

elements change into the helium-like stage of ionization at high T_{eff} , the radiative force is reduced, because the lines of this ionization stage are at very short wavelengths outside the flux maximum. Therefore, in spite of their higher luminosity, it is not clear that winds are more likely to exist at DAs with $T_{\text{eff}} > 60\,000$ K than at cooler ones.

If winds exist in hot DA white dwarfs at all, they should consist of metals only, since hydrogen is in hydrostatic equilibrium. Initial calculations for a DA with $T_{\text{eff}} = 66\,000$ K with $\log g = 7.7$ show that the outward flow of the elements C, N and O in an otherwise hydrostatic stellar atmosphere cannot exceed a value of the order of $10^{-19} M_{\odot} \text{ yr}^{-1}$. This maximum value can be derived due to the dependence of the radiative force on the abundance of the element, using arguments similar to those of Seaton (1996). It indirectly follows that the mass-loss rate of these elements cannot be significantly higher than $10^{-19} M_{\odot} \text{ yr}^{-1}$, because the stellar atmosphere would otherwise be rapidly emptied. As shown by Votruba et al. (2010) for the case of sdB stars, metallic winds are accelerated to velocities of several thousands of km s^{-1} , exceeding the escape velocity of the star. This suggests that even if mass loss is occurring, the metals would form a thin wind and would not be able to explain the circumstellar material seen here.

4.4 Ancient planetary nebulae

Given that one of the stars (WD 2218+706) is a bona fide CSPN, it is sensible to examine whether the observed circumstellar material can be associated with ancient, diffuse PNe. Following the approach of Bannister et al. (2003), the PN expansion velocities (v_{exp}) from Napiwotzki & Schönberner (1995) were compared to the $v_{\text{phot}} - v_{\text{circ}}$ values (Fig. 4). Given the broad consistency between the velocities measured here and those measured by Bannister et al. (2003), it is perhaps not surprising that this comparison yields roughly the same result. The range of v_{exp} values is broadly matched by the range of $v_{\text{phot}} - v_{\text{circ}}$ values, with a few outliers. Again, the $v_{\text{phot}} - v_{\text{circ}}$ value of WD 2218+706 is far from its v_{exp} , indicating that the non-photospheric high ions seen here may no longer be associated with the PN. Though Bannister et al. (2003) also used the presence of the PN TK2 at WD 1738+669 to explain the circumstellar

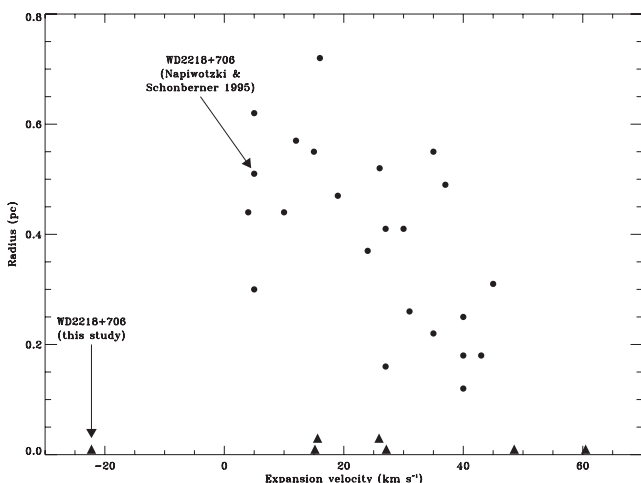


Figure 4. The PN expansion velocities (v_{exp}) from the Napiwotzki & Schönberner (1995) sample (circles) plotted with the $v_{\text{phot}} - v_{\text{circ}}$ values of the stars in this study (triangles). Since there are no nebula radius measurements for the stars here, they are plotted at 0 km s^{-1} . Overlapping $v_{\text{phot}} - v_{\text{circ}}$ values are offset for clarity.

high ions seen at this star, Frew & Parker (2006) found that this object is not actually a CSPN, citing the ionization of material in the Strömgren sphere of the white dwarf as giving the impression of a nearby PN. Coupled with the difference in v_{exp} and $v_{\text{phot}} - v_{\text{circ}}$ at WD 2218+706 and the similarity in v_{CS} and $v_{\text{ISM, pri}}$ at both WD 1738+669 and WD 2218+706, it seems that the circumstellar material seen at WD 2218+706 may, again, in fact be ionized ISM in the Strömgren sphere of the object (though this material may have originated in the PN at the star).

4.5 Summary

We have re-examined the hot white dwarf sample of Bannister et al. (2003) using an improved measurement technique, which for the first time has provided column densities for all of the observed circumstellar material. Unambiguous circumstellar detections are made at WD 0232+035, WD 0455–282, WD 0501+527, WD 0556–375, WD 0939+262, WD 1611–084, WD 1738+669 and WD 2218+706. Several sources for this circumstellar material (circumstellar discs, ionized ISM, stellar mass loss and ancient PNe) were examined.

Once thought to be a significant potential mechanism for the production of hot DA circumstellar features, mass loss was found not to be a plausible explanation for the observations here. Similarly, ancient PNe at the stars are unlikely to be the source of the circumstellar absorption seen in the spectra of WD 1738+669 and WD 2218+706, as was once thought.

The ‘circumstellar’ absorption seen in the spectrum of G191-B2B has previously been attributed to the ionization of the Hyades cloud by the hot white dwarf; this conclusion remains intact in this work. While the ionization of the ISM near WD 1738+669 and WD 2218+706 may be a credible source of the observed circumstellar features, some difficulty is met in linking the ionization of the ISM to the circumstellar features at WD 0455–282, WD 0556–375 and WD 0939+262. At these stars, v_{CS} does not match up well with the detected ISM components. Some agreement is seen between v_{CS} and $v_{\text{LISM, pred}}$ along the sight-lines to these stars, though the stars are too far away to ionize the LISM. It may therefore be the case that ISM cloudlets near the stars with velocities similar to those in the LISM are in fact being ionized. The measured column densities of the circumstellar material also lie within the range of ionized ISM column densities predicted by the Dupree & Raymond (1983) DA Strömgren sphere model.

