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Follow-up Observations of SPY White Dwarf + M-Dwarf Binaries

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Abstract. We present the results of follow-up observations of white-dwarf + M-dwarf binaries identified using spectra obtained as part of the SPY survey. Spectra of the Hα region were obtained with the SPIRAL spectrograph on the AAT telescope. Of the eleven stars observed, seven are binaries with periods in the range 2.8 hours to 7.7 days. We also show that one of our targets, WD 0137−349, has a brown dwarf companion.

1. Introduction

Models of the evolution of binary stars are extremely sophisticated but there are still many uncertainties associated with the synthesis of a binary star population. For example, the standard prescription for modelling a common envelope phase based on a balance of energies ($\alpha_{\rm CE}$ algorithm) predicts that the second white dwarf to form in a double-degenerate (DD) will, in general, be much less massive than the first white dwarf to form. This is a direct consequence of the dramatic shrinkage of the orbit predicted by the $\alpha_{\rm CE}$ algorithm and the core mass−radius relation for red giants. However, as mass ratio measurements for DDs become available it was clear that the white dwarfs in these binaries are of comparable mass (Maxted et al. 2002). This led Nelemans et al. (2000) to propose an alternative prescription for the interaction between a red giant and a star of comparable mass based on a balance of angular momenta ($\gamma_{\rm CE}$ algorithm).

The Supernova type Ia Progenitor surveY (SPY; Napiwotzki et al. 2001) gives us an unprecedented opportunity to test models of binary star evolution. The survey comprises high resolution spectra obtained with the UVES spectrograph on the VLT at two epochs for about 1000 white dwarfs. The main aim of the survey is to find progenitors of type Ia supernovae, i.e., DDs with a total mass above the Chandrasekhar mass and an orbital period of less than 12 hours. Up to March 2003 about 600 white dwarfs had been observed, of which 38 were found to be binaries with an M-dwarf companion. Of these, 18 showed a radial velocity shift between the two epochs of observation. We are following-up these WD+M binary stars in order to test the predictions of binary population synthesis models. For example, both the $\alpha_{\rm CE}$ algorithm and the $\gamma_{\rm CE}$ algorithm predict that there are large numbers of WD+M binaries with orbital periods of $10-100$ days, although the period distribution of these binaries differs between the models (Fig. 1).

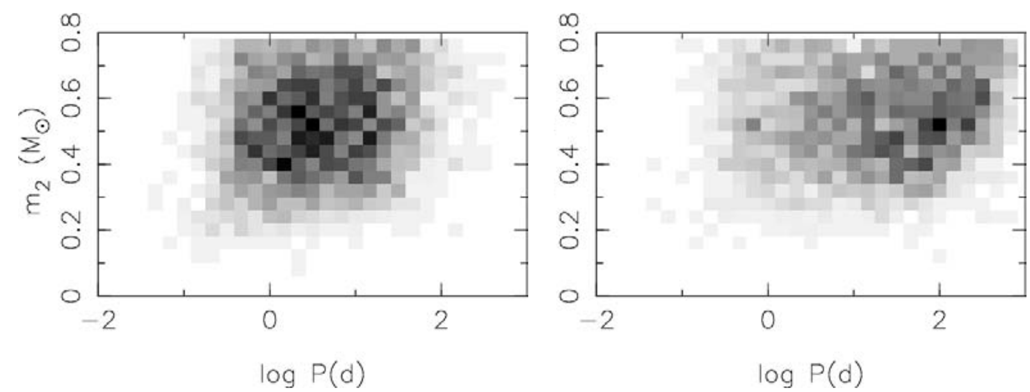

Figure 1. The predicted distribution of orbital period (P) and companion mass (m_2) for white dwarfs after one common envelope phase using the either the $\alpha_{\rm CE}$ algorithm (left panel) or the $\gamma_{\rm CE}$ algorithm (right panel)

We are also following-up WD+M binary stars from SPY in order to find eclipsing systems because detailed follow-up observations provide a direct measurement of the masses and radii of stars. This is illustrated in Fig. 2 for RR Cae. The masses of the stars are well determined provided that the radial velocity of both stars can be measured because the presence of an eclipse requires an inclination close to 90°. In contrast to previous studies of this binary, which lacked a spectroscopic orbit for the white dwarf, we find that the mass and radius of the M-dwarf companion are normal for a star of its spectral type (Maxted et al. 2006).

