Exploring New Worlds with TMT

Norio Narita (NAOJ)

on behalf of Japanese Science Working Group

Background of this Talk

- In 2010-2011, Japanese community summarized detailed science cases (DSC) as shown below
- Here I focus on some science cases which were not fully overlapped with the DSC by TMT in 2007

Outline

- Science Cases for First Light Instruments
  - WFOS: exploring atmospheres of transiting planets
  - IRIS: distinguishing micro-lensing host stars
- Science Cases for Future Instruments
  - High Spectral Resolution (Dispersion) Instruments
  - (High Spatial Resolution (Contrast) Instruments)
- Summary

Locations of Kepler Planet Candidates

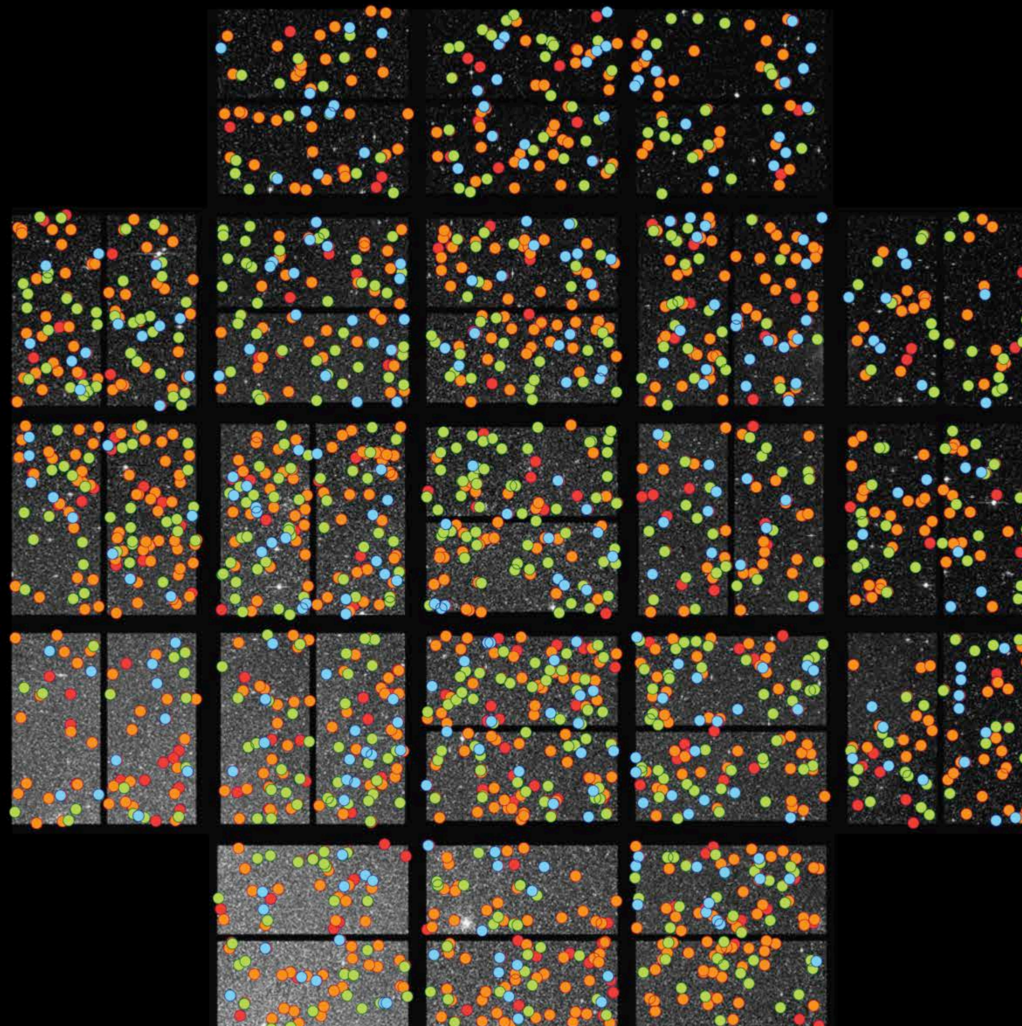
As of January 7, 2013

Earth-size

Super-Earth size
1.25 - 2.0 Earth-size

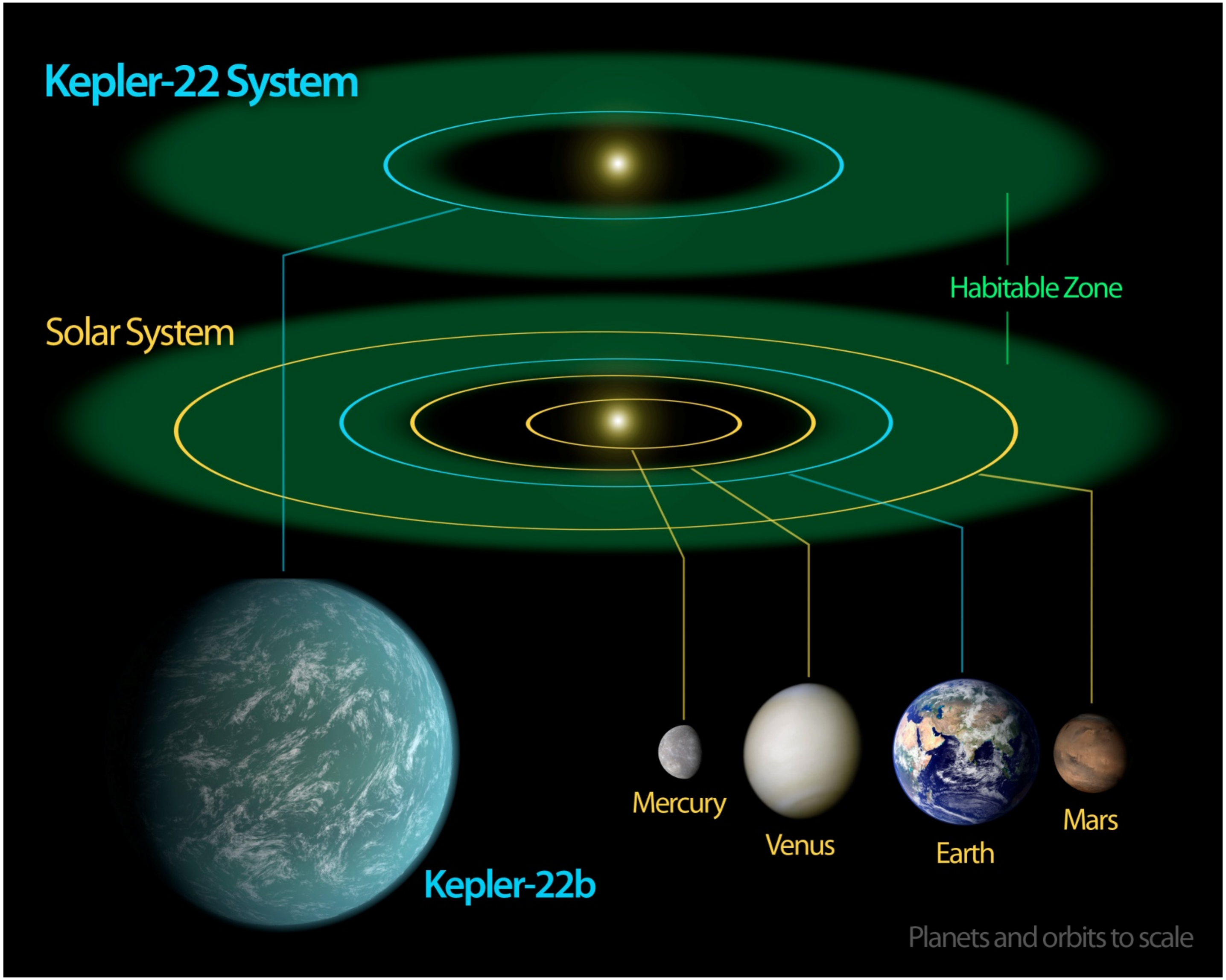
Neptune-size
2.0 - 6.0 Earth-size

Giant-planet size
6.0 - 22 Earth-size



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

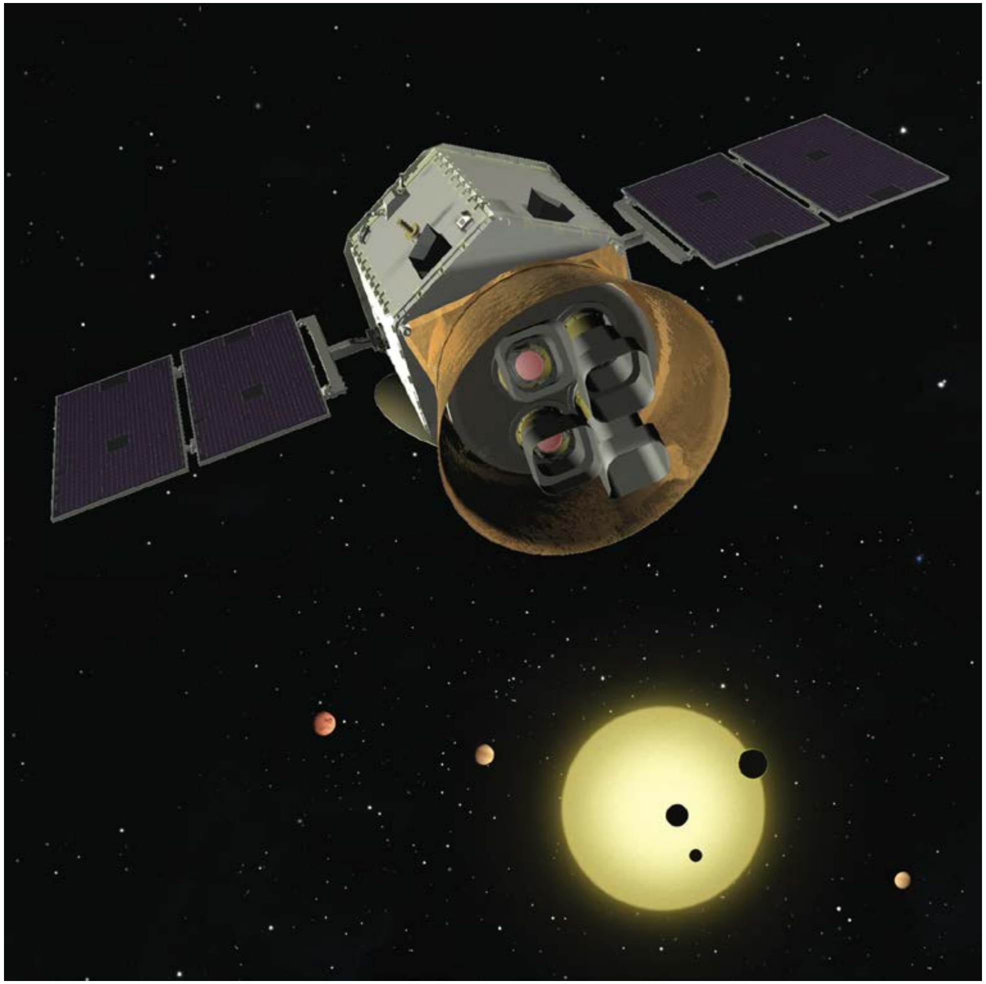
