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RESEARCH NOTE: LUMINOSITY FUNCTION OF THE STARS IN THE GALACTIC BULGE. DETERMINATION FROM A MAGNITUDE-LIMITED SAMPLE

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RESUMEN

Se ha construído la Función de Luminosidad (LF) de una muestra de estrellas en la región de baja absorción conocida como la Ventana de Baade (BW). Esta LF está corrida $\sim$ 1.5 mag hacia M_{bol} más brillantes con respecto a la que publican Frogel & Whitford (1987). Este hecho ha sido interpretado como el producto de la observación de dos poblaciones estelares ligeramente diferentes en la misma área, debido a la forma en que éstas han sido escogidas y a una diferencia de profundidad entre ambas muestras. La LF observada se puede descomponer en dos componentes Gaussianas, las cuales se han asociado a las contribuciones del disco y del bulbo respectivamente. La componente que hemos asociado con la contribución del disco en BW puede reproducirse razonablemente bien mediante la proyección e integración de la LF de las gigantes M en la vecindad solar. Este hecho apoya el que se haya asociado esta componente de la LF observada con la población estelar de disco. También se obtienen valores característicos para los radios del bulbo ($\sim$ 0.9 kpc) y del disco ($\sim$ 2.0 kpc).

ABSTRACT

We construct the observed Luminosity Function (LF) of a sample of stars in the low obscuration region known as Baade's Window (BW). This LF is shifted by $\sim$ 1.5 mag towards brighter M_{bol} with respect to that published by Frogel & Whitford (1987). This has been interpreted as produced by observations of slightly different stellar populations in the same area due to the way the stars have been selected, and to a difference in depth between both samples. The observed LF may be separated into two Gaussian components, they are respectively associated with the bulge and disc contributions. The component which we claim represents the disc contribution in BW may be reproduced reasonably well by projection and integration of the M giants' LF in the solar neighbourhood. This fact lends support to our associating the wide component of the observed LF with a disc-like stellar population. Values for the characteristic radii for the bulge ($\sim$ 0.9 kpc) and for the disc ($\sim$ 2.0 kpc) are derived.

Key words: **GALAXY – STELLAR CONTENT — STARS – LUMINOSITY FUNCTION, MASS FUNCTION**

1. INTRODUCTION

The stars in the galactic bulge have been the subject of very active research over the past few years. Photometric studies in the infrared as well as in the visible wavelengths have been undertaken (see Arp 1965; van den Bergh 1972; van den Bergh & Herbst 1974; Frogel & Whitford 1987, hereinafter FW; Terndrup 1988; Ruelas-Mayorga & Teague 1992a, among others). Other studies intended to determine the kinematics of the stars in the bulge and also aimed at

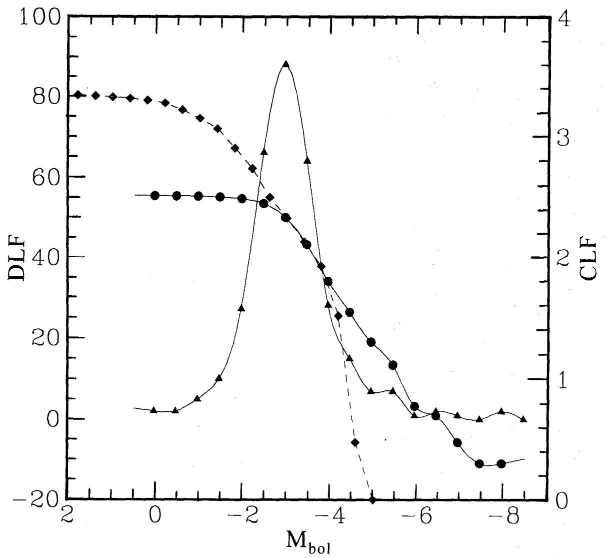

Fig. 1. This figure presents the observed differential luminosity function (DLF) —triangles— [left axis] and the logarithm of the cumulative luminosity function (CLF) [right axis] for both our data —filled circles— and for those of Frogel & Whitford (1987) —diamonds— [right axis].

finding their mean metallicity have been performed (see Mould 1983; Rich 1988; Sharples, Walker, & Cropper 1990; Tyson & Rich 1991; Ruelas-Mayorga & Teague 1992b).

