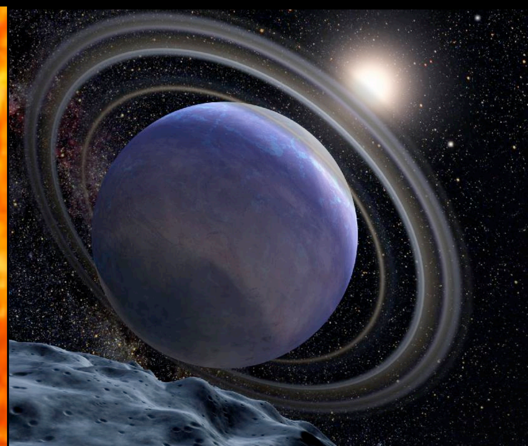
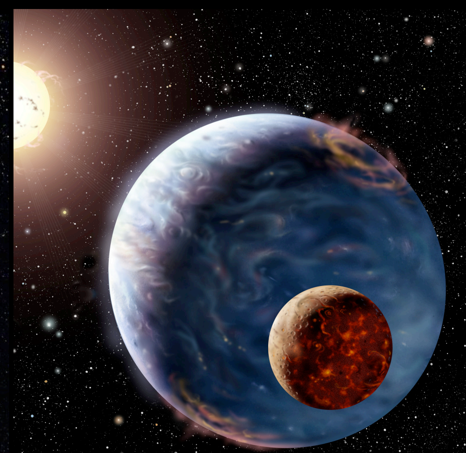
Properties of Exoplanetary Atmospheres: A Spitzer Portrait Gallery


Heather Knutson

UC Berkeley

Easier

Harder

Exoplanet Characterization 101:

What is the planet's bulk composition?

What is its temperature?

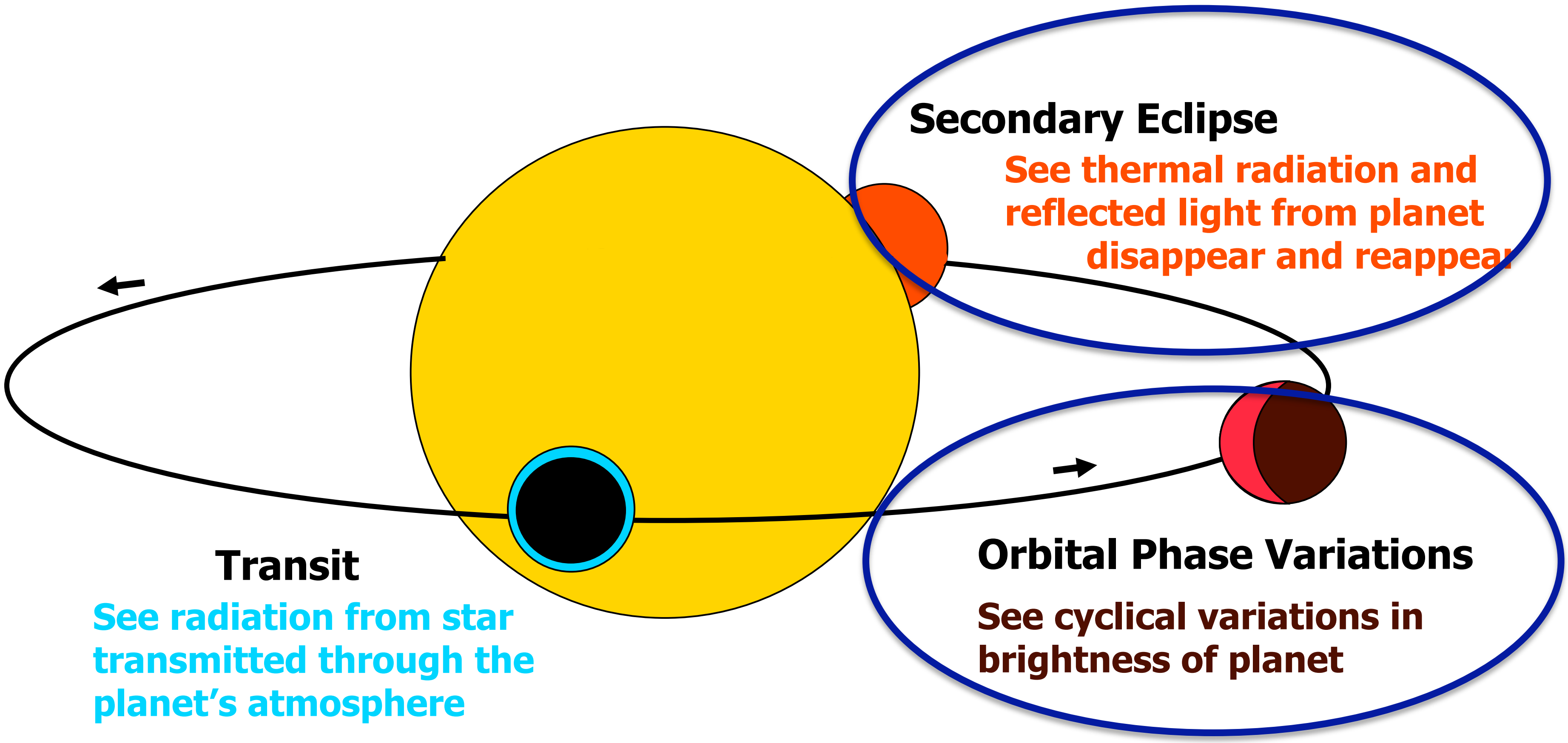
Its atmospheric composition?

What about atmospheric circulation?

Hot Jupiters are **good test cases** for exoplanet characterization (big, hot, lots available). Current challenge is to explain diversity in observed properties.

Kepler & CoRoT (and Mearth!) will soon enable the first studies of **smaller** and/or **cooler** transiting planets.

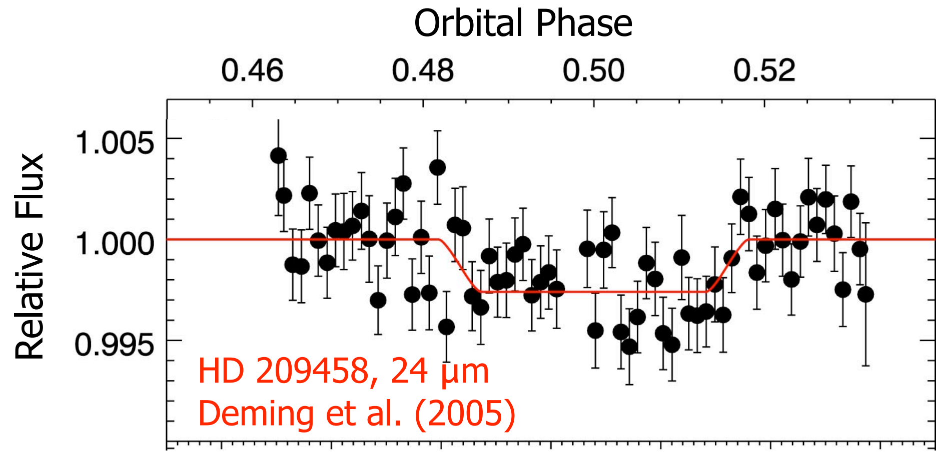
Transiting Planets as a Tool for Studying Exoplanet Atmospheres

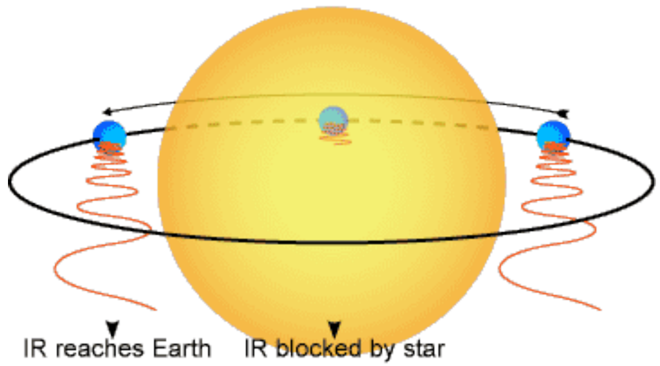


***Spitzer* has provided some of the best examples of these two phenomena to date.**

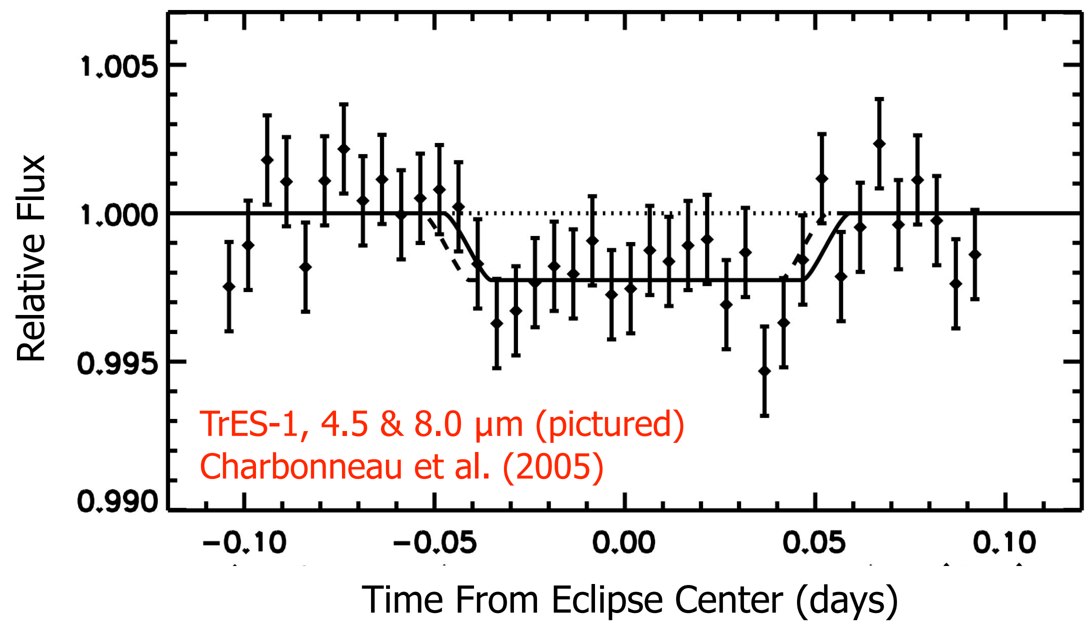
2005: First Detection of Light From An Extrasolar Planet

Can measure the planet's emitted flux without the need to spatially resolve the planet's light separate from that of the star.





