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Morphological classification of M85, NGC4394, NGC2336, NGC2841

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Abstract. In this work, we classified morphologically four galaxies (M85, NGC2336, NGC2841 and NGC4394) by studying their isophotal parameters, comparing the brightness profiles with empirical laws. In particular, we adopted the de Vaucouleur's profile for the bulge and an exponential law for the disk. We also modelled the brightness distribution, fitting the isophotes with ellipses. The observations were performed by the 67/92 Schmidt Telescope of the Asiago Astrophysical Observatory, in R-band filter. The results obtained show a reasonable agreement with the literature.

1. Introduction

Galaxies are morphologically classified, in agreement with the Hubble sequence, in ellipticals, lenticulars, spirals and irregulars (Fig. 1). Elliptical galaxies have regular shape, smooth and featureless light distribution and appear as ellipses. They are denoted by the letter E, followed by a number from 1 to 7 representing their apparent ellipticity. Lenticulars are denoted by S0. Spirals have a central concentration of stars, called bulge, and a flattened disk, with stars disposed in a spiral structure. They are divided in spirals and barred spirals, which have a bar-like structure across the bulge. These are denoted by letter S (spiral) or SB (barred spiral) followed by “a”, “b”, or “c” (Sa is a spiral with tightly-wounded arms and with a bright central bulge; Sc has less wounded spiral arms and a weak bulge.

Our work aimed to classify the observed galaxies in three ways: a) using the isophotes, approximated by ellipses, b) creating a model to be subtracted from the original images and analysing the residual image, c) analysing their brightness profiles.

Isophotes are defined as the lines that link the points of same brightness. Once the isophotes are approximated by ellipses, it is possible to analyse their ellipticity, position angle and the coordinates of the centre as a function of the semi-major axis. All these parameters give information about the morphology of a galaxy.

The second method is based on the modelling of the galaxy brightness, assuming the isophotes as ellipses, this time with fixed centre. Using the difference between the original image and the model, called residual image, it is possible to infer the morphology.

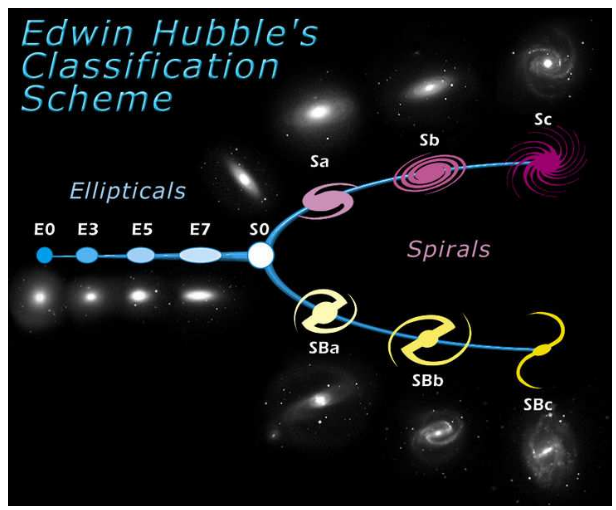

Fig. 1. Hubble's classification (wikipedia).

Finally, we can classify galaxies by calculating their T-Type, a number obtained from the difference between the bulge and the disk brightness. The T-Type is related to a class of galaxies according to the Simien & de Vaucouleurs (1986) classification (Table 1).

2. Observational data

The data we used were taken with the 67/92 Schmidt Telescope, of the Asiago Astrophysical Observatory. This telescope is equipped with a CCD system, SBIG STL-11000M, KAI-11000M detector with 4008 x 2672

