Multicolour photometry of edge-on and box/peanut galaxies

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Abstract. We report the main results of the joint Bulgarian-German project for photometry of edge-on galaxies suspected to have box/peanut structures. CCD images for 30 such galaxies were taken with the 2_m (24 galaxies) and 60_cm (17 galaxies) telescopes as follows: (U), B, V, R, I CCD frames from the 2_m RCC telescope at the Rozhen Observatory with typical resolution 12"/mm = 0.62"/pix with binning and rarely 0.31"/pix, CCD camera "Photometrics" and (B), V, R, I frames on the 60_cm telescope at the Belogradchik Observatory with typical resolution of 27.5"/mm = 0.78"/pix with 3x binning, CCD camera ST–8. Standard stars in selected clusters (M 92, NGC 7790 or M 67), bias, dark and flat field frames were taken every night to calibrate the observations. Typical exposure times were from 2 to 5 min, so the bulge/disk regions were clear presented. All of the objects, observed in the optics, were reduced and classified in an uniform manner. Five galaxies from the list have been reclassified as box/peanut ones. Surface photometry of NGC 5610 and isophote maps of 16 other box/peanut galaxies are presented here. The observations and photometry data are a part of the Bulgarian Virtual Observatory.
Key words: galaxies: box and peanuts, bars, surface photometry, X–structure

Introduction

Investigations of the edge-on disk galaxies are very important to understand the formation, ages, structure and evolutions of the galaxy nucleus and the galaxies itself. New statistical data give evidence that about 50 % from the edge-on disk galaxies exhibit "box/peanut bulges". The nature of these box/peanut structures, still not entirely clear, could be examined using multicolour CCD observations. The main goal is to check the mechanism of formation of these structures - accreting matter from nearby galaxies, internal instabilities in the bulges or combination of the reasons above. Clear shapes of the box/peanut structures could give us an additional evidences to check the evolution steps toward Hubble sequence – from SA to SB or from Sd to S0/Sa galaxies.

After first work of Dettmar (1989) a lot of significant correlations between magnitudes, morphological types, inclination, luminosities etc. were found and many typical X-structures were demonstrated to show the distribution of the stars in box/peanut bulges. The aim of the project was to get additional observational material for galaxies with box/peanut structures with better spatial resolution and to check some bulges under question concerning visibility of box/peanut characteristics. It is very important to look for traces of mergering or accreting from nearby satellite galaxies - practically no one galaxy without satellite contains box/peanut structure and vice versa.

A classification for bulges of a complete sample of 1350 edge-on disk galaxies derived from the RC3 (de Vaucouleurs et al., 1991) has been published in Luetticke et al., (2000). As Aronica et al., (2004) show, "...in the context of spiral galaxy evolution the understanding of bulge formation processes are of central importance. Hierarchical galaxy formation theories describe the bulge formation by collapse of a primordial gas cloud into clumps and a subsequent merging of these clumps. The disk forms after this process. Secular evolution of the disk is suggested as an alternative or additional scenario for bulge formation and evolution. The frequently observed box/peanut (B/P) shaped bulges in edge-on galaxies are supposed to be related to secular evolution effects in barred galaxies...". The close connection of bars and the b/p shape of bulges is observationally supported by the work of Bureau & Freeman (1999). Later on "the boxy and peanut-shaped bulges are bars viewed edge-on ..." have been confirmed by other authors too - see e.g. Bureau et al. (2006).

Vergani (2003) shows that the rate of bars in galaxies indicates the hybrid scenario as likely formation mechanism for thick box/peanut bulges: Interactions excite the development of a bar in a disk as a response to the perturbation of a companion, the light distribution reshapes into a boxy/peanut structure due to buckling.

Athanassoula (2008) reviewes two types of "bulges", the boxy/peanut bulges (B/P) and the discy bulges. The B/P bulges "... are *parts* of bars seen edge-on, have their origin in vertical instabilities of the disc and are somewhat shorter in extent than bars. Their stellar population is similar to that of the inner part of the disc from which they formed... The properties of the B/P correlate strongly with those of the bar: stronger bars have stronger peanuts, a more flat-topped vertical density distribution and have experienced more bucklings...". He concludes "...it is thus clear that classical bulges, B/P bulges and discy bulges are three distinct classes of objects and that lumping them together can lead to confusion. To avoid this, the two latter could be called B/P features and inner discs, respectively....".

