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Central Mg_2 indices for early-type galaxies⋆,⋆⋆

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Abstract. We present 210 new measurements of the central absorption line-strength Mg_2 index for 87 early-type galaxies drawn from the Prugniel & Simien (1996) sample. 28 galaxies were not observed before. The results are compared to measurements published previously as available in HYPERCAT, and rescaled to the Lick system. The mean individual internal error on these measurements is $0\overset{\text{m}}{.}009 \pm 0\overset{\text{m}}{.}003$ and the mean external error is $0\overset{\text{m}}{.}012 \pm 0\overset{\text{m}}{.}002$ for this series of measurements.

Key words: galaxies: elliptical and lenticular, cD — galaxies: fundamental parameters — galaxies: stellar content

1. Introduction

The existence of the the Fundamental Plane (FP) of early-type galaxies (Djorgovski & Davies 1987) results from very simple scaling relations (de Carvalho & Djorgovski 1989). The equilibrium status of galaxies (Virial Theorem) can be written (Prugniel & Simien 1997):

$$k_{\rm K}\sigma_0^2 = (2\pi)^{-1} k_{\rm S}(\mathcal{M}/L) L r_{\rm e}^{-1}, \qquad (1)$$

where $L, r_{\rm e}$ and σ_0 are respectively the luminosity, the effective radius, and the central velocity dispersion. $k_{\rm S}, k_{\rm K}$, and $\mathcal{M}/L$ are the three functions entering in the relations scaling respectively the gravitational energy, the kinetic energy, and the mass of galaxies.

The FP equation has the simple form

$$k_{\rm S} k_{\rm K} \mathcal{M}/L = L^{\beta}, \qquad (2)$$

with β ranging from 0.2 to 0.1 when going from the B to K-color band (e.g. Djorgovski & Santiago 1993). This weak dependence on the luminosity (the so called "tilt" of the FP - see Renzini & Ciotti 1993) implies the quasi-linearity of the scaling relations, i.e., the kinetic energy must be *almost* proportional to σ_0, the mass to the luminosity, and so on.

Studying the residuals from the FP as a function of other parameters gives insights into the details of the scaling relations. For instance, Prugniel & Simien (1994) expressed the contribution of the rotational support to the total kinetic energy as $k_{\rm K} = 1 + 0.81(V_{\rm max}/\sigma_0)^2$. The non-linearity of the scaling of the gravitational energy (non-homology of the spatial structure) has also been found by Busarello et al. (1996) (see also Prugniel & Simien 1996). Combined, these two effects account for roughly half the tilt of the FP in the B-band. The scaling of the mass is more complicated since it combines the characteristics of the stellar population to those of the dark halo. However, the correlation between the residuals to the FP and the color or Mg_2 (Prugniel & Simien 1996) indicates a strong contribution of the diversity of the stellar populations to the spread around the FP (Guzmán et al. 1992; Jørgensen et al. 1996). Because of the color-magnitude (and Mg_2-magnitude) relations, this accounts for the rest of the tilt of the FP in the B-band. The smaller tilt observed in the near IR (Recillas-Cruz et al. 1990; Scodeggio et al. 1998) confirms this. Then, unless some other unidentified phenomena add other compensatory tilts, the fraction of dark matter can be considered constant in the region probed by this analysis (i.e. within $1 - 2r_{\rm e}$).

These effects are of interest for the understanding of the physics of galaxies, but are also important when dealing with large-scale streaming, using the FP as a distance indicator (Dressler et al. 1987), since they potentially result in spurious peculiar velocities (e.g. Gregg 1992).

In order to go deeper in the analysis of the connection between the residuals to the FP and the characteristics

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⋆ Based on observations collected at the Observatoire de Haute-Provence.

⋆⋆ Tables 1, 3 and 4 are available in electronic form from the CDS, Strasbourg (via anonymous ftp to 130.79.128.5). Tables 1 and 3 are available from CDS only.

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of the stellar population we are continuing observational programs.

