Hot Jupiters: Orbital Phase Observations

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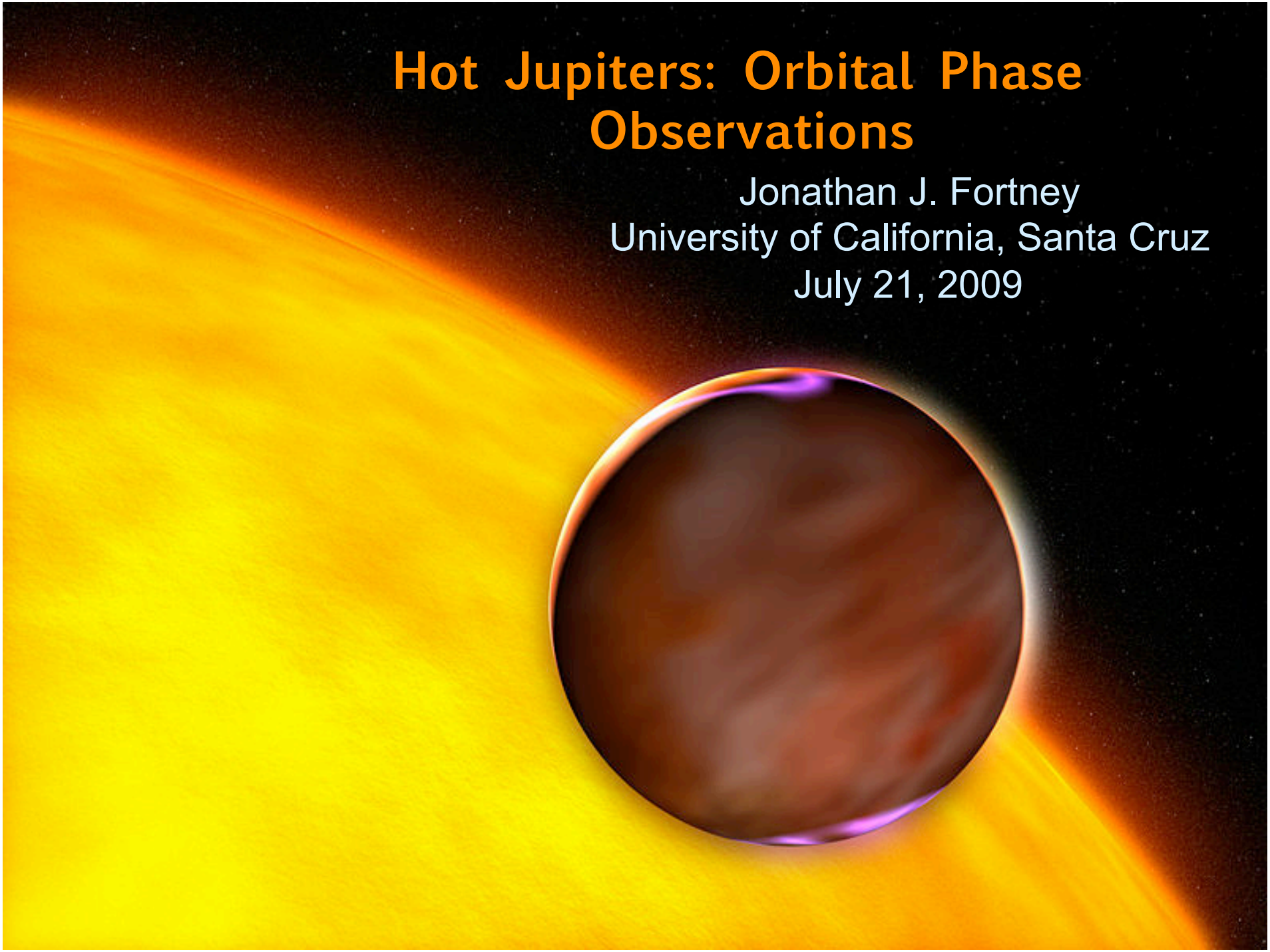
July 21, 2009

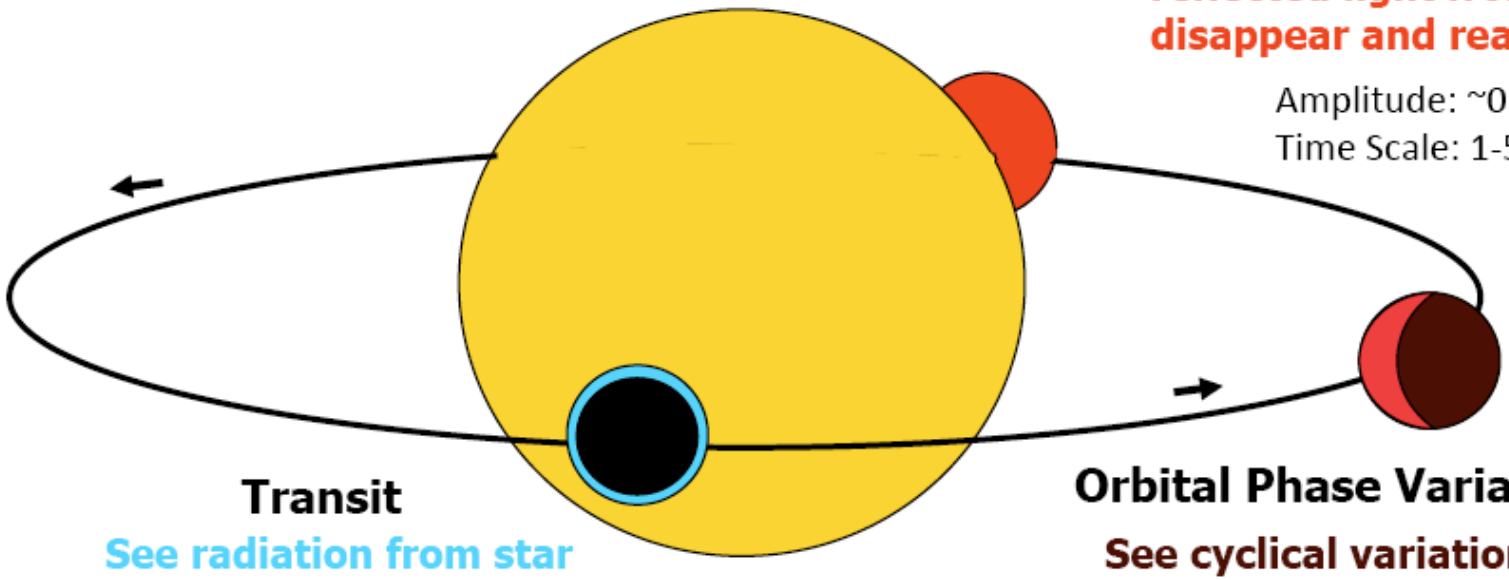


Putting It All Together: Transiting Planets as a Tool for Studying Exoplanet Atmospheres

Secondary Eclipse

See thermal radiation and reflected light from planet disappear and reappear

Amplitude: ~0.1%
Time Scale: 1-5 hours



Transit

See radiation from star transmitted through the planet's atmosphere

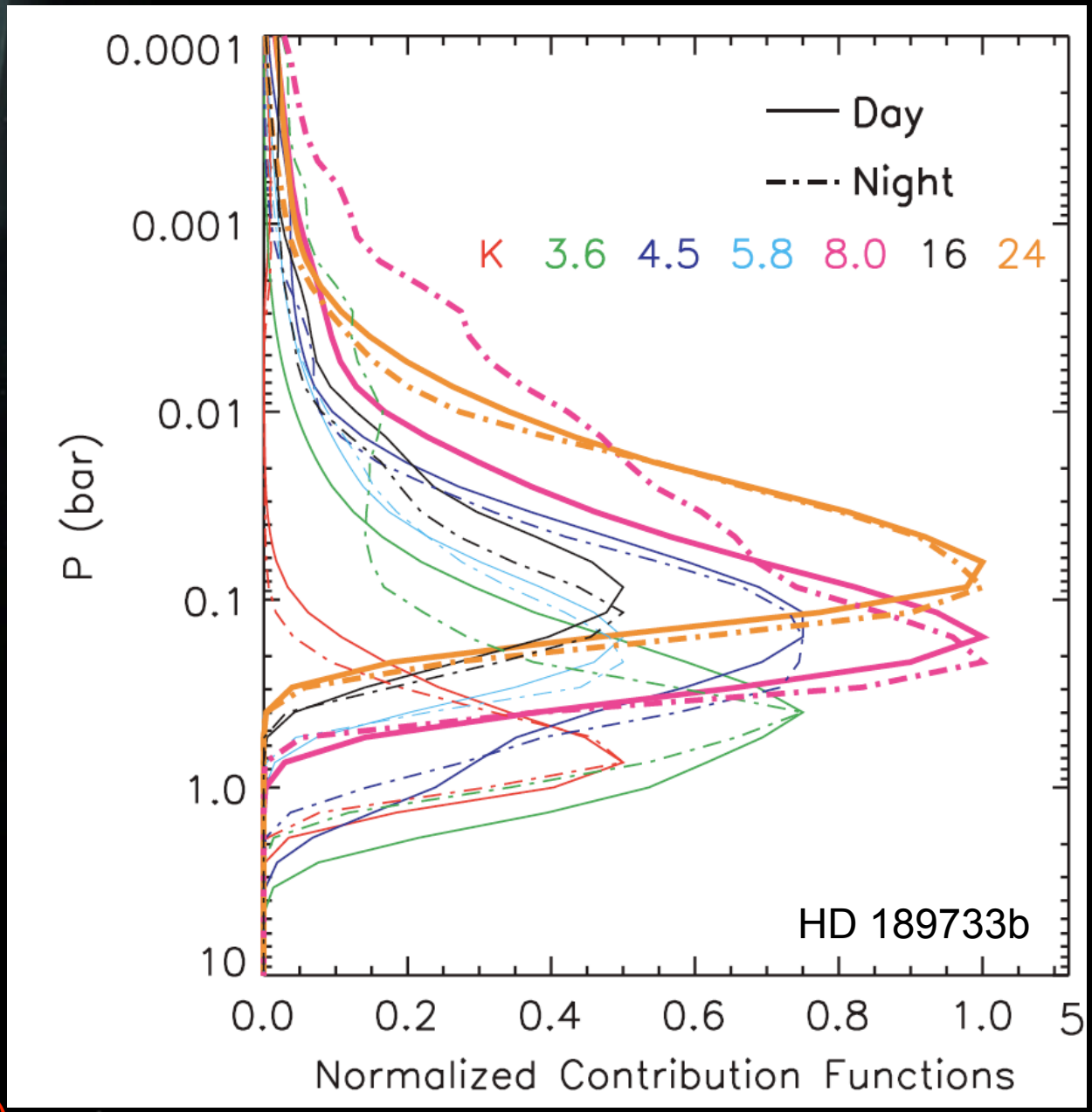
Transit depth: ~1%
Absorption feature: ~0.01%
Time Scale: 1-5 hours