It could also be, as suggested by Lallement et al. (2011), that these stars are ionizing either the evaporated remains of circumstellar rocky bodies or the analogues to the circumstellar discs seen at cooler white dwarf stars. Indeed, the v_{CS} of WD 1614–084 does not match any interstellar component, predicted or detected. Though the v_{CS} at WD 0232+035 does not line up with any measured or predicted ISM components, the Strömgren sphere of the object is more than large enough to ionize any material lost from its dwarf companion.

The potential implications of this to our understanding of the ISM are significant. Where previous studies attributed non-photospheric high ions to hot/cold gas interfaces, a picture of the distribution of the ISM has built up. Should at least some of the non-photospheric high ions observed have arisen in hot white dwarf Strömgren spheres, the conclusions drawn as to the structure of the ISM using hot/cold gas interface models would not be wholly correct, and our understanding of the ionized ISM will need to be revised. Similarly, should at least some of the circumstellar high ions here be due to the ionization of circumstellar material from evaporated

planetesimals/disrupted extrasolar minor planets, studies of systems such as these will provide a valuable insight into the evolution of extrasolar planetary systems through the hot white dwarf phase.

This work clearly shows the importance of understanding the white dwarf circumstellar environment to our understanding of the ISM and the end states of stellar and planetary system evolution, and provides a good case for the re-observation of stars where unresolved circumstellar material may be resident with higher resolution instruments to identify new cases of circumstellar absorption. High-resolution re-observation of the stars with circumstellar material here will also allow a better characterization of the ISM along the sight-lines to the stars. A detailed model of hot white dwarf Strömgren spheres, including advances in both our knowledge of hot white dwarf atmospheres and the ISM, is clearly required to better understand this phenomenon. Physical modelling of the interaction of planetesimals and circumstellar discs with the hot stars is a crucial future step to better understanding the evolution of extrasolar planetary systems at the white dwarf stage, and may provide testable predictions that can be compared to the quantities observed here.

5 COMMENTS ON INDIVIDUAL STARS

Details of the measurements made for each star are discussed here. Representative plots are shown in the interesting case of WD 0948+534 (Section 5.8).

5.1 WD 0050–335 (GD 659)

Bannister et al. (2003) found that a circumstellar component may be present in the co-added C IV doublet at $-2.97 \pm 3.00 \text{ km s}^{-1}$, while $v_{\text{phot}} = 34.28 \pm 0.27 \text{ km s}^{-1}$. The secondary component was relatively weak (6 mÅ) when compared to the photospheric component (36 mÅ). Though an F -test showed this second component was statistically preferred, it was similar to nearby noise features. Given the similarity of this previously identified circumstellar feature to the noise, and the inability to co-add doublet components in velocity space here, a circumstellar measurement is not made. The detected low ion ISM component along the line of sight to this star is close to the expected velocity of the LIC, and may be associated with it.

5.2 WD 0232+035 (Feige 24)

The data were obtained at two phases of the binary cycle: 0.73–0.74 (1997 November 29) and 0.23–0.25 (1998 January 4). The photospheric velocity varies between data sets, with $v_{\text{phot}} = 30.11 \pm 0.52$ and $128.23 \pm 0.31 \text{ km s}^{-1}$, respectively, at each binary phase. In the C IV doublet, a second, stationary set of absorption features is seen at $v_{\text{CS}} = 7.4 \pm 0.34 \text{ km s}^{-1}$. The column density of this component is $(2.8 \pm 0.13) \times 10^{13} \text{ cm}^{-2}$, and it has a b value of $6.4 \pm 0.5 \text{ km s}^{-1}$. A single, photospheric component in the O VI absorption lines is seen, consistent with the findings of Barstow et al. (2010).

The Si II and S II lines give $v_{\text{ISM,pri}} = 2.85 \pm 0.34 \text{ km s}^{-1}$ and $v_{\text{ISM,sec}} = 17.1 \pm 1.3 \text{ km s}^{-1}$. The projected v_{LISM} due to the LIC is found to be $18.1 \pm 1.13 \text{ km s}^{-1}$, near $v_{\text{ISM,sec}}$ but far from both $v_{\text{ISM,pri}}$ and v_{CS} . Given that the white dwarf has a M dwarf companion, it is possible that the observed circumstellar features are due to the ionization of the mass lost from the binary companion. Indeed, Kawka et al. (2008) reasoned that the observed O VI abundances seen in their post common envelope binary sample (which included

WD 0232+035) are due to the accretion of mass lost from binary companions, given the O VI reservoir at the top of the photospheres of the white dwarf sample of Chayer et al. (2006). It was, however, stated that the relatively large orbital separation of WD 0232+035 ($p = 4.23 \text{ d}$; Vennes & Thorstensen 1994) makes accretion from the binary companion much weaker than for the other binaries in their sample (with $0.33 < p < 1.26 \text{ d}$).

5.3 WD 0455–282 (REJ 0457–281)

Blueshifted features in the UV spectrum of this object were first reported in the C IV and Si IV absorption-line profiles (Holberg et al. 1998). Some evidence for circumstellar material in the 1239 Å N V absorption line was noted by Bannister et al. (2003). Here, $v_{\text{phot}} = 79.28 \pm 1.79 \text{ km s}^{-1}$, and the C IV, N V and Si IV circumstellar components are found at an average velocity of $18.8 \pm 3.47 \text{ km s}^{-1}$, with column densities of $(3.32 \pm 0.66) \times 10^{13}$, $(4.17 \pm 0.84) \times 10^{11}$ and $(3.71 \pm 0.74) \times 10^{12} \text{ cm}^{-2}$, respectively. The line of sight to the star traverses the Blue cloud (which has a projected velocity of $12.56 \pm 1.03 \text{ km s}^{-1}$), though this star is too far away from the cloud to account for the observed circumstellar absorption. Circumstellar material or unresolved ISM may account for this observation.

