Discovery of a peculiar DQ white dwarf\textsuperscript{*},\textsuperscript{**}

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Abstract. We report the discovery of a new carbon rich white dwarf that was identified during a proper motion survey for cool white dwarfs based on photographic material used for the construction of the Guide Star Catalog II. Its large proper motion ($\mu \simeq 0.48$ arcsec/yr) and faint apparent magnitude ($V \simeq 18.7$) suggest a nearby object of low luminosity. A low-resolution spectrum taken with the William Herschel Telescope clearly shows strong C\textsubscript{2} Deslandres-d’Azambuja and Swan bands, which identify the star as a DQ white dwarf. The strength of the Deslandres-d’Azambuja bands and the depression of the continuum in the Swan-band region are signs of enhanced carbon abundance for the given $T_{\text{eff}}$. Comparison of our spectrophotometric data to published synthetic spectra suggests $6000 \text{ K} < T_{\text{eff}} < 8000 \text{ K}$, although further analysis with specialized synthetic models appear necessary to derive both $T_{\text{eff}}$ and chemical composition. Finally, the range of spatial velocity estimated for this object makes it a likely member of the halo or thick disk population.

Key words. white dwarfs – stars: carbon – stars: kinematics – stars: individual: GSC2U J131147.2+292348 – astrometry – techniques: spectroscopic

1. Introduction

Star GSC2U J131147.2+292348 was identified during a proper motion survey for cool white dwarfs (WDs) based on photographic material used for the construction of the Second Guide Star Catalogue (GSC-II) (see, e.g., Lasker et al. 1995; McLean et al. 2000). The object is located near the North Galactic Pole (NGP) at $l \simeq 61^\circ$, $b \simeq 85^\circ$, is fast moving ($\mu \simeq 0.48$ arcsec yr\textsuperscript{-1}), and faint ($V \simeq 18.7$), as expected for a low luminosity object in the solar neighborhood. An accurate check on the SIMBAD database revealed that the star is not in the NLTT catalogue (Luyten 1979) but, quite surprisingly, is listed as a quasar candidate (object OMHR 58793) by Moreau & Reboul (1995), who measured an UV excess but did not detect any proper motion.

\textsuperscript{*} Based on observations made with the William Herschel Telescope operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias.

\textsuperscript{**} Based on observations made with the Italian Telescopio Nazionale Galileo (TNG) operated on the island of La Palma by the Centro Galileo Galilei of the INAF (Istituto Nazionale di Astrofisica) at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias.

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2. Observations and data analysis

2.1. Astrometry and photometry

Our material consists of Schmidt plates from the Northern photographic surveys (POSS-I, Quick V and POSS-II) carried out at the Palomar Observatory (see Table 1). All plates were digitized at STScI utilizing modified PDS-type scanning machines with 25 $\mu$m square pixels (1.7"/pixel) for the first epoch plates, and 15 $\mu$m pixels (1"/pixel) for the second epoch plates (Laidler et al. 1996). These digital copies of the plates were initially analyzed by means of the standard software pipeline used for the construction of the GSC-II. The pipeline performs object detection and computes parameters and features for each identified object. Further, the software provides classification, position, and magnitude for each object by means of astro-metric and photometric calibrations which utilized the Tycho2 (Høg et al. 2000) and the GSPC-2 (Bucciarelli et al. 2001) as reference catalogs. Accuracies better than 0.1–0.2 arcsec in position and 0.15–0.2 mag in magnitude are generally attained.

Star GSC2U J131147.2+292348 was part of the sample of WD candidates discovered after screening the high proper motion stars found in survey field 443 (Table 1). These were selected on the basis of their relative proper motions as derived by applying the procedure described in Spagna et al. (1996) to just the POSS-II plates, spanning $\pm 4$ years. The finding charts in Fig. 1 show the high proper motion of this object.
Table 1. GSC2 plate material used for the astrometry and the photographic photometry of the new DQ white dwarf.

<table>
<thead>
<tr>
<th>Field</th>
<th>Survey</th>
<th>Center (J2000)</th>
<th>Epoch</th>
<th>Pixel</th>
<th>Color</th>
<th>Emulsion + Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>XP443</td>
<td>POSS-II</td>
<td>13:04:15.2 +29:48:42</td>
<td>1993.288</td>
<td>15 µm</td>
<td>R_F</td>
<td>IIaF + RG610</td>
</tr>
<tr>
<td>N322</td>
<td>Quick V</td>
<td>13:06:56.6 +29:13:25</td>
<td>1983.294</td>
<td>25 µm</td>
<td>V_12</td>
<td>IIaD-Wratten 12</td>
</tr>
</tbody>
</table>

Russell et al. (1990). Also, recently acquired NIR images\(^1\) provided the \(J, H, K_\ast\) magnitudes in Table 2. Finally, Moreau & Reboul (1995) published the values \(U \approx 19.15\) and \(V \approx 19.10\). Note that their visual magnitude is fairly consistent with our \(V_12\), considering the above color transformation and the errors of the photographic photometry.