2. SPIRAL Observations and Results

We obtained spectra with the SPIRAL spectrograph on the Anglo-Australian Telescope for eleven WD+M stars from the SPY survey. SPIRAL is a fibre-fed spectrograph which provides spectra with a resolution $R \approx 7000$ around the Hα line. Observations were obtained over seven nights in June/July 2003. For two of the binaries observed we detected no radial velocity shift. One target was

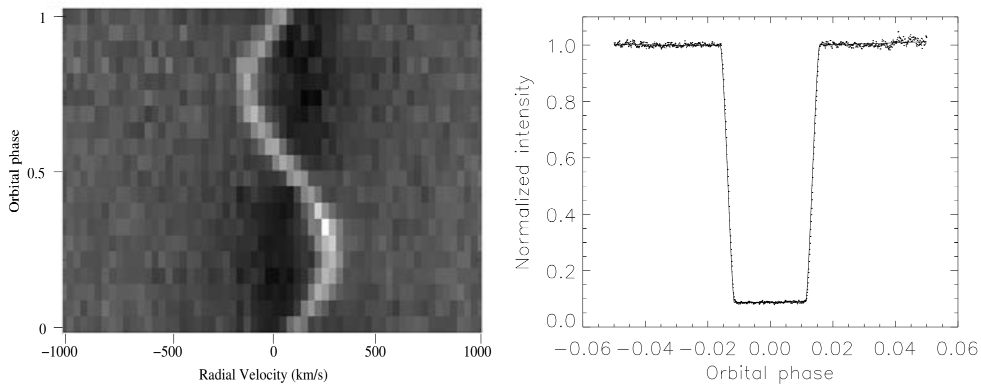

Figure 2. *Left panel:* The Hβ line of RR Cae plotted as a function of orbital phase. *Right panel:* The mean primary eclipse of RR Cae based on ten years of white-light photoelectric photometry from SAAO.

seen to be a visual binary from the acquisition images. One target has a very broad Hα line and appears to be a CV seen at low inclination. For seven of the binaries we were able to measure the orbital periods (Fig. 3). The histogram of the periods measured is shown in Fig. 4 and compared to the period distribution of WD+M binaries from the catalogue of Ritter & Kolb (2003). SPY is clearly a fruitful source of short period binaries, further high-precision radial velocity measurements will be required to see whether this sample also contains binaries with periods of $10-100$ days.

3. WD 0137−349

The SPY spectra of WD 0137−349 show a weak Hα emission line with a large radial velocity shift but no other indication of a companion. The SPIRAL observations of this star show some short-term variability but we were not able to measure the orbital period from the data available. We therefore obtained spectra with the UVES spectrograph on the VLT in a single run of two hours. The trailed spectra are shown in Fig. 5. The sharp absorption feature is the Hα line due to absorption by hydrogen in the atmosphere of the white dwarf star. The sinusoidal change in wavelength is due to the Doppler shift of the white dwarf as it orbits in a binary system. The emission feature seen moving in anti-phase to the absorption line arises in the atmosphere of the low mass companion to the white dwarf. The variation in the strength and width of this line show that it is produced by irradiation of one hemisphere of the companion by the white dwarf.

The mass ratio measured from these spectra combined with the mass of the white dwarf from an analysis of the Balmer lines show that the companion to WD 0137−349 is a brown dwarf with a mass of $0.053 \pm 0.006 M_{\odot}$. A more complete analysis and discussion is given in Maxted et al. (2006).

The near-infrared spectrum of WD 0137−349 shows that the spectral type of companion is about L8 (Fig. 6; Burleigh et al. 2006). This is the spectral type expected for a brown dwarf of this mass older than about 1 Gyr. This shows

