The Evolutionary Status of Early-type Galaxies in Abell 2390

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Abstract. We explore the evolution of the early-type galaxy population in the rich cluster Abell 2390 at $z = 0.23$. For this purpose, we have obtained spectroscopic data of 51 elliptical and lenticular galaxies with MOSCA at the 3.5 m telescope on Calar Alto Observatory. As our investigation spans both a broad range in luminosity ($-22.3 \leq M_B \leq -19.3$) and a wide field of view ($10' \times 10'$), the environmental dependence of different formation scenarios can be analysed in detail as a function of radius from the cluster center. In this paper, we present first results on the Faber-Jackson relation and, for a subsample of 14 galaxies with morphological and structural parameters from HST, we also investigate the evolution of the Kormendy relation and the Fundamental Plane. We find a mild luminosity evolution of the early-type galaxies in Abell 2390: our objects are on average brighter by $m_B \sim 0.4$ mag.

Keywords: galaxies, elliptical and lenticular, evolution, formation, fundamental parameters, cluster of galaxies, Abell 2390

1. Motivation and Sample Selection

Early-type galaxies are tightly correlated via three parameters, the effective radius $R_e$, effective surface brightness $\mu_e$ and velocity dispersion $\sigma$, that define a three dimensional parameter space called the Fundamental Plane (FP) (Dressler et al. 1987, Djorgovski & Davis 1987, Bender et al. 1992). Projections of this plane are the Faber-Jackson relation (FJR) (Faber & Jackson 1976), luminosity $L$ vs. $\sigma$, and the Kormendy relation (KR) (Kormendy 1977), $R_e$ vs. $\mu_e$. A study of such scaling relations over different cosmic epochs offers powerful tests of different aspects of galaxy evolution models and the hierarchical merging scenario.

One of the key questions of early-type galaxy evolution is when and within what timescales their stellar populations have been formed. Monolithic collapse models predict a burst of star formation at high redshift ($z_{\text{form}} \geq 2$) and a following passive evolution of the stellar populations, whereas in the hierarchical galaxy formation scenario the
assembly timescales for more massive galaxies are longer, resulting in somewhat younger mean ages.

Previous spectroscopic studies were limited to a small number of the more luminous galaxies. To overcome bias and selection problems of small samples, we focus in this study of the cluster Abell 2390 on a large number of objects \((N = 51)\), spanning a wide range in luminosity \(21.4 < B < 23.3; -22.4 < M_B < -19.2\) (down to \(M_B^* + 1\)) and a wide field of view of \(\sim 10' \times 10'\) (2.5 \(\times\) 2.5 Mpc), analogous to the investigation of Abell 2218 by Ziegler et al. (2001). With this large sample, it is possible to explore variations in early-type galaxy evolution as a function of distance from the cluster center as well as for different sub-populations like S0 or Balmer-line enhanced galaxies in a statistically significant way.

In this article a cosmological model with a deceleration parameter of \(q_0 = 0.1\) and a Hubble constant of \(H_0 = 65\) \(\text{km s}^{-1}\) \(\text{Mpc}^{-1}\) is assumed.

## 2. Observations

During two observing runs (Sept. 1999 and July 2000) we gained a total of 51 different early-type galaxy spectra using the MOSCA spectrograph at the 3.5 m telescope at Calar Alto Observatory in Spain. The instrumental resolution around H\(\beta\) and Mg\(b\) (5900 \(\leq\) \(\lambda\) \(\leq\) 6400 \(\AA\)) was 5.5 \(\AA\) FWHM, corresponding to \(\sigma_{\text{Inst}} \sim 100\) km s\(^{-1}\). The \(S/N\) varies 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), deep enough to determine structural parameters down to $B\text{rest} \sim 23$ magnitudes (Ziegler et al. 1999).

3. Data Reduction and Analysis

The reduction of the spectra was carried out using standard reduction techniques implemented within MIDAS and IRAF. Particular care was taken of the $S$-distortions of the MOSCA spectra. Examples of final extracted 1-dimensional spectra are plotted in Fig. 1. Velocity dispersions were calculated with the Fourier Correlation Quotient method described in Bender (1990). Absolute magnitudes were calculated from our ground-based $UBi$ imaging. Using SExtractor object positions were determined and performing aperture photometry apparent magnitudes were measured. After converting the Gunn $i$ magnitudes to Cousins $I$, apparent magnitudes were transformed to rest frame $B$ magnitudes with typical k-corrections of $m_{k-cor} \approx 1.2$. For those galaxies lying on HST F814W images structural parameters were determined by fitting the surface brightness profile with an $R^{1/4}$ and/or an exponential law profile (Saglia et al. 1997). A more detailed description will be presented in Fritz et al. (2002).

4. Results

The final $B$-band FJR is shown in Fig. 2. In comparison to the local Coma sample of Dressler et al. (1987) we find no significant evolution, our magnitudes are brighter by 0.23 mag on average. Depending on the accuracy of the velocity dispersion measurements, our galaxies were divided into two subsamples, high quality and low quality data. The quality parameter is a combination between various quantities, e.g. the velocity dispersion ($\sigma$) measurement itself (including the error in the single $\sigma$ and error in average $\sigma$), $S/N$ of the spectrum and possible contamination by sky-lines.

In Fig. 3 the KR for our HST galaxies is shown. Comparing the Coma sample of Bender et al. (1992) with our data, we find a similar result as with the FJR and again do not detect any significant luminosity evolution. Our magnitudes are brighter by $\sim 0.5$ magnitudes compared to the Coma objects.
Figure 2. The $B$-band Faber-Jackson relation for A2390 compared to the Coma sample of Dressler et al. (1987). The dot-dashed line shows the bisector fit along with 1 $\sigma$ errors (dotted lines) for the local Coma sample (filled squares). For the local bisector fit objects with $M_B > -19.5$ and $\log \sigma < 2.10$ were neglected. Under assumption of constant slope a principal components fit (solid line) along 1 $\sigma$ errors (dashed lines) for our A2390 sample is shown. The data are separated in high (filled circles) and low (open circles) quality data (see text for details). Typical error bars are plotted for two objects. Restricting our sample to the high quality data the same amount of luminosity evolution of $\bar{m}_B \sim 0.2$ mag as for the whole sample is found.

The FP in restframe $B$ for our sample is plotted in Fig. 4. Based on a smaller scatter than that of the KR and FJR, with the FP the same result is seen (brighter by $\bar{m}_B \sim 0.5$ mag), which indicates again only a modest luminosity evolution for A2390. From these results we conclude that at a look-back time of $\sim 3.3$ Gyrs most early-type galaxies of A2390 consist of an old stellar population and that the formation redshift of elliptical galaxies must be at a much higher redshift of about $z_{\text{form}} \geq 2$, which is in agreement with the formation picture of hierarchical merging in rich clusters (Kauffmann 1996).
Figure 3. The $B$-band Kormendy relation for A 2390 compared to the Coma sample of Bender et al. (1992). The dot-dashed line shows the local 100 iteration bootstrap bisector fit along with 1 $\sigma$ errors (dotted lines) together with the bisector fit for our A 2390 sample (solid line) with 1 $\sigma$ errors (dashed lines). Typical error bars are indicated for two galaxies.

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Figure 4. Edge-on view of the Fundamental Plane in restframe $B$ for A 2390 compared to the Coma sample of Bender et al. (1992). Symbol and line notations are analogous to Fig. 3. An FP evolution of $0.48 \pm 0.26$ mag ($1\sigma$) is found.

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