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# The EFAR Fundamental Plane

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**Abstract:** The EFAR project is a long-term study of 736 candidate early-type galaxies in 84 clusters lying in two regions towards Hercules-Corona Borealis and Perseus-Pisces-Cetus at distances 6000-15000 km/s. We are deriving a high quality determination of the Fundamental Plane for 434 confirmed early-type galaxies. This improves on previous work through 1) the large sample size, 2) the accurate determination of the photometric parameters (including seeing and sky subtraction corrections, simultaneous disk+bulge fitting, and simulations of systematic effects), 3) the large number of repeated spectroscopic observations, and 4) the well-determined selection function. The systematic effects of stellar population variations are estimated using the Mg$b$–$\sigma$ relation and appear to be small.

## 1. Introduction

The EFAR (Ellipticals FAR away) project started in 1986 to construct an accurate and homogeneous photometric and spectroscopic database for a large sample of early-type galaxies with redshifts 6000-15000 km/s, distributed in 83 clusters in the Hercules-Corona Borealis and Perseus-Pisces-Cetus regions. Our goals were to study the structural properties of elliptical galaxies and determine their peculiar motions in two independent regions outside the local supercluster using the Fundamental Plane distance estimator. Both scientific goals are important, since they provide powerful tests of theories of galaxy evolution and of the formation of large scale structure in the Universe.

We have completed the observing and data reduction phases of the project and are in the process of publishing the database and analyzing its astrophysical results. The following papers describe the results obtained up to now. Colless et al. (1993) present the photoelectric photometry database, Saglia et al. (1993) discuss the effects of seeing on the photometric properties of early-type galaxies, Wegner et al. (1996, Paper I) introduce the EFAR cluster and galaxy sample and its selection properties, Wegner et al. (1997, Paper II) present the spectroscopic database, Saglia et al. (1997, Paper III) the photometry database, and Saglia et al. (1996, Paper IV) the photometric fitting technique. In the following we summarize the properties of the photometric and spectroscopic database (Section 2) and discuss the method we are exploring to determine the EFAR Fundamental Plane, test its possible environmental dependencies and derive the peculiar velocities (Section 3). Section 4 gives our conclusions.

## 2. The Database

We invested 185 nights of photoelectric and CCD observations with 1m class telescopes and more than 100 nights of spectroscopic observations with 2m to 4m class telescopes to build up the EFAR database.

We collected 2846 R band CCD images for 776 galaxies with 87% of the galaxies having more than one profile. A total of 1278 photometric calibrations were obtained by means of photoelectric aperture magnitudes (in both the R and the B bands) and CCD R band photometry. Repeated calibrations show that a zero-point precision of 0.03 mag per observation has been achieved. We computed the circularly averaged surface brightness profiles and the photometric parameters of the EFAR galaxies using a seeing-convolved, $R^{1/4}$ plus exponential fitting algorithm which optimally combines multiple profiles and corrects for sky subtraction errors. The precision of the derived $D_n$ diameters, half-luminosity radii $R_e$, total magnitudes $m_T$ and average effective surface brightness $\langle SB_e \rangle$ is estimated with the help of extensive Monte Carlo simulations to test for systematic effects. We find that the systematic errors on $m_T$ and $R_e$ are less than 0.15 mag and 25% respectively for 90% of our sample, while the systematic errors on the combined quantity $\log R_e - 0.3\langle SB_e \rangle$ which enters the Fundamental Plane equation remain always smaller than 0.03 dex, and smaller than 0.015 dex for 90% of the galaxies. The morphological classification based on CCD images shows that 32% of the sample objects, visually selected from photographic images to be of early-type, are in fact spirals or barred S0 galaxies. The 68% of the galaxies classified as early-type can be subdivided into cD (8%), E (11% with a simple $R^{1/4}$ law best fit) and E/S0 (49% with a disk plus bulge best fit). Therefore most of the profiles deviate significantly from a de Vaucouleurs law, needing a non-negligible exponential component, with a typical “disk-to-bulge” ratio $D/B \approx 0.5$.

