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The formation and evolution of galaxies in a cosmological framework (a few recent highlights and open issues)

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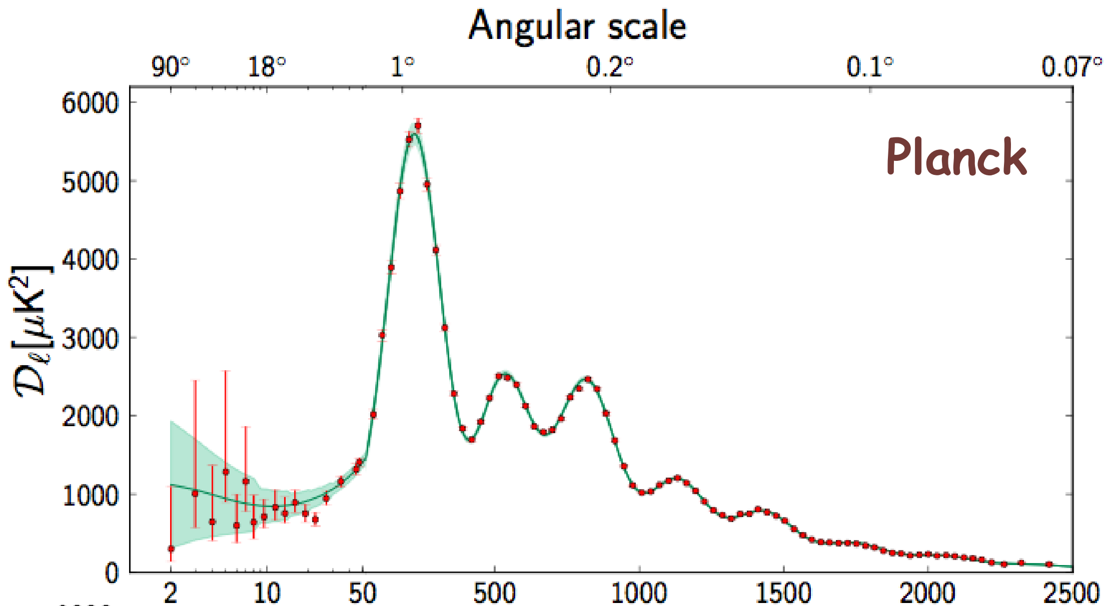
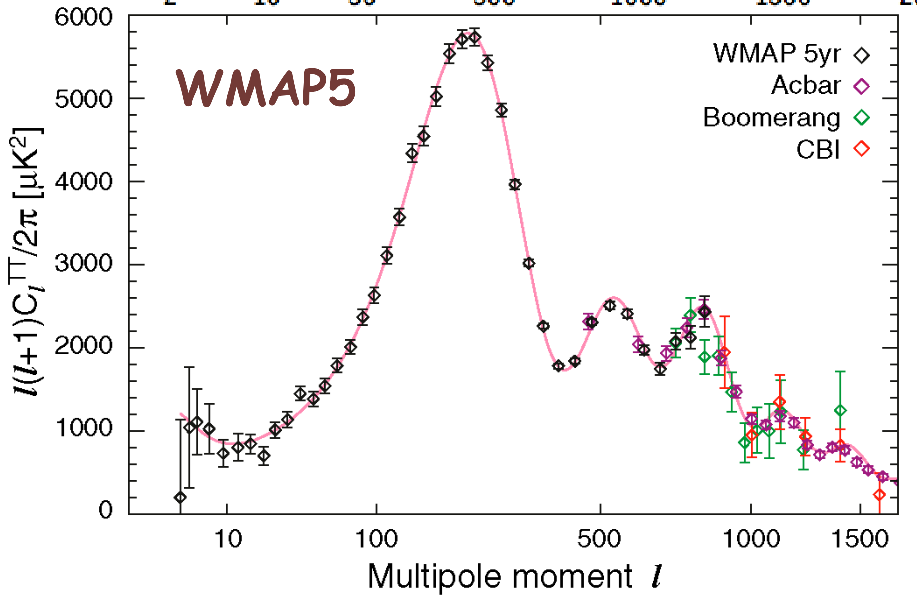
An era of "precision cosmology"





t_0 = 13.813 ± 0.047 *Gyr*
h = 0.673 ± 0.012
σ_8 = 0.828 ± 0.012
Ω_Λ = 0.685 ± 0.016
$\Omega_c h^2$ = 0.1198 ± 0.0026
$\Omega_b h^2$ = 0.02207 ± 0.02207
n_s = 0.9585 ± 0.0070

+ galaxy power spectrum
+ cosmic shear
+ Lyα forest
+ supernovae observations
+ baryon fraction in clusters
+ ....

Cooling
(metallicity, halo structure, conductivity)

Star formation
(threshold, efficiency, initial mass function)

Dust
(formation,distribution, heating and cooling)

GALAXY FORMATION

Mergers and Galaxy interactions
(morphological transformations, induced star formation)

SN Feedback
(IGM heating, IGM enrichment, efficiency, winds)

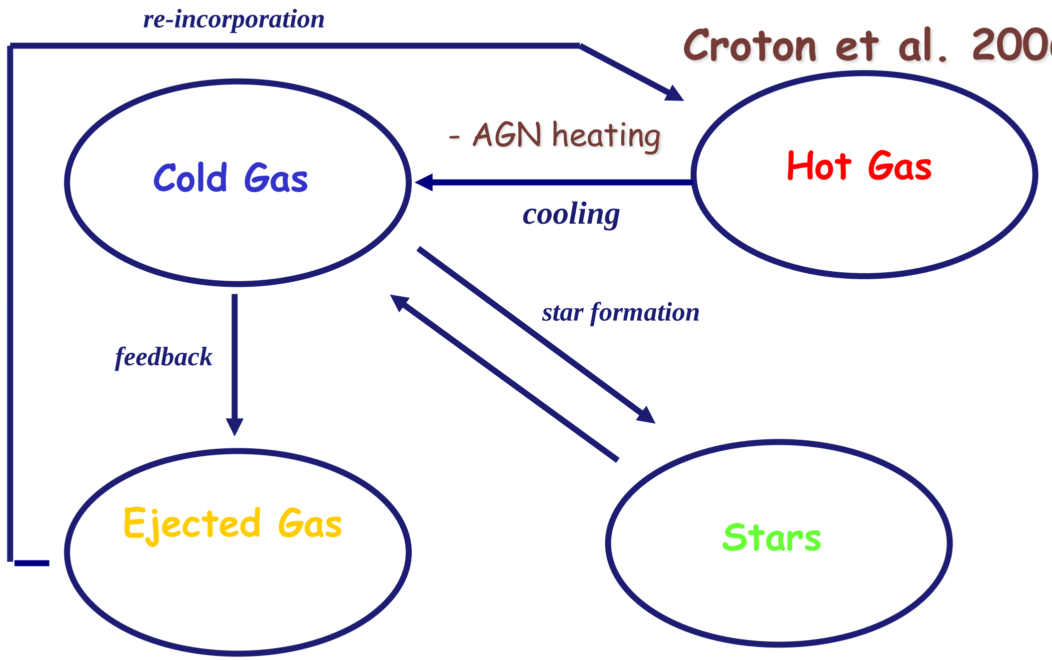
Stellar evolution
(spectro-photometric evolution, yields,feedback)

BHs and AGNs
(BH growth, quasar winds, radio bubbles)

