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DAZ White Dwarfs in the SPY Sample

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Abstract. We search for faint Ca II lines in the spectra of about 800 apparently single white dwarfs observed at high resolution for the SPY (ESO Supernova Progenitor Survey) survey. Photospheric Ca is detected in 24 DAZ; in 25 mostly hot objects the observed lines must be interstellar. The distribution of metal abundances is discussed and compared with the predictions of the accretion/diffusion scenario. We argue that the observations are easier to understand in a scenario of continuous ongoing accretion with rates varying with the conditions of the ambient medium, rather than with the strongly idealized "two phase accretion/diffusion scenario" of Dupuis et al. (1992, 1993a, 1993b).

1. Introduction

A breakthrough in the search for metal lines in cool DA white dwarfs came with the work of Zuckerman & Reid (1998) and Zuckerman et al. (2003) (henceforth Z98 and Z03), which increased the number of known DAZ to approximately 20. Although very large telescopes are necessary for this study, the effort is worthwhile. The accretion-diffusion scenario, which was developed from earlier suggestions by many authors in a series of three fundamental papers by Dupuis et al. (1992, 1993a,b), is not without serious problems as discussed in detail in Z03. Perhaps the most difficult problem is the lack of any correlation between objects with metals and the conditions of the interstellar matter from which they are presumably accreted (Aannestad et al. 1993). In this respect the new study of the DAZ is promising since the diffusion time scales in a DAZ with $T_{\rm eff}$ around 10000 K are only 10^3 yrs. as compared to $\approx 10^6$ yrs. in a DZ with helium-rich atmosphere with much deeper convection zone (Dupuis et al. 1992). The DAZ should therefore be accreting right now as we observe it or in any case still be very close to the place where accretion occurred. A DZ on the contrary could have traveled many parsec away from the accretion episode. The DAZ therefore promise to become a more efficient tool for the study of the relation between interstellar matter and accretion rates. In this paper we report on an extension of the search using a sample from the southern hemisphere observed with the VLT, which doubles the number of known DAZ.

2. Observations

The spectra of our sample were obtained as part of the search for close double degenerate binary systems in the ESO SN Ia progenitor survey (=SPY, Napiwotzki et al. 2001, 2003). A first part of about 200 white dwarfs of the total sample was analyzed by Koester et al. (2001). The selection of the sample, the specific nature of the search as a "filler project" for mediocre weather conditions, and the reduction procedures are described in the first paper. In the meantime the survey is almost finished and the present sample consists of approximately 1700 spectra for about 1000 objects. Preliminary atmospheric parameters (T_{eff},$\log g$) were determined for most objects using the "analysis pipeline" described in Koester et al. (2001); the final analysis is in preparation (Voss et al. 2005, in prep.).

3. Automated Search for the Ca II K Line and Measurements

Because of the very large amount of data we have developed automatic search routines to select a smaller sample for more detailed study. Identification of a Ca II K line employs three methods: direct integration of an equivalent width around the position of the K line, fit with a Gaussian, and fit with a Lorentzian profile. The probability for a real line being present was determined by a combination of all three results with some weighting determined from empirical tests. All spectra where a line was suspected were then individually inspected by eye. If the line was confirmed the equivalent width and Doppler velocity from the position of the line center were measured. The Doppler velocity of the hydrogen lines (all corrected to heliocentric velocities) was obtained from the SPY analysis for variable radial velocities. From the equivalent widths the Ca abundances were determined using the T_{eff} and $\log g$ from the preliminary fits described above and the same table of equivalent widths vs. abundances used in Z03. If no line is detected an upper limit is determined using the (spurious) equivalent width plus its 1σ error.

4. The DAZ and their Ca Abundances

Ca II lines in the spectra may indicate photospheric Ca, but may also be due to interstellar absorption. This is more likely for the hotter objects. The resonance lines should become unobservable above approximately 25000 K due to the ionization to Ca III; in addition the hotter stars tend to be farther away from the sun. We have used two criteria to select those objects, where the metals are very likely photospheric: T_{eff} below 25000 K and the difference between the radial velocities from Ca and the Balmer lines should be comparable to their combined 1σ errors. This "photospheric" sample includes 24 objects and is given in Table 1. We recover 6 objects in this table, which have been discovered as DAZ before by Z98 or Z03; they are marked as "DAZ"; the 18 other objects are new detections. We also found 25 objects with Ca, where the lines must clearly be interstellar because of the high $T_{\rm eff}$ or a large discrepancy in radial velocities.

