Characterization of Transiting Planet Atmospheres

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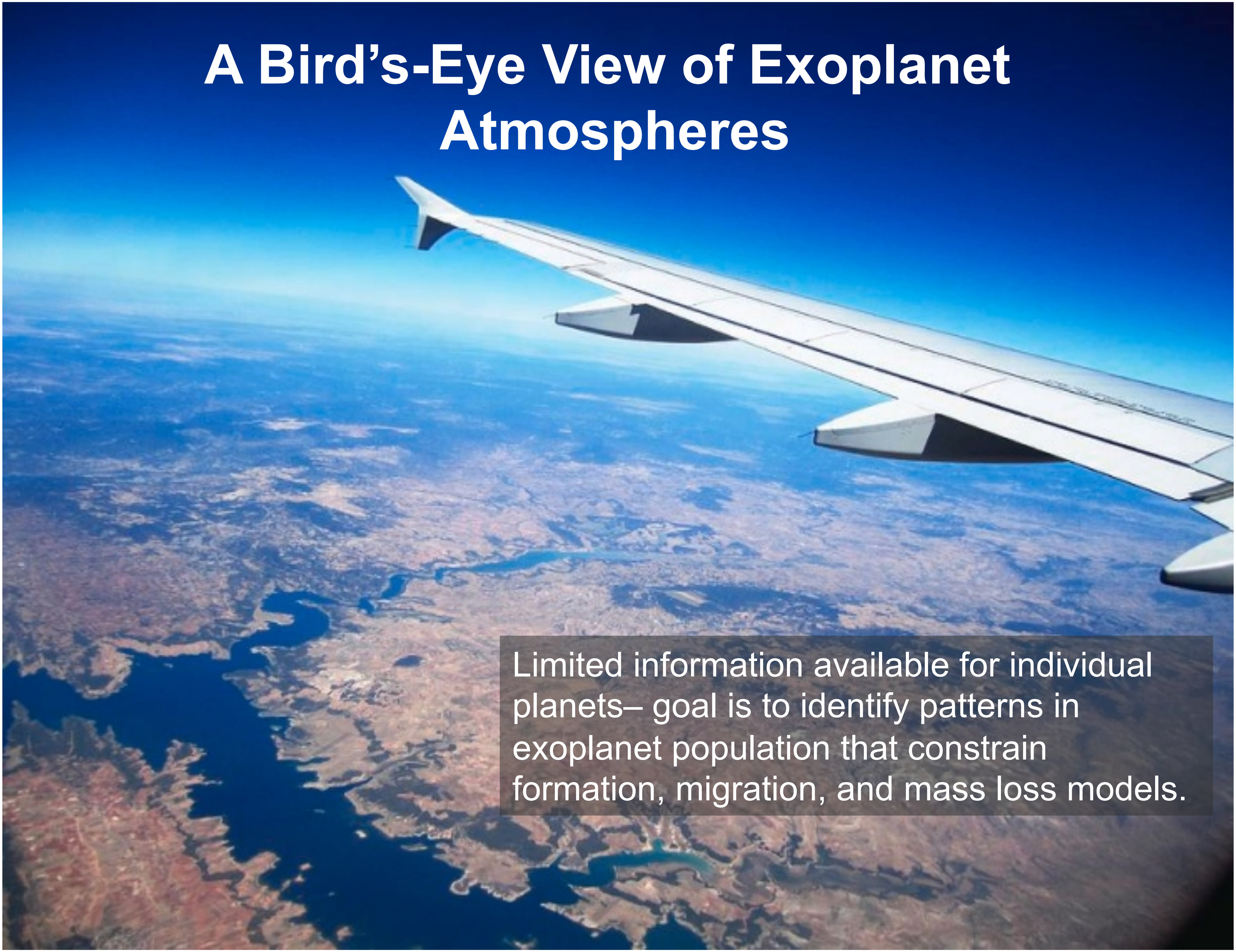
A Bird’s-Eye View of Exoplanet Atmospheres



Limited information available for individual planets– goal is to identify patterns in exoplanet population that constrain formation, migration, and mass loss models.

A Mass-Radius Diagram for Exoplanets

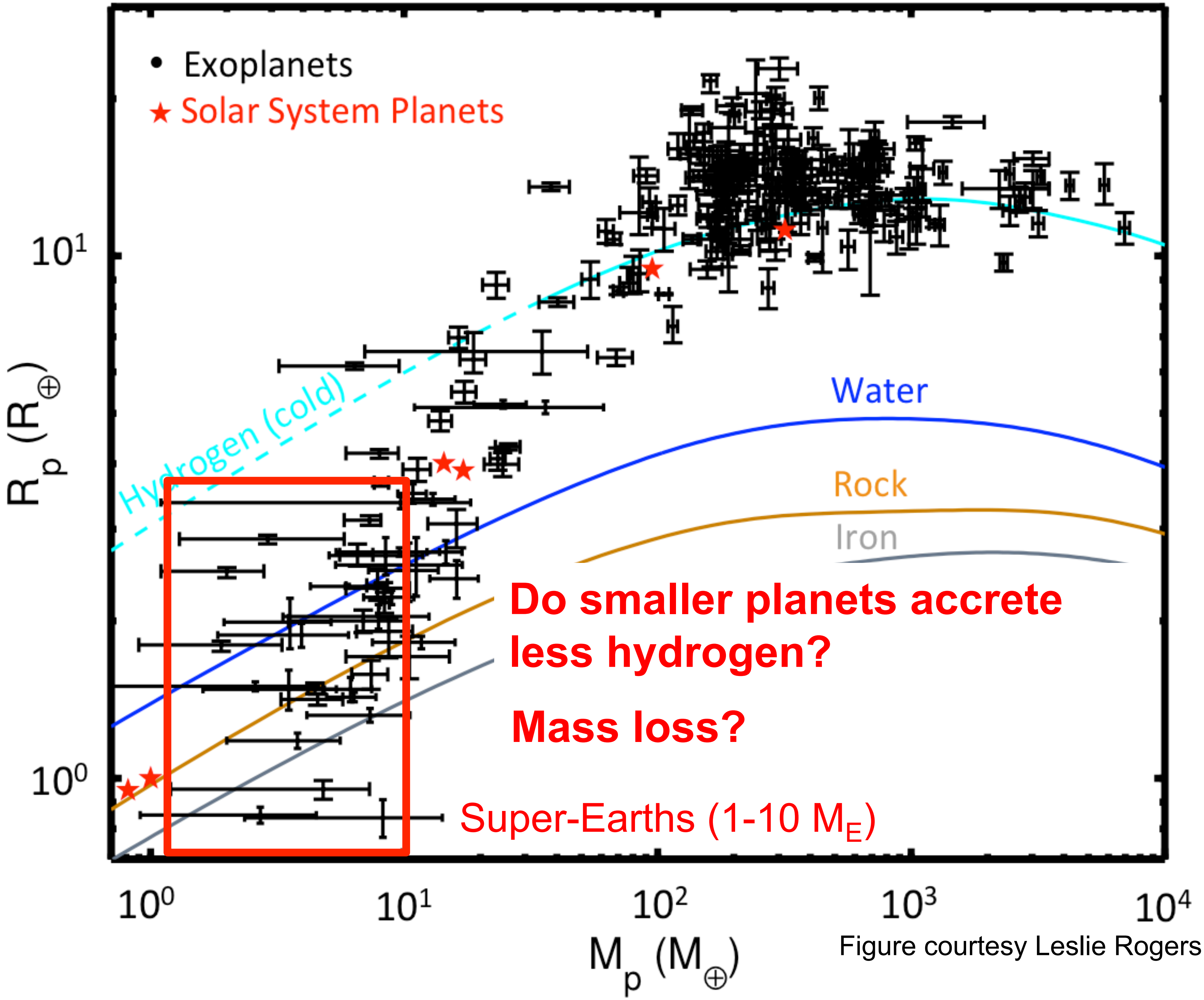
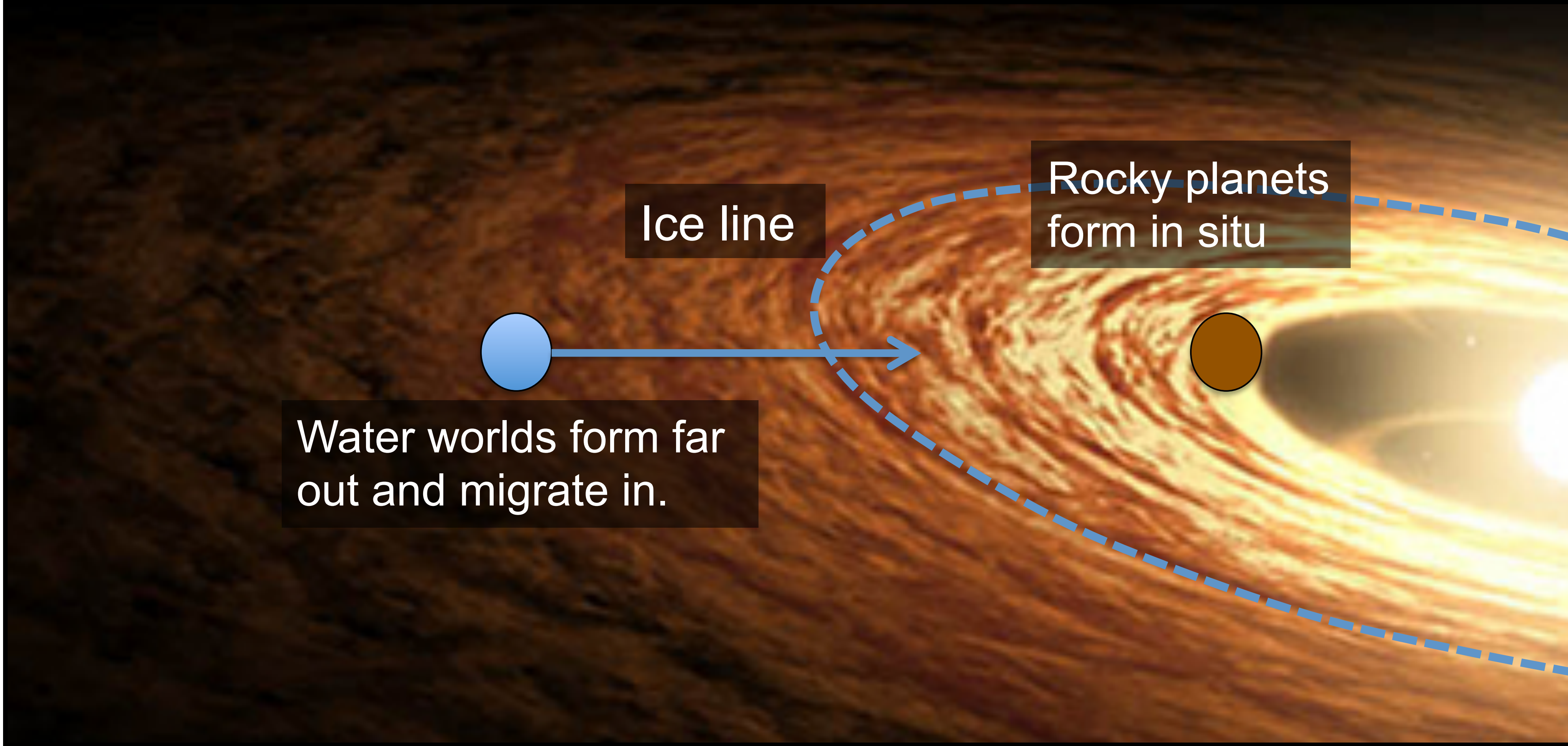


