Chemical composition of giants from two moving groups

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ABSTRACT

We present the stellar parameters of 19 K-type giants and their abundances for 13 chemical elements (Al, Ba, Ca, Fe, K, Mg, Mn, Na, Ni, Sc, Si, Ti and V), selected from two moving groups, covering the metallicity range of −0.6 < [Fe/H] < 0.2, based on high-resolution spectra. Most of the elemental abundances show similar trends as in previous studies, except for Al, Na and Ba, which are seriously affected by evolution. The abundance ratios of [Na/Mg] increase smoothly with higher [Mg/H], and those of [Al/Mg] decrease slightly with increasing [Mg/H]. The abundance ratios of [Mg/Ba] show a distinction between these two moving groups, which is mainly induced by chemical evolution and also partly by kinematic effects. The inhomogeneous metallicity of each star from the moving groups demonstrates that these stars had different chemical origins before they were kinematically aggregated. This favours a dynamical resonant theory.

Key words: stars: abundances – stars: fundamental parameters – Galaxy: evolution – open clusters and associations: individual: moving group 6 – open clusters and associations: individual: moving group 7.

1 INTRODUCTION

Research on moving groups can be traced back to a century ago, when Proctor (1869) discovered the two clearest moving groups in the solar neighbourhood: Hyades and Ursa Major. For nearly 100 years, these were the only moving groups to be known near Earth. Since data from the Hipparcos satellite have been available (ESA 1997), which consist of accurate parallaxes and proper motions, great progress has been made in the study of moving groups in the solar vicinity. Productive moving groups have been identified by their coherent kinematic structures, for example, Pleiades, Ursa, Hyades, Hercules, IC2391, Coma, the HR 1614 moving group, etc. (Chen et al. 1997; Dehnen 1998; Famaey et al. 2005; De Silva et al. 2007; Antoja et al. 2008; Famaey, Siebert & Jorissen 2008; Klement, Fuchs & Rix 2008). In their recent work, Zhao, Zhao & Chen (2009) have identified 22 moving-group candidates with the wavelet transform technique developed by Skuljan, Hearnshaw & Cottrell (1999). Although these statistical studies of large samples of stars have confirmed the existence of moving groups, the origins and evolution of moving groups still remain unclear.

According to Eggen (1996), moving groups are the mid-step between stars in open clusters and field stars. When the open clusters are disrupted by gravitational effects, their associations stretch into a tube-like structure around the Galactic plane, and then dissolve into the background after several Galactic orbits. This hypothesis – that moving groups are a result of the dispersion of stellar clusters – was restricted to young groups of stars with ages less than 1 Gyr, because disc heating and differential Galactic rotation would have dissolved older groups among the field stars. Another theoretical hypothesis in favour of the different dynamical origins of moving groups was put forward by Mayor (1972) and Kalnajs (1991). Dehnen (1998) pointed out that most moving groups observed in the solar vicinity could be formed by orbital resonances, related to the Galactic spiral structure, combined with the initial velocities of the stars (Skuljan et al. 1999). Famaey et al. (2005, 2007) observed a very wide range of ages for each of the kinematic structures in their Hertzsprung–Russell (H–R) diagram. They found that the Hyades moving group is a mixture of stars evaporated from the Hyades cluster and a group of older stars trapped at a resonance. Those minor kinematic groups are related to the accretion events in the Galaxy (Helmi et al. 2006). Nowadays, the second hypothesis, concerning the resonant mechanism, is considered to be the most plausible explanation for most moving groups (Antoja et al. 2008).

It is crucial to investigate the chemical composition of stars from the moving groups in order to better understand the origins and evolutionary histories of these groups and in order to find new clues and theories for such kinematic structures. In recent years, there

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Figure 1. Colour–magnitude diagram of our sample. The symbols denote the following: filled rectangles, the dwarfs of moving group 6; open rectangles, the dwarfs of moving group 7; filled triangles, the giants of moving group 6; open triangles, the giants of moving group 7; the filled circles, our sample stars of moving group 6; open circles, our sample stars of moving group 7.

have only been a few studies in which the abundances of moving-group stars, other than iron, have been analysed with high-resolution spectra. In this paper, we discuss 13 elemental abundances of 19 K-type giants from moving groups 6 and 7, which have been identified by Zhao et al. (2009) and which have opposite U-velocity. We analyse the discrepancy of the abundances between these two moving groups and we discuss the effects of their chemical evolution and kinematic structures. In Section 2, we present the stellar sample and observations. We describe the stellar atmospheric parameters in Section 3. In Section 4, we derive the elemental abundances of our sample stars and we estimate the uncertainties, while we give a detailed analysis and discussion of the results in Section 5. In Section 6, we summarize and give a conclusion.

