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The origin of the intra-cluster light and the formation of the brightest cluster galaxies

Gabriella De Lucia

INAF - Astronomical Observatory of Trieste

A premise

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- ✓ An element sometimes overlooked in classical discussions about environmental effects: galaxy structures form "*hierarchically*". In this framework a simple distinction between "*nature*" and "*nurture*" is difficult to accomodate

Physical mechanisms

Galaxy mergers:
e.g. Negroponte & White '82, Barnes & Hernquist '91, '92, '96 Mihos & Hernquist '94, '96,

WHERE : field + low velocity dispersion groups
WHAT : strong internal dynamical response

Harassment:
e.g. Spitzer & Baade '51, Richstone '76, Farouki & Shapiro '81, Moore et al. '96, Moore et al. '98

WHERE : in massive clusters
WHAT : some damage but less than mergers – at least on luminous members

Gas stripping:
e.g. Gunn & Gott '72, Cowie & Songaila '77, Nulsen '82, Quilis et al. '00

WHERE : very central regions of clusters
WHAT : suppression of SF, indirect influence on morphology

Strangulation:
e.g. Larson, Tinsley & Caldwell '80, Balogh, Navarro & Morris '00

WHERE : any "larger" structure
WHAT : suppression of SF, indirect influence (time-scale longer than gas stripping?)

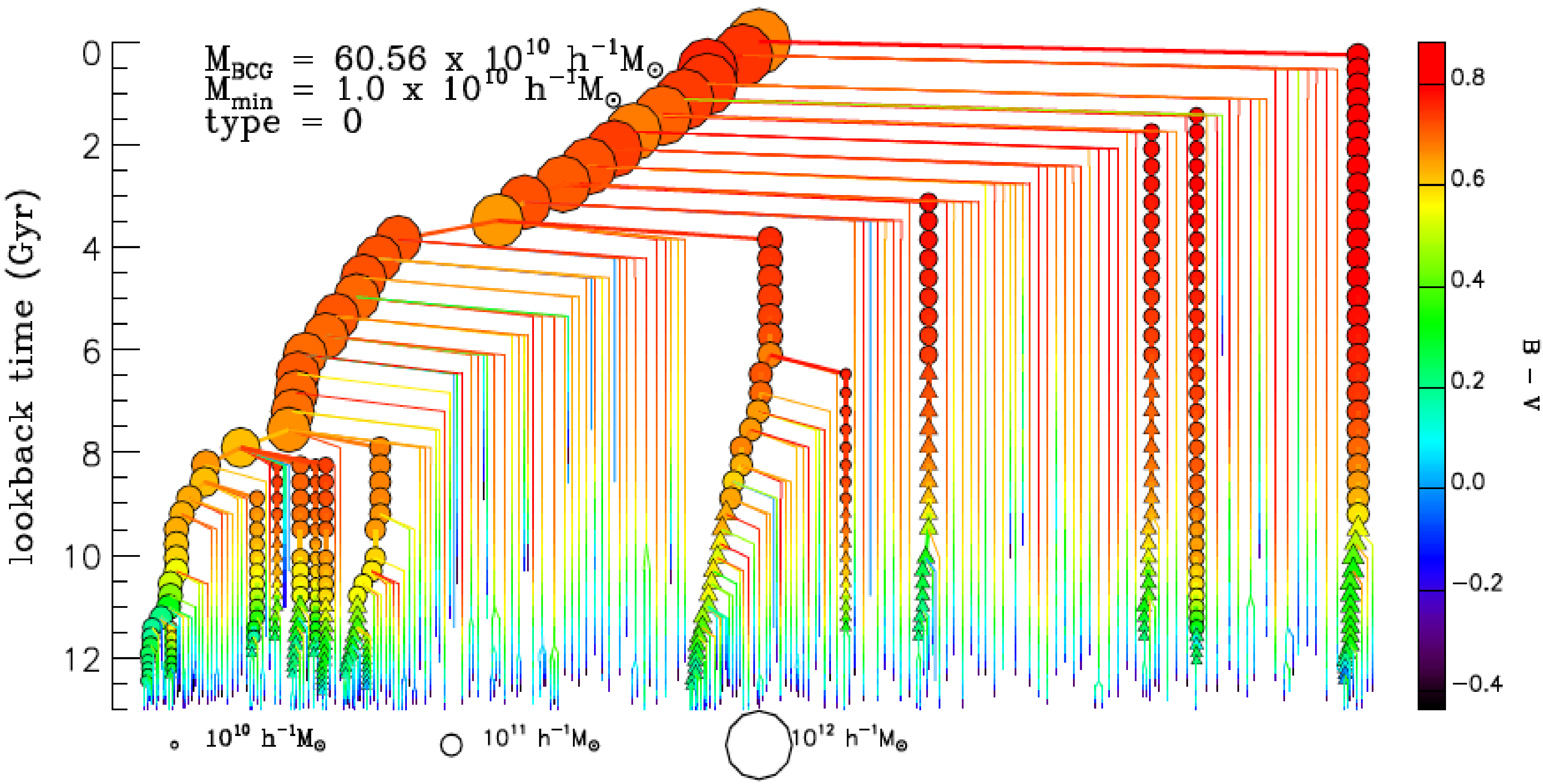
AGN heating:
e.g. Churazov et al. '01, Brueggen et al. '02, Della Vecchia et al. '04, Sijacki & Springel '06 +++++++++++

WHERE : centre of massive groups/clusters
WHAT : suppression of cooling flows

Cannibalism:
e.g. Ostriker & Tremaine '75, White '76, Makumuth & Richstone '84, Merritt '85

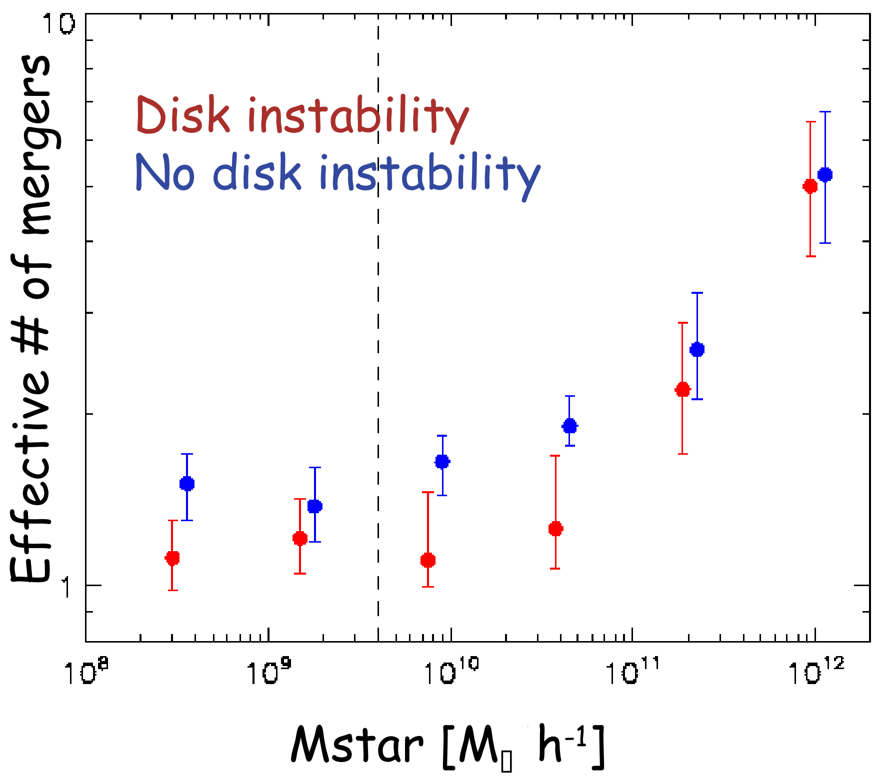
WHERE : groups and clusters
WHAT : formation of BCGs?

