THE RADIAL BRIGHTNESS PROFILES OF THE GALACTIC DISKS

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Abstract.

A brief review of the problems and methods concerning modeling of the radial profiles of the galaxies is given. It is shown that the Sersic's (1968) formula, with an exponential number N between 1 and 3, adequately represents the convex disk profiles. Our results show that the disk profile convexity correlates more with the relative mass of the bulge than with the absolute mass of the galaxy. Examples of iterative decomposition of both the profiles of the galaxies M 33 (with almost exponential disk), UGC 1400 (visible edge-on, with possible ring-like disk) and simulated profiles as well as a comparison of B,J and K profiles of the galaxies M 51 and M 74, are given.

Key wodrs: *galaxies – structures; galaxies – fundamental parameters*
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The investigations of the galaxies structure components include modeling of their brightness profiles. The aim of this approach is to find (1) an universal method for measuring galaxies sizes and magnitudes; (2) quantitative description of the Hubble sequence and scaling relations (e.g. fundamental plane), as well as (3) to reveal photometric indicators for the galaxy's "giantism" applicable in multidimensional Tully-Fisher type methods for distance estimation.

The simplest model of a spiral galaxy consists of bulge and disk components, whose observing radial brightness profiles could be presented by the Sersic's (1968) formula:

$$I_R = I_0 \exp(-(R/H)^N) \quad \text{or} \quad \mu_R = \mu_0 + C\, R^N \qquad (1)$$

Here I_0 is the central intensity, $\mu_0 = -2.5 \log I_0$ is the central surface brightness, the exponential number N defines the shape of the profile, H is the radial scale length (the characteristic distance from the center at which the intensity decreases e-times) and C = (1.087 H)$^{1/N}$ is coefficient in the magnitude representation of the profile. The de Vaucouleurs (1948) “1/4 law” for the giant elliptical galaxies and bulges of the early type galaxies, as well as the Freeman (1970) “exponential law” (suspected by de Vaucouleurs (1959)) for the disks are particular cases of (1) with N=1/4 and N=1, respectively.

Great amount of galactic profiles has been decomposed in the last 30 years by use of de Vaucouleurs model for the bulge and Freeman’s model for the disk (van der Kruit 2002; Anderson et al. 2004). However, in many cases of early type galaxies the central region of the disk seems to have plateau or depression. Thus the disk model with inner truncation may be applied (Kormendy 1977, Anderson et al. 2004). On the other hand, the contemporary investigations show that less massive bulges of late type galaxies (as well as less massive elliptical galaxies) tend to have more compact periphery than the de Vaucouleurs law predicts (Andredakis et al 1995). Such radial profiles may be modeled by (1) with N>½ , up to N = 2 (Gaussian function).

The deep observations helped to figure out also that the faint peripheral regions of the disks seem to be truncated and can be modeled with outer “cutt-off radius” (van der Kruit & Searle 1981, Barteldrees & Dettmar 1994). However, the deepest observations published by Pohlen et al (2002), show that the disks really has not truncation radius, but has convex brightness profiles. Pohlen et al. (2002) has modeled such profiles using two exponents – inner, corresponding to the Freeman’s model and outer – steeper (see also Pohlen et al. 2004).

Generally, the contemporary data shows that the disk brightness profiles are smoothly convex (even in the cases of the LSB and dwarf galaxies, independently of the environments); and in some cases of early type or bar galaxies the central brightness of the disks has a depression. Any modern model of the disk brightness profile must account for such features. However, the model of Freeman (1970) describes disk with (1) well prominent peak of the central brightness, (2) linear radial decrease of the brightness in magnitude scale and (3) infinite size. In the model with inner truncation (Kormendy 1977) the central peak may be absent, even if the disk has a ring-like shape, but the periphery remains infinite. In the model with sharp outer truncation (van der Kruit & Searle 1981) the central peak remains sharp and the cut-off-radius depends on the deepness of the observation. Finally, the central peak in the two exponent model of Pohlen et al. (2002) remains sharp and the profile is "broken".

