Annuaire de l'Université "St. Kliment Ohridski", Faculté de Physique, 99, 2006

SURFACE PHOTOMETRY OF 3 EARLY-TYPE GALAXIES IN THE VIRGO CLUSTER

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Надя Драганова, Филип Прюние. ПОВЪРХНОСТНА ФОТОМЕТРИЯ НА 3 ГАЛАКТИКИ ОТ РАНЕН ТИП В КУПА VIRGO

Представени са морфологичните изследвания на 3 галактики от ранен тип в купа Virgo с прилагане на методи на повърхностна фотометрия. Потвърдено е наличието на спирална структура в околоядрената област на IC 783 (с бар?) и IC 3328. Получено е наблюдателно свидетелство за съществуването на спирална структура и в IC 3653, досега класифицирана като елиптична галактика.

Nadia Draganova, Philippe Prugniel. SURFACE PHOTOMETRY OF 3 EARLY-TYPE GALAXIES IN VIRGO CLUSTER

Morphological research of 3 early-type galaxies in the Virgo cluster is presented. It is performed using methods of surface photometry. The existence of a spiral structure in IC 783 (with a bar?) and IC 3328 is confirmed. Observational evidence for a spiral structure is found also in the elliptical galaxy IC 3653.

Keywords: surface photometry, dwarf galaxies, spiral disks
PACS numbers: 95.75.De; 98.52.Wz; 98.65.Cw

1. INTRODUCTION

Contemporary telescopes and their facilities enable detection and photometry of faint extragalactic objects like early type dwarf galaxies. These galaxies are object of intensive research since half a century and their physics is still not enough clarified. Dwarf galaxies are known to exhibit diverse star formation histories: from a single very old episode to a series of bursts over most of the Hubble time. An interesting subgroup are the dwarf ellipticals (dE) which are distinguished from the normal E galaxies by their different morphology and low surface brightness. It is suggested that dEs are very similar to the fragments from which larger galaxies have formed [5]. An insight into the physical processes driving star formation in dEs might shed light on the star formation mechanisms in more massive elliptical galaxies. Another early type dwarf galaxies, introduced by Sandage & Binggeli [9], are the lenticular dwarfs (dS0). Unlike the case with dEs, the photometric profile of dS0s can be sucessfully decomposed into two components (bulge and disk) and there is direct evidence that they possess a disk. Most of the luminous dEs exhibit a well pronounced nucleus; they are classified as dE, N. A faint spiral structure is found in some dE, N galaxies like IC 3328. It lacks dust and prominent HII regions which points at a deficiency of gas [7]; therefore its disky nature is still not proved. As dS0 galaxies possess a disk component, a search for a spiral structure in them is also justified. Hence the interesting question: “Do most (if not all) of the early type dwarf galaxies possess a circumnuclear disk with a spiral structure?”

In the present paper we perform a new search for faint spiral structures in three early type galaxies in the Virgo cluster: IC 3328 (VCC 0856; already mentioned), IC 783 (VCC 0490) and IC 3653 (VCC 1871). We use high quality images taken with the cameras FORS1 at the Very Large Telescope (VLT) and ACS at the Hubble Space Telescope (HST). The distance to IC 783 and IC 3328 is almost the same but they belong to different subgroups in the Virgo cluster [6]. On the other side, IC 3328 and IC 3653 are members of a group dwarf ellipticals with well studied kinematical characteristics. Jerjen et al. (2000) already found a spiral structure in IC 3328 and argue that this galaxy is actually of type dS0 [7]. IC 783 was originally classified as S0 [3, 9]. It was studied for an existence of faint spiral structure and/or bar [2] and a two-arm spiral structure is found in the circumnuclear region $r_{gc} < 20''$. IC 3653 is classified as a normal elliptical galaxy [4, SP] but resembles IC 3328 in its kinematical characteristics; it has high central velocity dispersion [8]. Binggeli&Cameron suggest that all luminous dwarf ellipticals are fast rotators

and disk systems [3]. However, there is no evidences up to date for an existence of disk in IC 3653. Some general data on the chosen galaxies are given in Table 1.

