STATISTICAL RELATION BETWEEN APPARENT AND ABSOLUTE MAGNITUDES OF STARS IN A DISK-LIKE SUBSYSTEM

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ABSTRACT

A three-component model of the Galaxy was used to derive a statistical relation between the apparent and absolute magnitudes for stars which make the maximum contribution to the star-counts in a given Galactic subsystem. The results are tabulated for the thin disk (main sequence stars and red giants), the thick disk, and the spheroid. The model and photometric data used to specify the model parameters are briefly described. The results can contribute to the discussion of the limiting magnitude of the GAIA mission.

Key words: stellar distributions; Galactic models; GAIA

1. INTRODUCTION

The proposed ESA space interferometry mission GAIA will supply the scientific community with astrometric and photometric data of remarkable quality (Lindegren & Perryman (1994)). With scientific targets located in the Solar System, throughout the Galaxy, and in the galactic neighbourhood, the mission will have a major impact on different areas of astronomy and astrophysics. As a survey, the GAIA project will provide a huge stellar sample which is free of selection effects and complete up to a limiting magnitude ($V > 15.5$ mag). Stellar statistics based on GAIA observations will considerably improve our understanding of Galactic structure and the nature of stellar populations.

The final GAIA catalogue will contain a mixture of stars with different intrinsic luminosities belonging to different Galactic subsystems. Assuming a model of the Galaxy, we can predict which part of the Galactic populations will be probed by GAIA observations. The calculations were carried out with a three-component model of the Galaxy. The model parameters were specified by the use of photometric data for about 23 000 stars observed in the Galactic meridian (see Andruk et al. 1995). In order to achieve the best agreement between model and observations, we fitted the values of the dip (a_W) of the disk luminosity function, the correction to the absolute magnitude of disk red giants ($\Delta M_V^{\mathrm{red\,giants}}$) and the expression for interstellar extinction.

2. PHOTOMETRIC DATA

Photographic B magnitudes of 14 100 stars were obtained in 47 selected fields along the main Galactic meridian with the Kiev long-focus astrograph (40/550). The sample is complete up to $B = 14.5$ mag. The rms error of photographic B magnitudes is about 0.05 mag for brighter stars and increases to 0.3 mag for the faintest stars.

In addition, we included in the analysis the data for 8 800 stars obtained from Tautenburg Schmidt plates in two fields near the North Galactic pole. The internal accuracy of B and V magnitudes for intermediate stars ($11 \leq B \leq 15$ mag) is about 0.05 mag, whereas the magnitudes of brighter and fainter stars are of lower accuracy (0.1 mag). The Tautenburg sample is complete down to $B = 18$ mag.

In addition, photoelectric magnitudes and colours in the Johnson UBVR system were obtained for 943 stars in the programme fields. The observations were conducted mainly with the Zeiss-600 (60/760) telescope located on Mount Terskol in the North Caucasus. The external rms errors are 0.014, 0.026, 0.012, 0.016 mag for V magnitudes and colours $(U-B)$, $(B-V)$, and $(V-R)$, respectively. The data were used to specify the expression for interstellar extinction $A_V(R,b)$.

The best fit of the modelled colour distribution to observations was obtained with the modified Sandage law (Sandage (1972)):

$$\begin{aligned} A_V(R,b) &= 0.165(1.192 - |\tan b|) \cdot |\csc b| \cdot \\ &\quad \cdot [1 - \exp(-R\,|\sin b|\,h_{Za}^{-1})], \ |b| \leq 50^\circ, \\ A_V(R,b) &= 0, \ |b| > 50^\circ, \end{aligned} \tag{1}$$

where h_{Za} is the scale height of an extinction layer.

3. THE BASIC EQUATIONS AND RELATIONSHIPS

We used the first fundamental equation of stellar statistics for the j-th subsystem or stellar group:

$$A_j(V,l,b) = d\Omega \int_{V_{i1}}^{V_{i2}} dV \int_0^{R_{\mathrm{lim}}} D_j(\vec{r},M) F_j(M_V) R^2 dR \tag{2}$$

to calculate the number A_j of stars in a solid angle $d\Omega$ and in the i-th magnitude interval $\Delta V_i = V_{i2} - V_{i1}$ and:

$$A_j((B-V),l,b) = d\Omega \int_{(B-V)_{i1}}^{(B-V)_{i2}} d(B-V) \int_0^{R_{\rm lim}} D_j(\vec{r},M)F_j(M_V)R^2 dR \qquad (3)$$

to calculate the number of stars in the i-th colour index interval $\Delta(B-V)_i = (B-V)_{i2} - (B-V)_{i1}$. Here $F_j(M)$ is the luminosity function in the solar neighbourhood; R is the distance from the Sun; $R_{\rm lim}$ is the maximum distance from the Sun where a star of a given M_V appears as a star within a given ΔV magnitude interval; $\vec{r}$ is position of a star relative to the Galactic centre. The expressions for the space-density function $D_j(\vec{r},M)$ for each subsystem were taken from Bahcall (1986).

