

A Kinematical Study of the Galactic Disk using Red Clump Stars

S.J. Ribas, F. Figueras, and J. Torra

Abstract We determine kinematical properties of the Galactic disk using a large sample of Red Clump stars extracted from the UCAC2 catalogue using photometric data from 2MASS catalogue. The large sample compiled, more than 2 million stars with accurate enough distances and proper motions, allow us to trace the disk kinematics up to 2 Kpc from the Sun. First and second order galactic rotation parameters are determined and the Dehnen and Binney (1998) method [6] is used to characterize the velocity distribution function in a large area of the galactic plane. Extensive simulations have permitted to evaluate the capabilities of the method as well as the selection and completeness effects.

1 Introduction

It is difficult to study kinematics of the Galaxy at distances larger than 1 Kpc. At these distances is necessary to use a good distance indicator like the Red Clump giant stars. These stars have well known photometric properties that allow us to place them in the space using all-sky infrared catalogue, like 2MASS.

The appearance of catalogues like UCAC2 [12], with a high number of stars with proper motions, open a new window for large scale galactic kinematics studies. This catalogue only has proper-motions so we have to use statistical methods

Salvador J. Ribas

Consorci del Montsec, Pl. Major 1, 25691 Ager (Lleida) and Departament d'Astronomia i Meteorologia, Universitat de Barcelona, Mart i Franques 1, 08028 Barcelona e-mail: sribas@am.ub.es

Francesca Figueras and Jordi Torra

Departament d'Astronomia i Meteorologia & IEEC-UB, Institut de Ciències del Cosmos de la Universitat de Barcelona, Mart i Franques 1, 08028 Barcelona e-mail: cesca@am.ub.es and jordi@am.ub.es

Acknowledgement: This research has been supported by MCyT under contract AYA2006-15623-C02-02

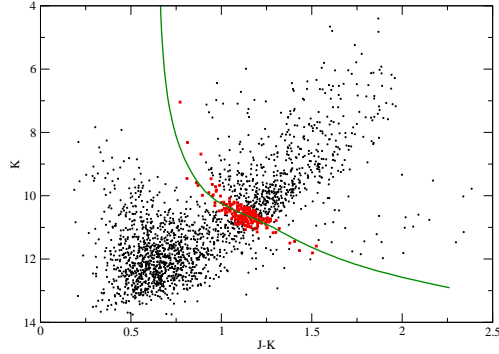
(least square and Dehnen & Binney [6]) to recover kinematic information in three dimensions from tangential velocity components.

2 Selection of Red Clump Stars

Red Clump stars have been selected using its well known JHK photometric properties (see [3]). We have used 2MASS infrared photometry [5] to extract a large sample of Red Clump stars from the UCAC2 [12] proper motion catalogue following the next steps:

- The sky has been divided in 3072 sectors with size depending on the galactic latitude.
- Color Magnitude Diagram (CMD) K/J-K has been plotted for each field (see Fig. 1).
- Well known absolute magnitude and color ($M_K = -1.65$ and $(J-K) = 0.65$) have been adopted for Red Clump stars.
- An extinction curve for each CMD has been computed according to [7].
- Stars near the extinction curve with 0.1 mag of error margin in $(J-K)$ have been selected as Red Clump stars.
- The fields have been manually supervised to confirm the compatibility of the Red Clump position and the extinction curve.
- Simulated samples from the Besançon Galaxy model [9] have been used to establish additional criteria on the K limiting magnitude to avoid dwarfs stars contamination [3].
- Reddening & photometric distances have been computed from observed and intrinsic $(J-K)$ colors and magnitudes (K).

Fig. 1 Example of a CMD for the field $l=29.5^\circ$ $b=0^\circ$ using [7]. All the UCAC2 stars are plotted in black, the Red Clump stars in red and finally the extinction line in green.



The compiled catalogue contains more than 2.5×10^6 Red Clump stars with heliocentric distances up to 5 Kpc and $\delta < 45^\circ$ because the higher declination stars are not yet published (UCAC3, in preparation).