Our sample also contains 454 apparently normal DA below $T_{\rm eff} \approx 30000$ K with no indication for metals, for which we have atmospheric parameter determinations. For these we determine upper limits for Ca/H as described above. Fig. 1a shows the results for these 478 objects. The most notable effect in this figure is the apparent increase of abundances and upper limits with temperature, which is of course a result of the decreasing line strength of the Ca line due to increasing ionization of Ca II. This is demonstrated by the solid line, which gives the locus of constant equivalent width of 15 mÅ according to our theoretical models (with $\log g = 8.0$). This is the approximate visibility limit for our best spectra; with decreasing S/N the limit moves upwards to higher EW.

Table 1. Hydrogen-rich white dwarfs with atmospheric Ca. Equivalent widths of the Ca II K line are in mÅ. The radial velocities (in km/s) are heliocentric and errors are 1σ errors; the Balmer velocities v_H are averages from Hα and Hβ.

object	EW [mÅ]	$T_{\rm eff}$ [K]	$\log g$	log Ca/H	v_H [km s^{-1}]	v_{Ca} [km s^{-1}]	rem
HS 0047+1903	270	16600	7.8	−5.6	25 ± 2	24 ± 3	
HE 0106−3253	107	15700	8.0	−6.4	57 ± 1	55 ± 1	
WD 0243−026	219	6800	8.2	−9.9	30 ± 2	30 ± 2	DAZ
HS 0307+0746	223	10200	8.1	−7.6	13 ± 2	13 ± 2	
WD 0408−041	77	14400	7.8	−7.1	21 ± 2	19 ± 1	
WD 1015+161	58	19300	7.9	−6.3	65 ± 2	67 ± 2	
WD 1116+026	135	12200	7.9	−7.3	47 ± 1	46 ± 1	
WD 1124−293	118	9700	8.1	−8.5	30 ± 1	29 ± 1	DAZ
WD 1150−153	208	12800	7.8	−6.7	25 ± 2	22 ± 2	
WD 1202−232	58	8800	8.2	−9.7	21 ± 1	23 ± 1	DAZ
WD 1204−136	125	11200	8.0	−7.7	37 ± 3	36 ± 2	DAZ
HE 1225+0038	38	9400	8.1	−9.7	12 ± 1	13 ± 2	
HE 1315−1105	74	9400	8.4	−9.2	33 ± 1	33 ± 1	
WD 1457−086	45	20400	8.0	−6.3	22 ± 2	19 ± 2	
WD 1614+160	31	17400	7.8	−7.2	−24 ± 1	−26 ± 3	
WD 1826−045	88	9200	8.1	−9.1	0 ± 2	−1 ± 1	DAZ
WD 2105−820	80	10300	8.0	−8.6	42 ± 3	45 ± 3	
WD 2115−560	294	9700	8.1	−7.6	4 ± 2	5 ± 1	
HS 2132+0941	66	13200	7.7	−7.7	−4 ± 1	−6 ± 3	
WD 2149+021	15	17300	7.9	−7.6	28 ± 1	26 ± 3	
HE 2221−1630	231	10100	8.2	−7.6	45 ± 3	45 ± 1	
HS 2229+2335	62	18600	7.9	−6.3	−12 ± 2	−12 ± 1	
HE 2230−1230	47	20300	7.7	−6.3	14 ± 2	11 ± 3	
WD 2326+049	238	12100	7.9	−6.8	42 ± 2	41 ± 1	DAZ

