

The radial scale length of the Milky Way

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Abstract. The radial scale length of the exponential component of the disc of the Milky Way has been determined in the near infrared. We have used the TMGS (Two Micron Galactic Survey) database which contains positions and K-magnitudes of about 700.000 stars distributed in several regions along the galactic plane. From those we have selected areas more than 5° off the plane to minimize the effect of extinction and the contributions of the young disc; and with longitudes ranging from 30° to 70° , to avoid contaminations from the central bulge, the bar and the molecular ring, in the inner end, and from the local arm, the warp and the truncation of the disc, in the outer end. We observed stars with magnitude $9 \leq m_K \leq 10$. The use of the NIR K-band also reduces the effect of extinction. In the observation region, $m_K = 9.5$ mag stars are K2-K5 III stars, with an absolute magnitude that is nearly constant, which also greatly simplifies the problem. We have obtained the value 2.1 ± 0.3 kpc for the radial scale length, which is a typical value when compared with external galaxies of similar types.

Key words: Galaxy: structure – Galaxy: fundamental parameters – Infrared: galaxies

1. Introduction

It is well known that normal discs of spiral galaxies have a component which can be fitted to an exponential (Freeman, 1970) with a radial scale length h . There are two basic reasons to undertake a new determination of the parameter h in the Milky Way:

a) There is a very large scatter in the values found in the literature. For instance, Kent, Dame and Fazio (1991) after reviewing previously reported values, found that they range from 1 to 5.5 kpc, and proposed an intermediate value of 3 kpc. van der Kruit (1986) obtained 5.5 kpc; Lewis and Freeman (1989) gave a value of 2.5 kpc, and so did Robin, Crezé and Mohan (1992), among others. This uncertainty is also too large in the NIR. Mikami and Ishida (1981) obtained a value of 1 kpc, Jones et al. (1981) 2 kpc, and Eaton et al. (1984) 3 kpc. Values of h in the NIR seem to be lower, but even this fact remains uncertain, despite its interest in the dynamic evolution of the disc.

b) Even if h is simply a fitting parameter for a distribution with frequent deviations from an exponential, it has become a natural radial length unit, very useful when comparing spiral galaxies with different sizes or unknown distances, and physically more significant than true length of angle units. The position of any morphological feature or typical lengths of disc phenomena are usually and hopefully expressed taking h as unit. Some of these features in our own galaxy may be considered normal or exceptional depending on the value of this normalizing length.

Probably the large scatter of data is a result of managing a large amount of data concerning different regions of the sky, which are difficult to analyse because of the contribution of many other complex components, such as bulge, star formation ring associated with the gas ring, bar, spiral arms, warp and so on. However, a proper choice of the wavelength and the region of the sky may render this problem a very simple one, which implies a more confident obtention of the parameter h .

This search specifically deals with, and aims at an improved determination of the radial scale length of the Milky Way disc.

We have chosen the K-band, in which extinction is very low. This also implies that the observed distribution closely resembles the true one. In addition, we have taken measurements at $b = 5^\circ$, rendering extinction negligible. We then

surveyed a galactic longitude range from 30° to 70° . This practically eliminates the contribution of bulge, ring and bar (Hammersley et al., 1994) which take place for $l < 30^\circ$, and the contribution of the Local Arm, warp and truncation (Porcel et al., 1997), which take place for $l > 70^\circ$. The contribution of the other spiral arms (not the Local Arm) is minimized taking $b = 5^\circ$, as they remain closer to the plane. Another advantage of working in the K-band is that the observed stars in the 9-10 magnitude range are practically only K2-K5 III stars, through the surveyed sky zone. This fact was realised after taking into account the previous analyses of Ruelas-Mayorga (1991), Wainscoat et al. (1992), Calbet et al. (1995) and our own initial calculations (Porcel, 1997). The light coming from these stars is 80 % of the total light from all stars in this magnitude range. This greatly simplifies the problem as the luminosity function can be approximated by a Dirac's delta function.

Observations were carried out with the Carlos Sánchez 1.5 m telescope at the Teide Observatory, as part of the Two Micron Galactic Survey (TMGS) project (Garzón et al., 1993; Hammersley et al., 1994; Calbet et al., 1995). Interpolation techniques were used to obtain a regular mesh from the series of discrete scans (Porcel, 1997; Porcel et al. 1997).

2. Results

As explained above we consider K2-K5 III stars. The luminosity function ϕ is defined as usual, i. e. $\phi(M)dM$ gives the number of stars per pc^3 with an absolute K magnitude in the interval $[M, M + dM]$. It is here approximated by a Dirac's function, i. e. $\phi(M) = \delta(M - M_0)$ centred at $M_0 = -2.5\text{mag}$. Its true dispersion is only 0.6 mag. The effect of a non-vanishing dispersion on absolute magnitude could be important, as the resulting value for the scale length could be affected by some sort of Malmquist bias. We have performed several numerical calculations using a gaussian distribution for the luminosity function, obtaining similar results. The final value of the estimated error is not affected either, as it mainly arises from the fitting process. Even though these kind of effects are difficult to evaluate, the approximation of the luminosity function by a δ - function was found to be a satisfactory assumption. In the fundamental equation of star counts (e. g. Mihalas and Binney, 1981; Gilmore and Reid, 1983; Calbet et al., 1995) the density function is also taken into account. It was assumed that:

$$n(R, z) = e^{-\frac{R-R_\odot}{h} - \frac{|z|}{h_z}} \quad (1)$$

where $n(R, z)$ is the density function, i. e. the number density of stars taking its local value as unit, R is the galactocentric distance, and z is the vertical coordinate. We take $R_\odot = 8.5$ kpc. The vertical exponential profile and the value of $h_z = 200$ pc were adopted from Wainscoat et al. (1992). We have repeated these calculations for different values of h_z and we have obtained similar results, i. e. neither the proposed value of h nor its estimated error are affected. Actually h is found to be noticeably independent of h_z . We therefore think that this choice for h_z cannot be an important source of errors.

