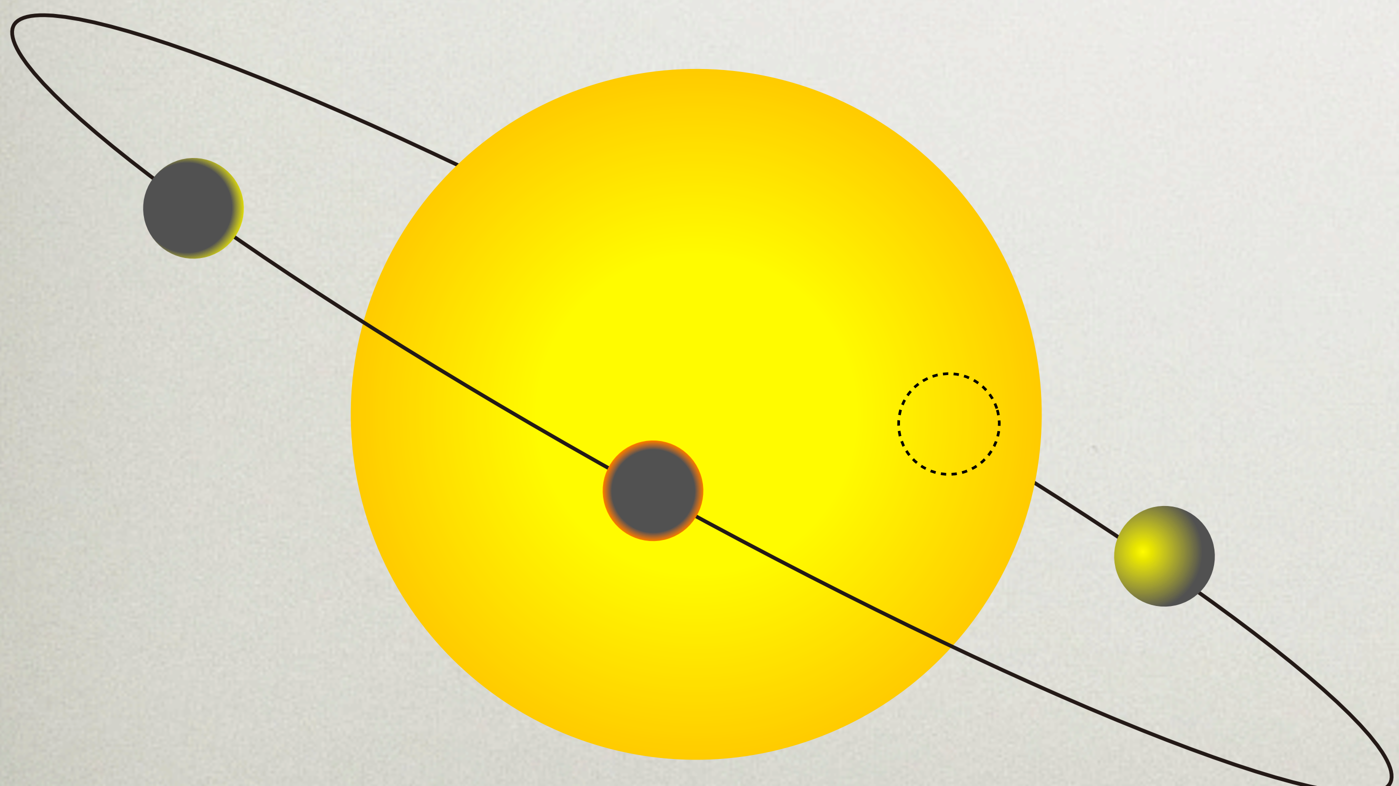
Pathways 2015

Pathways towards habitable planets

13-17 July 2015, Bern

What Can We Learn from
Atmospheres of Transiting Low-Mass Exoplanets
as a Stepping-Stone Towards Habitable Planets ?



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Thanks for collaboration:

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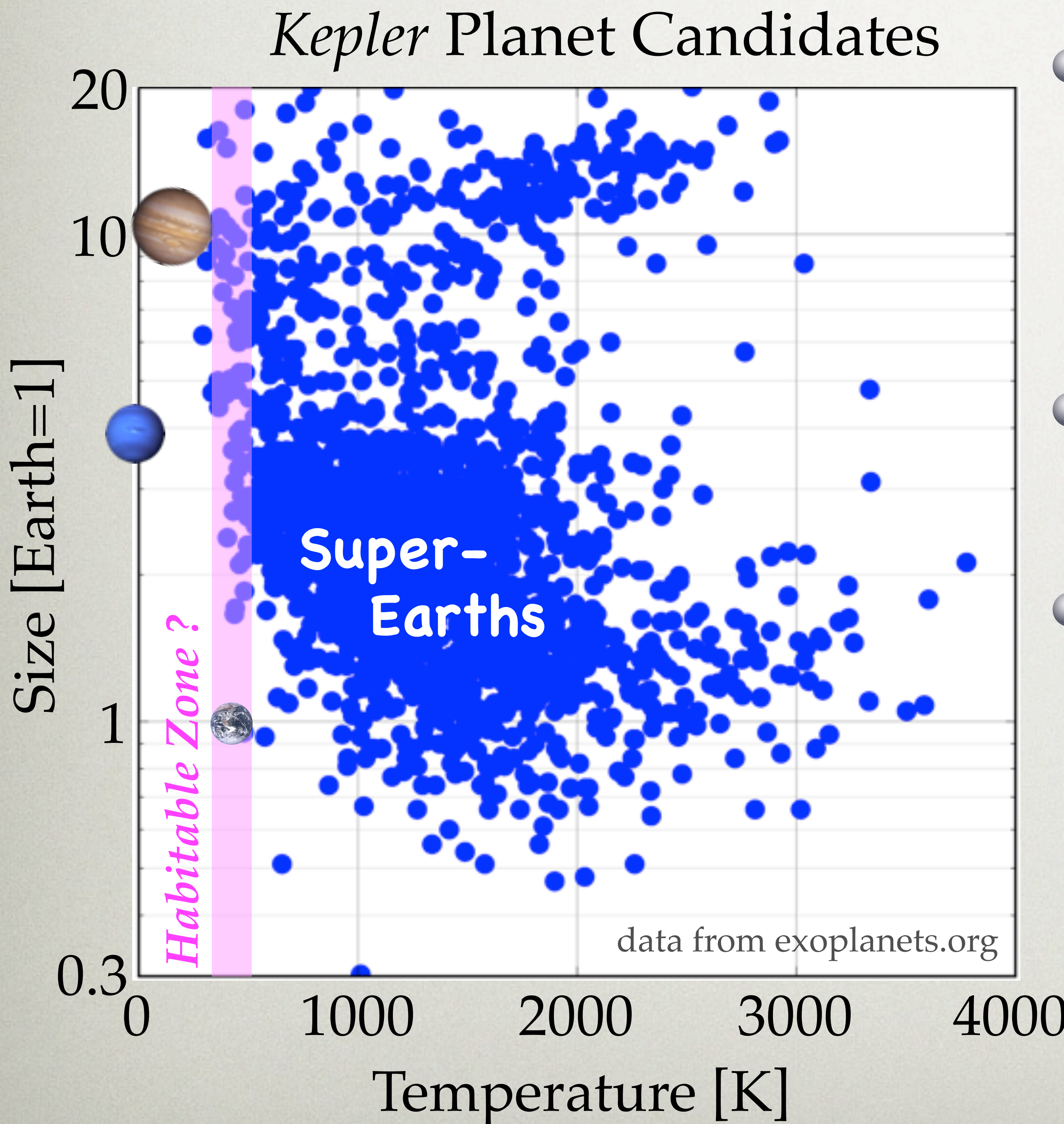
Y. Kawashima (UTokyo),
N. Narita, A. Fukui, Y. Hori (NAOJ)
etc.

Outline

Planets in this talk are quite uninhabitable !

- Diversity in bulk composition of transiting low-mass exoplanets
- Detectability of the mineral atmosphere of hot rocky low-mass planets
- Characterization of atmospheres of volatile-rich low-mass planets

Close-in Super-Earths



- No planet intermediate in size between the Earth & Neptune in the Solar System.

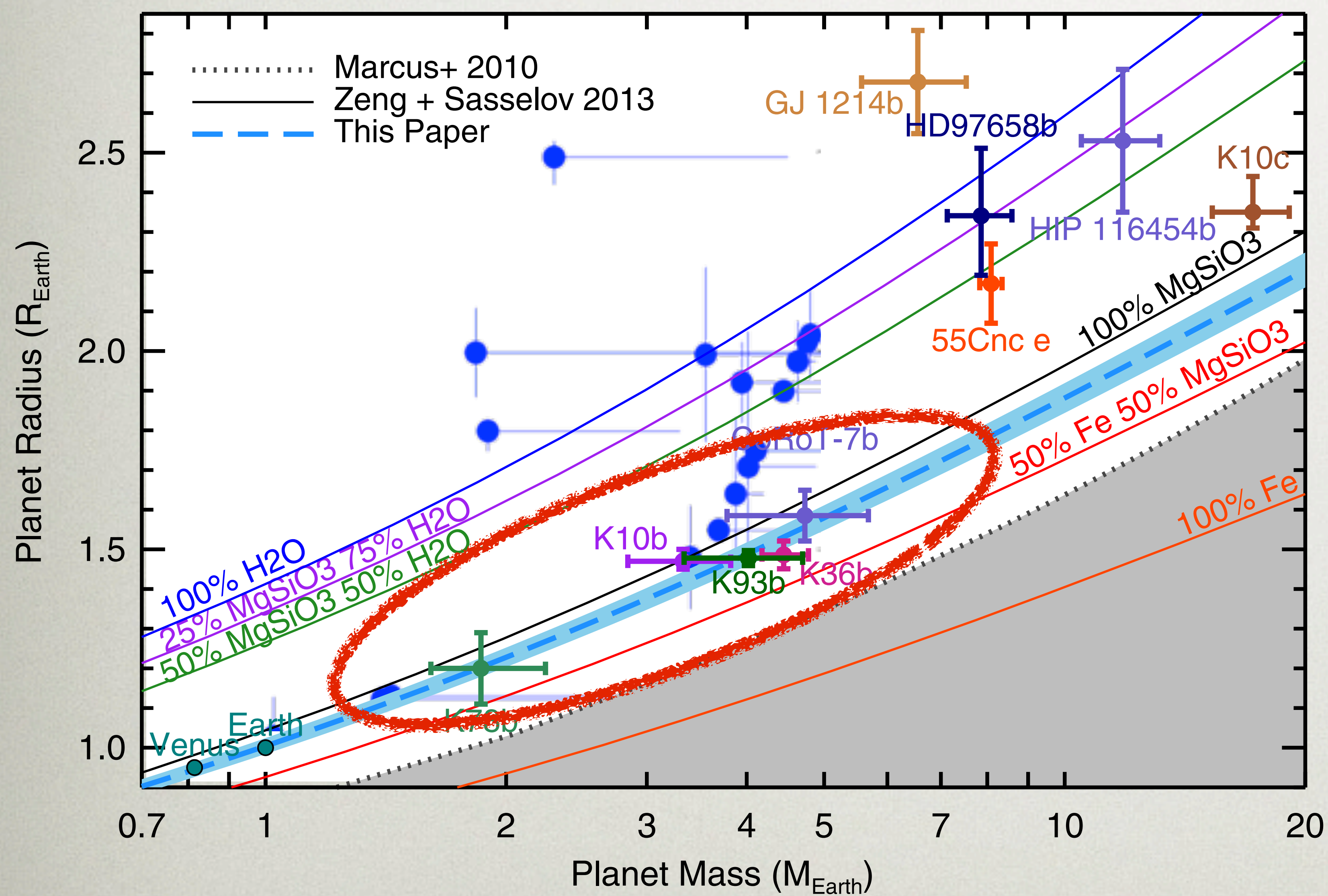
  "Super-Earths (SEs)"

- In contrast, SEs are common beyond the Solar System.
- Most of the SEs are orbiting close to their host stars

Important issue: To understand the properties and origin of close-in hot/warm SEs
as a stepping-stone to habitable worlds

What Are They Like?

