Properties of central galaxies formed through collisionless hierachical merging in small groups

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Context

Both simulations and observations show that at different redshift, galaxies are predominantly found in poor groups, where proximity to other galaxies and low relative velocities may lead to enhanced merging rates.

Observational evidence suggests that multiple dry merging contributes significantly to the growth of massive elliptical galaxies.

Method

Forty collisionless high-resolution simulations to investigate the formation of ellipticals in the group environment towards the end of the epoch that precedes the virialization of the entire galaxy system when the rate and strength of galactic encounters peak

Study of the scaling relations involving the optical properties of the brightest group galaxies (BGG) that form during the end of the pre-virialization epoch and its possible connection with the properties of the parent group

Initial Conditions

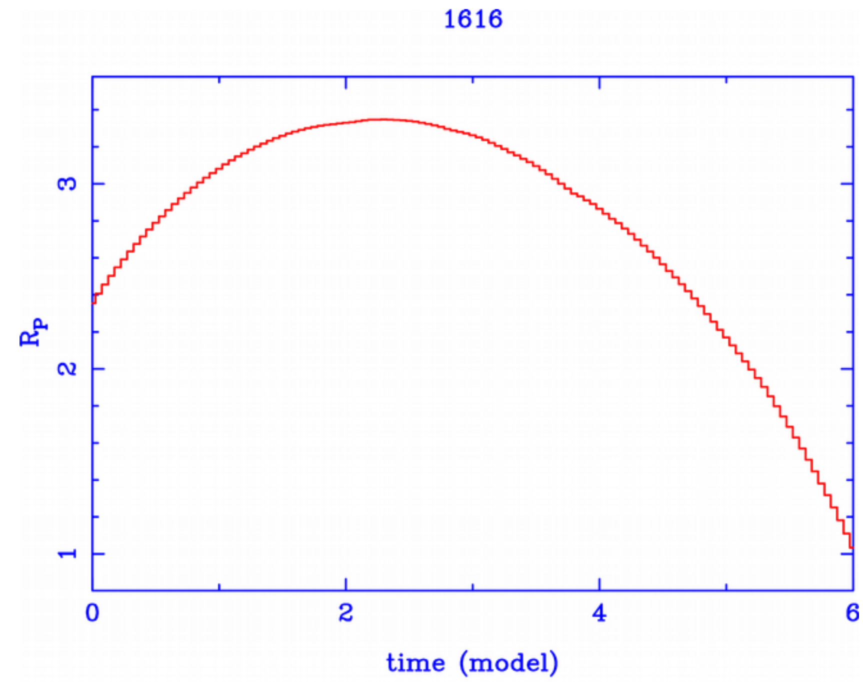
25 Galaxy halo masses are sampled from a Schechter (1976) pdf with M/M* > 0.05 and re-scaled to the values expected at z_i.

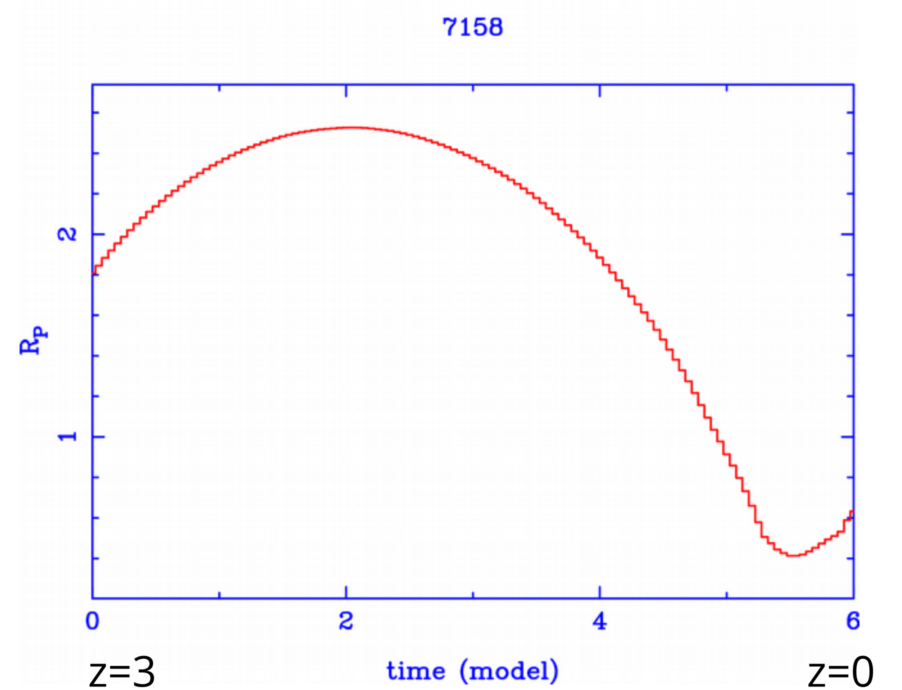
Properties of the stellar component scale with the total galactic mass under virial equilibrium.

Parameter values are calibrated using the (infrared) scaling relations inferred for the local universe (see e.g. Darriba & Solanes 2010).

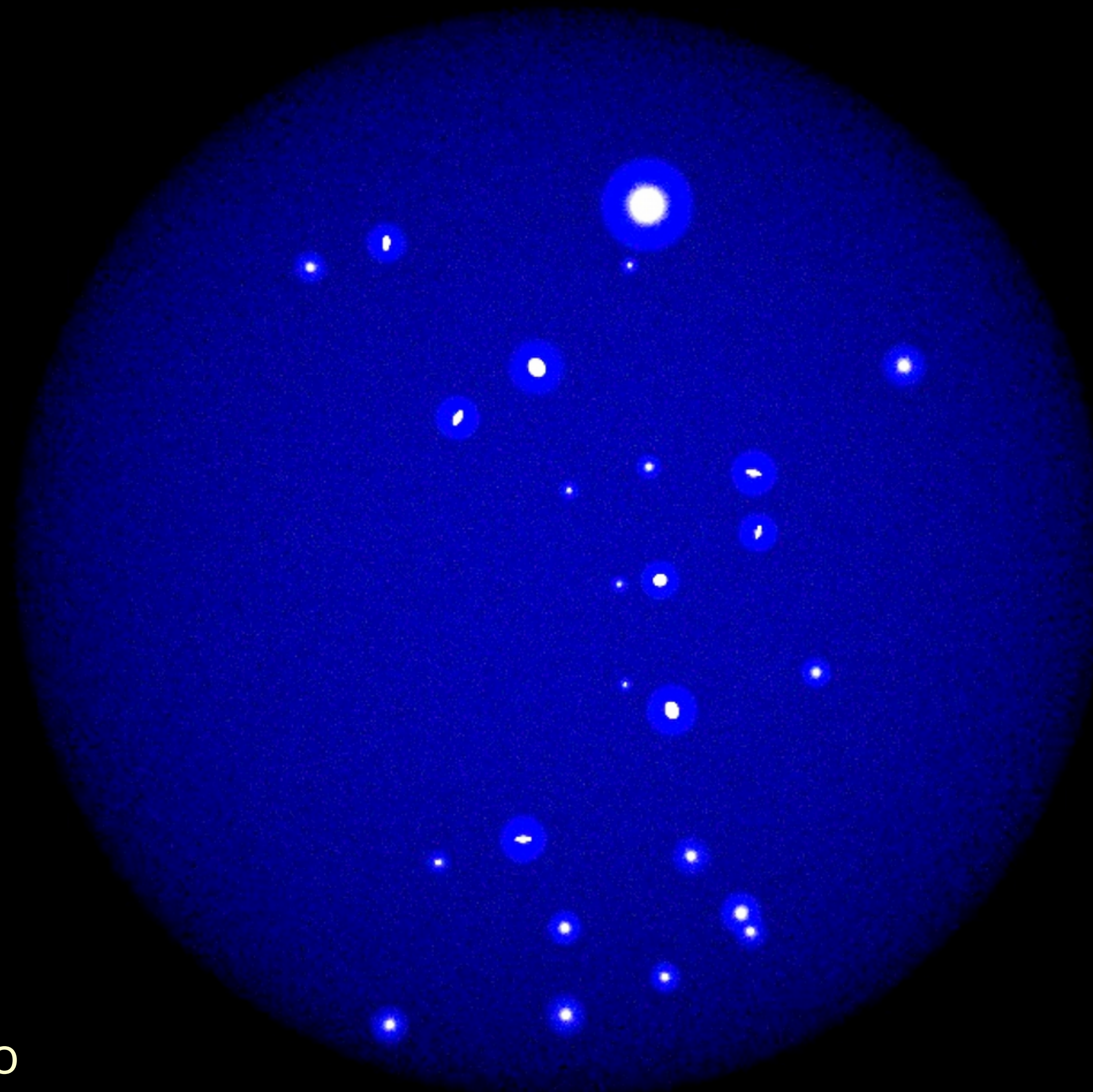
LTG fraction of 0.7 (0 for M/M* < 0.1), typical of the field. Disks' orientations are randomly chosen.

Groups start at $z_i = 3$ as top-hat overdensities expanding with the perturbed Hubble flow needed for $z_{coll} = 0$. $M_{group} = 10^{13} M_{\odot} = 10M^*$.



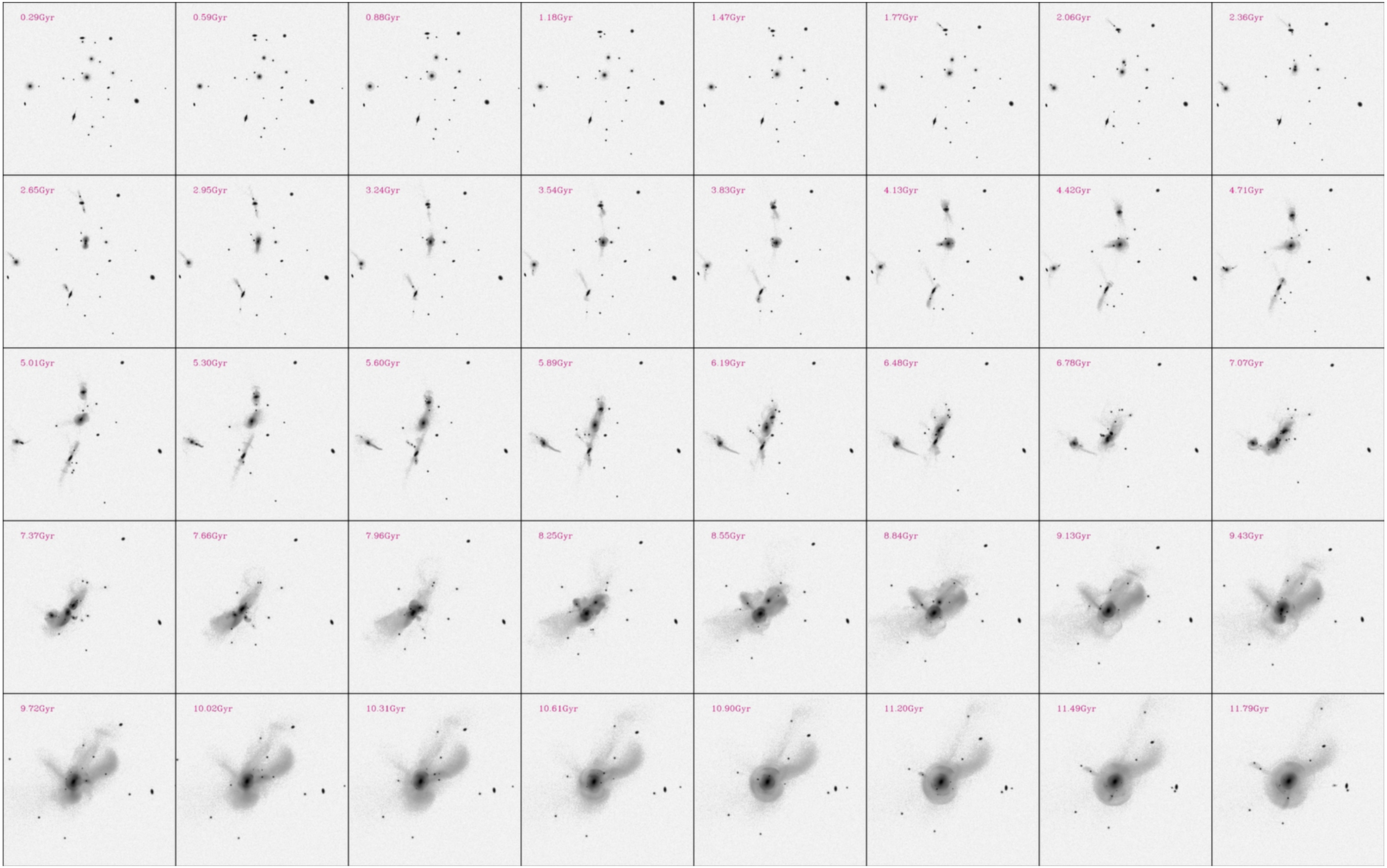


Initial Conditions



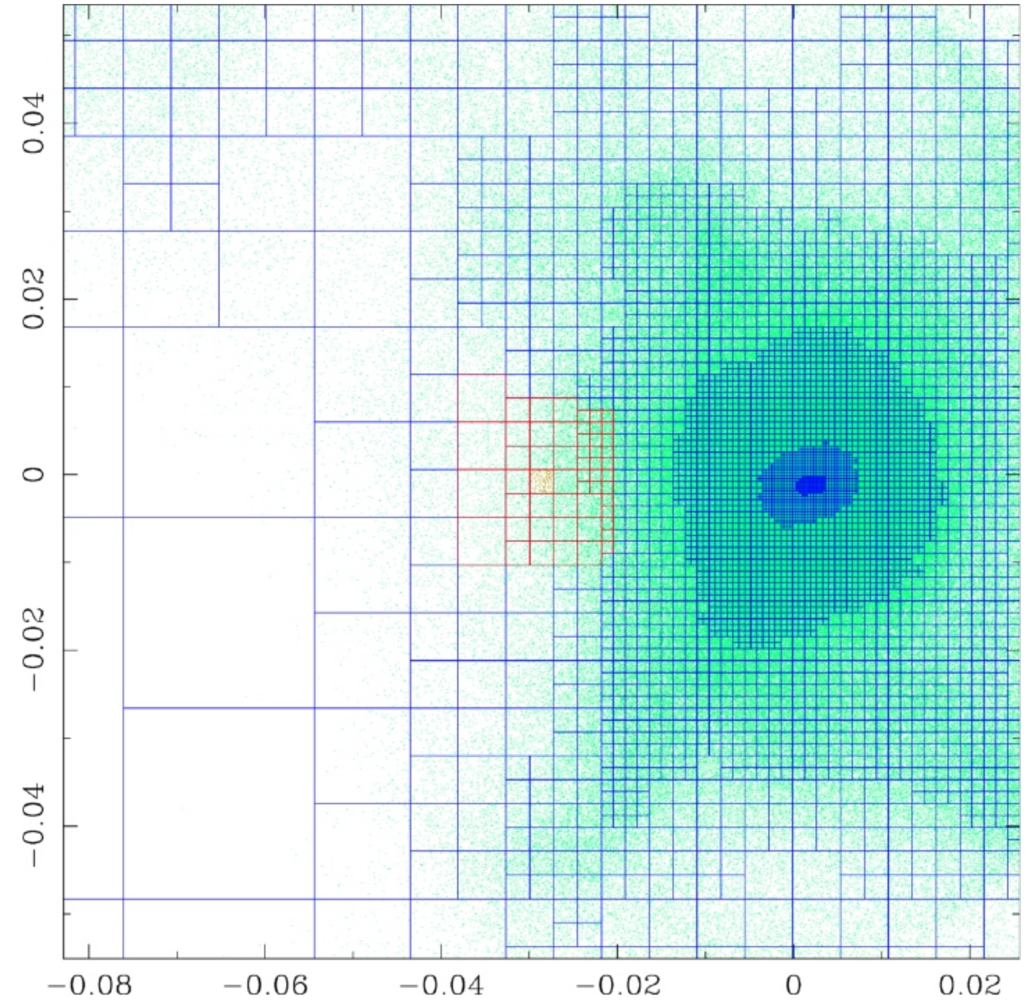
Total mass in *galaxies* (halo and visible) may change.

