Contrib. Astron. Obs. Skalnaté Pleso **50**, 601 – 606, (2020)
https://doi.org/10.31577/caosp.2020.50.2.601

Search for invisible satellites in eclipsing binary systems using photometric methods

I.M. Volkov[1,2]

[1] *Institute of Astronomy of the Russian Academy of Sciences, 48 Pyatnitskaya street, 119017 Moscow, Russia, (E-mail: hwp@yandex.ru)*

[2] *Sternberg Astronomical Institute, Lomonosov Moscow State University, Universitetskij Ave. 13, 119992 Moscow, Russia, (E-mail: kravts@yandex.ru)*

Received: October 15, 2019; Accepted: February 6, 2020

Abstract. We discuss small anomalies in the multicolour photometric light curves (LCs) of eclipsing binary stars which may indicate the presence of additional satellites in the systems.

1. Introduction

When investigating detached eclipsing binaries we often find that the systems are multiple. The periodic LIght Time Effect (LITE) in Eclipse Timing Variation (ETV) diagrams directly indicates the multiplicity of the system. Usually however, one needs to observe the system for a long time before the LITE reveals itself in an ETV diagram. In the short term, certain LC features may indicate the presence of a third body. They are:

1. Colour indices during eclipses show anomalies;
2. LC solutions show a large amount of third light;
3. System models based on LCs show inconsistencies with theoretical predictions.

Next we illustrate the above with examples.

2. Unusual colour index behavior in minima and extra light

V577 Oph was the first system in our observational program (Volkov & Volkova, 2009) that showed colour index anomalies in the minima, see Volkov (1990) and Fig. 1. We continued our observations and found that extra red light in the minima belongs to a third red companion orbiting the eclipsing star with a period of 20 years (Volkov & Volkova, 2010), see Fig. 1.

RW CrA and DX Vel are other eclipsing binaries demonstrating the presence of third light, not only indicated by colour index anomalies during eclipses, see

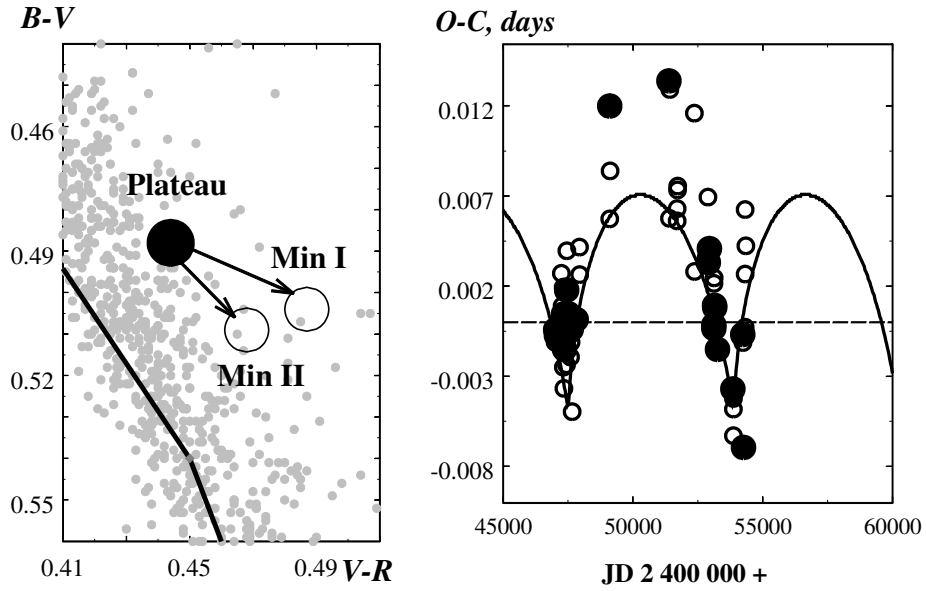

Figure 1. Left panel: V577 Oph in a $(B-V)$, $(V-R)$ diagram. The solid line is the standard main sequence from Straižys (1992). The grey points represent observations in the $WBVR$ system for stars in the Kornilov et al. (1991) catalogue. The filled circle marks the colour index of the combined light for V577 Oph. Open circles indicate colour indices in the minima. The right panel shows the ETV diagram of V577 Oph based on 20 years of observations, which strongly supports the idea of multiplicity of the system. Solid circles – LITE in eclipse timings; open circles – LITE in δ Sct pulsations of the main component.

Fig. 2 and Fig. 3, but also from their LC solutions. To fit the observations one needs to include large amounts of third light – 20 and 40 percent, respectively. Continuing the observations we found that these systems are multiple (Volkov et al., 2017), see the ETV diagrams in Fig. 2 and Fig. 3.

