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ASTRONOMY AND ASTROPHYSICS

Color distributions in E-S0 galaxies

I. Frequency and importance of dust patterns for various brands of E classified galaxies⋆

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Abstract. From the consideration of a sample of color distributions in 67 E classified objects of the Local Supercluster, it is found that local dust features are much more frequent and important in disky E's than boxy E's. The subclass of undeterminate objects, those which cannot be assigned to the diE or boE groups, is intermediate.

Subsets of objects of common properties are considered from the point of view of local dust features occurrence: giant boxy E's; minor boxy E's with rotational support; compact dwarfs; SB0-like E's.

It is noted that the detection of dust features is more than twice less frequent in Virgo cluster ellipticals than in the full sample, but the significance of this result is not clear.

Key words: galaxies: elliptical and lenticular, cD – galaxies: fundamental parameters – galaxies: ISM

1. Introduction

The frequency of dust features in E-classified objects has been studied by many authors, using a variety of techniques. Sadler and Gerhardt (1985) simply looked at the B images, while Ebneter et al (1988) enhanced the visibility of various features by comparing images with models built from an analysis in terms of elliptical isophotes. This technique was recently applied by van Dokkum and Franx (1995), using HST data.

Another popular technique has been the comparison of images taken in widely different color bands. This approach was followed by Sparks et al (1985), Véron-Cetty and Véron (1988), Kim (1989) and Goodfroij et al. (1994b). It has however its difficulty, i.e. the artefacts in the color distribution that may result from different PSF's in the two intercompared frames. This question has been considered by Vigroux et al (1988), Franx et al (1989), Peletier et al (1990), and will be treated also in a forthcoming paper of this series.

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⋆ Based on observations collected at the Canada-France-Hawaii Telescope and at the Observatoire du Pic du Midi

The B-R color distribution has recently been studied for a sample of 44 E-classified galaxies, using frames of sub-arcsec resolution obtained by the late J.L. Nieto and co-workers in 1989-91, mostly at the CFHT. The frames were intended to study the core profiles of these objects, and preliminary results were published by Nieto et al (1991a, 1991b). Note that the term "core" here means the innermost few arsec of a nearby galaxy, not a specific light distribution related to the King's model. For the analysis of the color distribution, a sample of relatively nearby galaxies was selected, i.e. objects in the Local Supercluster with $V_0 < 3000$ km/s, in order to keep the full advantage of the good resolution of most of the available frames.

Our study involves the analysis of the galaxian image in terms of the well known representation due to Carter (1978), and therefore the classification of E-galaxies in the boxy (boE), disky (diE) and undeterminate (unE) subclasses. Details about the favoured implementation of Carter's technique and the adopted classification of E-S0 galaxies are given in Michard and Marchal (1994). Now, the assignation of E-galaxies to the three subclasses has been shown by Carter (1987), Bender (1988), Nieto et al (1988), Bender et al (1989), to correlate with their kinematics, and perhaps other properties. Nieto et al (1991b) found that it also correlates with their empirical classification of galaxian cores as well resolved or quite unresolved at the CFHT resolution.

It was therefore deemed useful to study the occurrence of optical dust features for the various subclasses of E galaxies. The present paper describes the remarkable differences between the boE and diE subclasses from this point of view. The results from our B-R data have been supplemented using litterature data from Goudfrooij et al (1994a, 1994b) and Véron-Cetty and Véron (1988).

2. The data

2.1. Nieto's sample

A forthcoming paper of this series (Michard, in preparation) will give full details about the CFHT observations and a small set from the Pic du Midi. It will also contain a description of the

adopted reduction techniques. At this stage, only the following essential information is summarized:

1. CFHT observations, dec 1989 and apr 1990, for 22 sample galaxies. Cassegrain focus with scale 0.107 arcsec/pix and total field 641x1011 pixels. The galaxy was often away from the center of the field to get a PSF star inside the CCD target, so that the usable galaxian radius is between 10 and 30 arcsec.
2. CFHT observations, apr and jun 1991, for 19 sample galaxies, including 4 from the 1990 session. Prime focus with the HRcam, scale and total field as above. The HRcam observations are of lesser S/B ratio but the seeing is somewhat better. Same remark as above as regards the limits in reachable radius.
3. Pic du Midi observations, mar 1990, for 6 galaxies. Cassegrain focus of the 2m telescope with focal reducer, with scale 0.315 arcsec/pix and total field 320x512 pixels.
4. For the whole CFHT sample, the mean measured stellar FWHM were 0.72 arcsec in R and 0.86 in B. For the Pic du Midi subset, the corresponding values were 0.92 and 1.13 arcsec.
5. The Carter-like isophotal analysis was performed at least in the R color and often also in B. This allowed to revise the morphological classifications in Michard and Marchal (1994), and to supplement it for the few objects not in the sample of these authors.
6. The occurrence of optical dust markings was checked first by examining graphs of the azimutal distribution of B-R in a series of rings limited by isophotal contours. This was supplemented by 2D maps of the B-R index, needed to ascertain the geometry of the dust feature(s), and also by a careful examination of the B images. This proved useful in some doubtful cases, notably with frames of poor S/B. The technique of comparison of a frame with a model built from an ellipse fitting programme was available, but used only in specific cases where it was thought to bring a useful test.
7. The above operations led to a short description of the dust "patterns" in terms of patches, lanes, arcs.... Besides this was introduced a *dust pattern importance index*. or DPII, 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

Remark: The dust patterns of DPII 2 and 3 clearly affect the B isophotes, while those of importance 1 are not seen in the B frame alone (except in rare cases).

2.2. The complement sample

In Goudfrooij et al (1994a) are found the results of the Carter-like analysis, in the form of detailed graphs, for 56 E-galaxies from the RSA Catalogue. It was then easy to recover the classification of each object in the boE, unE and diE groups. In Goudfrooij et al (1994b), or GHJNN, color maps in B-I or V-I, supplemented by descriptive notes, are given for 34 of these objects. This information was used to recover the dust pattern importance index as defined above. Part of the objects without color maps in the Goudfrooij et al paper appear in the sample of Véron-Cetty and Véron (1988), or VCV, giving the opportunity to find the DPII: it is directly evaluated for objects mapped in their Fig. 1; it is put to -1 for objects with "possible dust" (their Table 1b), and to 0 for other galaxies. The maps of Sparks et al (1985) and Kim (1989) were not used, excepts for eventual checks, because no morphological subclasses are readily available, but for objects also in the GHJNN data.

2.3. The final sample

The Nieto's sample is made up of objects from the RSA Catalogue, although two compact dwarfs, NGC4486B and 5846A were added. The Hubble types are not taken from the RSA but rather from the RC2. The sample is not fully complete at the faint end of the RSA. Only galaxies that could be observed from the CFHT are included.

The photometric sample of Goudfrooij et al (1994a) contains 56 E type galaxies in the RSA and is complete to $B_T < 12$. Their subsample with color data in GHJNN is however reduced to 34 galaxies. For all the missing objects but 5, the needed color information was recovered from VCV.

The final sample is bound in distance by the condition $V_0 < 3000$km/s. The objects are "genuine" ellipticals from the usual catalogues, and from our own judgment in case of discrepancies. The list is 90% complete at B_T=12, the incompleteness increasing towards the RSA limit.

3. Results

3.1. Comments about mean parameters

The subclasses were obtained on the one hand from Michard and Marchal (1994), here revised or completed from the analysis of the Nieto's sample; on the other hand from an examination of the graphs of Goudfrooij et al (1994a). For 26 objects both sources could be used, giving somewhat discrepant results in 6 cases: these are due to uncertainties between either one of the two cells diE or boE and the intermediate unE. The adopted classification is entered in the Tables 2 and 3, and one might note a few changes from our above quoted paper.

The values of the DPII found for the 3 used sources are generally in fair agreement, as may be seen by scanning the relevant columns of the Tables. For 26 cases where a value is given from both the Nieto's sample Nv and another Av, we find $Nv - Av$=1 step in 10 cases, $Av - Nv$=1 step in 5 cases, and $Nv - Av$=0 in 11 cases. Most of the differences occur between the 0 and 1- steps of the DPII scale . There is an indication that the DPII values from the Nieto's sample are slightly larger than the others. This lack of homogeneity between the three DPII sources cannot have a significant effect upon the statistical result below.

Table 1. Statistics of the "dust pattern importance index" for each E subclass. The table gives the number of objects in each cell

Subcl.	0	1-	1	2	3	Total
boE	13	2	0	0	0	15
unE	15	6	3	2	1	27
diE	9	5	4	2	5	25
Total	37	13	7	4	6	67

The estimate based on the Nieto's sample has been prefered in most cases, with at least one exception, i.e. NGC4494: dust is detected in this object not only in the GHJNN source, but also by van Dokkum and Franx (1995), or vDF95.

