Chemical composition of clump stars in the open cluster NGC 6134

Šarūnas Mikolaitis, 1† Gražina Tautvaišienė, 1 Raffaele Gratton, 2 Angela Bragaglia 3 and Eugenio Carretta 3

1 Institute of Theoretical Physics and Astronomy, Vilnius University, Goštauto 12, Vilnius 01108, Lithuania
2 INAF - Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy
3 INAF - Osservatorio Astronomico di Bologna, Via Ranzani 1, I-40127 Bologna, Italy

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1 INTRODUCTION

Open clusters are important tools for the study of the Galactic disc as well as for understanding stellar evolution (e.g. Friel et al. 2002; Bragaglia et al. 2008; Jacobson et al. 2009; Santos et al. 2009). They are the best tool to understand whether and how the slope of the radial metallicity distribution changes with time, since they have formed at all epochs and their ages, distances and metallicities are more accurately derived than for the field stars. Open clusters are excellent laboratories for investigations of stellar evolution as well. Since cluster members were initially of approximately identical chemical composition, all changes in stellar atmospheres of evolved stars are related to internal and external processes of stellar evolution (see, e.g. Pallavicini 2003 and references therein). Changes of the abundances of carbon, nitrogen and oxygen are most often seen in evolved stars. The enhancement of CN bands and altered carbon isotope ratios in evolved stars of open clusters were already reported 30 yr ago (e.g. McClure 1974; Pagel 1974). However, the detailed analyses of abundances in stars of open clusters from high-resolution spectra are still necessary for understanding the processes of dredge-up and extra-mixing affecting the chemical composition of atmospheres in evolved low-mass stars. Detailed spectral analyses of CNO elements in stars of open clusters are still rather scarce (Gilroy 1989; Gilroy & Brown 1991; Luck 1994; Gonzalez & Wallerstein 2000; Tautvaišienė et al. 2000, 2005; Gratton et al. 2006; Origlia et al. 2006; Smiljanic et al. 2009, etc.). The Bologna Open Cluster Chemical Evolution project (BOCCE) is dedicated to constraining the formation and chemical evolution of the Galactic disc (Bragaglia & Tosi 2006; Carretta, Bragaglia & Gratton 2007, and references therein). This paper is a part of the effort to derive detailed elemental abundances in open clusters, with the final goal of deriving the time evolution of abundances in the Galactic disc. In particular, we concentrate here on carbon and nitrogen, but also derive abundances of more than 20 other chemical elements.

2 TOPIC OF THE STUDY

The open cluster NGC 6134 is an intermediate-age, moderately concentrated open cluster (Trumpler class II3m) located almost on the galactic plane ($\alpha_{2000} = 16^h27.8^m$, $\delta_{2000} = -49^\circ09.4'9$; $l = 324.91^\circ$, $b = -0.20^\circ$). The first extensive photometric study was published by Lindoff (1972) who derived a colour excess $E(B-V) = 0.45$, a distance of about 700 pc and an age of about 0.7 Gyr. These values were based only on UBV photographic data. Kjeldsen & Frandsen (1991) published UBV CCD data for 66 stars

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†E-mail: sarunas.mikolaitis@tfai.vu.lt

ABSTRACT

We present an analysis of high-resolution spectra of six core-helium-burning ‘clump’ stars in the open cluster NGC 6134. Atmospheric parameters ($T_{\text{eff}}$, log $g$, $v_t$ and [Fe/H]) were determined in our previous study by Carretta et al. (2004). In this study we present abundances of C, N, O and up to 24 other chemical elements. Abundances of carbon were derived using the C$_2$ Swan (0,1) band head at 5635.5 Å (FEROS spectra) and the C$_2$ Swan (1,0) band head at 4737 Å (UVES spectra). The wavelength interval 7980–8130 Å, with strong CN features, was analysed in order to determine nitrogen abundances and $^{12}$C/$^{13}$C isotope ratios. The oxygen abundances were determined from the [O I] line at 6300 Å. Compared to the Sun and other dwarf stars of the Galactic disc, mean abundances in the investigated clump stars suggest that carbon is depleted by about 0.2 dex, nitrogen is overabundant by about 0.3 dex and oxygen is underabundant by about 0.1 dex. This has the effect of lowering the mean C/N ratio to 1.2 ± 0.2. The mean $^{12}$C/$^{13}$C ratios are lowered to 9 ± 2.5. Concerning other chemical elements, the analysis of sodium and magnesium lines, lines of other α-elements, iron-group and heavier chemical elements gave abundance ratios close to the solar ones.

