The Mass and Radius of the Eclipsing Binary KIC 8736245

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Abstract

The stellar mass-radius relationship is fairly well understood for stars greater than ~0.8 solar masses. However, for late K and M dwarfs there is a well-known discrepancy between theory and observations, in that the observed radii are often larger than predicted by several percent. We examine the binary star system KIC 8736245 to help understand the nature of the discrepancy. We find that the stars have masses of roughly 0.96 and 0.76 solar masses on nearly circular orbits that exhibit a 36% primary eclipse depth and 15% secondary eclipse depth. Its orbital period is 5.07 days, making the binary more widely separated than most low-mass binary systems that have precise dynamical mass and radius estimates. This is important since tidal effects are suspected as the cause of bloating the stars. We use Kepler data supplemented with multicolor photometry from Mount Laguna Observatory (MLO) and spectroscopy from the Hobby-Eberly Telescope (HET). Preliminary results show that the primary star is slightly evolved.

Introduction

The theoretical mass-radius relationship reasonably allows us to predict the radii of most main-sequence stars. However, for low-mass stars—particularly in the 0.2-0.8 solar mass range—the radius tends to be up to 15% larger (Ribas 2006) than stellar models predict. This large discrepancy may be due to the stars getting "bloated" from stellar activity. This is especially the case for short period binary systems since they experience tidal synchronization, causing the stars to be spun up. KIC 8736245 has an orbital period of 5.07 days and the system has 1-3% peak-to-peak fluctuations in brightness due to several star spots.

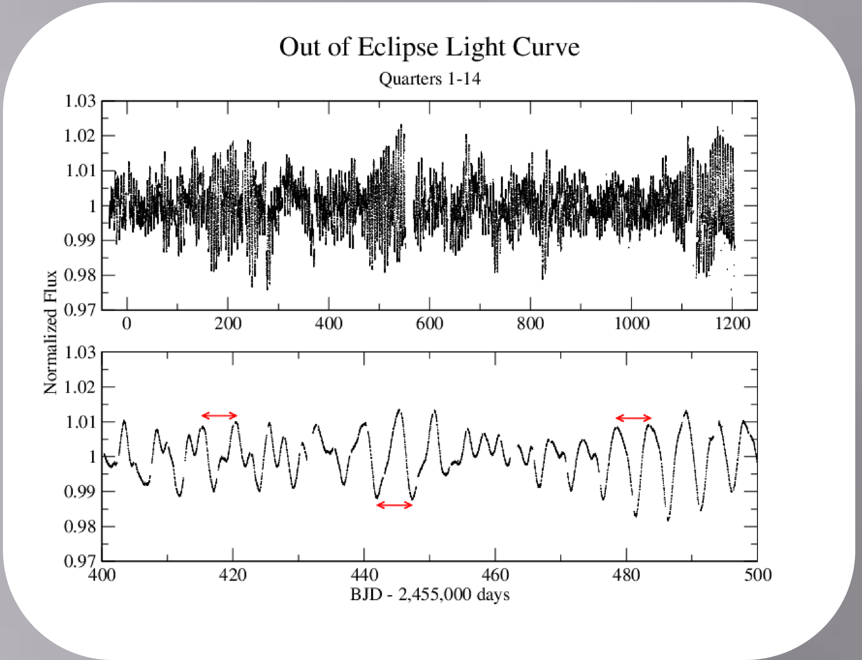


Figure 1: Normalized out of eclipse Kepler data showing spot variations. The red lines in the bottom plot are exactly the length of the orbital period.