Table 1. T-Type and Hubble's classification

T Type	Hubble
−5	E
−2	S0
+1	Sa
+3	Sb
+5	Sc

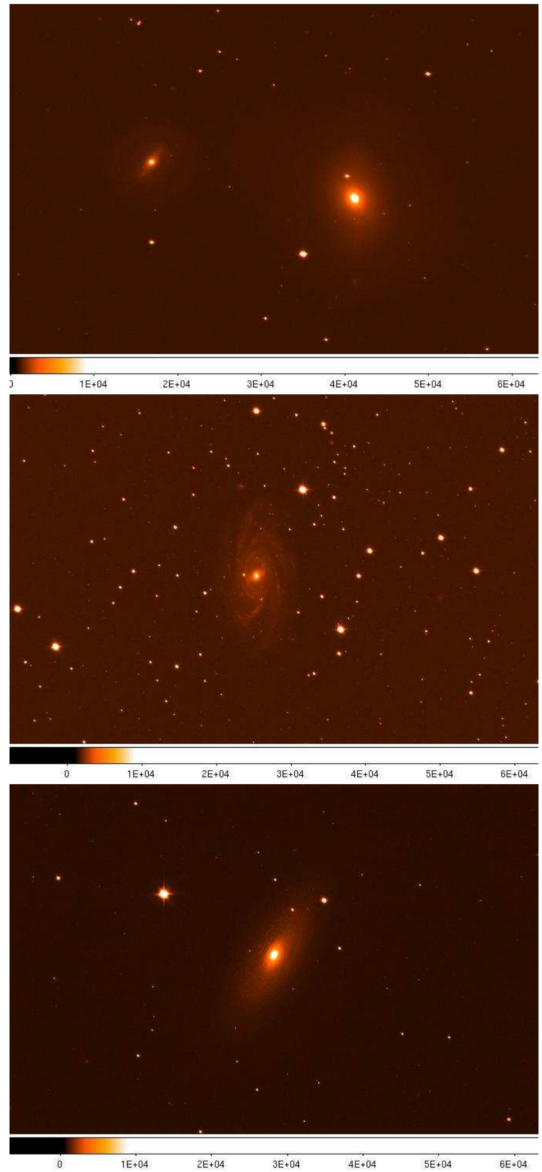

Fig. 2. Observed galaxies. Top: NGC4394 (*on the left*) and M85 (*on the right*); middle: NGC2336; bottom: NGC2841. 67/92 Schmidt Telescope + R filter, Asiago Observatory.

active pixels. Each pixel has a surface of 9 μm^2 and the scale factor is 0.86 *arcsec*/pixel. The images were taken using the R-band filter (Fig. 2). In Table 2 are shown the observational data.

The images were corrected by dark, which is the emission of the CCD due to its own temperature, and by flat field, in order to correct the non-uniform response of the CCD.

3. Work description

In our work we approximated isophotes to ellipses (with the task *ellipse* of the IRAF package). Then, using *ds9*, we created the first ellipse which represented the first guess of the galaxy limit brightness. Before setting the program to create the other ellipses, we had to mask the stars that, with their brightness, could disturb the isophotes determination. After that, the program was able to calculate the other isophotes (see Fig. 3 as an example). Some ellipses were clearly not representative of the galaxy and we deleted them.

We extracted some parameters from the ellipses such as: semi-major axis, internal flux, number of pixels restrained, coordinates of the centre, position angle, intensity, ellipticity. There were some ellipses in the table with the same number of pixels, thus we deleted all of them except one, trying to keep the increasing of the semi-major axis linear. We had to do this because those ellipses, describing the same isophotes, are useless. Then, we arranged a table in ascii format in order to build the diagrams with the program *TOPCAT*.

We applied the same procedure again, but this time fixing the coordinates of the centre. We created the ellipses representing the isophotes of the galaxies, now all concentric. At this point, we rejected all the ellipses that were too different from the structure of our galaxies and obtained a table containing all the parameters needed to build the diagrams (semi-major axis, internal flux, number of pixels restrained). The table must be revised, in this case as well, deleting the ellipses with the same number of pixels and trying to keep the increasing of the semi-major axis linear.