In the present paper we measure the central Mg_2-index for the 87 galaxies already accumulated in our library. This material consists in medium resolution spectra (3.2 Å FWHM), and relevant details on it are given in Sect. 2. In Sect. 3, we describe the measurements method and error analysis and present their reduction to the homogeneous system defined in Golev & Prugniel (1998). A comparison with other series of measurements (Sect. 4), taken from the HYPERCAT database[1], ascertains the level of reliability of our data and measurement procedure.

2. Sample and observations

The current sample has previously been selected for kinematical studies. It is composed of 87 early-type galaxies (S0s and ellipticals between E0 and E4). Kinematical parameters were published in a series of five papers (Prugniel & Simien 1994; Simien & Prugniel 1997a, 1997b, 1997c, 1998, hereafter collectively referred to as SP): the central velocity dispersion σ_0, the maximum rotational velocity $V_{\max}$ and, for some galaxies, the radial profile $\sigma(r)$ of the velocity dispersion, together with the rotation curve $V(r)$ are given in these papers. Although the sample is not complete in terms of limiting apparent or absolute magnitude, the galaxies of the sample span a wide range of intrinsic luminosity ($-22\overset{\mathrm{m}}{.}0 \lesssim M_B \lesssim -17\overset{\mathrm{m}}{.}5$), of central velocity dispersion ($70 \lesssim \sigma_0 \lesssim 330$ km s^{-1}), and, as a consequence, of metallicity. The observations were made at the 1.93 m telescope of the Observatoire de Haute-Provence equipped with the *CARELEC* long-slit spectrograph[2] (Prugniel et al. 1992). The detector was a Tektronix CCD with 512×512 pixels of 27 μm each. The slit width projected on the sky was 2.2 arcsec. *CARELEC* transforms the focal ratio from f/15.5 at the Cassegrain focus to a value six times faster, providing a scale of 1.1 arcsec px^{-1} in the spatial direction along the slit, and a FWHM spectroscopic resolution of 3.2 Å (or 1.8 px) corresponding to 1.8 Å px^{-1}. The selected setup with a reciprocal dispersion of 66 Å mm^{-1} is always centered on the Mg b λ5175 Å triplet, and it provides nearly 900 Å of spectral coverage around it.

During seven observing runs in the period 1993 - 1995, a total of 210 spectra of early-type galaxies have been collected. Typically, two 45-min exposures were obtained for each galaxy. For comparison purposes, 17 galaxies of the sample were observed in more than one run. All details about the runs and the logs of observations can be found in SP. At least two template stars of spectral type in the range G8-III to K3-III were observed at the beginning of each night.

3. Data reduction

3.1. Measurements and errors

We have used the wavelength-calibrated and sky-subtracted spectra resulting from the kinematical reduction presented in SP. In order to extract the central Mg_2-indices we have integrated the signal in the aperture of 2.2×5.5 arcsec.

The flux calibration has been performed using spectra of the kinematical template stars common with the KPNO Coudé Feed Spectrophotometric Library (*The Jones library* – see Leitherer et al. 1996). The spectra in this library are flux-calibrated and can be regarded as "approximately spectrophotometric" (Worthey & Ottaviani 1997). Seven late-type stars observed by us could be used for that purpose, totalling 11 spectra. The wavelength response of the system (atmosphere + telescope + spectrograph + CCD) was modelled by a second degree polynomial.

This small number of flux calibrators does not allow to perform a monitoring of the change in the atmospheric absorption, hence we determined the error due to the change in the flux calibration by comparing the Mg_2-values obtained with the 11 different response functions. Assuming that the distribution of these 11 calibrations is representative of changes of the flux calibration during the whole runs, we found the corresponding error on Mg_2 to be $\lesssim 0\overset{\mathrm{m}}{.}004$.

