19th European Workshop on White Dwarfs
ASP Conference Series, Vol. 493
Dufour, Bergeron, and Fontaine, eds.

Is the Oxygen-Rich White Dwarf SDSS J1242+5226 Accreting Water-Abundant Debris?

R. Raddi,[1] B. T. Gänsicke,[1] D. Koester,[2] J. Farihi,[3] J. J. Hermes,[1] S. Scaringi,[4,5] E. Breedt,[1] and J. Girven[1]

[1] *Department of Physics, University of Warwick, Gibbet Hill Road, Coventry CV4 7AL, UK;* r.raddi@warwick.ac.uk

[2] *Institut für Theoretische Physik und Astrophysik, University of Kiel,24098 Kiel, Germany*

[3] *University College London, Dept. of Physics & Astronomy, London, WC1E 6BT, UK*

[4] *Institute of Astronomy, Celestijnenlaan 200D, BUS 24013001, Leuven, The Netherlands*

[5] *Max Planck Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85748, Garching, Germany*

Abstract. We identified a new strongly metal polluted white dwarf, and report the determination of hydrogen and traces of O, Na, Mg, Si, Ca, Ti, Cr, and Fe in a helium-dominated atmosphere. The four most common rock-forming elements, i.e. O, Mg, Si, and Fe embody almost entirely the 10^{24} g of metals that are mixed in the convection zone. Oxygen is the most abundant of these four elements and we estimate that about 50–60% of it is in excess with respect to the amount expected from the accretion of mineral oxides. We suggest that the parent body that of the planetary debris detected in this white dwarf was composed by 28–48% water. We also note that a handful of other known debris-polluted white dwarfs, like GD 61, GD 16, and GD 362 may be the actively accreting examples of a larger number of stars that previously accreted water-rich debris. We speculate that the hydrogen content of DBA and DZ white dwarfs could have a similar origin.

1. Introduction

White dwarfs displaying traces of heavy elements in their atmosphere must have accreted from an external source. The diffusion of elements heavier than hydrogen or helium, depending on the $T_{\rm eff}$ and $\log g$, takes place within 10^4 to 10^7 yr in cool ($T_{\rm eff}$ < 20 000) helium-rich atmospheres (Koester 2009). Observational evidence for large amounts of metals in white dwarf atmospheres (Jura & Young 2014), and the discovery of circumstellar dusty and gaseous discs (Zuckerman & Becklin 1987; Gänsicke et al. 2006) are now commonly interpreted as due to disruption of extra-solar asteroids or planetesimals that subsequently accreted onto the white dwarf (Debes & Sigurdsson 2002; Jura 2003).

2. Spectral Analysis

We observed SDSS J1242+5226 (hereafter SDSS J1242) with the Intermediate dispersion Spectrograph and Imaging System (ISIS) at the 4.2-m William Hershel Telescope (WHT). The spectrum covers 3170–8800 Å and displays intense hydrogen and helium lines, in addition to other spectral features of O, Na, Mg, Si, Ca, Ti, Cr, and Fe (Fig. 1).

We analysed the spectrum with ad hoc model atmospheres described by Koester (2010). It is well reproduced by a $T_{\rm eff} = 13\,000$ K synthetic atmosphere (Fig. 1), where we fixed $\log g = 8.0$ as a measurement of the surfact gravity in this temperature range is notoriously unreliable. The hydrogen abundance is [H/He]= -3.68 ± 0.10.

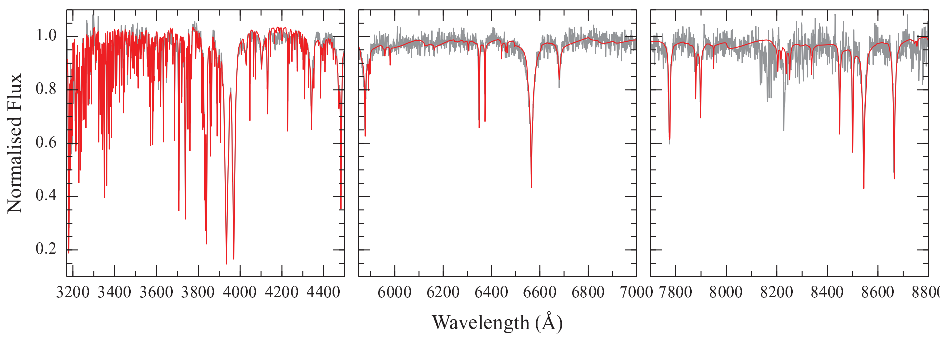

Figure 1. WHT/ISIS spectrum (grey) and best-fitting model atmosphere (red).

