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Chemical composition of evolved stars in the open cluster NGC 7789*,**

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Abstract. High-resolution spectra of six giants and three core-helium-burning "clump" stars in the open cluster NGC 7789 have been obtained with the SOFIN spectrograph on the Nordic Optical Telescope to investigate abundances of up to 20 chemical elements. Abundances of carbon were studied using the C_2 Swan (0, 1) band head at 5635.5 Å. 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. The overall metallicity of evolved stars in the cluster was found to be close to solar ([Fe/H] = -0.04 ± 0.05). Compared with the Sun and other dwarf stars of the Galactic disk, mean abundances in the investigated giant stars suggest that carbon is depleted by about 0.2 dex, and nitrogen and oxygen are close to solar. In the clump stars investigated, carbon is depleted by about 0.2 dex, the mean abundance of nitrogen is enhanced by 0.26 dex and oxygen is lower by 0.14 dex. This has the effect of lowering the mean C/N ratios to the value of 1.9 ± 0.5 in the giant stars and to the value of 1.3 ± 0.2 in the clump stars. The mean $^{12}C/^{13}C$ ratios are lowered to about the same value of 9 ± 1 in the giants and clump stars investigated. Concerning other chemical elements an overabundance of sodium is noticeable and of silicon and calcium one is suspected. Abundances of iron-group and heavier chemical elements in all nine stars were found to be close to solar.

Key words. stars: abundances – stars: atmospheres – stars: horizontal-branch – Galaxy: open clusters and associations: individual: NGC 7789

1. Introduction

Open clusters are important tools for the study of the Galactic disk as well as for understanding stellar evolution. Since cluster members initially were of identical chemical composition, all changes in stellar atmospheres are related to internal and external processes of stellar evolution. 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 years ago (e.g. Pagel 1974; McClure 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 were undertaken for giants in 20 open clusters by Gilroy (1989), abundances of more than 20 chemical elements in stars of 8 open clusters were analysed by Luck (1994), a number of other clusters to different extents were analysed by Bragaglia et al. (2001), Brown (1985), Brown et al. (1996), Cayrel et al. (1985), Friel et al. (2003), Gratton & Contarini (1994), Hamdani et al. (2000), King & Hiltgen (1996), Peterson (1992), Peterson & Green (1998), Shuler et al. (2003), Smith & Suntzeff (1987), Tautvaišienė et al. (2000) and references therein. In a recent review on oxygen and $\alpha-$element abundances in open clusters, Gratton (2000) has reached the conclusion that the results are still scarce and there are no data even for the easiest clusters.

The open cluster NGC 7789 ($\alpha_{2000} = 23^{\rm h}57^{\rm m}, \delta_{2000} = +56°42'.9$; $l = 115°.48, b = -5°.37$) is quite populous, its colour-magnitude diagram (CMD) shows a well-defined and extended red giant branch (RGB), a prominent "clump" of core-He-burning stars, many blue stragglers, and a main sequence (see Fig. 1). An extensive proper-motion membership analysis of NGC 7789 was carried out by McNamara & Solomon (1981), who identified 679 probable members brighter than $B \approx 15.5$. Radial velocity measurements were done by

* Table 1 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?A+A/431/933

** Based on observations made with the Nordic Optical Telescope, which is operated on the island of La Palma jointly by Denmark, Finland, Iceland, Norway, and Sweden, in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias.

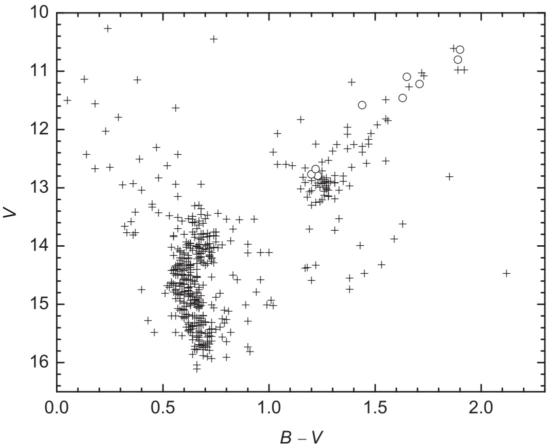

Fig. 1. The colour–magnitude diagram of the open cluster NGC 7789. The red giants and the core-He-burning "clump" stars analysed are indicated by the open circles. The diagram is based on UBV observations by Burbidge & Sandage (1958).

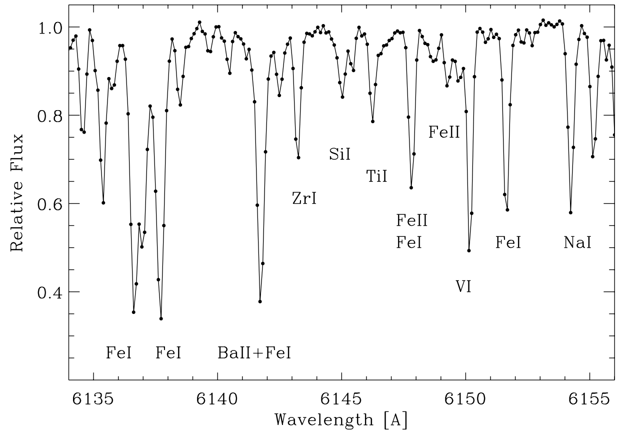

Fig. 2. Sample spectrum of the star K765.

