High-resolution spectroscopy of two carbon stars with long-term obscuration events

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ABSTRACT

In this paper, we provide an analysis of the high-resolution optical spectra of two carbon variables, V1983 Cyg and V2074 Cyg, which are presumed to be cool R Corona Borealis (RCB) stars, according to their photometric behaviour. The stars show irregular long-term visual light variations of relatively large amplitude, similar to those exhibited by RCB variables. Based on the comparison of our high-resolution spectra with those of various carbon stars, we conclude that both variables have spectral properties typical for cool N-type carbon stars. However, two major differences from the spectra of normal carbon stars have been noted: the presence of high-velocity (∼−60 km s⁻¹) components in the Na I D lines in both V1983 Cyg and V2074 Cyg and the unusually strong absorption in the Hα line in the spectrum of V1983 Cyg. The nature of these peculiarities is discussed. Although, according to their photometrical behaviour as well as their infrared properties, both V1983 Cyg and V2074 Cyg are ascribed to DY Persei (DY Per) type stars, we do not find any evidence that the two variables could be cool RCB stars similar to DY Per.


1 INTRODUCTION

Carbon stars are known to have a carbon-to-oxygen (C/O) ratio that is larger than unity in their photospheres, in contrast with what is usually observed for the interstellar medium. The carbon over-abundance on the surface of these stars is thought to be a result either of a third dredge-up during the thermal pulse phase near the top of the asymptotic giant branch (AGB) or of the mass transfer from the evolved binary companion. Thermally pulsating carbon stars are generally characterized by relatively large light variations. Based on the amplitude, period and regularity of the observed light changes, most of such carbon stars can be divided into either Mira (M), semiregular (SR) or irregular (Lb) variables. Both Mira and semiregular variables exhibit periodic or multiperiodic pulsations; irregular stars, in turn, do not show any signs of periodicity in their low-amplitude light variations (see Wallerstein & Knapp 1998, for review).

In some carbon stars, the pulsational or small-amplitude irregular variations are superposed by prominent random light obscuration episodes or long-term trends occurring on longer time-scales (e.g. Feast et al. 1984; Whitelock et al. 1997; Alksnis 2003). The obscuration events are observed for roughly one-third of carbon-rich Mira variables and an unknown fraction of SR and Lb variables (Whitelock et al. 2006). The rarity of the phenomenon among non-Mira variables can be deduced from the fact that among 96 irregular carbon stars studied by Alksnis & Alksne (1988), only five were noted to exhibit monotonic long-term trends or large amplitude variations (ΔR > 1 mag).

According to the near-infrared studies of carbon Mira variables showing long-term light obscurations, the preferable model of this phenomenon is the formation of the dust clouds in the line of sign (Whitelock et al. 1997; Feast, Whitelock & Marang 2003). As has been noted by Feast et al. (2003), principally this model is similar to that of obscuration events exhibited by well-known hydrogen-deficient carbon stars of R Corona Borealis (RCB) type, but the differences in light curves are a result of the property differences between Miras and RCBs. Typically, the light declines in RCB stars are deeper (up to 8 mag) and more rapidly developing than those observed for cool carbon stars. At their maximum light, RCB stars spectroscopically resemble F or G supergiants with a number of peculiarities in chemical composition (Asplund et al. 2000).

DY Persei (DY Per) is the only cool carbon star exhibiting RCB-like light drops (Alksnis & Jumike 1990), and it is spectroscopically confirmed to be a cool RCB star (Keenan & Barnbaum 1997; Začs et al. 2007). In this star, light dips up to 5.5 mag in red light are occurring at almost every cycle of the long-period pulsations and these have a slower fading rate in comparison with RCB stars (Alksnis

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et al. 2009). Stars with light curves reminiscent of this cool RCB (known as DY Per-type stars) have been found in both the Galactic bulge (Tisserand et al. 2008; Tisserand, Wyrzykowski & Wood 2011) and the Magellanic Clouds (Alcock et al. 2001; Tisserand et al. 2004, 2009; Kraemer et al. 2005; Soszyński et al. 2009). By analysing the spectral energy distribution of RCB and DY Per-type stars in the Magellanic Clouds, in the wavelength range from optical to infrared, Tisserand et al. (2009) have concluded that the the spectral energy distribution for DY Per-type stars is similar to that of ordinary carbon stars. The necessity for an abundance analysis of carbon stars with obscuration events has been mentioned by various authors.

Lloyd Evans (1997) have performed a medium-resolution spectroscopic monitoring of three Miras and one SRa star, which show dust fading episodes, in the 4650–5250 Å region, also covering the Na D and Hα lines. They found that the deep minima in V Hya and R Lep were accompanied by strong emission in the C2 5162–Å Swan band and less pronounced emission in R For. P Cygni profiles in the Na and K lines were found in V Hya, indicating high mass-loss rates. The high-velocity absorption components in the P Cygni profile seen in V Hya have been attributed to bipolar flow from the system. P Cygni profiles in resonance K i lines have also been found in R For and CL Mon by Barnbaum (1992).

In this paper, we present the first high-resolution spectroscopic analysis of two cool irregular carbon variables, V1983 Cyg and V2074 Cyg. These stars are likely to be cool RCB stars, according to their photometric behaviour. To verify the status of cool RCB stars, we perform a qualitative analysis of the spectra of both variables, by comparing them to the spectra of various carbon stars with known atmospheric parameters and chemical compositions. The detailed abundance analysis for V1983 Cyg and V2074 Cyg will be published in a separate paper.