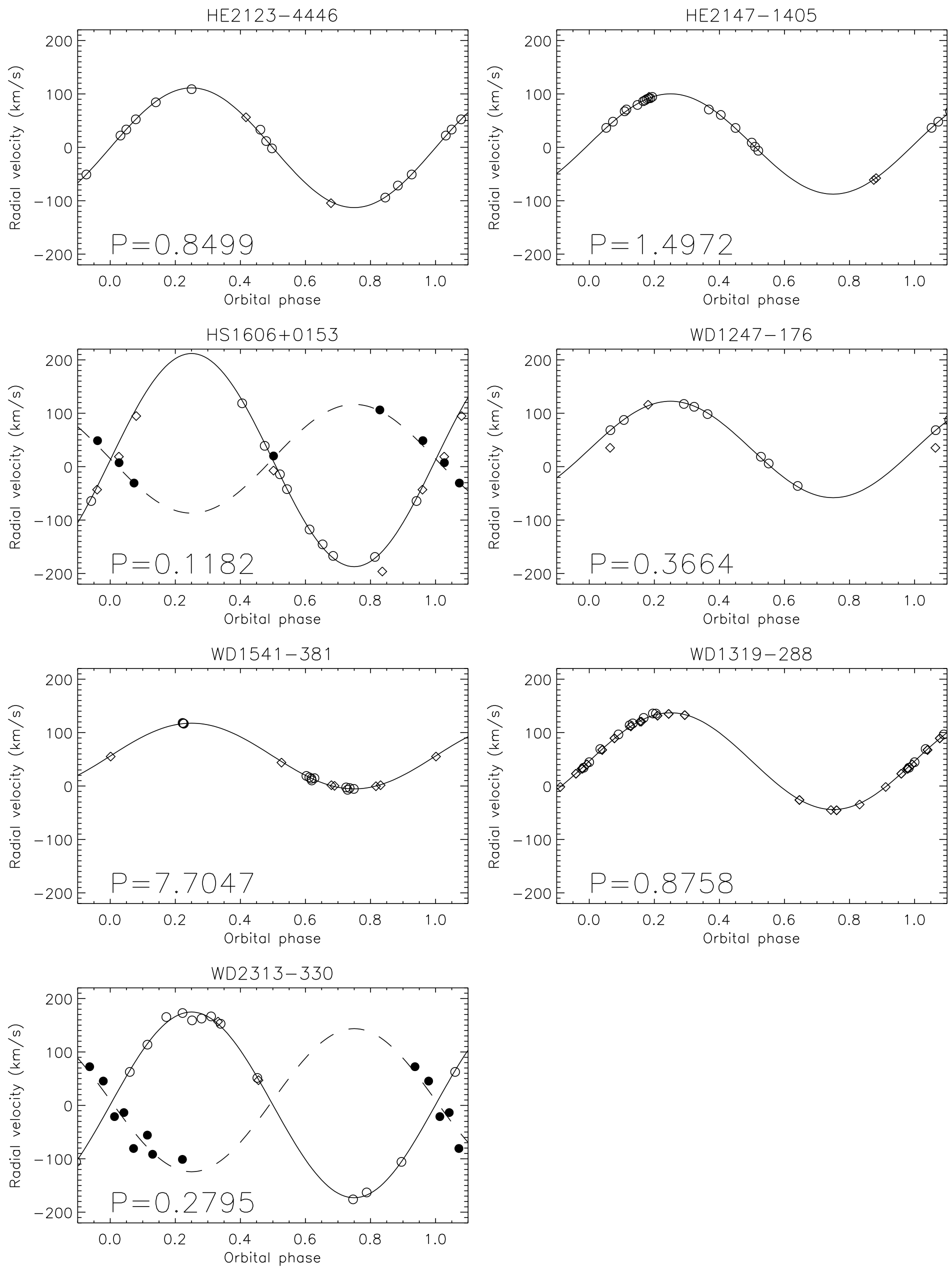

Figure 3. Radial velocities of companions to white dwarfs measured from the Hα emission line in our SPIRAL (open circles) and UVES (open diamonds) spectra as a function of orbital phase for the orbital periods indicated (measured in days). The radial velocity of the white dwarf is also shown in those cases where it could be measured (filled circles).

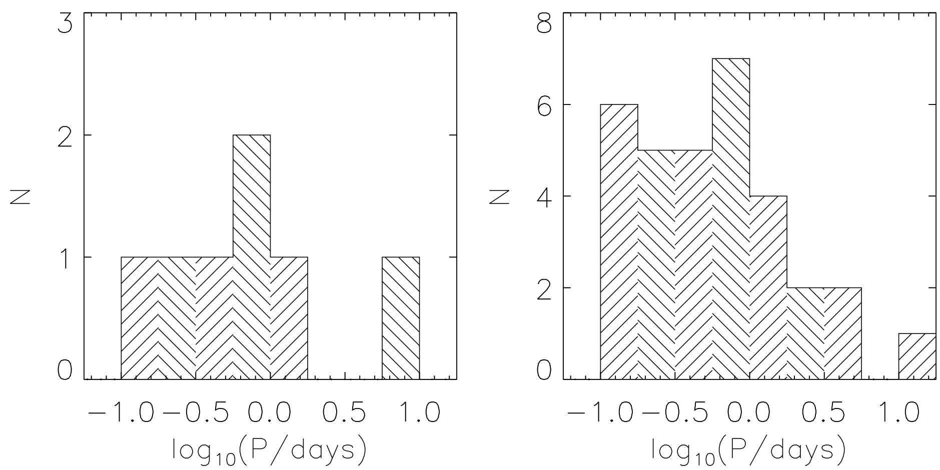

Figure 4. Orbital periods for seven new short-period WD+M binaries from the SPY survey (left panel) compared to the period distribution of WD+M binaries from the catalogue of Ritter & Kolb (2003)

