Observation of Exoplanet-Atmospheres by SWIMS

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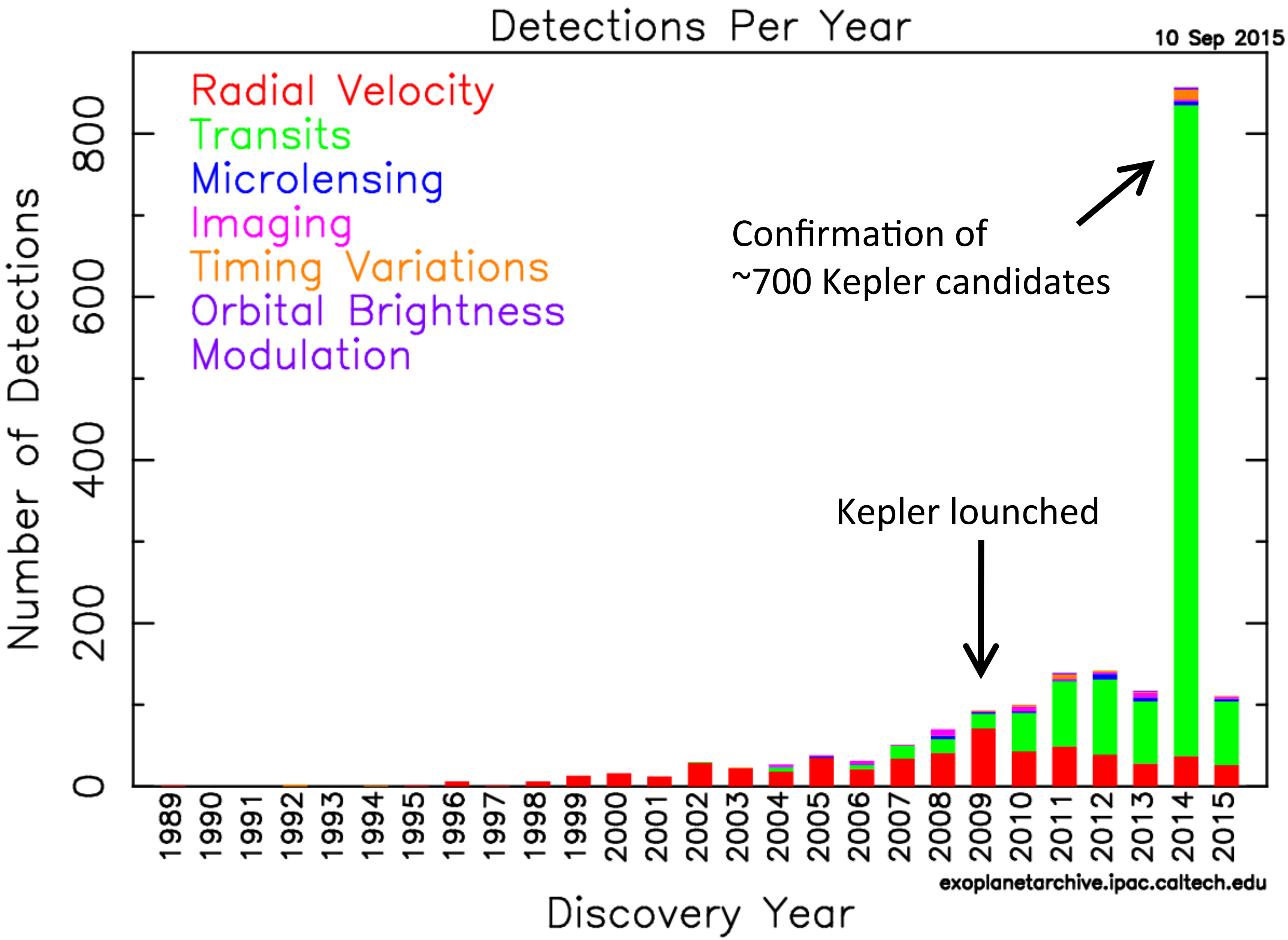
2015.9.18

