Systems of Galaxies in the SDSS: the Fundamental Plane

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The Fundamental Plane:
From Early Type Galaxies to Systems of Galaxies

- The study of the early type galaxies has allowed the discovery of a plane in the 3-D space of intrinsic properties of galaxies.

- This plane is known as the fundamental plane (FP) and is expressed as the relation between luminosity, size and intrinsic kinetic energy

- The FP provides information about physical properties, formation and evolution of systems can be obtained.

- The FP has been extensively used as a distance indicator playing an important role in the determination of the Hubble constant (H_0).

- The FP concept has also been extended to other systems such as galaxy clusters. Schaeffer et al. (1993), Adami et al. (1998), Fujita & Takahara (1999) and Fritsch & Buchert (1999).

- It has been confirmed the existence of a fundamental plane for these large systems.

- Another topic to be considered when the FP is analysed is the dynamical state of the sample.

- Fritsch & Buchert (1999) claim that clusters with less sub-structures (more relaxed) are the strongest tracers of the FP.

- They suggests that the dispersion around the FP is the result of systems of galaxies with a lower degree of relaxation.

- Beyond these preliminary results, all these authors agree that a larger sample is necessary to have significant statistical weight.

The Present Work

- Sloan Digital Sky Survey (SDSS): is the redlargest redshift survey of galaxies.

- Merchán & Zandivarez (2005) have identified groups of galaxies in this survey, providing the largest sample of groups.

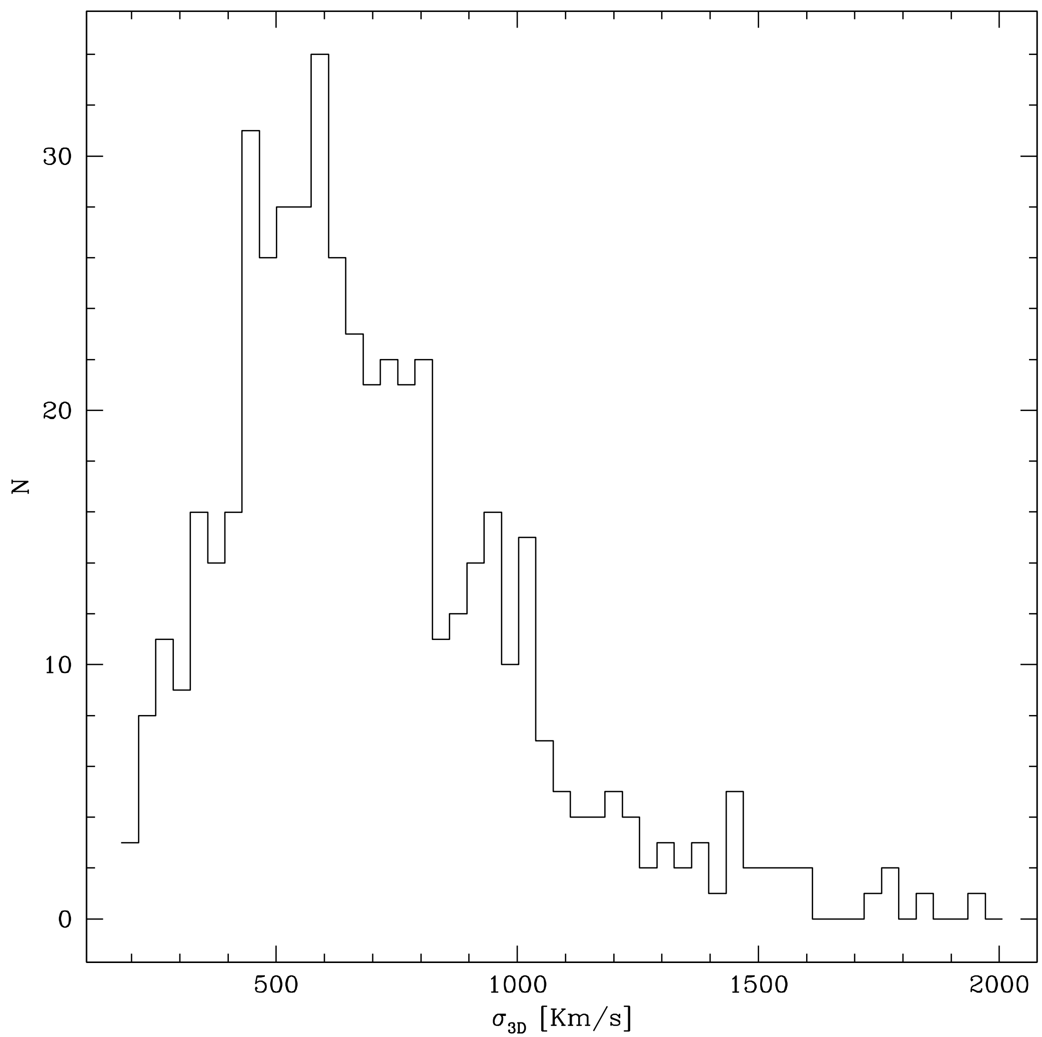
- A very reliable and homogeneous sample of groups is required: we only select those groups with at least 10 members.

