Astronomy & Astrophysics manuscript no. ms˙5
January 10, 2014

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arXiv:0906.4330v1 [astro-ph.GA] 23 Jun 2009

A spectroscopic study of the Open Cluster NGC 6475 (M 7)

Chemical Abundances from stars in the range T_{eff}= 4500-10000 K

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Received .....; accepted .....

ABSTRACT

Aims. Clusters of stars are key objects for the study of the dynamical and chemical evolution of the Galaxy and its neighbors. In particular chemical composition is obtained from different kinds of stars (hot main-sequence stars, cool main-sequence stars, horizontal-branch stars, RGB stars) using different methodologies. Our aim is to apply these methodologies to the stars of the Open Cluster NGC 6475. Obtaining a census of the most important elements we will be able to test their consistence. We finally want to establish more robust fundamental parameters for this cluster.
Methods. We selected high S/N high resolution spectra of 7 stars of the Open Cluster NGC 6475 from the ESO database covering the T_{eff} range 4500-10000 K and of luminosity class V (dwarf) and III (giants). We determined the chemical abundances of several elements. For hot stars (T_{eff}>9000 K) we applied the Balmer Lines fitting method to obtained atmospheric parameters. For cool stars (T_{eff}<6500 K) we used the FeI/II abundance equilibrium method. For the two groups of stars the use of different line-lists was mandatory. LTE approximation was used. For elements affected by NLTE deviation (C,N,O,Na,Mg) corrections were applied. The abundance of many elements were obtained from the measurement of the equivalent width of spectral lines. For those elements for which only blended lines were available (O, He) comparison of real spectrum with synthetic ones was used. Hyperfine structure was taken in account for V and Ba.
Results. First of all we showed that the two methodologies we used give abundances which are in agreement within the errors. This implies that no appreciable relative systematic effects are present for the derived chemical content of cool and hot stars. On the other hand giants stars show clear chemical peculiarities with respect the dwarf concerning light elements (up to Si) and maybe Ba. This fact can be explained as an evolutionary effect. Then, having a new estimation of the metallicity for the cluster ([Fe/H]=+0.03±0.02, [α/Fe]=-0.06±0.02) we fitted suitable isochrones to the CMD of the cluster obtaining the basic parameters (E(B-V)=0.08±0.02, $(m-M)_0$=7.65±0.05, Age=200±50).

Key words. Galaxy: Open Clusters and Associations:individual: NGC6475 - stars: abundances

1. Introduction

Metal abundance determination of individual stars in Galactic open clusters brings useful information on the formation and chemical evolution of a cluster itself, on the importance of mixing and rotation in the surface chemical properties of each star and, finally, allow to determine solid estimate of cluster bulk properties as distance, reddening, age and age spread. Very detailed studies are now available, like the ones on Coma Berenices (Gebran & Monier 2008), the Pleiades (Gebran et al. 2008), and Praesepe (Fossati et al. 2007, 2008), to make a few examples.
The ESO archive contains high resolution spectroscopic data of many stars in Galactic clusters which have been taken for different purposes, but that have never been fully investigated. We searched the archive and found several interesting cases, and present here a detailed analysis of individual high resolution spectra of stars in the open cluster NGC 6475. This cluster was studied before several times (Prosser et al. 1996, Fossati et al. 2007, Meynet et al. 1993, Kharchenko et al. 2005), and it turned out to have a reddening in the range 0.06-0.10 mag and a distance modulus not well constrained but in the range $(m-M)_V$=7.0-7.7 mag. Age was found to be in the range 170-220 Myr, and the metallicity is slightly super-solar ([Fe/H]=+0.14 according to Sestito et al. 2003). The cluster possesses both hot stars of spectral type around B, and evolved red giants of spectral type about K.
However a throughout chemical investigation of both cool and hot stars together has never been performed.
In this paper we describe in deep details the techniques in use to infer abundances for a variety of elements in hot and cool stars (both dwarf and evolved), giving special emphasis to the comparison of the results for elements belonging to the same group (α, iron peak or light elements). The results are then used to revise the fundamental parameters of the cluster.
The layout of this paper is as follows. In Sect. 2 we describe the observation material, **while in Sect. 3 the build-up of suitable line-lists is illustrated. In Sects. 4 and 5 we discuss the determination of atmospheric parameters for cool and hot stars respectively, and the abundance determination is analyzed in Sect. 6.** A brief re-visitation of the cluster parameters is finally given in Sect. 7, while the paper conclusions are highlighted in Sect. 8.

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Table 1. Basic parameters for the observed stars.

ID	α(h:m:s)	δ(°:′:″)	V(mag)	B-V(mag)	Sp.T.	RV_H(km/s)	$v_e$sini(km/s)	T_{eff}(K)	log(g)(dex)	v_t(km/s)
HD 162679	17:53:45.9	-34:47:29	7.16	0.03	B9V	-17.06	37	9962	3.46	0.40
HD 162817	17:54:27.1	-34:28:00	6.11	0.04	B9.5V	-15.66	65	9651	3.29	0.85
HD 162391	17:52:19.8	-34:25:00	5.85	1.10	G8III	-14.51	-	4800	1.60	1.83
HD 162587	17:53:23.5	-34:53:42	5.60	1.09	K3III	-17.18	-	4850	2.10	1.65
JJ10	17:53:54.2	-34:46:08	12.53	0.74	K0V	-14.87	-	5700	4.30	1.10
JJ22	17:53:08.9	-34:45:52	11.11	0.50	F5-G0V	-14.96	-	6300	4.05	1.25
JJ8	17:54:09.7	-34:53:13	13.30	0.87	K5V	-14.83	-	5400	4.50	0.85

2. Observations and Data Reduction

Observations of stars in the field of the open cluster NGC 6475 were carried out during August 2001 in the context of the ESO DDT Program ID 266.D-5655 (Bagnulo et al. 2003). This program had the aim of observing spectroscopically a large sample of field and cluster stars from ultraviolet (UV) to near infrared (NIR).

Observations were performed with UVES on board UT2(Kueyen) telescope in Paranal. Spectra of 32 stars candidate cluster members (selected from WEDBA database[1]) were obtained using the DIC1(346+580) and DIC2 (437+860) settings with a 0.5″ slit width. The spectra cover the wavelength range 3000-10000 Å with a mean resolution of 80000.

Data were reduced using the UVES pipeline (Ballester et al. 2000) where raw data were bias-subtracted, flat-field corrected, extracted using the average extraction method and wavelength calibrated. Sky subtraction was applied. Echelle orders were flux calibrated using the master response curve of the instrument, and an atmospheric extinction correction was applied. Finally, the orders were merged to obtain a 1D spectrum. All the reduced spectra can be downloaded from the UVES POP web interface[2].

