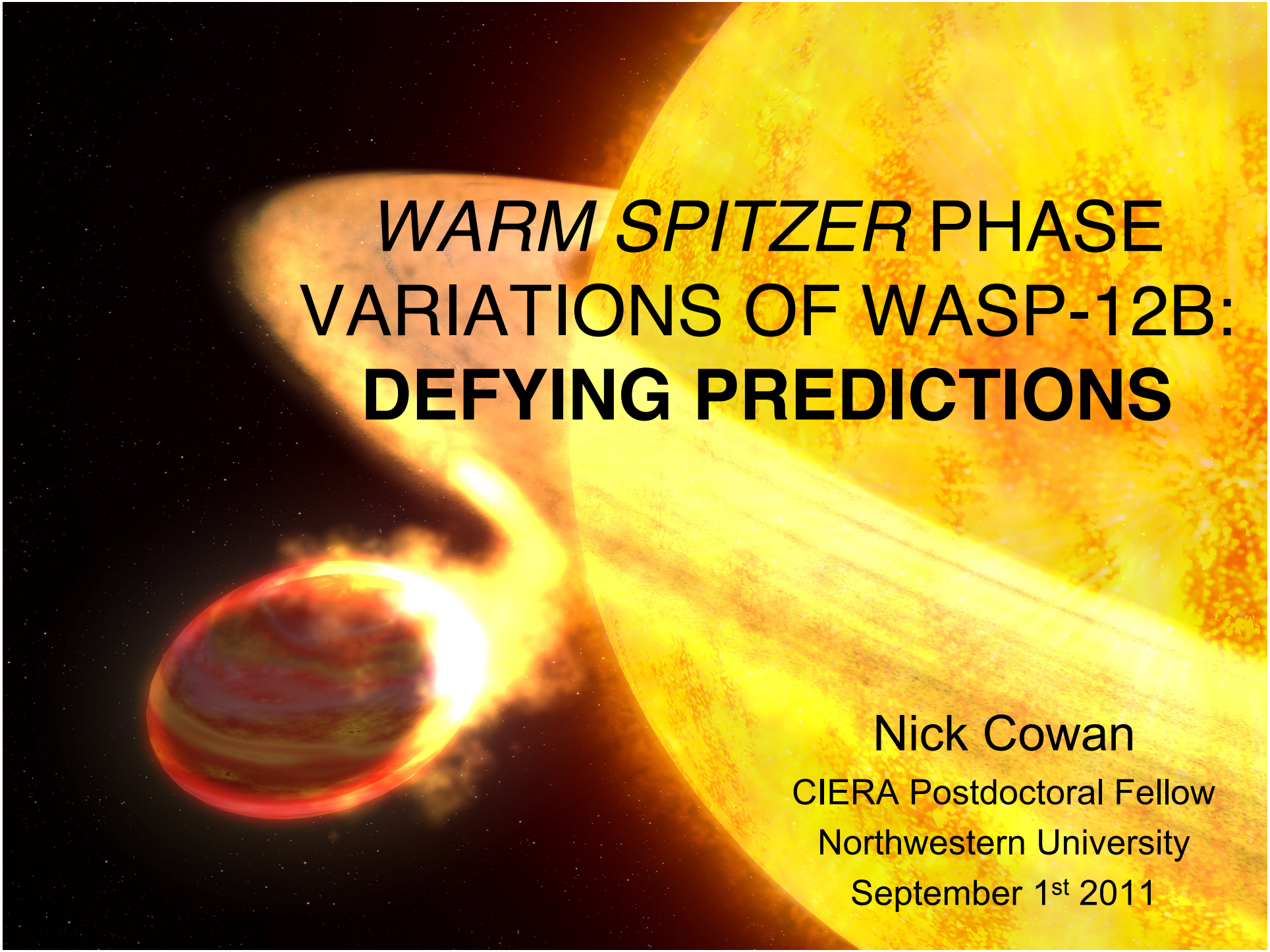
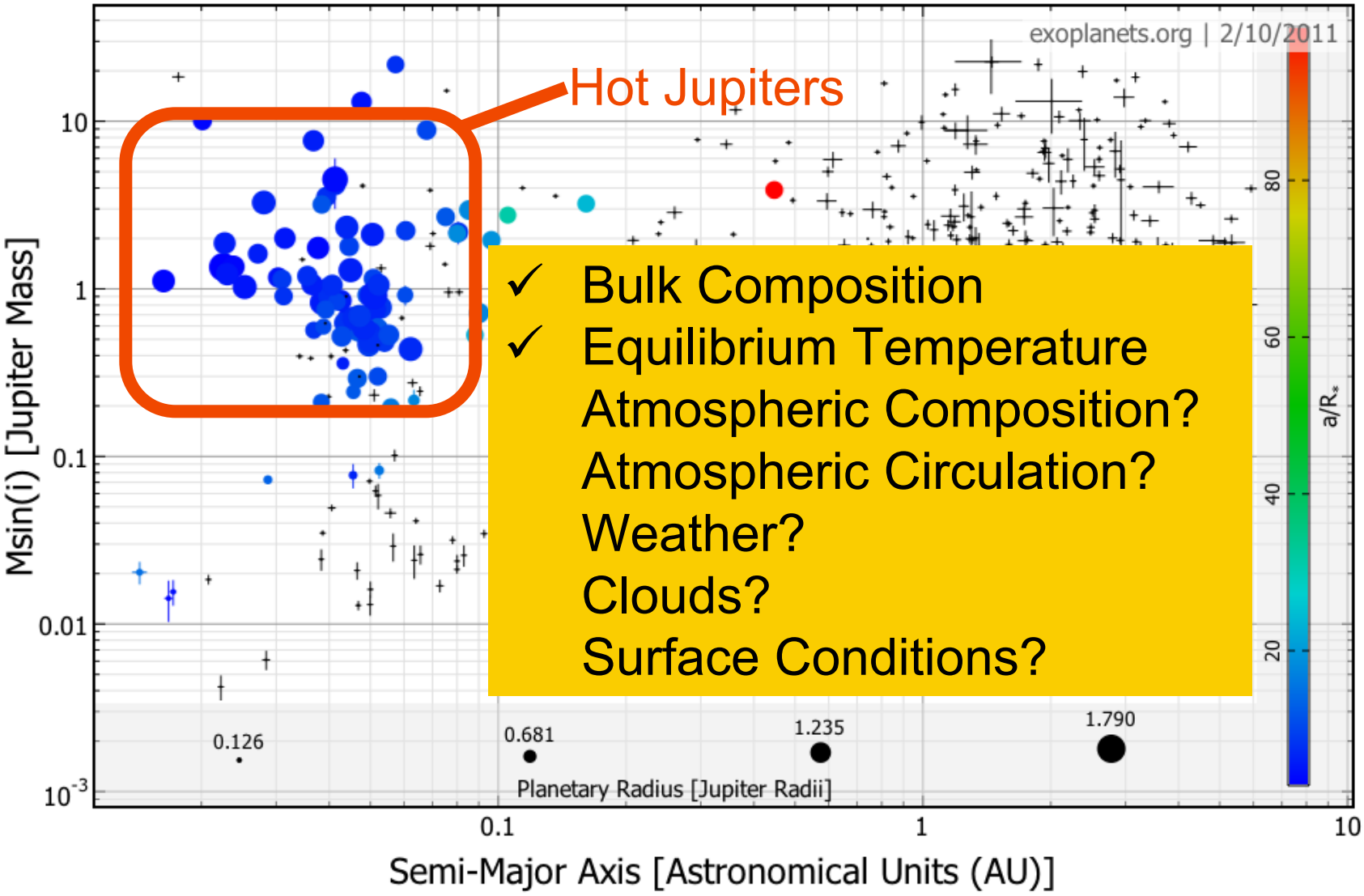