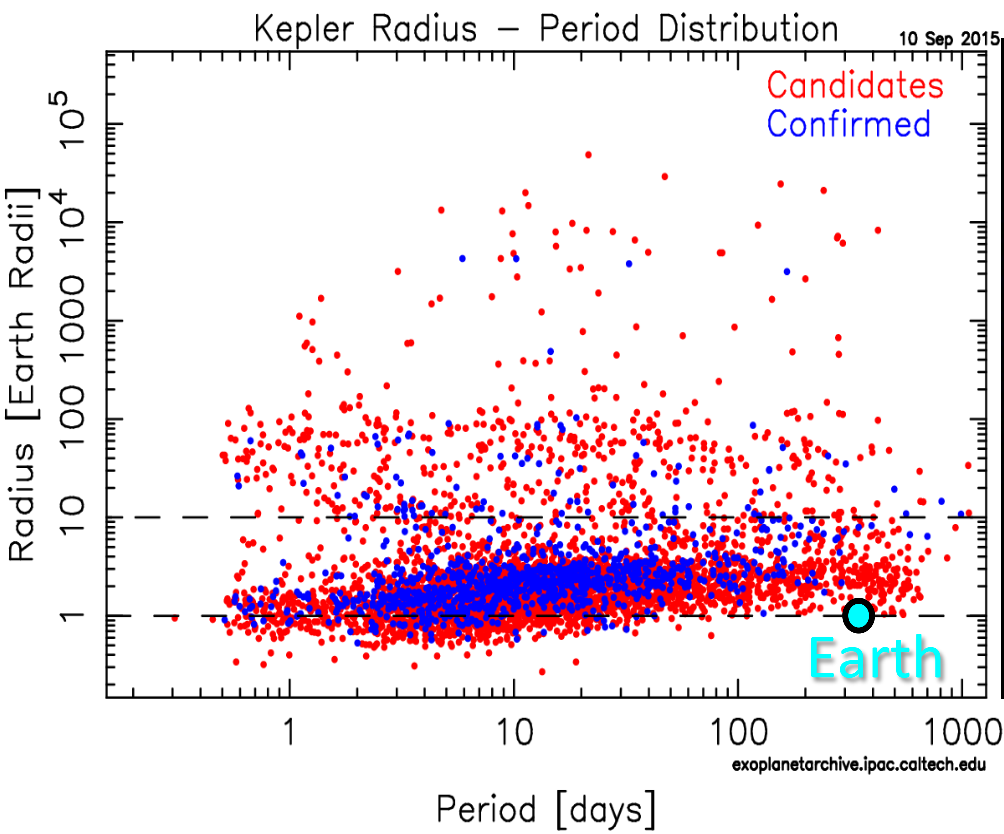
TAO/SWIMS Science WS 2015

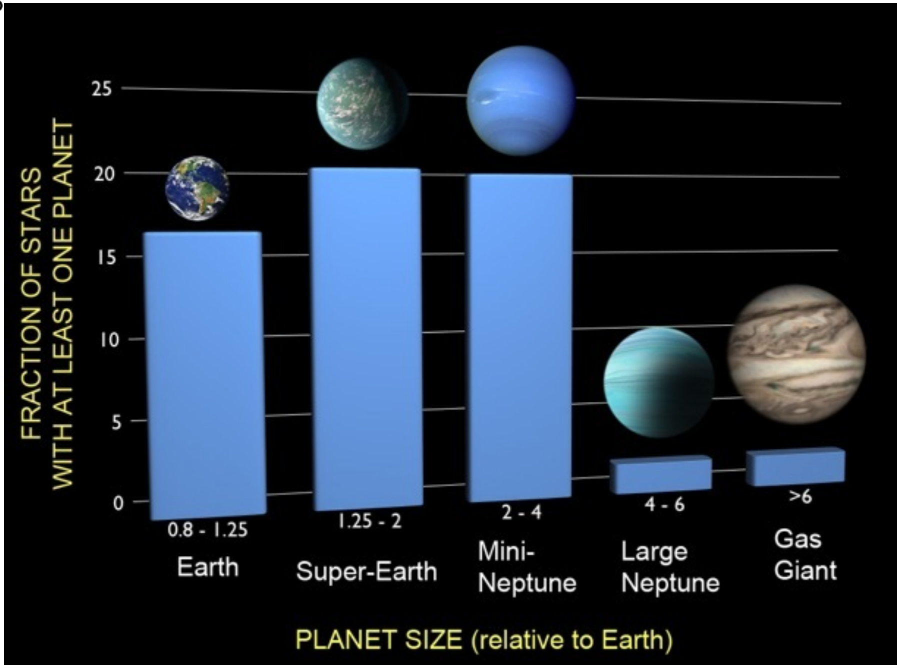
@Mitaka (the Institute of Astronomy, University of Tokyo)



1,890 exoplanets have been discovered by several techniques

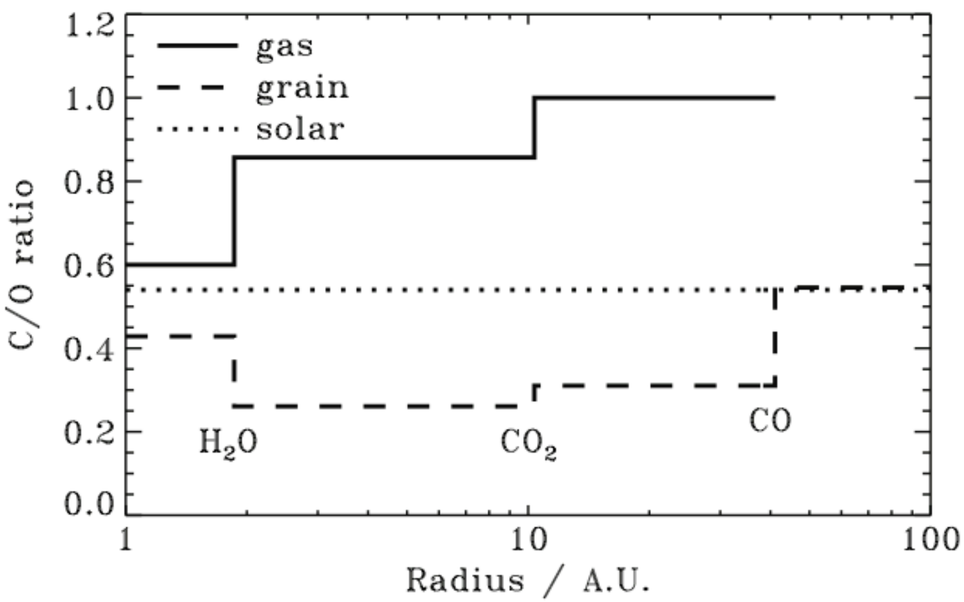
Kepler revealed new population: super-Earths



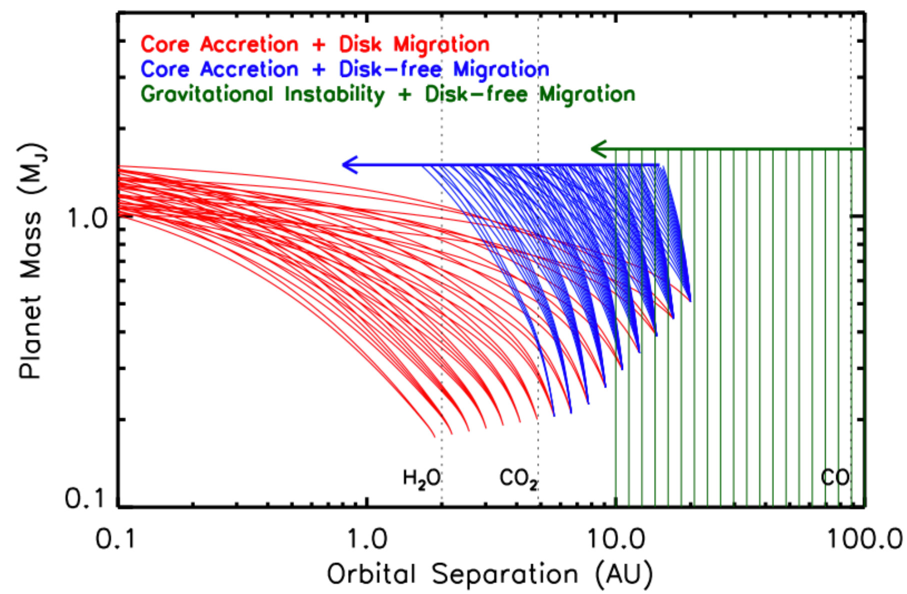


- Super-Earths are abundant in our Galaxy
- How they have formed?