Key words: stars: abundances – stars: atmospheres – stars: horizontal branch – open clusters and associations: individual: NGC 6134.
at the centre of the cluster and obtained $E(B - V) = 0.46$ and $m - M = 11.25$. Coravel radial velocity measurements and photometry in the $UBV$ and $CM_T T_2$ system of 24 red giants, supplemented by $DDO$ observations of 11 stars, were carried out by Claria & Mermilliod (1992) for membership and binarity analysis, who identified 17 red giant members and six spectroscopic binaries. The mean cluster radial velocity was found to be $-26.0 \pm 0.24$ km s$^{-1}$, the reddening $E(B - V) = 0.35 \pm 0.02$ and the distance about 760 pc. The weighted mean value of $[\text{Fe} / \text{H}] = -0.05 \pm 0.12$ was evaluated from the UV excesses. Strömgren photometry was analysed by Bruntt et al. (1999). They determined $E(b - y) = 0.263 \pm 0.004$, $E(B - V) = 0.365$, $[\text{Fe} / \text{H}] = 0.28 \pm 0.02$ and age $= 0.69 \pm 0.10$ Gyr. The colour–magnitude diagram (Bruntt et al. 1999) shows a `clump' of core-He-burning stars, several red giant branch (RGB) stars and a main sequence. From $BVRI$ CCD observations, Ahumada (2002) has determined a colour excess $0.29 < E(B - V) < 0.37$, age of 1.26 Gyr and a distance of about 1080 $\pm 50$ pc, which is larger than in the previous analyses.

Precise iron abundances from high-resolution spectra for six stars in this cluster have been determined by Carretta et al. (2004). An overall metallicity $[\text{Fe} / \text{H}] = 0.15 \pm 0.03$ with rms $= 0.07$ was found. Carretta et al. also computed the reddening from the temperatures – derived spectroscopically – and the Alonso, Arribas & Martínez-Roger (1999) colour–temperature relations, finding $E(B - V) = 0.363 \pm 0.014$, in very good agreement with Bruntt et al. (1999). Using the same spectra and method of analysis, in this paper we continue the detailed abundance investigations for the clump stars NGC 6134, 39, 69, 75, 114, 129 and 157. Elemental abundances in three other clump stars of this cluster (NGC 6134, 30, 99, and 202) have been investigated recently by Smiljanic et al. (2009).

2 OBSERVATIONS AND METHOD OF ANALYSIS

The spectra of three cluster stars (NGC 6134, 39, 114 and 157) were obtained with the spectrograph FEROS (Fiber-fed Extended Range Optical Spectrograph) mounted at the 1.5-m telescope in La Silla (Chile). The resolving power is $R = 48,000$ and the wavelength range is $\lambda \lambda$ 3700–8600 Å. The stars NGC 6134, 69, 75 and 129 were observed with the UVES spectrograph (UV-Visual Echelle Spectrograph) on the Unit 2 of the VLT ESO-Paranal telescope. The spectral coverage is $\lambda \lambda$ 3560–4840 Å, 5550–9460 Å and the resolving power is $R = 43,000$. More details can be found in Carretta et al. (2004).

Fig. 1 shows a map of the observed stars and their evolutionary status is indicated by their position in Fig. 2. All the stars belong to the red clump of the cluster. The log of observations and S/N are presented in the paper by Carraro et al. (2004). In the same paper all the main atmospheric parameters for the observed stars were determined. For convenience we present them in this paper as well (Table 1). The effective temperatures were derived by minimizing the slope of the abundances from neutral Fe I lines with respect to the excitation potential. The gravities ($\log g$) were derived from the iron ionization equilibrium. The microturbulent velocities were determined assuming a relation between $\log g$ and $\nu$. The ATLAS models with overshooting were used for the analysis. Fe I lines were restricted to the spectral range 5500–7000 Å in order to minimize problems of line crowding and difficulties in the continuum tracing bluward. Several examples of spectra are presented in Fig. 3. For more details and error estimates, see Carretta et al.

In this work we used the same model atmospheres and computing codes of the other BOCCE programme investigations (see Carretta et al. 2004). Definition of the continuum for the determination of the equivalent widths (EWs) is critical for programme stars. These objects are cool, of low-gravity and high-metallicity stars. The spectra were normalized to the continuum using ROSA software (Gratton et al. 1988), visually checking the output. The lines suitable for measurement were chosen using the requirement that the profiles be sufficiently clean to provide reliable equivalent widths. Inspection of the solar spectrum (Kurucz et al. 1984) and the solar line identifications of Moore et al. (1966) were used to avoid blends. Lines blended by telluric absorption lines were omitted from treatment.
as well. In order to avoid non local thermodynamical equilibrium (NLTE) overionization effects, mainly weak lines were selected for the analysis. Abundances of Na and Mg were determined with NLTE taken into account as described by Gratton et al. (1999).

The determination of carbon, nitrogen, oxygen, zirconium, yttrium, barium, lanthanum, cerium, neodymium and europium abundances was performed using spectral synthesis.

