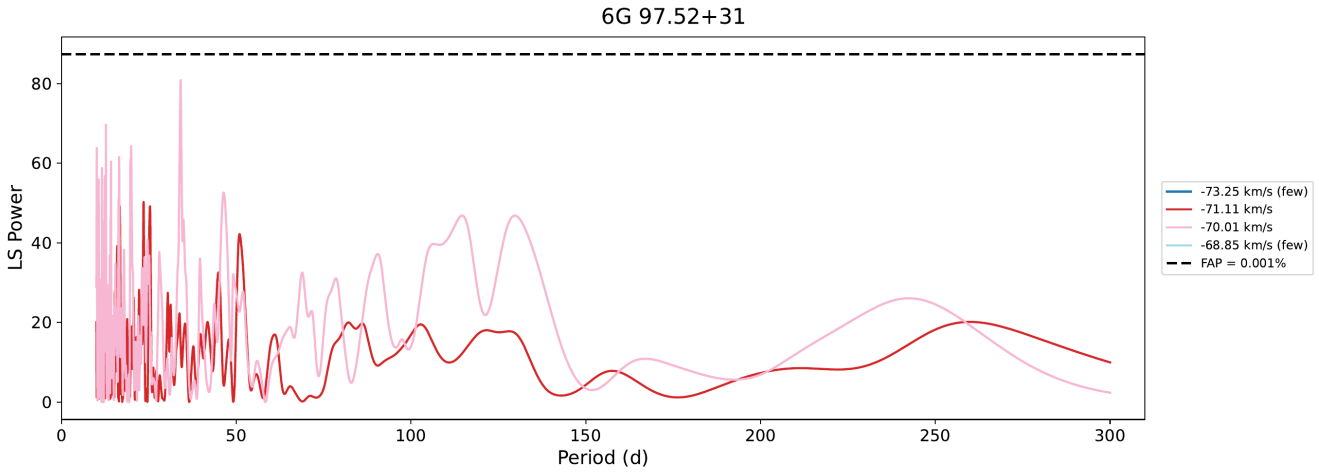


6G 97.52+31

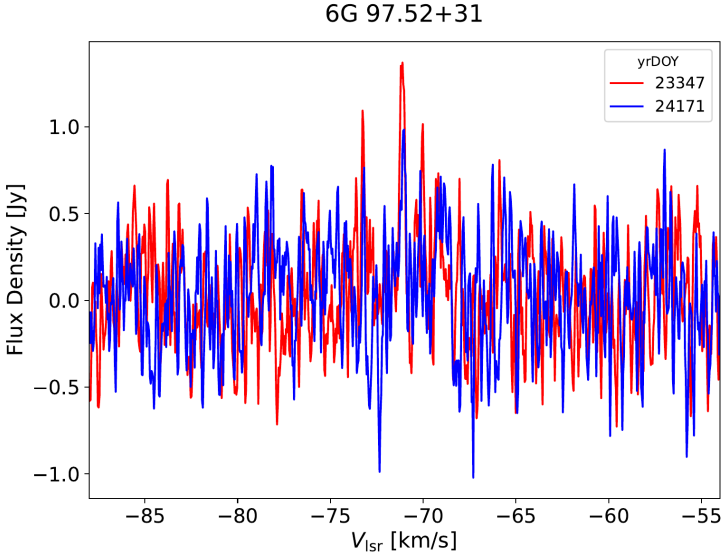
Light curve



Periodogram

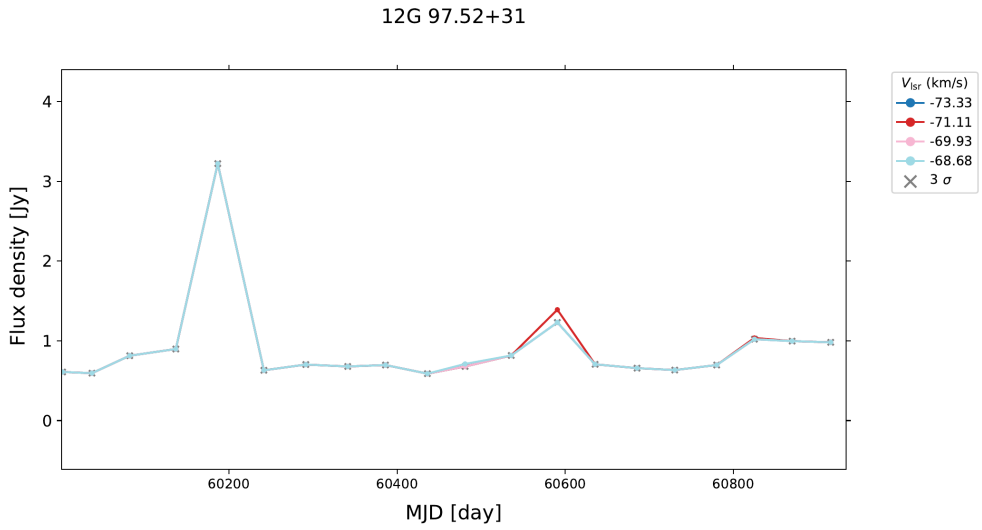


Spectrum

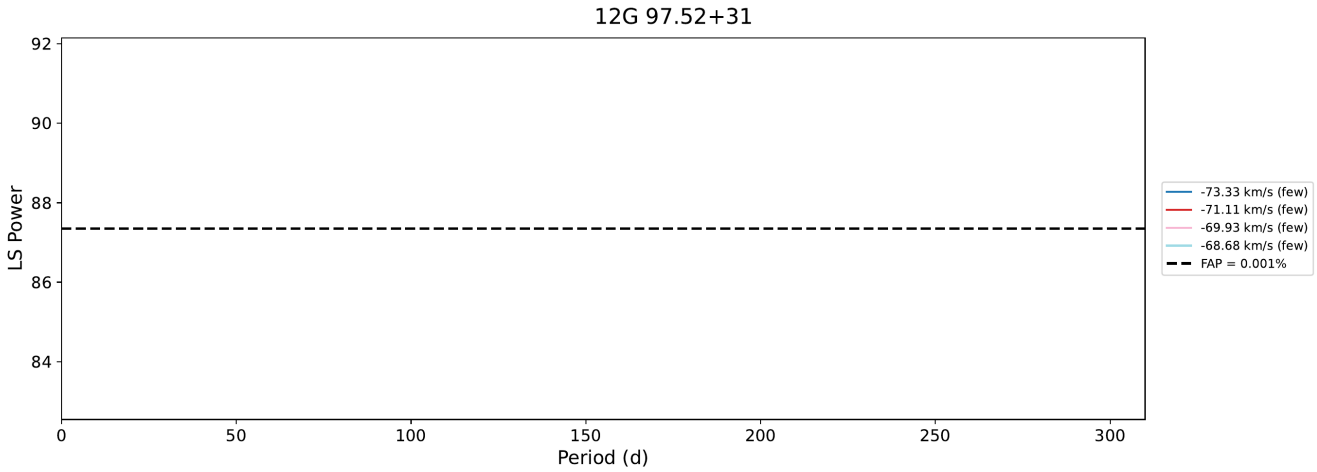


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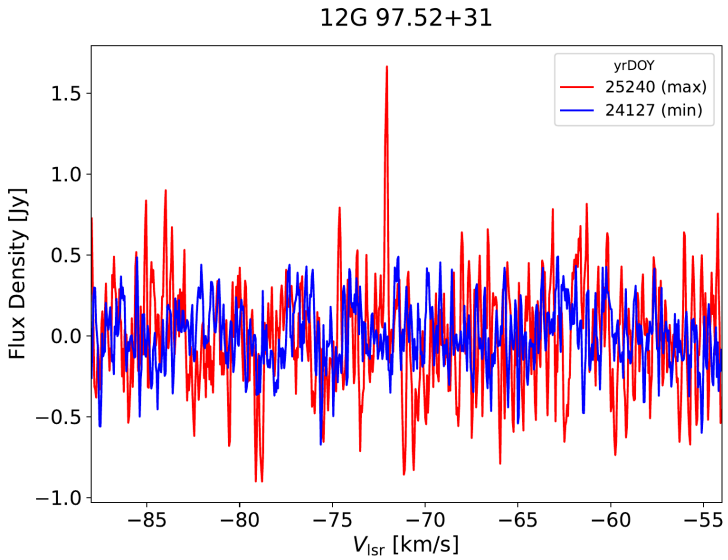
Light curve



Periodogram

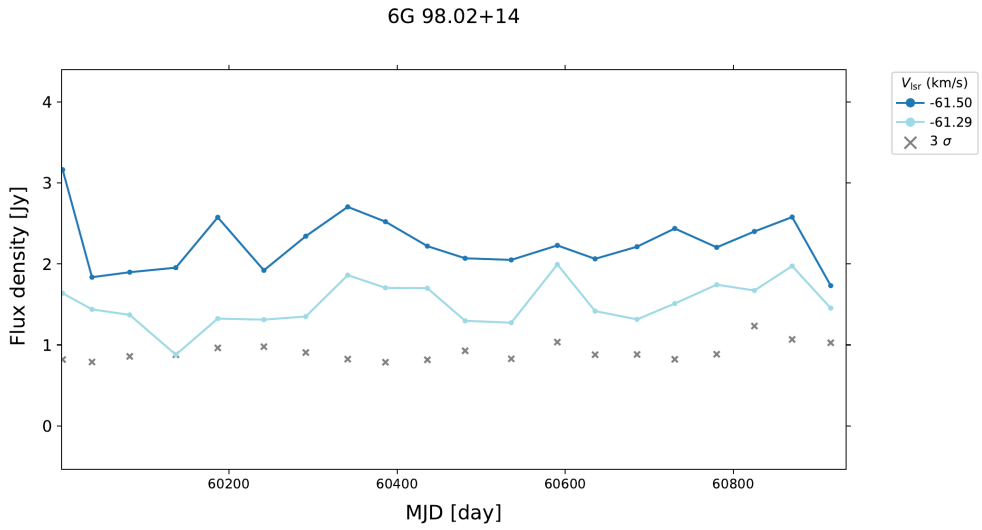


Spectrum

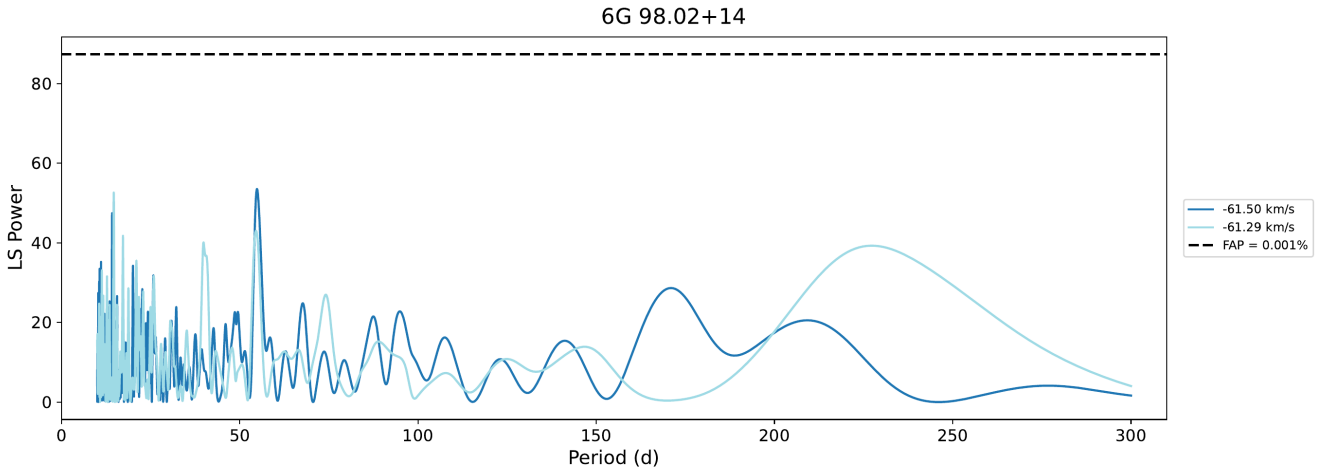


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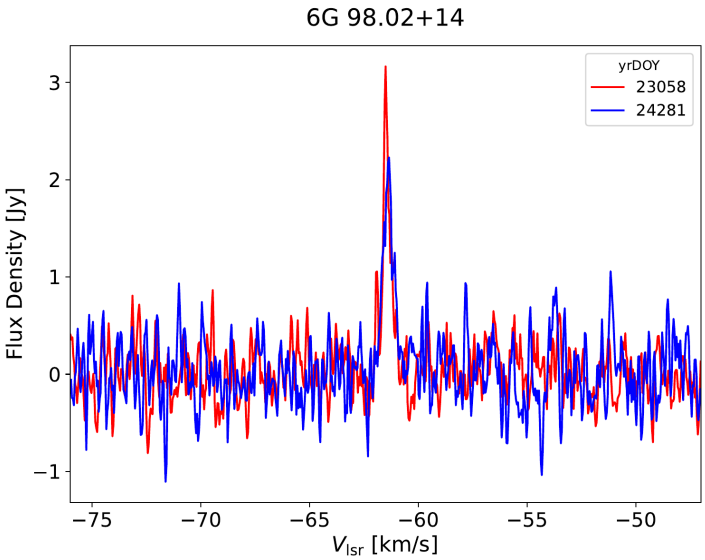
Light curve



Periodogram

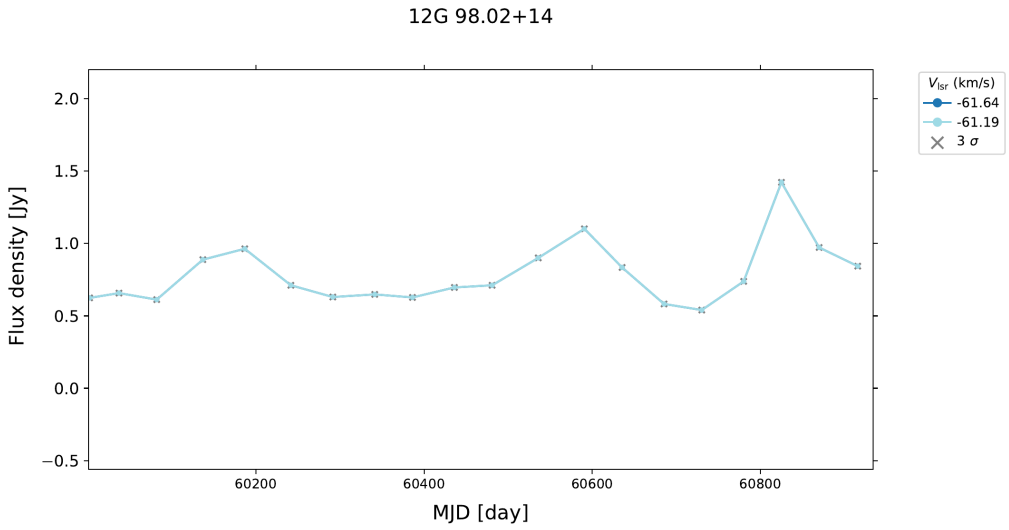


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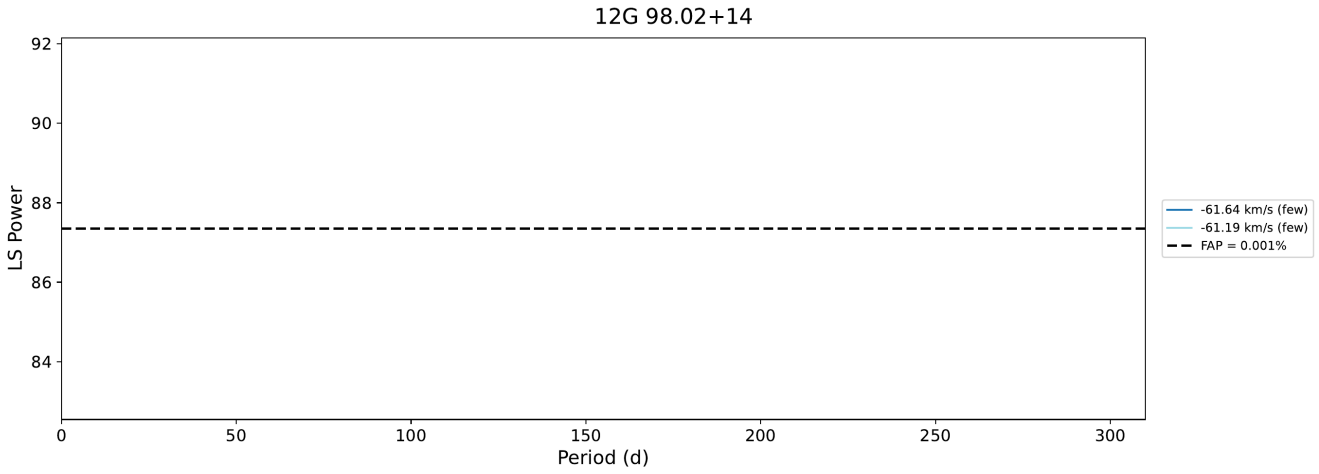


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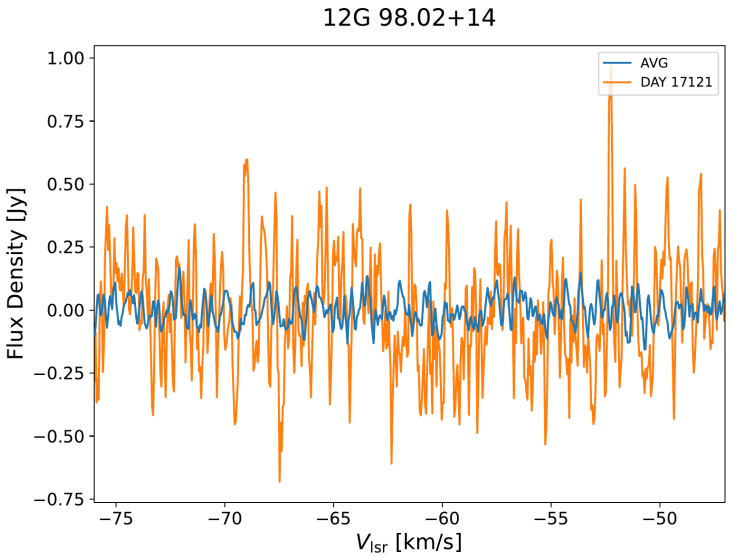
Light curve



Periodogram

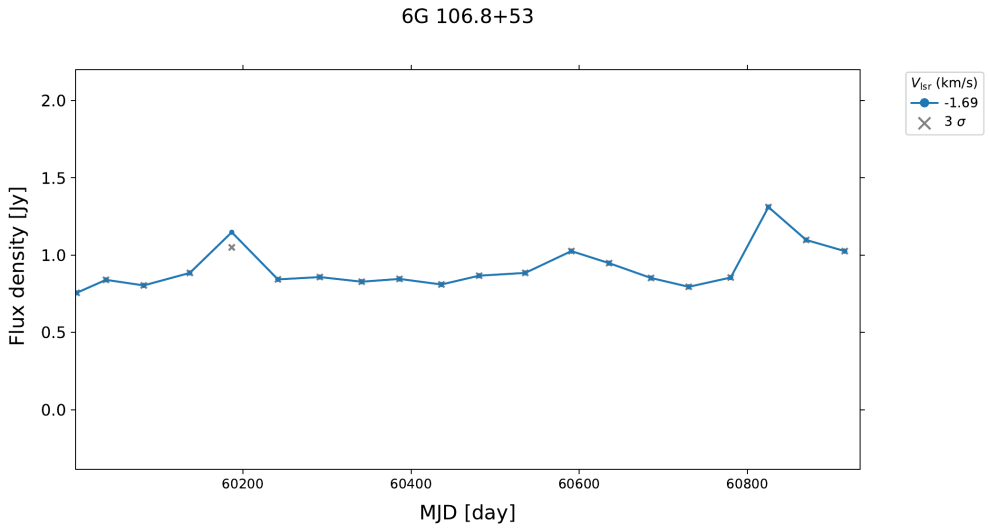


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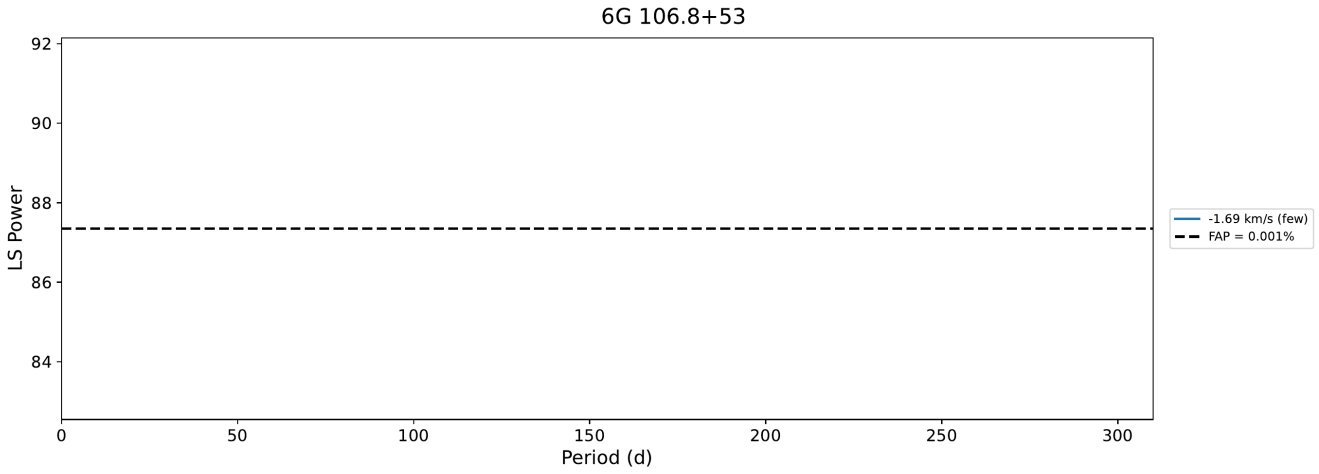


6G 106.8+53

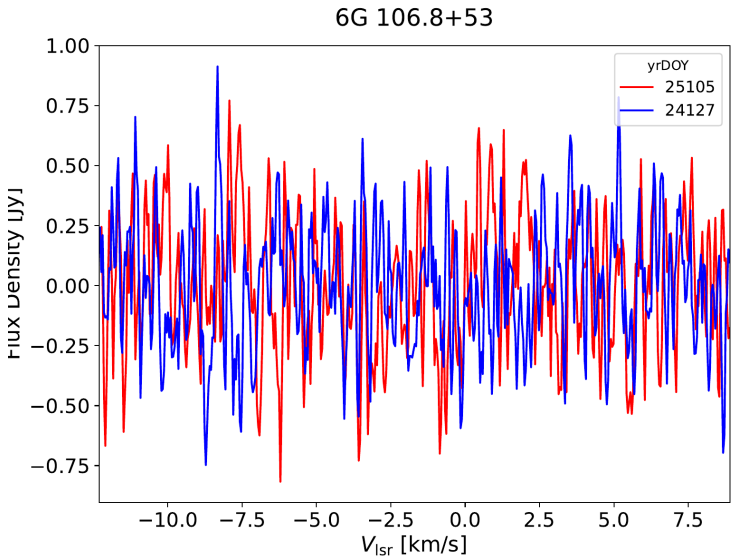
Light curve



Periodogram

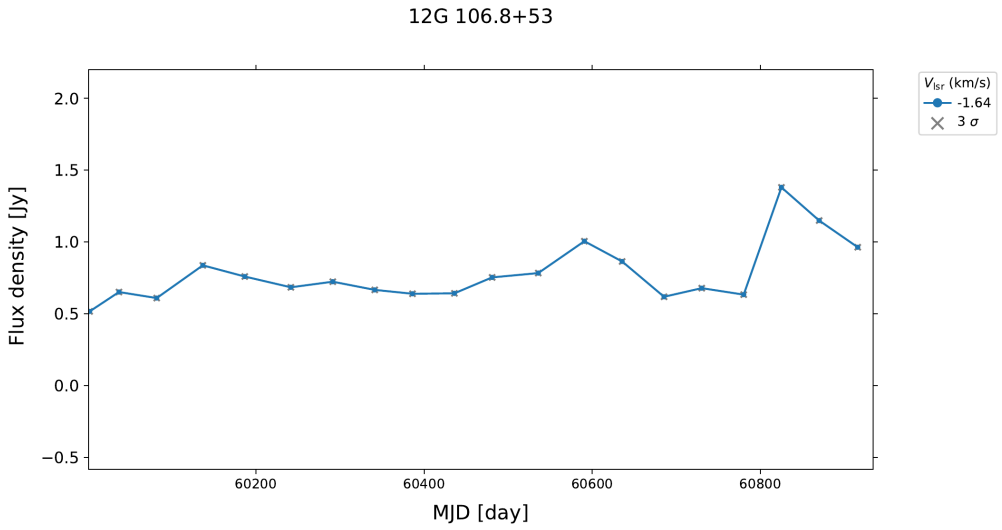


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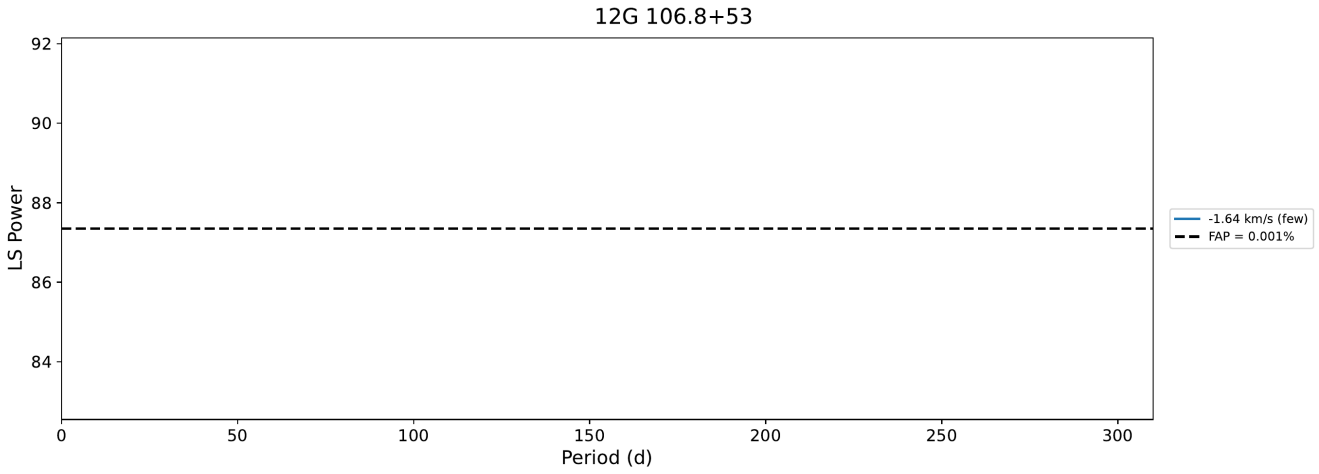


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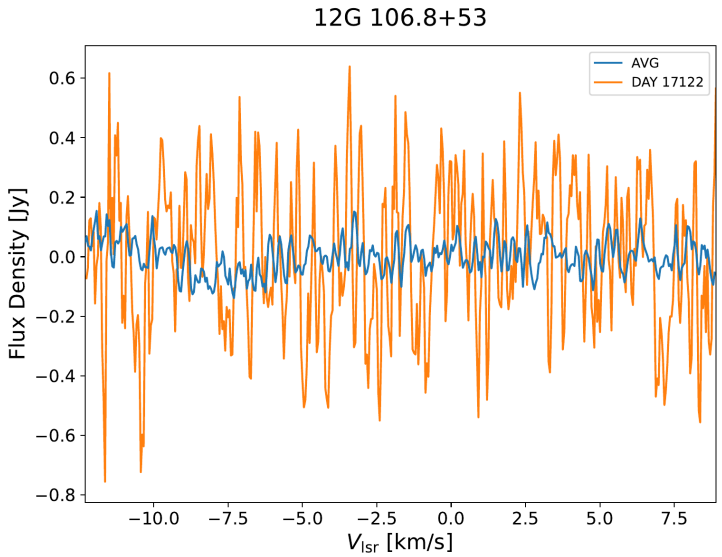
Light curve



Periodogram

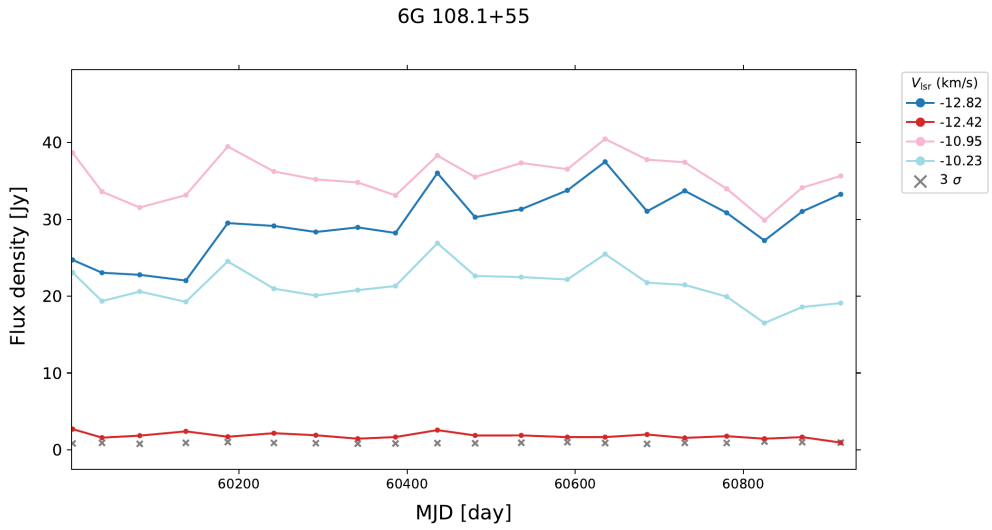


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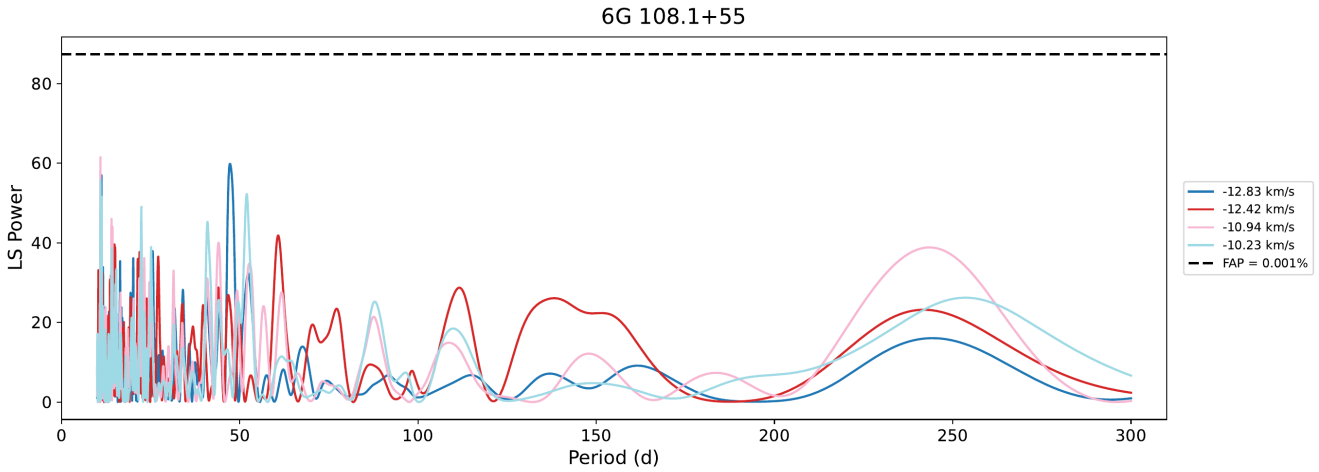


6G 108.1+55

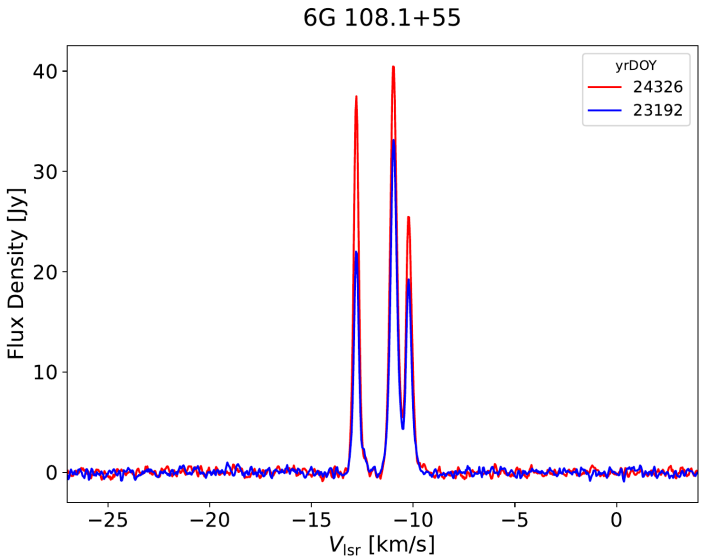
Light curve



Periodogram

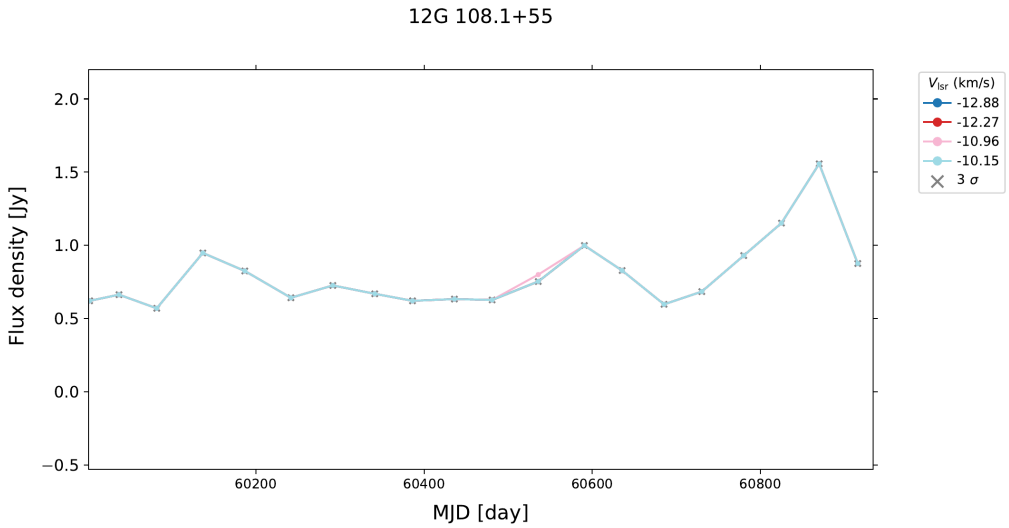


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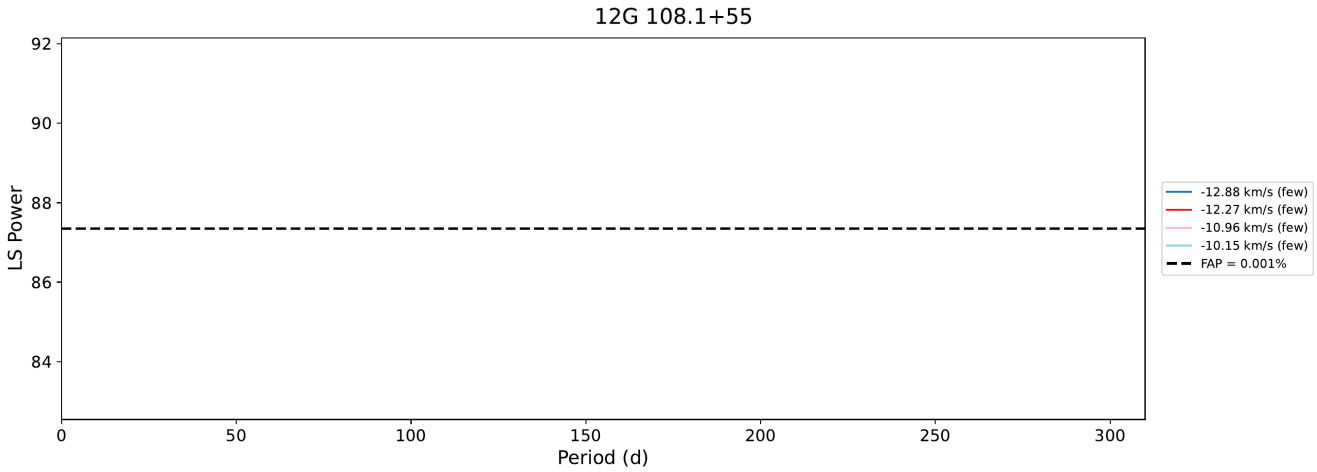


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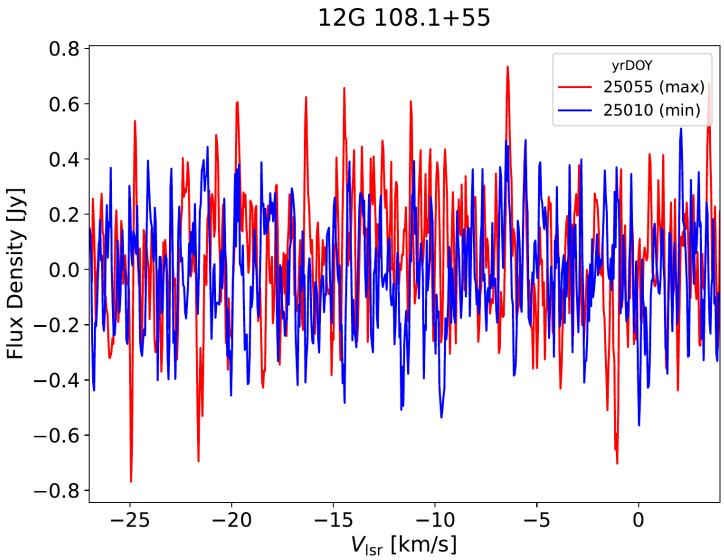
Light curve



Periodogram

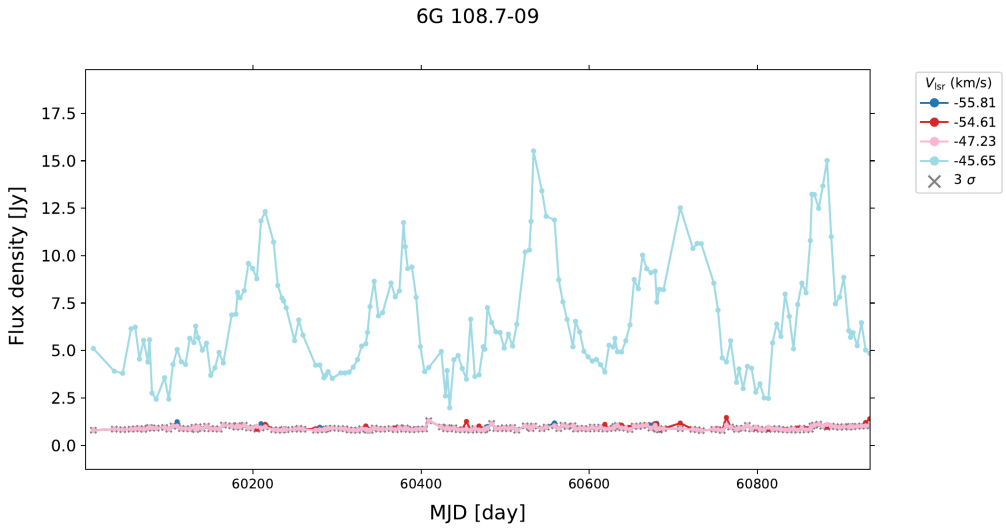


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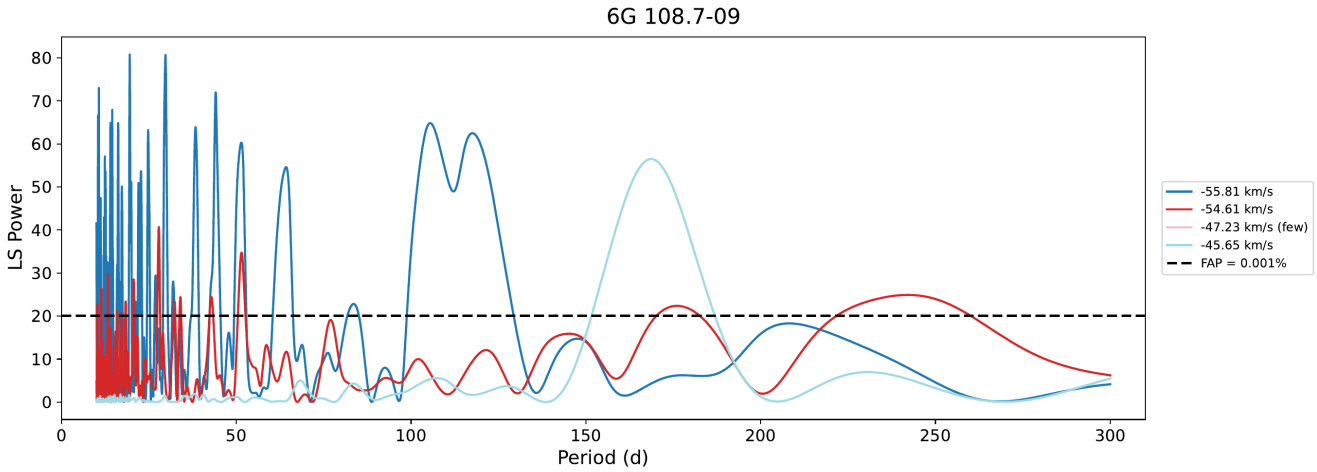


6G 108.7-09

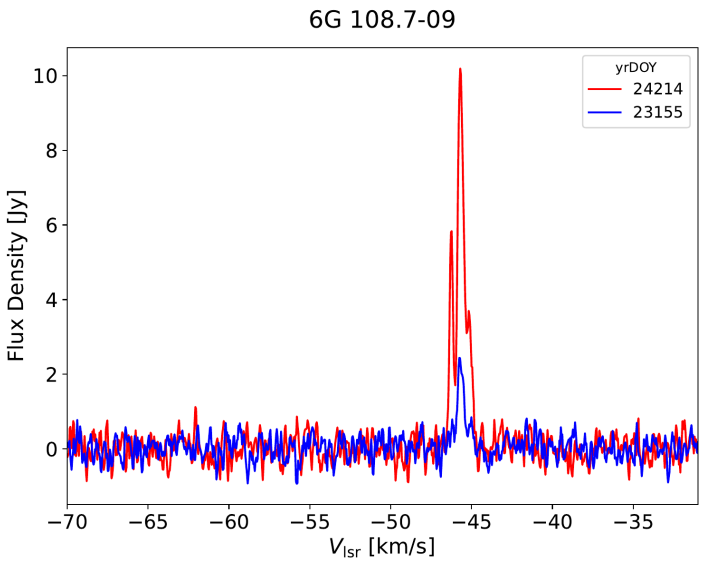
Light curve



Periodogram

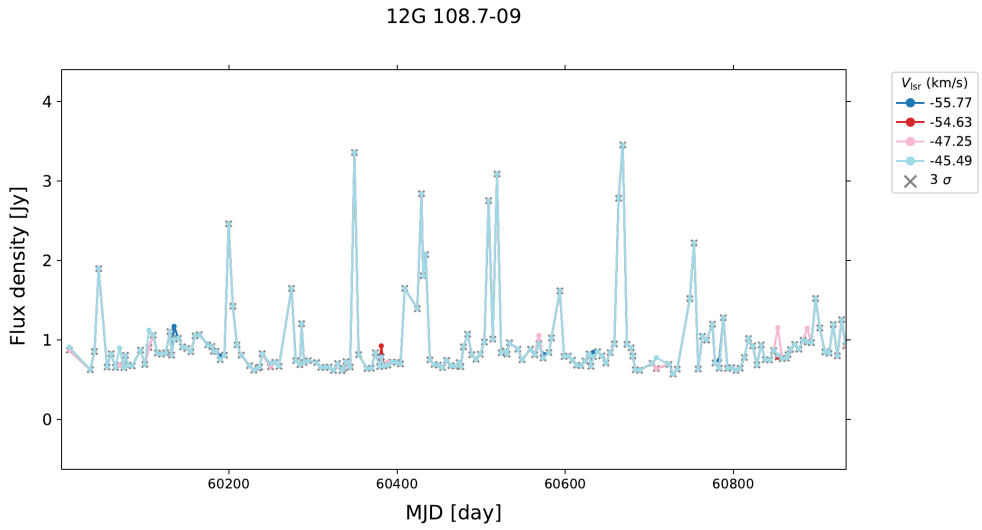


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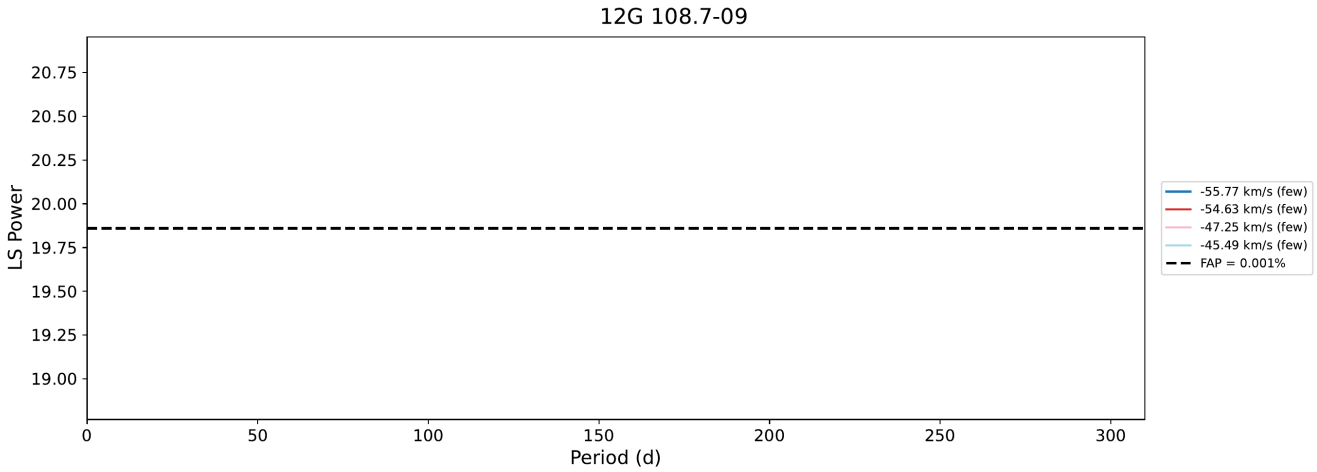


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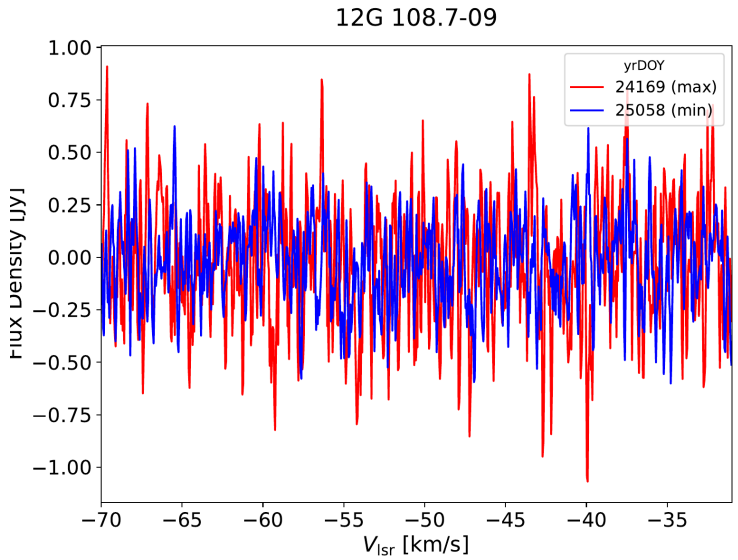
Light curve



Periodogram

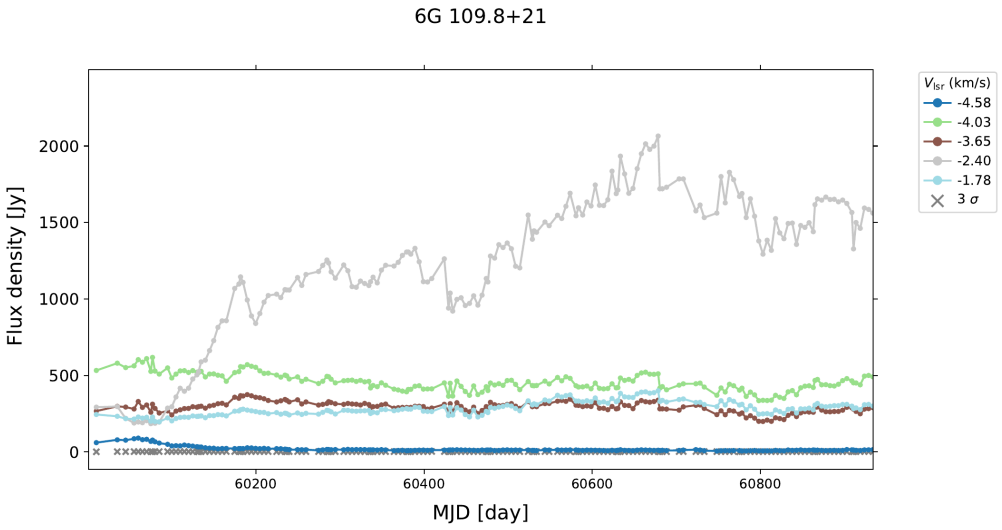


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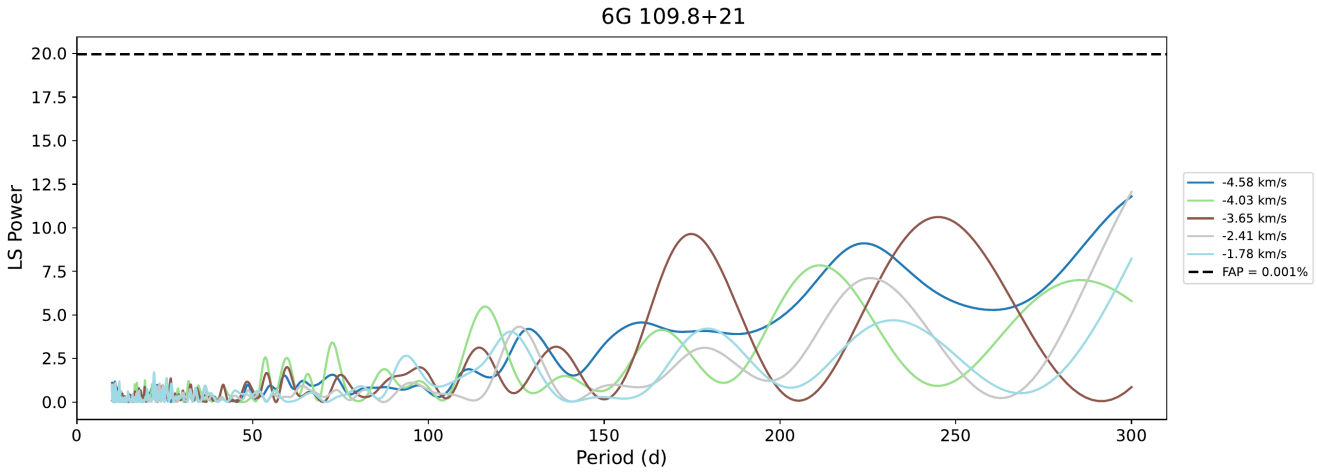


6G 109.8+21

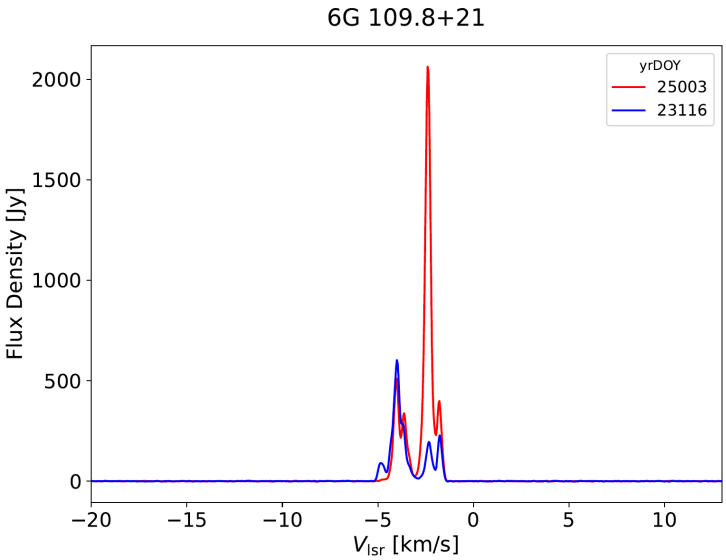
Light curve



Periodogram

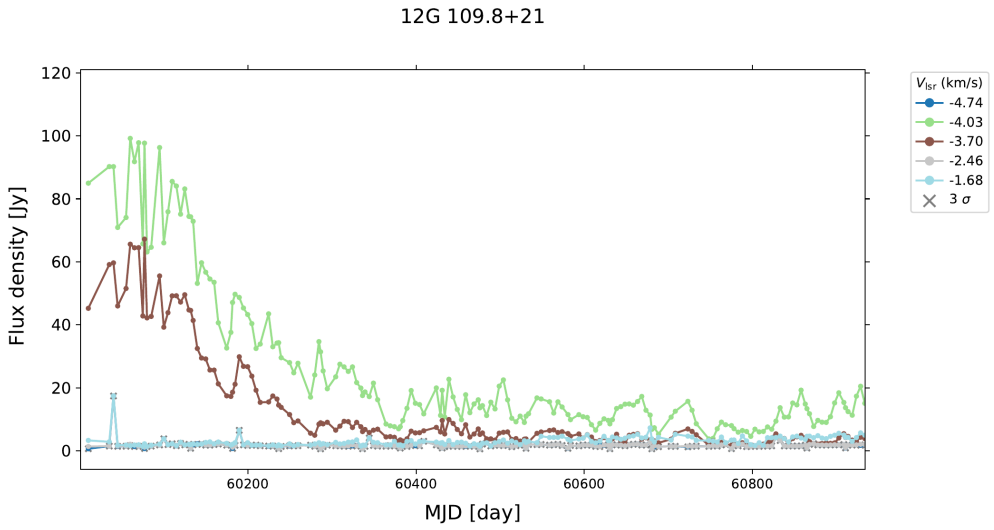


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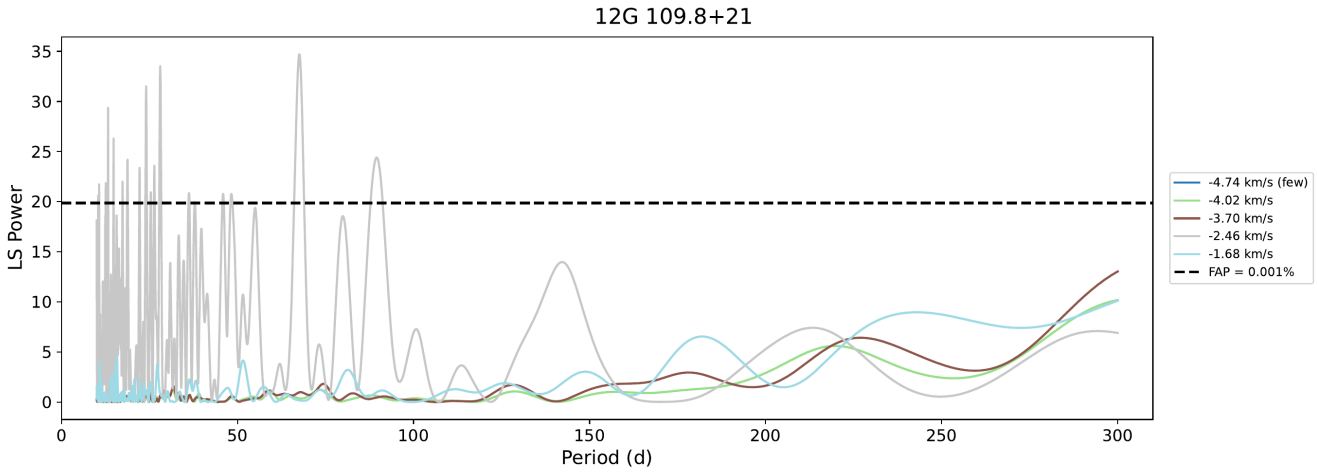


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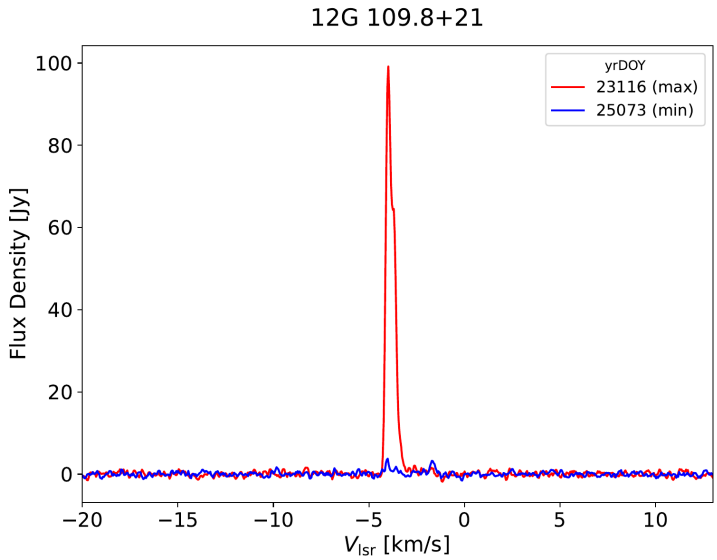
Light curve



Periodogram

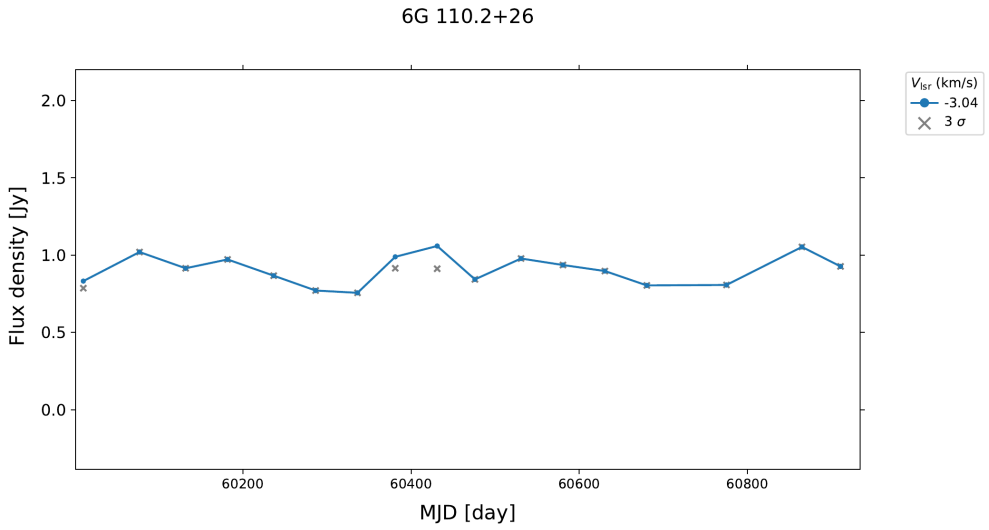


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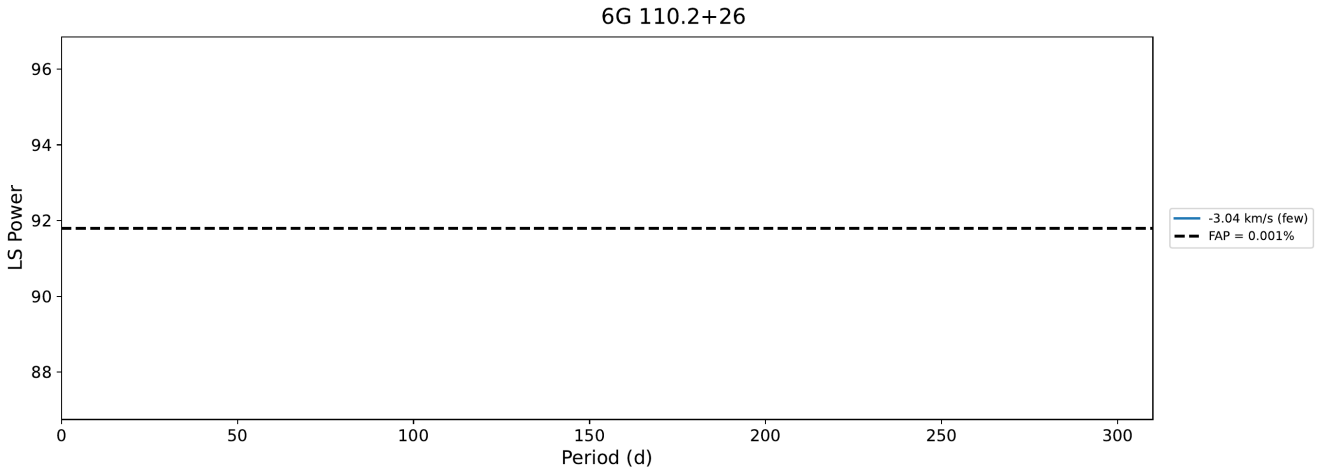


6G 110.2+26

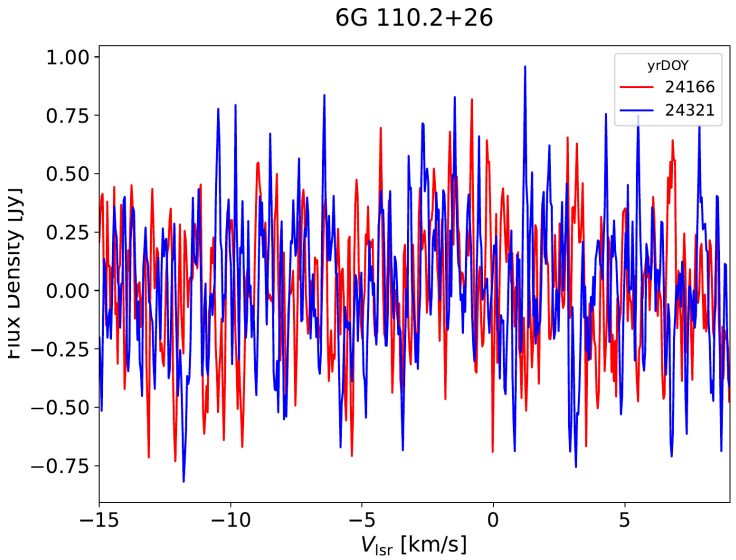
Light curve



Periodogram

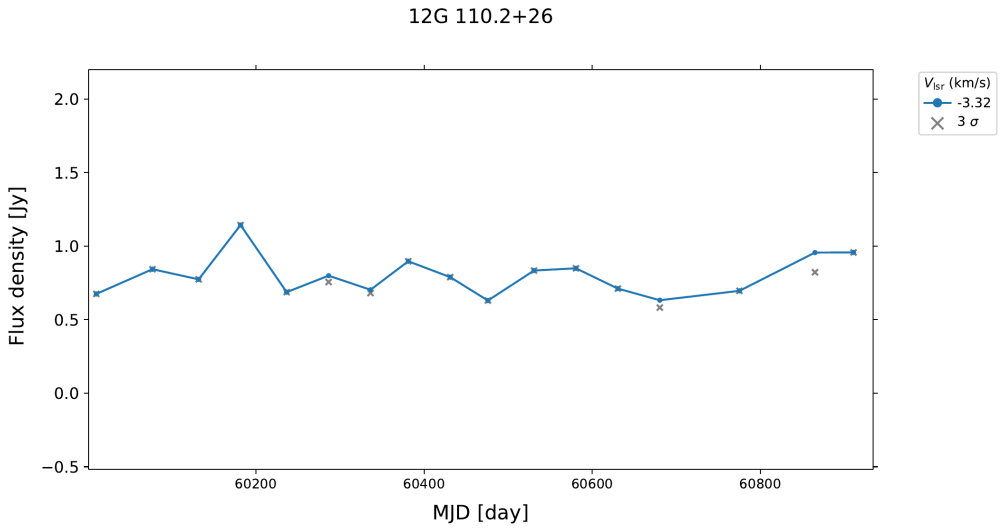


Spectrum

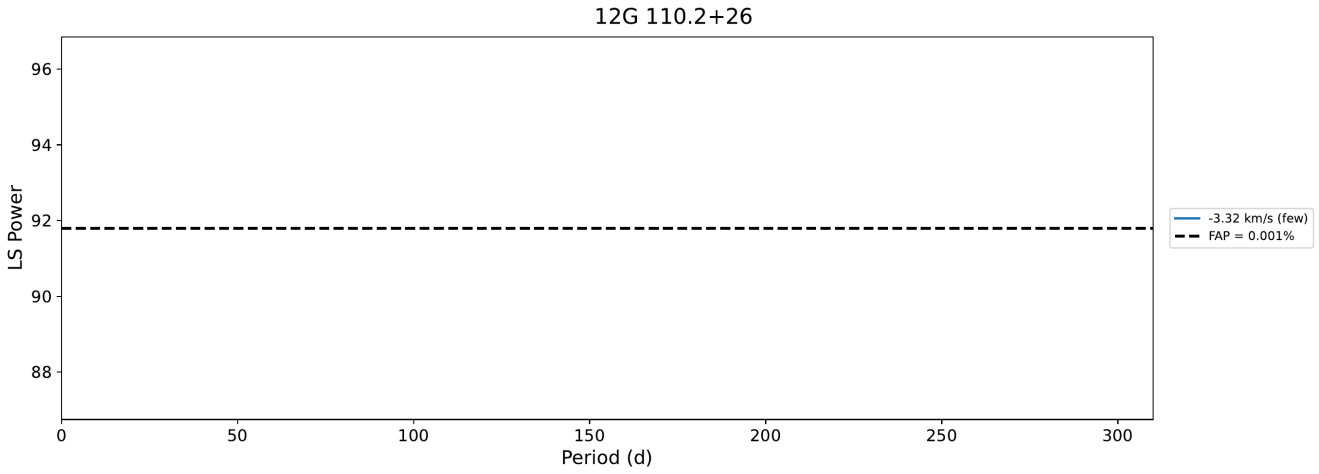


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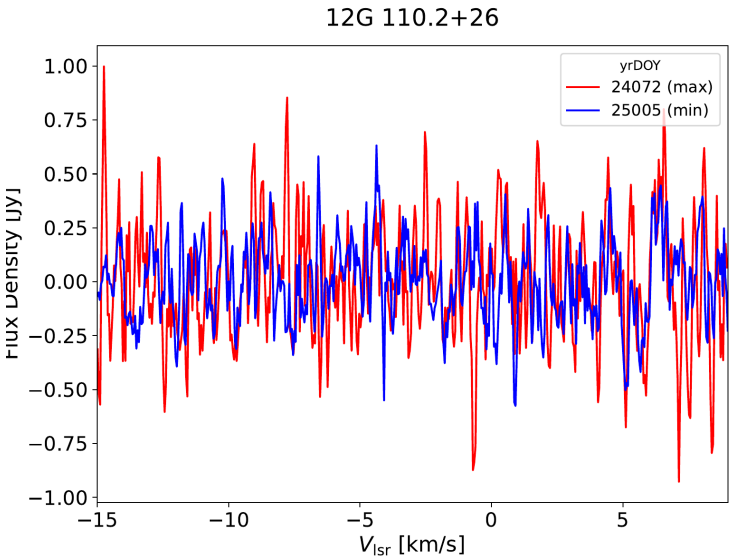
Light curve



