A search for binarity using FUSE observations of DAO white dwarfs

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ABSTRACT

We report on a search for evidence of binarity in Far-Ultraviolet Spectroscopic Explorer (FUSE) observations of DAO white dwarfs. Spectra recorded by FUSE are built up from a number of separate exposures. Observation of changes in the position of photospheric heavy element absorption lines between exposures, with respect to the stationary interstellar medium lines, would reveal radial velocity changes - evidence of the presence of a binary system. This technique is successful in picking out all the white dwarfs already known to be binaries, which comprise 5 out of the sample of 16, but significant radial velocity shifts were found for only one additional star, Ton 320. This object is also known to have an infrared excess (Holberg & Magargle 2005). DAOs can be separated broadly into low or normal mass objects. Low mass white dwarfs can be formed as a result of binary evolution, but it has been suggested that the lower mass DAOs evolve as single stars from the extended horizontal branch (Bergeron et al. 1994), and we find no evidence of binarity for 8 out of the 12 white dwarfs with relatively low mass. The existence of higher mass DAOs can also be explained if they are within binary systems, but of the four higher mass stars in the sample studied, PG 1210+533 and LB 2 do not exhibit significant radial velocity shifts, although there were only two exposures for the former object and the latter has an infrared excess (Holberg & Magargle 2005).

Key words: stars: atmospheres - white dwarfs - ultraviolet: stars.

1 INTRODUCTION

DAO white dwarfs, the prototype of which is HZ 34 (Koester, Weidemann, & Schulz 1979; Wesemael et al. 1993), are a group of white dwarfs that are observed to have both hydrogen and helium lines in their optical spectra, in contrast to the more common DAs, which exhibit only hydrogen absorption. Hence, the presence of detectable He must arise from the existence of a thin overlying H envelope or there must be a mixing process, dredging up He from the deeper layers of the stellar photosphere. Radiative forces appear to be too low to support sufficient quantities of helium to be able to produce the observed lines (Vennes et al. 1988). A thin H envelope might arise through float up of residual H in a He-rich DO atmosphere as objects transfer between the helium and hydrogen cooling channels (Fontaine & Wesemael 1987; Napiwotzki & Schöberner 1993). However, the discovery by Unglaub & Bues (1998, 2000) that the He\textit{II} line in the optical spectra of one DAO was better reproduced by a homogeneous rather than a layered atmospheric model was contrary to this view. Bergeron et al. (1994) performed a similar comparison on a sample of 14 DAOs, but found only one object for which a stratified model was preferred. Of the remaining objects, most were found to be comparatively hot and low gravity, implying they have low mass. Therefore, the progenitors of some of these DAOs are unlikely to have had sufficient mass to ascend the asymptotic giant branch (AGB), and instead they may have evolved from extended horizontal branch stars. It was suggested that, in these stars, weak mass loss may be occurring, a process that might be able to support the observed quantities of helium in the line forming regions of the DAOs (Unglaub & Bues 1998, 2000). Three objects (RE 1016-053, PG 1413+015 and RE 2013+400) were in close binary systems and have M dwarf (dM) companions. These have ‘normal’ temperatures and gravities, yet still have detectable helium lines in their optical spectra. This may be because mass is lost as the progenitor star passes through the common envelope phase, leading to the star being hydrogen poor, and allowing a weak process, such as mass loss, to mix helium into the line forming region of the white dwarf. Alternatively, these DAOs might be accreting from the wind of their companions - RE 0720-318, another DAO with a dM companion, has been shown to have changing helium abundance over time, which might be due to episodic accretion (Finley, Koester, & Basri 1997; Vennes, Thorstensen, & Polomski 1999). In addition, Dobbie et al. (1999) identified likely spatial non-uniformities in the surface abundance of helium, which are consistent with models of accretion. Finally, for one star in the Bergeron et al. (1994) sample (PG 1210+533), the He\textit{II} line profile was not reproduced satisfactorily by either chemically homogeneous or stratified models. In addition, its helium line strengths have been observed to change over a time period of ~15 years (Bergeron et al. 1994). This is not a high temperature, low gravity object (Bergeron et al. 1994).

