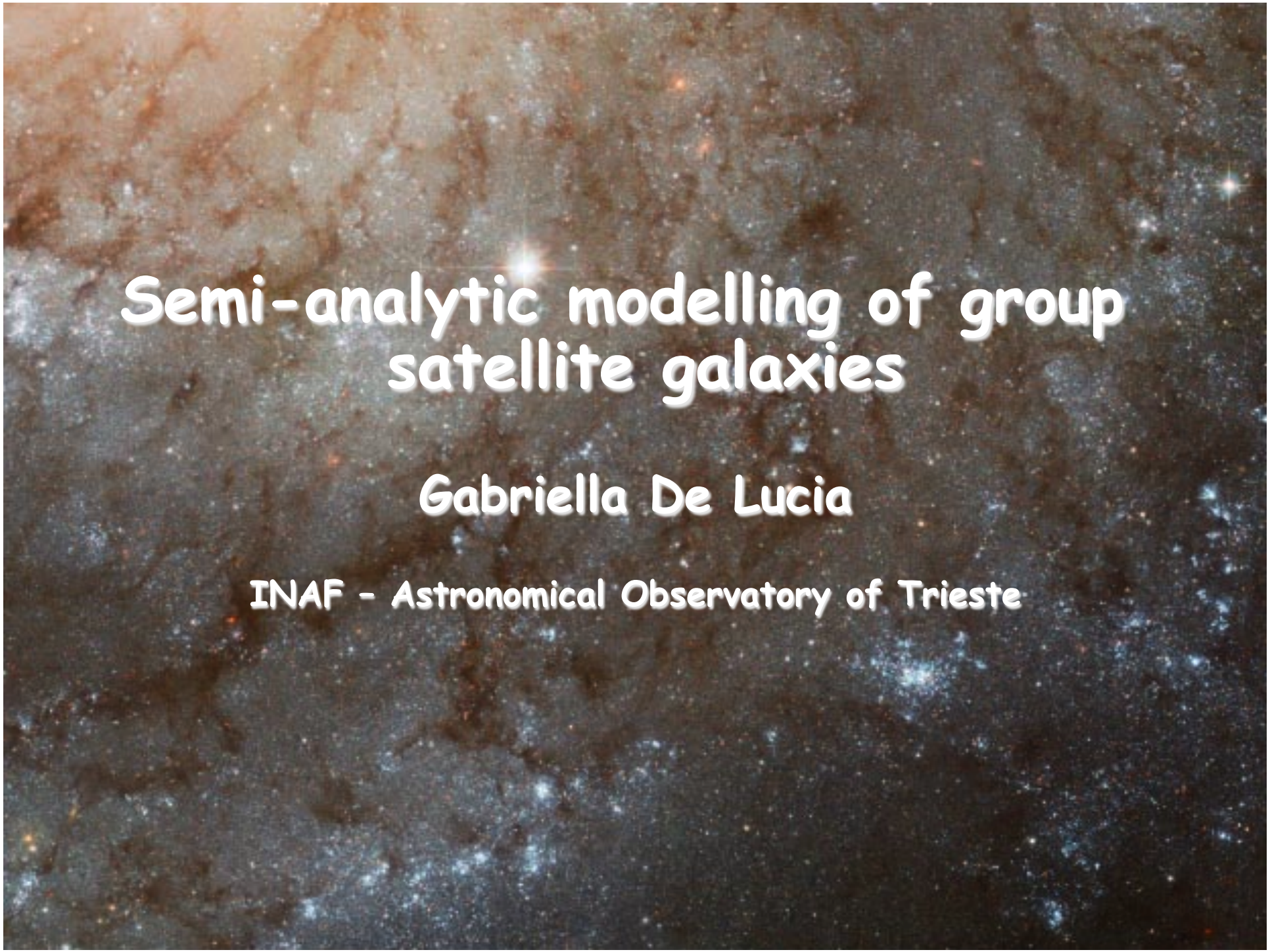
Semi-analytic modelling of group satellite galaxies
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Central and satellite galaxies

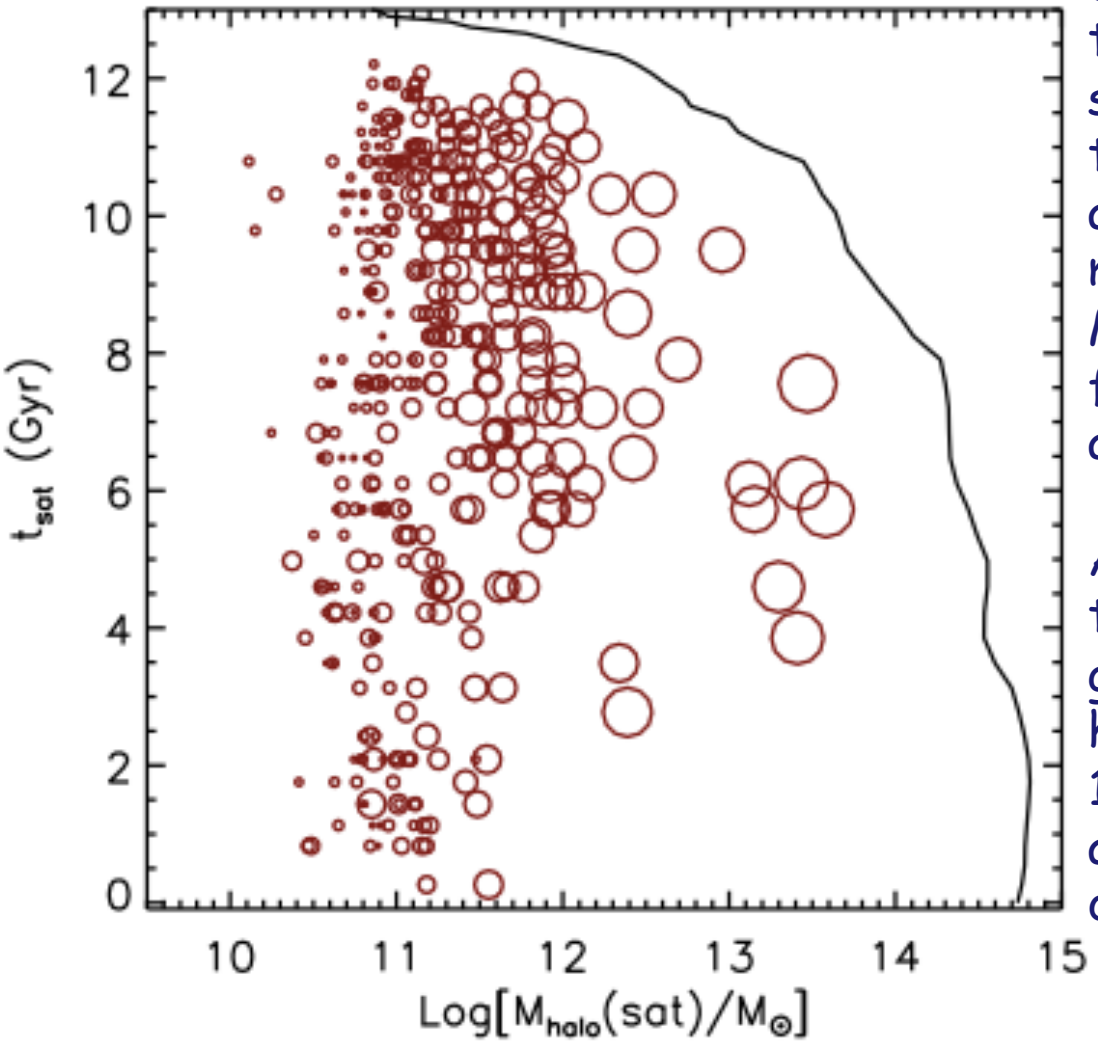
Credit: NASA/JPL-Caltech/GSFC/SDSS

The distinction is obvious (and convenient) from the theoretical point of view. Observationally, it is "easy" for clusters (not always, e.g. Coma), but often difficult (maybe inappropriate?) for lower mass systems.