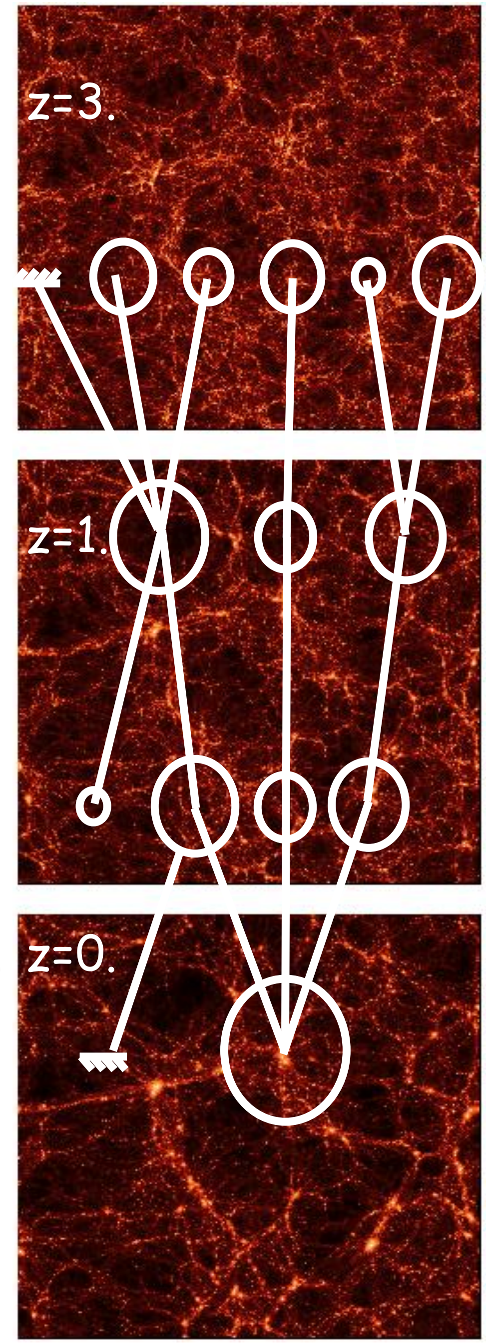
Semi-analytic models in a nutshell:

Baryonic physical processes are modeled using simple yet physically and/or observationally motivated prescriptions. The technique allows a large dynamic range to be accessed, a fast exploration of the parameter space, and an efficient investigation of the influence of different physical prescriptions. No description of the gas dynamics.

