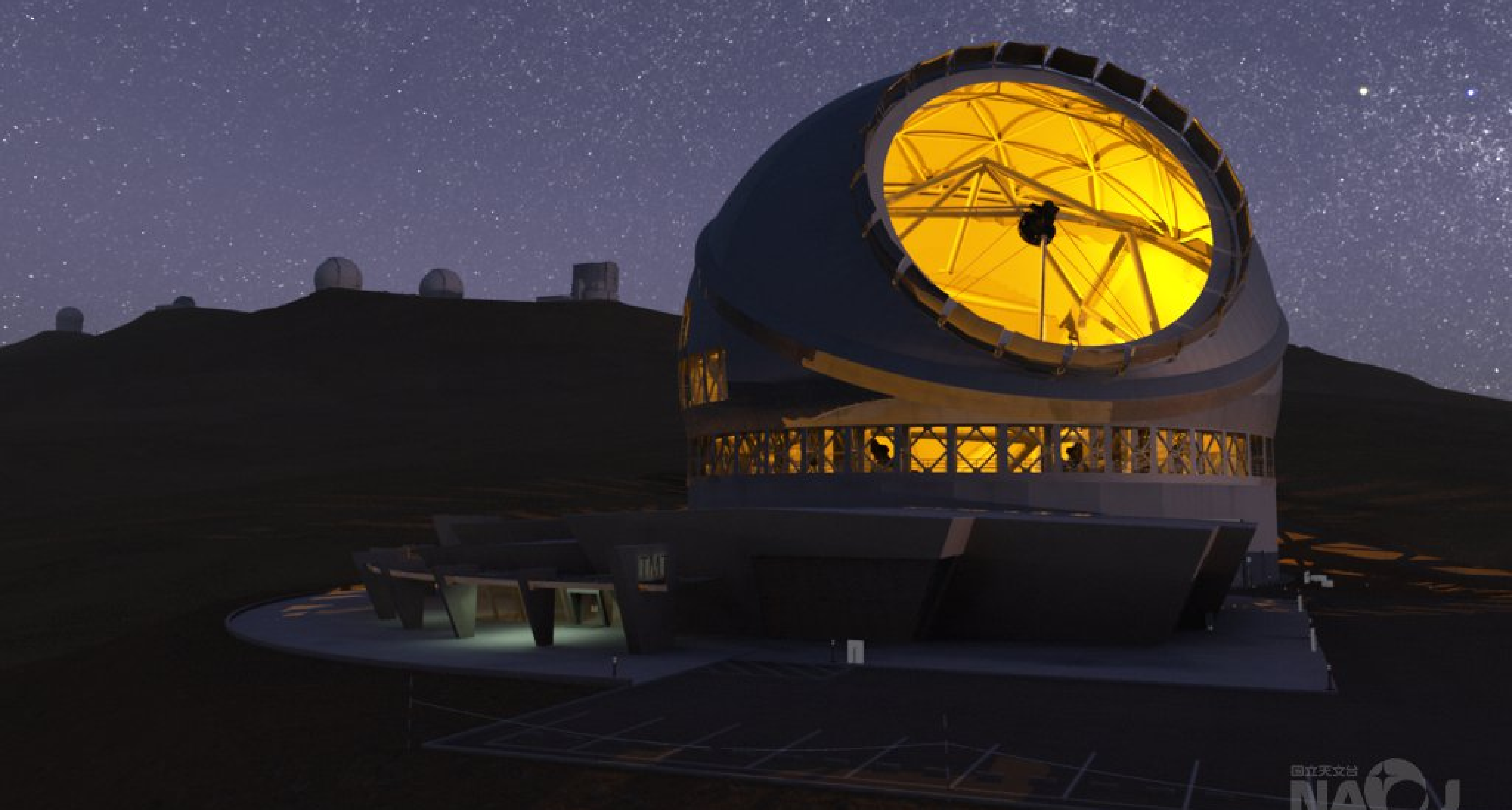
Toward Detections and Characterization of Habitable Transiting Exoplanets



Norio Narita (NAOJ)

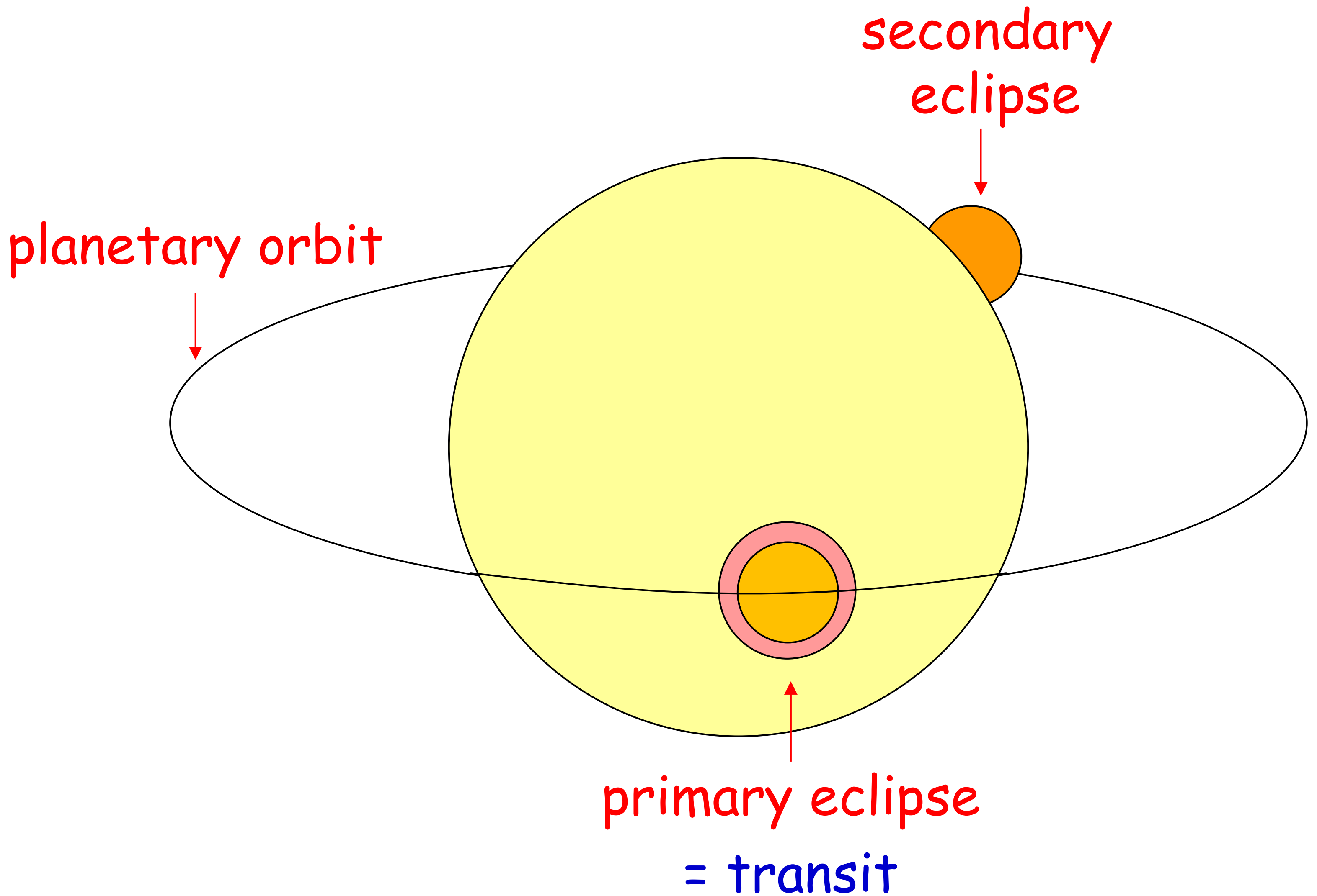
Outline

- Current Status and Next Step to Detect Habitable Transiting Exoplanets
- Methodology and Prospects of Characterizing Habitable Transiting Exoplanets
- Summary

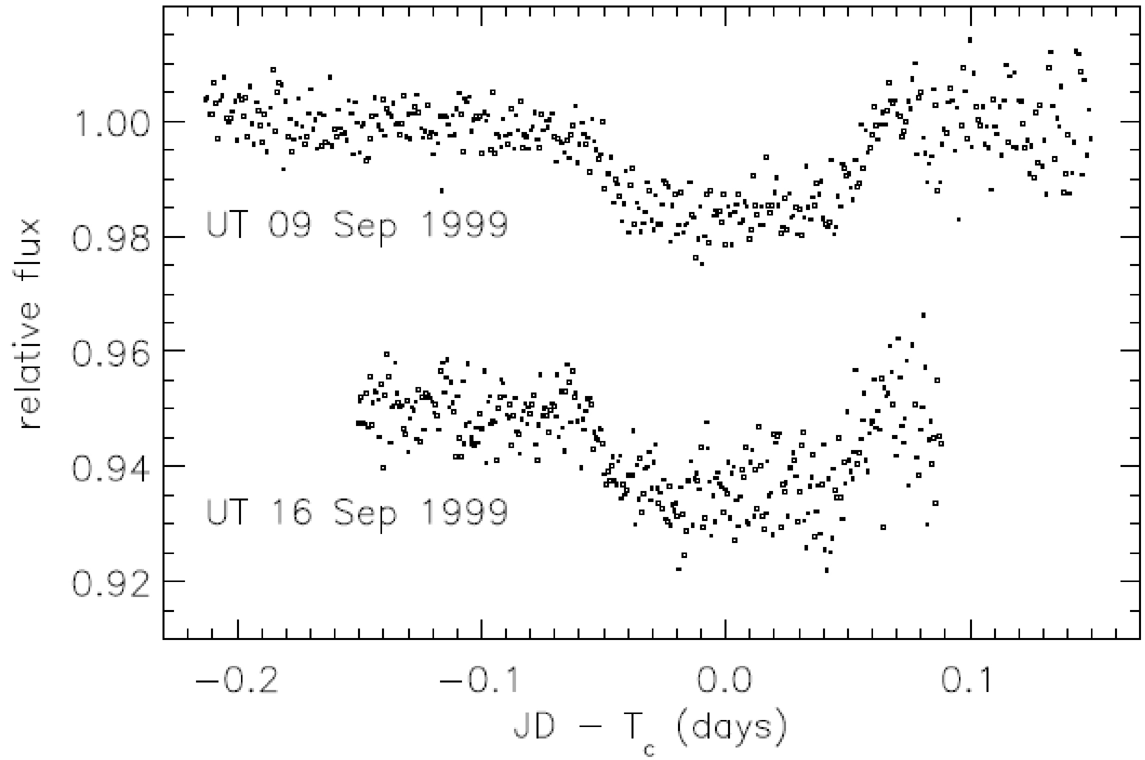
Various Exoplanet Detection Methods

- Radial velocity method
  - First detection in 1995, 500+ planets
- Transit method (this talk)
  - First detection in 2000, 400+ planets, 3000+ candidates
- Gravitational microlensing method
  - First detection in 2004, 20+ planets
- Direct imaging method
  - First detection in 2008, 10+ planets/brown dwarfs

What is Planetary Transit?