Periodogram

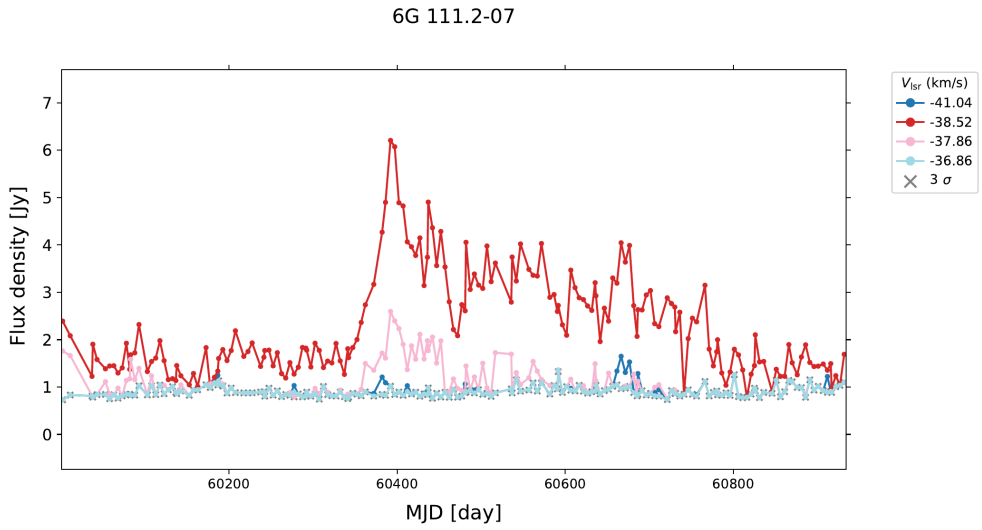


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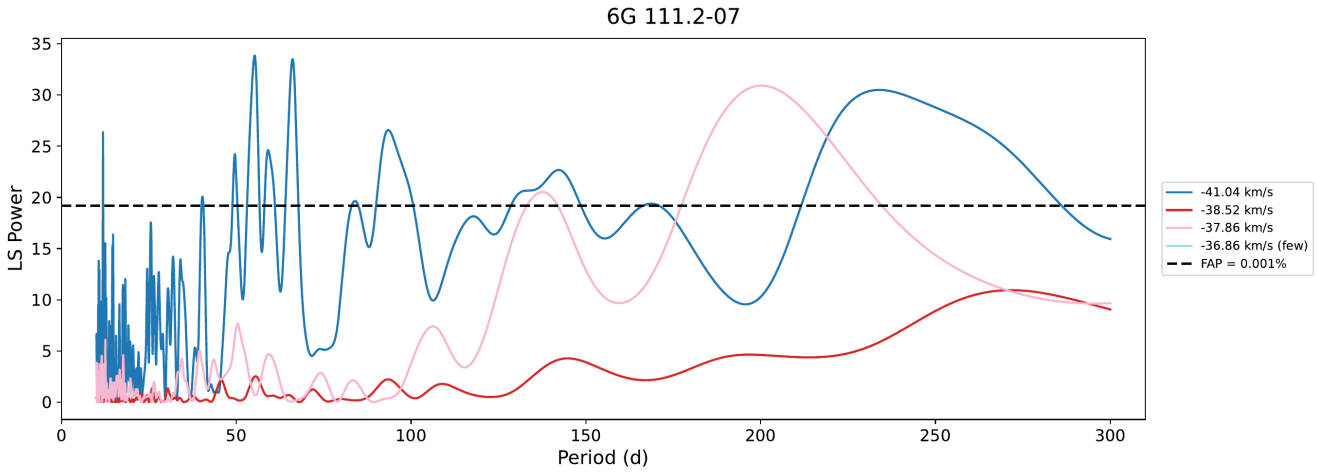


6G 111.2-07

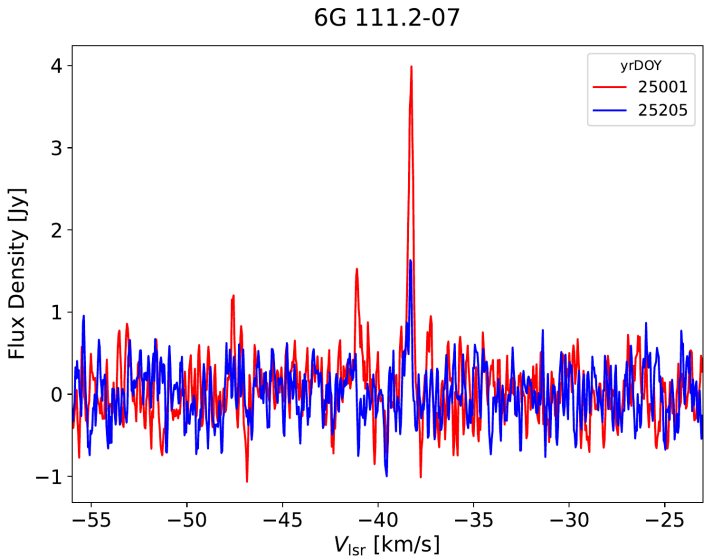
Light curve



Periodogram

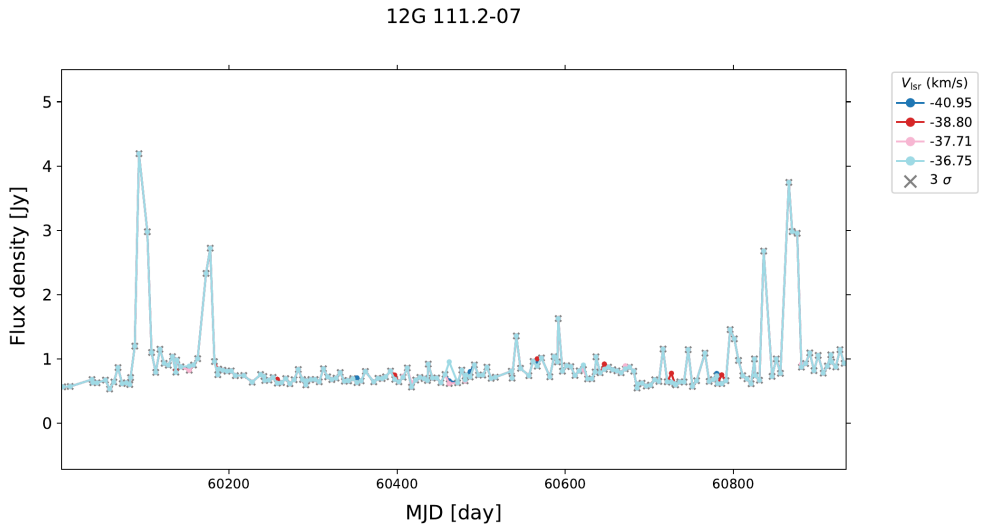


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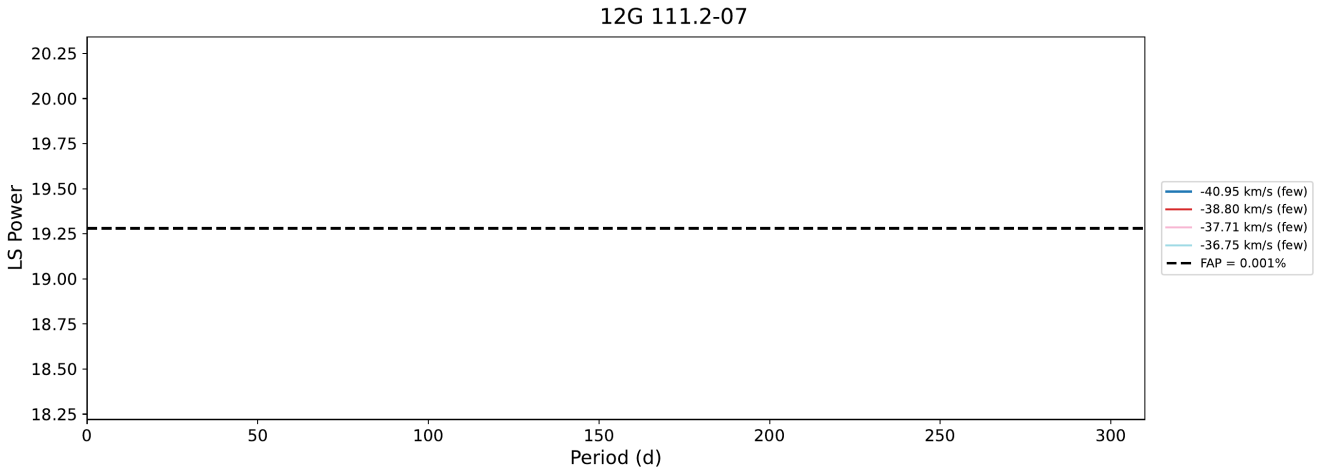


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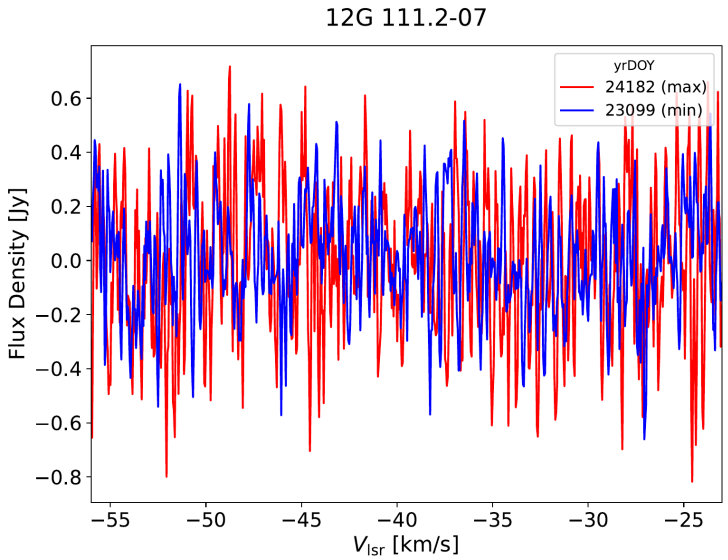
Light curve



Periodogram

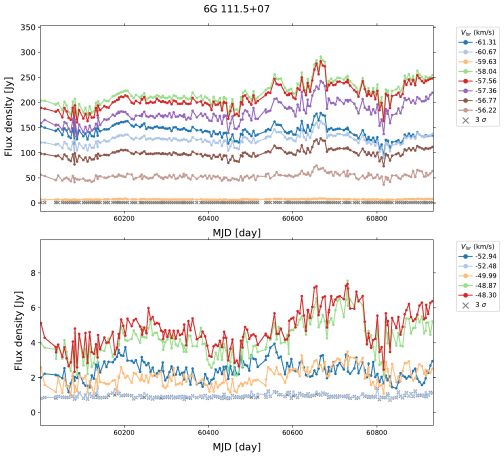


Spectrum

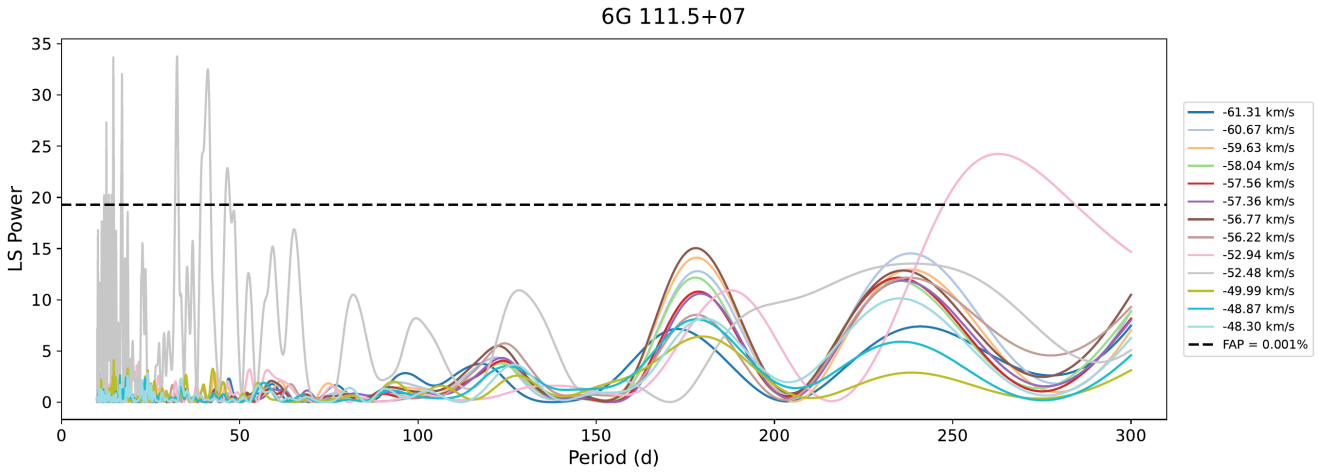


6G 111.5+07

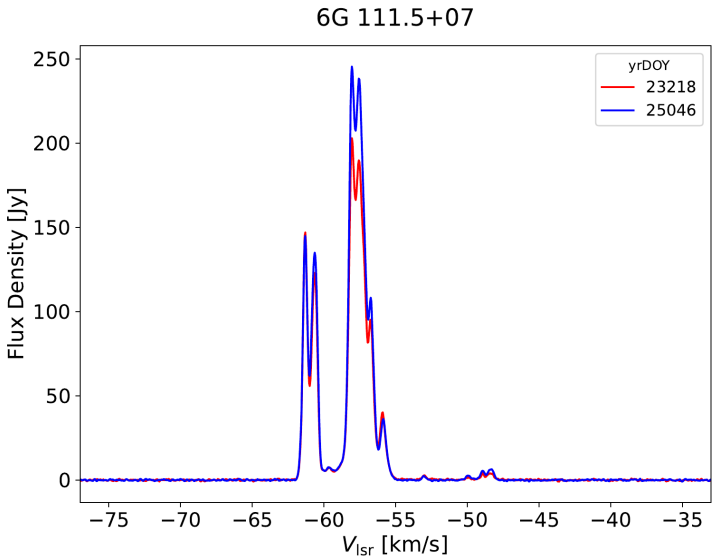
Light curve



Periodogram

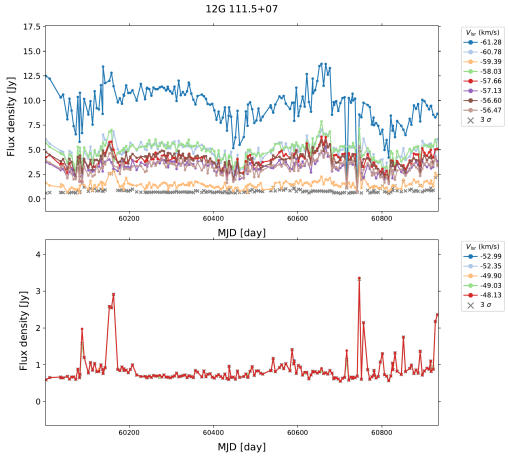


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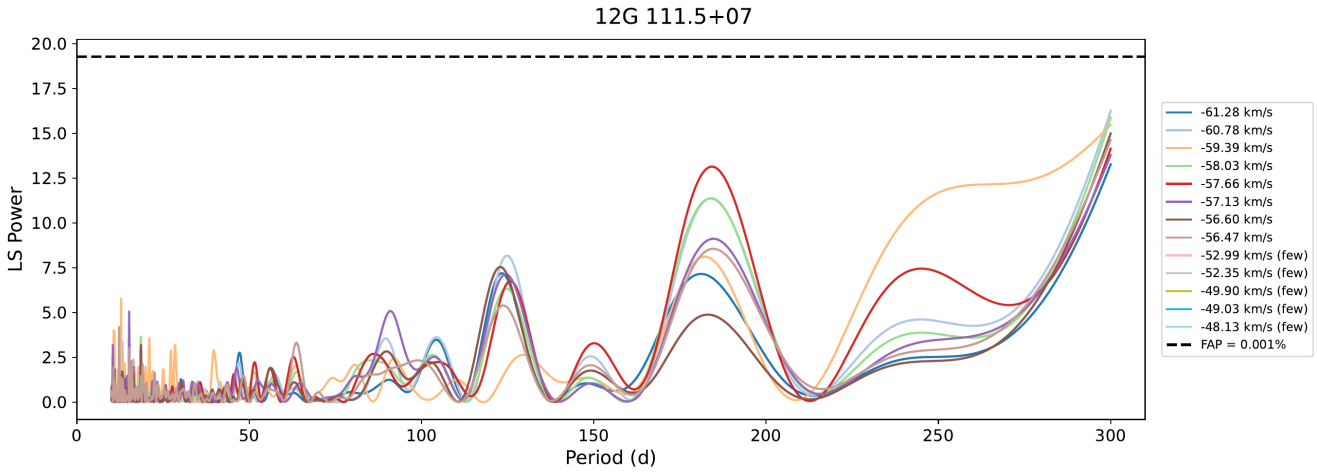


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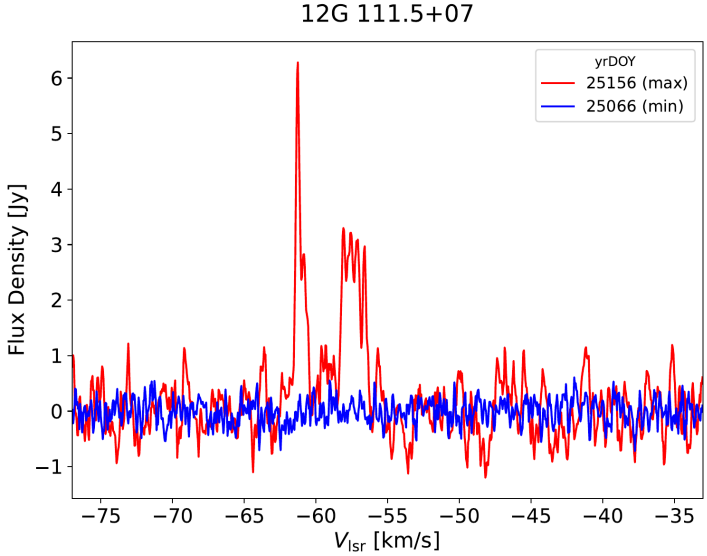
Light curve



Periodogram

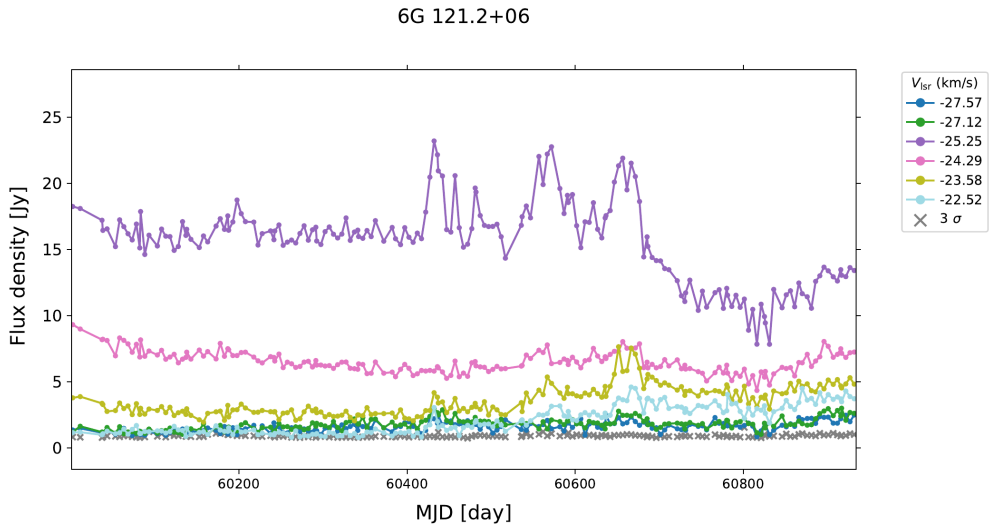


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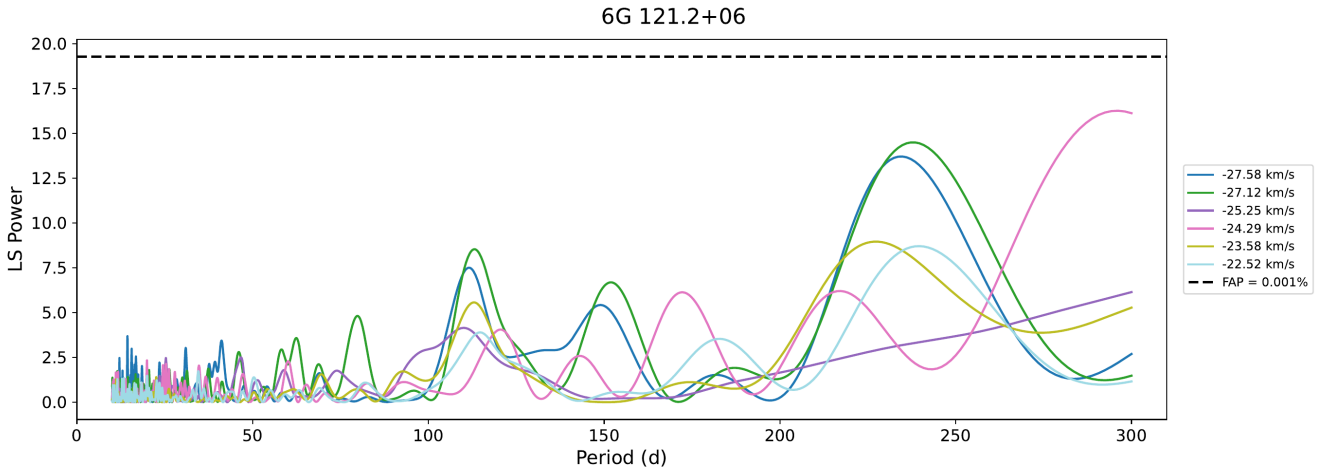


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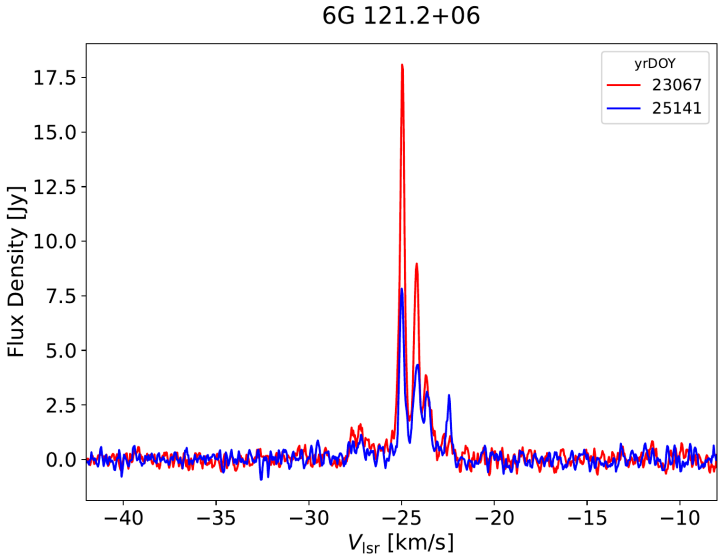
Light curve



Periodogram

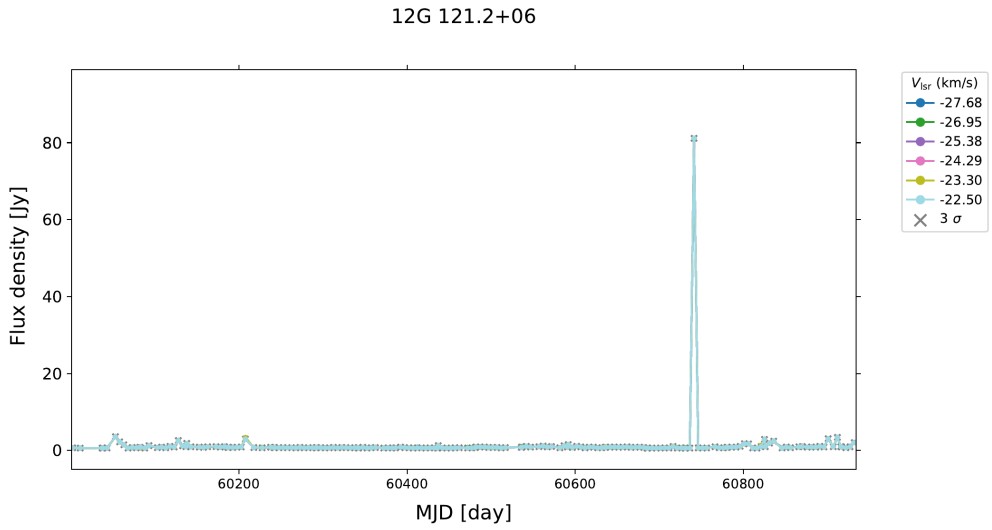


Spectrum

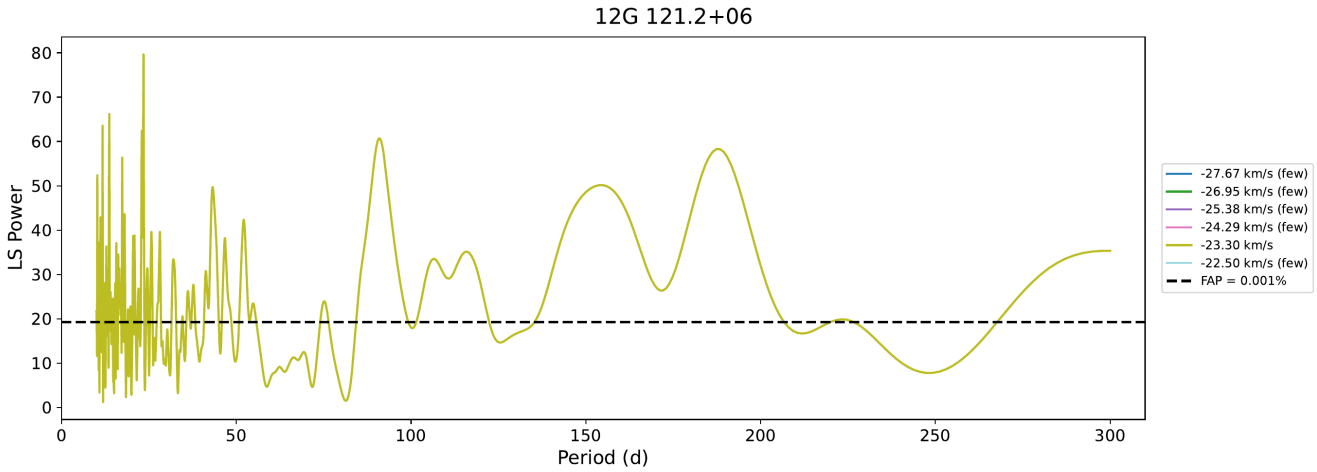


12G 121.2+06

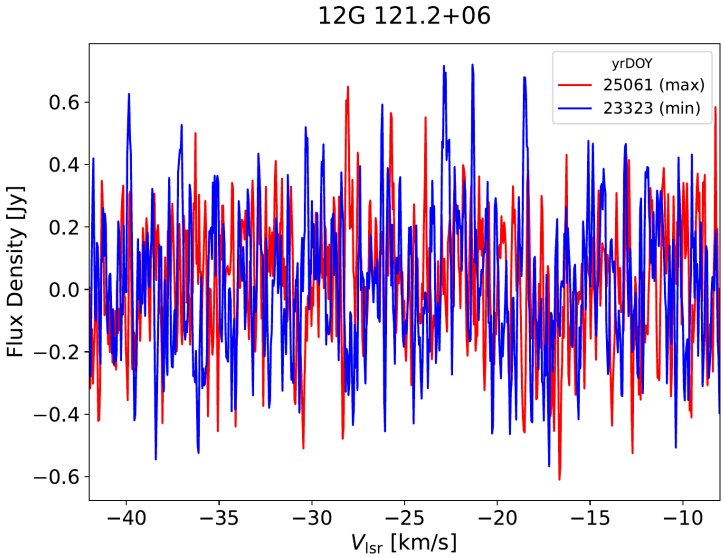
Light curve



Periodogram

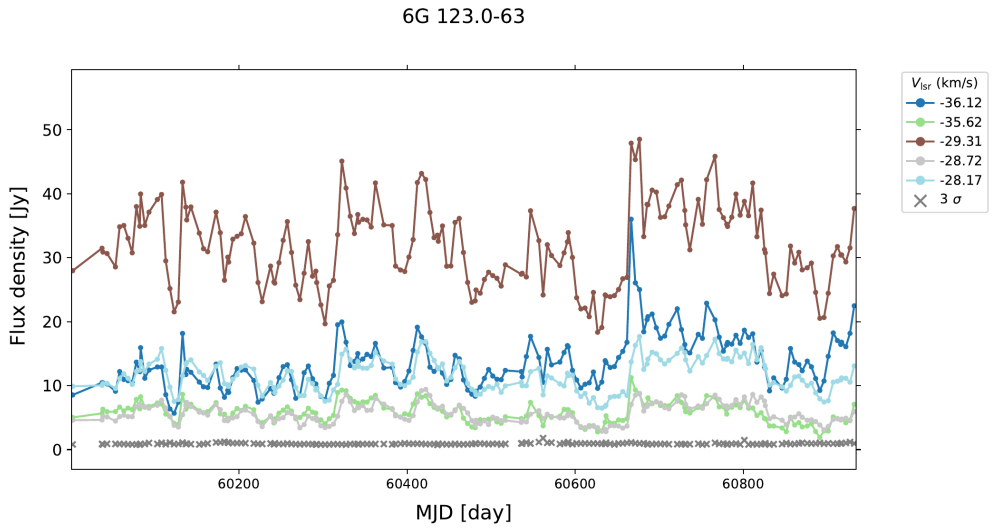


Spectrum

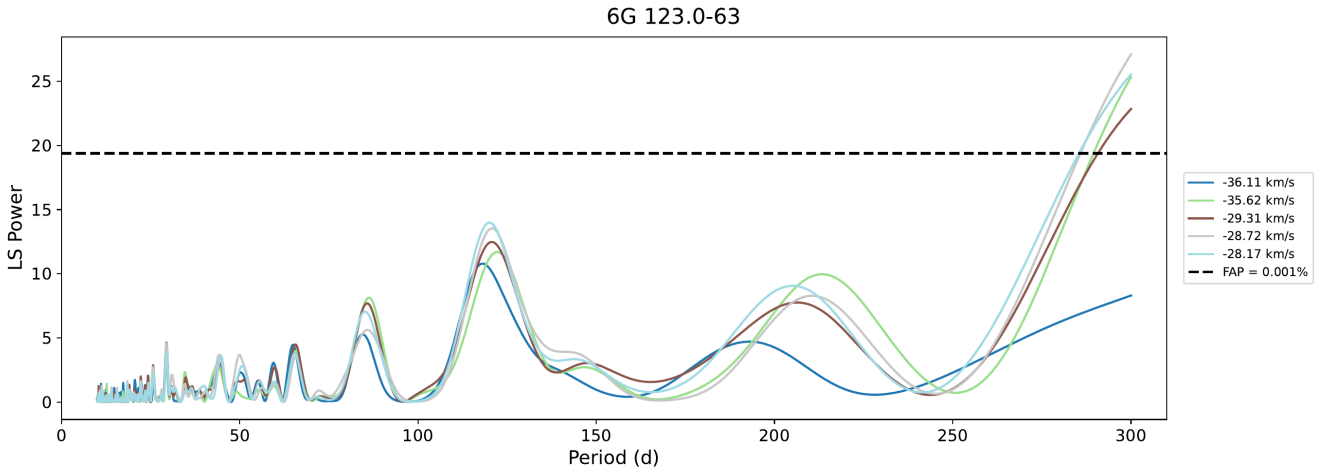


6G 123.0-63

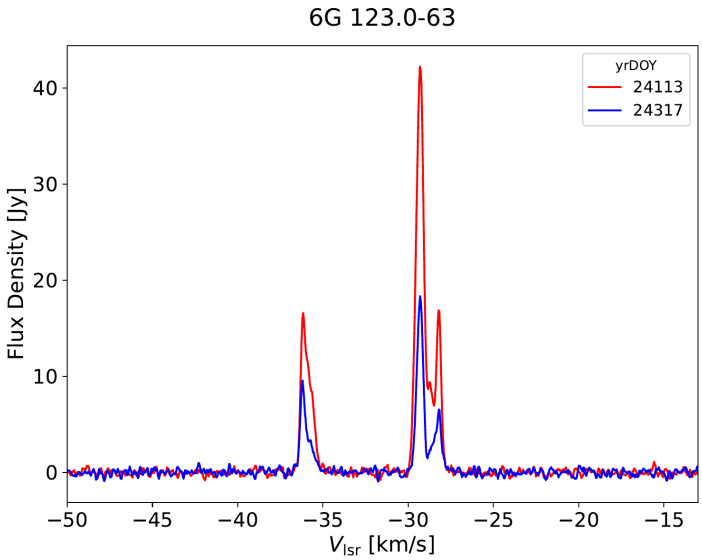
Light curve



Periodogram

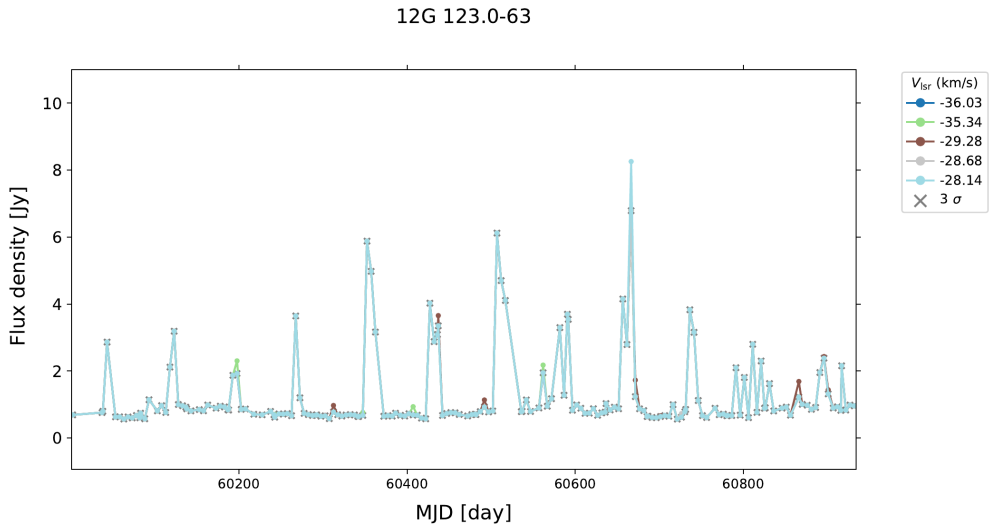


Spectrum

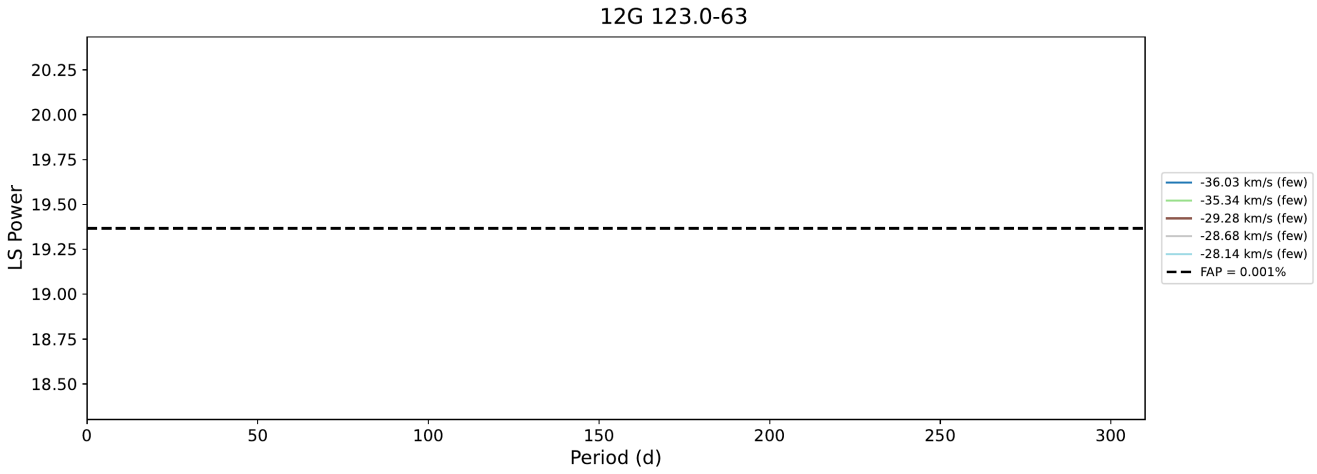


12G 123.0-63

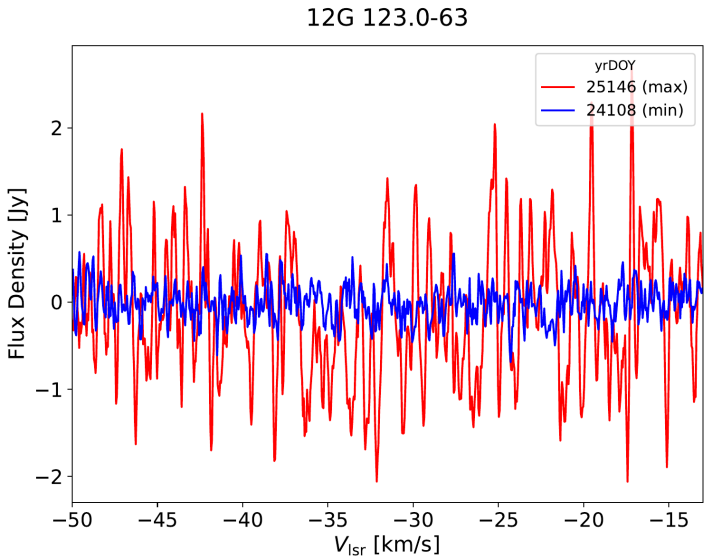
Light curve



Periodogram

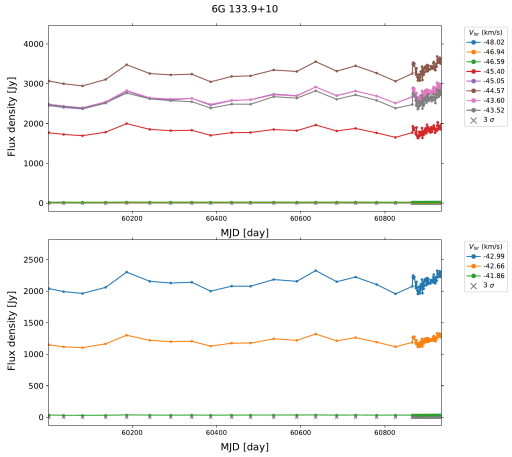


Spectrum

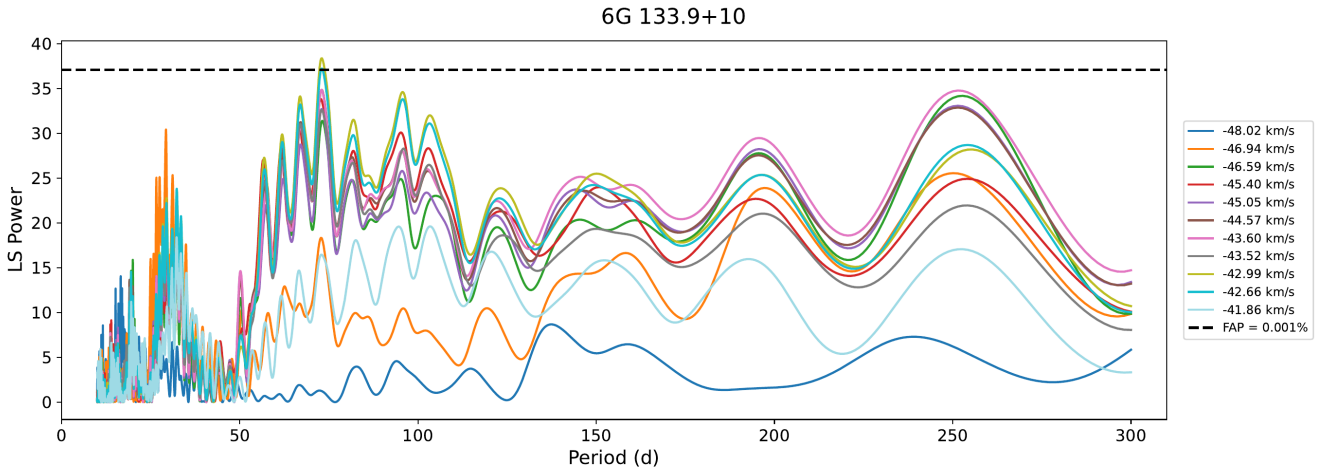


6G 133.9+10

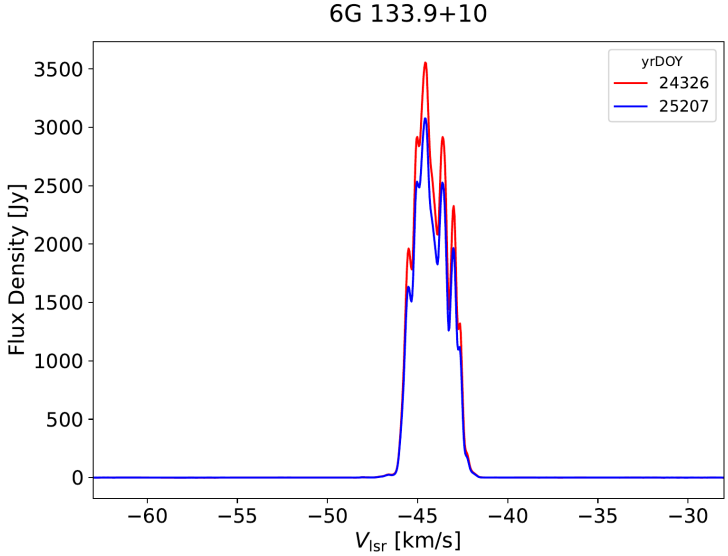
Light curve



Periodogram

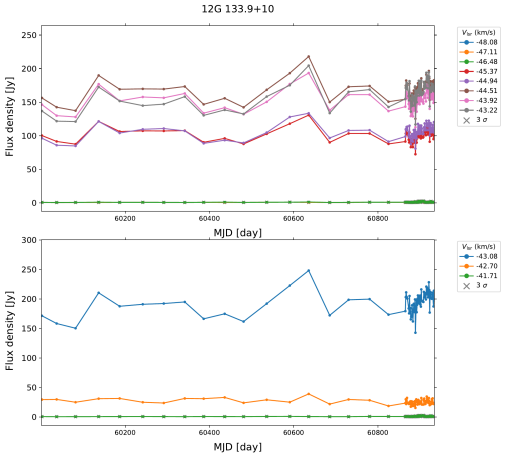


Spectrum

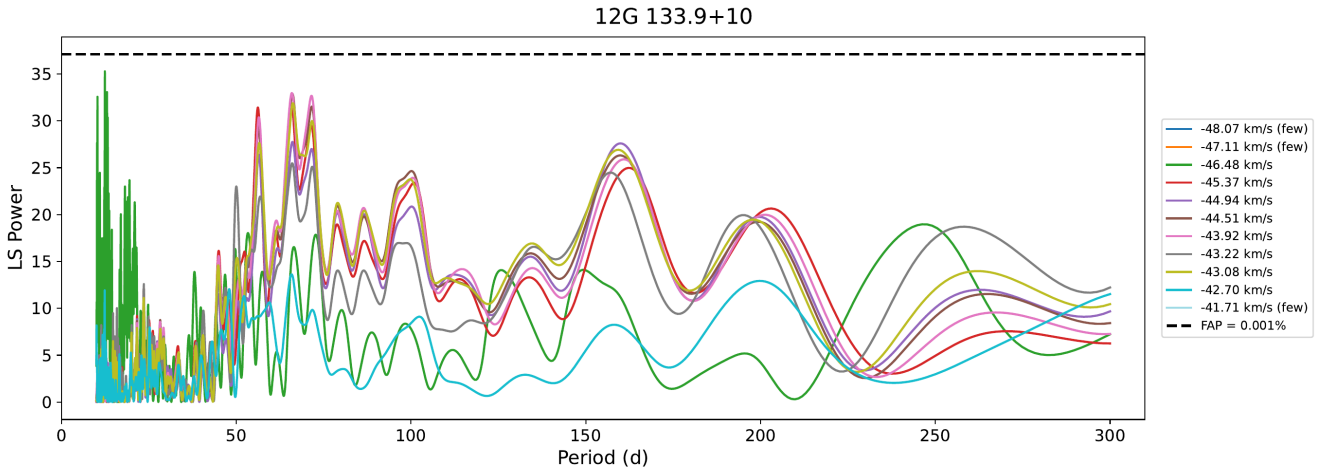


12G 133.9+10

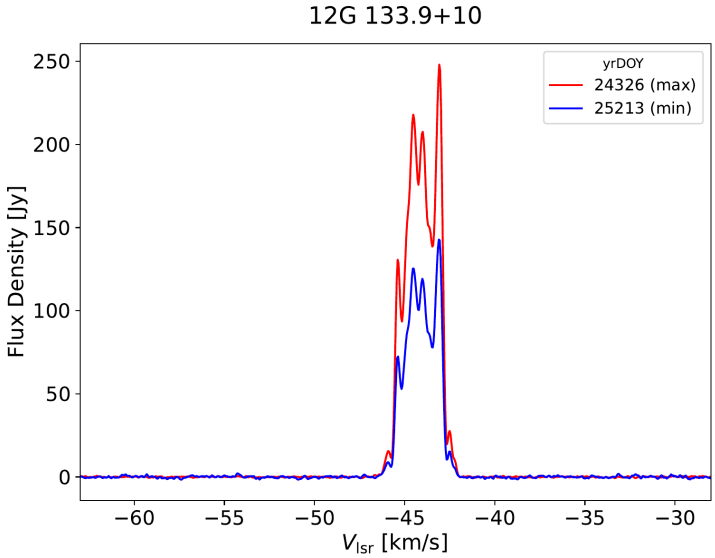
Light curve



Periodogram

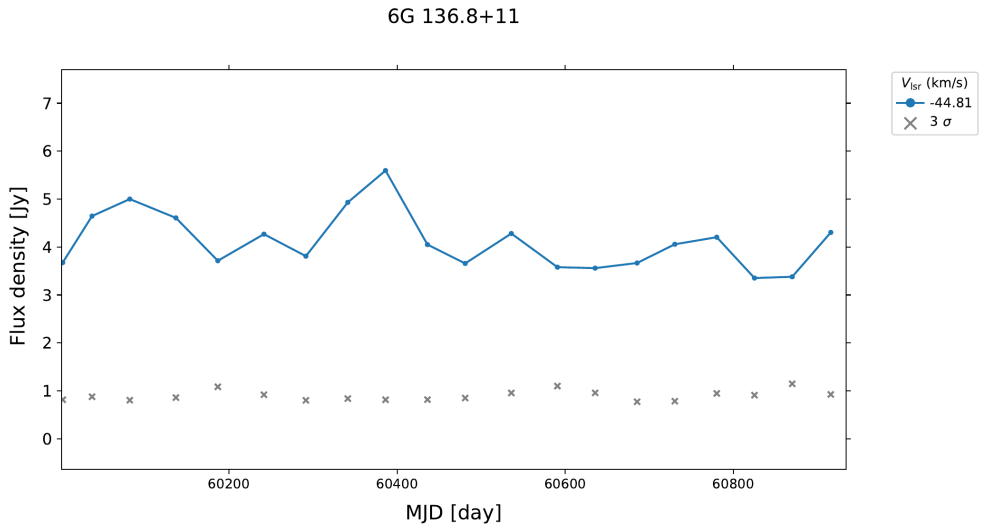


Spectrum

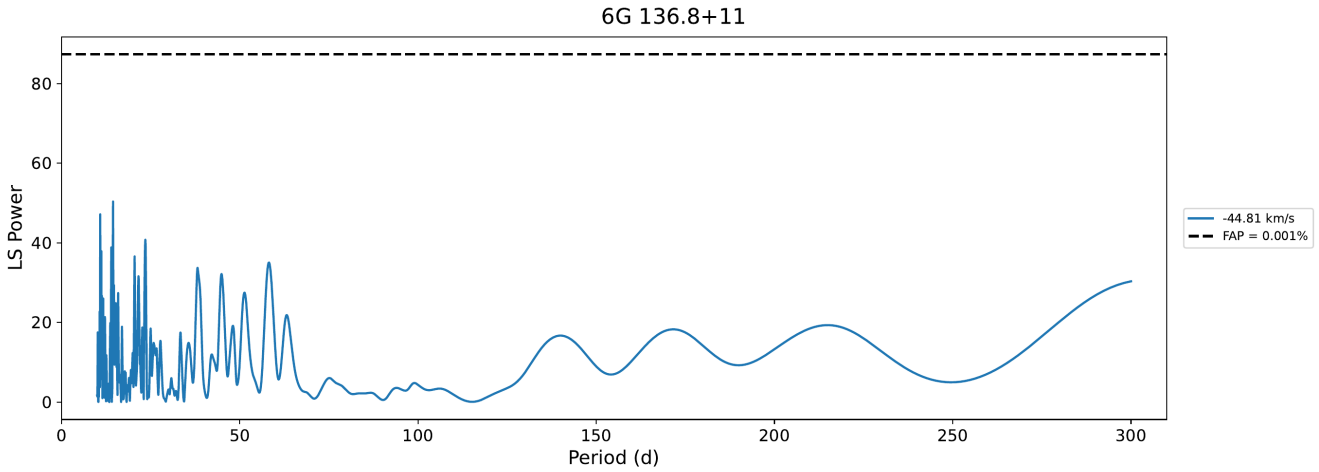


6G 136.8+11

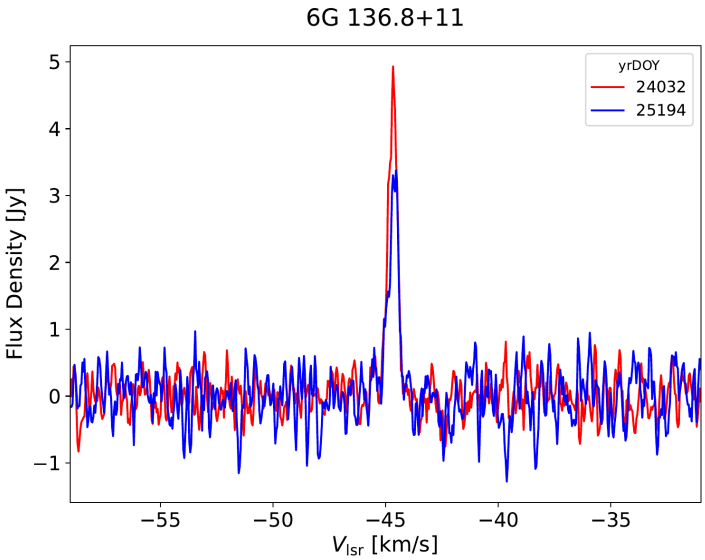
Light curve



Periodogram

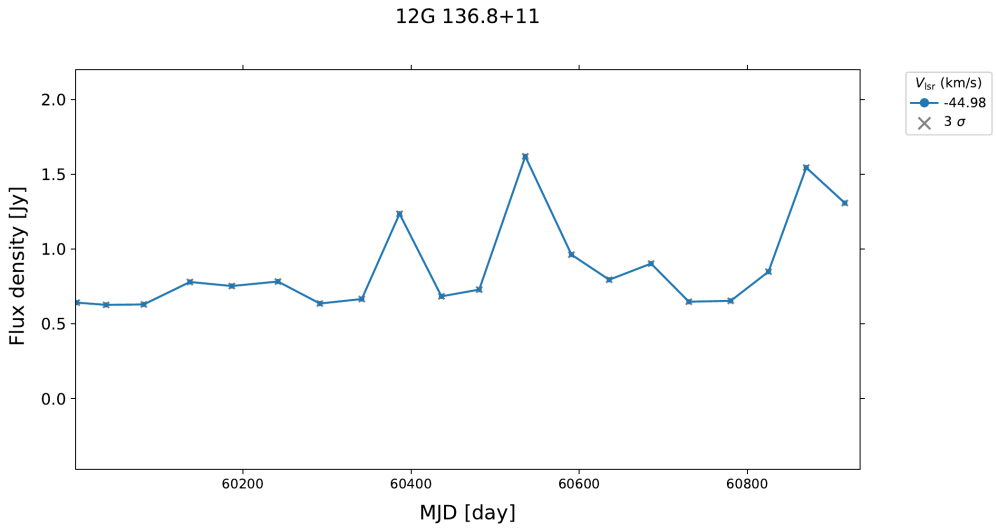


Spectrum

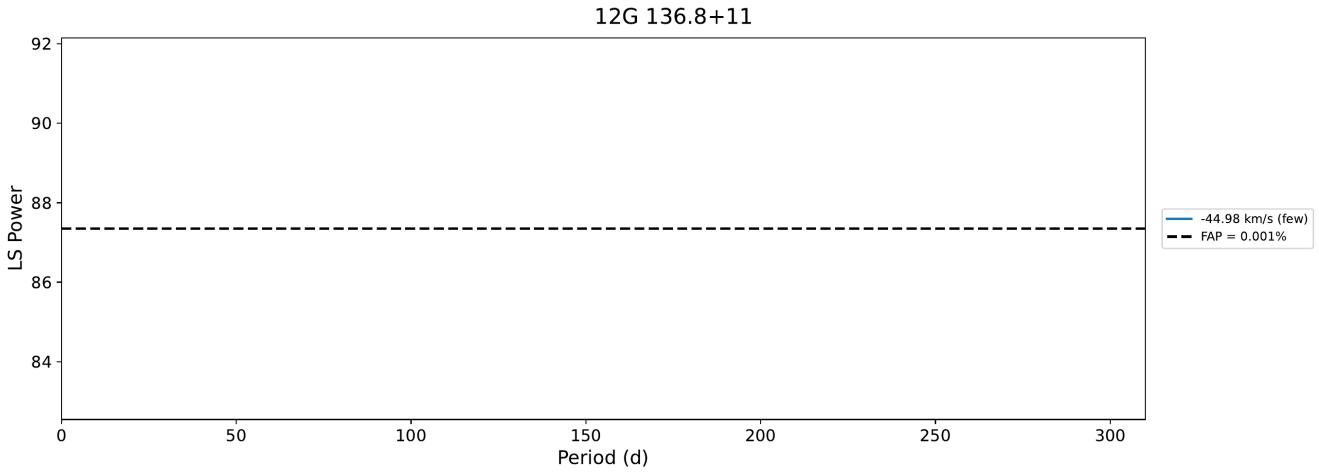


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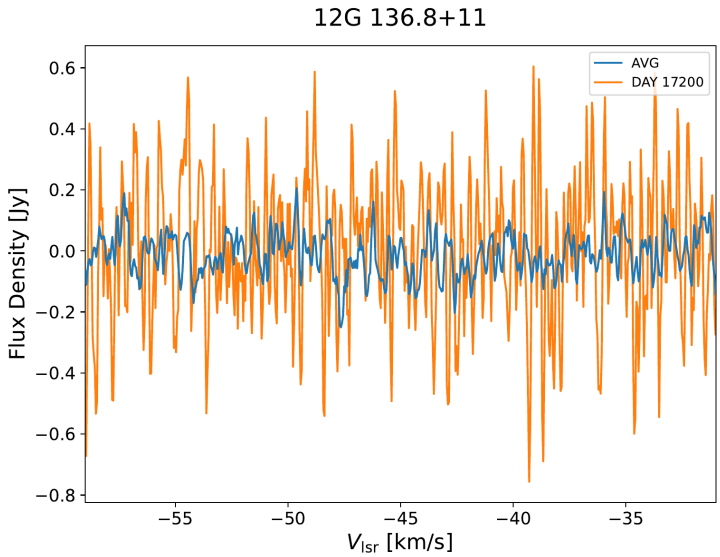
Light curve



Periodogram

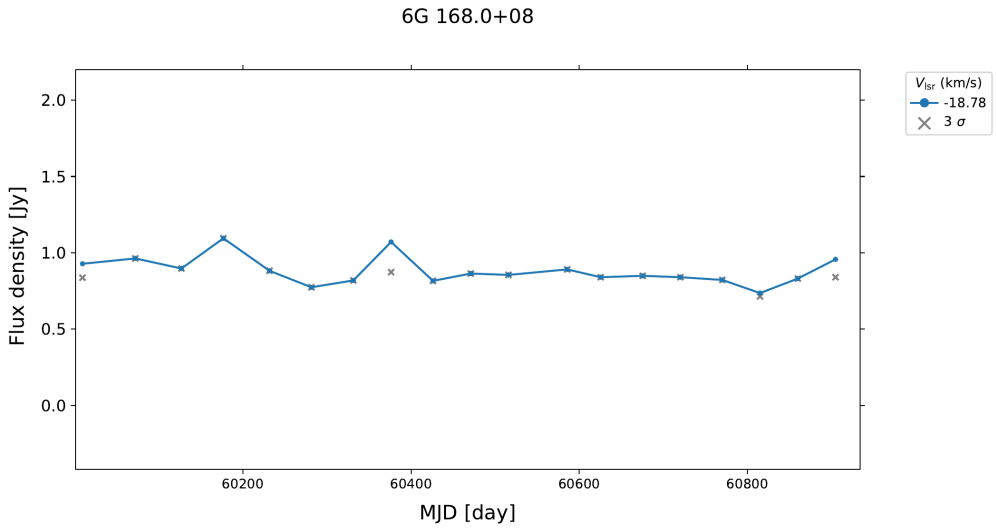


Spectrum

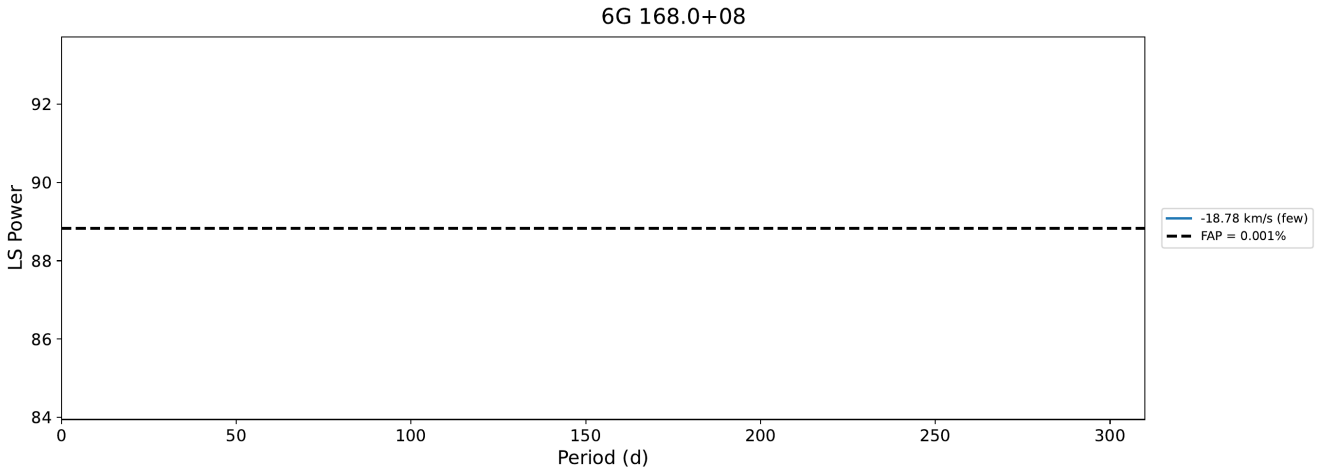


6G 168.0+08

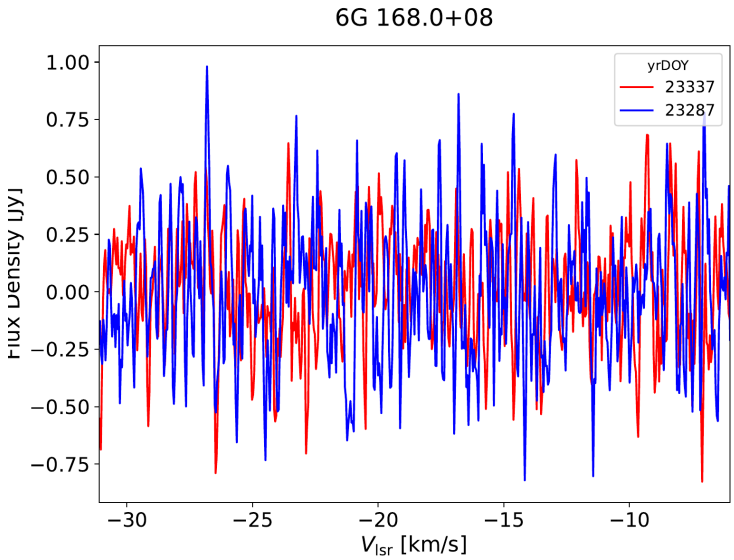
Light curve



Periodogram

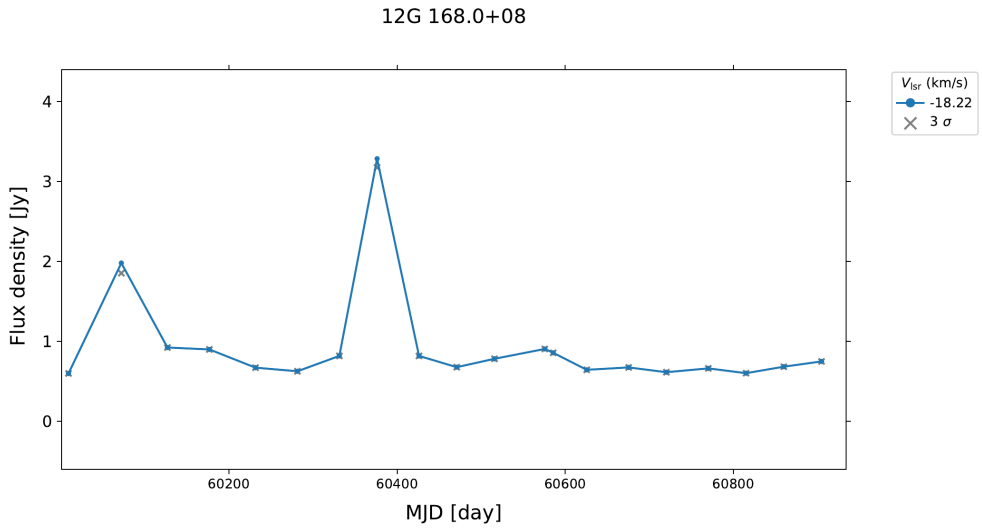


Spectrum

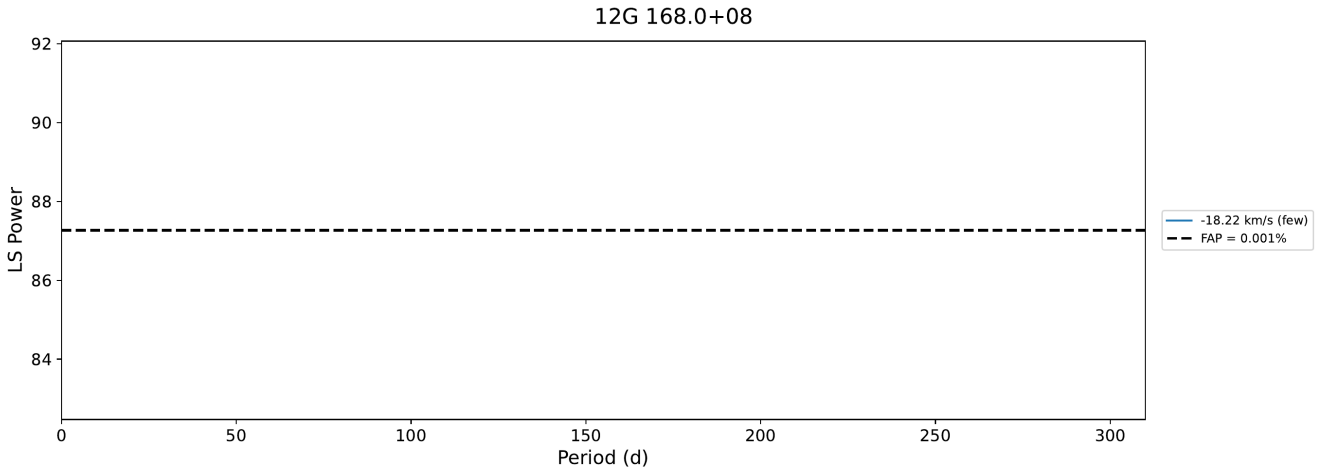


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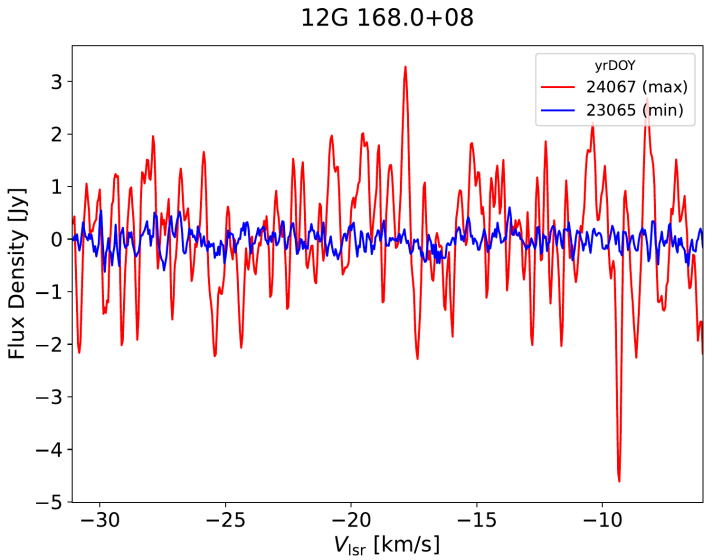
Light curve



Periodogram

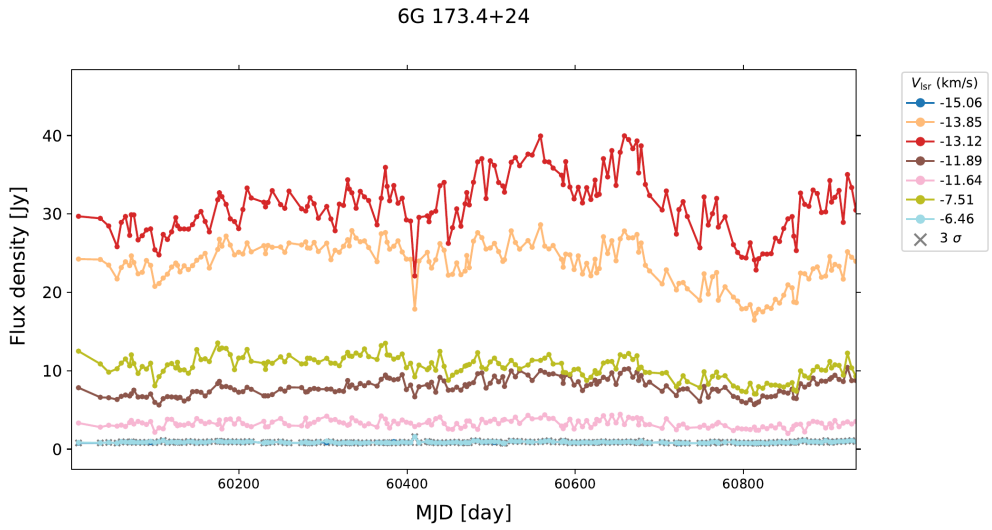


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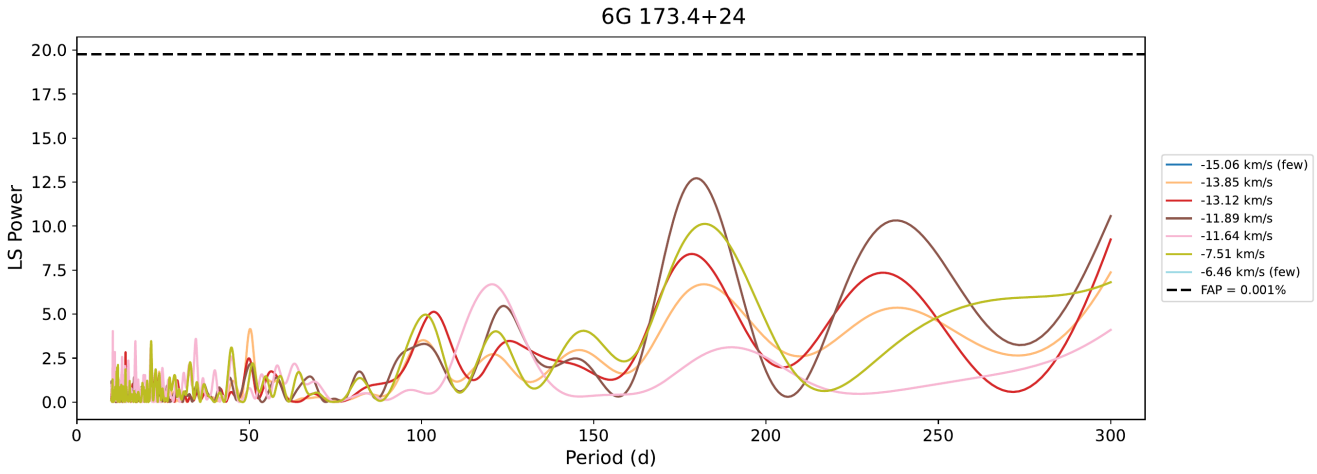