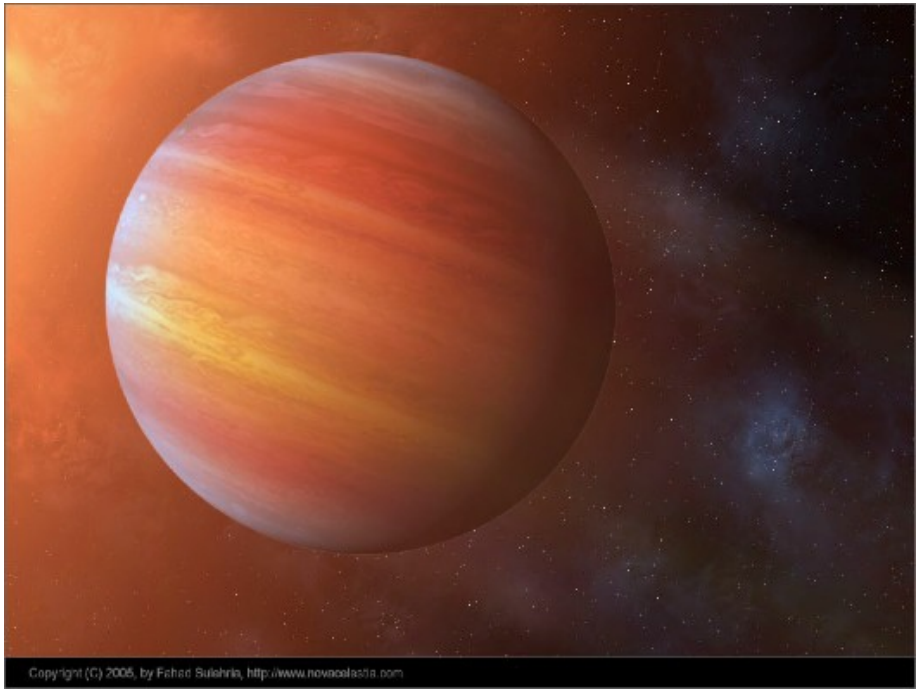
WARM SPITZER PHASE VARIATIONS OF WASP-12B: **DEFYING PREDICTIONS**

Nick Cowan
CIERA Postdoctoral Fellow
Northwestern University
September 1st 2011

Exoplanets


exoplanets.org | 2/10/2011
Hot Jupiters
✓ Bulk Composition
✓ Equilibrium Temperature
Atmospheric Composition?
Atmospheric Circulation?
Weather?
Clouds?
Surface Conditions?
Msin(i) [Jupiter Mass]
Semi-Major Axis [Astronomical Units (AU)]
Planetary Radius [Jupiter Radii]
0.126
0.681
1.235
1.790
a/R*

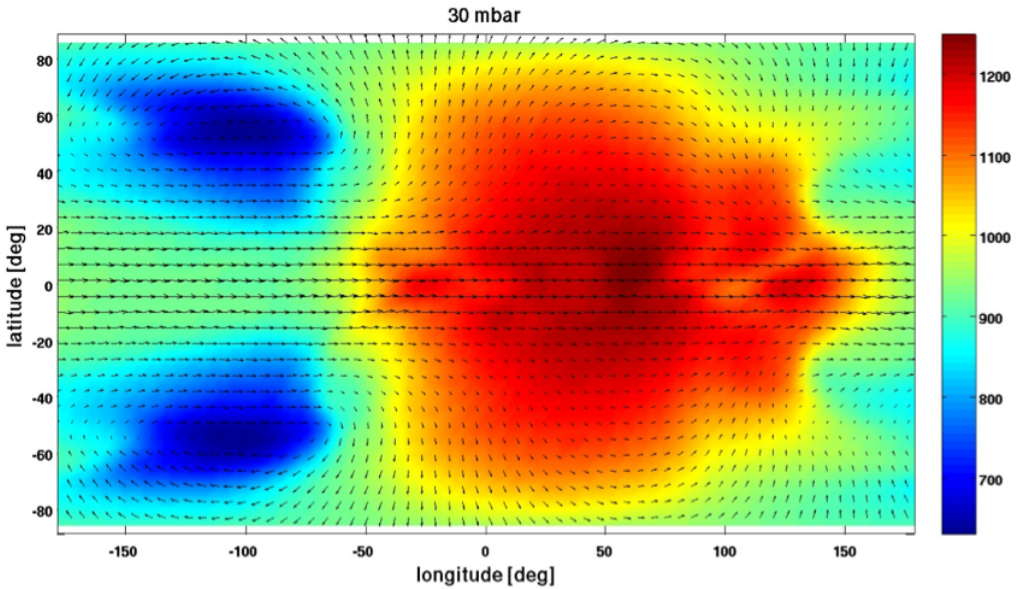
Hot Jupiter ≠ Jupiter



- Close to Star:
  $a \approx 10^{-2}\ a_J$
- High Irradiation:
  $F \approx 10^{4}\ F_J$
- Hot:
  $T \approx 10\ T_J$
- Strong Tides:
  $F_{tidal} \approx 10^{6}\ F_{tidal,\ J}$

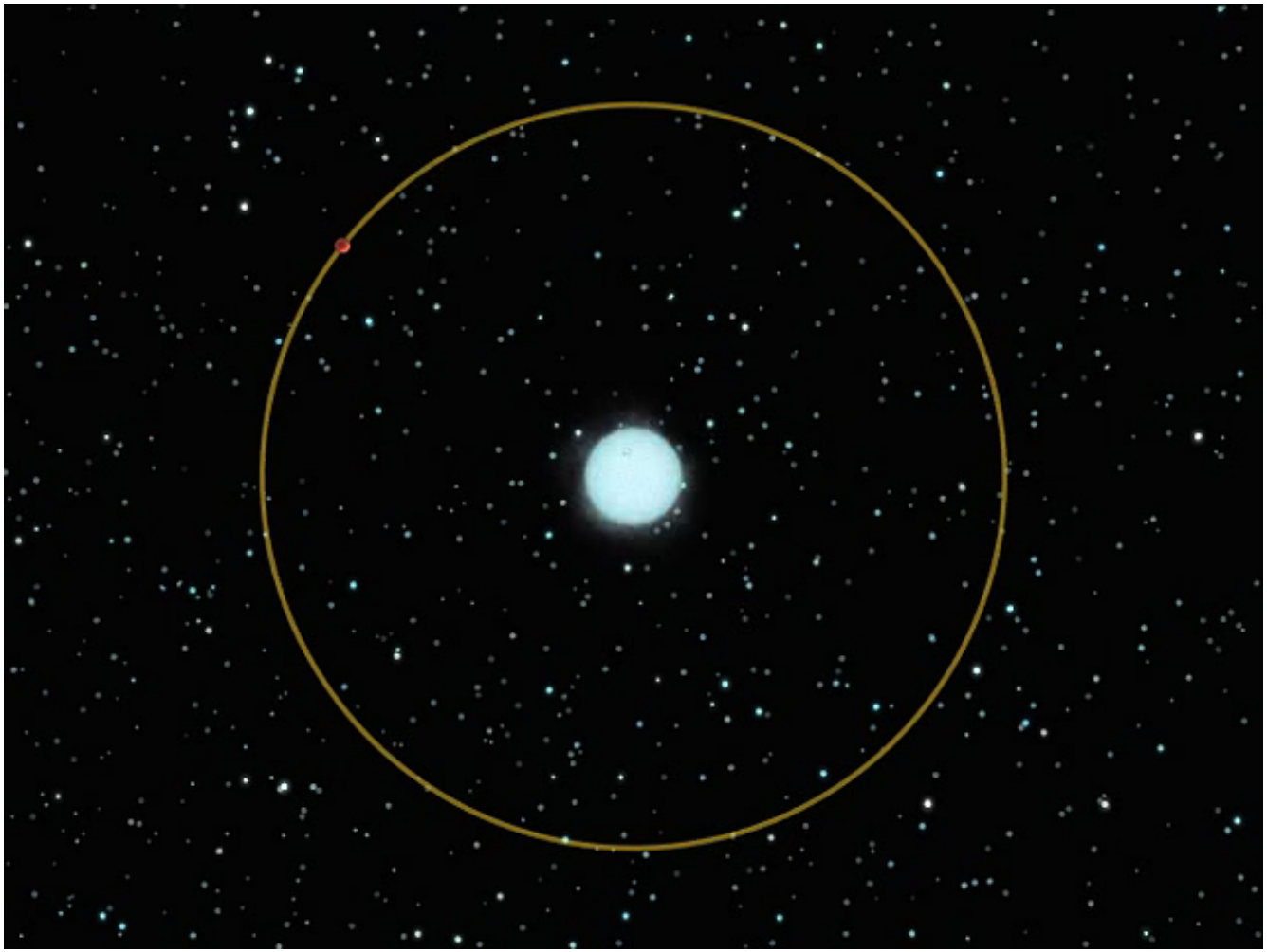
Hot Jupiter Expectations

1. High Temperatures
   - No Clouds
   - Significant Ionization
2. Large Power Budget
   - Day-Night forcing
   - Rapid Winds
3. Tidally Locked
   - Weak Coriolis Force
   - Large Storms

