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Colour distributions in E-S0 galaxies

VI. A discussion of colour gradients in ellipticals*

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Abstract. The data from the surveys by Franx et al. (1989), Peletier et al. (1990), Goudfrooij et al. (1994a), completed by our own measurements, have been used to build a sample of ellipticals with the full array of U−B, B−V, B−R and V−I colours, and corresponding gradients. A number of objects with data for only 3 colours are also considered. Photometric profiles were re-calibrated in a coherent colours system, and a seemingly successful attempt was made to improve gradients by minor corrections to adopted sky background values.

"External" probable errors are obtained for the revised data by comparisons between the various sources. These have poor statistical weight in U−B and V−I.

An ad hoc "standard" gradient Δ_s is defined as a weighted average of the four gradients in the above listed colours (or only three). The correlations of the various gradients to Δ_s are considered, and their slopes Δ_{U-B}/Δ_s,... are compared to the corresponding calculated ratios for current hypothesis regarding the origin of colour gradients in ellipticals, i.e. population gradients and large scale dust distributions. Both the ratios for the U−B and V−I colours are not compatible with the explanation in terms of diffuse dust but tend to agree with the explanation in terms of metallicity variations.

The correlation between the gradient Δ_{U-B} and the standard one Δ_s might be worse than could be explained by observational errors. Both population variations and possibly complex dust dustributions should be invoked to explain the complications of colour gradients.

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

1. Introduction

The distributions of colours in E-type galaxies have been studied in the past from two different point of views, obviously not independent. Some authors aimed at detecting unapparent dust patterns in such objects, and to obtain statistics of their occurrence and/or estimates of the amount of dust: see for instance Sparks et al. (1985), Véron-Cetty & Véron (1988), Kim (1989). Other were more concerned with the average run of colours with radius, as Vigroux et al. (1988), Franx et al. (1989) (Fal89), Peletier et al. (1990) (Pal90), Goudfrooij et al. (1994a) (Gal94). These two topics could of course be approached from the same observations, as in Gal94 and subsequent papers by Goudfrooij et al. (1994b, 1994c), and our contributions in previous papers of this series (Michard 1998a, 1998b, 1998c, 1999).

Trends for bluer colours at larger radii in E-type galaxies have long been known from aperture and surface photometry, and were generally attributed to gradients of the average metallicity, as evidenced by systematic changes of metallic line indices (see for instance the review by Kormendy & Djorgovsky, 1989). The Fal89 and Pal90 surveys introduced the U−R colour index, and demonstrated the generality of large outwards negative gradients in this colour, more than twice the corresponding gradients in B−R. Pal90 showed these gradients to be "consistent with a decrease in the [Fe/H] of approximately 0.20 per decade in radius" to quote their paper.

In Gal94 the B−V and B−I gradients were measured for a complete magnitude limited sample of 56 E-galaxies. It seems certain from far infrared observations, that E-galaxies contain more dust than apparent from optically seen patterns. Goudfrooij & de Jong (1995) estimated the amount of diffuse dust from IRAS data, and then used a model of Witt et al. (1992) to infer the B−I colour gradients induced by this dust. These were finally compared with measured gradients in Gal94 and found to be similar or smaller.

Another approach was taken by Wise & Silva (1996), using calculated colour gradients from their own theory of transfer in various models of dusty ellipticals on the one hand, and a consideration of the *ratios* of available U−R and B−R gradients on the other. They conclude that "measurements are not precise enough in many objects to provide tight constraints on the models".

Perhaps we might comment at this stage that population gradients exist in E-galaxies as proven by line spectra, while dust is certainly also present. It is a merit of the theoretical work quoted above to prove that dust could indeed be much more abundant than estimated from apparent patterns (absent or quite

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* Based in part on observations collected at the Observatoire de Haute-Provence and from the Centre de Données Stellaires, Strasbourg

elusive in many cases!) and probably play some role in broad band colours distributions. It is however unrealistic to neglect population changes in the discussion of colour observations, the more so when a metallicity sensitive index such as U−B is considered.

