A New Moving Group in the Local Arm

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Abstract

We present a new moving group clustered in kinematics, spatial position, and elemental abundances. Its spatial position is around the center of the Local Arm of the Milky Way. A convergent point method was taken to select candidate member stars. Among 206 candidate member stars, 74 are pre-main-sequence stars and some of them have stellar disks. We presume those pre-main-sequence stars belong to the Orion nebula. We suggest that this moving group is caused by the density wave of the Local Arm passing by.

Unified Astronomy Thesaurus concepts: Galaxy kinematics (602); Stellar associations (1582); Galaxy abundances (574)

1. Introduction

The existence of moving groups in the solar neighborhood has been known for over one century and they are believed to be from disrupted stellar clusters (Kapteyn 1905; Skuljan et al. 1997) at the beginning. Many moving groups got their names by their convergent points from a series of papers of Eggen, refer to Eggen (1996) for details. However, Dehnen (1998) pointed out that most moving groups in the solar neighborhood could be caused by orbital resonances. Later observations indicate dynamical effects of non-symmetric parts of the Galaxy may be responsible for most of the best known structures, such as the Sirius, Hyades, Pleiades, Hercules, and \(^\gamma\) Leo moving group (Famaey et al. 2005, 2007; Bensby et al. 2007; Famaey et al. 2008; Liang et al. 2018). With the Gaia DR2 data release, many new kinematic substructures in the solar neighborhood were found (Antoja et al. 2018; Katz et al. 2018; Ramos et al. 2018), which have been thought to be related to phase mixing. Nonetheless, there are still some moving groups belonging to dispersed stellar clusters. De Silva et al. (2007) concluded that the HR 1614 moving group is the remnant of a dispersed star-forming event according to its homogenous age and abundances. At least a part of the Sirius moving group is thought to be composed of remnants evaporated from a stellar cluster (Klement et al. 2008; Liang et al. 2017). Besides those known moving groups (Faherty et al. 2018), which might be parts of the larger kinematic picture, there are also many new moving groups lately found (Jose et al. 2008; Galli et al. 2013; Goldman et al. 2018; Röser et al. 2018; Yeh et al. 2019) close to star clusters or star-forming regions. As is known, clusters will disperse in response to many events such as sudden changes in mass driven by supernova or stellar wind, tidal interactions with the gravitational field, or internal relaxation. As clusters disperse, low-mass stars are preferentially lost, as they develop higher velocities than more massive cluster members. Some of the remnants of associations are becoming young moving groups before totally dissolving into the field, such as the Scorpius-Centaurus OB-association has been studied as a moving group for over a century. Many sophisticated codes have been developed to identify moving groups and their members as comprehensively as possible in the solar neighborhood such as the All Sky Young Association (ASYA; Torres et al. 2016), LocAting Constituent mEmbers In Nearby Groups (LACEwING; Riedel et al. 2017), and Bayesian Analysis for Nearby Young AssociatioNs (BANYAN; Gagné et al. 2014, 2016, 2018; Malo et al. 2014). However, the identification of star members of moving groups is not easy by only kinematics and photometry. It had better include additional chemical information. The chemical tagging technique (Freeman & Bland-Hawthorn 2002) is a credible way to judge whether a moving group originated from a stellar cluster. Some well-known moving groups have been studied with detailed chemical abundances from high-resolution spectra (Bensby et al. 2007; De Silva et al. 2007, 2011, 2013; Bubar & King 2010; Biazzo et al. 2012; Tabernero et al. 2012, 2017; Montes et al. 2016; Liang et al. 2018; Zhao et al. 2018). However, the number of stars that can be observed with high-resolution spectroscopy is still small. Therefore we turned to machine learning to obtain elemental abundances from low-resolution spectra.

