Chemical composition of evolved stars in the open cluster NGC 2506

Šarūnas Mikolaitis,1* Gražina Tautvaišienė,1 Raffaele Gratton,2 Angela Bragaglia3 and Eugenio Carretta3

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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ABSTRACT
In this study we present abundances of $^{12}\text{C}$, $^{13}\text{C}$, N, O and up to 26 other chemical elements in two first-ascent giants and two core-helium-burning ‘clump’ stars of the open cluster NGC 2506. Abundances of carbon were derived using the C2 Swan (0,1) band head at 5635.5 Å. The wavelength interval 7940–8130 Å, with strong CN features, was analysed in order to determine nitrogen abundances and carbon isotope ratios. The oxygen abundances were determined from the [O i] line at 6300 Å. NGC 2506 was found to have a mean $[\text{Fe/H}] = -0.24 \pm 0.05$ (standard deviation). Compared with 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 other chemical elements have abundance ratios close to solar. The C/N and $^{12}\text{C}/^{13}\text{C}$ ratios are lowered to 1.25 ± 0.27 and 11 ± 3, respectively.

Key words: stars: abundances – stars: atmospheres – stars: horizontal branch – open clusters and associations: individual: NGC 2506.

1 INTRODUCTION
This work describes our continued efforts to study the detailed chemical composition of stars in open clusters (Tautvaišienė et al. 2000, 2005; Mikolaitis et al. 2010, 2011). Open clusters have several very valuable features: they contain ensemble stars with a common age, initial chemical composition and distance; they are distributed across the entire Galactic disc and span a wide range of ages; stars inside a cluster are at different evolutionary stages. This makes open clusters valuable sources of information in many areas of astrophysical investigations.

In this work, our target of investigation is the open cluster NGC 2506 ($\alpha_{2000} = 08^h0.02^m, \delta_{2000} = -10^\circ46.2^\prime; l = 230.564, b = +09.935$). The Galactic orbit of this cluster was determined by Carraro & Chiosi (1994). It was found that the orbit of NGC 2506 has a small eccentricity (e = 0.03) and epicyclical amplitude ($\Delta R = 0.84\text{kpc}$), suggesting that it has not moved far away from the site of formation. The orbit remains confined at radial distances between 10.7 and 11.6 kpc, and along the z-direction it does not extend beyond 0.6 kpc.

Since the first studies by van den Bergh & Sher (1960) and Purgathofer (1964), NGC 2506 has many references in the literature. Relative proper motions for 724 stars in the region of NGC 2506 have been determined and their probabilities of membership derived by Chiu & van Altena (1981). According to the recent studies, NGC 2506 is a mildly elongated cluster containing about 1090 stars (Chen, Chen & Shu 2004): its generally accepted age is $t = 1.7\text{ Gyr}$ (Marconi et al. 1997), its turn-off mass $M = 1.69\text{ M}_\odot$ (Carretta et al. 2004, hereafter C04), its galactocentric and heliocentric distances $R_\odot = 10.38\text{kpc}$ and $d = 3.26\text{kpc}$ respectively (Bragaglia & Tosi 2006).

A high-resolution spectroscopic observation of NGC 2506 was already obtained 30 years ago by Geisler (1984). For the star 22012, a surprisingly low metallicity ($[\text{Fe/H}] = -0.67$) was determined and $[\text{Mg/Fe}]$ and $[\text{Si/Fe}]$ were found to be rather large (0.8 dex). Metallicity determinations using Washington-system photometry were also presented for this cluster in the same paper, with a value of $-0.93\text{ dex}$ using the $M - T_\text{c}$ colour index and $-0.51\text{ dex}$ using $C - M$. Later photometric observations of this cluster indicated quite a low metallicity as well. A value of $[\text{Fe/H}] = -0.55$ relative to the Hyades was determined from $UBV$ and DDO photoelectric photometry and $B$ and $V$ photographic photometry by McClure, Twarog & Forrester (1981). Using the same observational data and a new calibration, Fiatt, Claria & Abadi (1995) have determined $[\text{Fe/H}] = -0.48$. From Washington photoelectric photometry, $[\text{Fe/H}] = -0.58$ was determined by Geisler, Claria & Minniti (1992). However, a higher metal abundance of $-0.20\text{ dex}$ was

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

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

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obtained from high-resolution spectroscopy by C04, as averaged from two stars.