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Therefore, DAO white dwarfs form a relatively heterogeneous group. For some, the existence of cool, non-degenerate companions may play a significant role in the presence of photospheric He, either from prior common envelope evolution or from ongoing mass transfer. We investigate a sample of 16 DAO white dwarfs to determine how many exhibit evidence of short term radial velocity variations and thus may be members of close binary systems, using Far-Ultraviolet Spectroscopic Explorer (FUSE) data. FUSE spectra are built up from a number of exposures that last up to 90 minutes, which need to be combined to achieve the desired signal-to-noise of the proposer. Although the signal-to-noise of these exposures is far worse than in the final combined spectrum, strong interstellar and photospheric absorption features can still be identified. This investigation exploits this fact to search for radial velocity shifts in photospheric lines relative to the stationary interstellar medium lines, which might indicate the presence of short period binary systems.

2 OBSERVATIONS

Far-ultraviolet (far-UV) data for all the objects were recorded by the FUSE spectrographs. Table 1 lists the observations that were used, which were downloaded by us from the Multimission Archive (http://archive.stsci.edu/mast.html), hosted by the Space Telescope Science Institute. Overviews of the mission and in-orbit performance have been published by Moos et al. (2000) and Sahnow et al. (2000) respectively; below is a brief description of the instrument.

The FUSE instrument contains four separate co-aligned optical paths (channels), each having a mirror, a focal plane assembly and a diffraction grating, whose dispersed images share a portion of a detector. Light from the target enters into the apertures of all the channels simultaneously. To obtain optimal coverage over the full hydrogran Lyman series (apart from $\alpha$), two of the mirrors and two of the gratings are coated with LiF over a layer of aluminium, while the others are coated with SiC since the reflectivity of the Al+LiF is low below $\sim 1020 \AA$. Two microchannel plate detectors (1 and 2) are used, with each subdivided into two segments (A and B), which are separated by a small gap. Light from a SiC and a LiF channel falls onto each detector, resulting in 8 individual spectra. Thermal changes can result in rotations of the mirrors, hence most observations are carried out with the largest available aperture (LWRS, 30 x 30 arcsec) to prevent the target drifting outside the aperture.

In this aperture the point source resolution has been found to be good (Holberg & Magargle 2005), and has no infrared excess that might indicate a companion star, so it does not appear to fit in with any of the other DAOs.

As a number of improvements have been made to the calibration pipeline since the data were originally processed and archived, after they were downloaded the data were reprocessed using a locally installed version of the CALFUSE pipeline (version 2.0.5 or later). It was found that the wavelength calibration of each segment did not perfectly match with the others, so only data from the LiF 1A combination of mirrors and detectors were used. This should have the best calibration since it is used in the pointing of the telescope.

The sample consists of 16 DAO white dwarfs. Temperatures and gravities for these stars have previously been published by Good et al. (2004). In the sample, 5 are known binaries: RE 0720-318, Vennes & Thorstensen (1994), Barstow et al. (1993), PG 0834+500, Saffer, Livio, & Yungelson (1998), HS 1136+6646, Heber, Dreizler, & Hagen (1996), RE 2013+400, Pounds et al. (1993), Barstow et al. (1993), and the double-degenerate Feige 55 (Holberg et al. 1995). These stars are included in this analysis to assess the ability of the technique to detect white dwarfs in binary systems. In addition, Ton 320 and LB 2 have known infrared excesses that might indicate a companion (Holberg & Magargle 2005).

