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Color distributions in E-S0 galaxies

III. E-objects with “power-law” or “core-like” central profiles*

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Abstract. Measurements of the central red color peak occurring in E-type galaxies have been obtained from Nieto’s CFHT observations in B and R of 39 objects. A careful equalization of the PSF of the two frames involved in color maps and profiles was crucial in achieving significant results, although still affected by limited resolution. The class of the central light profile, i.e. “core-like” or “power-law”, was also derived.

The well known correlation between the class of central profile and the large scale morphology is somewhat improved. The distributions of central red peak amplitudes are obtained separately for the two classes of central profiles, and shown to be quite different; most objects with a core-like center also have a flat central color profile. The model of Silva & Wise (1996), for the production of broad cores by centrally located diffuse dust, is not supported. This is in agreement with recent HST results by Carollo et al. (1997) from a special subsample of objects with kinematically decoupled cores.

Key words: galaxies: elliptical and lenticular, cD – galaxies: ISM – galaxies: photometry

1. Introduction

Following early findings by Nieto et al. (1991b), recent HST observations by Jaffe et al. (1994) and Lauer et al. (1995) have shown that the central surface brightness (or SuBr) profiles of early-type galaxies can be sorted out in two classes, i.e. “power-law” and “core-like”, to use the terminology of the later authors. These projected profiles translate into a quite striking dichotomy in light density profiles, as calculated by Gebhardt et al. (1996). The two classes of nuclear profiles are correlated with other galactic properties, including luminosities and morphology according to Nieto et al. (1991b): disky E’s (or diE) and S0’s have power law central profiles, while cores are found mostly in bright boxy E’s (boE), or the intermediate class called “irregular” by Bender et al. (1989), and “undeterminate” (unE) by Michard & Marchal (1994). Similarly, power law profiles are found in fast rotators, and cores in slow rotation galaxies. These correlations are summarized in the Fig. 2 of the paper by Lauer et al. (1996).

An obvious question is to explain the two nuclear classes and associated properties, in terms of the formation and subsequent evolution of galaxies. This problem is discussed by Lauer et al. (1996), and in more detail by Faber et al. (1997). For these authors, high luminosity core galaxies result from gas poor mergers, followed by the disruption of the dense nuclei of cannibalized objects; this final step of the low density core formation is accomplished by the “waltz” of black holes from the merged components, as predicted by Ebisaki et al. (1991).

Silva & Wise (1996) have proposed, on the other hand, that core-like profiles might result from a nuclear concentration of diffuse dust, able to suppress the sharp central peak of the power-law profiles. They have modelized in detail this phenomenon, and predict that a strong central red peak will result from such central diffuse dust. Then a correlation is expected between the strength of any observed central red peak and the class of the SuBr profile. It is suggested by Silva & Wilse in the quoted paper that their predictions can be tested from high resolution ground based data, although good color HST observations will obviously be preferred.

The purpose of this paper is to present a new observational test of the predictions due to Silva & Wise, based upon CFHT frames obtained by Nieto and co-workers in 1989-91, with preliminary results given in Nieto et al. (1991a), (1991b). Although the presence of recognizable dust features and patterns complicate the issue, the test is certainly not positive at the present level of accuracy and resolution. The same conclusion has been obtained by Carollo et al. (1997) using HST observations of 15 galaxies with kinematically distinct cores. Although our data is of much lesser resolution, it extends the discussion to a sample of 39 ellipticals representative of a large range of luminosities and morphologies.

2. The data

2.1. Observations and resulting sample

The observations have been mostly obtained at the CFHT in bands B and R (Cousins’s definition). In two runs of December

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1989 and April 1990, the camera was at the Cassegrain focus with a scale of 0.107 arcsec/pixel. Due to the observer's wish to have a PSF star in the field, the attainable radial range is between 10 and 30 arcsec from the galaxian center. In the last two runs of April and June 1991, the so called HRCam at the Prime focus was used, giving practically the same scale and similar limitations in angular range. For these observations, the stellar images have a mean FWHM of 0.72 arcsec in R and 0.83 in B, with σ=0.15 in both colors.

The sample used here has been extracted from the original Nieto's sample by a restriction in distance, with $V_0 < 3000$km/s. There is a rough δ limit at -25 degrees. The Hubble E types have been selected from the Second Reference Catalogue of Bright Galaxies. The magnitude limit is the imprecise one of the Revised Shapley-Ames Catalogue of Galaxies, with a few dwarfs added. Altogether the sample cannot be claimed to be a complete one, but it is fairly representative of the population of ellipticals in the Local Supercluster. The total number of objects studied here is 39, after inclusion of two objects from Pic du Midi observations at circa 1 arcsec resolution.