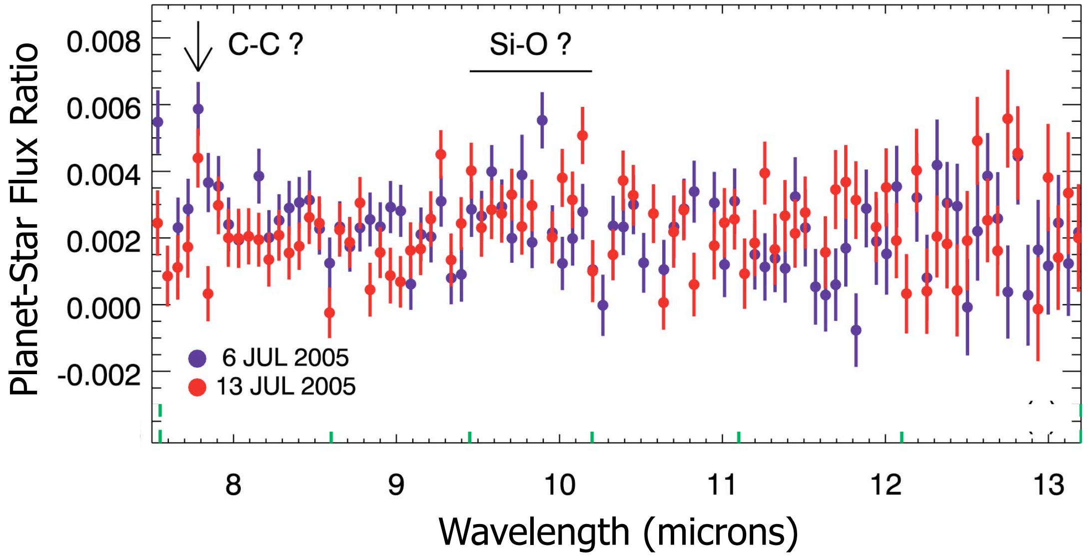
Observe the decrease in light as the planet disappears behind the star and then reappears.



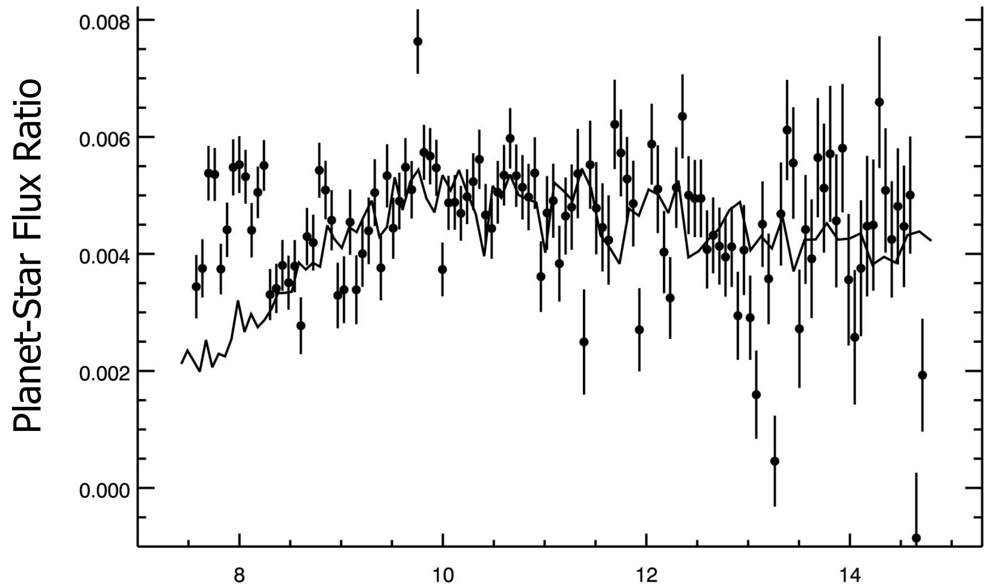
2007: First Spectrum for an Extrasolar Planet

IRS observations of two planets during secondary eclipse:

HD 209458b
Richardson et al. (2007)



HD 189733b
Grillmair et al. (2007)



Secondary Eclipse Observations of HD 189733b Constrain Atmospheric Structure, Composition

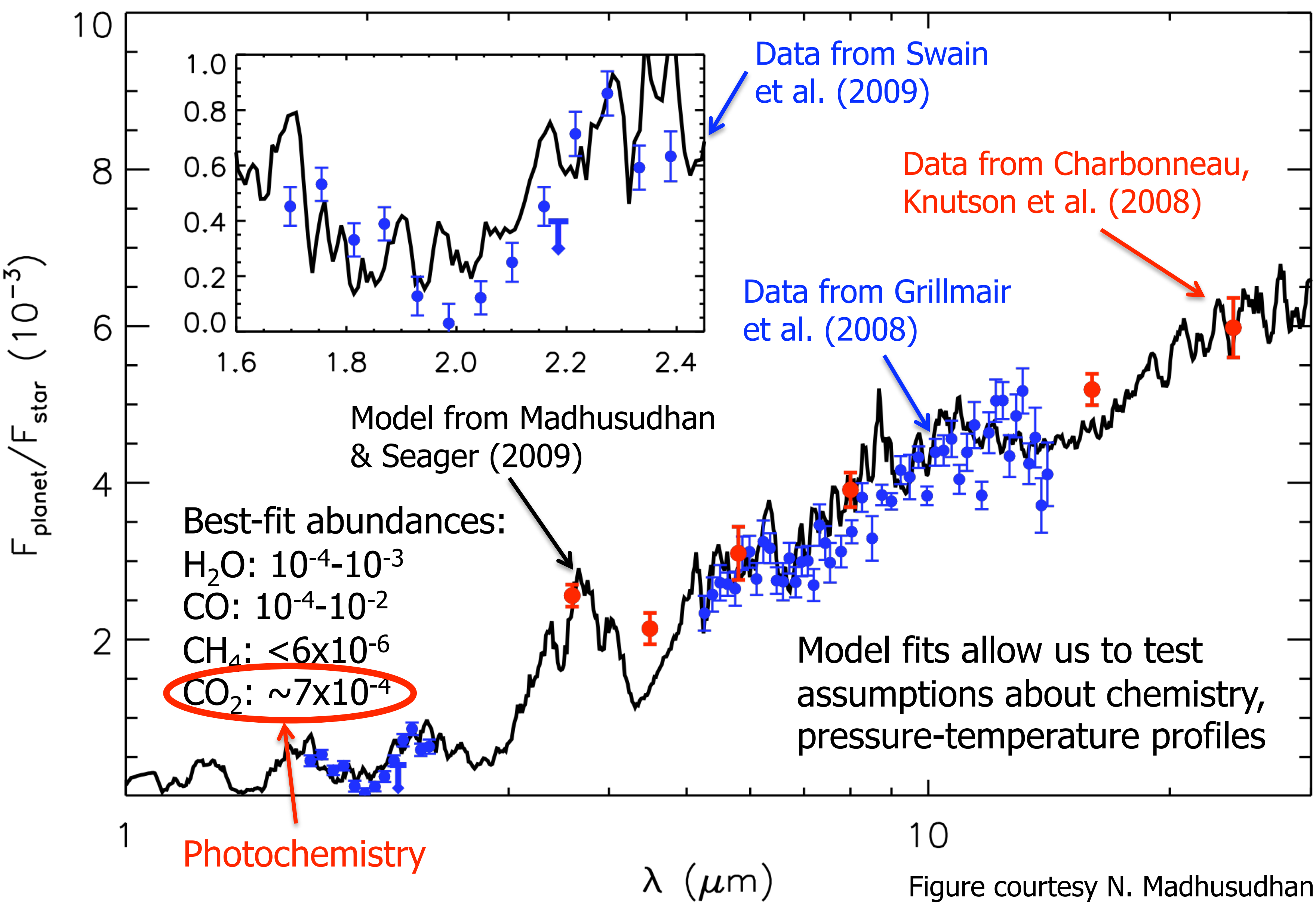
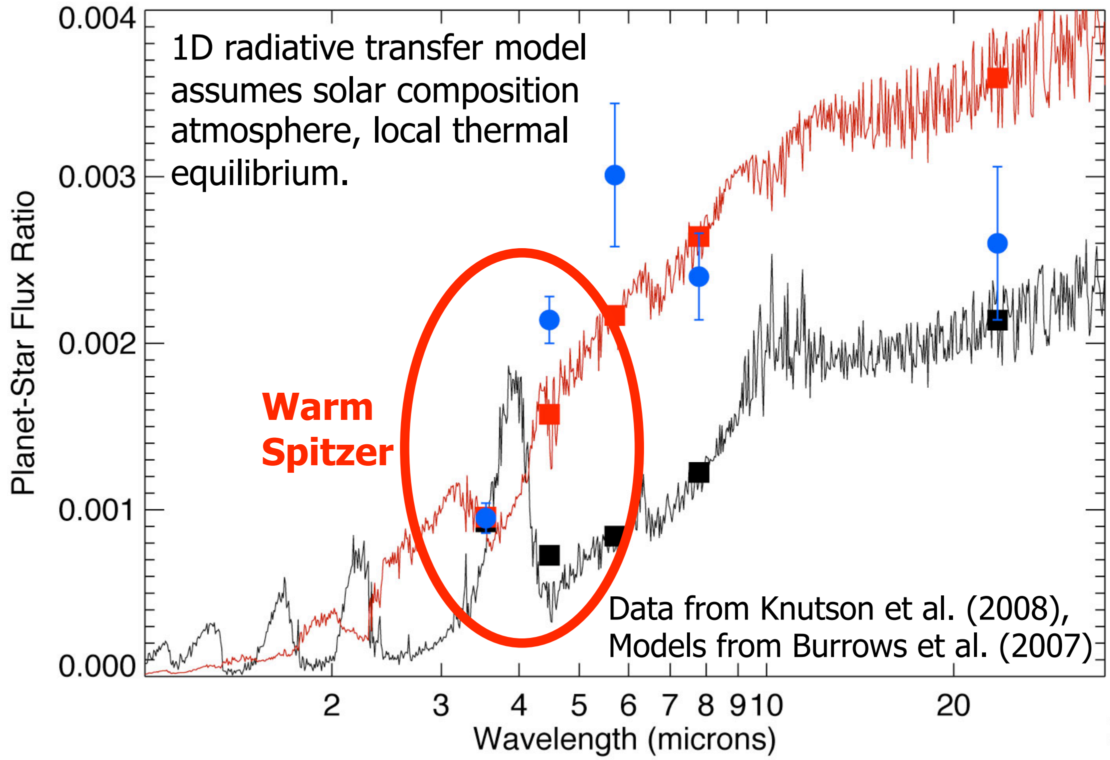
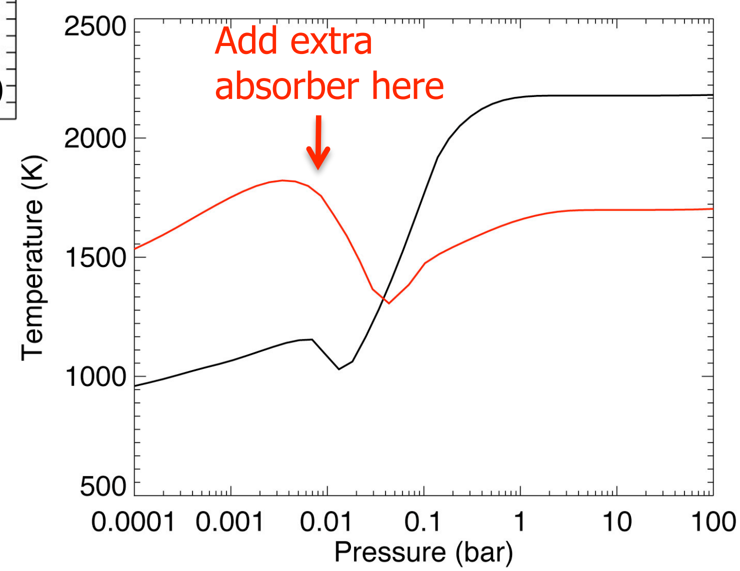


