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Stellar photometry and inclination of the nearest edge-on galaxy NGC 55

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Summary. BV stellar photometry to $V=23$ has been done in the edge-on irregular galaxy NGC 55, using both photographic and CCD material. The derived luminosity function does not differ from those found for other nearby galaxies.

The apparent distribution of stars perpendicular to the major axis of the galaxy (given by H I distribution) is found to be asymmetrical. We discuss the inclination and the thickness of the old and young components of the disk of NGC 55, using a comparison with the Large Magellanic Cloud. Our best estimate for the inclination is between 80°.8 and 81°.7, the scale height of the young disk is between 0.10 kpc and 0.14 kpc, and that of the old disk from 0.18 and 0.21 kpc. These inclinations and thicknesses explain qualitatively the asymmetry in the distribution of young stars.

Key words: galaxies, individual: NGC 55 – galaxies, irregular – galaxies, stellar content of – galaxies, disk of

1. Introduction

A solution of some interesting problems as for example the presence of a thick disk *à la* Gilmore (Gilmore, 1984) or the existence of bright blue halo stars may be found by looking at galaxies seen edge-on.

From this point of view, the galaxy NGC 55 belonging to the Sculptor group is a most interesting object. It is with NGC 3109 one of the two closest edge-on systems: we adopt a distance modulus of $B-M_B=25.85$, corresponding to a distance of ~ 1.5 Mpc (adopted after the distance of NGC 300; Graham, 1982, 1984). The inclination estimates vary from 80° (Hummel et al., 1986) to 85° (de Vaucouleurs and Freeman, 1972). Because of its relatively small distance this is one of the very few edge-on galaxies where the brightest stars can be easily resolved.

As will be discussed later, from a study of the apparent distribution of the gas and of the stellar populations perpendicular to the major axis it might be possible to find the real shape of the galaxy and to determine a true value of inclination.

It is also interesting to compare NGC 55 with the Large Magellanic Cloud (LMC), because both galaxies seem to be of the same morphological type. The appropriate values are presented in Table 1, which reveals also the similarity of these two nearby galaxies.

In this paper, the measurements and reduction techniques are described in Sect. 2, while the results are given in Sect. 3. Section 4 contains a discussion and the conclusions.

2. Stellar photometry: observations and reduction techniques

The galaxy has been observed photographically in two colors B, V with the ESO 3.6 m telescope by Azzopardi (details in Table 2). For the analysis, the best plate in each color has been selected. Four program fields (A, B, C, D) have been chosen (Fig. 1) to provide a deep stellar photometry and color-magnitude diagrams.

The plates have been scanned with the PDS microdensitometer at Laboratoire d'Astronomie Spatiale (LAS), Marseille. The images have been transformed from densities to intensities. Later on, two CCD sets of observations have been obtained by Azzopardi (Table 2). The pixel size of the double-density RCA CCD chip used in these observations corresponds to 0".337 on the sky. This allows a good sampling of the stellar images, which is especially useful in crowded fields. Only one field has been observed, corresponding to field B. Again, only the best quality frames in each color have been selected. A second set of shorter-exposure CCD data (hereafter CCD II) was necessary to provide zero-point coefficients for the first, deeper set of CCD observations (hereafter CCD I), by observing standard stars. The stellar magnitudes were obtained using the DAOPHOT software (Stetson, 1985, 1987). DAOPHOT is a star-profile fitting program, extremely useful for stellar photometry in crowded fields. It detects the objects, fits a point-spread function determined earlier from the best stellar profiles, and subtracts a local background.

The coefficients of conversion from instrumental magnitudes to the standard BV system have been obtained by means of second-order standards observed in the nearby galaxy NGC 300 (Pierre and Azzopardi, 1987).

In order to estimate the accuracy of the photometry a number of artificial stars of known magnitudes have been added at random positions to each V frame, and then reduced in the same way as the original frames. From the comparison of the recovered magnitudes with the known input values the distribution of errors as a function of magnitude can be estimated. We assume similar errors in B. The error in $B-V$ is $\sqrt{2}\sigma_V$.