2.1. Metals

With an the effective temperature of 13 000 K, this helium-dominated atmosphere has a deep convection zone, $\log M_{\rm cvz}/M_{\rm WD} \approx -5.4$. Considering the abundances from our spectral analysis, we estimate that at least 10^{24} g of metals are mixed in the convection zone of SDSS J1242, almost entirely in the form of O, Mg, Si, and Fe. Comparing the relative abundances of Mg, Si, and Fe, the latter seems to be underabundant in comparison with chondritic/achondritic rocks (Fig. 2), suggesting that the body accreted onto SDSS J1242 probably underwent differentiation (see e.g. Farihi et al. 2011).

2.2. Oxygen

Oxygen is the most abundant of the four rock-forming elements detected in SDSS J1242, making of this star an outlier in Fig. 3, along with GD 61 (Farihi et al. 2013) that is suspected to currently accrete water-rich debris. Zuckerman et al. (2007) determined only upper limits on the oxygen content of GD 362, but this star is mainly suggested to have accreted water-rich debris due to the presence of large amounts of photospheric hydrogen (see below).

If we take into consideration all the possible combinations between oxygen and metals, it appears that the parent body that underwent tidal disruption and was accreted by SDSS J1242 carried up to 50–70% more oxygen than what is needed for metals to form oxides (Fig. 4). We suggest that about 38 ± 10% of mass of the accreted body was made either of ice or hydrated minerals.

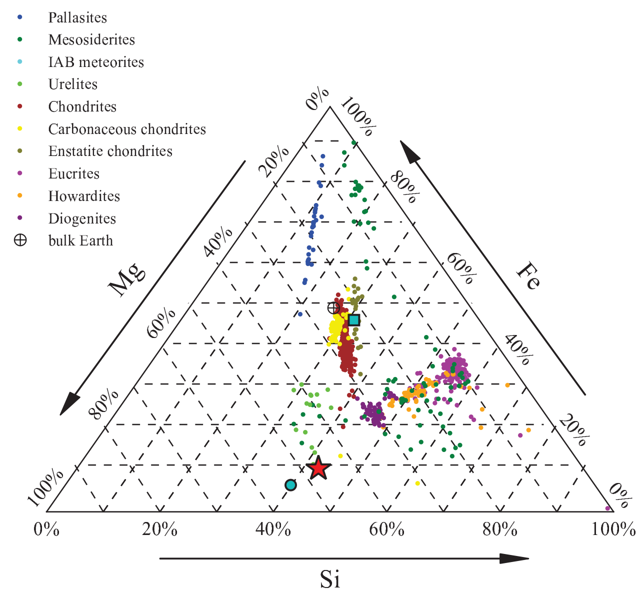

Figure 2. Relative mass-fraction of Fe, Mg, and Si in meteorites (Nittler et al. 2004) and bulk Earth (McDonough 2001). SDSS J1242 is represented by a red star, while GD 362 and GD 61 are the large square and circle respectively.