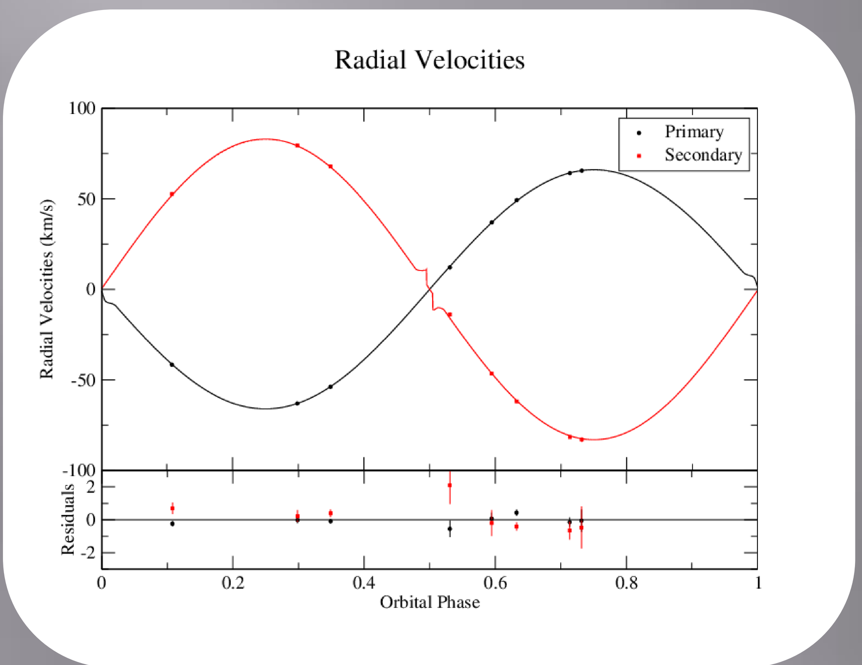


Figure 2: Modeled radial velocity measurements from the HET.

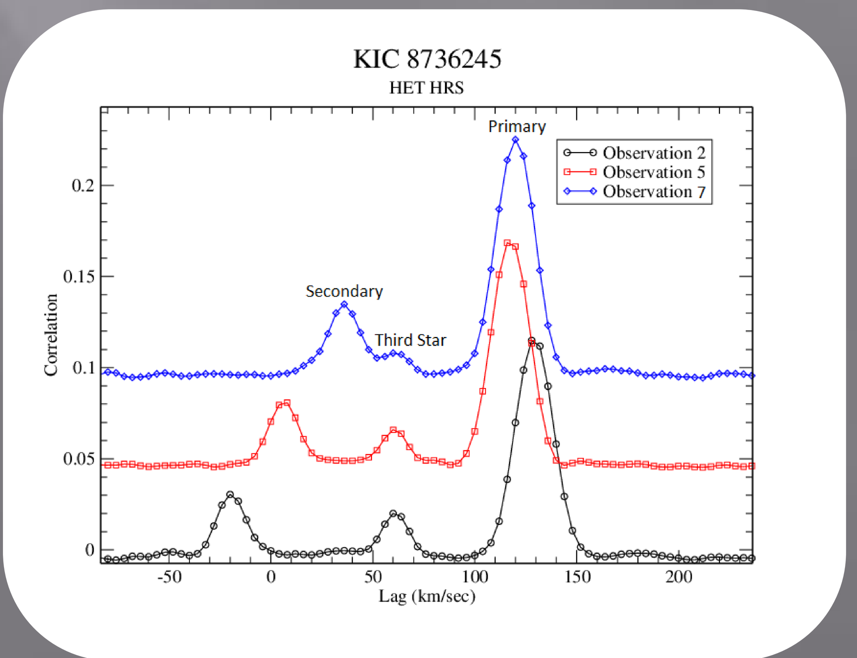


Figure 3: Broadening Functions used to measure the radial velocities. The central peak is from the third star.

Observations and Analysis

KIC 8736245 has a Kepler magnitude of 13.8 allowing easy follow-up with ground-based photometry. We obtained multi-color photometry from the MLO 24 and 40-inch telescopes. A total of eight nights were observed at MLO. On average our exposures were 1-2 minutes long. We observed the eclipses of KIC 8736245 in the BVRI filters. Most observations were made with the 24-inch telescope; the 40-inch telescope was used to observe in both the B and V filters. The eclipse duration was approximately 6 hours which sometimes resulted in observing only part of the eclipse.

