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PHASE CURVES OF WASP-103B

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ABSTRACT

WASP-103b is a short-period hot Jupiter.

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1. INTRODUCTION

Planets are inherently 3D objects. Short period, tidally locked planets are intensely irradiated on the day side, which can lead to dramatic

2. OBSERVATIONS AND DATA REDUCTION

We observed two full-orbit phase curves of WASP-103b with *HST*/WFC3 and one each with *Spitzer*/IRAC at 3.6 and 4.5 μm. We also reduced two additional WFC3 secondary eclipse observations from *HST*Program FIXME (PI: M. Zhao).

2.1. *HST/WFC3*

The *HST* observations consisted of two visits on 26-27 February and 2-3 August 2015. Each visit was 15 orbits in duration and spanned 23 hours. We took a direct image of the star with the F126N filter at the beginning of each orbit to determine the wavelength solution. The remainder of the orbit consisted of time-series spectroscopy with the G141 grism and the 256 x 256 pixel subarray. We used the SPARS10/NSAMP = 15 read-out mode, which has an exposure time of 103 seconds. The exposures were taken with the spatial scan observing mode with a scan rate of 0.03"/s, alternating between forward and backward scanning on the detector to diminish overhead time. The scan height was 25 pixels and the peak counts were 30k photoelectrons per pixel. We collected a total of 18 spatial scan exposures per orbit. Our analysis also uses secondary eclipse observations of WASP-103b from *HST* program 13660 (PI: M. Zhao), which obtained time series spectroscopy with the G141 grism using a similar setup. Further description of the observational design for this program is given in Star Cartier (in prep).

We reduced the data from both programs using a custom pipeline that has been developed for past analyses of WFC3 data (for details see Kreidberg et al. 2014a,b; Kreidberg 2015). The raw data exhibit time-dependent systematic trends typically seen in WFC3 light curves, which we correct using a systematics model of the form:

$$F_{\rm sys}(t) = (c\,S(t) + v_1\,t_{\rm v} + v_2\,t_{\rm v})(1 - \exp(-a\,t_{\rm orb} - b)) \quad (1)$$

where $t_{\rm v}$ is time elapsed since the first exposure in a visit and $t_{\rm orb}$ is time since the first exposure in an orbit. $S(t)$ is a scale factor equal to 1 for exposures with spatial scanning in the forward direction and s for reverse scans. In the fit, c, v_1, v_2, a, b, and s are free parameters. The first orbit in each visit shows larger systematic trends than subsequent orbits, so we exclude these data in our final analysis (a common practice; see e.g. Kreidberg et al. 2014a).

We fit the systematics model simultaneously with the physical parameters for the system. The complete model is

$$F(t) = F_{\rm sys}(t)\,[T(t) + (E(t) - 1)(1 + A\cos(2\pi(t-\theta)/P))] \quad (2)$$

where $T(t)$ is a transit model, $E(t)$ is an eclipse model, P is the planet orbital period, and A and θ are free parameters to fit the amplitude and offset for the thermal phase variation. The free parameters for the transit and eclipse model are the planet-to-star radius ratio r_p/r_s, the planet-to-star flux ratio f_p/f_s, and a linear limb darkening parameter. The eclipse model is normalized such that the flux during eclipse is 1 and out of eclipse is f_p/f_s, and the transit model is normalized to unity out of transit. The planet's orbital parameters are poorly constrained by the WFC3 light curve due to incomplete phase coverage, so we fix the inclination to $i = 84.54°$, the semi-major axis to stellar radius $a/R_s = 2.925$, based on the best fit to the *Spitzer* Channel 2 light curve (described below). We use the orbital period $P = 0.925545613$ day, and time of inferior conjunction $t_0 = 2456836.2964455$ from Southworth et al. (2015). All free parameters were assumed to have a common value for both *HST* visits, with the exception of c, v_1 and v_2, which were allowed to vary between visits. We explored adding an additional cosine term to model the thermal phase variation, but the additional degrees of freedom are not justified according to the Bayesian Information Criterion (BIC). The transit and eclipse models were calculated with the `batman` package (Kreidberg 2015).

2.2. *Spitzer*

he *Spitzer* observations had the following setup. Each phase curve observation consisted of 30 hours of time series photometry, which covered a full orbital revolution of the planet. The observations were timed to contain two eclipses with three hours of baseline on either side. We used 12 s exposures to maximize the duty cycle without saturating the detector. The dominant systematic in high-precision Spitzer time series is the intrapixel effect (variations in flux caused by imprecise pointing). To minimize this effect, we used PCRS peak-up to improve the pointing accuracy. We began each observations with a 30-minute position settling period, followed by three Astronomical Observation Requests (AORs) of equal duration. At the beginning of each AOR, the telescope was repointed to position the target in the "sweet spot" of the detector.

We reduced the data using the POET pipeline and fit the systematics with the BLISS mapping technique

(Stevenson et al. 2012). This technique creates a map of the intrapixel sensitivity while simultaneously fitting for other systematics and the physical parameters of the system. In addition to the intrapixel sensitivity map, we fit the data for a linear trend in time and used the same transit, eclipse, and phase variation model as in Equation

We tested the light curve fits for time-correlated noise by calculating the root mean square (rms) of the fit for a range of bin sizes. For white noise, the rms should decrease as the square root of the number of points in the bin. The 4.5 μm phase curve data follow this trend; however, the 3.6 μm data have larger than expected rms at large bin sizes. The time-correlated noise is also noticeable in the residuals to the light curve fit To account for additional uncertainty due to the correlated noise in this channel, we use the wavelet technique of Carter & Winn (2009).

3. LIGHT CURVE ANALYSIS

4. COMPOSITION OF THE ATMOSPHERE

4.1. *Retrieval*

We thank a lot of people.

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