We considered a three-component model of the Galaxy consisting of the thin disk (or disk), thick disk and spheroid populations. Further, we assumed two groups of stars in the thin disk, namely the main sequence stars and disk red giants. The distribution function of the apparent magnitudes is:

$$\mathbf{A}(V,l,b) = \sum_{j=1}^{4} A_j(V,l,b).$$

To model the observed colour index distribution, we consider eight essential types of stars: main sequence stars and disk red giants as the disk subsystem; subdwarfs and intermediate giants (or stars of the intermediate population before and after their main sequence turn-off point) and white dwarfs as the thick disk subsystem; extreme subdwarfs and spheroid giants (or stars of population II before and after their main sequence turn-off point) and horizontal branch stars as the spheroid subsystem. The corresponding distribution function of colour indices is:

$$\mathbf{A}((B-V),l,b) = \sum_{j=1}^{8} A_j((B-V),l,b).$$

The luminosity function of the disk main sequence was computed by the use of the equations given in Bahcall & Soneira (1980) but excluding disk red giants and taking into account the dip, i.e., a lack of stars within M_V interval from 6 to 10 (Starikova (1960), Wielen (1974)). The value of the dip, a_W, is obtained by a fit of the model to observed distributions of magnitudes and colours. The best agreement between the observations and the model was achieved if a value of 0.6 (in logarithmic scale) was assumed for the dip.

The luminosity functions of the thick disk and spheroid and the normalisation {thin disk:thick disk:spheroid} as {1:0.02:0.00125} were taken from Gilmore (1984). Additionally, the results obtained by Da Costa (1982) for globular clusters were used to model the influence of the horizontal branch in the spheroid luminosity function.

To construct the colour-magnitude diagram, we used the data of Chiu (1980) for the lower main sequence of the disk, whereas for stars earlier than spectral class G0 the data of Straižys (1977) were used. For the disk red giants we took the data from Morgan & Eggleton (1978) which were corrected for the shift $\Delta M_V^{\rm red\ giants}$ noted by Flynn & Mermilliod (1991). The best fit of the the observed colour distribution by the model given by Eq. (3) was obtained with the correction $\Delta M_V^{\rm red\ giants} = +0.5$ mag. The colour-magnitude diagram of the globular cluster 47 Tuc (Lee (1977)) was used for subdwarfs and giants of the thick disk. The extreme subdwarfs and giants of the spheroid are presented by the data for the old globular cluster $M\,92$ (Sandage (1982)). The white dwarfs and horizontal branch stars were taken from Chiu (1980).

4. RESULTS AND CONCLUSIONS

In order to model the distributions given by Equations (2) and (3), we assume the following parameters: the distance between the Sun and the Galactic centre is $R_0 = 8.5$ kpc; the height of the Sun above the Galactic plane is +20 pc; the axial ratio of the spatial distribution for the spheroid is $k = 0.85$, the scale length of the disk subsystems is $h_X = 4$ kpc and the scale height of the thick disk is $h_Z = 1.3$ kpc.

Following Schmidt (1963), and Mihalas & Binney (1981), we assume the the scale height $h_Z(M)$ from 90 to 350 pc corresponding to increasing M_V from 2.3 to 5.4 for main sequence stars of the disk whereas for the red giants, the scale height changes from 250 to 400 pc with an increasing M_V from −0.75 to 2.6. The parameters h_{Za} used in Eq. (1) is 114 pc (Sharov (1963)). Fig. 1 shows the number of stars per square degree modelled for different stellar subsystems and in three directions along the Galactic meridian.

Considering a total number of stars $A_j(V,l,b)$ in a disk-like subsystem j as:

$$A_j(V,l,b) = \frac{4}{3}\pi R_{\rm lim}^3 D_j(\vec{r},M)F_j(M_V)$$

and setting its partial logarithmic derivative with respect to V to zero, i.e., $\frac{\partial \log}{\partial V}(A_j) = 0$, we obtain a relation between the apparent magnitude V_m and the absolute magnitude M_V of stars which make a maximum contribution to the star-counts for the subsystem j:

$$V_m = -2.614 + M_V + A_V(R,b) - 5\cdot\log(\frac{\sin b}{h_Z} + \frac{\cos b \cos l}{h_X}) \qquad (4)$$

According to Eq. (4), V_m depends on the Galactic direction, scale height, scale length, and interstellar extinction. Table 1 gives V_m in five Galactic directions and for each stellar subsystem. Here we approximated the spheroid by a disk-like system with a scale length of 4 kpc and a scale height of 4 kpc.

