Mem. S.A.It. Vol. 75, 596

Memorie della

An attempt to derive Mg isotopic ratios in carbon stars

O. Zamora[1],C. Abia[1], P. de Laverny[2], and I. Domínguez[1]

[1] Departamento de Física Teórica y del Cosmos, Universidad de Granada, 18071 Granada, Spain, e-mail: zamora@ugr.es
[2] Observatoire de la Côte d´Azur, Départament Cassiopée, UMR 6202, BP 4229, 06304 Nice Cedex 4, France

Abstract. We discuss the use of the spectral range near 7570 Å to determine the Mg isotopic ratios in carbon stars using the $B'^2\Sigma^+$–$X\,^2\Sigma^+$ system of the MgH molecule. We also compare with the spectral range near 5140 Å that has been commonly used in normal stars (oxygen–rich stars). The region near 5140 Å is not the better choice for carbon stars because it is very crowded with CN and C_2 molecular bands and the localization of the continuum is complicated. The range near 7570 Å is less blended with molecular bands. The continuum is easy to locate and the isotopic splitting between MgH isotopic absorptions is larger. Unfortunately, we are not able to reproduce accurately the observed spectrum in this region and, moreover, the synthetic spectrum is not sensitive to large variations in the isotopic ratios.

Key words. Carbon stars – nucleosynthesis – stellar abundances

1. Introduction

Magnesium is one of the more abundant elements in the Universe. It is produced mainly by type II supernovae (SNe II) although asymptotic giant branch (AGB) stars can be another important source, at least for the heavy stable isotopes ^{25,26}Mg. Indeed, the contribution of intermediate mass AGB stars ($4 \leq M/M_{\odot} \leq 8$) may be dominant in the production of the heavy isotopes ^{25,26}Mg for [Fe/H] below -1, whereas SNe II would be responsible for most of the heavy Mg isotopes in the present-day interstellar medium (Fenner et al. 2003). The determination of Mg isotopic ratios is an important matter for several reasons: it is a excellent tool to study the chemical evolution of the Galaxy, providing us with information about the nuclear processes occurring in the stellar interior, improving, as a consequence, our knowledge of the stellar structure and evolution.

Giant *intrinsic* carbon stars are in the AGB phase. These stars have a ratio $C/O \geq 1$ in the envelope and owe their carbon enrichment to the operation of third dredge-up during the TP-AGB phase. Their low $T_{\rm eff}$ and the fact that $C/O > 1$ holds in the atmosphere makes their spectra difficult to analyze. The spectral region near 5140 Å has been used commonly in normal stars (O-rich) to determine the Mg isotopic ratios but in this region there is a strong C_2 band in carbon stars which

Send offprint requests to: O. Zamora
Correspondence to: Departamento de Física Teórica y del Cosmos, 18071 Granada, Spain

makes the continuum difficult to locate (see e.g. Barnbaum 1996). This implies that the resolution required for the determination of Mg isotopic ratios using the A $^2\Pi$–X $^2\Sigma^+$ system of MgH has to be very high, R $\approx$ 150,000 (e.g. Gay & Lambert 2000). However, the spectral range near 7570 Å is less blended with molecular bands and the continuum is easy to locate. In fact, Wallace et al. (1999) determined the Mg isotopic ratios in the Sun from a sunspot spectrum using the B$'^2\Sigma^+$–X $^2\Sigma^+$ system of MgH in this spectral region. They found ^{24}Mg:^{25}Mg:^{26}Mg = 76:12:12, very close to the terrestrial value of 79:10:11 (Rosman & Taylor 1998).

In the following sections we describe our attempt to determine the Mg isotopic ratios in a sample of carbon stars studying the two spectral ranges previously cited, 5140 and 7570 Å.

2. The sample

We have selected a sample of carbon stars with the following criteria, C/O ratio close to the unity (moderate intensity of CN and C_2 bands) and/or low metallicity (spectrum less crowded). We use high resolution (R $\approx$ 40,000) spectra. Our sample includes the normal (N-type) carbon star Z Psc in order to test if it is possible to determine the Mg isotopic ratios in this type of carbon star which is the most interesting and numerous. The basic atmospheric parameters have been taken from the literature. Table 1 shows the objects in our sample and their characteristics. The microturbulence was taken equal to 2.2 km s^{-1} for all the objects.