Table 3 compares the standard deviation of V and $B-V$ for the artificial star experiment with the mean standard deviation obtained from DAOPHOT. Artificial stars have magnitudes evenly distributed in the range $18<V<22$ so they are rather bright in the average compared to the observed stars and the mean

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Table 1. Properties of NGC 55 and the LMC

	NGC 55	LMC
Morphological type (RC2)	SBS9	SBS9
Adopted distance modulus	25.85 (as for NGC300, see Graham, 1982, 1984)	18.4 (Imbert, 1987)
Adopted distance	1.48 Mpc	48 kpc
Corrected *B* mag	7.48 (Hummel et al., 1986)	0.14 (RC2)
Absolute *B* mag	−18.4	−18.3
Optical diameter (RC2)	22.'9 (=9.85 kpc)	10.°8 (=9.0 kpc)
Apparent axis ratio		
B light	0.20 (RC2)	Seen almost face-on
H I	0.17 (Hummel et al., 1986)	
Total mass M_t	$1.4\ 10^{10}\ M_\odot$	$6.0\ 10^9\ M_\odot$ (very uncertain) (Meatheringham et al., 1987)
H I mass	$1.68\ 10^9\ M_\odot$ (RC2)	$5.4\ 10^8\ M_\odot$ (Hummel et al., 1986)
M_t/L_B (solar units)	3.93	1.85

Table 2. Material for photometry of NGC55

Type of image	Instrument	Color	Exposure time (min)	Date
Plates	ESO 3.6 m telescope, prime focus	*B*	20	November 1982
		V	40	
CCD I (first set of data)	ESO 3.6 m telescope, Cassegrain +EFOSC RCA SID 503	*B*	10	July 1986
		V	5	
CCD II (second set of data)	ESO 3.6 m telescope, Cassegrain +EFOSC RCA SID 503	*B*	4	December 1986
		V	2	

error is small. The large errors corresponding to the faintest values of *V* account in part for the spread in the main sequence (see Figs. 2 and 3).

3. Results

3.1. *Color-magnitude diagrams*

The color-magnitude diagrams (CMD's) have been built from the magnitudes obtained from DAOPHOT and transformed into the standard *BV* system for all fields. The photographic CMD is rather similar for the different fields although the space distribution of stars is not uniform. Some observed stars have magnitudes as faint as $V=22$, but all the samples are incomplete at this level. The large spread in $B-V$ is probably due to a combination of i) the rather average image quality yielding image crowding, ii) difficulties in background subtraction and iii) variations in interstellar extinction. The latter cause is certainly severe in a galaxy seen edge-on, where internal extinction may differ widely from star to star. The CCD stellar images are much better and the two first causes of spread are accordingly less important,

