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MONTE CARLO SIMULATIONS OF POST-COMMON ENVELOPE SDB STAR PLUS WHITE DWARF BINARIES

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Abstract. We present first results from Monte Carlo simulations of short-period sdB plus white dwarf binaries, with various possible distributions of orbital separation and secondary mass. We compare these results with our observed distributions and discuss the implications for the common envelope evolution.

Key words: binaries: close – methods: numerical – stars: hot subdwarfs – white dwarfs

1. INTRODUCTION

Radial velocity surveys show that a large fraction of sdB stars are in post-common envelope binaries with orbital periods between a few hours and several days (Green et al. 1997; Morales-Rueda et al. 2003, 2004; Green et al. 2005). Such short orbital periods suggest that they must have evolved via binary mass transfer and common envelope evolution. The vast majority of short-period sdB secondaries are not detectable from optical spectra or 2MASS fluxes, nor do they show reflection effects. Therefore, given their mass functions, nearly all such companions must be white dwarfs. Since sdB stars are relatively bright and numerous, they provide an extremely useful sample for studying interacting binary evolution.

2. SIMULATIONS

We used Monte Carlo simulations to investigate which distributions of orbital separation and minimum secondary mass are most compatible with the observed periods, radial velocity semi-amplitudes and minimum masses in a small, but representative, sample of sdB plus white dwarf binaries (Green et al. 2005). We assumed circular orbits and sdB masses of 0.49 $M_{\odot}$, in agreement with Saffer et al. (1994) and with recent asteroseismological results for four pulsating sdB stars (see the contribution by Green et al. 2006). The number of trials in each simulation is 50 000.

For our initial attempt, we assumed the simplest case of flat distributions for both the companion masses, m_2, and the orbital separations, a. Guided by the periods and minimum masses, m_2(min), derived from our observed sample, we randomly chose secondary masses and orbital separations independently of each

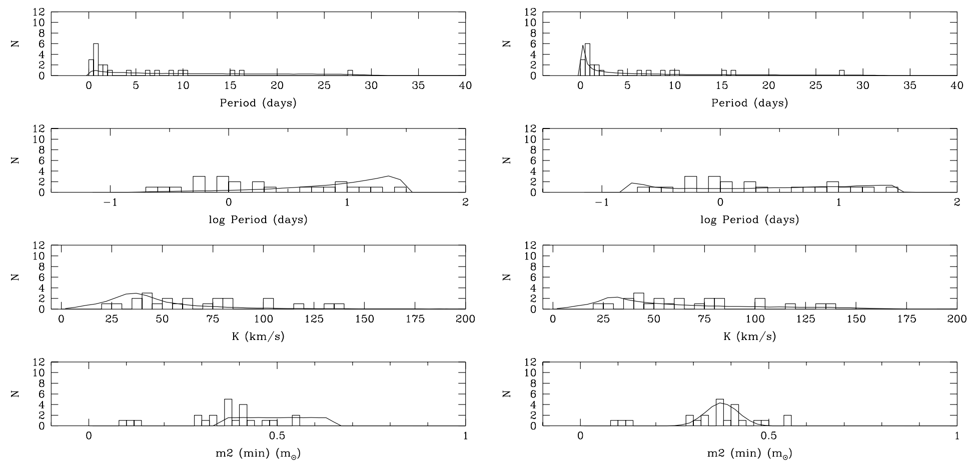

Fig. 1. Panel (a). Flat distributions for m_2 and a with $0.35 < m_2 < 0.65\,M_\odot$ and $1.3 < a < 40\,R_\odot$, respectively. Panel (b). A Gaussian distribution in the range m_2 with $0.25 < m_2 < 0.50\,M_\odot$, plus an exponential distribution for a.

other in the ranges $0.35 < m_2(\text{total}) < 0.65\,M_\odot$ and $1.3 < a < 40\,R_\odot$, respectively. We calculated the period and velocity amplitude for each simulated system using Kepler's law.

Another parameter needed to compare with the observed distributions is the orbital inclination. In each case, we selected the direction of the orbital axis of rotation by generating random values for x, y and z between 0 and 1, discarding any with $r > \sqrt{x^2 + y^2 + z^2}$ so that all orientations would occur with equal probability. Cos $i = x/r$ for an observer looking along the x-axis. The probability of seeing a particular inclination is proportional to sin i, resulting in a mean observed inclination from a large number of trials equal to 57.3° (1 radian), in agreement with theoretical expectation.

3. RESULTS

The following plots show the results of our Monte Carlo simulations (curves) compared to the observed histograms (boxes). We have adjusted the assumed parameters in each case to get the best fits. From top to bottom, the four panels display the comparisons as functions of the period, log period, observed velocity amplitude (K), and m_2(min).

Figure 1a shows that the best flat distributions are still a poor fit to the observed data: the periods and minimum masses are overestimated, while the velocity amplitudes are too small. Figure 1b shows an acceptable fit using a Gaussian mass distribution and an exponential distribution for the orbital separation, although the mass range is not quite large enough to include all the data points.

