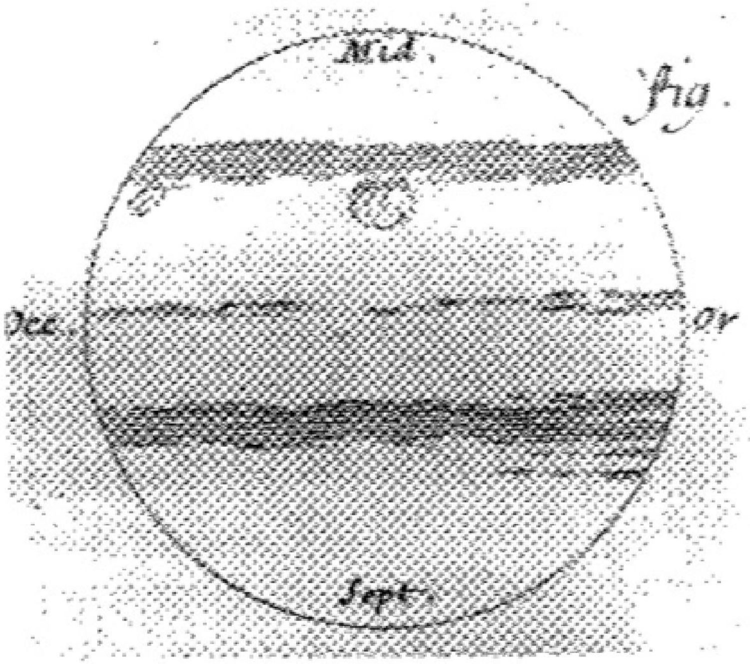
Observations of Gas-Giant Exoplanet Atmospheres

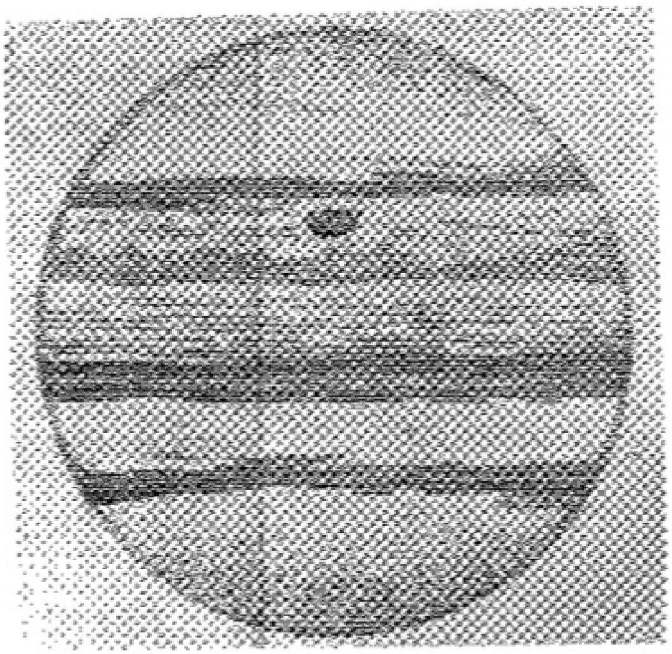

http://en.wikipedia.org/wiki/File:UpsilonAndromedae_D_moons.jpg

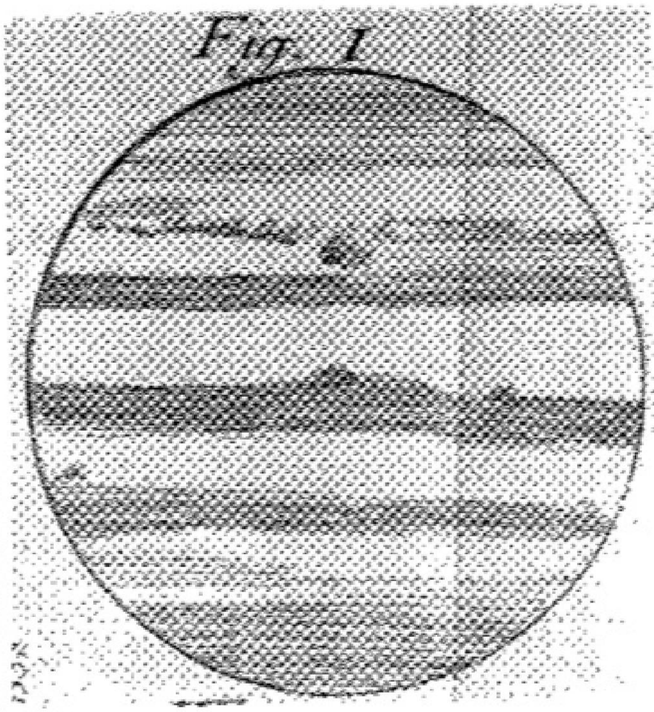
Brian Jackson - NASA/GSFC

Earliest Observations of a Jovian atmosphere



(A)


(B)



(C)

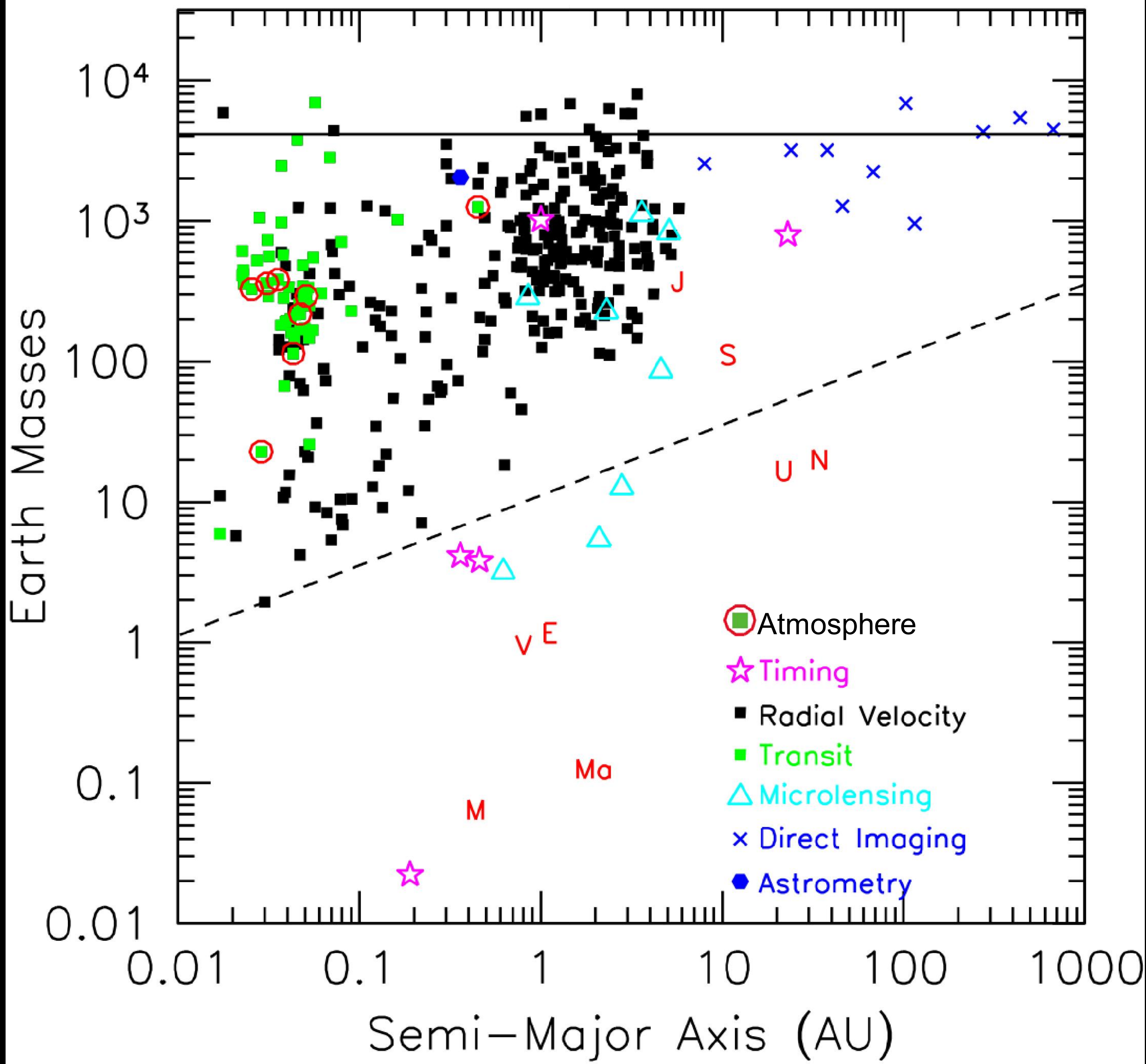
From Rogers (1995) The Giant Planet Jupiter.

Earliest Observations of Jupiter's Weather

"Campani affirms he hath observed by the goodness of his glasses certain protuberancies and inequalities, much greater than those that have been seen therein hitherto. He addeth, that he is now observing whether those sallies in the said planet do not change their scituation ….

The ingenious Mr. Hook did, some moneths since, intimate to a friend of his that he had observed some days before he then spoke of it a small spot in [one of the] belts …"

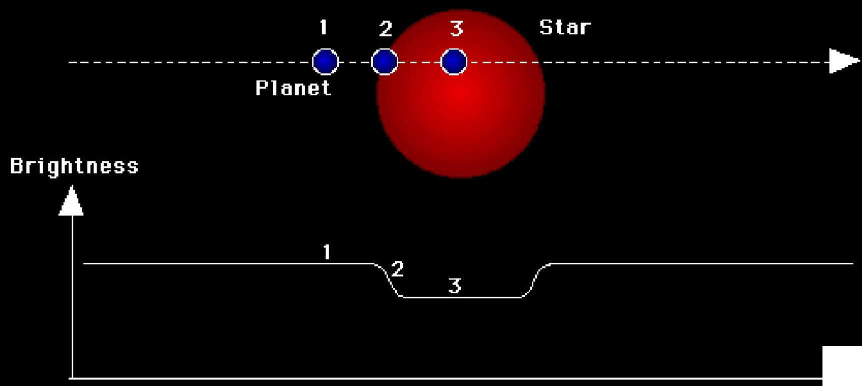
From Rogers (1995) <u>The Giant Planet Jupiter</u>.



Deming & Seager review in Nature 462, 301 (2009)

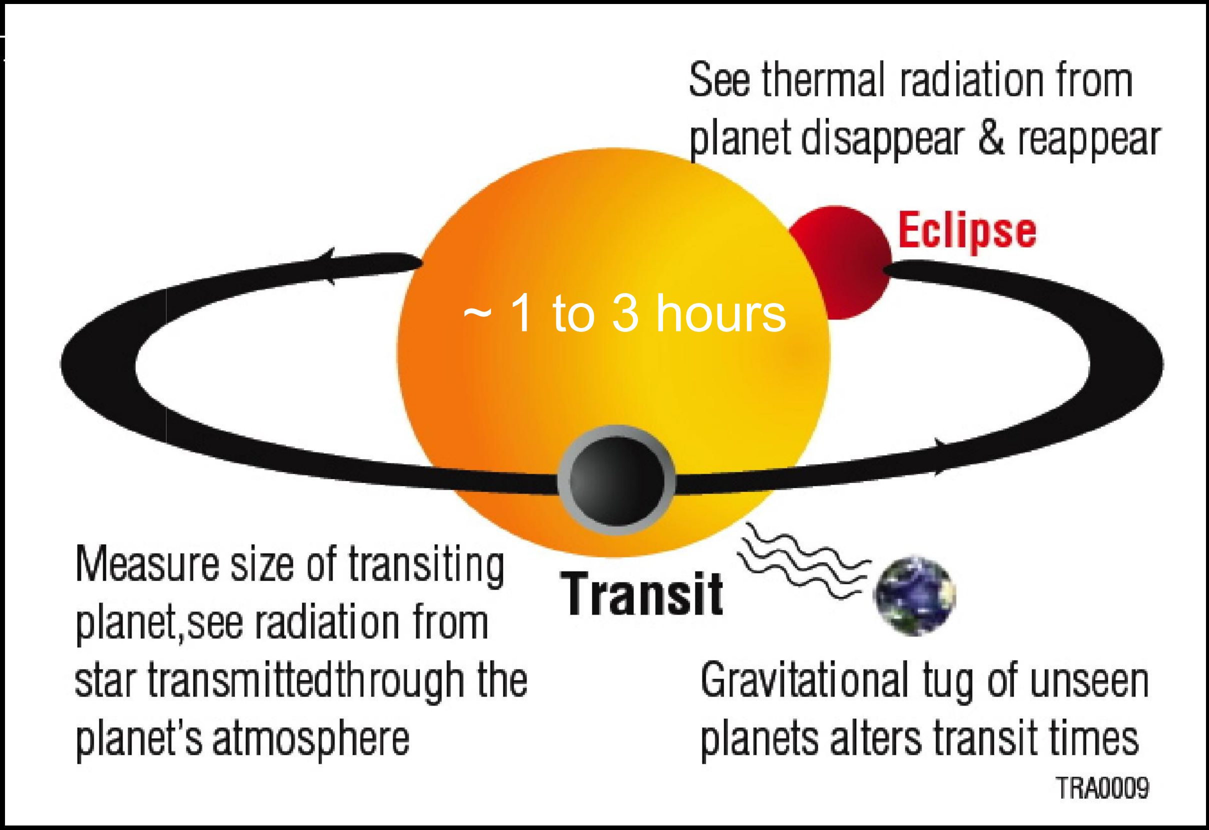
Also, Seager & Deming ARAA (2010), astro-ph/1005.4037

