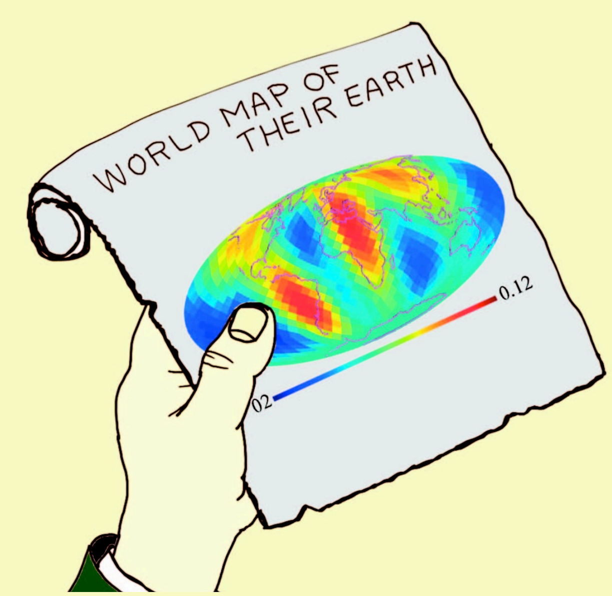
直接検出で系外惑星の何を知ることができるだろうか？

What can we know about exoplanets via "direct detection" ?

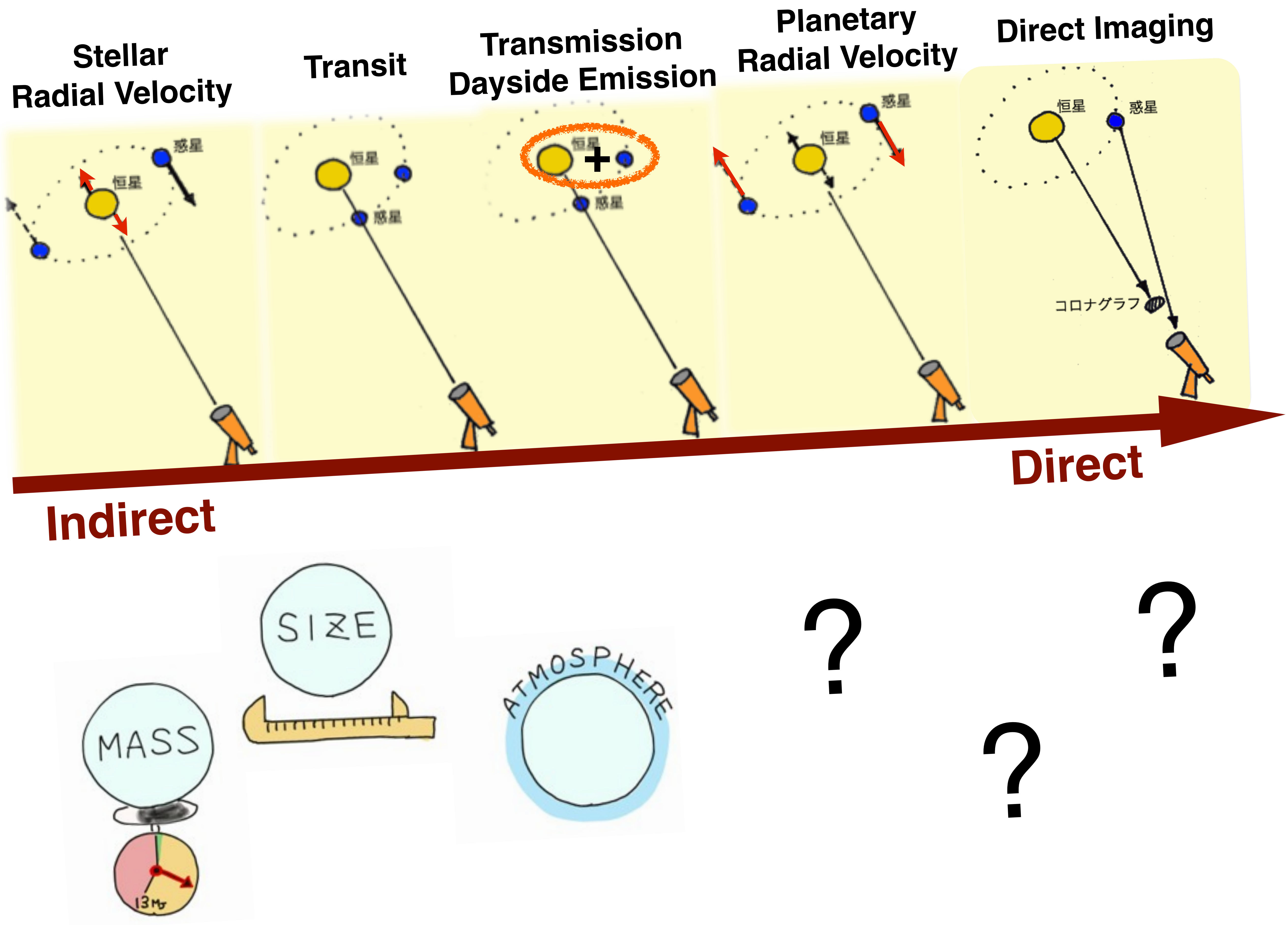
Hajime Kawahara

The University of Tokyo

Earth and Planetary Science



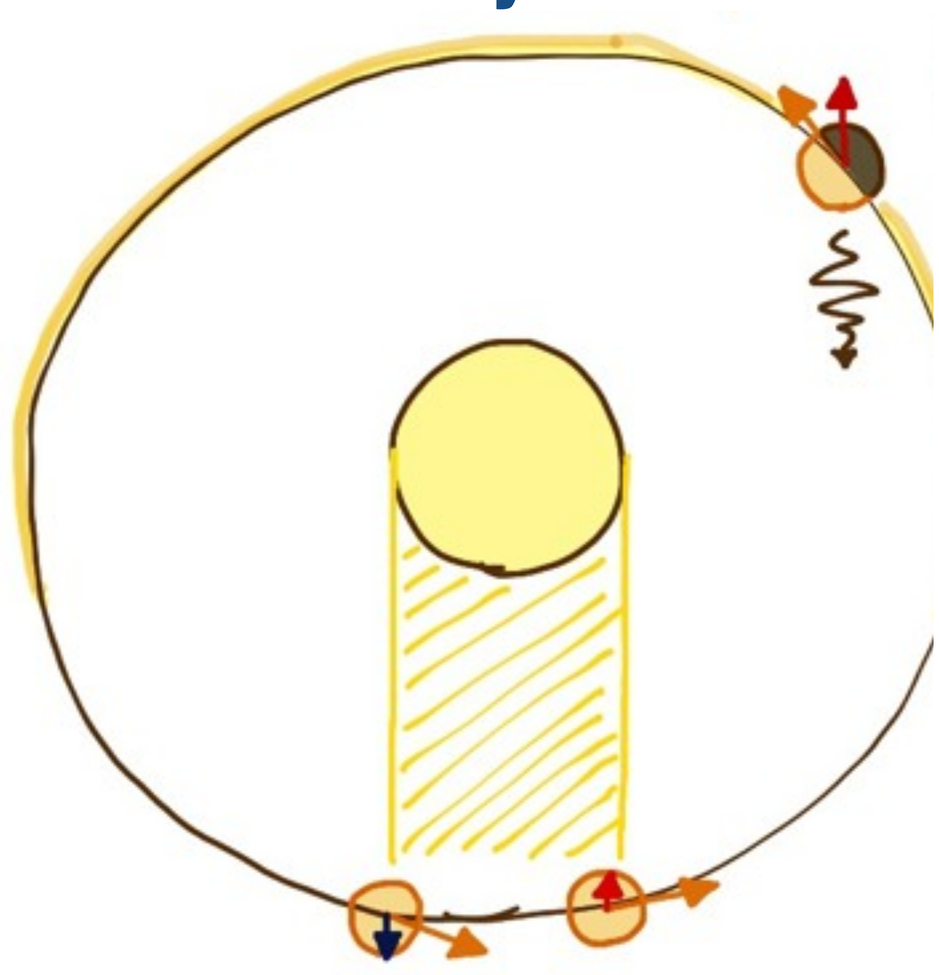
Direct Detection of Exoplanets is very Impressive !
But... What Really Can We Know ?



Stellar
Radial Velocity
Transit
Transmission
Dayside Emission
Planetary
Radial Velocity
Direct Imaging
惑星
恒星
コロナグラフ
Indirect
Direct
MASS
13MJ
SIZE
ATMOSPHERE
?
?
?

