The theoretical view of high-z Clusters

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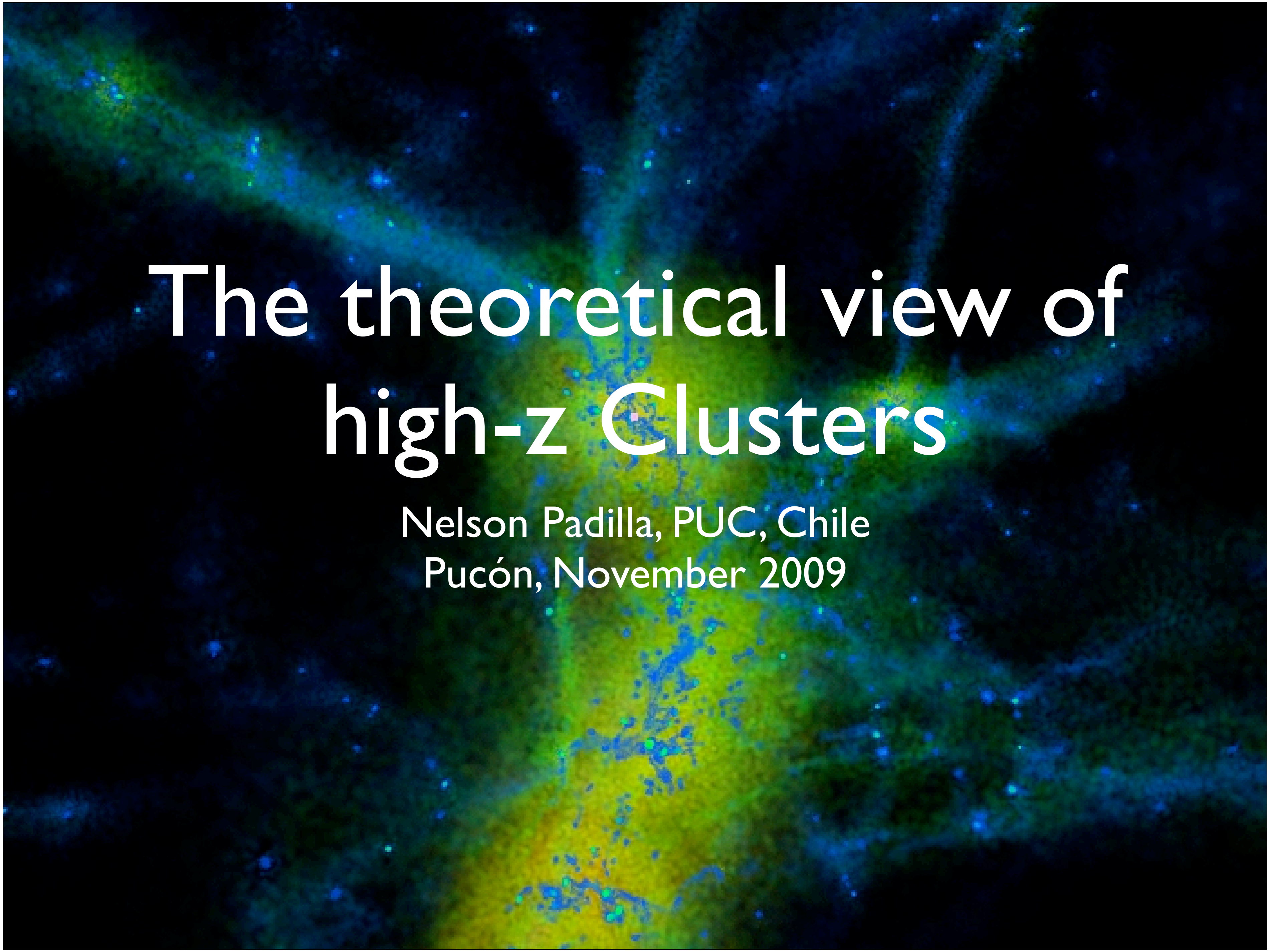
Pucón, November 2009



The Plan:

I) To see what the observations are telling us using models that agree with the cosmology, and with other observations at different redshifts (as many observations as possible).

II) Cosmological origin of clusters

How does the gas end up heated, cooled, reheated, in stars, in galaxies (how many, how extended), why are there stars outside galaxies, when did all this happen, etc.

This talk:

- Tools to study clusters from the theory side.
- Subject outline
  - Density peaks: when do Clusters form?
  - Physical processes in Clusters: baryon heating, cooling, ...
  - Galaxy formation

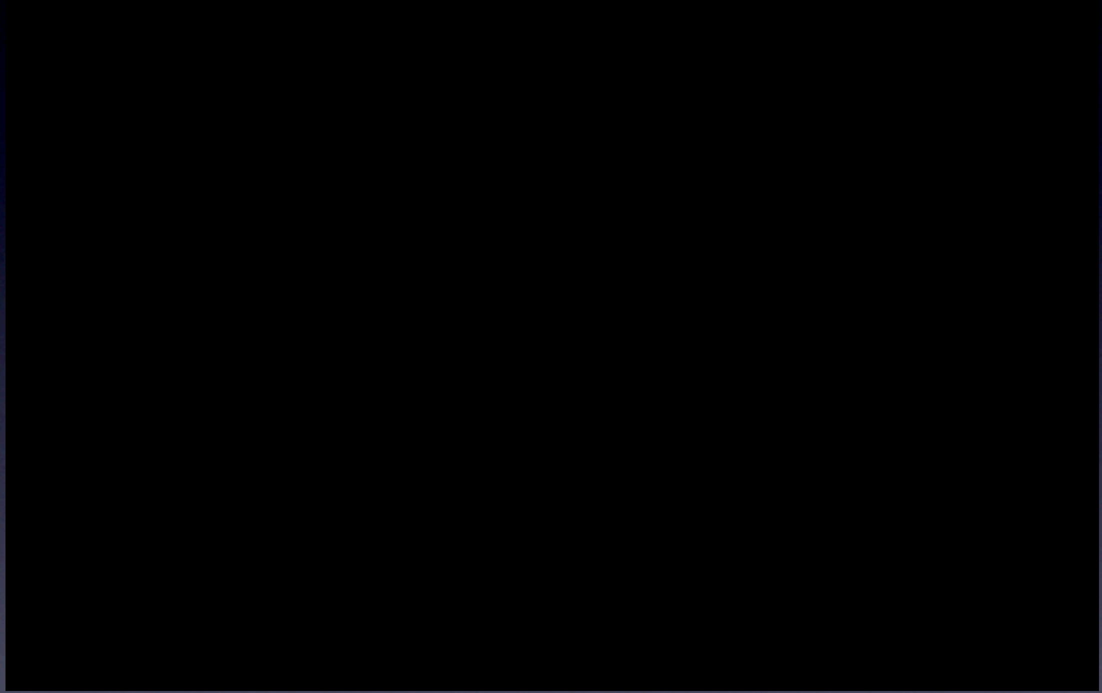
Cosmology with Clusters: see Gus Evrard´s Talk

Tool 1: Linear Theory + analytic approximations

Tool II: DM simulations

Density fields

- small initial fluctuations
- Growth via gravitational instability
- Downsizing

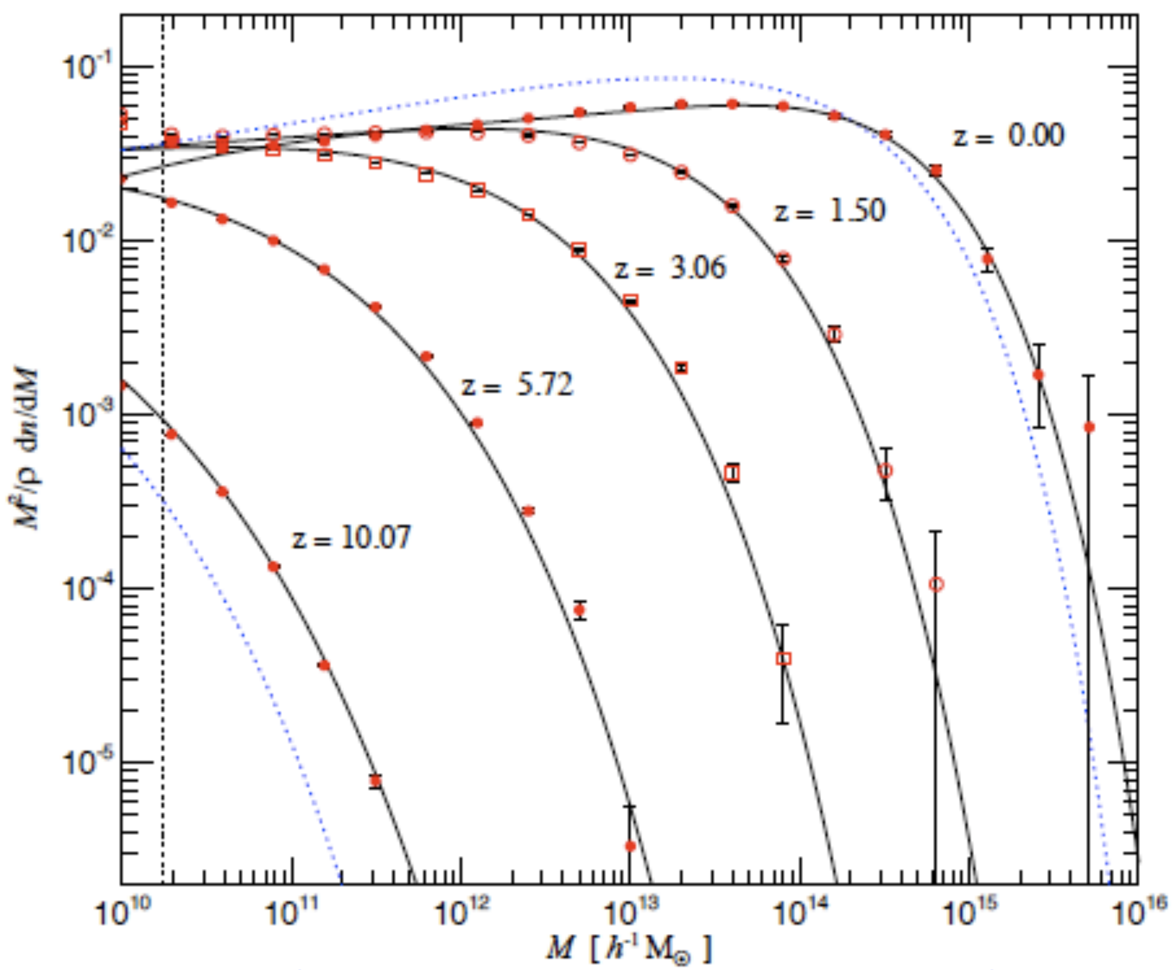


$$\begin{aligned}\delta_{\rm obs} \;=\; & b\,(\delta_m - 3\,\delta z) + A + 2D + (v^\alpha - B^\alpha)e_\alpha + E_{\alpha\beta}e^\alpha e^\beta \\ & - (1+z)\frac{\partial}{\partial z}\,\delta z - 2\,\frac{1+z}{H\,r}\,\delta z - \delta z - 5p\,\delta \mathcal{D}_L - 2\,\kappa \\ & + \frac{1+z}{H}\frac{dH}{dz}\,\delta z + 2\,\frac{\delta r}{r}\,, \qquad (36)\end{aligned}$$

Yoo, Fitzpatrick & Zaldarriaga (2009)

Mass Infall

Springel et al. (2005)



Solid: Jenkins et al. Dotted: PS

- Press Schechter

Bond 1991 Excursion set approach

Mass Infall

- Non spherical collapse by Sheth, Mo & Tormen

Main problem: three axes collapse at different epochs, so which is the appropriate δ_c?