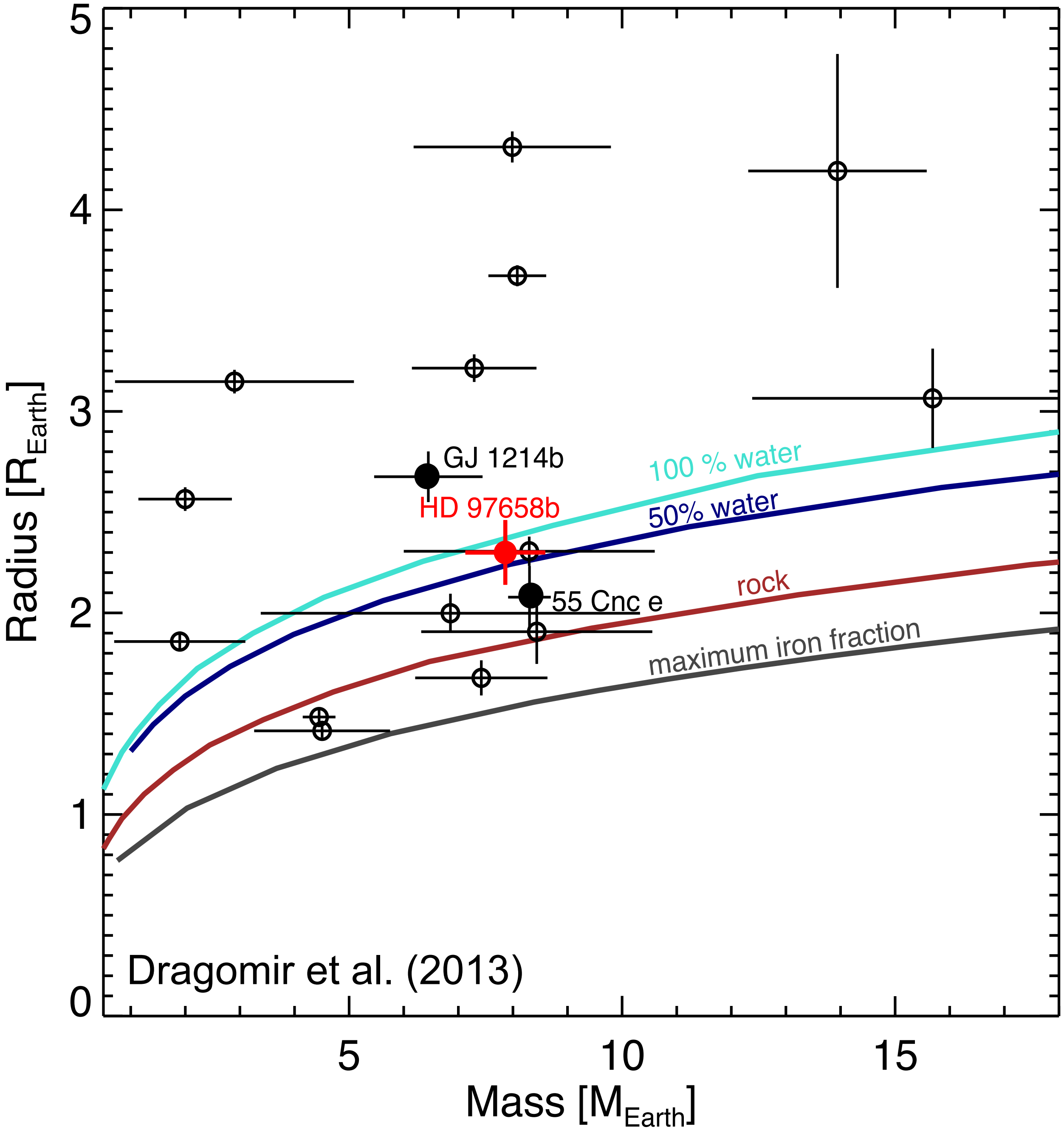
Figure courtesy Leslie Rogers

Composition as a Clue to Origin of Close-in Super-Earths

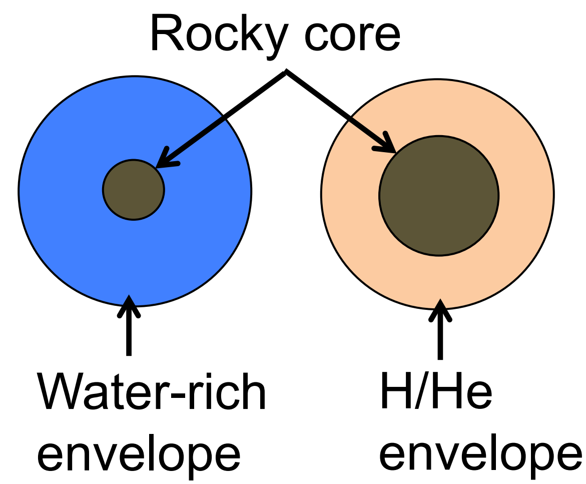


Premise: small planets grow by accreting solids, so bulk composition reflects that of the solids in the disk at the formation location.

Determining Super-Earth Compositions

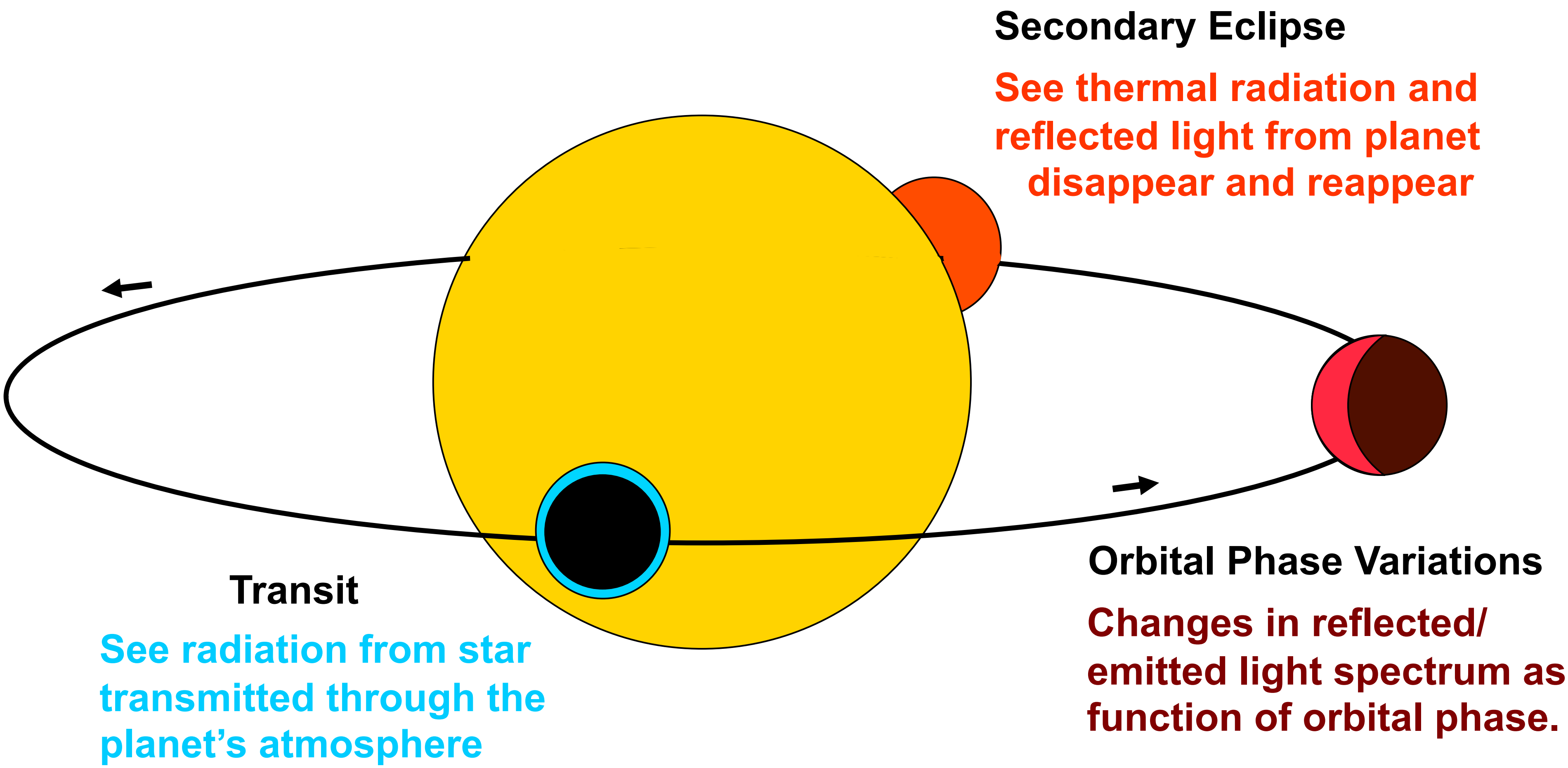


Caveat: the presence of thick atmospheres makes it difficult to **uniquely constrain** bulk compositions from mass and radius alone.

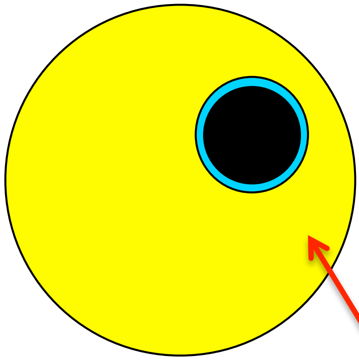


Water world (migrated from beyond ice line) **or rocky with a H/He envelope** (in situ formation)?

Observations of Eclipsing Systems Allow Us to Characterize Exoplanet Atmospheres



Scaling Laws for Transiting Planets

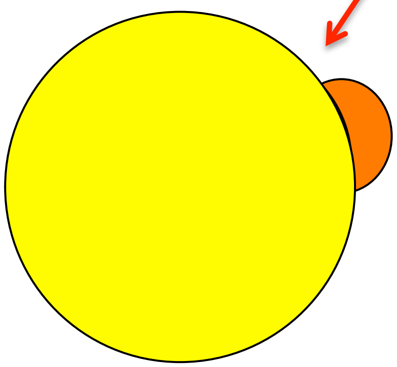


Absorption During Transit (%):

$$\frac{10R_p}{R_*^{\ 2}}\left(\frac{kT_p}{\mu g}\right)$$

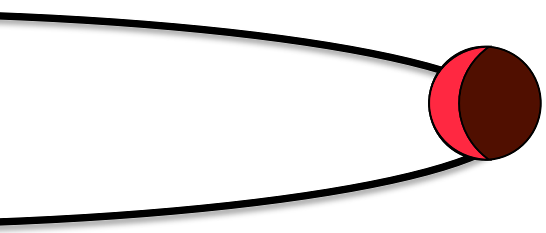
mean molecular weight

M stars preferred!



