THE RELATION BETWEEN HALO SHAPES, DYNAMICS & ENVIRONMENT

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Main Collaborators on various aspects of the project "Group Halo Shape-Dynamics-Environment relations":

- **Spyros Basilakos** (Kapteyn Inst. Groningen – Holland)
- **Stefan Gottlober** (Potsdam Univ. – Germany)
- **Cinthia Ragone** (IATE – Cordova- Argentina)
- **Hrant Tovmassian** (INAOE - Mexico)
- **Gustavo Yepes** (Univ. Autonoma de Madrid – Spain)

Main Themes of my Talk:

1. Introduction to hierarchical clustering scenario
2. Group Halo Shapes: (a) Shape determination & biases (b) Shapes-Mass relation (c)Shape-Environment relation
3. Group Halo Dynamics: (a) Definition of dynamical state (b) Dynamics – Shape relation, (c) Dynamics – Environment relation, (d) Dynamics – Alignment relation.
4. Group Alignments-Environment relation
5. Halo Dynamics-Shape-Environment cross-correlations

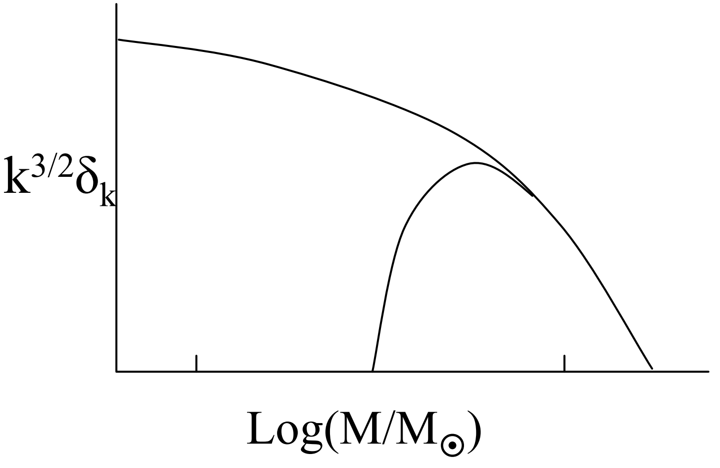
What does structure formation paradigm tell us:

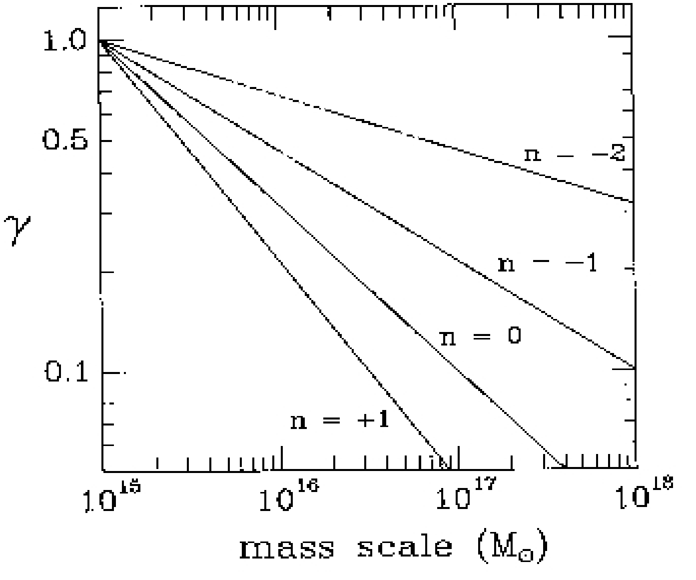
• CDM-like Power Spectra of initial perturbations predict a bottom-up scenario but with **roughly simultaneous formation of structure at large-scales.**

• Structures form by **gravitational instability** which as soon as it switches on creates **anisotropic structures (filaments, walls).**

• Galaxies & Clusters **form in high-density regions** (inside filaments & walls) by **anisotropic accretion and merging of smaller mass units.**

•**Roughly simultaneous formation of structure at different scales** creates **"cross-talk"** and thus correlated phenomena between these scales:

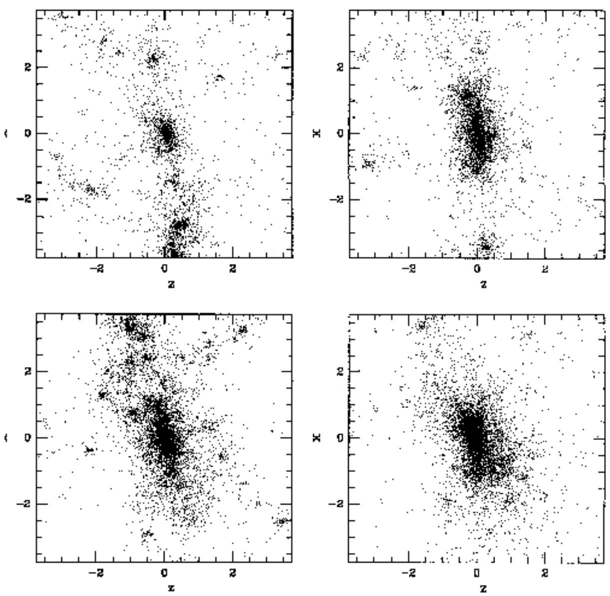




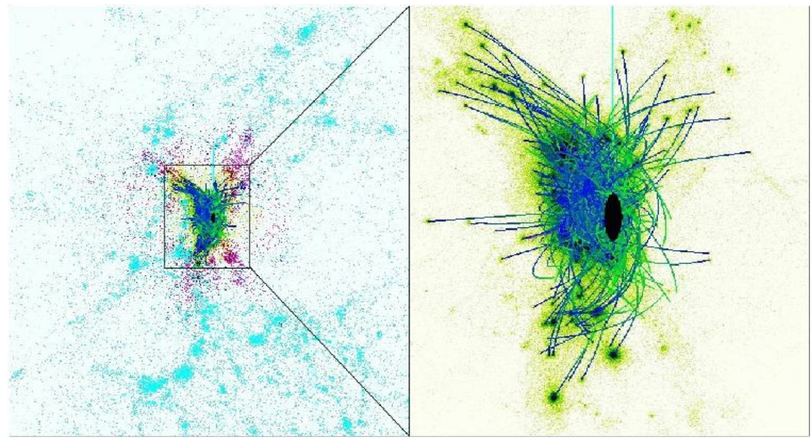
From West 1994

What does formation paradigm tell us:

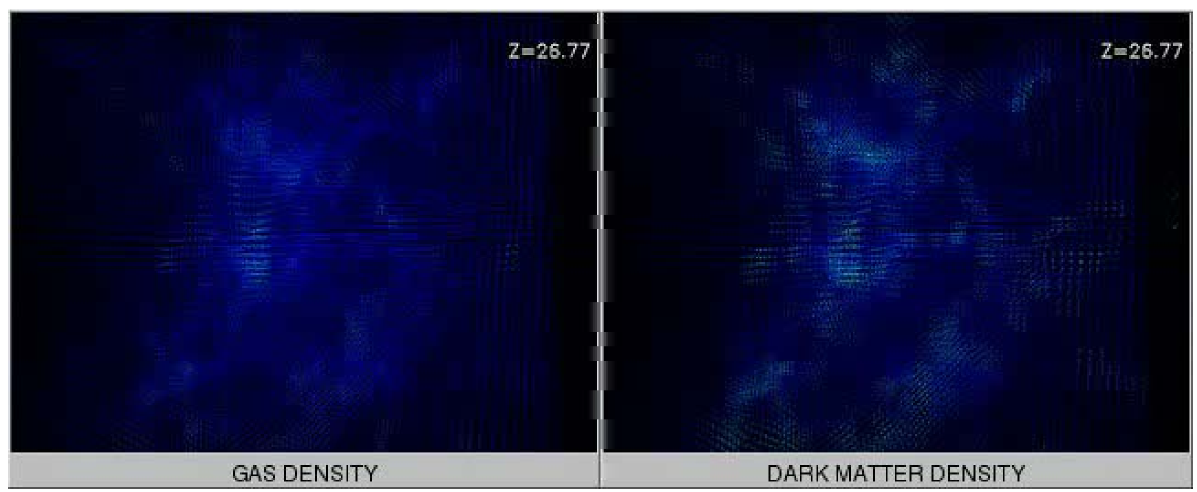
Clusters form by merging accreting matter along preferred directions (filaments) → generic in all hierarchical clustering models, like CDM (cf. Bardeen et al. 1986; Van Haarlem & Van der Weygaert 1993, Tormen 1997; Knebe et al. 2004), irrespective of the density parameter for as long as the spectral index is **n<-1**.



Van Haarlem & Van de Weygaert 1993



Knebe et al 2004



GADGET Simulations from Yepes, Gottlober, Muller…

PREDICTED HALO SHAPES: BBKS predicts that high-peaks of a Gaussian random field are more spherical than lower peaks.