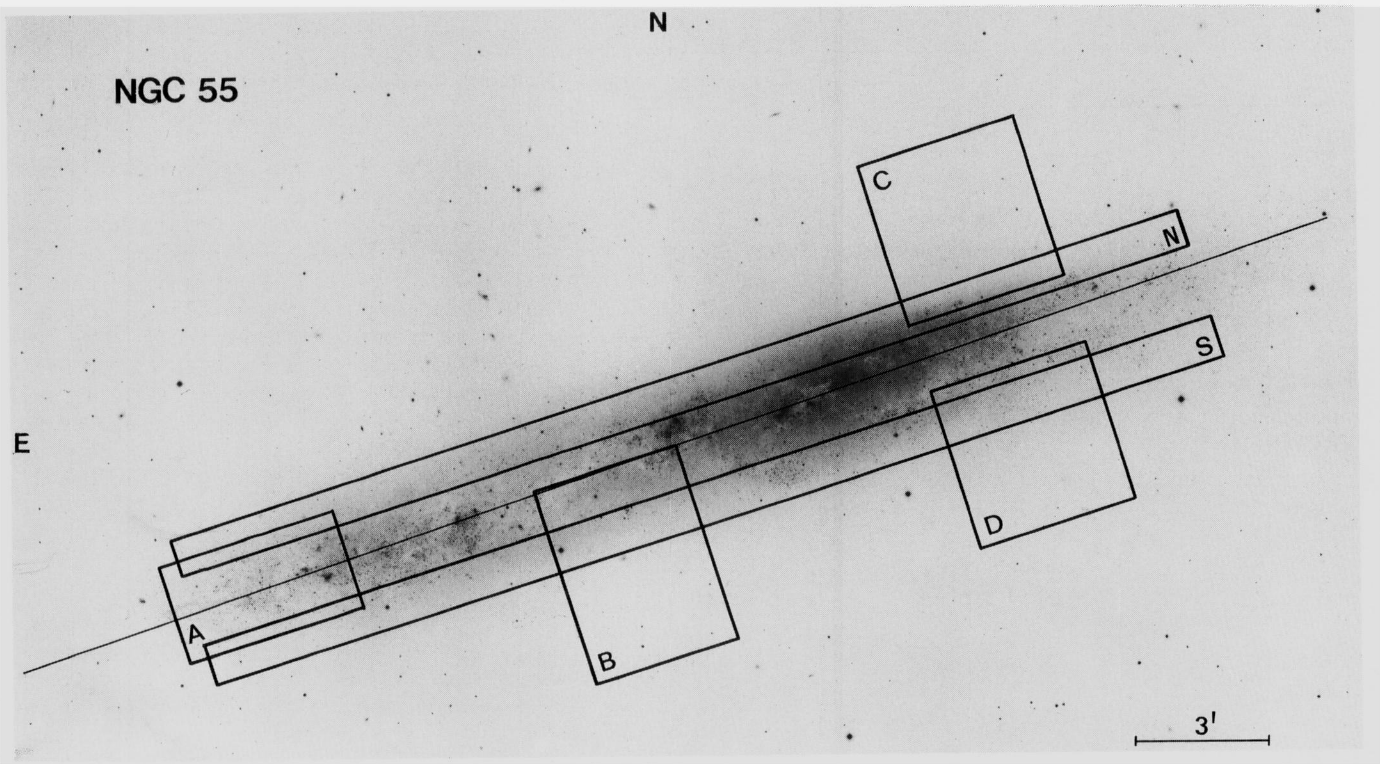

Fig. 1. An ESO photograph of the NGC 55 in blue light. The scale is 0″.14 pc^{-1}. Fields A, B, C, D, strips N, S are the program fields. Field B is the one observed also with CCD. The major axis of the galaxy is obtained from the H I distribution (Hummel et al., 1986)

Table 3. Errors in photometry of NGC 55

	V	$\sigma_{\text{Daophot}}(V)$	$\sigma_{\text{Daophot}}(B-V)$
Plates	Artificial stars ($17.9 < V < 20.9$)	0.049	0.069
	$V < 21.0$	0.132	0.187
CCD I	Artificial stars ($18.9 < V < 21.9$)	0.035	0.049
	$V < 20.5$	0.059	0.083
	$V > 20.5$	0.108	0.153

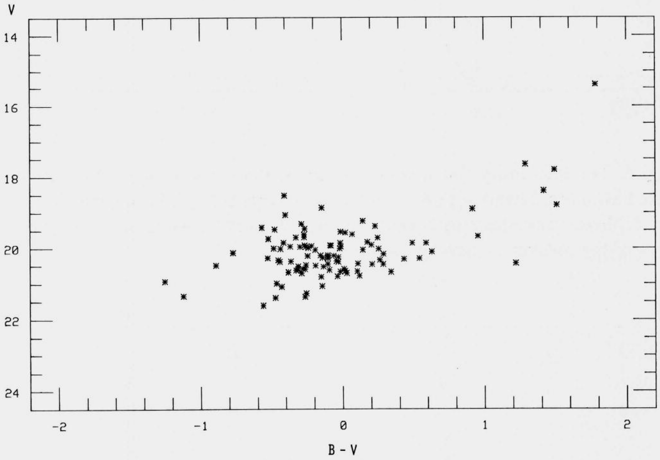

Fig. 2. The color-magnitude diagram of the field D (100 stars)

yielding a somewhat nicer CMD. The CMD for CCD I (Fig. 3) reaches $V = 23$ but is complete only to $V \simeq 21$. Following Pierre and Azzopardi (1987) we consider only the blue stars for the following discussion as most of the red stars are probably foreground with the exception of a few red supergiants and even rarer F–G supergiants belonging to NGC 55. We fix the color limit at an observed $B-V$ of 0.5, from the aspect of the CMD. The stars bluer than this limit form a "main sequence" that actually includes B and A supergiants.

