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Early-type Galaxies in the Cluster Abell 2390 at z = 0.23

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Abstract

To examine the evolution of the early-type galaxy population in the rich cluster Abell 2390 at $z = 0.23$ we have gained spectroscopic data of 51 elliptical and lenticular galaxies with MOSCA at the 3.5 m telescope on Calar Alto Observatory. This investigation spans both a broad range in luminosity ($-19.3 \geq M_B \geq -22.3$) and uses a wide field of view of $10' \times 10'$, therefore the environmental dependence of different formation scenarios can be analysed in detail as a function of radius from the cluster centre. Here we present results on the surface brightness modelling of galaxies where morphological and structural information is available in the F814W filter aboard the *Hubble Space Telescope (HST)* and investigate for this subsample the evolution of the Fundamental Plane.

1.1 Introduction

A key question of early-type galaxy evolution is when and within what timescales their stellar populations have been formed. In models based on a monolithic collapse a burst of star formation at high redshift ($z_f \gtrsim 2$) is followed by a passive evolution of the stellar populations. This is in contrast to the formation scenario of hierachical cluster models, presuming longer assembly timescales for the more massive galaxies and therefore resulting in somewhat younger mean ages.

In order to probe the evolution of galaxies, it it necessary to explore both the morphological evolution as well as the evolution of the luminosities and the mass-to-light (M/L) ratios of the galaxies. This can be best achieved with the Fundamental Plane (FP). In a three dimensional parameter space, defined by three parameters, the effective radius R_e, effective surface brightness μ_e and velocity dispersion σ, the FP establishes a tight correlation (Dressler et al. 1987, Djorgovski & Davis 1987). Projections of this plane are the the Faber-Jackson relation (FJR), luminosity L *vs.* σ relation, (Faber & Jackson 1976) and the Kormendy relation (KR), a correlation between R_e *vs.* μ_e (Kormendy 1977).

To overcome selection problems and possible limitations due to a small number of the more luminous galaxies of previous spectroscopic samples, we focus in this investigation of the cluster Abell 2390 on a large number of objects ($N = 51$), spanning a wide range in luminosity $23.3 > B > 21.4$, $-19.2 > M_B > -22.4$ and a wide field of view of $\sim 10' \times 10'$ (2.5×2.5 Mpc), analogous to the study of Abell 2218 by Ziegler et al. (2001). Furthermore the evolution of galaxies in age, metallicity and abundance ratios is investigated by analysing absorption line strengths, such as Hβ, Mg$_b$, Fe5270 and Fe5335 in comparison with the latest stellar population models. The determination of velocity dispersions of our galaxies makes it possible not only to study the Faber-Jackson and Mg–σ relations but also these relations in respect to the slope, scatter and zeropoint. With this large sample, it is possible to explore variations in early-type galaxy evolution not only in the dense core of a rich cluster but also in a less dense environment by incorporating galaxies at larger radii from the cluster centre. In addition different sub-populations (like E, S0, E+A) can be analysed with statistically significant reliability.

Through this article we adopt a cosmological model with a deceleration parameter of $q_0 = 0.1$, a Hubble constant of $H_0 = 65\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and a cosmological constant of $\Omega_\Lambda = 0$.

1.2 Observations and Sample Selection

The large spectroscopic sample of this study comprises a total of 63 spectra of 51 different early-type galaxies gained using the MOSCA spectrograph at the 3.5 m telescope at Calar Alto Observatory in Spain during two observing runs (Sept. 1999 and July 2000). The spectral resolution in the wavelength range $5900 \lesssim \lambda \lesssim 6400$ Angström (around the Hβ and Mg$_b$ lines) was 5.5 Angström FWHM, corresponding to $\sigma_{\rm inst} \sim 100$ km s^{-1}. Values for the S/N vary between 9.6 and 79.8 with an average value of $S/N \sim 41$.