Croton et al. 2006

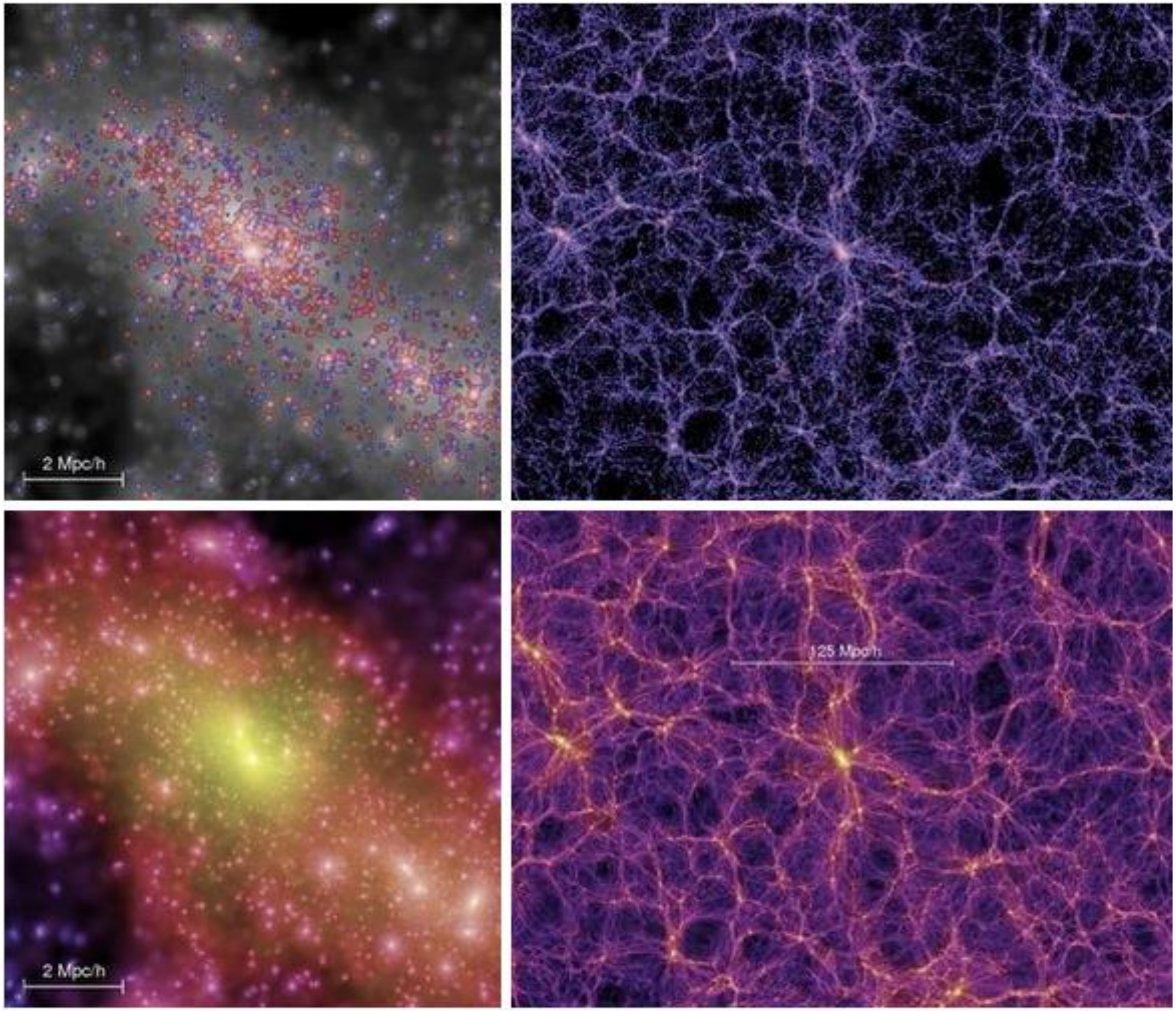


De Lucia, Kauffmann & White, 2004



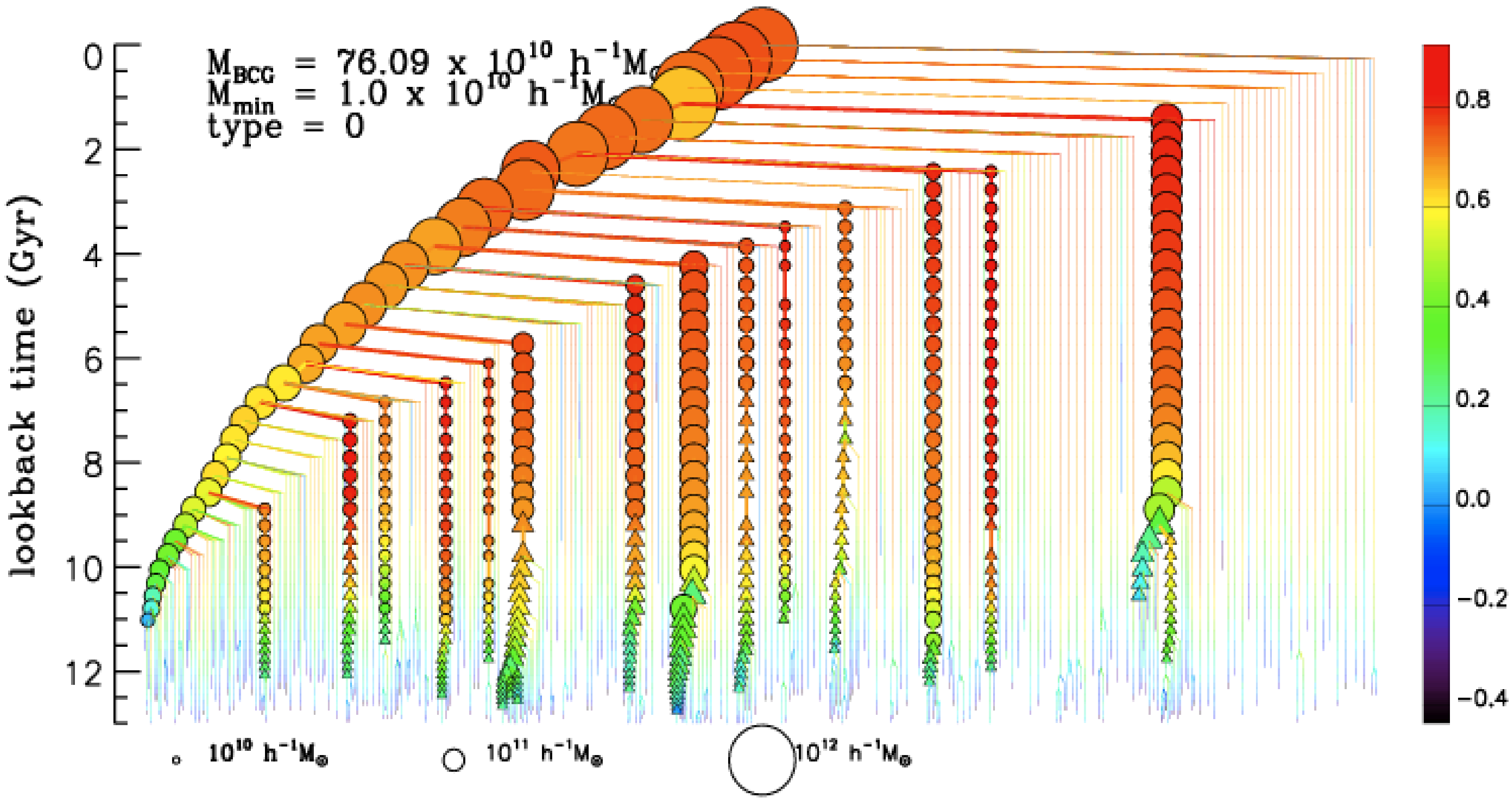
Kauffmann et al., 1999

The (public) Millennium galaxy catalogues:



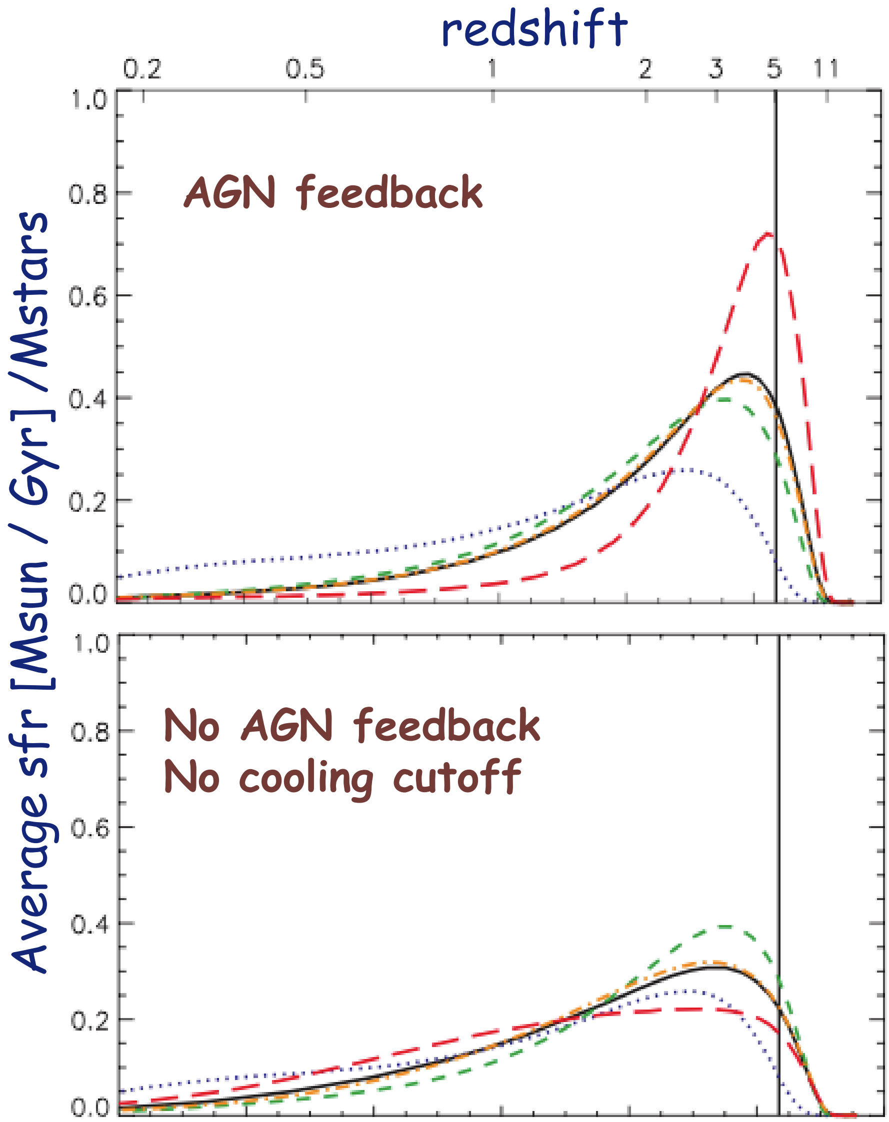
Different (independent) renditions of semi-analytic models have been run on the same simulation, and galaxy catalogues have been made publicly available through a relational database (in collaboration with GAVO)

The hierarchical formation of BCGs



De Lucia & Blaizot 2007

Distinction between assembly and formation



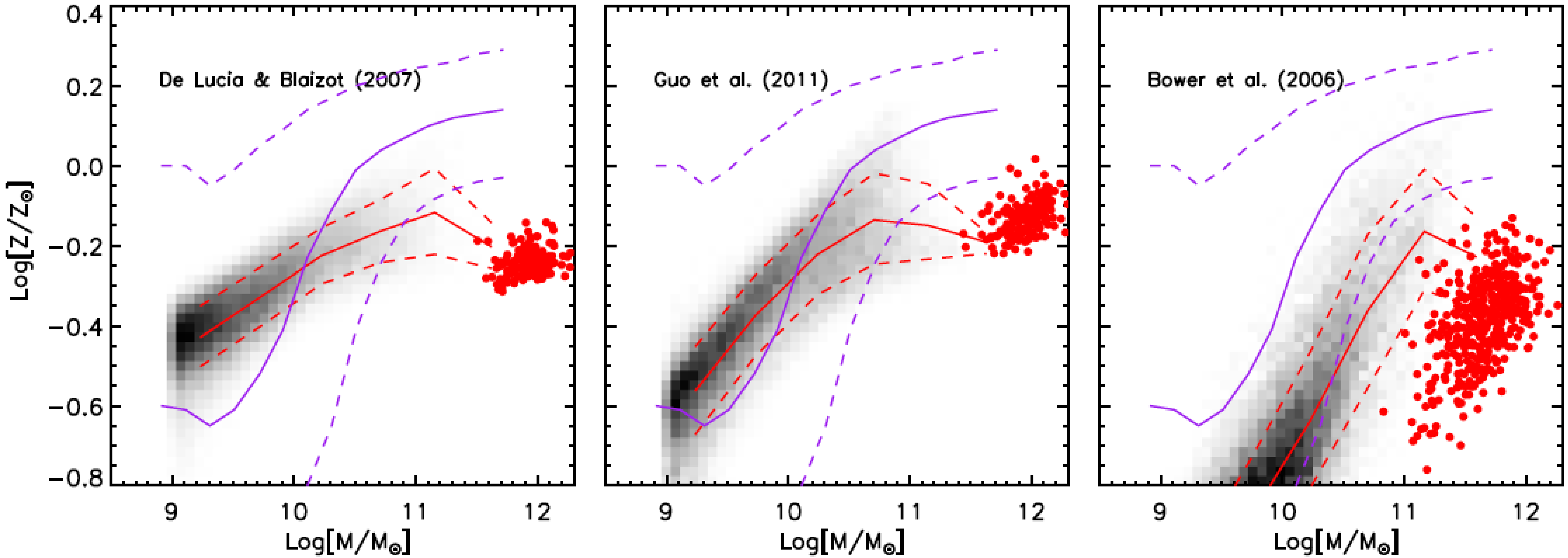
The suppression of gas cooling at late times by "radio mode" AGN feedback naturally gives rise to more extended star formation histories for less massive galaxies. This is in qualitative agreement with observational results (a more quantitative agreement needs to be shown, but how well do we measure the star formation history of galaxies?)

However, several indications that suppression of star formation, both in centrals and satellite galaxies takes place on too short time-scales in the models.