3. Model discrepancies

EQ Boo is a well known visual double system. One of the components is an eclipsing variable at a separation of $0\farcs9$, so we observe only the combined light of the triple system. Our first solution of the LC has shown discrepancies in the

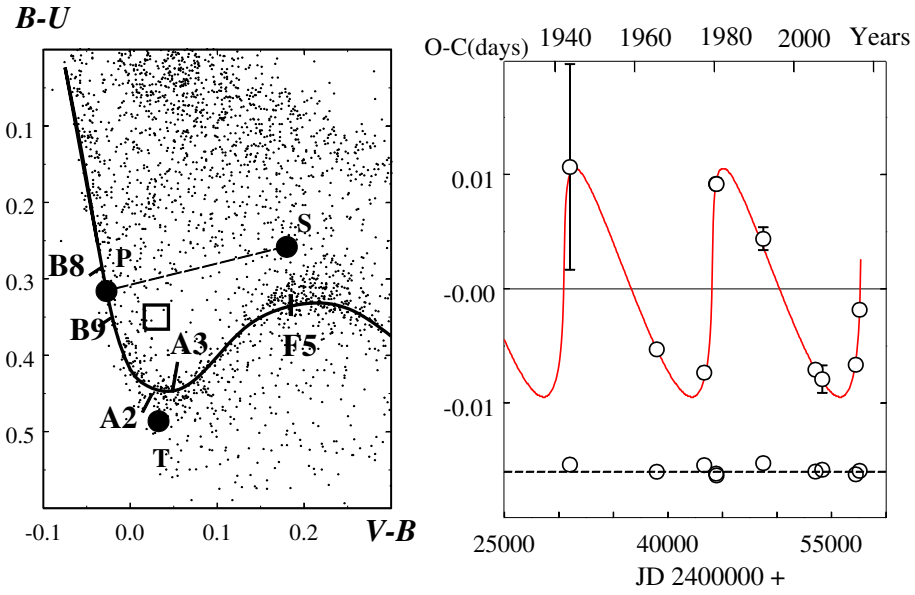

Figure 2. Left panel: RW CrA in a $(B-U)_W$, $(V-B)_W$ diagram. The solid line is the normal colour index sequence from Walraven & Walraven (1977). The points represent observations in the Walraven system from the Nitschelm & Mermilliod (1990) catalogue. The open square marks the colour index of the combined light. Observed indices of the primary (P) and secondary (S) components are designated by full circles. We see that the combined light does not lie on the line connecting the individual components, which indicates the presence of third light – (T). Right panel: the LITE in minima timings of RW CrA.

ages of the components (Volkov et al., 2011), see Fig. 4. The visual component should have a higher temperature and lower age than indicated by the LC solution. So we surmise the existence of one more dim red star in the system (Volkov et al., 2012). After decades of observations we found a small amplitude LITE in the ETV diagram of the system with a period of 5.62 years, see the right panel of Fig. 4, which we declare here for the first time. One should continue the observations of the system in order to correct this value.

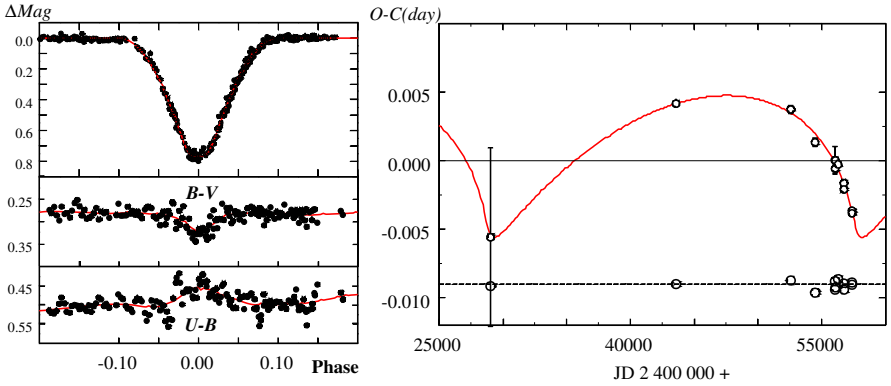

Figure 3. Left upper panel: DX Vel observations in primary minimum. Left bottom panels: the corresponding colour indices $B-V$ and $U-B$. Right panel: the LITE in minima timings of DX Vel.

