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 contains double-peaked emission lines of Ca II λλ 8498, 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 1228+1040, may be the result of the tidal disruption of an asteroid. Additional spectroscopy of the DAZ white dwarfs WD 1337+705 and GD362 does not reveal Ca II emission lines. GD362 is one of the few cool DAZ that display strong infrared flux excess, thought to be originating in a circumstellar dust disc, and its temperature is likely too low to sublimate sufficient amounts of disc material to generate detectable Ca II emission. WD 1337+705 is, as SDSS 1228+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 SDSS DR 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 et al. (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 (GD362, Becklin et al. 2005; Kilic et al. 2005; GD56, Kilic et al. 2006; WD 1150–153, Kilic & Redfield 2007; WD 2115–560, von Hippel et al. 2007). Two common characteristic of all those white dwarfs with circumstellar dust discs are their low temperatures, $T_{\text{eff}} < 15000$ K, and their substantial abundances of photospheric calcium (Koester et al. 1995; Zuckerman et al. 2003; Koester et al. 2008). No evidence for the presence of dusty discs has been found around white dwarfs hotter than $\sim 16000$ K (Kilic et al. 2006).

Recently, Gänsicke et al. (2006) detected emission lines of Ca II λλ 8498, 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 1228+1040. Time-resolved spectroscopic and photometric follow-up observations of SDSS 1228+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 1228+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 SDSS1228+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 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 1228+1040 with its circumstellar gas disc appears hence as the hot counterpart to G29–38 and the other cool DAZ harbouring dust discs. Gänsicke et al. (2006) identified SDSS J104341.53+085558.2 (henceforth SDSS 1043+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 1043+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 \( \approx 4000 \rightarrow 4700 \) Å at a resolution (FWHM) of \( \approx 0.9 \) Å. In the red arm, the R600R grating was used along with the low-fringing 4k×2k pixel REDPLUS detector, providing a spectral coverage of \( \approx 7460 \rightarrow 9100 \) Å at a resolution of \( \approx 2 \) Å. A total of 4 pairs of blue/red spectra with individual exposure times of 20 min were obtained under poor seeing (\( \sim 2.5^{\prime} \)) conditions. In June 2006, we also obtained WHT spectroscopy of GD 362, 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 SDSS spectrum, SDSS 1043+0855 displays double-peaked CaII \( \lambda \lambda 8498,8542,8662 \) lines (Fig. 1 right panel), though at substantially lower strengths compared to SDSS 1228+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 1043+0855 is fairly similar to those observed in SDSS 1228+1040 (Gänsicke et al. 2006), suggesting broadly similar parameters. No significant trace of CaII emission is found in WD 1337+705, within the limitations imposed by the CCD fringing. The red spectrum of GD 362 contains CaII in absorption from the white dwarf photosphere. The spectra from the blue arm reveal the presence of photospheric MgII \( \lambda 4481 \) absorption in SDSS 1043+0855 and WD 1337+705 (Fig. 1 right panel). GD 362 is too cold (Gianninas et al. 2004) to exhibit significant MgII \( \lambda 4481 \) absorption. The absence of Zeeman splitting 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 G165–7).
3 WHITE DWARF PARAMETER OF SDSS1043+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 1043+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 both the entire spectrum, as well as the normalised Hα to Hγ lines. The Balmer lines reach their maximum equivalent widths around $T_{\text{eff}} = 13 500$ K for log $g = 8$, or $\sim 1000$ K higher (lower) for log $g = 8.5$ (log $g = 7.5$), and consequently a fit to the normalised Balmer line profiles results usually in a “hot” and a “cold” solution of comparable quality. We use the fit to the entire data, continuum plus lines, to choose the solution which better agrees with the slope of the spectrum. Our fit includes Hα to Hγ lines, to choose the solution which better agrees with the slope of the continuum (hence the significant residuals with the best fit to the full spectral range (black line), which is dominated by the slope of the continuum (hence the significant residuals

Figure 2. Top right panel: the SDSS spectrum and flux error of SDSS 1043+0855 (gray 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 panel). Left panel: the best fit (black lines) to the to the normalised Hα.

Table 1. Photospheric Mg abundances and the combined equivalent width of the Ca II λ4428,8542,8662 triplet in SDSS 1043+0855, WD 1337+705, and SDSS 1228+1040.

| Object       | Mg x(⊙) | log(Mg/H) | EW(Ca II) [Å] |
|--------------|----------|-----------|---------------|
| SDSS 1043+0855 | 0.30 ± 0.15  | −4.94 ± 0.17  | 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    |

4 PHOTOSPHERIC Mg II ABUNDANCES AND CA II EMISSION LINE EQUIVALENT WIDTHS

We have determined the photospheric Mg abundances of SDSS 1043+0855 and WD 1337+305 by fitting TLUSTY/SYNSPEC models with the best-fit $T_{\text{eff}}$ and log $g$ but variable Mg abundances to the normalised 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, $v \sin i < 15$ km s$^{-1}$. We find for SDSS 1043+0855 a Mg abundance of $0.30 \pm 0.15$ times the solar value, or log(Mg/H) = $-4.94 \pm 0.17$. For WD 1337+705, our fit results in a Mg abundance of $0.07 \pm 0.01$ times the solar value, or log(Mg/H) = $-5.58 \pm 0.06$, which is in good agreement with the measurement of Zuckerman et al. (2003).

Both our and Zuckerman’s Mg abundance measurements are somewhat lower than that of Holberg et al. (1997), log(Mg/H) = $-5.35 \pm 0.10$, which was determined from a rather noisy spectrum.