- The parameters that define the FP can be sensitive to the selection of the groups centre $\rightarrow$ we implemented the iterative method described by Díaz et al. (2005).

- This technique reduces the contamination by substructure.

- The final sample (MZDM sample): 495 groups.

- Mean properties: $< z >= 0.077$, $\sigma = 642 \ km \ s^{-1}$ and $N_{mem} = 14$.



Our sub-sample includes both low and high mass systems of galaxies.

The set of parameters: Optical luminosity (R-band)

- The luminosity of a group of galaxies identified within a magnitude-limited galaxy sample needs to be corrected for incompleteness effects.

- We use the method described by Moore et al.(1993).

$$L_R = L_g + L_{corr} \tag{1}$$

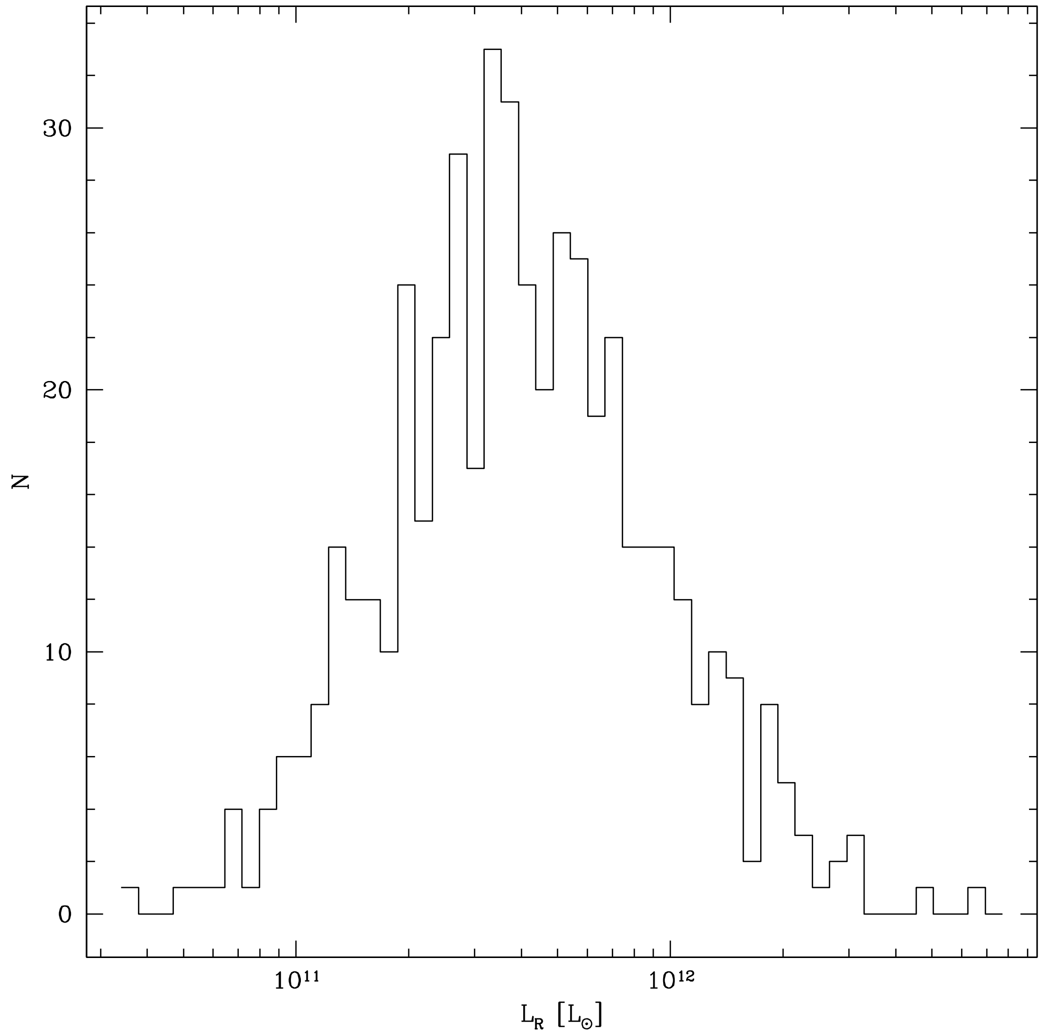
where

$$L_g = \sum_{i=1}^{Ngal} L_i \tag{2}$$

with $L_i = 10^{M_i - M_\odot}$, and

$$L_{corr} = N_{gal} \frac{\int_0^{L_{lim}} L_R \Phi_R(L) dL}{\int_{L_{lim}}^{\infty} \Phi_R(L) dL} \tag{3}$$

where $L_{lim} = 10^{0.4(M_\odot - M_{lim})}$ and $\Phi_R(L)$ is the luminosity function of galaxies in groups.