Possible Habitable Planet Kepler-22b



Kepler-22 Properties

- Planet
  - Period: 289.86 days
  - Radius: 2.4 R_E (super-Earth), transit depth: 500 ppm
  - Mass: not determined (only weakly constrained)
  - gaseous mini-Neptune or large ocean planet?
- Host Star
  - G5V star
  - B=11.5, R=11.7, J=10.5, H=10.2
  - distance: 190 pc (somewhat far away)

All-Sky Transit Survey: TESS



Led by MIT and approved by NASA in April 2013.

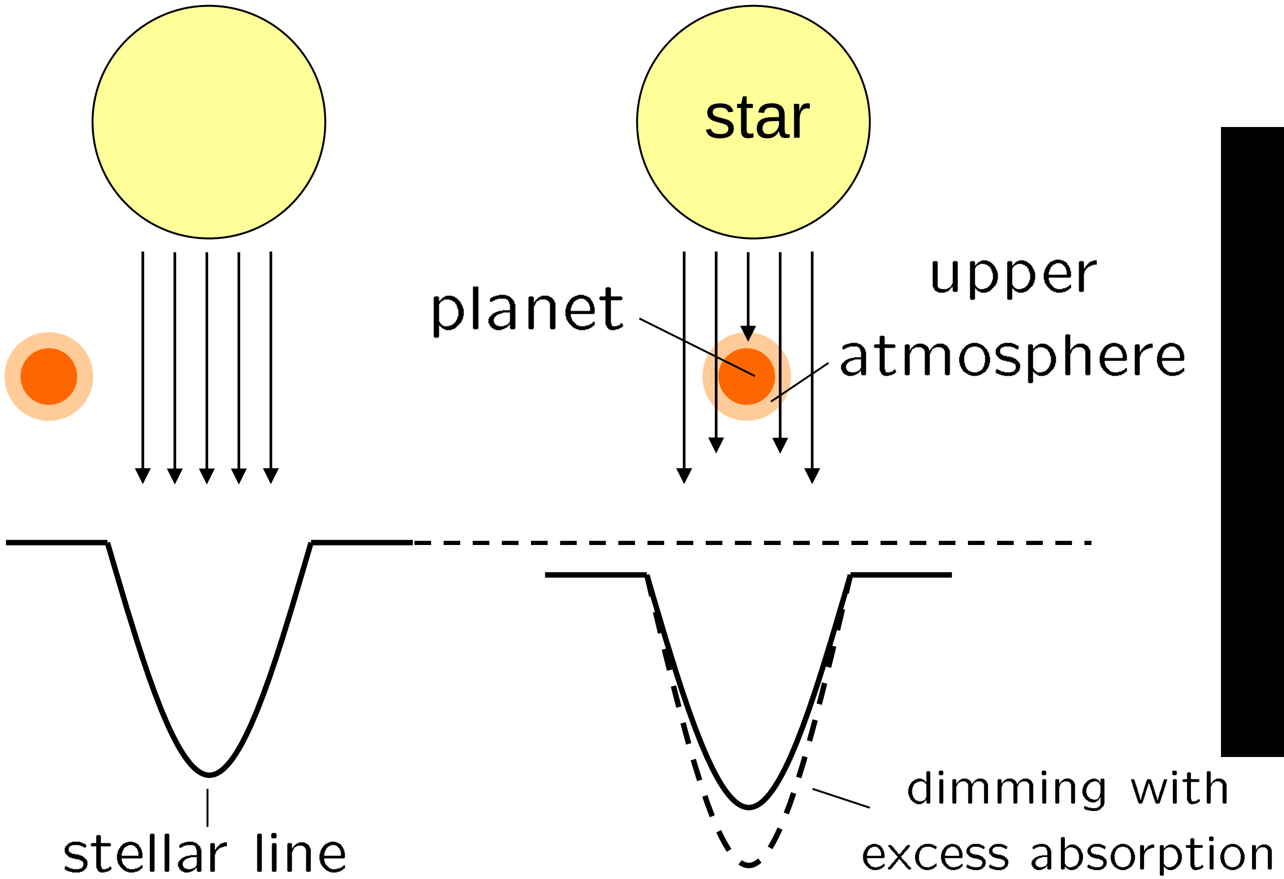
TESS will be launched in 2017.

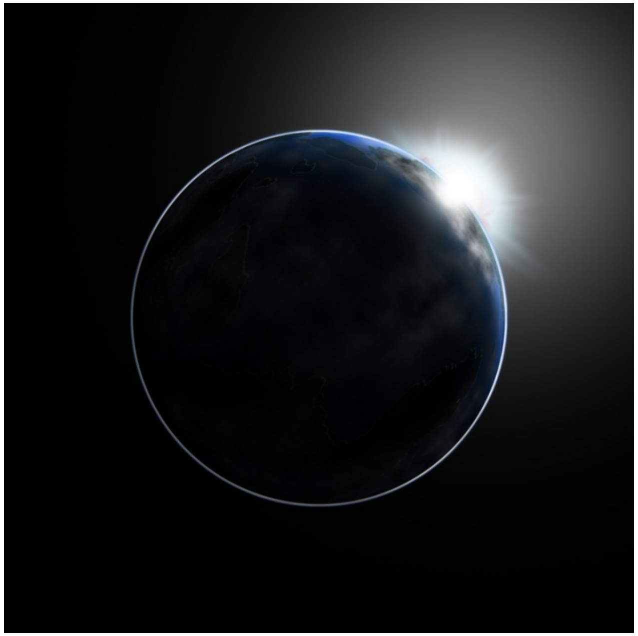
TESS Discovery Space

- Targets
  - Bright nearby stars with I = 4-12 mag (FGKM stars)
- Period of detectable planets
  - typically less than 10 days
  - up to ~60 days for JWST optimized fields
  - Planetary orbits with less than 10 (60) days period lie in habitable zone around mid (early) M stars
  - expected to discover ~500 Earths and super-Earths (including expected 5 ± 2 habitable planets) by early 2020s

