Period changes in low-mass eclipsing binaries

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Binary and Multiple Stars in the Era of Big Sky Surveys, Litomyšl, Czech Republic, September 9 - 13, 2024

1 Introduction

Low-mass binaries (LMB) and their multiple systems play an important role in the stellar astrophysics. Their origin and evolution is still an unresolved question in the star formation theory. Moreover, observations of low-mass stars show severe discrepancy between estimated and modeled parameters, where the models give some 10 - 15% smaller radii than observations while their effective temperatures are some 5% higher (e.g. Torres & Ribas 2002, Ribas et al. 2008, Han et al. 2017). Our previous period studies of several LMB were presented in Wolf et al. (2016, 2018, 2021).

2 Observations

LMB are relatively faint objects with short orbital period, rapid and deep eclipses, also interesting for amateur observers and their small telescopes with CCD techniques. Since 2006 systematical long-term light curve and eclipse monitoring of many eclipsing LMB was made at several observatories in Czech Republic:

- 65-cm reflecting telescope (D65) in Ondřejov observatory and CCD camera MII G2-3200 (Moravian Instruments, https://www.gxccd.com) with Johnson-Cousins BVRI filters (Fig. 1).
- 40-cm Ritchey-Chrétien telescope at Dark Sky Beskydy observatory and CCD camera MII C3 Pro mono with Baader LRGB Halfa filters (Fig. 2) https://www.darkskybeskydy.cz
- 35-cm SCT Celestron telescope at Valašské Meziříčí observatory with CCD camera MII G2-1600 (Fig. 3) https://www.astrovm.cz/cz/
- 28-cm SCT Celestron telescope at Valašské Meziříčí observatory with CCD camera MII G2-4000 (Fig. 4).
- 20-cm Newtonian telescope at South-Moravian Observatory with CCD camera MII G2-1600 (Fig. 5) https://south-moravian-observatory.jimdofree.com/

3 Period variation and light-time effect

The period analysis of three selected LMB was performed using all available mid-eclipse times found in the literature as well as our newly measured times and derived from TESS data. One of the best method to detect the third body orbiting the eclipsing binary is the light travel delay, or so-called *light-time effect* (LITE), associated with orbital motion of the third body (e.g. Irwin 1952, Mayer 1990, Sterken 2005). Bellow, we present three examples of *O-C* diagrams where the original solution of LITE turn out to be insufficient and unsatisfactory. Their corresponding *O-C* diagrams are discussed in Figs. 6 - 8.

4 Conclusion

In many systems the LITE is correct explanation of cyclic shape of *O-C* diagrams and the presence of the third body is well justified. On the other hand, in some cases we are probably dealing with yet unknown or misinterpreted dynamical phenomenon in binary stars, which is also observed in other eclipsing binaries of various types (PCEBs, CVs). Further measurements of eclipses are desirable to better understand this behavior.

Figure 1: The Mayer 65-cm reflecting telescope located at Ondřejov observatory, CCD camera in the primary focus. (Photo Kamil Hornoch)

Figure 2: The 40-cm Ritchey-Chrétien telescope at Dark Sky observatory in Beskydy, CCD camera MII C3 Pro mono. (Photo Tomáš Hynek)

Figure 3: The 35-cm SCT Celestron telescope with CCD camera MII G2-1600 at Valašské Meziříčí observatory. (Photo Ladislav Šmelcer)

Figure 5: The 20-cm Newtonian telescope with CCD camera MII G2-1600 at South-Moravian Observatory. (Photo Reinhold F. Auer)

Figure 4: The 28-cm Celestron telescope at Valašské Meziříčí observatory with the MII G2-4000 CCD camera. (Photo Ladislav Šmelcer)

