Lecture 6: Planet characterisation

Planetary density and surface gravity

Equilibrium temperatures and infrared phase curves

Transmission and occultation spectroscopy

Molecular fingerprinting

Stellar density

- **Seager & Mallén-Ornelas, 2003, ApJ 585, 1038**
- **Simplest case: circular orbit, i=90 degrees**
  - **Relative transit duration:**

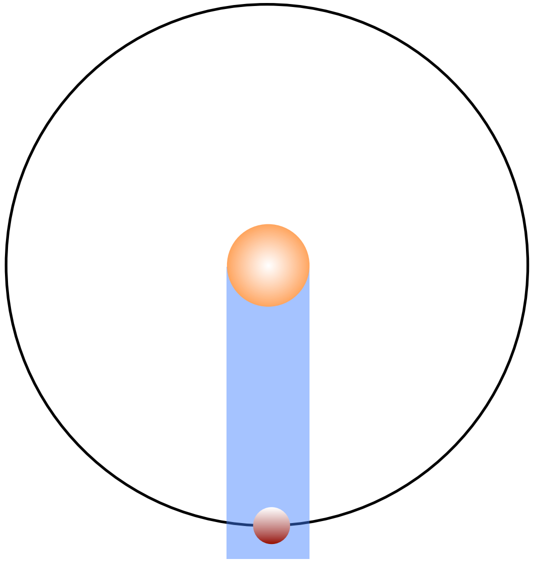
$$\frac{T}{P} \simeq \frac{2R_*}{2\pi a}$$

  - **Kepler's 3rd Law:**

$$a = \left(\frac{GM^* P^2}{4\pi^2}\right)^{1/3}$$

  - **Hence**

$$\frac{T}{P} \simeq \left(\frac{4}{\pi G P^2 \rho_*}\right)^{1/3}$$



Planetary surface gravity

- **Southworth, Wheatley & Sams 2007, MNRAS 379, L11**
- **Simplest case: circular orbit, i=90 degrees**
  - **Stellar orbital acceleration:**

$$\frac{dv_r}{dt} = \frac{2\pi K}{P} = \frac{GM_p}{a^2} = g_p \frac{R_p^2}{a^2}$$

  - **Inverse square law of gravitation:**

$$\frac{2\pi K}{P} = g_p \left(\frac{R_p}{R_*}\right)^2 \left(\frac{R_*}{a}\right)^2$$

Stellar radial acceleration at conjunction

Planet surface gravity

Transit depth

Transit duration

Planetary density

- **Need to know planet radius and surface gravity:**

$$g_p = \frac{GM_p}{R_p^2} = GR_p\rho_p = GR_*\left(\frac{R_p}{R_*}\right)\rho_p$$