6G 173.4+24

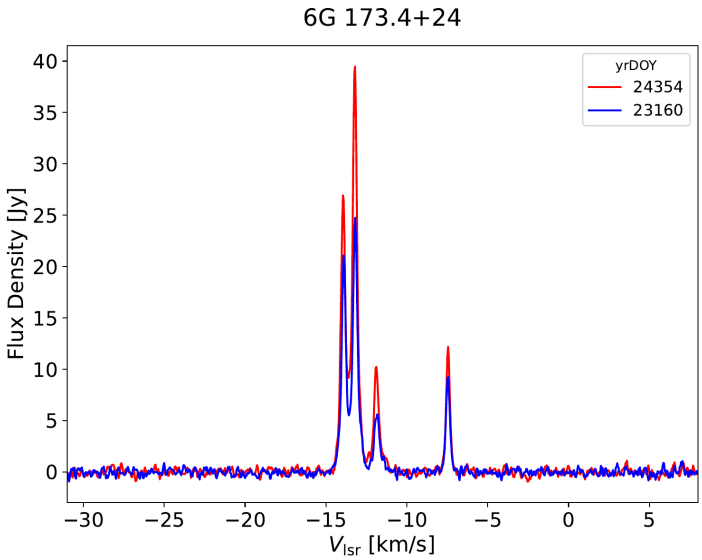
Light curve



Periodogram

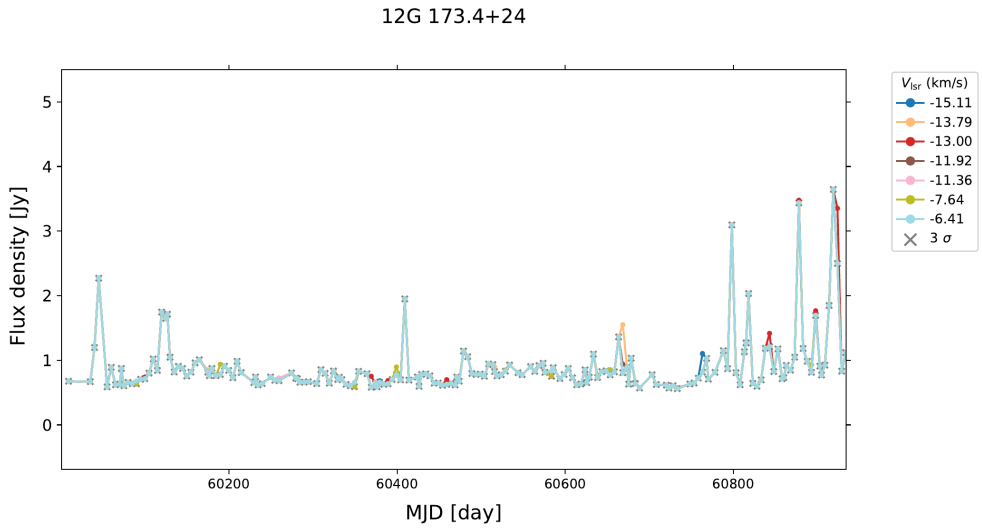


Spectrum

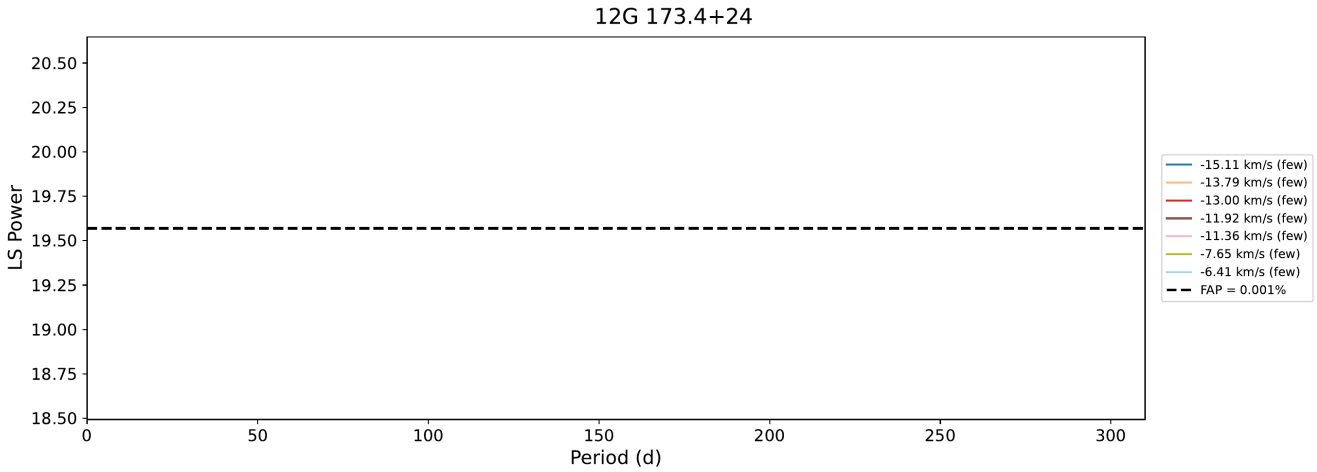


12G 173.4+24

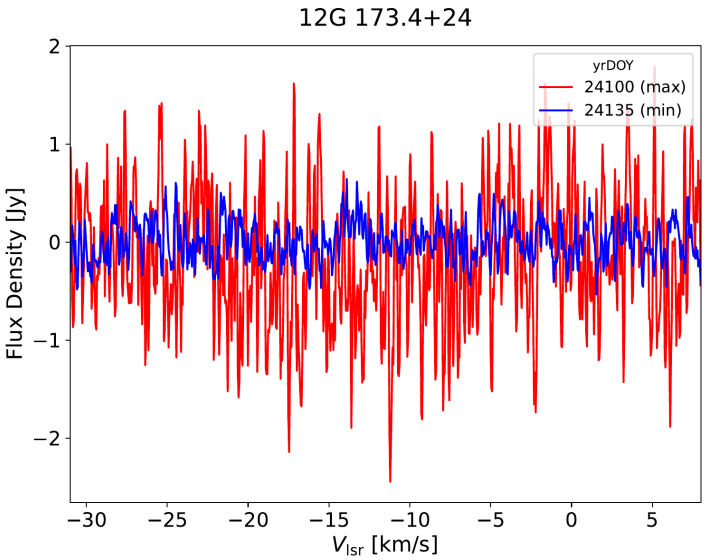
Light curve



Periodogram

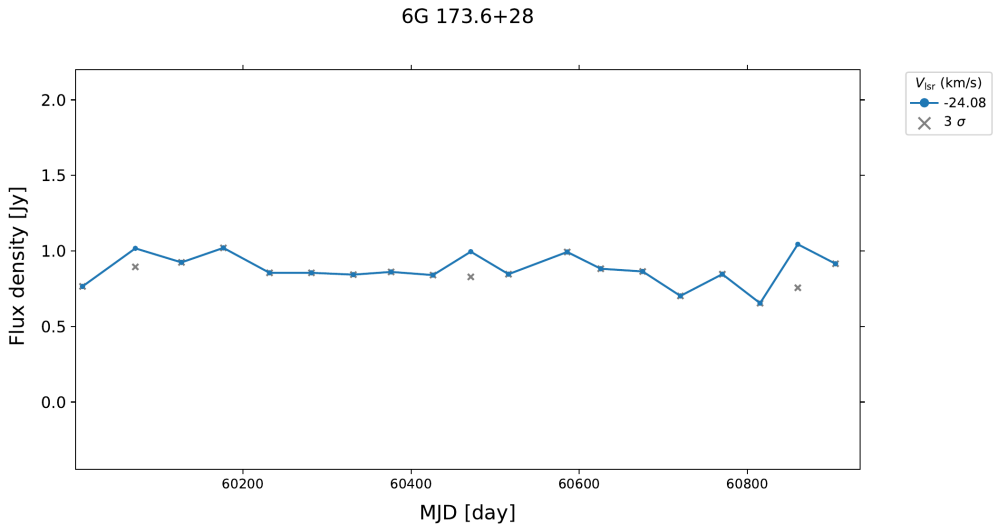


Spectrum

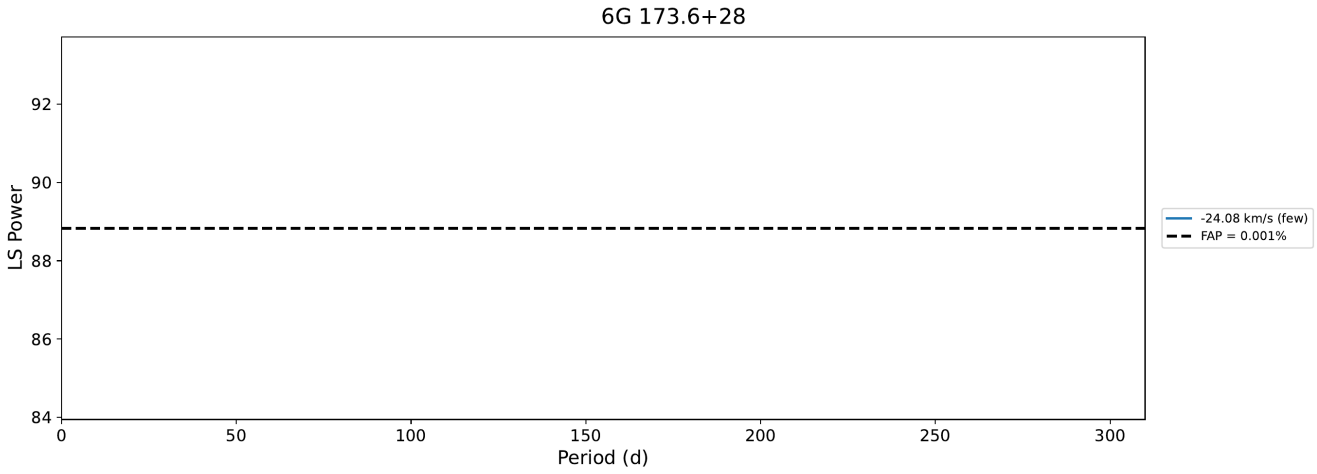


6G 173.6+28

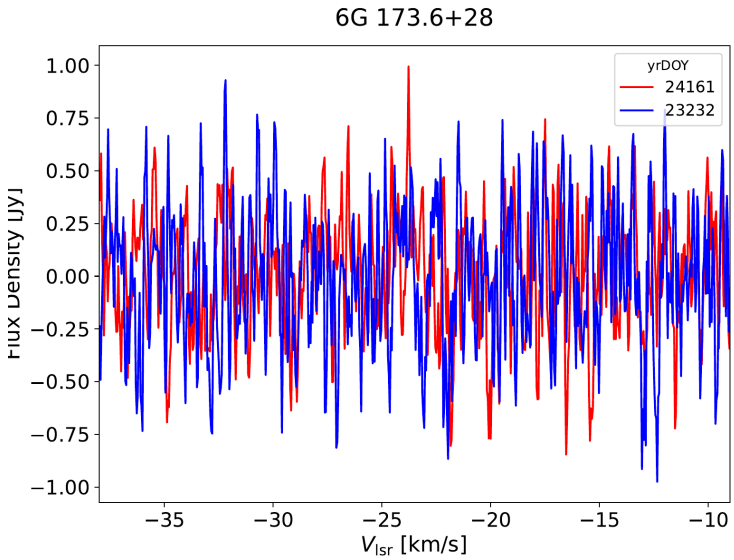
Light curve



Periodogram

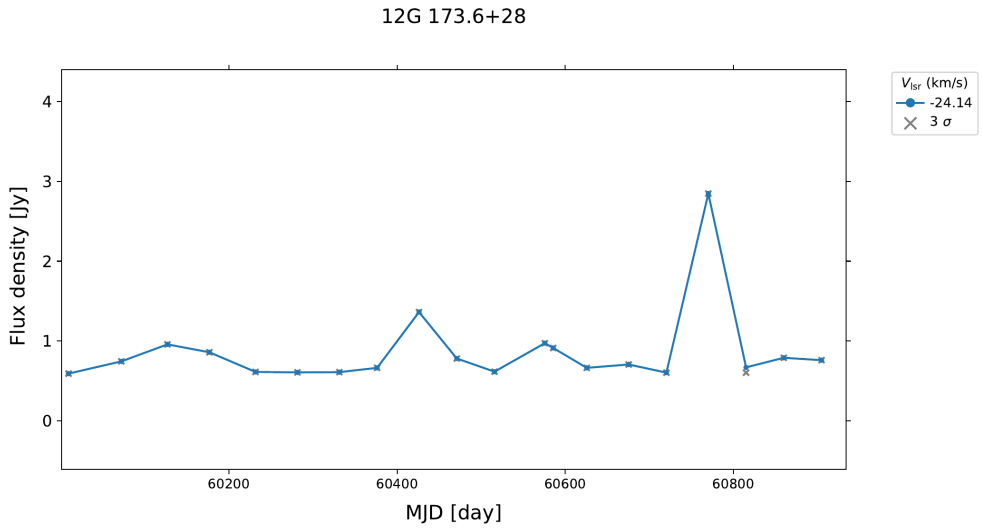


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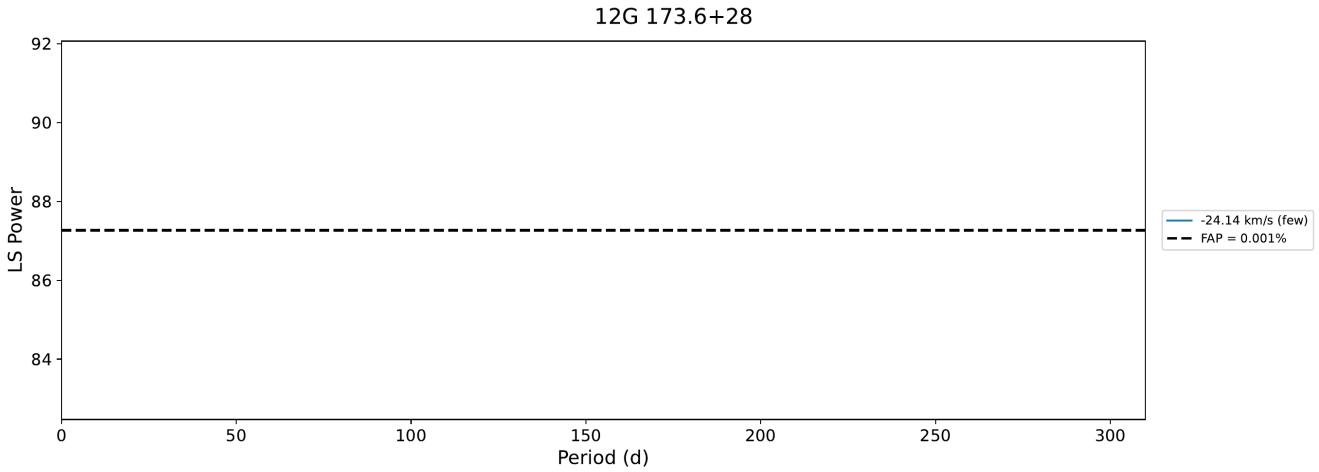


12G 173.6+28

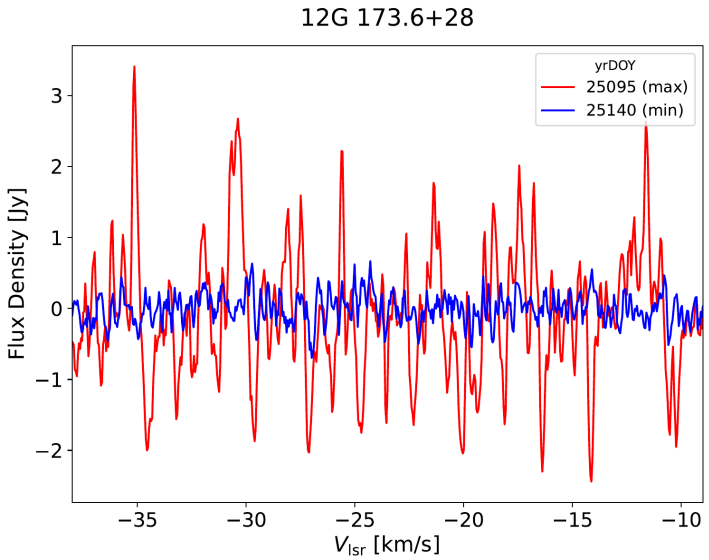
Light curve



Periodogram

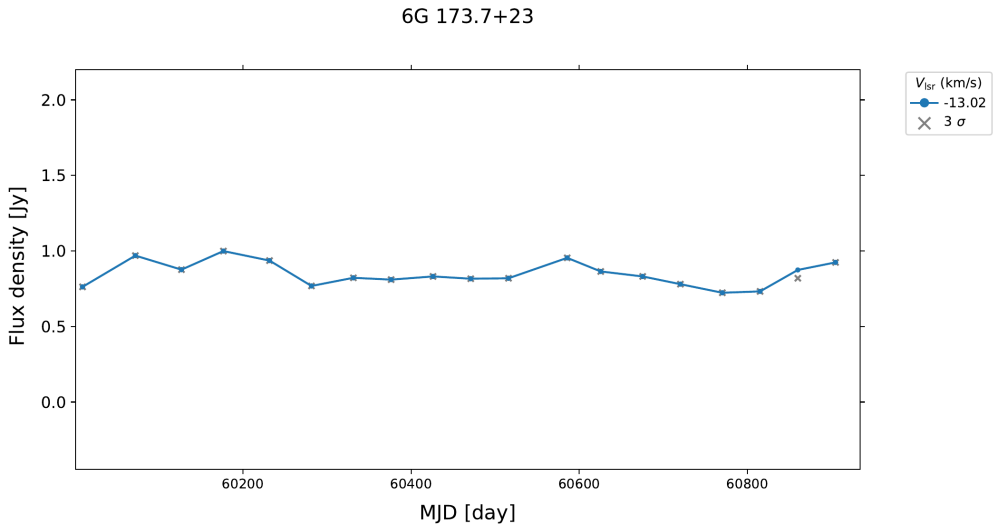


Spectrum

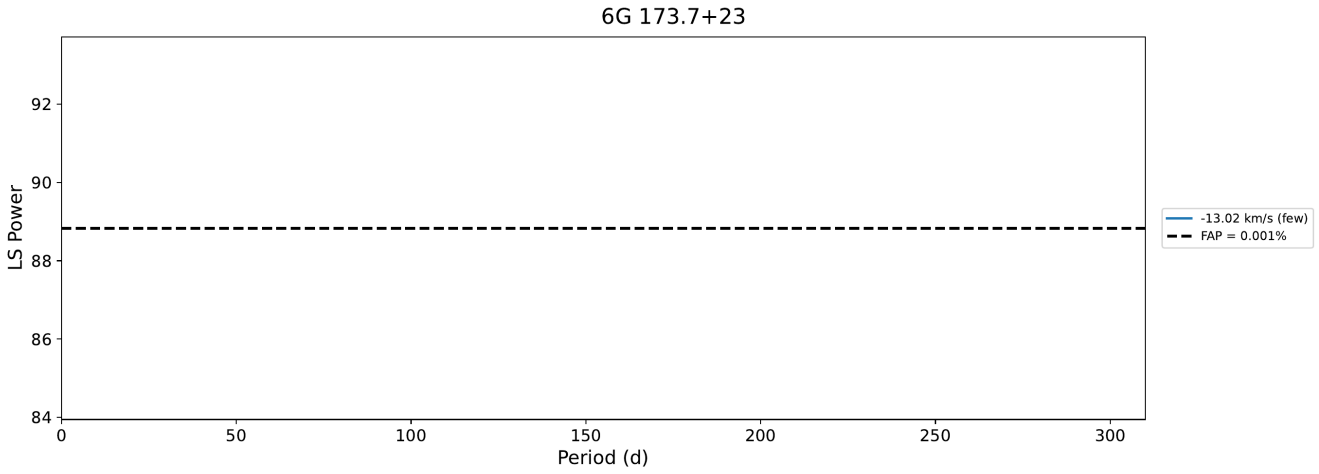


6G 173.7+23

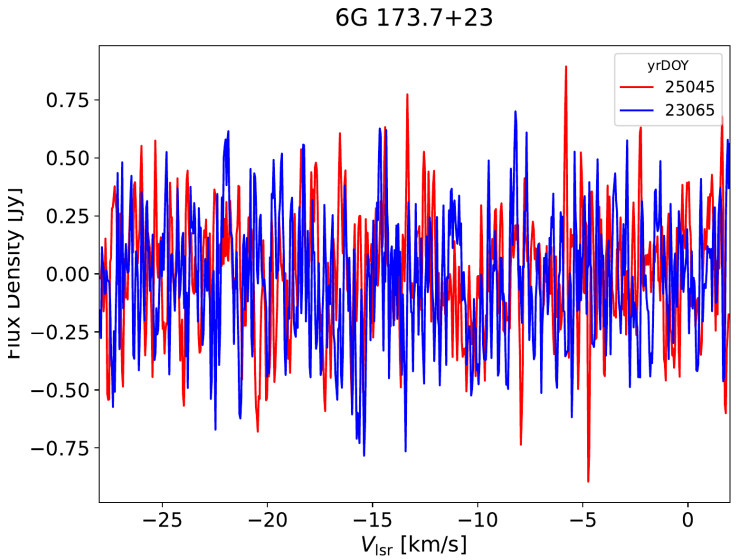
Light curve



Periodogram

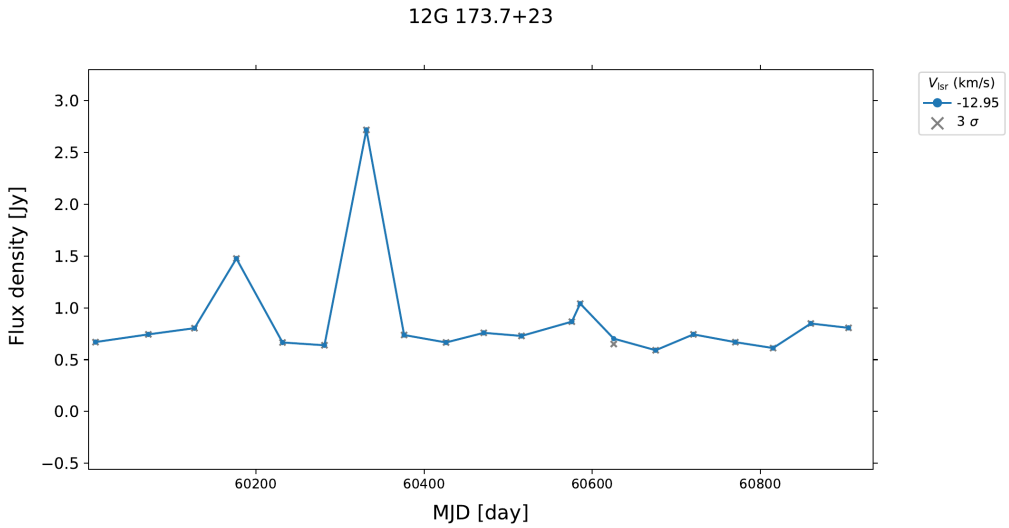


Spectrum

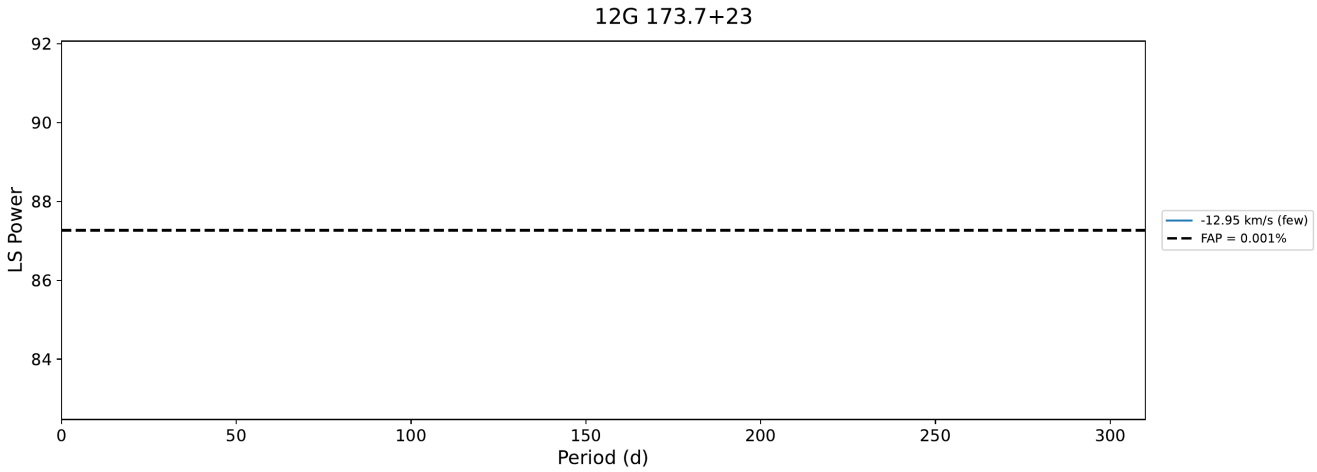


12G 173.7+23

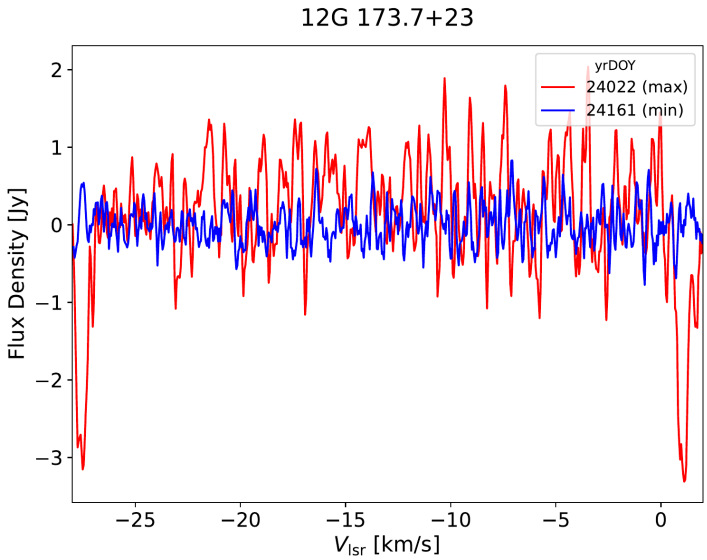
Light curve



Periodogram

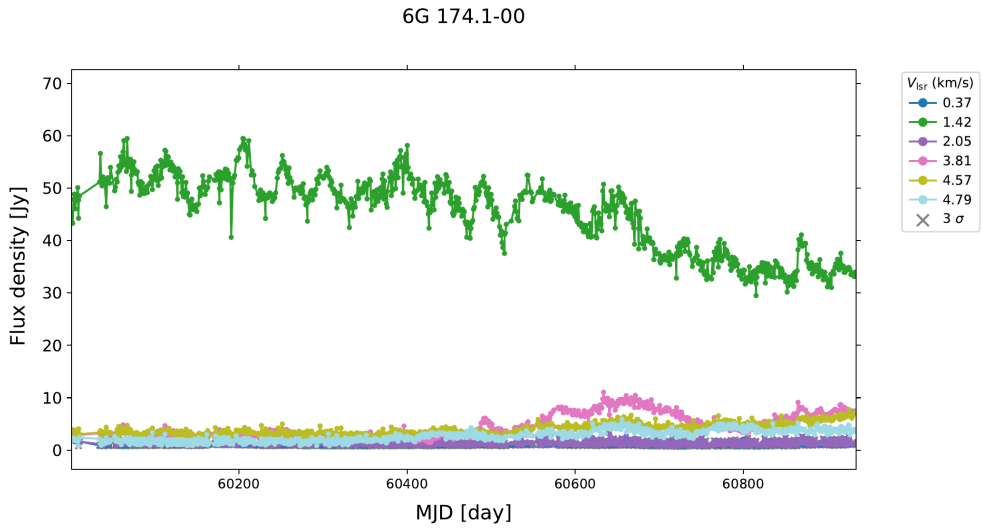


Spectrum

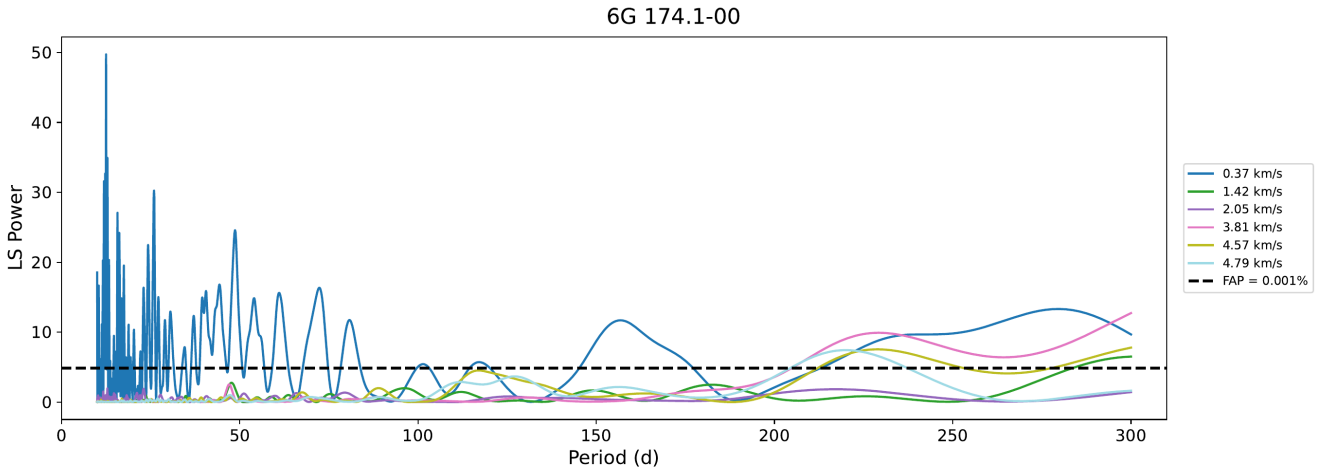


6G 174.1-00

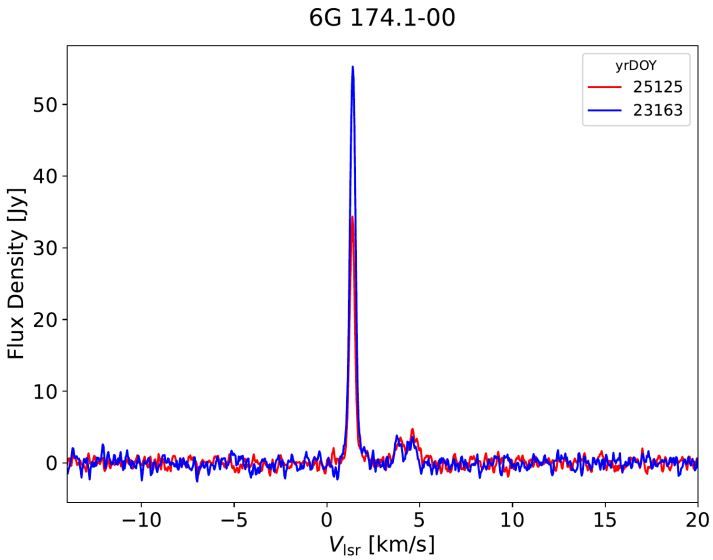
Light curve



Periodogram

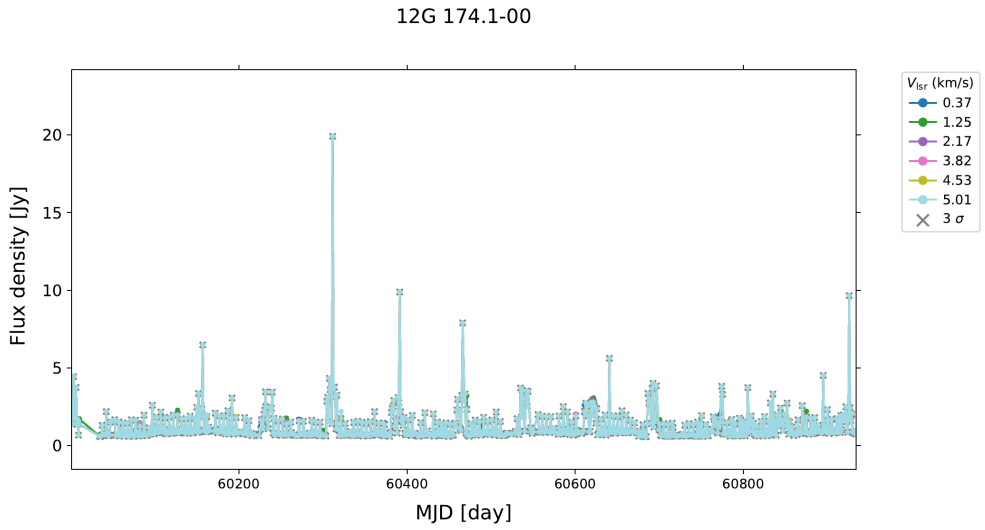


Spectrum

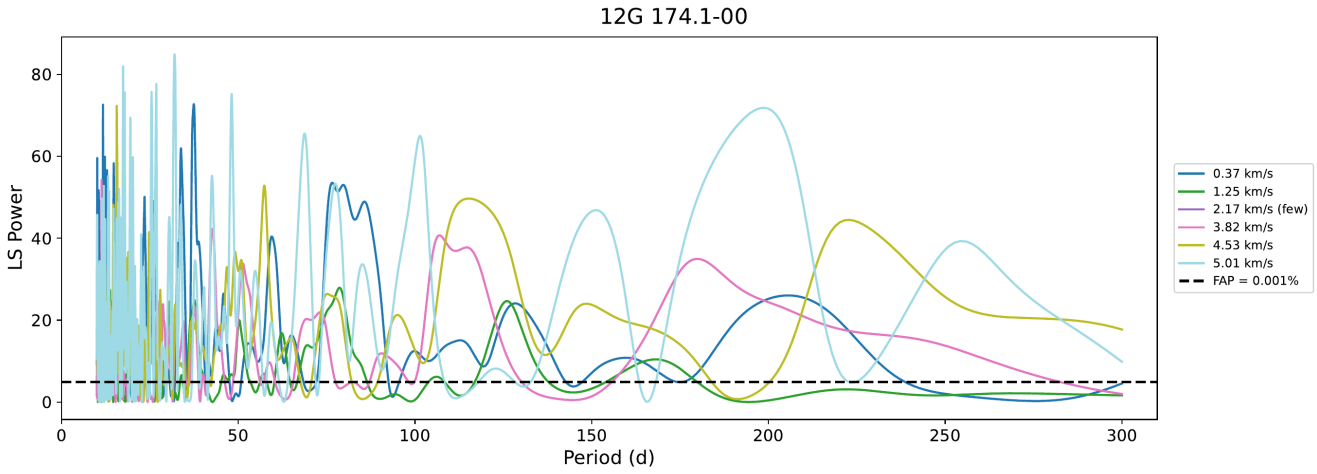


12G 174.1-00

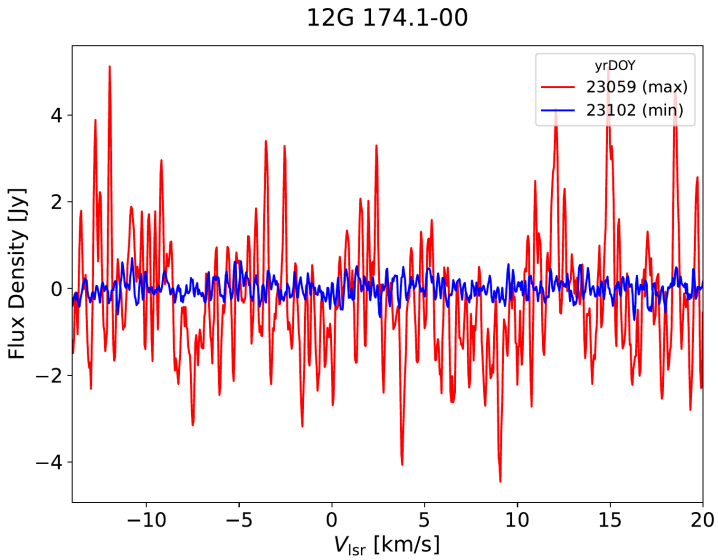
Light curve



Periodogram

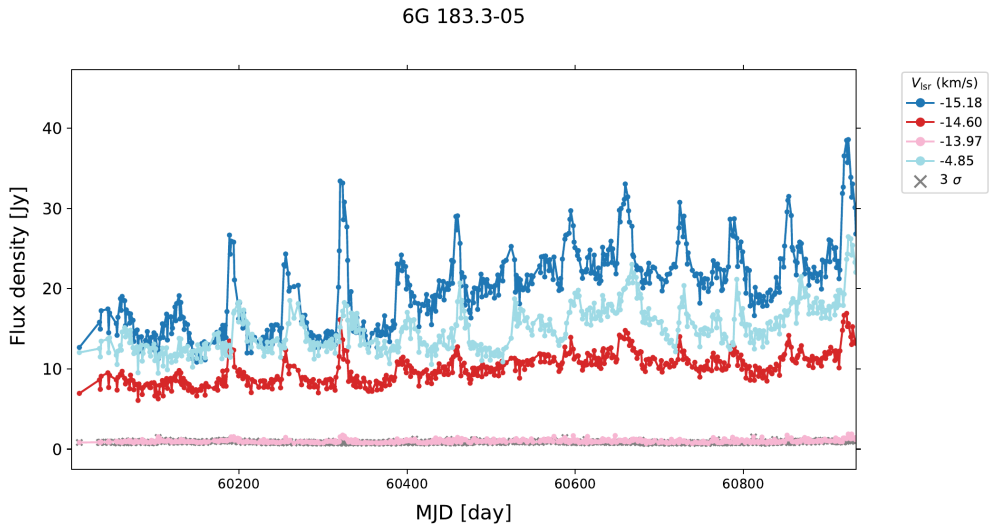


Spectrum

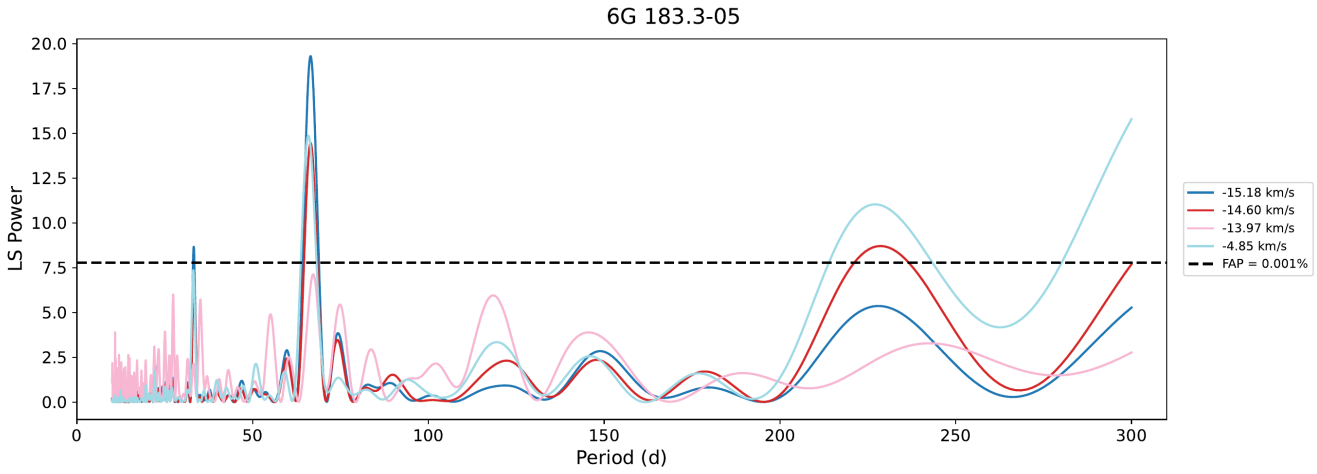


6G 183.3-05

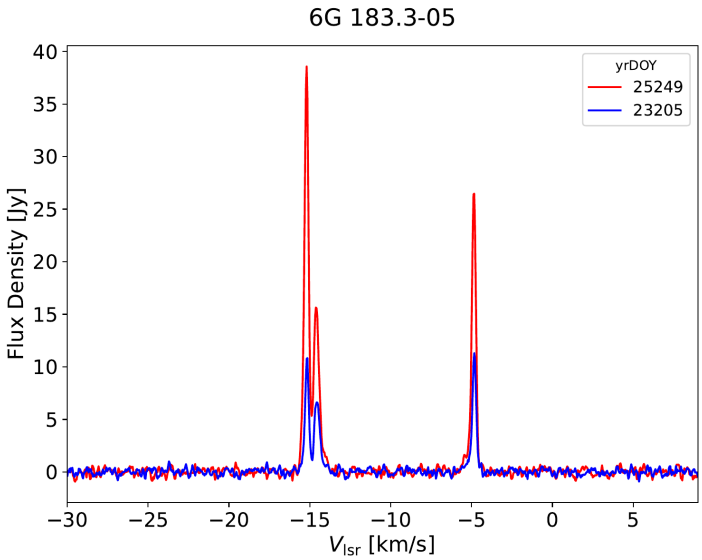
Light curve



Periodogram

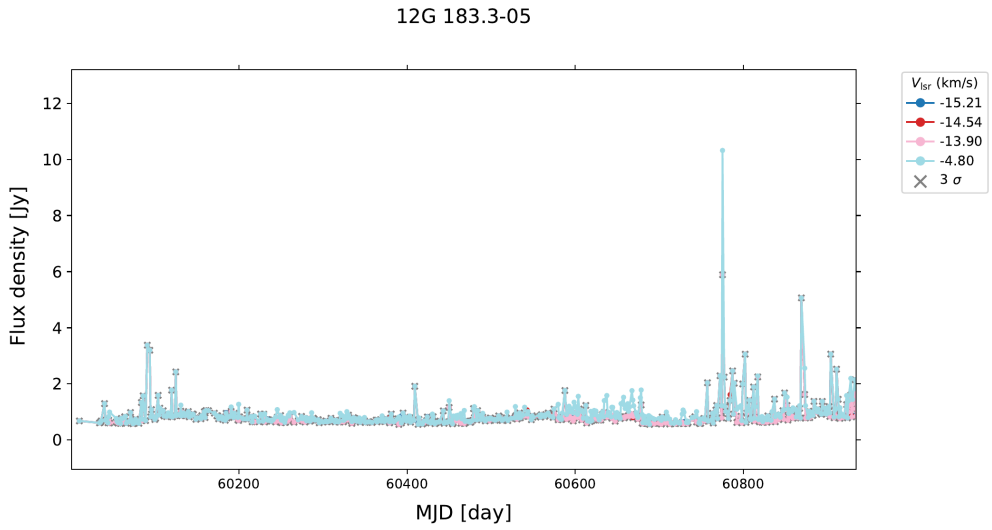


Spectrum

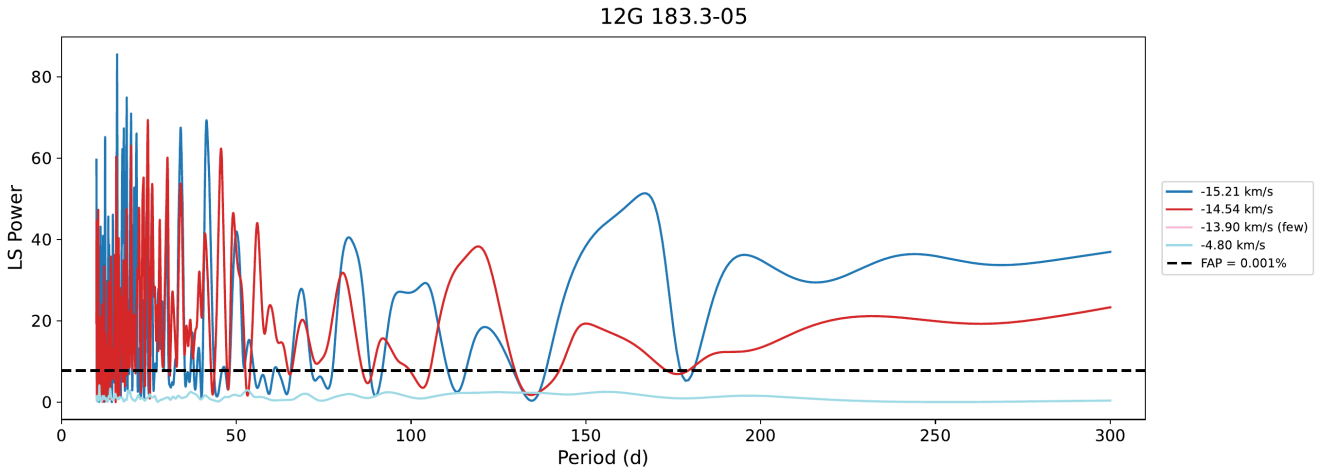


12G 183.3-05

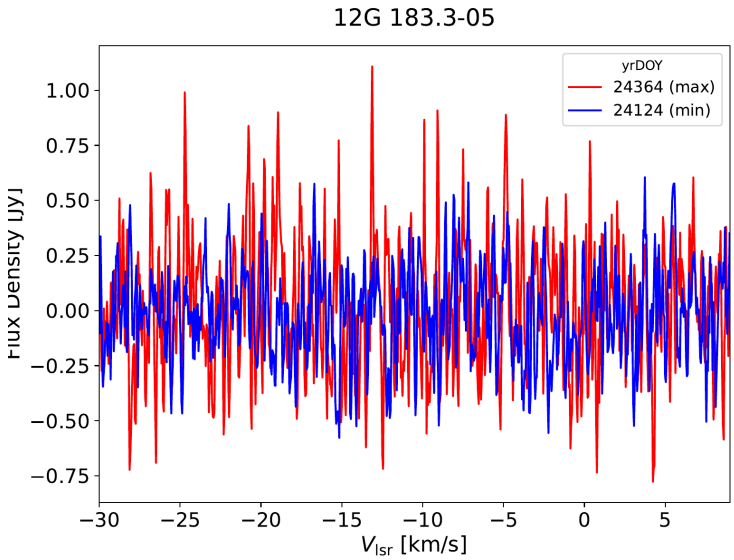
Light curve



Periodogram

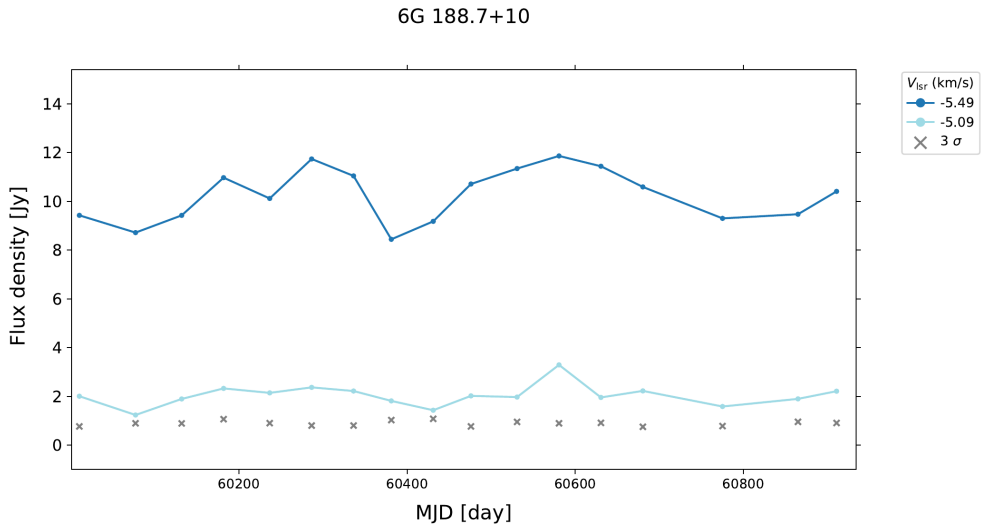


Spectrum

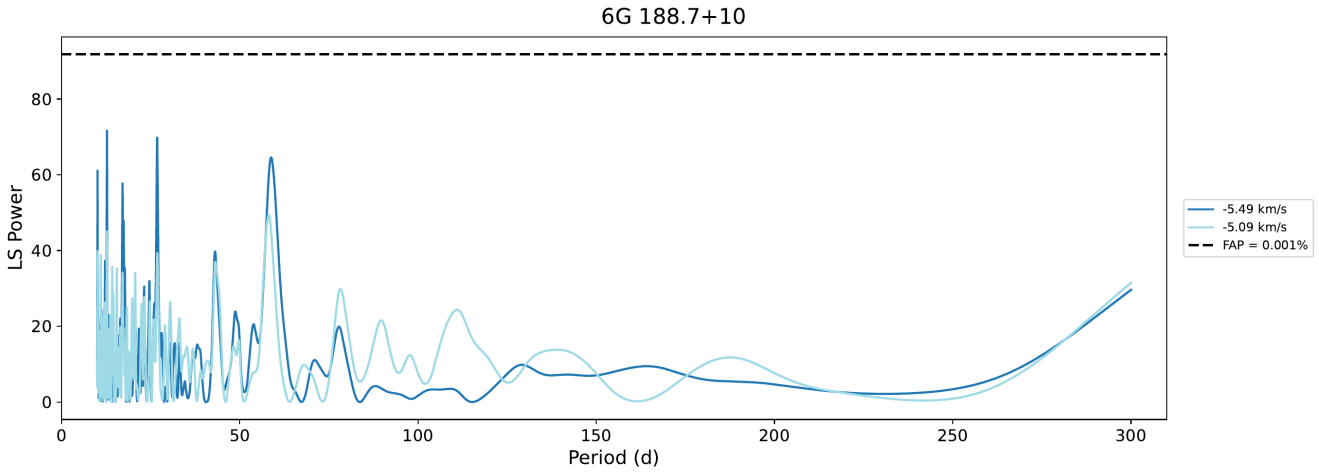


6G 188.7+10

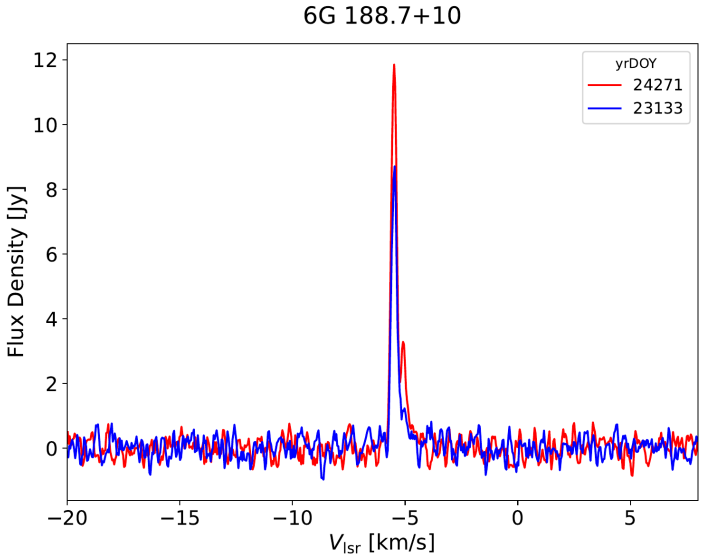
Light curve



Periodogram

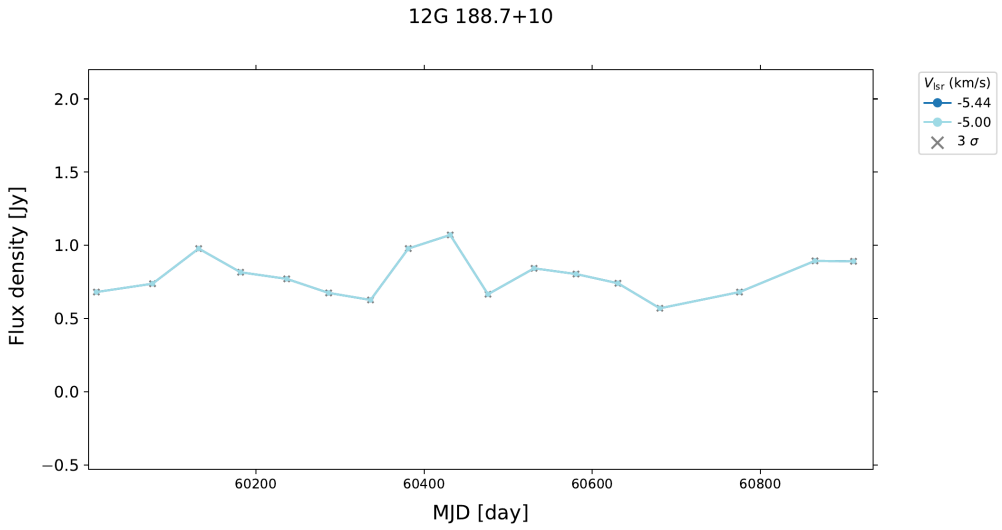


Spectrum

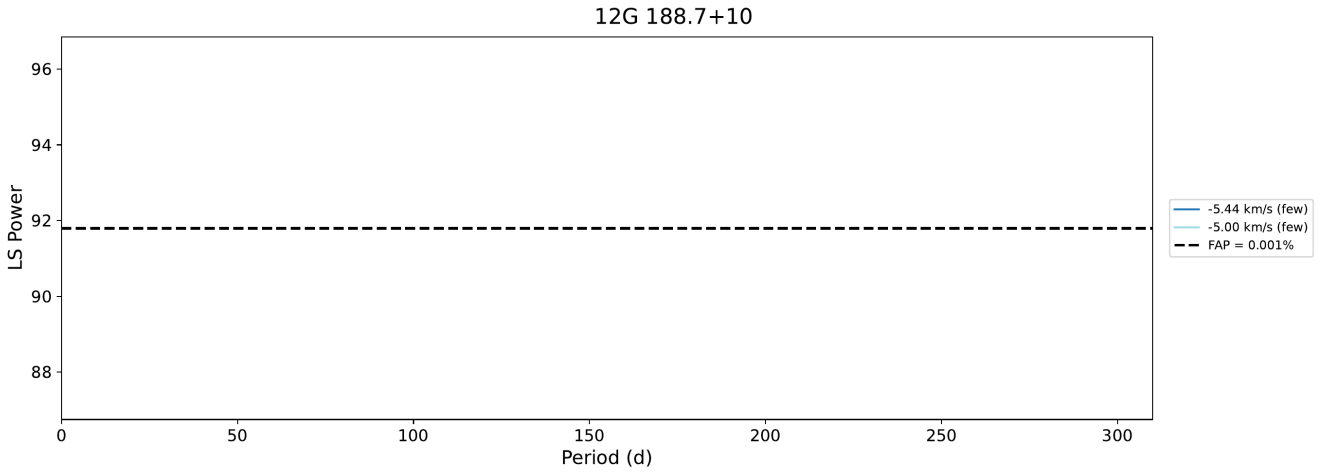


12G 188.7+10

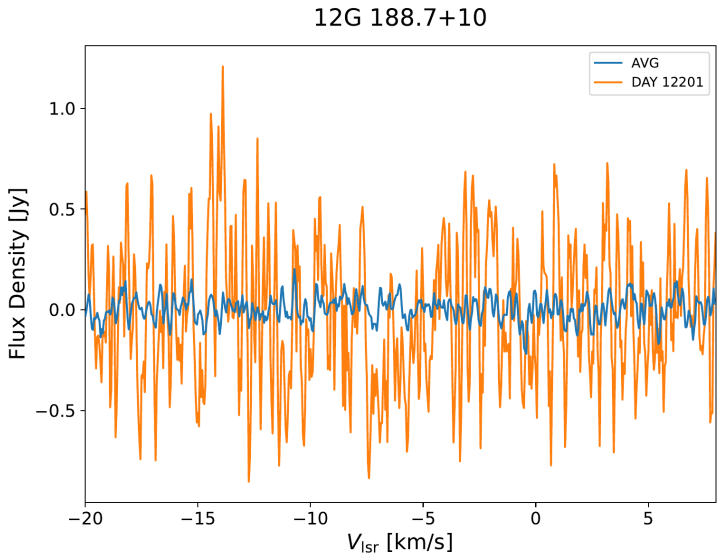
Light curve



Periodogram

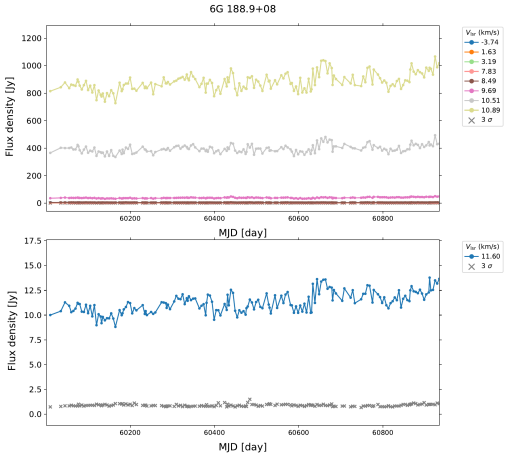


Spectrum

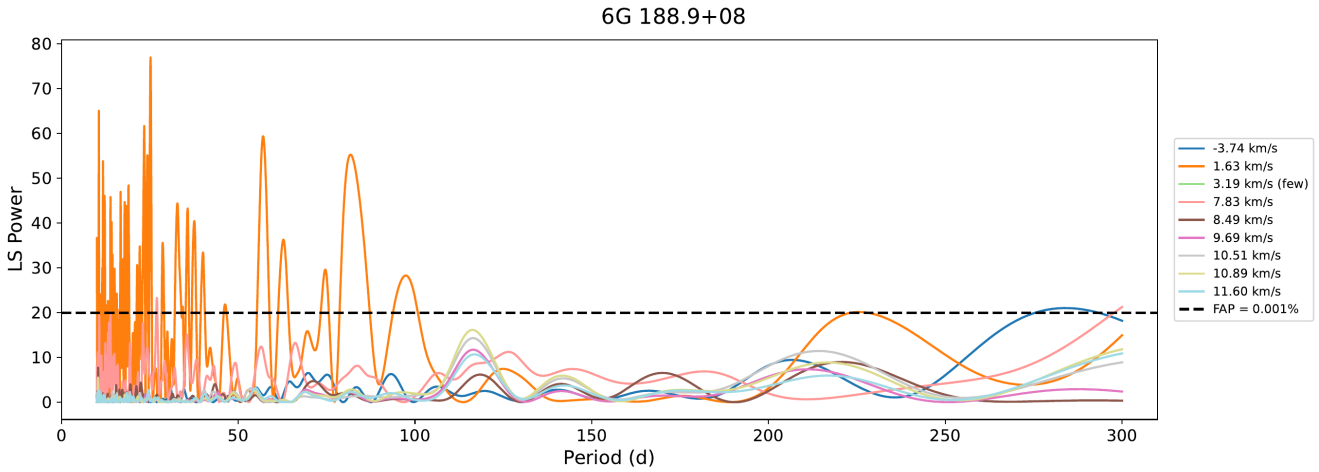


6G 188.9+08

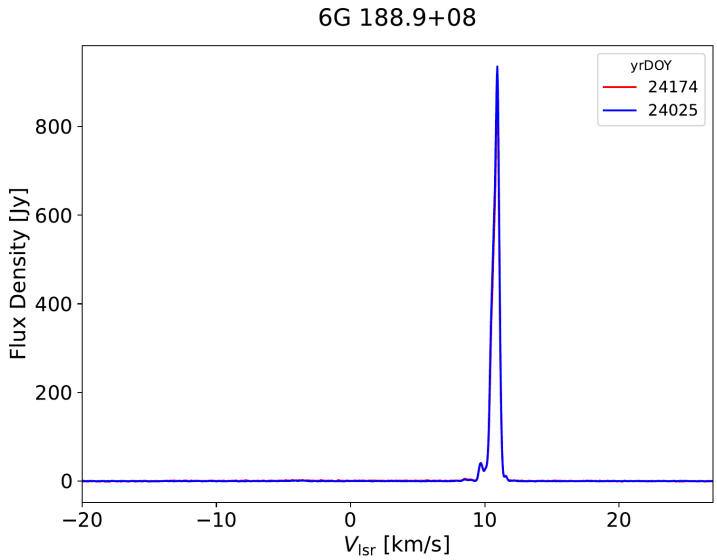
Light curve



Periodogram

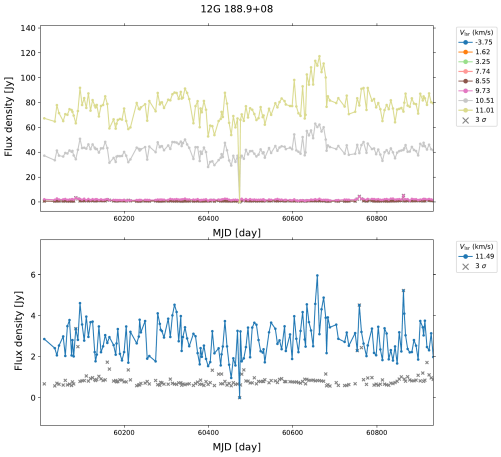


Spectrum

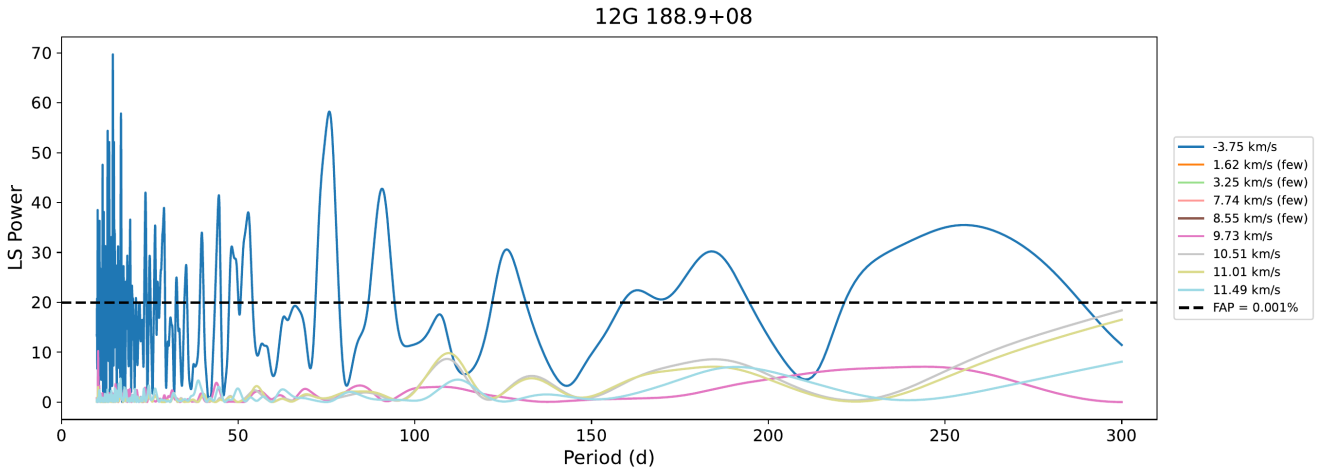


12G 188.9+08

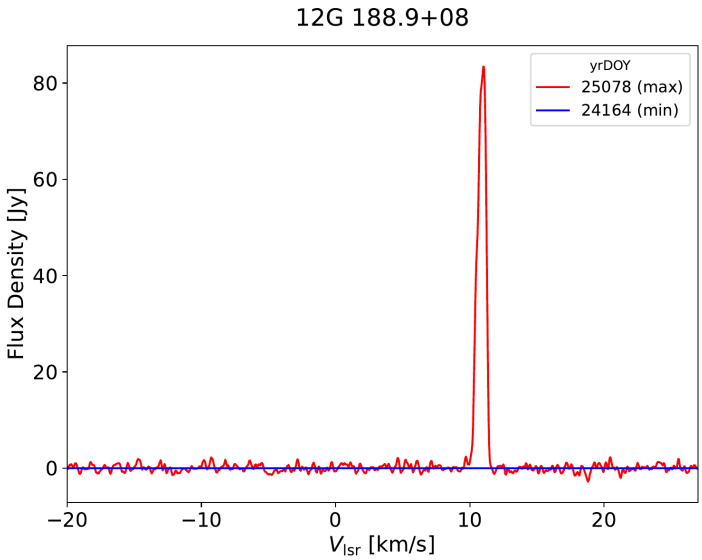
Light curve



Periodogram

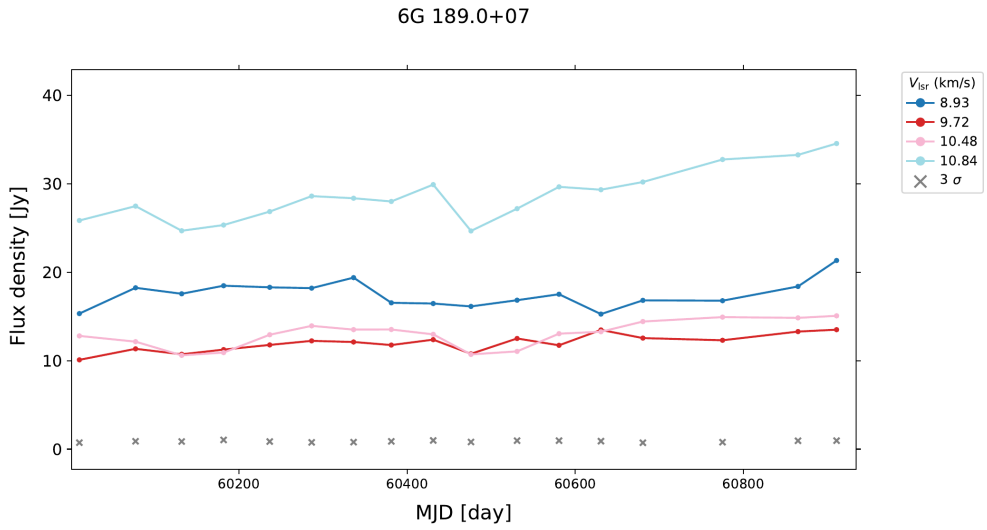


Spectrum

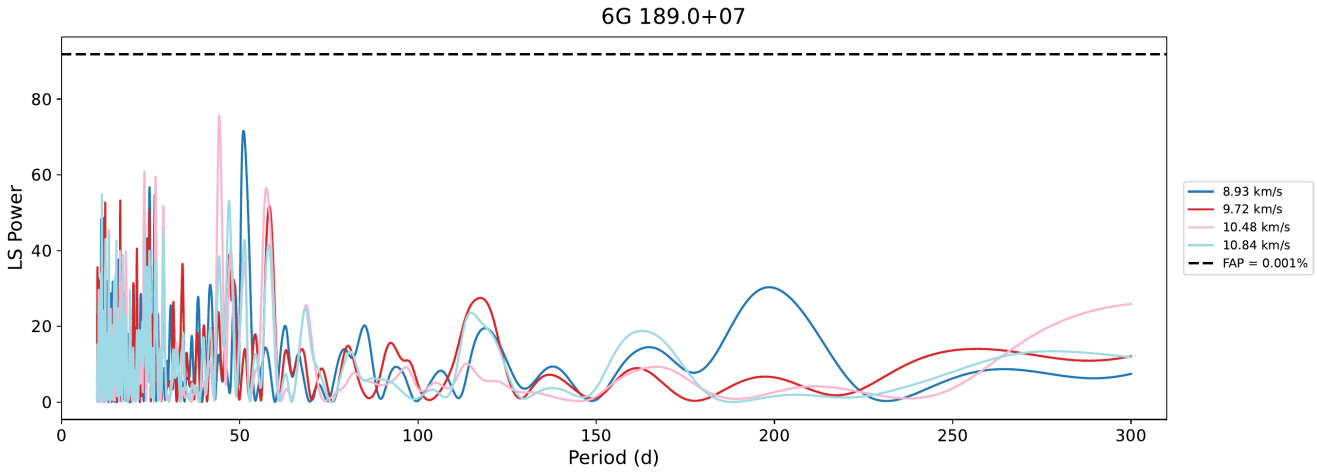


6G 189.0+07

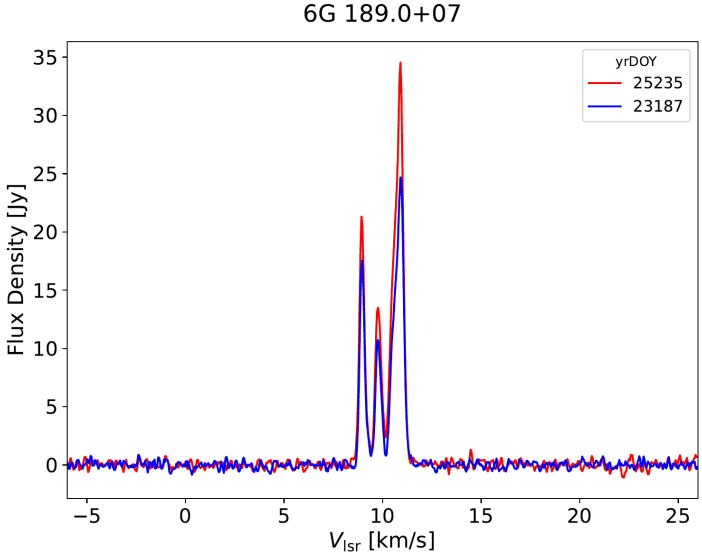
Light curve



Periodogram

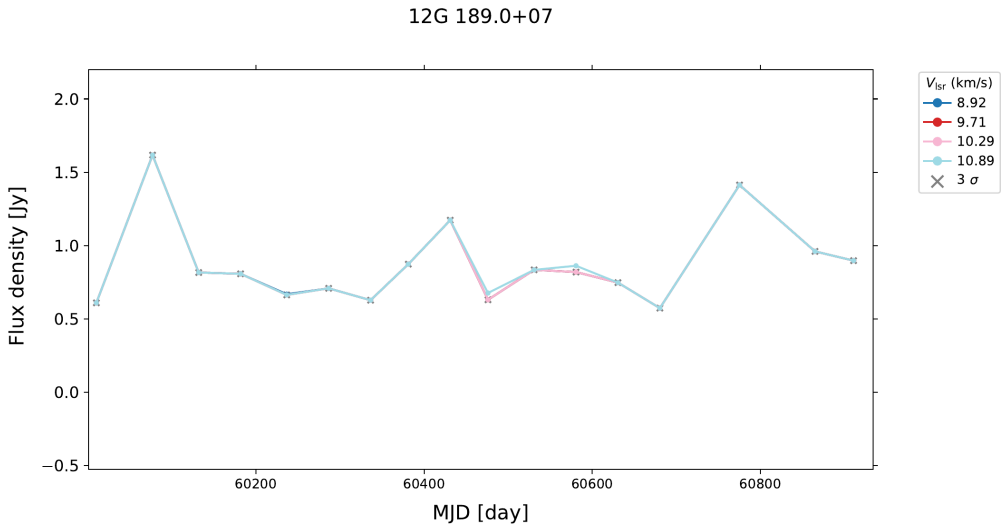


Spectrum

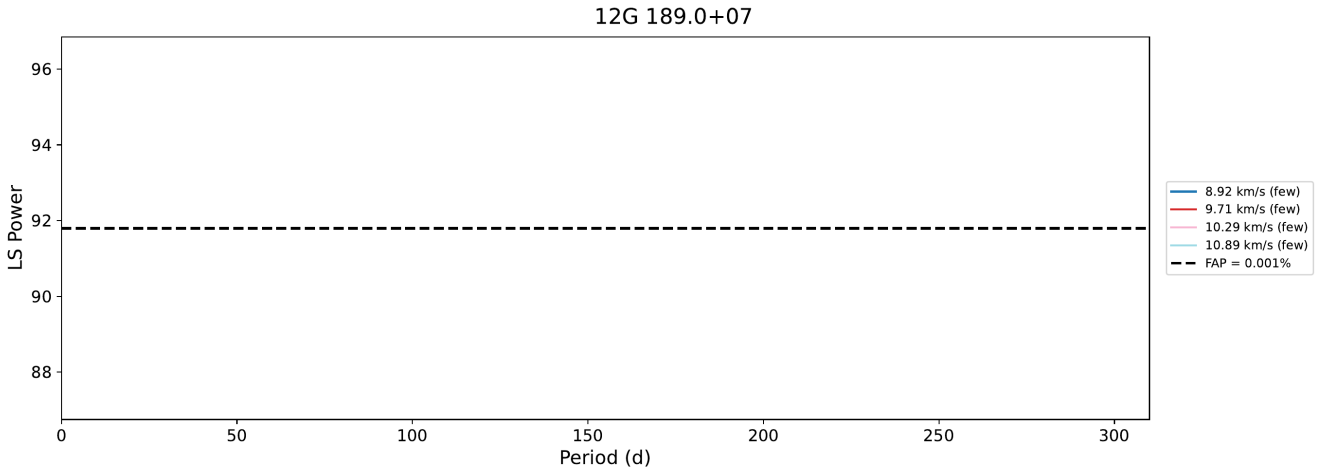


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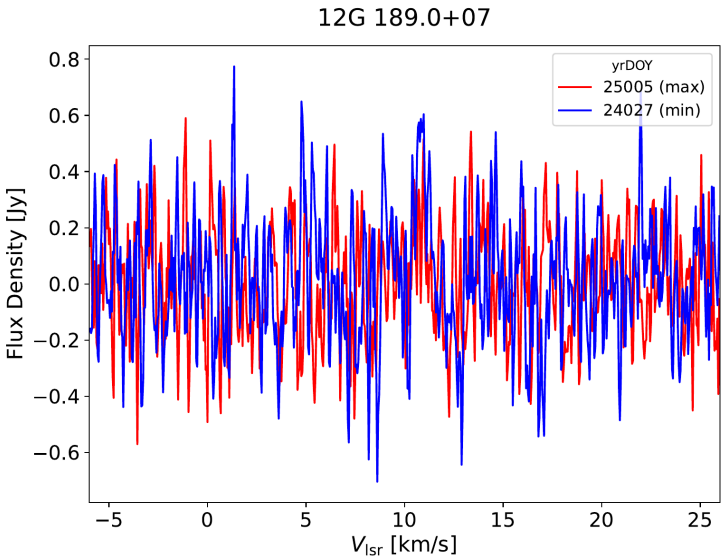
Light curve