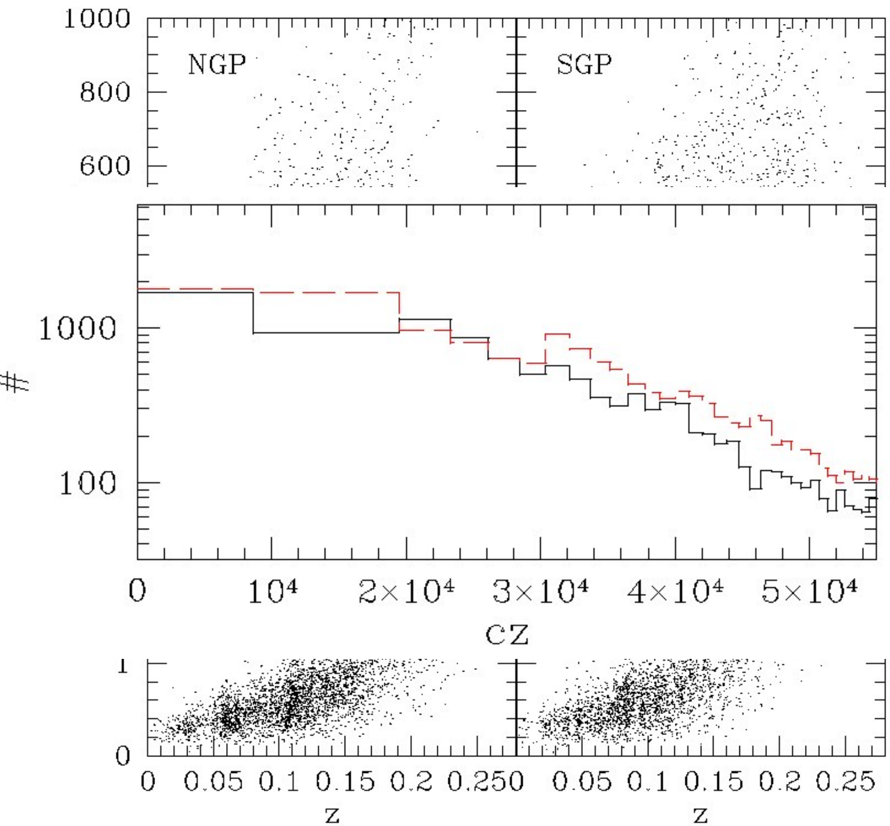
1. Group Halo Shapes

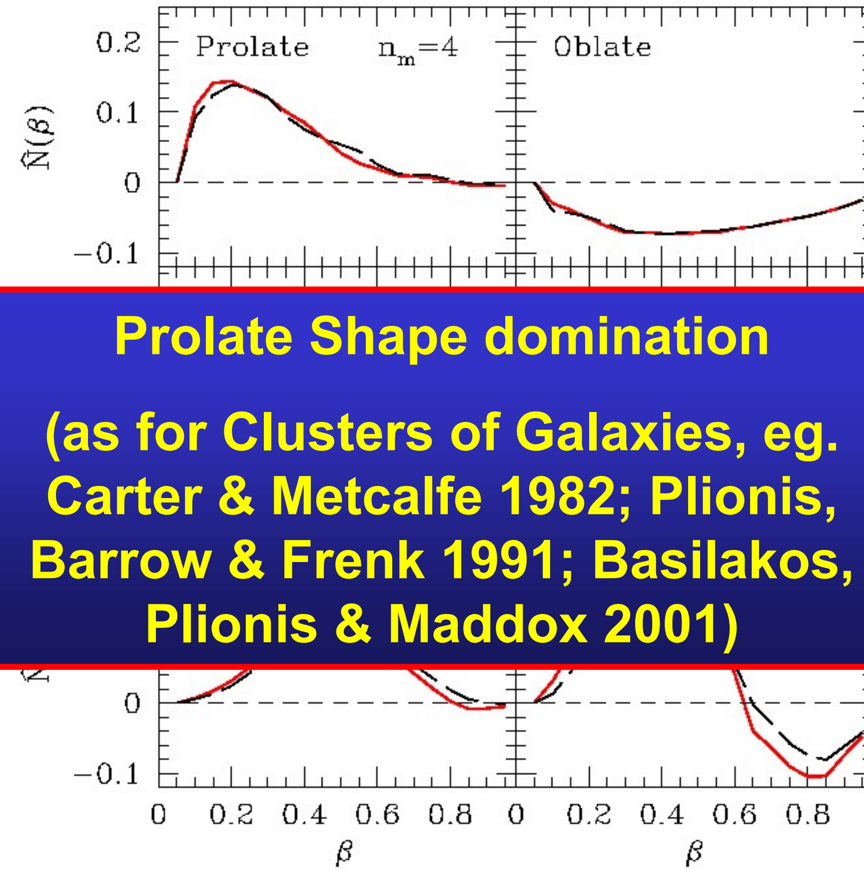
Analysis of the shape of ~2500 2dFGRS-**2PIGG** groups with z<0.1

Systematic effects due to decrease of selection function & increase of linking parameters as a function of redshift (eg. Frederic 1995)

$$\hat{f}(q) = q\int_0^q \frac{\hat{N}_o(\beta)\,d\beta}{(1-q^2)^{1/2}(q^2-\beta^2)^{1/2}} \qquad \hat{N}_o(\beta) = \frac{2\beta(1-\beta^2)^{1/2}}{\pi}\int_0^\beta \frac{d}{dq}\left(\frac{\hat{f}}{q}\right)\frac{dq}{(\beta^2-q^2)^{1/2}}$$

$$\hat{f}(q) = \frac{1}{q^2}\int_0^q \frac{\beta^2\hat{N}_p(\beta)\,d\beta}{(1-q^2)^{1/2}(q^2-\beta^2)^{1/2}} \qquad \hat{N}_p(\beta) = \frac{2(1-\beta^2)^{1/2}}{\pi\beta}\int_0^\beta \frac{d}{dq}(q^2\hat{f})\frac{dq}{(\beta^2-q^2)^{1/2}}$$





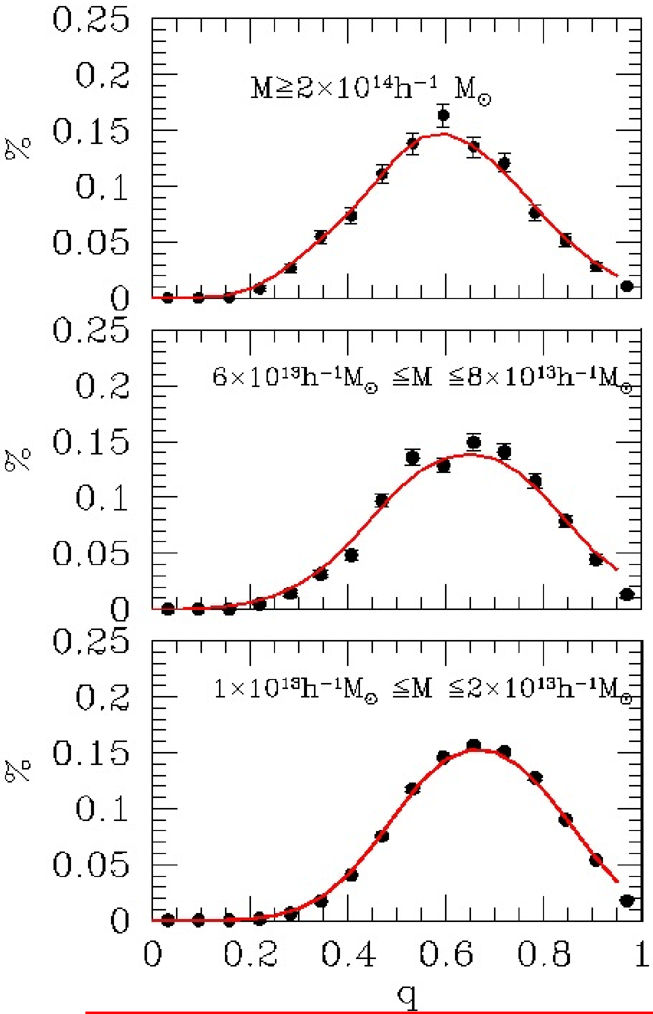
Prolate Shape domination

(as for Clusters of Galaxies, eg. Carter & Metcalfe 1982; Plionis, Barrow & Frenk 1991; Basilakos, Plionis & Maddox 2001)