Atmosphere as a tracer of planet formation history



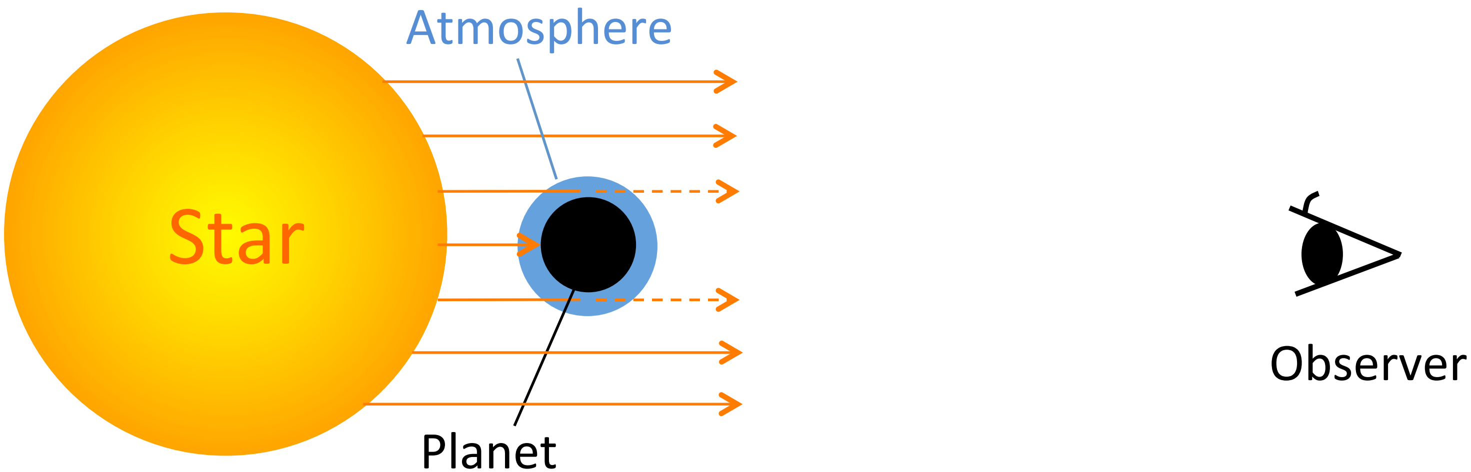
Öberg et al. 2011

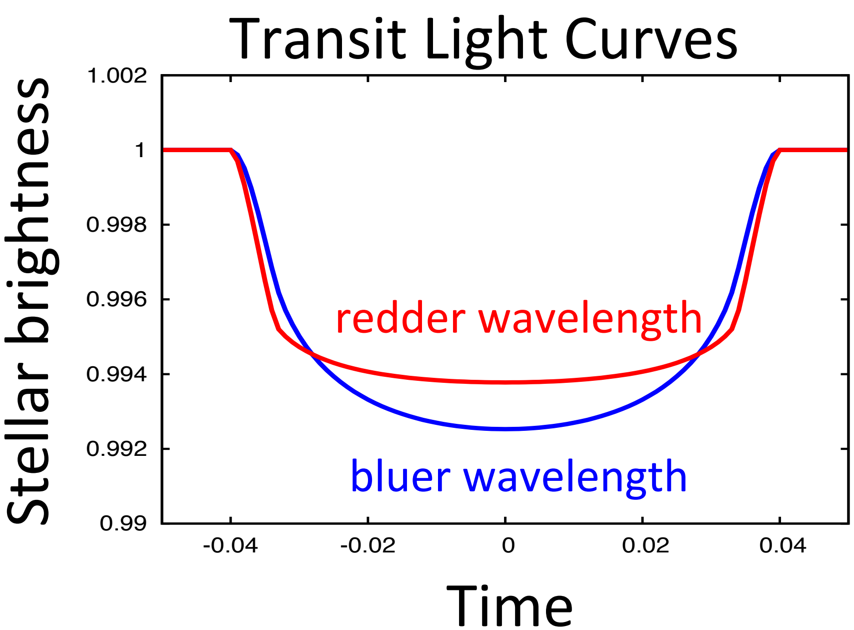


Madhusudhan et al. 2014

- C/O ratio (and water abundance) in planetary atmosphere can be a good tracer of where the planet forms
  - In proto-planetary disks, C/O ratio changes at the snow lines of H_2O, CO_2, and CO

Transmission spectroscopy





- When a planet transits, a part of the stellar light passes through the planetary atmosphere
- Atmospheric opacity changes with wavelength depending on the atmospheric composition

⇒ Atmosphere can be observed as a wavelength dependence of transit depth (=$(R_p/R_s)^2$)

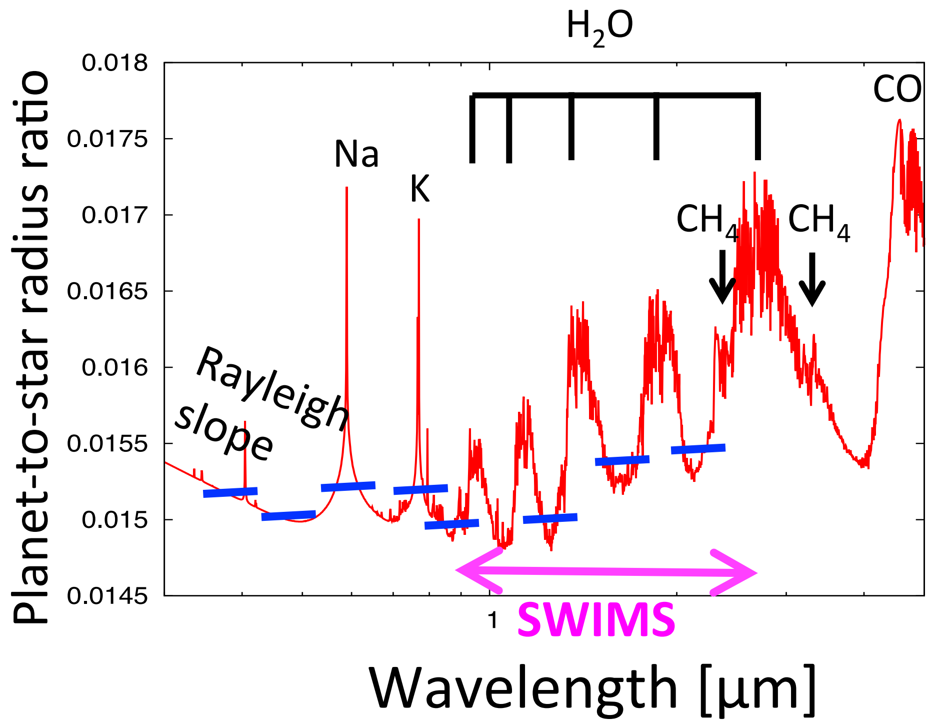
Three observational techniques

- **Multi-band Photometry**
  - Can probe overall spectral features
  - Small-to-mid class telescopes can be used
- **Low-resolution Spectroscopy**
  - Can probe Rayleigh slope in optical and molecular features in NIR
  - Necessary to use large telescopes