2.2. The measurements

The isophotal analysis according to Carter's (1978) principles was performed, and the classification in the diE, unE and boE subclasses was obtained. In the many cases were the observed radial range was not adequate, the subclass was taken from Michard & Marchal (1994).

Radial color profiles and 2D maps of the B-R color index were obtained from pairs of calibrated frames with matched PSF's.

The calibration was obtained from aperture photometry by Poulain (1988) and by Poulain and Nieto (1994). For the few galaxies not observed by these authors, miscellaneous sources were used.

The PSF's of corresponding B, R frames were equalized, as well as feasible, by convolving the sharpest one (generally R) by an ad hoc narrow gaussian, or sometimes a sum of two gaussian. *The matching of the PSF's in a color pair is a crucial step if one wishes to obtain significant colors in the seeing affected regions of the images*.

The following parameters have been introduced to summarize the properties of the color distributions:

1. when a pattern of red color features such as lanes, arcs, patches... (or other clear distorsions of the isochromes from the isophotes) was recognized, a "dust pattern importance index", or $DPII$ was estimated, giving a semi-quantitative indication of its extent and contrast in a scale of 0 to 3, with the following steps:
   . 0 no local dust feature detected.
   . 1- faint dust feature, perhaps doubtful.
   . 1 clear dust feature
   . 2 important dust feature
   . 3 outstanding dust feature
   In Paper I of this series (Michard, 1998a) the $DPII$ index has been obtained for a nearly complete sample of 67 ellipticals, using the present Nieto's sample supplemented by litterature data. The frequency and importance of dust patterns for various brands of E-classified galaxies were studied from statistics of this index. It was found that dust is much more frequently detected, and with more important patterns, among diE's than boE's, the unE's beeing intermediate.
2. for galaxies containing a disk, evidence for dust concentration in this disk was sought: the criteria were an asymmetry in light and color along the minor axis, as described for S0's by Michard & Simien (1993). and/or a flattening of the isochromes as compared to the isophotes. In case of positive evidence, the symbol dd for"dust in disk" was introduced.
   In Paper II of this series (Michard, 1998b) the validity of this evidence was discussed, and it was documented for a number of objects of high enough inclination, both the diE proper and other objects containing an inner "decoupled" disk (Nieto et al. , 1991a). The addition of the dd symbol still increases the proportion of disky galaxies with detected dust. In some cases, like NGC5322 and 5845, this dust appears as resolved thin lanes in HST frames by Lauer et al. (1995).
3. many E-galaxies contain a rather sharp *central red peak*, with an apparent break radius between circa 1.5 and 4 arcsec, where the color gradient changes from an inner large value to an outer much smaller one. To quantify this peak we introduced the color difference $\Delta C_{0,3}$ between the center and the isophote of mean radius 3 arcsec. Clearly this parameter is dependant upon the quality of the PSF equalization: various tests have shown that errors from this source may reach 0.03 magnitude. Very sharp peaks however, will be smoothed and partially washed out by the limited resolution of the color profiles and maps. For instance a color profile such as the one reproduced from HST WFPC2 data, in Fig. 1 of the Wise and Silva (1997) paper, will be affected in such a way that the "true" $\Delta C_{0,3}$ of 0.35, will be reduced to 0.20 by the mean PSF of our color maps.

The classification in core-like and power-law central profiles is given by Faber et al. (1997) for 18 galaxies of the present sample, and equivalently by Jaffe et al. (1994) in their classes I and II for 2 others. As a substitute for this information, the SuBr profiles of the objects in the sample have been classified into "flat topped" (or fto) and "sharply peaked" (or shp). For this purpose, the CFHT R images were partly deconvolved by Lucy's method, as implemented in the MIDAS package, using 27 iterations. The class of central profile was obtained from a comparison of the peak SuBr and FWHM before and after deconvolution; the value of the FWHM of the deconvolved profile was also considered. The 3 parameters show a bimodal distribution, and any of these generally points unambiguously to either the fto (core-like) or the shp (power-law) categories. There are however a few uncertain cases. *The agreement of the present crude classification technique with the HST results is excellent.*

Table 1. Measured parameters for 39 E-galaxies (1) subclass. (2) class of central profile, this work. (3) class of central profile, Faber at al, 1997. (4) class of central profile, Jaffe at al, 1994. (5) $DPII$ and code dd. (6) $\Delta C_{0,3}$. Symbol : added for uncertain data. Notes: NGC0636: Blue dot at the center. NGC3605, 3608: Pic du Midi observations by E. Davoust. NGC5322, 5845: Inner disk with dust lane in Lauer et al., 1995.