Recently I began to model the galactic disk profiles using the Sersic's (1968) formula (1) and also generalized this formula by adding 2nd and 3rd order terms. The 1st order formula (1) is well describing smooth convex profiles without strong central peak. The 2nd order can describe the disk's profile with strong central depression, even in the case of ring-like disk. The 3rd order formula is able to describe the whole profile of a galaxy with prominent bulge and disk and its inflex point is the natural dividing point between the bulge and disk profiles. This point is necessary for the decomposition. The 3rd order formula has the form

(2) $$I_R = I_0.\exp(-(R/H_1)^N - (R/H_2)^{2N} - (R/H_3)^{3N})$$

or $$\mu_R = \mu_0 + C_1.R^N + C_2.R^{2N} + C_3.R^{3N}$$

The decomposition procedure in the spirit of Kormendy (1977), but using the Sersic's formula both for the bulge and disk, is realized as C-language program.

The intermediate results of the profile decomposition of the galaxies M 33 and UGC 1400 into bulge and disk components are shown in Figure 1, according to the number of the iterations, given at the top of the graph. For the disk component the upper (overestimated) model curves correspond to the 1st iteration and for the bulge - the 1st iteration provides the most left (underestimated) profile. The short vertical line shows the position of the dividing point. In the case of the classic profile of M 33 in B-band (from de Vaucouleurs 1959) the final corresponding exponential numbers N for the bulge and disks are 1.07 and 1.80. In the case of the edge-on galaxy UGC 1400 in R-band, based on an isophote map, published by Karachentsev et al. (1992), the decomposition using 2nd order Sersic's formula is applied. It seems that this galaxy has disk with significant central depression. The optimal derived exponential number for the disk is N = 1.35. A decomposition with the 1st order Sersic's formula (1) provides results, which are very close to the presented results of the 1st iteration for UGC 1400 and the corresponding exponential bulge and disk numbers N are 2.22 and 2.84, respectively. These data correspond to the truncated bulge plus disk with inner and outer truncations.

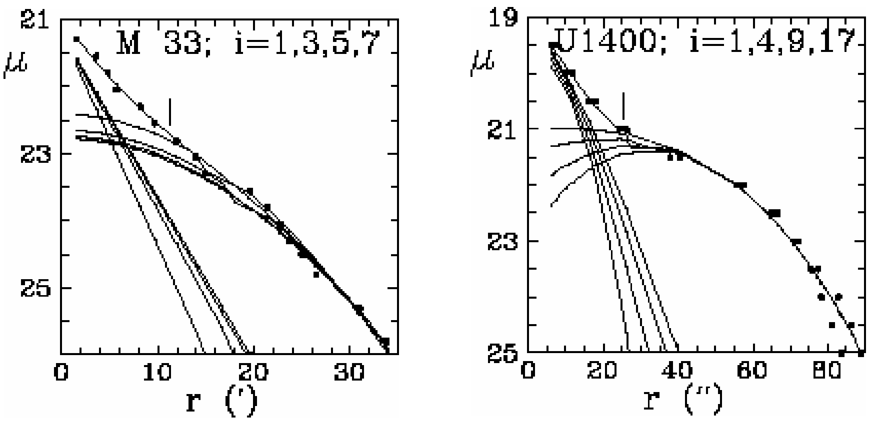


Fig.1. Intermediate results of the decomposition in the case of M 33, with almost exponential profile, and UGC 1400 (visible edge-on), with possible ring like disk. The number of the iterations is given at the top of the graph. The short vertical line shows the position of the dividing point between the bulge and disk components of the profile.

Decomposition of the simulated profiles where both bulge and disk profiles are fitted by the Sersic's formula (1) and normal noise with standard deviation 0.2 mag is added to the result profile, are shown on Figure 2. The simulated profiles experiments spread out on situations when the central intensity of the bulge is 3-50 times higher than that of the disk and when the scale length of the bulge is 5-20 times less than that of the disk. In such cases the decomposition technique provides good results. Unfortunately, the noise somewhat crucially affects the choice of the dividing point. Though, both the numerical simulations and the comparison of the results for nearby galaxies (Georgiev 2004) give evidences that the standard error estimations of the values N and μ_0 are about 25% and 0.3 mag for the disk.

