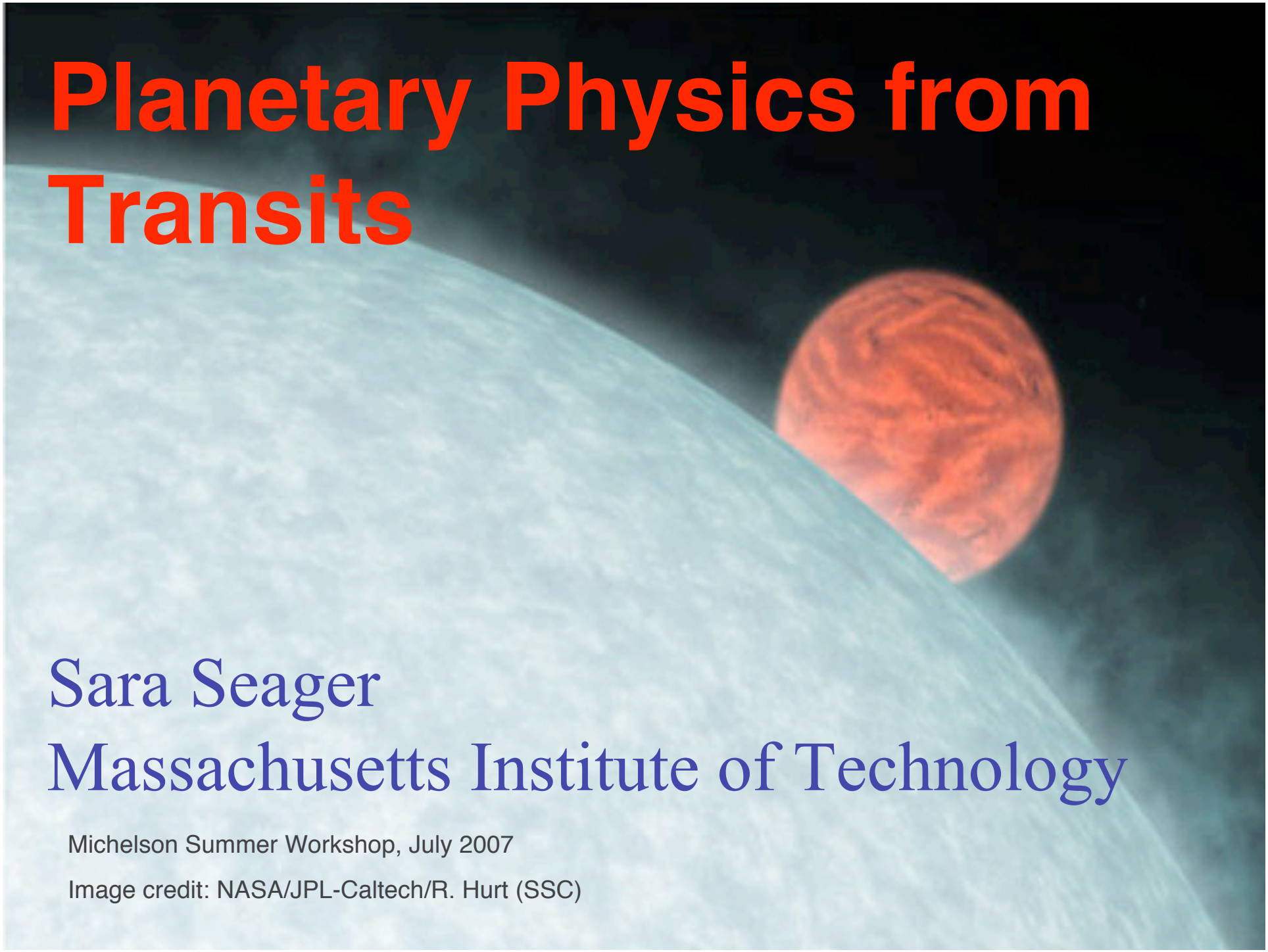
Planetary Physics from Transits

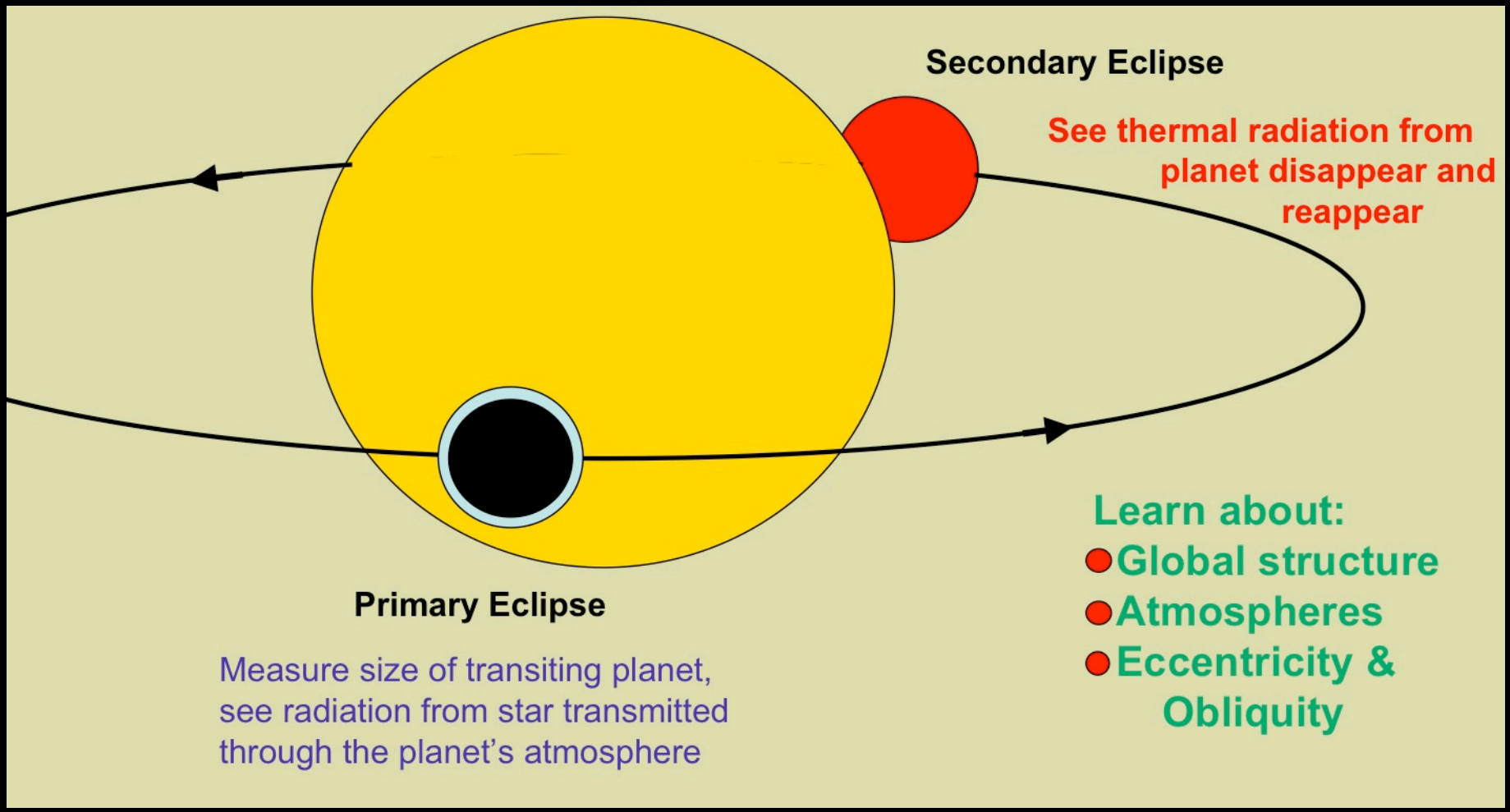


Sara Seager
Massachusetts Institute of Technology

Michelson Summer Workshop, July 2007

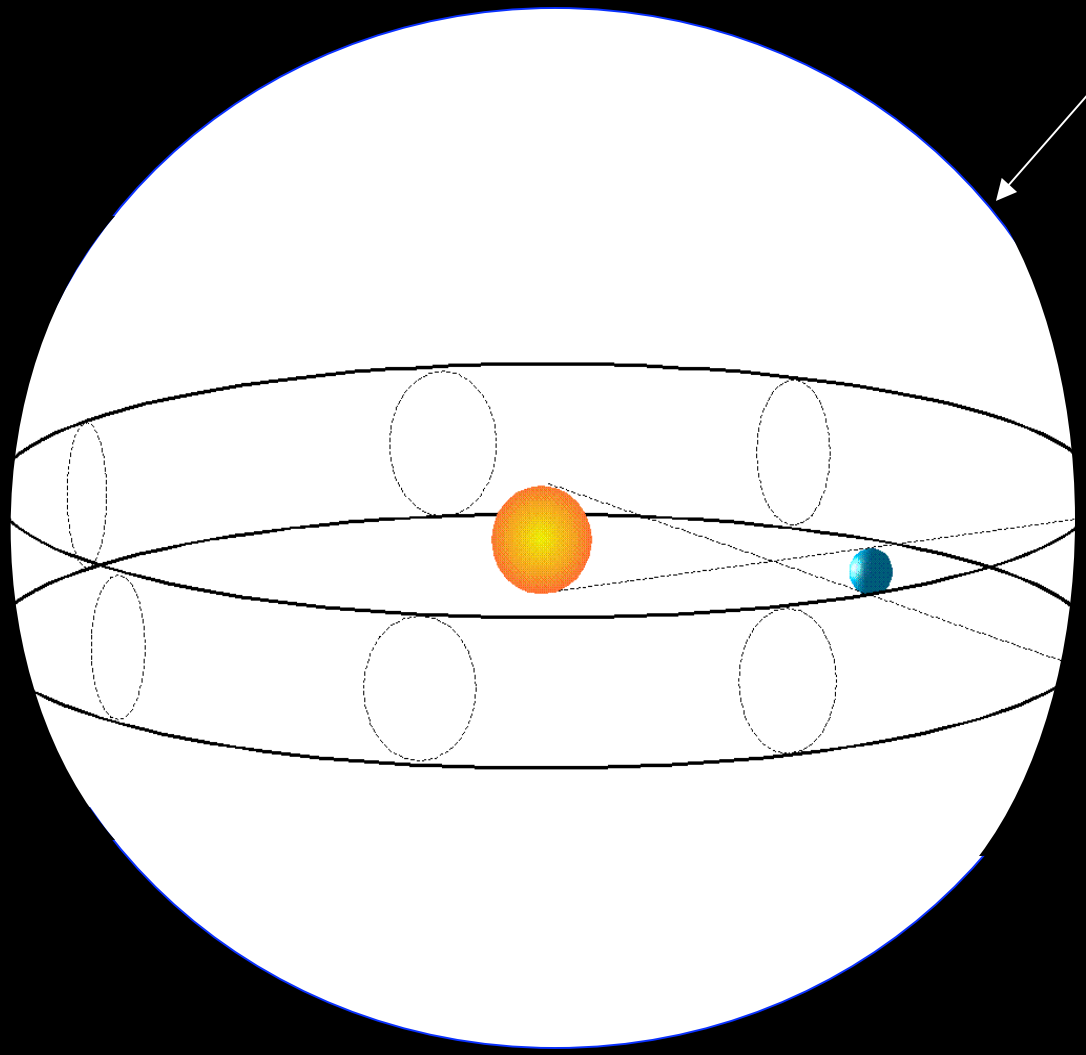
Image credit: NASA/JPL-Caltech/R. Hurt (SSC)

Transiting Planet Science



Courtesy T. Brown