1. Planetary Radial Velocimetry

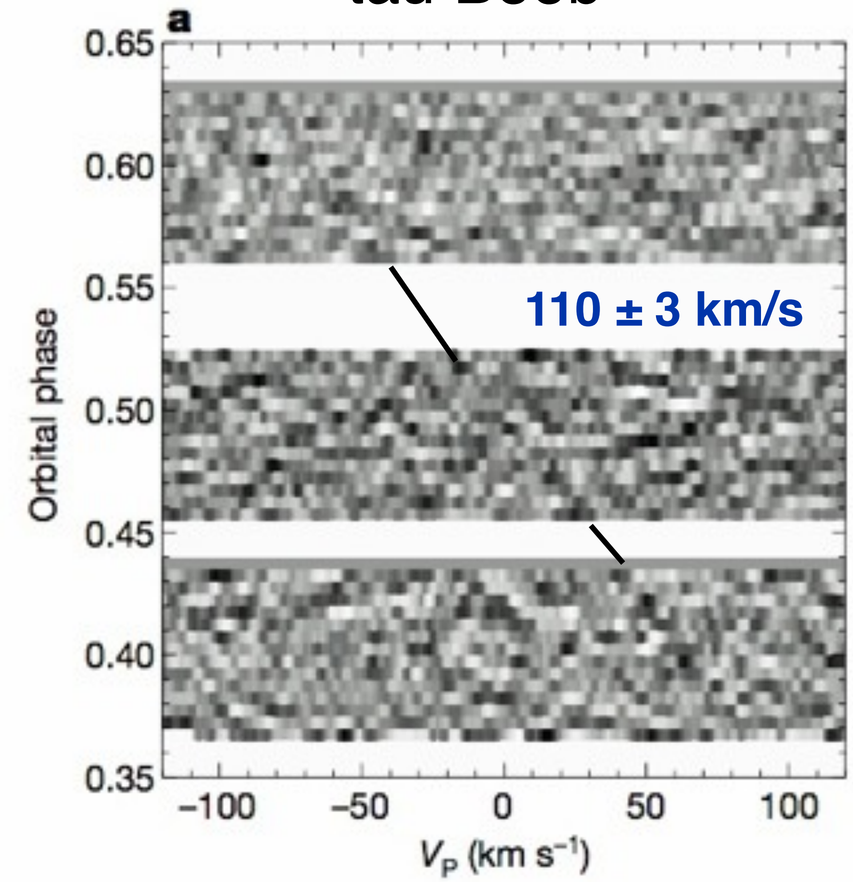
in dayside



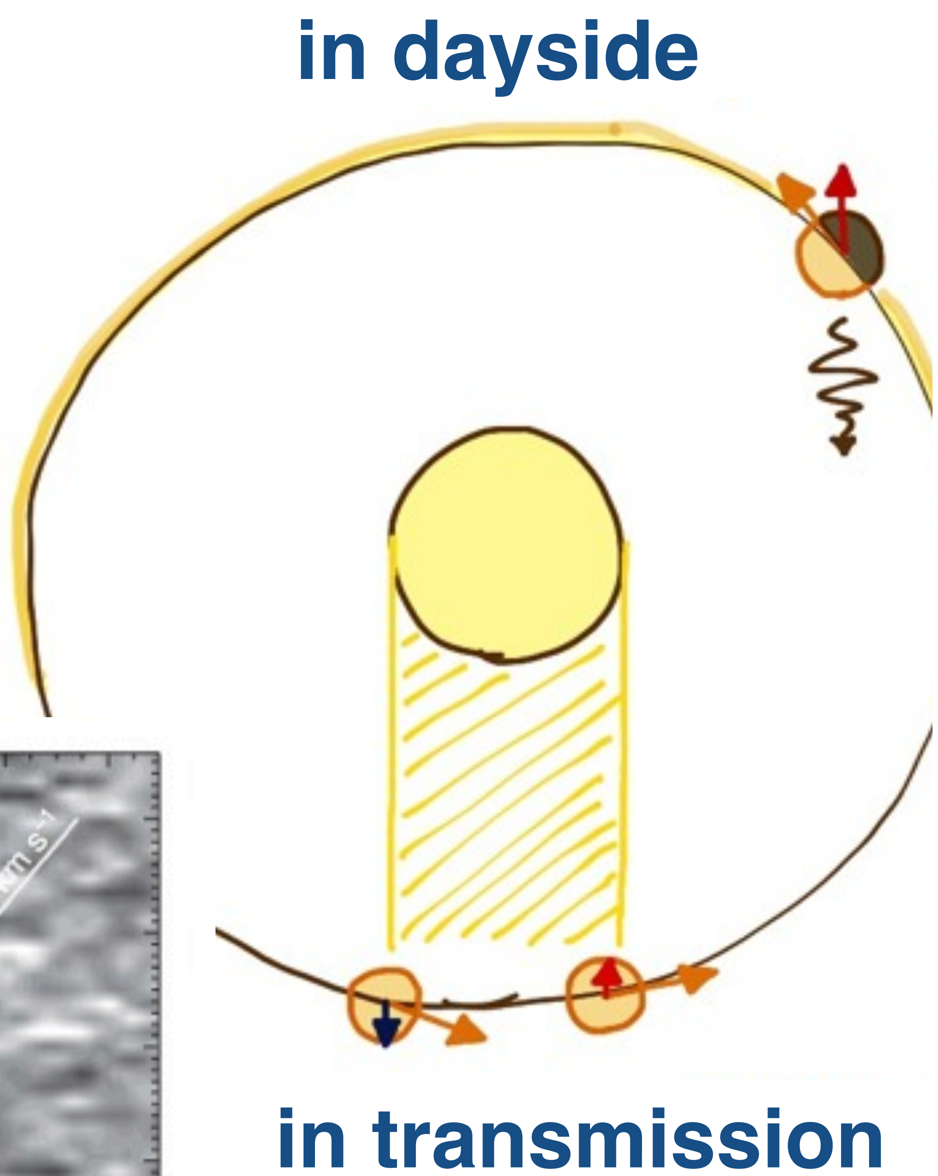
in transmission

PRV is derived from planetary absorption lines
in Stellar+Planet emission

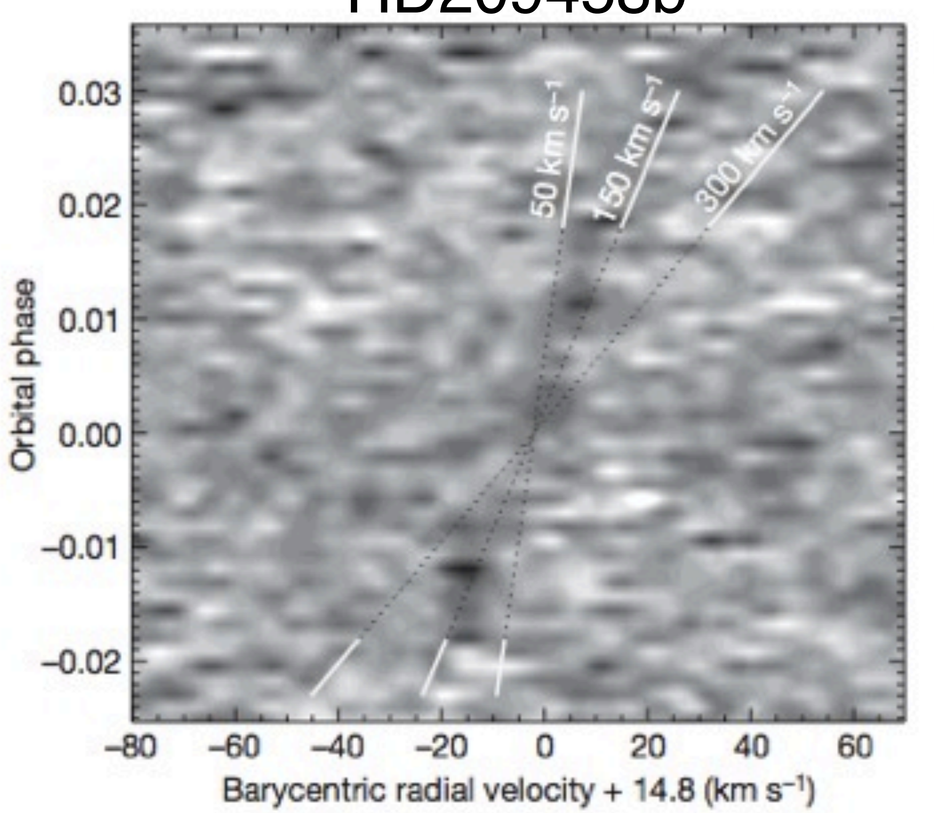
tau Boob



Brogi et al. 2012, Nature 486, 502



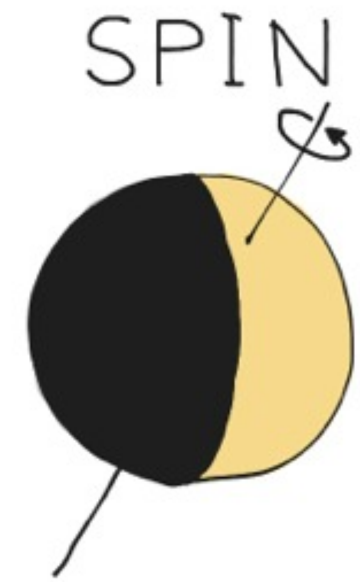
HD209458b



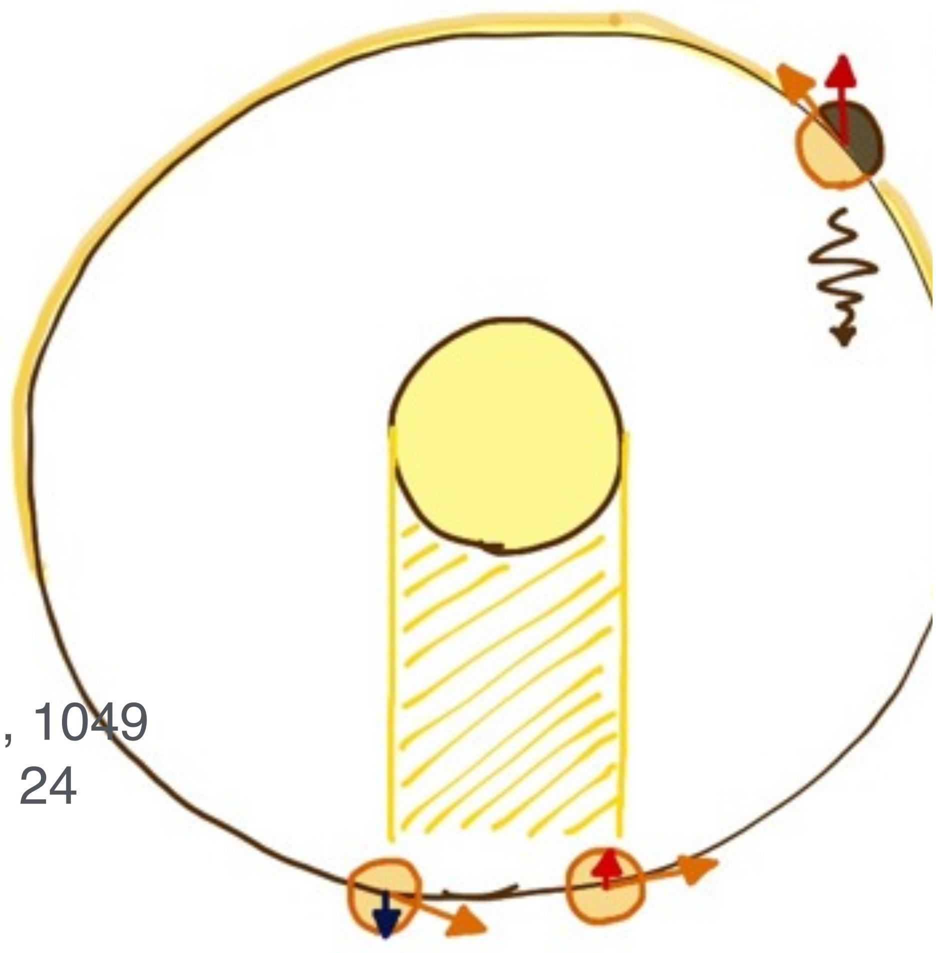
Snellen et al. 2010, Nature 465, 1049

VLT/CRIRES

CO Lines in K band