Here we present the first application of this approach for 22 profiles of the nearby galaxies M 31, MW (model), M 33, LMC, SMC and M83, published by different authors (cf. Georgiev 2004) and for 22 published profiles of near edge-on galaxies (Georgiev & Stanchev 2004a). The results show that the formula (1), with 1 < N < 4, is a good tool for "measuring" and comparing galactic disks. The conclusion is that the shape parameter N of the disk profile increases with the mass of the disk. Another more complete sample of 119 northern edge-on galaxies with a size between 2 and 7 arcmin, homogeneous distribution of the bulge-to-disk ratio and luminosity was studied by Georgiev et al. (2004a). They claimed that the convex shape of the disk profile is connected with the relative giantism of the bulge – the disks of spiral galaxies of earlier type tend to have more convex disk shapes. The conclusion is that the bulge-disk interaction results in a convex shape of the disk. Detection of ring-like disks using the 2nd order Sersic's formula is presented by Georgiev & Stanchev (2004b). Other examples are given by Georgiev et al. (2004b).

The comparison between the radial profiles of the face-on galaxies M 51 and M 74 is shown in Figure 3. The data from different sources show that these galaxies have radial disk profiles with convex shapes.

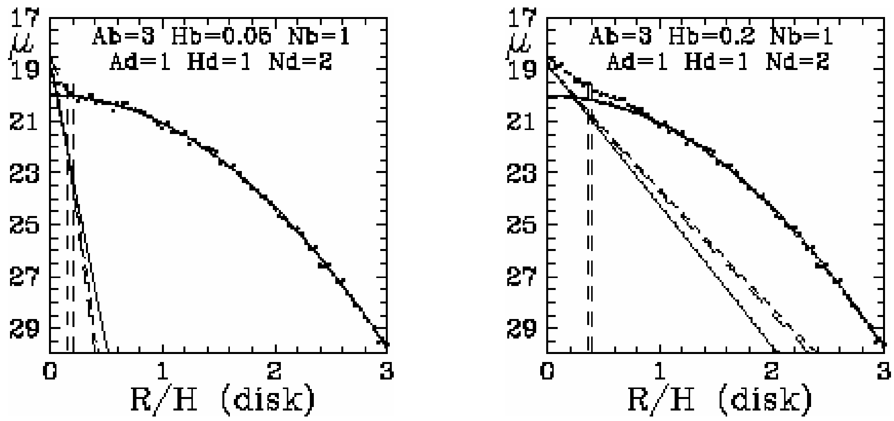
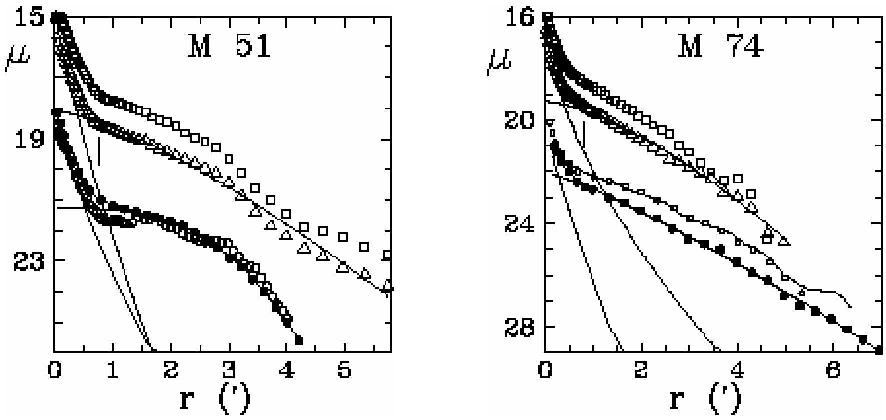


Fig. 2. Decompositions of simulated radial profiles of galaxies. The bulge and disk components (solid curves) are modeled through the 1st order Sersic's formula with exponential numbers Nb = 1 and Nd = 2.The other parameters are given in the top of the plots. Strong normal noise with standard deviation of 0.2

mag is added to the superposition of the bulge and disk models (dots). The results of decomposition using disk model according to the 1st or 2nd order Sersic's formula are presented with long dashes and short dashes, respectively. The vertical dashed lines indicate the dividing interval between the bulge and the disk.