NGC	(1)	(2)	(3)	(4)	(5)	(6)
0584	diE	shp	-	-	0 dd	0.11
0596	diEp	shp	$\setminus$	-	1-:	0.07
0636	diEp	shp	-	-	0	0.06:
0720	unE	fto	$\cap$	-	0	0.02
0821	diE	shp	-	-	1 dd:	0.05
1052	diE	shp	-	-	3	0.19
2768	diE	shp	-	-	3	0.16
2974	diE	shp	-	-	3	0.09
3377	diE	shp	$\setminus$	-	1- dd	0.10
3379	unE	fto	$\cap$	-	1-	0.05
3585	diE	shp	-	-	0 dd	0.06
3605	boE	shp	$\setminus$	-	0	0.14
3608	boE	shp	$\setminus$:	-	1-	0.08
3610	diE	shp	-	-	0 dd	0.10
3613	diE	shp	-	-	1-:	0.06
4125	diE	shp:	-	-	3	0.20
4261	boE	fto	-	I	1-	0.10
4365	boE	fto	$\cap$	I	0	0.02
4374	unE	fto	-	I	3	0.18
4387	boE	shp	$\setminus$	-	0	0.07
4406	boE	fto	$\cap$	-	0	0.03
4472	unE	fto	$\cap$	I	0	0.03
4473	diE	fto	$\cap$	II:	0 dd	0.11
4478	boE	shp	$\setminus$	II:	0	0.11
4486B	unE	fto	$\cap$	-	0	0.04
4494	unE	shp	-	-	0:	0.15
4551	boE	shp	$\setminus$	-	0	0.13
4564	diE	shp	$\setminus$	II	1- dd	0.12
4621	diE	shp	$\setminus$	-	0 dd	0.10
4649	boE	fto	$\cap$	-	0	0.00
4660	diE	shp	-	-	1 dd	0.09
5322	boE	shp:	-	-	0 dd	0.13
5576	boEp	shp	-	-	0	0.11
5638	unE	shp:	-	-	0	0.05
5813	unE	fto	$\cap$	-	1	0.09
5831	diE	shp	-	-	2	0.11
5845	diE	shp	-	-	0 dd	0.09
5846	unE	fto	-	-	0	0.03
5846A	unE	shp	-	-	0	0.05

Table 2. Distribution of the central red peak amplitudes $\Delta C_{0,3}$ for the two classes of nuclear profiles

$\Delta C_{0,3}$	0.-.03	.04-.06	.07-.09	.10-.12	$>$ .12	Sum
fto	6	2	1	2	1	12
shp	0	6	6	8	7	27
Sum	6	8	7	10	8	39

3. Comparison of the two classes of central profiles

The results of the above summarized measurements are presented in Table 1, and some possible inferences are described below.

3.1. The correlation between the nuclear class and the large scale morphology

Previously known results are here reinforced and perhaps completed. Among the 18 diE galaxies, 17 have a central profile of the shp class. The exception is NGC4473; its core profile is rather atypical, from the graphs in Byun et al. (1996). Among the boE's galaxies, giant objects like NGC4261, 4365, 4406, 4649 have a broad core (class fto). A number of high luminosity objects in the unE category are probably similar, but for their apparent flattening; these, i.e. NGC0720, 4374, 4472, 5813 and 5846 also have an fto core. On the other hand, the special group of minor boE's, long ago recognized by Nieto & Bender (1989) as rotation supported, and possible satellites to nearby giants, are in the shp class. These are in the present sample NGC3605, 4387, 4478, 4551.

3.2. Statistics of the central red peaks

A glance at the table shows that the amplitude of the central red peak, as estimated by the parameter $\Delta C_{0,3}$, is dependant upon the importance of detected dust, as represented by the $DPII$ index and dd symbol. Galaxies with an important dust pattern, such as NGC1052, 2768, 2974, 4125, 4374 generally show a large $\Delta C_{0,3}$, because the dust pattern has a maximum reddening at the galaxian center (except for NGC2974). On the other hand, when the dust pattern is faint or undetected, the values of $\Delta C_{0,3}$ are obviously dependant upon the class of the nuclear profile. Flat color distributions (small $\Delta C_{0,3}$) are associated with the fto class, as for the bright galaxies NGC0720, 3379, 4365, 4406, 4649, 5846 and the compact dwarf NGC4486B. Strong central red peaks (large $\Delta C_{0,3}$), are found mostly in the shp class, as in NGC0584, 3377, 3610, 4564, 4621 among diE's, NGC3605, 4478, 4551 (again the rotation supported minor objects!), 5322, 5576 among boE's, and NGC4494 among unE's.