2 DATA

2.1 Observations

The observations of V1983 Cyg, V2074 Cyg and DY Per were made during 2008 August on La Palma. High-resolution spectra (R = 67 000) were taken using the cross-dispersed high-resolution fibre-fed echelle spectrograph (FIES), during a single exposure for each star. The spectra cover a wavelength range of 3640–7360 Å, but the regions below ∼4750 Å (for V1983 Cyg) and ∼5165 Å (for V2074 Cyg) present a low signal-to-noise (S/N) ratio. For the purpose of wavelength calibration, ThAr exposures were taken after each observation.

The basic data reduction was performed using the FIES TOOL, automated data reduction software. The obtained spectra were bias-subtracted, normalized for flat-field and corrected for blazeshape. The accuracy of the wavelength calibration, performed using the spectrum of a TaAr lamp, was ∼0.03 Å.

Further spectra processing and analysis were carried out using the DECH20T code developed by Galazutdinov (1992). The spectra were shifted for the radial velocity values obtained by measuring the number of relatively uncontaminated CN lines selected over the whole spectral region. The heliocentric radial velocities were found to be −30.3 ± 0.7 and −50.8 ± 0.5 km s⁻¹ for V1983 Cyg and V2074 Cyg, respectively. We did not find any differences in the radial velocities that were derived from the molecular and atomic lines within the measurement error.

Finally, because the observed stars are highly variable, it is very important to know the photometric phase at the time of spectroscopic observations. The photometry of V1983 Cyg and V2074 Cyg, obtained at the Baldone Observatory within two weeks after our spectroscopic observations, shows that both stars were at their maximum brightness. DY Per was also at its brightest phase in 2008 August, according to the data provided by the American Association of Variable Star Observers (AAVSO).

2.2 Photometric data

V1982 Cyg and V2074 Cyg are irregular carbon variables that show relatively large amplitude long-term variations in the R band, according to the 30-yr photometric study by Alksnis (2003). These stars were first noticed by Alksnis & Alksne (1988), within their sample of 96 irregular carbon variables in a field in Cygnus, as having considerable light-fading episodes and prominent monotonic brightness increase. Fig. 1 shows the light curves of V1982 Cyg and V2074 Cyg in photographic B, V and R, according to the full set of photometric data obtained at the Baldone Observatory, kindly provided by A. Alksnis (for more details on these observations, see Alksnis 2003, and references therein). The B − V and V − R colours are also shown, and these are derived using pairs of observations separated by no more than 10 d.

During the period of photometrical observations, V1982 Cyg underwent several light obscuration events with durations ranging from 500 d to more than 1000 d and with amplitude in the red light from about 0.2 to 2.0 mag. The time interval between successive minima varied from 1000 to 2500 d. The most prominent feature of the V1982 Cyg light curve is the almost symmetrical deep minimum centred on ∼JD 244 7300. The rate of light decline in the red band during this dip was ∼0.003 mag d⁻¹. Besides the sharp fading episodes, the brightness of the star was gradually increasing, over an 8-yr period after the first observed minimum, by nearly 0.5 mag. This probably shows the recovery of the star to its maximum brightness. Observations of the B and V bands are less complete; however, it is obvious that the star became redder during the fading episodes. The variations of the B − R colour are large, ranging from B − R ∼ 4.0 mag in between light minima up to B − R ∼ 5.0–5.7 mag during the fading episodes.

V2074 Cyg presents a different photometric behaviour by exhibiting long-term trends in its light curve. Only two major light minima were observed for this star over the 30-yr period. The first, partially observed minimum was at least 1.7 mag deep in the R band. This was followed by a gradual recovery to the initial brightness during the next 10 yr. The second, shallower light minimum had an amplitude in the red light of ∼0.8 mag and a rate of decline of ∼0.0003 mag d⁻¹. Besides the long-term changes, there are smaller fluctuations in the star’s light curve, occurring on shorter time-scales (50–200 d). The measurements of V2074 Cyg’s brightness in the V band, and especially in the B band, are very occasional and they have a relatively large uncertainty because of the faintness of the star in these bands. However, the available data indicate that, at its maximum light, the average colour of the star was slightly bluer than during the minima.

The Two-Micron All-Sky Survey (2MASS) near-infrared JHK_s photometry data (Cutri et al. 2003) are available for both stars. Unfortunately, the 2MASS measurements fall into the continued gap of V2074 Cyg optical observations. Thus, the exact photometric phase of the star at that moment remains unknown. However, considering
the slow character of the observed light changes for this star, the occurrence of a sudden significant light drop seems to be unlikely. For 1983 Cyg, a measurement in the R band was performed 160 d after the 2MASS observations. Thus, we can suggest that the star was near its maximum brightness at the time of the near-infrared observations. Nevertheless, our further conclusions on the basis of 2MASS data for both stars should be considered with caution because of the uncertainty in the photometric phase at the time of the near-infrared observations.

