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Two kinematically different Large Magellanic Cloud old globular cluster populations unveiled from Gaia DR2 data sets†

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Abstract. We derive mean proper motions of 15 known Large Magellanic Cloud (LMC) old globular clusters (GCs) from the *Gaia* DR2 data sets. When these mean proper motions are gathered with existent radial velocities to compose the GCs' velocity vectors, we found that the projection of the velocity vectors onto the LMC plane and those perpendicular to it tell us about two distinct kinematical GC populations. Such a distinction becomes clear if the GCs are split at a perpendicular velocity of 10 km/s (absolute value). The two different kinematics groups also exhibit different spatial distributions. Those with smaller vertical velocities are part of the LMC disk, while those with larger values are closely distributed like a spheroidal component. Since GCs in both kinematic-structural components share similar ages and metallicities, we speculate with the possibility that their origins could have occurred through a fast collapse that formed halo and disk concurrently.

Keywords. galaxies: individual: LMC - galaxies: star clusters: general

1. Overview

To the best of our knowledge, one of the pioneering works on the kinematics of star clusters in the Large Magellanic Cloud (MC) was carried out by Schommer *et al.* (1992), who measured radial velocities (RVs) of ancient and intermediate-age clusters from near-infrared Ca II triple spectroscopy. From those measurements, they fitted an analytical expression to the distribution of points in the RV versus position angle plane that represent the rotation of a disk. Later, Grocholski *et al.* (2006) obtained near-infrared spectra centered on the Ca II triplet for a sample of intermediate-age clusters not included in the Schommer *et al.* (1992)'s sample, and their RVs confirmed that the joint cluster sample still shows a kinematics that resembles that of a rotating disk, and that the curved found by Schommer *et al.* (1992) still results in a good representation of the distribution of clusters in the RV versus position angle diagram. Sharma *et al.* (2010) observed some additional clusters using the spectroscopic setup employed by Schommer *et al.* (1992)

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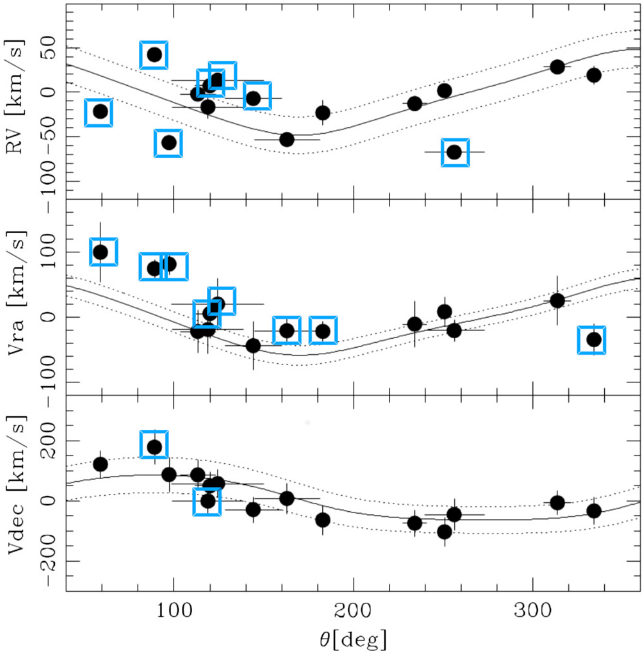

Figure 1. Line-of.-sight (top panel) and tangential (middle and bottom panels) velocity components of LMC GCs. The solid lines represent the best-fitted solution obtained by van del Marel & Kallivayalil (2014), while the dotted ones correspond to the 1σ dispersion based on the uncertainties in the disk inclination, dynamical center, rotation velocity, position angle of the line-of-nodes and the dispersion velocity.

and Grocholski *et al.* (2006) and arrived to fully consistent results, namely, star clusters in the LMC rotate following the motion of a disk.

The above results reveal that there have been almost 20 years of spectroscopic observations supporting the LMC cluster disk geometry. From then until the present, there are nearly ten years of investigation on the formation history, structure and chemical evolution of the LMC, during which has been assumed that clusters in the LMC rotate in a disk. In summary, the LMC rotating disk paradigm has been the general accepted interpretation of the kinematics of the LMC star cluster population.

However, focused on the RV versus position angle plane of the old LMC globular cluster (GC) population (top panel of Fig. 1), it would seem that some of them fall outside the expected fringe, as judged by the recent best-fitted solution for the LMC rotation curve obtained from HST proper motions and line-of-sight velocities of stars in 22 fields (van del Marel & Kallivayalil 2014). Fig. 1 shows that, although there is a general trend in the kinematics of GCs to follow the LMC disk rotation, those marked with light-blue open squares have RVs that clearly depart from that rotation pattern.