Mass vs. radius of super-Earths
with radii of < 2.7Re and masses measured to < 20% precision
from Dressing et al. (2015)



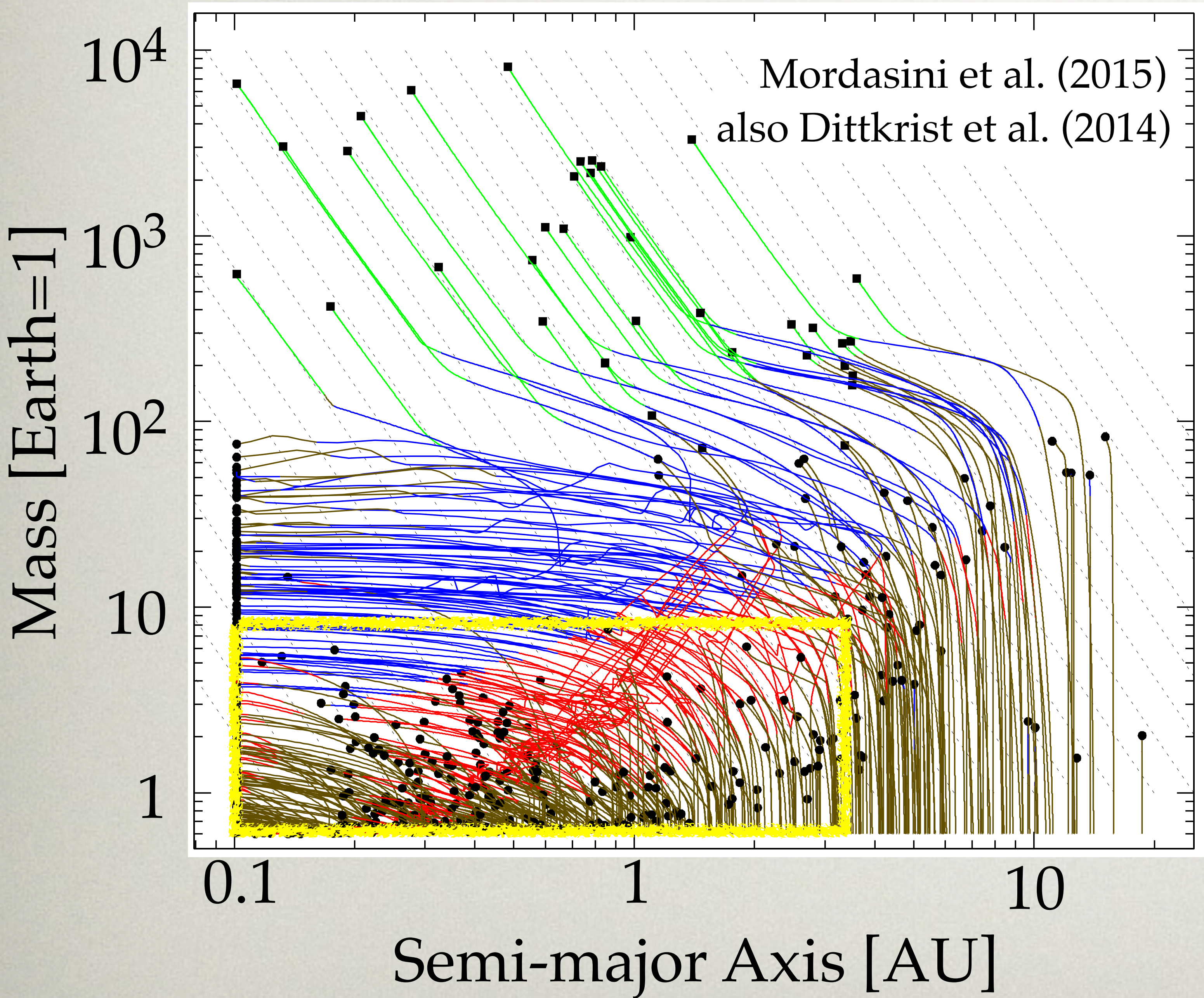
- Some of the SEs are closely similar to the Earth & Venus in bulk composition.

  ➜ Earth analogs?

- They are remnants that have experienced several processes.
- SEs are diverse in bulk composition.