in dayside

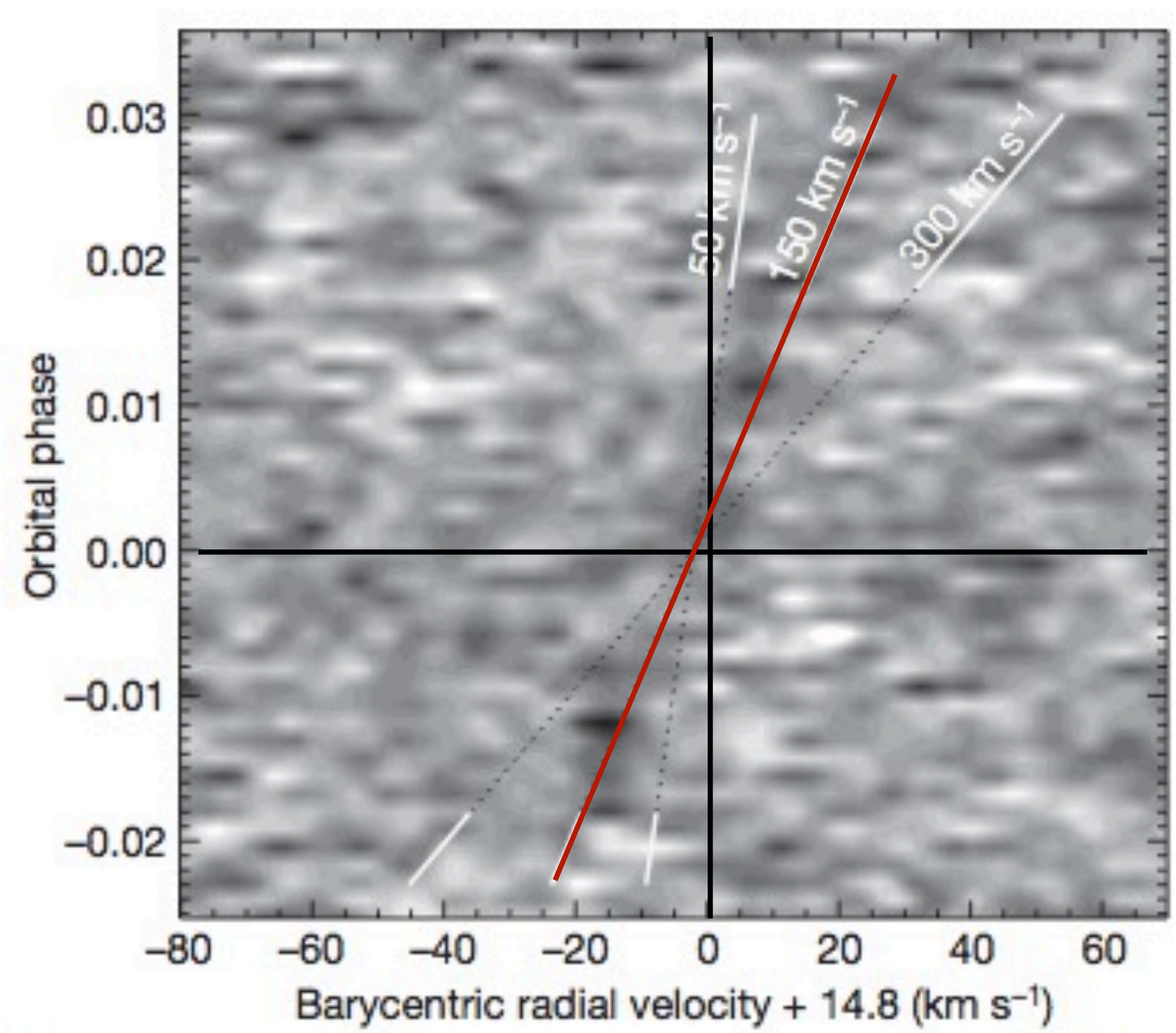


Kawahara 2012 ApJL, 760, 13

Snellen et al. 2010, Nature 465, 1049
Showman et al. 2012, ApJ 762, 24

in transmission

Day-to-Night Wind Effect on PRV in Transmission Spectra

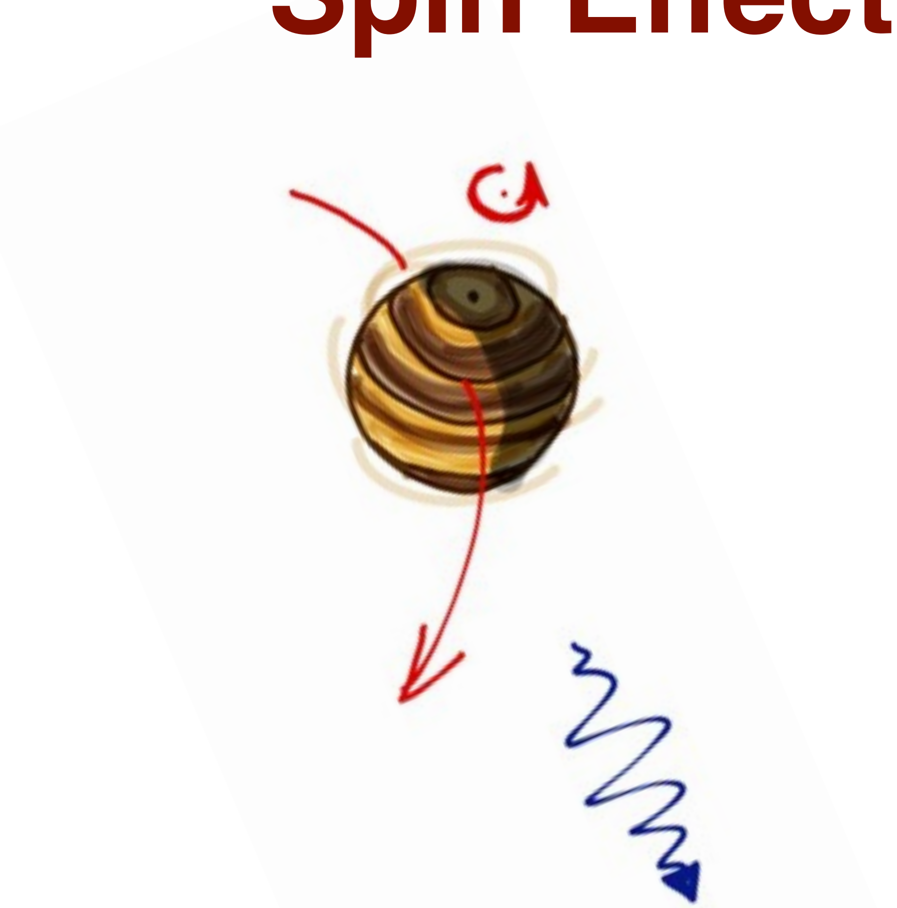


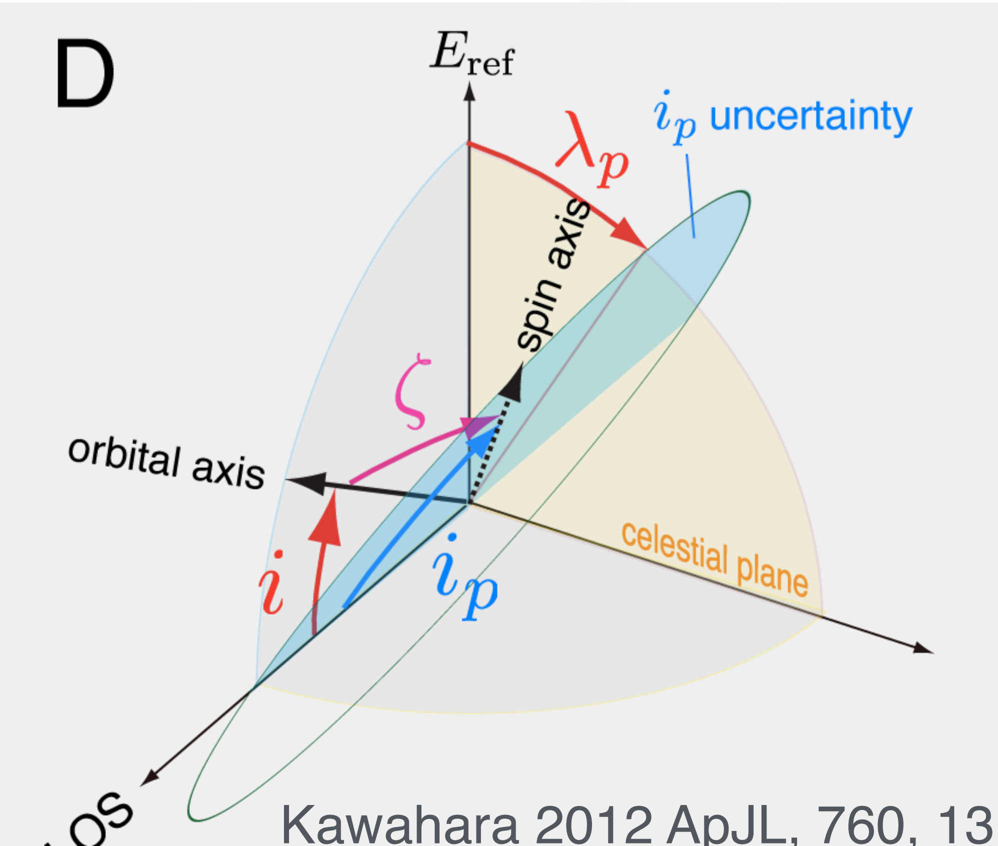
Snellen et al. 2010, Nature 465, 1049

Showman et al. 2012, ApJ 762, 24

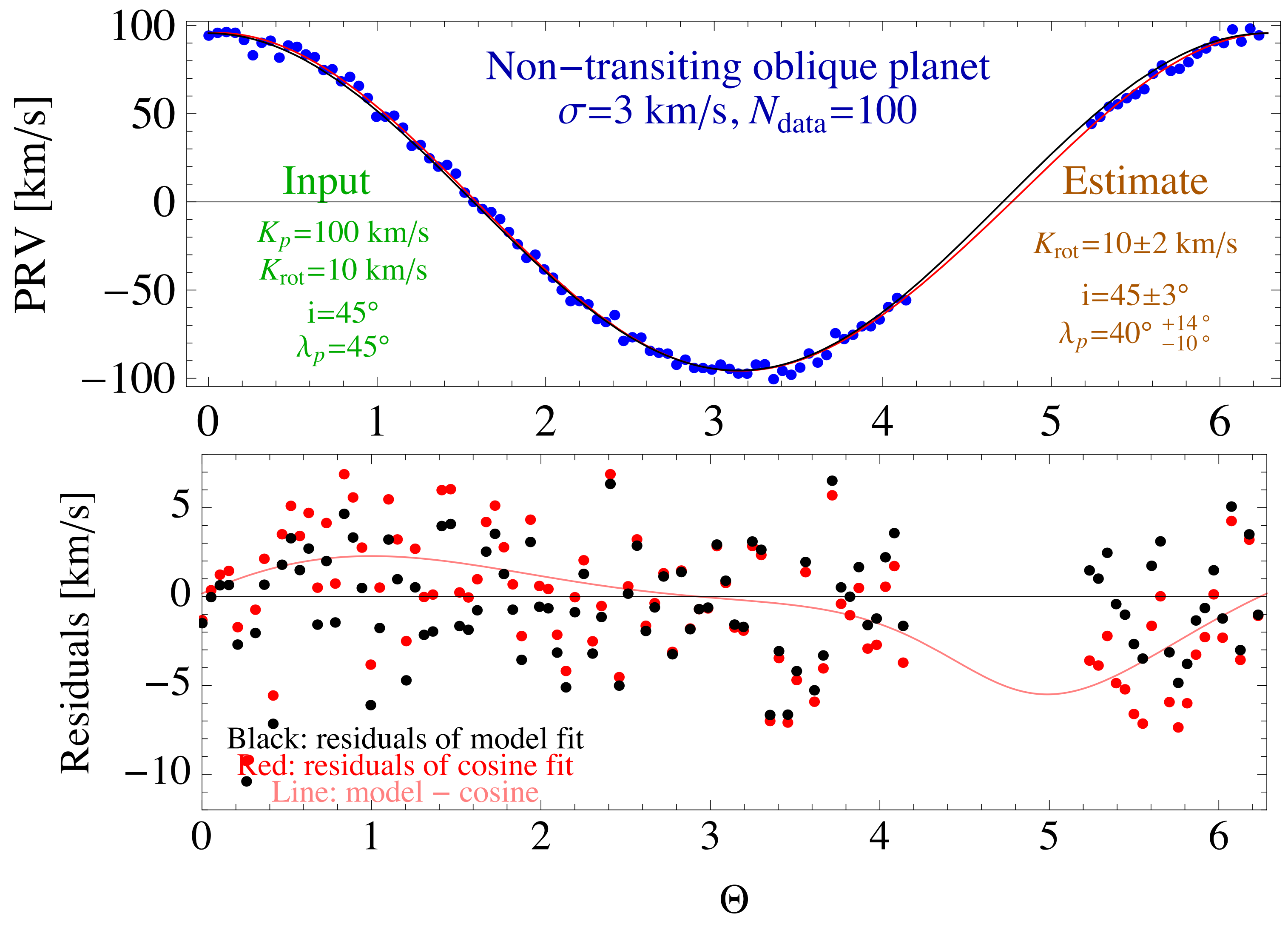
v = 2±1 km/s ? for HD209458b
or
small eccentricity