Recently Worthey & Ottaviani (1997) provided an elaborate mapping of the Lick system resolution which is about 8.4 Å at 5300 Å. Our spectra were transformed to this resolution by convolving them with an appropriate gaussian. The raw values of Mg_2-indices, $(Mg_2)_{\rm obs}$, were measured according to the Lick definition (see Worthey et al. 1994):

$$(\mathrm{Mg}_2)_{\rm obs} = -2.5 \log \left[\left(\frac{1}{\lambda_2 - \lambda_1} \right) \int_{\lambda_1}^{\lambda_2} \frac{F_{\rm I\lambda}}{F_{\rm C\lambda}} {\rm d}\lambda \right], \qquad (3)$$

where $F_{\rm I\lambda}$ is the flux (in ergs s^{-1} cm^{-2} Å^{-1}) in the Mg H and Mg b which are located at $\lambda\lambda 5154.125 - 5196.625$ Å. Here the local continuum, $F_{\rm C\lambda}$, represents the run of flux defined by a line connecting the flux levels at midpoints of the corresponding blue and red "continuum" bandpasses (which are actually pseudocontinua) at $\lambda\lambda 4895.125 - 4957.625$ Å and $\lambda\lambda 5301.125 - 5366.125$ Å.

For each individual spectrum the Mg_2-index error was first estimated as described in Cardiel et al. (1998), then the flux-calibration error was added quadratically to the obtained value.

We performed a series of tests to determine the sensitivity of our measurements to different sources of errors.

[1] The database HYPERCAT is developed and maintained at the Observatoire de Lyon (http://www-obs.univ-lyon1.fr/hypercat/).

[2] Details on the *CARELEC* long-slit spectrograph and its detectors, as well as the information about the 1.93 m telescope itself, are available on the WWW at http://www.obs-hp.fr

The dominant uncertainty comes from the photon noise (typically $\sim 0\overset{m}{.}007$). The uncertainty on the flux calibration and on the sky subtraction come after (the overall effect of both these sources of errors is $\lesssim 0\overset{m}{.}006$).

3.2. Velocity dispersion correction

Using the tabulation in Longhetti et al. (1998), we have adopted the following formula for the velocity dispersion correction:

$$(Mg_2)_{\sigma=0} = (Mg_2)_{obs} + 0.001 \log \sigma. \quad (4)$$

This correction (typically $\sim 0\overset{m}{.}002$) is in general well within the errors, but we applied it because it may bias the measurements in a systematic way.

3.3. Aperture correction

Because galaxies show radial gradients for the Mg_2-index, this index must be corrected for the effect of the increasing projected aperture size in the more distant galaxies which weakens their indices. The aperture correction of the observed index $(Mg_2)_{obs}$ was performed as it is proposed by Jørgensen et al. (1995) consistently with the procedures described in Golev & Prugniel (1998) catalogue. The adopted normalized aperture is equivalent to an angular diameter of 3.4 arcsec for the distance to the Coma cluster. The distances were estimated as in Golev & Prugniel (1998).

The mean aperture correction added to the raw measurements is $-0\overset{m}{.}016$ with an rms of $0\overset{m}{.}012$. The negative mean correction reflects the fact that our observations sample a physical aperture smaller than the normalisation aperture adopted in HYPERCAT (Golev & Prugniel 1998). Inverting Eq. (3) from Golev & Prugniel tells that in average the apertures used in our observations are 0.4 the normalisation radius.

The Mg_2-index measurements for the 210 individual spectra are presented in Table 1 (in electronic form only). This table gives the individual velocity-dispersion-corrected and aperture-corrected measurements. The distances (in km s^{-1}) used to compute the aperture correction can be found in the electronic version of Table 4. The mean internal error of individual measurements is $0\overset{m}{.}0093 \pm 0\overset{m}{.}0032$ which is typical of the values collected in HYPERCAT.

4. Comparison with HYPERCAT

In Golev & Prugniel (1998) we have presented a catalogue of published absorption-line Mg_2 indices of galaxies and globular clusters. This catalogue is maintained up-to-date in the HYPERCAT database and gathers more than 4000 Mg_2-index measurements for ~1500 objects from 69 observational datasets reported in 41 different publications. Below we have used this database for the sake of internal and external comparison of our measurements.

4.1. Internal comparisons

During each observing run, we observed between 10 and 30 galaxies. In most cases, each observation consisted in two spectra with the same position angle interleaved with a calibration-lamp spectrum (needed for the kinematical analysis to control the possible flexures in the instrument). Two to five galaxies in each run were repeated in another run. This allowed two types of internal comparison: (1) between two consecutive spectra, and (2) between observation repeated during different observing runs. The relevant statistics of these comparisons is summarized in Table 2.

