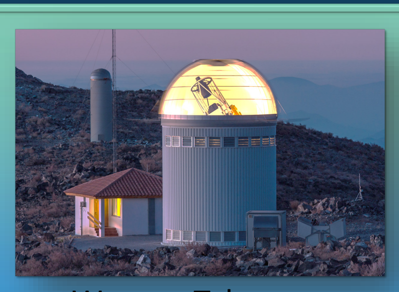
Contact:
mwrona@astrouw.edu.pl

One Thousand Heartbeat Stars in The OGLE Collection of Variable Stars

Marcin Wrona[1], Piotr Kołaczek-Szymański [2], Milena Ratajczak [1] & The OGLE Team [1,3]

[1]Astronomical Observatory, University of Warsaw, Al. Ujazdowskie 4, 00-478 Warszawa, Poland, [2]Astronomical Institute, University of Wrocław, Kopernika 11, 51-622 Wrocław, Poland, [3]Department of Physics, University of Warwick, Coventry CV4 7 AL, UK



Warsaw Telescope
Las Campanas Observatory, Chile

Astronomical Observatory
University of Warsaw

1.) What are heartbeat stars?

- Heartbeat stars (hereafter HBSs; Thompson et al. 2012) are a specific group of eccentric binaries. In these systems, the brightness variations are caused by a tidal deformation of the components and by other proximity effects (cf. Figure 1).

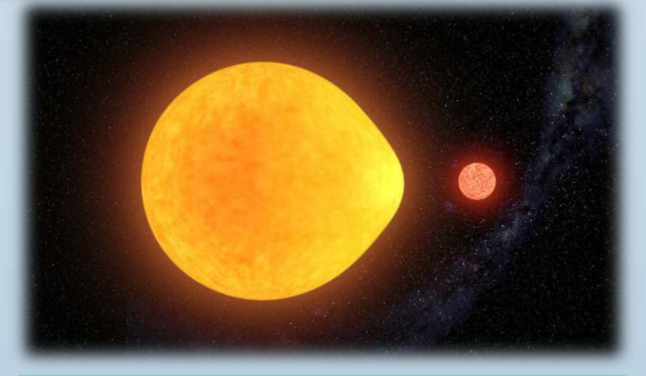


Figure 1: Artist's conception of the HBS. The strongest deformation and so the strongest brightness change appears during the periastron passage.
Credit: Gabriel Pérez Díaz (IAC)

- Kumar et al. (1995) provided a convenient analytical model of the tidally-driven flux variations in eccentric binaries (cf. equation below and Figure 2). We will refer to it as the Kumar's model.

$$\frac{\delta F}{F}(t) = S \cdot \frac{1 - 3\sin^3 i \sin^2(\varphi(t) + \omega)}{(R(t)/a)^3} + C$$

fractorial change of flux
orbital inclination
true anomaly
argument of the periastron
scaling factor
distance between components
semi-major axis
zero-point offset

- The Kumar's model allows for determination of the orbital parameters of the system (eccentricity, e, orbital inclination, i, and argument of the periastron, ω), based only on the shape of the light curve.