A common external dark halo is also included.



Time evolution of the visible mass component. Halos start as a spherical overdensity that at first expands linearly, then goes through the turnaround, and finally experiences a completely non-linear collapse.

Projected density images were generated using a cell and kernel density estimation. Cells are used only to accelerate the calculation



2D mass density is estimated by

$$\Sigma_{2D}(x,y) = \sum_{i=1}^{N} m_i K(x,y,x_i,y_i)$$

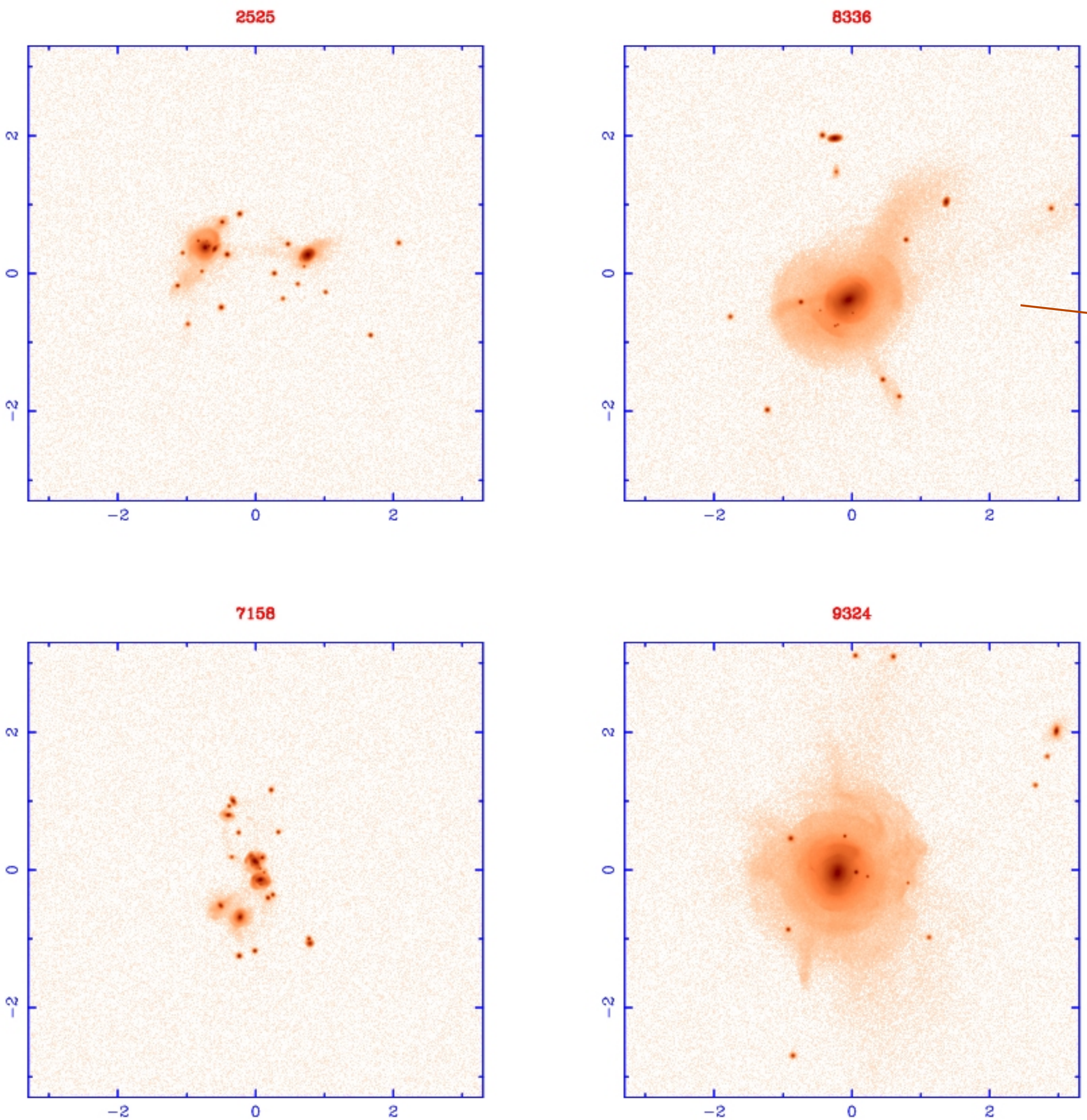
$$K(t;h) = \frac{7}{64\pi h^2}(t-2)^4(2t+1)$$

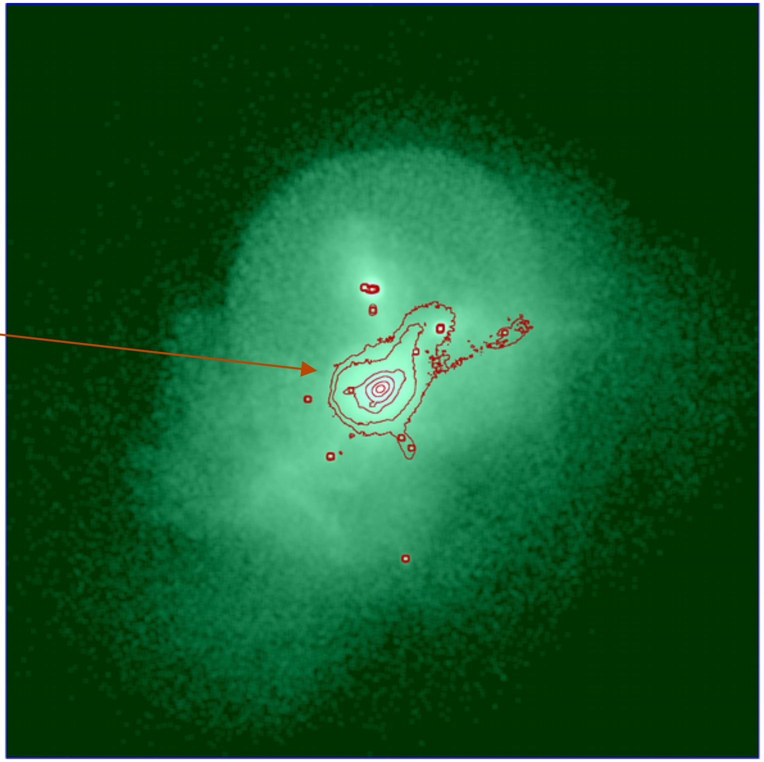
if $t \leq 2$; 0 otherwise

Only visible particles are included in the sum

$$t = \frac{1}{h}\sqrt{(x-x_i)^2+(y-y_i)^2}$$

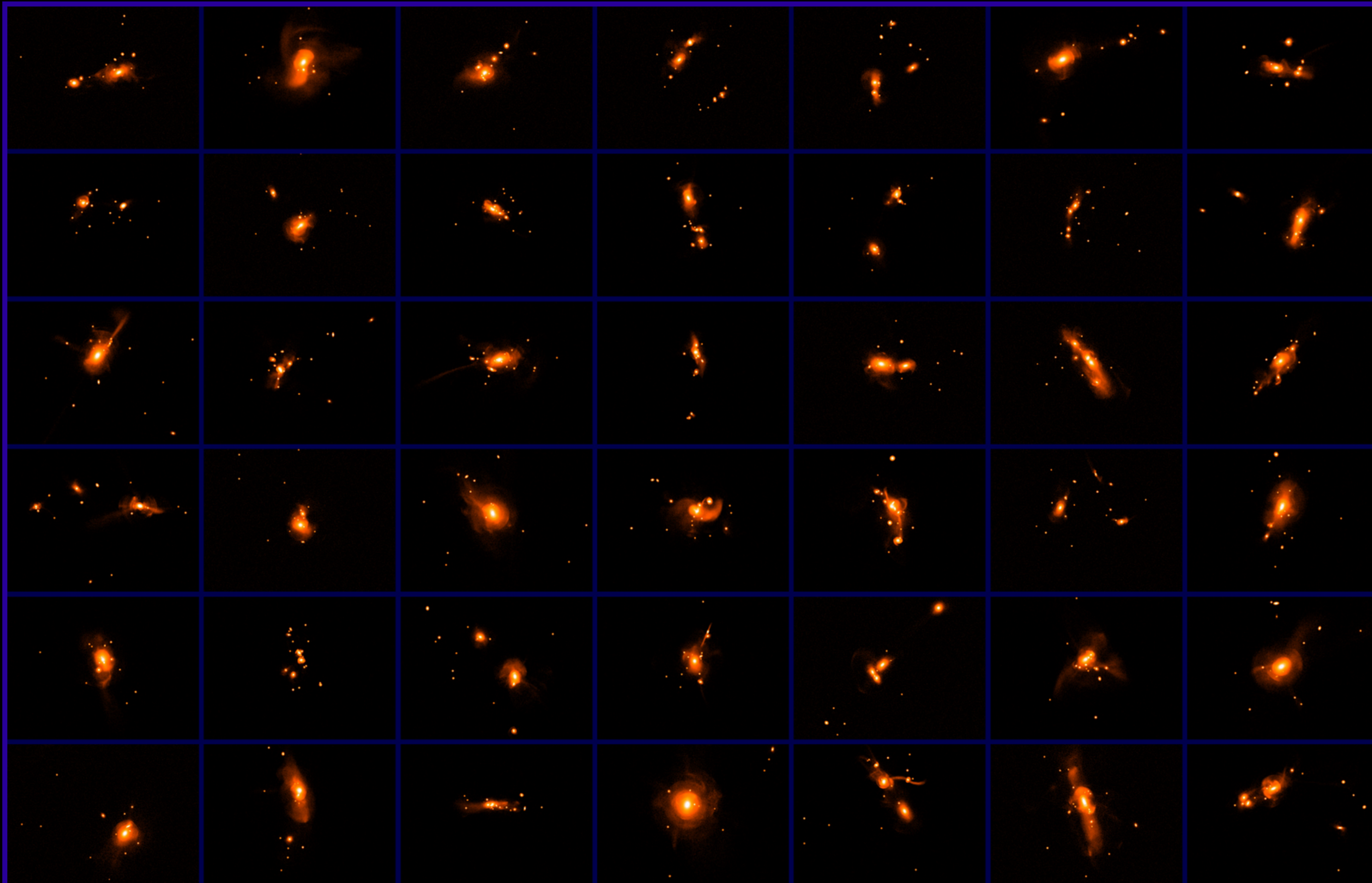
Projected density images were generated using a cell and kernel density estimation.





