GAIA spectroscopy of Carbon stars

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Abstract. GAIA spectra of a grid of Carbon stars have been obtained with the Asiago 1.82m telescope and computed via synthetic modeling. The spectral appearance of Carbon stars over the GAIA wavelength range is best described as a forest of closely spaced strong absorption lines (nearly all due to the CN molecule) that perform stupendously in terms of radial velocity accuracy, at the level of 0.1 km s^{-1} on a single GAIA well exposed spectrum at 17000 resolution. CaII triplet lines can still be recognized down to the coolest Carbon types, turning into emission in some carbon Miras. The completely different absorption pattern for $^{12}$CN and $^{13}$CN allows measurement of the $^{12}$C/$^{13}$C ratio. Smooth and marked spectral transitions are observed for Carbon spectra over the GAIA wavelength range, offering good prospects for classification.

1. Introduction

Classical Carbon stars are evolved objects at the tip of the AGB branch, and as such they are bright and visible over great distances in the Galaxy. The GAIA 8480-8740 Å wavelength range is placed toward the peak of the Carbon star spectral energy distribution, favouring their observation. The large and homogeneous observational database that GAIA will collect on Carbon star in the Galaxy and nearby dwarf satellites is obviously expected to deliver a fresh and a deeper view into the realm of this highly evolved type of stars.

Spectral surveys previously conducted over the GAIA wavelength range as well as grids of computed synthetic spectra have only marginally considered Carbon stars, whose appearance over the GAIA spectral interval is basically unknown.

To fill this gap, we have observed over the GAIA wavelength range a well distributed grid of Carbon stars mapping the Keenan and Morgan (1941) classification scheme (still a good and compact description of the spectrum) and selected from the Alksnis et al. (2001) catalogue, and computed a preliminary grid of synthetic spectra. This contribution outlines briefly the main results.
Figure 1. Spectra of some of the observed Carbon stars arranged along the classification sequence. Note the decrease in CaII visibility.

Figure 2. Spectra of some of the observed Carbon stars (continued from Figure 1). Note the CaII emission in U Cyg.
Table 1. List of Carbon stars for which high S/N and 20 000 resolution spectra over the GAIA wavelength range have been obtained with the Asiago 1.82 m + Echelle + CCD spectrograph. The majority of them is displayed in Figures 1 and 2.

| HD 156074 | C1,2 | 17 13 31.2 | +42 06 22 | 7.6 |
| Ros51     | C2,1 | 13 55 44.2 | -18 14 40 | 7.8 |
| CS 888    | C2,2 | 07 46 26.5 | -08 19 19 | 11.2 |
| HD 16115  | C2,3 | 02 35 06.5 | -09 26 34 | 8.2 |
| HD 47396  | NY Gem | C3,1 | 06 39 17.8 | +22 36 18 | 12.5 |
| BD +21.64 |     | C3,3 | 00 34 15.8 | +22 23 36 | 9.7 |
|           | V738 Mon | C3,4 | 06 43 12.5 | -08 45 30 | 9.9 |
|           | DV Lac  | C4,3 | 22 45 04.2 | +56 37 18 | 9.9 |
| HD 52432  | V614 Mon | C4,4 | 07 01 01.9 | -03 15 09 | 7.3 |
| HD 1546   | VX And  | C4,5 | 00 19 54.0 | +44 42 34 | 8.5 |
|           | BG Mon  | C5,2 | 06 56 22.8 | +07 04 12 | 9.2 |
| HD 25408  | UV Cam  | C5,3 | 04 05 53.9 | +61 47 40 | 7.6 |
|           | VW Gem  | C5,4 | 06 42 08.6 | +31 27 18 | 8.2 |
| HD 59643  | NQ Gem  | C6,2 | 07 31 54.5 | +24 30 13 | 7.7 |
| HD 92839  | VY UMa  | C6,3 | 10 45 04.0 | +67 24 41 | 6.0 |
| HD 42272  | TU Gem  | C6,4 | 06 10 53.1 | +26 00 53 | 7.4 |
|           | V Hya   | C6,5 | 10 51 37.3 | -21 15 00 | 9.7 |
| HD 63353  | W CMi   | C7,2 | 07 48 45.5 | +05 23 35 | 9.0 |
| HD 183556 | UX Dra  | C7,3 | 09 21 35.5 | +76 33 35 | 6.3 |
|           | TT Tau  | C7,4 | 04 51 31.3 | +28 31 37 | 7.9 |
| HD 34842  | UV Aur  | C8,1 | 05 21 48.9 | +32 30 43 | 9.6 |
| HD 192443 | RS Cyg  | C8,2 | 20 13 23.7 | +38 43 44 | 7.7 |
| HD 224855 | WZ Cas  | C9,1 | 00 01 15.9 | +60 21 19 | 7.1 |
| HD 193680 | U Cyg   | C9,2 | 20 19 36.6 | +47 53 39 | 6.7 |

2. Observed spectra

The observed spectra have been secured with the Asiago Echelle+CCD spectrograph at a resolution ~ 18 000 (close to the upper limit for the GAIA spectrograph) and S/N always in excess of 200 (thus all visible features are real and not noise artifacts). A list of the observed Carbon stars is given in Table 1, while Figures 1 and 2 show some of the spectra arranged into temperature sequences.

