On the massive disks in low surface brightness galaxies

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On the example of four low surface brightness galaxies we demonstrate that the mass-to-light ratio of their disks may be found from the condition of marginal gravitational stability. In this case their surface densities and halo/disk mass ratios appear to be rather typical for normal galaxies, and this does not conflict with their rotation curves.

Introduction

Some investigations of low surface brightness (LSB) galaxies lead to the conclusion that their disks may be significantly more massive than it is predicted by stellar population models (see e. g. [5]). In this case the commonly used point of view, that LSB galaxies are systems of low surface density where a dark halo dominates at all radii, appears to be doubtful. To verify the possibility of high density of stellar disks of LSBs we consider four galaxies of this type for which stellar velocity dispersion data were taken from [6]. These data allowed us to obtain the independent estimation of masses of LSB disks using the criterion of gravitational stability. That was the first time the disk masses of LSB galaxies were obtained by this method.

The method

The upper limit of disk surface density may be independently found on the basis of radial velocity dispersion distribution from the marginal gravitational stability criterion. This method was firstly developed in [4] and used in [7]. The critical value of radial velocity dispersion under which a thin collisionless isothermal disk is stable against the density perturbations at all wavelengths can be written in the following way:

$$c_{cr} = Q_c \cdot c_T \tag{1}$$

where Q_c is the Toomre stability parameter, $c_T \approx \frac{3.4 \cdot G \cdot \sigma_*}{\kappa}$ is the Toomre critical radial velocity dispersion, σ_* is the disk surface density, κ is the epicyclical frequency: $\kappa = 2 \cdot \Omega \cdot \sqrt{1 + (R/2\Omega)(d\Omega/dR)}$, where Ω is the angular velocity. Radial velocity dispersion can be found from the line-of-sight velocity dispersion measured along a slit which crosses the center of galaxy on the basis of the following formula

$$c_{obs}(r) = \left[c_z \cdot \cos^2 i + c_\phi \cdot \sin^2 i \cdot \cos^2 \alpha + c_r \sin^2 i \cdot \sin^2 \alpha\right]^{0.5} \tag{2}$$

and the additional conditions: $c_r = 2\Omega \cdot c_\phi/\kappa$ and $c_z = k \cdot c_r$, where $c_{obs}(r)$ is the line-of-sight velocity dispersion, c_z, c_ϕ, c_r are its vertical, azimuthal and radial components, i is the inclination of the disk of galaxy, α is the angle between the direction of slit and the major axis projected on the plane of a galaxy, the coefficient k was taken to be equal to 0.6. In the model of thin disk and axisymmetric perturbations the Toomre parameter is $Q_c = 1$. But in general the value of $Q_c(R)$ depends on many factors. In the current work the Toomre parameter was taken to vary with radius as it resulted from the dynamical modeling of 3D marginally stable disk [8]:

$$Q_c(r/h) = A_0 + A_1 \cdot (r/h) + A_2 \cdot (r/h)^2 \tag{3}$$

where $A_0 = 1.25$, $A_1 = -0.19$, $A_2 = 0.134$, and r/h is the distance from the center in the units of disk scalelength.