In this work, we analysed four stars in NGC 2506 observed by C04. Using a carefully selected line list, we redetermined the main atmospheric parameters, derived abundances of $^{12}$C, $^{13}$C and nitrogen, which will contribute to the expansion of a data base on abundances of mixing-sensitive chemical elements in open clusters. The degree of mixing in stars largely depends on their masses and metallicities. The available number of open clusters investigated so far is far from sufficient in order to make reliable models of stellar evolution (Charbonnel & Lagarde 2010; Mikolaitis et al. 2011 and references therein).

The data on abundances of heavier chemical elements in NGC 2506 will be used to study time evolution of abundances in the Galactic disc within the Bologna Open Cluster Chemical Evolution (BOCCE) study (Bragaglia & Tosi 2006; Carretta, Bragaglia & Gratton 2007).

### 2 Observations and Method of Analysis

The spectra of four stars (NGC 2506 438, 443, 456 and 459) were obtained with the Fiber-fed Extended Range Optical Spectrograph (FEROS) mounted at the 1.5-m telescope in La Silla (Chile) by C04. Two stars (438 and 443) belong to the red clump, the star 456 is a first-ascent giant and the star 459 is a red giant branch (RGB) tip giant (see Fig. 1 for the colour–magnitude diagram of NGC 2506 with these stars indicated). Small portions of the spectra are presented in Fig. 2. The resolving power is $R = 48\,000$ and the full wavelength range is $\lambda\lambda$ 3700–8600 Å. The spectrum of RGB-tip star 459 has the highest signal-to-noise ratio (S/N) of 110, while the S/N of the spectrum of star 456, which lies below the clump, is only 35. The log of observations and S/N values for individual stars is presented in the paper of C04.

Since the S/N ratios of stellar spectra observed in this cluster were much lower than in the other open clusters observed by C04 and investigated in our previous papers (Mikolaitis et al. 2010, 2011), we decided to try to redetermine the main atmospheric parameters of stars in NGC 2506 using more strictly selected lines.

Effective temperature, surface gravity and microturbulent velocity were derived using traditional spectroscopic criteria. The preliminary values of effective temperatures were derived using $(B - V)\_0$ colour indices and the temperature calibration by Alonso, Arribas & Martínez-Roger (2001). The interstellar reddening value $E(B - V) = 0.07$, as averaged from four determinations (Marconi et al. 1997; Schlegel, Finkbeiner & Davis 1998; Kim et al. 2001; Dias et al. 2002), was taken into account.

The spectroscopic effective temperatures were derived by minimizing the slope of the abundances obtained from neutral Fe I lines with respect to the excitation potential. Differences between the photometric and spectroscopic effective temperatures did not exceed 100 K. The gravities ($\log g$) were derived by forcing measured neutral and ionized iron lines to yield the same [Fe/H] value by adjusting the model gravity. The microturbulent velocities were determined by forcing Fe I abundances to be independent of the equivalent widths of lines.

The ATLAS models with overshooting were used for analysis of the spectra. Spectral lines were restricted to the spectral range 5500–8000 Å in order to minimize problems of line crowding and difficulties in continuum tracing in the blue region. After careful selection, the number of Fe I lines initially analysed by C04 was reduced from 137–102 to 47–49 in the brighter stars and from 83 to 35 in the fainter star NGC 2506 456. The number of Fe II lines was reduced from 13–10 to 6–5, respectively. This allowed us to minimize the scatter and increase the accuracy of the abundance and stellar atmospheric parameter determinations. The atmospheric parameters and iron abundances determined for the observed stars in NGC 2506 are presented in Table 1.

In this work we used the same method of analysis as in Mikolaitis et al. (2010, 2011) for the determination of abundances of other chemical elements. In the following, we give only some details about the spectral lines investigated.

C abundances were derived from the C I Swan 0–1 band head at 5630.5 Å; a fit of synthetic and observed spectra of this feature for the NGC 2506 459 spectrum is shown in Fig. 3. We derived oxygen abundances from synthesis of the forbidden [O I] line at 6300.3 Å. The gf values for $^{56}$Ni and $^{60}$Ni isotopic line components, which blend the oxygen line, were taken from Johansson et al. (2003). In Fig. 4, we show an example of spectrum synthesis for the [O I] line.