3 Kinematic Analysis: The Methods

Tangential heliocentric velocity components for selected stars have been computed using proper motions from UCAC2 data. The tangential heliocentric velocity components (V_l, V_b), at a given galactic longitude l and latitude b , can be written as a function of the galactocentric motion (Π, Θ, Z) of the Regional Standard of Rest (RSR) and the solar motion ($U_\odot, V_\odot, W_\odot$) respect to the Local Standard of Rest ($0, \Theta(R_\odot), 0$) as:

$$V_l = \Pi \sin(l + \theta) + \Theta \cos(l + \theta) - \Theta(R_\odot) \cos(l) + U_\odot \sin(l) - V_\odot \cos(l)$$

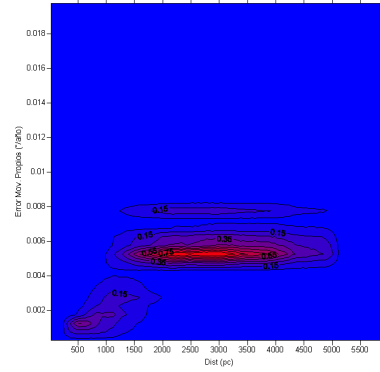
$$V_b = \Pi \cos(l + \theta) \sin(b) - \Theta \sin(l + \theta) \sin(b) + Z \cos(b) + \Theta(R_\odot) \sin(l) \sin(b) + U_\odot \cos(l) \sin(b) + V_\odot \sin(l) \sin(b) - W_\odot \cos(b)$$

In order to determine the galactic rotation parameters we use a two steps process:

1) $\Theta(R)$ is determined using a least square fit applied to ring galactocentric sectors assuming the solar motion from a close-to-sun subsample of Red Clump Stars and assuming $\Pi(R) = Z(R) = 0$. Outlier stars with 2.5σ have been removed where σ takes into account the contribution of the observational errors of each star, the least square model errors and the cosmic dispersion computed from the close-to-Sun subsample.

2) Dehnen & Binney [6] method is used to derive the velocity distribution function at each (R, θ) galactocentric position: The first and second order momentum of the velocity field are derived from 2D projected velocities (see [6]). The 3D velocity distribution is statistically recovered through a geometrical matrix, computed for each star (see [6] for further details). This method takes into account the observational errors on proper motions that are critical for faint stars (see Fig. 2) and the galactic rotation ($\Theta(R)$) at the RSR computed in the first step.

Fig. 2 Distribution of proper motion errors versus heliocentric distances of our sample. The sample shows a multi-modal profile due to the fact that UCAC2 is a compiled catalogue



4 Simulations

We have done several simulations to test the capabilities of the method. Pseudo-real star have been generated following:

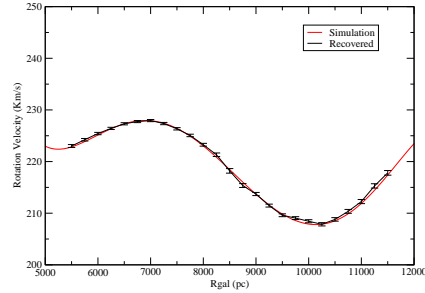
- The same position of a real star (same inhomogeneous distribution)
- Using tangential velocity components from a kinematic model (see table below)
- Observational errors following the real distribution (see table below)

Parameters adopted in the simulation
$\Theta(R)$: Rotation curve from Clemens (1985); $\Pi(R) = Z(R) = 0$ km/s
$R_{\odot} = 8.5$ Kpc, $(\Pi, \Theta)_{\odot} = (0, 220)$ km/s
Velocity of the Sun respect to the LSR $(U_{\odot}, V_{\odot}, W_{\odot}) = (6.2, 18.8, 6.6)$ Km/s
Second order moments of velocity distribution function: $(\sigma_R, \sigma_{\Theta}, \sigma_Z) = (36, 28, 19)$ Km/s constant at all (R, θ) Ellipsoid pointing to the Galactic Center.

