Multiple *Spitzer* Secondary Eclipses of WASP-12b

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ABSTRACT

WASP-12b is one of the largest planets yet discovered, with an inflated radius of 1.79 R_{Jup}. It also lies in very close proximity to its G-type star, with a semi-major axis of 0.0229 AU and orbital period of only 1.09 days. It is one of the hottest exoplanets discovered to date as well, with an equilibrium temperature of 2516 K for zero albedo and uniform redistribution of incident flux. We observed four secondary eclipses of the WASP-12b using Spitzer's Infrared Array Camera (IRAC), which yielded six separate eclipse lightcurves over the IRAC wavelengths (2x3.6, 2x4.5, 5.8, and 8.0 μm). From these observations, we are able to constrain the planet's orbital and atmospheric properties, such as eccentricity, atmospheric composition, and thermal structure. The secondary eclipse photometry is presented along with our analysis. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA, which provided support for this work.

BACKGROUND

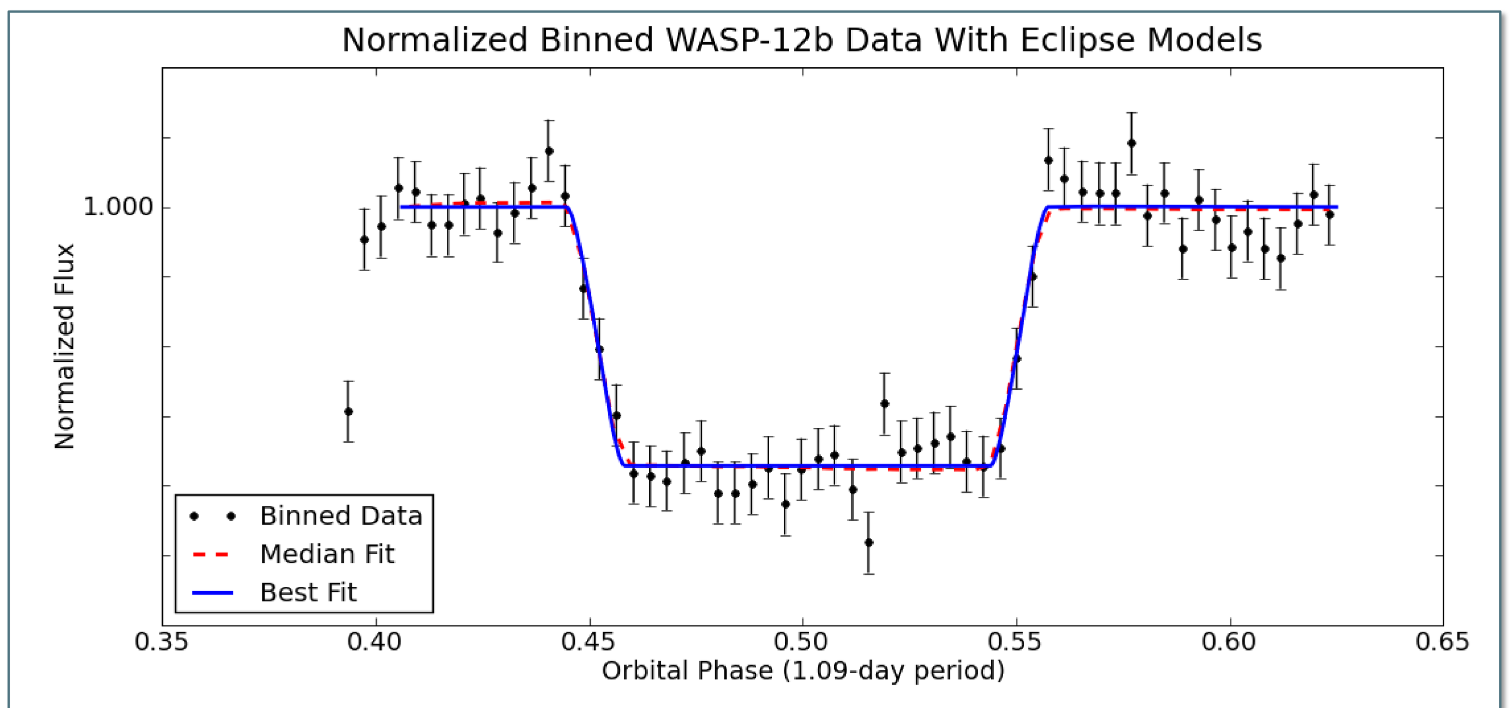
When exoplanets transit (pass in front of) their parent stars as viewed from Earth, one can constrain their sizes, masses, and orbits. Most transiting planets also pass behind their stars (secondary eclipse), which allows atmospheric characterization by measurement of planetary flux and constrains orbital eccentricity, *e*, through timing and duration of the eclipse. Because of its close proximity to its sun-like star (T = 6300 K), WASP-12b is highly irradiated and bright in the infrared wavelengths. Using *Spitzer's* Infrared Array Camera (IRAC), we observed eclipses on 2008 October 29 (4.5 and 8.0 μm), 2008 November 3 (3.6 and 5.8 μm), 2010 May 4 (4.5 μm), and 2010 May 5 (3.6 μm). We then performed a photometric analysis on the data. An atmospheric and dynamical analysis are currently being conducted.