Table 1. General data on the chosen galaxies in the Virgo cluster

Galaxy	RA (J2000)	DEC (J2000)	Type	*B*	Data		
					FORS1	ACS (WFC)	
				[mag]	*R*	F850LP	F475W
IC783	12:21:38.78	+15:44:42.7	dS0, N	14.60	yes	–	–
IC3328	12:25:57.81	+10:03:12.8	dE,N	14.25	yes	yes	yes
IC3653	12:41:15.72	+11:23:13.5	E3	14.80	–	yes	yes

2. SURFACE PHOTOMETRY

2.1. OBSERVATIONAL DATA

The sample images from the FORS1 archive have been taken in 1999 and 2000, in the red broadband filter R, with typical resolution of 0″.2 per pixel. We processed them preliminary to remove the bias and to perform a flat field correction. The ACS images do not need such processing and are downloaded from the Virgo Cluster Catalog (VCC). They have been taken with the Wide Field Channel (WFC) which allows an image scale of 0″.05 per pixel. The used broadband filters F475W (g´) and F850LP (z´) correspond respectively to B and I in the UBVRI system.

2.2. TECHNIQUES AND SOFTWARE

We apply to the chosen images two classical methods of surface photometry: unsharp masking and isophote modelling. Unsharp masking is especially useful when the background field around the galaxy is (relatively) bright. The other method is appropriate for E and S0 galaxies since their isophotes can be fitted by ellipses. However, in the case of dwarf galaxies, certain difficulties arise at faint surface brightness levels as noise becomes dominant and makes the isophotal contours very irregular and broad. Therefore we apply a modification of isophote modelling, called ‘moment analysis’[8]. The s^{th} order central moment of a fitting ellipse is defined as:

$$M_{pq} = \sum_{i,j} x_i^p y_j^q,$$

where (x_i, y_i) are the sample points, p, q are positive integers and $p + q = s$.

In the moment analysis method the zeroth (M_{00}), first (M_{10}, M_{01}) and second (M_{20}, M_{02}, M_{11}) central moments are used to calculate the equivalent radius r_n^* of the n^{th} isophotal level, the position of the center (x_c, y_c), the position angle q of the major axis and the axis ratio *b/a(n)*:

$$r_n^* = \sqrt{M_0(n)/\pi},$$

$$x_c \frac{M_x}{M_0}, \quad y_c = \frac{M_y}{M_0},$$

$$\sin\left(2\theta(n)\right) = 2\frac{M_{xy}^*(n)}{D(n)},$$

$$\frac{b}{a(n)} = \sqrt{\frac{T_r(n) - D(n)}{T_r(n) + D(n)}},$$

where

$$T_r(n) = M_{xx}^*(n) + M_{yy}^*(n),$$

$$D(n) = \sqrt{\left(M_{xx}^*(n) - M_{yy}^*(n)\right)^2 + 4\left(M_{xy}^*(n)\right)^2}.$$

The second order moments allow another, independent estimate of the ellipse area to be obtained. Thus the comparison between it and the one derived from M_{00} is a test for deviation from ellipticity. The diagnostic parameter is:

$$t(n) = \frac{2\left[\left(M_{xx}^*(n) M_{yy}^*(n)\right)^2 - M_{xy}^*(n)^2\right]^{1/4}}{r_n^*} - 1.$$

For perfect ellipses we have $t = 0$.

The surface photometry methods are implemented within the program package *pleinpot*, developed at the Observatory of Lyon. We use its recent version that can be downloaded from: http://leda.univ-lyon1.fr/pleinpot/pleinpot.html. Bright foreground (background) objects were preliminary masked.

3. RESULTS AND DISCUSSION

3.1. IC 783

The existence of a prominent disk and spiral structure in this galaxy have been surmised earlier (e.g. [1]). After unsharp masking of the FORS1 image (Fig. 1; upper right panel), we confirm the existence of a spiral structure. The

arms are not well pronounced and almost vanish at larger galactocentric distances. It is unclear where do they exactly begin; a ring-like pattern is observed. The conjecture for an inner ring in IC 783 was raised by Barazza *et al.* [2]; however, their result might be interpreted also as an evidence for existence of a bar.

