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CHEMICAL ABUNDANCES OF A-TYPE DWARFS IN THE YOUNG OPEN CLUSTER M6

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Abstract. Elemental abundance analysis of five members in the open cluster M6 (age ~90 myr) were performed using FLAMES-GIRAFFE spectrograph mounted on 8-meter class VLT telescopes. The abundances of 14 chemical elements were derived. Johnson and Geneva photometric systems, hydrogen line profile fittings, and ionization equilibrium were used to derive the atmospheric parameters of the stars. Synthetic spectra were compared to the observed spectra to derive chemical abundances. The abundance analysis of these five members shows that these stars have an enhancement (or solar composition) of metals in general, with some exceptions. C, O, Ca, Sc, Ni, Y, and Ba exhibit the largest star-to-star abundance variations.

Keywords: stars: abundances - stars: chemically peculiar - open clusters and associations: individual: M6

1 Introduction

Stars members of an open cluster are generally assumed to share common properties: same initial chemical composition, same age and same distance. Thus open clusters appear to be unique laboratories to constrain evolutionary models via abundance determinations. Especially, early type main sequence members of open clusters of different ages are excellent laboratories to study the competition between radiative diffusion and mixing mechanisms. Abundance analysis of the open clusters (or moving groups) Ursa Major, Pleiades, Coma Berenices, Praesepe, Hyades, NGC 5460 were performed by Monier (2005), Gebran & Monier (2008), Gebran et al. (2008), Gebran et al. (2010), Fossati et al. (2011).

M6 (=NGC 6405) is an open cluster located about 450-500 pc (e.g. Talbert 1965; Vleeming 1974; Paunzen et al. 2006) away in the constellation Scorpio. The first photometric study of M6, including numbering system of the cluster, was performed by Rohlfs et al. (1959). Various ages between 50 and 140 myr were derived by several authors for M6 (e.g. Vleeming 1974; North & Cramer 1981; Paunzen et al. 2006; Landstreet et al. 2007). We averaged these ages and adopted 90 ± 30 myr. M6 is a rich, young, and relatively close cluster. Thus, its brightness allows us to obtain good quality spectra of many members.

2 Observations

The 104 possible member stars have been observed using FLAMES-GIRAFFE spectrograph with MEDUSA fibers, mounted at UT2 (Kueyen), the 8 meter class VLT telescope in May and June, 2007 (Fossati et al. 2008). The spectral regions cover three wavelength intervals: 4500-5100 Å, 5140-5350 Å, and 5590-5840 Å at resolving powers of about 7500, 25900, 24200, respectively. Some of the spectra have very low signal-to-noise ratio which prevent us from performing a detailed abundance analysis. Only 42 members have Geneva seven-color photometric measurements that can be used to derive fundamental parameters. The cluster members are identified according to Rohlfs et al. (1959) classification.

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3 Effective Temperatures and Surface Gravities

3.1 Johnson UBV and Geneva Seven-Colour photometric systems

We mainly used Geneva seven-colour photometry to derive atmospheric parameters. Johnson UBV observations were used to estimate effective temperature only for the stars lacking Geneva photometry. The photometric data was retrieved from the WEBDA database. We adopted the colour excesses of E(B-V) = 0.15 ± 0.01 and E(B2-V1)=0.13 ± 0.01 for Johnson UBV and Geneva seven-colour photometric systems, respectively (e.g. Vleeming 1974; Nicolet 1981; Ahumada & Lapasset 1995). The calibrations of Kunzli et al. (1997), and Popper (1980) were used during the calculations for Geneva and Johnson systems, respectively.

3.2 Balmer Lines

The Balmer lines of hydrogen are reliable diagnostics for atmospheric parameters. The Balmer profiles are sensitive to both effective temperature and surface gravity variations. At higher temperatures, hydrogen lines are more sensitive to surface gravity variations.