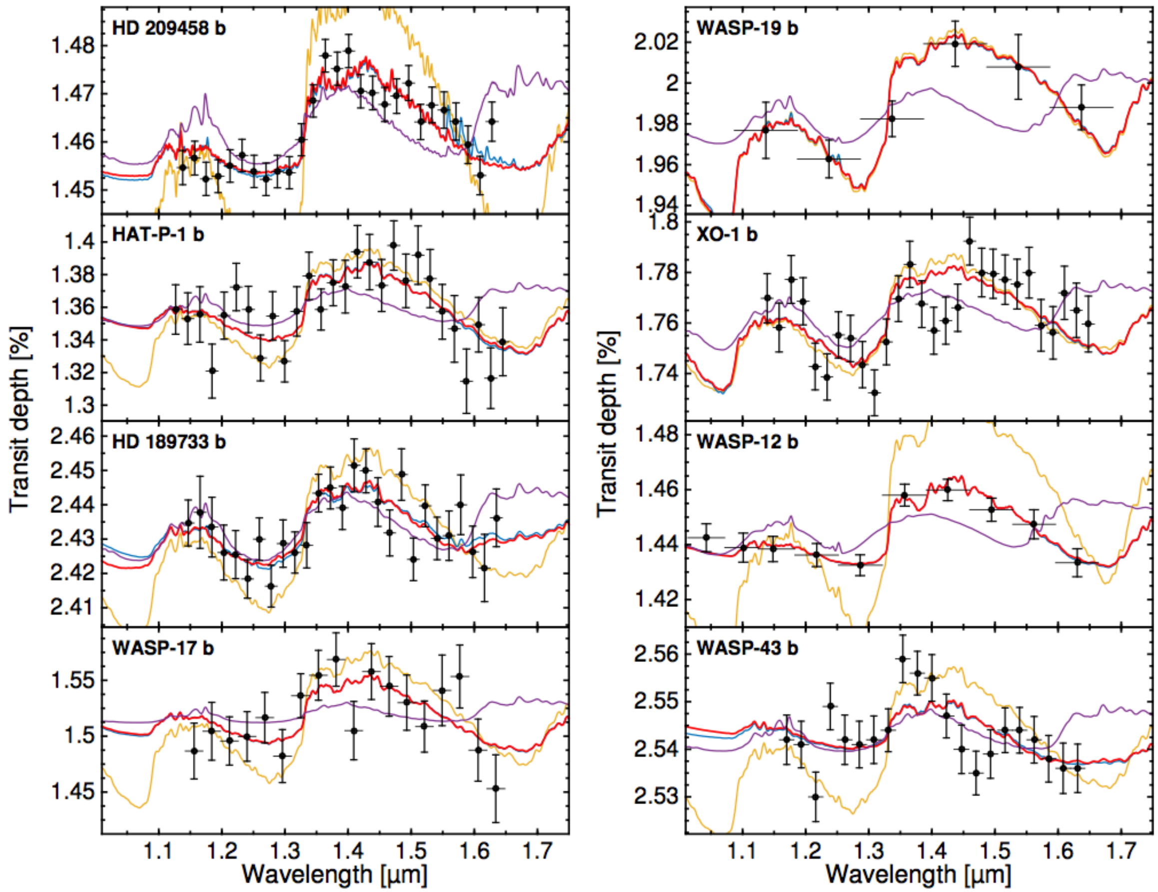
SWIMS

- **High-resolution Spectroscopy**
  - Can probe specific atomic and molecular lines
  - e.g., Na, K, CO

Theoretical transmission spectrum



Detections of water in hot Jupiters

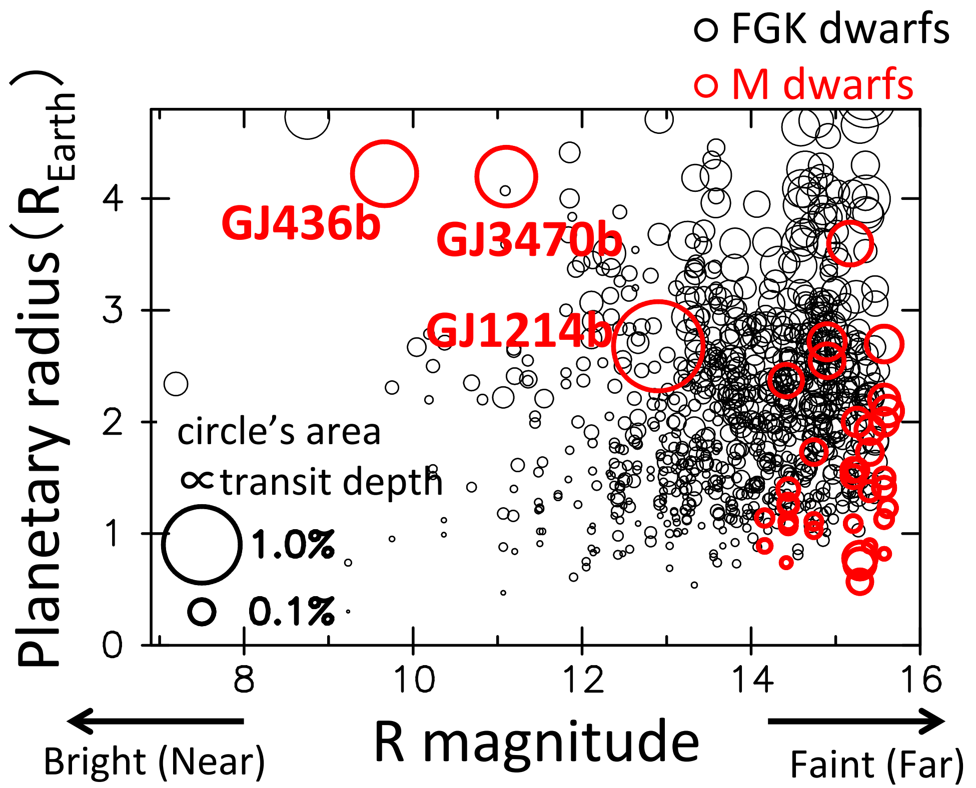


Benneke 2015

- Water (H_2O) have been detected in a number of hot Jupiters, mainly by HST/WFC3
- Many hot Jupiters have **C/O ratio < 0.9** (Benneke 2015)

Proving atmosphere of small planets

- Technical merit and demerit
  - Merit: low surface gravity → high atmospheric scale height
  - Demerit: shallow transit depth ($\delta = R_p^2/R_s^2$)
- Requirements
  - Small host stars (M dwarfs)
  - Nearby (bright) stars
- Currently, only one transiting super-Earth (GJ1214b) is known around nearby M dwarfs