Secondary Eclipse Depth (IR):

$$\left(\frac{R_p}{R_*}\right)^2\left(\frac{T_p}{T_*}\right)$$

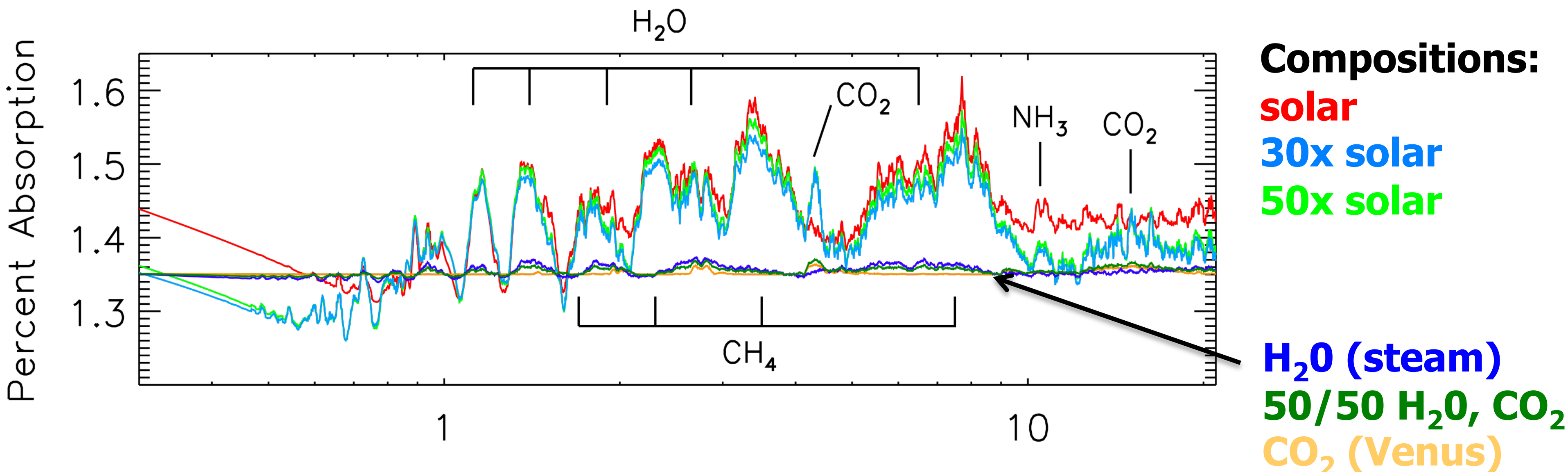


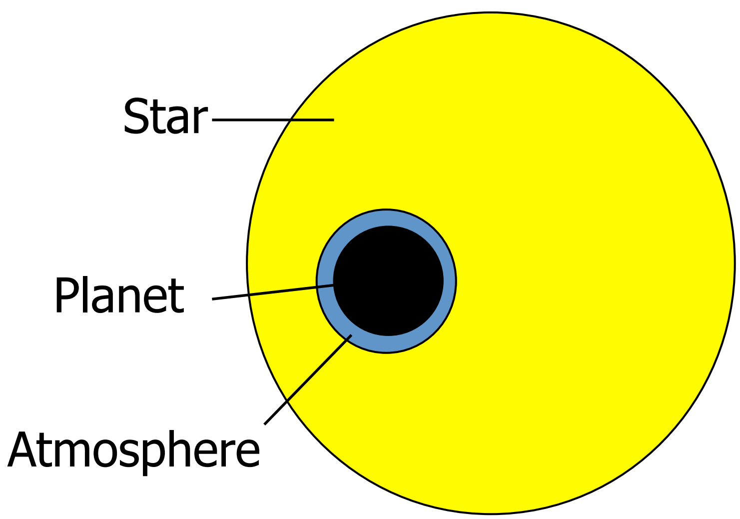
Orbital Phase Variations:

Always less than secondary eclipse depth.

Three ways to decrease signal: smaller planet, lower temperature, heavier atmosphere.

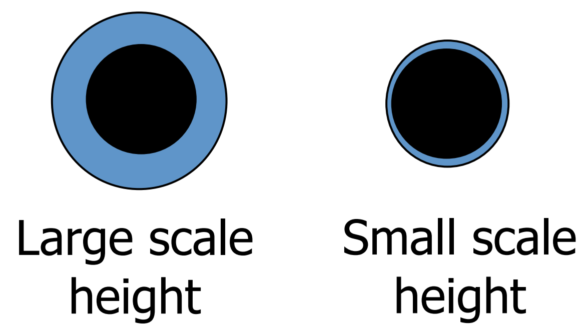
Transmission Spectroscopy Measures Mean Molecular Weight of Atmosphere





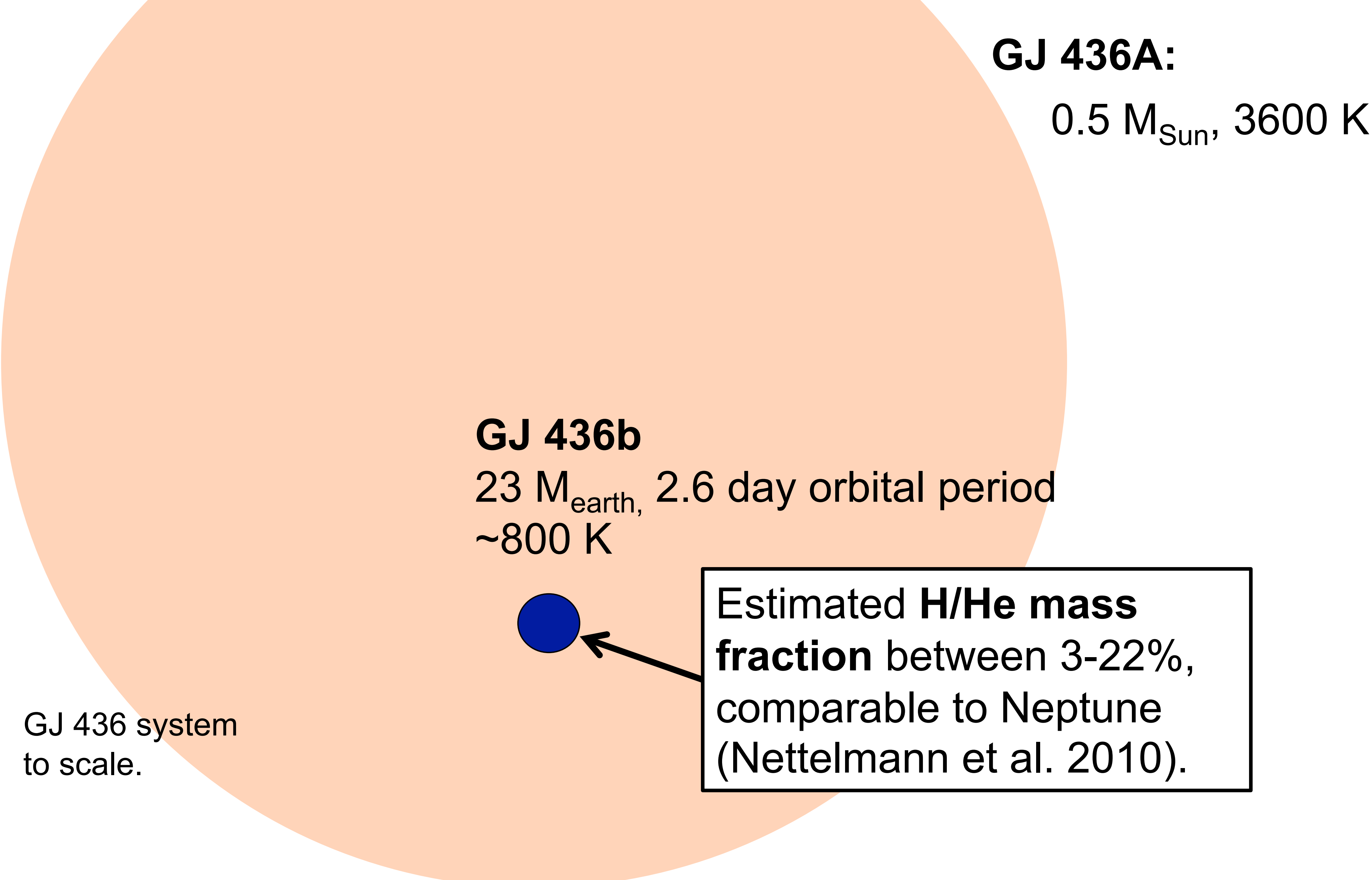
Scale Height

$$H = \frac{kT}{g\mu}$$

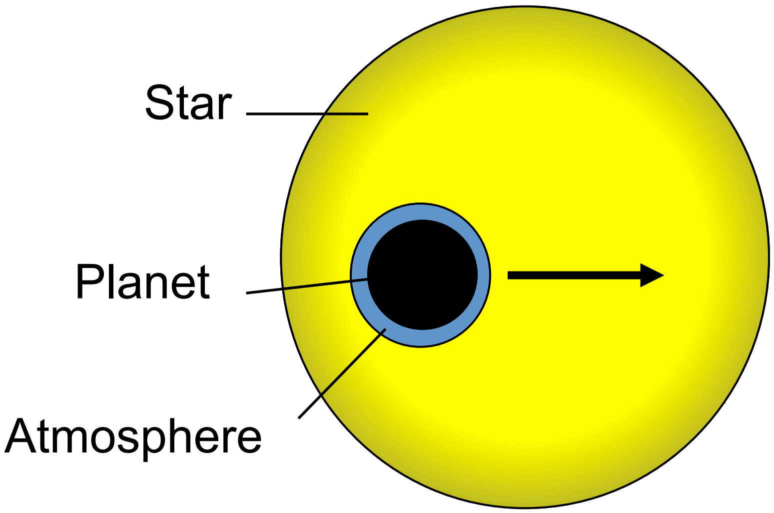


Miller-Ricci & Fortney (2010)