2 SAMPLE SELECTION AND OBSERVATIONS

Our observation targets were selected from moving groups 6 and 7 (Zhao et al. 2009), primarily depending on the Galactic space–velocity components (U, V and W). The stars from group 6 have a mean velocity of (38, –20, –15) km s\(^{-1}\), while the mean motions of group 7 are (–57, –45, –16) km s\(^{-1}\). These two moving groups have opposite directions of velocities towards the Galactic Centre, which indicates their different locations on the Galactic disc. The 19 K-type giants from the two moving groups (nine stars from moving group 6 and 10 stars from moving group 7) were observed. The colour–magnitude diagram of our sample of bright and cool stars is shown in Fig. 1, as well as the whole sample of stars from Zhao et al. (2009).

The observations were carried out with the Bohyunsan Optical Echelle Spectrograph (BOES; Kim et al. 2007) attached to the 1.8-m telescope at the Bohyunsan Optical Astronomy Observatory (BOAO) on two nights: 2009 March 1 and March 4. We used a 2K \(\times\) 4K CCD with wavelength coverage of 3700–9250 Å and we set the spectral resolution of the BOES to be about 45 000, corresponding to the 200-µm fibre. The average signal-to-noise (S/N) ratio of most stars turned out to be in the range of 100–200, except for HD 44412, which has a S/N ratio of 80 as a result of bad weather. Fig. 2 shows the portions of spectra for two typical stars, HD 15176 and HD 33862.

The spectra were reduced with standard IRAF\(^{1}\) pipeline for bias subtraction, flat-fielding, scattered-light subtraction, spectral extraction and wavelength calibration. Then, we used the MIDAS program for continuum normalization. We obtained the radial velocity using a cross-correlation method with a standard spectrum. Finally, we calculated the equivalent widths (EWs) using two methods. For intermediate-strong lines, we fitted the line profiles with a Gaussian function. The direct integration was used for strong unblended lines. We discarded some strong lines (EW > 110 mÅ for Fe\(\text{I}\) lines and EW > 150 mÅ for Ni\(\text{I}\) and Ca\(\text{I}\) lines), which are less sensitive to abundances.

The validity of the EW measurements was checked by comparing them to previous independent work by Takeda, Sato & Murata (2008, hereafter Takeda08), whose spectra were taken from the High Dispersion Echelle Spectrograph (HIDES) of the Okayama Astrophysical Observatory. These spectra have a resolution of about 67 000 and a S/N ratio of 100–300 for a common star, HD 61363, as shown in Fig. 3. The systematic differences between the two sets of EWs are given by a linear least-squares fitting function with a standard deviation of 3.6 mÅ: $EW_{\text{this work}} = 1.13 + 1.016EW_{\text{Takeda08}}$ (mÅ).

\(^{1}\) IRAF is distributed by the National Optical Astronomy Observatory, which is operated by Association of Universities for Research in Astronomy, Inc., under cooperative agreement with National Science Foundation.
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3 STELLAR ATMOSPHERIC PARAMETERS

The effective temperature $T_{\text{eff}}$ of our sample stars is determined from the $(B - V)$ and $(V - K)$ photometric data, using the empirical calibration relations of Alonso, Arribas & Martínez-Roger (1999, 2001). The $B$, $V$ and $K$ colour indices are obtained from the SIMBAD (operated at CDS, Strasbourg, France) data base.

We adopt the reddening estimation described by Schlegel, Finkbeiner & Davis (1998), Arce & Goodman (1999) and Beers et al. (2002) to obtain the colour excess $E(B - V)_A$. For nearby stars, the reddening value is calculated as $E(B - V) = [1 - \exp(-|D\sin b|/125)]E(B - V)_A$, where $D$ is the distance of the star and $b$ is the Galactic latitude. Then, we adopt $E(V - K) = 2.948 E(B - V)$ as the colour excess for $(V - K)$ (Schlegel et al. 1998).

We compare the results derived from $(B - V)$ and $(V - K)$, but excluding HD 26526, which has no $K$ value. The mean difference $(T_{\text{eff}}(B - V) - T_{\text{eff}}(V - K))$ is $18 \pm 90$ K. We also obtain the excitation equilibrium temperature by forcing a consistent iron abundance, derived from different Fe I lines with their excitation potentials, and we compare the results with those obtained from $(V - K)$. The mean difference $(T_{\text{eff}}(\text{eq}) - T_{\text{eff}}(V - K))$ is $40 \pm 87$ K. We plot the results for comparison in Fig. 4(a), and we find no systematic effect between these methods. Table 1 lists $T_{\text{eff}}$ derived by the photometric and equilibrium methods for our sample stars.