The Orion complex is the nearest site of the active star-forming region and it contains multiple stellar populations and complex substructures such as clusters, OB associations, and young stellar moving groups. Within star-forming Orion A and B molecular clouds, there are massive star clusters such as the Orion nebula cluster, NGC 2024, and NGC 2068. The Orion nebula cluster is significantly younger than other regions in Orion A, while Orion A is younger than the still larger Orion D region. Consequently, there is a gradient of increasing mean age and age spread as one moves from denser to less dense regions (Getman et al. 2014, 2018; Zari et al. 2019). Star-forming regions are hierarchically structured, containing both dense parts for which mass removal is slow compared to the local dynamical time, and diffuse parts for which it is fast (Krumholz et al. 2019). Kounkel et al. (2018) found that the Orion D group is in the process of expanding while Orion B is still in the process of contraction. Kounkel et al. (2018) also found that the proper motions of \(\lambda\) Ori are consistent with a radial expansion due to an explosion from a supernova. Zari et al. (2019) confirmed multiple events caused kinematic and...
physical structure rather than a simple sequential scenario. There are runaway stellar groups while there are stars going through gravitational infall (Getman et al. 2019; McBride & Kounkel 2019). Substructures inside the Orion nebula have been comprehensively studied by former researchers and they are not analyzed in this paper.

In Section 2, we describe the data and method used to identify a moving group. Section 3 presents candidate member stars of the newly found moving group in parameter space. In Section 3.4, we compared the newfound moving group with the known young stellar moving group OrionX. Finally, the main outcomes of our work and perspectives for the future are summarized in Section 4.

2. Data and Method

The data we used are 657,561 stars with machine-learning chemical abundances from the target sample from Liang et al. (2019), which are common stars of the LAMOST DR5 catalog (Zhao et al. 2012; Luo et al. 2015) cross-matched with the Gaia DR2 (Gaia Collaboration et al. 2018) catalog after the removal of duplicated sources. The Large sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is a national major scientific project built by the Chinese Academy of Sciences. They are mainly G, K giants with $T_{\text{eff}}$ between 4000 K and 5500 K. With parallax and proper motion from Gaia and radial velocity from LAMOST, three-dimensional velocity components for the stars were obtained. We calculated position $xyz$ and their velocity components $UVW$ in the right-handed rectangular coordinate system with origin at the Galactic center and axis parallel to the local standard of rest (LSR). In this coordinate system, the $x$-axis points from the Sun toward the Galactic center, the $y$-axis points along the direction of Galactic rotation of the LSR, and the $z$-axis points toward the north Galactic pole. The Sun is placed at a height of $z = 0.014$ kpc (Binney et al. 1997) and the Galactic radius is $R = 8.34$ kpc with the circular rotation speed of $V_c = 240$ km s$^{-1}$ (Reid et al. 2014). The peculiar velocities of the Sun with respect to the LSR are taken as $(11.1, 12.24, 7.25)$ km s$^{-1}$ (Schönrich et al. 2010). To show overdensities in the velocity space, the wavelet transform technique (Liang et al. 2017) is adopted. Since velocity substructures of stars within 200 pc have been studied extensively (Faherty et al. 2018), we choose to look into stars a little further away. We selected a sample of 32,111 stars with $-8.54$ kpc $> x > -9.04$ kpc, $|y| < 0.5$ kpc, and $|z| < 0.5$ kpc.

A convergent point method (Brown 1950; Jones 1971) has been used to select the member stars of a moving group. The classical convergent point method is based on the common space motion of member stars in a moving group resulting in converging proper motions, and many moving groups got their names from the convergent point. But our method is a little different from the classical convergent point method. We adopted all three components of velocity converging in a real position rather than two proper-motion components converging in a projected point on the celestial sphere. Our method mainly includes two steps. First we calculated the sum of the distance from a given point to the reverse extension line of each star’s velocity vector over all stars in the data sample and then minimized the sum to obtain the convergent point. After this, we removed those stars with the largest distances, which apparently do not belong to the new moving group. The procedure was repeated until the largest distance dropped in an acceptable range. Subsequently, all non-rejected stars are identified as members. Thus this procedure simultaneously determined member stars and the convergent point, which might imply the birth place. This method assumes that all member stars are moving away from one point. In fact strict convergence to one point is not necessary because of measurement errors and the internal velocity dispersion of a moving group.

