Hot Jupiters: Orbital Phase Observations

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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 $T_{\text{eff}}$ 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
Harrington et al. (2006), Science

- Very bright parent star
- Large phase variations imply large day/night temperature contrast
- Small energy redistribution to night side
- Only 5 data points
Spitzer, 8 and 24 µm

Knutson et al. (2007), Nature

The Gold Standard
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)
- 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
Small phase variation implies small day/night temperature contrast
- Large energy redistribution to night side
- Only 8 data points

Cowan et al. (2007), MNRAS
- Small phase variation implies small day/night temperature contrast
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HD 209458

Cowan et al. (2007), MNRAS
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
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?
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 $T_{\text{eff}}$
• 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