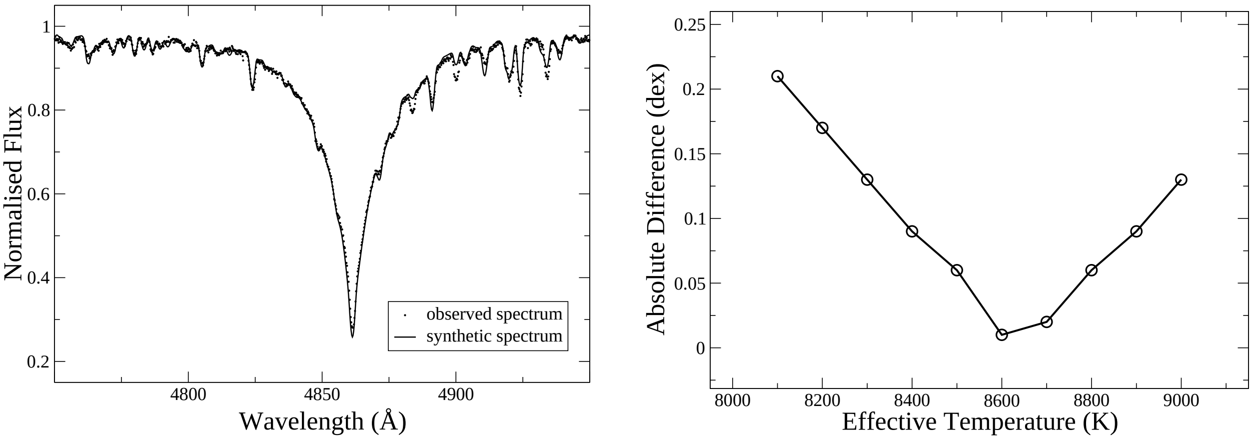

Fig. 1. Left: Comparison of the observed spectrum of NGC 6405 53 and the synthetic spectrum computed for $T_{\rm eff}$ = 8100 K, log g = 3.65, and solar abundances. **Right:** Effective temperature versus absolute difference between the iron abundances (with respect to the Sun) derived by using Fe I and Fe II lines for NGC 6405 53.

In order to derive atmospheric parameters, we compared synthetic H_β profiles computed by SYNSPEC48 (Hubeny & Lanz 1992) to the observed H_β lines (Fig. 1, left). The H_β profiles of the analyzed early type stars appear to be narrower than those computed for the atmospheric parameters derived from the Geneva seven-colour photometry. This suggests that the actual surface gravities of these stars should be lower than those derived from Geneva photometry.

3.3 Ionisation Equilibrium

The hydrogen Balmer lines do not suffice to derive effective temperature and surface gravity simultaneously. In order to obtain these parameters precisely, we used ionization equilibrium of iron lines. We plotted the variation of the absolute value of $[\mathrm{Fe/H}]_{\text{from Fe I lines}}$ - $[\mathrm{Fe/H}]_{\text{from Fe II lines}}$ as a function of effective temperature (Fig. 1, right).

As can be seen from Fig. 1, right for NGC 6405 53, the minimum of the curve shows that the effective temperature is close to 8650 K. This temperature is higher than the temperature derived from Balmer H_β lines (8100 K), while it is closer to the photometric temperature of 8380 K. The error of $T_{\rm eff}$ can be adopted as 150 K from Fig. 1, right.

4 Microturbulent Velocity

Microturbulent velocities should be derived as precisely as possible to derive reliable chemical abundances. In order to obtain this parameter, we used two methods. We first estimated the microturbulent velocity using

Pace et al. (2006)'s following calibration:

$$V_{\rm mic} = -4.7 \log(T_{\rm eff}) + 20.9 \text{ km s}^{-1}$$

Then, we plotted the standard deviations of the iron abundance calculated from many iron lines, according to various microturbulent velocity around that estimated value (Fig. 2, left). The minima in these plots yield the most likely microturbulent velocity. The shapes of the minima also indicate the accuracy of the microturbulent velocity. A sharp minimum provides a more precise value. The microturbulent velocities calculated by using this spectral method are consistent with those calculated from the calibration of Pace et al. (2006) in many cases.