![Figure 1](https://example.com/figure1.png)

*Figure 1.* The colour–magnitude diagram of the open cluster NGC 2506. The stars investigated in this work are indicated by filled squares. The diagram is based on UBV RI photometry by Marconi et al. (1997).

![Figure 2](https://example.com/figure2.png)

*Figure 2.* Samples of stellar spectra of all programme stars in NGC 2506. An offset of 0.5 in relative flux is applied for clarity.
Table 1. Adopted atmospheric parameters for observed stars in NGC 2506.

| Star | $V$ (mag) | $B - V$ (mag) | $T_{\text{eff}}$ (K) | log $g$ | $v_t$ (km s$^{-1}$) | [Fe/H] | $\sigma_{\text{Fe I}}$ | $n_{\text{Fe I}}$ | $\sigma_{\text{Fe II}}$ | $n_{\text{Fe II}}$ |
|------|-----------|---------------|-----------------|--------|----------------|-------|------------------|--------|----------------|--------|
| 438  | 13.234    | 0.944         | 5050            | 2.64   | 1.5            | −0.18 | 0.08            | 49      | 0.07            | 5      |
| 443  | 13.105    | 0.952         | 5050            | 2.60   | 1.6            | −0.24 | 0.07            | 47      | 0.06            | 5      |
| 456  | 13.977    | 0.919         | 4960            | 2.96   | 1.8            | −0.23 | 0.06            | 45      | 0.05            | 5      |
| 459  | 11.696    | 1.100         | 4660            | 2.16   | 1.7            | −0.29 | 0.06            | 49      | 0.05            | 6      |

*Star numbers, $V$ and $B - V$ from Marconi et al. (1997).

Figure 3. A small region of the NGC 2506 459 spectrum (solid black line with black dots) at the $C_2$ Swan (0,1) bandhead 5635.5 Å, plotted together with synthetic spectra (grey lines) with [C/Fe] values at $-0.19 \pm 0.05$ dex.

in NGC 2506 443. In spectra of NGC 2506 stars, the [O I] line was not contaminated by telluric lines.

The interval 7940–8130 Å containing strong $^{12}$C$^{14}$N features was used for the nitrogen abundance analysis. Unfortunately, a $^{12}$C/$^{13}$C ratio analysis using the $^{13}$C$^{14}$N feature at 8004.7 Å was not possible because of blending by telluric lines. Thus, we selected another $^{13}$C$^{14}$N feature at 7940.4 Å (see Fig. 5 for our example). 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 to the solar atlas of Kurucz et al. (1984).

The solar carbon and nitrogen abundances used in our work are log$A_C = 8.52$ and log$A_N = 7.92$ (Grevesse & Sauval 2000).

Abundances of Na and Mg were determined with non-local thermodynamical equilibrium (NLTE) taken into account, as described by Gratton et al. (1999). The calculated corrections did not exceed 0.03 dex for Na i and 0.09 dex for Mg i lines. Abundances of sodium were determined from equivalent widths of the Na i lines at 6154.2 and 6160.8 Å, those of magnesium from the Mg i lines at 4730.0, 5711.1 and 6318.7 Å and those of aluminium from the Al i lines at 7835.3 and 7836.1 Å.

The determinations of copper, zirconium, yttrium, barium, lanthanum, cerium, neodymium, praseodymium and europium abundances were performed by a spectral synthesis method. The copper abundances were derived using the Cu i line at 5218.2 Å, for which we adopted the hyperfine structure data of Steffen (1985). The zirconium abundances were determined from the Zr i lines at 4687.8 and 6127.5 Å. We adopted the barium hyperfine structure and isotopic composition for the Ba ii lines at 5853.7 and 6141.7 Å from McWilliam (1998) and for the line at 6496.9 Å from Mashonkina & Gehren (2000). Lanthanum abundances were determined from the...
La II lines at 6320.4 and 6390.5 Å, and cerium from the Ce II lines at 5274.2 and 6043.4 Å. Neodymium abundances were determined using atomic parameters presented by Den Hartog et al. (2003). Due to line crowding in the region of neodymium lines, only three Nd II lines were chosen: 5092.8, 5249.6 and 5319.8 Å.