Periodogram

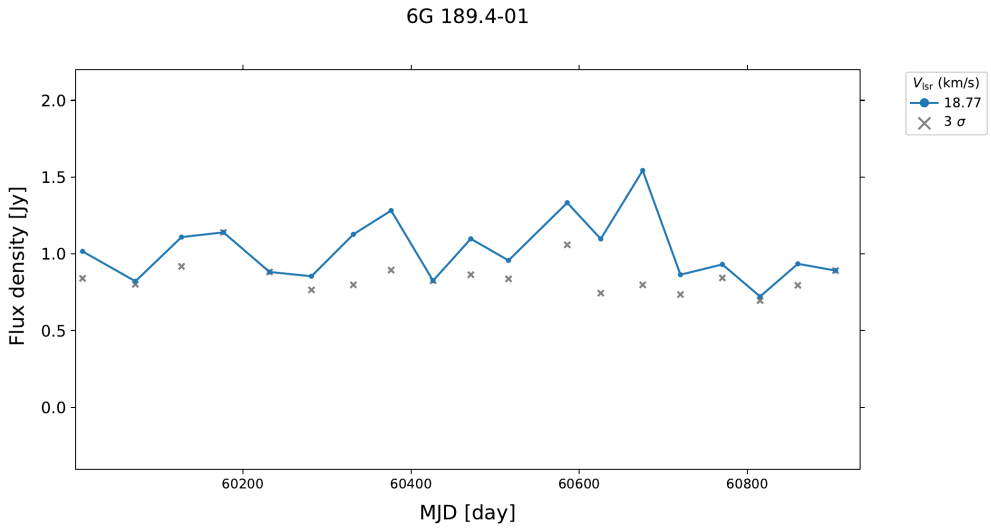


Spectrum

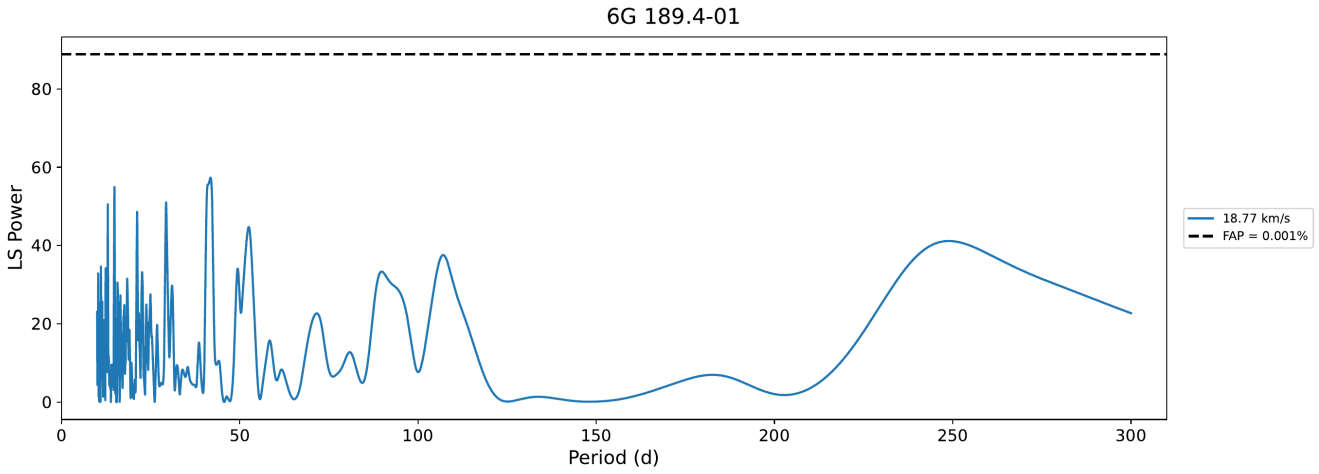


6G 189.4-01

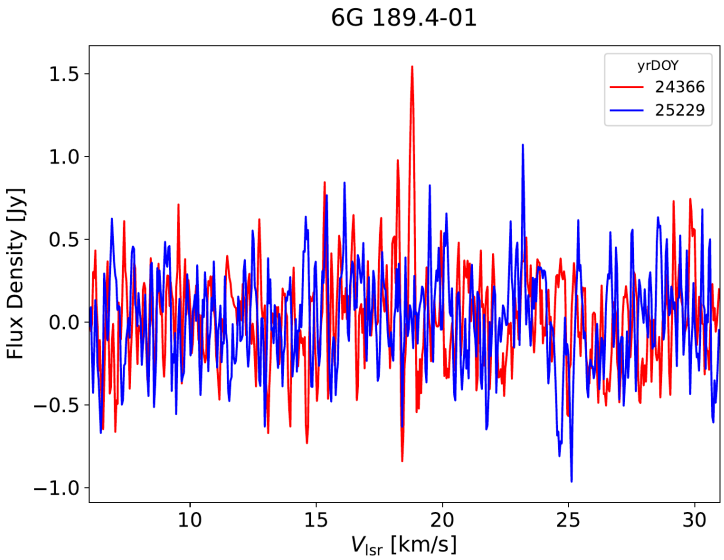
Light curve



Periodogram

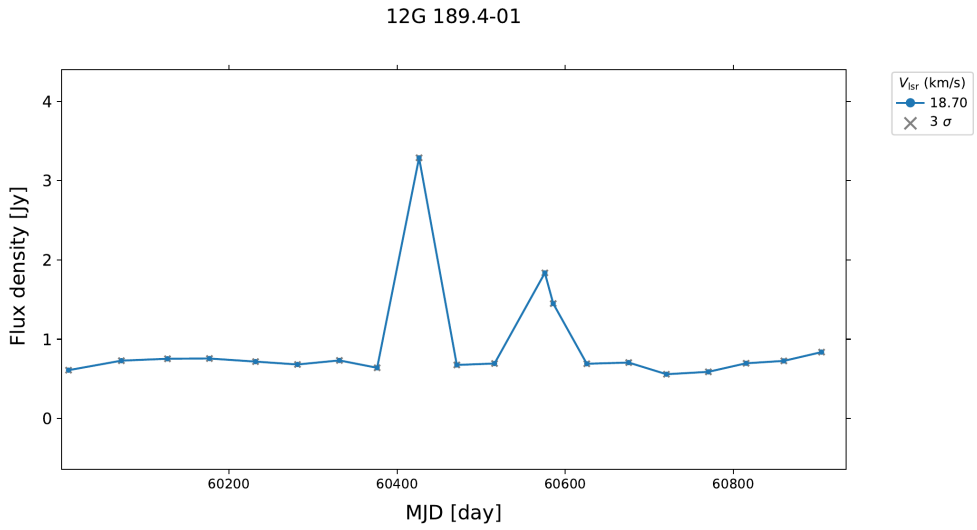


Spectrum

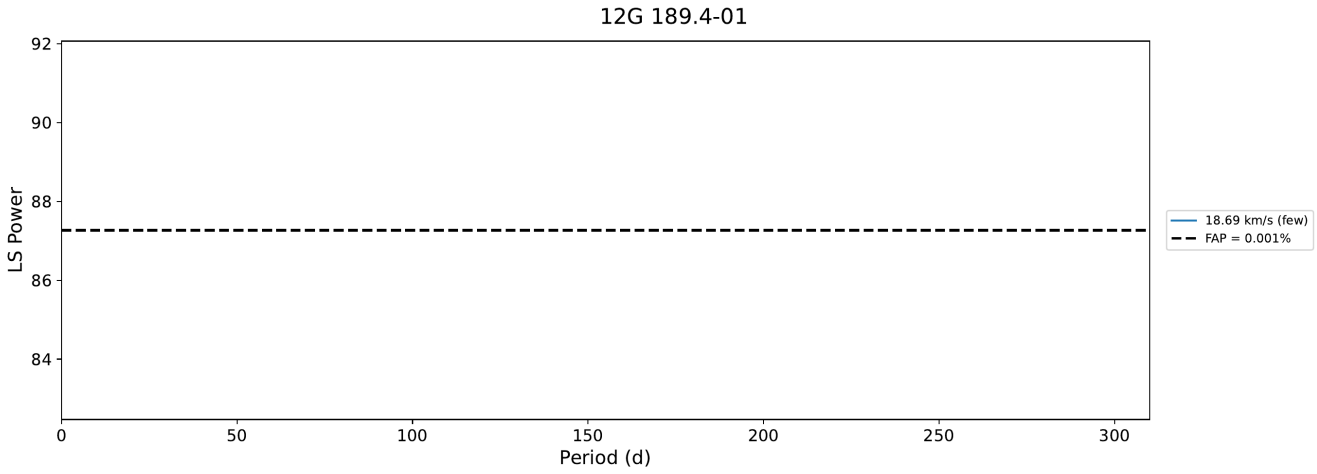


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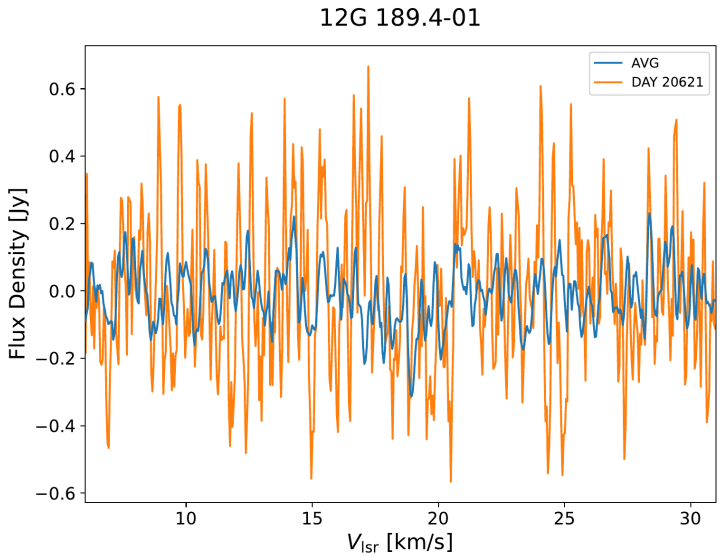
Light curve



Periodogram

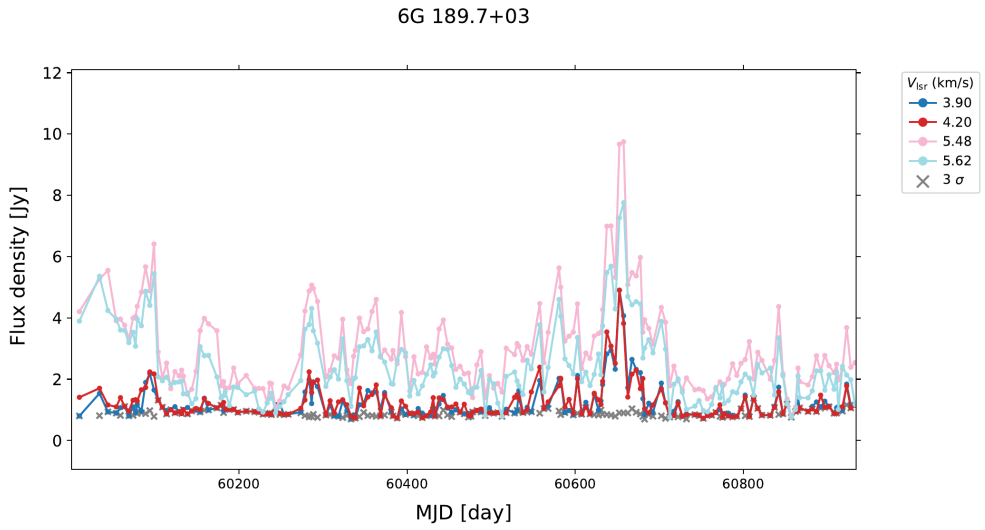


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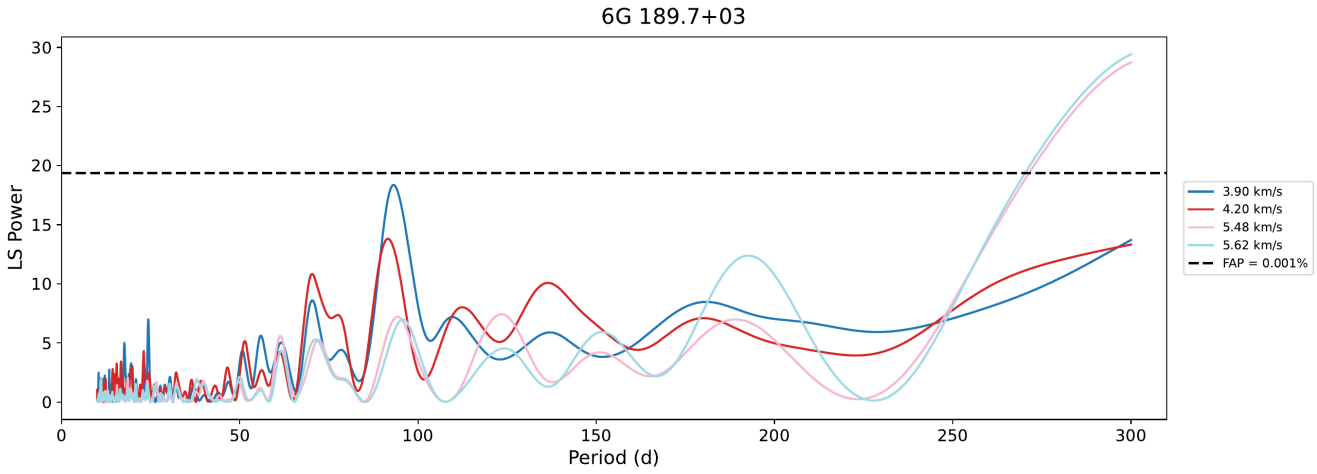


6G 189.7+03

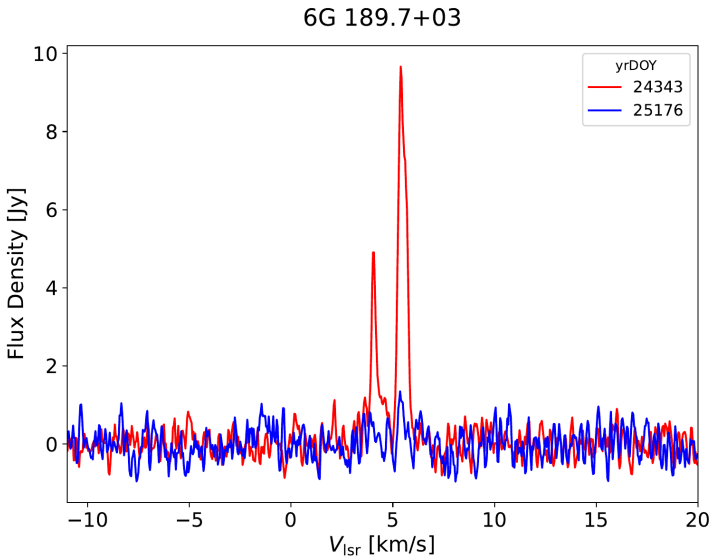
Light curve



Periodogram

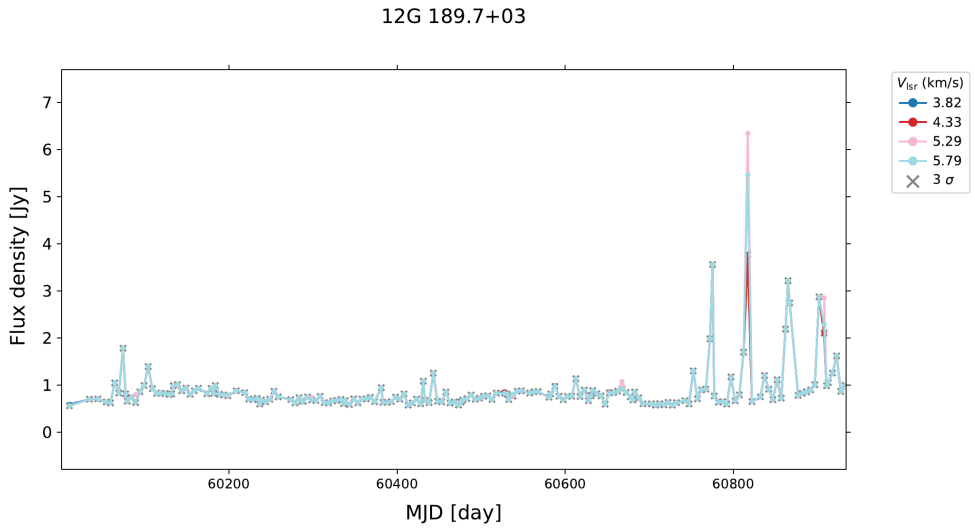


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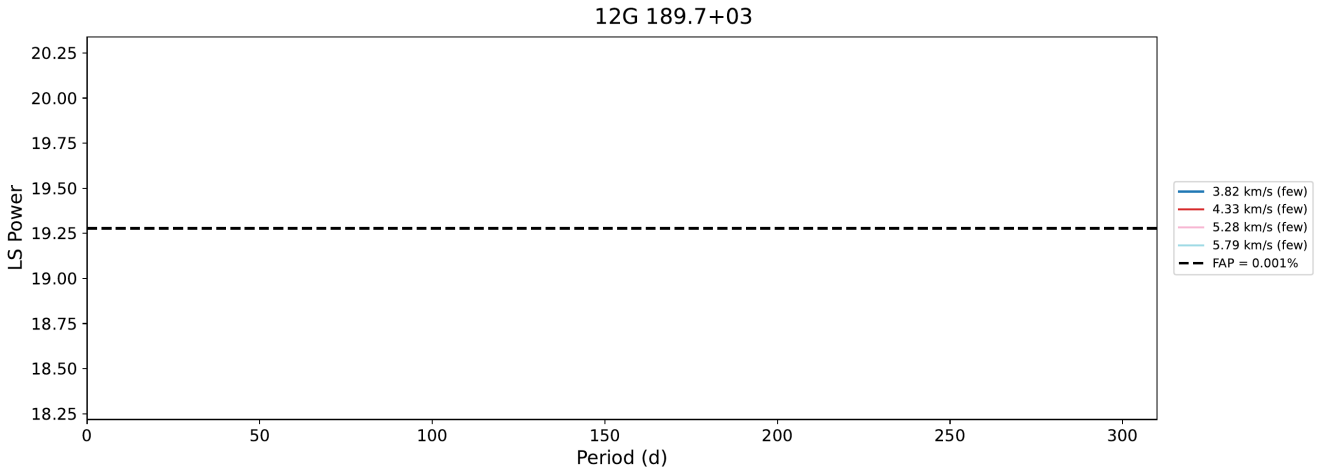


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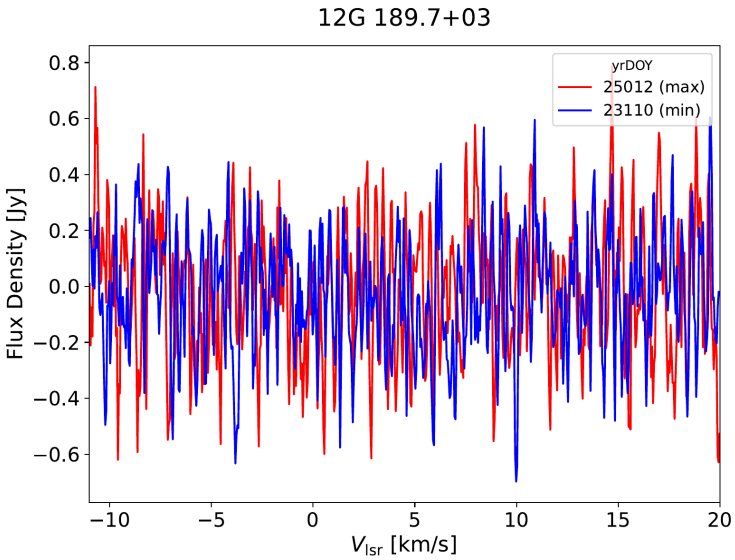
Light curve



Periodogram

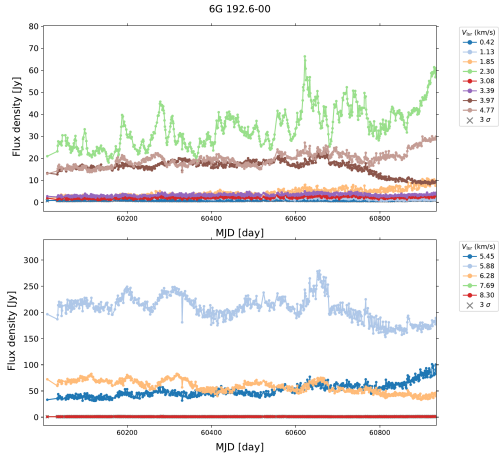


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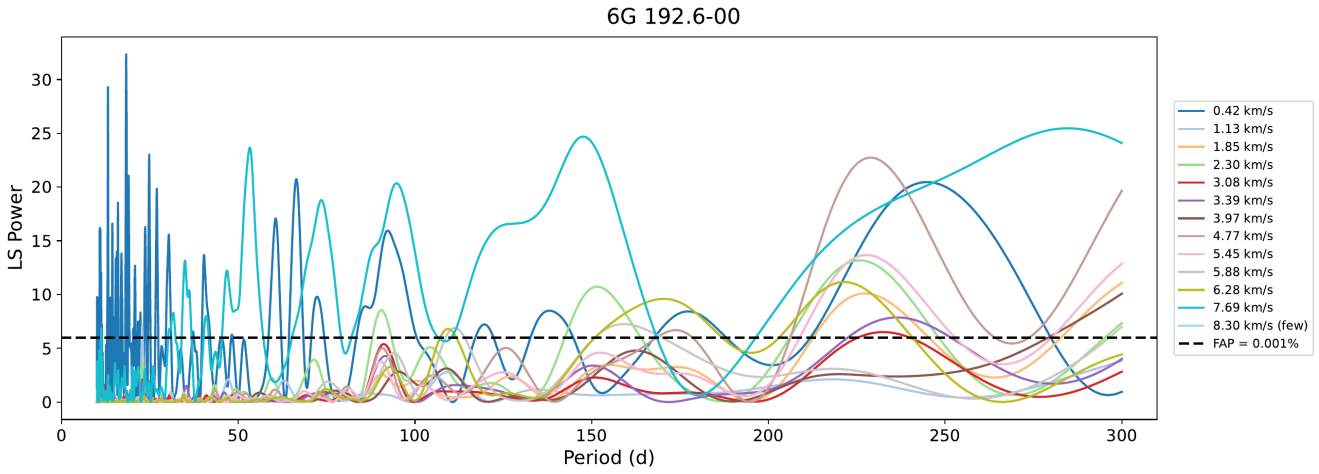


6G 192.6-00

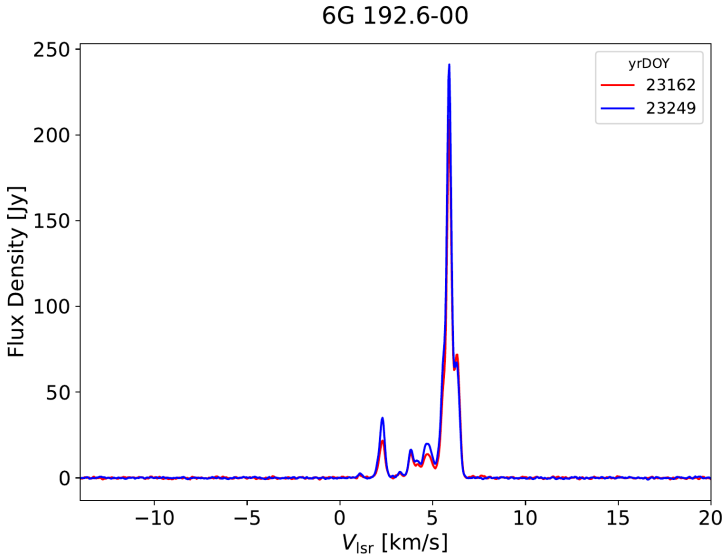
Light curve



Periodogram

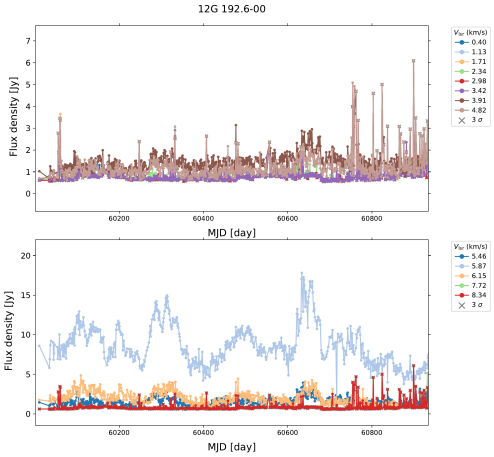


Spectrum

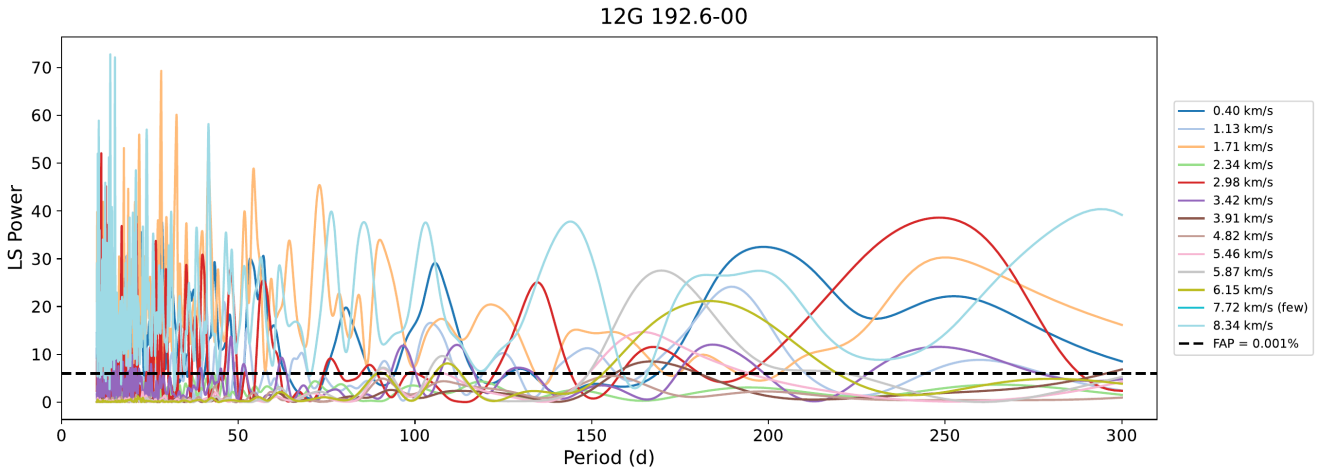


12G 192.6-00

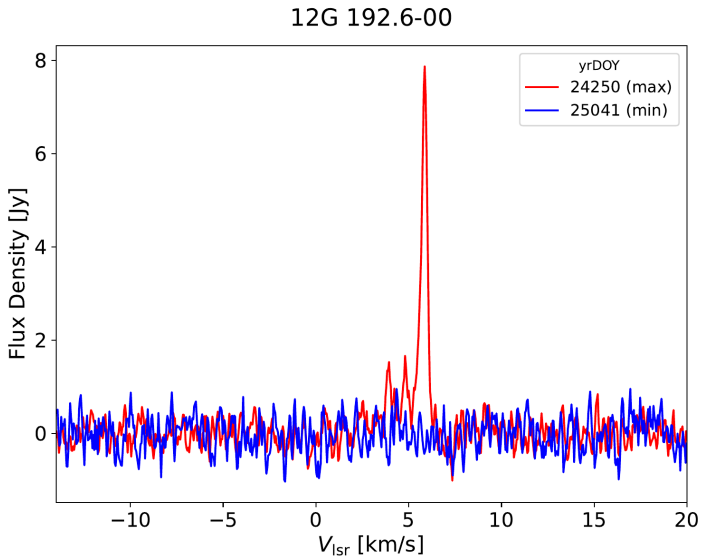
Light curve



Periodogram

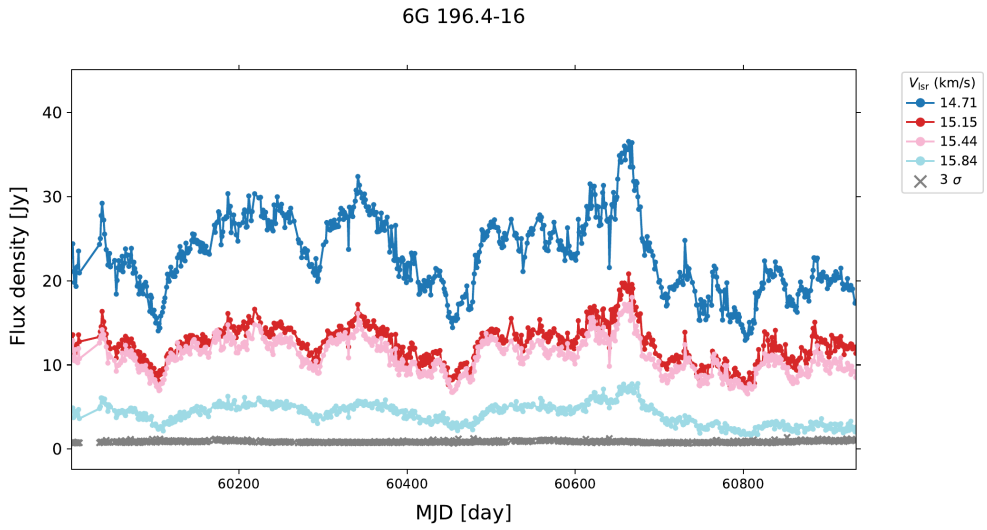


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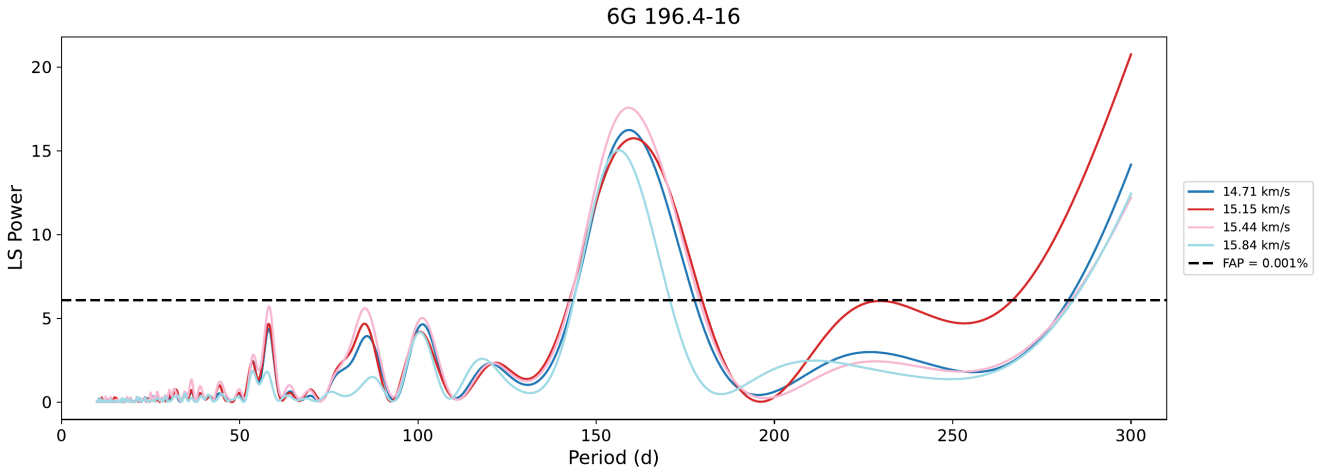


6G 196.4-16

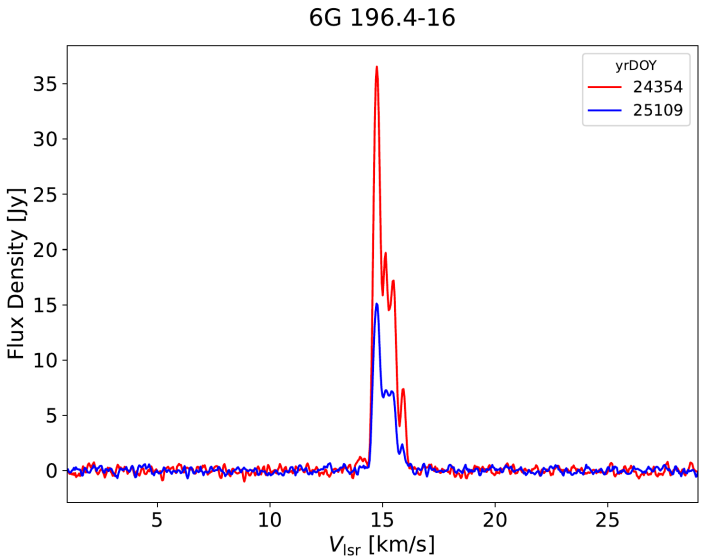
Light curve



Periodogram

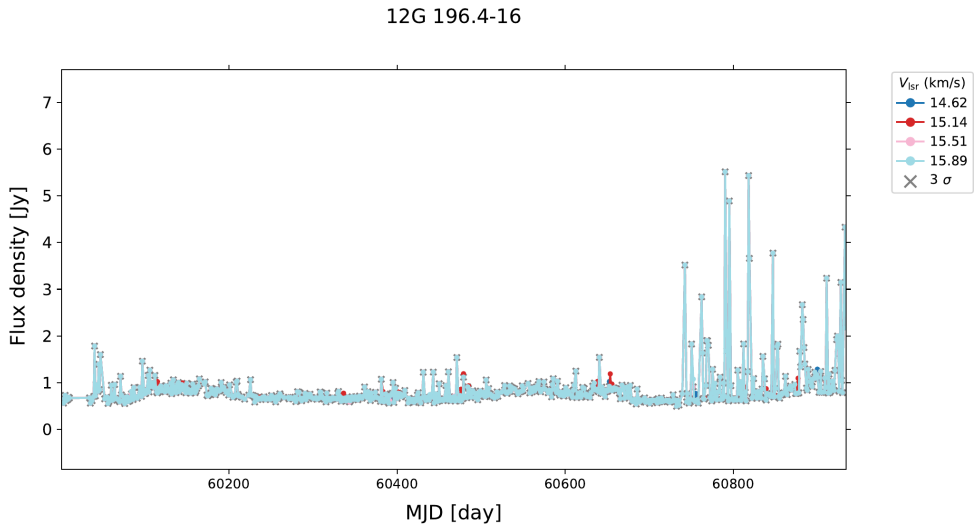


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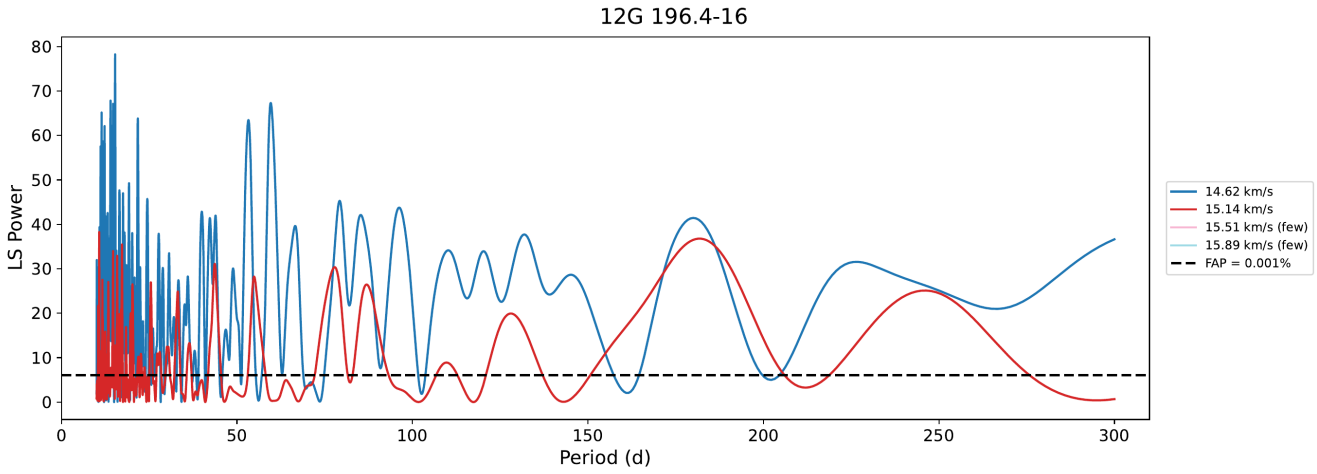


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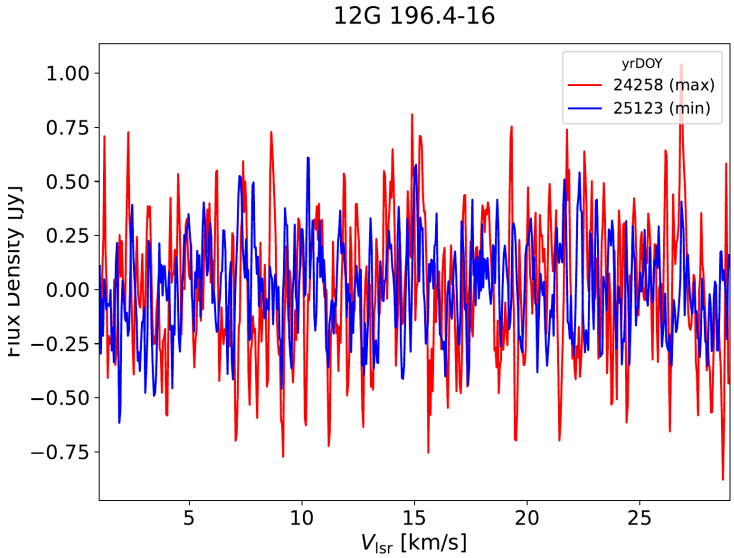
Light curve



Periodogram

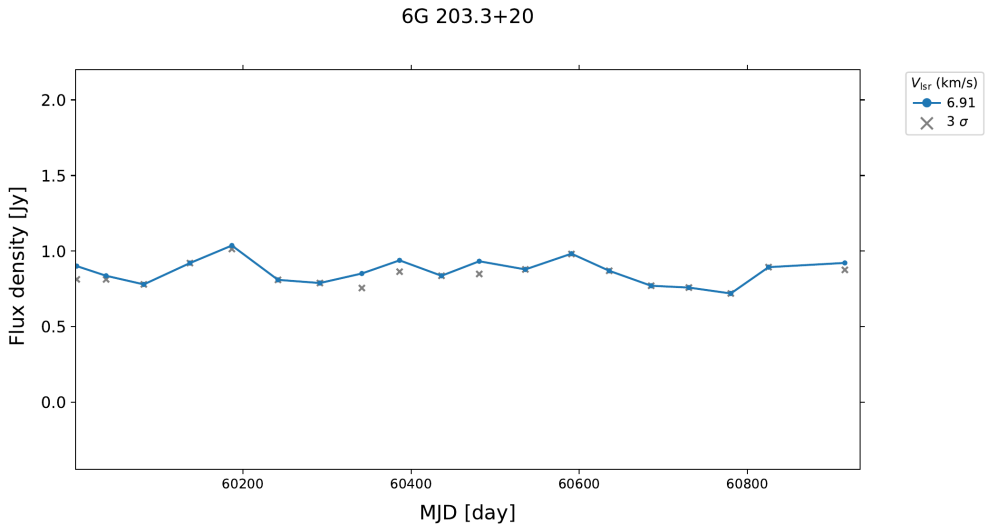


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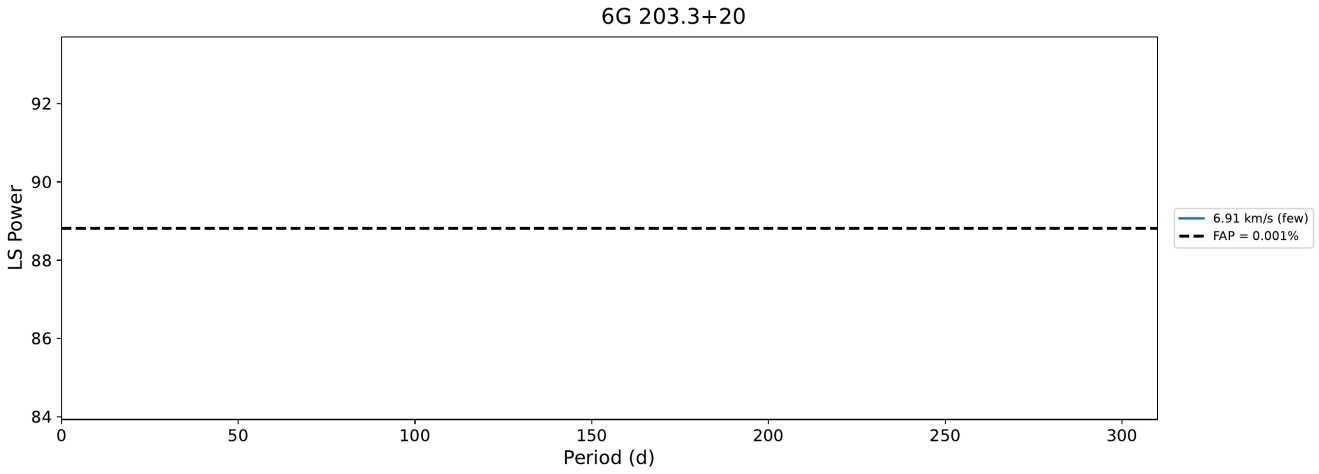


6G 203.3+20

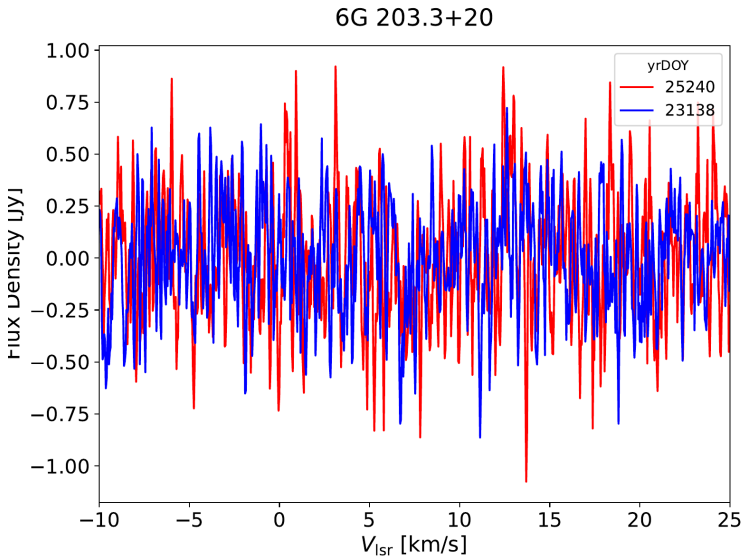
Light curve



Periodogram

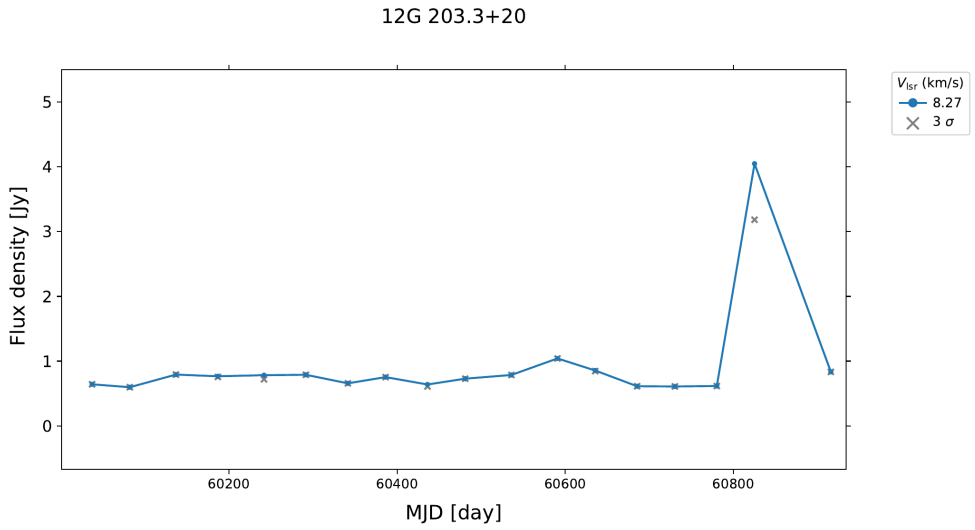


Spectrum

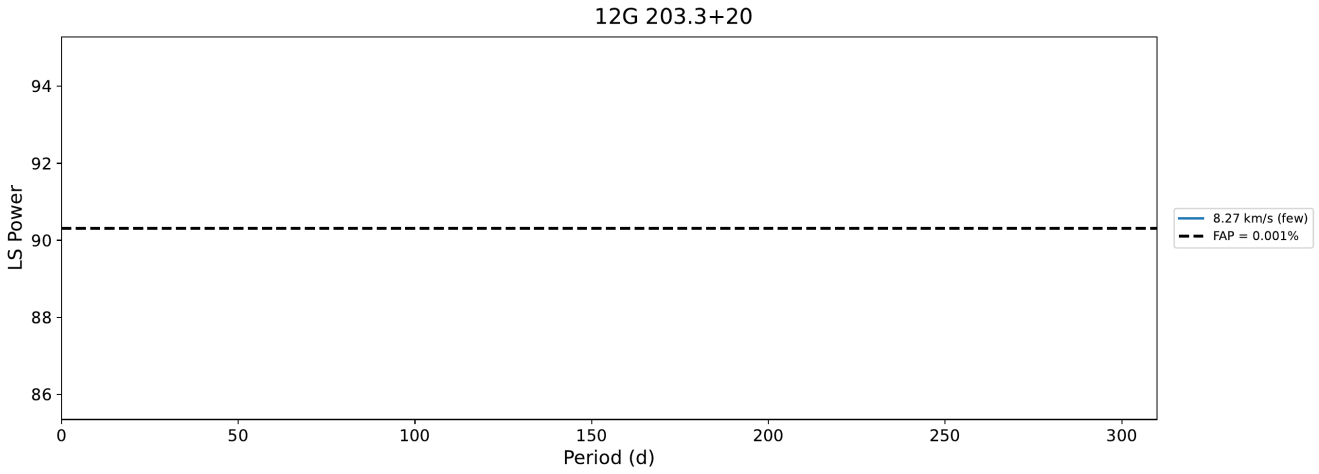


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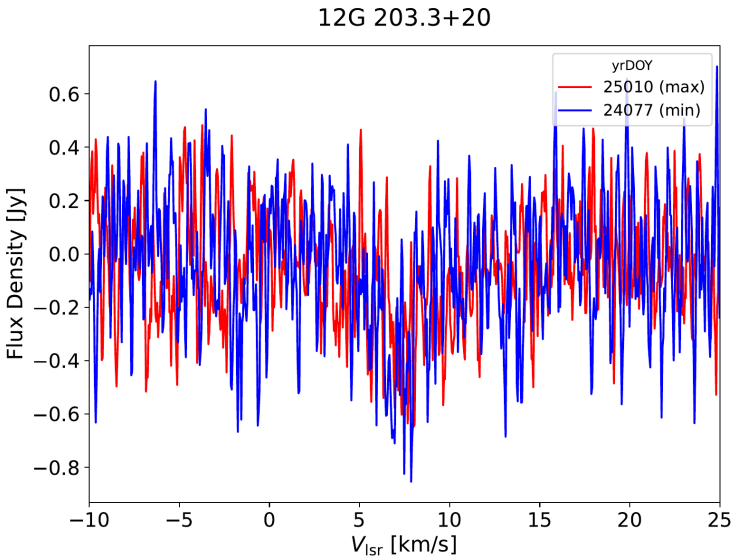
Light curve



Periodogram

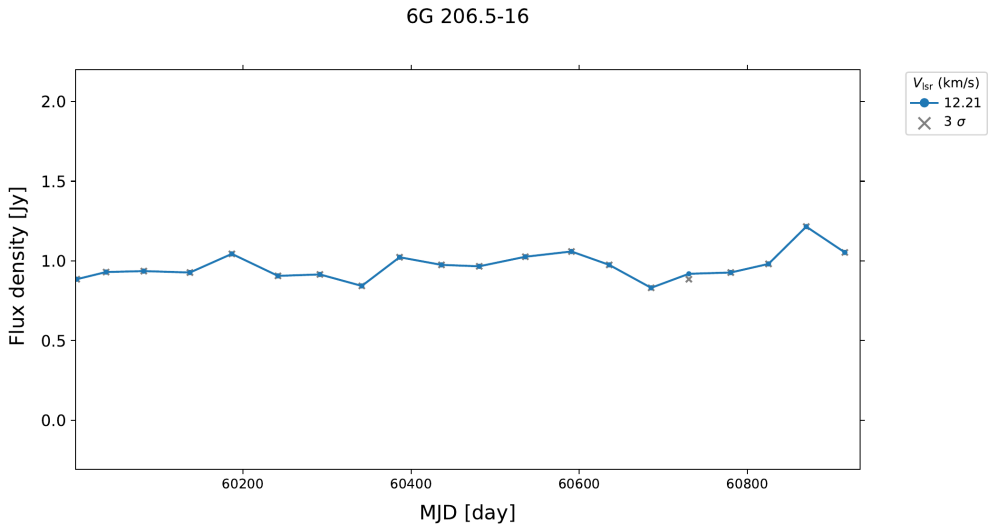


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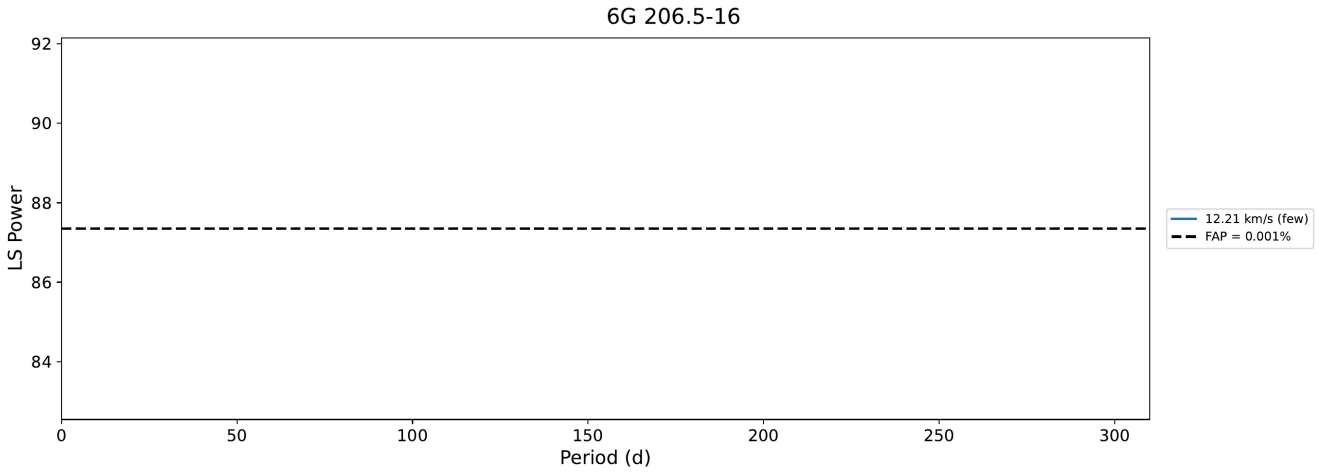