For C\textsubscript{2} determination in stars observed with FEROS, we used 5632–5636 Å interval to compare with observations of C\textsubscript{2} Swan (0,1) band head at 5630.5 Å. The same molecular data of C\textsubscript{2} as used by Gonzalez et al. (1998) were adopted for the analysis. For the stars observed with UVES, this spectral interval was not available, so we analysed several other Swan (1,0) bands at 4732.8 and 4735.3 Å with the molecular input data from Kurucz & Bell (1995). The interval 7980–8130 Å contains strong 12C\textsuperscript{14}N and 13C\textsuperscript{14}N features, so it was used for nitrogen abundance and 12C/13C ratio analysis. The molecular data for this CN band were provided by Bertrand Plez (University of Montpellier II). All gf values were increased by +0.021 dex to fit the model spectrum of solar atlas of Kurucz (1994). We derived oxygen abundance from synthesis of the forbidden [O\textsc{i}] line at 6300 Å. The gf values for 54Ni and 60Ni isotopic line components, which blend the oxygen line, were taken from Johansson et al. (2003).

Zirconium abundance was derived using Zr\textsc{ii} lines at 4687 and 6127 Å, barium from Ba\textsc{ii} 5853 and 6496 Å, lanthanum from La\textsc{ii} lines at 6320 and 6390 Å, cerium from Ce\textsc{ii} lines at 5274 and 6043 Å and neodymium from Nd\textsc{ii} 5093, 5293 and 5320 Å lines. Europium abundance was derived using Eu\textsc{ii} line at 6645 Å. The hyperfine structure for Eu\textsc{ii} line was used for the synthesis. The wavelength, excitation energy and total log gf = 0.12 were taken from Lawler et al. (2001), the isotopic fractions of\textsuperscript{151}Eu 47.77 per cent and\textsuperscript{155}Eu 52.23 per cent, and isotopic shifts were taken from Biehl (1976).

Oscillator strengths for the most important lines of other elements were taken mainly from an inverse solar spectrum analysis done in Kiev (Gurtovenko & Kostik 1989).

### 2.1 Estimation of uncertainties

The sources of uncertainty can be divided into two categories. The first category includes the errors which affect all the lines together, i.e. mainly the model errors (such as errors in the effective temperature, surface gravity, microturbulent velocity, etc.). The second category includes the errors that affect a single line (e.g. random errors in equivalent widths, oscillator strengths), i.e. uncertainties of the line parameters.

Typical internal error estimates for the atmospheric parameters are ±100 K for $T_{\text{eff}}$, ±0.3 dex for log g and ±0.3 km s\textsuperscript{−1} for $v_\text{t}$. The sensitivity of the abundance estimates to changes in the atmospheric parameters by the assumed errors is illustrated for the star NGC 6134\textsubscript{114} (Table 2). Possible parameter errors do not affect the abundances seriously; the element-to-iron ratios, which we use in our discussion, are even less sensitive.

The sensitivity of iron abundances to stellar atmospheric parameters were described in Carretta et al. (2004). The changes in temperature of 90 K, log g of 0.1 dex and 0.1 km s\textsuperscript{−1} for microturbulent velocity lead to $\Delta$[Fe/H] = 0.057, $\Delta$[Fe/H] = 0.011,

### Table 1. Atmospheric parameters of the programme stars.

| Star* | V      | $b - y$ | $T_{\text{eff}}$ (K) | log g | [Fe/H] | $v_\text{t}$ (km s\textsuperscript{−1}) |
|-------|--------|---------|----------------------|-------|--------|--------------------------------|
| 39    | 12.20  | 0.811   | 4980                 | 2.52  | +0.24  | 1.17                          |
| 69    | 12.36  | 0.811   | 4950                 | 2.83  | +0.11  | 1.13                          |
| 75    | 12.39  | 0.820   | 5000                 | 3.10  | +0.22  | 1.10                          |
| 114   | 12.07  | 0.841   | 4940                 | 2.74  | +0.11  | 1.14                          |
| 129   | 12.25  | 0.838   | 5000                 | 2.98  | +0.05  | 1.11                          |
| 157   | 12.25  | 0.820   | 5050                 | 2.92  | +0.16  | 1.12                          |

References: V and $b - y$ from Bruntt et al. (1999); Star numbers from Lindoff (1972).

