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Peculiarities and populations in elliptical galaxies

II. Visual-near IR colours as population indices⋆,⋆⋆

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Abstract. As a complement to the data collected and discussed in Paper I of this series, 2MASS near-IR images have been used, in connection with available V light aperture photometry, to derive the colours $V-J$, $V-K$, $J-H$ and $J-K$ within the effective aperture A_e: nearly the same complete sample of 110 E-type galaxies is treated. In Paper I these were classified, based on morphological criteria, into the "peculiar" (or *Pec*) and "normal" (or *Nop*) subsamples.
For the *Nop* subsample, the derived colour indices are tightly related to the galaxy masses, as measured by the central velocity dispersion σ_0, although with rather small slopes as regards $J-H$ and $J-K$. For the *Pec* subsample, the $V-J$ and $V-K$ colours behave as *UBV* and line-indices: part of the objects show *blue residuals* from the appropriate colour-σ_0 regression, which is evidence of a younger population mixed with the "normal" one traced by the *Nop* regressions; the other shows no deviations from the *Nop* subsample. The distinction among *Pec* objects between the *YP* family (NGC 2865 type), and the *NP* one (NGC 3923 type), is statistically supported, and generally confirmed in specific cases.

Key words. galaxies: elliptical and lenticulars, cD – galaxies: photometry

1. Introduction

The present paper introduces a complementary dataset into our previous discussion in Paper I (Michard & Prugniel 2004) of the relations between morphological peculiarities and stellar population indices in a nearly complete sample of local E-type galaxies. Indeed the publication of the Large Galaxies Atlas from 2MASS observations (Jarrett et al. 2003) was crucial to make possible the derivation of broad-band colours for many local galaxies of large apparent diameters.

According to classical calculations of the colours of stellar populations (Worthey 1994; Bressan et al. 1994), or to more recent such contributions (Bruzual & Charlot 2003), the near-infrared indices $J-H$ and $J-K$ accessible from 2MASS are not very sensitive to the properties of such populations as encountered in ellipticals. This is not the case however for indices measured across the broad near-IR maximum of the energy distribution of old stellar populations, typically $V-J$ or $V-K$, which provide good metallicity and/or age criteria. We have therefore derived these two colours, not neglecting of course $J-H$ and $J-K$, for 110 galaxies of the sample of Paper I.

In Sect. 1 the definition of the sample and of its previously determined morphological properties are briefly summarized. Then, the derivation of the new data, i.e. the four above-quoted colour indices, is described. Section 2 contains a discussion of these data which follows closely the steps of Paper I. We first derive the characteristic correlations between the galaxy mass, as measured by the central velocity dispersion σ_0, and the various population indices. Then the *residuals* from these regressions are calculated for the objects of the *Pec* subsample. For $J-H$ and $J-K$ these quantities are not much dependent on morphological peculiarities, as is the case for the ⟨Fe⟩ index. For $V-J$ or $V-K$ on the other hand, they behave like the other population sensitive colours and line-indices in Paper I.

It was shown there that the effects of morphological peculiarities on stellar populations could not be reduced to the "classical" picture (Schweizer et al. 1990; Schweizer & Seitzer 1992). The *Pec* subsample must be separated in two groups, the *YP* (or NGC 2865) family and the *NP* (or NGC 3923) family. Objects in the *YP* one show evidence of a younger population added to the standard old star mixture of ellipticals, while *NP* objects have quasi-normal populations.

2. The sample and the new data

2.1. Sampled objects

In Paper I we treated a nearly complete sample of confirmed ellipticals bound in distance to a modulus of 33.52 and brighter than $B_T = -18.8$. The sample is extracted from a catalogue by Prugniel & Simien (1996) with a few objects added: it

⋆ Based in part on observations collected at the Observatoire de Haute-Provence.
⋆⋆ Table 4 is only available in electonic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/429/819

contains 114 galaxies. In the present paper, this figure is reduced to 110:3 objects could not be measured in 2MASS frames and one was forgotten.