Method 1: Isophotes analysis

The first way to analyse the morphological structure is examining the isophotes with unfixed centre of our galaxies. With *TOPCAT* we created few graphs, which gave us a first identification of the galaxies morphological structure. For each galaxy, we plotted the ellipticity, position angle (P.A.), and the coordinates of the centre (x, y) versus the semi-major axis (see Fig. 4).

If ellipticity, position angle and coordinates are constant along the semi-major axis the galaxy is probably an elliptical. If there are variations, these suggest the presence of structures: the galaxy is probably a spiral. In particular, when the ellipticity changes while the position angle remains constant, can be inferred the presence of a bar.

Table 2. Galaxies and observational data

Galaxy	NGC2336	NGC2841	NGC4394	M85
Date	06/02/11	06/02/11	06/02/11	06/02/11
Hour	19:18:17	19:11:51	22:00:36	22:00:36
Exp.time	600	300	300	300
R.A.	07h 26m 58s	09h 22m 08s	12h 25m 33s	12h 25m 33s
Dec	+80^o 11' 15"	+50^o 58' 49"	+06^o 11' 43"	06^o 11' 43"

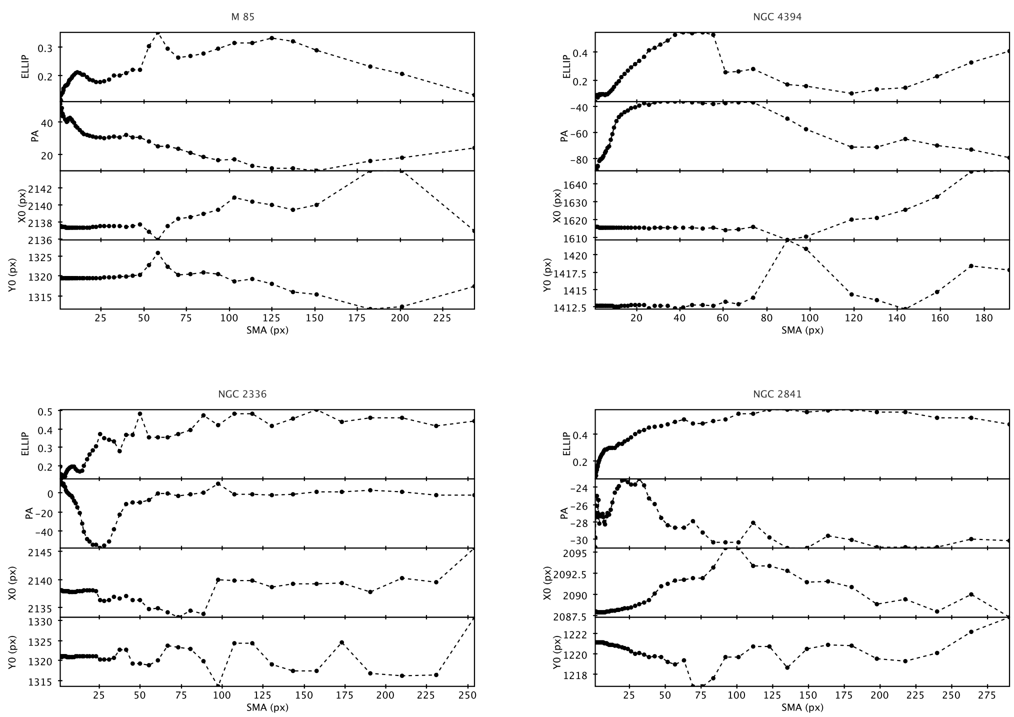

Fig. 4. Morphological parameters for all the galaxies as a function of the semi-major axes (SMA, *pixels*) of the ellipse. From the top to the bottom of each plot there are: ellipticity, P.A. (*degree*), coordinates of the centre in pixels (x, y).

Method 2: Residuals analysis

Using the *bmodel* task of IRAF on the isophotes with unfixed centre, we created an image that approximates the galaxy. Successively, we subtracted, pixel by pixel, the modelled image from the original one of the galaxy and we obtained a third image with the residuals (see Figs. 5 and 6). Isophotes approximation is regular and so will be the model: any irregular structure will be shown in the residual image. If in these images structures, such as bars or spiral arms are noticed, the galaxy is a spiral. If no structure is seen the galaxy is an elliptical.