3. Analysis

We have computed synthetic spectra for the sample stars using a modified version of the *Uppsala Synthetic Spectrum Package* 1988-03-24 version. The critical step is the calibration of the line list in the spectral ranges studied. For the range 5133 − 5141 Å, we have taken the line list calibrated by Shetrone (1996) and completed with molecular data by B. Plez (private communication). We recalibrate these line lists by fitting, by eye, both the solar photosphere and Arcturus' spectra. There are a few lines not well reproduced but we do reproduce within less than 1% the MgH transitions of interest (the isotopic splitting is about 0.1 Å) around 5134.5, 5138.7 and 5140.2 Å.

For the range 7570 − 7578 Å we have calibrated the line list using the atomic data of VALD and Kurucz databases, MgH transitions from Wallace et al. (1999) and the rest of molecular data from B. Plez (private communication). We calibrated and tested the line list using the sunspot 1981/03/24 No.1 (Wallace et al. 1999) solar photosphere and Arcturus spectra. To analyze the sunspot spectrum we used the atmosphere models of an umbral sunspot with $T_{\rm eff}$ = 3941 K (cool) and $T_{\rm eff}$ = 5028 K (hot) by Collados et al. (1994). However, these two models not reproduce well enough the observed sunspot spectrum, that seems to require an intermediate effective temperature. To solve this problem we re-calibrated the MgH $\log gf$ values by fitting the Arcturus spectrum adopting the model atmosphere parameters by Peterson et al. (1993). In this spectral region the MgH transitions of interest are 7570.719, 7577.341 Å (^{24}MgH), 7574.476 Å (^{25}MgH) and 7571.830 Å (^{26}MgH).

4. Results

The main problems to measure the Mg isotopic ratios in the range 5133 − 5141 Å in carbon stars are the presence of a strong C_2 band, the localization of continuum and the small isotopic splitting. Figure 1 and the upper panel of Figure 2 show two examples of theoretical fits in the 5140 Å region for the normal C-star Z Psc and the SC-type star WZ Cas.

In the range of 7570 − 7578 Å the previously mentioned problems are less important and we have the advantage of a larger isotopic splitting (greater than or equal to 1 Å).

4.1. Z Psc

Z Psc is an N-type carbon star of solar metallicity with *s*-element enrichment. Because of its abundance characteristics, Abia et al. (2001) conclude that this star is probably a TP-

Table 1. Sample of carbon stars. The column *s*-elements indicates if overabundances of these elements are detected or not in the star. The reference A01 is Abia et al. (2001), A03 is Abia et al. (2003) and Z04 is this work.

Star	Type	T_{eff}(K)	[Fe/H]	log g	C/O	$^{12}C/^{13}C$	*s*-elements	Ref.
Z Psc	N	2870	−0.01	+0.0	1.01	55	Yes	A01
WZ Cas	SC	3140	+0.00	+0.0	1.005	4	No	A01
HD 189711	CH	3100	−1.00	−0.2	1.10	15	Yes	A03
HD 76396	CH	4980	−2.00	+1.5	1.04	3	?	Z04

AGB star of low mass ($M \leq 3\ M_\odot$). Due to the low mass we do not expect a significant ^{25,26}Mg production (see models by Karakas & Lattanzio 2003) but we should expect solar Mg isotopic ratios in this star. In Figure 1 are shown two fits: dashed line corresponds to the terrestial values and the thick solid line to a model enhanced in heavy isotopes. The three regions of interest (marked by vertical lines) are saturated with C_2 and CN absorptions and the synthetic spectra are not sensitive to large variations in the Mg isotopic ratios so we cannot give a determination of Mg isotopic ratios in this star.

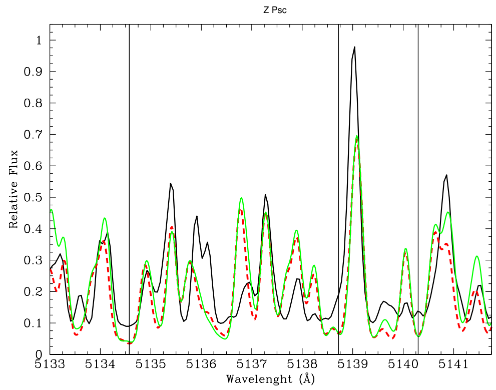

Fig. 1. Spectrum of Z Psc (thin continuous line) in the range 5133 − 5141 Å. The dashed line represents a synthetic spectrum with ^{25}Mg/^{24}Mg = 0.13 and ^{26}Mg/^{24}Mg = 0.14 (terrestial ratios); the thick solid line represents a synthetic spectrum with ^{25}Mg/^{24}Mg = 0.43 and ^{26}Mg/^{24}Mg = 0.44. Vertical lines indicate the position of ^{24}MgH transitions. ^{25,26}MgH lines are located to the left of ^{24}MgH ones and are not resolved in our spectra.