For all objects in the Paper I sample, such morphological peculiarities as isophote asymmetries, shells, jets or similar features, were studied and qualified by an ad hoc Σ_2 index. This is not a purely qualitative scale. It incorporates: i) actual measurements of the amplitude and radial range of asymmetries of the isophotal contours; ii) the careful counting of distinct "features" such as "shells" (Malin & Carter 1983), "ripples" (Schweizer & Ford 1984), "jets" or "fans". See Paper I for details.

The objects with $\Sigma_2 < 1$ are designed as "non peculiar" or "normal" and form the *Nop* subsample. The other galaxies are assumed "peculiar" and members of the *Pec* subsample; their Σ_2 reaches 10.6 for NGC 2865 and 10.3 for NGC 3923. In the present slightly modified sample, there are only 35 *Pec* objects instead of 37, as NGC 1344 and 3640 could not be measured in 2MASS.

2.2. Measurements

2.2.1. *V*-light data

Several authors, besides the well known Reference Catalogue of Bright Galaxies (RC2 and RC3), have fitted aperture photometry data to ad hoc "growth curves" in order to derive by extrapolation an asymptotic total magnitude, hence the effective aperture A_e and the corresponding integrated magnitude. An exploratory comparison of several sources (RC3; Michard & Marchal 1994; Prugniel & Simien 1996; Prugniel & Héraudeau 1998) shows puzzling accidental and systematic differences between them. For this reason the use of the original photometric data was preferred to the use of these catalogues in order to get an accurate V_e magnitude at the selected A_e. The choice of A_e is not critical for our present purpose, because the integrated colours change quite slowly with the limiting aperture. We used either the A_e values of Paper I, or those derived in Poulain (1988) and Poulain & Nieto (1994). Two techniques were used to obtain $V(A_e)$:

- Published aperture photometry could be interpolated at the chosen A_e. Our preferred sources were the observations by Poulain (1986, and above references), which are available for 89 objects. For the others we used the aperture photometry collected in the HYPERLEDA data base maintained by the Centre de Recherches Astronomiques de Lyon.
- Calibrated *V* frames from Observatoire de Haute-Provence were available for many northern objects (Michard & Marchal 1994; Idiart et al. 2002; HYPERLEDA data base). They are particularly useful to get reliable $V(A_e)$ by integration, especially for large objects where the measurements of aperture photometry do not extend as far as A_e. Since these frames were calibrated from the same sources as above, the two techniques give results in perfect agreement when they both apply.

2.2.2. Near IR data

It is quite straightforward to get *JHK* photometry precisely at the selected A_e, by integration of the 2MASS frames, either from the Large Galaxy Atlas or the Extended Source Catalogue. The colours $V-J$, $V-K$, $J-H$ and $J-K$ are readily derived.

2.2.3. Corrections

Tables of K-corrections have been recently published by Poggianti (1997) and Mannucci et al. (2001). The first source has been used because it agrees better, for optical colours, with the system used in Paper I.

The values of galactic extinction for each object have been taken from the RC3, while the relative coefficients for each colour are from Rieke & Lebofsky (1985). The galactic reddening for $V-J$ and $V-K$ is much larger than for the currently used optical colours. For instance the colour excess $E(V-K)$ is 2.74 $E(B-V)$, and important errors may be induced in the colours of objects of relatively low galactic latitude. An interesting possibility might be to use these "dust sensitive indices" for a search of the effects of internal dust on colours and colour gradients. Witt et al. (1992) compare the effects of internal dust in the *V* and *K* bands. Michard (in preparation) tries to ascertain dust effects in $V-J$ and $V-K$ radial gradients.