The distribution of our group luminosities extends from $3.41 \times 10^{10} L_\odot$ to $6.94 \times 10^{12} L_\odot$.

Velocity dispersions and radius

- σ: we apply the biweight estimator for groups with richness $N_{tot} \geq 15$ and the gapper estimator for poorer groups.

- Radius: we compute the projected group size using the rms projected physical separation of the galaxies respect to the group centre (Eke et al.2004a.)

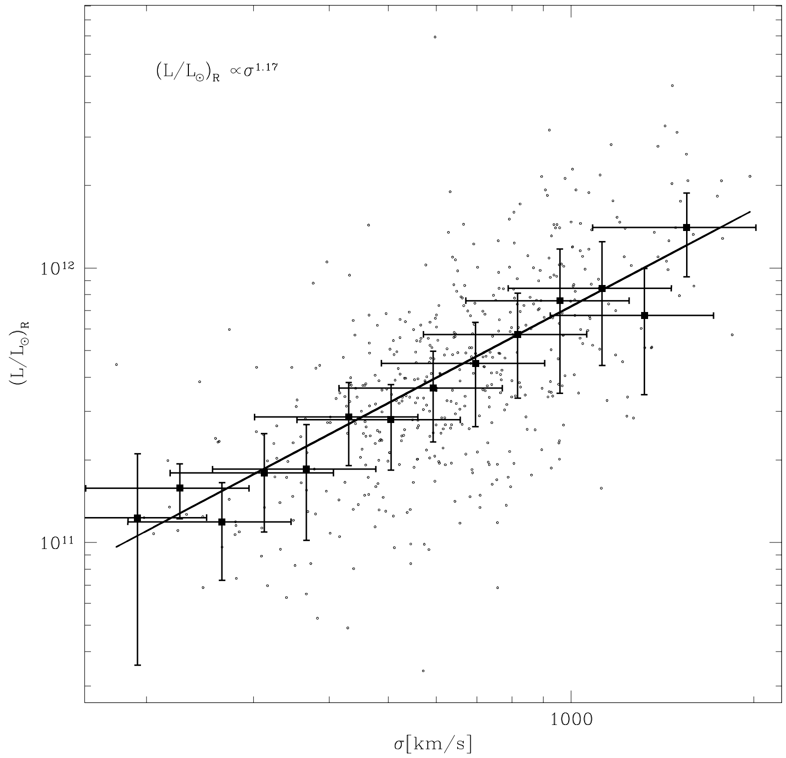
$$R = \sqrt{\frac{\sum_{j=1}^{Ngal} \; d_{jc}^{2}}{Ngal}} \quad (4)$$

where d_{jc} is the projected distance between the centre position and the j^{th} galaxy and Ngal is the number of group members.

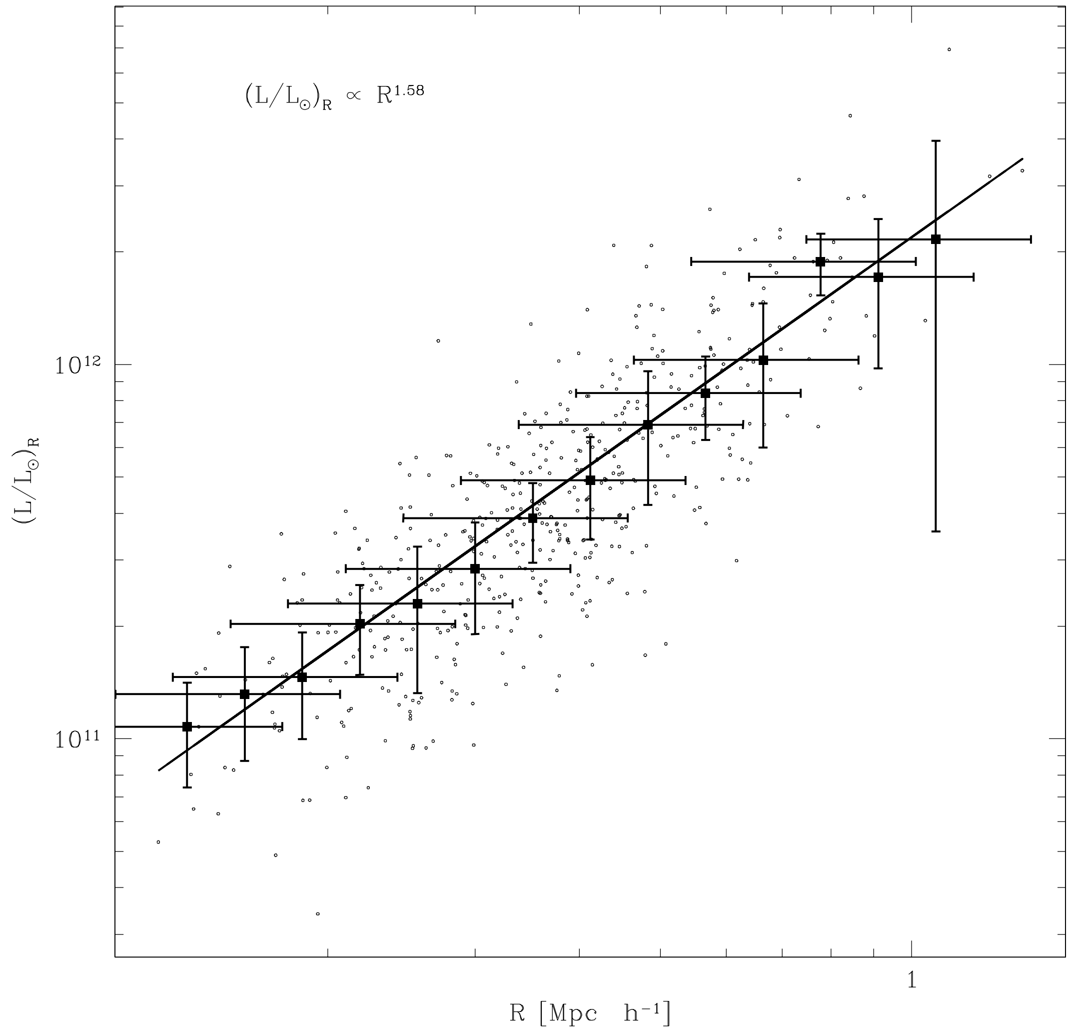
- The median radii of the sample is $(0.36 \pm 0.10) \; Mpc \; h^{-1}$.