Figure courtesy N. Madhusudhan

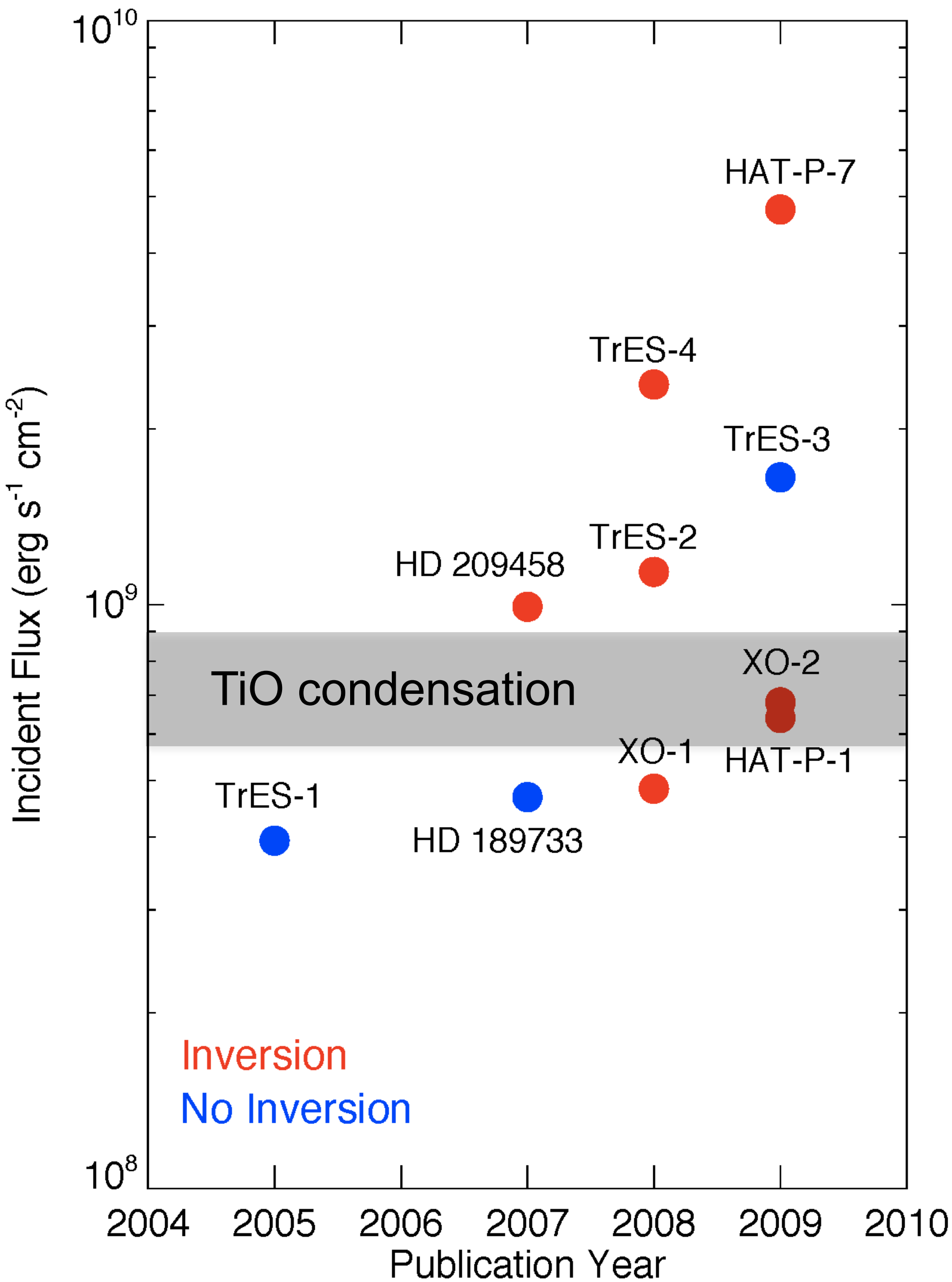
HD 209458b: Evidence for Two Classes of Hot Jupiter Atmospheres



Best described by a model with a temperature inversion and water features in emission instead of absorption.



Why would two hot Jupiters with similar masses, radii, compositions, and temperatures have such different emission spectra?



What causes temperature inversions in hot Jupiter atmospheres?

Gas phase TiO?

Problem: inversions do not appear to correlate with temperature

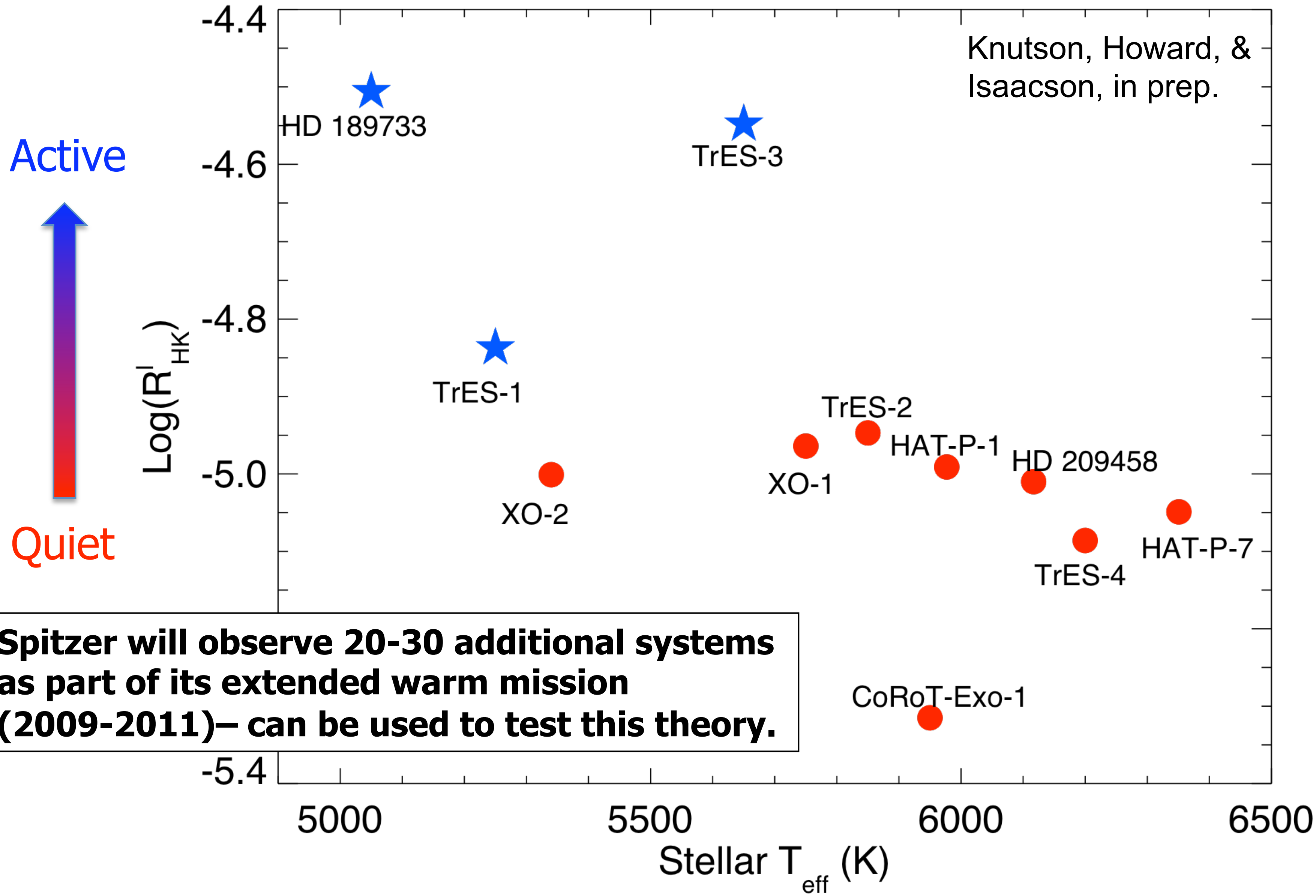
Non-equilibrium chemistry?

Sulfur compounds (Zahnle et al. 2009)

Other photochemical products?