Orbital Phase Variations

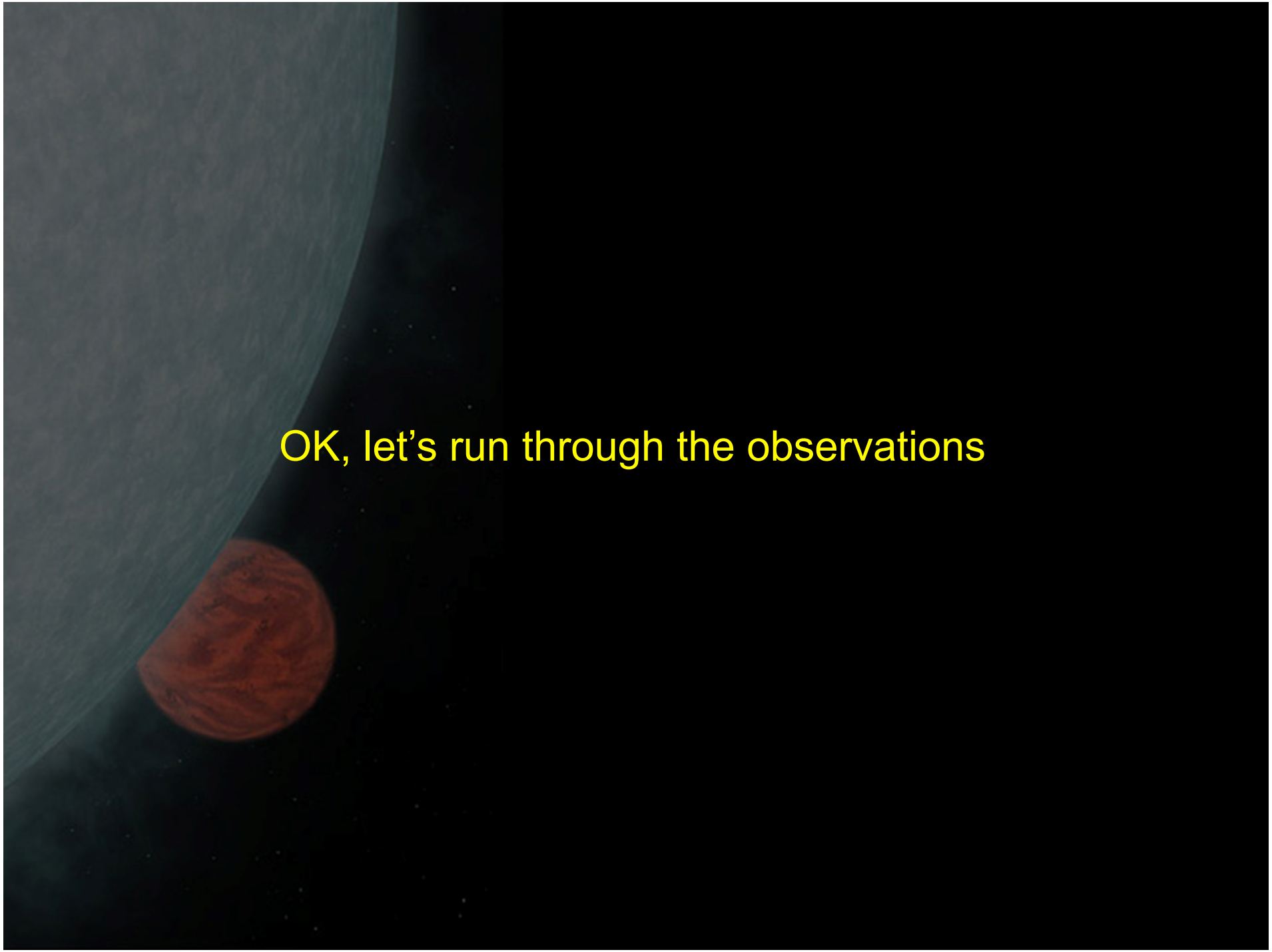
See cyclical variations in brightness of planet

Amplitude: ~0.01-0.1%
Time Scale: 30-100 hours

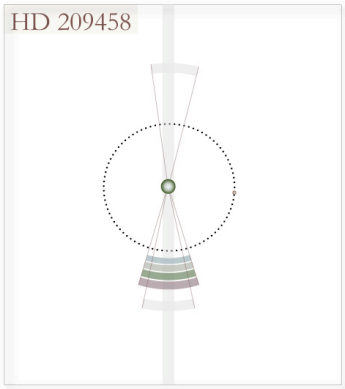
- Keep in mind that particular wavelengths probe particular depths in the atmosphere, such that no one wavelength can give us a day/night T_{eff} contrast
- At wavelengths where the opacity is low, we can see deeper into the atmosphere

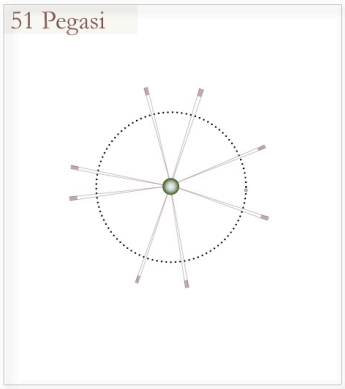


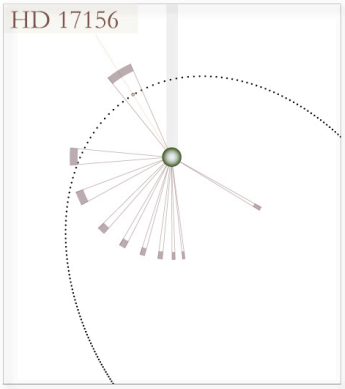
Knutson et al. (2009)

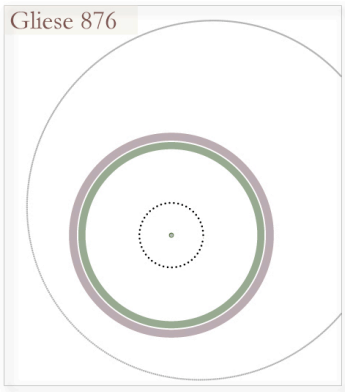

OK, let’s run through the observations

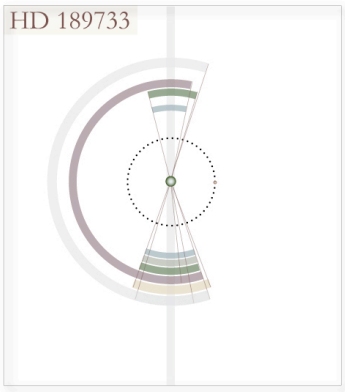
A Field Guide to the Spitzer Observations