- **Use stellar angular diameter θ and parallax π:**

$$R_* = \theta d = \frac{\theta}{\pi}$$

- **Hence get planetary bulk density:**

Stellar parallax

$$\rho_p = \frac{g_p \pi}{G\theta}\left(\frac{R_*}{R_p}\right)$$

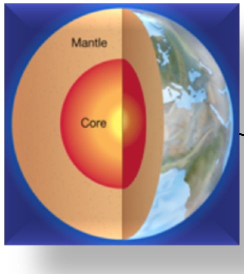
Stellar angular diameter

Transit depth

Bulk density and composition

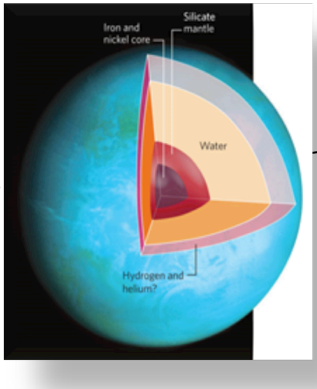
Earth

5.5 g/cm^3



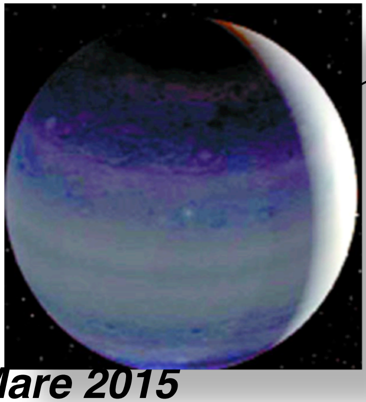
GJ1214b