We have measured the equivalent widths of the combined Ca II triplet in our WHT spectra of SDSS 1043+0855, SDSS 1228+1040 (from Gansicke et al. 2005), and WD 1337+705. For WD 1337+705, the WHT spectrum is consistent with no Ca II emission at all (Table I). Figure 3 shows the correlation between the photospheric Mg abundances in SDSS 1043+0855, SDSS 1228+1040, and WD 1337+705 and the equivalent widths of the Ca II triplet.
MORE SDSS 1228+1040 STARS IN SDSS DR4?

Gänsicke et al. (2006) visually inspected the spectra of 406 DA white dwarfs brighter than \( g = 17.5 \) from DR4, and the only viable candidate for the presence of Ca II emission lines was SDSS 1043+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 \( \lambda 8498,8542,8662 \) triplet in SuperMongo. In brief, this routine extracts and normalises 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 Å and 8725–9000 Å). In a second step, the combined equivalent width of the Ca II triplet is calculated by integrating the normalised spectrum in 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 gaseous discs (Gänsicke et al. 2006 and this paper) of dusty (e.g. Zuckerman & Becklin 1987; Reach et al. 2005; Dupuis et al. 1993), appears less likely in the view of the observations collected throughout the past 15 years. The detection of dusty (e.g. Zuckerman & Becklin 1987; Reach et al. 2005; Dupuis et al. 1993; Kilic et al. 2005; von Hippel et al. 2007; Becklin et al. 2005; Beeklin 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 (\( T_{\text{eff}} \lesssim 15,000 \) K) DAZ white dwarfs exhibit infrared excess, and it is currently not clear if the photospheric metals found in the remaining systems is also associated with the presence of planetary debris. von Hippel et al. (2007) show that the 5 confirmed white dwarfs with dusty discs have accretion rates at the upper end of what is observed in cool DAZ, 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 1228+1040 and SDSS 1043+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 PROOF

After the submission of this paper, Jura et al. (2007) reported the Spitzer detection of an infrared excess for white dwarf PG 1015+161 ($T_{\text{eff}} = 19,300$ K) suggesting that gas and dust discs may co-exist over a certain range in white dwarf effective temperature.

REFERENCES

Becklin, E. E., Farihi, J., Jura, M., Song, I., Weinberger, A. J., Zuckerman, B., 2005, ApJ Lett., 632, L119
Bergeron, P., Wesemael, F., Beauchamp, A., 1995, PASP, 107, 1047
Chayer, P., Leblanc, F., Fontaine, G., Wesemael, F., Michaud, G., Vennes, S., 1994, ApJ Lett., 436, L161
Dufour, P., Bergeron, P., Schmidt, G. D., Liebert, J., Harris, H. C., Knapp, G. R., Anderson, S. F., Schneider, D. P., 2006, ApJ, 651, 1112
Dupuis, J., Fontaine, G., Pelletier, C., Wesemael, F., 1993, ApJS, 84, 73
Eisenstein, D. J., et al., 2006, ApJS, 167, 40
Farihi, J., Zuckerman, B., Becklin, E. E., Jura, M., 2007, in Napiwotzki, R., Burleigh, R., eds., 15th European Workshop on White Dwarfs, ASP Conf. Ser., p. in press
Gänsicke, B. T., Marsh, T. R., Southworth, J., Rebassa-Mansergas, A., 2006, Science, 314, 1908
Gianninas, A., Dufour, P., Bergeron, P., 2004, ApJ Lett., 617, L57
Graham, J. R., Matthews, K., Neugebauer, G., Soifer, B. T., 1990a, ApJ, 357, 216
Graham, J. R., Reid, I. N., McCarthy, J. K., Rich, R. M., 1990b, ApJ Lett., 357, L21
Holberg, J. B., Barstow, M. A., Green, E. M., 1997, ApJ Lett., 474, L127
Hubeny, I., 1988, Comput.,Phys.,Comm., 52, 103
Hubeny, I., Lanz, T., 1995, ApJ, 439, 875
Jura, M., 2003, ApJ Lett., 584, L91
Jura, M., 2006, ApJ, 653, 613
Jura, M., Farihi, J., Zuckerman, B., 2007, ApJ, in press, arXiv:0704.1170
Kepler, S. O., Castanheira, B. G., Costa, A. F. M., Koester, D., 2006, MNRAS, 372, 1799
Kilic, M., Redfield, S., 2007, ApJ, 660, 641
Kilic, M., von Hippel, T., Leggett, S. K., Winget, D. E., 2005, ApJ Lett., 632, L115
Kilic, M., von Hippel, T., Leggett, S. K., Winget, D. E., 2006, ApJ, 646, 474
Koester, D., Wilken, D., 2006, A&A, 453, 1051
Koester, D., Provencal, J., Shipman, H. L., 1997, A&A, 320, L57
Kochterm, M. J., Koester, D., Rollenhagen, K., Napiwotzki, R., Voss, B., Christlieb, N., Homeier, D., Reimers, D., 2005, A&A, 432, 1025
Kuchner, M. J., Koserso, C. D., Brown, M. E., 1998, ApJ Lett., 508, L81
Reach, W. T., Kuchner, M. J., von Hippel, T., Burrows, A., Mullally, F., Kilic, M., Winget, D. E., 2005, ApJ Lett., 635, L161
von Hippel, T., Kuchner, M. J., Kilic, M., Mullally, F., Reach, W. T., 2007, ApJ, in press, astro-ph/0703473
Zuckerman, B., Becklin, E. E., 1987, Nat, 330, 138
Zuckerman, B., Koester, D., Reid, I. N., Hünsch, M., 2003, ApJ, 596, 477

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