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Bayesian Inference of Kinematics and Mass Segregation of Open Cluster

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Abstract. Based on the Bayesian Inference (BI) method, the Mixture-Model approach is improved to combine all kinematic data, including the coordinative position($\vec{x}$), proper motion ($\vec{\mu}$) and radial velocity(v), to separate the motion of the cluster from field stars, as well as to determine the intrinsic kinematic status and dynamical effects of the cluster, such as the mass segregation, anisotropy etc.. Meanwhile, the membership probability of individual stars are estimated as by product results. This method has been testified by simulation of toy models and also successfully used for well studied open clusters, such as M67 and NGC188. It is expected to largely help the studies of open clusters while combine the coming GAIA data.

Keywords. open cluster, mass segregation, bayesian inference, mixture model

1. Mixture Model and Bayesian Inference

Cluster members and field stars are assumed to have a mixture distribution in the position, proper motion and radial velocity spaces, $\Phi(\Theta) = \Phi_c(\Theta_c) + \Phi_f(\Theta_f)$, where $\Theta = (\Theta_c, \Theta_f)$ represents a set of parameters describe the distribution shapes of these two components, such as the number of cluster members N_c, the size of the cluster r_c , the average motion of the cluster $(\vec{\mu}_c, v_c)$ and the velocity dispersions of members and field stars (σ_c, σ_f) . The joint likelihood $(\mathcal{L})$ can be written as:

$$\log \mathcal{L} = \sum_i \log \Phi(i|\Theta) = \sum_i \log[N_c \phi_c^{\vec{x}} \phi_c^{\vec{\mu}} \phi_c^{v} + N_f \phi_f^{\vec{x}} \phi_f^{\vec{\mu}} \phi_f^{v}] \tag{1.1}$$

Then the bayesian inference are used to estimate all model parameters(Θ). The prior probability distribution function (PDF) of Θ_f can be obtained from the nearby regions of the cluster, if the data is from a large area survey. The post PDF of all parameters are determined by the Nested Sampling method (Feroz *et al.* (2008)), and then, the most possible value of these parameters, together with their uncertainties are measured from their marginal integrated post PDFs. Bayesian evidence (BE) are used to compare different distribution models, such as, King-model *vs* Gaussian in the coordinative position, whether or not asymmetrical in the proper motion dispersion of cluster members, and if the mass segregation parameters should be involved in. The membership probabilities of individual stars can be regarded as additional parameters that to be functions of the fitting parameters,

$$P_c(i) = \Phi_c(i|\Theta_c)/\Phi(i|\Theta) \tag{1.2}$$

2. Revisit of NGC188

We collected all the coordinative position($\vec{x}$), proper motion ($\vec{\mu}$) and radial velocity(v) data of 8012 stars deep to $V = 22.5$ mag., in the 0.75 deg^2 area of NGC188. Within this

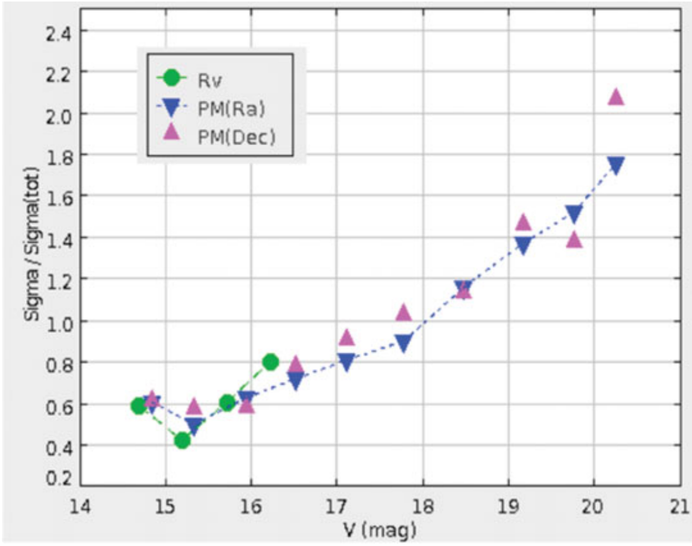

Figure 1. The magnitude dependent velocity dispersions of NGC188 cluster members.

sample, 7771 stars have $\vec{\mu}$ from Platais *et al.* (2003), and 1067 stars have v from Geller *et al.* (2008) or APOGEE.

The main results of NGC188 are: $\sigma_{\vec{\mu}} = 0.48 \pm 0.02$ mas/yr, $\sigma_v = 0.66 \pm 0.03$ km/s and $r_c = 3.12 \pm 0.18$ arcm. It is also found that, having radial velocity data included, the membership determination effectivity (Shao *et al.* (1996)) is largely increased form 0.75 to 0.96. Additionally, according to the BE comparison, the empirical King model is much better than a simple 2D-Gaussian distribution for the surface number density of this cluster. The BE also suggests the mass segregation is significant in either position or velocity spaces. These phenomena can be shown as the magnitude dependences of the velocity dispersion (see Fig.1) and the characteristic size (r_c) of this cluster.

3. Discussion and Further Works

This approach is expected to be able to merge different observational data, especially for those completeness or flux limitations seriously unmatched surveys. The on going work is applying this method to the LAMOST released data which contains a large amount radial velocities cover ~ 200 nearby open cluster regions. The galactic motions of these clusters will be detected by combining archive proper motions. If the coming GAIA data can be used, the accuracy of tangential velocity will be largely improved and the intrinsic kinematics of open cluster can be well investigated, though it is usually less than 1 km/s. There is an additional option that to combine the photometric and kinematic data as well, then the properties and memberships a cluster can be constrained not only in kinematics but also in stellar populations.

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