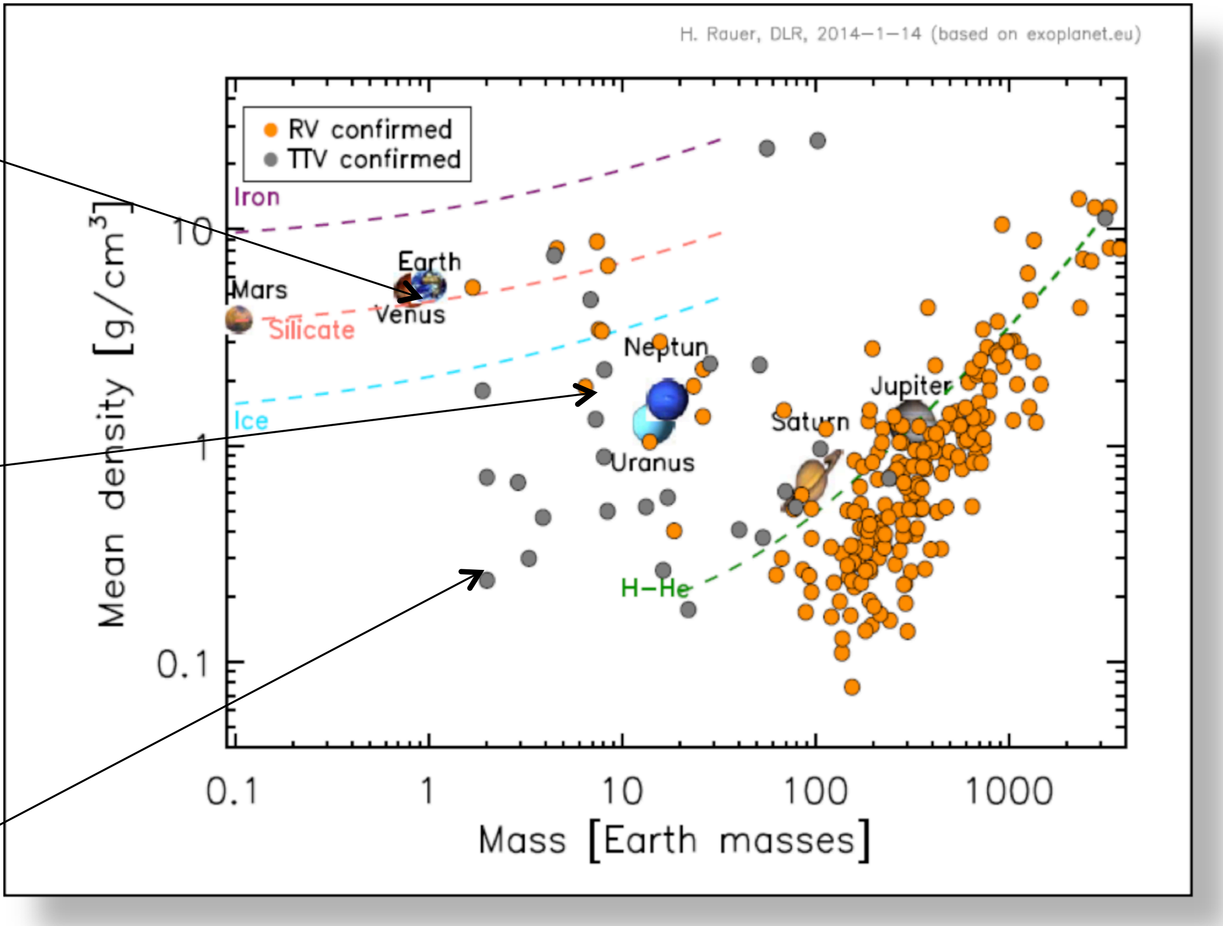
1.6 g/cm^3



Mini gas planets

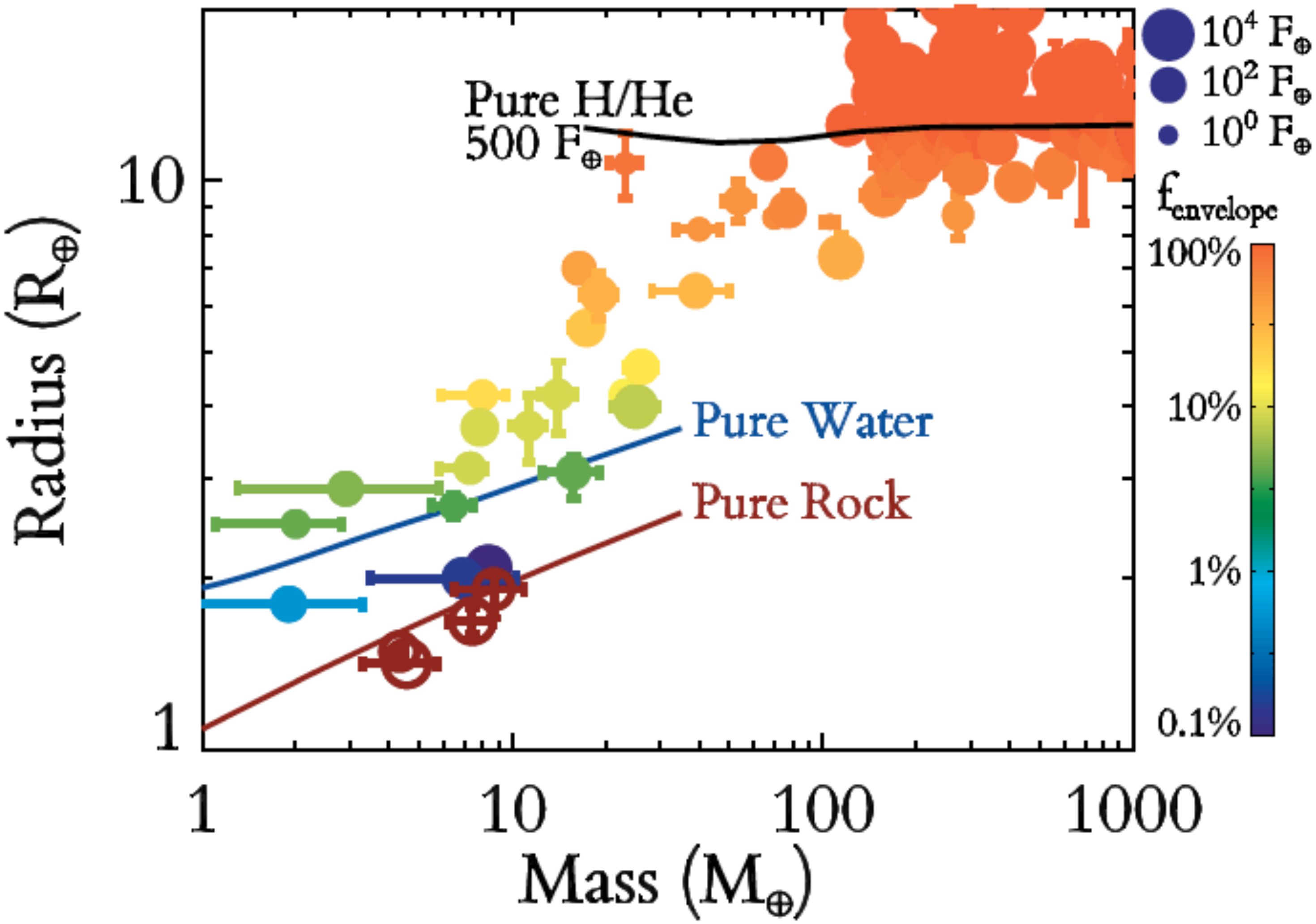
<~1 g/cm^3





Low-mass planets have a range of compositions and interior structures for similar masses.

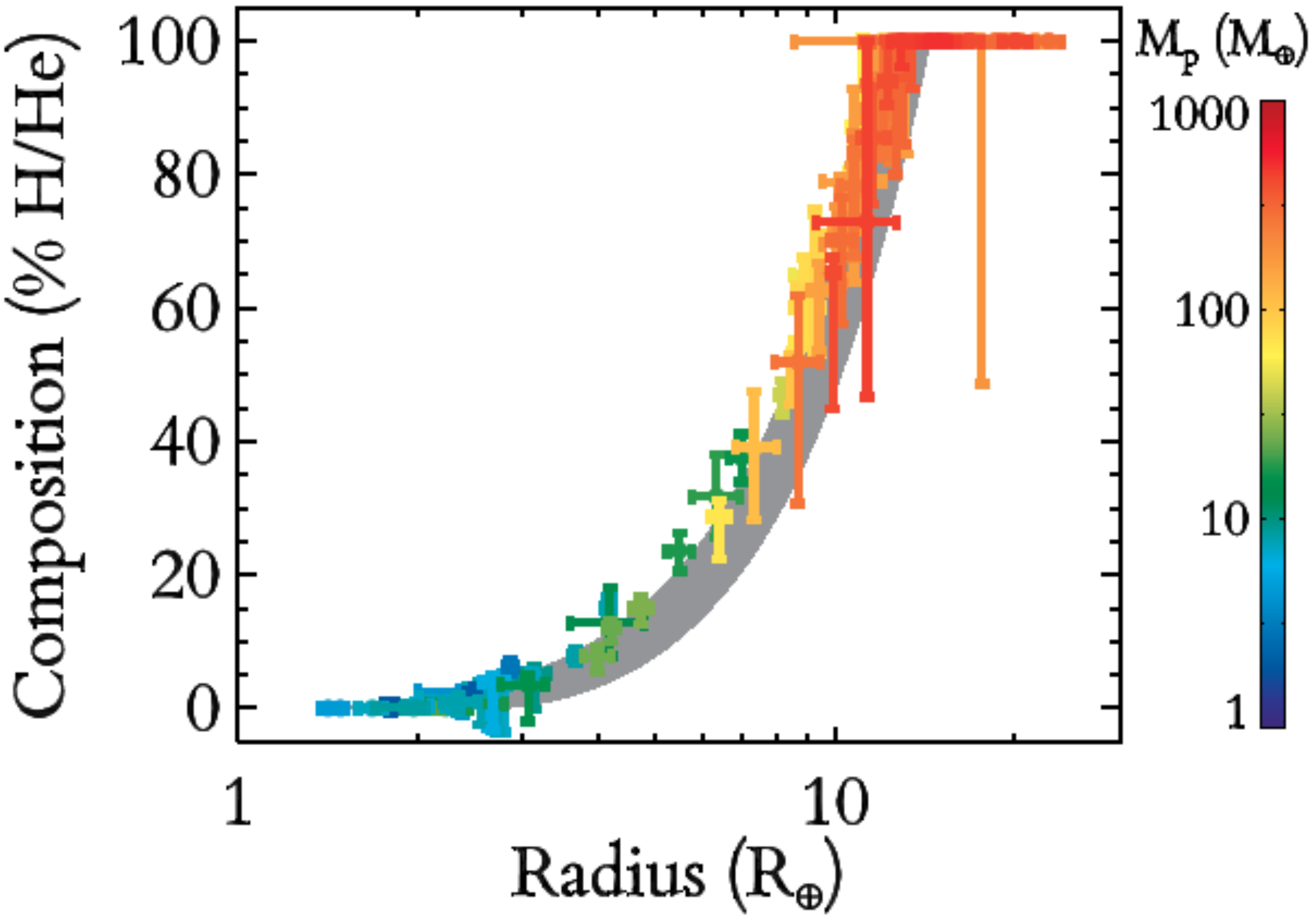
Radius as a proxy for sub-Neptune composition



Lopez & Fortney 2014, ApJ 792, 1

Radius and gaseous envelope fraction

Models of observed planets with varying water fraction (grey)



