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Evolution of the fundamental plane of early-type galaxies in the EGS

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Abstract

We studied the evolution of the Fundamental Plane in B and g-bands, for a sample of early–type galaxies in the redshift range $0.2 < z < 1.2$. Assuming that effective radii and velocity dispersions do not evolve with redshift, we found that the galaxies at $<z> \sim 0.7$ were 0.68 mag brighter in the B-band and 0.52 mag brighter in the g-band, than their local counterparts. However, the scatter in the FP for our high–redshift sample is reduced by half when we allow the FP slope to evolve, suggesting a different evolution of early–type galaxies according to their intrinsic properties. From the study of the Kormendy relation at different redshifts, we found the existence of a population of very bright and compact galaxies that were almost nonexistent at $z = 0$. The evolution of these compact objects would be mainly caused by an increase in size that could be explained by the action of dry minor mergers, more efficient by increasing the size that the stellar mass of galaxies. These bright and compact objects would be responsible for the evolution found in the Fundamental Plane.

1 Introduction

The Fundamental Plane (FP; [4, 3]) relating velocity dispersion, surface brightness and scale length for galaxies, presents an important tool to investigate the properties of early–type galaxies, to perform cosmological test and to compute cosmological parameters. Because the velocity dispersion is preventing the gravitational collapse, it can be used for estimating the galaxy mass by applying the virial theorem. Thus, the study of the FP and their change with redshift can provide valuable information on the dynamical masses and mass evolution of galaxies. Moreover, the FP relates structural properties of galaxies, such as sizes and luminosities with the dynamics, hence its study with redshift has important implications on the formation and evolution of elliptical galaxies.

Pioneering evolutionary studies of the FP were made at intermediate redshift ($z \sim 0.5$) for galaxies in clusters. For instance, [12] and [8] found that the FP at this redshift was similar to the FP for nearby galaxies, suggesting small changes on the structure of the older galaxies and a formation epoch at significantly higher redshift ($z_{\rm form} > 2$). In a subsequent work, [9] increased the sample of galaxies in a cluster at $z = 0.33$ to 53 galaxies, and derived mass–to–light ratios of the high–redshift early–type galaxies lower than those in Coma cluster by $\Delta \log(M/L_V) = -0.13 \pm 0.03$. This change in the $M/L_{\rm V}$ ratio would imply an increase of the V luminosity by ~ 0.3 mag if this evolution were caused by the passive evolution of stellar populations alone. In this sense, [13] and [14] found a similar result from a larger sample of field galaxies, deriving an average increase of the B luminosities by ~ -0.4 mag at $<z>= 0.4$.

While all previous authors found an evolution of the FP only in the offset, [11] find a change in the slope of the FP that can be interpreted as a mass–dependent evolution. According to this, massive galaxies evolve passively on longer time–scales, whereas less massive systems have more extended star–formation histories and continue to form stars at much later epochs. The recent studies of [5] for a sample of 24 field galaxies covering redshifts $0.20 < z < 0.75$, and [6] for a sample of 50 cluster galaxies at $z \sim 1$, also support the evolution in the slope of the FP for both field and cluster galaxies, suggesting that the internal properties of a galaxy are more important to its evolutionary history than its enviroment.

2 Data analysis

The sample consists of galaxies in the EGS sky region. The baseline for spectroscopy target pre–selection were the galaxies for which DEEP2 spectra (Data Release 3, DR3) in this field were available. The photometric data used here are part of AEGIS survey [2]. B, R, and I-band photometry were taken with the CFH12K mosaic camera, installed on the 3.6 m Canada–France–Hawaii telescope (CFHT). The data in the V-band (F606W) were taken from the HST catalogue and were obtained with the ACS camera. In addition, we used the z-band magnitudes of the Canada–France–Hawaii telescope legacy survey (CFHTLS), because the z-band at $z = 1$ roughly matches the rest–frame B-band photometry.