Method 3: Brightness profile

A third way to analyse the morphological structure of our galaxies is based on building their brightness profile. We had to derive new parameters from the isophotes with fixed centre using the package *TOPCAT*.

These parameters were: the semi-major axes (kpc) and the surface brightness (mag/arcsec^2). The sky-subtracted flux (counts/s) within each ellipse was given by:

$$\mathrm{flux} = \frac{(t_{\mathrm{flux_e}} - (n_{\mathrm{pix}} \times < I_{\mathrm{sky}} >))}{t_{\mathrm{exp}}} \quad (1)$$

where $t_{\mathrm{flux_e}}$ and n_{pix} are the total counts and the number of pixels inside each ellipse, respectively, $< I_{\mathrm{sky}} >$ is the mean sky intensity per pixel, and finally t_{exp} is the exposure time.

The surface intensity between two consecutive ellipses was obtained using the following formula:

$$I_{\mathrm{sup}} = (\mathrm{flux}_2 - \mathrm{flux}_1)/(\mathrm{area}_2 - \mathrm{area}_1) \quad (2)$$

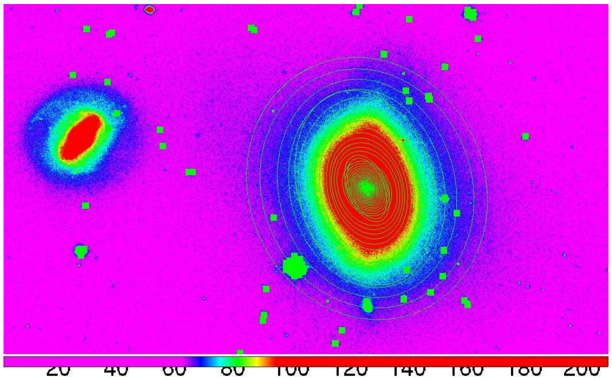

Fig. 3. Isophotes approximated by ellipses (in *green*) overlapped to M85 (the galaxy on the right). The ellipses has been obtained using the IRAF's task *ellipse*. The squares and clusters of squares (in *green*) are the masked stars (see text).

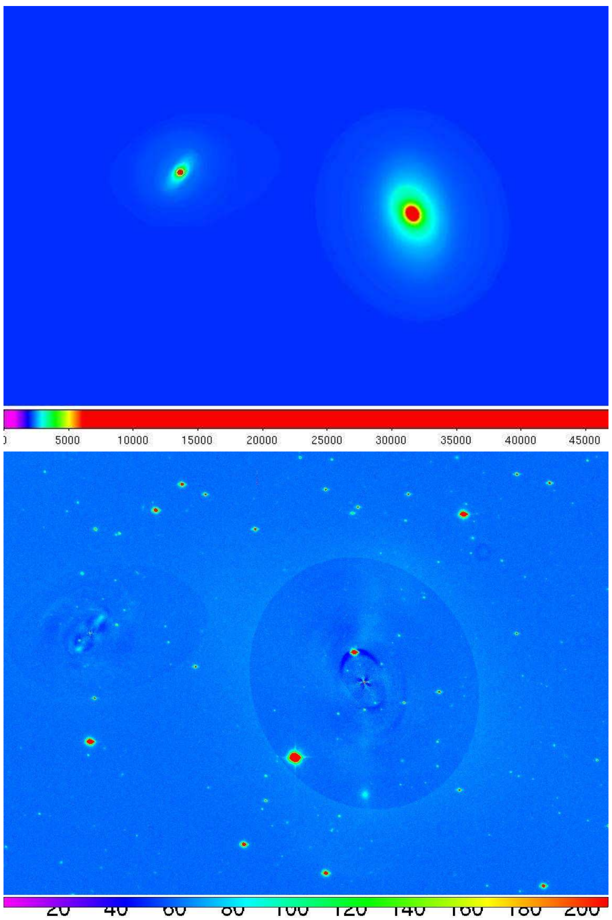

Fig. 5. The images show respectively the models (top) and residuals (bottom) of NGC4294 and M85. The models were created based on the ellipses that approximate the isophotes. The residual image was found through the subtraction of the model from the original image.

