DETECTABILITY OF GALACTIC KINEMATICAL PARAMETERS FROM PROPER MOTIONS

R.L. SMART
Space Telescope Science Institute

AND

M.G. LATTANZI
Space Telescope Science Institute,
Affiliated with the Astrophysics Division,
SSD, ESA; on leave from Oss. Astr. di Torino

Abstract. We discuss the inclusion of a warp structure (as discussed by Miyamoto et al. 1993) to a realistic galactic model. We investigate how the proper motions are effected by changes in the inclination, phase angle and spin velocity of the warp. It is shown that accurate proper motions of disk stars do reflect the variation of warp parameters. A simulation of OB stars with an apparent magnitude limit of 7.0, mimicing the early type content of the HIPPARCOS catalogue, indicates that variations of phase are probably not observable while detection of velocity variation is within the limit of the current precision.

1. Introduction

Highly accurate and precise proper motions are essential for a 3-dimensional detailed analysis of galactic structure, for example, the presence and role of dark matter as an essential constituent of the Milky Way (and of the local Galaxy in particular); the independent determination of K_z and, ultimately, of the local mass density; the warped structure of the Galaxy; and the dynamics of the bulge. This contribution is an attempt to estimate the possibilities of present and future high accuracy proper motion compilations like HIPPARCOS and GAIA (Lindegren and Perryman, this conference) in addressing those outstanding questions of galactic structure and evolution.

E. Høg and P. K. Seidelmann (eds.),
Astronomical and Astrophysical Objectives of Sub-Milliarcsecond Optical Astrometry, 233–237.

In our model special parameters are chosen to simulate the particular problem for which we seek to characterize its influence on the proper motions of a tracer population or all of the stars. We do not yet attempt to make our model match the observed proper motions; instead we only measure the changes in a given distribution as a function of the simulation parameters, hence providing limits for existing data, or, future observations. For this discussion we have limited our sample to OB stars with apparent magnitude brighter than 7th. This is for two reasons, to replicate the completeness limit of the HIPPARCOS catalogue and to pick stars that should follow the warp that is seen in HI observations.

The next section deals with the particulars of our basic model. In section 3 we discuss the inclusion of warp into our Galaxy and in section 4 we analyze the effect of this warp on the proper motions of typical young disk tracers. We change three parameters of the warp; inclination to the galactic plane, longitude of the ascending node, or "phase angle", and the modulus of the circular velocity in the warp plane. Special emphasis is given to the condition for the "observability" of the warp in the proper motions.

2. Parameters of the Galactic Model

We have constructed this simulation using the IDL computer language, which proved powerful for operating directly on whole vectors and matrices. The distribution of a given parameter is decided from a-priori assumptions, the parameter space is then "populated" using a Monte Carlo type process.

For example, we use an exponential density distribution of the form $\rho = \rho_o \exp(-z/z_o)$, with the parameters taken from Gilmore and Wyse (1985, hereafter GW) to populate the Z coordinate space. We assume that the stars are uniformly distributed in X and Y space which provides a simple geometric distribution function. The luminosity function is taken from Bachall and Soneria (1980, hereafter BS) with a modification that steepens the function when assigning a magnitude to halo stars, producing fainter stars for this population, as suggested by Gilmore (1983).

The simulation requires a user supplied direction, angular width and distance limit. In the following investigation, we chose 1^o slices at 45^o intervals out to 3000 pc. We then remove those stars that are below some given magnitude cutoff. The absorption is calculated using the procedure described in BS, reaching a maximum at b=1^o. In the discussion by BS they warn the reader against using this procedure below b=20° and further work on the model will investigate alternatives to this extrapolation. The generation of stars is continued until the number counts in eight 1^o areas of the slice match the number densities in BS to within 10%.

We now assign a velocity to the star. The initial galactocentric (U, V, W)

https://doi.org/10.1017/S007418090022812X Published online by Cambridge University Press

velocities are drawn at random from the peculiar velocity ellipsoids with dispersions taken from Mihalas and Binney (1981, hereafter MB). We add to these peculiar velocities the galactic rotation for the thin and thick disk V=(220,140) respectively and the solar motion [(+9, +12, +7) from MB], all in km/s.

Therefore our model of the Galaxy has 5 basic input parameters for each of the three populations, these are shown in Table 1.

TABLE 1. Galactic Simulation Parameters

Component	Thin disk	Thick disk	Halo
ρ_o [GW]	1.0	0.02	0.00125
z_o pc [GW]	300.	1000.	4500.
σ_u km/s [MB]	24	80	130
σ_v km/s [MB]	15	60	87
σ_w km/s [MB]	12	60	86

3. Inclusion of a Galactic Warp

The original impetus for undertaking this project was to understand how accurate proper motions might enable us to understand more completely the galactic warp. Our current understanding is based on HI, HII and CO radio observations, IRAS point source number counts and proper motions of OB type stars (Sparke 1993 for review). The generally accepted view is that the sun is almost directly on the line of nodes of this warp and that the warp starts just outside the solar orbit. Figure 1 shows the overall orientation where the XYZ frame is centered at the sun ($\odot$), i is the angle of inclination of the warp, ϕ is the phase angle.