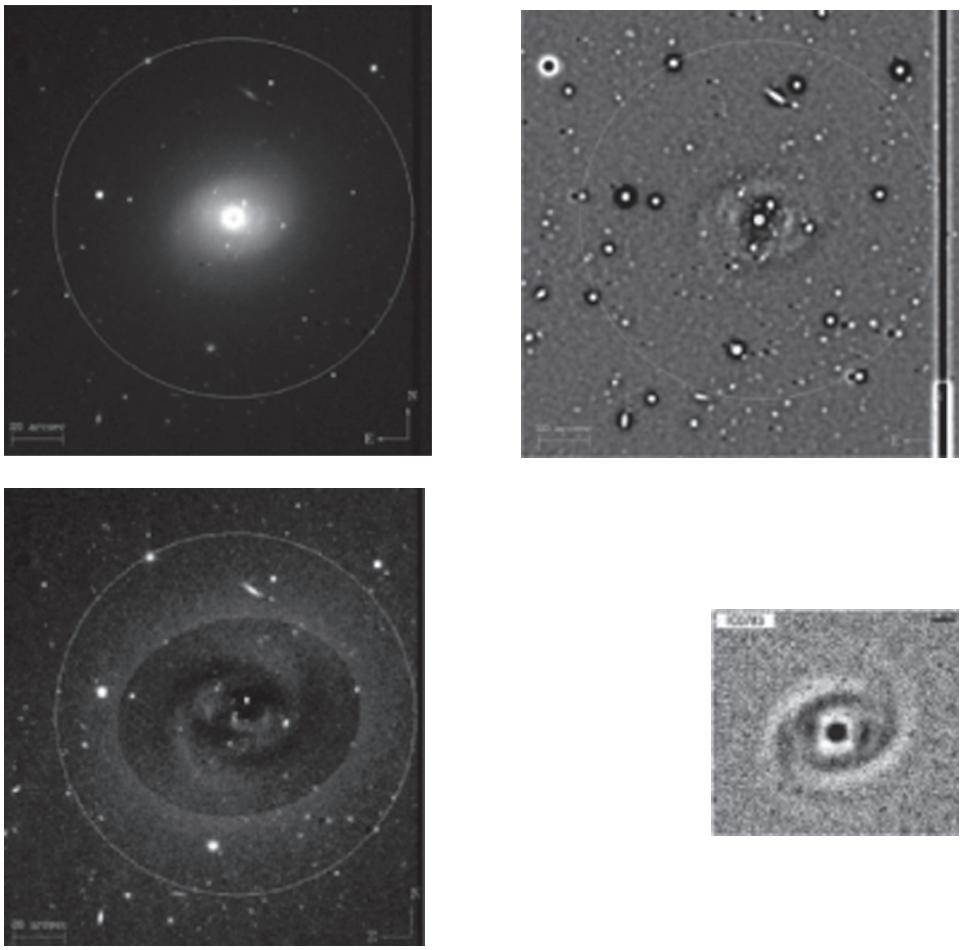

Fig. 1. Images of IC 783 in band R: original image (top left), unsharp masking by [2] and our results–unsharp masking (top right) and isophote modelling (bottom left) with fixed e, θ.

In the moment analysis method, the ellipticity e and the positional angle q are free parameters by default. (Their typical behaviour is illustrated in Fig. 2.) This approach does not produce a clear picture of IC 783. The reason

might be a more complex central structure, especially if it is not axisymmetric (bar-like). In that case the mean positional angles of the bar and of the the spiral arms could be essentially different in the region of overlapping. Indeed, the values of θ vary significantly in the region $r_{gc} \leq 5''$ (Fig. 2). Two groups with mean values ~130 and ~100 are distinguished. On the other side, ellipticity in the central region varies with a mean value of ~ 0.90 that decreases slowly toward the periphery.