2.2.4. Errors

- *Near IR colours*. The colour–colour diagram of $J-H$ and $J-K$ is quite tight, with $\sigma < 0.011$. Since the errors in the two colours are not uncorrelated, we can only state that their probable value cannot much differ from this σ-value. On the other hand, the colours $J-H$ and $J-K$ correlate well with the velocity dispersion $\log\sigma_0$, especially for the *Nop* subsample of regular and symmetric galaxies. The slopes of the relations of colour against $\log\sigma_0$ are small (see below), so that a large part of the residuals from the regressions are due to errors in the colours, although "cosmic scatter" is no doubt present. This situation is more extreme for the $H-K$ colour, which is nearly constant, but for errors. The standard deviations of these residuals is only 0.013 for $H-K$, a value which we consider as an upper limit to the probable error on the 3 measured near IR colours.
- *Errors in $V(A_e)$ and $V-JK$ colours*. From multiple observations Poulain & Nieto (1994) give a value of 0.038 for the mean error of one *V* measurement in one aperture. Since 4 or 5 of their measurements are involved in the interpolation of $V(A_e)$ for most of our sample, the probable error on this quantity could be near 0.018, if these combined measures were independent: this is not the case since they are obtained in a given night. We have obtained duplicate estimates of $V(A_e)$ for 24 galaxies using duplicate independent observations in Poulain (1986) and later papers. The standard deviation between pairs of $V(A_e)$ is 0.027: this points to a value of 0.019 for the probable error in a single measurement, in perfect agreement with the above derived figure.

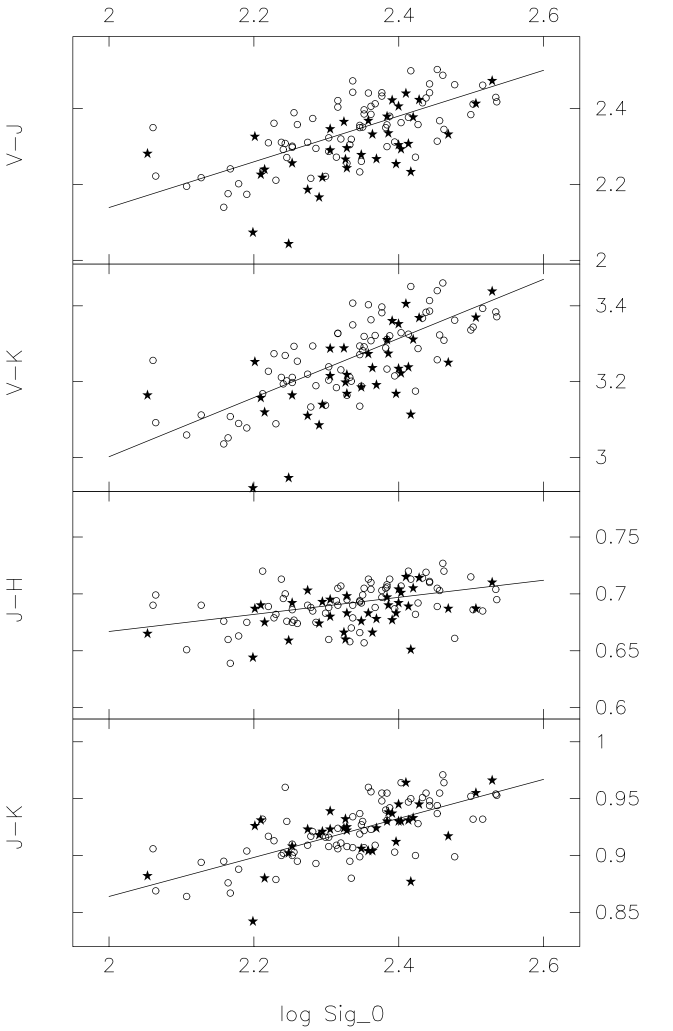

Fig. 1. The colour-σ_0 relations for *Nop* galaxies (circles and fitted lines), and *Pec* objects (stars). The calculated regressions for the *Nop* subsample are shown. In $V - J$ and $V - K$, part of the "peculiar" objects tend to be bluer than "normal". This effect is lessened in the high mass range, and much reduced in $J - H$ and $J - K$.

