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SDSS J104341.53+085558.2: a second white dwarf with a gaseous debris disc

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ABSTRACT

Intermediate-resolution spectroscopy of the white dwarf SDSS J104341.53+085558.2 (SDSS J1043+0855) contains double-peaked emission lines of Ca II λλ8498, 8542, 8662 and identifies this object to be the second single white dwarf to be surrounded by a gaseous disc of metal-rich material, similar to the recently discovered SDSS J1228+1040. A photospheric magnesium abundance of 0.3 times the solar value, determined from the observed Mg II λ4481 absorption line, implies that the white dwarf is accreting from the circumstellar material. The absence of Balmer emission lines and of photospheric He I λ4471 absorption indicates that the accreted material is depleted in volatile elements and, by analogy with SDSS J1228+1040, may be the result of the tidal disruption of an asteroid. Additional spectroscopy of the DAZ white dwarfs WD 1337+705 and GD 362 does not reveal Ca II emission lines. GD 362 is one of the few cool DAZ white dwarfs that display strong infrared flux excess, thought to be originating in a circumstellar dust disc, and its temperature is probably too low to sublimate sufficient amounts of disc material to generate detectable Ca II emission. WD 1337+705 is, like SDSS J1228+1040 and SDSS J1043+0855, moderately hot, but has the lowest Mg abundance of those three stars, suggesting a possible correlation between the photospheric Mg abundance and the equivalent width of the Ca II emission triplet. Our inspection of 7360 white dwarfs from the Sloan Digital Sky Survey Data Release 4 fails to unveil additional strong 'metal gas disc' candidates, and implies that these objects are rather rare.

Key words: stars: individual: SDSS J104341.53+085558.2 – white dwarfs.

1 INTRODUCTION

Two decades ago, Zuckerman & Becklin (1987) detected an infrared excess around the DA white dwarf G29−38 as part of their search for cool companions to white dwarfs. Graham et al. (1990b) and Kuchner, Koresko & Brown (1998) convincingly ruled out the presence of a low-mass stellar companion, and Graham et al. (1990a) suggested that the observed infrared excess is caused by a ring of circumstellar dust around the white dwarf, a model further developed by Jura (2003, 2006), and underpinned by *Spitzer* observations (Reach et al. 2005). Another four single white dwarfs with infrared excesses have since then been discovered (GD 362, Becklin et al. 2005; Kilic et al. 2005; GD 56, Kilic et al. 2006; WD 1150−153, Kilic & Redfield 2007; WD 2115−560, von Hippel et al. 2007), plus one additional candidate (G167−8, Farihi et al. 2007). Two common characteristics of all those white dwarfs with circumstellar dust discs are their low temperatures, $T_{\rm eff} < 15\,000$ K, and their substantial abundances of photospheric calcium (Koester, Provencal & Shipman 1997; Zuckerman et al. 2003; Koester et al. 2005). No evidence for the presence of dusty discs has been found around white dwarfs hotter than ≃16 000 K (Kilic et al. 2006).

Recently, Gänsicke et al. (2006) detected emission lines of Ca II λλ8498, 8542, 8662 in the DA white dwarf SDSS J122859.93+104032.9, which has a temperature of 22 000 K, much hotter than the five white dwarfs exhibiting infrared excess. The double-peaked shape of the Ca II emission lines unambiguously identifies the presence of a rotating ring of gas around SDSS J1228+1040. Time-resolved spectroscopic and photometric follow-up observations of SDSS J1228+1040 ruled out the possibility of it being a close binary system where an accretion disc would form from material lost by the companion star.

The detection of a strong Mg II λ4481 absorption line identifies SDSS J1228+1040 as a DAZ white dwarf, and indicates a photospheric magnesium abundance close to the solar value. Given that the gravitational sedimentation time-scales in the radiative atmosphere are very short (Koester & Wilken 2006) and radiative levitation is negligible (Chayer et al. 1994), it is clear that SDSS J1228+1040 is accreting from the circumstellar gas disc.