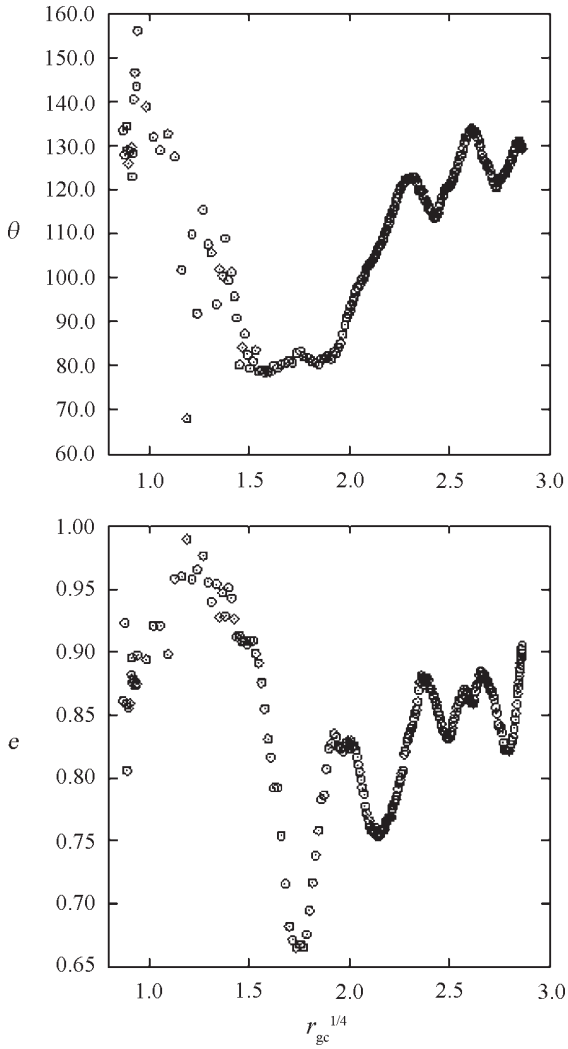

Fig. 2. Isophote modelling of IC 783 image: varying e and θ

Isophote modelling with fixed e = 0.80 and θ = 100.0, close to the mean values for the outer regions and for the galaxy as a whole, gives a result, shown in Fig. 1, bottom left. Two spiral arms are notable while the central structure appears to be rather a prolonged bar than a ring. (The black spot in the center is an effect from the method and is not linked with sme physical phenomenon.) Therefore we launched the procedure with fixed e = 0.92 and two values of θ =100.0, 130.0, reflecting the parameters' behaviour in the central region. The result is illustrated in Fig. 3: IC 783 resembles a barred galaxy of type SBb (NGC 1365; right panel).

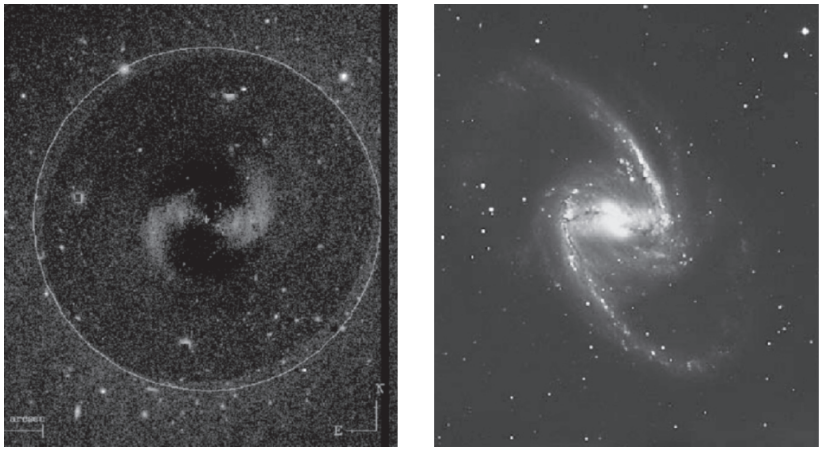

Fig. 3. Bar and spiral structure in IC 783. A typical barred galaxy (NGC 1365) is shown for comparison