Linear theory for ellipsoids predicts dependence on ellipticity, prolacity and even δ_c

Best option for this behaviour:

$$\frac{\delta_{ec}(e,p)}{\delta_{sc}} = 1 + \beta \left[5\,(e^2 \pm p^2)\, \frac{\delta_{ec}^2(e,p)}{\delta_{sc}^2} \right]^{\gamma}$$

with β=0.47, γ=0,615 and δ_{sc}=1.7 (sph. collapse)

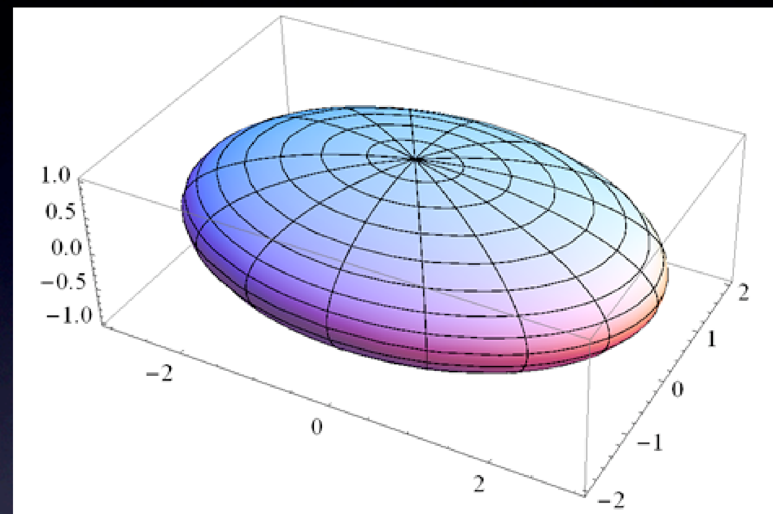
Typical values for gaussian field,

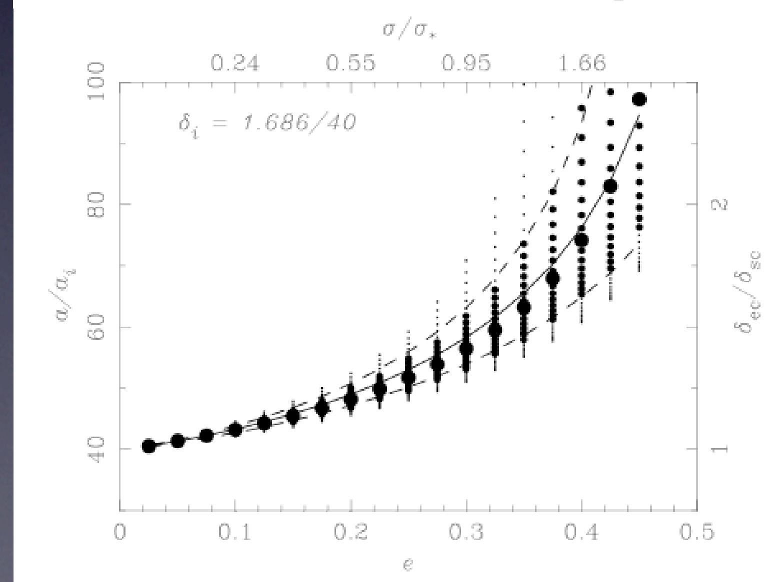
p=0

e=$(\sigma/\delta)/5^{1/2}$

so that,

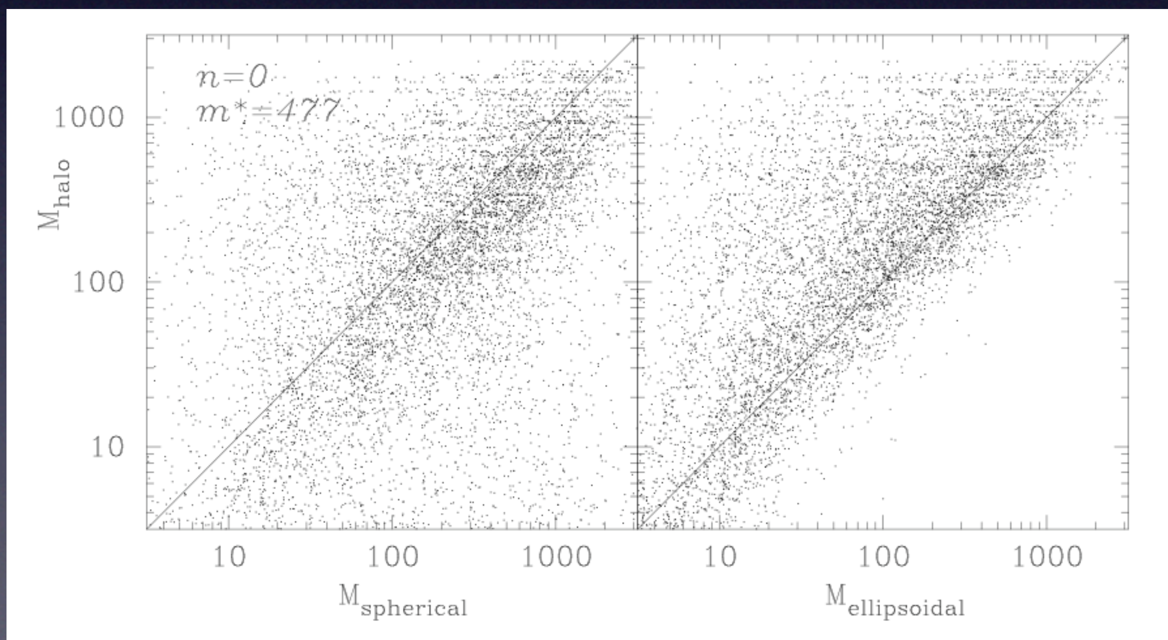
$$\delta_{ec}(\sigma,z) = \delta_{sc}(z) \left(1 + \beta \left[\frac{\sigma^2}{\sigma_*^2(z)} \right]^{\gamma} \right)$$





Mass Infall

- Non spherical collapse by Sheth, Mo & Tormen



Applied to Clusters

Mass function constraints on the Cosmology

- Eke, Cole & Frenk (1996) $\sigma_8 = (0.50 \pm 0.04)\Omega_0^{-0.53+0.13\Omega_0}$ for $\Omega_0 + \Lambda_0 = 1.$
- Sánchez, Padilla & Lambas (1998)

$$\sigma^2(R) = \Delta^2(k_{eff})$$

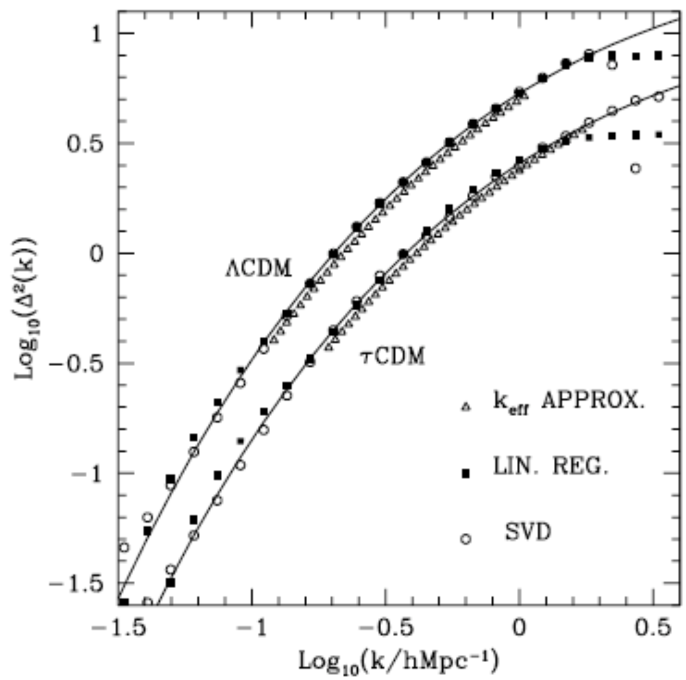
$$k_{eff} = \frac{1}{R}\left[9I(n)\right]^{\frac{1}{n}}$$

$$I(n) = \int_0^\infty y^{n-7}\left[\sin(y) - y\cos(y)\right]^2 \mathrm{d}y$$

$$\sigma(M) = \frac{\delta_c}{\sqrt{2}\Phi^{-1}\left[\Phi(\frac{\delta_c}{\sqrt{2}\sigma_8}) - \frac{G(M)}{\rho A}\right]}$$

$$G(M) \equiv \int_M^{M_8} \grave{M} n(\grave{M})\mathrm{d}\grave{M}$$

$$\Phi(x) = \mathrm{erf}(x) + \frac{2^{-p}}{\sqrt{\pi}}\Gamma\left(\frac{1}{2} - p\right) P\left(\frac{1}{2} - p, x^2\right)$$



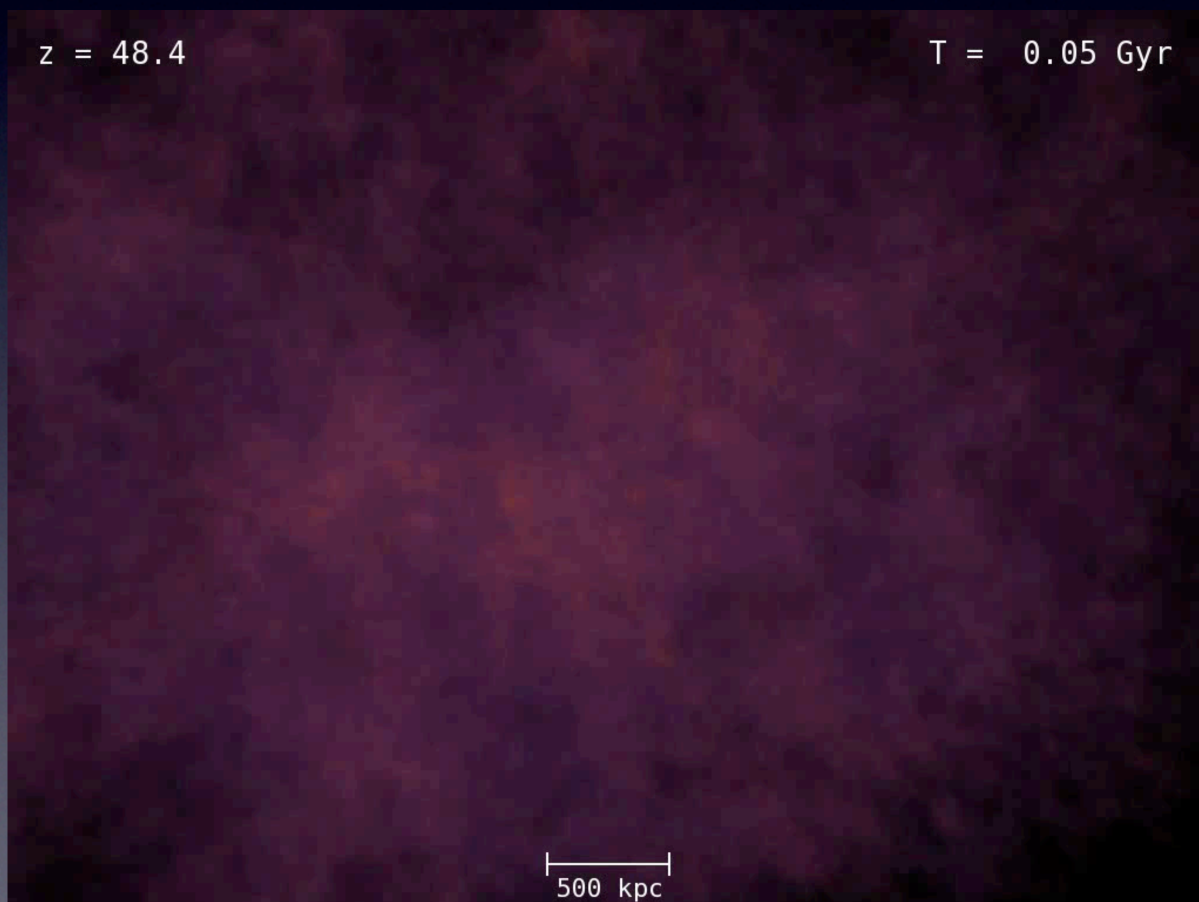
Mass infall

- Extended Press Schechter

$$\mathrm{d}N = \frac{1}{\sqrt{2\pi}} \frac{\Delta\omega}{(\Delta\sigma^2)^{3/2}} \exp\left[-\frac{(\Delta\omega)^2}{2\Delta\sigma^2}\right] \left|\frac{\mathrm{d}\sigma^2}{\mathrm{d}M}\right| \frac{M_0}{M}\,\mathrm{d}M$$

$$\omega = \delta_c / D(t) \quad \Delta\omega = \omega - \omega_0 \quad \Delta\sigma^2 = \sigma^2(M) - \sigma^2(M_0)$$