The absence of hydrogen or helium emission lines from the ring, along with the absence of helium absorption lines from the photosphere of the white dwarf, indicates that the circumstellar disc must

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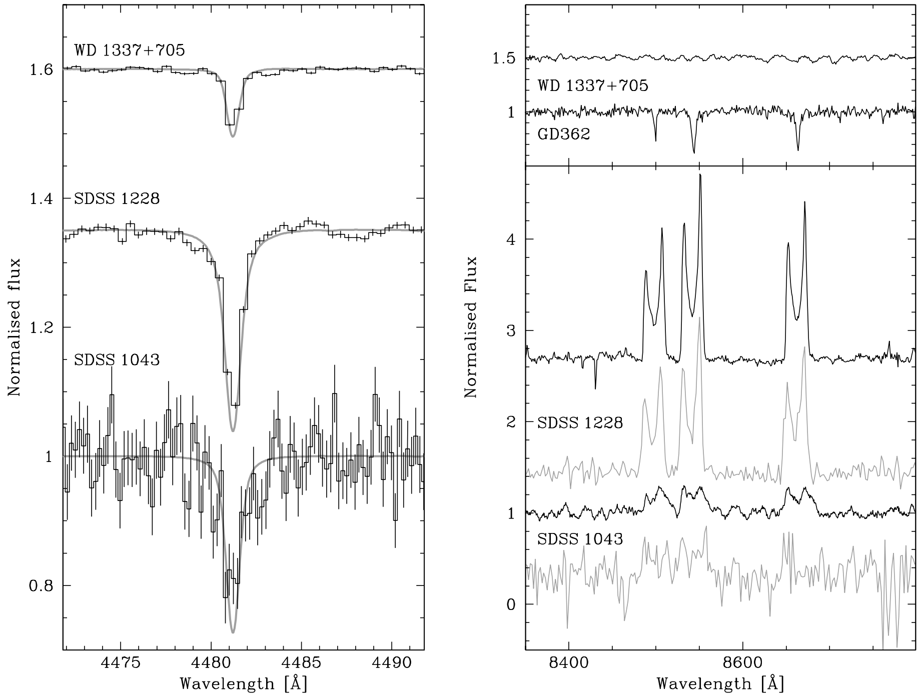

Figure 1. Left-hand panel: photospheric Mg II λ4481 absorption lines in the WHT spectra of WD 1337+705, SDSS J1228+1040 and SDSS J1043+0855 (black lines). Overplotted in grey are the best-fitting white dwarf models; the corresponding Mg abundances are given in Table 1. Right-hand panel: WHT (black lines) and SDSS (grey lines) spectra of SDSS J1043+0855, SDSS J1228+1040, WD 1337+705 and GD 362. All spectra are normalized to a continuum flux of one, and offset by suitable amounts. The top panel shows the WHT spectra of WD 1337+705 and GD 362 on a different flux scale.

be depleted in volatile elements, and Gänsicke et al. (2006) concluded that the most likely origin of this disc is a tidally disrupted asteroid. SDSS J1228+1040 with its circumstellar gas disc hence appears as the hot counterpart to G29−38 and the other cool DAZ white dwarfs harbouring dust discs. Gänsicke et al. (2006) identified SDSS J104341.53+085558.2 (henceforth SDSS J1043+0855) as a good candidate for being the second white dwarf with a circumstellar gaseous metal disc. We present here follow-up observations that confirm this suggestion.

2 OBSERVATIONS

Intermediate-resolution spectroscopy of SDSS J1043+0855 was obtained at the William Herschel Telescope (WHT) in service mode on 2007 February 3, using the double-arm spectrograph ISIS. The blue arm was equipped with the R1200B grating and a 4k × 2k pixel EEV detector, providing a spectral coverage of ≃4000–4700 Å at a resolution (FWHM) of ≃0.9 Å. In the red arm, the R600R grating was used along with the low-fringing 4k × 2k pixel RED-PLUS detector, providing a spectral coverage of ≃7460–9100 Å at a resolution of ≃2 Å. A total of four pairs of blue/red spectra with individual exposure times of 20 min were obtained under poor seeing (∼ 2.5 arcsec) conditions. In 2006 June, we also obtained WHT spectroscopy of GD 362, which is one of the cool ($T_{\rm eff} = 9740$ K, Gianninas, Dufour & Bergeron 2004) DAZ white dwarfs exhibiting infrared excess (Becklin et al. 2005; Kilic et al. 2005), and the hotter DAZ WD 1337+705 (Grw+70 5824), with an identical setup, except for using the 4.5k × 2k pixel Marconi detector in the red arm, which is subject to noticeable fringing in the red end of the spectrum. All data were reduced in a standard way using Starlink software and the PAMELA/MOLLY packages.