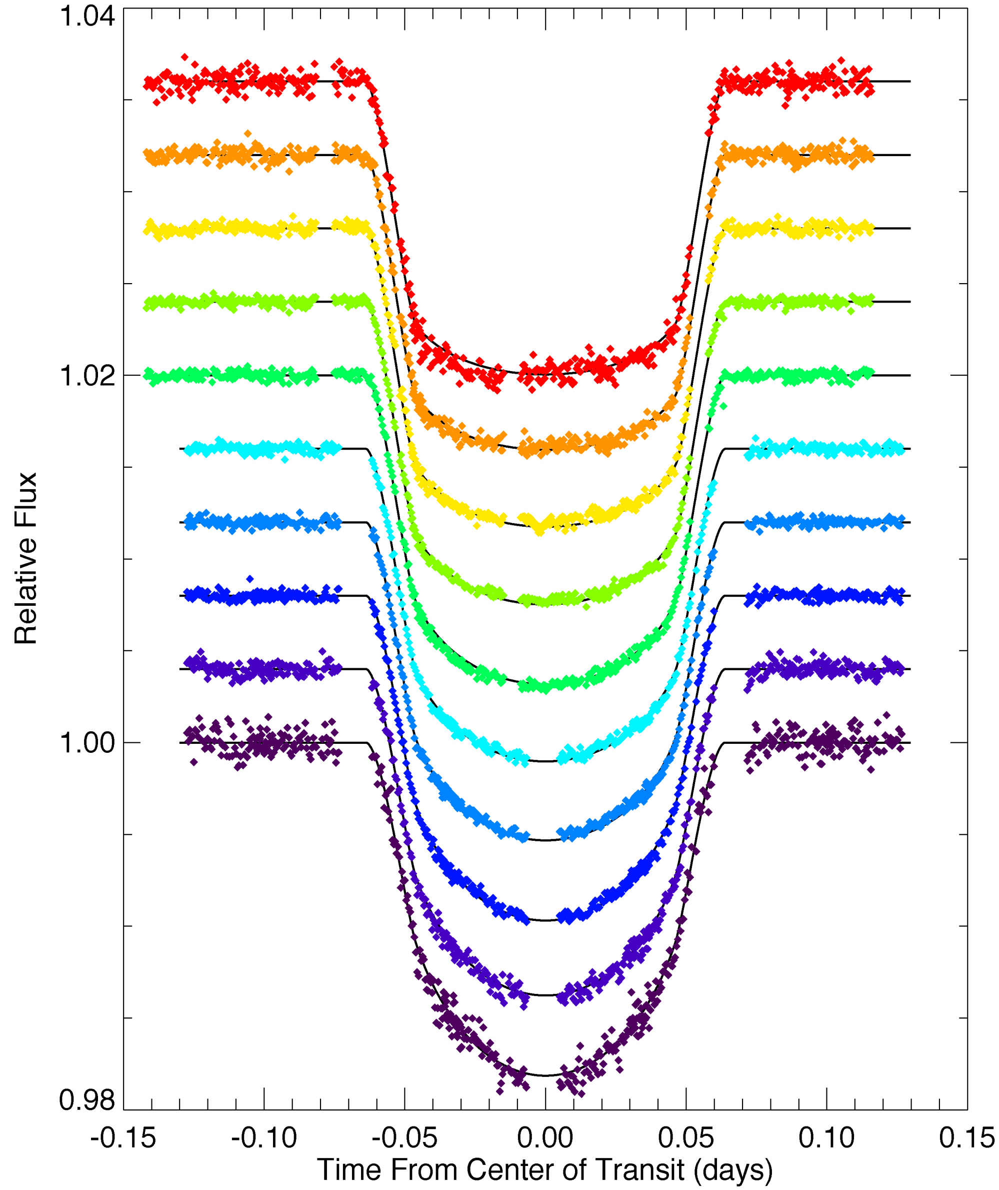
Characterizing the Warm Transiting Neptune GJ 436b



Characterizing Atmospheres With Transmission Spectroscopy

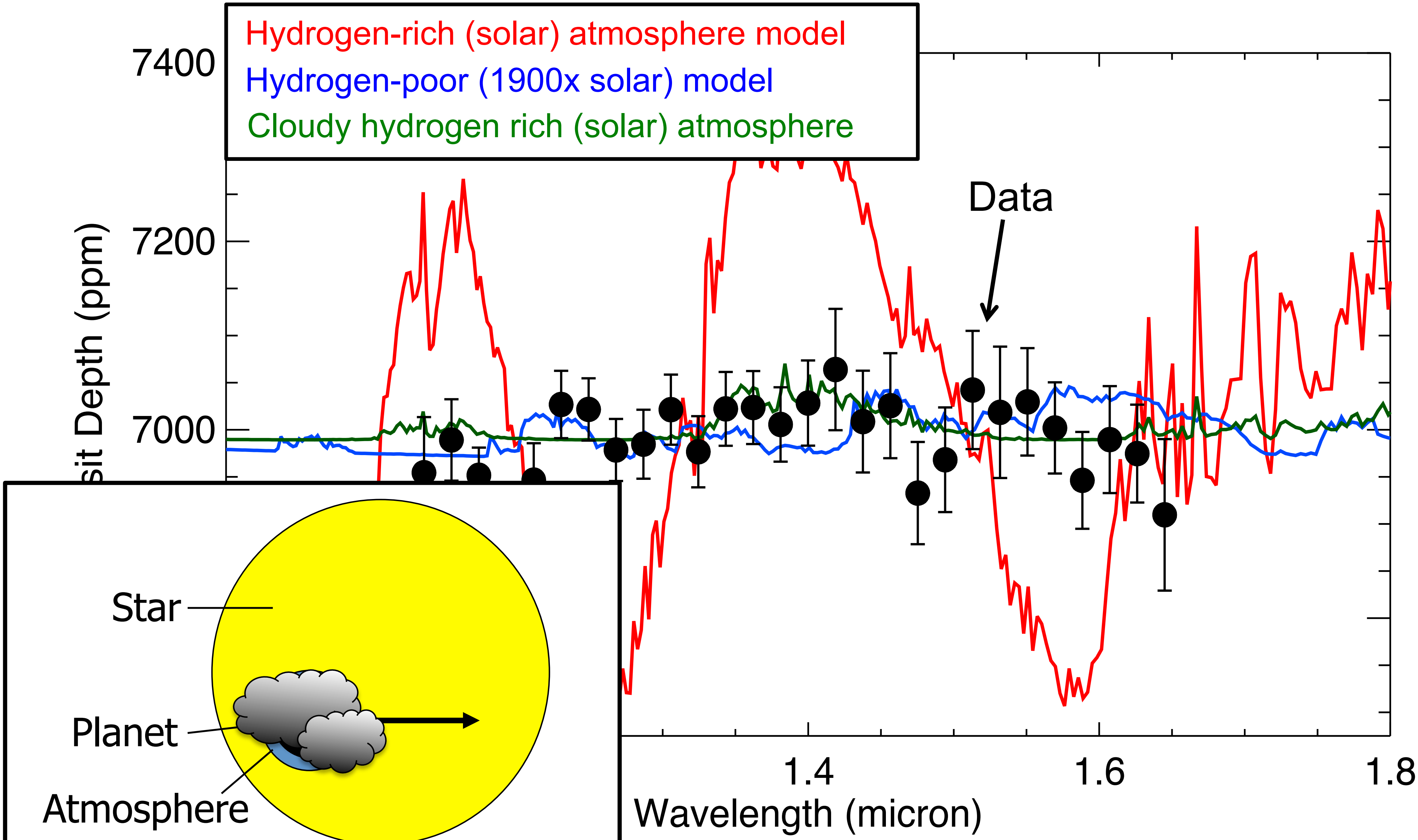


A good understanding of **limb-darkening** is needed in order to determine the planet's wavelength-dependent radius.



HST STIS transits of HD 209458b from 290-1030 nm (Knutson et al. 2007a)

A *Hubble Space Telescope* Transmission Spectrum for Warm Neptune GJ 436b



Super-Earth GJ 1214b also has similar clouds (Kreidberg et al. 2014)

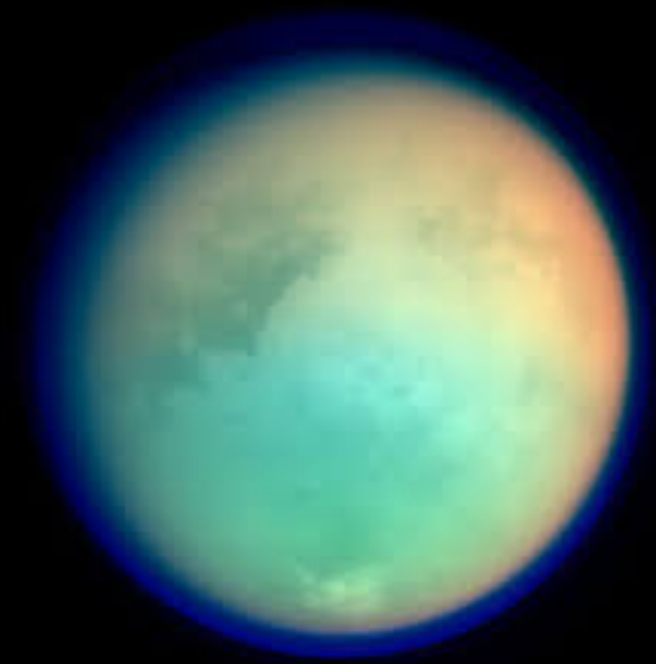
Knutson et al. (2014)

What Might Form Clouds on GJ 436b and GJ 1214b?

Condensate clouds like the Earth?

Zinc sulfide or potassium chloride (Morley et al. 2013)

Photochemical hazes like Titan?



Photochemistry converts methane to “soot” (long hydrocarbon chains)

