UW CMa: A Questionable Contact System

Herbert Pablo[1], Noel D. Richardson[2], Anthony F. J. Moffat[3],
the BEST and SASER

1. American Association of Variable Star Observers, 49 Bay State Rd., Cambridge, MA USA 02138
2. Ritter Observatory, The University of Toledo, 2801 W. Bancroft Toledo, OH USA 43606-3390
3. Département de physique and Centre de Recherche en Astrophysique du Québec (CRAQ), Université de Montréal, C.P. 6128, Succ. Centre-Ville, Montréal, Québec, H3C 3J7, Canada

Using BRITE and SMEI photometry in conjunction with concurrent spectroscopy we attempt a thorough analysis of the O supergiant binary UW CMa. We explore and confirm previously noted asymmetries in the light curve which we are unable to model effectively. We also find the presence of an unexplained frequency at twice that of the orbit. We then discuss the state of the binary and whether or not this system is truly in contact.

1 Introduction

Eclipsing binary stars have been classified, largely phenomenologically, since the early 20th century. It wasn't until Kopal (1955) that the first relationship was made between light curve shape and the physical state of the two stars. Kopal determined that binary system light curves could be classified as detached, semi-detached (where one component is losing mass to the other), or in contact where there is no separation between the two components. While detached systems are most often used for determining fundamental parameters due to their simplicity, this avoids the issue of binary interaction. While this may be acceptable for low-mass stars, for O-type stars nearly a quarter will go through a merger event (Sana et al., 2012). Since there is no current way to distinguish post-merger products, the only way to study this branch of evolution is through contact binaries which are the most likely merger candidates.

Such systems suffer two major pitfalls which must be addressed when trying to determine a binary solution. First, the spectral lines of the two components will have significant overlap at most binary phases, making disentangling lines for radial velocity measurements difficult. Second, since there is effectively one surface being illuminated by two separate energy sources, current modeling software is unable to adequately determine the temperature distribution. While these are significant obstacles, they can be overcome to some extent, provided that the contact status of the binary is known. This status is normally easy to determine using the light curve shape; however, the analysis in this paper on UW CMa will cast doubt on this assessment.

2 Observations

Our photometric data come from the BRITE-Constellation project[1] as well as the Solar Mass Ejection Imager (SMEI). The BRITE data spanned over 166 days using two red and one blue nanosats: BHr, BTr, and BLb (for a description of the satellites and the capabilities in orbit see Pablo et al. 2016). These data were reduced using the procedure outlined in Popowicz et al. (2017), and instrumental artifacts were removed in a procedure similar to Buysschaert et al. (2017). All data used for analysis were then binned on the orbital means and combined by filter where the point-to-point RMS error was 0.0025 and 0.019 parts per thousand (ppt) for the red and blue data respectively. The SMEI data were taken over 2888 days. The only reduction processes applied were sigma-clipping as well as phasing and removing of the year-long data artifacts.

Spectroscopy was taken by the SASER group in conjunction with the BRITE observations spanning December 2015 to April 2016 and totaling 78 spectra around the He 4686 line and He II 5411 line with a typical resolving power around 10,000 and a S/N of 100 or better per resolution element. Radial velocities (RVs) were measured using the HE 5411 line which was in absorption. This resulted in 23 RV points.

3 UW CMa

UW CMa is an eclipsing binary system consisting of O9Iabf+O9.7Ib components (Bagnuolo et al., 1994). It was first discovered to have spectroscopic variability by Frost (1906). The spectroscopic history of this system is detailed and analyzed in Stickland (1989) with the most notable point being that the binary has always been known as eccentric with $e \approx 0.12$. It is unclear when its photometric variability was discovered, but it was listed in Russell (1939) in a table of eccentric eclipsing binaries. The first full photometric analysis was done in Leung & Schneider (1978) where the system was first categorized as a contact binary. While they discuss the asymmetry in the radial velocity curve, they attribute it to distortion and not to eccentricity. A second point which is mentioned, but not fit, is the asymmetry in the egress of the secondary eclipse. This analysis was confirmed by Antokhina et al. (2011) using Hipparcos photometry. To date, there has been no analysis which has fit both the spectroscopic and photometric variability together.