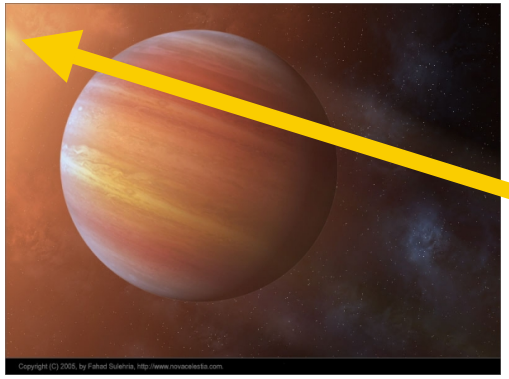


Showman et al. (2009)

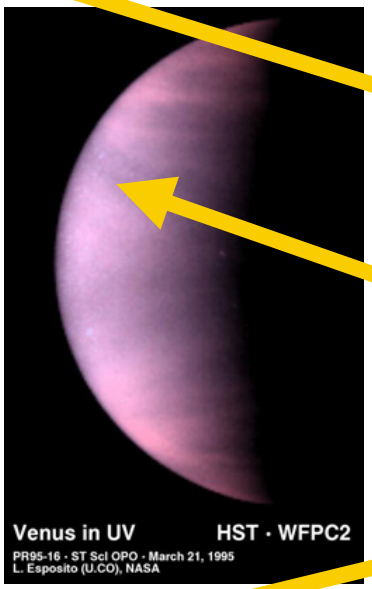
Eclipse



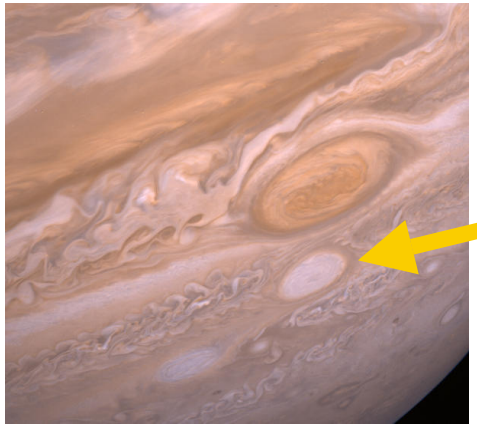
What Determines T_{day} (and T_{night})



$$T_{\rm day}(A,\varepsilon) = T_0(1-A)^{1/4}\left(\frac{2}{3}-\frac{5}{12}\varepsilon\right)^{1/4}$$

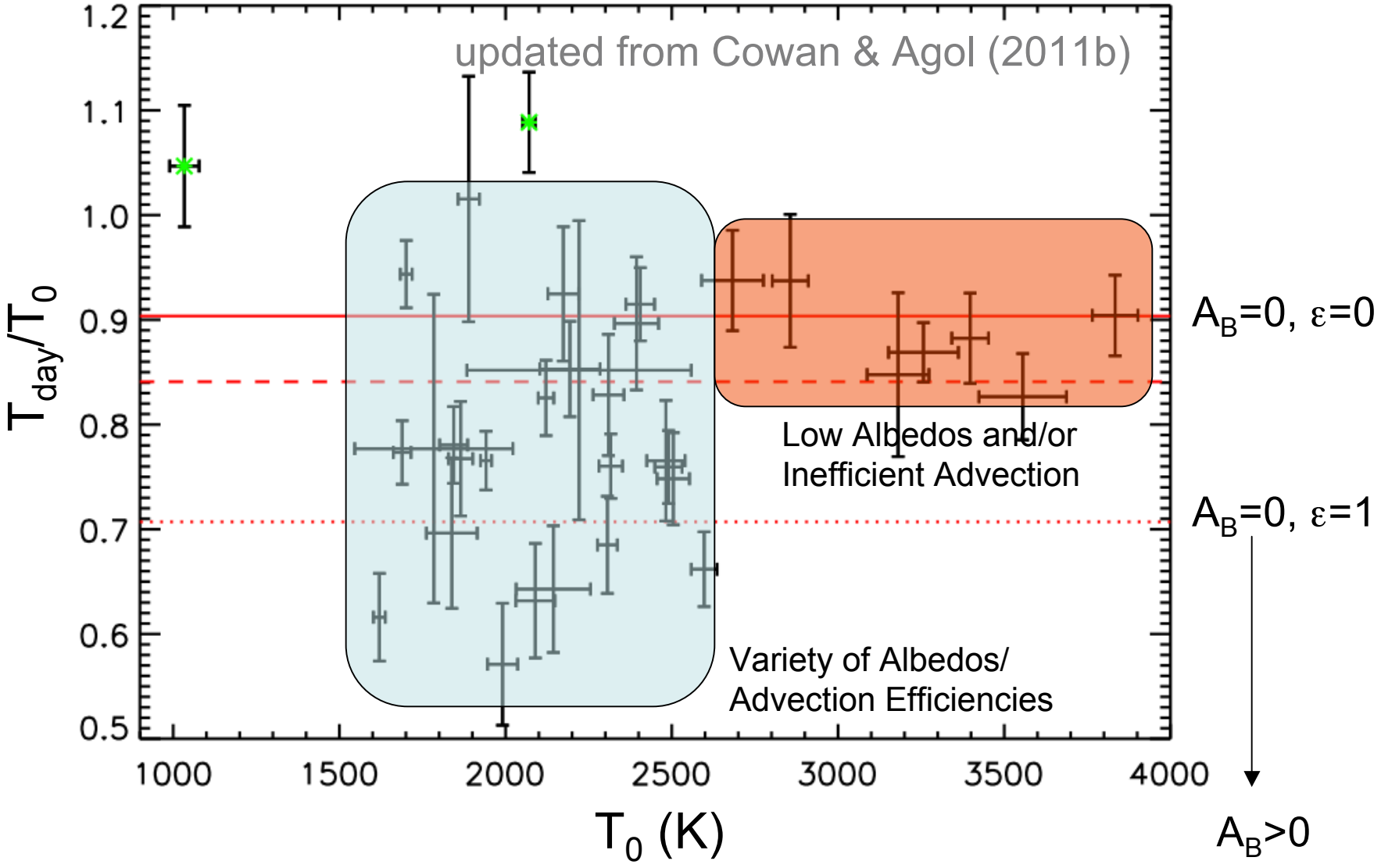


1. Bright Star: $T_0 = T_{\rm eff}\,(R_*/a)^{1/2}$
   - Doesn't affect *relative* brightness
2. Bond Albedo: A
   - Keeps planet cool
   - Less infrared light
3. Recirculation: $\varepsilon \approx \tau_{\rm rad}/(\tau_{\rm adv}+\tau_{\rm rad})$
   - Cools day-side
   - Warms night-side

