Tracing the Origin of Moving Groups. I. The γ Leo Moving Group with High-resolution Spectra from the Subaru Telescope

X. L. Liang1,2, J. K. Zhao1, G. Zhao1,2, W. Aoki3,4, M. N. Ishigaki5, T. Matsumo3,4, Y. Q. Chen1,2, X. M. Kong1, J. R. Shi1,2, and Q. F. Xing1

1 Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, People’s Republic of China
2 School of Astronomy and Space Science, University of Chinese Academy of Sciences, Beijing 100049, People’s Republic of China
3 National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan
4 Department of Astronomical Science, School of Physical Sciences, The Graduate University of Advanced Studies (SOKENDAI), 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan
5 Kavli Institute for the Physics and Mathematics of the Universe (WPI), Todai Institute for Advanced Study, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, 277-8583 Chiba, Japan; miho.ishigaki@ipmu.jp

Received 2018 March 4; revised 2018 June 24; accepted 2018 June 25; published 2018 August 6

Abstract

We present chemical abundances of 15 stars in the γ Leo moving group based on high-resolution spectra with the Subaru High Dispersion Spectrograph. The sample was picked up by applying wavelet transform to UVW velocity components of stars in the solar neighborhood. Both photometric and spectroscopic method have been used to determine the stellar parameters of stars. Abundances of 11 elements including Na, Mg, Al, Si, Ca, Ti, Cr, Fe, Ni, Y, and Ba are measured. Our results show that the member stars display a wide metallicity distribution with abundance ratios similar to Milky Way disk stars. We presume that the γ Leo moving group originated from dynamical effects that are probably related to the Galactic spiral arms.

Key words: stars: abundances – stars: kinematics and dynamics – solar neighborhood

1. Introduction

An increasing number of complex substructures has been discovered in the Milky Way by recent digital sky surveys (Klement et al. 2008; Zhao et al. 2009; Antoja et al. 2012). It is well known that the vicinal velocity field is clumpy and that most of the observed overdensities are made of spatially unbound groups of stars called moving groups. Eggen (1958–1998) has defined and investigated many moving groups, supposing that moving groups are from dissolving open clusters. Later, many theoretical models suggest that the overdensities of stars in some regions of the Galactic velocity ultraviolet (UV) plane may be a result of global dynamical mechanisms related to the nonaxisymmetry of the Galaxy (Famaey et al. 2005), namely the presence of the bar (Kalnajs 1991; Dehnen 2000; Fux 2001) and/or spiral arms (De Simone et al. 2004; Quillen & Minchev 2005). Since the late 1990s, the bar has been believed to be short and fast rotating for a long time. This was in very good agreement with the explanation of the Hercules moving group being due to the bar’s outer Lindblad resonance (Dehnen 2000). However, recent photometric studies of the Galactic center have shown that the bar could be longer, reopening the debate on the bar’s pattern speed and the origin of the Hercules moving group (Monari et al. 2017; Pérez-Villegas et al. 2017). Nowadays, the origins of these moving groups are explained by different theories or hypotheses, such as cluster disruption, dynamical effects, and accretion events. Freeman & Bland-Hawthorn (2002) put forward the chemical tagging technique to reassemble the ancient stellar forming aggregates in the Galactic disk. Since then, it has become popular to use detailed chemical abundances from high-resolution spectroscopy to disentangle the mechanism that has formed a certain stream. For example, Bensby et al. (2007) found a wide spread in the distributions of age and chemical abundances of the stars in the Hercules stream, and concluded that this group is compatible with being a dynamical feature. According to the homogeneity of the HR 1614 group in age and abundance, De Silva et al. (2007) concluded that it is the remnant of a dispersed star-forming event.

In the past, it was hard to determine the stellar members of moving groups due to the lack of parallaxes information, which will become available with the Gaia survey. Combined with a spectroscopic survey like LAMOST, we can determine accurate velocity coordinates of stars in the solar neighborhood. The γ Leo (Leonis) moving group has not been closely analysed before. The γ Leonis group was defined by Eggen (1959a, 1959b) using the convergent point method. Its existence has been confirmed by Skuljan et al. (1997). Antoja et al. (2012), using RAVE data, reidentified two peaks of the γ Leo moving group in the UV plane by wavelet transform, which is confirmed by Liang et al. (2017) using Gaia-TGAS (Brown et al. 2016; Prusti et al. 2016) cross-matched with LAMOST DR3 (Zhao et al. 2006; Cui et al. 2012; Zhao et al. 2012).