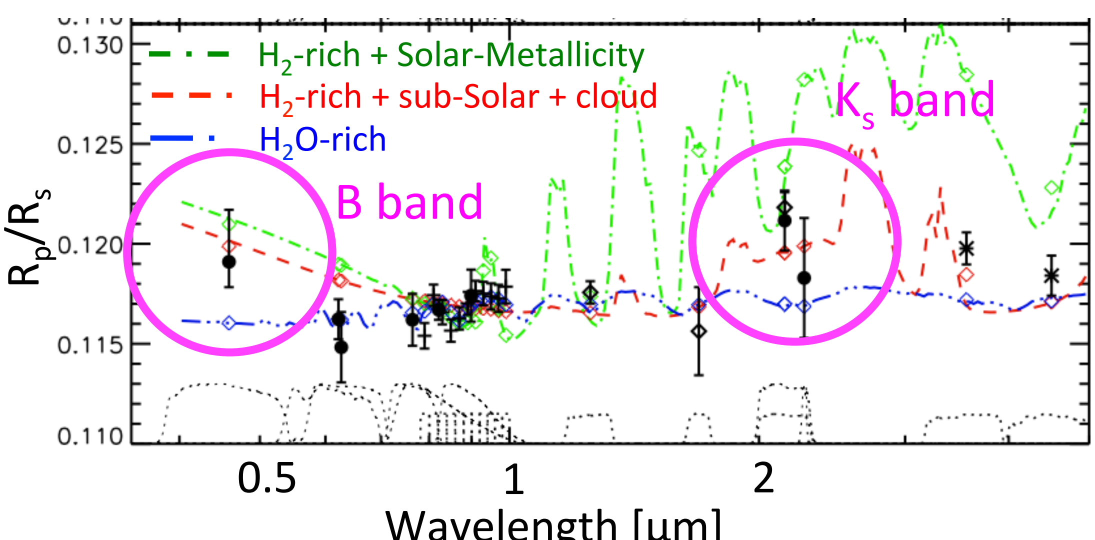


Super-Earth GJ1214b

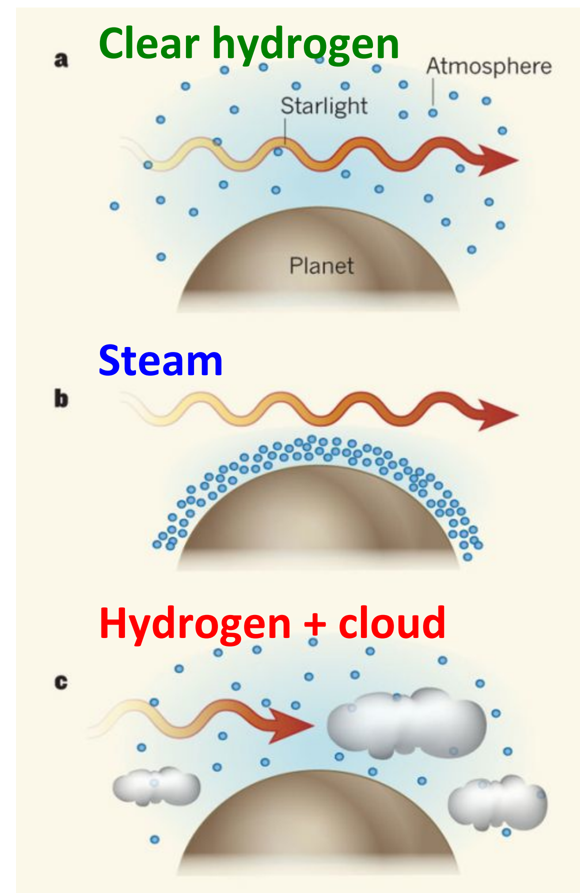
M_p	6.6 M_{Earth}
R_p	2.6 R_{Earth}
Period	1.6 days
R_s	0.2 R_{sun}

- The most famous super-Earth
  - Discovered in 2009 as the first transiting super-Earth around nearby M dwarf (Charbonneau+ 2009, Nature)

- Early observations showed a flat spectrum
  - Steam dominant or Cloudy？
  - **The NIR K_s and optical B bands were in debate**



de Mooij et al. (2011)



Our observations with 1.4m IRSF and 8.2m Subaru

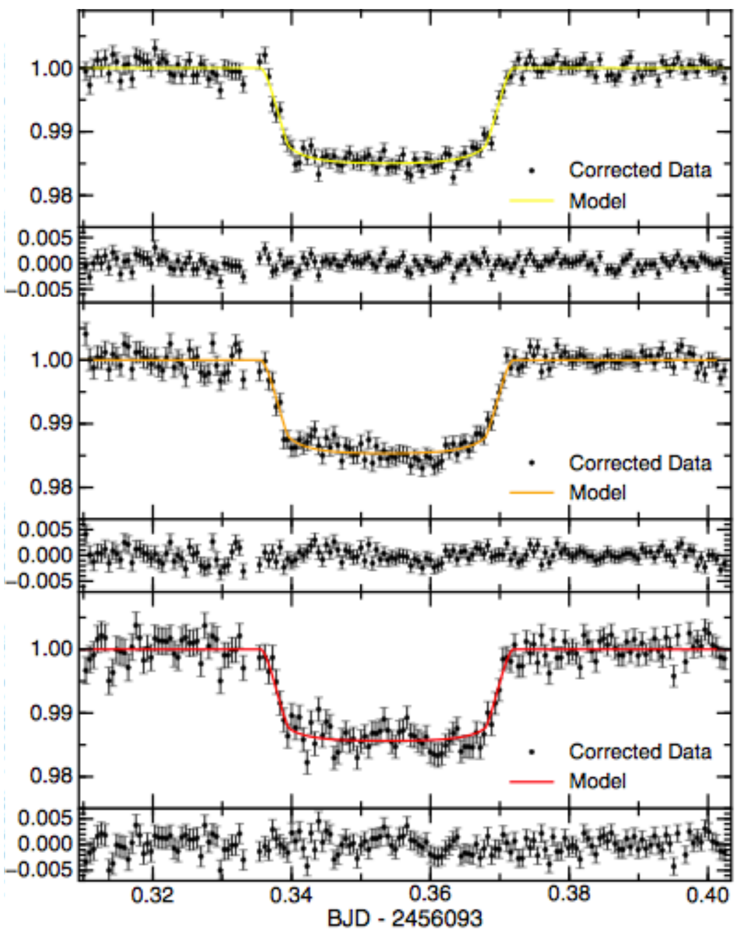
NIR J,H,Ks band photometry with 1.4m IRSF

