ESTIMATION OF THE LOCAL MASS DENSITY FROM AN F-STAR SAMPLE OBSERVED BY HIPPARCOS

H.A. Pham

DASGAL, URA 335 du CNRS, Observatoire de Paris, France

ABSTRACT

This work is dedicated to the determination of the local mass density from an F-stars sample observed by Hipparcos. We present here a maximum likelihood method in order to estimate the scale height of a tracer sample together with the Sun height. This method takes into account the limiting apparent magnitude of the tracer sample. Applying this method on a sample of F stars observed by Hipparcos, we find a scale height of 165 ± 5 pc. The estimated sun height is 9 ± 4 pc. The local volume mass density is 0.11 ± 0.01 $M_\odot\,pc^{-3}$.

Key words: local volume mass density; scale height; Sun height; likelihood maximum method; apparent magnitude censorship.

1. INTRODUCTION

Since the first dynamical determinations of the local mass density, performed by Kapteyn (1922) and by Oort (1932), many other studies have been carried out, leading to values between 0.09 and 0.28 $M_\odot\,pc^{-3}$. As the observed local mass density is 0.10 $M_\odot\,pc^{-3}$, these dynamical determinations lead to the problem of the existence of dark matter associated with the galactic disk.

Most of the local mass density determinations were based on the analysis of the density and velocity distribution of a tracer sample of stars. The determinations are connected to the gravitational force K_z perpendicular to the galactic plane, via the Poisson equation. Under certain conditions (isothermal stellar population in particular) this vertical force K_z can be written as a function of only the vertical velocity dispersion and the vertical Z-distribution, which depends on the scale height h_z and the Sun height above the galactic plane Z_0.

Up to now, the size of the tracer sample and the low accuracy of the distances and of the velocities were a major drawback to the local mass density estimations. The Hipparcos satellite's data, (very accurate positions, parallaxes and proper motions), in addition to accurate radial velocities should overcome this observational difficulty.

We present hereafter our estimation of the local mass density, obtained from an Hipparcos F-stars sample, with a maximum likelihood method which takes into account the apparent magnitude censorship.

2. THE SAMPLE

We have used a sample of about 10 000 F stars taken from the Hipparcos Survey.

We recall that the Hipparcos Survey is made of almost all stars until the limiting magnitude:

- $V_{\rm lim} = 7.3 + 1.1\sin(|b|)$ if the spectral type is later than G5;
- $V_{\rm lim} = 7.9 + 1.1\sin(|b|)$ if it is earlier or equal.

For this sample, we have the following data at our disposal:

- $\pi, \alpha, \delta, \mu_\alpha\cos(\delta), \mu_\delta$, magnitude Hp (Hipparcos Catalogue);
- Strömgren photometry b–y, m1, c1, H_β (for about 4000 stars);
- color indices $B - V$;
- radial velocities (Coravel data, Barbier-Brossat et al. (1997) and Duflot et al. (1995) catalogues) for about 2600 stars.

Since our sample is limited by the apparent magnitude, several numerical simulations were performed, in order to estimate the effects of this limitation on the scale height determination: 50 samples of 6000 stars without apparent magnitude censorship and 50 samples of 700 stars limited by the apparent limit magnitude 9 mag were simulated.

These simulations were realised with a uniform density law for the positions in the galactic plane, an exponential law for the heights Z above the galactic plane (parameter $1/h_z$ with $h_z = 200$ pc), a Gaussian distribution for the absolute magnitudes ($\mathcal{N}(M_o, \sigma_M)$, ($M_o = 3.5$ mag, $\sigma_{\rm M} = 0.5$ mag)).

This results in the apparent magnitude censorship decreasing the estimation of the scale height. This effect has to be taken into account. This is one of the aims of the method presented hereafter.

3. ESTIMATION OF THE SCALE HEIGHT: STATISTICAL METHOD

The maximum likelihood method presented here permits the estimation of the Sun height Z_o, the scale height h_z and also the absolute magnitude M_o and the dispersion σ_M of a tracer sample. This method takes also into account the apparent magnitude censorship.

