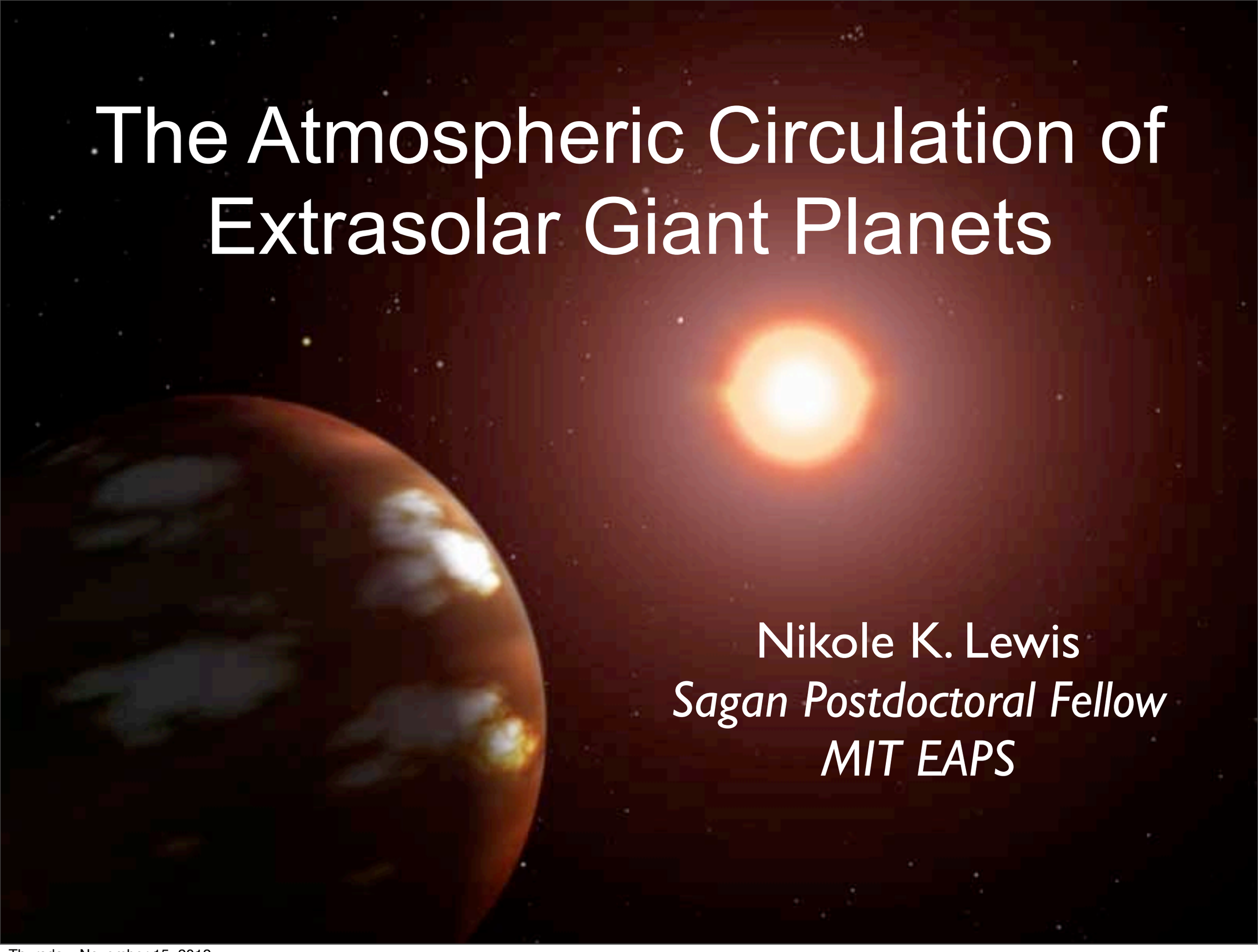
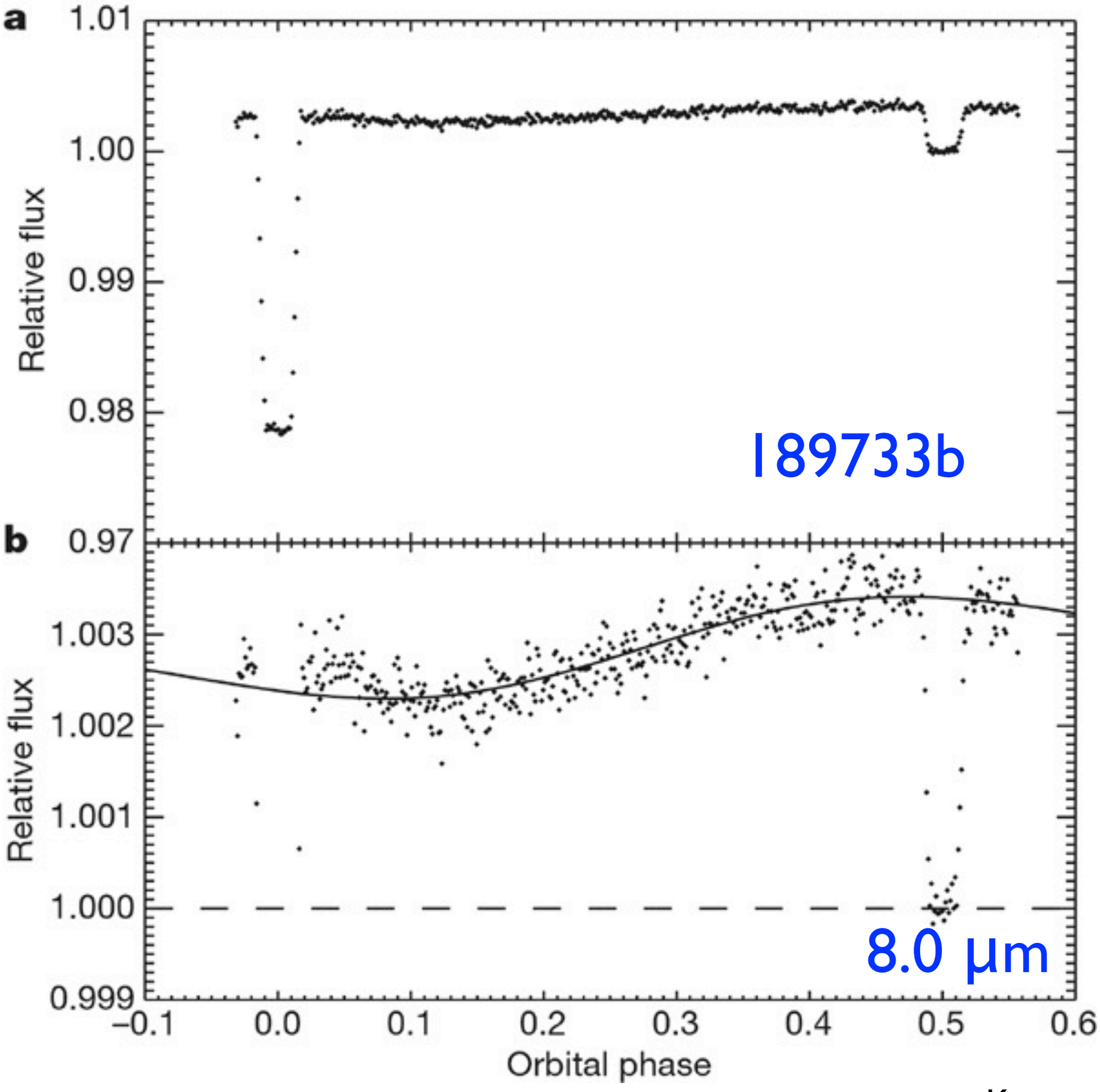
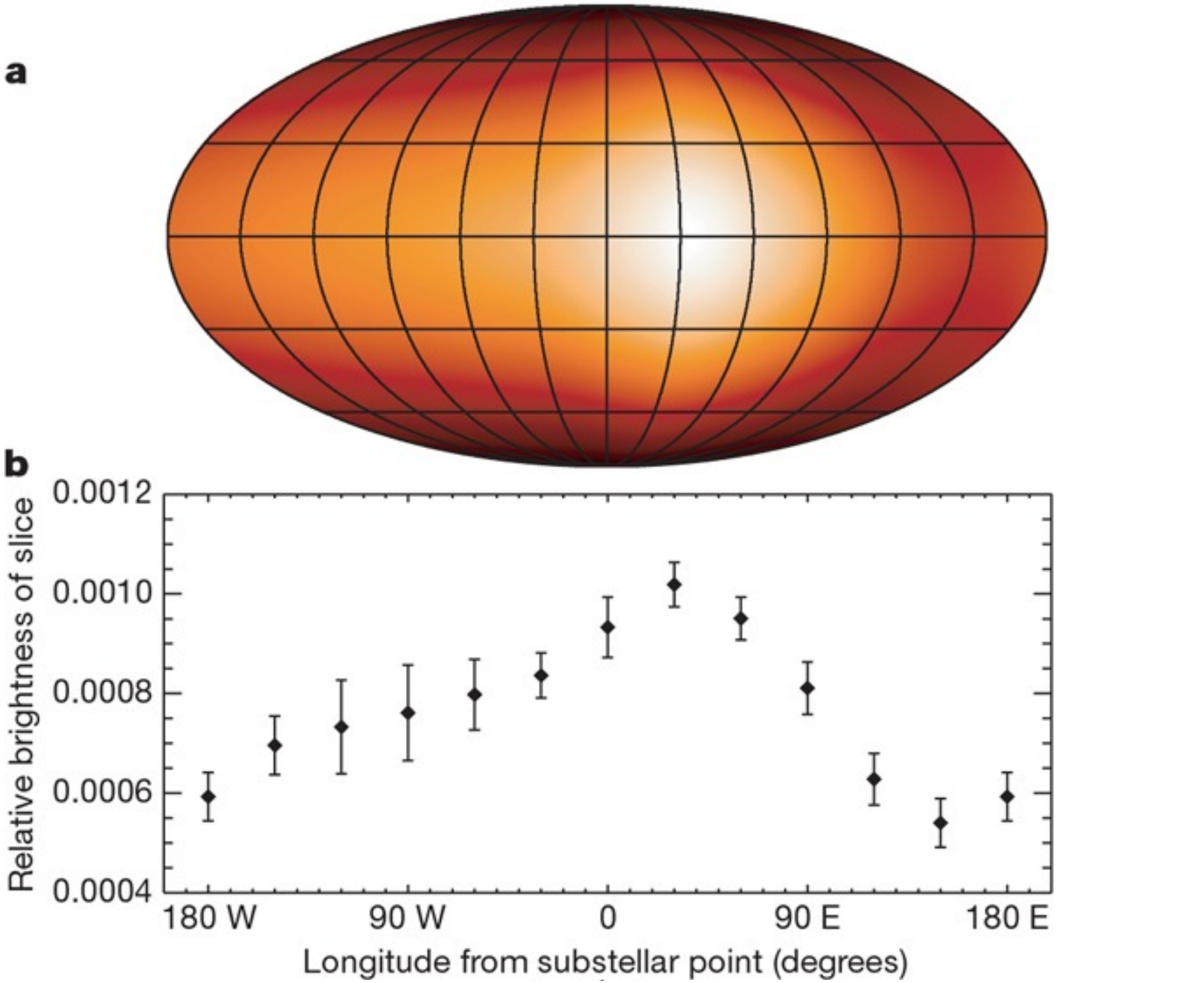
The Atmospheric Circulation of Extrasolar Giant Planets