### Table 2. Effects on derived abundances resulting from model changes for the star NGC 6134\textsubscript{114}.

| Species | $\Delta T_{\text{eff}}$ +100 K | $\Delta$ log g +0.3 | $\Delta v_\text{t}$ +0.3 km s\textsuperscript{−1} |
|---------|-------------------------------|---------------------|-----------------------------------------------|
| C(C\textsubscript{2}) | −0.05 | 0.03 | −0.01 |
| N(CN)   | 0.05 | 0.01 | 0.04 |
| O([O\textsc{i}]) | −0.02 | −0.05 | −0.01 |
| Na\textsc{ii} | 0.08 | −0.08 | −0.11 |
| Mg\textsc{ii} | 0.05 | −0.03 | −0.08 |
| Al\textsc{ii} | 0.07 | −0.01 | −0.05 |
| Si\textsc{ii} | −0.01 | 0.04 | −0.04 |
| Ca\textsc{ii} | 0.10 | −0.01 | −0.07 |
| Sc\textsc{ii} | −0.01 | 0.14 | −0.08 |
| Ti\textsc{ii} | 0.14 | −0.01 | −0.06 |
| Ti\textsc{iii} | 0.10 | −0.03 | −0.08 |
| V\textsc{ii} | 0.16 | 0.00 | −0.06 |
| Cr\textsc{ii} | 0.09 | −0.01 | −0.09 |
| Cr\textsc{iii} | 0.10 | −0.03 | −0.07 |
| Mn\textsc{ii} | 0.08 | −0.02 | −0.05 |
| Co\textsc{ii} | −0.09 | 0.03 | −0.05 |
| Ni\textsc{ii} | −0.05 | 0.03 | −0.12 |
| Cu\textsc{ii} | 0.01 | 0.02 | 0.01 |
| Zn\textsc{ii} | −0.02 | 0.04 | −0.09 |
| Y\textsc{ii} | −0.02 | 0.11 | −0.13 |
| Zr\textsc{ii} | −0.18 | 0.00 | −0.03 |
| Ba\textsc{ii} | −0.10 | 0.09 | −0.10 |
| La\textsc{ii} | 0.01 | −0.01 | 0.04 |
| Ce\textsc{ii} | 0.00 | 0.13 | −0.01 |
| Nd\textsc{ii} | −0.02 | 0.11 | −0.01 |
| Eu\textsc{ii} | 0.00 | 0.10 | −0.01 |
| 12C/13C | −1 | −1 | 0 |

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$\Delta[Fe/H]_I = -0.044$ and $\Delta[Fe/H]_II = -0.086$, $\Delta[Fe/H]_III = 0.107$, $\Delta[Fe/H]_IV = -0.043$, respectively.

Since abundances of C, N and O are bound together by the molecular equilibrium in the stellar atmosphere, we have also investigated how an error in one of them typically affects the abundance determination of another. $\Delta[O/H] = 0.10$ causes $\Delta[C/H] = 0.05$ and $\Delta[N/H] = -0.10$; $\Delta[C/H] = 0.10$ causes $\Delta[N/H] = -0.15$ and $\Delta[O/H] = 0.05$. $\Delta[N/H] = 0.15$ has no effect on either the carbon or the oxygen abundances.

The scatter of the deduced line abundances $\sigma$, presented in Table 3, gives an estimate of the uncertainty due to the random errors, e.g. in continuum placement and the line parameters (the mean value of $\sigma$ is 0.06 dex). Thus the uncertainties in the derived abundances that are the result of random errors amount to approximately this value.

3 RESULTS AND DISCUSSION

The abundances relative to hydrogen $[El/H]^1$ and $\sigma$ (the line-to-line scatter) derived for up to 26 neutral and ionized species for the programme stars are listed in Table 3. The average cluster abundances and dispersions about the mean values for NGC 6134 are presented in Table 3 as well.

3.1 Galactic radial abundance gradient

The open cluster radial abundance gradient was analysed and discussed many times during several decades (see e.g. Friel 1995; Twarog, Ashman & Anthony-Twarog 1997; Bragaglia et al. 2001, 2008; Friel et al. 2002; Carretta et al. 2004, 2005; Friel, Jacobson & Pilachowski 2005; Yong, Carney & Teixera de Almeida 2005; Sestito et al. 2006; Carretta, Bragaglia & Gratton 2007; Sestito, Randich & Bragaglia 2007; Jacobson, Friel & Pilachowski 2008; Sestito et al. 2008; Jacobson, Friel & Pilachowski 2009; Smiljanic et al. 2009; Pancino et al. 2010 and references therein). Twarog et al. (1997) first proposed that the open cluster abundance distribution is not a negative linear gradient but two separate distributions, each of constant metallicity, divided at $R_{gc} = 10$ kpc. Clusters in the inner part are of solar metallicity, while in the outer part the mean metallicity is about $-0.3$ dex. The recent investigations of open clusters, reaching also the more distant parts of the disc, show that maybe the gradient is not the same in all the discs: it is rather steep in the inner disc ($R_{gc} < 12-14$ kpc), and it flattens in the outer disc (cf. Carraro et al. 2004, 2007; Yong et al. 2005; Sestito et al. 2006, 2008; Jacobson et al. 2009).