For our purposes we selected stars having low rotation (v_R <100 km/s) allowing the measurement of equivalent width (EQW) of spectral lines.

Our choice left us with 7 members, **covering the spectral type range K5-B9 and of luminosity class V (dwarf) and III (giants).** S/N of their spectra vary from star to star and it is function of the wavelength, but it is greater than 200 in the worst case.

Membership was checked by radial velocity measurement that was obtained using the *fxcor* IRAF, which cross-correlates the observed spectrum with a template having known radial velocity. As templates we used two synthetic spectra, the former for cool stars and calculated for a typical Sun-like dwarf (T_{eff}=5777, log(g)=4.44, v_t=0.80 km/s, [Fe/H]=0.0), and the latter for hot stars and calculated for a typical A0V dwarf (T_{eff}=9500, log(g)=4.00, v_t=1.00 km/s, [Fe/H]=0.0). Spectra were calculated using the 2.73 version of SPECTRUM, the local thermodynamical equilibrium spectral synthesis program freely distributed by Richard O. Gray[3].

The error in radial velocity - derived from *fxcor* routine - is less than 1 km/s. According to the measured RV_H and to the typical velocity dispersion of Open Clusters (~1-2 km/s) all the selected stars turn out to be members. Finally, for the abundance analysis, each spectrum was shifted to rest-frame velocity and continuum-normalized.

In Table 1 we report the basic parameters of the selected stars: the identification (ID), the coordinates (α, δ), V magnitude, B-V color, Spectral Type (Sp.T.), heliocentric radial velocity (RV_H), rotational velocity for the hot stars ($v_e$sini), effective temperature T_{eff}, gravity log(g), and microturbolence velocity v_t (for determination of rotational velocity and atmospheric parameters see Sec. 4 and 5).

According to SIMBAD database[4], three of them (HD 162679, HD 162391, and HD 162587) are binaries, but no evidence of a double spectrum was found (no double peak in the cross-correlation function in the radial velocity determination). We conclude that the secondary component must have negligible influence on the spectral energy distribution, and so no effects on our spectroscopic analysis are expected.

We do not have any information on the other 4 stars, but 3 of them (JJ8, JJ10, JJ22, see Fig. 4) lie in the single star MS region, well detached from the binary sequence. In any case all of them show no evidence of a double spectrum or double peak in the cross-correlation function when the radial velocity determination was performed. Also in this case we conclude that the secondary component, if present, has negligible influence on the spectral energy distribution, and so no effects on our spectroscopic analysis are expected.

3. The line-lists

Early (Hot) and late (cool) type stars in our sample have few if not common spectral lines. For this reason we had to build two different line-lists for **the purpose of measuring their abundances**. Abundances for most of the elements can be obtained by the EQW method in both cases.

Line-list for cool stars was initially taken from Gratton et al. (2003). log(gf) parameters were then re-determined for each element by a solar-inverse analysis in order to remove the scatter in abundance with respect to the mean value. We measured the equivalent widths from the NOAO solar spectrum (Kurucz et al. 1984) by Gaussian fitting (and using a voight profile for the strongest lines) and derived the abundances using a model atmosphere for the canonical solar parameters: T_{eff}=5777 K, log(g)=4.44, v_t=0.80 km/s, logϵ(Fe)=7.50 dex.

Solar abundances we obtained from this line-list are reported in Table 2 and compared with Grevesse & Sauval (1998).

For some elements (Al and Nd) the agreement was not good ($\Delta A \geq 0.2$ dex); in this case we redetermined log(gf) values by averaging the data obtained from VALD & NIST[5] atomic parameters databases. Abundances from the new log(gf) parameters showed a better agreement ($\Delta A<0.1$ dex), and again they were adjusted by solar-inverse analysis. For N and O abundance we were forced to apply the spectral synthesis

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[1] http://www.univie.ac.at/webda/

[2] http://www.sc.eso.org/santiago/uvespop/index.html

[3] See http://www.phys.appstate.edu/spectrum/spectrum.html for more details.

[4] http://simbad.u-strasbg.fr/simbad/

[5] VALD and NIST database can be found at http://vald.astro.univie.ac.at/ and http://physics.nist.gov/PhysRefData/ASD/lines_form.html

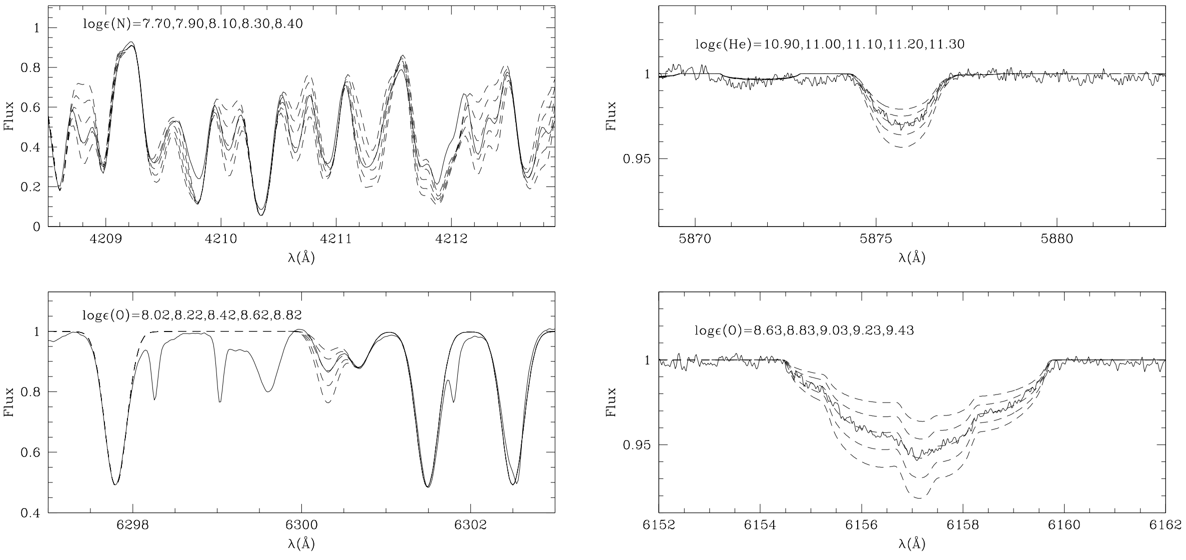

Fig. 1. Example of the spectral synthesis method used to derive N and O for cool stars (applied to #HD 162391, left panel), and He and O for hot stars (applied to #HD 162817, right panel). Continuous lines are the observed spectra, while dashed lines are synthetic spectra. Abundances used in the synthesis are indicated. For N abundace determination spectral regions of 0.4 Å width centered at 4209.8 and 4212.0 Å were rejected because of the very poor reproduction of the observed spectrum. The reason is that some lines are not identified in the solar spectrum. We tentativelly attributed these lines to Fe, which appears to be a bad choice, so we did not include the relative spectral regions in the fitting.