The objective of this paper is to trace the origin of the γ Leo moving group by chemical tagging. Section 2 describes our sample and observational information about this sample. In Section 3 we discuss stellar parameters, chemical abundance, and error analysis. The main results and discussions are given in Section 4. In the final section, we present conclusions and future expectations.

2. Sample Selection and Observation

2.1. Membership Criteria

Membership of a moving group is based on the stars’ velocities. The velocity components UVW are defined in a right-handed local standard reference coordinated system, which points to the directions of the Galactic center, Galactic...
rotation, and the north Galactic pole, respectively. Velocities were corrected to the local standard of rest where the Sun’s $U$, $V$, $W$ ($\text{km s}^{-1}$) were identified as the peaks and the size of the $\gamma$ Leo overdensity. Then, we took $1 \text{as}$ the radius of the $\gamma$ Leo moving group. We adopted all objects within the radius as candidate stars, taking into account typical errors of velocity about 5 $\text{km s}^{-1}$; the inner velocity dispersion of a moving group is more than 2 $\text{km s}^{-1}$ (Shkolnik et al. 2012). Seventy-seven candidate stars within 300 pc were selected, from which 18 stars have been observed with the Subaru Telescope. Table 1 lists their identifier, equatorial coordinate, parallax, proper motion components, and identifier name in the simbad astronomical database of 15 single stars (the other three stars are spectroscopic binaries).

### Table 1
Total Sample of Analyzed Stars

| id         | R.A.     | Decl. | $U$  | $V$  | $W$  | $\pi$ | pmra | pmdec | simbadname |
|------------|----------|-------|------|------|------|-------|------|-------|------------|
| J0158+3955 | 015836.1 | 39532 | 57.55| 3.04 | 4.12 | 3.81  | -26.33 | -5.67  | TYC2820-1624-1 |
| J0159+2636 | 015939.4 | 26362 | 62.21| -1.20| 2.59 | 3.48  | -24.79 | -14.93 | TYC1760-111-1 |
| J2111+4235 | 021144.4 | 42352 | 57.85| 2.63 | 6.50 | 3.57  | -20.40 | -3.25  | TYC2838-1980-1 |
| J216+4119  | 021649.4 | 41106 | 54.16| 6.99 | 3.29 | 3.35  | -21.96 | -2.36  | TYC2838-96-1 |
| J219+4506  | 021945.0 | 45068 | 55.98| 10.35| 4.43 | 4.86  | -34.69 | 1.86   | TYC3294-1261-1 |
| J219+5623  | 021948.7 | 56234 | 60.69| 8.76 | 5.35 | 6.55  | -49.37 | 13.81  | TYC3694-1282-1 |
| J1446+2955 | 144637.2 | 29502 | 55.74| 4.94 | 4.83 | 5.39  | 0.28   | -44.43 | TYC2022-417-1 |
| J1517+1026 | 151719.5 | 10261 | 61.44| 0.23 | -1.38| 4.80  | 25.87  | -42.56 | TYC923-1342-1 |
| J1735+2656 | 173524.6 | 26505 | 58.90| 8.16 | 2.28 | 5.11  | 3.46   | -48.10 | TYC2084-1906-1 |
| J1747+2228 | 174737.6 | 22284 | 57.09| -3.10| 4.96 | 4.28  | -6.54  | -41.72 | TYC1564-641-1 |
| J2101+0005 | 210113.2 | 00052 | 58.69| -2.84| 7.28 | 4.99  | -38.13 | -35.42 | TYC526-1195-1 |
| J2154+1418 | 215455.0 | 14181 | 54.51| -0.34| 6.71 | 3.59  | -27.73 | -24.14 | TYC1134-136-1 |
| J2208+2549 | 220801.3 | 25493 | 60.92| 1.12 | -2.56| 5.95  | -46.61 | -51.18 | TYC2208-1077-1 |
| J2235+0315 | 223522.8 | 03155 | 64.54| 3.18 | 6.92 | 4.97  | -50.22 | -33.95 | TYC572-172-1 |
| J2328+2620 | 232822.8 | 26205 | 58.02| 7.09 | 4.72 | 3.45  | -31.48 | -18.22 | TYC2253-1606-1 |