The Fundamental Plane

- A simple way to start the study of the FP is by analysing its different projections.



$L_R - \sigma$ relation. Solid line is the best fi t relation.



$L_R - R$ relation. Solid line is the best fit. Filled squares correspond to the median luminosities per bin of radius.

- Both, the $L_R - \sigma$ and the $L_R - R$ show a clear correlation in the sense that groups that have large radii or high velocity dispersions tend to be more luminous than those that are smaller or dynamically colder.

- We use a method that minimises the sum of the squared weighted orthogonal distances to an analytical curve (or surface).

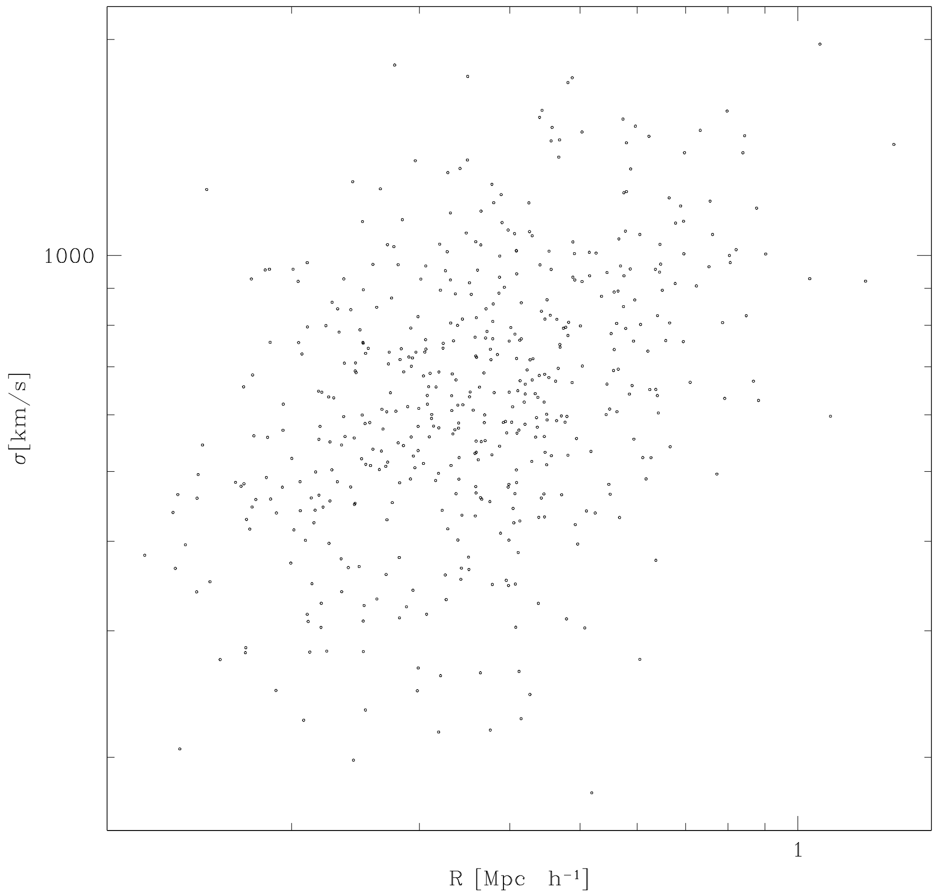
$$(L/L_\odot)_R = 10^{b_1}\, \sigma^{a_1} \tag{5}$$

with $a_1 = 1.17 \pm 0.09$ and $b_1 = 8.35 \pm 0.25$.