3.2. *Luminosity function*

For the very massive stars that we are considering, the extent of the main sequence in the HR diagram is still a subject of debate although many authors consider that it may encompass B and even A supergiants (Chiosi and Maeder, 1986). This is not very important for the intercomparison of galaxies provided that every author (and most do) consider all the blue stars, which are in practice well separated from the redder stars in the CMD. Here we derive the luminosity function for stars with $B-V \lesssim 0.5$. Galactic models show that in the direction of Sculptor the number of galactic blue stars is negligible in the observed magnitude range (Pierre and Azzopardi, 1987). We feel very uneasy to discuss the uncertainties due to the choice of the color cut-off, although this has been attempted by Freedman (1985). Figure 4 presents the luminosity function for 247 stars per bins of 0.5 magnitude. Down

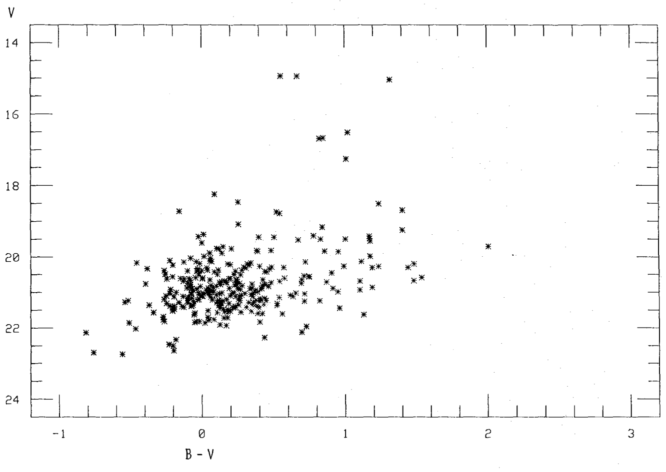

Fig. 3. The color-magnitude diagram of the field B (CCD I; 310 stars)

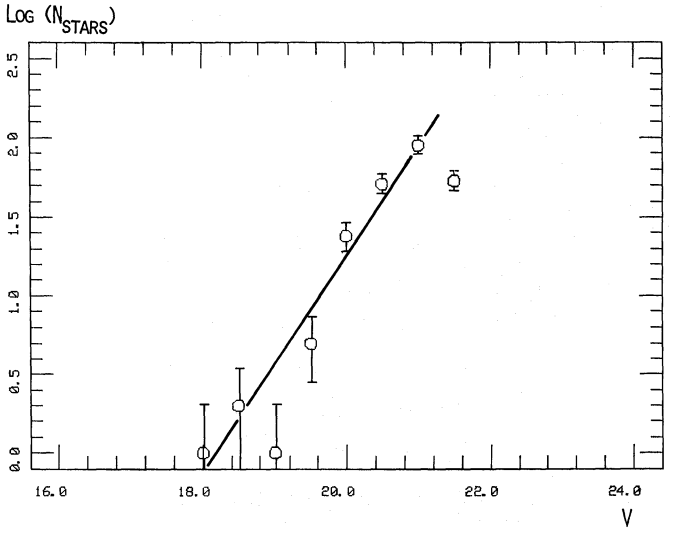

Fig. 4. The luminosity function composed of the main-sequence blue stars, taken from Fig. 3 (stars with $B-V<0.5$). The slope 0.72 ± 0.11 of the indicated line is obtained by a least-squares fit. The error bars are proportional to a square root of the number of stars in each bin

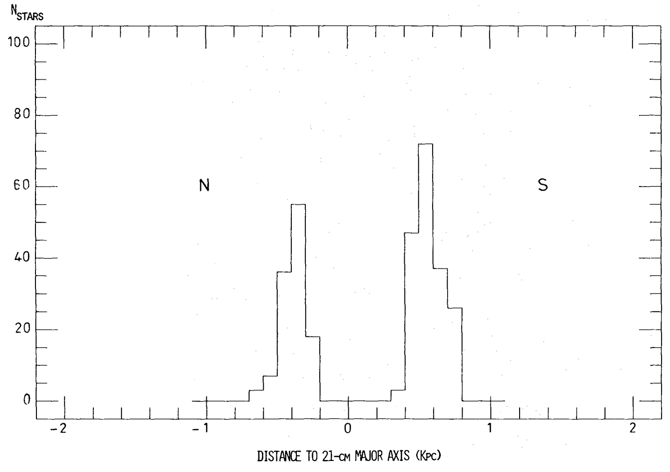

Fig. 5. A distribution of stars perpendicular to the major axis of NGC55 for strips S (southern part, 218 stars) and N (northern part, 133 stars). The histogram contains stars found on both a B and a V plate and only those with $B-V<0.5$. The asymmetry is evident