We have verified that there is no effects of the UCAC2 "hole" ($\delta > 45^\circ$ not available) on the derived kinematic parameters.

We have checked that our process is able to recover the simulated rotation curve in the range $[5.5, 11.5]$ Kpc (see Fig. 3). For the first and second order momentum we can recover the simulated parameters up to 1.5-2.0 Kpc and for the vertex deviation up to 1.0-1.5 Kpc (see Fig. 4).

Fig. 3 Comparison of the input and recovered values (error bars are indicated) for the galactic rotation curve.



5 Determining kinematic parameters

Our Red Clump stars are an excellent tracer of the massive stellar disk component. From Fig. 5 we can see that the computed rotation curve obtained for these stars at distances larger than 1 Kpc (approaching both Sagittarius and Perseus arms), dis-

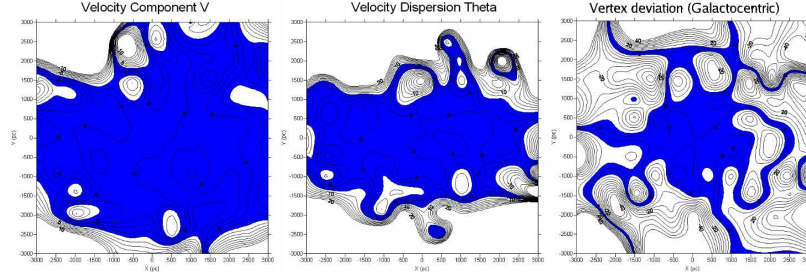


Fig. 4 Differences between simulated and recovered values [Units are in Km/s and deg] for first and second order momentum in the rotational direction and for the vertex deviation (plotted from -3 Kpc to +3 Kpc in each axis). The blue regions are the tolerance area of 2 Km/s for the first order, 4 Km/s for the second order and 4 deg. for the vertex deviation.

agree with the Brand & Blitz [2] and Clemens [4] rotation curve obtained from HI and HII data (see the left pannel of figure 5).

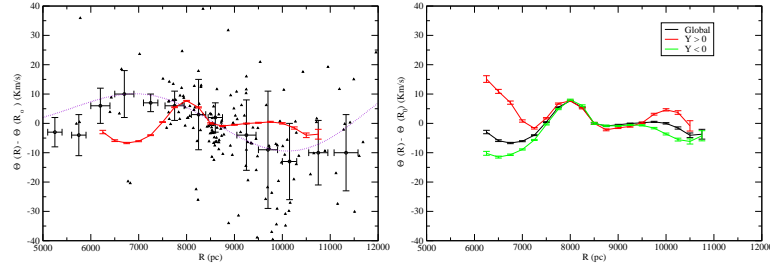


Fig. 5 In the left pannel the computed rotation curve for all regions in comparison with Brand & Blitz [2] (in black) and Clemens [4] (in violet). In the right pannel three different rotation curves obtained using different region of the galactic disk ($Y < 0$, $Y > 0$ & all the stars)

This kind of deviations from HI-HII standard rotation curves have been also found from stellar Hipparcos data (Fresneau, 2005) [8] and cepheid data (Zabolotskikh et al. 2003) [11]. We speculate that the different rotation curves obtained (see the right pannel of Fig. 5) in the direction to the galactic center may reflect the non-axisymmetric structure of the spiral arms [1] (work in progress).

Once $\Theta(R)$ has been derived, Dehnen & Binney method [6] has been used to derive the first and second order moments of the residual velocity as a function of the galactocentric position (R, θ, z). The stars with residuals tangential velocity larger than 100 Km/s have been excluded to avoid dwarf contamination and outliers.

We observe that Red Clump stars present important peculiar motions (see Fig. 6) due to local irregularities and non-axisymmetric potential. The comparison of these irregularities with those obtained from simulated data allow us to confirm that the gradients obtained for the vertex deviation are not an artifact. A comparative study of our results with theoretical approximations [10] is now in progress.