Geometric Transit Probability



Loser

P ~ (R_*/a)

Winner

P(0.05 AU) = 10%

P(1 AU) = 0.5%

P(5 AU) = 0.1 %

All known transiting planets have P < a few days

Physics from Transits

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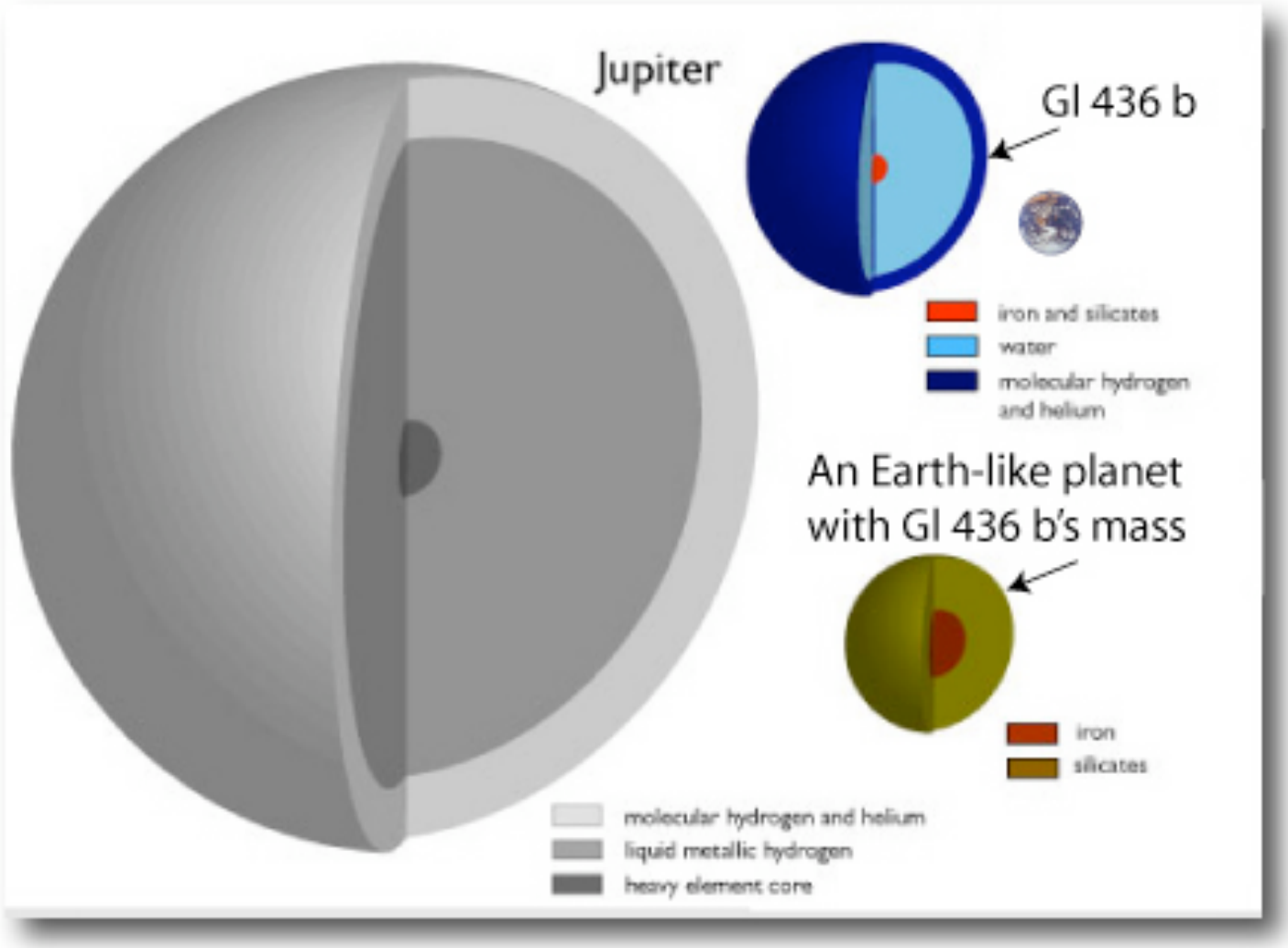
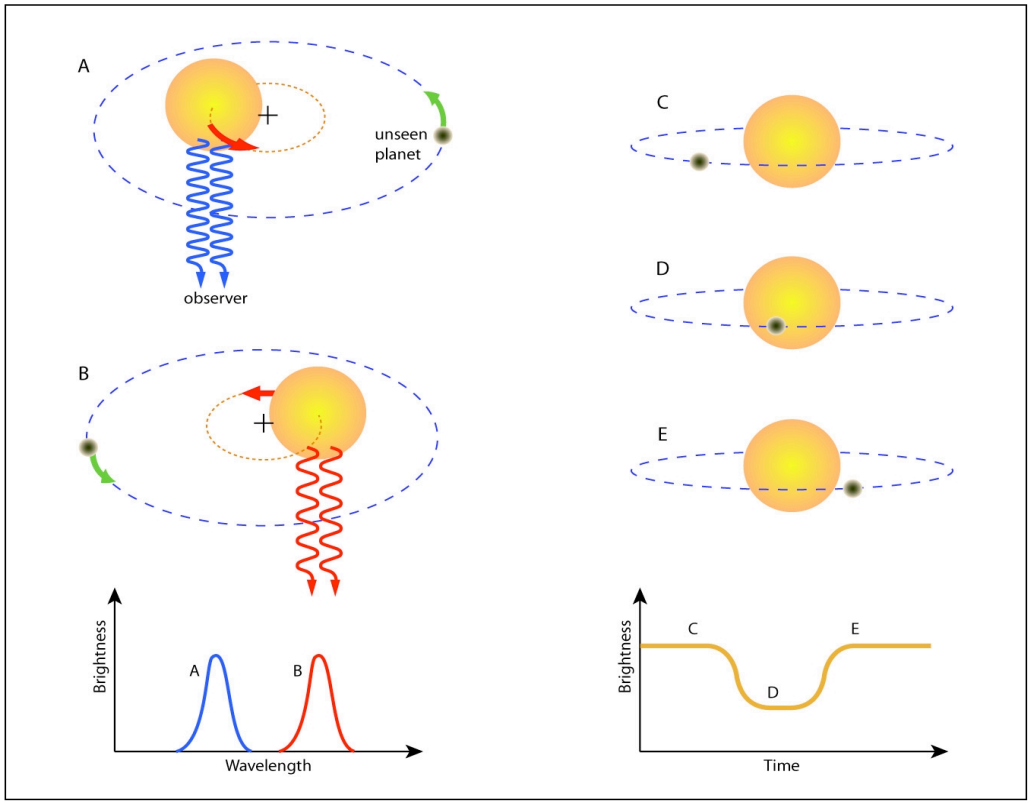
Interior Composition