DM particles follow always an extended distribution

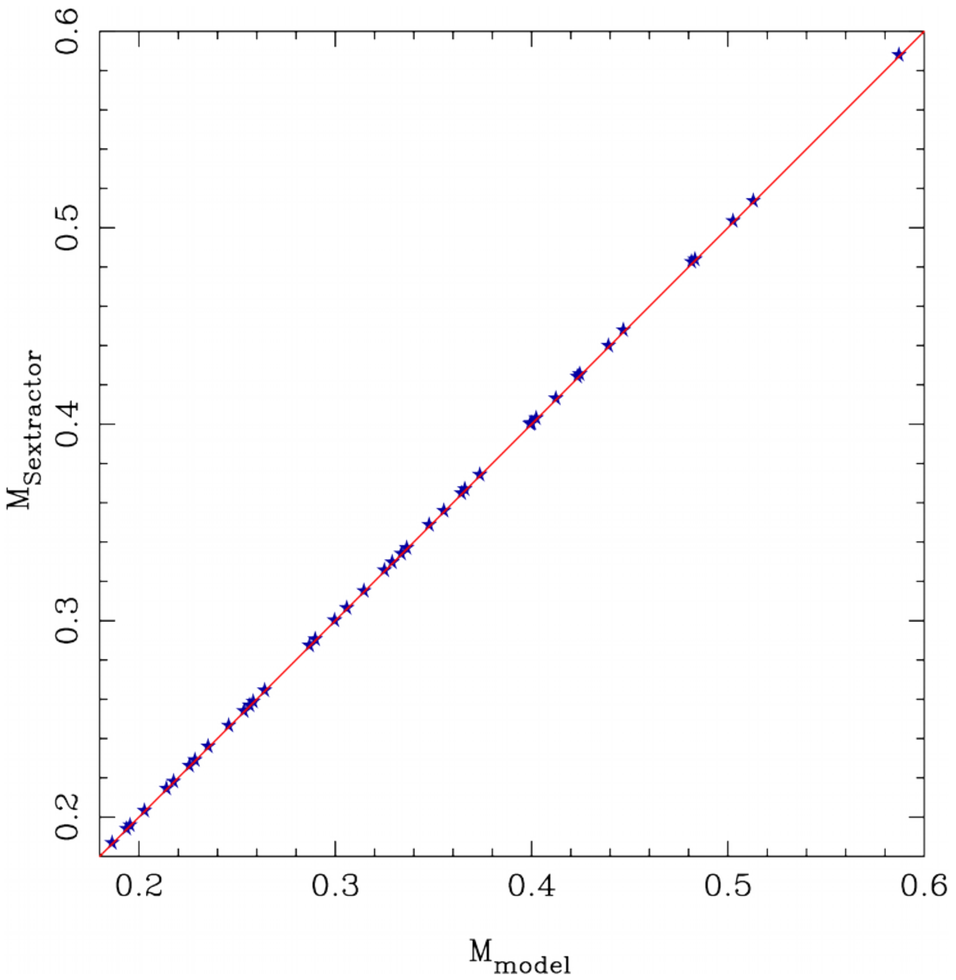
Low visible mass simulations may end as Compact Groups



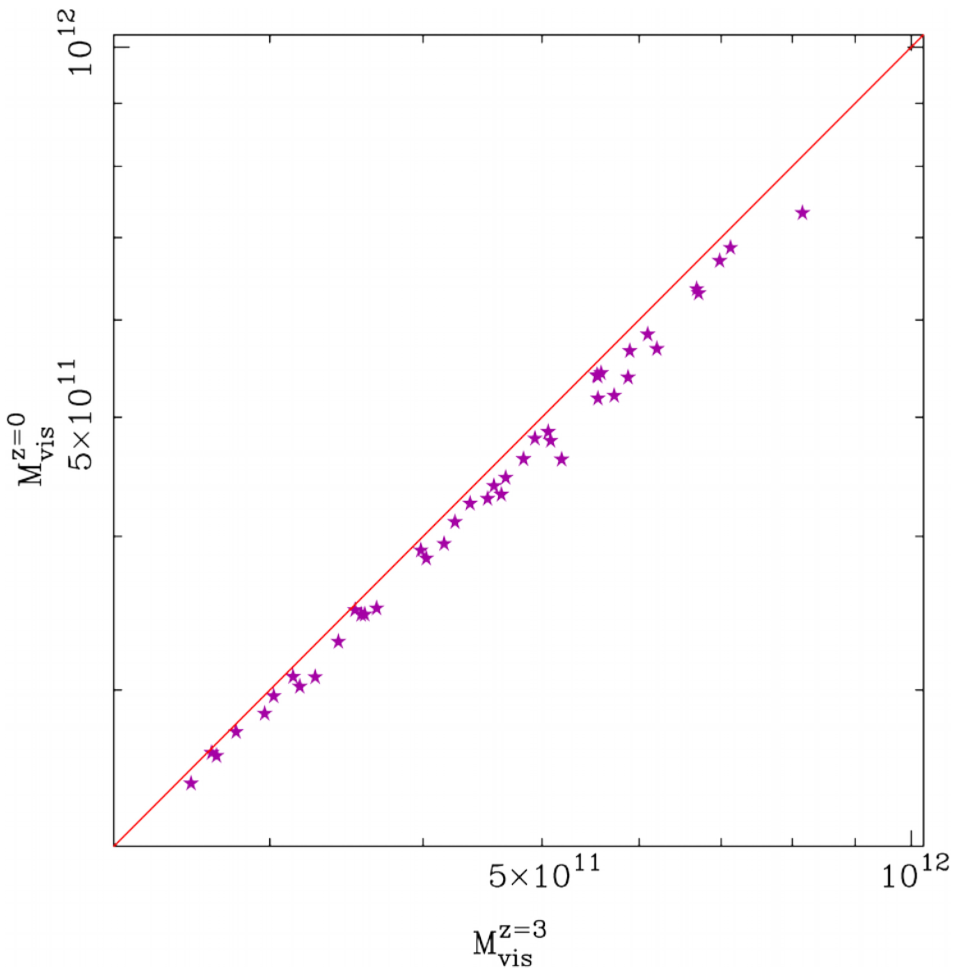
Final snapshots (z=0) for all the groups. Dominant BGG are the result of multiple mergers in the most massive groups (visible)

Mass estimation and galaxy identification

Sextractor was used to identify galaxies in the projected images

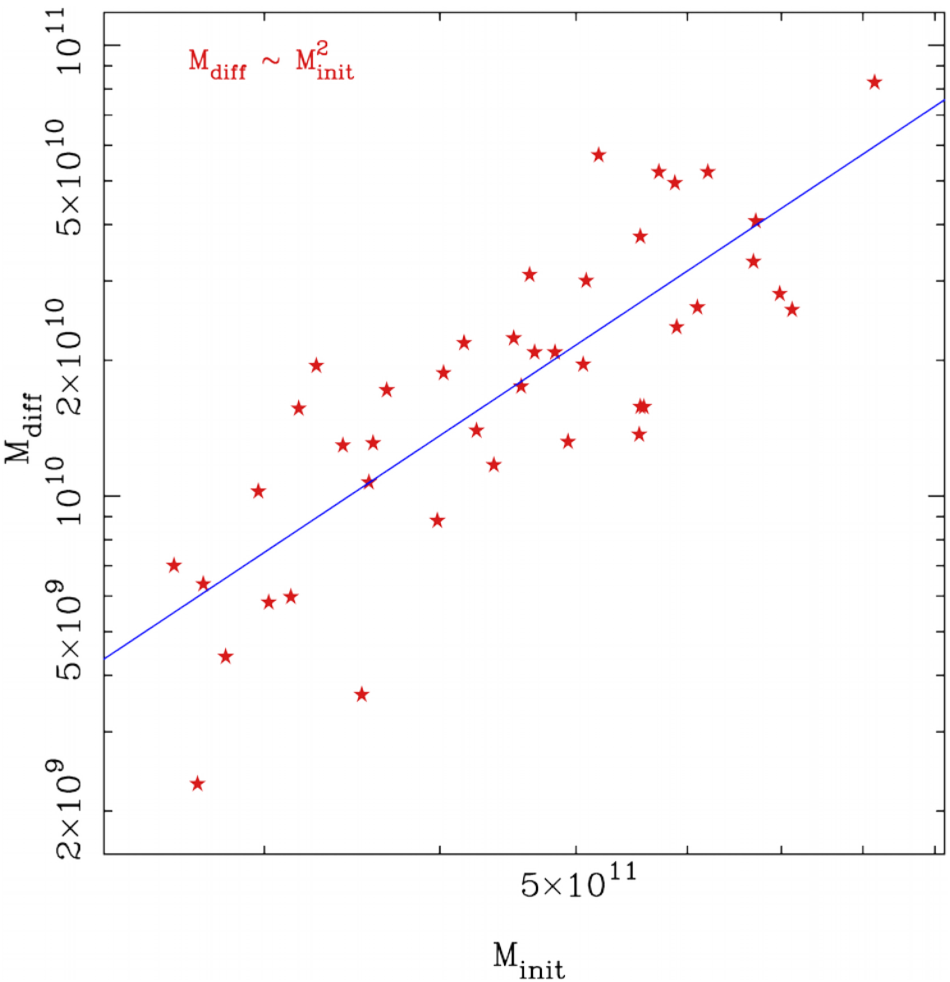


Comparison at z=3 (t=0)



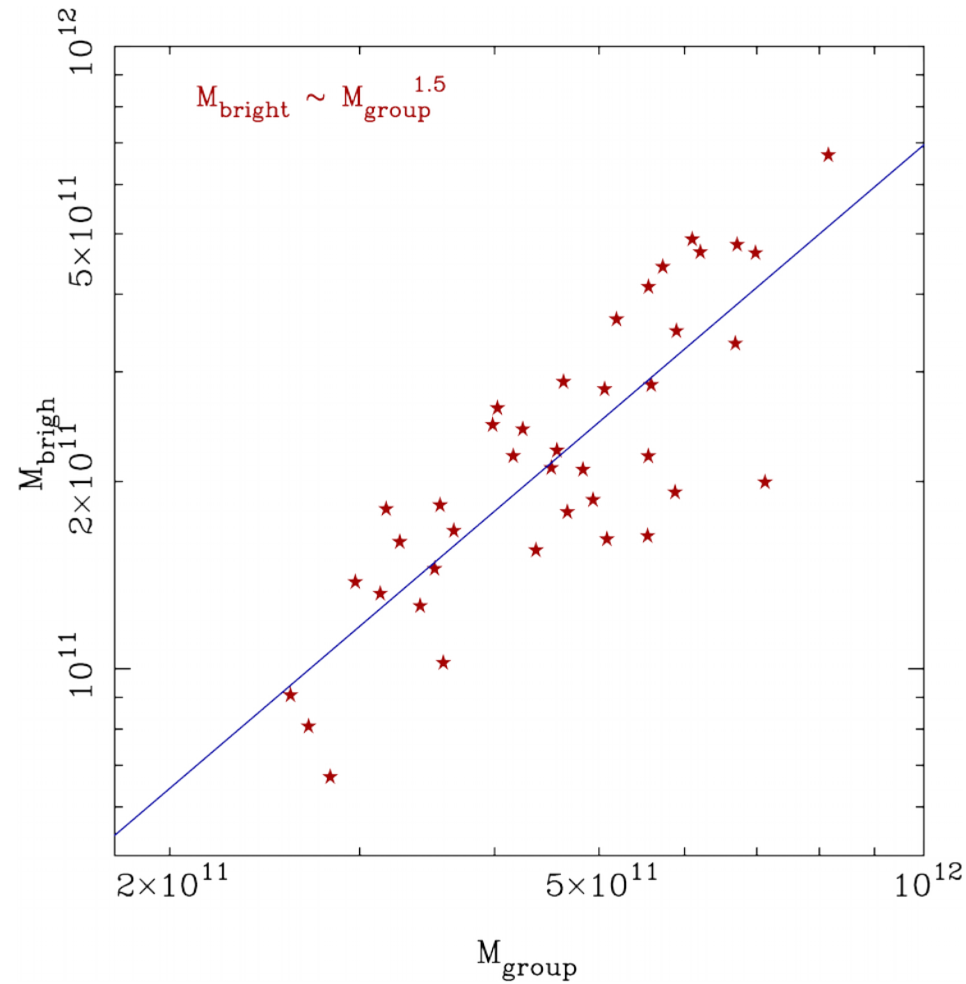
The final mass in galaxies smaller than mass at t=0. The difference appears as a diffuse stellar component

