16th European White Dwarfs Workshop IOP Publishing
Journal of Physics: Conference Series **172** (2009) 012019 doi:10.1088/1742-6596/172/1/012019

The Age of White Dwarf Companions

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Abstract. We carried out a spectroscopic investigation of single lined white dwarfs (WDs) in double degenerate (DD) systems and discuss their binary evolution. Simulated spectra of the Hα region are used to derive upper limits on the temperature of the invisible component and thus lower limits on the cooling age. This is done for a range of hypothetical secondary masses and a minimum cooling age deduced. Results are compared with the well known parameters of the visible primary, which allows us to determine a lower limit for the cooling age difference of both WDs. Most of the ten systems in our sample have a minimum age difference of not larger than 0.5 Gyr and their small orbital separation is highly suggestive of at least one unstable mass transfer phase. However, a stable first mass transfer phase is feasible as the age difference is less then 1 Gyr. The results imply that unstable mass transfer is the most likely final contact binary scenario to have occurred in DD systems but the first mass transfer phase is not constrained.

1. Introduction

Between 5 and 10% of white dwarfs (WD) reside in close binary systems with a WD companion (Napiwotzki et al. 2003, Marsh 2000), known as double degenerates (DDs). DDs must have come into contact and fallen towards each other as it is not possible for the stars to have evolved so close during giant branch phases. Orbital periods range from hours to a few days corresponding to separations of 2-3 $R_\odot$ at most. This implies that the binary must have gone through phases of intensive interaction affecting the evolution of the WD progenitors. One of the binary components evolving up the giant branch (RGB or AGB) will fill its Roche lobe and start to transfer mass to its companion. This can result in three possible outcomes (Nelemans et al. 2001):

- Conservative/stable mass transfer – The transferred mass is accreted by the companion and no mass is lost to the surroundings. The size of the orbit remains relatively large and can even increase.
- Standard common envelope – The rate of mass transfer is so high that not all of it can be accreted. Most of it is lost and forms a common envelope around the system. Friction causes a large reduction in the orbital separation.
- Envelope eject or double spiral-in – During the ejection of the common envelope both stars lose their envelope. Orbital radius greatly reduced and age difference very small (within 0.1Myr).

Different formation time scales can be expected for the three scenarios. Only very small age differences are allowed for DDs resulting from the double spiral-in channel. Stable mass transfer

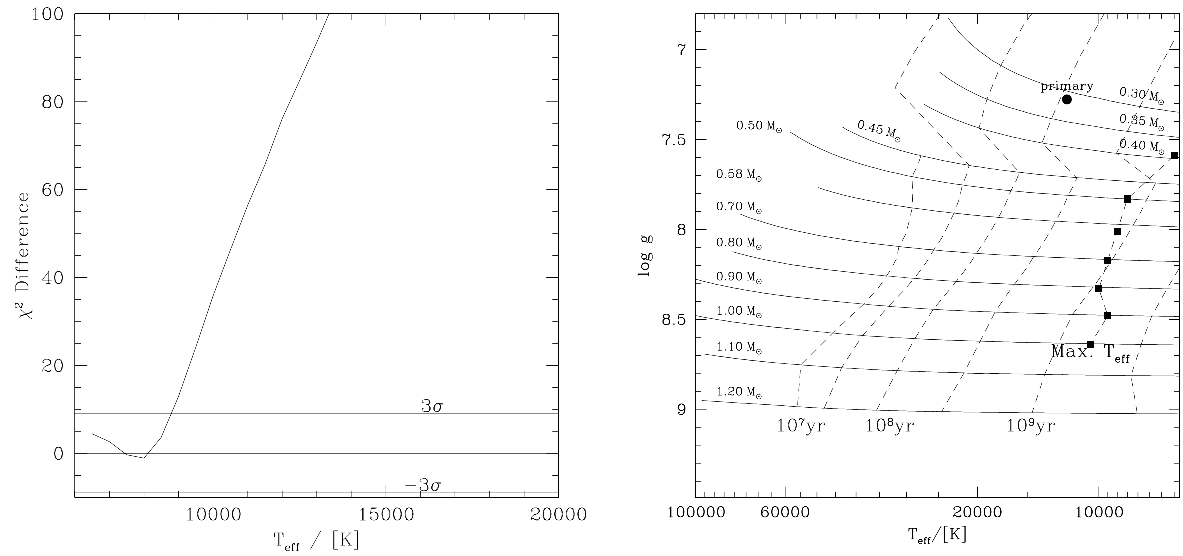

Figure 1. *Left:* Fit quality as a function of temperature for a $0.5\,M_\odot$ companion of HE0320−1917. The maximum possible temperature of the secondary is 8500 K. *Right:* H-R diagram with maximum $T_{\rm eff}$ for hypothetical seconday masses of HE0320−1917. Evolutionary tracks of Benvenuto & Althaus (1999) for masses (solid lines) are shown along with cooling ages (dashed lines).