Thogersen et al. (1993), Scott et al. (1995), and Gim et al. (1998a). The age evaluations of NGC 7789 are 1.1 Gyr as determined by Mazzei & Pigatto (1988), 1.2 Gyr (Martinez Roger et al. 1994), 1.3 Gyr (Carraro & Chiosi 1994), 1.6 Gyr (Gim et al. 1998b) or 1.4 Gyr as determined by Vallenari et al. (2000).

Such a populous open cluster is especially useful for testing stellar evolution models. For the detailed analysis we have selected six giants along the giant branch and three clump stars (see Fig. 1 for their location in the HR diagram). Abundances of C, N and O have not been investigated for this cluster previously. From high-resolution spectra, Pilachowski (1985) determined abundances of some metals in a sample of six stars, Pilachowski et al. (1984) investigated lithium abundances and reported an unusually strong lithium doublet $\lambda 6707$ line in some giant stars, Sneden & Pilachowski (1986) derived carbon isotope ratios for seven giant stars. We will refer to these papers when discussing our results. The clump stars of this cluster are investigated by means of high-resolution spectroscopy for the first time.

2. Observations and data reductions

The spectra were obtained at the Nordic Optical Telescope (NOT) with the SOFIN échelle spectrograph (Tuominen 1992) in July of 2001. The 3rd optical camera was used with an entrance slit width of 235 μm, providing a spectral resolving power of $R \approx 30\,000$. The CCD size covered simultaneously 25 spectral orders, each of 80–150 Å in length, located in the interval of 4500–8750 Å. The typical times of exposure were about 40 min for giants at the tip of the giant branch to 160 min for the clump stars. The spectra of the faintest stars were exposed to $S/N \geq 50$.

Reduction of the CCD images was done with the *4A* software package (Ilyin 2000). Procedures of bias subtraction, spike elimination, flat field correction, scattered light subtraction, extraction of spectral orders were used for image processing. A Th–Ar comparison spectrum was used for the wavelength calibration. The continuum was defined from a number of narrow spectral regions, selected to be free of lines. A sample spectrum of the star K765 is presented in Fig. 2.

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 NLTE overionization effects mainly the weak lines were selected for the analysis. The equivalent widths of the lines were measured by fitting of a Gaussian function. The line measurements are listed in Table 1 (available in electronic form at the CDS). The abundances of carbon, nitrogen, oxygen, yttrium and europium were determined using the spectrum synthesis technique.

3. Method of analysis and physical data

The spectra were analysed using a differential model atmosphere technique. The *Eqwidth* and *Synthetic Spectrum* program packages, developed at the Uppsala Astronomical Observatory, were used to carry out the calculations of theoretical equivalent widths of lines and synthetic spectra. A set of plane-parallel, line-blanketed, constant-flux LTE model atmospheres was computed with an updated version of the *MARCS* code (Gustafsson et al. 1975; Edvardsson et al. 1993) using continuous opacities from Asplund et al. (1997) and including UV line blanketing as described by Edvardsson et al. (1993).

The Vienna Atomic Line Data Base (VALD, Piskunov et al. 1995) was extensively used in preparing the input data for the calculations. Atomic oscillator strengths for this study were taken mainly from two sources: the first being an inverse solar spectrum analysis done in Kiev (Gurtovenko & Kostik 1989; Gurtovenko et al. 1983, 1985a, 1986), the second being high-precision laboratory measurements done in Oxford (Blackwell et al. 1982, 1983, 1986). The agreement of these two sets of gf values is very good, and the errors in the least-squares fit do not exceed ±0.07 dex (Gurtovenko et al. 1985b).

Using the gf values and solar equivalent widths of analysed lines from the cited sources we obtained the solar abundances, used later for the differential determination of abundances in the programme stars. We used the solar model atmosphere from the set calculated in Uppsala (Edvardsson et al. 1993) with a microturbulent velocity of 0.8 km s^{-1}, as derived from Fe I lines.

Abundances of carbon, nitrogen, oxygen, yttrium and europium were determined using the spectrum synthesis technique. The interval of 5632–5636 Å was synthesized and compared with observations in the vicinity of the C_2 Swan 0–1 band head at 5635.5 Å. The same atomic data of C_2 as used by Gonzalez et al. (1998) were adopted for the analysis. The interval of 7980–8130 Å, which contains strong CN features, was analysed in order to determine the nitrogen abundance and $^{12}C/^{13}C$ ratios. The molecular data for $^{12}C^{14}N$ and $^{13}C^{14}N$ were taken from ab initio calculations of CN isotopic line strengths, energy levels and wavelengths by Plez (1999, private communication), with all gf values increased by +0.03 dex to fit our model spectrum to the solar atlas of Kurucz et al. (1984). The oxygen abundances were derived from analysis of the forbidden [O I] line at 6300 Å, the yttrium abundances from the Y II line at 5402 Å, and the europium abundances from the Eu II line at 6645 Å. The europium line was calculated with hyperfine structure taken into account. The wavelength, excitation energy and total $\log g = 0.12$ was taken from Lawler et al. (2001), the isotopic fractions of ^{151}Eu 47.77% and ^{153}Eu 52.23% and isotopic shifts were taken from Biehl (1976). The parameters of accompanying lines in the intervals of spectral syntheses were compiled from the VALD database. In order to check the correctness of the input data, synthetic spectra of the Sun were compared to the solar atlas of Kurucz et al. (1984) and necessary adjustments were made to the line data.