Exploit *transits* to characterize exoplanet atmospheres…



Transits require photometric stability

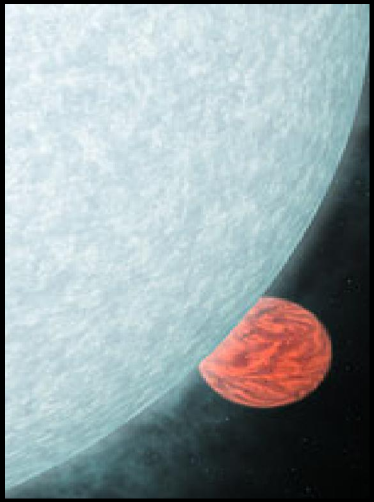
But tolerate poor image quality

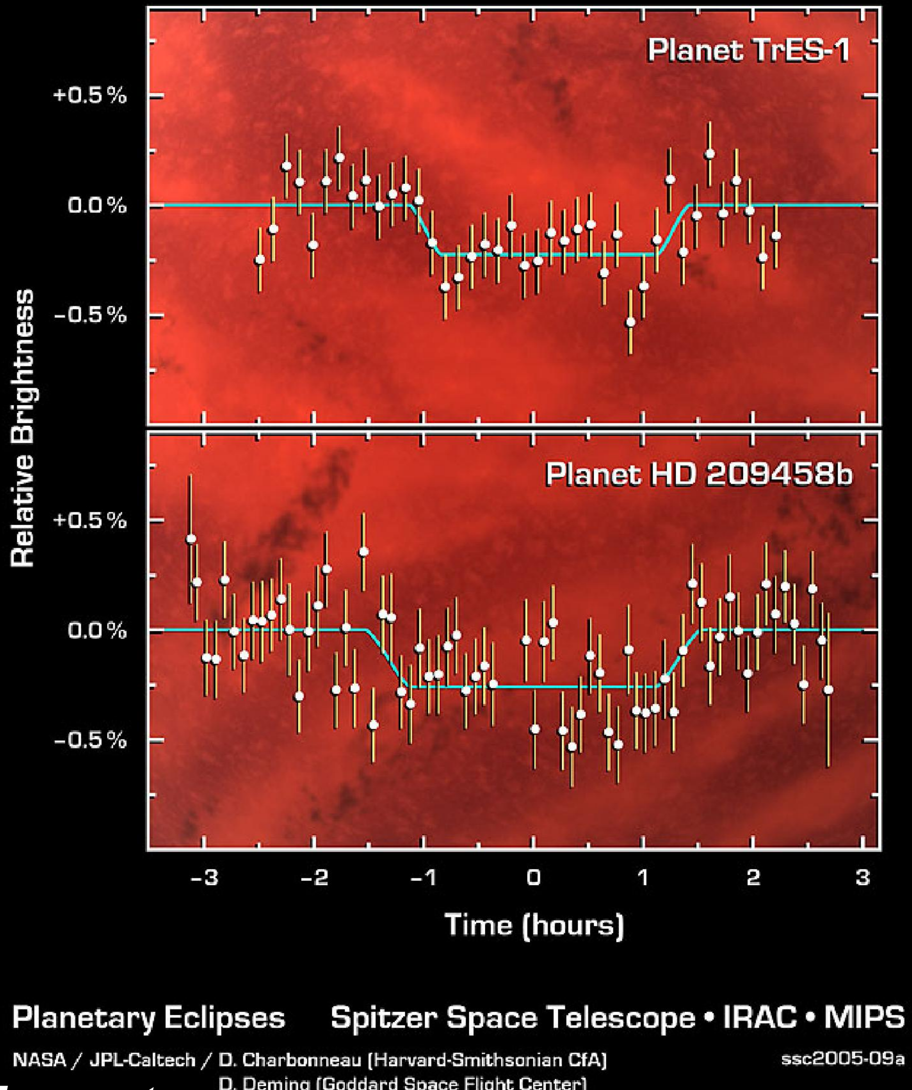


"First Light" Thermal Emission

Spitzer enables direct detection of IR light from the planets

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





Six Spitzer photometric bands can give a low resolution spectrum of the planet

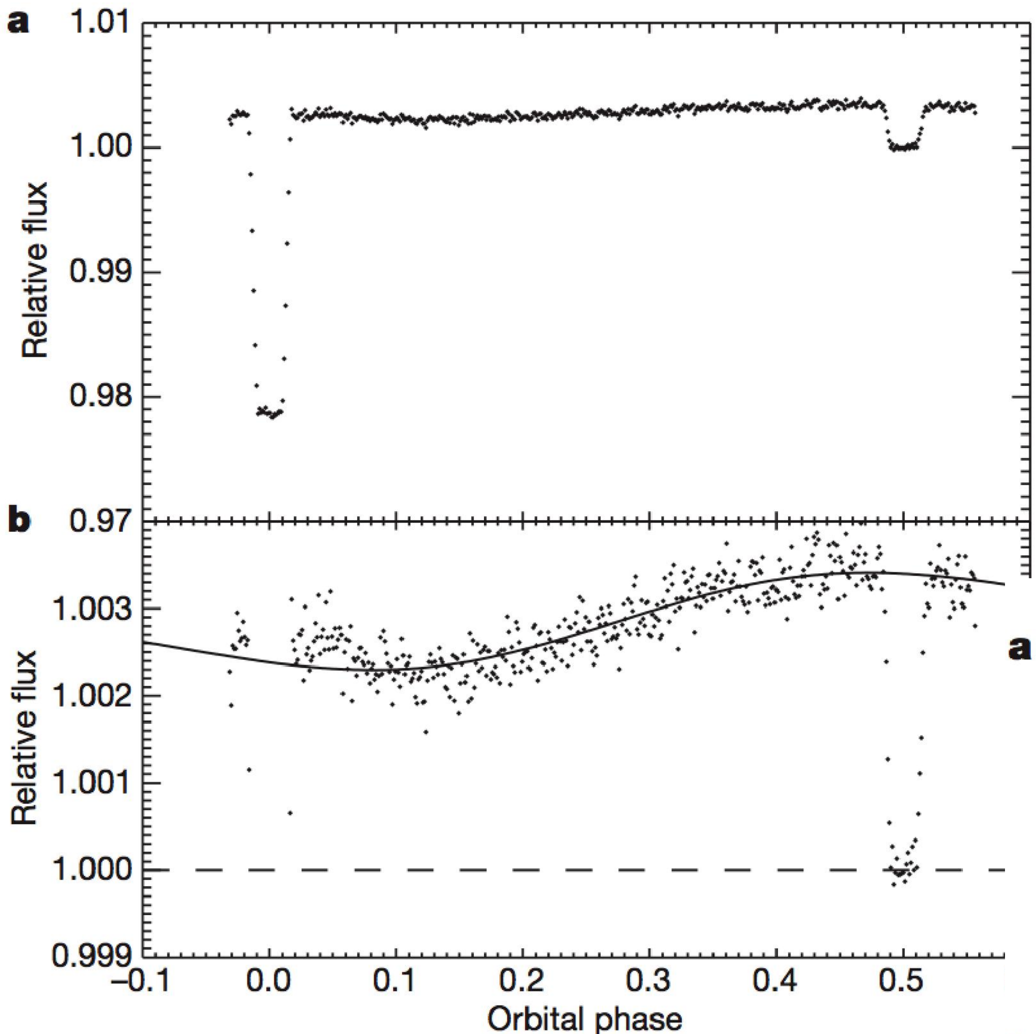
“First Light” Thermal Emission

…Charbonneau found himself locked in a race with Deming to be the first to detect the … secondary eclipse….

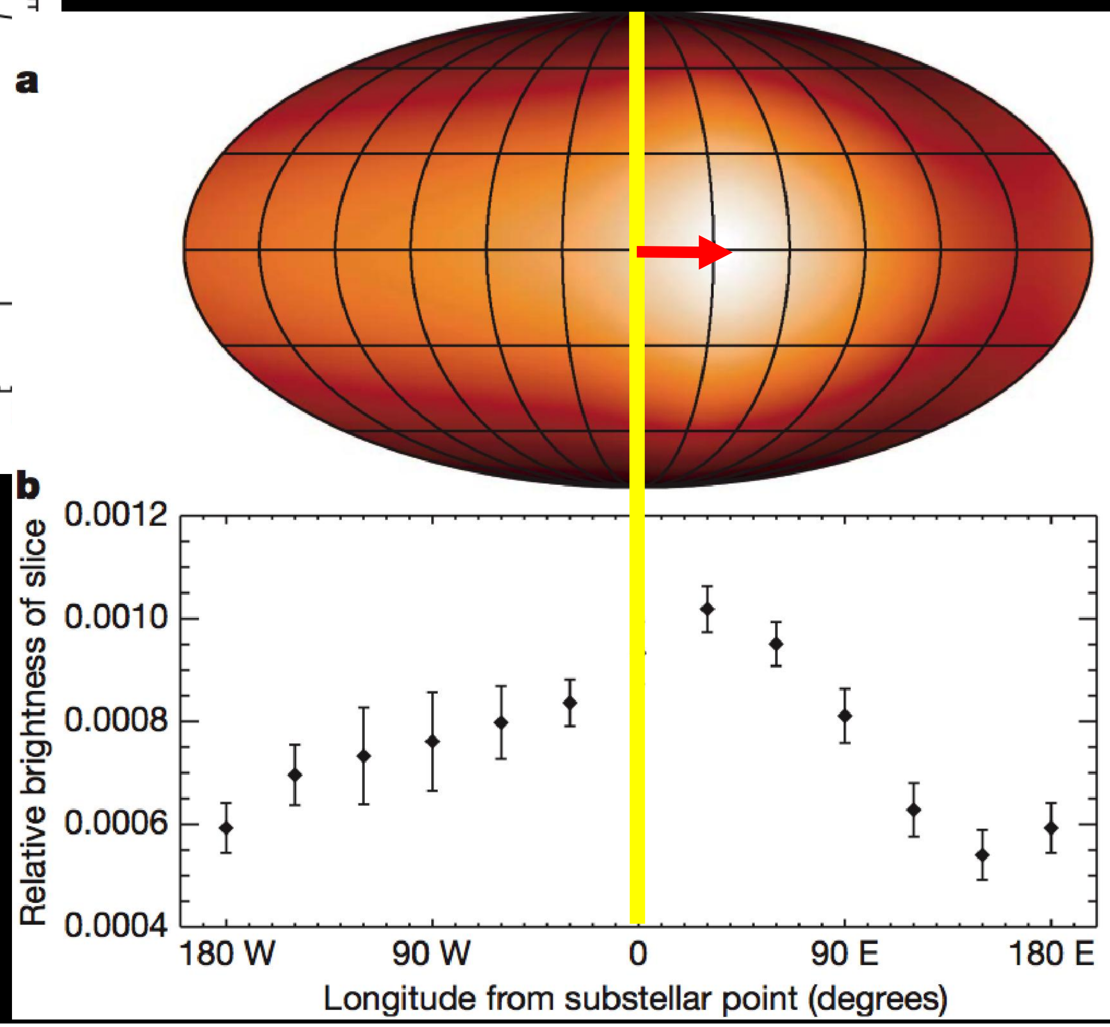
…Deming … was observing HD 209458 b, with the Spitzer Space Telescope…. Charbonneau, he knew, had collected data on [TrES-1] … a month earlier. “We didn't want to be second,” Deming recalls. “I was analyzing data while I was eating Christmas dinner. I had to catch Dave.”

In the end they published papers simultaneously and held a joint press conference.

--http://discovermagazine.com/2008/nov/10-how-long-until-we-find-a-second-earth/article_view?b_start:int=2&-C=

