The Properties of Binary Systems Containing RR Lyrae Stars

Nicholas Clark
Supervisor: Dr. Hilding Neilson

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RR Lyrae stars are population II, helium-burning stars, located on the Hertzsprung–Russell (HR) diagram instability strip (Neeley *et al.*, 2015). They evolve from red giant stars in the mass range of 0.7 $M_{\odot}$ to 2.2 $M_{\odot}$; this mass range is when electron degeneracy occurs in the stars core before helium burning begins, and creates a runaway reaction when it is overcome (Mocák *et al.*, 2008). This helium flash causes mass to be lost, which increases the system's orbital period. Despite being relatively common, RR Lyrae stars are rarely seen in binary systems. The majority of these systems have orbital periods on the order of 3000 days, with the shortest being 1000 to 1200 days (Hajdu *et al.*, 2021). There is an observational bias towards systems with lower orbital periods, however there is a cutoff at approximately 1000 days. A tidal interaction model is made to evolve red giant binary systems through time until they experience a helium flash, and see what the shortest possible orbital periods are without mass transfer or collisions occurring; these disrupt the final RR Lyrae star (Hut, 1981; Hills, 1983; Johnston *et al.*, 2012). A binary synthesis code called Binary C is used to evolve populations of binary systems through time, to explore the properties of these systems in more detail (Izzard *et al.*, 2009; Izzard & Halabi, 2018).

The Tidal interaction model, called the Dynamic Astronomical Binary Orbit Model (DABOM) finds that for a 1.0 $M_{\odot}$ primary red giant, with companions of various masses less than the red giant, the final orbital period, if 0.2 $M_{\odot}$ is lost, is approximately 1 year. DABOM also finds that faster the mass is lost, the greater the increase in orbital period. As well as this, increasing the amount of mass lost during the helium flash increases the final orbital period. Similar trends are observed with the system's eccentricity; more mass lost over a shorter period of time results in the eccentricity increasing more than if less mass were lost over a longer period. Tidal interactions will circularize eccentric orbits, so final eccentricities are increased from a starting circular orbit (Hut, 1981). This makes it easier to discern the impact of the mass loss event on the eccentricity. If half of the total mass of the system is lost instantly, an unbinding will occur (Hills, 1983). This makes it possible for relatively close orbits to increase to orbital periods of hundreds of years. Binary C finds that systems containing RR Lyrae stars are most common for low periods and circular orbits, however do exist for large periods and eccentricities. The attached plot shows the normalized probability distribution for lower orbital periods, as this is what the current observations are for. While binary C predicts larger orbits, they are less common.

DABOM provides an explanation for why there is a cutoff for short orbital periods: systems with shorter orbital periods evolve such that an RR Lyrae cannot form, or a collision happens. However, DABOM predicts that shorter orbital periods than what is observed are possible. This discrepancy may be because DABOM works with extreme cases, such as by assuming the starting system has no spin, allowing the stars to tidally evolve closer together (Hut, 1981). Another possible explanation is that larger amounts of mass are lost during the helium flash, such that the true minimum is what

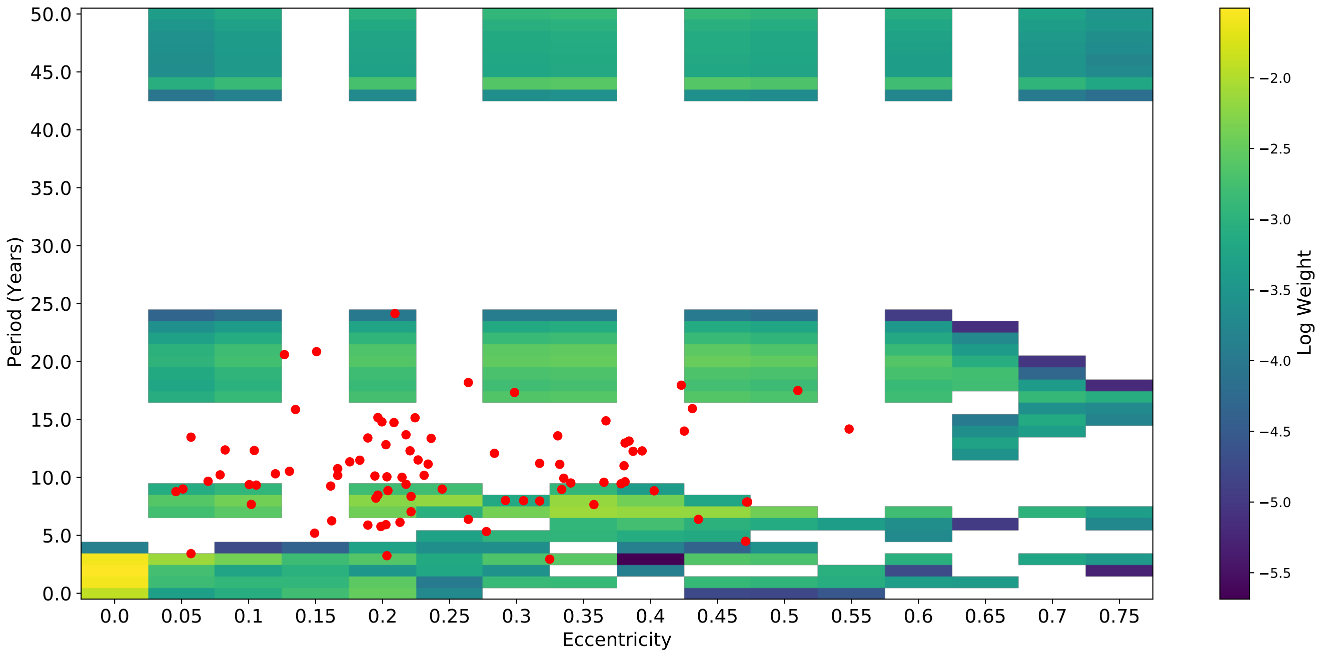

Figure 1: Period vs Eccentricity plot from Binary C, with observed systems included as red dots. Probability includes systems that have orbital periods greater than 50 years, and those that collided or were unbound, totalling 37% and 24% respectively. White space has a probability of 0%.

is observed in nature. The results from Binary C largely agree with DABOM, showing a lower minimum orbital period than what is observed. Currently, a draft paper of this research is being prepared. In the future, this draft will revised until the paper is ready for submission. Current things that are planned to be explored include running Binary C with more detailed collection of data to see if there are other kinds of stars currently being mistaken as RR Lyrae stars, determine some of the models that Binary C uses, and put DABOM on github.

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