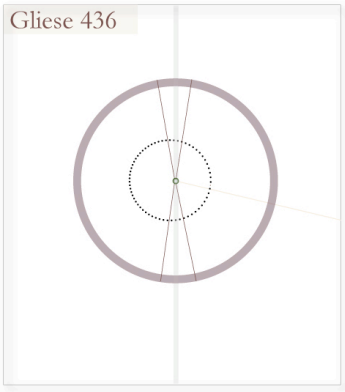


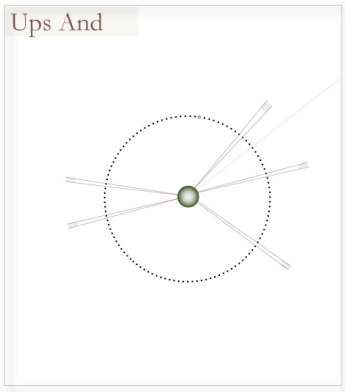


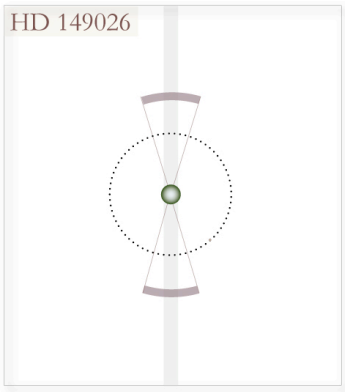


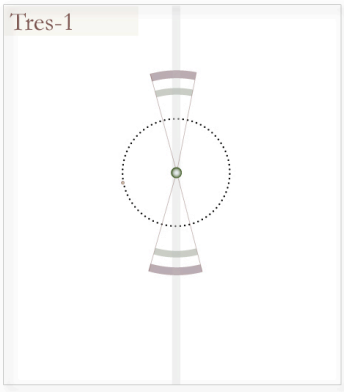


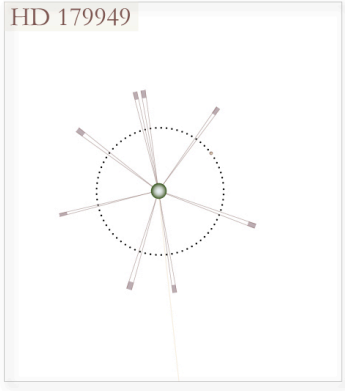


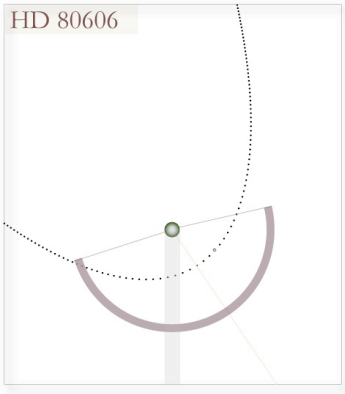


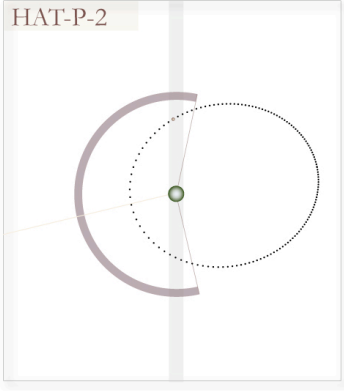








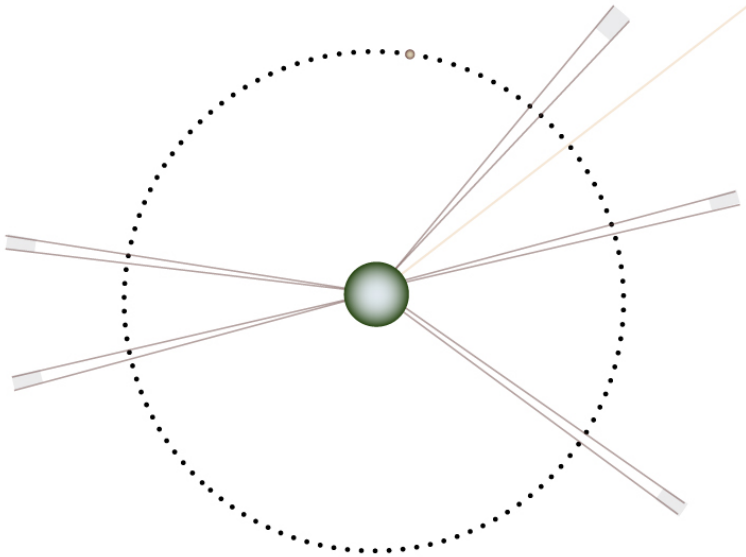




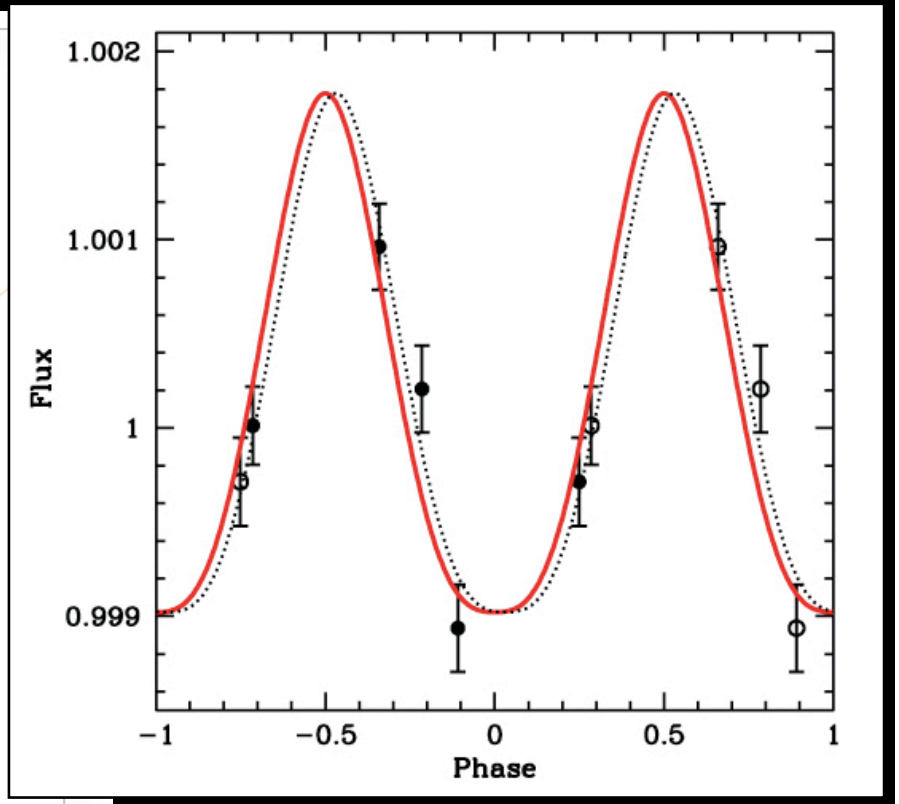
Laughlin & Fortney, oklo.org (2008)

Visit oklo.org on the Internet for more information.

Ups And

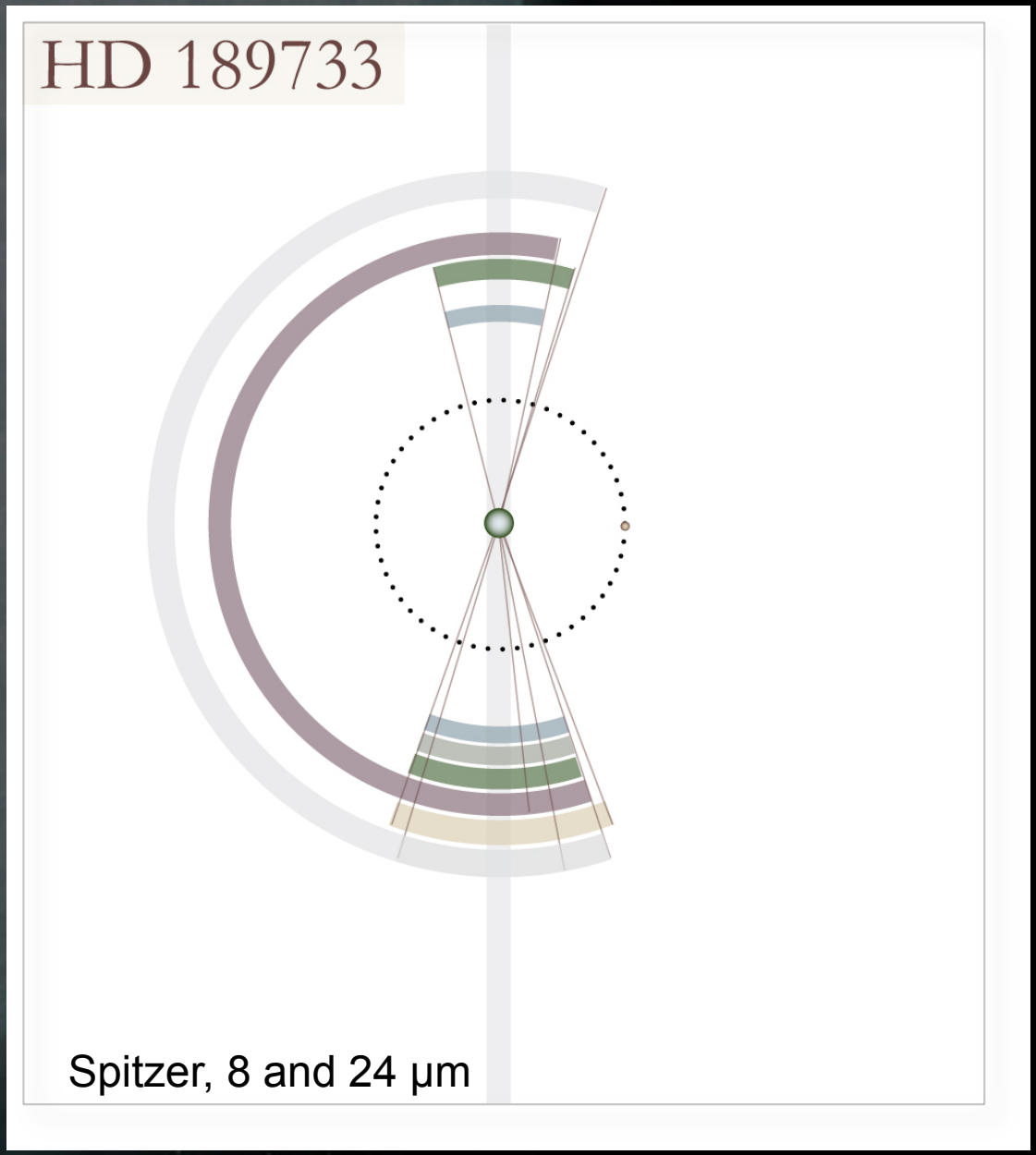


Spitzer, 8 μm



- Very bright parent star
- Large phase variations imply large day/night temperature contrast
- Small energy redistribution to night side
- Only 5 data points

