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$^{12}C/^{13}C$ ratios in giants of open clusters

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Abstract. The carbon isotopic ratio, $^{12}C/^{13}C$, is a tracer of the mixing events during the evolution along the giant branch, due to the conversion of ^{12}C into ^{13}C (and ^{14}N) via the CN cycle. A decrease of this ratio from 90, the solar value, to 20−25, is expected due to the first dredge-up. However, ratios down to 3−4, the CN cycle equilibrium value, have been observed in giants of the field, of globular and of open clusters. Observations seem to indicate a non-standard mixing in the RGB, probably beginning in the luminosity bump, when the outward moving hydrogen burning shell crosses the molecular weight barrier left by the convective layer in its maximum extent. We are currently analyzing a sample of 24 giants in 8 open clusters for which we determined $^{12}C/^{13}C$ from high resolution, high signal to noise spectra using spectrum synthesis. In this work we discuss the general characteristics of our results in comparison to previous analyses of giants in open clusters available in the literature.

Keywords. Stars: abundances, stars: evolution, stars: late-type

1. Introduction

In standard stellar evolutionary models, convection is the only mechanism to drive mixing. However, peculiar abundances indicating extra-mixing processes in low-mass red giants have long been recognized in open clusters (Gilroy 1989; Gilroy & Brown 1991; Tautvaišiene 2000, 2005), globular clusters (Pilachowski *et al.* 2003 and references therein), and field stars (Gratton *et al.* 2000) including ultra metal-poor ones (Spite *et al.* 2006). While the first dredge-up models predict the decrease of $^{12}C/^{13}C$ from ∼90 to ∼20, ratios down to ∼5 have been observed.

The extra-mixing might be related to meridional circulation and turbulence induced by rotation (Charbonnel 1994, 1995). It affects stars above the luminosity bump, where the outward moving hydrogen burning shell reaches the chemical discontinuity left by the convective layer at its maximum extent (Charbonnel *et al.* 1998; Palacios *et al.* 2006).

Regarding open clusters, Gilroy (1989) and Gilroy & Brown (1991) show that the extra-mixing would affect stars in clusters with turn-off mass (M_{TO}) $\leqslant$ 2.2 $M_\odot$. Luck (1994), however, found low $^{12}C/^{13}C$ in giants of clusters with M_{TO} larger than that. These intermediate mass stars, which start to burn He in a non-degenerate core, do not experience an extra-mixing during the RGB. However, as suggested by Charbonnel & Balachandran (2000), a similar extra-mixing episode might develope in the early-AGB.

In addition, although Gilroy & Brown (1991) found no difference in abundances between red giants and clump giants in M67, Tautvaišiene *et al.* (2000) showed that a

Table 1. Data of the clusters as listed by the WEBDA database, M_{TO} (see text), the number of stars analyzed in each cluster, and the range in $^{12}C/^{13}C$ determined for the stars in that cluster.

Cluster	$(m_V - M_V)$ (mag.)	E(B-V) (mag.)	Age (log yrs.)	Dist. (pc)	[Fe/H]	M_{TO}	Number of stars	Range in $^{12}C/^{13}C$
IC 2714	11.52	0.341	8.54	1238	−0.01	2.99	01	–
IC 4756	9.02	0.192	8.70	484	−0.06	2.62	05	10−17
NGC 3532	8.55	0.037	8.49	486	−0.02	3.13	05	10−22
NGC 3680	10.07	0.066	9.08	938	−0.09	1.94	01	–
NGC 5822	10.28	0.150	8.82	917	−0.02	2.38	05	11−17
NGC 6134	11.03	0.395	8.97	913	+0.18	2.11	03	12−14
NGC 6281	8.86	0.148	8.50	479	–	3.10	02	12−13
NGC 6633	8.44	0.182	8.63	376	–	2.78	02	18−21

difference in $^{12}C/^{13}C$ does exist, probably indicating a mixing process induced by the helium flash. A similar difference however, was not found in NGC 7789 (Tautvaišiene *et al.* 2005).

We are currently analyzing a sample of 24 giants in 8 open clusters in order to derive atmospheric parameters, stellar masses, and abundances for several elements and thus to improve the knowledge of the mixing processes in this stellar population. In this work we present our results of $^{12}C/^{13}C$ and discuss the general characteristics of them in comparison to previous analyses of giants in open clusters available in the literature.

2. Observations, atmospheric parameters and abundances

The spectra (R∼48000, $\lambda\lambda$ 3500−9200 Å) were obtained with the FEROS spectrograph (Kaufer *et al.* 1999) at the ESO 1.52m telescope (La Silla - Chile) for 24 stars of 8 open clusters. The typical S/N ratios range between 100 and 370.

The data of the open clusters are listed in Tab. 1. Age, E(B-V), distance, apparent distance modulus (m_V-M_V), and [Fe/H] are the ones listed by the WEBDA database.† From the isochrones of Schaller *et al.* (1992) with Z = 0.02 and for the exact ages of each cluster, M_{TO} was determined. The M_{TO} listed are from the red turn-off, the reddest point just before the short blueward excursion (see Fig. 1 of Maeder & Meynet (1991): the blue turn-off is indicated as point B and the red turn-off as R).

