Comparison of photometric parameters of LSB and HSB edge-on galaxies.

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Abstract

Photometric parameters of stellar disks and bulges for several edge-on galaxies from the Catalog of Flat Galaxies (FGC) were determined. We discuss a difference between photometric parameters of LSB and HSB galaxies from our sample.

Also we present results of R CCD photometry of edge-on galaxy RFGC 3647. Deprojecting this galaxy we show that it has thin LSB disk (central surface brightness $22''^{m}.2$ in R) and high ratio of radial to vertical scale lengths. It is shown that initially gaseous disk of the galaxy was unstable and its velocity dispersion was low. Stellar disk of this LSB galaxy was not heated significantly since that time.
Introduction

The main properties of LSB galaxies are low surface and volume density of stellar disks, low metallicity and star formation rates and they are more extended than "normal", HSB galaxies (see de Block etc., 1996, Bothun etc. 1997, Pickering etc.1994). The existence of LSB galaxies observed edge-on have remarked in papers of Karachentsev etc. (1992), in description of Flat Galaxies Catalog (Karachentsev etc., 1993). In works of Reshetnikov and Combes (1996, 1997, hereafter RC96, RC97) small sample of unwarped edge-on galaxies was investigated and some galaxies of the sample were suspected to be LSB galaxies.

There was no study of vertical structure of a sample LSB galaxies as well as a comparison of photometric parameters of LSB and HSB spirals obtained from observations of edge-on objects. We are using the sample of unperturbed galaxies from papers RC96 and RC97 for these purposes.

The sample of the galaxies.

Images of seven edge-on galaxies obtained in I (Causins) passband were taken at OHP observatory (France) in July 21-23 1993 by V.Reshetnikov and F.Combes (see RC96 where full description of CCD-device, processing and flux calibration had been done). Images were kindly provided us by V.Reshetnikov. Two galaxies of the sample, UGC 11838 and 11994, have larger surface brightness (hereafter SB) and belong to 2nd SB class according to FGC, whereas four of objects, UGC 11241, 11301, 11841 and 11859 have lower SB and belong to 3rd and 4th SB classes. Another one galaxy UGC 11132 doesn’t included into FGC but we found the photometric parameters for it because the inclination of the galaxy is not far from 90°.

Photometric deprojection.

Photometric parameters of disks and bulges of edge-on galaxies were obtained by fitting model surfaces to observed 2-D intensity distributions. The fitting regions for each galaxy were limited by ellipses oriented according to position angles of the galaxies. Major axis of the ellipse is chosen to be 0.9 \(D_{25}\) and minor axis equals to 0.1 of the major one (here \(D_{25}\) is the optical diameter). We assumed an exponential law of the distribution of volume luminosity density for both vertical and radial directions with scale lengths \(Z_e\) and \(R_e\) respectively. Distribution of model surface brightness was found by integration along the line of sight. Radial extension of the disks is assumed to be 1.3 \(D_{25}/2\) or about four radial scale lengths (see Zasov etc, 1991). Regions located close to the galactic planes and central regions were masked to evaluate parameters of the disks. All objects of our sample look quite symmetric on B, V and I images so we didn’t take into account the difference of the inclinations from 90°.

To fit the model surfaces to the real images of galactic disks we minimized the sum of squares of residuals changing the parameters of the model \(Z_e, R_e\) and central SB. To fit the bulge we used the result of subtraction best-fit disk model image from the real one. We used King’s function \(I_b(X,Y) = \frac{I_{b0}}{1 + \left(\frac{X^2 + Y^2}{R_{king}^2}\right)}\) to approximate SB distribution in the region of the bulge. Here \(I_{b0}\) and \(R_{king}\) are parameters of the model.

Results of the deprojection.

Parameters of best-fit models are shown in Table 1. You can see the name of the object (column 1), distance for \(H_0 = 75 \text{ km s}^{-1}\text{Mpc}^{-1}\) (2), radial scale length \(R_e\) (3), vertical scale length \(Z_e\) (4), \(Z_e/R_e\) relation (5), central surface brightness of the disks turned face-on in I passband (6), central SB of the bulges in I (7) and the class of SB according to FGC (8).
Central SB is found with the help of the calibration equations taken from RC96 and is corrected to the extinction in our Galaxy using the information from LEDA database.