With the aid of numerical simulations, this distinction is now routinely applied to observational data (not just for galaxy clusters). Distinction still used to interpret observational data.

Built-in in a hierarchical Universe

De Lucia et al. 2012

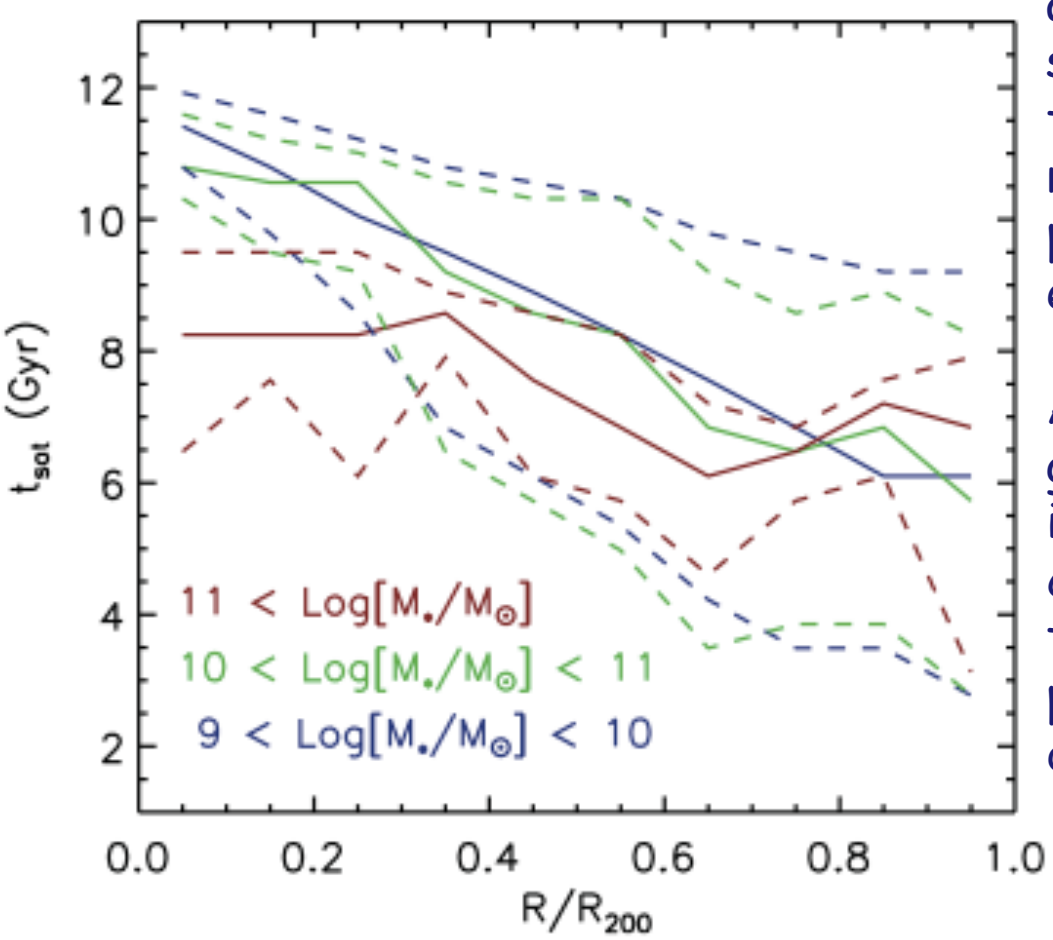


Slightly less than half of the most massive satellites in a cluster today have been accreted from haloes more massive than 10^13 Msun – a significant fraction have been accreted as 'centrals'.

About one third of low-to-intermediate mass galaxies accreted from haloes more massive than 10^13 Msun – almost all are satellites at the time of accretion.