Recently, Magrini et al. (2009) used a set of literature abundances of open clusters based on high-resolution spectroscopy to compare the gradient, and its time evolution, with their chemical evolution models. However, their sample is not homogeneous (distances, ages and abundances were taken from papers of many different groups) so it is not an ideal set, since systematics can mask or produce features in the distribution. The BOCCE project aims at collecting a homogeneous sample, well spread over the Galactic plane, covering all ages and metallicities. Fig. 4 displays the radial distribution of some elemental abundances for BOCCE clusters analysed so far, and for others in recent studies. The scatter is quite large at all radii, but NGC 6134 agrees well with results of other open clusters at the same $R_{gc}$ of 7.5 kpc.

1 In this paper we use the customary spectroscopic notation $[X/Y] \equiv \log_{10}(N_X/N_Y)_{\odot} - \log_{10}(N_X/N_Y)_{\odot}$

3.2 Carbon, nitrogen and oxygen

Since the [C I] 8727 Å line is blended with CN in spectra of red giants, and since the probability of increased strengths of CN molecular lines is present, the C$_2$ Swan (0,1) band head at 5635.5 Å is a quite popular feature for the carbon abundance determinations. It was used in our previous studies of giants (e.g. Tautvaisiené et al. 2000, 2005). In Fig. 5, a fit to the NGC 6134$_{157}$ spectrum at C$_2$ 5635.5 Å is shown. The Swan band (1,0) with the head at 4737 Å is rarely used for carbon abundance determinations, since the region is quite crowded by additional lines. Fortunately, two features of C$_2$ at 4732.8 and 4735.3 Å were clearly seen in the spectra obtained with the UVES spectrograph. In Fig. 6, we show an example of spectral fit to these C$_2$ bands for the star NGC 6134$_{75}$.

The interpretation of the carbon abundance in NGC 6134 can be done by a comparison with carbon abundances determined for dwarf stars in the Galactic disc. Shi, Zhao & Chen (2002) performed an abundance analysis of carbon for a sample of 90 F- and G-type main-sequence disc stars using C$_1$ and [C I] lines and found [C/Fe] to be about solar at the solar metallicity. The same result was found by Gustafsson et al. (1999) who analysed a sample of 80 late F and early G type dwarfs using the forbidden C[I] line. The ratios of [C/Fe] in our stars lie about 0.2 dex below the trend obtained for dwarf stars of the Galactic disc. Smiljanic et al. (2009) analysed carbon abundances in two stars of the same cluster NGC 6134$_{30}$ and NGC 6134$_{202}$ and also found [C/Fe] abundance ratios to be lowered by about the same amount.

The interval 7980–8130 Å, with 11 CN lines selected, was analysed in order to determine the nitrogen abundances. The mean nitrogen-to-iron abundance ratio in NGC 6134 is $[N/Fe] = 0.25 \pm 0.10$. Nitrogen-to-iron abundance ratios in the two clump stars, as investigated in NGC 6134 by Smiljanic et al. (2009), the [N/Fe] ratios are enhanced by 0.42 and 0.36 dex as well.

This shows that nitrogen is overabundant in these clump stars of NGC 6134, while [N/Fe] values in the main-sequence stars are about solar at the solar metallicity (cf. Shi et al. 2002). Reddy et al. (2003) investigated nitrogen abundances in a sample of 43 F–G dwarfs in the Galactic disc by means of weak N I lines. At a value of [Fe/H] of about $-0.2$ dex, which was well represented in their sample, [N/Fe] is about 0.2 dex. There were few stars of solar metallicity investigated in this study. Nevertheless, the authors make the extrapolation that at solar metallicity [N/Fe] values should be solar.

C/N ratios in our programme stars of NGC 6134 range from 0.98 to 1.48. For the stars NGC 6134$_{30}$ and NGC 6134$_{202}$, Smiljanic et al. also found C/N to be 0.99 and 1.41, respectively.

The solar carbon and nitrogen abundances used in our work are $A_{C} = 8.52$ and $A_{N} = 7.92$ (Grevesse & Sauval 2000), so the solar C/N = 3.98. Smiljanic et al. (2009) presented carbon and nitrogen values for 10 open clusters in total and found an average C/N ratio of about 0.98.

The analysis of oxygen abundance was performed using the most popular forbidden [O I] line at 6300 Å. In the spectra of NGC 6134 stars this line is not contaminated by telluric lines. In Fig. 7 we show an example of spectrum syntheses for [O I] line in NGC 6134$_{39}$ star. This line is blended by Ni I. The atomic data of Ni I were taken from Johansson et al. (2003).