The uncertainty on $T_{\text{eff}}(B - V)$ is estimated to be about 100 K, according to Alonso et al. (1999). The errors on the effective temperature derived from $(V - K)$ mainly come from the uncertainties on the $K$ indices, which induce a mean error of 105 K, slightly larger than the error estimation given by Alonso et al. (1999). We also estimate the uncertainty on the equilibrium temperature to be around 100 K, by adding perturbations of $T_{\text{eff}}$ to change the slope within a considerable range.

Figure 3. Comparison of the EWs measured in this paper with those of Takeda08 for the common star. The thick line represents the one-to-one relation, while the dashed line is the linear fit to the points.

Figure 4. (a) Comparison of effective temperatures derived using the photometric and equilibrium methods: filled triangles, $T_{\text{eff}}(B - V)$; open triangles, $T_{\text{eff}}(V - K)$. (b) Comparison of surface gravities derived by parallaxes and ionization balance of the Fe I and Fe II lines. (c) Abundance deviations derived from the Fe II and Fe I lines versus metallicity: filled circles, moving group 6; open circles, moving group 7; asterisks, HD 44412.
A}&

\begin{tabular}{cccccccc}
\hline
HD & $T_{\text{eff}}^{B-V}$ & $T_{\text{eff}}^{V-K}$ & $T_{\text{eff}}^{\text{bol}}$ & $T_{\text{eff}}$ & $\log g$ & $\xi$ & $[\text{Fe/H}]$
\hline
15176 & 4604 & 4556 & 4605 & 4556 & 2.437 & 1.3 & -0.09
26526 & 3810 & - & 3840 & 3810 & 0.521 & 1.3 & -0.54
33862 & 4818 & 4776 & 4836 & 4776 & 2.599 & 1.4 & -0.25
34303 & 4845 & 4854 & 4735 & 4735 & 3.160 & 1.1 & 0.15
40331 & 4755 & 4263 & 4288 & 4263 & 1.896 & 1.5 & -0.22
44412 & 3846 & 3792 & 3770 & 3770 & 0.635 & 1.9 & -0.59
48073 & 4842 & 4998 & 4910 & 4910 & 2.720 & 1.5 & -0.02
67174 & 3856 & 3976 & 3930 & 3930 & 0.860 & 1.5 & -0.41
80130 & 4745 & 4765 & 4845 & 4765 & 2.746 & 1.4 & -0.06
39723 & 4209 & 4217 & 4217 & 4217 & 1.763 & 1.5 & -0.04
45192 & 4359 & 4202 & 4268 & 4202 & 1.742 & 1.5 & -0.26
51397 & 4551 & 4585 & 4585 & 4585 & 2.369 & 1.5 & -0.19
61363 & 4792 & 4603 & 4692 & 4692 & 2.385 & 1.3 & -0.25
71704 & 4756 & 4757 & 4775 & 4775 & 2.507 & 1.4 & -0.24
75556 & 4312 & 4204 & 4265 & 4204 & 1.662 & 1.3 & -0.36
82104 & 3837 & 3902 & 3906 & 3902 & 0.971 & 1.5 & -0.49
85425 & 4670 & 4642 & 4772 & 4772 & 2.926 & 1.3 & 0.18
90250 & 4634 & 4650 & 4745 & 4650 & 2.618 & 1.4 & 0.00
95463 & 4317 & 4297 & 4336 & 4336 & 1.985 & 1.5 & -0.41
\hline
\end{tabular}

The surface gravity ($\log g$) is determined by

$$
\log g = \log g_\odot + \log \left( \frac{M}{M_\odot} \right) + 4 \log \left( \frac{T_{\text{eff}}}{T_{\text{eff}}^{\odot}} \right) + 0.4(M_{\text{bol}} - M_{\text{bol},\odot}).
$$

(1)

Here, $M$ is the stellar mass and $M_{\odot}$ is the bolometric magnitude, $M_{\text{bol}} = V + BC + 5 \log \pi + 5 - A_\lambda$, where $V$, $BC$, $\pi$ and $A_\lambda$ represent the apparent magnitude, bolometric correction, parallax and interstellar extinction, respectively. The parallaxes are also taken from the SIMBAD data base. The stellar masses are estimated from Yale–Yonsei stellar evolution tracks (Yi, Kim & Demarque 2003). The interstellar extinction adopted is $A_\lambda = 3.1E(B-V)$. The bolometric corrections are derived with estimated effective temperatures and metallicities (Alonso et al. 1999).

We also determine $\log g$ by forcing the Fe I and Fe II lines to give the same iron abundance. We compare the results between the two methods in Fig. 4(b), where the mean difference is 0.10 ± 0.26 dex. Most stars follow the one-to-one relation, while a few stars deviate significantly, so that we adopt the latter values for them. The deviations of abundances derived from the Fe I and Fe II lines with adopted log $g$ are plotted in Fig. 4(c).

