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THE FUNDAMENTAL PLANE OF RICH ABELL CLUSTERS

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RESUMEN

En este estudio exploramos la existencia del PF para una muestra final de 24 cúmulos de galaxias, donde el muestreo y señal al ruido de los datos permite un analisis confiable. Para tal fin, hemos introducido un nuevo formalismo para medir el tamaño y la dispersión de velocidades. Encontramos que efectivamente, el espacio de parámetros de los cúmulos de galaxias acepta un PF (PFC) $R \propto \sigma^{1.19\pm0.12} I^{-8.18\pm0.44}$, probando la hipótesis de virialización en las regiones centrales en los cúmulos de galaxias. Para hacer un estudio aún más autoconsistente, hemos obtenido el PF de las galaxias miembros encontrando similitud en las pendientes del PFC. Esto da importantes consecuencias, deduciéndose que el cociente masa-luminosidad debe tener la misma forma funcional para las galaxias elípticas como para los cúmulos de galaxias. Con nuestros datos demostramos que en efecto el cociente masa-luminosidad de los cúmulos ($\mathcal{M}/\mathcal{L} \propto \mathcal{L}^{0.54\pm0.22}$) sigue la misma ley de escalamiento que las galaxias elípticas. Este resultado impone una fuerte restricción a los modelos de formación de galaxias.

ABSTRACT

In this study we found the existence of the FP for a final sample of 24 galaxy clusters, where sampling and signal to noise of the data allows a reliable analysis. For this purpose, we have introduced a new formalism for measure size and velocity dispersion. We found that indeed the parameter space of galaxy clusters accepts a FP (CFP) $R \propto \sigma^{1.19\pm0.12} I^{-8.18\pm0.44}$, proved the hypothesis of virialized central regions in clusters of galaxies. To do a more autoconsistent analysis we obtain the FP of galaxy clusters and found similarity to the CFP, given important consequences, showing that the mass-luminosity ratio should have the same functional form for the cluster galaxies and galaxy clusters. We showed that in fact the mass-luminosity ratio of clusters of galaxies ($\mathcal{M}/\mathcal{L} \propto \mathcal{L}^{0.54\pm0.22}$) follows the same scaling law of elliptical galaxies. This result imposes a strong constraint to galaxies formation models.

Key Words: galaxies: clusters: general — galaxies: elliptical and lenticular, cD

1. GENERAL

There is evidence that collisionless systems,presents scaling laws. As an example, the parameter space of elliptical galaxies (dispersion (σ), I surface brightness and size R) accepts a dimension reduction to Fundamental Plane $R \sim \sigma^{4/3} I^{-5/6}$ (FP) (Djorgovski & Davis 1987; Recillas-Cruz et al. 1990). The FP is a consecuense of the virial theorem $M \propto \sigma^2 r$, but their slopes depends only for de $\mathcal{M}/\mathcal{L}$. If the $\mathcal{M}/\mathcal{L}$ follow a power law as a function of luminosity ($\mathcal{M}/\mathcal{L} \propto \mathcal{L}^{\theta}$), then:

$$M \propto \mathcal{M}/\mathcal{L}\mathcal{L} \propto \sigma^2 r\,,$$

$$\mathcal{M}/\mathcal{L}I \propto \sigma^2 r^{-1};\ \frac{\mathcal{L}}{r^2} \propto I\,,$$

$$r \propto \sigma^2 I^{-1} \mathcal{M}/\mathcal{L}^{-1}\,,$$

$$r^{1+2\theta} \propto \sigma^2 I^{-1} \mathcal{L}^{-\theta} r^{2\theta}\,,$$

$$r \propto \sigma^{\frac{2}{1+2\theta}} I^{-\frac{1+\theta}{1+2\theta}}\,. \quad (1)$$

It has been found that elliptical galaxies and globular clusters (Djorgovski 1995) remains to appear in a FP. So far only three studies have shown evidence of FPs for clusters of galaxies (CFP). But the results have not been conclusive. Schaeffer et al. (1993), found for first time the CFP, he used literature data and obtain the size of the cluster by fitting a de Vacoulers profile. Adami et al. (1998) obtain σ and used COSMOS data to generate a King and de Vacouleurs profile. Hradecky (2000) found the redshift and velocity dispersion using photographic catalog's and use a King profile. The diferences between the results of Schaeffer et al. (1993) and Adami et al. (1998) is the cause that the existence of the CFP are not yet acepted at all. We belive that these miss-matches are caused by the models used for parametrize the density profiles. For that cause, we optate to use a non-parametric model based in the surface brightness profile inded the density or numerical density profile. For this propoused we use