Courtesy G. Laughlin

Exoplanet Mass and Radius

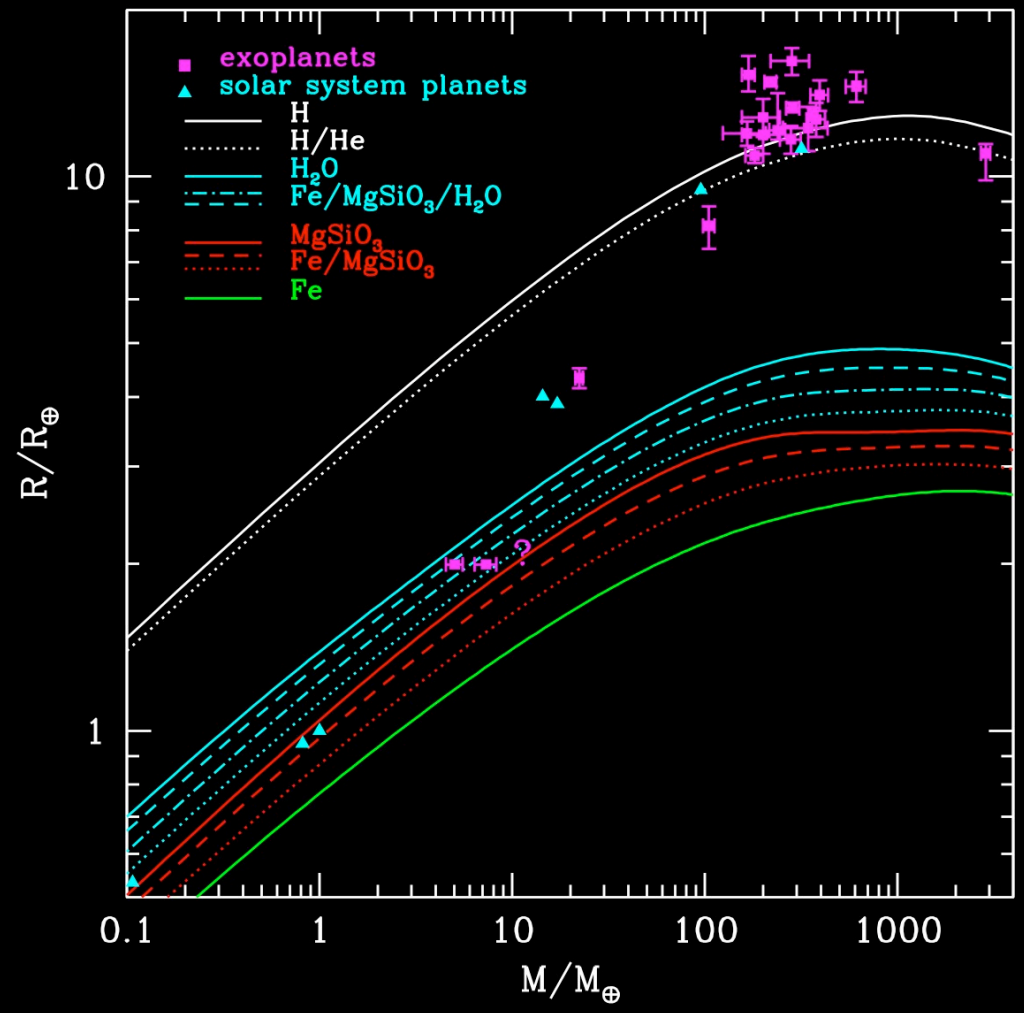


Doppler Method Transit Method

$$g_P = \frac{2\pi}{P} K_* \left[\frac{a}{R_*}\right]^2 \frac{1}{\sin i}$$

Seager and Mallen-Ornelas 2003
Southwick et al. 2007
Sozzetti et al. 2007

Exoplanet Mass-Radius Relations

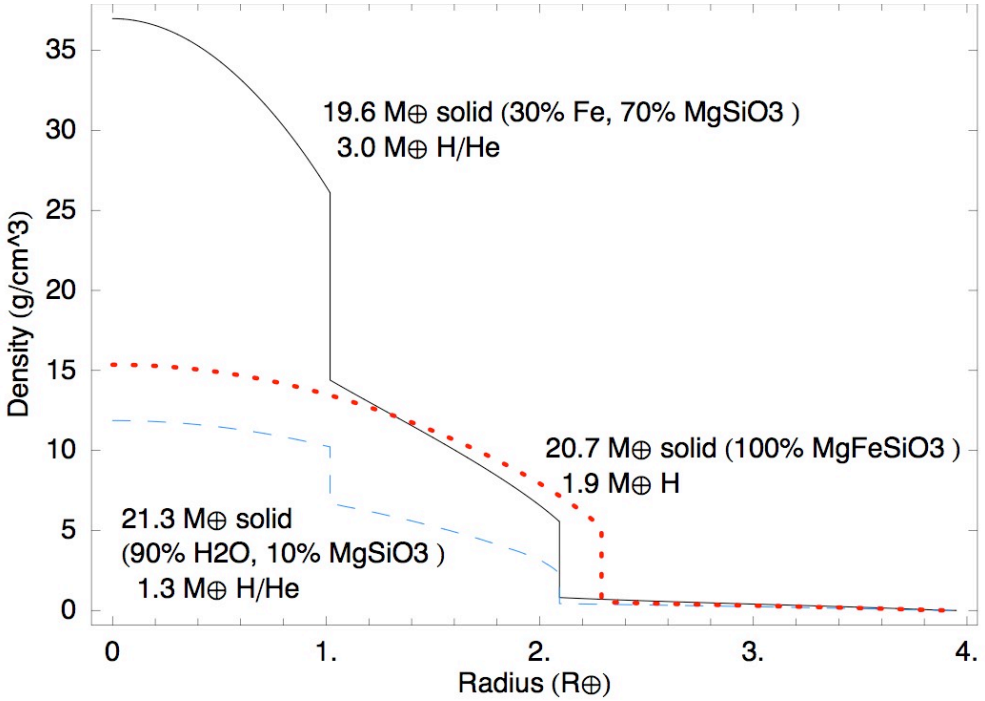


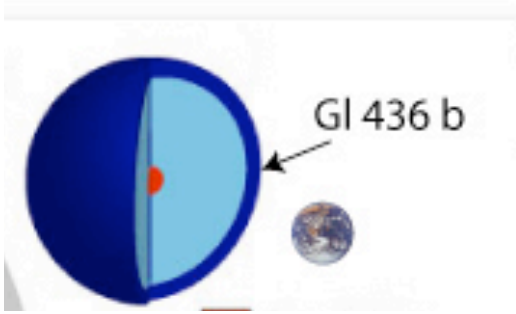
Seager, Kuchner, Hier-Majumder, Militzer ApJ, 2007

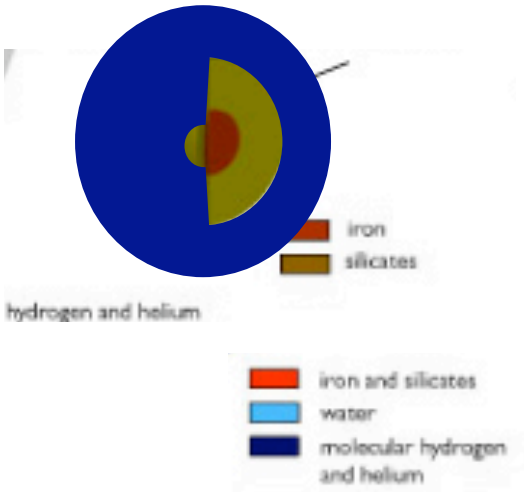
Zapolsky and Salpeter 1969
See also: Stevenson 1985, Valencia et al. 2006ab, 2007; Fortney et al. 2007; Sotin et al. 2007

We infer an exoplanet's bulk composition from its M and R

GJ 436b







GJ436b 4.33 +/- 0.18 $R_{\oplus}$

Deming et al. submitted to ApJL

See also Gillon et al.astro-ph

GJ436b may be a water planet with ~10% H/He, or it may be an iron/silicate planet with ~15% H/He, or something else.

