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The Ages of Early–Type Galaxies at $z \sim 1$

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Abstract. The study of the ages of early–type galaxies and their dependence on galaxy mass and environment is crucial for understanding the formation and early evolution of galaxies. We review recent works on the $\mathcal{M}/L$ ratio evolution, as derived from an analysis of the Fundamental Plane of early–type galaxies at $z \sim 1$ both in the field and in the clusters environment. We use the $\mathcal{M}/L$ ratio to derive an estimate of the galaxy age. We also use a set of high–S/N intermediate–resolution VLT spectra of a sample of early–type galaxies with $0.88 < z < 1.3$ from the K20 survey to derive an independent estimate of their age by fitting SSP model spectra. Taking advantage of the good leverage provided by the high sample redshift, we analyse the results in comparison with the ages obtained for the same sample from the analysis of the $\mathcal{M}/L$ ratio, and with the predictions of the current hierarchical models of galaxy formation.

1. Introduction

Everyone knows that the year of birth can be determined at first sight more accurately for a child rather than for a middle–aged person (except if he is celebrating his 65th anniversary!). The same is true for the ages of galaxies. Furthermore the finite speed of light and the large size of the Universe give us the possibility to study the galaxies which are now old, when they were a lot younger, by observing them at high redshift. This is precisely what we are trying to do with early–type galaxies (ETG), which are particularly important to date, since they contain most of the visible mass in the Universe and they trace its highest density peaks (Renzini 2006).

ETG are very regular structures, in fact a two–parameter family, as testified by the existence and tightness of the Fundamental Plane (FP, Djorgovski & Davis 1987). We can then hope that a relatively simple process has imprinted their characteristics during formation and evolution. A straightforward way to find the parameters driving this process is to look for correlations with the galaxy ages.