For V2074 Cyg, the measurements of the infrared flux from the IRAS observations are available in the on-line version of the IRAS Point Source Catalogue (Beichman et al. 1994). According to the optical photometry, the star was at its maximum light at the time of the IRAS observations. Unfortunately, for the 60 and 100 µm bands, only the upper limits of the flux density values are given. However, the measurements of fluxes at 12 and 25 µm have high and moderate quality flags, respectively, and thus these values could be used for the analysis.

2.3 Reddening and temperature

There are no measurements of the trigonometric parallaxes available for either V1983 Cyg or V2074 Cyg. To estimate the distances, we have used an assumption that all carbon stars have the same $M_K$ magnitude. We adopt the value of $M_K = -7.91 \pm 0.4$, which is the mean absolute $K_s$ magnitude of 300 carbon stars in the Large Magellanic Cloud (LMC), derived by Demers, Dallaire & Battinelli (2002). The $K_s$ magnitudes for the two variables were taken from the 2MASS photometry. To estimate the reddening in directions towards the stars, we used the three-dimensional Galactic interstellar extinction $A_{K_s}$ distribution map, as calculated by Marshall et al. (2006). With these data, we iteratively found the distances and corresponding reddening values, as listed in Table 1. We have estimated the distance uncertainty as roughly 0.8 kpc; however, given the uncertainty in the photometric phase during the infrared observations, it might be larger.

The effective temperatures for both carbon stars were derived from the photometric calibrations of the $(V - K)_0$, $(H - K)_0$ and $(J - K)_0$ colour indices by Bergeat, Knapik & Rutily (2001). The use of the narrow $K_s$-band magnitudes for this purpose should be acceptable, because Knapp, Pourbaix & Jorissen (2001) state that the $K_s$ magnitudes show good agreement and no evidence of systematic offsets from Johnson $K_s$-band magnitudes for carbon stars. For the $(V - K)_0$ index, we used the mean V-band magnitude of each star at its maximum light. The reddening corrections for the V, J and H bands were calculated by using the derived $A_{K_s}$ values and the coefficients of extinction given in Cardelli, Clayton & Mathis (1989), assuming that $A_K = 0.95 A_{K_s}$ (Dutra, Santiago & Bica

<table>
<thead>
<tr>
<th>Star</th>
<th>d (kpc)</th>
<th>$A_{K_s}$</th>
<th>$(J - H)_0$</th>
<th>$(J - K)_0$</th>
<th>$(H - K)_0$</th>
<th>$(V - K)_0$</th>
<th>$T_{eff}$ (K)</th>
<th>$K_{[12]}^a$</th>
<th>$[12] - [25]^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1983 Cyg</td>
<td>4.1</td>
<td>0.18</td>
<td>1.19</td>
<td>1.77</td>
<td>0.58</td>
<td>5.52</td>
<td>2761</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>V2074 Cyg</td>
<td>4.0</td>
<td>0.24</td>
<td>1.18</td>
<td>1.82</td>
<td>0.64</td>
<td>6.43</td>
<td>2557</td>
<td>1.67</td>
<td>0.19</td>
</tr>
</tbody>
</table>

$^a [12] = -2.5 \log (F12/28.3)$, where F12 is the IRAS flux density at 12 µm.

$^b [25] = -2.5 \log (F25/6.73)$, where F25 is the IRAS flux density at 25 µm.
2002). The mean effective temperature values from the three colour indices for both stars are given in Table 1. The agreement between $T_{\text{eff}}$ derived from each index is better than 50 K for V2074 Cyg and nearly 200 K for V1983 Cyg.

3 ANALYSIS OF THE SPECTRA

The high-resolution spectra of V1983 Cyg and V2074 Cyg are dominated by numerous absorption lines of $^{12}$C$^{12}$C Swan and $^{12}$C$^{13}$N Red molecular systems. The spectrum of V2074 Cyg exhibits stronger molecular features and is more crowded than that of V1983 Cyg; still, it is not as heavily obscured as the spectrum of DY Per, the star known to have large carbon overabundance in its atmosphere (Yakovina, Pugach & Pavlenko 2009). Despite a very low S/N in the 4978–4985 Å region, strong absorption features can be identified in the spectrum of V2074 Cyg at these wavelengths, which are absent in the spectra of V1983 Cyg and DY Per. They are likely to be caused by the presence of the Merrill–Sanford bands in V2074 Cyg, particularly the SiC$_2$ band at 4977 Å.

The closely spaced lines of molecular transitions cause complete obscuration of continuum and blending of nearly every atomic line in the spectra. This makes the abundance analysis from the line equivalent-width measurement very uncertain. Hence, in this paper, we deduce the atmospheric parameters and chemical properties of the two variables with the use of the comparative spectral analysis method. We employ the set of high-resolution echelle spectra of 87 carbon stars kindly given to us by C. Barnbaum. These spectra were obtained at the Lick Observatory between 1988 and 1991. They span the wavelength range from 5084 to 7852 Å and have a resolution of 0.13 Å at 6100 Å. The spectra have 40 spectral orders, separated by gaps of 34–52 Å. Full details on these spectra are given in Barnbaum (1994). The data on the atmospheric parameters and chemical compositions of the stars used in the analysis were collected from the works of Lambert et al. (1986), Abia & Isern (1997, 2000), Abia et al. (2002, 2010), Bergeat & Chevallier (2005), Zamora et al. (2009) and Ohmaka & Tsuji (1996).