3 METHODOLOGY

Only the LiF 1A segment is used in this experiment as it is the best calibrated. Even so, the wavelength scale can drift between exposures; this can be corrected for by reference to interstellar medium (ISM) lines, the radial velocity of which should be constant. The lines used are listed in Table 2 with their rest frame wavelengths from Morton (1991). Several of the lines were detectable in the spectra of every object. A Gaussian and a second order polynomial were used to model the line profile and continuum level respectively. The set of parameters that best reproduce the data were determined by a least-squares fitting routine that is part of the IDL language (CURVEFIT). In addition, a 1σ error on the central wavelength was returned by the fitting function. As the true redshift of the ISM lines is not known, and the FUSE wavelength calibration is insufficiently accurate, the mean position of the interstellar lines was taken to be the correct absolute calibration. The central wavelengths of photospheric lines were then measured in a similar way.

| Species | Lab. wavelength / Å |
|---------|---------------------|
| O I     | 988.6549            |
| Si II   | 989.8731            |
| Si I    | 1020.6989           |
| C I     | 1036.3367           |
| C II    | 1037.0182           |
| O I     | 1039.2304           |
| Ar I    | 1048.2199           |
| Fe II   | 1063.1764           |
| Ar I    | 1066.6599           |

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Table 2. ISM lines used to correct for wavelength calibration shifts between FUSE exposures, with rest frame wavelengths as listed by Morton (1991).

| Species | Lab. wavelength / Å |
|---------|---------------------|
| O I     | 988.6549            |
| Si II   | 989.8731            |
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and the number of times that the simulated level.

significance tests, and indicates whether or not the objects were out having to invoke motion in a binary. This was done 10 observations could be explained by measurement error alone, with-

compared to the \( \chi^2 \) of the fit to the real measurements to see if the system velocity is in-

ity equalled the system velocity and when the radial velocity is in-

in time relative to the period, the best fitting period, epoch, velocity semi-amplitude and system velocity leads to unpredictable results. Instead, the system velocity and velocity semi-amplitude were fit to the data for a range of peri-

ods and epochs, and the parameters that provided the least reduced \( \chi^2 \) of all the fits were recorded. The results are shown in Figure 2; already known to be in binary systems. The technique has successfully picked out all of the known binaries, and Figure 1 shows the radial velocity measurements for each of these stars. The radial velocity changes are clearly evident in each, although, of these, only Feige 55 has greater than 10 measurements, and has a complete orbit of radial velocity measurements, allowing the period and amplitude of the variations to be measured. The best fitting sine curve to the data was determined using the IDL CURVEFIT function, which uses a \( \chi^2 \) minimisation technique to determine the best fit model parameters to a function. The radial velocity of the white dwarf can be expressed in the following way:

\[
 v(t) = v_0 + v_{\text{max}} \sin \left( \frac{2\pi(t - t_0)}{P} \right)
\]

where the radial velocity \( v \) at time \( t \) is dependent on the system velocity \( v_0 \), the velocity semi-amplitude \( v_{\text{max}} \), the system period \( P \), and the epoch \( t_0 \). Since the FUSE observations were widely spaced in time relative to the period, the best fitting parameters, in particular the epoch, are very sensitive to the period and simultaneously fitting the period, epoch, velocity semi-amplitude and system velocity leads to unpredictable results. Instead, the system velocity and velocity semi-amplitude were fit to the data for a range of periods and epochs, and the parameters that provided the least reduced \( \chi^2 \) of all the fits were recorded. The results are shown in Figure 2; the best fitting period, velocity semi-amplitude and system velocity are 1.493 days, 74.99 km s\(^{-1}\) and -0.685 km s\(^{-1}\) respectively. This compares with 1.493 days, 77.4 km s\(^{-1}\) and 0.1 km s\(^{-1}\) measured by Holberg et al. (1995) from optical and International Ultraviolet Explorer (IUE) data, and a period of 1.489 days, velocity semi-amplitude of 80.377 km s\(^{-1}\) and system velocity of -1.19 km s\(^{-1}\) found by Kruk, Chayer, & Dupuis (2003), using FUSE data. In our calculation, \( t_0 \), which is the reference epoch when the radial velocity equalled the system velocity and when the radial velocity is increasing, was at 2451601.762 (heliocentric Julian date). Although the figure shows that visually the sine curve provides a good match