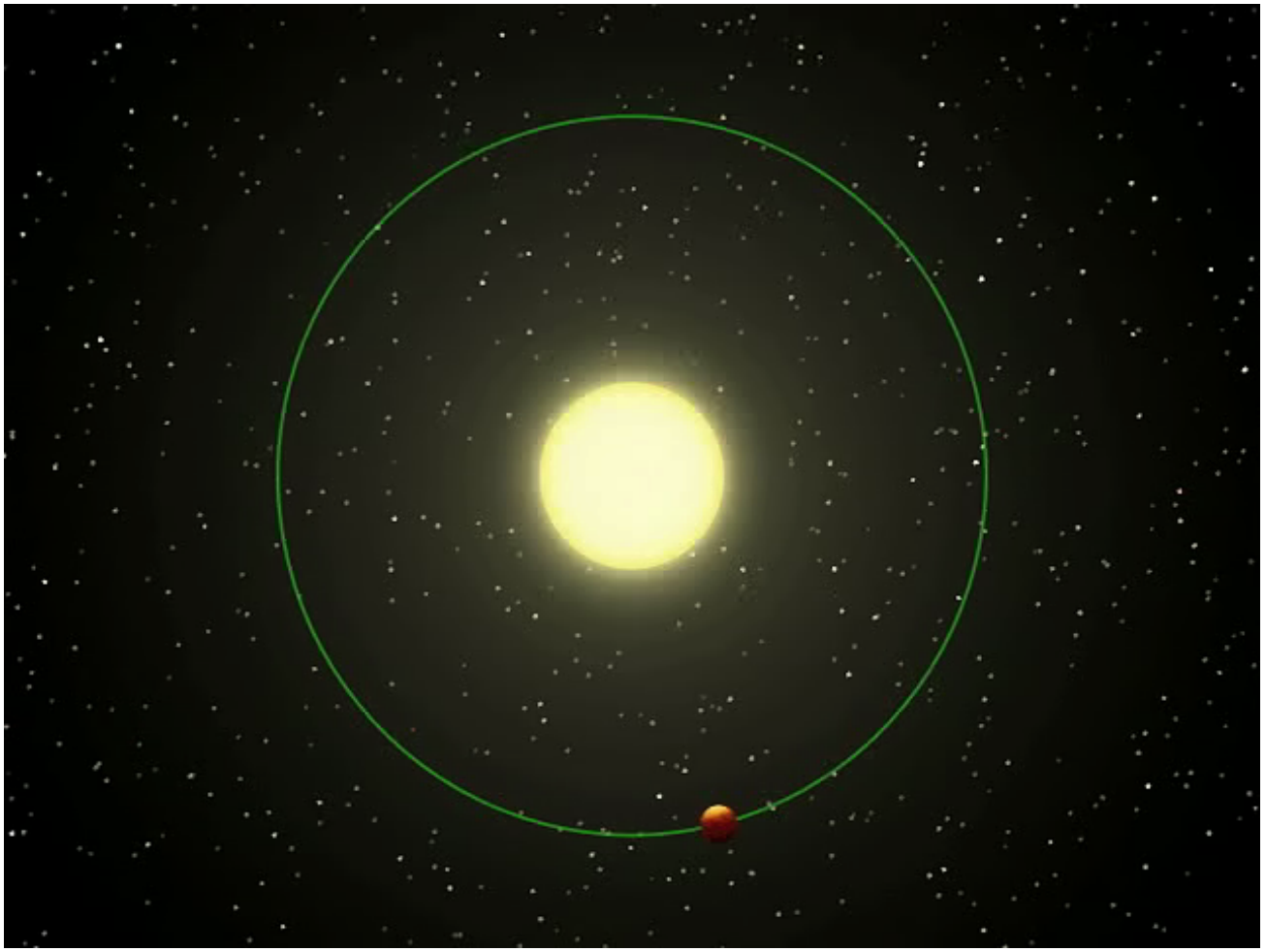


$$T_{\rm night}(A,\varepsilon) = T_0(1-A)^{1/4}\left(\frac{\varepsilon}{4}\right)^{1/4}$$

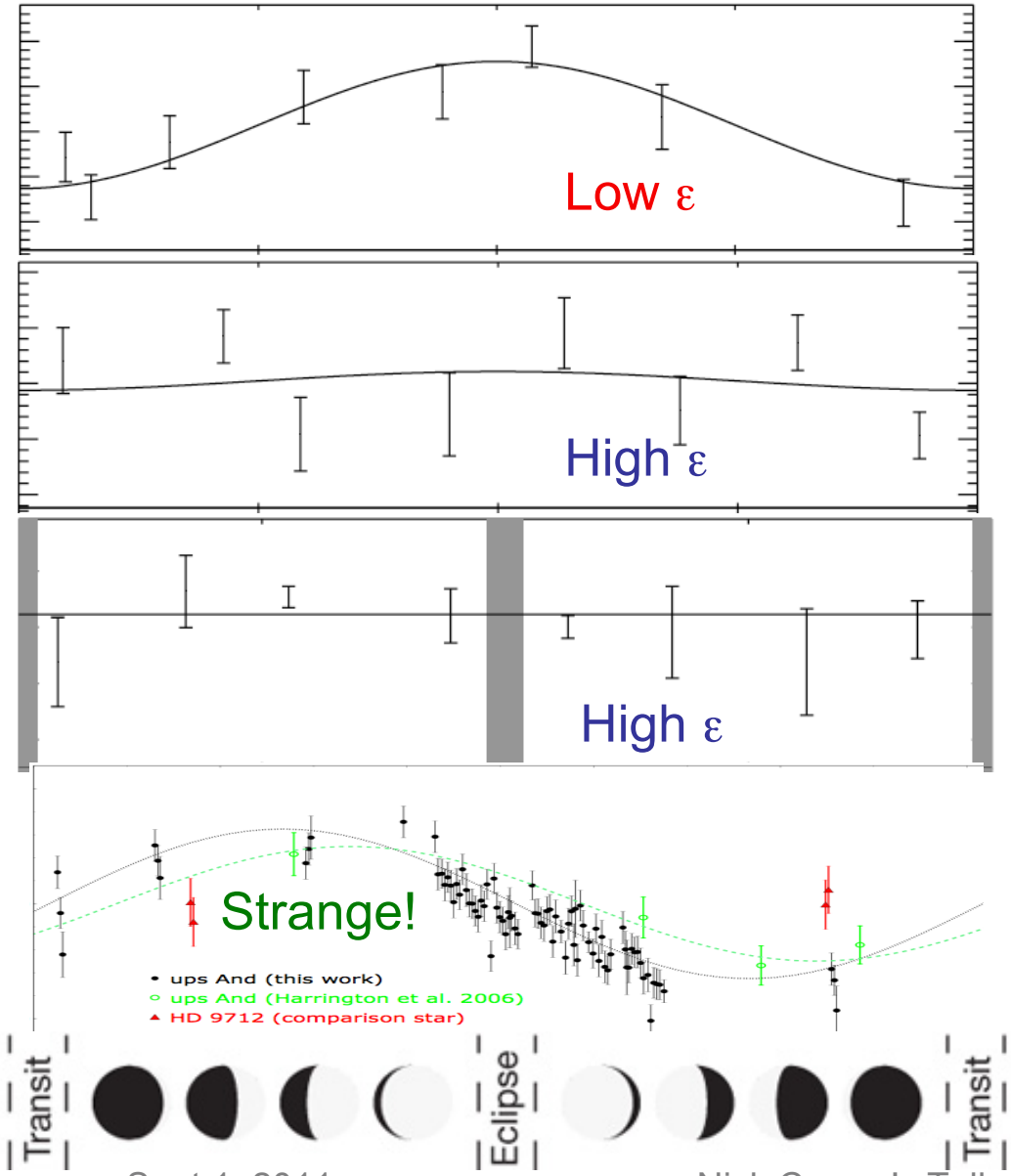
Are Hot Planets (disproportionately) Hotter?



Thermal Phases



Thermal Phases: Sparse



HD 179949 @ 8 micron
(Cowan, Agol & Charbonneau 2007)