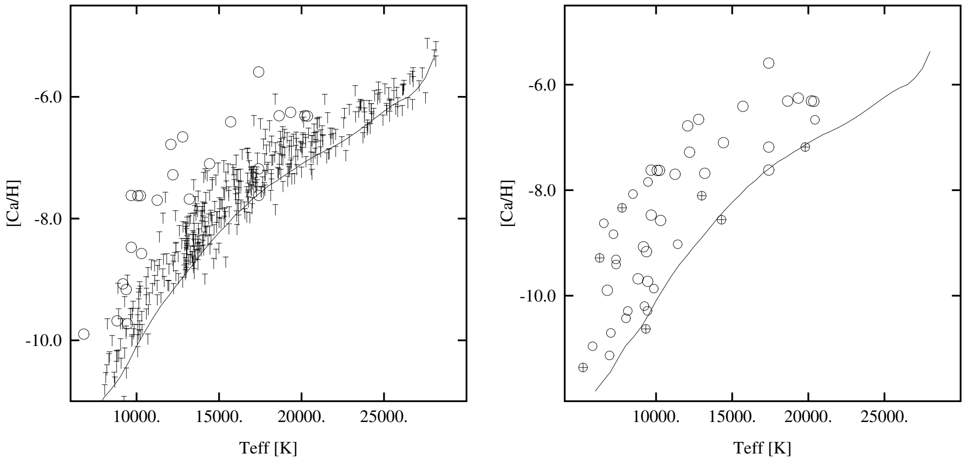

Figure 1. a: (left) Logarithmic Ca abundances [Ca/H] for 24 and upper limits for 454 DA white dwarfs of the SPY sample. Open circles are positive detections, the other symbols are upper limits. The solid line indicates a line of constant equivalent width of 15 mÅ, which is approximately the detection limit for the spectra with highest S/N. b: (right) Logarithmic Ca abundances [Ca/H] for the combined sample from this work (larger circles) with the results from Z03 (smaller circles). Included from the latter paper are the white dwarfs known or suspected to be in binary systems (circles with + sign).

5. Results and Discussion

Taking together the present and the Z03 positive detections in apparently single DA we have parameters and Ca abundances for 41 DAZ. These are shown – together with the data for 7 binaries from Z03 – in Fig. 1b. With the exception of one object, there seems to be an upper limit to the abundance around [Ca/H] $= -6.5$, which is approximated by several objects with $T_{\rm eff} = 12000$ - 20000 K. Below $T_{\rm eff} = 10000$ K the maximum observed abundance decreases, very likely reflecting the increasing depth of the convection zone and the dilution of the accreted matter within a much larger mass. The lower limit is set by the observational limits, strongly temperature-dependent due to the ionization of Ca II to Ca III.

As a basis for some conclusions from these results we use the scenario and results of the three Dupuis et al. papers (Dupuis et al. 1992, 1993a,b). It should be clear, however, and has been stated very clearly in those papers, that this scenario is highly idealized and needs refinement, when our knowledge about the nature of the local ISM advances. We concentrate on the 10000 K range and use estimates derived from the Dupuis et al. work. Using their Fig. 13 in the first paper, we find that the Ca surface abundance in a DA at 10000 K drops by 25 orders of magnitude in 7×10^4 yrs. This translates into a diffusion time scale $\tau_d = 10^3$ yrs, assuming a simple exponential decay.

From our observations in Fig. 1b we estimate an upper limit of -7.5 and a lower (observational) limit of -10.5 for the logarithmic abundances at 10000 K. If the upper limit corresponds to the steady state abundance for a white dwarf crossing a dense cloud of interstellar matter, we would expect the abundance to fall below the observational limit approximately 7×10^3 yrs after exit from the cloud, and we would expect the region between upper and lower limit to be homogeneously populated (exponential decay leads to constant times for one decade of the abundance). While the latter conclusion is supported by the observations, taking the Dupuis scenario literally we would expect many more objects at the upper limit, since the cloud crossing time – during which the abundances should stay constant at the steady state value – is assumed to be 10^6 yrs. Another conclusion would be that the percentage of DA with observable metals should approximate the ratio of the cloud crossing time to the time spent between encounters, that is 1:50. This is clearly at odds with the observations, which find a much larger fraction of DAZ (more than 20% in Z03).