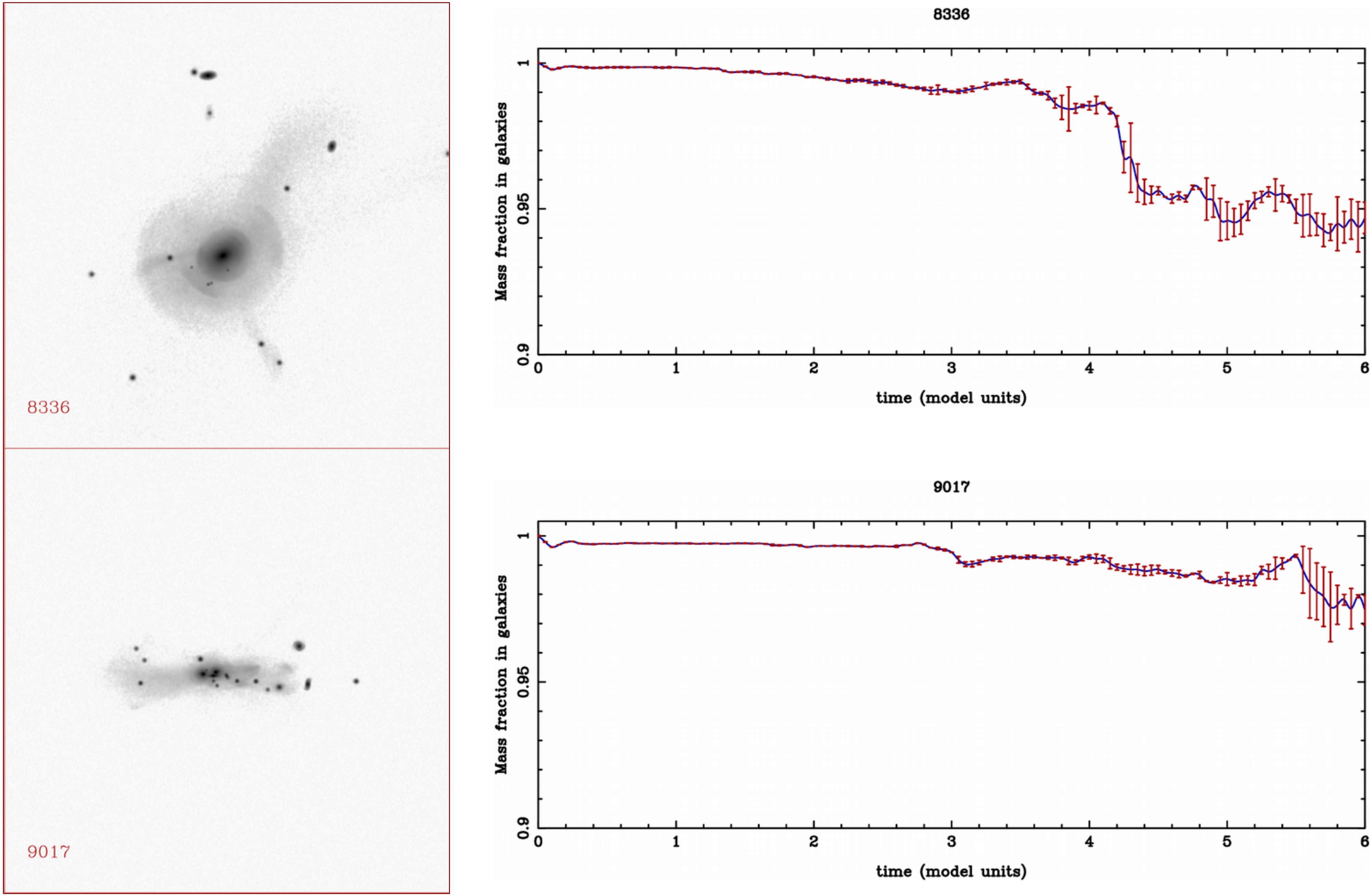
Diffuse component



Small amount of diffuse IGL, almost always less than the 10%

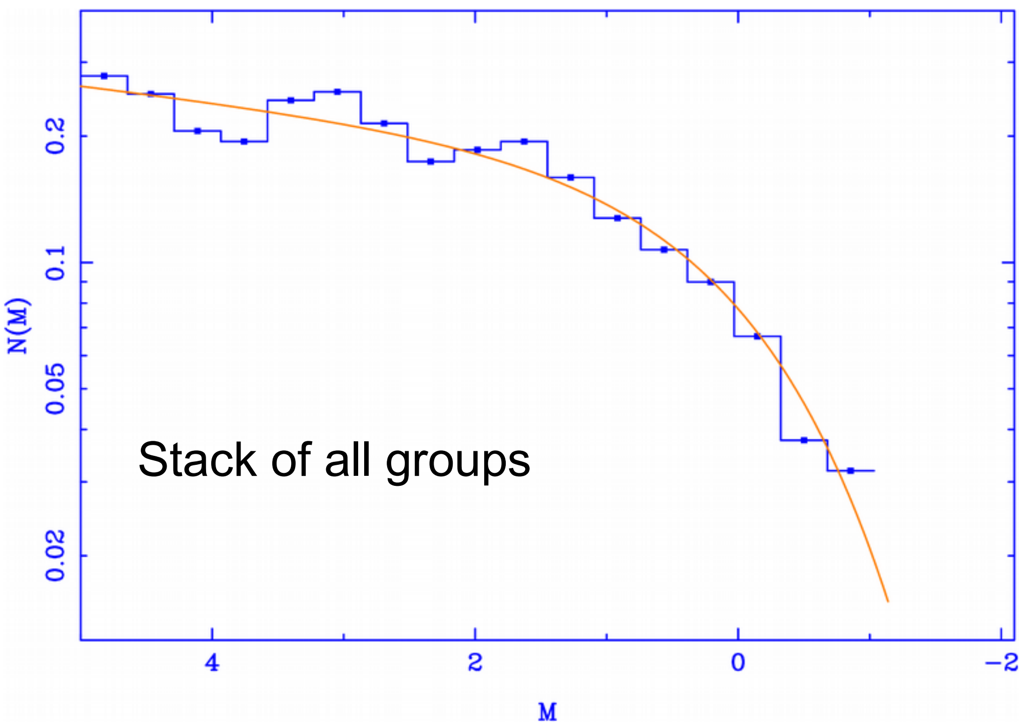
The larger the group, the brightest the BGG



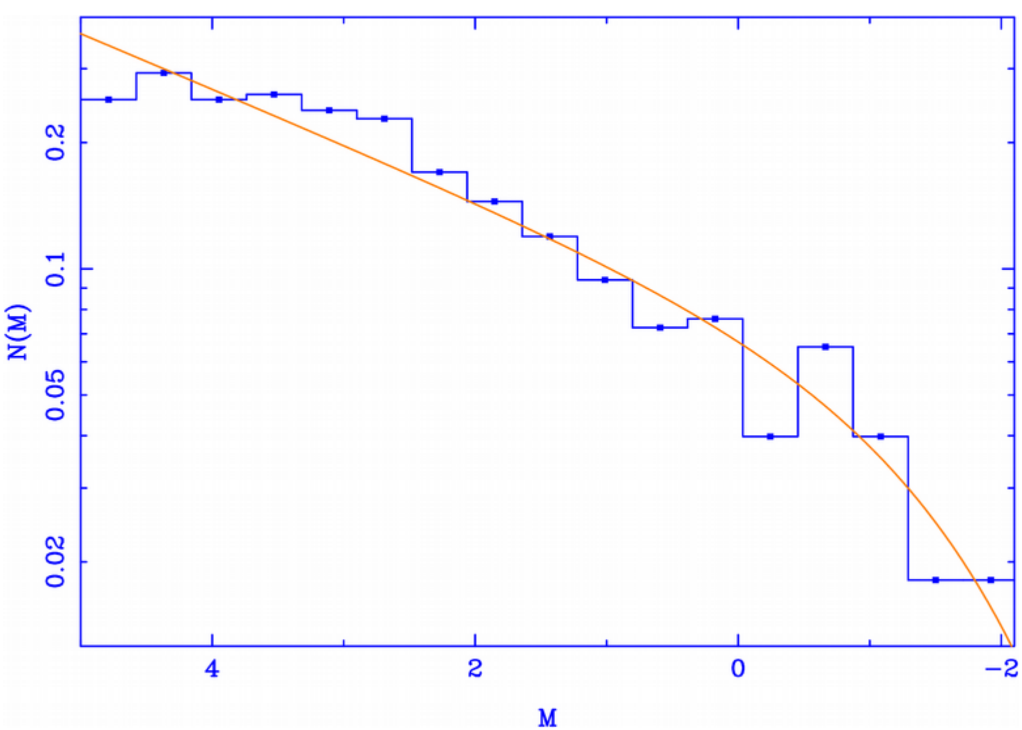


Two extreme cases, error bars are evaluated by comparing the three model projections