For this cluster, along with europium, another r-process element (praseodymium) was investigated. The praseodymium abundances were determined from the Pr II line at 5322.8 Å (in Fig. 6, a fit to the NGC 2506 438 spectrum is shown). Europium abundances were determined using the Eu II line at 6645.1 Å. A hyperfine structure for the Eu II line was used for the line synthesis. In Fig. 7, a fit to the Eu II line in the NGC 2506 438 spectrum is shown.

2.1 Estimation of uncertainties

The sensitivity of the abundance estimates to changes in the atmospheric parameters by the assumed errors (±100 K for $T_{\text{eff}}$, ±0.3 dex for $\log g$ and ±0.3 km s$^{-1}$ for $v_t$) is illustrated for the star NGC 2506 438 (Table 2). It is seen that 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 scatter of the deduced line abundances $\sigma$, presented in Table 3, gives an estimate of the uncertainty due to the random errors, for example in continuum placement and the line parameters (the mean value of $\sigma$ is 0.07). Thus the uncertainties in the derived abundances that are the result of random errors amount to approximately this value.

For the giant star 456, the spectrum of which has the lowest signal-to-noise ratio, we have tried to select lines for the analysis very carefully so that $\sigma$ values are not high. However, the results should still be considered with some caution. The same has to be said about the RGB-tip star 459, for which the [Fe/H] value was found to be 0.2 dex lower than for other investigated stars (Carretta et al. 2004).

Table 2. Effects on derived abundances resulting from model changes for the star NGC 2506 438. The table entries show the effects on the logarithmic abundances relative to hydrogen, $\Delta[\text{El/H}]$. Note that the effects on 'relative' abundances, for example $\Delta[\text{El/Fe}]$, are often considerably smaller than abundances relative to hydrogen, $[\text{El/H}]$.

| Species | $\Delta T_{\text{eff}}$ ±100 K | $\Delta \log g$ ±0.3 | $\Delta v_t$ ±0.3 km s$^{-1}$ | Total |
|---------|-------------------------------|-----------------------|-----------------------------|-------|
| C (C$_2$) | 0.03 | 0.03 | 0.00 | 0.04 |
| N (CN) | 0.03 | 0.01 | 0.02 | 0.04 |
| O ([OI]) | 0.02 | 0.03 | 0.01 | 0.04 |
| Na I | 0.07 | 0.03 | 0.06 | 0.10 |
| Mg I | 0.06 | 0.01 | 0.09 | 0.09 |
| Si I | 0.01 | 0.04 | 0.04 | 0.05 |
| Ca I | 0.09 | 0.02 | 0.10 | 0.13 |
| Sc II | 0.01 | 0.13 | 0.08 | 0.15 |
| Ti I | 0.14 | 0.01 | 0.08 | 0.16 |
| Ti II | 0.01 | 0.13 | 0.11 | 0.17 |
| V I | 0.15 | 0.01 | 0.06 | 0.16 |
| Cr I | 0.10 | 0.01 | 0.09 | 0.14 |
| Cr II | 0.05 | 0.12 | 0.07 | 0.15 |
| Mn I | 0.08 | 0.02 | 0.10 | 0.13 |
| Fe I | 0.08 | 0.00 | 0.09 | 0.12 |
| Fe II | 0.07 | 0.14 | 0.10 | 0.19 |
| Co I | 0.05 | 0.02 | 0.06 | 0.08 |
| Ni I | 0.03 | 0.02 | 0.08 | 0.09 |
| Cu I | 0.03 | 0.02 | 0.08 | 0.09 |
| Zn I | 0.02 | 0.07 | 0.08 | 0.11 |
| Y II | 0.02 | 0.10 | 0.11 | 0.15 |
| Zr I | 0.04 | 0.09 | 0.04 | 0.11 |
| Ba II | 0.02 | 0.12 | 0.08 | 0.15 |
| La II | 0.08 | 0.11 | 0.02 | 0.13 |
| Ce II | 0.01 | 0.13 | 0.05 | 0.14 |
| Pr II | 0.02 | 0.13 | 0.01 | 0.13 |
| Nd II | 0.02 | 0.11 | 0.06 | 0.12 |
| Eu II | 0.00 | 0.13 | 0.02 | 0.13 |
| C/N | 0.16 | 0.05 | 0.04 | 0.17 |
| $^{12}$C/$^{13}$C | 1.5 | 1.3 | 0.5 | 2 |
Since abundances of C, N and O are bound together by 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 \(\Delta [O/H] = 0.02\) and \(\Delta [N/H] = 0.10\) has no effect on either the carbon or the oxygen abundances.