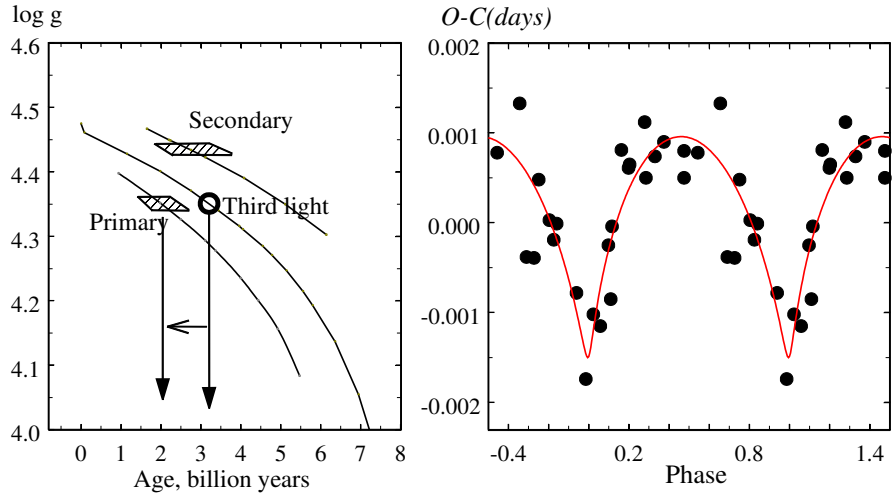

Figure 4. Left panel – the evolutionary tracks for stars with the same parameters as the EQ Boo components. If we suppose that all of the third light belongs to a single star we obtain a discrepancy in age with the primary component. Right panel – the ETV diagram for EQ Boo. A possible solution with a fourth body is shown with the red line.

4. Conclusions

The suggested LC features and LC solutions which can be found during the early stages of an eclipsing variable investigation may indicate the presence of invisible satellites in the system. Additional systems from our observational program such as V961 Cep (Volkov et al., 2010) and V491 Vul (a visual double similar to EQ Boo) require significant amounts of third light in their LC solutions. We expect that they will also be multiple star systems.

Acknowledgements. This study was in part supported by RNF grant 14-12-00146, RFBR grant 18-502-12025 and a scholarship of the Slovak Academic Information Agency (SAIA). The author acknowledges support from the Program of development of M.V. Lomonosov Moscow State University (Leading Scientific School 'Physics of stars, relativistic objects and galaxies.')

References

Kornilov, V. G., Volkov, I. M., Zakharov, A. I., et al., Catalogue of WBVR-magnitudes of bright stars of the northern sky. 1991, *Trudy Gosudarstvennogo Astronomicheskogo Instituta*, **63**, 1

Nitschelm, C. & Mermilliod, J. C., Up-to-date Walraven VBLUW photoelectric photometric catalogue. 1990, *Astron. Astrophys., Suppl. Ser.*, **82**, 331

Straižys, V. 1992, *Multicolor stellar photometry, Tucson : Pachart Pub. House*

Volkov, I. & Volkova, N., The Unique Triple System V577 Oph. 20 Years of Observations. 2010, in Astronomical Society of the Pacific Conference Series, Vol. **435**, *Binaries - Key to Comprehension of the Universe*, ed. A. Prša & M. Zejda, 323

Volkov, I. M., V577 Oph - an Eclipsing Binary with a delta Sct Type Primary Component. 1990, *Information Bulletin on Variable Stars*, **3493**

Volkov, I. M., Chochol, D., Grygar, J., Mašek, M., & Juryšek, J., Orbital period changes in RW CrA, DX Vel and V0646 Cen. 2017, *Contributions of the Astronomical Observatory Skalnate Pleso*, **47**, 29

Volkov, I. M., Chochol, D., Volkova, N. S., & Nikolenko, I. V., Is EQ Boo a Quadruple System? 2012, in IAU Symposium, Vol. **282**, *From Interacting Binaries to Exoplanets: Essential Modeling Tools*, ed. M. T. Richards & I. Hubeny, 89–90

Volkov, I. M. & Volkova, N. S., The physical parameters and orbit of the eclipsing binary system GSC 4596 1254 = SAO 3282. 2009, *Astronomy Reports*, **53**, 136, DOI: 10.1134/S106377290902005X

Volkov, I. M., Volkova, N. S., & Chochol, D., Physical parameters and orbit of the eclipsing binary BD +66 1663 = GSC 4479 412. 2010, *Astronomy Reports*, **54**, 418, DOI: 10.1134/S1063772910050057

Volkov, I. M., Volkova, N. S., Nikolenko, I. V., & Chochol, D., Multiplicity and apsidal motion in the eclipsing binary EQ Boo. 2011, *Astronomy Reports*, **55**, 824, DOI: 10.1134/S1063772911090095

Walraven, T. & Walraven, J. H., Five channel photometric observations of stars in the Magellanic Clouds and in the Milky Way. 1977, *Astron. Astrophys., Suppl. Ser.*, **30**, 245