Luminosity function evolution

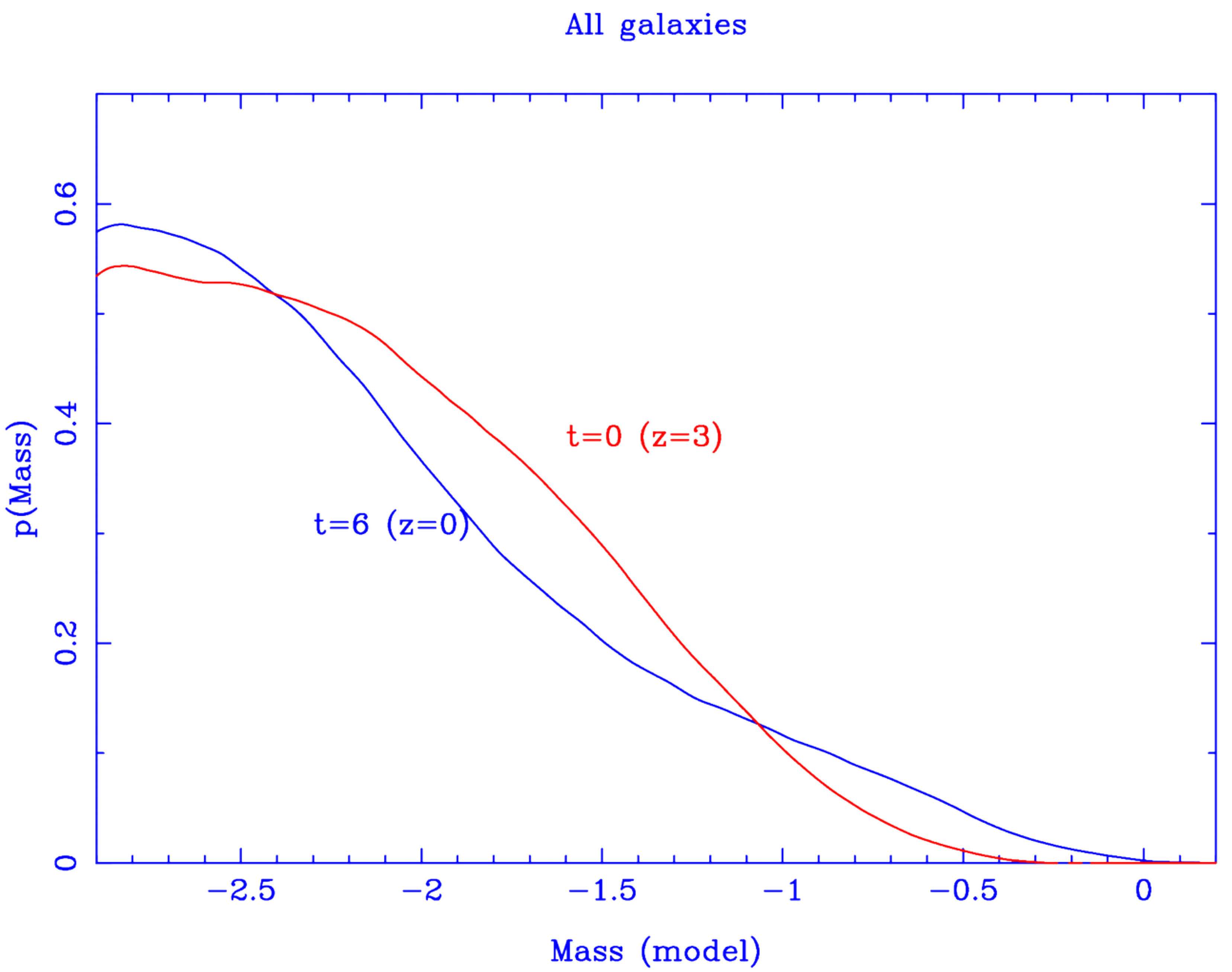


Initial conditions (z=3) α=-1

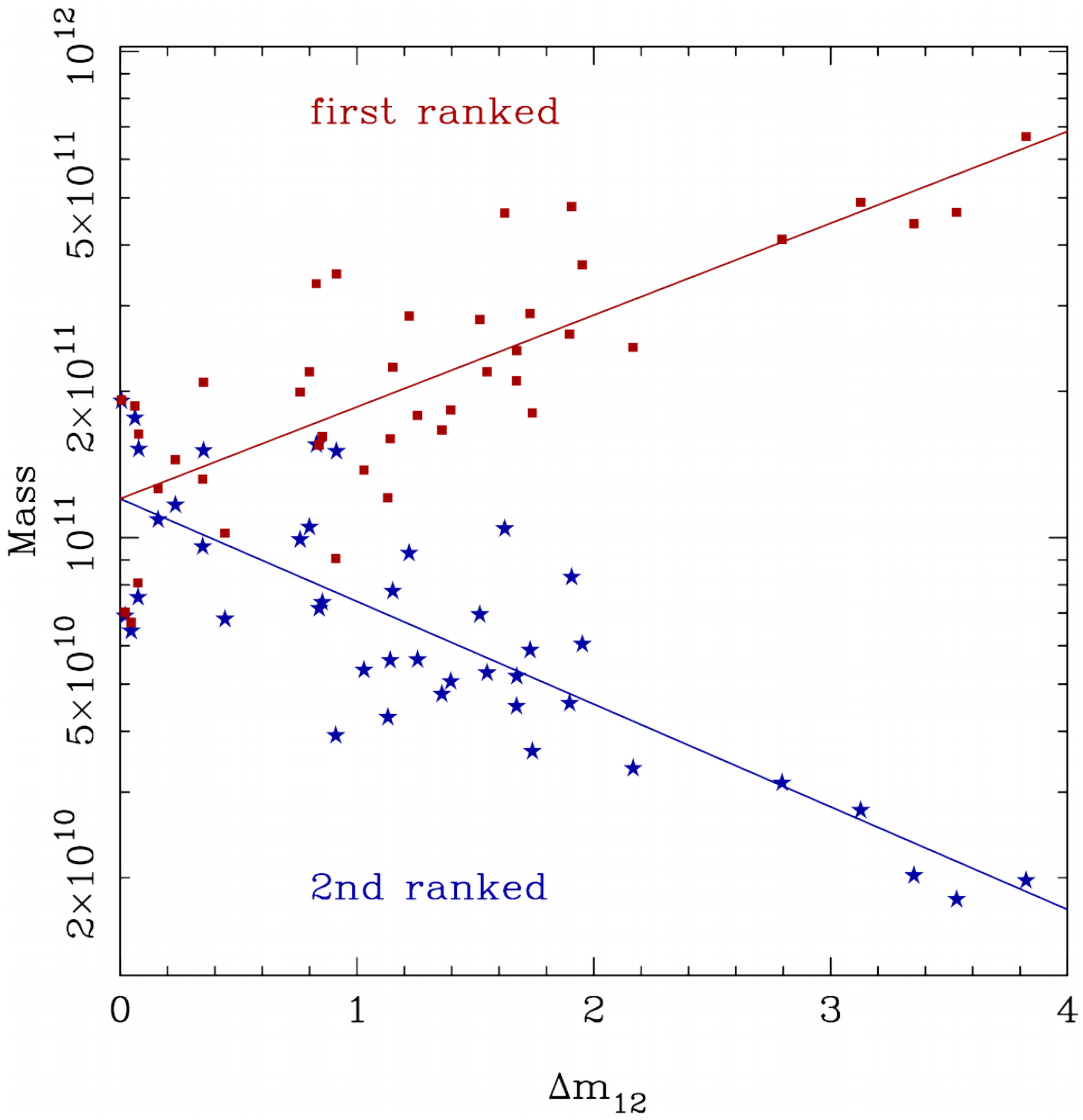


At end (z=0) α=-1.3

Massive galaxies appear as the result of mergers

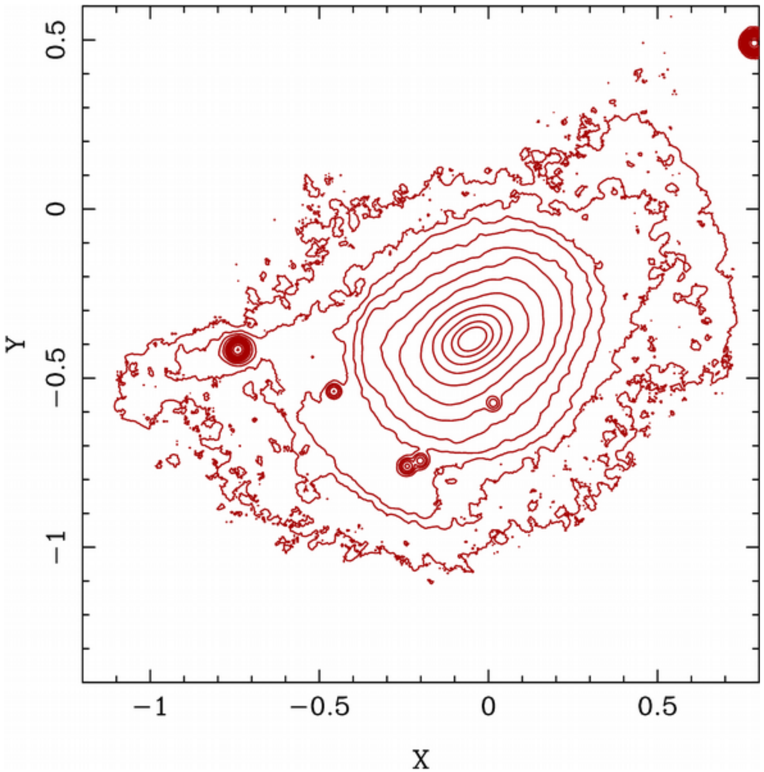


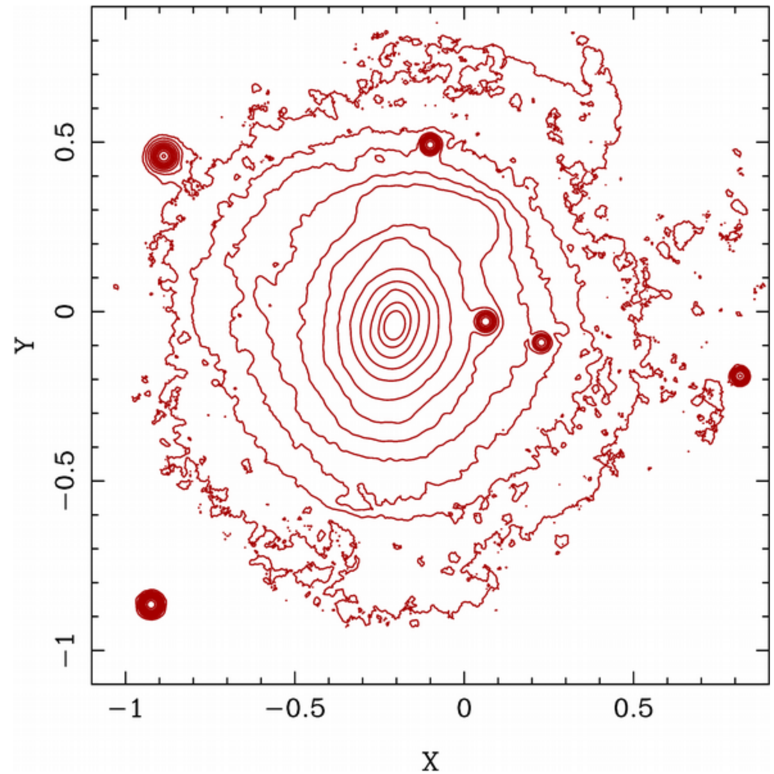
A BGG is mainly the result of mergers of intermediate mass galaxies, thus producing a dip in the luminosity function at z=0

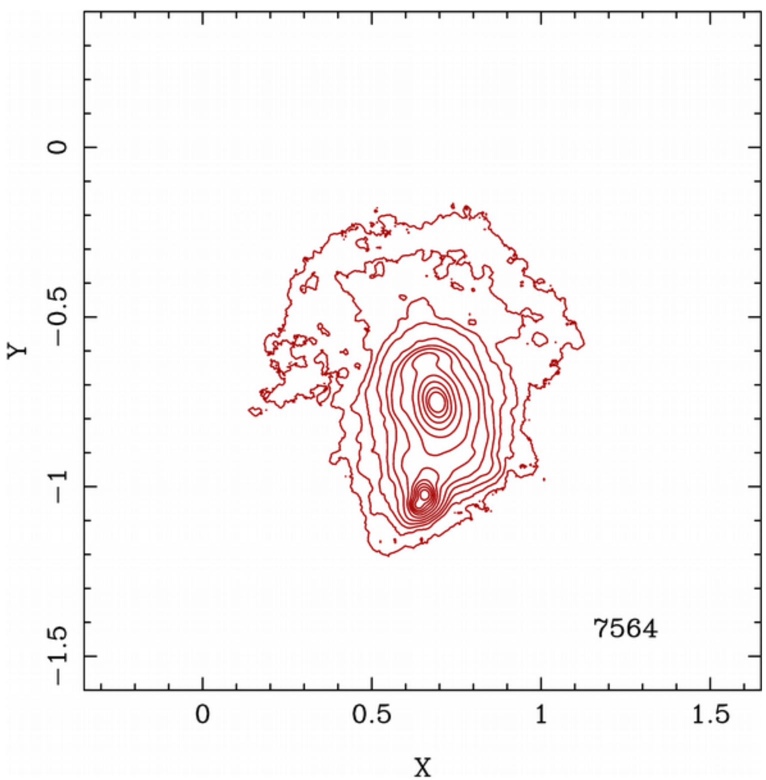


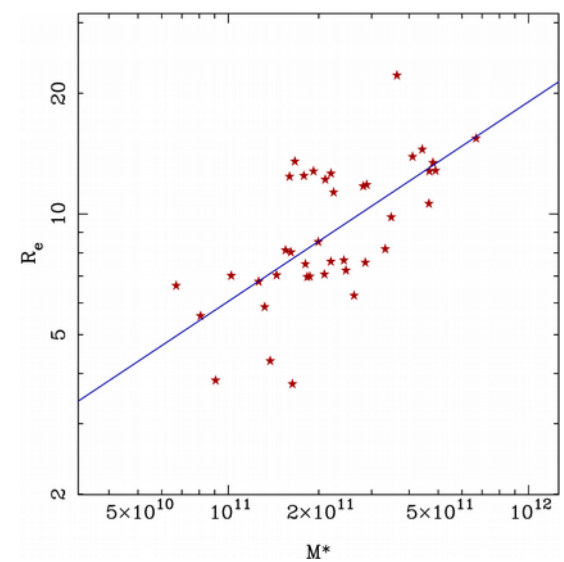
The magnitude step between the first and second ranked galaxies depends on the mass of those galaxies.

The linear fits indicate a slightly better result for M_2 (t=-8.86 *vs*. t=7.92 for M_1)