The error on the surface gravity comes from the uncertainty on parallaxes and the error on mass estimation. The mean uncertainty on log $g$ caused by the relative errors on parallaxes is 0.085 dex for our sample stars. We estimate the uncertainty on stellar mass to be about 0.3 $M_\odot$ by comparing the discrepancy between our derived mass with that estimated from the evolutionary tracks of Girardi et al. (2000), which will induce an uncertainty of about 0.12 dex in log $g$. The overall error on log $g$ is about 0.15 dex, which is consistent with the error estimated by the second method.

The microturbulence, $\xi$, is determined by requiring a zero slope relation between log $A_\lambda$ and $EW$. Only those Fe I lines with $10 < EW < 110$ mA are adopted. The uncertainty on microturbulence is estimated to be about 0.2 km s$^{-1}$.

The initial metallicity for our stars is set to the value of $[\text{Fe/H}] = 0.0$. We adopt the final results by iterating the whole processes of determining the atmospheric parameters $T_{\text{eff}}$, log $g$, $\xi$, and $[\text{Fe/H}]$ several times in order to make them consistent. We also set the original $[\text{Fe/H}]$ to -1.0 and we repeat the same procedures to check the consistency of the results. A typical difference for the final metallicity results is about 0.03 dex for the distinct original values. The final adopted stellar parameters for our sample stars are presented in Table 1.

### 4 ABUNDANCES AND ERROR ESTIMATION

The atomic lines selected for this research cover the spectral range of 5300–8000 Å. The log $gf$ values for these lines are taken from other works. Most of our atomic-line data are taken from Chen et al. (2000) and Liu et al. (2007, hereafter Liu07). For a few V I lines, the line data are chosen from Allen & Barbuy (2006). We empirically adopt the enhancement factor $\gamma$ of each element, as described by Chen et al. (2000). The atomic-line data used for each star are listed in Table A1, which is only available in the electronic version (see the Supplementary Material section). The same atomic-line data are adopted to obtain solar abundances, and our final results are differential values relative to the Sun.

We calculate the metal abundances with the $\text{ABONTEST}\$ program supplied by Dr Pierre Magain (Liege, Belgium), based on the homogeneous, plane-parallel and local thermodynamic equilibrium models of Castelli & Kurucz (2003). The program matches the observed EWs with theoretical values calculated based on the atmospheric model. It takes into account natural broadening, van der Waals damping broadening and thermal broadening.

We check the consistency of the stellar parameters with previous studies (McWilliam 1990; Schiavon 2007; Takeda08) for three common stars. The comparison of the effective temperature, gravity and metallicity of these stars is given in Table 2. The mean deviation of the effective temperature $\Delta T_{\text{eff}}$ is about 14.3 ± 51.4 K lower than the results of others, while the gravity difference $\Delta \log g$ is about 0.04 ± 0.24 dex, which is higher compared with other results. Our metallicity is systematically 0.09 ± 0.11 dex higher than the values from the literature, which is within the error on parameters. Comparing with the results of Takeda08, our metallicity of a common star, HD 61363, is slightly higher by the order of 0.06 dex. This might be a result of the deviation values of the EWs and microturbulence.

We derive the $[X/Fe]$ ratios of 12 elements (Al, Ba, Ca, K, Mg, Mn, Ni, Sc, Si, Ti and V) and we plot the trends in Figs 5–7, together with the results of the previous works of Liu07 and Takeda08 for comparison. We note that, for HD 44412, most of the results deviate seriously from other results because of the much lower S/N ratio of its spectrum and because it is the coolest star in our sample. So, we analyse our results without considering this star’s value.

The hyperfine structure (HFS) effect has been considered for the Ba, Mn, Sc and V elements. The adopted HFS data are taken from

### Table 2. Comparison of stellar parameters between this work and previous studies for common stars.

| HD    | $T_{\text{eff}}$ | log $g$ | $[\text{Fe/H}]$ | Previous work $T_{\text{eff}}$ | log $g$ | $[\text{Fe/H}]$
|-------|-----------------|--------|----------------|--------------------------------|--------|----------------
| 15176 & 4556          & 2.437  & -0.09         & 4540                          & 2.63   & -0.19         
| 61363 & 4692          & 2.385  & -0.25         & 4762                          & 2.33   & -0.31         
| 90250 & 4650          & 2.618  & 0.00          & 4639                          & 2.35   & -0.10         

[a] From McWilliam (1990).
[b] From Takeda08.
[c] From Schiavon (2007).
McWilliam (1998) and from Kurucz (Kurucz & Bell 1995), as presented in Table 3. The largest HFS corrections are about 0.18 dex for [Ba/Fe], −0.35 dex for [Mn/Fe] and −0.08 dex for [Sc/Fe]. For the V element, the HFS effect can lead to a correction as large as −0.55 dex, consistent with Liu07. The discrepancy of elemental abundances resulting from the HFS correction for these elements exhibits decreasing trends with increasing metallicity, as shown in Fig. 5. We adopt the results of [Ba/Fe], [Mn/Fe], [Sc/Fe] and [V/Fe] with HFS correction.