Table 3. Photospheric lines used to measure radial velocities.

| Species | Lab. wavelength /Å |
|---------|-------------------|
| Fv      | 997.5240          |
| Ovi     | 1031.9310         |
| Ovi     | 1037.6130         |
| Siv     | 1066.6140         |
| Oiv     | 1067.7680         |
| FeiV    | 1073.9480         |

Once the radial velocities had been measured, a test was performed to measure the significance of any differences found. To do this, a constant velocity line was fitted to the radial velocity measurements and the value of the \( \chi^2 \) statistic recorded. Then, this was compared to a simulation of how the data would look if the radial velocity of the object were constant, but with the measurements perturbed by random errors. To do this, randomly generated Gaussian distributed errors were calculated, the standard deviation of which was set equal to the error in each of the real radial velocity measurements, since the accuracy of the measurements depend on the length of exposure and number of lines used, and varied between measurements. A constant velocity line was then fit to the simulated measurements and the \( \chi^2 \) measured, and this was then compared to the \( \chi^2 \) of the fit to the real measurements to see if the observations could be explained by measurement error alone, without having to invoke motion in a binary. This was done 10\(^6\) times and the number of times that the simulated \( \chi^2 \) exceeded that of the real \( \chi^2 \) was measured. If this occurred in less than 99.7% of times, the radial velocity differences were taken to be significant at the 3\( \sigma \) level.

4 RESULTS

Table 4 lists the results of the radial velocity measurements and significance tests, and indicates whether or not the objects were...
Table 4. Results of the Monte Carlo analysis. Those objects that the calculations suggest have real radial velocity shifts at the $3\sigma$ level are underlined. The stars in bold are already known to have companions.

| Object       | Number of exposures | Best fitting vel / km s$^{-1}$ | Chance of variations occurring randomly |
|--------------|---------------------|-------------------------------|----------------------------------------|
| A 7          | 5                   | 38.8                          | 0.01540                                 |
| HS 0505+0112 | 3                   | 50.4                          | 0.02695                                 |
| PuVe 1       | 6                   | 17.5                          | 0.07894                                 |
| RE 0720-318  | 5                   | -194.4                        | 0.00000*                                |
| TON 320      | 9                   | 33.8                          | 0.00000*                                |
| PG 0834+500  | 3                   | -46.6                         | 0.00001                                 |
| A 31         | 4                   | 80.8                          | 0.01788                                 |
| HS 1136+6646 | 4                   | 53.2                          | 0.00000*                                |
| Feige 55     | 41                  | 4.2                           | 0.00000*                                |
| PG 1210+533  | 2                   | -3.3                          | 0.93316                                 |
| LB 2         | 5                   | 15.1                          | 0.09882                                 |
| HZ 34        | 4                   | 6.7                           | 0.56639                                 |
| A 39**       | 3                   | 2.2                           | 0.36889                                 |
| RE 2013+400  | 9                   | -15.2                         | 0.00000*                                |
| DeHt 5**     | 2                   | -40.9                         | 0.65238                                 |
| GD 561       | 2                   | -12.5                         | 0.61473                                 |

* In none of the Monte Carlo trials was the minimum $\chi^2$ achieved by fitting a constant velocity line to the real data less than the $\chi^2$ from fitting a constant velocity line to the simulated data.
** Velocity measurements made difficult by H$_2$ absorption.

to the data, the reduced $\chi^2$ statistic comparing the sine curve to the data is 23, indicating that the formal errors returned by the fitting function underestimated the true errors inherent in the technique; in addition, the fact that the fit statistic does not take into account that each exposure lasts $\sim$90 minutes, rather than being discrete measurements, may be contributing to the high value.