method because these lines are affected by severe blending with other spectral features. O abundances were obtained from the 6300 Å forbidden line, while N from CN features due to the Δv=-1 band of the violet system ($B^2\Sigma$-$X^2\Sigma$) near the band-head at 4215 Å. Line-lists for the synthesis of the O line and CN band were taken from the more complete lines compilation of SPECTRUM[6]. The list for the CN feature was calibrated on the Sun in order to match the synthetic spectrum with the NOAO one. In this case a complete calibration procedure would require also a comparison with the spectrum of a late type and well known stars (i.e. Arcturus), in order to adjust log(gf) value of those lines not present in the Sun, but affecting cooler stars such as HD 162391 and HD 162587. This is a very long process we will do in future papers. For the moment we can say that even without this adjustment the agreement between synthetic and observed spectra for HD 16391 and HD 162587 is satisfactory (see Fig. 1).

Another effect to consider is the hyperfine structure of the odd-numbered elements such as Sc, V, Co, Cu, Y and Ba. These elements possess non-zero nuclear spin, which result in considerable splitting of the lines into hyperfine components. According to McWilliam & Rich (1994), in the case of weak lines this split affects only the shape of the line and not the EQW, leaving the derived abundance un-altered. On the other hand strong lines are desaturated, increasing their EQW, whose final effect is a anomalously greater abundance for the element if no correction is applied.

For Sc, Co, Cu, and Y we considered only weak lines (EQW$\simeq$ 50 mÅ or lower according to McWilliam & Rich (1994)). For V and Ba only strong lines were available, and we derived their abundances from 6274, 6285 and 6812 Å features for V, and from 5853 and 6496 Å features for Ba respectively. In both cases spectral synthesis was applied and the hyperfine components were taken from McWilliam & Rich (1994) and McWilliam (1998). Ba lines have also isotopic components, and for the isotopic ratios we assumed the solar values as described in McWilliam (1998).

As a results of this procedure all our abundances agree with Grevesse & Sauval (1998) within 0.1 dex except for BaII for which a difference of ~0.20 dex was found (see Table 2).

Line-list for hot stars was taken from VALD (Kupka et al. 2000) database for a typical A0V solar metallicity star. Then log(gf) parameters were then re-determined by a inverse analysis measuring the equivalent widths on a reference spectrum: the Vega spectrum was chosen for this purpose. We measured EQWs on two Vega spectra, the first (4100-6800 Å wavelength range) obtained from Elodie database (Moultaka et al. 2004), and the second (3900-8800 Å wavelength range) from Takeda et al. (2007). Since Vega is a rotating star, EQWs were obtained from direct integration of spectral features. In the common wavelength range (4100-6800 Å) the measured EQWs were averaged. The atmospheric parameters for Vega were obtained in the following way. As for $T_{\rm eff}$, Vega is primary standard because both angular diameter and bolometric flux are available. From the literature we obtain the following information: f=29.83±1.20×10^{-9} W/m^2, θ=3.223±0.008 mas. Hence, we infer an effective temperature of 9640±100 K.

Since a direct estimate of Vega gravity is not available, we determined log(g) using H Balmer lines fitting. We obtained log(g)=3.97±0.05. The microturbulence velocity was obtained by minimizing the slope of the abundances obtained from FeI lines vs. EQW. We obtained v_t=1.02±0.05 km/s and logϵ(Fe)=7.02 dex. The iron content normalized to the Sun results [Fe/H]~-0.5, in agreement with previous determinations

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[6] See http://www.phys.appstate.edu/spectrum/spectrum.html and references therein.

(Qiu et al. 2001). Vega abundances we obtained are reported in Table 2 and compared with Qiu et al. (2001) and with the Sun.

Also in this case for some elements (He,O) we were forced to apply the spectral synthesis method which compares spectral features to synthetic spectra having different abundances of the studied element. In fact, spectral features of He (5875 Å) and O (6156-6158 Å) are composed by several blended lines of the element. Suitable line-lists for the synthetic spectrum calcolation were taken from VALD & NIST databases and the log(gf) values averaged.

It was not possible to derive He abundance for Vega because the target spectral line (5875 Å) was too contaminated by telluric lines.

All the analysis (both for the Sun and Vega, and for the target stars) was performed using the 2007 version of MOOG (Sneden 1973) under LTE approximation coupled with ATLAS9 model atmospheres (Kurucz 1992).

Spectral features affected by telluric contamination were rejected.

C, O, Na and Mg abundances were corrected for NLTE effects when necessary as described in the **next** Sections, while N content for Vega and the hot stars in our sample was corrected as described in Sec. 6.

4. Atmospheric Parameters for Cool stars

For cool stars (HD 162391, HD 162587, JJ10, JJ22, JJ8) the classical method for obtaining spectroscopic atmospheric parameters is to use the abundances from EQW of FeI/FeII lines. Initial estimates of the atmospheric parameter $T_{\rm eff}$ were obtained from the Sp.T. reported in Table 1 according to the relations given by Straizys & Kuriliene (1981). We then adjusted the effective temperature by removing any trend in the relation between the abundance obtained from Fe I lines and the excitation potential. At the same time, the input log(g) values were **set in order** to satisfy the ionization equilibrium of FeI and FeII until the relation:

$$\log\epsilon({\rm FeII})_{\odot} - \log\epsilon({\rm FeI})_{\odot} = \log\epsilon({\rm FeII})_{\star} - \log\epsilon({\rm FeI})_{\star}$$

was accomplished.

Finally, the microturbulence velocity was obtained by removing any slope in the relation between the abundance from FeI lines and the reduced EQW. Typical internal errors for this method and the S/N of our spectra are: $\Delta T_{\rm eff}\sim$30-40 K, Δlog(g)$\sim$0.1, $\Delta v_t\sim$0.05 km/s (see Marino et al. (2008)). Adopted values for the atmospheric parameters are reported in Table 1.

Abundances for most of the elements were obtained from EQW measurements. All the cool stars do not show evidence of rotation, and for this reason EQWs were obtained from Gaussian fitting of spectral features.