Spin Effect on PRV in Dayside Spectra





Kawahara 2012 ApJL, 760, 13

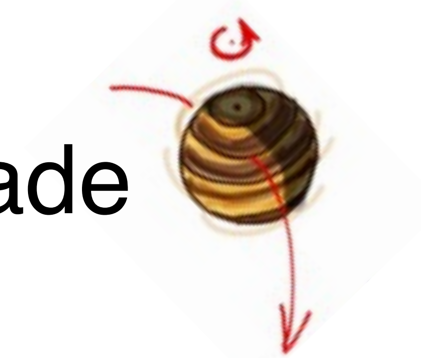


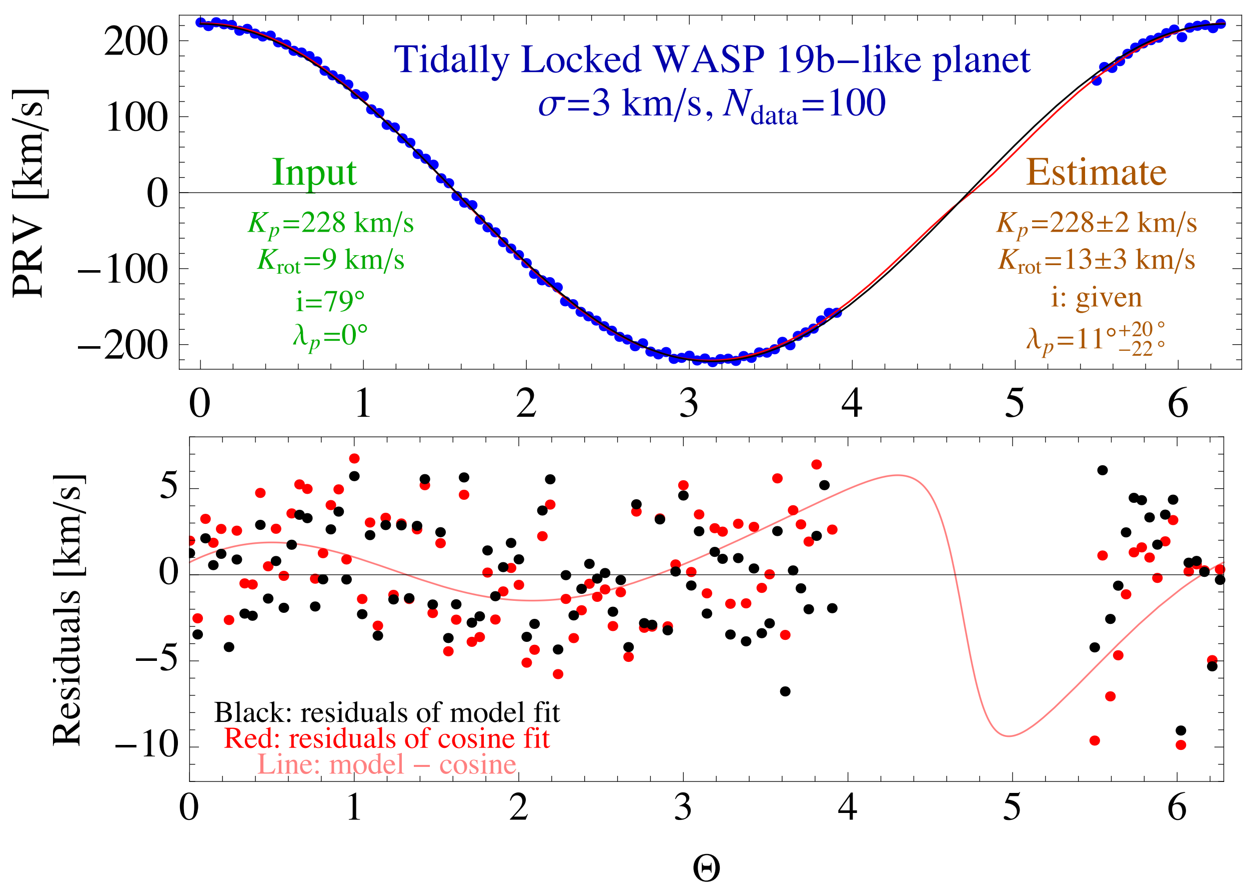
The PRV curve depends on a projected angle between an orbital axis and a spin axis

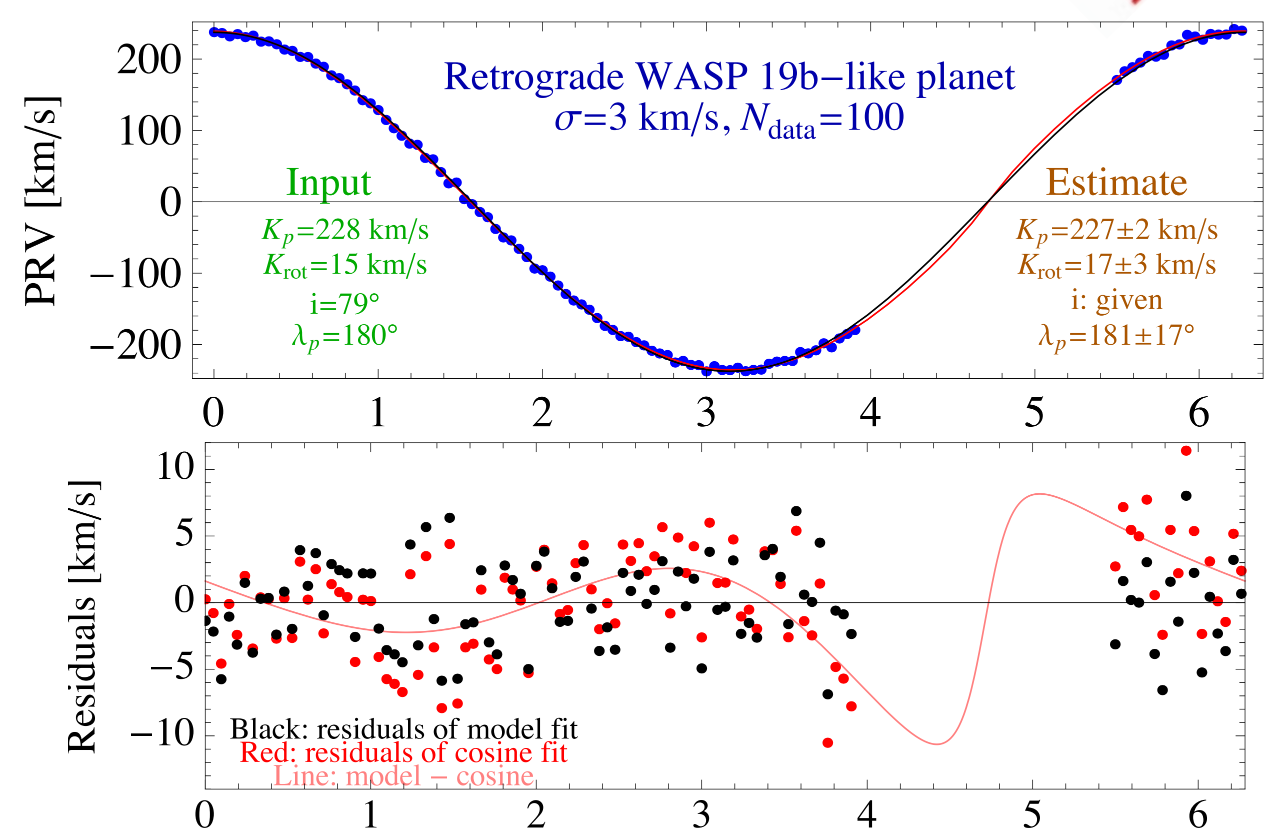
ex) Are Hot Jupiters Really Tidally Locked ?