Lopez & Fortney 2014, ApJ 792, 1

Planetary equilibrium temperature

$$\overbrace{\overbrace{\frac{4\pi R_P^2}{f}}^{\textbf{Radiating area}}\overbrace{\sigma T_{eq}^4}^{\textbf{Flux out}}}^{\textbf{Power out}} = \overbrace{\underbrace{\frac{4\pi R_*^2\sigma T_*^4}{4\pi a^2}}_{\textbf{Flux in}}\underbrace{\pi R_P^2}_{\textbf{Planet x-section}}(1-A)}^{\textbf{Power in}}$$

f=1 isotropic
f=2 dayside only

Bond albedo

Planetary equilibrium temperature

$$\overbrace{\overbrace{\frac{4\cancel{\pi R_P^2}}{f}}^{\text{Radiating area}}\overbrace{\cancel{\sigma}T_{eq}^4}^{\text{Flux out}}}^{\text{Power out}} = \overbrace{\underbrace{\frac{\cancel{4\pi}R_*^2\cancel{\sigma}T_*^4}{\cancel{4\pi}a^2}}_{\text{Flux in}}\underbrace{\cancel{\pi R_P^2}}_{\text{Planet x-section}}(1-A)}^{\text{Power in}}$$

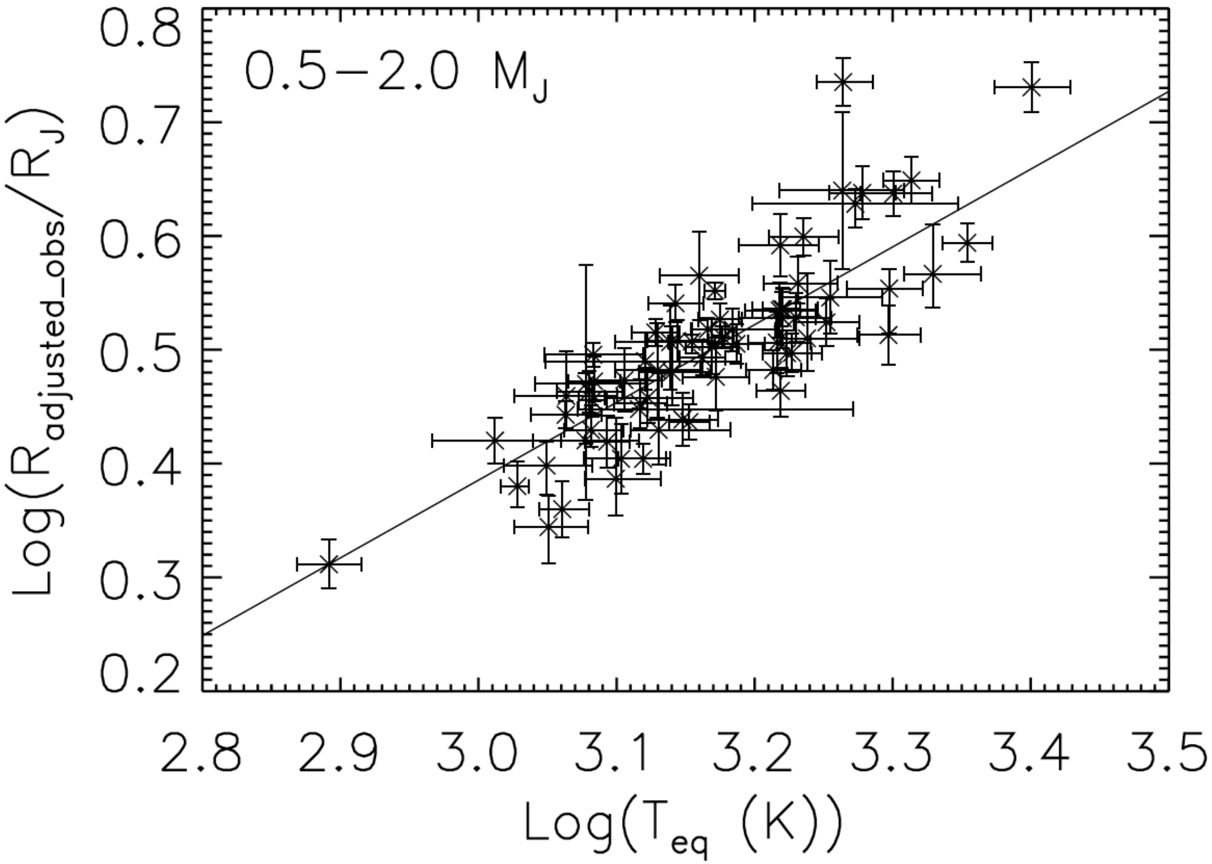
Bond albedo

f=1 isotropic
f=2 dayside only

$$T_{eq}^4 = T_*^4\frac{R_*^2}{4a^2}f(1-A)$$

Inflated hot Jupiters

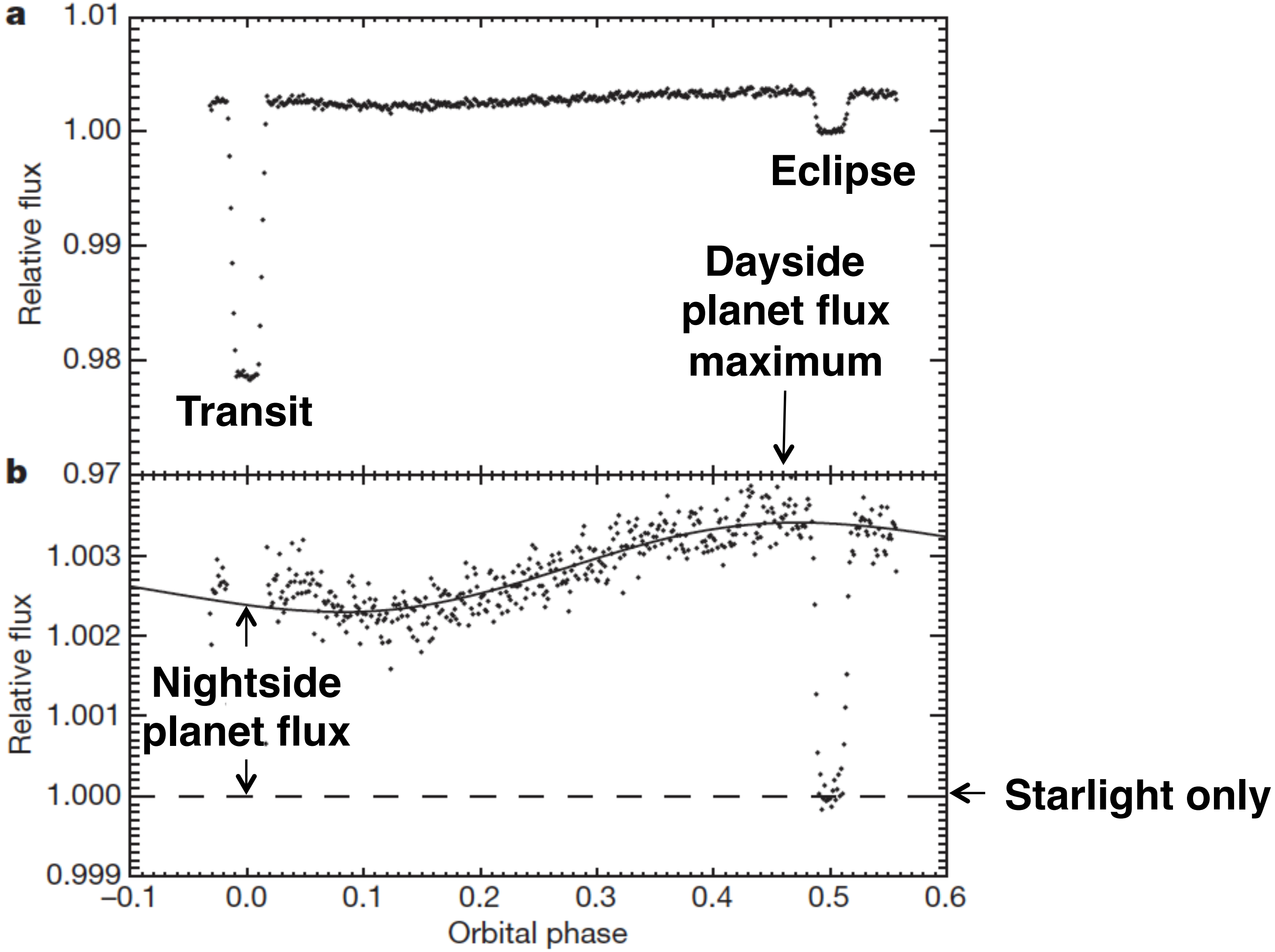
- **Planet radius versus T_{eql} for irradiated gas giants**