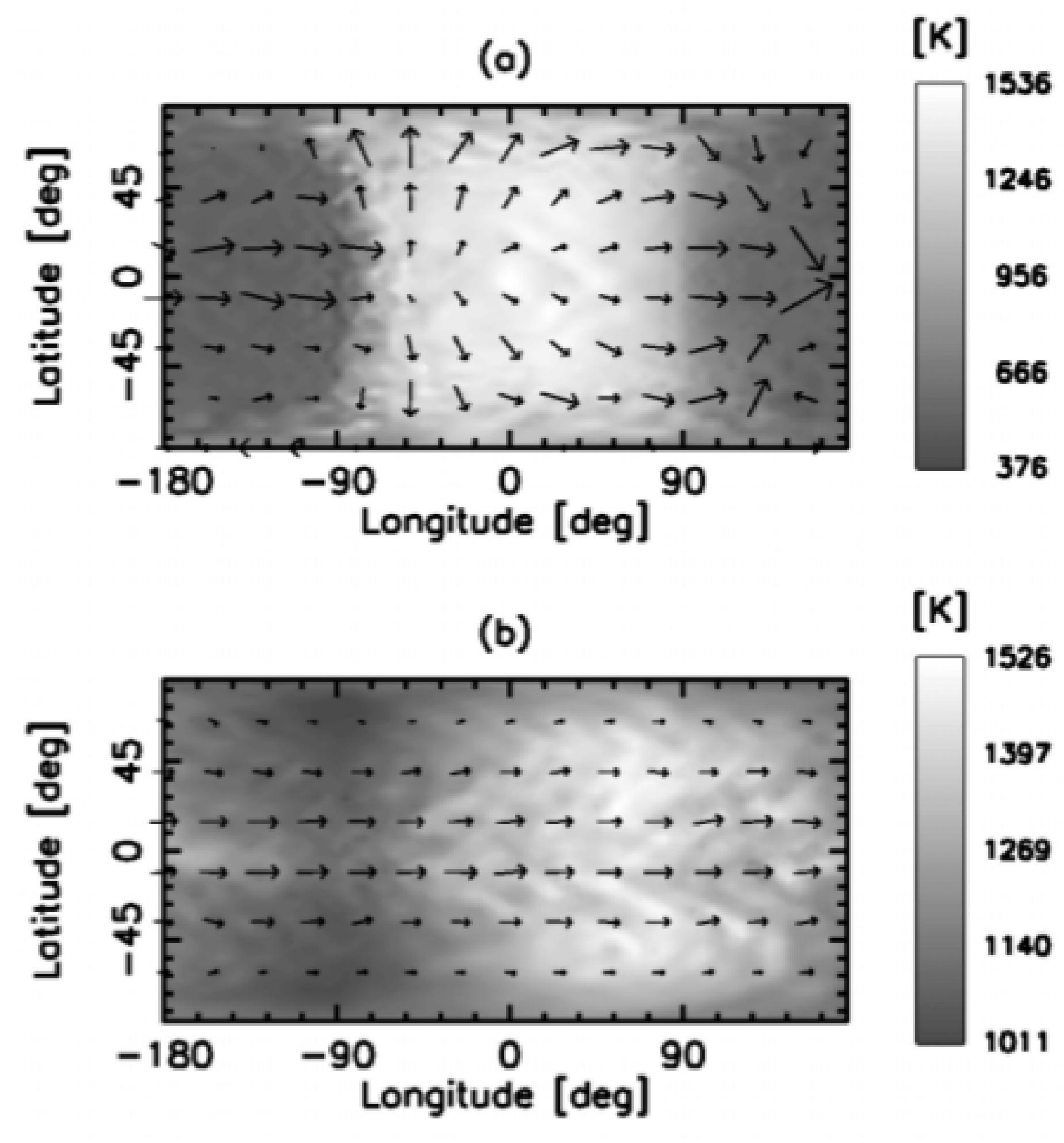


Knutson et al. (2007)
HD 189733 b
33 hrs of Spitzer time

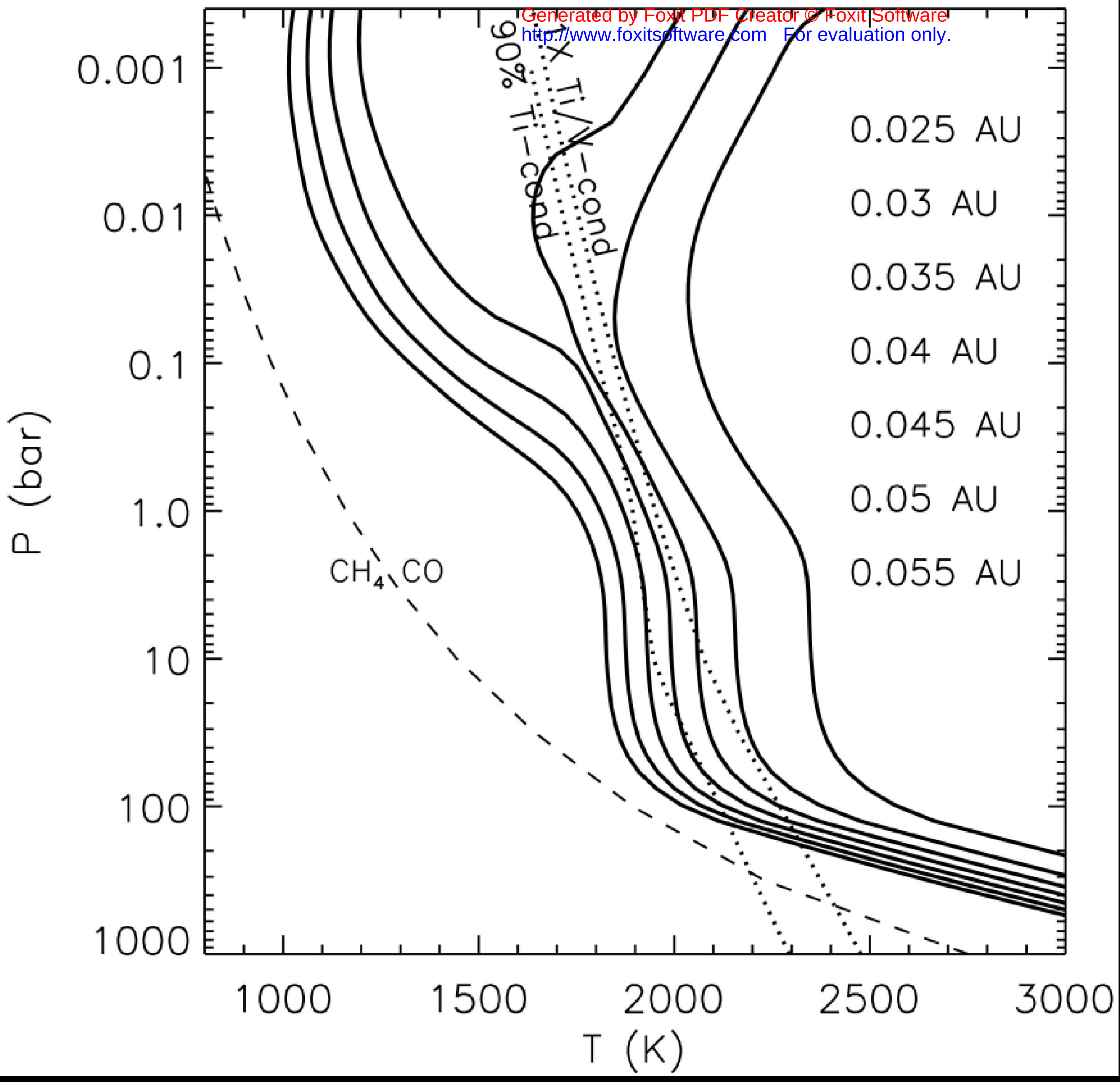


$$\tau_{\rm rad} \sim \frac{P}{g}\frac{c_P}{4\sigma T^3}$$

$$\tau_{\rm advec} = \frac{R_p}{U}$$

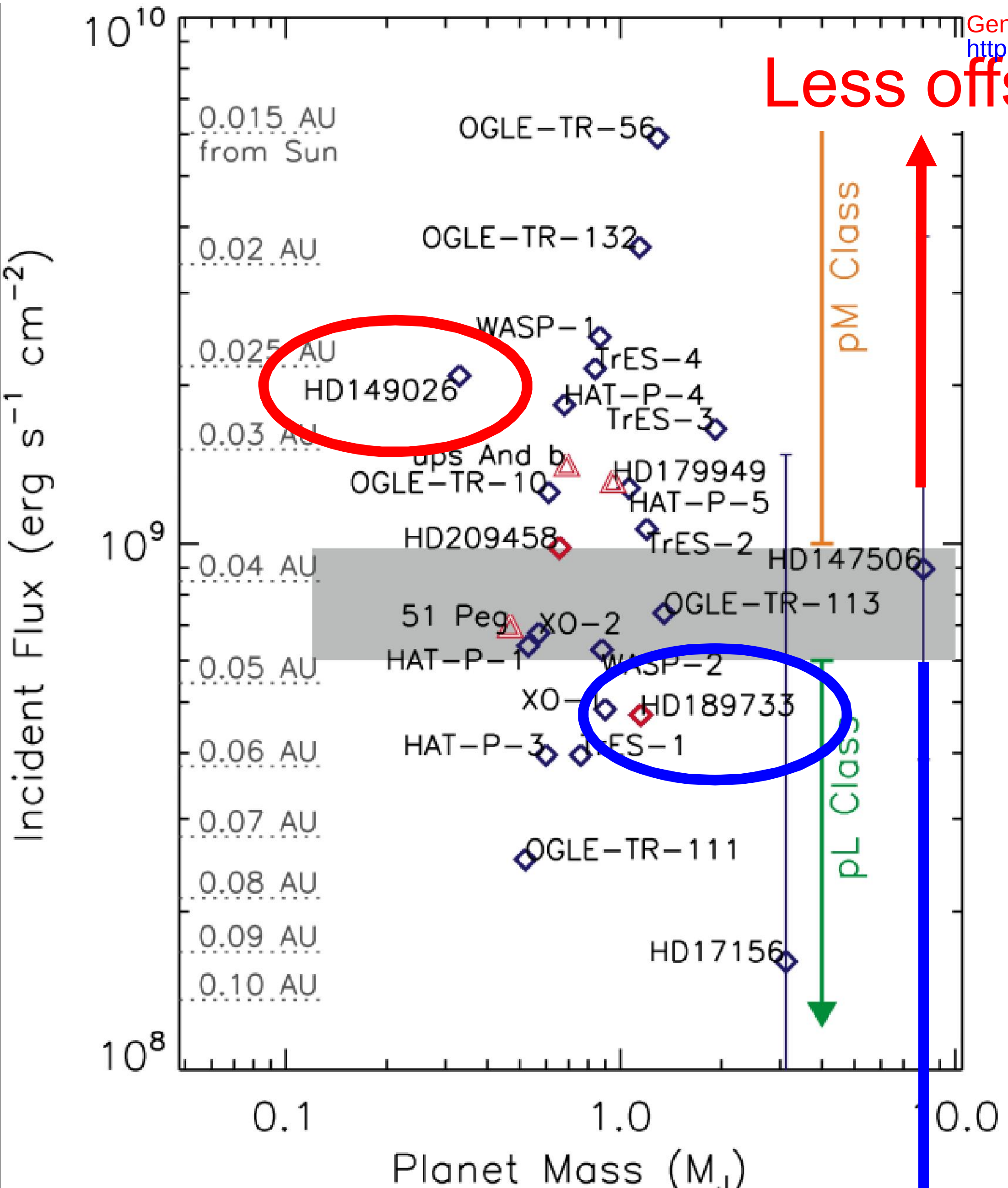


Cooper & Showman (2005)

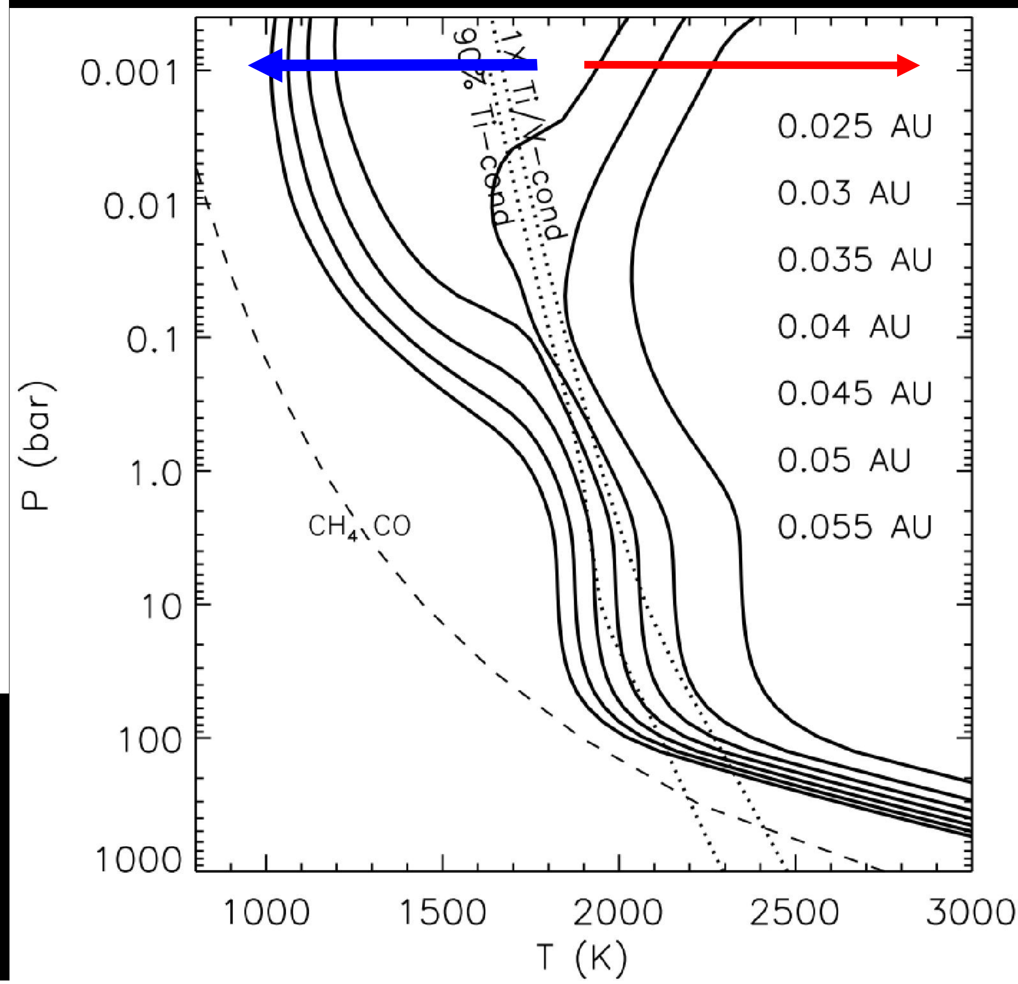


Fortney et al. (2003)

