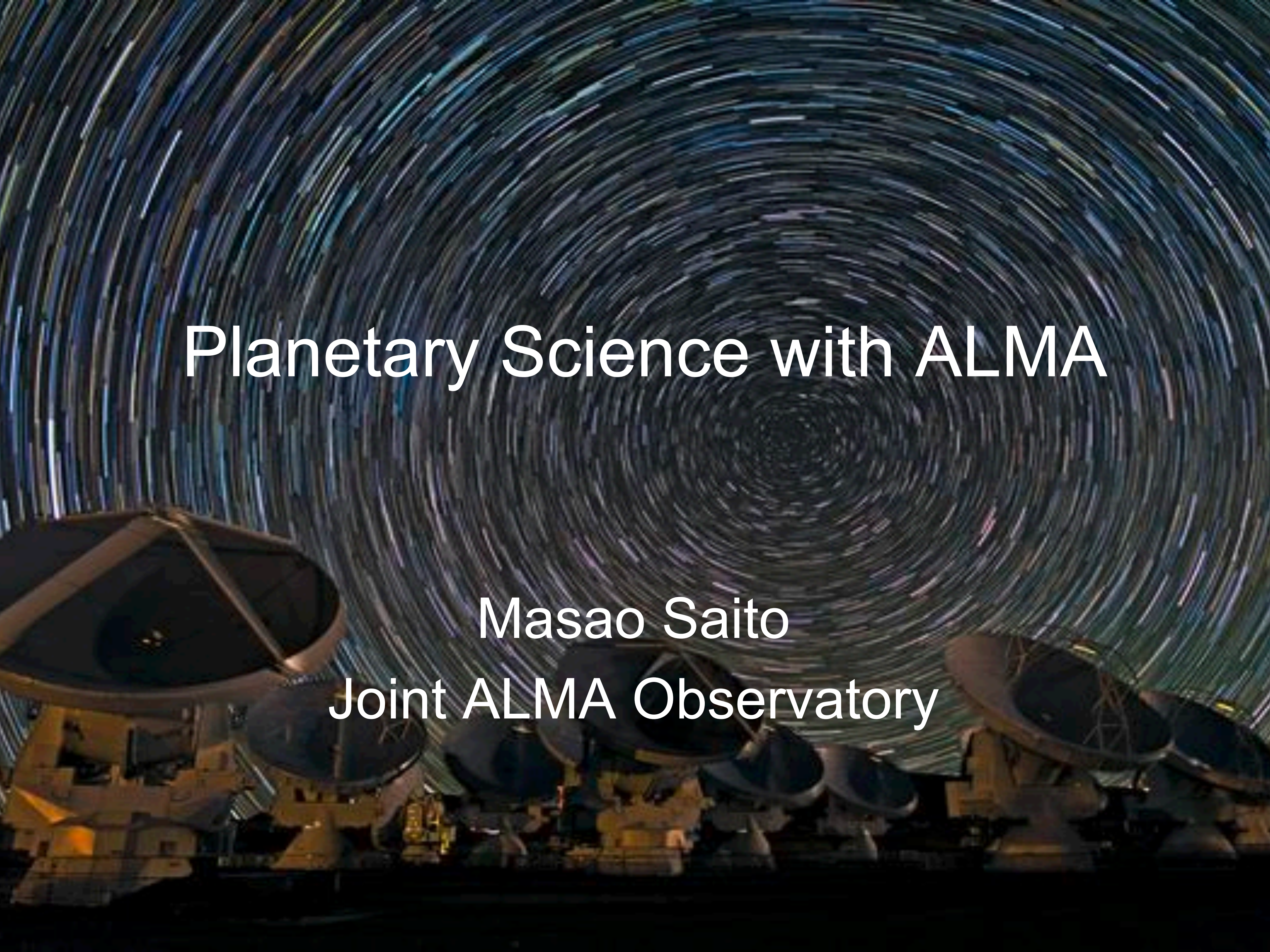
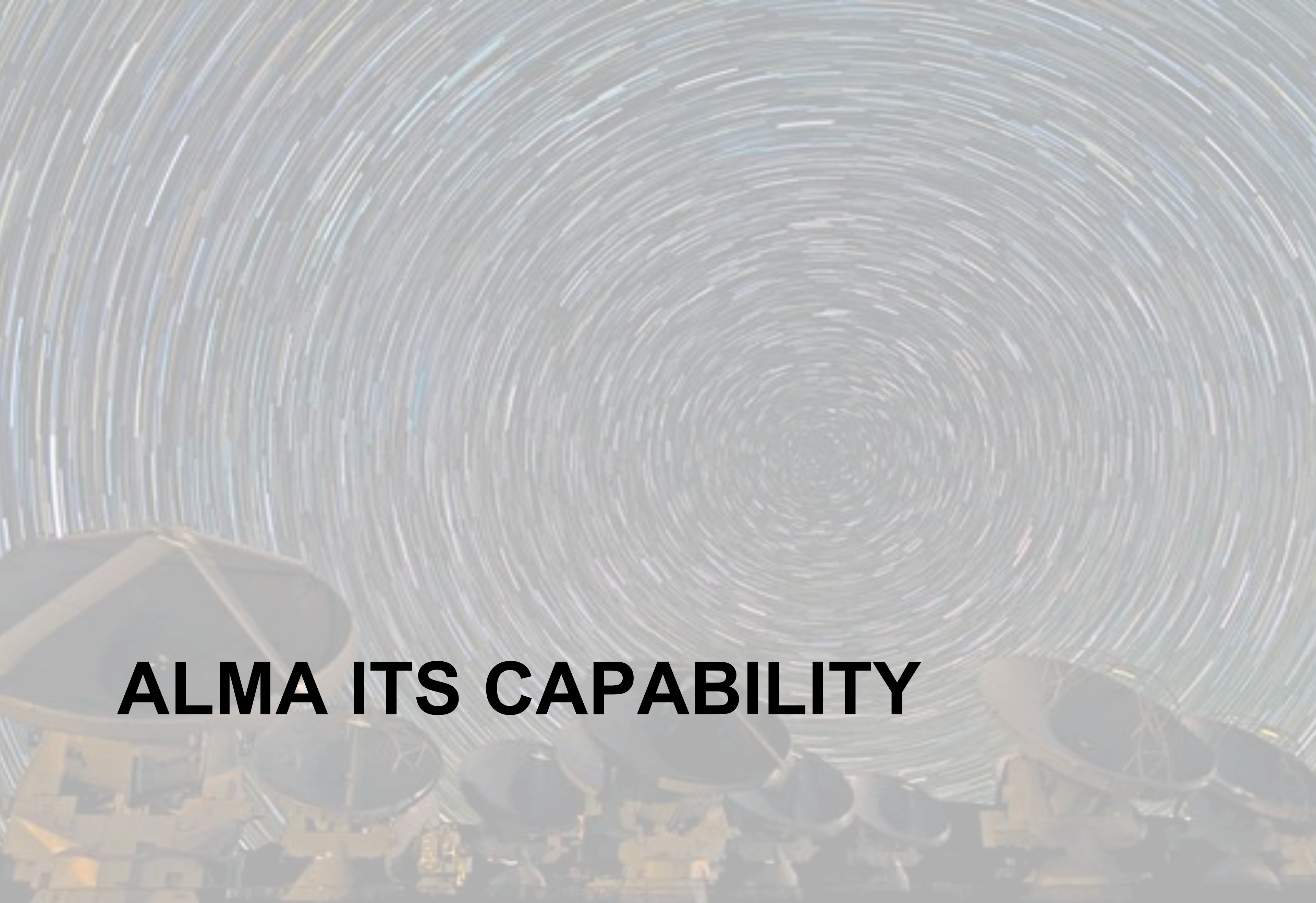


Planetary Science with ALMA

Masao Saito
Joint ALMA Observatory

Contents

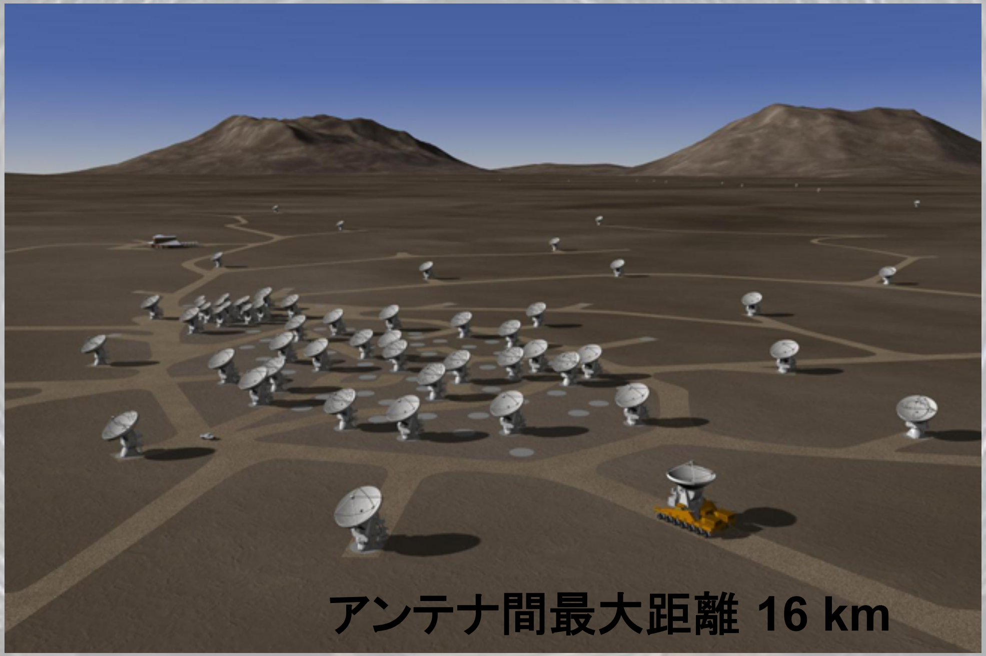
- ALMA: Its Capability
- Solary System Objects
- Exoplanets Detection
- Toward Future Capability
- Summary