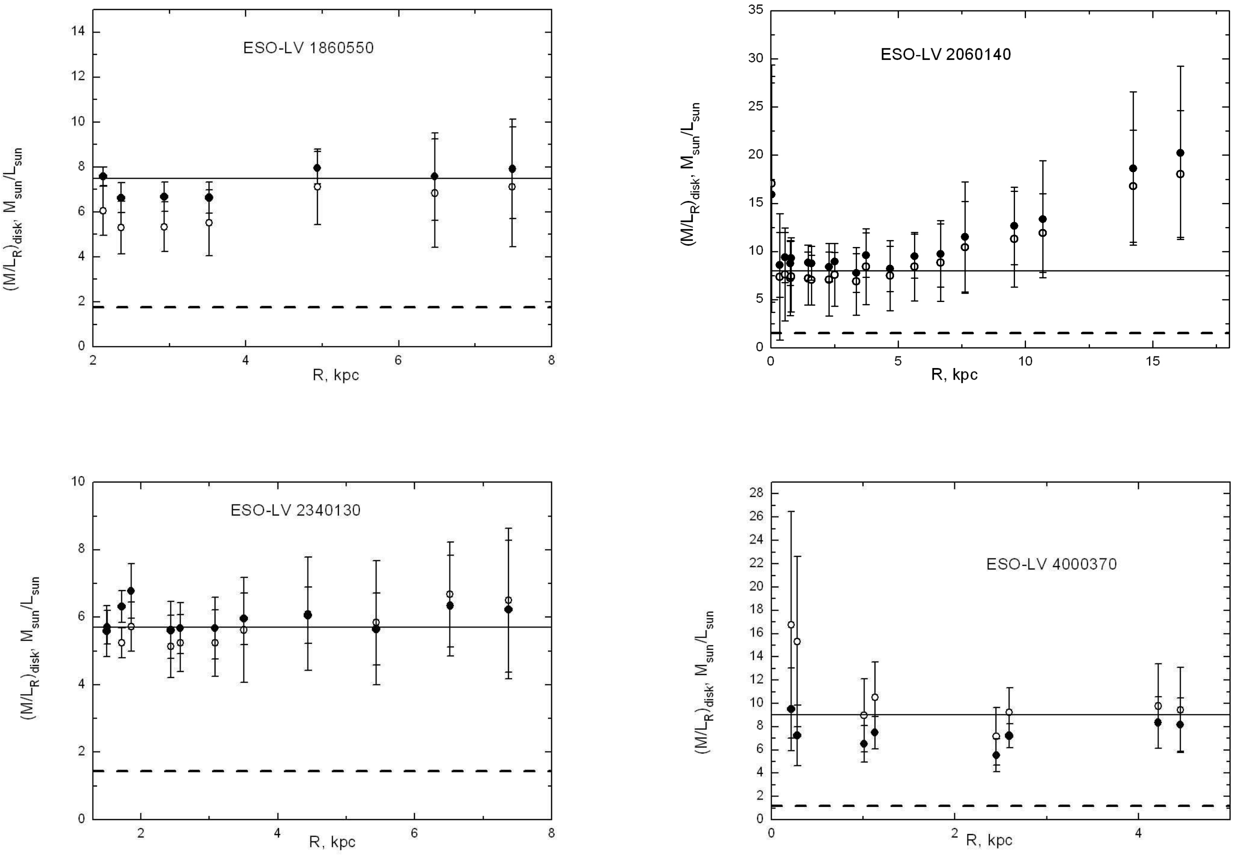

Figure 1: Radial profiles of $(M/L_R)_{disk}$ ratios estimated using the gravitational stability criterion. Open and filled circles correspond to the gas and stellar circular velocities. The dashed lines denote $(M/L_R)_{disk}$ ratios predicted by stellar population models [1]. The solid lines correspond to the mean values of $(M/L_R)_{disk}$ which were used for the decomposition of rotation curves.

Results and conclusions

The upper limit of disk mass was obtained for four giant LSB galaxies using the gravitational stability criterion (1); radial distribution of the velocity dispersion and rotation curves of stars and ionized gas were taken from [6]. The radial surface density profiles and the dynamical models of these objects were obtained. The surface density radial profiles obtained for marginal stable disks were used to estimate $(M/L_R)_{disk}$ (in solar units) for different galactocentric distances (see Fig. 1). The filled and open circles in Fig. 1 correspond to the gas and stellar circular velocities. The dashed lines denote $(M/L_R)_{disk}$ ratios predicted by stellar population models [1] for the metallicity $Z = 0.008$, the solid lines correspond to the mean values of $(M/L_R)_{disk}$ which were used for the decomposition of rotation curves. From Fig. 1 it follows that $(M/L_R)_{disk}$ ratios corresponding to the marginal stability criterion are several times higher than those predicted for low surface brightness disks by stellar population synthetic models.