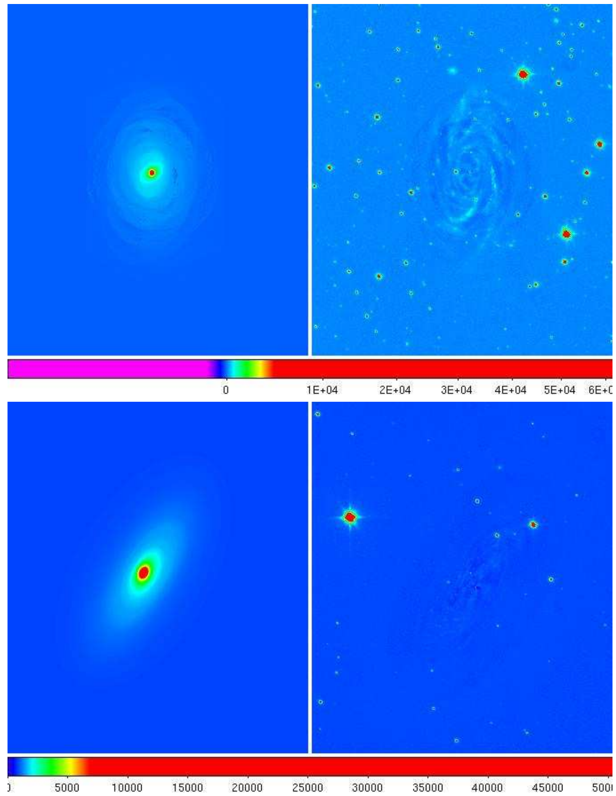

Fig. 6. The images show respectively the models (on the left) and residuals (on the right) for NGC2336 (top) and NGC2841 (bottom).

where area is the the number of pixel in each ellipse multiplied by the pixel area in arcsec^2 (0.4×0.4 arcsec^2).

At this point, it was possible to determine the instrumental surface brightness (μ) through the classical relation between intensity and magnitude (Karttunen et al. , 1996):

$$\mu = -2.5 \log I_{sup} \quad (3)$$

This value had to be calibrated taking into account the atmospheric extinction (given by $k\,x$, where k is the extinction coefficient and x the airmass) and the zero-point magnitude (m_0)

$$m_{cal}^{obs} = \mu + m_0 + k\,x \quad (4)$$

In our case, $m_0 + k\,x \approx 5$ and we adopted this value as calibration coefficient.

Finally, we built the surface brightness profile graphs, placing on the abscissa the semi-major axis and on the ordinate the observed calibrated brightness. At this point, we studied the surface brightness profile of each galaxy using two different laws. We described the brightness profile of the bulge (μ_{bulge}) using the de Vaucouleurs' law (Simien & de Vaucouleurs , 1986):

$$\mu_{bulge} = \mu_e + 8.325\,((r/r_e)^{1/4} - 1) \quad (5)$$

Table 3. Bulge and disk parameters

Object	μ_e	r_e (")	μ_0	h (")
NGC2336	26.0	35	23.8	45
NGC2841	24.0	40	23.2	75
M85	23.7	35	23.5	65
NGC4394	24.4	20	23.5	30