Nikole K. Lewis
Sagan Postdoctoral Fellow
MIT EAPS

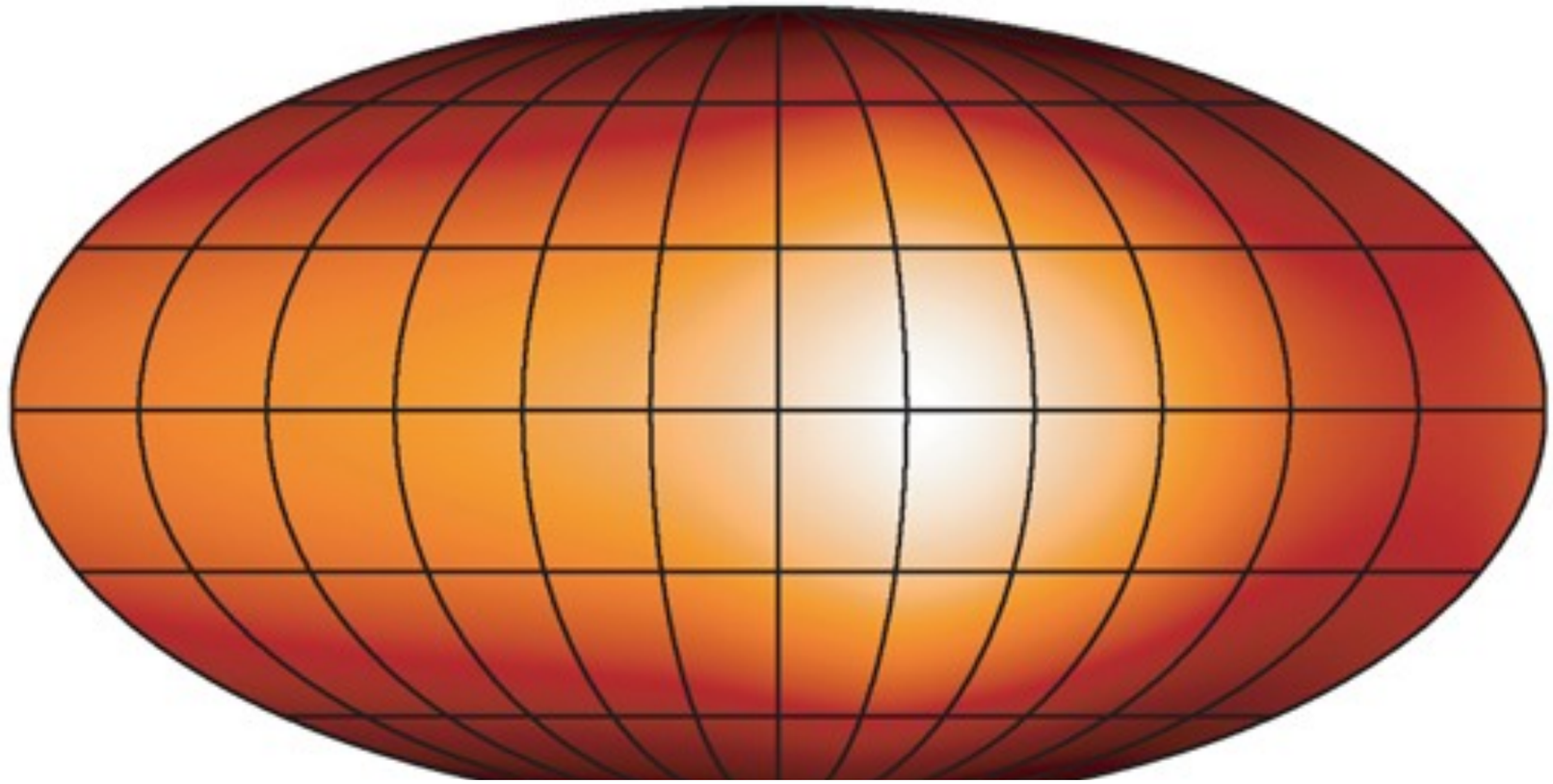


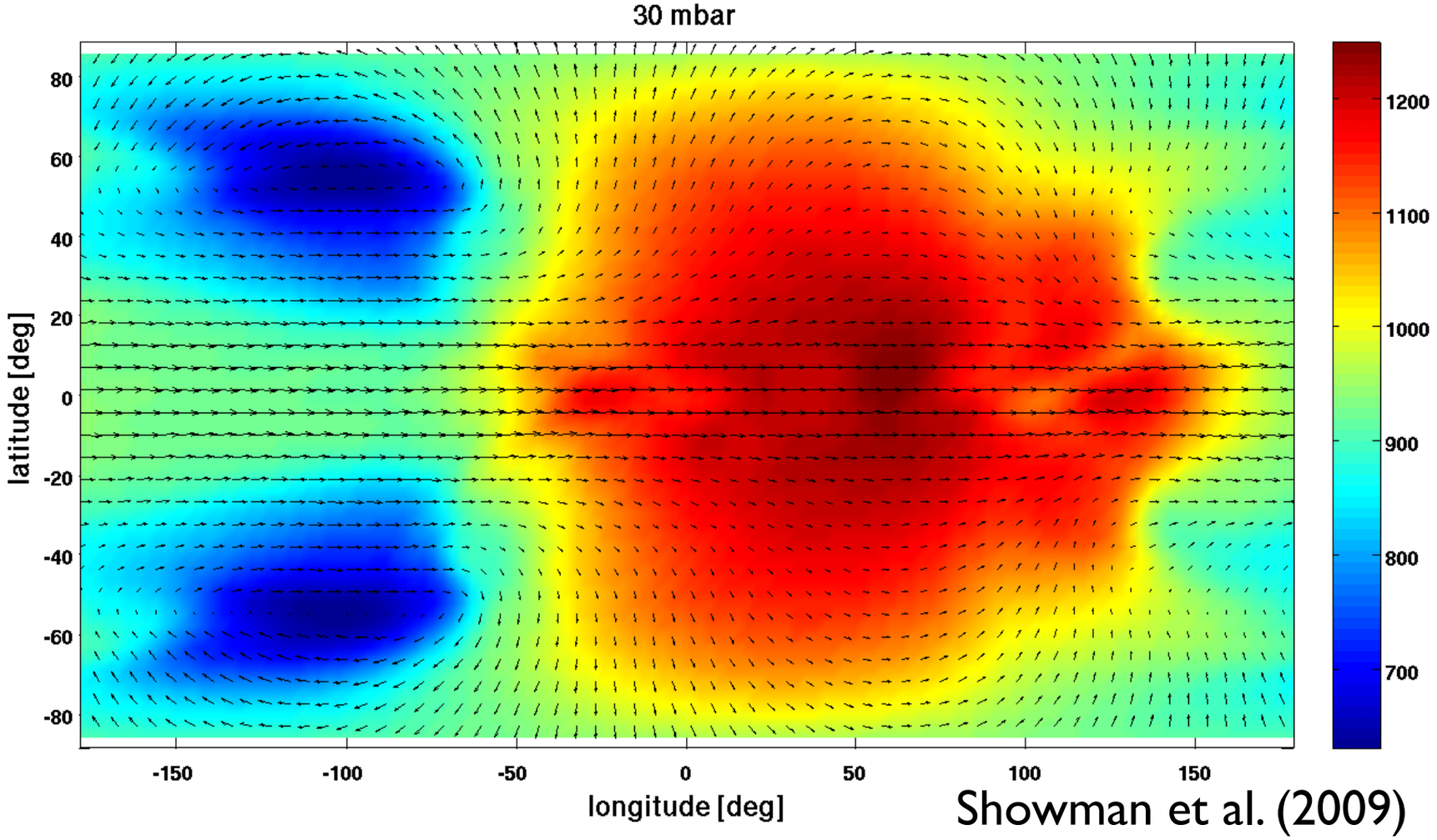
Knutson et al. (2007)