**Note.** The columns are, respectively: identifier; right ascension; declination; velocity components $U$, $V$, $W$ ($\text{km s}^{-1}$); parallax (mas); proper motion components (km s$^{-1}$) in right ascension and declination; and identifier names in the simbad astronomical database.

### Table 2
The Basic Stellar Parameters for Our 15 Stars

| id         | $V$ - $K$ mag | Mass ($M_\odot$) | $M_{bol}$ mag | $T_{eff,pho}$ (K) | $T_{eff,ab}$ (K) | $\log g_{pho}$ | $\log g_{ab}$ (km s$^{-2}$) | $\xi$ (km s$^{-1}$) | S/N |
|------------|---------------|-----------------|--------------|-------------------|-----------------|----------|------------------|--------------|-----|
| J0158+3955 | 1.26          | 1.4             | 3.36         | 6112              | 6389            | 4.14     | 4.23             | 1.4             | 81  |
| J0159+2636 | 1.51          | 1.1             | 3.86         | 5744              | 6204            | 4.12     | 4.03             | 1.1             | 72  |
| J2111+4235 | 1.38          | 1.2             | 3.66         | 5937              | 6351            | 4.14     | 4.25             | 1.2             | 76  |
| J2101+1122 | 1.48          | 1.1             | 4.38         | 5776              | 5972            | 4.33     | 4.34             | 0.7             | 60  |
| J219+4506  | 1.14          | 1.2             | 4.30         | 6341              | 5848            | 4.52     | 4.57             | 0.4             | 59  |
| J219+5623  | 0.48          | 1.2             | 2.68         | 5805              | 5780            | 4.46     | 4.34             | 0.6             | 123 |
| J1446+2955 | 1.64          | 0.9             | 5.04         | 5512              | 5597            | 4.43     | 4.42             | 0.5             | 82  |
| J1517+1026 | 2.10          | 0.8             | 4.68         | 5009              | 5034            | 4.06     | 4.04             | 0.5             | 50  |
| J1735+2650 | 1.52          | 1.1             | 4.58         | 5726              | 5616            | 4.40     | 4.30             | 0.5             | 57  |
| J1747+2228 | 1.68          | 0.9             | 4.67         | 5468              | 5896            | 4.29     | 4.30             | 0.9             | 80  |
| J2101+0005 | 1.39          | 1.2             | 3.91         | 5930              | 5645            | 4.25     | 4.24             | 0.7             | 73  |
| J2154+1418 | 1.06          | 1.1             | 3.94         | 6500              | 6508            | 4.37     | 4.44             | 1.6             | 69  |
| J2208+2549 | 1.55          | 0.9             | 4.98         | 5677              | 5688            | 4.49     | 4.47             | 0.5             | 53  |
| J2253+0315 | 1.40          | 1.1             | 4.47         | 5909              | 5740            | 4.40     | 4.37             | 0.6             | 40  |
| J2328+2620 | 1.33          | 1.2             | 3.84         | 6023              | 6197            | 4.25     | 4.22             | 1.1             | 58  |

**Note.** The columns are, respectively: identifier; color $V - K$; stellar mass; bolometric magnitude; effective temperature from photometry; effective temperature from spectroscopy; surface gravity from photometry; surface gravity from parallax; micro-turbulent velocity; and signal-to-noise ratio (S/N) at 5500 Å per pixel.
spectra, and wavelength calibration using Th arc lines. Cosmic-rays hits are removed by the method described in Aoki et al. (2005). The code HDSV (Zhao et al. 2007) was used to estimate heliocentric radial velocities and to normalize the spectra. The signal-to-noise ratio (S/N) of spectra varies from star to star (listed in Table 2), but the mean value is 68.2 per pixel at 5500 Å. Among the 18 observed stars, three were found to be double-lined spectroscopic binaries, and they were excluded from the sample. The remaining 15 stars have been analyzed. Solar spectrum (Moon spectrum) observed by the NAOC-Xinglong 2.16 m Telescope was acquired for correcting the zeropoint of elemental abundances.