3.2. IC 3328

The strongly winded two-arm spiral structure of the galaxy has a diameter of 4.5 *kpc* and is centered in the nucleus (Fig. 4, bottom right). Thus IC 3328 is similar to a lenticular dwarf (dS0). Jerjen *et al*. (2000) speculate that it is actually a dS0 galaxy that was misclassified as dE, N [7]. After unsharp masking, the spiral structure becomes evident and can be traced up to galactocentric distances of ~ 15-20″ (cf. the processed FORS1 image in Fig. 5). Again, as the case with IC 783, the approach of isophote modelling with varying e and q does not produce a clear picture of the spiral pattern. However, in view of the unsharped masked images from FORS1 and ACS, there is no evidence for existence of a complex central structure (bar or ring). Therefore we applied isophote modelling of the F850LP image with fixed ellipticity and positional angle, choosing the values from [7]: e = 0.905,

θ = 82.5, obtained from data in the neighboring photometric band R. Now the spiral structure is much more remarkable and can be traced up to $r_{gc} \geq 20''$. Hence we suggest that the surface brightness distribution in R and F850LP bands is very similar. The spiral arms on the F850LP image (after our isophote modelling) are faint; no specific details are seen close to the nucleus ($r \leq 3''$). A possible explanation can be that such details are associated with HII regions with significant luminosity in Ha, covered by the R passband (in the work [7]). The lack of bright HII regions and dust is evident at larger galactocentric distances which is typical for dE galaxies.

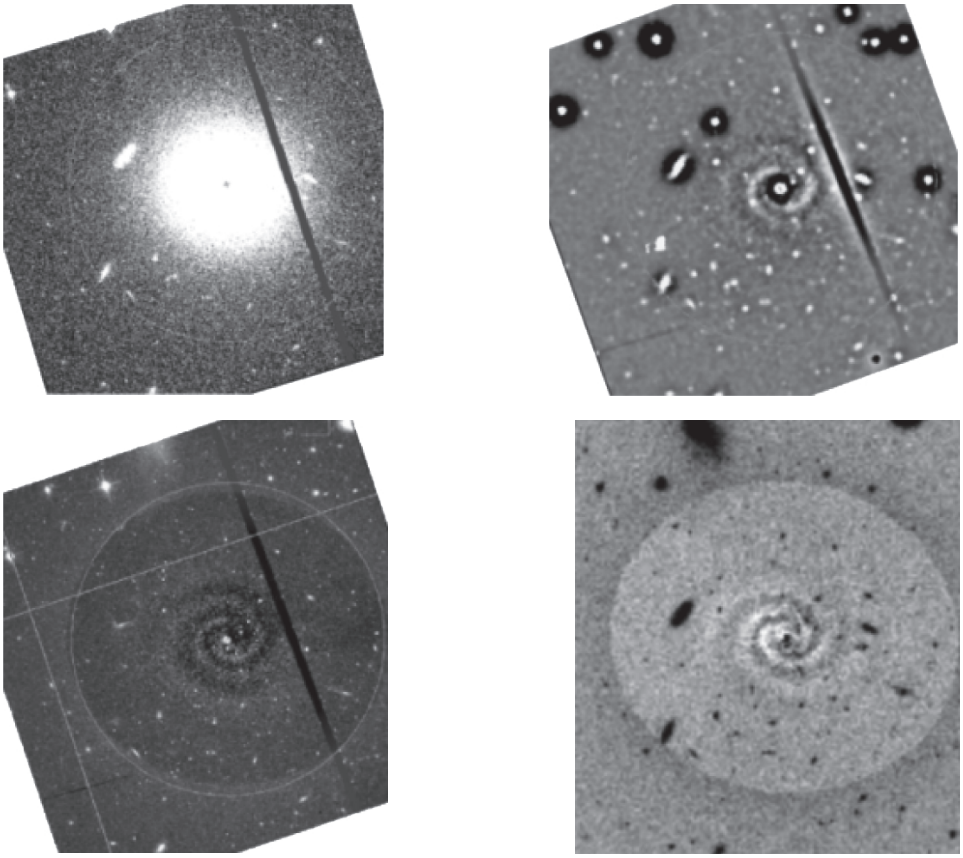

Fig. 4. ACS images of IC 3328 in F850LP band: original image (top left), processed through surface brightness fluctuations (SBF) method by [7] and our results–unsharp masking (top right) and isophote modelling (bottom left) with fixed *e*, θ