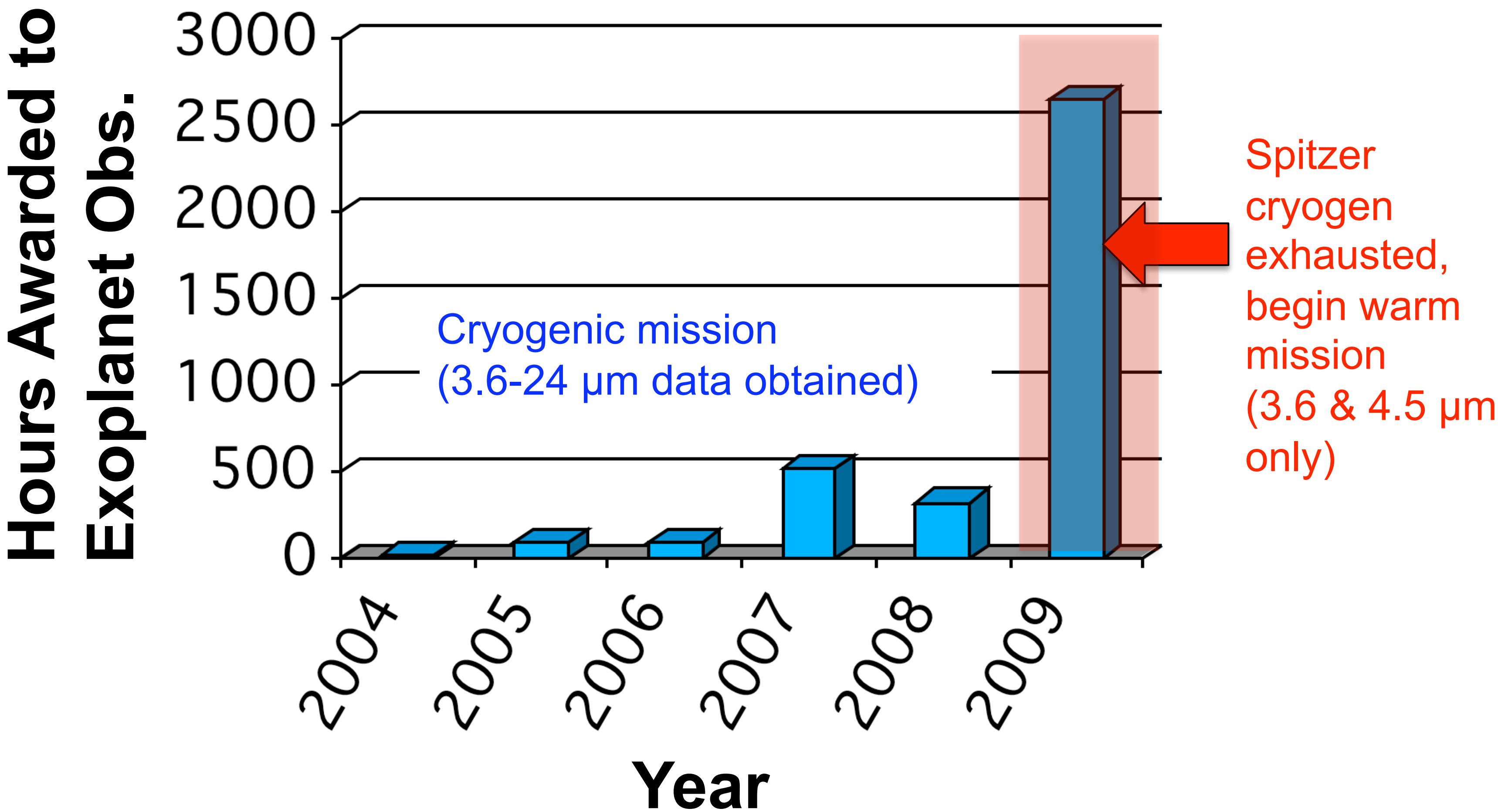
As described in Hubeny et al. (2003), Burrows et al. (2007, 2008), and Fortney et al. (2008)

A Correlation Between Stellar Activity and Temperature Inversions



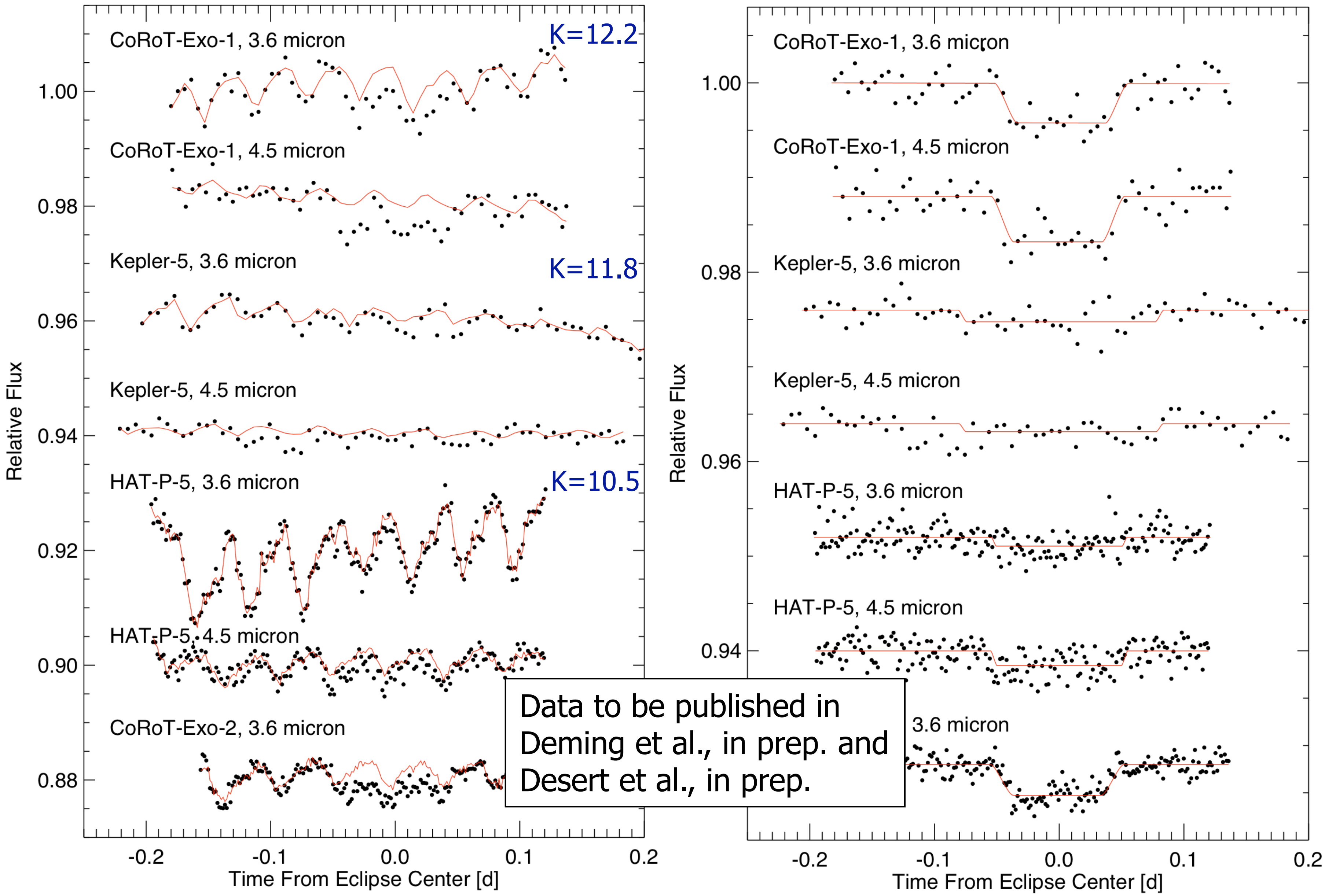
Spitzer will observe 20-30 additional systems as part of its extended warm mission (2009-2011)– can be used to test this theory.

The Spitzer Space Telescope's Extended Warm Mission



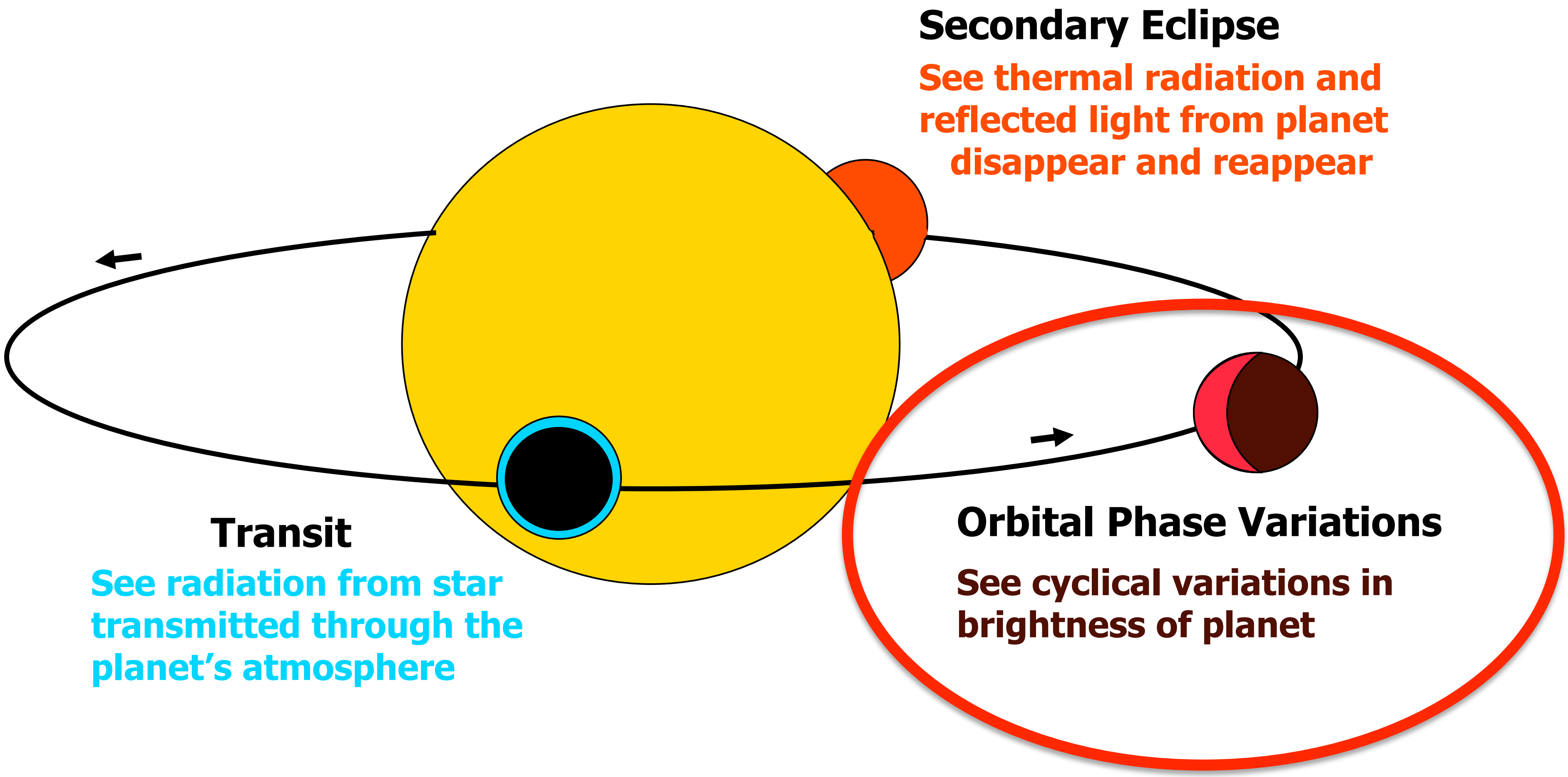
Large time allocations enable wide-ranging surveys of hot Jupiter atmospheres.