2012 June 14

J

H

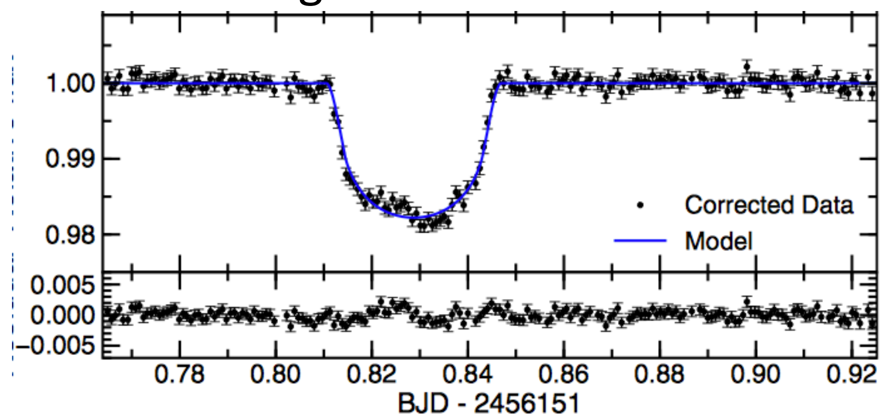
K_s



Optical B-band photometry with 8.2m Subaru

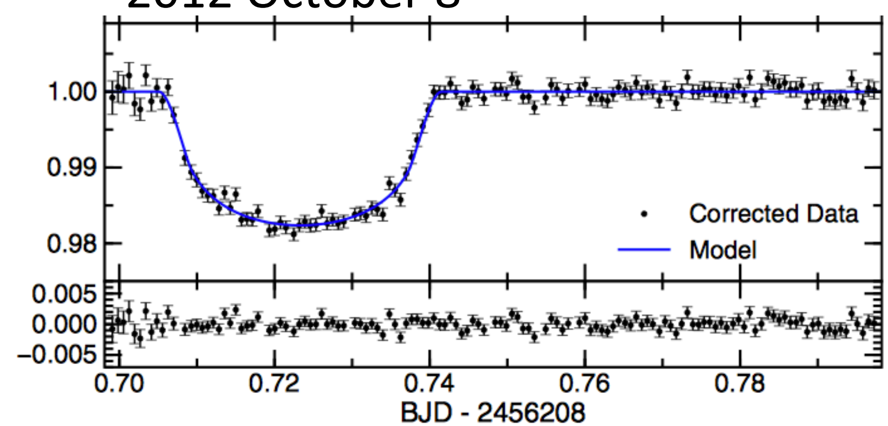
2012 August 12

B

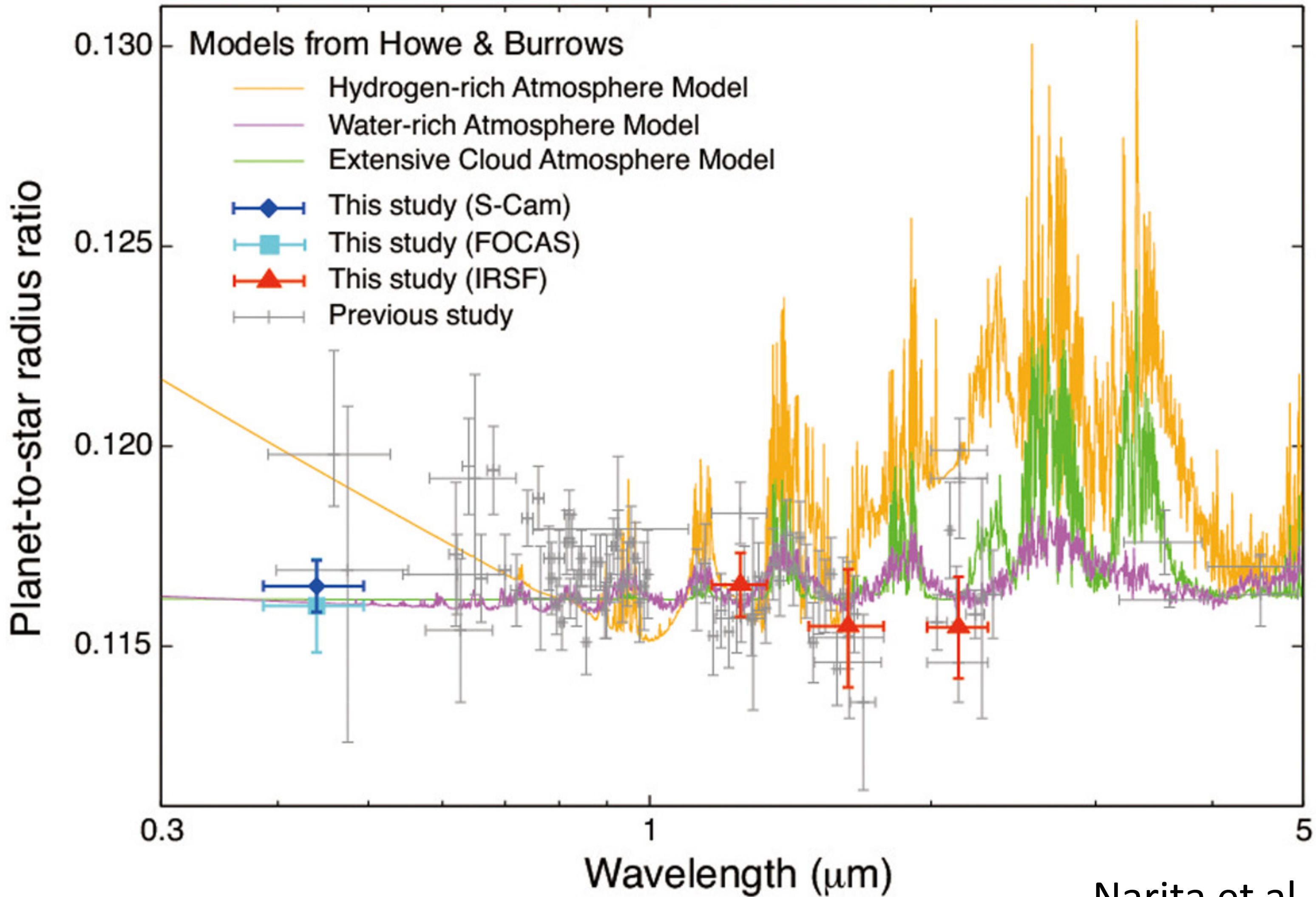


2012 October 8

B



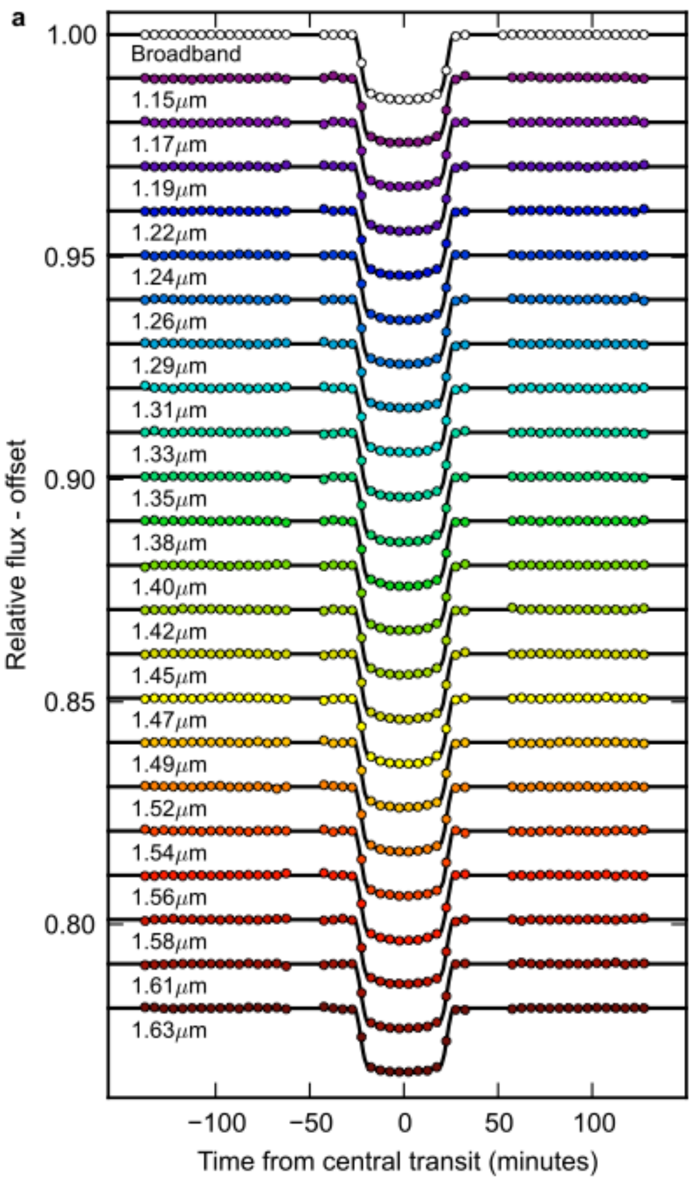
Observed Spectrum of GJ1214b

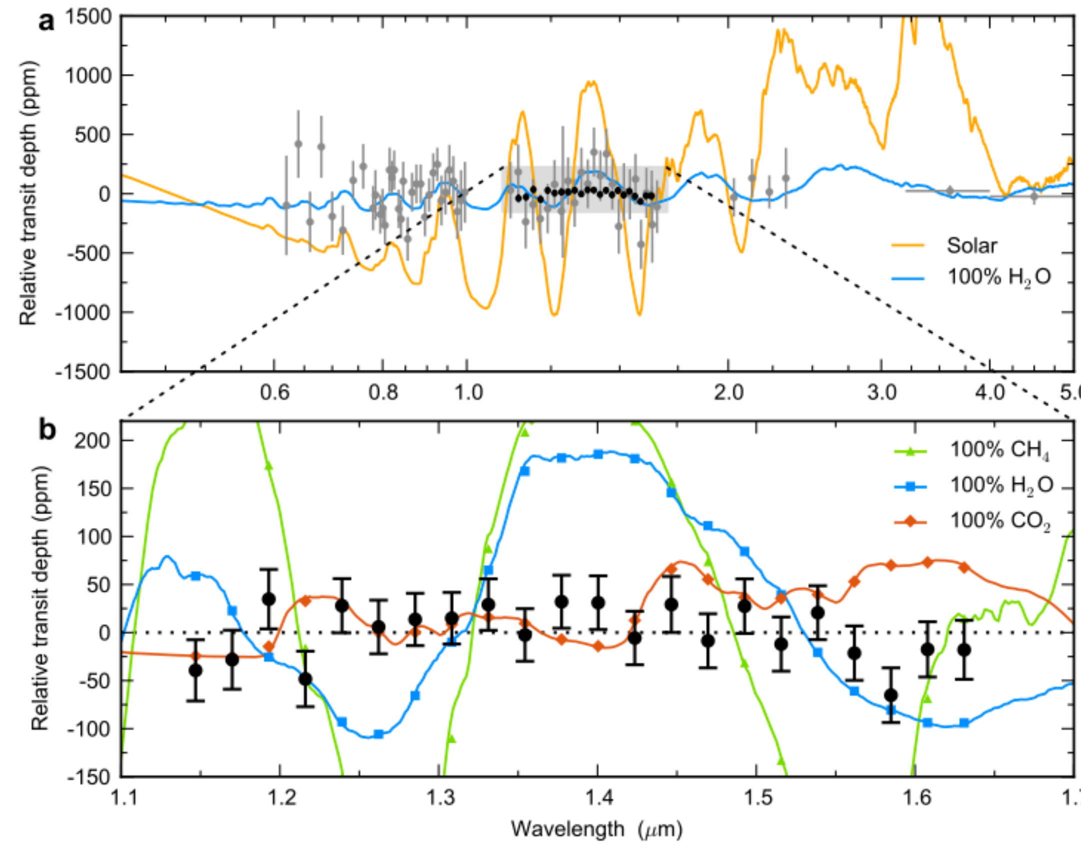


Narita et al. 2013a,b

We confirm the flat spectrum over optical and NIR

Intensive NIR Observations of GJ1214b by HST/WFC3

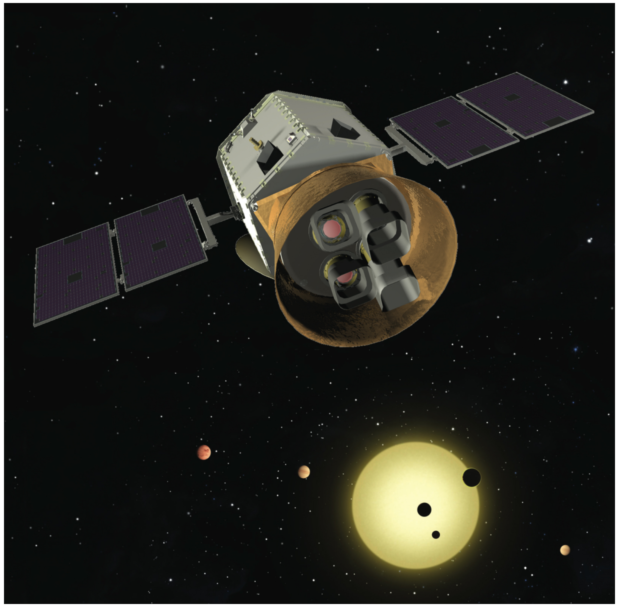


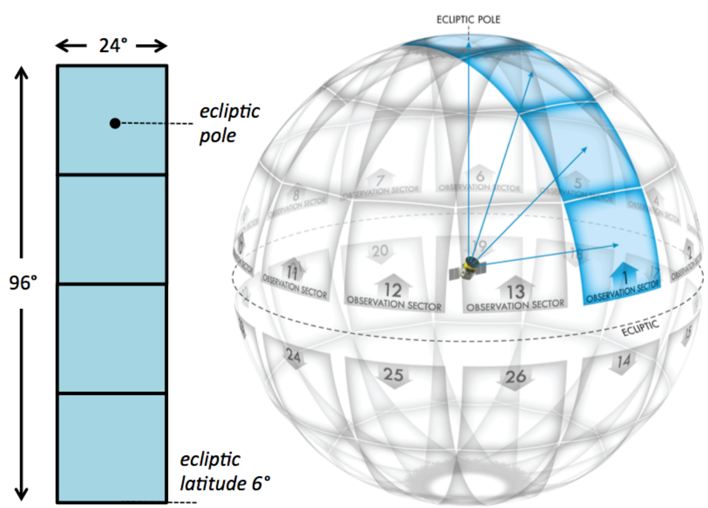


Kreidberg+ 2014, Nature

- 15 transits were obtained by HST/WFC3
- Still flat even with the marvelous precision
- Possibly covered by **a thick cloud layer**

All-Sky Transit Survey: TESS (by MIT/NASA)





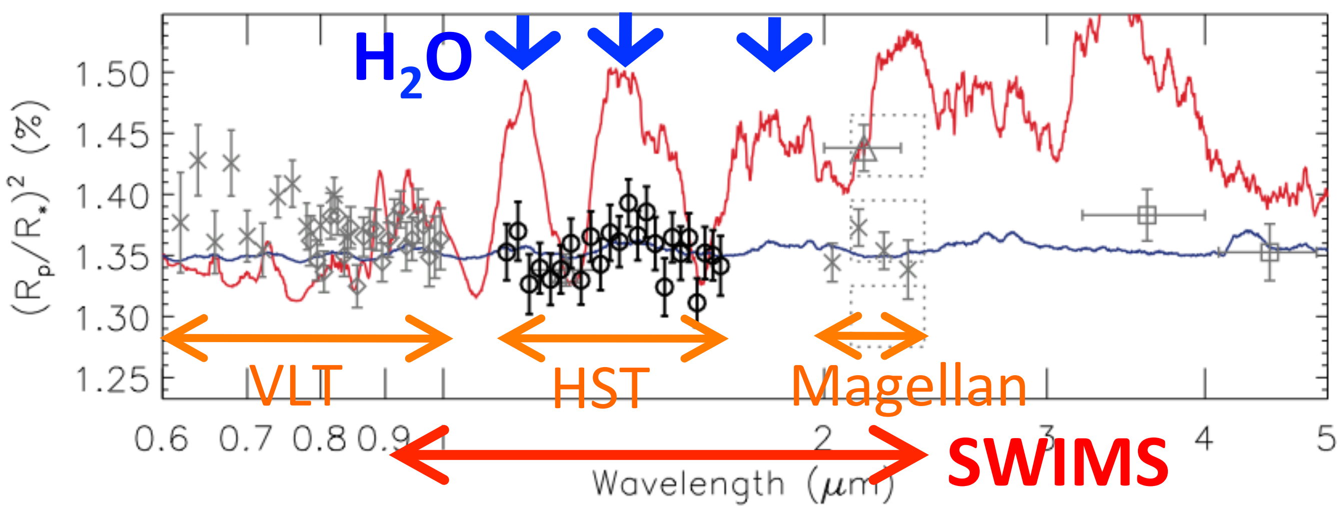
Ricker et al. (2014)

- TESS is an all-sky survey space telescope to be launched in late 2017 (mission length: two years)
