White Dwarfs as Probes of Fundamental Physics: Tracers of Planetary, Stellar and Galactic Evolution
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Masses of white dwarfs in symbiotic binaries

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Abstract. Masses have been computed for the white dwarfs (WDs) in eclipsing, mass exchange (symbiotic), WD–red giant (RG) binaries by using single-lined spectroscopic orbits, orbital inclinations, and the RG masses. Inclinations have been measured for 13 eclipsing symbiotic binaries. Using Gaia data the mass of the RG can be found from evolutionary tracks. Since the WD evolved from the more massive star in the binary, the WD should be more massive than predicted from the mass of the current RG. Typically the WD has a lower mass than expected implying a previous mass exchange stage for these systems.

Keywords. (stars:) binaries: eclipsing, (stars:) binaries: symbiotic, stars: evolution, stars: late-type, (stars:) white dwarfs

1. Introduction

WD binary systems with a late-type stellar companion include barium stars, extrinsic S-stars, CH stars and symbiotic stars. Symbiotic binaries and extrinsic S-star binaries contain the coolest, most evolved giants. The hallmark of symbiotic binaries is a mass flow from the late-type star that is accreted onto the WD. None of the late-type symbiotic giants fill their Roche lobes. A small number of WDs in symbiotics are possible supernova progenitors with masses near the Chandrasekhar limit. The large size difference between the RG and WD plus the range of separations where mass exchange takes place results in a large number of eclipsing systems among the symbiotics. Eclipsing systems are useful in measuring a number of parameters including the orbital inclination.

2. Spectroscopic Orbits

In a series of eight papers (Fekel *et al.* 2017, 2015, 2010, 2008, 2007, 2001, 2000a,b) we measured the single-lined spectroscopic orbit of the late-type star in 30 symbiotic binary systems. Two parameters from the orbital solution, eccentricity and mass function, can be used to evaluate the group statistically. Barium star abundances show that mass transfer took place from the progenitor of the WD to the progenitor of what is now the RG barium star. Barium stars, unlike symbiotics, do not have on-going mass transfer from

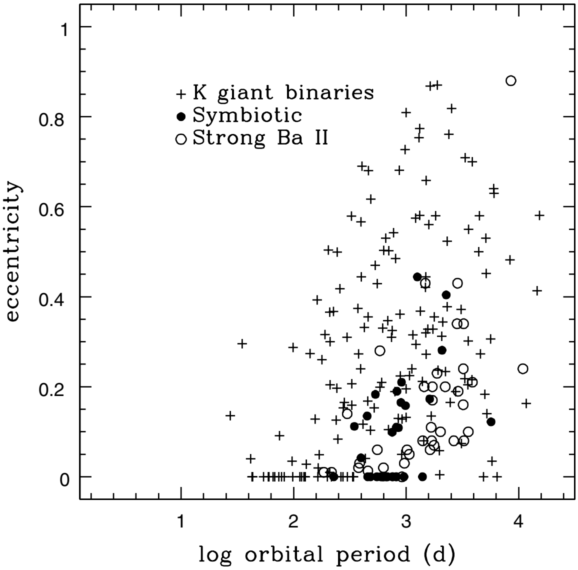

Figure 1. The eccentricity–period diagram for symbiotics taken from papers by Fekel et al. and for barium stars from van der Swaelmen *et al.* (2017). These are compared to the eccentricity–period diagram for normal K giant binaries from Mermilliod *et al.* (2007).

the RG to the WD. The eccentricities of both the barium stars and the symbiotics show the effect of the mass transfer (Fig. 1). An unanswered question is whether the symbiotic binaries underwent a previous state of mass transfer similar to that of the barium stars. Abundance analysis of symbiotic RGs (Gałan *et al.* 2017, 2016) shows some peculiarities, although much smaller than those of barium stars.

3. Mass Function

The mass function,

$$f(m) = m_{wd}^3 sin^3(i)/(m_{rg} + m_{wd})^2,$$

is a parameter that is derived from the single-lined binary orbital elements and relates the component masses and the inclination (i). For a large sample of orbits integration over the inclination produces a statistical mass ratio. The barium stars have been shown to have a nonuniform distribution of mass ratios with WD masses in the range 0.5–1 $M_\odot$ (Jorissen *et al.* 2019). The mass function of the symbiotics is clearly similar (Fig. 2). However, a larger sample of symbiotic binary orbits would be required for a detailed statistical analysis.

4. WD Masses

For eclipsing symbiotics the inclination can be solved geometrically. A few systems have precise inclinations from Raman-scattered emission lines observed with spectropolarimetry Harries & Howarth (2000). For the systems with known inclination the mass function gives the mass ratio. The giant's luminosity can be computed from the Gaia distance, K band photometry, and the bolometric correction. The effective temperature is from the spectral type. The mass of the giant was found using evolutionary tracks computed using FuNS. All of the symbiotics in this sample are on the early AGB or red giant branch, and mass loss to this point has not been large so the current and main sequence masses are similar.

