Secondary Eclipses of Transiting Planets

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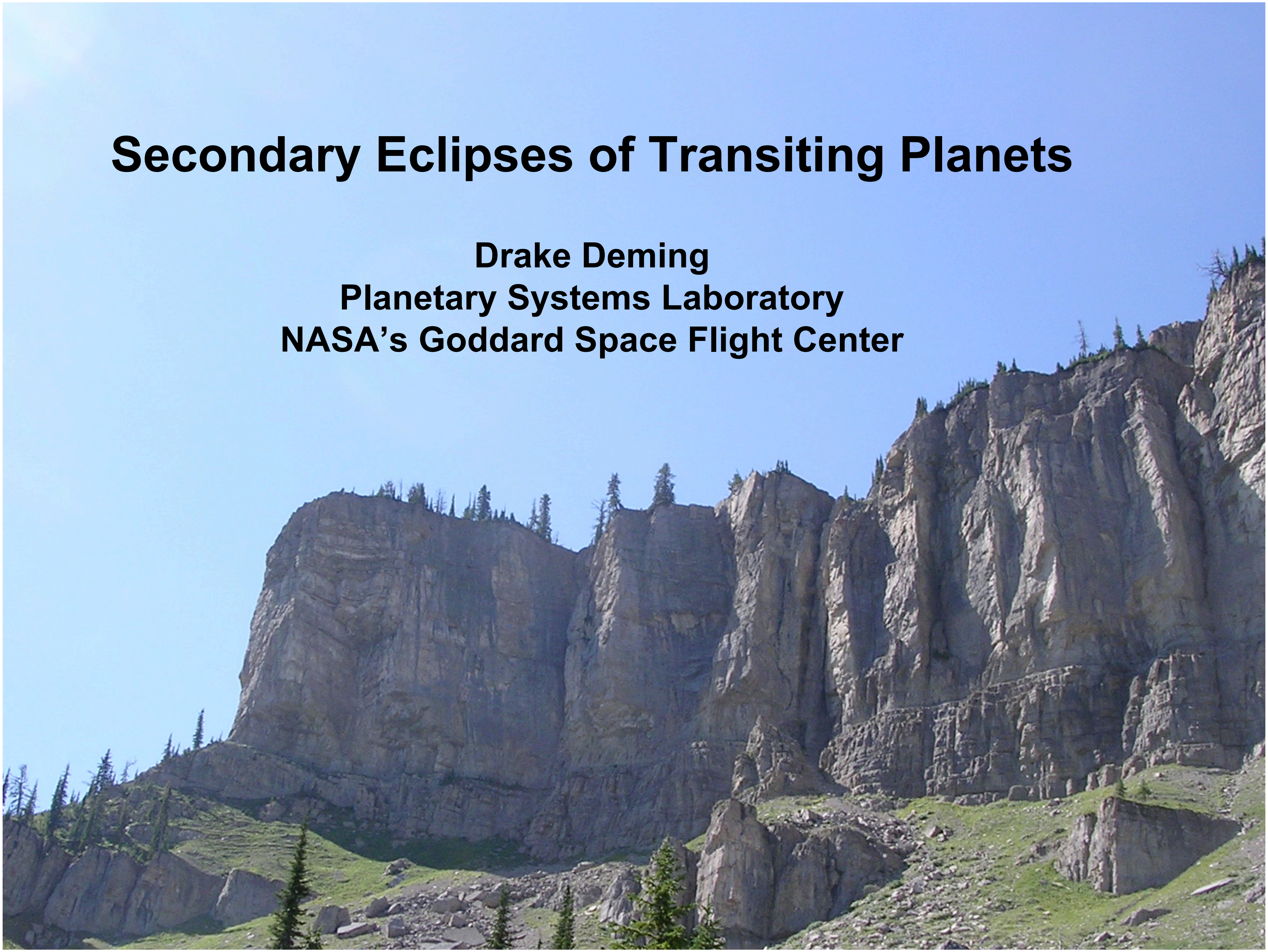
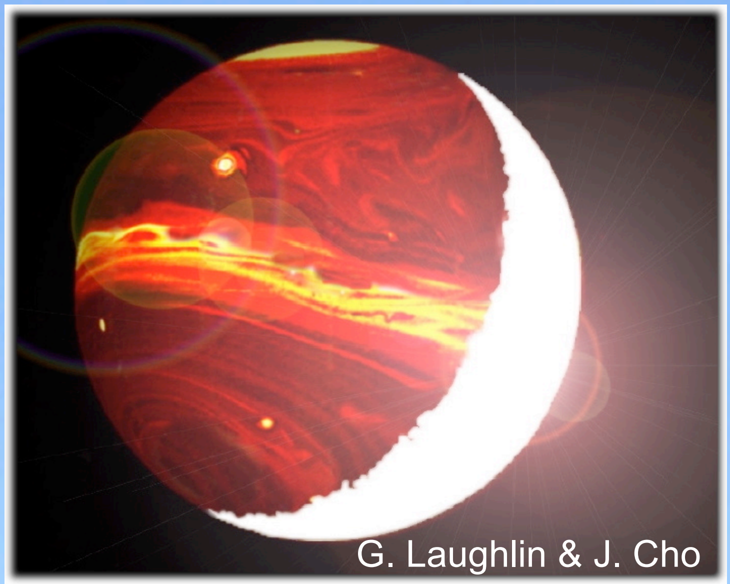




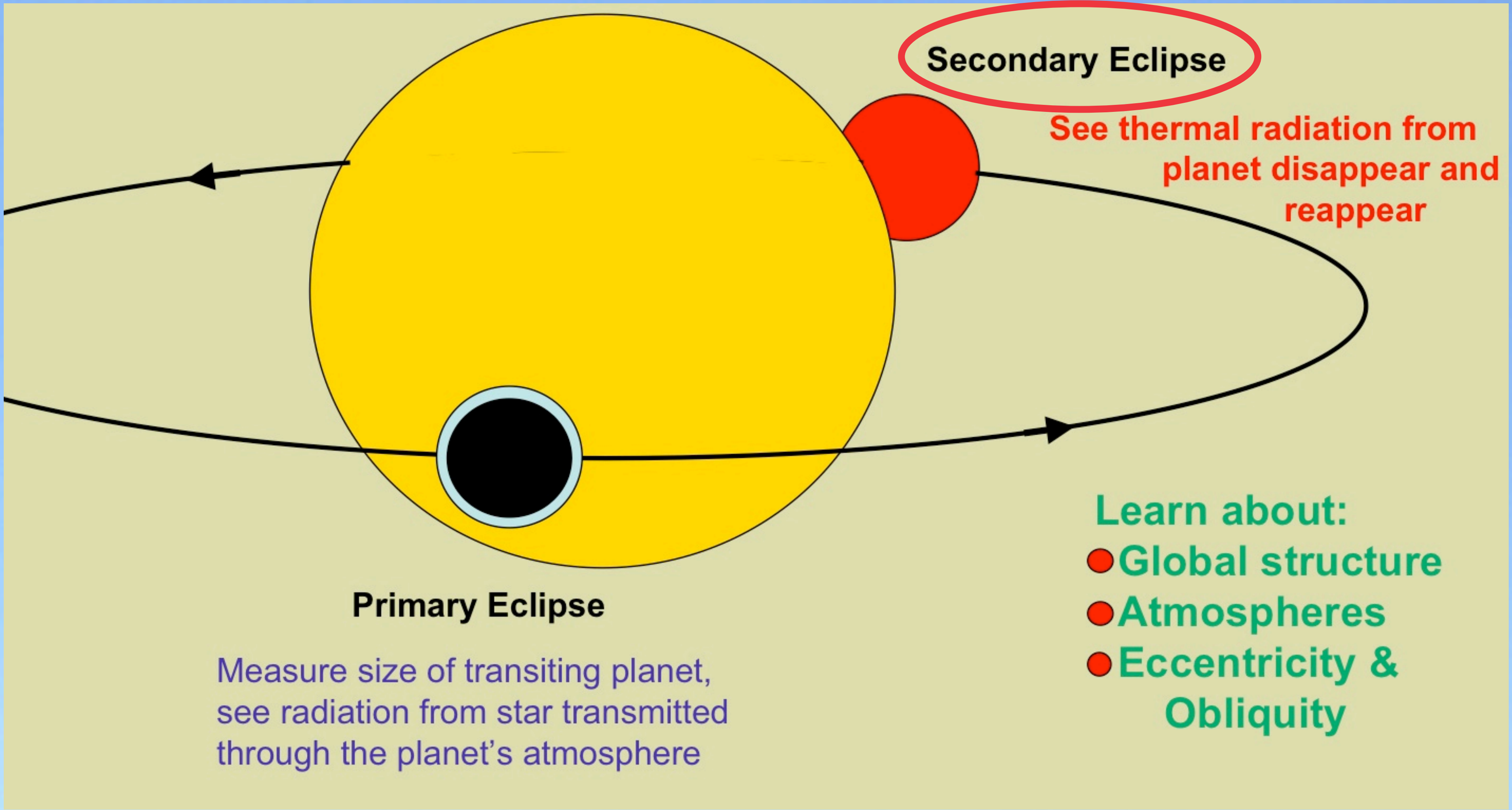
Spitzer:

Secondary eclipse photometry

- **hot Jupiters**
- **a hot Neptune**
- **hot Earths?**

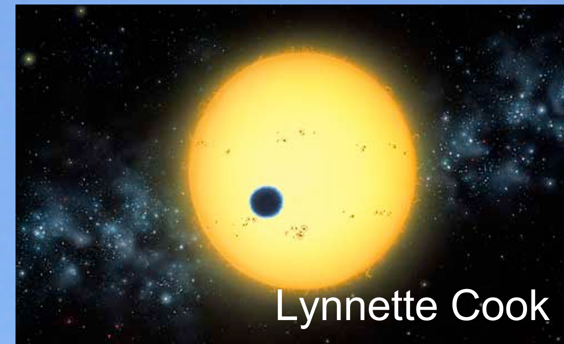
Occultation spectroscopy

Transiting Planet Science



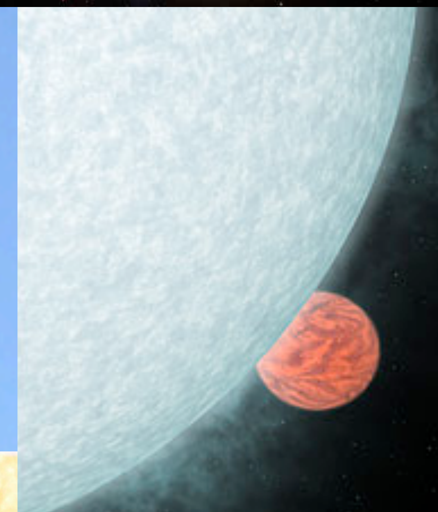
Courtesy Lori Allen

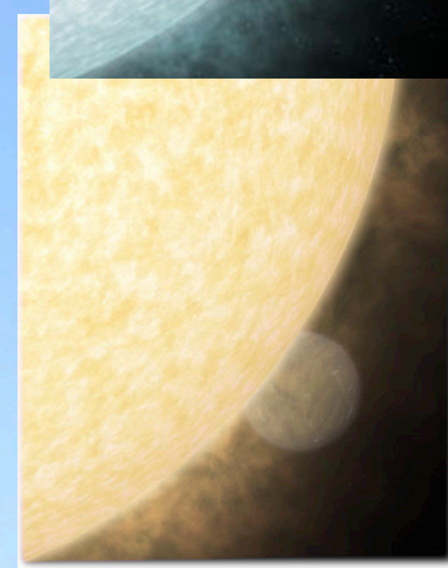
Atmosphere Follow-up



Three different and complementary kinds of atmosphere measurements are possible with transiting planets. [Seager et al. 2005]

- Transit $[R_p/R_*]^2 \sim 10^{-2}$
  - Transit radius -> density
- 1) Emission spectra $T_p/T_*(R_p/R_*)^2 \sim 10^{-3}$
  - Emitting atmosphere $\tau \sim 1$
  - Temperature and ∇T
- 2) Transmission spectra $atm/R_*^2 \sim 10^{-4}$
  - Upper atmosphere
  - Exosphere (0.05-0.15)
- 3) Scattered light spectra $p[R_p/a]^2 \sim 10^{-5}$
  - Albedo, phase curve
  - Scattering atmosphere
  - (Polarization)