Characterization of their Atmospheres

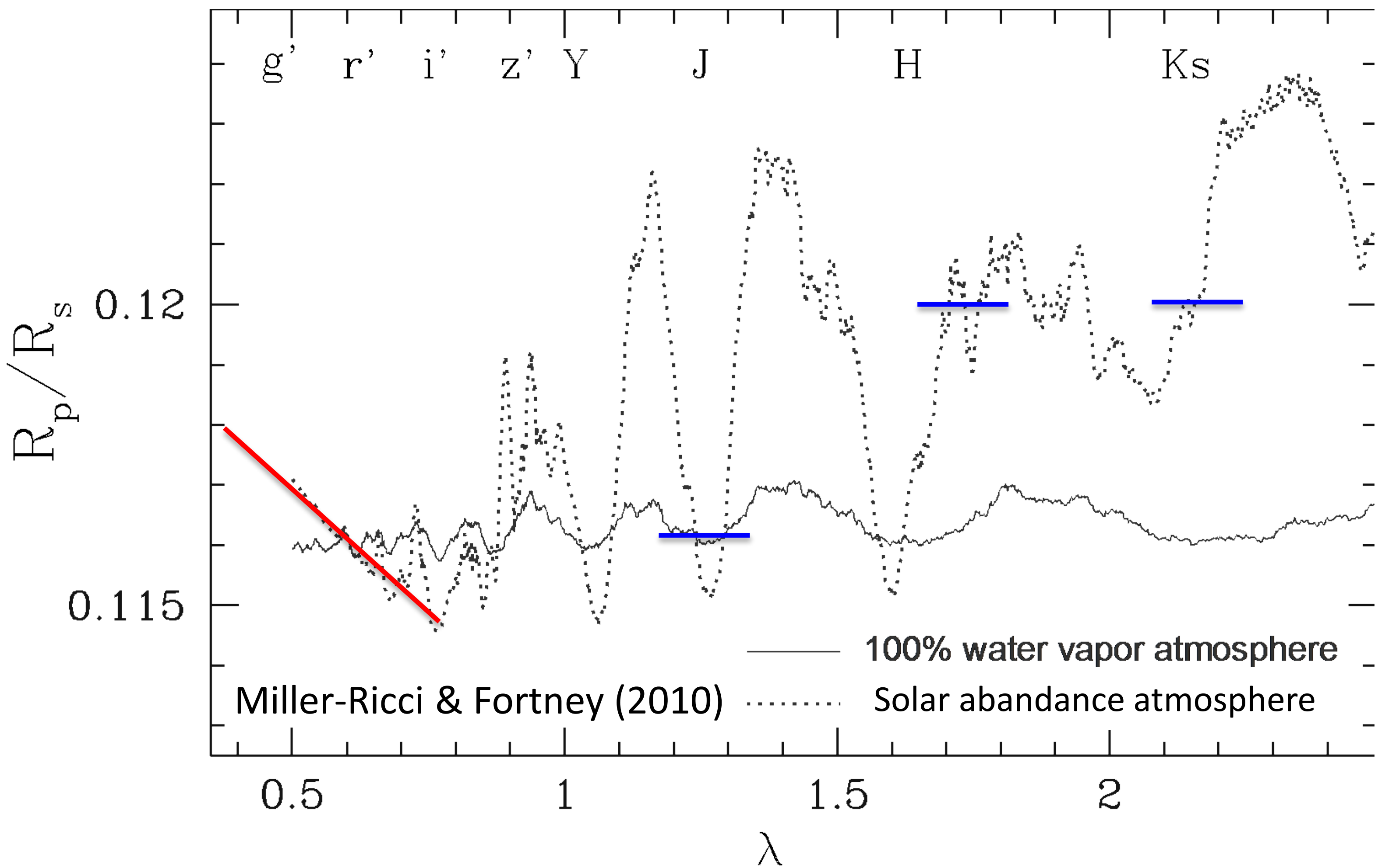
Transmission Spectroscopy





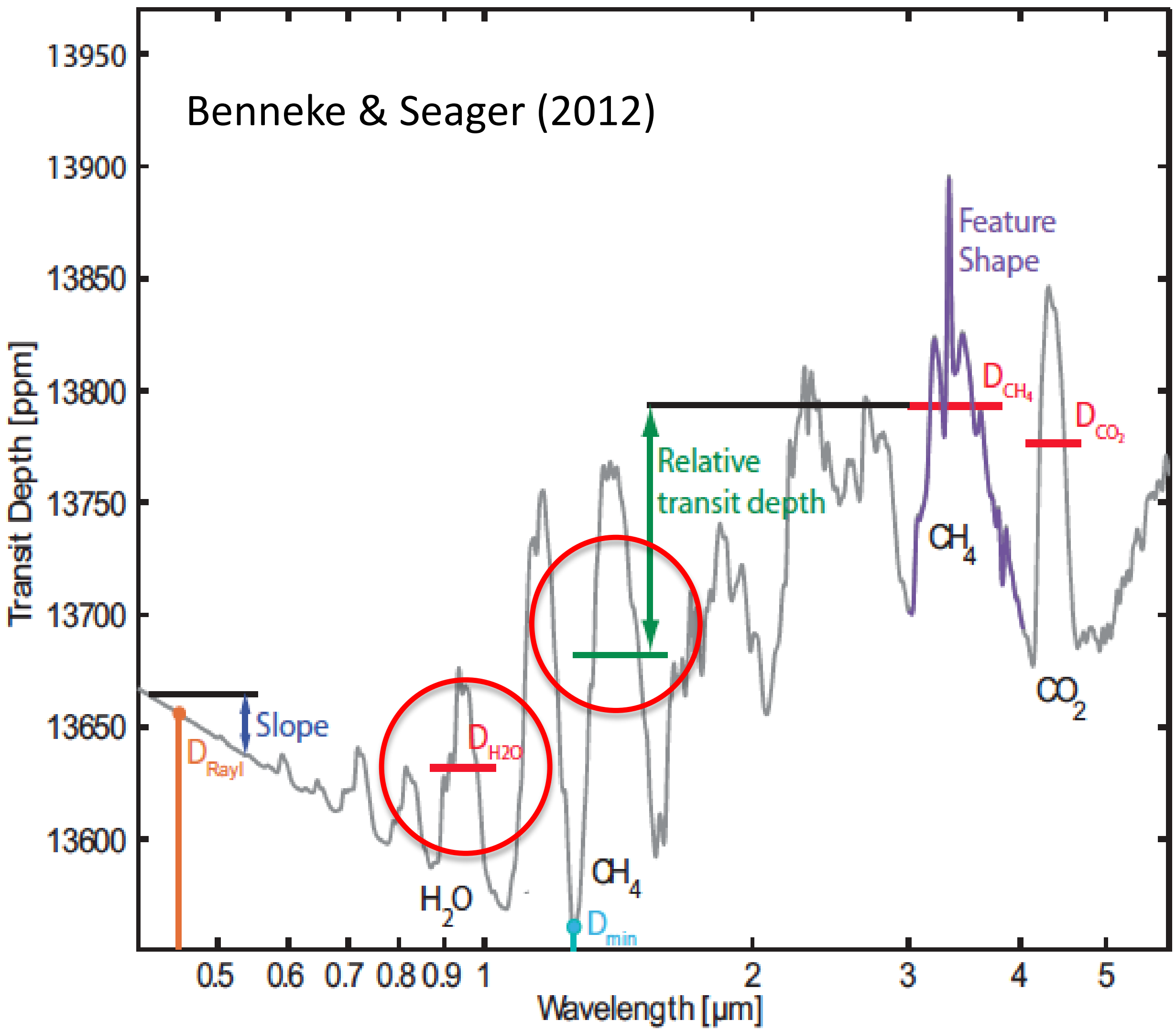
Transit depths depend on lines / wavelength reflecting atmosphere

Discriminating Major Components of Atmosphere



Model for super-Earth GJ1214b based on Miller-Ricci & Fortney (2010)

Various atmospheric models were calculated by Howe & Burrows (2012)



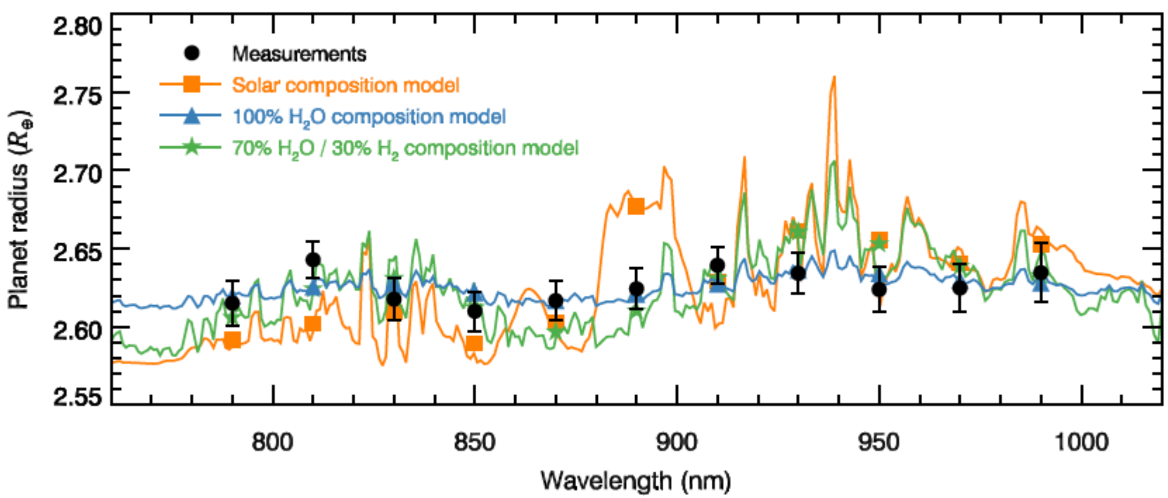
Optilal-NIR region has some features of atmospheric compositions