To measure the radius and temperature of the two stars we use photometric data in several different filters, since the eclipse depth differs in each filter. The Kepler data for KIC 8736245 shows that the stars in this system are spotted, which especially complicates measuring masses and radii since the spots affect the brightness of the star—see Figure 1. This means, for example, that the areas out of eclipse are often "uneven", which forces us to include the spots in our modeling. We measured the stars' spin period using the autocorrelation function on the out of eclipse portions of the Kepler data. We found the orbital and spin periods to be the same, indicating the system is sufficiently old to have reached spin-orbit equilibrium (synchronous rotation).

Spectroscopic radial velocity data from the HET are used to measure the masses. The radial velocities, shown in Figure 2, indicate this system has a circular orbit, which is confirmed by a secondary eclipse at phase 0.5. The spectra for KIC 8736245 also revealed the presence of a third star that is most likely a background star with small probability of being associated with the system, shown in Figure 3. This implies the source of starlight contamination cannot be resolved and must be included in our models.

We model the data using the Eclipsing Light Curve (ELC) code (Orosz & Hauschildt 2000) and tiling the stars with stellar atmosphere intensities. We fit for the mass, radius, temperature of each star, and the time of conjunction. We also fit for the inclination, contamination, and star spot size, latitude and longitude, and temperature ratio for two spots on each star. We must account for not only contamination in the Kepler light curve, a result of Kepler's large apertures, but also contamination of the MLO data since the third light is unresolved—see Figure 4. In total we fit for 27 parameters in ELC.