The hierarchical formation of BCGs



De Lucia & Blaizot 2007

Mergers and accretions



How large is the number of progenitors of elliptical galaxies? And how does this vary as a function of mass?

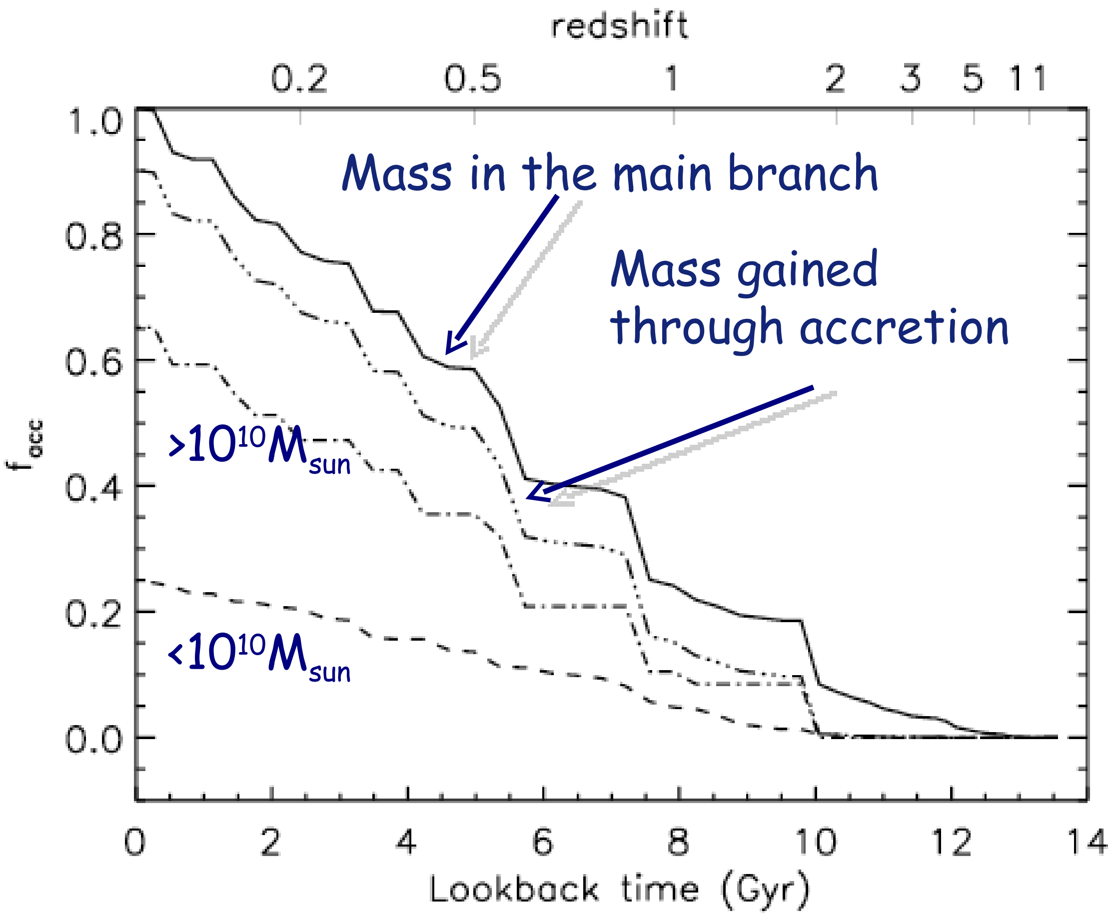
$$N_{\rm eff} = \frac{M^2_{\rm final}}{2\sum_i m_i M_{i,\rm form}}$$

In the case all stars formed in a single object: N=1.
In general, it is a fractional value because of the weighting by the galaxy mass in which stars formed

N.B. This figure includes BCGs

De Lucia et al., 2006

How the BCGs gained their mass

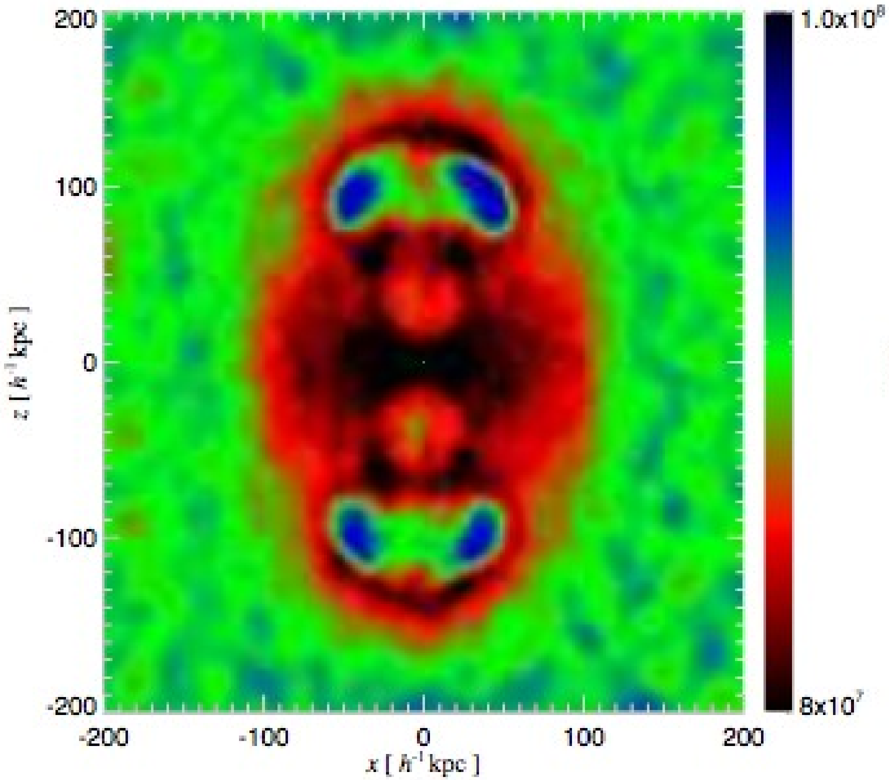


Most of the stars of this BCG were not formed in the main branch, but were instead accreted steadily over time. Most of the mass growth is due to accretion -> most of the stars formed in separate entities mostly as a result of quiescent star formation.