3. Abundance Analysis

3.1. Equivalent Width Measurements and Model Atmospheres

The elemental abundances were determined based on equivalent widths (EWs) measured line by line with a Gaussian fit. The atomic data of all the lines we used are taken from Kong et al. (2017). To estimate the accuracy of EWs measurement, we compared our EWs of the Moon spectrum with those of Bensby et al. (2014). The linear least squares fit for the two sets of data is

\[ \text{EW}_{\text{this work}} = 1.0225(\pm0.0054)\text{EW}_{\text{Bensby}} + 1.055(\pm0.351) \text{ mÅ}, \]

and the standard deviation is about 2.3 mÅ. Figure 1 shows a comparison of the two EWs sets and their linear fit line. The model atmospheres were interpolated from LTE Kurucz model atmospheres (Kurucz 1993) and the theoretical EWs for individual lines were calculated using the ABONTEST8 code supplied by Dr. P. Magain.

3.2. Stellar Parameters

Stellar parameters are estimated by two methods: photometric and spectroscopic. For the photometric method, effective temperatures \( T_{\text{eff}} \) were derived from the photometric color index \( V - K \) according to empirical calibration relations given by Alonso et al. (1996). The apparent magnitudes are adopted from SIMBAD Astronomical Database (Wenger et al. 2000). Most stars’ color excess \( E(B - V) \) are obtained from the Galactic Dust Reddening and Extinction website\(^6\) (Schlafly & Finkbeiner 2011). However, for J0219+5623, we suspect that the value 0.43 obtained by this method is an overestimate, and we take 0.03 from the 3D Dust Mapping website\(^7\) (Green et al. 2015) as \( E(B - V) \) to estimate this star’s effective temperature. Surface gravity \( \log g \) is calculated from basic relation between bolometric magnitude, effective

---

\(^6\) http://irsa.ipac.caltech.edu/applications/DUST/
\(^7\) http://argonaut.skymaps.info/
temperature, stellar mass, and surface gravity:
\[ \log \frac{g}{g_\odot} = \log \frac{M}{M_\odot} + 4 \log \frac{T_{\text{eff}, \odot}}{T_{\text{eff}}} + 0.4(M_{\text{bol}} - M_{\text{bol}, \odot}), \]

where
\[ M_{\text{bol}} = V_{\text{mag}} + BC + 5 \log \pi + 5. \]

The parallax \( \pi \) (mas) is taken from Gaia-Tgas (Brown et al. 2016; Prusti et al. 2016). The bolometric corrections are calculated using the relation given by Alonso et al. (1995). Most of our stars are turn-off stars, while for two sub-giant stars (J1735+2650 and J0159+2636), we used formulae provided by Alonso et al. (1999) to calculate the effective temperature.

Figure 3. Photometric \( T_{\text{eff}} \) vs. spectroscopic \( T_{\text{eff}} \) and photometric log \( g \) vs. spectroscopic log \( g \). The dashed line indicates the unit slope.

Figure 4. [X/Fe] vs. [Fe/H] for \( \alpha \)-elements (Mg, Si, Ca, and Ti). Blue filled circles are member stars; green pluses are comparison stars from Bensby et al. (2014); red triangles are comparison stars from Venn et al. (2004).
Stellar mass is estimated by interpolation of the evolutionary tracks of Yi et al. (2003) for $T_{\text{eff}}$ and $M_{\text{bol}}$.