In addition to thermal and microturbulent Doppler broadening of lines, atomic line broadening by radiation damping and van der Waals damping were considered in the calculation of abundances. Radiation damping parameters of lines were taken from the VALD database. In most cases the hydrogen pressure damping of metal lines was treated using the modern quantum mechanical calculations by Anstee & O'Mara (1995), Barklem & O'Mara (1997) and Barklem et al. (1998). When using the Unsöld (1955) approximation, correction factors to the classical van der Waals damping approximation by widths (Γ_6) were taken from the literature: Na I: Holweger (1971), Ca I: O'Neill & Smith (1980), Ba II: Holweger & Müller (1974), Fe I: Simmons & Blackwell (1982). For all other species a correction factor of 2.5 was applied to the classical Γ_6 ($\Delta\log C_6 = +1.0$), following Mäckle et al. (1975). For lines stronger than $W = 100$ mÅ the correction factors were selected individually by inspection of the solar spectrum.

Table 2. Atmospheric parameters of the programme stars.

Star*	V	$B-V$	$T_{\rm eff}$ K	$\log g$	[Fe/H]	$v_{\rm t}$ km s^{-1}
415	10.63	1.89[J]	3850	0.5	–0.03	1.6
468	11.10	1.64[JKR]	4190	1.3	–0.08	1.9
501	11.22	1.71[JKR]	4090	1.1	–0.07	1.7
605	12.79	1.25[JKR]	4860	2.4	–0.02	1.6
665	12.77	1.20[JKR]	4970	2.4	0.00	1.6
669	11.46	1.65[J]	4180	1.2	–0.15	1.8
732	12.68	1.23[JKR]	4900	2.3	0.02	1.6
751	10.80	1.84[BS]	3920	0.7	–0.01	1.5
765	11.58	1.48[JKR]	4430	1.8	–0.04	1.7

References: J – Janes (1977); JKR – Jahn et al. (1995); BS – Burbidge & Sandage (1958).
* Star numbers from Küstner (1923).

4. Atmospheric parameters and abundances

The preliminary effective temperatures for the stars were determined using the $(B-V)_0$ colour indices and the temperature calibrations by Alonso et al. (2001). The colour indices used are presented in Table 2. They were dereddened using the value $E_{B-V} = 0.28$, which is an average of results obtained in 10 studies (Burbidge & Sandage 1958; Arp 1962; Strom & Strom 1970; Jennens & Helfer 1975; Janes 1977; Clariá 1979; Twarog & Tyson 1985; Martinez Roger et al. 1994; Gim et al. 1998b; Vallenari et al. 2000). Afterwards all temperatures were checked so that equal abundance results would be obtained from lines of different excitation potentials. For the star K 468 the temperature had to be increased by 110 K and for K 751 and K 765 decreased by 70 and 80 K, respectively. Corrections of the temperatures of K 501, K 665 were not necessary and for the other stars did not exceed 40 K. The gravities were found by forcing Fe I and Fe II to yield the same iron abundances. For stars in this cluster Pilachowski (1985) computed the $\log g$ from the distance modulus, the turn-of mass, and bolometric corrections. For some stars this method gave rather large differences in abundances determined from neutral and ionized lines of iron: for the star K353 $[{\rm Fe/H}]_{\rm Fe\,I}-[{\rm Fe/H}]_{\rm Fe\,II} = 0.5$, for the star K637 the difference is 0.4 dex. In our study, we decided to use the method of ionization equilibrium; in this case abundances of neutral and ionised species are consistent. For a comparison, we evaluated the surface gravities from the distance modulus and the turn-off mass as well. The values of the distance modulus and the interstellar reddening were taken from Vallenari et al. (2000). The bolometric corrections were taken from Allen's Astrophysical Quantities (1999). The turn-off mass of the cluster stars of 1.6 $M_\odot$ was taken from Faulkner & Cannon (1973). It is difficult to evaluate how much the mass of the stars decreases due to mass loss on the giant branch. For instance, in the clump stars of the open cluster M 67 the mass loss is evaluated to be about 0.6 $M_\odot$ (Tripicco et al. 1993). If we accept a mass loss of about 0.2 $M_\odot$ for all the investigated stars we obtain a systematic difference of $\log g$ determined from the method of ionization equilibrium and the canonical formula of about 0.1 dex for the clump stars and 0.3 dex for the stars at the tip of the giant branch. The spectroscopic $\log g$ values are lower. With the stellar mass assumed, the difference of the spectroscopic $\log g$ between the clump stars and the stars at the tip of the giant branch gives a difference in V magnitude of about 2.6 mag, which is larger than the observed difference by 0.5 mag. The sensitivities of abundances to differences in $\log g$ are presented in Table 4. The microturbulent velocities were determined by forcing Fe I line abundances to be independent of the equivalent width. The derived atmospheric parameters are listed in Table 2.

The abundances relative to hydrogen [A/H][1] and σ (the line-to-line scatter) derived for up to 22 neutral and ionized species for the programme stars are listed in Table 3.