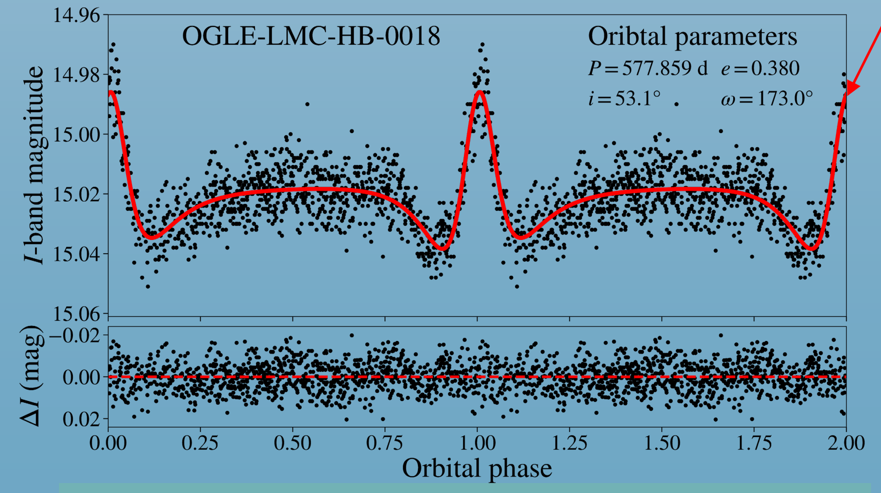


Figure 2: Phase-folded light curve with fitted Kumar's model (red line) and residual magnitudes.

2.) How can we find HBSs?

- One of the possible ways is to search for a prominent shape of the light curve.

- There is a plethora of possible shapes of the HBSs' light curves (cf. Figures 3 and 4). The HBSs with $\omega \simeq 0°$ or $\omega \simeq 180°$ during the heartbeat (the moment of the periastron passage), show two minima and one maximum of brightness, while for $\omega \simeq 90°$ we can see two maxima and one minimum. With increasing value of i parameter, the minima are getting deeper.

- Moreover, for low eccentric orbits, the light curves have sinusoidal-like shapes, similar to the ellipsoidal variables with circular orbits. With increasing e, the phase range of the heartbeat is getting narrower. For $e \simeq 0.8$, the duration of the heartbeat is only about 10% of the orbital period.