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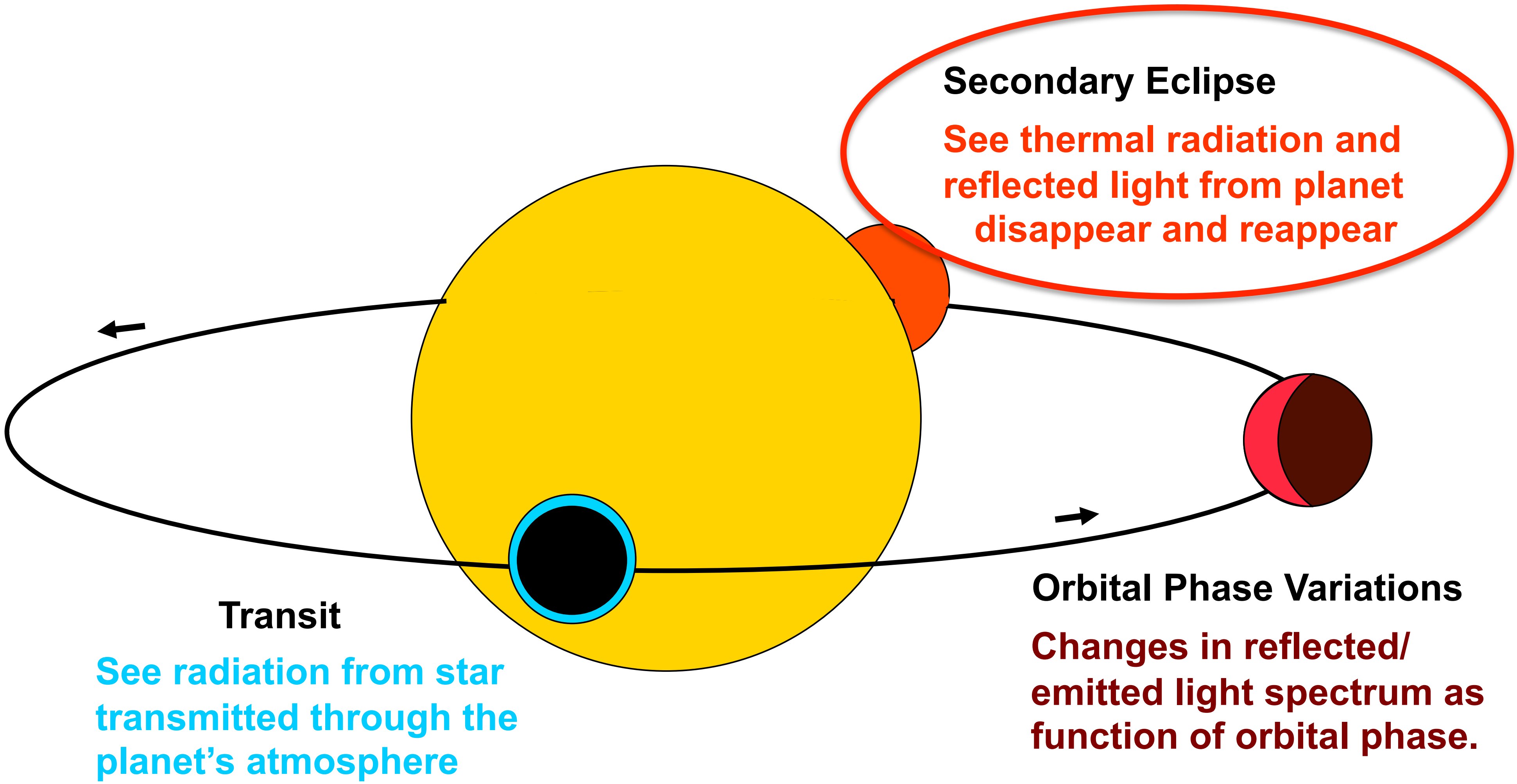
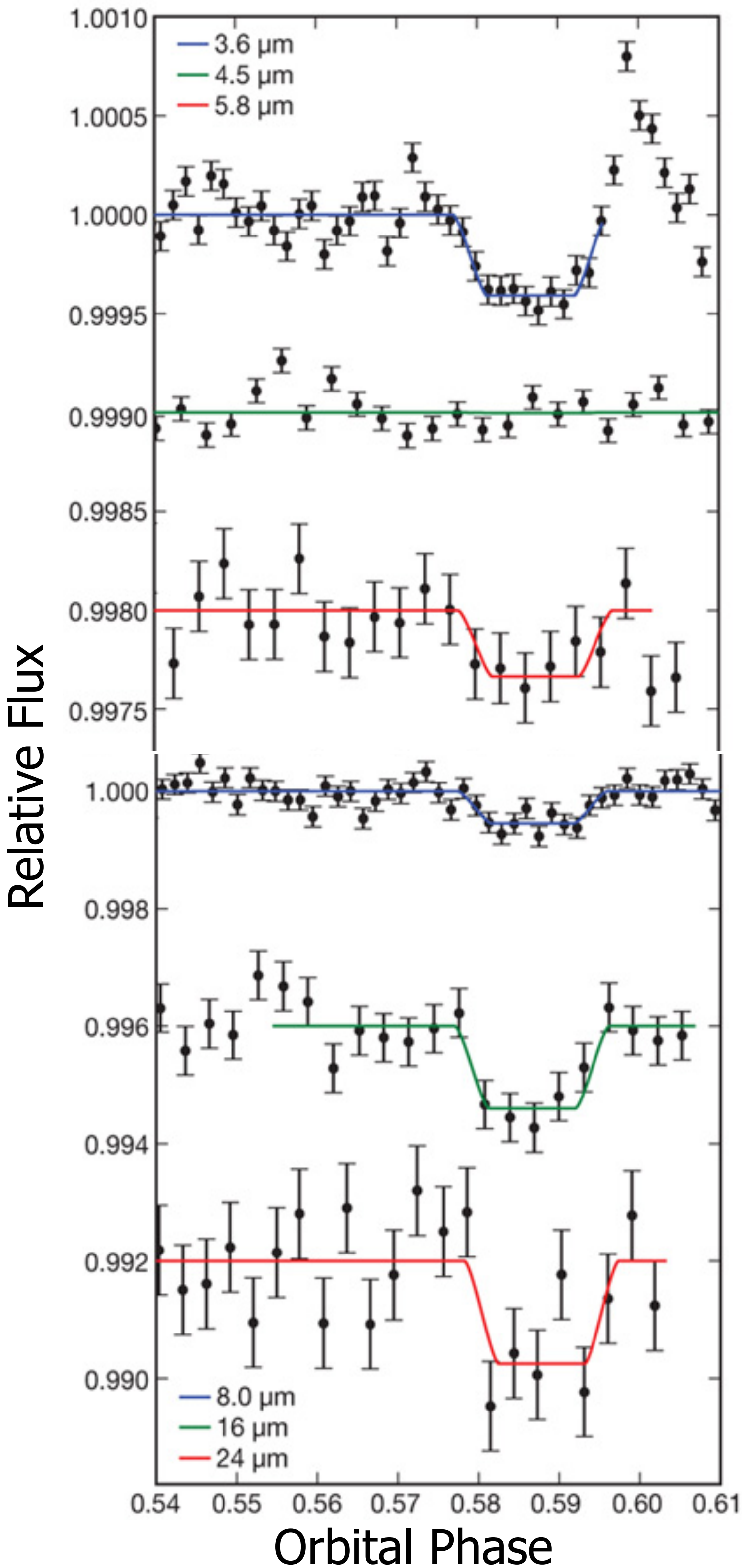
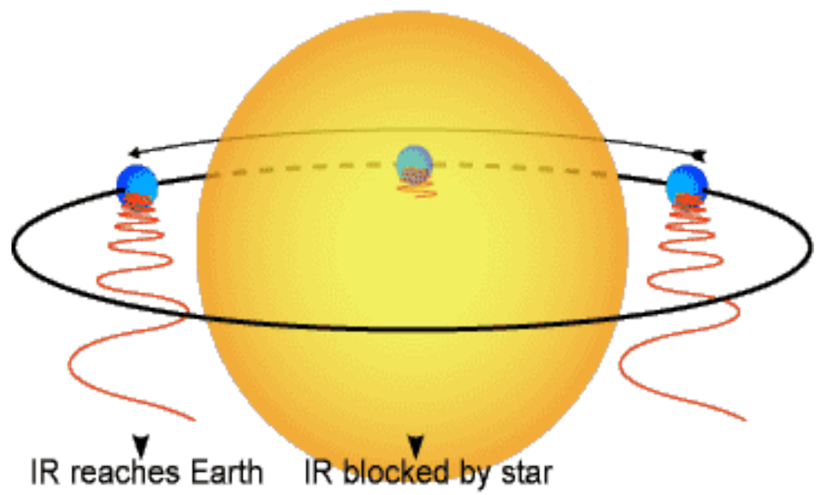




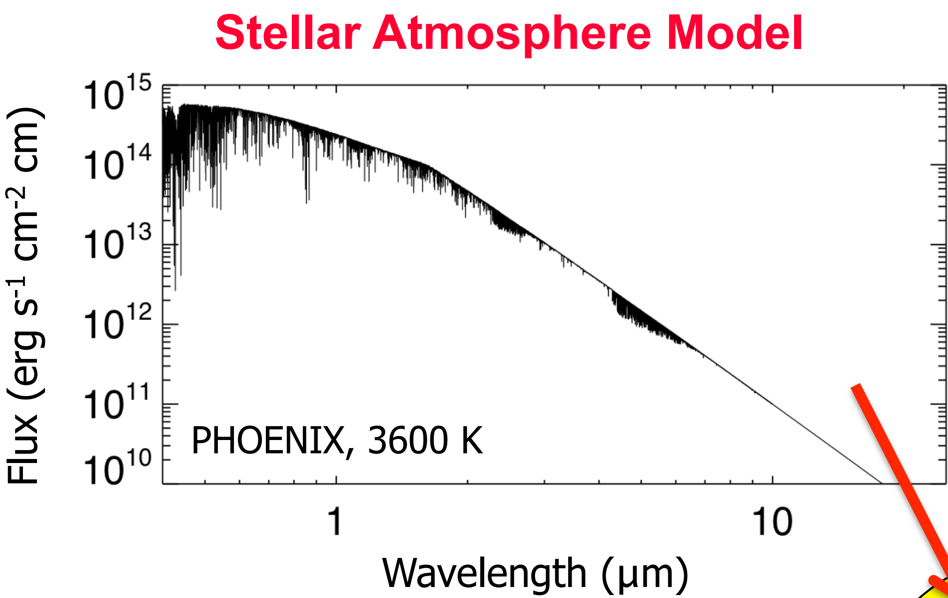
Constraints on GJ 436b's Dayside Emission Spectrum from *Spitzer*

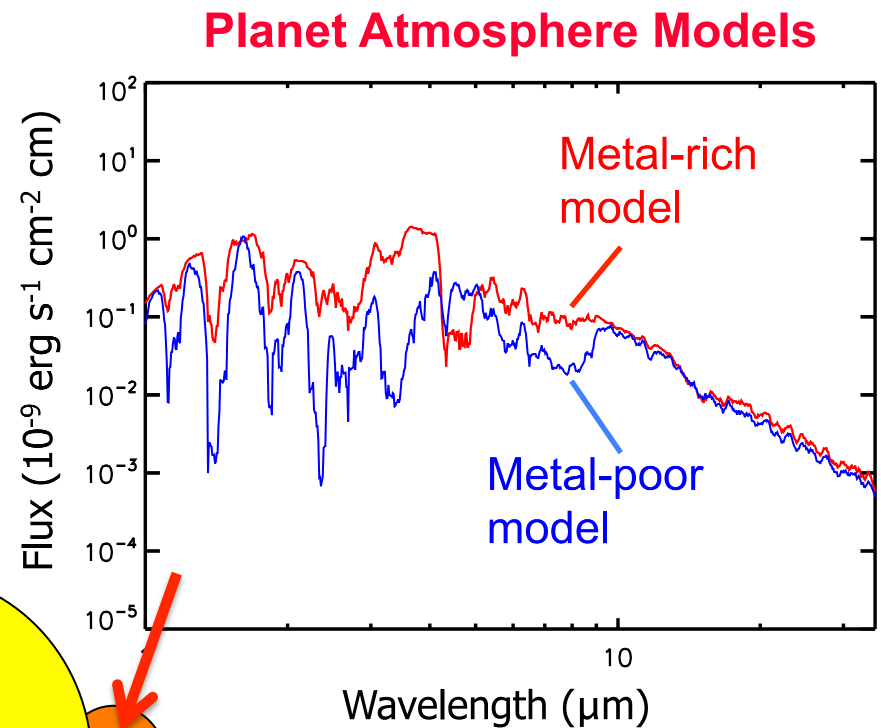
Stevenson et al. (2010, 2012)

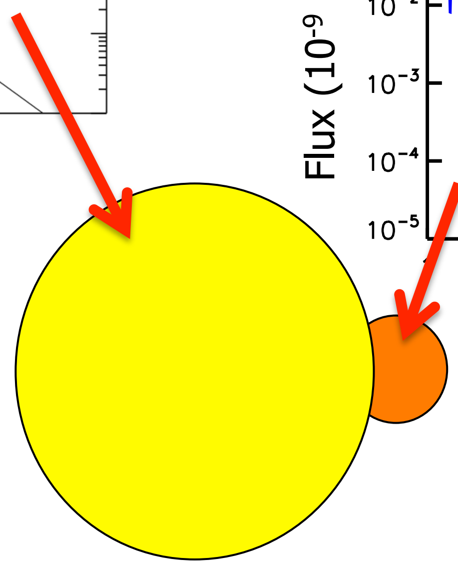


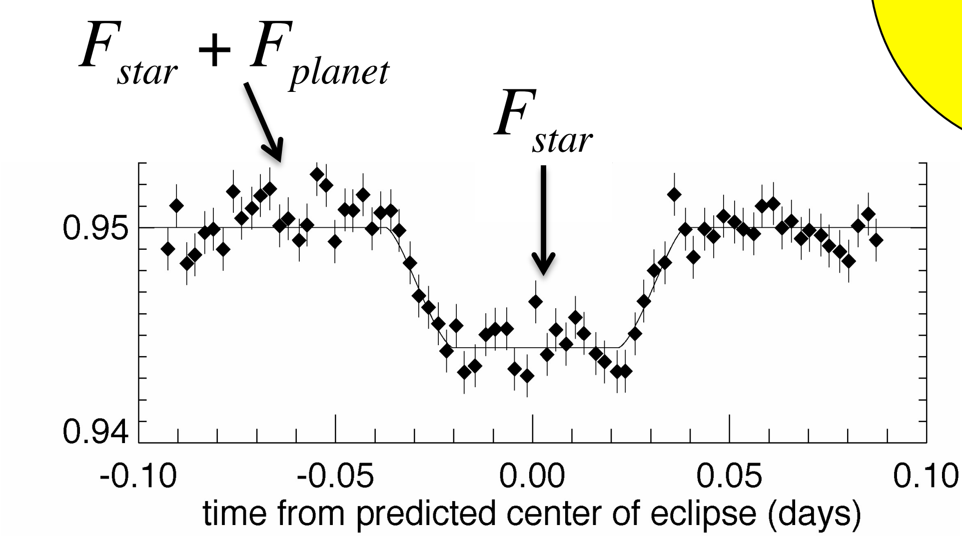
Observe the decrease in light as the planet disappears behind the star and then reappears.

