GALACTIC BULGE FROM TMGS STAR COUNTS

M. LÓPEZ–CORREDOIRA, F. GARZÓN, P. L. HAMMERSLEY,
T. J. MAHONEY AND X. CALBET

Instituto de Astrofísica de Canarias
E-38200 La Laguna, Tenerife, Spain

Abstract. The bulge of the Galaxy is analysed by inverting K-band star counts from the Two-Micron Galactic Survey in a number of off-plane regions. Assuming a non-variable luminosity function within the bulge, we derive the top end of the K-band luminosity function, which shows a sharp decrease brighter than $M_K = -8.0$ when compared with the disc population, and the stellar density function, whose morphology is fitted to triaxial ellipsoids with the major axis in the plane at an angle with line of sight to the Galactic centre of 12° in the first quadrant. The axial ratios are $1 : 0.54 : 0.33$ and the distance of the Sun from the centre of the triaxial ellipsoid is 7860 pc.

We use some off-plane regions in the Galactic bulge ($10° > |b| > 2°$, $|l| < 15°$) taken from TMGS (Two-Micron Galactic Survey; Garzón et al. 1993) up to nineth K magnitude. The total sky coverage is some 75 deg^2 of sky. In the areas considered, the contribution to the star counts will be primarily from the disc and bulge and the extinction is low (between 0.05 to 0.5 mag at K) and not too patchy (Garzón et al. 1993).

In order to isolate the bulge component a model disc was subtracted from the total counts: Wainscoat et al. (1992; hereafter WCVWS), which has been used because it provides a good fit to the TMGS counts in the region where the disc dominates (Cohen 1994). So $N_{K,\mathrm{bulge}}(m_K) = N_K(m_K) - N_{K,\mathrm{disc}}(m_K)$ and (in rad^{-2})

$$N_{K,\mathrm{bulge}}(m_K) = \int_0^\infty \Phi_{K,\mathrm{bulge}}(m_K+5-5\log_{10} r - a_K(r)) D_{\mathrm{bulge}}(r) r^2 dr, \quad (1)$$

where $\Phi_{K,\mathrm{bulge}}(M) = \int_{-\infty}^{M} \phi_{K,\mathrm{bulge}}(M)dM$, ϕ is the normalised luminosity function ($\int_{-\infty}^{\infty} \phi(M)dM = 1$), D is the density, and a_K is the extinction in the line of sight according to WCVWS.

With the change of variables $\rho_K = 10^{0.2a_K(r)}r$ and $\Delta_K = D(r)\frac{r^2 dr}{\rho_K^2 d\rho_K}$ we transform the equation (1) of counts in the bulge into

$$N_K(m_K) = \int_0^{\infty} \Phi_K(m_K + 5 - 5\log_{10}\rho_K)\Delta_K(\rho_K)\rho_K^2 d\rho_K. \qquad (2)$$

The density is obtained by inverting this equation: Δ is the unknown function and Φ is the kernel of a Fredholm integral equation of the first kind.

When the luminosity function Φ, is the unknown instead of Δ, then we can make a new change of variable $M_K = m_K + 5 - 5\log_{10}\rho_K$ and we obtain a new first kind of Fredholm equation:

$$N_K(m_K) = 200(\ln\,10)10^{\frac{3m_K}{5}} \int_{-\infty}^{\infty} \Delta_K(10^{\frac{5+m_K-M_K}{5}})10^{\frac{-3M_K}{5}} \Phi_K(M_K)dM_K, \qquad (3)$$

where Φ is now the unknown function and Δ_K is the kernel.

Both integral equations are inverted using Lucy's statistical method (Lucy 1974). This method is fairly insensitive to the high-frequency fluctuations and in our tests with known functions, which are similar to that of the bulge, gave good results (note: this method would not be applicable to the disc as a whole). Fig. 1 shows the outcome of a numerical simulation where we introduce an initial Δ function, obtain the counts through (2) adding a Poissonian equivalent noise over a square degree of sky and invert by Lucy's algorithm: the final Δ is similar to the initial Δ in spite of noise.

We solved first for the luminosity function for each region using the WCVWS bulge density. Then, assuming that the luminosity function is independent of the position (while our assumption may not be not strictly true, it is still a reasonable approximation between about 250 pc and 1200 pc from the galactic plane) we average it and use for inverting (2) to derive a new density distribution. The new density was then used to improve the luminosity function, etc. The whole process was iterated three times which was enough for the results to stabilize as can be seen in the Fig. 2: we see how the result of the third iteration is very close to the first; i.e. stabilization is reached in the first iterations.