METHODOLOGY

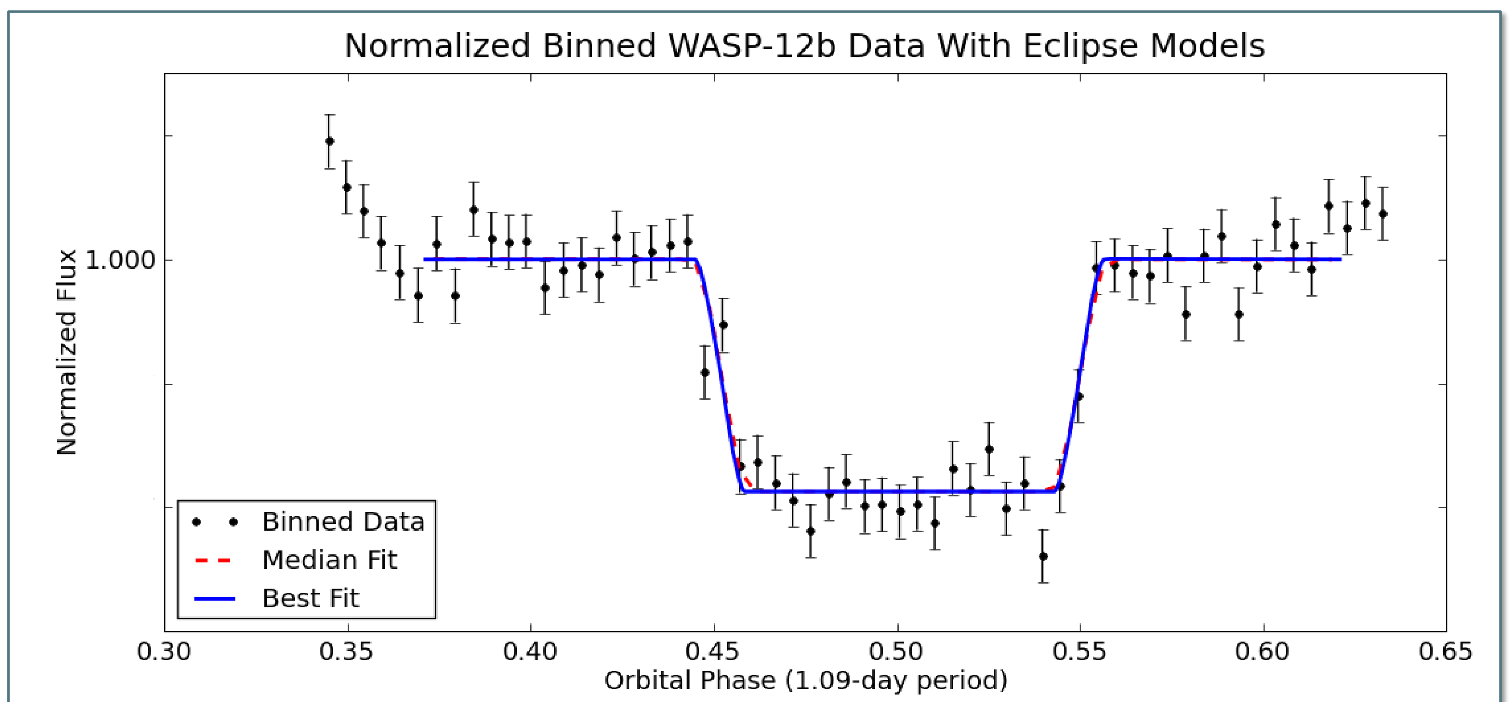
Spitzer's data pipeline applied all standard image corrections, producing the basic calibrated data we analyzed. Interpolated aperture photometry is then performed on each data set to reveal the respective light curves at each wavelength. We then model the results using a Markov-chain Monte Carlo (MCMC) fitting routine. IRAC's first two channels (3.6 and 4.5 μm) are known to show a sensitivity variation with respect to the centroid position known as the "intra-pixel effect" (Charbonneau et al. 2005, Stevenson et al. 2010, Campo et al. 2010). To minimize this effect, each target had fixed pointing. We correct this systematic by first binning the data into a 2D grid and the bilinear interpolate the flux data points between bins (pixel mapping; see figures below). The data also show evidence of a time dependent array sensitivity ("ramp") which we correct by assessing multiple model fits. Choice of the best fit is chosen by comparing the eclipse depth S/N, standard deviation of the normalized residuals, and the Bayesian Information Criterion (BIC), given by the formula:

$$BIC = \chi^2 + k\ln(N),$$

where *k* is the number of free parameters and *N* is the number of data points.



Secondary eclipse on 2008 November 3 at 3.6 μm



Secondary eclipse on 2010 May 5 at 3.6 μm

RESULTS

Our MCMC fitting routine fits a Mandel & Agol (2002) eclipse lightcurve simultaneously with the systematic models and produces an eclipse depth, along with other model parameters associated with each eclipse. The depths are then run through an atmospheric analysis to produce a planetary spectrum. The depths are also integrated with a model spectrum of the host star to produce brightness temperature values for each wavelength (Harrington, 2007). Initial estimates indicate that WASP-12b has a brightness temperature of ~2700 K making it one of the hottest exoplanets discovered to date. The full atmospheric analysis is currently in progress. The times of secondary eclipse are also analyzed in a MCMC orbital fit, along with transit and radial velocity data (Campo et al. 2010). A preliminary orbital fit suggests an eccentricity consistent with zero, indicating a circular orbit. These new results will appear in a paper by Hardy et al., currently in preparation.

CONCLUSIONS

The observations of WASP-12b's secondary eclipse indicate that the planet is very hot and most likely has a circular orbit. Recent radial velocity data by Husnoo et al. 2010 support this conclusion. The measured eclipse depths will characterize the atmospheric properties of the planet, and constrain the dayside temperature. A full report of the eclipse observations from 2008 is currently available in the paper by Campo et al. 2010 on arXiv. The newest observations from 2010 will be reported in a paper by Hardy et al., which is currently in preparation.