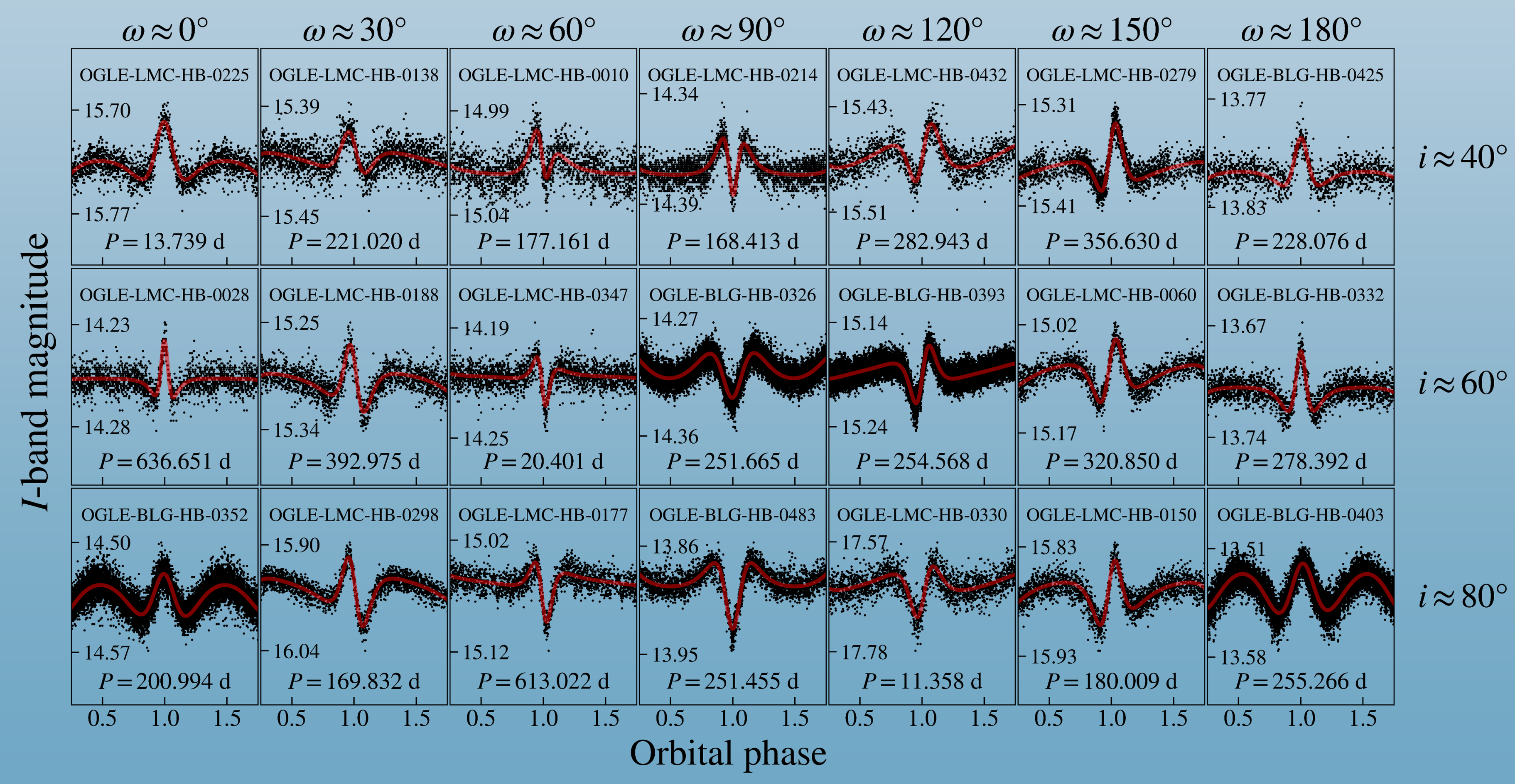


Figure 3: Phase-folded light curves of the sample of OGLE HBSs with different shapes. Note the symmetry of the right- and left-hand half of figure along the vertical axis.