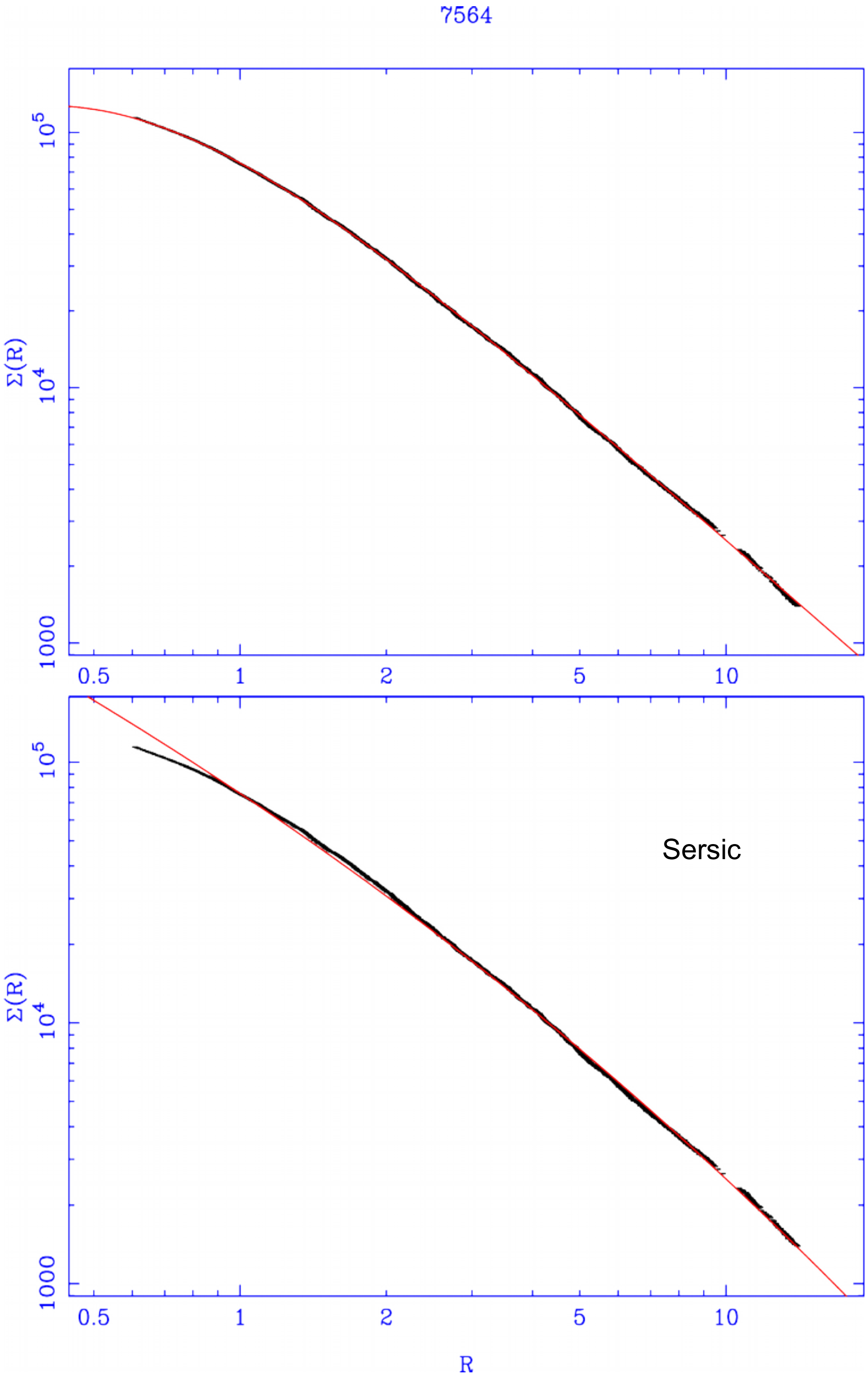




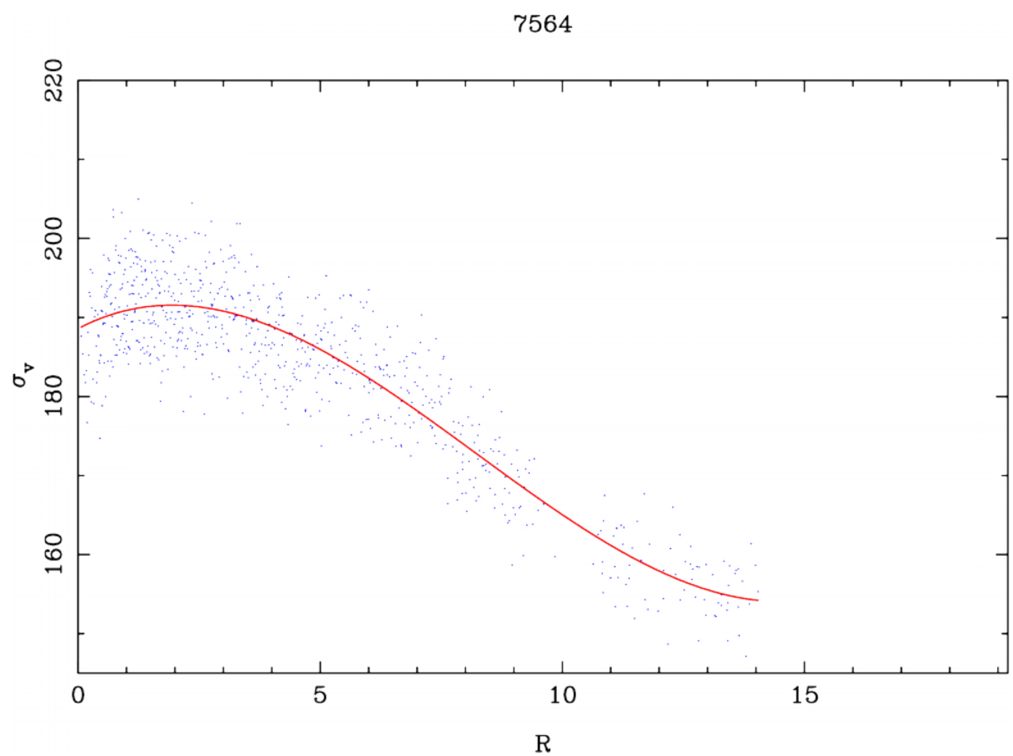


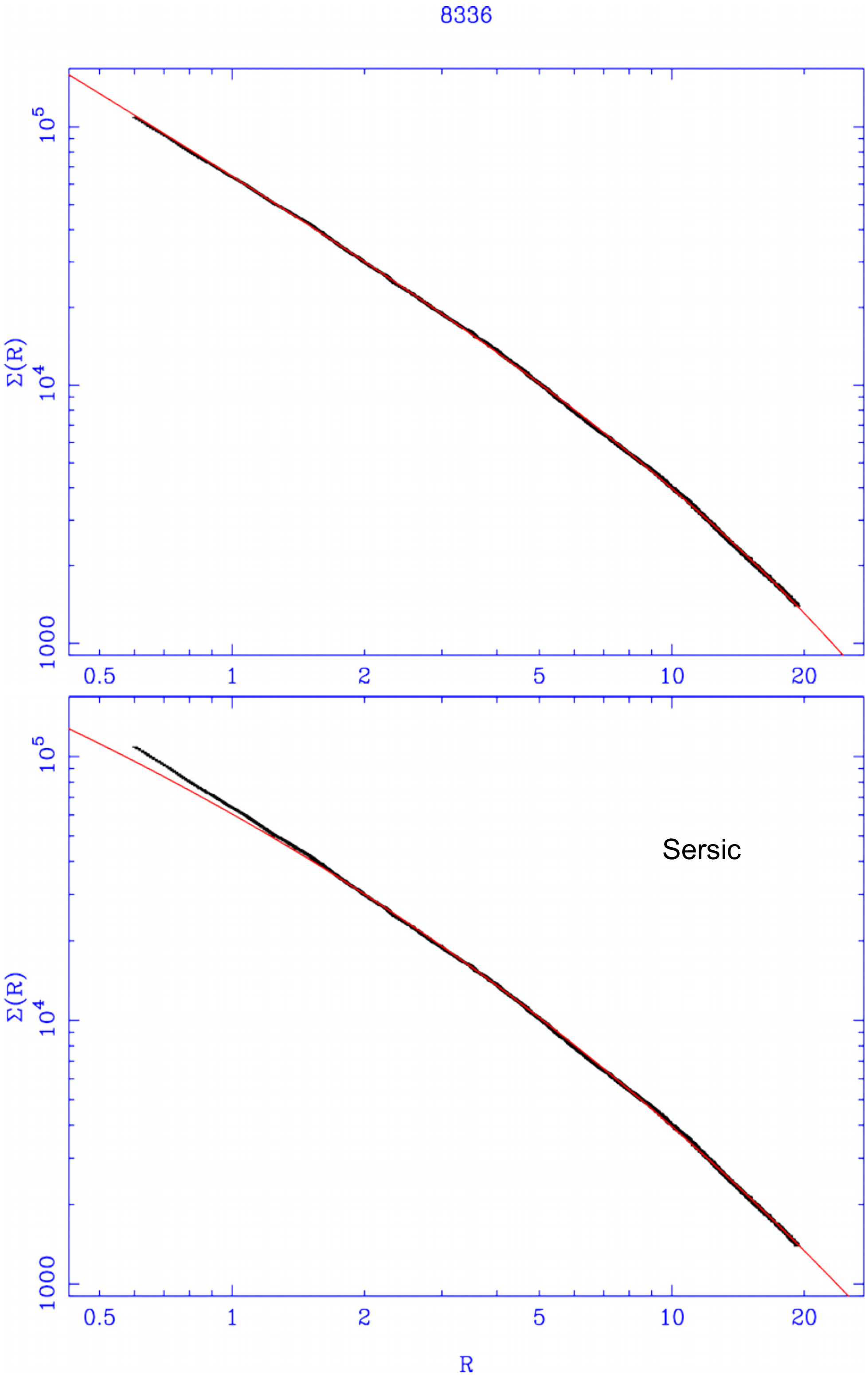


BGG may show elliptical galaxy properties



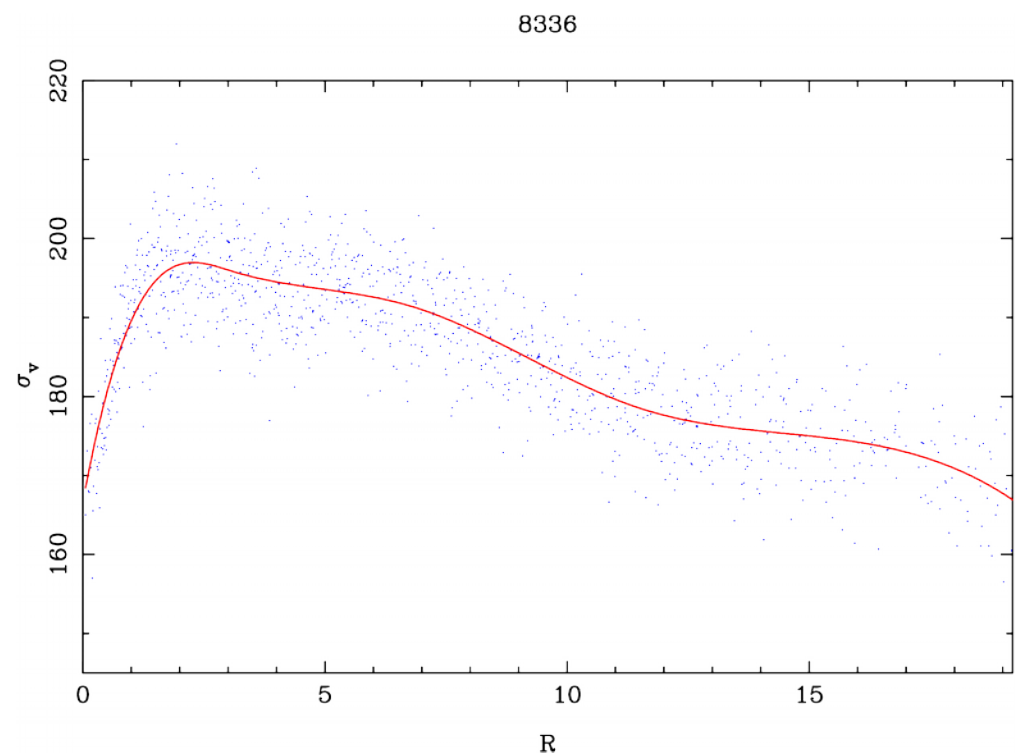
Sersic profile does not fit well enough the central regions. In fact, a second component law, such as the Nuker profile, provides with a better fit.



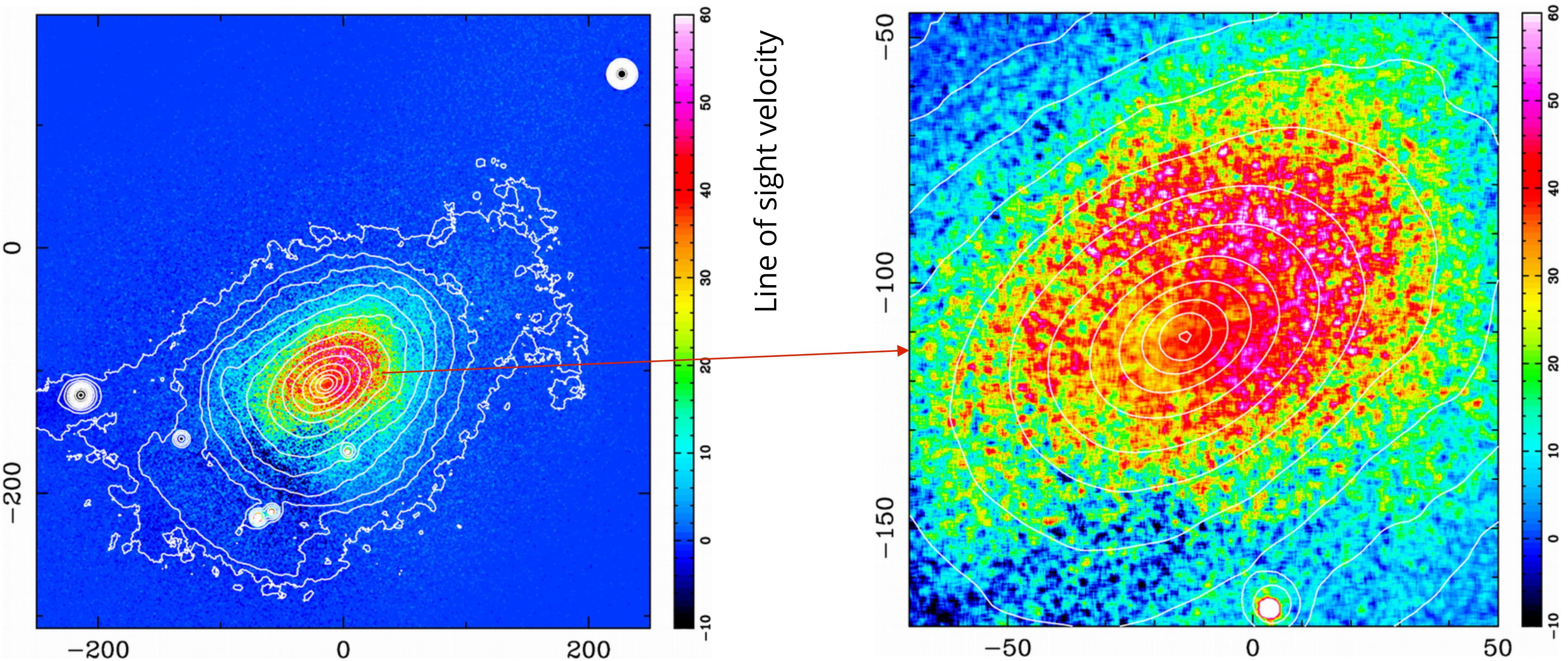


The velocity dispersion profile may drop at the very center.

Our BGG are not really massive ellipticals since the mass of their progenitor group is never high.



Rotation



BGGs may show rotation with small amplitude, as it is expected in galaxies formed by multiple mergers

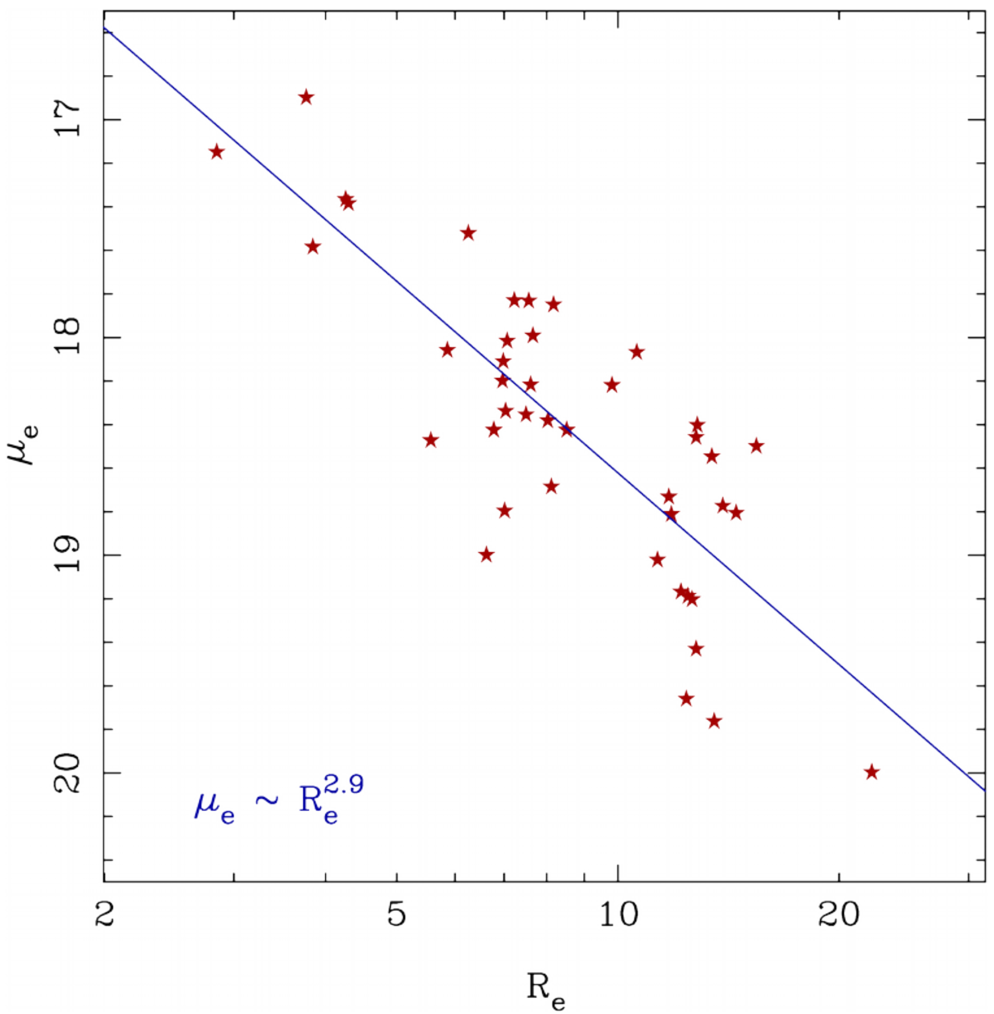
Scaling laws

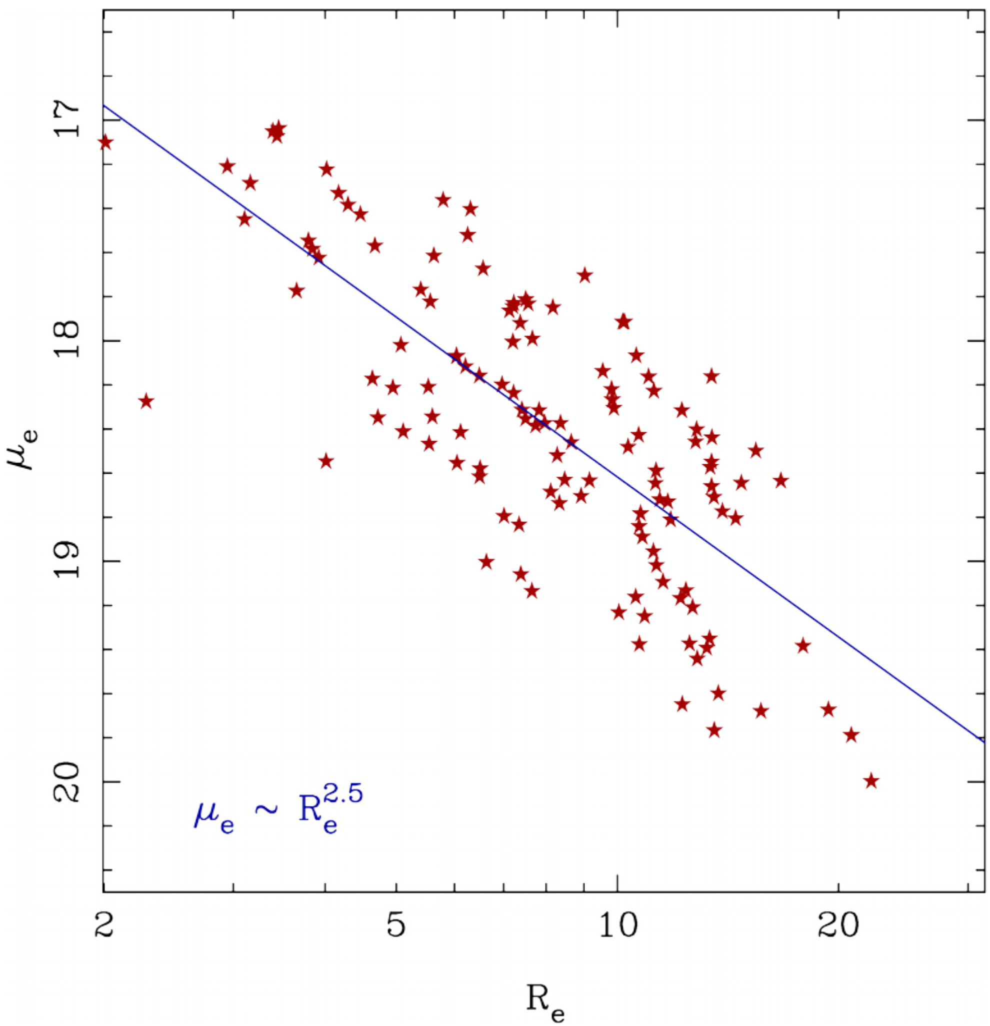
Does the group dominant galaxy follow the scaling laws that are observed in early type galaxies?