$$(L/L_\odot)_R = 10^{b_2}\, R^{a_2} \tag{6}$$

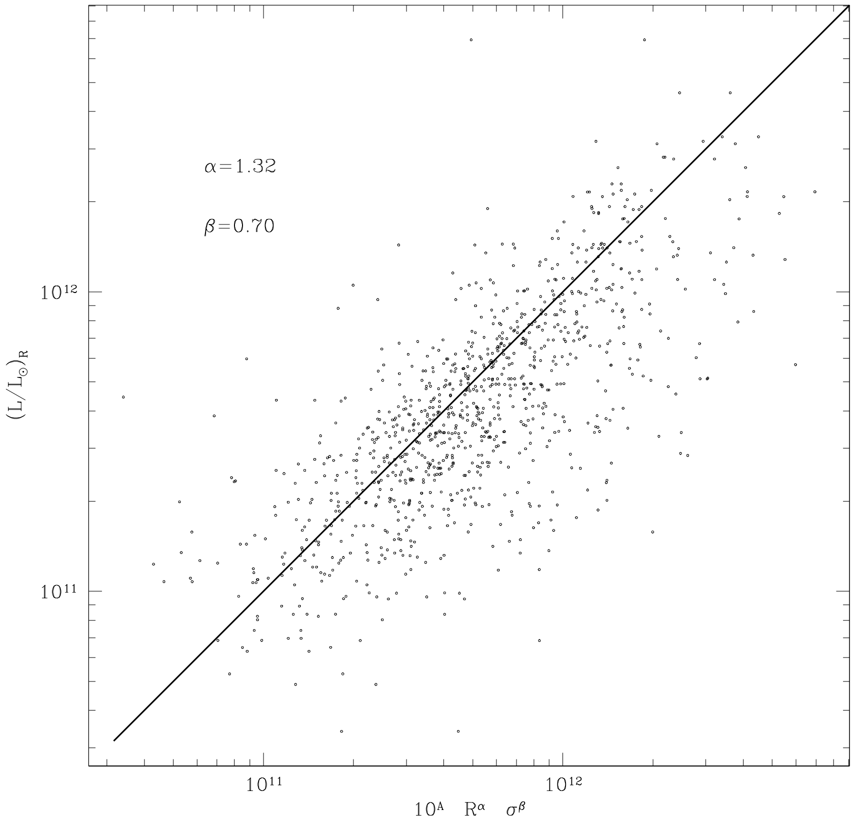
where $a_2 = 1.58 \pm 0.06$ and $b_2 = 12.34 \pm 0.03$.

- $R - \sigma$: larger groups tend to have higher velocity dispersions; however, the correlation is marginal.



σ-R relation.

- $L_R - \sigma - R$ (FP):



$$(L/L_\odot)_R = 10^A \, R^\alpha \, \sigma^\beta \tag{7}$$

- $\alpha = 1.32 \pm 0.06$, $\beta = 0.70 \pm 0.05$ and $A = 10.3 \pm 0.2$.

Origin of the observed dispersion

- Even though a good correlation is found, one of the key questions is the origin of the observed dispersion, which could be a consequence of the contribution of groups with different characteristics.

- Several authors have found that clusters lie in a plane in the 3-D space of $L-\sigma-R$. Nevertheless, they still discuss how the fundamental plane must be defined.

- Should all the groups lie in the same plane?

- Or, is the FP only well defined for groups with some particular physical properties?

- The assumption of virial state implies that clusters have a constant mass to light ratio, which suggests that groups should lie in a plane defined by $L \propto R\sigma^2$.

- Nowadays, we know that not all the clusters are virialized, and that the dynamical equilibrium is less common in groups.

- A more realistic determination of the dynamical state of groups is thus necessary.

- The size of our group sample gives us a unique opportunity to test whether group dynamical state is one of the factors responsible for the observed dispersion.

- The dynamical state of a group can be studied in different ways.

- We apply two complementary parameters: a dimensionless crossing time, τ, and the early type fraction in groups, f_1.

- τ:

$$\tau = H_0 \, t_c = \frac{400}{\pi} \, \frac{\Delta}{\sigma} \tag{8}$$

where Δ is the mean projected galaxy separation in a group, and σ is the 3-D velocity dispersion.

- τ reflects the dynamical evolution since it is proportional to the inverse of the number of times that a galaxy could have traversed the group from its formation to the present time.

- f_1: If the morphology of galaxies in groups and clusters are the result of environmental processes that subsequently transform galaxies between different morphological classes, early type galaxies should be more numerous in evolved clusters than in young less evolved systems.

- The fraction of early type galaxies per group is computed after splitting the galaxy sample into 3 spectral types.

- The fraction f_1 is: $f_1 = N_1/N$, where N and N_1 group total number of members and the number of early type galaxies, respectively.