Fif. 3. Comparison between the radial profiles of the galaxies M 51 and M 74 in B, J and K bands. The B-band data for M 51 are taken from the papers by Okamura et al. (1976, dots, decomposed) and Boroson (1981, circles) and in the case of M 74 – from Natali et al. (1992, dots, decomposed), Shostak & van der Kruit (1984, circles) and Wevers et al. (1986, solid curve). The J and K data from 2MASS (Jarret et al. 2003) are presented by triangles (decomposed) and squares.

The encouraging results when fitting the convex disk profiles with the Sersic's formula, with an exponential number $N_d > 1$, gives possibilities to reanalyze many published galaxies profiles. In the future we intend to investigate the scaling relations for the disk components of the spiral galaxies using deep observations, both published and our own.

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References:

A n d e r s o n K. S., S. M. B a g g e t t, W. F. B a g g e t t , 2004, AJ 127, 2085
A n d r e d a k i s Y.C., R. F. P e l e t i e r, M. B a l c e l s, 1995, MNRAS 275, 874
B a r t e l d r e e s A., R.-J. D e t t m a r, 1994, A&AS 103,475
B o r o s o n T., 1981, ApJ 46,177
d e V a u c o u l e u r s G., 1948, Ann. Astrophys. 11, 247
d e V a u c o u l e u r s G., 1959, ApJ 130, 728
F r e e m a n K.C. 1970, ApJ 160, 811
G e o r g i e v T. B., 2004, Aerospace researches in Bulgaria, in print
G e o r g i e v T. B., O. I. S t a n c h e v, 2004a, Bulgarian Journal of physics, in print.
G e o r g i e v T. B., O. I. S t a n c h e v, 2004b, Publ. Astron. Obs. Belgrade, in print
G e o r g i e v T. B., O. I. S t a n c h e v, P. L. N e d I a l k o v , 2004a, Annuaire d'Universite de Sofia, in print
G e o r g i e v T. B., O. I. S t a n c h e v, P. L. N e d i a l k o v , I. Y. G e o r g i e v, N. A. K o l e v a, 2004b, in this issue,.
J a r r e t T. H., T. Chester, R. Cutri, S. E. S c h n e i d e r, J .P. H u c h r a, 2003, AJ 125, 525 .
K a r a c h e n t s e v I., T. G e o r g i e v, S. K a j s i n, A. K o p y l o v, V. S h e r g i n, V. R y a d c h e n k o, 1992, Astron. Astrophys. Transactions. 2, 265
K o r m e n d y J.., 1977, ApJ 217, 406
M e s t e l L., 1963, MNRAS 126, 553
N a t a l i G., F. P e d i c h i n i, M. R i g h i n i, 1992, AA 256, 79
O k a m u r a K., T. K a n a z a v a, K. K o d a i r a, 1976, PASJ 28, 329
P o h l e n M., R.-J. D e t t m a r R.-J., R. L u e t t i c k e, G. A r o n i c a, 2002, A&A 392, 807
P o h l e n M., J. B e c k m a n, S. H u t t e m e I s t e r, J. K n a p p e n, P. E r w i n ,R.-J. D e t t m a r, arXiv:astro-ph/0405541, 2004
S e r s i c J.-L., Atlas de Galaxies Australes 1968 (Obs. Astron.Univ.Nat.Cordoba)
S h o s t a k G. S, P. v a n d e r K r u I t, 1984
V a n d e r K r u i t P. C . 2002, in eds. G.S. da Costa and E.M.Sad ler, Dynamics, Structures and History of the Galaxies, ASP Cof. Serr. Vol.273 P.7
v a n d e r K r u i t P. C., L. S e a r l e 1981, A&A 95, 105
W e v e r s B. M.H. R., P.C. v a n d e K r u i t, R. J. A l l e n, 1986, A&AS 66, 605