The purpose of the present work is to reconsider the discussion of colour gradients in ellipticals, using simultaneously the 4 optical colours U−B, B−V, B−R, V−I, rather than only one pair. The sample is therefore made up, as a first step, of objects in common to the Gal94 sample and the Fal89+Pal90 samples. This was supplemented with hitherto unpublished observations obtained at the Observatoire de Haute Provence. Some data from Bender & Möllenhof (1987) (BM87) were also used. The number of objects with complete 4 colours data is 26; a few other with only 3 colours available were also considered in the discussion.

2. The revision of literature data

2.1. Description

The data from the Fal89, Pal90 and Gal94 surveys were obtained in machine readable form from files kindly provided by the authors. Those by Gal94 may also be obtained from CDS, Strasbourg. The data files were entered into ad hoc MIDAS procedures, allowing the following operations:

1. check the run of colour against $\log r$ and eventually introduce small "corrections" to the adopted sky-background levels, in order to obtain a nice linear plot (if feasible!). This exercize is conducted simultaneously upon the 3 passbands (and colours) available in each dataset, to minimize the introduced corrections.
2. calculate synthetic images and calibrate these against the same sources as our own, primarily Poulain's UBVRI photometry (Poulain 1988; Poulain & Nieto 1994), in order to place all data in an homogeneous system, with UBV in Johnson's and RI in Cousins's systems.

Remark: Measurements from BM87 for 7 Virgo objects were incorporated in the present discussion. Gradients in V−I, or R−I, were recovered from the published graphs. The V−I colours at $r_e/2$ were found from a correlation between this quantity and the mean colours within r_e given by Poulain in his surveys: these two colours are equal within errors.

2.2. Short discussion

2.2.1. Changes in background values and colour gradients

As the observations in Fal89 and Pal90 were performed largely with a small telescope and a relatively large field, their sky-background estimates were generally good enough to require little ad hoc "corrections". Thus we treated 29 files from Fal89: the changes in background were less than 1% in 3/4 of the cases and reached 2% in only two cases. For Pal90, the corresponding figures for 51 files treated are nearly the same. The data in Gal94 were obtained with cameras having low fields of view,

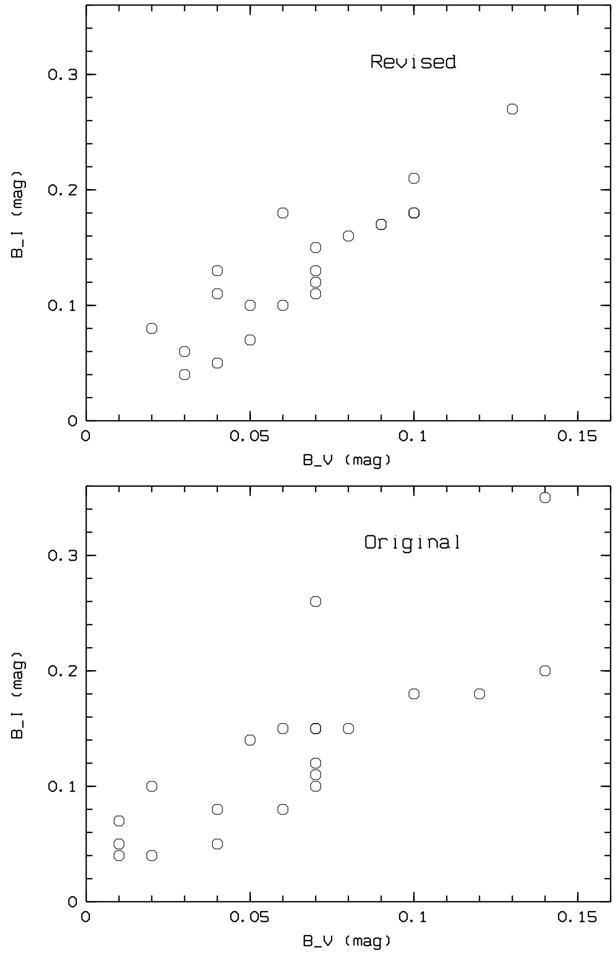

Fig. 1. The correlations between the gradients in B−I and B−V from Gal94 data before (upper graph) and after (lower graph) the described revision. Our "corrections" clearly improves the correlation.

and, notwithstanding the care of the authors in recovering good background values, we were led to more frequent and somewhat larger changes. We treated 88 files: the "corrections" were less than 1% in 70% of cases but were larger than 2% in 8 cases.