to $V=21$ we assume that the sample is complete. The least-squares fit gives a slope of 0.72 ± 0.11. As mentioned above the luminosity function is surely affected by the effects of internal extinction. The latter is certainly not constant from star to star and could vary from a minimum galactic value ~ 0.0 (cf. Burnstein and Heiles, 1984) to a very large value. A way out is to trace on the CMD oblique lines corresponding to variable extinction, obeying the law $\Delta V / \Delta(B-V) = 3$, and to count stars between those lines. The scale on the ordinate axis gives thus the unreddened absolute magnitude scale. Unfortunately this restricts further the already limited dynamical range of the observations. The slope of the luminosity function derived in the above way is 0.66 ± 0.12. The result is consistent (within the errors) with the previously derived value of 0.72 ± 0.11 and with the slopes of the luminosity function found for other galaxies, for example, for M33: 0.67 ± 0.05; NGC2403: 0.70 ± 0.14; NGC300: 0.66 ± 0.05; Leo A: 0.62 ± 0.09 (Freedman, 1985); LMC: 0.61 ± 0.05; NGC300: 0.57 ± 0.05 (Pierre and Azzopardi, 1987).

3.3. Vertical distribution of stars

In addition to the fields A, B, C, D, stars belonging to two strips N, S approximately equidistant from the major axis of the galaxy (Fig. 1) have been measured on the plates. The major axis has been determined as the axis of the isophotes of the H I distribution given by Hummel et al. (1986). The strips have been reduced in the same manner as the other fields. Blue stars ($B-V<0.5$) found on both a B and a V plate have been counted down to $V \simeq 22$ and their numbers have been plotted per bins of 100 pc of projected distance to the major axis (Fig. 5). The distribution of stars in the northern and southern parts of the galaxy is somewhat asymmetrical.

4. Discussion

From the previous sections we see that the galaxy NGC55 does not show any exceptional behaviour. The slope of the luminosity function is similar to the value found for its close neighbour NGC300 (Pierre and Azzopardi, 1987) and consistent with those given by Freedman (1985) for other nearby galaxies. The result obtained for NGC55 confirms that the slope of the upper luminosity function, then of the mass function and of the initial mass function, does not vary significantly from galaxy to galaxy.

Although for an irregular galaxy of the type of NGC55 the distribution of young stars is expected to be rather irregular, the degree of asymmetry in their distribution with respect to the major axis (Fig. 5) tells us something about the thickness of the disk of young stars and interstellar matter and about the inclination of the galaxy. If this disk was very thin, as assumed by Hummel et al. (1986) for H I in order to calculate an inclination (80°) for NGC55, the distribution of stars should be symmetrical with respect to the major axis. Similarly, of the galaxy was seen exactly edge-on, the distribution of stars should also be symmetrical and the scale height of its H I component would be $36''.4 \simeq 260$ pc from the width along the minor axis.

Clearly we are in an intermediate case as the distribution of stars is not symmetrical; the thickness of the Population I in NGC55 is not very small, but smaller than 260 pc (H I scale height), and its inclination may be somewhat larger than 80°, although it is not completely edge-on. Unfortunately, the distribution of young stars is too irregular to allow us to say much more.

Little can be derived in this respect from the distribution of light which is certainly dominated by a thicker distribution of relatively old stars. The old star system seems to be less flattened than the H I system as shown by a comparison of the apparent axis ratios. The old star population contributes the most to the optical size of the galaxy and its axis ratio is 0.20 (RC2), whereas young stars should have approximately the same thickness as the gas and their axis ratio being then about 0.17 (Hummel et al., 1986). Given the quality of the data, we believe the difference in the axis ratios to be significant. We will now use these apparent ratios and a comparison with what we know of the LMC in order to attempt to say more about the parameters of NGC 55. The vertical (z) distribution of a population of gas or stars in hydrostatic equilibrium depends on its velocity dispersion and on the run of the gravitational force perpendicular to the disk, attracting stars and gas to the plane. The space density distribution $\varrho(z)$ and velocity dispersion in the z-direction $\langle V_z^2\rangle^{1/2}$ are related to the gravitational force K_z by the well-known equations:

$$\frac{\partial K_z}{\partial z} = -4\pi G \varrho(z), \tag{1}$$

$$\frac{\partial \varrho}{\partial z} = \frac{\varrho K_z}{\langle V_z^2\rangle}. \tag{2}$$