Accretion & Migration

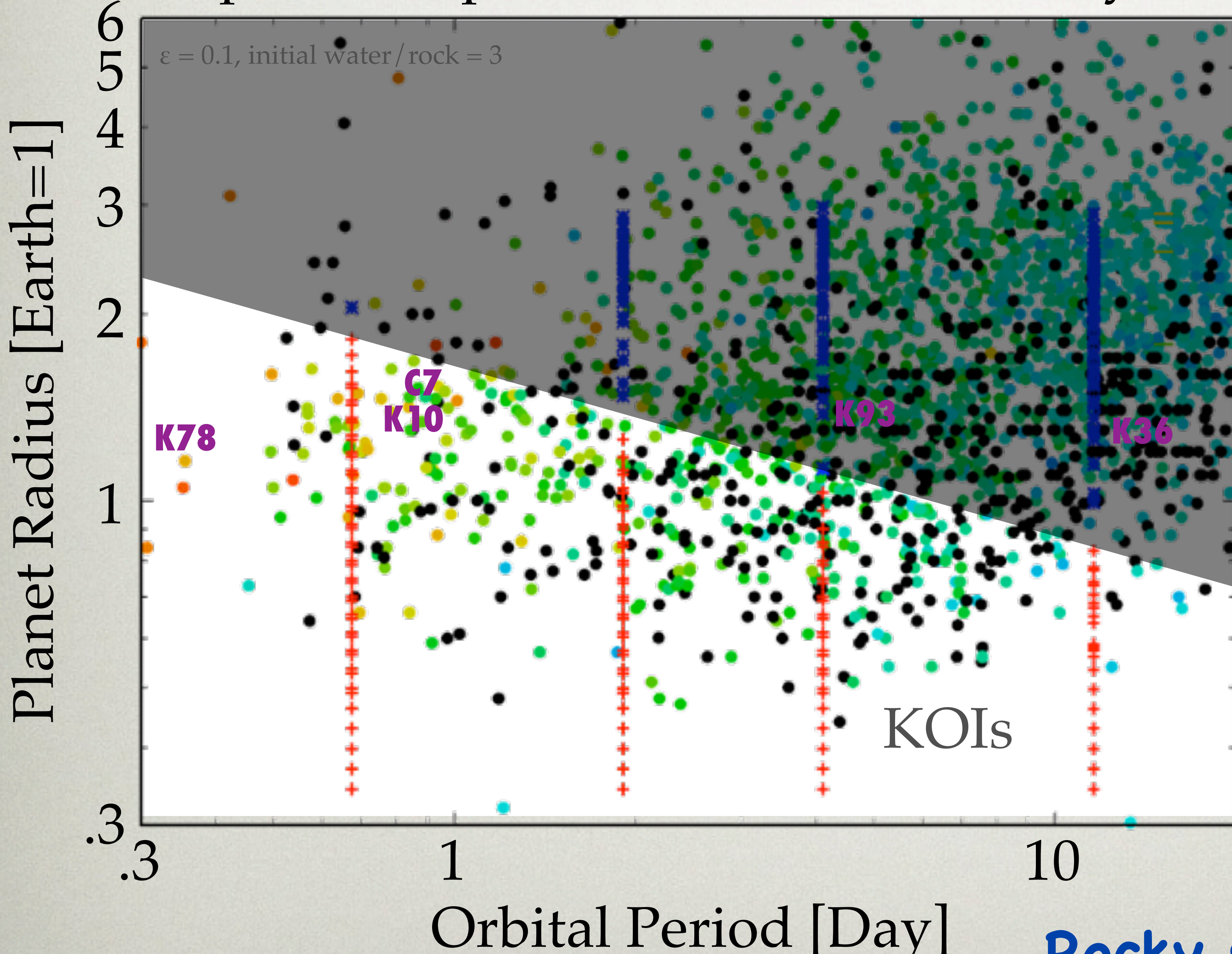
Bern Population Synthesis Models

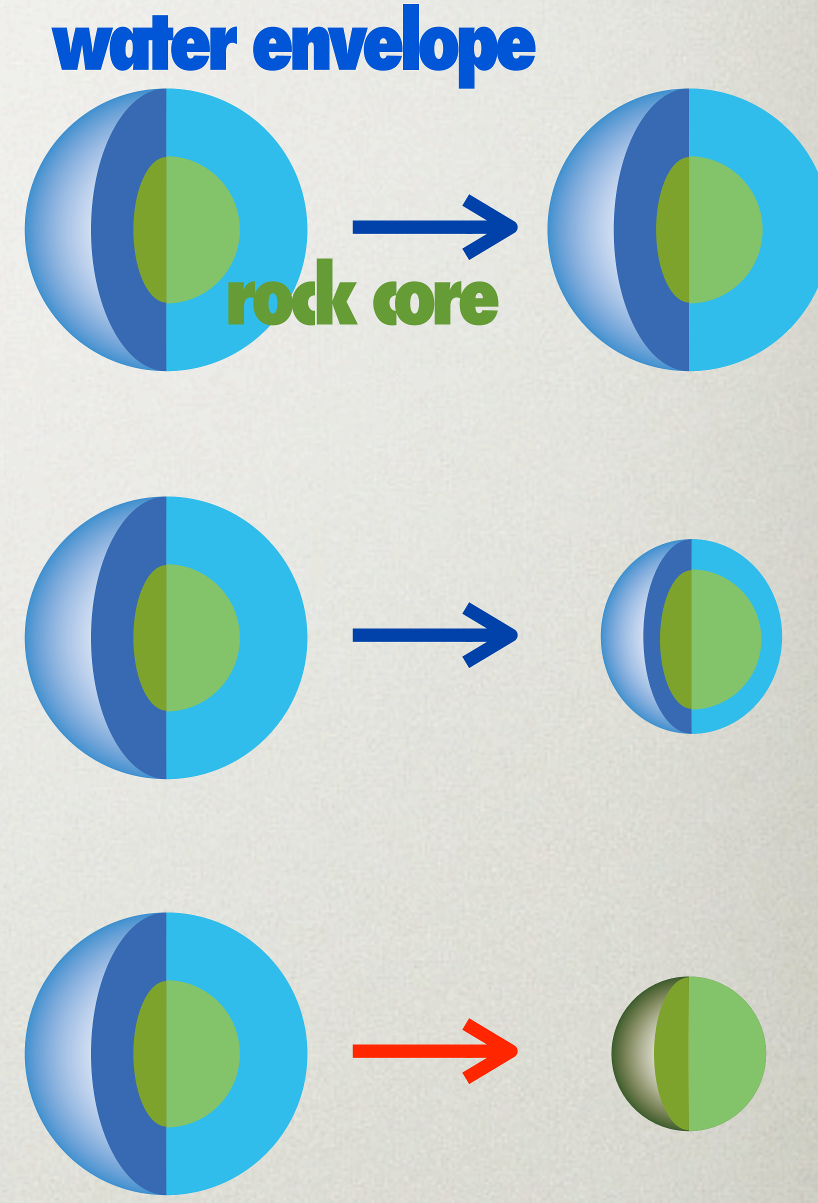


- Super-Earths migrate wildly in a complicated way
  - ➜ Close-in SEs may have come from beyond the snowline
- Planets in HZs are not always habitable planets.

Photo-evaporation of Icy super-Earths

Fate of icy super-Earths that undergo photo-evaporative mass-loss for 10 Gyr

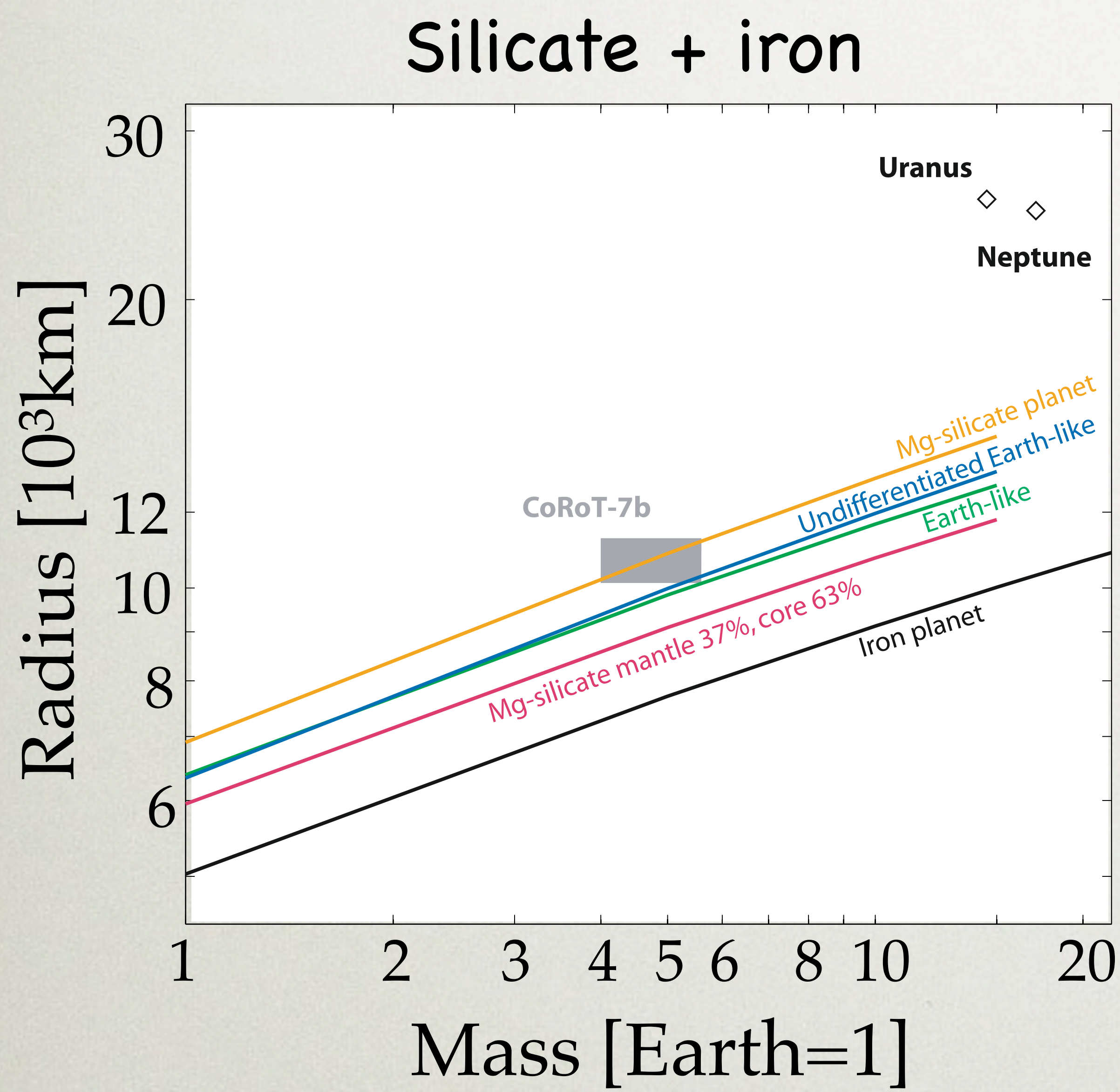


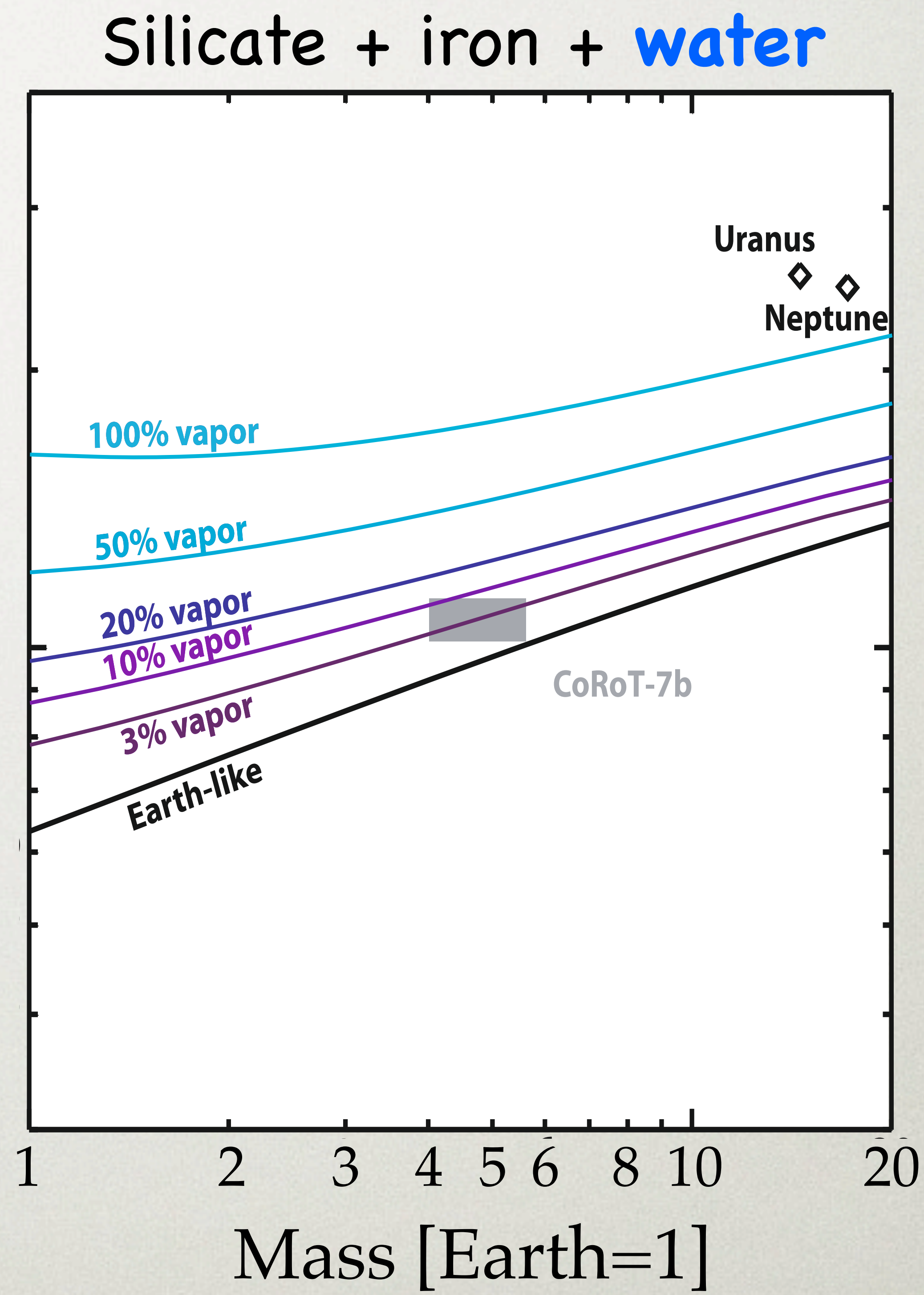


Rocky super-Earths might be remnants of icy planets.

