HOW DO THE STELLAR DISC AND THICK DISC STOP ?

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1. Abstract

As part of a stellar population sampling program, a series of photometric probes at various field sizes and depths have been obtained in a low extinction window in the galactic anticentre direction. Very deep CCD frames probe the most external parts of the disc, providing strong evidence that the galactic density scale length for the old disc population is rather short (2.5 kpc) and drops abruptly beyond 5.5-6 kpc.

Deeper frames in the I band allow to estimate photometric distances and confirm the position of the disk edge. A few stars are found at larger distances. Their number is exactly what we expect if the thick disk does not have any cutoff. We discuss the implications for the formation and evolution of the disc, for the star formation threshold, and for the origin of the thick disc population.

2. Introduction

Efforts to sample star distributions in the galactic plane should face both the problem of overcrowding and the complex structure of the absorbing layer. For these reasons the outer part of our own galactic disc is very poorly known. The radial scale length of the density decrease is controversial and we have nearly no indication what happens at the end.

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Three previous papers (Mohan et al. 1988, and Robin at al. 1992a,b) present the first results of a stellar population sampling program, including a series of photometric probes at various field sizes and depths in a low extinction window in the galactic anticentre direction. Wide field photometry in UBV in the magnitude range 12-17 is shown to interpret unambiguously in terms of extinction and stellar density. The interpretation partially uses the galactic model developed by Robin and Crézé (1986), Bienaymé et al. (1987) and Haywood et al. (1994). The model ingredients which play a role in the present investigation are the density law of the galactic disc (radially exponential) and the luminosity function from Wielen et al. (1983). Strong constraints are set on the radial structure of the disc: the galactic disc scale length is found to be 2.5 $\pm$ 0.3 kpc. Based on this scale length and assuming no dramatic change in the luminosity function one can predict what should normally happen at faintest magnitudes.

3. Deep observations towards the anticentre

Deep CCD observations in the UBVI bands have been obtained at the 3.6 meter CFH Telescope in a low extinction window at low latitude in the direction of the galactic anticentre. A detailed description of the 1987-1988 observation campaign and data analysis aspects is given elsewhere (Robin et al. 1992a). Observations cover four neighbouring fields around l=179.7deg and b=2.8 deg adding up to 29 square arcminutes. The detection limit is about magnitude 28 in V, while the completeness limit corresponding to a photometric accuracy better than 0.1 is 25 in V and 22.5 to 24 in B depending on the frame. The 1993 observation campaign allowed us to acquire V and I data complete to 25 in both bands, allowing us to have a colour index V-I down to this magnitude.

4. The edge of the old disc

The (V, B-V) distribution of stars resulting from this investigation is given in figure 1. The thin line is just a guide to compare the position of stars in both diagrams. Faint star count predictions with no cutoff in the disc deviate strongly from the observations at the faint end and there is a clear excess of blue stars in the down left part of figure 1a. The bulk of disc contributors in this magnitude range is made of disc dwarfs beyond 5.5 kpc.

All disagreements in the V, B-V diagram vanish if the stellar disc ends abruptly at 5.5 kpc as also shown in the V star counts in figure 1c, while the small number of remaining stars could own to the thick disc population (see section 5 and fig. 2).