This is done by taking the following observables: the apparent magnitude m, the parallax π, and the positions l and b. Since the scale height estimation and the apparent magnitude limit are dependent, it is necessary to take a spatial model and a luminosity model. We have chosen for the spatial model, a uniform density law in the galactic plane (limited by a disk of length A; A being an arbitrary large enough constant), and an exponential or sech^2 law for the Z-distribution.

For the luminosity model we have taken a normal law $\mathcal{N}(M_o, \sigma_M)$ for the absolute magnitude M.

Finally, in the case of an exponential law for the vertical distribution, the density probability function is:

if $\quad m \leq m_{\mathrm{lim}}, \quad (\cos(b)/A) \leq \pi, \quad 0° \leq l \leq 360°$

and $\quad -90° \leq b \leq 90°$:

$$f_{\mathrm{mlim}}(m, \pi, l, b) \sim e^{\frac{-(m+5\log(\pi)+5-M_o)^2}{2\sigma_M^2}} \times e^{-\frac{1}{h_z}\left|\frac{\sin(b)}{\pi}+Z_o\right|} \times \frac{\cos(b)}{\pi^4}$$

else $f_{\mathrm{mlim}}(m, \pi, l, b) = 0$

Similar statistical methods have been carried out by Luri (1995) for luminosity calibration or by Arenou (1995) for his determination of the global zero-point of Hipparcos parallaxes.

4. RESULTS

4.1. Preliminaries

- As we are interested in the scale height determination of the thin disk, we have eliminated the metal poor stars ($[\frac{Fe}{H}] \leq -0.2$) and the high velocity stars (tangential velocity > 65 km s^{-1}).

- We have sampled our stars in $B-V$ groups, because the spectral types and the luminosity classes are not known for all stars. We can so determinate M_o and σ_M for more homogeneous groups. The $B-V$ groups are:

$B-V$	corresponding spectral type
0.30 – 0.35	F0 – F2
0.35 – 0.40	F2 – F3
0.40 – 0.50	F4 – F7
0.50 – 0.60	F7.5 – G1

- Finally we have eliminated most of the stars which do not belong to the main sequence by iterations on the absolute magnitude in order to obtain a sample of F dwarfs.

4.2. Determination of the Scale Height and of the Sun Height

These determinations were realised with an exponential and a sech^2 vertical distribution, with the different $B-V$ sub-samples limited at the apparent magnitude 7.9 mag and at the survey limit magnitude. The results are reported in Figures 1 and 2.

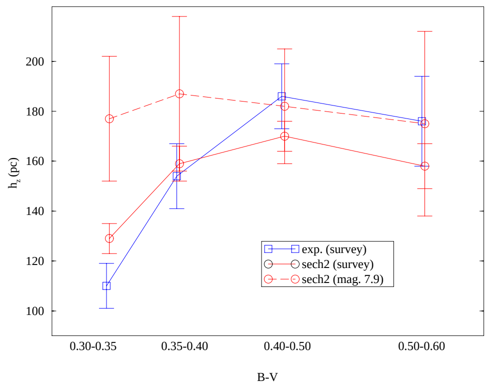

Figure 1. Estimation of the scale height for the different $B-V$ sub-samples and for different limit magnitude.

The errors bars presented in the figures were obtained using the Fisher Information. We have shown that these errors are of the same magnitude as the dispersion of the results obtained on 80 simulated star samples (Pham 1996).

We find that the 2 vertical distribution (exp and sech^2) lead to the same estimations for h_z and Z_o. These estimations are similar for the different $B-V$ sub-samples (except for the h_z-estimation in the first $B-V$ group, this may be explained by an incompletness of the survey sample in this range of $B-V$).

We have also implemented an analogous method which takes into account the error measurements on the parallaxes. This method leads also to the same results.

Finally our estimation of the scale height of our sample made of thin disk stars with age mostly between

1 and 4 Gyrs is:

$$h_z = 165 \pm 7 \text{ pc}$$

And the Sun height estimate is:

$$Z_o = 9 \pm 4 \text{ pc}$$

This estimate is in good agreement with the values founded by Pandey & Mahra (1987) (10 ± 4 pc from the study of the interstellar matter distribution) and by Brand & Blitz (1993) (13 ± 7 pc from the study of the local molecular clouds).