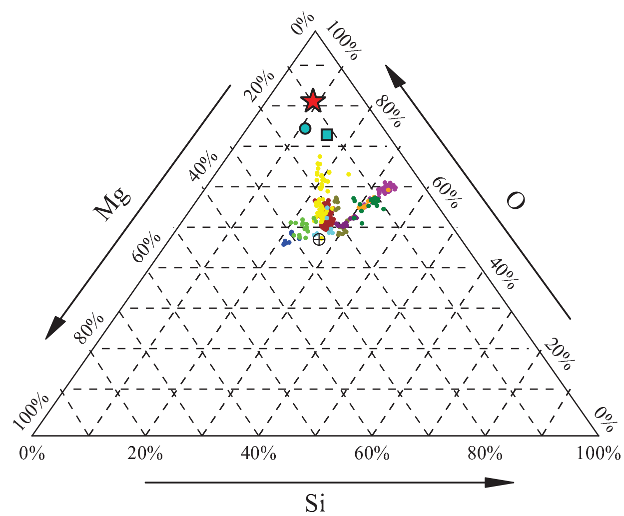

Figure 3. Relative mass-fraction of O, Mg, and Si. Symbols as in Fig. 2.

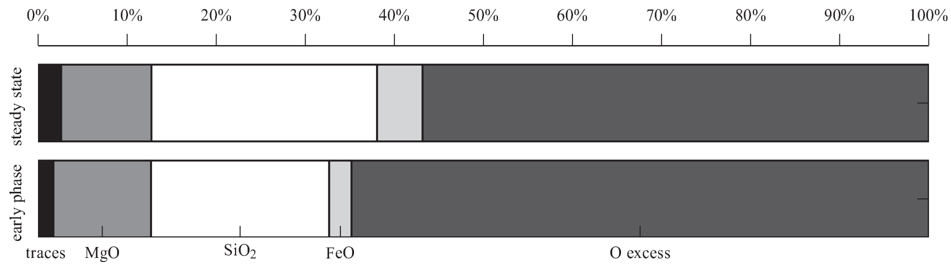

Figure 4. Fraction of oxygen in metal oxides for SDSS J1242, considering it to be observed either during an early phase of accretion or in the steady-state. Traces oxides include: Na_2O, Al_2O_3, CaO, TiO_2, Cr_2O_3.

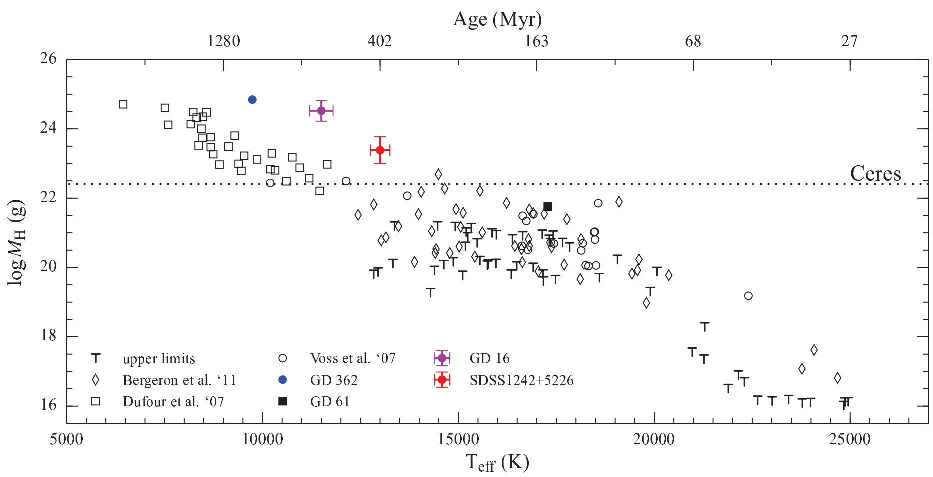

Figure 5. Hydrogen mass mixed in the convection zone of white dwarfs with helium-dominated atmospheres.

2.3. Hydrogen

The photospheric hydrogen abundance in SDSS J1242 implies a mass of $M_H \approx 10^{24}$ g, which is uniformly mixed within the convection zone. Comparing our result to other measures of hydrogen in helium-rich white dwarfs from the literature (Fig. 5), we notice that SDSS J1242 holds about one order of magnitude more hydrogen than other white dwarfs within the same range of temperatures. It also displays more hydrogen than the solar system asteroid Ceres, assuming that is composed to 25% by ice (Michalak 2000; McCord & Sotin 2005). A handful of other metal-polluted white dwarfs show similar hydrogen-excesses: GD 16, GD 362. While no oxygen-abundances are confirmed for these two stars, the detection of dusty discs demonstrates that they are currently accreting planetary debris, which suggests that the hydrogen-excess is likely related to their evolved planetary systems. On the other hand, SDSS J1242 does not display near-infrared excess, but it might still be currently accreting from an attenuated debris disc (Farihi et al. 2010).