3. New Moving Group

3.1. Count Density in the $U$, $V$ Coordinate

In Figure 1, the left subplot shows a contour of the wavelet transform of the $U$, $V$ density distribution of the selected star sample, while the right subplot shows the contour of the wavelet transform of the $U$, $V$ density distribution of the selected star sample without pre-main-sequence stars (explained later). The median uncertainties values of $U$, $V$, and $W$ are respectively 3.7, 3.3, and 2.5 km s$^{-1}$ of the selected star sample. The spatial region of this selected sample is similar to region 3 in Liang et al. (2017) and it contains the spatial region of V6 from Ramos et al. (2018). Therefore our contours look very similar to subplot (b) of Figure 5 of Liang et al. (2017) and subplot (f) of Figure 5 of Ramos et al. (2018).
However, the peak around \((0, 7)\) km s\(^{-1}\) in our figure is much more significant than theirs, which are only in dense regions but are not density peaks. We call it a new moving group candidate since it is so obvious for the first time. The difference between our data and Liang et al. (2017) lies in that this sample is selected from LAMOST DR5 cross-matched with Gaia DR2 rather than Gaia DR1 TGAS. The Tycho-Gaia Astrometric Solution (TGAS) is a primary astrometric data set of Gaia DR1, which contains the positions, parallaxes, and mean proper motions for about two million of the brightest stars in common with the Hipparcos and Tycho-2 catalogues. The difference between our data and Ramos et al. (2018) mainly lies in that Ramos et al. (2018) used the Gaia DR2 sample and we used only G.K giants with radial velocity from LAMOST. There are about 1868 stars around the peak in the \(UV\) coordinate of our sample. After we applied the convergent point method we got 206 stars as candidate members in which 74 stars are pre-main-sequence stars. Velocity directions of those stars at first. However, as the right subplot in Figure 1 shows, that overdensity peak is still there after we removed those pre-main-sequence stars at\(x, y, z\) = (\(-8.70, –0.15, –0.12\)) kpc. As shown in Figure 1, those points in the left subplot are selected candidate members in which the red dots represent normal giants while the blue dots represent the pre-main-sequence stars. Pre-main-sequence stars take up about one-third of the candidate members, therefore we thought this overdensity might be caused by pre-main-sequence stars at first. However, as the right subplot in Figure 1 shows, that overdensity peak is still there after we removed those pre-main-sequence stars. Thus we think pre-main-sequence stars only contribute partly to the number density peak in that velocity region.

### 3.2. Effective Temperature and Gravitational Acceleration

Figure 2 shows the \(T_{\text{eff}}\) versus \(\log g\) distribution of the candidate members. The red dots represent normal giants and the blue dots represent pre-main-sequence stars for all of the figures in this paper. To make sure the pre-main-sequence stars are rightly classified, we checked the spectra of those stars at the region of the pre-main-sequence stars in Figure 2. Those apparently not pre-main-sequence stars were kicked out as normal stars. Spectra of those pre-main-sequence stars have hydrogen emission lines and some have forbidden lines of elements like nitrogen, sulfur, and so on. Table 1 lists our

![Figure 2. \(T_{\text{eff}}\) vs. \(\log g\) distribution of candidate members.](image-url)
measured equivalent widths of lithium 6707 Å along with the signal-to-noise ratio in the r band (snrr) from the LAMOST spectra. Since we used low-resolution spectra, those equivalent widths are very rough estimations. Those pre-main-sequence stars are naturally much younger than G, K giants. We speculate that they are clustered together for different reasons.

### 3.3. Chemical Abundances

Figure 3 shows the $\alpha/M$ versus $[M/H]$ distribution of candidate members of the new moving group. The median metallicity value of pre-main-sequence stars is $-0.506$ while the median metallicity value of giants is $-0.068$. There is a $-0.438$ dex difference between them but metallicity values of pre-main-sequence stars usually have been systematically underestimated. According to spatial positions, those pre-main-sequence stars should belong to that Orion nebula and their metallicity should be the solar abundance. For the spectra of many pre-main-sequence stars, there are emission lines within absorption lines and some lines become totally emission lines. Since the neural network in Liang et al. (2019) is dominated by most stars with absorption lines, elemental abundances shall be wrongly estimated for stars with emission lines. Figure 4 shows parts of spectral features of a pre-main-sequence star of member stars as an example. Those forbidden lines and wide Hα line indicate that this star may have a stellar disk.

