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Star formation history of early–type galaxies in low density environments

III. The isophote shape parameter and nuclear line–strength indices

R. Rampazzo[1], **M. D'Onofrio**[2], **P. Bonfanti**[1], **M. Longhetti**[3], **and L. Reduzzi**[4]

[1] Osservatorio Astronomico di Brera, Via Brera 28, I-20121 Milano, Italy
[2] Dipartimento di Astronomia, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy
[3] Institut d'Astrophysique, 98 bis, Boulevard Arago, F-75014 Paris, France
[4] Istituto di Fisica Applicata, Università di Milano, Via Brera 28, I-20121 Milano, Italy

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Abstract. Using two line–strength indices, H+K(CaII) and $\Delta 4000$, sensible to the age of the stellar population, we analyze the correlations between the shape and the 'galaxy age' suggested by de Jong & Davies (1997) on the basis that discy galaxies have higher H_β indices.

By enlarging their sample with the present one, we find that the significance of the correlation a_4/a vs. line– strength indices disappears.

We conclude that the 'age of the stellar population of early-type galaxies' is not correlated to the isophote shape parameter.

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

1. Introduction

The measure of the isophotal shape parameter a_4/a, i.e. the coefficient of the fourth cosine term of the residuals of the isophotal interpolation, as function of the galactocentric distance, (Bender et al. 1989 and reference therein) has become routine when early–type galaxy photometry is performed. Since its definition, it has been considered a key element in understanding the formation/evolution of the early–type galaxies (Bender et al. 1989; Schweizer 1992 and reference therein). Both static experiments on light decomposition (Rix & White 1990) and numerical simulations (Stiavelli et al. 1991; Fullagar et al. 1992; Governato et al. 1993; Lima-Neto & Combes 1995) have begun to cast doubts about the capability of a_4/a to produce evidences connected to the galaxy history. As expected a_4/a is partly determined by projection effects. Moreover, different formation mechanisms could produce, without distinction, galaxies predominantly boxy ($a_4/a < 0$) or discy ($a_4/a > 0$). At the same time, a_4/a is a "measure" of the link between ellipticals and lenticular galaxies (Capaccioli et al. 1990).

Recently, de Jong & Davies (1997: dJD97 hereafter) correlated the values of a_4/a available from the literature for a sample of elliptical galaxies with the line–strength index H_β derived by Gonzalez (1993: G93 hereafter). The trend of the correlation they observe indicates that discy ellipticals have higher values of H_β than boxy objects. The H_β index is considered sensible to the age of the galaxy (Buzzoni et al. 1992; Worthey 1992; G93). The combination of H_β and [MgFe] has been identified as able to break the degeneracy between age and metallicity (Worthey 1994). dJD97 suggest that the observed trend can be brought about by a contaminating young population and associate it to the presence of the discy component. They simulated the contamination of a 12 Gyr old population by a 2 Gyr old stellar component, corresponding to a small fraction of 10% of the total galaxy mass, showing that the latter is sufficient to explain the above trend. This small fraction in mass is consistent with estimates of disc–to–total light ratio obtained by detailed galaxy surface photometry. dJD97 speculate about the origin of the discy component. The stellar mass loss or an accretion event are considered by dJD97 as possible origin. They suggest that the metallicity of the discy component, obviously not yet available, could be the discriminating parameter.

Other indices are considered sensitive to the age of the stellar population, in particular those located in the "blue" part of the spectrum as described in Longhetti et al. (1998a and reference therein). Besides H_β in this note we analyze the correlations between the isophotal shape parameter a_4/a and the line–strength indices H+K(CaII) and $\Delta 4000$ in order to further investigate the validity of the relation between shape and age found by dJD97.

The note is organized as follows. In Sect. 2 the salient characteristics of the sample in low density environment (LDE) are resumed. In Sect. 3 we summarized the characteristics of $5''$nuclear indices we use in the study. We investigate in Sect. 4 the correlations between the nuclear indices sensible to the age of the galaxy stellar population and the isophotal shape parameter.

Send offprint requests to: R. Rampazzo

2. The sample of galaxies in LDE

The sample of early–type galaxies in LDE analyzed in this paper is fully described in Longhetti et al. (1998 a, b: Paper I and Paper II respectively thereafter). Briefly, our sample is composed of 21 shell galaxies in the southern hemisphere taken from the list of Malin & Carter (1983) and of 30 pair members from the Reduzzi & Rampazzo (1995) catalogue. The average total apparent B–magnitude (deduced from the Lauberts & Valentijn 1989 catalogue: ESO-LV hereafter) is $\langle B_T\rangle = 12.8\pm1.5$ ($9.1 \leq B_T \leq 15.0$) and $\langle B_T\rangle = 13.6\pm1.1$ ($11.3 \leq B_T \leq 15.7$) for shell galaxies and pair members respectively. The average morphological type is $\langle T\rangle = -3.3\pm1.2$ and $\langle T\rangle = -2.7\pm1.4$. One of the shell galaxies (ESO 240-010) has a double nucleus and we refer to it as two separate objects. A large fraction of pair members show fine structures as reported in Paper I.