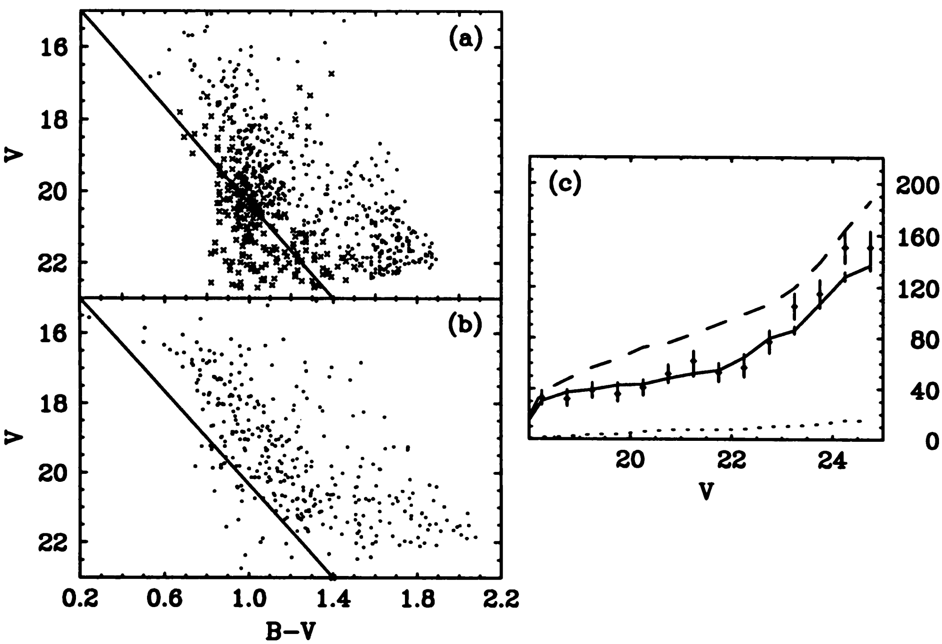

Figure 1. (V,B-V) distribution towards to the anticenter. (a) Model prediction (dots: Disc stars at distance closer than 5.5 kpc; crosses: disc stars at distance larger than 5.5 kpc. (b) Data sample. The thin line is just a guide to compare the position of stars in both diagrams. (c) V counts (Diamonds: data with 1 sigma Poisson error bars; dotted line: model with no disc cutoff; solid line: model with a disc cutoff at 5.5 kpc).

The cutoff cannot be explained by an absorbing cloud, because external galaxies, HI column density and UBV diagrams all give a maximum extinction of 1.2 to 1.4 magnitude. This is also in agreement with the fact that the fields are inside Special Area 23 selected by Kapteyn as a low extinction window.

Density distributions with scale lengths larger than the adopted 2.5 kpc would impose a still closer cutoff (at 3.5 kpc from us if $h_R = 3.5$ kpc) while shorter scale lengths are hardly compatible with the observations of bright stars in the same region (Mohan et al. 1988).

5. Where is the thick disc edge ?

Figure 1 shows that some stars are seen at distances larger than 5.5 kpc. Do these stars belong to the thick disc or old disc ?

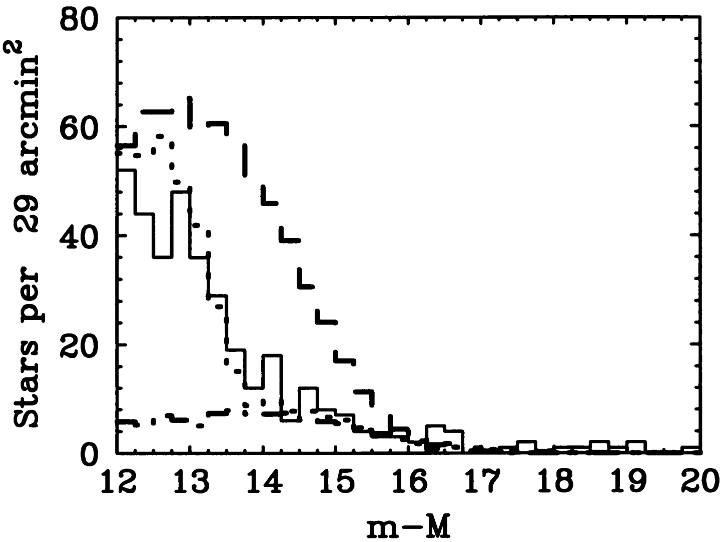

Figure 2. Histogram of distance indicator V-M_V for stars at V<24. Data: solid line. Model: All stars with disc edge at 5.5 kpc : dotted line; All stars without disc edge: dashed line; thick disc only: dotted-dashed line.

V-I colours provide a distance indicator which may be used to grossly trace the density law, although the V-I index used as luminosity indicator is slightly metal sensitive. As long as we compare distance indicators computed by the same formulae on data and on model simulations, the small error due to metallicity variations is accounted for in the model.