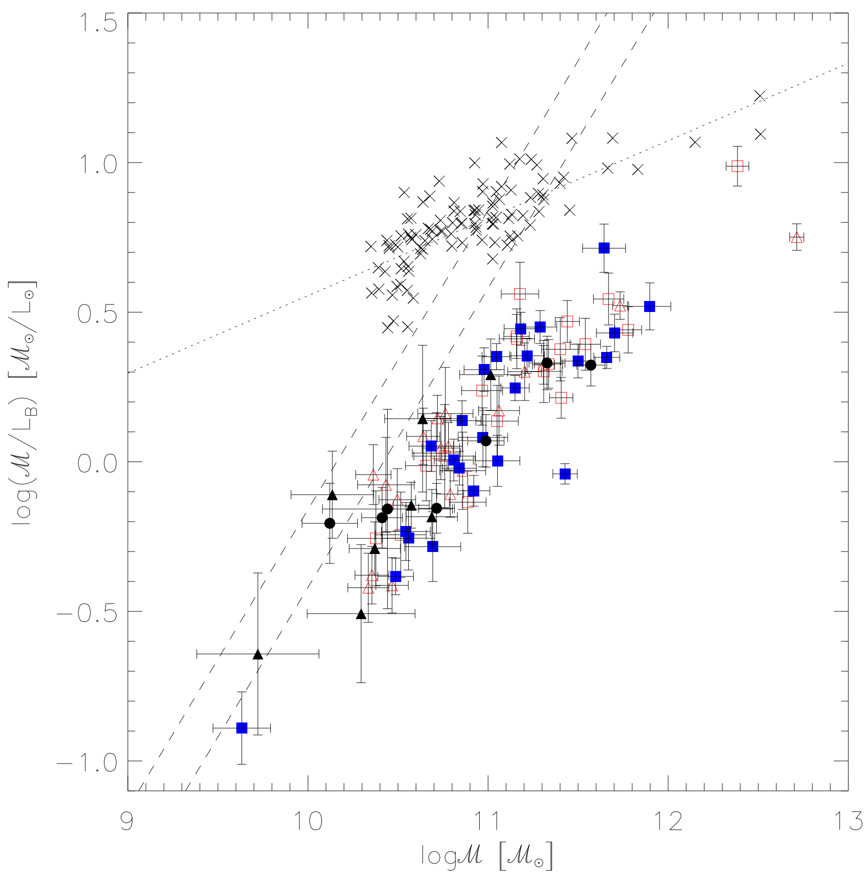

Figure 1. The $\mathcal{M}/L$ ratio in the B-band as a function of galaxy mass for local ETG in the Coma Cluster (Jørgensen et al. 2006) (black crosses), for field ETG at $z{\sim}1$ from the K20 survey (di Serego Alighieri et al. 2005) both in the CDFS field (filled black circles) and in the Q0055 field (filled black triangles), for field ETG at $z{\sim}1$ in the GOODS area (Treu et al. 2005) (filled blue squares), and for the ETG in two clusters (Jørgensen et al. 2006) at z=0.835 (open red squares) and at z=0.892 (open red triangles). The dotted line is a fit to the Coma ETG, while the upper and lower dashed lines represent the $M_B = -20.0$ and $M_B = -20.5$ magnitude limits of di Serego Alighieri et al. (2005) and of Jørgensen et al. (2006) respectively. The changes in $\mathcal{M}/L_B$ from high redshift to $z = 0$ decrease with galaxy mass in all environments and are similar in the field and in the clusters.

2. Ages from the Analysis of the Fundamental Plane

The analysis of the FP provides a simple way to estimate galaxy ages (di Serego Alighieri, Lanzoni & Jørgensen 2006a). The FP can be seen as a relationship between the $\mathcal{M}/L$ ratio and the mass, by a simple coordinate conversion (Bender, Burstein & Faber 1992). Figure 1 shows a compilation in these coordinates of the FP data on ETG at $z \sim 1$ both in the field (di Serego Alighieri et al. 2005;

Treu et al. 2005) and in the clusters (Jørgensen et al. 2006), compared to the ETG at $z = 0$. The evolution of the $\mathcal{M}/L$ ratio in the last 10 Gyr is larger for the smaller mass galaxies. Although this trend is enlarged by selection effects due to the magnitude limited samples, as shown by the dashed lines in Figure 1, nevertheless it cannot be totally explained by them (van der Wel et al. 2005).