We characterize the density of the environment using the parameter N_{tot} given in the ESO-LV. This parameter gives the surface galaxy density within one degree from a specific object. ESO-LV considers that the value $N_{tot} \geq 9$ describes rich environments, such as the Fornax cluster. The average $\langle N_{tot}\rangle$ value for pair members is 2$\pm$1.5, while for shell galaxies is 1.5$\pm$0.9 indicating that galaxies in the sample are located in very low density regions.

The basic sample of dJD97 is composed of galaxies in the G93 sample. Ellipticals in the G93 sample include 7 galaxies in the centre of the Virgo cluster, but the bulk of them are located in loose groups and/or in the field. An analysis of fine structure made by Schweizer et al. (1990) on a set of early-type galaxies include 15 objects in the original G93 sample. The fine structure parameters, Σ, for these objects ranges from 0.0 to 3.7, revealing, according to Schweizer et al. the presence of post interacting objects. Furthermore, G93 noticed that his sample contain many galaxies showing [OIII] in emission.

We then consider that our sample, composed of pair members and shell galaxies, has similar characteristics of the original G93 sample both because is composed of field objects and because it contains objects showing fine structure. We then believe it may be added with confidence to the original dJD97 sample in order to study the validity of the correlation between a_4/a and H_β they found.

3. H_β Δ4000 and H+K(CaII) indices

Among all the indices in the Lick-IDS system the $H\beta$ index is the most widely adopted as age indicator. Like all the Balmer absorptions, the $H\beta$ line appears very weak in the cold stellar types (M, K), while its intensity grows with temperature, reaching its maximum value in the A type stars spectra. The H_β index measurement could be contaminated by the infilling due to the presence of the possible emission component. This certainly is the case of some early-type galaxies in our sample, since we are considering interacting or post–interacting objects. A detailed analysis of the presence of emission lines is discussed in Paper II.

G93 applied a correction to the H_β index using the [OIII](λ 5007) emission line. This correction has been questioned by Carrasco et al. (1995). Furthermore, the range of the ratio [OIII]/H_β is quite large in LINERs and HII regions making the emission correction rather uncertain (Phillips et al. 1986; Ho et al. 1993). At difference of dJD97, we then prefer to use the uncorrected H_β value. This is not relevant to the reserch of a correlation between the index and the shape parameter as dJD97 found that their relation is valid also for uncorrected H_β values.

The nuclear indices of the Lick-IDS system are indicated in Paper I as *red* indices since they cover a part of the optical spectrum between 4200 and 6400Å. The "blue" part of a galaxy spectrum is, anyway, much more sensitive to the age of the stellar population than the "red" one. In Paper I we measured three *blue* line–strength indices, not present in the Lick set, in the wavelength range $3750 < \lambda <$ 4200Å, namely, H+K(CaII) and Hδ/FeI indices, defined by Rose (1984, 1985), and the $\Delta4000$ index defined by Hamilton (1985).

The H+K(CaII) index represents the ratio between the central intensity of the H(CaII)+$H\varepsilon$ line (a blend of the H(CaII)3968.5Å with the Balmer $H\varepsilon$) and that of K(CaII)3933.7Å line. Like H_β this index is again a measure of the presence of the Balmer line. Also in this case the $H\varepsilon$ in emission could contaminate the measure.

The $\Delta4000$ index maps the break at 4000Å. It is defined as the ratio of the average fluxes (for frequency unit) measured in the spectral ranges [4050Å-4250Å] and [3750Å-3950Å]:

$$\Delta(4000\text{Å}) = \frac{F_\nu[4050\text{Å} - 4250\text{Å}]}{F_\nu[3750\text{Å} - 3950\text{Å}]}. \qquad (4)$$

The definition of this index needs a measure of fluxes per frequency units [Hz^{-1}], while data are calibrated in counts per wavelength units [Å^{-1}]. The ratio between fluxes/Å has been multiplied by a correction factor:

$$(\lambda_1/\lambda_2)^2 = (4150/3850)^2 = 1.162$$

where λ_1 and λ_2 represent the central wavelength of the two spectral bandpasses adopted for the Δ(4000Å) measure. This index gives information about the stellar parameters of the *turn off* stars, and consequently about the mean age of the stellar population (Worthey 1992). The $\Delta4000$ index is clearly not contaminated by emission lines.