ALMA ITS CAPABILITY

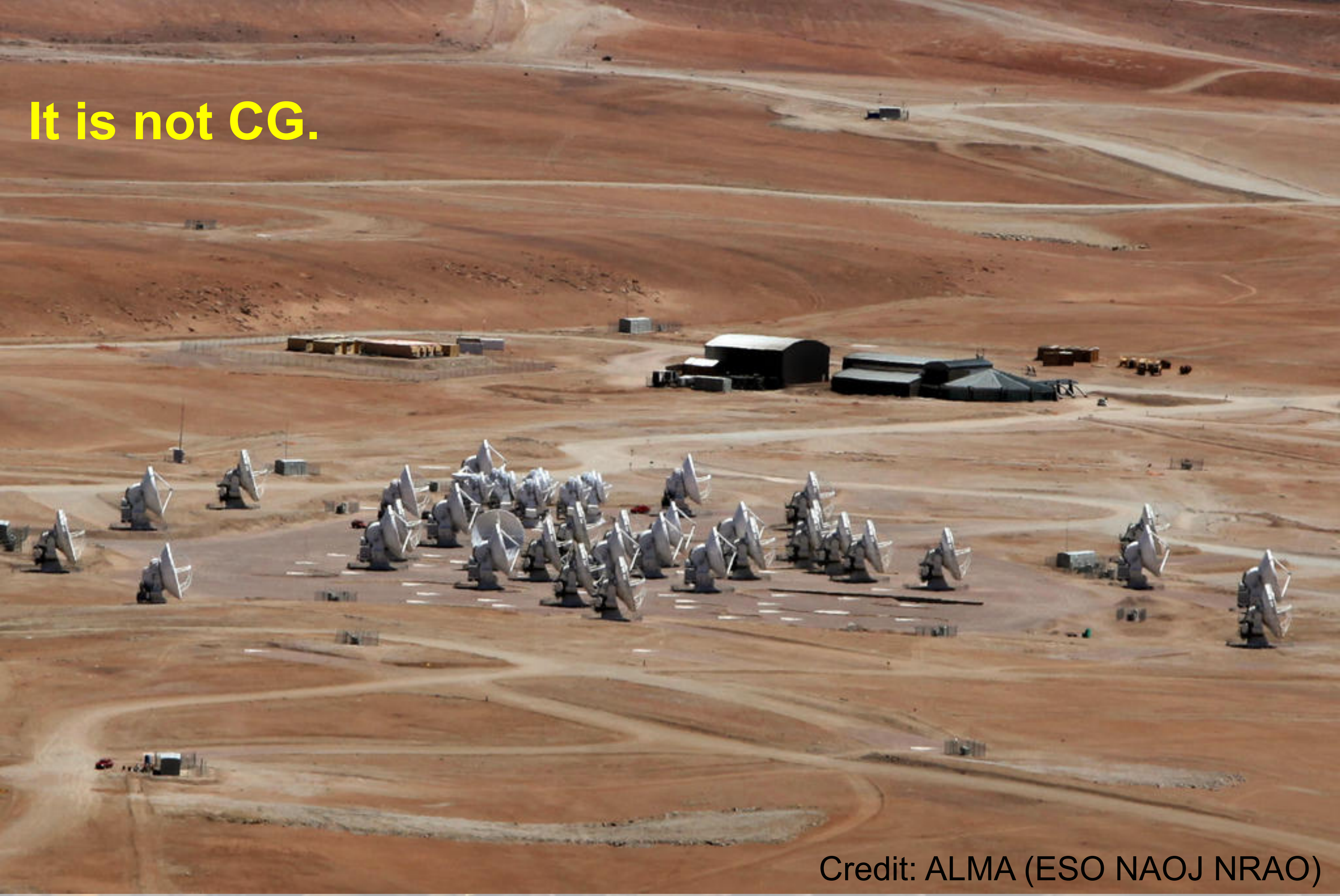
ALMA Overview

- ALMA is an ultimate scale mm/submm interferometer
- ALMA is a large scale mm/submm interferometer
  - International Project by EA, EU, NA, Chile
  - At Atacama Desert at 5000m above sea level
  - 54 12-m antennas, 12 7-m antennas
  - Angular Resolution **0.01 arcsec**
  - Sensitivity：**30 – 100 times better** than existing telescopes
  - Started Early Science Operation in 2011



Credit: ALMA (ESO NAOJ NRAO)

It is not CG.



Credit: ALMA (ESO NAOJ NRAO)

ALMA Specifications

- Top Three Science Requirements to Design ALMA
  - **Detect** spectral line emission from CO or C II in a normal galaxy **at a redshift of z=3**
  - Image the **gas kinematics in protostars** and **protoplanetary disks** around young Sun-like stars at a distance of **150 pc**
  - Provide **precise images** at an **angular resolution of 0.”1**.

ALMA Main Specifications

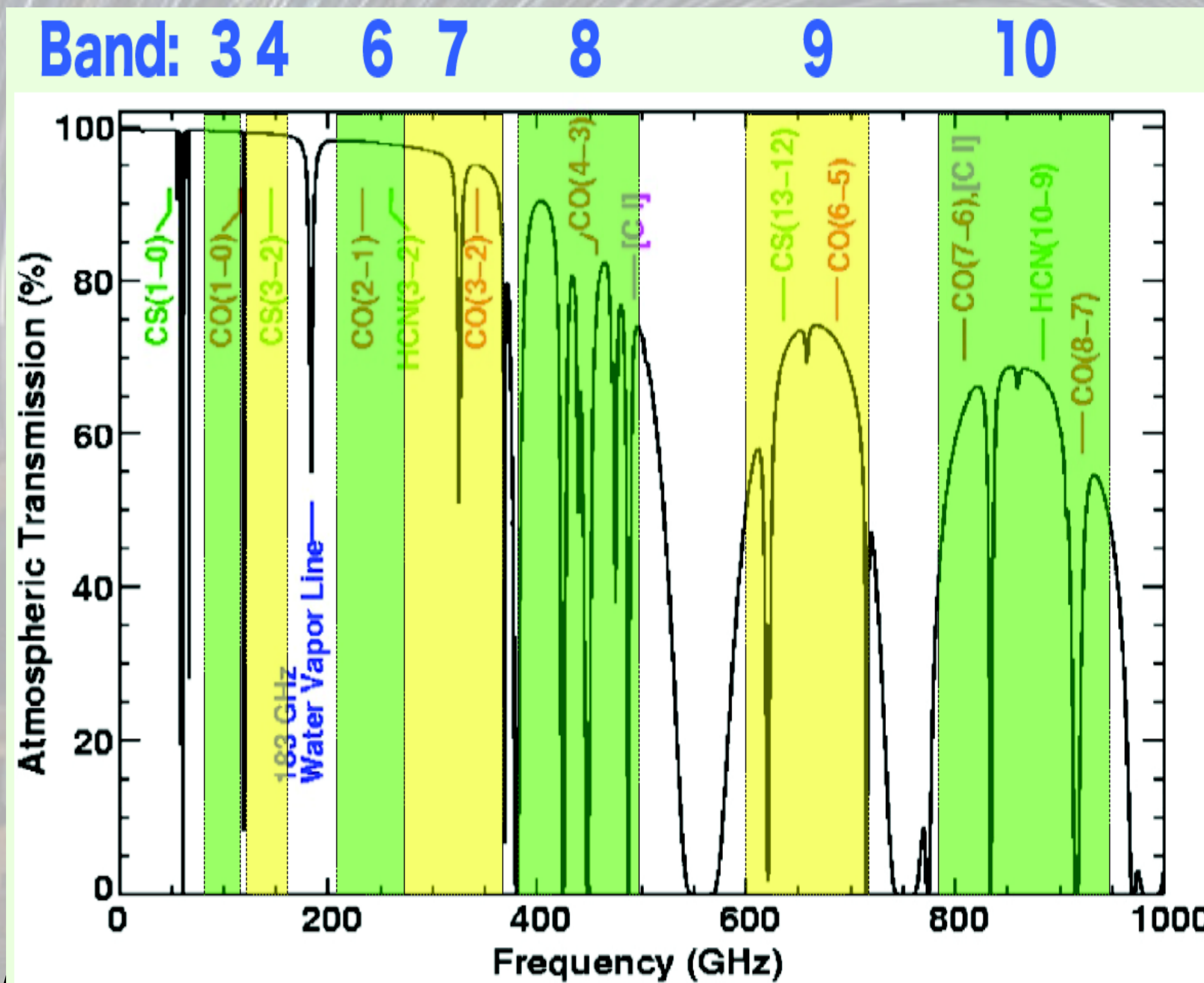
Antennas		12m x 50 12m x 4 + 7m x 12
		25/20 μm 0″.6 pointing
Resolution		0″.01 – 10″
Receivers		See Table
Correlator	Bandwidth	16 GHz/baseline (8IFx2GHz)
	Resolution	3.8 kHz (0.012 km/s at 100 GHz)
Dynamic Range	Image	50000:1 (with self-cal)
	Spectrum	10000:1 line-to-line
	Spectrum	1000:1 line-to-continuum
Flux Scale	Relative	< 1 % at mm, < 3 % at submm

ALMA Band Coverage

ALMA Bands			FOV
1	35-50*		140”
2	67-90		
3	84-116	2SB: 4-8 GHz	60"
4	125-163	2SB: 4-8 GHz	45"
5	163-211	2SB: 4-8 GHz	35”
6	211-275	2SB: 5-10 GHz	26"
7	275-373	2SB: 4-8 GHz	17"
8	385-500	2SB: 4-8 GHz	13"
9	602-720	DSB: 4-12 GHz	9"
10	787-950	DSB: 4-12 GHz	7"

Band 1 and 5 are under development.