Plionis, Basilakos & Tovmassian 2004

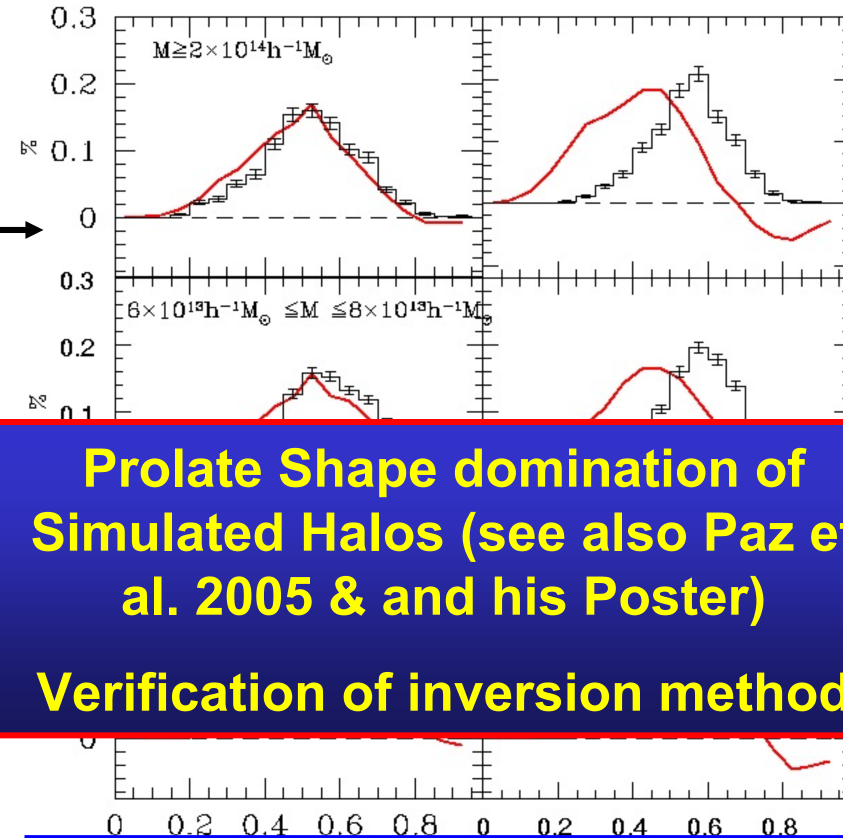
1. Group Halo Shapes

Simulation Verification: We have checked these results with simulated group halos (Ragone, Plionis & Basilakos 2006) by projecting in 2D the distribution of halo particles of halos with known 3D shape and deprojecting to recover 3D axis ratio (under assumption of prolatness or oblatness).



Distribution of axis ratios of 2D projection of 3D triaxial prolate-like groups

Inversion technique →



Prolate Shape domination of Simulated Halos (see also Paz et al. 2005 & and his Poster)

Verification of inversion method

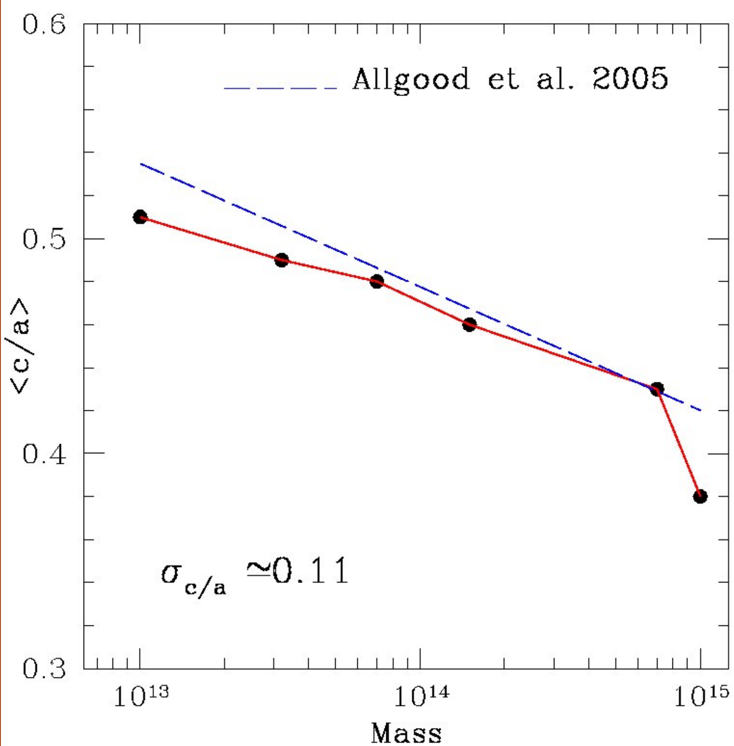
2D analogue to 3D shape (fitting a mean prolate or oblate spheroid to the triaxial ellipsoid)

$$Q_p = \frac{(b+c)}{2a}, \qquad Q_o = \frac{2c}{a+b}$$

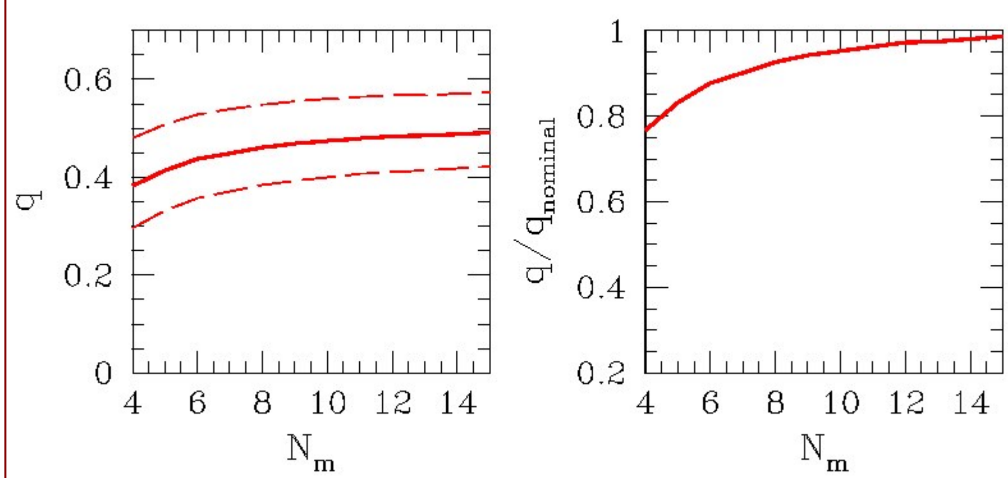
1a. Group Halo Shapes – Mass correlation

Simulation ΛCDM Halos show Mass-flattening relation (Jing & Suto 2002; Allgood et al 2005, Kasun & Evrard 2005, etc)

Dynamical evolution alters BBKS predictions



Observationally, very difficult to quantify such dependence due to discreteness effects. Below we show dependence of projected groups axis-ratio with number of group members. Red lines depicts expected trend due to discreteness.



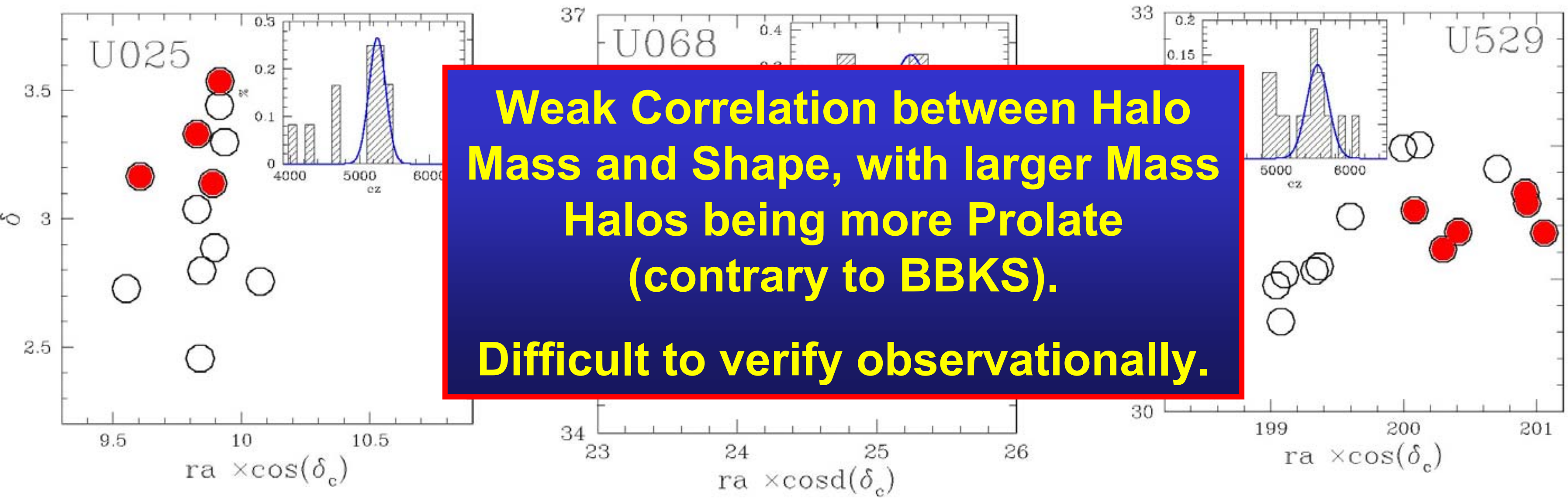
IMPORTANT:

This relation corresponds to an overall anticorrelation between Mass and c/a of **R=-0.12** with a random probability of 10^{-10}

1a. Group Halo Shapes – Mass correlation

Furthermore, groups detected with FoF or any other algorithm are bound to suffer from a variety of biases, which may remain unquantified.

Below is a small selection of high velocity dispersion USGC groups found within their volume limited range (Ramella et al.)



Weak Correlation between Halo Mass and Shape, with larger Mass Halos being more Prolate (contrary to BBKS).