The oxygen abundance results as a function of galactocentric distance are shown in Fig. 4. Similarly to other open clusters, [O/Fe] in NGC 6134 stars is lower than the solar value by about 0.2 dex. Oxygen abundances were not investigated in NGC 6134 by Smiljanic et al. (2009).
Table 3. Abundances relative to hydrogen [El/H]. The quoted errors, \(\sigma\), are the standard deviations in the mean value due to the line-to-line scatter within the species. The number of lines used is indicated by \(n\). The last two columns give the mean [El/Fe] and standard deviations for the cluster stars investigated.

| Species       | [El/H] | \(\sigma\) | \(n\) | [El/H] | \(\sigma\) | \(n\) | [El/H] | \(\sigma\) | \(n\) | [El/H] | \(\sigma\) | \(n\) | Mean [El/Fe] | \(\sigma\) | \(n\) |
|---------------|-------|------|-----|-------|------|-----|-------|------|-----|-------|------|-----|-----------------|-------|-----|
| C (\(C_2\))  | -0.15 | 0.04 | 1   | -0.07 | 0.04 | 2   | -0.20 | 0.07 | 2   | -0.25 | 0.04 | 2   | -0.26 | 0.11 |
| N (CN)       | 0.43  | 0.14 | 11  | 0.47  | 0.16 | 10  | 0.49  | 0.14 | 11  | 0.40  | 0.05 | 11  | 0.41  | 0.07 | 11  |
| O (\(O_i\))  | -0.04 | 0.01 | 1   | 0.03  | 0.01 | 1   | 0.08  | 0.01 | 1   | -0.05 | 0.01 | 1   | 0.00  | 1   | -0.14 | 0.05 |
| NaI          | 0.13  | 0.07 | 3   | 0.17  | 0.06 | 3   | 0.17  | 0.06 | 3   | 0.28  | 0.04 | 2   | 0.25  | 0.07 | 2   |
| MgI          | 0.07  | 0.06 | 4   | 0.15  | 0.06 | 4   | 0.11  | 0.07 | 4   | 0.23  | 0.04 | 3   | 0.17  | 0.03 | 3   |
| AlI          | 0.08  | 0.08 | 2   | 0.32  | 0.07 | 2   | 0.28  | 0.06 | 2   | 0.15  | 0.02 | 2   | 0.08  | 0.04 | 2   |
| SiI          | 0.20  | 0.08 | 12  | 0.17  | 0.07 | 12  | 0.21  | 0.06 | 12  | 0.36  | 0.09 | 5   | 0.21  | 0.07 | 5   |
| CaI          | 0.21  | 0.06 | 12  | 0.38  | 0.08 | 12  | 0.20  | 0.05 | 12  | 0.10  | 0.07 | 9   | 0.06  | 0.04 | 9   |
| ScII         | 0.20  | 0.05 | 9   | 0.25  | 0.08 | 9   | 0.20  | 0.08 | 9   | 0.31  | 0.03 | 3   | 0.13  | 0.03 | 3   |
| TiI          | 0.25  | 0.07 | 18  | 0.27  | 0.08 | 18  | 0.23  | 0.03 | 18  | 0.18  | 0.08 | 5   | 0.05  | 0.06 | 5   |
| TiII         | 0.10  | 0.05 | 8   | 0.22  | 0.06 | 8   | 0.04  | 0.04 | 8   | 0.30  | 0.09 | 2   | 0.40  | 0.07 | 2   |
| V i          | 0.23  | 0.03 | 9   | 0.39  | 0.04 | 9   | 0.24  | 0.05 | 9   | 0.32  | 0.09 | 2   | 0.22  | 0.08 | 2   |
| CrI          | 0.08  | 0.08 | 24  | 0.25  | 0.08 | 24  | 0.11  | 0.07 | 24  | 0.30  | 0.08 | 12  | 0.27  | 0.05 | 12  |
| CrII         | 0.03  | 0.06 | 6   | 0.24  | 0.03 | 6   | 0.10  | 0.06 | 6   | 0.25  | 1   | 0.25 | 1   | 0.17  | 1   |
| MnII         | 0.28  | 0.03 | 6   | 0.32  | 0.08 | 6   | 0.32  | 0.05 | 6   | 0.25  | 0.08 | 2   | 0.15  | 0.04 | 2   |
| CoI          | 0.24  | 0.07 | 8   | 0.35  | 0.06 | 8   | 0.40  | 0.05 | 8   | 0.31  | 0.07 | 4   | 0.18  | 0.02 | 4   |
| NiI          | 0.17  | 0.08 | 36  | 0.27  | 0.07 | 36  | 0.31  | 0.07 | 36  | 0.24  | 0.07 | 21  | 0.11  | 0.07 | 21  |
| CuI          | 0.13  | 0.06 | 3   | 0.24  | 0.07 | 3   | 0.27  | 0.05 | 3   | 0.32  | 1   | 0.30 | 1   | 0.10  | 1   |
| ZnI          | 0.03  | 0.05 | 2   | 0.11  | 0.05 | 2   | 0.11  | 0.05 | 2   | 0.18  | 0.04 | 2   | 0.18  | 0.09 | 2   |
| ZnII         | 0.1  | 0.03 | 6   | 0.16  | 0.02 | 6   | 0.27  | 0.06 | 6   | 0.35  | 1   | 0.25 | 1   | 0.30  | 1   |
| ZrI          | 0.01  | 1    | 1   | 0.15  | 0.1  | 1    | 0.23  | 0.2  | 1    | 0.20  | 0.07 | 2   | 0.05  | 0.07 | 2   |
| BaII         | 0.24  | 0.01 | 2   | 0.31  | 0.02 | 2   | 0.40  | 0.05 | 2   | 0.30  | 0.05 | 2   | 0.10  | 0.07 | 2   |
| LaII         | 0.11  | 1    | 1   | 0.17  | 0.29 | 1    | 0.45  | 0.07 | 2   | 0.29  | 0.01 | 2   | 0.22  | 0.05 | 2   |
| CeII         | 0.21  | 0.07 | 2   | 0.30  | 0.06 | 2   | 0.37  | 0.05 | 2   | 0.30  | 0.20 | 1    | 0.15  | 1    | 0.11  |
| NdII         | 0.33  | 0.05 | 3   | 0.40  | 0.06 | 3   | 0.35  | 0.03 | 3   | 0.40  | 1   | 0.40 | 1   | 0.30  | 1   |
| EuII         | 0.15  | 1    | 1   | 0.15  | 0.20 | 1    | 0.35  | 0.25 | 1    | 0.12  | 1   | 0.12 | 1   | 0.06  | 1   |
| C/N          | 1.05  | 1.48 | 110 | 1.10  | 1.41 | 141 | 0.98  | 1.38 | 12  | 1.23  | 0.22 |
| \(^{12}\)C/\(^{13}\)C | 6 ±1  | 9 ±1 | 12 ±1 | 7 ±1 | 8 ±1 | 12 ±1 | 9 ±1 | 2.5 |
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Figure 4. Radial distribution of open cluster abundances. Open squares show results by Bragaglia et al. (2001, 2008), Carretta et al. (2004, 2005, 2007) and Sestito et al. (2006, 2007, 2008). The result of this study is marked as a filled square. Crosses show results presented in the papers by Friel, Jacobson & Pilachowski (2005) and Jacobson et al. (2008, 2009), pluses – Yong et al. (2005), triangles – Smiljanic et al. (2009) and reversed triangles – Pancino et al. (2010).