Corrections applied to 5$''$ nuclear indices, are reported in Paper I. In particular, the correction for the galaxy velocity dispersion has been obtained using original kinematic data discussed in Paper II.

4. Study of the correlations between a_4/a H_β, H+K(CaII) and Δ4000 line–strength indices sensible to the age of the stellar populations

We discuss the dJD97 correlation **(1)** adding to their sample the set of our galaxies for which a measure of a_4/a is available and **(2)** verifying it on the new set of indices sensible to the age, namely H+K(CaII) and $\Delta4000$ defined above.

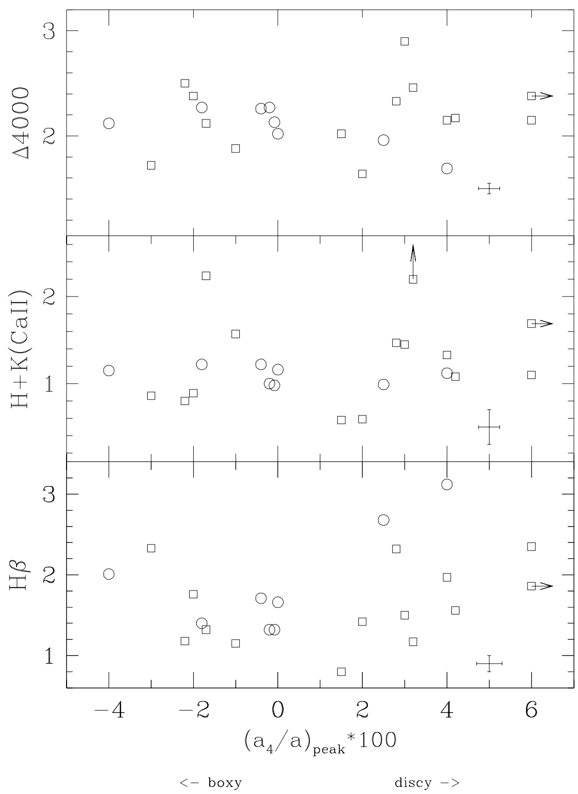

Fig. 1. The a_4/a isophote shape parameter vs. the H_β (*bottom panel*), H+K(CaII) (*intermediate panel*) and $\Delta4000$ (*upper panel*) 5″nuclear line–strength indices. Shell galaxies and pair members are represented with open circle and open square symbols respectively. Error quoted both for a_4/a and line–strength indices are the typical formal errors coming from observations.

It is quite difficult to select a value of a_4/a along the isophotal shape radial profile which characterizes the entire galaxy, so several and different strategies have been adopted by different authors (see the discussion in Governato et al. 1993). We consider that a representative value of a_4/a is the 'peak' value of the distribution as function of the radius, similarly to the original definition in Bender et al. (1989). We set this parameter to zero those which have an irregular shape profile. Values of the a_4/a for pair members and shell galaxies have been obtained from the photometry of Bender et al. (1989), Caon et al. (1994), Goudfrooij (1994), Jörgensen et al. (1992), Jörgensen (1995), Reduzzi & Rampazzo (1996), Reid et al. (1994) and Sparks et al. (1991).

As a first step we study the correlation between a_4/a and H_β of galaxies in the G93 sample (30 objects). The correlation coefficient is given in the first row of Table 1 and is consistent with the conclusion reached by dJD97. We find indeed that the probability of obtaining a correlation coefficient r_0=0.37 by chance is less than 5.2%. According to Pough & Winslow (1966) this is at the limit of a significant correlation. As noticed by these authors the result is independent of the system of H_β values adopted (i.e. corrected or not for the emission contamination and the aperture radius at which the value is determined). The

Table 1. Correlation between a_4/a and H_β, H+K, and $\Delta4000$

α	N.	A	B	r_0	P_N	sample
H_β	30	1.70±0.04	0.08±0.03	0.37	5.2	G93
H_β	14	1.56±0.15	0.03±0.02	0.25	39.9	P
H_β	8	1.90±0.17	0.18±0.09	0.66	8.0	S
H_β	22	1.67±0.11	0.04±0.02	0.25	27.6	F
H_β	52	1.69±0.05	0.04±0.02	0.26	6.3	G
H+K(CaII)	14	1.40±0.28	0.04±0.03	0.15	60.3	P
H+K(CaII)	8	1.10±0.03	-0.01 ± 0.01	-0.36	38.0	S
H+K(CaII)	22	1.29±0.17	0.04 ± 0.03	0.18	43.2	F
$\Delta4000$	14	2.16±0.10	0.02±0.01	0.25	39.7	P
$\Delta4000$	8	2.09±0.04	-0.06 ± 0.03	-0.73	4.3	S
$\Delta4000$	22	2.14±0.06	0.01±0.01	0.14	55.6	F