Martinez-Valpuesta (2010) shows that barred galaxies represent more than 2/3 among disk galaxies. The evolution of barred galaxies is deeply influenced by the dynamics of the bar. Moreover, the evolution of the bar itself determines the morphology of the rest of the galaxy. Using numerical simulations "how the morphology of the bar changes with time to form a peanut/boxy shaped bulge and how these bulges are related to the bar itself in the edge-on galaxies" have been demonstrated.

1 Observations and data reduction

The observations were planned in two stages:

1. Taking CCD images for ca. 30 edge–on galaxies – with and without box/peanut structures to check the validity of classifications based on the Palomar Observatory Sky Survey and checking the prominence of X-structure in different colours
2. Taking deep two colour frames of selected box/peanut galaxies for detailed study of their bulges

To solve the first the above mentioned problems following observational data were collected:

1. (U), B, V, R, I CCD frames at the 2-m RCC telescope on Rozhen observatory with typical resolution 12"/mm = 0.62"/pix with binning and rarely 0.31"/pix without binning , CCD camera "Photometrics" for 24 objects:
   - box/peanut galaxies type 1-3 - i.e. real box/peanut structures NGC 493, 669, 684, 1589, 2424, 5403, 5470, 5673, 5854 - 9 objects
   - Control sample of non box/peanut galaxies NGC 1032, 2549, 5014, 5610, 5707, 6368, 6504, 6928, 7013, IC 4263 and UGC 8085, 9389, 10214, 10227, 11571 – 15 objects.

i4263r -35,-35:35,35 20.6:22.8:0.2 i4263v -60,-60:60,60 21.1:23.8:0.25	n5470r -40,-40:40,40 21.4:23.8:0.2 n5470v -40,-40:40,40 22:23.8:0.2	n684r -34,-34:34,34 17.6:21.2:0.2 n684v -34,-34:34,34 18.3:20.9:0.2
n1032r -60,-60:60,60 16:23.4:0.25 n1032v -60,-60:60,60 16:23.4:0.25	n5610r -40,-40:40,40 19.6:23:0.15 n5610v -40,-40:40,40 19.5:23.4:0.15	n6928r -52,-52:52,52 17.7:23.2:0.25 n6928v -52,-52:52,52 18.2:23.8:0.25
n1589r -20,-20:20,20 19.3:22.3:0.2 n1589v -20,-20:20,20 9.5:21.6:0.25	n5673r -89,-89:89,89 17.2:23.4:0.25 n5673v -89,-89:89,89 17.2:23.8:0.25	n7013r -20,-20:20,20 16.8:20:0.1 n7013v -20,-20:20,20 17.2:20:0.1
n2424r -70,-70:70,70 18:22.8:0.25 n2424v -70,-70:70,70 18.6:22.8:0.25	n5707r -62,-62:62,62 17.7:23.8:0.25 n5707v -62,-62:62,62 18.3:24:0.25	u10214r -50,-50:50,50 19.2:23.4:0.25 u10214v -50,-50:50,50 19.8:23.8:0.25
n2549r -50,-50:50,50 16.3:22.4:0.2 n2549v -50,-50:50,50 16.9:22.4:0.2	n5854r -40,-40:40,40 18.4:23.8:0.2 n5854v -40,-40:40,40 19:23.8:0.2	u10227r -65,-65:65,65 19.5:23.6:0.25 u10227v -65,-65:65,65 20.1:23.8:0.25
n493r -50,-50:50,50 20.2:23.4:0.15	n6368r -35,-35:35,35 17.9:23.4:0.15 n6368v -35,-35:35,35 18.9:23.4:0.15	u11571r -54,-54:54,54 19:22.8:0.15 u11571v -54,-54:54,54 19.4:23.8:0.15
n5014r -39,-39:39,39 18.7:23.8:0.25 n5014v -39,-39:39,39 19.2:23.8:0.25	n6504r -40,-40:40,40 14:21.2:0.25 n6504v -58,-58:58,58 14.2:21.4:0.25	u8085r -46,-46:46,46 20.9:23.8:0.2 u8085v -46,-46:46,46 21.4:23.8:0.2
n5403r -50,-50:50,50 20.7:23.6:0.15 n5403v -50,-50:50,50 21.6:23.6:0.15	n669r -38,-38:38,38 16:21:0.2 n669v -38,-38:38,38 19.3:21.6:0.2	u9389r -48,-48:48,48 20.5:23.4:0.15 u9389v -48,-48:48,48 20.5:23.4:0.15