Although Fig. 1b matches the observations surprisingly well with uncorrelated secondary masses and orbital separations, theory suggests that a more massive secondary should eject its common envelope at a larger separation, while a less massive one would need to spiral inwards to a smaller separation. In fact, observed sdB binaries generally do tend to have larger m_2(min) at longer periods. We constructed a simple empirical relation using the upper envelope in a plot of observed minimum mass vs. log period (Figure 2), which also fits two eclipsing sdB+WD systems. (Two other, apparently rare, eclipsing sdB+WD systems with extremely short periods have secondary masses $>0.50\,M_\odot$, and do not fit any picture with correlated m_2 and a. They must result from a different evolutionary path, and are not considered further in these simulations.) Figure 3 shows the results of using this dashed curve to derive m_2 from the period. An upper mass limit of $0.65\,M_\odot$ (Fig. 3a) produced too few longer period binaries, but a similar curve with an upper limit of $0.75\,M_\odot$ (Fig. 3b) fit the observations quite well.

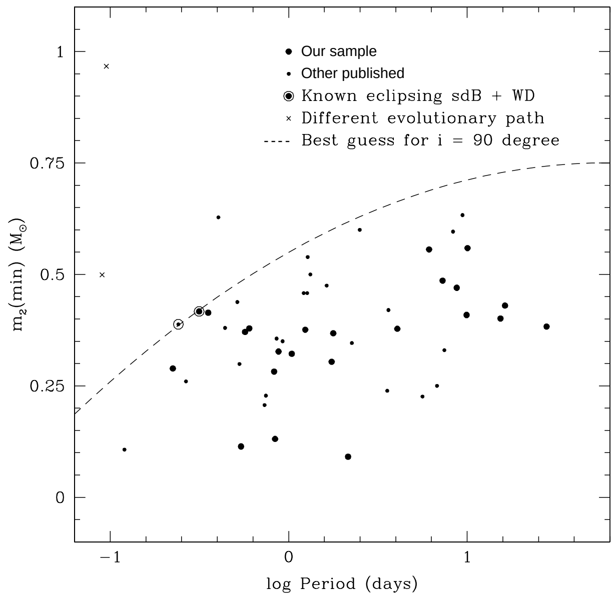

Fig. 2. The adopted relation between m_2 and orbital period (dashed curve). Orbital inclinations less than 90° scatter the observed points down from this curve.

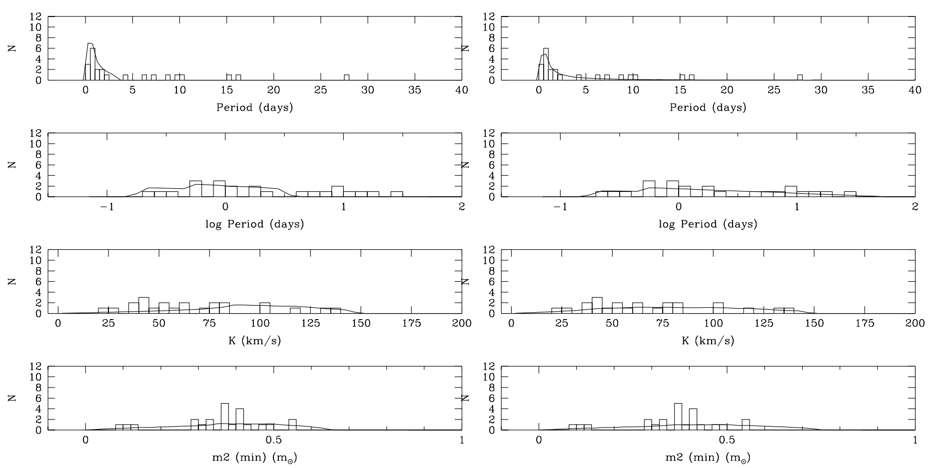

Fig. 3. Panel (a). Flat distributions over the ranges $0.35 < m_2 < 0.475\,M_\odot$ ($N = 15\,000$) and $0.475 < m_2 < 0.65\,M_\odot$ ($N = 35\,000$). Panel (b). Flat distributions for $0.35 < m_2 < 0.475\,M_\odot$ ($N = 10\,000$) and $0.475 < m_2 < 0.75\,M_\odot$ ($N = 40\,000$).

We also tried Gaussian mass distributions instead of the flat distributions in Figure 3, but they produced two discrete humps as a function of orbital period, which are not seen in the data. Eliminating the humps required such large spreads in the Gaussians that the distributions approached the flat case.

4. CONCLUSIONS

Our two most successful simulations are shown in Fig. 1b, for uncorrelated m_2 and a, and in Fig. 3b, where we attempted a supposedly more realistic correlated scenario. While Fig. 3b shows a seemingly better fit, it also requires that 80 % of the white dwarf companions have masses greater than the He core flash value, which is difficult to believe. If most of the WD's in sdB+WD binaries were to experience their initial mass transfer on the AGB, then the subsequent separations would be too large to allow a second mass transfer at the first red giant branch tip, which is needed to produce a sdB star. The better-looking fits in Fig. 3b, compared to Fig. 1b, are most likely due to a larger number of free parameters. Given the small number of observed data points, an upper mass limit of $0.65\,M_{\odot}$ in Fig. 1b would produce a fit that is nearly as successful, with a much more reasonable distribution of companion masses. Thus the most believable results so far suggest that white dwarf companion masses might not be correlated with their orbital separation after all.

While these initial efforts are interesting, it is obvious that we need to obtain orbital parameters for a larger complete sample in order to better constrain future Monte Carlo investigations.

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