We estimate the uncertainties on abundances for our sample stars from two sources. One source is the internal error resulting from the scatter of our abundance results from individual lines. This error is calculated by dividing the standard deviation of derived abundances by a square root of the numbers of lines used (√N).

2 http://kurucz.harvard.edu/linelists.html

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for a typical star, HD 33862, in our sample. The uncertainties on abundances for most chemical elements are less than 0.1 dex.

5 RESULTS AND DISCUSSION

5.1 Abundances between upper red giants and red clump giants

Most of our sample stars are upper red giants, which have a brighter absolute magnitude with cooler effective temperature than red clump giants, and they are influenced more seriously by stellar evolution. We analyse our results of elemental abundances, compared with the work of Liu07 and Takeda08 on red clump giants. We find that most chemical elements show similar abundance trends, with the exceptions of Al, Na and Ba – evolution effects contribute significantly to these. We plot [X/Fe] of Mn, Ni, V, Ca, Mg, Si, Ti, K and Sc versus [Fe/H] in Fig. 6, and the trends of Al, Na and Ba are shown in Fig. 7. The abundance ratios of these elements for our sample stars are listed in Table 5.

The iron-peak elements are believed to have the same patterns as iron. The values of [Mn/Fe] increase with higher metallicity in our work, which is consistent with Takeda08. The trends of [Ni/Fe] are flat with −0.6 < [Fe/H] < 0.2 for our stars. Our results for [Ni/Fe] show systematic higher values (∼0.05 dex) than those of Takeda08, but our results are consistent with Liu07. The [V/Fe] values show larger scatter for some of our stars with relative lower effective temperature, because the V lines are very sensitive to temperature (Allen & Barbuy 2006). Moreover, the V lines of those stars are so strong that they could be contaminated by other lines.

The α elements are primarily produced by Type II supernovae (SN II) nucleosynthesis and they exhibit enrichment in metal-poor stars (Woosley & Weaver 1995). All these elements show increments towards lower metallicity and exhibit turn-off trends to flatter patterns at [Fe/H] ∼ −0.2 with slight differences. This is in good agreement with the previous studies of Takeda08 and Liu07. We notice that the trend of [Mg/Fe] is steeper than other α elements and our results for [Ti/Fe] show slightly larger scatter.

For odd-Z light elements, [K/Fe] exhibits a larger dispersion, as reported by Wang et al. (2011), because only one strong line is available. We divide our stellar spectra by the spectrum of the B-type star, HD 5394, observed on the same night in order to check the effect of H₂O lines. We find no change in our results, which demonstrates the insignificant influence of H₂O lines for our K line. [Sc/Fe] shows a flat pattern, which is consistent with Takeda08. [Al/Fe] decreases with increasing metallicity for [Fe/H] < −0.2, and becomes flat towards higher metallicity. Although the trend of [Al/Fe] is similar to Liu07, our results are richer at [Fe/H] < −0.4. [Na/Fe] also shows enrichment at [Fe/H] < −0.4, which could be a result of stellar evolution effects. For other stars, the trend of [Na/Fe] is consistent with Takeda08 and Liu07.

Barium is produced mainly by the s process, which can be used as the stellar evolution tracer. We consider that there is a turn off at [Fe/H] ∼ −0.2 in the trend of [Ba/Fe] versus [Fe/H], which is consistent with the results of Chen et al. (2000) and Liu07. Yet, our results for [Ba/Fe] show enrichment at [Fe/H] < −0.4, which indicates that these stars are seriously affected by the evolution process.

5.2 Abundance analyses of Na, Al, Mg and Ba

Na and Al are thought to be produced in SNe II and SNe Ib/c (Nomoto, Thielemann & Yokoi 1984), in contrast to the production of...
Figure 6. Abundance ratio [X/Fe] for Mn, Ni, V, Ca, Mg, Si, Ti, K and Sc versus [Fe/H]: filled circles, moving group 6; open circles, moving group 7; asterisks, HD 44412; crosses, Takeda08; rectangles, Liu07.