Atmospheric parameters were obtained using Fe I and Fe II lines. The effective temperature ($T_{\rm eff}$) was derived through the Fe I excitation equilibrium, the surface gravity (log g) through the Fe I and Fe II ionization equilibrium and the microturbulence velocity (ξ) by requiring the Fe I abundances to have null correlation with the equivalent widths. The grids of model atmosphere by Castelli & Kurucz (2003) were adopted. Oscillator strengths (log gfs) are the same adopted by Smiljanic *et al.* (2006).

The $^{12}C/^{13}C$ ratios were determined from the ^{12}CN and ^{13}CN bands at 8005 Å as in Barbuy *et al.* (1992) and da Silva *et al.* (1995), using spectrum synthesis (see a description of the codes in Coelho *et al.* 2005). The carbon abundance determined using the C_2 Swan band at 5135 Å was considered to be $^{12}C + ^{13}C$.

† The WEBDA database can be accessed via internet in the address: http://www.univie.ac.at/webda/

3. Discussion

In this section we discuss the general characteristics of the abundances derived for the sample stars. A complete discussion, including abundances of C, N, and O, will be presented elsewhere (Smiljanic *et al.* 2006b, in preparation). Most of the sample stars are probably He core burning clump giants. At least three are probable AGBs and only five are first ascent red giants. A clear comparison between clump and red giants in the same cluster is precluded by the small number of stars per cluster in our sample. We note however that in the three clusters (IC 4756, NGC 5822, and NGC 6134) where both clump and red giants were observed, no clear difference in the $^{12}C/^{13}C$ ratio is apparent.

The stars in the clusters IC 4756, NGC 5822 and NGC 6134 do show clump and red giants with smaller ratios than predicted for the first dredge-up, indicating the existence of an extra-mixing. On the other hand the two stars in the cluster NGC 6633, with $M_{TO} = 2.78\ M_{\odot}$, have no indication of extra-mixing. These observations seem to agree with the general picture accepted in the literature.

However we note that the clusters NGC 3532 and NGC 6281, both with $M_{TO} = 3.1\ M_{\odot}$, have giants with $^{12}C/^{13}C$ ratios smaller than expected for the first dredge-up. Since an extra-mixing episode during the RGB for these intermediate mass stars is not expected they might actually be early-AGB stars. In these stars the carbon isotopic ratio was probably modified after the core-He exhaustion by an extra-mixing episode as suggested by Charbonnel & Balachandran (2000).

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References

Barbuy, B., Jorissen, A., Rossi, S.C.F. & Arnould, M. 1992, *A&A* 262, 216
Castelli, F. & Kurucz, R.L. 2003, *Proceedings of the IAU Symposium 210* A20
Charbonnel, C. 1994, *A&A* 282, 811
Charbonnel, C. 1995, *ApJ* 453, L41
Charbonnel, C, Brown, J.A. & Wallerstein, G. 1998, *A&A* 332, 204
Charbonnel, C. & Balachandran, S.C. 2000, *A&A* 359, 563
Coelho, P., Barbuy, B., Meléndez, J., Schiavon, R.P. & Castilho, B.V. 2005, *A&A* 443, 735
da Silva, L., de La Reza, R. & Barbuy, B. 1995, *ApJ* 448, L41
Gilroy, K.K. 1989, *ApJ* 347, 835
Gilroy, K.K. & Brown, J.A. 1991, *ApJ* 371, 578
Girardi, L., Bressan, A., Bertelli, G. & Chiosi, C. 2000, *A&AS* 141, 371
Gratton, R.G., Sneden, C., Carretta, E. & Bragaglia, A. 2000, *A&A* 354, 169
Kaufer, A., Stahl, O., Tubbesing, S., Norregaard, P., Avila, G., Francois, P., Pasquini, L. & Pizzella, A. 1999, *The Messenger* 95, 08
Luck, R.E 1994, *ApJS* 91, 309
Maeder, A. & Meynet, G. 1991, *A&AS* 89, 451
Palacios, A., Charbonnel, C., Talon, S. & Siess, L. 2006, *A&A* 453, 261
Pilachowski, C., Sneden, C., Freeland, E. & Casperson, J. 2003, *AJ* 125, 794
Schaller, G., Schaerer, D., Meynet, G. & Maeder, M. 1992, *A&AS* 96, 269
Smiljanic, R., Barbuy, B., De Medeiros, J.R. & Maeder, A. 2006, *A&A* 449, 655
Spite, M., Cayrel, R., Hill, V., Spite, F., François, P., Plez, B., Bonifacio, P., Molaro, P., Depagne, E., Andersen, J., Barbuy, B., Beers, T.C., Nordström, B. & Primas, F. 2006, *A&A* 455, 291
Tautvaišiene, G., Edvardsson, B., Puzeras, E. & Ilyin, I. 2005, *A&A* 431, 933
Tautvaišiene, G., Edvardsson, B., Tuominen, I. & Ilyin, I. 2000, *A&A* 360, 499

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