We speculate that the apparent broad correlation between T_{eff} ($\equiv$ age) and atmospheric hydrogen content, seen in Fig. 5, could be explained as the relic hydrogen originating from past water-rich accretion events. The hydrogen could be either carried by comets (see e.g. Veras et al. 2014) or water-rich asteroids and planetesimals (in this case also large quantities of heavy metals are accreted too). Given that both the diffusion time scales of metals and the life times of debris discs are always short compared to the cooling ages of these stars, it is unlikely to observe them during a phase of active accretion. However, hydrogen from such accretion episodes will gradually accumulate. One example of a star currently accreting water-rich debris is GD61 (Farihi et al. 2013), however, once this accretion episode ends, GD61 will appear as a inconspicuous DBA.

3. Summary and Conclusions

SDSS J1242 is a new heavily metal-polluted white dwarf. We detected abundant hydrogen and traces of eight metals in its helium-dominated atmosphere. O, Mg, Si, and Fe are the major components of the planetary debris accreted by this star, with oxygen being the most abundant. From the balance between oxygen and metals, we estimate that up to 38 ± 10% of the mass of the disrupted parent body was made of ice or hydrated oxides. We hypothesise that accretion of water-rich minor bodies (comets or asteroids) could considerably contribute to the large masses of hydrogen that are detected in many white dwarfs with helium-rich atmospheres.

Acknowledgments. The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. 320964 (WDTracer).

References

Bergeron, P., Wesemael, F., Dufour, P., Beauchamp, A., Hunter, C., Saffer, R. A., Gianninas, A., Ruiz, M. T., Limoges, M.-M., Dufour, P., Fontaine, G., & Liebert, J. 2011, ApJ, 737, 28
Debes, J. H., & Sigurdsson, S. 2002, ApJ, 572, 556
Farihi, J., Brinkworth, C. S., Gänsicke, B. T., Marsh, T. R., Girven, J., Hoard, D. W., Klein, B., & Koester, D. 2011, ApJ, 728, L8
Farihi, J., Gänsicke, B. T., & Koester, D. 2013, Science, 342, 218
Farihi, J., Jura, M., Lee, J.-E., & Zuckerman, B. 2010, ApJ, 714, 1386
Gänsicke, B. T., Marsh, T. R., Southworth, J., & Rebassa-Mansergas, A. 2006, Science, 314, 1908
Girven, J., Brinkworth, C. S., Farihi, J., Gänsicke, B. T., Hoard, D. W., Marsh, T. R., & Koester, D. 2012, ApJ, 749, 154
Jura, M. 2003, ApJ, 584, L91
Jura, M., & Young, E. D. 2014, Annual Review of Earth and Planetary Sciences, 42, 45
Koester, D. 2009, A&A, 498, 517
— 2010, MmSai, 81, 921
McCord, T. B., & Sotin, C. 2005, Journal of Geophysical Research (Planets), 110, E05009
McDonough, W. F. 2001, in Lunar and Planetary Science Conference, vol. 32 of Lunar and Planetary Science Conference, 2005
Michalak, G. 2000, A&A, 360, 363
Nittler, L. R., McCoy, T. J., Clark, P. E., Murphy, M. E., Trombka, J. I., & Jarosewich, E. 2004, Antarctic Meteorite Research, 17, 231
Veras, D., Shannon, A., & Gänsicke, B. T. 2014, ArXiv e-prints. 1409.7691
Zuckerman, B., & Becklin, E. E. 1987, Nat, 330, 138
Zuckerman, B., Koester, D., Melis, C., Hansen, B. M., & Jura, M. 2007, ApJ, 671, 872