of Mg. The cycle of Na–Al–Mg is crucial to nucleosynthesis in our results because these elements can partly reflect the chemical evolution histories of our giants. We plot the abundances of Na and Al relative to Mg versus [Mg/H] in Fig. 8 for comparison with the works of Luck & Heiter (2007, hereafter LH07) and Liu07 without non-local thermodynamic equilibrium (NLTE) correction, because Mg can be seen as a better metallicity tracer (Cayrel et al. 2004). Our results for [Na/Mg] increase smoothly with higher [Mg/H], which can be fitted by the relation [Na/Mg] = 0.007 + 0.064 [Mg/H], while the results of Liu07 show a steeper increasing trend. The results of LH07 show larger scatter, so that it is difficult for us to find an explicit relation. Our results for [Na/Mg] display overabundance at lower [Mg/H], with respect to those of Liu07, for those stars that have evolved to the upper-tip red giant branch. The reason for this is that the abundance of Na will be enriched as a result of the Ne–Na cycle from deeper layers being dredged to the surface. This has also been found in some studies of giants (Andrievsky et al. 2002; Mishenina et al. 2006). Our results for [Al/Mg] decrease slightly with increasing [Mg/H], and we have the relation [Al/Mg] = 0.054–0.116 [Mg/H], which is different from the trend of Liu07 but consistent with that of LH07. This might also be a result of the effects of evolution, because the sample of LH07 has a wider range of evolution than that of Liu07. The trends of Na–Al–Mg indicate that Mg abundances are less affected by possible nucleosynthesis and mixing than those of Na or Al (Langer, Hoffman & Sneden 1993).

We find that our results for most elemental abundances are in good agreement for both moving groups 6 and 7, except for the Mg and Ba elements. The [Mg/Fe] for the stars of moving group 7 is slightly higher (~0.04 dex) than for the stars from moving group 6. We also note that the [Ba/Fe] values for the stars of moving group 7 are slightly smaller (~0.10 dex) than for the stars of moving group 6, which is in contrast with the results for [Mg/Fe]. The trends of [Ba/Fe] versus metallicity for the stars of the two moving groups also show a discrepancy. The contrasting trends of Mg and Ba demonstrate that these two elements are predominantly synthesized in different progenitor mass ranges (Arnone et al. 2005).

Bearing in mind that [Ba/H] is a better indicator for investigating the evolution effect, we plot the abundance ratio [Mg/Ba] versus [Ba/H] in Fig. 9. This shows the decreasing trend of [Mg/Ba] with higher [Ba/H] for both moving groups, and represents the anticorrelation of abundances between Ba and Mg. In order to investigate
the effect of evolution better, we compare our results with those of Allen & Barbuy (2006), whose sample includes giants, subgiants and dwarfs for barium-rich stars. Although the ranges of [Ba/H] are different in these two samples, the trend of [Mg/Ba] versus [Ba/H] shows consistency, which can be well fitted by a linear relation $[\text{Mg/Ba}] = -0.116 - 1.184 \times [\text{Ba/H}]$, based on the data of Allen & Barbuy (2006) and on our results. The reason for this is probably that the X process sites are the atmospheres of asymptotic giant branch (AGB) stars (Busso, Gallino & Wasserburg 1999), which is different from the Mg element that is essentially all produced by SN II explosions. Although our sample stars are not barium-rich stars, the evolution effect can be reduced by comparing stars with similar [Ba/H] ratios. We note that the values of [Mg/Ba] are higher for the stars of moving group 7 than for the stars of moving group 6, as shown in the region within the dashed box in Fig. 9. Such differences might indicate the distinct chemical evolution traces of these two moving groups.

5.3 Kinematic analysis

To further investigate the origins and evolution traces of moving groups 6 and 7, it is important to carefully analyse our abundance results of some chemical elements with dynamical effects. The kinematical parameters of our sample stars are taken from Famaey et al. (2005). The stars of moving group 7 have smaller values of minimum Galactocentric distance ($R_{\text{min}}$) and higher mean height towards the Galactic disc ($Z_{\text{max}}$) than those of moving group 6, corresponding to their larger Galactic velocity of ($U$, $V$) values, as described by Nordström et al. (2004). In Fig. 10, we plot the abundance ratios of [Mg/Ba] for our stars with kinematical parameters of $R_{\text{min}}$ and $Z_{\text{max}}$, in order to analyse the discrepancy between the abundances of moving groups 6 and 7, which have opposite $U$-velocity. We select stars carefully from the area shown in the dashed box in Fig. 9, with [Ba/H] $\sim 0.05$, to reduce the effects of stellar evolution. We find that the mean values of [Mg/Ba] are $-0.072 \pm 0.090$ for moving group 7 and $-0.229 \pm 0.147$ for moving group 6, with a discrepancy of about 0.16 dex. This could be induced by their different kinematics with different $R_{\text{min}}$ values (see Fig. 10). The scatter of the results is slightly larger for moving group 6, which shows a dependence on $Z_{\text{max}}$. In spite of this, the distinction in [Mg/Ba] between these two moving groups cannot be eliminated by other factors. Thus, we can elaborately conclude that such an abundance discrepancy might indicate different chemical synthesis histories for the two moving groups.