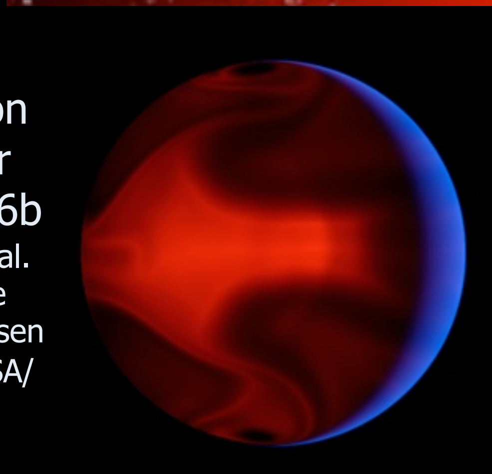
First Warm Mission Data: Four Planets



Data to be published in Deming et al., in prep. and Desert et al., in prep.

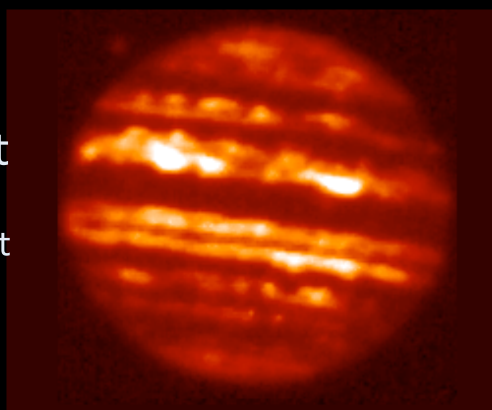
Transiting Planets as a Tool for Studying Exoplanetary Atmospheres





Circulation model for HD 80606b

Laughlin et al. 2009, image credit D. Kasen (UCSC)/NASA/ JPL-Caltech



Jupiter at 4.8 μm.

Image credit Glen Orton

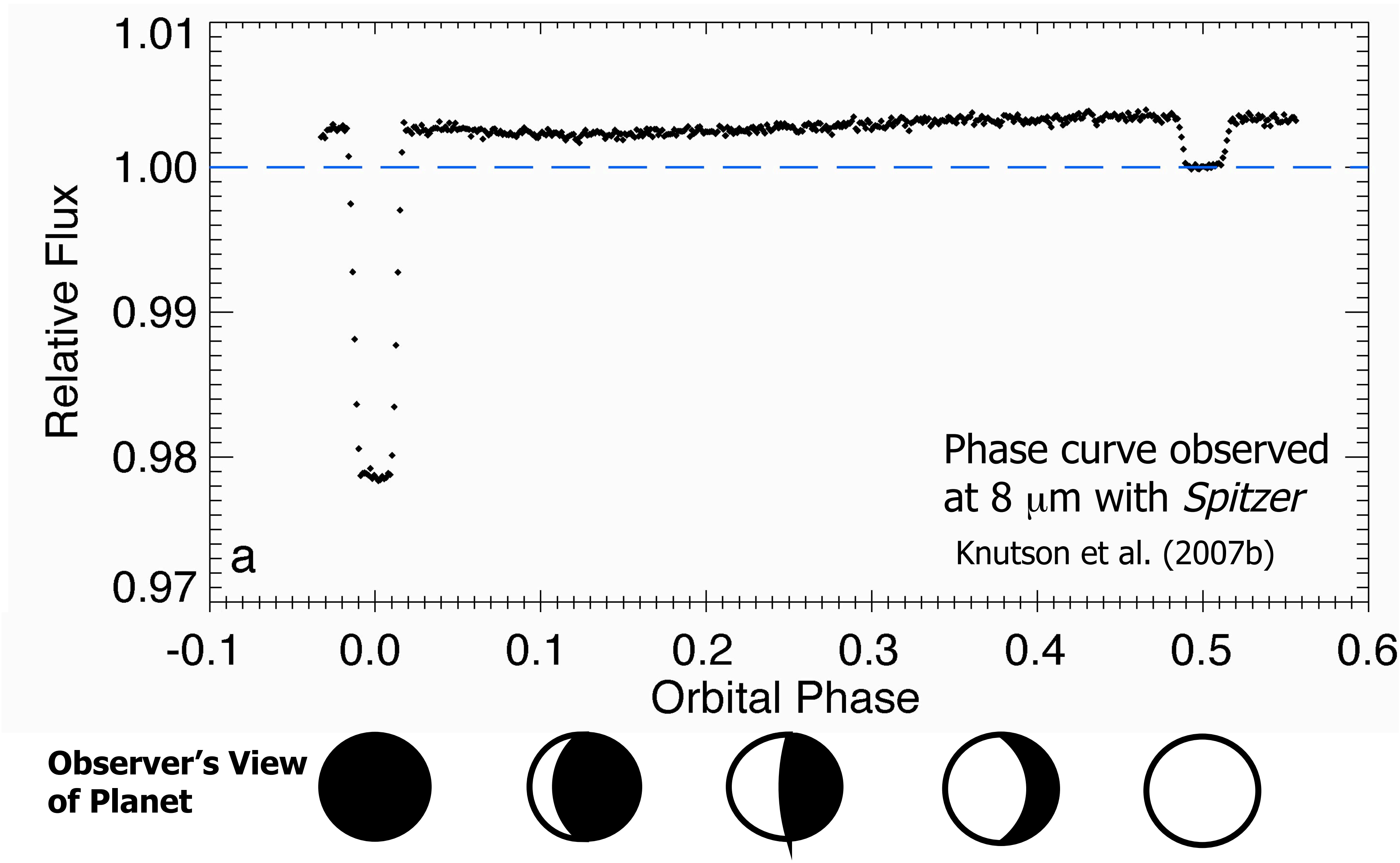
What does the atmospheric circulation look like?

Close-in exoplanets should be **tidally locked**, may have large thermal and/or chemical gradients between the two hemispheres.

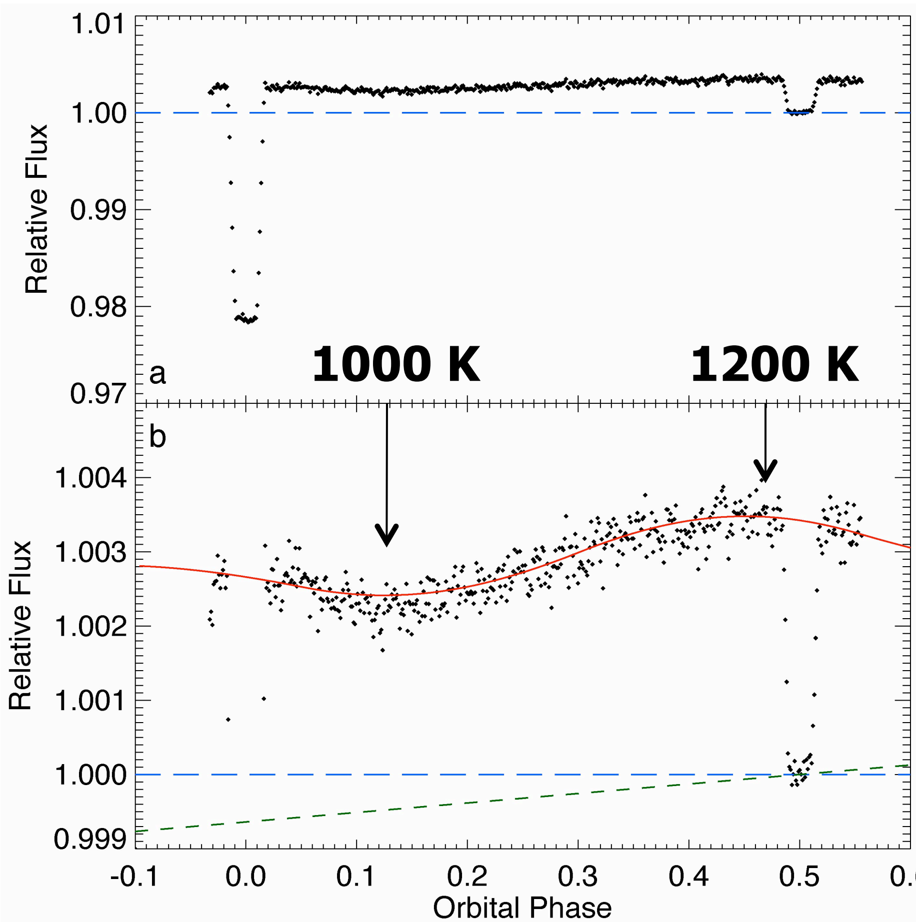
Planet's slow rotation means that the circulation should be **global in scale** (few broad jets, large vortices).

Image credit: ESA/C. Carreau

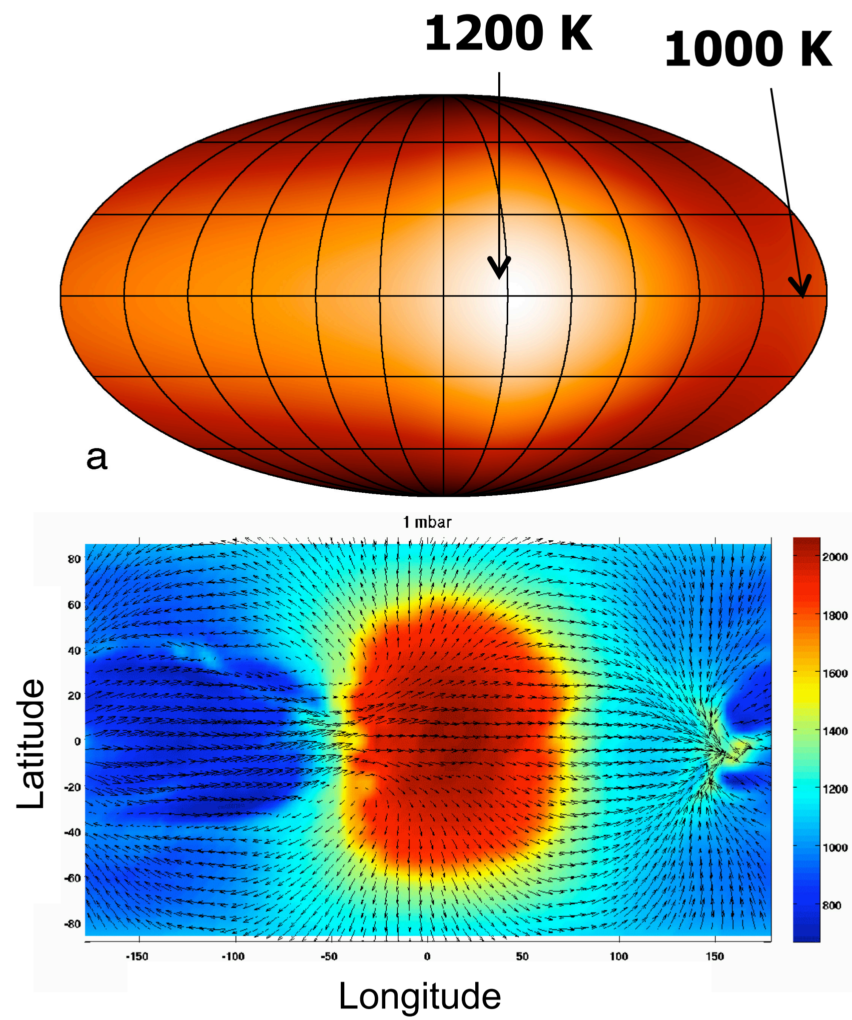
As the World Turns:
HD 189733b Over Half an Orbit