These so called "corrections" to the sky-background values adopted by the observers may appear arbitrary, since there is no obvious physical reason for the colours in E galaxies to remain linear in $\log r$ up to the largest r values. They might instead tend towards definite limits at large r, when stellar populations reach some average, and dust is nearly gone. We assume that the present observations do not reach this asymptotic region. In Fig. 1 we compare the correlation diagrams of the B−V and B−I gradients obtained from the Gal94 data before and after the revision of the background values. The expected correlation is clearly improved by our "corrections", which is an a posteriori justification for our procedure. On the other hand, the correlation between the B−R and U−R gradients is not good, as already noted in Pal90, and is barely improved by our revision of background values.

The new derived gradients may differ from the original ones for other reasons than changes to the background values, because we sometimes modified also the inner radius limit in the gradient calculations. First, when the object was known to contain an important inner dust pattern the heavily affected region was left out of the fit: this applies to NGC1052, 2768, 2974, 3665, 4278, 4374. Second we consider that Gal94 were not stringent enough in applying inner cutoffs to the colour data before the least square fit. Judging from the appearance of the colour graphs we often used a more restricted fitting range.

The newly derived gradients do not differ much from the original. A little statistic of the New–Old values give the following results:

. Fal89 and Pal90 data together:
Δ_{B-R} N=22 mean $= .005$ $\sigma = 0.02$
Δ_{U-R} N=21 mean $= .012$ $\sigma = 0.05$
. Gal94 data:
Δ_{B-V} N=25 mean=-.002 $\sigma = 0.024$
Δ_{B-I} N=21 mean=.005 $\sigma = 0.049$.
The objects with large dust patterns are rejected from this last comparison.

2.2.2. New calibrations

The possible improvement in calibrations arise mainly from the availability of the above quoted Poulain's aperture photometry. A comparison of New−Old colours, taken of course at the same radii and before the usual corrections for K-effect and galactic extinction, gives the following results:

. Fal89: B−R, 9 cases, mean -0.295, $\sigma = 0.032$ a large mean difference due to the use of Johnson's R in Fal89.
U−B, 8 cases, mean -0.021, $\sigma = 0.039$
. Pal90: B−R, 13 cases, mean -0.053, $\sigma = 0.044$
U−B, 13 cases, mean -0.025, $\sigma = 0.084$
. Gal94: B−V, 19 cases, mean -0.015, $\sigma = 0.035$
V−I, 16 cases, mean 0.040, $\sigma = 0.18$
again indicating that the I photometry of Gal94 contains a number of poor calibrations, leading to several unrealistic V−I (see also Michard 1999).

While the present new colour calibration is more homogeneous it does not necessarily leads to smaller random errors than the original ones. It should be noted that the data files used for the Fal89 and Pal90 surveys are truncated in B and U to some inner radius of several arcsec, corresponding to the limit where the colours were thought to be reliable by the authors. To build synthetic images for the new calibrations, this inner range had to be extrapolated, a procedure likely to introduce errors in the results. We shall come back below to this question.

3. The OHP observations and data reduction

3.1. Observations

In the course of their morphological study of E-S0 galaxies, Michard and Marchal (1994) obtained in 1990/94 numerous frames of ellipticals at the 120cm telescope of the Observatoire de Haute-Provence. Among these, two series were of interest for the present work, as adding usable complements to the bulk of the data.

The first group contains 10 objects observed in UBVRI, i.e. NGC596 (U not usable), 1052, 2300 (R missing), 2768, 3377, 3379, 3610, 3613, 4125, 4564. In the second, there are 9 more galaxies observed in B and V only, i.e. NGC2974, 3605, 3608, 3640, 3665, 4278, 4494, 4636, 5322. Pic du Midi observations for NGC821 were added.