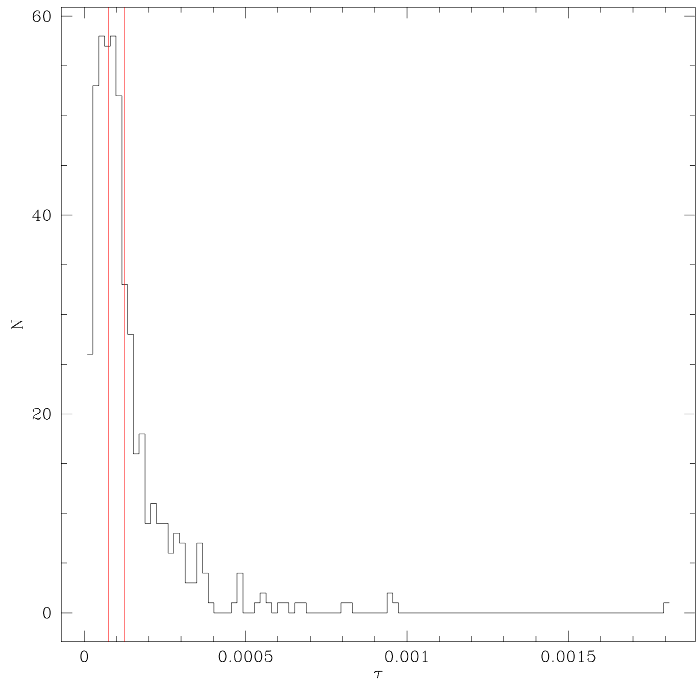
- f_1 should reflect the degree of relaxation of a system.

- Neither τ nor f_1 are strongly correlated with the redshift nor with the group mass.

FP vs. dynamical state of groups

- We define subsamples according to their corresponding τ values:

(1) more evolved: $\tau \leq \tau_1 = 7.6 \times 10^{-5}$,
(2) intermediate evolution: $\tau_1 < \tau \leq \tau_2 = 1.26 \times 10^{-4}$,
(3) less evolved: $\tau > \tau_2$.



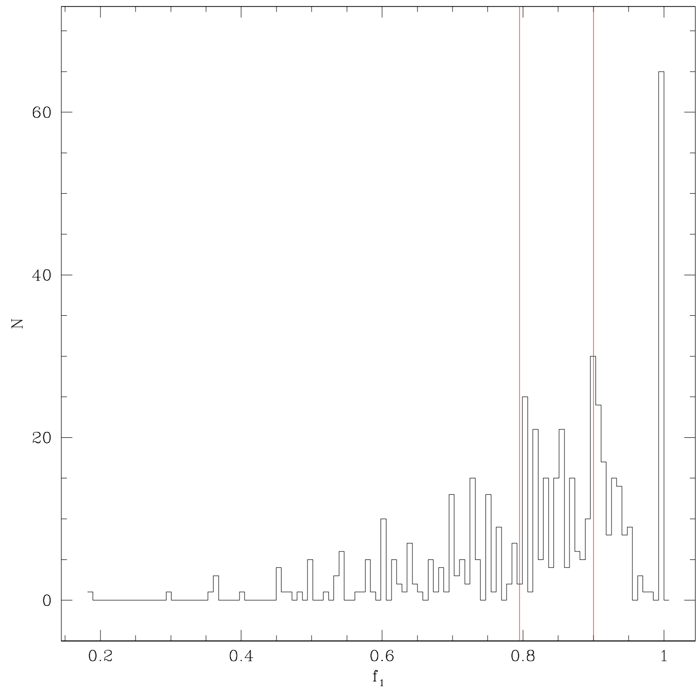
- We find no differences between these planes and the defined by the whole sample. Neither of the 3 subsamples shows differences in the scatters.

- Fraction of early type galaxies:

(1)less evolved $f_1 \leq frac_1 = 0.795$,

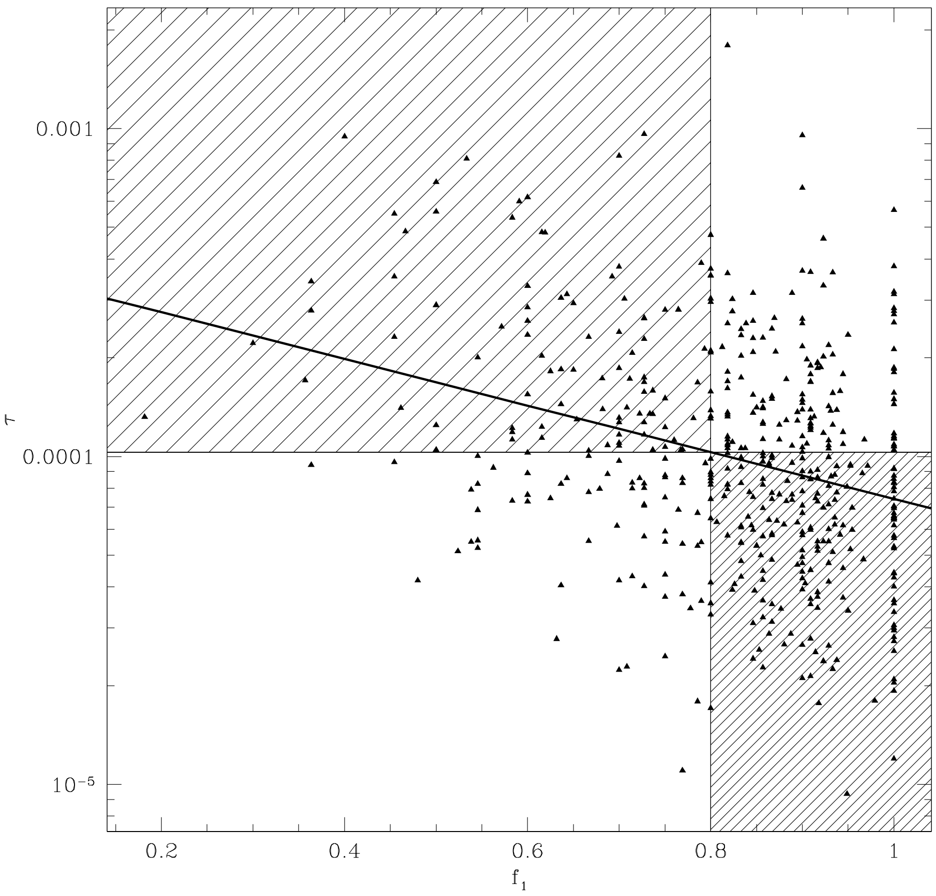
(2)intermediate evolution $frac_1 < f_1 \leq frac_2 = 0.9$

(3) more evolved $f_1 > frac_2$.



- Applying the same analysis used for τ, we find no differences in the fitted FPs as in the orthogonal dispersions for the three different subsamples.

- Finally, we seek for a correlation between τ and f_1.



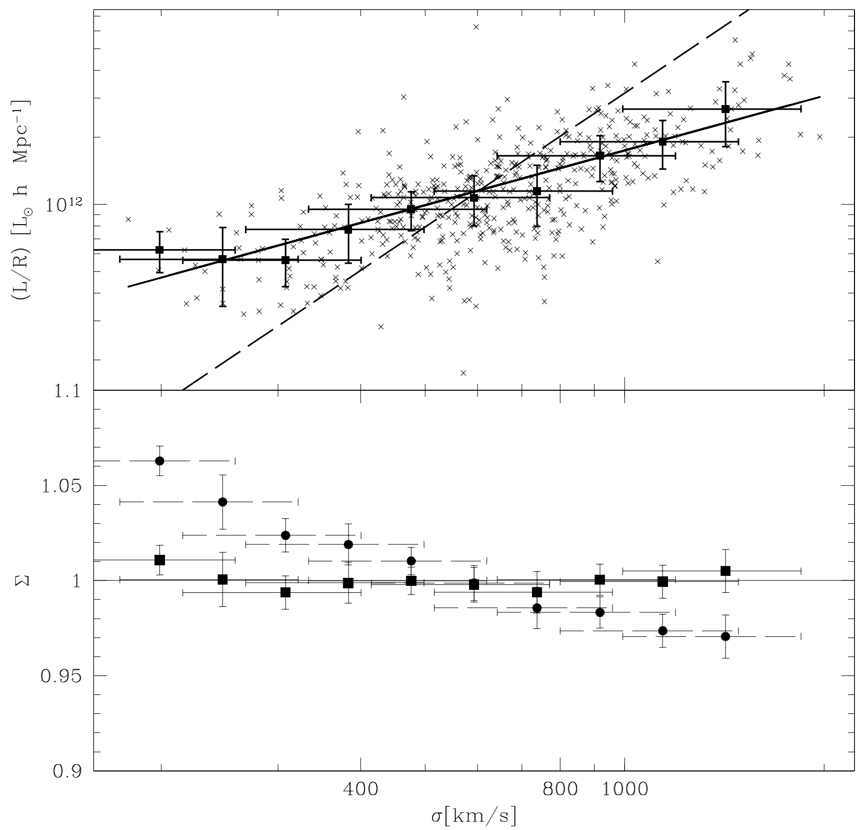
- We combine both parameters to pick up two subsamples, corresponding to the more (narrow hatched region) and less (wide hatched region) evolved groups:
  (1) $\tau \leq \tau_* = 1.03 \times 10^{-4}$ and $f_1 > f_* = 0.8$
  (2) $\tau > \tau_*$ and $f_1 \leq f_*$.

- We compute the plane and the orthogonal scatters around the FP for each subsample.

- The results are the same found before. Both subsamples have the same behaviour.