We have also made use of the grid of model atmospheres of carbon giants computed by Ya. V. Pavlenko with the SAM12 code (Pavlenko 2003). The grid represents the extension of the set of model atmospheres introduced by Pavlenko & Yakovina (2009) towards the lower $T_{\text{eff}}$ and C/O ratio. The models used cover the effective temperatures in the ranges of $T_{\text{eff}} = 2000$–3000 K and C/O = 1.007–3.162. All the models were calculated assuming solar metallicity, the same gravity value log $g$ and C/O velocity $\xi$ = 3 km s$^{-1}$. For calculations of synthetic spectra, we used the linelists of C$_2$ and CN molecules computed by B. Plez, kindly given to us by O. Zamora. The atomic line data were obtained from the Vienna Atomic Line Data base (VALD; Kupka et al. 2000).

3.1 C/O ratio

The shape of the carbon star spectrum is mainly determined by the effective temperature and C/O ratio values, because the carbon-bearing molecules are generally the main source of absorption throughout the visual region (Barnbaum 1994). The calculations of synthetic spectra show that, besides $T_{\text{eff}}$ and the C/O ratio, there are two other parameters significantly affecting the shape of the spectrum: the metallicity and the carbon isotopic ratio. In our comparative analysis, we assume that carbon stars with similar optical spectra have close values of the above-mentioned parameters.

By comparing our high-resolution spectra with those of various carbon stars of different $T_{\text{eff}}$, C/O ratio, spectral type and other parameters, for both V1983 Cyg and V2074 Cyg we have been able to identify a group of stars whose spectra, in general, closely reproduced the shape and line intensities of the spectra of our variables. According to Barnbaum (1994), all these stars are of spectral type N and they exhibit semiregular or irregular variations. The stars with spectra similar to V1983 Cyg have effective temperatures of $T_{\text{eff}} \approx 2800 \pm 100$ K and relatively low C/O ratios in the range of 1.02–1.14. The spectrum of V2074 Cyg shows better agreement, with the stars having $T_{\text{eff}} \approx 2600 \pm 100$ K and higher C/O ratios in range of 1.14–1.52. Note that the mentioned effective temperature intervals for both our variables are in good agreement with the values estimated by their photometric colour indices. A more thorough study of the spectral regions dominated by strong molecular absorption lines (excluding the strongest Swan system bandheads, because these are not covered with the Lick spectra) has revealed several almost entirely corresponding spectra. These spectra are used in our subsequent comparative analysis, assuming that our variables have similar C/O ratios (i.e. $\sim 1.05$ for V1983 Cyg and $\sim 1.25$ V2074 Cyg). Table 2 lists the parameters of such comparison stars, as extracted from the literature.

3.2 $^{12}$C/$^{13}$C

An inspection of the spectra of both V1983 Cyg and V2074 Cyg did not reveal any evidence of a very low $^{12}$C/$^{13}$C isotopic ratio in either star. The strong isotopic features typical of J-type carbon stars, which are known to be highly enriched in carbon isotope ($^{13}$C/$^{12}$C = 15), are not enhanced in our high-resolution spectra. Unfortunately, the region around 8000 Å, usually used for carbon isotopic ratio diagnostics, was not covered in our observations. We found that an accurate estimation of the $^{12}$C/$^{13}$C ratio from the available spectral region is problematic; nevertheless, we have been able to designate lower limits for both stars.

For V1983 Cyg, the region around the $^{13}$C$^{13}$C (1, 0) bandhead at 4752 Å is available. This bandhead is strong in the J-type star, UV Cam, compared to what is observed in our spectrum. In the latter, no sign of enhanced isotopic absorption was identified at these wavelengths (see Fig. 2). The synthesis of this region suggests that for a star with $T_{\text{eff}} = 2800$ K and C/O = 1.05, this bandhead might have significant strength if $^{12}$C/$^{13}$C < 20 (see Fig. 2). Apparently, at higher isotopic ratios, the strength of this bandhead is negligible, because the spectrum of U Hya ($T_{\text{eff}} = 2825$ K, C/O = 1.05 and $^{12}$C/$^{13}$C = 32) does not exhibit any appreciable absorption as a result of the isotopic carbon in this region (Fig. 2).

The spectrum of V2074 Cyg is not exposed at these wavelengths. Therefore, in order to estimate the $^{12}$C/$^{13}$C ratio, we have used the region at 6130–6131.5 Å, which appears to be sensitive to the $^{12}$C/$^{13}$C ratio in carbon stars that have $T_{\text{eff}}$ and C/O ratios close to those estimated for V2074 Cyg. Indeed, an inspection of the Lick
synthetic spectra calculated for the atmosphere of a carbon star with $T_{\text{eff}} = 2800$ K, C/O = 1.05 and different $^{12}\text{C}^{13}\text{C}$ ratios: 10, 20, 30 and 90. Lower panel: the same region but for the N-type star U Hya (dashed line) and the J-type star UV Cam (solid line); the respective $^{12}\text{C}/^{13}\text{C}$ ratios are given in brackets.