Orbital parameters for RE 0720-318 and RE 2013+400 have been published by Vennes, Thorstensen, & Polomski (1999). These parameters can be used to predict the radial velocity of the white dwarfs at the time of the FUSE observations in order to check for consistency with our radial velocity measurements. For RE 0720-318, it was noted that the predicted radial velocities were out of phase with the measurements by a small amount, and that the magnitudes of the velocities were also slightly different. To quantify these differences the set of parameters that best matched the measured quantities were found by searching around the values given by Vennes, Thorstensen, & Polomski (1999). Predicted radial velocities were calculated for values between $\pm 3\sigma$ of the Vennes, Thorstensen, & Polomski (1999) quantities for the time when the velocities increase through their mean value and the velocity semi-amplitude of the orbit. The value of the orbital period was not varied since Vennes, Thorstensen, & Polomski (1999) quote this number to high precision, and a change of $1\sigma$ in the period resulted in a change in $\chi^2$ of only $<0.001$. Since the FUSE observations sample only a limited part of the white dwarf orbit, there is insufficient information to find both the mean radial velocity and velocity semi-amplitude. Therefore, we also did not attempt to vary the mean radial velocity from the value given by Vennes, Thorstensen, & Polomski (1999). For each combination of parameters, $\chi^2$ was calculated, and the set of parameters that gave the lowest $\chi^2$ recorded. This resulted in the following set of parameters for the orbit of RE 0720-318: reference Julian date when the radial velocities increase through the mean, 2452226.649 (a decrease compared to the Vennes, Thorstensen, & Polomski (1999) ephemeris of 1.38 of their sigmas), mean white dwarf radial velocity, 51.7 km s$^{-1}$, velocity semi-amplitude, 81.8 km s$^{-1}$ (1.62$\sigma$ higher than the Vennes, Thorstensen, & Polomski (1999) value, although this will also incorporate any error in the mean velocity), and period, 1.26243 days. The $\chi^2$ for these parameters is 3.95, compared to 140.97 for the values given by Vennes, Thorstensen, & Polomski (1999). Figure 3 shows the measured radial velocities for RE 0720-318 and the velocities that were predicted using these parameters.

The procedure described above was also followed for RE 2013+400. However, for this object the FUSE observations cover a greater proportion of the orbit than for RE 0720-318. It was therefore possible to vary the period and mean radial velocity from the numbers given by Vennes, Thorstensen, & Polomski (1999) to obtain values for these parameters also. The set of orbital parameters found for RE 2013+400 were: reference Julian date when ve-
Figure 1 – continued

Figure 2. Feige 55 radial velocities folded onto the best fitting period, with a sine curve overplotted.

Figure 3. RE 0720-318 radial velocities folded onto the period, with the predicted radial velocities overplotted.

Figure 4. RE 2013+400 radial velocities folded onto the period, with the predicted radial velocities overplotted.

The sixth object for which significant radial velocity changes were found was Ton 320, which has an infrared excess and thus is suspected to be within a binary system (Holberg & Magargle 2005). The radial velocity measurements for this object are shown in Figure 5. In contrast to the radial velocity measurements for the known binaries, shown in Figure 1, the radial velocities seen for Ton 320 appear relatively constant, apart from the second, sixth and seventh measurements out of the total of nine, and no sinusoidal nature to the velocity shifts is obvious. Therefore, it is possible that this is a spurious detection of radial velocity changes, due to an underestimation of the errors in the radial velocity measurements. Alternatively, this object may be within a binary system, with the sinusoidal nature of the radial velocity variations hidden within the errors, or by the separation of the exposures. To investigate this possibility, the range of periods to which the radial velocity measurement technique is sensitive for this object was first found. To determine this, the radial velocity changes that would occur between the observations made by FUSE were calculated for situations where the object was assumed to be in a binary system with a number of different inclinations and at a number of different phases at the time of first observation. The white dwarf was assumed to have a mass of 0.5 M_☉, while a conservative value of 0.1 M_☉ was assumed for the companion; a more massive companion will result in larger ra-
dial velocity shifts. The radial velocity shift that was assumed to be detectable was set to the maximum error in the velocity measurements for the object (3.46 km s\(^{-1}\) for Ton 320). For each period, the number of times where radial velocity changes would be detectable was counted and normalised relative to the total number of trials, with the results plotted in Figure 6. The plot demonstrates that the probability of detecting radial velocity changes is limited by this separation in time and, although the period is a multiple of the separation in time of the exposures. For LB 2, with five exposures, a better than 90% chance of detecting radial velocity changes if it were within a binary system for period up to 1 day, and with the additional exposures, the separation in time of the measurements is less significant. PuWe 1 has six exposures, but these were recorded in two observations, separated in time by over a year. The probability of detecting radial velocity changes is limited by this separation in time and, although better than for PG 1210+533, the five continuous measurements for LB 2 provides the best chance of detecting radial velocity shifts less than a day. Therefore, to improve the significance of these non-detections of radial velocity shifts, longer observations are required.

