Mass determination of open clusters using kinematics data

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Abstract. We estimate the mass of three open clusters, NGC 2168, NGC 188, NGC 6819, using kinematics data of open cluster stars member. Radial velocity data determined from WIYN survey and proper motion determined from Gaia DR2. Using virial theorem and projected-mass estimator method we estimate the mass of star open clusters. Both methods give a reasonable result for all clusters mass. The accuracy of estimated mass affected by some parameters such as membership probability of stars sample, the distance, age, and angular radius of open clusters. We estimate the mass of clusters within a central radius of the cluster. The mass of open clusters using virial theorem is 4056 M\textsubscript{\odot} (d < 7 pc) for NGC 2168, 2776 M\textsubscript{\odot} (d < 8 pc) for NGC 188, and 4244 M\textsubscript{\odot} (d < 1.6 pc) for NGC 6819. Using projected mass estimator we get 5833 M\textsubscript{\odot} (d < 7 pc) for NGC 2168, 3326 M\textsubscript{\odot} (d < 8pc) for NGC 188, and 3518 M\textsubscript{\odot} (d < 1.6pc) for NGC 6819.

Keywords: kinematics data and open clusters

1. Introduction

There are a large number of open star clusters in our galaxy, especially in our galactic disk. Several study have been done to determine the mass of some star open clusters. Leonard & Merritt by using projected mass estimator method determine the mass of open clusters M35. They estimate the dynamical mass of M35 within the central radius 3.75 pc lies between 1600 and 3200 M\textsubscript{\odot} \cite{1}. Geller et al. by using velocity dispersion of radial velocity determine the mass of open cluster NGC 188. They use radial velocity data from WIYN survey to estimate the mass of NGC 188 using virial mass theorem and estimate a mass of 2300 ± 460 M\textsubscript{\odot} \cite{2}. Yang et al. calculate a tidal mass of NGC 6819 using modified version of the point-mass Galactic model and averaging it with photometric mass. They obtain the total mass of ~2700 M\textsubscript{\odot} for NGC 6819 \cite{3}.

GAIA DR2 produces high precision for kinematics data for large number of stars, especially for proper motion and parallax \cite{4}. Combined proper motion data from GAIA DR2 and radial velocity from WIYN survey we could get kinematics data with high precision for three open cluster we choose; NGC 2168 (M35) \cite{2}, NGC 188 \cite{5}, and NGC 6819 \cite{6}. This paper is organized as follows. Section 2 provides short description of the parameter of open clusters and the membership reduction. In Section 3, we explain the methods that we use to determine the mass using kinematics data. Section 4 shows our result and analysis. Section 5 present conclusion.

2. Clusters parameters and membership reduction

Table 1 shows the parameters of NGC 2168, NGC 188, and NGC 6819 that determined from MWSC (Milky Way Star Clusters) catalogue \cite{7}. We choose these three open clusters because it had a huge number of data of radial velocity from WIYN and proper motion from GAIA DR2.
The membership reduction is done by using membership probability that provided by WIYN catalogue. The membership probability is calculated based on radial velocity data. We choose the stars with membership probability > 90% to become the member of open cluster. Beside the membership probability we also consider the distance of the stars using GAIA Distance catalogue [8]. We choose stars with distance within the distance from the centre of cluster ± 100 pc. Table 2 shows the number of stars for each cluster that meet both condition.

**Table 1. Parameters of NGC 2168, NGC 188, and NGC 6819**

| Parameter       | NGC 2168 | NGC 188 | NGC 6819 |
|-----------------|----------|---------|----------|
| RA(J2000)       | 06 09 12.6 | 00 47 24.0 | 19 41 16.8 |
| E(J2000)        | +24 21 36 | +85 15 18 | +40 11 42 |
| Distance (pc)   | 830      | 2000    | 2360     |
| Age (log t)     | 8.255    | 9.650   | 9.210    |
| r (deg)         | 0.98     | 0.57    | 0.2      |

**Table 2. Number of stars of NGC 2168, NGC 188, and NGC 6819 that meet required condition.**

|                | NGC 2168 | NGC 188 | NGC 6819 |
|----------------|----------|---------|----------|
| Number of Stars| 236      | 268     | 321      |

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Figure 1. Velocity dispersion in tangential direction (top) and radial direction (bottom) for NGC 2168. R shows the distance from the centre of the clusters.
3. Method
We determine virial mass and projected mass of the three clusters. To determine the virial mass we need radial velocity dispersion that determined from radial velocity data. We use virial mass formula from equation (4) from [9] with assumption that all the bodies have equal masses. Projected mass determined using both radial and tangential velocity dispersion. We use projected mass estimator formula from equation (19) from [1].