Built-in in a hierarchical Universe

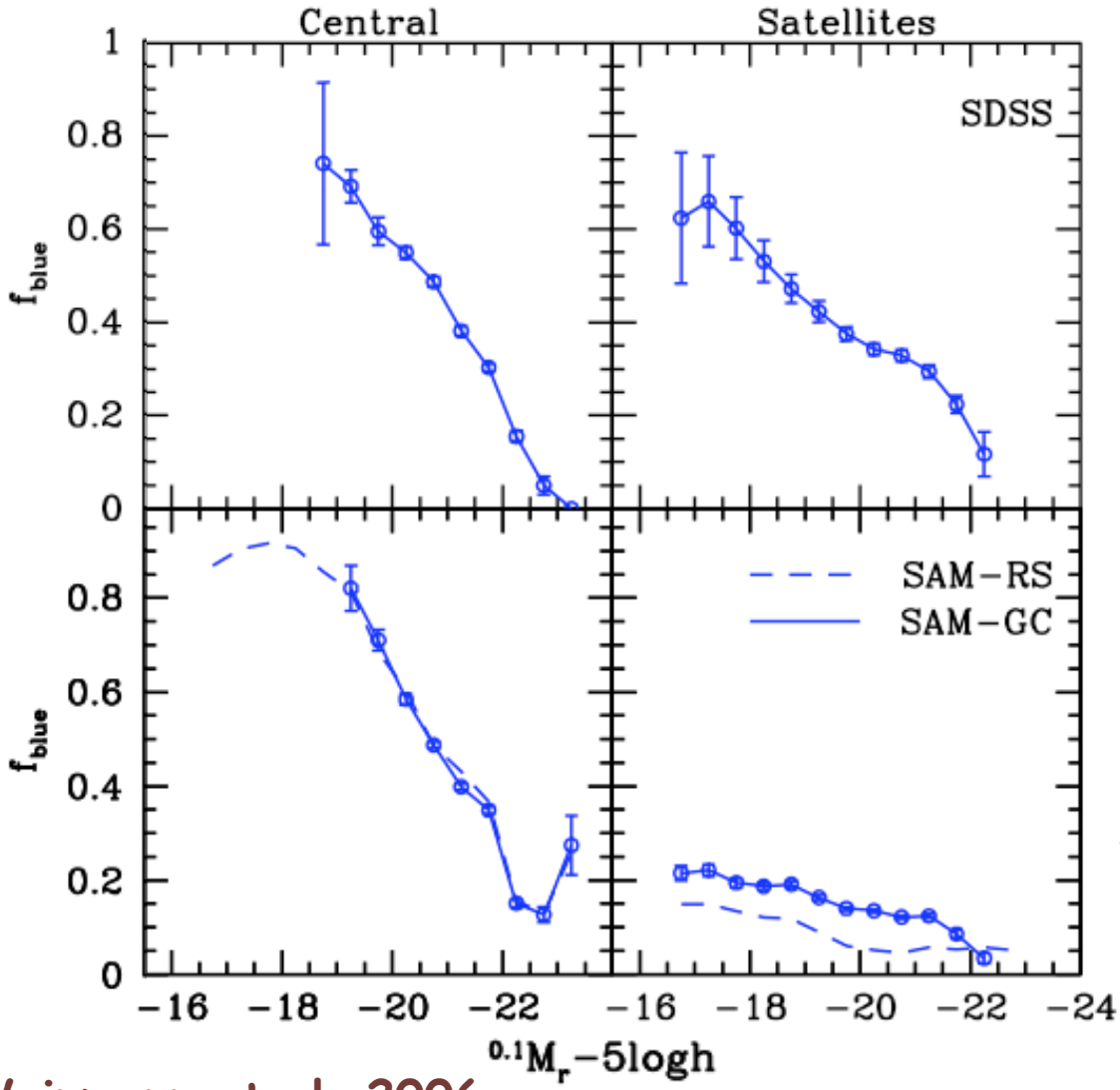
De Lucia et al. 2012



Dynamical friction + short orbital times of haloes accreted early on creates a strong correlation between the accretion time and the radial distance from the parent halo centre (e.g. Gao et al. 2004).

A radial dependence of galaxy population is, at least in part, a natural consequence of the fact that mixing of the galaxy population is incomplete during cluster assembly.

Over-quenching of satellite galaxies



Weinmann et al. 2006

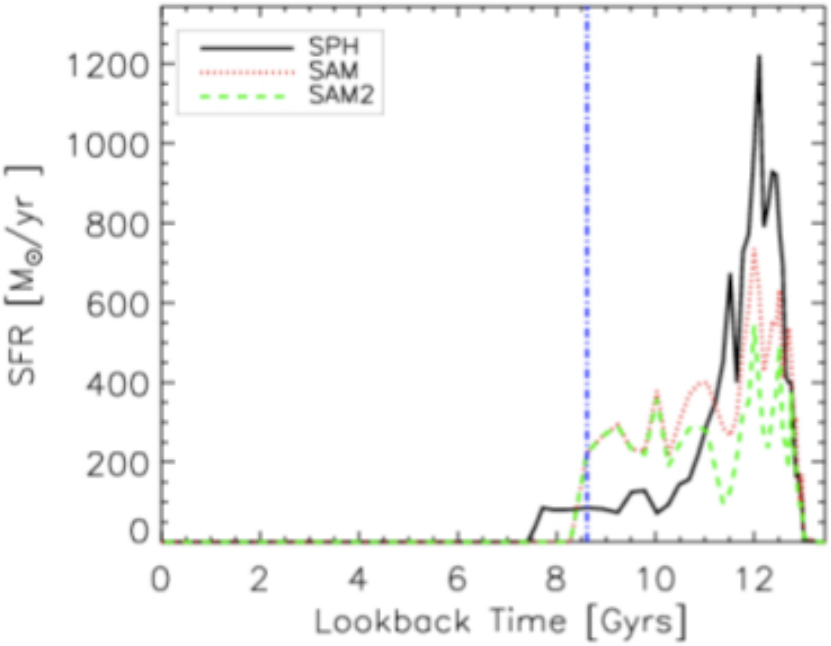
The fraction of blue (satellite) galaxies in the models is below the observational data, more so in low-mass haloes.

This problem is shared by all models published in those years (see e.g. Fontanot et al. 2009).

Is this due to an over-simplified treatment of the "strangulation"?

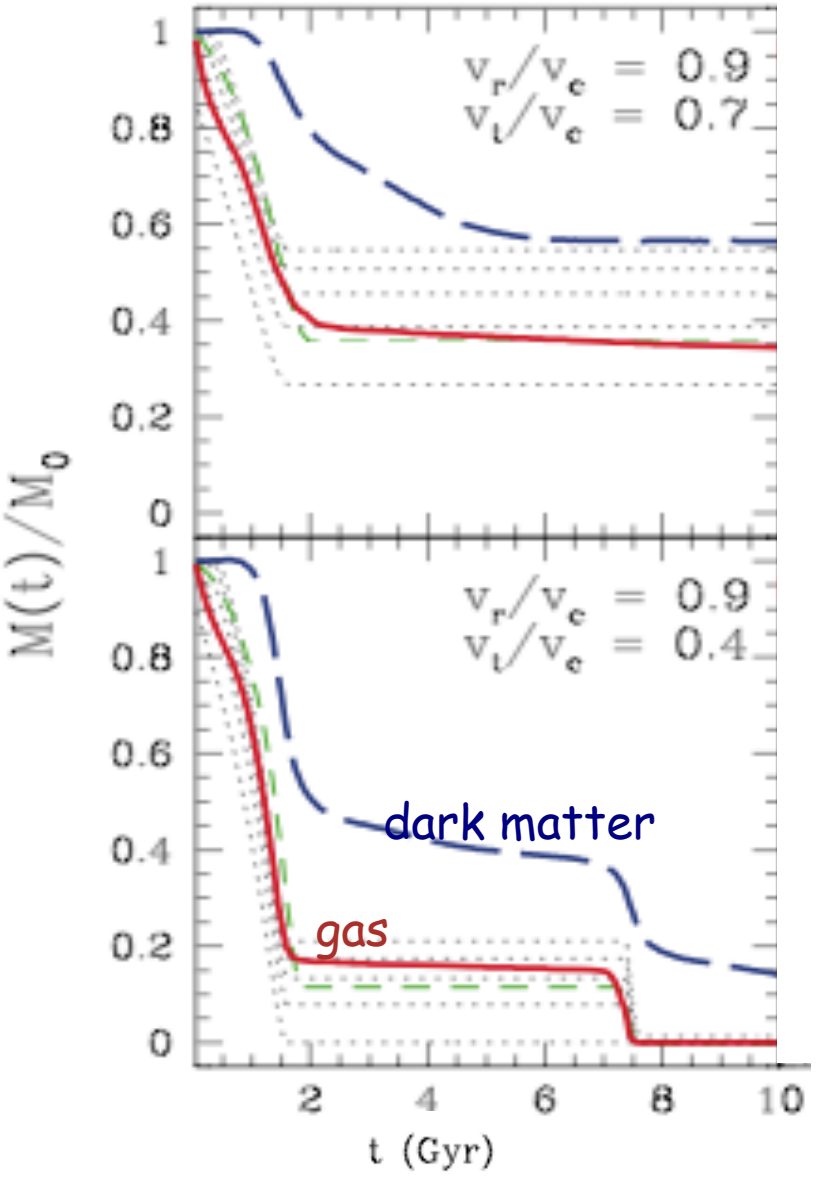
Strangulation

Later controlled simulations showed that hot gas is indeed significantly stripped at first pericentre but (depending on the orbit) some fraction can stay attached to the galaxy for several Gyrs. If this gas cools, it can increase the fraction of active satellites.