Knutson et al. (2007)

a





Showman et al. (2009)

Atmospheric Timescales

- Advection

$$\tau_{\rm advect} \sim \frac{a}{U},$$

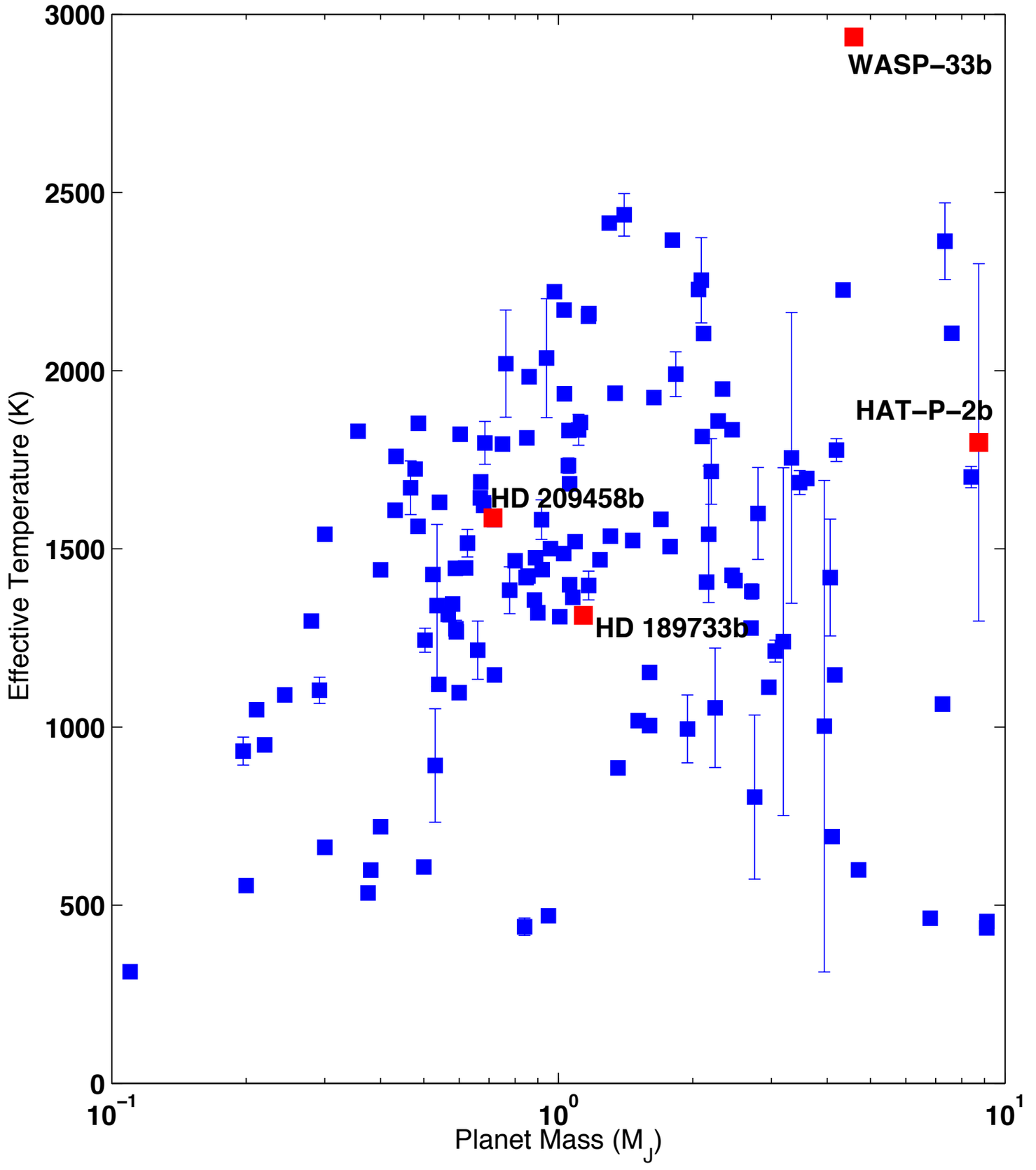
$$U \sim \sqrt{R \Delta T_{\rm horiz} \Delta \ln p}$$

- Radiation

$$\tau_{\rm rad} \sim \frac{\Delta p}{g} \frac{c_p}{4 \sigma T^3}.$$

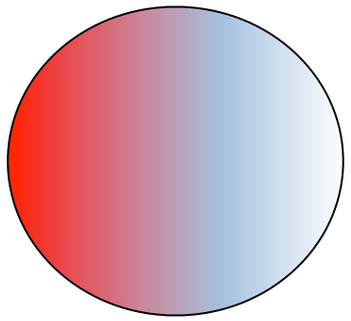
- Chemistry

$$\tau_{chem} \sim \exp\left(\frac{1}{T}\right)$$



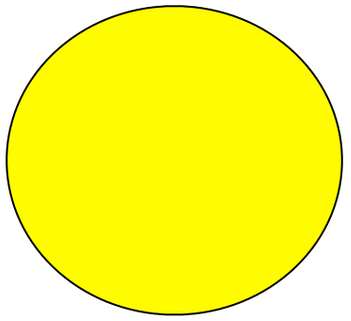
A Warm Spitzer Survey of Atmospheric Circulation

What about a 8 M_{Jup} planet with a highly **eccentric orbit**?



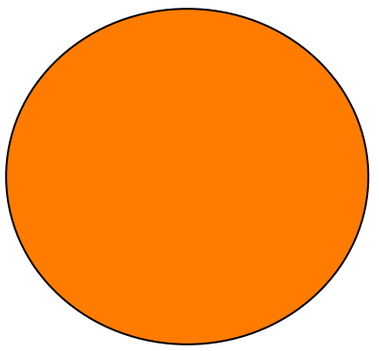
HAT-P-2b
Mass: 8.0 M_{Jup}
Radius: 0.98 R_{Jup}
T_{equil}=1100-2200 K

Benchmark system



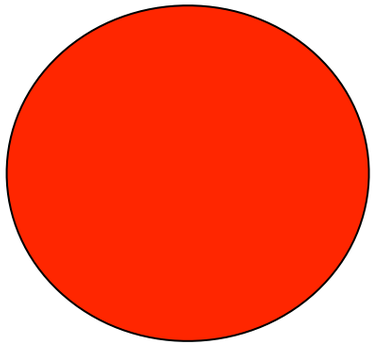
HD 189733b
Mass: 1.15 M_{Jup}
Radius: 1.15 R_{Jup}
T_{equil}=1200 K

How do **temperature inversions** affect the day-night circulation?