Fig. 1. Surface photometry results from Rozhen observations

ic34r -50,-50:50,50 17.6:20.5:0.1 ic34v -50,-50:50,50 20:21.6:0.1	n2549r -50,-50:50,50 16.6:21.8:0.2 n2549v -50,-50:50,50 18.4:23.2:0.2	n7013r -60,-60:60,60 17.4:21.6:0.15 n7013v -60,-60:60,60 19.6:23.2:0.15
ic4263r -50,-50:50,50 17.2:23:0.25	n493r -70,-70:70,70 20.8:24.2:0.15	n7817r -65,-65:65,65 18.9:22:0.2 n7817v -65,-65:65,65 20.5:23.4:0.2
n1032r -60,-60:60,60 18.1:22.4:0.15 n1032v -60,-60:60,60 19.1:23.2:0.15	n5014r -50,-50:50,50 18.6:21.6:0.25	u11571r -45,-45:45,45 19.8:22.3:0.15 u11571v -45,-45:45,45 21.8:23.8:0.15
n128v -65,-65:65,65 19.8:23.4:0.2	n5610r -34,-34:34,34 19.2:22:0.2 5 n5610v -34,-34:34,34 21.3:23.8:0.15	u260r -50,-50:50,50 19.8:22:0.2 u260v -50,-50:50,50 21.8:23.4:0.2
n1589r -50,-50:50,50 17.8:21.8:0.15 n1589v -50,-50:50,50 19.8:23.4:0.15	n676r -60,-60:60,60 15.2:21.6:0.25 n676v -60,-60:60,60 17:24:0.4 2	u8085r -25,-25:25,25 20.4:21.5:0.1 u8085v -25,-25:25,25 22.4:23.3:0.1
n2424r -40,-40:40,40 18.2:20.5:0.15 n2424v -40,-40:40,40 20.2:23.4:0.2	n684r -70,-70:70,70 17.7:21.8:0.2 n684v -70,-70:70,70 19.4:23:0.2	

Fig. 2. Surface photometry of B/P galaxies from Belogradchik observations

2. (B), V, R, I – frames at the 60_cm telescope on Belogradchik observatory with typical resolution of 27.5"/mm = 0.78"/px with 3x binning, CCD camera ST–8 for 17 objects:

- box/peanut galaxies – NGC 128, 493, 676, 684, 1589, 2424 and UGC 260 – 7 objects.
- Control sample NGC 1032, 2549, 5610, 6928, 7013, 7817, IC 34, 4263, UGC 8085, 11571 – 10 objects

Second topic of our investigations was the detailed study of deep two color frames of selected box/peanut galaxies. For this we observed:

- 6 objects in B and R colors on the 1.23 m telescope at Calar Alto, Spain with typical exposures 25 and 15 minutes respectively - NGC 2424, 4013, 4710, 4845, 5529 and 5965 and the spatial resolution of 20"/mm = 0.50"/px and these and 6 more objects – NGC 3079, 5073, 5746, MGC 12526, MCG 13371 and MCG 13513 in the near infrared H and K with the MAGIC camera (Aronica & Petrov, 2001).
- 6 more objects on the 2-m telescope of Rozhen Observatory with typical exposures 25 and 15 minutes in B and R color respectively and spatial resolution of 12"/mm = 0.31"/px – NGC 128, 532, 973, 1175, 7640 and UGC 11973. The last two of them are FIR sources according to IRAS Point Source Catalog.

Every night we got the standards in selected clusters - M92, NGC 7790 or M67 and bias, dark and flat field frames to calibrate our observations. Typical exposure times for these observations were 2 to 5 min, so the bulge/disk regions are clear visible at the limiting surface brightness for the Belogradchik sky, about 23 $mag/arsec^2$ and for Rozhen sky, about 25 $mag/arcsec^2$ (in V-band).

