**Astronomy**
**&** **Astrophysics**

# Discovery of a peculiar DQ white dwarf[⋆,⋆⋆]

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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 $C_2$ 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 $T_{\mathrm{eff}}$. Comparison of our spectrophotometric data to published synthetic spectra suggests 6000 K $< T_{\mathrm{eff}} <$ 8000 K, although further analysis with specialized synthetic models appear necessary to derive both $T_{\mathrm{eff}}$ 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 halo 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 $l \simeq 61°$, $b \simeq 85°$, is fast moving ($\mu \simeq 0.48$ arcsec yr$^{-1}$), 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.

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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 astrometric 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 ~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.

| Field | Survey | Center (J2000) | Epoch | Pixel | Color | Emulsion + Filter |
|-------|--------|----------------|-------|-------|-------|-------------------|
| XJ443 | POSS-II | 13:04:14.7 +29:48:37 | 1995.234 | 15 $\mu$m | $B_J$ | IIIaJ + GG385 |
| XP443 | POSS-II | 13:04:15.2 +29:48:42 | 1993.288 | 15 $\mu$m | $R_F$ | IIIaF + RG610 |
| XI443 | POSS-II | 13:04:20.7 +29:44:17 | 1991.299 | 15 $\mu$m | $I_N$ | IV-N + RG9 |
| N322 | Quick V | 13:06:56.6 +29:13:25 | 1983.294 | 25 $\mu$m | $V_{12}$ | IIaD+Wratten 12 |
| XE322 | POSS-I | 13:06:55.5 +29:13:25 | 1955.288 | 25 $\mu$m | $E$ | 103a-E + red plexiglass |
| XO322 | POSS-I | 13:06:56.1 +29:13:24 | 1955.288 | 25 $\mu$m | $O$ | 103a-O unfiltered |
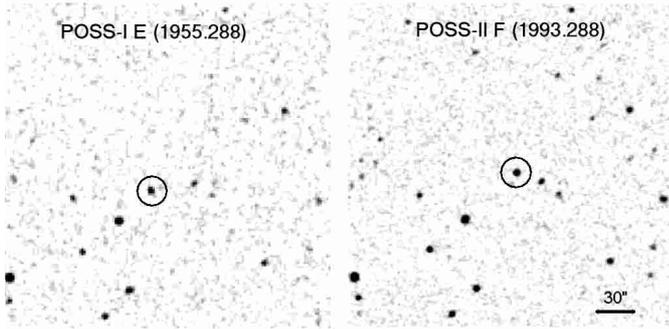


**Fig. 1.** First epoch (POSS-I, XE322) and second epoch (POSS-II, XP443) plates in the direction of the newly discovered WD, the encircled star near the field center. The large relative motion of the object is evident.

The astrometry and photometry of GSC2U J131147.2+292348 are given in Table 2. The position refers to the epoch of the most recent plate (XJ443), while the accurate proper motion was computed by combining the image locations of the star as measured on the 6 different plates of Table 1, which span ~40 years. The photographic magnitudes are given in the natural photometric system of the POSS-II and Quick-V plates as defined by the emulsion-filter combinations in Table 1.

In particular, the transformation between the photographic and Johnson $V$ is $V_{12} = V - 0.15(B - V)$ according to

**Table 2.** Astrometry and photometry of GSC2U J131147.2+292348. The position was determined from plate XJ443 (epoch 1995.234, equinox J2000), while all of the available plates were used for the proper motions. The error of the photographic photometry is better than 0.2 mag ($1\sigma$).

| $\alpha$ (h m s) | $\delta$ (d m s) | $\mu_\alpha \cos\delta$ | $\mu_\delta$ |
|------------------|------------------|-------------------------|--------------|
| (J2000) | (J2000) | (arcsec/yr) | (arcsec/yr) |
| 13 11 47.21 | +29 23 48.0 | $-0.382 \pm 0.002$ | $0.286 \pm 0.005$ |

| $B_J$ | $V_{12}$ | $R_F$ | $I_N$ |
|-------|----------|-------|-------|
| 19.6 | 18.7 | 18.1 | 17.5 |

| $J$ | $H$ | $K_s$ |
|-----|-----|-------|
| $17.48 \pm 0.05$ | $17.13 \pm 0.10$ | $17.08 \pm 0.12$ |

Russell et al. (1990). Also, recently acquired NIR images[1] provided the $J$, $H$, $K_s$ magnitudes in Table 2. Finally, Moreau & Reboul (1995) published the values $U \simeq 19.15$ and $V \simeq 19.10$. 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 spectrographic 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 spectrograph.