Defining as usual $\mathcal{A}(l, b)$, as the number of stars per squared degree with magnitude between 9 and 10, the fundamental equation of star counts becomes

$$\mathcal{A} = \omega \int_9^{10} dm \int_0^\infty C \delta(M - M_0) e^{-\frac{R-R_\odot}{h} - \frac{|z|}{h_z}} r^2 dr \quad (2)$$

where ω is the solid angle, C is a constant and r is the distance from the Sun. This expression is easily transformed into

$$\mathcal{A}(l) = C_3 e^{-\frac{R_0 - R_\odot}{h}} \quad (3)$$

where

$$R_0 = (R_\odot^2 + r_0^2 \cos^2 b - 2R_\odot r_0 \cos b \cos l)^{1/2} \quad (4)$$

C_3 is another constant, and

$$r_0 = 10^{\frac{m - M_0 + 5}{5}} = 2.5 \text{ kpc} \quad (5)$$

As b is taken to be constant, R_0 is a function only of l , and therefore \mathcal{A} is a function only of l . Equation (3) predicts a linear function relation between $\log \mathcal{A}$ and R_0 . The results are plotted in Figure 1. In this figure, error bars represent Poisson errors. After fitting (using a standard chi-squared method as described in Press et al., 1992), we obtained

$$h = (2.1 \pm 0.3) \text{ kpc} \quad (6)$$

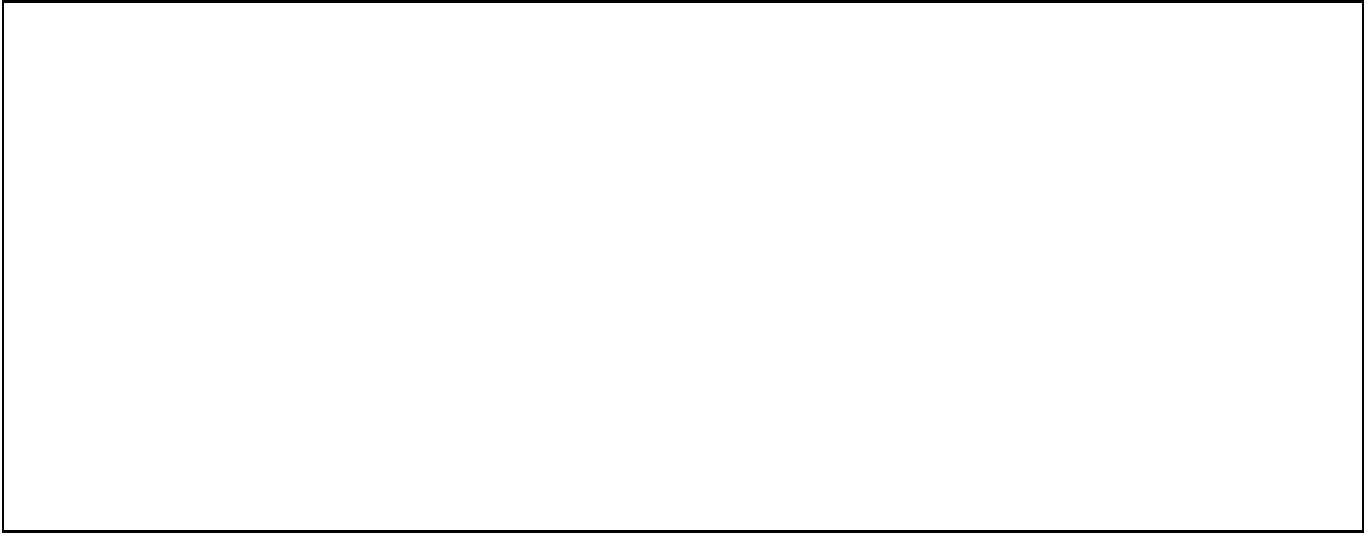


Fig. 1. Log of the number of K=9-10 magnitude stars per squared degree as a function of $R_0(l)$ defined in the text.

3. Conclusions

The value we propose, $h = (2.1 \pm 0.3)$ kpc has been obtained by choosing the most appropriate conditions for this task. This value is similar to typical values for other galaxies (de Grijs and van der Kruit, 1996; Peletier et al., 1994; de Jong, 1996). This value seems quite low when compared with the obtained values in the optical (see for instance van der Kruit, 1986; and Barteldress and Dettmar, 1994) but it is well known that the exponential scale lengths decrease with increasing wavelength (de Grijs and van der Kruit, 1996; Peletier et al., 1994; de Jong 1996, Tully et al., 1996). Peletier et al. (1994) found that the ratio h_B/h_K is in the range 1.2-2 in a sample of 37 Sb's and Sc's edge-on galaxies, with this ratio increasing with axis ratio, showing that it is an effect that is mostly due to extinction. In this case our determination of the radial scale length of the Milky Way is compatible with values in optical bands as large as 4 kpc. Our value is virtually free of extinction effects, so it is a proper determination of the true scale length of the mass distribution of the Milky Way disc. A similar value (2.3 ± 0.1 kpc) has been obtained by Ruphy et al. (1996). Fux and Martinet used indirect methods based on the asymmetric drift equation, and also obtained a similar value ($2.5^{+0.8}_{-0.6}$ kpc). We therefore conclude that with respect to the radial scale length, our galaxy is a typical one.

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