In the runs of 1990/92 the CCD camera with RCA targets had a field of view of about 4x7 arcmin with a pixel of 0.84 arcsec. In the 1993/94 runs, a new Tek512 CCD allowed a field of 7x7 arcmin for a pixel size of 0.76 arcsec. Since the seeing at the OHP is usually in the $2-3''$ range, the sampling is just adequate.

Finally, a number of frames obtained by P. Prugniel were also used. These are available from the HYPERCAT, an online data base created and maintained by himself and colleagues (http://www-obs.univ-lyon1.fr/hypercat/). These show NGC1600, 1700 (observed twice), 2300, 3379, 3610, 4486. UBVRI are available for the first three objects, U is missing for the others. Part of these frames, taken in 1995, had the same characteristics than our 1993/94 material, while the latter ones (1997), were taken with a Tek1024 CCD giving a field of near 11x11 arcmin and a pixel size of 0.68 arcsec. The thinned Tek CCD's were affected by the "red halo" phenomenon, and the V−I data proved unreliable.

3.2. Data reduction

Our reduction procedure entails the following steps:

1. The images of a colour set are prepared by substracting a background, extracting parasitic objects, calibrating against the aperture photometry data, and applying a cosmetic treatment.
2. The best image in a colour set is analysed according to the principles of Carter (1978). The object is described by a set of isophotes 0.1 mag distant from one another, each represented by a "Reference ellipse" and a series of harmonic coefficients detailing the deviations from the ellipse.
3. The frames are calibrated against the results of aperture photometry, using whenever possible the homogeneous data by Poulain (1988) or Poulain & Nieto (1994). After calibration, the R and I bands are in Cousins's system, although an i filter according to Gunn was used in the observations.
4. A procedure of PSF matching is applied to lessen the effects of "differential seeing", that is the errors upon colour measurements resulting from the different PSF's of the two used frames. A discussion of these, and references to previous work, may be found in Paper IV of this series (Michard 1999). In the same Paper IV and in Paper V (Michard & Poulain 2000), our technics of PSF matching are described. In the present work we often tried to match the various frames in a colour set to the PSF of the *best one*, usually in the R or i band: this implies deconvolution by narrow correcting functions. When the two PSF's in a pair differ too much, so that the deconvolution might give rise to "ringing", the match was obtained by convolution of the best frame.

5. The effect of the red halo phenomenon upon the V−I colours from the 1994/97 frames strongly depends upon the size and flattening of the studied object. It may be corrected, *in principle*, by a compensating convolution of the two frames, the V one with the I band PSF and conversely. For various technical reasons this procedure is not fully successful, and part of the V−I data was rejected.
6. Isophotal colours $C_1 - C_2$ are then measured, using the previously determined set of isophotal contours to locate corresponding points in the two frames of a selected pair. A fit of the colour against $\log r$ (where r is the mean isophotal radius) is then performed in a carefully selected range of r, where the data are supposedly devoid of large systematic errors. It provides the reference colour at a specified r and the gradient $d(C_1 - C_2)/d\log r$ noted $\Delta_{C_1-C_2}$.

The adopted procedure offers the possibility to introduce small corrections to the initially adopted sky-background values, in order to cancel out the characteristic deviations from linearity that occur in the plot of $C_1 - C_2/\log r$ in the presence of background errors. This procedure may easily be criticized, since it introduces a perhaps unwanted constraint upon the determination of colour gradients (see also 2.2.1).

4. Results

4.1. Derivation of probable errors

Probable errors were derived from comparisons between the homogeneized data from various sources. Duplicate OHP observations were also considered, in an attempt to recover error estimates for this particular source.