The conclusions which have been found as to the nature of the stellar population in the galactic bulge are contradictory and certainly there is yet no consensus as to the stars' origin and physical characteristics. For a number of years now it has been accepted more or less generally that the stars in the bulge correspond to a stellar population that is old and very metal rich; although these stars present a series of peculiarities when compared with local stars of the same spectral type.

In this research note we shall report our preliminary determination of the LF of a magnitude-limited sample of stars in a low absorption region towards the galactic bulge. In § 2 we discuss the observations, § 3 outlines our analysis and finally § 4 summarizes our main conclusions.

2. THE OBSERVATIONS

The observations were collected with the Infrared Photometer attached to the 1.9-m telescope at the Mount Stromlo and Siding Spring Observatories. They were obtained scanning our detector at sidereal rate over four low absorption areas, two of which are contained within BW, and two others very near this area. Subsequently we performed detailed JHK photometric observations of subsamples of the stars found in the scans.

We use the bolometric corrections to the K magnitude (BC_K) as a function of $J-K$ colour given by Frogel & Whitford (1987) properly transformed to the Anglo Australian Observatory (AAO) IR system in which our K magnitudes are given (see McGregor & Hyland 1981; Ruelas-Mayorga & Teague 1992a).

3. ANALYSIS

In this section we report only the main results of our analysis (for full details see Ruelas-Mayorga, Noriega-Mendoza, & Román-Zúñiga 1995). In Figure 1 we present both the Differential Luminosity Function (DLF) —triangles— [number of sources within an arbitrary area with absolute bolometric magnitude in the interval (M−1/2, M+1/2)] and the Cumulative Luminosity Function (CLF) —filled circles— [number of sources within an arbitrary area down to absolute bolometric magnitude equal to M]. This function is referred to the vertical axis on the right. The diamonds illustrate the Frogel & Whitford (1987) BW CLF (FWCLF) displaced and reddened appropriately as if their stars were in the exact same position as ours.

It is important to note that our CLF shows the following characteristics:

i) A strong decrease around $M_{bol} \sim -3$ which corresponds to M4-M5 III stars.

ii) When compared with the FWCLF we see that both functions coincide in value in the interval $-4.5 \leq M_{bol} \leq -2.5$.

iii) They have a similar slope in the same interval.

Figure 2 shows our DLF —triangles— as well as that from Frogel & Whitford (1987) —filled circles— after the latter has been divided by 4. This scaling has little importance and is intended solely to produce graphs of comparable dimensions. From this figure we clearly see that these LFs do not coincide but appear shifted by $\sim$ 1.5 mag. An error in the value of A_K would produce an effect like this one; however, its value would need to be so large that it seems unlikely to us. Differences in the value of the distance modulus (DM) can also produce such a shift; we adopt DM = 14.7 while FW take DM = 14.3, these values allow only for a 0.4 shift.

As of yet we have no clear understanding of the $\sim$ 1.5 mag shift between our DLF and that of FW, however we can suggest two mechanisms which might cause this shift:

i) A difference in depth between our sample and that of FW might cause this problem. If we assume naively that the point at which the DLF stops increasing, as we move from bright to faint magnitudes, represents the limit of completeness, then our limit is $M_{bol} \sim -2.7$ and FW's limit is $M_{bol} \sim -2.2$. This causes only a shift of $\sim$ 0.5 mag.

ii) In Ruelas-Mayorga & Teague (1992a) we pointed out the fact that the selection procedure fol-