Tidally Locked

Retrograde





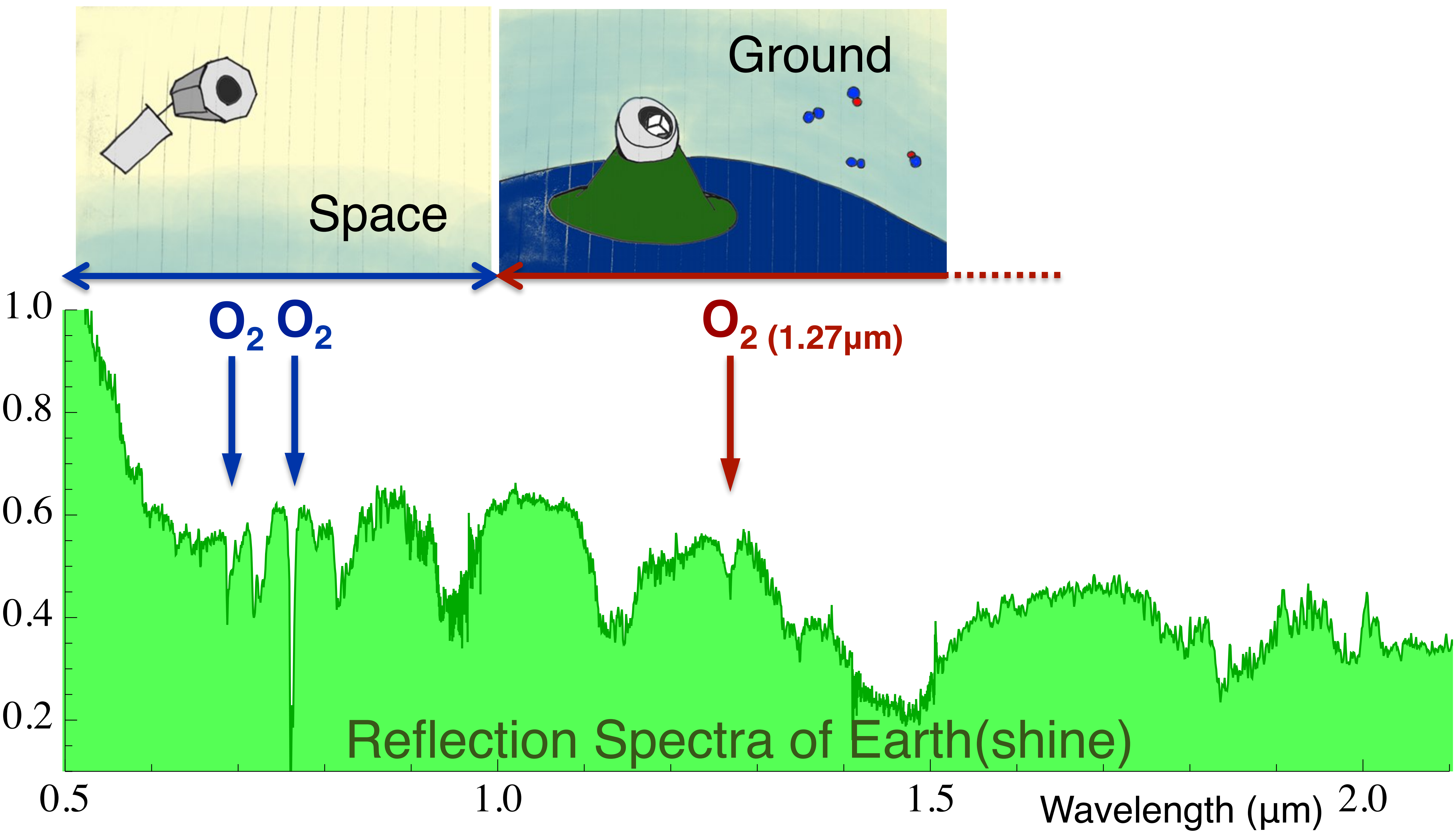


Kawahara 2012 ApJL, 760, 13

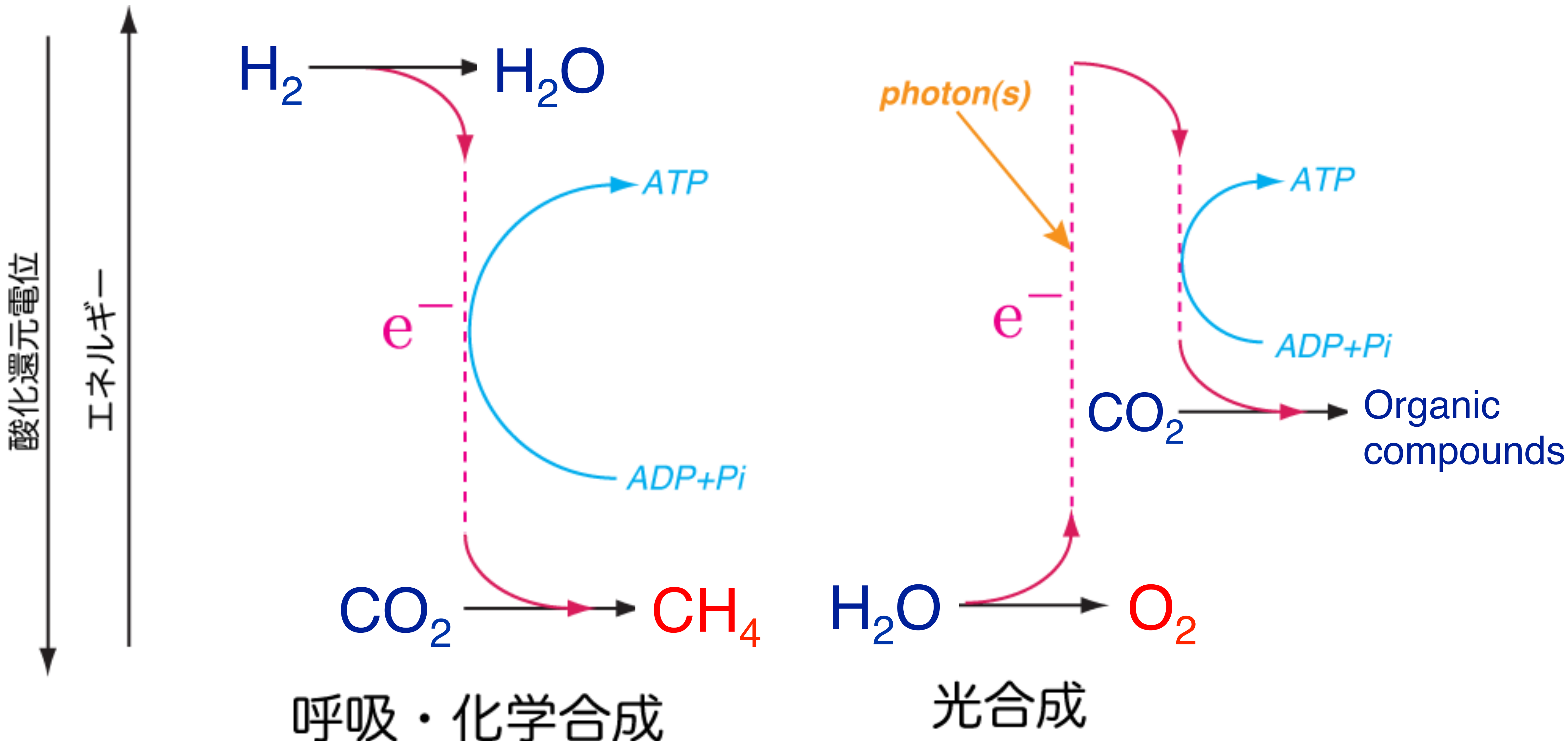
CRIRES on VLT, IRD on Subaru
or high dispersion spectrometer in ELTs
(R~100,000)