Elisabeth Adams, Seager, Elkins-Tanton, submitted to ApJL

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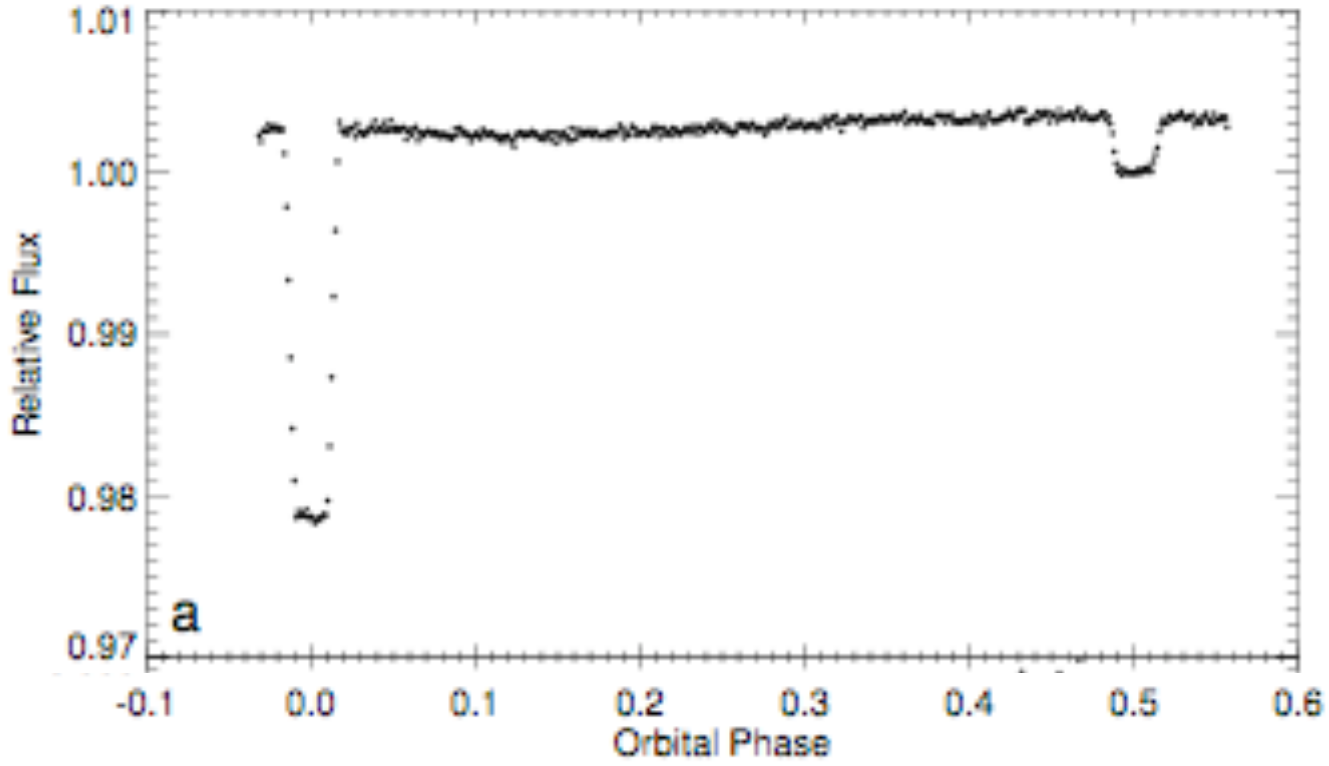
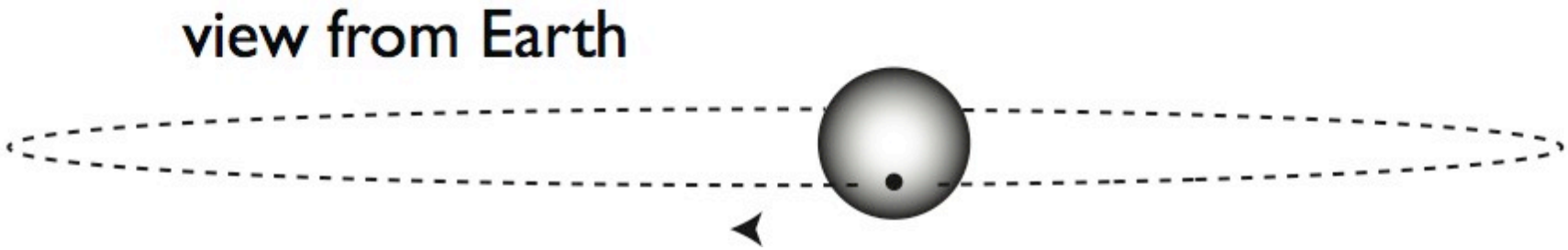
Primary and Secondary Eclipse



HD189733 phase curve
from Knutson et al. 2007

Eccentricity from Primary and Secondary Eclipse Times



GJ436b e = 0.16 +\- 0.012

Deming et al. submitted to ApJL

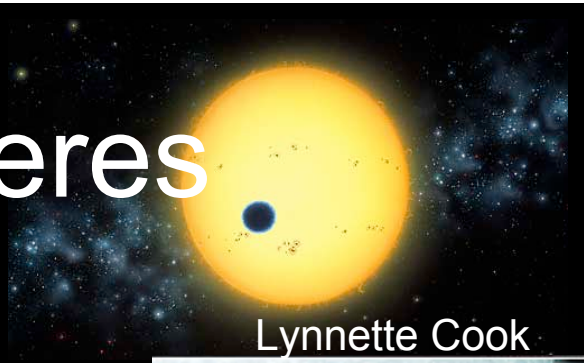
Figure courtesy G. Laughlin

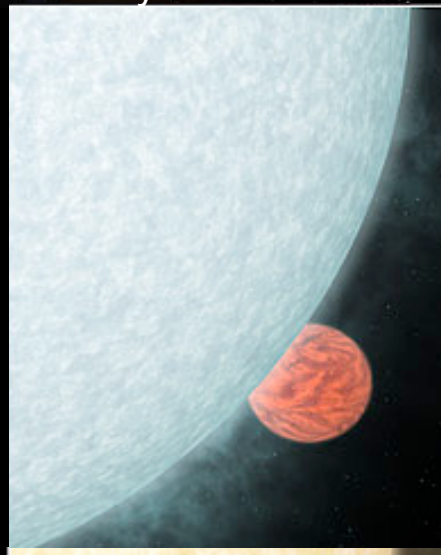
Transit Planet Atmospheres

- Transit $[R_p/R_*]^2 \sim 10^{-2}$
  - Transit radius -> density
- Thermal Emission $T_p/T_*(R_p/R_*)^2 \sim 10^{-3}$
  - Emitting atmosphere $\tau \sim 2/3$
  - Temperature and ∇T
  - Thermal phase curve
- Transmission Spectra $atm/R_*^2 \sim 10^{-4}$
  - Upper atmosphere
  - Exosphere (0.05-0.15)
- Reflection $p[R_p/a]^2 \sim 10^{-5}$
  - Albedo
  - Reflected light phase curve
  - Polarization
  - Scattering atmosphere