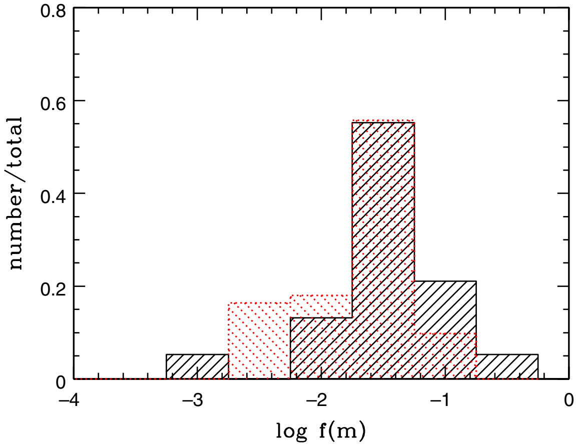

Figure 2. The solid line hatched histogram is the mass function distribution for symbiotic binaries. The dotted line hatched histogram is the strong and weak barium star mass function distribution. Symbiotic mass functions are from Fekel et al. and barium star mass functions from Jorissen *et al.* (2019).

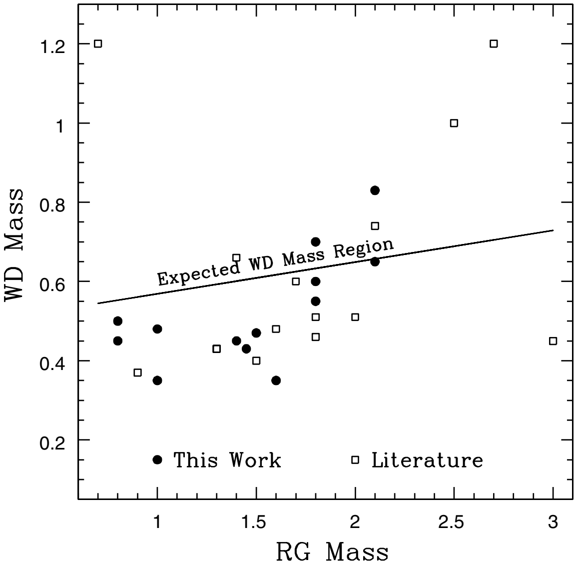

Figure 3. Masses for the WD in symbiotic binaries as a function of the RG mass. The WD evolved from the more massive member of the binary and should have a WD mass above the prediction for the WD mass from the mass of the current RG. The WD initial mass–final mass relation is the solid line (Cummings *et al.* 2018).

The resulting masses for the symbiotic binary RGs and WDs are shown in Fig. 3. The WD progenitor had to have a larger initial mass than that of the current RG so the expectation is that the WD masses sould be larger than predicted using the current RG mass. Given the uncertainties, the WD mass should scatter around the values predicted by the initial–final mass relation. However, Fig. 3 shows that systems with RG masses less than ~1.6 $M_\odot$ typically contain WDs with masses considerably lower than expected. The existence of these low masses for symbiotic WDs has been previously noted in the literature. A summary of the masses determined by a variety of other techniques can be found in Mikołajewska (2003).

The initial-final mass relation shown in Fig. 3 is for single (or non-interacting) star. For single stars with low initial mass (M<1.5 $M_\odot$) a minimum CO WD mass can be produced, $\sim$0.45 $M_\odot$. These stars develop a fully degenerate core during the first RGB and He ignition cannot occur before the He-core mass attains this limit. The limit coincides with the lower end of the theoretical initial mass-final mass relation corresponding to an initial mass of 0.6 $M_\odot$. However, most of the WD masses shown in Fig. 3 are less than 0.45 $M_\odot$.

There are two possible scenarios for the origin of these low mass WDs. Both scenarios require binary mass exchange during the evolution of the WD progenitor. The first is that the low mass WDs are He-rich. This implies that the progenitor, a star with initial mass $<$ 1.8 $M_\odot$, lost its H-rich envelope envelope during the RGB before He ignition when the core mass was lower than the critical mass. Mass transfer could be driven by either Roche lobe overflow or a common envelope stage. The second, discussed by Prada-Moroni & Straniero (2009), concerns 1.8 $M_\odot$<M<2.5 $M_\odot$ progenitors. In this case, the He-core is only partially degenerate, so that He ignition can occur when the core mass is as small as $\sim$0.35 $M_\odot$. If these stars lose their envelope during the He burning phase, the mass of the resulting CO WD could be as small as those shown in Fig. 3.

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