If we assume that the velocity distribution is gaussian and the velocity dispersion $\langle V_z^2\rangle^{1/2}$ is independent of z, the solution of the above equations is (after van der Kruit and Searle, 1981)

$$\varrho(z) = \varrho_0 \operatorname{sech}^2(z/z_0), \tag{3}$$

where

$$z_0 = \frac{\langle V_z^2\rangle^{1/2}}{(2\pi G \varrho_0)^{1/2}},$$

$$K_z = -4\pi G \varrho_0 z_0 \tanh(z/z_0). \tag{4}$$

This allows us to calculate the thickness of a group of stars with given velocity dispersion if K_z is known. To solve this problem for NGC 55 in a crude way, we assume, taking benefit from the close similarity between NGC 55 and the LMC, that the velocity dispersions for the gas and for the old stars are the same for both systems. We consider the inclination as a free parameter, to be determined between 80° and 90°. Then we assume a space density distribution as

$$\varrho(R,z) = \varrho_0 \exp(-R/h) \operatorname{sech}^2(z/z_0)$$

(van der Kruit, 1981), where R is the distance to the rotation axis and h a disk scale length. We derive the scale heights of gas and of old stars and compare the projected scale heights to what is observed.

The LMC is seen almost face-on and we know the velocity dispersion for some stellar samples. As recently found by Meatheringham et al. (1987), the $\langle V_z\rangle^{1/2}$ for H I is 5.4 km s^{-1} while for old stars (planetary nebulae) it is 19.1 km s^{-1}. The value for the young stars is almost the same as for the H I as observed by Prévot et al. (1985): $\langle V_z^2\rangle^{1/2}$ for KM supergiants is ~ 5.3 km s^{-1}. However, even older objects than planetary nebulae can be observed in the LMC: long-period variables (with ages $\gtrsim 10^{10}$ yr). Their velocity dispersion is $\simeq 30$ km s^{-1} (Bessell et al., 1986). From the model of van der Kruit and Searle (1981), the authors derived a scale height of 0.3 kpc for these very old stars. Let us assume for the moment that the z-distribution of light is the same as that of the long-period variables. Then we can calculate the z-distribution of both the gas and the light for NGC 55 and compare with the observations in order to derive the inclination. The best agreement is obtained when the inclination is $81\overset{\circ}{.}7$ and the appropriate data are: $z_0^* \simeq 0.21$ kpc and $z_0^{\text{H I}} \simeq 0.14$ kpc. The derived value for the old stars differs slightly from the one found by Bessell et al. in the LMC because of the difference in total mass between the LMC and NGC 55 (Table 1). The total mass for NGC 55 has been derived with the simple assumption of spherical symmetry:

$$M_{\text{gal}} = R V_{\text{circ}}^2 / G.$$

Inserting the observed values for the optical radius of NGC 55 ($R = 11\overset{'}{.}45 \simeq 4.9$ kpc; RC2) and for the rotational velocity ($V_{\text{circ}} = V_{\text{max}}^{\text{rot}} = 110$ km s^{-1}; Hummel et al., 1986) we derive $M_{\text{gal}} = 1.4\ 10^{10}\,M_{\odot}$.

If we now assume that the planetary nebulae are more representative of the population which dominates the light of NGC 55 and the LMC, the corresponding velocity dispersion is reduced to 19.1 km s^{-1} and the scale height is also reduced. With the same method as above, we find an inclination of $80\overset{\circ}{.}8$, and $z_0^* = 0.18$ kpc and $z_0^{\text{H I}} = 0.10$ kpc. Thus the most probable value of the inclination is between $80\overset{\circ}{.}8$ and $81\overset{\circ}{.}7$.

Turning back to the apparent distribution of the blue stars it is clear that the thickness of the disk can account qualitatively for the apparent asymmetry in their distribution. It is easy to realize that because of interstellar extinction in the disk the far side should show more stars than the near one. Thus the northern side is the near one, provided that the galaxy is not too distorted.

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