5.4 WD 0501+527 (G191-B2B)

WD 0501+527 is one of the best studied hot white dwarfs. In keeping with the results of Bannister et al. (2003), circumstellar C IV is seen at $8.9 \pm 0.07 \text{ km s}^{-1}$ and the averaged $v_{\text{phot}} = 24.51 \pm 0.16 \text{ km s}^{-1}$. $N(\text{C IV}) = (1.04 \pm 0.1) \times 10^{14} \text{ cm}^{-2}$, and a b value of $5.65 \pm 0.18 \text{ km s}^{-1}$ (near that of Vennes & Lanz 2001) is measured for the circumstellar material. Two components are measured in the ISM, with the primary at $8.5 \pm 0.18 \text{ km s}^{-1}$ and the secondary at $19.3 \pm 0.03 \text{ km s}^{-1}$, agreeing with the values found by Sahu et al. (1999) and Redfield & Linsky (2004). Two LISM clouds are traversed by the line of sight to WD 0501+527. The Hyades cloud has a projected velocity of $9.35 \pm 1.32 \text{ km s}^{-1}$, matching both v_{CS} and $v_{\text{ISM,pri}}$, suggesting that the Hyades cloud may be responsible for the primary ISM component and the observed circumstellar material; the electron density of the Hyades cloud along the line of sight to WD 0501+527 supports this association (Redfield & Falcon 2008). However, though Redfield & Linsky (2004) also suggest the absorption seen at v_{CS} is due to the photoionization of the Hyades cloud by WD 0501+527, the metal depletion value of this line of sight is anomalous when compared to the other sight-lines through the Hyades cloud, signalling some caution must be observed here. It may be the case that some material with a velocity similar to the Hyades cloud, closer to the star (at a distance of 50 pc) is in fact being ionized. The LIC, with a projected velocity of $19.1 \pm 1.1 \text{ km s}^{-1}$, is likely to be responsible for the observed secondary ISM component. The O VI 1032 Å line has a single component at $19 \pm 2.3 \text{ km s}^{-1}$ and is attributed to the photosphere, in agreement with both Savage & Lehner (2006) and Barstow et al. (2010).

5.5 WD 0556–375 (REJ 0558–373)

$v_{\text{phot}} = 25.37 \pm 2.03 \text{ km s}^{-1}$. Circumstellar material is again seen in the C IV doublet (giving $v_{\text{CS}} = 10.2 \pm 1.07 \text{ km s}^{-1}$), with an averaged column density of $(4.67 \pm 0.62) \times 10^{13} \text{ cm}^{-2}$ and $b = 11 \pm 1.3 \text{ km s}^{-1}$. Three ISM components are seen in the ISM detected at 7.8 ± 1 , 19.9 ± 1.7 and $36 \pm 2.3 \text{ km s}^{-1}$ (ordered by equivalent width). The sight-line to WD 0556–375 traverses the Blue cloud, which has a projected velocity of $11.36 \pm 0.95 \text{ km s}^{-1}$, overlapping

with v_{CS} within errors, and near $v_{\text{ISM, pri}}$. However, like the other stars with circumstellar absorption, this star lies at too great a distance (295 pc) to ionize the LISM; either another ISM cloud with a similar velocity to the Blue cloud is present near enough to the star to facilitate photoionization or circumstellar material of the type describe by Lallement et al. (2011) is present.

5.6 WD 0621–376 (REJ 0623–371)

No clear evidence for circumstellar material is seen at this star. v_{phot} is measured at $39.44 \pm 0.25 \text{ km s}^{-1}$, while a single component ISM fit gives $v_{\text{ISM}} = 15.8 \pm 0.4 \text{ km s}^{-1}$. As with WD 2211–495, the inconsistency seen in the centroid positions of the C IV doublet components ($v_{1548} = 37.6 \pm 0.6 \text{ km s}^{-1}$, $v_{1550} = 48.5 \pm 0.7 \text{ km s}^{-1}$) for this star was used to indicate the possible presence of unresolved circumstellar material by Bannister et al. (2003). Indeed, the relatively poor resolution of the *IUE* [SWP] data may hide the shifted circumstellar material, and higher resolution data may allow this material to be resolved.

5.7 WD 0939+262 (Ton 021)

The C IV and Si IV doublets both display circumstellar material, giving $v_{\text{CS}} = 9.38 \pm 6.59 \text{ km s}^{-1}$. When the N V and O V lines are included, $v_{\text{phot}} = 36.5 \pm 0.47 \text{ km s}^{-1}$. The average column density for the C IV doublet is $(8.05 \pm 0.21) \times 10^{12} \text{ cm}^{-2}$ with a b value of $8.3 \pm 1.75 \text{ km s}^{-1}$; for Si IV, it is $(1.81 \pm 0.36) \times 10^{12} \text{ cm}^{-2}$ with a b value of $11.65 \pm 5.28 \text{ km s}^{-1}$. The ISM is found to have one component at $-2.1 \pm 0.2 \text{ km s}^{-1}$. Though v_{LISM} (due to the LIC) is predicted to be at $10.81 \pm 1.29 \text{ km s}^{-1}$, (lining up well with v_{CS}) for reasons discussed for WD 0455–282 and WD 0556–375 this LISM cloud cannot be ionized by this star, implying that the observed circumstellar material may reside in a ‘LIC-like’ cloud or in a circumstellar disc.