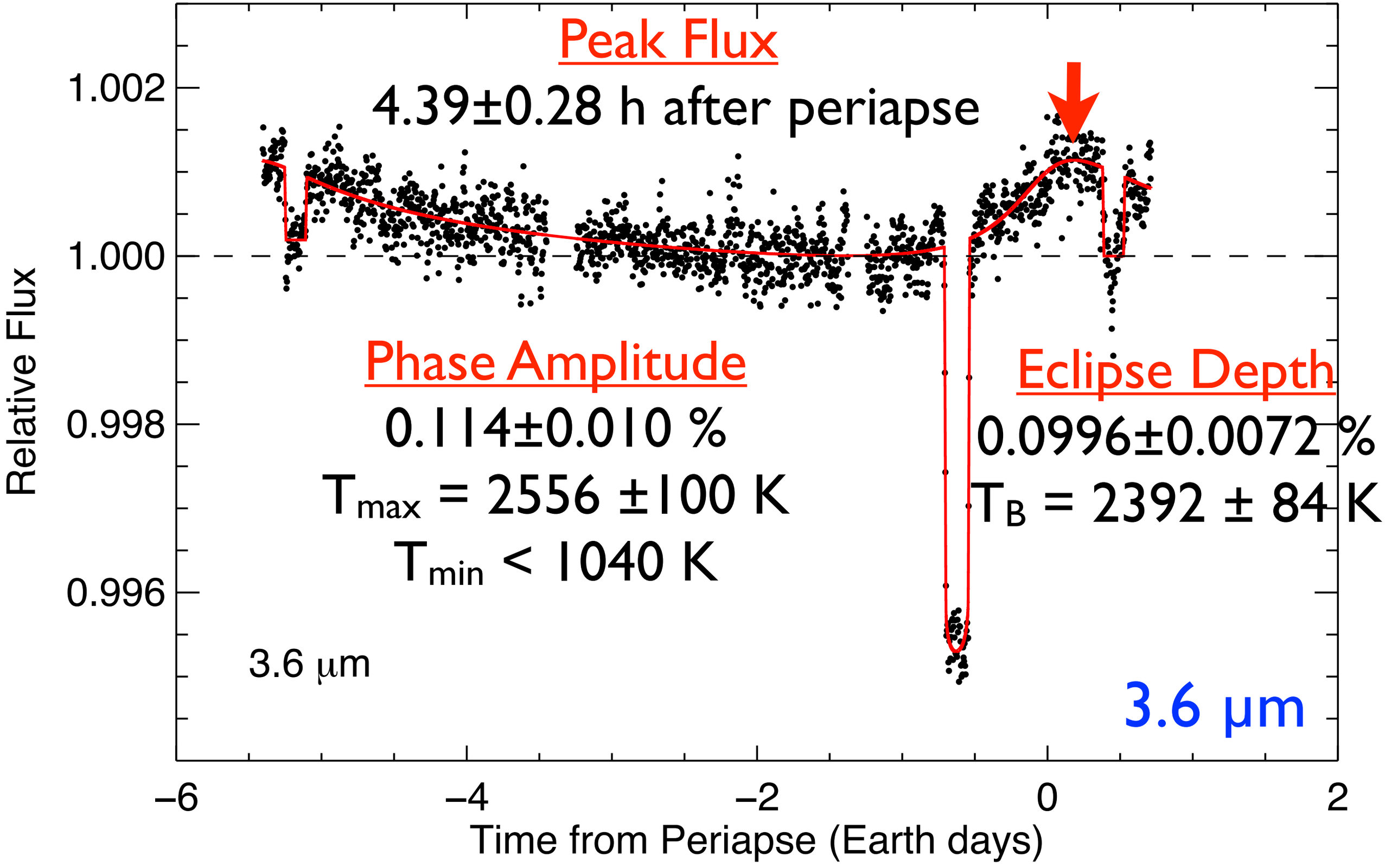
HD 209458b
Mass: 0.66 M_{Jup}
Radius: 1.32 R_{Jup}
T_{eqil}=1450 K

What does the atmospheric circulation look like in the **high-flux limit**?



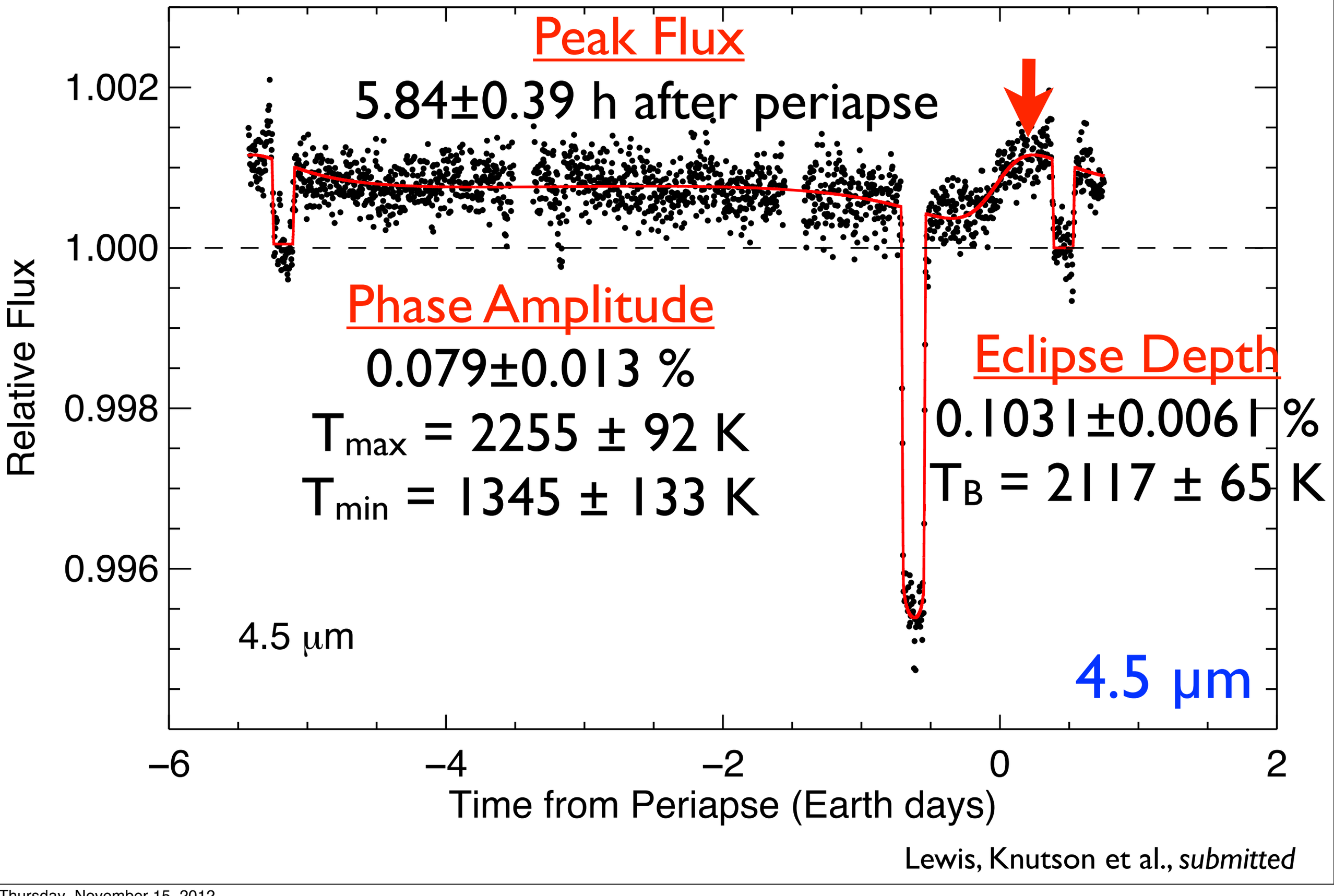
WASP-33b
Mass: 4.59 M_{Jup}
Radius: 1.438 R_{Jup}
T_{eqil}=2700 K