2. Direct Imaging with E-ELTs

Well Known Virtue of Direct Imaging = Spectroscopy



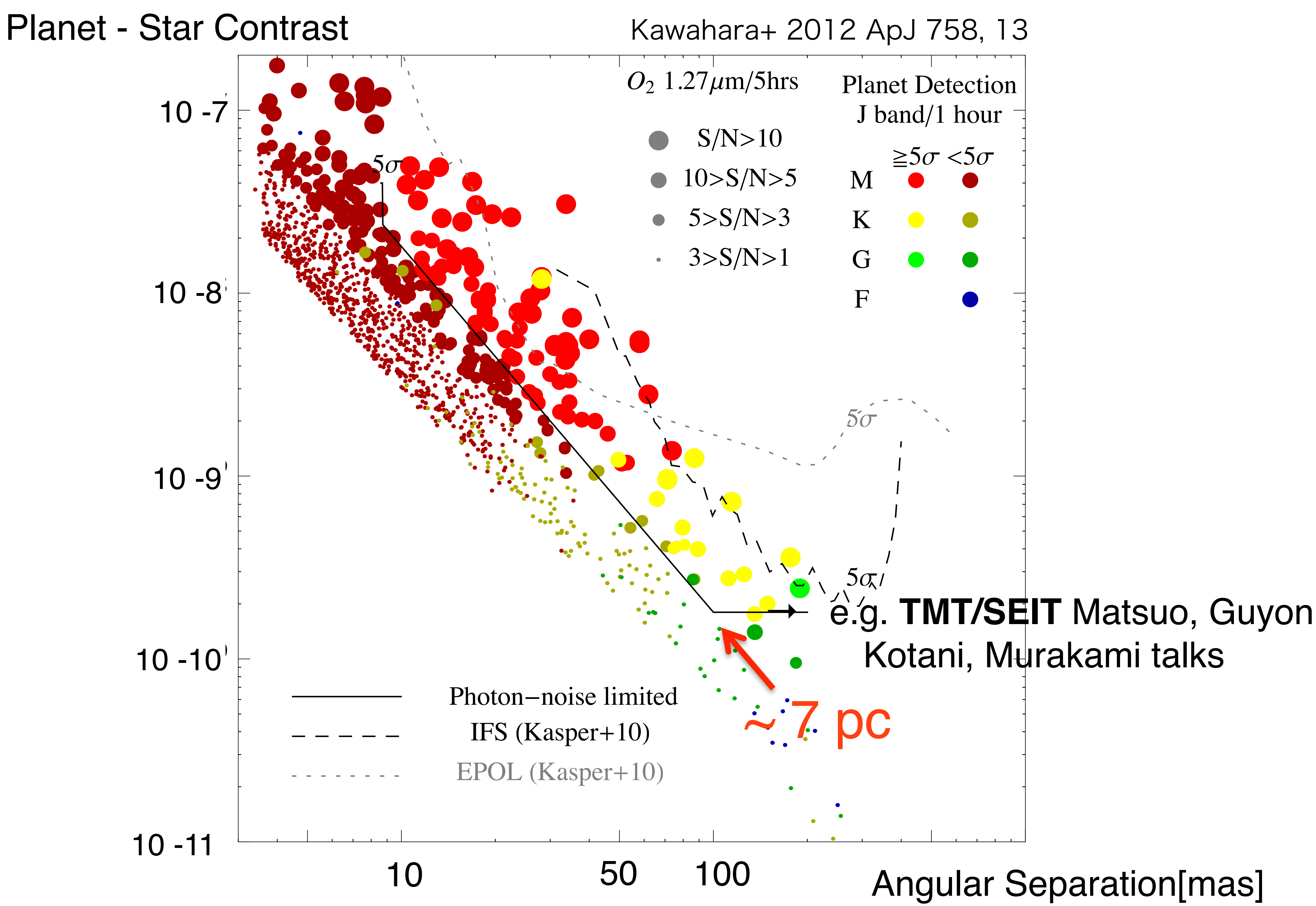
Metabolic Biomarker



de Duveの図を改変

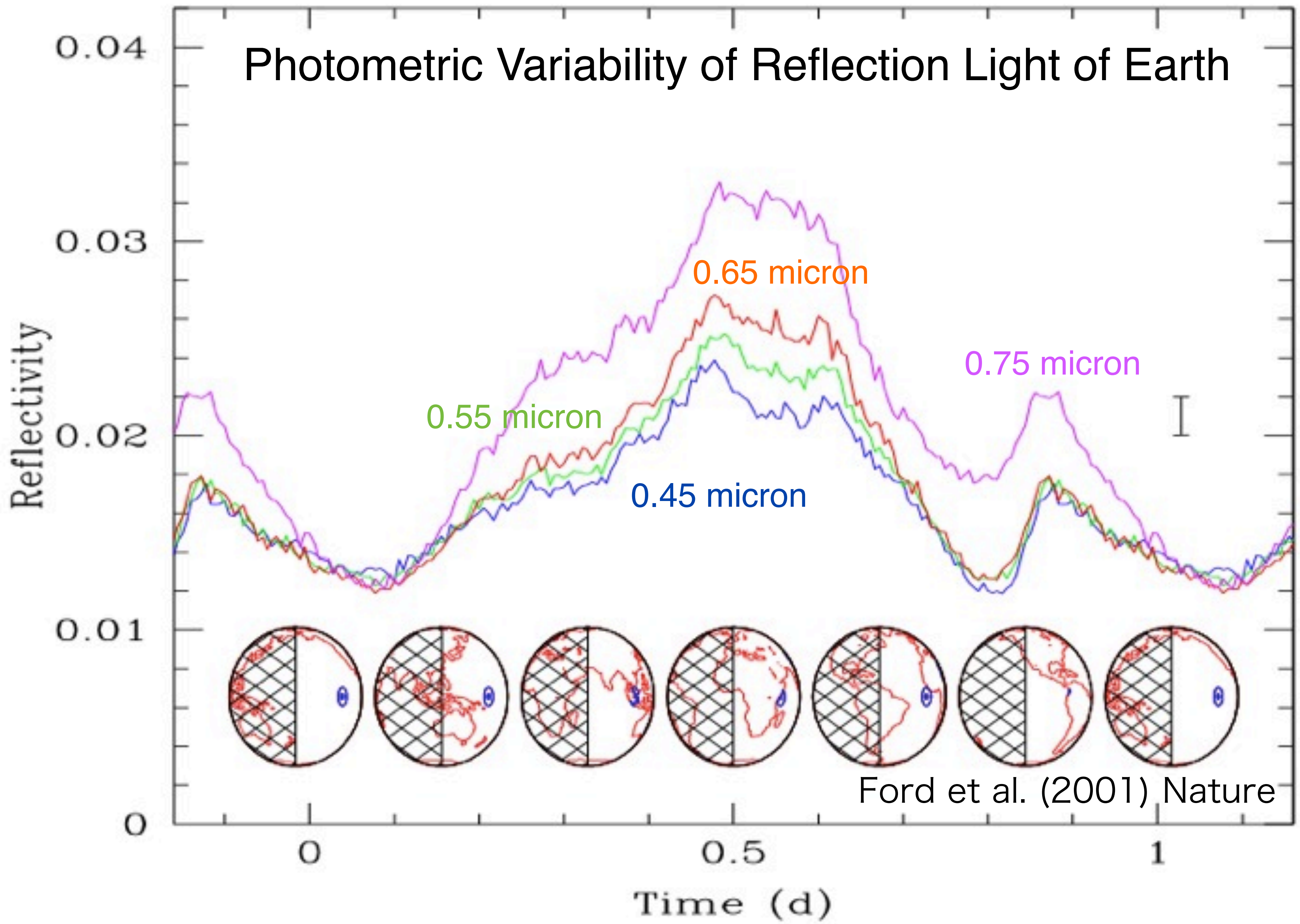
respiration　　　photosynthesis

a Hypothetical Earth-twin at Inner Habitable Edge around Nearby Stars

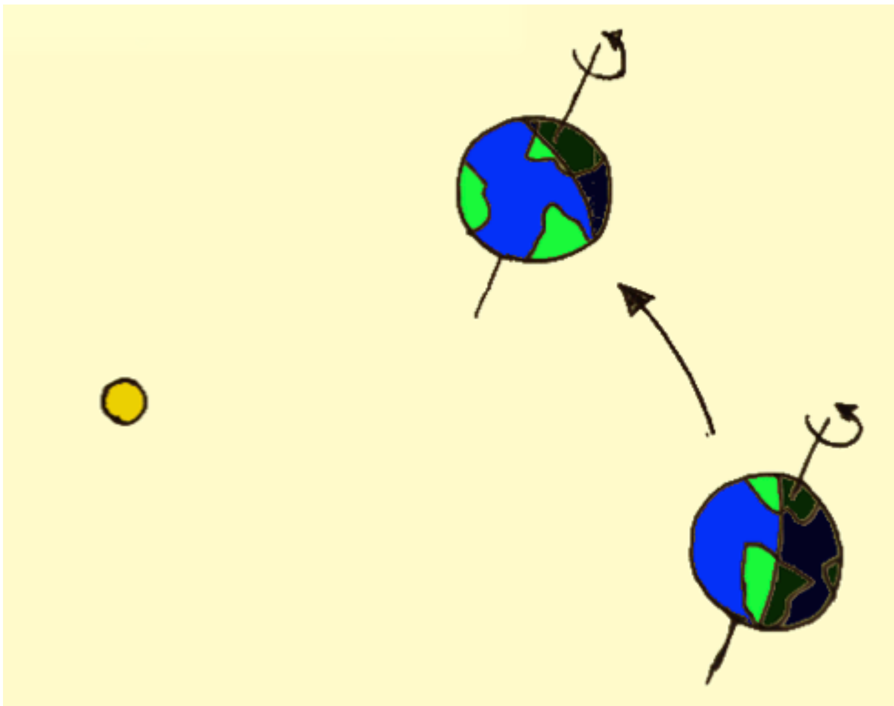


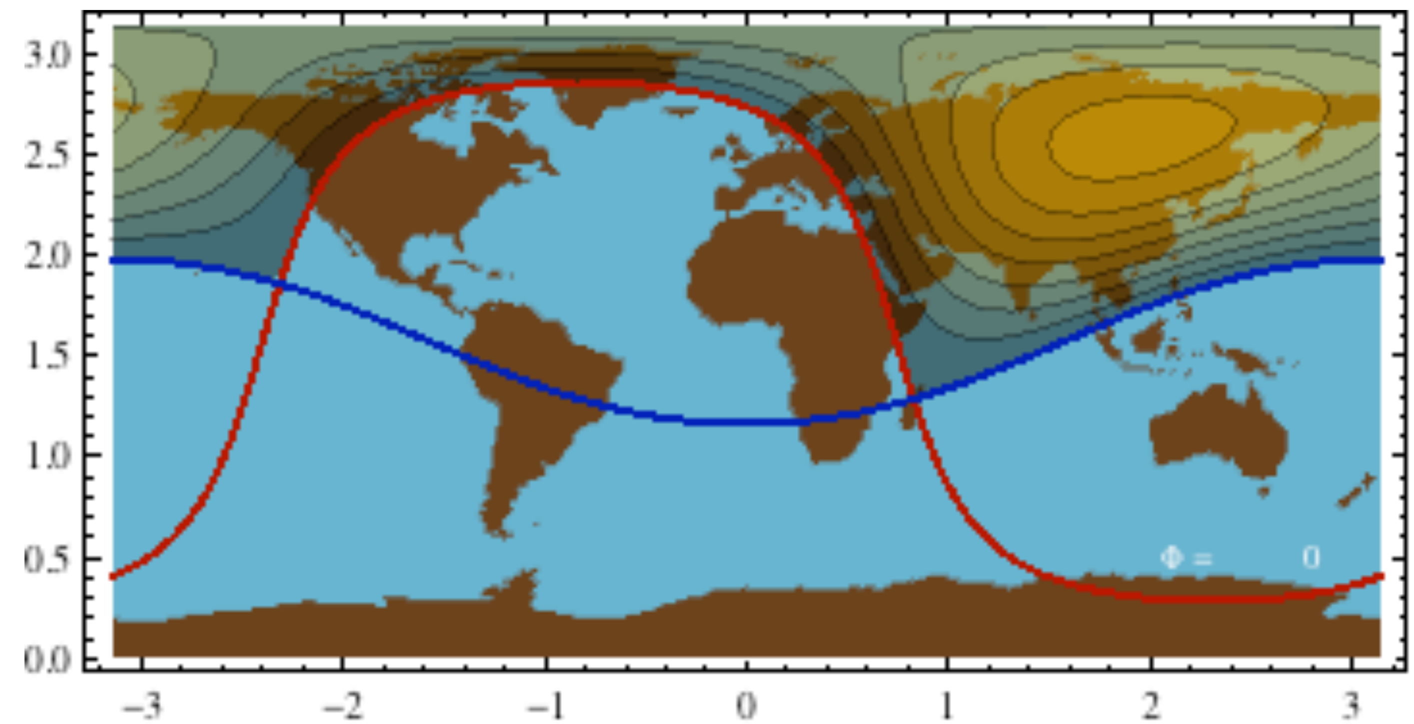
3. Direct Imaging with High Precision/ Stable Photometry

Less Known Virtue of Direct Imaging = Surface Inhomogeneity and Mapping



Spin-Orbit Tomography





Intensity (planet/star)

Reflectivity

$$d(t) = \int \underline{W(t, \phi, \theta; \mathbf{w})}\, m(\phi, \theta)\, d\,\Omega + \epsilon$$

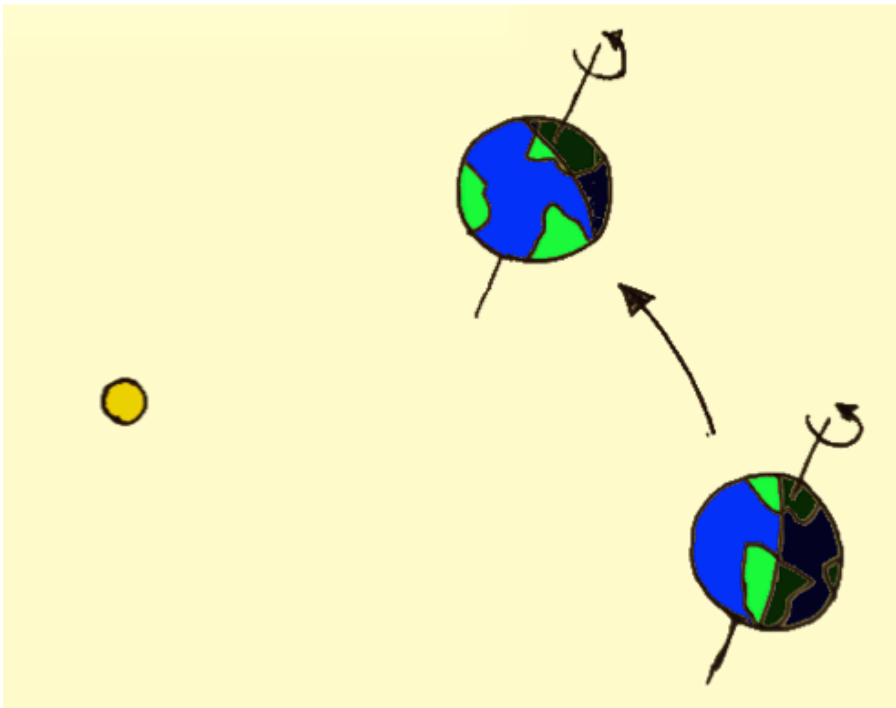
Weight at planetary surface(ϕ, θ)