3.2. The basic results

The full derived data are given in Tables 2 and 3, both with the following content:

(1) Galaxy identification.

(2) Sources of classification: m2 Michard and Marchal (1994), n analysis of the "Nieto's sample", g graphs in Goudfrooij et al (1994a).

(3) Adopted classification.

(4) Summary of dust features description in our study of the "Nieto sample".

(5) Summary of dust features description in the complement sample.

(6) Source of column (5), either GHJNN for Goudfrooij et al (1994b) or VCV for Véron-Cetty and Véron (1988).

(7) DPII according to our study.

(8) DPII according to the data in GHJNN.

(9) DPII according to the data in VCV.

(10) Adopted DPII from previous columns.

Remarks: NGC3156 and 4742 have been rejected from Nieto's sample because they have quite anomalous color distributions. NGC1275 is rejected from the complement sample as anomalous, and NGC6482 because of an ill placed star. Besides this it is probably an S0.

3.3. Statistics for the full sample

The distribution of the DPII for the 3 subclasses of E galaxies is given in Table 1. It is striking that for 87% of the boE's there are no dust features detected (DPII = 0). This proportion falls to 36% for diE's, while it takes the intermediate value of 55% for the ambiguous unE objects. One may also note that, of the 10 objects with important or outstanding dust patterns (DPII = 2 or 3) 7 are in the diE, 3 in the unE, and 0 in the boE subclasses.

Remark: The difference between the distributions of the DPII for the three morphological subclasses of ellipticals is qualitatively unchanged if only the Nieto's sample of 42 objects and the corresponding indices are used.

3.4. Dust features in recognized subsets of E objects

The following subsets of galaxies with common properties have been considered from the point of view of dust feature occurrence (see also Michard, 1994 for further discussion of these groupings):

1. Giant boE/unE galaxies. The 5 biggest galaxies in the Virgo cluster, i.e. NGC4374, 4406, 4472, 4486 and 4649 are prototypes of this group, characterized by rather high luminosities and extended envelopes above the $r_{1/4}$ law. Michard (1994) quotes other "candidates" to this subset, NGC 4261, 4365, 4494(?), 5322(?), 5576, 5813 being in the present sample. To this tentative list we would like to add NGC0720 and 5846, the last one after correction of its Hubble type from SA0 to unE. *This subset of objects generally have very little apparent dust, with the notable exception of NGC4374.*
2. Minor satellite boE's . These were recognized by Nieto and Bender (1989) as a family of small boxy objects, with rotational support, and possible satellites of a massive nearby galaxy. The objects of this subset, i.e. NGC3605, 4387, 4478, 4551 *do not show any dust features.*
3. Dwarfs compact E's. *No evidence of dust features* was found in NGC4486B and NGC5846A. These are difficult objects, even at the scale and resolution of the CFHT frames.
4. "SB0-like" ellipticals. These are disky objects characterized by very large isophotal twists, and have been compared to SB0's by Nieto et al (1992). This proposed analogy is discussed by Michard (1994), who introduces the diEp subclass for this kind of morphology. NGC0596, 0636, 1537 are so classified, and their DPII is 0 or -1.

3.5. Dust detection completeness?

The techniques used here detect dust "patterns" only if the isochromes present sufficiently apparent deviations from the isophotes. Nearly symmetric dust concentrations towards the galaxian center, or towards the disk if such a component is present, will be missed. In Paper II and III of this series, some efforts have been made to find evidence for this "diffuse" dust, and a number of more or less conclusive cases have been found.

The present detections of dust "patterns" have been compared with HST deconvolved images in Jaffe at al (1994), Lauer et al (1995), and with the results of vDF95. The HST frames show that we have missed the dust lanes in NGC4697, 5322 and 5845, that is two diE's and one boE's. Comparing with vDF95 for individual objects, we find agreement for 12 cases out of 16 in common. Statistically, we detect dust in 30 galaxies out of 67, while in vDF95 "certain" cases of dust detection number 31 out of 64 galaxies: the proportions are similar.

In conclusion, although the present DPII estimates miss a few dust features either too symmetrical, or too tiny for ground based observations, such incompleteness is unlikely to affect significantly the above results.