Morphology was determined through visual classification using the $V+I$ images of ACS. Finally, we selected the E/S0 galaxies that had at least one absorption line in the spectrum for determining the velocity dispersion, such as E–band region (Fe line, $\lambda\lambda$5270), G–band region (Fe and Ca lines, $\lambda\lambda$4300), and the H + K region (double CaII line, $\lambda\lambda$3934, 3969). The double absorption line of sodium or the triple absorption line of magnesium were not used because they could not be deblended, because of an insuficient spectral resolution. The final sample of galaxies with photometric information in the B, V, R, I and z-bands in the redshift range $0.2 < z < 1.2$ that were also classified as E/S0 consists of 135 galaxies.

The structural parameters of these galaxies were obtained by fitting de Vaucouleurs stellar profiles to the ACS I–band images, using the GALFIT code. To check the effect on the FP of the structural parameters obtained using different profiles, Sérsic and bulge–to–disc decomposition models were also fitted to our sample of galaxies. We found good agreement in the FP derived from the three models. Velocity dispersions were calculated by extracting the stellar kinematics from the galaxy spectrum, using a maximum penalized likelihood approach.

3 The fundamental plane

The FP relates the effective radius r_e, the central velocity dispersion σ, and the surface brightness within the effective radius SB_e in the following form:

$$\log r_e = a \log \sigma + b\ SB_e + c\ . \quad (1)$$

To derive the evolution of the FP we divided our sample into two redshift ranges: galaxies at $z < 0.35$ with a mean value of 0.27; and a high–redshift sample, which is made of galaxies at $z > 0.35$ with a mean value of 0.68. The local sample is composed of only 13 galaxies. This number of galaxies is insufficient for determining the local FP parameters, but it can be used to calibrate the local FP used as comparison to the high–redshift galaxies, since both samples were analysed following the same procedure. We accordingly adopt for the local coefficients the same values used by [7] in the rest–frame B-band: $a = 1.25$ and $b = 0.32$, and calculated the zeropoint c for the local and high–redshift samples by using a non–linear weighted least–squares fit. In Fig. 1 we present the edge–on projection of the FP in the local (left) and high–redshift samples (center), in addition to the zeropoint and total rms scatter obtained in each case. For our local sample we obtained a zeropoint of $c = -9.093$, which agrees well with the previous result of [7] (-9.062). However, we found a different FP intercept for the high–redshift galaxies. This difference in the zero–point is usually interpreted as a difference in surface brightness caused by luminosity evolution, under the assumption that all early–type galaxies evolve in the same way, i.e. that the coefficients a and b are independent of the redshift. From the change in the zeropoint of the FP we found a brightening of 0.68 mag in the B-band for early–type galaxies at $\langle z \rangle = 0.7$. Nevertheless, the rms scatter obtained in the high–redshift sample under this assumption is twice the local value. This means that either there is an evolution in the FP rms scatter, or the high–redshift galaxies follow a FP that is tilted with respect to the local one.

To investigate the last possibility, we recalculated the FP coefficients without any previous assumption. The result is presented in Fig. 1 (left). The resulting plane is tilted with respect to the local one, and it has a rms scatter of $\sigma_{\rm tot} = 0.112$, in good agreement with the local value. In addition, this high–redshift FP presents a rms scatter that is half of that obtained using the local a and b coefficients.

The change of the FP with redshift seems to indicate a different evolution of early–type galaxies according to their intrisic properties, such as total mass, size or luminosity. In the next section we analyse the Kormendy relation [10] to clarify which of these properties is responsible for the change found in the present work.