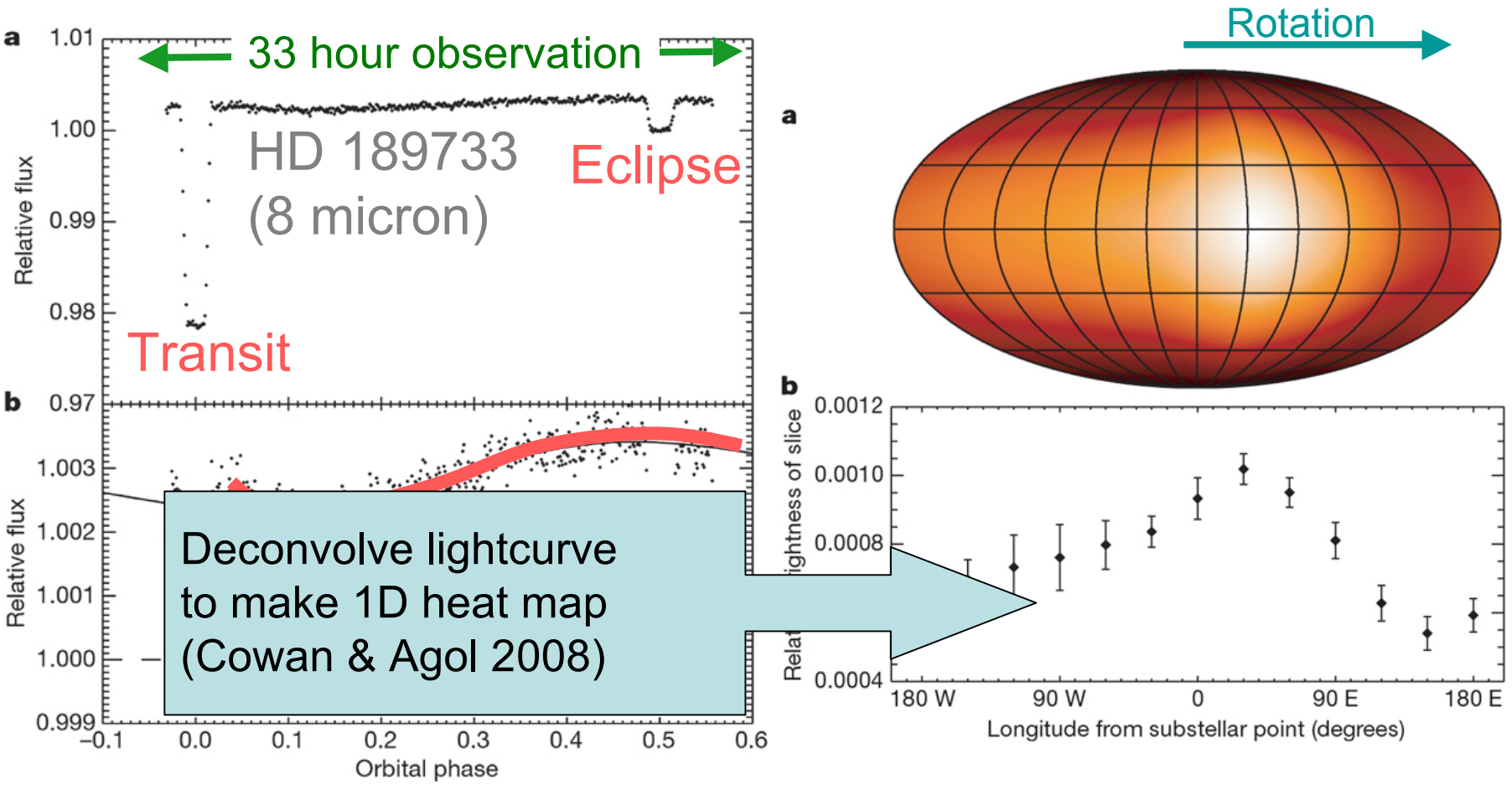
51 Peg @ 8 micron
(Cowan, Agol & Charbonneau 2007)

HD 209458 @ 8 micron
(Cowan, Agol & Charbonneau 2007)

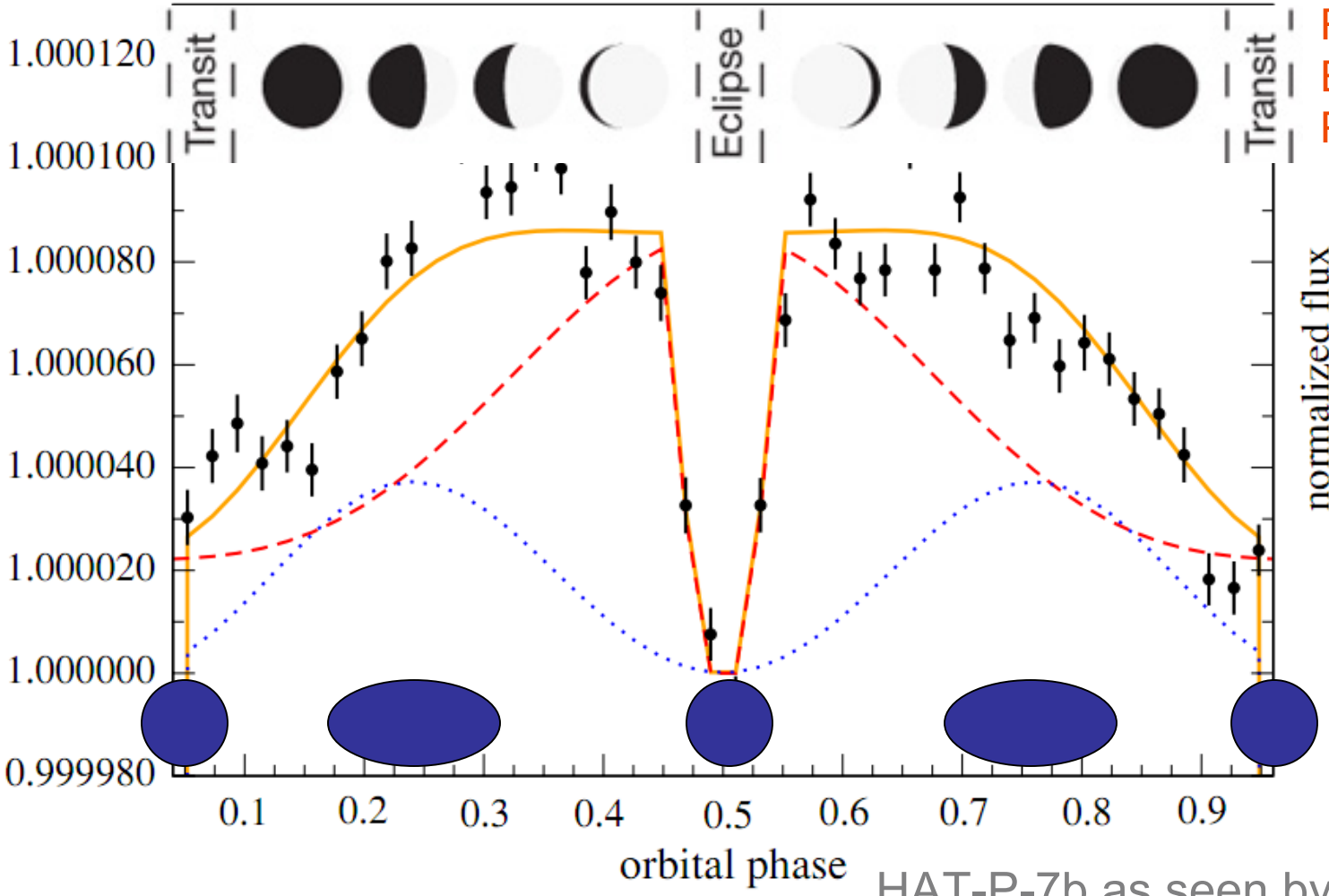
Ups Androm. @ 24 micron
(Crossfield et al. 2010)

Thermal Phases: Continuous

(Knutson et al. 2007, 2009a, b)



Ellipsoidal Variations

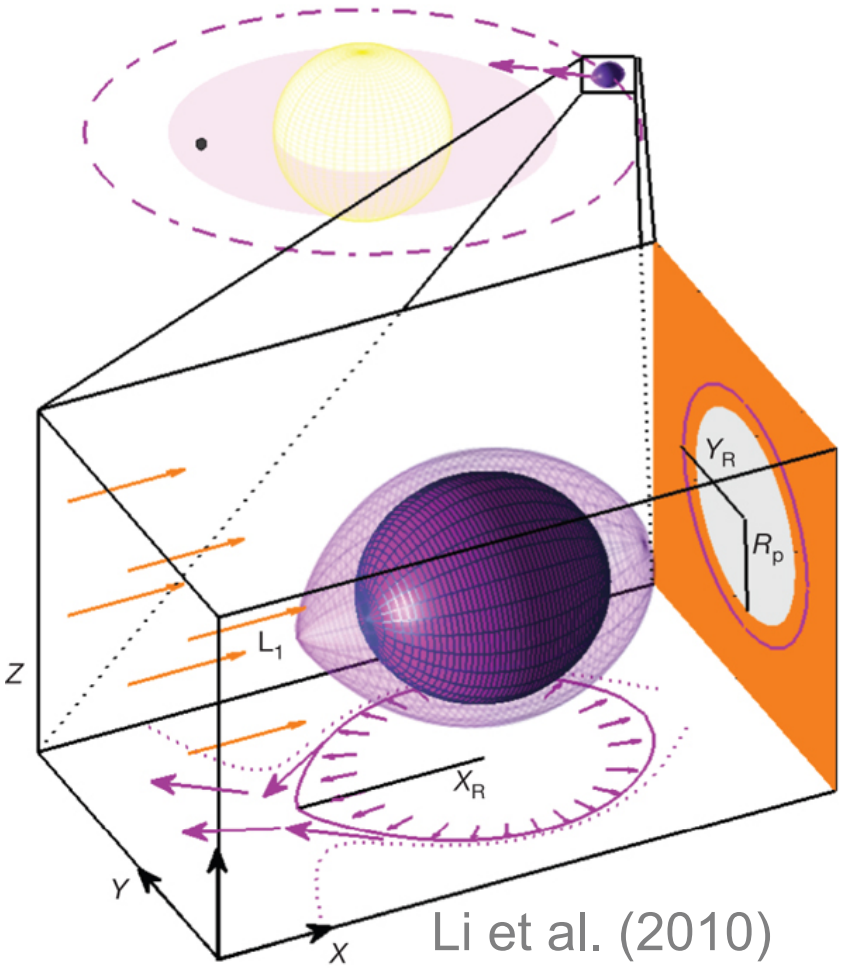


Reflected/
Emitted
Planet Light

Projected
Area

HAT-P-7b as seen by *Kepler*
(Welsh et al. 2010)