Table 5. Stellar abundance ratios [X/Fe]. Note that HFS corrections have been adopted for [Ba/Fe], [Mn/Fe], [Sc/Fe] and [V/Fe].

| HD    | [Al/Fe] | [Ba/Fe] | [Ca/Fe] | [K/Fe] | [Mg/Fe] | [Mn/Fe] | [Na/Fe] | [Ni/Fe] | [Sc/Fe] | [Si/Fe] | [Ti/Fe] | [V/Fe] |
|-------|---------|---------|---------|--------|---------|---------|---------|---------|---------|---------|---------|-------|
| 15176 | 0.13    | 0.26    | 0.01    | -0.14  | 0.03    | -0.05   | 0.09    | 0.07    | -0.04   | 0.08    | 0.02    | -0.05 |
| 26526 | 0.33    | 0.49    | 0.23    | 0.07   | 0.24    | -0.07   | 0.35    | 0.06    | 0.04    | 0.13    | 0.17    | 0.15  |
| 33862 | 0.16    | 0.15    | 0.09    | 0.08   | 0.11    | -0.10   | 0.12    | 0.06    | -0.00   | 0.13    | 0.17    | 0.04  |
| 34303 | 0.06    | 0.05    | -0.13   | -0.24  | 0.02    | -0.00   | 0.09    | 0.07    | 0.04    | 0.03    | -0.03   | 0.00  |
| 40331 | 0.08    | 0.40    | 0.02    | -0.27  | 0.04    | -0.11   | 0.09    | 0.02    | 0.02    | 0.07    | 0.05    | -0.10 |
| 44412 | 0.75    | 0.17    | 0.06    | 0.53   | 0.01    | 0.32    | 0.13    | -0.49   | 0.38    | -0.08   | 0.15    | 0.15  |
| 48073 | 0.15    | 0.26    | 0.04    | -0.01  | 0.02    | -0.03   | 0.20    | 0.04    | -0.01   | 0.03    | 0.03    | 0.09  |
| 67174 | 0.22    | 0.61    | 0.17    | -0.03  | 0.14    | -0.12   | 0.16    | 0.11    | -0.07   | 0.13    | 0.10    | 0.17  |
| 80130 | 0.10    | 0.28    | -0.02   | -0.09  | 0.07    | -0.10   | 0.05    | 0.03    | 0.02    | 0.11    | -0.04   | -0.02 |
| 39723 | 0.19    | 0.35    | 0.04    | -0.28  | 0.10    | -0.00   | 0.24    | 0.11    | -0.05   | 0.16    | -0.03   | -0.04 |
| 45192 | 0.21    | 0.23    | 0.03    | -0.29  | 0.21    | -0.14   | 0.15    | 0.03    | 0.06    | 0.02    | 0.03    | -0.21 |
| 51397 | 0.24    | 0.19    | 0.01    | -0.14  | 0.13    | -0.10   | 0.11    | 0.05    | -0.06   | 0.13    | -0.03   | -0.04 |
| 61363 | 0.12    | 0.28    | 0.11    | 0.01   | 0.14    | -0.14   | 0.17    | 0.06    | 0.04    | 0.14    | -0.04   | -0.05 |
| 71704 | 0.19    | 0.18    | 0.13    | 0.02   | 0.16    | -0.09   | 0.09    | 0.07    | 0.02    | 0.14    | 0.03    | 0.03  |
| 75556 | 0.29    | 0.05    | 0.10    | -0.13  | 0.31    | -0.14   | 0.12    | 0.06    | 0.01    | 0.17    | 0.04    | 0.08  |
| 82104 | 0.46    | 0.35    | 0.16    | 0.00   | 0.32    | -0.12   | 0.32    | 0.09    | -0.01   | 0.25    | 0.17    | 0.31  |
| 85425 | 0.06    | 0.12    | -0.04   | -0.21  | 0.07    | 0.04    | 0.11    | 0.07    | -0.01   | 0.13    | 0.02    | 0.03  |
| 90250 | 0.10    | 0.10    | -0.05   | -0.15  | 0.09    | -0.07   | 0.08    | 0.08    | -0.02   | 0.14    | -0.05   | -0.01 |
| 95463 | 0.27    | 0.08    | 0.10    | -0.09  | 0.22    | -0.05   | 0.15    | 0.10    | 0.06    | 0.16    | 0.15    | 0.09  

Figure 7. Abundance ratio [X/Fe] for Al, Na and Ba versus [Fe/H]: filled circles, moving group 6; open circles, moving group 7; asterisks, HD 44412; crosses, Takeda08; rectangles, Liu07.
Chemical composition of giants from two moving groups

