Contamination of RR Lyrae stars from Binary Evolution Pulsators

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Binary Evolution Pulsator (BEP) is an extremely low-mass member of a binary system, which pulsates as a result of a former mass transfer to its companion. BEP mimics RR Lyrae-type pulsations but has different internal structure and evolution history. We present possible evolution channels to produce BEPs, and evaluate the contamination value, i.e. how many objects classified as RR Lyrae stars can be undetected BEPs. In this analysis we use population synthesis code StarTrack.

1 Context

To date, only one BEP (Binary Evolution Pulsator), namely OGLE-BLG-RRLYR-02792 (Pietrzyński et al. 2012), has been reported to exist inside the RR Lyrae (RRL) instability strip (IS) in the Hertzsprung-Russel diagram. Thanks to its eclipses, physical parameters of both components were determined, including the mass of the pulsator of only 0.261 $M_\odot$ – clearly too small for an RRL star. But without visible eclipses BEPs could be undistinguishable from bona fide RRLs. Relatively large number of such undetected RRL imposters might affect statistics-based calculations involving RR Lyrae stars, like age or distance determinations.

2 Results of population synthesis

The number of BEPs has been calculated with use of a synthesis population code StarTrack (Belczynski et al. 2008), and compared to the number of RRLs in order to establish the contamination value. For this task, StarTrack has been fine-tuned for more precise reproduction of low-mass binaries below $10\,M_\odot$ experiencing thermally unstable mass loss. The population synthesis over the Hubble time was performed on a sample of 5×10^5 binaries with randomly drawn initial parameters (mass m, mass ratio q, orbital period p, and eccentricity e). If at any point of binary evolution after the mass transfer (MT), one of objects entered RRL IS (defined in terms of luminosity and temperature, i.e. $5000\,\mathrm{K} < T_{\mathrm{eff}} < 7400\,\mathrm{K}$ and $16\,L_\odot < L < 100\,L_\odot$, Bono et al. 1997) it was considered as BEP. The population synthesis yielded a dataset of 6947 BEP objects. Using the same sample number and initial parameters range, the number of RRLs was estimated to 8583, given that only 20% of stars with initial mass between 0.8 and 0.9 $M_\odot$ would evolve through the RRL IS. Because binaries constitute about 50% of all systems, the number of BEPs must be reduced by half; and the remaining number must be reduced again by a factor of 100, because BEPs

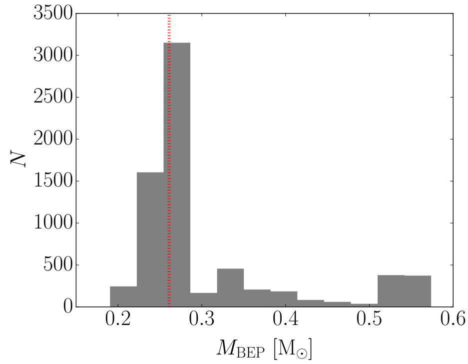

Fig. 1: Mass distribution in the BEP dataset. Red dotted line indicates the mass of the OGLE-BLG-RRLYR-02792, $M = 0.261$ M$_\odot$.

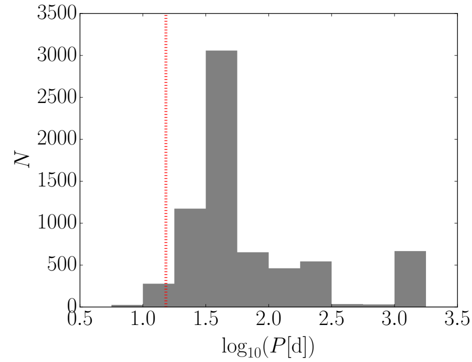

Fig. 2: Orbital period distribution in the BEP dataset. Red dotted line indicates the orbital period of the OGLE-BLG-RRLYR-02792, $P = 15.2434$ d.

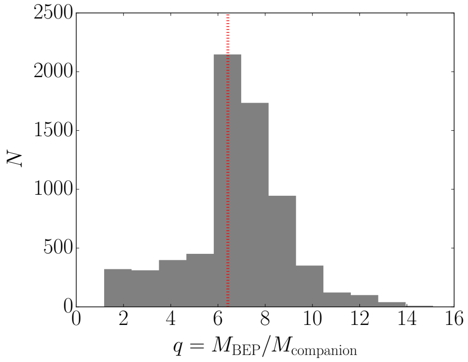

Fig. 3: Mass ratio period distribution in the BEP dataset. Red dotted line indicates the mass ratio of the OGLE-BLG-RRLYR-02792, $q = 6.42$.