The objects were selected on the basis of ground-based Gunn i-band images (500 sec) obtained with the Palomar 5 m Hale telescope. Additional imaging data from Mt. Palomar is available in the U (3000 sec) and B (500 sec) filter bands and the WFPC2 camera onboard the *Hubble Space Telescope (HST)* observed A 2390 in the F555W and F814W filter (10800 sec each).

1.3 Reduction and Analysis

All spectra were reduced using standard reduction techniques implemented within MIDAS and IRAF. Examples of final 1-dimensional spectra in rest frame wavelengths are plotted in Fig. 1.1. The velocity dispersions were evaluated with the Fourier Correlation Quotient method as described in Bender (1990).

Absolute magnitudes for all galaxies were calculated from our ground-based UBi photometry. Using SExtractor (Bertin & Arnouts 1996), object positions were determined and performing aperture photometry apparent magnitudes were measured. The total Gunn i magnitudes were transformed to rest frame B and rest frame Gunn r magnitudes with typical k-corrections of $m_B \approx 1.2$ and $m_r \approx 0.34$, for HST objects according to their morphology.

1.4 HST Photometry

The surface brightness models for our galaxies were constructed using our F814W image. As pointed out by Ziegler et al. (1999), an exposure time of ~ 10 ksec is deep enough to determine structural parameters down to $M_{B\,\rm rest} \sim 23$ mag.

1.4.1 Structual Parameter Analysis

Structural properties were determined by fitting the surface brightness profile as determined from the HST F814W images with an $R^{1/4}$ and an exponential law profile, both separately and in combination (Saglia et al. 1997). For the bulge profile a special form of the Sérsic profile (Sérsic 1968), the classical de Vaucouleurs profile, in the following form was applied:

$$\Sigma(R) = \Sigma_e \exp\left\{-7.67\left[(R/R_e)^{1/4} - 1\right]\right\} \tag{1.1}$$

$\Sigma(R)$ is the surface brightness at R along the semimajor axis and Σ_e is the effective surface brightness. The disk profile is well represented by an exponential law, defined as:

$$\Sigma(R) = \Sigma_0 \exp\{-(R/h)\} \tag{1.2}$$

where Σ_0 is the (face-on) central surface brightness for the disk and h the exponential disk scale length. In total structural parameters could be determined for 14 galaxies out of 15 for which we also have obtained spectra. In Fig. 1.1 examples of the surface brightness profile fitting are shown. Values for the total magnitude I_{tot}, the central surface brightness μ_0, the effective radius R_e and the effective radius of the bulge $R_{e,b}$, and the disk-to-bulge ratio D/B are listed. The model for the S0 galaxy # 2138 shows the existence of a small disk component at $R^{1/4} \sim 1.25$ ($R \approx 2.44''$). In the case of the elliptical (E) galaxy # 2592 no disk component is seen. Both galaxies are well reproduced by a combination of a de Vaucouleurs profile and a model for an underlying disk component.

1.5 The Fundamental Plane at intermediate Redshift

In Fig. 1.2 the Fundamental Plane (FP) for A 2390 in rest frame Gunn r is illustrated. The figure also shows the FP for the local Coma samples of Jørgensen et al. (1996) (JFK96), Jørgensen (1999) (J99) and for the intermediate redshift cluster of A 2218 by Ziegler et al. (2001) at $z = 0.18$. A morphological analysis of the HST galaxies revealed that our sample splits nearly equally into elliptical and lenticular (S0) galaxies. 7 galaxies were classified as elliptical, 6 as lenticular and one as a early-type spiral (Sa). Both families are uniformly distributed along the Fundamental Plane (see Fig. 1.2). Compared to the sample of 115 Coma galaxies we deduce a modest luminosity evolution of $\overline{m}_r = 0.12 \pm 0.19$ mag for the overall sample. This result is in agreement with the predictions of the hierarchical merging scenario for rich clusters (Kauffmann 1996).