From the derivation of the probable errors for the near IR colours within A_e on the one hand, and the $V(A_e)$ values on the other, we estimate the probable error on $V - J$ or $V - K$ to lie near their quadratic sum of 0.023, *and adopt 0.025 as a reasonable value.*

3. The relations of the *VJHK* colours with the velocity dispersion

The properties of the colour indices collected here may be described as follows:

1. *Graphs*. The correlations between the galaxy mass, as represented by the central velocity dispersion $\log \sigma_0$, and the newly derived colours $V - J$, $V - K$, $J - H$ and $J - K$ are plotted in Fig. 1, with distinct symbols for the *Nop* and *Pec* subsamples. For $V - J$, $V - K$ the diagrams are similar to $B - V$ or $U - V$ (see Paper I), with part of the *Pec* galaxies distinctly bluer than implied by the relatively tight correlations of the *Nop* subsample. Part of the "peculiar", however, have normal colours, or nearly so, especially in the higher $\log \sigma_0$ range. The $J - H$ and $J - K$ colours appear generally not sensitive to morphological peculiarities.
   A check has been made of an eventual effect of large galactic extinction errors, by plotting the diagrams of Fig. 1, for $V - J$ and $V - K$, with distinct symbols for the objects with large extinction, $A_g > 0.5$ in the RC3 notation. These however appear well mixed with the others.
2. *Reference correlations for the Nop sample.* In Table 1 are given the correlations between the colours collected here and $\log \sigma_0$. The coefficients of correlation and the slopes for $V - J$, $V - K$ are as large as for the classical luminosity indicator $U - V$, while the σ values are not much larger. The $J - K$ from 2MASS on the other hand, might be as useful a luminosity indicator as $B - V$ for "normal" ellipticals. The slope becomes quite small for $H - K$ and the σ-value of 0.013 was taken above as an upper limit of probable errors in the 2MASS derived colours.
3. *Colour residuals of Pec galaxies from the reference* $\log \sigma_0$ *relations*. Table 2 gives the O–C residuals between the observed colours of the 35 *Pec* galaxies and the ones predicted from the above reference relations: these are noted $\Delta V - J$ and similarly for other colours. The "Mean Index of Younger Population" (*MIYP*), defined in Paper I as a weighted mean of the $\Delta U - B$, $\Delta B - V$, ΔMg_2, ΔMg_b, $\Delta H\beta$ residuals, has been added to the table for comparison. Also added is our classification of *Pec* objects into the *YP* family (type NGC 2865) with evidence of mixing of a young population, and the *NP* one (type NGC 3923) with no such evidence. Table 3 summarizes the statistics of the O–C residuals in Table 2.
4. *Comparison with Paper I results*. It appears from Table 2 that the $\Delta V - J$ and $\Delta V - K$ residuals are generally compatible with our classification of objects into the *YP* and *NP* families, i.e they show large negative values for the first one and remain near zero for the other. Notable exceptions are NGC 2768 and 4406, too blue for their *NP*: classification (doubtful), IC 3370 too red for the *YP* family and NGC 7454 found much too red. The $V - J$ residuals are correlated with the ad hoc index *MIYP*: we find $\Delta V - J \simeq 2 \times MIYP$ with a dispersion of 0.060 about this regression, or 0.054 rejecting the outlyer NGC 7454. This

Table 1. Populations of the "normal" Es (*Nop* subsample). The correlations between the central velocity dispersion and the various colour-indices are given in the form $y = px + y0$, where $x = \log \sigma_0$ (1) Index; (2) Number of objects (not taking into account the 1 to 3 rejected by the least squares routine); (3) Mean value C_m (4) Slope p; (5) Intercept y_0; (6) Standard deviation σ; (7) Coefficient of correlation ρ.

Index	N	C_m	p	y_0	σ	ρ
$V - J$	74	2.341	0.604 ± .068	+0.932 ± .007	.060	0.73
$V - K$	73	3.263	0.780 ± .076	+1.441 ± .008	.071	0.74
$J - H$	75	0.692	0.075 ± .018	+0.517 ± .002	.017	0.44
$J - K$	73	0.921	0.172 ± .019	+0.520 ± .002	.018	0.72
$H - K$	71	0.230	0.084 ± .014	+0.035 ± .001	.013	0.57

Table 2. Residuals of the *VJHK* colours of ellipticals in the *Pec* subsample, against the standard relations calculated for the *Nop* subsample between Indices and the central velocity dispersion. (1) Name; (2) Σ_2 index of peculiarity; (3) $\Delta V-J$, $V-J$ residuals; (4) $\Delta V-K$, $V-K$ residuals; (5) $\Delta J-H$, $J-H$ residuals; (6) $\Delta J-K$, $J-K$ residuals; (7) "Mean Index of Younger Population" or *MIYP* (see definition in text) in mag; (8) Character of population: YP, Young Population present, NP, probably normal population, : doubtful.

