GAEA: an overview

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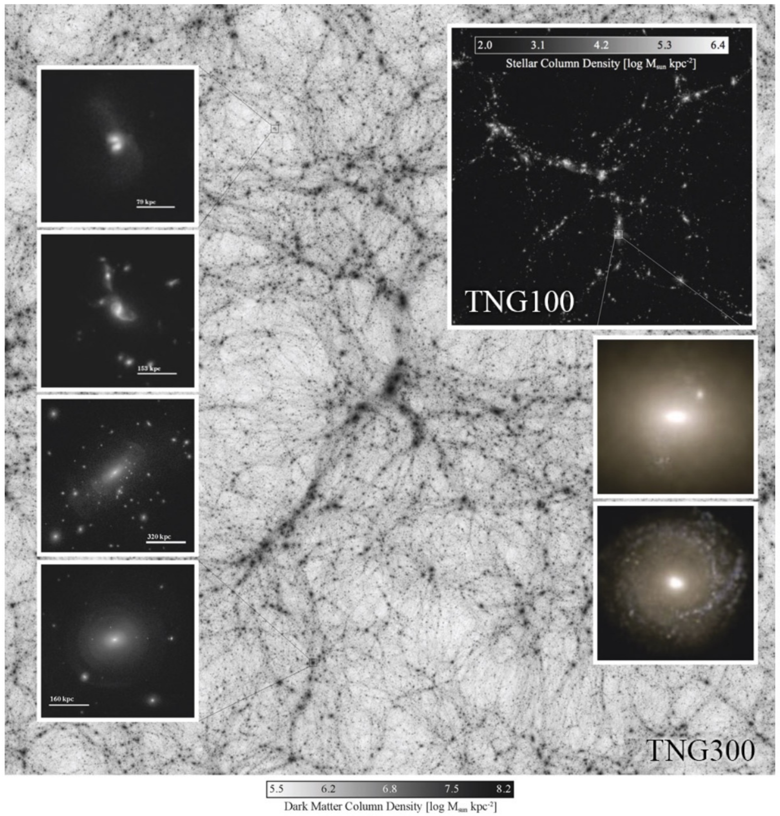
Semi-analytic vs hydro

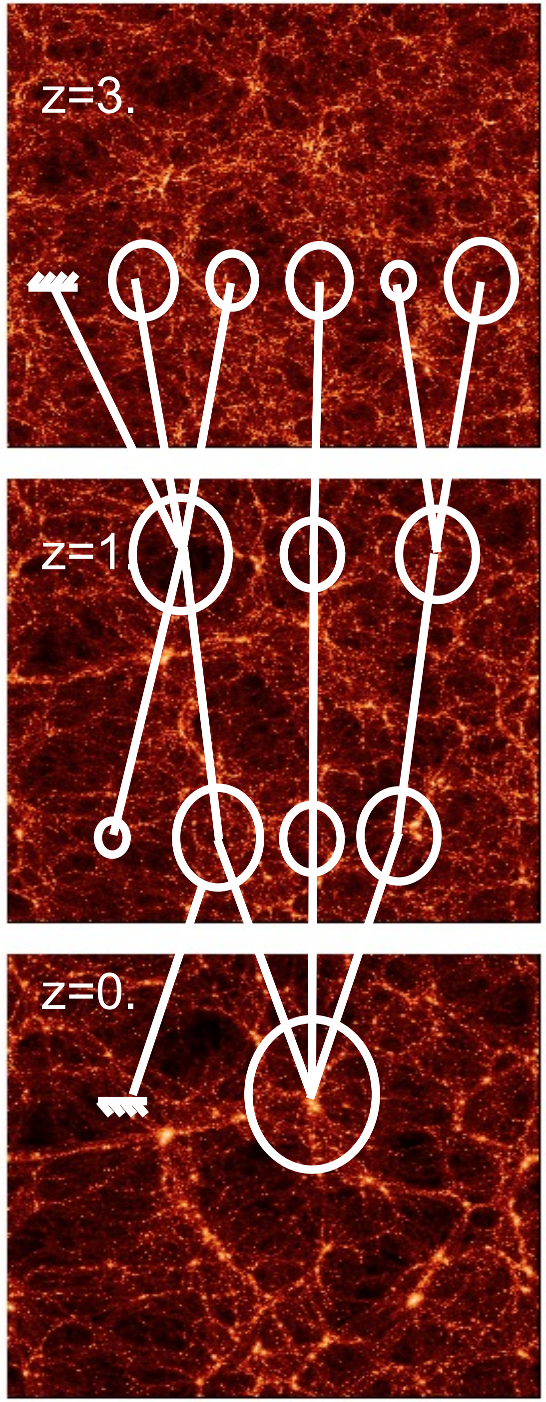
- Both rely on simple, yet physically and/or theoretically motivated prescriptions to model the evolution of the baryons.
- Semi-analytic can access very large range of (mass and spatial) resolution in large computational volumes, with still limited computational times