5.8 WD 0948+534 (PG 0948+534)

Three ISM components are found here, in keeping with the results of Bannister et al. (2003). The primary component is at $-18.45 \pm 0.42 \text{ km s}^{-1}$, with the secondary and tertiary components at -1.60 ± 0.63 and $22.6 \pm 0.8 \text{ km s}^{-1}$. In contrast, Bannister et al. (2003) found the -1.6 km s^{-1} component had an equivalent width larger than that of the -18.45 km s^{-1} component. In the S II line, the model equivalent widths are similar at 32.14 and 30.99 mÅ for the -18.45 and -1.6 km s^{-1} components, respectively. However, the Si II line has model equivalent widths of 39.20 and 25.63 mÅ for the -18.45 and -1.6 km s^{-1} components, clearly making the -18.45 km s^{-1} component the primary. One absorbing component is statistically preferred for the high ions (Fig. 5), with an averaged v_{phot} of $-17.09 \pm 1.73 \text{ km s}^{-1}$. Caution must be exercised here; the modelling technique simply fits the absorption features with Gaussian profiles, and does not include physically robust stellar absorption-line profiles. Indeed, modelling this object with a single component stellar model has proved difficult (Dickinson et al. 2012).

Considerable spread is seen between the high ions ($v_{\text{O V}} = -10.03 \text{ km s}^{-1}$, $v_{\text{C IV}} = -16 \text{ km s}^{-1}$). Bannister et al. (2003) used the inconsistencies in the centroid positions of the absorption features in WD 0621–376 and WD 2211–495 to infer the possible existence of unresolved circumstellar material in the spectra of the stars. Though not statistically preferred, a hint of a secondary component can be seen in the C IV doublet (most obviously in the 1548 Å line). Fitting with two components gives $v_{\text{phot, C IV}} = -17.6 \pm$

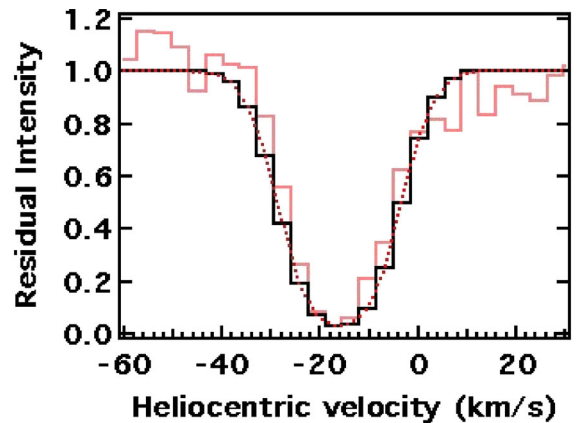


Figure 5. The 1548 Å C IV line of WD 0948+534, fitted with a single absorbing component at -16 km s^{-1} . The dark solid line shows the model, while the dotted line signifies the model components. The lighter solid line is the observed data. This plotting convention is used in all subsequent line profile plots.

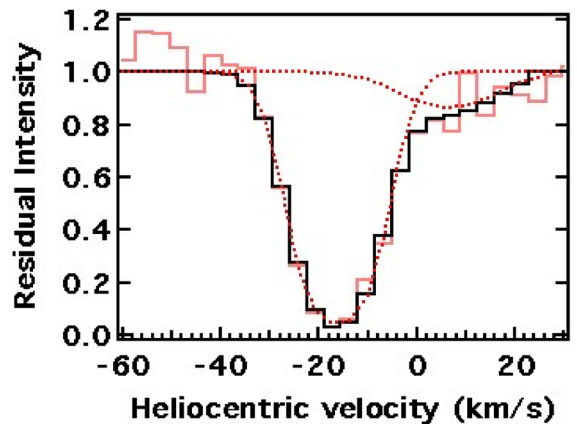


Figure 6. The 1548 Å C IV line of WD 0948+534, fitted with two absorbing components at $v_{\text{phot, C IV}} = -17.6 \text{ km s}^{-1}$ and $v_{\text{circ, C IV}} = 1.65 \text{ km s}^{-1}$.

0.39 km s^{-1} and $v_{\text{circ, C IV}} = 1.65 \pm 7.22 \text{ km s}^{-1}$ (Fig. 6). The large error on $v_{\text{circ, C IV}}$ can be put down to the fact that the circumstellar material is not resolved. Applying this to the N V, O V and Si IV lines (Fig. 7) gives an averaged v_{phot} of $-17.09 \pm 1.72 \text{ km s}^{-1}$ and $v_{\text{CS}} = 0.2 \pm 5.40 \text{ km s}^{-1}$. An examination of the 1031.912 O VI line in the *FUSE* data also reveals two possible components at -22.9 ± 1.2 and $15.7 \pm 2.8 \text{ km s}^{-1}$. Given that the *FUSE* velocity resolution ($\sim 15 \text{ km s}^{-1}$) is poorer than that of the STIS [E140M] data ($\sim 7 \text{ km s}^{-1}$) and that the absolute velocity calibration may not be the same for both the STIS and *FUSE* data, the secondary component at 15.7 km s^{-1} is deemed the circumstellar component. Using the STIS measurements, $v_{\text{CS shift}} = -17.29 \pm 5.7 \text{ km s}^{-1}$ and $v_{\text{ISM, sec}} - v_{\text{phot}} = -18.69 \pm 1.8 \text{ km s}^{-1}$, implying that if it is present, the circumstellar material may be related to the secondary ISM component.

However tempting the presence of circumstellar material may be in explaining both the difficulty in modelling the absorption-line profiles of the star and the inconsistency in the centroid positions of the high ions, one absorbing component is still statistically preferred. Higher resolution data may shed further light on this enigmatic object.

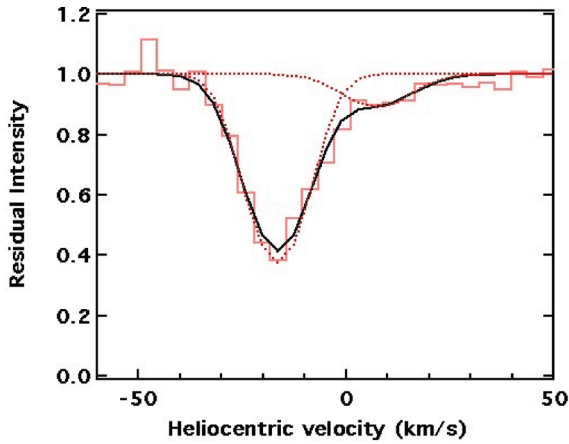


Figure 7. The 1393 Å Si IV line of WD 0948+534, fitted with two absorbing components at $v_{\text{phot, Si IV}} = -16.9 \text{ km s}^{-1}$ and $v_{\text{circ, Si IV}} = 3.5 \text{ km s}^{-1}$.