4.1. Estimation of uncertainties

The sources of uncertainty can be divided into two categories. The first 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. The second 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 scatter of the deduced line abundances σ, presented in Table 3, gives an estimate of the uncertainty due to the random errors in the line parameters (the mean value of σ is 0.10). Thus the uncertainties in the derived abundances that are the result of random errors amount to approximately this value.

Typical internal error estimates for the atmospheric parameters are: ±100 K for $T_{\rm eff}$, ±0.3 dex for $\log g$ and ±0.3 km s^{-1} for $v_{\rm t}$. The sensitivity of the abundance estimates to changes in the atmospheric parameters by the assumed errors is illustrated for the star K665 (Table 4). 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.

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. Δ[O/H] = −0.10 causes Δ[C/H] = −0.04 and Δ[N/H] = 0.10, Δ[C/H] = −0.10 causes Δ[N/H] = 0.14 and Δ[O/H] = −0.03. Δ[N/H] = −0.10 has no effect on either the carbon or the oxygen abundances.

Other sources of observational error, such as continuum placement or background subtraction problems are partly included in the equivalent width uncertainties discussed at the beginning of this section.

5. Discussion

As follows from the nine stars investigated, the mean abundance of iron in NGC 7789, [Fe/H] = −0.04 ± 0.05, is quite similar to solar. The solar metallicity was evaluated for this cluster also from DDO and *UBV* photometry by Janes (1977). Canterna et al. (1985) obtained a value of −0.05 dex of the overall metallicity from photometry in the Washington system. Some other photometric analyses give sub-solar [Fe/H] values: −0.2 (Jennens & Helfer 1975), −0.25 (Vallenari et al. 2000), −0.35 (Clariá 1979). In most cases, the photometric metallicity evaluations are based on the shape of the colour–magnitude diagram (CMD); thus they have a general limitation, as there is a dependence on interstellar reddening. The E_{B-V} values for NGC 7789 are quite different from one paper to another, being 0.22 in the work by Clariá (1979) and 0.32 in the work by Martinez Roger et al. (1994). From the medium-resolution spectra, Friel & Janes (1993) determined [Fe/H] = −0.26 ± 0.10 for this cluster. From the high-resolution spectroscopy of six stars of the cluster, Pilachowski (1985) determined [Fe/H] = −0.1 ± 0.2.

The star K765 is in common with the work by Pilacowski (1985). The difference in effective temperature of this star is only 20 K, the value of E_{B-V} is the same in both studies. The logarithm of the surface gravity differs by 0.3 dex, most probably because of differences in its determination. For this reason, or perhaps because we used the method of synthetic spectra, the mean value of [Eu/Fe] in the cluster according to our work is +0.02 dex and according to the work by Pilachowski [Eu/Fe] = 0.3.

There are two stars in common (K501 and K669) with the paper by Sneden & Pilachowski (1986). The purpose of this paper was to investigate ^{12}C/^{13}C in seven stars, and since this kind of analysis does not require very accurate atmospheric parameter values, the authors did not attempt to be very precise. Our effective temperature for the star K501 is lower by 60 K and for K669 it is higher by 80 K, $\log g$ in our work is lower by 0.4 dex for both stars.

As follows from the present work, the mean abundance of iron in NGC 7789 is quite similar to the metallicity of another open cluster of the Galactic disk M 67 (−0.03, Tautvaišienė et al. 2000), which was analysed by essentially the same technique as used in the present work.

The average cluster abundances and dispersions about the mean values for NGC 7789 are presented in Table 5 and discussed in the following subsections. The comparison of the determined elemental abundances has been made with results for field dwarfs of the Galactic disk since the main sequence stars in NGC 7789 have not been investigated yet. The comparison with unevolved field stars may help to reveal evolutionary abundance changes in the evolved stars we investigate in this cluster.

5.1. 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, we analysed the C_2 Swan (0, 1) band head at 5635.5 Å. This feature was used in several of our previous studies of giants (Tautvaišienė et al. 2000, 2001).

The evaluation of the carbon abundance can be done by a comparison with carbon abundances determined for dwarf stars in the Galactic disk. Shi et al. (2002) performed an abundance analysis of carbon for a sample of 90 F and G type main-sequence disk stars using the C I lines and found [C/Fe] to be about solar at the solar metallicity. Gustafsson et al. (1999), using the forbidden [C I] line, made an abundance analysis of carbon for a sample of 80 late F and early G type dwarfs. As is seen from Fig. 3, the ratios of [C/Fe] and [C/O] in our stars lie by about 0.2 dex below the trends obtained for dwarf stars of the Galactic disk analysed in this study. There is no noticeable difference in carbon abundances between giant and clump stars investigated.

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

Table 3. Abundances relative to hydrogen [A/H]. The quoted errors, σ, 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.