For N and O abundance we were forced to apply the spectral synthesis method as said in the previous section. See Fig.1 for an example of the synthesis for N and O applied to #HD 162391. In addition we applied the spectral synthesis method to the forbidden blended CI line at 8727 Å to complete the C abundances obtained from EQW of the other unblended C features.

CI-8727 is formed strictly in LTE mode at odd with the other features (λ=4775,5052,5380 Å), so our aim was to compare the abundances obtained from the two set of lines to evaluate possible NLTE effects. We did not find significant differences (Δ[C/H]<0.05, in agreement with Takeda & Honda 2005), and therefore we did not apply any NLTE corrections to the derived abundance for this element.

Na content was derived from the 5682-5688 and 6154-6160 Å doublets, while Mg one from 5711,6318,6319 high exitacion lines. Both Na and Mg lines are known to be affected by a not negligible amount of NLTE effect. **For this reason abundances obtained in LTE approximation have been corrected according to Gratton et al. (1999). Each line was treated separately because the amount of the correction is a function of the EQW, besides the atmospheric parameters of the star. In Table 2 and 3 we report only the mean LTE and NLTE abundances for the Sun and for our targets respectivelly.**

Unfortunately incompleted sources of NLTE correction for Al abundances are available in literature, which provides corrections for dwarf or sub-giants stars in the range K0-F5 (Baumueller & Gehren 1997 and Gehren et al. 2004). However, according to Asplund (2005) NLTE corrections for Al are important for metal poor stars ([Fe/H]<-0.5) and less important at decreasing temperature. Also gravity appears to have a (small) influence on the correction but no data are available for giant stars. Since cool stars in our sample are metal rich and the two giants (HD 162391 and HD 162587) are very cool ($T_{\rm eff}\sim$4800 K), we estimate that no NLTE corrections appear necessary for this element.

5. Atmospheric Parameters for Hot stars

Atmospheric parameters of hot stars (HD 162679, HD 162817) are routinely determined by fitting the Balmer lines of observed spectra with synthetic ones. For our analysis we used a sets of ATLAS9 model atmospheres calculated for solar metallicity (roughly the metallicity of the cluster as derived by this study). Starting from these model atmospheres we calculated spectra with Lemke's version of the LINFOR program (developed originally by Holweger, Steffen, and Steenbock at Kiel University).

To achieve the best fit, we used a routine which employs a χ^2 test. The σ necessary for the calculation of χ^2 is estimated from the noise in the continuum regions of the spectra .The fit program normalizes model spectra *and* observed spectra using the same points for the continuum definition. We used the Balmer lines H_β to H_{12} (excluding H_ϵ to avoid the CaII H line) for the fit.

The formal errors given by the routine are ΔT=10-20 K, Δlog(g)=0.005-0.01, which, according to Moehler & Sweigart (2006) are half of the true value. For this reason we assumed as internal uncertainties for our determinations of: $\Delta T_{\rm eff}$=20-40 K and Δlog(g)=0.01-0.02 dex.

Microturbulence velocity was obtained by removing any trend in the relation between abundance and reduced EQW for FeI and FeII lines and the typical internal error is 0.1 km/s, obtained as in Marino et al. (2008).

The adopted values for the atmospheric parameters are reported in Table 1.

Abundances for most of the elements were obtained from EQW measurements. The selected hot stars show clear evidence of rotation. As a consequence, we refrained to obtain EQWs from a Gaussian fitting, but used a direct integration of spectral features.

On the other hand, for some elements (He,O) we were forced to apply the spectral synthesis method as explained in Sec. 3. See

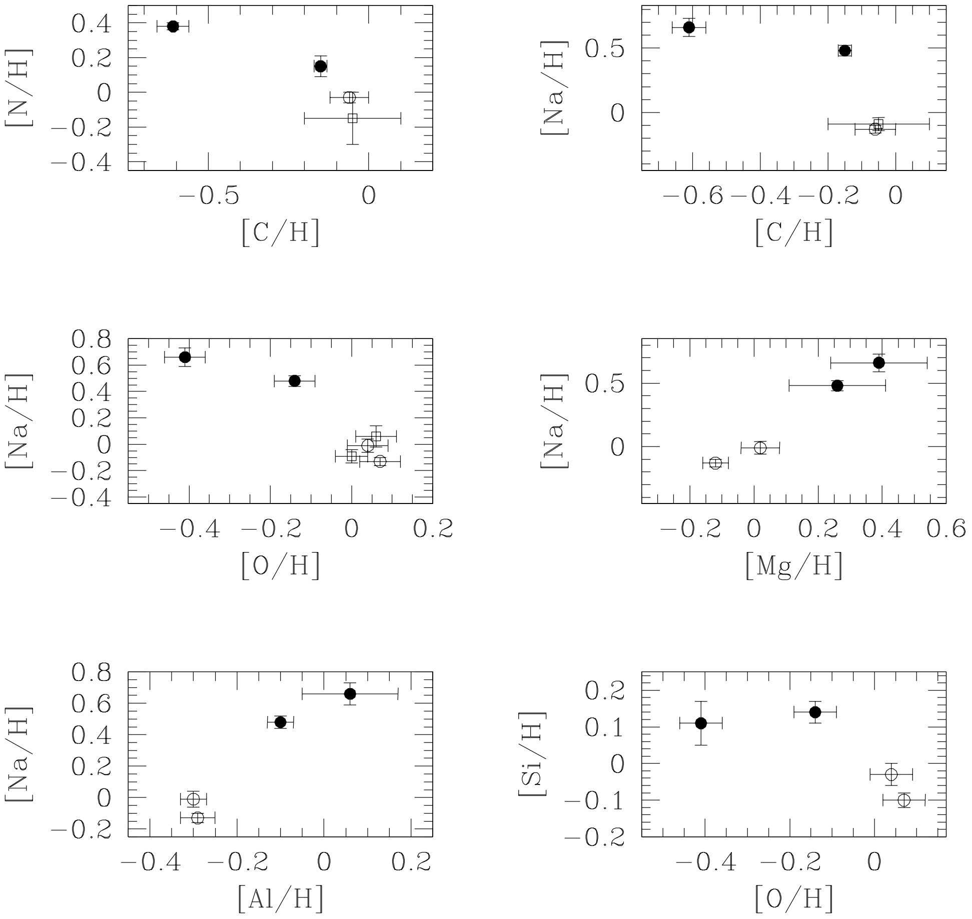

Fig. 2. The correlations N-C, Na-C, Na-O, Na-Mg, Na-Al, and Si-O for our stars. Filled circles are the giants, open ones are the cool dwarf, while open squares are the hot dwarfs.

Fig.1 for an example of the synthesis for He and O applied to #HD 162817.