De Lucia et al. 2006

The metallicities of model galaxies

De Lucia & Borgani 2012

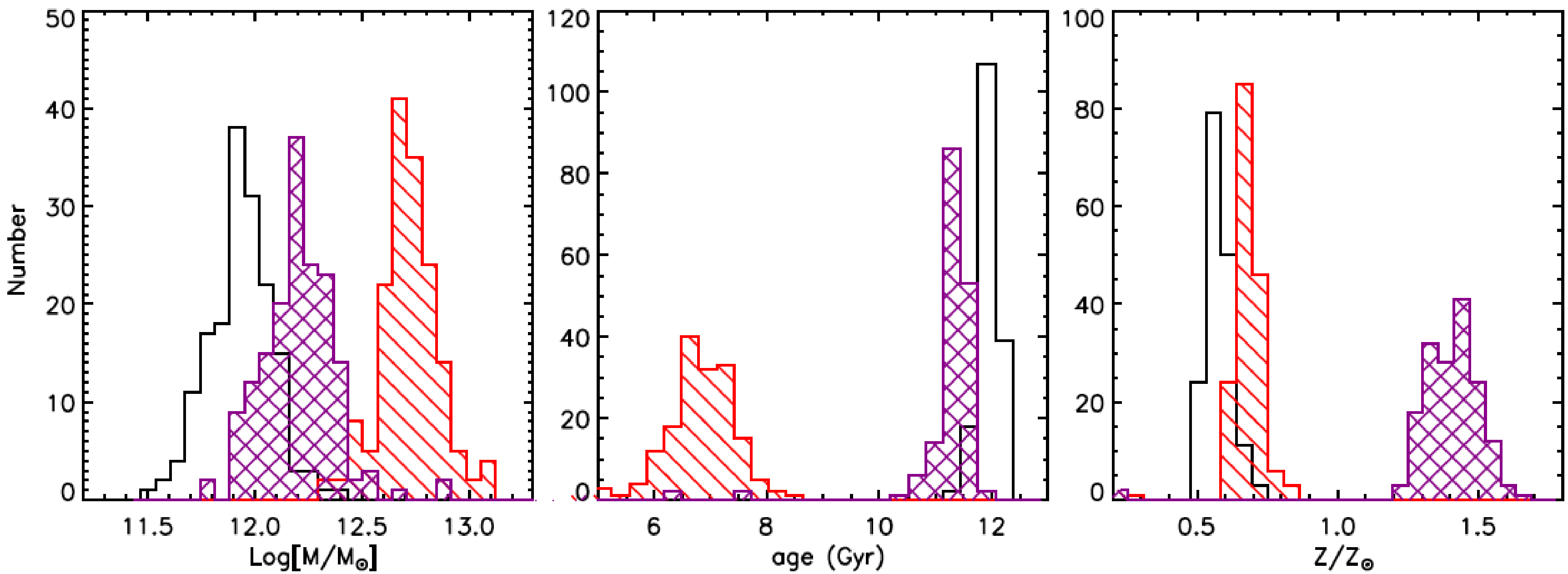


Strong SN feedback establishes a steep mass-metallicity relation for the low-mass to intermediate-mass galaxies. At the most massive end, the model mass-metallicity relation turns over and is offset with respect to the observational measurements significantly.

Observational uncertainties are still large (in this case larger for the less massive galaxies). And one should consider that measurements are usually made within some small region while model metallicities are "total".

The stellar populations of massive galaxies

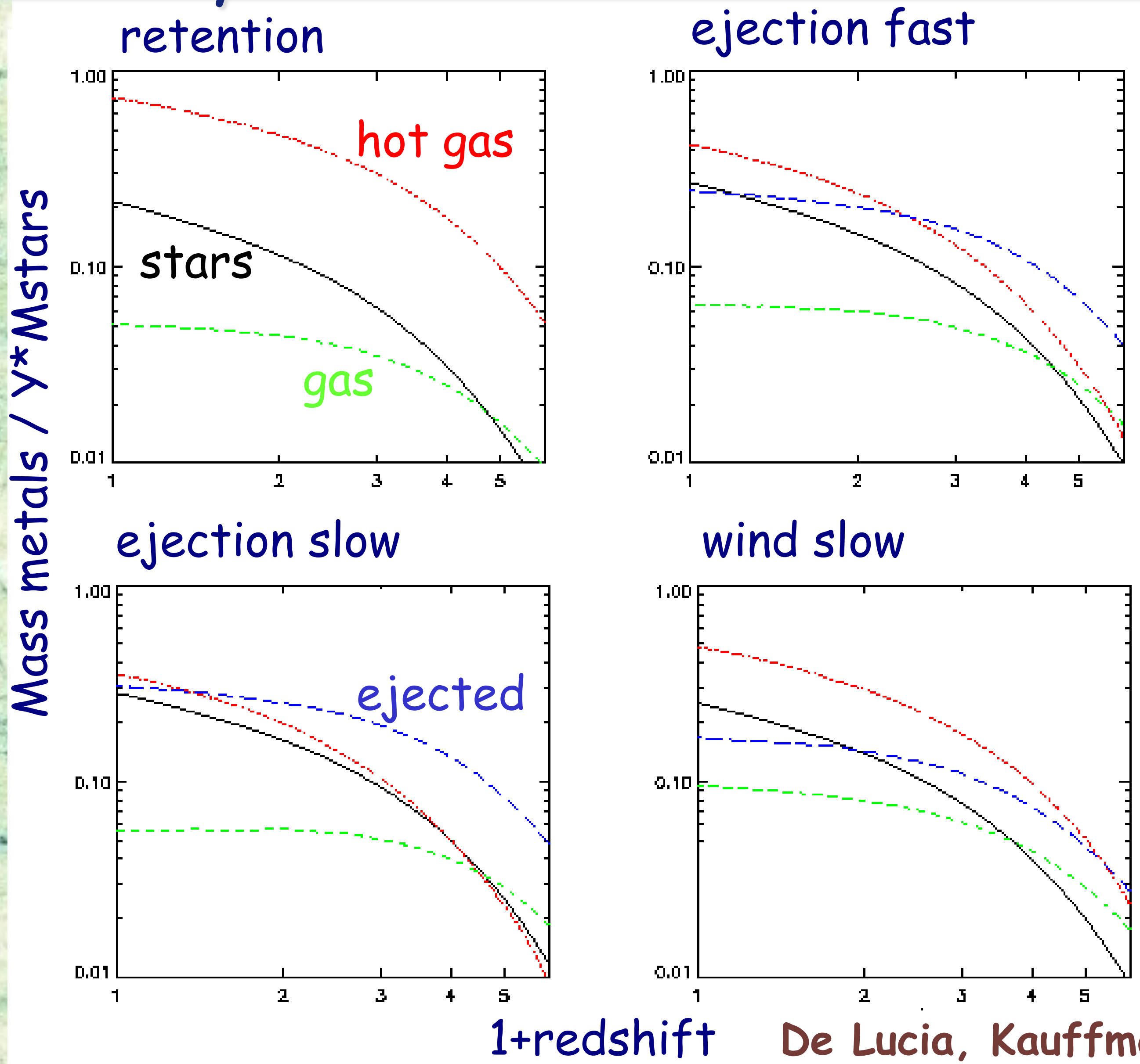
De Lucia & Borgani 2012



Switching off the radio mode AGN feedback increases only slightly the metallicity of the most massive galaxies, but makes them significantly younger. A different scheme for supernovae feedback has much stronger influence (because it affects significantly the properties of the accreted satellite galaxies).

Uncertainties: yields, IMF. But hard to imagine these would solve problem. Star formation time-scale of these galaxies is too short to enrich them.