4.2. WZ Cas

WZ Cas is an SC-type carbon star. It is probably the most favorable star in our sample to determine the Mg isotopic ratios. WZ Cas has $^{12}C/^{13}C \approx 4$ which could be a signature of an intermediate-mass star ($4 \leq M/M_\odot \leq 8$) which is suffering hot bottom burning (HBB). However, it does not present *s*-element enhancements (Abia & Isern 2000). In Figure 2 are shown two fits: the dashed line corresponds to the terrestial Mg isotopic ratios and the thick solid line represents a model depleted in heavy Mg isotopes. For the range of 5130 Å (upper panel), the Mg-heavy-isotopes-depleted model fits the observed spectrum better than the terrestial one. In the vicinity of 7570 Å the synthetic spectrum is almost insensitive to the variation of Mg isotopic ratios. We cannot give a measurement of Mg isotopic ratios for this star, only argue that the Mg-heavy-isotopes-depleted model might be a lower limit.

4.3. HD 189711

This star is a CH-type carbon star of [Fe/H] ≈ −1 with overabundances of *s*-elements, as shown by Abia et al. (2003). CH stars of low metallicity are believed to be extrinsic carbon stars but for this star in particular, the observed *s*-element abundance pattern can be fitted well but with an intrinsic or extrinsic nature (see Abia et al. 2003 for details). Thus, to infer the nature of this star by study of the *s*-element abundance pattern is quite uncertain. Unfortunately, we obtain a small difference between synthetic spectra calculated with a large