Another estimate which can be derived from the short visibility of the metals is that a typical white dwarf with a space velocity of 20 km/s can only have traveled about 0.13 pc since the end of the accretion episode. This confirms again the statement made in the introduction, that the DAZ must still be very close to the place where accretion occurred.

The steady state abundance is given by (see Dupuis et al. 1993a)

$$X_{ss} = \frac{\tau_d \dot{M} X_\odot}{(\Delta M_{cz}/M)(M/M_\odot)}$$

with stellar mass M, accretion rate $\dot{M}$ in $M_\odot$/yr, diffusion time scale τ_d, mass in the convection zone ΔM_{cz}, and solar metal abundance $X_\odot$. We are assuming here that the accretion occurs with solar composition material. Using estimates for a $0.6\,\mathrm{M}_\odot$ DA white dwarf we find the necessary accretion rates for the upper abundance limit of [Ca/H] = −7.5 to be $\dot{M} = 10^{-15}\,M_\odot\,\mathrm{yr}^{-1}$. For the lower limit ([Ca/H] = −10.5) we find $\dot{M} = 10^{-18}\,M_\odot\,\mathrm{yr}^{-1}$. These numbers are completely consistent with the numbers derived by Dupuis et al. for the accreting helium-rich white dwarfs.

Can these accretion rates be sustained by the conditions of the local ISM? Our knowledge is far from complete, though promising advances are currently occurring through the work of Redfield & Linsky (2002, 2004); Lehner et al. (2003) and others. The emerging picture is that the Local Bubble (within 70 pc) contains very little cold gas in the form of H I or H_2. The dominant phase of the ISM is the warm phase with typical temperatures of about 7000 K. Though the distribution of this gas is not yet known in much detail, Redfield & Linsky (2004) are able to distinguish from 1 to 3 individual components in the absorption lines of many different ions along the lines of sight. Assuming a typical H I density of 0.1 cm^{-3} they derive typical length scales for these clouds between 0.1 and 11 pc, with a mean value of 2.2 pc. With a very simple calculation, assuming that all the clouds within 50 pc (where most of their targets are located) cover the solid angle of the whole sky twice, we find a filling factor ranging from 0.5% to 50%, consistent with the observed DAZ fraction. The crossing times for such clouds would however still be large compared to the visibility times after the cloud encounter, in conflict with the homogenous distribution of abundances.

This problem leads us to consider an alternative scenario, in which the abundances in all observed objects are considered as steady state abundances for ongoing accretion in slightly different ambient conditions. If we take the "cloud sizes" discussed by Redfield & Linsky (2004) as the typical scale for changes in LISM conditions the time scale connected with that would be larger than 10^5 yrs for a white dwarf traveling at 20 km/s, much larger than the diffusion time scale and enough to reach approximately steady state. As shown above the accretion rates necessary to explain the observed abundances would be $10^{-15} - 10^{-18}\,M_\odot\,\mathrm{yr}^{-1}$. Koester (1976) and Wesemael (1979) have argued that the Hoyle-Bondi accretion formula is not applicable at the low densities of the warm ISM phase and that therefore accretion rates would be insignificant. This has, however, been disputed by Alcock & Illarionov (1980), who argue that in a partially ionized plasma interactions are always strong enough to lead to accretion close to the Hoyle-Bondi value. If we follow their arguments the accretion rate is $\dot{M} = 2.5\pi(GM)^2)\,\rho_\infty/v^3 \approx 2\times10^{-17}M_\odot/\mathrm{yr}$ and an easily possible variation of a factor of 50 up and down due to variations of relative velocity v or hydrogen density ρ_∞ could explain all observations.

While we believe that this paradigm shift from "two-phase" to continuous accretion combined with heavy element diffusion is supported by our new observations and the simple arguments above, many questions remain open. We will probably in the near future understand much better the detailed structure of the LISM through work along the lines of Redfield & Linsky (2002, 2004) and Lehner et al. (2003). The calculation of diffusion time scales needs to be extended to hotter DA, to be able to determine the accretion rates more accurately. And finally and probably most difficult, the accretion rates under conditions relevant for white dwarfs need more study.

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