REFERENCES

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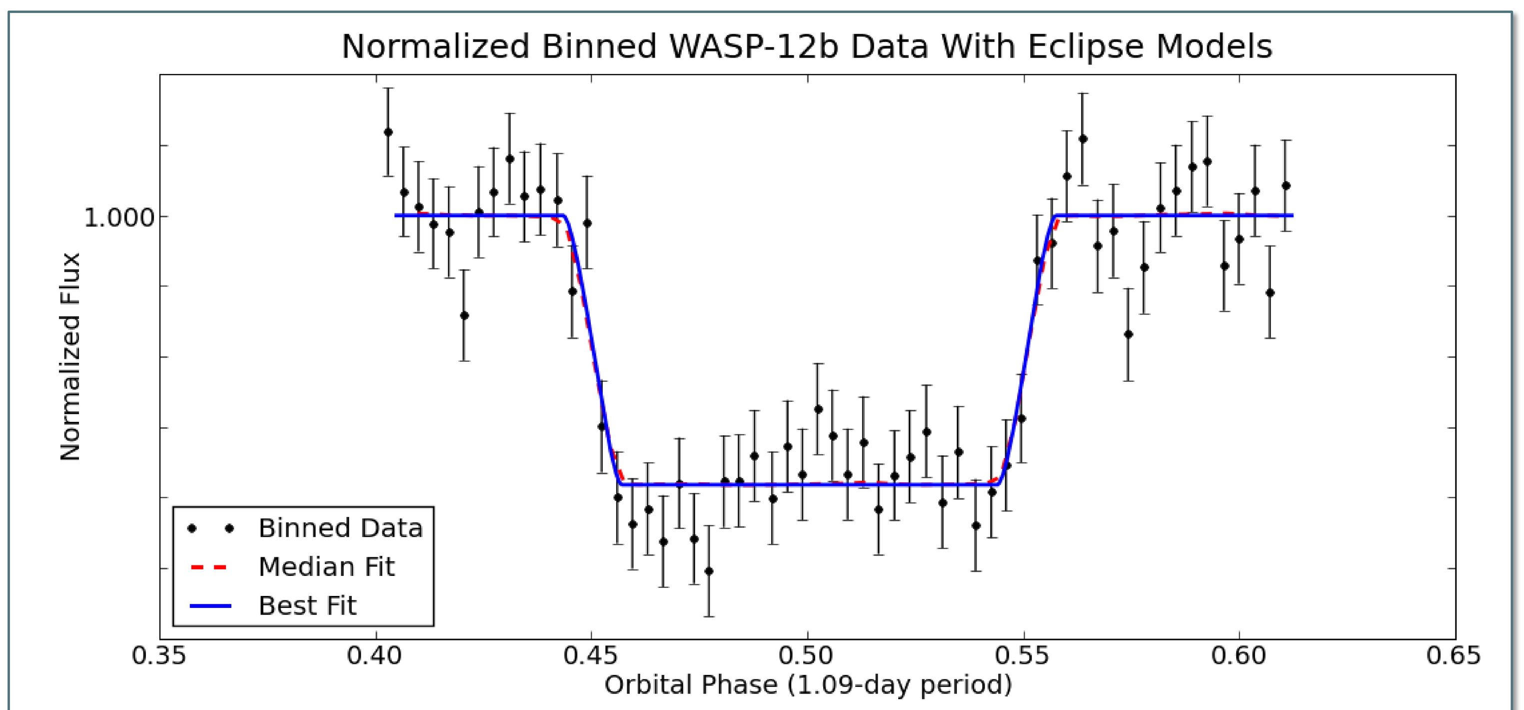
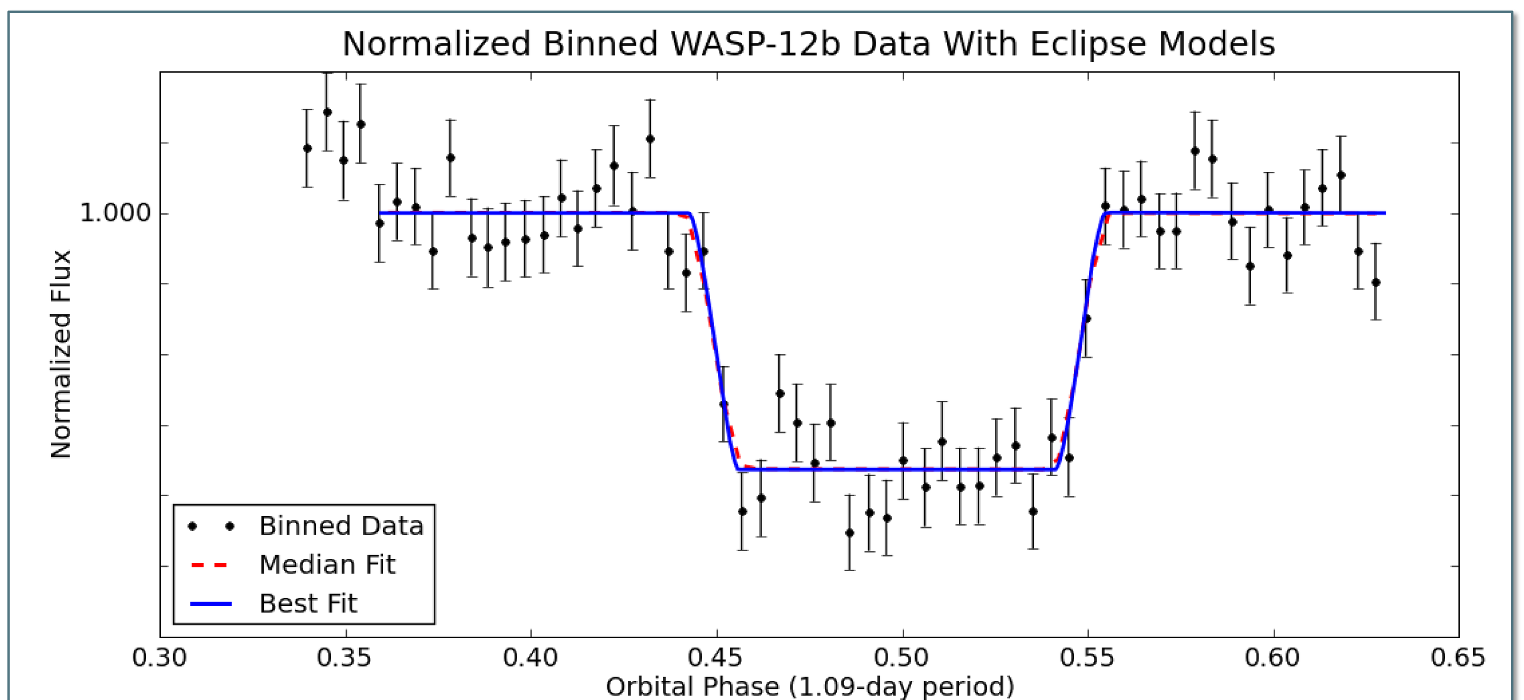
- Stevenson, Kevin B. et al., 2010, Nature, 464, 1161S
- Campo, Christopher J. et al., 2010, ApJ, *submitted*
- Husnoo, N. et al., 2010, arXiv, 1004.1809H
- Nymeyer, S. et al., 2010, ApJ, *submitted*
- Hardy, Ryan A. et al., 2010, *in preparation*