Figure 2. Upper panel: the spectrum of V1983 Cyg (filled circles) in the region around the $^{13}\text{C}^{13}\text{C}$ (1, 0) bandhead at 4752 Å. The lines represent synthetic spectra calculated for the atmosphere of a carbon star with $T_{\text{eff}} = 2800$ K, C/O = 1.05 and different $^{12}\text{C}^{13}\text{C}$ ratios: 10, 20, 30 and 90. Lower panel: the same region but for the N-type star U Hya (dashed line) and the J-type star UV Cam (solid line); the respective $^{12}\text{C}/^{13}\text{C}$ ratios are given in brackets.

Figure 3. Spectra of carbon stars with different $^{12}\text{C}^{13}\text{C}$ ratios in the region around 6131 Å (see text). The filled circles represent the spectrum of V2074 Cyg and the dotted, dashed and dash-dotted lines denote R Scl, W Ori and RY Dra, respectively. The comparison stars have temperatures from 2500 to 2680 K and C/O ratios in the range of 1.16–1.34, according to Lambert et al. (1986). The respective $^{12}\text{C}^{13}\text{C}$ ratios of the stars are shown in brackets. The grey lines represent the synthetic spectra of V2074, calculated for no $^{13}\text{C}$ and for $^{12}\text{C}^{13}\text{C}$ C = 4 and 20.

spectra of carbon stars with $T_{\text{eff}} = 2600 \pm 100$ K and C/O = 1.16–1.34 has revealed that in the stars with high isotopic ratios, this region is relatively clear of absorption. However, strong absorption features were presented in all J-type stars, which indicates that these features are likely to be isotopic $\text{C}_2$ and CN lines (see Fig. 3). The results of spectral synthesis support this conclusion. The results show that, at given values of $T_{\text{eff}}$, C/O ratio and solar metallicity, the atomic and non-isotopic molecular $\text{C}_2$ and CN absorption is expected to be relatively weak at these wavelengths, but at low $^{12}\text{C}^{13}\text{C}$ ratios several strong isotopic CN and $\text{C}_2$ lines are present (see Fig. 3). For the spectral synthesis of this region, we used the molecular line lists from the Kurucz data base, which provides a better fit for the observed spectra. However, the positions and intensities of isotopic $\text{C}_2$ and CN lines are still not well reproduced. From the above analysis, we conclude that the isotopic ratio of V2074 Cyg must be relatively high, at least above 20.

3.3 Metallicity and $s$-process elements

In order to estimate the metallicity and average $s$-process element abundances in the two variables, we have compared the line strengths of selected atomic and ionic lines in our spectra and the spectra of comparison stars. For this purpose, first we matched the molecular absorption features around the lines selected for analysis. Then, if the intensity of the lines of some particular element was systematically weaker (stronger) in our spectrum, we ascribed this to a lower (higher) abundance of this element in our star’s photosphere with respect to the comparison star. In this qualitative analysis, we have avoided regions that either are dominated by telluric lines or have a low S/N ratio. We convolved our spectra down to fit the resolution of the Lick spectra. Some differences in the line intensities are expected to a result of the different origin and initial resolution of the spectra. To control the magnitude of this mismatch, we used our spectrum of DY Per, comparing it with the Lick spectrum of this star.

The inspection of the V1983 Cyg spectrum shows that, for this star, the metallic lines (e.g. the lines of Fe, Ti and Cr) are of lesser intensity that those observed in TY Oph. According to Abia et al. (2002), TY Oph is slightly enriched in metals relative to the Sun by having $\text{[M/H]} = 0.1$. However, the same lines in V1983 Cyg are slightly enhanced or have similar strength in comparison to TT Cyg. Because TT Cyg is slightly metal-poor ($\text{[M/H]} = -0.1$), we conclude that V1983 Cyg should have a solar metallicity near to or slightly lower than this. The strength of the $s$-process element lines (Zr, Ba and Y) are similar or slightly more intense in V1983 Cyg than in TT Cyg, for which the average abundance of the $s$-process elements, as listed in Abia et al. (2002), is $\langle\text{[s/M]}\rangle = 0.96$. However, the same lines are typically weaker in TT Cyg in comparison to TY Oph, although TY Oph has $\langle\text{[s/M]}\rangle = 0.54$, according to the same source. Nevertheless, the comparison to other stars reveals that the strength of the $s$-process element lines in V1983 Cyg is consistent with those enhanced abundances with respect to the Sun.

In the spectrum of V2074 Cyg, the Fe, V and Ti lines are typically slightly weaker or similar to those in the spectra of the comparison stars, U Cam and V Aql. According to Abia et al. (2002), both these stars are slightly metal-poor, with $\text{[M/H]} = -0.09$ and $-0.05$, respectively, so we conclude that the average metallicity of V2074 Cyg might also be slightly below solar. In turn, the intensities of the two strong $s$-process element lines, Ba II 6496.9 Å and Y I 6435 Å, in the spectrum of V2074 Cyg are much higher than those in V Aql, for which $\langle\text{[s/M]}\rangle = 0.2$, according to Abia et al. (2010). In U Cam ($\langle\text{[s/Fe]}\rangle = 0.55$), the same lines have a similar or slightly lower strength than in our star. In general, the intensities of the Zr, Y and Ba lines throughout the spectrum of V2074 Cyg are typically similar or higher than those of both comparison stars. Thus, the enhancement in the $s$-process elements is evident for our star.