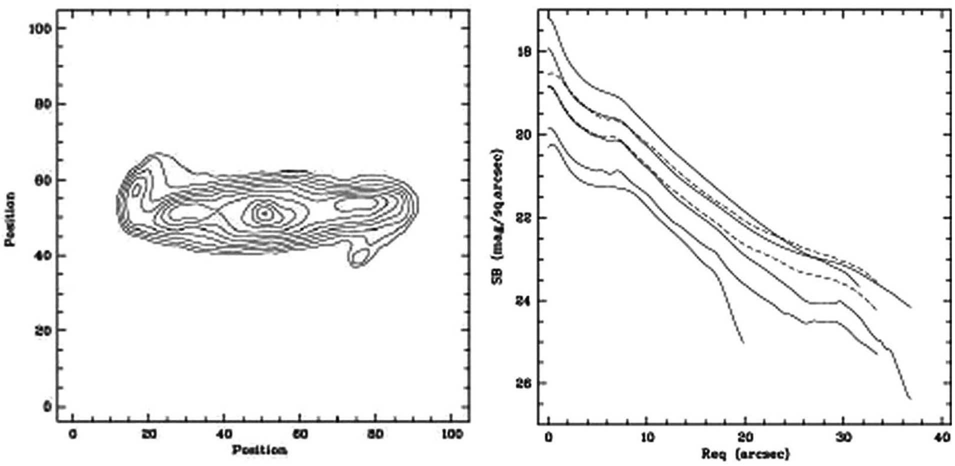

Fig. 3. Surface photometry of NGC 5610 B/P galaxy (Petrov et al., 2005)

All of the frames we got were reduced in the following manner:

1. Bias and Flat frames for the 2_m telescope, as well as Dark and Flat frames for the 60_cm telescope data

2. Removal of the cosmic ray events from the frames
3. Aligning of the images to get AVERAGED from several exposures frames for each color
4. Normalizing the data to the local sky background
5. Transformation of pixels in arcseconds to have real images
6. Determining the night sky brightness, using the observed standards
7. Calibration of the images in $mag/arcsec^2$
8. Getting the characteristics of bulge/disk regions to prove X–structures – i.e. box/peanut bulges in each colour