We compute this apparent distance indicator using a polynomial fit of the absolute V magnitude to the V-I index for disc stars from the calibrations of Bessel (1991a and b) for types earlier than M4 and Leggett (1992) for later types.

$$M_V = 2.43 + 3.80 * (V - I) - 0.0724 * (V - I)^2$$

Figure 2 shows the histogram of our indicator (V-M_V). The sample has been restricted to V<24 in order to have a more accurate distance indicator. We see that the model with a disc edge and no thick disc edge perfectly fit the data. The model without a disc edge overestimates the number of stars at m-M>13 (r≥5) by a large factor. The number of observed stars at m-M>14 corresponds exactly to model prediction for the thick disc with no cutoff.

The thick disc model results from a global investigation of the thick disc population based on magnitude and colour star count data in 19 fields well distributed in longitude and latitude (Robin et al., 1994). Such star counts turn out to tightly constrain thick disc parameters. It has a scale height of 760 pc, a local density 5.6% of the disc and a scale length of 2.5 to 3 kpc. In the present study the use of a larger scale length for the thick disc would have given too large a number of stars at m-M>14.

6. Discussion

The analysis of star counts towards the anticenter enable us to emphasize that :

- UBV data on the magnitude range 12 to 25 from Schmidt plates and CCD frames give and estimate a disc scale length of 2.5 ± 0.3 kpc.
- CCD data to magnitude 23 in B and V show the existence of a sharp cutoff in the radial distribution at 5.5 kpc from the sun (R=14 kpc).
- I band photometry allow to go deeper in magnitude and distance. A distance indicator is computed from V-I. It confirms the position of the disc cutoff. The small number of stars appearing at r>5.5 kpc is compatible with what we expect if the thick disc has no radial cutoff.

Most external disc galaxies show a radial truncation. These cutoffs seem to arise within 1 kpc or less (van der Kruit, 1988) and are found at R_{max} / $h_R = 4.5 \pm 1.0$. In our Galaxy star counts in the anticentre (Robin et al. 1992a) give a radial scale length of 2.5 ± 0.3 kpc, rather short value but recently confirmed by the Fux and Martinet (1994) kinematic determination and close to the COBE measurement (3 kpc, Weiland et al., 1994). Together with the presently determined cutoff, it implies a ratio R_{max}/h of 5.6 ± 0.6 if $R_\odot = 8.5$ kpc in agreement with the observed ratio in external galaxies.

Our determination of the radial extent of the old disc does not conflict with the possibly larger extent of young stars or star forming regions if an evolutionary scenario like the one of Larson (1976) is realistic (where the star formation propagates from the centre of the Galaxy to the outer part). In this case one expects to find only recent star formation in the outer part of the Galaxy and no old disc stars.

Concerning the small number of remaining stars at large distances, we have shown that their number and distance distribution coincide exactly with what we expect from the thick disc if it has no cutoff. However direct measurements of kinematics and/or metallicities of these stars would be needed. While no accurate spectra can be obtained at these magnitudes (V>23) one can get reasonably accurate proper motions from CCD on a time baseline of ten years.

Our study implies that the thick disc does not stop like the disc in the external part of the Galaxy. This fact confirms previous results showing that the thick disc is significantly different from the old thin disc. There remains at least two scenarios compatible with this result. The first emphasizes that the thick disc had formed from a merger event at the beginning of the formation of the thin disc (Quinn, Hernquist and Fullagar, 1993). These authors show that the resulting thick disc would have a slightly larger extent than the thin disc. The second scenario explains the thick disc as being formed during the collapse of the gas into the disc, stopped due to star formation (Burkert et al., 1992). In this case as well the thick disc would extend at larger radii than the thin disc, as observed in our data.

Acknowledgements

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DISCUSSION

Kraft: How did you disentangle the extinction determination (based on U-B vs B-V) from the metallicity gradient in the disk toward the anti-center?

Robin: The metallicity gradient in the disk has not the same effect as the extinction in (U-B, B-V) diagrams. The slope is steeper. We account for this gradient in model simulations in order to treat the extinction free of this effect.

P. van der Kruit: You have your disk edge at about 14kpc, while HII regions have been reported at 20-25 kpc from the center. In external galaxies stellar disks and HII region distribution always have similar extents. How do you reconcile that?

Robin: Our data show a significant truncation in the disk and not at all compatible with disk exponentially decreasing for ever. We think that the remote HII regions in the Galaxy are exceptions and probably they would not be significant in external galaxies.

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