WASP-12b: a Tortured World

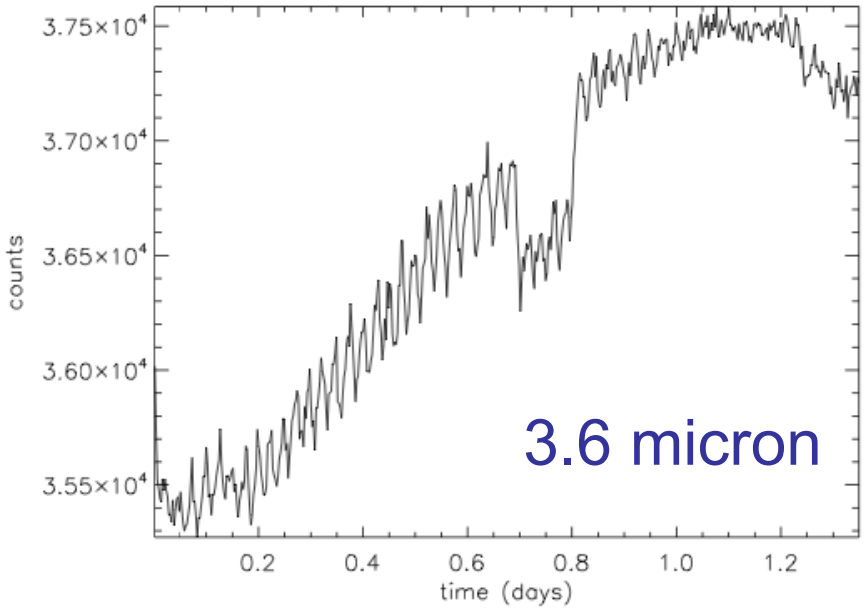


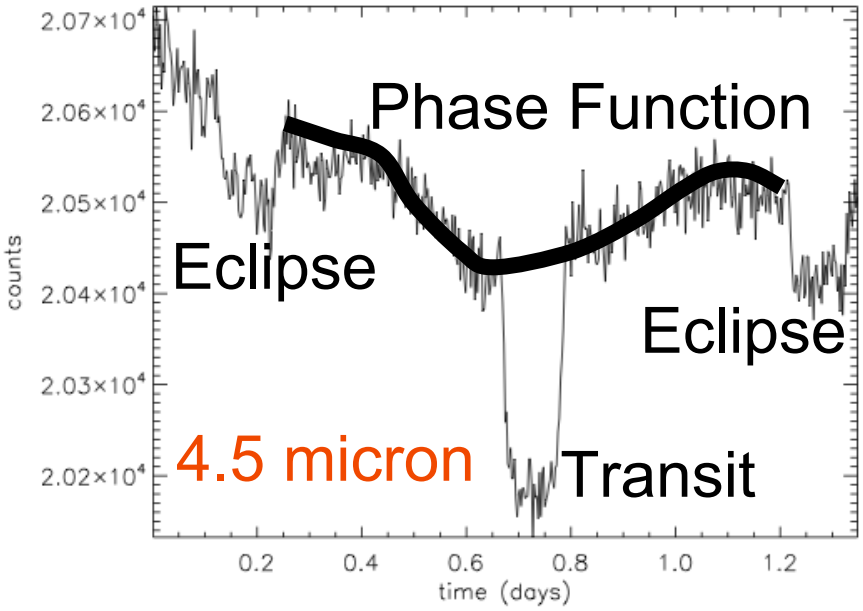
Li et al. (2010)

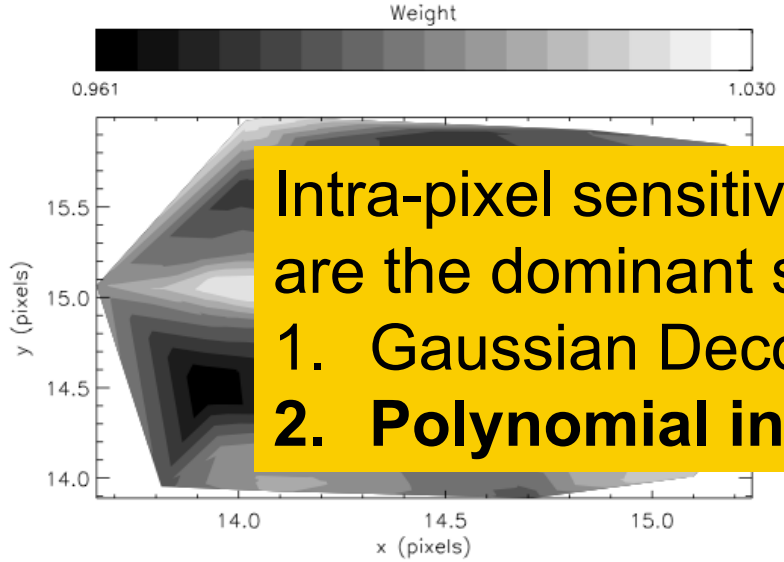
- Tidally Warped: **Prolate Planet**
- ~1 day orbit: **Oblate Planet**
- T_{day}≈3000 K: **MHD Effects**
- Big R_p, small a:
  Roche-Lobe Overflow
- **Accretion on Star/ Bow Shock**
- Peculiar Eclipse Depths:
  High C/O ratio

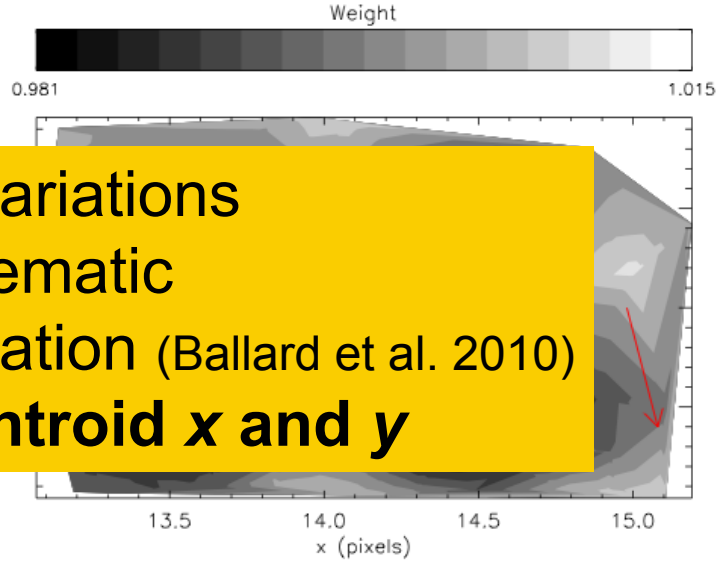
(Hebb et al. 2009; Ragozzine & Wolf 2009; Li et al. 2010; Lai et al. 2011; Leconte et al. 2011; Fossati et al. 2010; Vidotto et al. 2010; Llama et al. 2011; Madhusudhan et al. 2011)