The usual way to analyse the evolution in $\mathcal{M}/L$ ratio as a function of redshift is to compare it with the fit done by van Dokkum & Stanford (2003) for the massive ETG ($\mathcal{M} > 10^{11}\mathcal{M}_{\odot}$) of several clusters for redshifts up to z=1.3. However this procedure is largely unsatisfactory, since, first, these massive cluster galaxies are not necesarily a uniform reference class, and, second, it prevents by construction from studying the lower mass cluster galaxies, which are those more likely to show any downsizing effect. Therefore, in order to study how the star formation history of ETG depends on the galaxy mass and the environment, we are proposing a different approach (di Serego Alighieri, Lanzoni & Jørgensen 2006a), which consists in interpreting the changes in $\mathcal{M}/L$ ratio as age differences. In fact it has been shown that other possible interpretations, i.e. systematic structural changes and partial support by rotation, can only explain a small fraction of the observed differential evolution of $\mathcal{M}/L_B$, and that this evolution correlates with the rest-frame $U - B$ colour, thereby providing independent evidence for changes in the stellar populations (di Serego Alighieri et al. 2005). Maraston (2005) has used evolutionary population synthesis models to estimate the $\mathcal{M}/L$ for simple stellar populations with variable age (Fig. 2).

We have then estimated the luminosity weighted average stellar age for each $z \sim 1$ ETG from the $\mathcal{M}/L_B$ obtained from the FP parameters and using the metallicity derived from the observed velocity dispersion (Thomas et al. 2005). The results are shown in Figure 3 and clearly show the downsizing effect, i.e. the age correlates with the galaxy mass both in the clusters and in the field, and there appears to be no difference in age due to the environment (di Serego Alighieri, Lanzoni & Jørgensen 2006a,b).