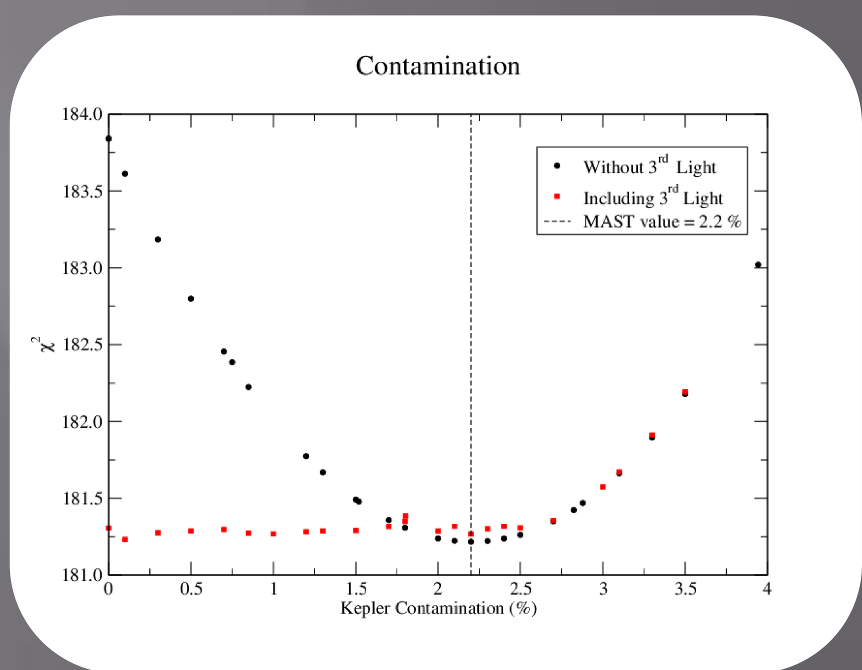
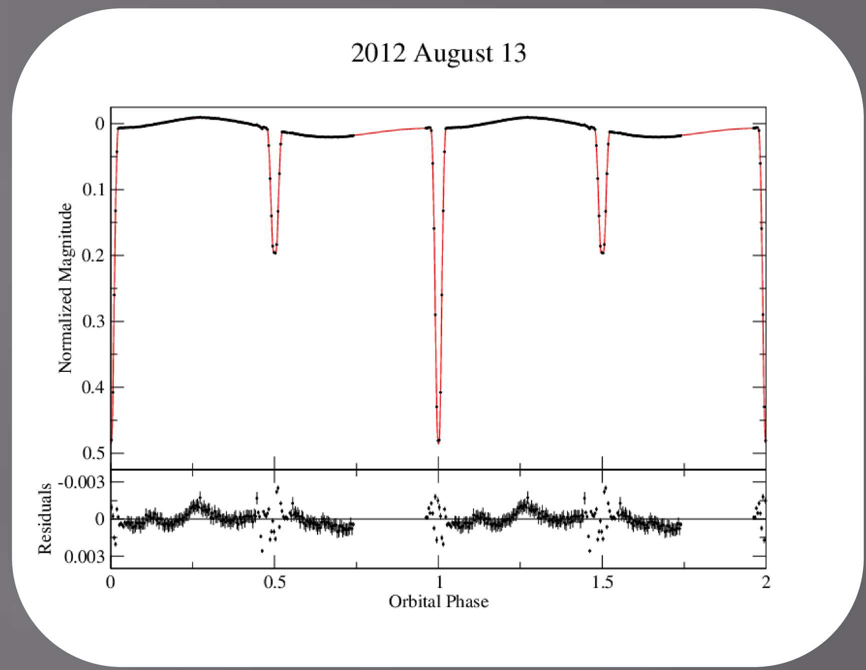
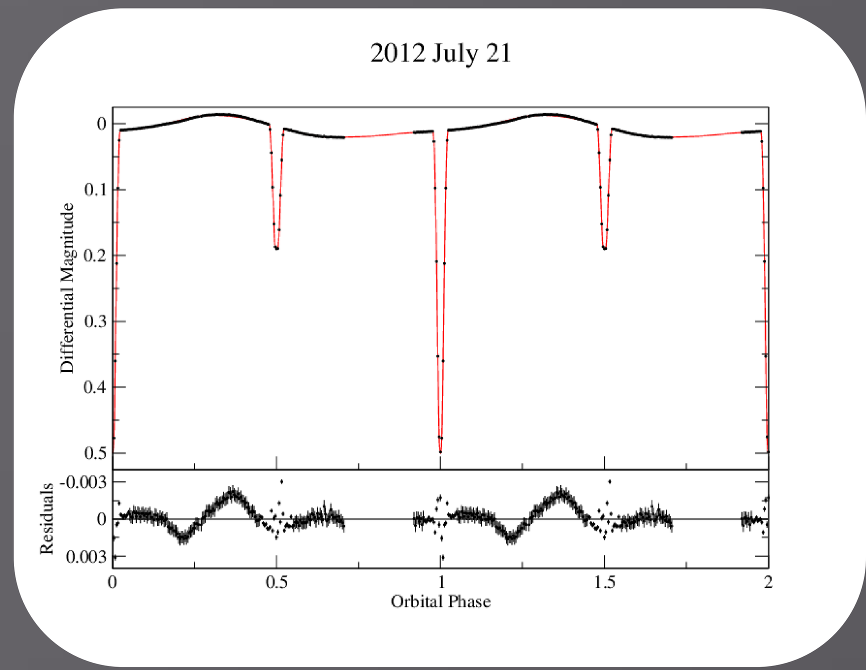