The results of these comparisons performed on the corrected measurements are:

- The rms difference between two consecutive observations of the same galaxy is $0\overset{m}{.}000 \pm 0\overset{m}{.}0096$. The only significant differences allowed to reject discrepant measurements affected by badly placed spikes due to cosmic-rays.
- The internal comparison did not reveal any evidence for significant zero-point difference (greater than $0\overset{m}{.}005$) between the observing runs. But the relevance of this diagnostics is limited by the small number of comparison points (see below the external comparisons).

The internal comparison between the repeated measurements of the same galaxies reveals a mean error of $0\overset{m}{.}008$ (the same order of magnitude as the total mean internal error of $0\overset{m}{.}0093$), in agreement with the analysis of the error sources in the previous section.

4.2. External comparisons

Most of the galaxies in our sample were previously measured, in particular by the Lick group (Davies et al. 1987 – hereafter LICK, and Faber et al. 1989 – hereafter 7Sam). Recently the full Lick/IDS (Image Dissector Scanner) database of Mg_2 indices for 381 galaxies and 38 globulars was published by Trager et al. (1998 – hereafter Lick98). This dataset should be regarded as the last version of the Lick/IDS line-strength index system, and we re-scaled all the HYPERCAT data to it.

The estimate of the external errors, and of the corrections to the Lick98 system is done iteratively, and globally for all the HYPERCAT datasets, by inter-comparing these datasets. The comparisons are performed on the aperture-corrected data. For present datasets, the significant intersections are with the LICK dataset (Davies et al. 1987) and with Lick98.

Table 2. Internal and external comparisons. The first column lists our datasets (with the total number of observed spectra in brackets), Cols. 2 – 8 show the internal comparisons between these datasets. Columns 9, 10 and 11 show the comparisons (ours − literature) between the datasets of Col. 1 and, respectively, Lick98, LICK, and HYP (for HYPERCAT). The first row of each cell is the number of measurements compared. The second is the mean difference: (line) − (Col.), and the third is the rms. The diagonal (in italics) shows the comparison between consecutive observations of the same galaxy

Dataset (1)	Mar93 (2)	Nov93 (3)	Nov94 (4)	Dec94 (5)	Jan95 (6)	Mar95 (7)	Jun95 (8)	Lick98 (9)	LICK (10)	HYP (11)
Mar93	*5*							12	22	12
(12 spectra)	*0.000*							−0.005	−0.011	−0.004
	0.042							0.037	0.038	0.031
Nov93		*20*	19	2	14	6		28	34	36
(36 spectra)		*0.000*	−0.005	−0.024	−0.004	−0.008		−0.005	−0.008	−0.003
		0.010	0.011	0.000	0.008	0.006		0.013	0.010	0.009
Nov94			*40*	15	15			25	24	28
(28 spectra)			*0.000*	0.000	0.007			−0.005	−0.003	−0.002
			0.006	0.008	0.015			0.006	0.010	0.005
Dec94				*6*	8			4	2	12
(14 spectra)				*0.000*	0.006			−0.006	−0.002	0.000
				0.007	0.011			0.006	0.001	0.003
Jan95					*24*	8	2	28	45	44
(45 spectra)					*0.000*	0.000	−0.025	−0.005	0.004	−0.001
					0.009	0.014	0.000	0.020	0.019	0.012
Mar95						*24*	6	30	51	51
(53 spectra)						*0.000*	0.001	0.005	0.008	0.003
						0.015	0.006	0.016	0.013	0.010
Jun95							*10*	13	18	22
(22 spectra)							*0.000*	0.007	0.001	0.001
							0.008	0.016	0.010	0.005

After these comparisons, for 59 galaxies in common with other datasets a difference of Mg_2(our) − Mg_2(HYPERCAT) = $0\overset{m}{.}018 \pm 0\overset{m}{.}002$ was found. Such difference between flux-calibrated measurements, like ours, and the Lick/IDS data which are normalized via quartz flat field are indeed not surprising. Analysing the details of the pair-comparisons, we adopted a correction of 0.019 for all datasets except Mar93 (0.025) and Mar95 (0.016).

The parameters of our datasets are given in Table 3 (available in electronic form only).