For the spectroscopic method, effective temperature is determined by adjusting excitation equilibrium, requiring the slopes of lower excitation potential versus $\log \epsilon(\text{Fe I})$ close to zero. Surface gravity ($\log g$) is determined from the ionization equilibrium method, which forces $\log \epsilon(\text{Fe I})$ equal to $\log \epsilon(\text{Fe II})$. Microturbulence is determined, as the abundances of FeI lines show no trend with EWs. We iterate the fitting with a $3\sigma$ rejection of the deviant Fe lines after the first determination of the stellar parameters. The parameters from this spectroscopic method are adopted as our final parameters to calculate the abundances. In Figure 2, we plot stars’ positions in an HR diagram. The abscissa labels spectroscopic effective temperature and the ordinate labels luminosity. The dotted line is a $Y^2$ isochrone with age = 1.2 Gyr from Yi et al. (2001).

The resulting stellar parameters are listed in Table 2. Figure 3 shows comparisons of $T_{\text{eff}}$ and $\log g$ from the two methods. The average and standard deviation of $\Delta T_{\text{eff}}$ are 66 K and 270 K, respectively. The systematic effect between these methods may be mainly caused by uncertainties of extinction. The average and standard deviation of $\Delta \log g$ are 0.007 and 0.069, respectively. We suppose the systematic deviation for $\log g$ can be ignored. The uncertainties of $\log g$ are mainly caused by uncertainties of stellar effective temperature and uncertainties of the mass from parallax errors and extinction.

We adopted the photospheric solar abundance of Asplund et al. (2009) to calculate $[\text{X}/\text{H}]$ values. To estimate the offset of

Figure 5. $[\text{X}/\text{Fe}]$ vs. $[\text{Fe}/\text{H}]$ for Fe-peak, odd-Z and s-process elements (Al, Ba, Cr, Ni, Na, and Y). Blue filled circles are member stars; green pluses are comparison stars from Bensby et al. (2014); red triangles are comparison stars from Venn et al. (2004).
| id         | ΔEW(+2.3) | ΔEW(+100) | Δlog g(+0.12) | ΔFe/H (+0.11) | Δζ(+0.1) | σ_{total} |
|------------|------------|------------|----------------|----------------|------------|------------|
| J1517+3955 | 0.04       | 0.07       | -0.01          | -0.00          | -0.03      | 0.09       |
| J0159+2636 | 0.05       | 0.06       | -0.02          | 0.00           | -0.03      | 0.09       |
| J0211+4235 | 0.05       | 0.06       | -0.04          | 0.00           | -0.03      | 0.10       |
| J0216+4119 | 0.05       | 0.08       | -0.03          | 0.00           | -0.02      | 0.11       |
| J0219+4506 | 0.05       | 0.09       | -0.03          | 0.00           | -0.02      | 0.12       |
| J0219+5623 | 0.05       | 0.09       | -0.03          | 0.00           | -0.02      | 0.11       |
| J1446+2955 | 0.05       | 0.08       | -0.03          | 0.00           | -0.02      | 0.11       |
| J1517+1026 | 0.05       | 0.05       | -0.02          | -0.00          | -0.02      | 0.09       |
| J1735+2650 | 0.05       | 0.08       | -0.03          | -0.00          | -0.02      | 0.09       |
| J1747+2228 | 0.05       | 0.08       | -0.03          | -0.00          | -0.02      | 0.09       |

**Table 4**

The Uncertainties of the Abundances
the derived abundances with respect to their results, we used the Moon spectrum to gain the solar parameter. The gained effective temperature, surface gravity, micro-turbulent velocity and metallicity are $T_{\text{eff}} = 5779$ K, $g = 4.35$, $\xi = 0.85$ km s$^{-1}$, and log $\epsilon(\text{Fe}) = 7.61$, respectively. Thus, when calculated the metallicity [Fe/H] of other stars, we subtracted a extra 0.11 dex for system correction. The final stellar abundances in the [$X$/H] are presented in Table 3 and abundance distributions are plotted in Figure 4, 5. Moreover, we overplotted the abundances of field stars from Bensby et al. (2014) and Venn et al. (2004) as comparison stars.