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TABLE 1

LIST OF THE 24 RICH ABELL CLUSTERS USED IN THESE STUDY

Name	RA (J2000)	DEC (J2000)
A0085	00:41:46.2	−09:19:02.9
A0168	01:15:01.0	+00:18:30.7
A0671	08:28:46.7	+30:30:12.5
A0690	08:39:34.4	+28:50:40.2
A0957	10:14:00.3	−00:52:32.6
A0999	10:23:21.8	+12:55:35.5
A1142	11:00:55.8	+10:27:34.4
A1314	11:34:31.2	+49:04:39.7
A1377	11:47:05.8	+55:39:32.7
A1424	11:57:48.6	+05:05:46.3
A1650	12:58:55.0	−01:45:52.2
A1663	13:02:40.9	−02:34:53.5
A1750	13:30:57.1	−01:53:12.3
A1767	13:35:42.5	+59:15:51.2
A1773	13:42:06.6	+02:14:38.3
A1809	13:53:07.7	+05:12:17.5
A2149	16:01:00.7	+53:58:21.0
A2169	16:01:00.7	+53:58:21.0
A2197	16:28:57.5	+40:50:25.3
A2199	16:28:45.9	+39:33:29.3
A2255	17:13:00.5	+64:01:19.1
A2399	21:57:39.0	−07:45:23.1
A2593	23:24:20.8	+14:38:30.6
A2670	23:54:22.5	−10:23:04.3

the original definition of Petrosian radi (Petrosian 1976).

In § 2, we discuss the methods used to obtain the values of σ, the radius of the cluster and the surface brightness. In § 2.1, we discuss the final results of these study.

2. DATA REDUCTION

Our data sample are composed 24 Rich Abell Clusters that are listed in Table 1, using all aviable spectroscopic and photometric data within a radius of 30 arminutes, limited only by redshift ($z < 0.1$). Once obtained the data, we need filtered to eliminate the out layers and backgraund contamination, see Figure 1. First we use a color magnitud realtion discovered by Lopez-Cruz et al. (1997) to select all galaxies that lie in these relation, wich implies that these galaxies are cluster members (López-Cruz et al. 2004).

These method eliminate the backgraund contamination, but not eliminate all the out layers. To

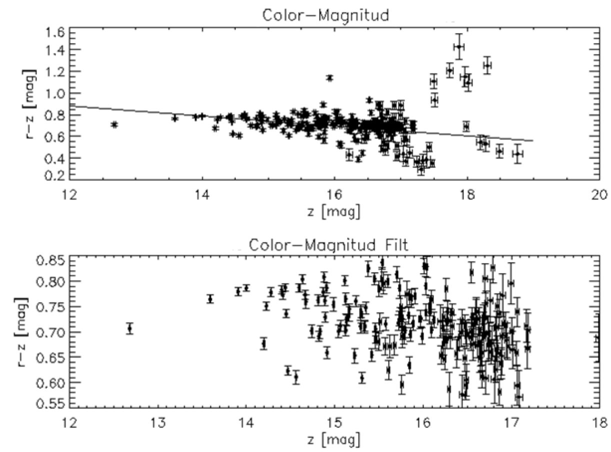

Fig. 1. Color-Magnitude Relation. In the top image we plot all the data obtained within a radius of 30 arcminutes for an especific cluster, (in these case is Abell 85). In the down image we plot all the galaxies in the CM relation, filtered the backgraund contamination.

depure more the data sample, we apply the Yahil & Vidal (1977) iterative method. For that, we propoused use a velocity limited as $v_{\rm lim} = \sigma_i\sqrt{\alpha}$ where σ_i is the velocity dispersion of the i'th iteration, and α is a scale parameter thay has values fot 2 to 6. If α is 2 then $v_{\rm lim}$ is the scape velocity of the cluster. If we eliminated a part of the sample using this dynamical criteria, like the escape velocity, we obtain a new data set, and using it, we can obtain a new escape velocity and in consequence a new part of the sample is eliminated. Using it like a iterative process, and when it converge, it given us the most real dynamical parameters of the cluster, and eliminate the out layers. Each velocity dispersion is estimated by the population standar deviation for each iteration using a χ^2 test asuming a gaussian velocity distribution (Figure 2).

Cluster of galaxies are not a spherical. We do a transformation of the original base to another that can be approach like a elliptical shape. For do that, we use the method used by Athanassoula et al. (1990) to find the centroids, ellipticities and position angles obtained by the moments of projected spatial distribution of galaxies, and then, construct concentric elliptical rings as show in the Figure 3. Counting the total flux of all galaxies inside and obtaining the surface brigness profile.