2. Analysis and results

In order to explore more deeply whether the LMC GCs rotate in a disk, we obtained for the first their three space velocity components in a framework where V_X and V_Y are in the LMC plane, and V_Z is perpendicular to that plane. These space velocity components were derived from properly transforming RVs and proper motions into V_X, V_Y and V_Z values (van del Marel *et al.* 2002). The RVs were taken from Piatti *et al.* (2018), while the mean proper motions were derived from *Gaia* DR2 proper motions of individual cluster members. We constrained the cluster stars to those with parallaxes $|\varpi| < 3\sigma(\varpi)$

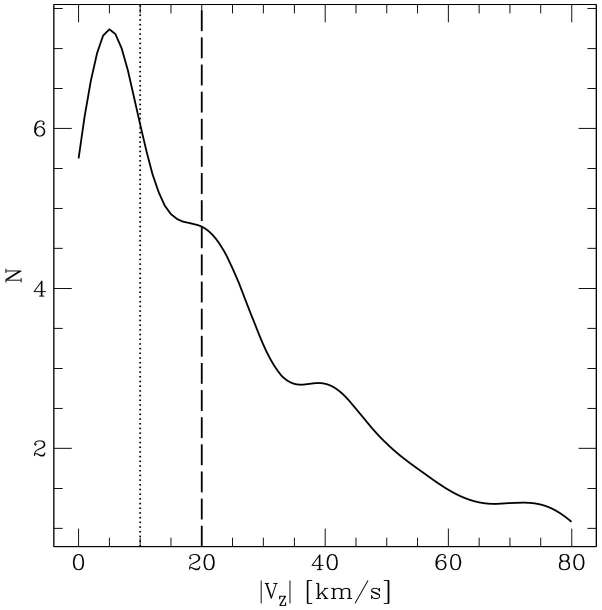

Figure 2. V_Z distribution of LMC GCs. Dotted and long dashed lines indicate the limits of $V_Z < 10$ and >20 km/s, respectively.

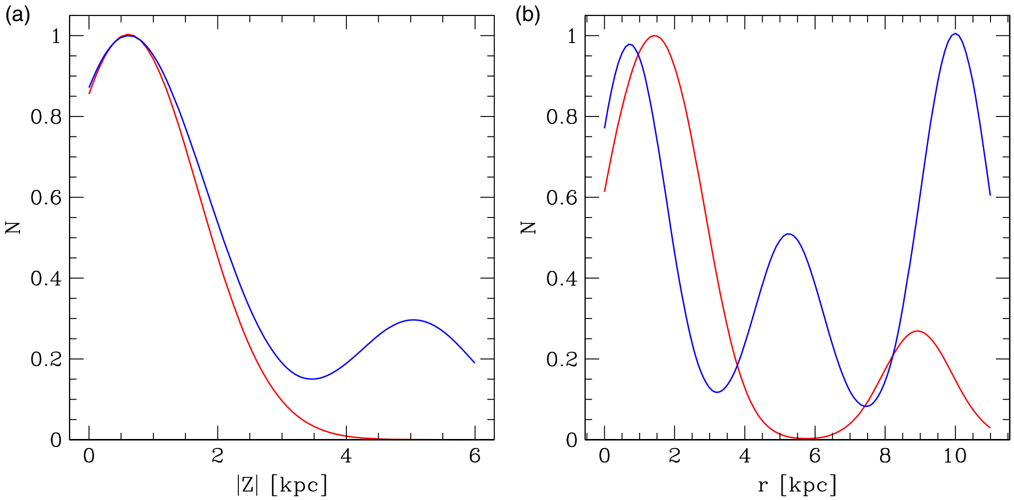

Figure 3. Histograms of heights (left) and deprojected distances (right) for GCs with $|V_Z| < 10$ km/s (red lines) and >20 km/s (blue lines), respectively.

(Vasiliev 2018), located within the tidal radii taken from Piatti & Mackey (2018), and with proper motion errors (RA, Dec.) < 0.1 mass/yr, excess noise `epsi` < 1, and significance of excess of noise (`sepsi`) < 2, respectively. Middle and bottom panels of Fig. 1 show the velocity components along the RA and Dec. axis, respectively, obtained from the derived mean proper motions and the relationship $V_{RA,Dec.} = 4.7403885 \times D_o \times \mu_{Ra,Dec.}$, where D_o is the distance to the LMC center of mass (= 50.1 kpc, van del Marel & Kallivayalil 2014). As can be seen, some GCs still fall outside the boundaries of the rotating disk. This findings suggest that some GCs do not share a disk rotation kinematics.

Bearing in mind the above outcomes, we built the distribution function of V_Z, looking for any hints of a velocity dispersion larger than that found by van del Marel & Kallivayalil (2014). Fig. 2 depicts the resulting histogram, which remarkably shows a wide range of V_Z. This means that there are some GCs with V_Z component as relatively high as not to be tied to LMC disk rotation.

We split the whole sample of GCs into two groups, namely: those with $|V_Z| < 10$ km/s and >20 km/s, respectively, with the aim of looking into any correlation of $|V_z|$ with the cluster properties. Particularly, we found that the spatial distribution of both subsamples (see Fig. 3) tells us that the GCs which rotate following closely the LMC disk rotation ($|V_Z| < 10$ km/s) do not usually reach large heights out of the LMC plane (|Z|) nor large deprojected distances from the LMC center (r) either. Conversely, GCs with larger $|V_Z|$ components ($|V_Z| > 20$ km/s) can be seen not only in the innermost regions of the LMC, but also far away from it. These different spatial patterns suggest that the different V_Z regimes are coupled with distinct spatial distribution, in the sense that those GCs with $|V_Z| < 10$ km/s are linked to a disk-like galactic component, while those with $|V_Z| > 20$ km/s would appear to belong to a spheroidal galactic structure.

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