Saro et al. 2010

McCarthy et al. 2008

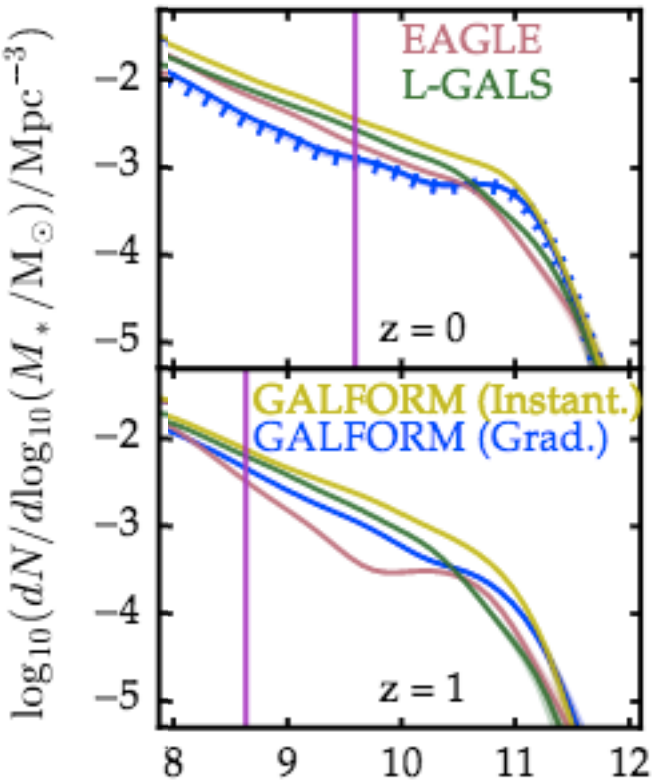


Better but still not that good

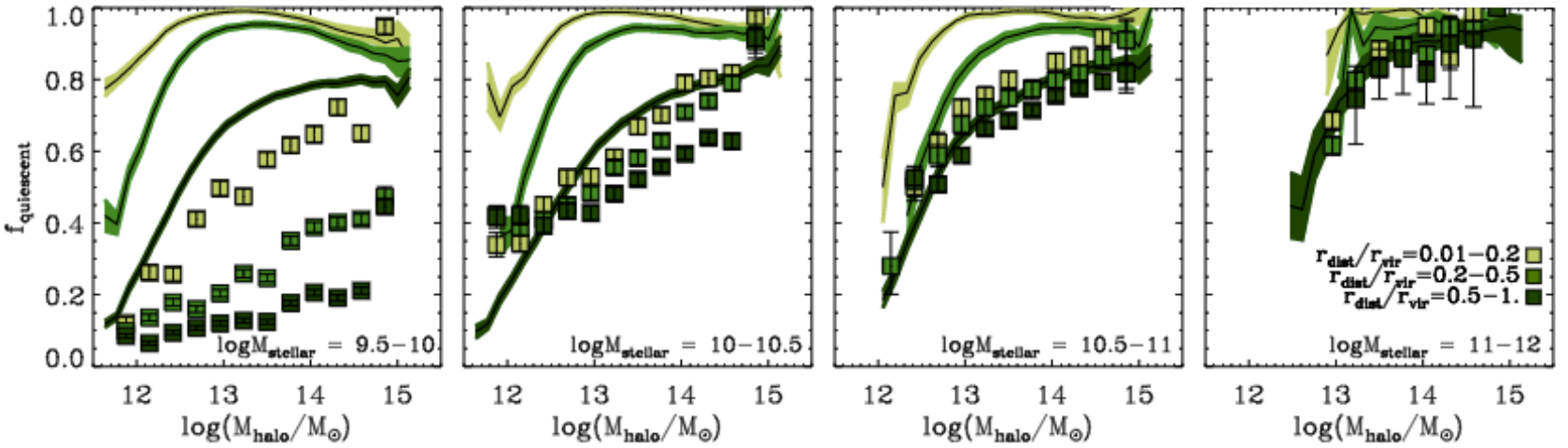
Modified treatment of satellite galaxies (a more gradual stripping of the hot gas and sometimes a modification of the timings) improve the agreement with observational data.

Most models (including simulations) however, still over-predict the fraction of quiescent satellites with the problem becoming worse for low stellar masses.