To estimate the errors of photometric parameters taken by our method we have constructed the sample of model surfaces. Each model surface was constructed by summing the exponential disk turned edge-on, the King’s bulge and the noise. It is found that our method allows us to evaluate the photometric parameters of disks and bulges with errors not more than 10 %. Also we applied our method to the images of NGC 4244 taken from ING archive (were obtained at JKT telescope at La Palma) and found a better agreement between obtained and published in the paper of van der Kruit and Searle (1981) values of vertical and radial scales.

The dependence of $R_e$, $Z_e$, $Z_e/R_e$ and $\mu_{0d}$ on SB class is shown at Fig.1. One can see that surface brightness of disks found for the galaxies of 4th SB class is about $1.6^{m5}$ lower than for 2nd SB class. It’s well consistent with division of galaxies into LSB and HSB objects (see for example Tully, Verhejen, 1997, McGaugh, 1996). Our sample is too small to understand if the scales $R_e$ and $Z_e$ depend on SB class. But relation $Z_e/R_e$ has a tendency to be lower for the objects of 4th SB class.

As one can see from Fig.1d, disks of three galaxies of our sample have low central SB. One of them, UGC 11841, have a scale length more than 10 Kpc what is tipically for giant LSB galaxies like Malin 1 (see Pickering, Impey, 1996). Note that this galaxy have a minimal value of $Z_e/R_e$ in our sample. Such value is expected for “flat” halo-dominated galaxies (Zasov etc., 1991).

Relative magnitudes of the bulges of our galaxies are plotted at Fig.2a depending on SB class. One can see that the bulges of our LSB galaxies have larger relative luminosity than the bulges of HSB spirals. At the same time the central surface brightness of the bulges almost does not show its dependence on SB class (Fig 2b).

The remnants we got subtracting the model disk and the bulge from the real image enables us to assume that there are additional components in the central parts of UGC 11132, 11859, 11994. These galaxies probably include bars or lenses not considered in our model.

**Table 1.**

| Name UGC | D  | $R_e$ | $Z_e$ | $Z_e/R_e$ | $\mu_{0d}$ | $\mu_{0b}$ | $R_{king}$ | SB class |
|-----------|----|------|------|----------|------------|------------|------------|----------|
| 11132     | 37.9 | 2.8  | 0.67 | 0.24     | 20.9       | 21.7       | 0.3        | -        |
| 11230     | 94.7 | 8.2  | 1.96 | 0.24     | 21.6       | 23.3       | 0.6        | 4        |
| 11301     | 60.0 | 8.7  | 1.37 | 0.16     | 20.9       | 23.0       | 0.2        | 3        |
| 11838     | 46.3 | 4.1  | 0.82 | 0.20     | 21.3       | 26.9       | 0.1        | 2        |
| 11841     | 79.9 | 11.7 | 1.58 | 0.14     | 21.8       | 22.3       | 0.8        | 4        |
| 11859     | 40.2 | 3.2  | 0.51 | 0.16     | 22.2       | 20.9       | 0.7        | 4        |
| 11994     | 65.0 | 4.3  | 0.95 | 0.22     | 19.7       | 23.6       | 0.2        | 2        |

**Galaxy RFGC 3647.**

We also explored the galaxy RFGC 3647 which images were taken with better resolution. This object is a good example of edge-on ”thin” galaxy and belongs to 4th SB class according to Revised Flat Galaxies Catalog (FRGC, Karachentsev etc., 1999). Observations of the galaxy were held in July 7, 1999, using 6-m telescope of Special Astrophysical Observatory. The images were taken with 300 sec. exposition in Cousin’s R passband by I.Karachentsev and S.Kajsin. Estimated seeing was 1.0” FWHM. CCD device Tekram
with 1024x1024 pixels provided resolution 0.206 arcsec/pixel. Images of Landolt’s standards taken at the same night were used for the calibration purposes. One can see the masked image of the galaxy after the standard reduction and calibration (Fig. 3).

We used the procedure described before and obtained the photometric parameters of the disk (radial $R_e$ and vertical $Z_e$ scales of the disk, both for exponential approximation, its central surface brightness $\mu^d_{R_e}$) and the bulge (central surface brightness $\mu^b_{R_e}$ and core radius $R_{king}$, both for King’s bulge). The main parameters of the galaxy are shown in Table 2. All values of surface brightness are corrected for the extinction in our Galaxy.