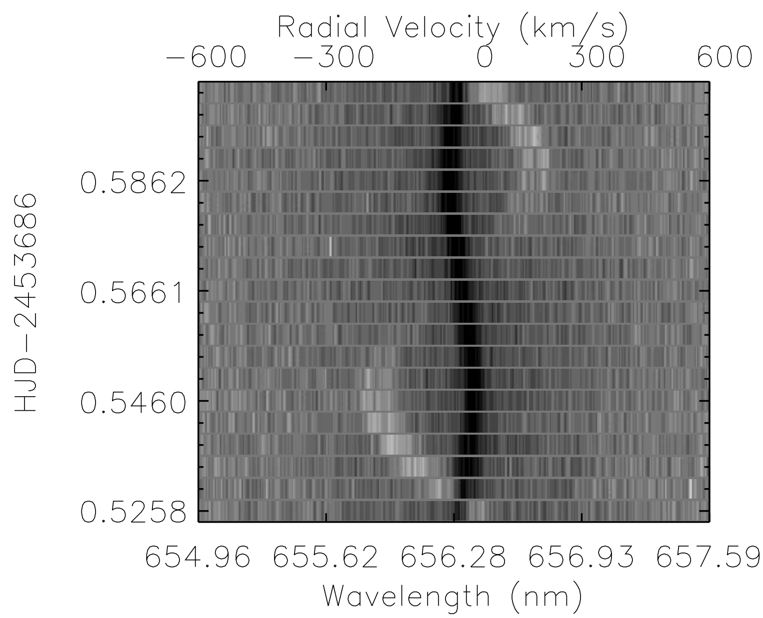

Figure 5. Trailed spectrograms of WD 0137−349. The radial velocity is indicated assuming a rest wavelength of 656.276nm. The time of observation is indicated on the y-axis. The exposure time are indicated by vertical extent of each spectrogram. The spectra have been normalised so the continuum value is 1. The grey-scale representation is a linear scale from 0.4 (black) to 1.4 (white).

that the companion to WD 0137−349 was not strongly affected by the common envelope phase.

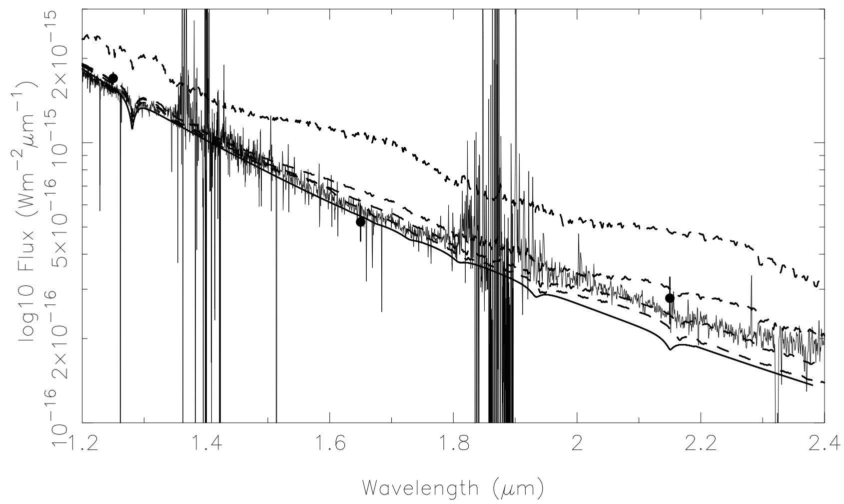

Figure 6. The near infrared spectrum of WD 0137−349 obtained with the GNIRS spectrum on Gemini–South compared to a synthetic white dwarf spectrum from a pure-H model atmosphere normalised using the observed V band magnitude (solid line). Also shown are the synthetic white dwarf spectrum combined with spectra of known brown dwarfs scaled to the appropriate distance as follows (dashed lines, top-to-bottom): L0, L6, L8 and T5. The high noise level in the 1.35μm−1.42μm and 1.8μm−1.95μm regions is caused by telluric water bands.

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