### 3.3. Error Analysis

To estimate abundance uncertainties due to errors associated with EWS measurements and stellar parameters, we analyzed the sensitivities of abundance to changes of each quantity separately with the others unchanged. Table 4 lists the abundance differences induced by changing the equivalent widths $\Delta$EW = 2.3 mA, effective temperature $\Delta T_{\text{eff}} = 100$ K, the surface gravity $\Delta\log g = 0.12$, the iron abundance $\Delta[\text{Fe/H}] = 0.11$ dex, and the micro-turbulent velocity $\Delta\xi = 0.1$ km s$^{-1}$, respectively. We took $\Delta$EW = 2.3 mA,

![Figure 6](image-url)  
**Figure 6.** Comparison of $[\alpha$/Fe] vs. [Fe/H] between $\gamma$ Leo moving group with other moving groups. The red filled circles are member stars of $\gamma$ Leo moving group. Black squares are member stars of Hercules moving group from Ramya et al. (2016). Diamond are member stars of the Sirius moving group from Tabernero et al. (2017). Triangles are member stars of the Hyades moving group from De Silva et al. (2011). Pluses and crosses are member stars of the AF66 and Arcturus moving group, respectively, from Ramya et al. (2012). See the text for details.
because the standard deviation of our measured EWs of the Moon spectrum with those of Bensby et al. (2014) is about 2.3 mÅ. The typical error in the stellar parameters $\Delta T_{\text{eff}}, \Delta \log g$ and $\Delta \xi$ are estimated based on our spectroscopic derivation, namely according to the slope changes. We took the $\Delta [\text{Fe}/\text{H}] = 0.11$ dex because the maximum random error of $[\text{Fe}/\text{H}]$ in the measurements is about 0.11 dex. Finally, we adopt the square root of the quadratic sum of the errors of all factors as the total error $\sigma_{\text{total}}$. We did not consider the NLTE effects which may cause larger scatter and overestimated abundances. As Table 4 shows, apart from the total error of Na abundance of a star (J0158+3955) that reaches 0.19 dex, the largest uncertainty is 0.14 dex. The titanium is more sensitive to changes of parameters than other elements, and the largest abundance error appears in the $\Delta [\text{Ti}]$ column for most stars. These uncertainties do not change the result of abundance distribution.

4. Result and Discussion

Figure 4 shows the abundance ratios of these elements for our sample and comparison stars. The metallicity of the 15 γ Leo moving group member stars ranges from $-0.67$ to 0.35. The mean value and standard deviation are, respectively, 0.03 and 0.24. The large dispersion demonstrates they are not from a chemically homogeneous origin.

α-elements (Mg, Si, Ca, and Ti) are mainly produced in Type II supernovae (SN II) nucleosynthesis, while iron is produced in both SN II and SN Ia events. The $[\alpha/\text{Fe}]$ ratio is a key chemical signature, because it well reflects the star formation history of the stellar system. As found in the comparison stars in solar neighborhood, all of these four α-elements abundances of 15 member stars show decreasing trend with increasing metallicity for lower metallicities, and they reach a plateau at higher metallicity (Edvardsson et al. 1993; Chen et al. 2000).

The α-elements abundance $[\alpha/\text{Fe}] = ([\text{Mg}/\text{Fe}]+[\text{Si}/\text{Fe}]+[\text{Ca}/\text{Fe}]+[\text{Ti}/\text{Fe}])/4$ ranges from −0.045 to 0.114. The mean and standard deviation of member stars’ α-elements abundances are 0.031 and 0.062, respectively. In Figure 6, we compared $[\alpha/\text{Fe}]$ with $[\text{Fe}/\text{H}]$ of γ Leo moving group with other known moving groups. The metallicity of the γ Leo moving group spreads a relatively large range. The dispersion of metal members’ α-elements abundance is large too, but it’s close to the Hyades moving group and AF06 moving group. At lower metallicity, the $[\alpha/\text{Fe}]$ distribution of the γ Leo moving group is similar to those of AF06 moving group, while at higher metallicity, the $[\alpha/\text{Fe}]$ distribution of the γ Leo moving group is close to the Hercules moving group.