5 DISCUSSION

Evidence for binarity has been found for only 6 DAOs. These 6 are all known, or suspected to be in binary systems from other observations. This suggests that the technique we have adopted is a valid way of searching for binarity in the remainder of the sample. DAO white dwarfs can broadly be separated into two categories: ‘normal’ mass white dwarfs, generally in binary systems, or low mass stars with possible winds. To investigate what category each DAO falls into, we calculate the mass of each white dwarf by combining the temperatures and gravities measured by Good et al. (2004) with the evolutionary models of Bloecker (1995) and Driebe et al. (1998); these are listed in Table 5. Since Good et al. (2004) found differences between the best fitting model to their optical and far-UV data, we list mass estimates from both. This introduces a large uncertainty in the mass measurements, with the \textit{FUSE} estimates generally higher, and in some cases up to 0.2 M\(\odot\) different to the optical measure. To simplify the discussion, we use the optical mass here, since the mass could not be calculated for three objects (PG 0834+500, HS 1136+6646 and HS 0505+0112) from \textit{FUSE} data as their temperatures were so extreme. It should be noted that if the \textit{FUSE} masses are correct, most of the DAOs would have a relatively ‘normal’ mass for a white dwarf, although they are hotter than a typical DA, and so would be post-AGB stars, rather than having to have evolved from the extended horizontal branch or in a binary system. We divide the

by Hillwig, Honeycutt, & Robertson (2000). However, other solutions that provide higher values of \(\chi^2\) are possible, but more closely spaced measurements are required to constrain the fit and to determine with certainty if Ton 320 lies within a close binary system.

The remaining objects are those for which no significant radial velocity changes were found. However, the significance test for radial velocity changes was only narrowly failed by a number of these: A 7, HS 0505+0112, PuWe 1, A 31 and LB 2 (which Holberg & Magargle (2005) identified as having an infrared excess), for which the result of the significance test was <0.1. The radial velocity measurements for these objects are shown in Figure 7. Finally, radial velocity plots for PG 1210+533, HZ 34, A 39, DeHt 5 and GD 561, for which the results of the significance tests were >0.1, are shown in Figure 8. However, none of these objects have more than 6 exposures, which limits the sensitivity of the method; Figure 9 demonstrates the probability of detecting radial velocity shifts for periods between 0.1 and 10 days, for PuWe 1, PG 1210+533 and LB 2. PG 1210+533 has only two exposures from a single \textit{FUSE} observation, and therefore our method for detecting binarity is least sensitive for this object, with the sensitivity beginning to decline above 0.1 days and strongly decreasing where the period is a multiple of the separation in time of the exposures. For LB 2, with five exposures, a better than 90% chance of detecting radial velocity changes if it were within a binary system for period up to 1 day, and with the additional exposures, the separation in time of the measurements is less significant. PuWe 1 has six exposures, but these were recorded in two observations, separated in time by over a year. The probability of detecting radial velocity changes is limited by this separation in time and, although better than for PG 1210+533, the five continuous measurements for LB 2 provides the best chance of detecting radial velocity shifts less than a day. Therefore, to improve the significance of these non-detections of radial velocity shifts, longer observations are required.

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objects into groups; the higher mass stars all have $>0.55 \, M_\odot$ from the optical measurements, while the remainder are put into a lower mass group.