HAT-P-2b



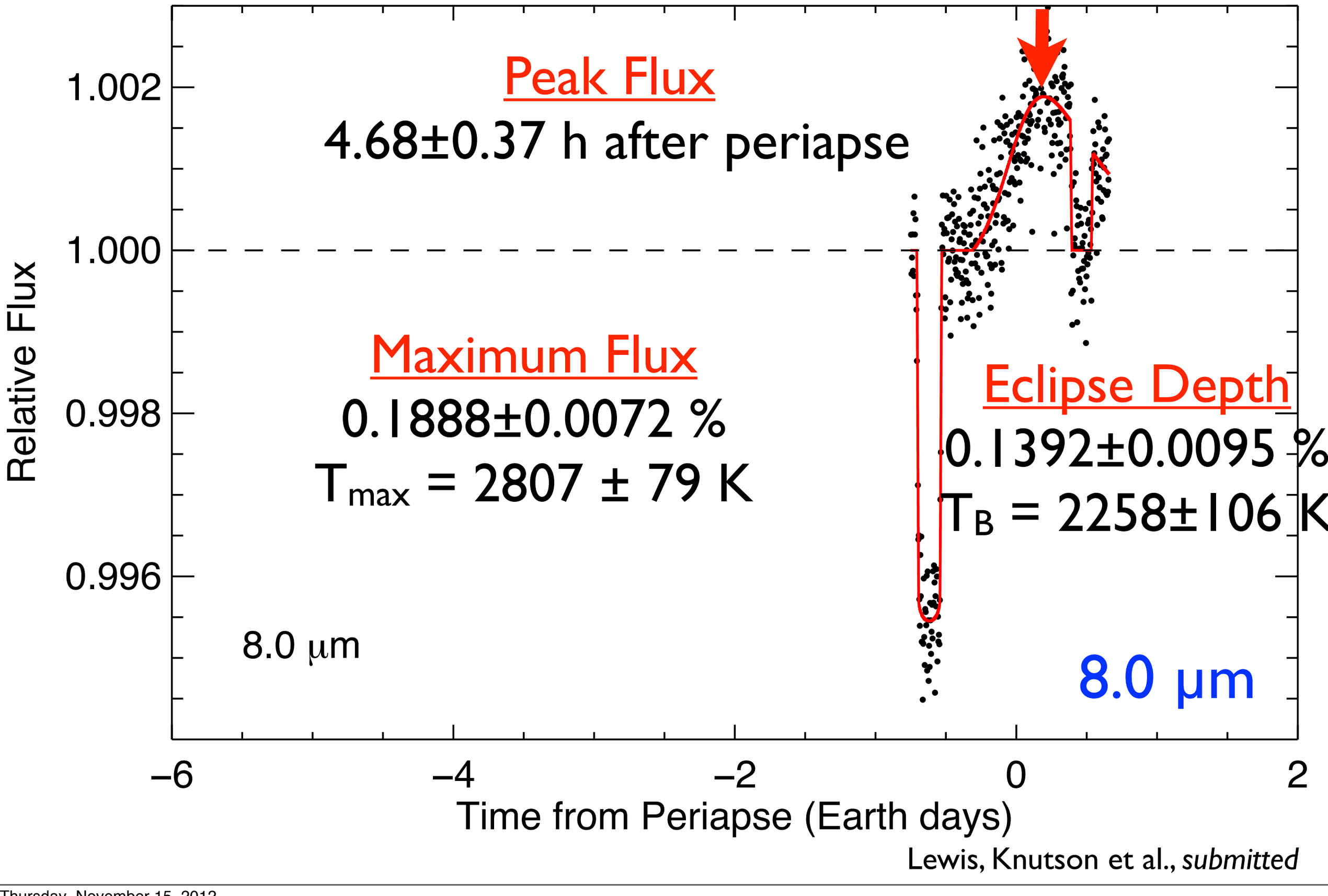
Lewis, Knutson et al., *submitted*

HAT-P-2b

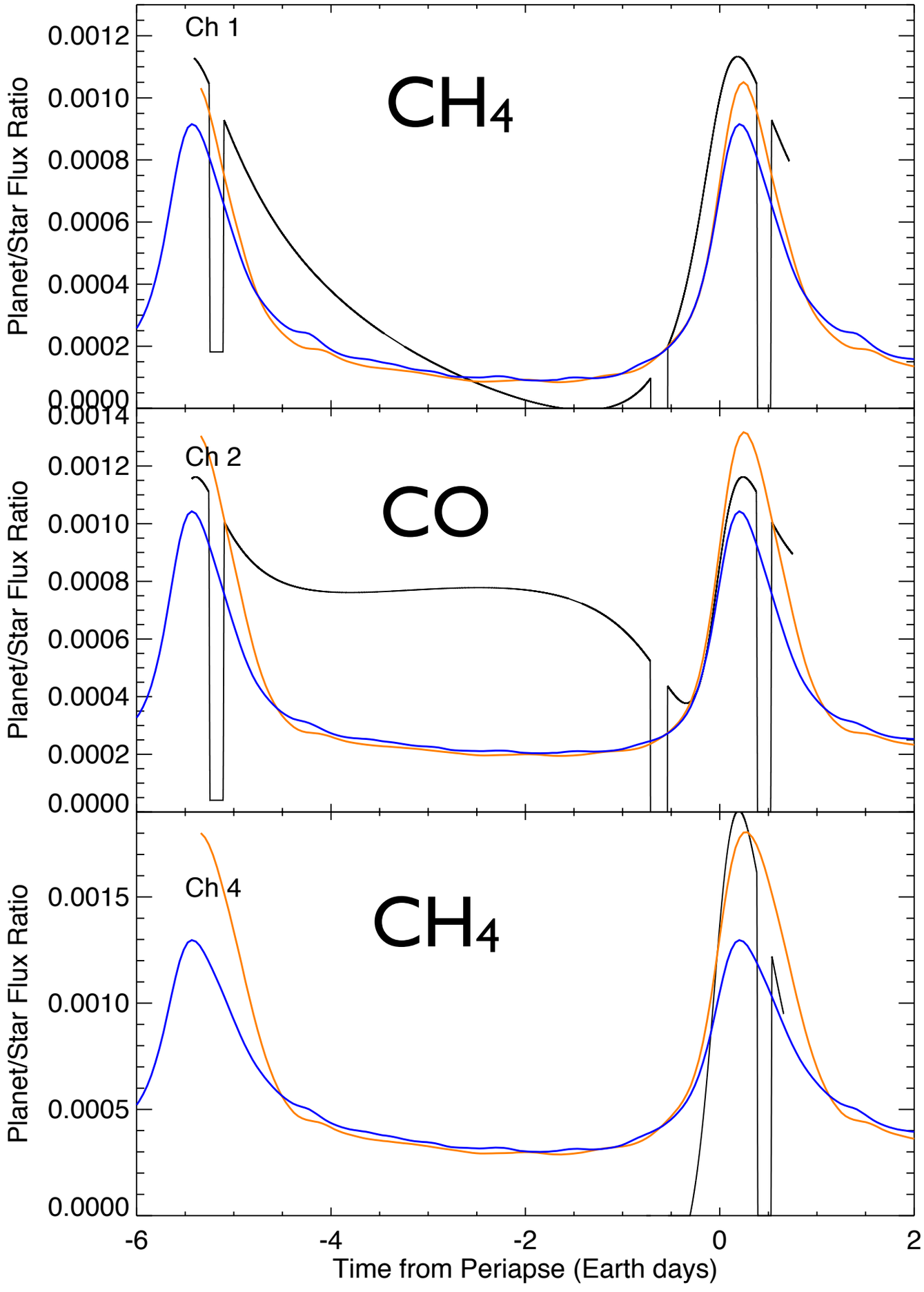


Lewis, Knutson et al., *submitted*

HAT-P-2b



Lewis, Knutson et al., *submitted*



HAT-P-2b Models

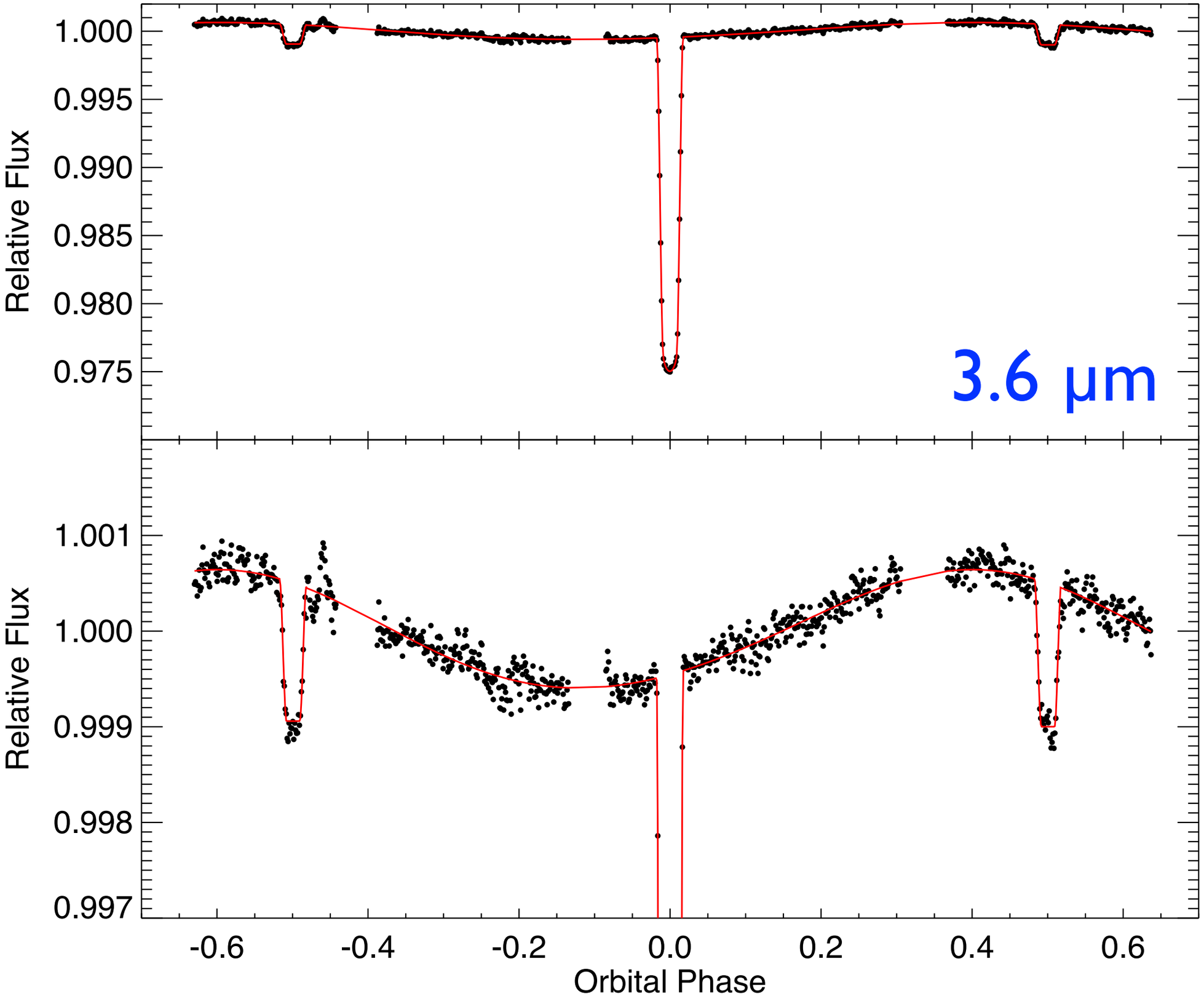
- Our models assume a solar composition cloud-free atmosphere in thermo-chemical equilibrium.