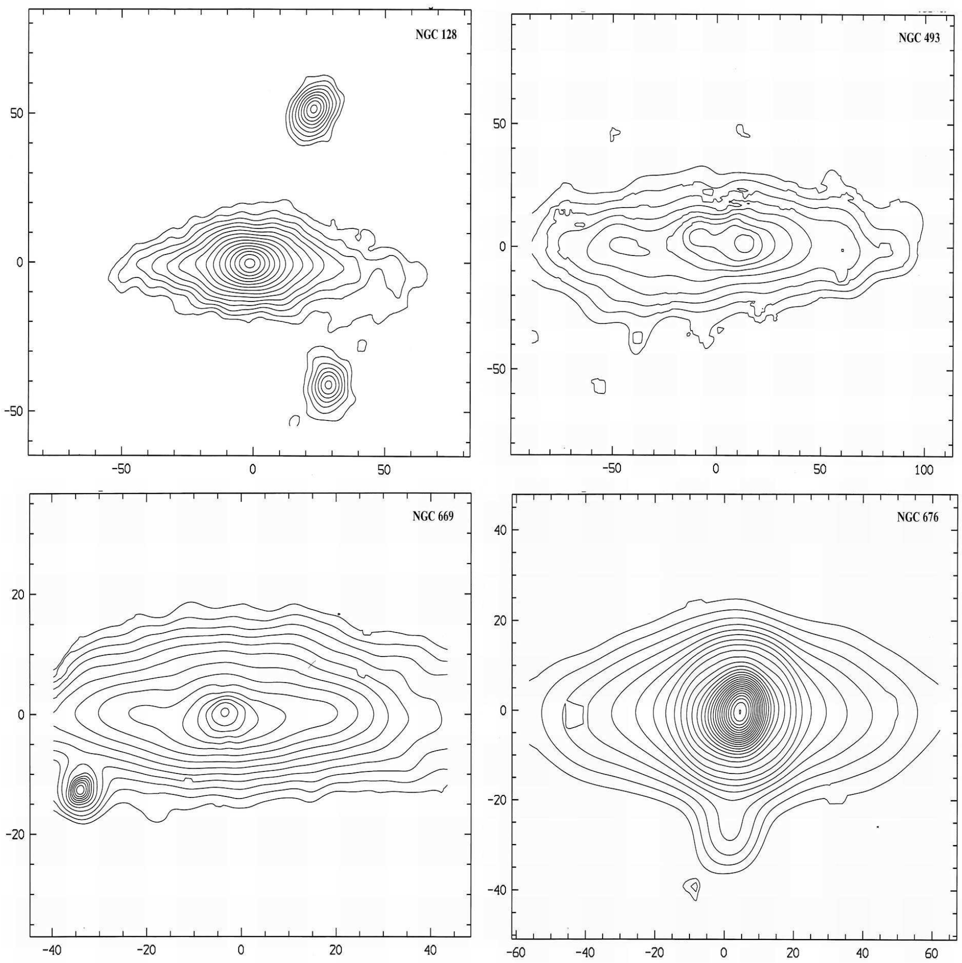

Fig. 4. Isophote maps of the B/P galaxies NGC 128, NGC 493, NGC 669 and NGC 676

For all observed and reduced images distribution of the surface brightness was examined using MIDAS reduction package. The results from Rozhen observations are presented in Table 1 (Fig.1). The results from Belogradchik observations are presented in Table 2 (Fig.2). Details for all the observations may be found in Petrov (2008).

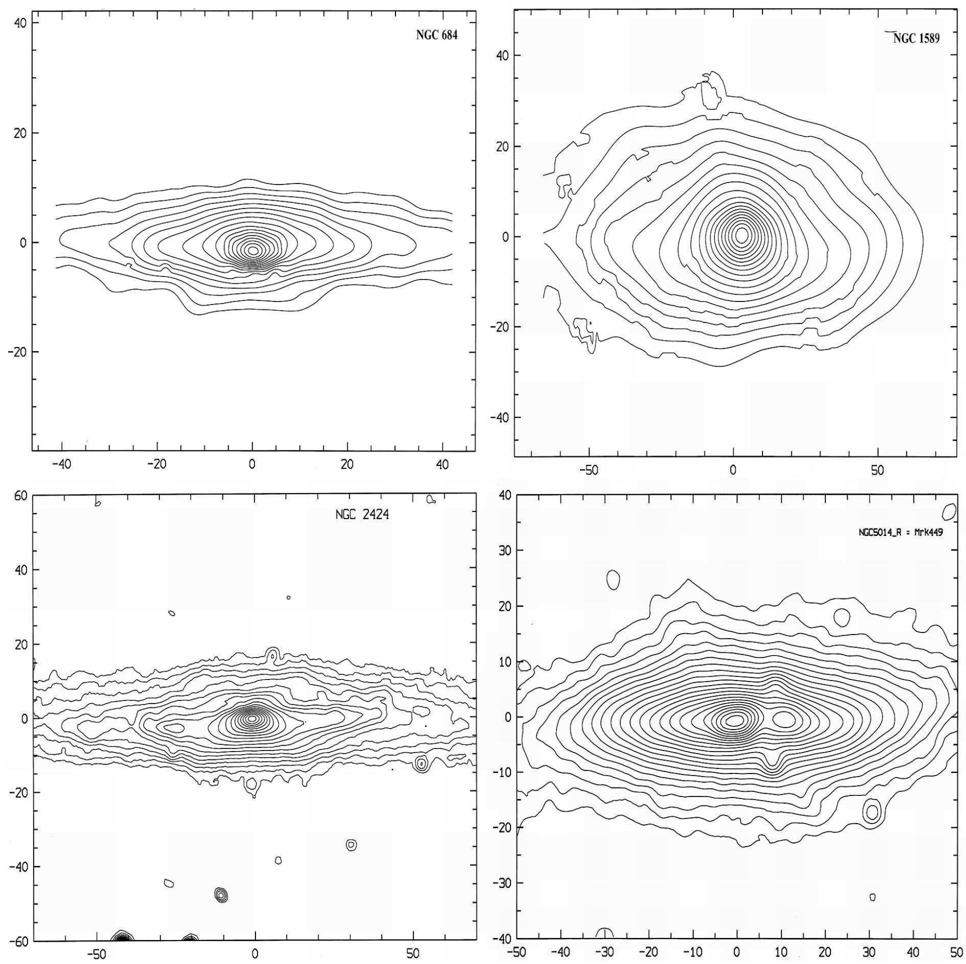

Fig. 5. Isophote maps of the B/P galaxies NGC 684, NGC 1589, NGC 2424 and NGC 5014

2 Basic results from these observations

Below we present the basic results from the study of box/peanut galaxies:

1. About 25 % of the edge–on galaxies, classified from Luetticke (1999) as type 4 and 5, i.e, non box/peanut, but ellipsoidal or unclassified, in fact belong to the type 3 box/peanut bulges. Among the listed above these are NGC 5014, 5610, 6368, UGC 8085 and 9389.