The decomposition of the rotation curves of ionized gas (filled circles) and stars (open circles) corresponding to the marginally stable disk into exponential disk, pseudo-isothermal dark halo and King's bulge components is shown in Fig. 2. The stellar rotation curves were corrected for asymmetric drift according to [2]. The radial scalelengths of disks were taken to be equal to the photometrical scalelengths obtained in R band by [6]. From Fig. 2 it follows that the models corresponding to the marginal gravitational stability criterion provide a reasonable fit to the observed rotation curves.

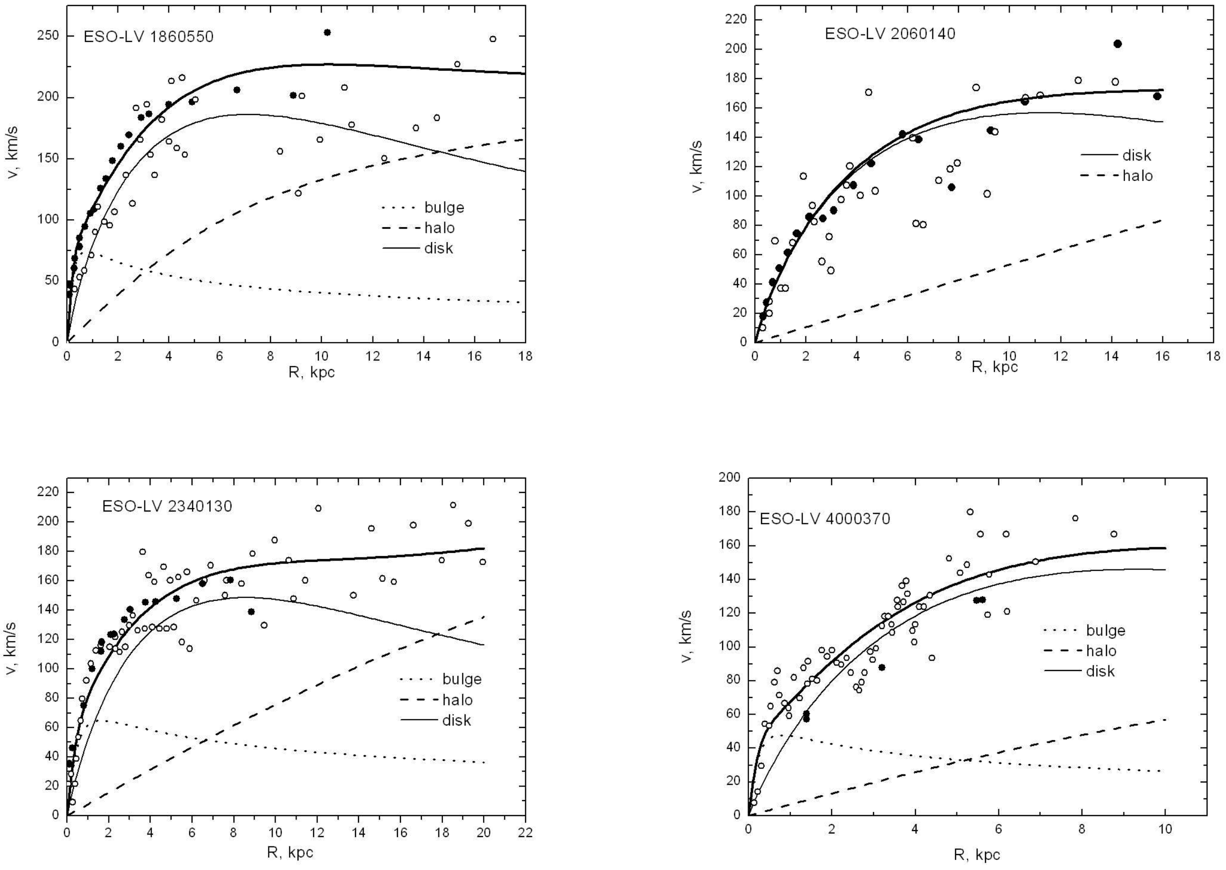

Figure 2: The decomposition of the rotation curves of ionized gas (filled circles) and stars (open circles)