Metallicity as a constraint for feedback



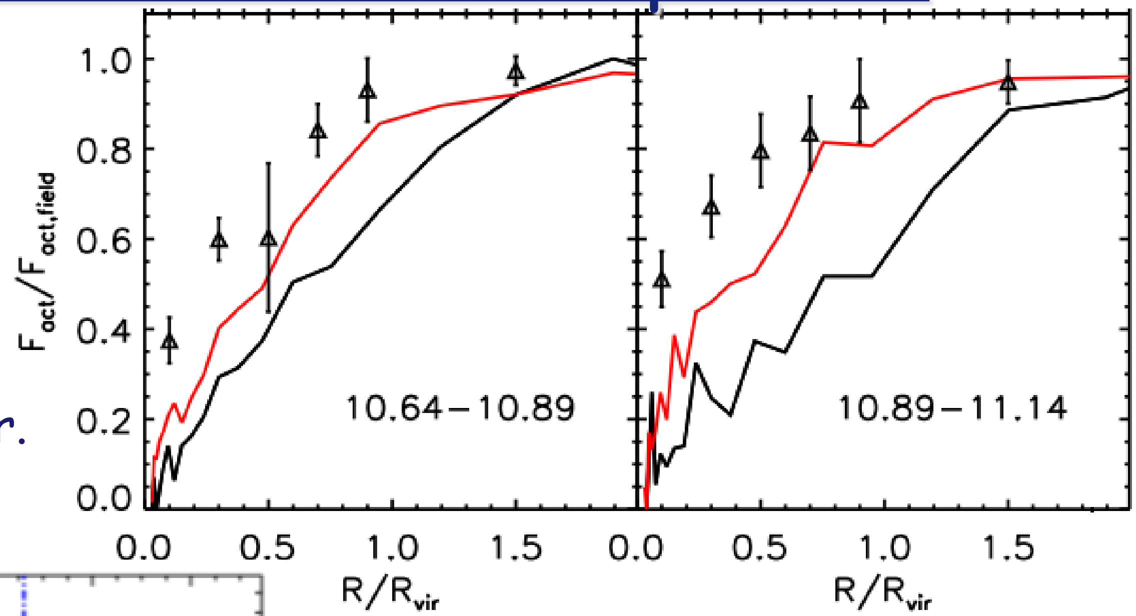
Metal content (and its evolution as a function of cosmic time) for different baryonic components in three alternative supernovae feedback schemes.

The relative contributions in different phases are very sensitive to different schemes (caveat: cosmic variance)

De Lucia, Kauffmann & White 2004

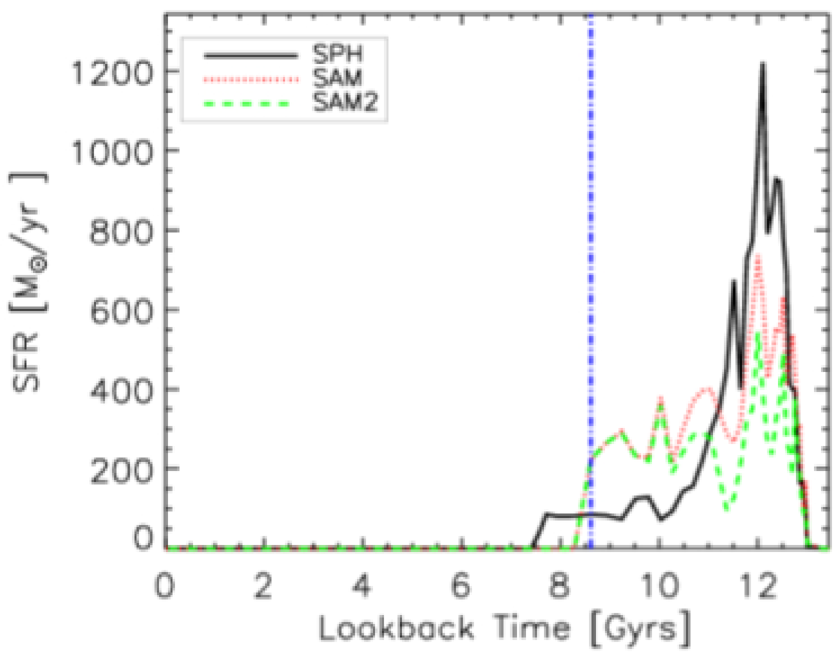
Low-mass galaxies tend to bee too passive

Most (all) semi-analytic models over-predict the fraction of passive galaxies. In the past years, this has been mainly attributed to stripping of hot reservoir.



Guo et al. 2011

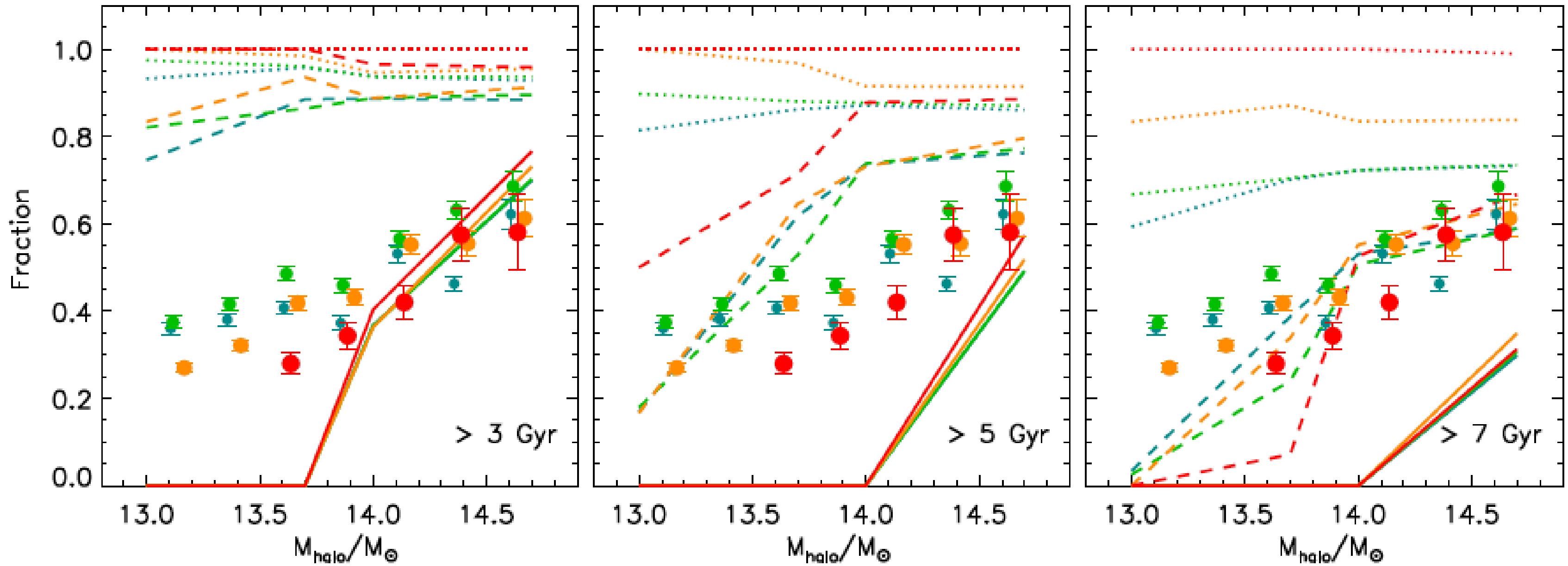
Saro et al. 2010



Results from simulations are not conclusive (more work is needed), but seems to suggest that residual cooling on satellites is limited to the most massive ones. Is there a more fundamental problem with the treatment of star formation and feedback for satellite galaxies?