2.2. Spectroscopy

Spectroscopy of GSC2U J131147.2+292348 was obtained on the night of 2001 January 29 using the intermediate dispersion spectroscopic and imaging system (ISIS) on the 4.2-m William Herschel Telescope on the island of La Palma. The 5700 Å dichroic was used to split the light and feed to the blue and red arms of the spectograph.

We used the R158B grating on the blue arm, which gave a nominal dispersion of 1.62 Å/px and useful wavelength coverage from 3200 to 5700 Å. (The dichroic cuts in at wavelengths >5700 Å, and at short wavelengths, the sensitivity falls off with the quantum efficiency of the detector.) On the red arm, we used the R158R grating to give a nominal dispersion of 2.9 Å/px covering from 5500 to 8000 Å. A blocking filter (GG495) was also used on the red arm to cut out second order blue light. A 30-min exposure was made using a 1-arcsec slit. Subsequent exposures were taken of the spectrophotometric standards Feige 67 and Feige 34 to enable flux calibration of the primary target. We took arc lamp exposures to enable wavelength calibration and tungsten lamp exposures for the pixel-to-pixel sensitivity variation and enable flat fielding.

The data were reduced within the IRAF environment, following standard procedures. No attempt was made to correct for extinction, both standards and targets were measured with an airmass \(\leq 1.1\). Observations were made with a slit width of 1.02 arcsec, which corresponds to 4 detector pixels in the blue, i.e. a dispersion of 6.5 Å per resolution element. For the red arm, the pixel scale is 0.36 arcsec per pixel, leading to a resolution element of size 3 pixels, i.e. a resolution of 8.2 Å. The blue and red arm spectra have been Gaussian smoothed at these resolutions.

Good agreement between the red and blue arm spectra was found in the overlap region, with fluxes agreeing to better than 10% in the range 5600–5700 Å.

\(^1\) Taken with the NICS camera on the 3.6-m TNG telescope on La Palma.
bands due to C_2 molecules. The four Swan bands with bandheads at λ = 4382, 4737, 5165, and 5636 Å are clearly identified, along with the less common Swan band at 6191 Å. In addition, strong Deslandres and d’Azambuja (D-d’A) absorption bands are also present in the blue part of the spectrum at 3600, 3852, and 4102 Å. These bands have been observed in the spectra of WDs with carbon rich atmospheres (DQ WDs) and temperatures T_eff = 8000 K just examined above 6500 K. Finally, the spectrum in Fig. 2 shows an evident depression of the continuum in the Swan-band region.

The spectral energy distribution (SED) of DQ stars changes with T_{eff} and carbon abundance as shown by the model atmosphere spectra presented in Koester et al. (1982) and Wegner & Yackovich (1984). Figure 5 of Wegner & Yackovich gives an indication on what to expect for different combinations of T_{eff} and C:He abundance. Swan bands are generally present, while D-d’A bands start to become visible in models with C:He \simeq 10^{-6} at T_{eff} \simeq 6600 K and with C:He \simeq 10^{-2} at T_{eff} \simeq 10 000 K.

3. On the nature of GSC2U J131147.2+292348

The flux-calibrated spectrum of GSC2U J131147.2+292348 is shown in Fig. 2. The signal-to-noise is around 10 for the whole spectrum, increasing slightly to the red. This noise level is clearly visible in the spectrum, and limits our ability to detect weak features.

The crosses in Fig. 2 represent the fluxes at different effective wavelengths as derived from the B_1, V_{12}, R_F, and I_N photographic magnitudes in Table 2. The ultraviolet flux was derived from the photographic U magnitude of Moreau et al. (1995). The agreement appears reasonably consistent with the 10% and 20% accuracy levels of the flux-calibrated spectroscopy and the photographic photometry, respectively.

The spectrum appears dominated by strong absorption bands due to C_2 molecules. The four Swan bands with bandheads at λ = 4382, 4737, 5165, and 5636 Å are clearly identified, along with the less common Swan band at 6191 Å. In addition, strong Deslandres and d’Azambuja (D-d’A) absorption bands are also present in the blue part of the spectrum at 3600, 3852, and 4102 Å. These bands have been observed in the spectra of WDs with carbon rich atmospheres (DQ WDs) and temperatures T_{eff} = 8000 K and increasingly higher C:He ratios. The effect is to boost band strengths, thus depressing the continuum in the Swan-band region.

Although the models with T_{eff} = 8000 K just examined seem consistent with the appearance of the C_2 band systems observed in the spectrum of our WD, the relative flux at blue wavelengths (below \sim 4100 Å) is probably too high compared to the observed SED in Fig. 2. In this regard, an attempt to find a black body compatible with the observed spectrum at λ > 7000 Å, the NIR fluxes from our JHK_s magnitudes, and with the blue peaks in the D-d’A region, resulted in a black-body temperature of \sim 6000 K. (Note that in this case the depressed continuum occurs in the region of maximum black-body emission.)

