WASP-8b: The Spitzer Characterization of a Cool and Eccentric Exoplanet.

Patricio Cubillos[1], Joseph Harrington[1], Nikku Madhusudhan[2], Kevin Stevenson[1], Jasmina Blecic[1], Christopher Campo[1], Ryan Hardy[1] and David Anderson[3].

[1]University of Central Florida, [2]Princeton University, [3]Keele University.

pcubillos@fulbrightmail.org

ABSTRACT

WASP-8b is a 2.2 M_{JUP} exoplanet on an eccentric, 8.16-day orbit. With an equilibrium temperature of 942 K is the coolest Hot Jupiter observed with the *Spitzer Space Telescope*. Here we present our analysis of six photometric light curves of WASP-8b during secondary eclipse observed in the 3.6, 4.5, and 8.0 μm bands of the Infrared Array Camera (IRAC). We modeled the lightcurves to constrain the orbital parameters and determine the planet's day-side infrared emission. Using a radiative transfer code, we constrained the temperature profile, chemical composition, and energy redistribution. We also modeled the thermal variations due to the eccentricity of the orbit. The model solves the energy balance equation in a one-layer grid over the planet surface.

OBSERVATIONS AND DATA ANALYSIS

The planet orbits the brighter component (WASP-8A) of a binary stellar system. Using the *Spitzer* IRAC instrument, in December 2008 and July 2010, we observed one 3.6 μm, three 4.5 μm, and two 8.0 μm secondary eclipses of the WASP-8 system. The secondary star (WASP-8B) is only 3.7 pixels away from WASP-8A (Figure 1), requiring additional care in the data analysis.

We used our Photometry for Orbits, Eclipses, and Transits (POET) pipeline to produce the lightcurves (e.g., Cubillos et al. 2012, Stevenson et al. 2011). POET finds the center position of the stars in the array with a double-Point-Spread-Function (PSF) fitting routine. Following Crossfield et al. (2010), we created the model PSF with Tiny Tim software. After removing WASP-8B's flux (either by subtracting the PSF model or using a circular mask), we obtained the lightcurves from interpolated circular aperture photometry (Harrington et al. 2007). We modeled the lightcurves as the multiplication of the eclipse curve (Mandel & Agol 2002), the detector temporal (*ramp*) and spatial (*intrapixel*) systematics (Figure 2).

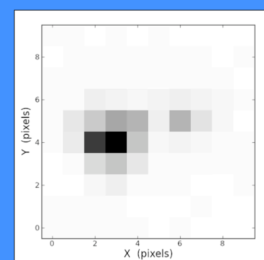

Figure 1:
The WASP-8 system as seen by *Spitzer* at 4.5 μm. The gray scale goes from zero (white) to 70% of the maximum flux of WASP-8A (black).

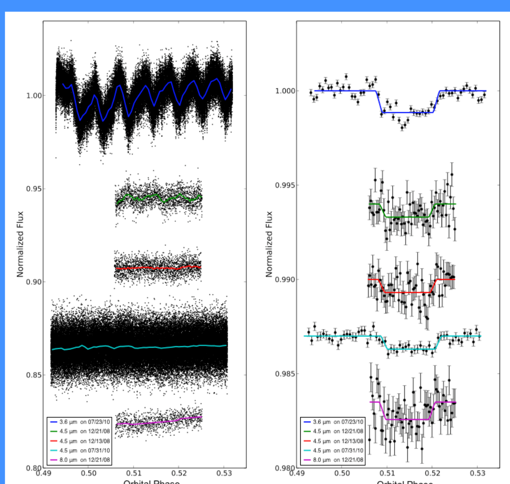

Figure 2:
Raw (left), and systematics-corrected (right) secondary-eclipse lightcurves of WASP-8b at 3.6, 4.5, and 8.0 μm. The colored lines are best-fit models (see legend). The error bars in the right panel are the 1-σ uncertainties. Our treatment of IRAC's systematics is documented by, e.g., Stevenson et al. (2011), Blecic et al. (2011). WASP-8b's eclipse depths are comparable and even smaller than the systematics. The main oscillation at 3.6 μm is due to the intrapixel effect. We were forced to discard one of the 8.0 μm ligtcurves because of a combination of strong systematics, bad telescope pointing, and low signal to noise.