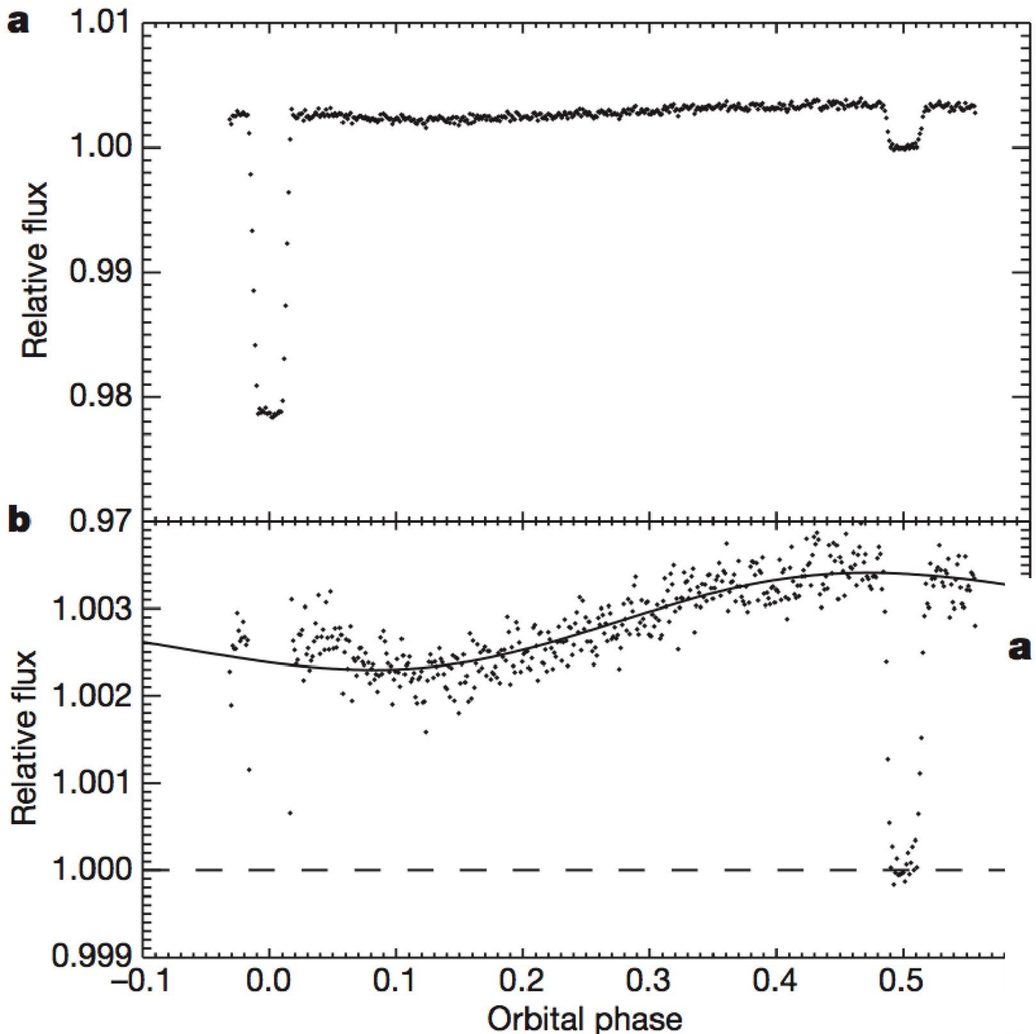
Less offset

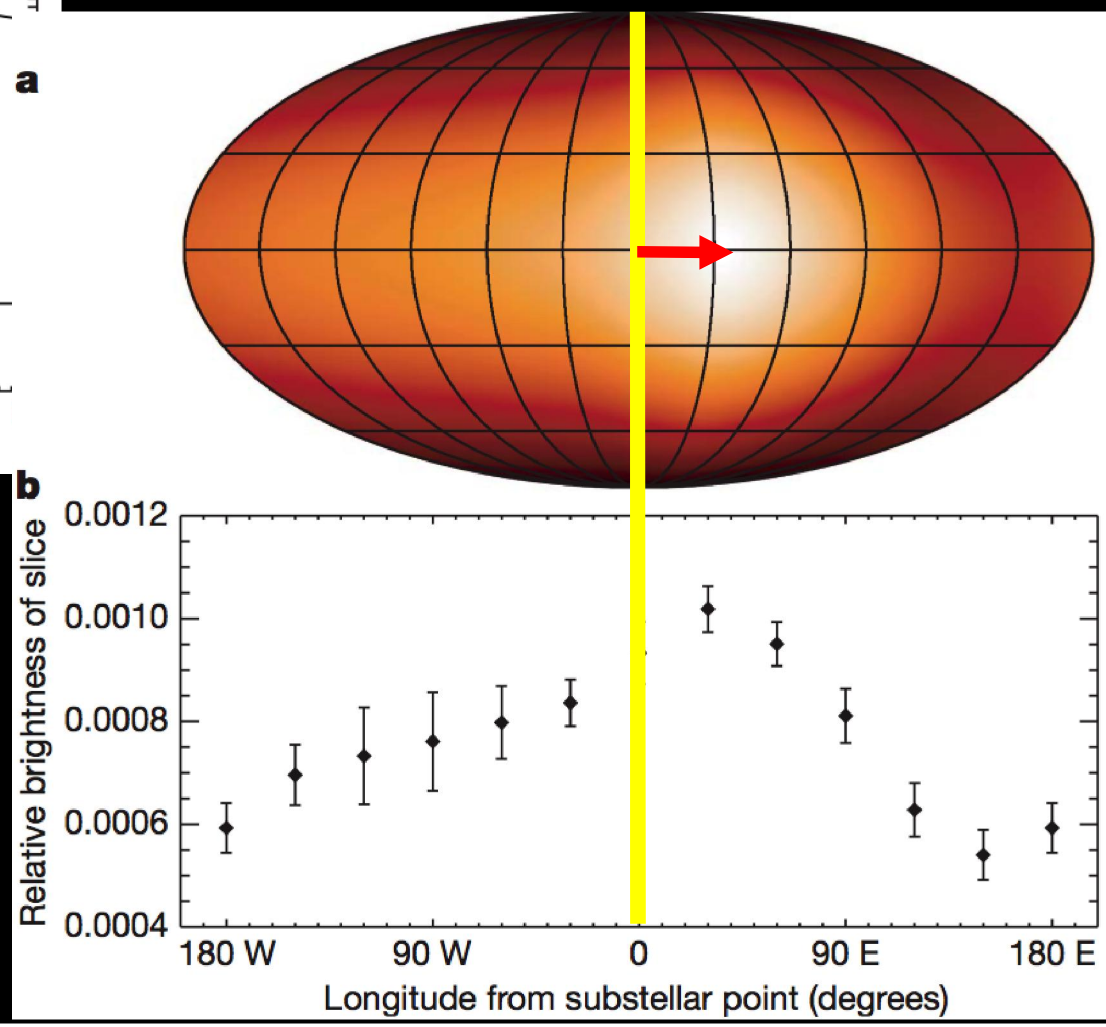


Fortney et al. (2003)

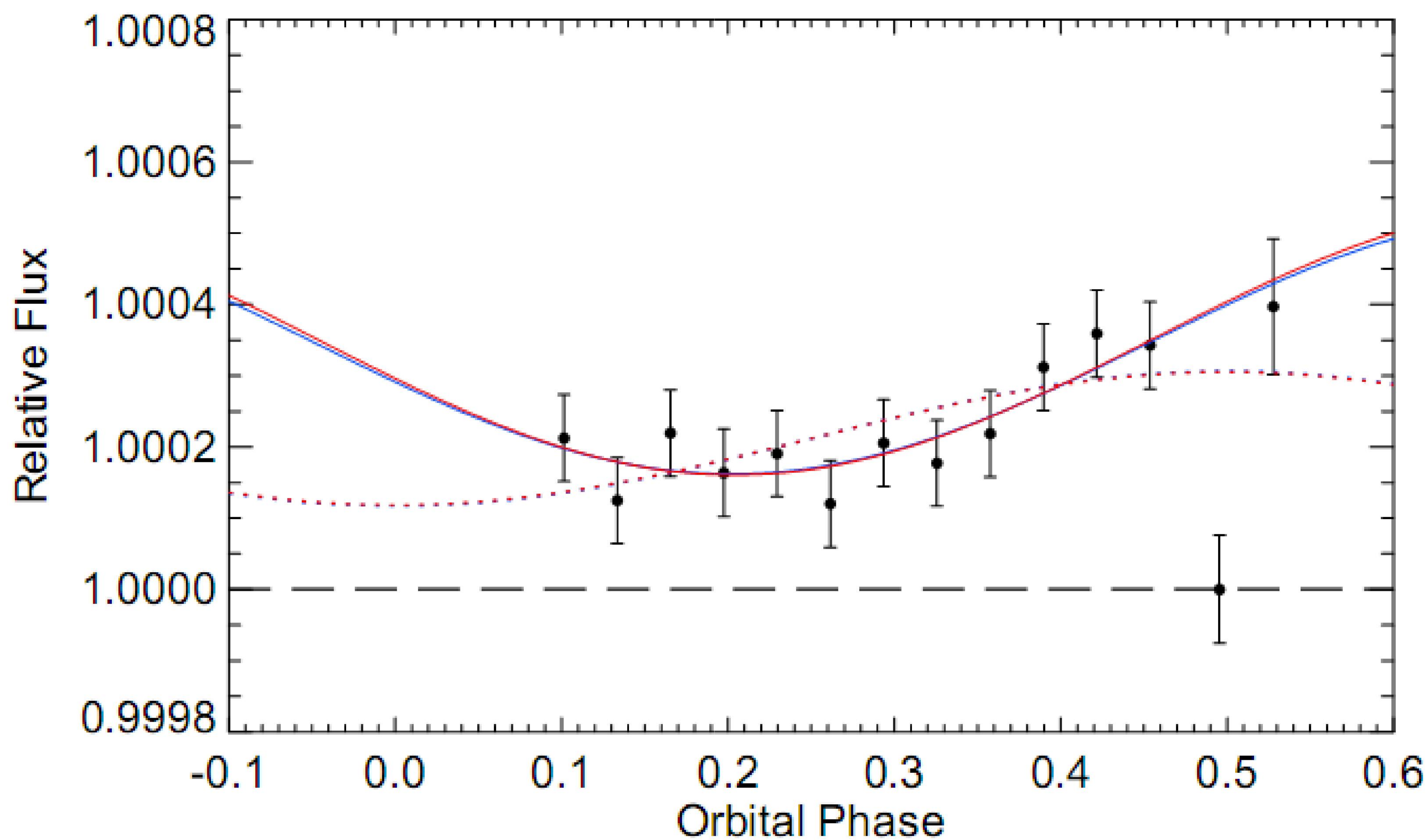


More offset

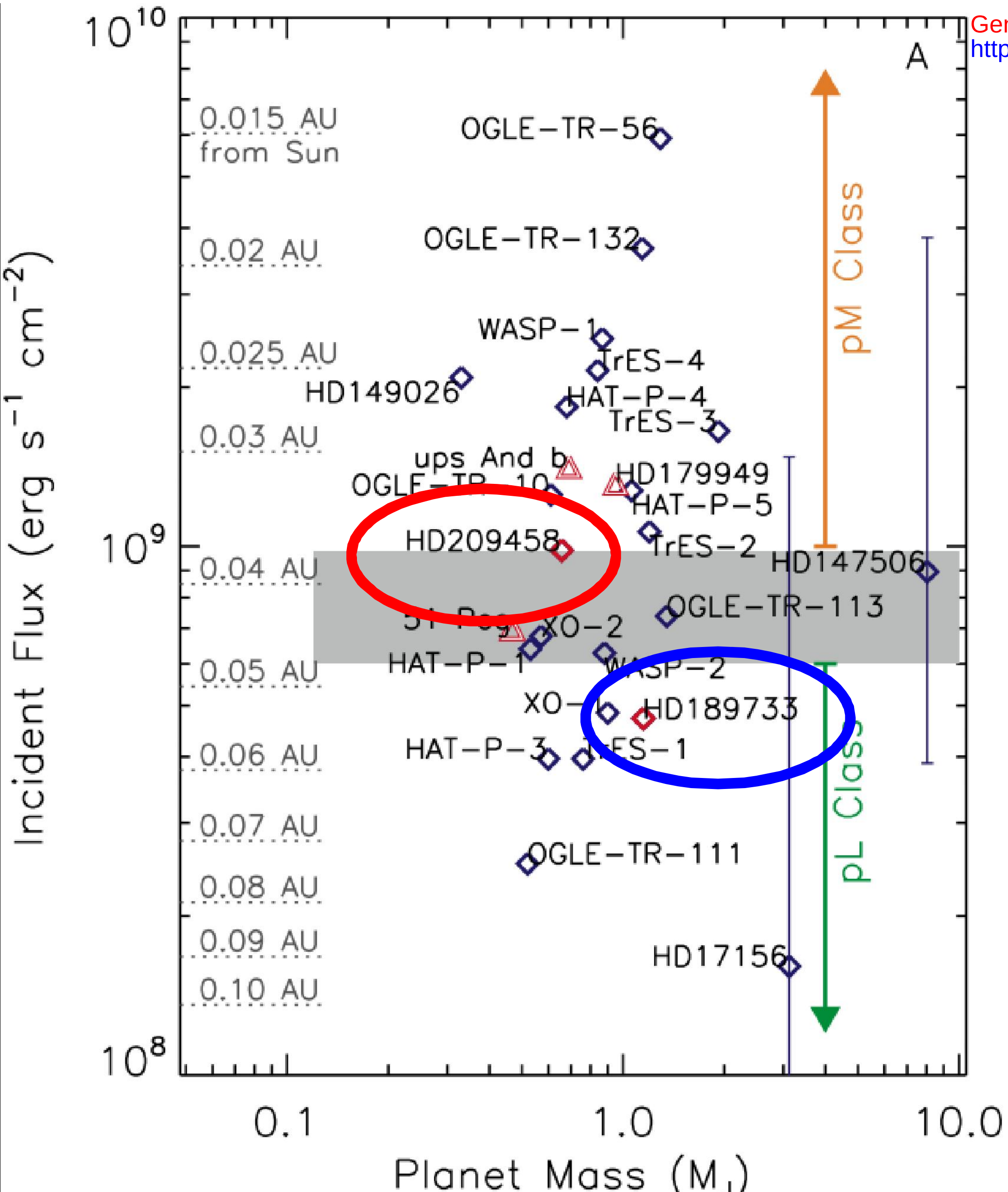




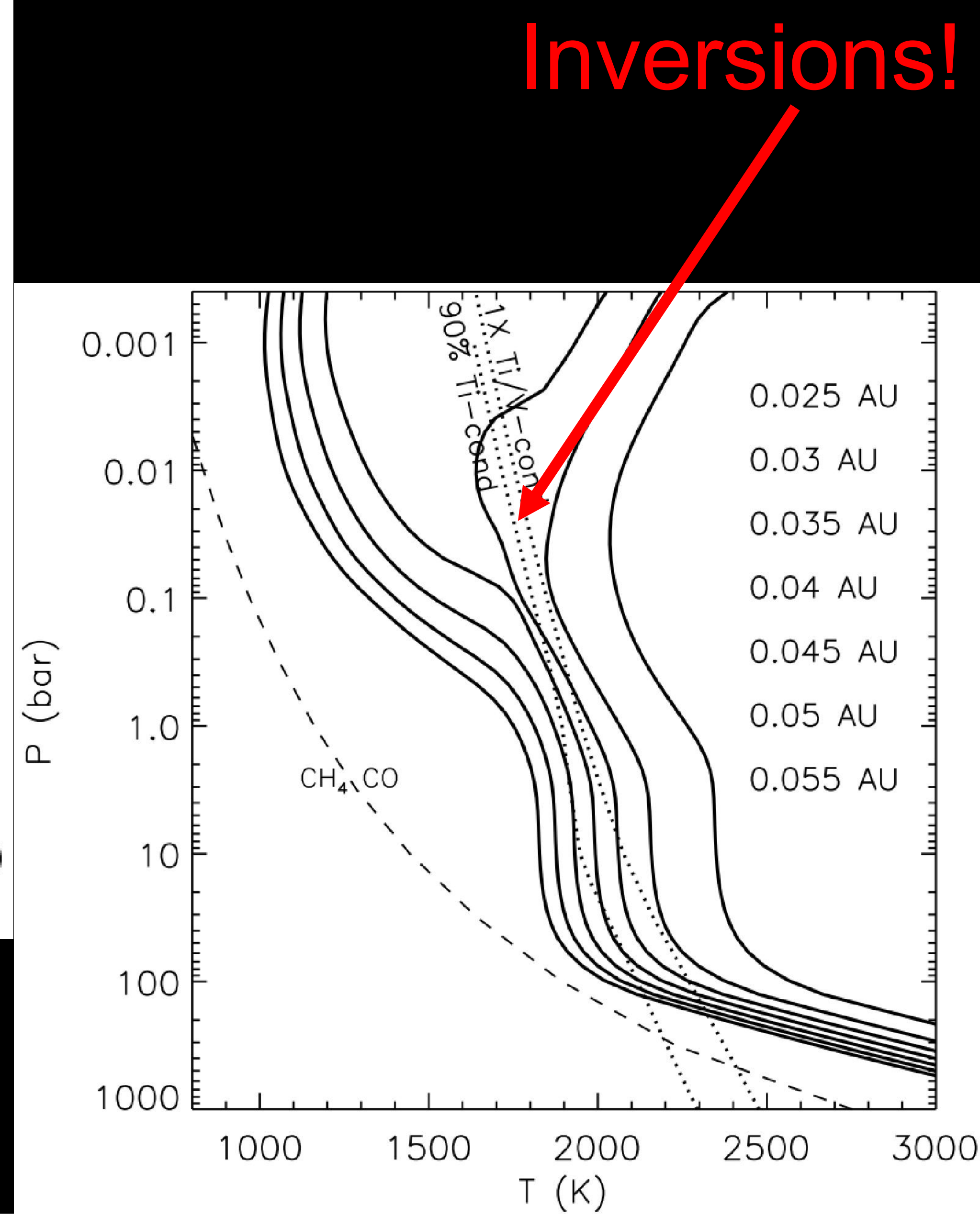
Knutson et al. (2007)
HD 189733 b
33 hrs of Spitzer time