5.9 WD 1029+537 (REJ 1032+532)

In good agreement with the $v_{\text{phot}} = 38.16 \pm 0.40 \text{ km s}^{-1}$ found by Bannister et al. (2003), a value of $v_{\text{phot}} = 37.98 \pm 0.21 \text{ km s}^{-1}$ is found here. $v_{\text{ISM}} = 0.95 \pm 0.79 \text{ km s}^{-1}$, again matching up with the value of $0.84 \pm 0.21 \text{ km s}^{-1}$ found by Bannister et al. (2003). No circumstellar material is seen at this star.

5.10 WD 1057+719 (PG 1057+719)

No evidence for circumstellar material is found in the spectrum of this white dwarf, nor is there any photospheric C IV, N V, O V or Si IV. A value of $v_{\text{ISM}} = -0.2 \pm 1.0 \text{ km s}^{-1}$ is obtained.

5.11 WD 1123+189 (PG 1123+189)

Using the S II and O I lines, ISM components are seen at -4.75 ± 3.18 and $2.15 \pm 2.96 \text{ km s}^{-1}$. The high uncertainties on these measurements are due to the saturation of the O I line. No photospheric absorption features are seen. The C IV, O V and Si IV lines are not covered by the STIS [E140H] data, which cover 1160–1360 Å. Again, the N V doublet cannot be co-added to obtain a v_{phot} estimate in the same way as it was by Bannister et al. (2003).

5.12 WD 1254+223 (GD 153)

WD 1254+223 is another white dwarf in which no C IV, N V, O V and Si IV absorption features are seen. A v_{ISM} measurement of $-15.4 \pm 1.6 \text{ km s}^{-1}$ is obtained, consistent with the values of both Bannister et al. (2003) and Holberg et al. (1998); these values disagree with the v_{ISM} values found by Redfield & Linsky (2004) by around -5 km s^{-1} , probably due to the use of higher resolution data in the latter study. O VI was seen in the *FUSE* spectrum and is attributed to the ISM, in keeping with the findings of Barstow et al. (2010).

5.13 WD 1314+493 (HZ 43)

Neither photospheric nor circumstellar absorption lines are seen in the spectrum of this DA. The v_{ISM} measured here using the low-ionization lines ($-6.6 \pm 0.1 \text{ km s}^{-1}$) is similar to the value found by Redfield & Linsky (2002), and is close to the projected velocity ($-6.15 \pm 0.74 \text{ km s}^{-1}$) of the North Galactic Pole (NGP) cloud along the line of sight to the star.

5.14 WD 1337+705 (EG 102)

With a $T_{\text{eff}} = 22\,090 \text{ K}$, it is perhaps not surprising that no photospheric high ions are observed in the spectrum of WD 1337+705. Though no circumstellar material is detected, WD 1337+705 is another white dwarf in which the accretion of circumstellar material can be used to explain the observed photospheric metal abundances. Holberg, Barstow & Green (1997a) found Mg II and Si II in the optical spectrum of WD 1337+705, with Al II and Al III later detected in the *IUE* spectrum (Holberg et al. 1998). The Al abundance (1.5×10^{-8}) measured by Bannister et al. (2003) is in excess of that predicted by Chayer et al. (1995a). Holberg et al. (1998) also found a C II line with a velocity that compared poorly to both the photosphere and the ISM along the sight-line of the star. While recent radiative levitation studies of objects in this temperature range predict some C, Al and Si in the photosphere of WD 1337+705, accretion must still be occurring to explain the observed photospheric abundances (Chayer & Dupuis 2010; Dupuis et al. 2010). Zuckerman & Reid (1998) detected a significant amount of Ca in the optical spectrum of WD 1337+705 ($\text{Ca}/\text{H} = 2.5 \times 10^{-7}$), often used to infer the accretion of terrestrial-like extrasolar planet remnants (e.g. Zuckerman et al. 2003; Farihi et al. 2010). All of this evidence suggests WD 1337+705 may be accreting circumstellar material. However, no gas disc emission is seen at WD 1337+705 (Burleigh et al. 2010, 2011) and no infrared excess has been found (Mullally et al. 2007). Consideration must be given to the fact that infrared excesses are not seen at all stars that exhibit photospheric metals (Farihi et al. 2009), and therefore the lack of an infrared excess should not be taken as firm evidence for there being no circumstellar debris.

5.15 WD 1611–084 (REJ 1614–085)

WD 1611–084 is the coolest star ($T_{\text{eff}} = 38\,840 \text{ K}$) to display unambiguous signs of circumstellar material. Photospheric detections of C IV, N V and Si IV give $v_{\text{phot}} = -40.77 \pm 3.56 \text{ km s}^{-1}$. Circumstellar C IV and Si IV are present at an average velocity of $-66.67 \pm 2.05 \text{ km s}^{-1}$, with column densities of $(9.77 \pm 1.95) \times 10^{12}$ and $(3.53 \pm 0.71) \times 10^{12} \text{ cm}^{-2}$, respectively. A photospheric O VI feature is seen in the *FUSE* spectrum of this DA. As seen by Bannister et al. (2003), the velocities of the absorption features are inconsistent across the high ions. Here, the circumstellar C IV is shifted by $-23.55 \pm 3.96 \text{ km s}^{-1}$ with respect to the photospheric C IV component; the circumstellar Si IV is shifted by $-30.6 \pm 0.64 \text{ km s}^{-1}$. Given the poor match to any detected ISM absorption, the non-photospheric material seen in the spectrum of this star may be located near the star in a circumstellar disc or be further evidence of the vaporization of planetesimals material.