- Disequilibrium carbon chemistry could exist in HAT-P-2b's atmosphere

- Exact timing of peak flux could be influenced by rotation rate assumption

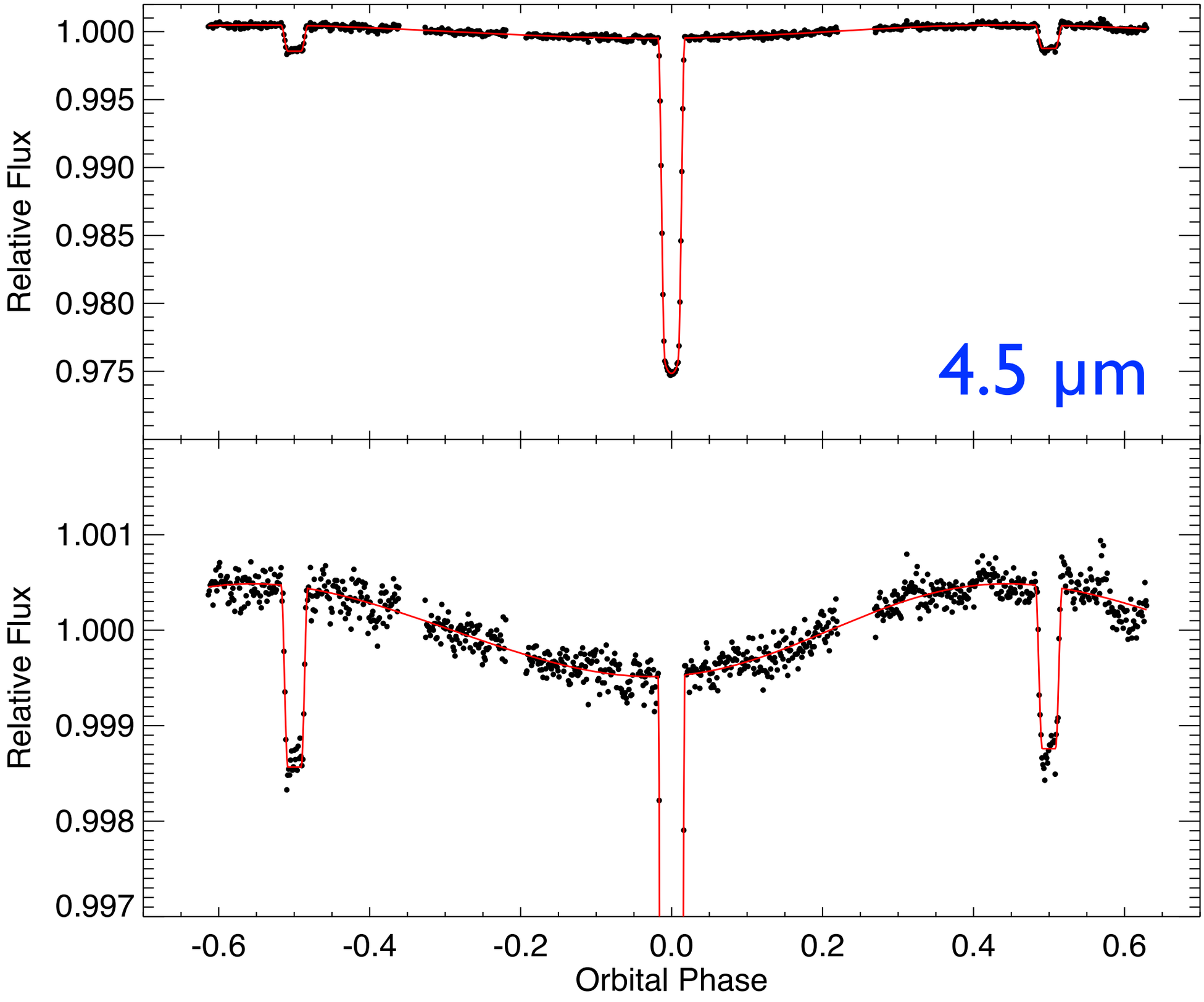
Lewis, Showman, et al., *in prep*

HD 189733b



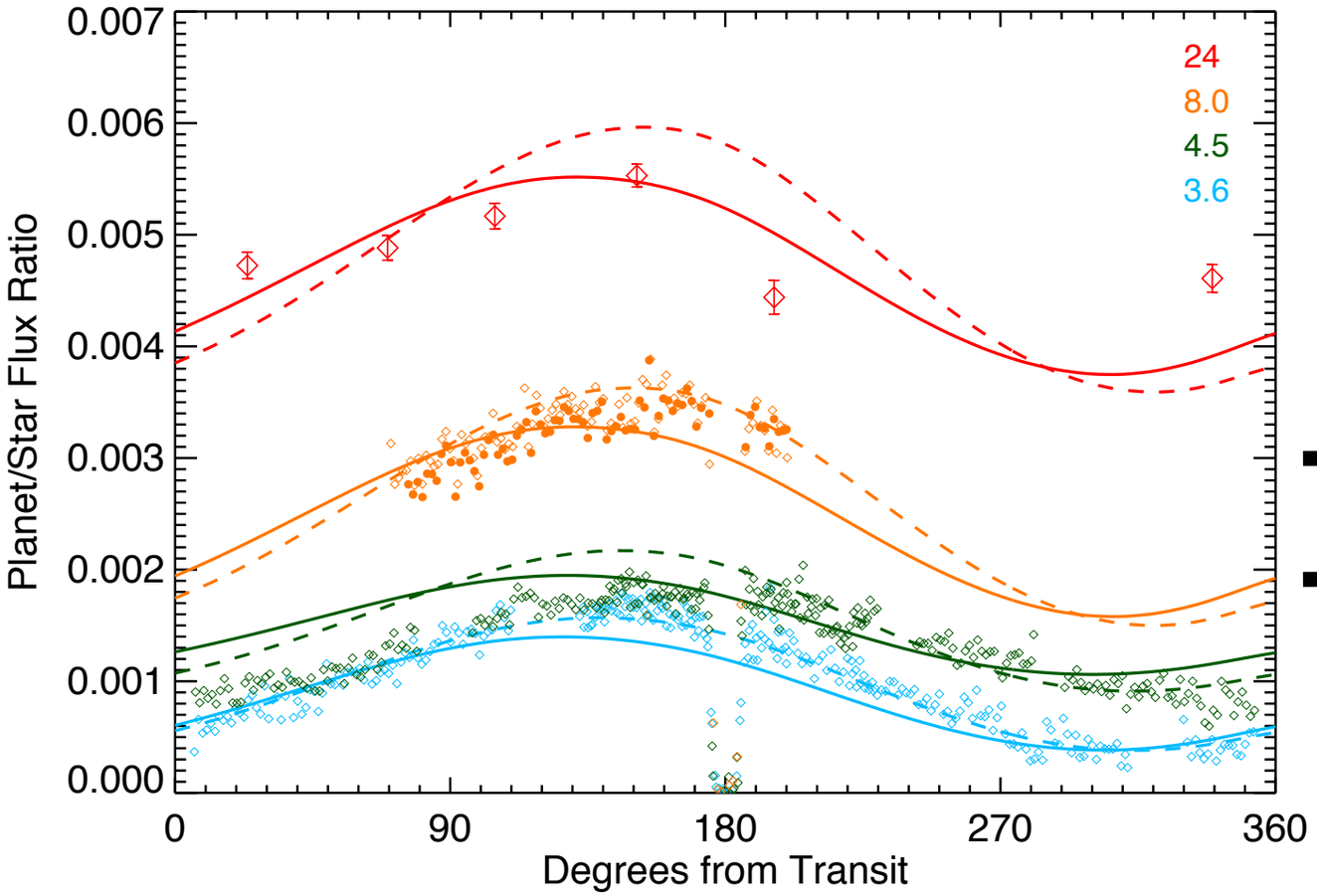
Knutson, Lewis et al. (2012)

HD 189733b



Knutson, Lewis et al. (2012)