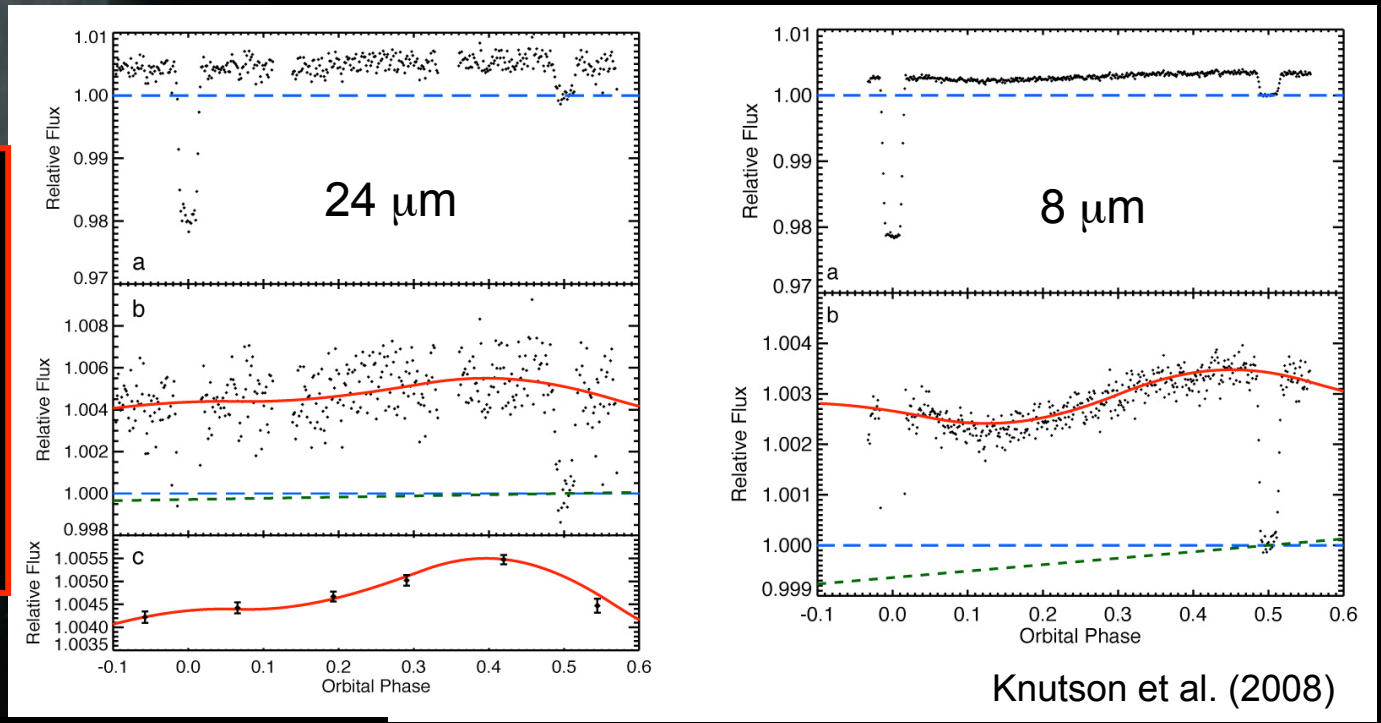
Harrington et al. (2006), Science



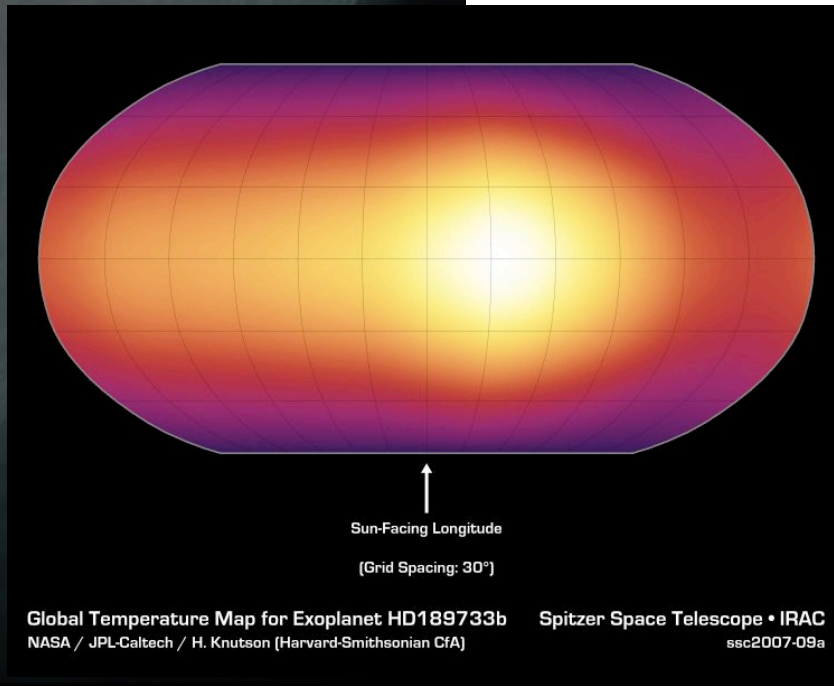
The Gold Standard

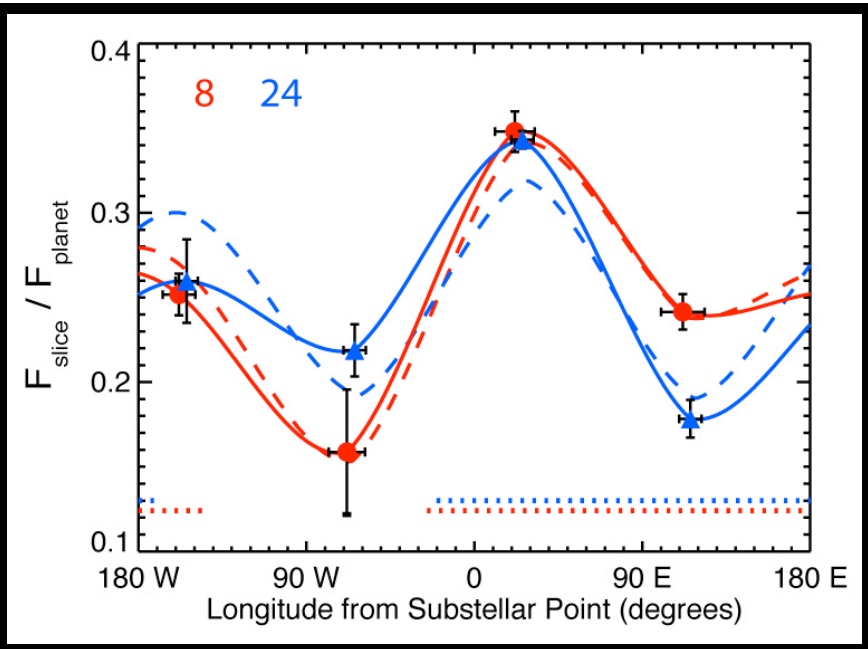
Knutson et al. (2007), Nature

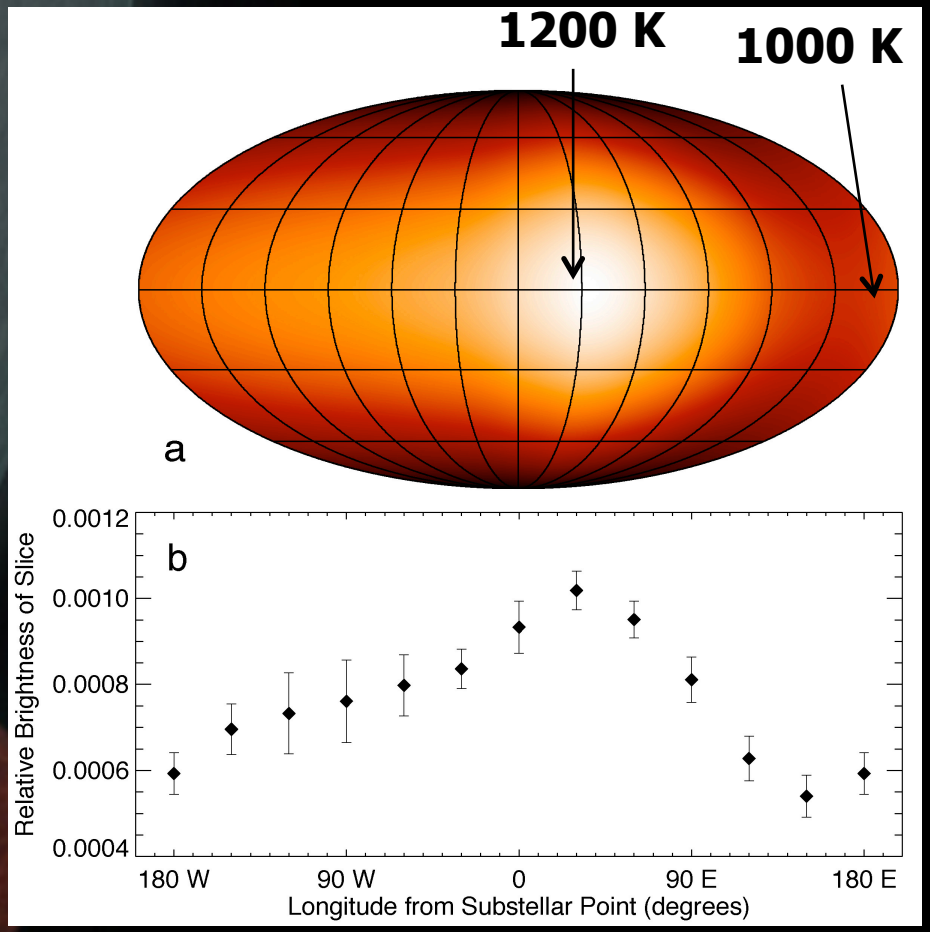
Detailed Characterization: Going from light curves to "orange slice" brightness maps of planetary emission



Knutson et al. (2008)

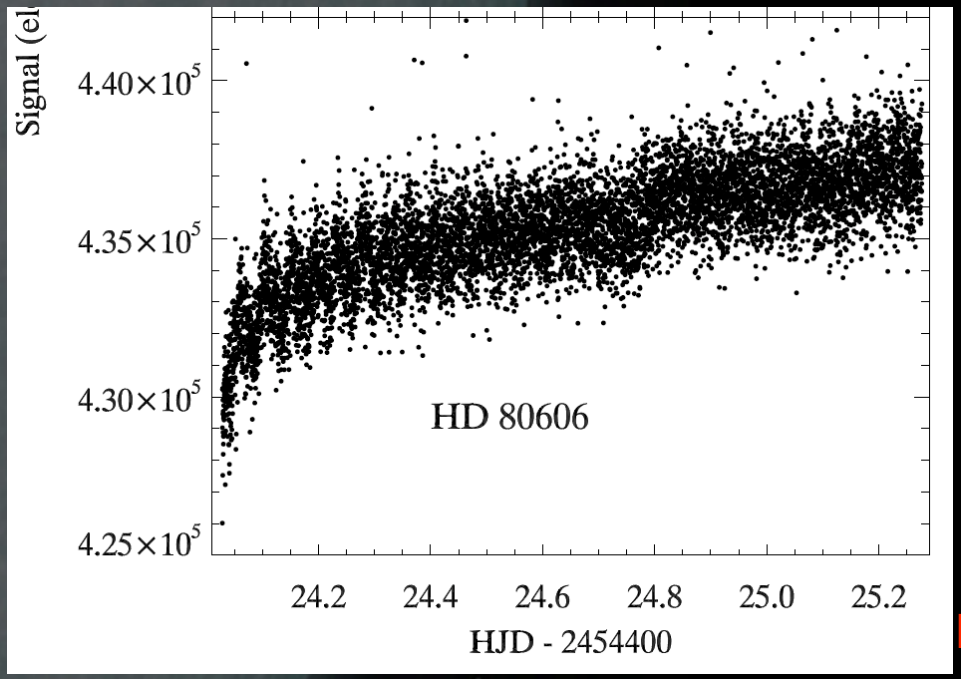






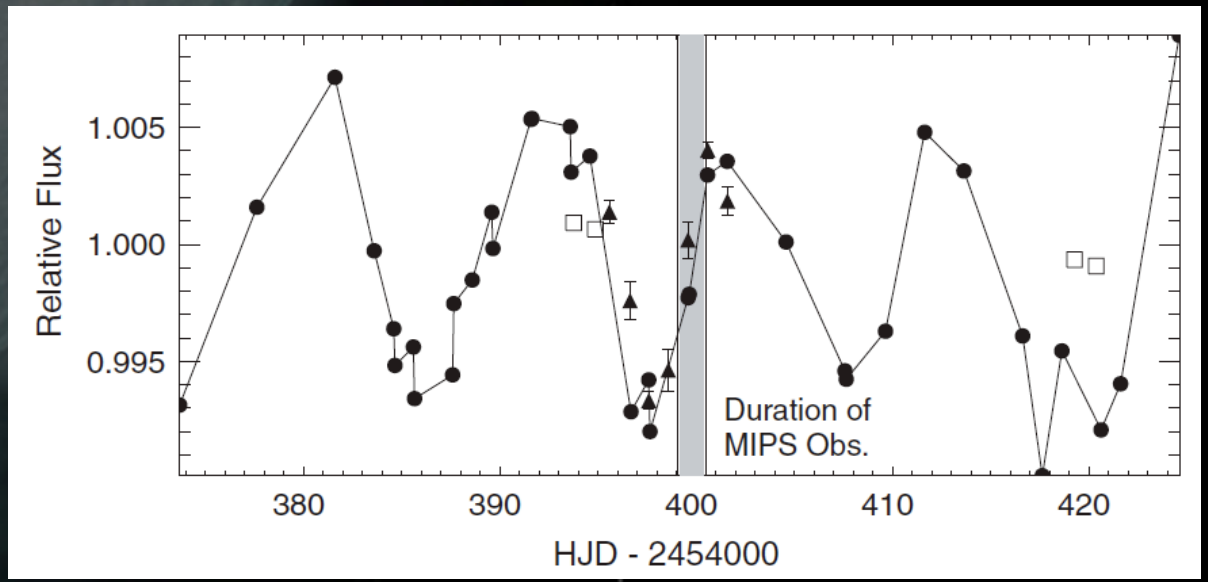
- Exoplanet temperature map
- Hot and cold spots on the same hemisphere