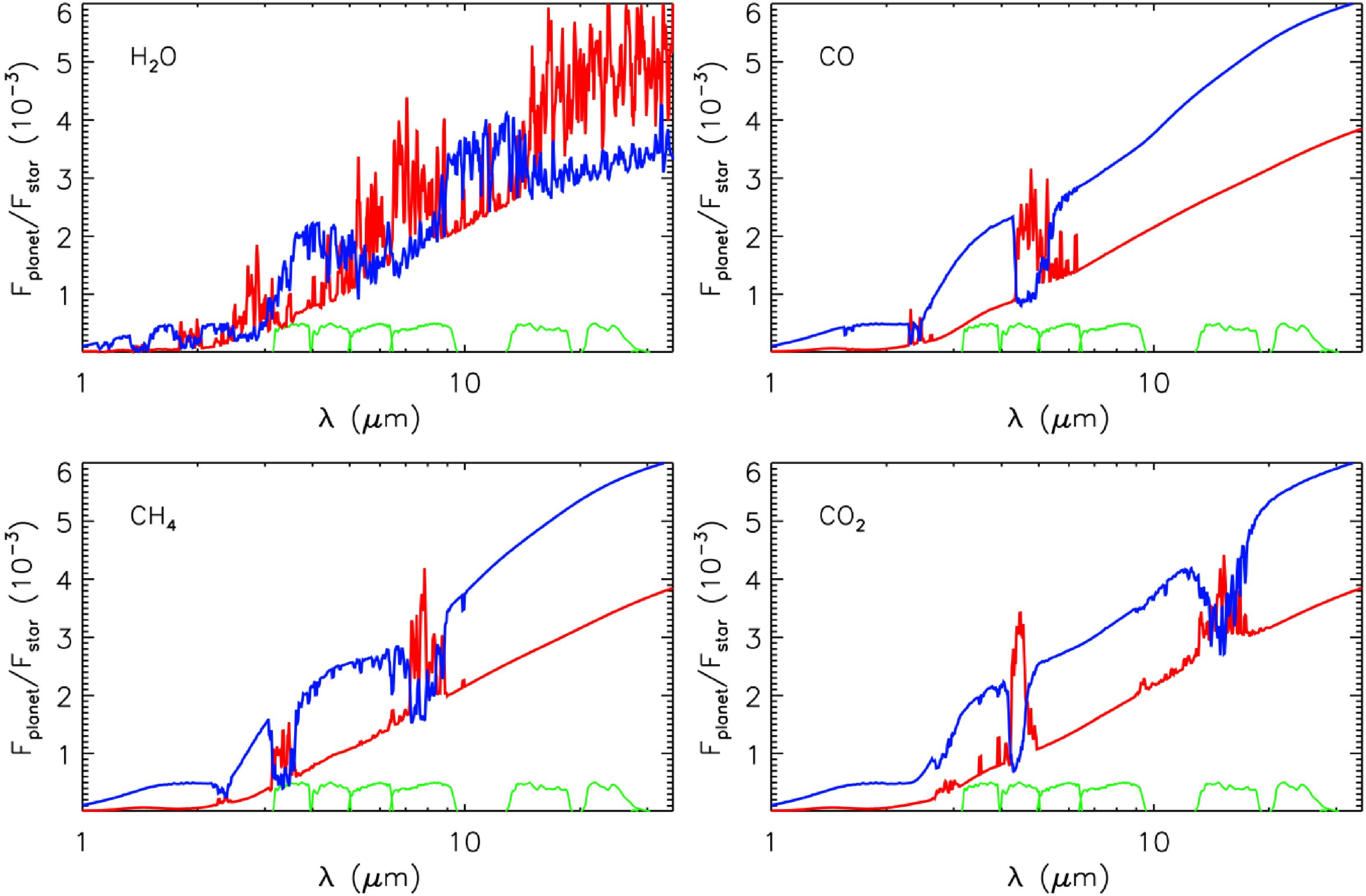


Knutson et al. (2008)



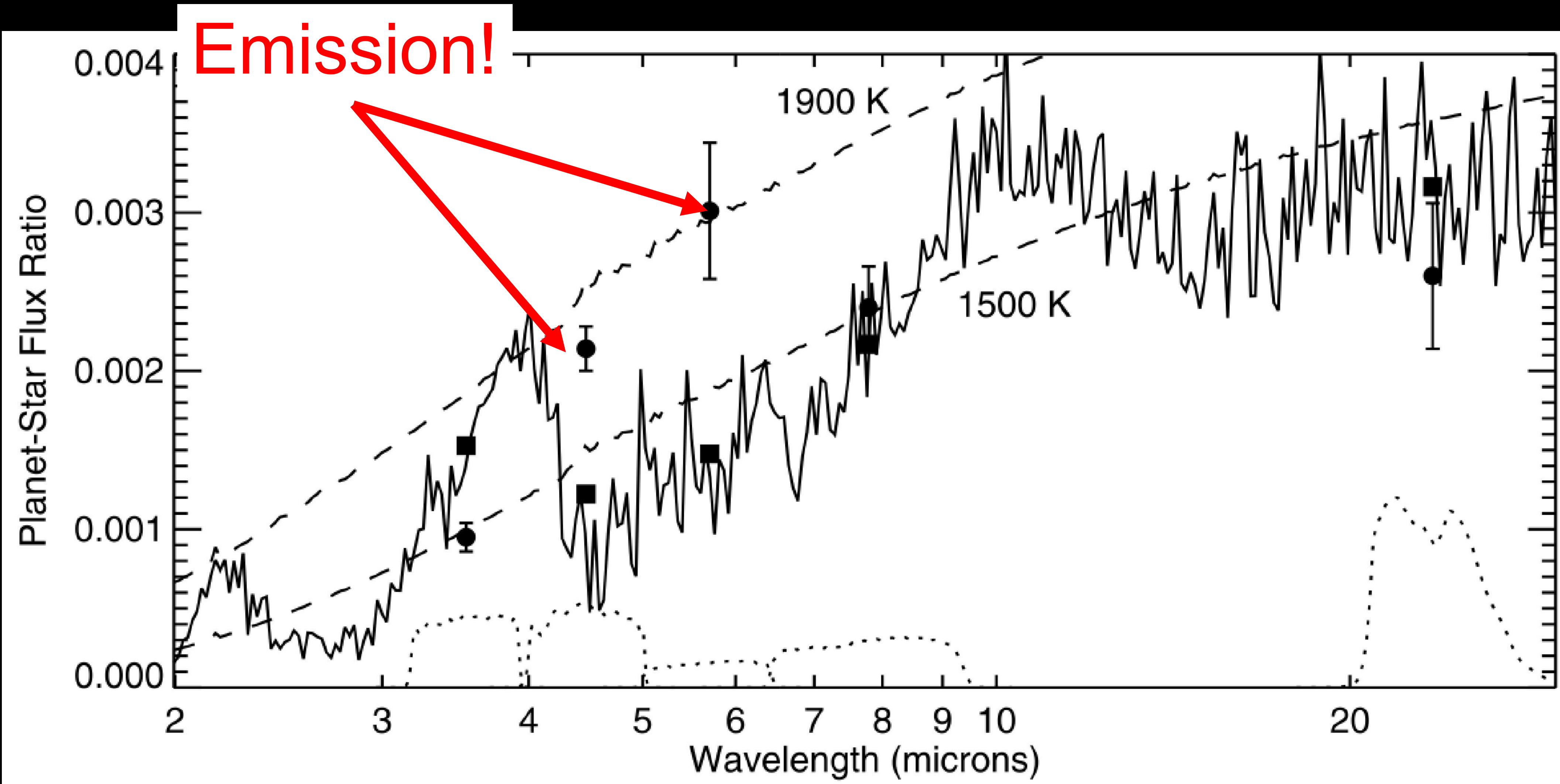
Fortney et al. (2003)



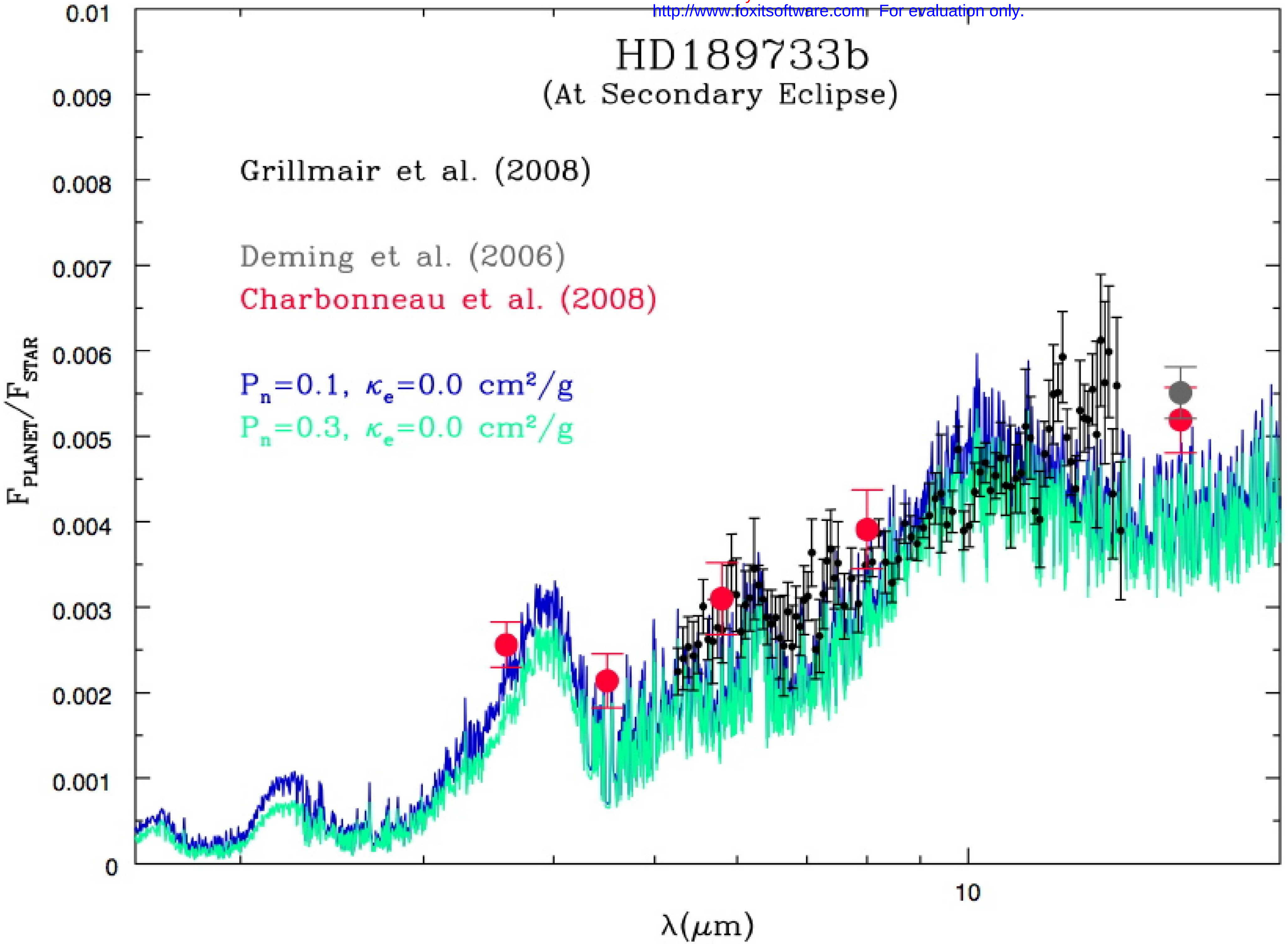


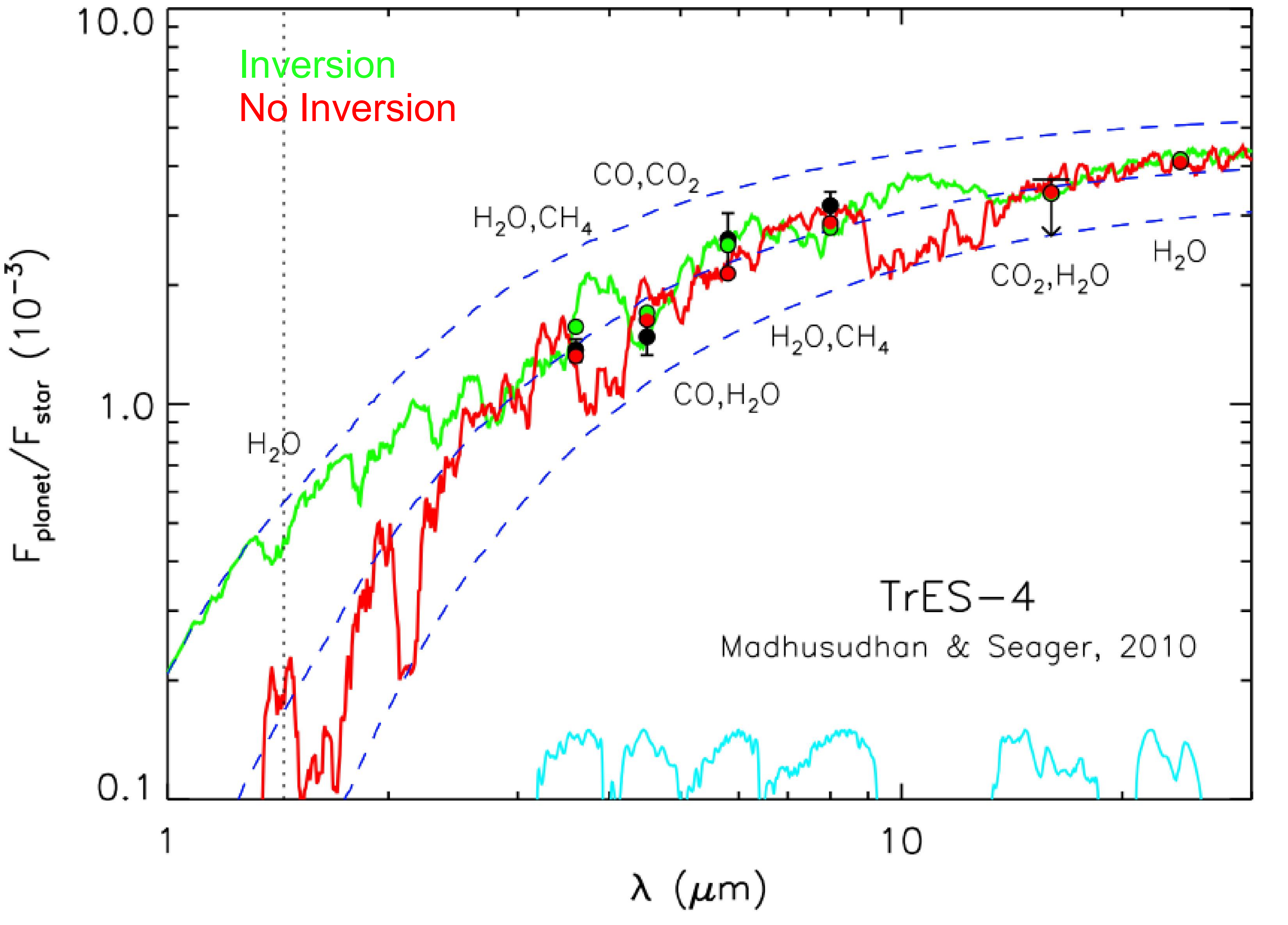
Madhusudhan & Seager (2010)