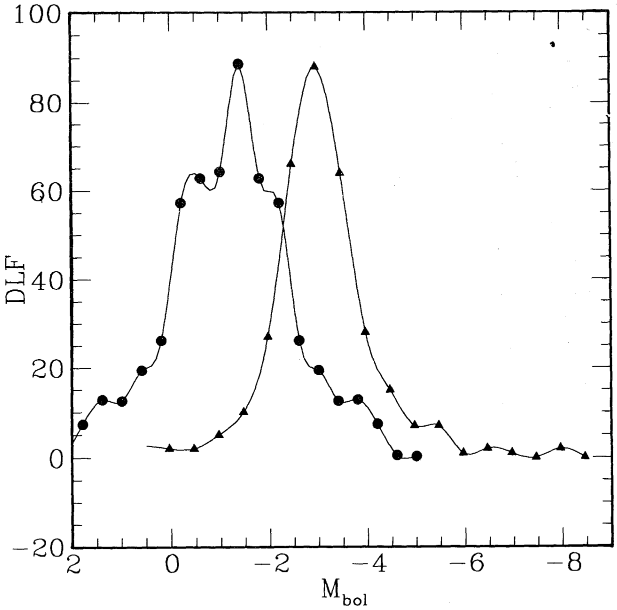

Fig. 2. Differential luminosity functions for our data (triangles) and for Frogel & Whitford's data (filled circles). Note the difference in M_{bol} for the maxima. This difference may be interpreted as produced by slightly different stellar populations in our sample and in that of FW, and also by a difference in depth between our sample and theirs.

lowed by FW did not ensure the presence of all the stars important in the IR wavelengths. This suggests that any conclusions drawn from the FW IR paper are prone to error and/or slight modification. It is in this sense that we say that FW obtained the LF of a stellar population different from ours.

Recently DePoy et al. (1993) have conducted a two dimensional IR study of BW; one of their conclusions is that no apparent lack of detection of stars is noticed between this IR study and the Blanco, McCarthy & Blanco (1984), and Blanco (1986) 'I' plates from which FW obtained the stars for their 1987 paper. Unfortunately the very region in which we did find the discrepancy could not be observed in the above mentioned two dimensional IR paper, leaving the discrepancy pointed out by Ruelas-Mayorga & Teague (1992a) still outstanding.

A detailed analysis of our DLF reveals that it may be adjusted by two Gaussian functions:

i) One wide and low, which presumably stands for the disc contribution and is represented mathematically by the following expression:

$$N_{\rm disc}(M_{bol}) = 21exp\left[-\frac{(M_{bol}+2.96)^2}{2(1.16)^2}\right] \quad .$$

It is clear from simple projection effects that the disc should also contribute to the observed DLF. Besides, we shall mention below the fact that the wide component of the DLF is well reproduced by a combination of solar neighbourhood M-giants (for full details see Ruelas-Mayorga et al. 1995); this lends plausibility to our associating the wide component of the DLF with a disc contribution.

ii) A second one that is narrow and tall, which stands for the bulge and whose mathematical representation is the following

$$N_{\rm bulge}(M_{bol}) = 67exp\left[-\frac{(M_{bol}+2.96)^2}{2(0.53)^2}\right] \quad .$$

Numerical simulations of the observations of a disc and bulge, down to a limiting magnitude reveal that the observed DLF is indeed the combination of two Gaussians, whose standard deviation in magnitudes is closely related to the actual physical extent in kiloparsecs of the disc and bulge components. A full presentation of these simulations shall be given elsewhere (Ruelas-Mayorga et al. 1995).

In order to study whether there really is a disc-like component in BW, we take the LF in the solar neighbourhood for M III stars from Ruelas-Mayorga (1991a) and calculate the total M III distribution in the solar vicinity. Figure 3 illustrates this function. The tall-solid line represents the total function whereas all the other lines show the distribution of individual M spectral types. As later spectral types are reached, a shift towards brighter M_{bol} is noted.

This distribution is now integrated and projected out to a distance of 8.75 kpc. This operation gives the apparent distribution of the M giant stars as if they were located at the distance of the galactic centre.

