THE EFAR PECULIAR VELOCITY FIELD

R.P. Saglia,[1] Matthew Colless,[2] David Burstein,[3], Roger L. Davies,[4] Robert K. McMahan, Jr.[5] and R. Watkins[6], Gary Wegner[6]

[1] *Institut für Astronomie und Astrophysik, D-81679 Munich, Germany*
[2] *Mount Stromlo and Siding Spring Observatories, ACT 2611, Australia*
[3] *Dept of Physics and Astronomy, ASU Tempe, AZ 85287-1504*
[4] *Dept of Physics, University of Durham, DH1 3LE, UK*
[5] *Dept of Physics and Astronomy, Chapel Hill, NC 27599-3255*
[6] *Dept of Physics and Astronomy, Dartmouth College, Hanover, NH 03755*

ABSTRACT. The EFAR collaboration has measured the structural parameters (half-luminosity radii, total magnitudes, central velocity dispersions and Mg indexes) of galaxies in 84 clusters of the Hercules-Corona Borealis and Pisces-Cetus regions, with redshifts 6000< cz <15000. Analysing this database by means of a Maximum Likelihood algorithm, the Fundamental Plane relation derived is in agreement with existing determinations, and used to determine the peculiar velocities (PV) of the clusters. We find that the mean peculiar velocities in the two regions are small and compatible with zero motions. We rule out at the 3σ level the large bulk flow motion measured by Lauer and Postman (1994). We suggest that distances derived using cD galaxies might be biased due to stellar population effects.

1 Introduction

The EFAR collaboration (Wegner et al. 1996, Paper I) has collected spectroscopic (Wegner et al. 1998, Paper II) and photometric (Colless et al. 1993, Saglia et al. 1993, Saglia et al. 1997a, 1997b, Papers III and IV) data for galaxies in 84 clusters of the Hercules-Corona Borealis and Pisces-Cetus regions, with redshifts 6000< cz <15000, plus a sample of calibration galaxies. 676 galaxies have redshifts, dispersions and Mg indices, 674 galaxies have R-band calibrated CCD images, and 591 have both, of which 483 have early-type morphology. The primary goal of the project is to use the Fundamental Plane correlation between the global properties of early-type galaxies (Djorgovski & Davies 1987, Dressler et al. 1987) to measure the peculiar motions of clusters in regions outside the local supercluster (Saglia et al. 1999, Paper VI, Colless et al. 1999, Paper VII). The sample size allows the 3σ detection of motions similar to the ones detected locally (Lynden-Bell et al. 1988), and therefore is a sensitive test of cosmological models of large scale structure (Watkins et al. 1999, Paper VIII). The survey, however, does not cover the whole sky and is not suited to determining dipole motions (cf. Lauer and Postman 1994, Hudson et al., this volume). Finally, the structural properties of early-types (De Jong et al. 1999, Paper IX) and their stellar populations (Colless et al. 1998, Paper V) can be studied in detail.

The dataset includes the galaxy redshifts cz and central velocity dispersions σ, the central line indexes Mg_2 and Mgb and the galaxy photometric parameters in the R-band (the half-luminosity radii R_e and average effective surface brightness $\langle SB_e \rangle$). Care was taken to determine the galaxy selection function cluster by cluster, and to estimate the random and systematic errors affecting the photometric and spectroscopic quantities, by analysing repeat measurements and performing extensive Monte Carlo tests. The parameters of the disk and bulge components of the galaxies are also available, allowing a reliable morphological classification of the objects.

Here we derive the Fundamental Plane equation (§2) for the sample and determine the peculiar velocities of the clusters (§3), measuring the mean motions of the two regions and comparing the results with previous surveys. Conclusions are drawn in §4.

2 The Fundamental Plane

The commonly used methods to find the coefficients of the FP are of the least-squared type: one minimizes the orthogonal (absolute or squared) residuals from the plane (Jørgensen et al. 1996, Pahre et al. 1997, Scodeggio et al. 1997) or the (square) residuals from one of the variables (Hudson et al. 1997). Ample discussion of problems related to selection is given by Willick (1996) and Teerikorpi (1997). However, none of these approaches is able to deal effectively with the multiple problems that the EFAR datasample poses: (i) the factor two in redshift range, (ii) the strong selection effects, (iii) the non-negligible and widely varying measurement errors, (iv) the presence of hard limits imposed on the sample, (v) the intrinsic scatter of the relation. We developed a maximum likelihood (ML) algorithm based on gaussian modelling of the data distribution in the FP which copes with all these difficulties. Extensive Monte Carlo simulations (Paper VI) show that the method is superior to the "classical" approaches, allowing the unbiased determination of the FP parameters and peculiar motions.