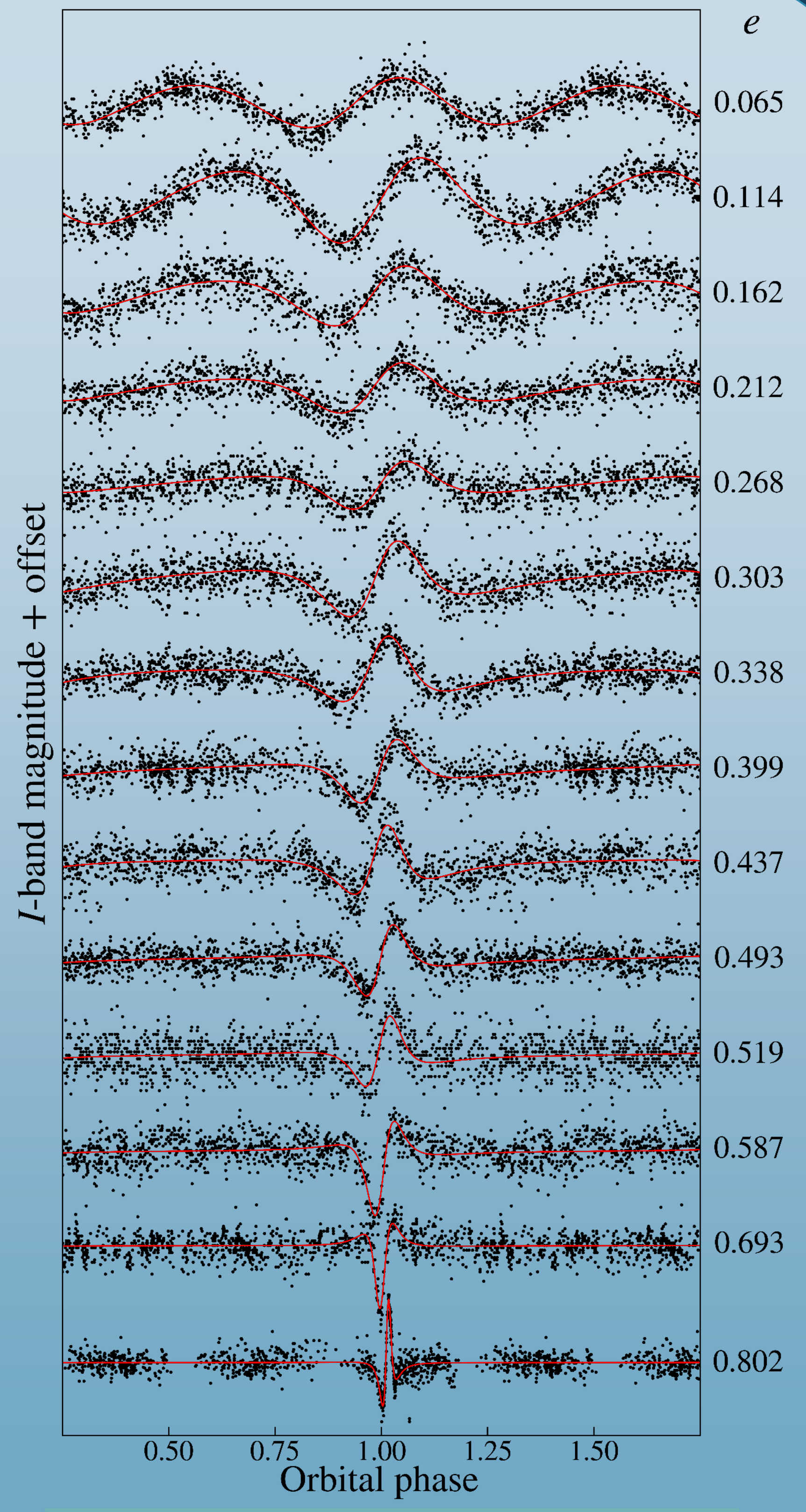


Figure 4: Shape of the HBS's light curve as a function of eccentricity, e. The light curves were normalized to similar amplitude of brightness.

4.) Evolutionary status of the OGLE HBSs

- Based on the Hertzsprung-Russell diagram (Figure 6), we see that our HBS sample forms at least two separate groups of different evolutionary status.

- The first group of about 90 systems consists of an early-type primary star lying on (or close to) the main sequence.

- The second group of about 900 systems contains a red giant.

- In Figure 6, however, the markers show the location of the primaries with the assumption that the light contamination from the companion is negligible, which may not be correct.

In Figure 6, with colored lines, we marked the MIST v1.2 evolutionary tracks, which were computed with the Modules for Experiments in Stellar Astrophysics (MESA) code.

The tracks can be generated via the MIST project website:
http://waps.cfa.harvard.edu/MIST/index.html