Table 2. Morphological subclasses and dust pattern importance index for 67 E-type galaxies (1st part)

Notes to the Table:
NGC1537 no color map in GHJNN (1994b); DPII adopted from comments in GHJNN (1994a)
NGC2974 no dust detection in VCV (?)
NGC3136 poor data due to many overlying stars

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
NGC0584	m2n	diE	no pattern, redder majA?	none	VCV	0	-	0	0
NGC0596	m2ng	diEp	ft. core pattern?	none	VCV	1-	-	0	1-
NGC0636	m2n	diEp	no pattern, small blue core	-	-	0	-	-	0
NGC0720	m2g	unE	no pattern	none	VCV	0	-	0	0
NGC0821	m2ng	diE	ft. minA lane	none	VCV	1	-	0	1
NGC1052	m2n	diE	prominent pattern	-	-	3	-	-	3
NGC1395	g	unE	-	none obvious	GHJNN	-	0	0	0
NGC1399	g	unE	-	none obvious	GHJNN	-	0	0	0
NGC1404	g	unE	-	none	VCV	-	-	0	0
NGC1407	g	unE	-	ft. ring	GHJNN	-	1-	0	1-
NGC1537	g	diEp	-	poss. dust	GHJNN	-	1	-	1
NGC2325	g	boE	-	none obvious	GHJNN	-	0	0	0
NGC2768	m2	diE	str. pattern, minA oriented	-	-	3	-	-	3
NGC2974	m2ng	diE	str. pattern, minA lane	dust lanes	GHJNN	3	3	?	3
NGC2986	g	unE	-	none	VCV	-	-	0	0
NGC3136	g	boE	-	ft. lane?	GHJNN	-	1-	-	1-
NGC3193	m2g	unE	no pattern	-	-	0	-	-	0
NGC3250	g	boE	-	none	VCV	-	-	0	0
NGC3377	m2ng	diE	ft. pattern, redder majA	dust lane	GHJNN	1-	1	-	1-
NGC3379	m2ng	unE	poss. ft. core pattern	-	-	1-	-	-	1-
NGC3557	g	unE	-	none	VCV	-	-	0	0
NGC3585	n	diE	no pattern, redder majA	-	-	0	-	-	0
NGC3605	m2n	boE	no pattern	-	-	0	-	-	0
NGC3608	m2ng	unE	ft. lane ?	none obvious	GHJNN	1-	0	-	1-
NGC3610	m2ng	diE	no pattern, redder majA	bluer disk	GHJNN	0	0	-	0
NGC3613	m2g	diE	poss. ft. core pattern	-	-	1-	-	-	1-
NGC3640	m2ng	boE	no pattern	small lane	GHJNN	0	1-	-	0
NGC3706	g	diE	-	none	VCV	-	-	0	0
NGC3872	m2n	diE	small lane near majA ?	-	-	1-	-	-	1-
NGC3962	g	unE	-	small lane	GHJNN	-	1-	-	1-
NGC4125	m2g	diE	str. pattern, majA oriented	str. lane	3	3	-	3	
NGC4261	m2ng	boE	small core arclet	red nucleus	GHJNN	1-	0	1-	1-
NGC4278	m2g	unE	-	prominent pattern	GHJNN	-	3	-	3

4. Discussion and conclusion

Classifying galaxies, either in their Hubble types or subclasses, is not a rigorous exercize, and assigning an ad hoc "dust pattern importance index" (DPII) is not fully objective! The statistical difference between boE's and diE's, as regards the distribution of their DPII seems however large enough to be significant.

It seems well established, from both the morphology and the kinematics, that diE galaxies are oblate objects containing a disk component; many such objects would be classified S0 if seen at a larger inclination: see references and discussion in Michard (1994). The same is true for a large part of the unE's, at least one half, where the disk is missed due to unsufficient inclinations: cf Rix and White (1990). The boE's, and the other unE's, are diskless objects of uncertain geometry. *There is clearly a correlation between the presence of a disk and the presence (and importance) of local dust features*. The properties of the unE galaxies do not contradict this conclusion. Since near face-on diE's form more than half the unE subclass, the proportion of dust features detection among the unE's is quite in line with the advocated correlation between disks and dust features.