Bower et al. (1991), Lacey & Cole (1993)



Acquarius project

Mass infall

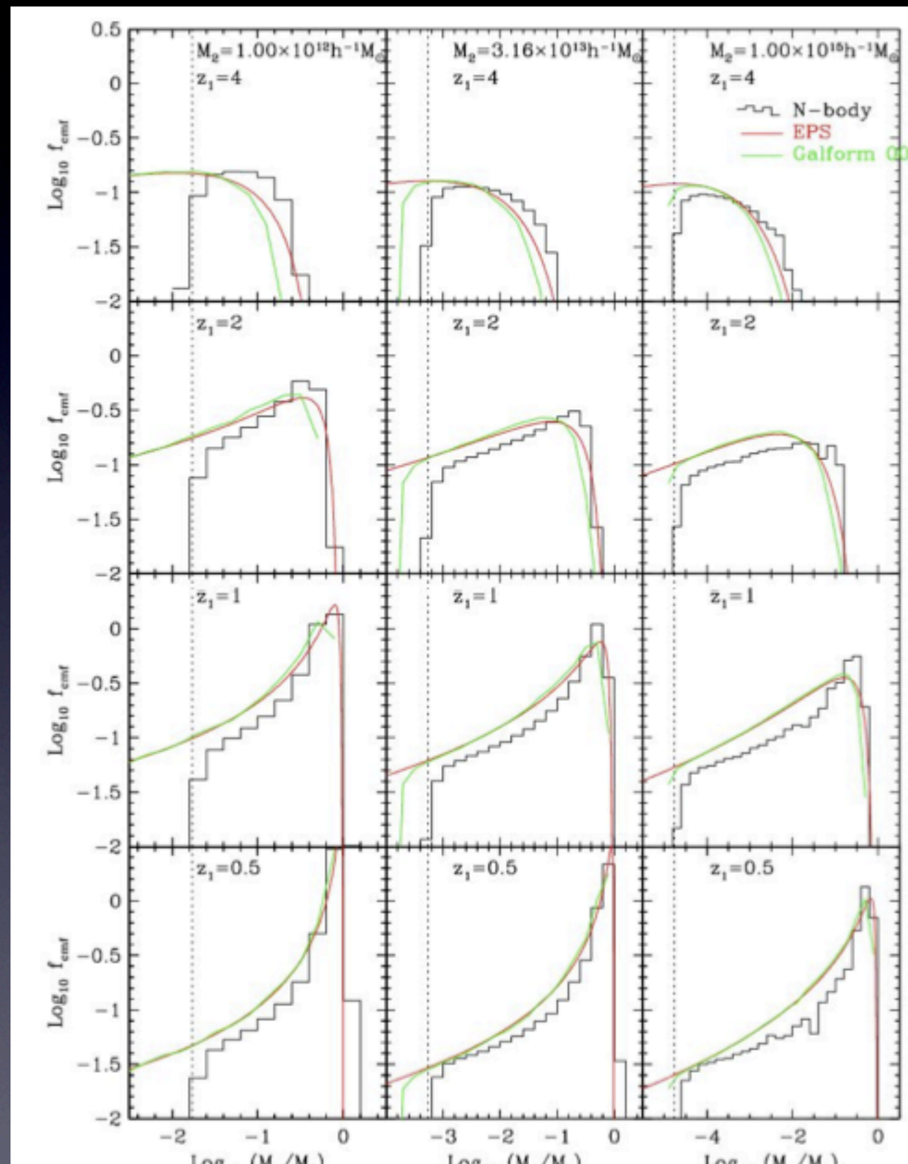
- Extended Press Schechter

$$\frac{dN}{dM_1} \rightarrow \frac{dN}{dM_1} G(\sigma_1/\sigma_2, \delta_2/\sigma_2)$$

$$G(\sigma_1/\sigma_2, \delta_2/\sigma_2) = G_0 \left(\frac{\sigma_1}{\sigma_2}\right)^{\gamma_1} \left(\frac{\delta_2}{\sigma_2}\right)^{\gamma_2}$$

$$G_0 = 0.61, \gamma_1 = 0.27, \gamma_2 = 0.0$$

Mass distributions of the largest and second largest progenitors



Parkinson, Cole & Helly (2007)

Applied to Clusters

Extended PS and the formation of the first haloes

- Angulo & White (2009)

DM particle: neutralino

Fluctuations that survive: 0.7pc or $10^{-8} M_{sun}$ and up

Affected haloes: much higher masses (do they accrete clumps or difuse matter?)

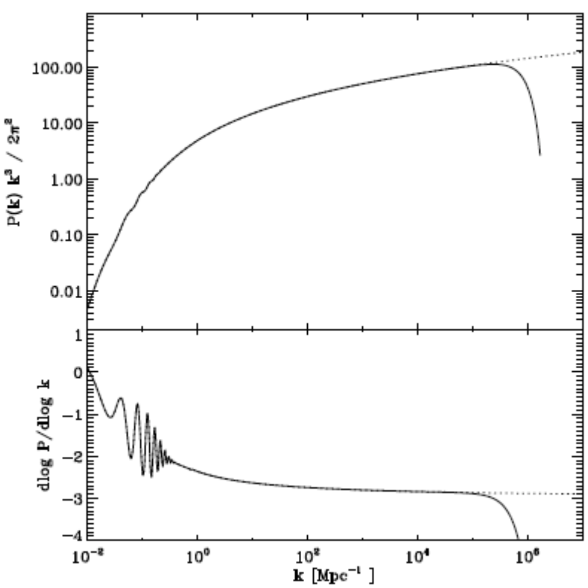
DM simulations? only in 2050. So, extended PS.

Applied to Clusters

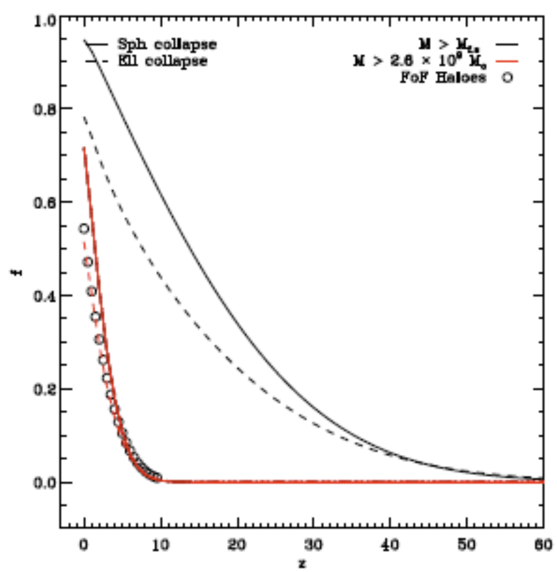
Extended PS and the formation of the first haloes

- Angulo & White (2009)

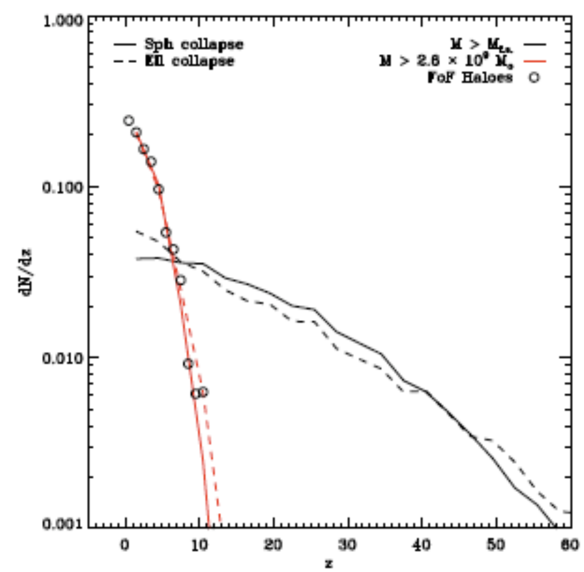
Effect on P(k)



Mass in coll. objects



Redshift of accretion



Applied to Clusters

Extended PS and the formation of the first haloes

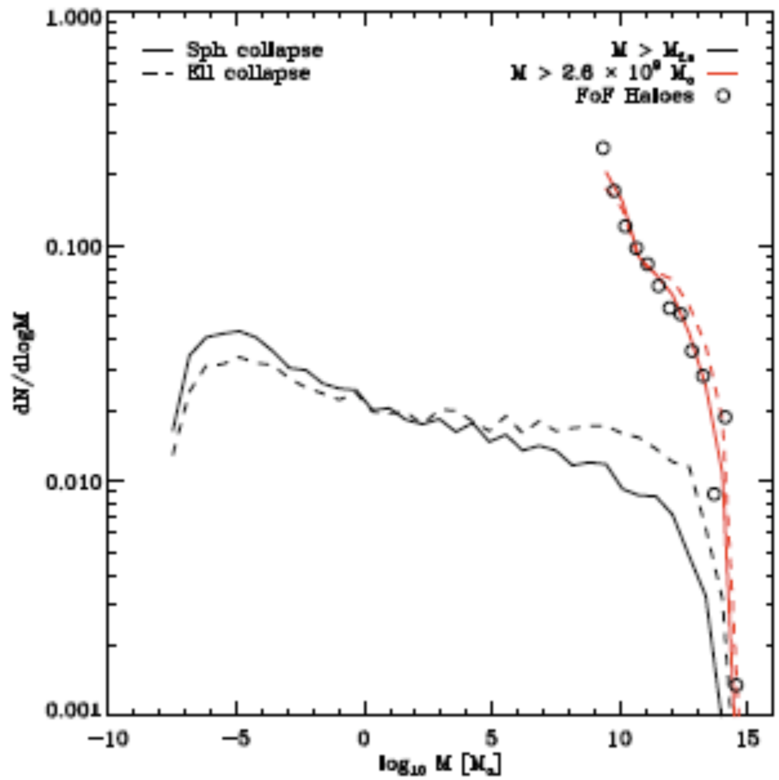
- Angulo & White (2009)

Mass of the first collapsed object:

5-7 orders of mag. larger than M_{fs}

Almost flat distribution

Likely tidal disruption of M_{fs} clusters at infall.



Applied to Clusters

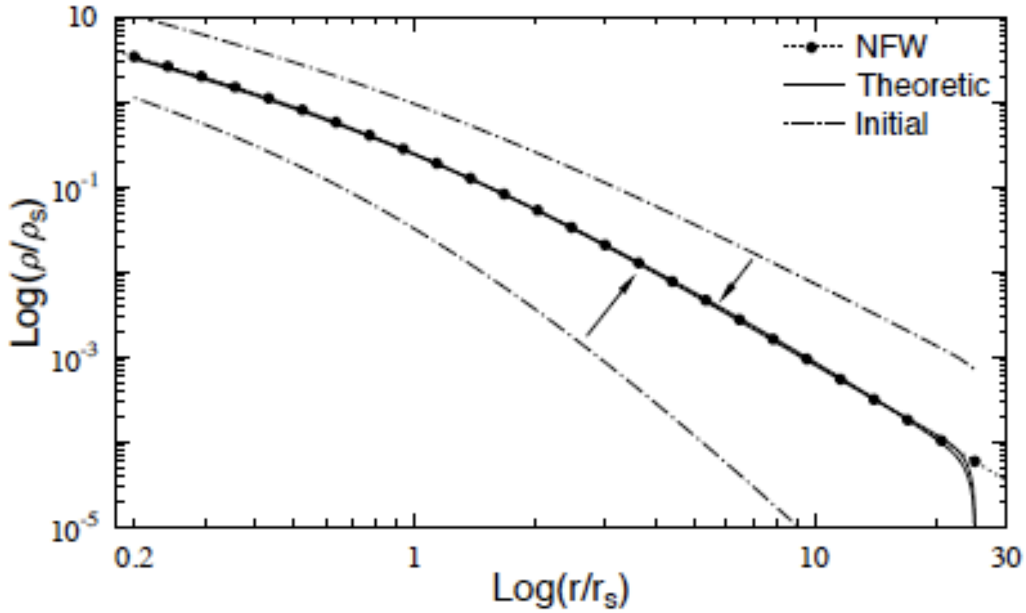
Density profiles

- Ping He, 2009

Produces a NFW profile using:

Isolated halo:
I) Energy Conservation
II) Mass Conservation
III) Virialization

And the principle of maximum entropy



NFW profile, with discussion on the internal slope, 0 to -2, with influence from baryons (including SMBH?)