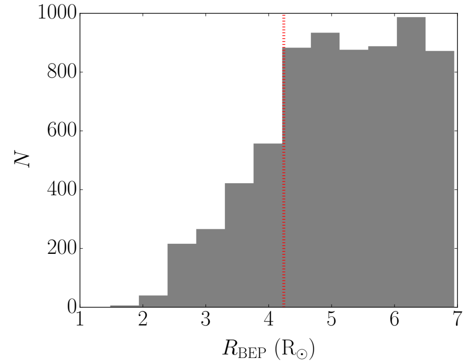

Fig. 4: Radius distribution in the BEP dataset. Red dotted line indicates the radius of the OGLE-BLG-RRLYR-02792, $R = 4.24$ R$_\odot$.

cross the IS 100 times faster than RRLs. Above considerations are summarized in following formulae:

$$C = \frac{N_{\rm BEP}}{N_{\rm RRL} + N_{\rm BEP}} \times 100\% \ , \quad N_{\rm BEP} = ST(m,q,a,e) \times 0.5 \times 0.01 \ , \qquad (1)$$

where $ST(m,q,a,e)$ represents the StarTrack output, i.e. the number of BEPs found in the sample of 5×10^5 binaries, given the initial parameters. Thus, the contamination value is $C = 0.4\%$. This marginal value reassures that undetected BEPs should not affect statistics-based calculations involving RR Lyrae stars, like age or distance determinations.

Distributions of masses, radii, orbital periods, and mass ratios of the sample of 6947 BEPs are presented in Figures 1–4. Red dotted lines indicate the values of parameters of the first BEP object, OGLE-BLG-RRLYR-02792, as reported by Pietrzyński et al. (2012). In all cases the lines lay well inside the distributions, meaning that the measured physical and orbital parameters of the first BEP system are successfully reproduced by StarTrack. Distributions in Figs. 1, 2 and 4 seem to be cut off towards

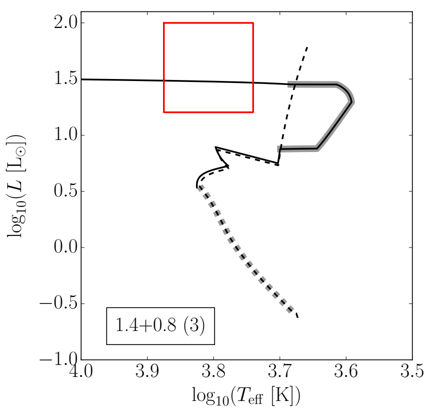

Fig. 5: Evolutionary tracks in the Hertzsprung-Russel diagram of a binary system with initial masses 1.4 (solid line) and 0.8 (dotted line) $\mathrm{M}_\odot$ and initial orbital period 3 d. Red line encloses the RRL area in the IS. The MT phase is marked with thick lines.

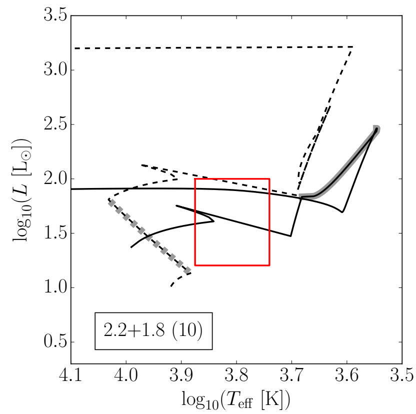

Fig. 6: Evolutionary tracks in the Hertzsprung-Russel diagram of a binary system with initial masses 2.2 (solid line) and 1.8 (dotted line) $\mathrm{M}_\odot$ and initial orbital period 10 d. Red line encloses the RRL area in the IS. The MT phase is marked with thick lines.

larger values, because only BEP objects with luminosities below 100 $\mathrm{L}_\odot$ were studied. Nevertheless, this indicates that slightly more massive BEP objects could exist, and mimic pulsators in the IS above RRL area.

Two main evolution channels to produce BEPs are presented in Figures 5 and 6, and differ the most on the Red Giant Branch during the MT phase. In the less massive system (Fig. 5) the BEP progenitor has its envelope removed without experiencing the helium flash and enters the IS as an exposed degenerated helium core, while in the more massive system (Fig. 6) the BEP progenitor undergoes the helium flash at the end of the MT and crosses the IS while burning helium in the core.

In our future work, current study of BEP occurrence in the RRL area will be extended to the entire IS.

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