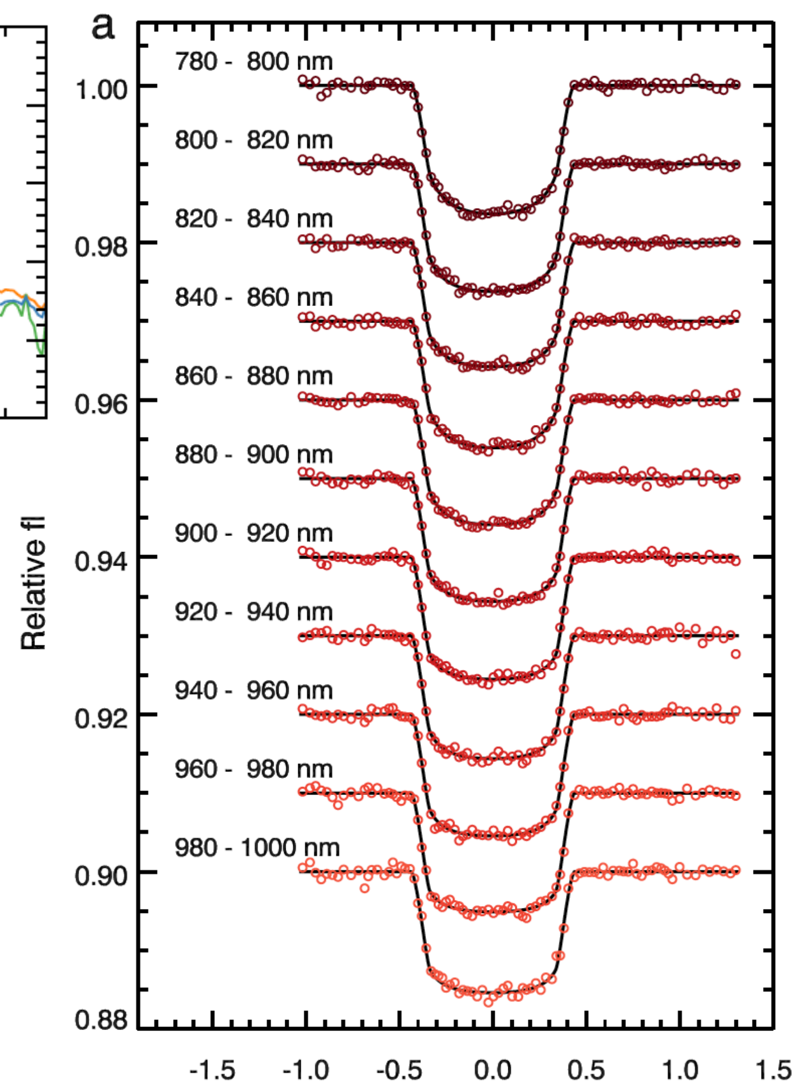
Transmission Spectroscopy by MOS

- 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

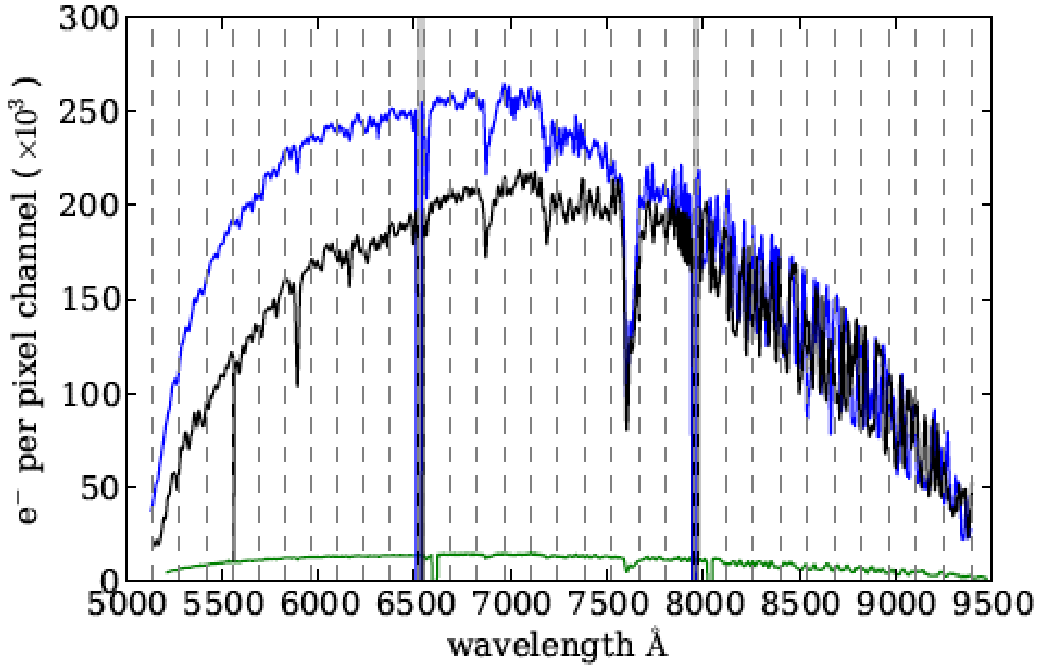
Example by Bean et al. (2010)

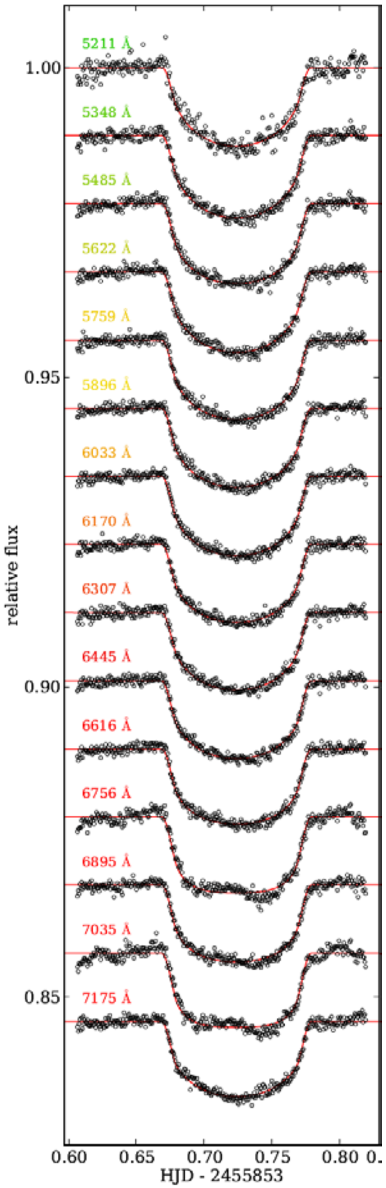




- Instrument: VLT/FORS2
- Target: GJ1214b (V=14.7)
- Integration: 20 nm (R ~ 30)
- Precision: 331-580 ppm

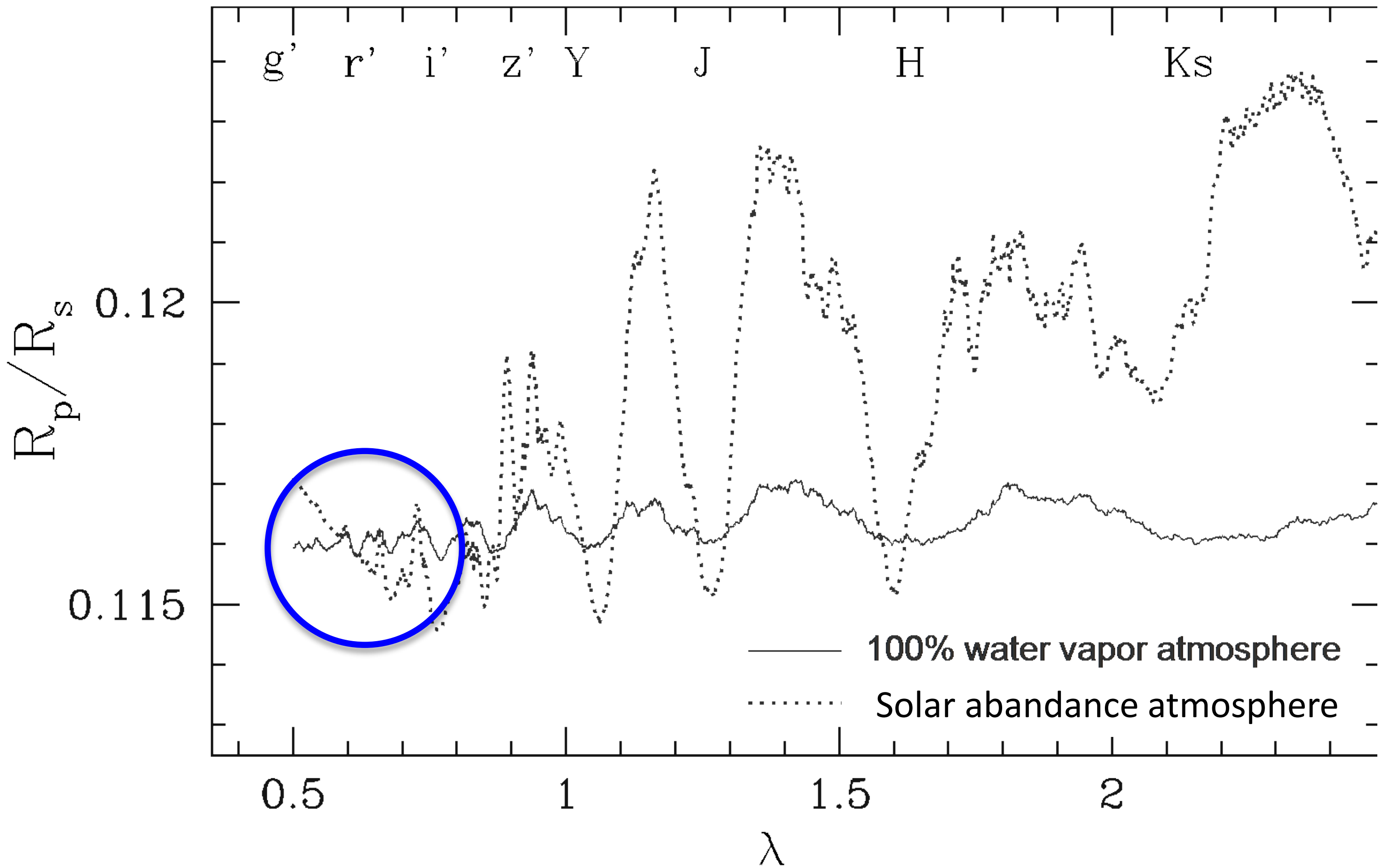
Recent Example by Gibson et al. (2012)





- 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 Scattering



One can tell whether the atmosphere is dominated by hydrogen or not

Advantages and Prospects of TMT/WFOS

- Only telescope among ELTs which can observe the Kepler field (northern hemisphere) -> over E-ELT/GMT
- Transits are time-limited -> over small visible space telescopes (e.g., EChO, CHEOPS)
- Complementary wavelength to JWST/SPICA