Applied to Clusters

Clustering of clusters

- Li, Mo & Gao, 2008 (and many other works)

Simple models where the clustering depends only on mass need to be adapted to this phenomenology.

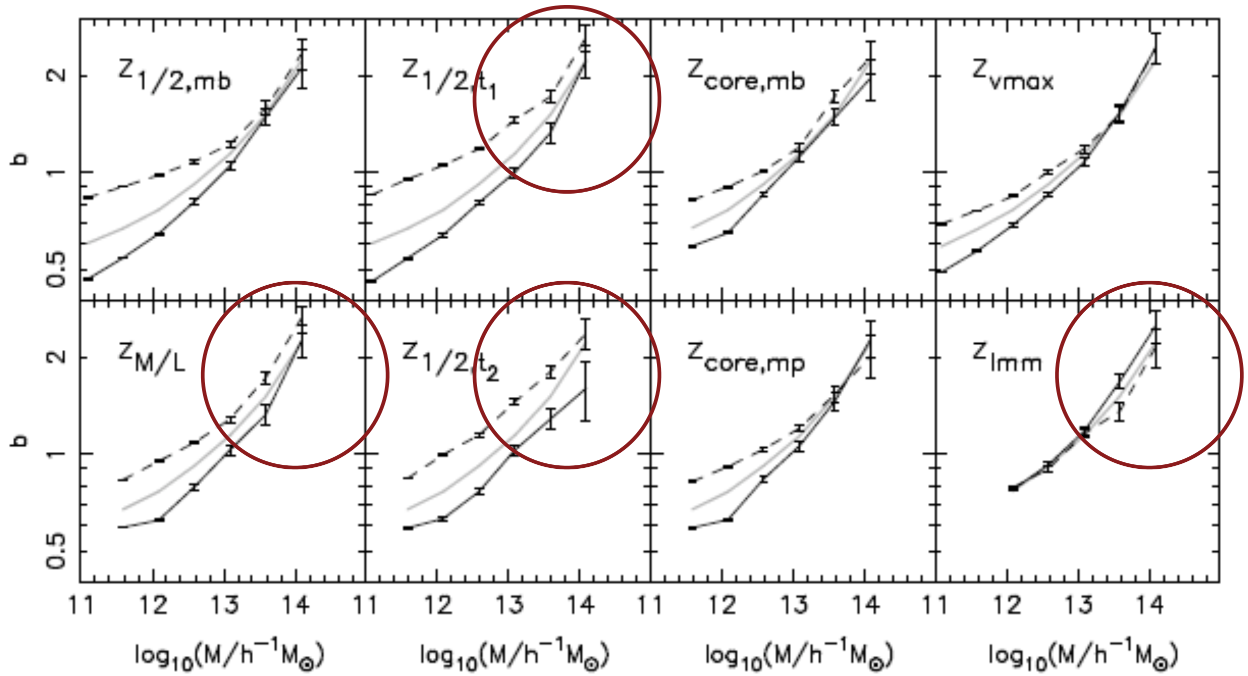


Figure 4. Age dependence of halo bias. Formation time used is indicated in each panel. Dashed lines are for oldest 20% halos while solid lines are for youngest 20% halos; the thick gray lines represent the bias of all the halos regardless of their ages. Error barshows the Poisson error.

There is a definite need for numerical simulations to ensure merger trees respond to the assembly bias.

Tool III:
SAMs and Hydro

(with stellar population synthesis models)

Mass Infall

- Ceccarelli et al 2010 (Infalls via filaments)
- Pivato, Padilla & Lambas (2006)
- Filaments in cosmological numerical simulations (Colberg et al., 2005, Gonzalez & Padilla 2010)

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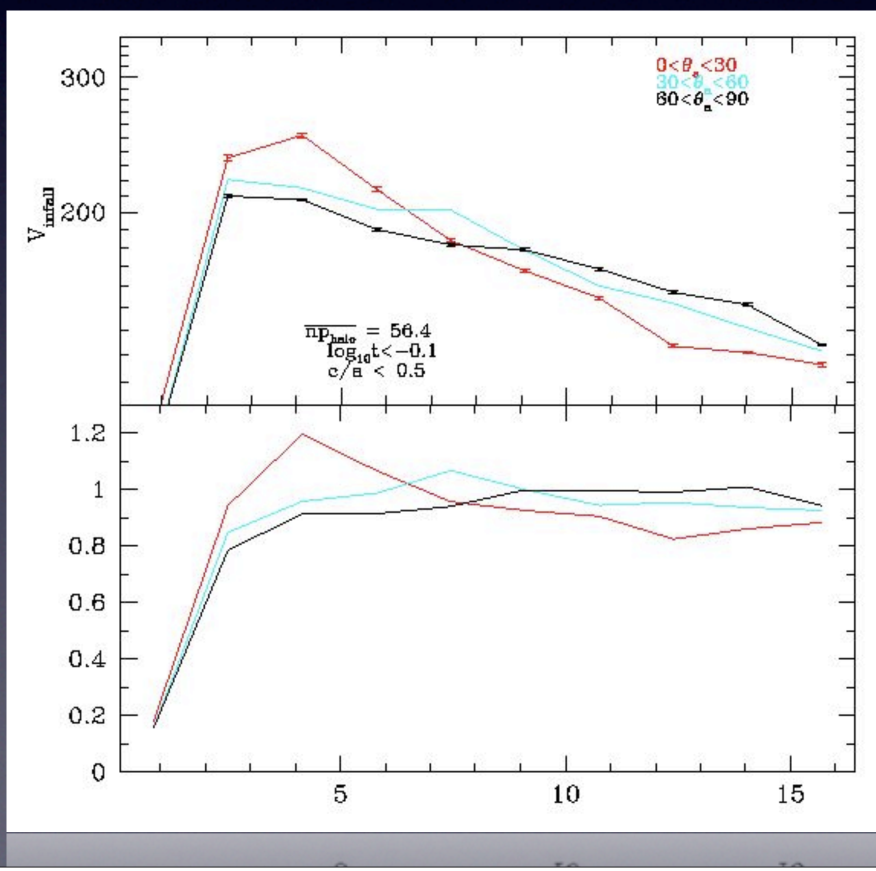
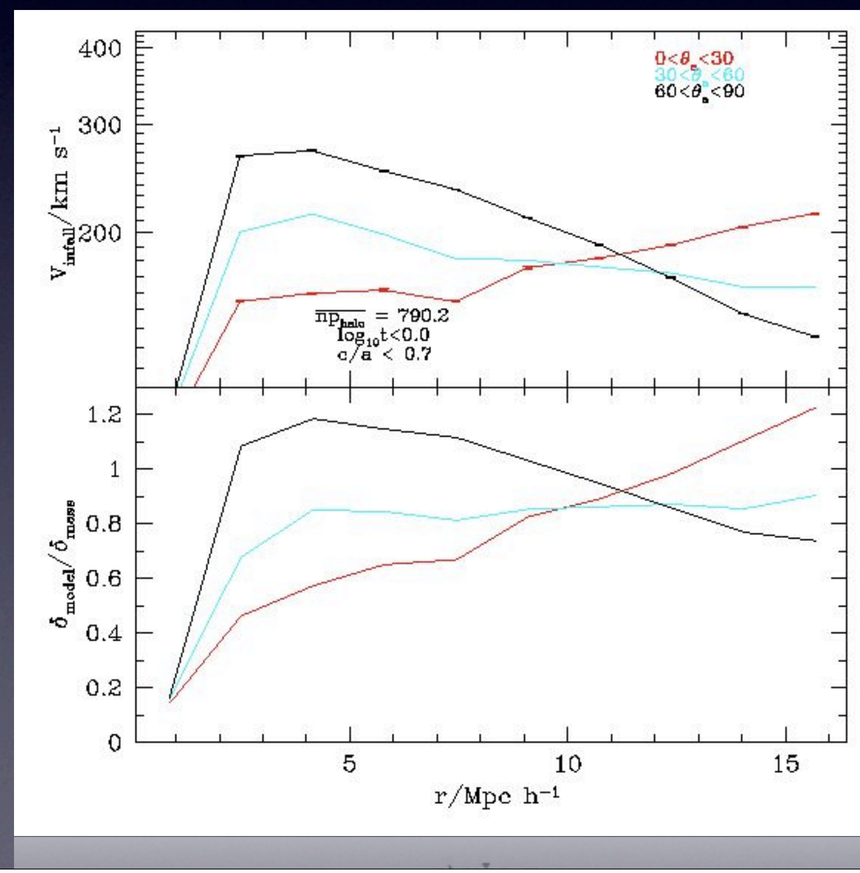


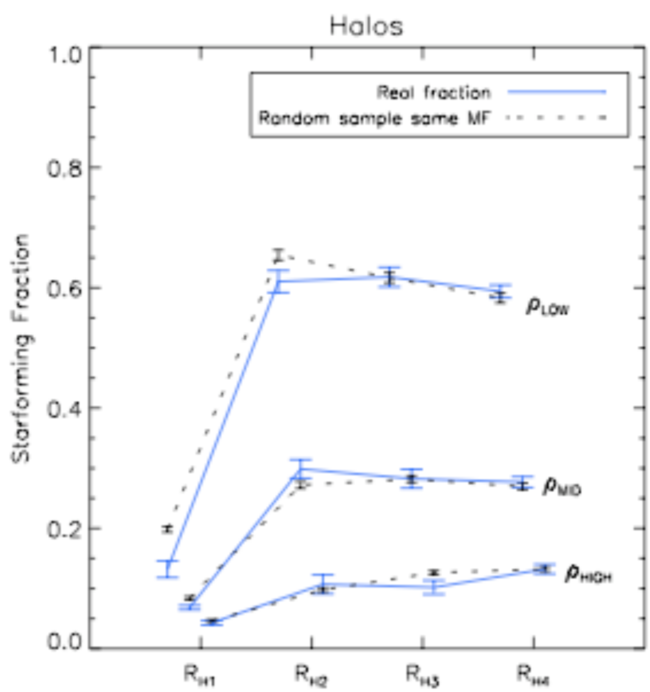


Applied to Clusters

The material arrives pre-processed?

Louise Edwards talk, McGee et al. (2009), Porter et al. (2008), Wilman et al. (2008)

Galaxies evolve within groups before they fall onto Clusters of galaxies.