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 ≤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.

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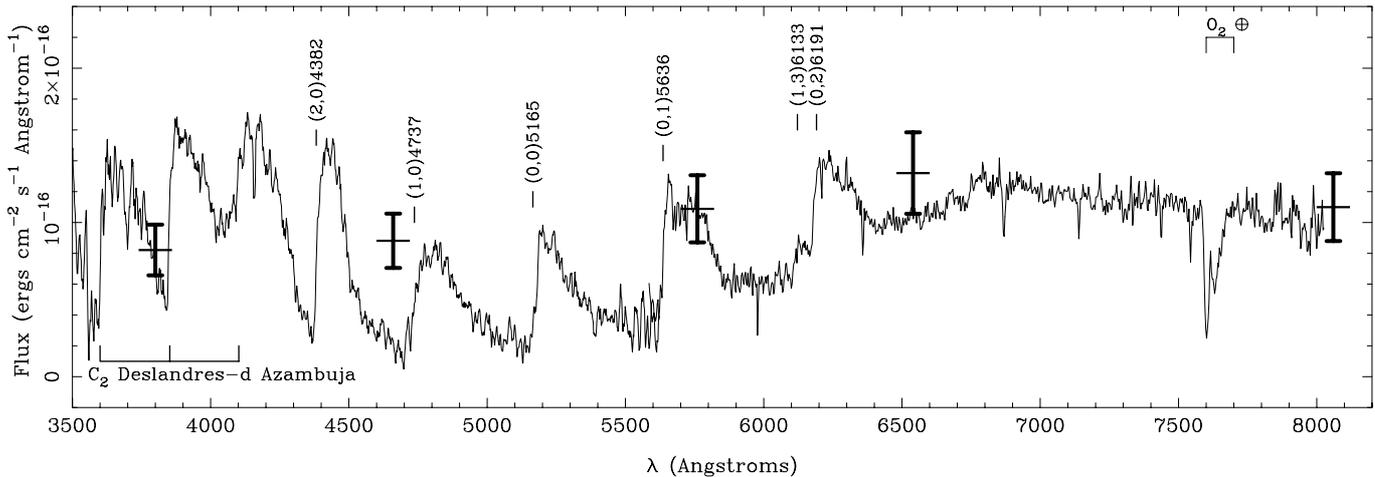[1] Taken with the NICS camera on the 3.6-m TNG telescope on La Palma.

**Fig. 2.** The WHT optical spectrum of GSC2U J131147.2+292348. Vertical marks indicate the locations of the strong $C_2$ Deslandres-d'Azambuja and Swan bands, and of the telluric $O_2$. The crosses refer to the fluxes (with $\pm 20\%$ error bars) derived from the $B_J$, $V_{12}$, $R_F$, $I_N$ photographic photometry of Table 2 and the $U$ mag from Moreau & Reboul (1995).

## 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 $B_J$, $V_{12}$, $R_F$, 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 $\lambda = 4382$, 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[2] above 6500 K. Finally, the spectrum in Fig. 2 shows an evident depression of the continuum in the Swan band region between 4500 and 6200 Å.

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 $\gtrsim 10^{-6}$ at $T_{eff} \simeq 6600$ K and with C:He $\gtrsim 10^{-2}$ at $T_{eff} \simeq 10\,000$ K.

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 $\approx 10^{-4}$. 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.