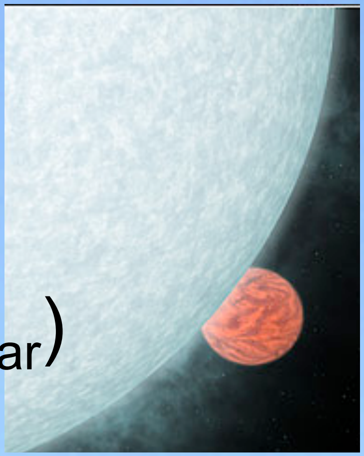




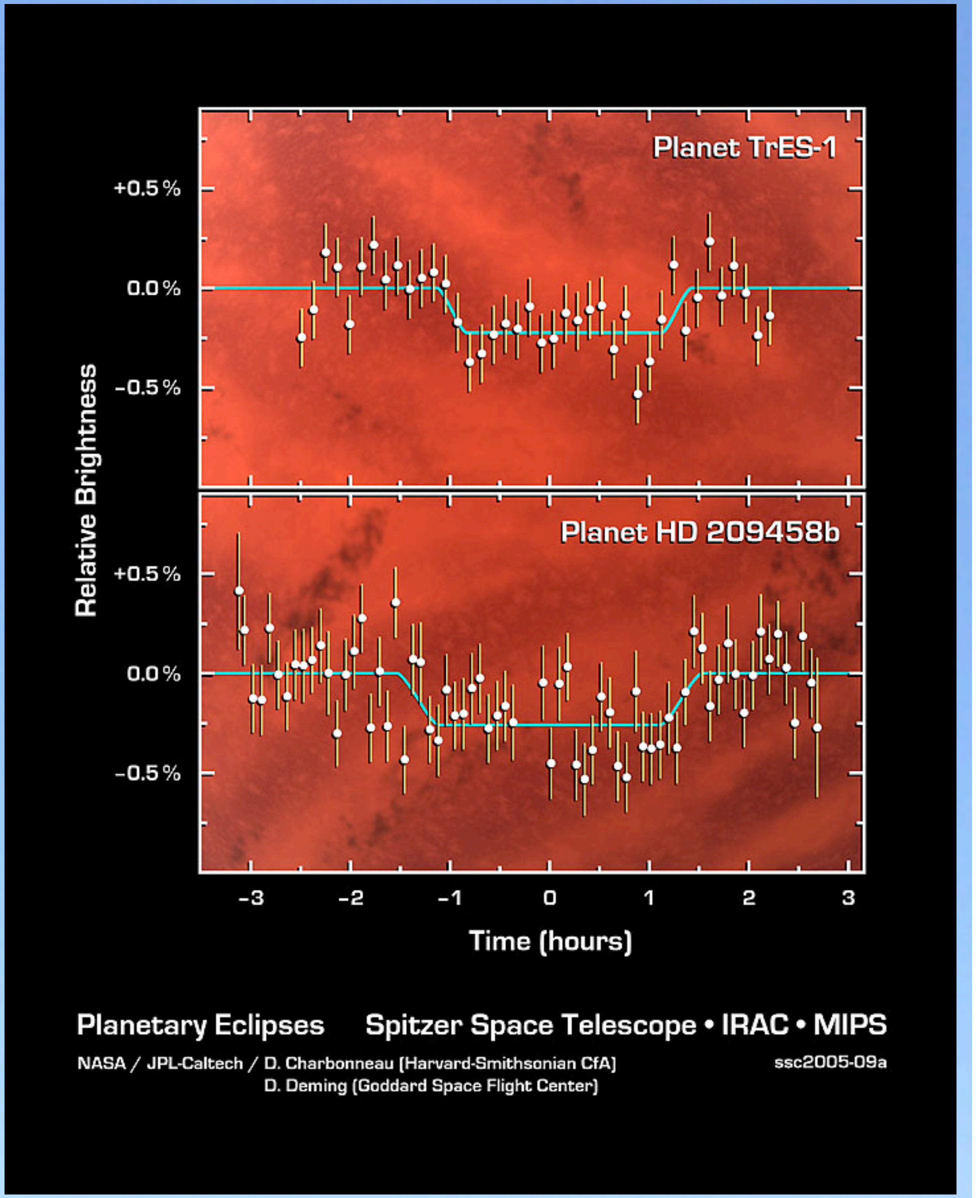
Secondary Eclipse Thermal Emission

Spitzer enables direct detection of IR light from the planets

eclipse depth ~ $(R_p/R_{star})^2(T_p/T_{star})$



yields T ~ 1100K



Eclipse of HD 189733B

eclipse depth ~ $(R_p/R_{star})^2(T_p/T_{star})$

Dominant term

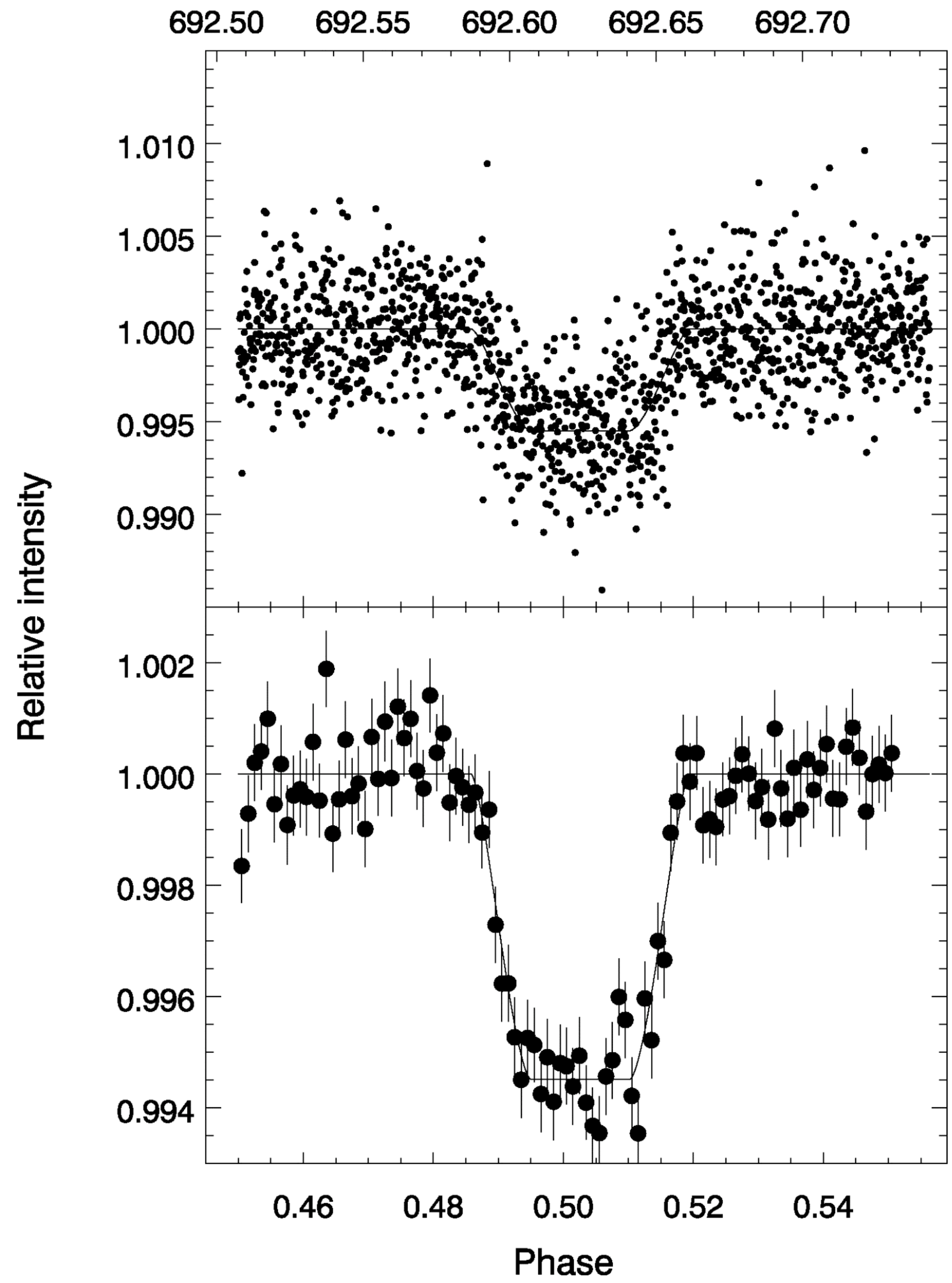
$T_p \sim T_{star}\ \Delta^{0.5}$

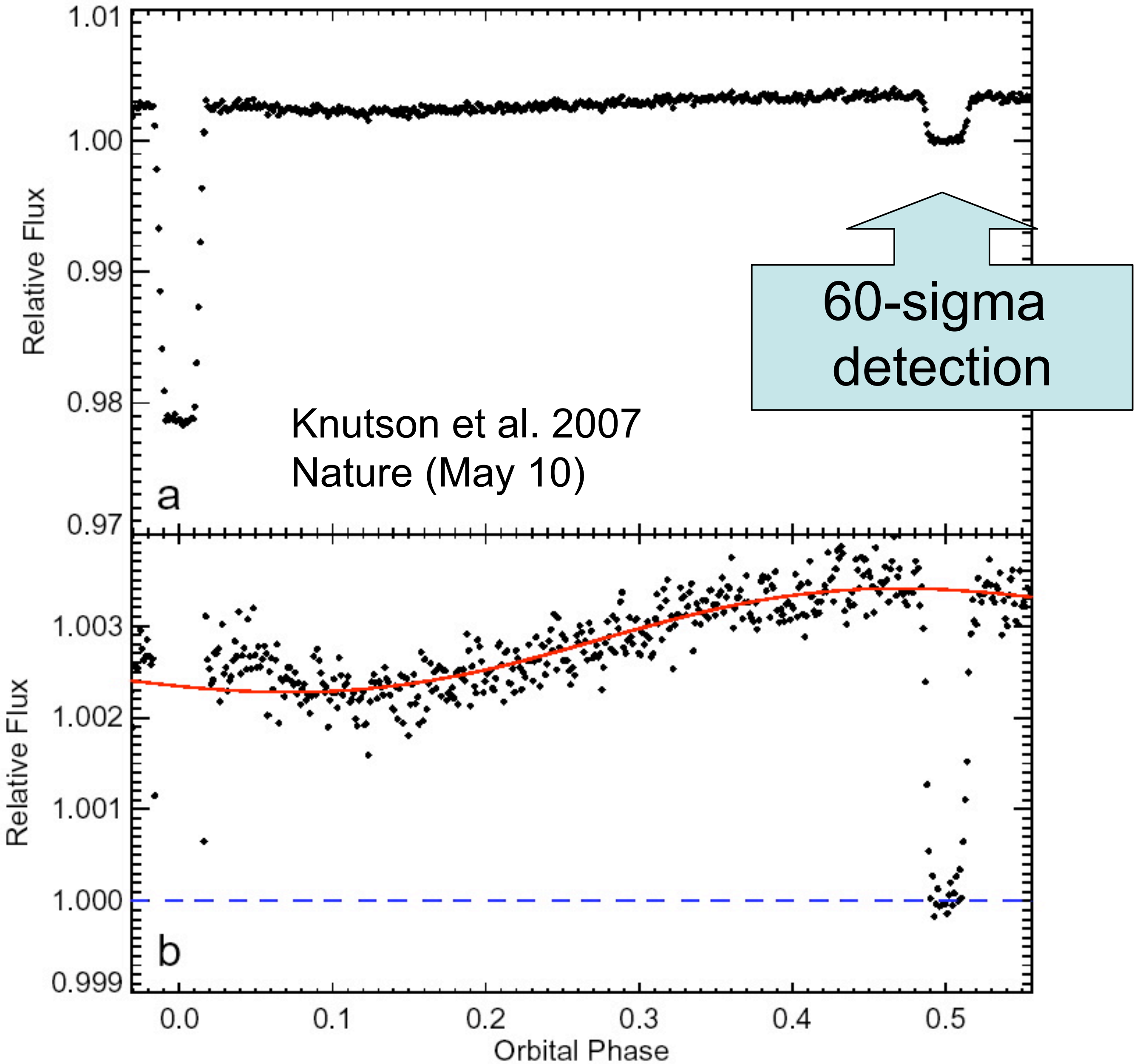
lower main-sequence stars allow high S/N planet detection

HD 189733b (K3V)