ATMOSPHERIC ANALYSIS

We used the eclipse depths to statistically infer the molecular abundances and pressure-temperature (*P-T*) profile of WASP-8b's atmosphere by combining a one-dimensional atmospheric model with an MCMC sampler (Madhusudhan & Seager 2009, 2010). We computed millions of atmospheric models to sample the parameter space. The main molecules included in the models were CO, CO_2, H_2O, and CH_4. Figure 3 shows the data points and a representative model of WASP-8b.

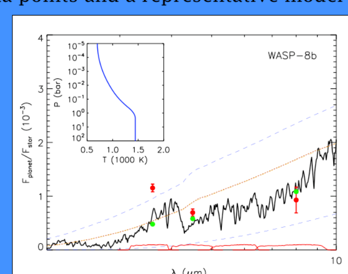

Figure 3:
WASP-8b's day-side atmospheric spectrum. The black curve is a representative model spectrum. The green points are the model fluxes integrated over the *Spitzer* bands (red curves). The red points with error bars are the measured eclipse depths. The orange dashed line is a blackbody spectrum at T = 1200 K. The blue dashed lines are blackbody curves corresponding to the lowest and highest temperatures of the *P-T* profile (700 K and 1443 K). The planet's atmosphere does not show thermal inversion (inset), which is expected for the less-strongly irradiated planets (Fortney et al. 2008). The 3.6 point is too high based on current equilibrium models; we are currently exploring non-equilibrium mechanisms to explain it. The model spectra indicate low redistribution to the night side and low albedo.

ORBITAL THERMAL VARIATION

The 3.6 μm brightness temperature (1550 K) is far higher than expected, even for periastron passage. The eccentricity makes the planet receive a different amount of energy along the orbit. We modeled the thermal variations by solving the energy balance differential equation in a one-layer grid over the planet's surface (Cowan et al. 2011). These simulations ultimately depend on the radiative time scale (τ_{rad}) and the rotational angular velocity (ω_{rot}) of the planet (Figure 4). The planet is expected to be in pseudo-synchronization (ω_{rot} ≈ orbital angular velocity at periastron, $\omega_{orb,p}$).

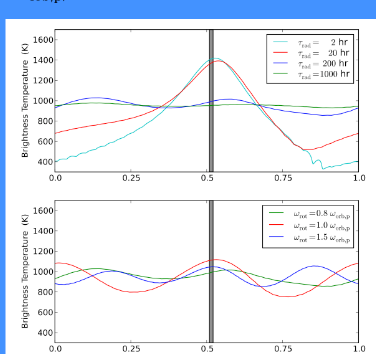

Figure 4:
Brightness temperature curves of WASP-8b as observed from Earth over one orbital period. The gray region marks the secondary eclipse (coincident with periastron). Top panel: Simulations for different radiative times. Bottom panel: Simulations with τ_{rad} = 200 hr for different angular rotational velocities, independent of ω_{rot}. All curves are limited to temperatures less than 1150 K. The top panel shows that simulations with τ_{rad} < 10^2 hours reach brightness temperatures as hight as ~1400 K at secondary eclipse, close to the 3.6 μm brightness temperature.

Acknowledgments:
Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA, which provided support for this work.

http://planets.ucf.edu/

References:
- Blecic et al. 2011, ApJ, submitted.
- Cowan et al. 2011, ApJ, 726, 82.
- Crossfield et al. 2010, ApJ, 723, 1436.
- Cubillos et al. 2012, ApJ, in prep.
- Fortney et al. 2008, ApJ, 678, 1419.
- Harrington et al. 2007, Nat, 447,691.
- Madhusudhan & Seager 2009, ApJ, 707, 24.
- Madhusudhan & Seager 2010, ApJ, 725, 261.
- Mandel & Agol, 2002, Apj, 580, L171.
- Stevenson 2011, Apj, submitted.