The First Discovery of a Transiting Exoplanet



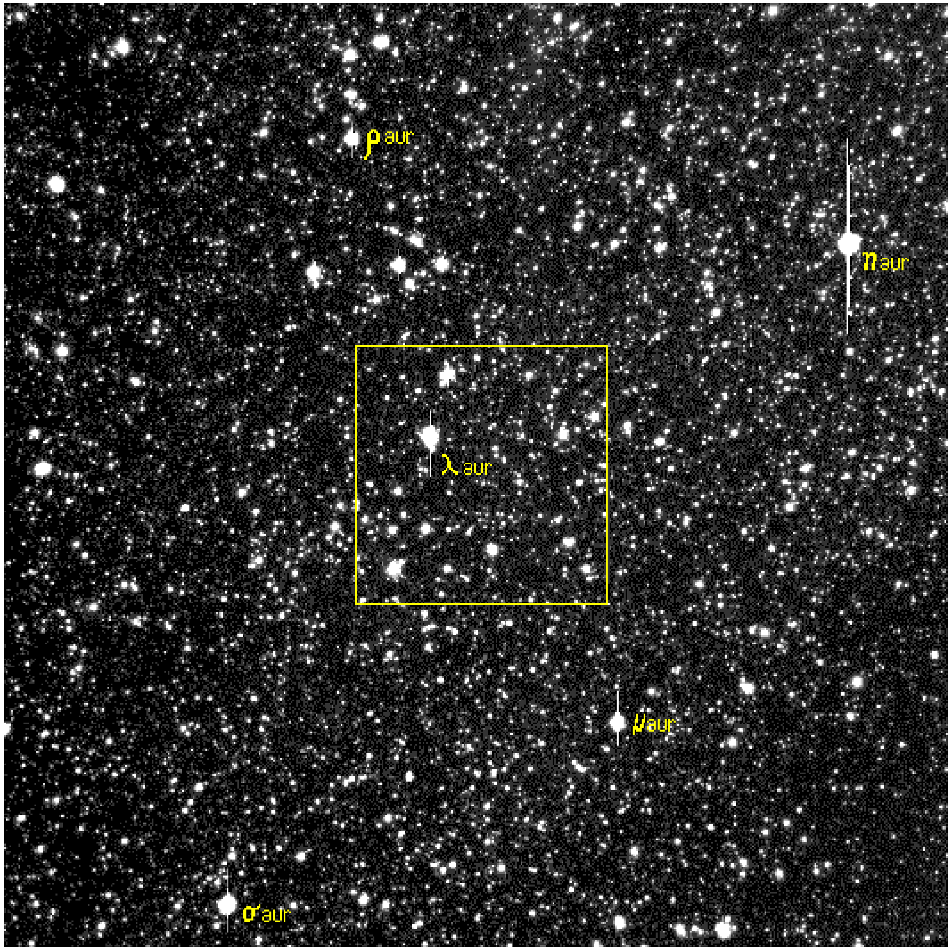
Charbonneau et al. (2000)

Transits of “hot Jupiter” HD209458b

Features of Transits

- Can determine planetary radius
  - Other methods cannot do this
- Can determine planetary true mass and density when combined with the RV method
  - The density is important information to infer planetary internal structure (gas, rock, iron, etc)
- Can characterize planetary atmosphere and orbit (later)