As anticipated from its Sloan Digital Sky Survey (SDSS) spectrum, SDSS J1043+0855 displays double-peaked Ca II λλ8498, 8542, 8662 lines (Fig. 1, right-hand panel), although at substantially lower strengths compared with SDSS J1228+1040. The relatively low quality of the *I*-band spectra prevents a dynamical analysis of the disc emission, but the morphology of the line profiles in SDSS J1043+0855 is fairly similar to those observed in SDSS J1228+1040 (Gänsicke et al. 2006), suggesting broadly similar parameters. No significant trace of Ca II emission is found in WD 1337+705, within the limitations imposed by the CCD fringing. The red spectrum of GD 362 contains Ca II in absorption from the white dwarf photosphere. The spectra from the blue arm reveal the presence of photospheric Mg II λ4481 absorption in SDSS J1043+0855 and WD 1337+705 (Fig. 1, left-hand panel). GD 362 is too cold (Gianninas et al. 2004) to exhibit significant Mg II λ4481 absorption. The absence of Zeeman oting in the Ca triplet limits the magnetic field strength in GD 362 to $\lesssim 30$ kG [see Dufour et al. (2006) for the weakly magnetic DZ white dwarf G165−7].

3 WHITE DWARF PARAMETERS OF SDSS J1043+0855

We have used a grid of model spectra calculated with TLUSTY/SYNSPEC (Hubeny 1988; Hubeny & Lanz 1995) to analyse the SDSS and WHT spectra of SDSS J1043+0855. The model atmospheres were computed assuming a pure hydrogen composition and local thermodynamic equilibrium (LTE), and sequences of synthetic spectra were subsequently calculated for a variety of Mg abundances. In order to determine the temperature and surface gravity of the white dwarf, we fitted the entire spectrum, as well as the normalized Hα to Hϵ lines. The Balmer lines reach their maximum