results in a substantial mass increase of the companion, which will speed up its subsequent evolution. Since it is a very short lived phase, no such effect is expected during the common envelope. We derive lower limits on the age of the secondary WD and therefore an age difference estimate of the primary and secondary's formation. This may be used with the theoretical predictions to rule out possible evolutionary scenarios for a binary system. The aim of this investigation is to compare the resulting limits with predicted distributions for the different channels.

2. Determining Maximum Secondary Temperatures

The DDs investigated have been classified SB1 in the Supernova type Ia Progenitor surveY (SPY; Napiwotzki et al., 2003), meaning that no obvious contribution from the secondary is present in the spectra. We use SPY spectra of the Hα region to constrain the secondary's contribution in a quantitative way. We consider just the Hα line because its core is the most prominent feature in the spectra of DA WDs. SPY is a high resolution, high signal-noise spectroscopic study which uses a large input sample of WDs combined from many surveys. Systems are confirmed DD due to radial velocity (RV) fluctuations. The data set contains six binary systems for which orbital solutions and parameters for the brighter primary star are already known and published in Nelemans et al. (2005). Four other non-published systems were used with well established primary parameters. For the latter four systems the RV and thus position of the Hα core is not constrained. In these cases a worst case was assumed with the secondary line core close to the primary's. Using a fitting program, FITSB2 (Napiwotzki et al. 2004), synthetic spectra are created and compared to the observed, and the χ^2 calculated. The parameters which produce fits outside 3σ confidence limits can be excluded with our attention focused on the possible solutions. The last good fit defines a maximum temperature for a given mass component of the secondary star. This was done for secondary masses of 0.4–1.0 $M_\odot$ at a 0.1 $M_\odot$ increment. Fig. 1 shows HE0320−1917 as an example.

Table 1. Overview of the primary parameters and secondary limits. The columns give primary mass (M_1), effective temperature of the primary ($T_{\rm eff,1}$), cooling age of the primary ($\tau_{\rm cool,1}$), assumed secondary mass (M_2), maximum secondary temperature (Max. $T_{\rm eff,2}$) and minimum secondary cooling age (Min. $\tau_{\rm cool,2}$). The last column indicates if the fit quality increased by more than 3σ with a secondary component, therefore making the system a SB2 candidate. We show minimum ages for all hypothetical masses of HE0320−1917 and then the youngest calculated age with its corresponding mass for all other systems.

Object	M_1 [$M_\odot$]	$T_{\rm eff,1}$ [K]	$\tau_{\rm cool,1}$ [Gyr]	M_2 [$M_\odot$]	Max. $T_{\rm eff,2}$ [K]	Min. $\tau_{\rm cool,2}$ [Gyr]	SB2?
HE0320−1917	0.29	12 000	0.3327	0.4	6 500	2.337	Y
				0.5	8 500	0.7505	
				0.6	9 000	0.8344	
				0.7	9 500	0.9409	
				0.8	10 000	1.116	
				0.9	9 500	1.685	
				1.0	10 500	1.561	
HE1511−0448	0.48	50 000	0.0001	0.4	41 000	0.0026	Y
WD0326−273	0.51	9 300	0.6883	0.5	6 500	1.474	-
WD1013−010	0.44	8 000	0.8449	0.5	6 500	1.474	-
WD1210+140	0.29	32 000	0.0232	0.6	9 000	0.834	-
WD0101+048	0.48	8 600	1.517	0.5	6 500	1.474	-
HE0131+0149	0.33	14 500	0.2541	0.8	26 000	0.0646	Y
WD0216+143	0.34	27 000	0.0433	0.5	30 000	0.0088	-
WD0341+021	0.30	21 500	0.0747	1.0	26 000	0.1419	Y
WD1824+040	0.31	14 000	0.2817	0.5	10 000	0.4492	Y