A total of 1325 spectra have been collected for 666 EFAR galaxies plus 48 galaxy standards. We used both long-slit and fiber-fed spectrographs, spanning the rest-frame wavelength range 4800-5290 Å, covering the $H\beta$, Mg, and Fe absorption features in the redshift range 6000-15000 km/s, with several spectra going from CaI H+K (3933 Å) to NaI D (5892 Å). The typical resolution was $\Delta\lambda = 1-2$Å, or $\sigma_{instr} = 80-150$ km/s, and we reached a typical signal-to-noise ratio S/N$\approx$ 26 per Å. We derive galaxy redshift and central velocity dispersions $\sigma$ using the cross-correlation algorithm and we estimate the precision of the results by means of Monte Carlo simulations. We find that the typical precision of our redshifts is better than 30 km/s, and of our $\sigma$ values $\sim$ 10%. We can determine reliably the Mg$b$ index, while we find that the $\mathrm{Mg}_2$ index is subject to significant systematic effects. We apply aperture corrections to both $\sigma$ and Mg$b$ values which take into account the slit width, the galaxy distance and the galaxy size.

## 3. The EFAR FP and Mg$b$–$\sigma$ relation

The Fundamental Plane (Dressler et al. 1987, Djorgovski and Davis 1987) is the correlation between the structural parameters of elliptical galaxies $\log R_e$, $\log\sigma$ and $\langle SB_e\rangle$, $\log R_e = a\log\sigma + b\langle SB_e\rangle + c$. The parameters $(a, b)$ are in the range $a \approx 1.1 - 1.4$, $b \approx 0.3 - 0.35$ and depend on the chosen photometric band, with larger values of $a$ at longer wavelengths (see Pahre, this volume). The zero-point of the relation, $c$, allows the determination of distances with better than 15% precision per object. The unbiased determination of the coefficients of the EFAR FP must take into account the selection effects, which vary from cluster to cluster, the presence of well-defined exclusions (e.g., due to resolution we cannot observe galaxies with $\sigma \leq 100$ km/s) and the errors of the data. We are developing a maximum likelihood algorithm to address the problem and testing the results with simulations. Fig. 1a shows the distribution of the EFAR early-type galaxies in the edge-on FP for one (not yet optimized but reasonable) choice of parameters ($a = 1.2$, $b = 0.3$). Cluster redshifts are used to estimate distances with $H_0 = 50$ km/s/Mpc. The rms of the histogram of the residuals (which does not take into account the peculiar motions) is 0.11 dex (Fig. 1b). Systematic variations of the galaxy properties from cluster to cluster can in principle induce spurious peculiar velocities (Silk 1989, Guzman & Lucey 1993, Gregg 1995). The Mg–$\sigma$ relation permits us to check that the stellar population variations from cluster to clusters are small. Fig. 1c shows that the Mg$b$–$\sigma$ relation for the EFAR galaxies does not deviate from previous determinations. The histogram of the zero-points of the relation for the sample of the EFAR clusters (Fig. 1d) has an rms of 0.02 dex. This suggests that environmental effects, if present, are small.

## 4. Conclusions

We described the first results of the EFAR project, which measured the structure parameters of 434 early-type galaxies at redshifts 6000-15000 km/s in 84 clusters in the Hercules-Corona Borealis and Pisces-Perseus-Cetus regions. We are developing a maximum likelihood algorithm to determine the EFAR FP and peculiar motions. The effects of stellar populations are estimated using the Mg$b$–$\sigma$ relation and appear to be small.

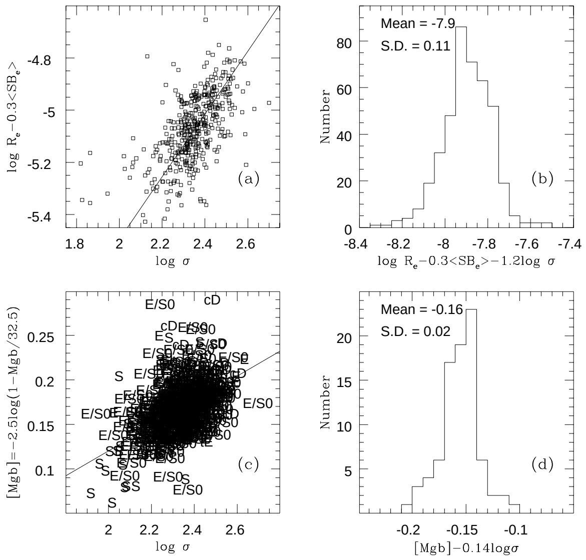


**Figure 1.**(a) The edge-on view of the EFAR FP for $a = 1.2$ and $b = 0.3$. (b) The histogram of the residuals from the relation. c) The EFAR Mg$b$–$\sigma$ relation. d) The histogram of the cluster zero-points of the relation.

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