From spectral synthesis we were able to measure also the projected rotational velocity of the stars (reported in Table1) by confronting the shape of the spectral lines with synthetic spectra. The typical rotational velocity error is 3-5 km/s (obtained by comparing rotational velocities from different lines).

Na abundance was derived from the 5889-5895 Å doublet, known to be affected by strong NLTE effect. NLTE correction for this element can be large (up to -0.50 dex according to Takeda et al. 2003). For hot stars in our regime a full discussion of NLTE correction for Na-double is done in Mashonkina et al. (2000). For our targets a correction of -0.30 dex is required.

Also the O triplet at 6156-6158 Å is affected by NLTE and in this case we applied corrections by Takeda (1997).

The NLTE correction for N, necessary for hot stars, is quite a disputed issue (see Takeda 1992 and Lemke & Venn 1996) and will be discussed in Sec. 6, while C abundances were corrected according to Takeda (1992).

No NLTE corrections are available in literature for He or Mg in our $T_{\rm eff}$ regime. However the Mg abundances we obtained in LTE approximation well agree with those ones obtained from cool dwarf stars, so we conclude that the NLTE correction is not necessary in this case.

For He we simply give the LTE value because any detailed NLTE treatment is beyond the purpose of the paper. However in Villanova et al. (2009) we studied a sample of hot Globular Cluster members in a $T_{\rm eff}$-log(g) regime comparable to the hot stars of the present paper. We found a He content in very good agreement with the primordial value for the Universe, which suggest that for objects cooler than 10000 K NLTE correction for He in not very important. We leave to a future paper a detailed discussion about this argument.

6. Results of the spectroscopic analysis

Chemical abundances we obtained are summarized in Table 3. Table 3 demonstrates that there is a good agreement between hot and cool dwarf stars as far as the abundances of common elements are concerned, being the mean abundances of the two groups in agreement within 0.10-0.15 dex in the worst case.

Based on this good agreement, we can conclude that HD 162679 and HD 162817 are normal A/B objects, not affected by deviation of the superficial abundances, which

Table 3. Abundances ($\log(N_{el.}/N_H)+12$) obtained for our stars. The absolute (9th column) and referred to the Sun (10th column) averaged abundances were calculated rejecting the two giant stars (see Sec. 6).

El.	HD 162679	HD 162817	HD 162391	HD 162587	JJ10	JJ22	JJ8	<logϵ(El)>	<[El./H]>
HeI	11.10±0.05	11.10±0.05	-	-	-	-	-	11.10±0.04	+0.17±0.04
CI	8.33	-	7.89±0.05	8.35±0.02	-	-	8.44±0.06	-	-
CI$_{NLTE}$	8.45	-	-	-	-	-	-	8.44±0.01	-0.06±0.01
NI	8.20	-	8.33±0.02	8.10±0.06	7.92±0.04	-	7.92±0.03	7.92±0.02	-0.03±0.02
NI$_{NLTE}$	7.80	-	-	-	-	-	-	-	-
OI	8.97±0.04	9.03±0.05	8.42±0.05	8.69±0.05	8.87±0.05	-	8.90±0.05	-	-
OI$_{NLTE}$	8.83±0.04	8.89±0.05	-	-	-	-	-	8.87±0.02	+0.04±0.02
NaI	6.53±0.05	6.68±0.08	6.84±0.07	6.73±0.04	6.38±0.05	-	6.25±0.03	-	-
NaI$_{NLTE}$	6.23±0.05	6.38±0.08	6.98±0.07	6.80±0.04	6.31±0.05	-	6.19±0.03	6.24±0.05	-0.08±0.05
MgI	7.43	7.61±0.09	7.59	7.60	7.54±0.06	7.45±0.03	7.43±0.04	-	-
MgI$_{NLTE}$	-	-	7.95	7.82	7.58±0.06	7.56±0.03	7.44±0.04	7.53±0.04	-0.03±0.04
AlI	-	-	6.49±0.11	6.33±0.03	6.13±0.03	-	6.14±0.04	6.13±0.01	-0.30±0.01
SiI	-	-	7.72±0.06	7.75±0.03	7.58±0.03	7.52±0.04	7.51±0.02	7.53±0.02	-0.08±0.02
CaI	-	-	6.40±0.10	6.41±0.06	6.44±0.04	6.39±0.05	6.35±0.04	6.40±0.01	+0.01±0.01
ScII	-	3.02	-	-	3.05±0.04	3.04±0.05	3.07±0.06	3.05±0.01	-0.07±0.01
TiI	-	-	4.91±0.05	4.98±0.03	4.90±0.03	4.92±0.05	4.96±0.02	4.95±0.02	+0.01±0.02
TiII	4.87±0.04	4.95±0.04	4.99±0.03	4.93±0.04	4.89±0.02	4.87±0.04	4.91±0.05	4.91±0.02	-0.05±0.02
VI	-	-	3.83±0.01	3.96±0.01	3.92±0.02	-	4.03±0.01	3.94±0.04	-0.06±0.04
CrI	-	-	5.68±0.06	5.72±0.03	5.69±0.02	5.74±0.05	5.65±0.02	5.68±0.02	+0.05±0.02
CrII	5.72±0.05	5.82±0.07	5.72±0.11	5.81±0.06	5.69±0.04	5.66±0.04	5.59±0.02	5.65±0.04	-0.02±0.04
FeI	7.46±0.08	7.55±0.05	7.52±0.01	7.56±0.01	7.54±0.01	7.51±0.01	7.47±0.05	7.53±0.02	+0.03±0.02
FeII	7.47±0.03	7.62±0.03	-	-	-	-	-	7.54±0.07	+0.03±0.07
CoI	-	-	4.87±0.06	4.95±0.06	4.74±0.03	-	4.79±0.02	4.79±0.05	-0.06±0.05
NiI	-	-	6.28±0.04	6.29±0.02	6.21±0.02	6.25±0.02	6.19±0.01	6.22±0.02	-0.06±0.02
CuI	-	-	-	-	3.98	-	4.06±0.05	4.05±0.05	-0.14±0.05
ZnI	-	-	4.63	4.48	4.46±0.02	-	4.48	4.46±0.05	-0.15±0.05
YII	-	-	-	2.40	2.27±0.03	-	2.36±0.05	2.30±0.05	+0.06±0.05
BaII	-	-	2.60±0.05	2.65±0.02	2.46±0.01	-	2.42±0.01	2.44±0.02	+0.13±0.02
LaII	-	-	-	-	-	-	1.39	1.39	+0.13
CeII	-	-	-	1.59	-	-	1.72±0.04	1.71±0.04	+0.18±0.04
NdII	-	-	-	-	-	-	1.95	1.95	+0.31