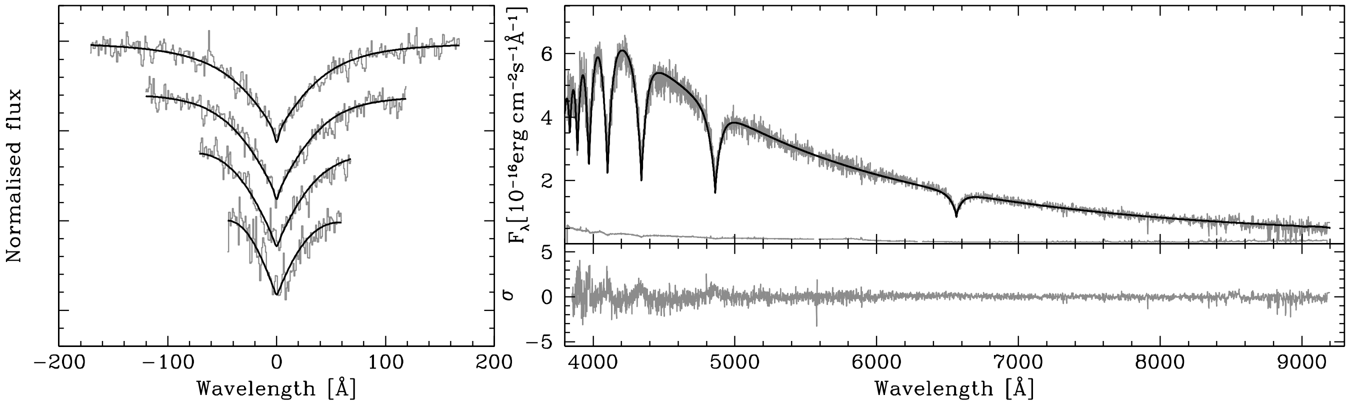

Figure 2. Top right-hand panel: the SDSS spectrum and flux error of SDSS J1043+0855 (grey lines; plate 1240, MJD 52734, fibre 37), along with the best fit to the full spectral range (black line), which is dominated by the slope of the continuum (hence the significant residuals in the Balmer lines, shown in the bottom right-hand panel). Left-hand panel: the best fit (black lines) to the normalized Hβ to Hϵ line profiles (grey lines, top to bottom), which is used to determine the effective temperature and surface gravity ($T_{\rm eff} = 18\,330$ K, $\log g = 8.09$).

equivalent widths around $T_{\rm eff} = 13\,500$ K for $\log g = 8$, or ∼1000 K higher (lower) for $\log g = 8.5$ ($\log g = 7.5$), and consequently a fit to the normalized Balmer line profiles results usually in a 'hot' and a 'cold' solution of comparable quality. We used the fit to the entire data, continuum plus lines, to choose the solution that better agrees with the slope of the spectrum. Our fit includes Hα–Hϵ. The higher Balmer lines, even though more sensitive to the surface gravity (e.g. Kepler et al. 2006), are of too poor a quality in the SDSS data to be useful. The best-fitting $T_{\rm eff}$ and $\log g$ and their 1σ errors are obtained from a bicubic spline interpolation to the χ^2 values on the $T_{\rm eff}$–$\log g$ grid covered by our model spectra.

The parameters from the best fit to the normalized line profiles are $T_{\rm eff} = 18\,330 \pm 523$ K and $\log g = 8.09 \pm 0.11$ (Fig. 2). Using an updated version of the evolutionary sequences in Bergeron, Wesemael & Beauchamp (1995), a white dwarf mass of $M_{\rm wd} = 0.67 \pm 0.07\,{\rm M}_\odot$, a radius of $8.55 \pm 0.65 \times 10^8$ cm and a cooling age of 1.3×10^8 yr are derived. The flux scaling factor between the observed and model fluxes implies a distance of 224 ± 18 pc. We find good agreement with the surface gravity determined by Eisenstein et al. (2006) with their AUTOFIT procedure, $\log g = 8.06 \pm 0.07$. Our effective temperature is hotter by ∼1300 K compared with their value of $T_{\rm eff} = 17\,044 \pm 288$ K, suggesting that differing details in the fitting procedure cause systematic uncertainties that can be somewhat larger than the statistical errors.

4 PHOTOSPHERIC MG II ABUNDANCES AND CA II EMISSION-LINE EQUIVALENT WIDTHS

We have determined the photospheric Mg abundances of SDSS J1043+0855 and WD 1337+305 by fitting TLUSTY/SYNSPEC models with the best-fitting $T_{\rm eff}$ and $\log g$ but variable Mg abundances to the normalized Mg II λ4481 line profile observed in the WHT spectra. The widths of the observed Mg II lines are consistent in both cases with very low rotational velocities, $v \sin i < 15\,{\rm km\,s^{-1}}$. We find for SDSS J1043+0855 a Mg abundance of 0.30 ± 0.15 times the solar value, or $\log({\rm Mg/H}) = -4.94^{+0.17}_{-0.30}$. For WD 1337+705, our fit results in a Mg abundance of 0.07 ± 0.01 times the solar value, or $\log({\rm Mg/H}) = -5.58 \pm 0.06$, which is in good agreement with the measurement of Zuckerman et al. (2003). Both our and Zuckerman et al.'s Mg abundance measurements are somewhat lower than that of Holberg, Barstow & Green (1997), $\log({\rm Mg/H}) = -5.35 \pm 0.10$, which was determined from a rather noisy spectrum.

Table 1. Photospheric Mg abundances and the combined equivalent width of the Ca II $\lambda\lambda$8498, 8542, 8662 triplet in SDSS J1043+0855, WD 1337+705 and SDSS J1228+1040.