In Figure 5, we show other elemental abundance distributions of candidate members of this new moving group. The red dots are candidate member stars, the blue dots are pre-main-sequence stars, and the background gray dots are all stars around the density peak of wavelet transform as a comparison. It’s clear that elemental abundance distributions of candidate members are too scattered to be from a cluster. Chemical distributions of those pre-main-sequence stars cluster together although there might be systematic errors for each elemental abundance. Since those pre-main-sequence stars should all come from the Orion nebula, their elemental abundances should be like solar abundances. Each emission line has a different effect on different elements, therefore chemical abundances of pre-main-sequence stars have been wrongly estimated in various degrees relative to solar abundances. Since the neural network in Liang et al. (2019) is not specially designed for pre-main-sequence stars, abundances for pre-main-sequence stars are not accurate but their elemental abundances do clump together. Thus we suggest that machine learning can be used to classify pre-main-sequence stars. For those giants of the moving group, they are not from a stellar cluster. We think they have been clustered before pre-main-sequence stars were born by some other reason.

### 3.4. Spatial Distribution and Other Velocity Distributions

Figure 6 shows distributions of candidate members in spatial coordinates and other velocity coordinates. The top two subplots respectively show $y$ versus $x$ and $z$ versus $x$, while the bottom two subplots respectively show $W$ versus $U$ and $W$ versus $V$. The green dots represent member stars of OrionX from Bouy & Alves (2015), while the black dots represent stars listed in the Appendix of Kos et al. (2019), which shows the spatial position of Orion nebula. It can be seen that those blue pre-main-sequence stars distribute more compactly than red normal giants and that they are surrounded by normal giants in both spatial coordinates and velocity coordinates. According to spatial positions, those pre-main-sequence stars should belong to the Orion nebula. Pre-main-sequence stars in a star-forming region, such as the Orion nebula, have been extensively studied by former research. Therefore, this paper focuses on G, K giants of candidate members that have not been studied. The black curve in the $y$ versus $x$ subplot represents the center of the Local Arm of our Galaxy from Reid et al. (2014). As can be seen, those candidate members are around the center of the Local Arm. We think this new moving group should be related to the Local Arm. Those pre-main-sequence stars from the new moving group are experiencing diffusion from their birth place, while for those G, K giants it could be a density wave that drove them to be there with clumped velocity. Now candidate members of the new moving group are moving away from the convergent point.

### 3.5. Comparison with OrionX

Figure 7 presents candidate members in the Galactic coordinate where the abscissa is the Galactic longitude and the ordinate is the Galactic latitude. The red dots represent normal giant stars, the blue dots represent pre-main-sequence stars, and the green dots represent member stars of OrionX from Bouy & Alves (2015). OrionX is an young stellar moving group (mainly young O, B type stars) close to the Orion nebula. It is obvious that those pre-main-sequence stars are very close

### Table 1

(Continued)

| Obs. ID | EW (mA) | snrr |
|--------|---------|------|
| 505210149 | 660.85759 | 234.05 |
| 505215016 | 559.57665 | 223.75 |
| 505215049 | 623.60200 | 214.47 |
| 505210051 | 658.80352 | 79.08 |
| 505215016 | 629.24914 | 134.43 |
| 505209051 | 682.32856 | 98.52 |
| 505209122 | 713.66930 | 134.43 |
| 553606212 | 599.17672 | 119.65 |
| 553608180 | 699.95209 | 150.53 |
| 553608236 | 642.95106 | 52.61 |

Figure 3. $\alpha/M$ vs. $[M/H]$ distribution of candidate members. Red dots are G, K giants while blue points are pre-main-sequence stars.
to OrionX in the Galactic coordinate and they are all inside the sky range of those G, K giants. It is known that moving groups can originate from the diffusion/evaporation of clusters. Therefore we speculate that pre-main-sequence stars of the new moving group are parts of star diffusion. Young stars move away from their birth place along with old stars, which were gathered there by a density wave, so that when the spiral arm moves away, the old star birth region can change to be less dense as a non-arm region. It is natural to think that when the peak of the density wave comes, matter gathering together might have stimulated star-forming events (Roberts 1969).

