RAA 2014 Vol. **14** No. **2**, 159–164 doi: 10.1088/1674–4527/14/2/004
http://www.raa-journal.org *http://www.iop.org/journals/raa*

Research in Astronomy and Astrophysics

Membership determination of open cluster NGC 188 based on the DBSCAN clustering algorithm

Xin-Hua Gao

School of Information Science and Engineering, Changzhou University, Changzhou 213164, China; *mativestar@163.com*

Received 2013 September 26; accepted 2013 October 15

Abstract High-precision proper motions and radial velocities of 1046 stars are used to determine member stars using three-dimensional (3D) kinematics for open cluster NGC 188 based on the density-based spatial clustering of applications with noise (DBSCAN) clustering algorithm. By implementing this algorithm, 472 member stars in the cluster are obtained with 3D kinematics. The color-magnitude diagram (CMD) of the 472 member stars using 3D kinematics shows a well-defined main sequence and a red giant branch, which indicate that the DBSCAN clustering algorithm is very effective for membership determination. The DBSCAN clustering algorithm can effectively select probable member stars in 3D kinematic space without any assumption about the distribution of the cluster or field stars. Analysis results show that the CMD of member stars is significantly clearer than the one based on 2D kinematics, which allows us to better constrain the cluster members and estimate their physical parameters. Using the 472 member stars, the average absolute proper motion and radial velocity are determined to be (PM$_\alpha$, PM$_\delta$) $= (-2.58 \pm 0.22, +0.17 \pm 0.18)$ mas yr^{-1} and $V_r = -42.35 \pm 0.05$ km s^{-1}, respectively. Our values are in good agreement with values derived by other authors.

Key words: Galaxy: open clusters and associations: individual (NGC 188) — stars: kinematics — Hertzsprung-Russell diagram — techniques: radial velocities

1 INTRODUCTION

Open clusters have long been regarded as powerful tools for studies of the Galactic disk and evolution of stars (Friel 1995; Hou et al. 2002; Chen et al. 2003). Membership determination is the first step to study an open cluster, which can directly influence estimation of physical parameters. Various methods have been used for membership determination based on proper motions, radial velocities, photometric data and their combination (Vasilevskis et al. 1958; Sanders 1971; Zhao & He 1990; Wu et al. 2006; Zhao et al. 2006; Gao & Chen 2010). In general, there are two main types of independent methods for membership determination: photometric and kinematic (Cabrera-Cano & Alfaro 1990). Membership derived based on a kinematic method (proper motions or radial velocities) is generally believed to more reliable, because the kinematic method can be established on the basis of strict mathematical models, so that model parameters and membership probabilities can be easily obtained.

The theoretical foundation for the kinematic method is that member stars of an open cluster share similar spatial motions and proper motions, and that radial velocity distributions of cluster and field stars are assumed to follow a gaussian distribution. However, the assumption of a gaussian distribution is not always true. The method of using kinematics to assign memberships will fail when the cluster-to-field star ratio is small (Cabrera-Cano & Alfaro 1990) or centroids of cluster or field stars are too close to be segregated (Javakhishvili et al. 2006; Gao & Chen 2010). This method also becomes ineffective when there is significant internal motion or rotation in a cluster (Slovak 1977; Javakhishvili et al. 2006).

In this paper, we attempt to identify member stars using 3D kinematics of open cluster NGC 188 using the DBSCAN clustering algorithm (Ester et al. 1996). The DBSCAN clustering algorithm can find arbitrarily shaped clusters in parameter space that are affected by background noise. 3D kinematic data allow us to obtain a rather pure sample of cluster members, and moreover, the effectiveness of membership determination with DBSCAN will be examined.

2 DATA AND METHOD

2.1 Data

A kinematic method needs high-precision kinematic data (proper motions or radial velocities), but few open clusters have a large, homogeneous set of radial velocities. NGC 188 ($l = 122.9°$, $b = +22.4°$) is one of the oldest open clusters (Bonatto et al. 2005; Fornal et al. 2007; Meibom et al. 2009). NGC 188 was selected by the WIYN open cluster study (WOCS; Mathieu 2000) as a target. High-precision astrometry data have been obtained using old photographic plates from various large aperture reflectors in combination with a collection of CCD frames (Platais et al. 2003). A new catalog of proper motions and positions for 7812 objects down to $V = 21$ mag in the 0.75 deg^2 area around NGC 188 has been obtained. The highest precision for proper motion of well-measured stars is 0.15 mas yr^{-1}. High-precision proper motions are advantageous for membership determination, and high-precision radial velocities for 1046 stars in the direction of NGC 188 have also been measured (Geller et al. 2008). The brightest stars are measured to a precision of 0.25 km s^{-1} while the precision of the faintest stars is 0.55 km s^{-1}. By cross-matching the two catalogs, 1046 stars with high-precision proper motions and radial velocities are obtained. The 1046 stars will be used for membership determination based on the density-based spatial clustering of applications with noise (DBSCAN) clustering algorithm in 3D kinematic space.