Transmission at ALMA Site



Nearly Best condition

ALMA Evolution

	Cycle 0	Cycle 1 Now	Full Oper.
12-m array	16	32	50
7-m array	0	9	12
TP array	0	2	4
Band	3,6,7,9	3,6,7,9	3,4,6,7,8,9,10

ALMA Sensitivity

- In general, the noise level of n-antenna array is written below.

$$\Delta S = \frac{2kT_{sys}}{\eta_q[\eta_a \pi (D/2)^2][n_p N(N-1)\Delta\nu\Delta t]^{0.5}} \rho$$

相関器効率 → η_q

Effective aperture area → $\eta_a \pi (D/2)^2$

# of polarization → n_p

# of antenna → N

Bandwidth → $\Delta\nu$

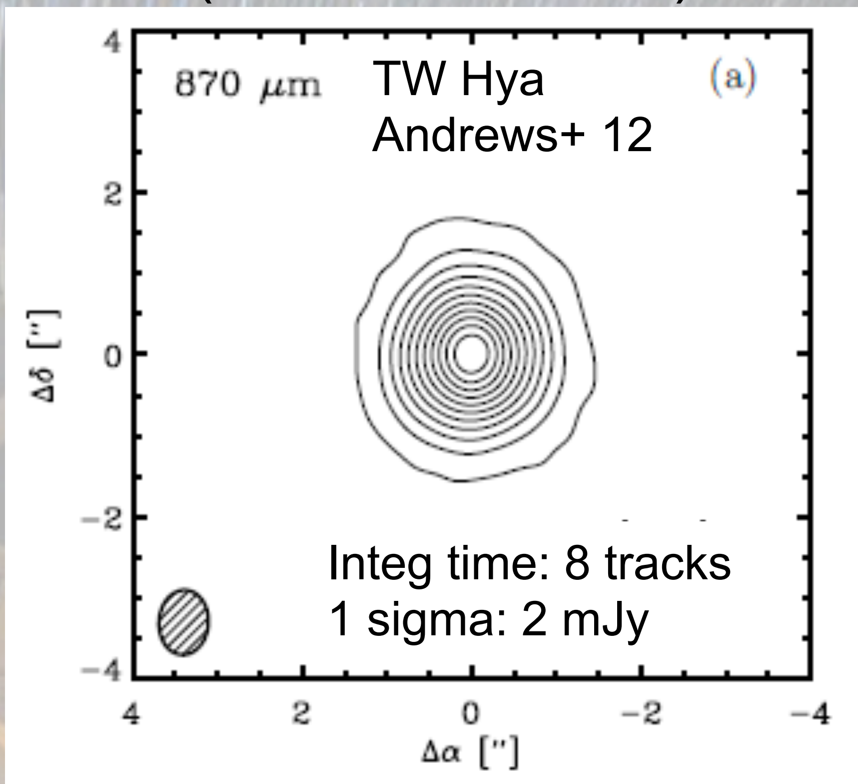
Integ time → Δt

Coherence → ρ

ALMA vs SMA

ALMA is a snapshot array compared to existing arrays.

SMA (8 x 6 m antenna)



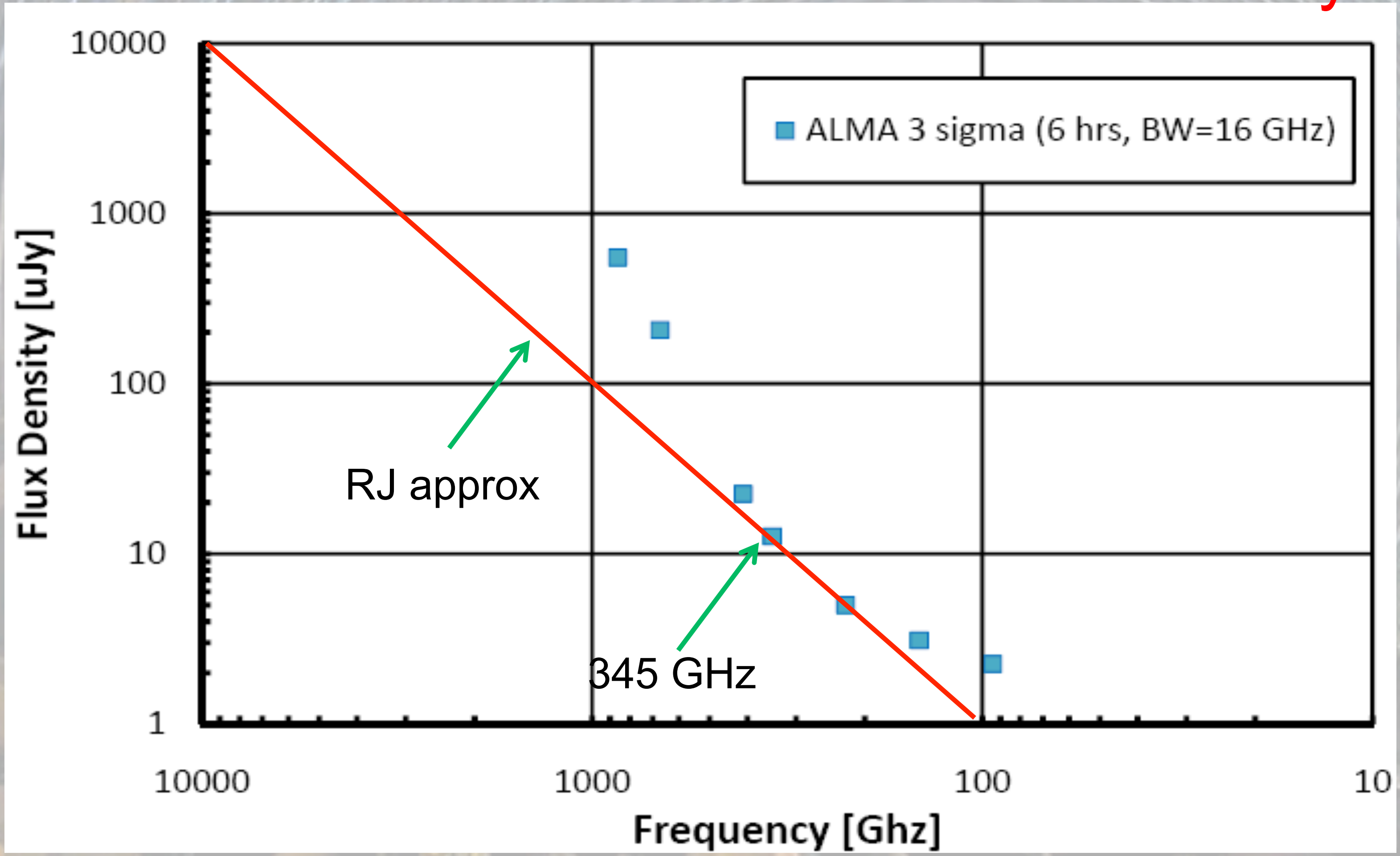
ALMA (32 x 12 m antenna)
Cycle 1 on-going