First Longitudinal Temperature Profile for an Exoplanet: HD 189733b's Hot Night Side

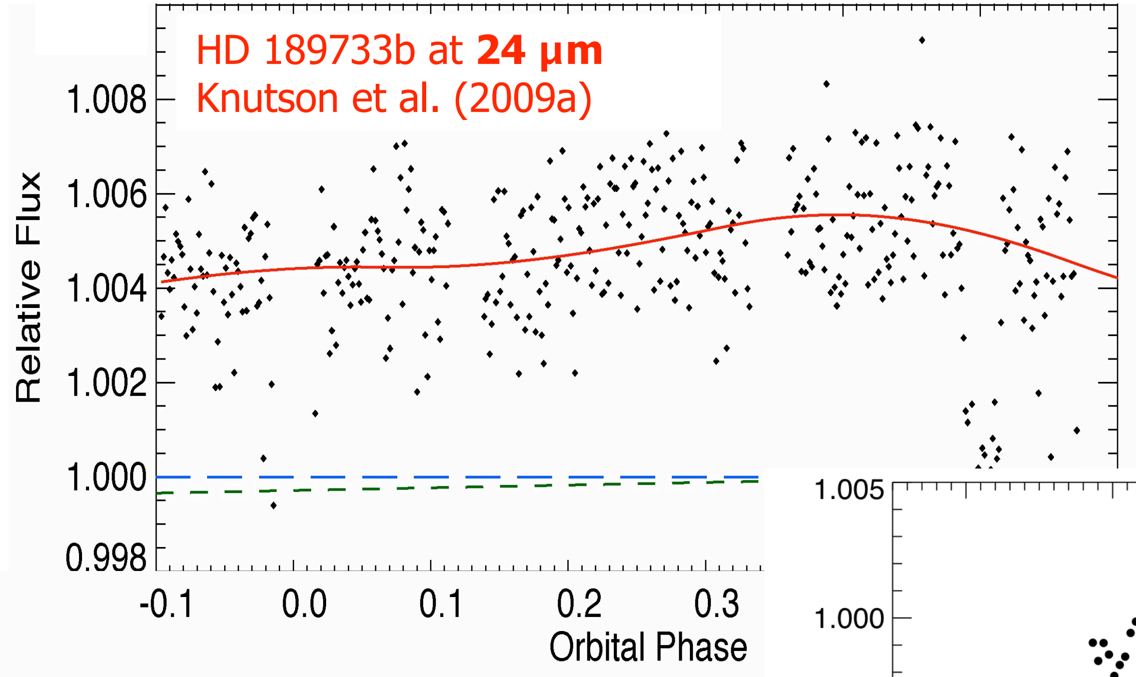


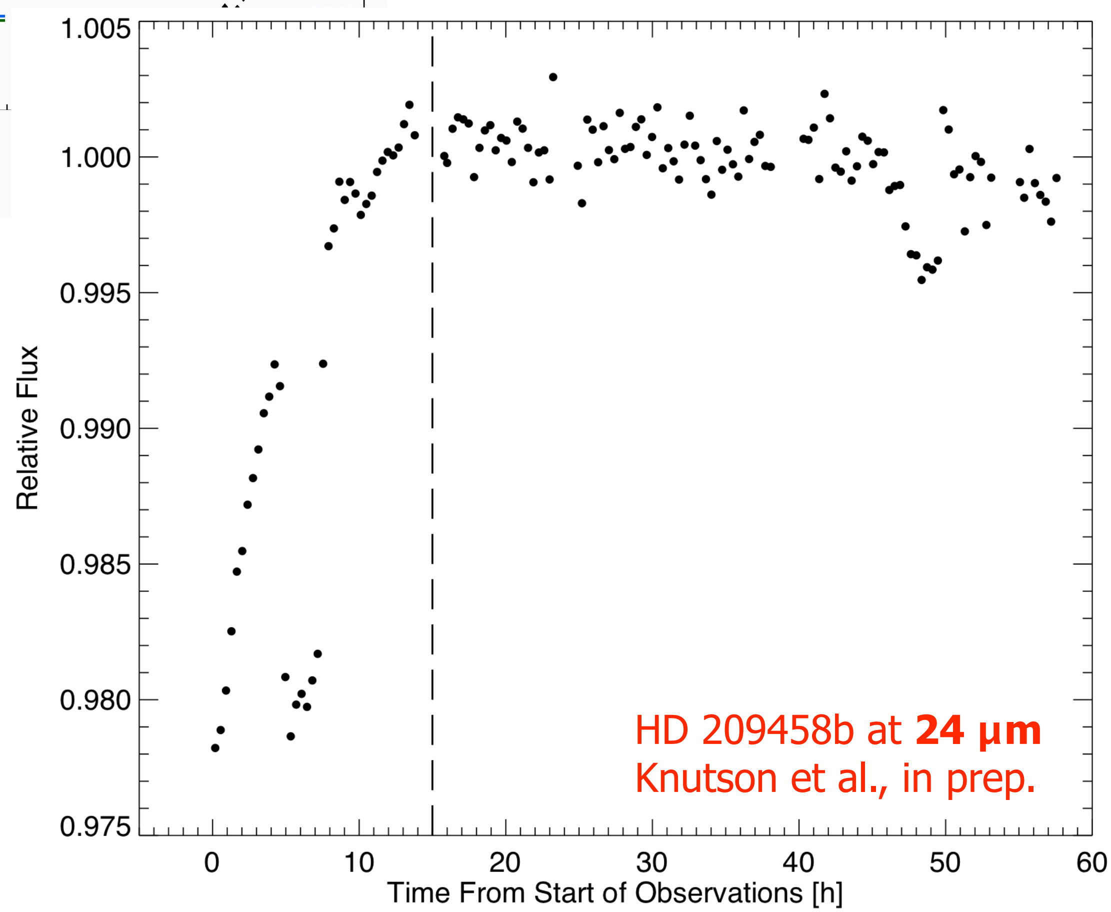
Spitzer 8 µm observations of HD 189733b
(Knutson et al. 2007b)



Circulation model for HD 189733b
(Showman et al. 2009)

NEW: A 24 µm Phase Curve for HD 209458b

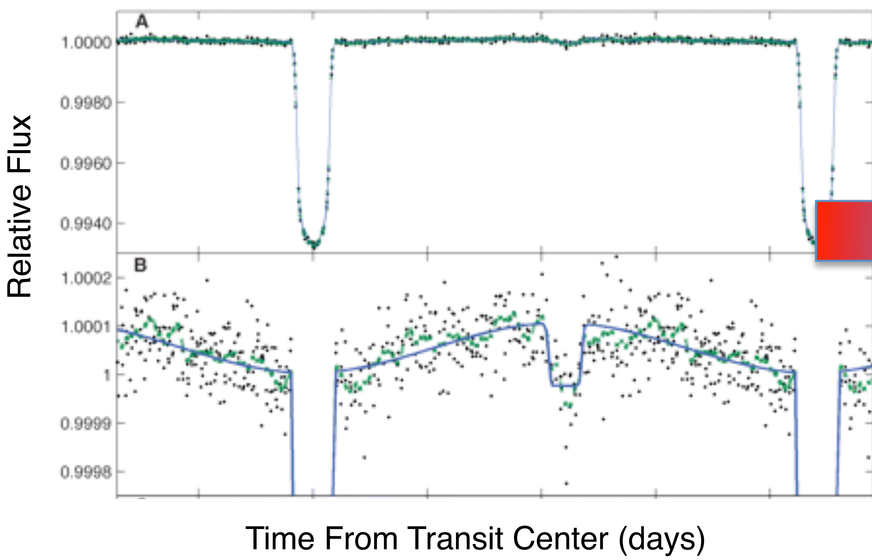




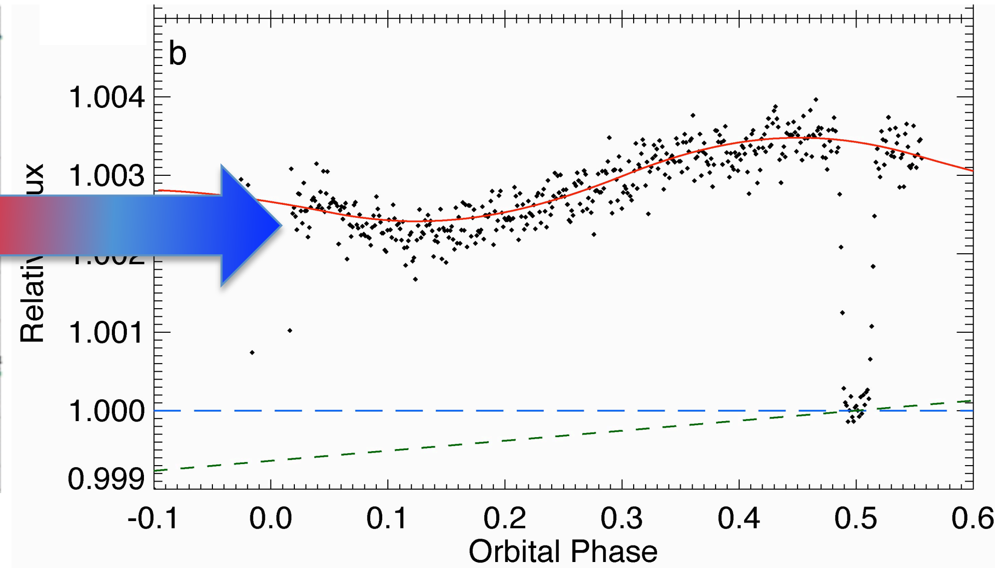
Both HD 189733b and HD 209458b have warm night sides.