Two components are seen in the ISM, giving $v_{\text{ISM, pri}} = -34.7 \pm 1.5 \text{ km s}^{-1}$ and $v_{\text{ISM, sec}} = -13 \pm 3.2 \text{ km s}^{-1}$. The projected velocity of the G cloud (which is traversed by the sight-line to WD 1611–084) is $-29.26 \pm 1.12 \text{ km s}^{-1}$, and does not compare well with $v_{\text{ISM, pri}}$, $v_{\text{ISM, sec}}$ or v_{CS} .

5.16 WD 1738+669 (REJ 1738+665)

In the case of WD 1738+669, the averaged $v_{\text{phot}} = 30.49 \pm 0.28 \text{ km s}^{-1}$, with C IV, O V and Si IV exhibiting clear non-photospheric absorbing components at $v_{\text{CS}} = -18.36 \pm 4.23 \text{ km s}^{-1}$, giving $v_{\text{CS, shift}} = -48.53 \pm 4.49 \text{ km s}^{-1}$. The measured column densities are $(5.55 \pm 0.61) \times 10^{13}$, $(2.35 \pm 0.29) \times 10^{11}$ and $(3.26 \pm 0.17) \times 10^{12} \text{ cm}^{-2}$ for the circumstellar C IV, O V and Si IV, consistent with the C IV and Si IV column densities of

$(5.01 \pm 0.48) \times 10^{13}$ and $(5.50 \pm 0.13) \times 10^{12} \text{ cm}^{-2}$ found by Dupuis et al. (2009). A circumstellar component is not seen in the N v doublet as in Bannister et al. (2003), due to the inability to co-add doublet components using the measuring technique utilized here. The *FUSE* O vi doublet displays two components at $-32.7 \pm 3.4 \text{ km s}^{-1}$ (the circumstellar component) and $14.9 \pm 1.1 \text{ km s}^{-1}$ (the photospheric component). This gives a $v_{\text{O vi shift}} = -47.6 \pm 3.6 \text{ km s}^{-1}$, similar to that obtained from the STIS measurements. Using the S ii lines, $v_{\text{ISM}} = -20 \pm 0.3 \text{ km s}^{-1}$, comparing well with v_{CS} , but not with the predicted v_{LISM} of $-2.91 \pm 1.37 \text{ km s}^{-1}$ (due to the LIC).

5.17 WD 2023+246 (Wolf 1346)

Again, neither high ion nor circumstellar absorption is seen at this star. Like WD 1337+705, the recent studies by Chayer & Dupuis (2010) and Dupuis et al. (2010) show that in spite of the inclusion of radiative levitation effects, accretion is ongoing. Burleigh et al. (2010, 2011) did not find evidence for a circumstellar gas disc emission and no infrared excess has been observed (Mullally et al. 2007).

5.18 WD 2111+498 (GD 394)

No non-photospheric absorption is seen at this star. The *IUE* data show no C iv, N v or O v absorption, and the GHRS data only cover the 1290–1325 and 1383–1419 Å ranges. $v_{\text{ISM}} = -7.6 \pm 1.3 \text{ km s}^{-1}$, and the GHRS Si iv absorption lines give $v_{\text{phot}} = -7.28 \pm 1.42 \text{ km s}^{-1}$. WD 2111+498 is well known to have an overabundance of silicon, when compared to model predictions (Holberg et al. 1997b). Coupled with a periodic variability in the extreme-UV ($p = 1.150 \pm 0.003$), the inhomogeneous accretion of silicon-rich material has been suggested to account for the high silicon abundance (Dupuis et al. 2000). While Barstow et al. (2003) provided upper limits to the iron and nickel abundances of this star, an analysis by Chayer et al. (2000) found a near solar Fe abundance using the Fe iii lines in the *FUSE* spectrum of WD 2111+498. Since Chayer et al. (1995a) predicted an extremely subsolar Fe abundance, an external source of material was again invoked to explain the observed abundance. Vennes et al. (2006) found that WD 2111+498 in fact had a higher Fe abundance than both WD 0232+035 and WD 0501+527. Schuh, Dreizler & Wolff (2002) could not model WD 2111+498 using their self-consistent diffusion/radiative levitation models, citing the accretion of circumstellar material disturbing the diffusion/radiative balance. Since no radial velocity variations have been seen in WD 2111+498 (Saffer, Livio & Yungelson 1998), there is no evidence for a binary companion from which material may be being accreted, suggesting the accretion of circumstellar material may be occurring. However, in a search for circumstellar gas discs, Burleigh et al. (2010, 2011) found no emission from Ca ii, Fe ii or Si ii in the optical spectrum of this star, and no infrared excess is detected (Mullally et al. 2007).

5.19 WD 2152–548 (REJ 2156–546)

The v_{phot} of WD 2152–548 is measured at $-14.94 \pm 0.46 \text{ km s}^{-1}$, while $v_{\text{ISM}} = -9.2 \pm 0.53 \text{ km s}^{-1}$. The projected v_{LISM} due to the LIC is $-9.73 \pm 1.31 \text{ km s}^{-1}$, matching v_{ISM} . Bannister et al. (2003) found a hint of a circumstellar component at $-1.65 \pm 0.76 \text{ km s}^{-1}$ in the co-add of the C iv doublet. Since this feature was on the edge of detectability in the co-add, and co-addition in velocity space cannot be preformed here, this possible circumstellar feature is not modelled.

5.20 WD 2211–495 (REJ 2214–492)

No circumstellar material is seen at this star. A value of $v_{\text{phot}} = 32.33 \pm 1.37 \text{ km s}^{-1}$ is obtained from the C iv, N v, O v, Si iv absorption features, while the S ii line gives $v_{\text{ISM}} = -1.1 \pm 0.4 \text{ km s}^{-1}$.

Like the fits of WD 0948+534 presented earlier, the 1548 Å component of the C iv doublet is slightly asymmetric and statistically better fitted with one component. A substantial difference in the centroid velocities of the C iv doublet is noted both here, with $v_{1548 \text{ Å}} = 30.5 \pm 0.7 \text{ km s}^{-1}$ and $v_{1550 \text{ Å}} = 37.9 \pm 0.8 \text{ km s}^{-1}$, and by Bannister et al. (2003), implying an unresolved circumstellar component may be present. No other lines display a hint of a secondary component.