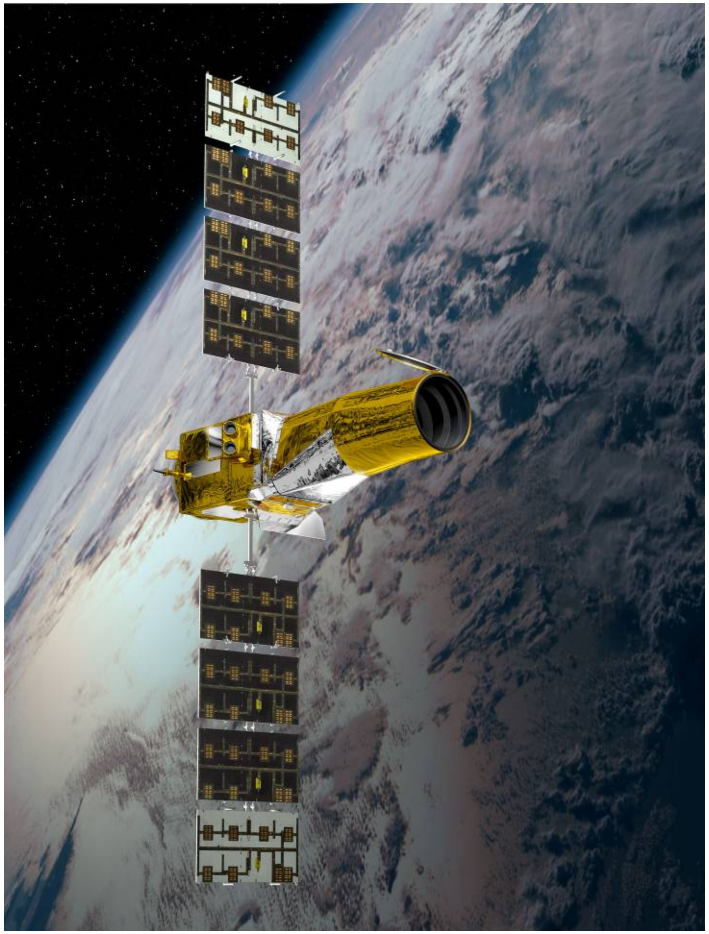
How to Detect Transiting Exoplanets



From TrES survey

One can search for periodic dimming from this kind of data

Space Mission for Transiting Planet Search



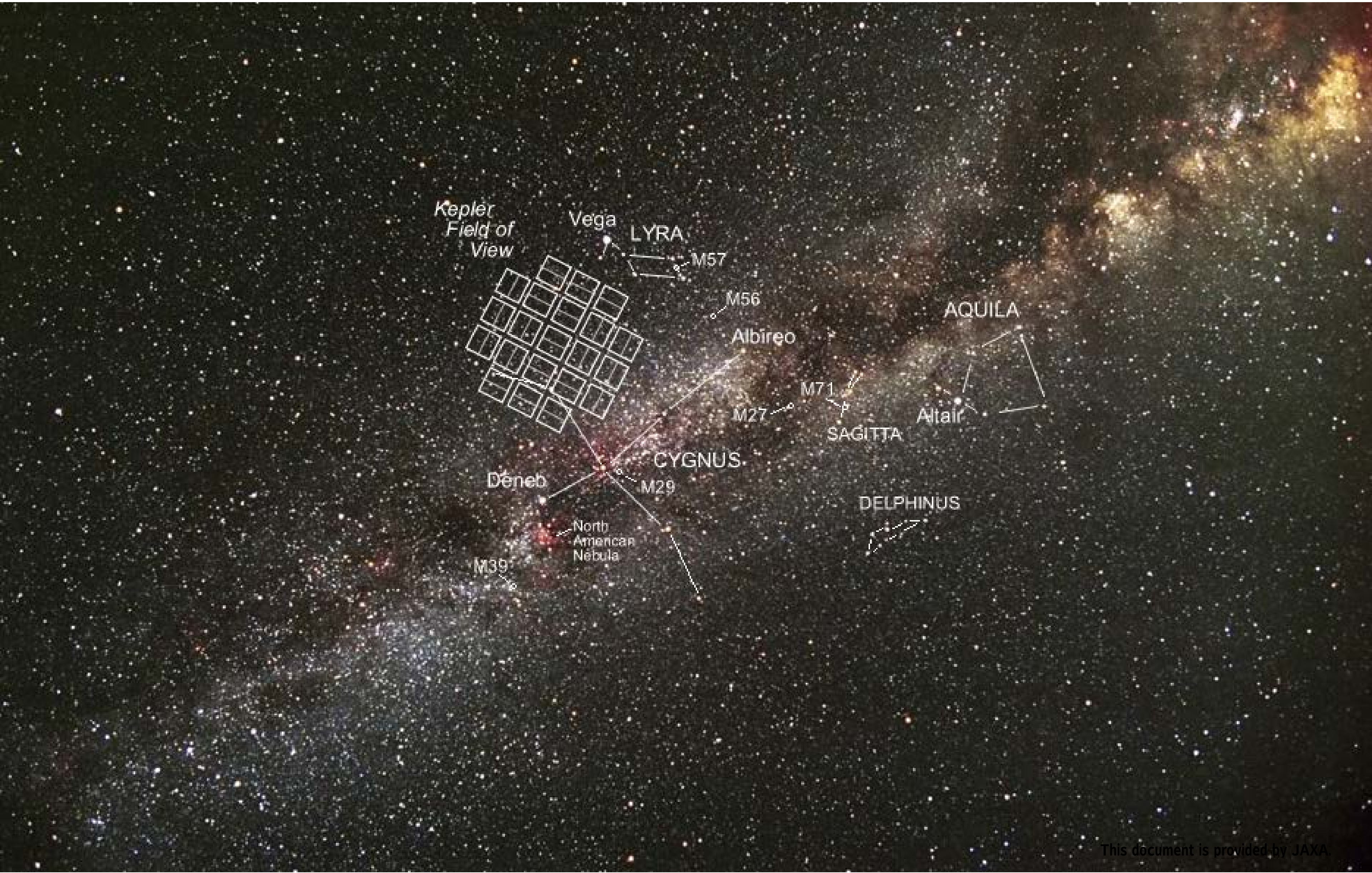
CoRoT

launched 2006/12/27

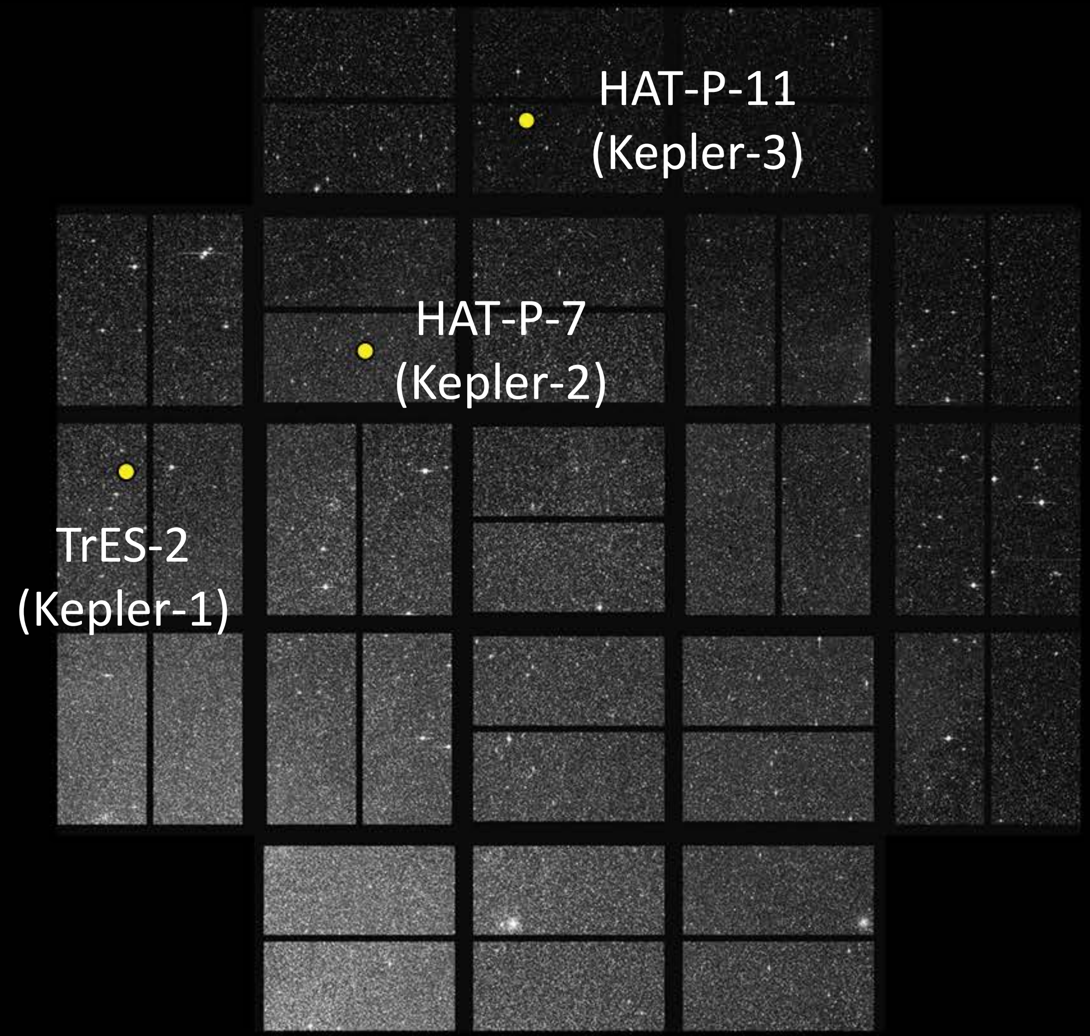
Kepler

launched 2009/3/6

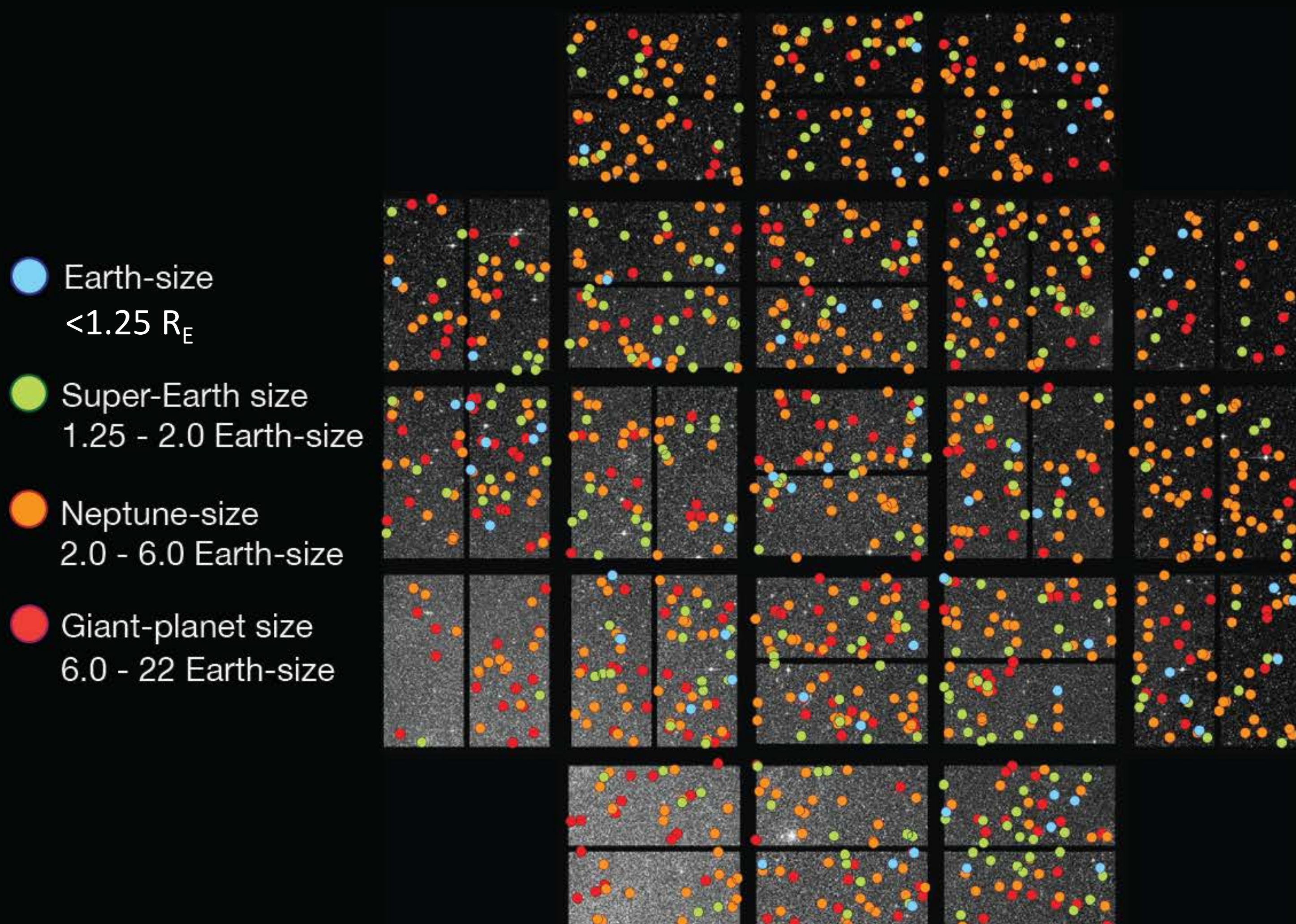
Kepler Field of View



Pre-Kepler Transiting Planets



First 4 Month Kepler Planet Candidates

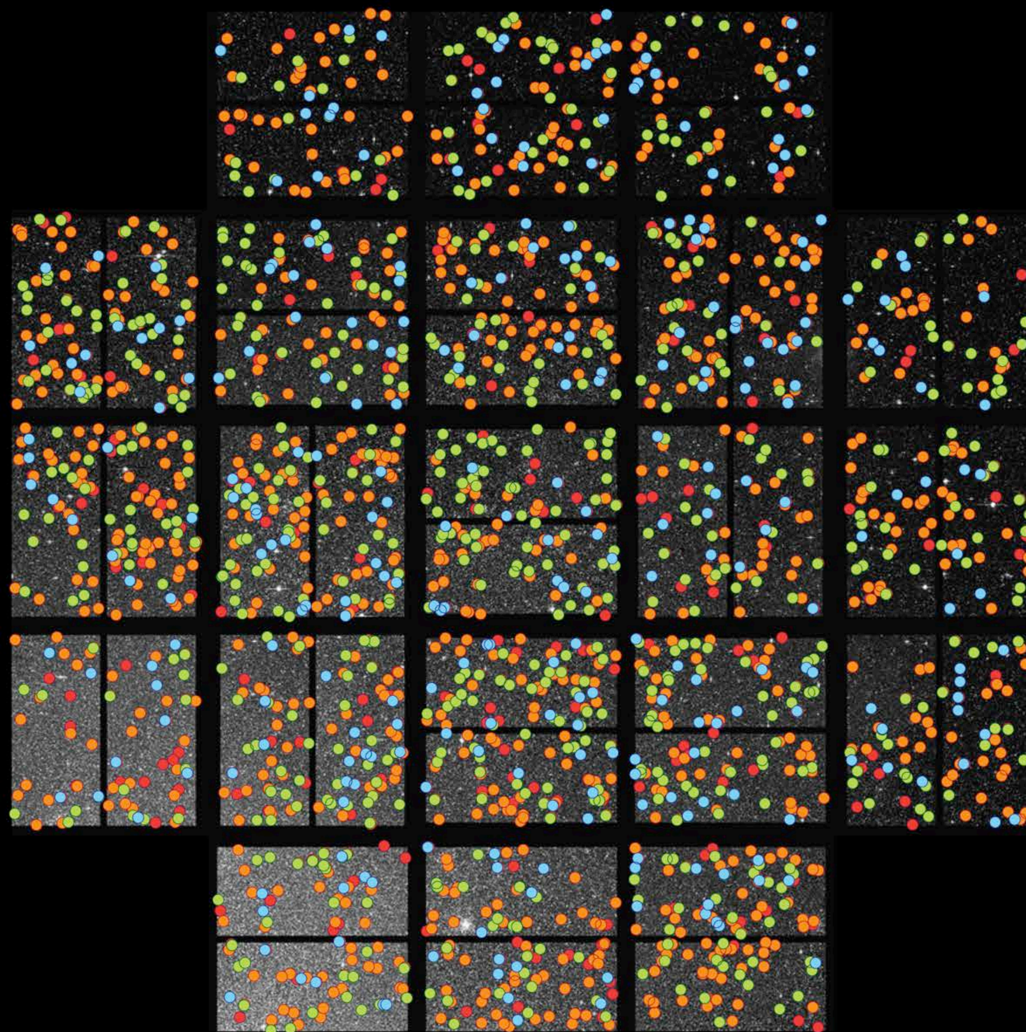


1235 Planet Candidates

Locations of Kepler Planet Candidates

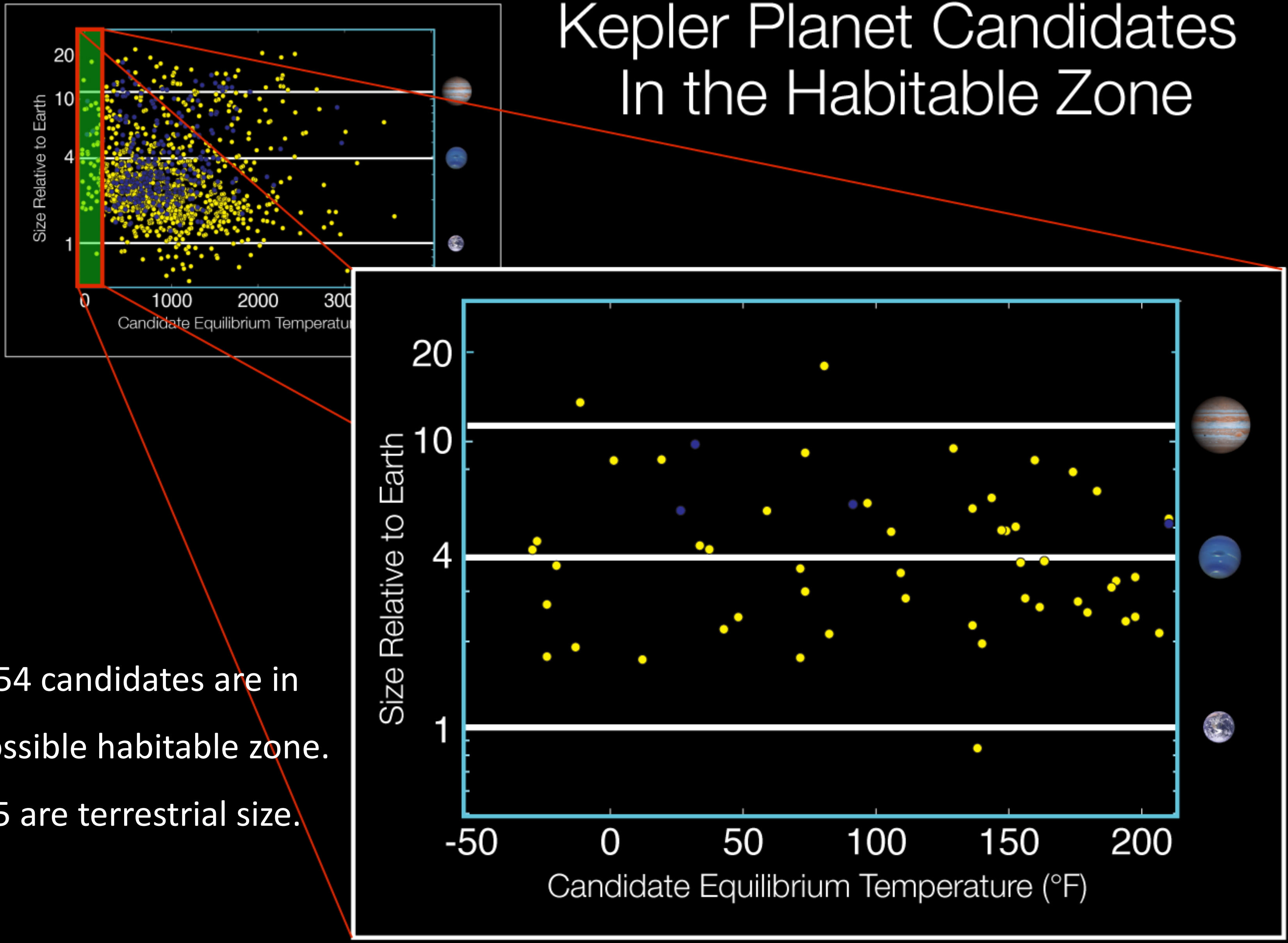
As of January 7, 2013

- Earth-size <1.25 R_E
- Super-Earth size 1.25 - 2.0 Earth-size
- Neptune-size 2.0 - 6.0 Earth-size
- Giant-planet size 6.0 - 22 Earth-size



2740 planet candidates (2013/01) -> 3277 candidates (2013/06)

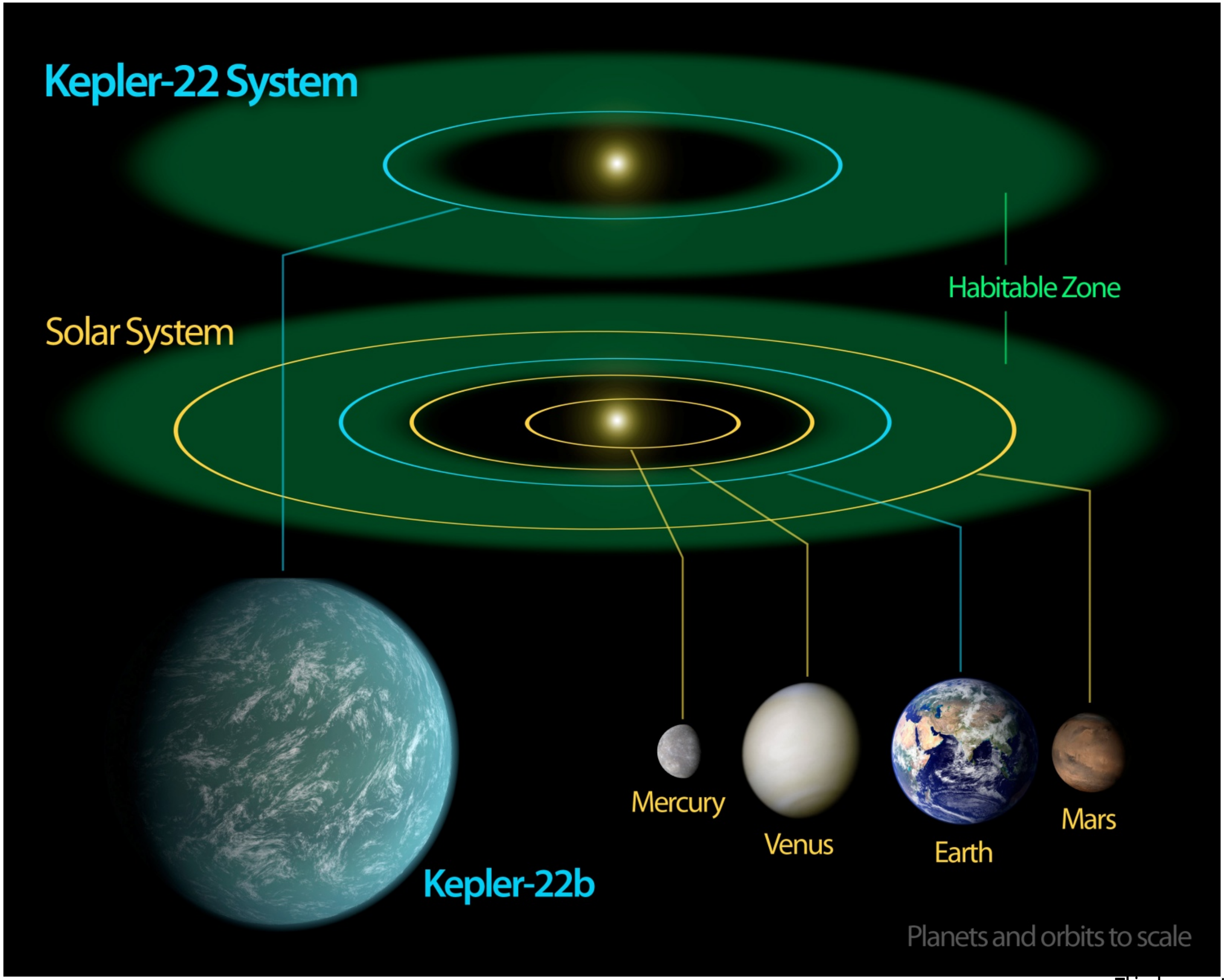
Kepler Planet Candidates In the Habitable Zone