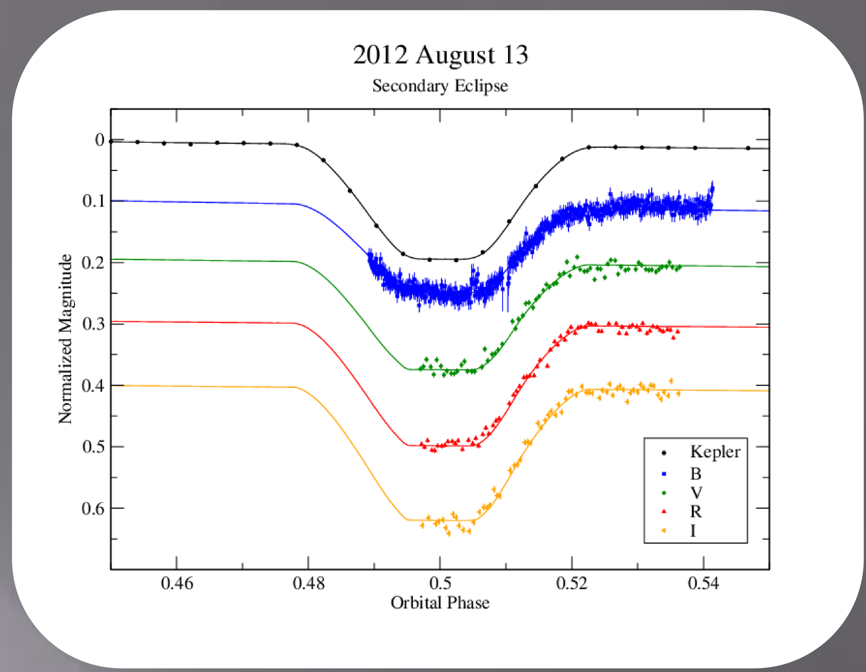
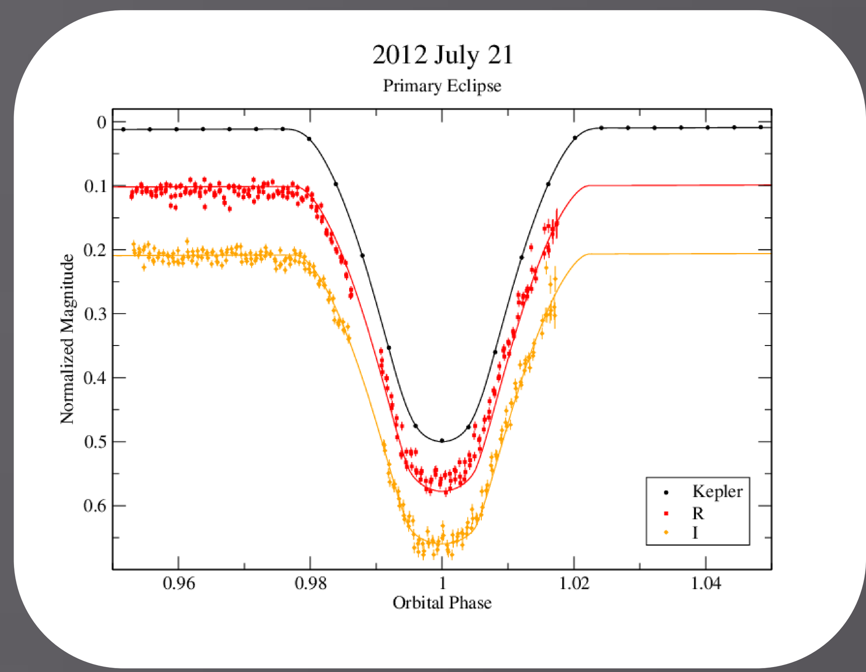