Figure from Kurosaki, Ikoma, & Hori (2014)

Degeneracy in Composition





Unable to distinguish between dry and wet super-Earths only from mass-radius relationship

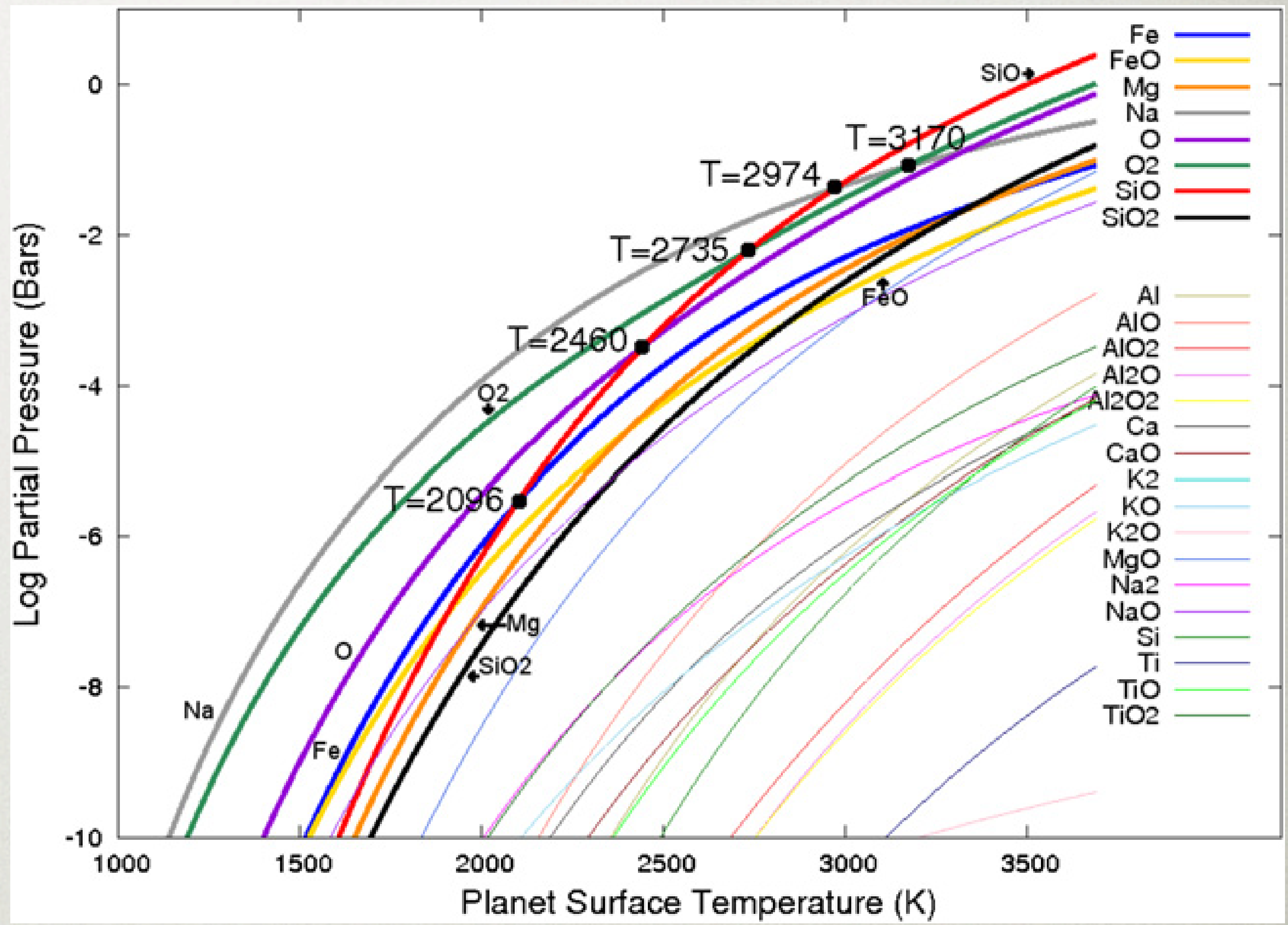
Figure from Valencia, Ikoma, Guillot+ (2010)

Atmosphere of Close-in *Dry* Rocky Planet

Artist's image of CoRoT-7b (ESA)

Molten silicate surface
"magma ocean"
similar to the primordial Earth

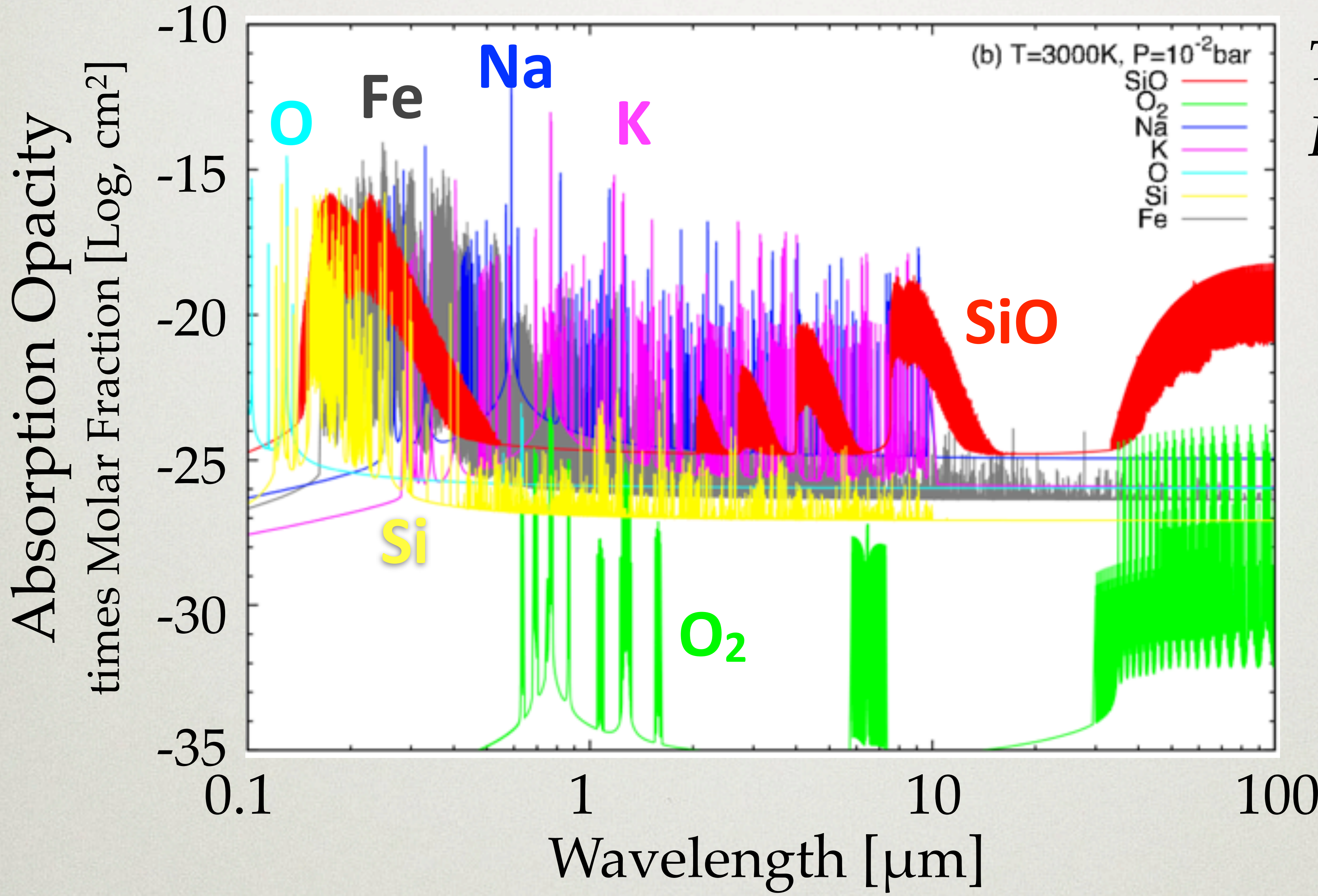
Calculated composition of atmosphere
on top of the magma ocean
from Miguel et al. (2011)



The atmosphere consists of Na, K, Fe, SiO gases etc.,
which we call **"the mineral atmosphere".**

Radiative Absorption

Ito, Ikoma, Kawahara et al. (2015, ApJ)



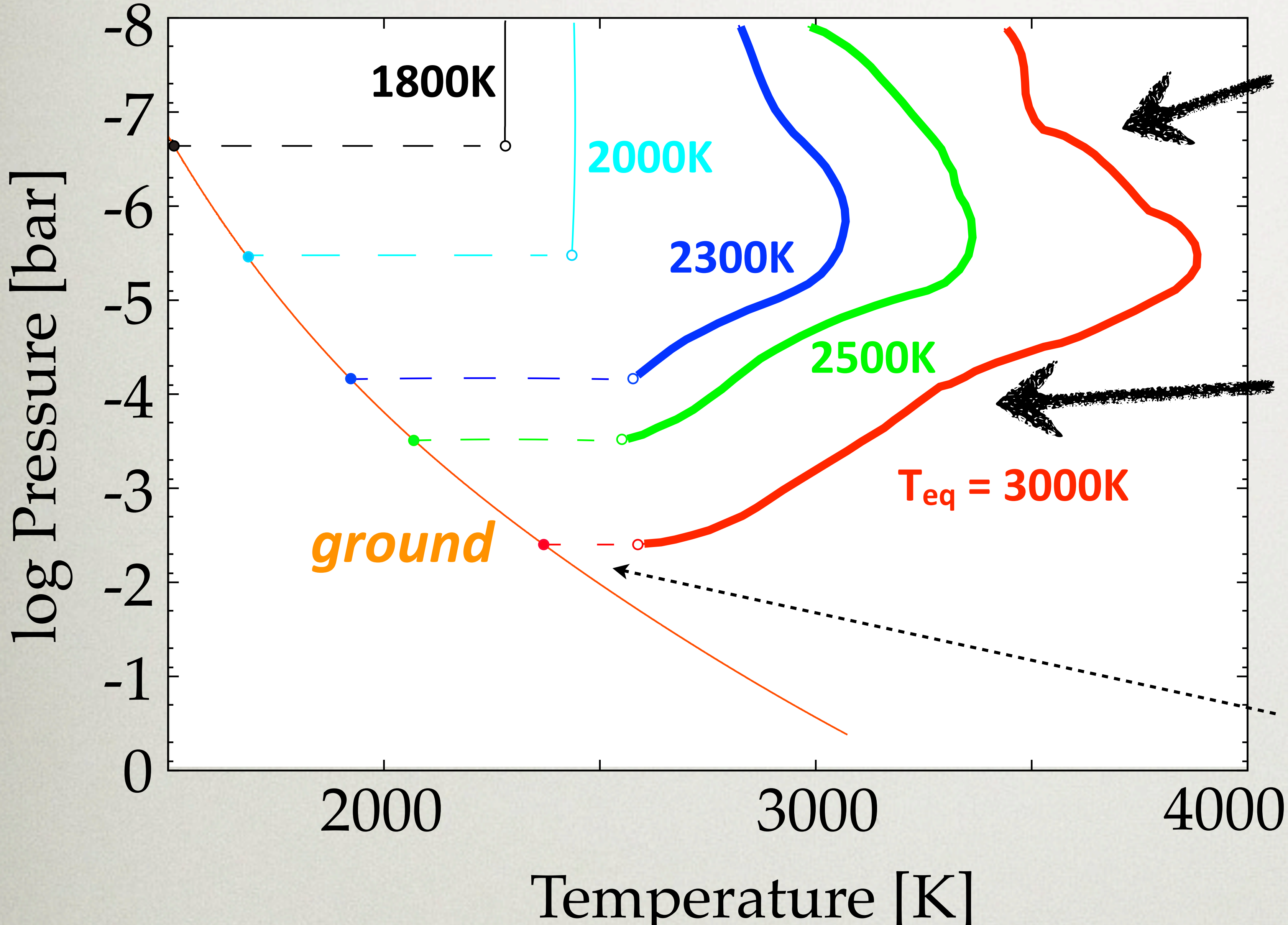
$T = 3000\text{K}$

$P = 10\text{mbar}$

- **Absorption of Na, K & Fe dominates in the visible region.**
- **SiO absorbs UV well.**
- **SiO also absorbs IR well, especially at ~4 and 10μm**

Temperature Profile

Ito, Ikoma, Kawahara et al. (2015, ApJ)



Dissociation of SiO

Thermal Inversion

due to strong UV absorption by SiO and Vis absorption by Na & K, which dominate IR absorption.