Name	Σ_2	$\Delta V-J$	$\Delta V-K$	$\Delta J-H$	$\Delta J-K$	*MIYP*	Pop.
NGC 0596	2.1	–0.030	–0.050	–0.008	–0.021	–0.033	YP
NGC 1395	3.8	0.026	0.038	–0.005	0.013	0.004	NP
NGC 1399	2.0	0.015	0.023	0.003	0.012	0.006	NP
NGC 1537	2.2	0.065	0.093	0.005	0.028	–0.009	NP
NGC 1549	7.0	–0.041	–0.040	–0.009	0.002	–0.012	NP:
NGC 1653	3.5	–0.089	–0.094	–0.009	0.002	–0.034	YP
NGC 1700	3.8	–0.037	–0.029	–0.006	0.008	–0.053	YP
NGC 2768	1.2	–0.099	–0.093	0.004	0.007	–0.017	NP:
NGC 2865	10.6	–0.246	–0.249	–0.027	–0.004	–0.135	YP
NGC 2974	3.6	0.030	0.033	–0.025	0.005	0.015	NP
NGC 3557	4.3	–0.158	–0.214	–0.047	–0.058	–0.044	YP
NGC 3585	2.8	–0.071	–0.089	–0.017	–0.017	–0.012	YP:
NGC 3610	6.8	–0.040	–0.008	0.007	0.031	–0.059	YP
NGC 3613	1.7	–0.094	–0.090	0.006	0.005	–0.018	YP:
NGC 3923	10.3	0.008	0.009	0.001	0.000	0.018	NP
NGC 4125	2.5	–0.095	–0.099	–0.017	–0.003	–0.014	YP
NGC 4374	2.1	–0.090	–0.117	–0.015	–0.027	–0.019	YP:
NGC 4406	3.1	–0.124	–0.143	–0.014	–0.020	–0.012	NP:
NGC 4552	3.9	–0.016	–0.019	0.007	–0.003	0.019	NP
NGC 4767	3.3	–0.033	–0.025	–0.010	0.007	0.012	NP:
NGC 4976	5.2	–0.186	–0.238	–0.038	–0.056	–0.072	YP
NGC 5018	8.0	–0.070	–0.058	–0.031	0.012	–0.088	YP
NGC 5061	3.2	–0.148	–0.143	–0.015	0.005	–0.080	YP
NGC 5077	4.8	0.053	0.083	0.017	0.030	–0.008	NP
NGC 5322	2.6	–0.027	–0.050	–0.028	–0.022	–0.038	YP
NGC 5557	6.7	–0.082	–0.086	–0.009	–0.004	–0.031	YP
NGC 5576	8.0	–0.119	–0.106	0.015	0.012	–0.065	YP
NGC 5846	4.2	0.047	0.053	–0.019	0.006	0.015	NP
NGC 5982	6.8	–0.076	–0.080	0.007	–0.002	–0.039	YP
NGC 6411	3.0	–0.036	–0.035	0.006	0.001	–0.023	YP:
NGC 7454	2.5	0.110	0.121	–0.006	0.009	–0.030	YP:
NGC 7507	4.6	0.013	–0.008	–0.011	–0.021	0.026	NP
NGC 7619	2.0	–0.032	–0.028	–0.018	0.004	0.014	NP
NGC 7626	1.4	0.025	0.032	0.015	0.008	0.025	NP
IC 3370	7.7	0.023	0.047	0.005	0.023	–0.038	YP

may be compared with the distribution of the $\Delta V-J$ in Table 3.

We have also plotted the correlation diagram between $V-J$ and Mg_2, to check for large colour errors perhaps due to inaccurate galactic extinction corrections. NGC 4976 (A_g = 0.96) is too blue for its Mg_2, possibly due to too large an adopted A_g value. The reverse is true for NGC 7454 (A_g = 0.25), again much too red in $V-J$ for its spectral index.