TMT/WFOS will be able to characterize major atmospheric compositions, especially important for habitable super-Earths

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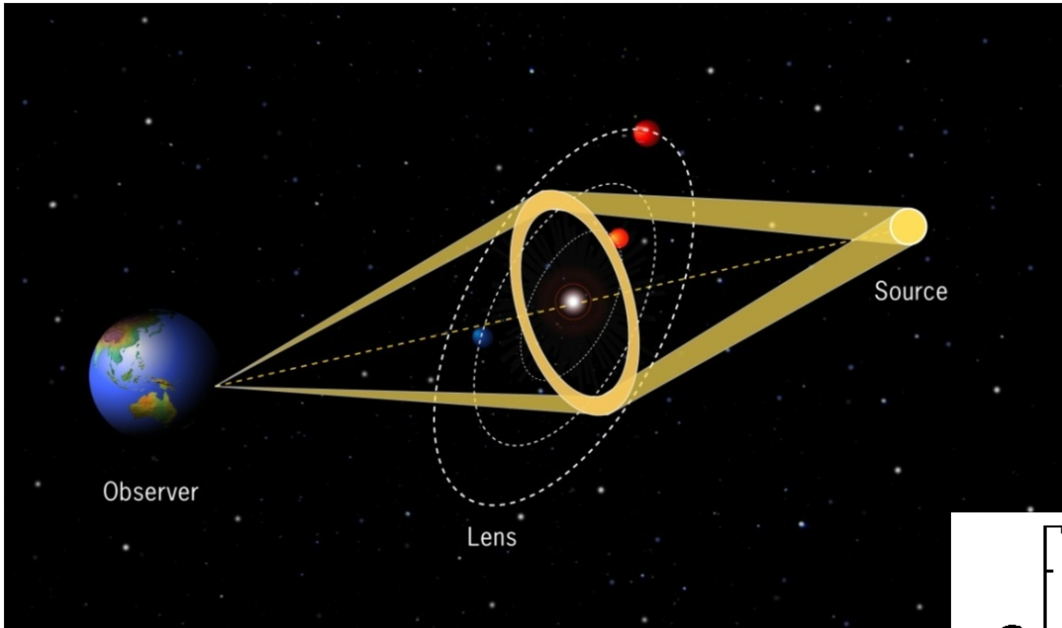
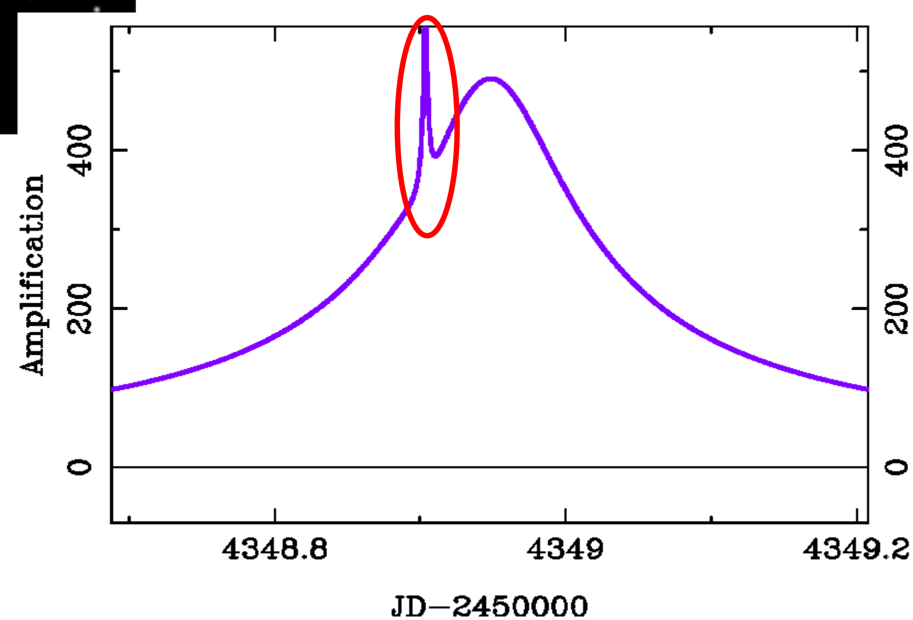
Planetary Microlens Follow-up

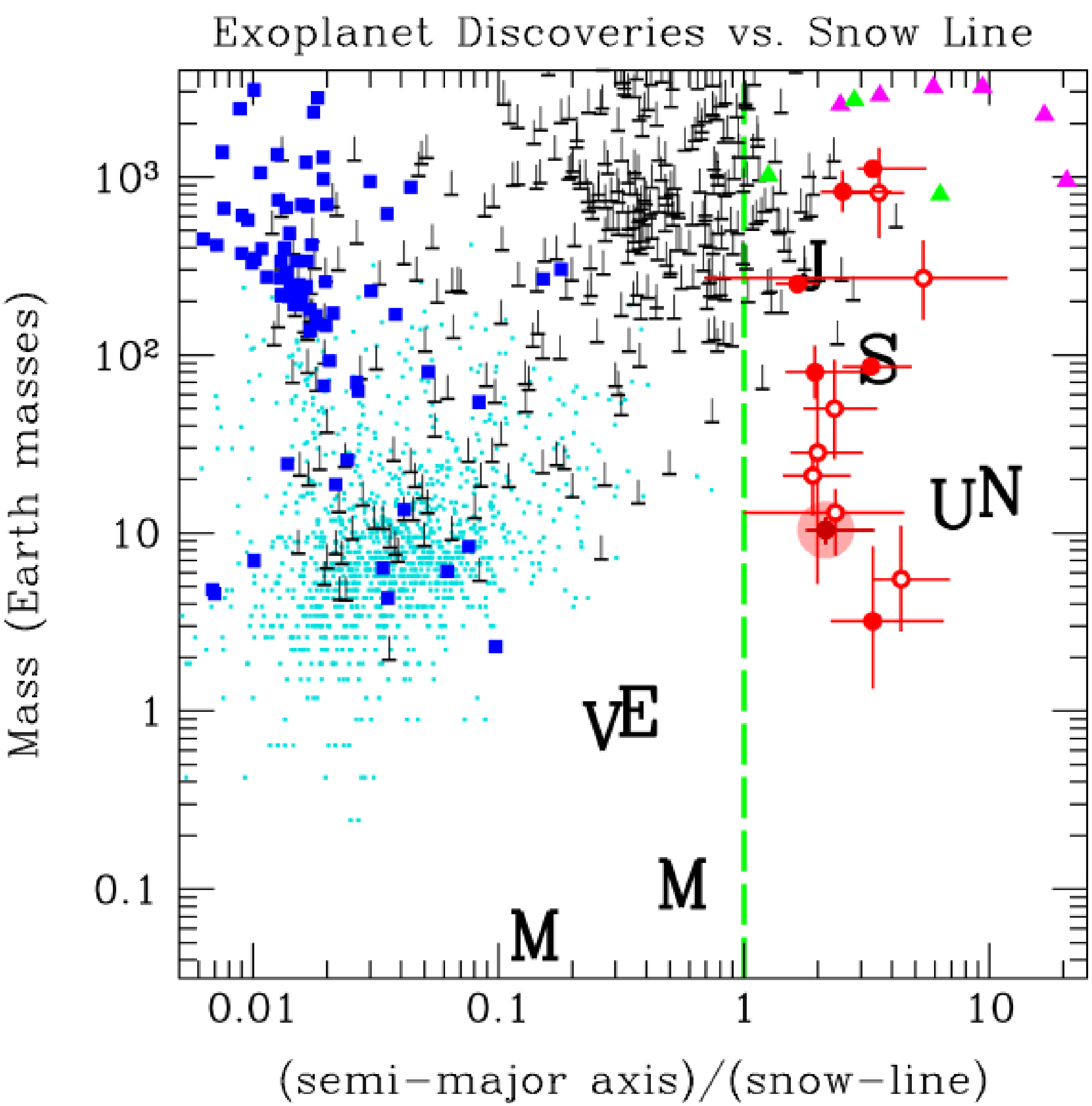


Planets can be detected by anomaly during a microlens event, when the lens star (with a planet) passes in front of the source star



Ground-based surveys (e.g., OGLE, MOA) and future space-based survey (e.g. WFIRST) will find many planets via this method

Planet Distribution



- •RV
- •Transit
- •Candidates by Kepler
- •Direct image
- •Microlensing :

Mass measurements

Mass by Bayesian

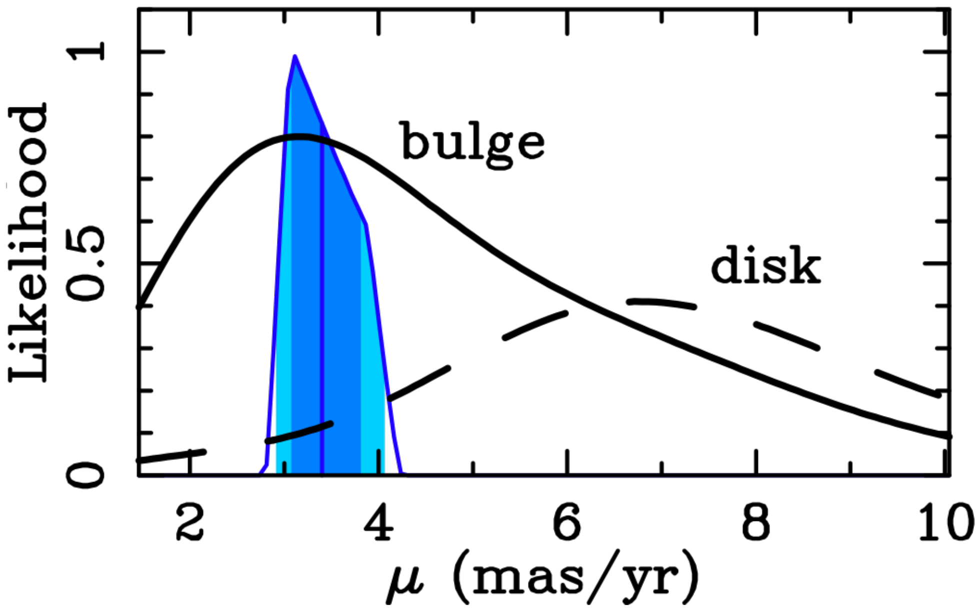
Only half of planets have mass measurements.