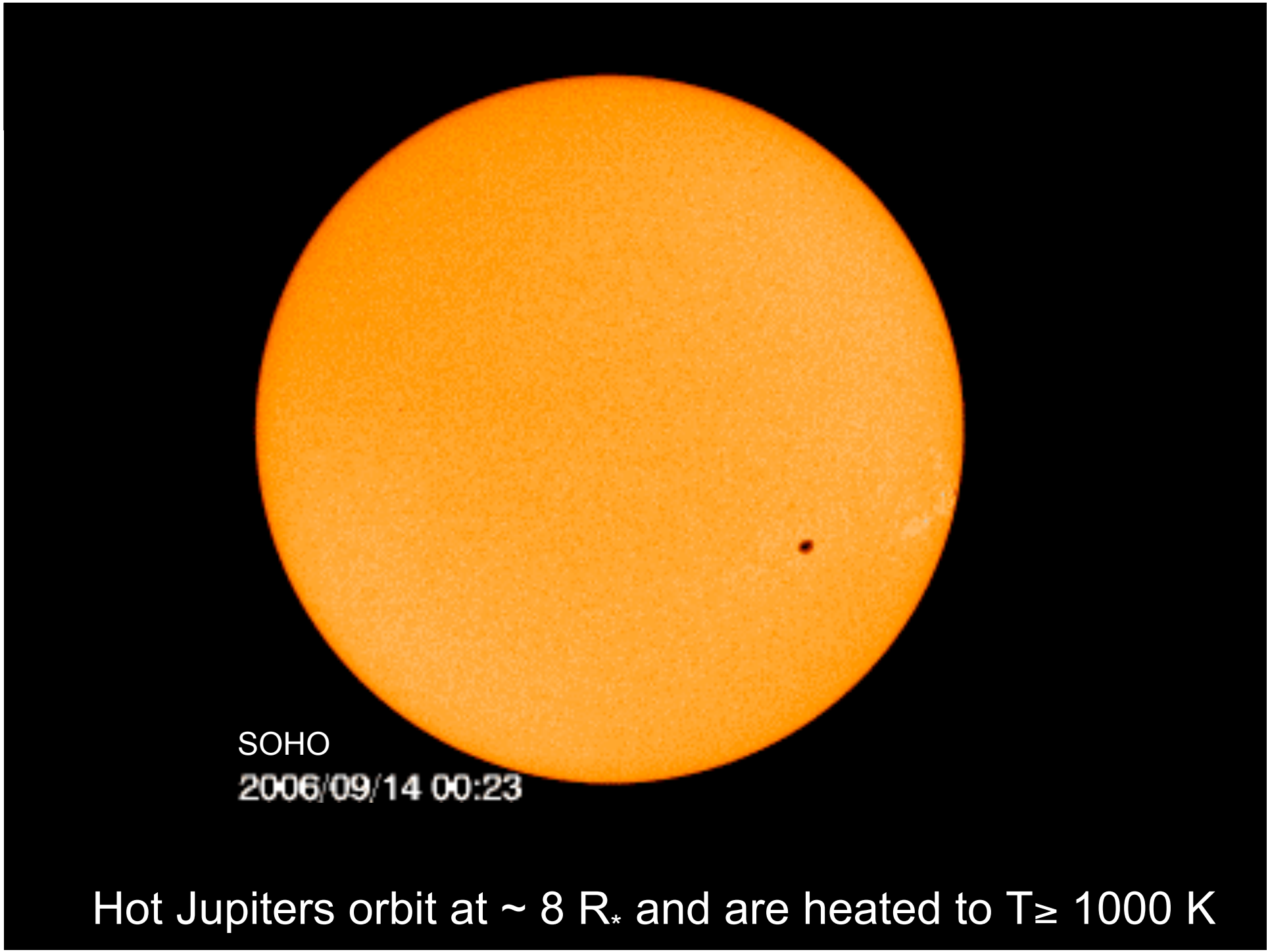
Each gives complementary information

Seager et al. 2005


Lynnette Cook

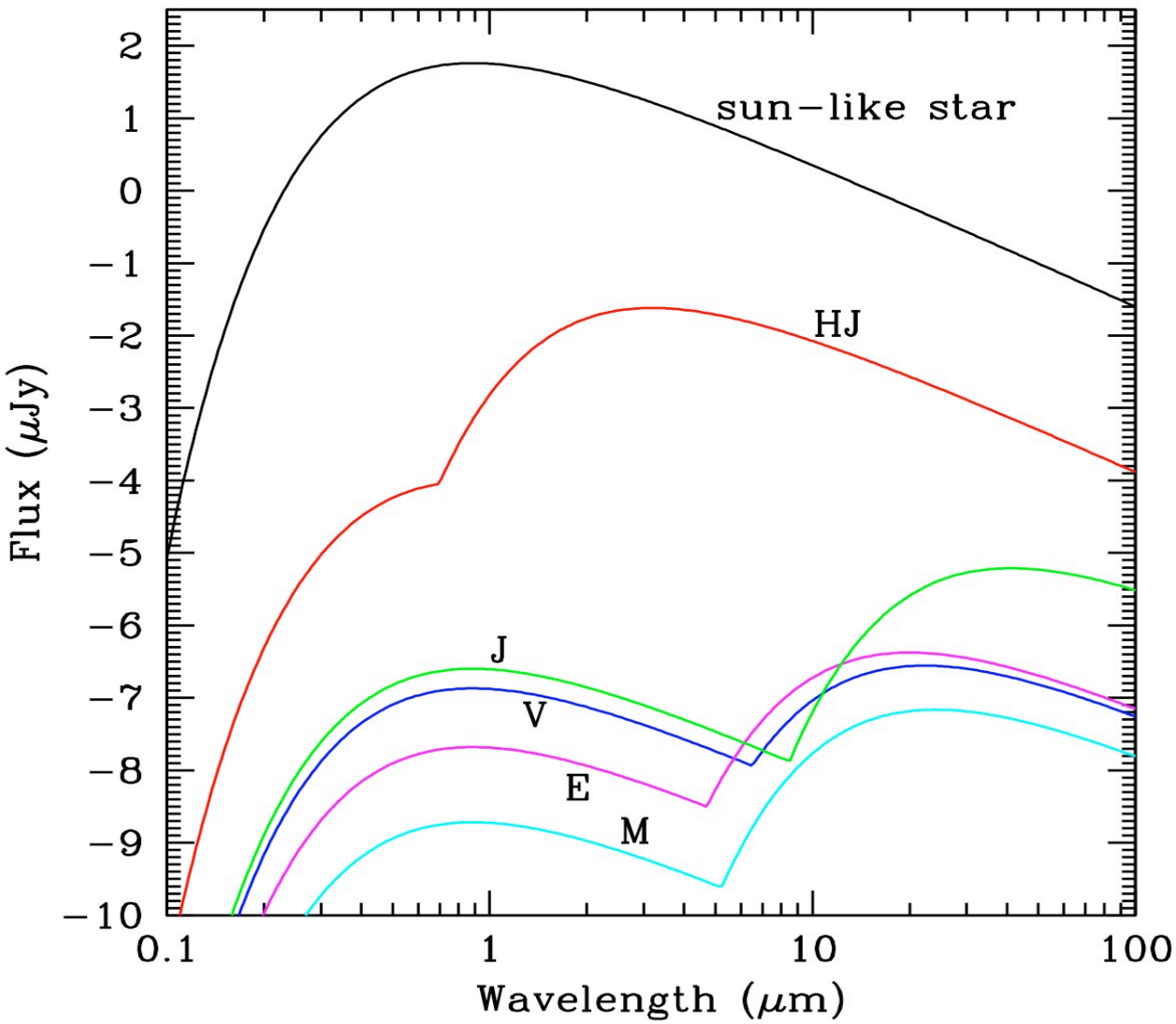



NASA/JPL-Caltech
R. Hurt (SSC)