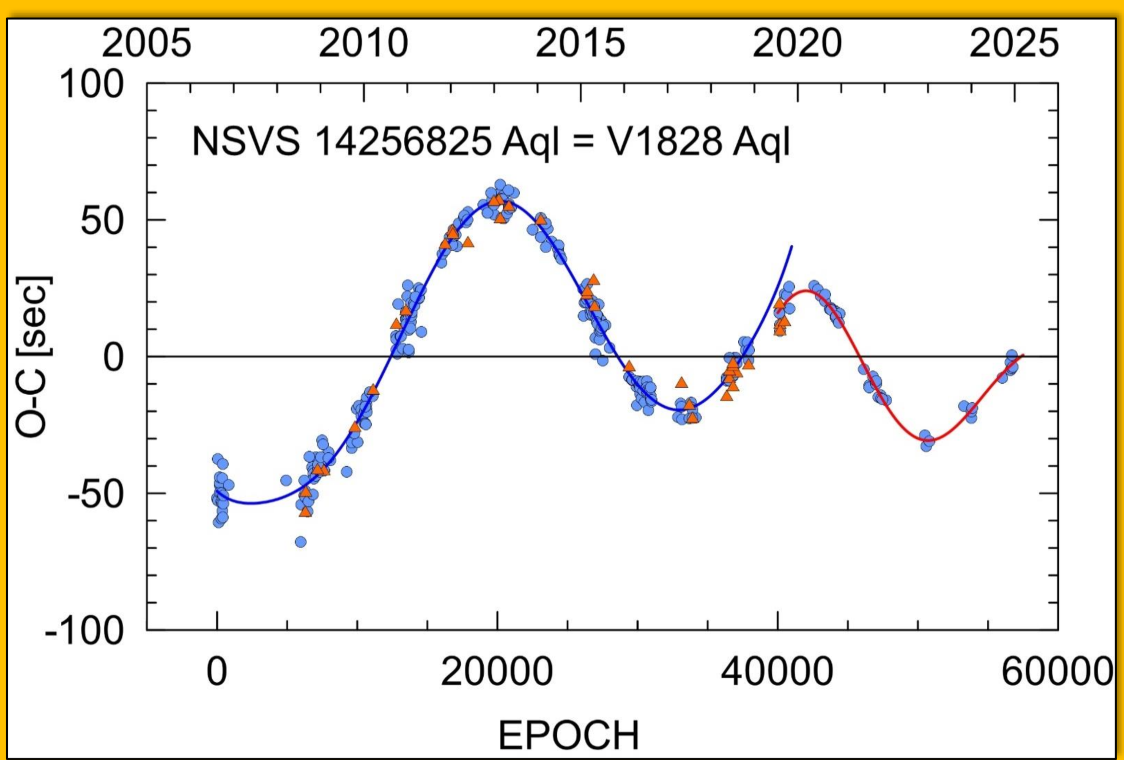

Figure 6: Period changes in the current *O-C* diagram of NSVS 14256825 = V1828 Aql. Primary and secondary eclipses are plotted as blue circles and orange triangles, resp. Previous solution of LITE with the third-body period P_3 about 9 yr (blue curve) is not longer valid. Variations of *O-C* values cannot be interpreted as a single LITE. Compare with the similar *O-C* diagram of the well-known PCEB HW Vir, where sinusoidal oscillations of *O-C* values have been dampened in recent years.