Enoch et al 2012, A&A 540, A99

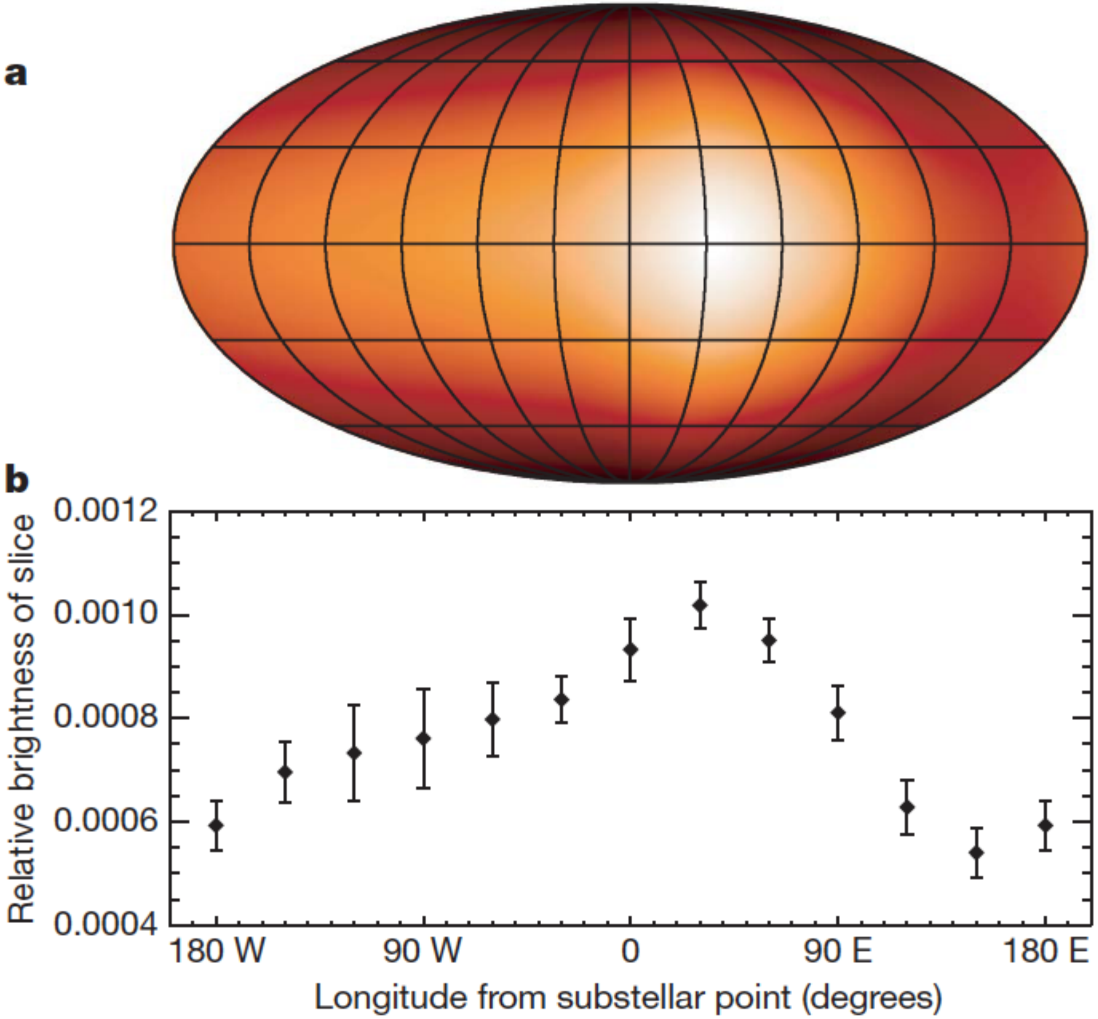
Phase curve of HD 189733b

- **Knutson et al 2007, Nature 447, 183**



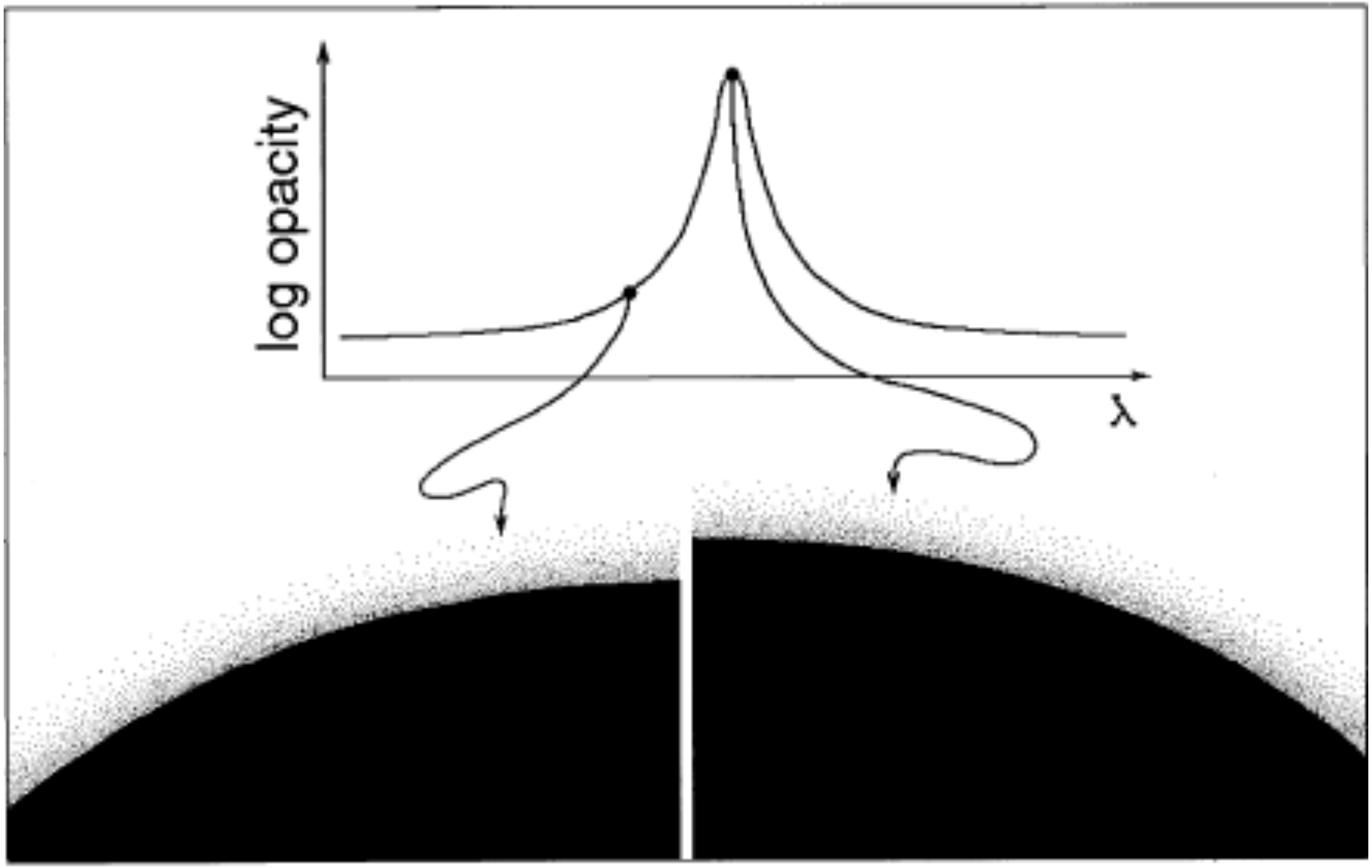
Brightness map of HD 189733b

- **Knutson et al 2007, Nature 447, 183**



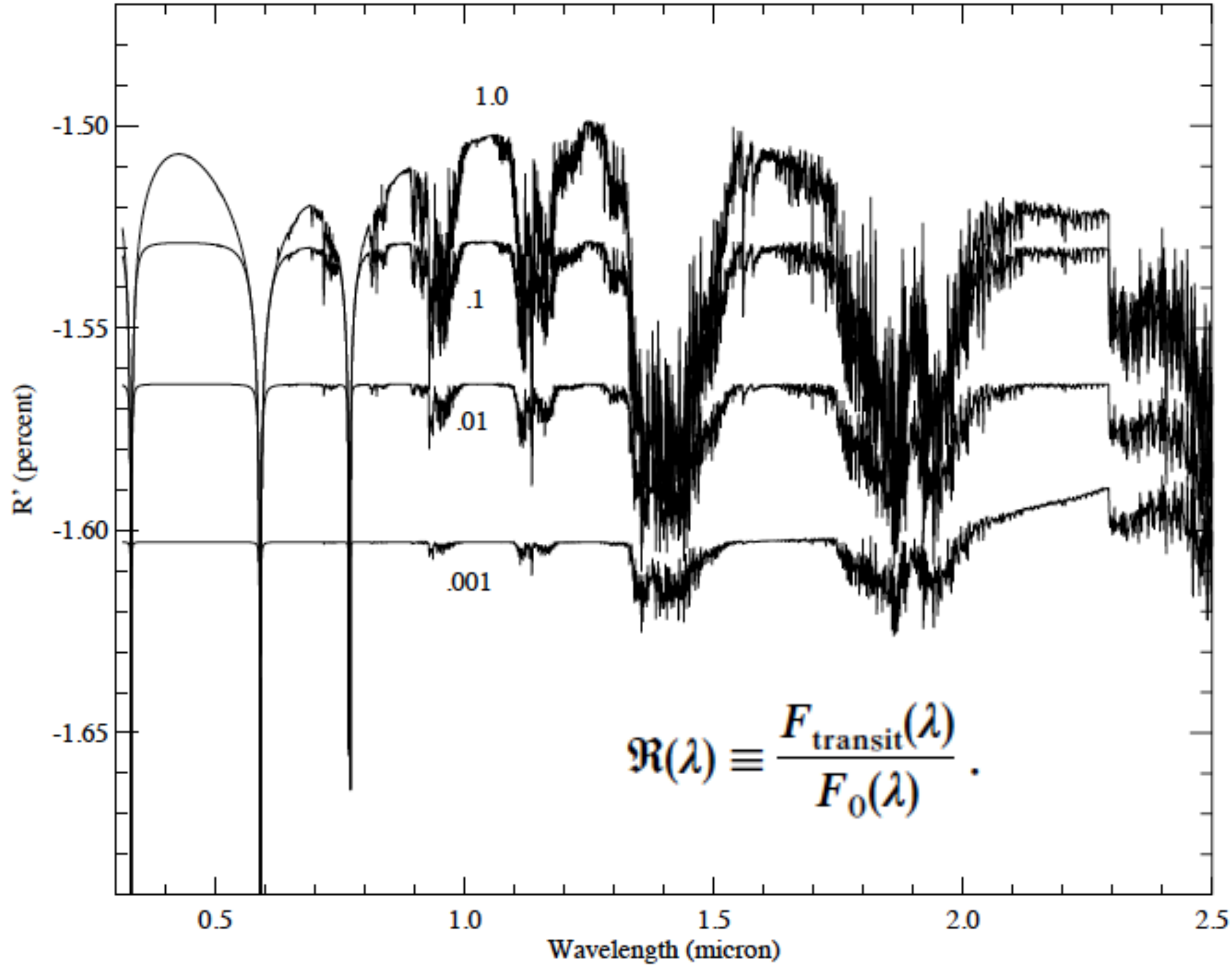
Transmission spectroscopy

cf. Elyar Sedighati presentation