- TESS will monitor nearby, bright stars (*I*<13) ⇔ Kepler (*I*>13)
- TESS will find **~500** super-Earths, **>100** of which are suitable for atmospheric study

Ground-based followup observations are important from ~2018

Merits of SWIMS

- SWIMS will have a good synergy with TESS
  - **TESS:** late 2017~ (ecliptic north), late 2018~ (ecliptic south)
  - **SWIMS:** ~early 2018 (Subaru), late 2018~ (TAO)
- Low absorption by telluric H_2O at TAO site
  - Enables to probe **H_2O** in exoplanetary atmospheres
- Large FOV offers many targets
  - Simultaneous spectroscopy of bright comp. star(s) is necessary
  - 8.6' FOV (with TAO) is good for J<9 targets



Transit spectrum of GJ1214b as of 2011

Berta+ 2011

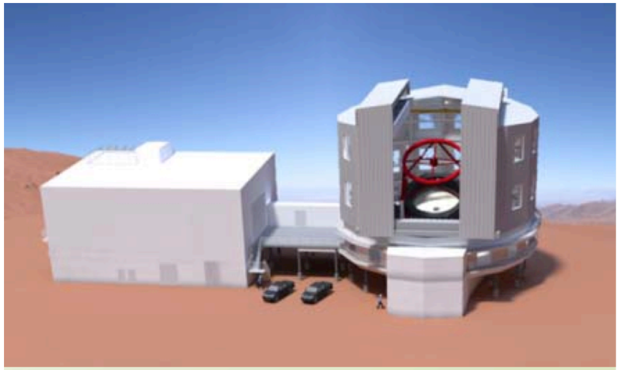
Can be a bridge between MuSCAT and TMT

- A new multi-band camera **MuSCAT**
  - Recently developed for the 188cm telescope at OAO (PI:Narita)