2.2 Membership Determination

DBSCAN is a widely used clustering algorithm, which requires just two input parameters: the search radius (Eps) and the minimum number of points required to form a cluster (MinPts). It begins with an arbitrary starting point. The point's Eps-neighborhood is retrieved, and if it contains a sufficient number of points, a cluster forms. The DBSCAN algorithm does not require one to specify the number of clusters, and it can find arbitrarily shaped clusters in parameter space. If a point has more than the specified number of points ($\geq$ MinPts) within its defined Eps-neighborhood, it is a "core point." If a point has fewer points ($<$ MinPts) in its Eps-neighborhood, but it is in the Eps-neighborhood of a core point, then it is a "border point." A "noise point" is any point that is neither a core point nor a border point. In general, a core point contains significantly larger number of points in its Eps-neighborhood than a border point. For open clusters, a core point can reasonably be regarded as a member star while a border or noise point can be regarded as a field star.

According to the proper motions and radial velocity distribution of the 1046 stars, the input parameters (MinPts, Eps) are set to (25, 1). It must be noted that the coverage of radial velocities is much larger than that of proper motions, and it is obvious that different scales between radial velocities and proper motions will affect the outcome of clustering with DBSCAN. In order to make proper motions and radial velocities have roughly the same scale, all radial velocities are multiplied by a factor of 0.2. Finally, 472 core points are obtained by the DBSCAN clustering algorithm, all of which can be regarded as member stars of NGC 188.

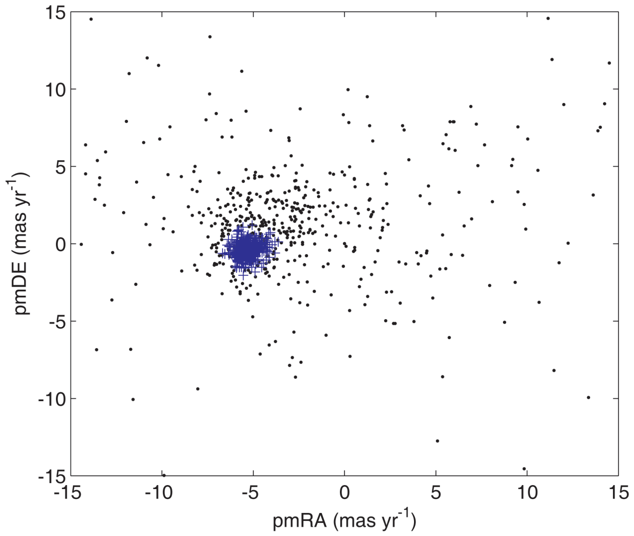

Fig. 1 Vector point diagram showing the proper motion of 472 member stars derived by the DBSCAN clustering algorithm. The pluses indicate 472 member stars, and the dots denote 574 field stars.

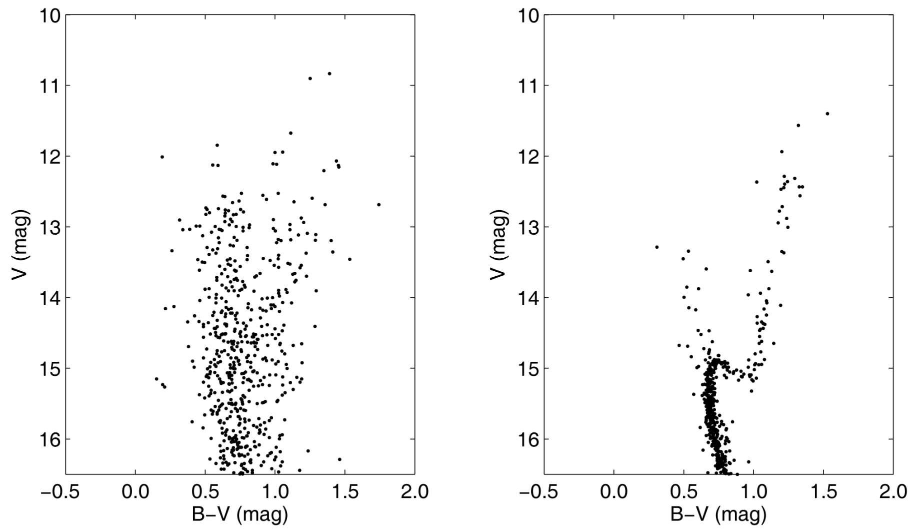

Fig. 2 (*Left*) CMD of 574 field stars. (*Right*) CMD of 472 member stars based on 3D kinematics.