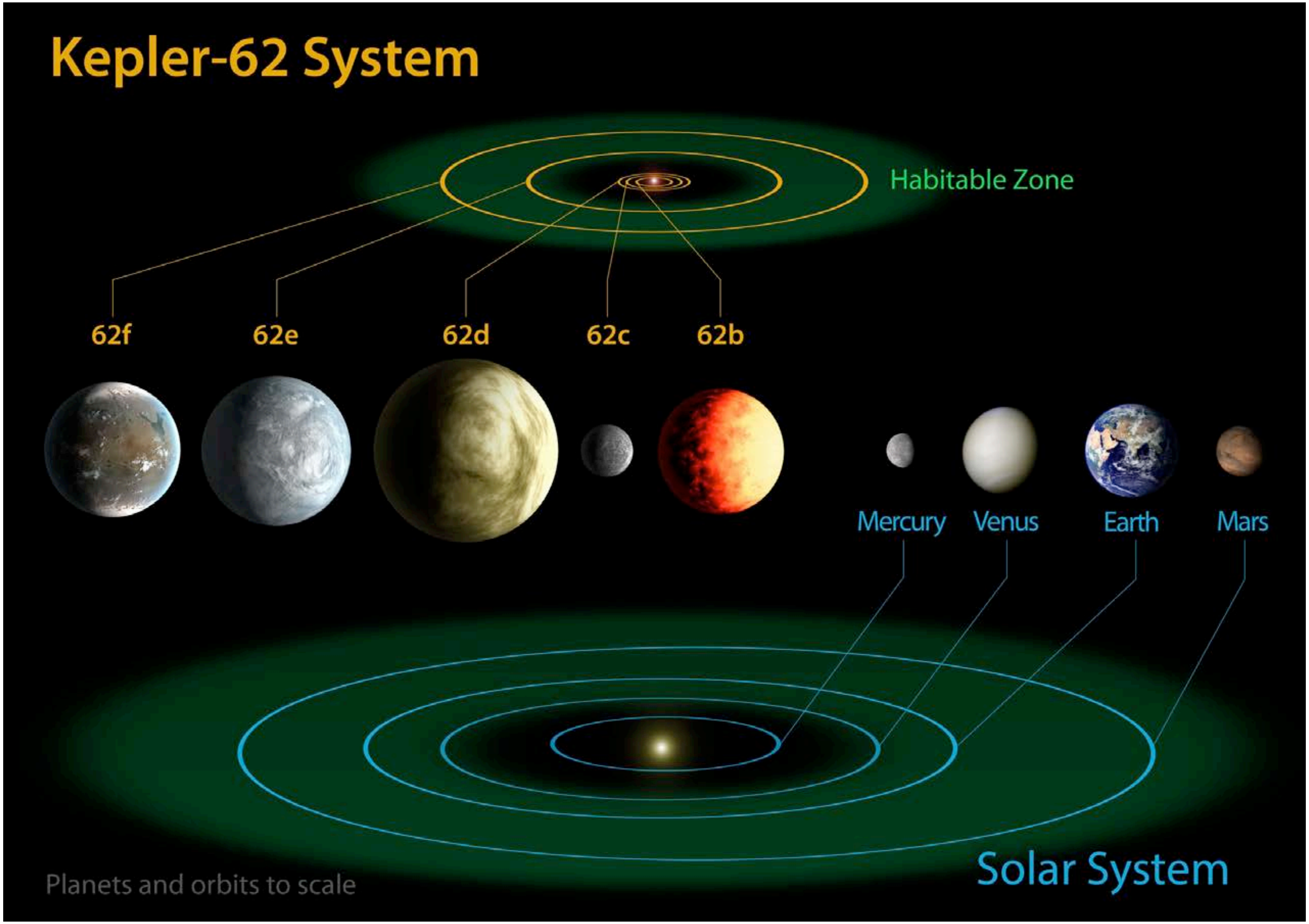
54 candidates are in possible habitable zone.

5 are terrestrial size.

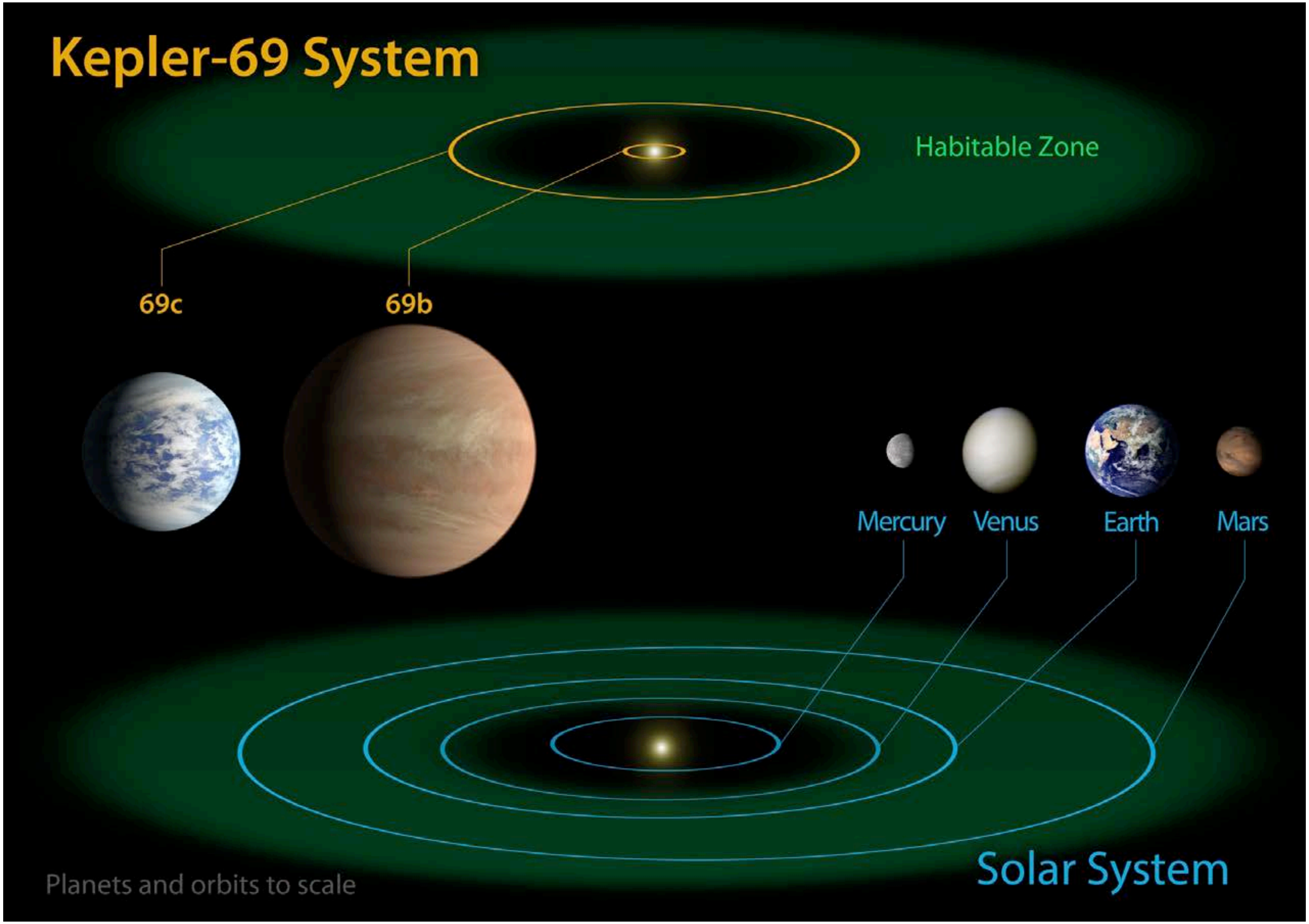
Possible Habitable Planet reported in 2011



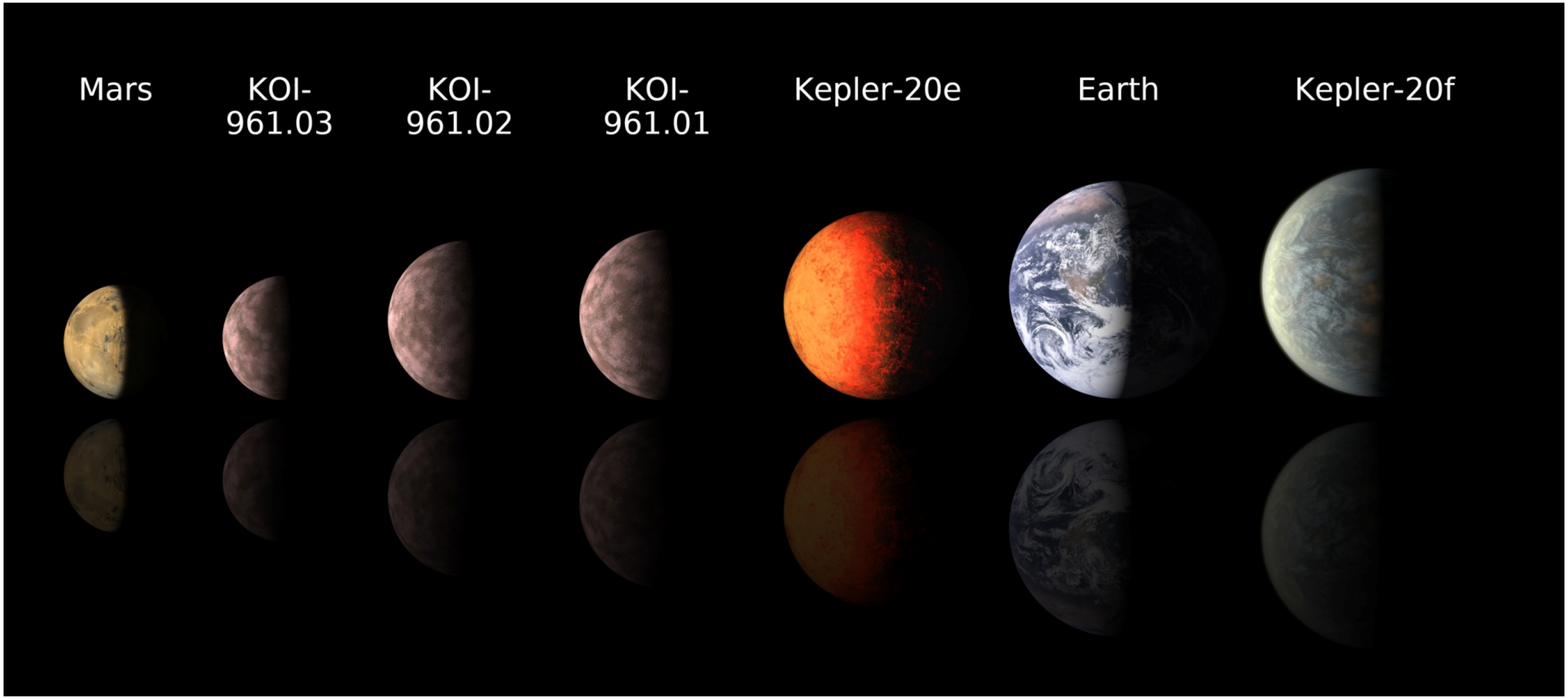
Habitable Super-Earths reported in 2013



Habitable Super-Earths reported in 2013



(Sub-)Earth-sized Planets



Earth-sized planet Kepler-20f

Mars-sized planet KOI-961.03 (renamed as Kepler-42d)

Kepler's Weakness

- Kepler targets relatively faint and far stars
  - Although over 3000 candidates discovered, RV follow-ups for all targets are difficult
  - Further characterization studies are also difficult