Comparison to Models



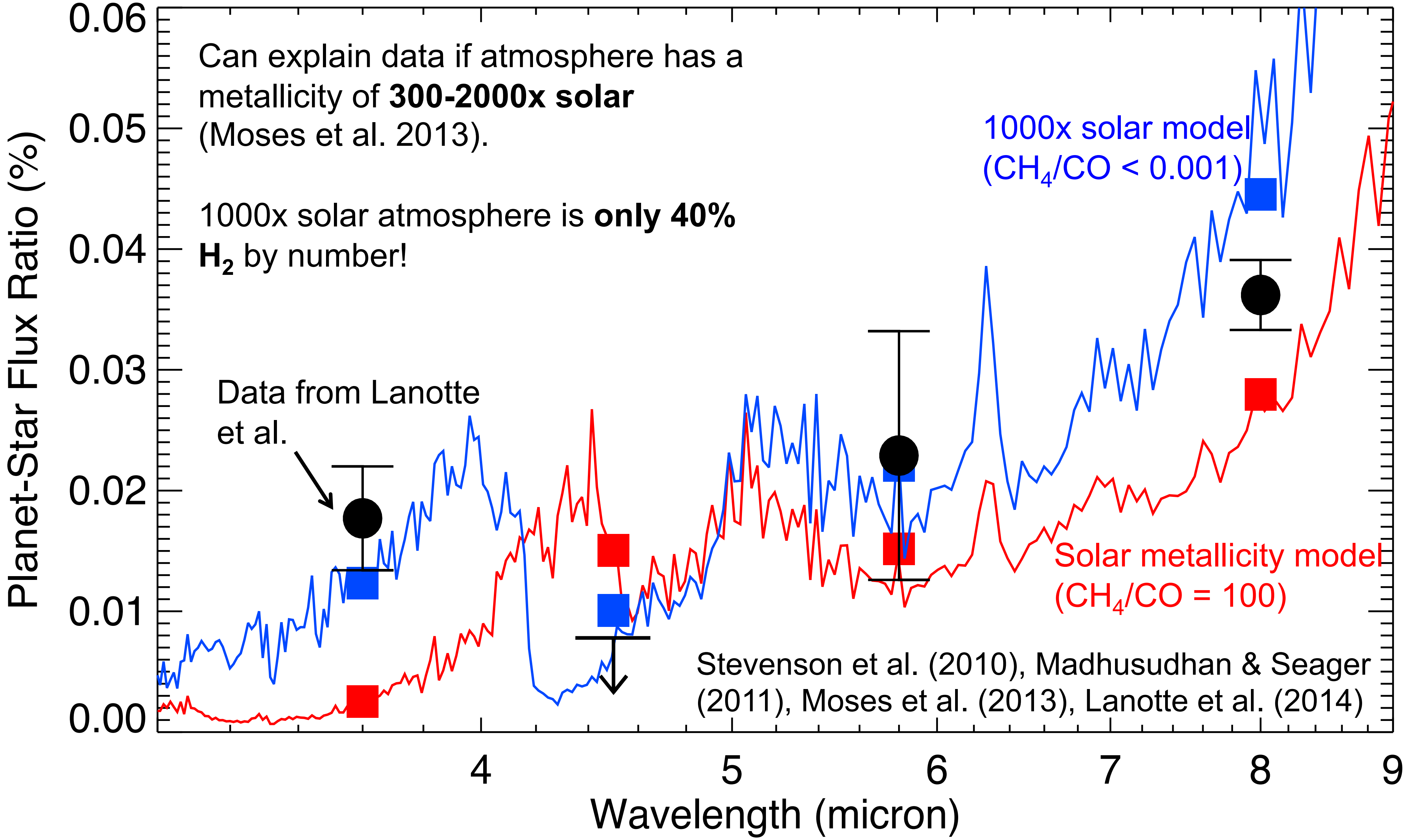






$$depth(\%) = \frac{F_{planet}}{F_{star} + F_{planet}} \approx \frac{F_{planet}}{F_{star}}$$

GJ 436b: A Warm Neptune With a Metal-Rich Atmosphere



Models courtesy M. Line & J. Fortney

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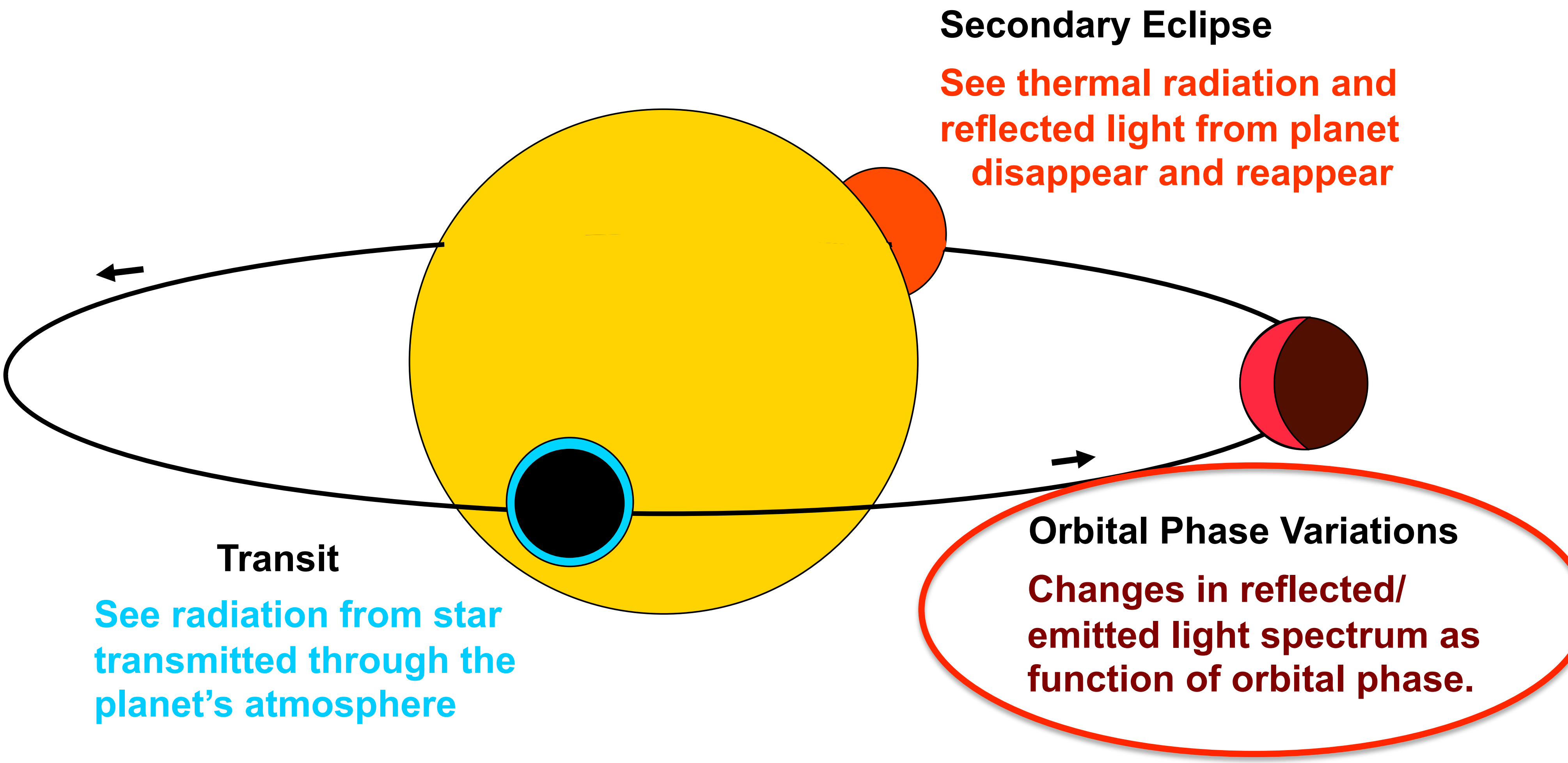
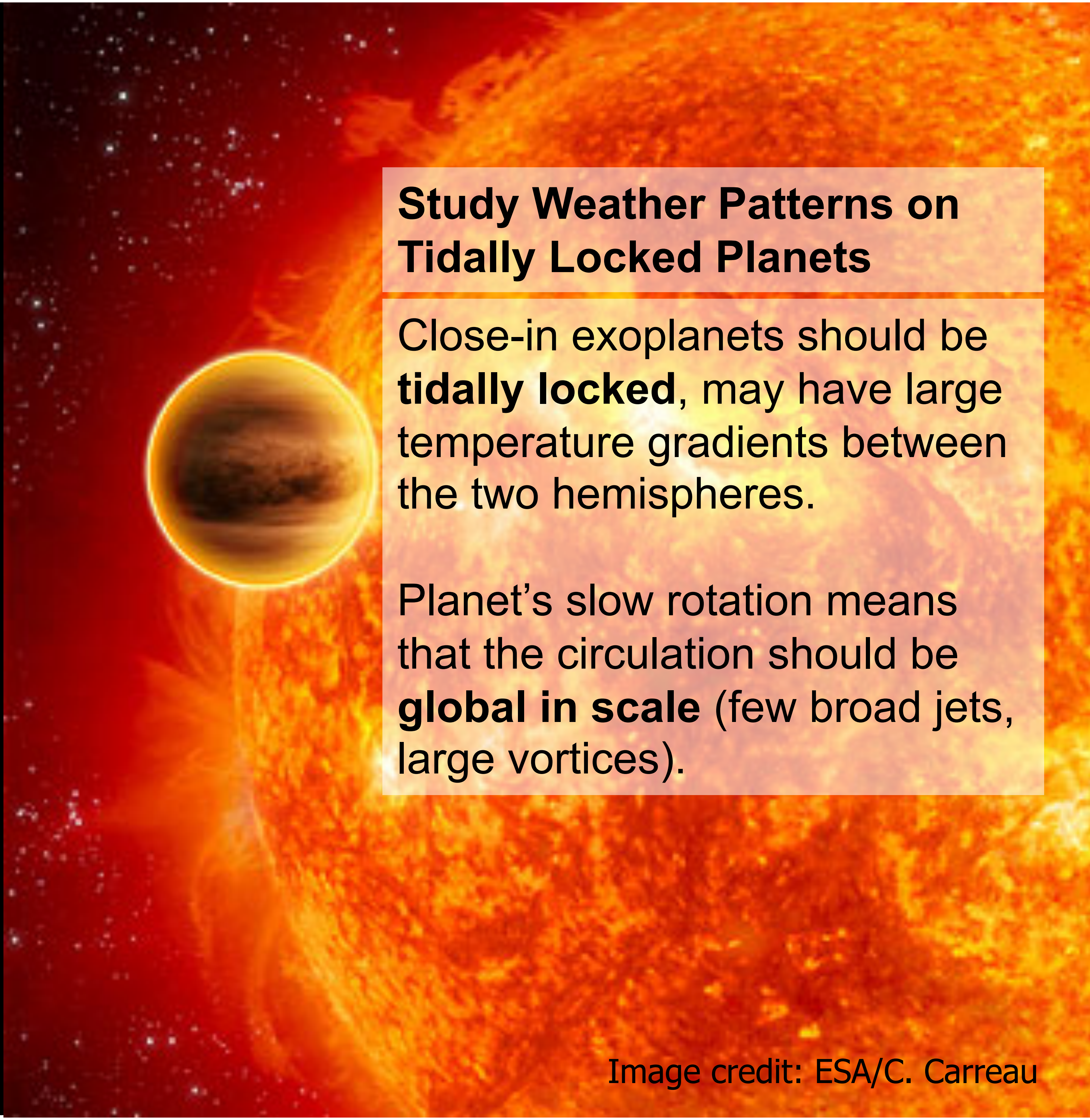