The obtained luminosity function is shown in the Fig. 3 and it is accurate enough (the number of bulge stars is large enough compared with possible sources of contamination) down to $M_K \sim -9.5$. The coincidence of our luminosity function with that of WCVWS for the faintest stars is due to the fact that we used their luminosity function to initiating the iteration

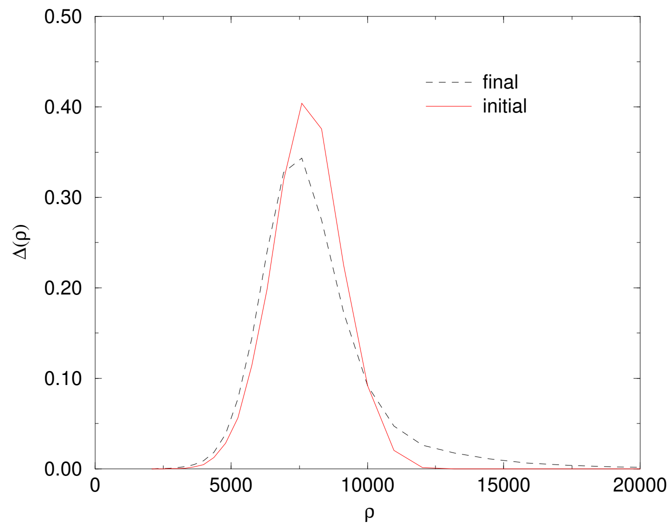

Figure 1. Recovery of the theoretical luminosity function through the inversion proccess.

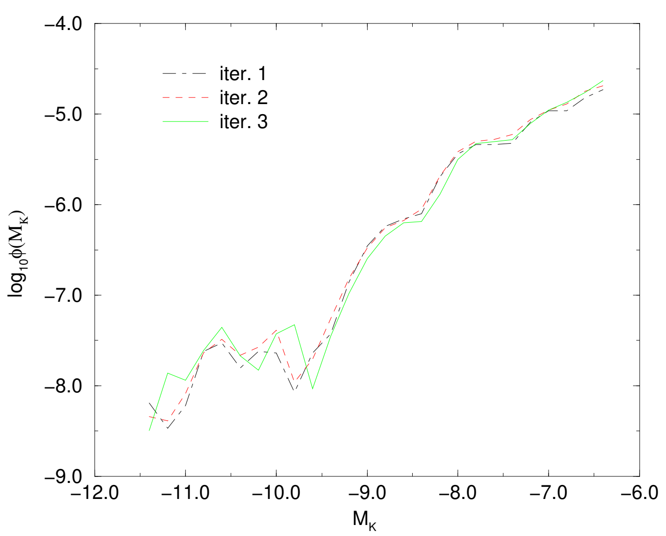

Figure 2. Luminosity function in the first three iterations.

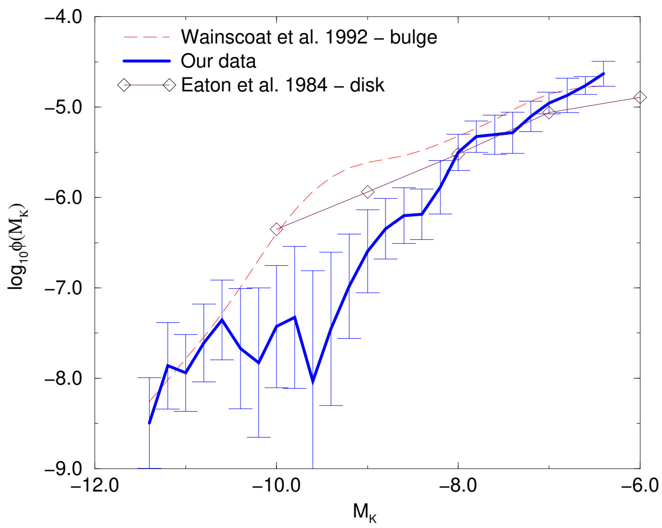

Figure 3. Luminosity function of the bulge stars in the K band: the thick solid line is the third and final iteration. Comparisons with the same luminosity function in the first iteration, WCVWS in the bulge and Eaton et al. (1984) in the disc are also provided.

process. Practically speaking, this overlapping corresponds to an effective normalization to the WCVWS luminosity function in the range $M_K > -7$.

Fig. 3 shows that for $-10 < M_K < -7$ the bulge luminosity function is significantly lower than that of the disc (Eaton et al. 1984). The discrepancy with WCVWS could arise from their not having taken into account that the brightest stars in the bulge are up to 2 magnitudes fainter than the disc giants (Frogel & Whitford 1987). This would shift the luminosity function to the right.

The morphology of the bulge can be examined by fitting the isodensity surfaces to $D(\vec{r}) = D(r, l, b)$. We fitted three-dimentional ellipsoids with two axes in the Galactic plane, x and y (we have ignored a possible tilt out of the plane), to 20 isodensity surfaces (from 0.1 to 2.0 star pc^{-3}, in steps of 0.1) with four free parameters: R_0, the Sun-Galactic centre distance; K_z and K_y, the axis ratios with respect the major axis x; and α the angle between the major axis of the triaxial bulge and the line of sight to the Galactic centre.

The four averaged parameters have been fitted for the 20 ellipsoids and the results are: $R_0 = 7860 \pm 90$ pc, $K_z = 3.0 \pm 0.9$, $K_y = 1.87 \pm 0.18$ and $\alpha = 12 \pm 6$ deg. We can also express the axial ratios as $1 : 0.54 : 0.33$.

The errors are calculated from the average of the ellipsoids, and so do not include possible systematic errors. Hence, the true errors are larger that stated but tests suggest that they do not alter the general findings of this paper. These numbers indicate that the bulge is triaxial with the major axis close to the line of sight towards the Galactic centre. The error in K_z is quite large and is due to a non-constant axial ratio of the ellipsoids. There is a trend towards increasing K_z with proximity to the centre, i.e. the outer bulge is more circular than the inner bulge.

References

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