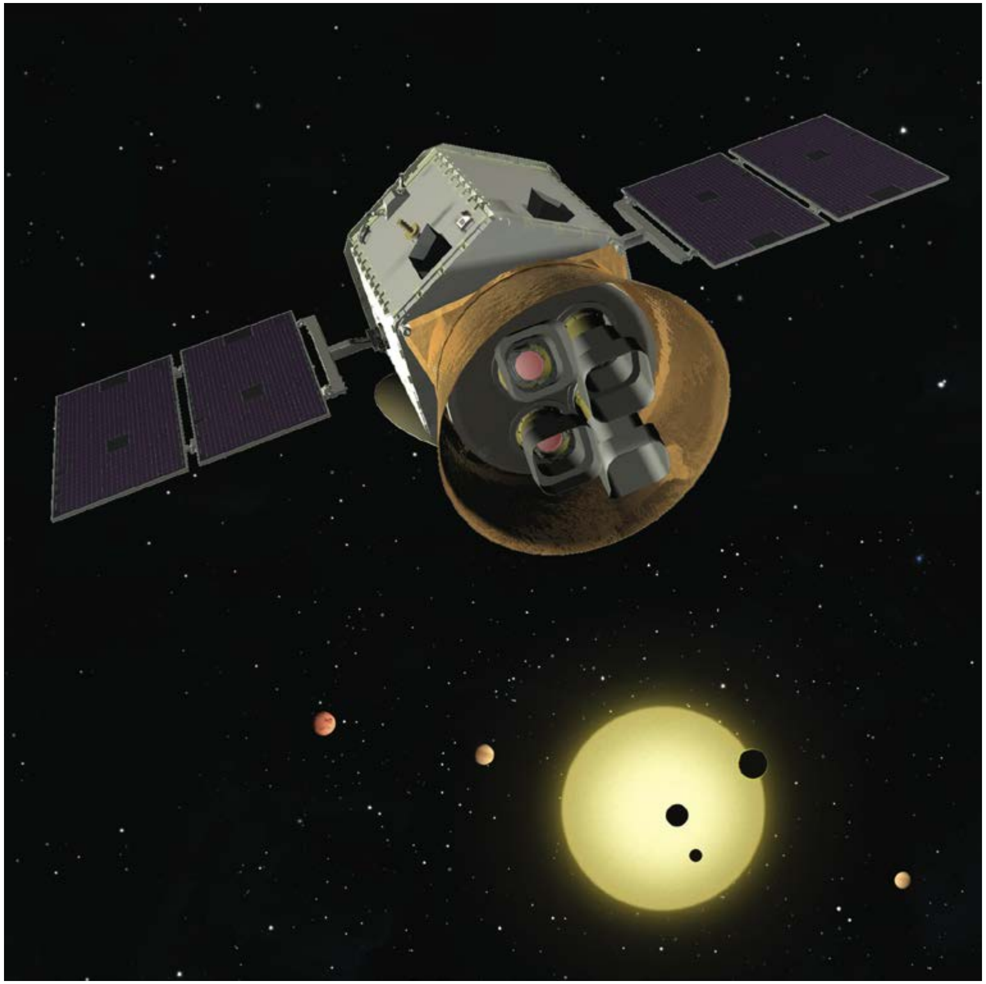
➢ Kepler is good for statistical studies, but not for detailed studies for each planet

Strategy of Future Transit Survey

- Future transit surveys will target nearby bright stars to detect terrestrial planets in habitable zone

- Ground-based transit survey for nearby M dwarfs
  - MEarth lead by D. Charbonneau at Harvard
  - Other teams all over the world
  - IRD transit group
- Space-based all-sky transit survey for bright stars
  - TESS (Transiting Exoplanet Survey Satellite) by MIT team

All-Sky Transit Survey: TESS



Led by MIT and approved by NASA in April 2013.

TESS will be launched in 2017.

Outline

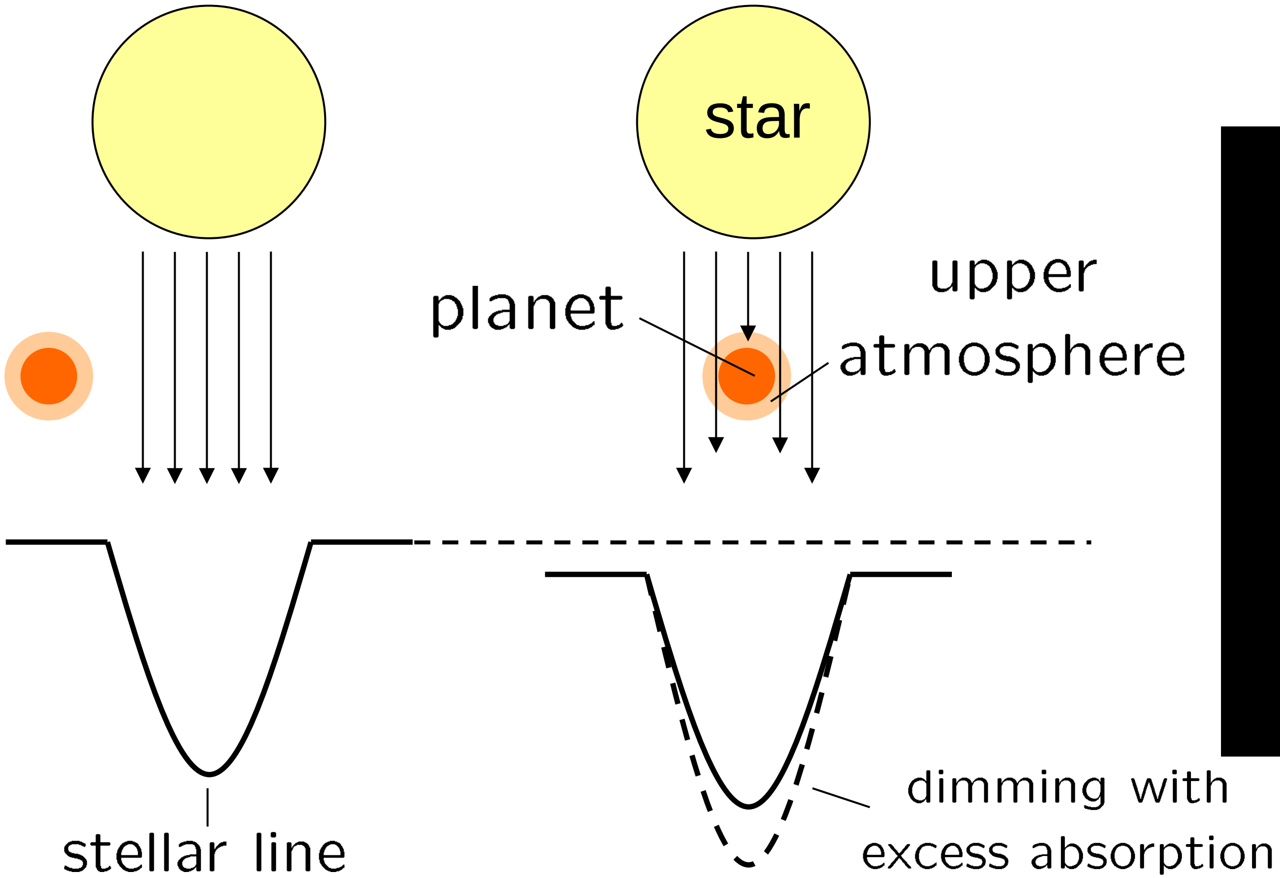
- Current Status and Next Step to Detect Habitable Transiting Exoplanets
- Methodology to Characterize Transiting Exoplanets and Future Prospects
- Summary

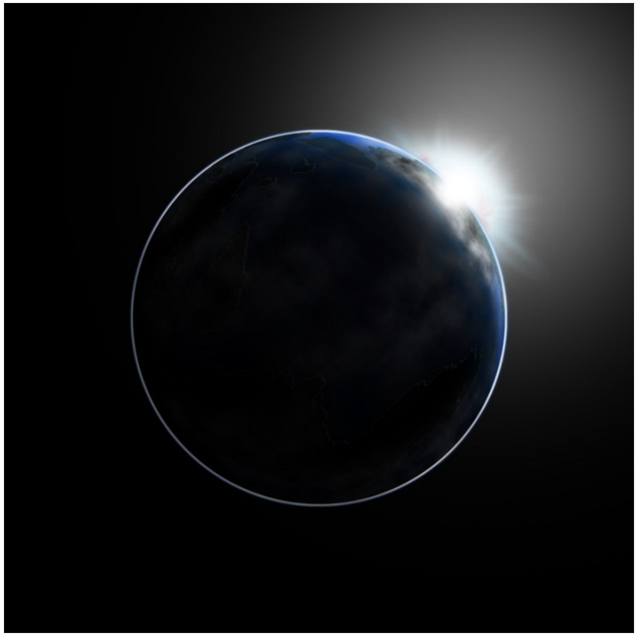
What we would like to study for Habitable Planets?

1. What are components of their atmospheres?
   - Important information to infer habitability
   - Do they have hydrogen atmosphere?
   - Hydrogen is strong green house gas and affect habitability (Pierrehumbert & Gaidos 2011)
2. How do they form?
   - Uncovering their migration mechanism