From the discussion above, it is evident that much is still to be learned about the properties of this new DQ star, and the reliable determination of its temperature and chemical composition must await more detailed atmosphere models. Also, improved spectral coverage in the UV, below 3500 Å, would probably be of help in better constraining model calculations.

A SED with C_2 bands similar in strength to those observed in our spectrum requires a much enhanced C:He ratio for the given T_{eff}. This can be seen by comparing the models in Fig. 5 of Wegner & Yackovich with those in their Figs. 2 and 3. At temperatures between 6000 K and 7000 K, deep absorption bands are produced with C:He \simeq 10^{-4}. At T_{eff} = 8000 K, carbon abundance has to increase to a rather extreme value, C:He = 0.9, for the simultaneous presence of strong D-d’A and Swan bands in the synthetic SED (bottom panel of Fig. 3 of Wegner & Yackovich). This model bears the most resemblance with the spectrum of our WD, however, it does not show any evidence of the continuum depression seen in the observed spectrum. Theoretical evidence that such depression of the continuum emission could occur is provided in Koester et al. (1982). Their Fig. 1 displays theoretical C_2 spectra at T_{eff} = 8000 K and increasingly higher C:He ratios. The effect is to boost band strengths, thus depressing the continuum in the Swan-band region.

From the discussion above, it is evident that much is still to be learned about the properties of this new DQ star, and the reliable determination of its temperature and chemical composition must await more detailed atmosphere models. Also, improved spectral coverage in the UV, below 3500 Å, would probably be of help in better constraining model calculations.

Finally, an approximate photometric parallax for GSCU J131147.2+292348 was estimated from the absolute magnitudes of theoretical models of non-DA stars. From the values...
in Tables 2 and 4 of Bergeron et al. (1995) for pure helium atmosphere WDs and averaging the distance moduli computed for the $IJK_\alpha$ bands (which are not affected by the strong C$_2$ absorption bands) we estimate the distances $d \approx 70, 80,$ and 90 parsecs for $T_{\text{eff}} = 6000$ K, 7000 K, and 8000 K, respectively.

This distance interval corresponds to a range of tangential velocity $V_{\text{tan}} = 4.74 \cdot \mu \cdot d \approx 160–200$ km s$^{-1}$ and galactic components$^3$ with respect to the LSR from $(U, V) = (148.1, +9.6)$ to $(U, V) \approx (193.3, +10.8)$ km s$^{-1}$, for $d = 70$ pc and 90 pc, respectively. These relatively high values are not consistent with the velocity distribution of the thin disk, while they are consistent with the kinematics of the halo or thick disk stellar population$^3$.

4. Conclusions

We have discovered a new carbon rich white dwarf (DQ), which shows very strong C$_2$ Deslandres-d’Azambuja and Swan bands. To the best of our knowledge, no other object is known today which such a strong simultaneous evidence of the two molecular band systems associated with C$_2$.

Comparisons to published synthetic spectra suggest $6000 < T_{\text{eff}} < 8000$ K, while a black-body fit to the observed fluxes at $\lambda > 7000$ Å, and to the peaks below $\sim 4100$ Å supports the possibility that $T_{BB} \sim 6000$ K. Therefore, it is evident that the reliable determination of temperature and chemical composition of GSCU J131147.2 cannot await any more detailed atmosphere model calculations. Anyhow, it is likely that the carbon abundance in the atmosphere of this WD is significantly enhanced compared to other known DQ stars of similar temperature.

A photometric distance of 70–90 parsecs has been estimated, which implies a relatively large spatial velocity and makes this new DQ white dwarf a likely member of the halo or thick disk population. Of course, a direct determination of the distance will be the only way to derive model independent absolute magnitude and kinematics for this object.

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References

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$^3$ Assuming a solar motion of $U_\odot = 10.00$ km s$^{-1}$ and $V_\odot = 5.25$ km s$^{-1}$, as from Dehnen & Binney (1998). The $(U, V)$ components are computed from $\mu_\alpha \cos \delta, \mu_\delta$ only. However, given the high galactic latitude of this star ($b \approx 85^\circ$), the unknown $V_\odot$ component would contribute less than 4% and 7.6% to the $U$ and $V$ values, respectively.

$^4$ Here, we have adopted the velocity ellipsoids $(\sigma_U, \sigma_V, \sigma_W; v_0) = (34, 21, 18; 6)$ km s$^{-1}$ and $(61, 58, 39; 36)$ km s$^{-1}$ for the thin and thick disk respectively (Table 10.4 of Binney & Merrifield 1998). The halo ellipsoid $(\sigma_U, \sigma_V, \sigma_W; v_0) = (160, 89, 94; 217)$ km s$^{-1}$ is from Casertano et al. (1990). Note that these kinematics parameters are still not well established. In particular the estimated $(U, V)$ components would result consistent with the halo kinematics, but only marginally with the thick disk parameters, recently derived by Chiba & Beers (2000).