Na and Al are odd-Z elements and thought to be produced in SN II and SN Ib/c (Nomoto et al. 1984). Though it’s not quite clear in Al, the Na distribution of member stars obviously shows a upturn (Edvardsson et al. 1993; Shi et al. 2004) in the comparison stars. Stars of the γ Leo moving group follow this trend, although the sample size of this study is still limited. Al lines of the star J2154+1418 are so weak that they are not included in our analysis. The iron-peak elements (Cr, Ni) are believed to have the same patterns as iron. The scatters of $[\text{Cr}/\text{Fe}]$ and $[\text{Ni}/\text{Fe}]$ of the member stars are small as the comparison stars. Y and Ba are light and heavy neutron-capture elements, respectively. The abundances of these elements in member stars have relatively large errors, and comparison stars distribute in a wider range. According to these chemical abundances, we suggest the stars of the γ Leo moving group are born in situ.

5. Conclusion

We have observed 18 candidates of the γ Leo moving group members selected by the UBV criteria from the LAMOST survey. Three stars are spectroscopic binaries and excluded from the sample. For the remaining 15 stars, a detailed abundance analysis is carried out. The abundance pattern of member stars shows no evident difference from those of comparison stars. The large dispersion of metallicity in member stars suggests that the γ Leo moving group is not from some chemically homogeneous origin. We suppose the γ Leo moving group is originated from dynamical effects, perhaps related to the effect of the spiral arms. For example, Figure 18 of Antoja et al. (2011) shows that it is possible that spiral arms can generate a structure at this velocity region. However, small variations of the simulation parameter can produce very different velocity structures. In the future, we will do some dynamical simulations to better understand the origin the γ Leo moving group.

The Gaia’s high-precision astrometric data brings great convenience to the study of moving groups in the solar neighborhood. Chemical abundances from high-resolution spectra play an important role in disentangling the degeneracy of many causes determining the local velocity structures.

We thank Bharat Kumar Yerra, Li Haining, Tan Kefeng, and Liu Yujuan for their constructive suggestions and discussions. This work is supported by the Astronomical Big Data Joint Research Center, co-founded by the National Astronomical Observatories, Chinese Academy of Sciences, and the Alibaba Cloud. This study is supported by the National Natural Science Foundation of China under grant Nos. 11390371, 11233004, U1431106, 11573035, 11625313, and 11603033, the National Key Basic Research Program of China (973 program), 2014CB845701 and 2014CB845703, and JSPS—CAS Joint Research Program. W.A. is partially supported by JSPS KAKENHI grant No. 16H02168.

ORCID iDs

X. L. Liang @ https://orcid.org/0000-0001-9283-8334
J. K. Zhao @ https://orcid.org/0000-0003-2868-8276
W. Aoki @ https://orcid.org/0000-0002-8975-6829
M. N. Ishigaki @ https://orcid.org/0000-0003-4656-0241
T. Matsuno @ https://orcid.org/0000-0002-8077-4617
Q. F. Xing @ https://orcid.org/0000-0003-6663-3100

References

Alonso, A., Arribas, S., & Martínez-Roger, C. 1995, A&A, 297, 197
Alonso, A., Arribas, S., & Martínez-Roger, C. 1996, A&A, 313, 873
Alonso, A., Arribas, S., & Martínez-Roger, C. 1999, A&AS, 140, 261
Antoja, T., Figueras, F., Romero-Gómez, M., et al. 2011, MNRAS, 418, 1423
Antoja, T., Helmi, A., Bienaymè, O., et al. 2012, MNRAS, 426, L1
Aoki, W., Honda, S., Beers., T., et al. 2005, ApJ, 632, 611
Asplund, M., Grevesse, N., Sauval, A. J., et al. 2009, ARA&A, 47, 481
Bensby, T., Feltzing, S., & Oey, M. S. 2014, A&A, 562, A71
Bensby, T., Zinn, R., Oey, M. S., & Feltzing, S. 2007, ApJL, 663, L13
Brown, A. G. A., Vallenari, A., Prusti, T., et al. 2016, A&A, 595, A2
Chen, Y. Q., Nissen, P. E., Zhao, G., Zhang, H. W., & Benoni, T. 2000, A&AS, 141, 49
Cui, X., Zhao, Y., Chu, Y., et al. 2012, RAA, 12, 1197