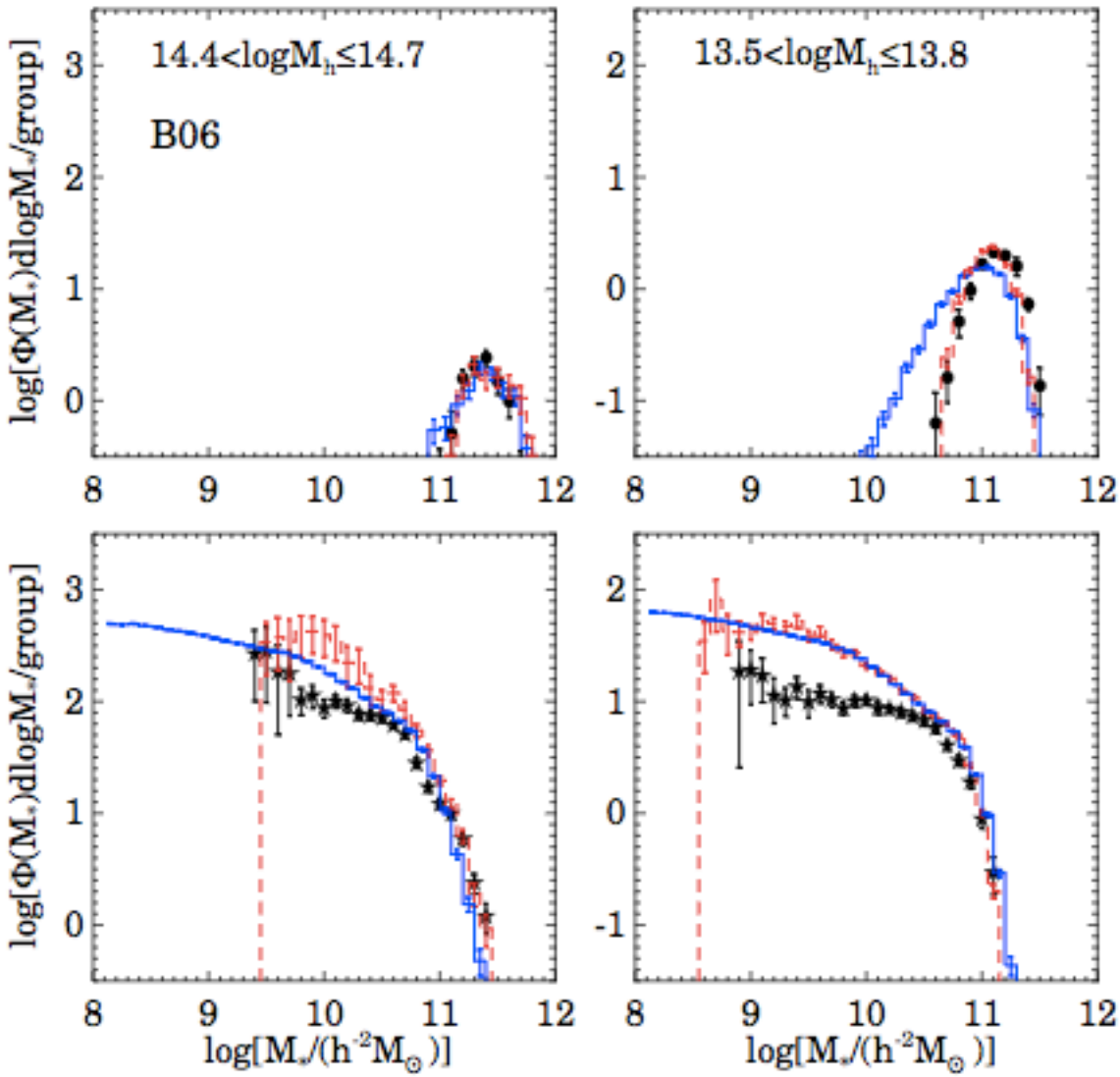
Guo et al. 2016



Hirschmann et al. 2014



Excess of (satellite) galaxies



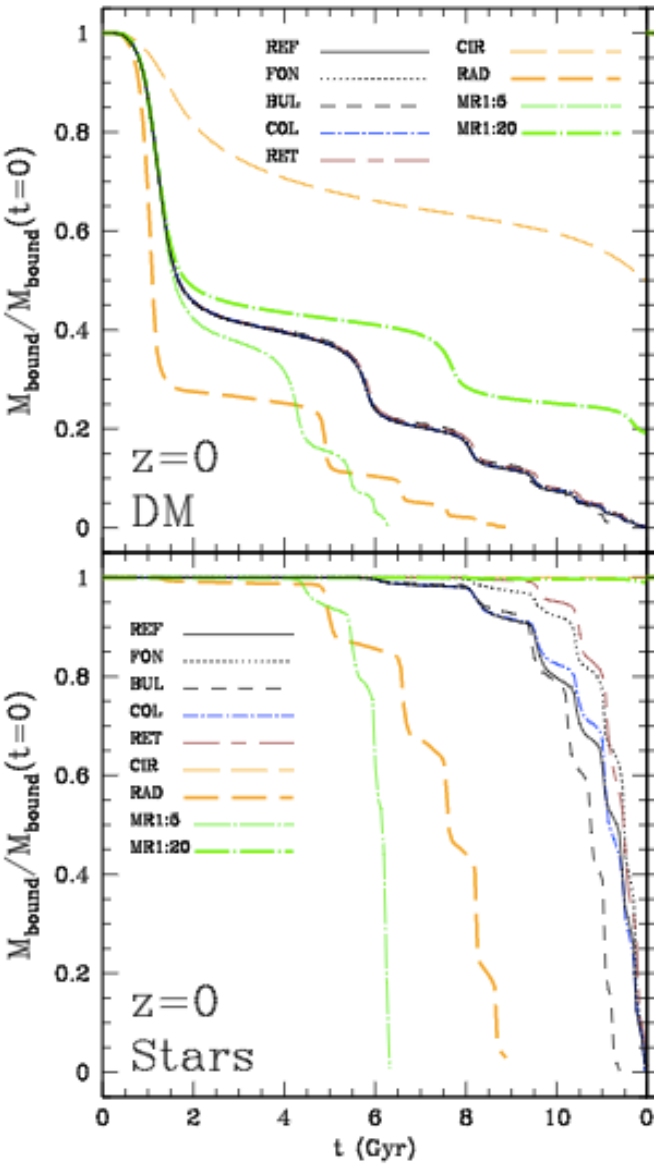
Liu et al. 2010

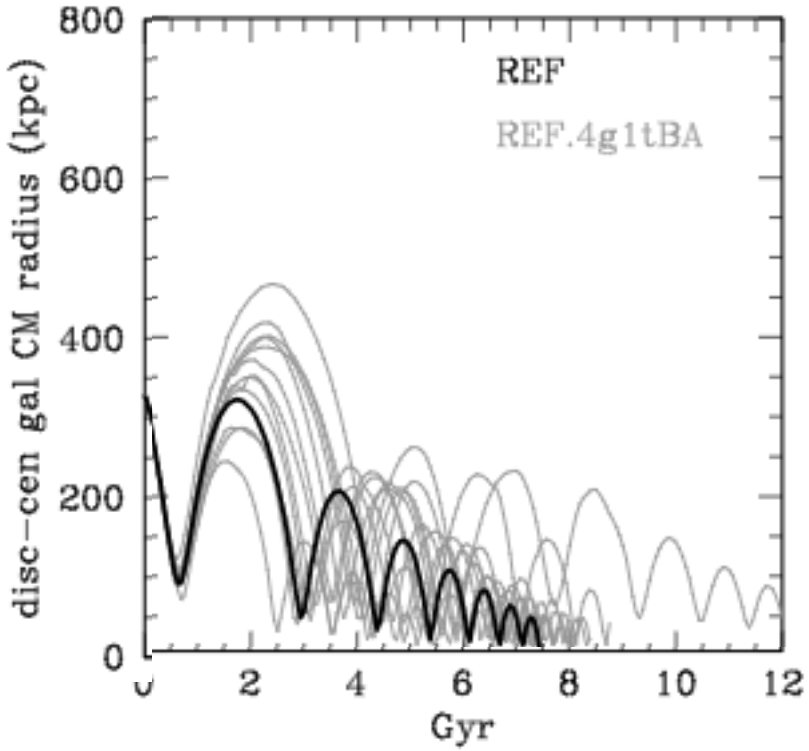
Models tend to over-predict the number densities of low to intermediate mass galaxies.

This problem is shared by all models published in those years (see e.g. Fontanot et al. 2009, Wang et al. 2013).

How much can this be alleviated by the inclusion of a treatment for stellar stripping (and the formation of diffuse stellar component)?