Need to resolve the lens star to measure masses of the lens star/planet

Muraki+ 2011

TMT can resolve source and lens stars

Average relative proper motion of lens and source star: μ= 6 +- 4mas/yr



Resolution:

•1.2x2.2μm/8.2m= 66mas
(~80mass in VLT/NACO and Keck AO)

•1.2x2.2μm/30m=18mass

Required time to separate by 2 × psf:

◆8.2m: $T_{8.2} = 22^{+44}_{-9}$ yr

◆30m: $T_{30} = 6^{+12}_{-2}$ yr

What TMT/IRIS Can

- Many microlens planets will be found by the first light of IRIS
  - possibly including habitable planets

- Need several years, but IRIS can determine masses of such outer planets (complementary to RV/transit)
  - useful for comparisons with planet population synthesis

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Science Cases for Future Instruments

- The larger mirror is the biggest TMT's advantage over 8-10m telescopes and space telescopes

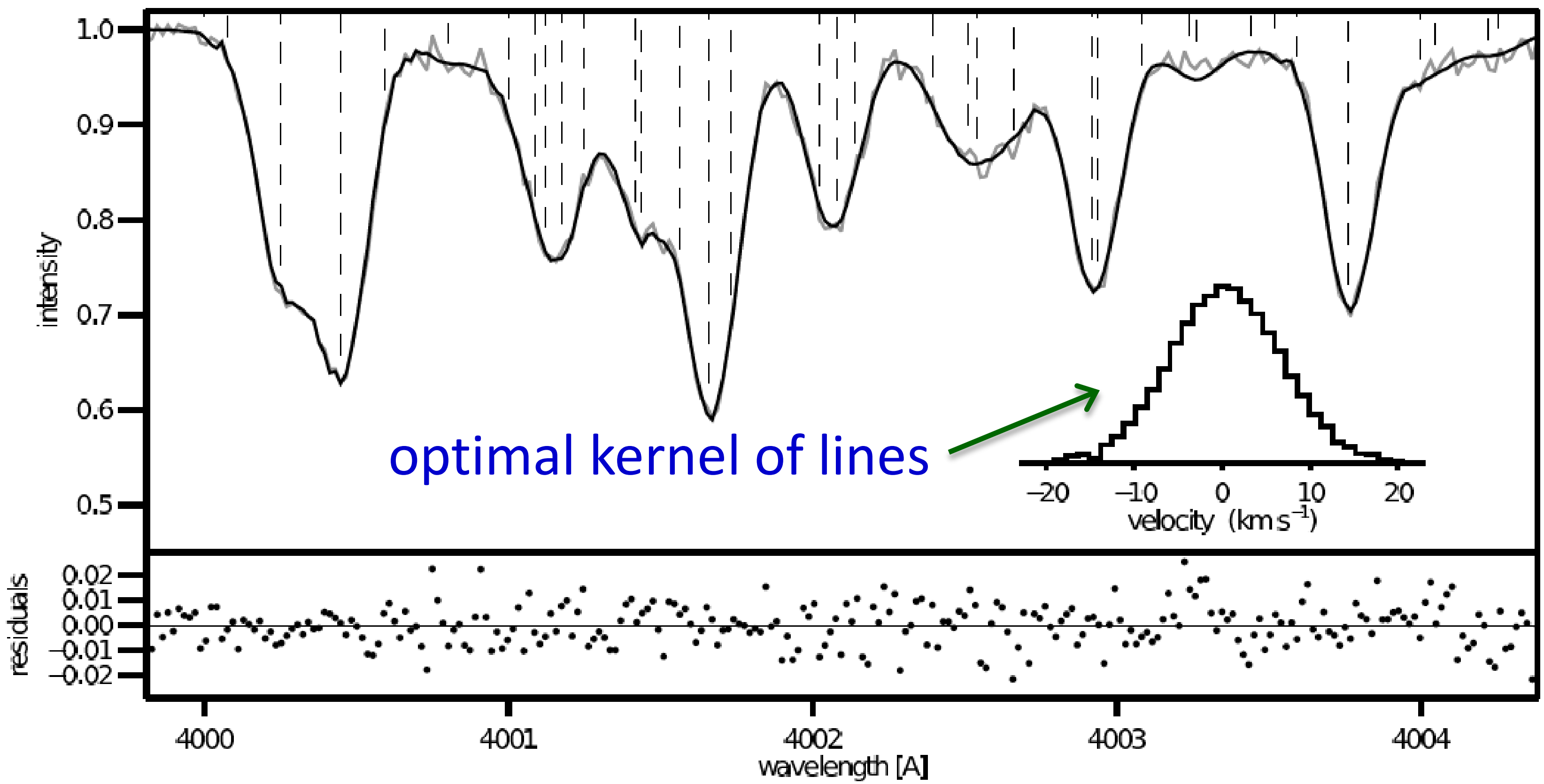
- To make the most of this advantage
  - High Spectral Resolution (Dispersion) Instruments
  - High Spatial Resolution (Contrast) Instruments

What TMT High Dispersion Instruments Can

- When a planet transits
  - direct detection of planet's shadow and orbital obliquity

- When a planet is located nearly behind the host star
  - direct detection of planet's atmospheric emissions and orbital motion