affects peculiar (Ap/Bp) stars. This results agrees with Folsom et al. (2007), where authors find a normal solar chemical composition, within the errors, for HD 162817. On the other hand Folsom et al. (2007) showed that the other NGC 6475 A/B stars in their sample have peculiar composition and present a huge variation of solar scaled abundances of many elements (from C up to Ba) with respect the mean chemical content of the cluster as traced by cool dwarf or giant stars. This variation can reach the value of ±2.0 dex, depending on the element. Our variation, if present, is lower than 0.10-0.15 dex for all the element we studied. Because of this we confirm that HD 162679 and HD 162817 do not present surface abundance peculiarities of Ap/Bp stars. This result can be easly explained by the high rotation of HD 162679 and HD 162817 ($v_e$sini>35 km/s), which, according to Hempel & Holweger (2003), mixes the stellar envelope inhibiting diffusion processes which cause chemical anomalies.

Based on this fact we can affirm also that no appreciable differential systematic errors affect the two methods used for abundance analysis, which was one of the main aims of this paper. In any case differential systematic errors, if present, are lower than 0.10-0.15 dex for all the chemical abundance we determined..

About the consistence of our atmospheric parameters for hot stars, Folsom et al. (2007) find for HD 162817 a larger temperature (~300 K) and gravity (~0.1 dex), however in agreement with our values within 1σ. Only rotational velocity is out of the 3σ limits. This is not critical for our results, except in the case of He and O abuncances, where spectral synthesis was used. However Fig. 1 shows that the adopted $v_e$sini value well reproduces the observed spectrum.

A second interesting result concerns light elements (from C to Si), that show clear trends (as we can see in Fig. 2) defined by the abundances of the two giant (filled circles). Those stars turned out to be more C/O-poor and N/Na-rich with respect to the dwarfs (open circles and squares).

These trends or correlations are similar to those found for Globular Clusters (GC), where they seem to be primordial and due to the different composition of the interstellar medium from which stars of different ages were formed (see Gratton et al. 2004 for extensive references) with C/O-poor and N/Na-rich stars representing the younger generation.

In our case trends are fully explained as an evolutionary effect due to the migration of light elements produced by the H-burning cycle from deeper regions up to the photosphere after stars have left the MS.

However the two phenomena can be correlated, because in Globular Clusters the younger generation of C/O-poor and N/Na-rich stars is thought to be born from material polluted by ejecta of the young massive stars belonging to the older generation. The favorite classes of candidate polluters are three: fast-rotating massive main-sequence stars (Decressin et al. 2007), intermediate-mass AGB stars (D'Antona et al. 2002), and primordial population III stars (Choi & Yi 2007).

In these stars the original superficial abundance of light elements is altered by mixing phenomena concerning products of the H-burning process at high temperature (Langer et al. 1993,

Table 2. Abundances for the Sun and Vega as obtained from the line lists used in this work. Abundances for the Sun are compared with Grevesse & Sauval (1998) (Sun$_{\rm GS98}$), those for Vega with Qiu et al. (2001) (Vega$_{\rm Qi01}$). For some elements (C, N, O, Na, & Mg) NLTE correction were applied and both LTE and NLTE abundances reported. For V and Ba we took into account the hyperfine structure affecting their lines.

El.	Sun	Sun$_{\rm GS98}$	Vega	Vega$_{\rm Qi01}$
HeI	-	10.93	-	-
CI	8.50	8.52	8.52	8.46
CI$_{\rm NLTE}$	-	-	8.57	-
NI	7.95	7.92	7.98	8.00
NI$_{\rm NLTE}$	-	-	7.58	-
OI	8.83	8.83	8.82	9.01
OI$_{\rm NLTE}$	-	-	8.74	-
NaI	6.37	6.33	6.63	6.45
NaI$_{\rm NLTE}$	6.32	6.33	6.33	-
MgI	7.54	7.58	7.14	6.81
MgI$_{\rm NLTE}$	7.56	7.58	-	-
AlI	6.43	6.47	-	-
SiI	7.61	7.55	-	-
CaI	6.39	6.36	5.65	5.41
ScII	3.12	3.17	2.56	2.33
TiI	4.94	5.02	-	-
TiII	4.96	5.02	4.52	4.58
VI$_{\rm Hyp}$	4.00	4.00	-	-
CrI	5.63	5.67	-	-
CrII	5.67	5.67	5.20	5.19
FeI	7.50	7.50	7.03	6.94
FeII	7.51	7.50	7.01	6.93
CoI	4.85	4.92	-	-
NiI	6.28	6.25	-	-
CuI	4.19	4.21	-	-
ZnI	4.61	4.60	-	-
YII	2.24	2.24	-	-
BaII$_{\rm Hyp}$	2.34	2.13	1.85	0.81
LaII	1.26	1.17	-	-
CeII	1.53	1.58	-	-
NdII	1.59	1.50	-	-

Prantzos et al. 2007) like C,N,O, and Na, as is the case of giant stars studied in this paper.

In this picture evolved stars in NGC 6475 could simply be the present day version of those AGB intermediate-mass polluter stars present during the first millions of years of a GC lifetime that caused the correlation we see nowaday, and that are now disappeared.

According to Table 3 giants present also a overabundance of Ba of $\sim$0.2 dex with respect the dwarf, but this is more difficul to interpretate for us also if some evolutionary mixing phenomenon cannot be ruled out.

The last two columns of Table 3 report the 'absolute' and 'refered to the Sun' averaged abundances of the cluster as obtained from from out 7 stars. Light element **and Ba** values were calculated rejecting the two giant stars. **Also N abundance of #HD 162679 was rejected in the calculation of the mean N content because no *a priori* NLTE correction could be applied (see the following discussion).**

Averaged abundances were calculated using the weighted mean, where the weight w is obtained from the abundance error σ as w=σ^{-2}. For some elements we could not obtain the error, and we simply assumed σ=0.15, which is our upper limits for the error on abundance when a single line is used.

Error on the mean abundance is the r.m.s. divided by the root square of the number of stars used for the calculation, except for N and He, were this procedure gives unreliably low errors. For those elements error on the mean was assumed to be the mean error on the single star, divided by the root square of the number of stars.