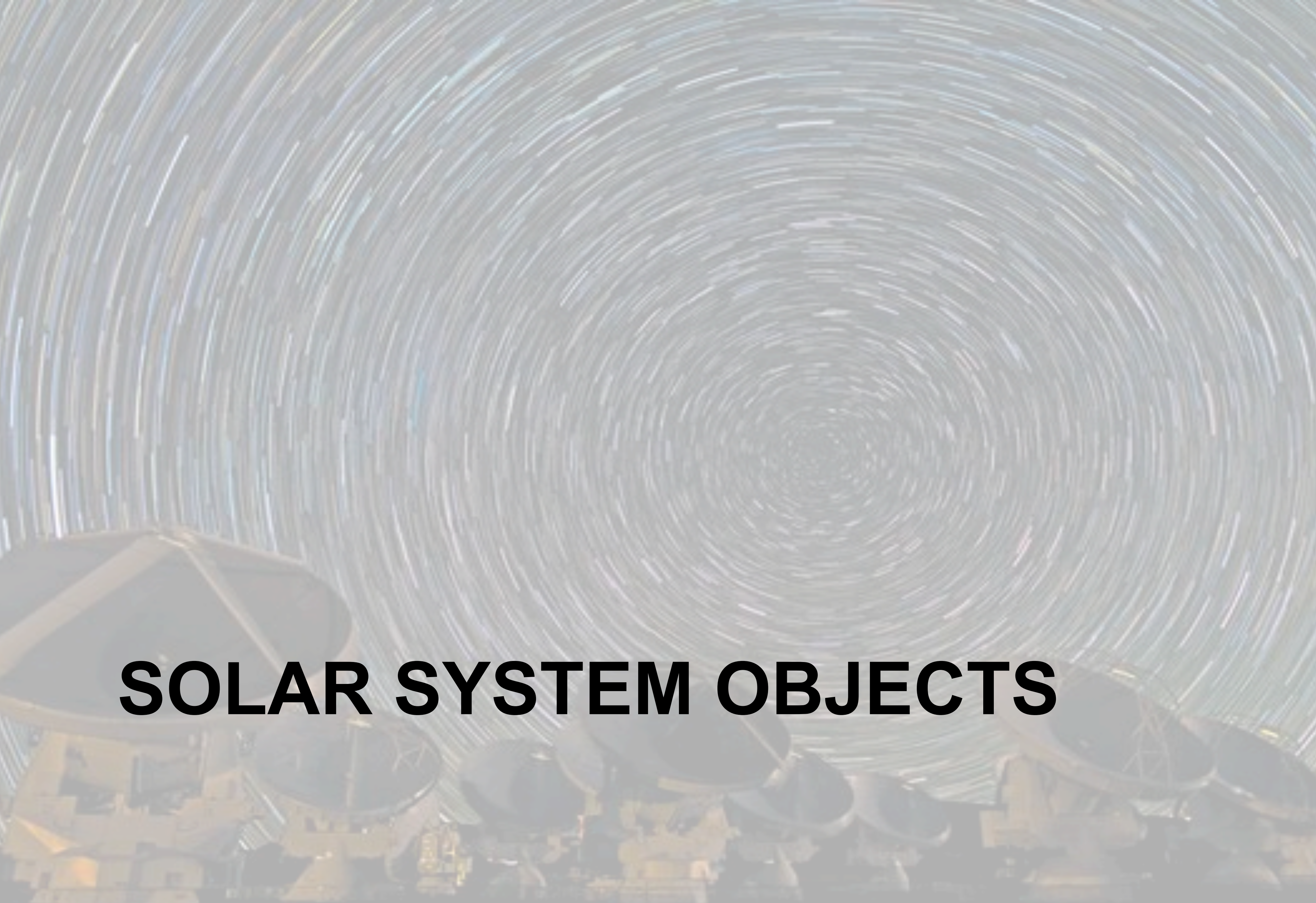
Required Integ Time is

3 seconds

Continuum Sensitivity

Band 6 or 7 is most sensitive to detect BlackBody objects





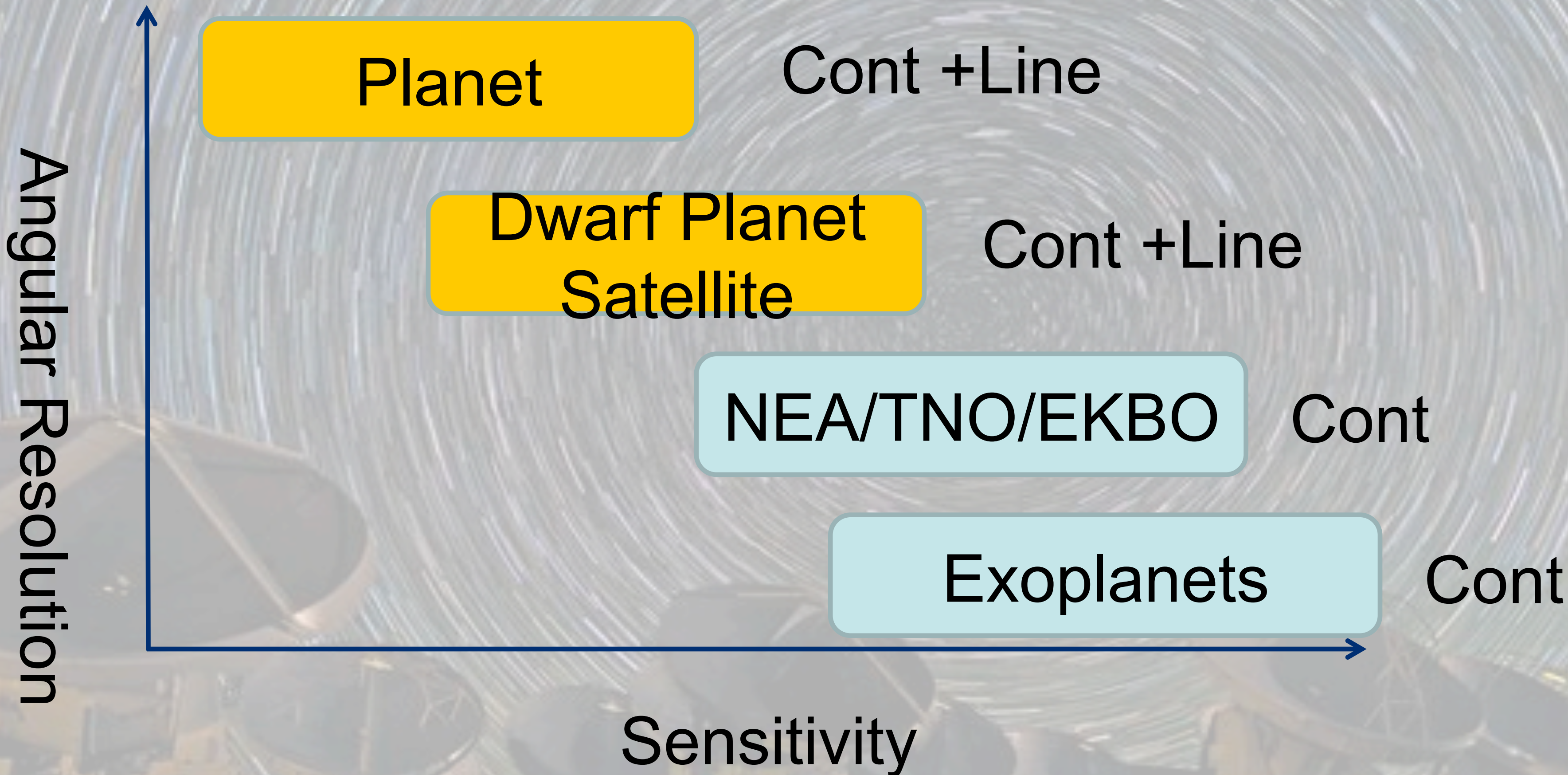
SOLAR SYSTEM OBJECTS

Types of Observations

- Solar Planets
  - Line
- Satellites/KB Objects
  - Continuum (flux calibration)
  - Line
- Extra-Solar Giant Planets
  - Giant planets
  - Proto-Giant planets

ALMA & Satellite Complementary
- Monitor ⇔ Instantenous
- Overview ⇔ Specific position

Type of Observatios

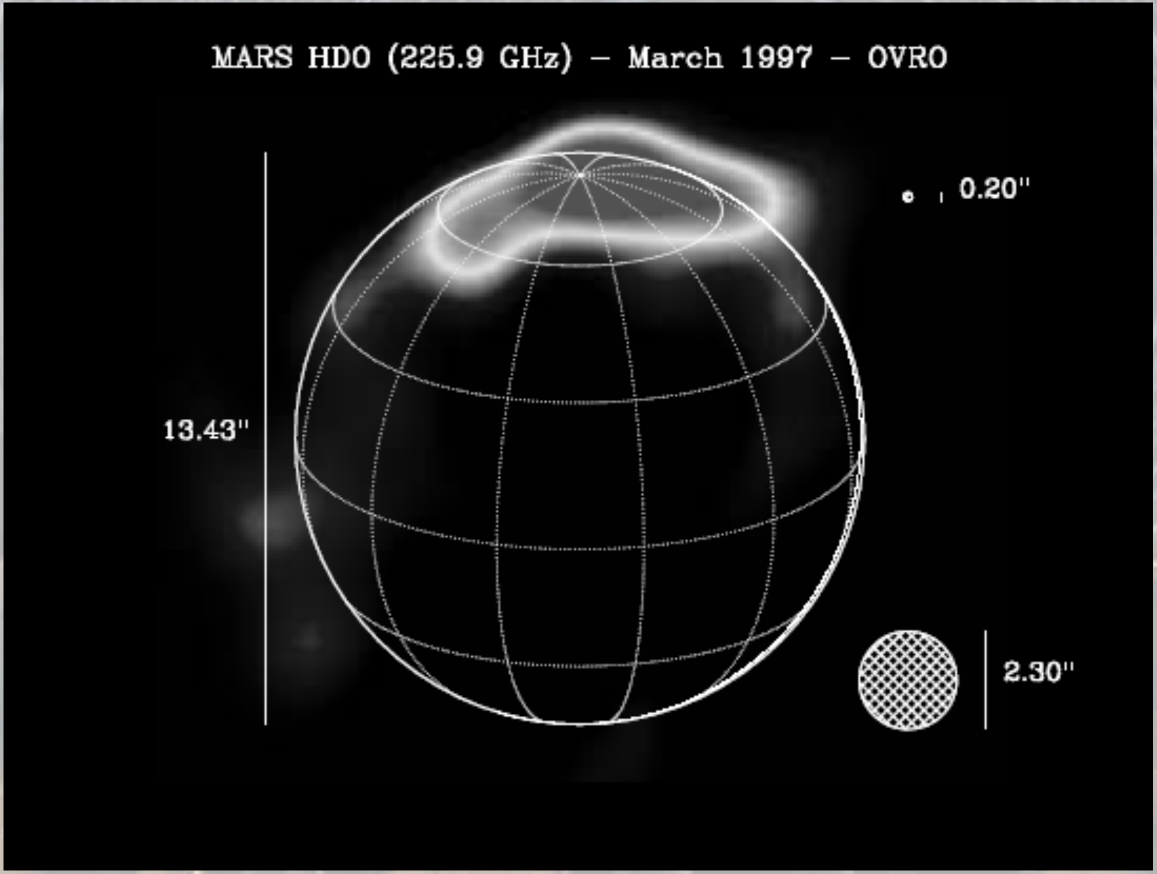


Various Observation Proposed

- 4.1 Planetary Atmospheres
- 4.1.1 The dynamics of Mars' and Venus' middle atmopheres
- 4.1.2 The three-dimensional water cycle of Mars
- 4.1.3 Chemistry in the atmospheres of Venus and Mars
- 4.1.4 Composition and dynamics of giant planet stratospheres
- 4.1.5 Search for broad lines in the tropospheres of the giant planets
- 4.1.6 Mapping the continuum emission from the giant planets
- 4.1.7 Chemical-dynamical couplings in Titan's atmosphere
- 4.1.8 Volcanism at Io
- 4.1.9 The atmospheres of Triton, Pluto and other transneptunians (TNO) objects
-
- 4.2 Planetary Surfaces and Dynamics
- 4.2.1 Albedos, sizes and surface properties of transneptunian objects
- 4.2.2 Mapping the surfaces of the Moon, Mercury and Mars
- 4.2.3 Mapping the surfaces of large icy bodies
- 4.2.4 Structure and composition of Saturn's rings
- 4.2.5 Mapping the surfaces of larger asteroids
- 4.2.6 Sizes and albedoes of NEAs
- 4.2.7 Astrometry of NEAs and TNOs
- 4.2.8 Radar observations of NEAs

Mars: water?