The comparison of disk masses of different LSB-galaxies obtained from our models (filled circles) and from models based on the linear theory of density waves [5] (open circles) with those referred to the largest disk models is shown in Fig. 3. From this figure it follows, that the obtained mass models appear to be close to the models of largest disk, where stellar disks have largest possible contribution to the rotation curves. The scatter of points on this diagram is within the uncertainties of the methods used. The error bars in Fig. 3 correspond to the errors of the input data used to obtain the disk masses but not to the method uncertainties.

A comparison between the parameters estimated using the gravitational stability criterion and stellar population models is presented in Table 1. The half-thicknesses of isothermal self-gravitating marginally stable disks: $z_* = \frac{c_z^2}{\pi G \sigma_*}$ at the fixed distance $R = h$ are compared with those resulted from the densities obtained using photometric data. In the later case the self-consistent equilibrium equations were solved for stellar and gaseous components of a disk in the gravitational field of rigid massive spheric pseudo-isothermal dark halo. The disk surface densities and dark halo mass fractions resulted from marginally stable model and photometric data are also compared in Table 1. The mean uncertainty of the values listed in Table 1 due to the errors of the input data is 30 %.

From Table 1 it can be seen that the photometric models lead to the higher contribution of dark halo to the rotation curve in comparison with marginally stable models (see the last two columns). The photometric models for normal stellar population give $2 - 2.5$ times thicker disks in comparison with the marginal stable ones (the relative disk thicknesses are shown in the second and third column). Note that the estimates of z_*/h corresponding to the marginal stability criterion better agree with those expected for LSB galaxies from the relationship between the de-projected surface brightness and disk thickness, found in [3]. In that paper the objects with lower surface brightness have lower z_*/h.

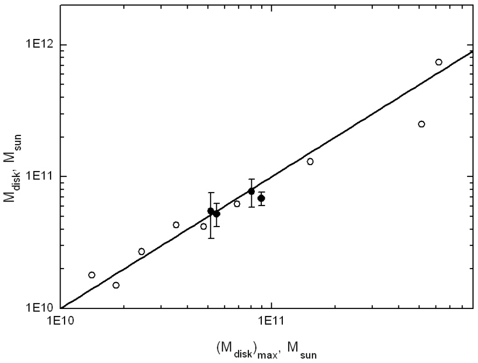

Figure 3: Comparison of LSB disk masses obtained using our models (filled circles) and models of [5] (open circles) with those referred to the largest disk models. Black line corresponds to $M_{disk} = (M_{disk})_{max}$.

Table 1: Comparison of the parameters, estimated using gravitational stability criterion (a) and stellar population models (b).

Name	z_*/h		σ_{0*}, M_{sun}/pc^2		M_{halo}/M_{disk}	
	a	b	a	b	a	b
ESO-LV 1860550	0.1	0.2	1000	240	1.1	11
ESO-LV 2060140	0.2	0.4	450	68	0.7	9.1
ESO-LV 2340130	0.1	0.3	590	150	0.9	7.4
ESO-LV 4000370	0.2	0.4	520	85	0.5	26

The disk masses of four LSB-galaxies obtained from the local gravitational stability criterion appear to be significantly higher than it can be expected from their photometrical data in the assumption of normal stellar population being in agreement with the observed rotation curves. The corresponding mass models are close to the models of largest disk. Hence, either the disks of these galaxies are strongly dynamically overheated and thick, or their densities and masses are quite typical for high surface brightness galaxies.

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