Credit: IllustrisTNG media

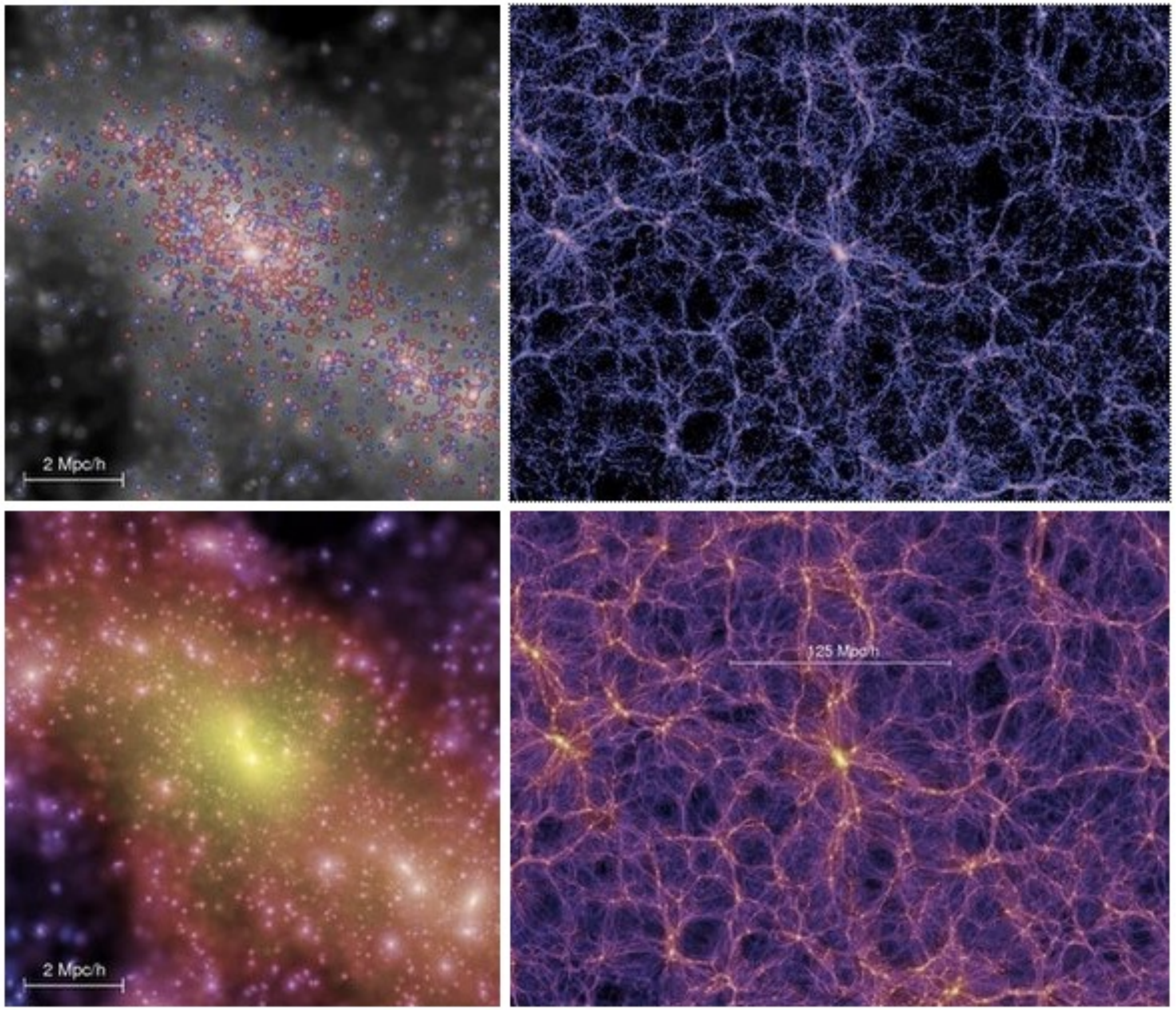


- An explicit description of gas dynamics only in hydro-simulations. “Internal” galaxy structure (resolution is very important here)