6G 206.5-16

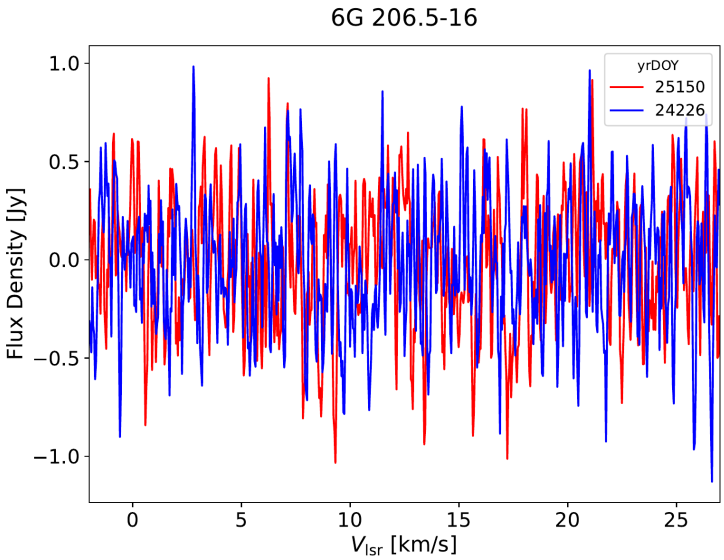
Light curve



Periodogram

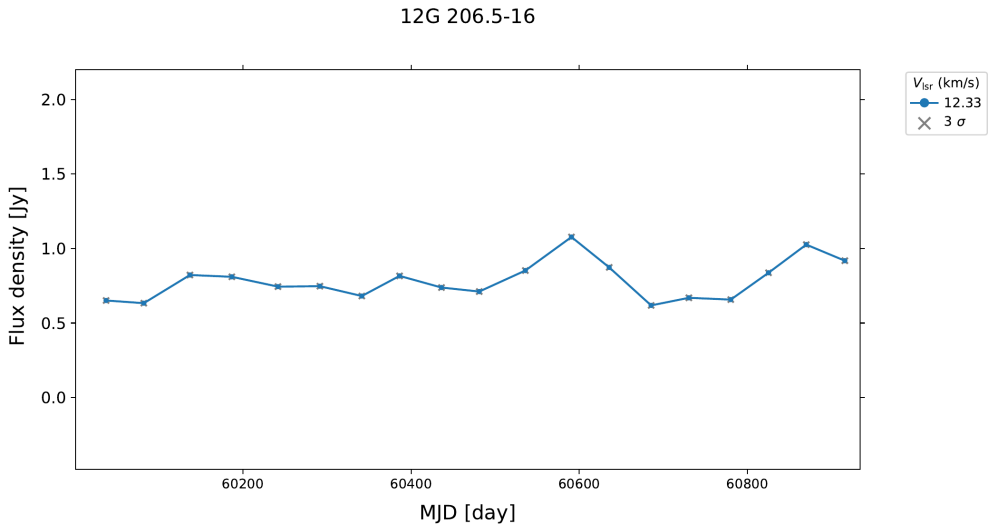


Spectrum

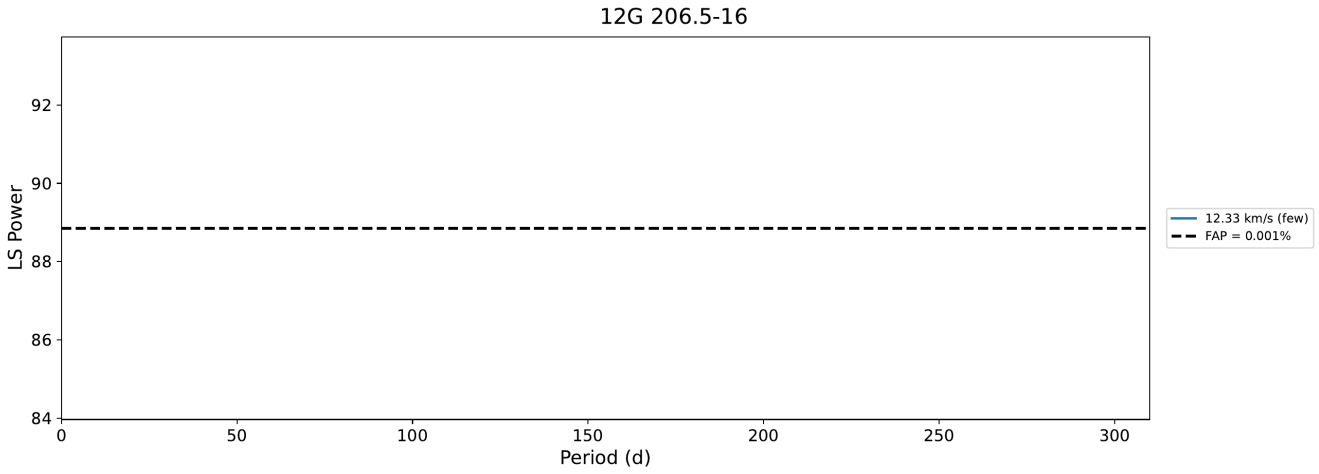


12G 206.5-16

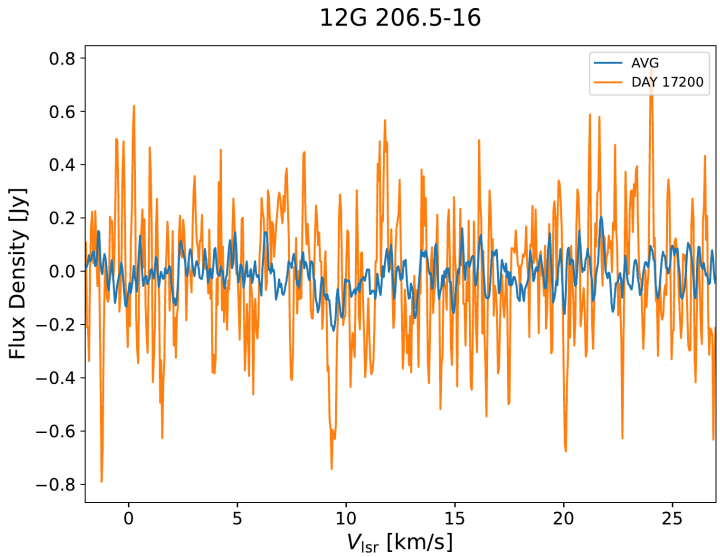
Light curve



Periodogram

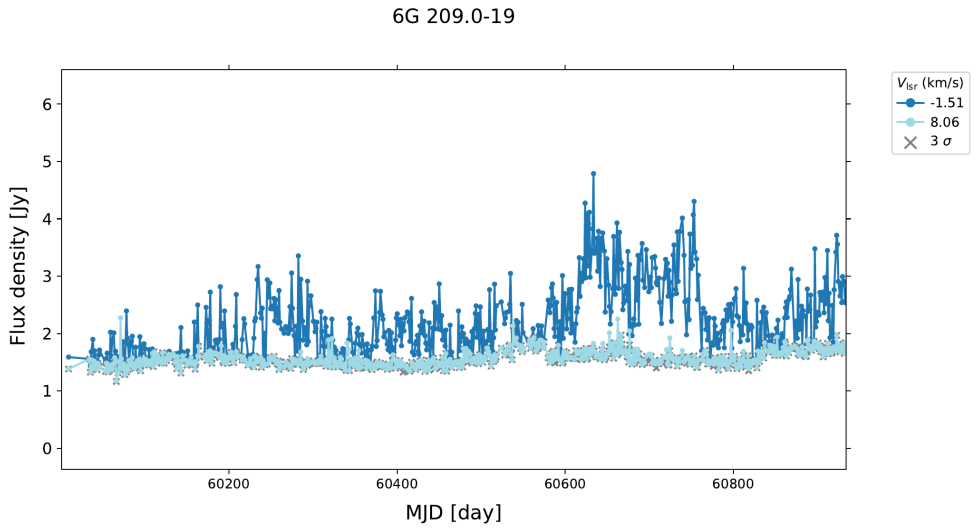


Spectrum

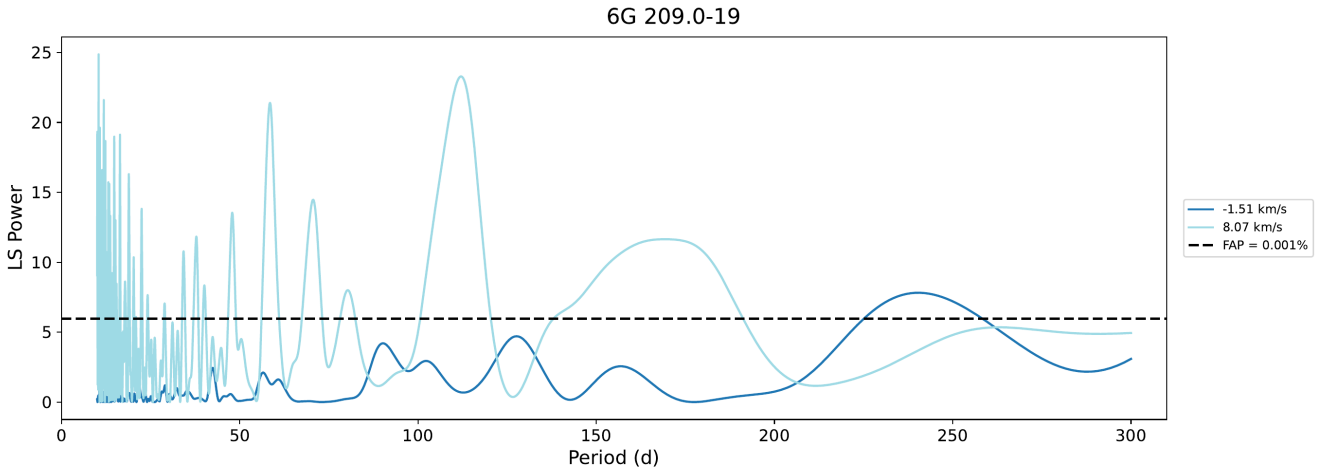


6G 209.0-19

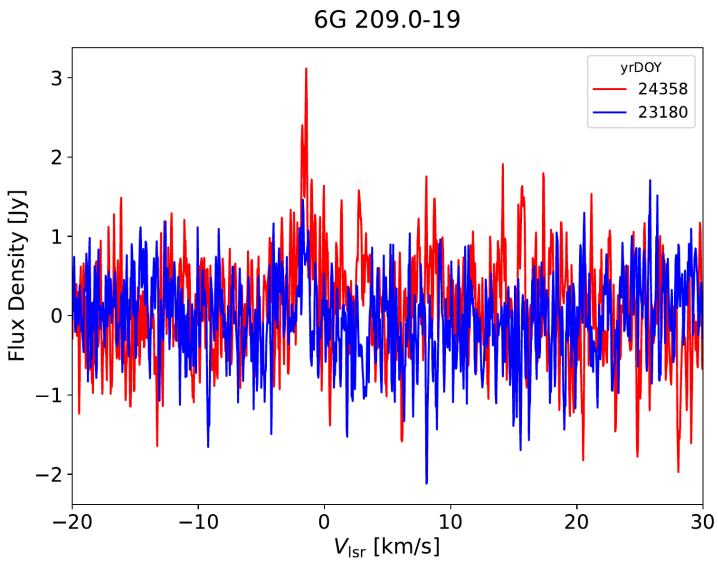
Light curve



Periodogram

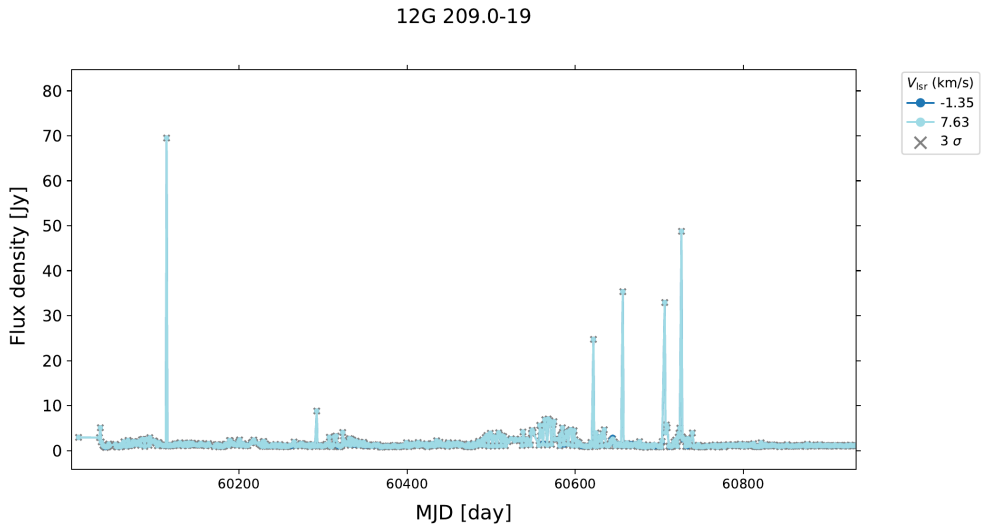


Spectrum

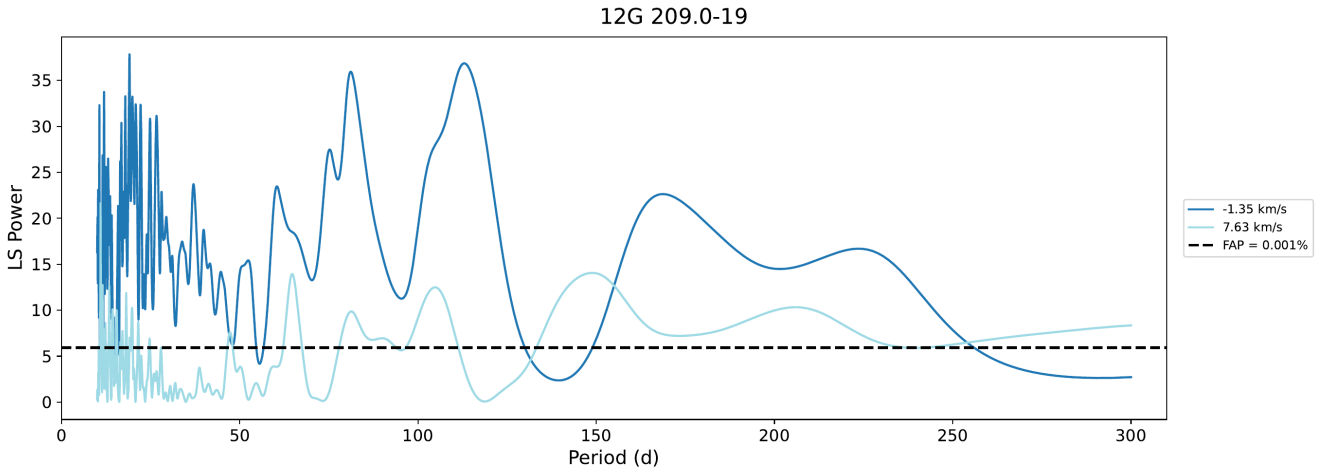


12G 209.0-19

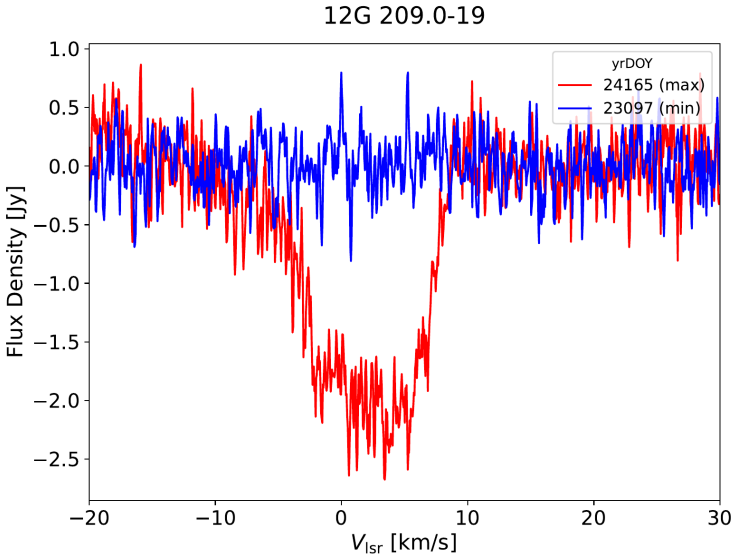
Light curve



Periodogram

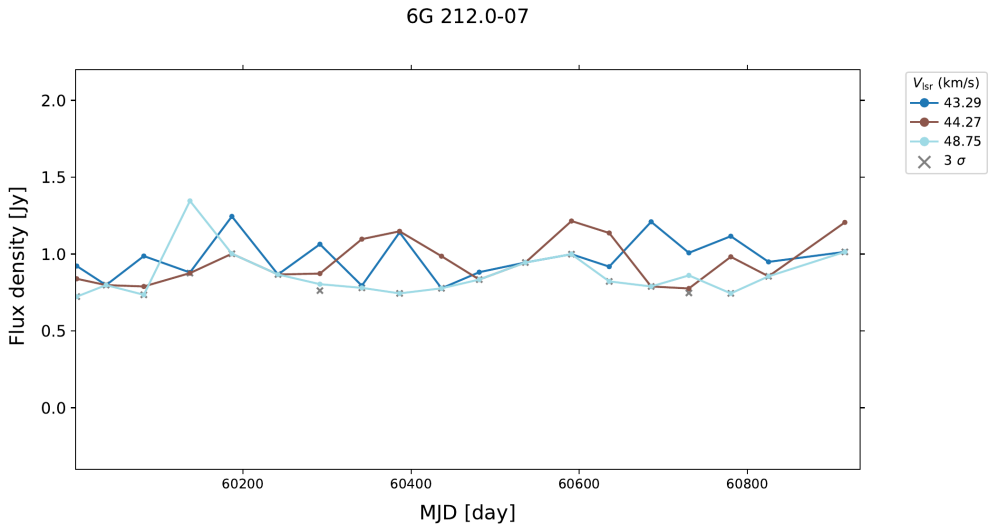


Spectrum

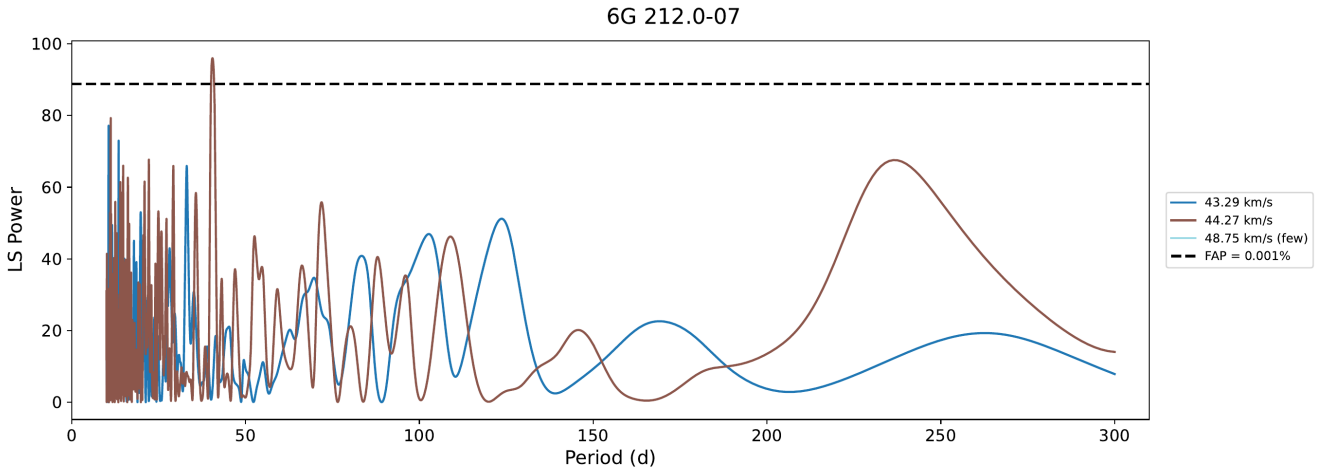


6G 212.0-07

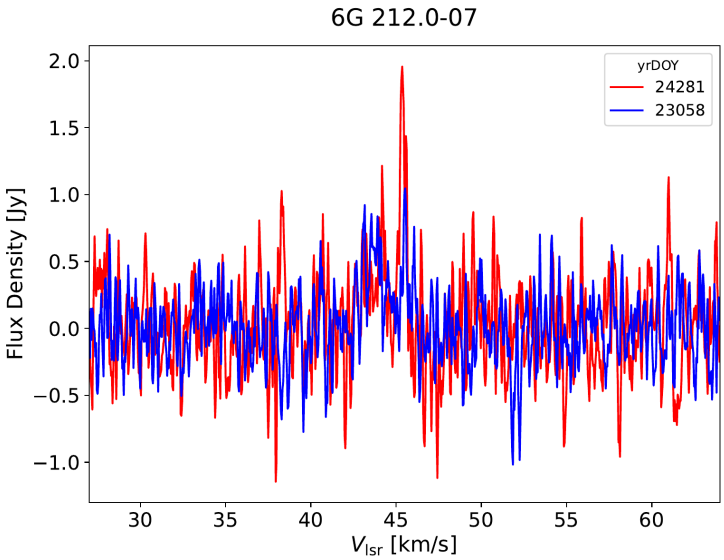
Light curve



Periodogram

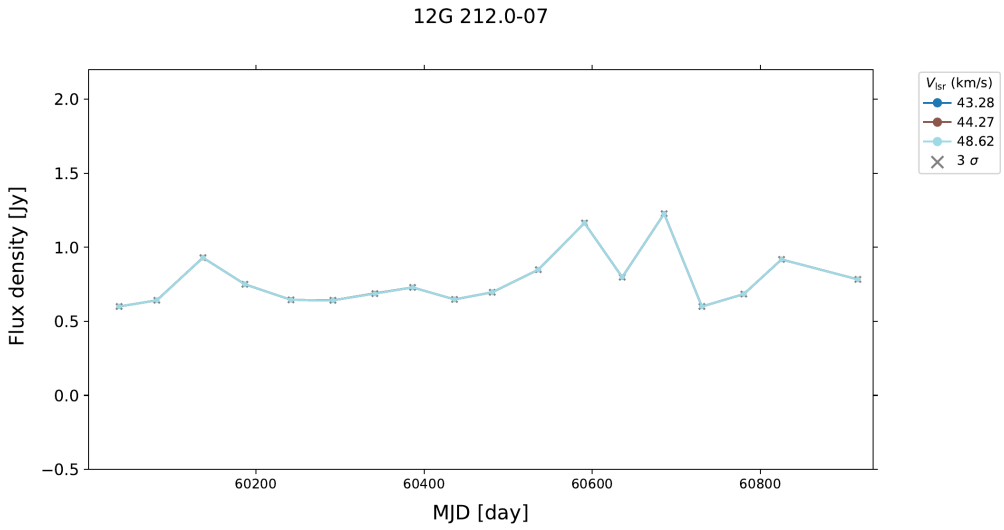


Spectrum

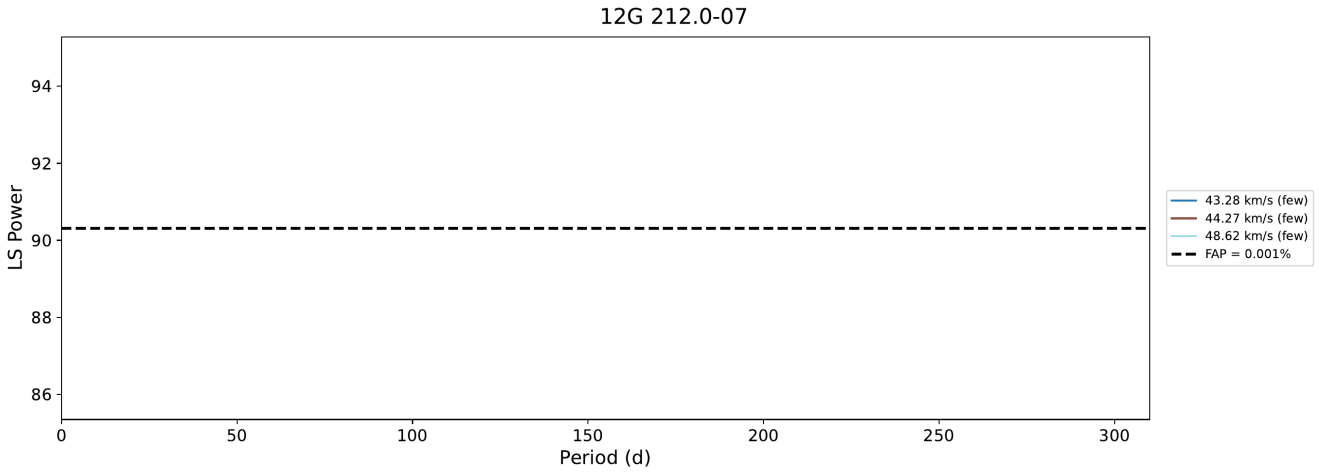


12G 212.0-07

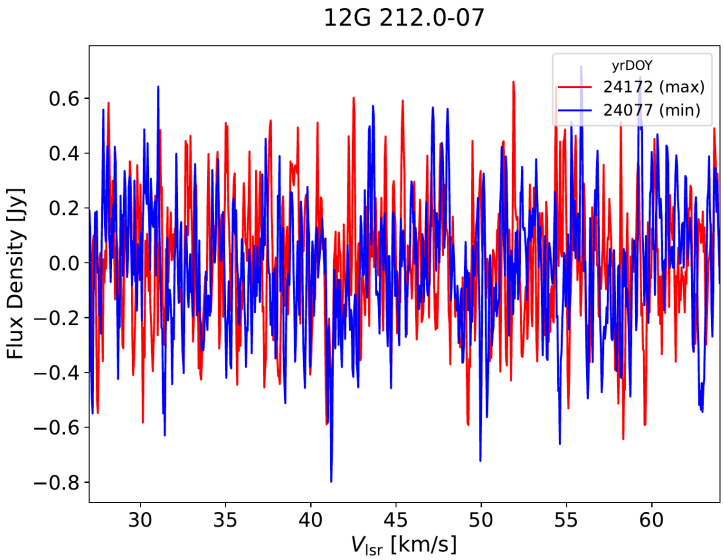
Light curve



Periodogram

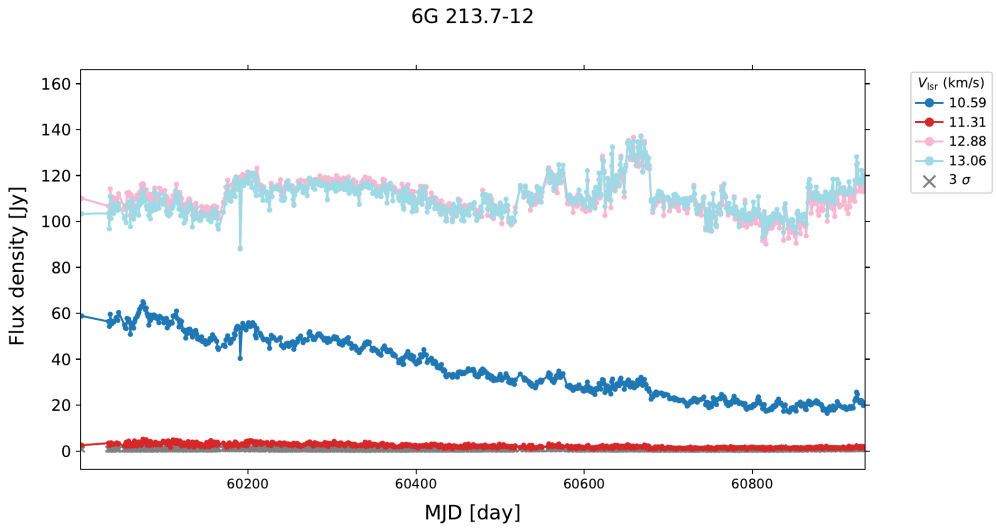


Spectrum

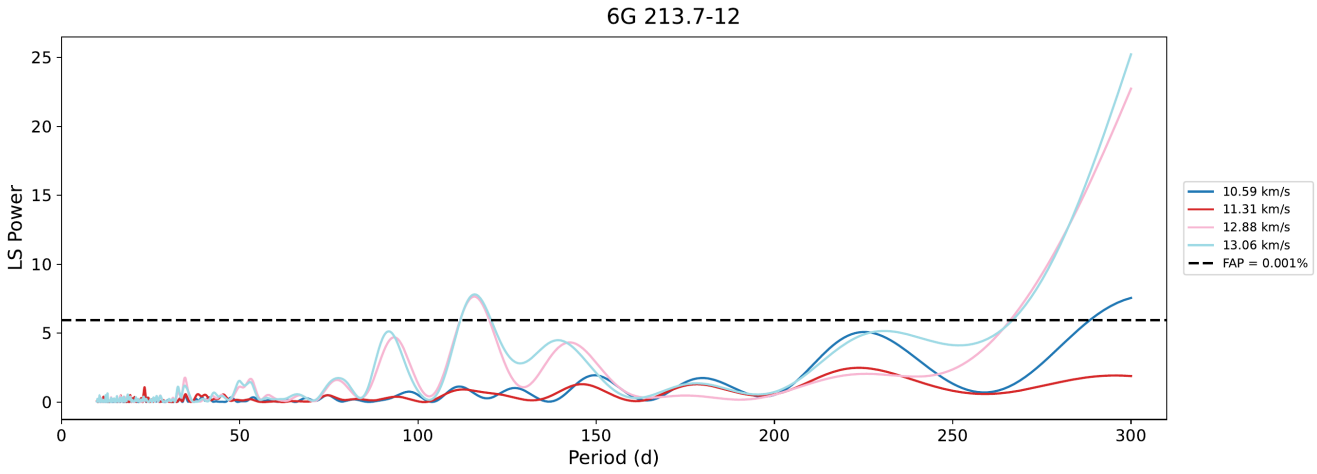


6G 213.7-12

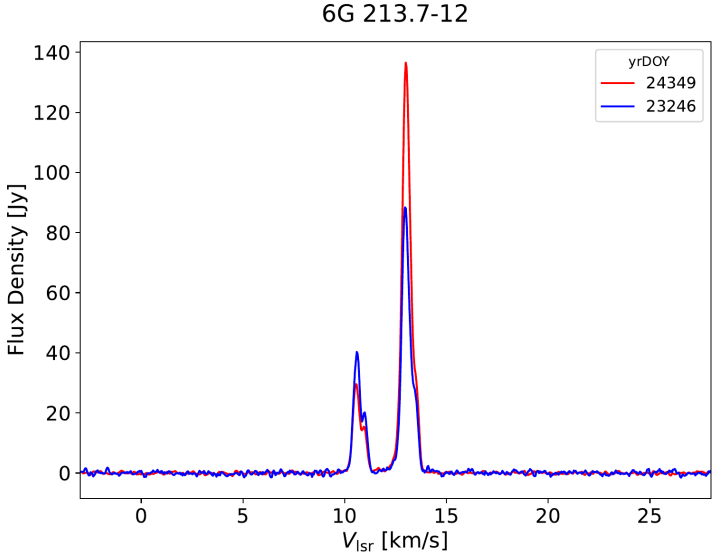
Light curve



Periodogram

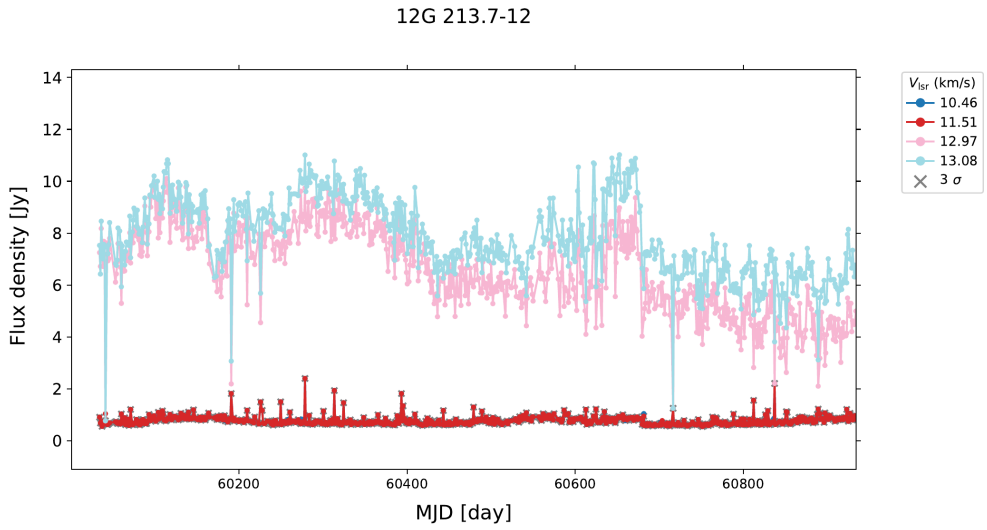


Spectrum

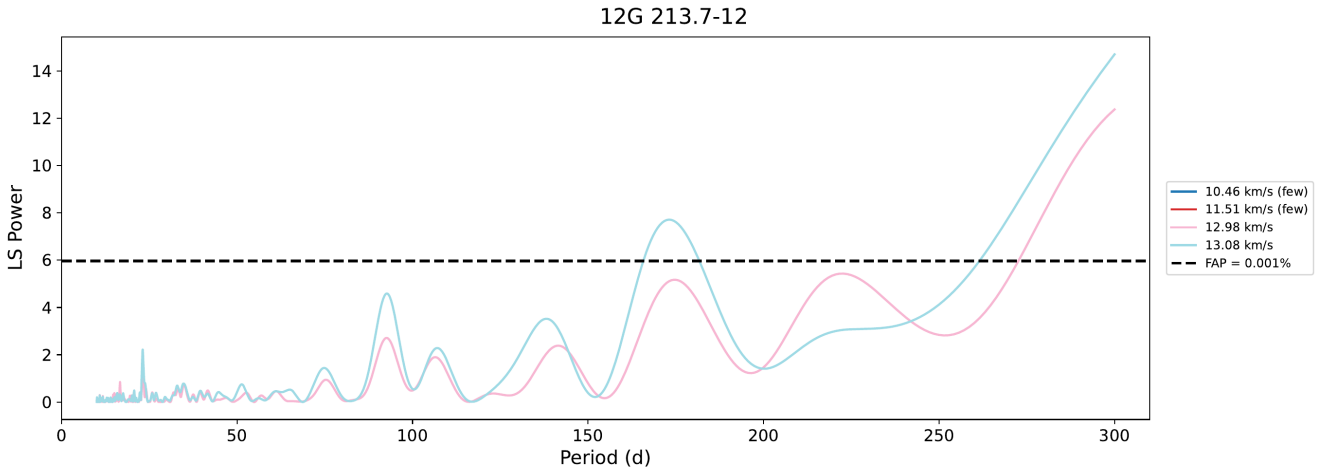


12G 213.7-12

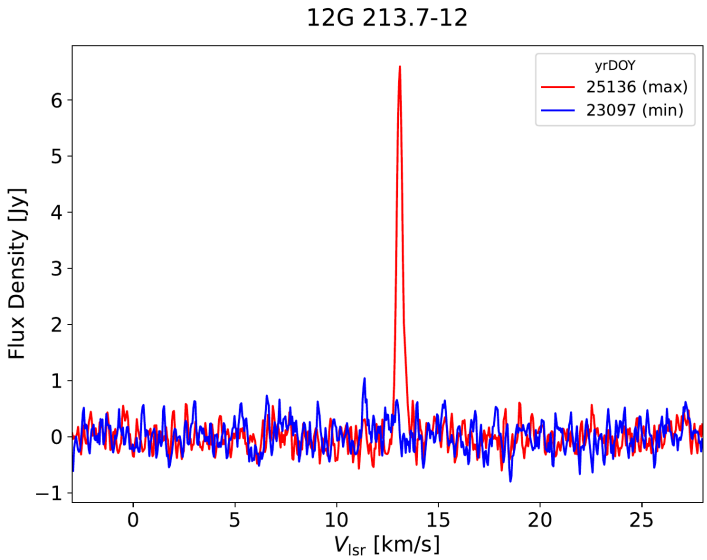
Light curve



Periodogram

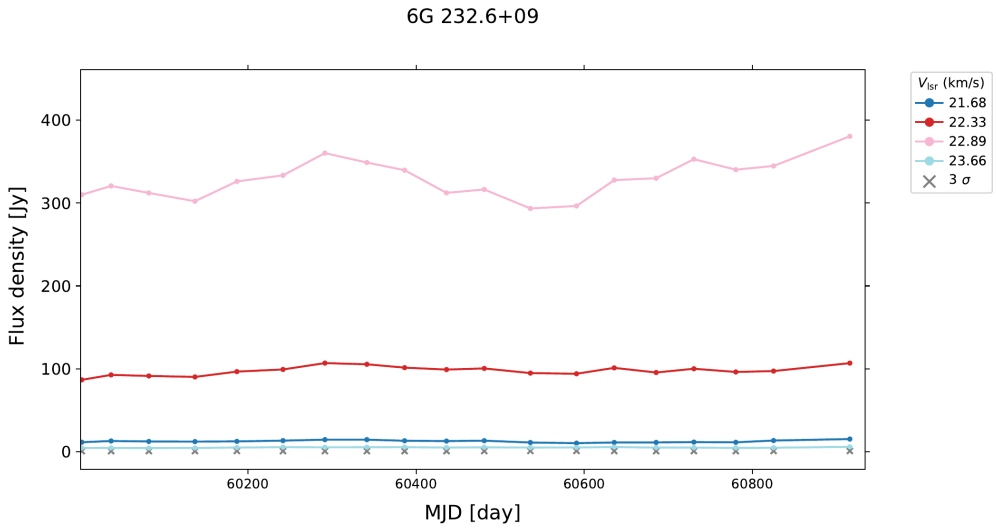


Spectrum

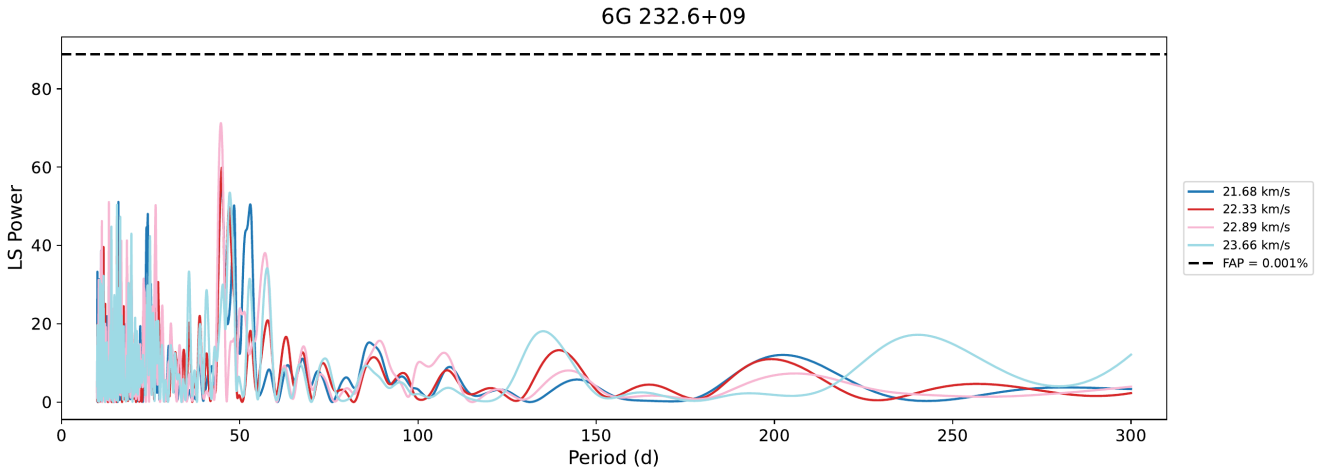


6G 232.6+09

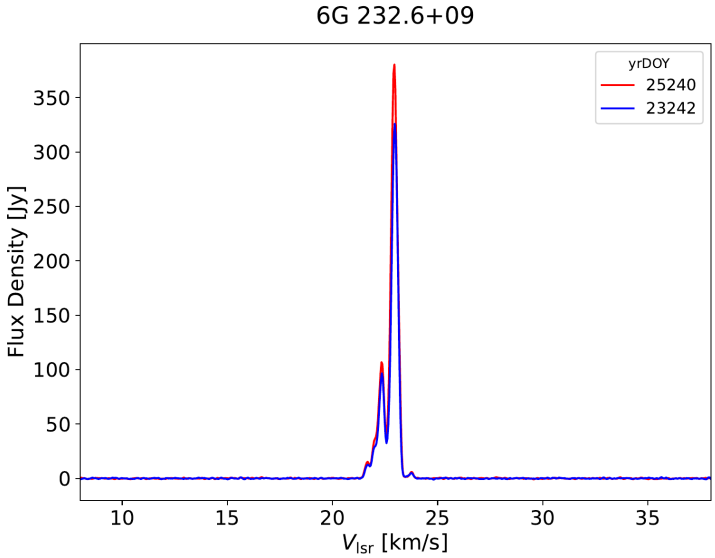
Light curve



Periodogram

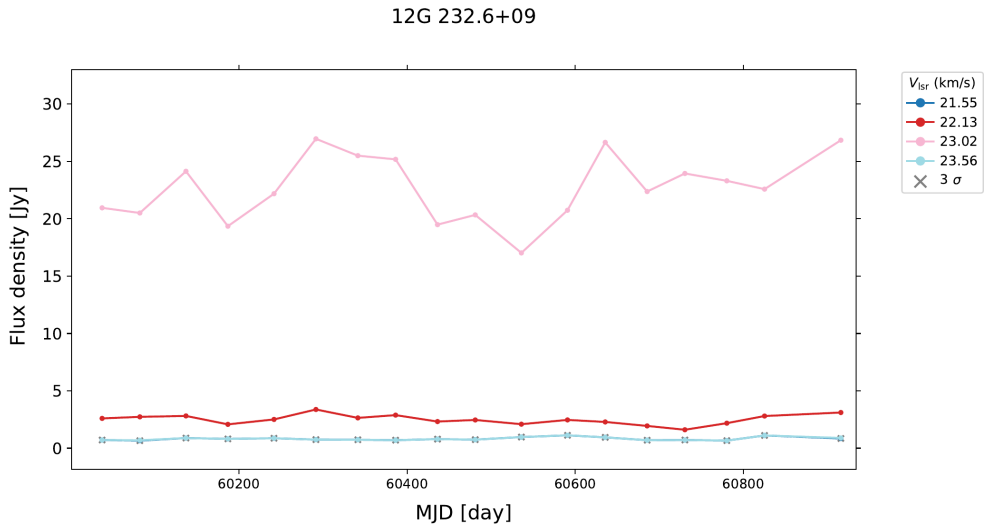


Spectrum

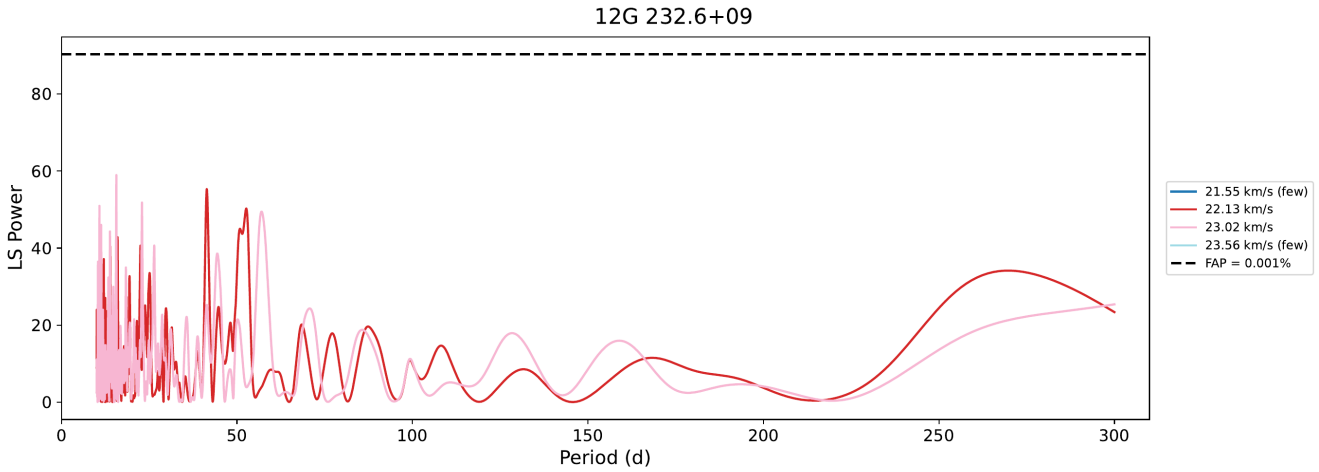


12G 232.6+09

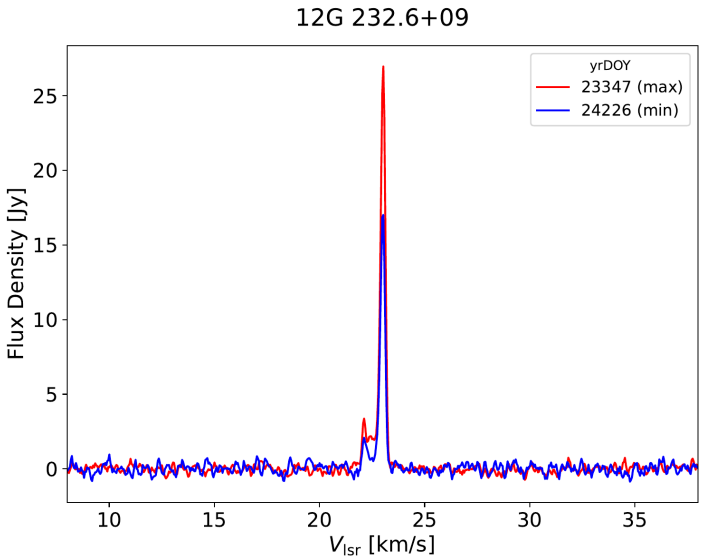
Light curve



Periodogram

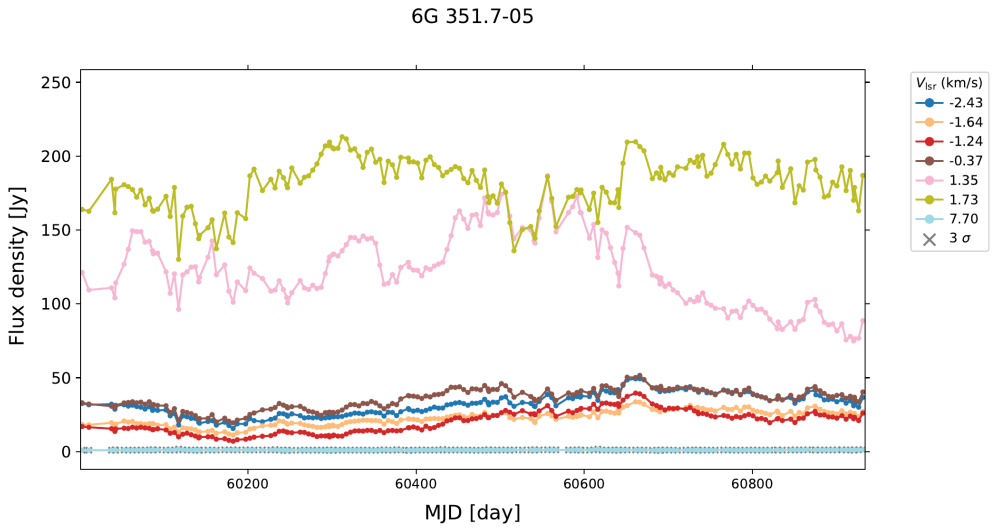


Spectrum

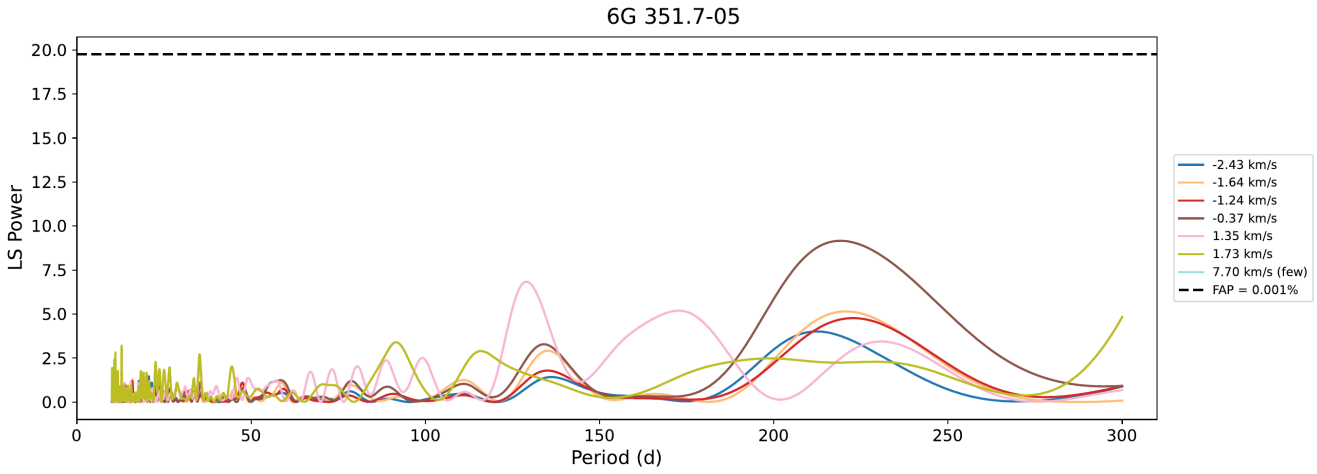


6G 351.7-05

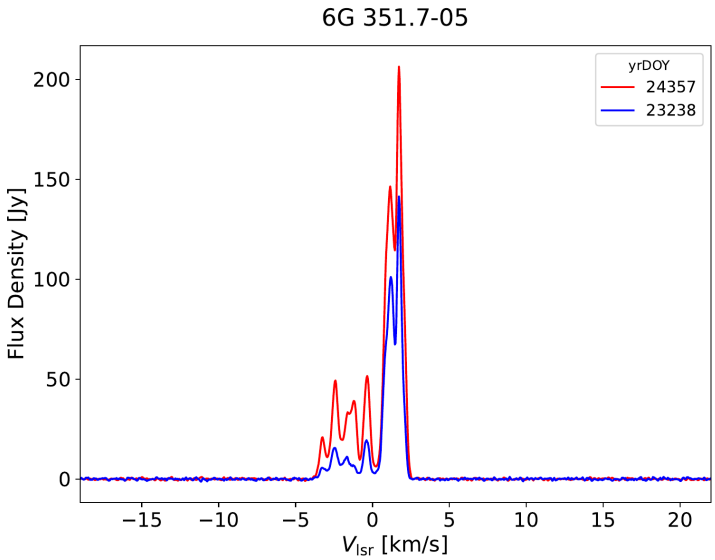
Light curve



Periodogram

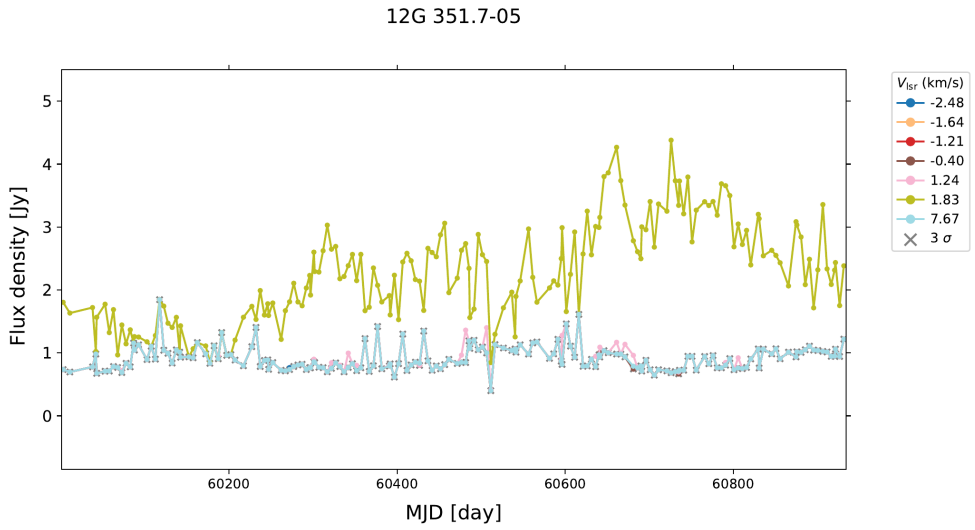


Spectrum

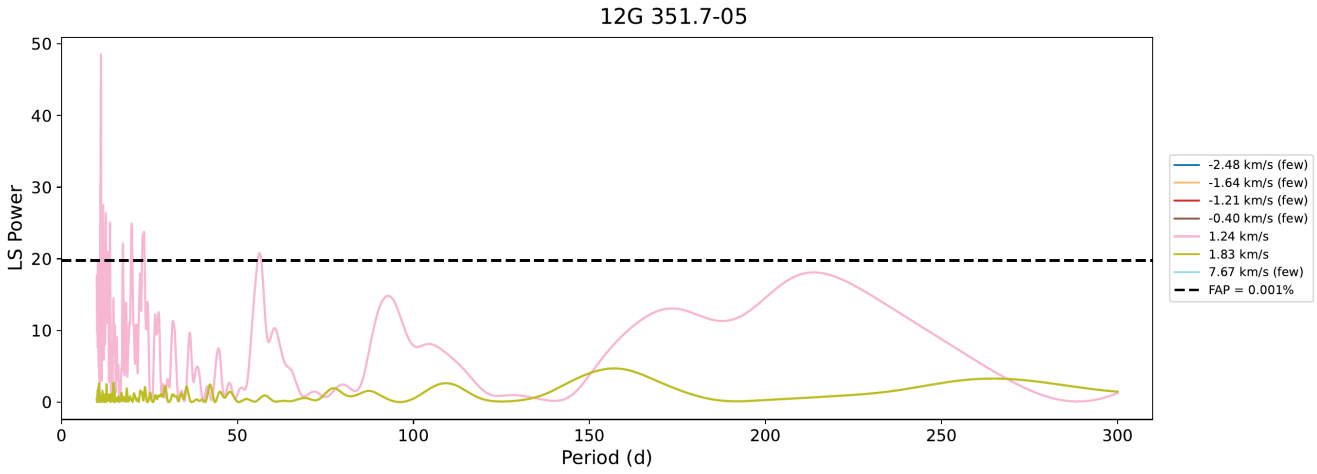


12G 351.7-05

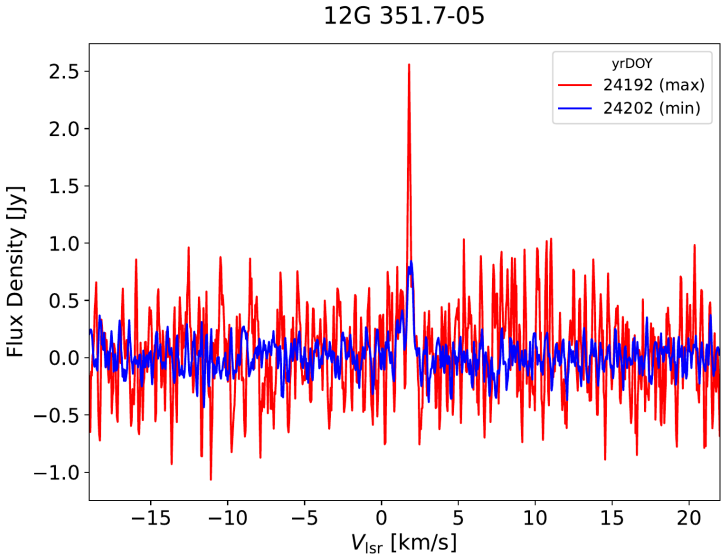
Light curve



Periodogram

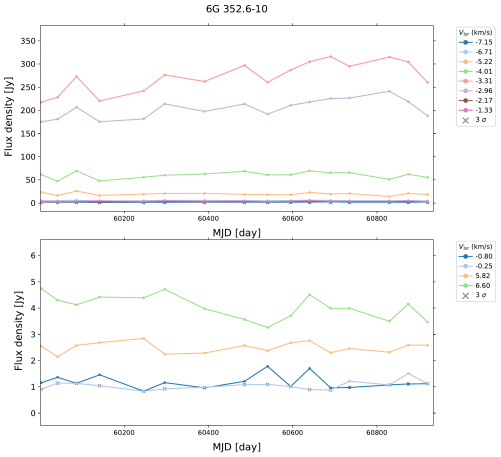


Spectrum

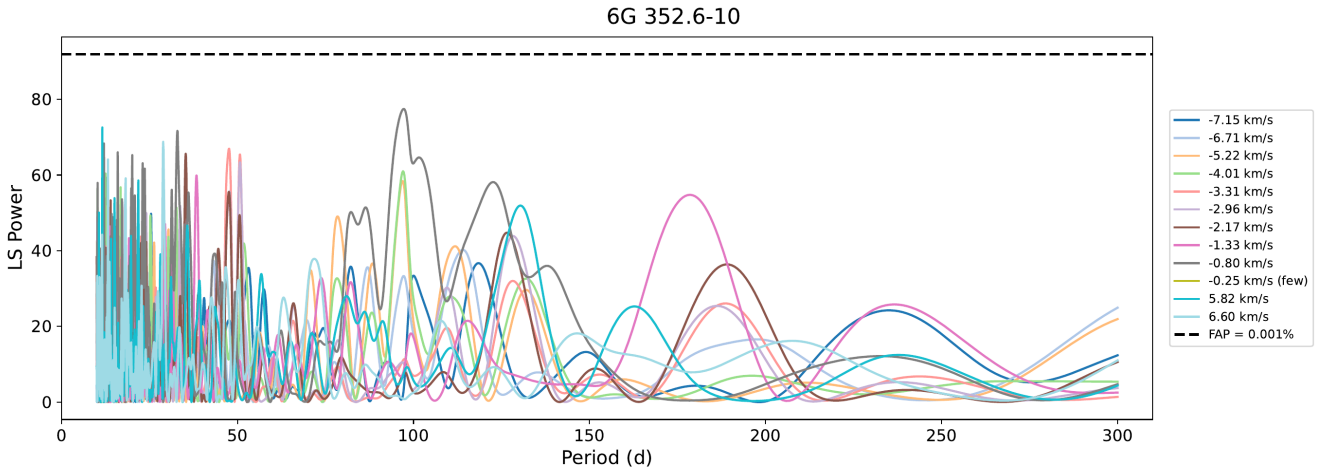


6G 352.6-10

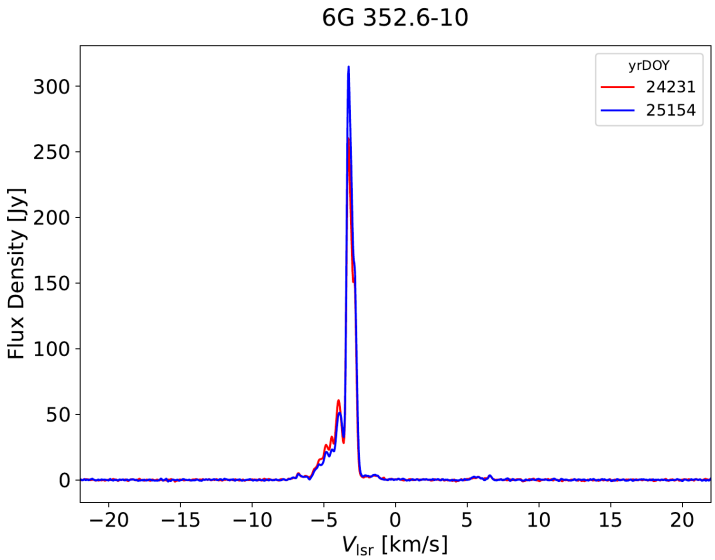
Light curve



Periodogram

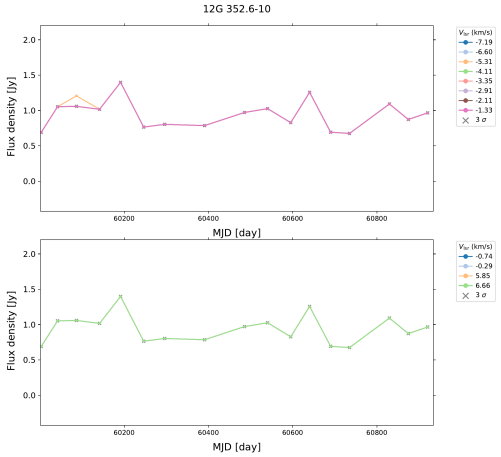


Spectrum

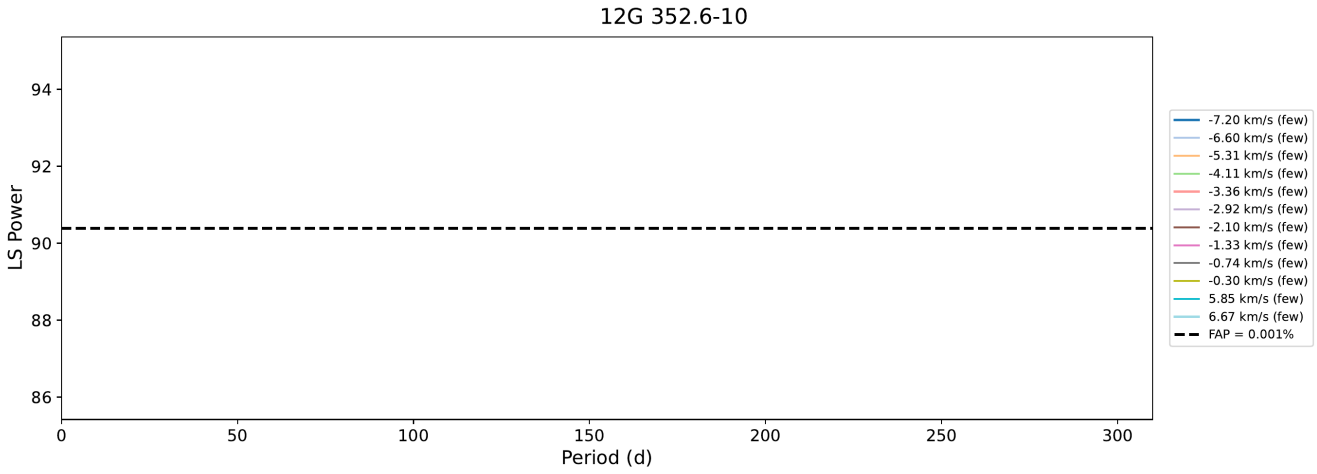


12G 352.6-10

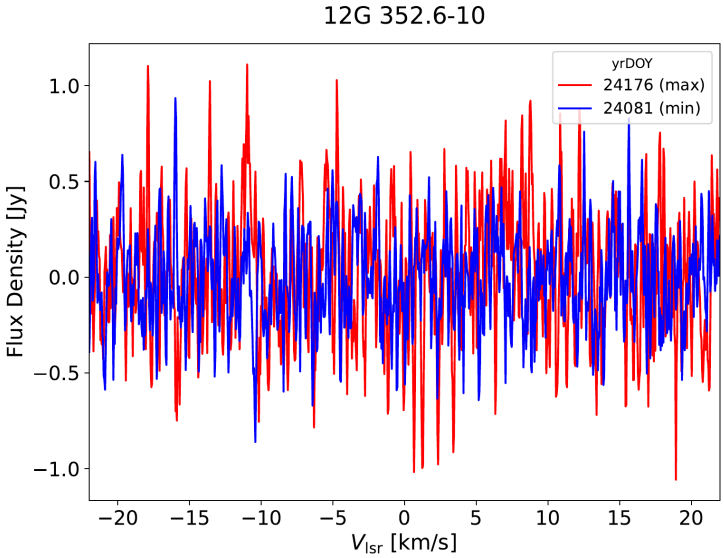
Light curve



Periodogram

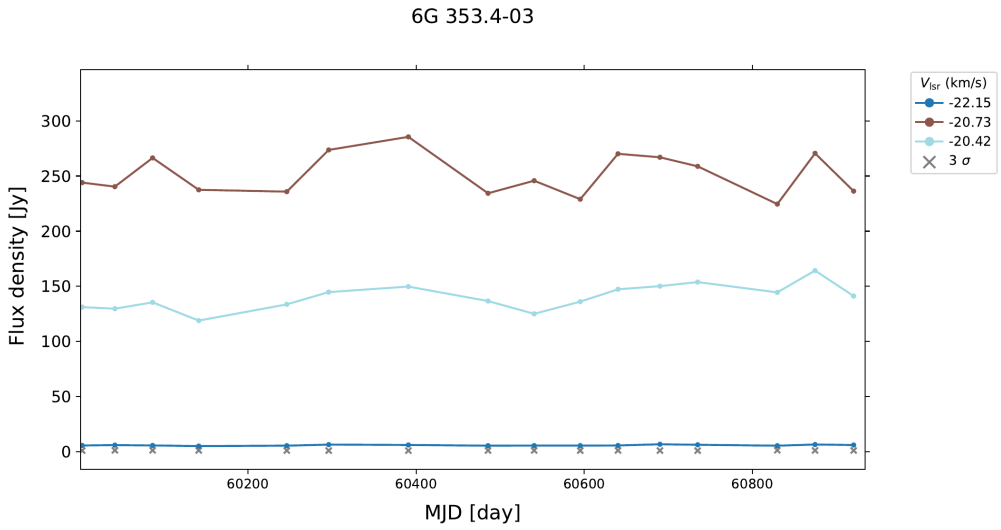


Spectrum

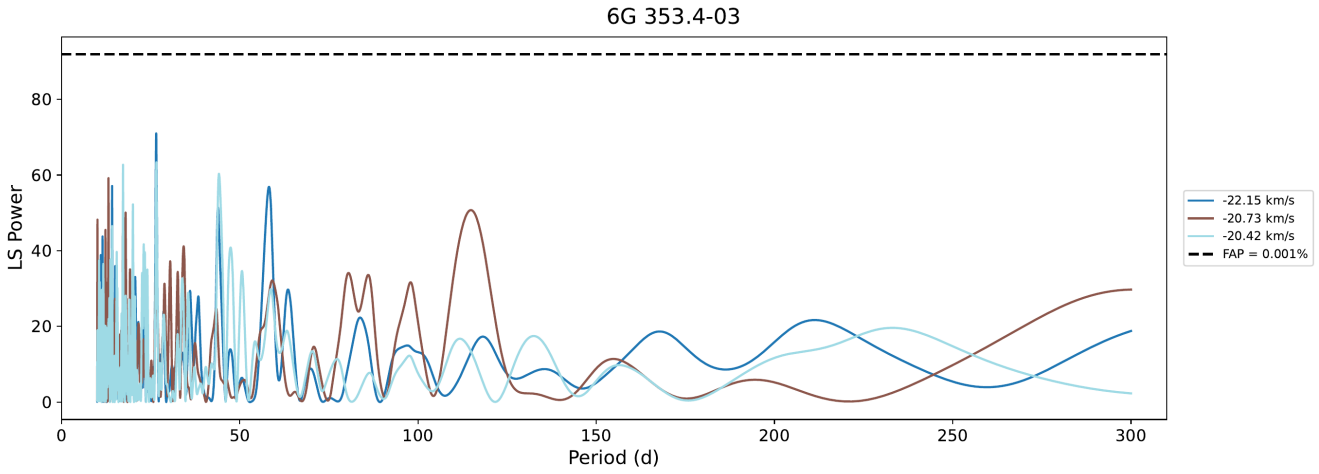


6G 353.4-03

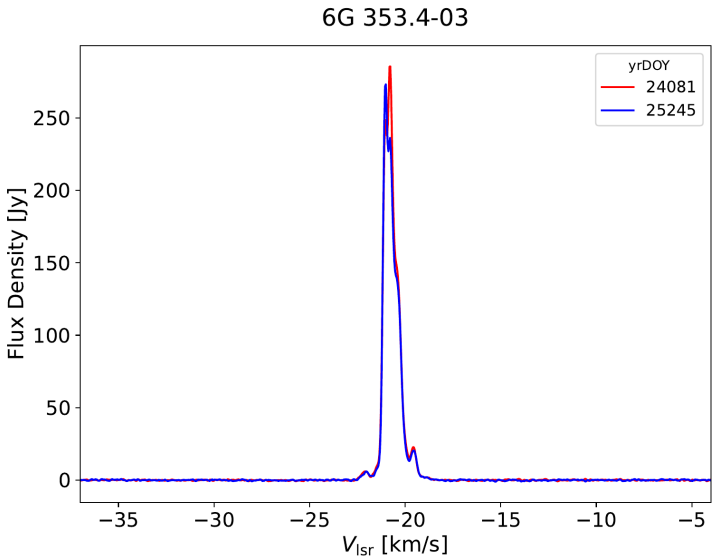
Light curve



Periodogram

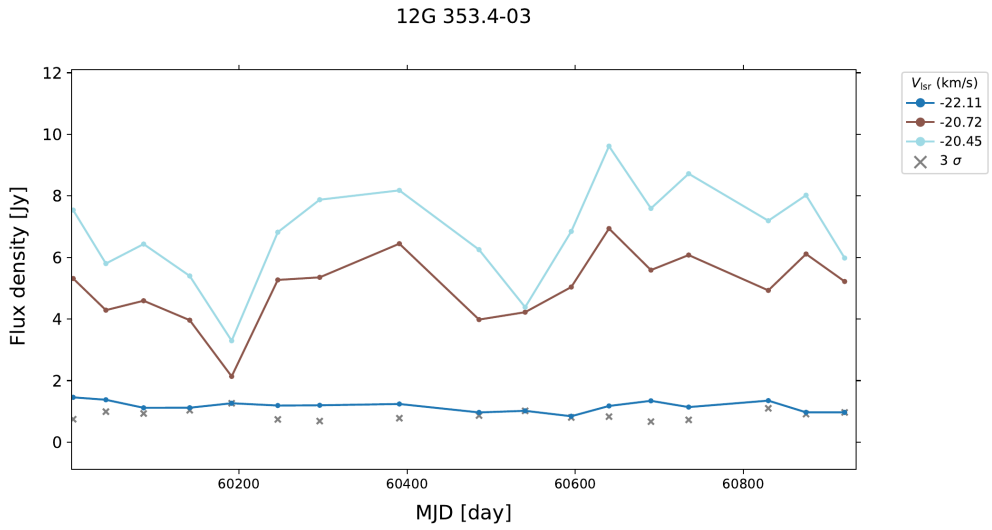


Spectrum

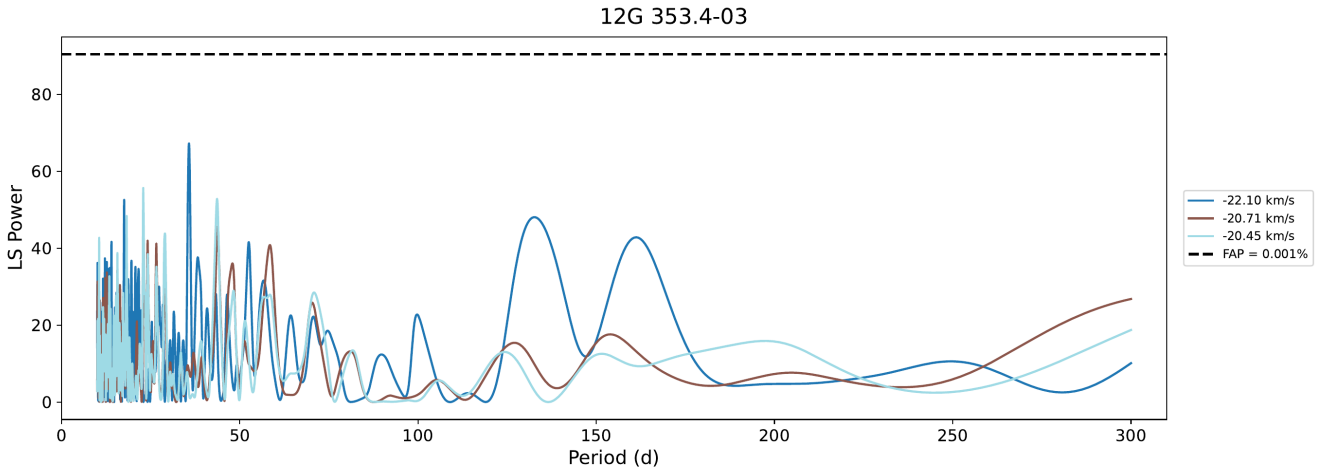


12G 353.4-03

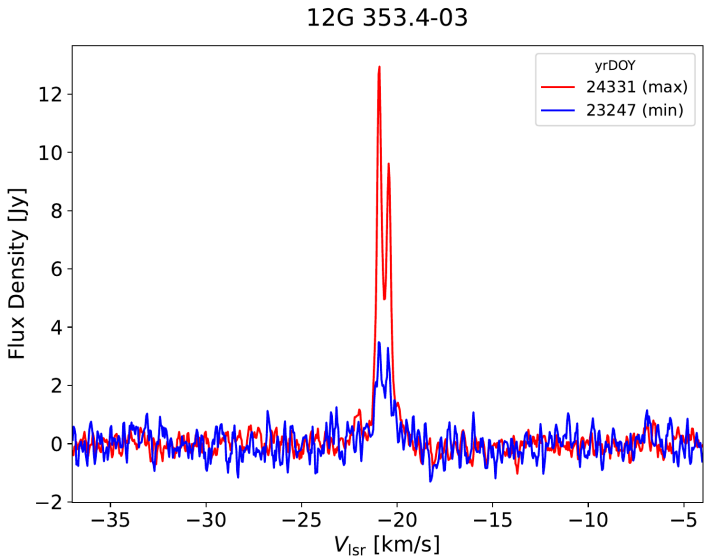
Light curve



Periodogram

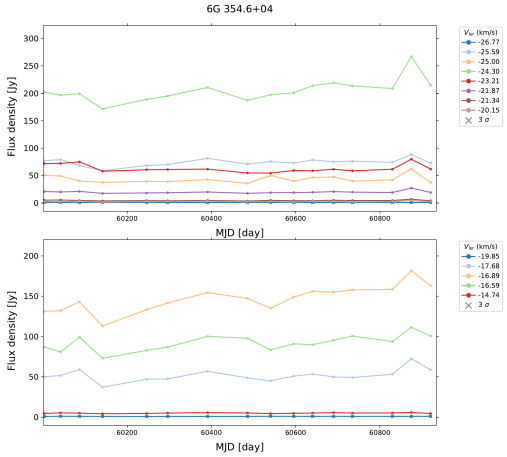


Spectrum

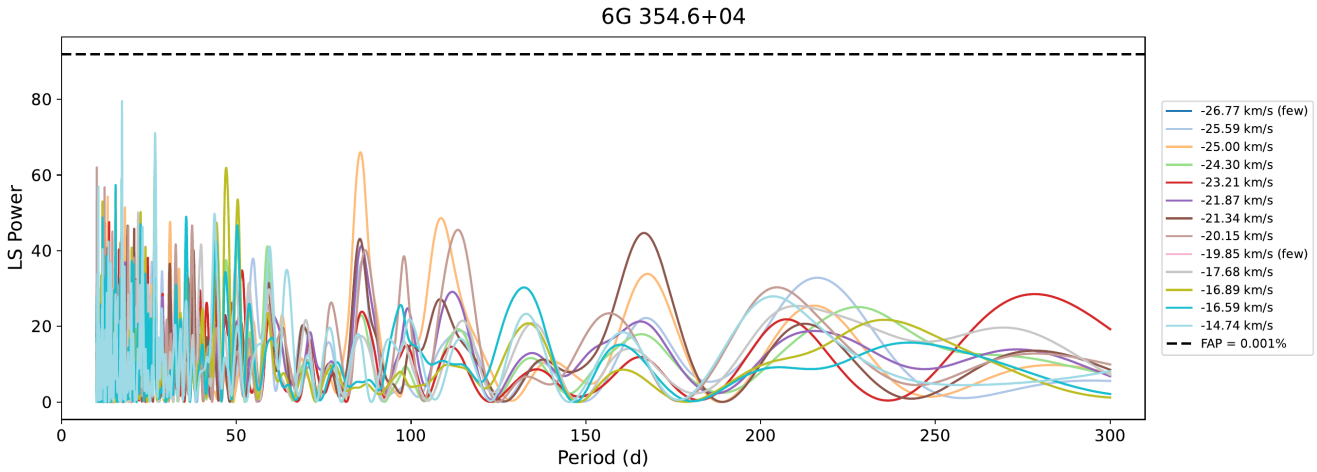


6G 354.6+04

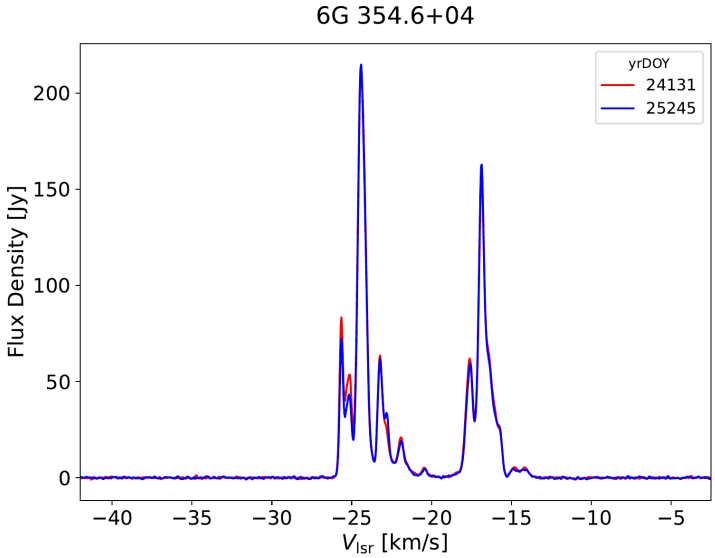