De Lucia & Blaizot 2007

The "radio-mode" of AGN feedback

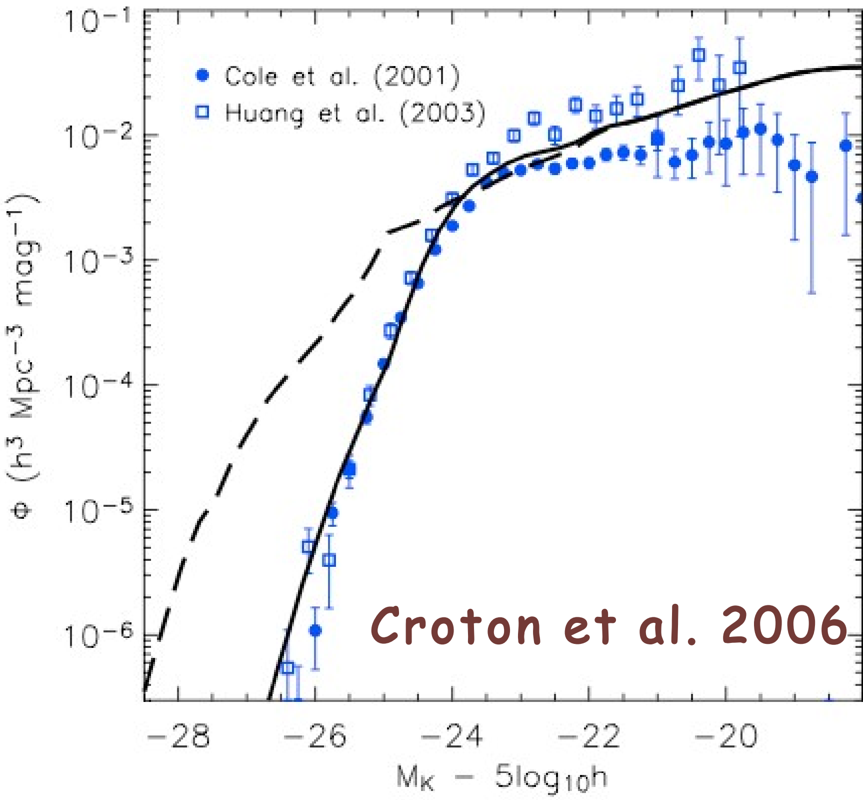
Sijacki & Springel (2006)



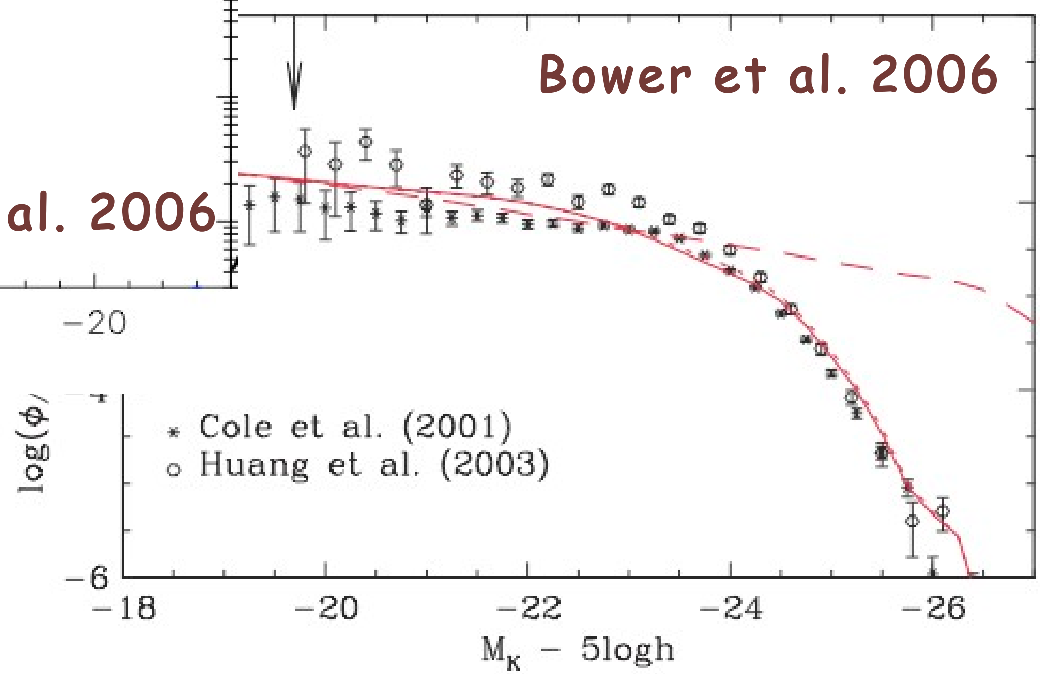
"Success" depends on the duty-cycle (i.e. how recurrent are the bubbles), on the geometry of the energy injection, gas viscosity, etc.

Ensemble-averaged power from radio galaxies seems sufficient to offset the mean level of cooling (but steep dependency of radiative cooling function on density)

The "radio-mode" of AGN feedback

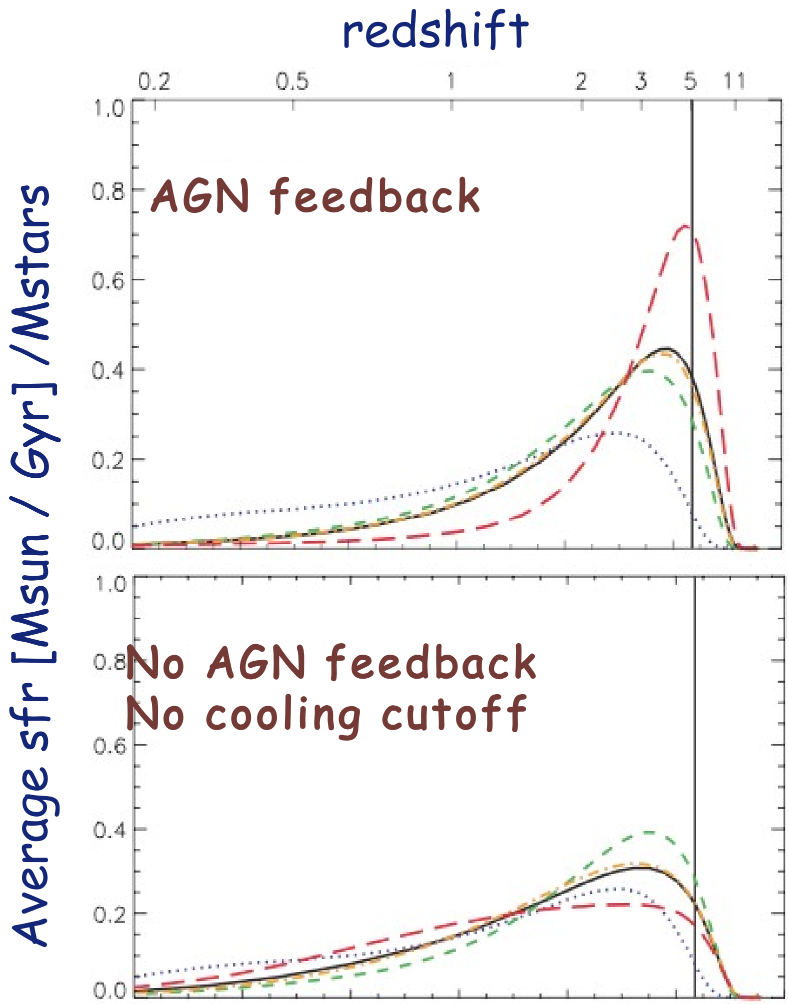


AGN heating suppresses the excess of bright objects and helps getting a smooth turn-over in the luminosity-function



Different (quite simple) models, same conclusion

Why it works (or not?)