The left subplot of Figure 8 presents candidate members in the proper-motion coordinate, where the abscissa is the proper motion in R.A. and the ordinate is the proper motion in decl. The red dots represent normal giant stars, the blue dots represent pre-main-sequence stars of our candidate members, the green dots represent member stars of OrionX from Bouy & Alves (2015), and the black dots represent member stars of ASCC 16, ASCC 18, ASCC 20, ASCC 21, and ASCC 21a from Kos et al. (2019). There is one common pre-main-sequence star between our candidate members and ASCC21. Stars from Kos et al. (2019) are basically enclosed by OrionX and our pre-main-sequence stars are enclosed by our giants. Our pre-main-sequence stars have larger dispersion than Kos et al. (2019) because their stars were born in the Orion nebula recently while our stars have started moving away. The right subplot of Figure 8 presents candidate members in the $M_G$ versus $G_{bp} - G_{rp}$ coordinate, and $M_G$, $G_{bp}$, and $G_{rp}$ are absolute magnitudes. For stars from Kos et al. (2019), we set the extinction to $A_v = 0.25$ as they did in that paper. For other stars, extinctions were obtained from the Gaia DR2 catalog if provided, and if not provided, extinctions were obtained from Galactic Dust Reddening and Extinction website$^4$ (Schlafly & Finkbeiner 2011). The color–magnitude diagram shows that our pre-main-sequence stars and OrionX may have similar ages as to the stars from Kos et al. (2019). Parts of our giants are very close to the distribution region of the black dots while

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$^4$ http://irsa.ipac.caltech.edu/applications/DUST/
Figure 5. Abundance distributions of candidate members. Red dots are G, K giants while blue dots are pre-main-sequence stars.
Figure 6. Spatial and other velocity distributions of candidate members.

Figure 7. Distribution of candidate members in the Galactic coordinate.
other are apparently field stars. In a word, we think that pre-
main-sequence stars of the new moving group came out of the
Orion nebula and that they are moving away with OrionX and
giants of the new moving group driven by a density wave.

4. Conclusion

In summary, we detected a new moving group from the cross-
matched G, K giant star sample between the LAMOST DR5
catalog and the Gaia DR2 catalog and candidate member stars
gathered in spatial position, kinematics, and chemical abundances
catalog and the Gaia DR2 catalog and candidate member stars
matched G, K giant star sample between the LAMOST DR5
giants of the new moving group driven by a density wave.

In the star-forming region. In the future, we hope to explore how
density waves affect all those star-forming regions.