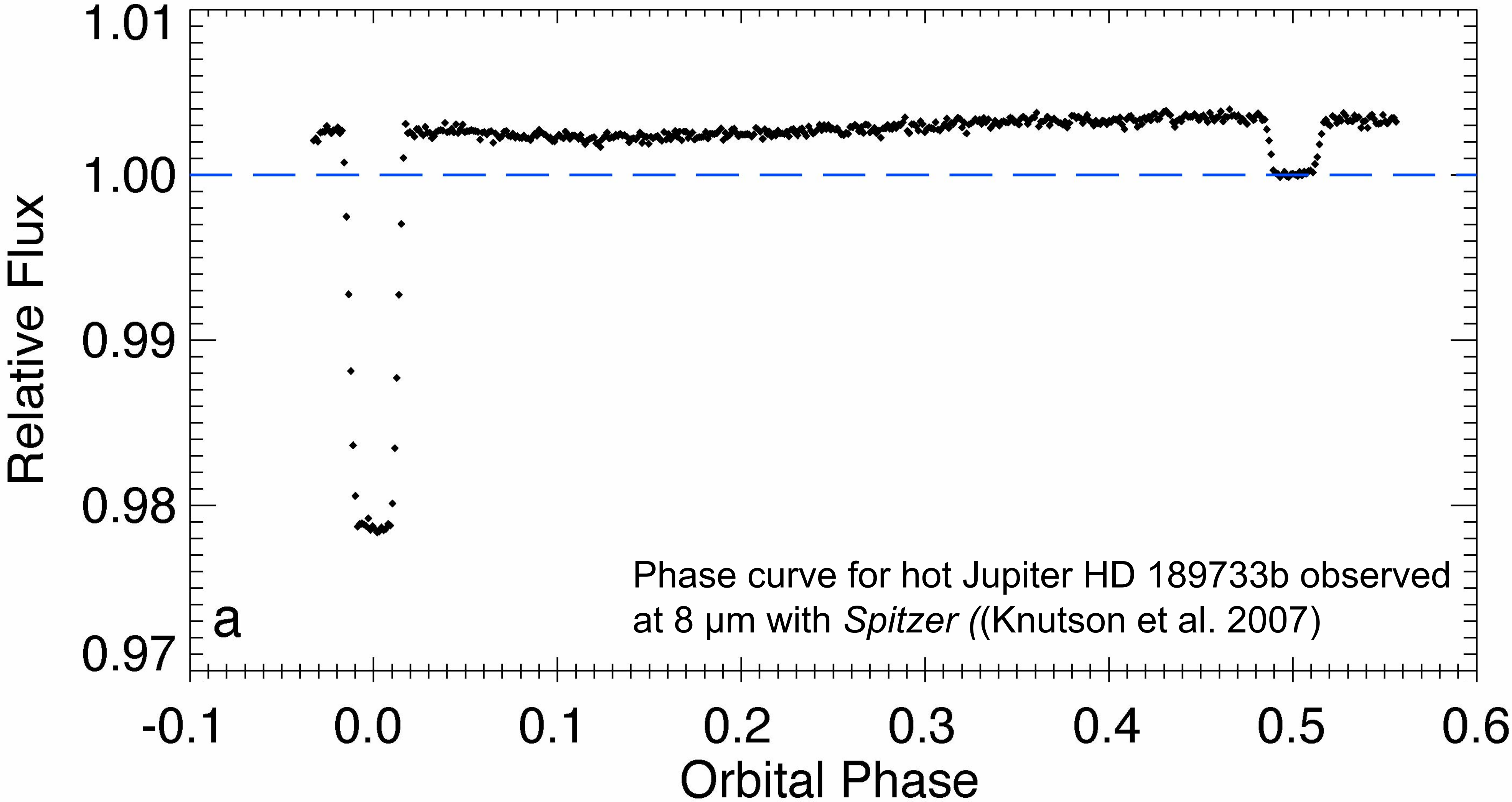
Study Weather Patterns on Tidally Locked Planets

Close-in exoplanets should be **tidally locked**, may have large temperature gradients between the two hemispheres.

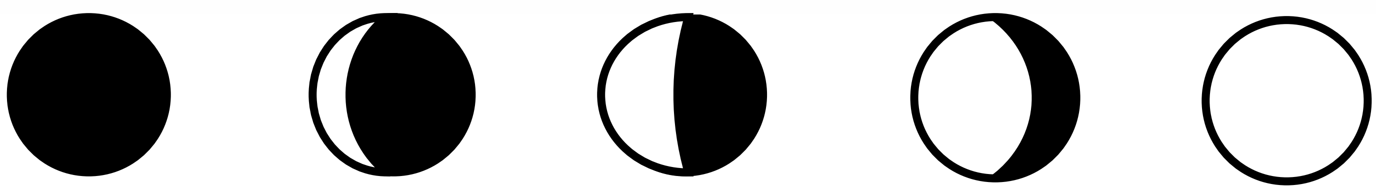
Planet's slow rotation means that the circulation should be **global in scale** (few broad jets, large vortices).