We determine the EFAR Fundamental Plane using the ML algorithm and consider the 20 best clusters of the sample with 7 or more objects. In order to fix the zero-point, we require the average of the FP cluster shifts to be zero. This is equivalent to setting the Coma cluster (nearly) to rest with respect to the Cosmic Microwave Background. Our present best solution is:

$$\log R_e = a \log \sigma + b \langle SB_e \rangle + c, \qquad (1)$$

where $a = 1.28 \pm 0.15$, $b = 0.33 \pm 0.02$ and $c = -8.6 \pm 0.6$. The 1σ errors are derived from Monte Carlo simulations. They bracket the variations of the best-fit parameters observed when different datasets are considered (restricting the attention to clusters with 10 or more galaxies, changing the morphological selection, varying the D_W cut or the maximum allowed selection weight, etc.), or when Burstein and Heiles (1984) or Schlegel et al. (1998) absorption corrections are used. The FP coefficients are consistent with previous determinations, based on nearby galaxies.

3 The Peculiar Velocity Field

Using the solution found above, we determine the distances and peculiar motions for all clusters. No correlation is seen between the cluster FP shifts against the zero-point differences of the Mg$-\sigma$ relation. This indicates that stellar population effects are not playing an important role. For a detailed discussion of the Mg$-\sigma$ relation of the EFAR clusters see Colless et al. (1998, Paper V). No correlations are seen between the galaxy redshifts relative to the cluster cz and the residuals from the cluster FP, indicating the reality of the clusters and validating the cluster assignments. Once the cluster shifts are taken into account, the robust estimate of the scatter about the FP relation, at the 68% level of the absolute differences, is 0.085 dex, or 22% in distance. The peculiar velocities of individual clusters are in the range ± 2000 km/s with a typical error of ≈ 1300 km/s. Therefore, no individual cluster's peculiar velocity is detected at a significant level. Within the large errors, the distances compare well with previous determinations (Hudson et al. 1997, Scodeggio et al. 1997).

The mean peculiar velocities, determined by averaging over samples of clusters, can be detected with a higher precision, $\approx$ 200 km/s. Fig. 1 shows the components of the peculiar velocities of clusters with 4 or more galaxies, averaged in radial bins 2000 km/s wide, as a function of the central bin redshift. The mean motions are compatible with zero within the errors to the most distant bin. The rms motions are also compatible with small values. We estimate the intrinsic rms of the peculiar velocities using a maximum likelihood approach, taking into account the (large) errors. We find that the rms in the Galactic x-y plane are small, $\lesssim$ 300 km/s. Slightly larger values are obtained orthogonal to the Galactic plane, especially in the $b < 0$ region. The errors are of the order of 400 km/s.

Fig. 2 shows the peculiar veloci-

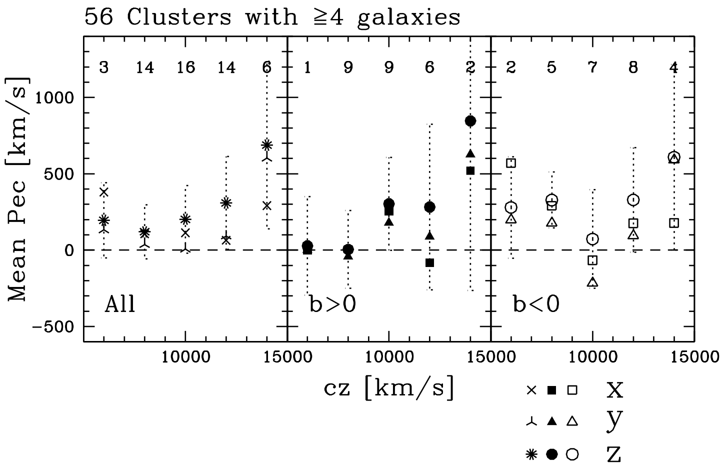

Figure 1. *The peculiar velocities averaged in bins 2000 km/s wide. Clusters with 4 or more galaxies are considered. Errors are shown dotted. The numbers give the clusters per bin. The symbols refer to the x, y, z galactic directions.*

ties of clusters with 4 or more galaxies and redshifts less than 15000 km/s, as a function of the cosine of the angle with the direction of the Lauer and Postman (1994) dipole. The best-fit bulk flow to the data gives $V_{bulk} = 143 \pm 158$ km/s, but is not a very good representation of the data, having a rather large value of the reduced χ^2 (1.379, corresponding to 0.031 probability). The Lauer and Postman solution has a reduced χ^2 of 1.656 and is ruled out to 0.002 probability. Monte Carlo simulations (Fig. 3) show that the EFAR sample should be able to detect the LP flow to 3σ, if present. Therefore, the present data rule out the LP flow at this significance level. Similar simulations performed for the SMAC dipole (Hudson et al., this volume) show that the EFAR sample cannot detect clearly the SMAC signal, being nearly orthogonal to it.