Artificial Jump in temperature

because thermal conduction was neglected for simplicity.

This T-P profile may show emission features that are detectable via secondary-eclipse observation

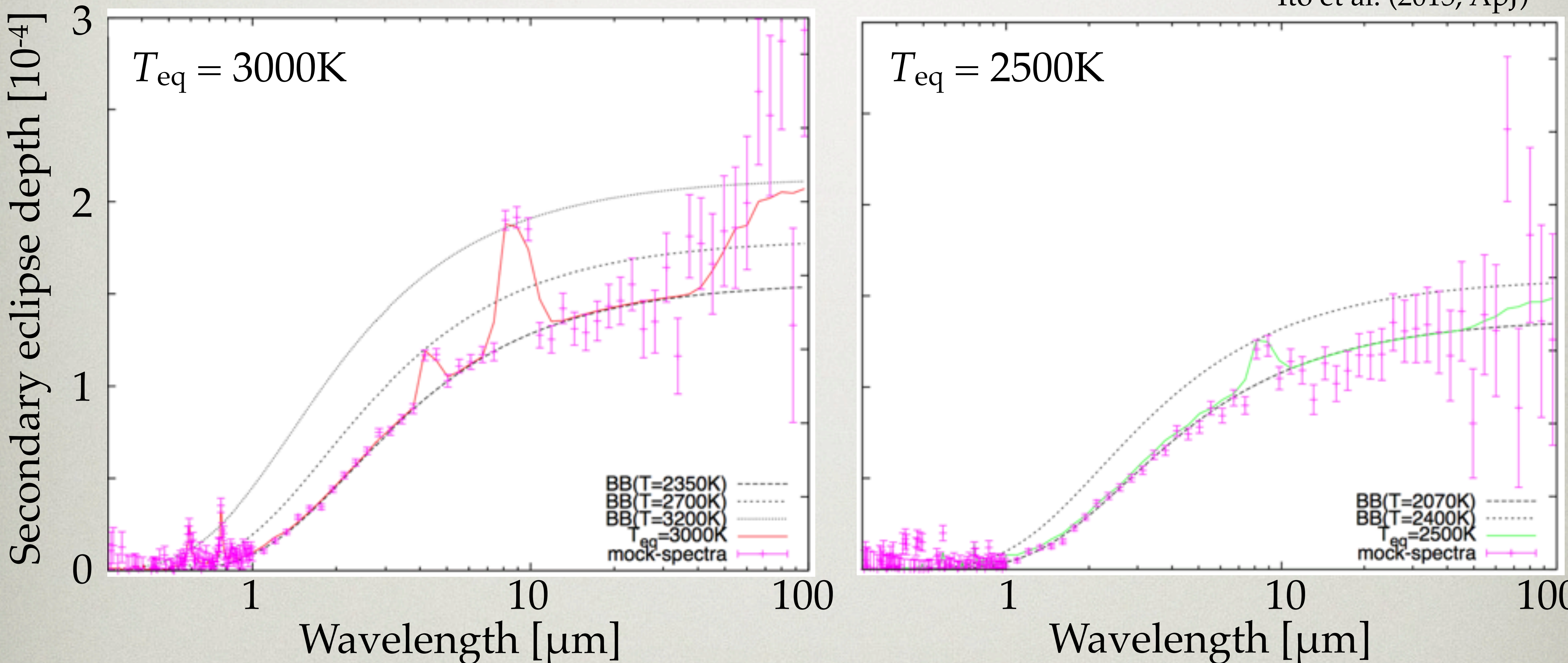
Secondary Eclipse Depth

Mock spectrum of a super-Earth with a mineral atmosphere

orbiting a G star 100pc far from Sun by a 5m space telescope

(Observation time = 10 hour, Resolving power = 100 (Vis) & 10 (IR), Photon-noise limited)

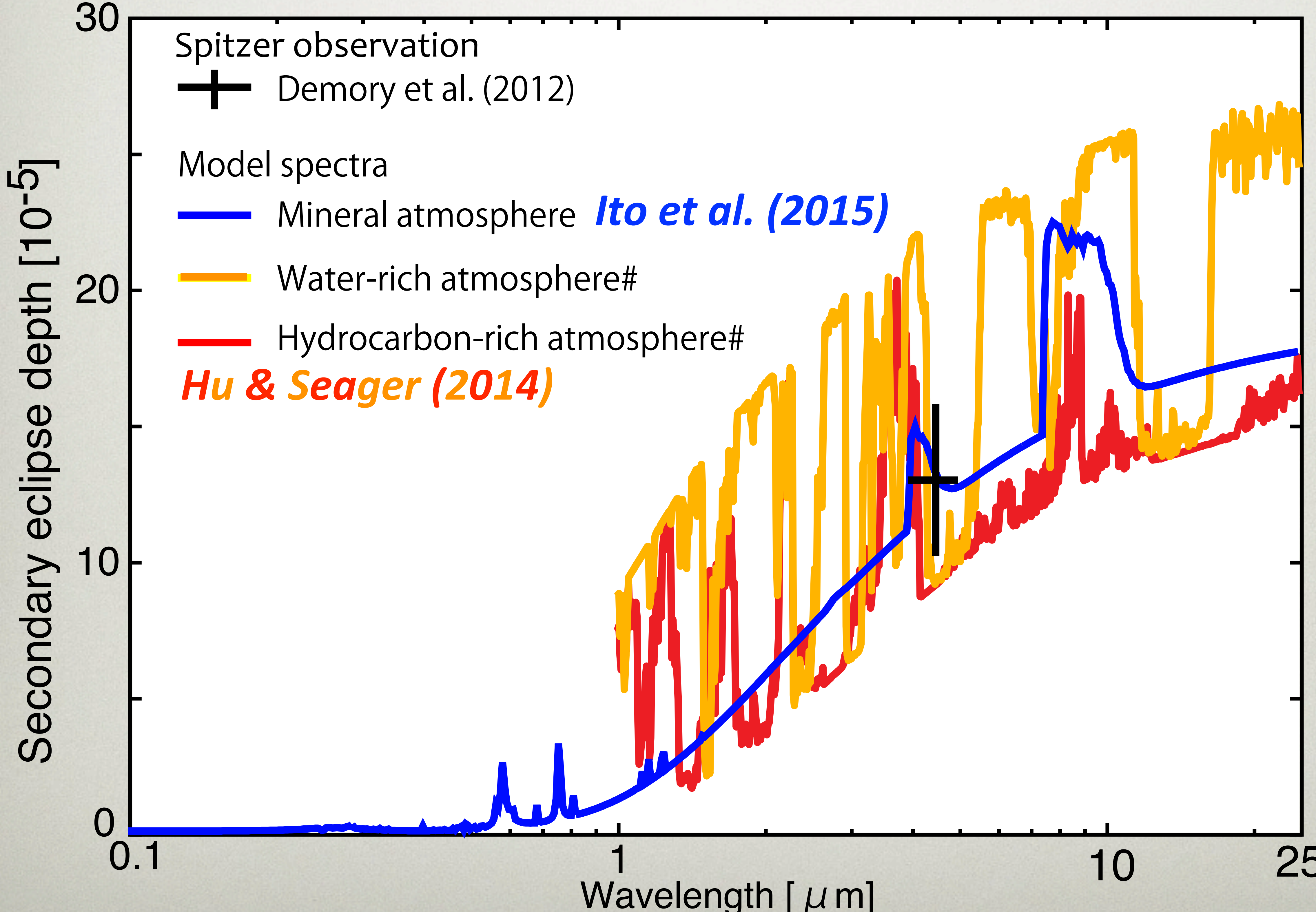
Ito et al. (2015, ApJ)



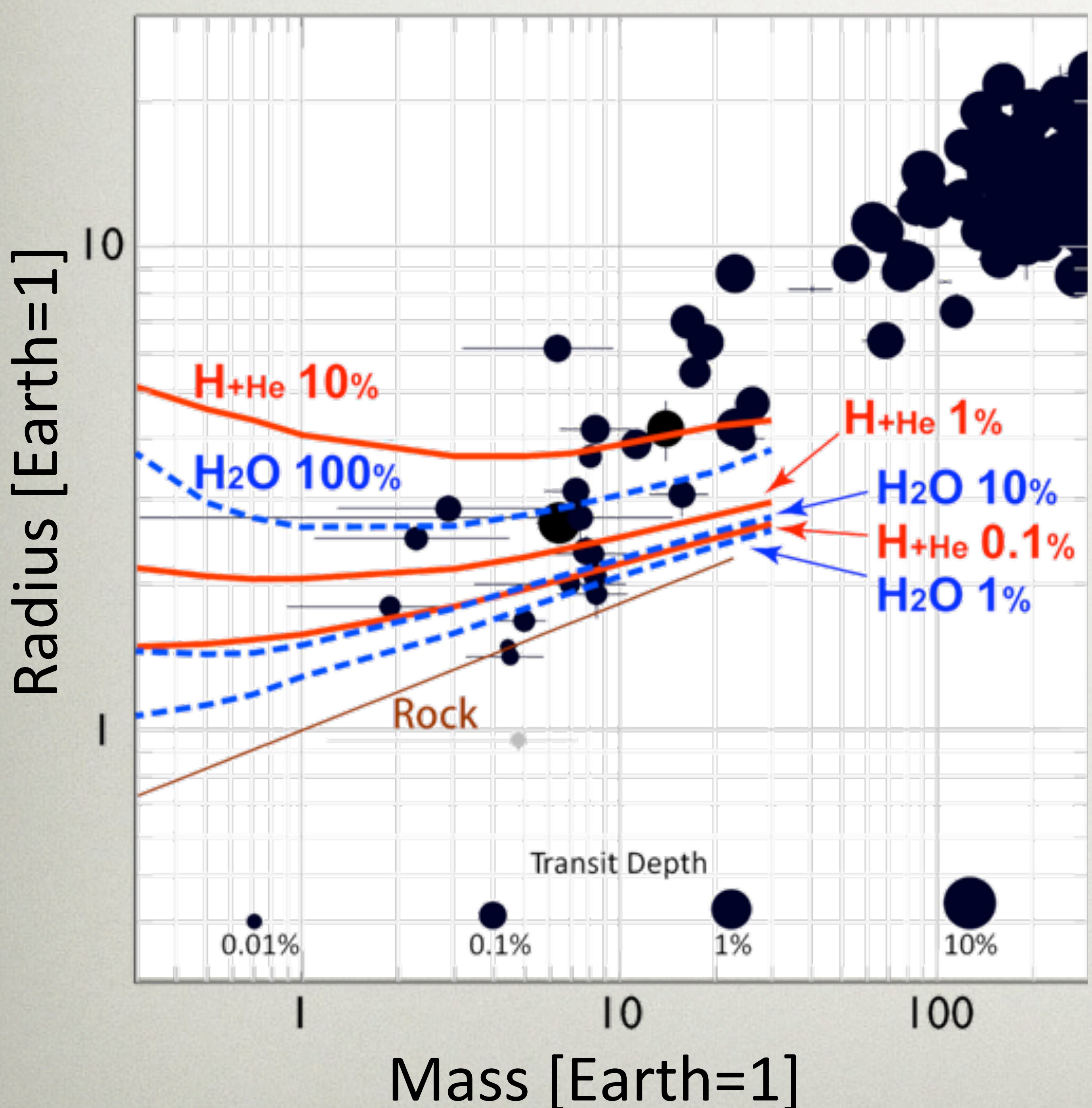
Detectable are the SiO features at 4 & 10 μm from a super-Earth with T_{eq} > 2500K.