Characterization of their Atmospheres

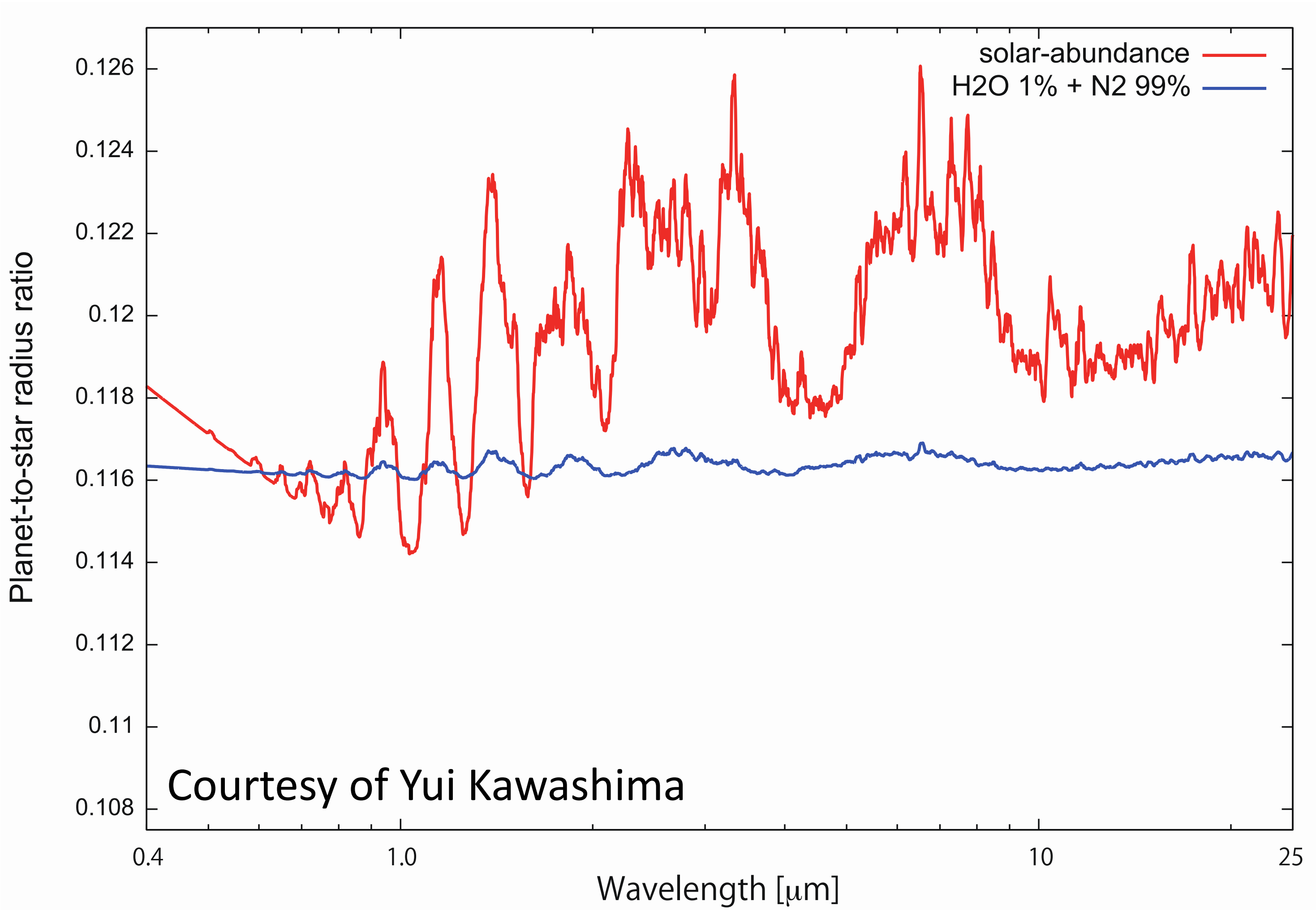
Transmission Spectroscopy





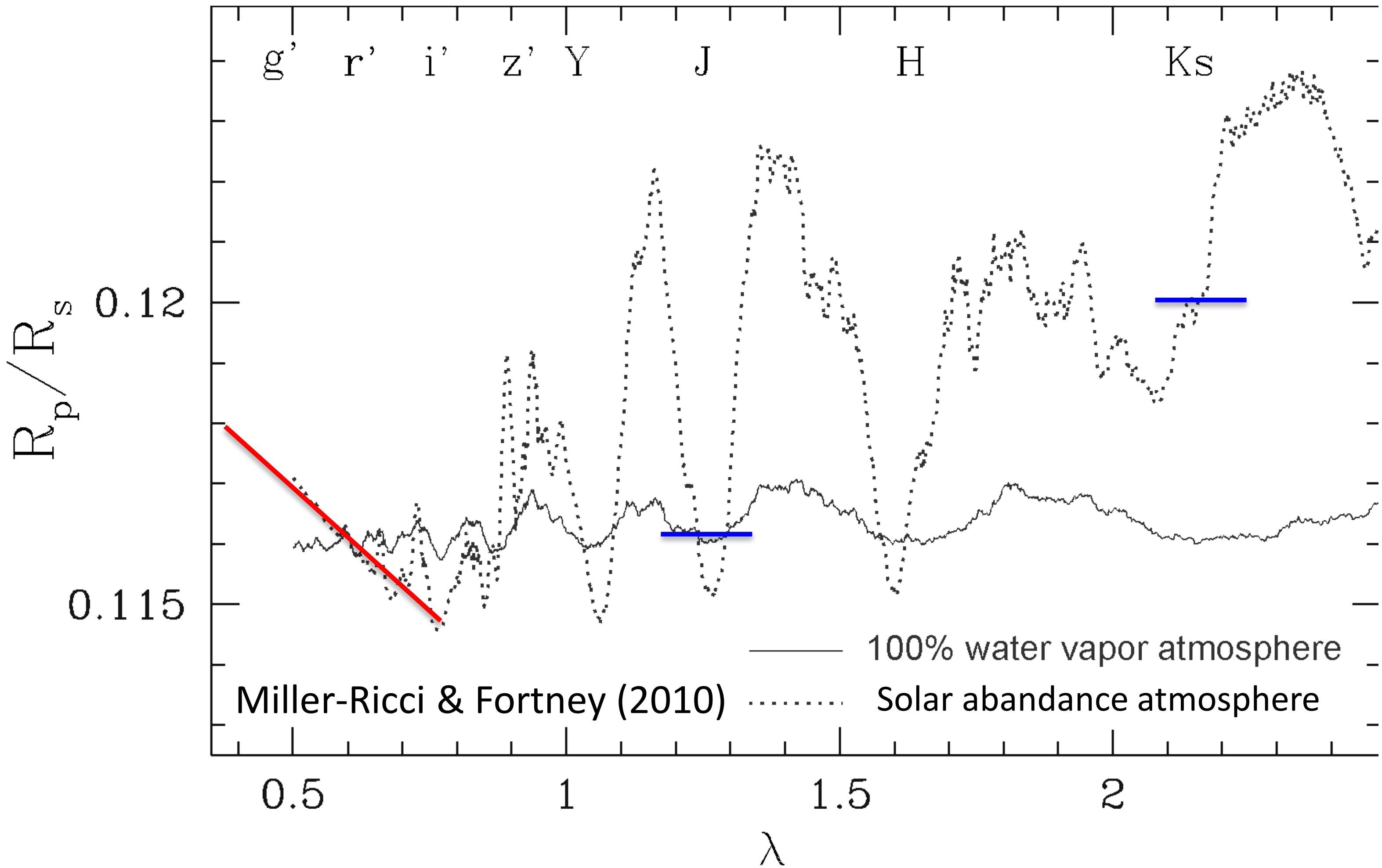
Transit depths depend on lines / wavelength reflecting atmosphere

Differences of Transmission Spectra



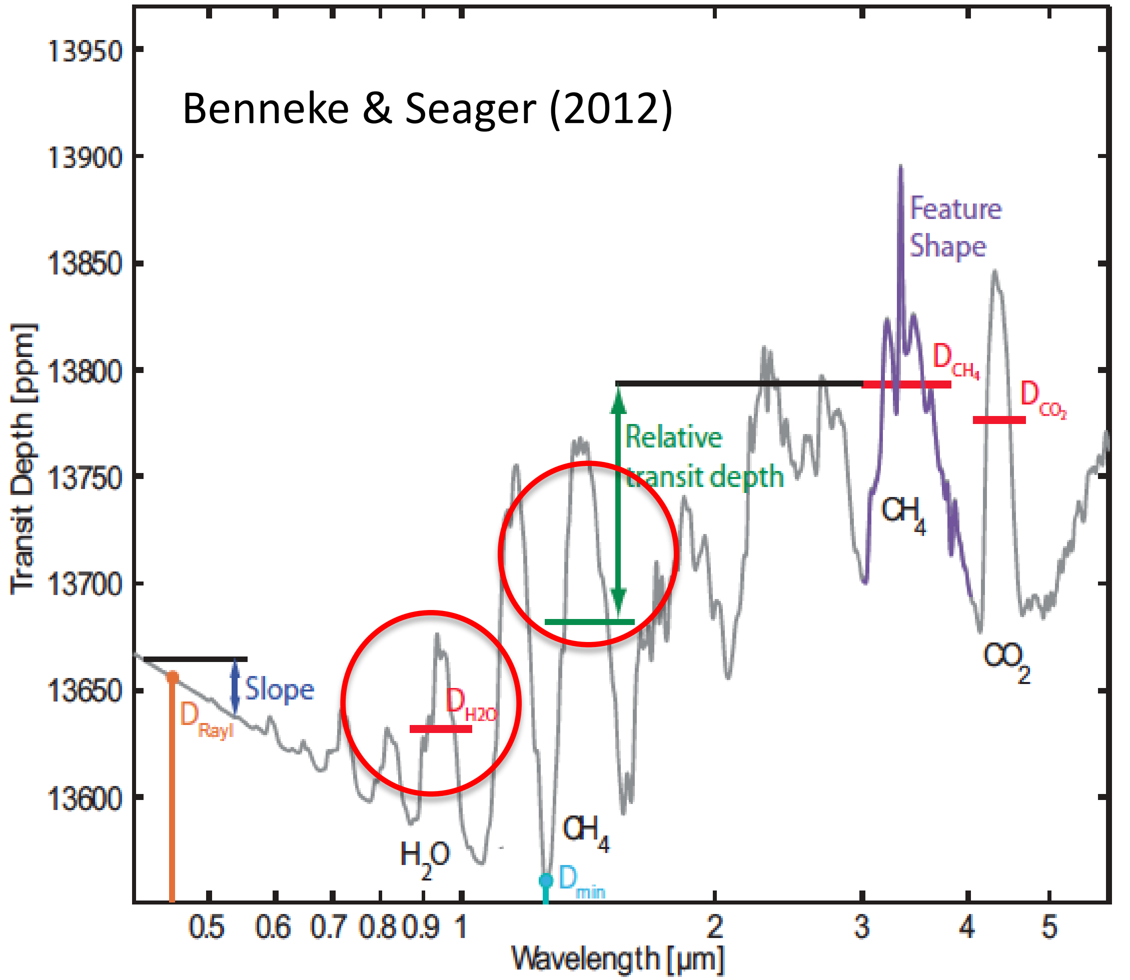
Super-Earths may have hydrogen-rich atmosphere, which has a large atmospheric scale height

Discriminating Hydrogen-Rich Atmosphere



One can tell whether a planet has hydrogen-rich atmosphere or not by multi-color transit photometry

Other Spectroscopic Features



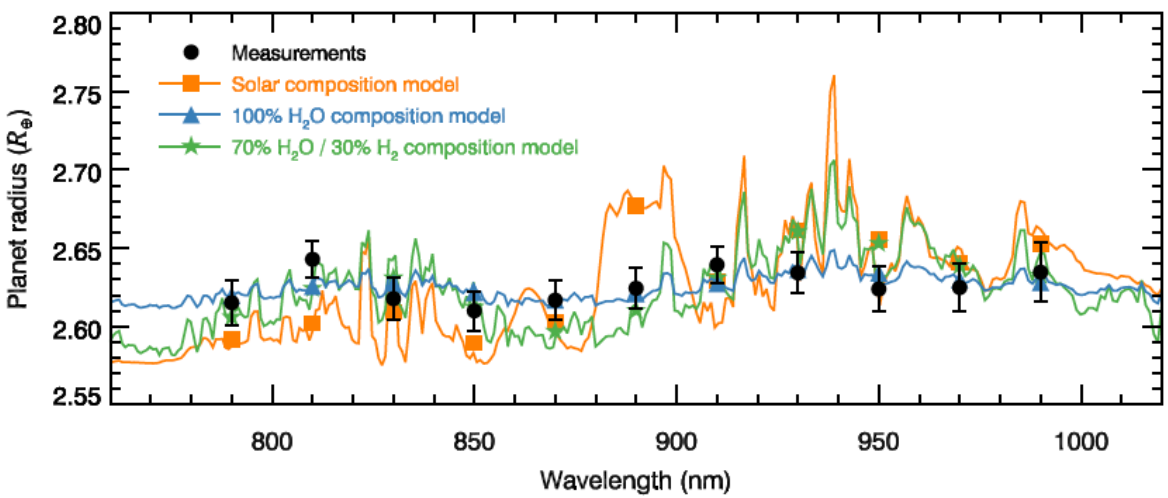
Optilal-NIR region has some features of atmospheric compositions

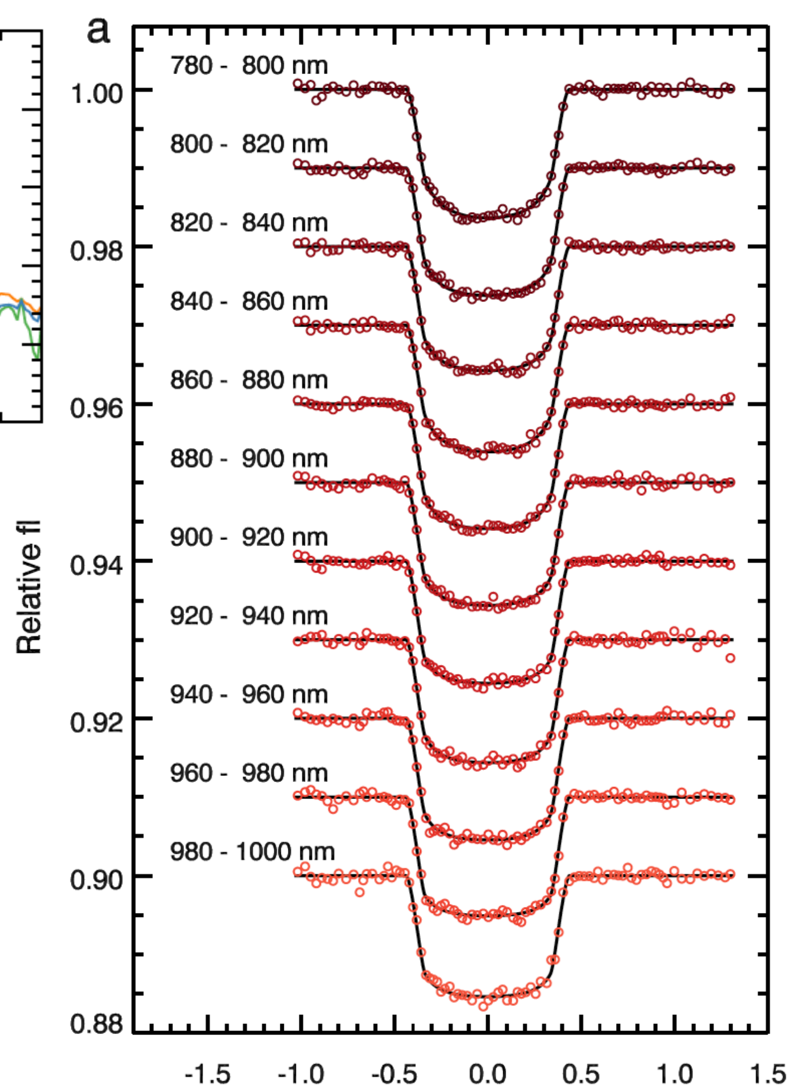
Transmission Spectroscopy by MOS

- One can do transmission spectroscopy using MOS (multi-object spectrograph) instruments
  - VLT/FORS2, Gemini/GMOS, Magellan/MMIRS already reported excellent results

- Simultaneously observe target and reference stars
  - using very wide slit (~10”) to avoid light-loss from slits
  - integrate wavelength to create high precision light curves

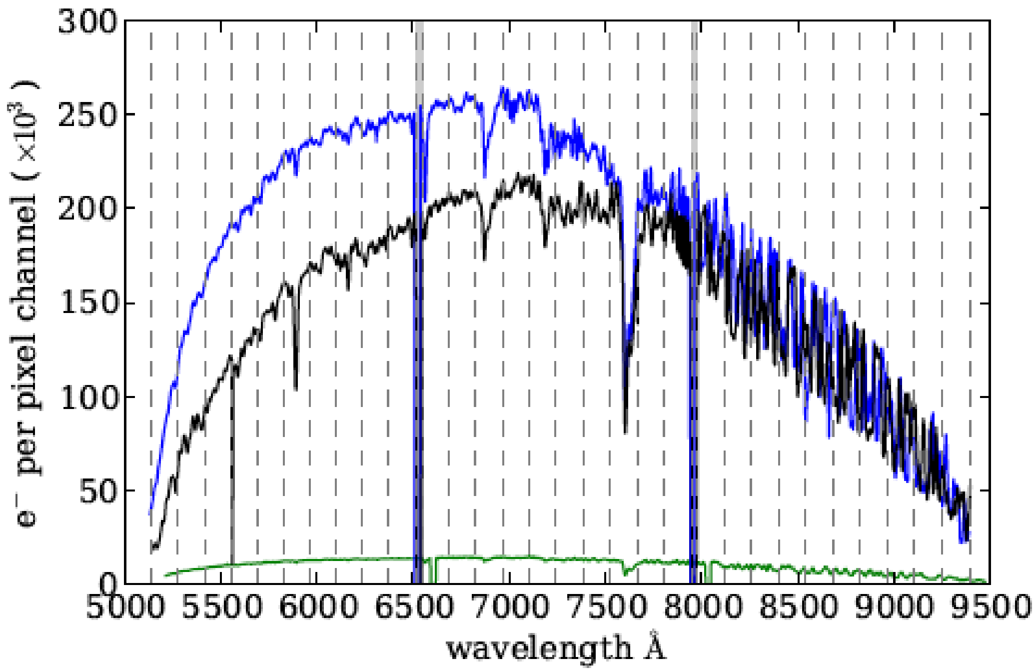
Example by Bean et al. (2010)