The strength of the Li I resonance doublet line at 6707.8 Å in both V1983 Cyg and V2074 Cyg is compatible with no enrichment

2 http://kurucz.harvard.edu/molecules.html
in this element. In this region, our spectra resemble carbon stars with \( \log(e(Li)) < -1 \).

Fig. 4 shows the spectra of our two variables in comparison with the spectrum of DY Per, in which the lines of the s-process elements are known not to be significantly enhanced (Dominy 1985; Keenan & Barnbaum 1997; Zács et al. 2007). Also, the spectrum of a typical N-type star, TY Oph, is shown, and this possesses a moderate enhancement of s-process elements. As can be seen from the figure, the appearance of the absorption features in our spectra more closely resembles a normal N-type star. The synthetic spectra of V1983 Cyg and V2074 Cyg are also shown, as calculated for the atmospheres of carbon giants with atmospheric parameters close to those estimated for our variables, that is, \( T_{\text{eff}} = 2800 \) and 2600 K and C/O = 1.05 and 1.26, respectively. \( ^{12}\text{C}/^{13}\text{C} = 40 \), solar metallicity and abundances of s-process elements enhanced by 1.0 dex with respect to solar values. As can be seen, a generally good fit of the observed spectra can be achieved using these roughly estimated parameters, supporting our qualitative analysis.

3.4 Hydrogen

The spectra of cool carbon variables often exhibit Balmer lines in emission (e.g. Barnbaum 1994), and these are interpreted in terms of shock wave propagation through the atmosphere of the long-period variable star (Willson 1976). Still, the presence of notable absorption in the H\( \alpha \) line is not expected in the spectrum of a carbon star with low photospheric temperature. As observed for α line is not expected in the spectrum of a period variable star (Willson 1976). Still, the presence of notable of shock wave propagation through the atmosphere of the long-emission (e.g. Barnbaum 1994), and these are interpreted in terms

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The spectra of cool carbon variables often exhibit Balmer lines in emission (e.g. Barnbaum 1994), and these are interpreted in terms of shock wave propagation through the atmosphere of the long-period variable star (Willson 1976). Still, the presence of notable absorption in the H\( \alpha \) line is not expected in the spectrum of a carbon star with low photospheric temperature. As observed for α line is not expected in the spectrum of a period variable star (Willson 1976). Still, the presence of notable of shock wave propagation through the atmosphere of the long-emission (e.g. Barnbaum 1994), and these are interpreted in terms

3.5 Na I D lines

Fig. 6 shows the velocity structure of the Na I D lines (\( \lambda \lambda 5895.92, 5889.95 \)) in the spectra of both stars under study. In the spectrum of V1983 Cyg, the Na I D lines consist of four well-determined components, three of which are apparent blends of several lines. The sharp line at 14 km s\(^{-1}\) and the strong blend centred on \(-11.5 \text{ km s}^{-1}\) are probably of interstellar origin (the velocity of the particular component is given here as a mean value derived from the D1 and D2 lines). The broad component near the stellar radial velocity consists of at least two blended lines. Probably, the sharp line, which is slightly redshifted with respect to the stellar velocity, originates from the interstellar matter. Finally, in the most blueshifted component of the Na I D lines, two blended subcomponents can be recognized as having heliocentric radial velocities of \(-78.6 \text{ and } -89.1 \text{ km s}^{-1}\). These lines are likely to arise from the circumstellar matter, expanding at velocities of \(-48.7 \text{ and } -59.2 \text{ km s}^{-1}\) with respect to the star.
The structure of the Na i D lines in the spectrum of V2074 Cyg is more complicated. A strong broad absorption feature extends from about $-90$ to $0$ km s$^{-1}$, which is probably a blend of the stellar, circumstellar and interstellar components. The heliocentric velocity arising from galactic rotation in the line of sight towards V2074 Cyg is in the range of $0$ to about $-25$ km s$^{-1}$ at the star's distance ($\sim 4$ kpc). Therefore, we suggest that the lines within the corresponding velocities originate from the interstellar matter following the galactic rotation. The component at $-48$ km s$^{-1}$ has a velocity closest to the stellar value and it is likely to originate from the stellar photosphere. The other (at least three) components of the broad blend surrounding the stellar line could arise from the circumstellar shells; however, the interstellar origin must not be excluded. There are two more absorption components of the Na i D line outside the broad blend. The most blueshifted component (centred at about $-106$ km s$^{-1}$) is probably associated with circumstellar matter moving away from the star at a velocity of about $-55$ km s$^{-1}$. The origin of the most redshifted component, with a heliocentric velocity arising from galactic rotation in the line of sight towards V2074 Cyg, is marked with an asterisk in both plots. The components that are likely to originate from a circumstellar shell (CS) and interstellar matter (ISM) are indicated (see text).

### DISCUSSION AND CONCLUSIONS

Our qualitative analysis of the high-resolution spectra of V1983 Cyg and V2074 Cyg suggests that both stars have spectroscopic properties that are generally typical of N-type carbon stars (i.e. low effective temperatures, strong absorption bands of C$_2$ and CN molecules, no significant enrichment in carbon isotope, enhancement in $s$-process elements and a nearly solar metallicity). Lithium abundance is estimated to be low in both stars, also typical of regular N-type carbon stars (Denn et al. 1991; Abia & Isern 1997). Our spectral classification is supported by near-infrared photometry – in the two-colour $J - H$ versus $H - K$ diagram, both V1983 Cyg and V2074 Cyg fall into the region occupied by N-type carbon stars, according to Totten, Irwin & Whitelock (2000). The comparison of our spectra with those of normal N-type stars in the available regions has revealed two unusual spectral features as follows: high-velocity components in the Na i D lines in the spectra of both stars and the presence of the H$\alpha$ line in absorption in V1983 Cyg.