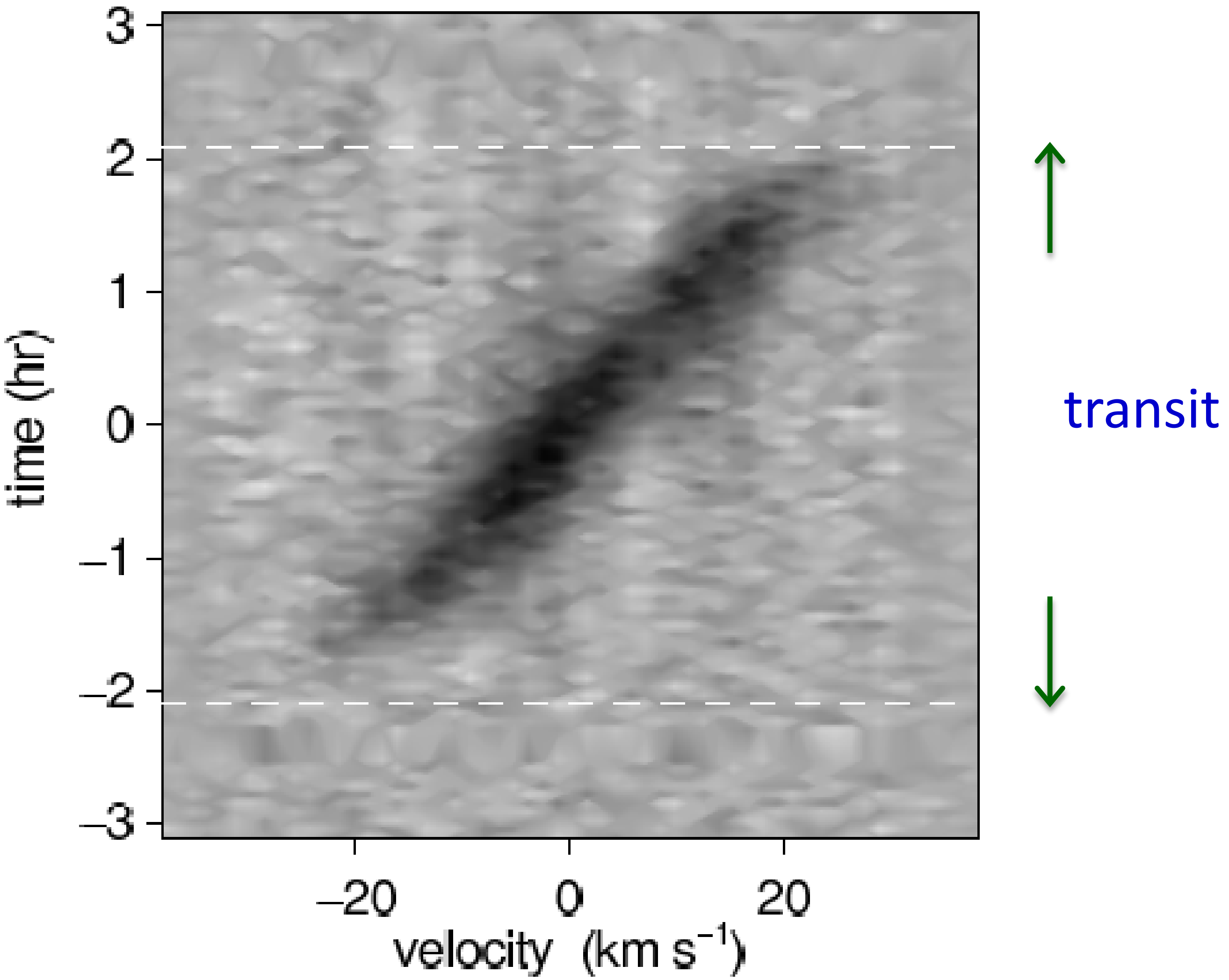
Planet’s Shadow in Stellar Lines



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

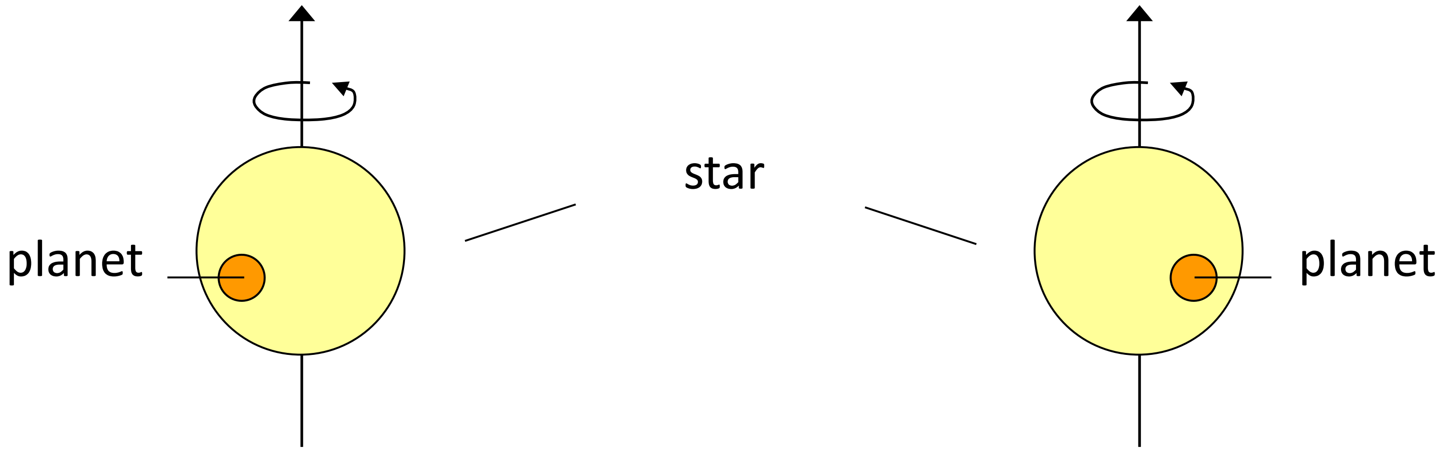
Albrecht et al. (2013)

Planet’s Shadow in Stellar Lines



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

Rossiter effect of transiting planets



the planet hides an approaching side
→ the star appears to be receding

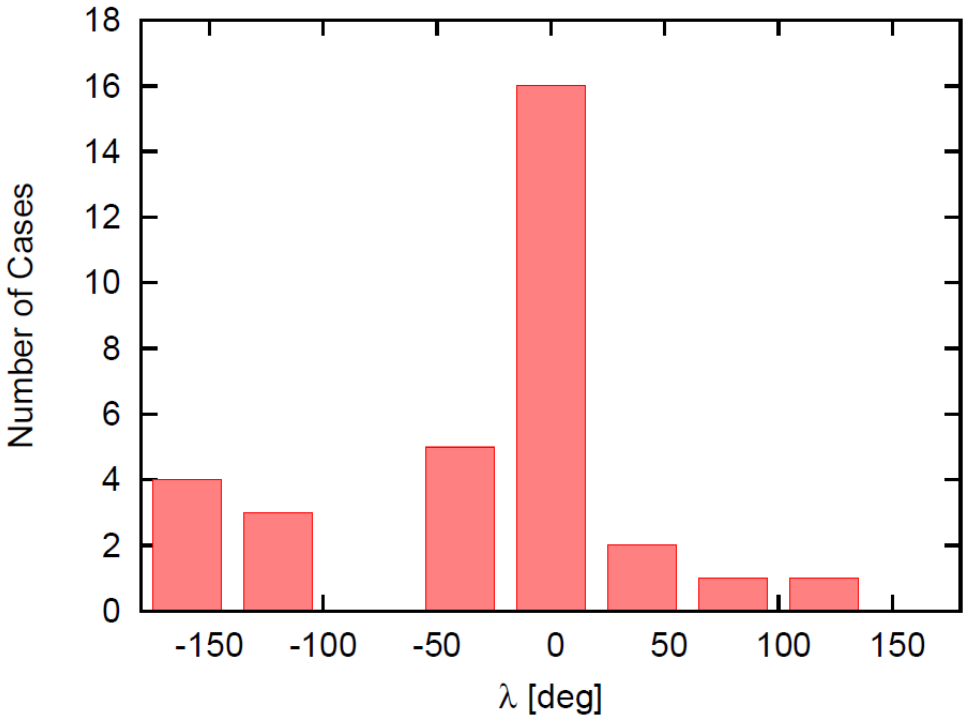
the planet hides a receding side
→ the star appears to be approaching

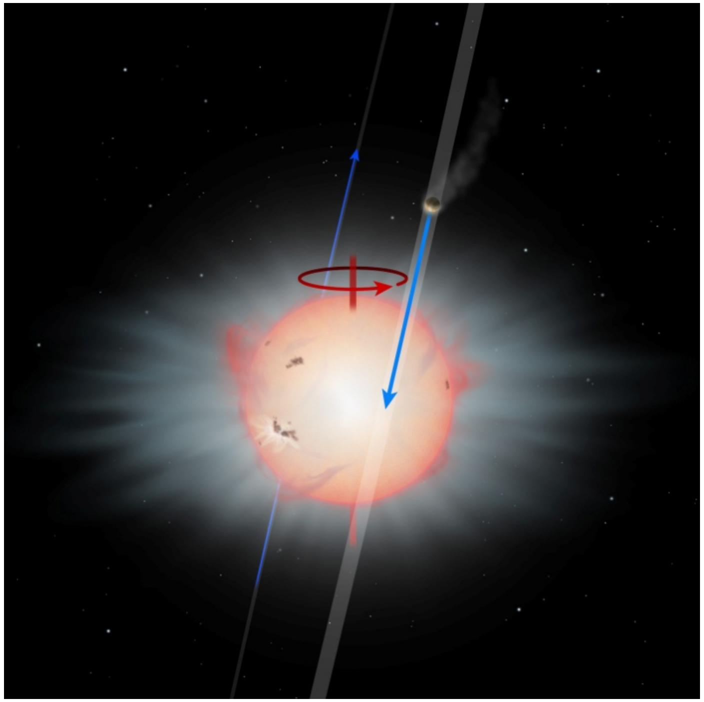
One can measure the obliquity of the planetary orbit relative to the stellar spin axis.

⇓

The obliquity can tell us orbital migration mechanisms of exoplanets.

What we learned from the Rossiter effect



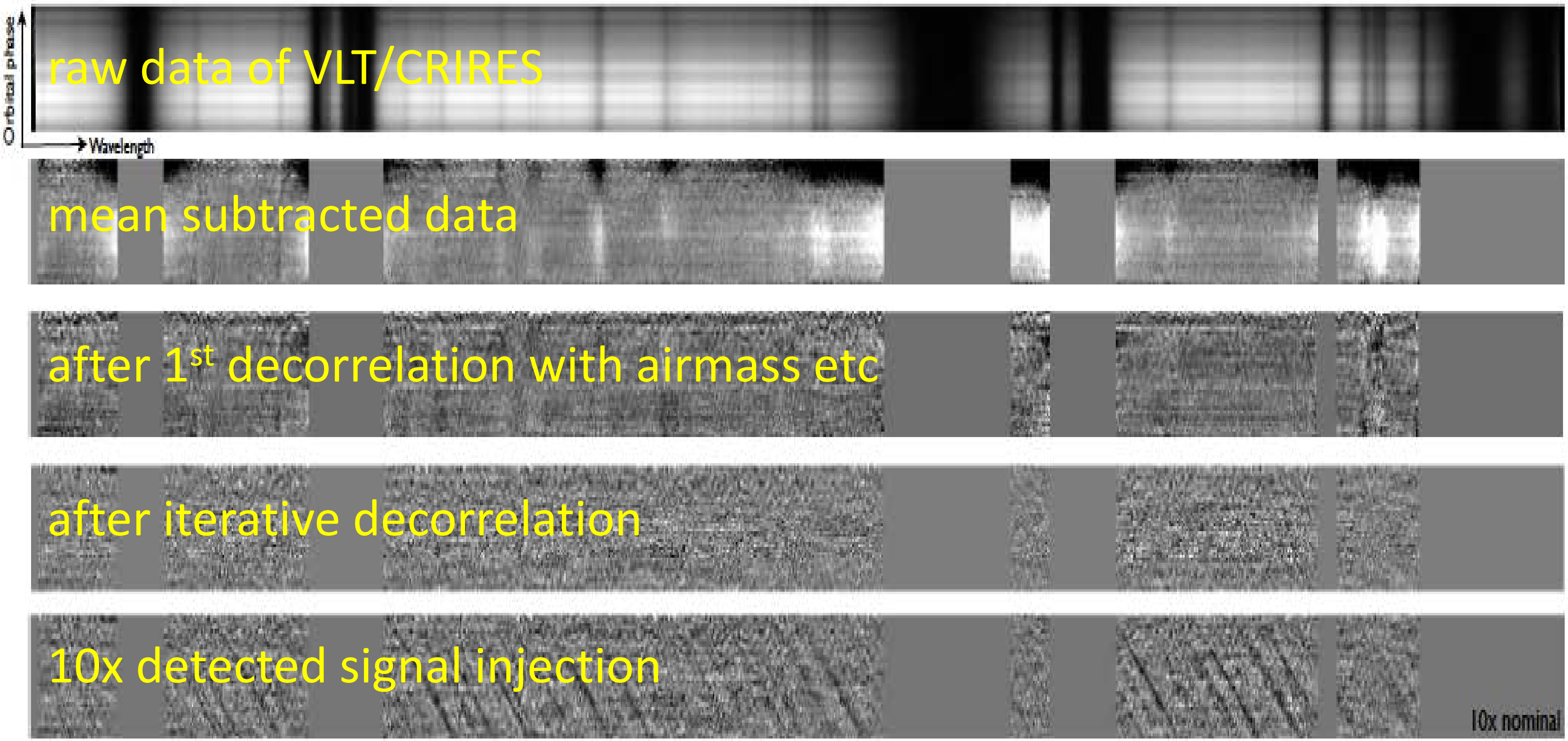


- For Jovian planets, tilted or retrograde planets are not so rare (1/3 planets are tilted)
- How about low-mass (Earth-like) planets?