Since for a given $\mathcal{M}/L$ ratio the age decreases with metallicity (Fig. 2) and velocity dispersion, hence with mass, the downsizing effect would be even stronger, if we assume a fixed metallicity for all galaxies.

3. Ages from Fits of Spectral Synthesis Model to the Spectra

Looking for an independent estimate of the ages obtained from the FP parameters, we have recently been experimenting with ages obtained by fitting the observed intermediate resolution spectra of the $z \sim 1$ field ETG from the K20 survey (di Serego Alighieri et al. 2005) with synthetic model spectra (Pozzetti et al. in preparation). Preliminary results have been obtained using high resolution SSP–based atmosphere models by Bertone et al. (in preparation) and the metallicitiy derived from the velocity dispersion, as in the previous section. Figure 4 shows the comparison of these preliminary results with the ages obtained from the FP parameters. This comparison shows that, although for the majority of the galaxies the ages obtained with the two methods are consistent, there are a number of cases which are discrepant, some with larger FP ages and others with smaller ones. More work needs therefore to be done to understand these discrepancies and to gain sufficient confidence in the estimated ETG ages.

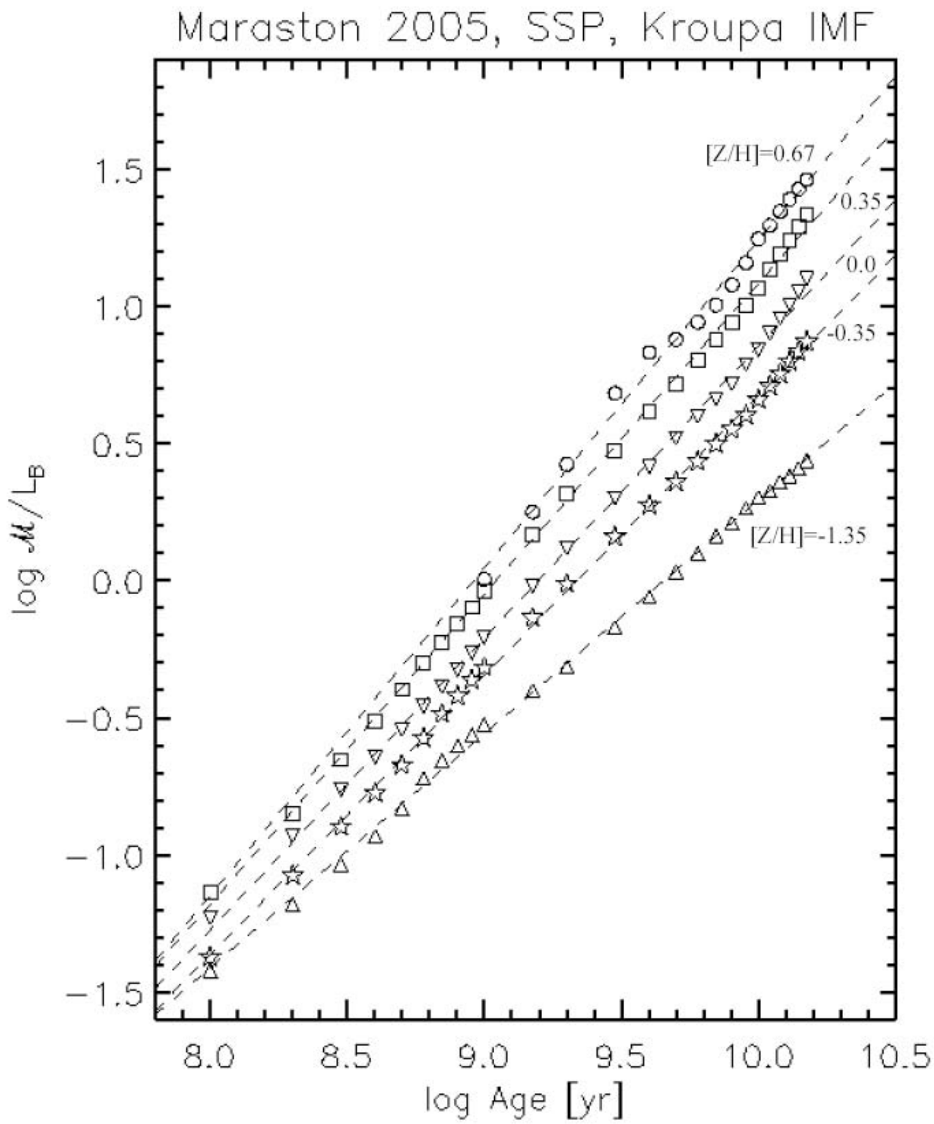

Figure 2. The dependence of the $\mathcal{M}/L_B$ ratio on the age as derived by Maraston (2005) for simple stellar populations with a Kroupa (2001) IMF for five different metallicities.

For this purpose we are also planning to constrain ages using the spectral indices (e.g. Renzini 2006 and references therein).

4. Summary and Future Work

We have used the scaling parameters of ETG (luminosity, effective radius, and velocity dispersion) to evaluate $\mathcal{M}/L_B$ ratio changes as a function of redshift (for $0 < z < 1.3$), galaxy mass and environment. The $\mathcal{M}/L_B$ ratio evolves faster