4.1.1. Errors in colour gradients

Various possibilities were considered:

1. The gradients from OHP observations and the various surveys were intercompared with the following results:
   . Δ_{B-V}(OHP)-Δ_{B-V}(Gal94): N=18; mean=-0.009; $\sigma = 0.026$
   . Δ_{V-I}(OHP)-Δ_{V-I}(Gal94): N=8; mean=-0.043; $\sigma = 0.027$
   . Δ_{B-R}(OHP)-Δ_{B-R}(Pal90): N=6; mean=-0.003; $\sigma = 0.023$
   . Δ_{U-B}(OHP)-Δ_{U-B}(Pal90): N=5; mean=-0.038; $\sigma = 0.10$.
2. The Δ_{B-V} from Gal94 and Δ_{B-R} from Fal89 and Pal89 together (or F&P) were intercompared. Since the Δ_{V-R} gradients are very small according to BM87, their "cosmic scatter" is expected to be also small, and the differences are largely due to errors of measurements. They thus may provide another estimate of these.
   The results are, respectively for the data before and after the present revision of gradients:
   . Before Δ_{V-R} (Gal94)-(F&P): N=26; mean=-0.019; $\sigma = 0.043$
   . After Δ_{V-R} (Gal94)-(F&P): N=26; mean=-0.016; $\sigma = 0.031$
   This comparison again shows the non negligible improvement resulting from our teatment of the original data.
3. The tests from duplicate OHP data were performed as explained in our previous Paper V (see Michard & Poulain 2000), either measuring pseudo-colours from pairs of frames taken in the same pass-band, or comparing colours undependently measured. From 8 such experiments, we find a mean error of 0.035 for a single gradient estimate using OHP data.

Summing up the above results we note first that systematic errors in gradient measurement are not excluded! Our OHP data give V−I gradients smaller in the mean by 0.04 than the results derived from the Gal94 survey. This systematic effect dominates this particular comparison. For the other series, it appears that random errors in Δ_{B-V} and Δ_{B-R} may be about 0.02, but reaches probably 0.05 or more for Δ_{U-B}, as a result of poorer S/N ratio and reduced contrast of E galaxies against background in the U band.

4.1.2. Errors in reference colours

The "reference colour" is calculated, at some specific r value, from a linear fit to the colour variations against $\log(r)$. Although the same sources have been used to recalibrate the various colour data, residual errors occur in reference colours, due primarily to background effects. Uncertainties in the description of the central ranges of the objects are also likely to introduces errors, as noted above. In the following comparisons, reference colours were taken at r values of 15, 20 or 25 arcsec depending upon the properties of the object (size and dust patterens).

1. The comparison between reference colours from OHP data and other sources gives the following results:
   . B−V(OHP) - B−V(Gal94): N=18; mean=0.000; $\sigma = 0.028$
   . V−I(OHP) - V−I(Gal94): N=8; mean=0.020; $\sigma = 0.034$
   . B−R(OHP) - B−R(Pal90): N=5; mean=-0.008; $\sigma = 0.017$
   . U−B(OHP) - U−B(Pal90): N=4; mean=-0.019; $\sigma = 0.020$
   after rejection of an outlying value.
2. The tests from duplicate OHP data give:
   . C1−C2: N=8; mean=0.002; $\sigma = 0.013$

From these comparisons it seems that the mean error of a reference colour is about 0.02 or somewhat better.*This also applies to the mean colours derived below, because the number of multiple measurements is not large, except for B−V.*

4.2. Mean results

In Table 1 are listed so called "mean" reference colours at a specified positions in V surface brightness and radius, corrected for galactic reddening and the K-effect according to the precepts and data in the RC3. Mean logarithmic gradients have also been obtained. It should be realized that there is often only

Table 1. Mean colours and gradients. Reference colours, corrected for galactic extinction and K-effect, are given at the radius where the V-band surface brightness μ_V is 20. The reference is taken farther out if an important dust pattern is present (noted in the right column). Abbreviations for sources: B: BM87; F: Fal89; P: Pal90; G: Gal94; M: OHP observations by Michard and Marchal; H: HYPERCAT data base.