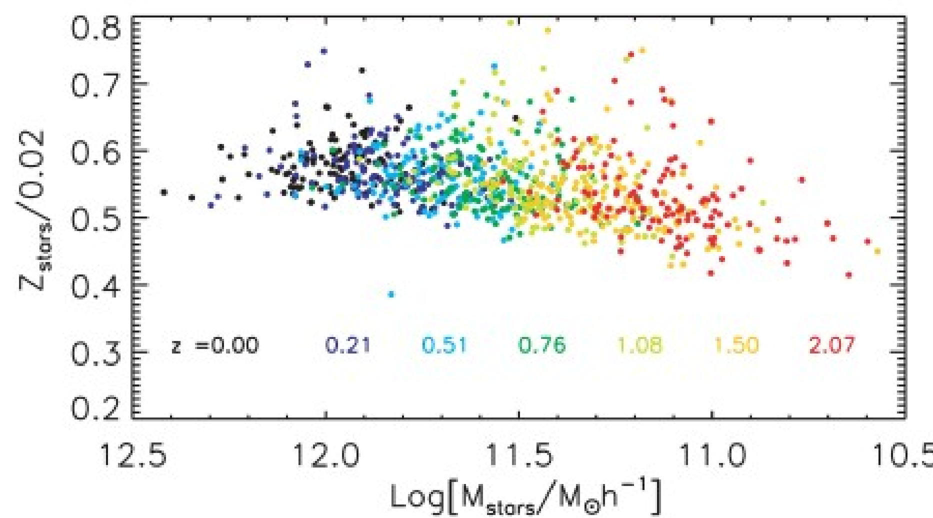


De Lucia et al. 2006

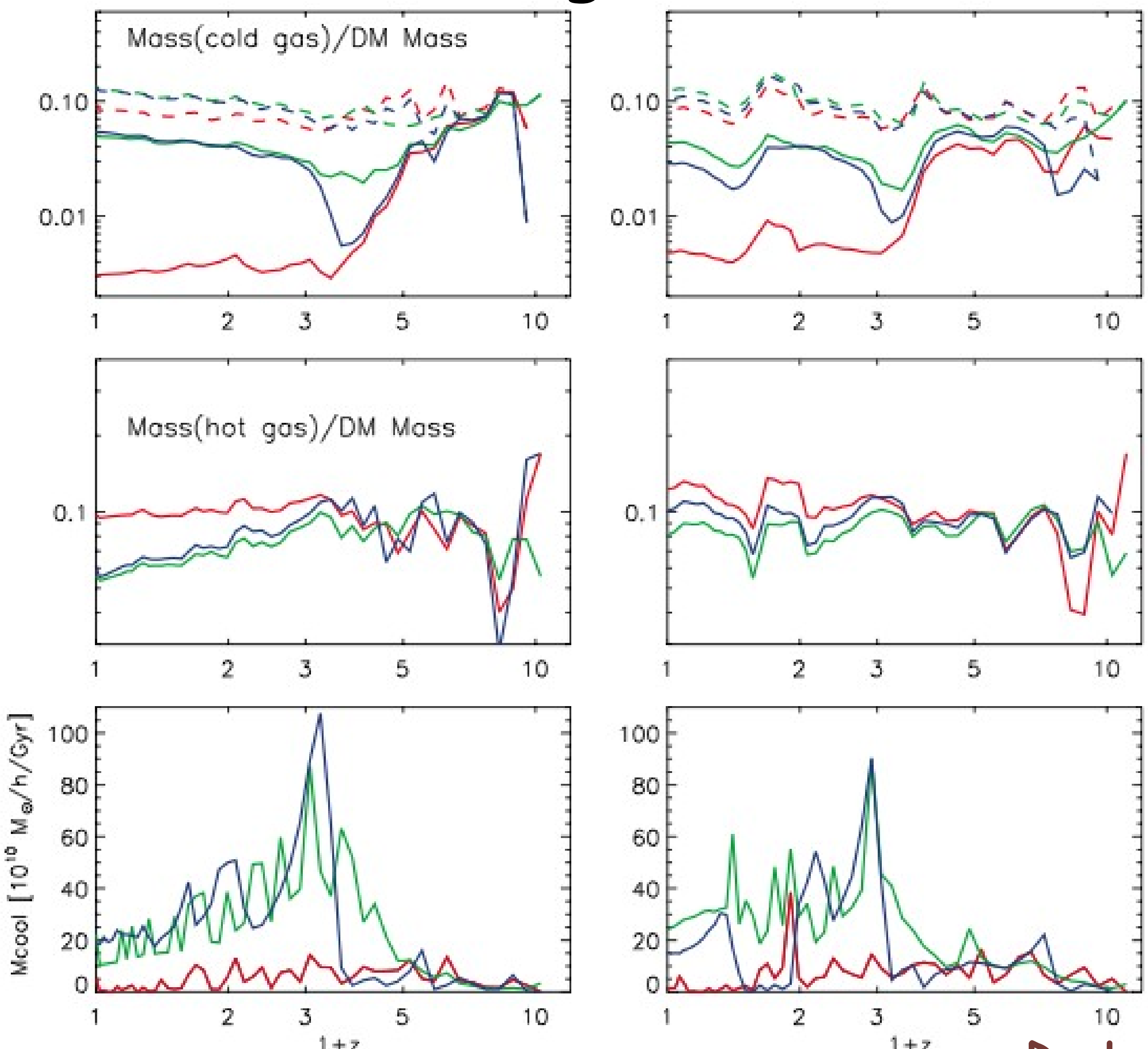
The suppression of late gas cooling naturally gives rise to shorter SFHs for more massive galaxies, in qualitative agreement with obs. (see also Fontanot et al. 2009)

BUT: is suppression too efficient?