5.21 WD 2218+706

WD 2218+706 has previously had circumstellar C iv and Si iv identified in its UV spectrum (Bannister et al. 2003). Here, v_{phot} and v_{CS} were found at -40.04 ± 1.11 and $-17.8 \pm 1.05 \text{ km s}^{-1}$, with $v_{\text{ISM, pri}} = -15.3 \pm 2.64 \text{ km s}^{-1}$ and $v_{\text{ISM, sec}} = -1.2 \pm 4.01 \text{ km s}^{-1}$. $N(\text{C iv}) = (1.19 \pm 0.17) \times 10^{13} \text{ cm}^{-2}$ and $N(\text{Si iv}) = (7.98 \pm 0.59) \times 10^{12} \text{ cm}^{-2}$. The line of sight to WD 2218+706 traverses the LIC, which has a projected velocity of $4.47 \pm 1.37 \text{ km s}^{-1}$, comparing poorly to v_{CS} and the primary ISM component.

5.22 WD 2309+105 (GD 246)

WD 2309+105 does not display any signs of circumstellar material in its high ion absorption-line profiles. The STIS [E140M] data yield a v_{phot} of $-13.45 \pm 0.13 \text{ km s}^{-1}$, lining up with the value of $-13.29 \pm 0.25 \text{ km s}^{-1}$ found by Bannister et al. (2003). Given the lack of circumstellar material in the C iv, N v, O v and Si iv lines, and the O vi non-detection reported by Barstow et al. (2010), the *FUSE* spectrum is not examined here.

5.23 WD 2331–475 (REJ 2334–471)

Circumstellar material is not observed. A double component fit was statistically preferred for the Si iv doublet (at 34.00 and 54.64 km s^{-1}) and the N v 1243 Å component (at 19.7 and 43.51 km s^{-1}) by Bannister et al. (2003). However, since neither of the components were consistent across the N v and Si iv features and the secondary components were not unambiguous, circumstellar material is not modelled here. The v_{phot} measured is $38.88 \pm 0.72 \text{ km s}^{-1}$, and $v_{\text{ISM}} = 14.3 \pm 0.7 \text{ km s}^{-1}$.

ACKNOWLEDGMENTS

NJD, MAB, MB and JF acknowledge the support of STFC. BYW would like to acknowledge Guaranteed Time Observer funding for this research through NASA Goddard Space Flight Center grant 005118. We thank Ian Crawford for useful comments and suggestions.

REFERENCES

- Abbott D., 1982, *ApJ*, 259, 282
 Asplund M., Grevesse N., Jacques Sauval A., Scott P., 2009, *ARA&A*, 47, 481
 Bannister N., Barstow M., Holberg J., Bruhweiler F., 2003, *MNRAS*, 341, 477
 Barstow M., Good S., Holberg J., Hubeny I., Bannister N., Bruhweiler F., Burleigh M., Napowotzki R., 2003, *MNRAS*, 341, 870