Table 4. Bulge and disk intensities

Object	I_e	B	I_0	D
NGC2336	$2.5\text{x}10^{-11}$	$3.7\text{x}10^{-7}$	$3.0\text{x}10^{-10}$	$4.0\text{x}10^{-6}$
NGC2841	$2.5\text{x}10^{-10}$	$4.8\text{x}10^{-6}$	$5.0\text{x}10^{-10}$	$1.8\text{x}10^{-5}$
M85	$3.3\text{x}10^{-10}$	$4.8\text{x}10^{-6}$	$4.0\text{x}10^{-10}$	$1.1\text{x}10^{-5}$
NGC4394	$1.7\text{x}10^{-10}$	$8.1\text{x}10^{-7}$	$4.0\text{x}10^{-10}$	$2.3\text{x}10^{-6}$

where r_e is the distance from the centre in which we find half of the light of the bulge, and μ_e is the surface brightness within r_e. The disk can be described by an exponential law:

$$\mu_{disk} = \mu_0 + 1.085\,(r/h) \qquad (6)$$

where μ_0 is the surface brightness in the centre and h represents the distance at which

$$I = I_0/e \qquad (7)$$

For an elliptical galaxy, the brightness profile is entirely described by the first law (eqn. 5), while in the case of a spiral galaxy one law is not sufficient to describe the whole galaxy. In particular, it is needed a law describing the component of the disk (eqn. 6).

We found the parameters empirically in order to reproduce the surface brightness profiles shown in Fig. 7, the values are given in Table 3. After this, by using eqn. (3), we obtained the surface brightness of each component.

The bulge and disk total intensities were calculated by means of the following equations and are summarized in Table 4:

$$I^{tot}_{bulge} = 11.93\, I_e\, r_e^2 = B \qquad (8)$$

$$I^{tot}_{disk} = 2\pi\, I_0\, h^2 = D \qquad (9)$$

We found the morphological type using the T-Type scale (Simien & de Vaucouleurs , 1986). From the ratio B/(B+D) we found Δm using the following equation:

$$\Delta m = -2.5 \log\left[B/(B+D)\right] \qquad (10)$$

With Δm it is possible to obtain the parameter T by exploiting the graph reported in Simien & de Vaucouleurs (1986). See Table 5.

Table 5. T-Type Classification

Object	$B/(B+D)$	Δm	T
NGC2336	0.08	2.74	~5
NGC2841	0.21	1.69	~3
M85	0.31	1.27	~1.5
NGC4394	0.26	1.46	~3

4. Results

In this work, we classified the morphological type of four galaxies, NGC2336, NGC2841, M85 and NGC4394, adopting three different methods: a) isophote analysis, b) residual analysis, c) brightness profile. The isophotes, approximated by ellipses, were obtained in two ways, with free and fixed centres. The ellipses with free centres were used to analyse the isophote parameters (ellipticity, position angle, and the coordinates of the centre (x,y) as a function of the semi-major axis), and to built the models of the galaxies in order to find the residual maps subtracting the model from the original images. Ellipses with fixed centre were used to obtain the brightness profile and then we fitted it through the composition of two models, one for the bulge and the other for the disk. Concerning the first method we gave only an approximate classification, whether the galaxy is an elliptical or a spiral, with or without a bar. With the residuals method, peculiar structures become evident, obviously the results depended on the quality of the model. Finally, from the brightness profile analysis it was not possible to reproduce bars or other peculiar structures because the models we built were based on two components: bulge and disk.

With the first method, we found a well defined trend, with sometimes some variations, both in ellipticity and position angle up to 40 arcsec from the centre. In NGC2841 the variations affect the centre coordinates too. In the case of M85, we found a variation of the centre coordinates and ellipticity between 50 and 60 arcsec, where the position angle shows a regular trend. This could be due to a not corrected determination of the ellipses. If we remove these points, the trend becomes regular for all the parameters excluding the inner parts of the galaxy (< 10 arcsec), where a variation in position angle and ellipticity is however seen. Finally, M85 is an S type galaxy with probably inner substructures. The presence of substructures, on the other hand, is clear in the other three objects, therefore we can conclude that the morphological type is S. The residual images show substructures indicative of spiral arms in all the objects but M85. In this case, the residuals show a cross shape feature, typical of elliptical galaxies, although it appears weakly distorted like spiral arms, indicating that the morphological type could be intermediate between E and S (an S0), but the presence of a disk is undoubted. Furthermore, the residuals of NGC2336