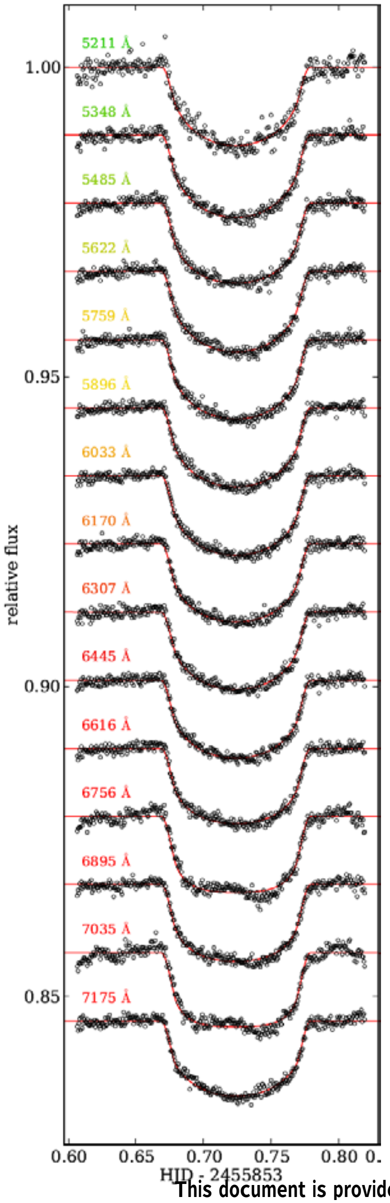




- Instrument: VLT/FORS2
- Target: GJ1214b (V=14.7)
- Integration: 20 nm (R ~ 30)
- Precision: 331-580 ppm

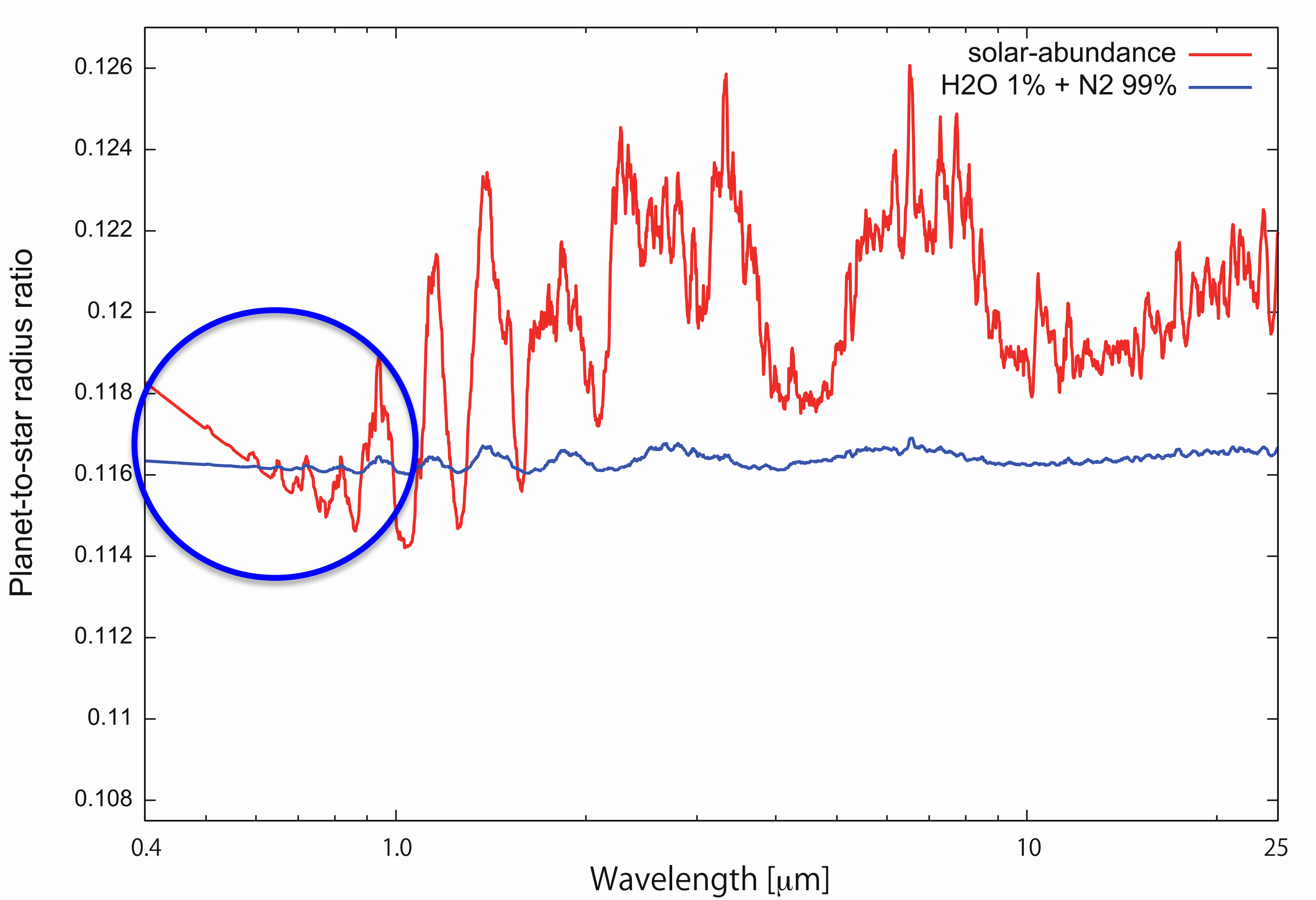
Recent Example by Gibson et al. (2012)





- Instrument: Gemini South/GMOS
- Target: WASP-29b (V=11.3)
- Integration: about 15 nm (R ~ 40)
- Precision: ~400 ppm

Optical MOS is useful to see Rayleigh Slope



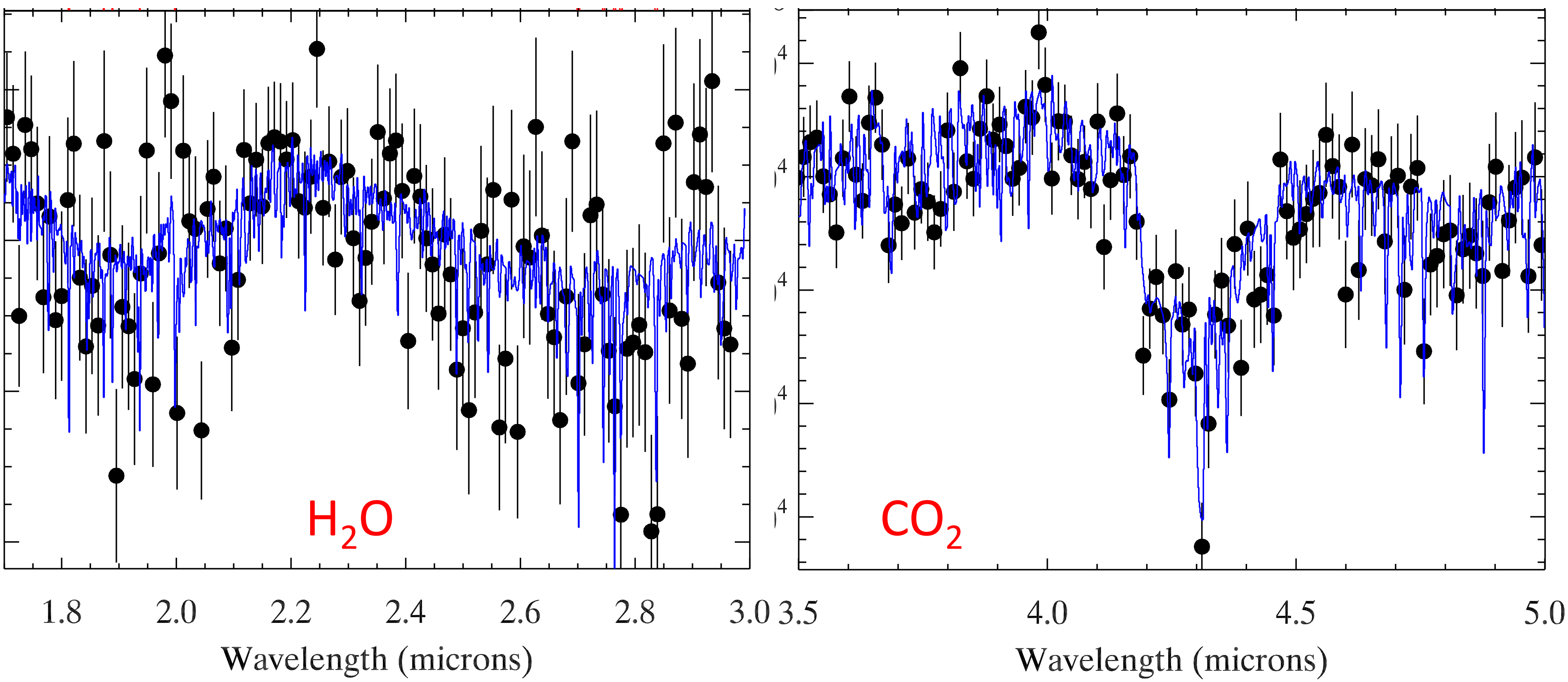
One can tell whether the atmosphere is dominated by hydrogen or not and possible existence of haze particle

Kepler-22 Properties

- Planet
  - Period: 289.86 days
  - Radius: 2.4 R_E (super-Earth), transit depth: 500 ppm
  - gaseous mini-Neptune or large ocean planet?
- Host Star
  - G5V star
  - B=11.5, R=11.7, J=10.5, H=10.2
- TMT's optical MOS instrument (WFOS) can measure the Rayleigh slope in optical wavelength

Transmission Spectroscopy with Space Telescopes

JWST/SPICA can characterize NIR-MIR transmission spectra



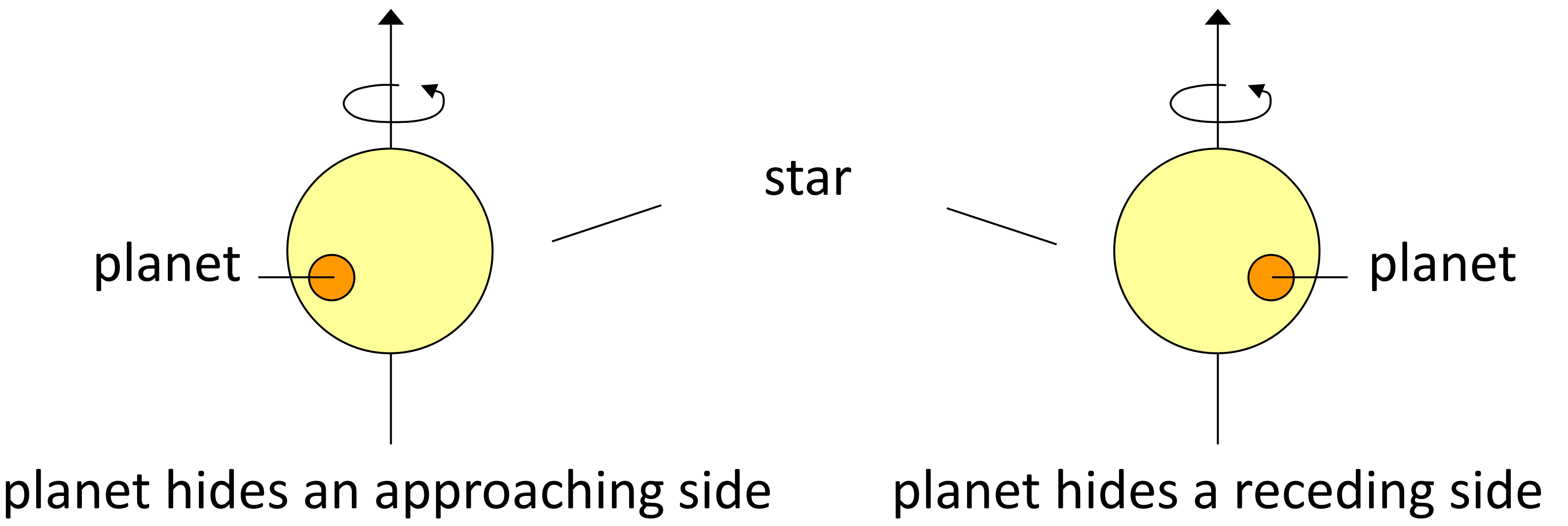
Simulated ~100hr detections of molecules in atmospheres of habitable transiting super-Earths (Deming et al. 2009)