From Table 1 we conclude that with the limiting magnitude $V = 16$ mag, all disk red giants located in the vicinity of the North Galactic pole will be observed by GAIA, whereas the thick disk and the spheroid will be mostly represented by stars brighter than $M_V = 3$ and $M_V = 1$ respectively.

As an example, to study the question of the dip of the luminosity function for the thick disk ($M_V \approx 7$), statistically significant samples of stars fainter than $V = 20$ mag are needed.

M_V [mag]	$(B-V)$ [mag]	h_Z [pc]	$V_m[mag]$ ($l=0°$, $b=10°$)	$V_m[mag]$ ($l=0°$, $b=50°$)	$V_m[mag]$ ($b=90°$)	$V_m[mag]$ ($l=180°$, $b=50°$)	$V_m[mag]$ ($l=180°$, $b=10°$)
		Disk	main	sequence			
-5	-0.31	90	6.7	2.7	2.2	2.8	7.2
-1	-0.18	90	10.7	6.7	6.2	6.8	11.2
3	0.34	148	15.6	11.8	11.2	11.9	16.5
7	1.08	350	21.0	17.5	17.1	17.9	23.4
11	1.57	350	25.0	21.5	21.1	21.9	27.4
15	1.88	350	29.0	25.5	25.1	25.9	31.4
		Disk	red	giants			
-1	1.75	250	14.1	9.1	8.4	9.1	14.1
0	1.35	283	15.5	10.4	9.6	10.4	15.5
1	1.07	327	17.1	11.7	11.0	11.7	17.1
2	0.95	372	18.6	13.0	12.2	13.0	18.6
3	0.60	400	20.0	14.2	13.4	14.2	20.0
4	0.45	400	21.0	15.2	14.4	15.2	21.0
		Thick	disk				
-1	1.60	1300	16.7	13.2	12.0	13.2	16.7
1	0.98	1300	18.7	15.2	14.0	15.2	18.7
3	0.77	1300	20.7	17.2	16.0	17.2	20.7
5	0.56	1300	22.7	19.2	18.0	19.2	22.7
7	1.00	1300	24.7	21.2	20.0	21.2	24.7
9	1.38	1300	26.7	23.2	22.0	23.2	26.7
11	1.55	1300	28.7	25.2	24.0	25.2	28.7
			Spheroid				
-3	1.40	4000	17.2	16.9	12.4	16.9	17.2
-1	0.90	4000	19.2	18.9	14.4	18.9	19.2
1	0.68	4000	21.2	20.9	16.4	20.9	21.2
3	0.55	4000	23.2	22.9	18.4	22.9	23.2
5	0.50	4000	25.2	24.9	20.4	24.9	25.2
7	0.95	4000	27.2	26.9	22.4	26.9	27.2
9	1.35	4000	29.2	28.9	24.4	28.9	29.2

Table 1: Statistical relation between the apparent V_m and absolute M_V magnitude.

REFERENCES

Andruk, V., Kharchenko, N., Schilbach, E., Scholz, R.-D., 1995, Astron. Nachr., 316, in press

Bahcall, J.N., 1986, Ann. Rev. Astron. Astrophys., 24, 577

Bahcall, J.N., Soneira, R.M., 1980, ApJS, 44, 73

Chiu, L.-T.G., 1980, ApJS, 44, 31

Da Costa, G.S., 1982, AJ, 87, 990

Flynn, C., Mermilliod J.C., 1991, A&A, 250, 400

Gilmore, G., 1984, MNRAS, 207, 223

Lee, S.W., 1977, A&AS, 27, 381

Lindegren, L., Perryman, M.A.C., 1994, The GAIA mission, Supplementary Information submitted to the Horizon 2000+ Survey Committee, September 1994.

Mihalas, D., Binney, J., 1981, Galactic Astronomy, Freeman, San Francisco

Morgan, J.G., Eggleton, P.P., 1978, MNRAS, 182, 219

Sandage, A., 1972, ApJ, 178, 1

Sandage, A., 1982, ApJ, 252, 553

Schmidt, M., 1963, ApJ, 137, 758

Sharov, A.S., 1963, Astron. Zhurn., 40, 900

Starikova, G.A., 1960, Astron. Zhurn., 37, 476

Straižys, V., 1977, Multicolour photometry of stars, Mokslas, Vilnius.

Wielen, R., 1974, in G. Contopoulos (ed.), Highlights of Astronomy, 3, Reidel, Dordrecht, 395

Figure 1: *The modelled surface density [stars/degree^2] in three directions along the Galactic meridian. The short-dashed, long-dashed, and dashed-dotted lines correspond to the disk main sequence stars, disk giants, thick disk and spheroid, respectively. The total density is marked by a solid line.*