Things to worry about



The detector "ramp": Non-linear increase in measured flux, w/ time

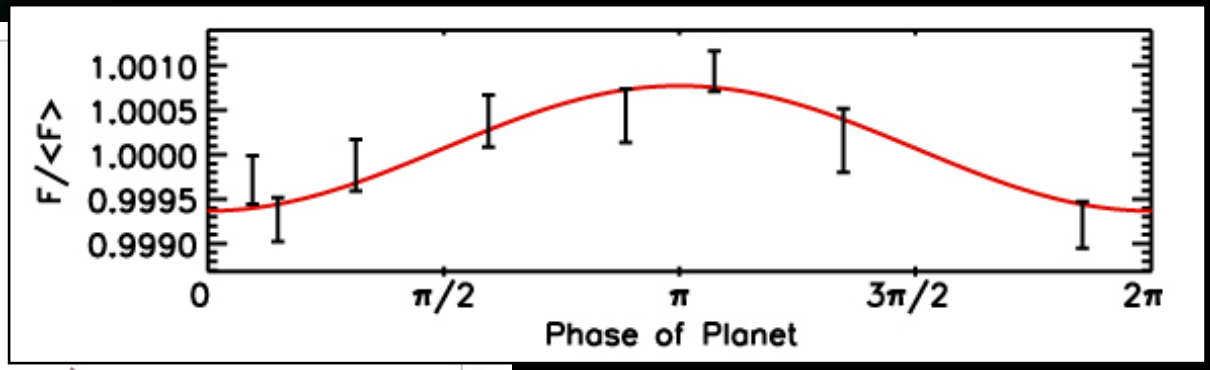
Laughlin et al. (2009)

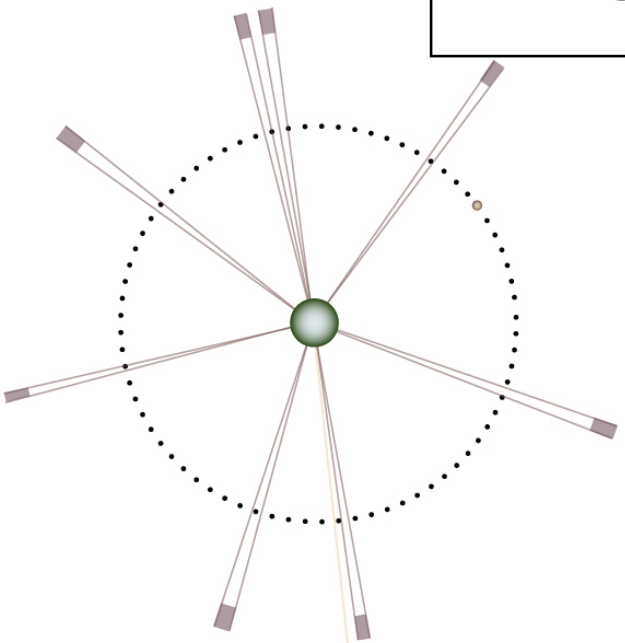


Starspots: Use concurrent optical observations to gauge importance

Knutson et al. (2009)

HD 179949





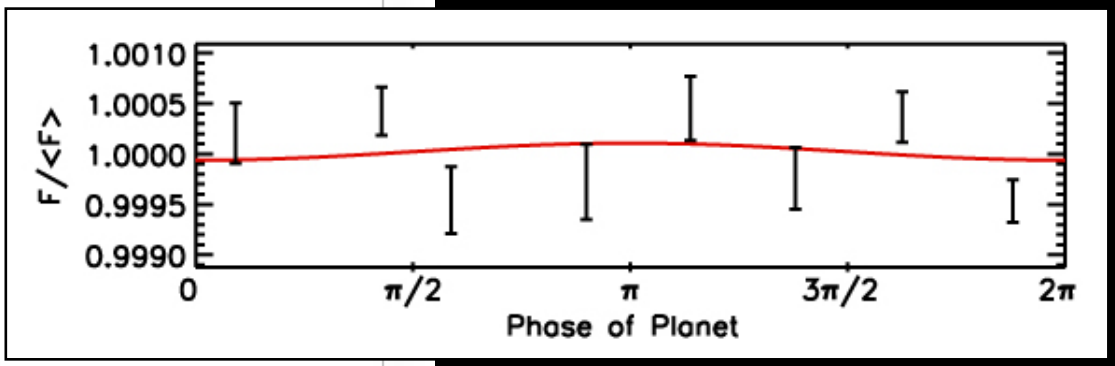
Spitzer, 8 μm

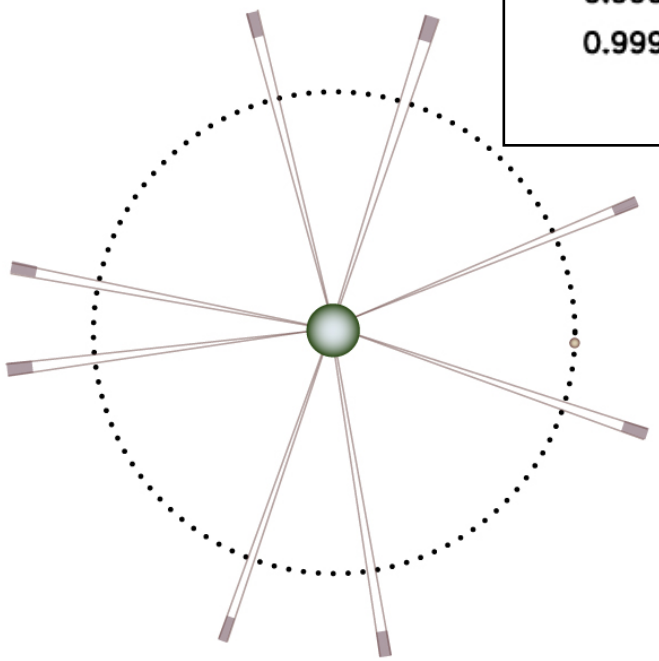
- Large phase variations imply large day/night temperature contrast
- Small energy redistribution to night side
- Only 8 data points

- Cowan et al. also monitored stable non-planet-hosting stars

Cowan et al. (2007), MNRAS

51 Pegasi





Spitzer, 8 μm

- Small phase variation implies small day/night temperature contrast
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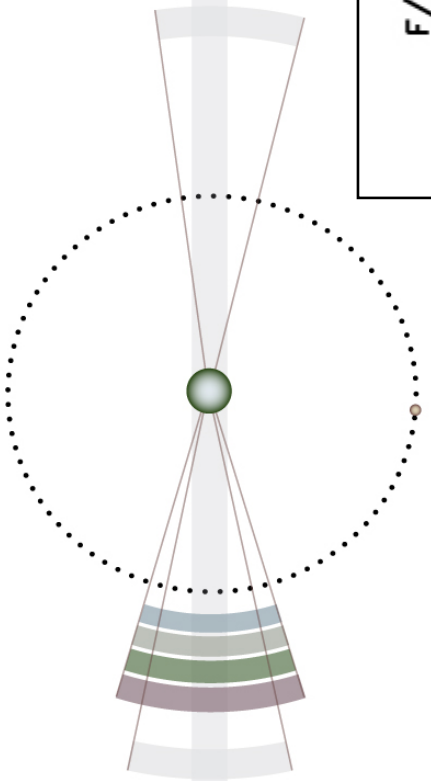
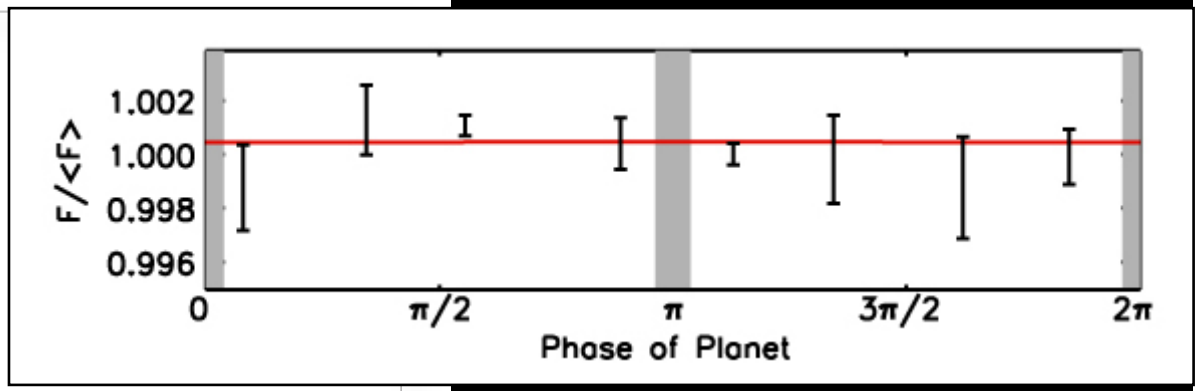
Cowan et al. (2007), MNRAS

HD 209458



Spitzer, 8 μm



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Cowan et al. (2007), MNRAS

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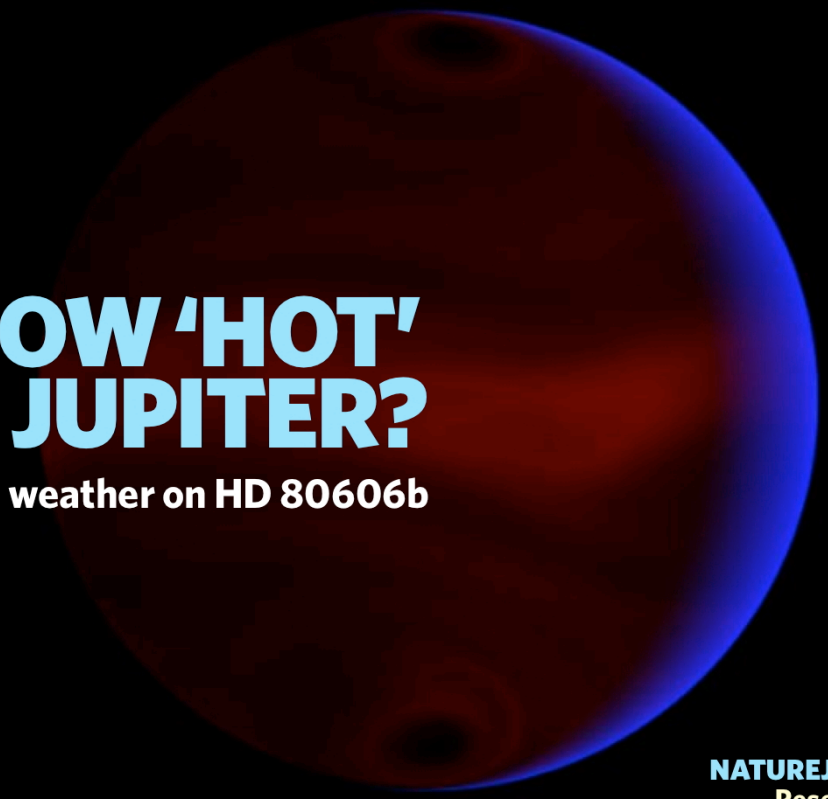


HOW 'HOT' A JUPITER?