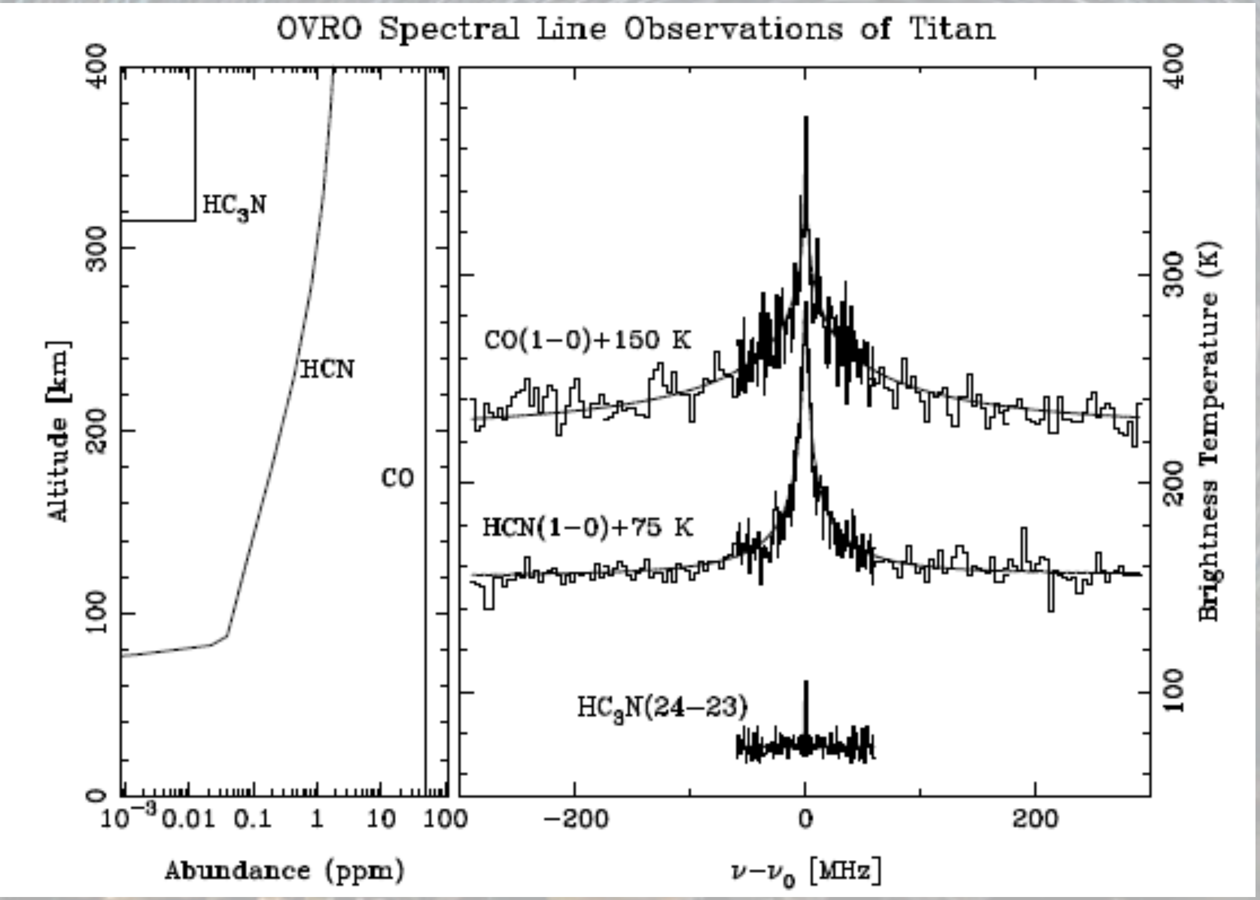
Atmospheric Composition, Kinematics, Variation



Gurwell+ 99

Titan: CO/HCN

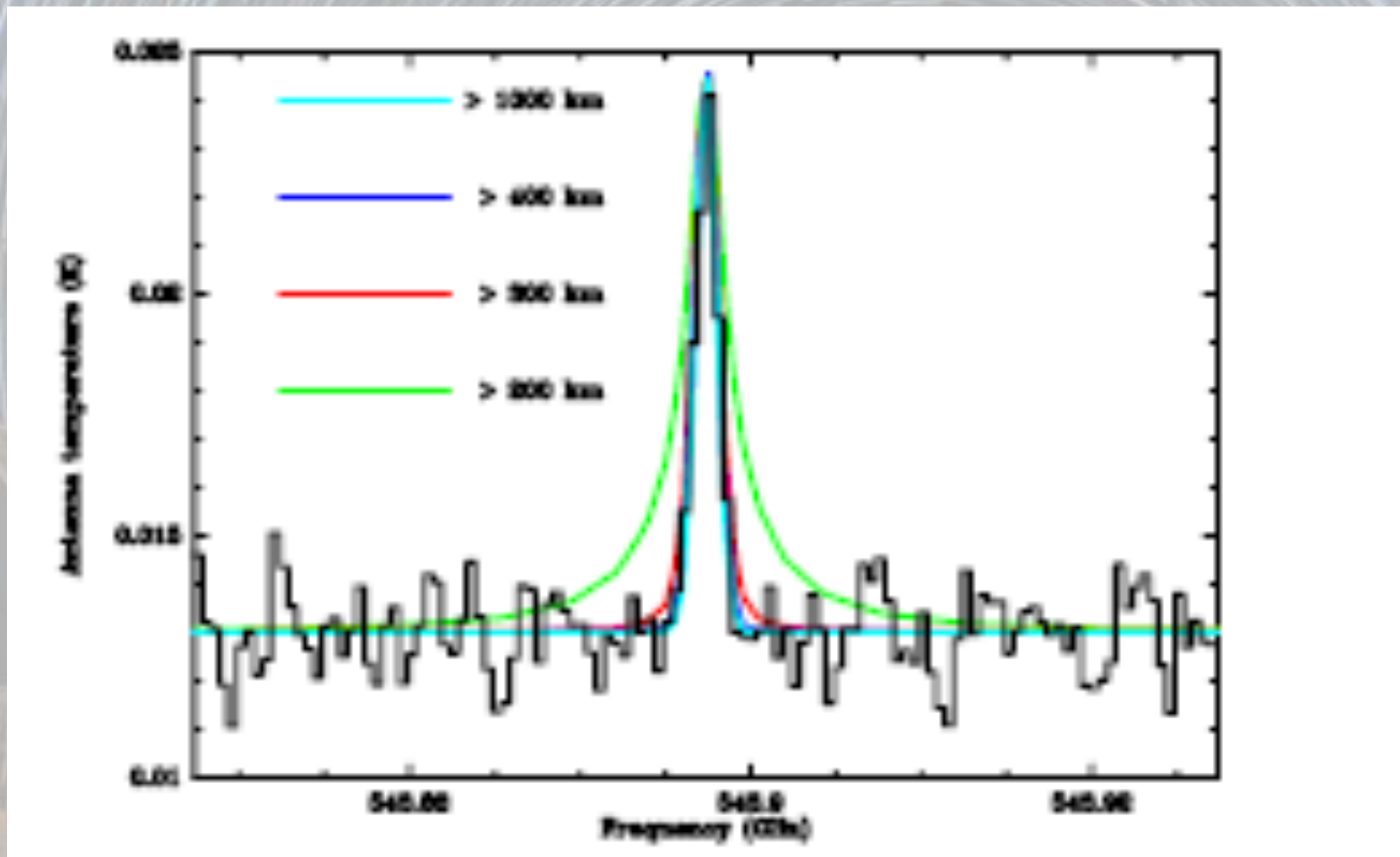
Vertical distribution of Atmosphere



Gurwell+ 99

Titan: HNC

Atmospheric Composition, Kinematics

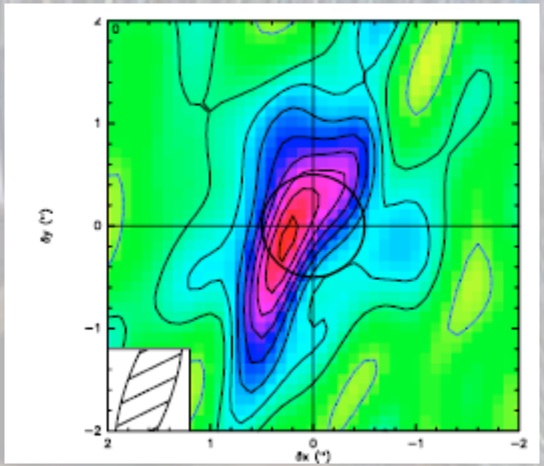


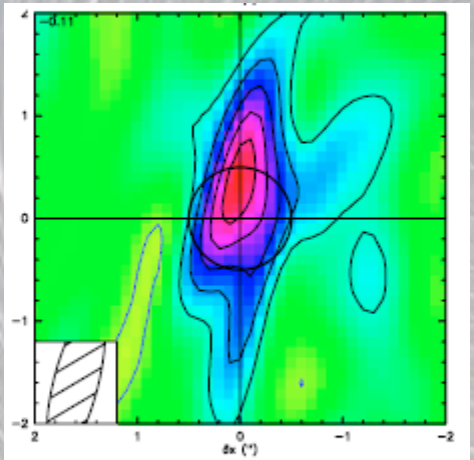
Moreno+ 11

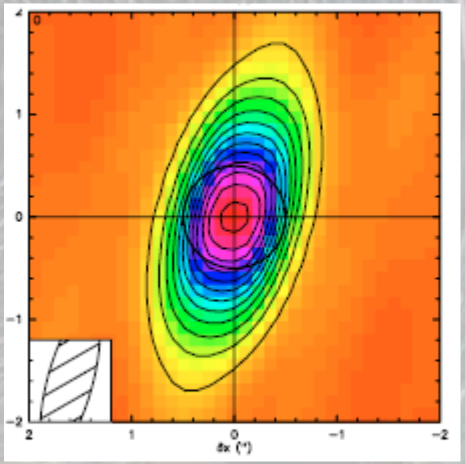
IO: SO2

Atmospheric Kinematics

Line shift of 330 ± 100 m/s > 75 m/s (solid rotation)