The environmental quenching efficiency

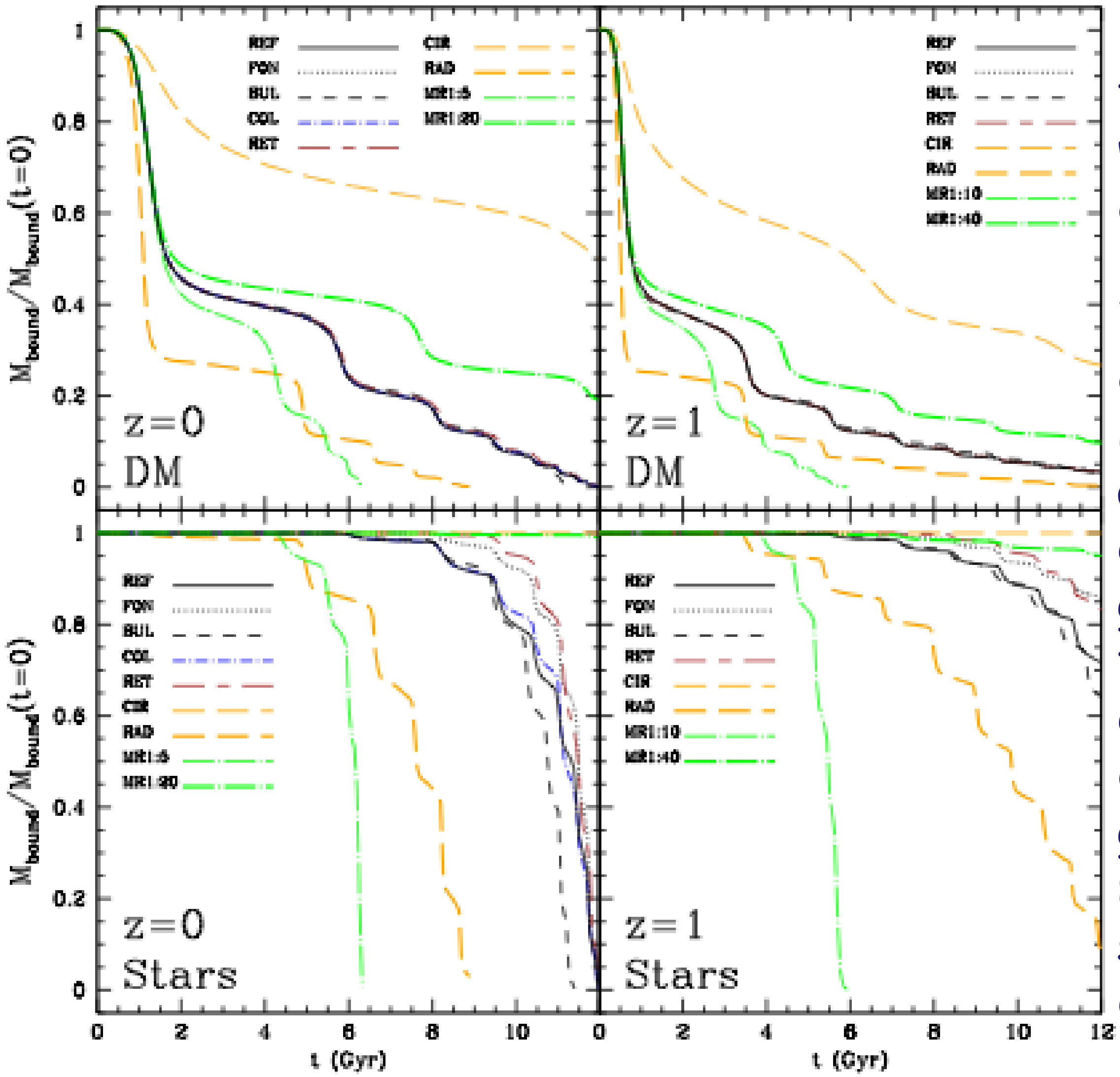
De Lucia et al. 2012



The fraction of satellite affected by environment varies (albeit weakly) with halo mass, increasing from ~40% to ~60% over the halo mass range considered. It also varies weakly with stellar mass: a lower fraction of the most massive satellites have been affected by the environment.

Structure formation naturally predicts that fraction of galaxies that have spent significant time in haloes of mass Mcrit decreases with increasing Mcrit. Comparison suggests that the critical environment is given by 10^{13} M_{sun} haloes over 5-7 Gyr time-scale

The importance of group environment

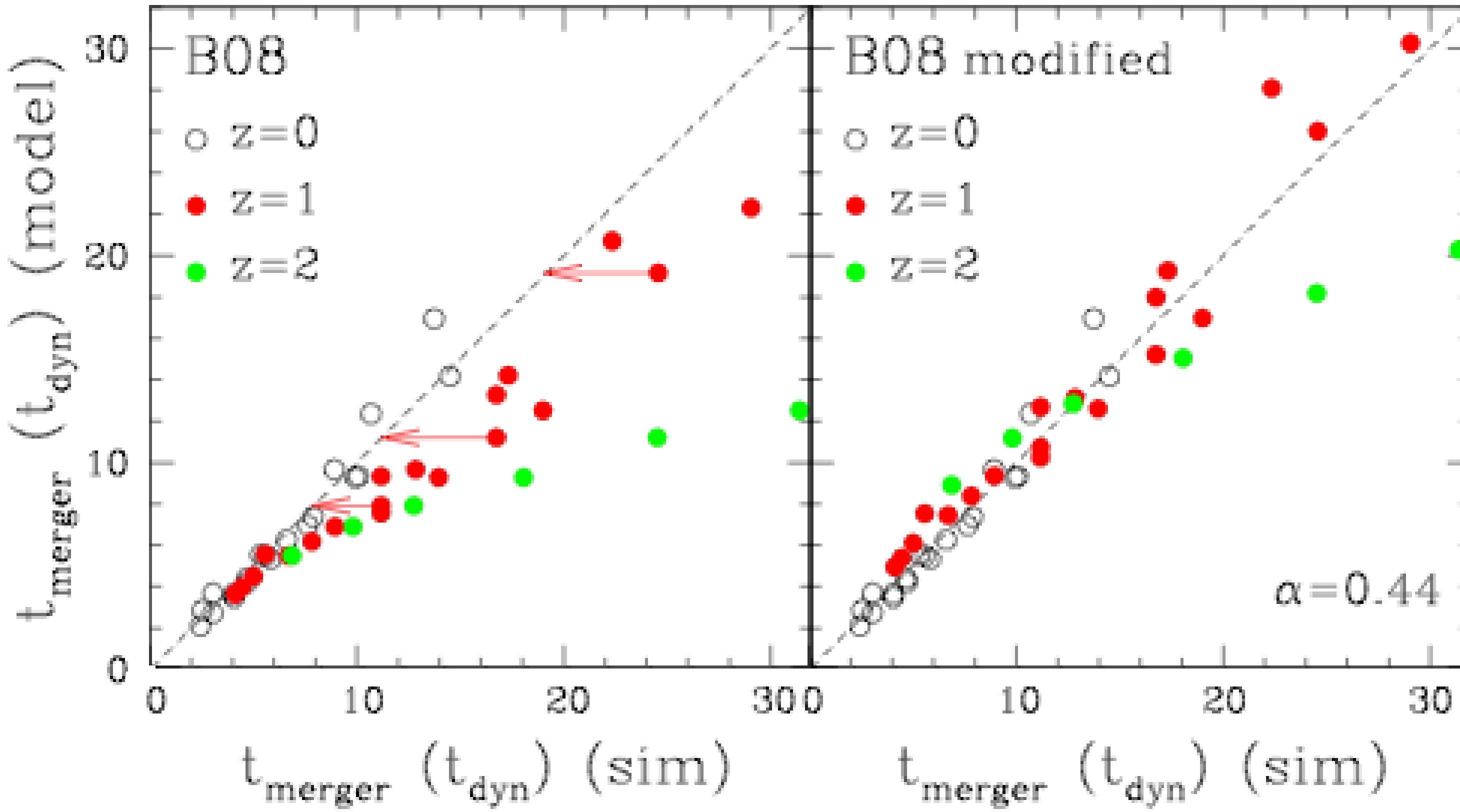


Unfortunately, most of the published numerical work has focused on the cluster mass scale.

To fill this gap, we have carried out a series of numerical simulations aimed to study the evolution of a disc galaxy within the global tidal field of a group environment. Both the disc galaxy and the group are modeled as multi-component N-body systems composed of dark matter and stars.