The evidence for a spiral structure points to existence of young stellar population with flux maximum in the blue optical band and in the UV. Therefore we used also an image of IC 3328 obtained in the ACS filter F475W. Isophote modelling with varying e and θ or fixed θ =82.5 [7] reveals the spiral structure although not very clearly. The values of the positional angle at different galacto-centric distances r give an essentially different mean value (in comparison with the F850LP image): ~140. This can be a real effect of spatial displacement of the younger arm population in respect to the older and, respectively, effect of a shift of the whole structure, observed in F475W. Fixing θ =140, we obtained through isophote modelling a clear spiral structure (Fig. 6, right panel). Some technical difficulties with masking of foreground (background) objects did not allow us to trace the spiral structure at larger galactocentric distances.

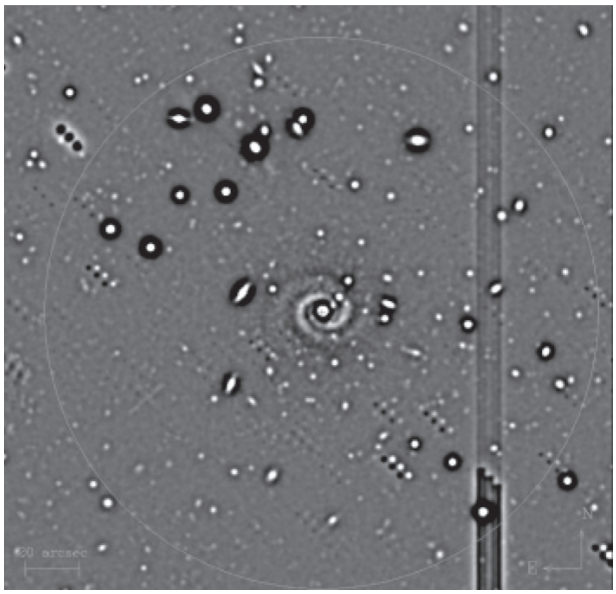

Fig. 5. IC 3328: unsharp masking in photometric band R (FORS1). The image was smoothed additionally

Eventually, the existence of a spiral structure in IC 3328 is confirmed using blue and infrared ACS images. A difference in colors of the origional and output image would show whether this structure is disky or not. This raises again the issue of the (mis)classification of dE galaxies with a disk component.

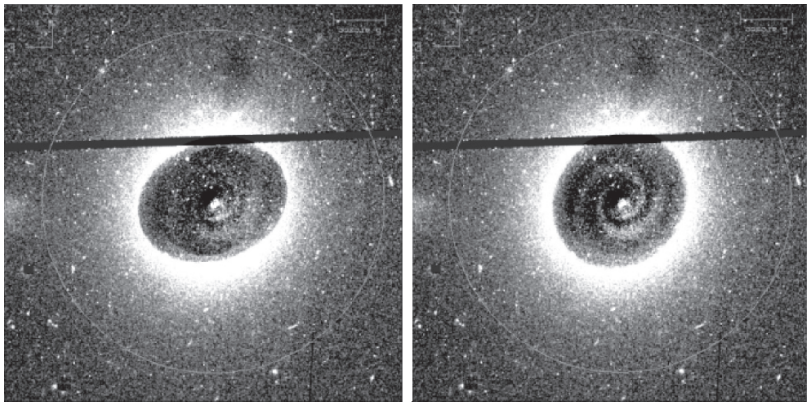

Fig. 6. Isophote modelling of ACS images of IC 3328, obtained in F475W passband: with varying (left) and fixed e and θ (right)