To calculate the velocity dispersion we divide the cluster into several regions by making rings with different radius from the centre. For each cluster we divide the cluster into four rings with the outer rings is centre radius of the cluster obtained from MWSC catalogue [7]. The reason we choose the outer rings is because most of the star are inside this radius, so we want to make sure that in every ring have at least 2 stars in it. After we sure that each of the ring have at least 2 stars, then we could calculate the velocity dispersion in that region for the tangential and radial direction.

4. Results and analysis
Figure 1 shows the radial and tangential velocity dispersion for NGC 2168. The value of velocity dispersion for both direction are less than ~1 km/s which is a normal value for open clusters. To calculate the error of the velocity dispersion, we use standard error formula, equation (1),

\[ SE = \frac{\sigma}{\sqrt{2n}} \]  

(1)

Where \( \sigma \) is standard deviation for all stars in each ring and \( n \) is the number of stars.

![Figure 1: Radial and tangential velocity dispersion for NGC 2168.](image)

**Figure 2.** Velocity dispersion in tangential direction (top) and radial direction (bottom) for NGC 188. R shows the distance from the centre of the clusters.
Figure 3. Velocity dispersion in tangential direction (top) and radial direction (bottom) for NGC 6819. R shows the distance from the centre of the clusters.

For both directions in Figure 1, the velocity dispersion have a similar value which is between 0.7~0.9 km/s. The similarity indicates that the velocity distribution on radial and tangential direction maybe isotropic. The trend of velocity dispersion for both direction is also similar, have high value close to the cluster core and decrease with the radius. The decreasing with the radius shows that the region near centre is more crowded than the outer region. This also show that the region with high population of stars or higher mass will make the velocity dispersion bigger than the less populated region. Using this velocity dispersion we obtain the virial mass of ~4056 $M_\odot$ and projected mass of ~5833 $M_\odot$ within the radius R < 7pc for NGC 2168. This mass is in the range of the mass that Leonard and Merritt [1] determined.

Figure 2 shows the velocity dispersion of NGC 188 on radial and tangential direction. The NGC 188 have a slightly bigger centre radius than NGC 2168 and the value of velocity dispersion is also smaller than NGC 2168. These might have a relation with the clusters age. The NGC 188 is older cluster than NGC 2168, so NGC 188 had already expanding more than NGC 2168. The expansion of the clusters make the radius bigger and decreasing the number density of stars, causing the velocity dispersion also smaller than more dense and younger cluster, NGC 2168. Velocity dispersion in radial and tangential direction also have slightly different value that indicate that the velocity distribution is not quite isotropic. This is maybe caused by the evolution of cluster that make an asymmetric expansion. Using the velocity dispersion we obtain the virial mass of ~2776 $M_\odot$ and projected mass of ~3326 $M_\odot$ within the radius R < 8pc for NGC 188. This mass is within the range of the mass that Bonatto et al. [10] determined. The velocity dispersion of NGC 6819 is shown in Figure 3. The value of tangential velocity dispersion is similar with the previous clusters, but the radial velocity dispersion is larger than the previous clusters. This large velocity dispersion could be caused by the error of radial velocity determination because the distance of NGC 6819 is the farthest among the three, so higher precision instrument is needed to determine same data with high accuracy. This also could be caused that the velocity distribution of NGC 6819 is not asymmetric that make the velocity at our radial direction is bigger than the tangential component. Using the velocity dispersion we obtain
the virial mass of $\sim 4244 \, M_\odot$ and projected mass of $\sim 3518 \, M_\odot$ within the radius $R < 8 \, pc$ for NGC 6819. The mass of NGC 6819 that we obtain is still in the range of the mass that determined by Yang et al. (2013) [3].

5. Conclusion
In this paper, we have determined the virial mass and projected mass of NGC 2168, NGC 188, and NGC 6819. The mass is derived from velocity dispersion in radial and tangential direction. The velocity dispersion is similar for all cluster except for NGC 6819 which have a larger value of radial velocity dispersion. We obtain the virial mass of the three clusters ranging from $\sim 2700$ to $\sim 4300 \, M_\odot$ and the projected mass ranging from $\sim 3300$ to $\sim 5900 \, M_\odot$. Theoretically this mass range is normal for normal open clusters which have number of star from 100 to $10^4$ stars. We need to do further study to be sure that the masses we obtain is accurate, especially about the membership determination and the accuracy of kinematics data.

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