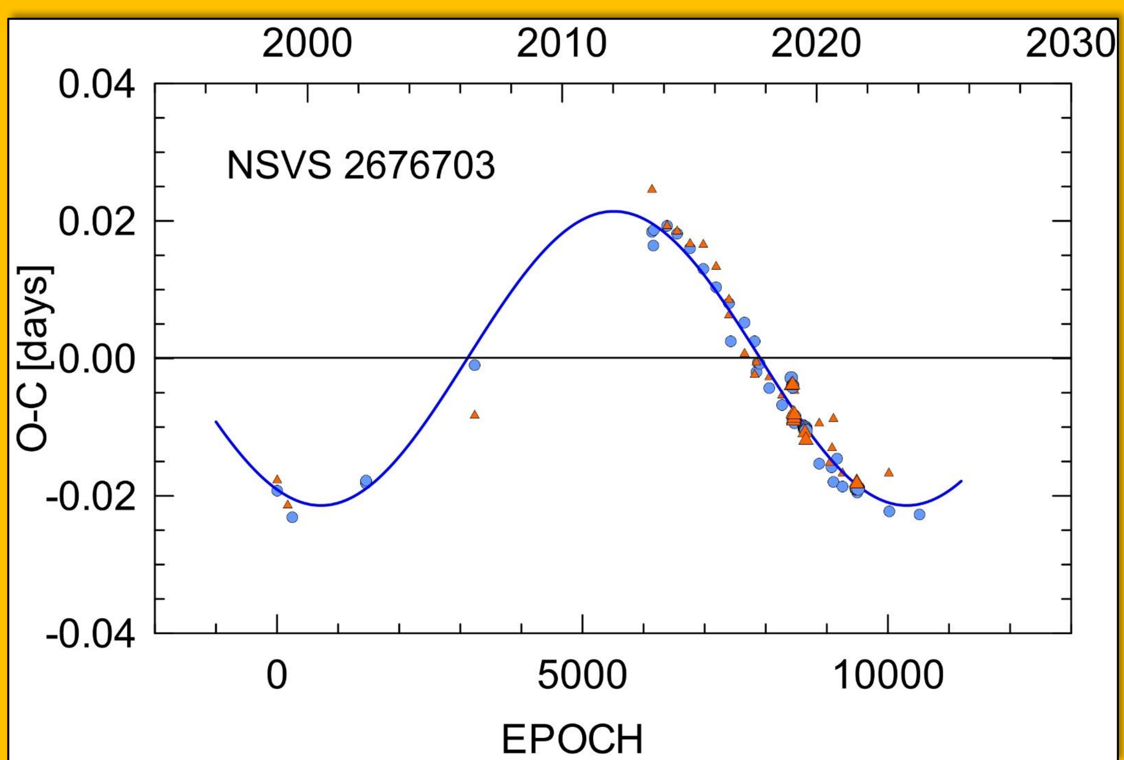

Figure 7: Present *O-C* diagram for NSVS 2676703 where data from TESS satellite (larger symbols) were also used. The blue sinusoidal curve represents our solution of LITE with the period of 22.8 yr and a relatively large semi-amplitude about 30 minutes. Assuming coplanar orbits and the masses of both components $M_1 = 1.2\ M_\odot$ and $M_2 = 0.72\ M_\odot$, the minimal mass of the third body follows $M_{3,min} = 0.9\ M_\odot$. Unfortunately, such a bright third body is not visible in the light curve solution.