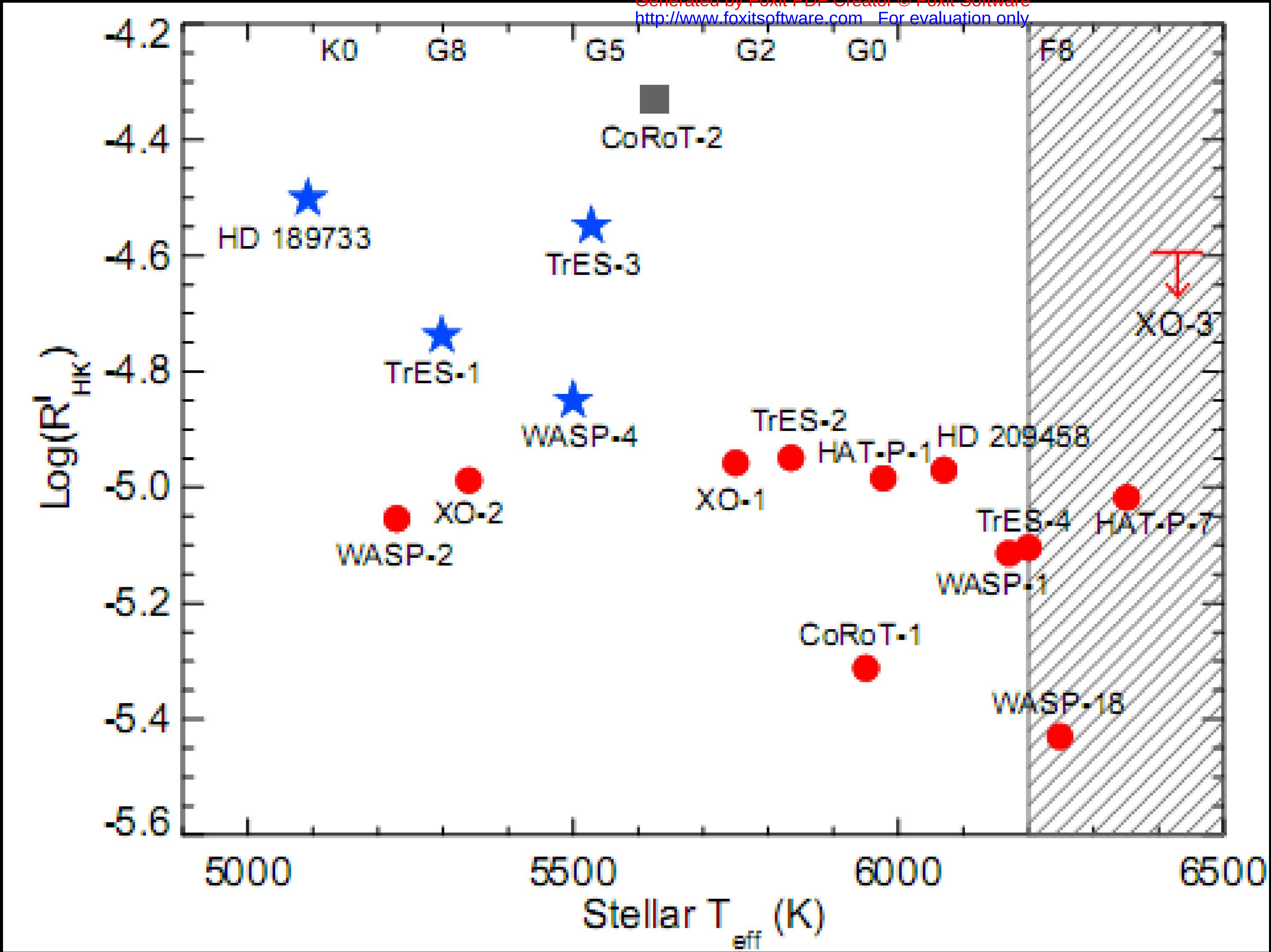
HD 209458 b



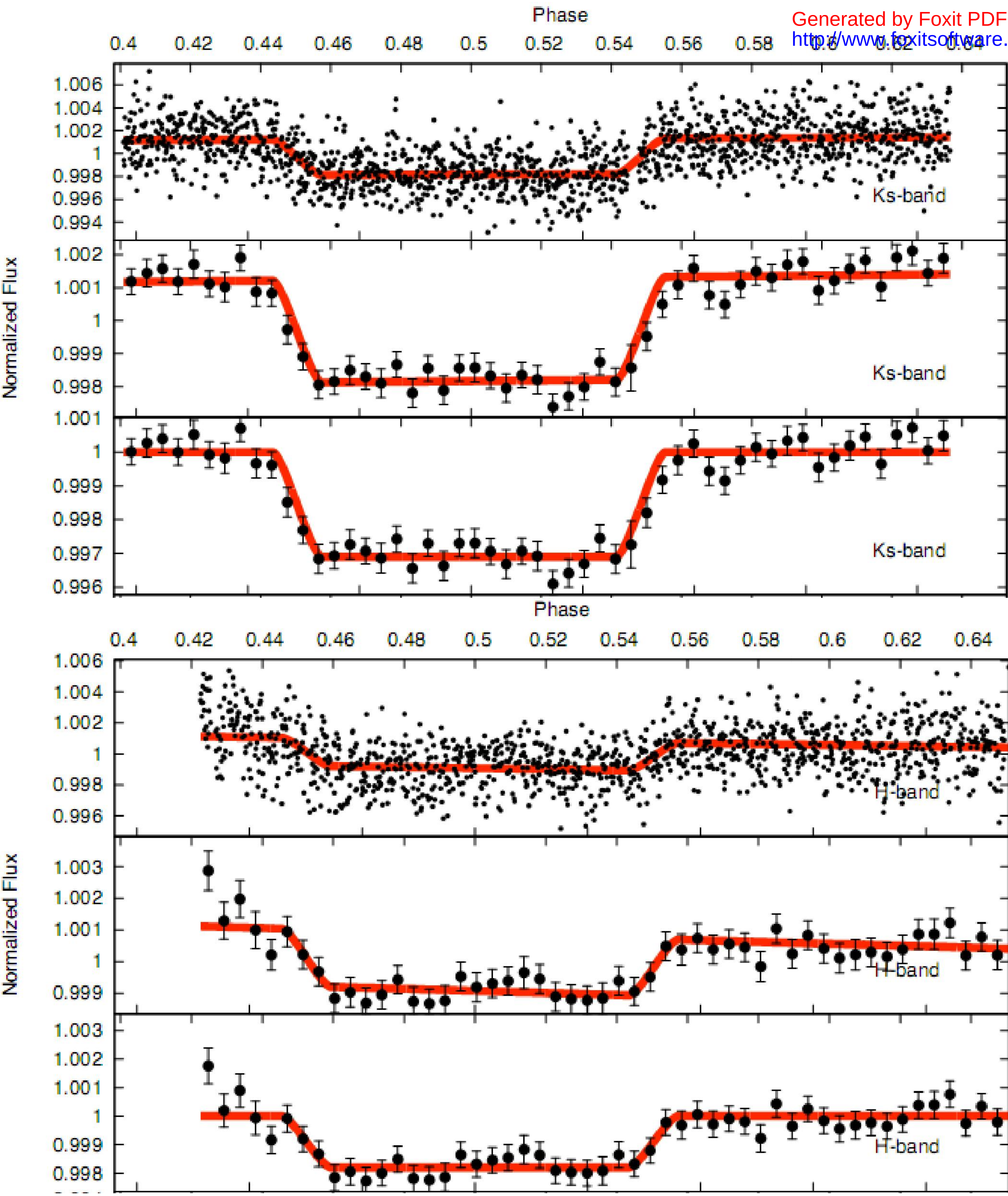
Knutson et al. (2008)

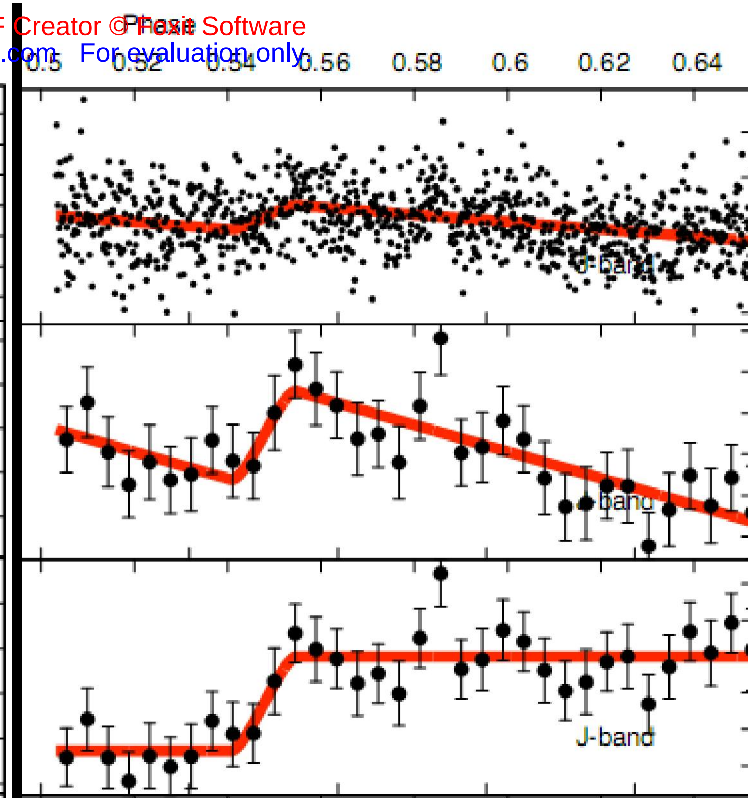

HD189733b
(At Secondary Eclipse)
Grillmair et al. (2008)
Deming et al. (2006)
Charbonneau et al. (2008)
P_n=0.1, κ_e=0.0 cm²/g
P_n=0.3, κ_e=0.0 cm²/g
F_{PLANET}/F_{STAR}
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
10
λ(μm)


Inversion
No Inversion
CO,CO2
H2O,CH4
H2O
CO2,H2O
H2O,CH4
CO,H2O
H2O
TrES−4
Madhusudhan & Seager, 2010
Fplanet/Fstar (10−3)
10.0
1.0
0.1
1
10
λ (μm)



Knutson et al. (2010)