4 Binary Analysis

Using PHOEBE (Prša & Zwitter, 2005), a binary simulation and fitting program, we determined a reasonable set of parameters which gave models in good agreement with both the BRITE light curves and radial velocity curves. For the initial fit we fixed several parameters including $e = 0$ as this is assumed to be a contact system. The primary temperature was fixed at 33750 K as it is already well constrained

[1] Based on data collected by the BRITE-Constellation satellite mission, designed, built, launched, operated and supported by the Austrian Research Promotion Agency (FFG), the University of Vienna, the Technical University of Graz, the Canadian Space Agency (CSA), the University of Toronto Institute for Aerospace Studies (UTIAS), the Foundation for Polish Science & Technology (FNiTP MNiSW), and National Science Centre (NCN)

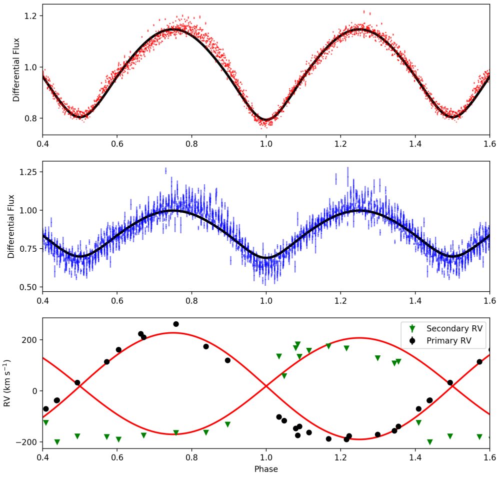

Fig. 1: Light curves from the BRITE red filter (top) and blue filter (middle). The radial velocities of the primary (black circles) and secondary (green inverse triangles) are shown in the bottom plot. For the top two plots the best-fit model is shown in black for the light curves and in red for the RVs.

spectroscopically. The secondary temperature was not fixed as there is a small but noticeable difference in the depth of the primary minimum. Using our manually derived input parameters we fit the 4 data products simultaneously using the mcmc wrapper *emcee* (Foreman-Mackey et al., 2013). The fit was done using 50 walkers which semi-independently probe the parameter space and was allowed to burn in for several thousand iterations. Once convergence was reached the system was allowed to run for over 2000 iterations. The results of the best fit from this procedure are shown in Fig. 1.

Unfortunately, the fit is lacking in several areas. The clear distortion in the secondary eclipse as well as the displacement of the maximum have not changed since Antokhina et al. (2011) and are still poorly fit. There is a small but noticeable discrepancy in the primary RV, but the secondary RV differences are quite pronounced. While these discrepancies could be partially explained by poor separation near periastron, this does not appear to be the only issue.

5 Fourier Analysis

For detailed Fourier analysis it is necessary to remove the binary variability as it is significantly stronger than most other signals. Since the binary fit is not ideal this is done instead using a template method. Using the phased light curves, we bin and interpolate to create a template of the binary variation which is then subtracted off. The Fourier transform after the binary variability is removed is shown in Figure 2. There is only one clear peak visible in both BRITE and SMEI data at 0.45 c d^{-1} which is twice the orbital frequency (within the errors). Normally this frequency

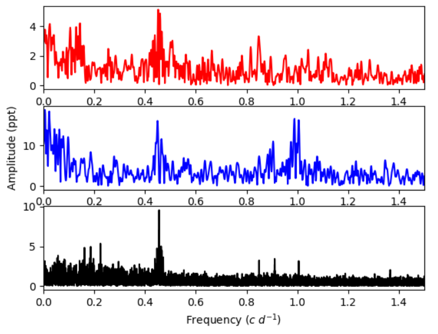

Fig. 2: Fourier Transform of BRITE red filter (top), BRITE blue filter (middle), and SMEI (bottom).

is suspect in an eclipsing binary as it could be a remnant of the orbit due to poor subtraction. However, the frequency is not always present, which one would expect if it was related to the orbit.