Light curve



Periodogram

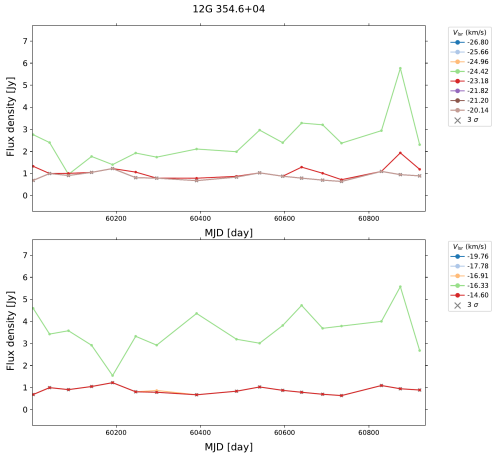


Spectrum

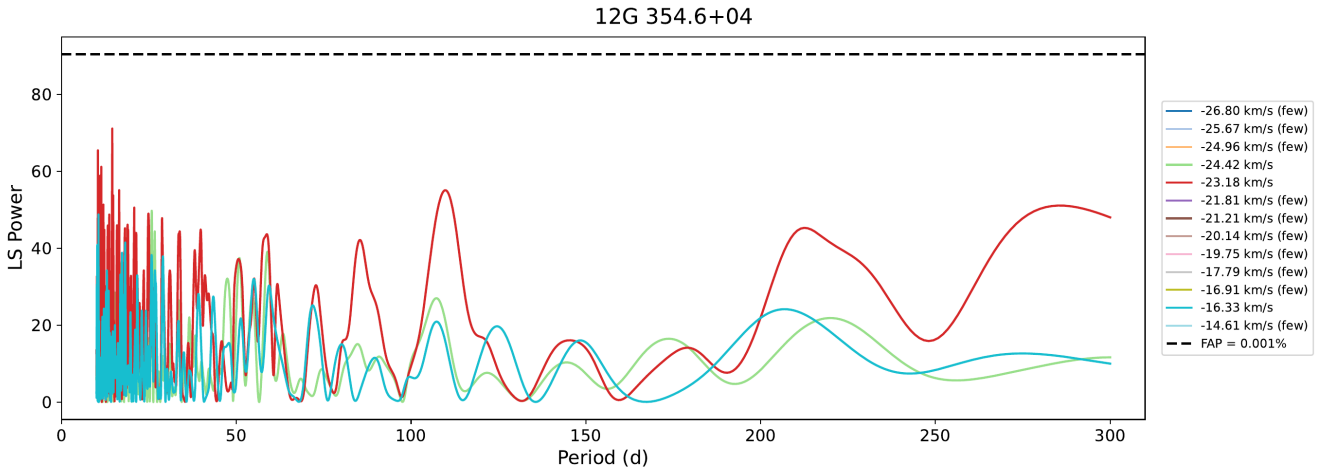


12G 354.6+04

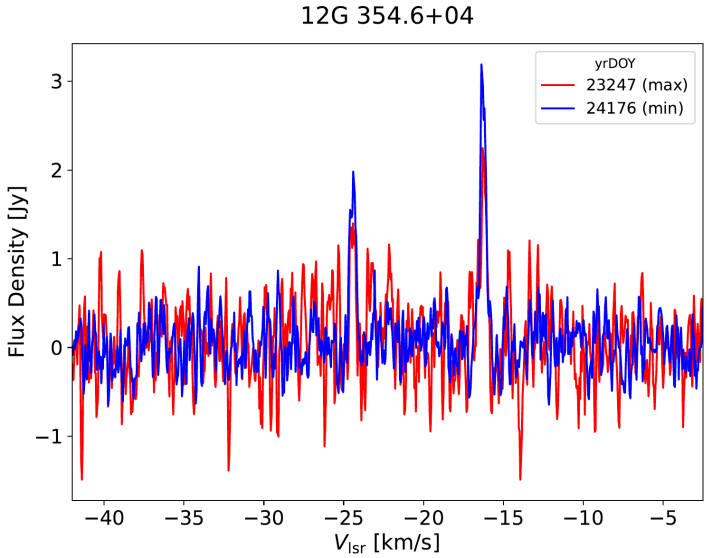
Light curve



Periodogram

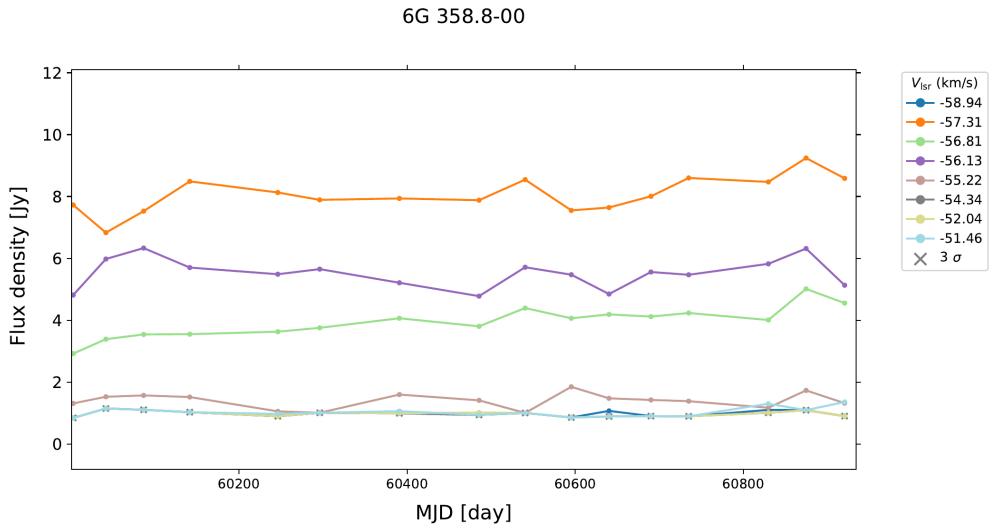


Spectrum

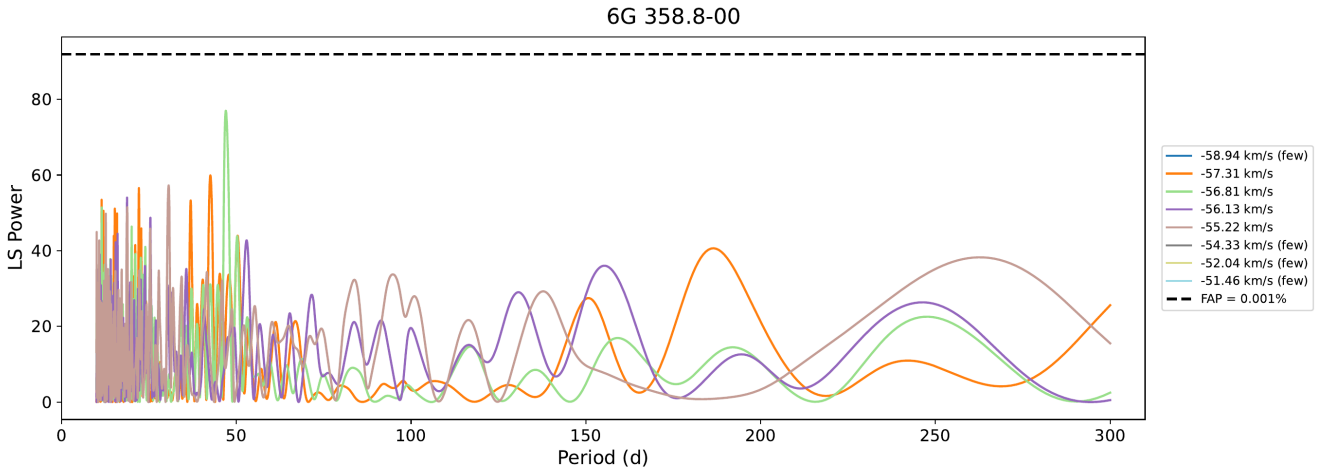


6G 358.8-00

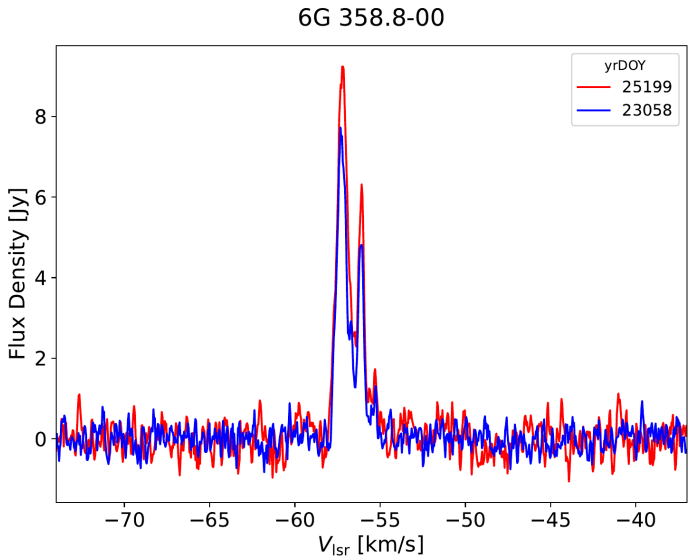
Light curve



Periodogram

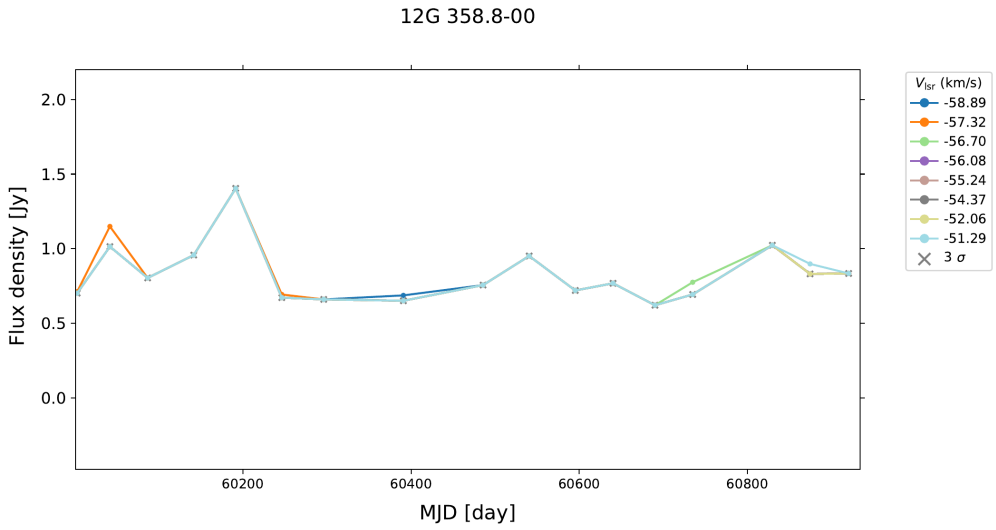


Spectrum

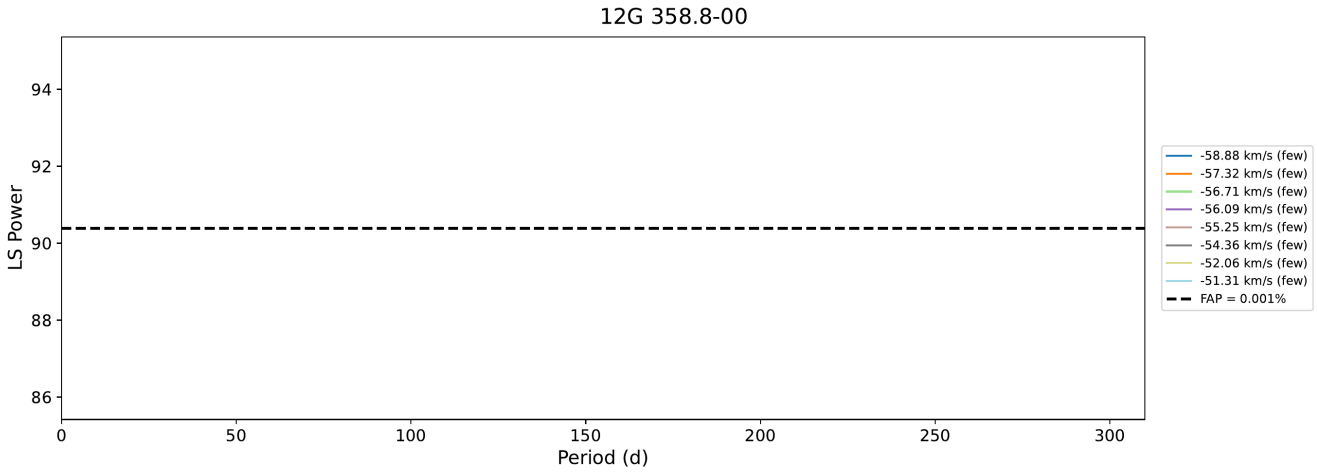


12G 358.8-00

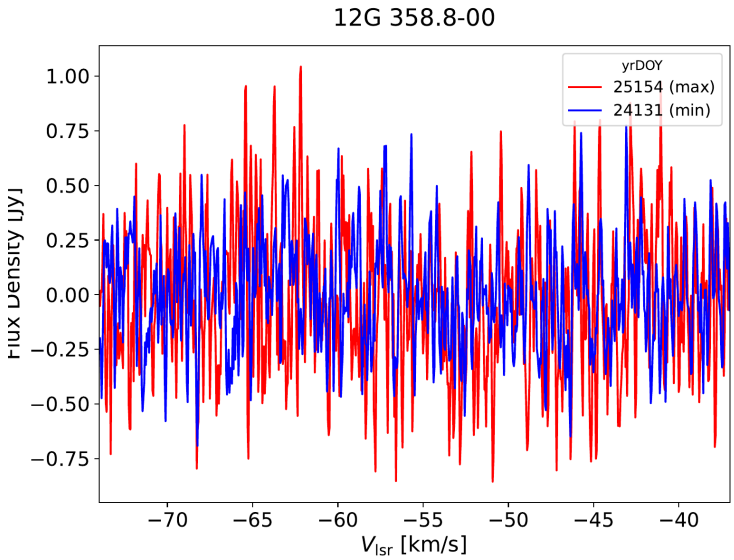
Light curve



Periodogram

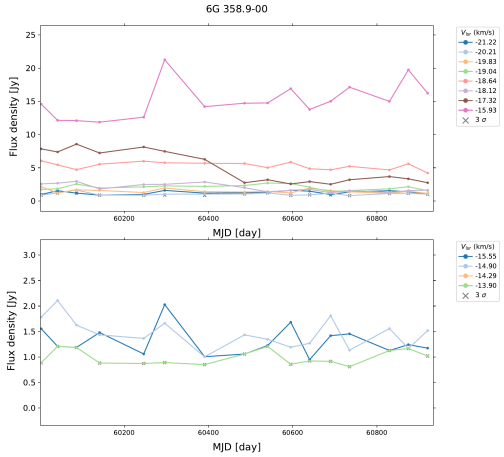


Spectrum

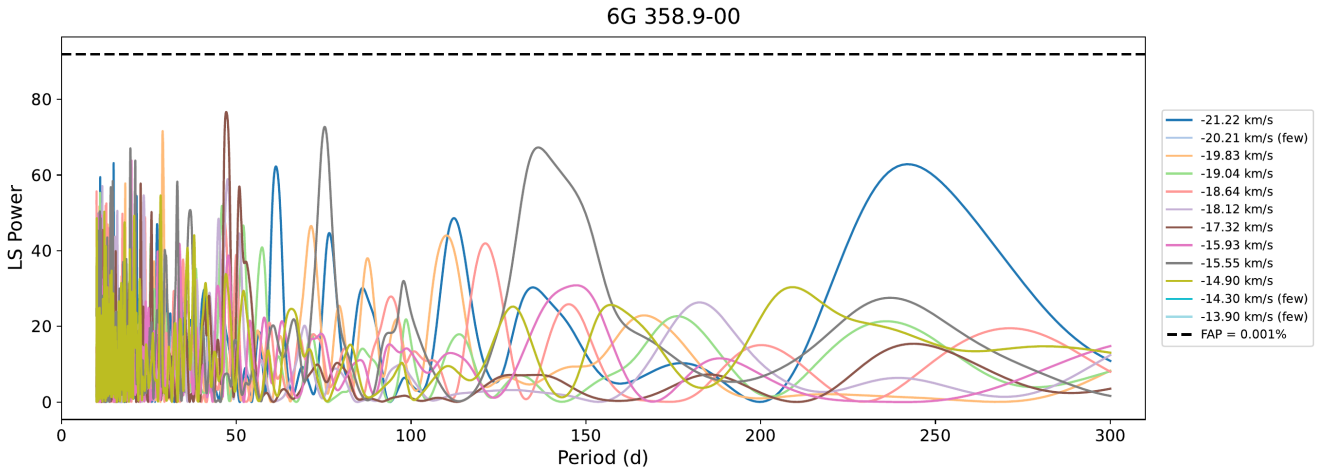


6G 358.9-00

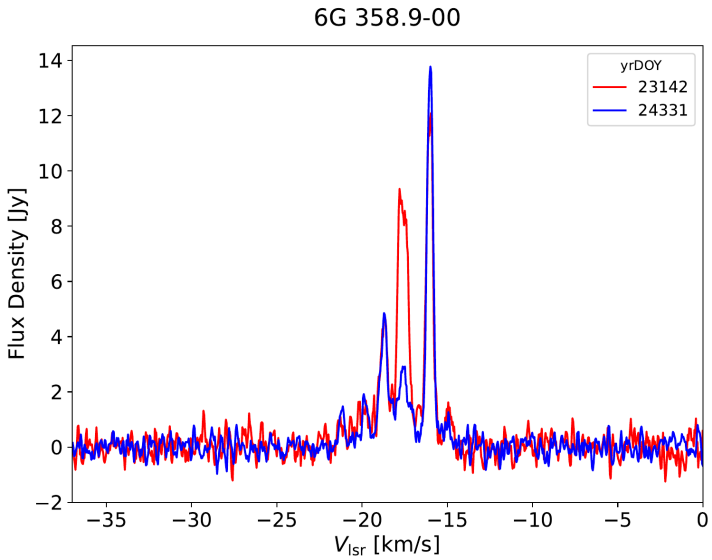
Light curve



Periodogram

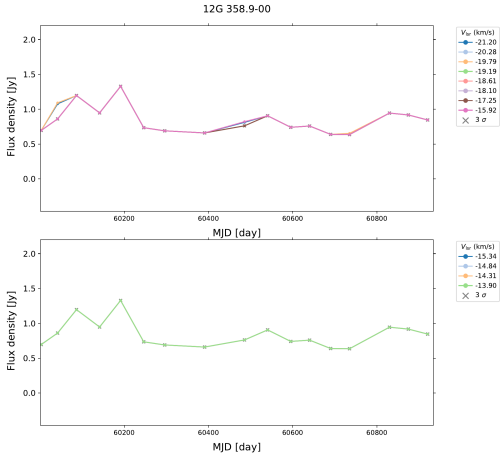


Spectrum

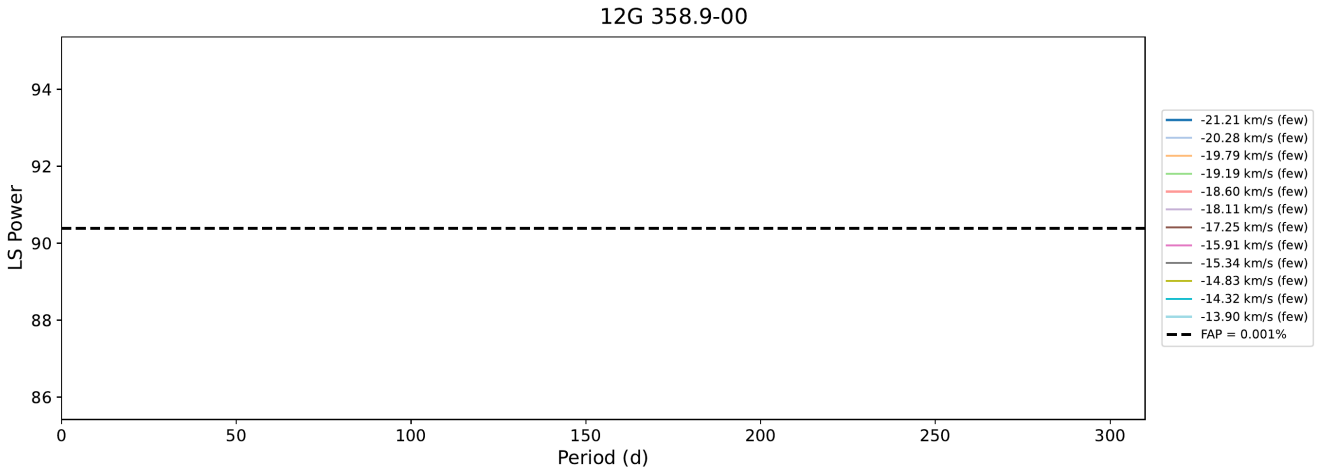


12G 358.9-00

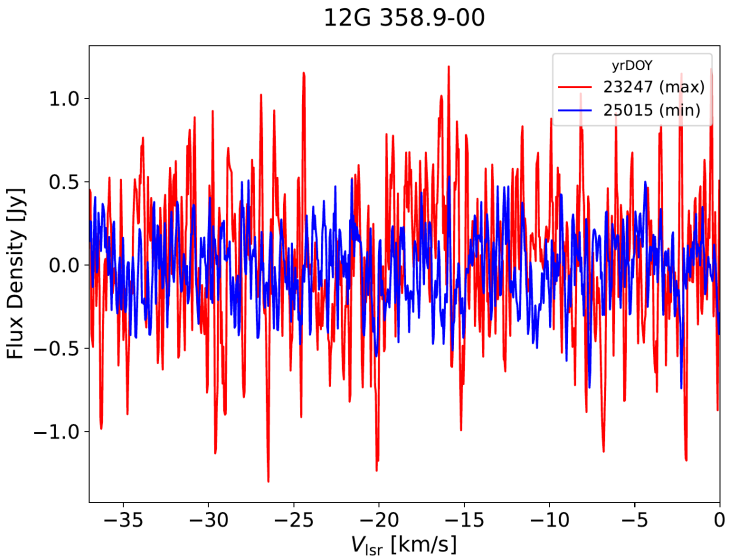
Light curve



Periodogram

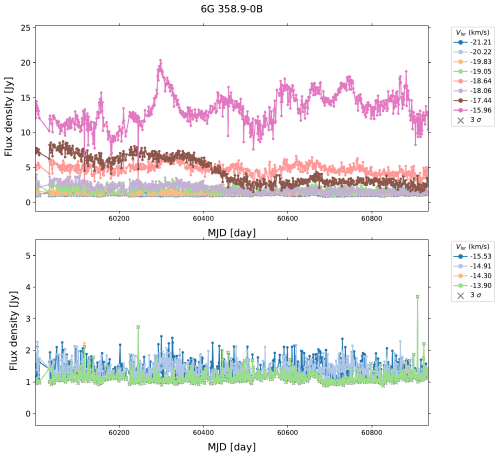


Spectrum

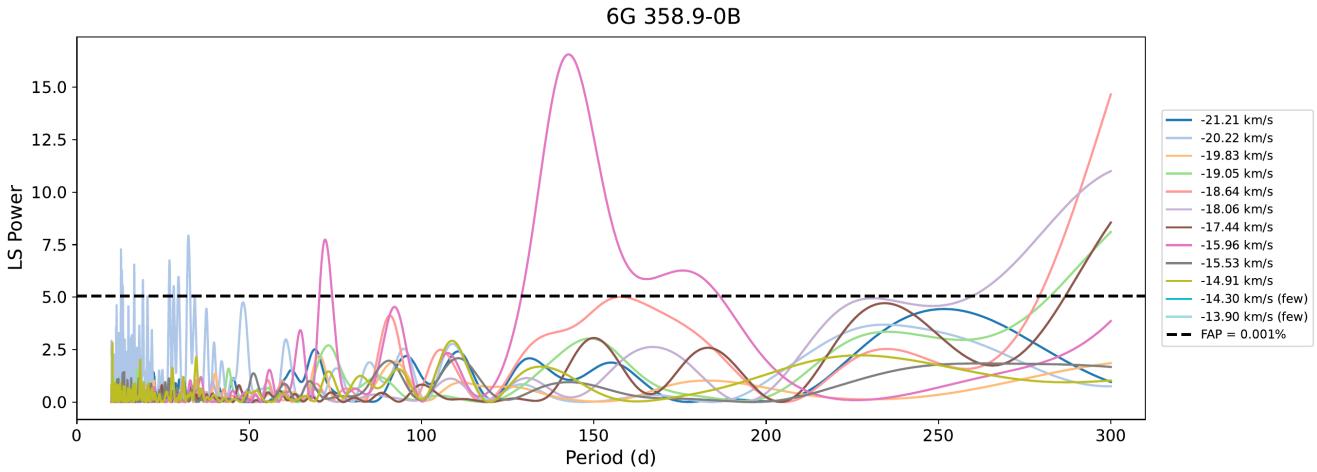


6G 358.9-0B

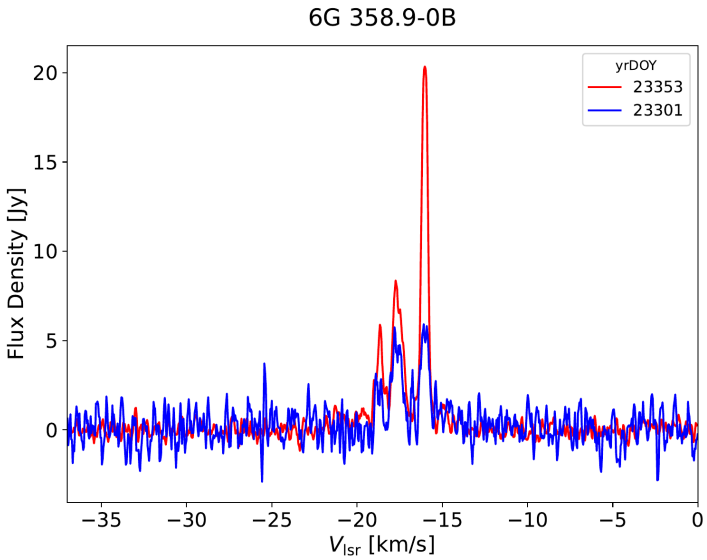
Light curve



Periodogram

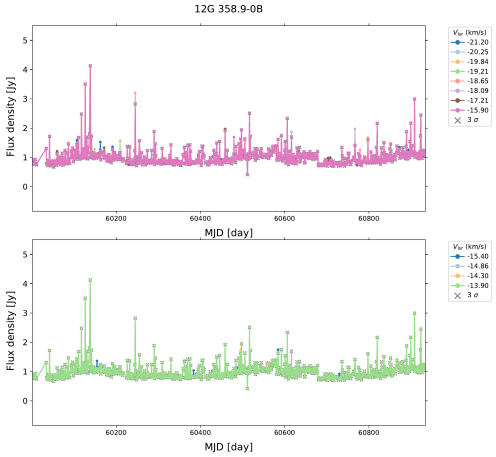


Spectrum

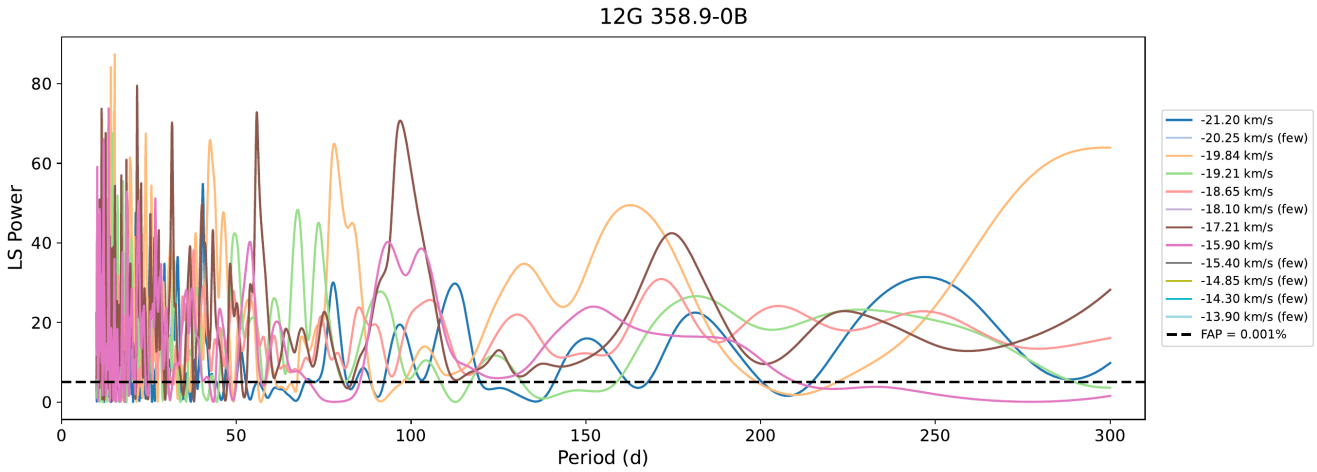


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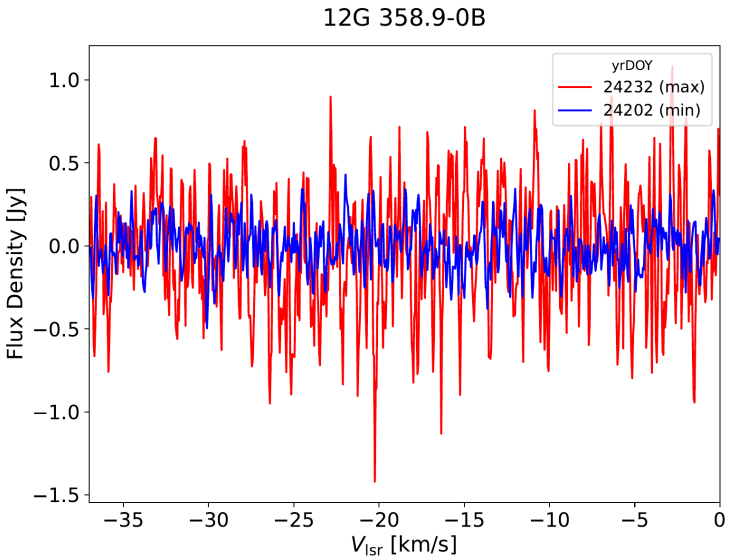
Light curve



Periodogram

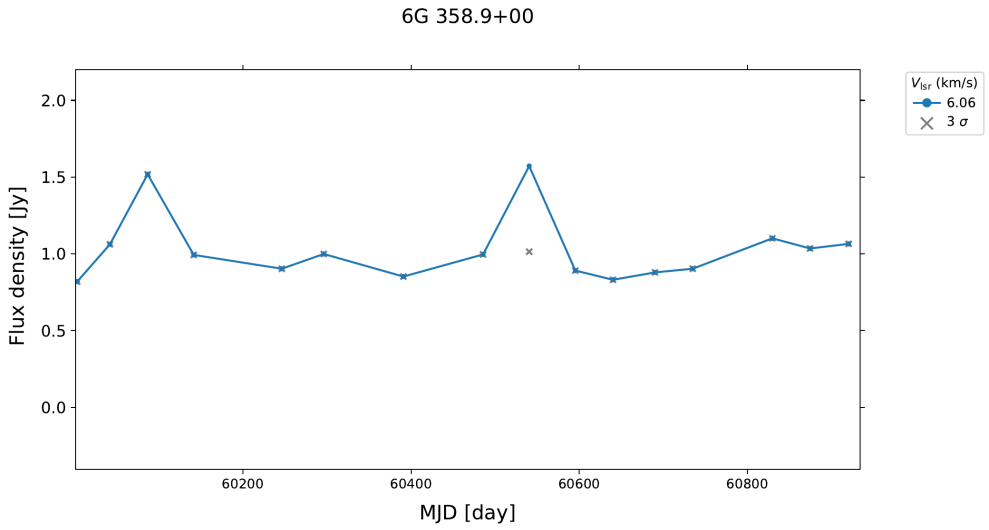


Spectrum

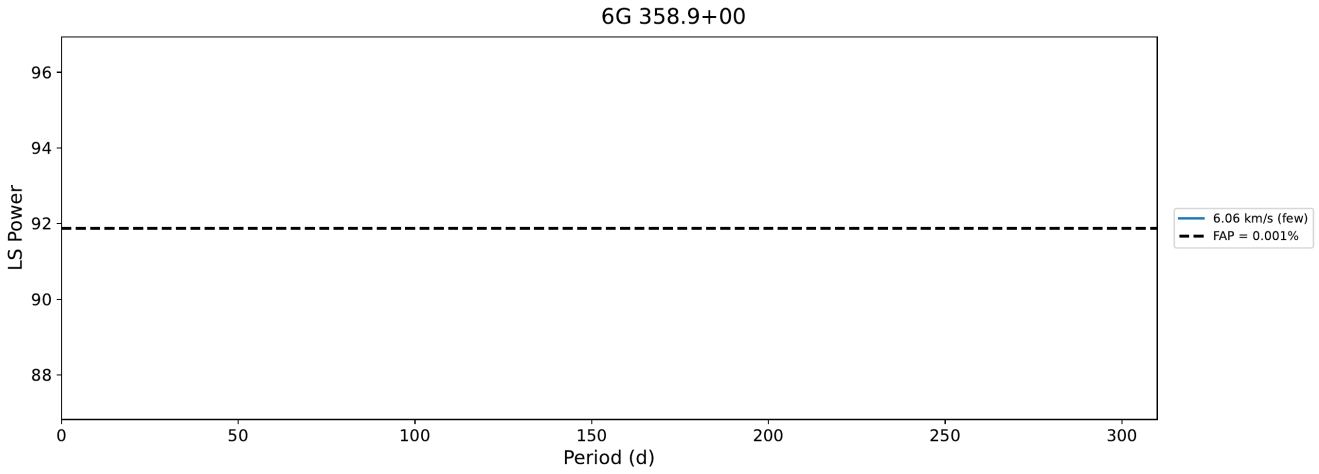


6G 358.9+00

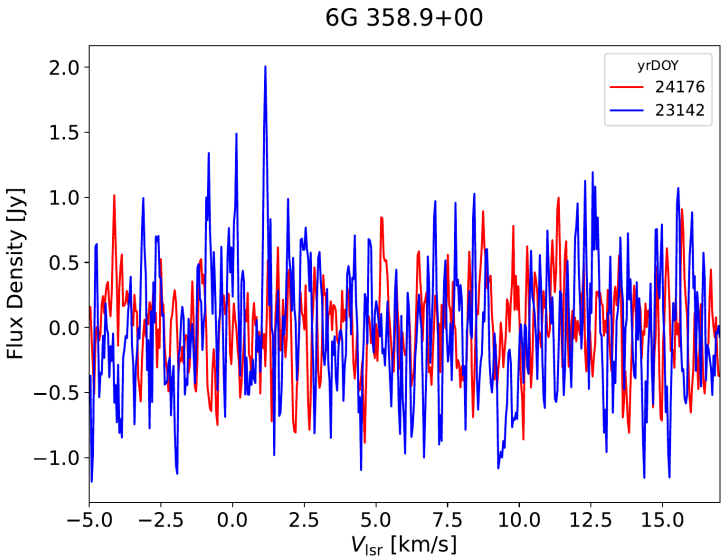
Light curve



Periodogram

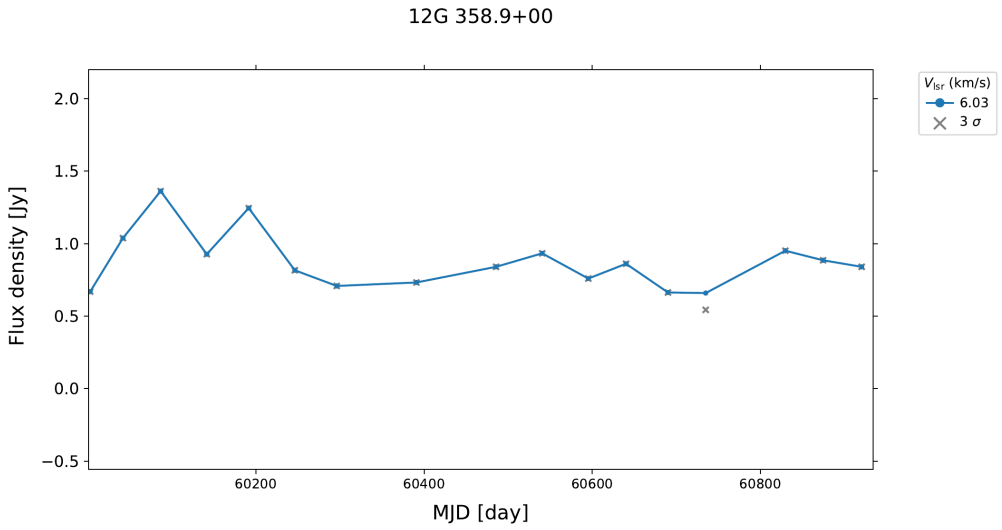


Spectrum

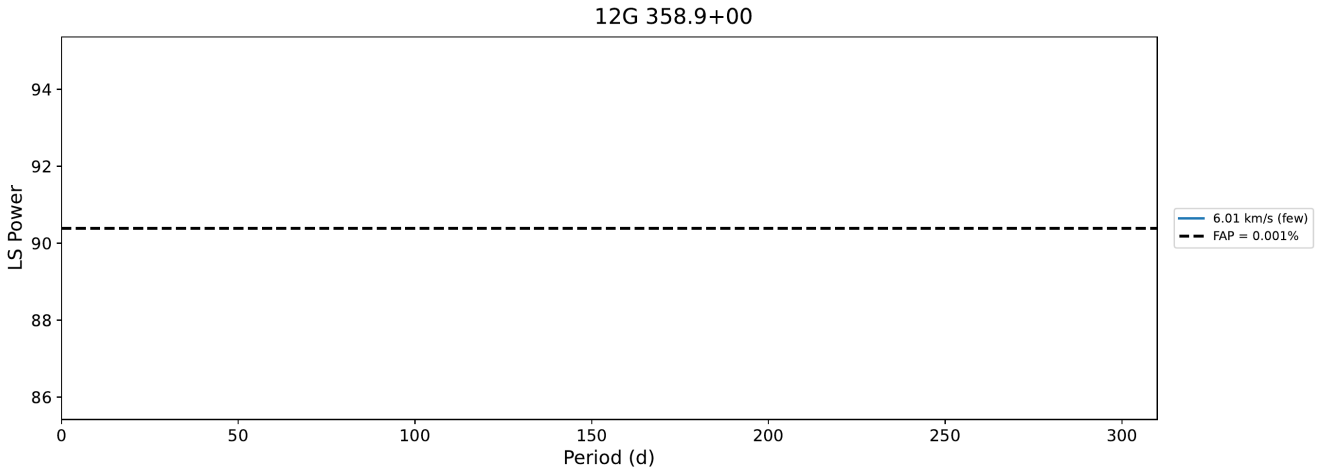


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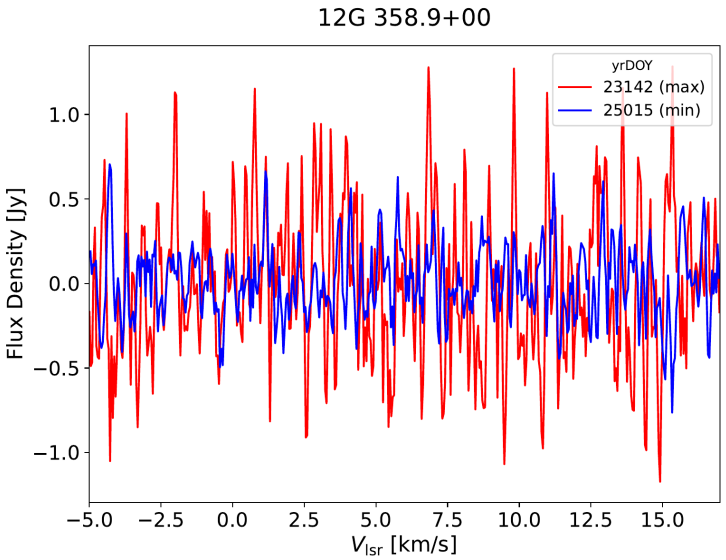
Light curve



Periodogram

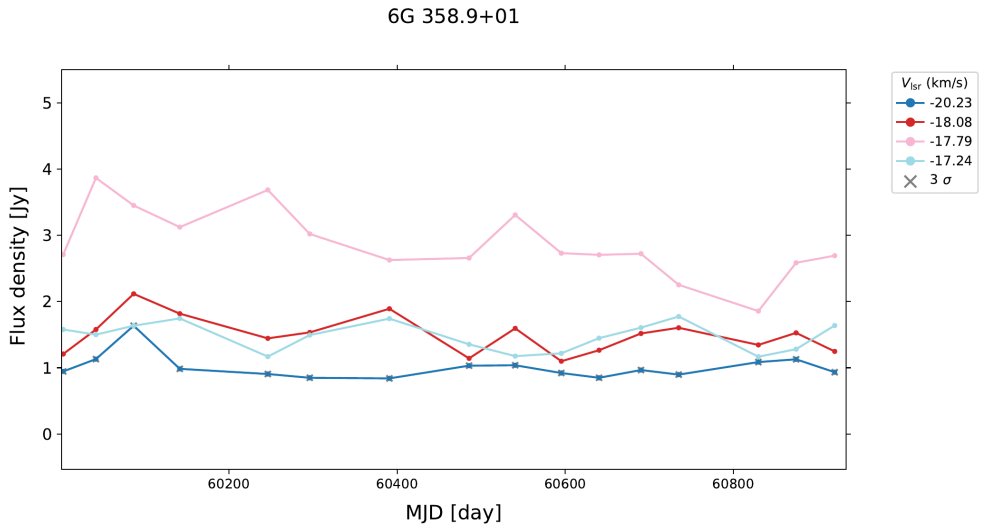


Spectrum

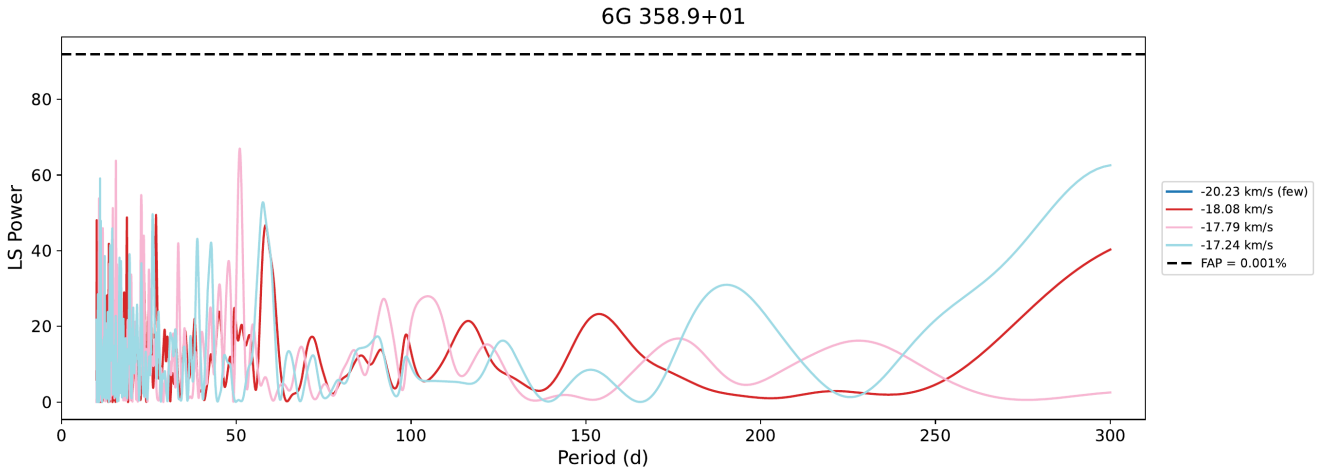


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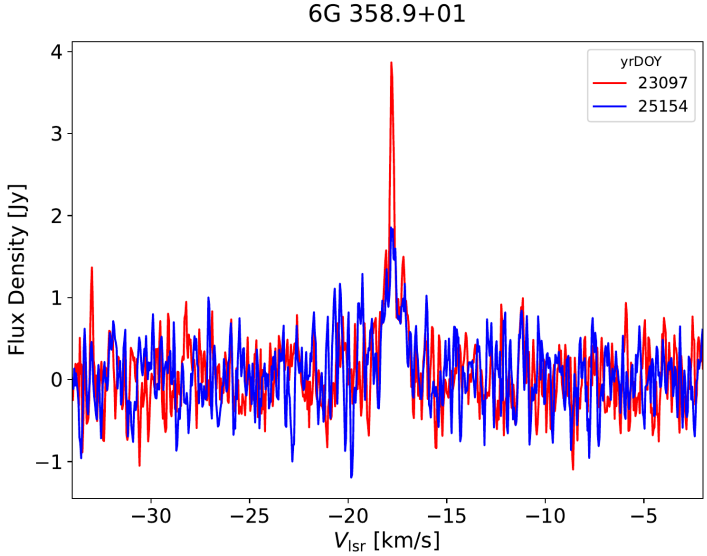
Light curve



Periodogram

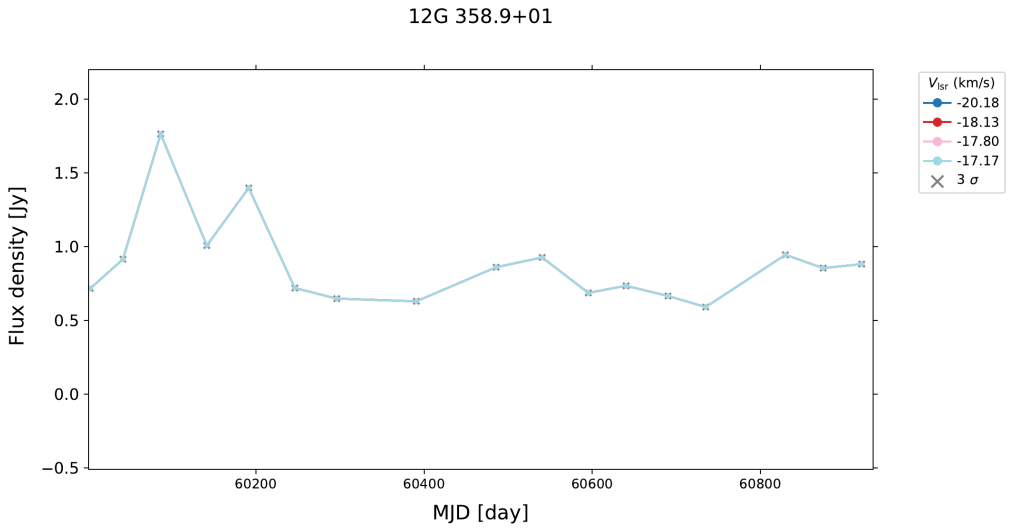


Spectrum

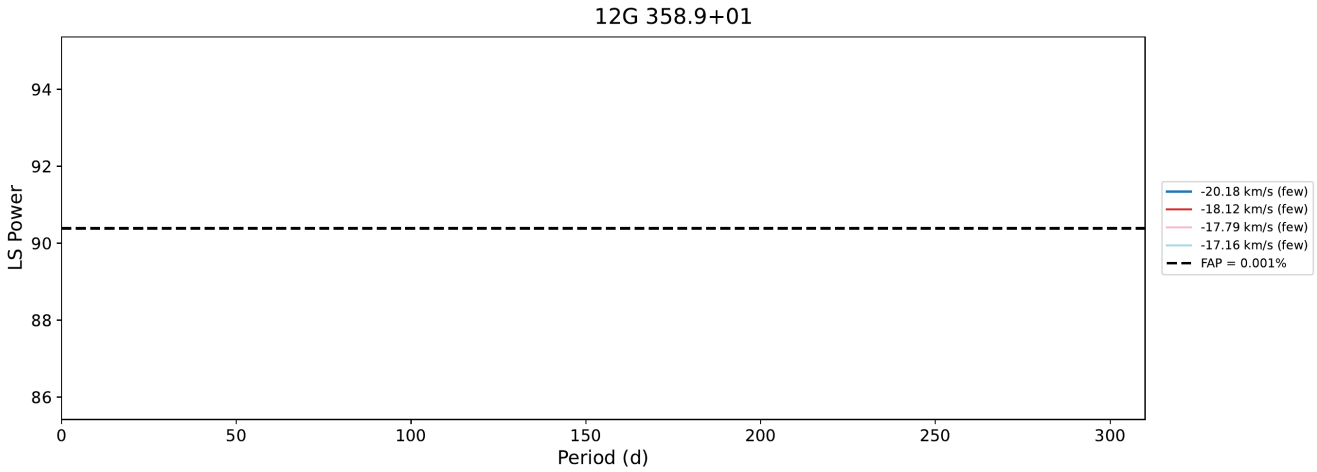


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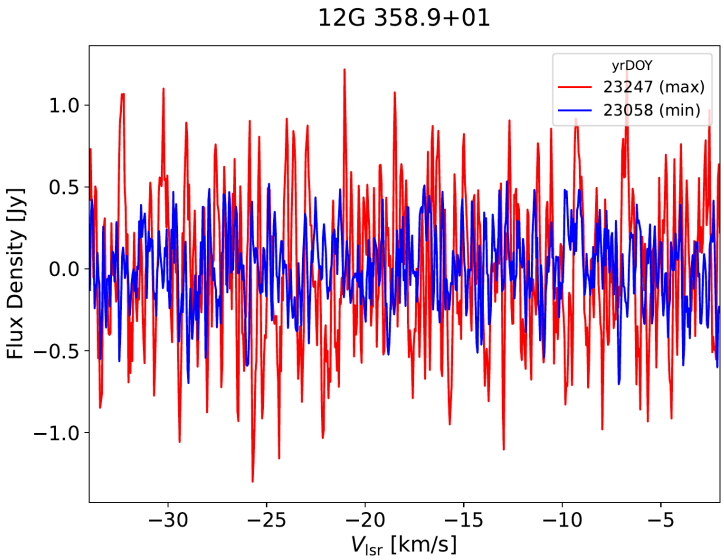
Light curve



Periodogram

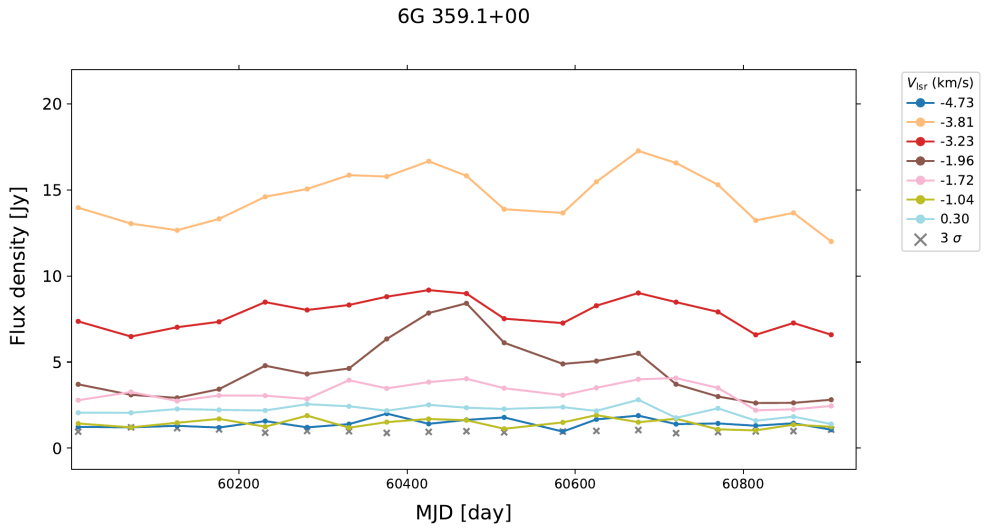


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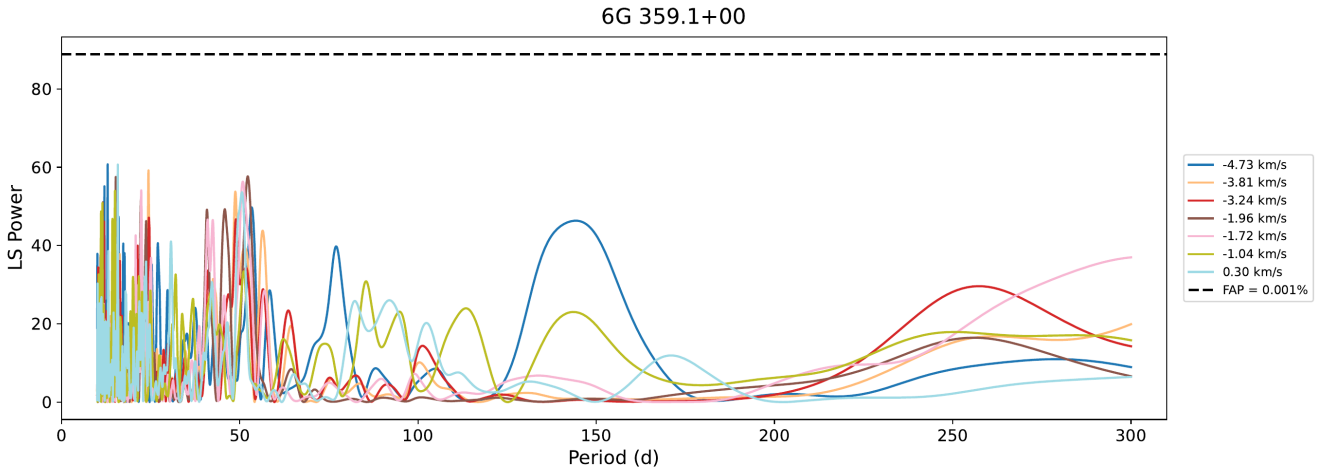


6G 359.1+00

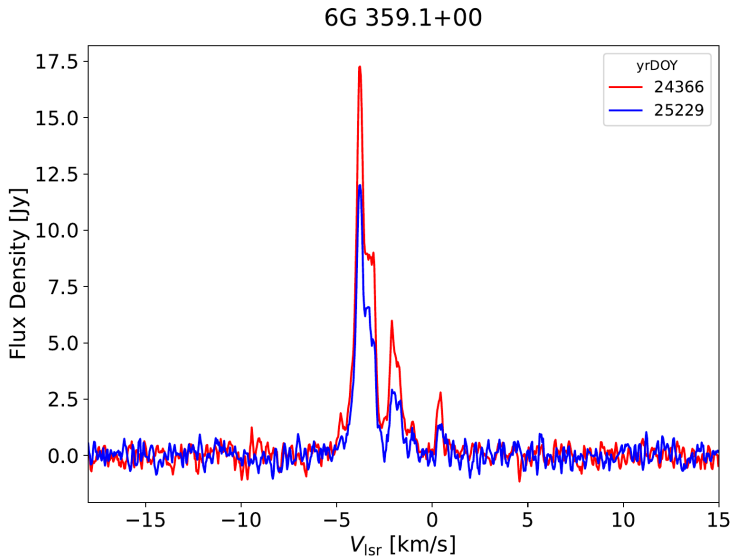
Light curve



Periodogram

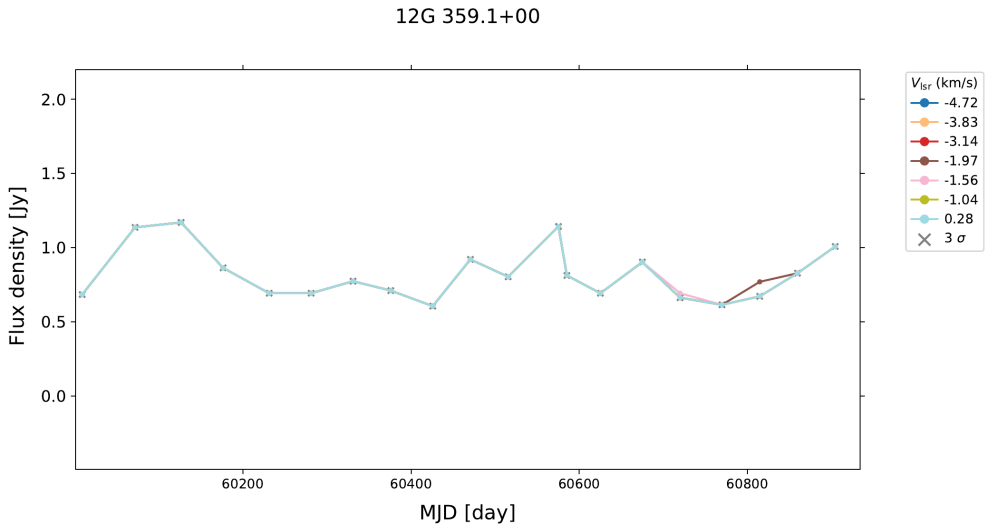


Spectrum

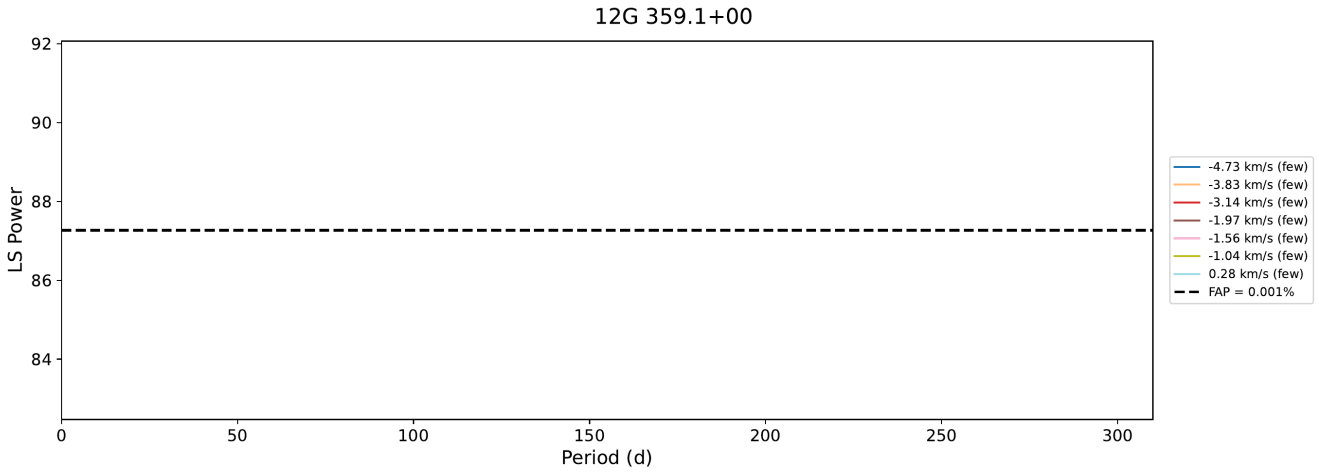


12G 359.1+00

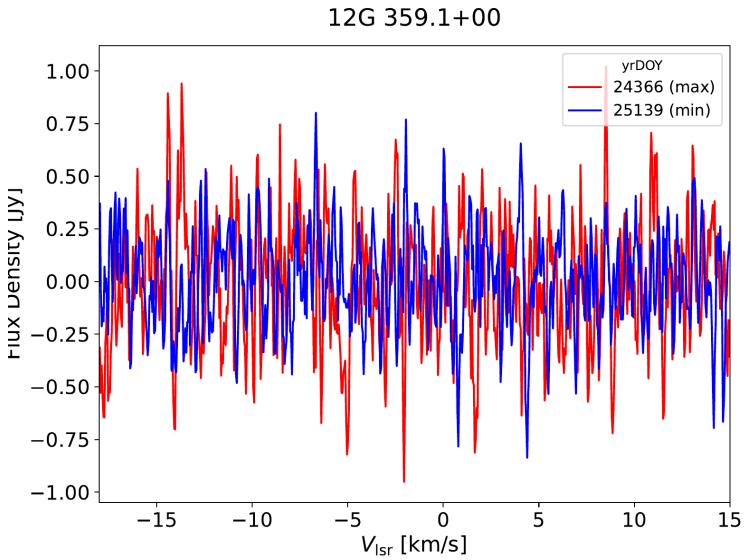
Light curve



Periodogram

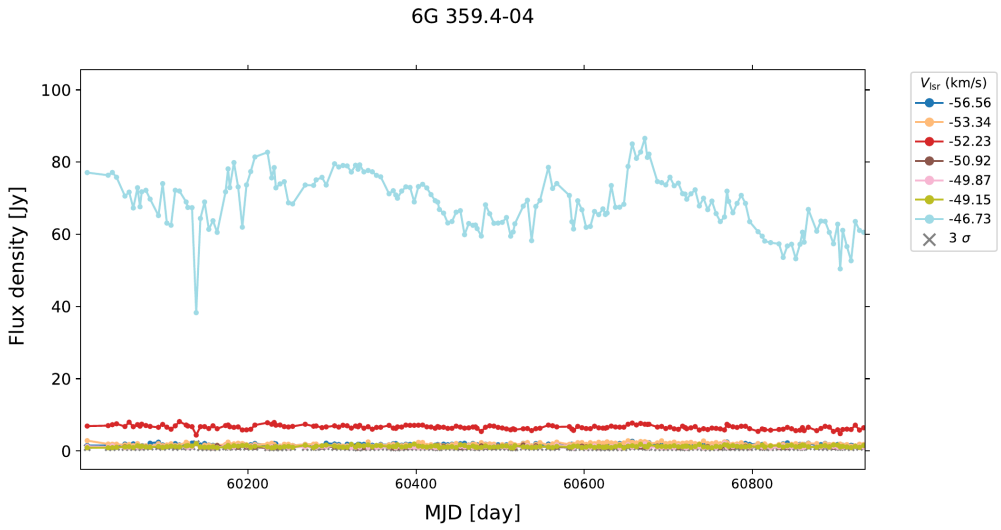


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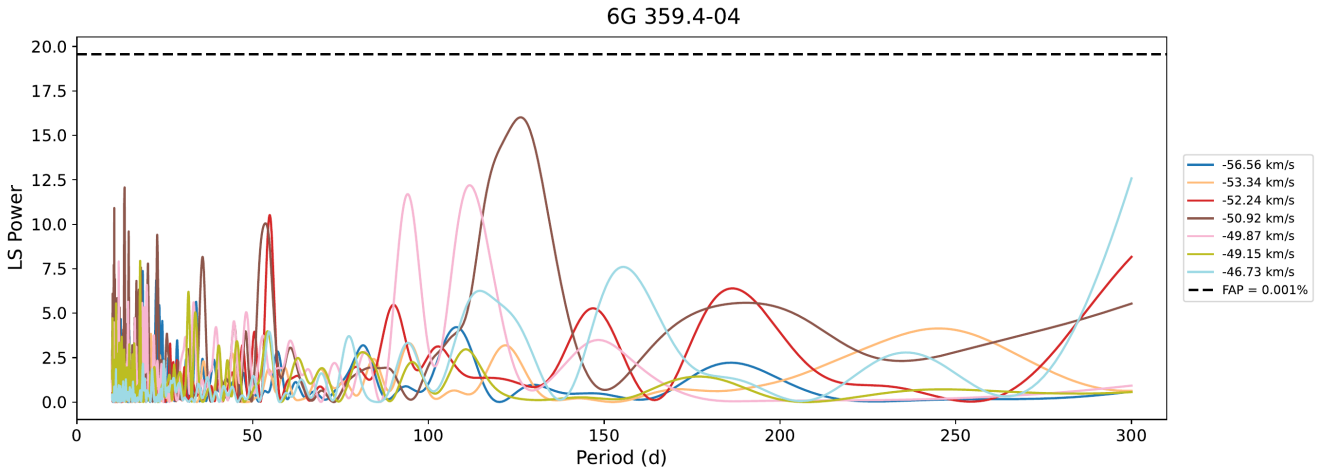


6G 359.4-04

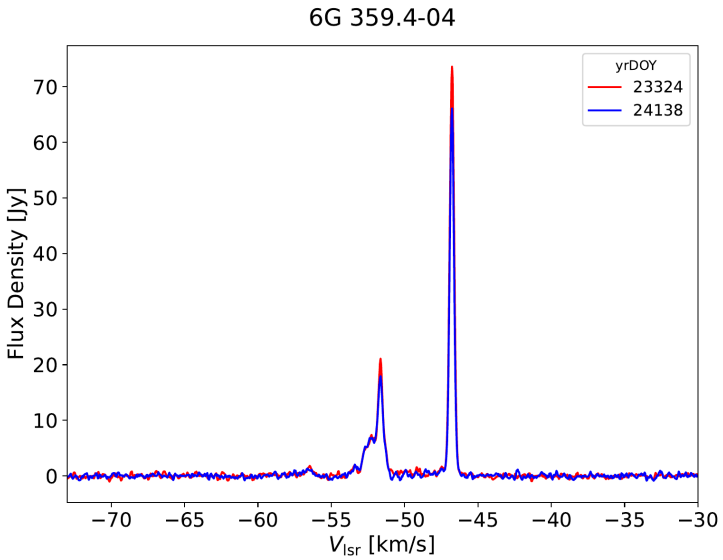
Light curve



Periodogram

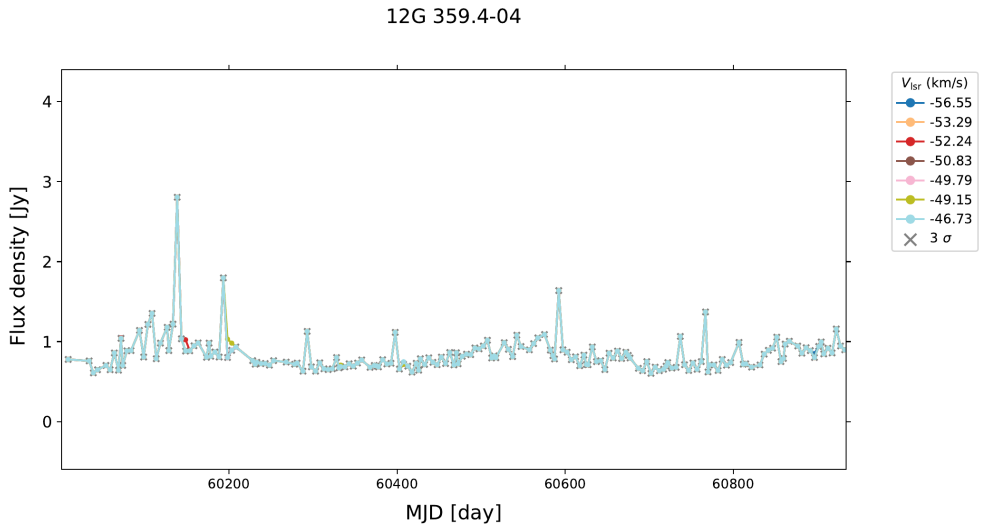


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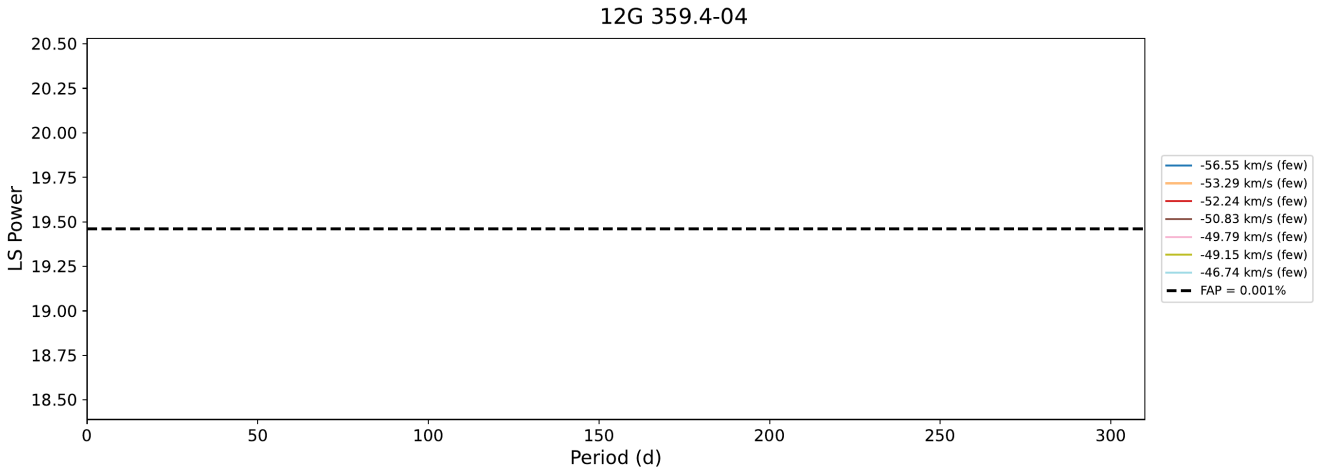