Other sources of uncertainties were described in detail by Mikolaitis et al. (2010).

### 3 RESULTS AND DISCUSSION

The abundances of different chemical elements relative to iron [El/Fe] and \(\sigma\) (the line-to-line scatter) derived for up to 30 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 2506 are presented in Table 3 as well. Except for carbon and nitrogen, the majority of the investigated chemical elements have abundance ratios close to the solar ones. In NGC 2506, the mean cluster \([\alpha/Fe] \equiv 1/2([\text{Mg/Fe}]+[\text{Si/Fe}]+[\text{Ca/Fe}]+[\text{Ti/Fe}])/4 = 0.00 \pm 0.06\) (s.d.).

In the remainder of this section, we will discuss the carbon and nitrogen abundance results in more detail. Investigations of abundances of these chemical elements in atmospheres of clump and giant stars of open clusters may provide comprehensive information on chemical composition changes during their evolution along the giant branch and at the helium flash.

The average value of carbon-to-iron ratio in NGC 2506 is \([C/Fe] = -0.19 \pm 0.08\). We compared the carbon abundance in NGC 2506 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 (MS) disc stars using \([C]_\alpha\) and \([C]_\beta\) lines and found \([C/Fe]\) to be about solar at the solar metallicity. Roughly solar carbon abundances were found by Gustafsson et al. (1999), who analysed a sample of 80 late F- and early G-type dwarfs using the forbidden \([C]_\alpha\) line. The ratios of \([C/Fe]\) in our stars lie about 0.2 dex below the values obtained for dwarf stars of the Galactic disc.

The mean nitrogen-to-iron abundance ratio in NGC 2506 is \([N/Fe] = 0.32 \pm 0.03\). This shows that nitrogen is overabundant in these evolved stars of NGC 2506 by 0.3 dex, since \([N/Fe]\) values in Galactic MS stars are about solar at solar metallicity (cf. Shi et al. 2002).

\(^{12}\text{C}/^{13}\text{C}\) and C/N ratios may provide important information on mixing processes in stars. The mean \(^{12}\text{C}/^{13}\text{C}\) and C/N ratios in the NGC 2506 stars investigated are equal to 11 \pm 3 and 1.25 \pm 0.27, respectively. In Mikolaitis et al. (2011) we have compiled recent data on \(^{12}\text{C}/^{13}\text{C}\) and C/N ratios in clump stars of open clusters. The clump stars have accumulated all chemical composition changes that have happened during their evolution along the giant branch, so they are very useful indicators of abundance alterations.

In Figs 8 and 9, we compare the mean \(^{12}\text{C}/^{13}\text{C}\) and C/N ratios of cluster clump stars as a function of turn-off mass with theoretical models of the first dredge-up, thermohaline mixing (TH),
Figure 8. The average carbon isotope ratios in clump stars of open clusters as a function of stellar turn-off mass. The models of the first dredge-up, thermohaline mixing (TH) and rotation-induced mixing (V) are taken from Charbonnel & Lagarde (2010). The CBP model of extra-mixing is taken from Boothroyd & Sackmann (1999). Filled square, this work; open squares, Mikolaitis et al. (2010, 2011) and Tautvaišienė et al. (2000, 2005); open triangles, Smiljanic et al. (2009); reversed open triangle, Luck (1994); open circles, Gilroy (1989). A typical error bar is indicated.

Figure 9. The average carbon-to-nitrogen ratios in clump stars of open clusters as a function of stellar turn-off mass. The meaning of symbols are as in Fig. 8.