It is of course not proven that boE objects do not contain dust, nor that dust in E galaxies reduces to the component seen as local features. The reverse is probably true, as indicated by Goudfrooij and de Jong (1995), or Wise and Silva (1996), to reconcile estimates of the dust content from optical and IRAS observations, while explaining the color gradients in ellipticals. In a forthcoming paper of this series, evidence will also be given

Table 3. Morphological subclasses and dust pattern importance index for 67 E-type galaxies (end)

Notes to the Table:
NGC4486B and 5846A, compact dwarfs
NGC4697, 5322, 5845, dust feature in HST frames

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
NGC4365	m2ng	boE	no pattern	none	VCV	0	-	0	0
NGC4374	m2g	unE	str. pattern, minA lane	str lane	VCV	3	2	2	2
NGC4387	m2n	boE	no pattern	-	-	0	-	-	0
NGC4406	m2	boE	no pattern	none	VCV	0	-	0	0
IC3370	g	unE	-	asym. lane	VCV	-	1	1	1
NGC4472	m2	unE	no pattern	dust lane?	VCV	0	-	1-	0
NGC4473	m2ng	diE	no pattern, redder majA	bluer disk	GHJNN	0	0	-	0
NGC4478	m2n	boE	no pattern	-	-	0	-	-	0
NGC4486	m2g	unE	-	none obvious	GHJNN	-	0	0	0
NGC4486B	n	unE	no pattern	-	-	0	-	-	0
NGC4494	m2n	unE	no pattern	small minA lane	GHJNN	0	1-	-	1-
NGC4551	m2n	boE	no pattern	-	-	0	-	-	0
NGC4564	m2ng	diE	ft. core pattern, redder majA	none	GHJNN	1-	0	-	1-
NGC4589	m2g	diE	-	str. lane	GHJNN	-	2	-	2
NGC4621	m2ng	diE	no pattern, redder majA	none	VCV	0	-	0	0
NGC4649	m2	boE	no pattern	none	VCV	0	-	0	0
NGC4660	m2ng	diE	color pattern near majA	poss. dust	GHJNN	1	1-	-	1
NGC4697	m2g	diE	-	none	GHJNN	-	0	0	0
NGC4696	g	unE	-	horseshoe lane	GHJNN	-	2	2	2
NGC5018	g	diE	-	prominent pattern	GHJNN	-	3	-	3
NGC5044	g	unE	-	faint ring	GHJNN	-	1-	0	1-
NGC5061	g	boE	-	none	VCV	-	-	0	0
IC4296	g	unE	-	none obvious	GHJNN	-	0	-	0
NGC5322	m2ng	boE	redder inner disk?	none obvious	GHJNN	0	0	-	0
NGC5576	m2g	boEp	no pattern	marginal traces	GHJNN	0	1-	-	0
NGC5638	n	unE	no pattern	-	-	0	-	-	0
NGC5813	m2ng	unE	asym. B-R pattern	patchy	GHJNN	1	1-	1-	1
NGC5831	m2n	diE	B-R pattern near majA	-	-	2	-	-	2
NGC5845	n	diE	no pattern, redder inner disk?	-	-	0	-	-	0
NGC5846	m2n	unE	no pattern	-	-	0	-	-	0
NGC5846A	n	unE	no pattern	-	-	0	-	-	0
NGC7144	g	unE	-	none	VCV	-	-	0	0
IC1459	g	unE	-	patches	GHJNN	-	1	1-	1
NGC7507	g	unE	-	small arc	GHJNN	-	1	1-	1

of a concentration of diffuse(?) dust in the disk of disky objects of sufficient inclination to the line of sight.

A search for an environmental influence upon the occurrence of local dust features in E-type galaxies might be of great interest. As a first step in this direction, we consider the subsample of 14 objects in the Virgo cluster, less than 6 degrees from NGC4486, as compared to our full sample. In Virgo there is an astonishing deficit of ”dusty” objects, only 3 out of 14, instead of 45% for the total sample. On the other hand this same Virgo subsample shows an excess of boE’s, i.e. circa 43%, as compared to the complete sample where this proportion is 22%. This involves both the subsets of giant and minor boE’s considered above. Since boE’s are dustless, their number in Virgo can possibly explain the rarity of dusty objects, without recourse to some genuine lack of dust in the cluster ellipticals. In view of the small numbers involved, one cannot be sure that this ”overpopulation” of boE’s in Virgo is significant.

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