1.6 Conclusions

We have investigated 51 members of the A 2390 early-type galaxy population, both over a broad range in luminosity ($-19.3 \geq M_B \geq -22.3$) and a wide field of view of $10' \times 10'$. Structural properties of the HST subsample were analysed by combining an $R^{1/4}$ and an exponential law profile for accurate surface brightness modelling. From the Fundamental Plane for A 2390 we find a mild evolution of $\overline{m}_r = 0.12 \pm 0.19$ mag, which is in agreement with predictions of hierachical models of cluster formation.

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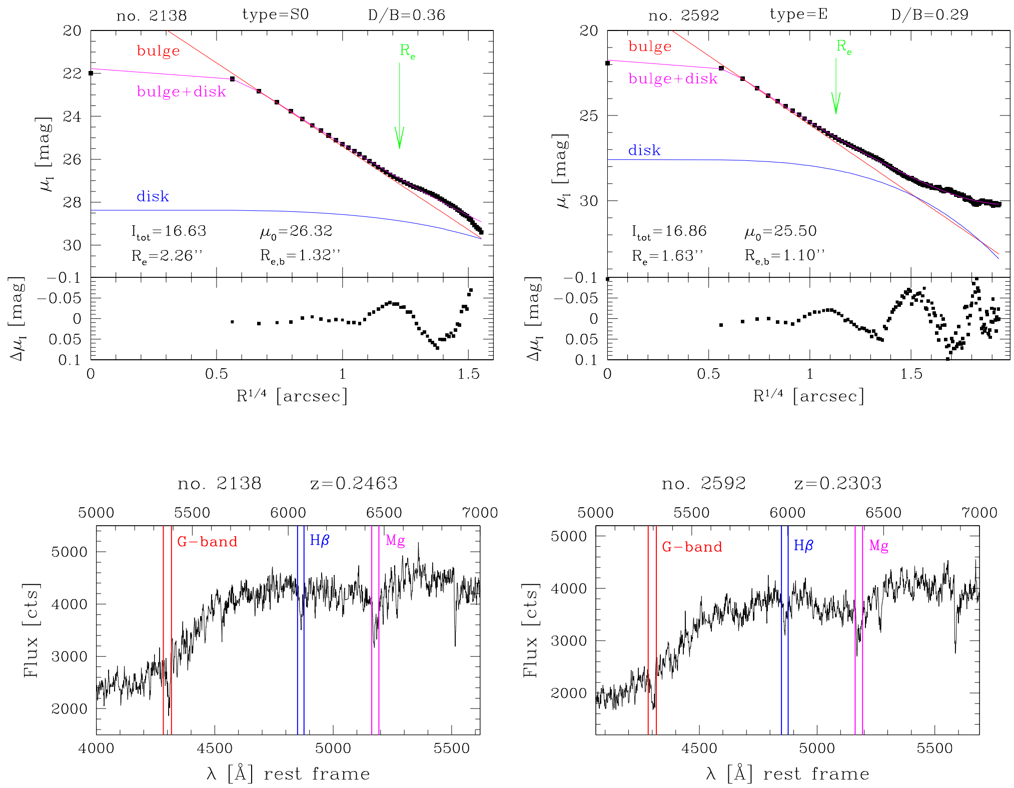

Fig. 1.1. **Upper panel:** I_{814} Surface Brightness profiles of the two objects # 2138 (S0) and # 2592 (E). The total I_{814} magnitude (ZP and extinction A_{F814W} corrected) is plotted against the radius $R^{1/4}$ (in arcsec). Filled squares show the observed profile, lines the different best models for the bulge (de Vaucouleurs law), disk (exponential law) component fit and for a combination of bluge and disk components. The arrow indicates the position of the effective radius R_e. Different structural parameters are shown (see text for details). The inset gives the residuals $\Delta\mu_I$ between the observed profile and the modelled fit as a function of $R^{1/4}$. **Lower panel:** Spectra (not flux-calibrated) of the corresponding galaxies with determined redshift. The lower x-axis represents the rest frame wavelengths, the upper one the observed wavelengths (both in Angström). The ordinate gives the flux in counts (1 ADU=1.1 e^{-1}). Prominent absorption features are marked.