Table 2 gives the distributions of the $\Delta C_{0,3}$ parameter for the two classes of central SuBr profiles. These distributions are certainly different, but in a sense opposite to the one expected from the model by Silva & Wise. There are however a few cases of fto (core-like) galaxies, showing a significant central red peak, i.e. NGC4261, 4374, 4473; these show optical dust in various other forms. It is not excluded that a central diffuse dust component is also present, and might play some role in producing a core-like profile.

4. Discussion and conclusion

The amplitude of the central red peak detected in E-galaxies, as estimated by the parameter $\Delta C_{0,3}$, are affected by tolerable random errors of the order of 0.03, but also systematically lowered due to the limited resolution of the present data. This resolution however, does not vary much from object to object in the sample: it is then hoped that the statistical distributions in Table 2 are roughly valid, and the difference of the results found for the two classes significant. It may then be concluded that *our data do not support the model of Silva & Wise for the production of cores by screens of diffuse dust.*

The issue will no doubt be settled by the expected extensive color data from the HST. The work of Carollo (1996), Carollo et al. (1997) introduces a sample of 15 ellipticals with "kinematically distinct cores". Since these appears similar in all respects to objects with "normal cores", the correlation between the gradients in brightness and V-I color (Fig. 11 in the Carollo et al., 1997 paper) was taken as evidence against the model of Silva & Wise. The present results from a larger and unbiased sample, although observed at a much worse resolution, reinforce this conclusion.

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References

Bender, R., Surma, P., Döbereiner, S., Möllenhof, C., Madejsky, R., 1989,A&A, 217, 35
Byun, Y., Grillmair, C.J., Faber, S.M., Ajhar, E.A., Dressler, A., Kormendy, J., Lauer, T.R., Richstone, D., Tremaine, S., 1996, AJ, 111, 1889
Carollo, C.M. 1996, in "The Nature of Elliptical Galaxies", 2d. Stromlo Symp., Canberra, 26-30 aug 1996, Ed. M. Arnaboldi, G.S. Da Costa, P. Saha, ASP Conf. Ser., 1997
Carollo, C.M., Franx, M., Illingworth, G.D., Forbes, D.A., 1997, ApJ, 481, 710
Carter, D., 1978, MNRAS, 182, 797
Ebisuzaki, T., Makino, J., Okamura, S.K., 1991, Nature, 354, 212
Faber, S.M., Tremaine, S., Ajhar, E.A., Byun, Y., Dressler, A., Gebhardt, K., Grillmair, C.J., Kormendy, J., 1997, AJ, 114, 1771
Gebhardt, K., Richstone, D., Ajhar, E.A., Lauer, T.R., Byun, Y., Kormendy, J., Dressler, A., Faber, S.M., Grillmair, C.J., Tremaine, S., 1996, AJ,112, 105
Jaffe, W., Ford, H.C., O'Connell, R.W., van den Bosch, F.C., Ferrarese, L., 1994, AJ, 108, 1567
Lauer, T.R., Ajhar, E.A., Byun, Y., Dressler, A., Faber, S.M., Grillmair, C.J., Kormendy, J., Richstone, D., Tremaine, S., 1995, AJ, 110, 2622
Lauer, T.R., Faber, S.M., Tremaine, S., Ajhar, E.A., Byun, Y., Dressler, A., Gebhardt, K., Grillmair, C.J., Kormendy, J., Richstone, D., 1996, in "The Nature of Elliptical Galaxies", 2d. Stromlo Symp., Canberra, 26-30 aug 1996, Ed. M. Arnaboldi, G.S. Da Costa, P. Saha, ASP Conf. Ser., 1997
Michard, R., 1994, A&A, 288, 401
Michard, R., 1998a, A&A, submitted
Michard, R., 1998b, A&A, submitted
Michard, R., Marchal, J., 1994, A&AS, 105, 81
Nieto, J.L., Bender, R. 1989, A&A, 215, 266
Nieto, J.L., Bender, R., Arnaud, J., Surma, P., 1991a, A&A, 244, L25
Nieto, J.L., Bender, R., Surma, P., 1991b, A&A, 244, L37
Nieto, J.-L., Bender, R., Poulain, P., Surma, P., 1992, A&A, 257, 97
Poulain, P., 1988, A&AS, 72, 215
Poulain, P., Nieto, J.L. 1994, A&AS, 103, 573
Silva, D.R., Wise, M.W., 1996, ApJ, 457, L15
Wise, M.W., Silva, D.R., 1996, in "The Nature of Elliptical Galaxies", 2d. Stromlo Symp., Canberra, 26-30 aug 1996, Ed. M. Arnaboldi, G.S. Da Costa, P. Saha, ASP Conf. Ser., 1997