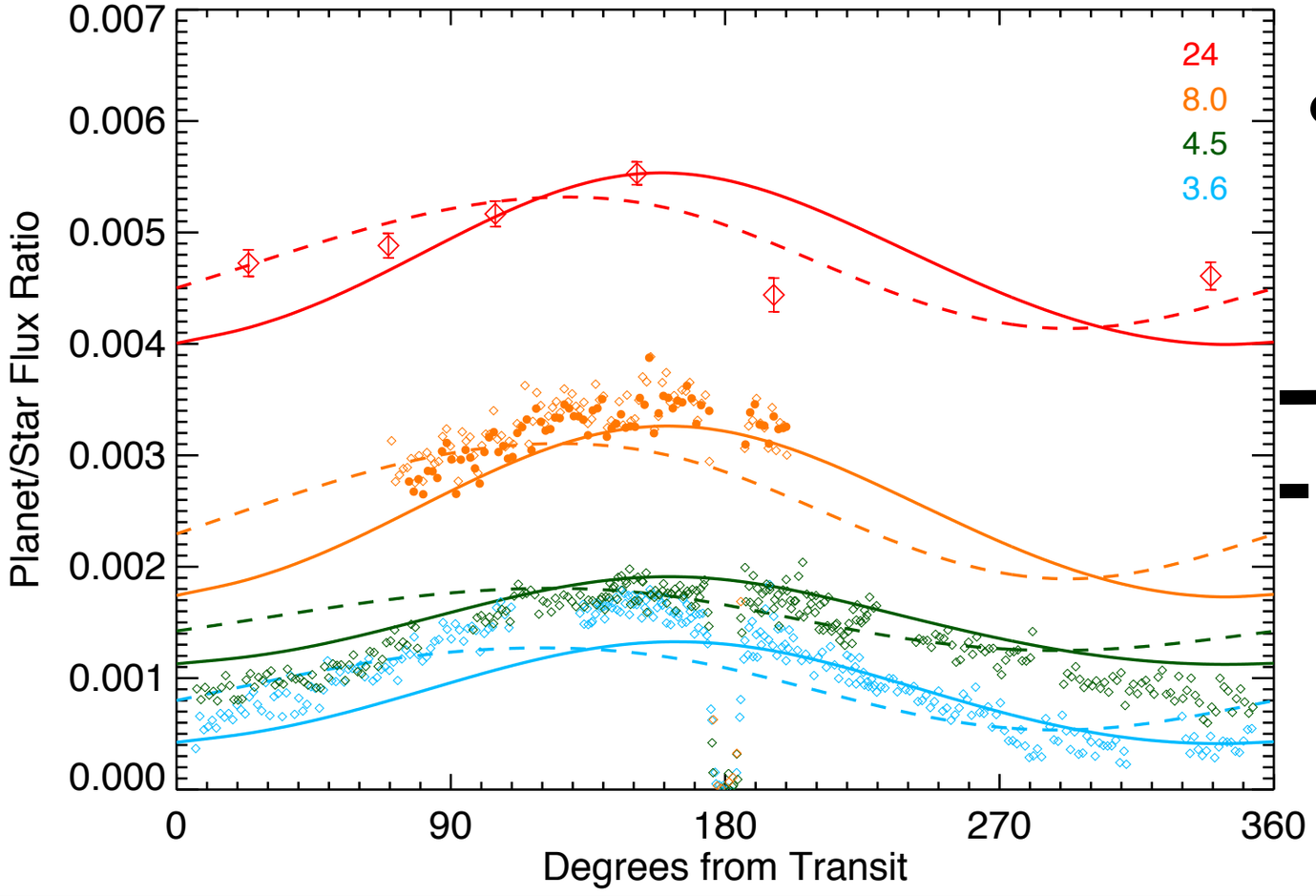
HD 189733b Models



- Composition Test

—— 1x Solar Composition

- - - 5x Solar Composition



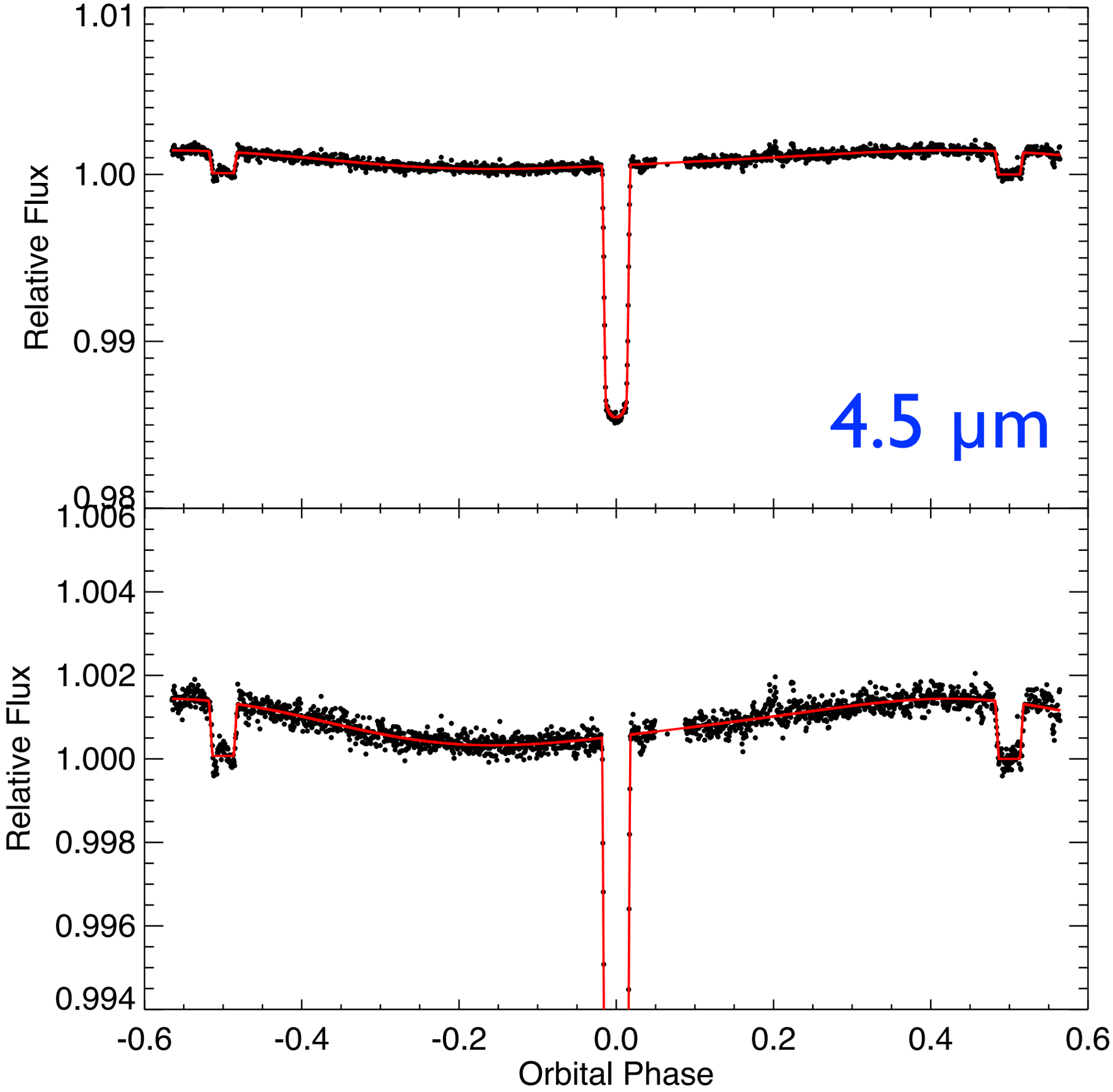
- Rotation Rate Test

—— Slow rotator (2x P_{orb})

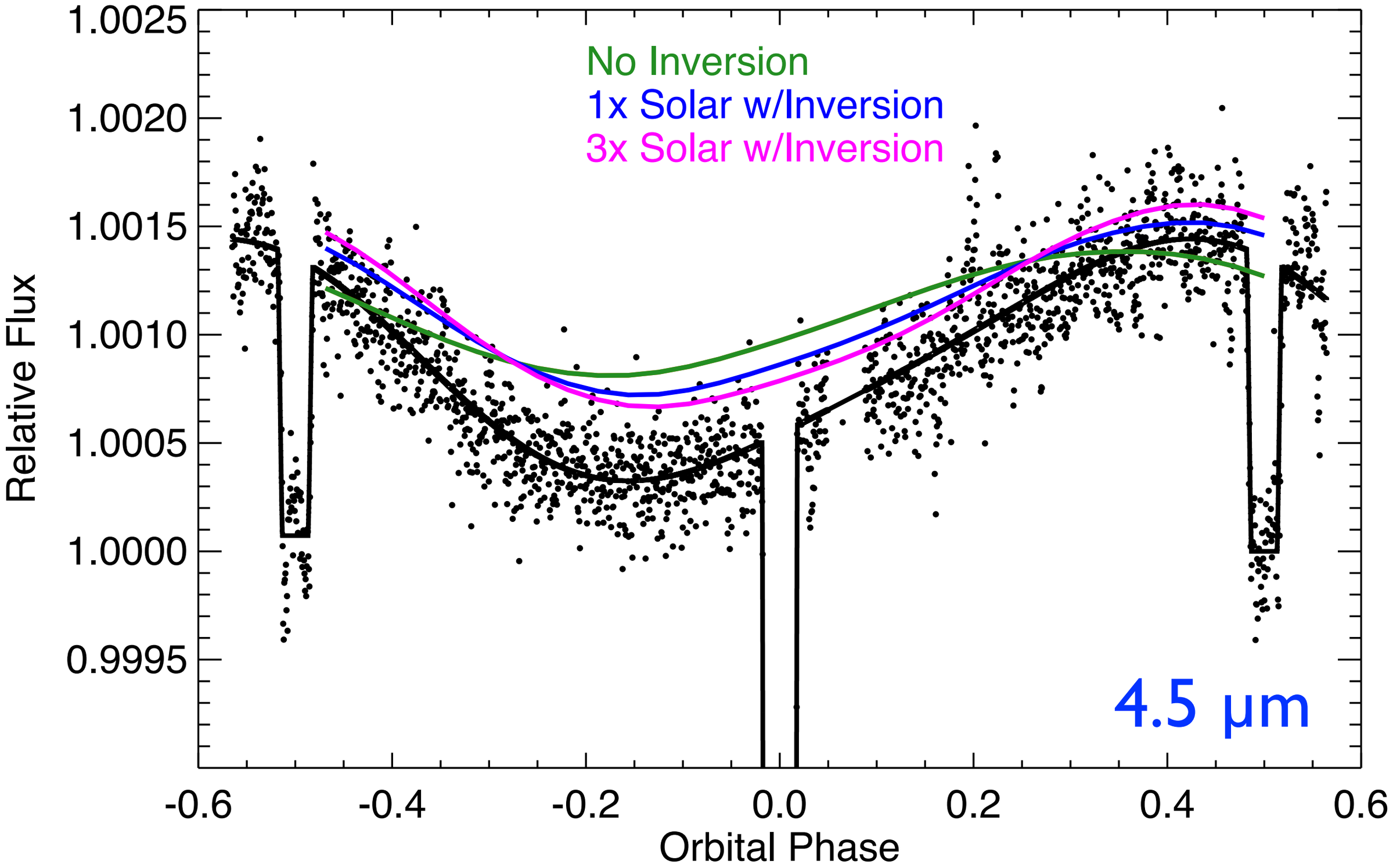
- - - Fast rotator (0.5x P_{orb})