The vector point diagram (VPD) of proper motion for the 1046 stars can be seen in Figure 1. The 472 member stars show a more compact distribution in the VPD than the 574 field stars. We also plot the color-magnitude diagram (CMD) for the 574 field stars and the 472 member stars (see Fig. 2), and it can be seen that the CMD of the 472 member stars shows a well-defined main sequence and a red giant branch. A few blue stragglers can also be seen from the CMD, and they are more luminous and bluer than stars at the main sequence turn-off point (see Fig. 2).

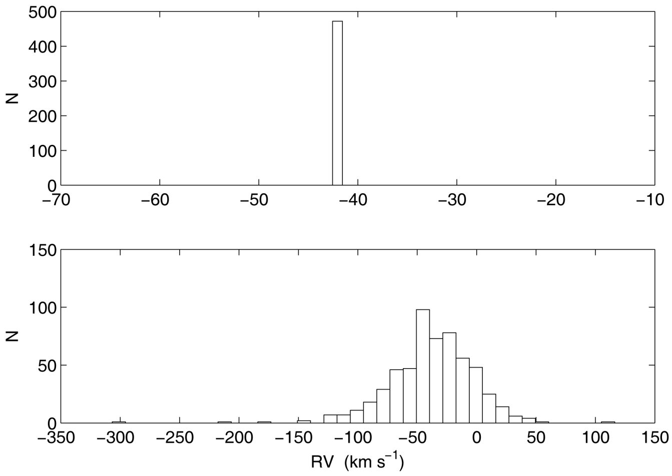

Fig. 3 (*Top*) Radial velocity histogram of 472 member stars based on 3D kinematics. (*Bottom*) Radial velocity histogram of 574 field stars.

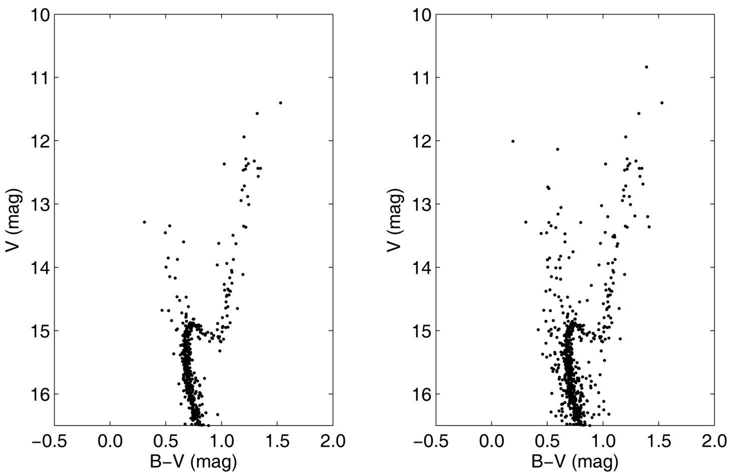

Fig. 4 (*Left*) CMD of 472 member stars based on 3D kinematics derived in the 3D kinematic space. (*Right*) CMD of 651 member stars derived in the 2D kinematic space.

The distribution of radial velocities for member and field stars can be seen in Figure 3, where all member stars share similar radial velocities. Among our 472 member stars, 435 stars are determined to have a high probability of membership (Prb>0.7) in the catalog of Platais et al. (2003). When comparing our 472 member stars with the catalog of Geller et al. (2008), we find that the number of stars with membership probabilities higher than 0.7 is 401. We can reasonably conclude that these 472 core points determined by the DBSCAN clustering algorithm are very likely to be member stars of NGC 188.

The same input parameters (MinPts, Eps)= (25, 1) are used to determine membership in 2D kinematic space (proper motion), and 651 member stars based in 2D kinematics (core points) are obtained. Theoretically speaking, 3D kinematic space can provide a better constraint for membership determination. It can be seen from Figure 4 that the main sequence and red giant branch of member stars based on 3D kinematics are significantly clearer than member stars based on 2D kinematics.