- Barstow M., Boyce D., Welsh B., Lallement R., Barstow J., Forbes A., Preval S., 2010, *ApJ*, 723, 1762
- Barstow M. et al., 1993, *MNRAS*, 264, 16
- Bruhweiler F., Kondo Y., 1981, *ApJ*, 248, 123
- Burleigh M. et al., 2010, in Werner K., Rauch T., eds, *AIP Conf. Proc. Vol. 1273, 17th European White Dwarf Workshop*. AIP, New York, p. 473
- Burleigh M. et al., 2011, in Schuh S., Drechsel H., Heber U., eds, *AIP Conf. Proc. Vol. 1331, Planetary Systems Beyond the Main Sequence*, AIP, New York, p. 289
- Chayer P., Dupuis J., 2010, in Werner K., Rauch T., eds, *AIP Conf. Proc. Vol. 1273, 17th European White Dwarf Workshop*. AIP, New York, p. 394
- Chayer P., LeBlanc F., Fontaine G., Wesemael F., Michaud G., Vennes S., 1994, *ApJ*, 436, 161
- Chayer P., Fontaine G., Wesemael F., 1995a, *ApJS*, 99, 189
- Chayer P., Vennes S., Pradhan A., Thejl P., Beauchamp A., Fontaine G., Wesemael F., 1995b, *ApJ*, 454, 429
- Chayer P., Kruk J., Ake T., Dupree A., Malina R., Siegmund O., Sonneborn G., Ohl R., 2000, *ApJ*, 538, 91
- Chayer P., Oliveira C., Dupuis J., Moos H., Welsh B., 2006, in Sonneborn G., Moos H. W., Anderson B.-G., eds, *ASP Conf. Ser. Vol. 348, Astrophysics in the Far Ultraviolet: Five Years of Discovery with FUSE*. Astron. Soc. Pac., San Francisco, p. 209
- Chu Y.-H. et al., 2011, *AJ*, 142, 75
- Debes J., Sigurdsson B., 2002, *ApJ*, 572, 556
- Debes J., Hoard D., Wachter S., Leisawitz D., Cohen M., 2011, *ApJS*, 197, 38
- Dickinson N., Barstow M., Hubeny I., 2012, *MNRAS*, 412, 3222
- Dupree A., Raymond J., 1982, *ApJ*, 263, 63
- Dupree A., Raymond J., 1983, *ApJ*, 275, 71
- Dupuis J., Chayer P., Vennes S., Damian J., Kruk J., 2000, *ApJ*, 537, 977
- Dupuis J., Oliveira C., Hébrard G., Moos H., Sonnentrucker P., 2009, *ApJ*, 690, 1045
- Dupuis J., Chayer P., Hénault-Brunet V., 2010, in Werner K., Rauch T., eds, *AIP Conf. Proc. Vol. 1273, 17th European White Dwarf Workshop*. AIP, New York, p. 412
- Farihi J., Zuckerman B., Becklin E., 2008, *ApJ*, 674, 431
- Farihi J., Jura M., Zuckerman B., 2009, *ApJ*, 694, 805
- Farihi J., Barstow M., Redfield S., Dufour P., Hambly N., 2010, *MNRAS*, 404, 2123
- Frew D., Parker Q., 2006, in Barlow M. J., Méndez R. H., eds, *Proc. IAU Symp. 234, Planetary Nebulae in our Galaxy and Beyond*. Cambridge Univ. Press, Cambridge, p. 49
- Gänsicke B., Marsh T., Southworth J., Rebassa-Masergas A., 2006, *Sci*, 314, 1908
- Gänsicke B., Marsh T., Southworth J., 2007, *MNRAS*, 380, L35
- Gänsicke B., Koester D., Marsh T., Rebassa-Masergas A., Southworth J., 2008, *MNRAS*, 391, L103
- Holberg J., Bruhweiler F., Anderson J., 1995, *ApJ*, 443, 753
- Holberg J., Barstow M., Green E., 1997a, *ApJ*, 474, 127
- Holberg J., Barstow M., Lanz T., Hubeny I., 1997b, *ApJ*, 484, 871
- Holberg J., Barstow M., Sion E., 1998, *ApJS*, 119, 207
- Holberg J., Barstow M., Sion E., 1999, in Solheim S.-E., Meistas E. G., eds, *ASP Conf. Ser. Vol. 169, 11th European Workshop on White Dwarfs*. Astron. Soc. Pac., San Francisco, p. 485
- Indebetouw R., Shull J., 2004, *ApJ*, 605, 205
- Jura M., 2003, *ApJ*, 584, 91
- Jura M., 2006, *ApJ*, 653, 613
- Jura M., 2008, *ApJ*, 135, 1785
- Jura M., Farihi J., Zuckerman B., 2007, *ApJ*, 663, 1285
- Jura M., Farihi J., Zuckerman B., 2009, *AJ*, 137, 3191
- Kawka A., Vennes S., Dupuis J., Chayer P., Lanz T., 2008, *ApJ*, 675, 1518
- Kilic M., Redfield S., 2007, *ApJ*, 660, 641
- Kilic M., von Hippel T., Legget S., Winget D., 2005, *ApJ*, 632, 115
- Kilic M., von Hippel T., Legget S., Winget D., 2006, *ApJ*, 646, 474
- Koester D., Wilken D., 2006, *A&A*, 453, 1051
- Lallement R., Welsh B., Barstow M., Casewell S., 2011, *A&A*, 533, 140
- Marsh M., Barstow M., Buckley D., Burleigh M., Holberg J., Koester D., O'Donoghue D., Penny A. A. E. S., 1997, *MNRAS*, 286, 369
- Melis C., Farihi J., Dufour P., Zuckerman B., Burgasser A., Bergeron P., Bochanski J., Simcoe R., 2011, *ApJ*, 732, 90
- Mullally F., Kilic M., Reach W., Kuchner M., von Hippel T., Burrows A., Winget D., 2007, *ApJS*, 171, 206
- Napiwotzki R., Schönberner D., 1995, *A&A*, 301, 545
- Redfield S., Falcon R., 2008, *ApJ*, 683, 207
- Redfield S., Linsky J., 2002, *ApJS*, 139, 439
- Redfield S., Linsky J., 2004, *ApJ*, 602, 776
- Redfield S., Linsky J., 2008, *ApJ*, 673, 283
- Saffer R., Livio M., Yungelson L., 1998, *ApJ*, 502, 394
- Sahu M. et al., 1999, *ApJ*, 523, 159
- Savage B., Lehner N., 2006, *ApJS*, 162, 134
- Schuh S., Dreizler S., Wolff B., 2002, *A&A*, 382, 164
- Seaton M., 1996, *Ap&SS*, 237, 107
- Strömgren B., 1939, *ApJ*, 89, 526
- Su K. et al., 2007, *ApJ*, 657, 41
- Tat H., Terzian Y., 1999, *PASP*, 111, 1258
- Unglaub K., 2007, in Napiwotzki R., Burleigh M. R., eds, *ASP Conf. Ser. Vol. 372, 15th European Workshop on White Dwarfs*. Astron. Soc. Pac., San Francisco, p. 201
- Unglaub K., 2008, *A&A*, 486, 923
- Vallerga J., 1998, *ApJ*, 497, 921
- Vallerga J., Vedder P., Craig N., Welsh B., 1993, *ApJ*, 411, 729
- Vennes S., Lanz T., 2001, *ApJ*, 553, 399
- Vennes S., Thorstensen J., 1994, *AJ*, 108, 1881
- Vennes S., Chayer P., Dupuis J., Lanz T., 2006, *ApJ*, 652, 1554
- Vink J., de Koter A., Lamers H., 2001, *A&A*, 369, 574
- von Hippel T., Kuchner M., Kilic M., Mullally F., Reach W., 2007, *ApJ*, 662, 544
- Votruba V., Feldmeier A., Krticka J., Kubat J., 2010, *Ap&SS*, 329, 159
- Welsh B., 1991, *ApJ*, 373, 556
- Welsh B., Lallement R., 2005, *A&A*, 436, 615
- Welsh B., Lallement R., 2010, *PASP*, 122, 1320
- Welsh B., Sfeir D., Sirk M., Lallement R., 1999, *A&A*, 352, 308
- Welsh B., Lallement R., Vergely J.-L., Raimond S., 2010a, *A&A*, 510, 54
- Welsh B., Wheatley J., Siegmund O., Lallement R., 2010b, *ApJ*, 712, L199
- Zuckerman B., Reid I., 1998, *ApJ*, 505, 143
- Zuckerman B., Koester D., Reid I., Hünsch M., 2003, *ApJ*, 596, 477

This paper has been typeset from a $\text{\TeX}/\text{\LaTeX}$ file prepared by the author.