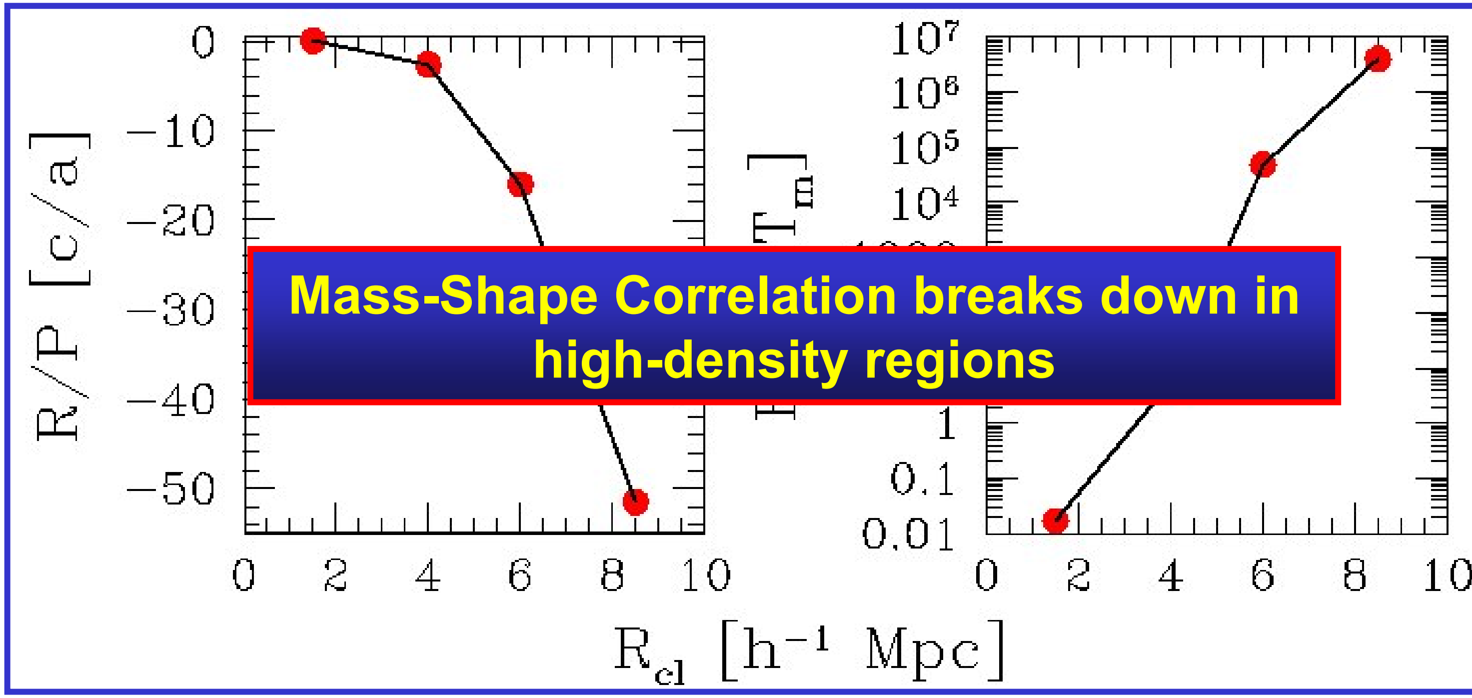
Difficult to verify observationally.

Could be either nearby groups (within the same filamentary LSS), merging groups or even unrelated projections due to variable linking length.

Both the Shape and Dynamics (applying virial arguments) of these “groups” will bias relevant studies.

1b. Group Halo Shapes – Environment dependance

Does the ***Halo Mass- Shape correlation*** depend on the local environment?



Mass-Shape Correlation breaks down in high-density regions

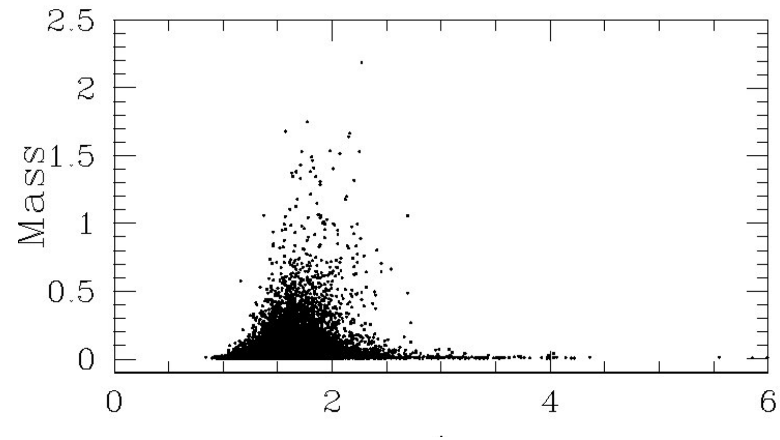
Correlation signal as a function of distance of Halos from Large Hosts ($M>10^{14}$ Mo) show break-down of the correlation near the vicinity of rich clusters (***Ragone & Plionis 2006*** – in preparation)

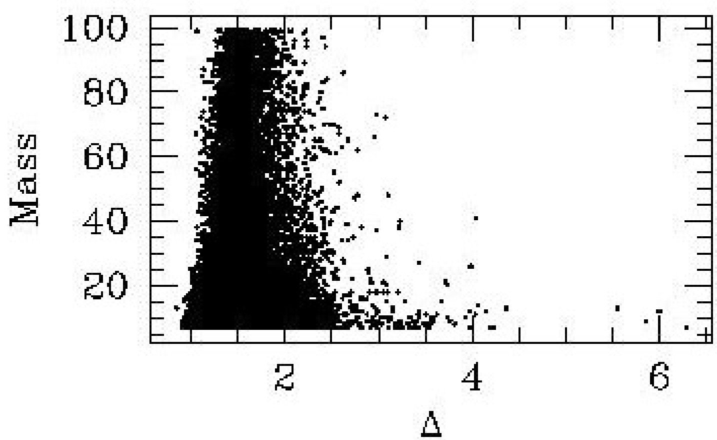
2. Group Halo Dynamics

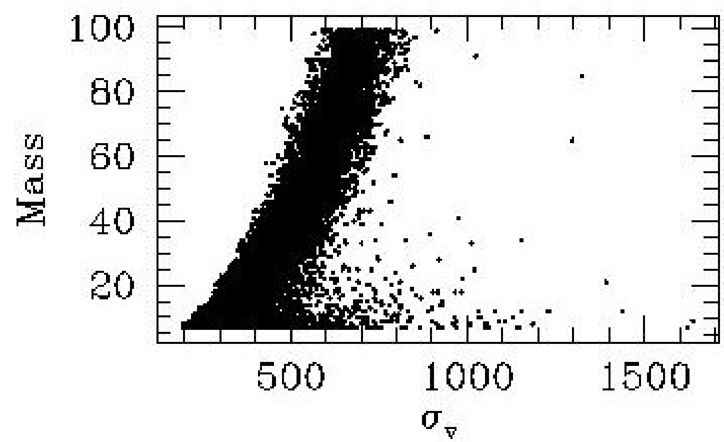
Using a ΛCDM simulation of L=500 h^{-1} Mpc with 512^3 DM particles and the Dressler & Shectman 1998 substructure statistic (**Δ-deviation**) (***Ragone & Plionis 2006*** – in preparation)

$$\delta_i^2 = \frac{N_{nn}}{\sigma_v^2}\left[(\bar{v}_{local} - \bar{v})^2 + (\sigma_{v,local} - \sigma_v)^2\right]$$