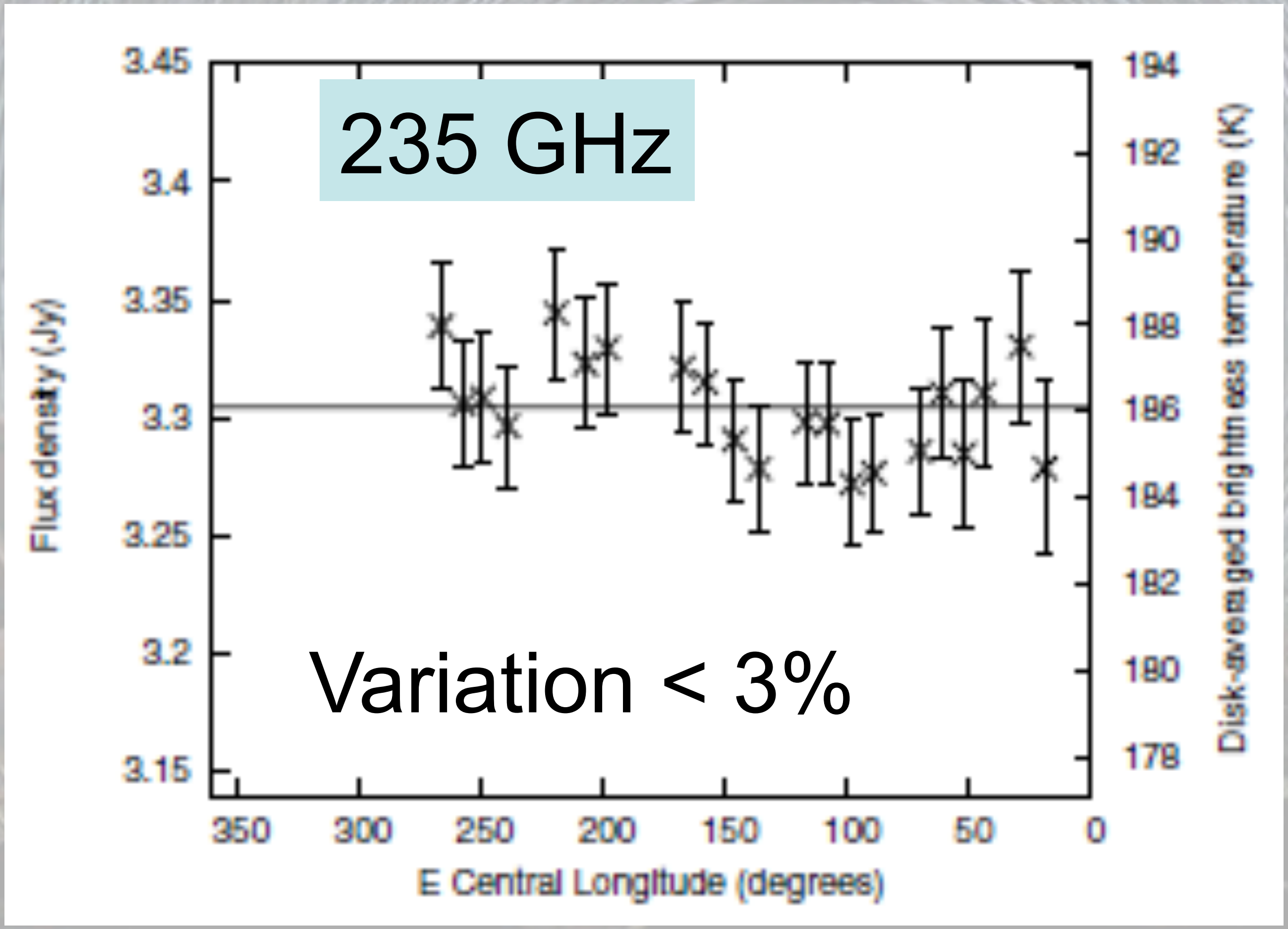
Left: leading side line emission. 1”.5 x 0”.5 beam
Right: trailing side line emission.

Continuum
217 GHz

Moullet +07

Light Curve of Ceres

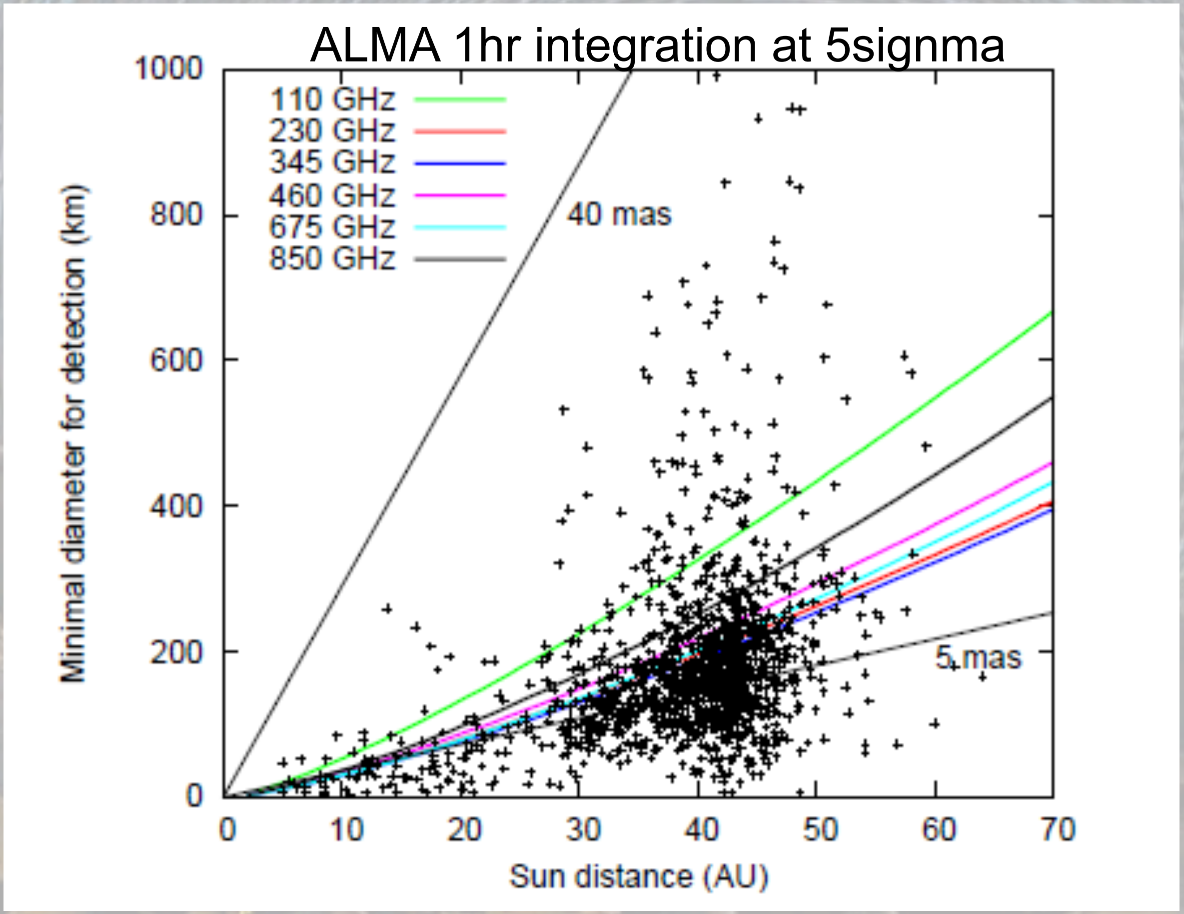
Study brightness temperature distribution