NGC	μ_V	$r0$	B−V	Δ_{B-V}	V−I	Δ_{V-I}	B−R	Δ_{B-R}	U−B	Δ_{U-B}	Source	Note
0596	20.0	12.9	0.90	0.05	1.16	0.08	1.43	0.06	—	—	GM	—
0720	20.0	16.7	0.94	0.07	1.23	0.04	1.50	0.05	0.52	0.23	FG	—
1052	20.5	21.8	0.92	0.08	1.21	0.06	1.50	0.13	0.49	0.17	PM	dust
1395	20.0	19.1	0.95	0.02	1.27	0.04	1.58	0.06	0.55	0.19	FG	—
1399	20.0	22.9	0.96	0.05	1.22	0.05	1.54	0.05	0.52	0.12	FG	—
1404	20.0	21.7	0.95	0.04	1.21	0.07	1.47	0.11	0.51	0.09	FG	—
1407	20.0	21.3	0.93	0.03	1.27	0.03	1.53	0.01	0.61	0.11	FG	—
1549	20.0	22.1	0.92	0.06	1.21	0.04	1.46	0.07	0.42	0.10	FG	—
1600	20.0	10.9	0.96	0.05	1.21	—	1.55	0.07	0.56	0.13	PH	—
1700	20.0	11.5	0.88	0.08	1.13	0.06	1.40	0.07	0.47	0.12	FH	—
2300	20.0	13.1	1.00	0.04	1.30	0.05	1.58	0.11	0.61	0.20	PGMH	—
2768	20.5	26.9	0.90	0.08	1.18	0.02	1.44	0.09	0.51	0.15	PM	dust
2986	20.0	12.7	0.96	0.00	1.23	0.02	1.53	0.04	0.55	0.14	FG	—
3377	20.0	17.5	0.85	0.09	1.11	0.05	1.38	0.09	0.35	0.17	PGM	—
3379	20.0	24.6	0.93	0.06	1.22	0.04	1.52	0.06	0.51	0.15	BPGMH	—
3610	20.0	12.1	0.79	0.05	1.03	0.05	1.32	0.03	0.41	0.11	GMH	—
3613	20.0	13.8	0.91	0.07	1.14	0.08	1.47	0.08	0.51	0.13	GM	—
3665	21.0	25.7	0.90	0.09	—	—	1.44	0.11	0.48	0.08	PM	dust
4125	20.5	27.8	0.89	0.07	1.16	0.06	1.41	0.06	0.53	0.13	GM	dust
4261	20.0	16.8	0.97	0.05	—	—	1.56	0.11	0.62	0.16	BPG	—
4278	20.5	22.0	0.91	0.10	1.13	0.11	1.41	0.18	0.49	0.22	PGM	dust
4374	20.0	25.9	0.93	0.05	1.15	0.04	1.48	0.07	0.56	0.15	BPG	dust
4406	20.0	27.5	—	—	1.21	0.07	1.51	0.07	0.54	0.12	BP	—
4472	20.0	38.0	—	—	1.24	0.06	1.58	0.03	0.58	0.14	BP	—
4486	20.0	31.5	0.94	0.10	1.24	0.07	1.53	0.08	0.54	0.26	PGH	—
4564	20.0	14.0	0.89	0.10	1.14	0.06	1.44	0.13	0.40	0.15	GM	—
4636	20.0	23.2	0.92	0.06	1.22	0.04	1.49	0.09	0.50	0.22	BPM	—
4697	20.0	26.8	0.89	0.04	1.16	0.01	1.45	0.06	0.42	0.15	PG	—
5813	20.0	11.6	0.95	0.09	1.27	0.08	1.54	0.06	0.54	0.08	PG	—
7144	20.0	11.5	0.96	0.07	—	—	1.55	0.13	0.40	0.24	FG	—
1459	20.0	19.5	0.89	0.05	1.25	0.06	1.48	0.06	—	—	FG	IC num.

one measurement for each object and colour. Indications upon the sources of measurements are given in the table. We emphasize that reference colours and gradients have been obtained *outside the regions affected by important dust patterns.*

A complete table of all new and "revised" measurements may be obtained from the author upon request.

4.3. Discussion of gradients

As examplified by Fig. 1, gradients in different colours are clearly correlated, notwithstanding the rather large errors of individual measurements. Relative values of the gradients thus convey information upon their physical cause(s). To obtain relative gradients less influenced by measuring errors, we proceeded as follows: first we defined a mean gradient for each object, as a weighted average of the gradients in the four derived colour indices. Several such mean gradients were tried, but they lead to similar results, so that only the simplest is used here, i.e. $\Delta_3 = (\Delta_{B-V} + \Delta_{V-I} + \Delta_{B-R})/3$. Then we calculated the regressions $\Delta_{B-V} = a_{B-V}\,\Delta_3$, and similar for other colours. No constant term is retained here, as they are thought to be physically meaningless, and proved to be of doubtful statistical significance. The results of the comparisons are then these 4 different a values with their mean errors, as derived from the dispersions around the regression.