An inspection of the Na i D region throughout the available high-resolution spectra of various carbon stars indicates that the presence of pronounced high-velocity absorption components is not common. Only a few stars of the Lick sample exhibit components in the Na i D lines that are moving with respect to the star with velocities exceeding 30 km s$^{-1}$, and these are more likely not to be of interstellar origin. The most remarkable velocities are found for the cool RCB star DY Per, which has a maximal outflow velocity of about $-150$ km s$^{-1}$, and the binary SRa variable V Hya, which has a high-velocity component of about $-90$ km s$^{-1}$, with both stars at maximum light. The latter star is known to have a peculiar circumstellar envelope with a bipolar molecular outflow (Kahane, Maizels & Jura 1988) and a wind velocity $\sim 200$ km s$^{-1}$, according to millimetric molecular line observations (Knapp, Jorissen & Young 1997). V Hya is thought to be an AGB star at the early stage of evolution into a bipolar protoplanetary nebula (Tsuji et al. 1988). It has an unusual optical spectrum, showing many emission lines (Lloyd Evans 1991) and severe spectral broadening (Barnbaum, Morris & Kahane 1995), which is different from our carbon variables.

Herbig (2009) has detected high-velocity Na i D components in the spectrum of the binary companion of carbon star Mira UV Aur, which suggests that they originate from the shells ejected by the carbon star at a velocity of at least $116$ km s$^{-1}$. As Herbig notes, this velocity considerably exceeds the typical outflow velocity for carbon stars. This is also true for our two variables, because, according to the data on the expansion velocities from millimetric observations and the predictions of the hydrodynamical models (see Bergeat & Chevallier 2005, and references therein), typical outflow velocities in normal carbon stars are about $10$ km s$^{-1}$, but the highest values do not usually exceed $30$ km s$^{-1}$.

The high-velocity ($\sim 200$ km s$^{-1}$) blueshifted absorption components in Na i D are common in the spectra of RCB stars (e.g. Clayton 1996; Rao & Lambert 2008). The ejections of the dust clouds in these stars are thought to be triggered by the atmospheric pulsations (Woitke, Goeres, & Sedlmayr 1996). The connection between the radial pulsation phase and the onset of decline has been shown for several RCB stars (e.g. Crause, Lawson & Henden 2007). Although the light curves of the two variables do not exhibit any periodic component, nevertheless, the periodicity in low-amplitude light variations cannot be entirely excluded before performing more accurate photometric observations. Still, there are several other irregular stars known to exhibit RCB-like declines (White lock et al. 2006, 2009; Menzies et al. 2010). This indicates that the presence of pulsations is probably not a necessary condition for the appearance of long-term obscuration events in carbon stars.

While discussing the origin of the high-velocity components in Na i D lines, it is worth noting that several carbon stars are known to have geometrically thin detached CO shells, showing expansion velocities of 12.5–23 km s$^{-1}$ (i.e. slightly higher than usually observed for carbon stars; e.g. Olofsson et al. 1993; Schöier, Lindqvist & Olofsson 2005). Out of the four available spectra of such stars (i.e. TT Cyg, S Sco, U Cam and R ScI), the first three demonstrate close correspondence with one of our spectra. However, despite the unusual properties of these stars in the molecular radio lines (line doubling) and infrared flux (excess radiation at 60 $\mu$m), they are known to be ‘normal’ N-type stars, according to optical observations. Indeed, all these stars are semiregular and they do not show any peculiarities in chemical composition with respect to other N-type carbon stars from the samples of Lambert et al. (1986) and Abia et al. (2002). The spherically symmetric detached CO shells of these stars are thought to have formed as a result of a...
very high mass-loss rate episode during a recent He-shell flash (e.g. Olofsson et al. 1990; Schöier et al. 2005).

Limited conclusions can be made about the properties of the circumstellar environment of the two variables, based on the available infrared data. The position on the two-colour ($J - H$)$_0$ versus ($H - K$)$_0$ diagram for carbon stars in Whitelock et al. (2006) indicates that both V1983 Cyg and V2074 Cyg have relatively thin circumstellar shells typical of non-Mira variables with low mass-loss rates. V2074 Cyg has IRAS $K_{12} - [12]$ and $[12] - [25]$ colours typical of non-Mira carbon variables (see fig. 2 of Whitelock et al. 2006). The $K_{12} - [12] \sim 1.7$ colour of this star corresponds to the moderate dust mass-loss rate of about $2.5 \times 10^{-7} M_\odot$ yr$^{-1}$, according to the tight correlation between these parameters obtained for Mira variables (Whitelock et al. 1994). A similar value, but for a gas mass-loss rate, is found from the correlation for AGB stars and protoplanetary nebulae found by Bieging et al. (2006). This value is slightly higher than the median gas mass-loss rate of $\sim 10^{-7} M_\odot$ yr$^{-1}$ found for irregular carbon variables by Olofsson et al. (1993).