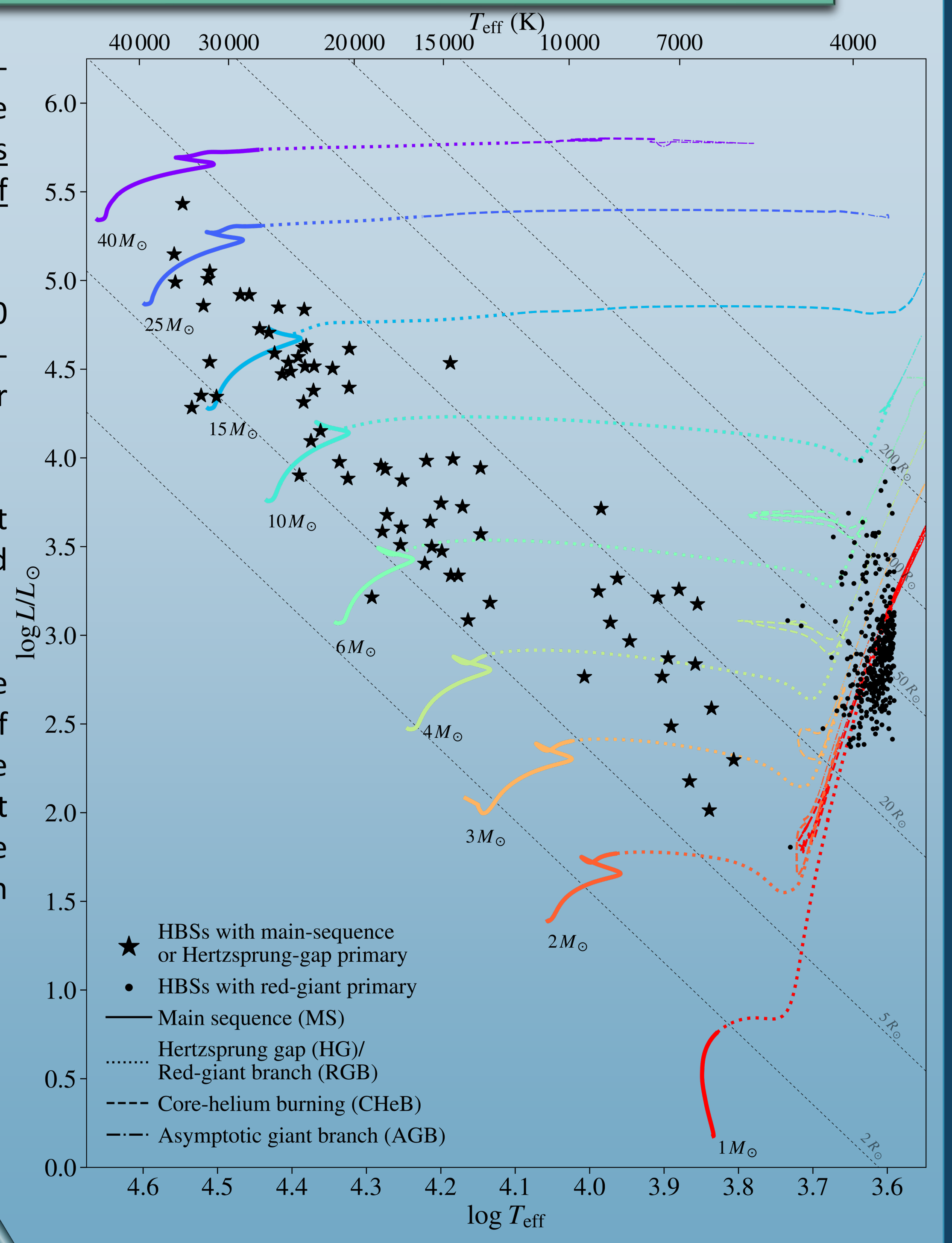


Figure 6: Hertzsprung-Russell diagram for the LMC subsample of the OGLE HBSs

3.) How many HBSs have we found?

- We searched for HBSs in both public and non-public data of the OGLE project* (Udalski et al. 2015).

- In total, we have found 996 candidates for HBSs. **We increased the number of cataloged HBSs fivefold.** The collection consists of 515 stars located toward the Galactic bulge (GB), 441 located in the Large Magellanic Cloud (LMC), and 40 in the Small Magellanic Cloud (SMC).

* *The Optical Gravitational Lensing Experiment (OGLE) is a long-term sky survey, which has been exploring the southern sky for almost three decades. Exposures are collected in the Cousins I-band and Johnson V-band.*
The OGLE project uses the 1.3-meter Warsaw Telescope located at Las Campanas Observatory, Chile.
For more information about the OGLE project, we encourage the reader to visit our website: http://ogle.astrouw.edu.pl/