Evidence for a Diversity of Day-Night Circulation Patterns

Large day-night brightness gradient
HAT-P-7 / Kepler



Small day-night brightness gradient
HD 189733b / Spitzer



Large gradients:

u And b* (Harrington et al. 2006)

HD 179949* (Cowan et al. 2007)

HAT-P-7 (Borucki et al. 2009)

* non-transiting planet, brightness/ temperature gradient degenerate with unknown orbital inclination and planet radius

Intermediate gradients:

HD 149026 (Knutson et al. 2009c)

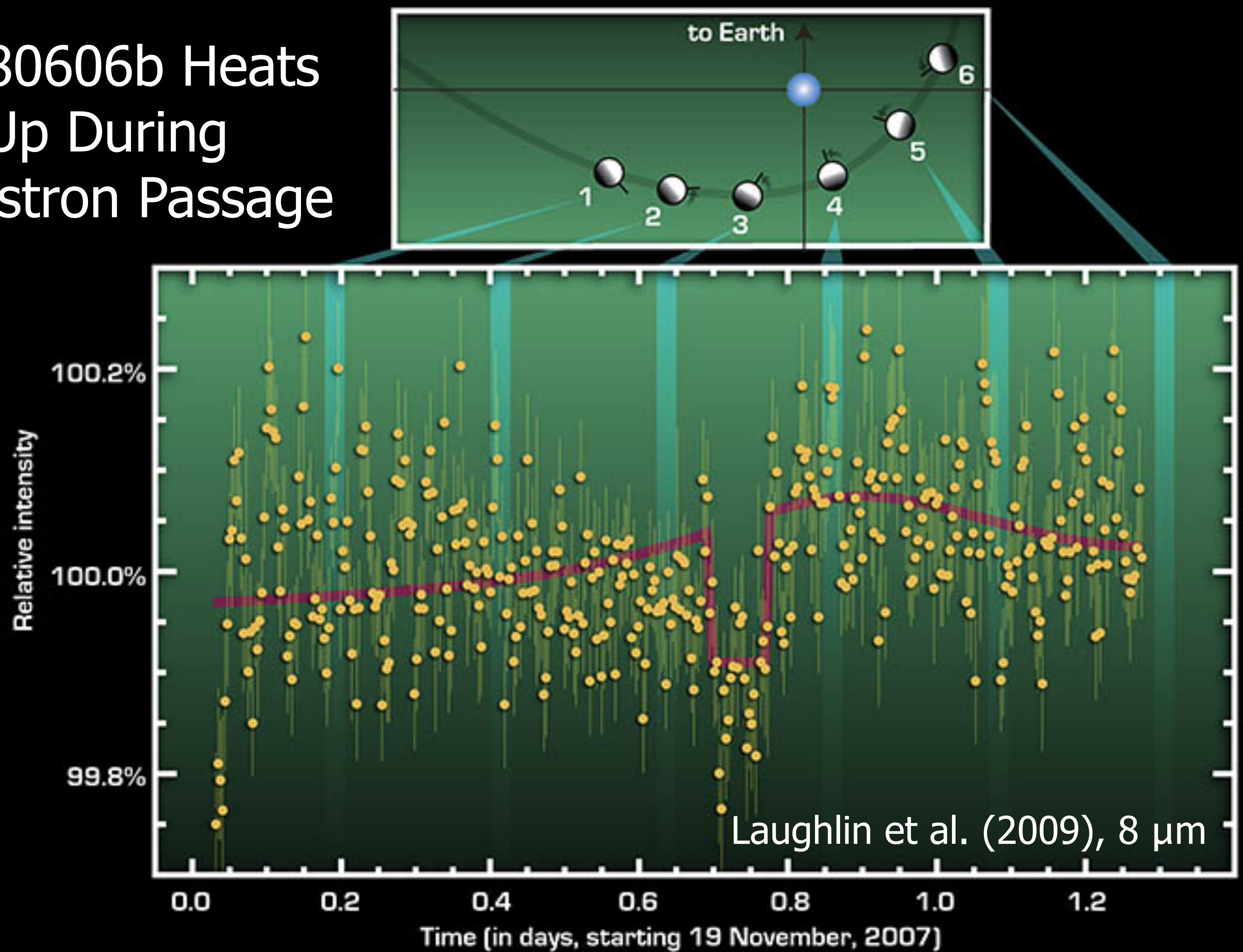
Small gradients:

HD 189733b (Knutson et al. 2007, 2009a)

HD 209458 (Cowan et al. 2007, Knutson et al.2010, in prep.)

What causes these diverse behaviors?

HD 80606b Heats Up During Periastron Passage



Spitzer will obtain phase curves for several more eccentric planets (HAT-P-2, HD 17156, XO-3) during the warm mission.

The need for multi-wavelength observations:

Planets are not blackbodies (and we shouldn't treat them that way).

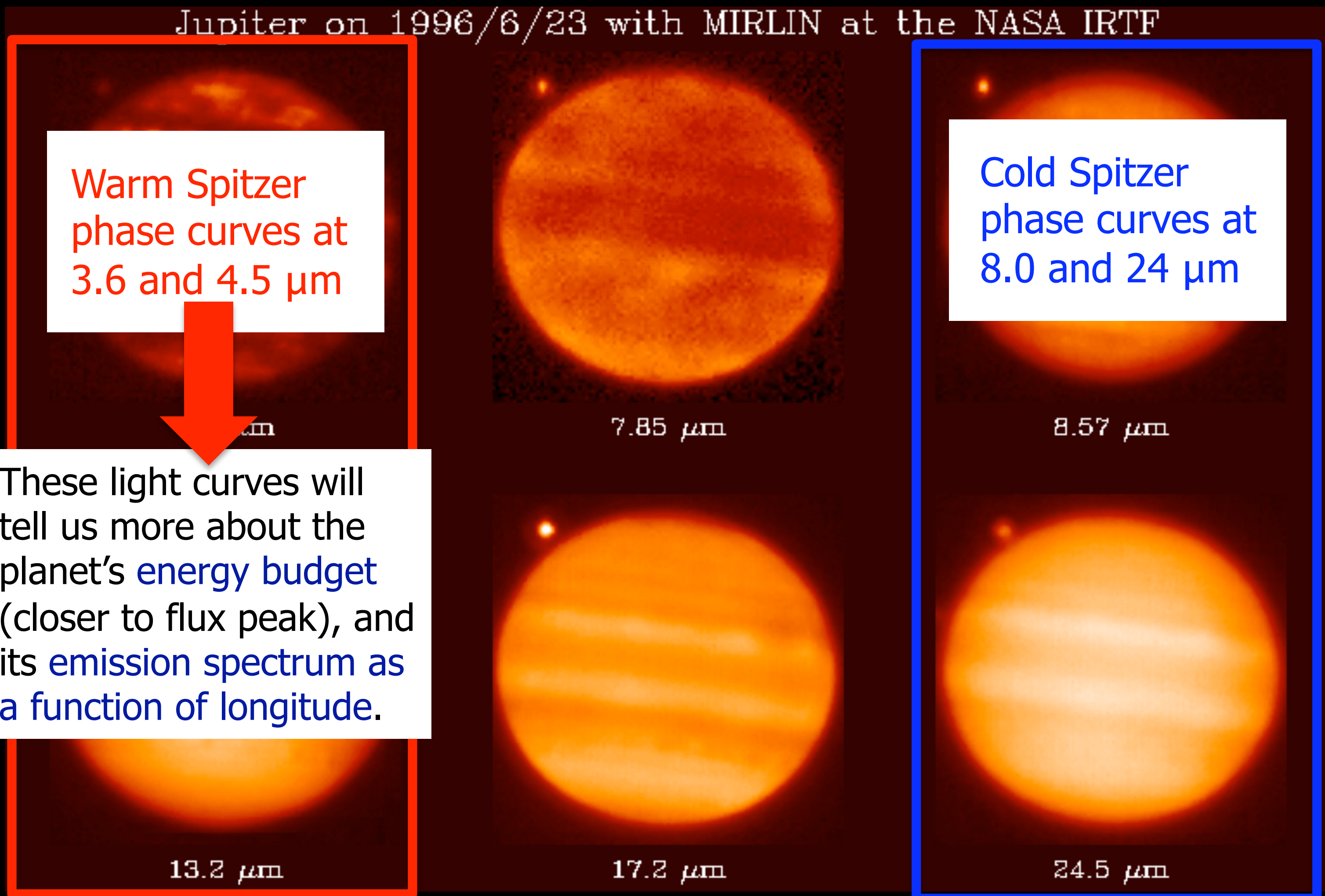
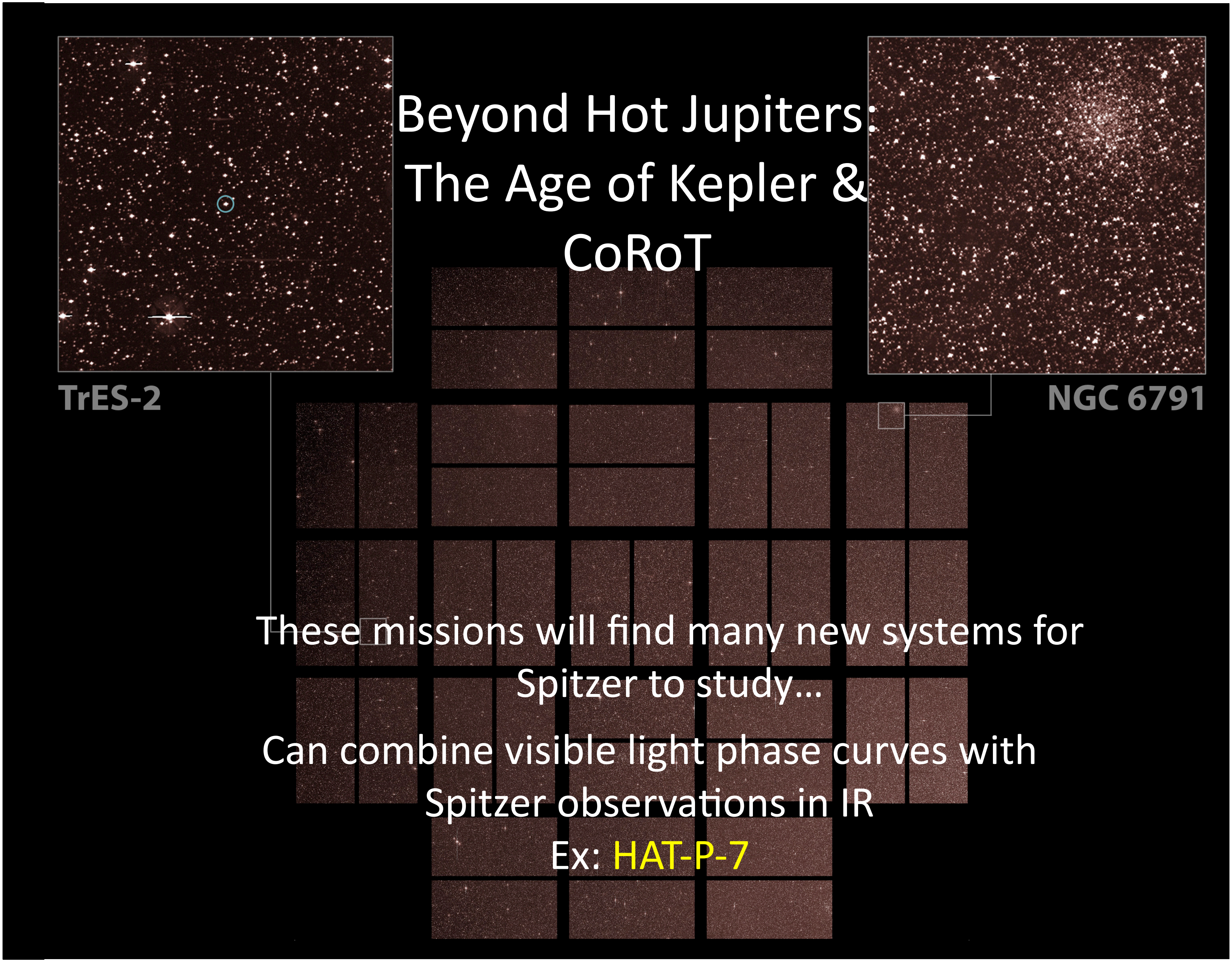