We summarize in Table 2 the final comparisons between the LICK and Lick98 datasets, our datasets and the HYPERCAT homogenized data. The residual zero-points are negligible, and the mean differences give estimates of the internal errors (on the diagonal of the table are comparisons between consecutive observations; on the other positions are comparisons between different observing runs), and external errors (last three columns). The comparison between our fully corrected measurements and HYPERCAT values is presented in Figs. 1 and 2 (the distributions of residuals with the two major datasets of Table 2 have basically the same form).

Note that the mean residuals between the fully corrected data and the HYPERCAT values are not strictly null, but simply statistically unsignificant. This is because the homogenisation process (Golev & Prugniel 1998) rests on pair-wise comparison and iteratively determines zero-points and weights for all the datasets in HYPERCAT. Such process is not stable and thus is hand-controlled at each iteration (this control consists in under-relaxing the corrections to damp the oscillations).

We also searched for correlations between the mean difference of our Mg_2-index measurements and any of these datasets (as some non-linearity in the whole acquisition chain could produce). We did not find any significant effect.

In Table 4 we present the mean corrected value of Mg_2 rescaled to the Lick system and the corresponding rms error for the 87 galaxies in the sample. In the electronic version of the table more information for each galaxy is provided, e.g. the flow-smoothed velocity used for aperture correction (defined as the velocity of the cosmologic flow associated with the galaxy).

5. Conclusion

We have presented 210 new central Mg_2 measurements for 87 galaxies rescaled to the Lick/IDS system.

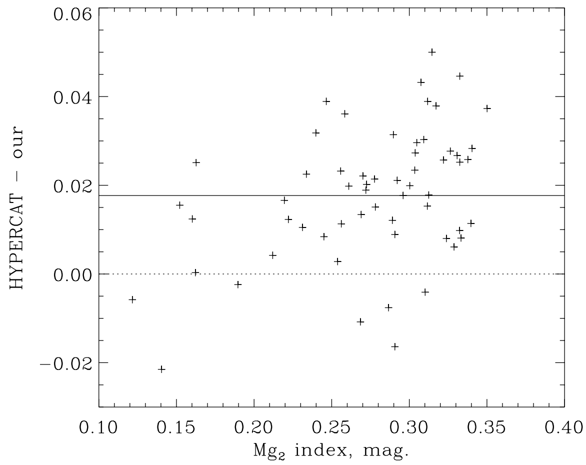

Fig. 1. Comparison between our fully corrected Mg_2-index measurements and HYPERCAT values for 59 galaxies in common

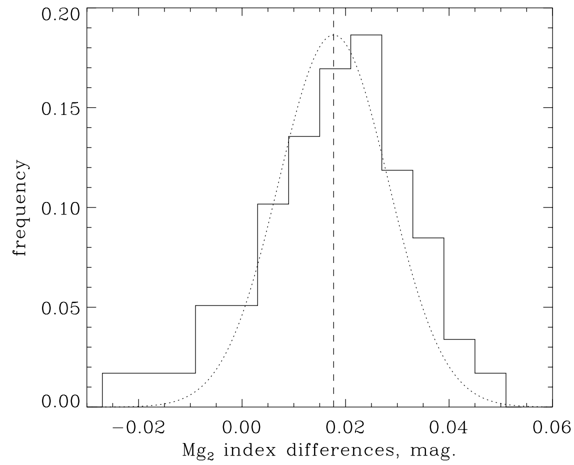

Fig. 2. The distribution of the differences between our Mg_2-index measurements and HYPERCAT values

The mean individual internal error on these measurements is $0\overset{m}{.}009 \pm 0\overset{m}{.}003$ and the external error is $0\overset{m}{.}012 \pm 0\overset{m}{.}002$.

Beside providing Mg_2 measurements for 28 new galaxies, this analysis shows the suitability of our spectra for line-strength measurements. We will extend this work by measuring the spatial profiles of line strength indices along the major axis of galaxies, and use this data to go further into the analysis and interpretation of the scaling relations involving the stellar population. Two preliminary reports are published in Prugniel & Golev (1998) and Golev et al. (1998).