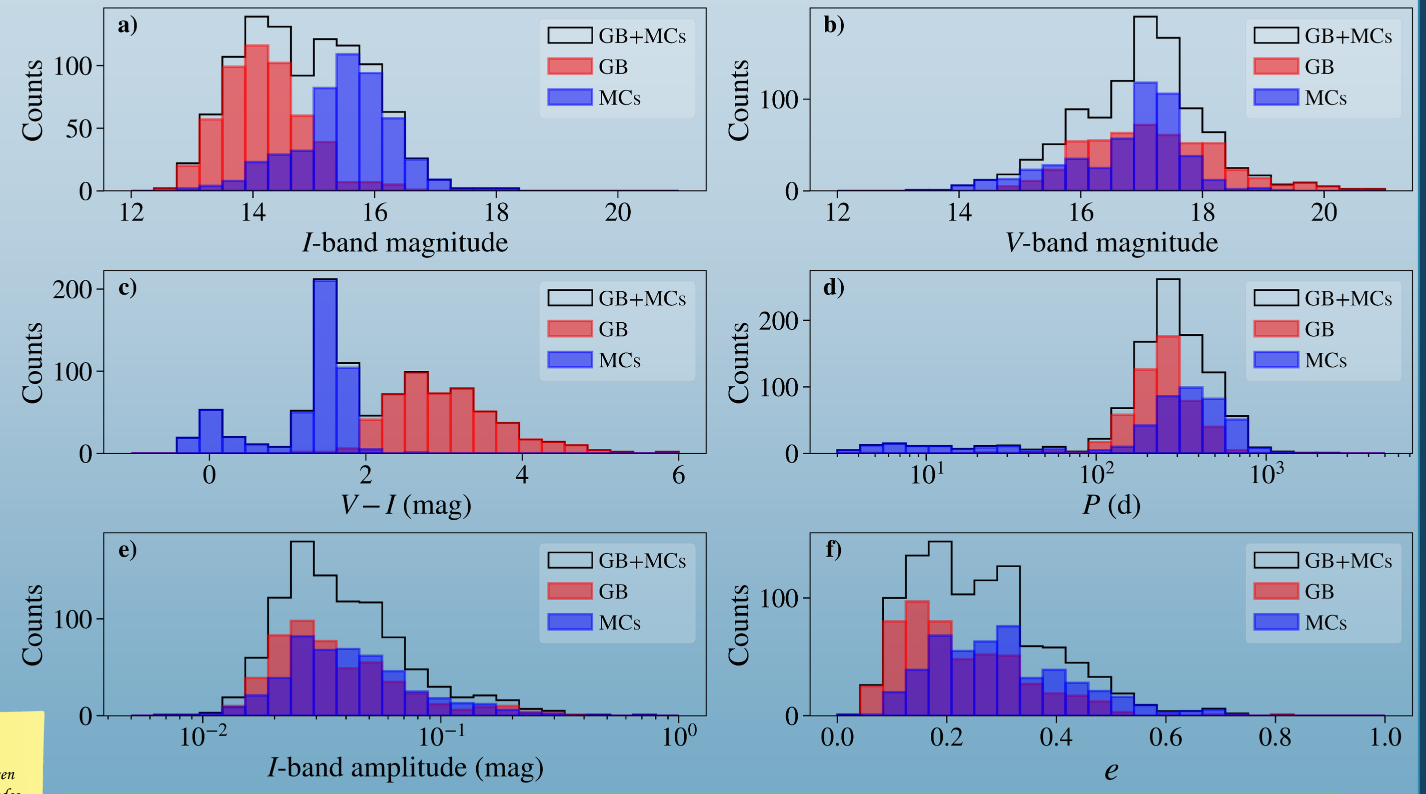


Figure 5: Histograms of basic observational and orbital parameters of the OGLE HBSs located toward the Galactic bulge (GB, red boxes) and in the Magellanic Clouds (MCs, blue boxes). With the solid black line, we denote a histogram of combined samples of the HBSs from all locations.

5.) Highlights from the analysis

- Here, we present one of the main results from our analysis. HBSs containing an RG fit into well-known period-luminosity (PL) relations (cf. Figure 7). The notable aspect is that HBSs seem to stick to the long-period group of eclipsing and ellipsoidal variables (known as sequence E), but also to the LSP stars (known as sequence D).