Table 3. Mean deviations of the *VJHK* colour indices of morphologically peculiar Es (*Pec* subsample) against the standard relations calculated for the *Nop* ("normal") subsample. Ind. index studied; *N* number of objects; *mRes* mean residuals; σ standard deviation.

Ind.	*N*	*mRes*	σ
$V-J$	35	$-0.046 \pm .016$	0.089
$V-K$	35	$-0.047 \pm .017$	0.100
$J-H$	35	$-0.008 \pm .003$	0.017
$J-K$	35	$-0.001 \pm .003$	0.020
$H-K$	35	$+0.005 \pm .003$	0.017

4. Concluding discussion

The $V-J$, $V-K$, $J-H$ and $J-K$ colours within A_e have been obtained for 110 ellipticals already studied in Paper I, using 2MASS data and published results of aperture photometry. The photometric accuracy of the 2MASS calibration has been verified to be quite good: a probable error of 0.013 magnitude is evaluated for the two near-IR colours. The probable error is found to be 0.025 for the two visible-IR colours. *The complete results of our measurements are collected in Table 4, to be made available at the CDS, Strasbourg.*

The correlations between the velocity dispersion $\log \sigma_0$ and the colours of the 75 "non peculiar" objects, forming the *Nop* subsample, have been found to be very good (Fig. 1 and Table 1). Their dispersion, i.e. 0.06 for $V-J$ and 0.07 for $V-K$, are distinctly larger than expected from known errors in the variables. There is a "cosmic dispersion", with two probable physical causes. On the one hand, there are small fluctuations in the parameters (say mean age and mean metallicity) describing the stellar population of each object; on the other, there are also fluctuations in the small amount of residual dust in ellipticals, producing a variable reddening, changing from galaxy to galaxy and from colour to colour. It might be feasible to disentangle these two sources of cosmic dispersion in the colour distributions of ellipticals.

The colours of morphologically peculiar objects, i.e. the *Pec* subsample of 35 galaxies, have been discussed as in Paper I: the O–C *residuals* between the observed colours and those expected from the calculated regressions of the *Nop* subsample have been evaluated (Table 2). These are generally not large and of limited significance for $J-H$ and $J-K$. For $V-J$, $V-K$, as for other colours and line–indices used in Paper I, there is a striking dichotomy between a family of objects with large negative residuals and another with near zero residuals: these have been termed the *YP* (type NGC 2865) and the *NP* family (type NGC 3923). The residuals in $V-J$ and $V-K$ correlate with *MIYP*, the Mean Index of Young Population introduced in Paper I to describe the various populations by reference to the standard one of the *Nop* sample. They also agree, but for a few conflicting cases (4 out of 35), with the classification in the *YP* and *NP* groups introduced there.

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References

Bressan, A., Chiosi, C., & Fagotto, F. 1994, ApJS, 94, 63
Bressan, A., Chiosi, C., & Tantalo, R. 1996, A&A, 311, 425
Bruzual, G., & Charlot, S. 2003, MNRAS, 344, 1000
Idiart, T., Michard, R., & de Freitas Pacheco, J. 2002, A&A, 383, 30
Jarrett, T. H., Chester, T., Cutri, R., et al. 2003, AJ, 125, 525
Mannucci, F., Basile, F., Poggianti, B. M., et al. 2001, MNRAS, 326, 745
Michard, R., & Marchal, J. 1994, A&AS, 105, 481
Michard, R., & Prugniel, P. 2004, A&A, in press
Poggianti, B. M. 1997, A&AS, 122, 399
Poulain, P. 1986, A&AS, 64, 225
Poulain, P. 1988, A&AS, 72, 215
Poulain, P., & Nieto, J.-L. 1994, A&AS, 103, 573
Prugniel, P., & Simien, F. 1996, A&A, 309, 749 (PS96)
Prugniel, P., & Héraudeau, P. 1998, A&AS, 128, 299
Rieke, G. H., & Lebofsky, M. J. 1985, ApJ, 288, 618
Schweizer, F., & Seitzer, P. 1992, AJ, 104, 1039 (SS92)
Schweizer, F., Seitzer, P., Faber, S. M., et al. 1990, ApJ, 364, L33
Worthey, G. 1994, ApJS, 95, 107