Using the 472 members, an average absolute proper motion (-5.33 ± 0.02, -0.42 ± 0.02) mas yr^{-1} is derived. After subtracting the average proper motion of 70 galaxies (-2.75 ± 0.22, -0.59 ± 0.18) mas yr^{-1} as described by Platais et al. (2003), the absolute proper motion of NGC 188 is determined to be (PM$_\alpha$, PM$_\delta$)=(-2.58 ± 0.22, $+0.17 \pm 0.18$) mas yr^{-1}. The radial velocity $V_r = -42.35 \pm 0.05$ km s^{-1} is also obtained based on the 472 member stars. Our absolute proper motion and radial velocity agree well with values determined by other authors (Platais et al. 2003; Geller et al. 2008).

3 CONCLUSIONS AND DISCUSSION

Membership determination is a very important step for the study of open clusters. By applying a new method, the DBSCAN clustering algorithm, 472 member stars are selected from 1046 stars in the direction of open cluster NGC 188. The CMD of the 472 3D kinematic member stars shows a well-defined main sequence and red giant branch, which indicates that our membership determination is very effective.

Compared with the CMDs of 3D (proper motion and radial velocity) and 2D (proper motion) kinematic member stars, we find that member stars based on 3D kinematics show a clearer main sequence and red giant branch in their CMD. 3D kinematic space allows us to better constrain the cluster members and estimate their fundamental parameters. Using the 472 member stars, the absolute proper motion and radial velocity of the cluster are determined to be (PM$_\alpha$, PM$_\delta$)=(-2.58 ± 0.22, $+0.17 \pm 0.18$) mas yr^{-1} and $V_r = -42.35 \pm 0.05$ km s^{-1}, respectively.

The kinematic method for membership determination is based on strict mathematical models. Cluster and field stars are generally assumed to follow gaussian distributions.

- The DBSCAN clustering algorithm is insensitive to the shape of clusters, and it can effectively segregate cluster members without any mathematical models or assumptions about the distribution of stars.
- The DBSCAN clustering algorithm is sensitive to density, so that the input parameters (MinPts, Eps) can have an impact on the results.

Generally speaking, the DBSCAN clustering algorithm has some advantages over the kinematic method, but it cannot obtain membership probabilities for individual stars.

Acknowledgements We are very grateful to the anonymous referee for many useful comments and suggestions, which helped us to substantially improve the manuscript. We also thank Prof. Li Chen from Shanghai Astronomical Observatory for his helpful comments. This work is supported by the School Foundation of Changzhou University (Grant No. ZMF1002121).

References

Bonatto, C., Bica, E., & Santos, J. F. C., Jr. 2005, A&A, 433, 917
Cabrera-Cano, J., & Alfaro, E. J. 1990, A&A, 235, 94
Chen, L., Hou, J. L., & Wang, J. J. 2003, AJ, 125, 1397
Ester, M., Kriegel, H., Sander, J., & Xu, X. 1996, in Proceedings of the Second International Conference on Knowledge Discovery and Data Mining, 96, 226
Fornal, B., Tucker, D. L., Smith, J. A., et al. 2007, AJ, 133, 1409
Friel, E. D. 1995, ARA&A, 33, 381
Gao, X.-H., & Chen, L. 2010, RAA (Research in Astronomy and Astrophysics), 10, 761

Geller, A. M., Mathieu, R. D., Harris, H. C., & McClure, R. D. 2008, AJ, 135, 2264
Hou, J.-L., Chang, R.-X., & Chen, L. 2002, ChJAA (Chin. J. Astron. Astrophys.), 2, 17
Javakhishvili, G., Kukhianidze, V., Todua, M., & Inasaridze, R. 2006, A&A, 447, 915
Mathieu, R. D. 2000, in ASPC, 198, Stellar Clusters and Associations: Convection, Rotation, and Dynamos, eds. R. Pallavicini, G. Micela, & S. Sciortino, 517
Meibom, S., Grundahl, F., Clausen, J. V., et al. 2009, AJ, 137, 5086
Platais, I., Kozhurina-Platais, V., Mathieu, R. D., Girard, T. M., & van Altena, W. F. 2003, AJ, 126, 2922
Sanders, W. L. 1971, A&A, 14, 226
Slovak, M. H. 1977, AJ, 82, 818
Vasilevskis, S., Klemola, A., & Preston, G. 1958, AJ, 63, 387
Wu, Z.-Y., Zhou, X., Ma, J., Jiang, Z.-J., & Chen, J.-S. 2006, PASP, 118, 1104
Zhao, J. L., & He, Y. P. 1990, A&A, 237, 54
Zhao, J.-L., Chen, L., & Wen, W. 2006, ChJAA (Chin. J. Astron. Astrophys.), 6, 435