Figure 5. Small region of NGC 6134 spectrum (solid black line with black dots) at C2 Swan (0,1) band head 5635.5 Å, plotted together with synthetic spectra with [C/Fe] values lowered by −0.2 dex (lower grey line) and −0.25 dex (upper grey line).

In Fig. 8, [O/Fe] are plotted as a function of C/N ratios. The values of NGC 6134 are in agreement with other studies. At smaller C/N ratios [O/Fe] are lower.

3.3 Carbon isotope ratios

The 12C/13C ratios were determined for all programme stars from the (2,0) 13C14N feature at 8004.728 Å with a laboratory wavelength adopted from Wyller (1966). In Fig. 9 we show a small portion of NGC 6134 spectrum together with three theoretical lines for carbon isotopic ratio determination. We find that the mean 12C/13C ratios are lowered to about 9 ± 2.5 in the clump stars investigated. Smiljanic et al. (2009) found for this ratio the value of 12 and 13 for their two stars in NGC 6124. The 13C/13C ratio in the solar photosphere is equal to 89 (Coplen et al. 2002).

The number of papers with carbon isotope ratios determined for red clump stars in open clusters is not numerous. In Fig. 10 we plot the mean carbon isotope ratios of clump stars in different open clusters as a function of turn-off mass and compare them with the theoretical models of the first dredge-up by Boothroyd & Sackmann (1999) and Charbonnel (1994).

For NGC 6134 we plot the mean 12C/13C ratio 10 ± 3 as averaged from clump stars investigated in our study and by Smiljanic et al. (2009). The mass of the programme stars $M = 2.34 \, M_{\odot}$ was obtained by Carretta et al. (2004) reading the turn-off values on the Girardi et al. (2000) isochrones for solar metallicity at the age of the cluster of 0.7 Gyr as determined by Bruntt et al. (1999).

In Fig. 10, we also present results for clump stars in five other open clusters investigated by Smiljanic et al. (2009). Data for M 67 and NGC 7789 clump stars come from Tautvaišienė et al. (2000, 2005). From Gilroy (1989) we selected four clusters with well-defined red clump stars (NGC 752, NGC 2360, M 67 and IC 4756). Luck (1994) derived carbon isotope ratios for eight open clusters; however, it is very difficult to identify stars of red clump in them.

