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3D asymmetrical kinematics of mono-age populations from LAMOST and Gaia common red clump stars

H.-F. Wang[1,2,3], Martín López-Corredoira[4], Y. Huang[1] and Jeffrey L. Carlin[5]

[1]South−Western Institute for Astronomy Research, Yunnan University, Kunming, 650500, P. R. China
email: hfwang@bao.ac.cn

[2]Department of Astronomy, China West Normal University, Nanchong 637009, China

[3]LAMOST Fellow

[4]Instituto de Astrofísica de Canarias, E-38205 La Laguna, Tenerife, Spain

[5]LSST, 950 North Cherry Avenue, Tucson, AZ 85719, USA

Abstract. With the LAMOST DR4 and Gaia DR2 common red clump giant stars, we investigate the three-dimensional kinematics of Milky Way disk stars in mono-age populations between Galactocentric distances of R = 6 and 15 kpc. We confirm the 3D asymmetrical motions of recent works, and provide time tagging of the Galactic outer disk asymmetrical motions. Radial motions present a north-south asymmetry in the region corresponding to recent density and velocity substructures that were sensitive to the perturbations in the early 6 Gyr. What's more, we discover a new velocity substructure in the north side corresponding to density dip found recently ("south-middle opposite") in the radial and azimuthal velocity. Meanwhile, the vertical velocity with clear vertical bulk motions or bending mode motions has no clear asymmetry corresponding to the in-plane asymmetrical features.

Keywords. kinematics, dynamics, Galaxy, disk, structure

1. Introduction

Many years ago, we often assumed the potential is in equilibrium or stationary to interpret observations for galaxies. This was shown to be an invalid assumption with the evidence for a Galactic North-South asymmetry in the number density and bulk velocity of solar neighborhood stars revealed by Widrow *et al.* (2012). These observations began what is known as Galactoseismology for the Milky Way. With modern large scale Galactic surveys, Galactoseismology is starting to become reality, in which we can unravel the chemo-dynamical history of the disk, and in turn infer its history of accretion and the characteristics of the satellite galaxies (Antoja *et al.* 2018).Our home galaxy disk is a typical dynamical system that is perturbed by bars, giant molecular clouds, spiral structures, warps, tidally disrupting satellite galaxies, and dark matter subhalos. Some imprints will be left on stars by these processes (Widrow *et al.* 2012). We are entering into the golden era of galactoseismology with the help of Gaia data.

2. Sample

A sample of over 150,000 primary Red Clump (RC) stars and a small fraction of secondary stars from the LAMOST Galactic spectroscopic surveys is selected based on their

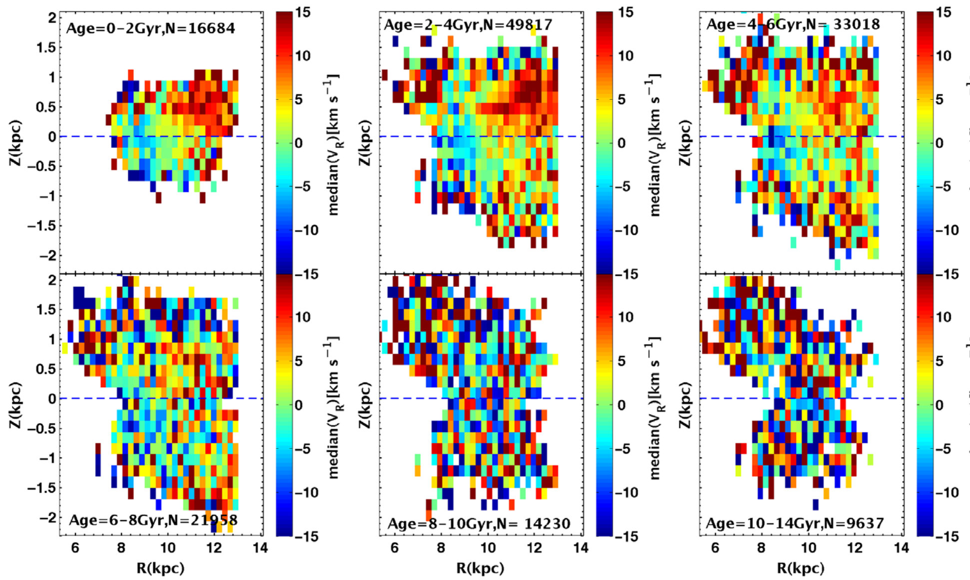

Figure 1. The radial asymmetrical structures in the R, Z plane of the LAMOST-Gaia stars in different age populations. Each panel is colored as median velocity in different age bins. The top panel has clear asymmetries from 0-6 Gyr. Each pixel plotted in this figure has at least 10 stars.

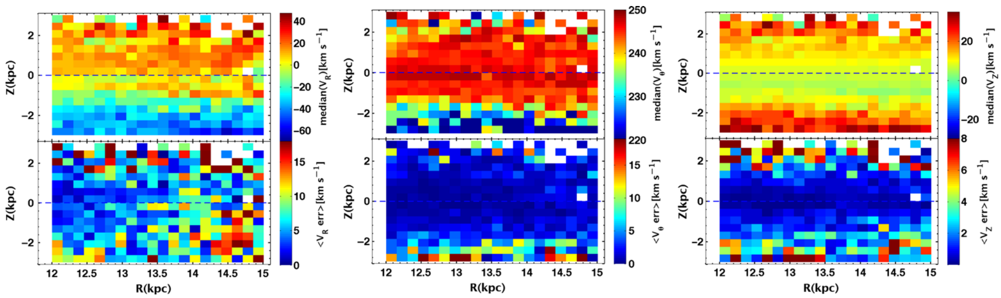

Figure 2. Figure 4. 3D velocity distribution and error analysis in the R,Z plane.

positions in the metallicity-dependent effective temperature-surface gravity and color-metallicity diagrams with the help of asteroseismology data. Thanks to the LAMOST spectra and the Kernel Principal Component Analysis (KPCA) method, the uncertainties of distances for our primary red clump stars are no more than 5 to 10 percent, and the stellar masses and ages are 15 and 30 percent.

3. Results

Fig. 1 shows the variation of Galactocentric radial velocity V_R with age in the R,Z plane and the numbers of stars used to produce the maps are given in each panel. We can see the large prominent velocity structure on the northern $(0 < Z < 2\,kpc)$ side from $9 < R \lesssim 12$ kpc in the first three panels, in which V_R has a positive gradient and becomes stronger. We also note that there is the north-south asymmetry at the location of $R \sim$ 9–12 kpc, $Z \sim$ 0.5 kpc with redder bins named and confirmed as north near substructure. From this figure, we can see it disappears around 6-8 Gyr, which implies that the sensitive time of north near substructure to the perturbers is around 6 Gyr.

Fig. 2 shows that Edge−on views of the kinematics of the disk derived using the red clump giant sample. From left to right, bins show the median velocity V_R, V_θ, V_Z (in km s^{-1}) of RC stars within each bin. Each bin contains at least 5 stars. The asymmetric region corresponding to the south middle and south middle opposite density structures is evident in the radial and rotational velocity distributions. The right panel shows vertical bulk motions at all radii without clear north-south asymmetry (Wang *et al.* 2019, 2020).

References

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