TH together with rotation-induced mixing for stars at the zero-age main sequence having rotational velocities of 110, 250 and 300 km s\(^{-1}\) computed by Charbonnel & Lagarde (2010), the cool-bottom processing (CBP) model by Boothroyd & Sackmann (1999) and previous investigations of \(^{12}\text{C}/^{13}\text{C}\) and C/N ratios by Mikolaitis et al. (2010, 2011), Tautvaišienė et al. (2000, 2005), Smiljanic et al. (2009), Luck (1994) and Gilroy (1989). The turn-off mass of stars in NGC 2506 was taken from C04. The typical error bars are indicated as well (cf. Charbonnel & Lagarde 2010).

The \(^{12}\text{C}/^{13}\text{C}\) values we derive for the stars in the open cluster NGC 2506 confirm the observational evidence that theoretical models for stars with larger turn-off masses should consider larger extra-mixing, probably dominated by the former rotation on the main sequence (Mikolaitis et al. 2011; Charbonnel & Lagarde 2010).

In NGC 2506, the mean C/N ratios in the clump stars are lowered slightly more (1.04 ± 0.11) than in the first-ascent giants (1.47 ± 0.08). This reminds us of an unanswered question about the He-flash influence on mixing processes of CN-processed material in giants. In the clump stars the \(^{12}\text{C}/^{13}\text{C}\) ratios are also lowered to smaller values (8 and 10) than in the RGB-tip star 459, for which the ratio is equal to 14. The differences in \(^{12}\text{C}/^{13}\text{C}\) and C/N ratios in clump stars and giants might be caused by the He flash.

The He-flash influence on the extra-mixing of CN-cycled material at stellar surfaces still has to be investigated both theoretically and observationally. Theoretical calculations indicate that the nature of nucleosynthesis and mixing depends upon the degree of degeneracy in the He core and, hence, the intensity of the explosion: intermediate flashes produce the most efficient mixing (Despain 1982; Deupree 1986; Deupree & Wallace 1987). Attempts to model this violent event of stellar evolution are continuing (e.g. Schlattl et al. 2001; Cassisi et al. 2003; Dearborn, Lattanzio & Eggleton 2006; Mocnik et al. 2010 and references therein).

Precise observations of RGB-tip stars and clump stars in clusters are most useful in order to uncover the effects of the He-core flash. In the previously investigated open clusters M67 and NGC 7789 we also found some differences in the mean \(^{12}\text{C}/^{13}\text{C}\) and \(^{12}\text{C}/^{14}\text{N}\) ratios when comparing giants and clump stars (Tautvaišienė et al. 2000, 2005). In M67, with a mass of turn-off stars of about 1.2 M\(_{\odot}\), the mean \(^{12}\text{C}/^{13}\text{C}\) in giants 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. In the clump stars observed, the means are lower: \(^{12}\text{C}/^{13}\text{C}\) = 16 ± 4 and \(^{12}\text{C}/^{14}\text{N}\) = 1.4 ± 0.2. In NGC 7789 we also investigated the first-ascent giants located above the red giant bump and more evolved clump stars. The mass of turn-off stars is about 1.6 M\(_{\odot}\). The mean \(^{12}\text{C}/^{14}\text{N}\) ratio is 1.9 ± 0.5 in the giants and 1.3 ± 0.2 in the clump stars; however, the \(^{12}\text{C}/^{13}\text{C}\) ratios are very similar for all stars investigated, 9 ± 1. A RGB-tip star and two clump stars were investigated in the cluster NGC 3532 by Smiljanic et al. (2009). The mean \(^{12}\text{C}/^{13}\text{C}\) ratio in the clump stars is 11 ± 1, while that in the RGB-tip star is larger and equal to 20. However, the C/N ratios are about the same. Three clump stars and one RGB-tip star were investigated in the open cluster IC 4561 by Mikolaitis et al. (2011). Due to the different [Fe/H], which is lower by 0.4 dex than that of other cluster stars, the RGB-tip star is not reliable enough for investigations of possible tiny effects of the He-core flash.

\(^{12}\text{C}/^{13}\text{C}\) ratios depend little on stellar atmospheric parameters and are sensitive indicators of mixing processes; hence their analysis has to be continued. We plan to address this topic in forthcoming papers.

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