De Lucia & Blaizot (2007



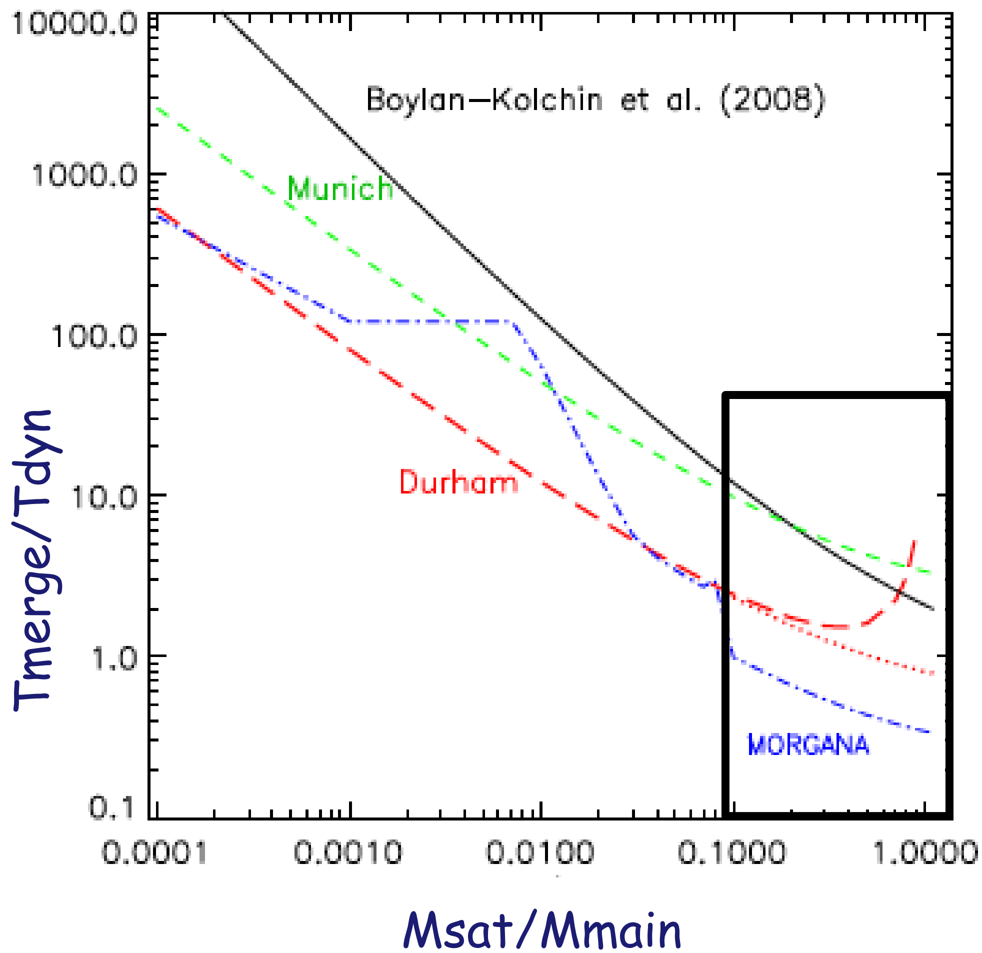
A comment on cooling



Different cooling models predict different cooling rates for massive haloes -> the relative importance of AGN feedback will be different in different models

De Lucia et al. (2010)

Modeling mergers in SAMs



Different 'fudge' factors, different approximations about Coulomb logarithm and orbital distributions (not shown) are used in different SAMs.

Note this is important for the assembly history of massive galaxies, for the timing of bulge formation, and for evolution of the bright end of the mass function.

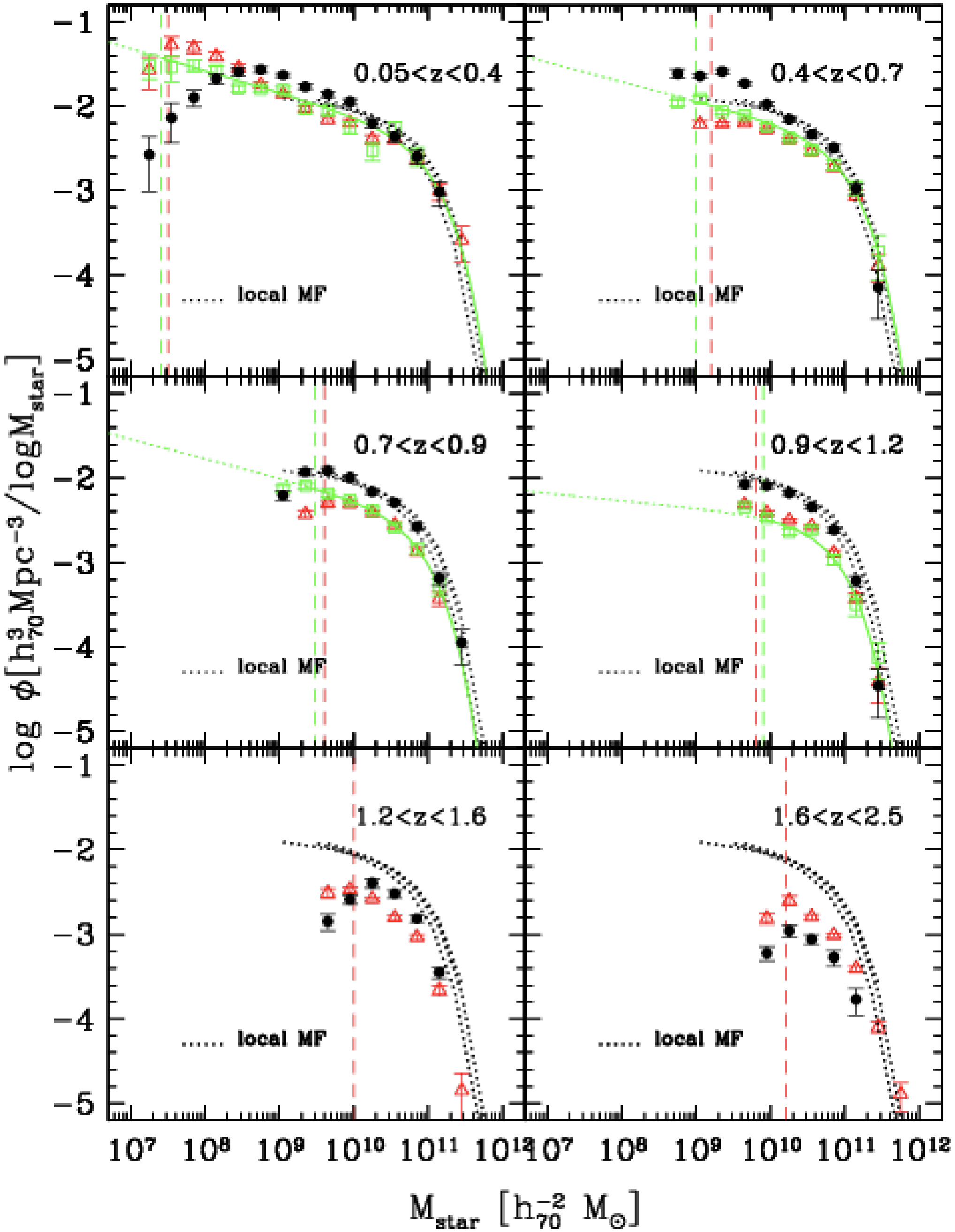
De Lucia et al. (2010)

1 VVDS mock
Masses from SED fitting

Models predict an increase in mass by a factor 2-4 (depending on the stellar mass) since z~1

The agreement with the observed mass functions is quite good. No significant deficit - rather an excess of faint and intermediate mass galaxies

With the VVDS team
Courtesy of Lucia Pozzetti
(also Stringer et al. 2008, Fontanot et al. 2009)