On the other hand the same quantities Δ_3 and corresponding relative slopes a_{B-V}, a_{V-I}, a_{B-R}, a_{U-B} can be estimated from available theoretical work: we have derived these parameters from Worthey (1994), assuming that gradients result from the metallicity variations of a single burst stellar population, from similar work by Bressan et al. (1994) and also by Tantalo et al. (1996). On the other hand the same parameters can be estimated for gradients assumed to be due to diffuse dust, using calculations by Witt et al. (1992) and Wise & Silva (1996). Some approximations have to be made in using these works, but they should not have significant influence upon the conclu-

Table 2. Relative gradients in 4 colours expressed in terms of the mean Δ_3. Sources of data are: (1) Observed, Table 1. (2) Worthey (1994), (3) Bressan et al. (1994), (4) Tantalo et al. (1996), (5) Wise & Silva (1996), (6) Witt et al. (1992), (7) law of Galactic extinction

Data	a_{B-V}	σ	a_{V-I}	σ	a_{B-R}	σ	a_{U-B}	σ
(1)	0.92±.11	.014	0.83±.12	.014	1.23±.14	.017	2.14±.48	0.066
(2)	0.83	—	0.96	—	1.21	—	2.27	—
(3)	0.78	—	0.96	—	1.25	—	1.48	—
(4)	0.82	—	0.96	—	1.23	—	1.71	—
(5)	—	—	—	—	1.00	—	0.64	—
(6)	0.59	—	1.40	—	1.01	—	0.34	—
(7)	0.90	—	1.26	—	1.58	—	0.51	—

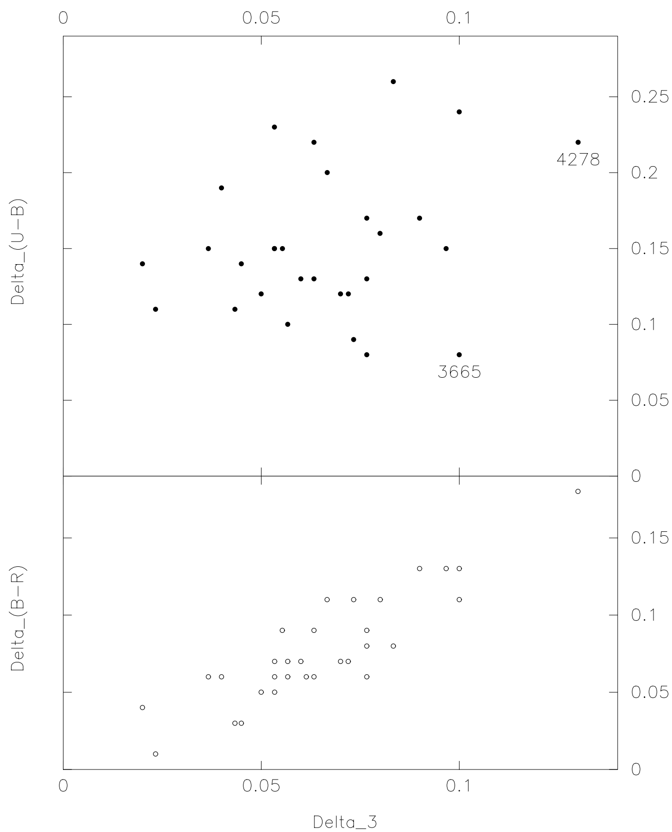

Fig. 2. Correlation diagrams between the mean gradient Δ_3 (abscissae) and the Δ_{B-R} (bottom) and Δ_{U-B} gradients. The U−B against Δ_3 correlation may be even worse than implied by the large errors of measurements for this colour.

sions: the colour systems in the various used theoretical works are not always the same, and eventually also differ from the one of the observations, but this is of negligible consequence for our purpose. Also the evaluation of colour gradients from Witt et al. (1992) tables is not rigorous (see below).