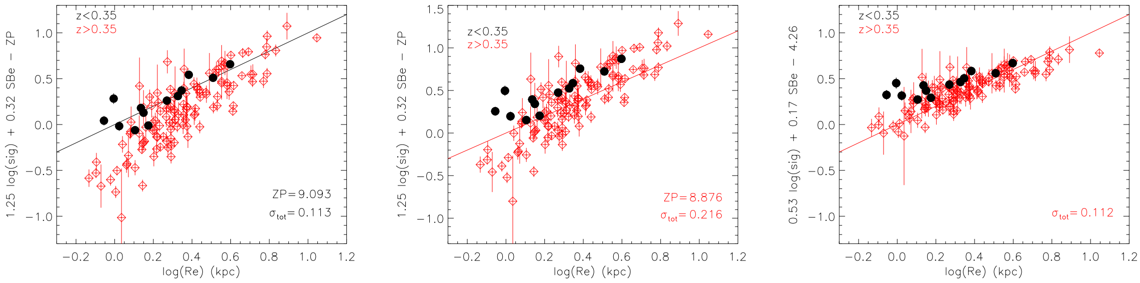

Figure 1: Edge–on projection of the FP in the B-band fitting the galaxies at $z < 0.35$ (left) and fitting the data at $z > 0.35$ (center, right). The black points represent the galaxies with $z < 0.35$, and the open red diamonds are the objects with $z > 0.35$. The galaxies in panels left and center are fitted using the parameters a and b obtained for local galaxies from the literature. The zero–point (ZP) and the rms scatter ($\sigma_{\rm tot}$) are shown in both cases. In the right panel, the parameters a, b, and the zero–point were obtained by fitting the galaxies at $z > 0.35$, through a non–linear weighted least–squares fit.

4 The Kormendy relation

One of the main dificulties in studying the evolution of the Kormendy relation is the bias caused by the limited luminosity of the high–redshift samples, which can be affecting the results. Our high–redshift galaxies have absolute magnitudes brigher than the local ones, so that we need a local sample covering a wide range of luminosity for comparison with our high–redshift galaxies.

The largest sample of local galaxies is likely the Sloan Digital Sky Survey database (SDSS). [1] derived the FP relations in the g, r, i, and z-bands from a magnitude–limited sample of nearly 9000 early–type galaxies in the SDSS, covering a redshift range of $0.01 < z < 0.3$. The structural parameters of the SDSS sample were obtained by fitting a de Vaucouleurs model to the observed surface brightness profile that accounts for the effects of seeing. For comparison with our high–redshift sample, we used the surface brightnesses and the effective radii obtained by these authors only in the g-band. Then, we calculated the rest–frame g-band magnitudes for our sample of galaxies. In the left panel of Fig. 2 we present the Kormendy relation in the g-band for our sample of galaxies with the Sloan data. Again, we found good agreement for the galaxies in the local sample. On the other hand, the evolution previously found for the high–redshift sample is not as clear here. For a proper comparison, we limited our high–redshift sample and the SDSS one to the same luminosity range, $-21.5 > M_g > -22.5$, which roughly corresponds to $-21.0 > M_B > -22.0$. We present the results in the right panel of Fig. 2. The largest objects in our high–redshift sample agree well with the local ones, and therefore no evolution in size or luminosity is found for these objects. However, we have a population of objects with low effective radius and high surface brightness that is not present in the local sample. We calculated the number of objects with $R_{\rm e} < 2$ kpc and luminosities $-21.5 > M_g > -22.5$ that exist in the comoving volume corresponding to each sample. In the SDSS sample of [1] ($V_{\rm p} = 0.26$ Gpc^3), we found $\sim$ 96 obj/Gpc^3, while the result for our high–redshift sample ($V_{\rm p}$ = 0.001 Gpc^3) is $\sim$ 24000 obj/Gpc^3, i.e. only the 0.4% of these objects with $R_{\rm e} < 2$ kpc and total luminosity $-21.5 > M_g > -22.5$ exist in the local universe. Then, an evolution in luminosity or size since $z = 1$ is necessary to explain the decrease in number of these bright and compact objects.