Figure 4: Comparing chi-squared verses a set Kepler contamination depending on whether third light is an additional parameter in ELC. The chi-squared reaches a minimum when third light is used for any contamination level less than 2.5%, thus we cannot assume the correct contamination level is given by MAST at 2.2%.





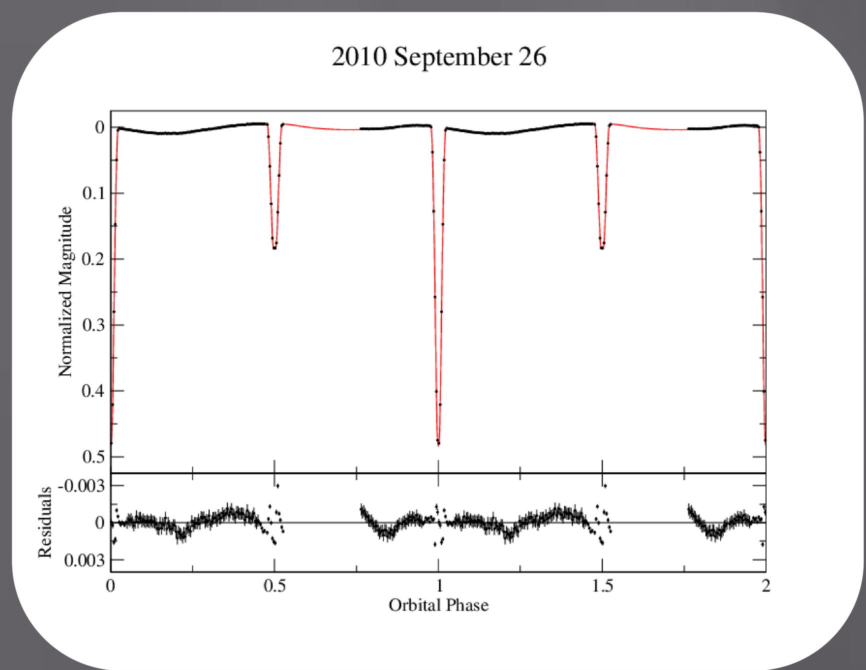


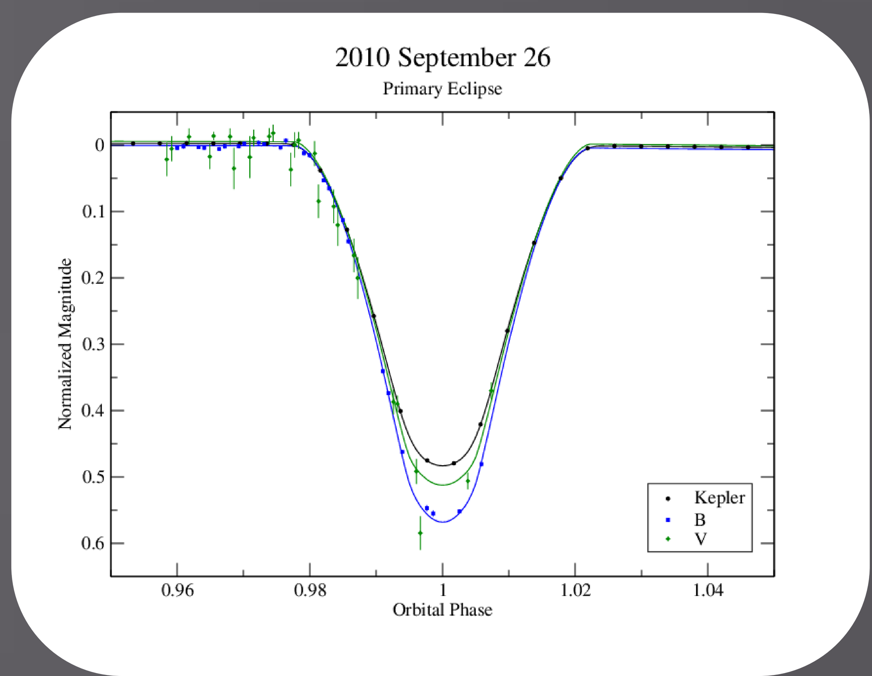


Figures 5-10: Best fit models for three nights observed at MLO. The upper plot of each set is the Kepler data with residuals. The lower plot of each set includes MLO data. For the plots directly above and to the left, each filter is offset by 0.1 magnitudes. The plot on the bottom left is shown without any offsets to emphasize the depth differences between filters.

Table 1: Preliminary parameter range estimates.

Star Properties		
	Star 1	Star 2
Mass (M_{Sun})	0.96 – 0.98	0.75 – 0.79
Radius (R_{Sun})	1.28 – 1.31	0.76 – 0.81
System Properties		
Orbital Period (days)	5.069482	
Separation Distance (R_{Sun})	14.88	
Inclination (°)	88.8 – 89.3	
Mass Ratio (M_2/M_1)	0.79 – 0.80	
Radius Ratio (R_1/R_2)	1.62 – 1.68	
Temperature Ratio (T_2/T_1)	0.86 – 0.88	





Results

While still ongoing, our preliminary results are presented in Table 1. We find the masses to be approximately 0.96 and 0.76 solar masses and the radii to be 1.30 and 0.78 respectively. The temperature is currently not tightly constrained, but we estimate the primary star to be between 5600 and 6300 K. We used the Dartmouth isochrones (Dotter et al. 2008) to calculate an age and metallicity of the system. This is a work in progress. As inferred from the radius, the primary star is slightly evolved consistent with a rough age of 8-9 Gyrs. We will further refine the models for KIC 8736245 and measure errors for each fitted parameter using five additional nights of ground-based observations.

Acknowledgements

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