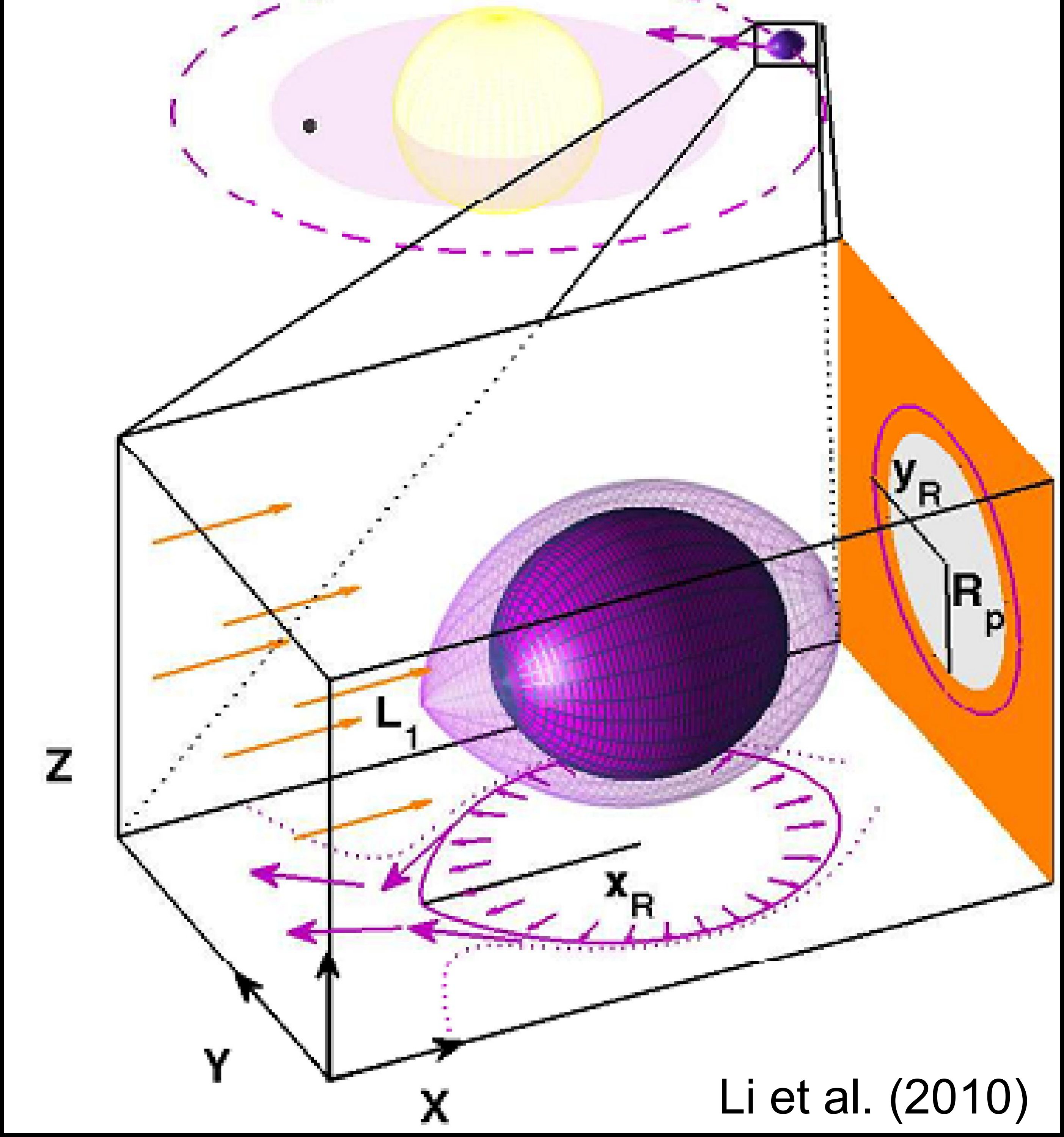


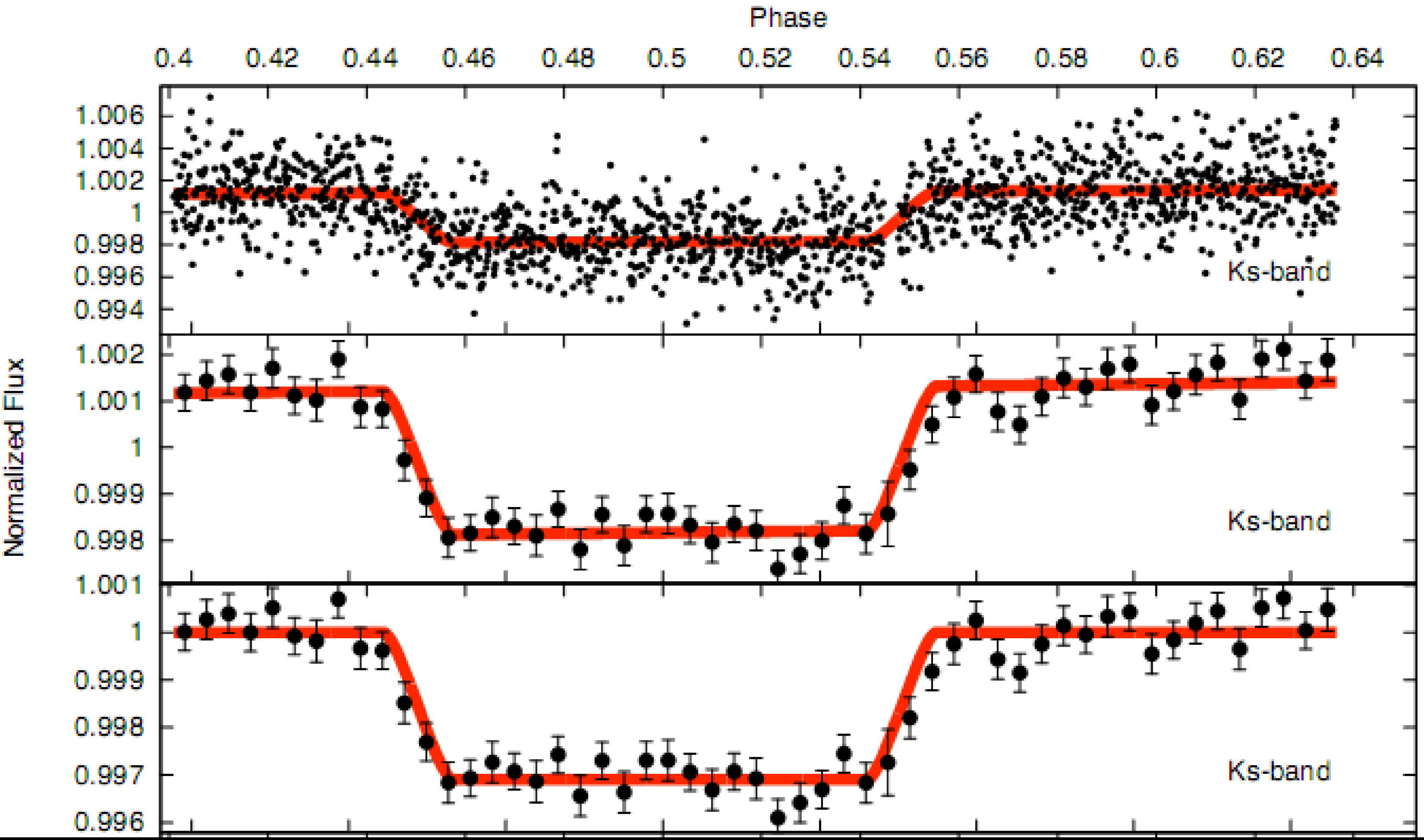


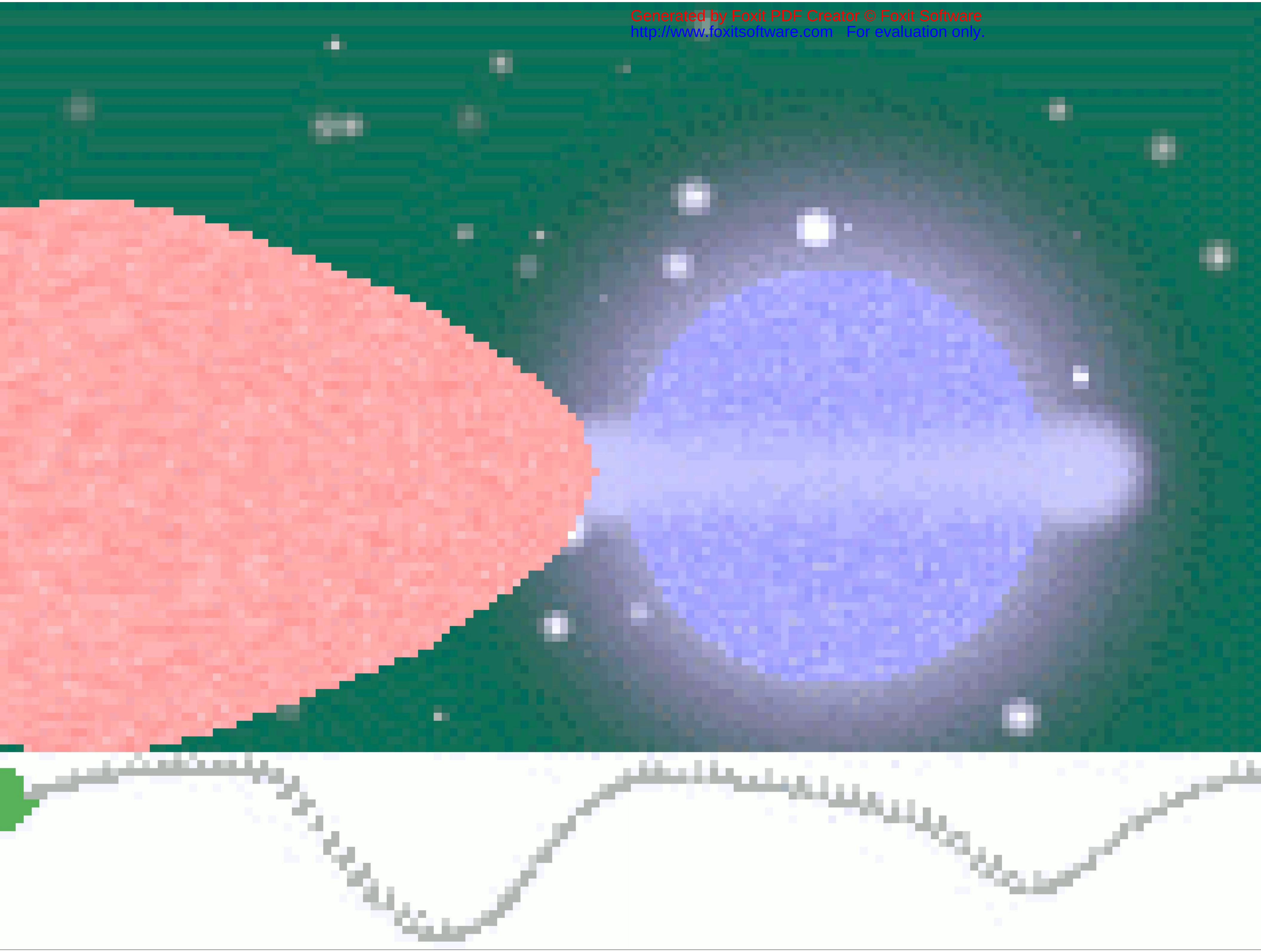
Croll et al. (2010)

Secondary transit of WASP-12 b

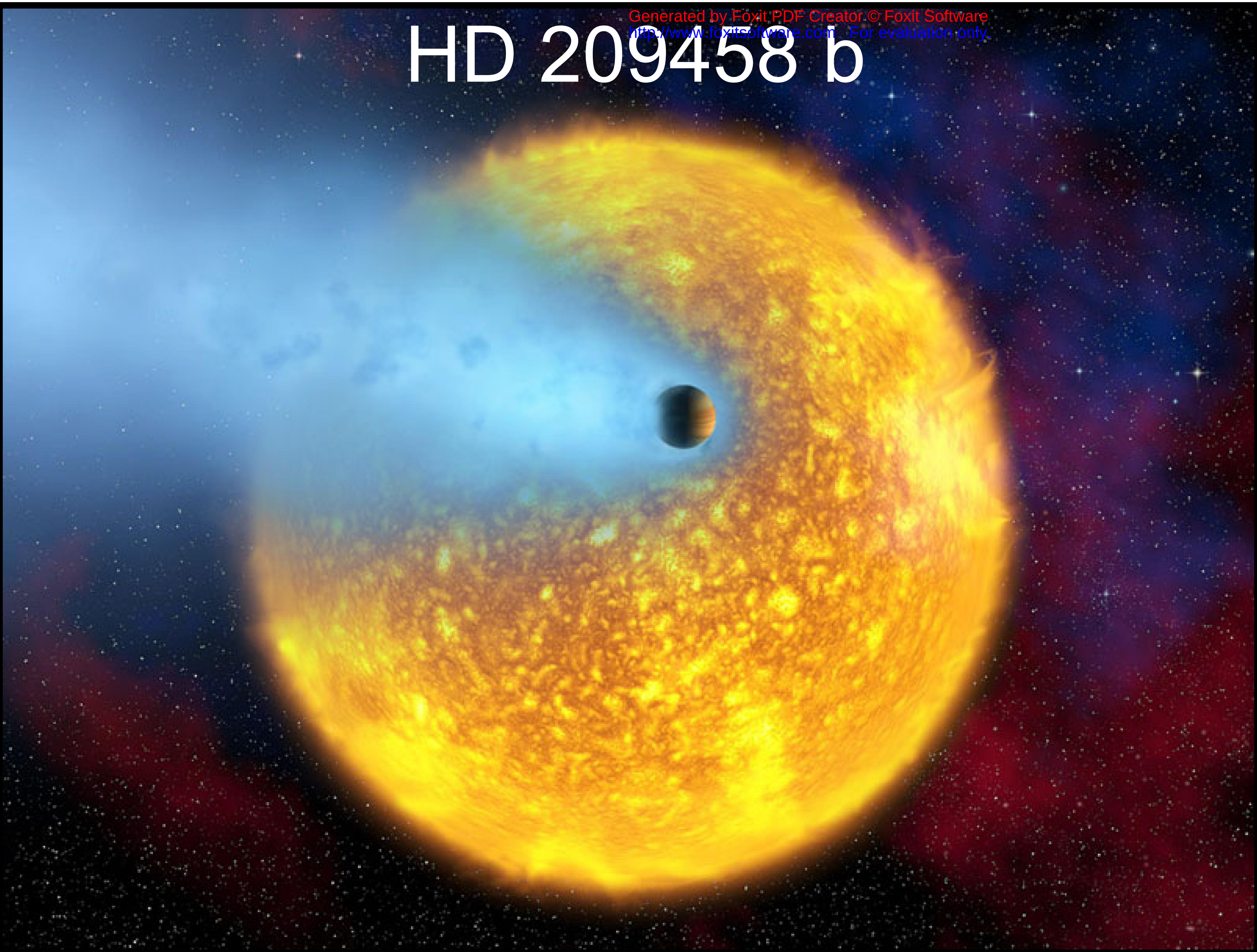
Ground-based observations at
Ks (2.15um),
H (1.6um), &
J (1.25um)-bands

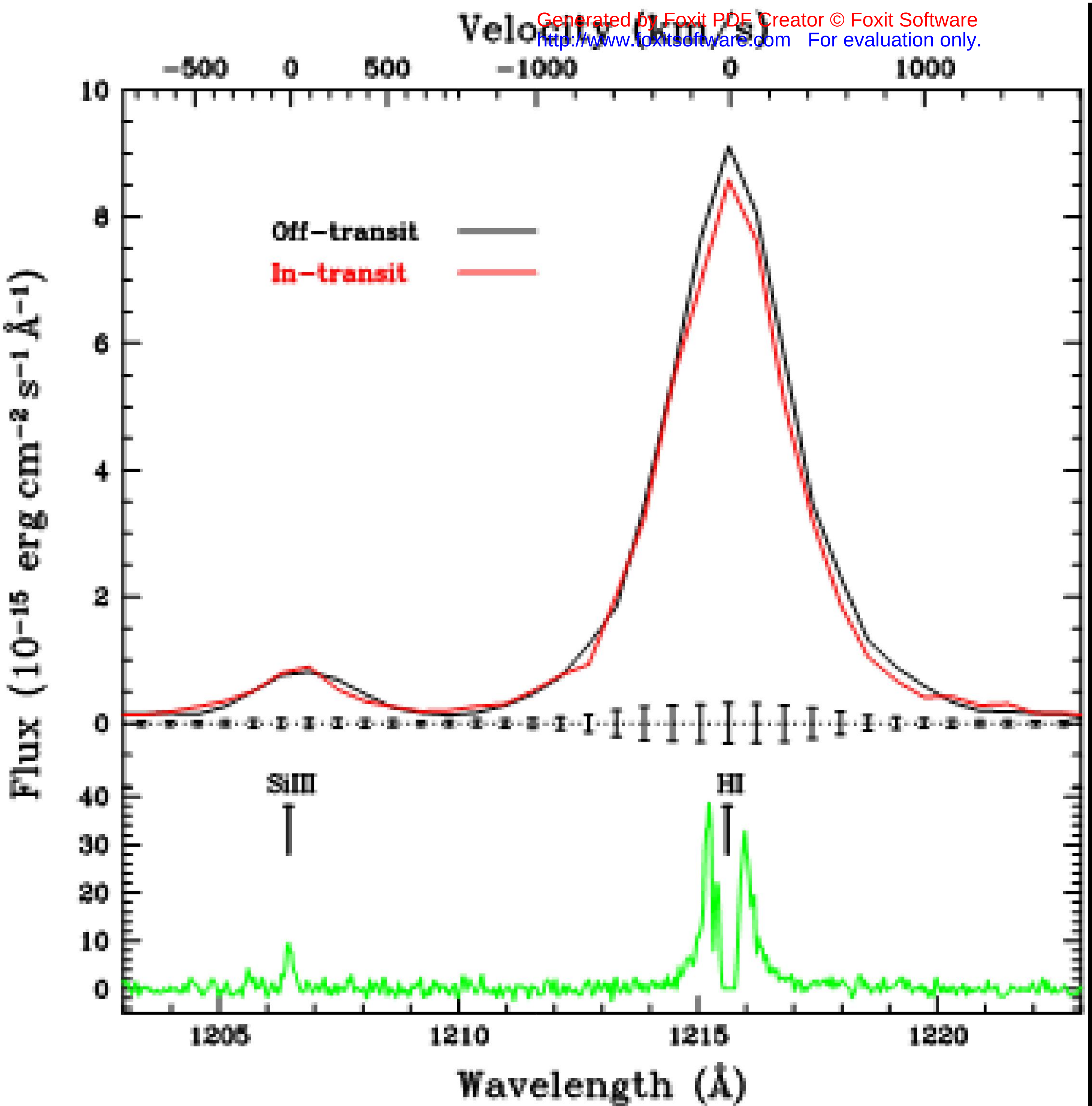

y_R
R_p
L_1
Z
x_R
Y
X
Li et al. (2010)


Phase
0.4
0.42
0.44
0.46
0.48
0.5
0.52
0.54
0.56
0.58
0.6
0.62
0.64
Normalized Flux
1.006
1.004
1.002
1
0.998
0.996
0.994
Ks-band
1.002
1.001
1
0.999
0.998
Ks-band
1.001
1
0.999
0.998
0.997
0.996
Ks-band