Moullet +10

Trans-Neptunian Objects: Size

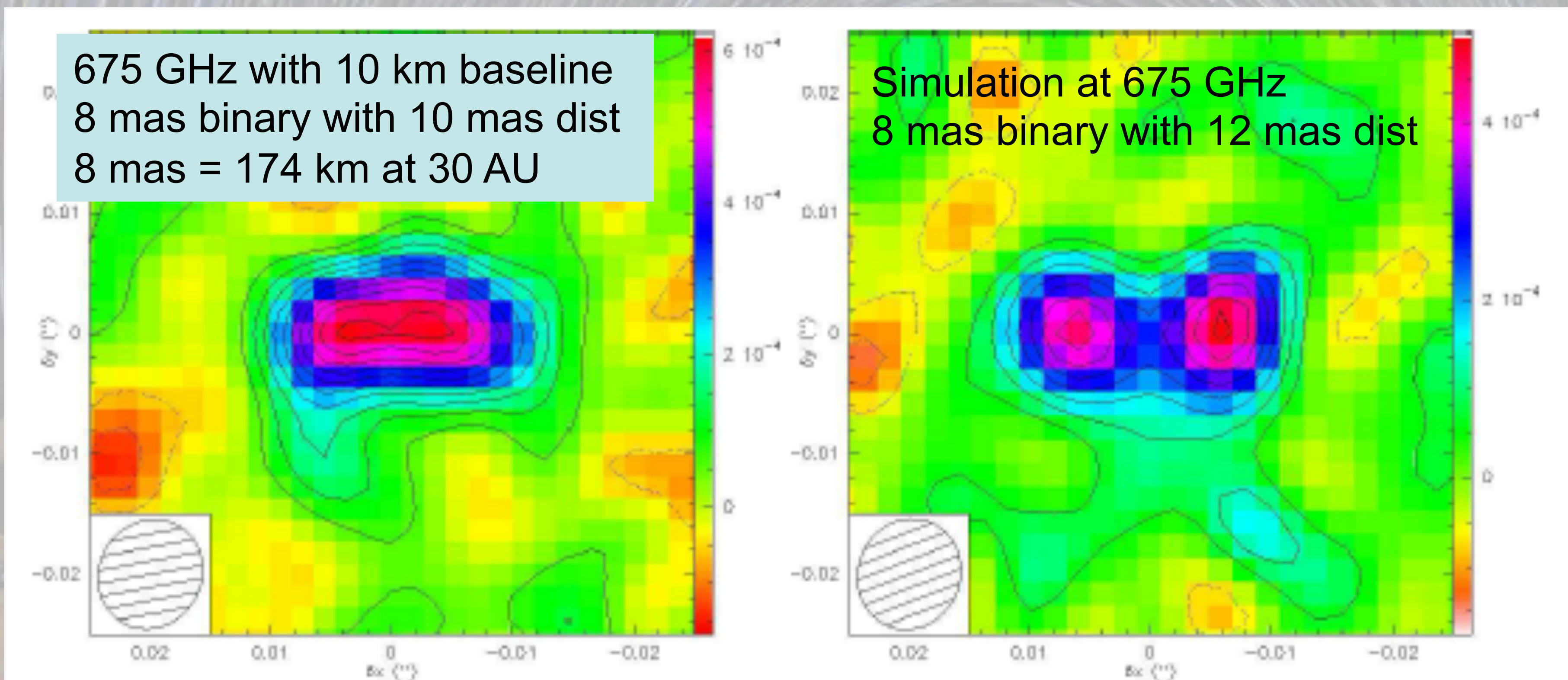
Determine the equivalent size and albedo



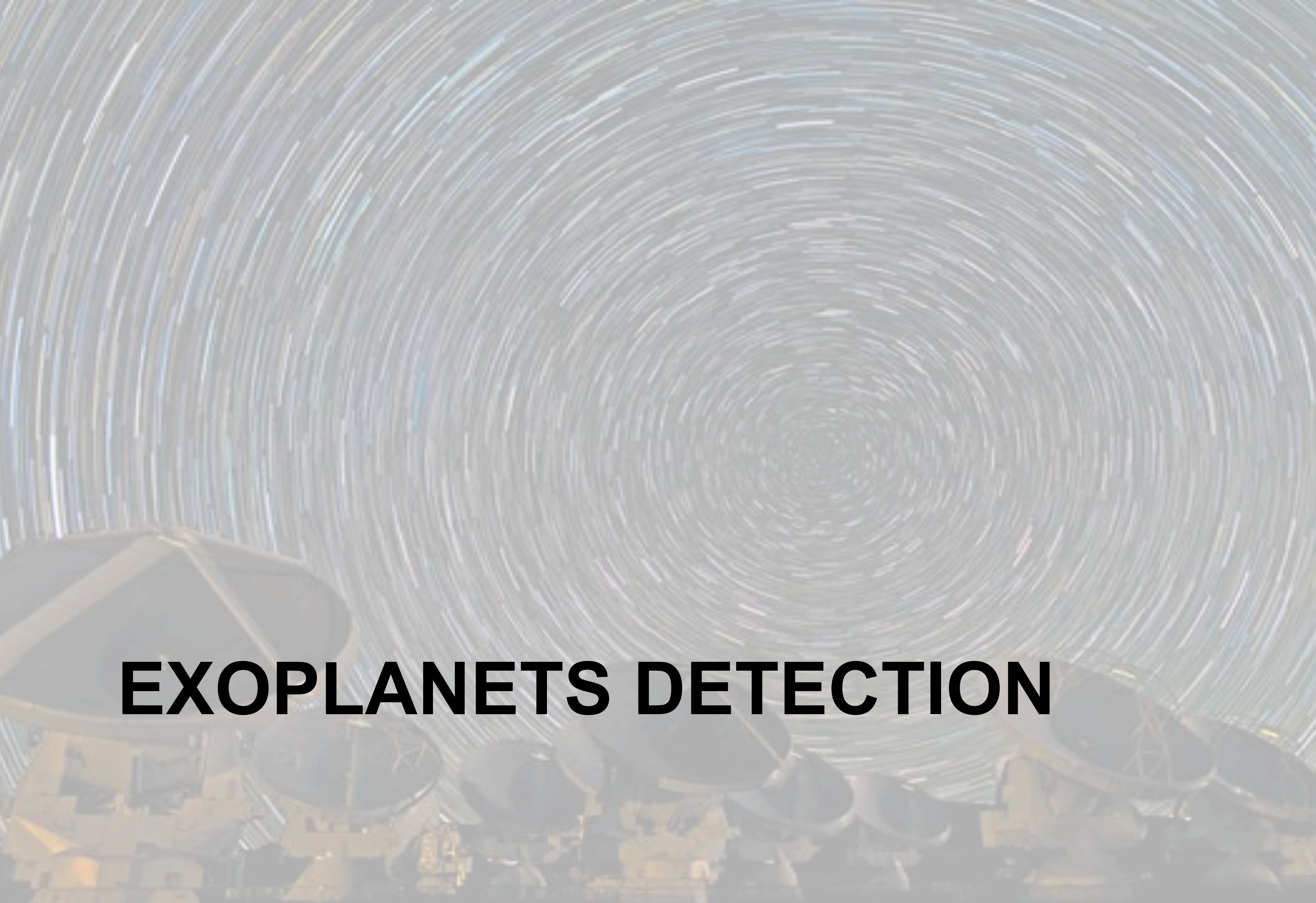
Moullet +11

Trans-Neptunian Objects

Binary Fraction, Separation, Total Mass



Moullet+11



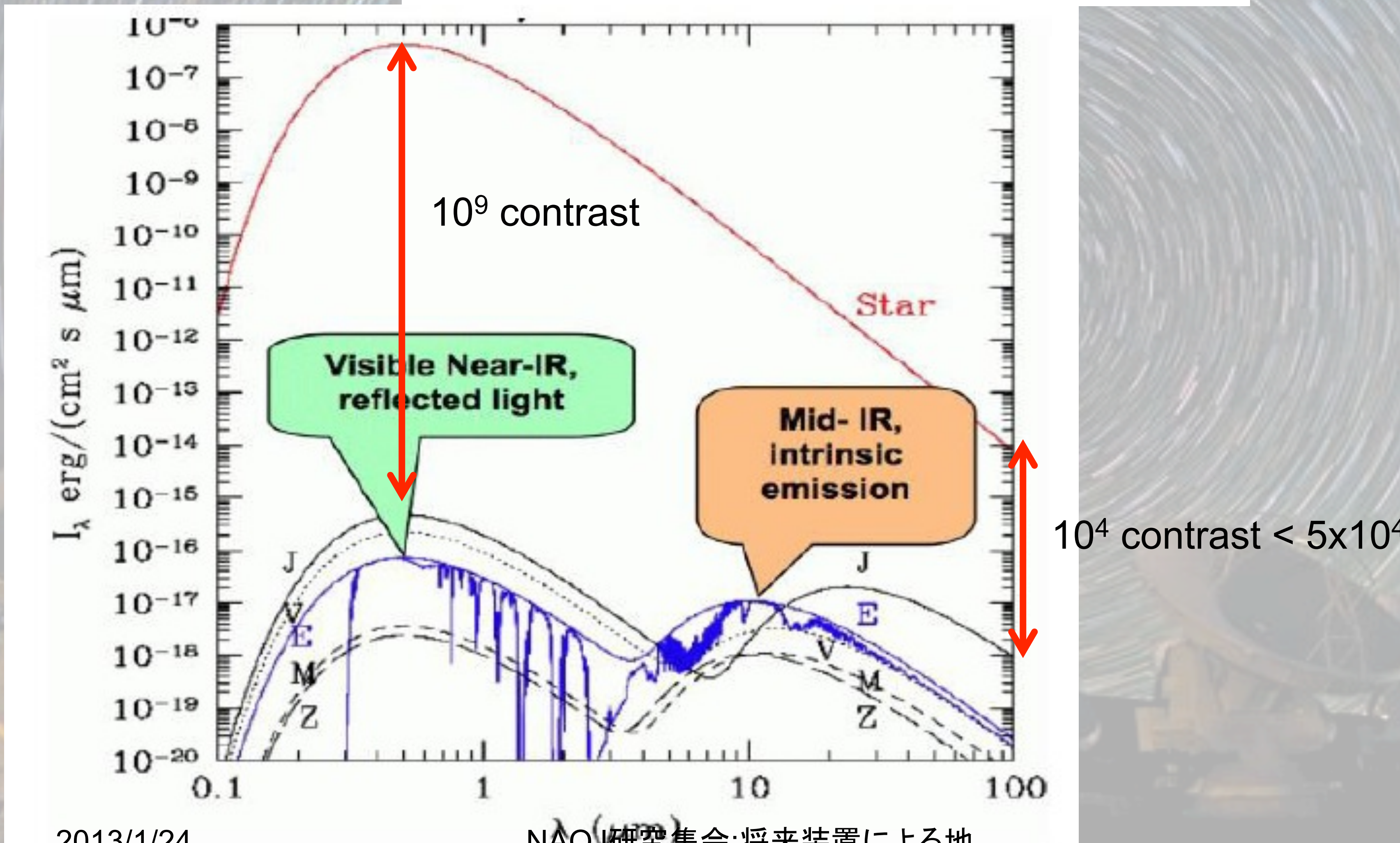
EXOPLANETS DETECTION

Detection of Exoplanets

- Direct Imaging
- Light Curve ofTransit Objects
- Astrometry <= not mentioned today