González & Padilla (2009)

Similar results in Lagos, Cora & Padilla (2008) SAM

Mass Infall

- Filaments in cosmological numerical simulations

Colberg et al. (2005)

visual inspection

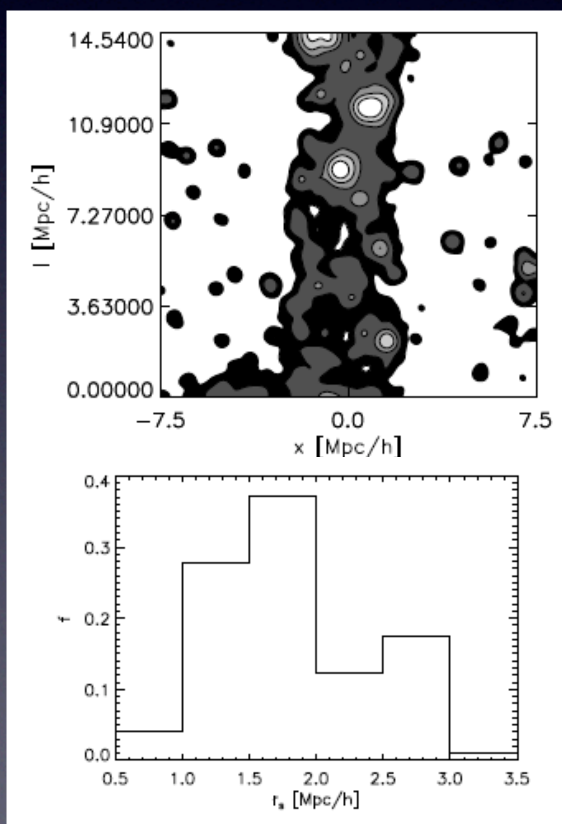
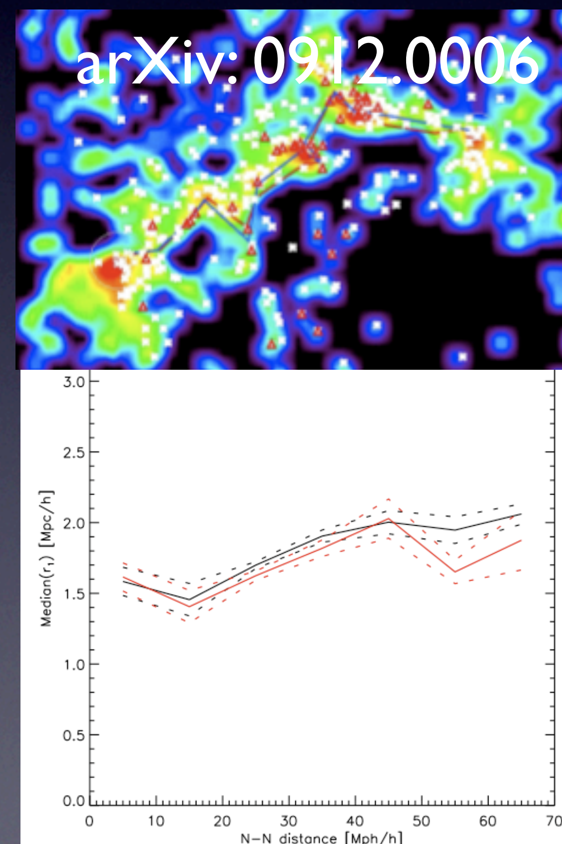


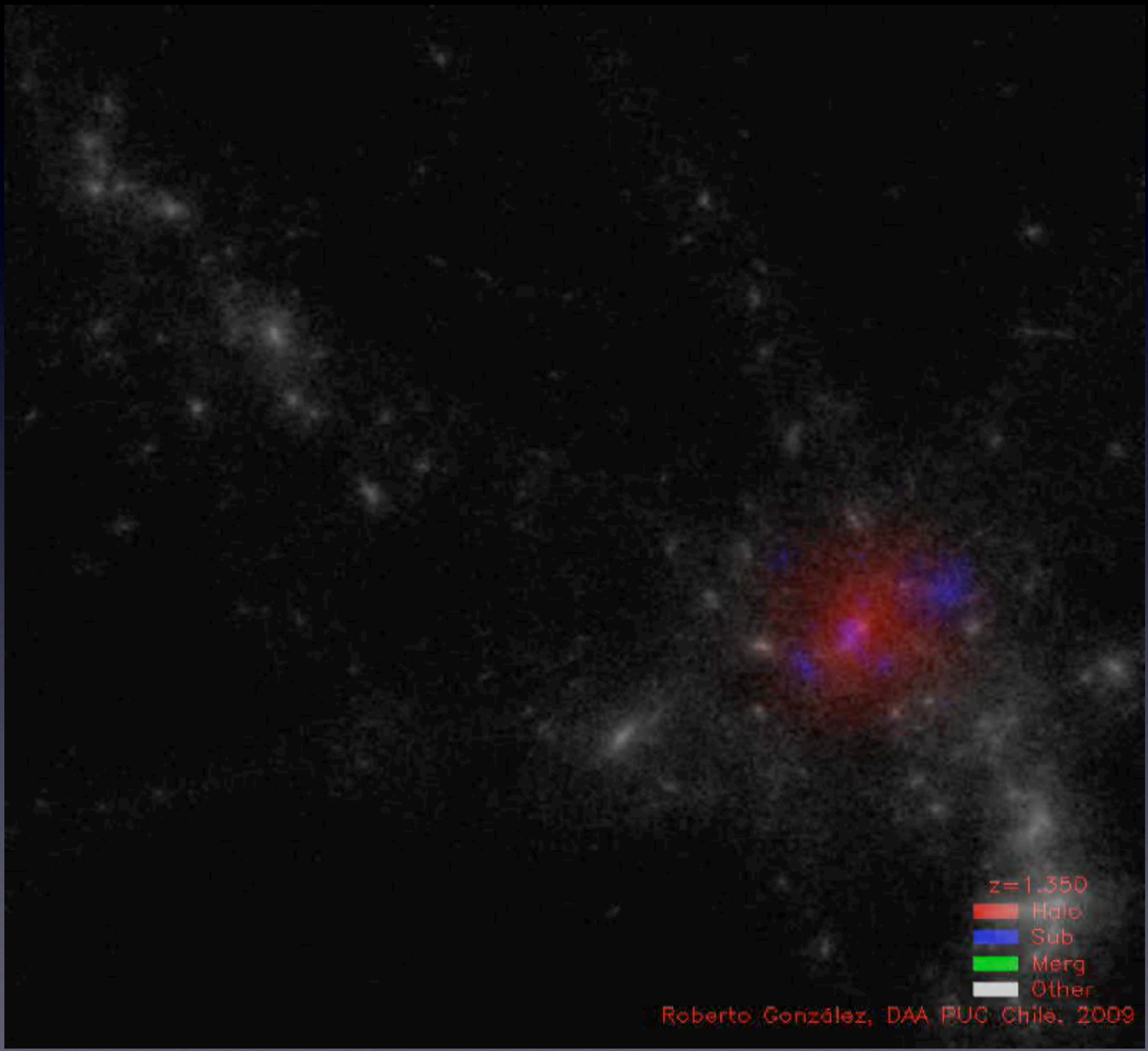
Figure 9. Distribution of scale radii r_s of straight filaments.

González & Padilla (2010)



Automatic algorithm

Sub-halo (galaxy) mergers



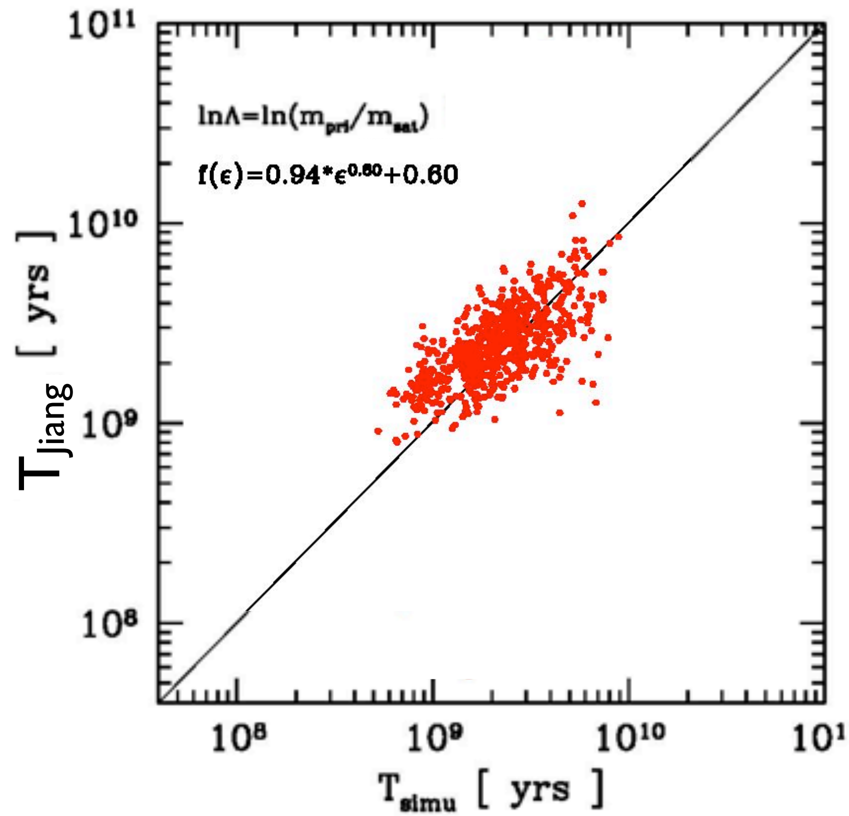
Sub-halo (galaxy) mergers

Galaxy orbits decay due to dynamical friction

- Lacey & Cole (1993)
  - Analytic
  - Point mass galaxies
  - Orbit averaged quantities

$$t_{DF} = 0.5 f(\varepsilon) V_C r_c^2 / CGm \ln(\Lambda)$$

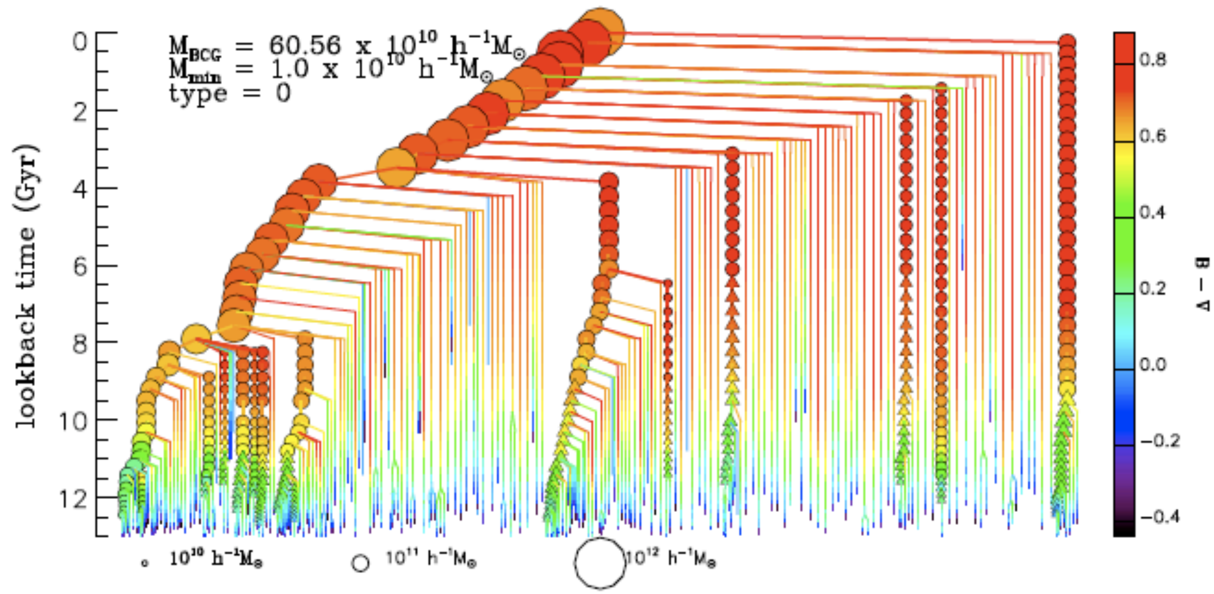
- Jiang et al 2007 (see also Boylan-Kolchin et al 2007)