We use the Petrosian radius to define a scale parameter independent of a profile fitting. The Petrosian radius is a radio that the SB differs to the average SB at that radio a η magnitudes (Petrosian 1976; Peebles 1976) (see equation 2). We have only

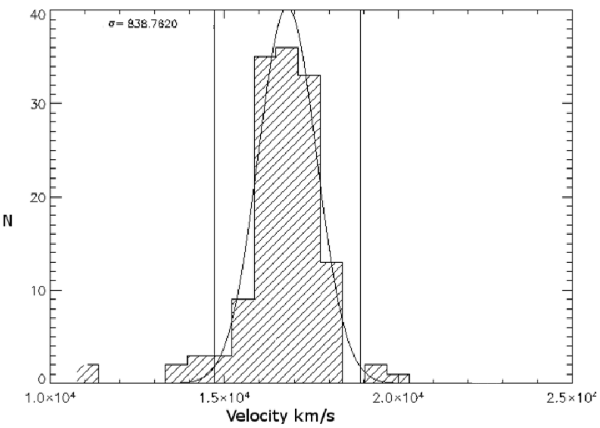

Fig. 2. We use the Yahil & Vidal (1977) iterative method, as a membership criteria. The velocity dispersion is estimated by the population standard deviation asuming a Gaussian velocity distribution.

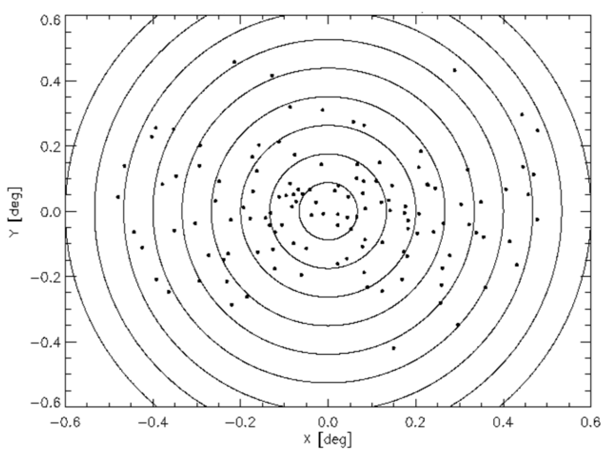

Fig. 3. The Surface Brightness of the cluster was obtained by integrating the galaxies total magnitudes in concentric elliptical rings. The centroids, ellipticities and position angles were obtained by the moments of projected spatial distribution of galaxies (Athanassoula et al. 1990).

discrete data, but it can be constructed as a function of counting the total flux of the galaxies inside in each elliptical ring:

$$\eta(r) = -2.5 \log_{10} \left(\frac{\langle I \rangle_r}{I(r)} \right) . \qquad (2)$$

2.1. *Final Results*

Finaly, we obtain the CFP (see Figure 4) with the form:

$$\log_{10} r_\eta = 1.19{\pm}0.121 \left[\log_{10} \sigma + 0.23 \langle \mu \rangle_\eta \right] {-}8.18{\pm}0.371 . \qquad (3)$$

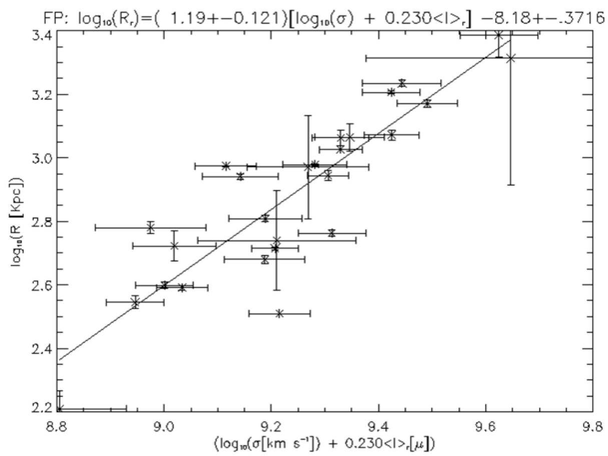

Fig. 4. Final CFP of 24 clusters of galaxies using the Petrosian radii at 0.2 magnitudes. This results, considering the errors, agree with the FP found by Djorgovski & Davis (1987).