Hot Jupiters orbit at ~ 8 R_* and are heated to T≥ 1000 K

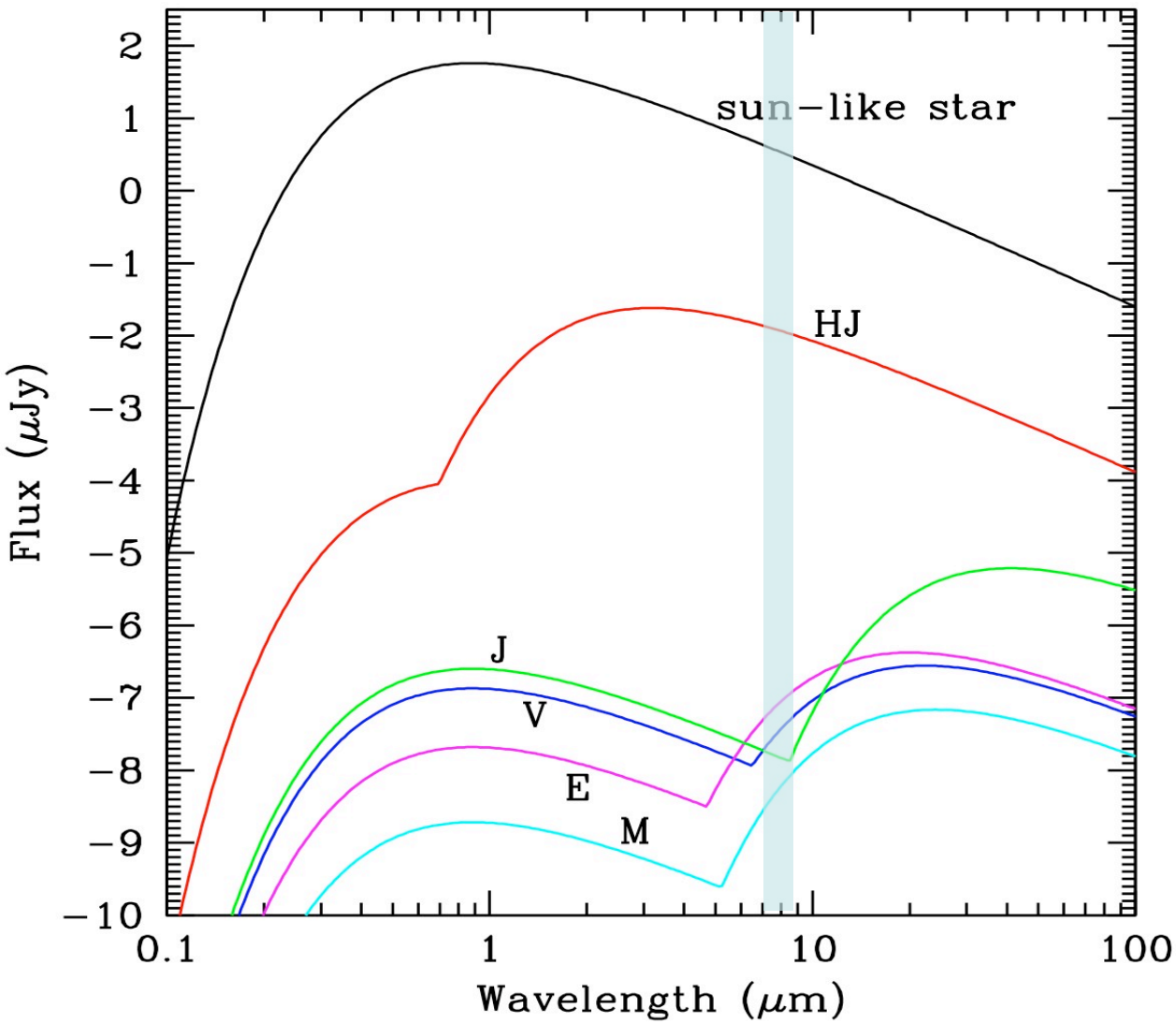
The Solar System at 10 Parsec



Planets have two flux peaks

Seager et al. 2003

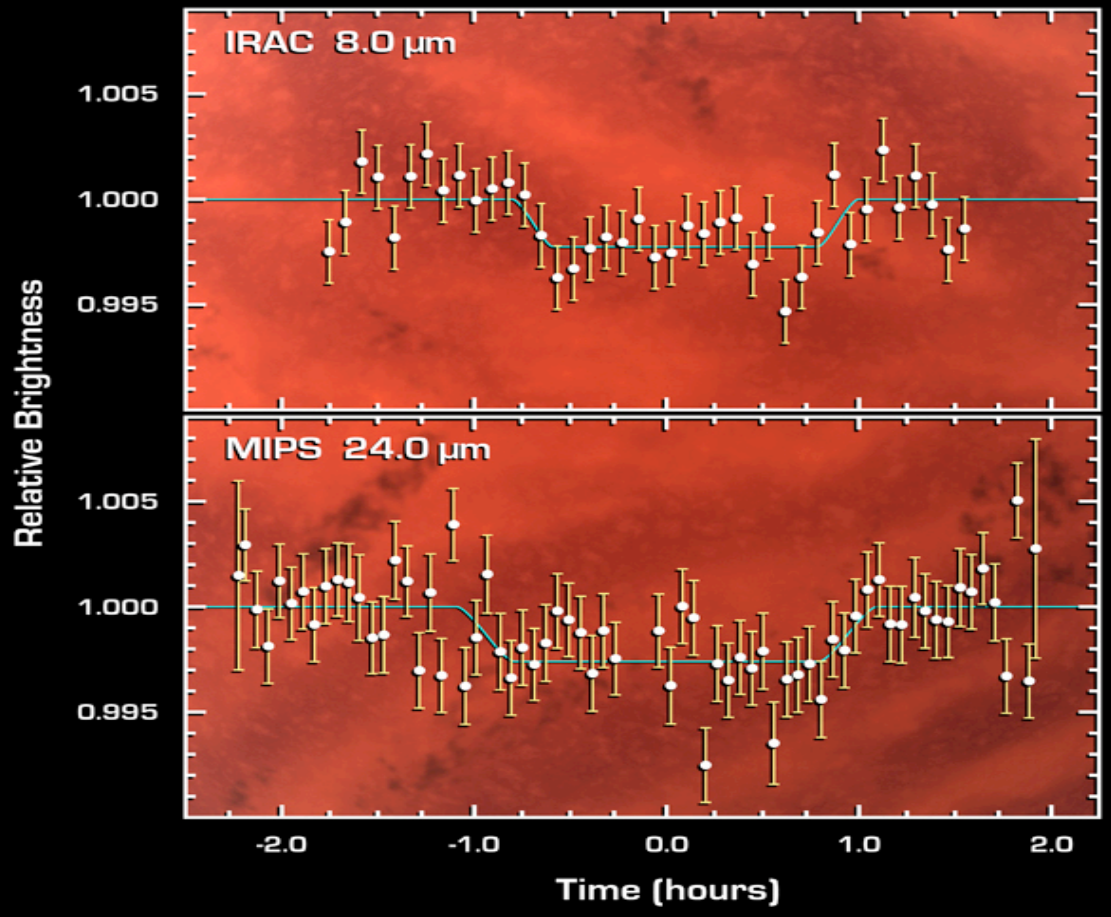
The Solar System at 10 Parsec



Planets have two flux peaks

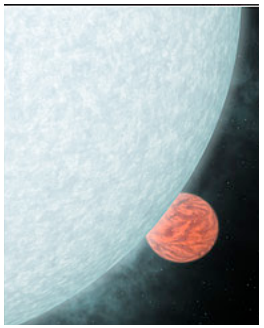
Seager et al. 2003

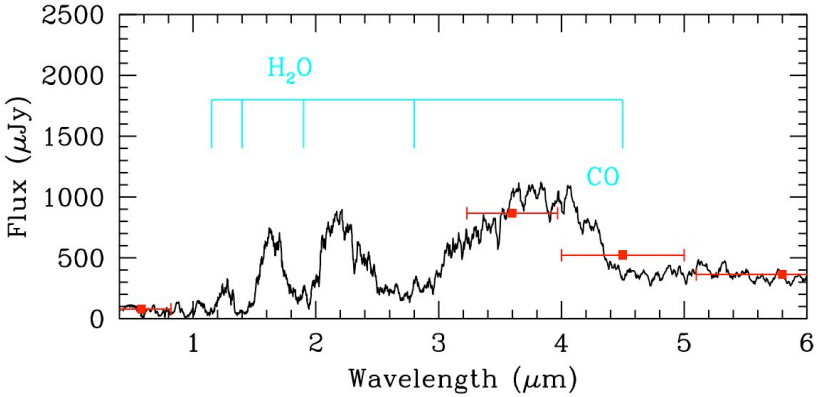
Secondary Eclipse

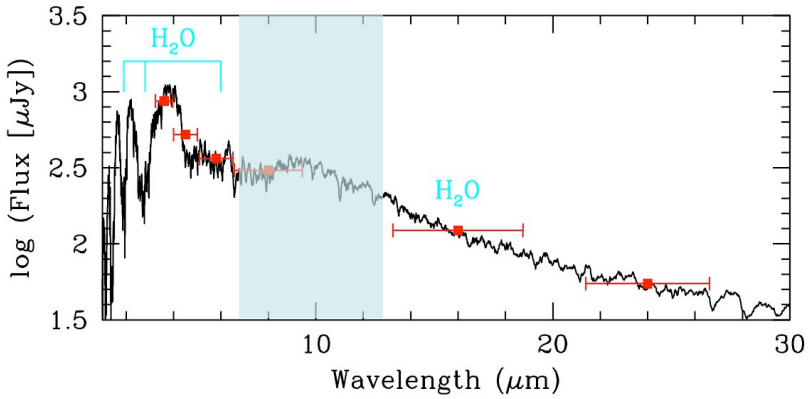


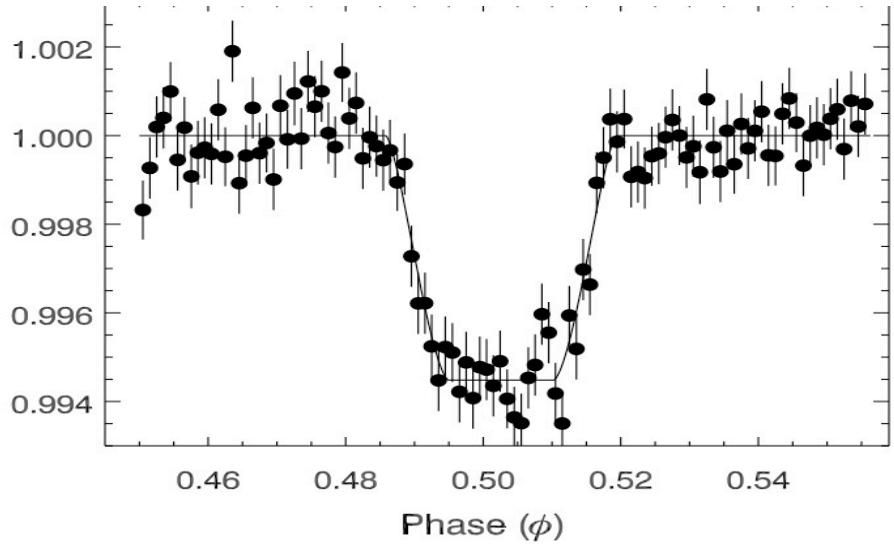
Charbonneau et al. 2005, Deming et al. 2005

Secondary Eclipse









HD189733 16 μm

Flux ratio = 0.551% ±0.030%

$T_p/T_*(R_p/R_*) \sim 5 \times 10^{-3}$

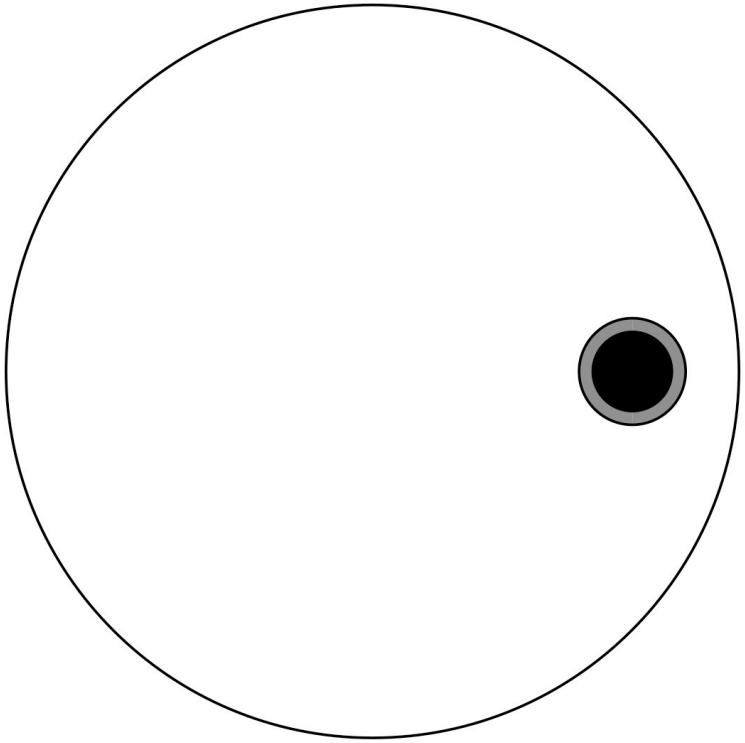
T_b = 1117+/-42 K

Deming, Harrington, Seager, Richardson 2006

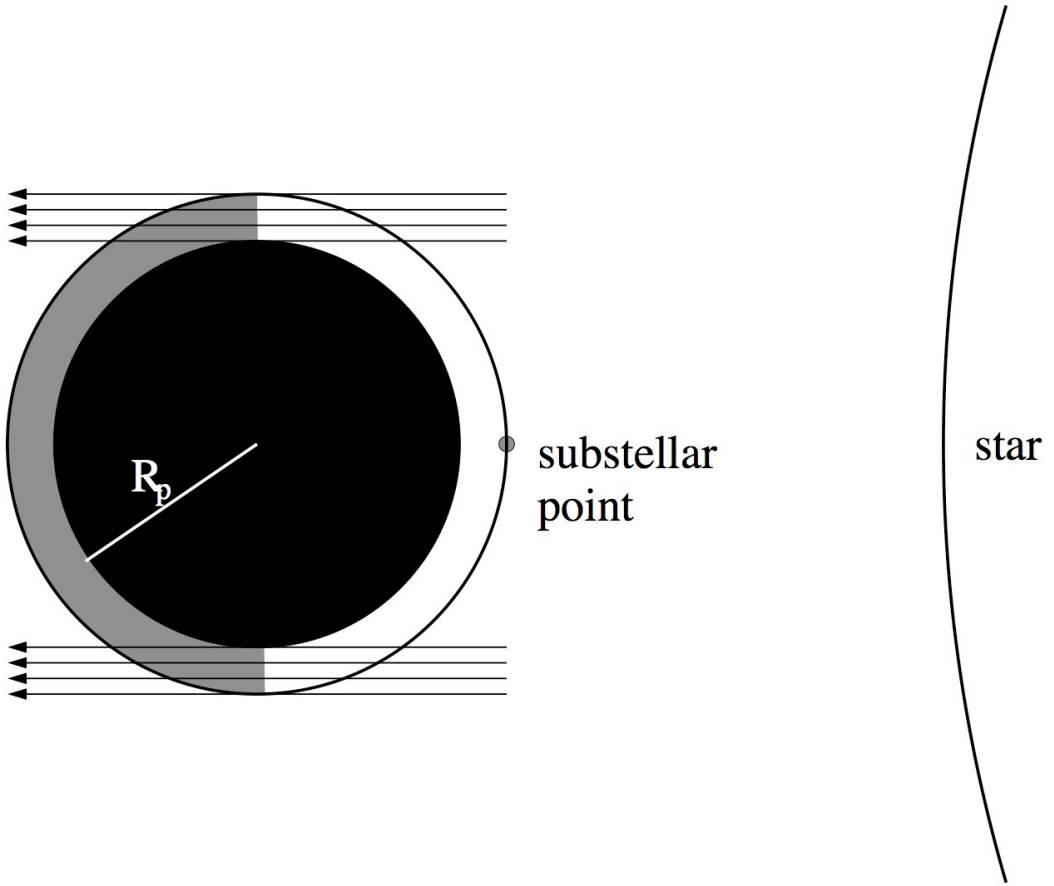
Seager et al. 2005

Four different hot Jupiters have published Spitzer secondary eclipses. All can be fit with black body spectra!