- We conclude that, using the parameters τ and f_1 to study the group dynamical state, the fundamental plane does not show signs of evolution.

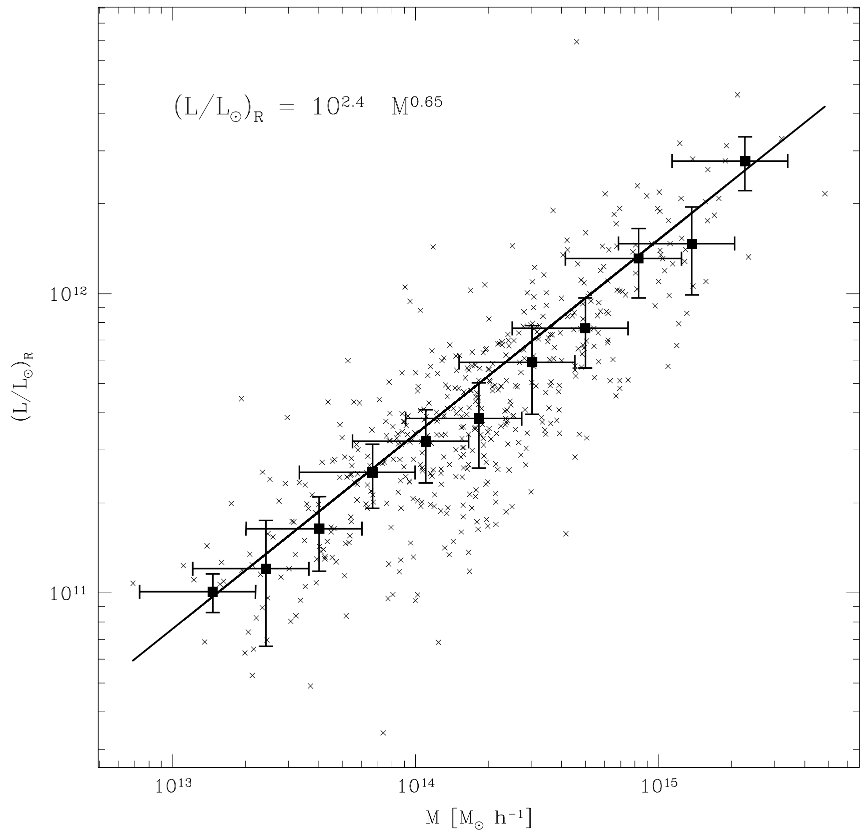
Testing the Virial Assumption



Upper panel: $(L/R) - \sigma$ relation. Filled squares are the median values per bin of σ. Solid line is the best fit to the median data points. Dashed line is the relation expected from the virial equilibrium assumption. Lower panel: Ratios between median values and the linear relations. Filled squares corresponds to best fit, and filled circles are computed with the virial prediction.

Mass to light ratio

- The fact that the FP we measure is different from the one expected assuming virial equilibrium ($L \propto R\sigma^2$) means that the mass to light ratio must vary.



- Our result is in agreement (within 2 σ_a) with the results obtained by Girardi et al. (2000), and it is also comparable (within σ_a) with the results of Popesso et al. (2004).

- It should be noted that L varies almost linear with $\sigma(\beta \sim 1)$ (quadratic in the virial case).

- Then the M/L ratio must increase with σ, it means with M.

- Our result implies $M/L \propto M^{0.36\pm0.06}$, it means that the mass to light ratio of galaxy groups is not constant.

- M/L varies up to a factor of ~ 6 from low to high mass groups.

- The group sample analysed in our work presents a steeper slope of the M/L vs M relation, in comparison with previous works on groups and clusters of galaxies but they are in good agreement within 1 σ-level.

- The median mass to light ratio of our sample is $(M/L)_{med} = (418 \pm 194)M_\odot/L_\odot$.

- In order to check the stability of our results against a different choice of the group size.

- We repeated our analysis using the group standard virial radius and the virial mass provided by Merchán & Zandivarez 2005.

- The $L - M$ relation does not depend on the definition of the radius or mass.

- Comparing the orthogonal scatter produced by the two different selection of the size parameters, we find that the characteristic radius proposed by Eke et al. (2004a) produces the smaller scatter in both, the fundamental plane and the $L - M$ fits, and it also produces smaller errors in the fitted parameters.

Conclusions

- We study whether the more numerous galaxy systems, the galaxy groups, lie in the so-called ”fundamental plane”, defined by their physical properties.

- We analyse large and homogeneous subsample of the Merchán & Zandivarez (2005) catalogue of groups.

- We find that these groups define a plane given by $L_R \propto R^{1.3}\ \sigma^{0.7}$ which is different from the plane that is expected if one assumes virial equilibrium.

- We also analyse the aloofness from the plane as a function of the dynamical state of groups and their redshifts.

- We find that none subsample has a tendency to lie farther or closer from the FP.

- We also find that the mass to light ratio increases with group mass as $(M/L_R) \propto M^{0.36}$.

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