Raw WASP-12b Photometry



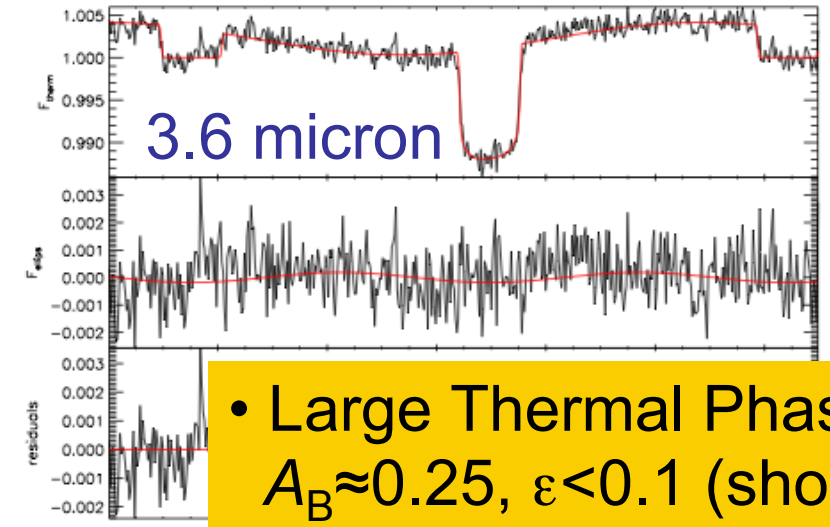


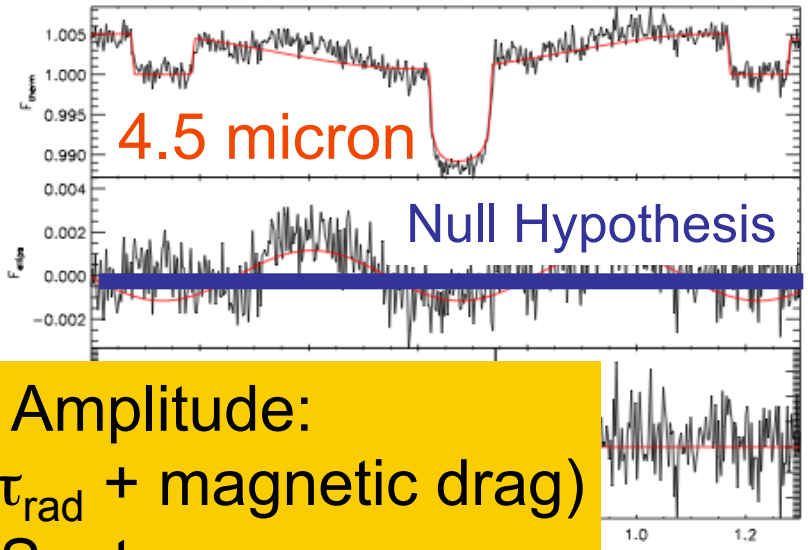




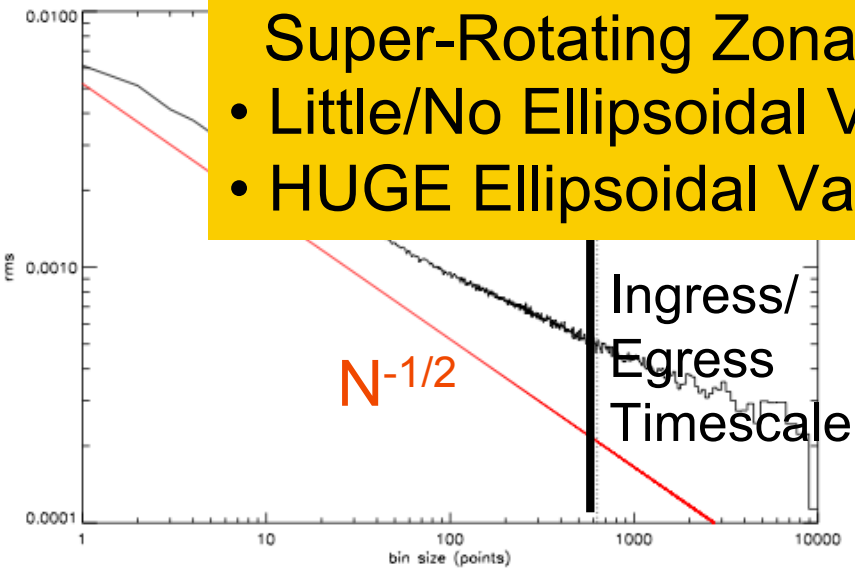
Intra-pixel sensitivity variations
are the dominant systematic
1. Gaussian Decorrelation (Ballard et al. 2010)
2. **Polynomial in Centroid *x* and *y***