Table 2 contains observed values and theoretical estimates for the relative gradients a_{B-V}, a_{V-I}, a_{B-R}, a_{U-B} in terms of the mean one Δ_3. The "sources" for various lines are as follows:

1. Calculated values from observations in Table 1.
2. Worthey (1994), Table 5A, colour differences for models of age 17 Gyr with [Fe/H] 0.5 and -0.5.
3. Bressan et al. (1994), Table 3, colour differences for models of age 15.8 Gyr with Z=0.02 and Z=0.008.
4. Tantalo et al. (1996), colour differences for models of age 15.8 Gyr with Z=0.02 and 0.004.
5. Wise & Silva (1996), Table 2, their preferred model with $\gamma = 0.5$ and $\alpha = 1$. Since only Δ_{B-R} and Δ_{U-R} are given, the Δ_3 is here assumed to be equal to Δ_{B-R}.
6. Witt et al. (1992), E galaxy model with $\tau_V = 2$. The colour gradients are estimated by comparing the tabulated emergent light at galaxian center, with the one along a line of sight at very large r, and therefore unaffected by dust and with zero colours in Witt at al. conventions.
7. law of galactic absorption: it would correspond to a thin galaxy.

A glance at Table 2 shows that *the models where colour gradients result exclusively from diffuse dust throughout the galaxies do not agree with the obsevations: the calculated a_{U-B} values are much too small and the a_{V-I} too large*. On the other hand the relative observed colour gradients are compatible with gradients induced by metallicity variations. In the evaluation of the parameter a_{U-B}, the theories of the evolution of old stellar populations deviate more from each other than they do from the present observed gradients!

In Fig. 2 we compare the correlations between the Δ_3 mean gradients and the Δ_{B-R} and Δ_{U-B} gradients respectively. Other plots for Δ_{B-V} and Δ_{V-I} are of similar appearance as the one for Δ_{B-R}, but for the average slope. The correlation between Δ_{B-R} and Δ_3 is good and probably limited mainly by errors of measurements. On the other hand the correlation between Δ_{U-B} and Δ_3 is very bad, as also illustrated by the large corresponding σ in Table 2. Our estimate of random errors in the Δ_{U-B} is too uncertain to tell if this large dispersion is real, at least in part.

It should be noted however that Δ_{U-B} is very sensitive to metallicity variations and relatively little to the effects of diffuse dust. The reverse is true for the other colour gradients entering the Δ_3 mean. *If various amounts of diffuse dust, together with unequal metallicity gradients, occur in E-galaxies (as is probably true!), then important variations in the ratio of Δ_{U-B} to Δ_3 (or other dust sensitive gradients such as Δ_{V-I}) are possible.* As an argument in favor of this hypothesis one may note that the two objects with the smallest ratio of Δ_{U-B} to Δ_3 are

NGC3665 and 4278, that is the two galaxies with the largest amount of *apparent* dust in the sample (noted at the right in the graph of Fig. 2)

5. Conclusion

Using literature data and available OHP frames, we have produced a sample of 26 ellipticals with full colour data in B−V, V−I, B−R and U−B, plus 5 more with only three colours available. The data have been placed in a unique colour system. Some objective estimates of errors have been obtained, but they remain statistically unsufficient.

The gradients in each colour Δ_{B-V}, Δ_{V-I}, Δ_{B-R} and Δ_{U-B} have been correlated with the mean Δ_3 of the first three values. These correlations are good in B−V, V−I, B−R, with σ values not larger than estimated errors. It is poor in U−B with a possible contribution of "cosmic scatter". The calculated slopes may be compared with theoretical estimates based upon metallicity variations on the one hand, and upon diffuse dust effects on the other. It appears that the second hypothesis cannot explain the observed relative gradients, while the first one may be more adequate (Table 2).

New observations in U−B are needed to ascertain the respective contributions of real variations and measurement errors in the observed gradients for this colour, as compared to mean gradients such as Δ_3. Observed gradients might be due to contributions of both population gradients and diffuse dust in defining the colours.

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