Dry or Wet Rocky Super-Earth?

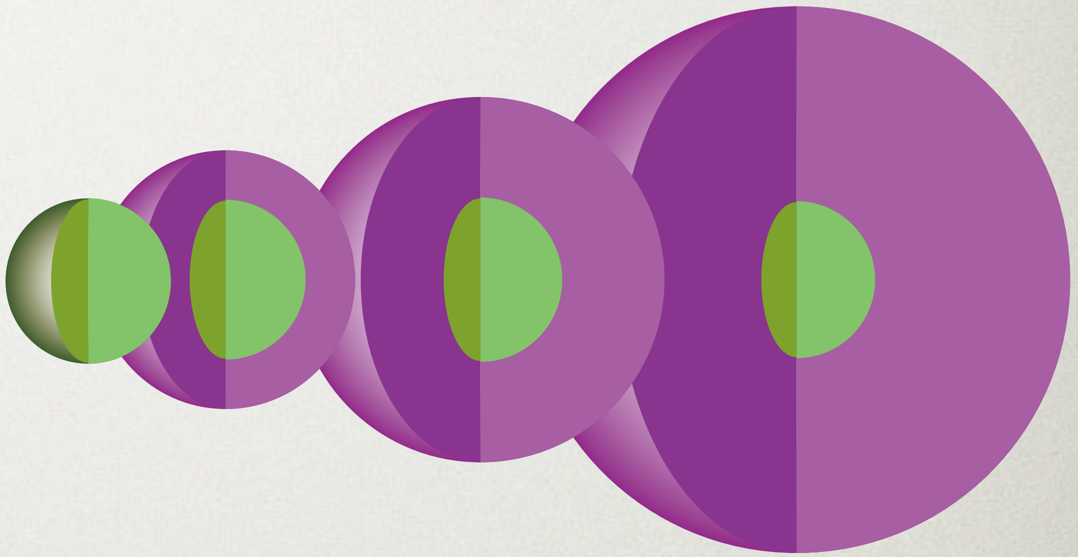
Application to 55 Cnc e



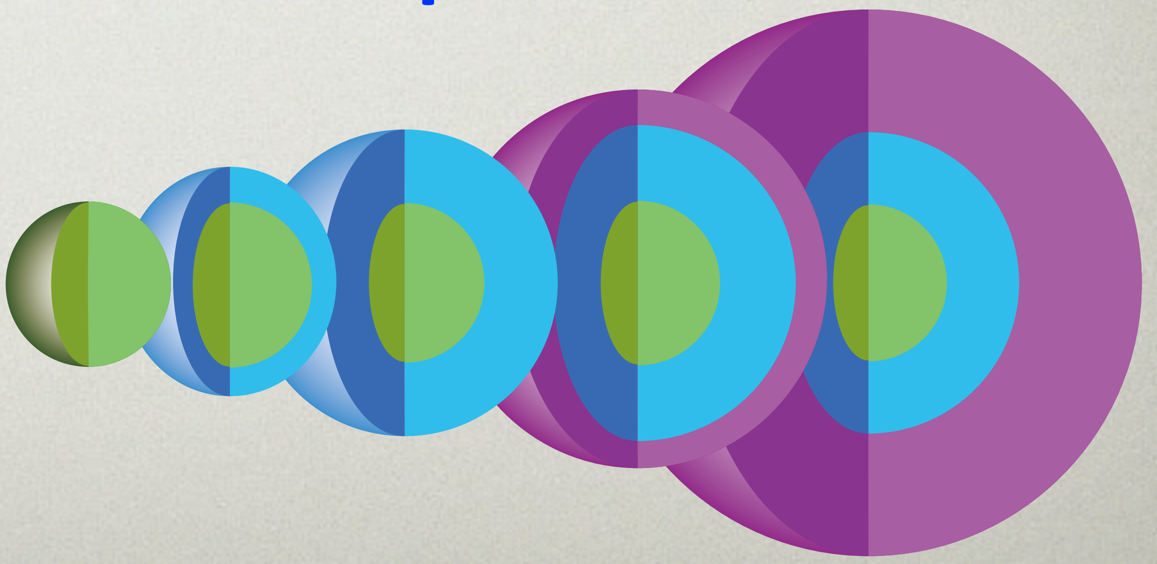
Low-Density Super-Earths



1) Rocky Super-Earths
w/ H-He Atmospheres



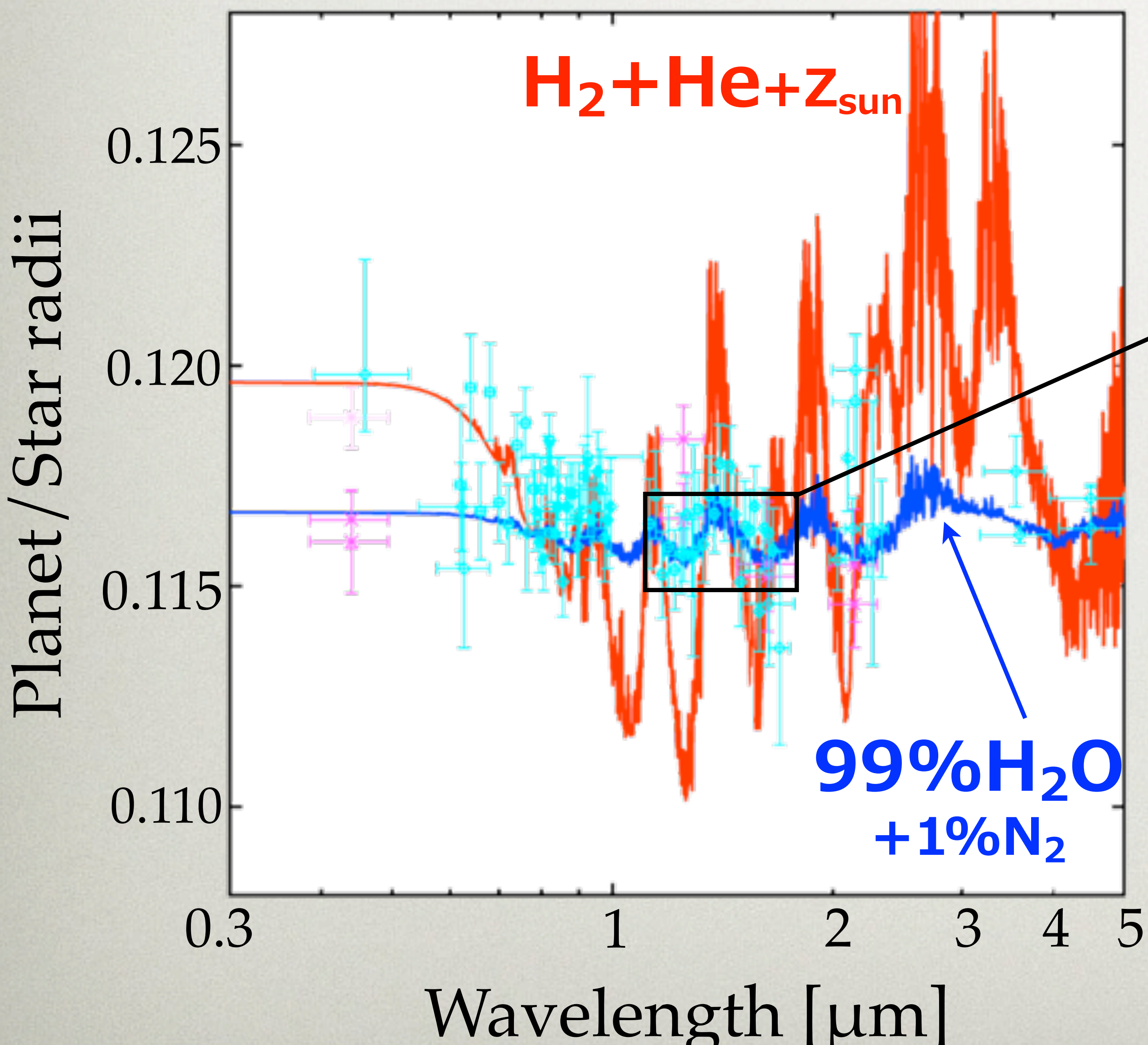
2) Water-Rich Super-Earths
"Mini-Neptunes"



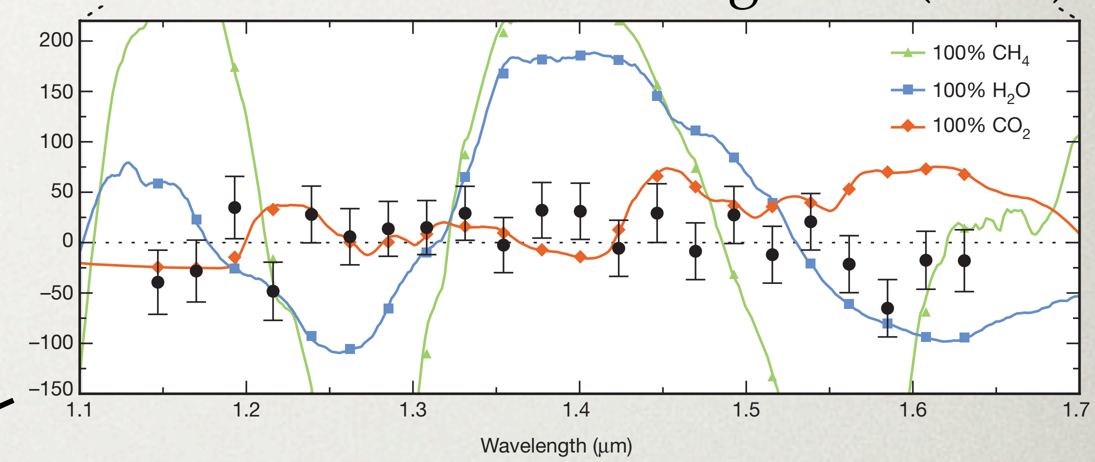
Transmission Spectrum of Atmosphere

The case of GJ 1214 b

Ground-based observations
modified from Narita, Fukui, Ikoma+ (2013)