- Recently, Soszyński et al. (2021) showed that LSPs are systems that contain an RG and a stellar or sub-stellar companion. Since the RG part of the HBSs form a group in a similar region of the PL diagram, thus it is likely that they are binary systems as well.

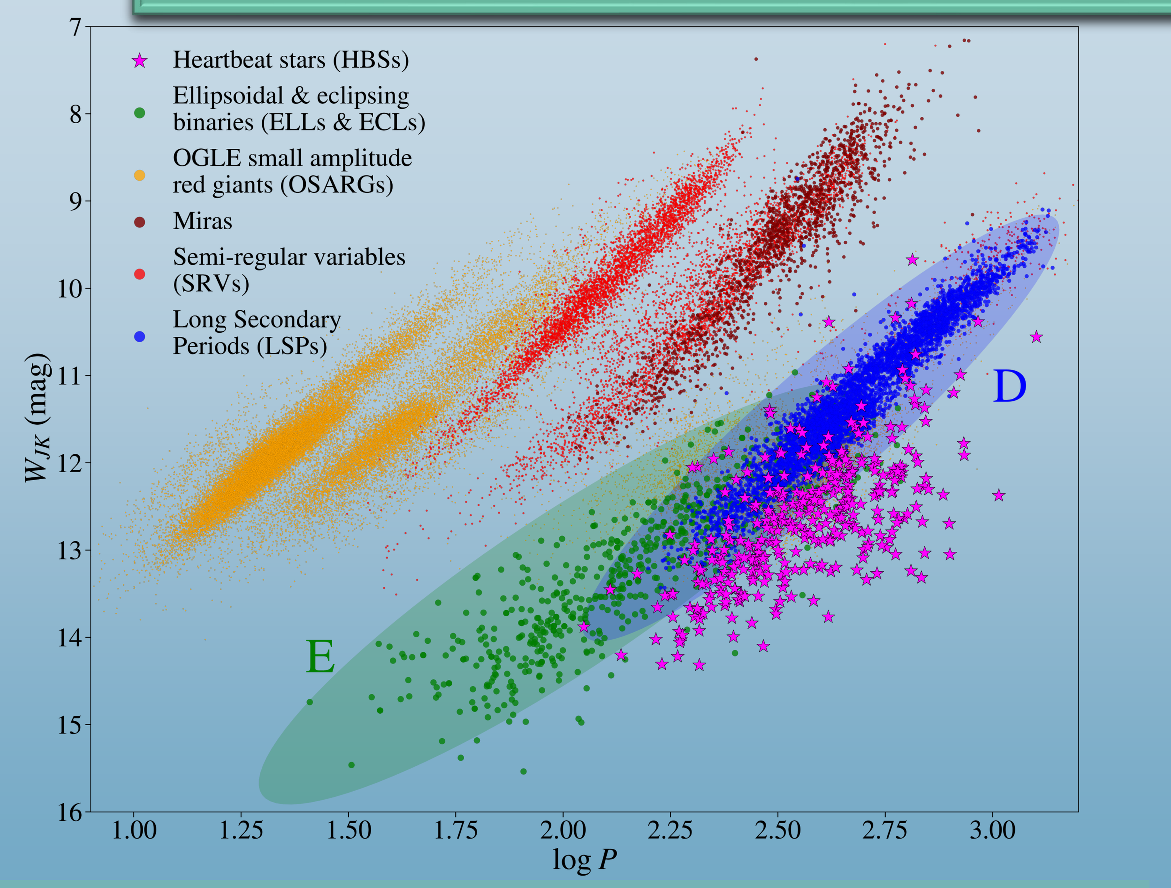


Figure 7: PL diagram for Long Period Variables, ellipsoidal and eclipsing binaries and HBSs. Presented sample includes variables from the LMC. As a luminosity we used extinction-free $W_{JK} = K_S - 0.686(J - K_S)$ Wesenheit index.