Metallicity of the cluster turns of to be solar or almost solar for most of the elements, especially for iron peak and α (C,O,Mg,Si,Ca,Ti). In particular the cluster has:

$$[\mathrm{Fe/H}] = +0.03 \pm 0.02\ \mathrm{dex},\ \ [\alpha/\mathrm{Fe}] = -0.06 \pm 0.02\ \mathrm{dex}$$

In spite of this some elements deviate considerably from the solar composition. He turns out to be supersolar by 0.17 dex. This translates in:

$$\mathrm{Y} = 0.33 \pm 0.02$$

We underline the fact that He was determined in LTE approximation, as discussed before.

Al turns out to be strongly subsolar ($\sim$-0.3 dex). Cu and Zn result under-abundant by about -0.15 dex, while La,Ce, and Nd are over-abundant. Finally s-process elements Y and Ba show **a overabundance of $\sim$0.1 dex**. The chemical content of the cluster with respect of the Sun is plotted in Fig. 3.

Some additional discussion is needed for N abundance of the stars HD 162679. For Vega (that has similar parameters as HD 162679) Takeda (1992) and Lemke & Venn (1996) reports two different values for the NLTE correction: the former gives -0.8 dex, while the later -0.4 dex. Comparing N abundance of HD 162679 with the mean of the dwarf stars (JJ8 and JJ10) we see that a correction of $\sim$-0.3 dex is required to match the two values. We conclude that our data suggest that the right NLTE correction is the one by Lemke & Venn (1996). So we applied this value to our data, both to HD 162679 and to Vega.

Finally, we want to compare our results with Sestito et al. (2003), which determined cluster metallicity from a sample of 30 dwarfs. They give a value of +0.14±0.06 for iron content. The agreement with our results is within 1.5 σ. We attribute this difference to the used methods. Sestito et al. (2003) obtain temperature and microturbulence from photometry using previously calibrated colour-T$_{\rm eff}$ and v$_{\rm t}$-T$_{\rm eff}$-log(g) relations. At odd with that, our T$_{\rm eff}$ and v$_{\rm t}$ values were obtained directly from spectra. Therefore it is not surprising that the two results do not perfectly agree.

7. NGC 6475 basic parameters revisited

Basing on the detailed chemical analysis detailed in the previous Sections, we revise here the cluster fundamental parameter using the Padova suite (Girardi et al. 2000) of stellar models and isochrones. Previous determinations of cluster properties are described in Meynet et al. (1993) and Kharchenko et al. (2005). They derive a logarithmic age of 8.35-8.22 respectivelly, which is compatible with the distance of 280±26 pc determined by Robichon et al. (1999).

The cluster metallicity is basically solar, and therefore adopting Z = 0.019 seems quite an adequate compromise, provided that the amount of $\alpha-$element under-abundance is almost negligible within the errors. The procedure is highlighted in Fig. 4, where photometric data taken from Prosser et al. (1996) are compared

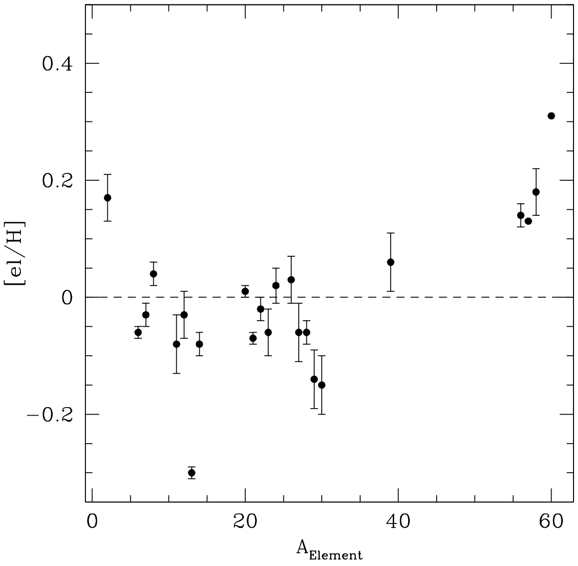

Fig. 3. Abundances of the cluster with respect of the Sun.

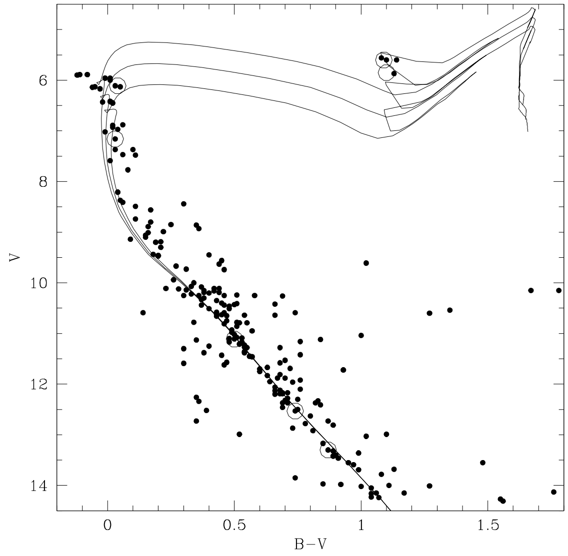

Fig. 4. CMD of NGC 6475. Isochrones of 150, 200, and 250 Myr are plotted. Open circles indicate stars analyzed spectroscopically and confirmed to be cluster members.

with three solar metallicity isochrones for ages of 150, 200, and 250 Myr.

In general the fit is good, especially for the Main Sequence. For Turn-off and Red-clump regions (were the cluster population is not well defined) the fit is not well constrained and stars seems to cover a age range between 150 (**giants**) and 200-250 Myr (**TO stars**). **A reason for this mismatch could be that giant stars do not have the same superficial abundance with respect the dwarf due to evolutionary phenomena, which are not considered in the isochrones**. The age we derive is therefore 200±50 Myr.

The fit has been obtained shifting the isochrones by E(B-V)=0.08, and $(m\text{-}M)_V$=7.65. A reddening of 0.08 mag is confirmed also by the two-colors diagram (U-B vs. B-V, not reported here), where the few blue stars having UBV magnitudes are well fitted by the ZAMS obtained from Padova isochrones shifted by the previously reported reddening. This value lies in the middle of the range given by literature (0.06-0.10 mag).

Basing on a visual inspection, we estimate errors of 0.02 and 0.05 mag. on reddening and apparent distance modulus, respectively. We infer a distance of 300±10 pc, in agreement with previous estimates and which is the value also reported in WEBDA. We underline the fact that reddening and distance of the cluster are very well constrained by our study, mainly because we could confirm the former parameter obtained by the isochrone fitting by the two-colors diagram. On the other hand age is not well determined because the Turn-Off and Red-Clump regions of the cluster are not well defined.

8. Conclusions

We studied a sample of stars belonging to the Open Cluster NGC 6475 (M7) covering a wide range in temperature (4500-13000 K) **and gravities (both dwarf and giants)**. Spectroscopic data were obtained from the UVES POP database, while photometric ones from WEBDA database.