3. Discussion on Companion Ages and Possible SB2 Systems

The results are summarised in Table 1 and suggest nearly all of the systems companions have a larger cooling time than the primary. Only in three systems the secondary could be younger but it must be emphasised that we only determine lower age limits. In addition, for one of these cases (and some other) we are constrained by our cool model grid boundary of 6500 K. In the cases where the secondary is definitely older, all of the secondaries are older by more than 0.1 Myr therefore ruling out a double spiral-in scenario. Nelemans et al. (2001) consider 1Gyr an approximate maximum age difference for a secondary to have undergone an initial stable mass transfer before a common envelope. In all but one of our sample this is a feasible evolutionary path.

Some of our χ^2 results indicate possible detections of secondary components in the spectra; HE0320−1917, HE1511−0448, HE0131+0149, WD0341+021 and WD1824+040 are all candidate SB2s and further analysis of the spectra may confirm the features of the secondary. Fig 2 shows the spectra and χ^2 plots of WD1824+040, a SB2 candidate. These systems may be useful as they are close to the SB1/SB2 borderline and will show at what mass and temperature one might expect to see features appear in the combined spectra.

4. Conclusion

We test possible evolutionary scenarios of DDs by computing the cooling age of ten systems and comparing the primary with hypothetical secondary masses. The secondary age in nearly

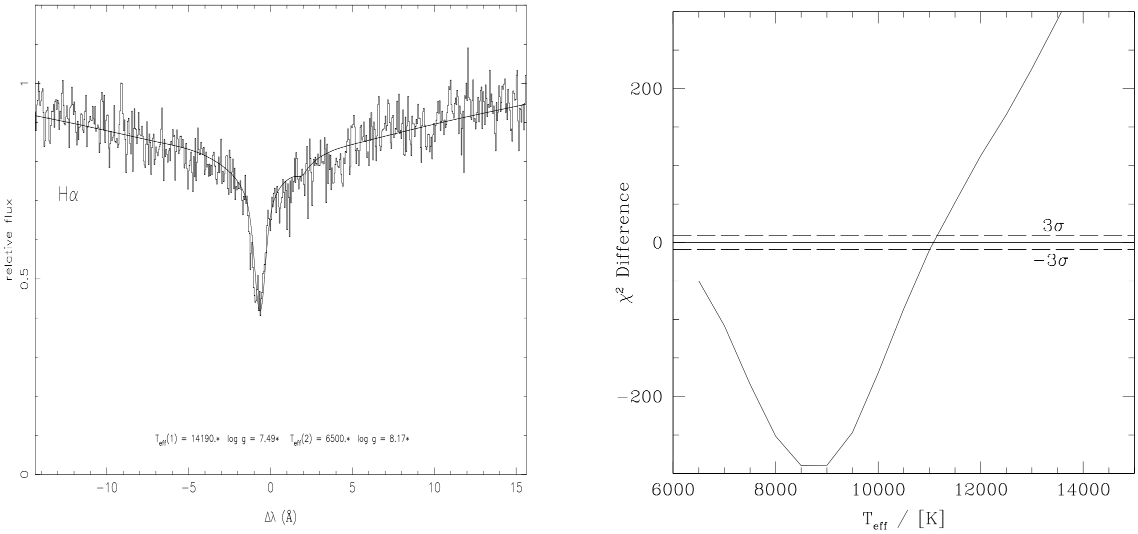

Figure 2. *Left:* Fit to one of the spectra of WD1824+040 with an apparent detection of the seconqdary. The primary (1) and secondary (2) atmospheric parameters are displayed in the plot. *Right:* Summary of fit quality for various different temperature secondaries. The maximum temperature of the secondary is 11,000 K.

every case is larger than the primary as expected. None of the older secondaries have a small enough cooling age difference for a double spiral-in to have occured. In all systems the minimum age difference is below 1Gyr, therefore the first mass transfer phase may have been stable or unstable. The results agree with current models which suggest, if the hypothetical mass is close to the primary's the cooling ages are similar. Additionally, the results of the systems without orbital solutions show that limits can be obtained without knowing orbital parameters of the system and with a conservative estimate a meaningful limit can be deduced.

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