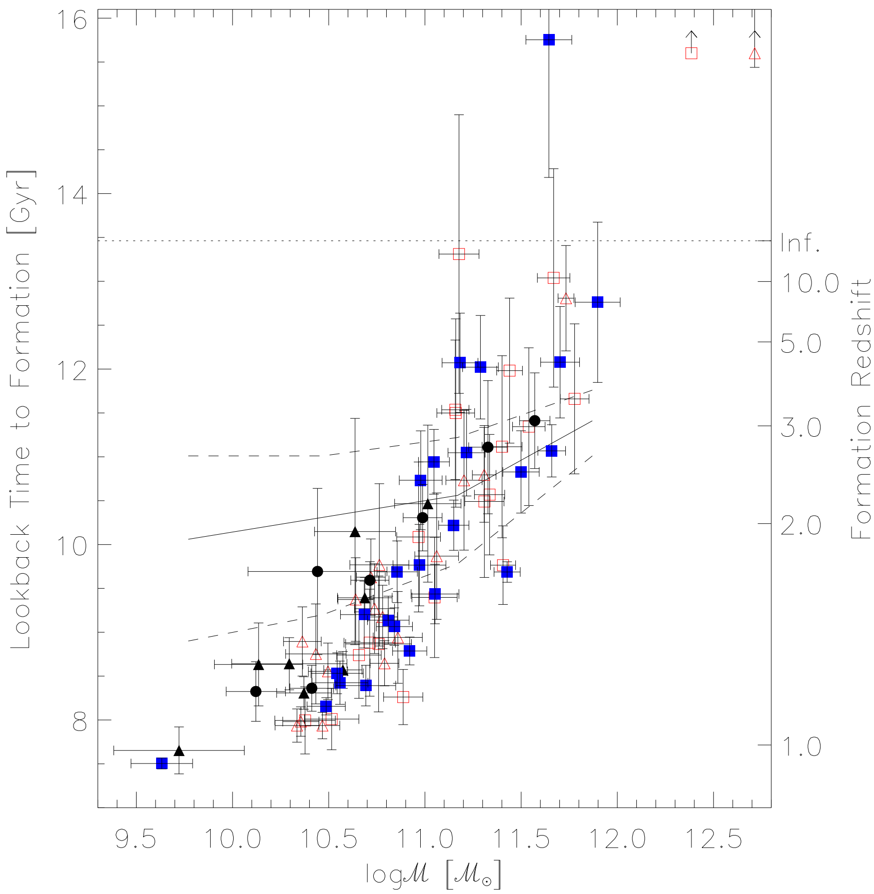

Figure 3. The formation epoch for the ETG shown in Figure 1 (same symbols), evaluated as explained in the text. The two upward pointing arrows indicate that the two most massive cluster ETG are out of the figure (their ages amount to 16.4 and 23.4 Gyr). The continuous line shows the median model ages obtained by De Lucia et al. (2006) from a semianalytic model of hierarchical galaxy evolution, while the dashed lines are their upper and lower quartiles. More massive ETG form earlier in all environments, and the ages are not influenced by the environment.

for lower mass galaxies both in the field and in the clusters, and the evolution does not depend on the environment. Interpreting the $\mathcal{M}/L$ ratio changes as age differences we infer that the age increases with mass (downsizing) both in the field and in the clusters, and field galaxies have the same age as cluster galaxies with the same mass. We are currently obtaining independent estimates of the age of the $z \sim 1$ ETG by fitting the observed spectra with sythesis models and by using the spectral line indices. In addition we will use a different independent approach by deriving the metallicity (and the related age) directly from the fits to the spectra.

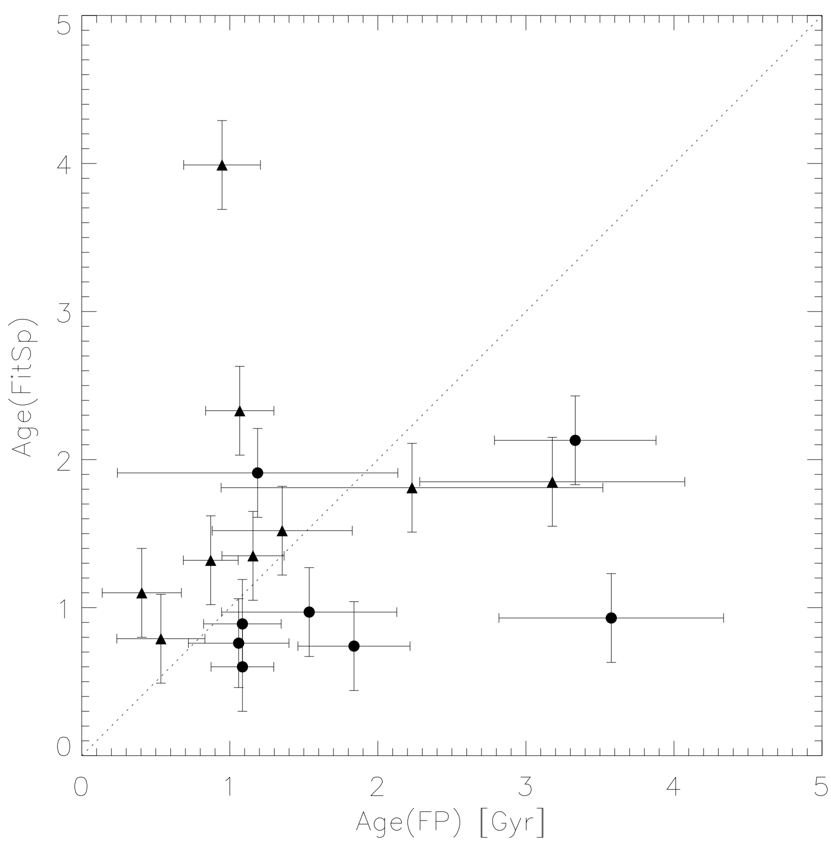

Figure 4. Comparison of the ages obtained from the FP parameters with those obtained from fits of spectral synthesis models to the spectra of ETG at $z \sim 1$ from the K20 survey of di Serego Alighieri et al. (2005).

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