This projected magnitude distribution has the same width as that for the solar neighbourhood and with a maximum of observed sources equal to 120 centred at $M_{bol} \sim -1.5$ which agrees with the maximum of the FWLF. Our LF is centred at $M_{bol} \sim -3$ which rather agrees with the distribution produced by the combination of M3 to M8+ III stars. The width of the theoretical distribution produced by the combination of M3 to M8+ III stars ($\sim$ 2.5 mag) and that of the distribution observed by us ($\sim$ 2.0 mag), agree reasonably well. The maximum number of sources seen on the bright component of this latter theoretical distribution for M III stars in the solar neighbourhood is $\sim$ 1600 kpc^{-3}. This figure, when projected towards BW, predicts a maximum observed number of: $\sim 1600 \times 2 \times 10^{-2} = 32$ sources, which agrees reasonably well with the maximum observed number (21) of sources for the wide component of our LF. Our claim that this component may be disc produced receives an important support from

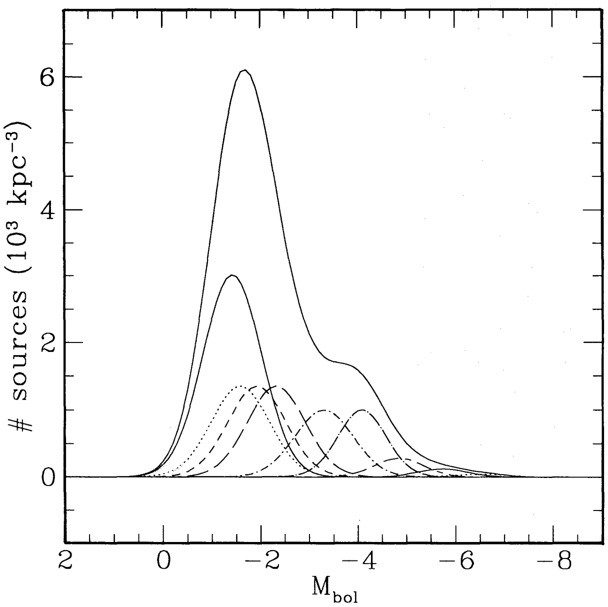

Fig. 3. Local distribution for the M III stars (tall-solid line). The lines represent the individual contributions of spectral types from M0 to M8 III. As later spectral types are reached, a shift towards brighter M_{bol} is noted.

this computation. This calculation clearly suggests that there is in our sample of stars in BW a subsample that can consistently be interpreted as composed of members of the disc population and as having physical characteristics (brightness and maybe mass, age and metallicity) similar to those of the stars in the solar neighbourhood.

4. SUMMARY

i) We obtain, for a sample of stars in the BW area, their bolometric LF aided with our *JHK* photometry and the calibration published by Frogel & Whitford (1987).

ii) The LF may be decomposed into 2 Gaussian components. Each may be consistently associated with the disc and bulge contributions to the observed stellar population.

iii) The bulge contribution turns out to be narrow with respect to M_{bol} with a characteristic radius of ~ 0.9 kpc.

iv) The disc contribution is wide with respect to M_{bol} and has a characteristic radius of ~ 2.0 kpc.

v) The wide component may be perfectly reproduced when the LF for M3 to M8+ giant stars in the solar neighbourhood is projected over the BW area and integrated over a distance equal to R_0 (8.75 kpc). This suggests that there must be a component of the stellar population in the regions surrounding the galactic centre with very similar characteristics to those of the stars in the disc of our galaxy. This component is what we have claimed to be the disc contribution to the stellar population in BW (see Ruelas-Mayorga & Teague 1992a,b; 1993a).

vi) Our LF and that of Frogel & Whitford are centred at $M_{bol} \sim -3.0$ and -1.5 respectively. This has been interpreted partly as produced by observations of slightly different stellar populations in the same area due to the way they have been selected, and partly due to a difference in depth between our sample and that of FW's.

vii) An important section of the Frogel & Whitford LF has been interpreted as disc-produced.

viii) A comparison between our derived LF and that of FW reveals that we have sampled a bulge stellar population brighter than that observed by FW.

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