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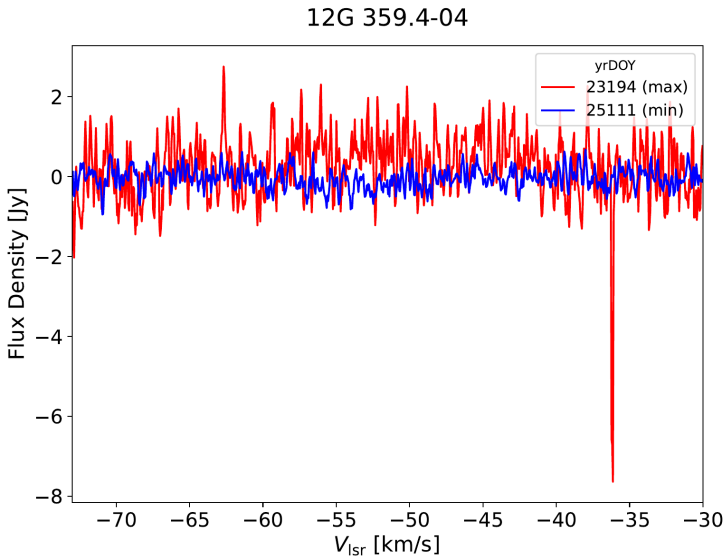
Light curve



Periodogram

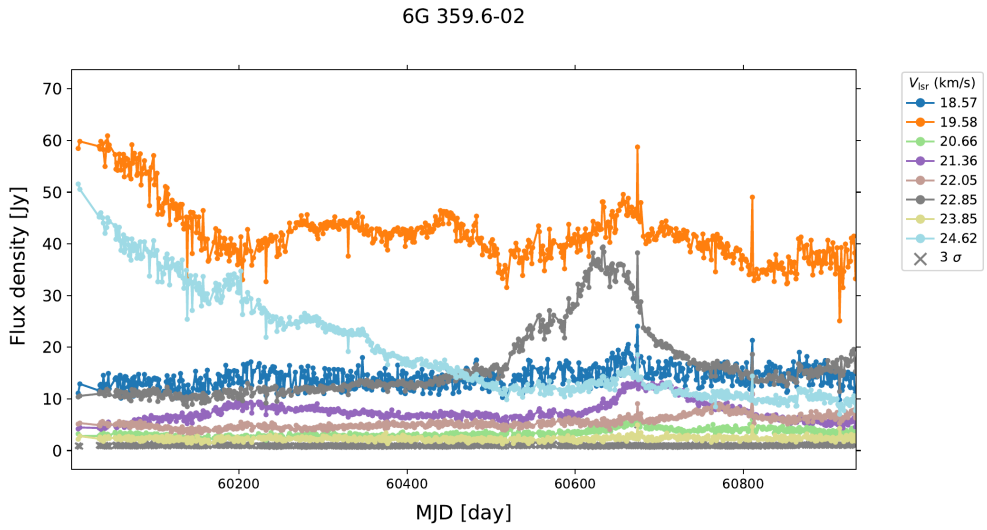


Spectrum

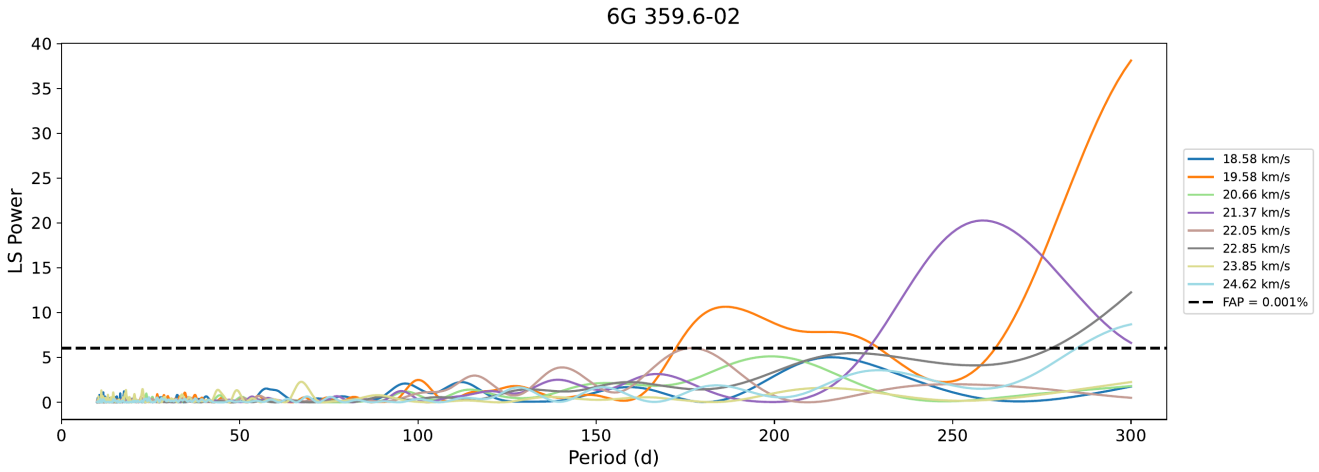


6G 359.6-02

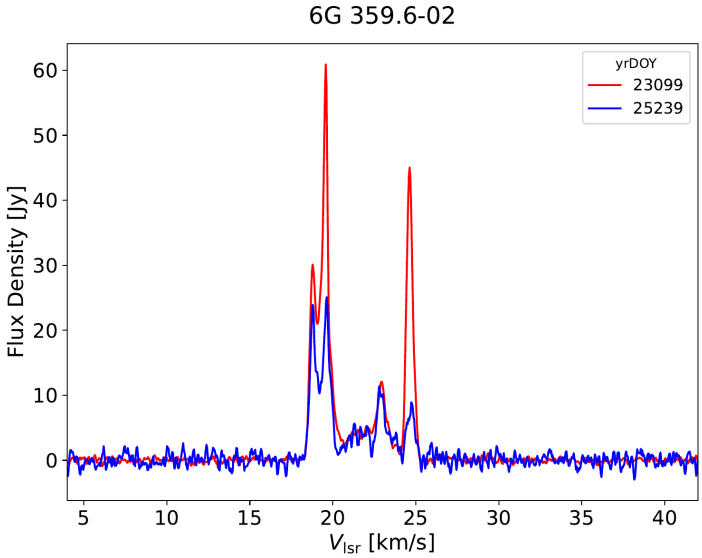
Light curve



Periodogram

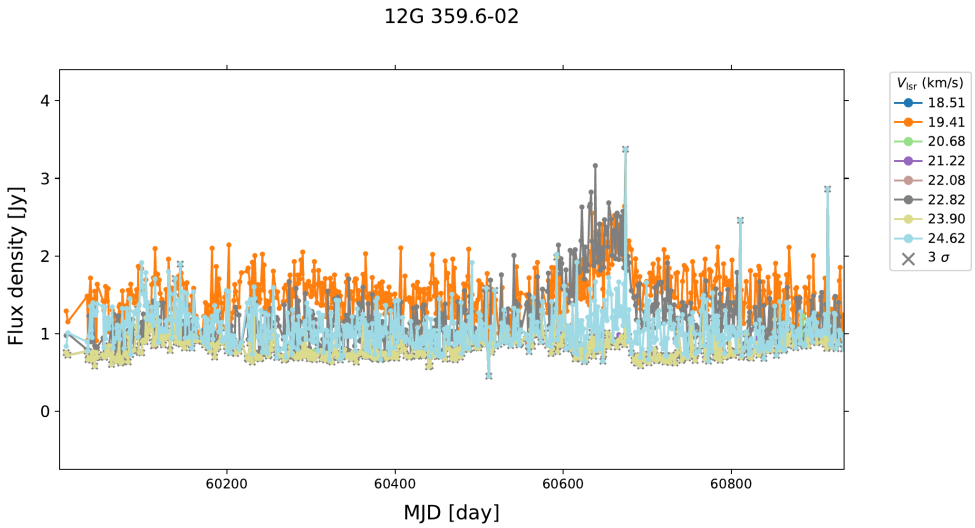


Spectrum

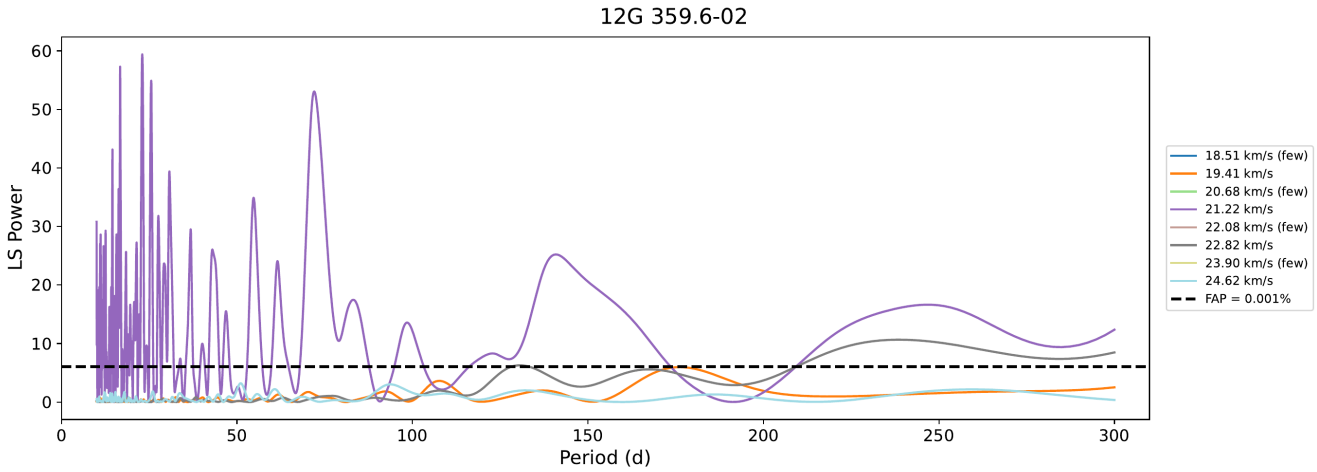


12G 359.6-02

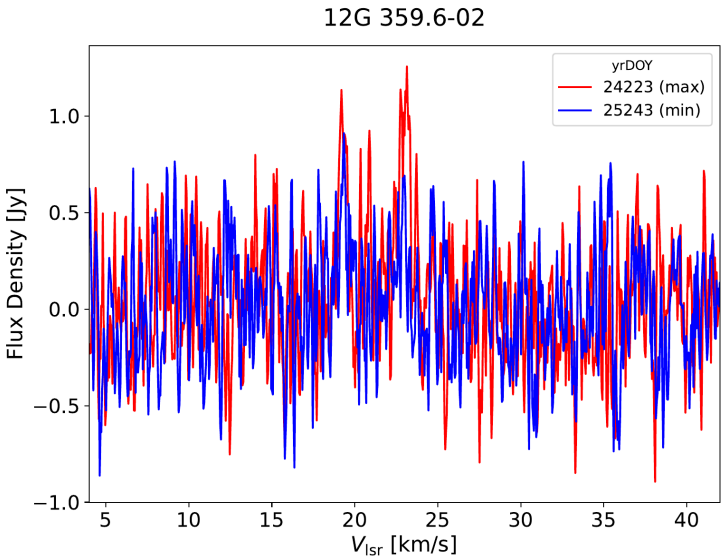
Light curve



Periodogram

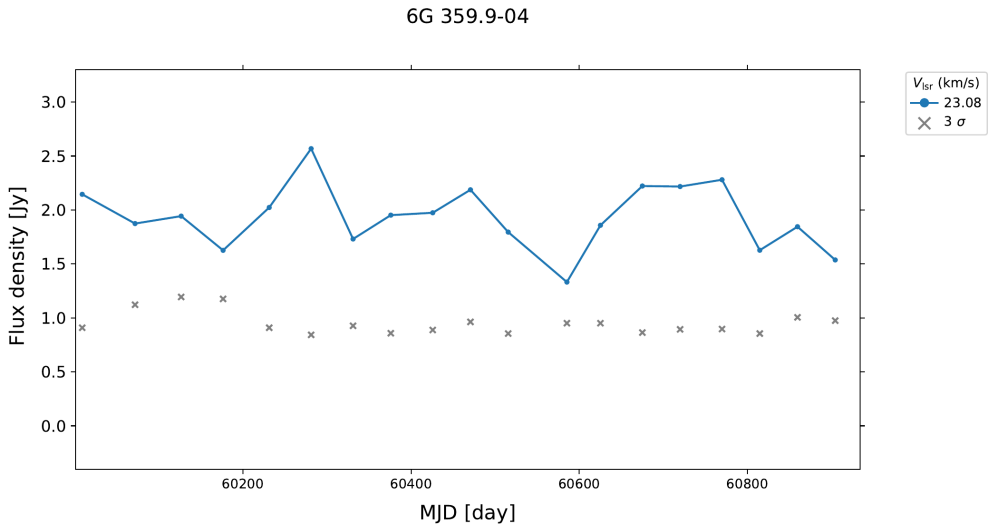


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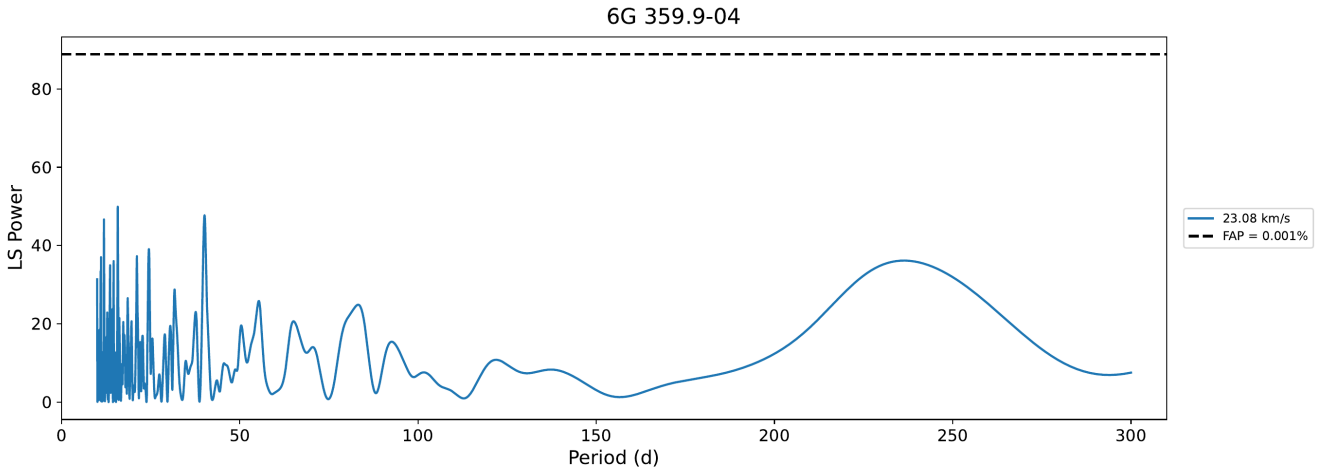


6G 359.9-04

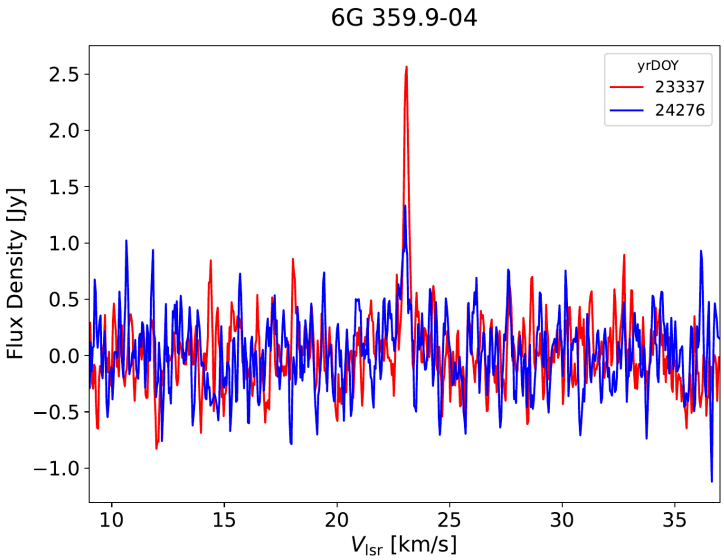
Light curve



Periodogram

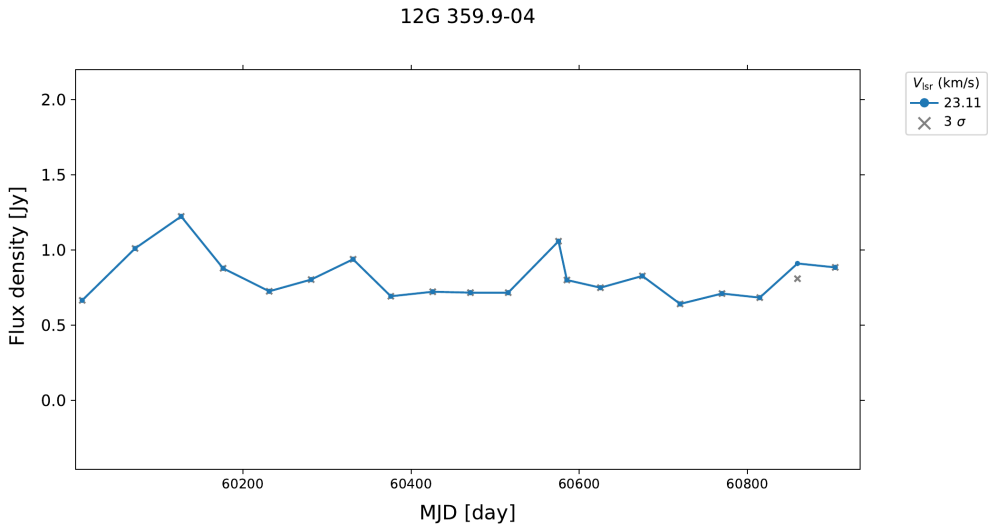


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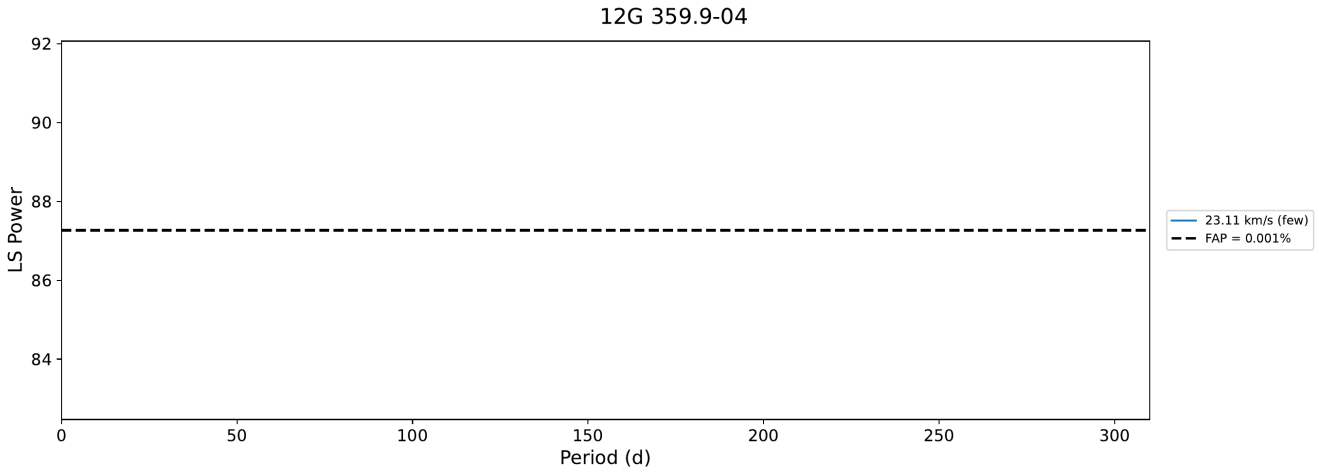


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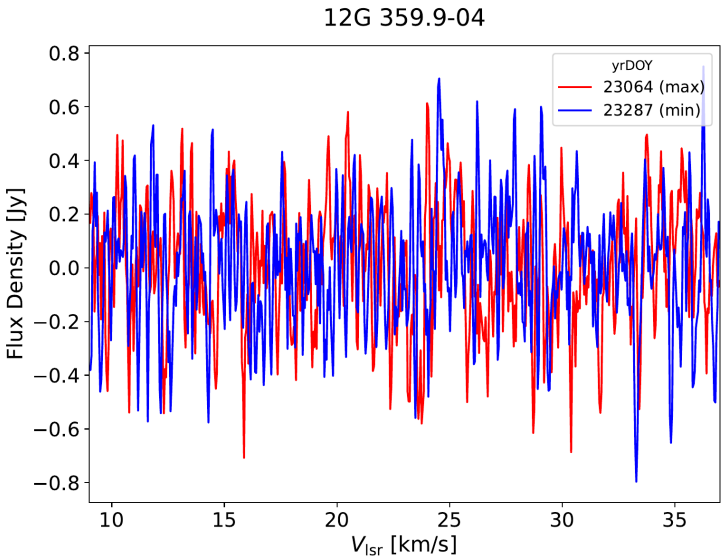
Light curve



Periodogram

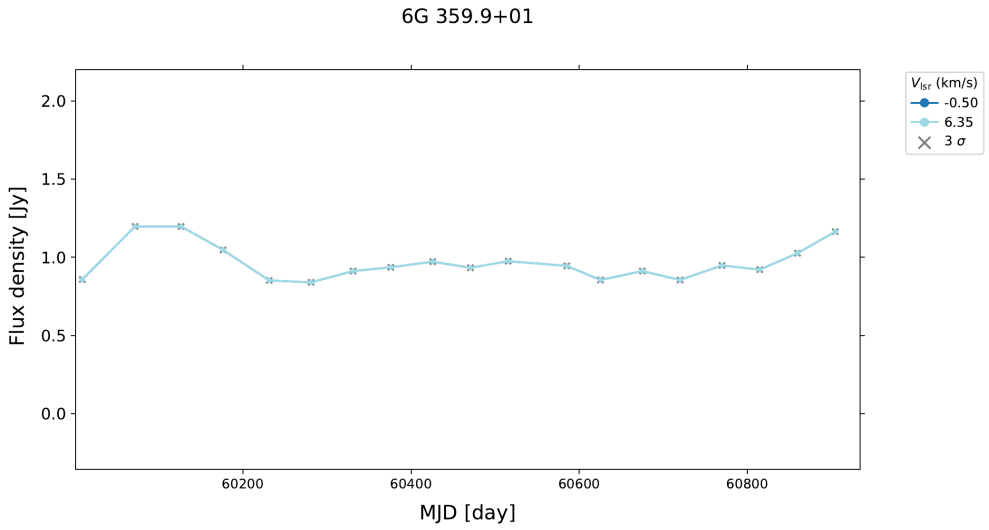


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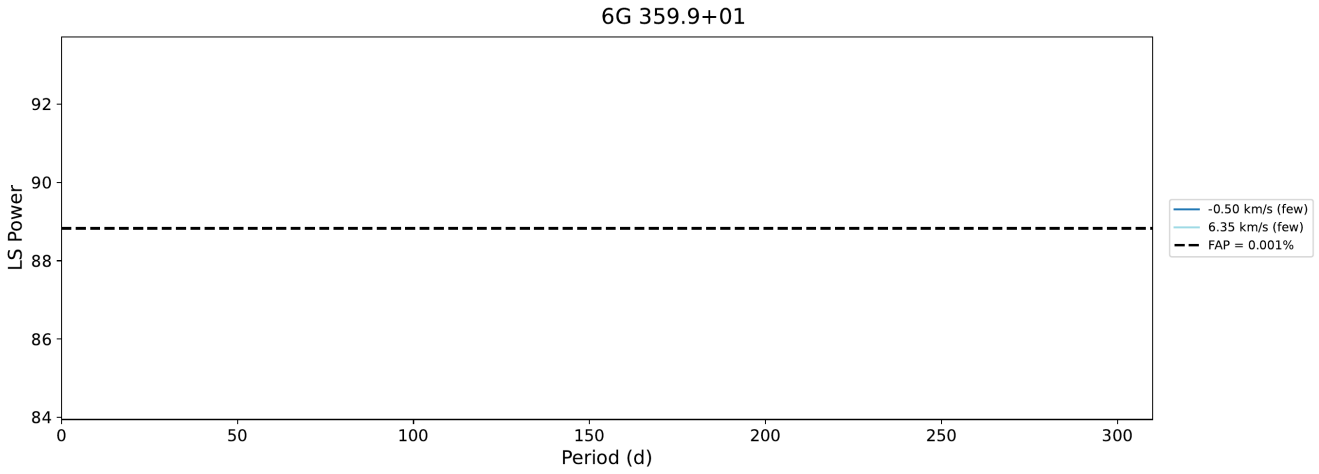


6G 359.9+01

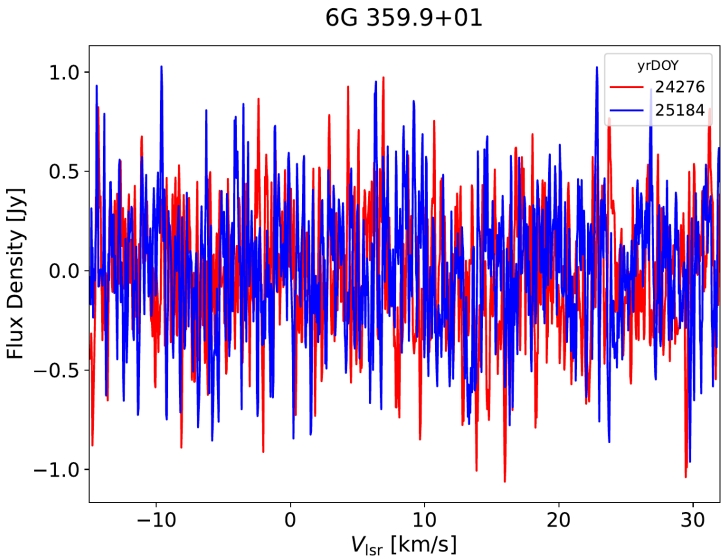
Light curve



Periodogram

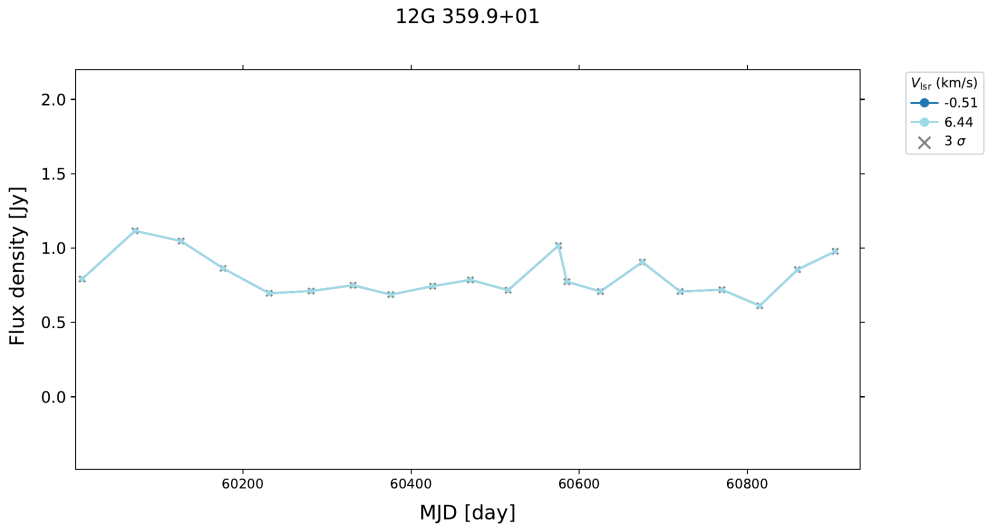


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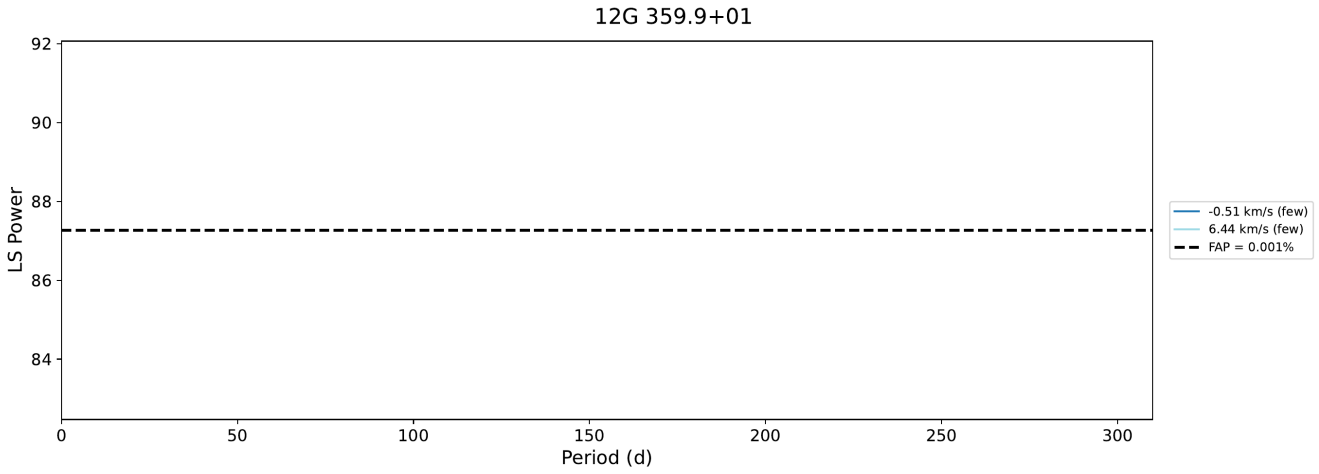


12G 359.9+01

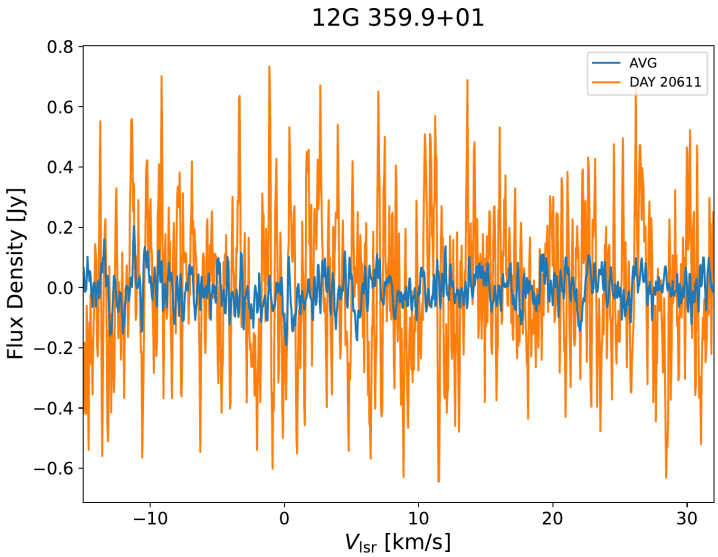
Light curve



Periodogram

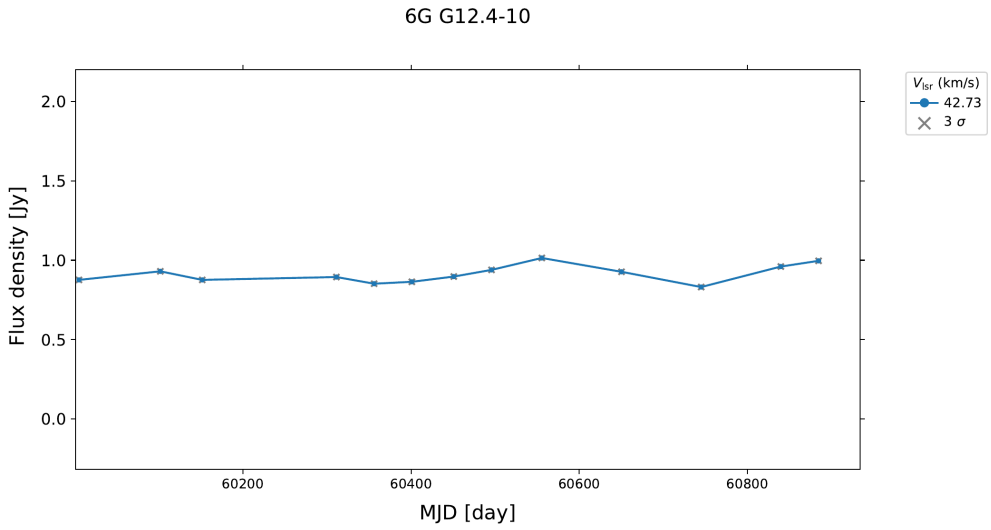


Spectrum

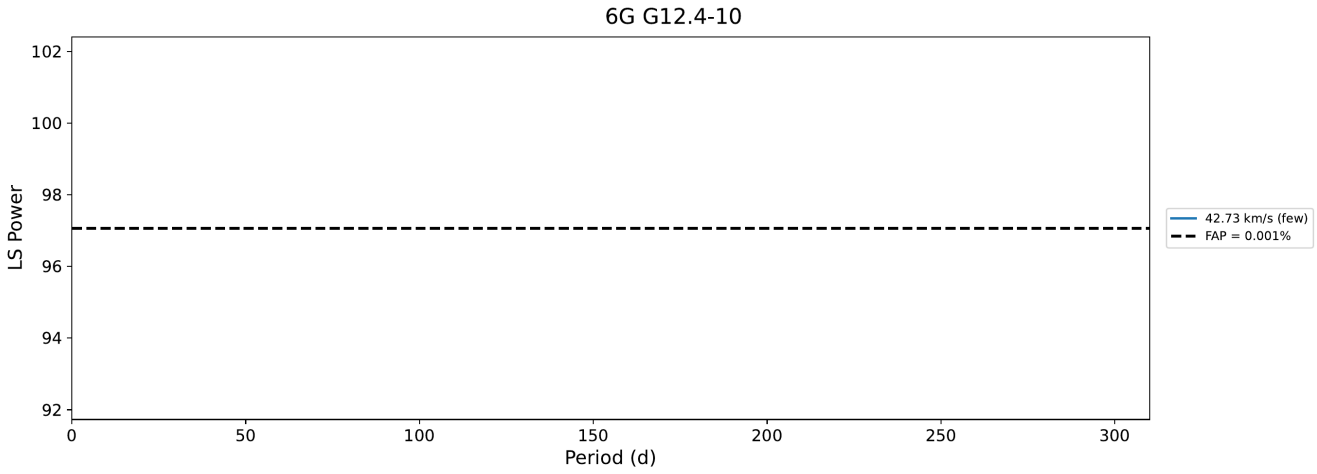


6G G12.4-10

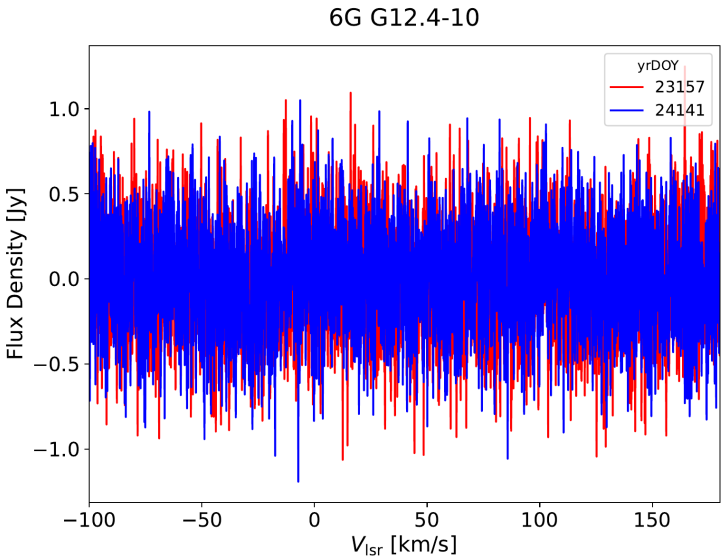
Light curve



Periodogram

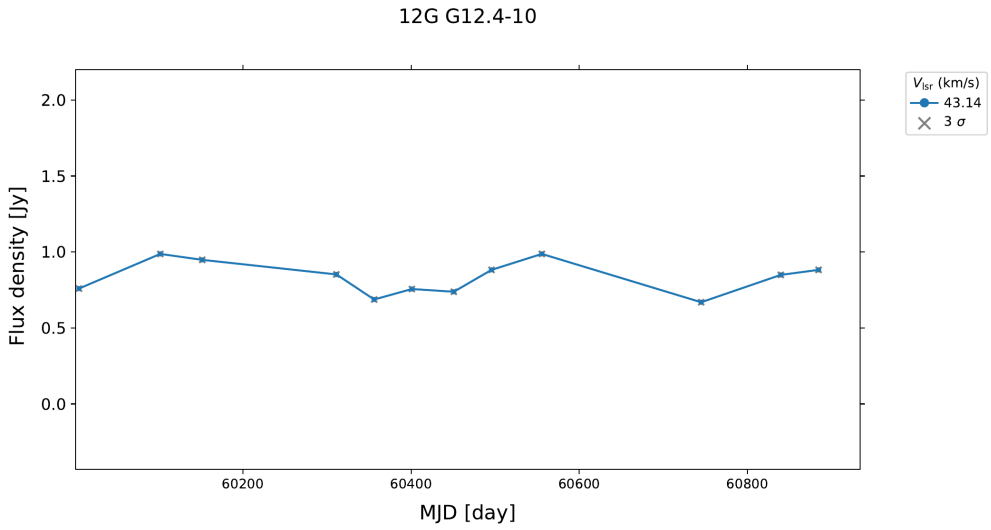


Spectrum

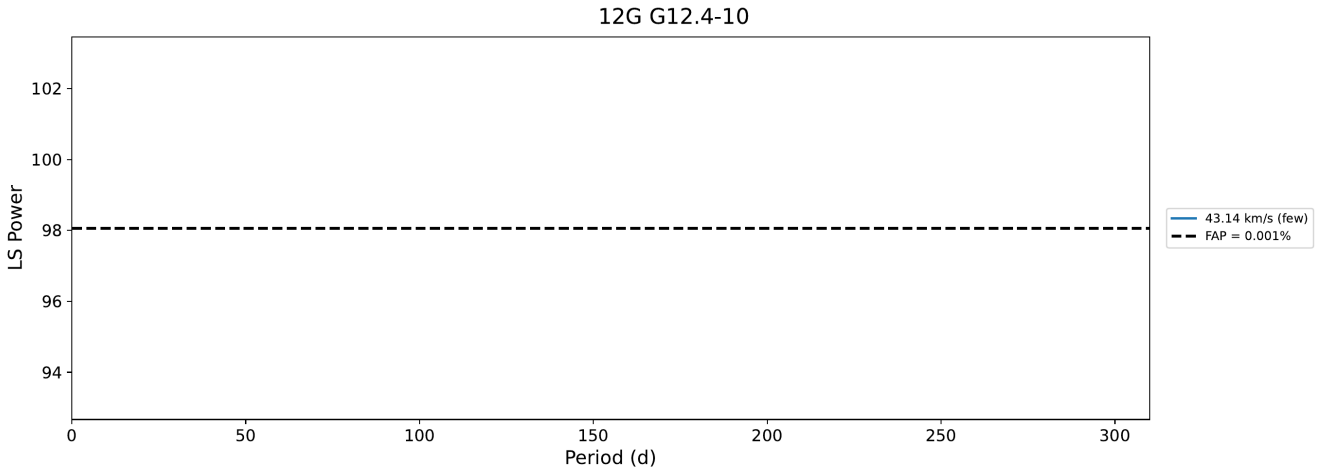


12G G12.4-10

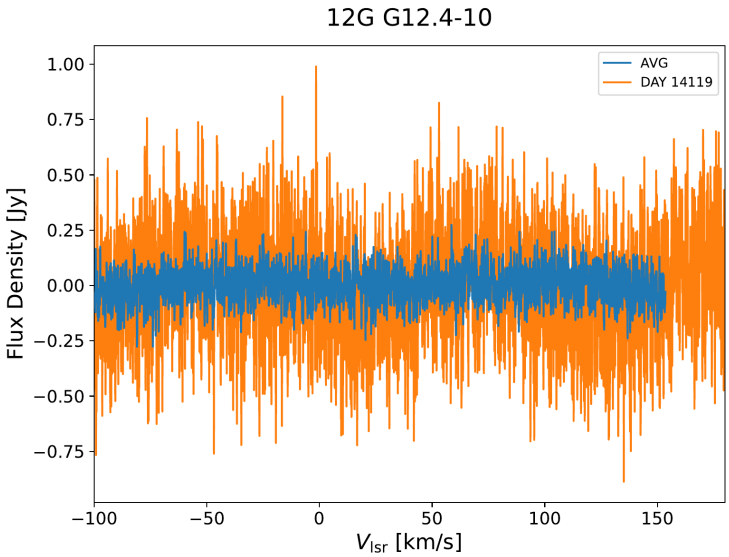
Light curve



Periodogram

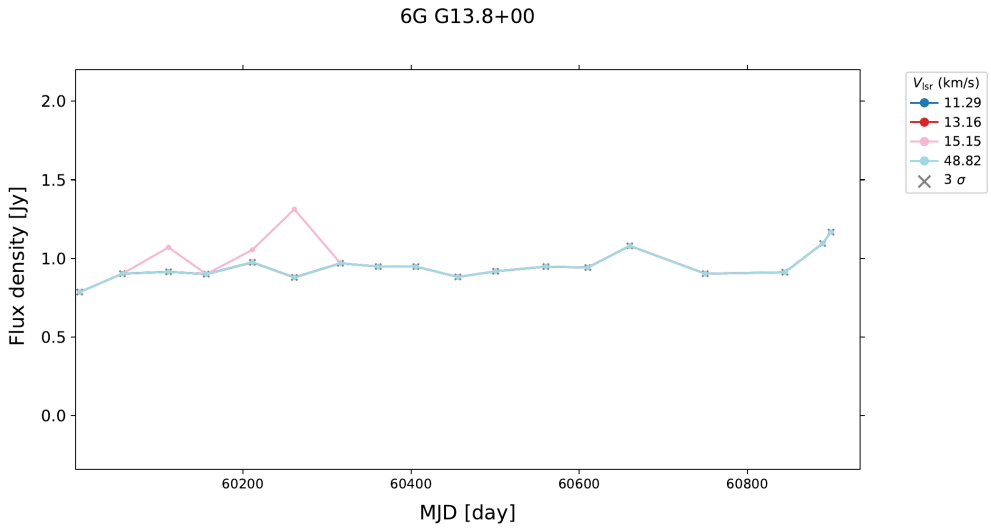


Spectrum

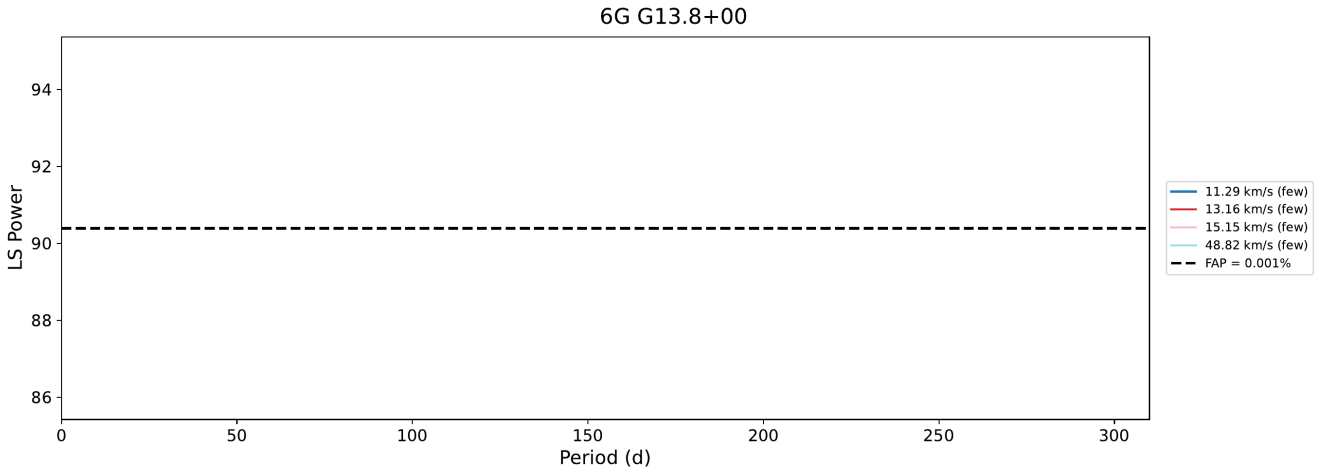


6G G13.8+00

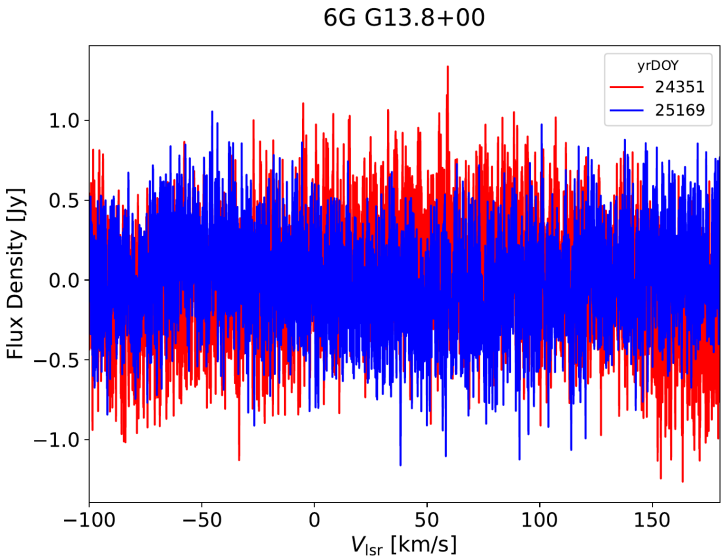
Light curve



Periodogram

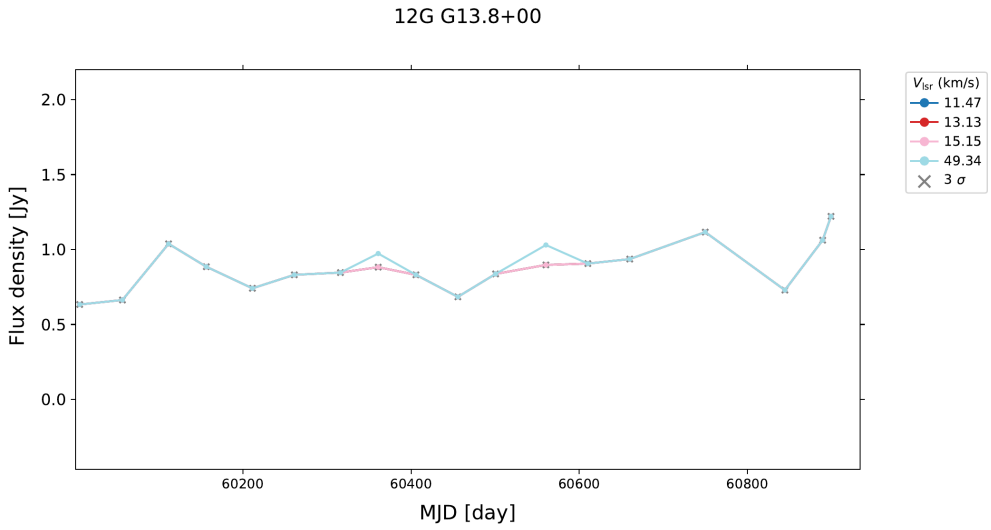


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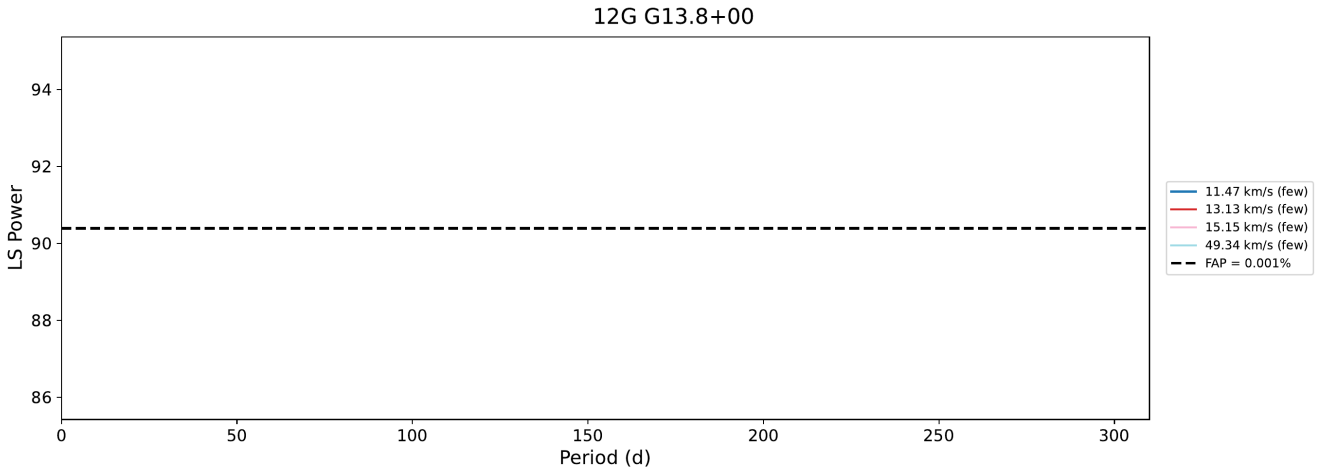


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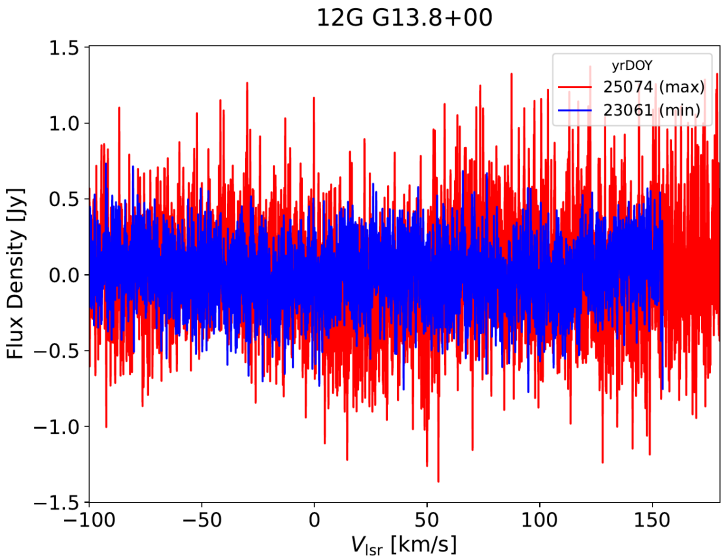
Light curve



Periodogram

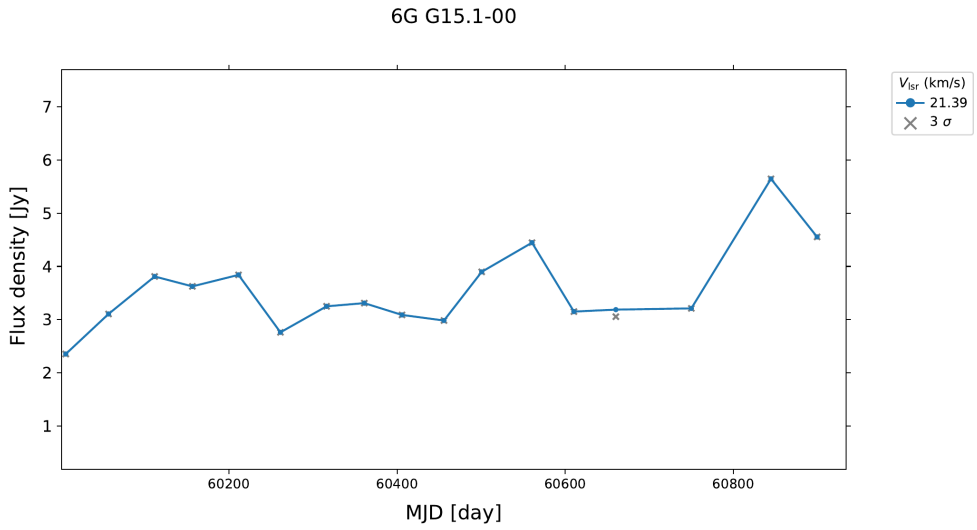


Spectrum

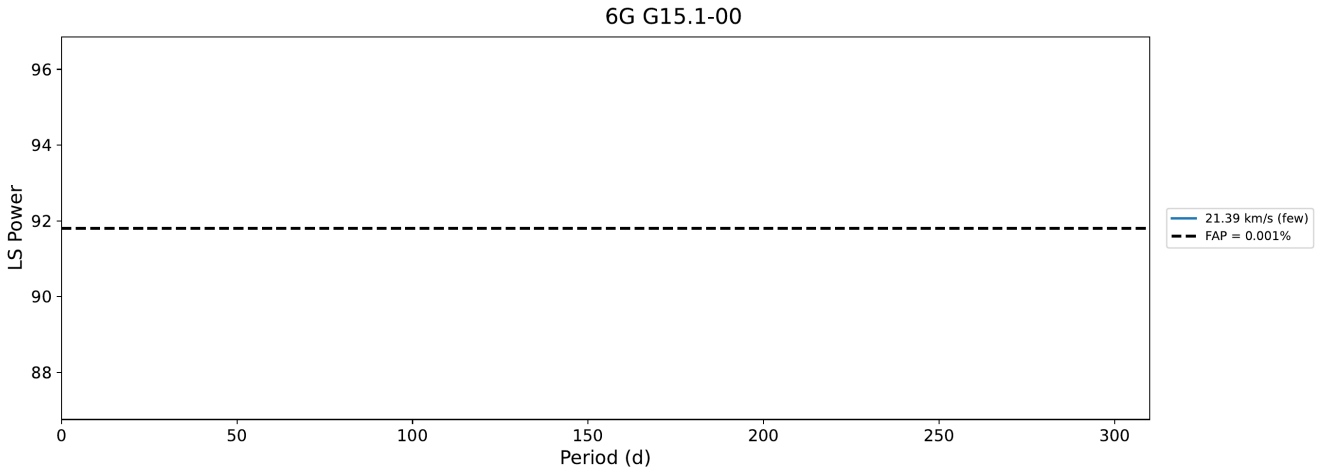


6G G15.1-00

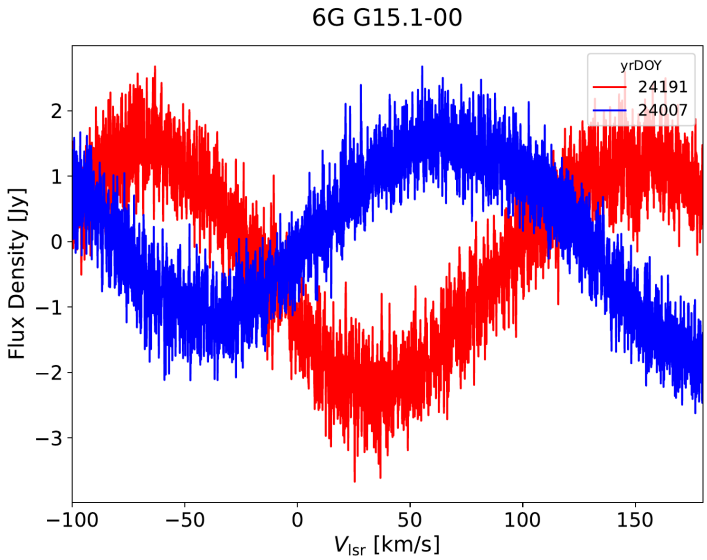
Light curve



Periodogram

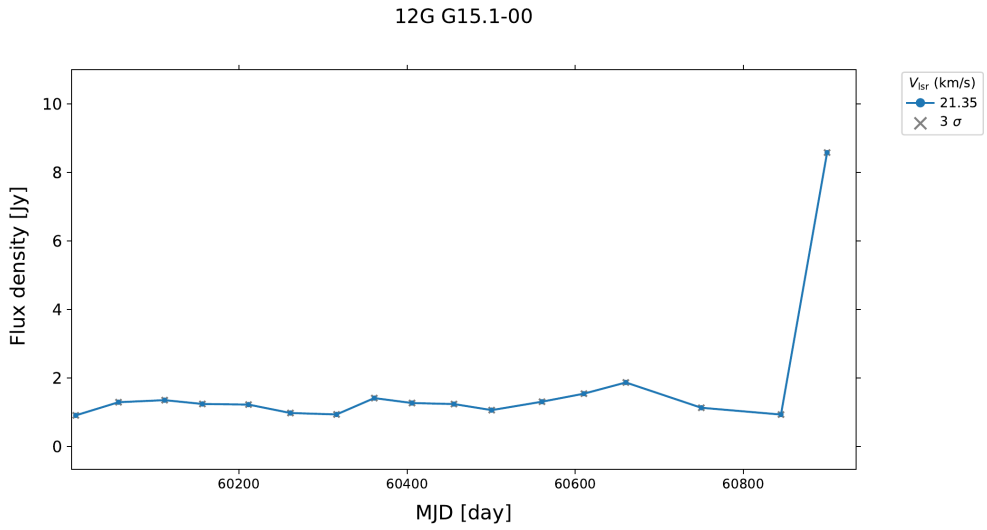


Spectrum

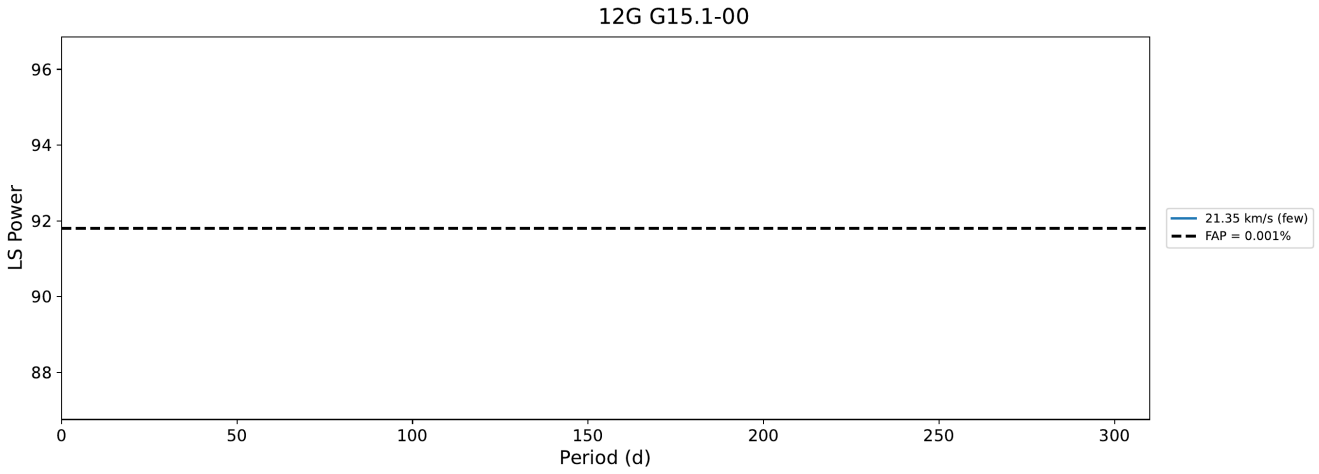


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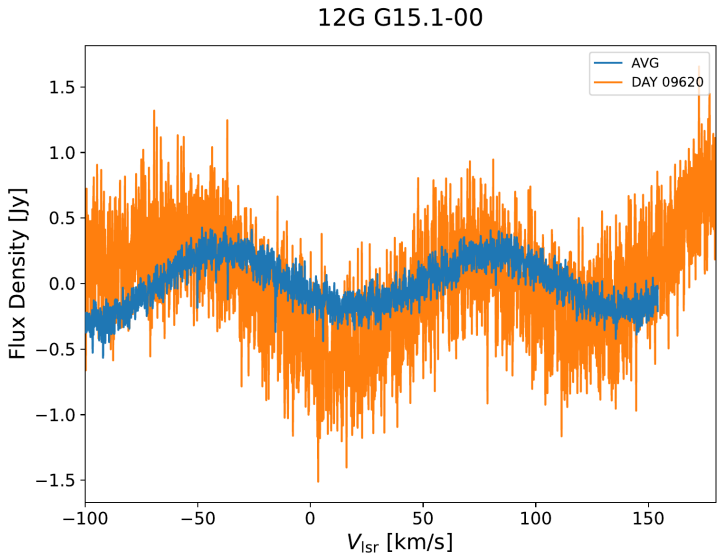
Light curve



Periodogram

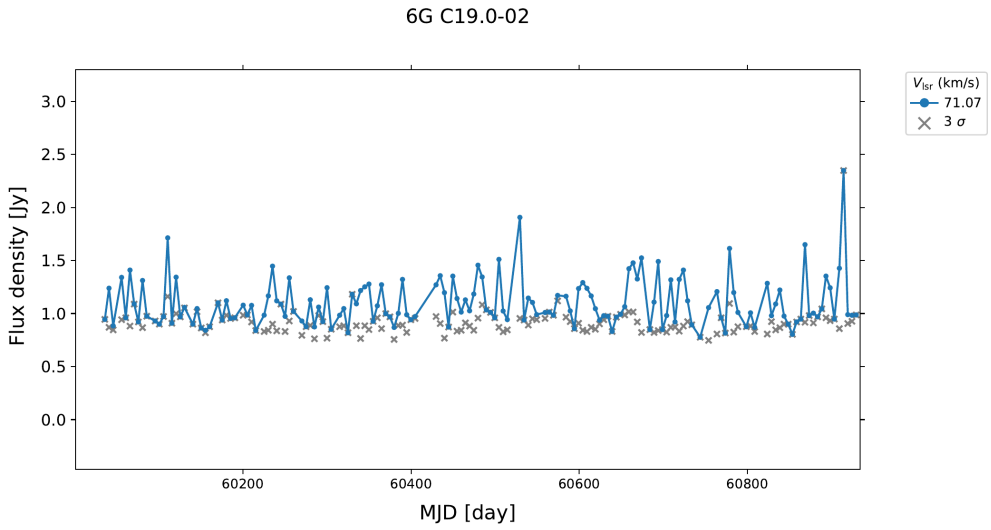


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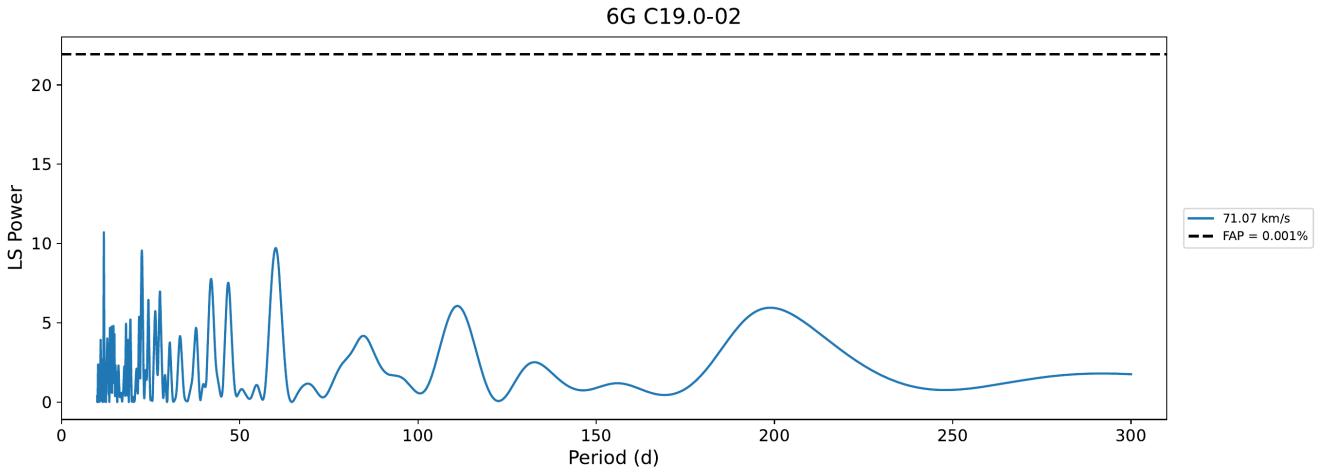