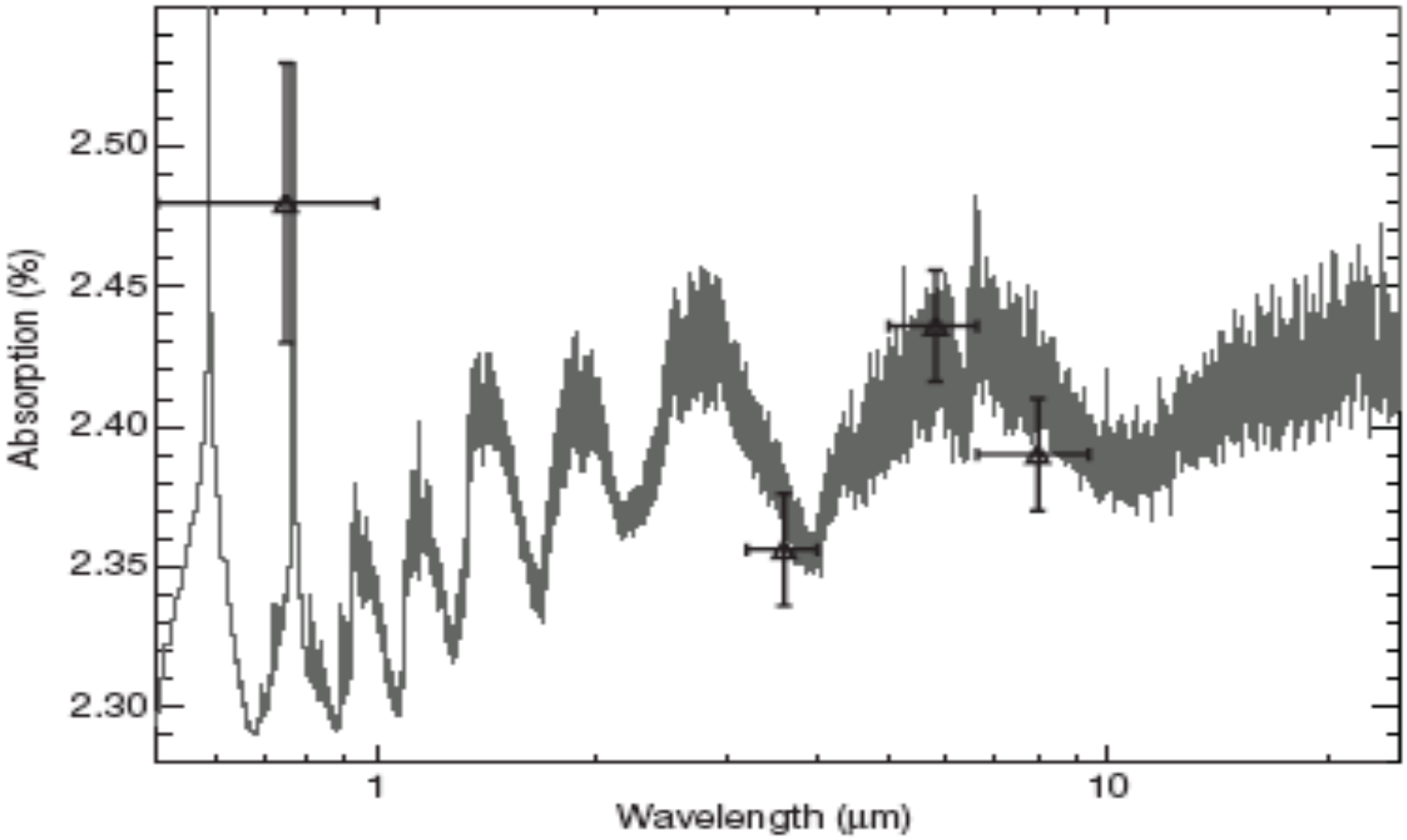
Transmission Spectra



Transmission Spectra



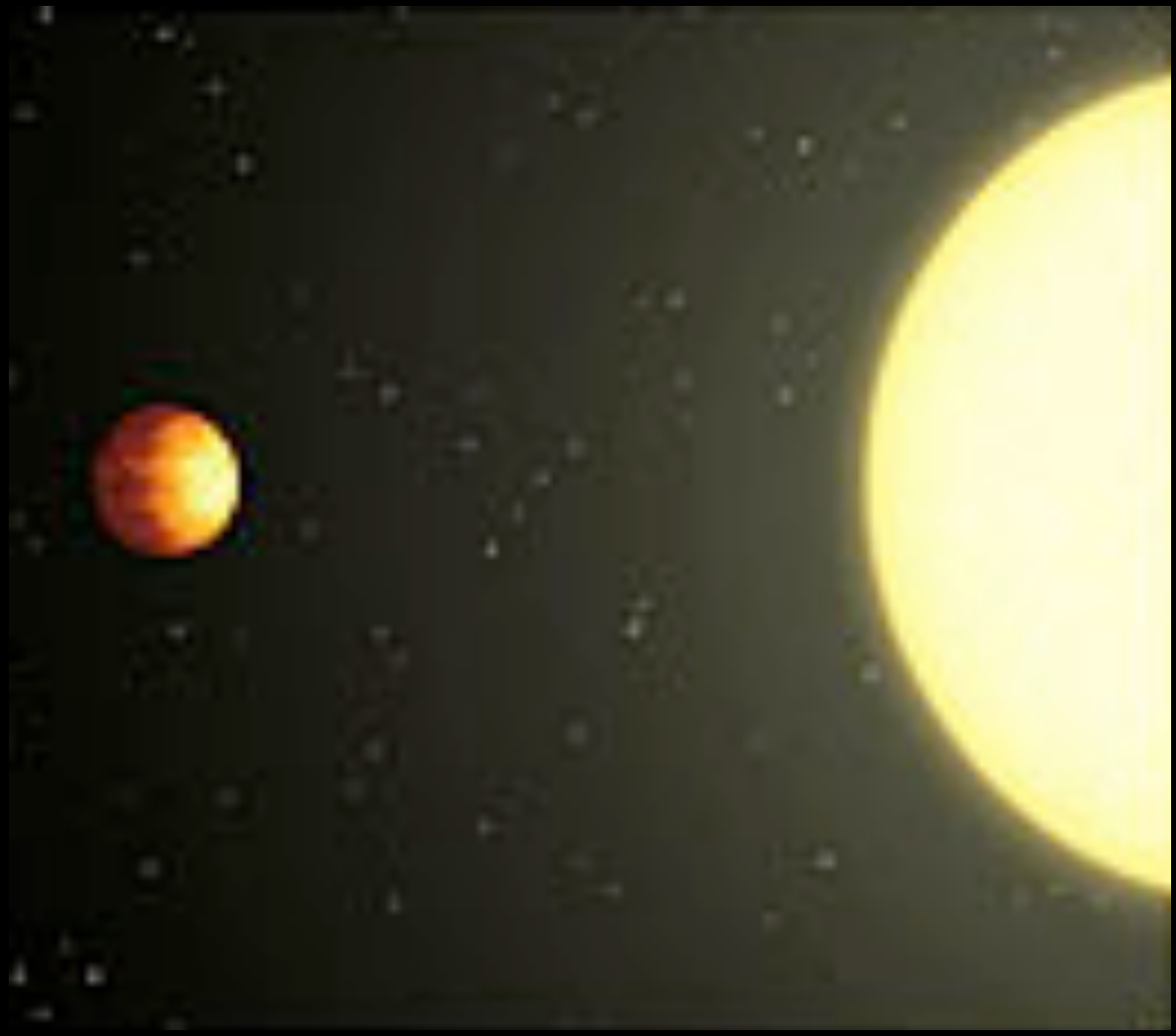
Transmission Photometry



Water vapor on HD189733

G. Tinetti et al. 2007

Hot Jupiters are Tidally-Locked



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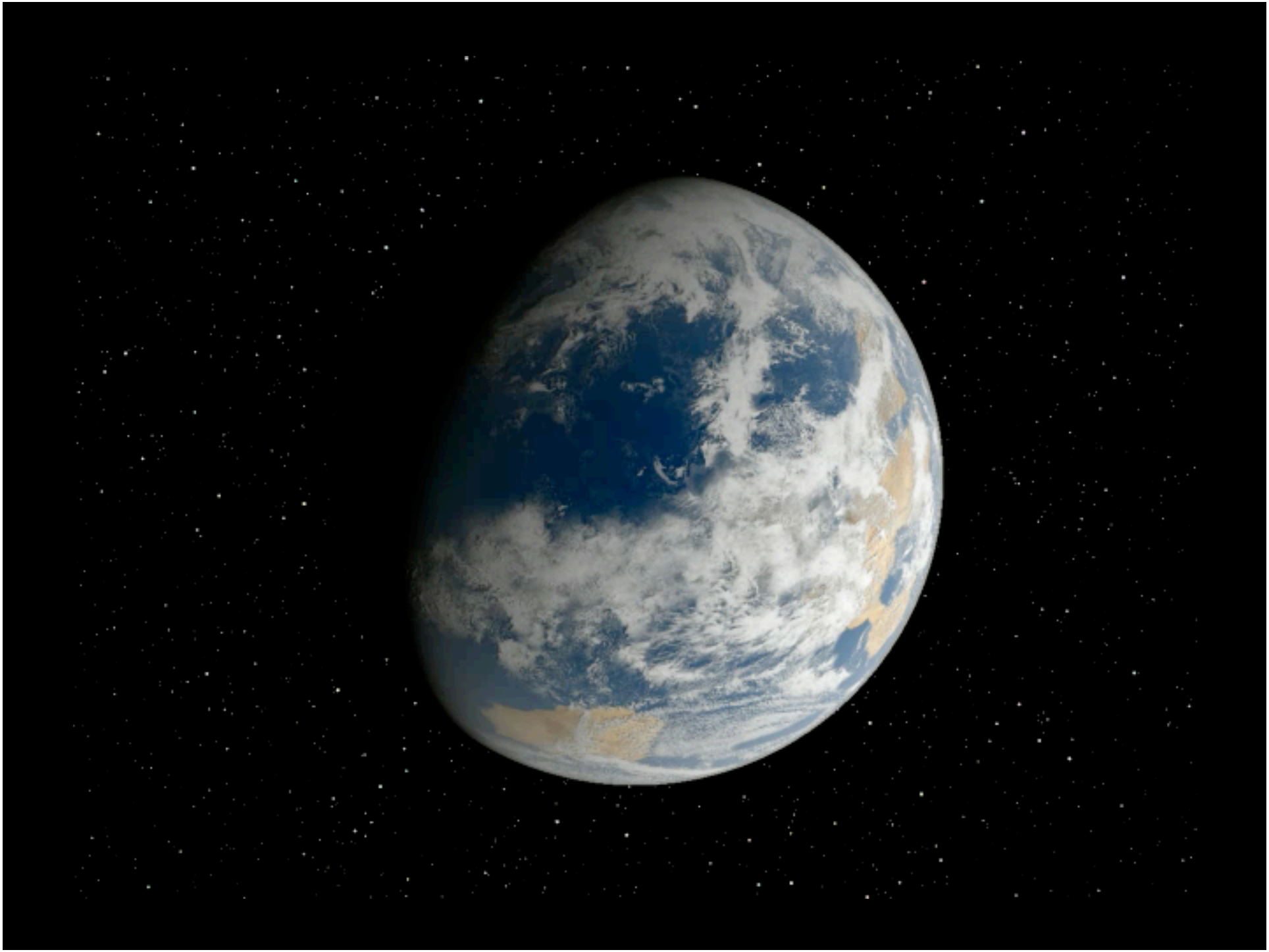
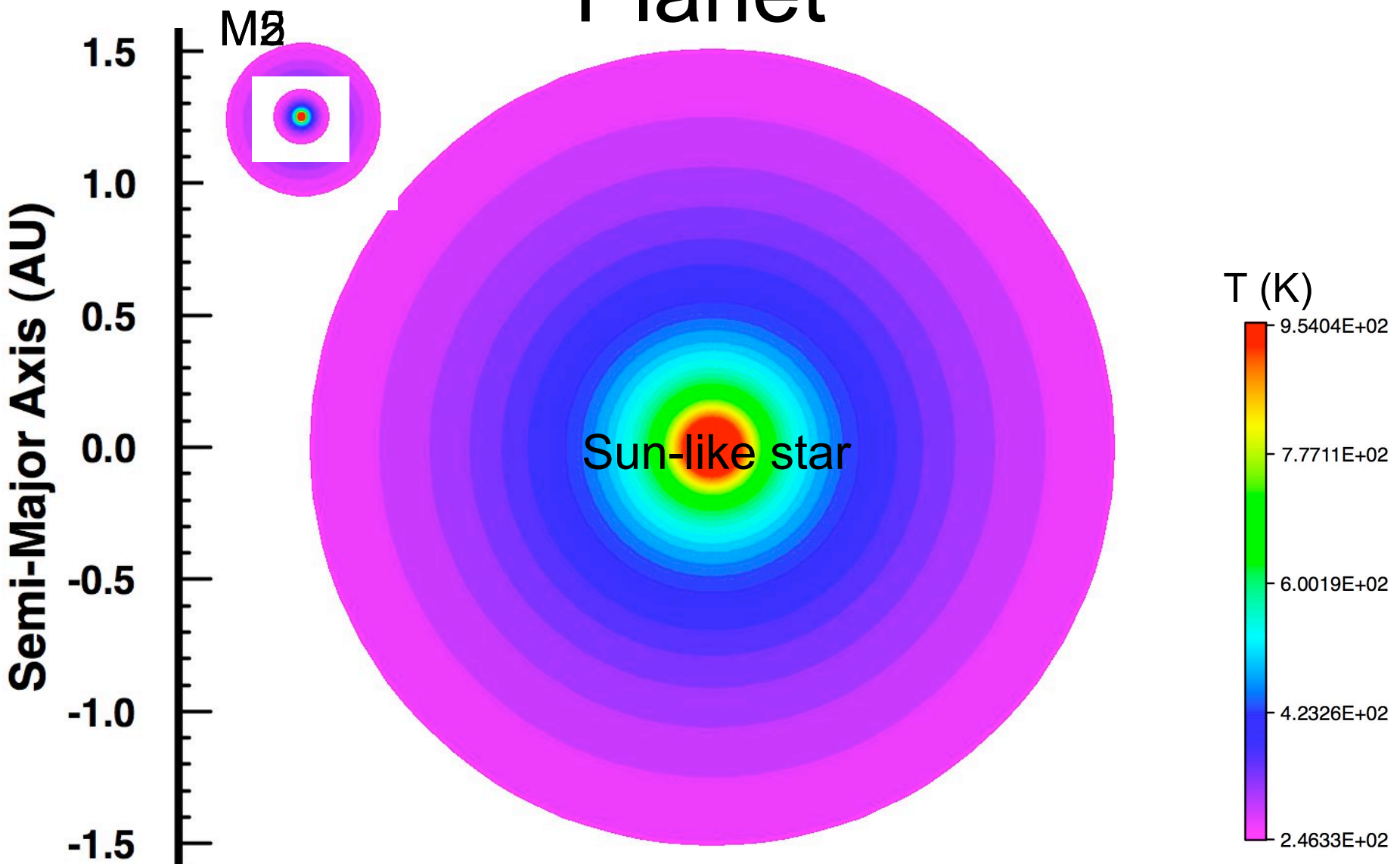


The Race to Find a Habitable Planet

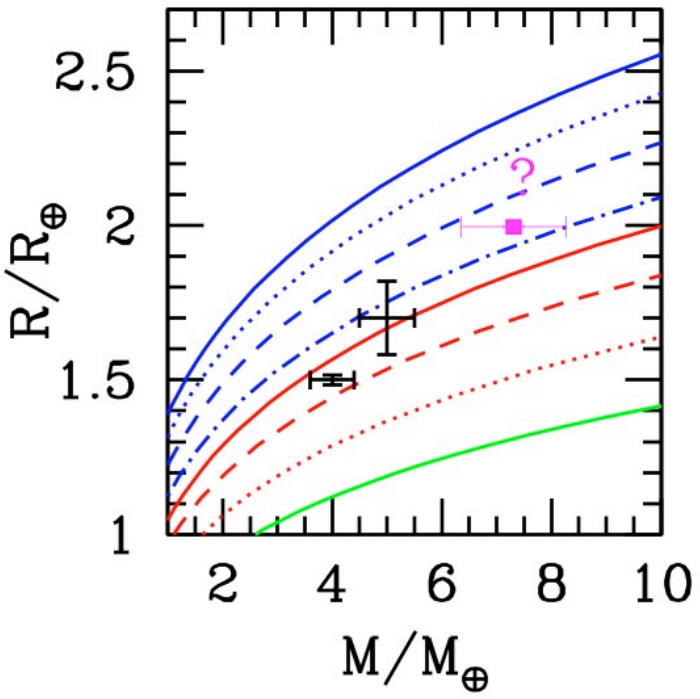


In the News: Gl 581 c

What we know

- A three-planet system
  - a) M 16 $M_\oplus$, a = 0.041 AU
  - b) M = 5.03 $M_\oplus$, a = 0.073 AU
  - c) M = 7.7 $M_\oplus$, a = 0.25 AU
- Star has T_{eff} ~ 3400K

Gl 581 Udry et al. 2007



What we do not know

- Radius
- Surface Temperature

GJ 436b: example

- T_b = 712 +/- 36 K

Deming et al. submitted to ApJL

$$T_{eq} = T_* \left[\frac{R_*}{a}\right]^{1/2} \left[f(1-A_B)\right]^{1/4}$$

Planetary Physics from Transits

Primary Transit: Bulk Composition from M and R

- ✓Densities of ~20 hot Jupiter exoplanets
- ✓Density for 1 hot Neptune

Secondary Eclipse

- ✓T_b of 4+ exoplanets
- ✓Eccentricity

Transit Transmission Photometry

- ✓Sodium and water vapor detections

Transiting Super Earths are Highly Anticipated