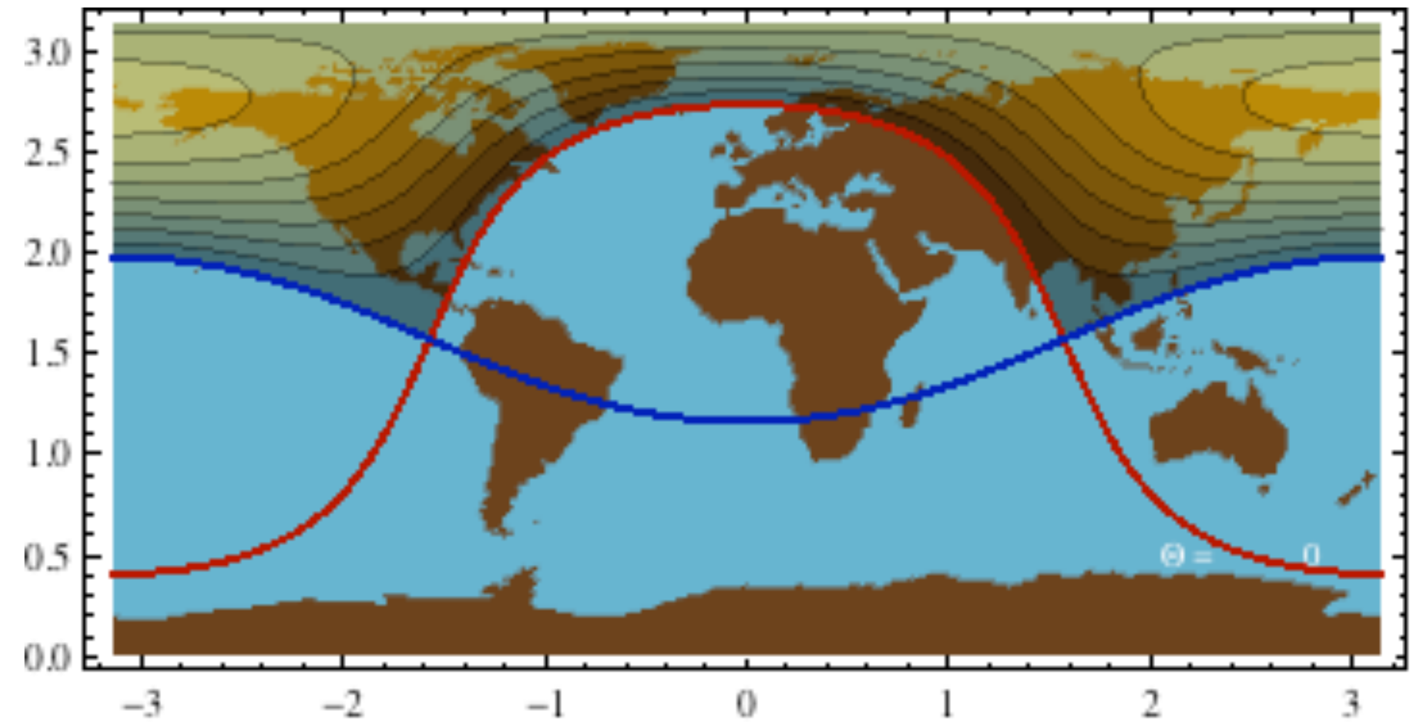
Noise

1D Mapping : Cowan+2009, Oakley and Cash 2009, Fujii+2010,11

2D Mapping : Kawahara & Fujii 2010, 11, Fujii and Kawahara 2012

Spin-Orbit Tomography





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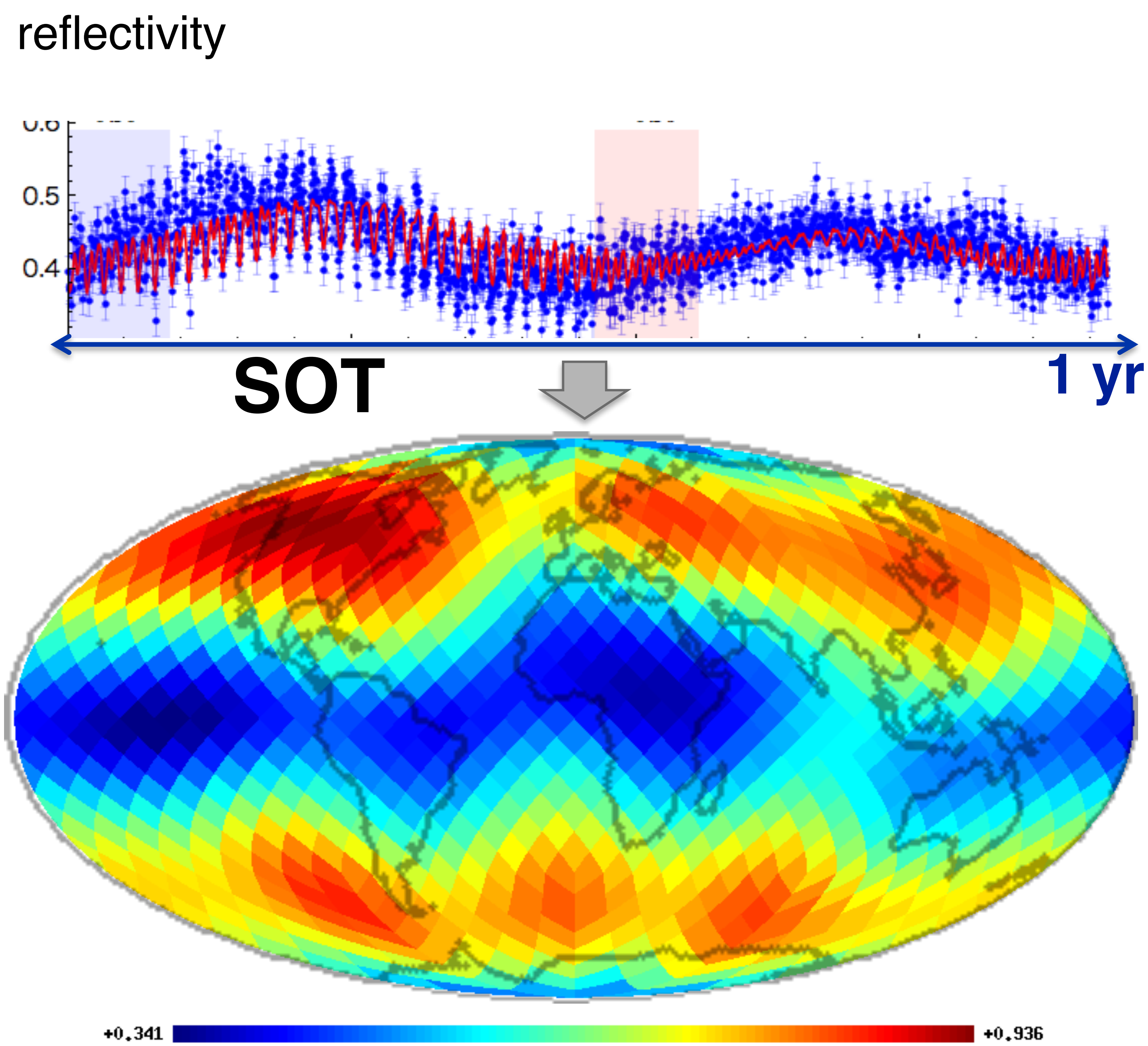
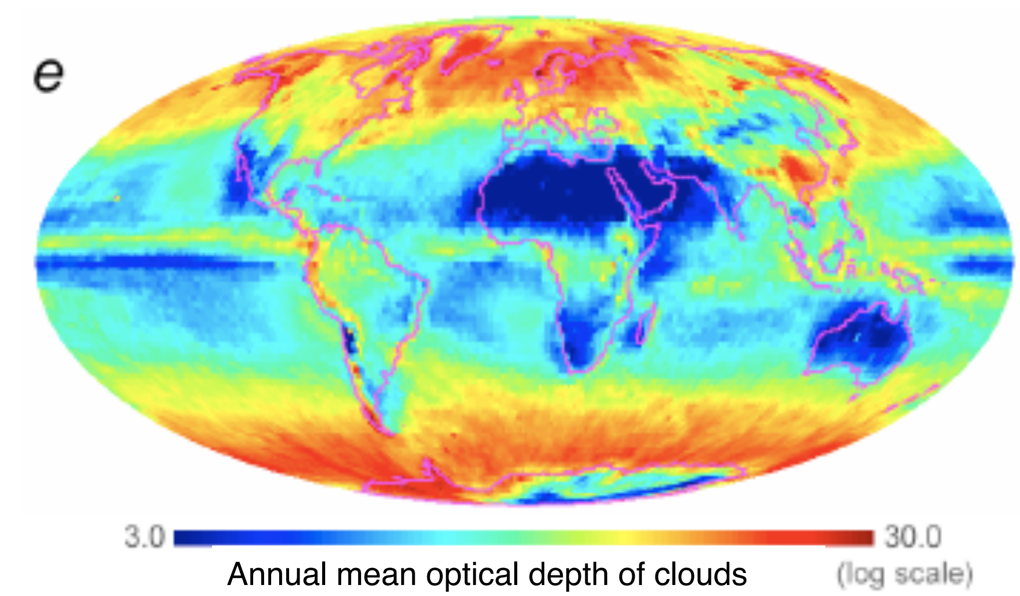
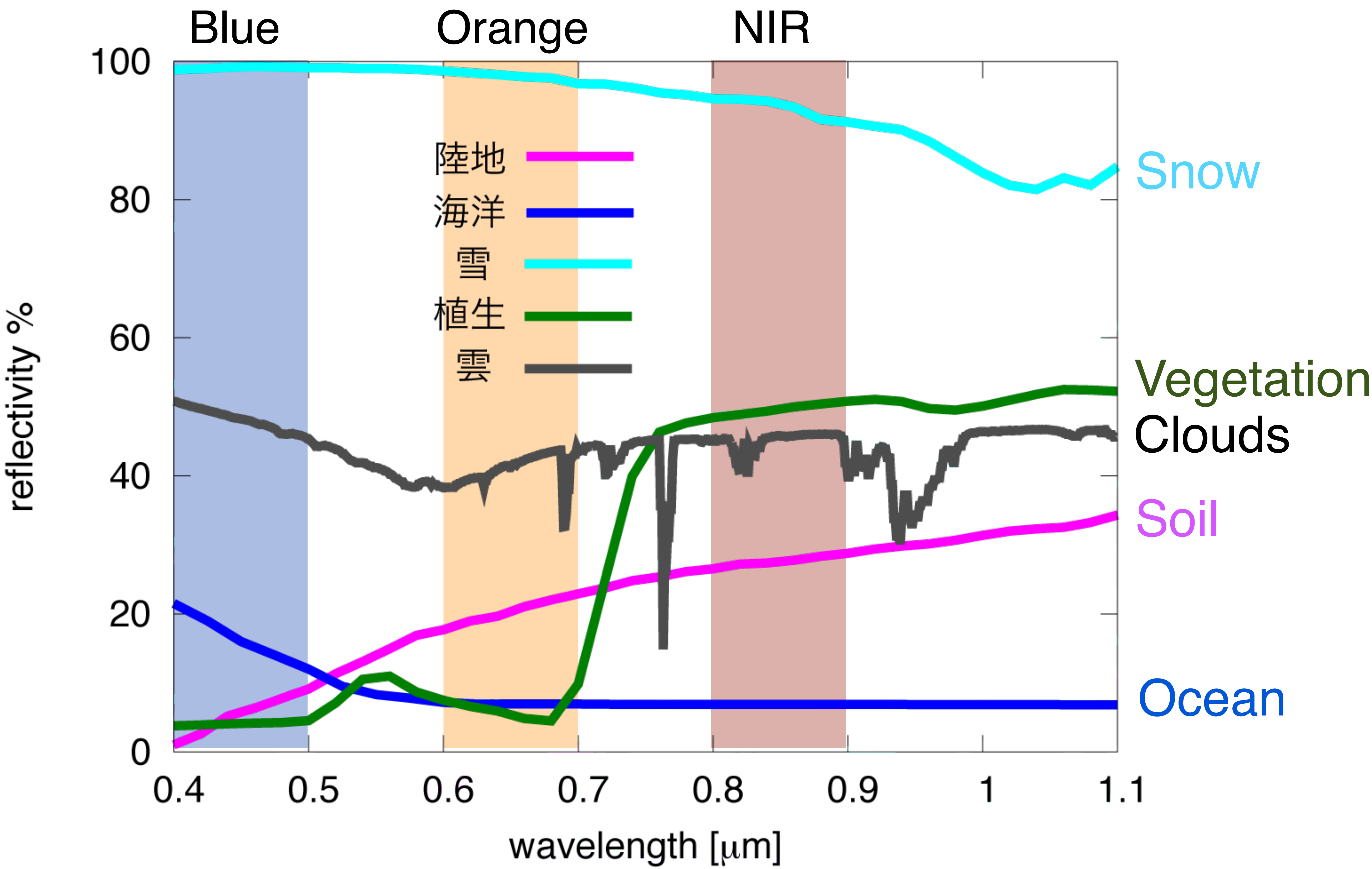
Spin-Orbit Tomography

