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) clas-
sification 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 20000 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.

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2. Observed spectra

The observed spectra have been secured with the Asiago Echelle+CCD spectrograph at a resolution ~ 18000 (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
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 ≤ Tₚ ≤ 3500 K and 0 ≤ log g ≤ 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), Gooorvitch (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 Vₜ = 3.5 km s⁻¹,
Sequences \( T_{\text{eff}} = 2500 \, - \, 3000 \)
\[
\log \, O = 8.920 \quad \log \, C = 8.923 \\
^{12}\text{C}/^{13}\text{C} = 1/0 \, - \, 7/3
\]

Figure 4. A dependence of synthetic spectra of Carbon stars on input parameters.

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, Guliermo & Wallerstein 2000, and references therein). Taking into account refined input parameters for synthetic spectra computations, different parameterization’s algorithms (see Jones
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 \(^{12}\text{C}\) and \(^{13}\text{C}\) variants, allowing a determination of the \(^{12}\text{C}/^{13}\text{C}\) 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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Unsold, A. 1949, Physik der Sternatmosphären, Springer