3.3. IC 3653

Although IC 3653 is classified as a galaxy of type E3 [10], it is a typical elliptical dwarf in respect to its morphology and photometric characteristics (cf. Fig. 4 and Fig. 7 (left panel); Table 1). Unsharp masking of its ACS image in F850LP passband gives no evidence for existence of a disk. The result of isophote modelling with fixed (averaged) ellipticity and positional angle is completely different though ambiguous (Fig. 8). A centrally-symmetric pattern of two prolonged bright arms resembles the beginnings of unfolded spiral structure. As in the case with the F475W image of IC 3328, some technical problems did not allow covering of the whole galaxy with the modelled surface brightness distribution. Thus the question about the existence of a spiral disk in IC 3653 remains open. It is unclear as well, where exactly do the spiral arms begin and is there a bar in the circumnuclear region.

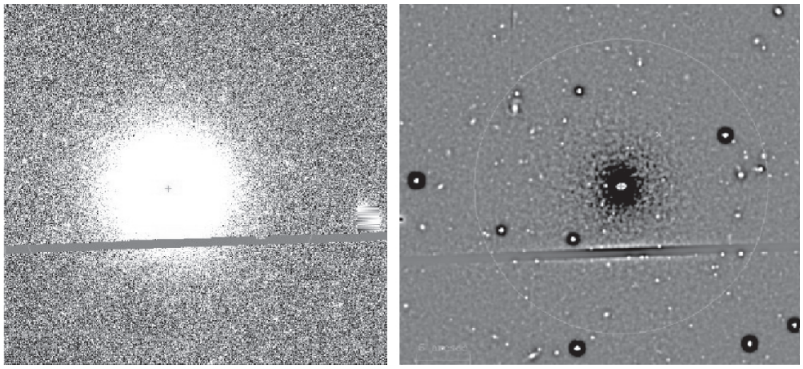

Fig. 7. Images of IC 3653 in F850LP passband: original (left) and after unsharp masking (right)

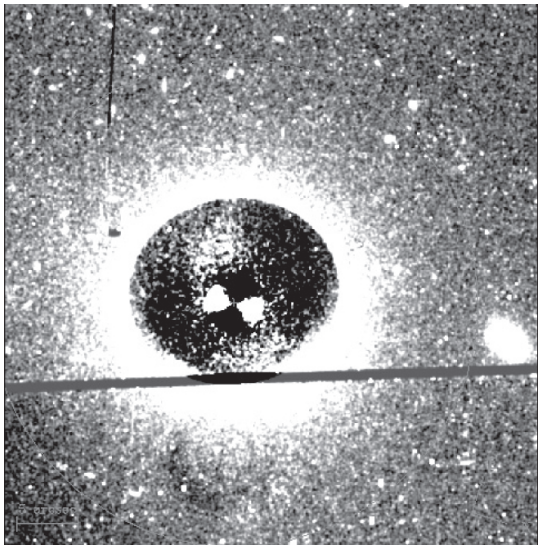

Fig. 8. Evidence for a spiral structure in IC 3653. The isophote modelling was performed with fixed e, θ

4. CONCLUSION

The presented results from surface photometry of 3 early type galaxies in the Virgo cluster lead us to the following conclusions:

- The existence of a spiral structure in IC 783 and IC 3328 is confirmed. For the latter object this is done for first time using an ACS image in blue light (F475W). The disky nature of the spiral structure can be proved by finding out a difference with the color gradient (F475W-F850LP) of the bulge. This would clarify the issue of the (mis)classification of IC 3328 as type dE, N.
- Careful adjusting the isophote modelling parameters produces an image of IC 783 that testifies to the existence of a bar. Further research in other photometric filters would shed light on its nature.
- Observational evidence for the existence of spiral structure in the circumnuclear region of IC 3653 is found. The presence of a bar is possible but has to be confirmed.

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Received December 2005

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