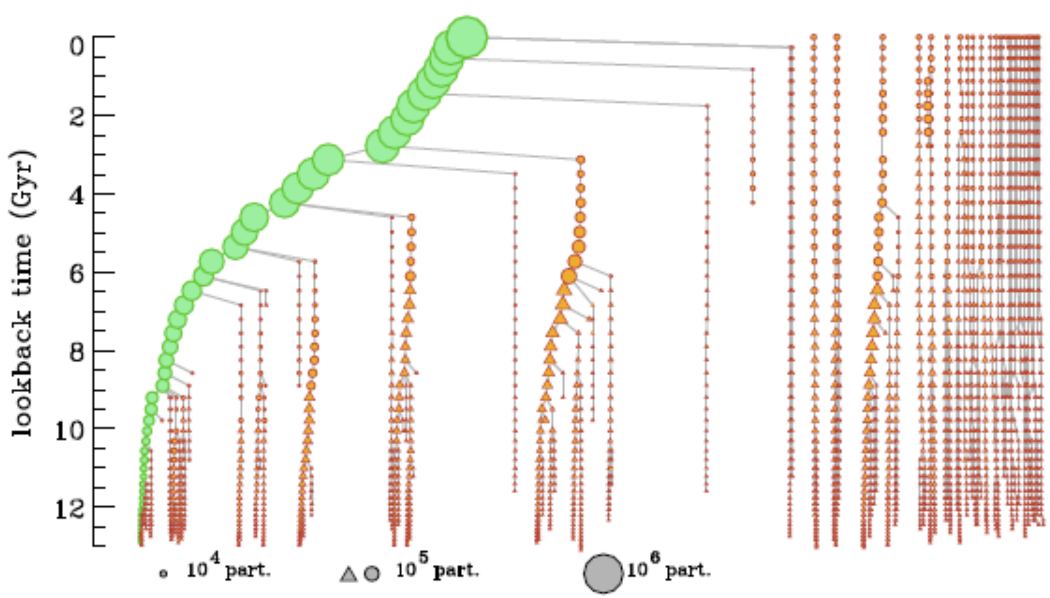


$$T_{\rm fit} = \frac{0.94\epsilon^{0.60} + 0.60}{2C} \frac{m_{\rm pri}}{m_{\rm sat}} \frac{1}{\ln[1 + (\frac{m_{\rm pri}}{m_{\rm sat}})]} \frac{r_{\rm vir}}{V_{\rm c}} \ .$$

Formation of BCGs (De Lucia et al 2006)

Applied to Clusters





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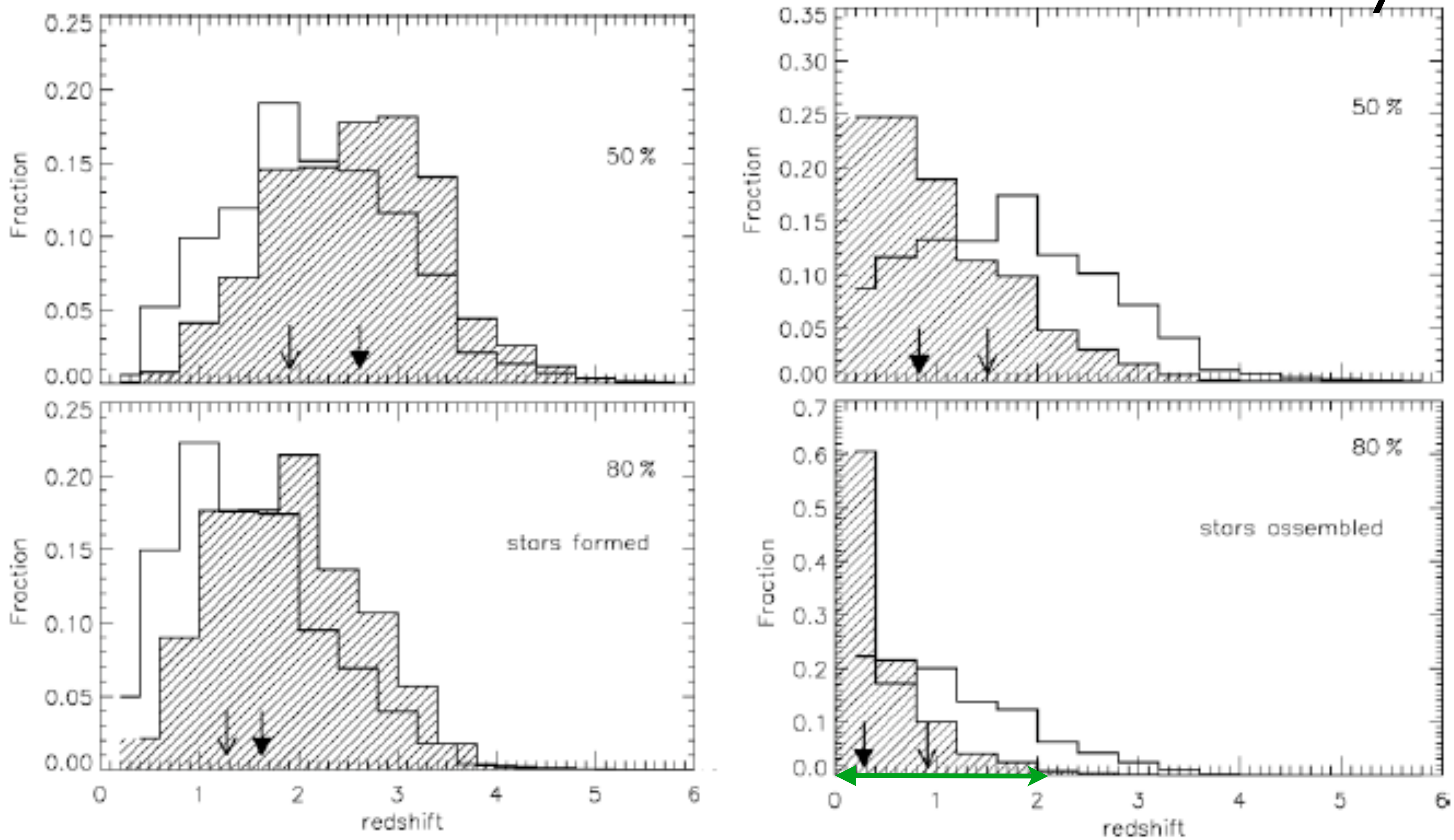
Applied to Clusters

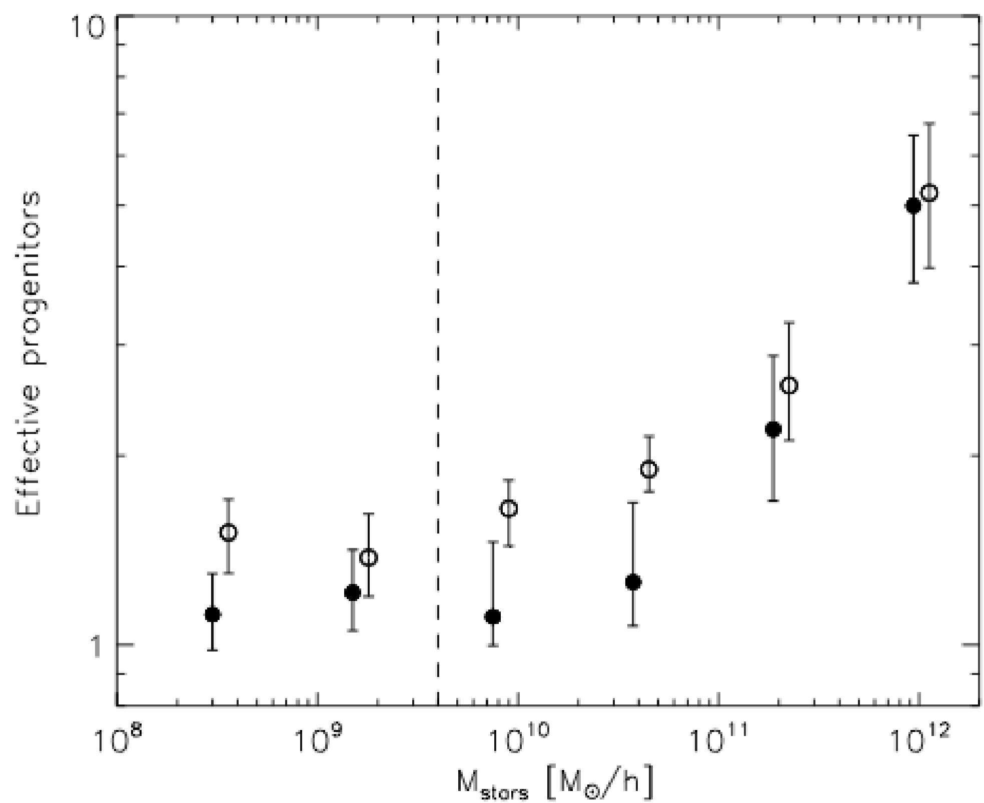


if we have the wrong dynamical friction timescales

Applied to Clusters

Mergers of subhaloes: how many individual mergers in BCGs?

Formation of BCGs
(De Lucia et al 2006)



Applied to Clusters

Mergers of subhaloes: how many individual peaks in clusters?

- Halo model approaches
- Extent of sub-peaks in clusters: QbC

Talk by Sebastián López

Poster by Heather Andrews

Baryonic Mass Infall

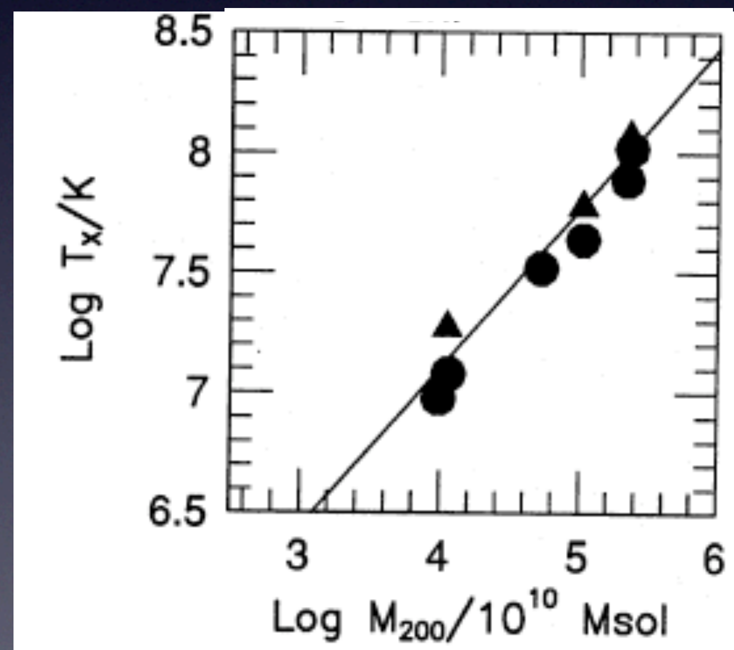
- Gas in DM haloes is heated to T_{vir}
- Gas Cooling from Hot Gas reservoir (Rees & Ostriker, 1977, White & Rees, 1978)
- Cool gas via filaments (Binney 1977, Dekel & Birnboim, 2003, Katz et al., 2003)

Baryonic Mass Infall

- Gas in DM haloes is heated to T_{vir}

$$kT_X = (1.38\ \text{keV})\beta^{-1} \times \left(\frac{M_{\rm vir}}{10^{15}\ h^{-1}\ M_\odot}\right)^{2/3} \left[\frac{\Omega_0}{\Omega(z)}\right]^{1/3} \Delta_{\rm vir}^{1/3}(1+z),$$

Eke et al. (1996)
Voit & Donahue (1998)