Kawahara and Fujii 2010,2011,
Fujii and Kawahara 2012



Retrived map of blue band (0.4-0.5 micron)

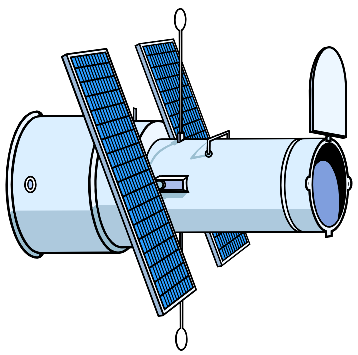




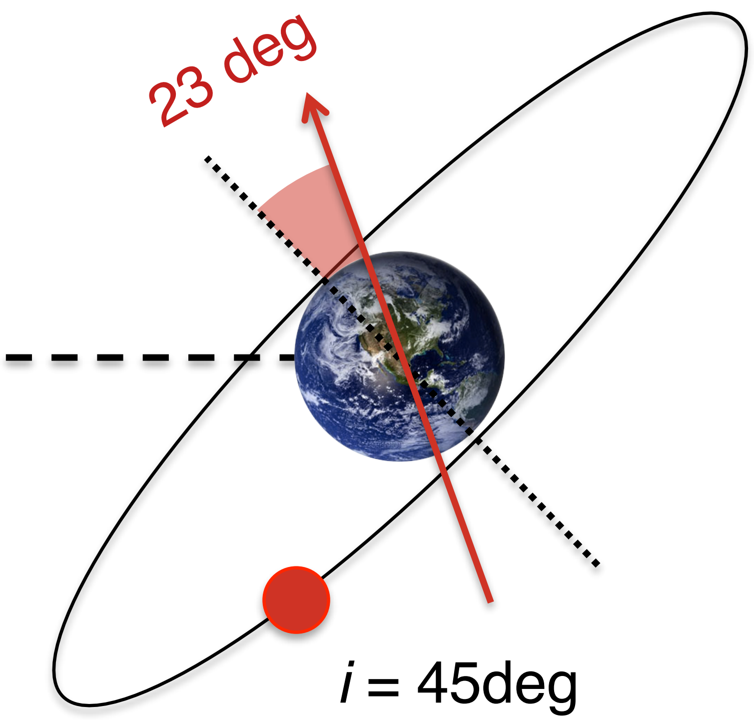
Blue
Orange
NIR
100
80
60
40
20
0
reflectivity %
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
wavelength [μm]
陸地
海洋
雪
植生
雲
Snow
Vegetation
Clouds
Soil
Ocean

Spin-Orbit Tomography

Requirement: stability of relative flux (planet/star) measurement within a few % during 0.5 year

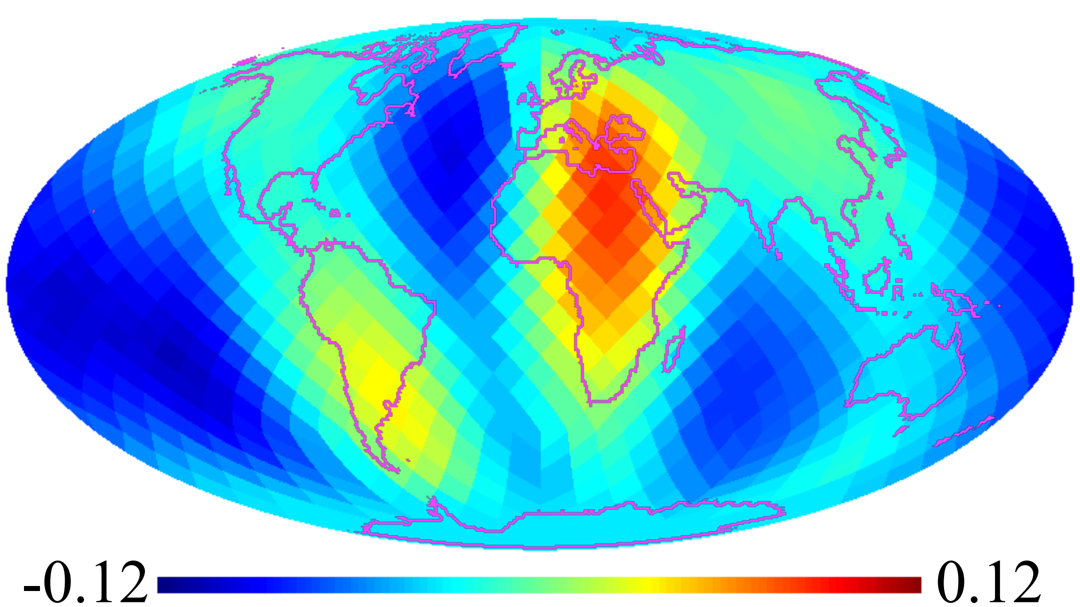


10 pc ~ 30光年

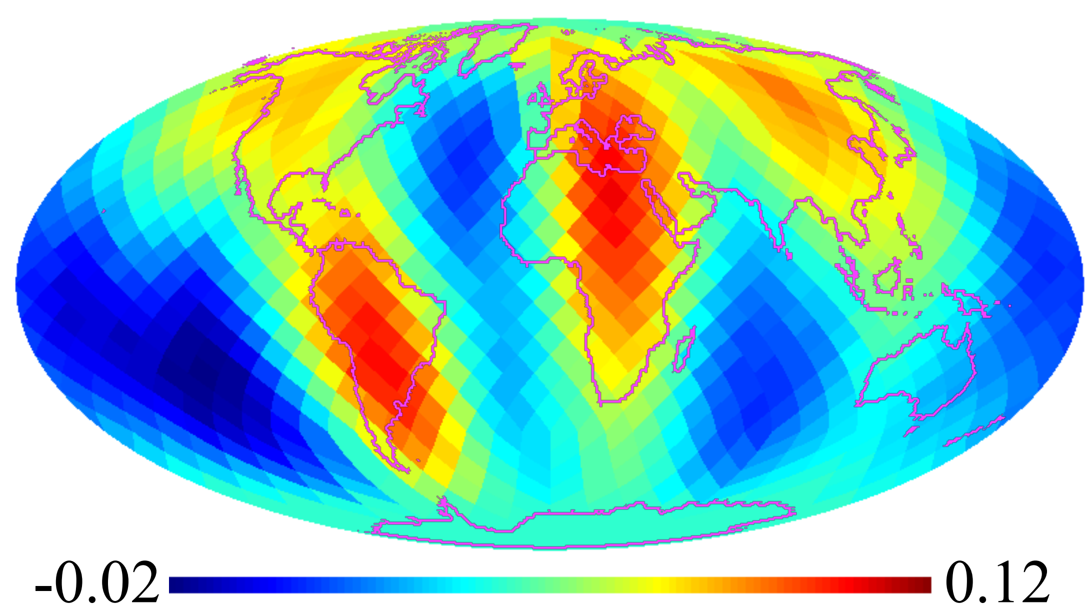


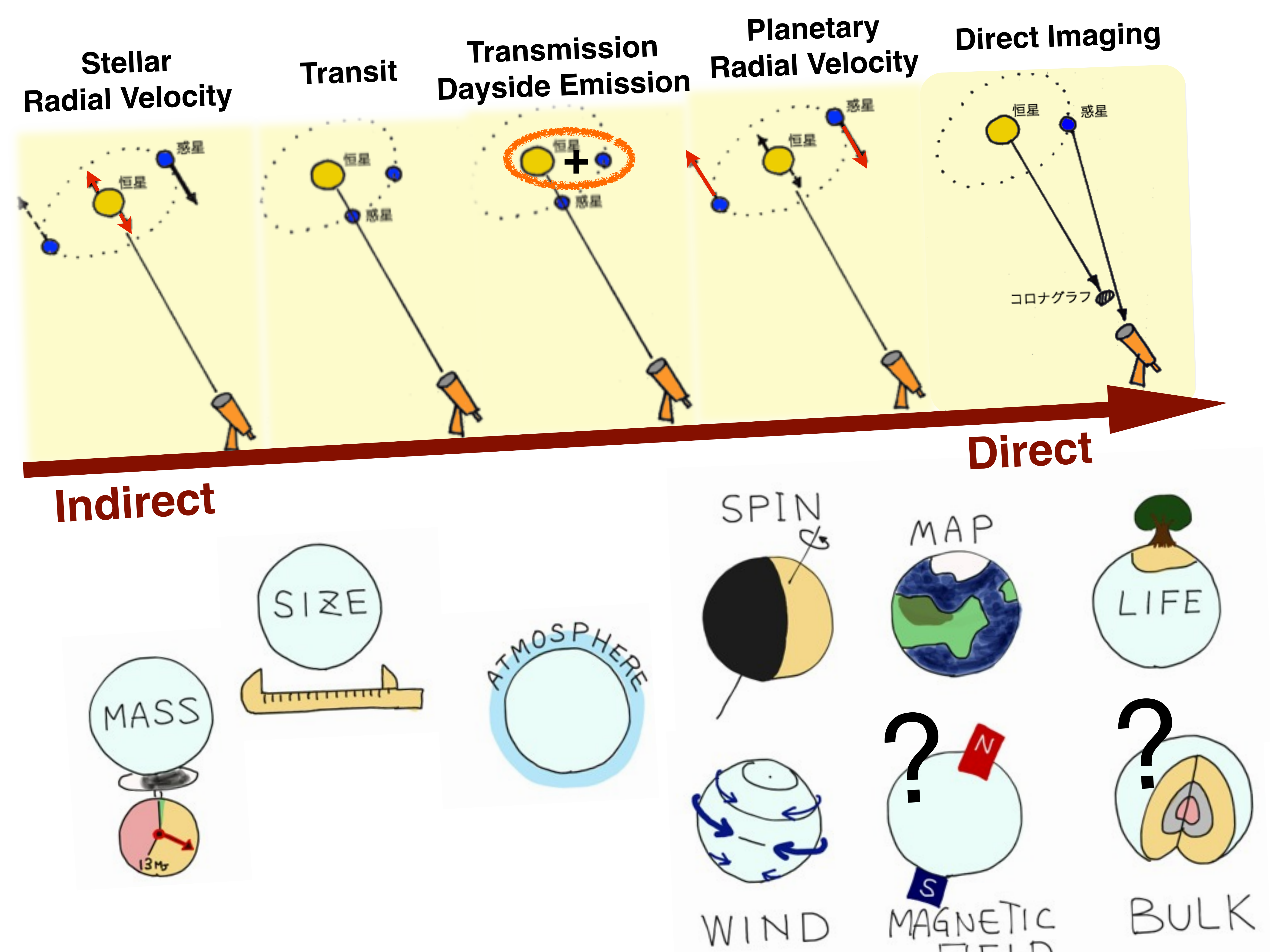
4 - 15 m telescope

NIR-Blue (SN=100)



NIR-Orange (SN=100)





Stellar Radial Velocity
Transit
Transmission Dayside Emission
Planetary Radial Velocity
Direct Imaging
惑星
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コロナグラフ
Indirect
Direct
MASS
SIZE
ATMOSPHERE
SPIN
MAP
LIFE
WIND
MAGNETIC
BULK
N
S
?