32σ detection at 16 μm

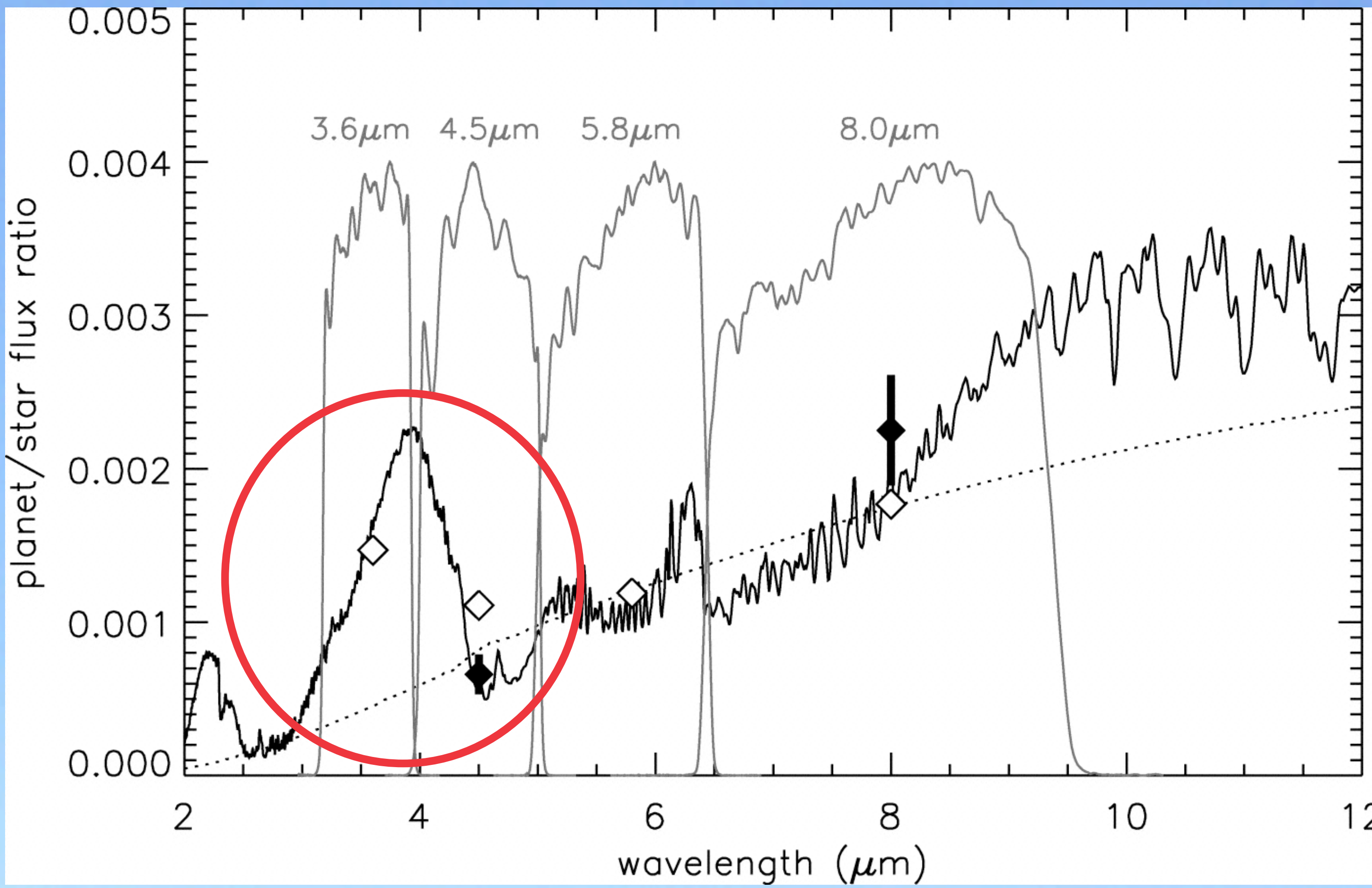
Deming et al. 2006, ApJ 644, 560

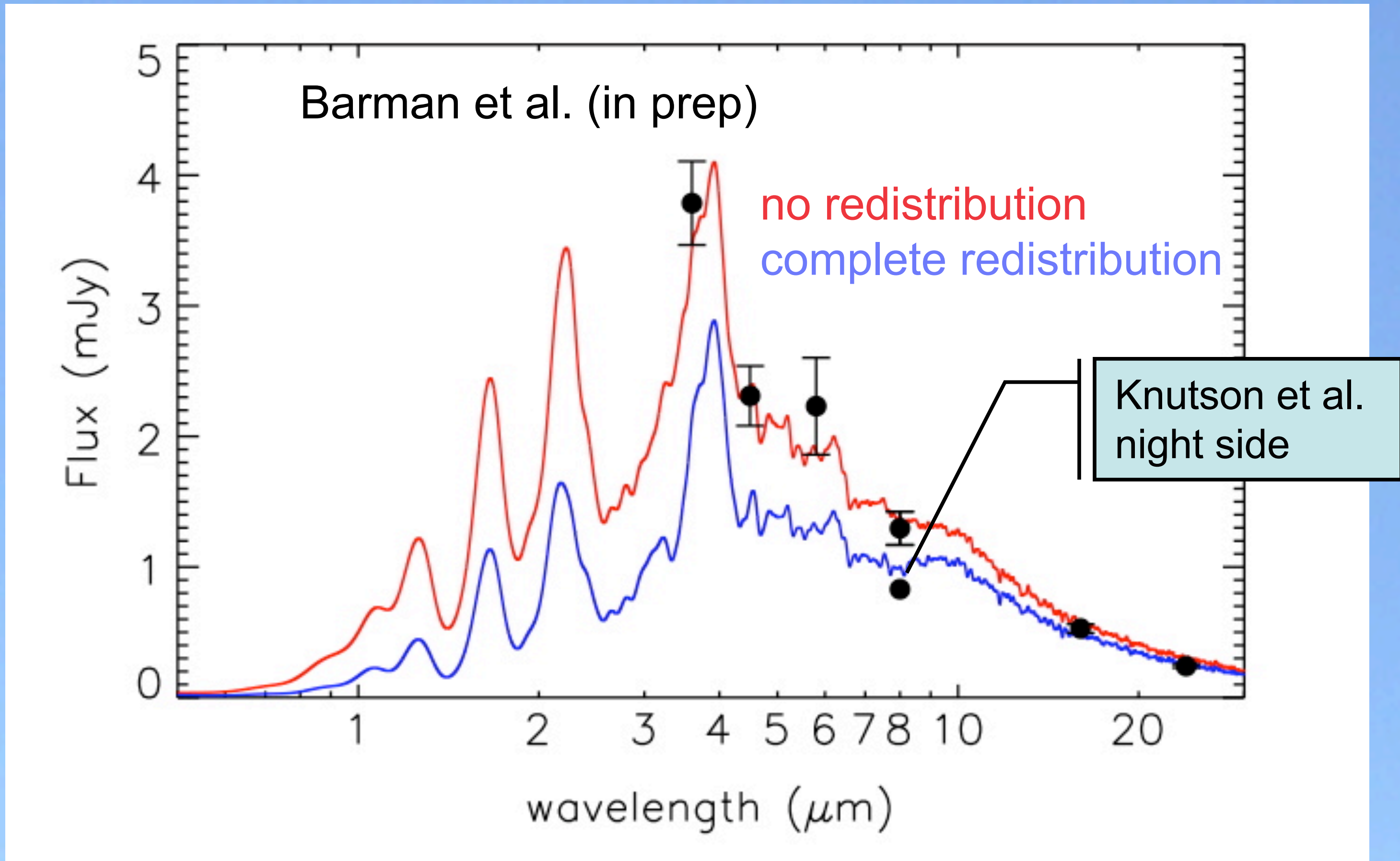




1.01
1.00
0.99
0.98
0.97
Relative Flux
a
Knutson et al. 2007
Nature (May 10)
60-sigma
detection
1.003
1.002
1.001
1.000
0.999
b
0.0
0.1
0.2
0.3
0.4
0.5
Orbital Phase

Spitzer photometry - 4 IRAC bands, + 16, 24 microns produces a broad-band spectrum

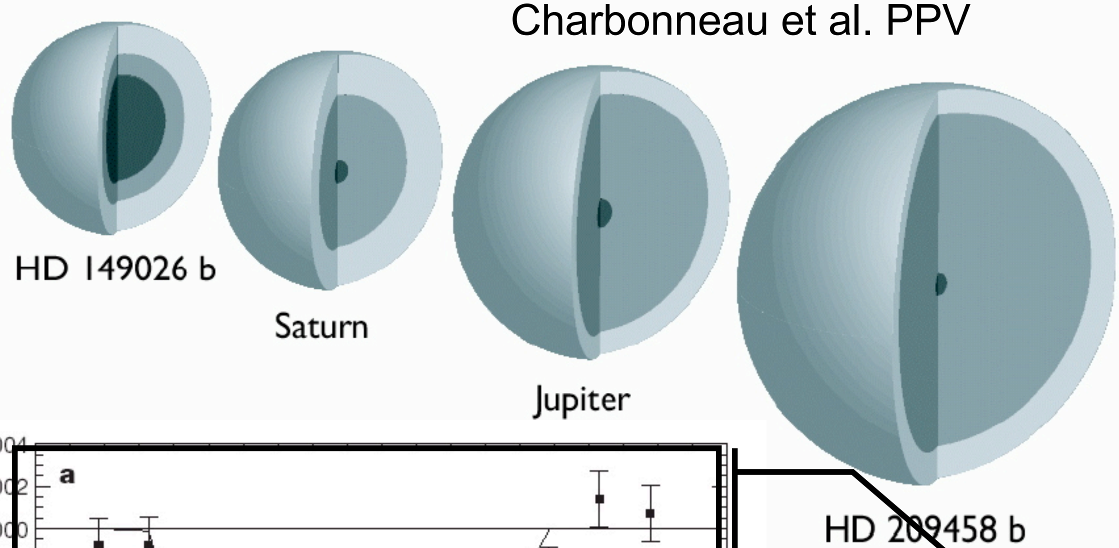


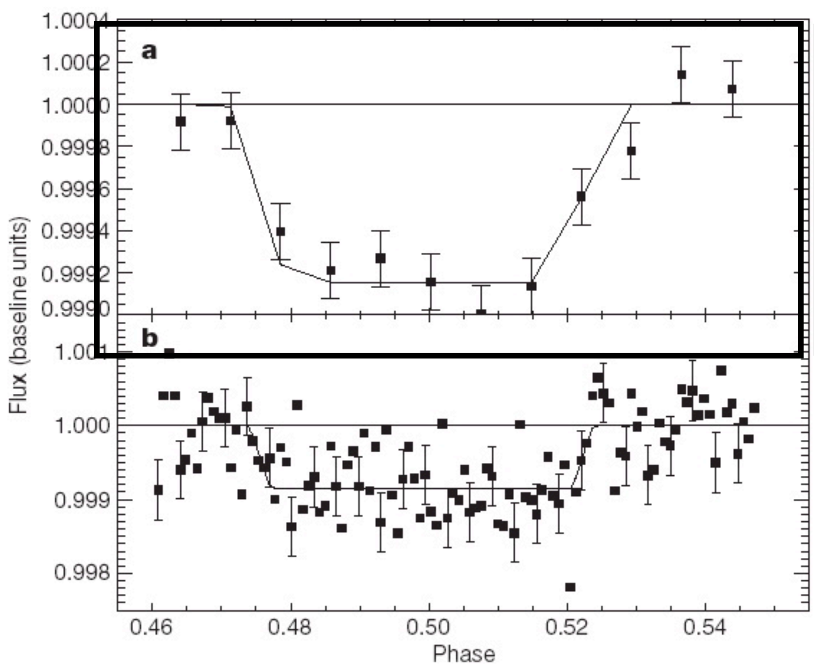


Barman: circulation is depth-dependent (stronger below ~ 0.1 bar) predicts H & K fluxes *below* the blue curve