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Table 4. Fully corrected values of Mg_2 indices, rescaled to the Lick system. The galaxy's identifiers are listed in first column. Columns 2 and 3 contain corrected Mg_2-index values and the corresponding rms errors. In Col. 4 N are the numbers of individual spectra used

Identifier (1)	Mg_2 (corr) (2)	rms error (3)	N (4)
NGC 0097	0.277	0.008	2
NGC 0383	0.325	0.008	2
NGC 0430	0.300	0.009	2
NGC 0499	0.332	0.004	4
NGC 0584	0.258	0.007	2
NGC 0680	0.268	0.005	3
NGC 0855	0.050	0.009	2
NGC 0890	0.257	0.004	4
NGC 0990	0.256	0.006	2
NGC 1016	0.319	0.007	2
NGC 1023	0.286	0.003	6
NGC 1060	0.331	0.017	1
NGC 1132	0.275	0.014	2
NGC 1175	0.308	0.005	2
NGC 1199	0.293	0.006	2
NGC 1209	0.285	0.008	1
NGC 1426	0.231	0.012	2
NGC 1461	0.282	0.006	2
NGC 1521	0.263	0.007	3
NGC 1573	0.321	0.010	2
NGC 1653	0.288	0.005	4
NGC 1684	0.281	0.014	1
NGC 1713	0.297	0.010	2
NGC 1726	0.283	0.005	5
NGC 2314	0.310	0.008	2
NGC 2329	0.286	0.005	4
NGC 2332	0.301	0.008	3
NGC 2340	0.321	0.008	2
NGC 2549	0.257	0.003	8
NGC 2563	0.328	0.007	2
NGC 2685	0.215	0.004	5
NGC 2695	0.299	0.006	2
NGC 2732	0.234	0.003	6
NGC 2768	0.261	0.003	8
NGC 2986	0.309	0.006	2
NGC 3158	0.344	0.006	2
NGC 3193	0.264	0.010	1

Table 4. continued

Identifier (1)	Mg_2 (corr) (2)	rms error (3)	N (4)
NGC 3370	0.122	0.006	2
NGC 3818	0.276	0.011	1
NGC 3853	0.280	0.007	2
NGC 3862	0.313	0.007	2
NGC 3893	0.122	0.009	1
NGC 3921	0.134	0.006	2
NGC 4239	0.140	0.013	2
NGC 4270	0.230	0.004	2
NGC 4283	0.259	0.011	1
NGC 4318	0.186	0.006	2
NGC 4339	0.249	0.006	2
NGC 4340	0.243	0.006	2
NGC 4429	0.271	0.005	2
NGC 4434	0.242	0.004	3
NGC 4435	0.228	0.005	2
NGC 4442	0.291	0.004	2
NGC 4458	0.216	0.006	2
NGC 4461	0.277	0.005	2
NGC 4464	0.225	0.005	2
NGC 4468	0.166	0.013	2
NGC 4476	0.145	0.007	2
NGC 4478	0.244	0.004	4
NGC 4479	0.219	0.011	3
NGC 4489	0.193	0.010	2
NGC 4552	0.319	0.008	1
NGC 4636	0.249	0.030	2
NGC 4638	0.256	0.010	1
NGC 4874	0.310	0.011	2
NGC 4886	0.247	0.011	2
NGC 5129	0.279	0.011	1
NGC 5353	0.327	0.004	2
NGC 5424	0.285	0.005	4
NGC 5490	0.330	0.005	3
NGC 5557	0.299	0.004	2
NGC 5854	0.171	0.007	2
NGC 5864	0.217	0.009	1
NGC 5966	0.260	0.006	2
NGC 6137	0.329	0.017	2
NGC 6146	0.287	0.004	2
NGC 6166	0.307	0.028	1
NGC 7177	0.188	0.009	1
NGC 7331	0.218	0.007	1
NGC 7332	0.218	0.004	4
NGC 7457	0.159	0.005	3
NGC 7660	0.321	0.008	2
NGC 7727	0.284	0.006	2
NGC 7778	0.286	0.009	2
NGC 7785	0.281	0.007	2
UGC 03696	0.293	0.005	3
UGC 03792	0.228	0.018	2