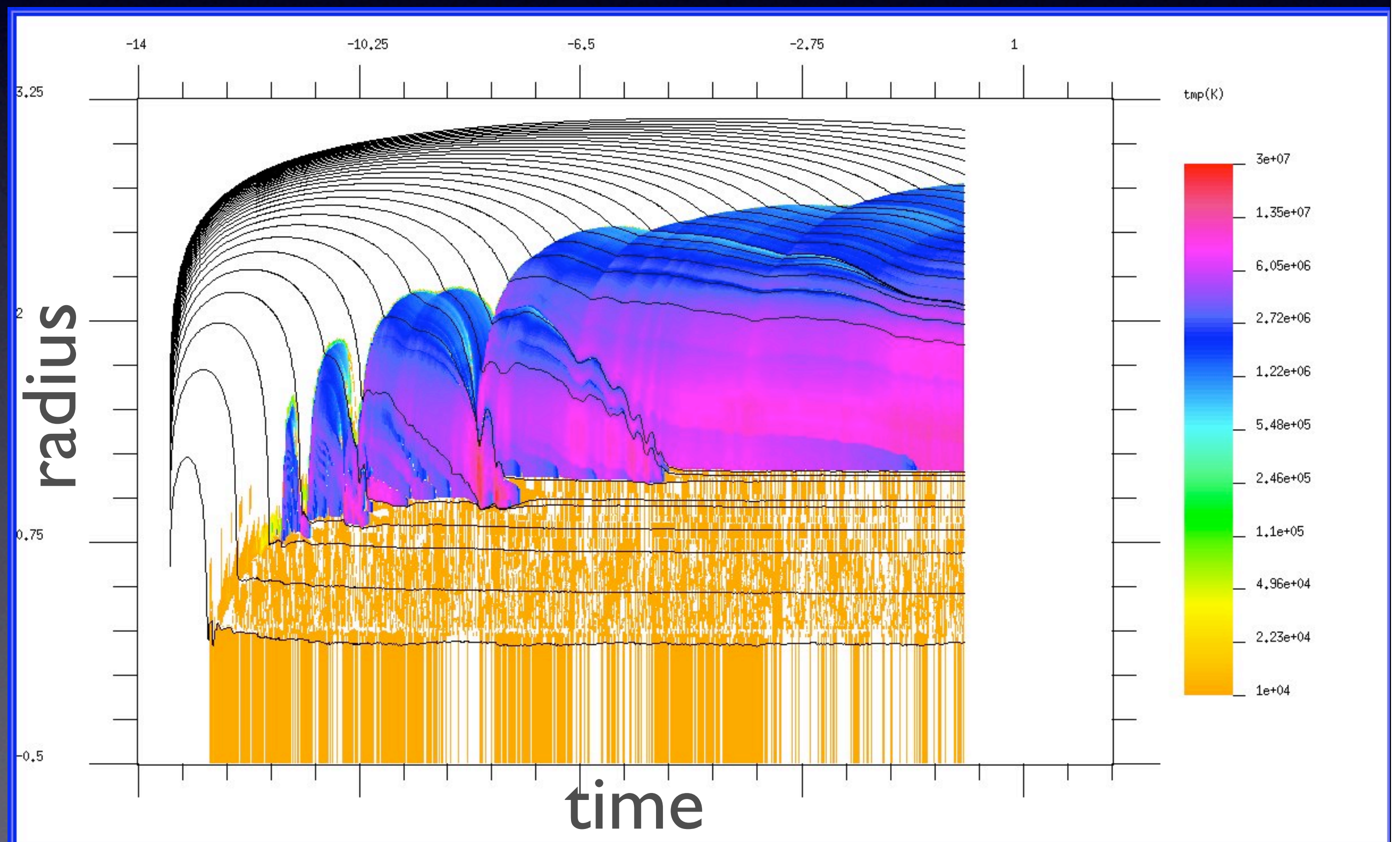
Navarro, Frenk & White, 1995

Baryonic mass infall halting mechanisms

Gas cooling from hot reservoir

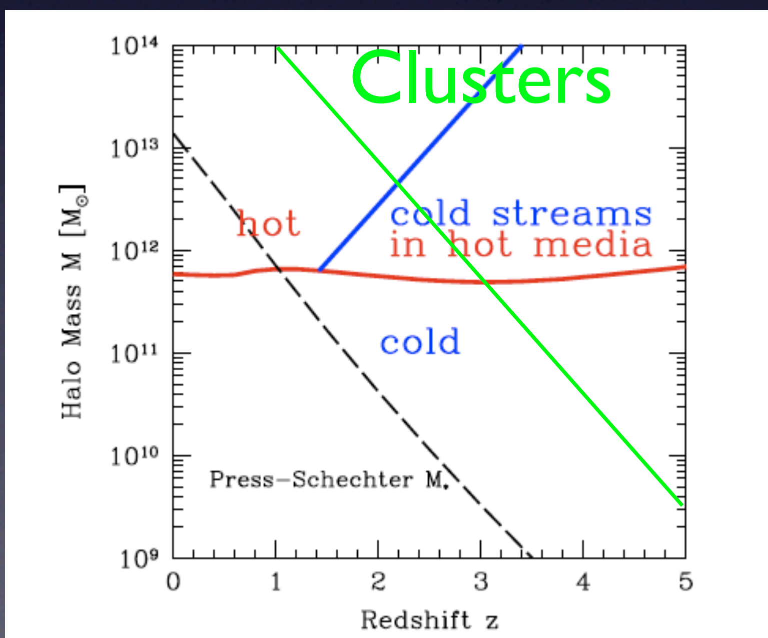
Lagrangian simulations by Birnboim & Dekel (2004)

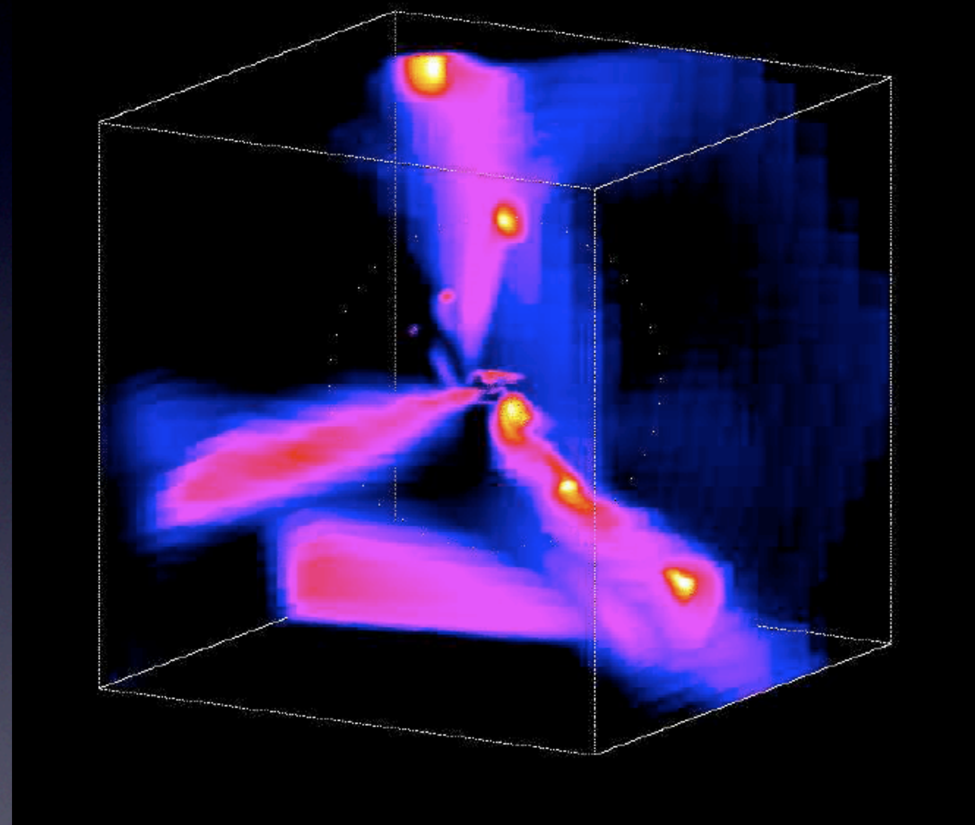
Birnboim et al., (2007)



Baryonic mass infall halting mechanisms

- Infall of gas via filaments

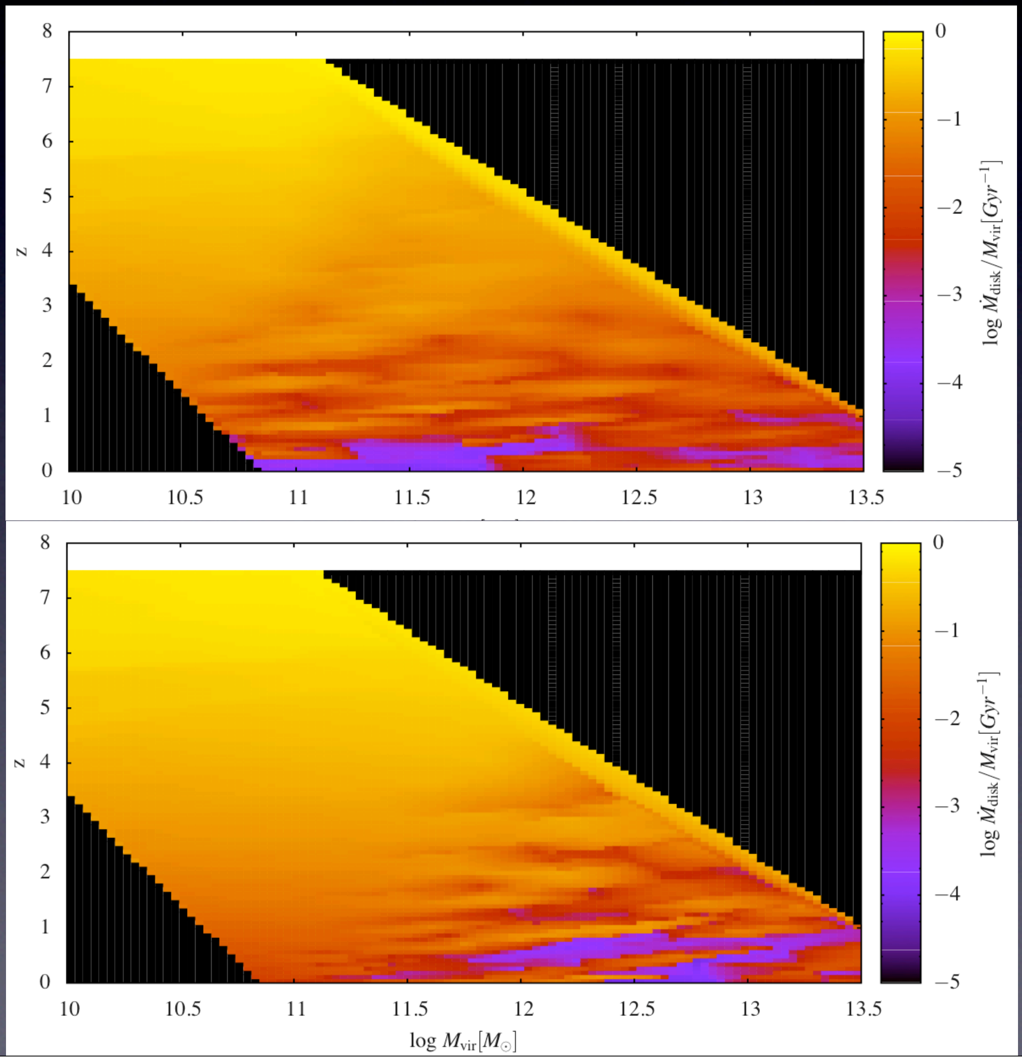




Dekel et al., 2008

Baryonic mass infall halting mechanisms

- Gas heating and cooling



Star formation and mass infall halting

Forming stars in discs of cooled gas, and associating to this formation SN explosions (enrichment) and AGN.