Brown 2001, ApJ 553, 1006

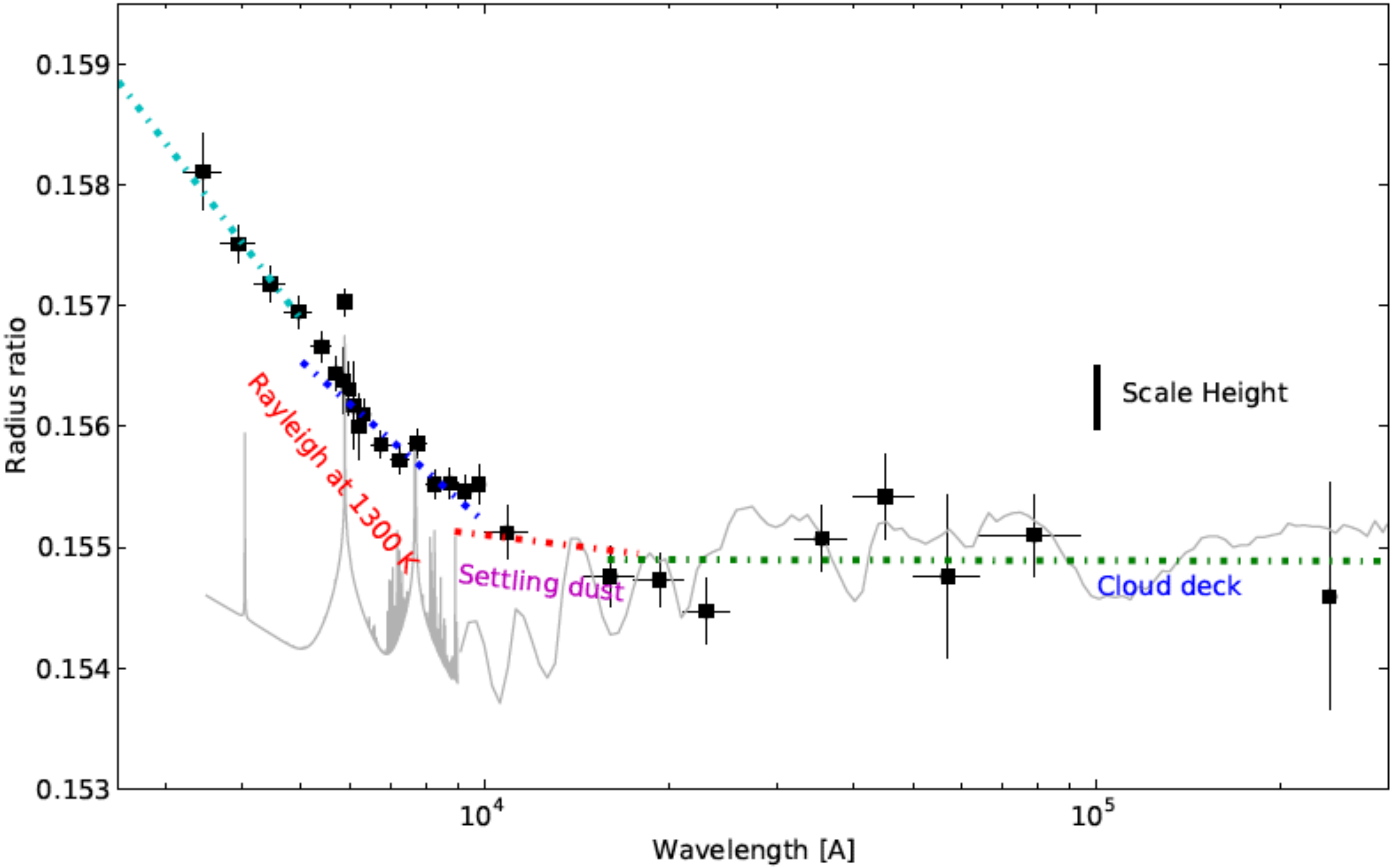
Transmission spectroscopy



$$\Re(\lambda) \equiv \frac{F_{\text{transit}}(\lambda)}{F_0(\lambda)} .$$

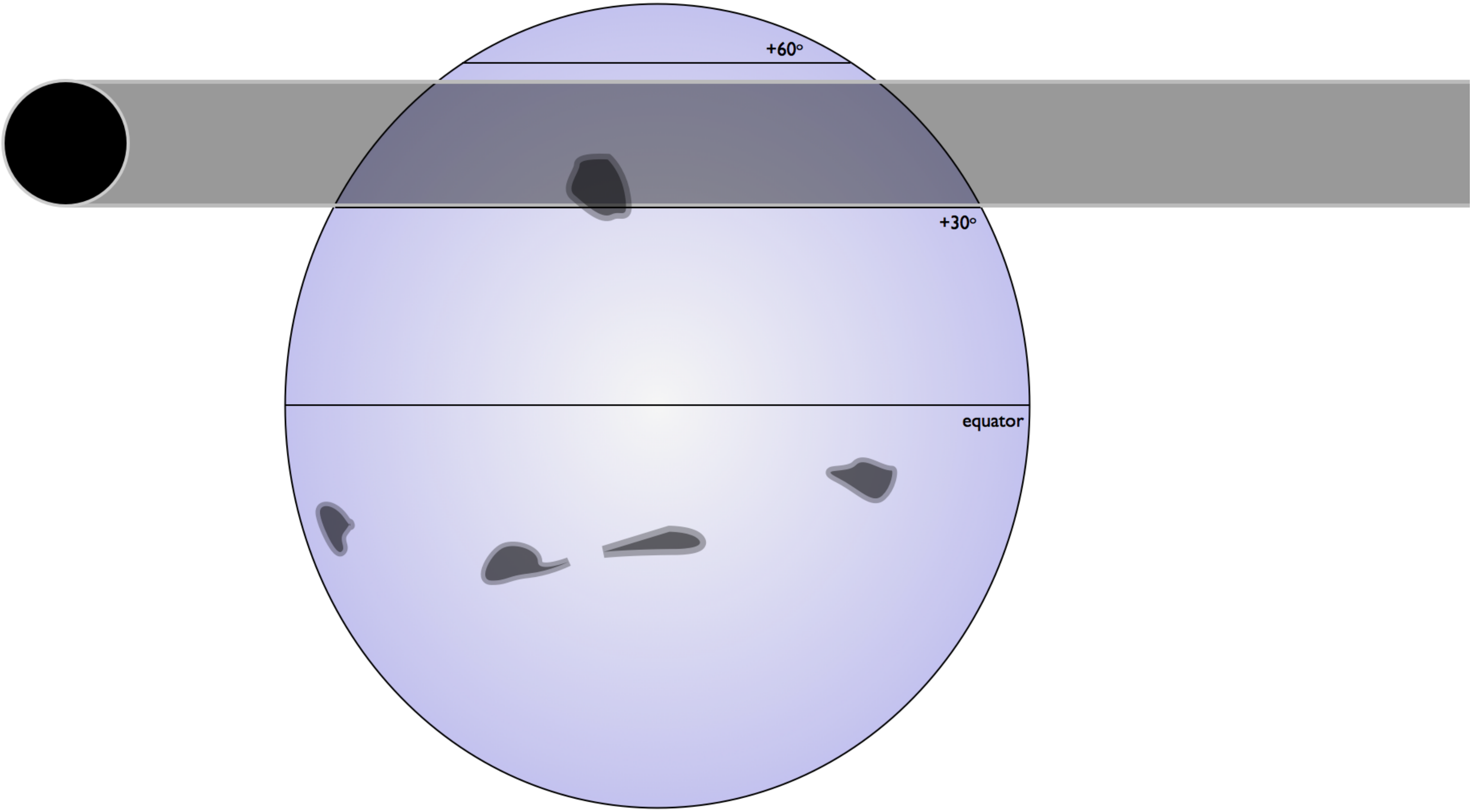
Brown 2001, ApJ 553, 1006

HD 189733's dusty atmosphere



Pont et al 2013, MNRAS 432, 291

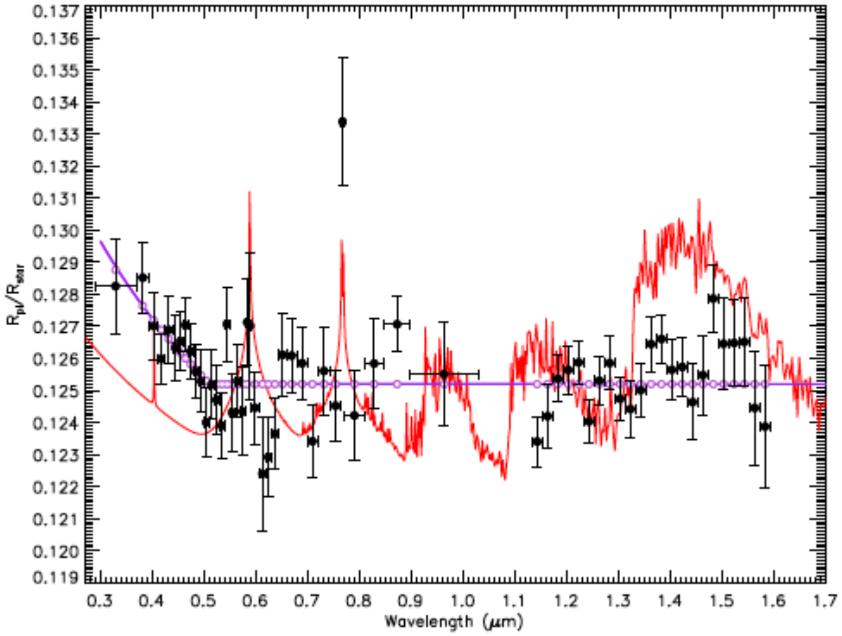
Unocculted spots deepen transits!



