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Quadruple systems with two eclipsing binaries

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Abstract. Bound pairs of eclipsing binaries have been studied for the last 10 years as parts of more complex multiple systems. We present new findings on these somewhat neglected objects, as well as motivation for their study. Detection methods, parameter distributions, resonances, and interesting sky distributions are discussed.

Key words: stars: binaries: eclipsing – stars: fundamental parameters

1. Introduction

Doubly eclipsing systems, i.e. 2+2 quadruples with two eclipsing binaries, are still rather overlooked and attract no special attention. However, as we have shown in Zasche et al. (2019), several aspects make these objects worthy of study.

Their occurrence in stellar populations is much higher than anticipated, so we should be able to identify many more. A huge majority are real quadruples, as opposed to pairs of doubles projected into the same direction, and we should be able to measure relative component motions. They also can be used to complete the statistics of 2+2 quadruples, which are still very incomplete. Finally, the 3:2 resonance in 2+2 systems seems the most prominent one, a result not noticed prior to analysis of our large compilation of doubly eclipsing stars. These resonances should play an important role in multiple-star system formation and evolution.

2. Why study 2+2 quadruples?

Several justifications for a special focus on 2+2 quadruples can motivate analysts and observers and underscore the importance of knowledge about star formation, evolution, dynamics, and the Universe.

2.1. Under-occurance in the northern hemisphere

Due to reduced numbers of doubly eclipsing systems in the northern sky (see Fig. 1), our analysis led to a suspicion that undiscovered northern examples exist, available for observers with smaller-size telescopes. Possibly surveys like *TESS* can observe enough data points for particular objects to measure both periods. However, a significant number were discovered by chance in the northern sky, where no systematic search was done, by amateur astronomers (typically monitoring other targets in the same field). See Zasche et al. (2019) for a list. Therefore, we propose a special attention to northern doubly eclipsing systems, possibly to initiate a focused search.

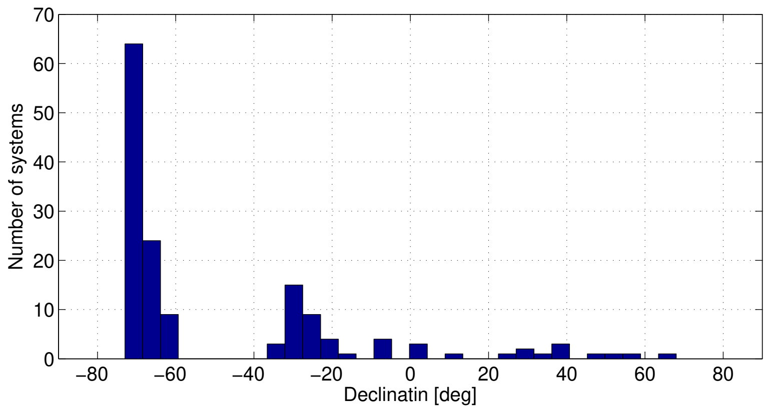

Figure 1. Distribution of currently known doubly eclipsing systems on the sky with respect to their declination. Southern peaks (mostly due to the OGLE surveys) are clearly visible.

2.2. Long term monitoring

We also call for long-term photometric monitoring of these systems. This should be quite easy for observers with relatively small telescopes. Our request for these observations follows from the period of the two doubles around their barycenter being typically of the order of several years to decades. Hence, collecting only times of eclipses would be very fruitful for deriving the large orbit. Some photometric surveys are doing well, but their cadency and time span are not always suitable for these studies.

2.3. More detailed view missing

A huge majority of doubly eclipsing systems lack detailed analysis. Most were only discovered as showing two distinctive periods, but light curve analysis of both pairs is typically missing. In-depth analyses of light curves and radial velocities, with some attempt to study the eclipse timing variations (hereafter

ETV) signals, were done only for several systems such as V994 Her, V482 Per, 1SWASP J093010.78+533859.5, and a few stars from the *Kepler* and *Corot* fields. Such analysis is missing for the others and urgently needed for subsequent analysis as a quadruple, to obtain physical parameters of all four components and their orbits. Unfortunately, most are rather faint for obtaining their spectra with smaller telescopes.

2.4. Distribution of periods

The ratio of the two eclipsing periods shows a remarkable tendency. As in our paper (Zasche et al., 2019), a peak near a ratio of 1.5 corresponds to the 3:2 mean motion resonance (see Fig. 2). A much less significant excess close to ratio 2.5 is also visible, as well as a dearth of systems close to 2:1 resonance. It is still not very clear why a peak at 3:2 resonance is present even where the respective orbital periods are of the order of a decade or even more, where dynamical interaction of the two pairs should be very weak. Detailed modelling of formation and subsequent orbital evolutionary scenarios should be done to reveal true origins. A theory for these resonant systems is still missing, although a first attempt in this respect was a publication on 1:1 mean motion resonance by Breiter & Vokrouhlický (2018), but with a strict limitation to planar configurations. In some respects this treatment resembles a distribution of periods in exoplanetary systems, as pointed out e.g. by Quinn et al. (2019).

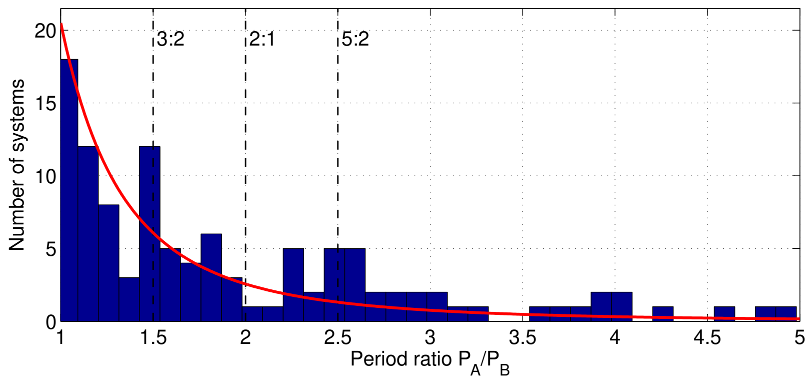

Figure 2. Distribution of period ratios of known doubly eclipsing systems.

3. Detection prospects and limitations

Selection effects influence our parameter statistics. For example, doubly eclipsing systems composed of equal mass pairs (i.e. $M_{\rm Pair\ B}/M_{\rm Pair\ A}$ close to 1) are preferentially discovered since, with very incomparable pairs, the dominant one causes the the other pair's eclipses to be very shallow and hardly detectable. For example, the doubly eclipsing system KIC 4247791 (or KOI-28, see Lehmann et al. 2012), with its rather shallow eclipses of Pair B, would probably be missed with our detection limits. The inclinations of the inner pairs can cause a similar effect. On the other hand, the inclination of the outer orbit can cause the amplitude of ETV to increase and decrease as this angle is changed from coplanar orientation. Also the limitations of the orbital periods (of inner as well as outer orbits) play an important role in analysis. However, the latter can be changed with dedicated observations of better precision (hence detecting also shallower eclipses) and increased time span (hence convincingly detecting longer outer orbit periods over 2 decades, which was our principal limitation with OGLE data).

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