Table 2. Main parameters of FRGC 3647.

| Parameter          | Value         |
|--------------------|---------------|
| R.A.(2000.0)       | 20h 49m 32.7s |
| Dec.(2000.0)       | +58° 06' 17"  |
| Distance for $H_0 = 75$ | 36.8 Mpc     |
| $R_e$              | 5.2 Kpc       |
| $Z_e$              | 0.7 Kpc       |
| $\mu^d_{R_e}$      | 22.2 mag/arcsec$^2$ |
| $Z_e/R_e$          | 0.13          |
| $R_{king}$         | 0.3 Kpc       |
| $\mu^b_{R_e}$      | 19.8 mag/arcsec$^2$ |

As we can see from the Table 2 the central surface brightness of the disk is about $22^m.2$ in R that is in order of $1^m.5$ lower than its value for HSB spirals. Total luminosity of the bulge is $2^m$ lower than the disk’s one. So RFGC 3647 should be located close to UGC 11301 on Figures 1 and 2. The radial extension of the disk of RFGC 3647 (limited by the level of S/N = 3) is about $2.7 R_e$ which is lower than the typical value for HSB galaxies.

To investigate how the vertical scale length varies along the radius of the galaxy we considered few cuts along the minor axis of the galaxy (see Fig.4). In central parts ($R < 2$ kpc) the bulge makes $Z_e$ a bit lower whereas in outer regions mean value of $Z_e \approx 0.66 Kpc$ doesn’t change systematically along the radius. At the large distances from the center the disk of the galaxy is slightly curved so last points at Fig.4 ($R > 8$ kpc) shows us increasing of $Z_e$.

The photometric parameters obtained from the observations of edge-on galaxy enables us to investigate the stability of gaseous disk before the main event of star formation (i.e. when the disk was completely gaseous).

One can compare the critical surface density (according to the stability criterion of Polyachenko, see Polyachenko etc. 1997, Zasov, Bizyaev 1996) and the initial surface density of the gas (mostly in stars now), see Fig 5a.

Parameters of galactic halo, disk and bulge obtained by decomposition of the rotation curve combined with results of the photometric deprojection allow us to estimate the velocity dispersion of the stellar disk, see Fig.5b. Note that the velocity dispersion of stellar population doesn’t decrease with time and the curve shows an upper limit of velocity dispersion of initial gaseous disk of the galaxy. We use artificial rotation curve constructed by combining the scale length of the disk, value of maximum of rotative
velocity (150 km/s according to HI-observations by Seeberger et al., 1994) and general form of rotation curves (Swaters et al., 2000).

As we can see from Fig. 5 the instability criterion may play its role when the galactic disk forms. The values of velocity dispersion in gaseous and stellar disks of this LSB galaxy were rather small (especially in outer regions) compared to lower limit observed for this value at the present time.

Conclusions

In the frames of our small sample the galaxies classified as 4th class of SB in the Flat Galaxies Catalog have disks with low central surface brightness and relatively bright bulges. Deprojecting "thin" edge-on galaxy RFGC 3647 we show that it has LSB disk (central surface brightness 22\m2 in R) and high ratio of radial to vertical scale lengths.

Surface density of initially gaseous disk was higher than critical density and gravitational instability should be an essential factor affecting the fragmentation of the disk. At the same time the stellar disk of the galaxy was not heated significantly and its velocity dispersion is quite low this time.

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FIGURES

Fig.1. The dependence of $R_e$, $Z_e$, $Z_e/R_e$ and $\mu_{0d}$ on the class of surface brightness (according to FGC catalog).

Fig.2. a) Difference between the total magnitudes of bulges and disks versus the SB class of the galaxies.
   b) Central surface brightness of the bulges almost does not show its dependance on the SB class.

Fig.3. R-image of RFGC 3647 after the standard reduction, calibration and masking. Surface brightness varies between 16 and 23 $\text{mag/arcsec}^2$ (corrected to the extinction in the Galaxy). Size of the frame is about 1.5x3.1 arcmin.

Fig.4. Radial behaviour of the vertical scale length of RFGC 3647.

Fig.5. a) Stellar surface density (solid curve) and critical surface density (dashed) versus the radial distance.
   b) The radial behaviour of the velocity dispersion for totally gaseous disk estimated using the photometric parameters and results of decomposition of rotation curve of the galaxy.