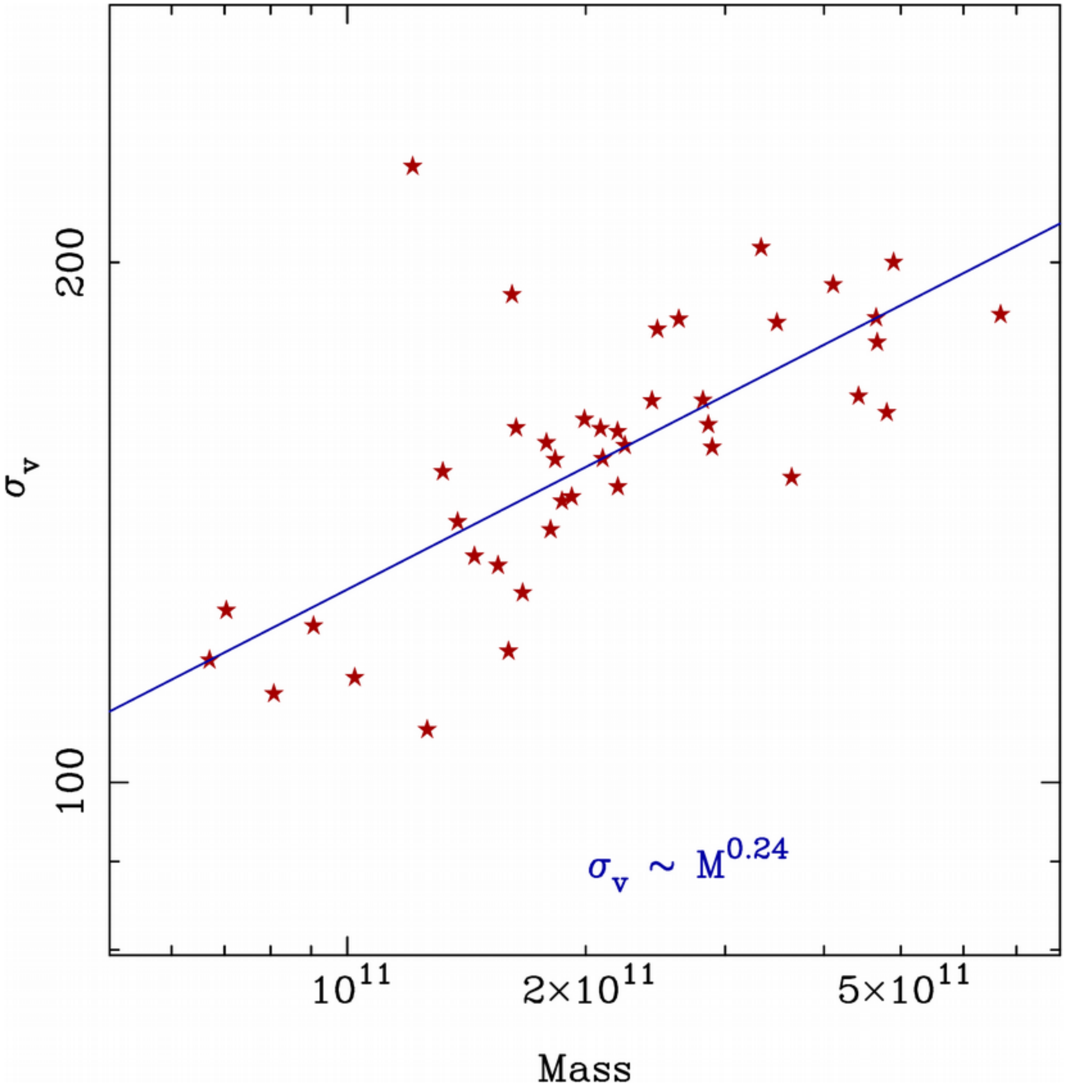
A good enough photometric band to compare is K, since this and is the one that better trace stellar mass. We are comparing with values observed at the present epoch.

BGG follow the Kormendy relation, although the slope is found to be lower than the one observed at K

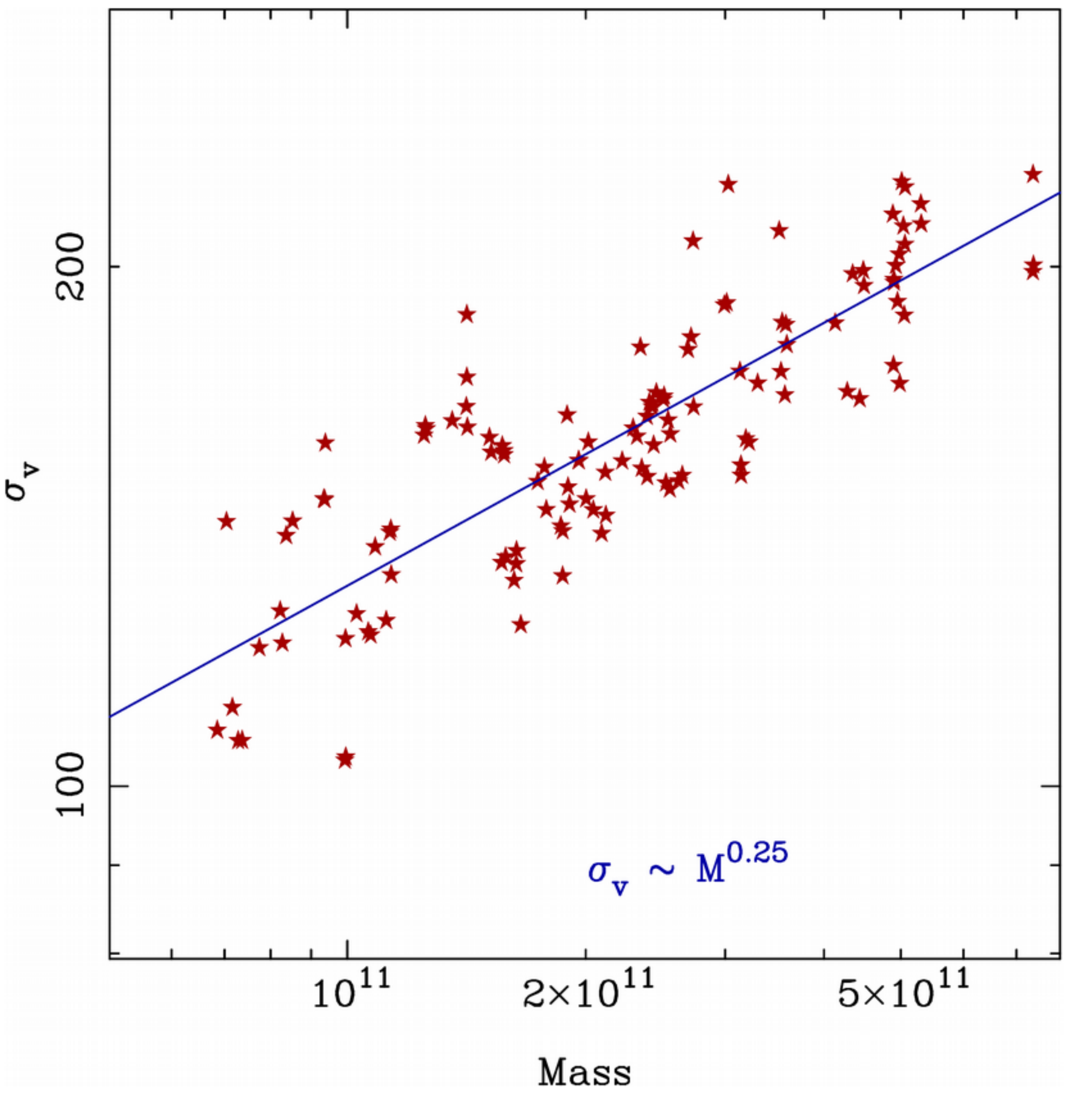
The same result is obtained if the three orthogonal projections are included in the relation



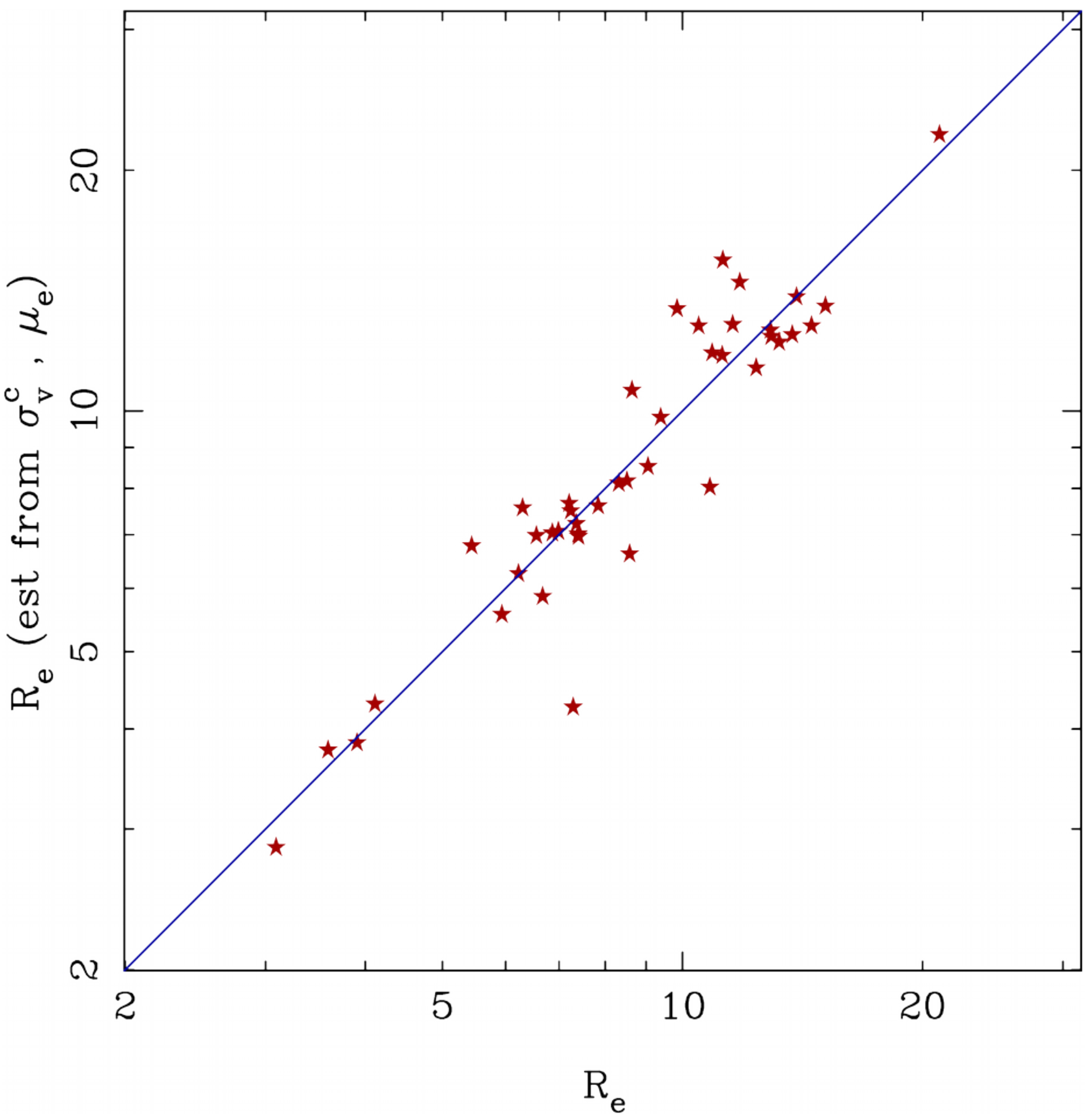




BGG follow the Faber-Jackson relation



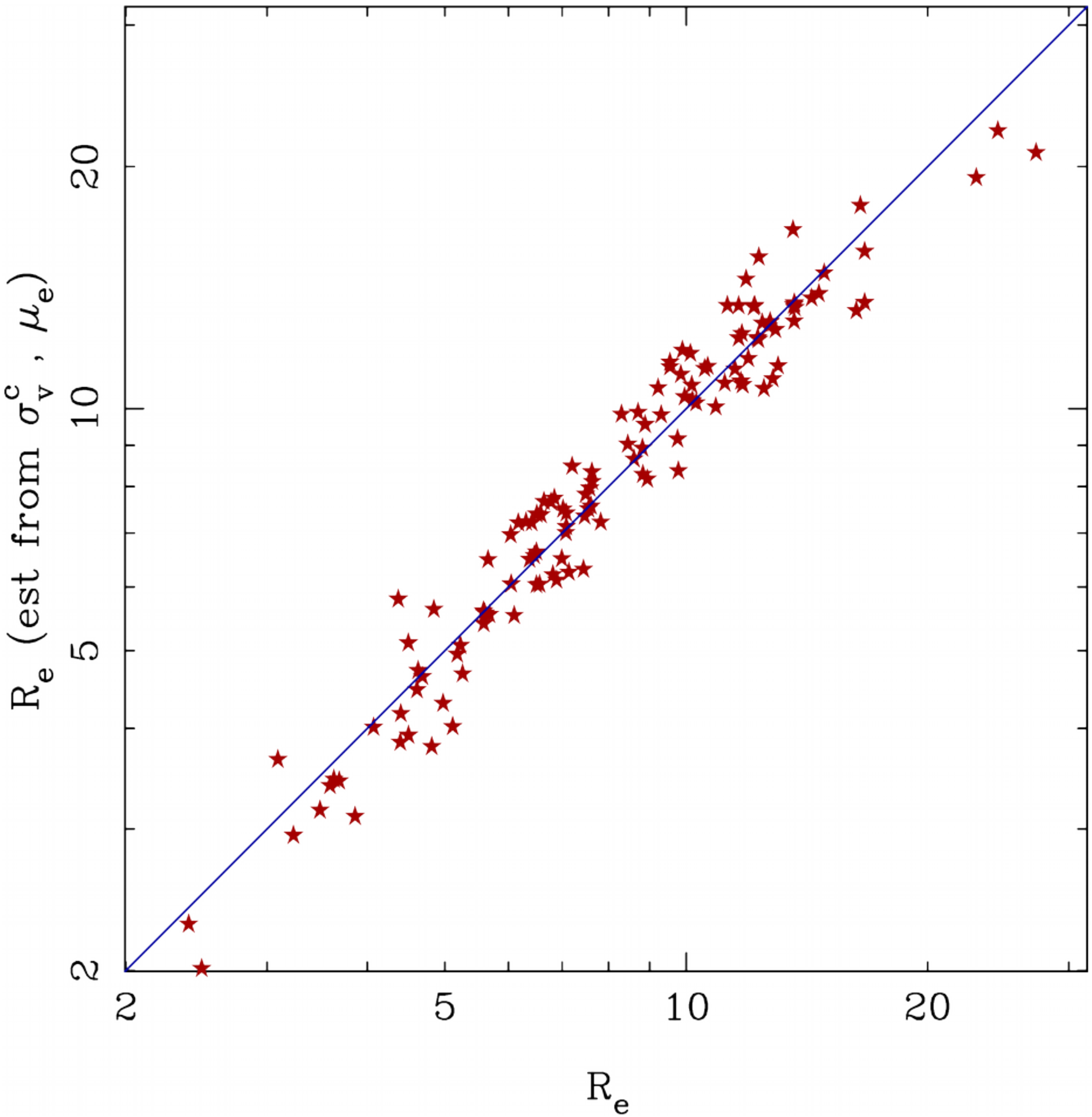
The same result is obtained if the three main projections are included



BGG also lie on the fundamental plane.