Stellar stripping and merging times





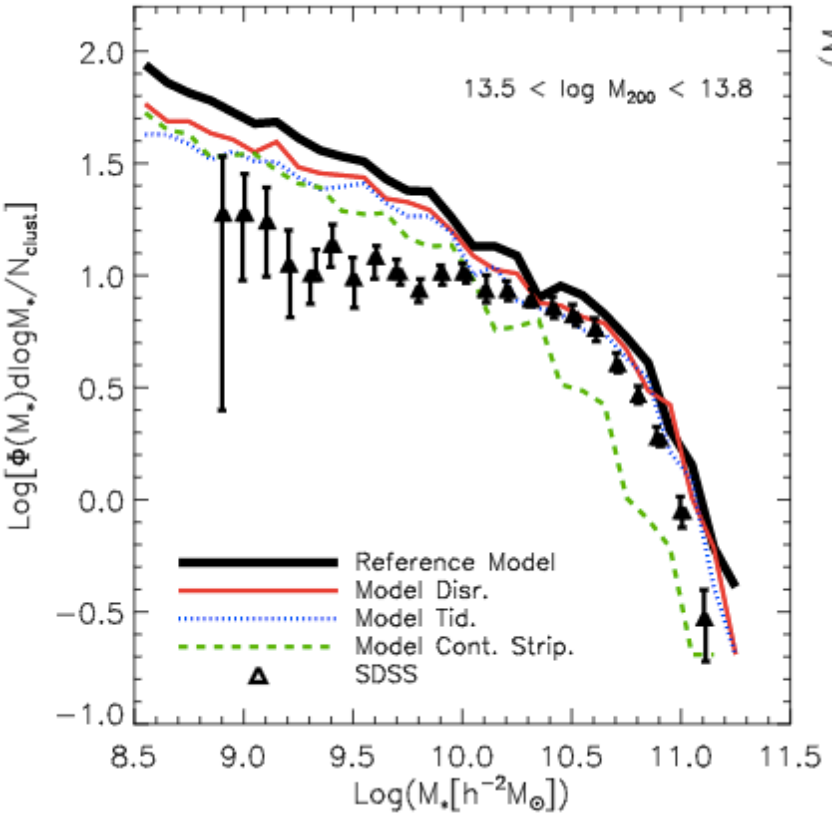
Stellar stripping starts only after dark matter has been significantly reduced; depends strongly on the orbit of the satellite (unsurprising) and on presence of other galaxies (often neglected).

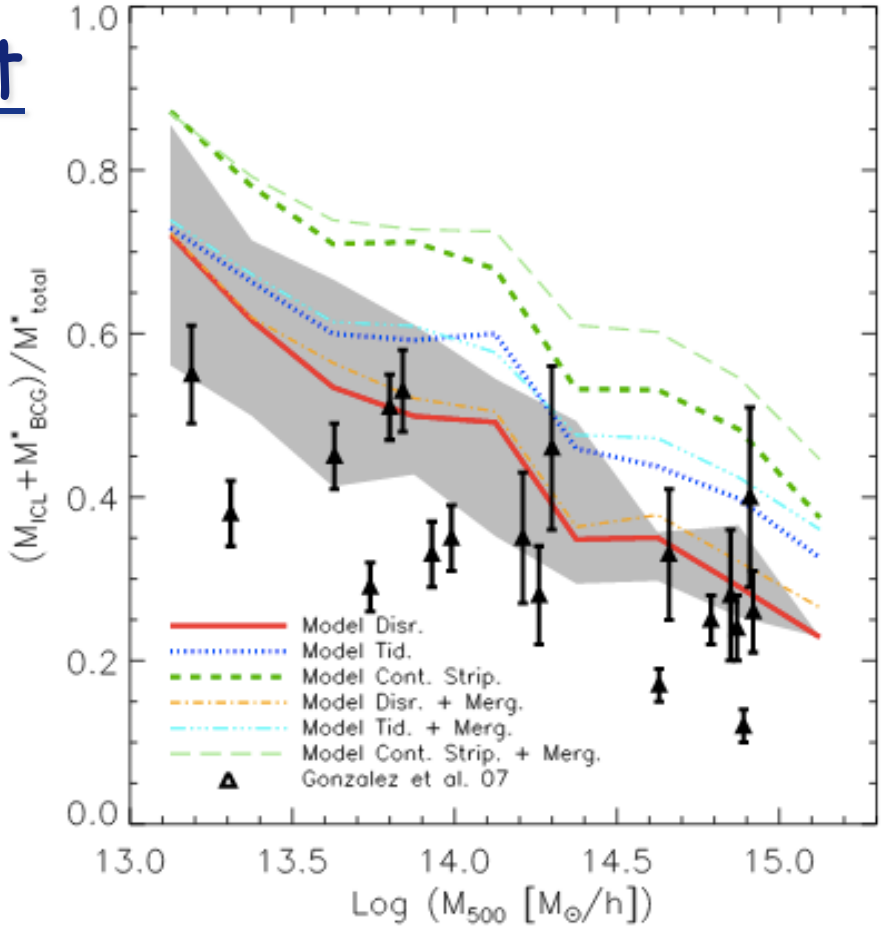
Villalobos et al. 2012, 2014

Diffuse stellar component

A merger channel plus tidal stripping of stars associated with satellites. Qualitative agreement with observational data.

Contini et al. 2014

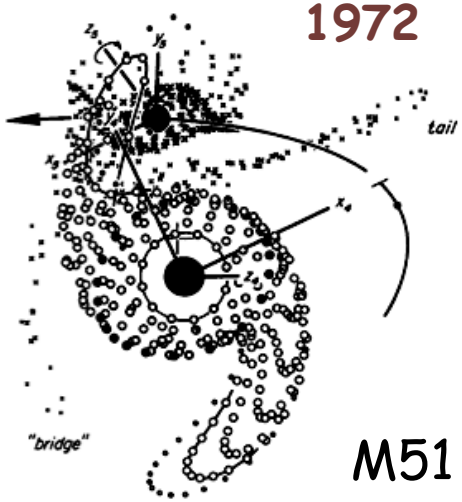




Only a moderate influence on the stellar mass/abundance of intermediate to low mass galaxies that are still over-abundant with respect to data..