2. We report NGC 5610 as a new case of an intermediately inclined barred spiral galaxy with a peanut shaped bulge (Petrov et al., 2005). The ellipticity and the position angle of this galaxy, measured at the isophote at 25 B_mag/sq.arcsec, are 0.67±0.02 and 99.7±1.1 degree, respectively. The galaxy inclination estimated from the ellipticity is 70.7±1.2 degree. The weight–averaged bar length, ellipticity and position angle are 17.3±0.5 arcsec (or 5661.7±162.3 pc), 0.83±0.01 and 92.1±0.6 degree, respectively. Laurikainen et al. (2011) showed "... boxy/peanut/x-shaped structures are identified in many barred galaxies, even though the galaxies are not seen edge-on, indicating that vertical thickening is not enough to explain these structures..." — Fig.3.

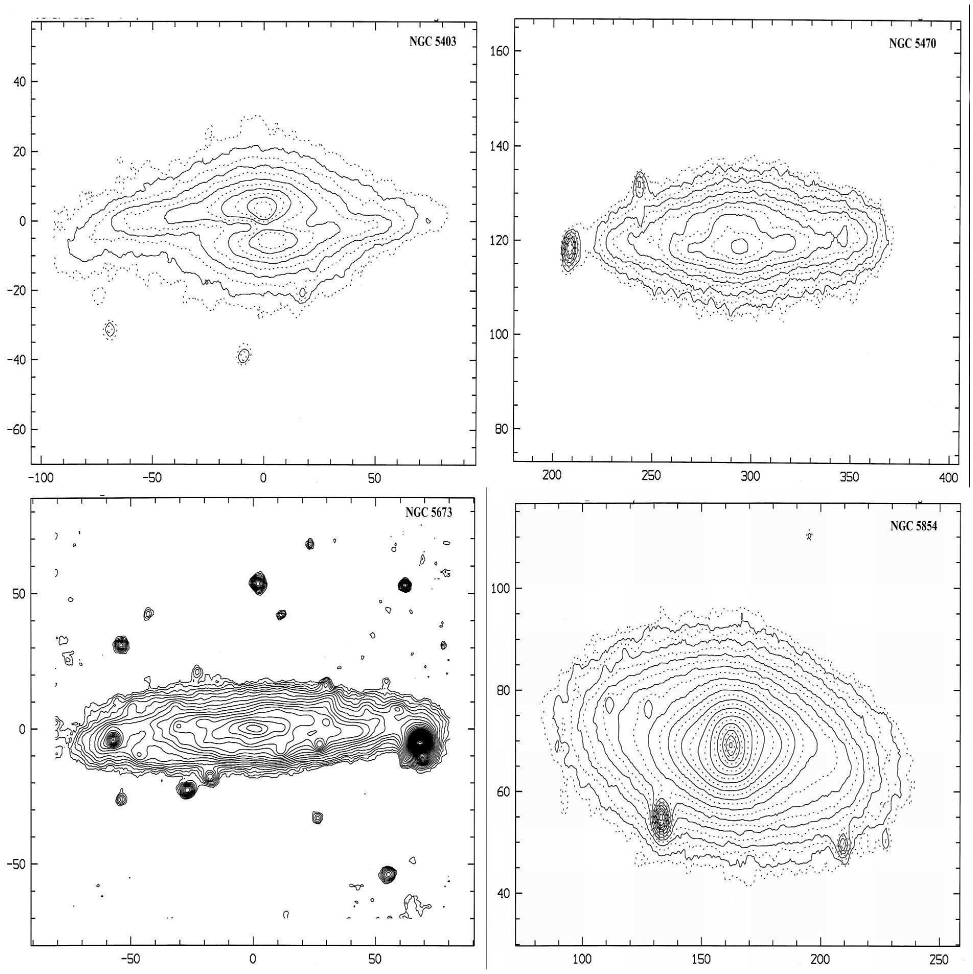

Fig. 6. Isophote maps of the B/P galaxies NGC 5403, NGC 5470, NGC 5673 and NGC 5854

3. There is no significant difference in the bulge/disk shapes in the different colours, so, it is enough for detailed study to use e.g. B and R images.