$R_e = -6.5 + (1.24\pm0.14)\sigma_v + (0.26\pm0.02)\mu_e$

Values for mass (or K if M/L(K)~1)

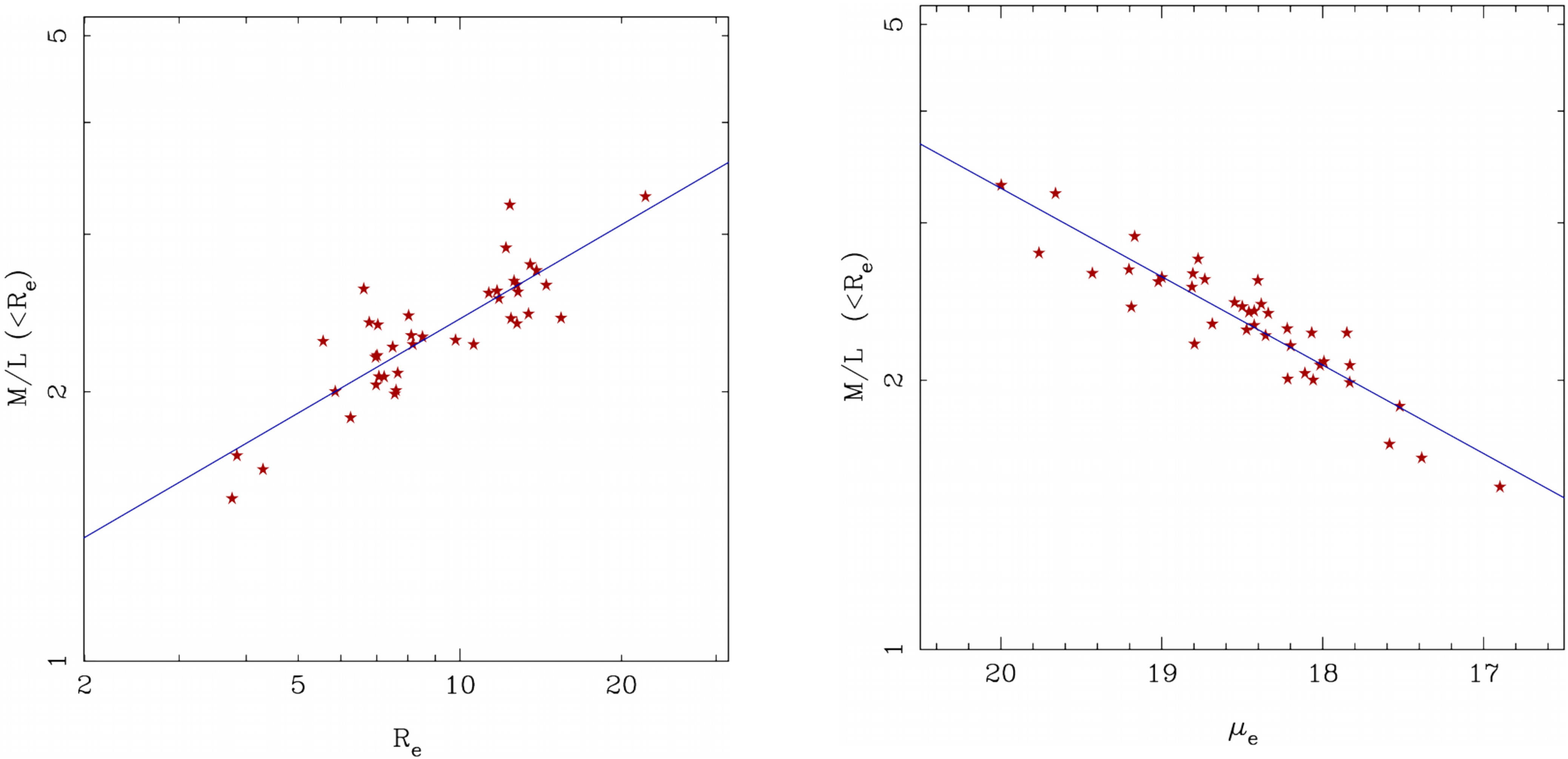


The result when using all projections agree, with smaller dispersion.

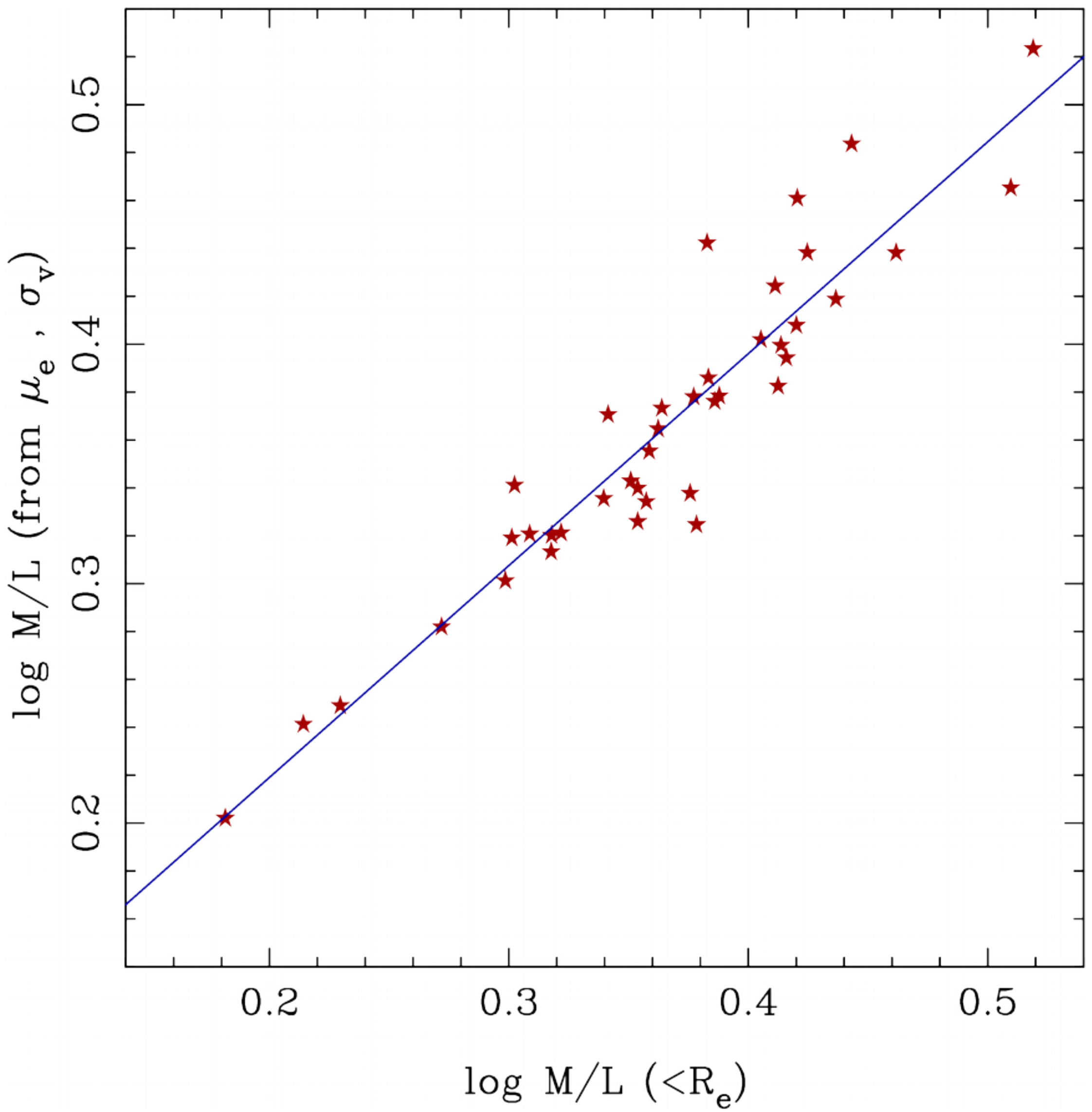
$$R_e = -7.4 + (1.52 \pm 0.05)\sigma_v + (0.27 \pm 0.01)\mu_e$$

Values for mass ($M^*/L^*(K) \sim 1$). Coefficients are very close to those by La Barbera et al (2010), at the K band (-7.48, 1.48, .0.3)

The fundamental plane and M/L



M/L does not correlate alone neither with σ_v nor the mass, but it does depends on R_e and even better on μ_e



It is thus possible to substitute R_e by M/L as one of the axis of the FP.

Conclusions

A set of simulations of merging in collapsing groups allow us to show that a BGG is produced as a result of multiple mergers.

- There exist a luminosity function evolution. More massive galaxies are produced as result of the merger of intermediate ones, thus depleting the intermediate mass of the LF and thus producing a dip that is observed in CG

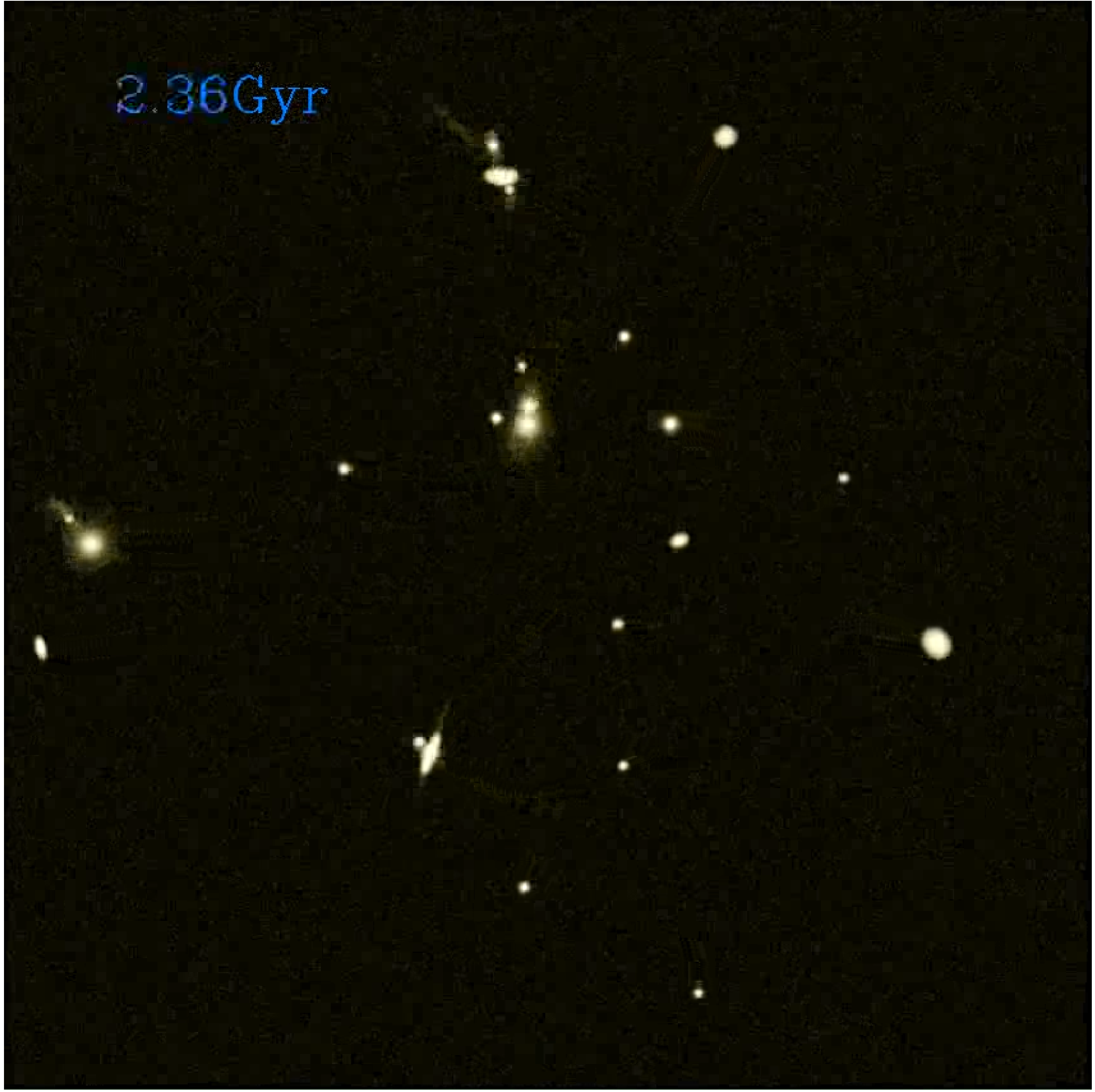
- A small fraction (less than 10%) of the visible material is detected as a diffuse component. The diffuse fraction increase with the visible mass

- The magnitude gap between the first and second ranked galaxies grows with the mass.

- BGG show elliptical galaxies properties. It is found that a Nuker-type profile is needed, since the Sersic profile is not able to fit the very centre.

- They resemble well the values obtained in the K band for the Faber-Jackson, Kormendy and Fundamental plane relations.

- Galaxy M/L also obeys a FP type relation; M/L is independent of the mass.



Evolution of visible mass. Halos first expands linearly, then they go through the turnaround, and finally experience a completely non-linear collapse.