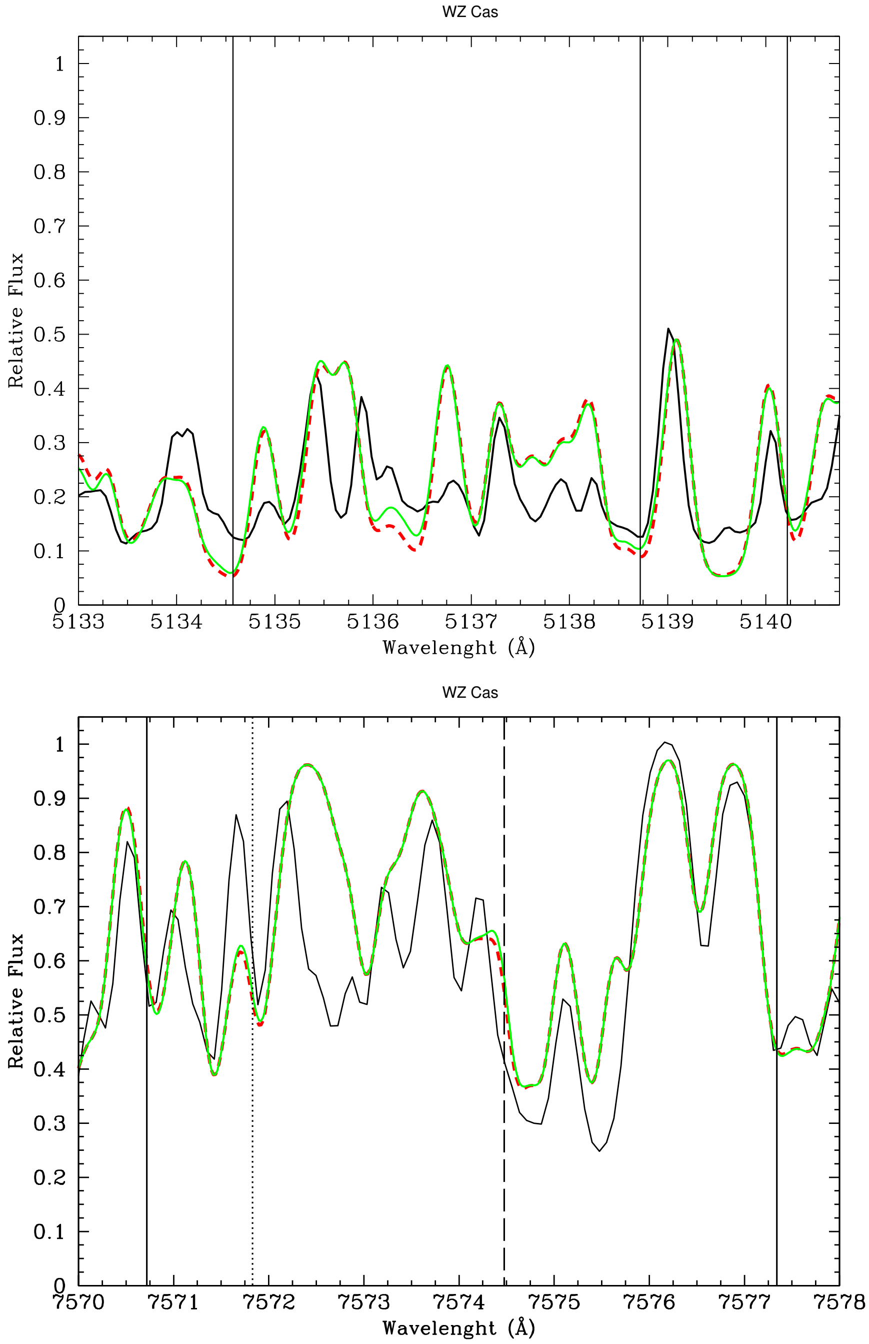

Fig. 2. Spectrum of WZ Cas (thin continuous line). Upper panel: range of 5133 – 5141 Å. The dashed line represents a synthetic spectrum with $^{25}Mg/^{24}Mg = 0.13$ and $^{26}Mg/^{24}Mg = 0.14$ (terrestial Mg ratios); the thick solid line represents a synthetic spectrum with $^{25}Mg/^{24}Mg = 0.02$ and $^{26}Mg/^{24}Mg = 0.06$. Vertical lines have the same meaning as in Figure 1. Lower panel: 7570 – 7578 Å range. The dashed line represents terrestial isotopic Mg ratios; the thick solid line represents a synthetic spectrum with $^{25}Mg/^{24}Mg = 0.02$ and $^{26}Mg/^{24}Mg = 0.06$. Vertical lines indicate the position of ^{24}MgH (solid), ^{25}MgH (dashed) and ^{26}MgH (dotted) lines.

variation in the Mg isotopic ratios. Thus we are not able to determine its value in this star.

4.4. HD 76396

Finally, we try to determine the Mg isotopic ratios in the CH-type star HD 76396. Few data are available for this star in the literature so we have determined in this work its relevant parameters. Similar to the previous case of HD 189711, we obtain that the synthetic spectra are completely insensitive to a large variation in the Mg isotopic ratios in both spectral ranges.

5. Conclusions

After the analysis of our sample of carbon star in the intervals 5133 – 5141 Å and 7570 – 7578 Å, we conclude that it is not currently possible to determine the Mg isotopic ratios in these stars from spectra at optical wavelengths. In the range 7570 – 7578 Å the synthetic spectra are almost insensitive to changes in the Mg isotopic abundances while in the range of 5133 – 5141 Å the spectra are blended with strong carbon molecular bands and the localization of the continuum is rather uncertain. Furthermore, the observed spectra are not well reproduced theoretically. Atmosphere models and the available line lists should be improved to solve these problems before trying a new determination.

An alternative would be the observation of the MgNC transitions at millimetre wavelengths, as was done for the carbon star IRC+10216 (Guelin et al. 1995; Kahane et al. 2000). However, this technique can only be used in very bright objects such as IRC+10216. Therefore the problem of the determination of the Mg isotopic ratios in carbon stars still remains open. The future development of the ALMA project could help to solve this problem.

References

Abia C., Domínguez I., Gallino R., Busso M., Straniero O., de Laverny P., Wallerstein G., 2003, PASA, 20, 314
Abia C. et al., 2002, ApJ, 579, 817
Abia C., Busso M., Gallino R., Domínguez I., Straniero O., Isern J., 2001, ApJ, 559, 1117
Abia C., Isern J., 2000, ApJ, 536, 438
Abia C., Wallerstein G., 1989, MNRAS, 293, 89
Barnbaum C., Stone R. P. S., Keenan P. C., 1996, ApJS, 105, 419
Collados M., Martínez-Pillet V., Ruiz Cobo B., del Toro Iniesta J. C., Vazquez M., 1994, A&A, 291, 622
Fenner Y., Gibson B. K., Lee H.-C., Karakas A. I., Lattanzio J. C., Chieffi A., Limongi M., Yong D., 2003, PASA, 20, 340
Gay P. L., Lambert D. L., 2000, ApJ, 533, 260
Guelin M., Forestini M., Valiron P., Ziurys L. M., Anderson M. A., Cernicharo J., Kahane C., 1995, A&A, 297, 183
Kahane C., Dufour E., Busso M., Gallino R., Lugaro M., Forestini M., Straniero O., 2000, A&A, 357, 669
Karakas A. I., Lattanzio J. C., 2003, PASA, 20, 279
Peterson R. C., Dalle Ore C. M., Kurucz R. L., 1993, ApJ, 404, 333
Shetrone M. D., 1996, AJ, 112, 2639
Wallace L., Hinkle K., Li G., Bernath P., 1999, ApJ, 524, 454