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 $\lambda > 7000$ Å, the NIR fluxes from our $JHK_s$ magnitudes, and with the blue peaks in the D-d'A region, resulted in a blackbody temperature of $\sim$6000 K. (Note that in this case the depressed continuum occurs in the region of maximum blackbody 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.

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

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[2] This temperature seems to be the lower limit for DQ stars, and might be associated with the transition of $C_2$ into $C_2H$ molecules (Bergeron et al. 2001).

in Tables 2 and 4 of Bergeron et al. (1995) for pure helium atmosphere WDs and averaging the distance moduli computed for the $IJHK_s$ bands (which are not affected by the strong $C_2$ absorption bands) we estimate the distances $d \approx 70$, 80, and 90 parsecs for $T_{eff} = 6000$ K, 7000 K, and 8000 K, respectively.

This distance interval corresponds to a range of tangential velocity $V_{tan} = 4.74 \cdot \mu\,d \simeq 160$–200 km s$^{-1}$ and galactic components[3] with respect to the LSR from $(U, V) \simeq (-148.1, +9.6)$ to $(U, V) \simeq (-193.3, +10.8)$ km s$^{-1}$, for $d = 70$ pc and 90 pc, respectively. These relatively high values are not consistent $(3\sigma)$ with the velocity distribution of the thin disk, while they are consistent with the kinematics of the halo or thick disk stellar population[4].

## 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 $6000 < T_{eff} < 8000$ K, while a black-body fit to the observed fluxes at $\lambda > 7000$ Å, and to the peaks below ~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+292348 must await 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.

## References

Bergeron, P., Wesemael, F., & Beauchamp, A. 1995, PASP, 107, 1047

Bergeron, P., Leggett, S. K., & Ruiz, M. T. 2001, ApJS, 133, 413

Binney, J., & Merrifield, M. 1998, Galactic Astronomy (Princeton Univ. Press)

Bucciarelli, B., García Yus, J., Casalegno, R., et al. 2001, A&A, 368, 335

Casertano, S., Ratnatunga, K. U., & Bahcall, J. N. 1990, ApJ, 357, 435

Chiba, M., & Beers, T. C. 2000, AJ, 119, 2843

Dehnen, W., & Binney, J. J. 1998, MNRAS, 298, 387

Høg, E., Fabricius, C., Makarov, V. V., et al. 2000, A&A, 355, 27

Koester, D., Weidemann, V., & Zeidler-K.T., E. M. 1982, A&A, 116, 147

Laidler, V. G., Sturch, C. R., Greene, G. R., et al. 1996, BAAS, 188, 54.21

Lasker, B. M., McLean, B. J., Jenkner, H., Lattanzi, M. G., & Spagna, A. 1995, Future Possibilities for Astrometry in Space, Cambridge (England, UK), June 19–21, 1995, ed. M. A. C. Perryman, F. van Leeuwen, & T.-D. Guyenne, ESA SP-379, 137

Luyten, W. J. 1979, NLTT, Minneapolis, Univ. of Minnesota

McLean, B. J., Greene, G. R., Lattanzi, M. G., & Pirenne, B. 2000, ADASS IX, Kohala Coast (HI, USA), Oct. 3–6, 1999, ed. N. Manset, C. Veillet, & D. Crabtree, ASP Conf. Ser., 216, 145

Moreau, O., & Reboul, H. 1995, A&AS, 111, 169

Russell, J. L., Lasker, B. M., Sturch, C. R., & Jenkner, H. 1990, AJ, 99, 2059

Spagna, A., Lattanzi, M. G., Lasker, B. M., et al. 1996, A&A, 311, 758

Wegner, G., & Yackovich, F. H. 1984, ApJ, 284, 257

[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 ($b \simeq 85°$), the unknown $V_r$ component would contribute less than 4% and 7.6% to the $U$ and $V$ values, respectively.

[4] Here, we have adopted the velocity ellipsoids $(\sigma_U, \sigma_V, \sigma_W; v_a) = (34, 21, 18; 6)$ 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 $(\sigma_U, \sigma_V, \sigma_W; v_a) = (160, 89, 94; 217)$ 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).