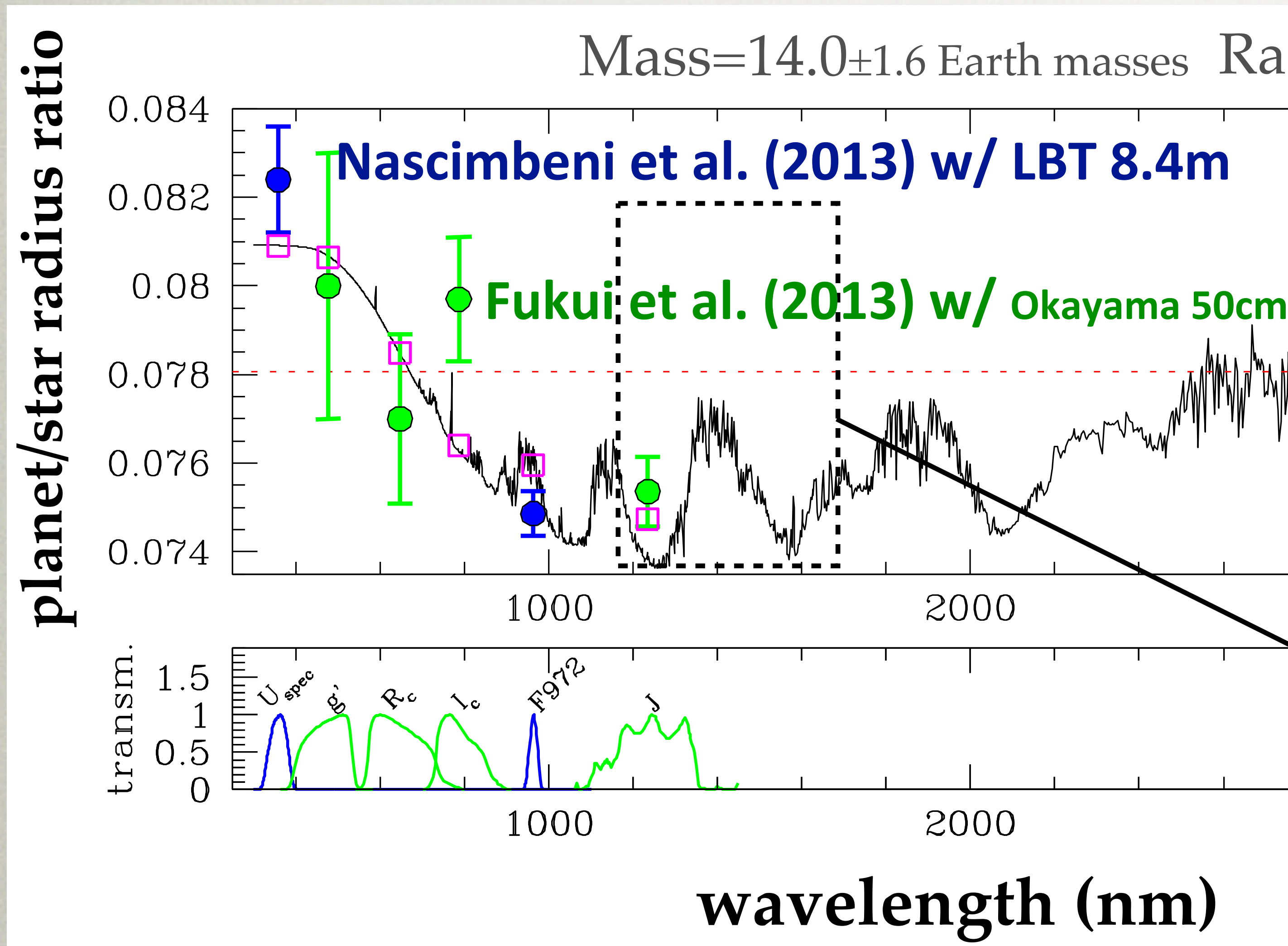
Observation by HST
Kreidberg et al. (2014)

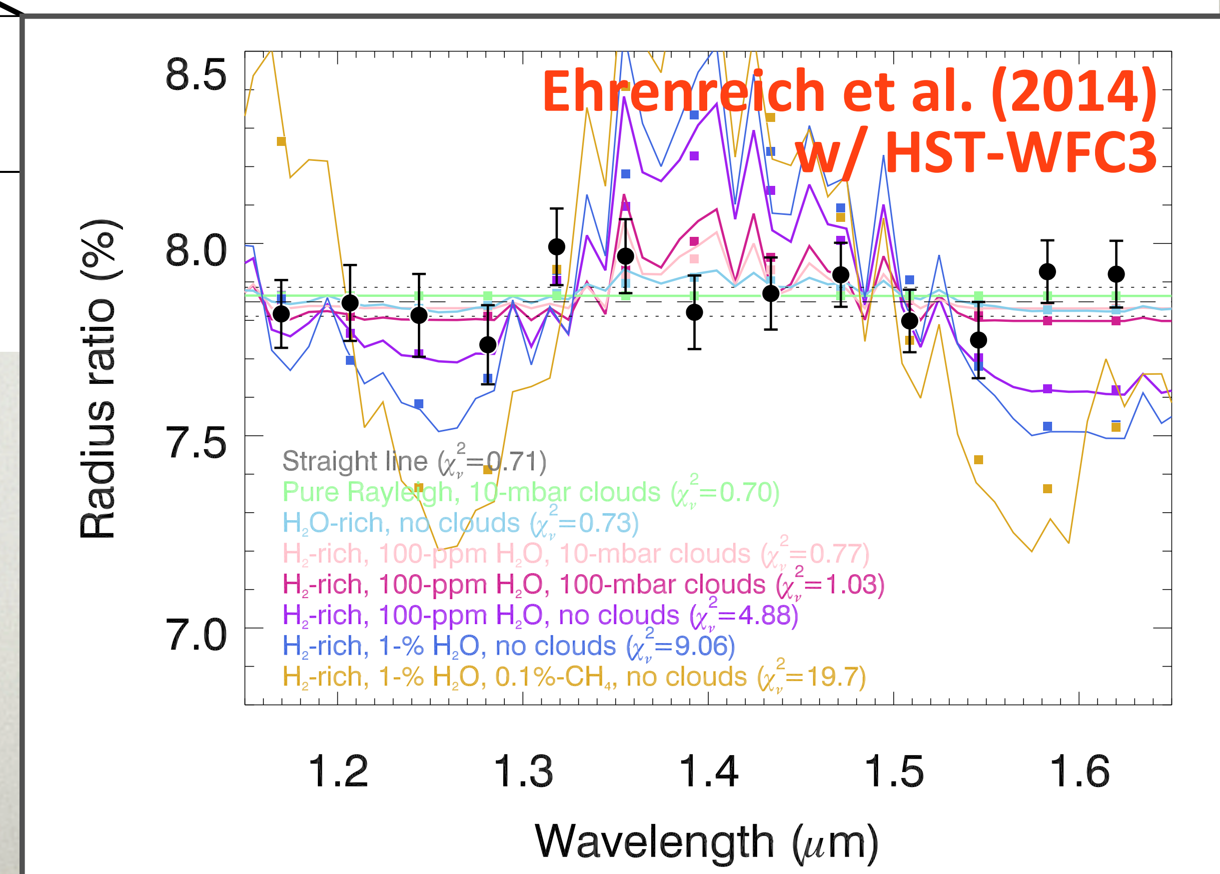


- Aimed to clarify whether GJ1214b has a H-dominated or H_2O-dominated atmosphere.
- **Flat Spectrum**
  => Thick haze/cloud layer prevents us from looking into the atmosphere