Secondary eclipse on 2008 October 29 at 4.5 μm



Secondary eclipse on 2010 May 4 at 4.5 μm

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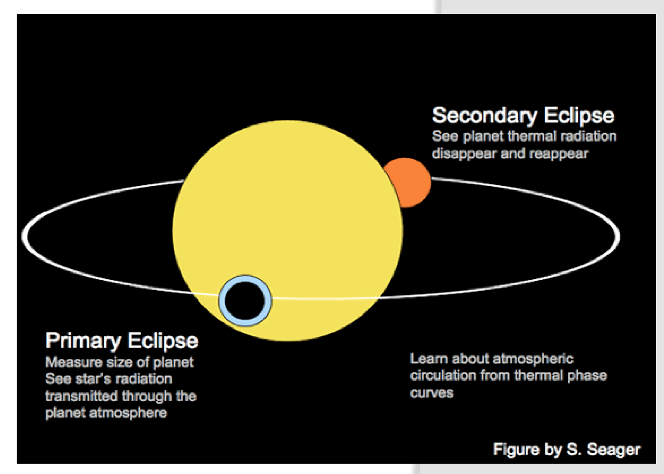
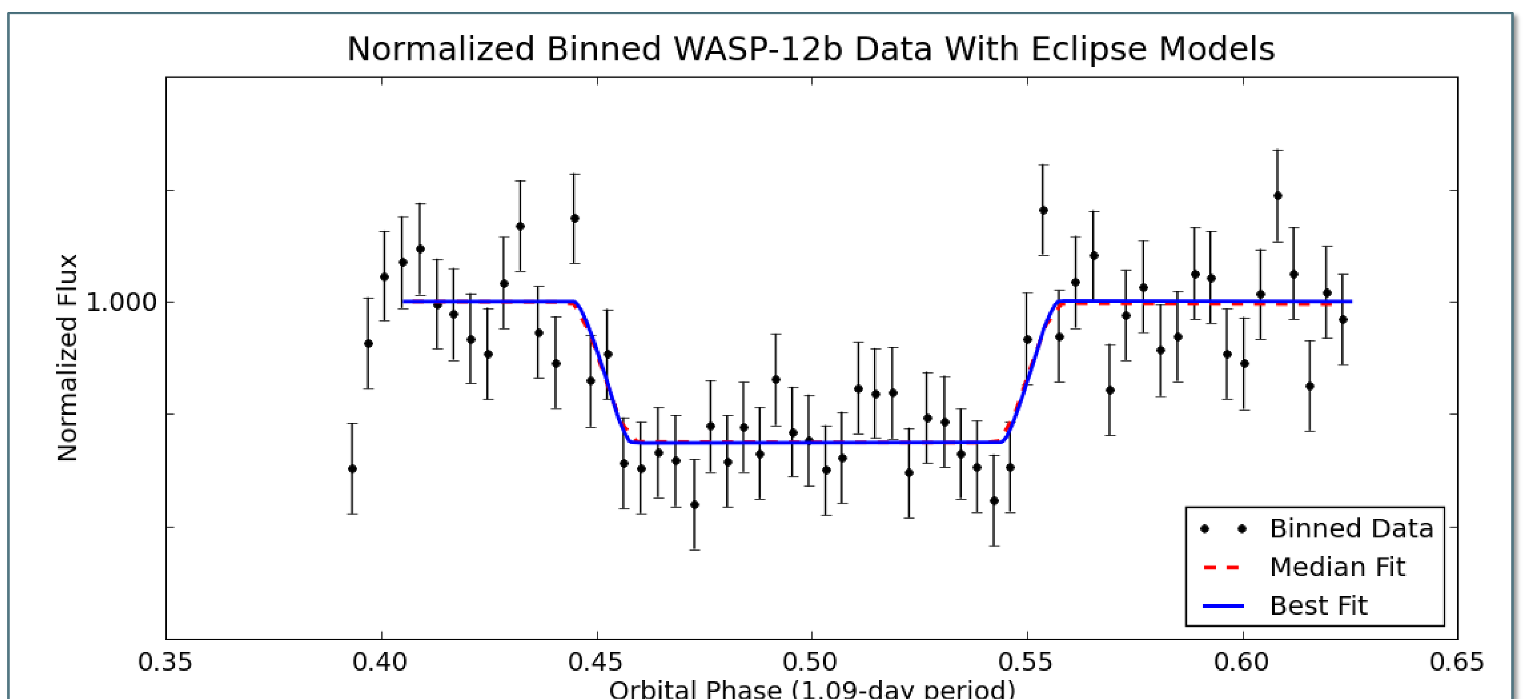
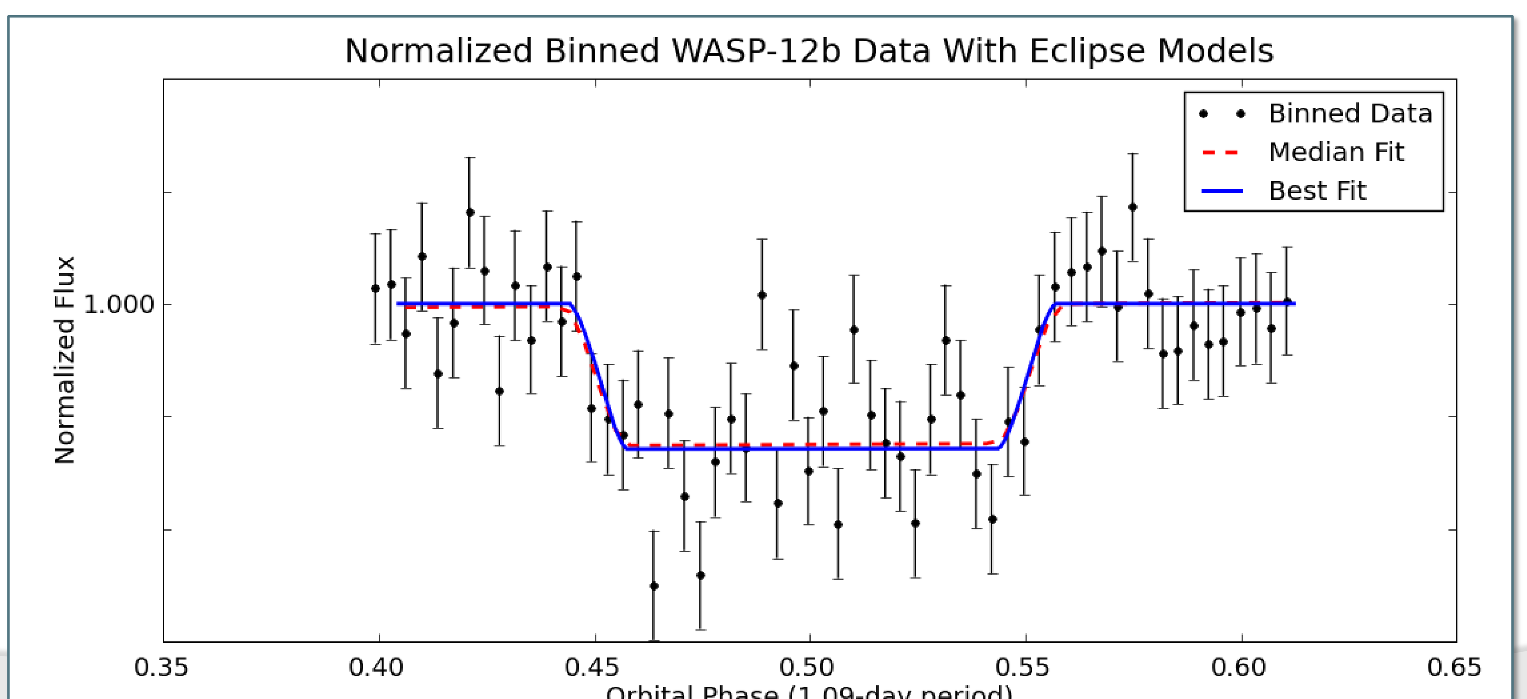
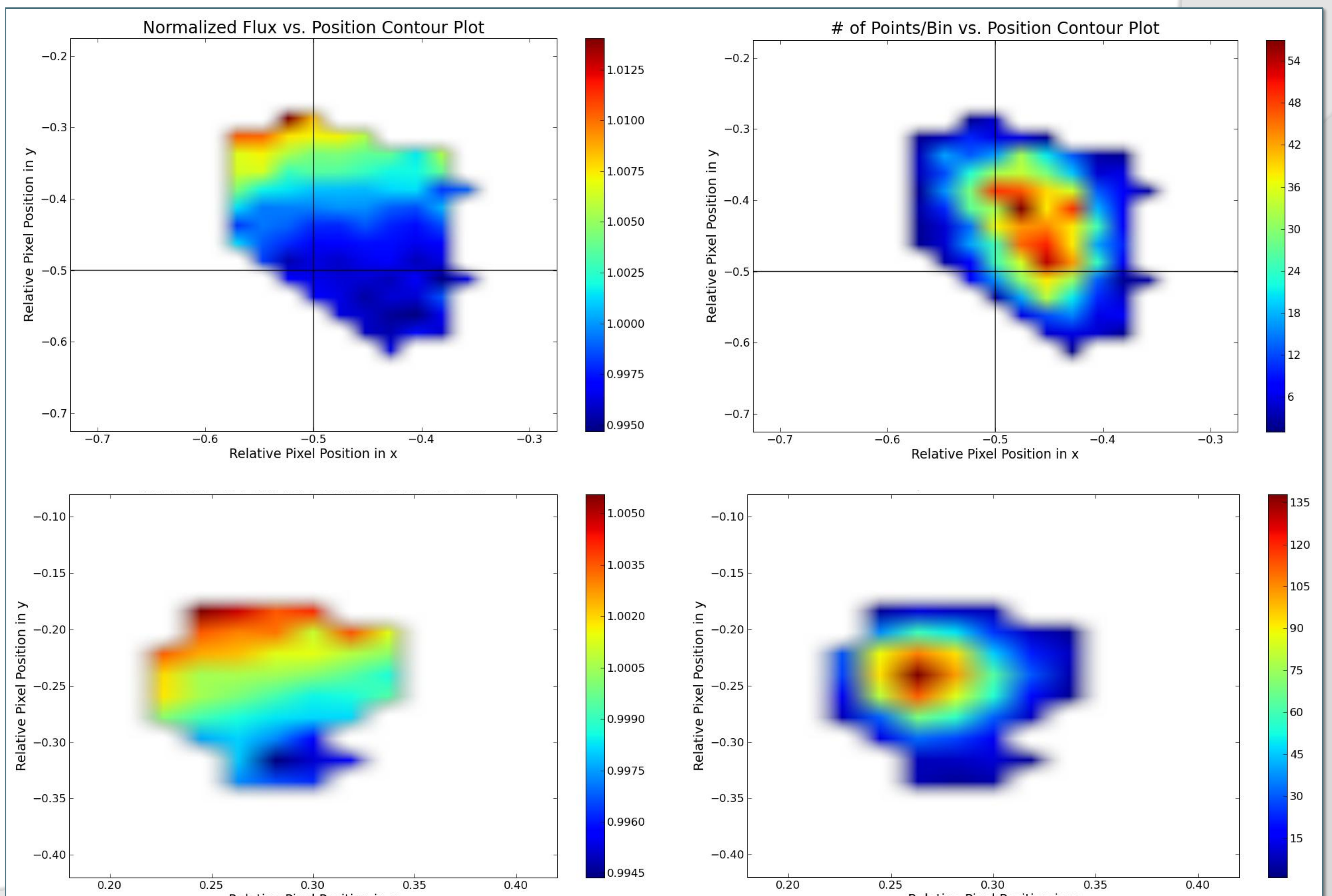




Secondary eclipse on 2008 November 3 at 5.8 μm



Secondary eclipse on 2008 October 29 at 8.0 μm



Pixel map (flat field) for 3.6 μm (top, array position x = 77, y = 56) and 4.5 μm (bottom, array position x = 125, y = 127). The data are from the 2010 observations. The black lines represent a pixel boundary. The plot on the left shows the flux versus position, while the plot on the right shows the number of data points versus position. In the channel 1 case (3.6 μm), the pixel was most sampled near a pixel boundary with three other pixels, while channel 2 was observed in the bottom right quadrant of the pixel. The sensitivity appears to increase in the vertical direction. In both channels, there is roughly a ~1% variation in sensitivity throughout the data set. This effect must be corrected to produce the final eclipse lightcurve.