$$\Delta = \sum_i \delta_i$$

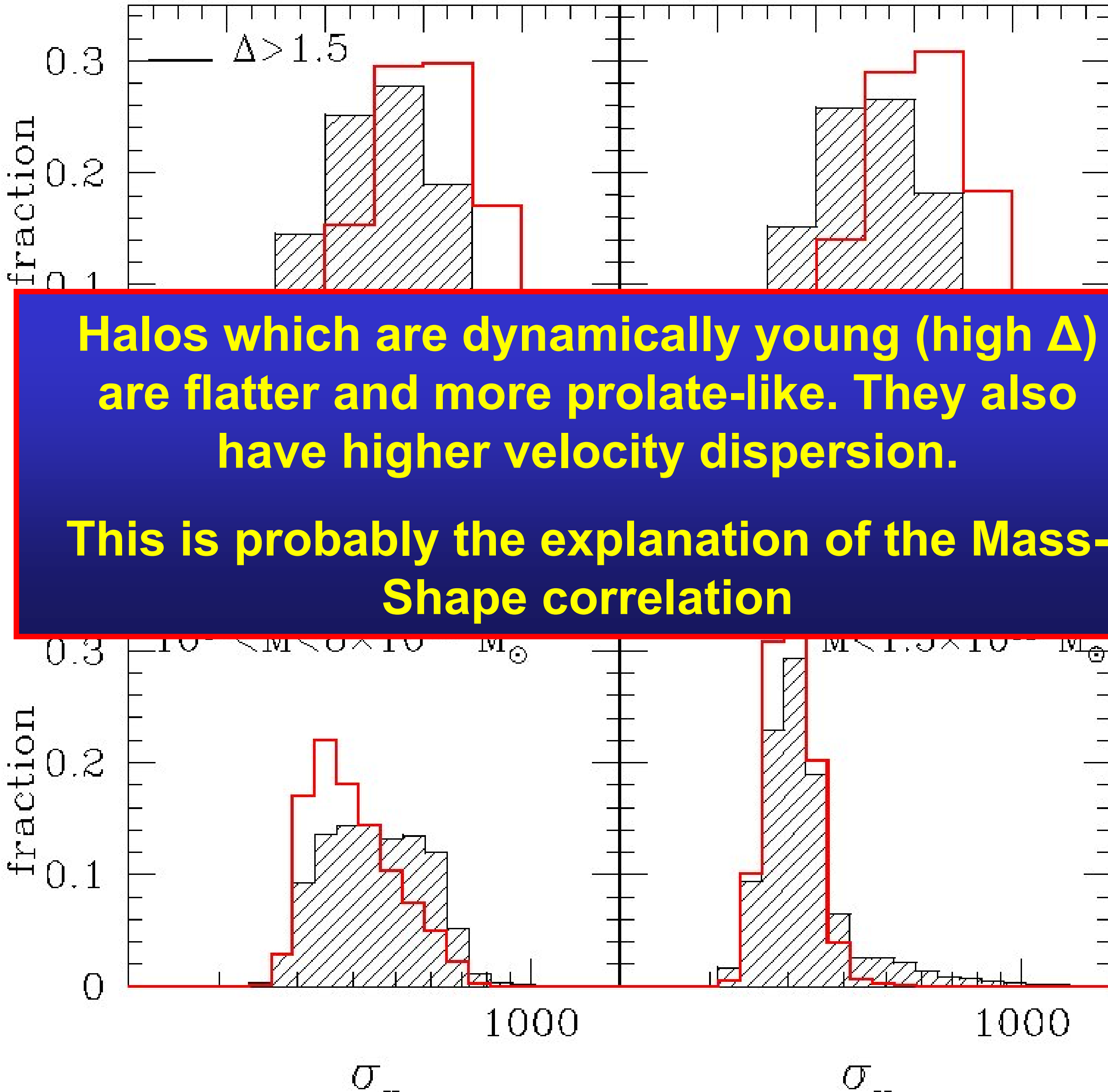






There is a **weak Mass-Δ** correlation but a stronger **Mass-σ_v correlation, as expected from definition of groups as virialized Halos.**

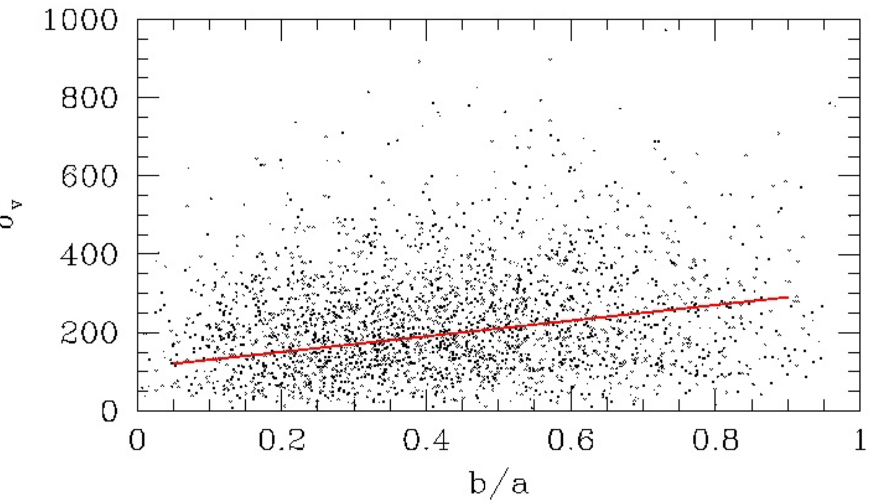
2a. Group Halo Dynamics – Shape correlation

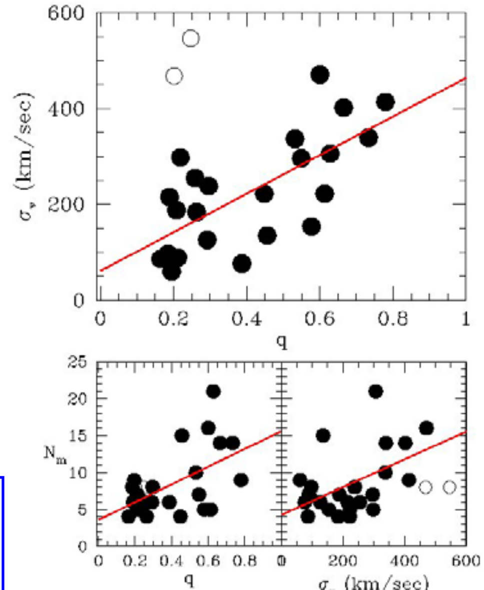


Halos which are dynamically young (high Δ) are flatter and more prolate-like. They also have higher velocity dispersion.

This is probably the explanation of the Mass-Shape correlation

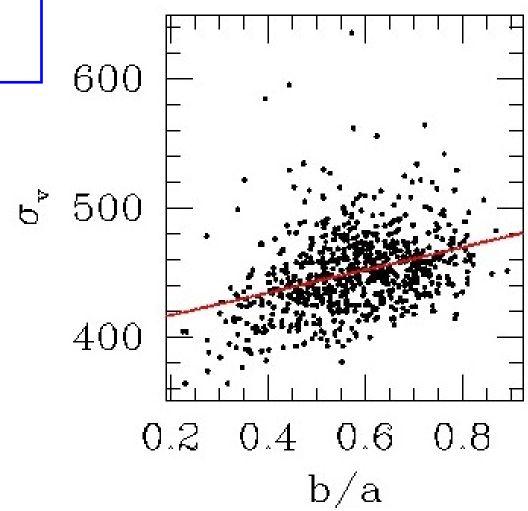
2a. Group Halo Dynamics – Shape correlation





From a detailed study of the environment of ~25 HCG we find similar result but much stronger correlation, which persists after correcting for discretness effects.

2PIGG group velocity dispersion increases with group sphericity (due to discreteness? rather opposite effect). Also similar correlation (and as weak) found also for simulated Halos (>100 partciles)!

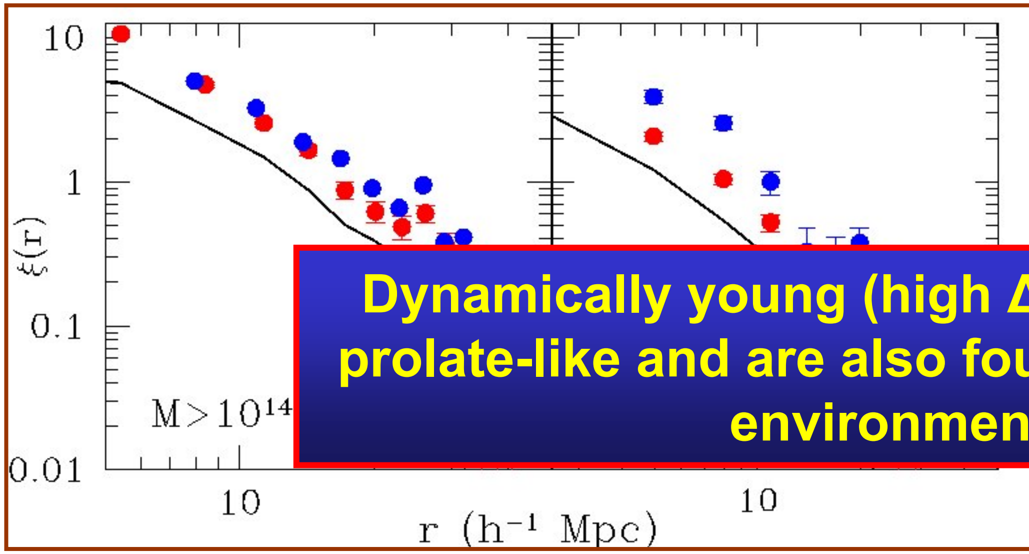


Single Mass Halos ($M=3x10^{13}$ Mo) show similar but even stronger correlation than overall Halo population.

What is the cause of this correlation ? Could be an indication of higher degree of virialization but also orientation effect at work !