Our aim was to determine abundances of a wide range of elements (from He to Nd) in different kinds of objects, which require different methodologies of analysis. Parameters (T_{eff} and log(g)) for cool MS and Giant stars were obtained by the FeI/II abundance equilibrium method, while for hot MS stars they were determined from the shape of H Balmer lines. For the two group of objects two sets of line-lists were used, calibrated on the Sun and Vega respectively. Abundances were obtained in LTE aproximation, but for several elements (C,N,O,Na,Mg) NLTE correction from literature was applied and hyperfine structure was considered for Vanadium **and Barium**.

Abundances of common elements in hot and cool MS stars agree very well (within 0.1 dex), allowing to conclude that the methods used for the two kind of objects are not affected by appreciable relative systematic errors.

On the other hand abundances for the two giants stars do not agree with the ones obtained for MS as far as light elements and Ba are concerned. This is an indication of an evolutionary effect which changes the photospherical chemical composition when stars leave the MS. These stars could be the present day version of those massive polluters present during the first millions of years of a GC lifetime, that altered the chemical composition of the intracluster medium from which they formed as discussed in Sec. 6. This contamination is visible nowaday in the Na-O anticorrelation found to affect almost all GCs.

The Cluster turns out to have solar composition ([Fe/H]=+0.03,[α/Fe]=-0.06) within ±0.1 dex for most of the elements. A overabundance was found for He and heavy elements (Ba,La,Ce,Nd), while a strong underabundance was found for Al.

Finally the Cluster parameters were revised. We obtained E(B-V)=0.08, $(m\text{-}M)_V$=7.65, and a age of about 200 Myr.

Acknowledgements. This study made use of ESO, SIMBAD and WEBDA databases.

References

Asplund, M. 2005, ARA&A, 43, 481
Bagnulo, S., Jehin, E., Ledoux, C., et al. 2003, The Messenger, 114, 10
Ballester, P., Modigliani, A., Boitquin, O., & The ESO Paranal Science Operations Team. 2000, ESO Messenger, 101, 31
Baumueller, D. & Gehren, T. 1997, A&A, 325, 1088

Choi, E. & Yi, S. K. 2007, MNRAS, 375, L1

D'Antona, F., Caloi, V., Montalbán, J., Ventura, P., & Gratton, R. 2002, A&A, 395, 69

Decressin, T., Meynet, G., Charbonnel, C., Prantzos, N., & Ekström, S. 2007, A&A, 464, 1029

Folsom, C. P., Wade, G. A., Bagnulo, S., & Landstreet, J. D. 2007, MNRAS, 376, 361

Fossati, L., Bagnulo, S., Landstreet, J., et al. 2008, A&A, 483, 891

Fossati, L., Bagnulo, S., Monier, R., et al. 2007, A&A, 476, 911

Gebran, M. & Monier, R. 2008, A&A, 483, 567

Gebran, M., Monier, R., & Richard, O. 2008, A&A, 479, 189

Gehren, T., Liang, Y. C., Shi, J. R., Zhang, H. W., & Zhao, G. 2004, A&A, 413, 1045

Girardi, L., Bressan, A., Bertelli, G., & Chiosi, C. 2000, A&AS, 141, 371

Gratton, R., Sneden, C., & Carretta, E. 2004, ARA&A, 42, 385

Gratton, R. G., Carretta, E., Claudi, R., Lucatello, S., & Barbieri, M. 2003, A&A, 404, 187

Gratton, R. G., Carretta, E., Eriksson, K., & Gustafsson, B. 1999, A&A, 350, 955

Grevesse, N. & Sauval, A. J. 1998, Space Science Reviews, 85, 161

Hempel, M. & Holweger, H. 2003, A&A, 408, 1065

Kharchenko, N. V., Piskunov, A. E., Röser, S., Schilbach, E., & Scholz, R.-D. 2005, A&A, 438, 1163

Kupka, F. G., Ryabchikova, T. A., Piskunov, N. E., Stempels, H. C., & Weiss, W. W. 2000, Baltic Astronomy, 9, 590

Kurucz, R. L. 1992, in IAU Symposium, Vol. 149, The Stellar Populations of Galaxies, ed. B. Barbuy & A. Renzini, 225–+

Kurucz, R. L., Furenlid, I., Brault, J., & Testerman, L. 1984, Solar flux atlas from 296 to 1300 nm (National Solar Observatory Atlas, Sunspot, New Mexico: National Solar Observatory, 1984)

Langer, G. E., Hoffman, R., & Sneden, C. 1993, PASP, 105, 301

Lemke, M. & Venn, K. A. 1996, A&A, 309, 558

Marino, A. F., Villanova, S., Piotto, G., et al. 2008, A&A, 490, 625

Mashonkina, L. I., Shimanskiĭ, V. V., & Sakhibullin, N. A. 2000, Astronomy Reports, 44, 790

McWilliam, A. 1998, AJ, 115, 1640

McWilliam, A. & Rich, R. M. 1994, ApJS, 91, 749

Meynet, G., Mermilliod, J.-C., & Maeder, A. 1993, A&AS, 98, 477

Moehler, S. & Sweigart, A. V. 2006, A&A, 455, 943

Moultaka, J., Ilovaisky, S. A., Prugniel, P., & Soubiran, C. 2004, PASP, 116, 693

Prantzos, N., Charbonnel, C., & Iliadis, C. 2007, A&A, 470, 179

Prosser, C. F., Randich, S., & Stauffer, J. R. 1996, AJ, 112, 649

Qiu, H. M., Zhao, G., Chen, Y. Q., & Li, Z. W. 2001, ApJ, 548, 953

Robichon, N., Arenou, F., Mermilliod, J.-C., & Turon, C. 1999, A&A, 345, 471

Sestito, P., Randich, S., Mermilliod, J.-C., & Pallavicini, R. 2003, A&A, 407, 289

Sneden, C. 1973, ApJ, 184, 839

Straizys, V. & Kuriliene, G. 1981, Ap&SS, 80, 353

Takeda, Y. 1992, PASJ, 44, 649

Takeda, Y. 1997, PASJ, 49, 471

Takeda, Y. & Honda, S. 2005, PASJ, 57, 65

Takeda, Y., Kawanomoto, S., & Ohishi, N. 2007, PASJ, 59, 245

Takeda, Y., Zhao, G., Takada-Hidai, M., et al. 2003, Chinese Journal of Astronomy and Astrophysics, 3, 316

Villanova, S., Piotto, G., & Gratton, R. G. 2009, ArXiv e-prints