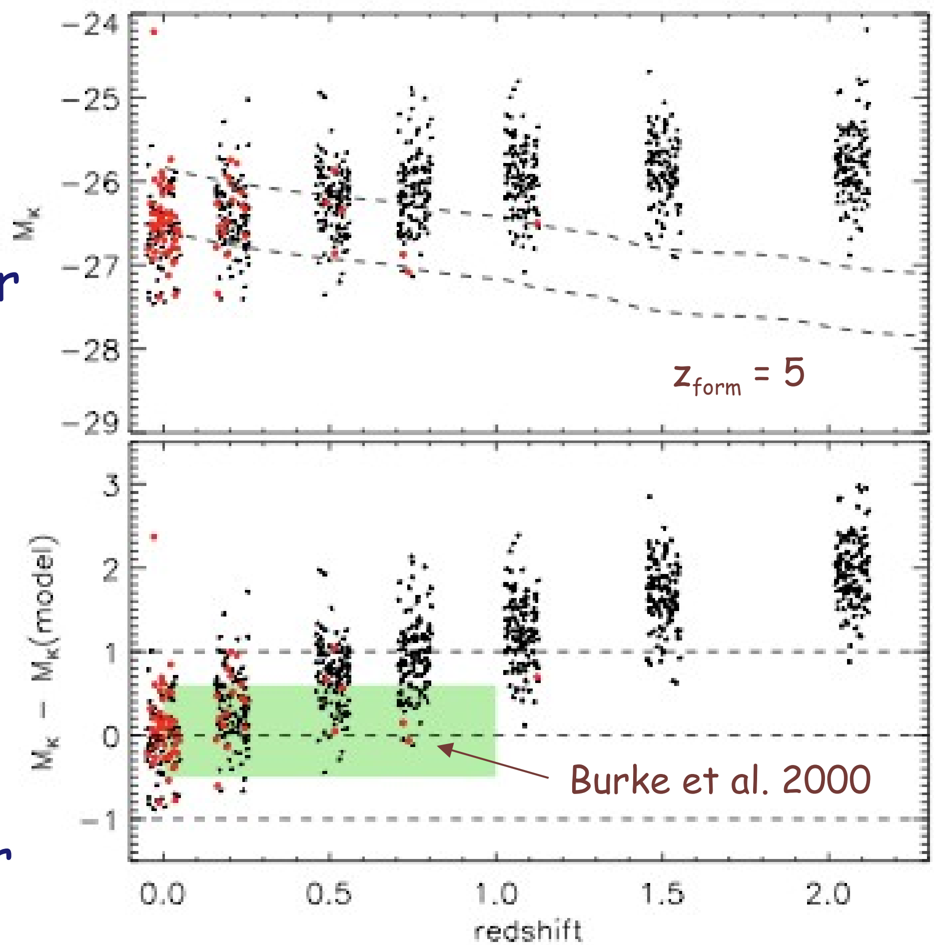


Mass growth of BCGs

Observational data seem to be compatible with no or little growth since z~1, but recent work find evidence for recent accretion events

One important caveat: the intra-cluster light (see also Monaco et al. 2006)

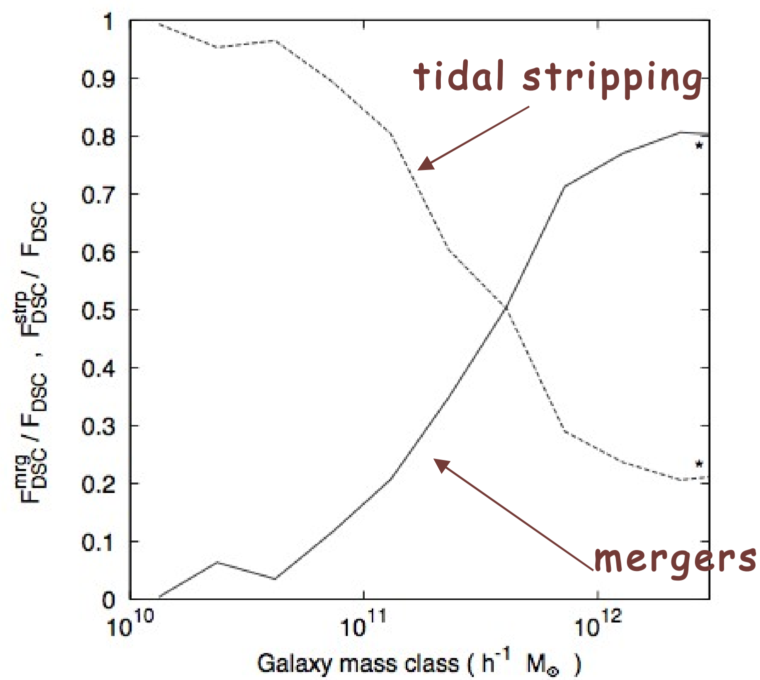
Model magnitudes do not include stars stripped from other cluster galaxies and/or unbound during mergers

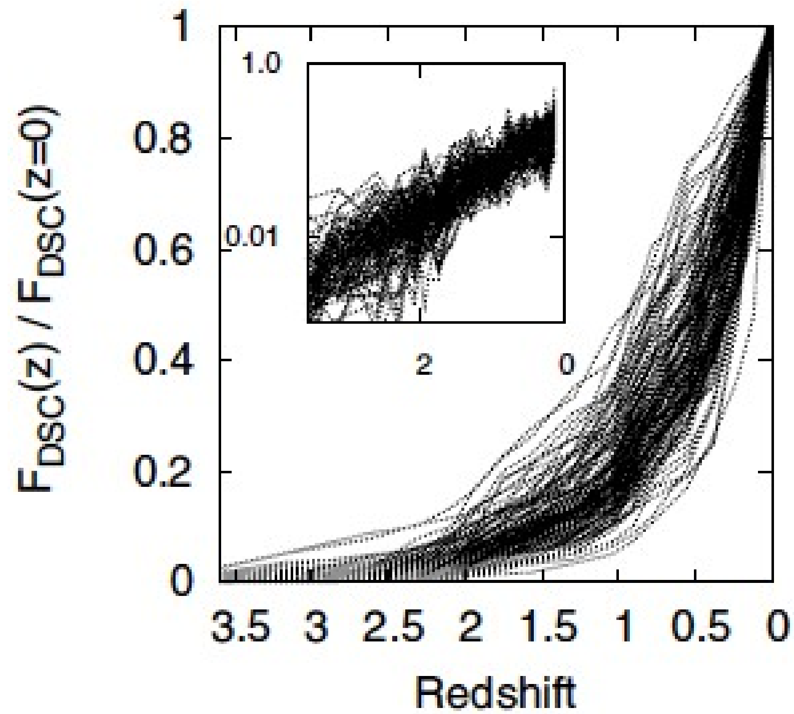


De Lucia & Blaizot 2007

The origin of intra-cluster stars

The production of the DSC is a cumulative process, with no preferred time-scale. There is a large halo-to-halo scatter. Bulk of it becomes unbound at z~1.





Formation of DSC parallels that of the BCGs: most of it comes from particles unbound during mergers, with a minor fraction coming from tidal stripping of satellites.

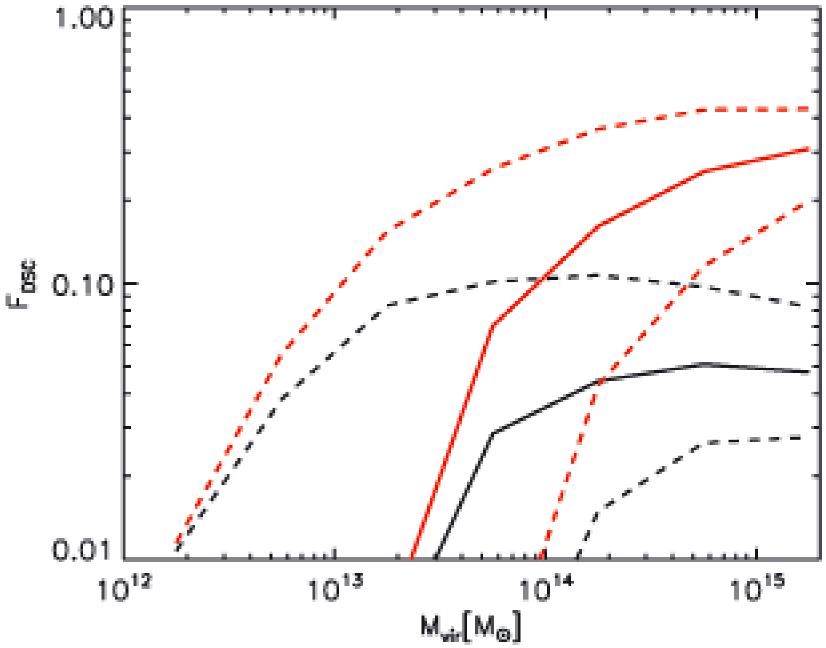
Murante et al. 2007 (see also Willman+ 2004, Rudick+ 2006, …)

Caveats

- ✓ The global fraction of DSC depends on the resolution (increases with higher resolution). Its value has not converged yet and it is generally higher than measured in observations.
- ✓ It depends (albeit weakly) on the method that is adopted to distinguish between BCGs and DSC.
- ✓ A significant fraction of the DSC (up to 30%) forms in cold gas clouds stripped from infalling structures. It is not clear if (and how much of) this `intra-cluster star formation' is affected by numerical resolution. (Fluid instabilities might be able to destroy these clouds and suppress this star formation).
- ✓ Most of the DSC comes from mergers associated with massive galaxies but these simulations do not reproduce well the observed mass function.