From Fig. 10, it is seen that 12C/13C values in the clump stars are much below the predictions of first dredge-up, and for most of
3.4 Sodium and aluminium

Sodium and aluminium are among the chemical elements for which observations of abundance anomalies are also present. The O–Na anticorrelation has been observed among the brightest red giants in Galactic globular clusters for a long time (see Kraft 1994; Da Costa 1998; Denissenkov & Herwig 2003 and references therein). An overabundance of Na could appear, due to the deep mixing from layers of the NeNa cycle of H burning. Extensive theoretical studies of deep mixing in stellar atmospheres have been made by Denissenkov & Weiss (1996), Denissenkov & Tout (2000), Denissenkov & Herwig (2003), Gratton, Sneden & Carretta (2004) and references therein. However, the explanation of abundance changes by deep mixing has been eliminated by the determination of an Na–O anticorrelation in less evolved stars down to the main sequence (Gratton et al. 2001; Thévenin et al. 2001; Ramirez & Cohen 2002; D’Orazi et al. 2010). For a recent discussion of the Na and O abundances in open clusters, see De Silva et al. (2009), who explicitly addressed the problem of the (not seen) Na–O anticorrelation.

Abundances of sodium were determined from the NLTE analysis of Na I lines at 5682.64, 6154.23 and 6160.75 Å. The Na I line at 5682.64 Å was not available for the analysis of UVES spectra. Abundances of aluminium were determined from Al I lines at 7835.30 and 7836.13 Å.

The stars in our sample do not show overabundance either of sodium or of aluminium (Fig. 4).

3.5 The α-elements, iron group and heavier elements

According to observations of main sequence stars in the Galactic disc, abundance ratios of α-process elements to iron at the solar
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In NGC 6134, the mean cluster $\alpha$/Fe = $\frac{1}{3}$([Mg/Fe] + [Si/Fe] + [Ca/Fe] + [Ti/Fe]) = 0.02 ± 0.03 (s.d.), which is very close to the solar value.

As it is seen from Table 3, the ratios of abundances of iron group, $s$- and $r$-process elements to iron are close to solar.

3.6 Final remarks

Convection, the only mechanism of internal mixing taken into account by standard stellar evolution models, is not able to account for carbon and nitrogen abundance alterations seen in clump stars of open clusters. The clump stars provide information on chemical composition changes, which have happened during their evolution along the giant branch and during the helium flash. Extra-mixing processes may become efficient on the red giant branch when stars reach the so-called RGB bump, and may modify the surface abundances. It is known that alterations of $^{12}\text{C}/^{13}\text{C}$ and $^{12}\text{C}/^{14}\text{N}$ ratios depend on stellar evolutionary stage, mass and metallicity (see Charbonnel, Brown & Wallerstein 1998; Gratton et al. 2000; Chanamé, Pinsoneault & Ternudp 2005; Smiljanic et al. 2009 for more discussion).

In the open cluster M67 (Tautvaišienė et al. 2000), we did not find evidence for extra-mixing in first-ascent giants (the mass of turn-off stars in this cluster is about 1.2 $M_\odot$). In the M 67 giants investigated, the mean $^{12}\text{C}/^{13}\text{C}$ ratio is lowered to the value of 24 ± 4 and the $^{12}\text{C}/^{14}\text{N}$ ratio to the value of 1.7 ± 0.2, which is close to the corresponding predictions of the first dredge-up (Boothroyd & Sackmann 1999). Evidence of extra-mixing has been detected only in the clump stars observed, where the mean $^{12}\text{C}/^{13}\text{C}$ ratio is lowered to the value of 16 ± 4, and the $^{13}\text{C}/^{14}\text{N}$ ratio to 1.4 ± 0.2. In giants and clump stars investigated by Tautvaišienė et al. (2005) in NGC 7789, $^{12}\text{C}/^{13}\text{C}$ ratios are about the same, 9 ± 1, but $^{12}\text{C}/^{14}\text{N}$ ratio is 1.9 ± 0.5 in giants and 1.3 ± 0.2 in clump stars.

In NGC 6134 we investigated only clump stars. The mean $^{12}\text{C}/^{14}\text{N}$ ratio in these clump stars, 1.2 ± 0.2, and the mean $^{12}\text{C}/^{13}\text{C}$ ratio 9 ± 2.5, indicate a large extra-mixing, which is even larger than it is foreseen by the CBP model (Boothroyd & Sackmann 1999) for stars of a similar turn-off mass. $^{12}\text{C}/^{13}\text{C}$ ratios for the majority of clump stars in other open clusters also lie below the CBP trend (Gilroy 1989; Tautvaišienė et al. 2000, 2005; Smiljanic et al. 2009). Further studies are required both on the theoretical and observational sides in order to improve our understanding of mixing processes in low- and intermediate-mass giants.

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