What E-ELT's High Dispersion Spectrographs Can

- Transmission spectroscopy
  - Can detect atmospheric atomic/molecular absorptions

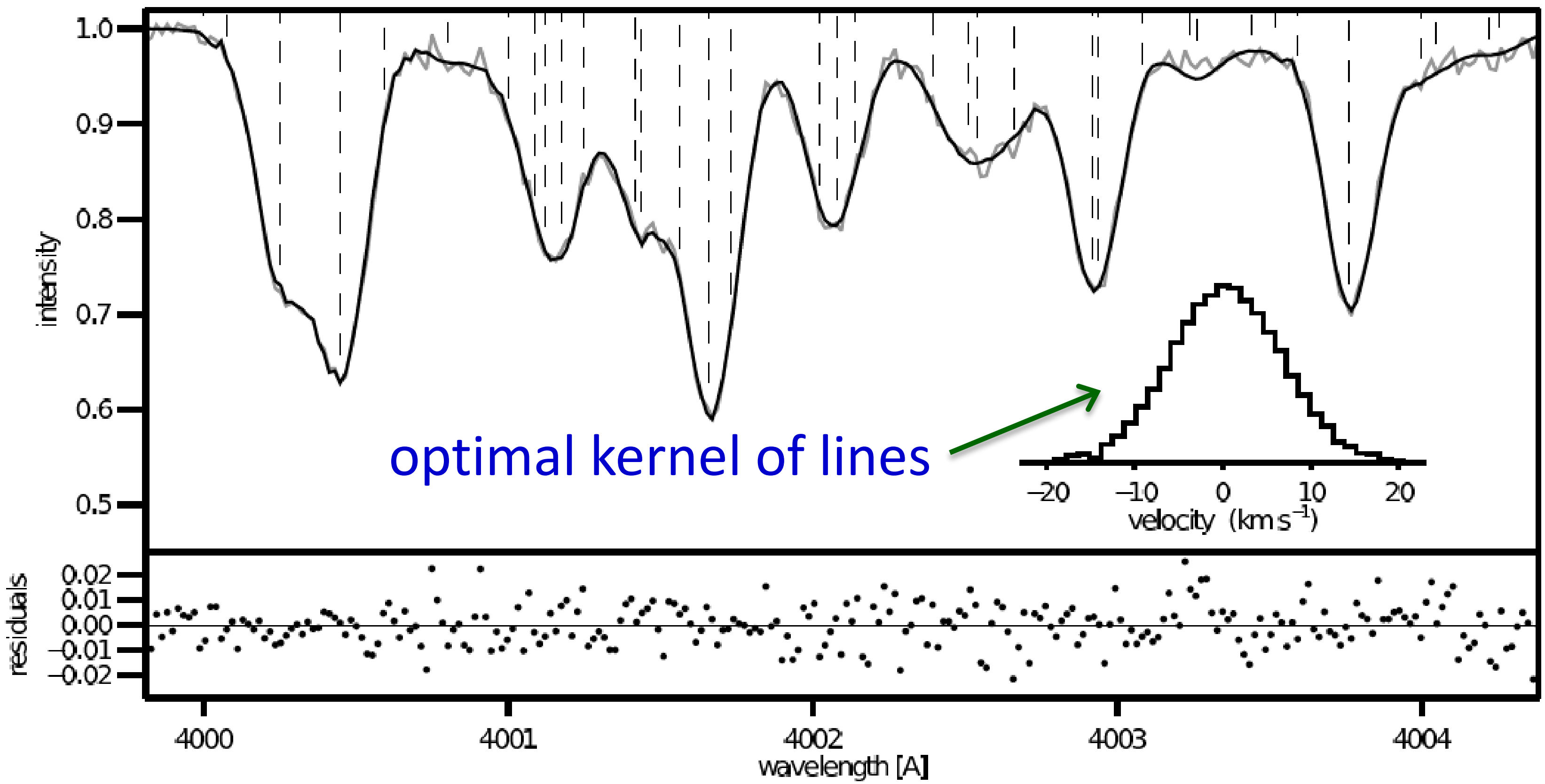
- High dispersion instruments can directly detect planet's shadow and can measure orbital obliquity
  - Important information to infer ``how do they form?''

What is Planet's Shadow?



Planet removes a part of velocity component of stellar lines

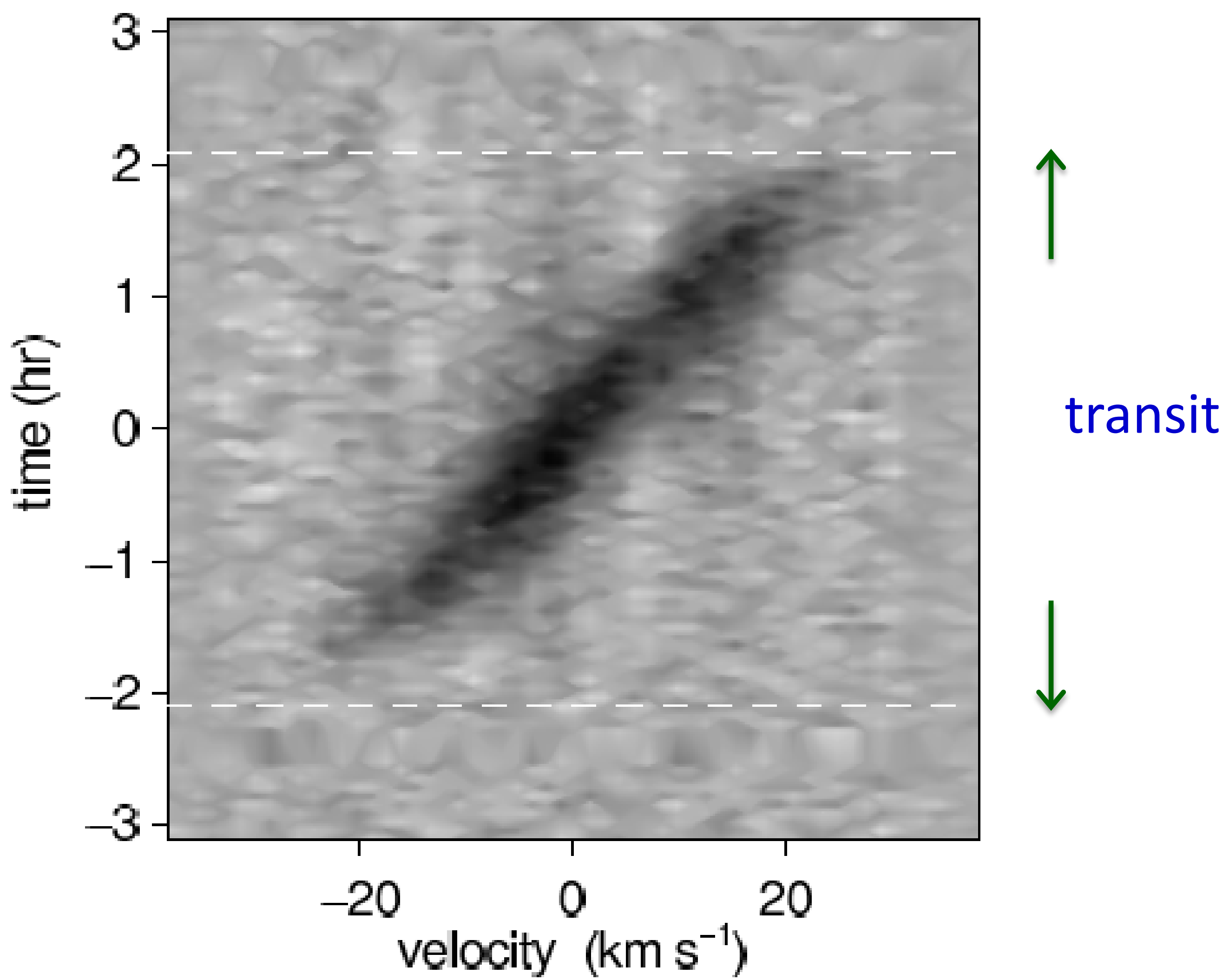
What happen to Shape of Stellar Lines



Stellar lines of HAT-P-2 taken with Keck/HIRES

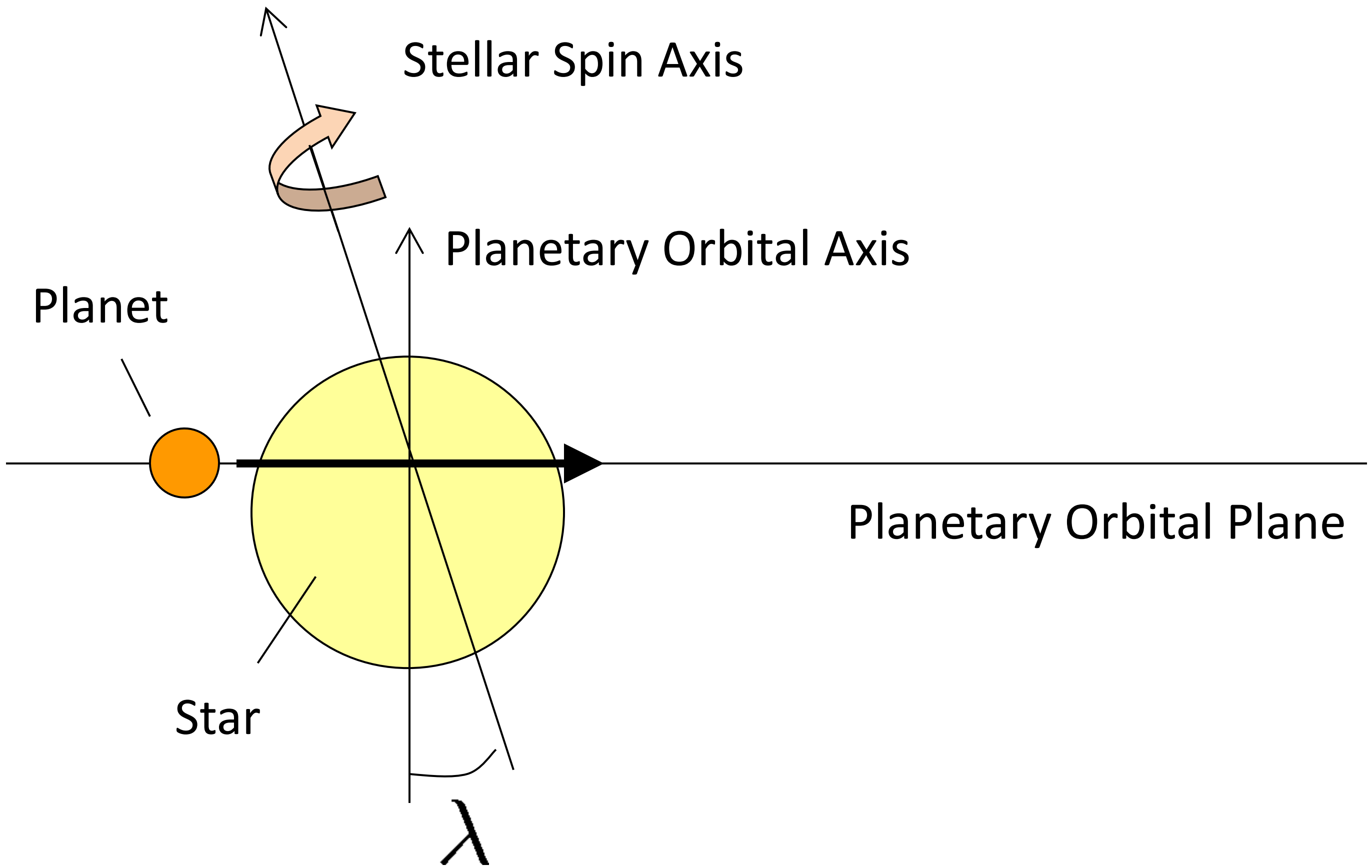
Albrecht et al. (2013)

Planet's Shadow in Stellar Lines



This shadow shows a trajectory of the planet in front of the star

What we can learn by planet's shadow



The obliquity tells us planetary migration mechanisms of exoplanets.

Like our Solar System or experienced dynamical migration.

Capability of E-ELT's High Dispersion Spectrographs

- Can detect planet's shadow and measure orbital obliquity of smaller planets
  - TMT can reveal migration history for smaller planets
  - which means, TMT can answer an aspect of "how planetary systems form"

Summary

- Ongoing and future transit survey (TESS) will discover habitable transiting planets in Solar neighborhood
- Future E-ELTs and space telescopes will work on characterizing their atmospheres and formation mechanisms