6 Discussion

The work on this system, while preliminary, is not well constrained. While our results agree roughly with those of previous works, there are many unanswered questions in this system. Chief among them is the mystery of the asymmetry at egress. The interesting thing is that this feature looks essentially the same and is at the same place in phase over light curves which span over 40 years. This implies that there is a permanent location on the surface of one star, likely the secondary, which is at a different temperature than the rest of the star. While this is possible, our literature searches have not been able to find a single similar contact system.

At this point it is worth exploring whether the assumption of a contact system is valid at all for this system. The light curve is so pronounced and the period so short that it is hard to imagine any other possibility. However, there is some evidence for this system not being in contact, namely the issue of eccentricity. While Leung & Schneider (1978) are able to explain this discrepancy through distorted line profiles, what they are not adequately able to explain is the displaced maximum. It has always been assumed that it was related to the asymmetry at egress, but a similar shift would be visible in an eccentric system. If we make the ansatz that this system is detached then we must also be able to explain the shape of the light curve in a non-contact system. As it turns out, a new paper using PHOEBE 2 on misaligned binaries, where the orbital axis is not aligned with the rotation axis, shows light curves with similar shapes to what we see, including the unusual asymmetries in the ingress and egress of eclipses (Horvat et al., submitted). As the pole is hotter than the equator, a misaligned binary where the pole is in our line of sight would act like a permanent spot and could explain the light curve variability. As this feature is still in the testing phase in PHOEBE 2 we are unable to make the proper simulations for testing, but we will be able to in the coming months. Moreover, this misalignment not only has an effect on the light curve, but also on the RV curves, distorting the

Rossiter-McLaughin effect. In order to test this hypothesis further we aim to take high precision spectroscopic measurements to search for this effect.

Acknowledgements. This work is based on data collected by the BRITE-Constellation satellite mission, built, launched and operated thanks to support from the Austrian Aeronautics and Space Agency and the University of Vienna, the Canadian Space Agency (CSA), and the Foundation for Polish Science & Technology (FNiTP MNiSW) and National Science Centre (NCN). NDR acknowledges postdoctoral support by the University of Toledo and by the Helen Luedtke Brooks Endowed Professorship. AFJM is grateful for financial aid from NSERC (Canada) and FQRNT (Quebec).

References

Antokhina, E. A., Srinivasa Rao, M., Parthasarathy, M., *New A* **16**, 177 (2011), arXiv: 1011.1739

Bagnuolo, W. G., Jr., et al., *ApJ* **423**, 446 (1994)

Buysschaert, B., et al., *A&A* **602**, A91 (2017), arXiv: 1704.00576

Foreman-Mackey, D., Hogg, D. W., Lang, D., Goodman, J., *PASP* **125**, 306 (2013), arXiv: 1202.3665

Frost, E. B., *ApJ* **23** (1906)

Kopal, Z., *Annales d'Astrophysique* **18**, 379 (1955)

Leung, K.-C., Schneider, D. P., *ApJ* **222**, 924 (1978)

Pablo, H., et al., *PASP* **128**, 12, 125001 (2016), arXiv: 1608.00282

Popowicz, A., et al., *A&A* **605**, A26 (2017), arXiv: 1705.09712

Prša, A., Zwitter, T., *ApJ* **628**, 426 (2005), arXiv: astro-ph/0503361

Russell, H. N., *ApJ* **90**, 641 (1939)

Sana, H., et al., *Science* **337**, 444 (2012), arXiv: 1207.6397

Stickland, D. J., *The Observatory* **109**, 74 (1989)