Object	Mg $\times(\odot)$	log(Mg/H)	EW(Ca II) (Å)
SDSS 1043+0855	0.30 ± 0.15	$-4.94^{+0.17}_{-0.30}$	21.2 ± 1.2
WD 1337+705	0.07 ± 0.01	-5.58 ± 0.06	-0.7 ± 0.1
SDSS 1228+1040	0.70 ± 0.10	-4.58 ± 0.06	61.1 ± 0.2

We have measured the equivalent widths of the combined Ca II triplet in out WHT spectra of SDSS J1043+0855, SDSS J1228+1040 (from Gänsicke et al. 2006) and WD 1337+705. For WD 1337+705, the WHT spectrum is consistent with no Ca II emission at all (Table 1). Fig. 3 shows the correlation between the photospheric Mg abundances in SDSS J1043+0855, SDSS J1228+1040 and WD 1337+705, and the equivalent widths of the Ca II triplet.

5 MORE SDSS J1228+1040 STARS IN THE SDSS DATA RELEASE 4?

Gänsicke et al. (2006) visually inspected the spectra of 406 DA white dwarfs brighter than $g = 17.5$ from Data Release 4, and the

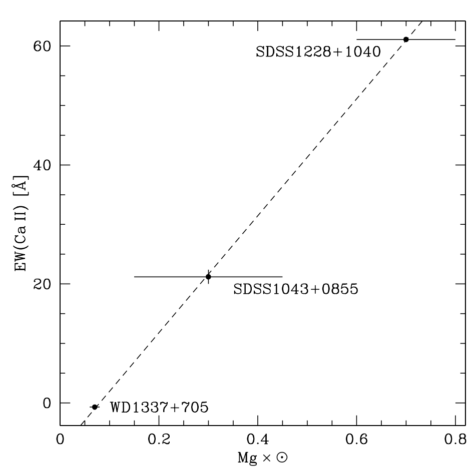

Figure 3. Correlation of the Mg abundance in the white dwarf photosphere and the equivalent width of the Ca II $\lambda\lambda$8498, 8542, 8662 triplet in the three hot DAZ white dwarfs observed by us in the *I* band.

only viable candidate for the presence of Ca II emission lines was SDSS J1043+0855. In order to put a more quantitative constraint on the number of white dwarfs with circumstellar discs of metal-rich gas, we implemented an automated measurement of the Ca II λλ8498, 8542, 8662 triplet in SUPERMONGO. In brief, this routine extracts and normalizes the white dwarf spectrum in the wavelength range 8000–9200 Å, dividing it by a first-order polynomial fit to the line-free continuum (8000–8450 and 8725–9000 Å). In a second step, the combined equivalent width of the Ca II triplet is calculated by integrating the normalized spectrum over the range 8465–8690 Å, dividing by the bandwidth of this interval, and subtracting the corresponding continuum contribution. The flux errors of the spectrum are propagated in an equivalent fashion. We downloaded the SDSS spectra of all DA white dwarfs from the Eisenstein et al. (2006) list, only excluding those classified as DA+K binaries (but including those with an uncertain binary classification, DA+K:), resulting in a total of 7360 individual objects. Subjecting those spectra to the procedure outlined above produced a list of 300 white dwarfs with a 3σ excess in the Ca II triplet over the neighbouring continuum. The SDSS spectra of these objects were then visually inspected.

Both SDSS J1228+1040 and SDSS J1043+0855 were recovered by this automated search as the two most obvious Ca II emission-line candidates. The vast majority of additional candidates turned out to be faint ($\sim i > 19$) white dwarfs with substantial residuals from the night sky subtraction. A total of eight additional rather weak candidates for Ca II emission were identified and are listed in Table 2. While this exercise confirms the finding of Gänsicke et al. (2006) that white dwarfs with gaseous metal discs are rare, it also shows that the SDSS data are of sufficient quality only for the brightest ∼2000 DA white dwarfs from Eisenstein et al.'s (2006) list. A proper assessment of white dwarfs fainter than $i \sim 19$ will require better data, with a particular emphasis on a good skyline subtraction.