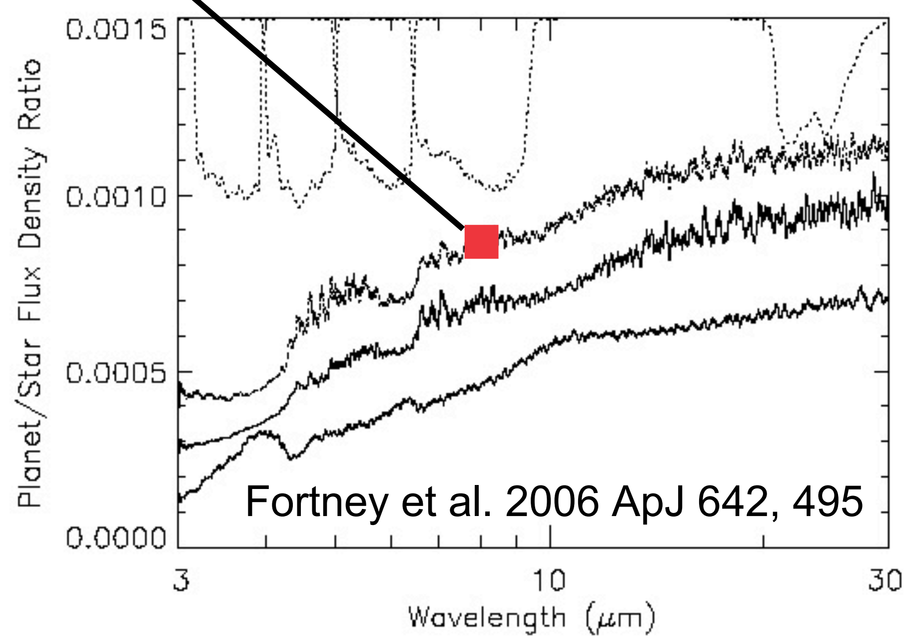
The Hottest Planet: HD 149026b

Charbonneau et al. PPV





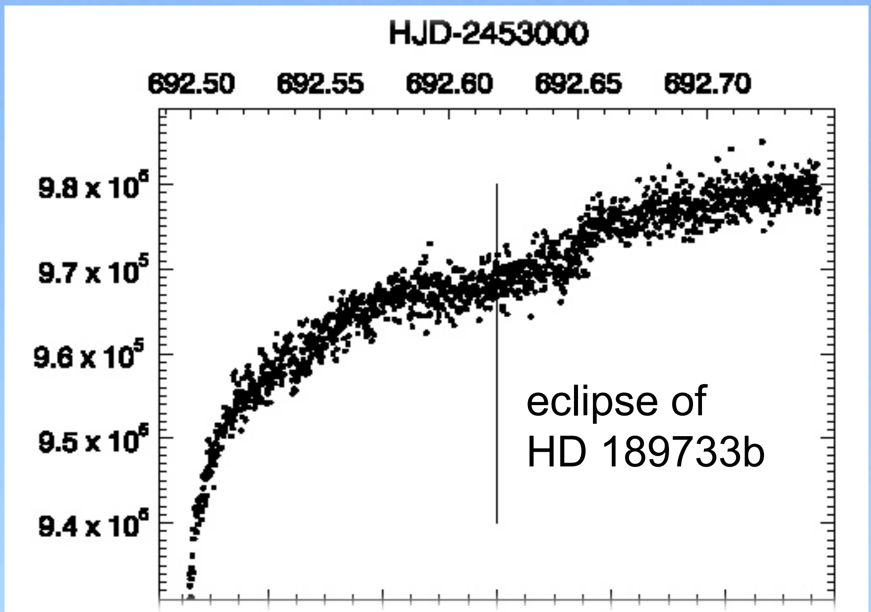
Harrington et al. 2007 Nature 447, 691

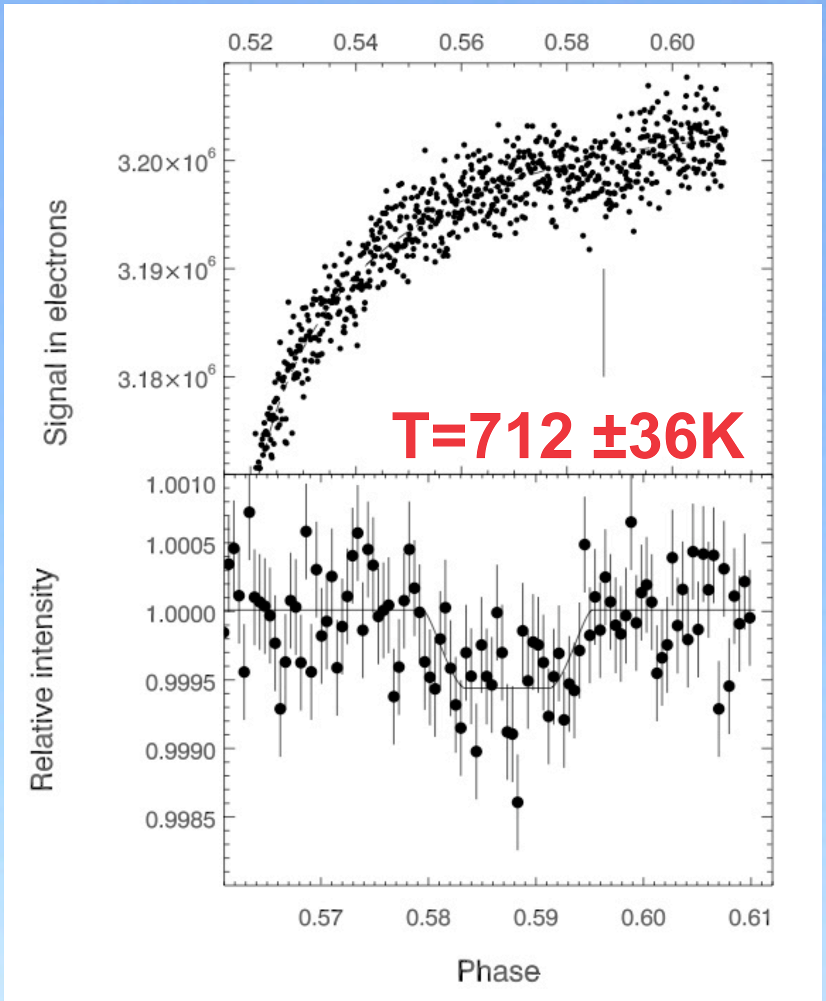


Fortney et al. 2006 ApJ 642, 495

Secondary eclipse of a *hot Neptune* (GJ436b)

(see astro-ph/0707.2778)





tidal heating?

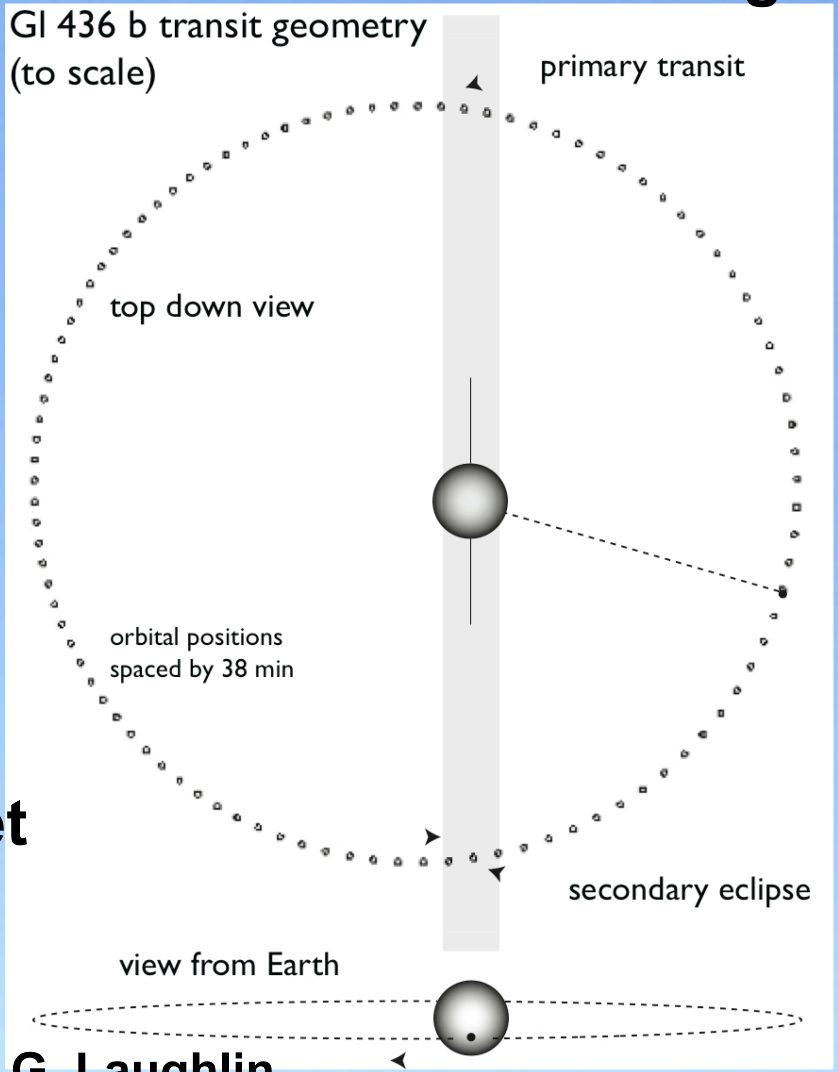
www.oklo.org

Teq = 640K

Tobs = 712 ± 36K
(with caveats...)

***If* the difference is tidal luminosity then**
Q ~ 7000

Requires a second planet to maintain *e*



G. Laughlin

Can Spitzer detect thermal emission from a super-Earth?

GJ 876d vs. 209458b

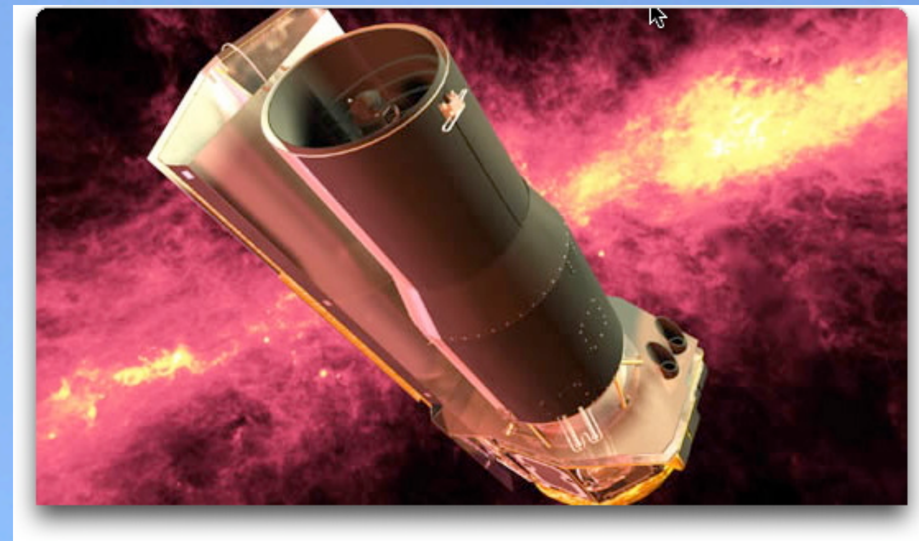
d= 5 pc	d = 47 pc
T ~ 800K	T~1200K
R ~ 0.1 Rj	R = 1.35Rj

Fluxes will be comparable..