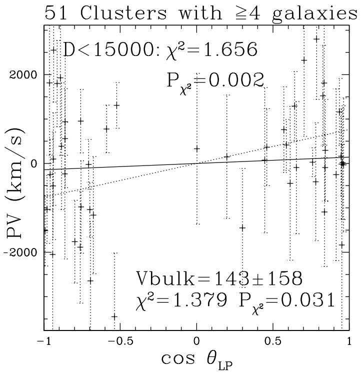

Figure 2. *The cluster's peculiar velocities as a function of the cosine of the angle with the direction of the Lauer and Postman dipole. Clusters with 4 or more galaxies are considered. The full line shows the best-fit to the data, the dotted line the expected signal. Errors are also shown dotted.*

Since Lauer and Postman (1994) used only the brightest cluster galaxies to determine the distance to clusters, it is worthwhile to compare them with the FP ones, which include also less luminous early-type objects. A possible trend is observed (see Fig. 4) between the ratio of the EFAR and LP distances and the residuals from the best fitting FP for the 30 cD galaxies in common for the two samples, in the sense expected from errors in distance (parallel to the solid line). Fig. 5 shows the correlation between the Fundamental Plane and the Mg$-\sigma$ residuals for all the cD galaxies of the EFAR sample. These galaxies appear to have systematically positive shifts from both relations (see histograms). This suggests that the stellar populations of cD galaxies are more metal rich (or older, or both) than the ones of nor-

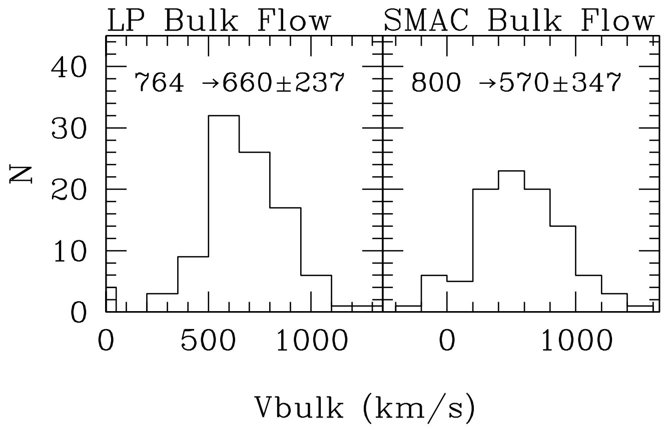

Figure 3. *The histograms of the LP (left) and the SMAC (right) bulk flow motion as determined in 99 simulations of the EFAR database. The input value of the bulk flow, the mean and rms of the recovered simulated motions are also given. The EFAR sample is able to detect the LP motion to 3σ. The SMAC signal can escape detection, because its direction is nearly orthogonal to the EFAR clusters.*

mal ellipticals, and therefore have fainter average surface brightnesses. When used to determine distances, they appear to be at smaller distances than the other cluster early-type galaxies and give biased distance estimates when used alone. This fact alone does not explain the detection of the large dipole motion by Lauer and Postman (1994), but questions the use of BCG as reliable distance indicators.

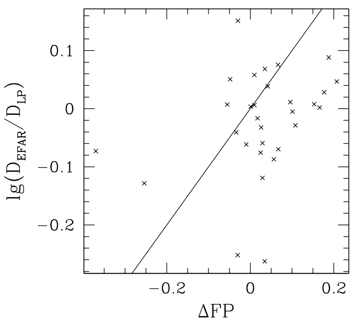

Figure 4. *The ratio of the EFAR to the Lauer and Postman distances as a function of the residuals from the best-fitting Fundamental Plane of the 30 cD galaxies in common. Errors in distance move points on the line.*

4 Conclusions

The EFAR collaboration has measured the peculiar velocities of clusters in the Hercules-Corona Borealis and Pisces-Cetus regions, with redshifts 6000$< cz <$15000. The mean peculiar velocities, computed (jointly or separately) for both regions and as a function of redshift, are small, compatible with zero. The rms of the flow is also compatible with small values, but affected by larger uncertainties. The data are incompatible at the 3σ level with the dipole motion quoted by Lauer and Postman (1994). We suggest that distance estimates based on cD galaxies might be systematically biased due to stellar population effects. The geometry of the EFAR sample does not allow a similar stringent test of motions detected by the SMAC collaboration (Hudson et al., present volume). The small amplitude of the mean flows found here is in line with the findings of recent determinations of the peculiar velocities of cluster (Giovanelli et al. 1998) and field galaxies (Giovanelli et al. 1996, Müller et al. 1998), using both spirals and ellipti-

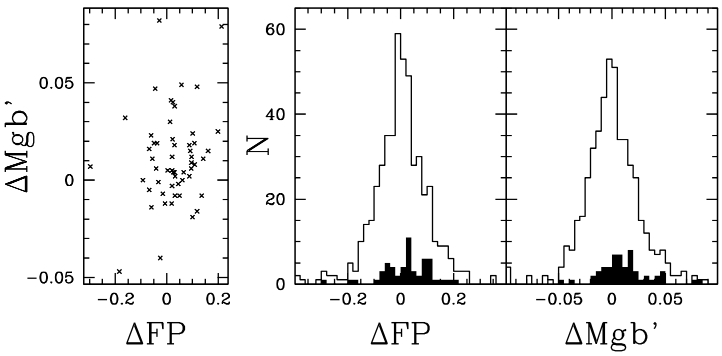

Figure 5. *The correlation between the Fundamental Plane and the Mg−σ residuals for the cD galaxies of the EFAR sample (left). These galaxies appear to have systematically positive shifts from both relations. The histograms (center and right) of the residuals from both relations (shaded areas) appear shifted with respect to the ones of E and E/S0 galaxies.*

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Acknowledgments

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