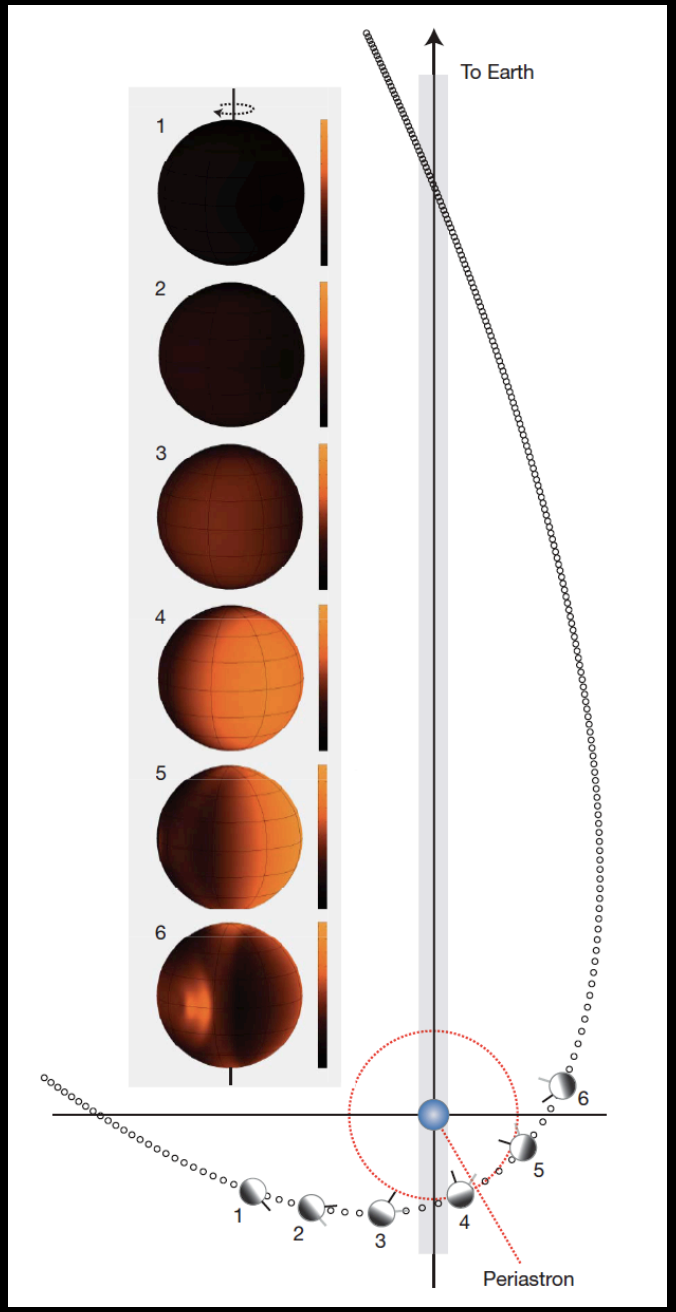
The weather on HD 80606b

NATUREJOBS
Research assessment

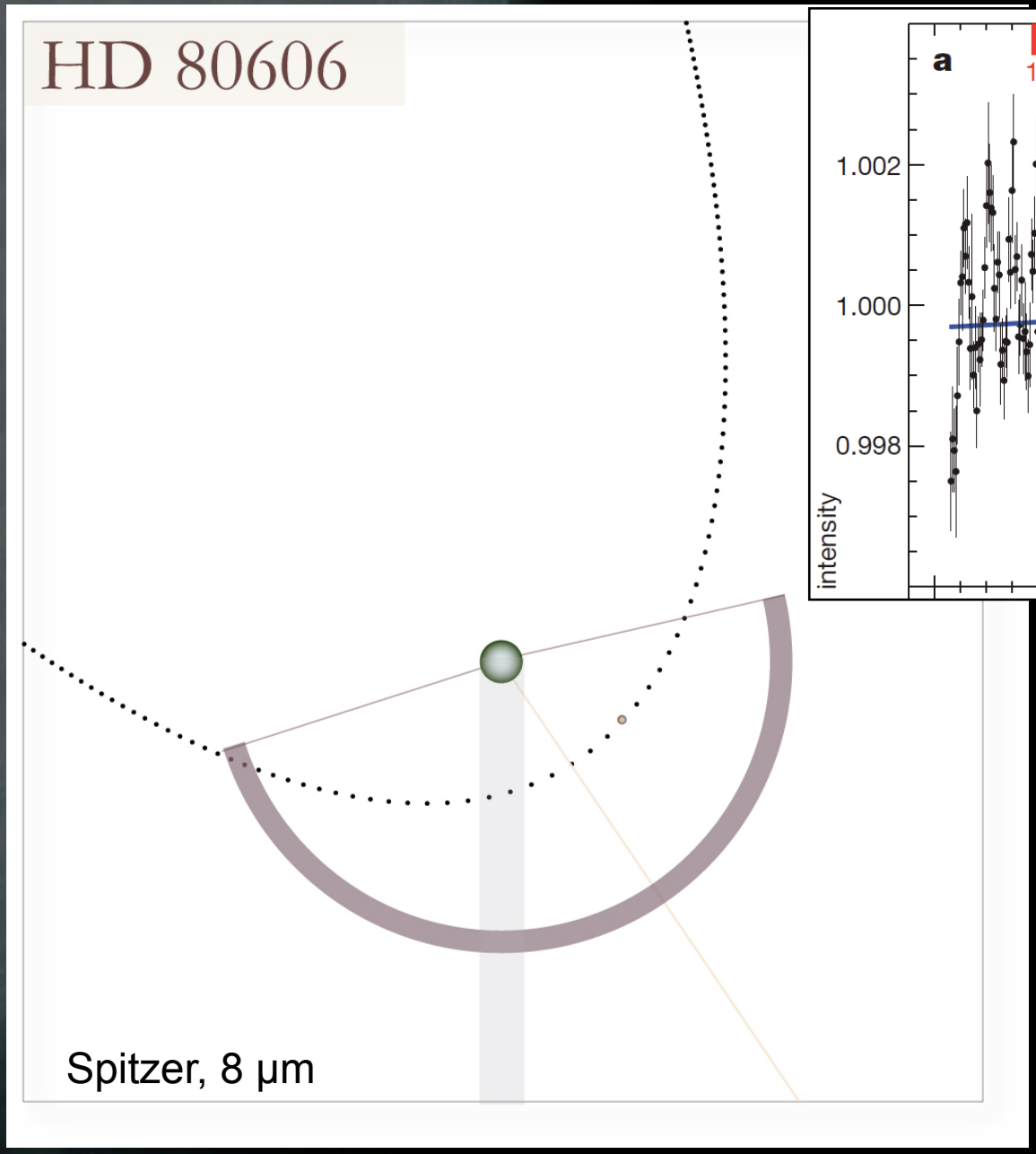
DECISION MAKING
The role of the unconscious

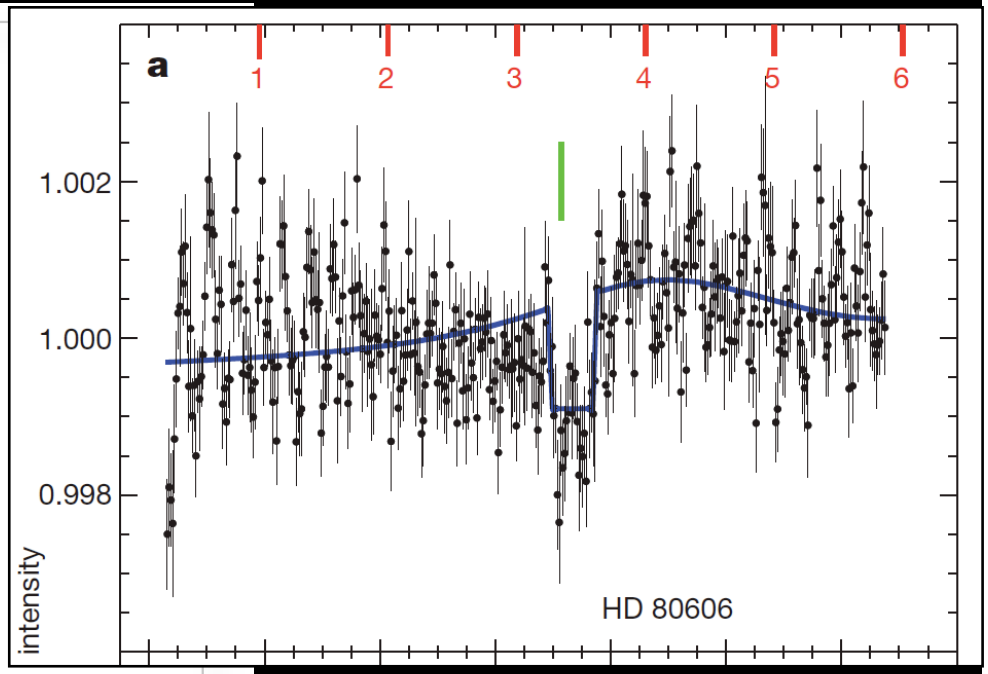
SORGHUM GENOME
Blueprint for drought tolerance