But no eclipse

Spitzer spectra of two hot Jupiters:

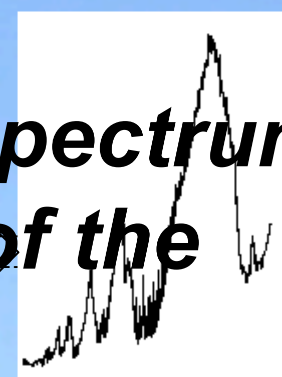
Richardson et al. Nature 445, 892
Grillmair et al. ApJ 658, L115
Swain et al. astro-ph/0702593



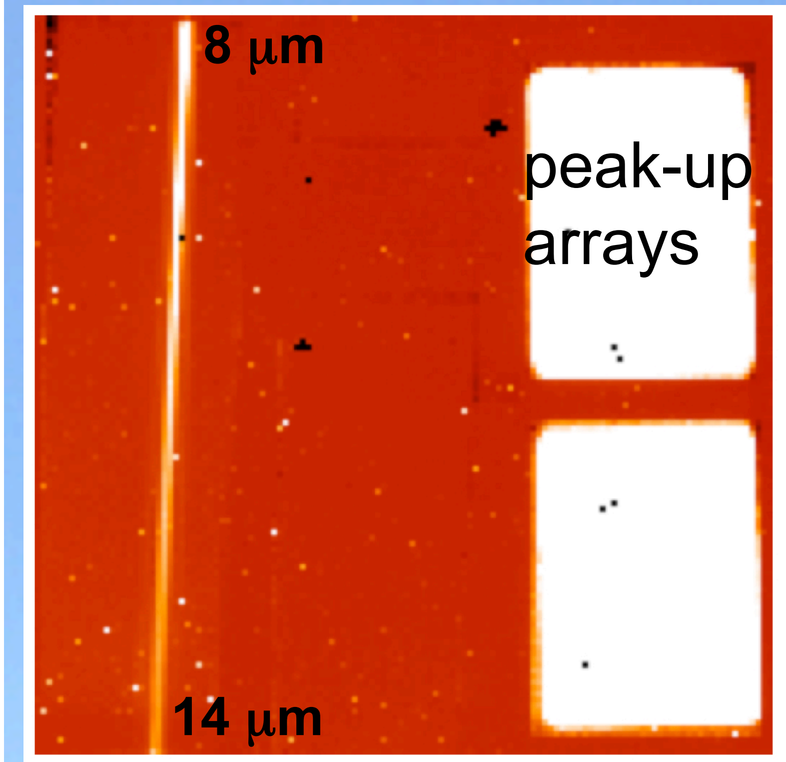
Observe spectru planet

But... we actually derive the spectrum from the wavelength dependence of the secondary eclipse amplitude

Subtract to derive planet spectrum



Observe stellar spectrum

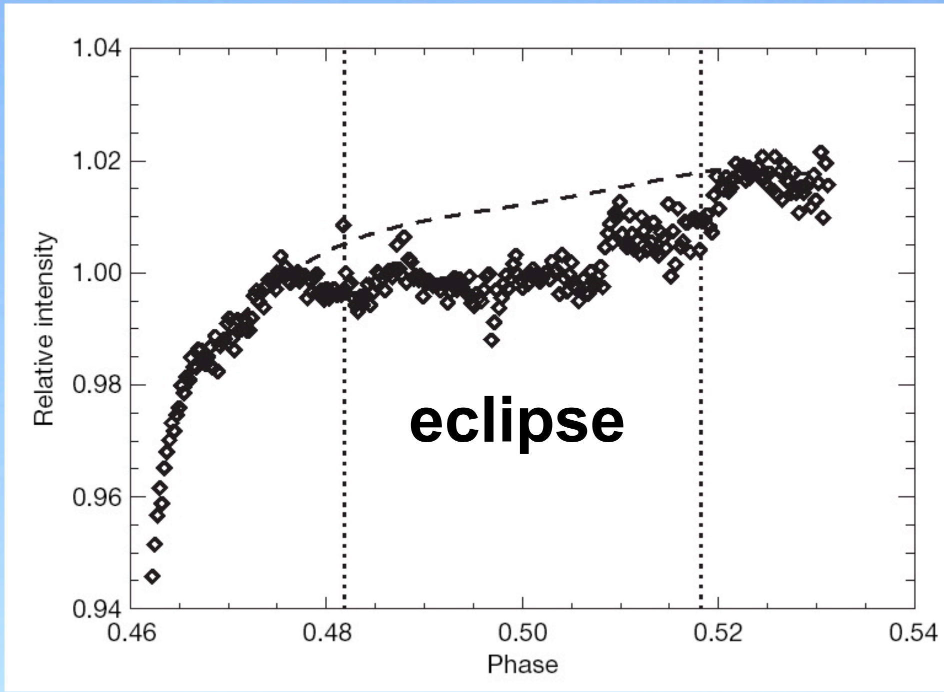


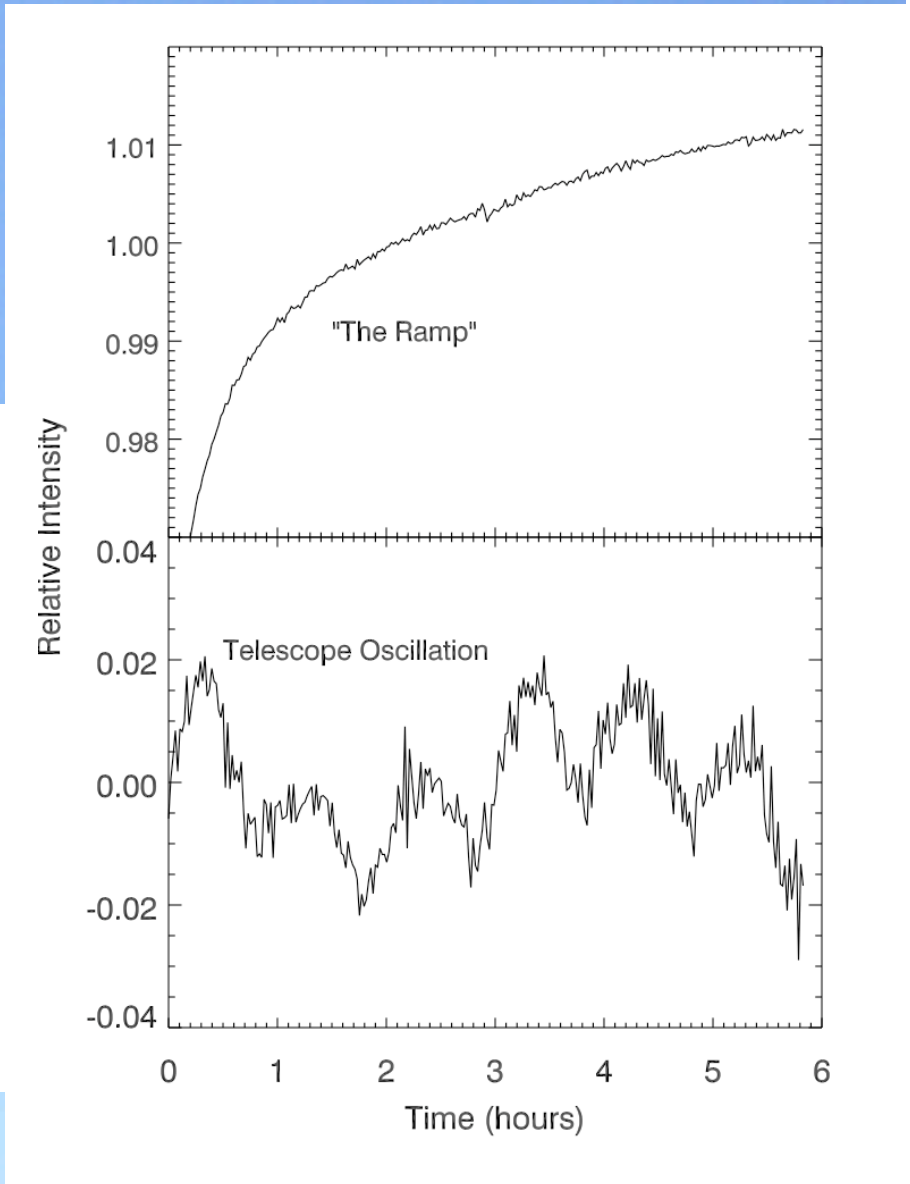
Spitzer/IRS observations of HD 209458b:

2 eclipses, 6-hours each; 7/2005
60-sec exposures; 280/eclipse
telescope nod at center of eclipse
$\lambda/\Delta\lambda \sim 100$