Transmission Spectrum of Atmosphere

The case of GJ 3470 b



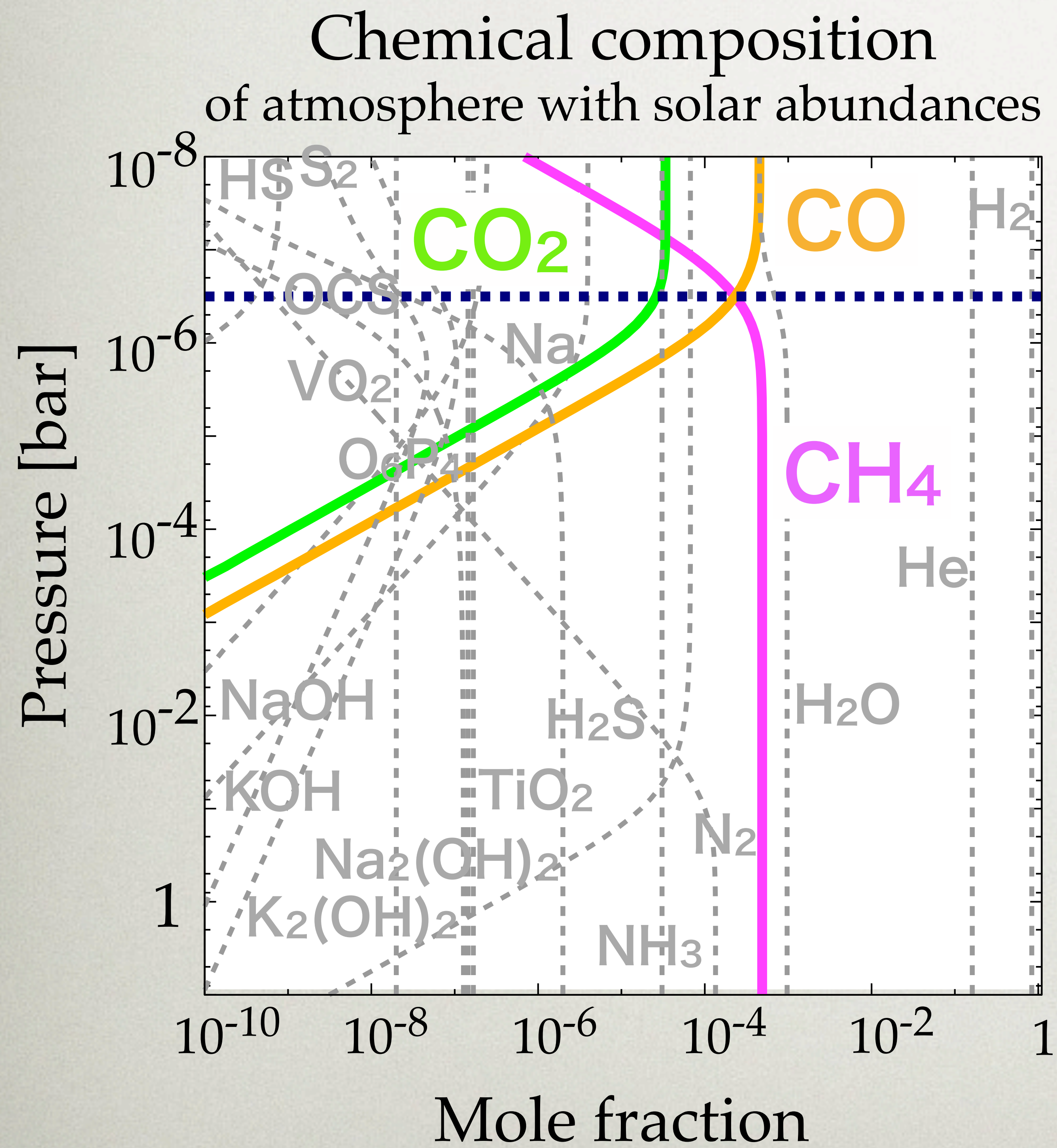


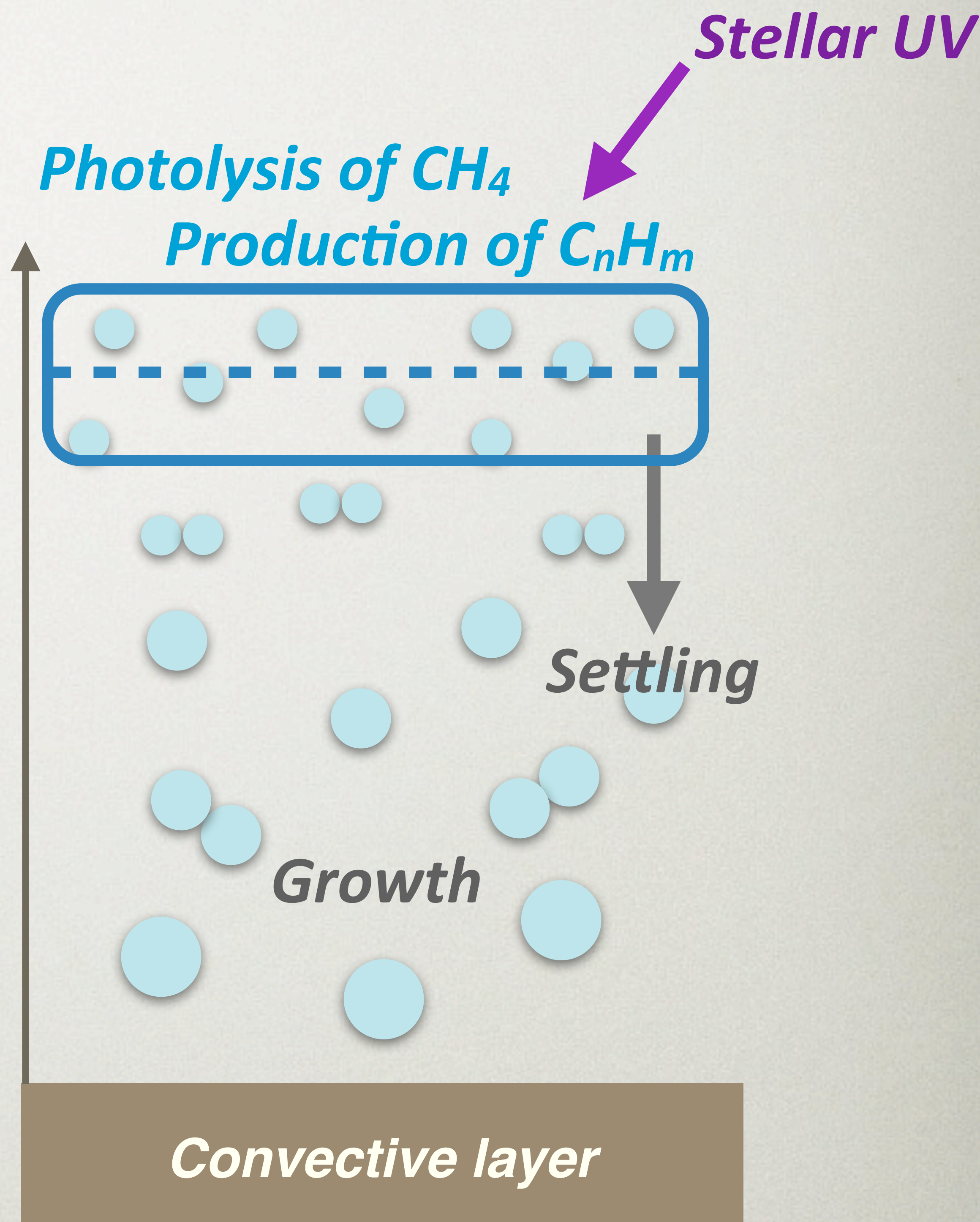
Rayleigh slope in Vis.

+ Flat feature in NIR

→ Particles of relatively small size (<~0.1 μm)

Hydrocarbon Haze



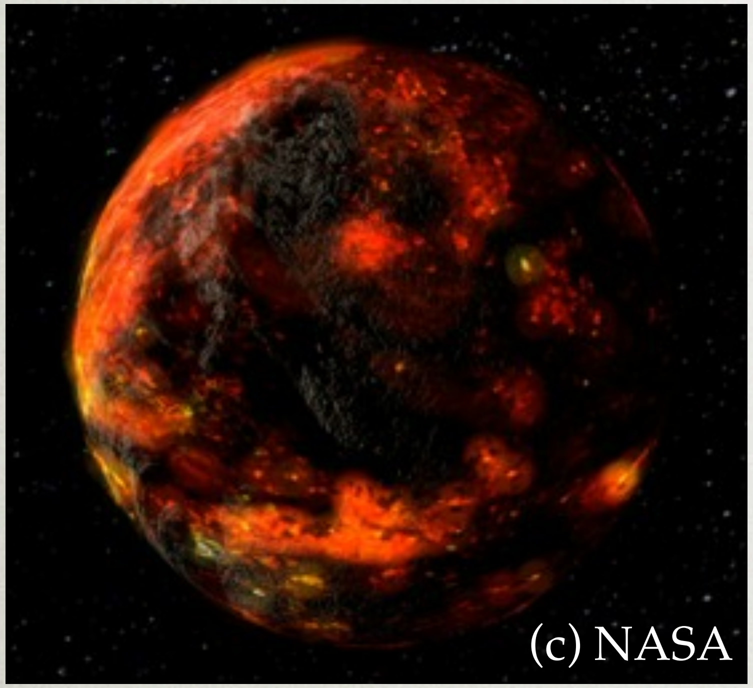


Kawashima & Ikoma (in prep)

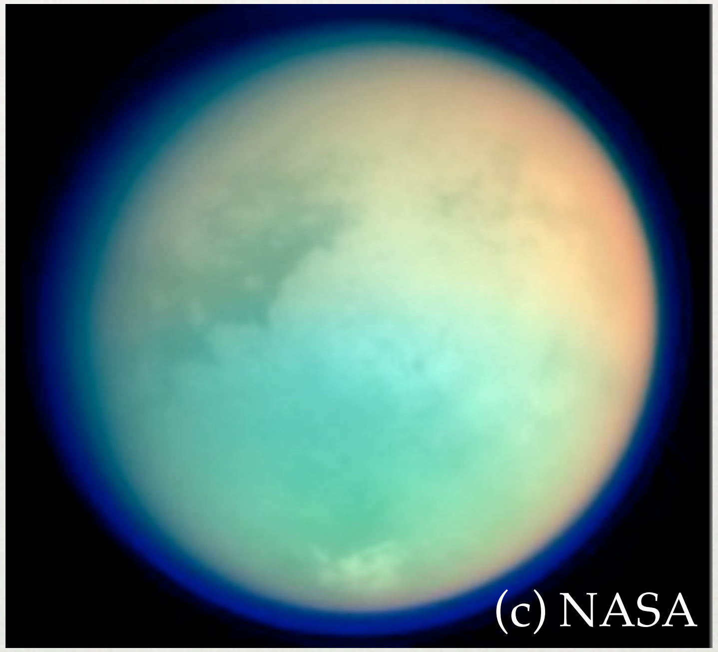
Synergies?

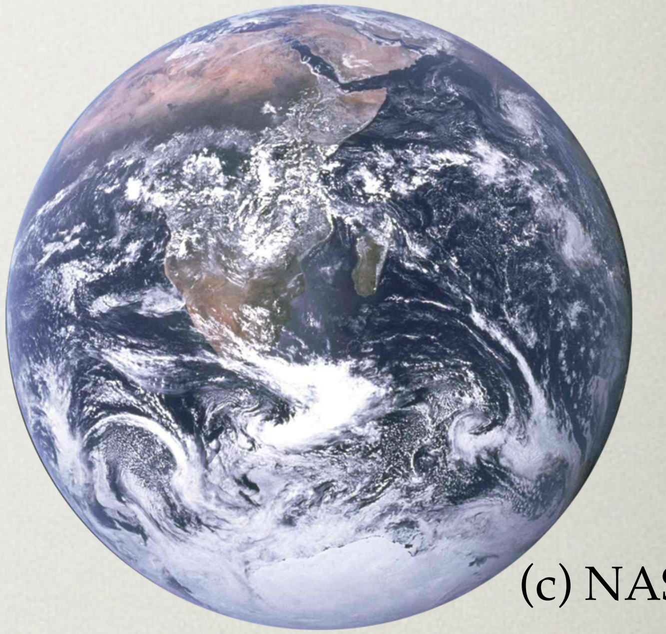
Primordial Earth → Early Earth → Present Earth

Magma ocean



Reducing gas + Haze





(c) NASA

Need to know much about haze

- ✓relationship between haze properties and atmospheric conditions (e.g., composition, temperature, UV)
- ✓knowledge from haze in the atmospheres of Titan and the Solar System giant planets

Summary & Conclusions

- We are clearly approaching Earth analogs. Planets detected so far are, however, quite uninhabitable.
- Understanding the compositional diversity of close-in super-Earths and its origin is crucial for understanding those of planets in habitable zones.
- The "mineral" atmosphere of hot super-Earths could be an interesting target for future space-based observation.
- The atmosphere of low-density super-Earths has been explored intensively via transmission spectroscopy.
    - ➡ However, understanding properties of haze is a bottleneck to further studies, which needs the synergy between studies of the solar-system planets and exoplanets.