Notes. N in column 2 is the number of points in the linear interpolation $a_4/a = A + B\ \alpha$. Legenda: G93 = the Gonzalez (1993) sample; F = total field sample; S = shell sample; P = southern pair sample; G= the field + the G93 sample. P_N is the probability that N measurements of two uncorrelated variables give a correlation coefficients r lower than r_0. This gives an indication of the presence of a correlation. In particular, $P_N(|r| >= r_0) \leq 5$ (%) indicates the presence of a significant correlation. $P_N(|r| >= r_0) \leq 1$ (%) indicates that the correlation is highly significant (Pough & Winslow 1966))

above result confirm us that a_4/a values we adopt are consistent with those derived by dJD97, which are not explicitly given in their paper. The slightly lower significance found by us with respect DJD97 is determined from the fact they discarded from their fit objects with $\epsilon \leq$0.15 i.e. 11 objects, corresponding to about 1/3 of their entire sample, why we use the entire set of objects.

We then study the a_4/a – H_β correlation for our sample (pairs members + shell galaxies) and for to the global sample (our + G93), indicated indicated with F and with G in Table 1 respectively. The F sample is composed of 22 galaxies for which we have both an accurate measure of the index and a "safe" determination of a_4/a actually much less than the number of galaxies for which we have indices. Anyway, it corresponds to an increase of ≈70% of the original dJD97 sample. Adding this sample, the correlation between a_4/a and H_β loses its significance as may be deduced from the correlation probability, P_N, given in Table 1.

We continue the study looking for a correlation between the isophotal shape parameter and the other indices sensible to the age of the stellar population. Fig. 1 and Table 1, in which the coefficients are given, indicate that there is no significant correlation between them. Only in the case of shell galaxies, 8 objects in total, the correlation suggests that discy objects have lower $\Delta4000$ i.e. discy objects seems younger than boxy ones. It is clear that a much larger sample is necessary to draw a firm conclusion on these objects.

5. Summary and conclusions

In this note we re-considered the relationships between the shape parameter, a_4/a and the H_β line–strength index. Our basic sample (Paper I) is composed of galaxies in the field, most of which show signatures of present/past interaction. Also the bulk of the G93 sample, used by dJD97, is composed of field galaxies, some of which show a complex fine structure. With this new set of galaxies we sensibly increase the number of objects for which it is possible to test the relationship found by dJD97. Besides H_β we consider also H+K(CaII) and $\Delta 4000$ indices sensible to the age of a galaxy stellar population. A further advantage is that $\Delta 4000$ measure is not contaminated by emissions.

Enlarging the original dJD97 sample with the present one, the correlation between a_4/a and H_β becomes not significant. 'Blue' indices, H+K(CaII) and $\Delta 4000$ confirm the lack of correlation with the shape parameter. We wish to emphasize that a large dispersion in the H_β indices is present not only in the interacting sample but also in the dJD97 one. We think that this is a consequence of the presence in dJD97 of galaxies showing morphological peculiarities. According to Schweizer et al. (1990) there are in the sample objects which have to be interpreted as post interacting objects. Starbursts induced by the interaction are probably responsible for the large spread in the indices which reflect the luminosity weighted, "average age" of the stellar population of the galaxies examined.

In this framework, in the global sample (G93 + our) do not represent different classes of objects but different phases of the galaxy evolution driven by the interaction. Starting from unperturbed objects in the dJD97 sample (e.g. those with $\Sigma = 0.0$) the global sample is a collection of snapshots of different interaction phases. Indices of some galaxies appears "nearly" indistinguishable from those of unperturbed objects, as the burst is old enough, the recovering time depending on the strength of the burst (see Bressan et al. 1996). Other galaxies have traces of recent star formation. They lurk not only among higher H_β values but also among low values as a consequence of a possible infilling of the emission component. The large dispersion found also in the H+K(CaII) and $\Delta 4000$ indices gives futher support to this view.

In contrast to dJD97, discy isophotes do not appear to be the signature of a young disc component. Our scenario does not predict any correlation between stellar population and the isophote shape. Merging processes tend to destroy or weakening stellar disks rather than create them (see Barnes 1998 and references therein). Most of SPH simulations, both in cases of major/minor merging (Barnes & Hernquist 1991; Mihos & Hernquist 1994) as well as in simple encounters (Noguchi 1988) show that the gas, the necessary ingredient for triggering bursts of star formation, is rapidly driven toward the primary galaxy center and concentrates in a compact region.

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