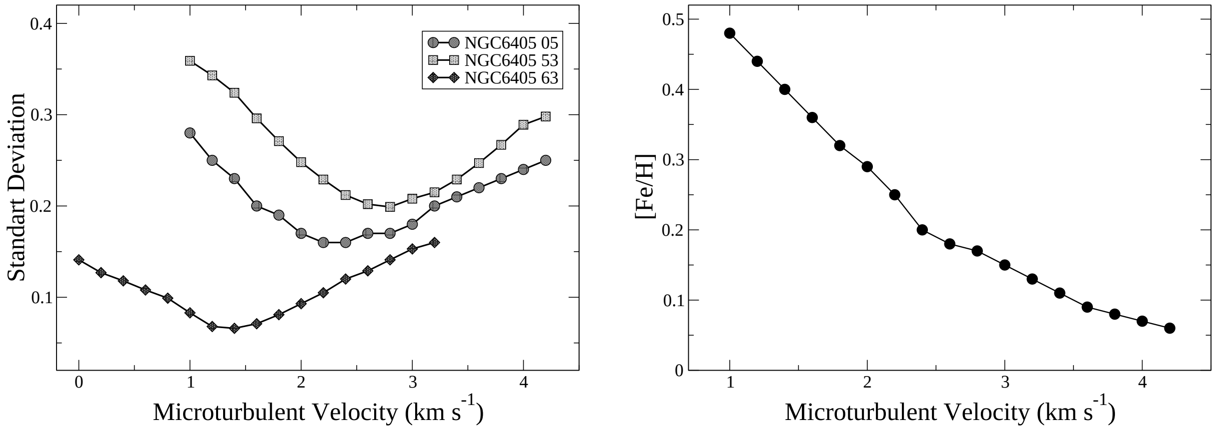

Fig. 2. Left: The standard deviation of the iron abundance derived from Fe I and Fe II lines versus microturbulent velocity for the three stars of the cluster. The standard deviations given for NGC 6405 53 were shifted by +0.05 for display purpose only. **Right:** Effective temperature versus absolute difference between the iron abundances (with respect to the Sun) derived by using Fe I and Fe II lines for NGC 6405 53.

In order to test the effects of microturbulence on the derived abundances, we performed the abundance analysis of unblended iron lines for assumed $v_{\rm mic}$ varying around the estimated value, in steps of 0.2 km s^{-1} for NGC 6405 05 (Fig. 2, right). A change of 0.2 km s^{-1} in microturbulence corresponds to an abundance change between 0.02-0.05 dex for this star.

5 Abundance Analysis

In order to perform the abundance analysis, we used model atmospheres and synthetic spectra. Model atmospheres were calculated by using ATLAS9 (Kurucz 1979), assuming a plane parallel geometry, a gas in hydrostatic and radiative equilibrium and LTE. During the computations, we used prescriptions of Smalley (2004) for the mixing length ratio. The atomic data was firstly constructed from Kurucz's gfhyperall.dat*, and then updated by using VALD, NIST databases and recent publications. Hyperfine structure was taken into account. Synthetic spectra are computed by using SYNSPEC48, assuming Grevesse & Sauval (1998) solar chemical composition.

6 Results and Discussion

Temperatures of 9100, 9400, 8650, 9400, 9900 K were adopted for the stars numbered 05, 47, 53, 71, and 95. Log g values are close to the value of 4.1, except no. 53 having lower value (3.65). We derived the abundances of 14 elements for the five members of M6 (Fig. 3). C, O and Ca abundances are close to solar or often slightly underabundant. All stars exhibit Sc deficiency, while Mg, Cr and Ni appear to be overabundant for the stars nos. 05, 47 and 53. Fe abundances are slightly scattered around the solar iron abundance. The largest star-to-star variations occur for the elements of C, O, Ca, Sc, Ni, Y and Ba.

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[*] `http://kurucz.harvard.edu/LINELISTS.html`.

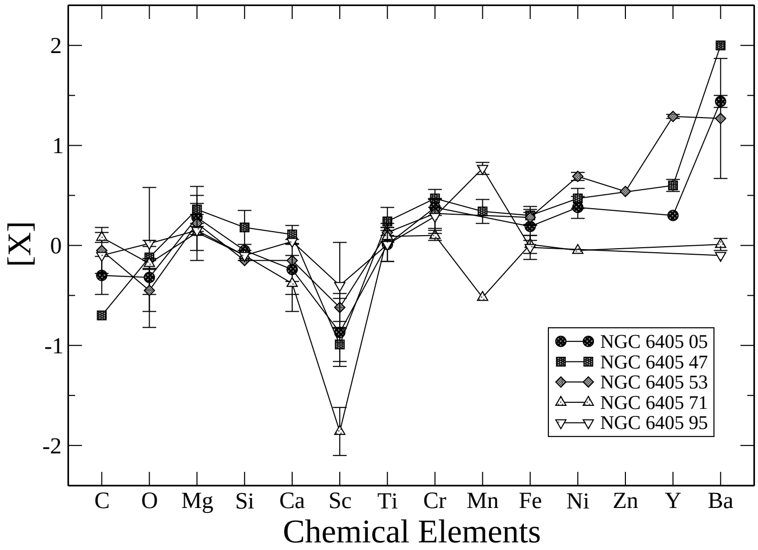

Fig. 3. The derived abundances of the elements with respect to the Sun for the five members of the cluster.

The abundances of the elements heavier than Mg are larger than solar for NGC 6405 47, except for Sc. The elements of Cr, Ni, Y and Ba are overabundant for this star. The abundance pattern for this star resembles that of a hot Am star.

The ongoing analysis of the remaining members will enable us to derive the general abundance pattern of the M6 cluster and address the chemical heterogeneity (star to star variations) of A stars in this open young cluster.

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