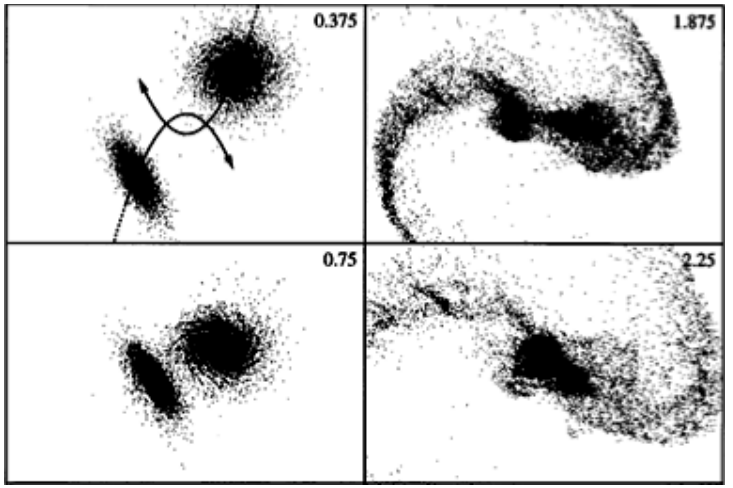
Galaxy mergers

Toomre & Toomre 1972

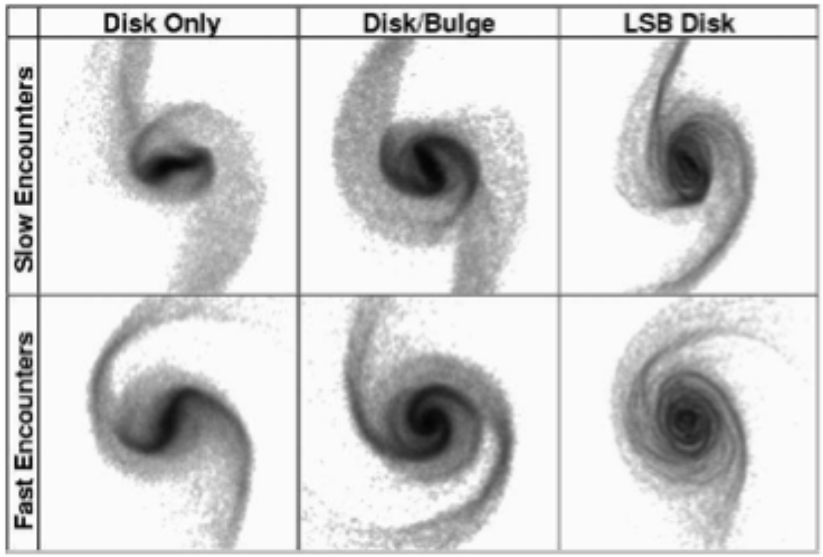


M51

Strong internal dynamical response driving the formation of asymmetries in the disk that leads to the inflow of gas towards the central region and its compression.



Barnes & Hernquist 1996



Mihos 2004

A bulge or of a lowered disk surface density stabilizes the system against the growth of instabilities.

In a sufficiently close encounter, violent relaxation destroys the dynamically cold disk and produces a kinematically hot merger remnant.

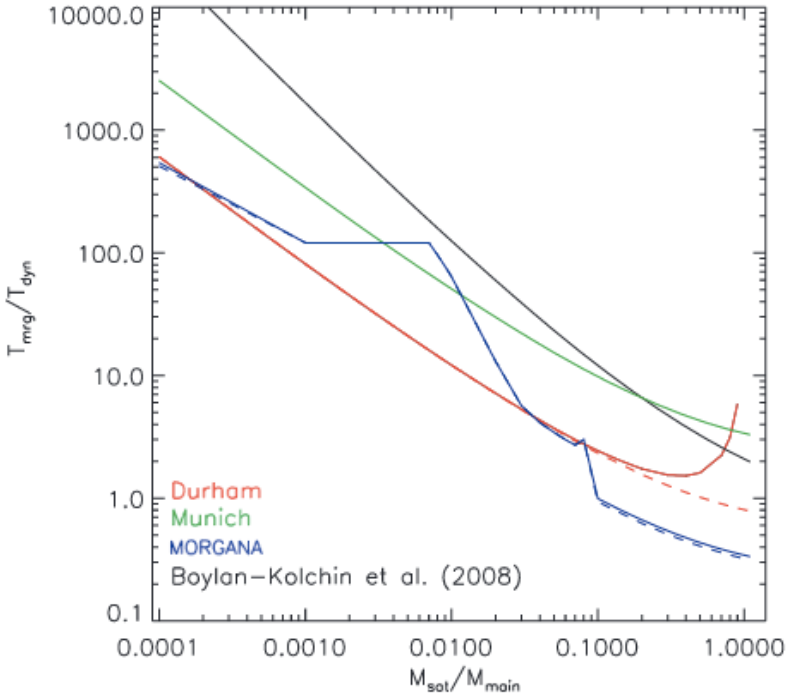
Presumed connection with AGN activity.

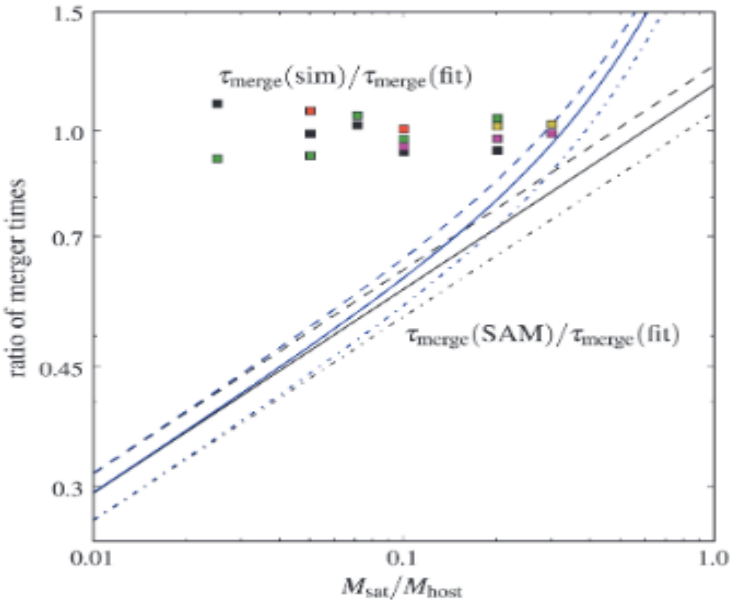
Galaxy mergers

Controlled simulations show that the classical Chandrasekhar formula tends to over-estimate merging times.

$$\frac{\tau_{\rm merge}}{\tau_{\rm dyn}} = 1.17 \frac{f_{\rm df}\,\Theta_{\rm orb}}{\ln\Lambda} \frac{M_{\rm host}}{M_{\rm sat}}$$