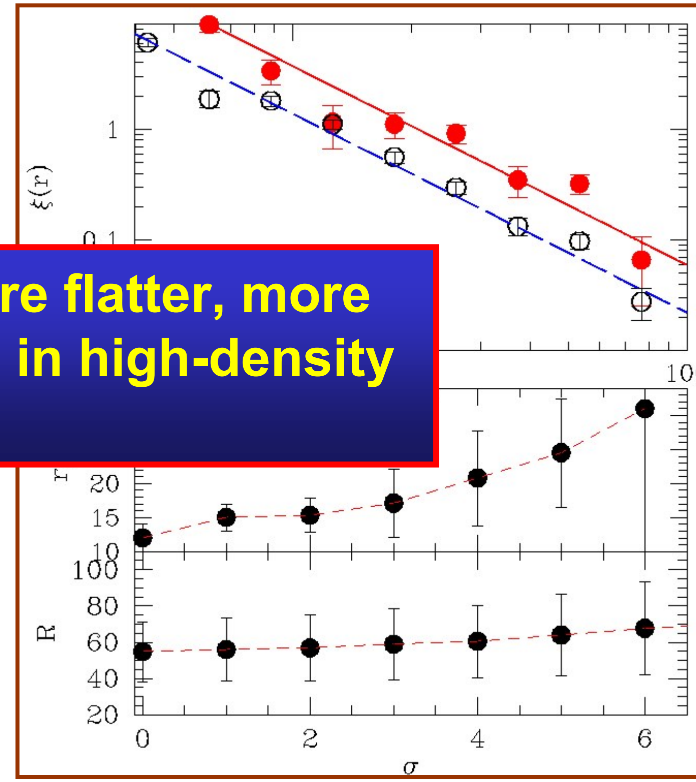
2b. Group Halo Dynamics – Environment correlation

2-p spatial correlation analysis shows that dynamically young Halos are more clustered than virialized ones; ie., they are found in high-density regions.

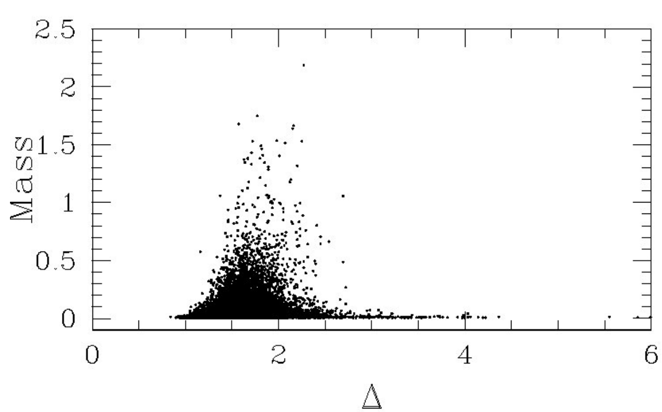


Dynamically young (high Δ) are flatter, more prolate-like and are also found in high-density environments !

Simulation Halos



APM clusters (Plionis & Basilakos 2002)



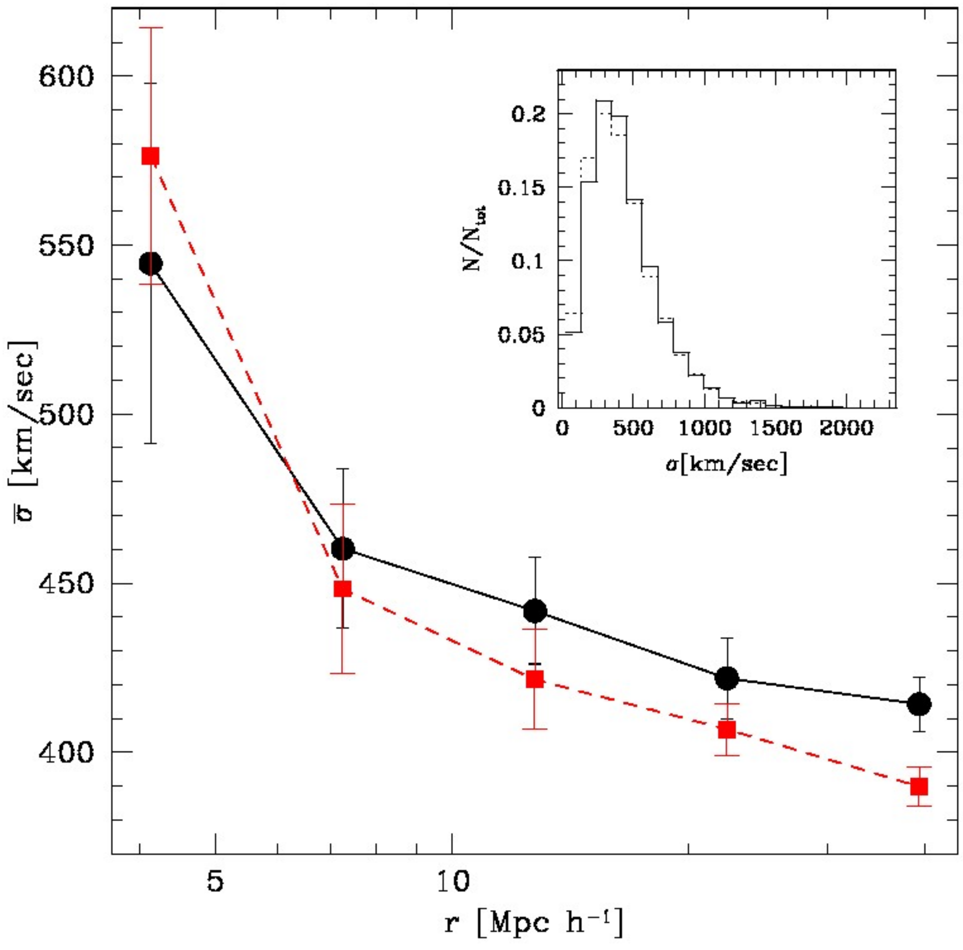
Could the Δ-ξ(r) relation reflect the well known Halo Richness-ξ(r) relation?

Could be due to a **Richness-Δ** weak correlation but Δ-ξ(r) correlation is also true for small mass range for which no Δ-ξ(r) correlation is present.

2b. Group Halo Dynamics – Environment correlation

Group Velocity dispersion correlates with distance from massive host

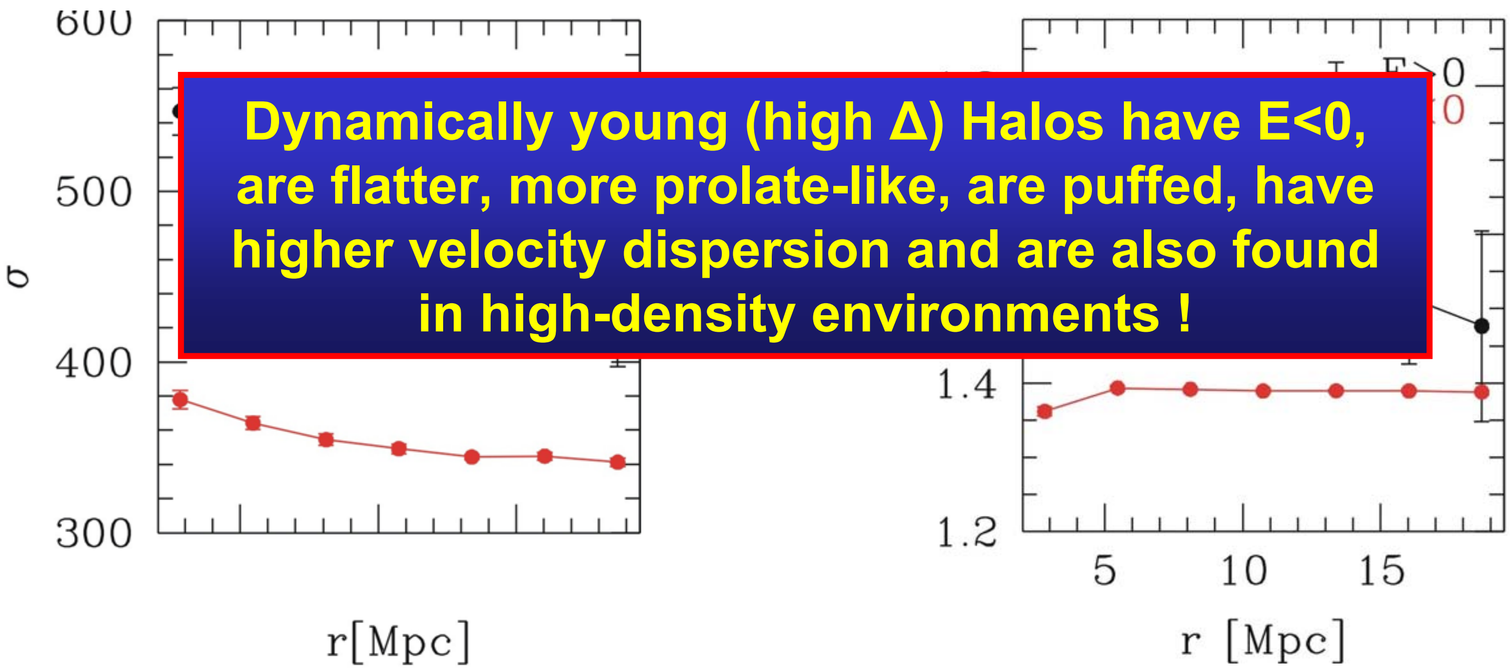
Ragone et al 2004: Group velocity dispersion versus distance from massive host (Virgo Simulations and 2dFGRS groups)



2b. Group Halo Dynamics – Environment correlation

Divide the groups in bound and non-bound objects.