	K415 (tip-giant)			K468 (giant)			K501 (giant)			K605 (clump)		
Species	[A/H]	σ	n	[A/H]	σ	n	[A/H]	σ	n	[A/H]	σ	n
C (C_2)	–0.22		1	–0.35		1	–0.27		1	–0.25		1
N (CN)				–0.06	0.03	65	0.00	0.02	65	0.33	0.03	65
O ([O I])	–0.23		1	–0.14		1	–0.12		1	–0.12		1
Na I	0.30		1	0.24		1	0.30		1	0.21		1
Mg I	0.17		1	0.01		1	0.23		1	0.17		1
Al I	–0.01	0.07	2	0.12	0.03	2	0.17	0.13	2	0.23	0.05	2
Si I	0.08	0.12	4	0.14	0.14	6	0.14	0.11	5	0.12	0.03	6
Ca I	–0.02	0.14	3	0.15	0.07	3	0.07	0.07	3	0.18	0.11	4
Sc II	–0.10		1	–0.09		1	–0.07		1	–0.06		1
Ti I	–0.20	0.08	5	–0.12	0.10	9	–0.07	0.10	8	0.02	0.16	14
V I	0.02	0.03	2	0.02	0.10	4	0.24	0.15	4	0.08	0.10	12
Cr I	–0.26	0.07	4	–0.13	0.07	4	–0.10	0.09	4	0.01	0.07	3
Fe I	–0.03	0.12	17	–0.08	0.10	22	–0.07	0.07	20	–0.02	0.08	24
Fe II	–0.03	0.05	2	–0.08	0.03	3	–0.07	0.04	4	–0.02	0.04	4
Co I	–0.06	0.12	3	0.19	0.12	4	0.06	0.02	3	0.02	0.05	5
Ni I	–0.10	0.16	12	–0.09	0.14	14	–0.03	0.16	14	–0.04	0.14	12
Y II	–0.10		1	0.20		1	0.20		1	0.03		1
Zr I	–0.01	0.13	3	–0.24	0.01	2	–0.21	0.10	3	–0.10	0.08	3
Ce II	–0.10		1	0.09		1	–0.02		1			
Pr II				–0.03		1	0.01		1			
Eu II	–0.18		1	0.04		1	–0.02		1	0.08		1
C/N				2.04			2.75			1.05		
$^{12}C/^{13}C$	9	±3		10	+6/–4		9	±4		10	+9/–5	

	K665 (clump)			K669 (giant)			K732 (clump)			K751 (tip-giant)		
Species	[A/H]	σ	n	[A/H]	σ	n	[A/H]	σ	n	[A/H]	σ	n
C (C_2)	–0.20		1	–0.30		1	–0.20		1	–0.22		1
N (CN)	0.24	0.03	65	0.12	0.03	65	0.22	0.03	65			
O ([O I])	–0.11		1	–0.05		1	–0.10		1	–0.16		1
Na I	0.21		1	0.09		1				0.18		1
Mg I	0.10		1	0.01		1				0.17		1
Al I	0.10	0.02	2	0.10	0.09	2	0.20	0.02	2	0.09	0.06	2
Si I	0.15	0.10	7	–0.01	0.12	7	0.09	0.09	7	0.10	0.14	5
Ca I	0.21	0.08	4	–0.01	0.16	3	0.16	0.09	3	0.11	0.06	2
Sc II	–0.16	0.03	2	–0.15		1	0.03		1	–0.04	0.01	2
Ti I	0.00	0.17	15	–0.22	0.14	8	0.07	0.14	16	–0.12	0.15	6
V I	0.11	0.09	9	–0.09	0.14	7	0.03	0.08	10	–0.15		1
Cr I	0.06	0.01	2	–0.20	0.09	5	0.02	0.03	3	–0.14	0.08	2
Fe I	0.00	0.05	19	–0.15	0.10	24	0.02	0.07	22	–0.01	0.11	18
Fe II	0.00	0.07	3	–0.15	0.02	3	0.02	0.01	3	–0.01	0.06	3
Co I	–0.10	0.12	4	0.02	0.04	5	–0.04	0.14	3	0.07	0.09	2
Ni I	0.01	0.11	9	–0.11	0.14	15	–0.10	0.12	15	–0.04	0.15	10
Y II	0.09		1	0.11		1	0.02		1	0.05		1
Zr I	0.19	0.09	2							0.10	0.13	3
Ce II	0.03		1	0.11		1				–0.02		1
Pr II							0.15		1	0.01		1
Eu II	0.10		1	–0.05		1	0.00		1	–0.20		1
C/N	1.45			1.51			1.51					
$^{12}C/^{13}C$	9	±2		11	+7/-5		7	±2		8	+6/–3	

Table 3. continued.

	K765 (giant)		
Species	[A/H]	σ	n
C (C_2)	–0.24		1
N (CN)	0.21	0.03	65
O ([OI])	–0.01		1
Na I	0.27		1
Mg I	0.23		1
Al I	0.20	0.09	2
Si I	0.10	0.06	7
Ca I	0.07	0.02	2
Sc II	0.04	0.03	2
Ti I	–0.04	0.12	12
V I	0.13	0.13	9
Cr I	–0.10	0.07	3
Fe I	–0.04	0.09	22
Fe II	–0.04	0.07	3
Co I	0.23	0.04	4
Ni I	–0.04	0.10	13
Y II	0.21		1
Zr I	–0.11	0.13	3
Ce II	0.19		1
Pr II	0.08		1
Eu II	0.06		1
C/N	1.41		
$^{12}C/^{13}C$	11	+6/–4	

Table 4. Effects on derived abundances resulting from model changes for the star K665. The table entries show the effects on the logarithmic abundances relative to hydrogen, Δ[A/H]. Note that the effects on "relative" abundances, for example [A/Fe], are often considerably smaller than abundances relative to hydrogen, [A/H].