4.3. Relation Age-Velocity Dispersion

We have plotted in Figure 3 the vertical component W of the velocities against the logarithm of the ages for our sample stars which have radial velocity data (for the calculus of W) and Strömgren photometry (for the calculus of the effective temperature, of the metallicity [Fe/H], (Arenou 1993) and so for the determination of the ages (Asiain 1993, Sabas 1997).

We can see an increase of the vertical velocity with stellar age, varying from 8.8 ± 0.4 km s^{-1} for stars of 1 Gyr, to 11.5 ± 0.9 km s^{-1} for stars between 2 and 3.2 Gyrs.

4.4. Estimation of the Local Mass Density

We have now determined the scale height and the age of the different $B-V$ sub-samples. We can then assign a vertical velocity dispersion to each different group, so it is possible to estimate the local mass density.

In the case of a sech^2 vertical distribution and under certain conditions (isothermal population and R-gradient of $\sigma^2_{RZ} = < v_R v_Z >$ neglected), we can write

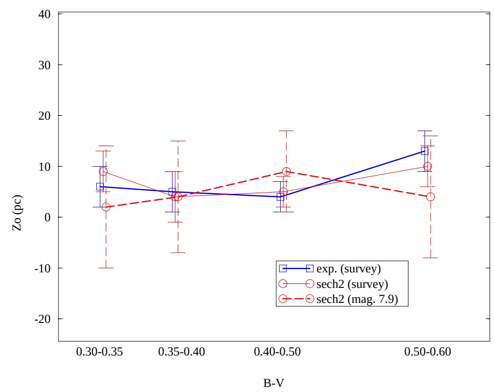

Figure 2. Estimation of the Sun height for the different $B-V$ sub-samples and for different limit magnitude.

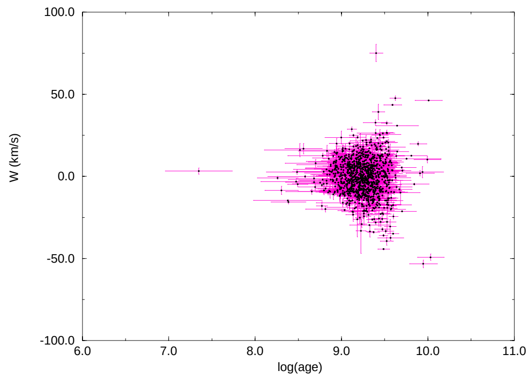

Figure 3. Vertical velocity W versus log(Age) for 1099 stars of the sample.

the local mass density as:

$$\rho(0) = \frac{\sigma^2_{zz}}{2\pi G h^2_z} \tag{1}$$

We find a local mass density estimation of:

$$\rho(0) = 0.11 \pm 0.01 \text{ M}_\odot \text{ pc}^{-3}$$

The actual observed mass density is 0.10 M$_\odot$ pc^{-3} (Kuijken & Gilmore 1989). The missing observed mass announced by Bahcall (1984) (almost 50 per cent of the Galactic disk is invisible) is then completely reduced. This agrees with the study of Kuijken & Gilmore (1989) who found no evidence for any significant unidentified mass in the galactic disk.

REFERENCES

Arenou, F., 1993, thesis, Paris

Arenou, F., 1995, A&A, 304,52

Asiain, R., 1993, tesina, Barcelona

Bahcall, J.N., 1984, ApJ, 276, 169

Barbier-Brossat, M. et al., 1997, A&AS, in press

Brand, J., Blitz, L., 1993, A&A, 275, 67

Duflot, M., Figon, P., Meyssonnier, N., 1995, A&AS, 114, 269

Kapteyn, J.C., 1922, ApJ, 55, 302

Kuijken, K., Gilmore, G., 1989, MNRAS, 239, 651

Luri, X., 1995, thesis, Barcelona

Oort, J., 1932, BAIN, 6249

Pandey, A.K., Mahra, H.S., 1987, MNRAS, 226, 635

Pham, H.A., 1996, thesis, Paris

Sabas, V., 1997, thesis, Paris