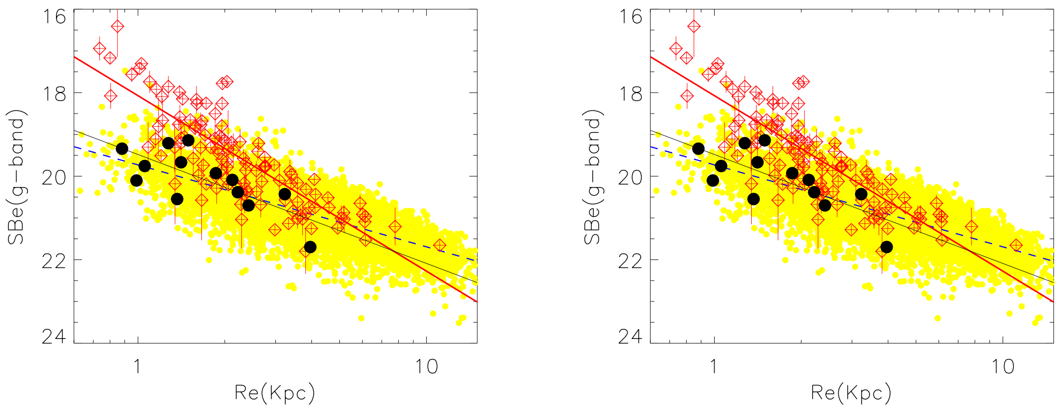

Figure 2: *Left panel*: Kormendy relation in the g-band for the early–type galaxies in our sample. The black points represent the galaxies with $z < 0.35$, and the open red diamonds are the objects with $z > 0.35$. The small yellow points represent the early–type galaxies of SDSS [1]), and the dashed blue line is the linear fit to this whole sample. The thin black line represents the weighted fit to our local sample, and the thick red line is the weighted fit to our high–redshift sample. In the right panel we present the same as for the left panel, but limit our high–redshift sample and the SDSS one to the objects with absolute magnitudes in the range $-21.5 > M_g > -22.5$. The dot–dashed line correspond to $M_g = -21.5$.

For studying the processes driving the evolution of these objects, we analysed the luminosity–size and stellar mass–size relations. We think that the evolution of these compact objects is mainly caused by an increase in size, which could be explained by the action of "dry" minor mergers that act increasing the size of the galaxies more than the mass.

Finally, we studied the effect of these bright and compact objects in the FP by comparing the galaxies with $-21.5 > M_g > -22.5$ of our high–redshift sample and the SDSS one. The previous evolution found in the FP seems to be caused mainly by these galaxies, which have virtually disappeared at $z = 0$. Unfortunately, we cannot distinguish a change in the tilt from an increase in the scatter of the FP caused by these population of objects, because our high–redshift sample is biased to the brightest galaxies.

5 Conclusions

We studied the evolution of the FP in B and g-bands, using a large sample of 135 early–type galaxies in the redshift range $0.2 < z < 1.2$. Assuming that effective radii and velocity dispersions do not evolve with redshift, we found that the galaxies at $<z>\sim 0.7$ were 0.68 mag brighter in the B-band and 0.52 mag brighter in the g-band, than their local counterparts. However, the scatter in the FP for our high–redshift sample is reduced by half when we allow the FP slope to evolve, suggesting a different evolution of early–type galaxies according to their intrinsic properties, such as total mass, size or luminosity.

From the study of the Kormendy relation at different redshifts, we found the existence of a population of very compact ($R_e < 2$ kpc) and bright galaxies ($-21.5 > M_g > -22.5$), of which there are only a small fraction (0.4%) at $z = 0$. For studying the processes driving the evolution of these objects, we analysed the luminosity–size and stellar mass–size relations. We think that the evolution of these compact objects is mainly caused by an increase in size.

The evolution found in the fundamental plane seems to be caused mainly by this population of very compact and bright galaxies. Unfortunately, we cannot distinguish a change in the slope from an increase in the scatter of the fundamental plane because our high–redshift sample is biased to the brightest objects.

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