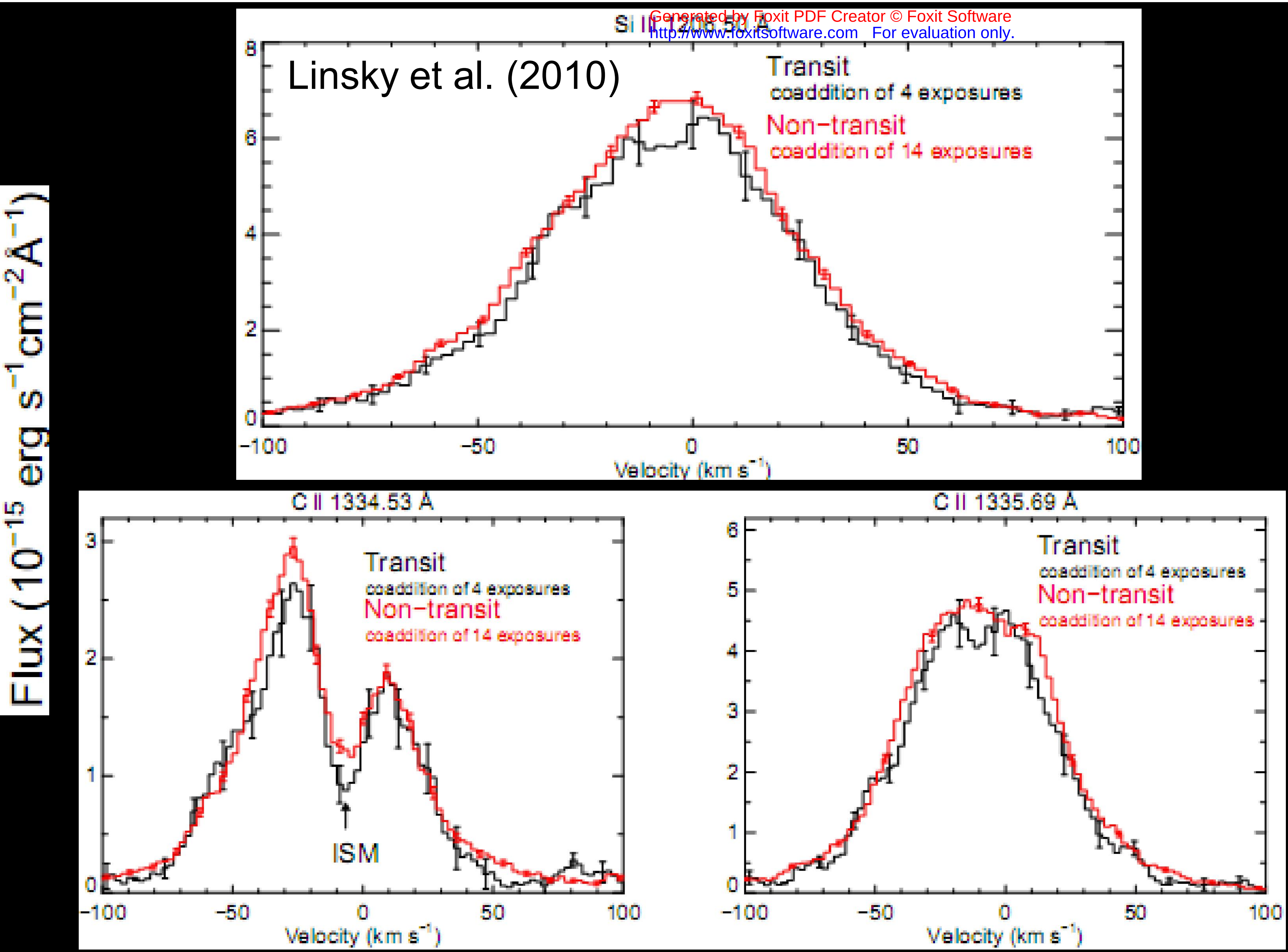


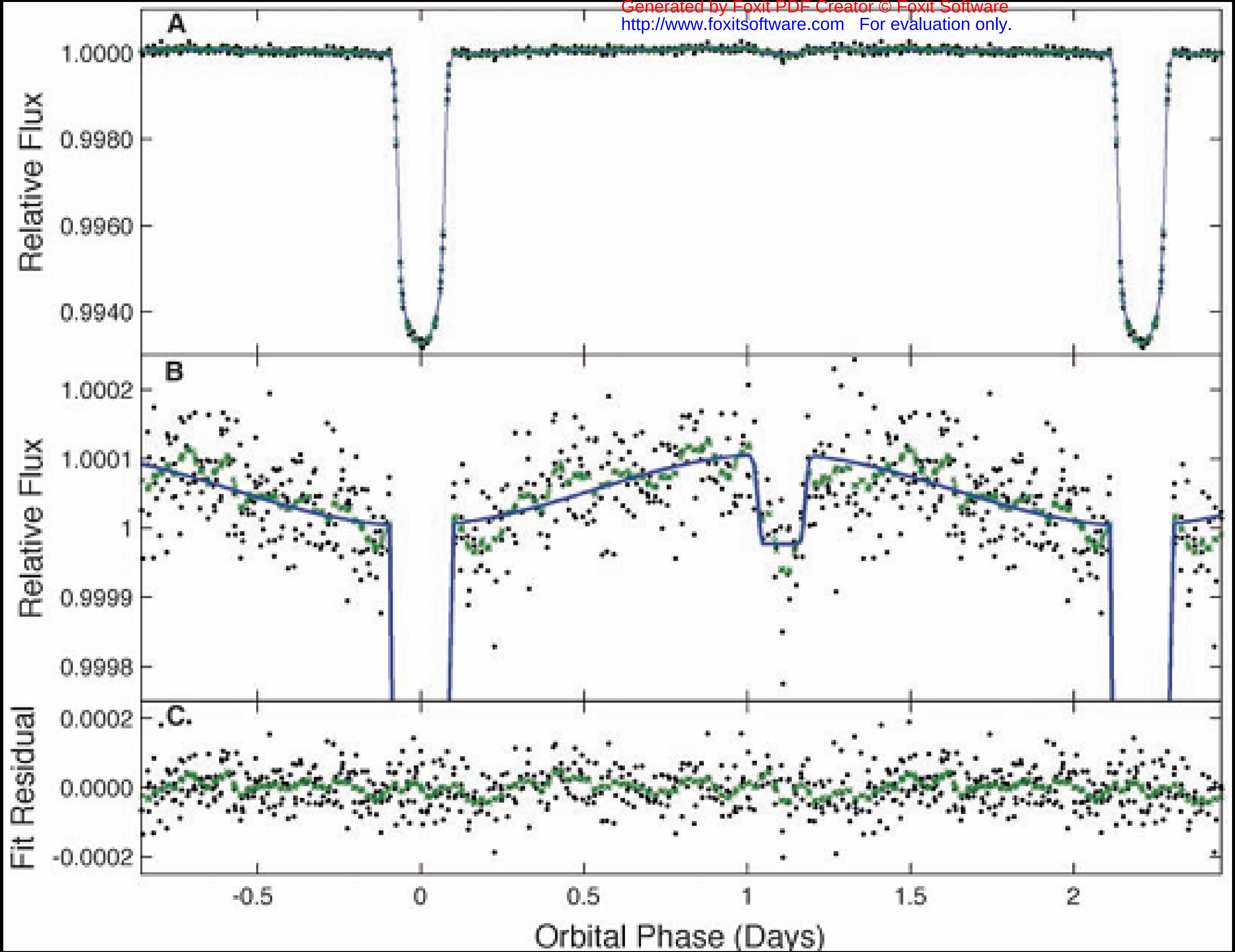
HD 209458 b



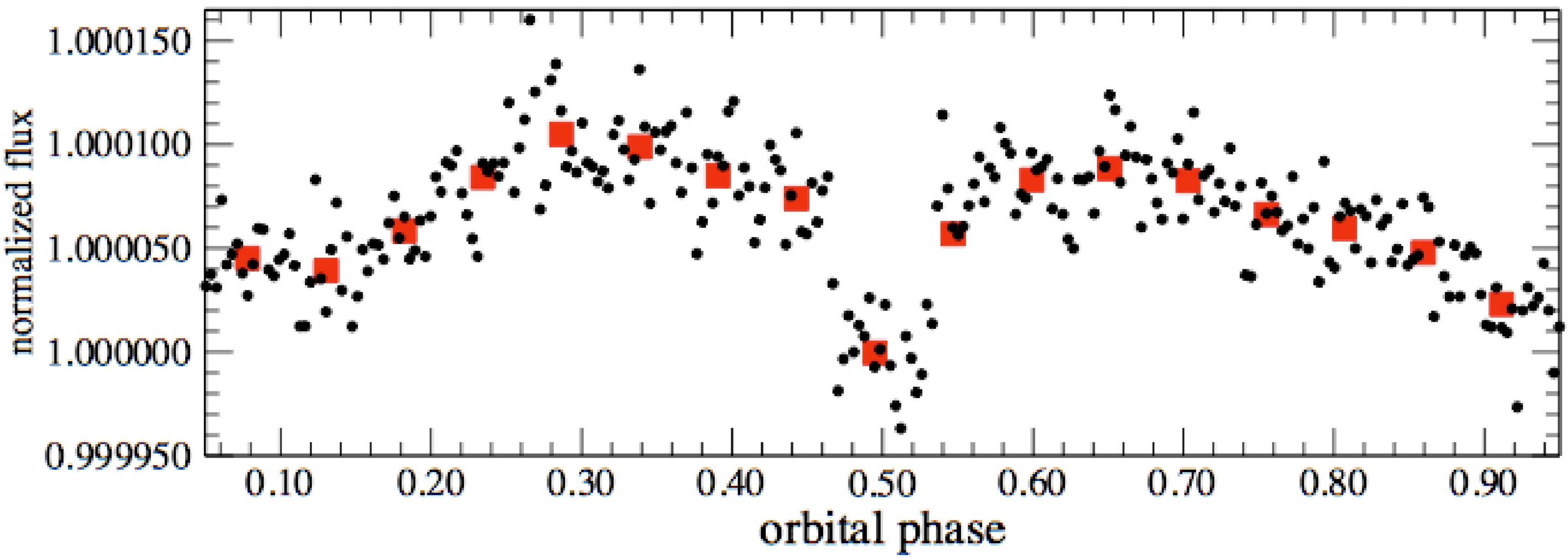


Vidal-Madjar et al. (2004)


Si III 1206.50 Å
Linsky et al. (2010)
Transit
coaddition of 4 exposures
Non−transit
coaddition of 14 exposures
Velocity (km s⁻¹)
Flux (10⁻¹⁵ erg s⁻¹cm⁻²Å⁻¹)
C II 1334.53 Å
Transit
coaddition of 4 exposures
Non−transit
coaddition of 14 exposures
ISM
Velocity (km s⁻¹)
C II 1335.69 Å
Transit
coaddition of 4 exposures
Non−transit
coaddition of 14 exposures
Velocity (km s⁻¹)



Borucki et al. (2009)



Welsh et al. (2010)

~ 30% of FGKM stars host superEarths, based on:

Microlensing (Gould et al. 2006, ApJ 644, 237)

Radial Velocity Surveys (Mayor et al. 2009, ApJ 493, 639)

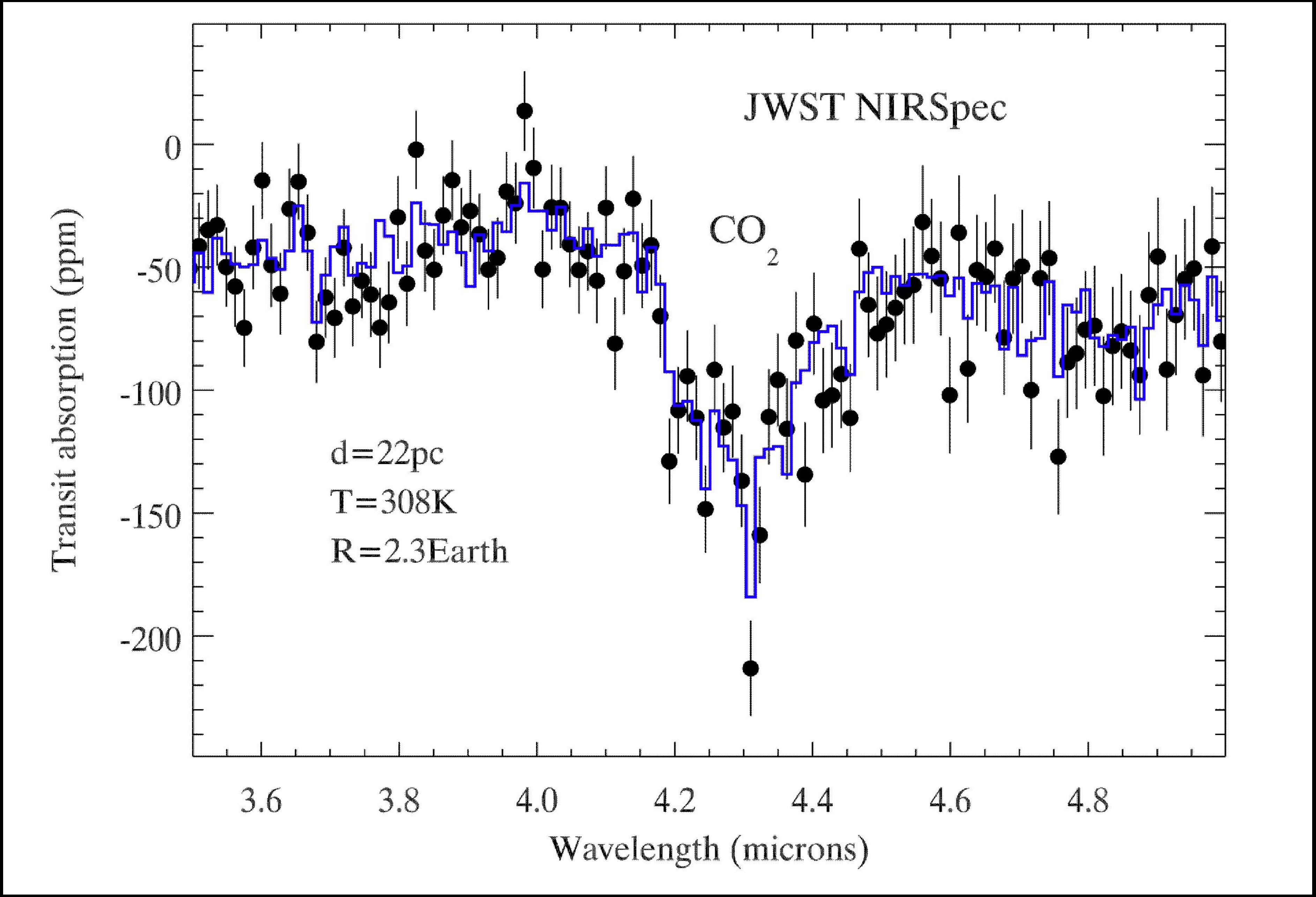
Their atmospheres initially contain: H_2, H_2O, CO, CO_2

Elkins-Tanton & Seager 2008
ApJ 685, 1237
Schaefer & Fegley 2009,
astro-ph/0909.4050
Miller-Ricci et al. 2009,
ApJ 690, 1056

Both thermal and non-thermal atmospheric escape rates are uncertain… so we here adopt the intermediate H_2 case of Miller-Ricci et al.


The James Webb Space Telescope
6.5 m diameter
26 m^2 collecting area
0.7 - 25 microns
TEREX
© S. Seager

Example of carbon dioxide in a habitable SuperEarth



"*Mensus eram coelos, nunc terrae metior umbras Mens coelestis erat, corporis umbra iacet.*

I measured the skies, now the shadows I measure. Skybound was the mind, earthbound the body rests."

Johannes Kepler