$$E = \frac{1}{2}\sigma^2 M_g - \frac{Gm^2 N(N-1)}{R_{vir}}$$



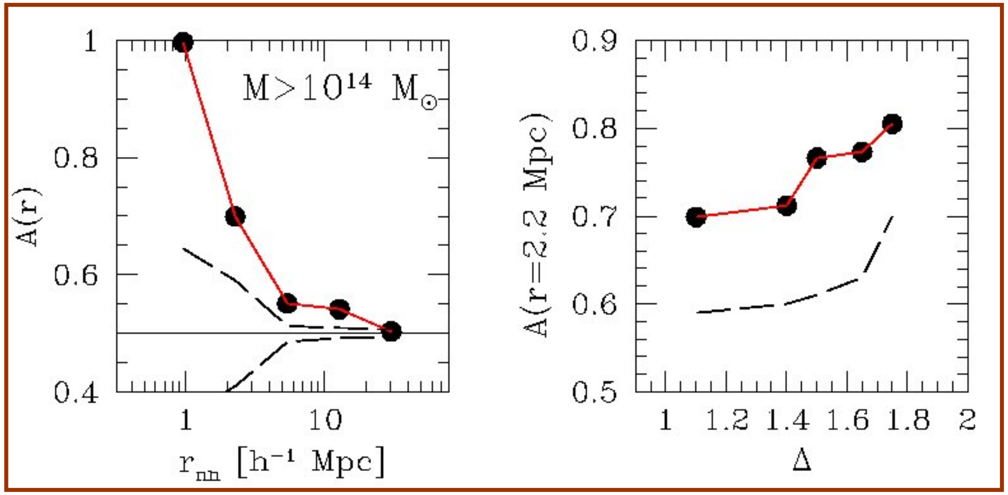
Dynamically young (high Δ) Halos have E<0, are flatter, more prolate-like, are puffed, have higher velocity dispersion and are also found in high-density environments !

The unbound groups are correlated with the sub-structured halos and their fraction increasers with decreasing distance from large Hosts. Similarly, for the velocity dispersion.

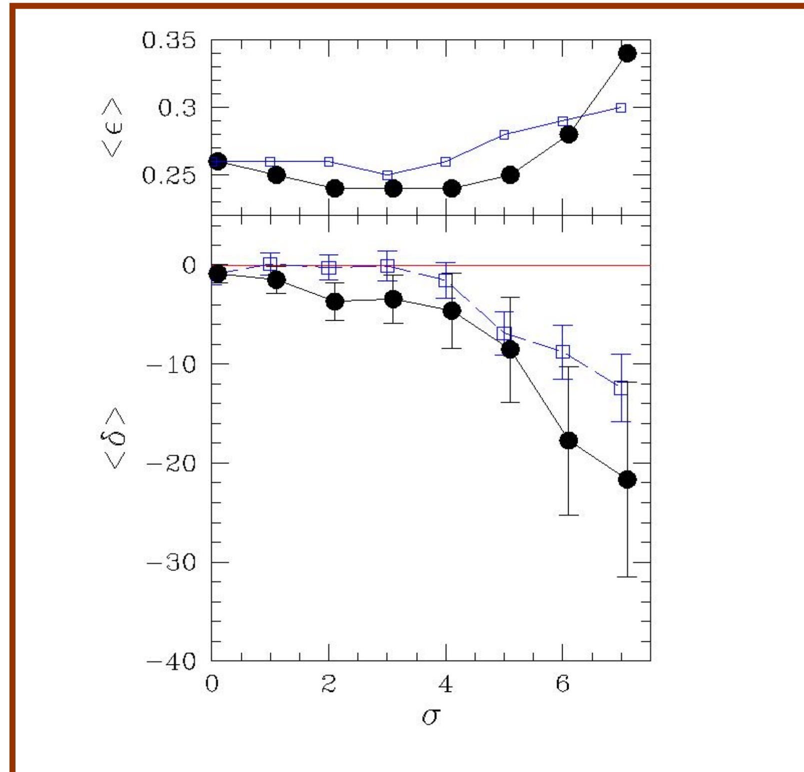
2c. Group Halo Dynamics – Alignment correlation

Alignment of Halos also indication of dynamical state (Plionis & Basilakos 2002; Plionis et al. 2003).

$$A(r) = \langle |\mathbf{e}_l \cdot \mathbf{e}_k| \rangle (r)$$



Simulation Halo Major axis Alignment, as a function of NN distance

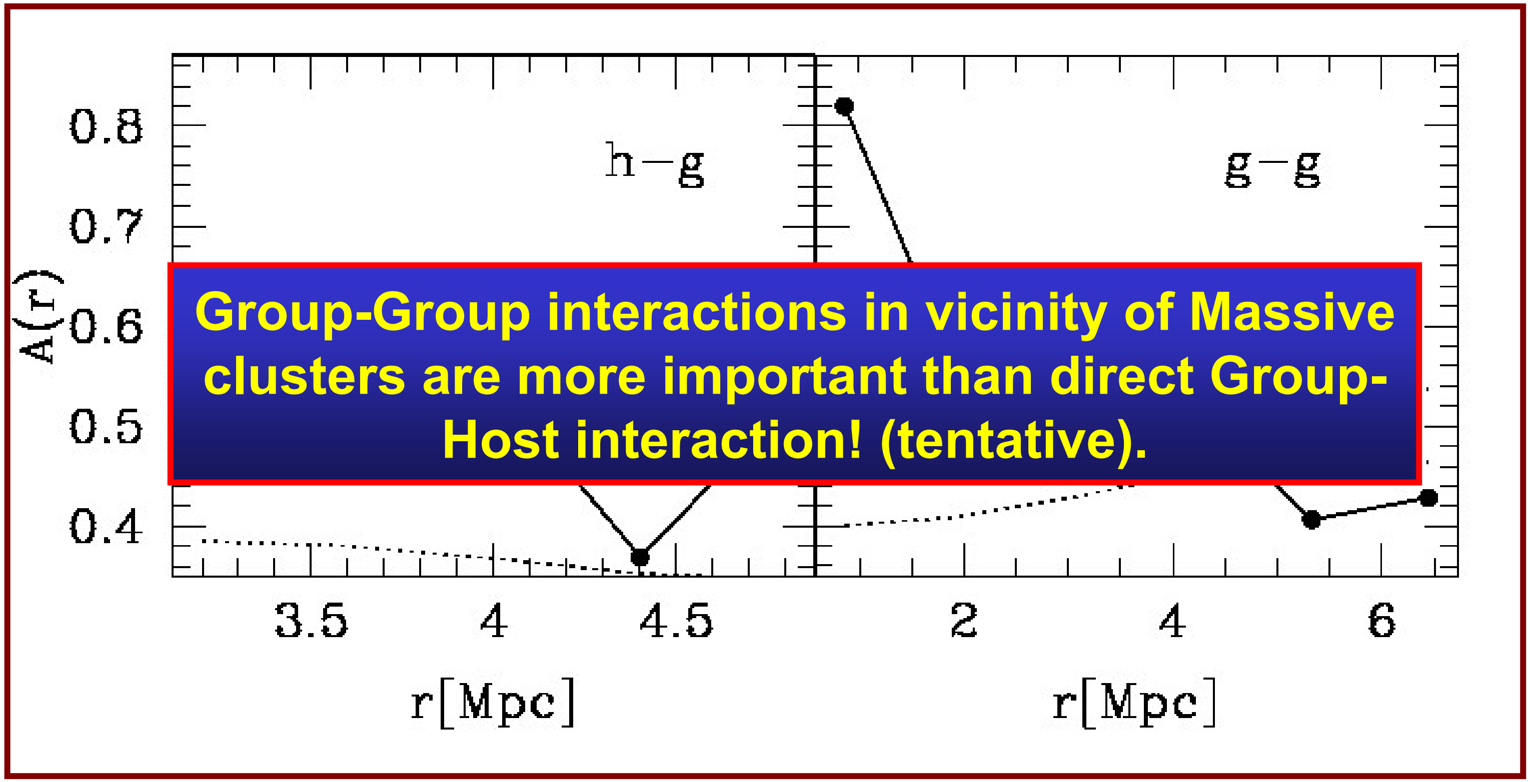


APM clusters (Plionis & Basilakos 2002)

Clusters with significant substructure are more aligned with Nearest Neighbour and reside preferentially in superclusters, as indicated also from ξ(r). Consistent also with REFLEX clusters (Schuecker et al 2001)