To include a warp we have to consider the velocities in the correct order, before the application of the thin disk rotation and the local solar motion. The warp velocity is added directly in the warp frame using the longitude in this frame (l_w). Then we rotate the velocity and position vectors to the galactic frame. This change is shown in equation 1 (Note: The $\mathbf{R}_1$, $\mathbf{R}_2$, $\mathbf{R}_3$ are rotations matrices about the x, y and z axis respectively).

$$\begin{pmatrix} U' \\ V' \\ W' \end{pmatrix} = \mathbf{R_3}\,(-\theta) \;\; \mathbf{R_1}\,(-i) \left(\mathrm{V_{warp}} \begin{pmatrix} \sin l_w \\ \cos l_w \\ 0 \end{pmatrix} \right) + \begin{pmatrix} U \\ V \\ W \end{pmatrix} \qquad (1)$$

The U', V', W' are then corrected for the motion of the LSR and the solar motion to give U'', V'', W'' which in turn provide proper motions in

https://doi.org/10.1017/S007418090022812X Published online by Cambridge University Press

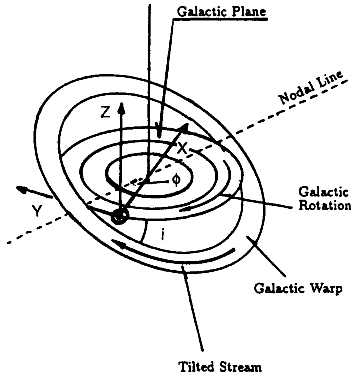

Figure 1. Geometry of the Simulated Galactic Warp (modified from Miyamoto et al. 1993). The sun is indicated with the symbol ⊙.

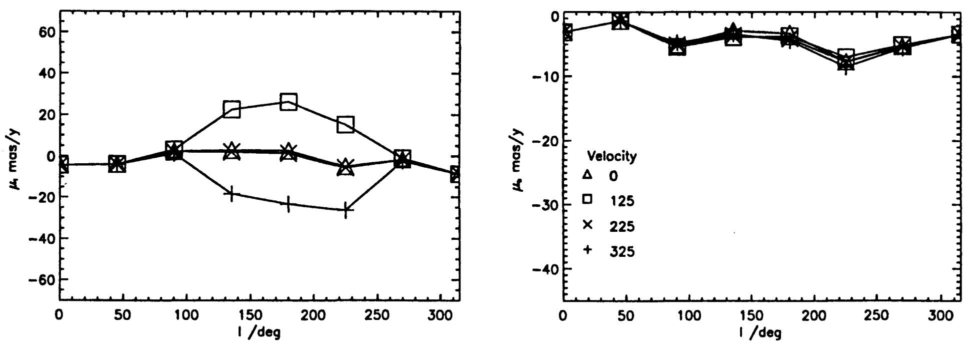

Figure 2. The effect of varying warp stream velocity on the proper motion in galactic coordinates (μ_l on the left and μ_b on the right) vs galactic longitude for OB stars brighter than 7th apparent magnitude.

galactic coordinates and radial velocity viz:

$$\begin{pmatrix} \mu_l \\ \mu_b \\ V_r \left(\frac{1}{4.74\, r}\right) \end{pmatrix} = \frac{1}{4.74\, r} \mathbf{R_3}\,(b)\ \mathbf{R_2}\,(l) \begin{pmatrix} U'' \\ V'' \\ W'' \end{pmatrix} \qquad (2)$$

where r is the sun-star distance, l and b are the galactic longitude and latitude of the star.

https://doi.org/10.1017/S007418090022812X Published online by Cambridge University Press

4. Discussion

We have examined the effect of varying the inclination, velocity within the 'tilted stream' (see figure 1) of the warp, and the phase angle on the proper motions. Figure 2 shows the effect of varying the velocity. The main discriminant is the longitude proper motion where for no warp and a warp with velocity 225km/s we have a maximum difference of about 4mas/yr. Examination of similar graphs for phase angle shows that for small changes of 5° we see no difference and for 30° we see changes of only 3mas/yr. From this simulation we conclude that velocity differences in the galactic warp might be observable by HIPPARCOS, while phase angle differences probably will require a factor of ten improvement in precision.

5. Acknowledgments

We wish to thank Stefano Casertano, Larry Taff and Kavan Ratnatunga for many useful and stimulating discussions. RLS expresses his thanks to the IOC of symposium 166 and the American Astronomical Society for providing support to attend this meeting. We would also like to thank the referee for valuable comments that increased the clarity of this paper.

References

Mihalas, D. and Binney, J., 1981, *Galactic Astronomy*, W.H.Freeman, San Francisco.
Gilmore, G., 1983. *Mon. Not. R. astr. Soc.*,**207**,223.
Gilmore, G., and Wyse, R. F. G., 1985. *AJ*,**90**,2015.
Bahcall, J. N., and Soneira, R. M. 1980. *ApJS*,**44**,73.
Miyamoto, M., Soma, M., and Yoshizawa, M. 1993. *AJ*,**105**,2138.
Sparke, L.S., 1993. *Back to the Galaxy*, Aip Conf. **278**, eds S. Holt and F. Verter.