What TMT HROS/NIRES can

- Dramatically improve SNR and time-resolution!
  - It is important since planet shadow or RM anomaly is time-variable
  - without enough time resolution, the signal can be diluted
- TMT/HROS and NIRES 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"

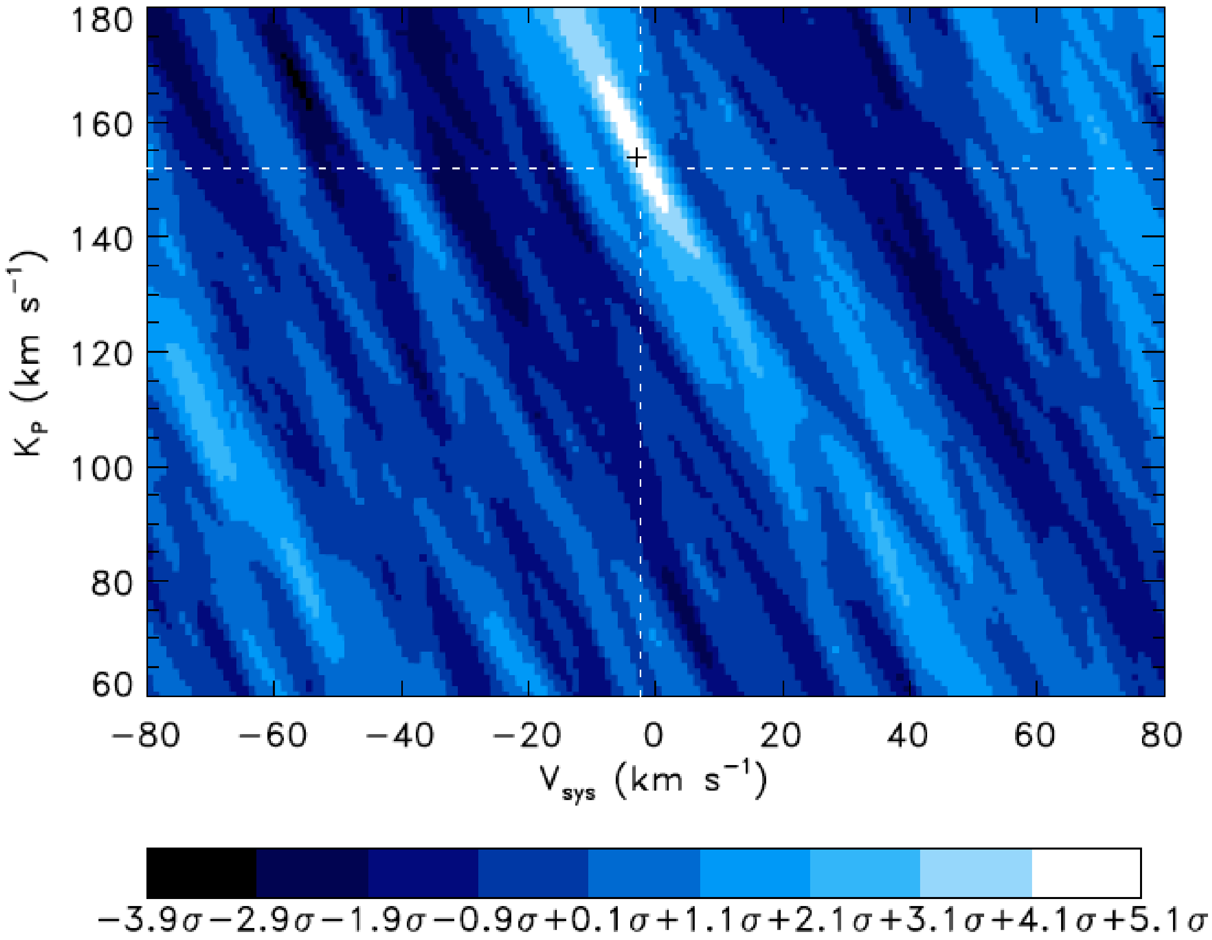
Planet’s Atmospheric Emission



Water emission lines at 3.2 micron with heavy telluric contamination

Birkby et al. (2013)

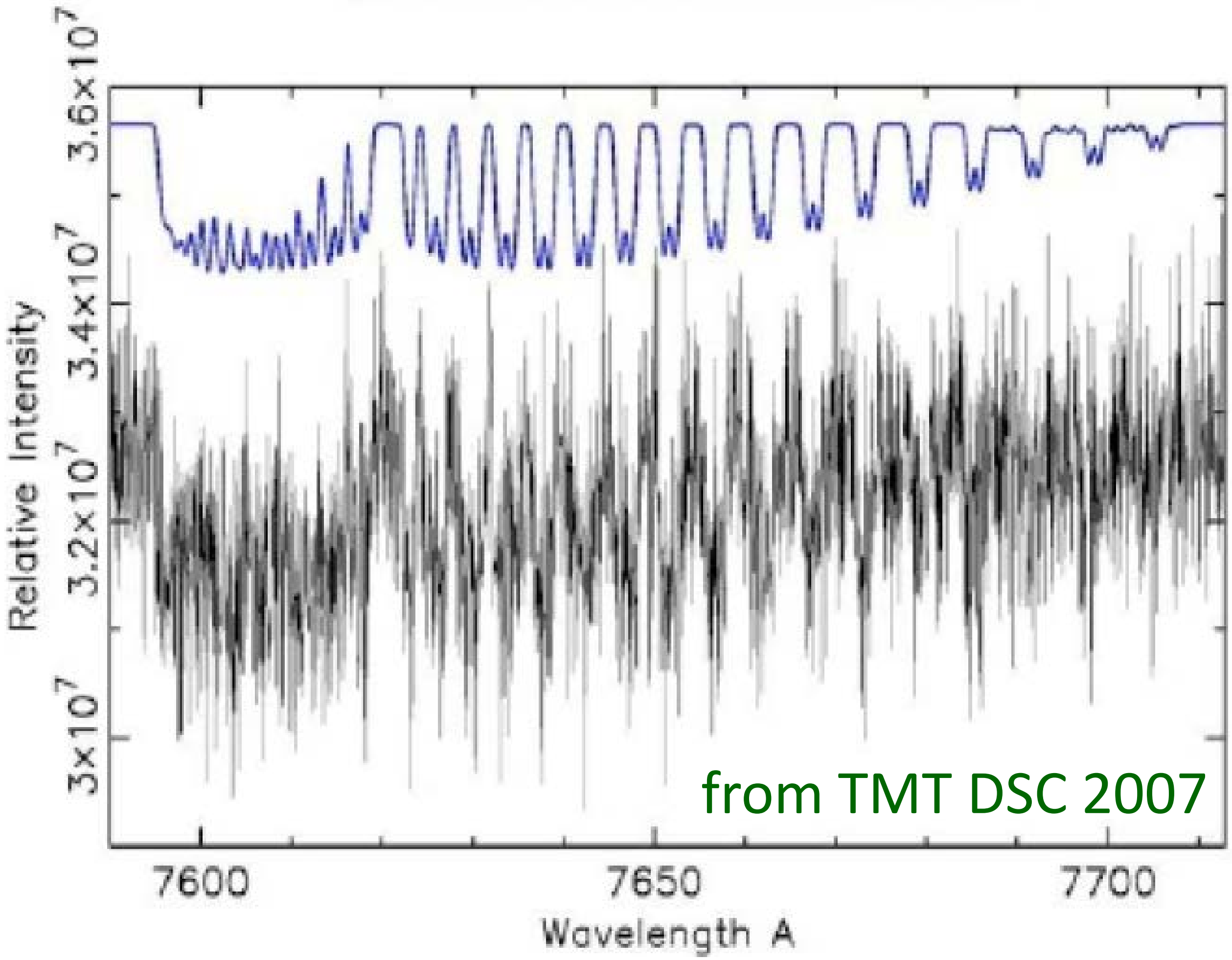
Detection of Water and Orbital Motion



Water emissions were detected even in heavy telluric contamination!

Also, this method is applicable to non-transiting planets

Transmission Spectroscopy with HROS/NIRES



Moreover, this analysis method encourages transmission spectroscopy with HROS/NIRES for some interesting lines

Summary

- TMT’s instruments can do various detailed studies for extrasolar planets
  - atmosphere
  - mass
  - orbit
- Which let us learn much more about other worlds