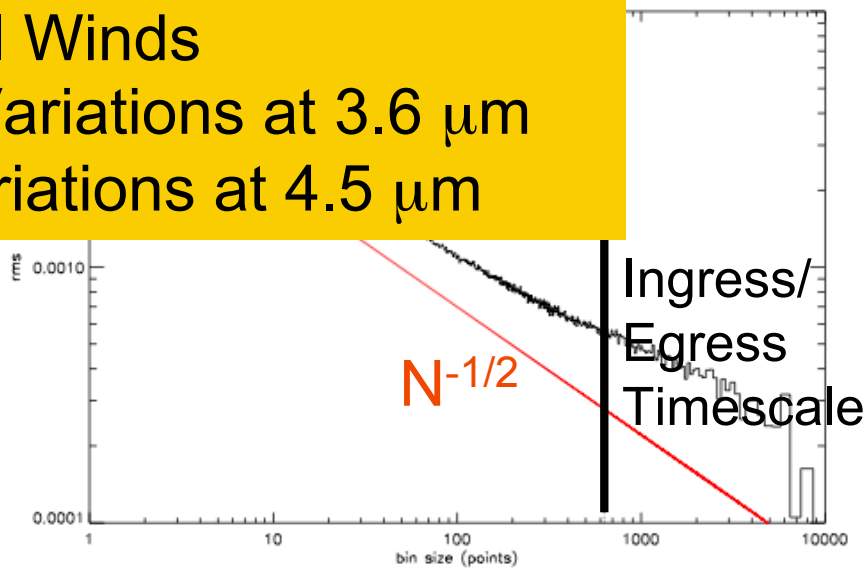
Polynomial Pixel Map



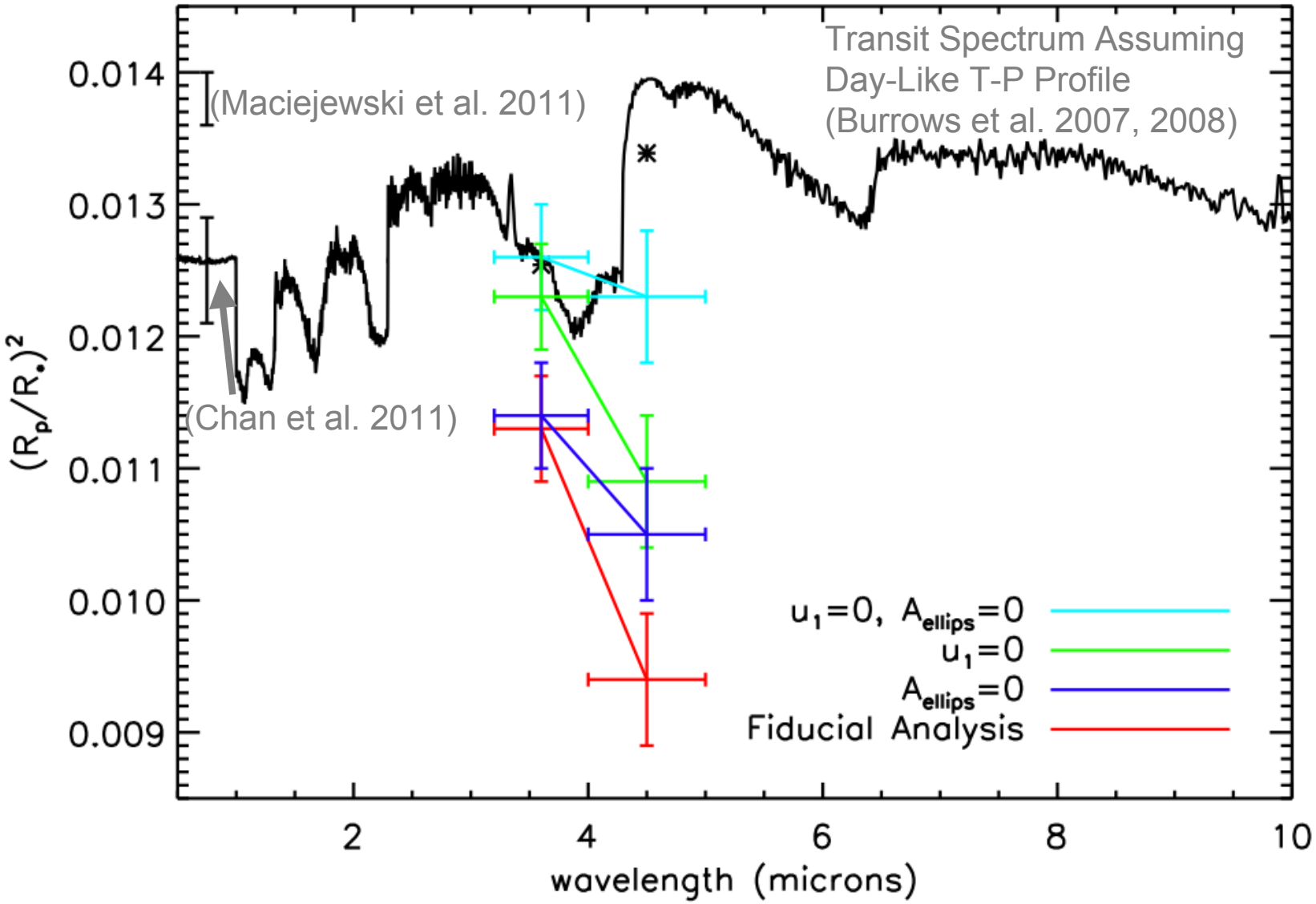


- Large Thermal Phase Amplitude: $A_B \approx 0.25$, $\varepsilon < 0.1$ (short τ_{rad} + magnetic drag)
- Eastward Shift of Hot-Spot: Super-Rotating Zonal Winds
- Little/No Ellipsoidal Variations at 3.6 μm
- HUGE Ellipsoidal Variations at 4.5 μm

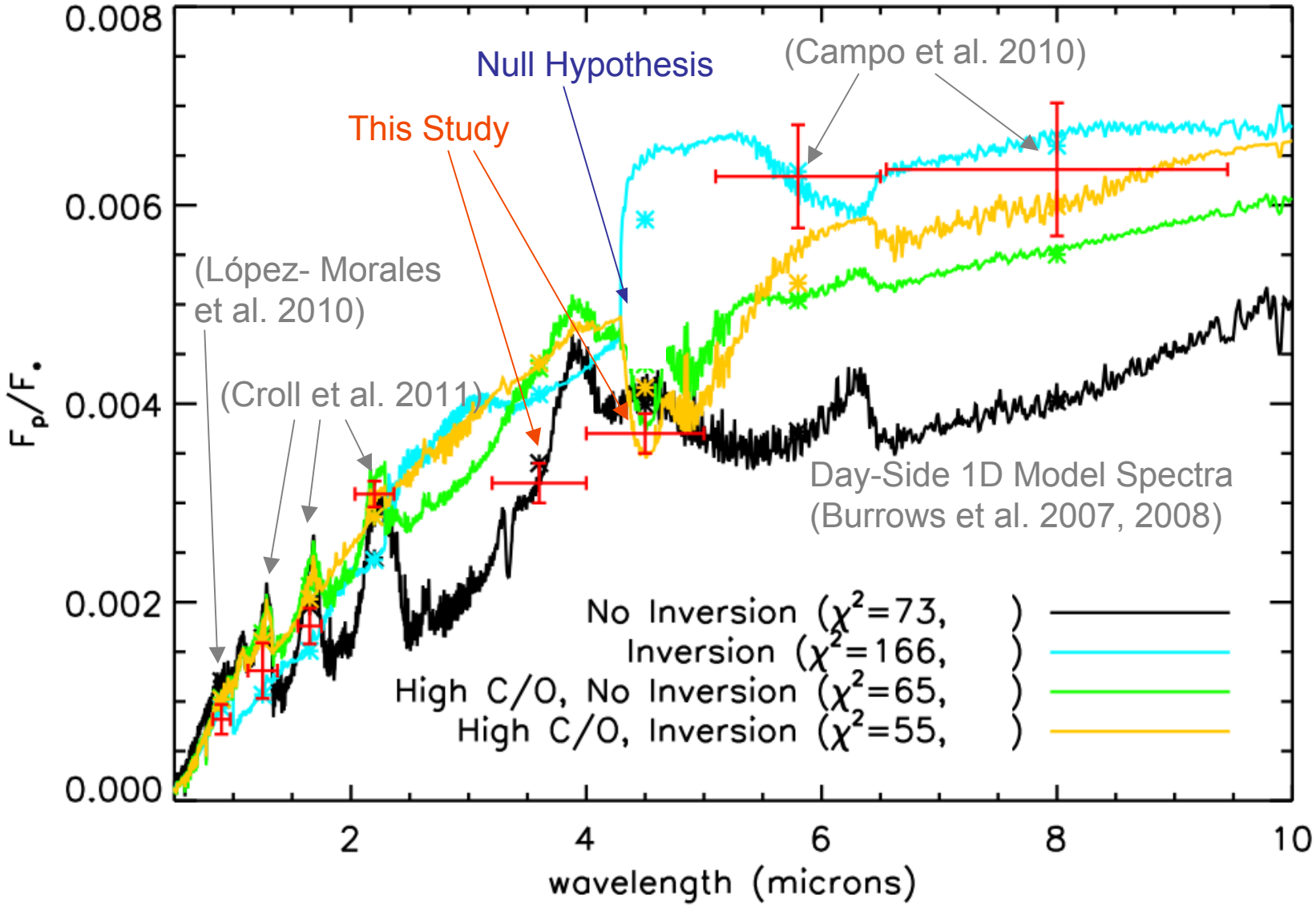




Transmission Spectrum



Day-Side Emergent Spectrum



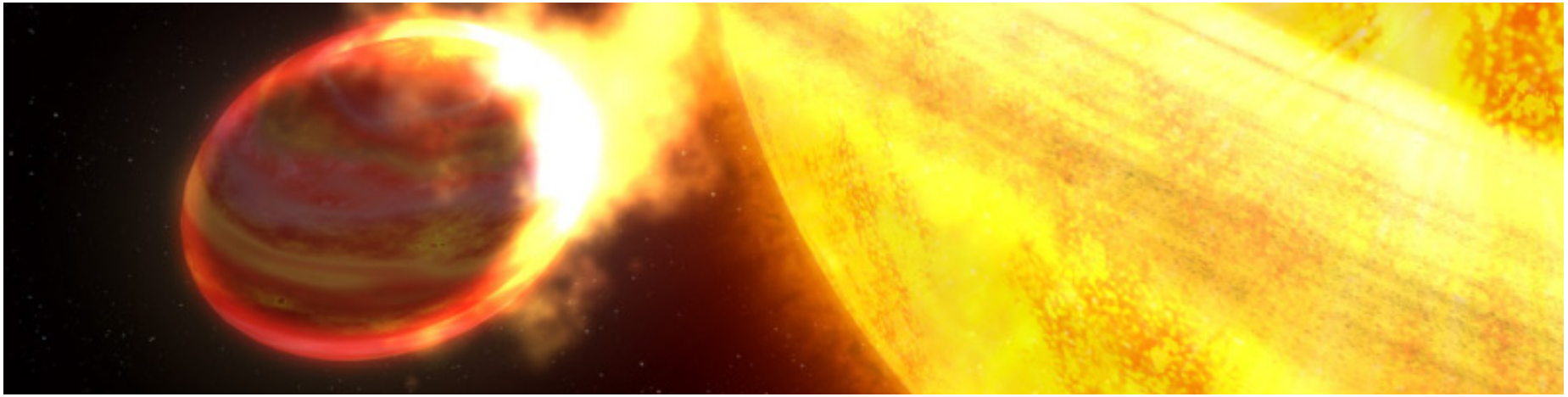
Choose Your Own Adventure

1. Prediction-Buster

- Roche-Lobe Opaque at 4.5 μm
- Weird Composition (not just high C/O)

2. Null Hypothesis

- Ellipsoidal Variations As Predicted
- Solar Composition




QUESTIONS?