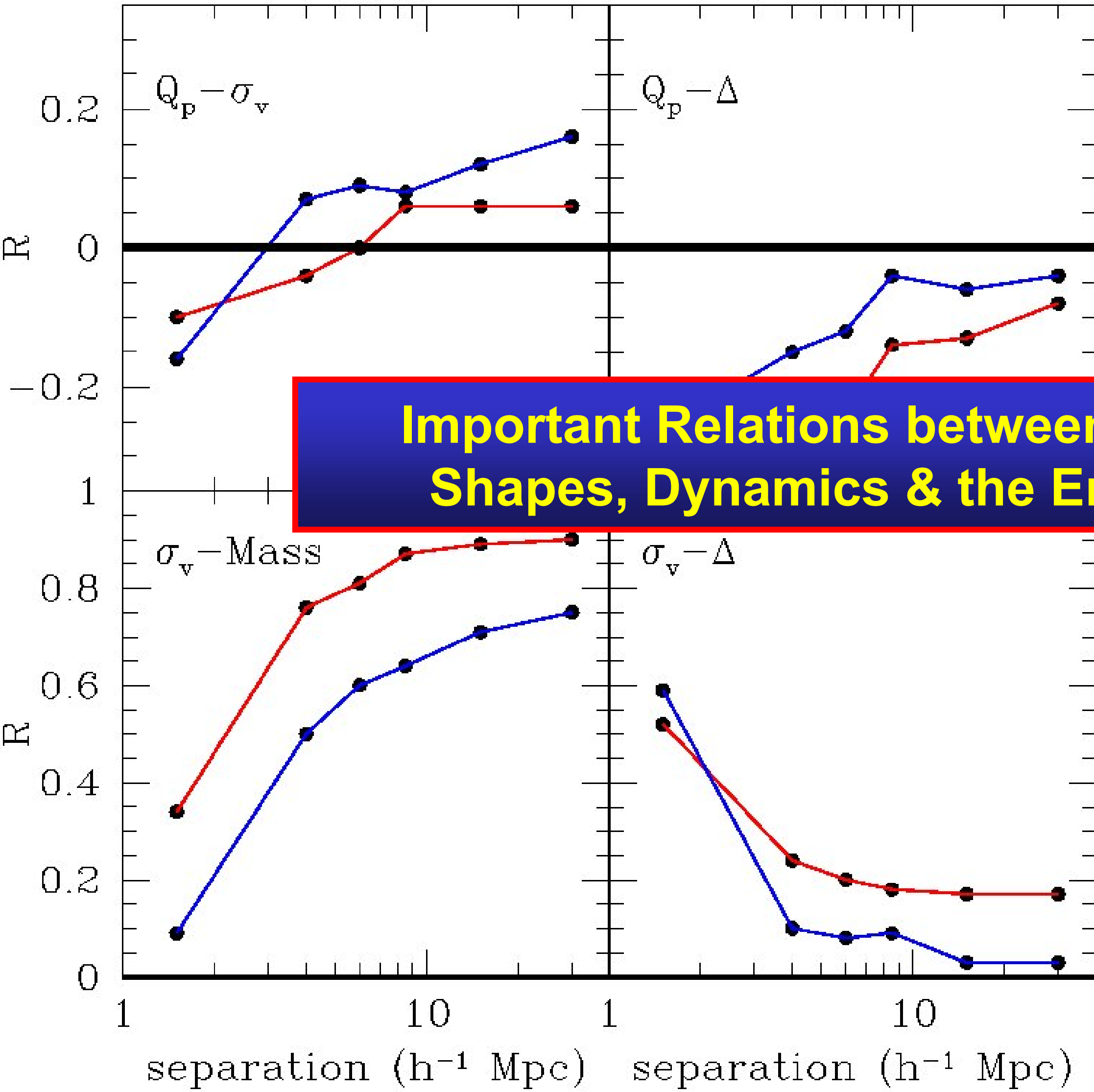
3. Group Halo Alignment – Environment correlation

Alignment of Halos also indication of dynamical state (Plionis & Basilakos 2002; Plionis et al. 2003).



The lack of Host-Group alignment (in the vicinity of the host) whilst there is at least tentative evidence for a Group Halo-Halo alignment signal indicating that interactions between neighboring groups (in the vicinity of Clusters) are more important for the internal group dynamics than the direct effect of the Host.

4. Group Halo Shape – Dynamics – Environment Cross-correlations



Important Relations between Group Halo Shapes, Dynamics & the Environment.

1. Near Massive clusters, the Halo σ_v– Mass (virial) relation breaks down.
2. The Halo σ_v near Massive Hosts is dominated by substructure and merging.
3. ... halos are more ... r Massive host ... distances (weak anticorrelation).
4. Near Massive hosts, halos with large σ_v are more prolate, while the opposite is true far from the hosts.

Supercluster Shape – dynamics/Alignment correlations !

Faltenbacher et al (2002) analysing a ΛCDM simulation, found a “Filamentary” alignment between the cluster major axes and the line connecting them.

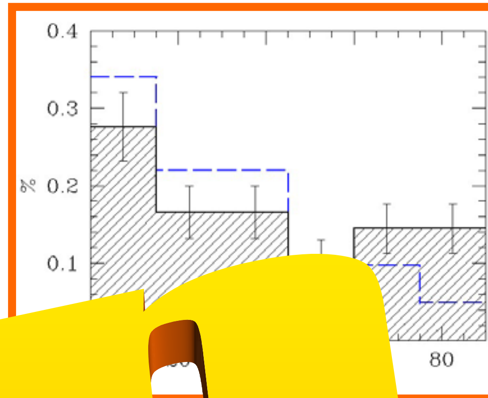
$$\mathcal{H}_1 = VS^{-1},\ \mathcal{H}_2 = SC^{-1} \text{ and } \mathcal{H}_3 = C$$

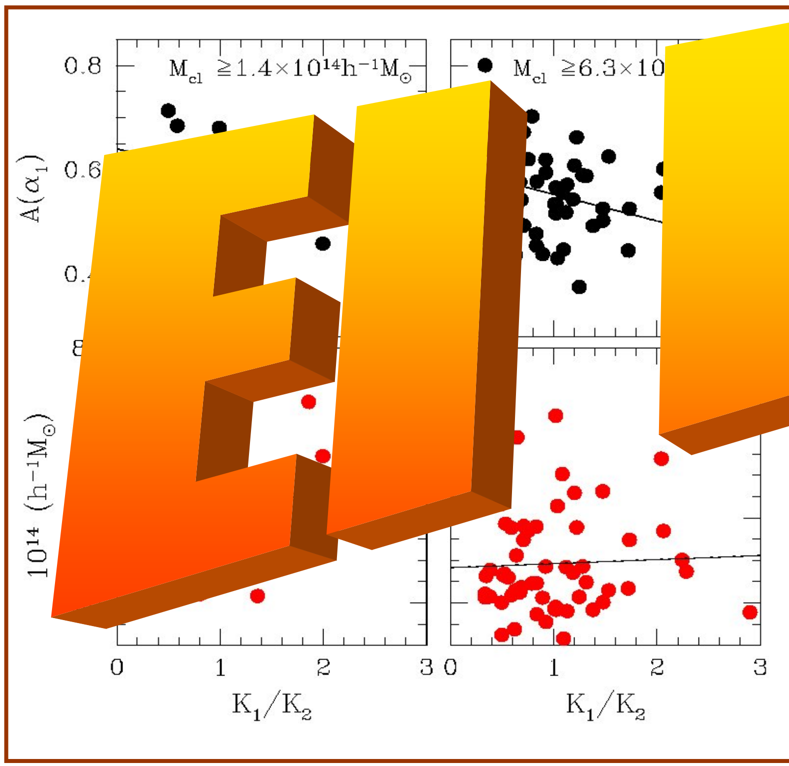
dimensionless shapefinders:

$$K_1 = \frac{\mathcal{H}_2 - \mathcal{H}_1}{\mathcal{H}_2 + \mathcal{H}_1} \qquad K_2 = \frac{\mathcal{H}_3 - \mathcal{H}_2}{\mathcal{H}_3 + \mathcal{H}_2}$$

(i) Pancakes if $K_1/K_2 > 1$
(ii) Filaments if $K_1/K_2 < 1$
(iii) Triaxial structures if $K_1/K_2 \approx 1$ and
(iv) Spheres if $I_1 = I_2 = I_3$ and $K_1 = K_2 = 0$.

$$A(r) = \langle |\mathbf{e}_l \cdot \mathbf{e}_k| \rangle (r)$$





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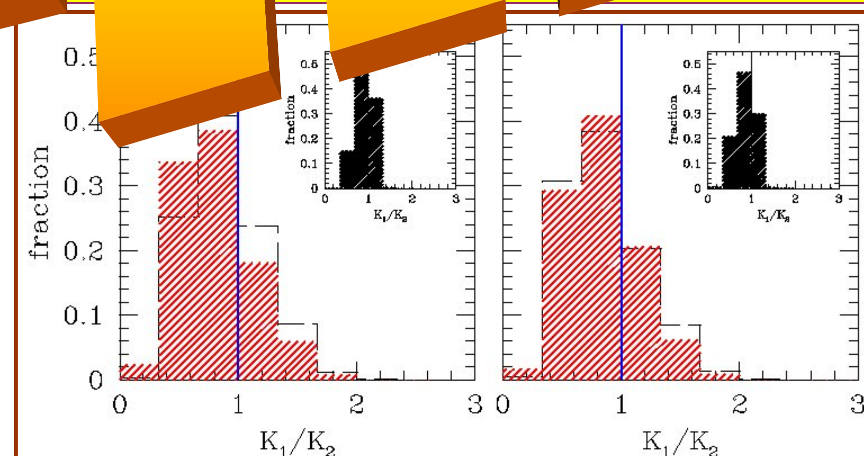

ΛCDM GADGET simulation of L=512 h^{-1} Mpc

(512^3 DM particles + 2 x 512^3 gas particles)