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HST astrometry: the Galactic constant Θ_0/R_0

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Abstract. From multi-epoch WFPC2/HST observations we present astrometric measurements of the absolute motion of the bulge stars. The presence of an extra-galactic point-source candidate allows us to measure the difference between the Oort constants, $A - B = \Theta_0/R_0$. We find: $\Theta_0/R_0 = 27.6 \pm 1.7$ km s^{-1} kpc^{-1}.

Key words. astrometry – Galaxy: fundamental parameters

1. Introduction

In Bedin et al. (2001), two *HST* deep observations of the globular cluster M4, separated by a time base line of ~ 5 yr, allowed us to obtain a pure sample of main sequence stars in M4. The identification of an extra-Galactic point source enables us to use the proper motions of field stars (which were junk in Bedin et al. 2001) to measure a fundamental parameter of the Galaxy.

2. Measure of the constant Θ_0/R_0

M4 is a globular cluster projected on the edge of the Galactic bulge ($\ell \simeq -9°$, $b \simeq 16°$). We expect only a small number of foreground disk stars in our fields, but in the background we look through the edge of the bulge at a height of ~ 2 kpc. Although at such heights the density of the bulge is rather low, the volume we are probing is sizable, so that we see a large number of bulge stars. Their absolute proper motion (PM) is just the reflection of the Sun's angular velocity with respect to that point; from that PM we can derive the value of the angular velocity of the LSR with respect to the Galactic center, which is the fundamental Galactic-rotation constant $A - B = \Theta_0/R_0$ (cf. Kerr & Lynden-Bell 1986).

To derive is value we need to: (1) find the mean distance of the bulge stars whose motion we are observing, (2) correct the observed PM for the velocity of the Sun with respect to the LSR, and (3) relate the corrected PM to the angular velocity of the LSR with respect to the Galactic center.

For the distance of the bulge stars that we are observing, we assume the following working hypotheses: (1) Disk and halo stars are a negligible component of the field stars in our M4 images, i.e., the field stars are mainly bulge members. (2) The bulge stars on our line of sight are part of a spherical spatial distribution around the Galactic center. (3) Our observations go deep enough that we do not loose stars on the far side of the bulge. From these

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assumptions, it follows that we can express the distance of the centroid of the bulge stars along our line of sight (we will refer to it as the bulge) as a geometrical constant×the distance of the Sun from the Galactic center. This distance is $R = R_0\ \cos\ell\cos b$. If we take $R_0 = 8.0$ kpc, then $R = 7.6$ kpc. Next, to link (Θ_0/R_0) to the observables, and to estimate the Solar corrections, we introduce the following formulas. These express the PM observed in the direction $(\ell,\ b)$ as a function of the velocity vector in a Galactic rest frame defined as $(U_{\rm abs}, V_{\rm abs}, W_{\rm abs}) = (U, V + \Theta_0, W)$

$$\left\{\begin{array}{l} \mu_{\ell\cos b} = \frac{(U_{\rm abs}^2+V_{\rm abs}^2)^{1/2}\sin(\phi-\ell)}{kR_0\cos\ell\cos b}, \\ \mu_b = \\ \frac{(((U_{\rm abs}^2+V_{\rm abs}^2)^{1/2}\cos(\phi-\ell))^2+W_{\rm abs}^2)^{1/2}\sin(\psi-b)}{kR_0\cos\ell\cos b}, \\ \phi = \tan^{-1}\frac{V_{\rm abs}}{U_{\rm abs}}, \\ \psi = \tan^{-1}\frac{W_{\rm abs}}{(U_{\rm abs}^2+V_{\rm abs}^2)^{1/2}\cos(\phi-\ell)}, \end{array}\right. \quad (1)$$

where $k = 4.74$ is the equivalent in km s^{-1} of one astronomical unit per tropical year.

At this point we can correct our observations of the motion of the bulge for the Sun's peculiar velocity, and obtain the components due exclusively to the LSR circular motion around the Galactic center (which is related to Θ_0/R_0)

$$\left\{\begin{array}{l} \mu_{\ell\cos b}^{\rm LSR} = \mu_{\ell\cos b}^{\rm observed} - \mu_{\ell\cos b}^{\odot} \equiv X, \\ \mu_b^{\rm LSR} = \mu_b^{\rm observed} - \mu_b^{\odot} \equiv Y, \end{array}\right. \quad (2)$$

where we introduced X and Y to be more concise. In the case of the LSR we have $(U_{\rm abs}, V_{\rm abs}, W_{\rm abs}) = (0, \Theta_0, 0)$, and so from Eq. 1 we have $\mu_{\ell\cos b}^{\rm LSR} = \frac{-1}{k\cos b}\Theta_0/R_0$, $\mu_b^{\rm LSR} = \frac{\tan b\tan\ell}{k}\Theta_0/R_0$, and combining them in quadrature, we get

$$\left\{\begin{array}{l} \Theta_0/R_0 \pm \sigma_{\Theta_0/R_0} = F\sqrt{X^2+Y^2} \pm F\sigma \\ F = k\cos b[1+\sin^2 b\tan^2\ell]^{-1/2} \\ \sigma = \sqrt{\sigma_X^2+\sigma_Y^2} \end{array}\right. \quad (3)$$

Fig. 1 shows the PMs in Galactic coordinates. The origin has been set at the extra-galactic point source labeled QSO. We drew a heavy circle at a radius of 4 times the semi-interquartile distance of the field stars from their median position (for stars with PM larger than 5 mas yr^{-1} with respect to the cluster mean). We assumed the stars inside the circle to belong to the same distribution, and calculated the mean from them. The σ has been taken to be the 68.27th percentile of the distribution of sizes of the PMs with respect to the mean. In Fig. 1 the three thin circles show 1, 2, 3σ. *This is the mean absolute motion of the bulge* and it is shown as an arrow in Fig. 1. With Eq. 1 we can estimate the Solar correction adopting: a Solar motion, and a Galactocentric distance; consequently from Eq. 2 we can estimate X and Y.

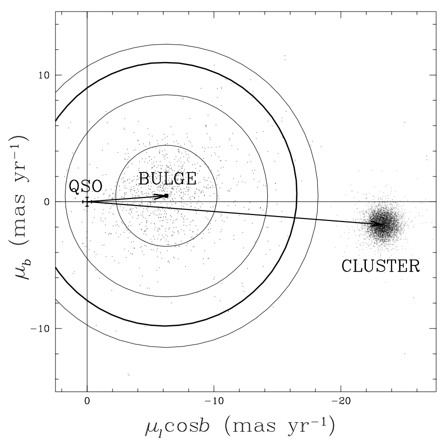

Fig. 1. Vector-point diagram of all the independent measurements of the in Galactic PMs. The arrows indicates the mean motion of the cluster and the bulge with respect to an extragalactic source.

The absolute motion of the bulge—corrected for the Sun's peculiar motion—allows us to get a direct estimate of the Oort-constant difference $(A - B)$, which is related to the transverse velocity of the LSR (Θ_0) and its Galactocentric distance (R_0), according to Eq. 3, by $(A - B) \pm \sigma_{(A-B)} = \Theta_0/R_0 \pm \sigma_{\Theta_0/R_0} = 27.6 \pm 1.7$ km/s kpc. The quoted error is internal and corresponds to an uncertainty of 7%.

References

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