Murante et al. 2007; Dolag et al. 2010; Puchwein et al. 2010

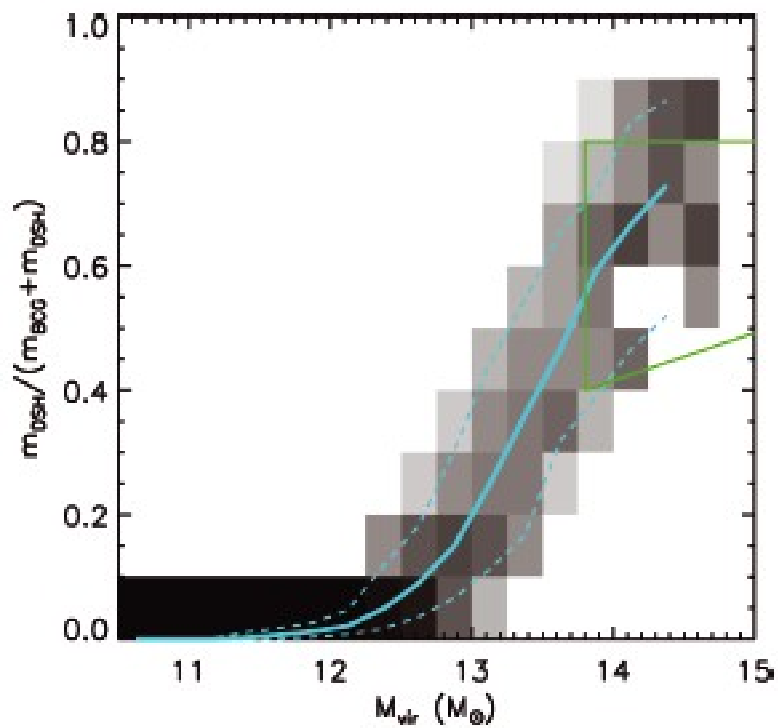
The diffuse component in semi-analytic models



Guo et al. 2011

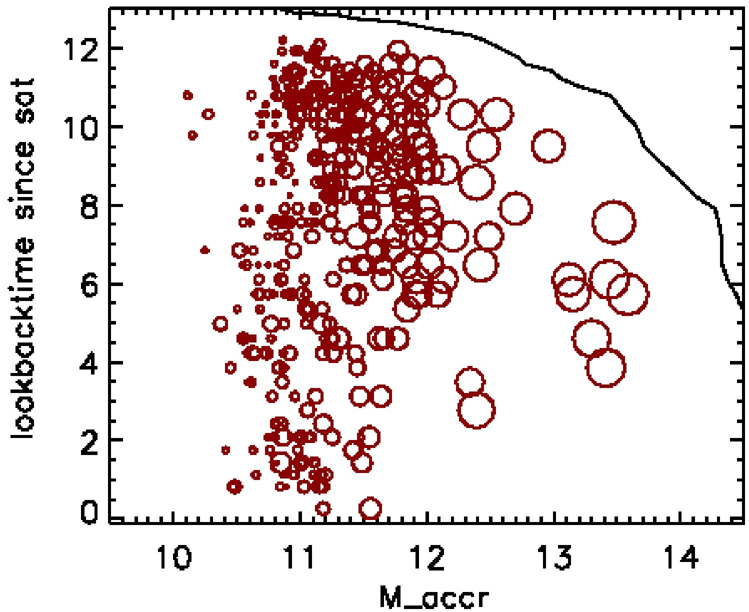
If DSC is assumed to come only from disrupted satellites, the predicted fractions are low w.r.t. observational estimates

Somerville et al. 2008

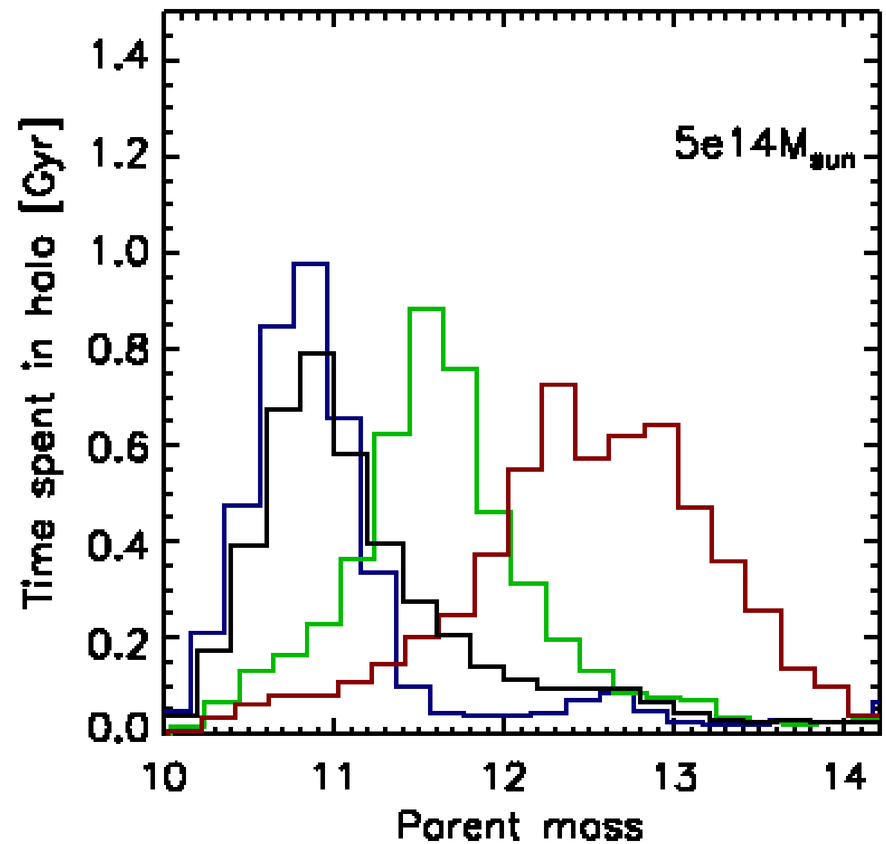


The addition of a `scattered' channel during merger increase the expected fraction. (An upper limit is used).

The environmental history of galaxies



Important piece of information when interpreting environmental studies. "Nature" and "nurture" difficult to disentangle in hierarchical cosmogony.