Species	$\Delta T_{\rm eff}$ −100 K	$\Delta \log g$ +0.3	$\Delta v_{\rm t}$ +0.3 km s^{-1}
C (C_2)	0.02	0.03	0.00
N (CN)	–0.07	0.01	0.00
O ([OI])	0.01	–0.05	–0.01
Na I	–0.09	–0.08	–0.11
Mg I	–0.03	–0.03	–0.08
Al I	–0.05	–0.01	–0.05
Si I	0.02	0.04	–0.04
Ca I	–0.10	–0.01	–0.07
Sc II	0.01	0.14	–0.08
Ti I	–0.14	–0.01	–0.06
V I	–0.16	0.00	–0.06
Cr I	–0.09	–0.01	–0.09
Fe I	–0.07	0.01	–0.09
Fe II	0.08	0.15	–0.12
Co I	–0.09	0.03	–0.05
Ni I	–0.05	0.03	–0.12
Y II	–0.02	0.11	–0.29
Zr I	–0.18	0.00	–0.03
Ce II	0.00	0.13	–0.01
Pr II	–0.02	0.14	–0.01
Eu II	0.00	0.10	–0.01

Table 5. Mean cluster abundances of NGC 7789, and standard deviations.

Species	[A/H]	σ	[A/Fe]	σ
C (C_2)	–0.25	0.05	–0.21	0.03
N (CN)$^{\rm Giants}$	0.07	0.12	0.15	0.13
N (CN)$^{\rm Clump}$	0.26	0.06	0.26	0.08
O ([OI])	–0.12	0.06	–0.07	0.09
Na I	0.23	0.07	0.28	0.07
Mg I	0.13	0.09	0.18	0.07
Al I	0.13	0.07	0.18	0.08
Si I	0.10	0.05	0.14	0.05
Ca I	0.10	0.08	0.14	0.07
Sc II	–0.07	0.07	–0.02	0.07
Ti I	–0.08	0.10	–0.03	0.07
V I	0.04	0.12	0.09	0.12
Cr I	–0.09	0.11	–0.05	0.09
Fe I	–0.04	0.05		
Fe II	–0.04	0.05		
Co I	0.04	0.11	0.09	0.14
Ni I	–0.06	0.04	–0.02	0.05
Y II	0.09	0.10	0.13	0.13
Zr I	–0.05	0.16	–0.02	0.13
Ce II	0.04	0.10	0.09	0.13
Pr II	0.04	0.07	0.08	0.05
Eu II	–0.02	0.11	0.02	0.12
$^{12}C/^{13}C$	9	1		
C/N$^{\rm Giants}$	1.93	0.53		
C/N$^{\rm Clump}$	1.34	0.20		

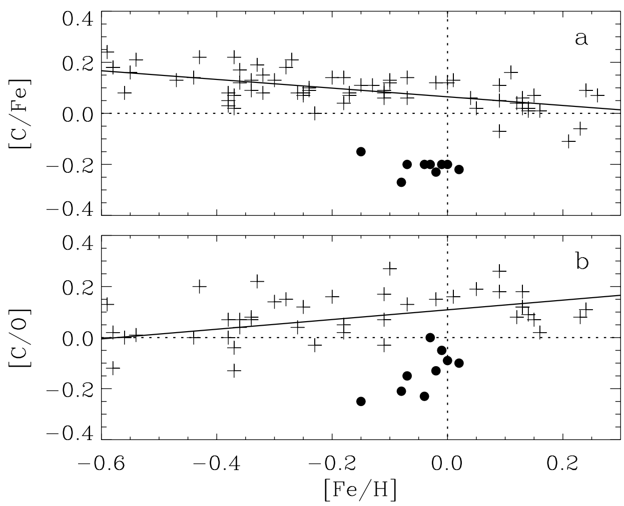

Fig. 3. [C/Fe] **a)** and [C/O] **b)** as a function of [Fe/H]. Results of this paper are indicated by filled circles, results obtained for dwarf stars of the Galactic disk (Gustafsson et al. 1999) by "plus" signs and the full line.

The wavelength interval 7980–8130 Å, with 65 CN lines selected, was analysed in order to determine the nitrogen abundances. The mean nitrogen abundance, as determined from the giants, is [N/H] = 0.07 ± 0.12 and from the clump stars [N/H] = 0.26 ± 0.06.

Determinations of nitrogen abundances in Galactic disk stars are not numerous. For metal-abundant stars, as follows from the compilation by Samland (1989), a concentration of [N/Fe] ratios with a rather large scatter lies at the Solar value in the [Fe/H] interval from +0.3 dex to about −1.0 dex. Reddy et al. (2003) investigated nitrogen abundances in a sample of 43 F–G dwarfs in the Galactic disk 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. In the work by Shi et al. (2002) [N/Fe] values in the main-sequence stars are also about solar at the solar metallicity.

Thus, in the NGC 7789 stars investigated, when compared to the Galactic field dwarf stars, the nitrogen abundances are enhanced. Also it is noticeable that the enhancement is larger in the clump stars: [N/Fe] = 0.15 ± 0.13 in the giants and [N/Fe] = 0.26 ± 0.08 in the clump stars. Consequently, the mean C/N ratios are lowered to the value of 1.93 ± 0.53 dex in the giants and to the values of 1.34 ± 0.20 dex in the clump stars. As follows from the Solar carbon and nitrogen abundances accepted in our work – $\log A_{\rm C} = 8.52$ and $\log A_{\rm N} = 7.92$ (Grevesse & Sauval 2000) – the solar C/N = 3.98.