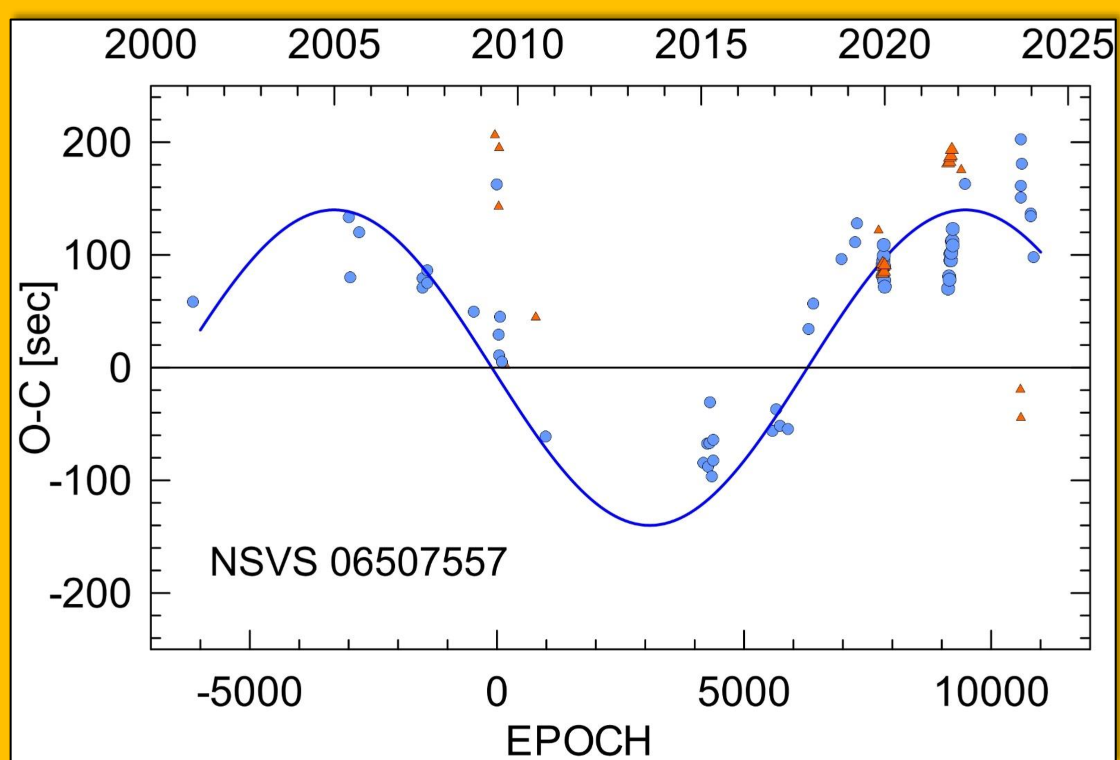

Figure 8: Current *O-C* diagram for NSVS 6507557 with TESS data (larger symbols). Primary and secondary eclipses are plotted as blue circles and orange triangles, resp. The blue sinusoidal curve represents possible LITE with a period of 15.3 yr and a semi-amplitude of about 140 sec. Short-time deviations from the sinusoidal course are clearly visible, esp. around the epochs 8000 - 9000 (TESS data). This points to other dynamic effect(s) that apply in this systém.

Acknowledgements. The research of MW and PZ was supported by the project Cooperatio-Physics of the Charles University in Prague. HK and KH were supported by the project RVO 67985815. The authors would also like to thank Lenka Kotková, Ondřejov observatory, Jan Vraštil, Charles University Prague, and Marek Chrastina, Masaryk University Brno, for their important contribution to photometric observations. TH would like to thank Jan Zahájský (Supra Praha) and Martin Myslivec, who played significant role in putting the whole set in Beskydy observatory into operation. Following internet-based resources were used in research for this paper: the SIMBAD database operated at CDS, Strasbourg, France, and the NASA's Astrophysics Data System Bibliographic Services. This paper includes data collected by the TESS mission. The funding for the TESS mission is provided by the NASA Science Mission Directorate. This research is part of ongoing collaboration between professional astronomers and the Czech Astronomical Society, Variable Star and Exoplanet Section.

REFERENCES

Han, E., Muirhead, P.S., Swift, J.J., et al. 2017, *AJ*, 154
Irwin, J. B., 1952, *ApJ*, 116, 211
Mayer, P. 1990, *BAICz*, 41, 231
Ribas, I., Morales, J.C., Jordi, C., et al. 2008, *Mem. Soc. Astr. Ital*. 79, 562
Sterken C., ed. 2005, The Light-Time Effect in Astrophysics: Causes and cures of the O-C diagram, *ASP Conference Series* Vol. 335
Torres, G. & Ribas I. 2002, *ApJ*, 567, 1140
Wolf, M., Zasche, P., Kučáková, H. et al. 2016, *A&A*, 587, A82
Wolf, M., Kučáková, H., Zasche, P. et al. 2018, *A&A*, 620, A72
Wolf, M., Kučáková, H., Zasche, P. et al. 2021, *A&A*, 647, A65