Pont et al 2013, MNRAS 432, 291

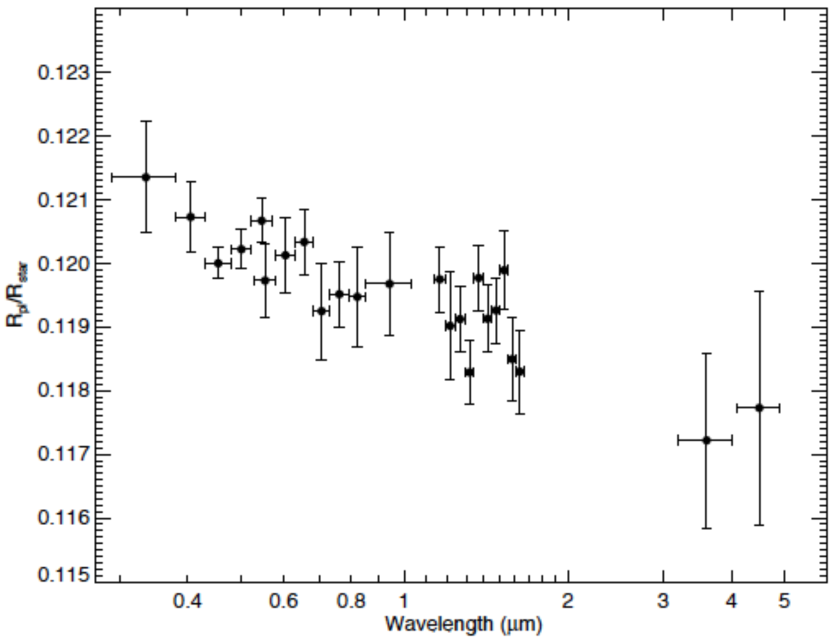
HST transmission spectroscopy survey

WASP-31b



Sing et al 2015, MNRAS 446, 2428

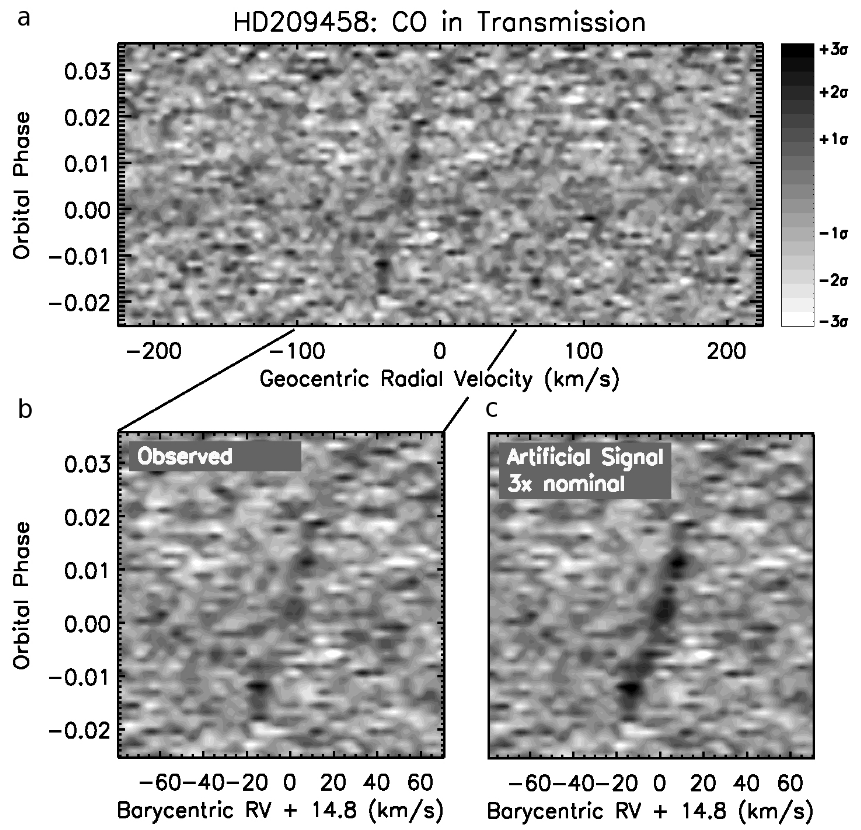
WASP-12b

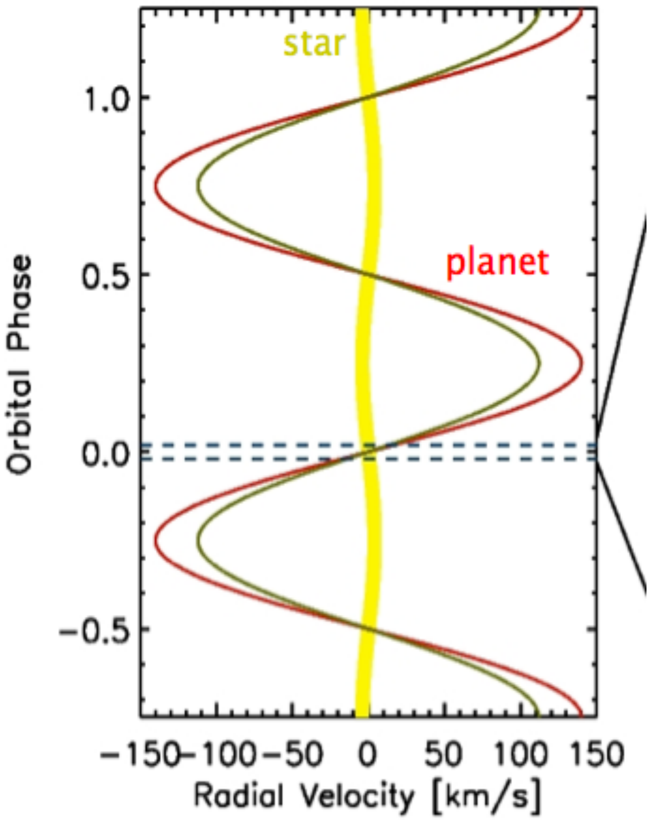


Sing et al 2015, MNRAS 436, 2956

CO in transmission in HD209458b (CRIRES@VLT)

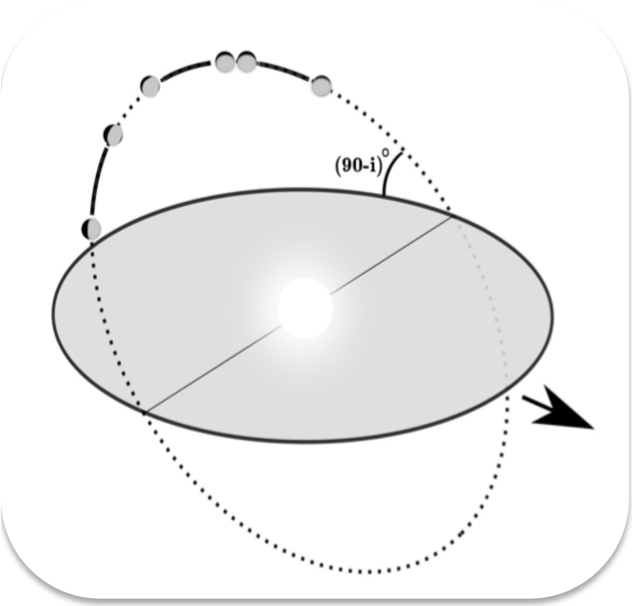
(Snellen et al. *Nature* 2010)