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References
Antoja, T., Helmi, A., & Romero-Gómez, M. 2018, Nat., 561, 360
Bensby, T., Zinn, A. R., Oey, M. S., & Feltzing, S. 2007, ApJ, 663, L13
Biazzo, K., D’Orazi, V., Desidera, S., et al. 2012, MNRAS, 427, 2905
Binney, J., Gerhard, O., & Spergel, D. 1997, MNRAS, 288, 365
Bouy, H., & Alves, J. 2015, A&A, 584, A26
Brown, A. 1950, ApJ, 112, 225
Bubar, E. J., & King, J. R. 2010, AJ, 140, 293
De Silva, G. M., D’Orazi, V., Melo, C., et al. 2013, MNRAS, 431, 1005
De Silva, G. M., Freeman, K. C., Bland-Hawthorn, J., et al. 2007, AJ, 133, 694
De Silva, G. M., Freeman, K. C., Bland-Hawthorn, J., et al. 2011, MNRAS, 415, 563
Dehnen, W. 1998, AJ, 115, 2384
Eggen, O. J. 1996, AJ, 111, 1615
Faherty, J. K., Bochanski, J. J., Gagné, J., et al. 2018, ApJ, 863, 91
Famaey, B., Jorissen, A., Luri, X., et al. 2005, A&A, 430, 165
Famaey, B., Pont, F., Luri, X., et al. 2007, A&A, 461, 957
Famaey, B., Siebert, A., & Jorissen, A. 2008, A&A, 483, 453
Freeman, K., & Bland-Hawthorn, J. 2002, ARA&A, 40, 487
Gagné, J., Lafrenière, D., Doyon, R., et al. 2014, ApJ, 783, 121
Gagné, J., Lafrenière, D., Doyon, R., et al. 2016, in IAU Symp. 314, Young
Stars Planets Near the Sun, ed. J. H. Kastner, B. Stelzer, & S. Metchev
(Cambridge: Cambridge Univ. Press), 49
Gagné, J., Mamajek, E. E., Malo, L., et al. 2018, ApJ, 856, 23
Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2018, A&A, 616, A1
Galli, P. A. B., Bertout, C., Teixeira, R., et al. 2013, A&A, 558, A77
Getman, K. V., Feigelson, E. D., & Kuhn, M. A. 2014, ApJ, 787, 109
Getman, K. V., Feigelson, E. D., Kuhn, M. A., et al. 2018, MNRAS, 476, 1213
Getman, K. V., Feigelson, E. D., Kuhn, M. A., & Garnire, G. P. 2019, MNRAS, 487, 2977
Goldman, B., Röser, S., Schilbach, E., et al. 2018, ApJ, 868, 32
Jones, D. H. P. 1971, MNRAS, 152, 231
Jose, J., Pandey, A. K., Ohja, D. K., et al. 2008, MNRAS, 384, 1675
Kapteyn, J. C. 1905, KNAB, 8, 691
Katz, D., Antoja, T., Romero-Gómez, M., et al. 2018, A&A, 616, A11
Klement, R., Fuchs, B., & Rix, H.-W. 2008, ApJ, 685, 261
Kovács, J., Bland-Hawthorn, J., Asplund, M., et al. 2019, A&A, 631, A166
Kounkel, M., Covey, K., Suárez, G., et al. 2018, AJ, 156, 84
Krumholz, M. R., McKee, C. F., & Bland-Hawthorn, J. 2019, ARA&A, 57, 227
Liang, X., Zhao, J., Chen, Y., et al. 2019, ApJ, 887, 193
Liang, X., Zhao, J., Osawa, T. D., et al. 2017, ApJ, 844, 152
Liang, X., Zhao, J. K., Zhao, G., et al. 2018, ApJ, 863, 4
Luo, A.-L., Zhao, Y.-H., Zhao, G., et al. 2015, RAA, 15, 1095
Malo, L., Artigau, É., Doyon, R., et al. 2014, ApJ, 788, 81
McBride, A., & Kounkel, M. 2019, ApJ, 884, 6

Figure 8. Distribution of candidate members in the proper-motion coordinate and the color–magnitude diagram.
Montes, D., Tabernero, H. M., & González Hernández, J. I. 2016, in IAU Symp. 314, Young Stars Planets Near the Sun, ed. J. H. Kastner, B. Stelzer, & S. Metchev (Cambridge: Cambridge Univ. Press), 37
Ramos, P., Antoja, T., & Figueras, F. 2018, A&A, 619, A72
Reid, M. J., Menten, K. M., Brunthaler, A., et al. 2014, ApJ, 783, 130
Riedel, A. R., Blunt, S. C., Lambrides, E. L., et al. 2017, AJ, 153, 95
Roberts, W. W. 1969, ApJ, 158, 123
Röser, S., Schilbach, E., Goldman, B., et al. 2018, A&A, 614, A81
Schlafl y, E. F., & Finkbeiner, D. P. 2011, ApJ, 737, 103
Schönrich, R., Binney, J., & Dehnen, W. 2010, MNRAS, 403, 1829
Skuljan, J., Cottrell, P. L., & Hearnshaw, J. B. 1997, ESASP, 402, 525

Torres, C. A. O., Quast, G. R., & Montes, D. 2016, in IAU Symp. 314, Young Stars Planets Near the Sun, ed. J. H. Kastner, B. Stelzer, & S. Metchev (Cambridge: Cambridge Univ. Press), 77
Yeh, F. C., Carraro, G., Montalto, M., et al. 2019, AJ, 157, 115
Zari, E., Brown, A. G. A., & de Zeeuw, P. T. 2019, A&A, 628, A123
Zhao, G., Zhao, Y. H., Chu, Y. Q., et al. 2012, RAA, 12, 723
Zhao, J. K., Zhao, G., Aoki, W., et al. 2018, ApJ, 868, 105