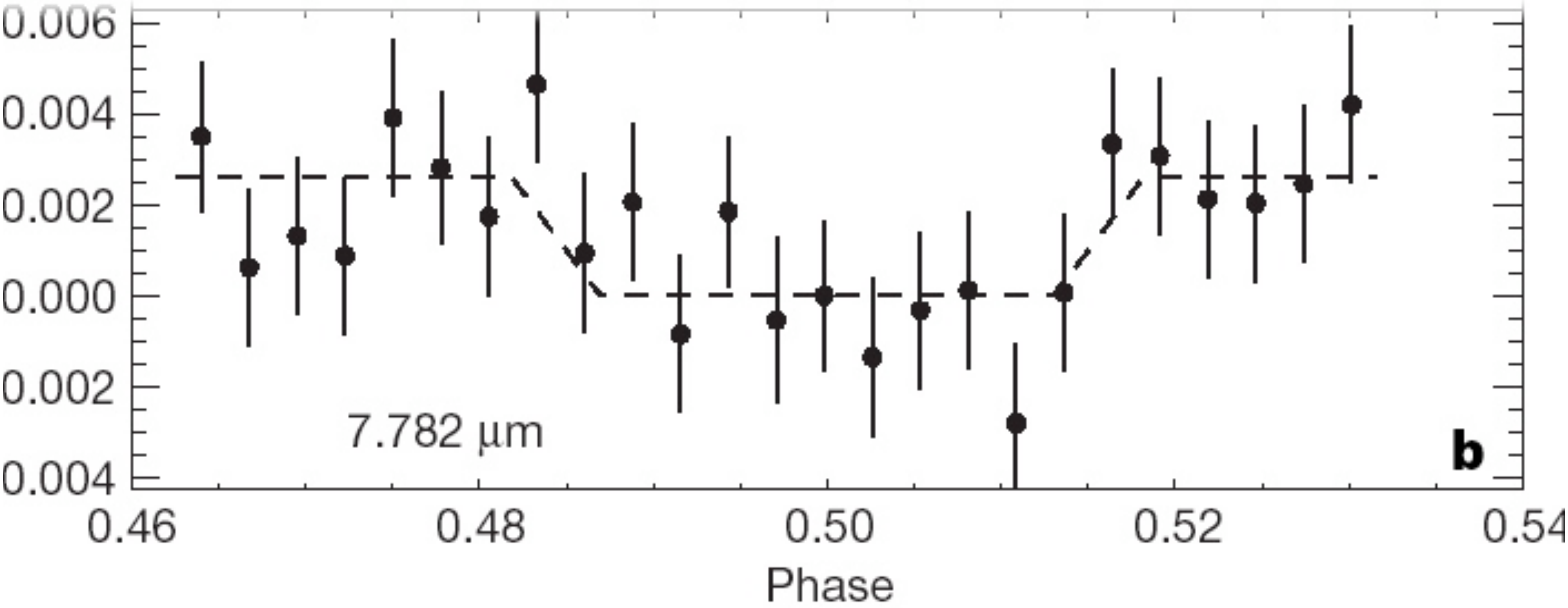
S/N in combined light:
~100 per pixel per spectrum
→ S/N ~ 100 sqrt(280)/sqrt(2)
~ 1200 star+planet
~ 4 on planet...!
photon-limited

Our analysis corrects for two instrument & telescope effects

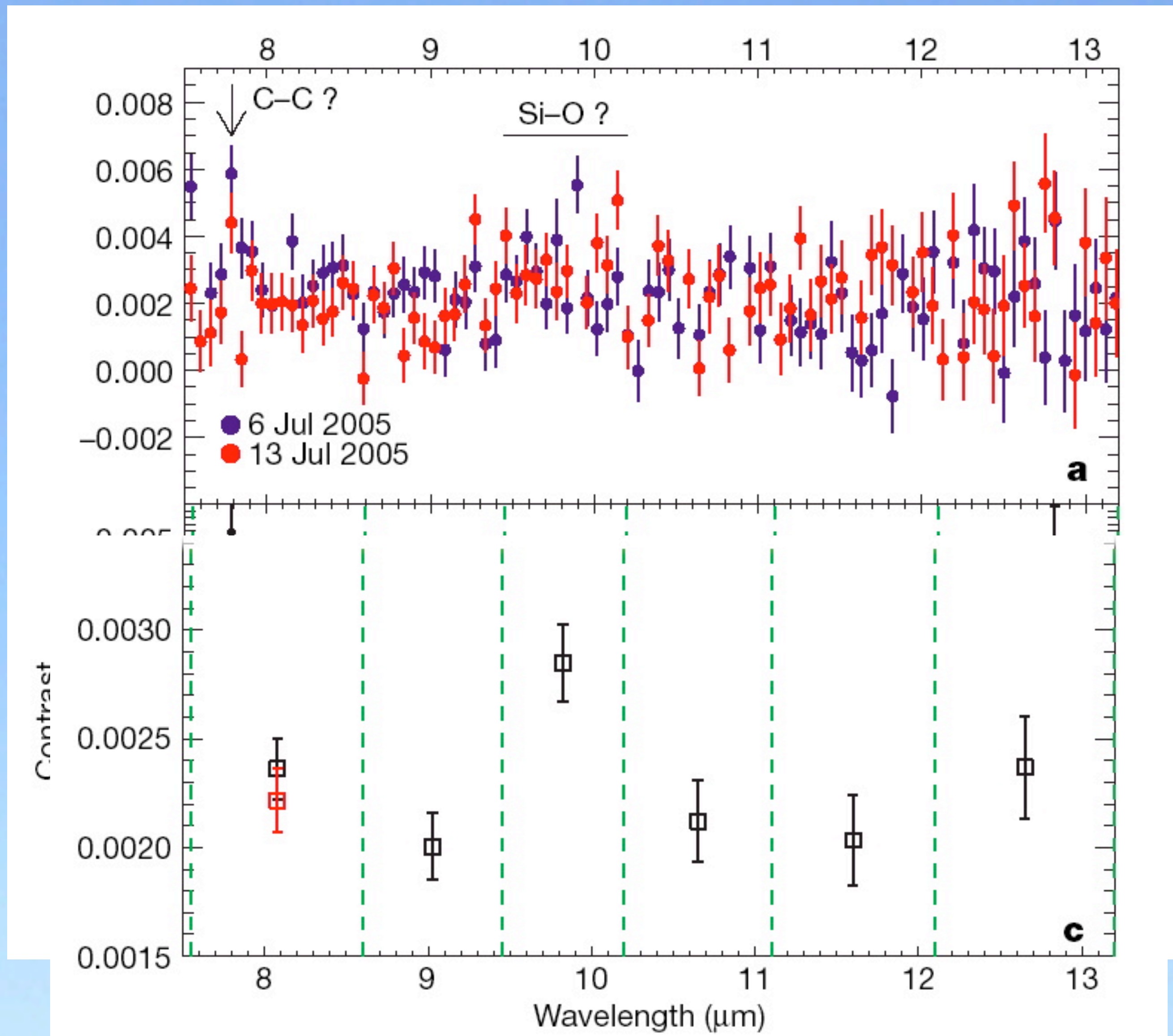




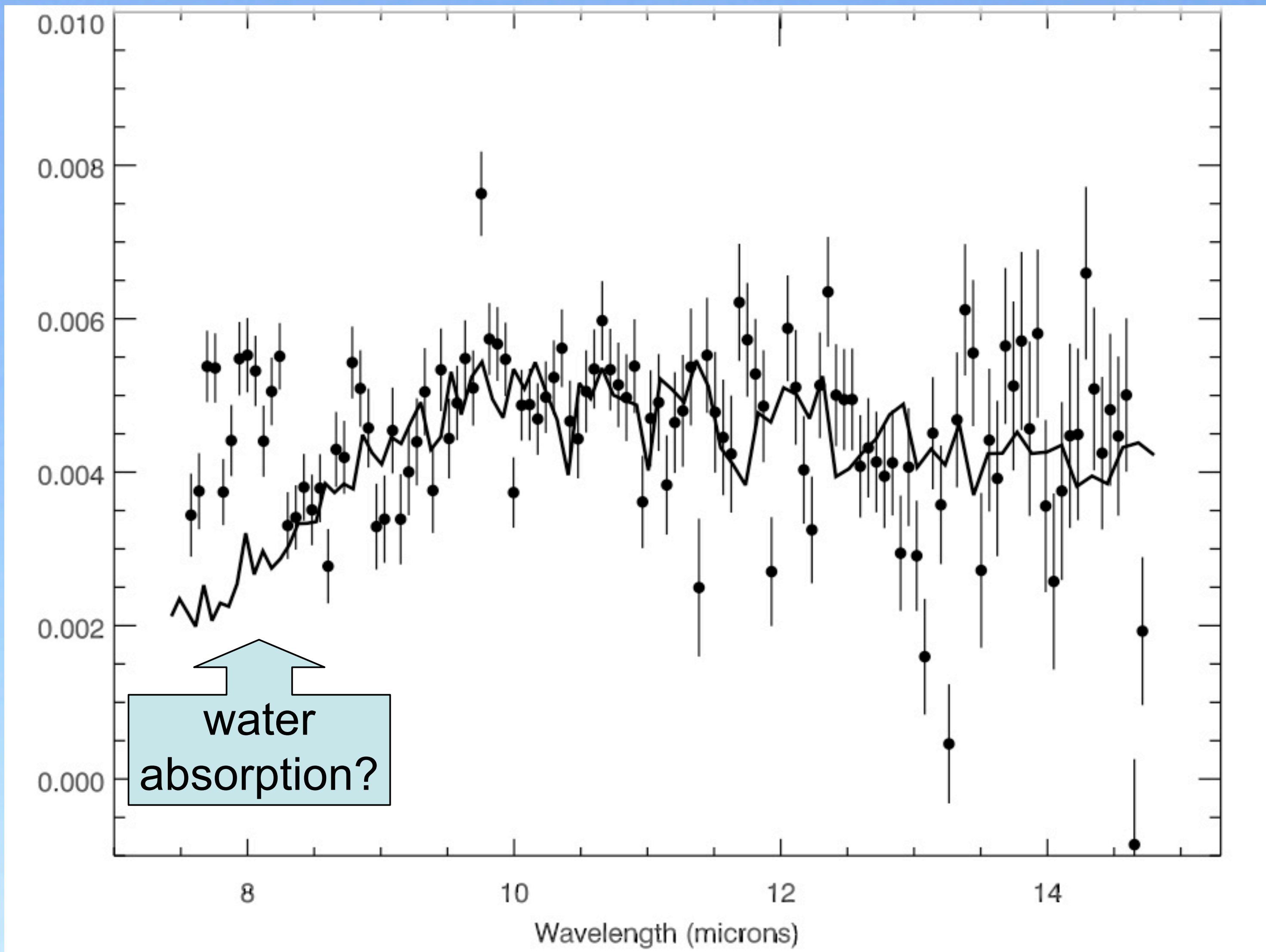
Method of analysis:



Results...