Villalobos et al. 2012

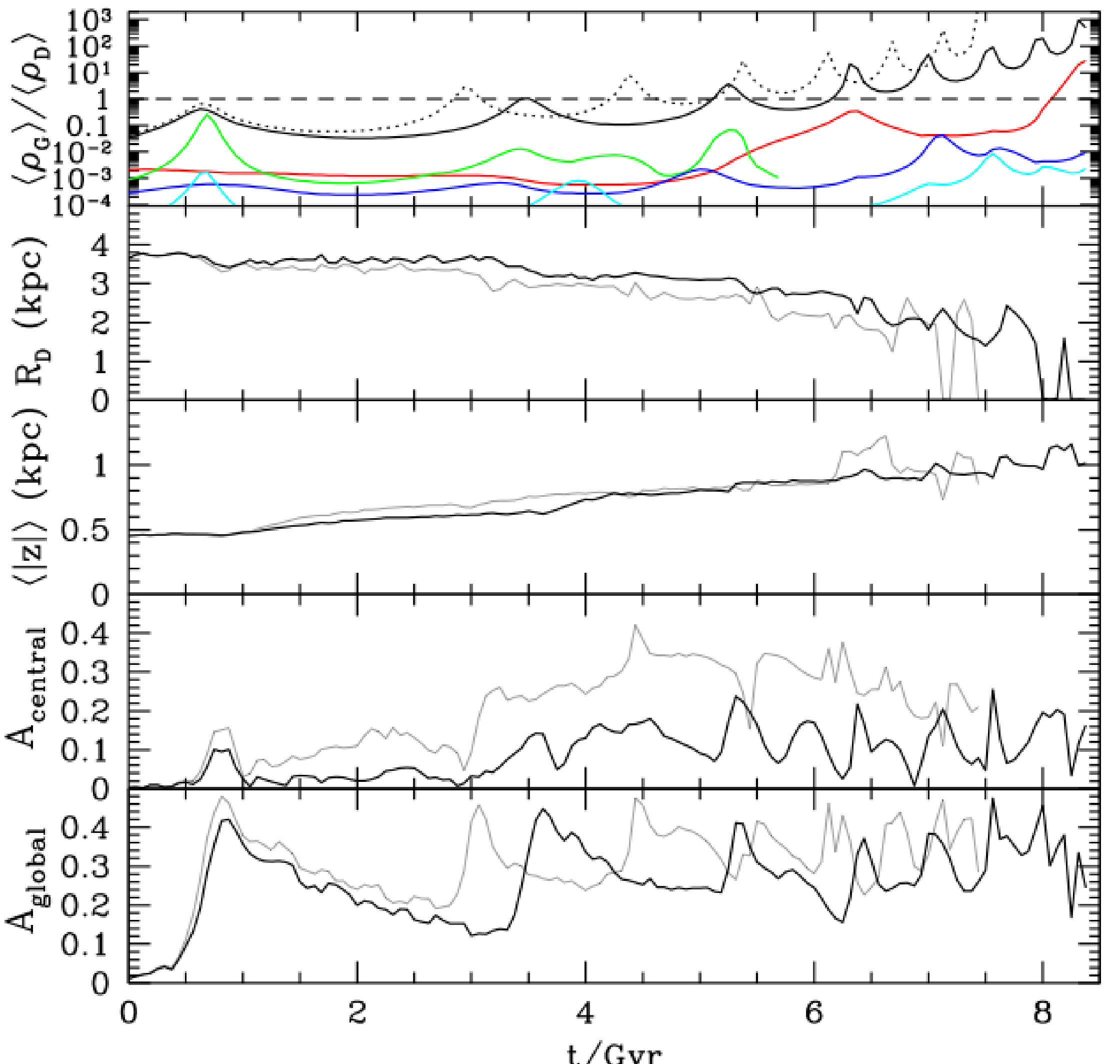
An improved prescription for merger times



Prescriptions available under-estimate merger times at high redshift. We find this is due either to the fact that the evolution of halo concentration of satellites has been neglected (previous isolated merger simulations) or because long times and mergers with high initial orbital circularities are under-represented (cosmological simulations).

Villalobos et al. 2013

Prescription to model tidal stripping:



We find that discs start suffering structural transformations when the mean density of the group, within the orbit of the galaxy is of the same order of the mean galaxy density.

We have used derived fitting formulae from our simulations that allow us to model the fraction of stars stripped as a function of time since accretion. We have used this within a SAM to model the formation of the ICL

Villalobos et al. 2012, Villalobos et al. in preparation

Closing remarks

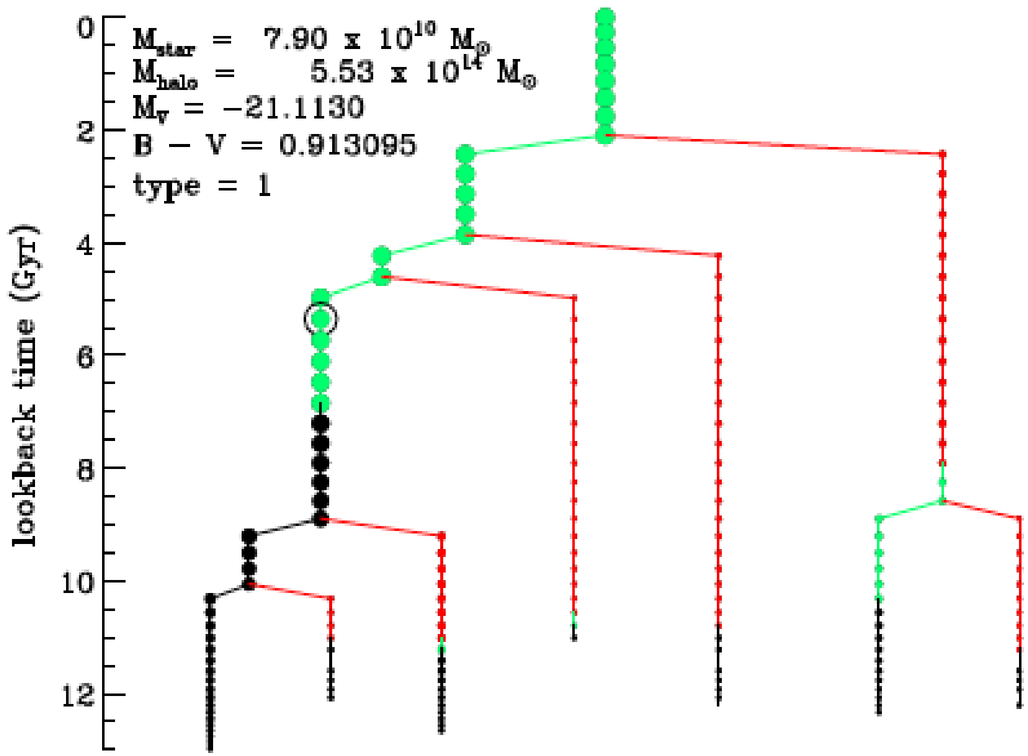
- ✓ Semi-analytic models represent a powerful tool to study galaxy formation in a cosmological context. As other theoretical models, they are not meant to (and cannot) be “definitive”.

- ✓ All recent models combine a relatively strong SN feedback with a model for AGN feedback to suppress cooling at the centre of relatively massive haloes. Our observational and physical understanding of both processes is rather poor so that both are described using quite schematic prescriptions.

- ✓ Metallicities (and more in general metallicity distributions in different baryonic components) can provide strong constraints on different feedback processes. A under-utilized resource in this framework; lot of data coming along for resolved stellar populations (e.g. CALIFA, MANGA, etc).

- ✓ Nature-nurture (as well as mass-environment) debate is ill-posed in the hierarchical framework. Critical environment that of low velocity dispersion groups. More theoretical work is needed in order to clarify the influence and time-scales of different physical processes in this environment.

The "environmental history" of galaxies



Galaxy history = tracing the main progenitor at each redshift

Two critical times:

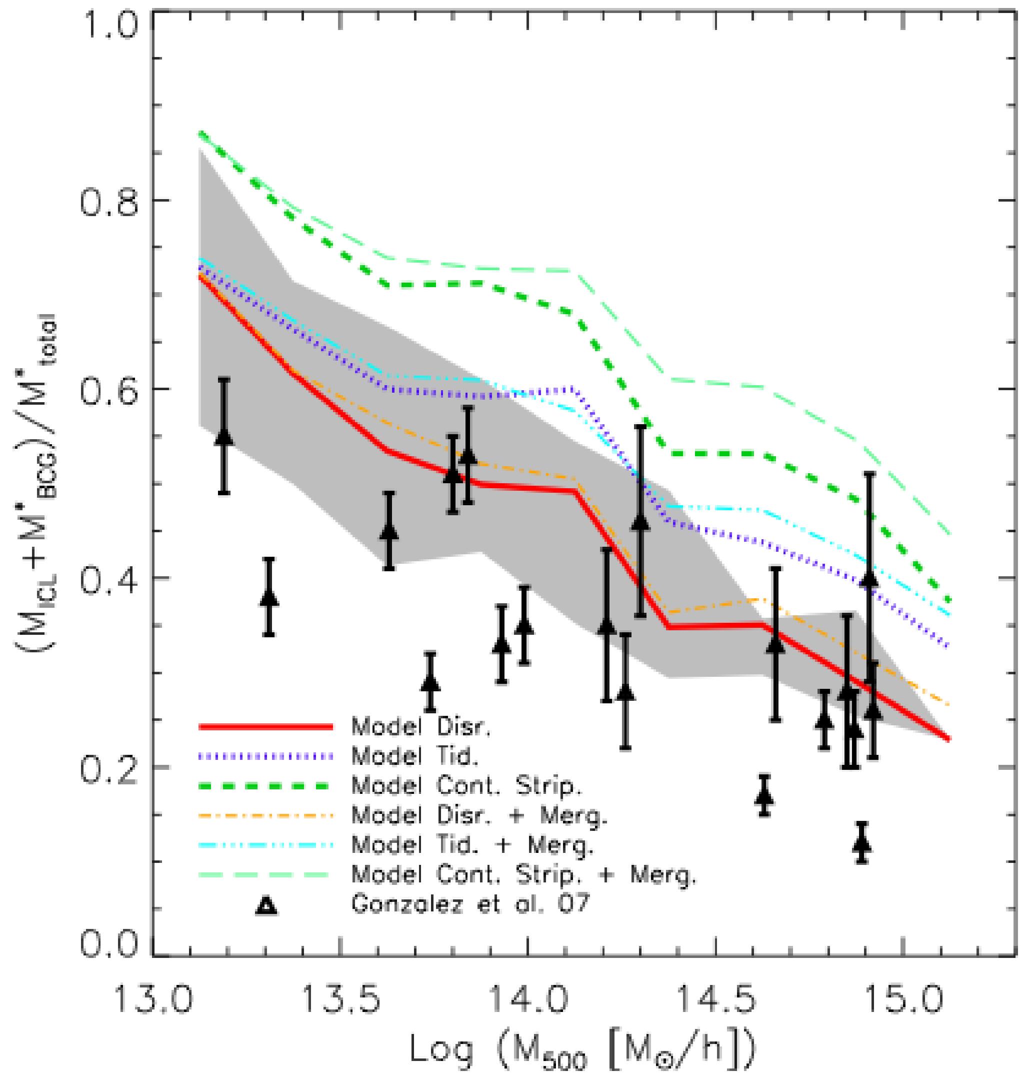
(i) t_{sat}: the galaxy becomes satellite of a more massive halo

(ii) t_{halo}: the galaxy falls on the main progenitor of final cluster

The adoption of different characteristic times is mainly responsible for the disagreement between published studies (McGee et al. 2009, Berrier et al. 2009)

We focus on galaxies selected from our simulated box at z=0. To investigate trends as a function of halo mass, we consider 15 haloes in different mass bins: 10^{13}, 5×10^{13}, 10^{14} and 5×10^{14} Msun

Modelling the formation of the ICL:



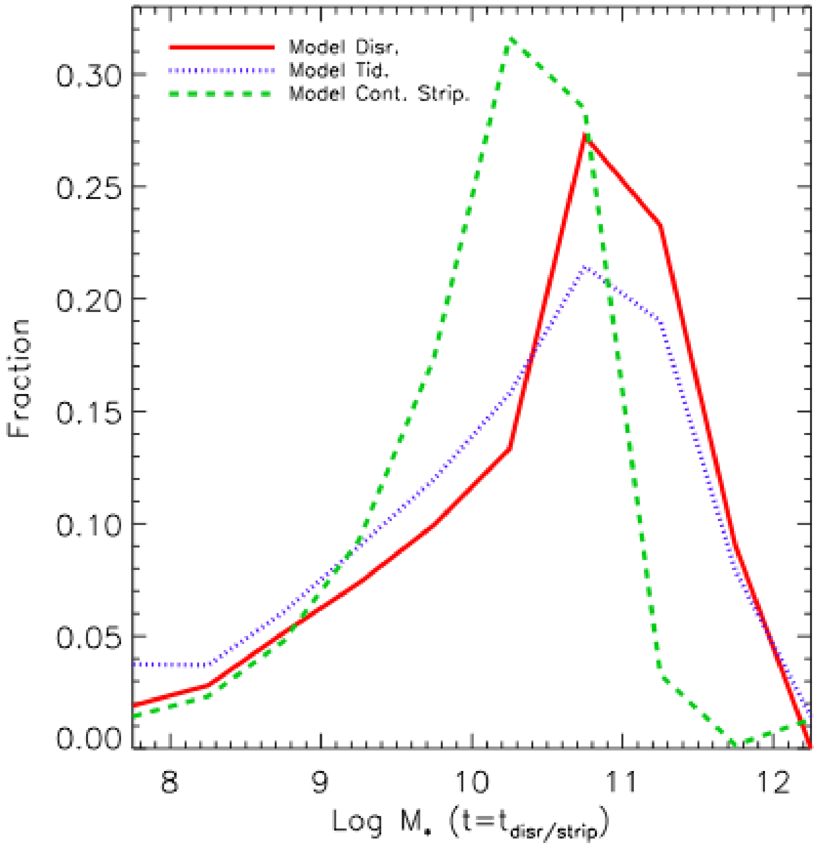
Contini et al. submitted

The halo-to-halo scatter at the cluster mass scale is largely due to a variety of halo accretion histories.

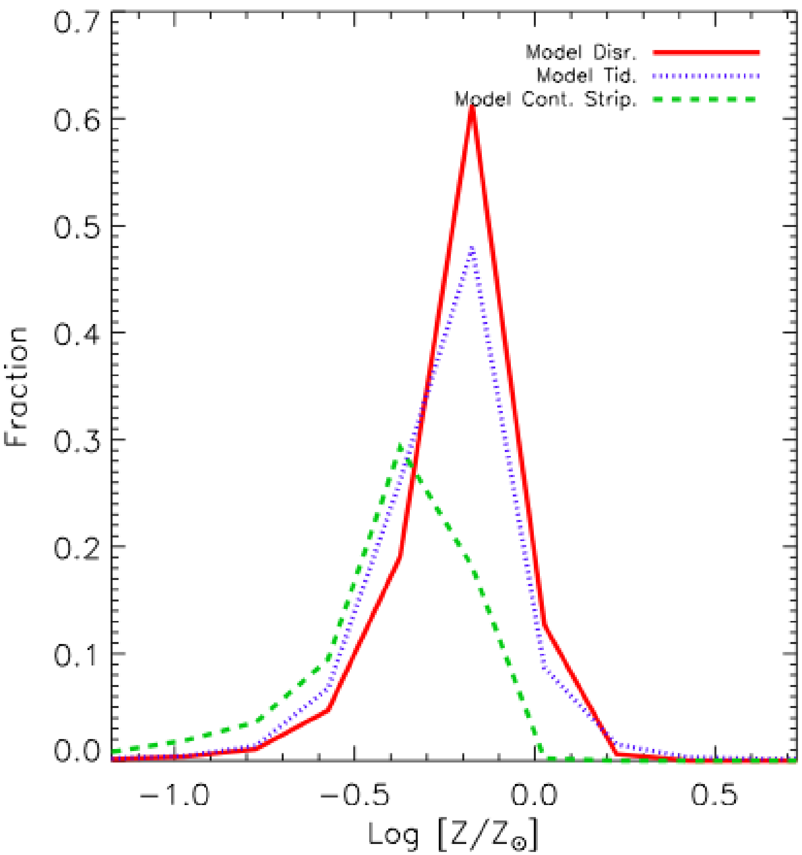
At the group scales, the scatter is rather due to variations in the timings (and number) of individual accretions of relatively massive satellite galaxies.

Tidal stripping contributes for most of the ICL, while mergers contribute for about 15%, independent of halo mass. 5-25% of the ICL has been accreted during the hierarchical growth of haloes.

Modelling the formation of the ICL:



Relatively broad range of metallicity (note that this is based on IRA – can be improved). Metal tagging represent a promising approach to constrain the models.



Main contributors to the ICL are relatively massive satellite galaxies, that are dragged closer to the centre on short time-scales due to dynamical friction.

Contini et al. submitted