Knutson, Lewis et al. (2012)

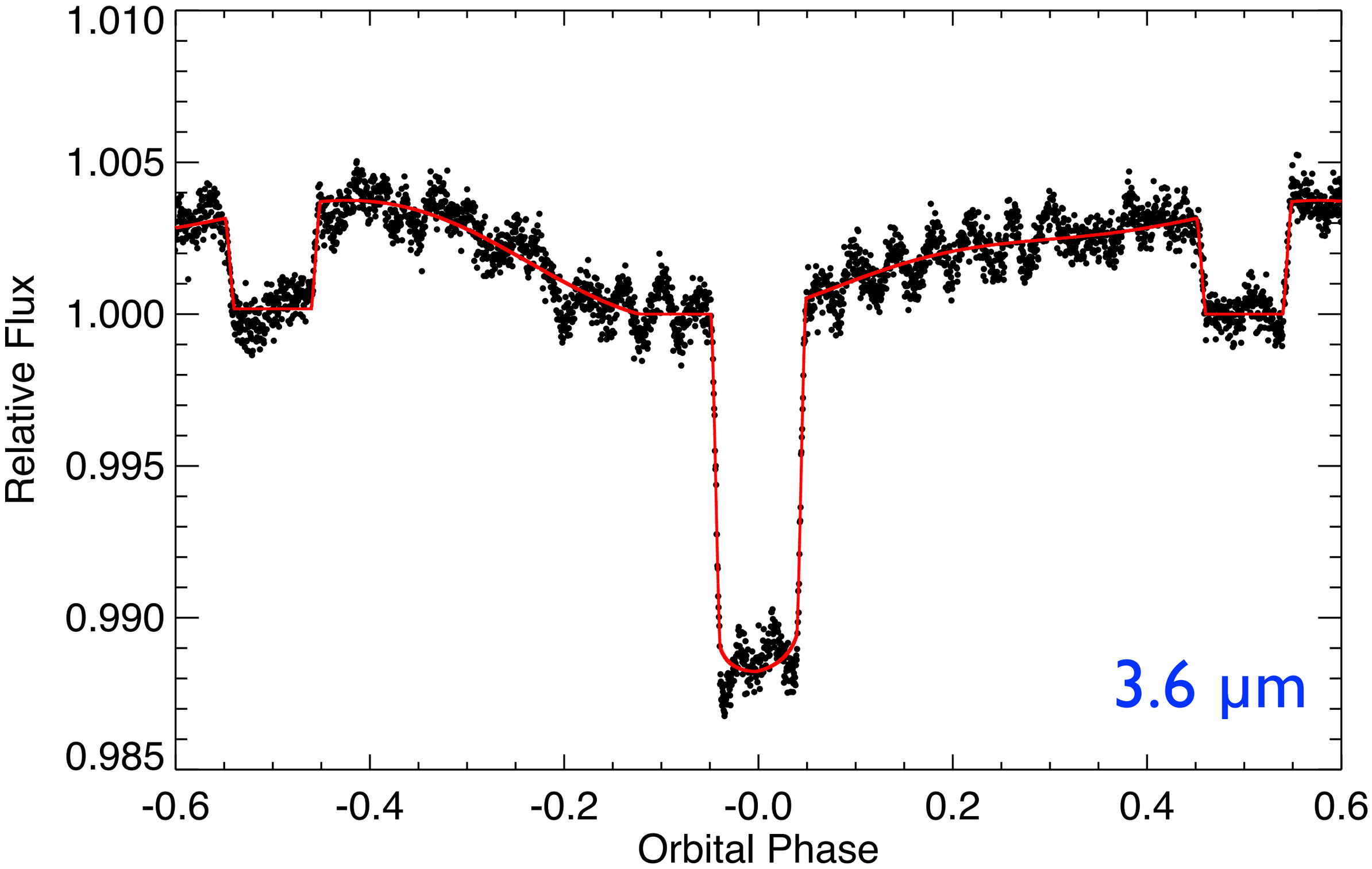
HD 209458b


1.01
1.00
0.99
0.98
Relative Flux
4.5 μm
1.006
1.004
1.002
1.000
0.998
0.996
0.994
Relative Flux
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
Orbital Phase

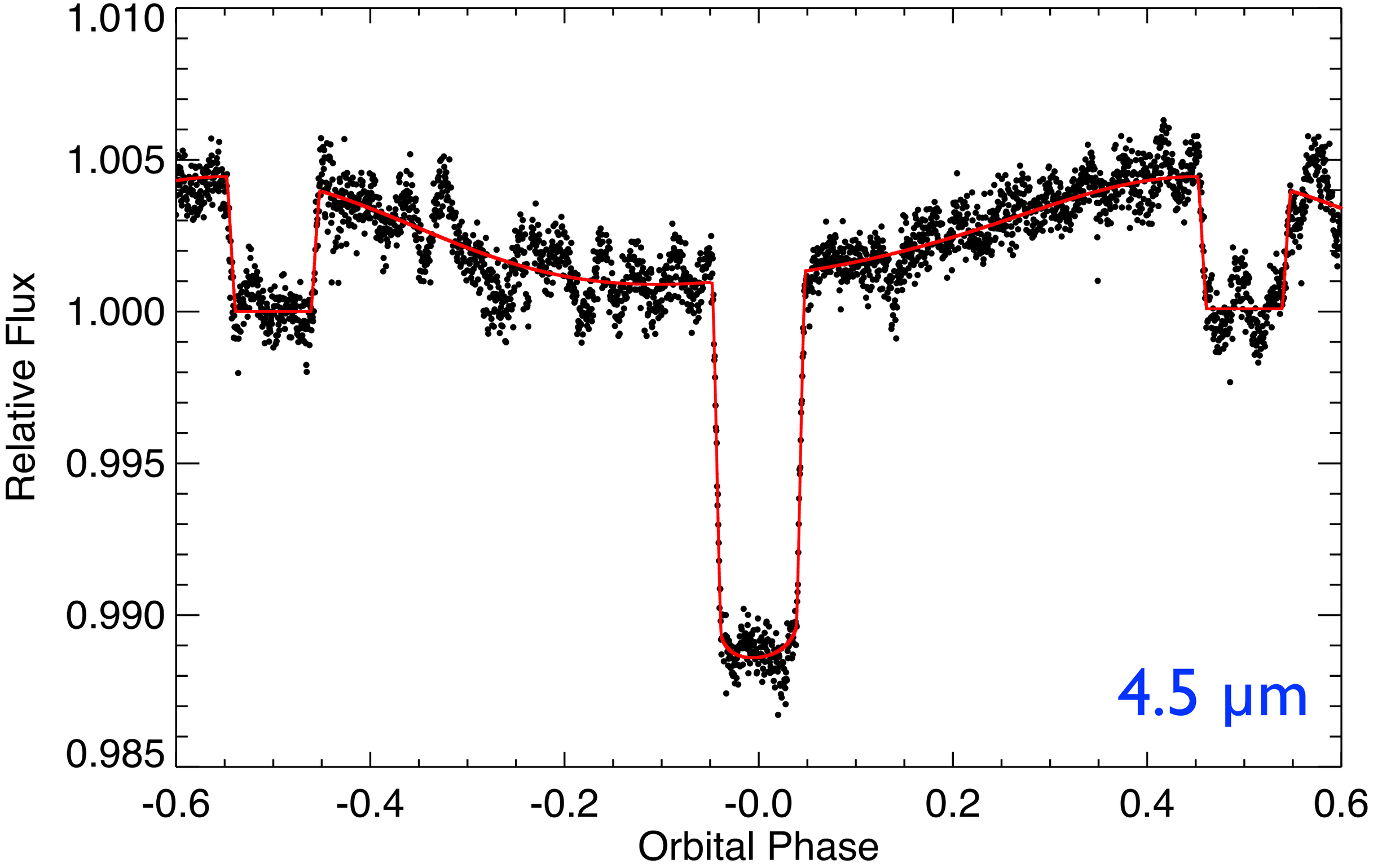
HD 209458b Models



WASP-33b


1.010
1.005
1.000
0.995
0.990
0.985
Relative Flux
-0.6
-0.4
-0.2
-0.0
0.2
0.4
0.6
Orbital Phase
3.6 μm

WASP-33b


1.010
1.005
1.000
0.995
0.990
0.985
Relative Flux
-0.6
-0.4
-0.2
-0.0
0.2
0.4
0.6
Orbital Phase
4.5 μm

Conclusions

- Three-dimensional atmospheric models that treat radiative, advective, and chemical processes consistently are key to understanding the basic wind and thermal structure of exoplanet atmospheres.

- Phase-curve observations of hot-Jupiters allow observers to directly measure thermal gradients in exoplanet atmospheres and relate those gradients to global circulation patterns.

- Exoplanet modeling efforts need to further explore the effects of disequilibrium chemistry and clouds on global circulation patterns.

- More than a dozen full-orbit phase-curve observations now completed, with more to come!