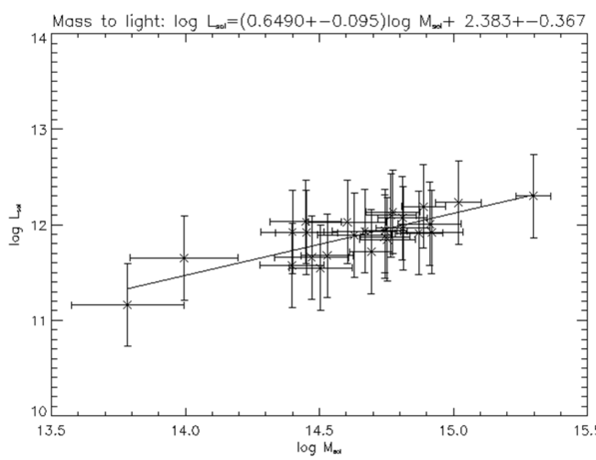

Fig. 5. Plot of the total luminosity within a virial radius versus the virial mass. Using the surface brightness profile to obtain the total luminosity inside an specific radius. The slope indicate the power law of mass-to-light ratio.

These result agree with the FP of early-type of galaxies found by Djorgovski & Davis (1987):

$$\log_{10} r \propto 1.34 \left[\log_{10} \sigma + 0.25 \langle \mu \rangle \right] .$$

Aditionaly we found in independent form, the virial mass and the total luminosity at virial radius integrating the surface brightness profile, and obtain the $\mathcal{M}/\mathcal{L}$ for each cluster (see Figure 5). Indicate that the power law of the mass-to-light ratio is

$$\mathcal{M}/\mathcal{L} \propto L^{0.54 \pm 0.225} ,$$

And using the results of the slopes of the CFP

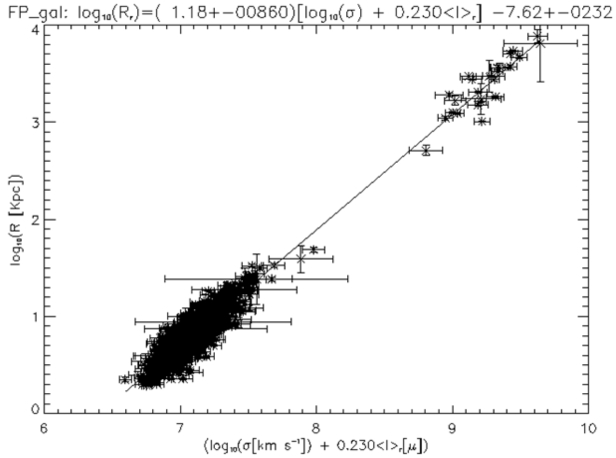

Fig. 6. Universal Fundamental Plane. We plot the CFP together with the FP of the galaxy members, and we demonstrating that both have the same slope. We do a shift in the zero point in CFP and FP for comparison.

and remember equation 1 we found:

$$\theta = \frac{2 - 1.19}{2(1.19)} = 0.34 \pm 0.068\,,$$

for the velocity dispersion exponent and

$$\theta = 5(0.23) - 1 = 0.15 \pm 0.39\,,$$

for the surface brightness exponent. The diferences betwen them indicate an upper limit and lower limit considering the error bars of the data. Djorgovski & Davis (1987) found a value of $\theta = 0.25$ for early-types of galaxis, wich is in our limits of measure and given an agrement with them. To make an autoncistent study, we can use the SLOAN data, and obtain, for all the cluster galaxies that we used, the velosity dispersion (found by a cross-correlation method using the spectra of the galaxies) and the surface brightness of each galaxies (using the Petrosian magnitudes and Petrosian radi) to generate the FP of galaxy clusters with the same methods used to obtain the CFP. These FP are:

$$\log_{10} r_\eta = 1.14 \pm 0.019 \left[\log_{10}\sigma + 0.23\,\langle\mu\rangle_\eta\right]$$
$$-7.3 \pm 0.052\,.$$

The CFP and FP plotted together are showed in the Figure 6, showing that they have the same slope, but have an off-set in consecuence of the diferences of $\mathcal{M}/\mathcal{L}$ for clusters and galaxies.

2.2. *Conclusions*

1. The CFP is an extension of the FP.
2. $\mathcal{M}/\mathcal{L} \propto L^{0.25}$ for early type galaxies and clusters of galaxies.
3. Galaxy (Kpc) and cluster (Mpc) formation might be regulated by occupation number of dark matter haloes.
4. The CFP could be used as a cosmological tests: N-body simulations showed that the width of the CFP varies as a function of Ω_Λ and Ω_m.
5. It is important to establish the FP and the CFP plane for high-z clusters (GTC, SASSIR).

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