Conclusions

All the data and results were combined in the common database of the Department Galaxies and Cosmology of the Institute of Astronomy, Bulgarian Academy of Sciences. Data are presented in FITS format and two sets of data are available -– raw data, including flat field images and calibrating images too and reduced data.

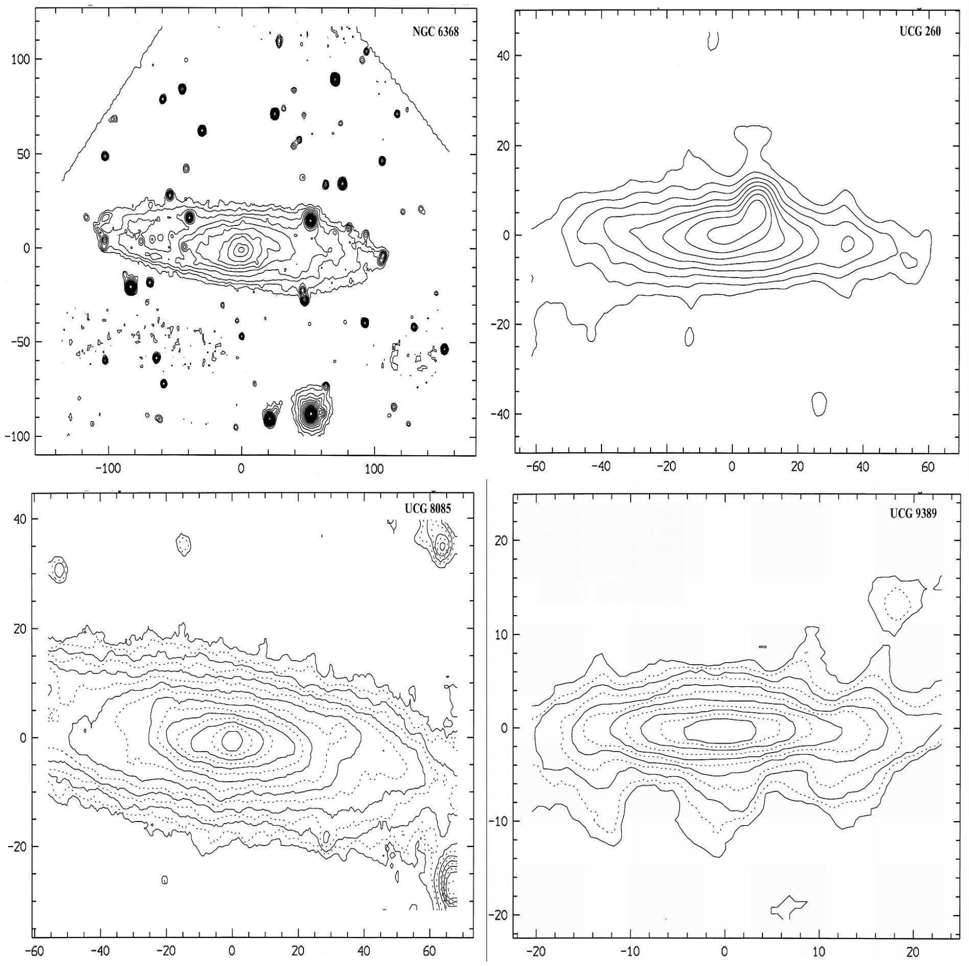

Fig. 7. Isophote maps of the B/P galaxies NGC 6368, UGC 260, UGC 8085 and UGC 9389

We presented in 4 figures the results from the surface photometry as isophote maps of all B/P galaxies studied :

Fig.4 shows the galaxies NGC 128, 493, 669 and 676.

In the Fig.5 results from the surface photometry of galaxies NGC 684, 1589, 2424 and 5014 are presented.

Fig.6 presents the surface photometry for the galaxies NGC 5403, 5470, 5673 and 5854.

The results from the surface photometry of galaxies NGC 6368, UGC 260, 8085 and 9389 are presented In the last Fig.7.

Galaxies NGC 5014, 5610, 6368, UGC 8085 and 9389 have type 3 box/peanut bulges .

There is no significant difference in the bulge/disk shapes in the different colours.

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