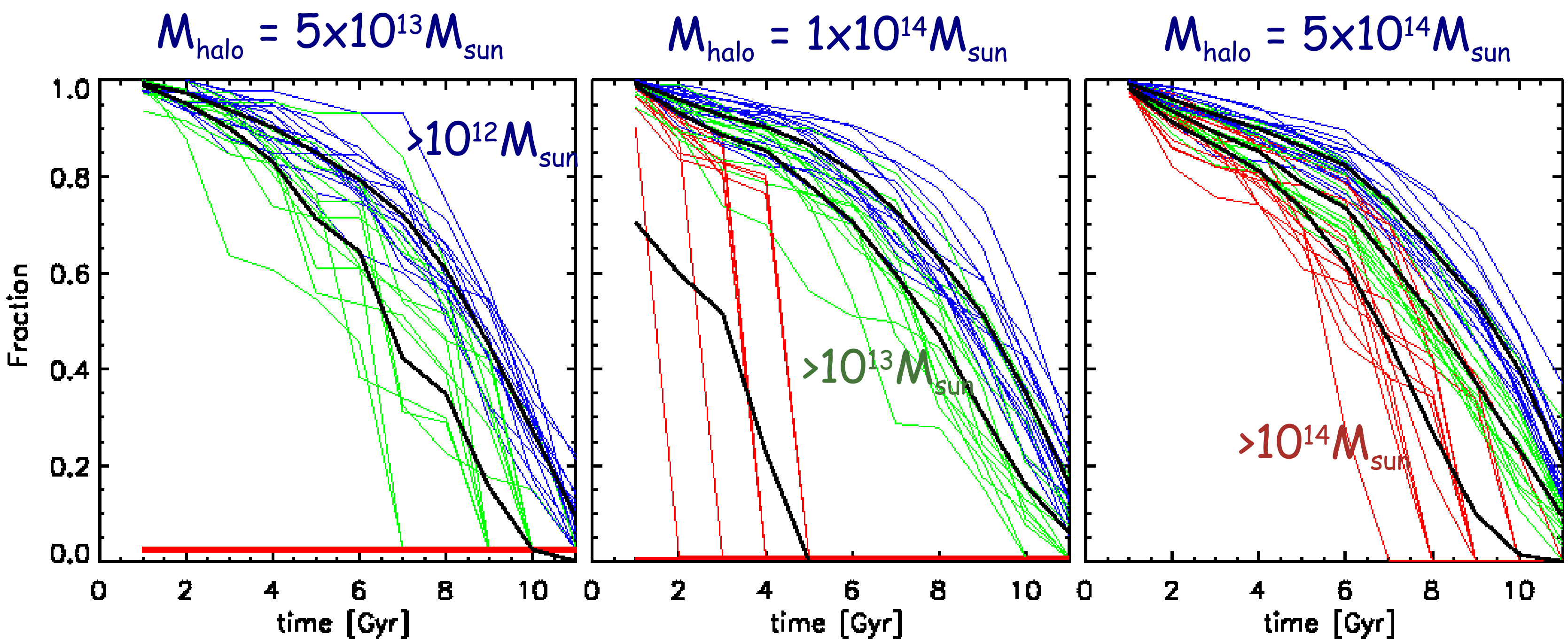


N.B. A significant fraction of the cluster galaxies are accreted onto the main progenitor of the final cluster when they are already satellites.

De Lucia et al., in preparation (see also Berrier et al. 2009, McGee et al. 2009)

The environmental history of galaxies

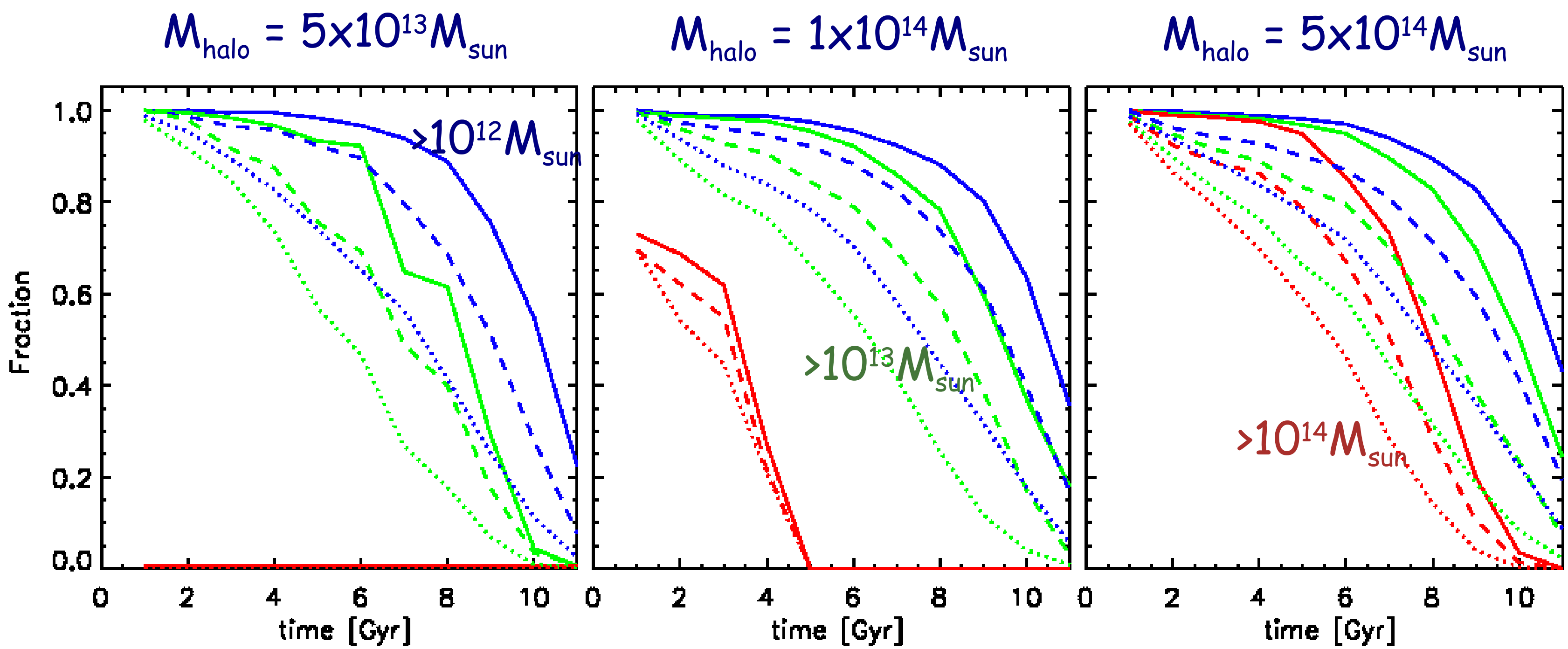
De Lucia et al., in preparation



Large halo-to-halo scatter that would reflect in a scatter in the observed fraction of red/passive galaxies. Trends do not depend significantly on galaxy mass.

The environmental history of galaxies

De Lucia et al., in preparation



But a clear dependence as a function of cluster-centric distance. This is a natural consequence of the incomplete mixing of cluster galaxy populations: galaxies closer to the centre were accreted earlier.

Conclusions (and open issues)

- ✓ Some suppression of gas condensation (at low z and in relatively massive haloes) is needed in order to explain the cooling flow problem. Current models implement "simple" recipes. Details (duty cycle, geometry, etc.) are still to be understood.
- ✓ Mergers (and accretions) play an important role in the formation of massive galaxies, but number of important mergers relatively low and still some uncertainties in the modelling.
- ✓ Formation of the intra-cluster light is associated with that of the massive cluster galaxies. More observational data (distributions, chemical compositions) are coming. Detailed theoretical predictions are needed.
- ✓ Difficult to understand the role of nature and nurture. One piece of the information that needs to be taken into account is the "environmental history of galaxies".