- A large sample of RG HBSs allows us to prove the hypothesis that for a given luminosity, eccentric binary systems need higher eccentricity for higher orbital periods (cf. Figure 8).

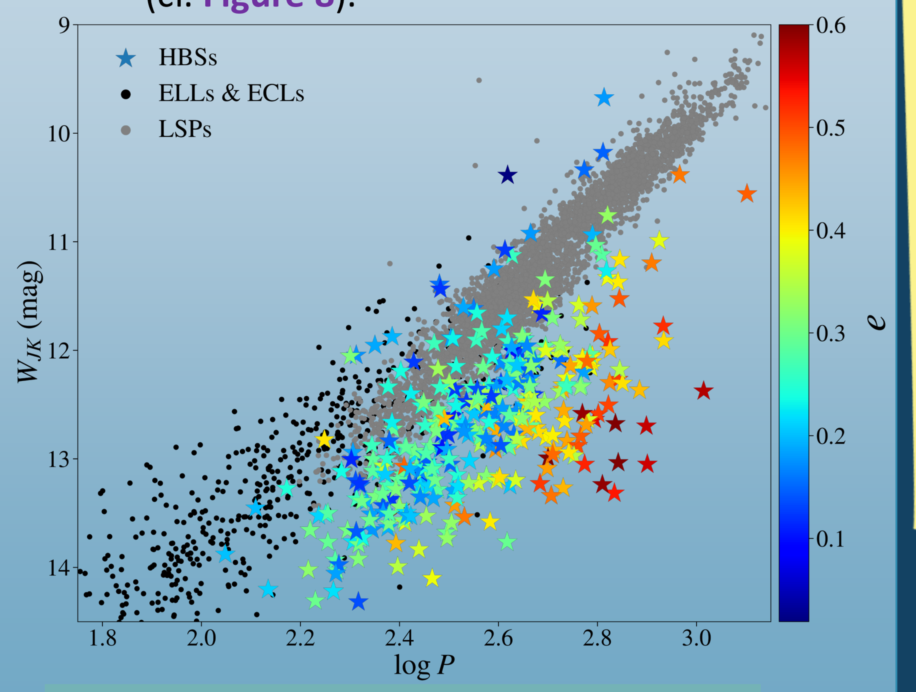


Figure 8: Close-up view on the long period part of the PL diagram for stars located in the LMC.

For more details and results of our work, please look forward to our two articles which will be published soon!

Ideas for future work:

1. Spectroscopic observations – only simultaneous modeling of the radial velocity changes and light curves will allow for both independent determination of orbital parameters and verification of the correctness and limitations of the Kumar's model.
2. Asteroseismology – in our sample of HBSs we identified tidally-exited oscillations in about 5% of them with a total number of 78 different modes. How can we use them to study the interior of the star?
3. Evolution of binary stars – what are mechanisms that prevent circularization of HBSs orbits? How are they able to maintain and how did they gain orbital eccentricities (frequently exceeding 0.5)?
4. Undoubtedly, there are much more HBSs both in Galaxy and MCs waiting to be discovered!

References

- Thompson, S.E., Everett, M., Mullally, F., et al., 2012, *ApJ*, 753, 86.
- Kumar, P., Ao, C.O., & Quataert, E.J., 1995, *ApJ*, 449, 294.
- Udalski, A., Szymański, M.K., & Szymański, G. 2015, *Acta Astronomica*, 65, 1
- Soszyński, I., Olechowska, A., Ratajczak, M., et al., 2021, *ApJL*, 911, L22.

Acknowledgements

This poster has been supported by the Polish National Science Centre grant OPUS 16 no. 2018/31/B/ST9/00334 and MAESTRO 8 no. 2016/22/A/ST9/00009. PKS acknowledges support from the Polish National Science Centre grant PRELUDIUM 18 no. 2019/35/N/ST9/03805.

National Science Centre Poland