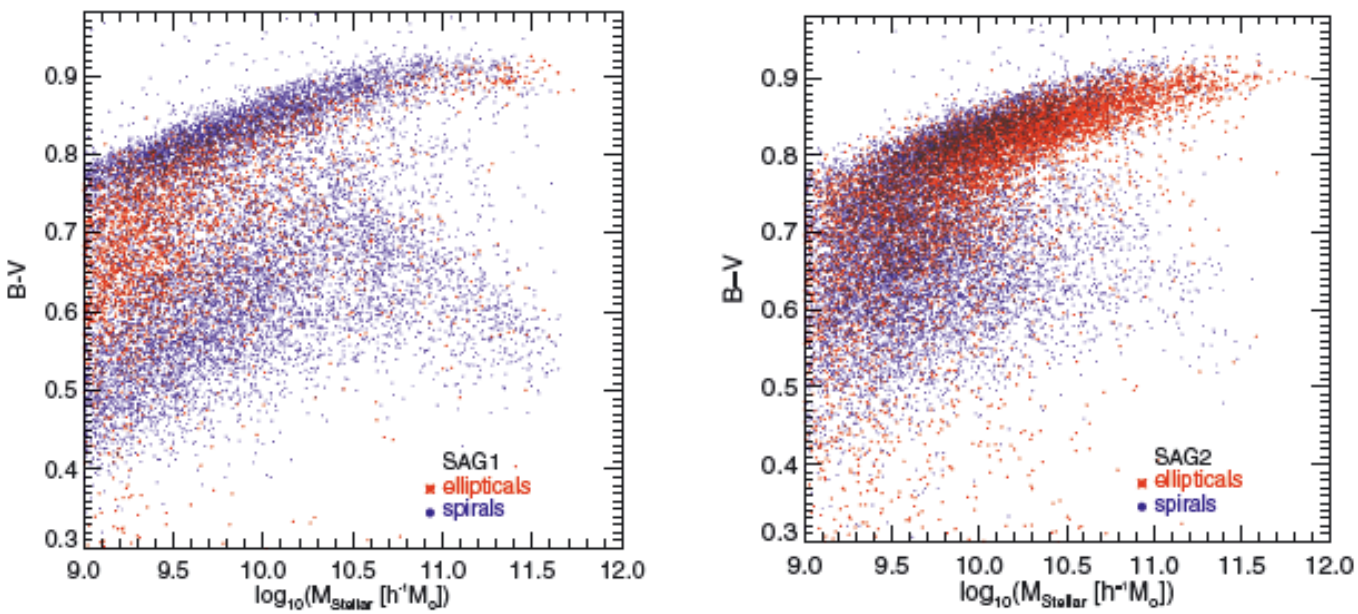
Interactions in clusters (for small galaxies)

An for massive galaxies, AGN Feedback
(Croton et al. 2006, Bower et al., 2006, Lagos, Cora & Padilla, 2008)
SN superwinds (Baugh et al., 2005), Gravitational Heating (Birnboim)

AIMs:
to produce sensible metallicities, old BCGs
and Red Sequences

Applied to Clusters

The red sequence from AGN quenching:

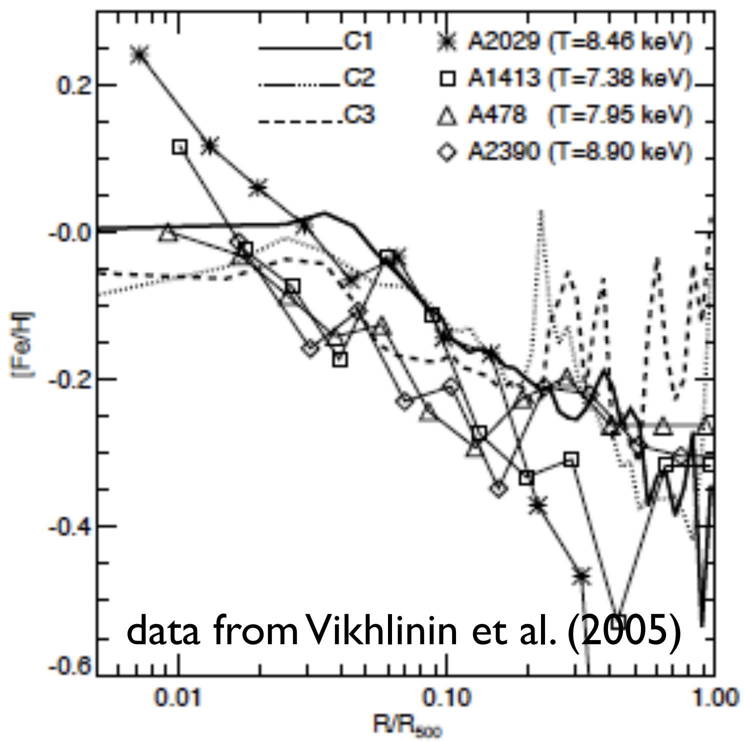


Lagos, Cora & Padilla (2008)

Applied to Clusters

The metallicity gradients in clusters using SAMs and Hydro together.

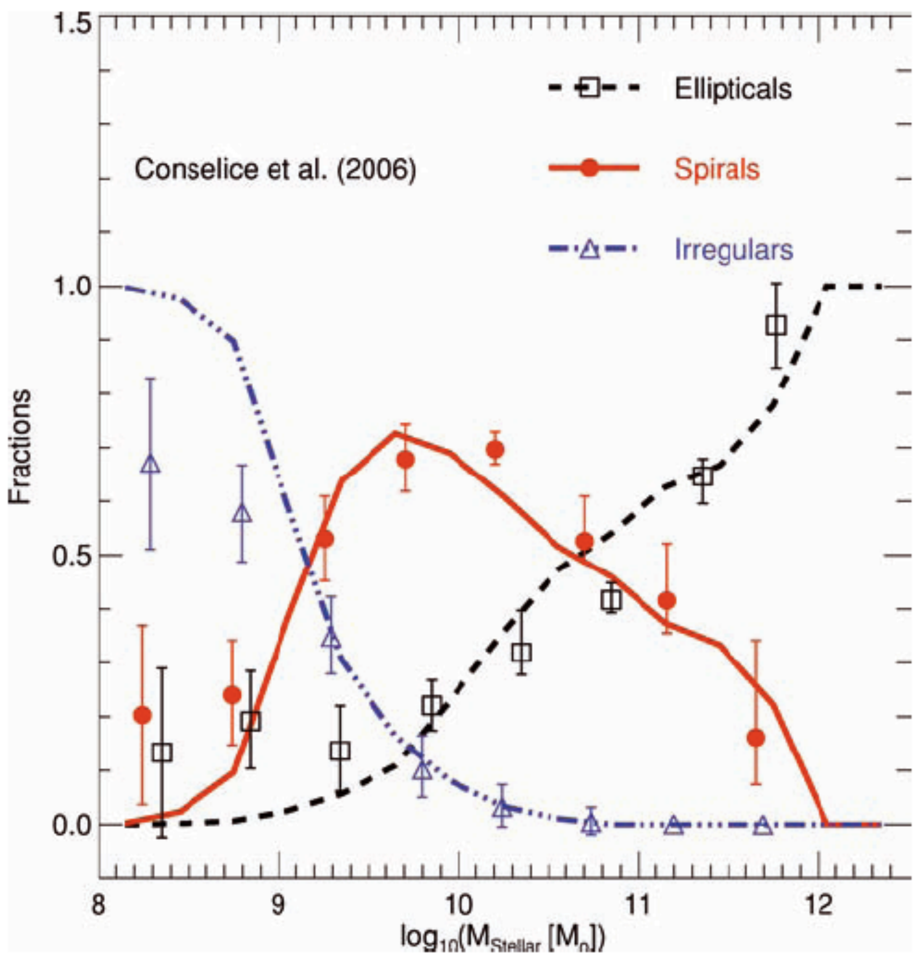
Galaxies need to expel their metals out to distances of 100kpc in order to fit the observations

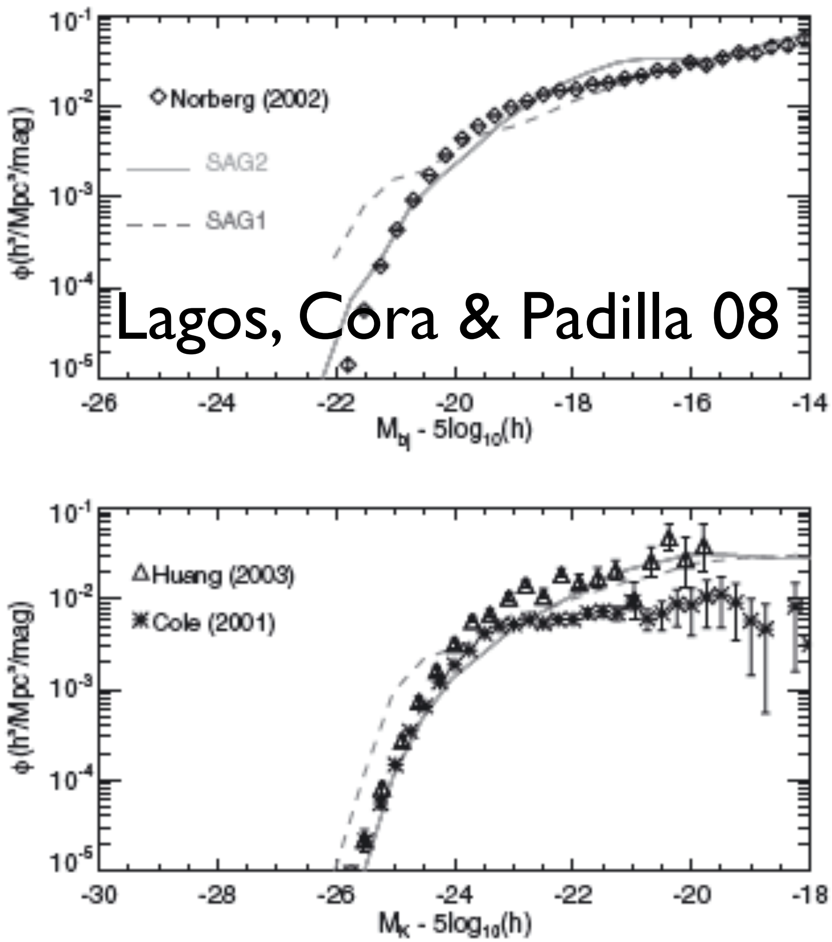


Cora, Tornatore, Tozzi & Dolag (2008)

And how do these galaxies look like today?

Applied to Clusters

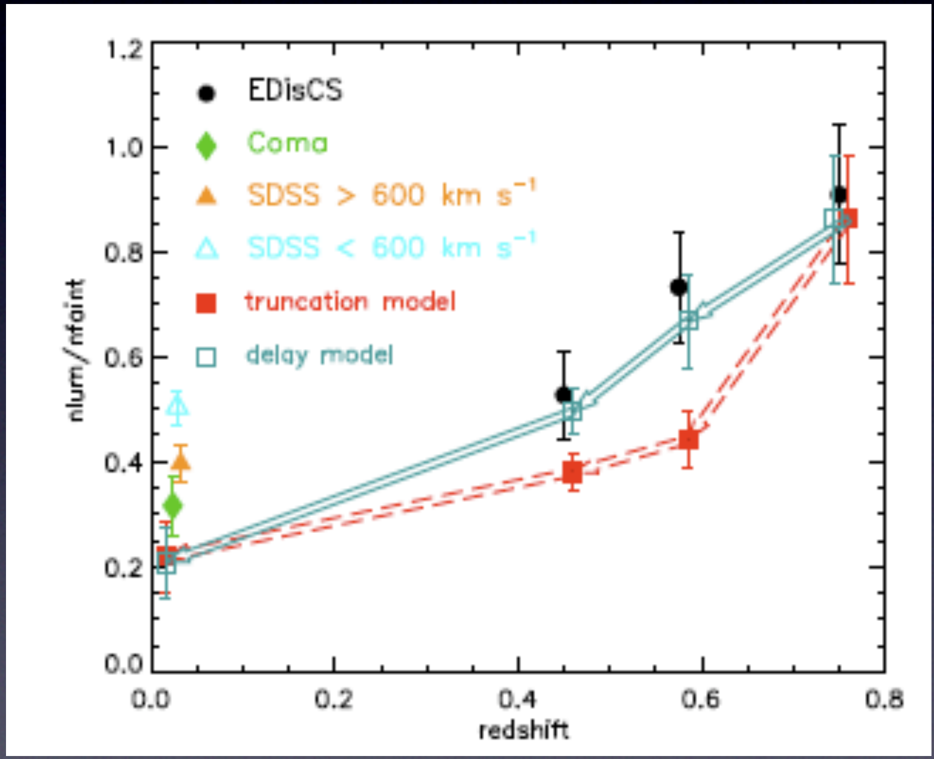




Tool IV: stellar population synthesis models

Growth of the red sequence

Allows to interpret results but does not ensure the descendants will look like measured z=0 galaxies.



De Lucia et al., 2006

Do these galaxies evolve into a SDSS LF?

Also talks by Diego Capozzi and by Nicola Menzi (in a couple of minutes)

Sumary

- Tool I: provides direct relation between cosmological model and distributions of haloes. Differences with fully non-linear models help improve the analytic approach.
- Tool II: simulations; these are essential in understanding the different processes ignored in Tool I.
- Tool III: the baryon physics can be followed using different levels of resolution and detail.

These can be used to study high redshift Clusters
and at the same time
ensuring a reasonable population of final z=0 gals.

- Tool IV: helps understand observations, but on itself does not allow to look after the z=0 population.