It is similar to that observed for U Cam, which is a star with a young detached shell (Lindqvist et al. 1999). Unfortunately, the available data are not sufficient to judge if the high-velocity components seen in absorption, and both these stars are J-type stars. Another star with a strong Balmer absorption, BD +2$^\circ$ 3336, known as a binary system (McCruire 1997), has been classified as an N-type star by Barnbaum et al. (1996). However, the recent analysis of the chemical composition performed by Zamora et al. (2009) resulted in the reclassification of this star as belonging to a CH spectral type. Thus, to date, no N-type carbon stars are known to show H$\alpha$ in strong absorption.

A considerable absorption in the H$\alpha$ line is expected to be observed in the spectrum of a cool carbon star in the presence of an active chromosphere, as has been shown by semi-empirical chromospheric modelling (Luttermoser et al. 1989). According to spectra from the International Ultraviolet Explorer (IUE), there is evidence of a chromosphere existing in some non-Mira N-type stars; however, the optical spectra of these stars do not exhibit any chromospheric features (Luttermoser 2000). Observations of the ultraviolet spectra of V1983 Cyg would be interesting in this respect.

We can look for another possible explanation for the appearance of the H$\alpha$ line in the spectrum of V1983 Cyg in the presence of a hotter companion star contributing to the spectrum of the carbon star. The well-studied binary V Hya is known to exhibit such a combined spectrum. The higher Balmer lines are presented in absorption in this star and they have a radial velocity different from the stellar velocity, likely arising from the companion star (Lloyd Evans 1991). In V1983 Cyg, the H$\alpha$ line is also slightly blueshifted with respect to the star’s photospheric velocity. More observations are required in order to establish whether the value of the shift is changing with time. Whitelock et al. (2006) have discussed the possibility that the obscuration events observed in carbon stars could be the consequence of the possible binarity of these stars. However, beside the H$\alpha$ absorption, no other indications of a combined spectrum or other evidence of binarity of V1983 Cyg have been found.

Alksnis (2003) has characterized the light drops of V1983 Cyg as being similar to those observed for DY Per. In contrast to the photometric similarity, our spectroscopic analysis suggests that these stars have different spectral properties, as follows. (i) According to the high-resolution spectroscopic studies of DY Per performed by Keenan & Barnbaum (1997) and Začs et al. (2007), this star exhibits a significant hydrogen deficiency, consistent with its classification as a cool RCB star. If the H$\alpha$ absorption line, as seen in the spectrum of V1983 Cyg, originates from its atmosphere, the hydrogen deficiency is clearly rejected for this star. (ii) The s-process elements in the spectrum of DY Per are known to be not significantly enhanced. In turn, the spectrum of V1983 Cyg shows the enhancement of the s-process elements similar to that observed in most N-type stars. (iii) The modelling of the spectral energy distribution of DY Per (Yakovina et al. 2009) shows that the C/O ratio in this star might be enormously high compared to normal carbon stars. For V1983 Cyg, the C/O value was estimated to be typical for N-type carbon stars. (iv) Finally, although the velocities of the Na I D components in the spectrum of V1983 Cyg are considerably higher than those normally observed in carbon stars, in the spectrum of DY Per such components have velocities that are almost three times higher (Začs et al. 2005), which is close to what is observed for RCB stars. Hence, the spectral properties of V1983 Cyg do not indicate that it could be a cool RCB star like DY Per. Similar conclusions can be drawn from a comparison of the spectra of DY Per and V2074 Cyg.

We note that the photometric light curves of both V1983 Cyg and V2074 Cyg exhibit much similarity with those of DY Per-type stars found in the Magellanic Clouds and in the Galactic bulge, which generally have smaller amplitudes of light drops and a slower rate of long-term light variations in comparison with DY Per. For instance, in the sample of Tisserand et al. (2009), the gradual and prolonged luminosity increase of LMC–DY Per-8 is similar to that observed for V2074 Cyg, but the photometric curve of the star SMC–DY Per-4 is reminiscent of the fragments from the light curve of V1983 Cyg. The very low fading rates estimated for our two variables place them among the slowest DY Per-type stars. Alcock et al. (2001) and Tisserand et al. (2009) have found evidence for significant carbon isotope overabundance in DY Per-type stars. However, some stars in their samples show no traces of the $^{13}$C isotope, as found in the case of our two variables. Because the available data on DY Per-type stars indicate that they might be ordinary carbon stars exhibiting ejection events (Tisserand et al. 2009), V1983 Cyg and V2074 Cyg could belong to this group of variables. The results of the abundance analysis for DY Per-type stars will reveal if all these stars form an evolutionary homogeneous group.

The nature of the observed long-term light obscurations in the light curves of V1983 Cyg and V2074 Cyg remains uncertain. The fading episodes are apparently similar to RCB-like declines, relatively well studied in Mira variables, so the obscuration mechanism could be the same. Theoretical simulations of the circumstellar dust evolution of a carbon-rich AGB star, using two-dimensional models, have shown that the hydrodynamical, radiative or thermal instabilities have led to a development of dust clouds around AGB stars (Woitke & Niccolini 2005). The optical reddening of V1983 Cyg and V2074 Cyg during the light minima does not contradict the dust formation model; however, more observations are necessary to confirm it.

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