The $^{12}C/^{13}C$ ratios were determined for all programme stars from the (2,0) $^{13}C^{14}N$ feature at 8004.728 Å with a laboratory wavelength adopted from Wyller (1966). We find that the mean $^{12}C/^{13}C$ ratios are lowered to about the same value of 9 ± 1 in the giants and clump stars investigated. Ratios of $^{12}C/^{13}C$ were investigated for seven stars in NGC 7789 by Sneden & Pilachowski (1986). They found carbon isotope ratios in the range 10–30.

The same carbon and nitrogen changes are seen in atmospheres of giant stars in the Galactic field and in clusters (cf. Weiss & Charbonnel 2004; Charbonnel 2003; Smith & Martell 2003; Gratton et al. 2000, and references therein).

5.2. 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) and references therein. However, the explanation of abundance changes by deep mixing has recently been challenged by the determination of an O–Na anticorrelation in less evolved stars down to the main sequence (Gratton et al. 2001; Thevenin et al. 2001; Ramirez & Cohen 2002).

The stars in our sample, as determined from the Na I lines at 5682.64 Å and 6154.23 Å show a slight overabundance of sodium (Fig. 4). Aluminium was investigated using Al I lines at 7835.30 Å and 7836.13 Å. [Al/Fe] values within the errors agree well with the results from the field dwarf stars (Fig. 4). The majority of other open clusters also have enhanced [Na/Fe] ratios. Looking at the correlation of [Na/Fe] ratios with the Galactocentric distances of the clusters, presented recently by Friel et al. (2003), it is interesting to notice that [Na/Fe] is larger for open clusters with smaller Galactocentric distances. The result of [Na/Fe] in NGC 7789 with $R_{\rm GC}$ = 9430 ps fits well to this correlation.

5.3. The α-elements Mg, Si, Ca and Ti

According to observations of the main sequence stars in the Galactic disk, abundance ratios of α-process elements to iron at the solar metallicity are solar or slightly higher. In the study by Edvardsson et al. (1993) [Mg/Fe], [Si/Fe] and [Ti/Fe] for almost all of the stars lie slightly above the solar ratio, [Ca/Fe] are solar (see Fig. 4). In the study of Reddy et al. (2003), [Mg/Fe] and [Si/Fe] values are above the solar, while [Ca/Fe] and [Ti/Fe] are exactly solar.

In NGC 7789, the mean cluster $[\alpha/{\rm Fe}] \equiv \frac{1}{4}([{\rm Mg/Fe}] + [{\rm Si/Fe}] + [{\rm Ca/Fe}] + [{\rm Ti/Fe}]) = 0.11 \pm 0.08$(s.d.). From the comparison of the individual elements with the Galactic disk field sample of Edvardsson et al. (1993) (Fig. 4) it can be suspected that abundances of Si and Ca are slightly higher than in the field dwarfs. The mean [α/Fe] ratios in a majority of open clusters investigated are higher than in the Sun, the overabundance of silicon is most noticeable (cf. Brown et al. 1996; Bragaglia et al. 2001; Friel et al. 2003).

5.4. Iron group an heavier elements

In the NGC 7789 stars investigated the abundances of iron group chemical elements are close to solar (Table 5) and have much less scatter around the mean values than in the work by Pilachowski (1985).

In our spectra there are not many lines for the analysis of abundances of s- and r-process elements. For the determination of the yttrium abundances we used the spectral synthesis of the Y II line at 5402 Å, the abundance of zirconium was determined using equivalent widths of Zr I lines at 6127.48, 6134.57 and 6143.18 Å, and the abundance of cerium was determined using only one line at 6043.38 Å. The analysis gave a scatter around the mean cluster abundances of these s-process dominated elements of ±0.13 dex with the mean abundances close to solar.

Two r-process-dominated chemical elements, Pr II and Eu II, were investigated in our work. The praseodymium abundance was determined using the Pr II line at 5322.71 Å and the europium abundance from the Eu II line at 6645 Å. The abundances obtained for these elements are also close to solar.

5.5. Final remarks

The change in the surface composition of a star ascending the giant branch is predicted by theoretical calculations. When a star evolves up the giant branch its convective envelope deepens and CN-cycle products are mixed to the surface of the evolving star, causing the surface $^{12}C/^{13}C$ and $^{12}C/^{14}N$ ratios