MEDICAL ISOTOPE SUPPLY
Accelerators versus nuclear reactors



nature 457, 505-346 29 January 2009
www.nature.com/nature
no7229 npg

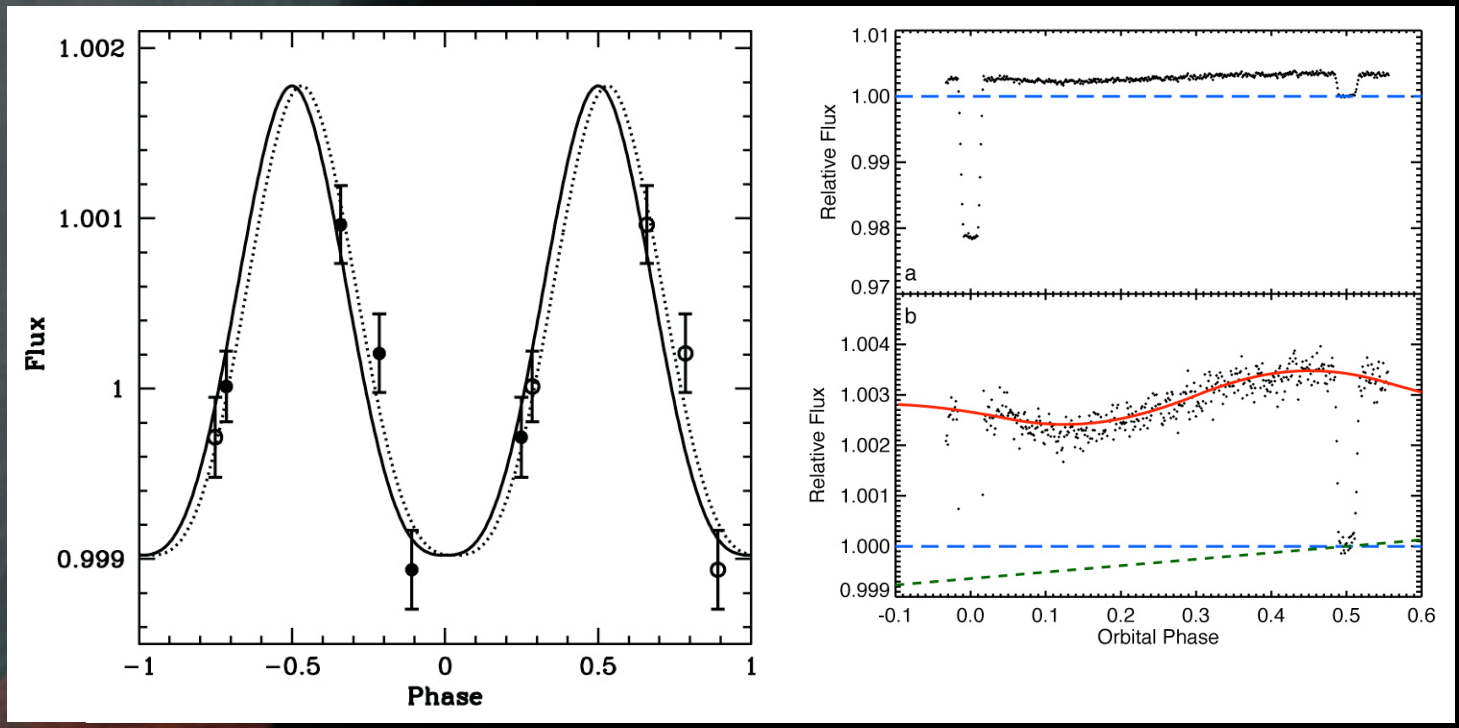




Comparison with 2-layer atmospheric dynamics model to derive the radiative time constant in the atmosphere of HD 80606b.

Laughlin et al. (2009), Nature

Day/Night Contrasts: Large and Small!

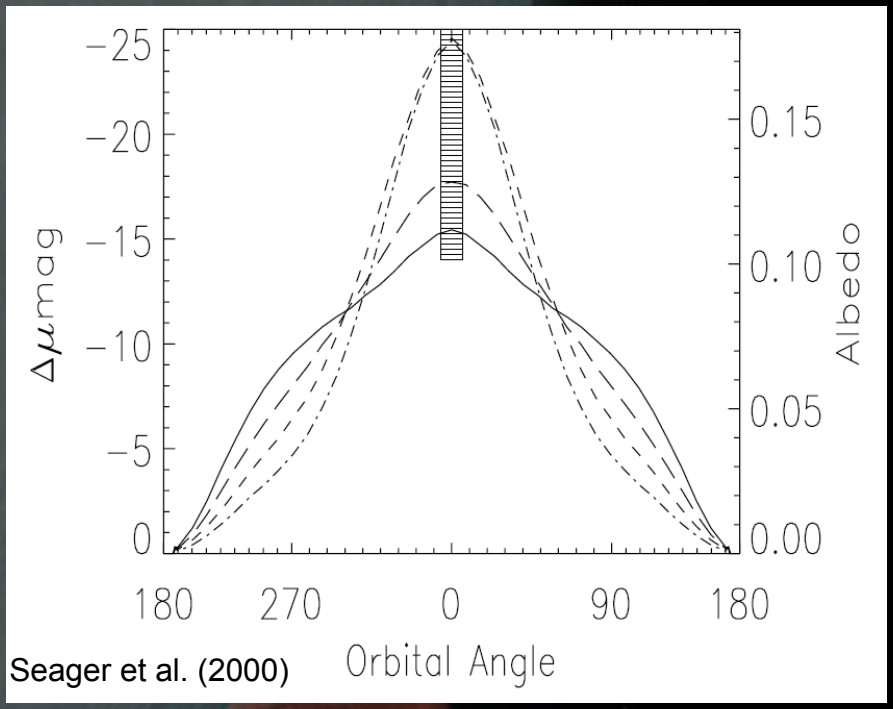


Harrington et al. (2006), Science

Knutson et al. (2007), Nature

Spitzer observations: large day/night temperature variations on a bit shakier ground

Light Curves at Optical Wavelengths



Seager et al. (2000)

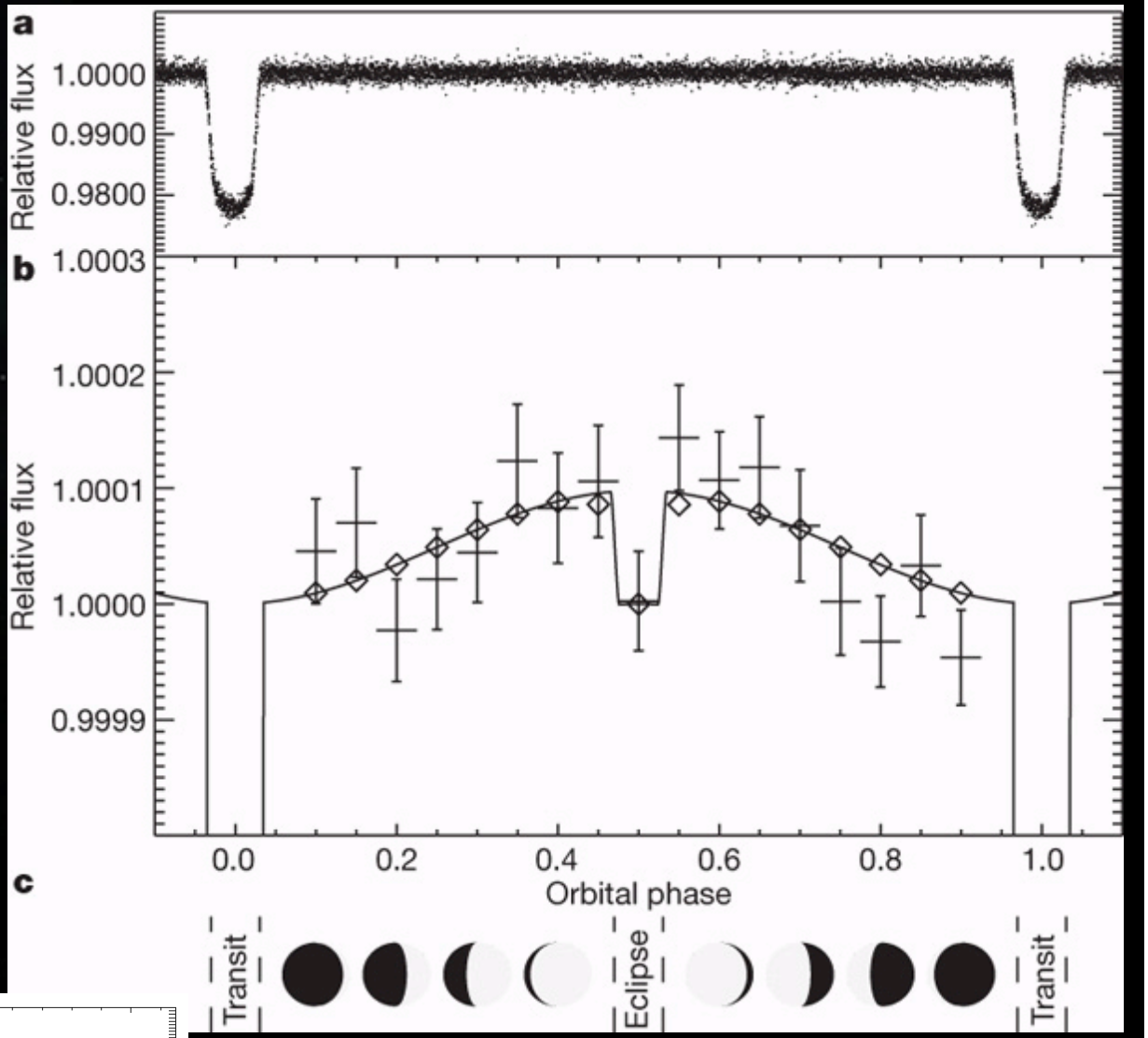
- Earlier in the decade, scattered ("reflected") light was expected to be seen, as a function of orbital phase

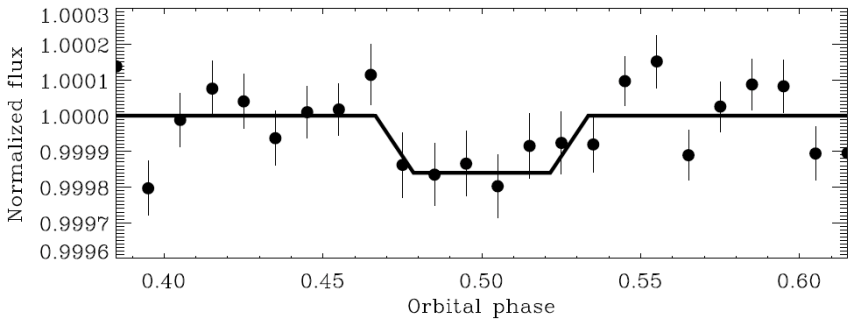
- However, measured Spitzer temperatures and MOST upper limits imply that hot Jupiters absorb nearly all incident light upon them
  - Very little reflected light
  - But perhaps measurable thermal emission at optical wavelengths (Lopez-Morales & Seager 2007, others)

CoRoT-1

CoRoT has done it!