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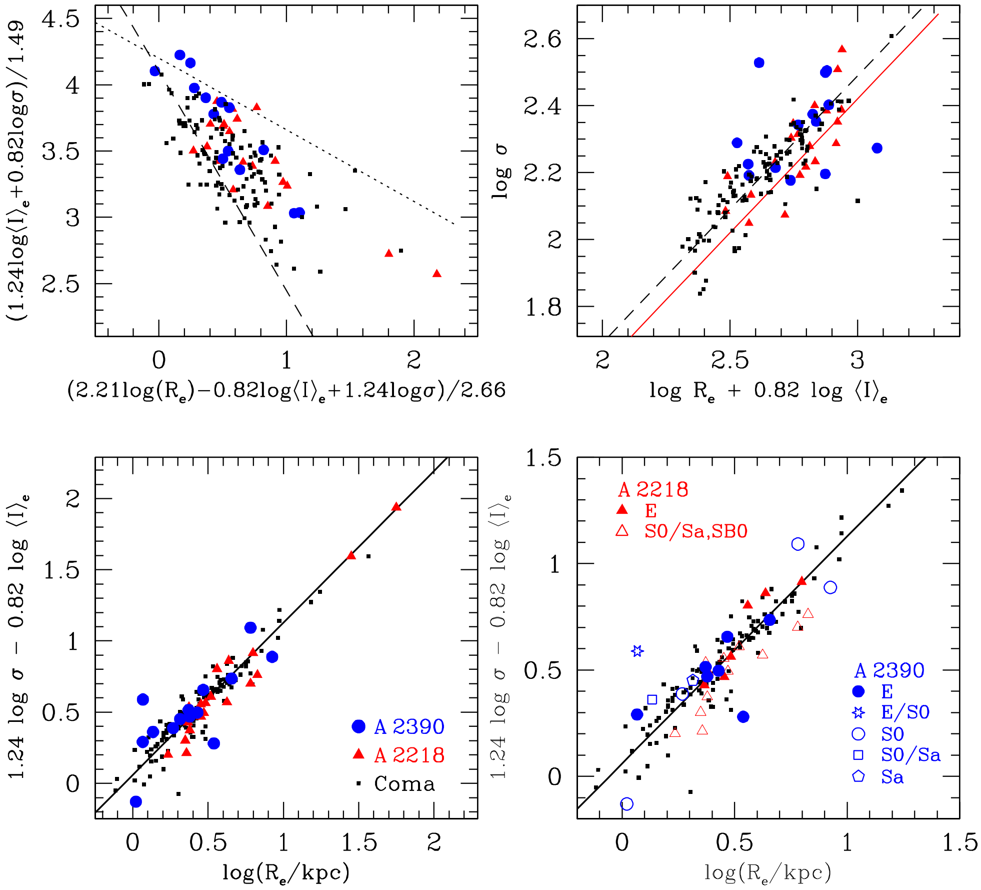

Fig. 1.2. Fundamental Plane for A 2390 in rest frame Gunn r. Circles represent our A 2390 objects, triangles the early-type galaxies of A 2218 ($z = 0.18$), small squares the Coma galaxies of JFK96 and J99, respectively. *Upper panel, left:* Face on FP. The dotted line indicates the so-called exclusion zone for nearby galaxies (Bender et al. 1992) and the dashed line the luminosity limit for the completeness of the Coma sample $M_{r\mathrm{T}} = -20.75$ mag. *Upper panel, right:* FP edge-on, along the short axis. The dashed line marks the relation for the local Coma sample, following JFK96, the solid line the fit for the A 2218 galaxies. Our galaxies are more spread in respect to Coma but show a similar behaviour as the A 2218 galaxies. *Lower panel:* Edge-on FP. The solid line represents the fit for the local Coma objects. On the left side a zoom of the edge-on FP with a separation into different morphologies of the A 2390 and A 2218 galaxies is shown. Compared to the local Coma sample we find an FP evolution of $\overline{m}_r = 0.12 \pm 0.19$ mag.

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