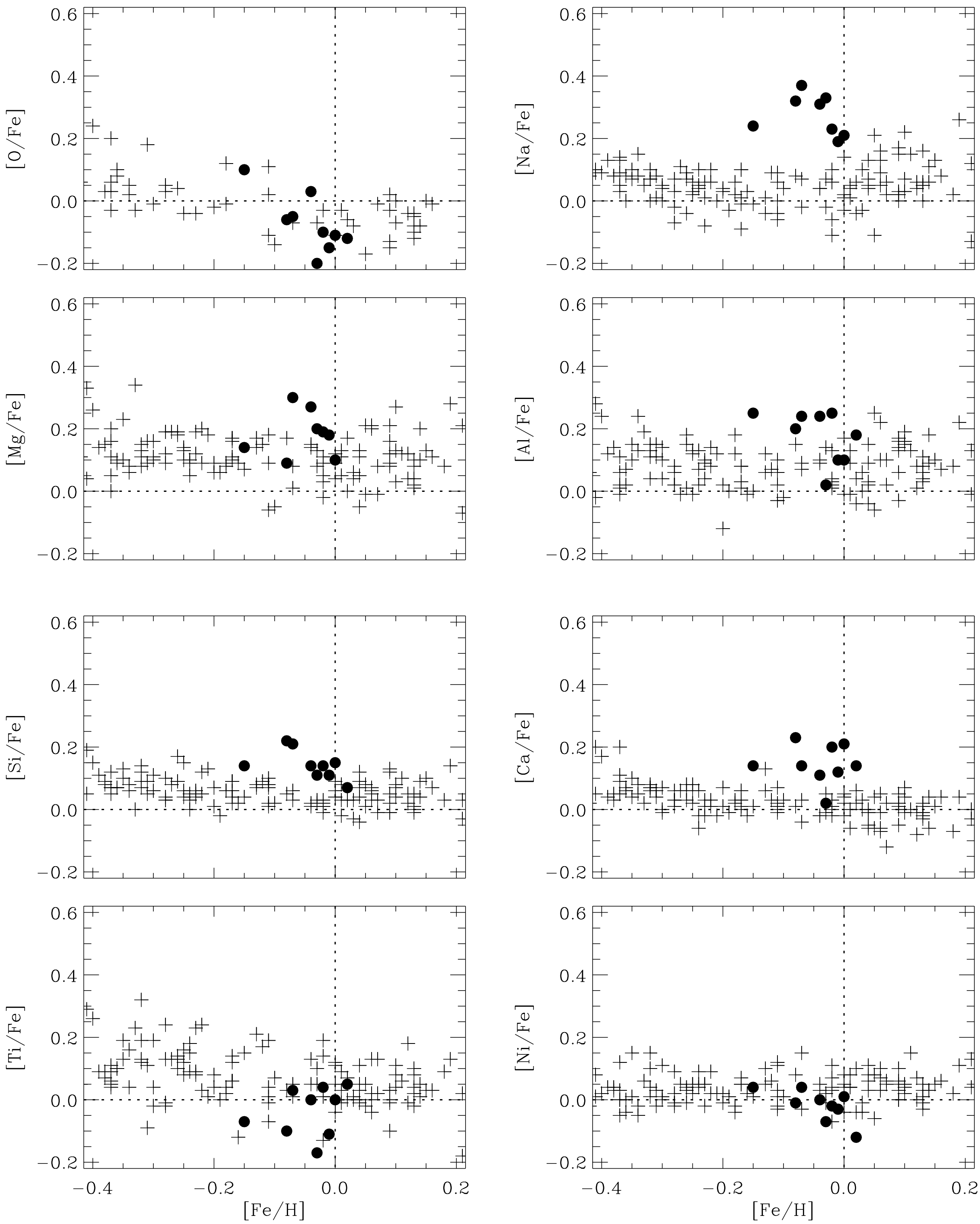

Fig. 4. Element to iron ratios as a function of iron [Fe/H]. Results of this paper are indicated by filled circles, results obtained for dwarf stars of the galactic disk (Edvardsson et al. 1993) by "plus" signs.

to drop. These ratios decrease with increasing stellar mass and decreasing metallicity. Extra-mixing processes may become efficient on the red giant branch when stars reach the so-called luminosity function bump, and may modify the surface abundances (see Charbonnel et al. 1998 for more discussion).

The first and only evidence on the evolutionary state at which this non-standard mixing actually starts and how effective it is has to come from observations. Stars of different masses and metallicities are affected by extra-mixing to a different extent (cf. Boothroyd & Sackmann 1999). In the open cluster M 67 (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 $^{12}C/^{13}C$ ratio is lowered to the value of 24 ± 4, and the $^{12}C/^{14}N$ 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. Their mean $^{12}C/^{13}C = 16 \pm 4$ and $^{12}C/^{14}N = 1.4 \pm 0.2$ agree well with predictions of extra-mixing by Boothroyd & Sackmann (1999).

In NGC 7789 we also investigate the first-ascent giants located above the red giant bump and more evolved clump stars. This provides information on chemical composition changes along the evolutionary sequence. In NGC 7789 with the mass of turn-off stars of about 1.6 $M_{\odot}$ (Faulkner & Cannon 1973), the mean $^{12}C/^{14}N$ ratios are also different, in the giants $^{12}C/^{14}N = 1.9 \pm 0.5$ and in the clump stars 1.3 ± 0.2; however, the $^{12}C/^{13}C$ ratios are very similar for all the stars investigated, 9 ± 1, and indicate a larger extra-mixing than it is foreseen by Boothroyd & Sackmann (1999) for stars of a similar turn-off mass.

Note that according to theoretical predictions of extra-mixing (Boothroyd & Sackmann 1999), changes of $^{12}C/^{14}N$ ratios in solar metallicity stars lower C/N ratios after the 1st dredge-up by not more than 0.1 dex in stars of all the masses modelled (1.00–2.25 $M_{\odot}$). However, the differences of C/N ratios in giants and clump stars of the open clusters M 67 and NGC 7789 are larger. The question of whether this disagreement is caused by observational or theoretical reasons, or perhaps by effects of helium-core-flash, still has to be answered. We hope that the results presented in this work will contribute to answering the fundamental questions of stellar evolution.

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