Grillmair et al. results for 189733b:



Candidate explanations for lack of water absorption:

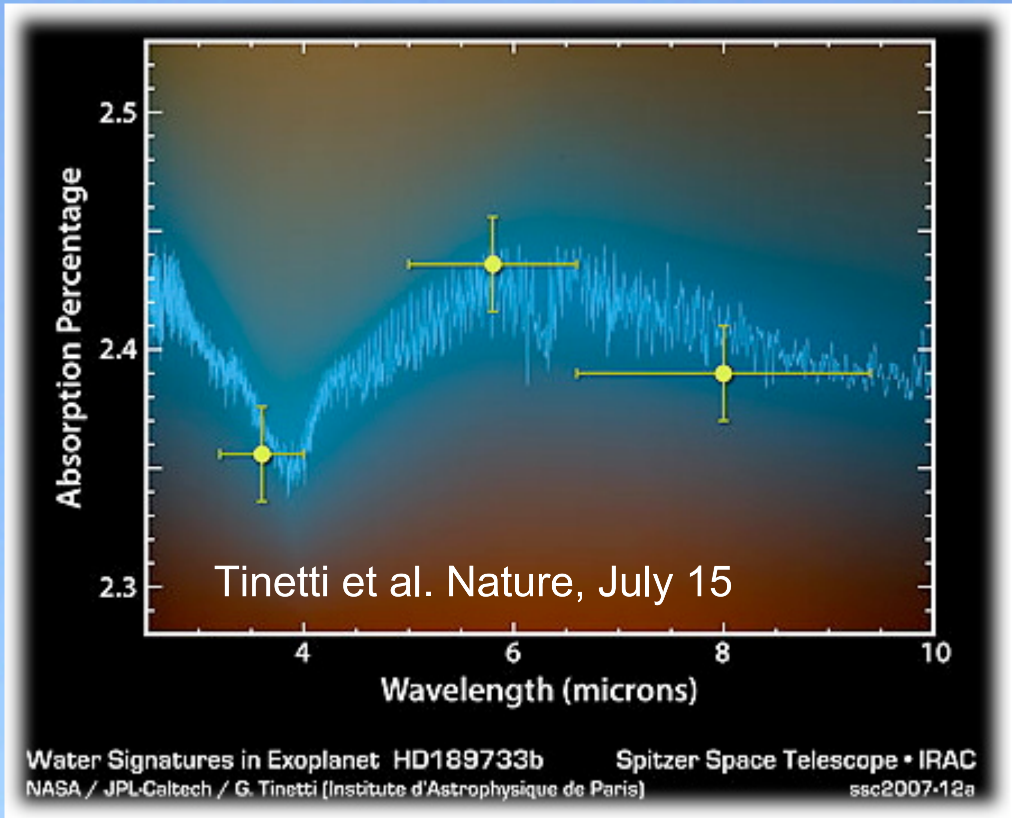
~~**Planet(s) have no water**~~

Masked by high clouds

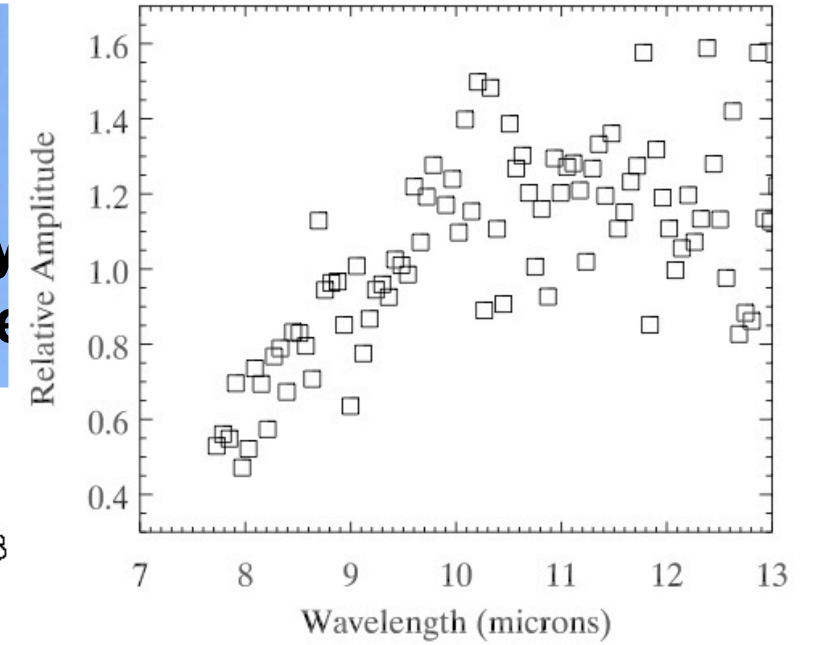
Temperature gradient perturbation

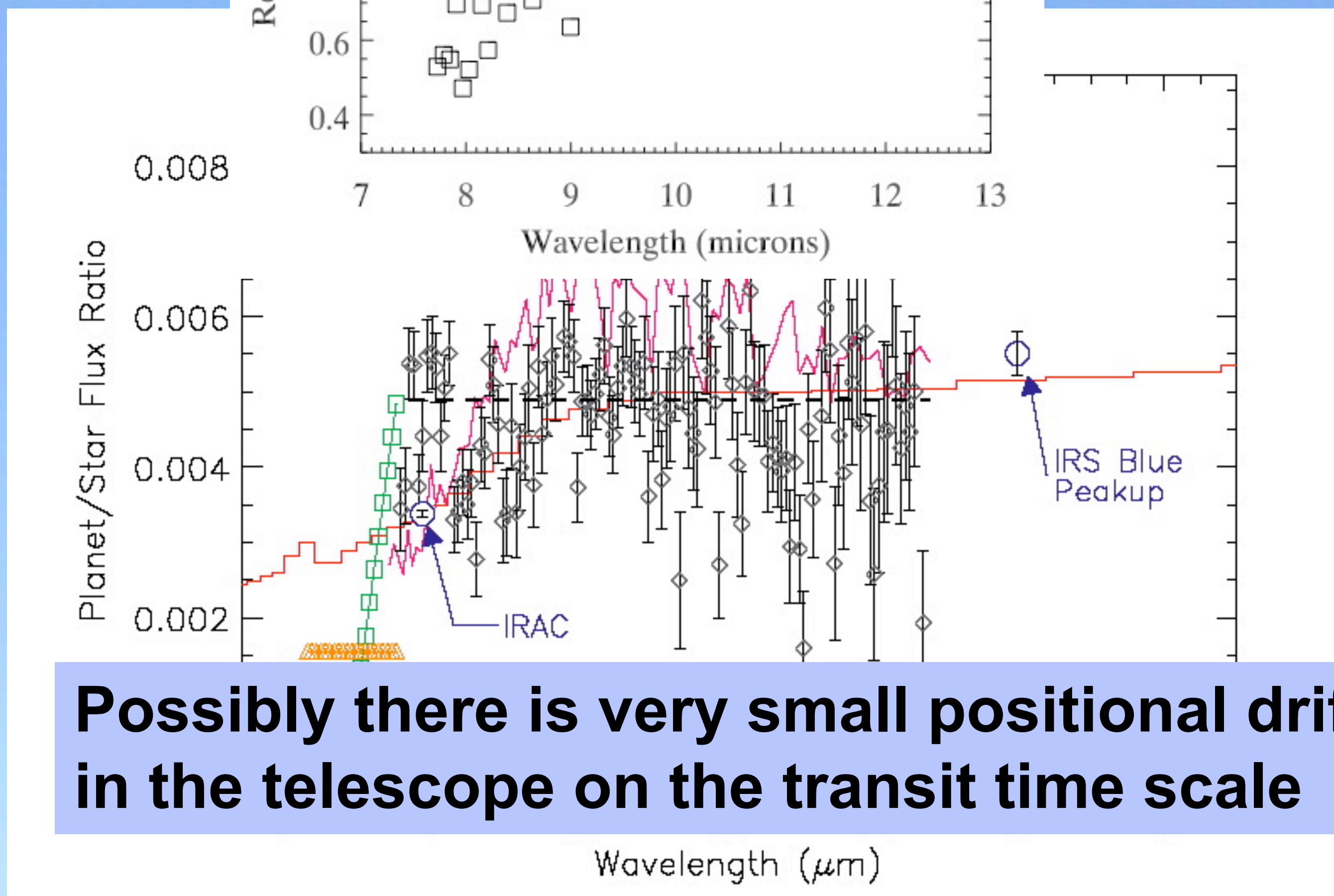
Water is seen in absorption during transit

Instrumental systematics?



Fortney [...] n/0705.2457) point out a se[...] e Spitzer data

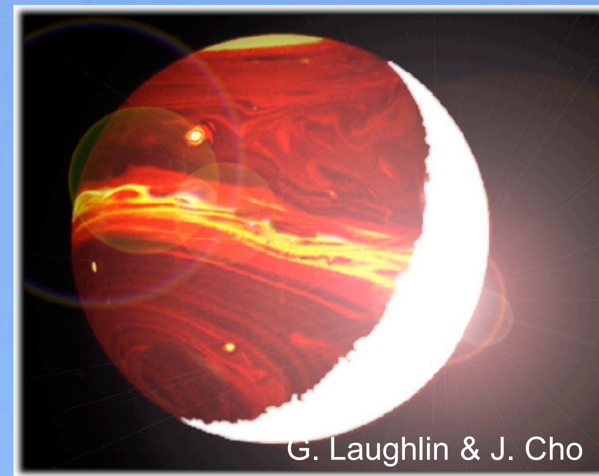




Possibly there is very small positional drift in the telescope on the transit time scale

Summary:

Spitzer secondary eclipse photometry attains high S/N, so we can....



measure broad-band spectra of hot Jupiters
- learn about their composition, circulation

extend the Spitzer measurements to:
- hot Neptunes
- hot super-Earths

exploit eclipses to do spectroscopy ($\lambda/\Delta\lambda \sim 100$)
- emission features in HD 209458b
- we do not see water absorption from 7 to 8 μm
- some inconsistencies remain

Many more Spitzer observations are underway in GO-4