Of the DAOs with comparatively high mass, evidence for binarity was found for RE 0720-318 and RE 2013+400 (both of which are DAO+dM binaries), but not for PG 1210+533 and LB 2. Only two exposures were obtained for PG 1210+533, while LB 2 has 5, and it might be possible that radial velocity shifts were missed because the separation in time of exposures was insufficient, because the system was viewed at an unfavourable phase, or if the radial velocity measurement technique were insufficiently sensitive. In addition, if a system is at high inclination, no radial velocity variations would be detectable. This may indeed be the case for LB 2, which was identified by Holberg & Magargle (2005) as having an infrared excess. It should also be noted that for this object the mass determined from the Lyman line results is lower than that obtained from the Balmer line results and using the lower mass would place LB 2 in the lower mass group. As shown in Figure 7, since there are fewer exposures for PG 1210+533, the method is less sensitive than for LB 2. However, it is still 80% likely that radial velocity shifts would be detected by this experiment if it were in a binary system with period less than almost a day, unless its period hap-

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**Figure 7.** Plots of the radial velocity measurements made for objects where the chances of the radial velocity variations occurring randomly were less than 0.1.

**Table 5.** Mass determined by combining the temperature and gravity determinations from Balmer and Lyman line measurements of Good et al. (2004) with the evolutionary models of Bloecker (1995) and Driebe et al. (1998).

| Object      | Balmer $M_\odot$ | Lyman $M_\odot$ |
|-------------|------------------|-----------------|
| A 7         | 0.508±0.020      | 0.673±0.018     |
| HS 0505+0112| 0.509±0.017      | -               |
| PuWe 1      | 0.499±0.027      | 0.663±0.060     |
| RE 0720-318 | 0.566±0.046      | 0.630±0.013     |
| TON 320     | 0.507±0.017      | 0.578±0.013     |
| PG 0834+500 | 0.453±0.020      | -               |
| A 31        | 0.491±0.025      | 0.578±0.013     |
| HS 1136+6646| 0.511±0.008      | -               |
| Feige 55    | 0.439±0.017      | 0.518±0.002     |
| PG 1210+533 | 0.595±0.031      | 0.590±0.022     |
| LB 2        | 0.557±0.049      | 0.521±0.009     |
| HZ 34       | 0.417±0.019      | 0.477±0.032     |
| A 39        | 0.455±0.036      | 0.531±0.018     |
| RE 2013+400 | 0.642±0.046      | 0.661±0.009     |
| DeHt 5      | 0.470±0.024      | 0.412±0.018     |
| GD 561      | 0.464±0.029      | 0.442±0.023     |
Figure 8. Plots of the radial velocity measurements for stars where the chances of the observed changes in radial velocity occurring randomly were greater than 0.1.

6 CONCLUSIONS

FUSE data have been used to measure the radial velocity variations in 16 DAO white dwarfs, from the position of the photospheric heavy element absorption lines in their spectra. The technique was found to be successful in detecting radial velocity variability in all the known binaries, and even with only 2 exposures there is better than a 80% chance of observing velocity changes if the period of the system is less than a day, apart from where the period is a multiple of the temporal separation of exposures.

Radial velocity variations were only detected for those objects already known or suspected to be binaries, although it is possible that some of the others possess binary companions that are too highly inclined, or which were observed at unfavourable phases or have orbital periods too long with respect to the time span covered by our observations to be detected. Of the low mass DAOs, significant changes in radial velocity were observed for only four of the twelve objects, suggesting that the majority of this type of DAO do not exist in binary systems and may therefore have evolved as single stars from the extended horizontal branch. No evidence of binarity was found for two of the four higher mass white dwarfs in the sample. One of these objects, LB 2, has an infrared excess and
Figure 9. The probability of detecting radial velocity variations for PuWe 1, PG 1210+533 and LB 2.

hence may in fact have a companion. The presence of helium in the spectrum of the other, PG 1210+533, is still unexplained.

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