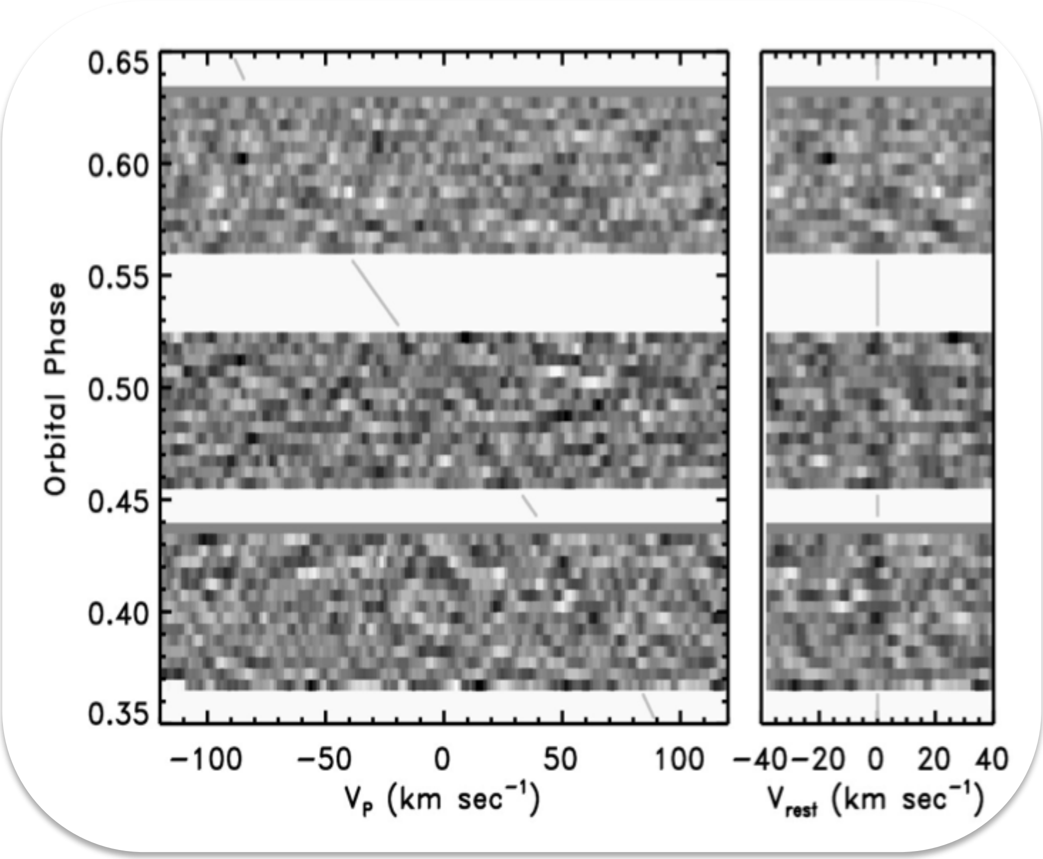


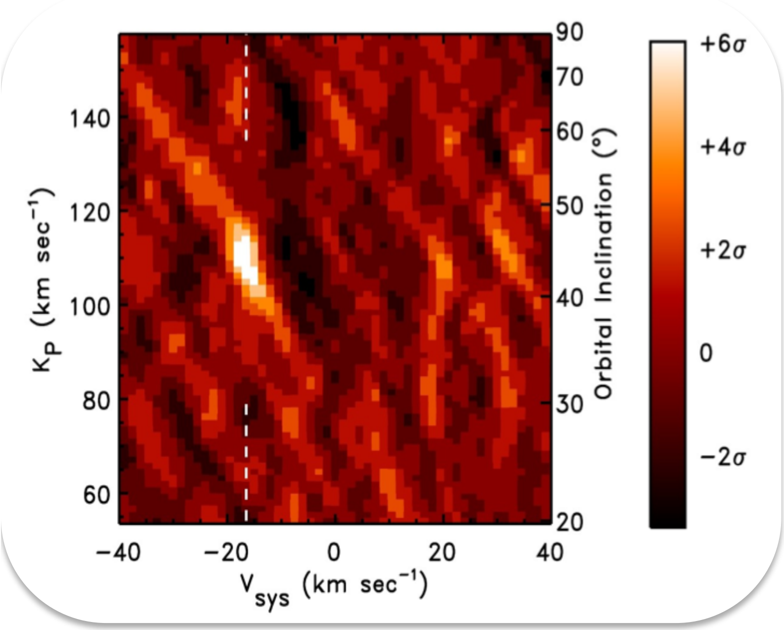
- **Reveals planet orbital velocity**
- **Solves for masses of both planet and star (model independent)**
- **Evidence for blueshift (high altitude winds?)**

CO in dayside spectrum of tau Bootis b (CRIRES@VLT)



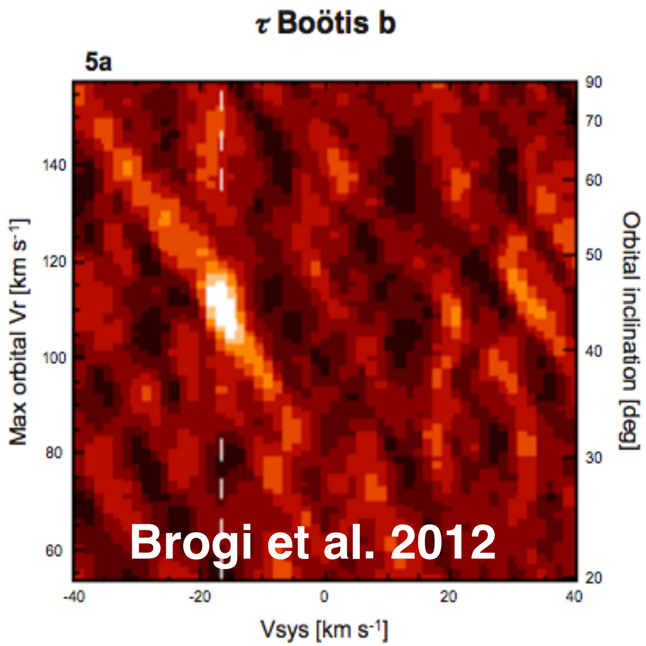
First detection of non-transiting planet→ inclination, mass

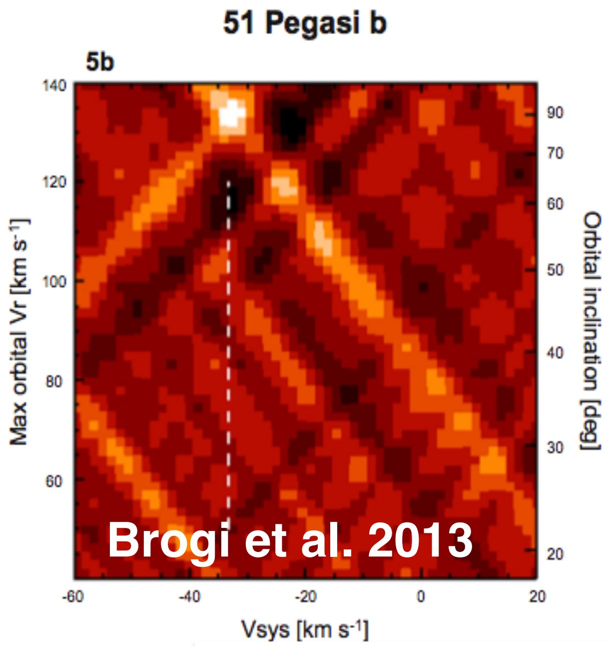


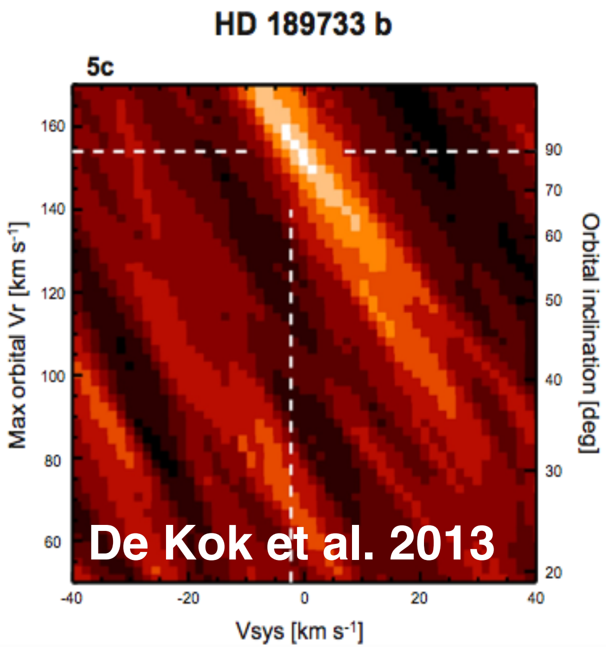


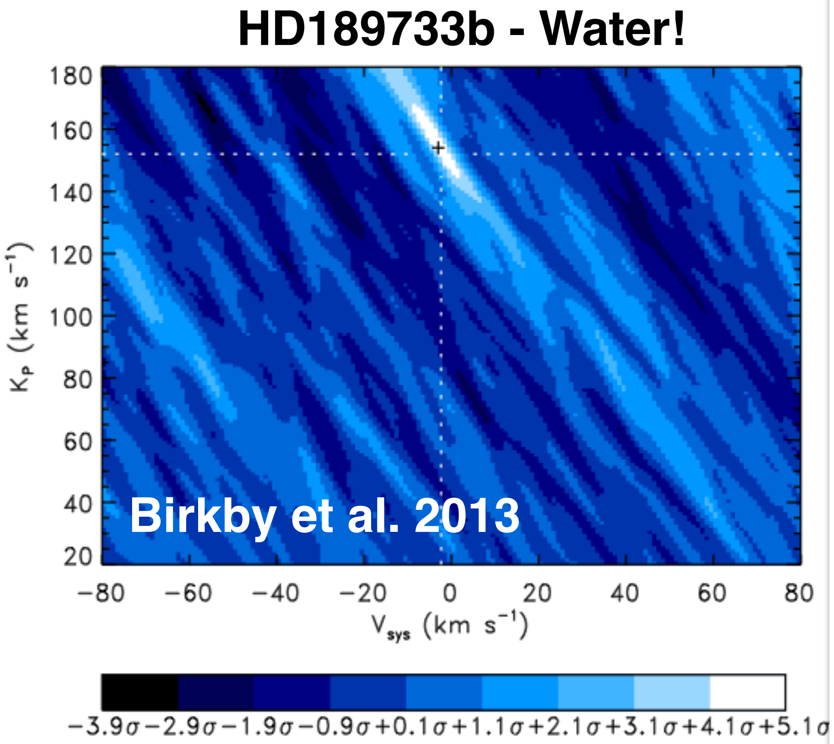
Brogi et al. 2012, Nature 486, 502

CO in dayside spectra of hot Jupiters









Stepping-stone for the ELTs

Summary

- **Planet bulk density gives clues to composition**
- **IR phase-curve studies reveal day-night temperature contrast**
- **Transmission "spectroscopy" probes aerosols, atmospheric absorbers**
- **Tomographic "molecular fingerprinting" allows unambiguous identification of molecular species with rich IR absorption spectra**
  - **also works for dayside IR emission from non-transiting planets.**