6 CONCLUSION

In this paper, we have determined the stellar atmospheric parameters and chemical abundances of 19 K-type giants from moving groups 6 and 7, which have anti-\(U\) velocity towards the Galactic Centre, based on the high-resolution spectra obtained at the BOAO, covering the metallicity range \(-0.6 < [\text{Fe/H}] < 0.2\). From the results on open clusters (Friel et al. 2002; Yong, Carney & de Almeida 2005; Bragaglia et al. 2008; Pancino et al. 2010) for comparison. The metallicity of our stars from each moving group covers a wider range than that of open clusters at \(R_g \sim 7.5\) kpc. The values of [Fe/H] spread out to about \(-0.5\) dex for our sample, which is different from the values for open clusters, \(-0.2 < [\text{Fe/H}] < 0.2\). The values of the metallicity scatter for our sample of stars from moving groups 6 and 7 are 0.22 and 0.20 dex, which are much larger than those of open clusters, which have a scatter less than 0.05 dex. Such a wider metallicity range and larger abundance scatter point to the chemical inhomogeneity of moving groups 6 and 7, although each has a kinematic coherence in the velocity space. The inhomogeneity of these two moving groups, different from open clusters, could indicate that the stars of moving groups 6 and 7 had different chemical origins before they were kinematically gathered and that both moving groups are not the dispersed remnants of clusters or star-forming events, but rather the result of the kinematic effects of the Galactic spiral structure. So, we would not expect these kinematic groups to be chemically homogeneous and coeval. Our results for moving groups 6 and 7, which show distinct behaviours with respect to open clusters, support the hypothesis that concerns the mechanisms of dynamical resonance.

groups. We find no explicit relations for the Mg and Ba abundances with different \(Z_{\text{max}}\).

In Fig. 11, we plot the [Fe/H] distributions with the mean Galactocentric distances \((R_g)\), together with the results of previous studies on open clusters (Friel et al. 2002; Yong, Carney & de Almeida 2005; Bragaglia et al. 2008; Pancino et al. 2010) for comparison. The metallicity of our stars from each moving group covers a wider range than that of open clusters at \(R_g \sim 7.5\) kpc. The values of [Fe/H] spread out to about \(-0.5\) dex for our sample, which is different from the values for open clusters, \(-0.2 < [\text{Fe/H}] < 0.2\). The values of the metallicity scatter for our sample of stars from moving groups 6 and 7 are 0.22 and 0.20 dex, which are much larger than those of open clusters, which have a scatter less than 0.05 dex. Such a wider metallicity range and larger abundance scatter point to the chemical inhomogeneity of moving groups 6 and 7, although each has a kinematic coherence in the velocity space. The inhomogeneity of these two moving groups, different from open clusters, could indicate that the stars of moving groups 6 and 7 had different chemical origins before they were kinematically gathered and that both moving groups are not the dispersed remnants of clusters or star-forming events, but rather the result of the kinematic effects of the Galactic spiral structure. So, we would not expect these kinematic groups to be chemically homogeneous and coeval. Our results for moving groups 6 and 7, which show distinct behaviours with respect to open clusters, support the hypothesis that concerns the mechanisms of dynamical resonance.

6 CONCLUSION

In this paper, we have determined the stellar atmospheric parameters and chemical abundances of 19 K-type giants from moving groups 6 and 7, which have anti-\(U\) velocity towards the Galactic Centre, based on the high-resolution spectra obtained at the BOAO, covering the metallicity range \(-0.6 < [\text{Fe/H}] < 0.2\). From the results
of abundances combined with kinematical parameters, we conclude that the abundances of most elements show similar trends as in previous studies on giants (Liu07; Takeda08) except for Al, Na and Ba, because of the evolution effects on our upper red giants. The iron-peak elements have the same patterns as iron. The $\alpha$ elements (Ca, Mg, Si and Ti) exhibit increasing trends towards lower metallicity and show the turn-off trends to flatter patterns at $[\text{Fe/H}] \sim -0.2$. 

$[\text{K/Fe}]$ exhibits a larger dispersion while $[\text{Sc/Fe}]$ shows a flat solar pattern. The abundances of Al, Na and Ba exhibit overabundances at $[\text{Fe/H}] < -0.4$ for the more evolved stars.

Our results for $[\text{Na/Mg}]$ increase smoothly with higher $[\text{Mg/H}]$ and those for $[\text{Al/Mg}]$ decrease slightly with increasing $[\text{Mg/H}]$, because these are significantly affected by stellar internal evolution. The abundance ratios $[\text{Mg/Ba}]$ for the stars of moving groups 6 and 7, with similar $[\text{Ba/H}] \sim 0$, are distinct from each other by an order of 0.16 dex. This could be induced by their distinct chemical evolution histories, corresponding to their different kinematics. The inhomogeneous $[\text{Fe/H}]$ values of the stars of these two moving groups present different chemical origins for stars from each moving group, and this favours the dynamical resonant theory. In the future, in order to further investigate the origins and evolution of these kinematic structures in the Galaxy, the sample of stars can be enlarged and spread out to other moving groups.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article.

Table A1. All atomic-line data used for each sample star.

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