  - Can obtain g, r, z band images simultaneously
  - For validation and first characterization of TESS planets
- **TMT**
  - Can search for biomarkers in habitable planets

OAO 188cm/MuSCAT

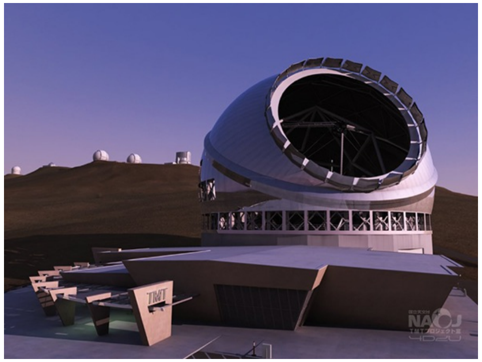
Validation and coarse atmospheric survey

TAO/SWIMS



Detailed characterization of super-Earth atmospheres

TMT



Toward atmospheres of habitable planets

Summary

- Super-Earths are abundant in our Galaxy, but their formation mechanism is still an open question
- Atmospheric study of super-Earths is a key to understand their formation histories
- The all-sky transit survey telescope TESS will be launched in late 2017, which will discover >100 super-Earths suitable for atmospheric characterization
- **SWIMS has a good synergy with TESS, a good sensitivity to H_2O, and can observe many bright targets**
- SWIMS can be a bridge toward the biomarker search with TMT