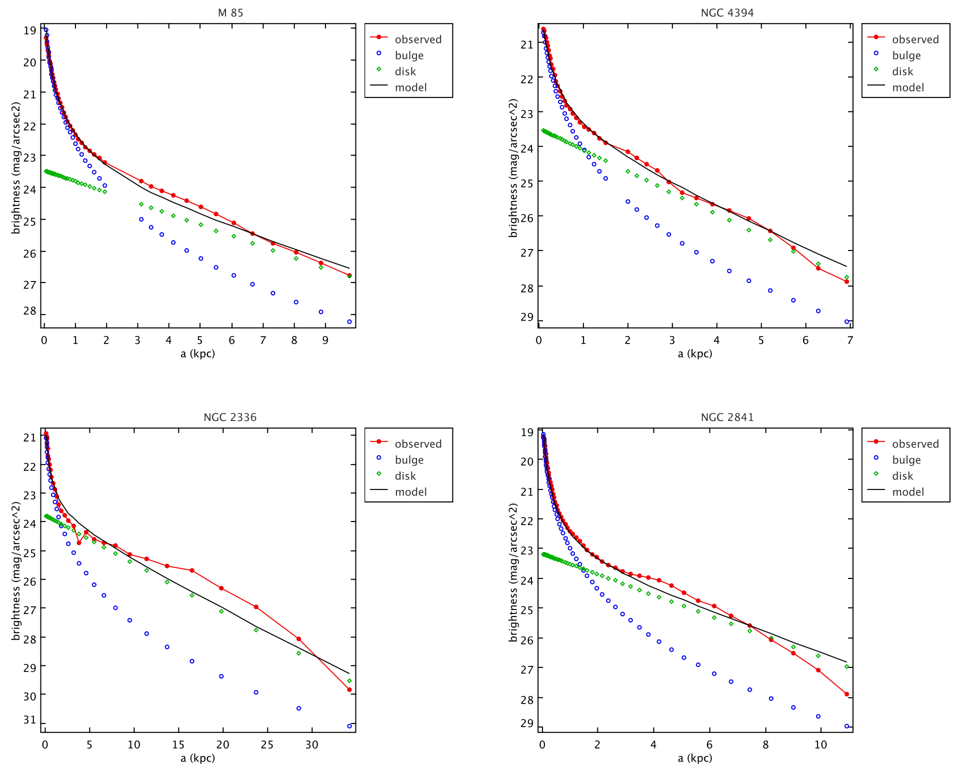

Fig. 7. For each galaxy are indicated: the brightness profile, mag/arcsec^2 (*dotted-solid-red line*, the isophotes were approximated by ellipses with fixed centre); the bulge (*blue circles*) and disk (*green diamonds*) model profiles, and the composition of both models (*black-solid line*) versus the major semi-axes, in kpc.

Table 6. Classification results

Object	methods			SIMBAD
	1	2	3	
NGC2336	S	SB	Sc	SBc
NGC2841	S	S	Sb	Sb
M85	S	E/S	Sa	S0
NGC4394	S	SB	Sb	SBb

and NGC4294 show a clear evidence of bars. Finally, from the brightness profile we confirmed the S type for all the galaxies.

As final step, we compared our results with the official data (SIMBAD). The results are summarized in Table 6. Concerning NGC2336, NGC2841 and NGC4394, our findings are in agreement with the published morphological types. M85 is classified as an S0 galaxy. With the third method we obtained a later morphological type, Sa, which means that the disk component was overestimated. This could be due to an incorrect model used to fit the profiles, in fact we applied only the de Vaucouleurs' law. The presence of possible substructures in the inner parts of the galaxy pointed out with the first method could be real, because this galaxy is a product of a recent merger (Lauer et al., 2005).

References

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