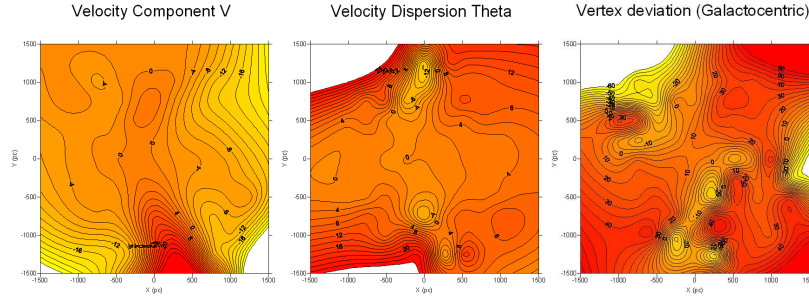


Fig. 6 First and second order momentum in the rotational direction and vertex deviation [Units are in Km/s and deg.] for the real sample (only positions between -1.5 to +1.5 Kpc are shown)

References

1. Benjamin, R.A.: The Spiral Structure of the Galaxy: Something Old, Something New... In: H. Beuther, H. Linz, T. Henning (eds.) *Massive Star Formation: Observations Confront Theory*, *Astronomical Society of the Pacific Conference Series*, vol. 387, pp. 375–+ (2008)
2. Brand, J., Blitz, L.: The Velocity Field of the Outer Galaxy. *Astronomy and Astrophysics***275**, 67–+ (1993)
3. Cabrera-Lavers, A.: Ph.D. thesis, IAC (2004)
4. Clemens, D.P.: Massachusetts-Stony Brook Galactic plane CO survey - The Galactic disk rotation curve. *The Astrophysical Journal***295**, 422–428 (1985). DOI 10.1086/163386
5. Cutri, R.M., Skrutskie, M.F., van Dyk, S., Beichman, C.A., Carpenter, J.M., Chester, T., Cambresy, L., Evans, T., Fowler, J., Gizis, J., Howard, E., Huchra, J., Jarrett, T., Kopan, E.L., Kirkpatrick, J.D., Light, R.M., Marsh, K.A., McCallon, H., Schneider, S., Stiening, R., Sykes, M., Weinberg, M., Wheaton, W.A., Wheelock, S., Zacarias, N.: 2MASS All Sky Catalog of point sources. (2003)
6. Dehnen, W., Binney, J.J.: Local stellar kinematics from HIPPARCOS data. *Monthly Notices of the Royal Astronomical Society***298**, 387–394 (1998)
7. Drimmel, R., Cabrera-Lavers, A., López-Corredoira, M.: A three-dimensional Galactic extinction model. *Astronomy and Astrophysics***409**, 205–215 (2003). DOI 10.1051/0004-6361:20031070
8. Fresneau, A., Vaughan, A.E., Argyle, R.W.: Density Wave Streaming Motions in Stars along the Sagittarius Spiral Arm. *The Astronomical Journal***130**, 2701–2716 (2005). DOI 10.1086/497288
9. Robin, A.C., Reylé, C., Derrière, S., Picaud, S.: A synthetic view on structure and evolution of the Milky Way. *Astronomy and Astrophysics***409**, 523–540 (2003). DOI 10.1051/0004-6361:20031117
10. Theis, C., Vorobyov, E.: Stellar Velocity Distribution in Galactic Disks. ArXiv e-prints (2008)
11. Zabolotskikh, M.V., Rastorguev, A.S., Dambis, A.K.: Kinematic Properties of Young Subsystems and the Rotation Curve of our Galaxy. *Communications of the Konkoly Observatory Hungary* **103**, 167–172 (2003)
12. Zacharias, N., Urban, S.E., Zacharias, M.I., Wycoff, G.L., Hall, D.M., Monet, D.G., Rafferty, T.J.: The Second US Naval Observatory CCD Astrograph Catalog (UCAC2). *The Astronomical Journal***127**, 3043–3059 (2004). DOI 10.1086/386353