6 DISCUSSION AND CONCLUSIONS

The discovery of gaseous discs around the two moderately hot white dwarfs SDSS J1228+1040 and SDSS J1043+0855 and dust discs around white dwarfs with $T_{\rm eff} \lesssim 15\,000$ K indicates that the white dwarf temperature plays a crucial role in determining the phase state of circumstellar debris discs. von Hippel et al. (2007) explored the range of white dwarf effective temperatures for which the sublimation radius is inside the Roche radius for tidal disruption, and found good agreement with the observational evidence.

The origin of metals in the photospheres of white dwarfs has been intensively debated (see Koester & Wilken 2006; Kilic & Redfield 2007; von Hippel et al. 2007). A purely interstellar origin, e.g. as worked out in detail by Dupuis et al. (1993), appears less likely in view of the observations collected throughout the past 15 years. The detection of dusty (e.g. Zuckerman & Becklin 1987; Reach et al. 2005; Becklin et al. 2005; Kilic et al. 2005; von Hippel et al. 2007) and gaseous discs (Gänsicke et al. 2006, and this paper) of hydrogen- and helium-depleted material offers a viable alternative at least for some systems: accretion from tidally disrupted asteroids (Jura 2003). However, only a relatively small fraction of the cool ($T_{\rm eff} \lesssim 15\,000$ K) DAZ white dwarfs exhibit infrared excess, and it is currently not clear if the photospheric metals found in the remaining systems are also associated with the presence of planetary debris. von Hippel et al. (2007) show that the five confirmed white dwarfs with dusty discs have accretion rates at the upper end of what is observed in cool DAZ white dwarfs, and our observations give some evidence that the strength of the Ca II emission correlates with the the photospheric Mg abundance (Fig. 3). It may hence be that the white dwarfs with clearly visible discs represent only the 'tip of the iceberg'.

The Ca II emission lines detected in SDSS J1228+1040 and SDSS J1043+0855 offer substantially dynamical insight into the structures of the circumstellar discs, and long-term monitoring of these line profiles appears worthwhile to probe for evolution of the disc radii and eccentricities.

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NOTE ADDED IN PRESS

After the submission of this paper, Jura, Farihi & Zuckerman (2007) reported the *Spitzer* detection of an infrared excess for the white

Table 2. Confirmed (in italics) and candidate white dwarfs with Ca II λλ8498, 8542, 8662 emission. $T_{\rm eff}$ and $\log g$ are determined from fitting the SDSS spectra as described in Section 3. The combined equivalent width for the triplet is given.

SDSS J	g	$T_{\rm eff}$(K)	$\log g$	EW(Å)	Notes
015854.17+123813.3	18.1	7910 ± 30	8.45 ± 0.10	8.1	1
023543.07+005557.0	18.4	10307 ± 142	8.58 ± 0.15	19.4	1,2
075409.24+485058.1	19.4	35154 ± 1877	7.70 ± 0.33	134	
090555.02+034006.3	19.0	16149 ± 576	7.99 ± 0.13	28.4	
093956.34+390712.2	19.4	9081 ± 209	8.43 ± 0.35	41.6	1
104341.53+085558.2	17.5	18330 ± 523	8.09 ± 0.11	21.2	3
111701.96+000322.9	19.2	20804 ± 807	8.07 ± 0.15	33.6	2
122859.93+104032.9	16.7	22292 ± 296	8.29 ± 0.05	61.1	4
144849.62+024024.9	17.7	15246 ± 315	7.50 ± 0.08	13.9	
224753.21-000230.2	19.0	7641 ± 308	8.73 ± 0.72	18.4	1

Notes: (1) too cold for sublimating circumstellar material at the tidal destruction radius of the white dwarf (e.g. Jura 2003); (2) more than one SDSS spectrum available, excess clearly visible only in one of them; (3) this paper; (4) the white dwarf parameters differ very slightly with respect to those in Gänsicke et al. (2006) owing to improvements in our fitting procedure.

dwarf PG 1015+161 ($T_{\rm eff}$ = 19 300 K), suggesting that gas and dust discs may co-exist over a certain range in white dwarf effective temperature.

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