The features progress with the temperature index is quite evident, suggesting that a detailed classification scheme can be devised for Carbon stars over the GAIA wavelength range.

The collected spectra have been cross-correlated with templates from the synthetic grid (see below) to estimate the accuracy that can be achieved in the
Identifications

$T_{\text{eff}} = 3000$

$\log g = 8.920 \quad \log C = 8.923 \quad \frac{^{12}C}{^{13}C} = 7/3$

global
atomic
lines

$^{12}C$-$^{13}C$

$^{12}C$-$^{13}C$

$^{13}C$-$^{13}C$

$^{12}C$+$^{14}N$

$^{13}C$+$^{14}N$

$^{12}CH$

$\text{SiH}$

$\text{MgH}$

8500  8550  8600  8650  8700  8750  $\lambda$(Å)

Figure 3. Synthetic spectra of diatomic molecules over the GAIA wavelength region.

radial velocities. As expected, the accuracy turned out to be impressively good: all spectra displayed in Figures 1 and 2 can be cross-correlated to 0.1 km s$^{-1}$ error. This is evidently due to all pixels being part of strong lines, thus all pixels carrying a strong radial velocity information.

3. Synthetic spectra

We computed a grid of stellar model atmospheres with $2500 \leq T_{\text{eff}} \leq 3500$ K and $0 \leq \log g \leq 1$ by SAM12 program (Pavlenko 2002, http://www.mao.kiev.ua/staff/yp/TOP-mod.htm). SAM12 is a modification of ATLAS12 (Kurucz 1999, http://kurucz.harvard.edu/).Opacity sampling treatment was used to account for atomic and molecular absorption. Atomic and molecular line data were taken from Kurucz (1993), Goorvitch (1994) and/or VALD (Kupka et al. 1999). Chemical equilibrium was computed for the case of carbon-rich plasma, i.e. C/O $> 1$. Molecular constants of chemical equilibrium were taken from Tsuji (1973).

A grid of synthetic Carbon spectra has been computed for the indicated atmospheric parameters by WITA6 program (Pavlenko 1999). Computations were carried out for the same opacity sources and abundances as in model atmosphere computations. We adopted a micro-turbulent velocity $V_t = 3.5$ km s$^{-1}$,
Voigt profiles were taken for all lines, and damping constants were from VALD (Kupka et al. 1999) and Kurucz (1993) databases, or computed in the framework of classical Unsold (1949) approach.

4. Results

We carried out an identifications of all molecular features observed in the region. To do it, we computed synthetic spectra taking into account only line lists of a given species. Results are showed in Figure 3. The main contributors to line opacity are the CN molecule and the atomic lines.

A sample of synthetic spectra computed by taking into account absorption by all species are showed in Fig. 4. In general, C-giant spectra show a dependence on a larger number of input parameters than M stars at the same temperature. The impact of temperature and $^{12}\text{C}/^{13}\text{C}$ on computed spectra is showed in Figure 4. A more general approach should consider the effects on the computed spectra of different micro-turbulent velocities, [Fe/H] and [He/H], stellar winds and sphericity effects. Detailed consideration of these effects lies beyond the scope of this contribution. Extensive studies of carbon stars are carried out by various groups (cf. Wallerstein & Knapp 1998, Guiermo & Wallerstein 2000, and references therein). Taking into account refined input parameters for synthetic spectra computations, different parameterization’s algorithms (see Jones

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et al. 2002, Pavlenko & Jones 2002) can be used to derive more precisely the fundamental parameters of Carbon stars.

Our analysis of computed and observed spectra of Carbon stars over the GAIA wavelength range indicates that (a) the CN molecule is by far the strongest shaper of the Carbon stars appearance in the GAIA wavelength range, (b) other molecules (in particular C2) play a negligible role, (c) the spectral pattern of the CN molecule is completely different for the 12CN and 13CN variants, allowing a determination of the 12C/13C ratio from GAIA spectra, (d) CaII lines in absorption are recognizable over the whole Carbon star sequence, (e) CaII lines can appear in emission in some carbon Miras (perhaps only at selected pulsation phases), and (f) the Carbon star perform stupendously in term of accuracy of radial velocities.

References

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