Image credit G. Orton

Will have full-orbit, multi-wavelength phase curves for five planets spanning 3.6-24 μm (up to four bands per planet, 1138 hours, PI H. Knutson) by end of 2011.

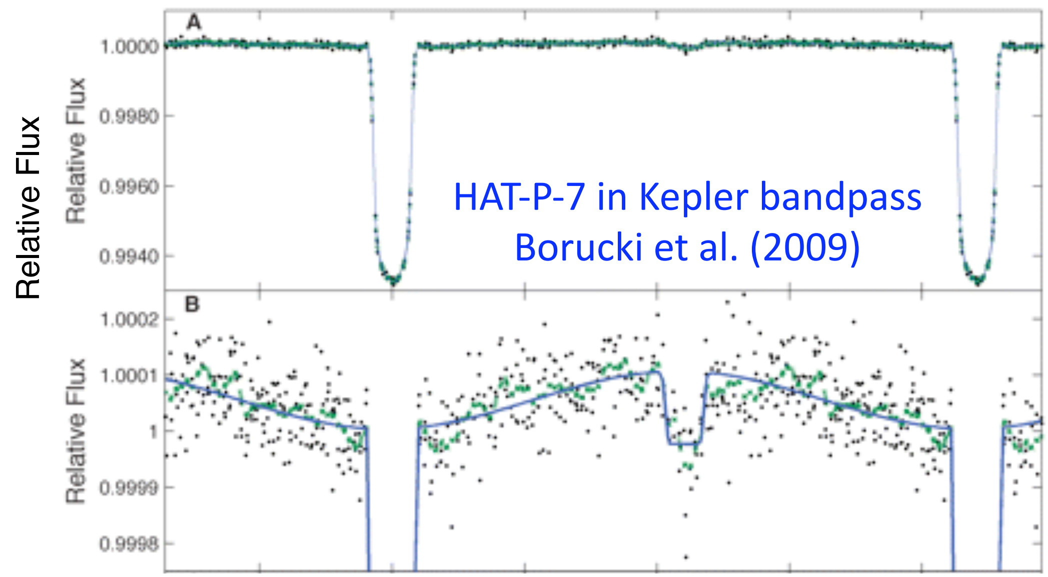
Beyond Hot Jupiters: The Age of Kepler & CoRoT

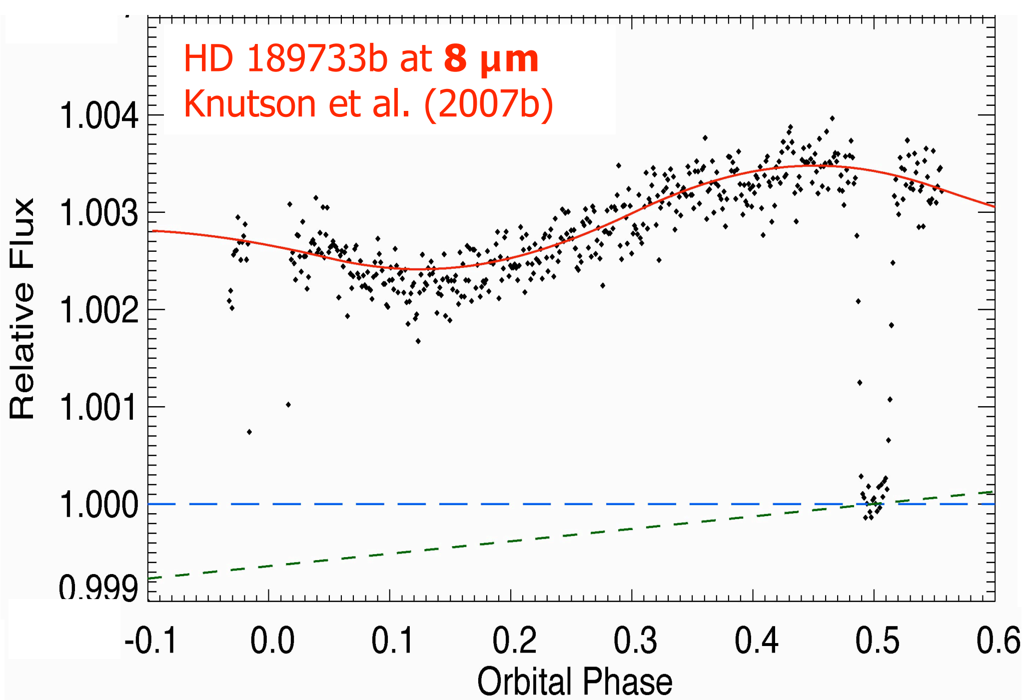


These missions will find many new systems for Spitzer to study…

Can combine visible light phase curves with Spitzer observations in IR

Ex: HAT-P-7





The Power of Combined Kepler/CoRoT + Spitzer Observations

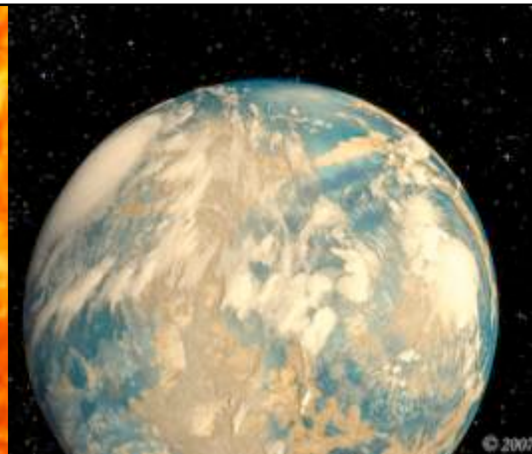
Reflected

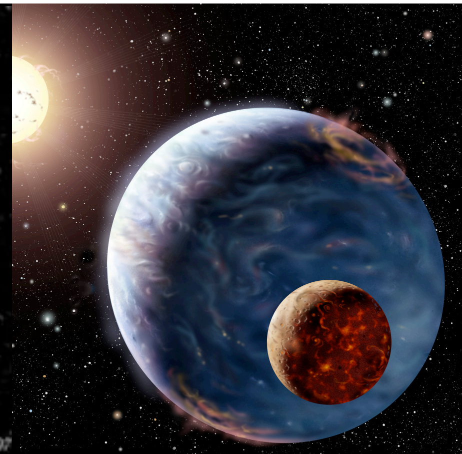
+

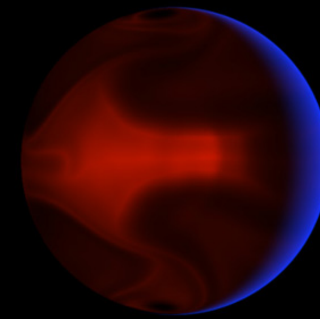
Thermal*

= Albedo

*Will only have IR secondary eclipse data (including some JHK from ground-based obs.) for a majority of systems.

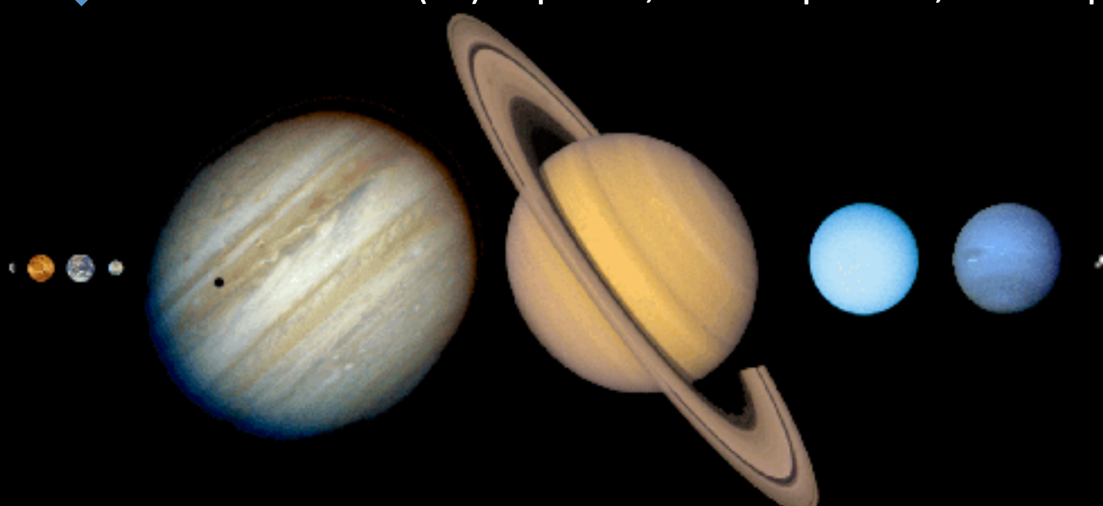






The future is now:

1. Studies of hot Jupiters are transitioning from an exploration phase to a survey phase with the goal of explaining the observed diversity in their properties.
2. These same techniques will soon be applied to a much wider range of planet types, including eccentric planets, cool(er) Jupiters, hot Neptunes, and superhot Super-Earths.



Warm Spitzer will be at the forefront of both areas

>2600 total hours of exoplanet observing time