Direct Detection of Exoplanets

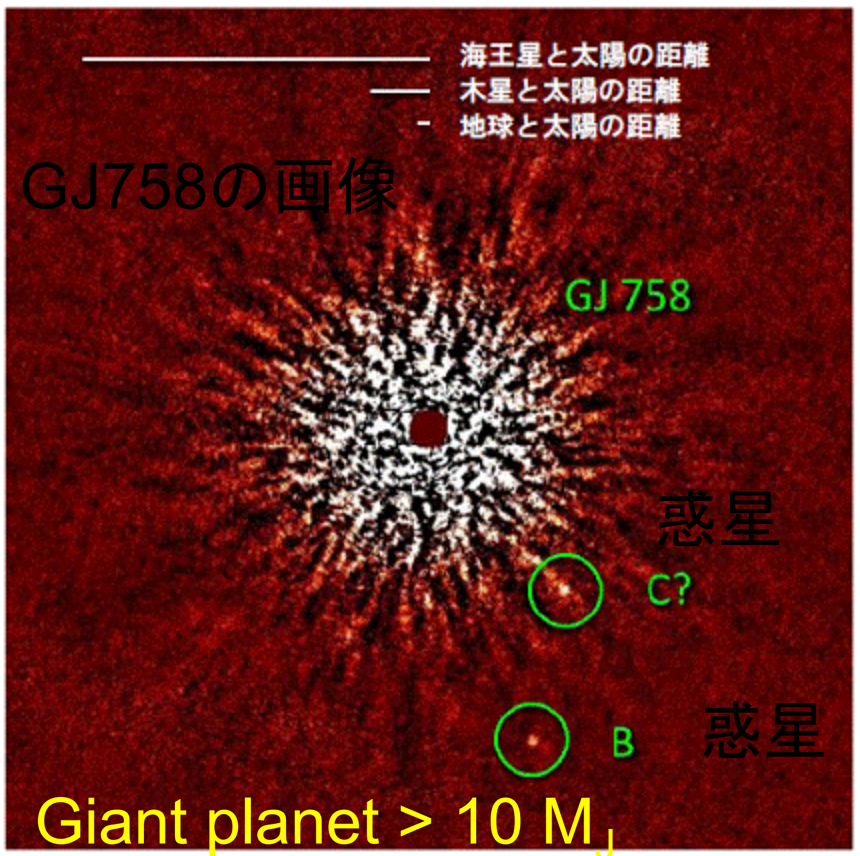
SED of Solar system objects at 10 pc distance



Extra Solar Giant Planets

Giant Planets are directly imaged.

> 850 planets since 1995



Dynamic Range

Overcome Dynamic Range Issue

- It is not trivial for ALMA to achieve a high dynamic range of 10^4 dependent distance from a bright object.
- Strategy
  – Late type stars (K, M) e.g. 0.1 Mo with 10^{-3} Lo
  – Known distant giant planets
  – Transit objects

Feasibility of Transit Targets

Jupiter/Super-Jupiter detectable with ALMA

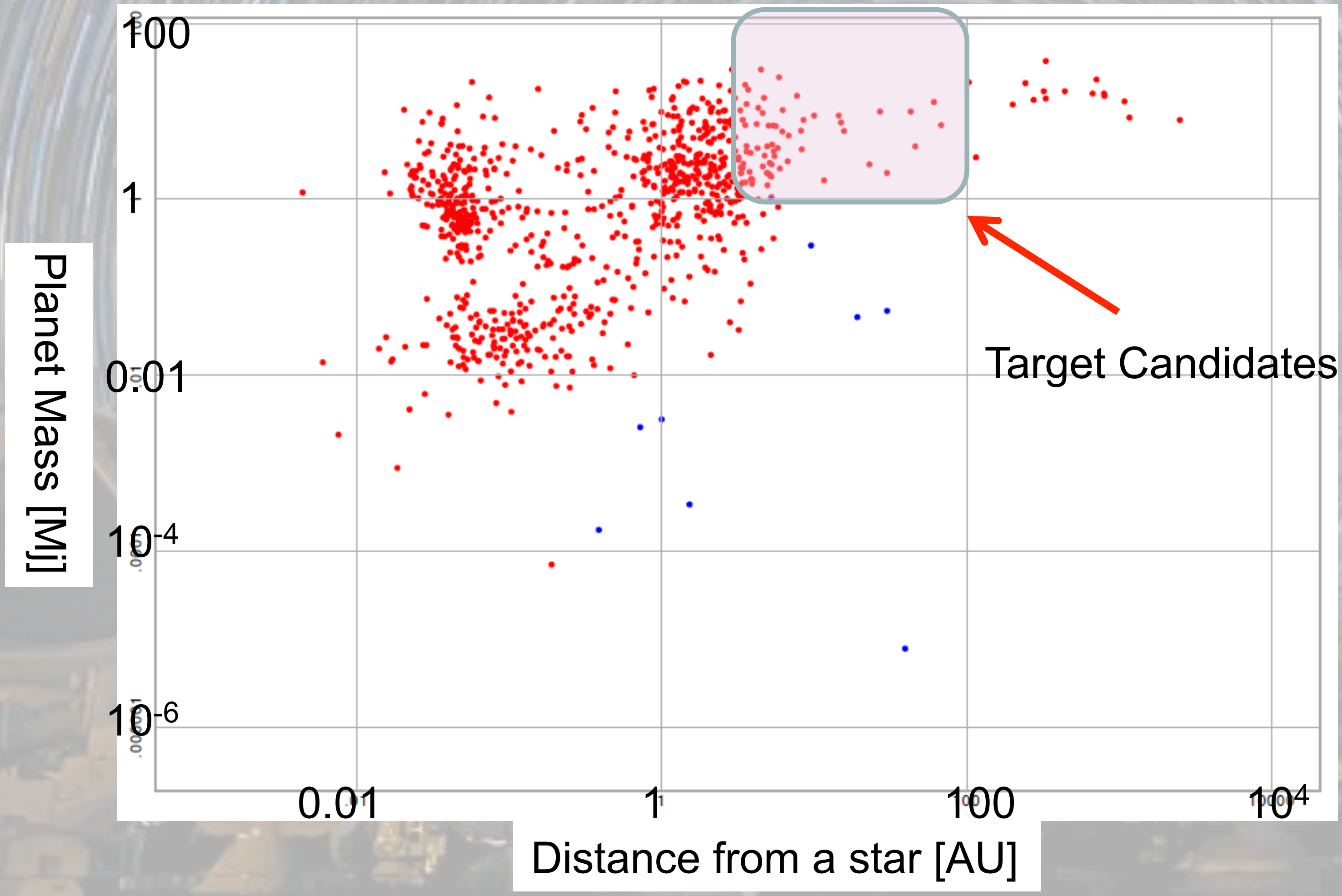
- Consider 2 cases
  - Jupiter (T=200 K, R=1 Rjup)
  - Super Jupiter (T=200 K, R=2.5 Rjup)
  - Flux densities at 345 GHz (uJy)

Distance (pc)	Jupiter	Super Jupiter
1	10.0	62.3
2	2.49	15.6
5	0.40	2.49
10	0.10	0.62

Yellow: detectable

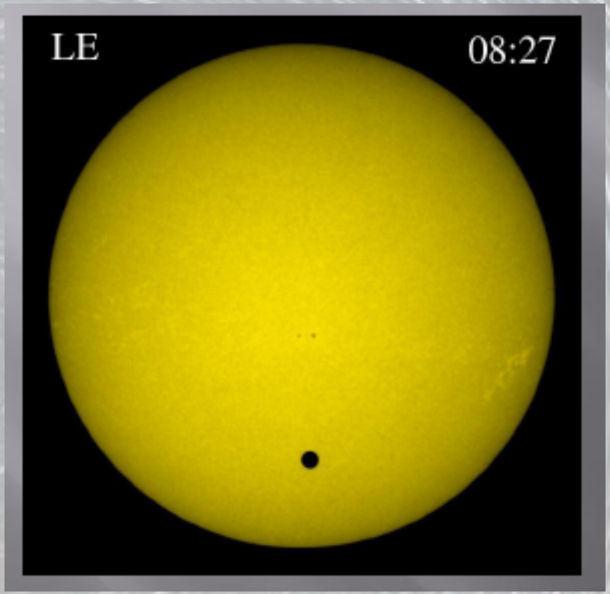
Target Candidates

Massive Planets exist at reasonable distance



Transiting Planets

- Orbits nearly edge-on
- A solar-like star
  - 1 % for Jupiter size planet
  - 0.01 % for Earth size planet
- Technically Feasible
  - Star itself is 2 mJy at 3.8 pc
  - 1 % = 20 uJy at 3.8 pc for a few hours
  - Advantage to OPT/IR?



Venus transit on 08-Jun-2006.

TOWARD FUTURE CAPABILITY

Enhancement of ALMA

- Antenna
  - Increase Diameter
  - Increase Efficiency
- Receiver
  - Decrease Receiver Noise
  - Increase Bandwidth
- Backend
  - Increase Bandwidth
- Correlator
  - Increase Bandwidth
  - Increase quantum efficiency

Moreover
Decrease Coherence Loss
Improve calibration Technique
Improve Imaging Technique

Summary

- ALMA powerful capability opens various planetary science
- Solar System studies with ALMA
- Detection of Extra Solar Giant planets
- Toward Future
  - Lessons learned from ALMA should be reflected to a future array design.