6G C19.0-02

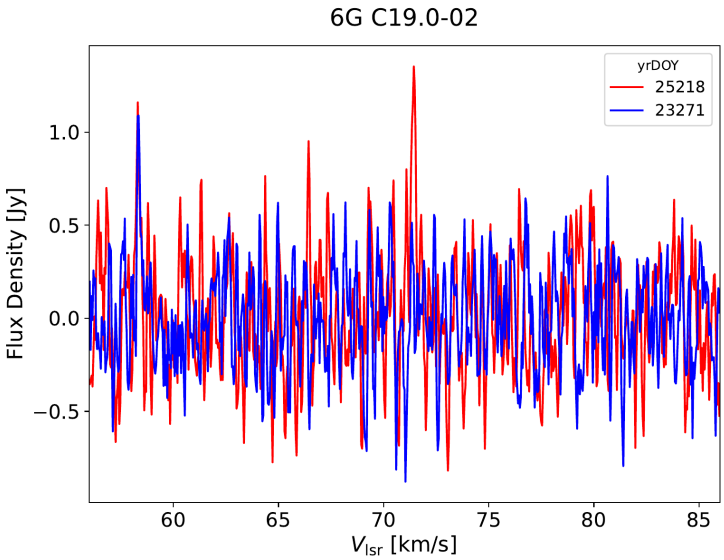
Light curve



Periodogram

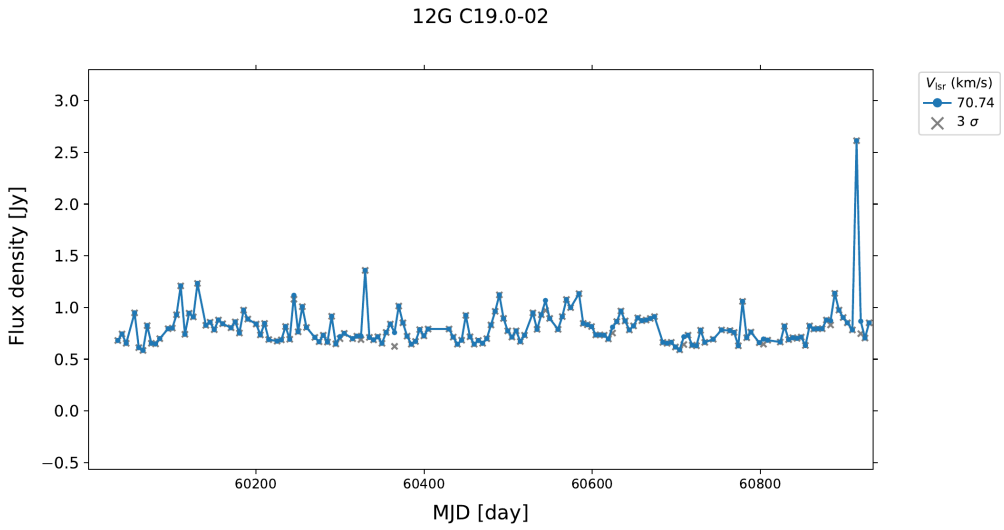


Spectrum

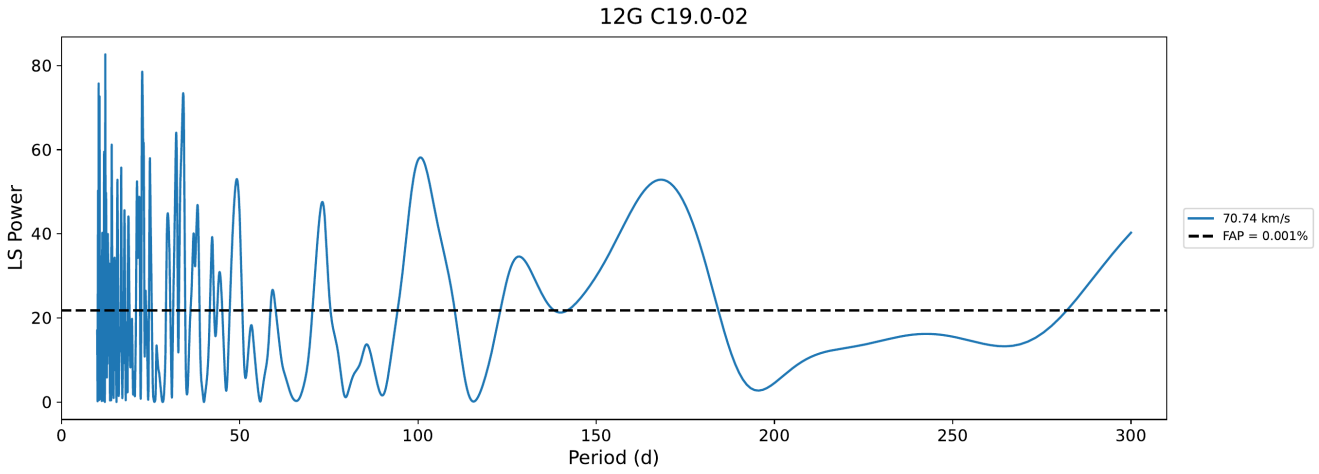


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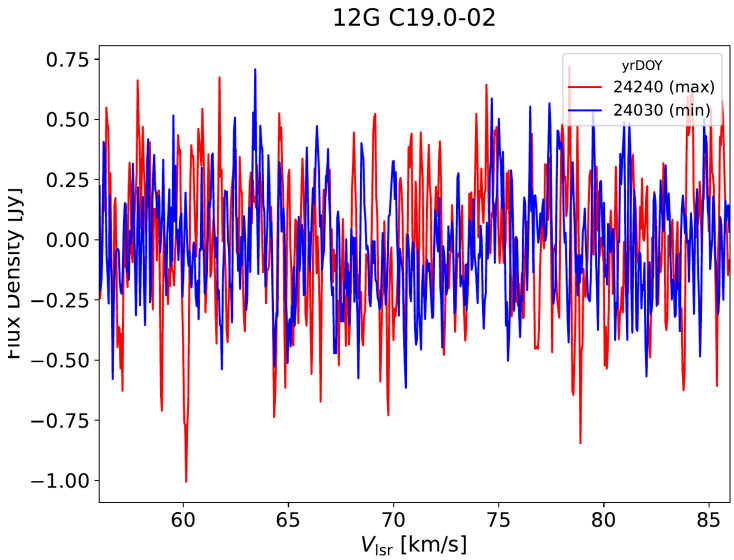
Light curve



Periodogram

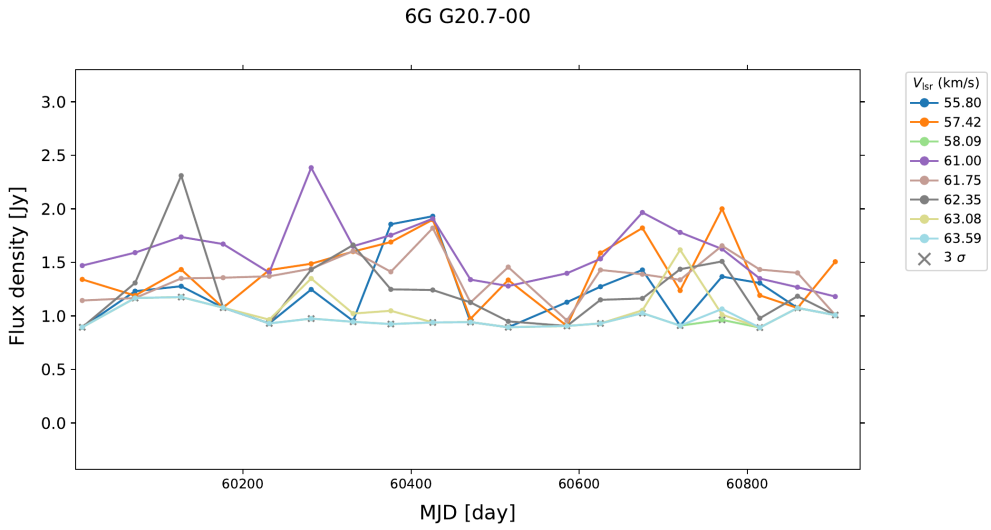


Spectrum

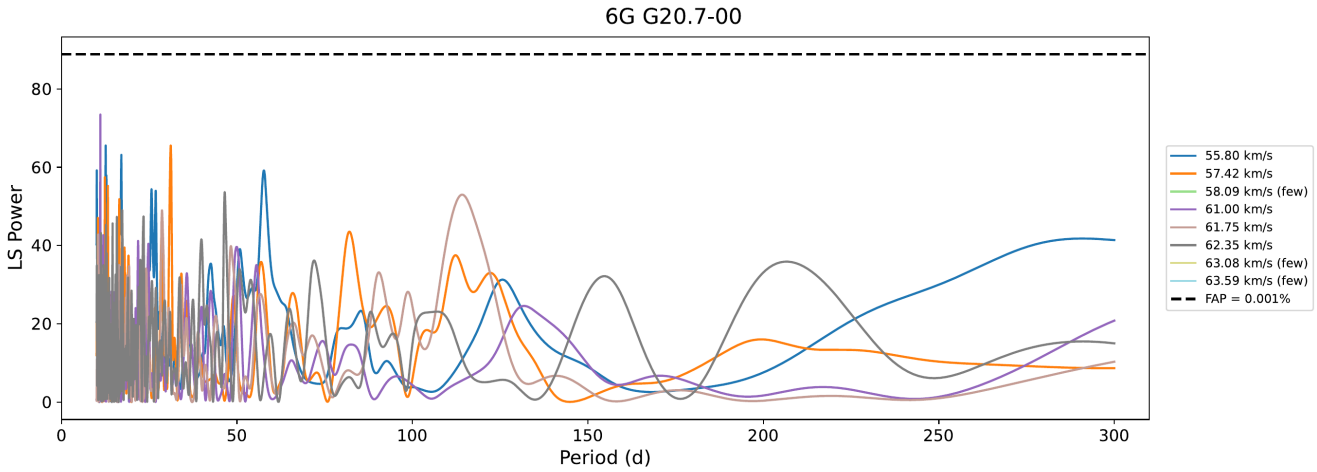


6G G20.7-00

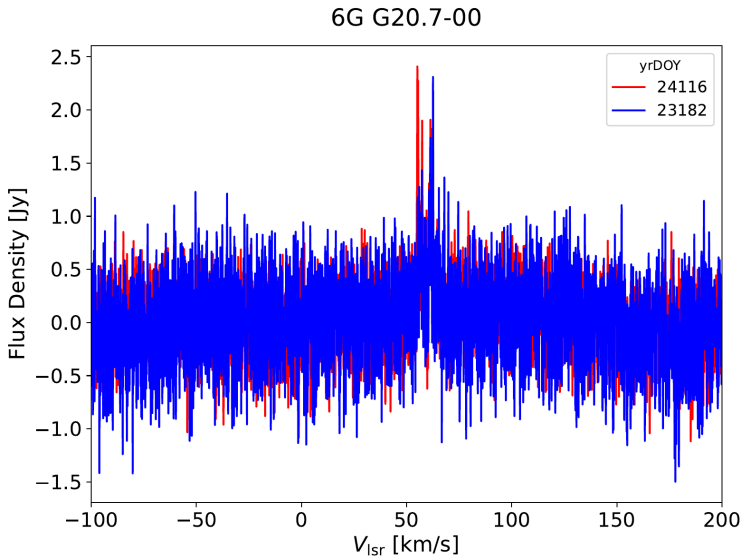
Light curve



Periodogram

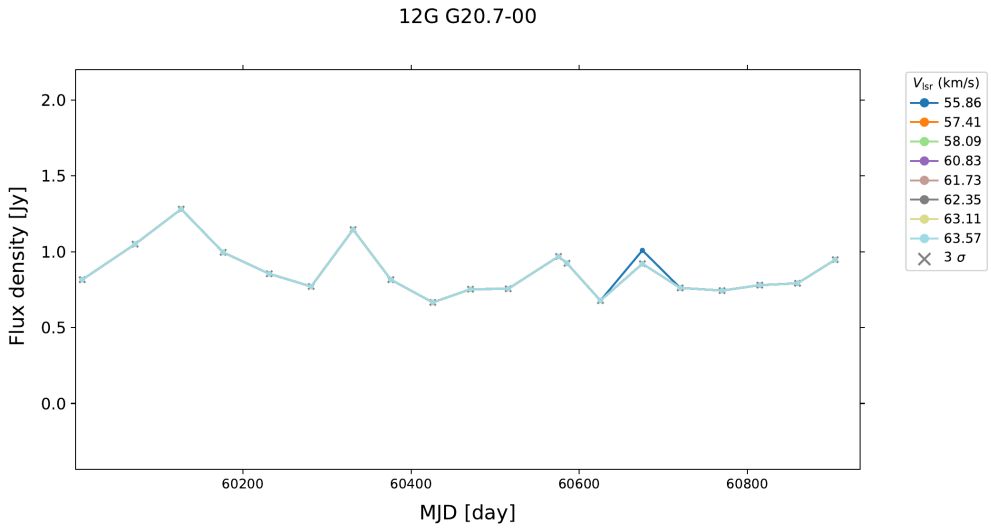


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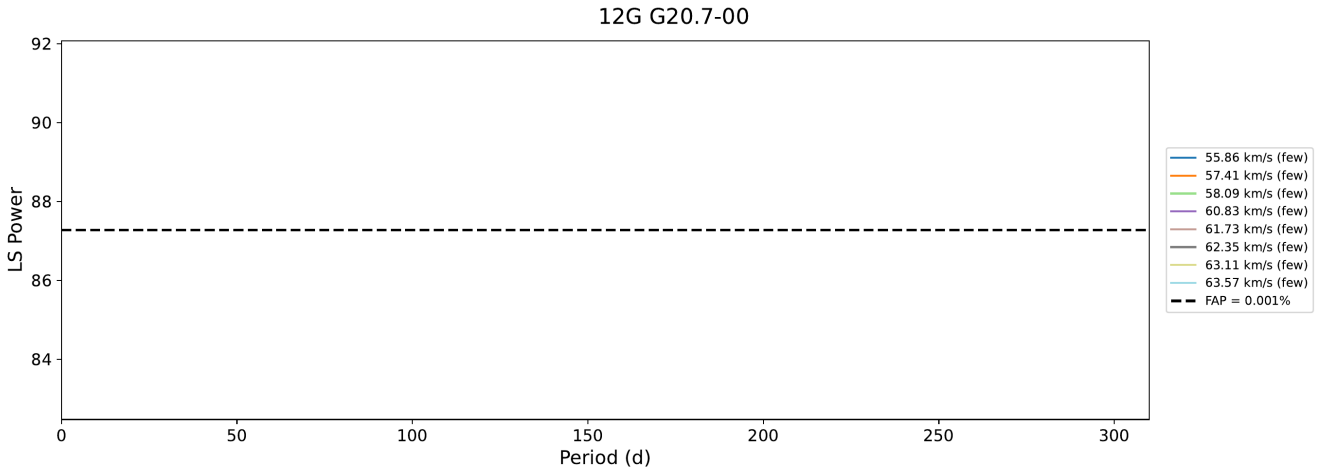


12G G20.7-00

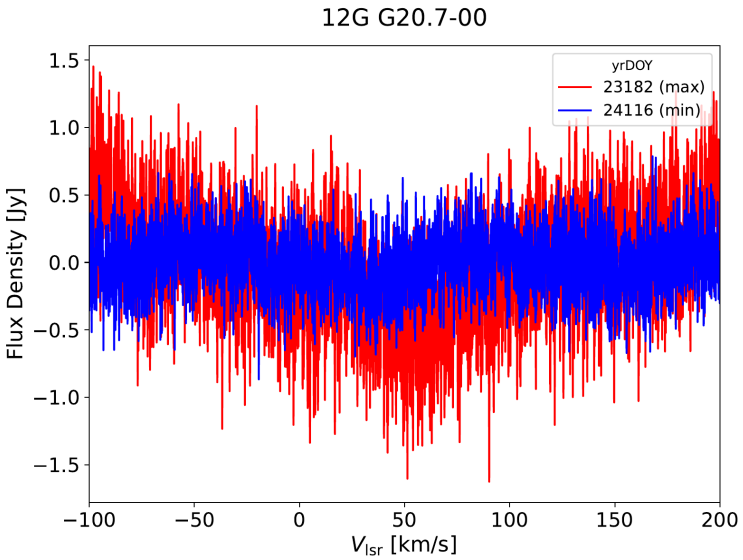
Light curve



Periodogram

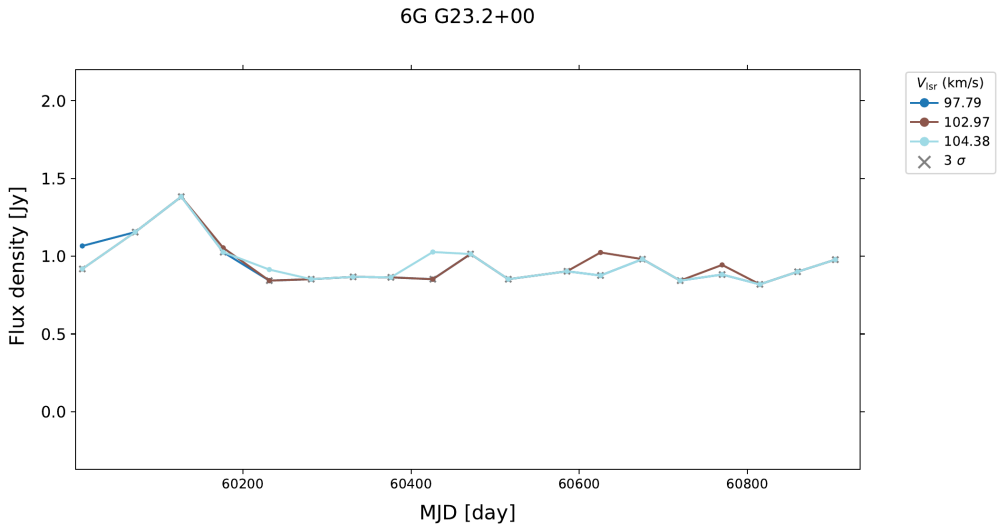


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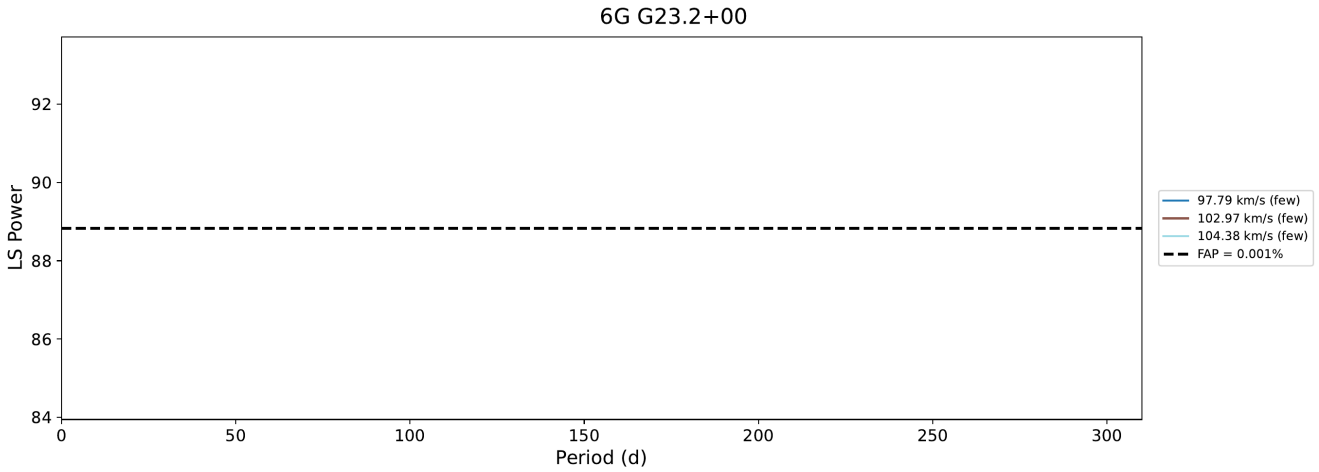


6G G23.2+00

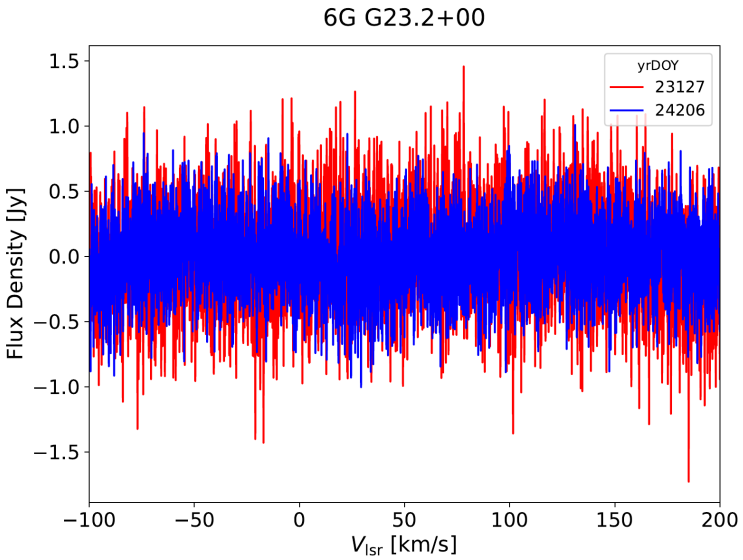
Light curve



Periodogram

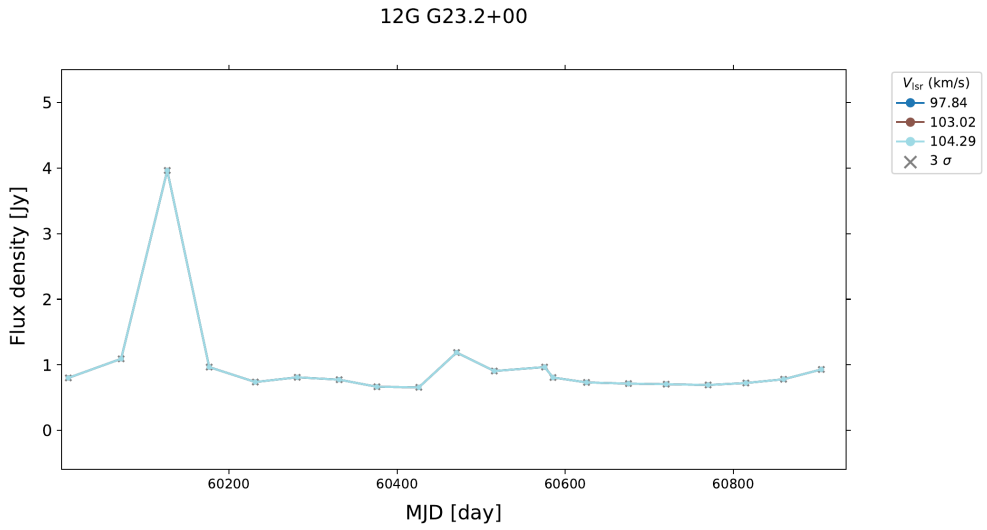


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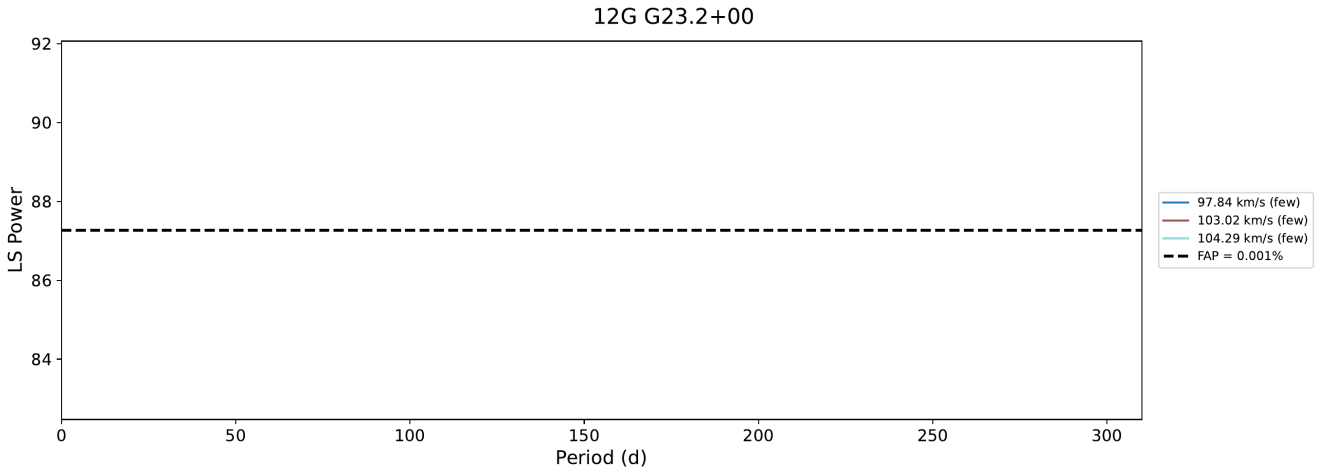


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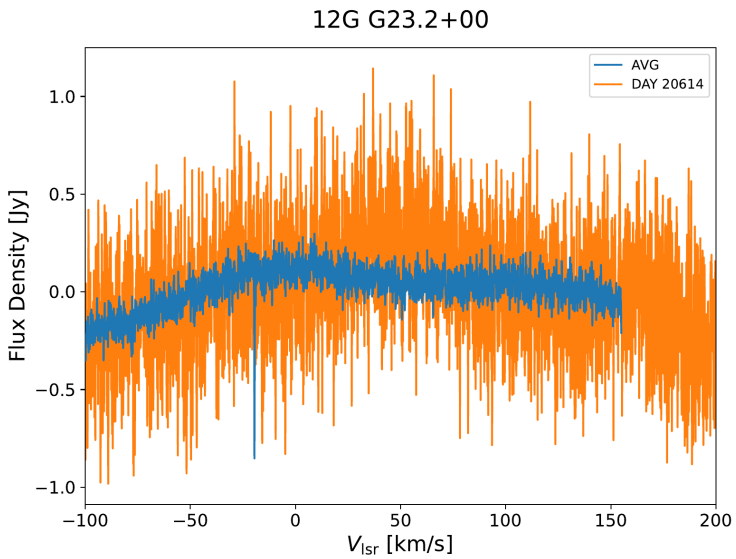
Light curve



Periodogram

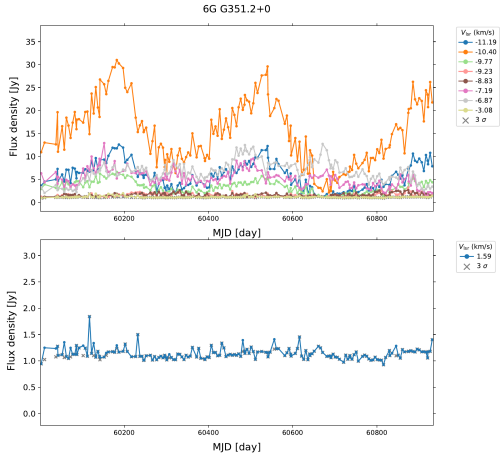


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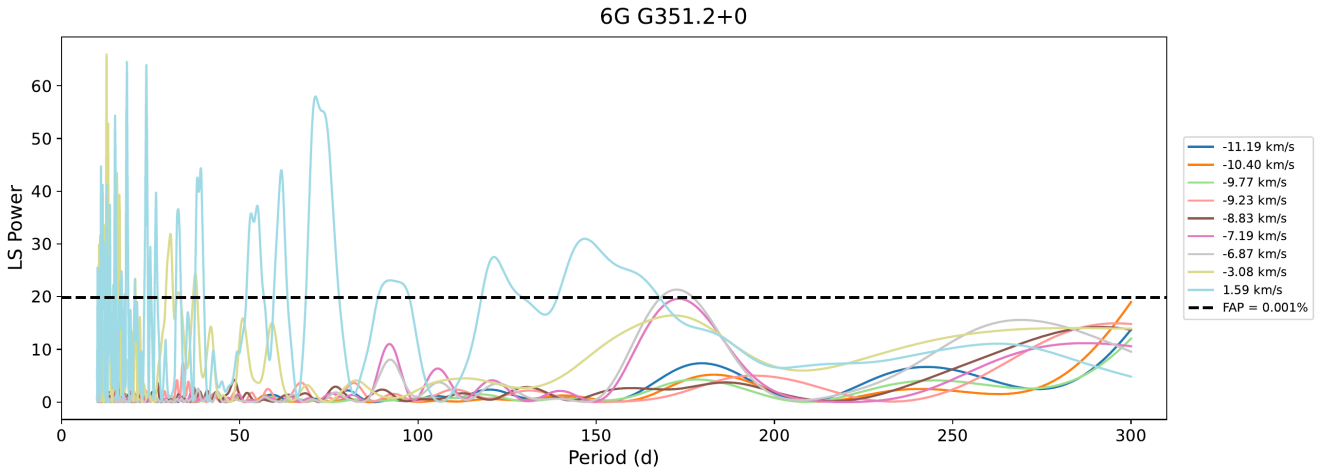


6G G351.2+0

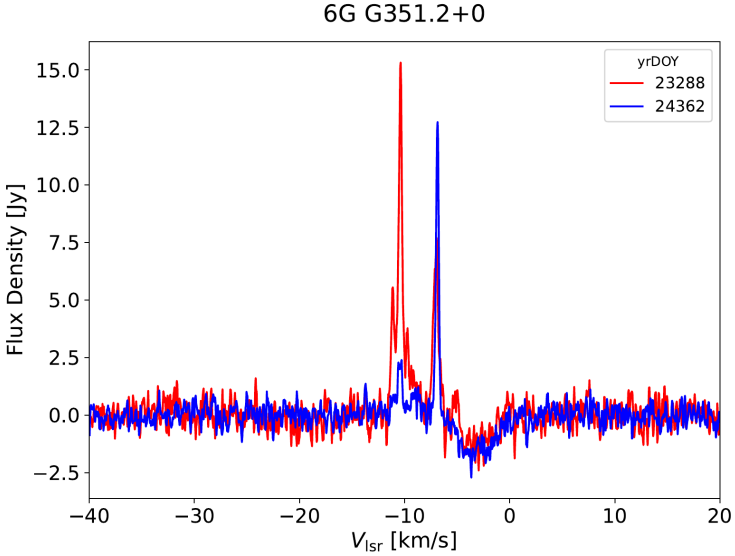
Light curve



Periodogram

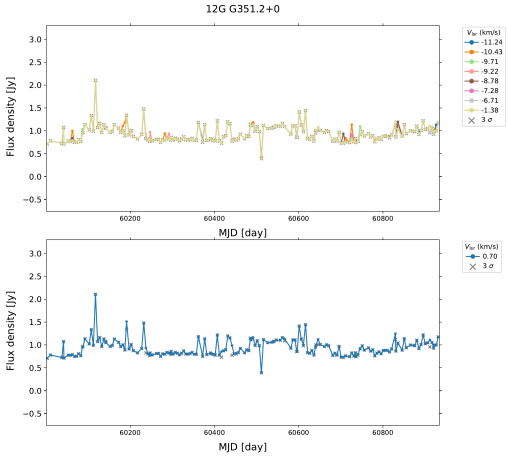


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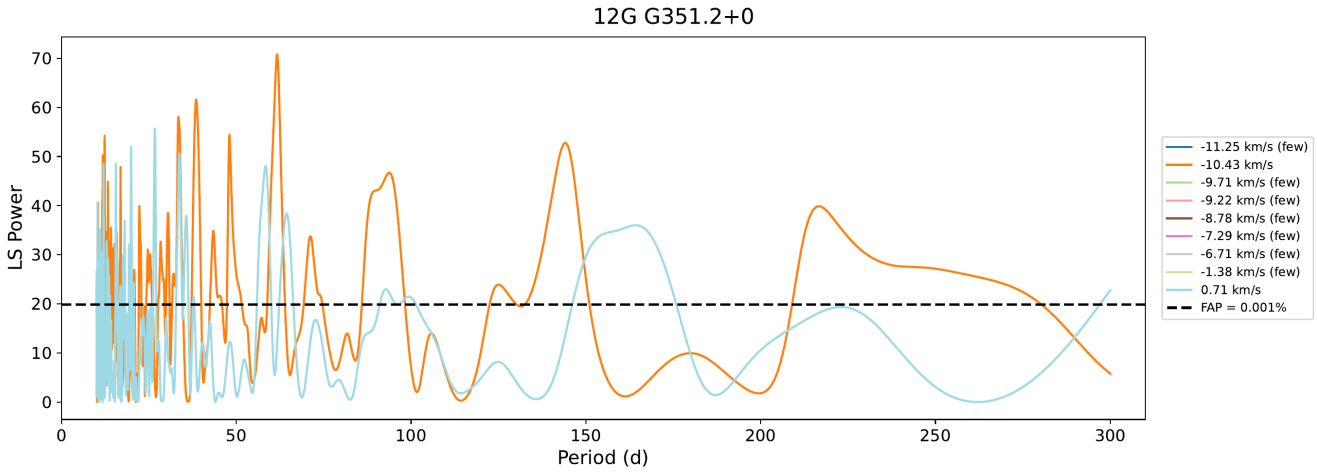


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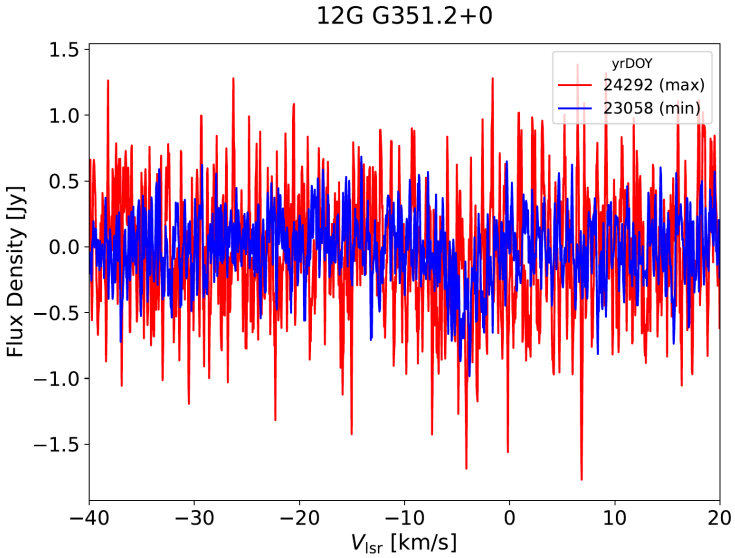
Light curve



Periodogram

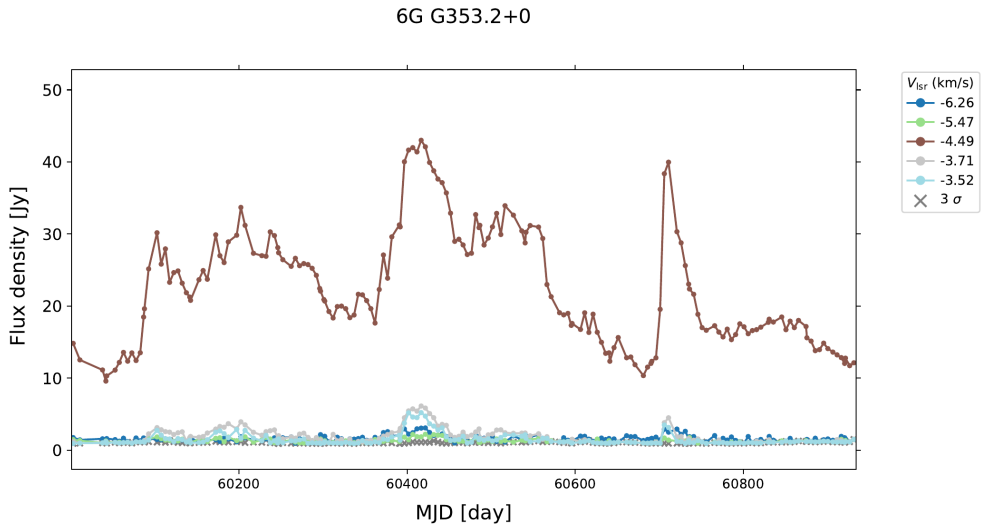


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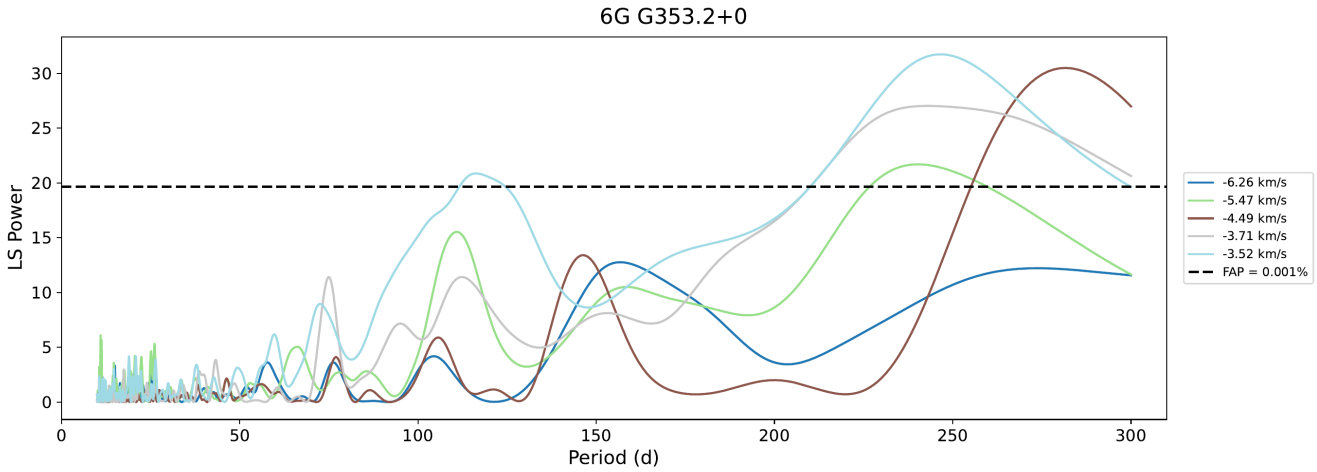


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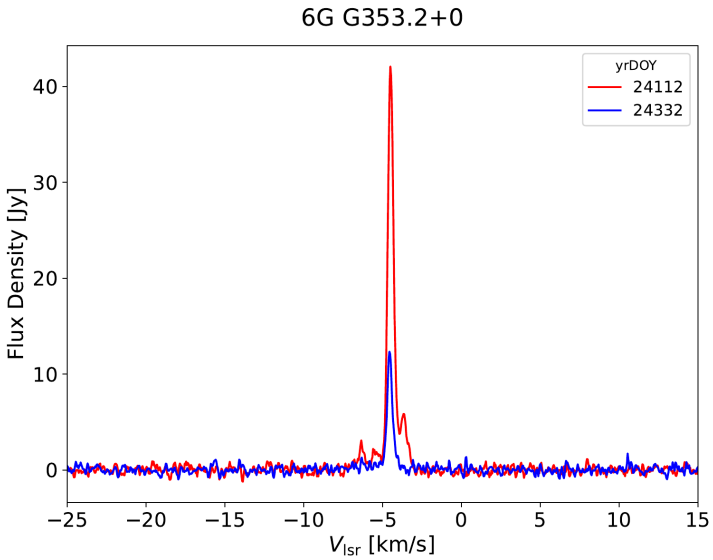
Light curve



Periodogram

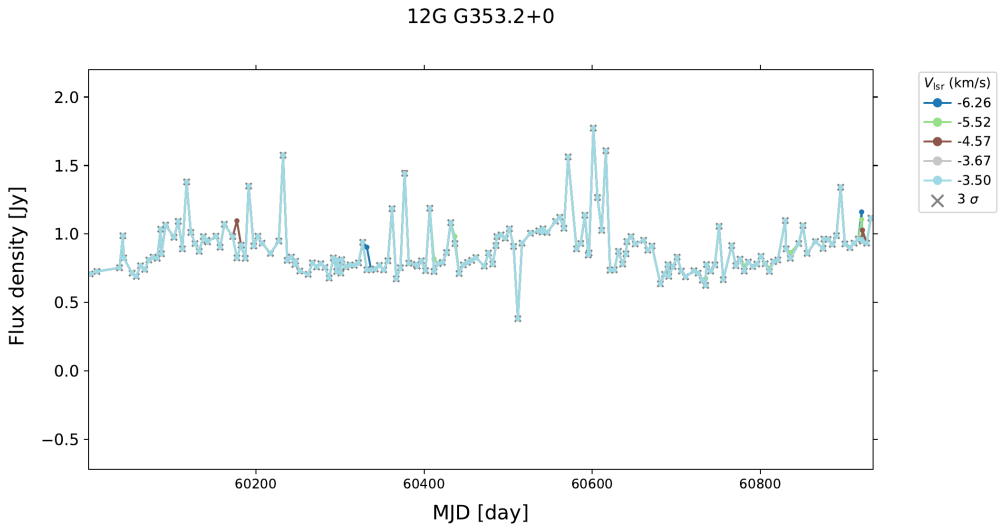


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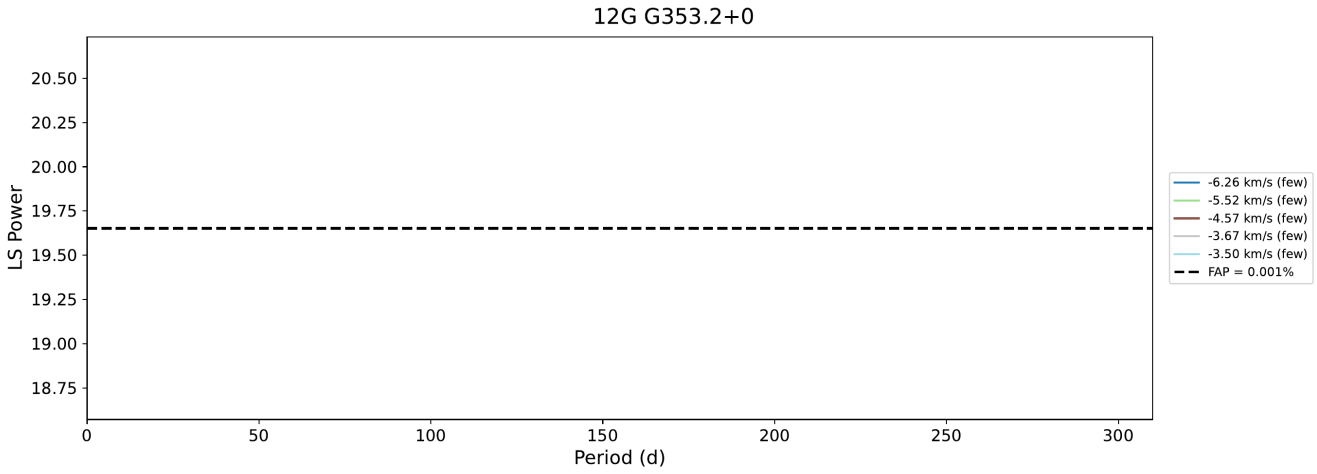


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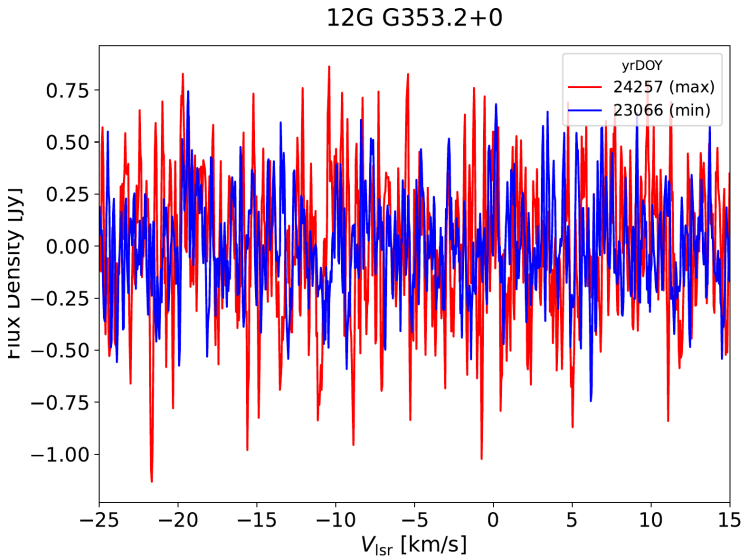
Light curve



Periodogram

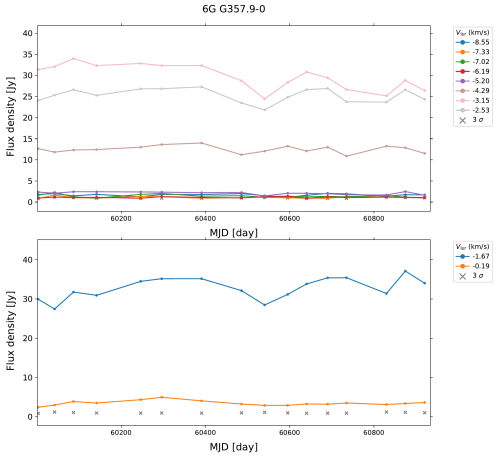


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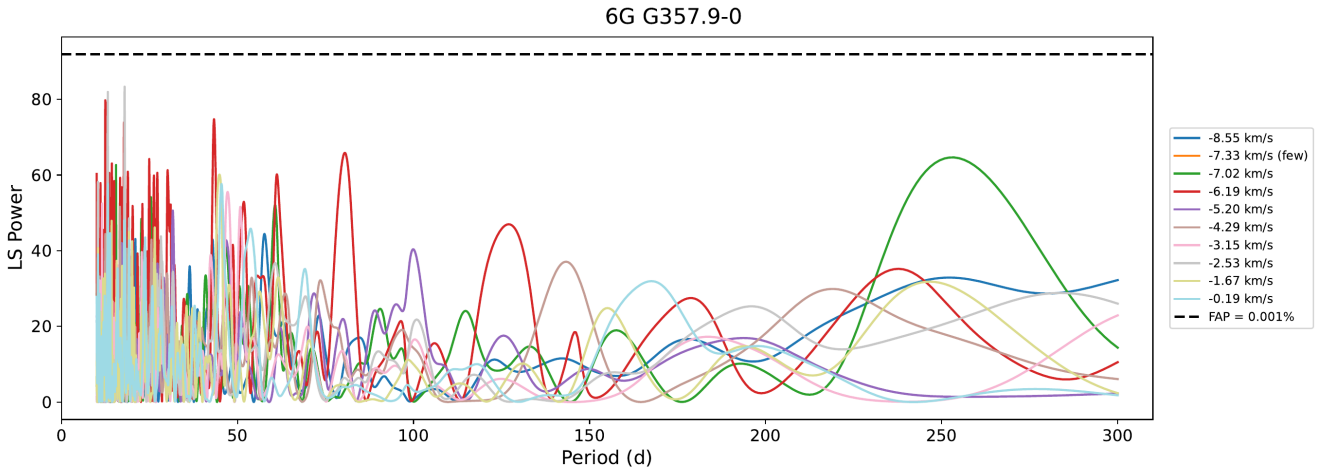


6G G357.9-0

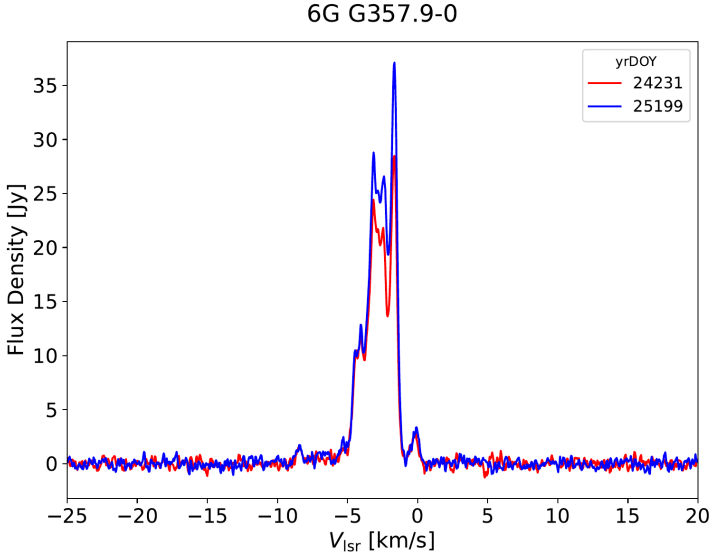
Light curve



Periodogram

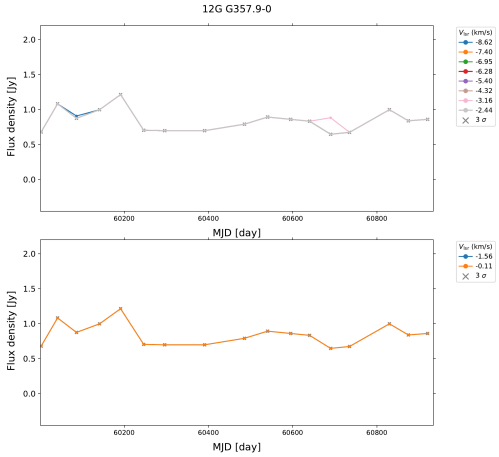


Spectrum

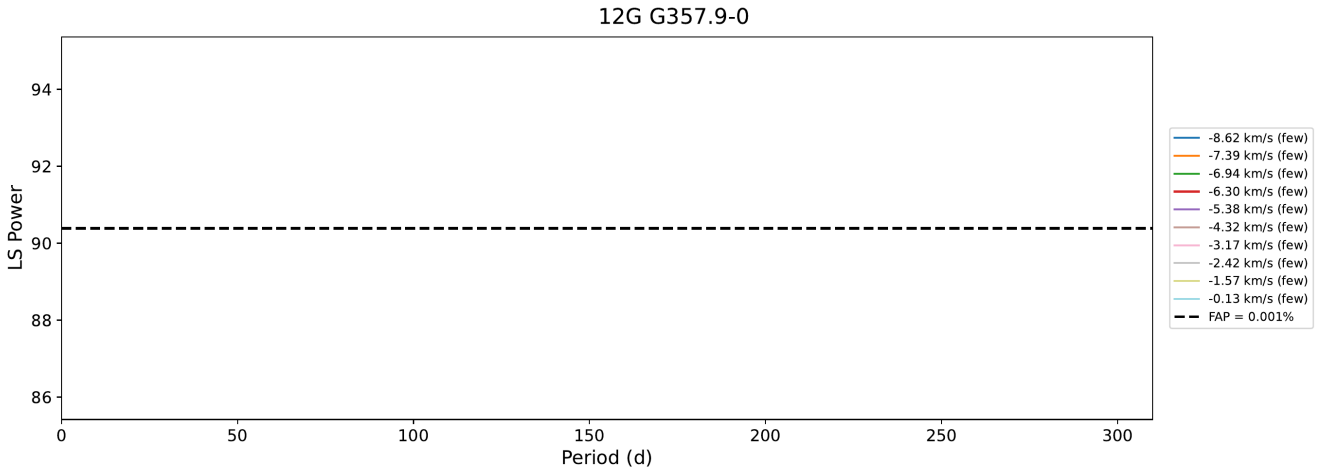


12G G357.9-0

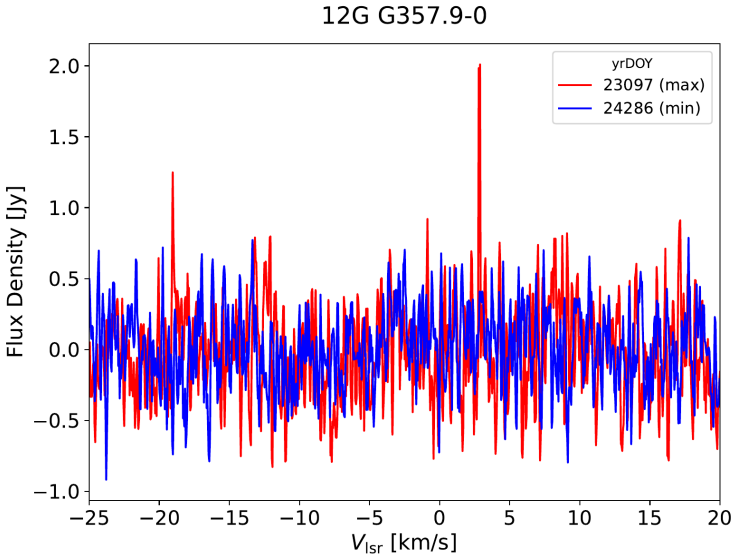
Light curve



Periodogram

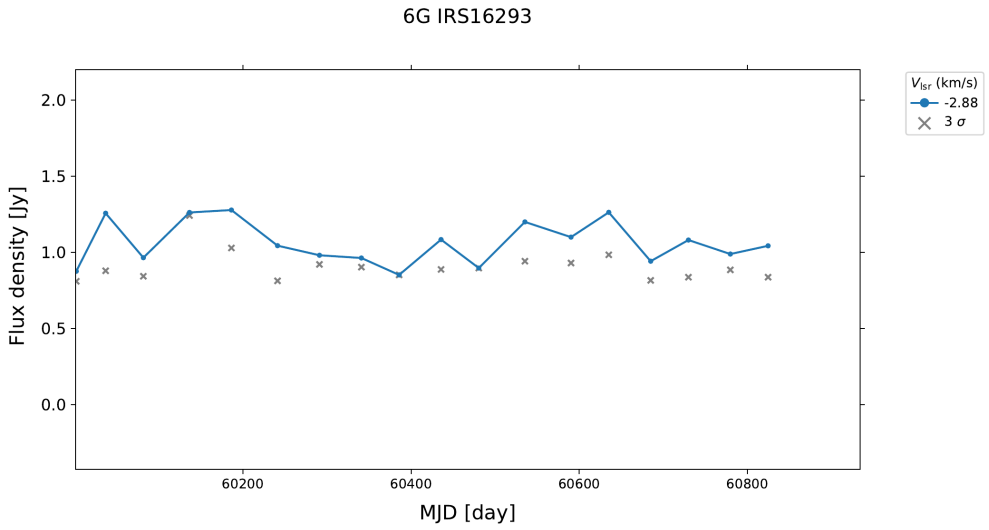


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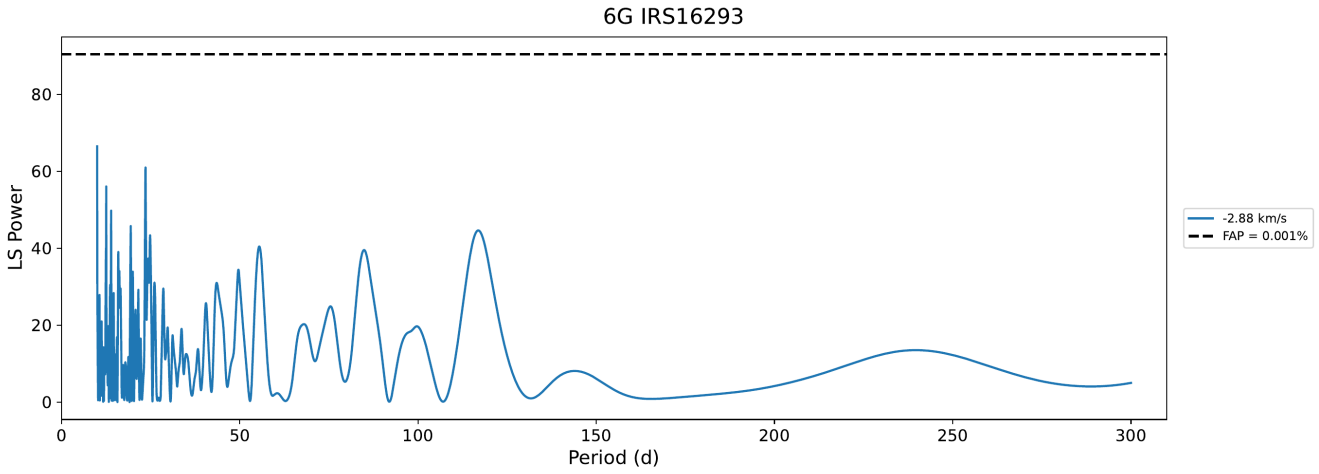


6G IRS16293

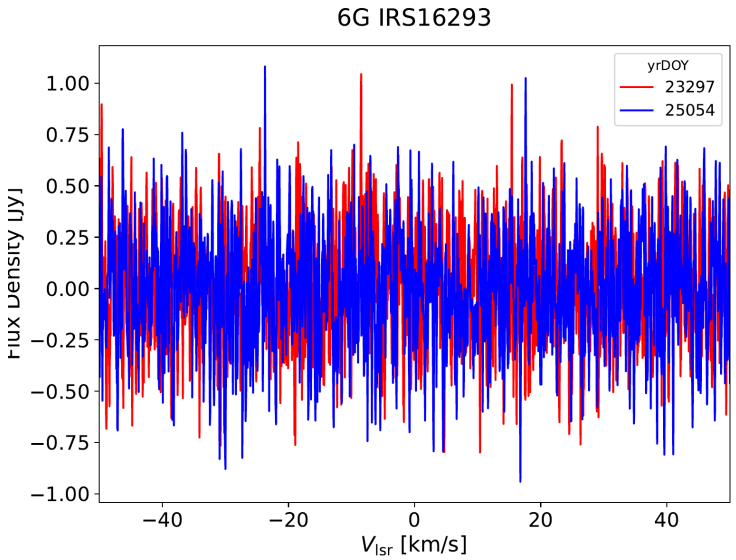
Light curve



Periodogram

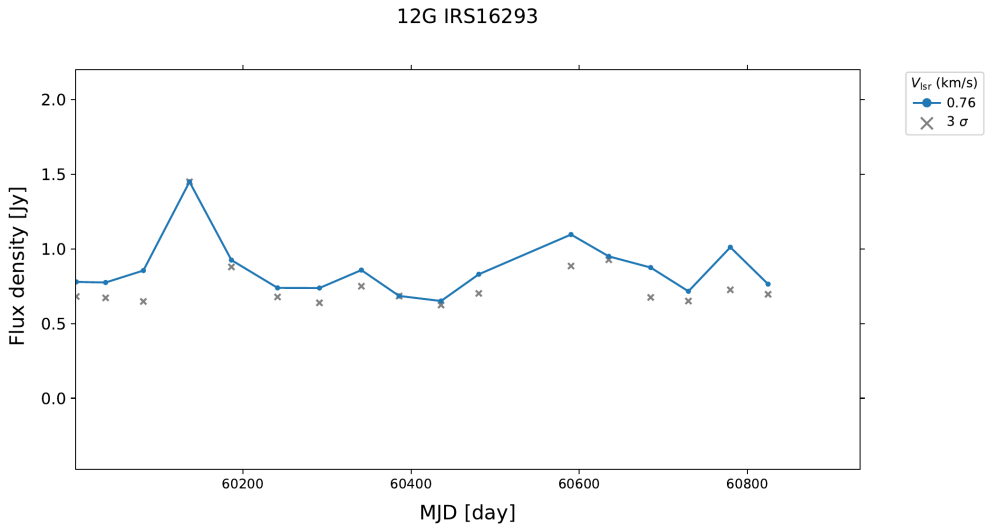


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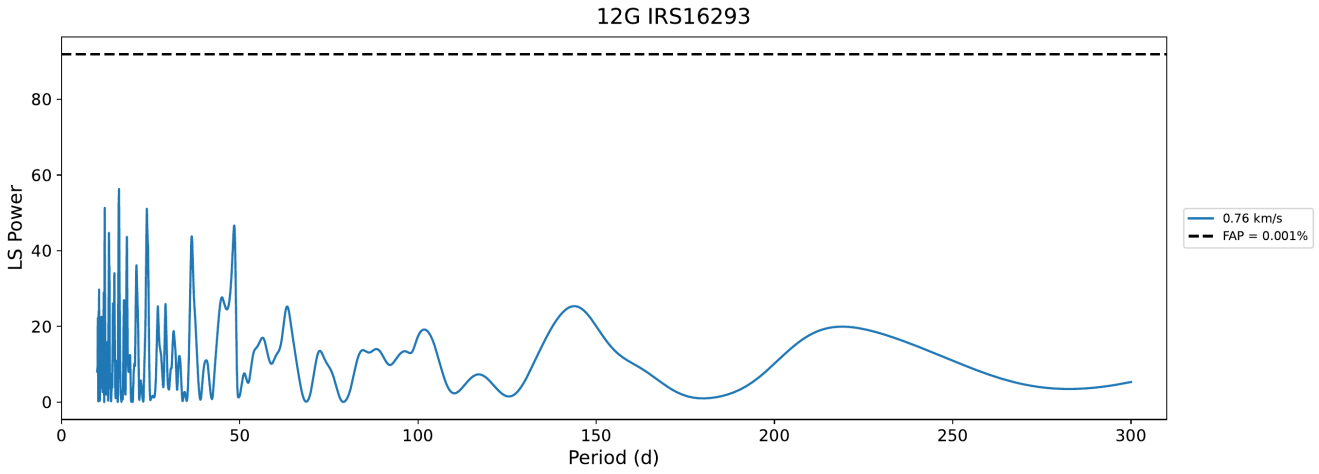


12G IRS16293

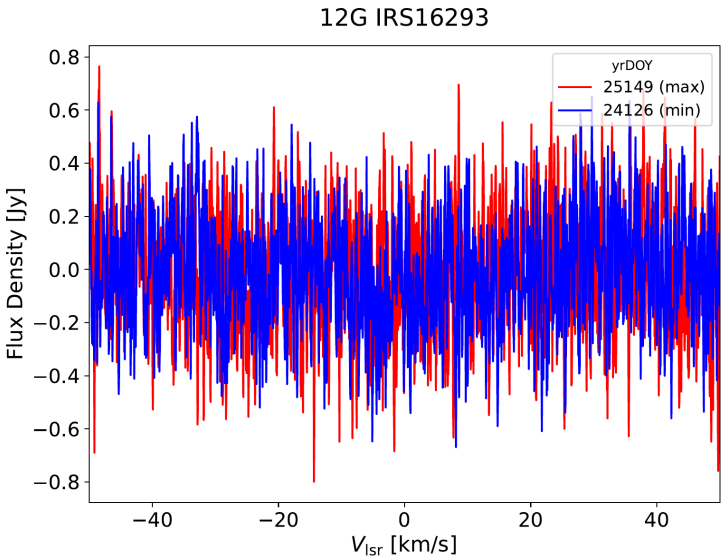
Light curve



Periodogram

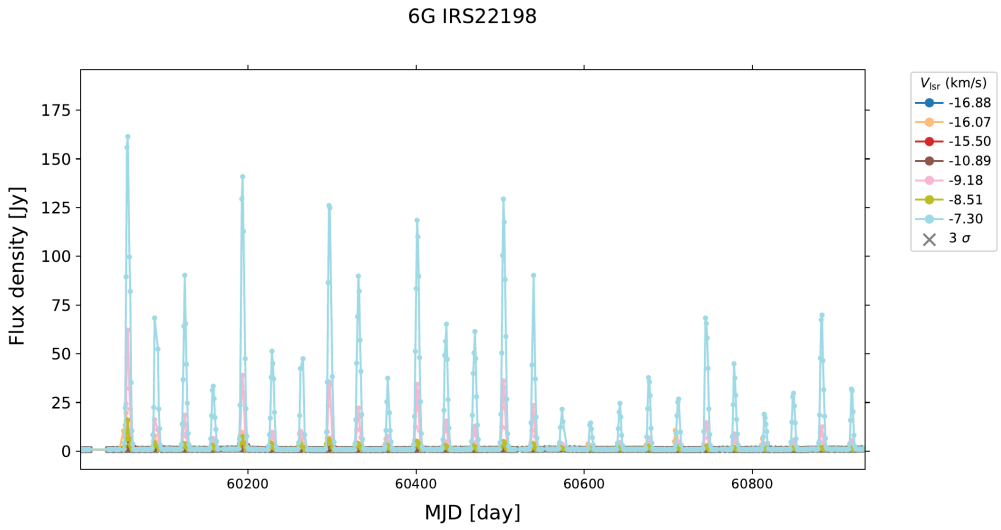


Spectrum

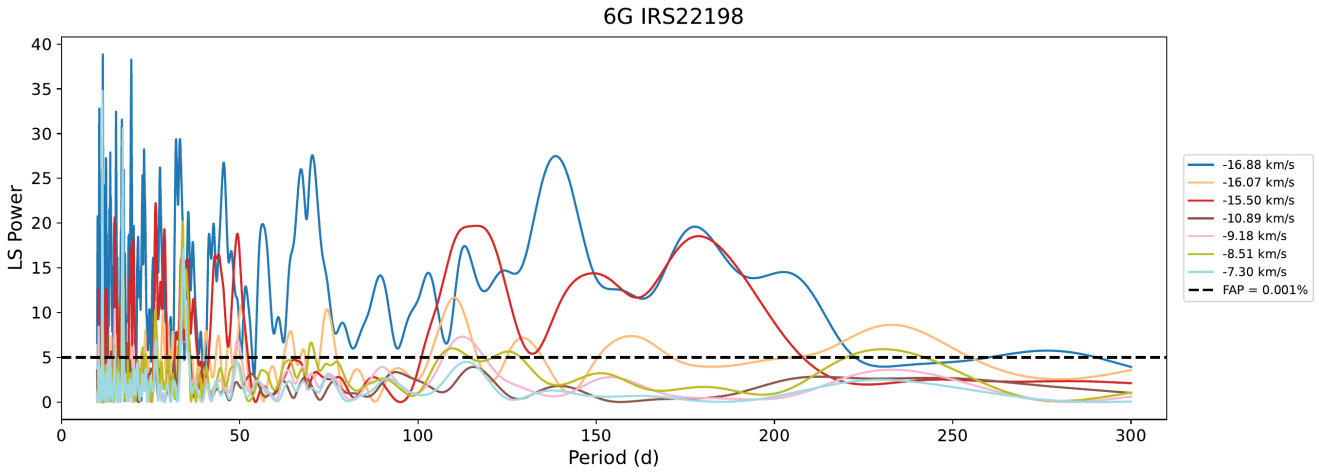


6G IRS22198

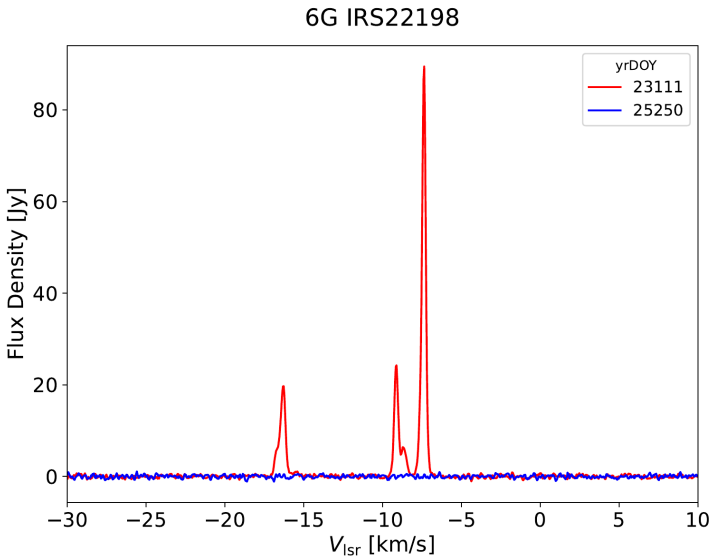
Light curve



Periodogram

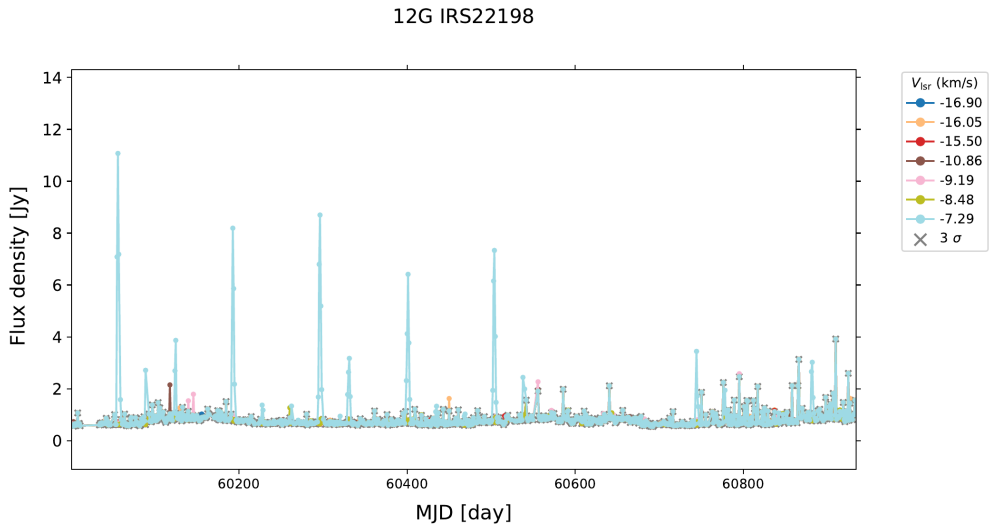


Spectrum

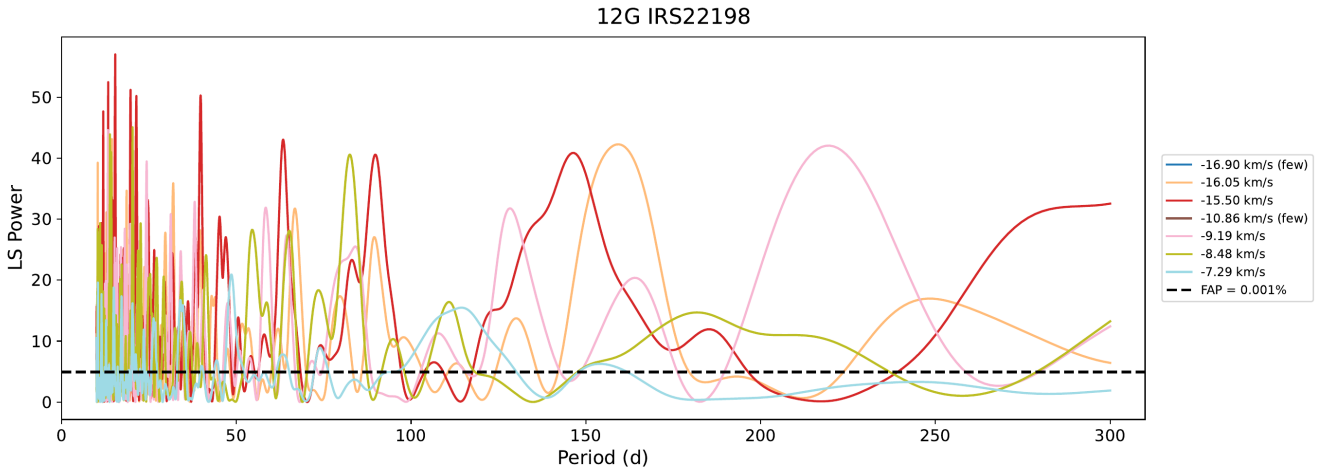


12G IRS22198

Light curve



Periodogram



Spectrum