Image credit: ESA/C. Carreau

Constraints on Atmospheric Circulation from Phase Curve Observations



Observer's View of Planet



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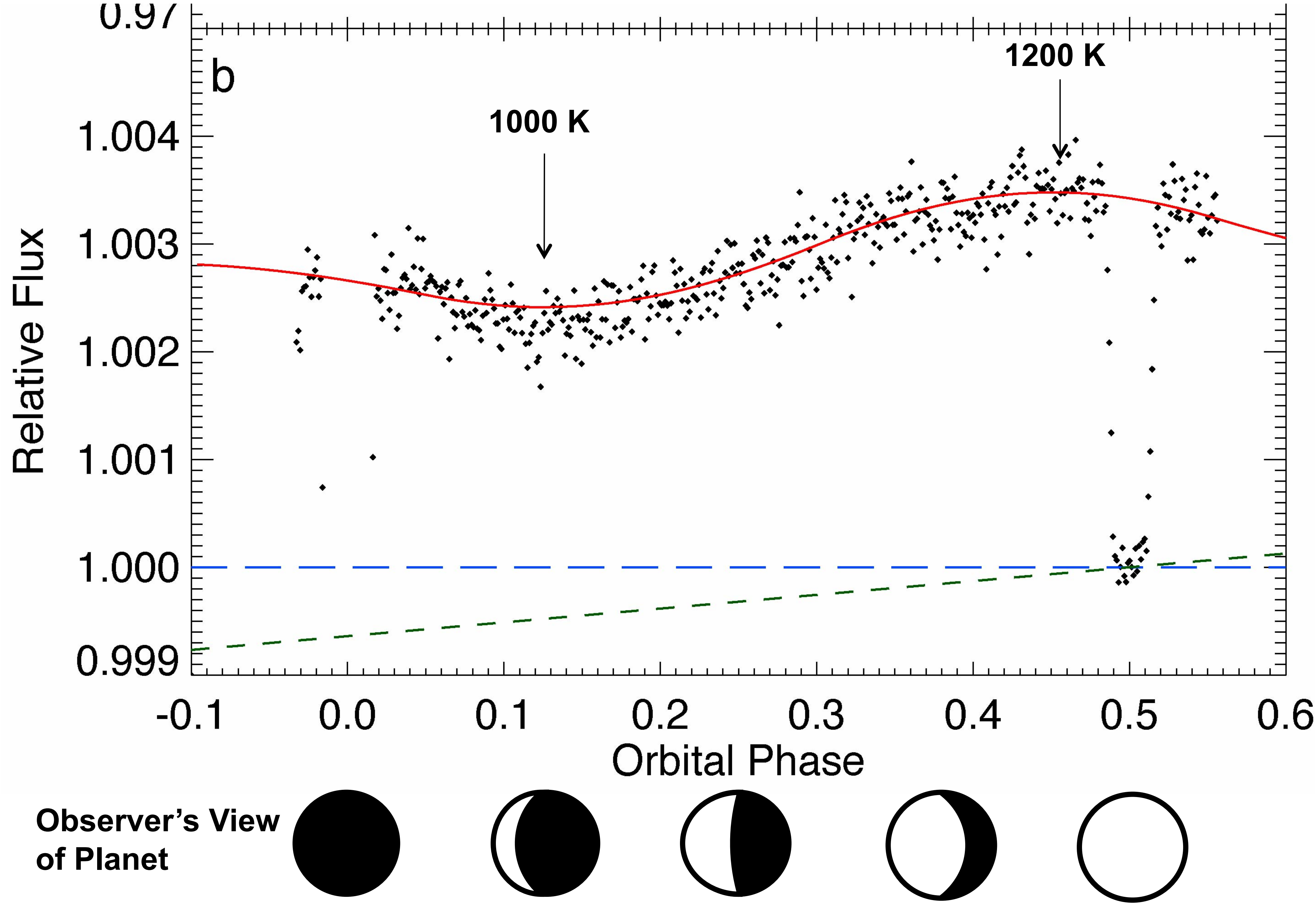
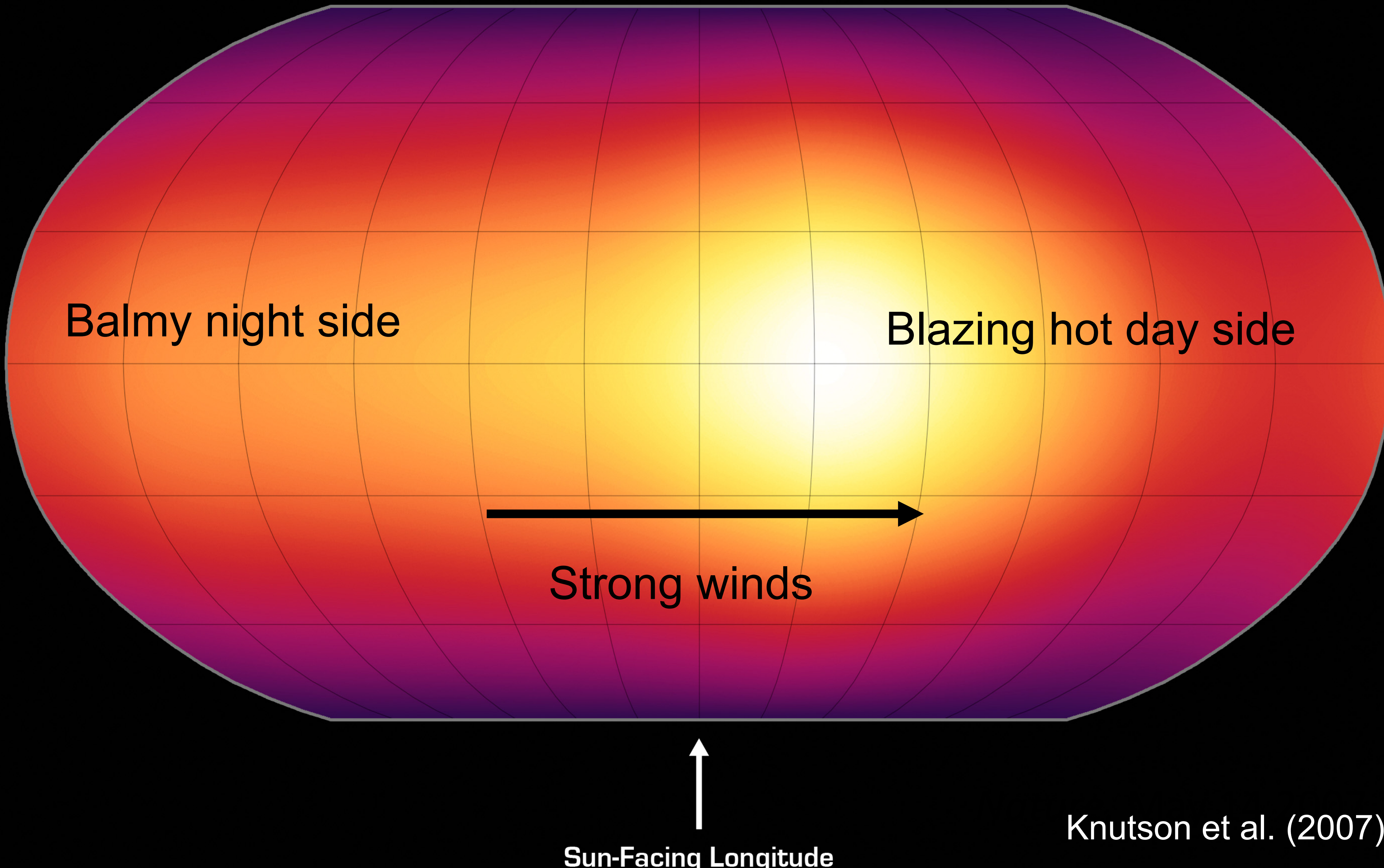
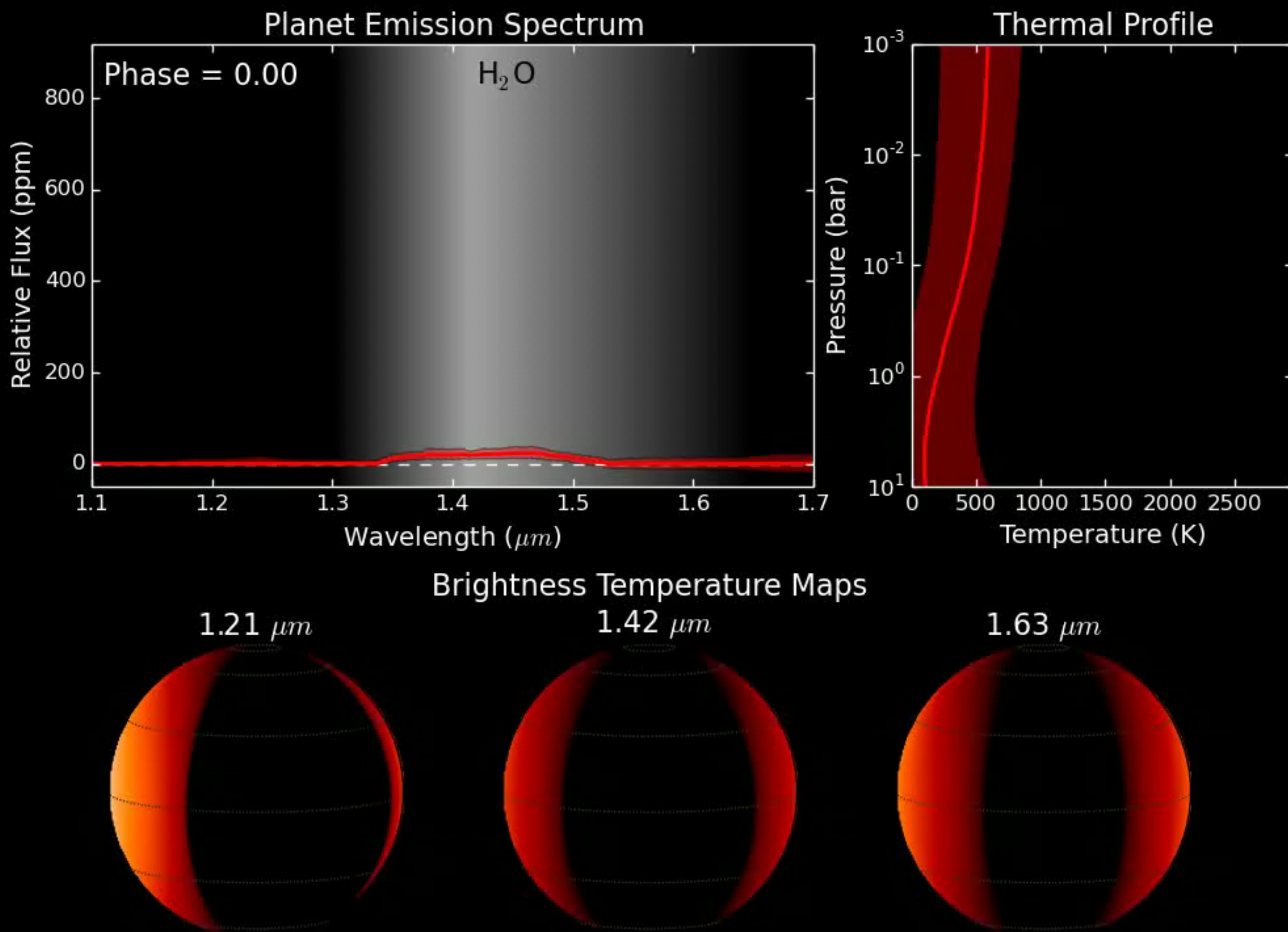


Phase Curves Allow Us to Map Atmospheric Circulation Patterns for Tidally Locked Planets



Knutson et al. (2007)

Multi-Wavelength Observations Map Thermal + Chemical Gradients in Atmosphere



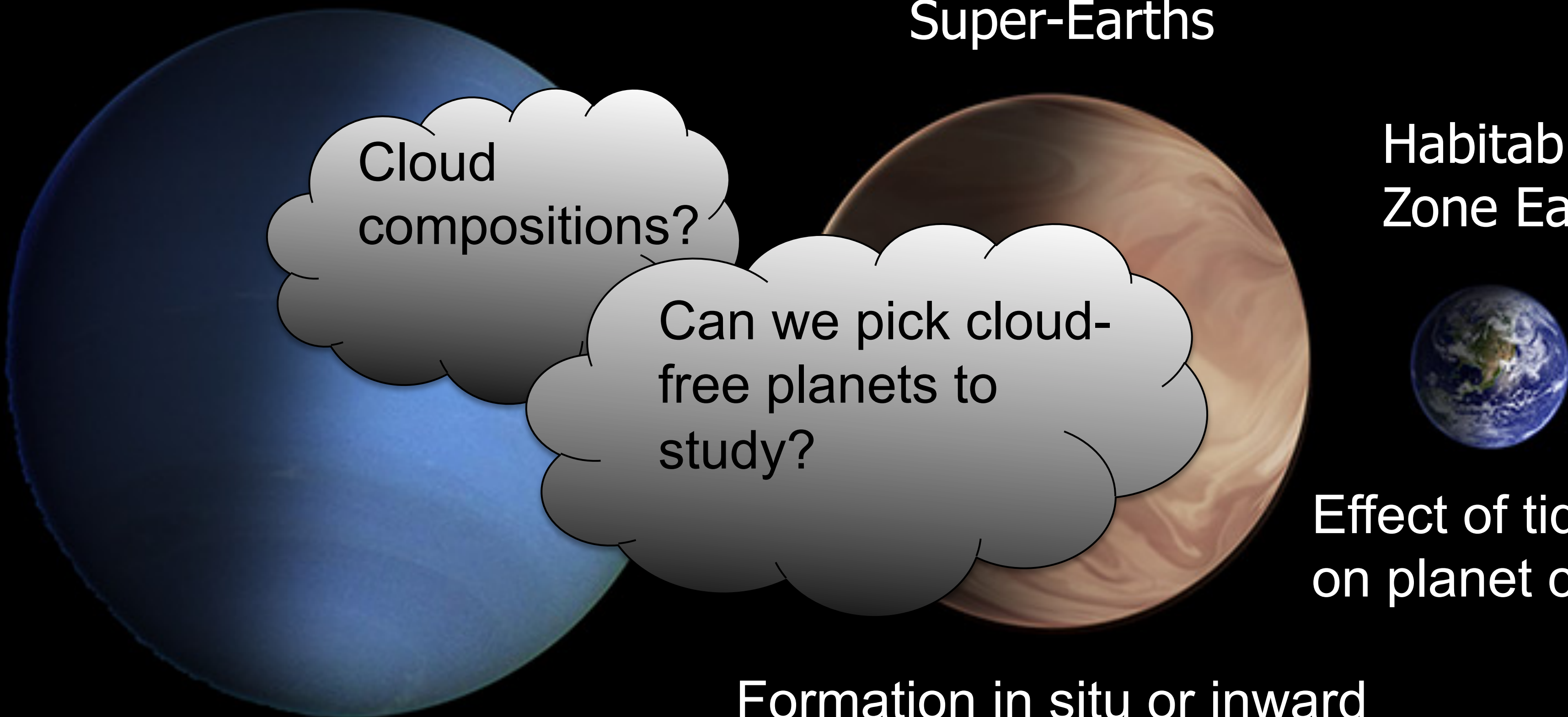
Stevenson et al. (2014)

Conclusions: What Can We Learn from Atmosphere Studies?

Gas Giants

Super-Earths

Habitable
Zone Earths



Effect of tidal locking
on planet climate?

Formation in situ or inward
migration?

Does atmospheric
metallicity increase with
decreasing mass?

Planets drawn
to scale.