Boylan-Kolchin et al. 2008



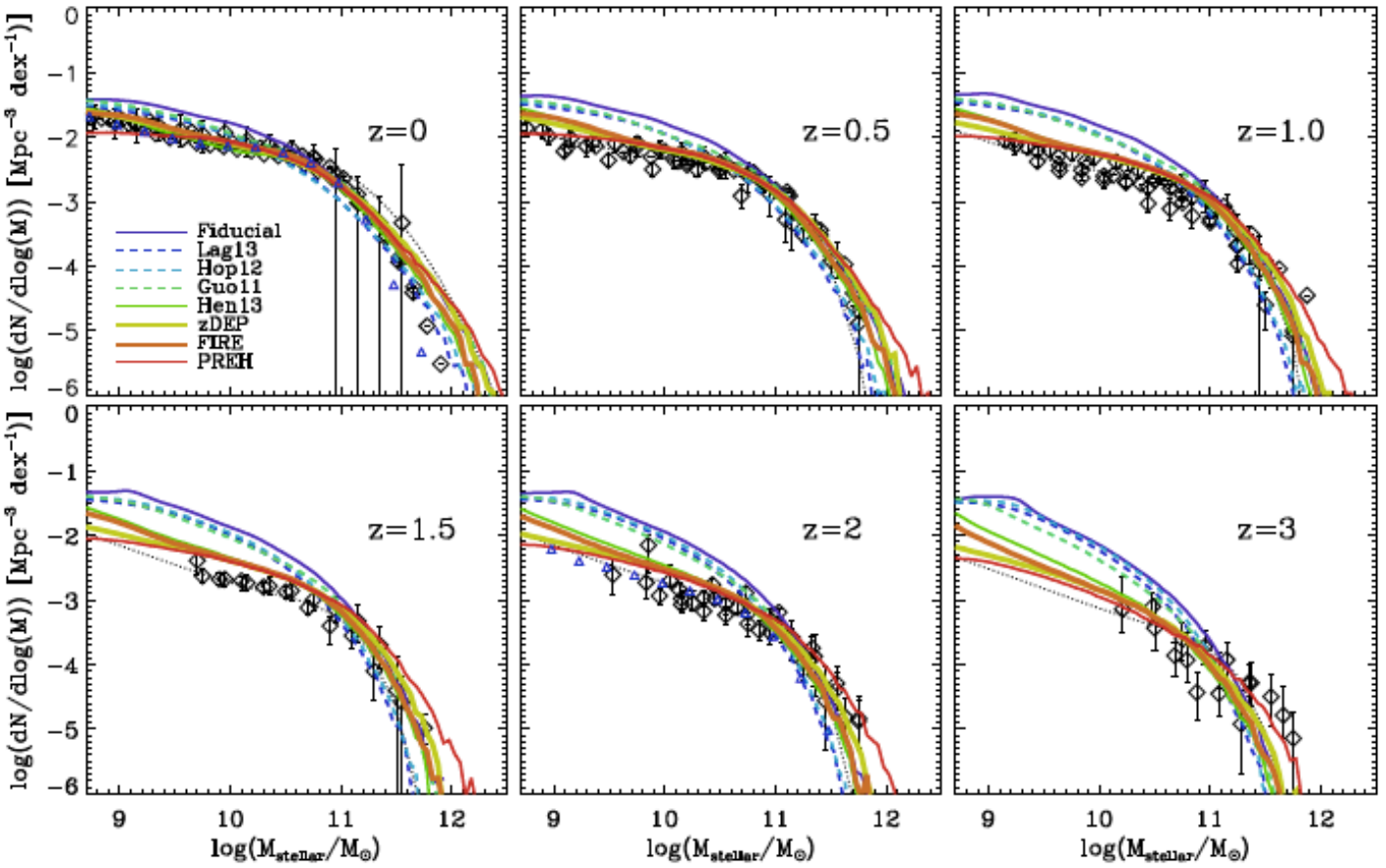


Different parametrizations adopted in different models. Can affect the mass and accretion history of centrals, and the number of satellites.

Note that the same formula is used at all redshifts and no scatter is accounted for due to the presence (and different mass and spatial distribution of other satellite galaxies in the same halo)

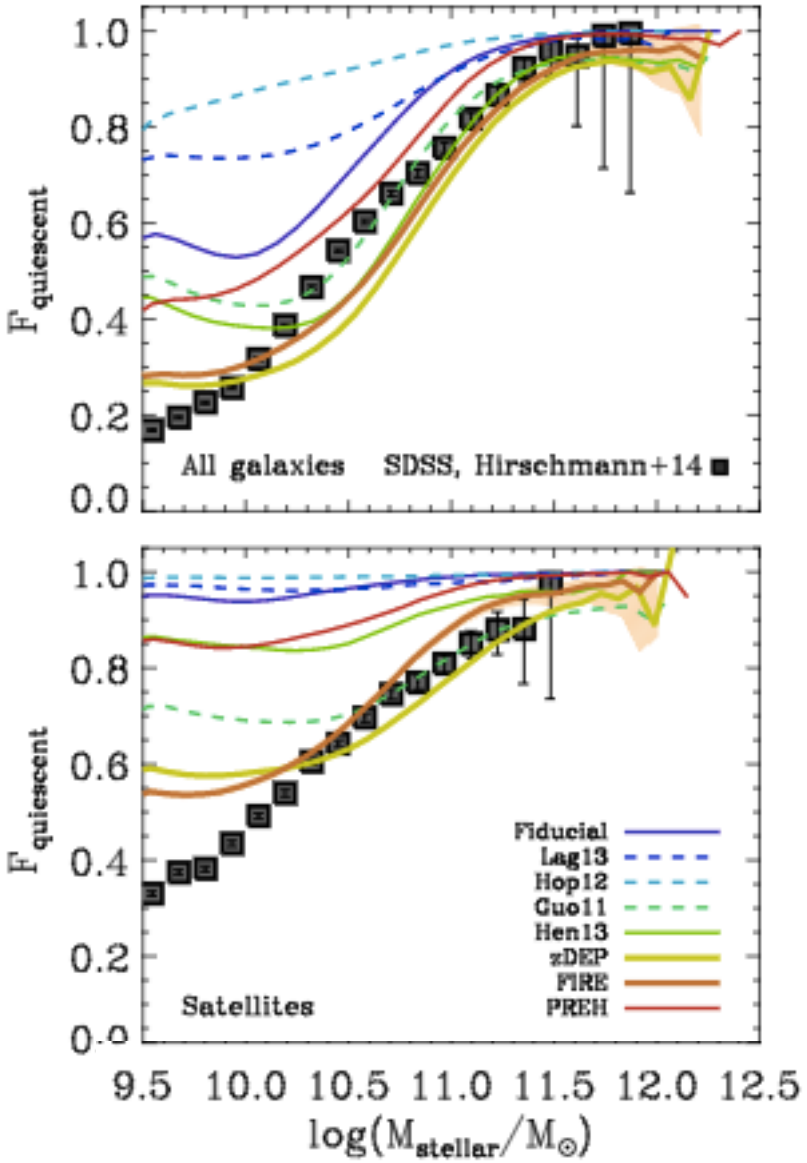
Is satellite treatment important?

Hirschmann et al. 2016



Updated chemical enrichment treatment (non instantaneous recycling of metals, gas, and energy) plus updated scheme for stellar feedback – INSTANTANEOUS STRIPPING OF HOT GAS

Is satellite treatment important?



Model reproduces nicely quiescent fraction of both central and satellite galaxies as a function of stellar mass (plus other important constraints like the mass-metallicity relation)

Primarily driven by change in physical properties of galaxies at accretion (i.e. before they become satellites).

Updated treatment of satellite important only at lowest masses considered.

Hirschmann et al. 2016

Concluding remarks:

✓ Galaxy evolution takes place in a hierarchical framework: galaxies experience different environments during their life-time. A correct interpretation of the observational data needs to take into account the environmental history of galaxies.

✓ Satellites and centrals are different "by construction" in SAMs (but they turn out to be very different in hydro-sims as well). Very difficult to keep star formation going on for very long times particularly for lower mass satellites.

✓ Over-quenching and over-production of satellite galaxies with low and intermediate masses a serious problem for theoretical models of galaxy formation in the last decade. An improved treatment of the satellite evolution can alleviate the problems, but does not solve them.

✓ Group pre-processing important for low-to-intermediate mass galaxies. For these, additional `environmental' processes are clearly needed to reproduce the observed trends.