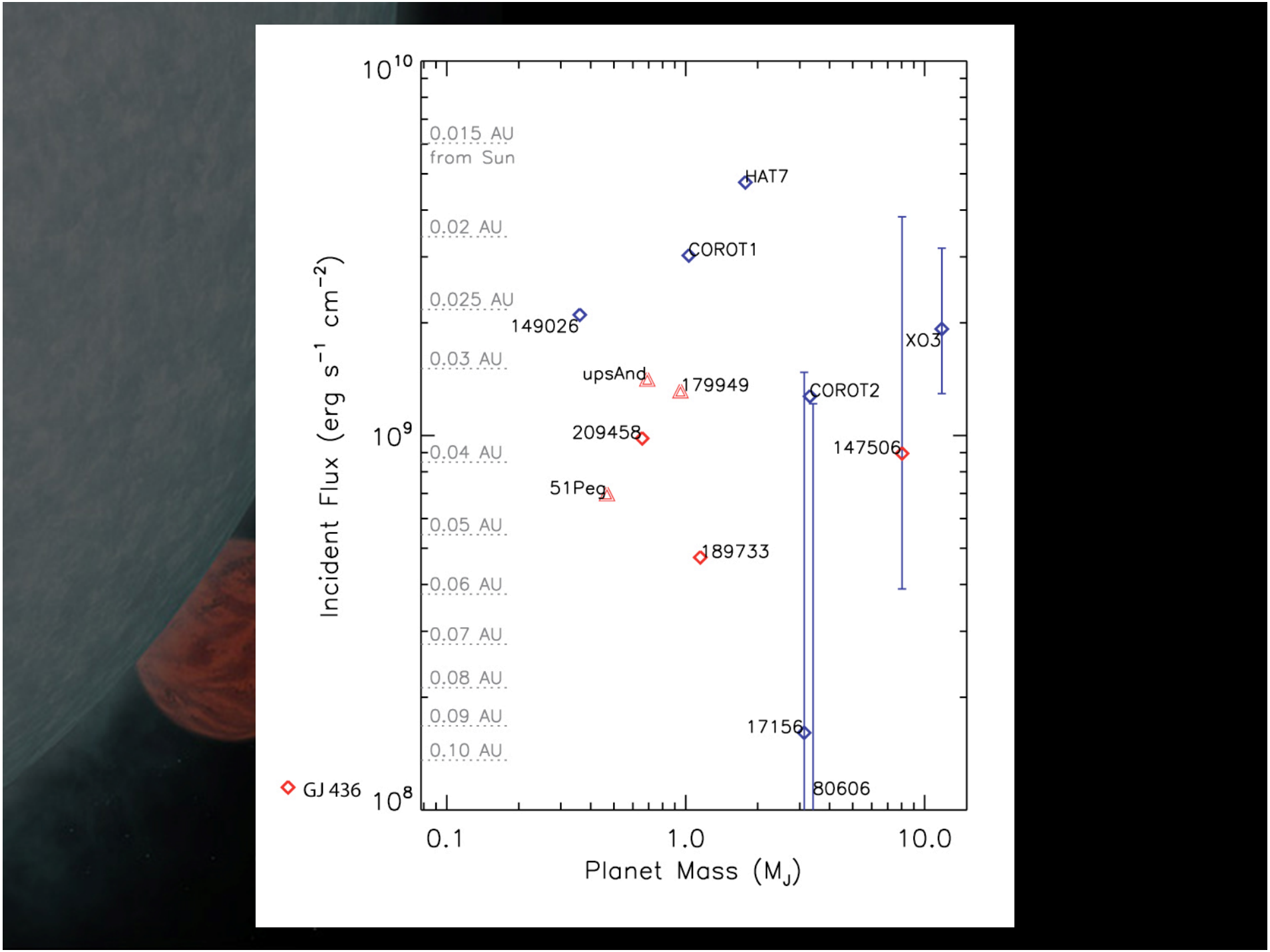
Alonso et al. (2009a), A&A

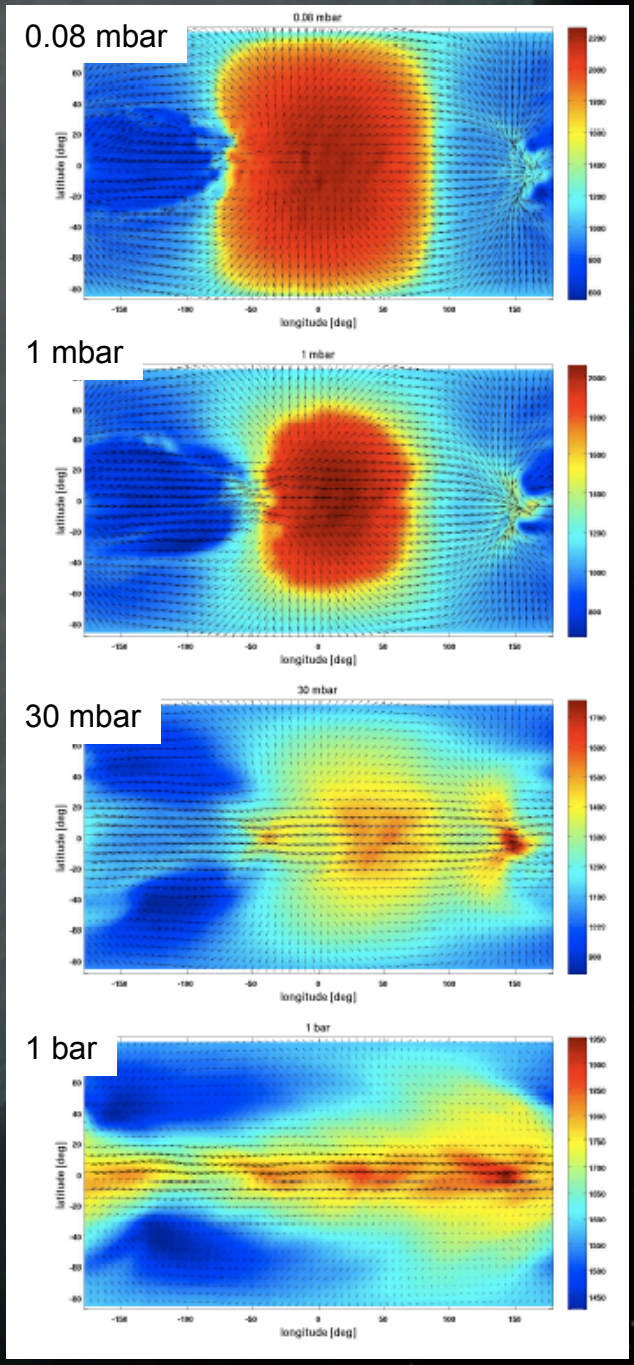




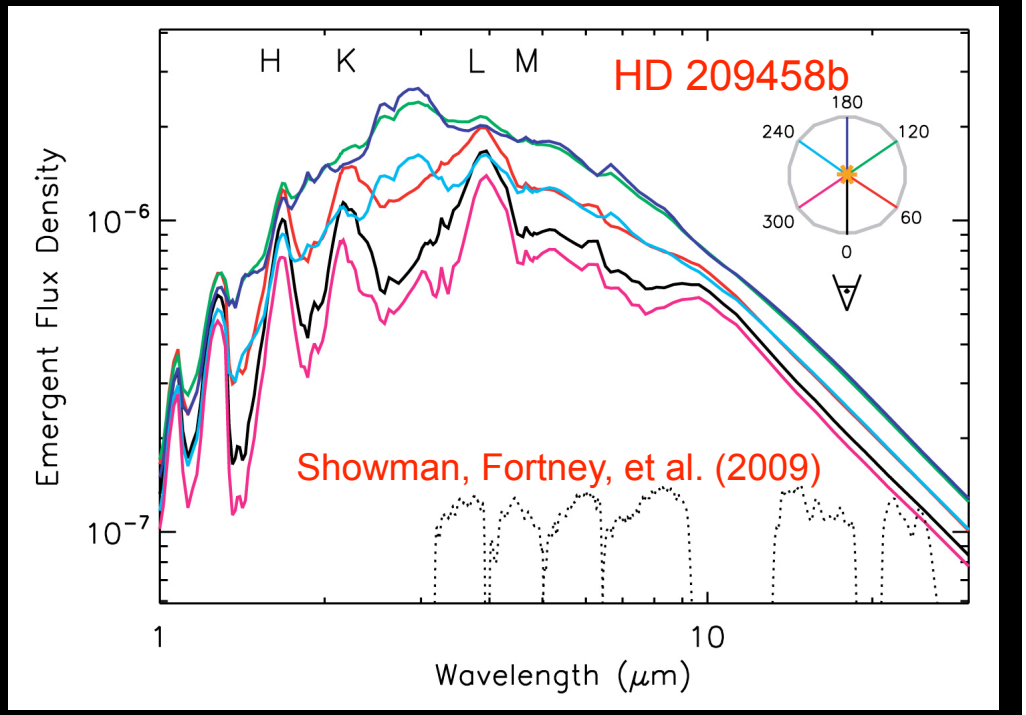
Snellen et al. (2009), Nature


Kepler?


10^{10}
10^{9}
10^{8}
0.015 AU
from Sun
0.02 AU
0.025 AU
0.03 AU
0.04 AU
0.05 AU
0.06 AU
0.07 AU
0.08 AU
0.09 AU
0.10 AU
HAT7
COROT1
149026
XO3
upsAnd
179949
COROT2
209458
147506
51Peg
189733
17156
80606
GJ 436
0.1
1.0
10.0
Incident Flux (erg s^{-1} cm^{-2})
Planet Mass (M_J)



These light curves serve on constraints on 2D and 3D models of hot Jupiter atmospheres



Conclusions

- Spitzer observations have been extremely important
  - Clear evidence for relatively good homogenization and winds in HD 189733b
  - Some evidence for large day/night contrasts on more heavily irradiated planets, but not clear-cut
- There will be much more data than we have right now
  - Unpublished Cold Spitzer Data
  - Warm Spitzer
- Multiple wavelengths will allow for more robust constraints on day/night T_{eff}
- Planets can appear relatively more or less homogenized as a function of wavelength
- Kepler may enable optical light curves for some planets and perhaps will show planet variability over 300+ orbits