Kauffmann et al., 1999



State-of-the-art >15 years ago



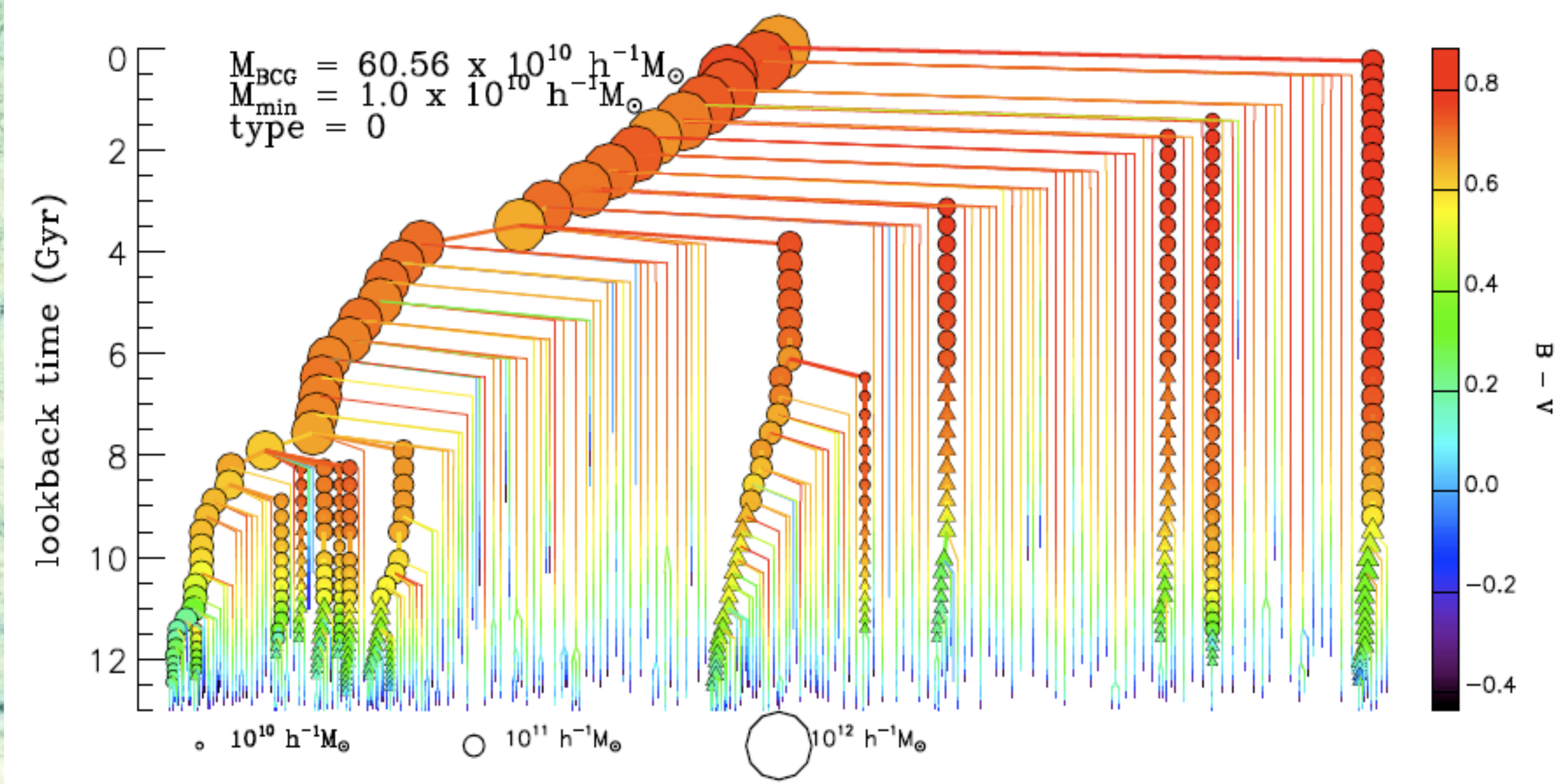
Springel et al. 2005

The first large database made publicly available.

Overall, quite good agreement with the observed local Universe.

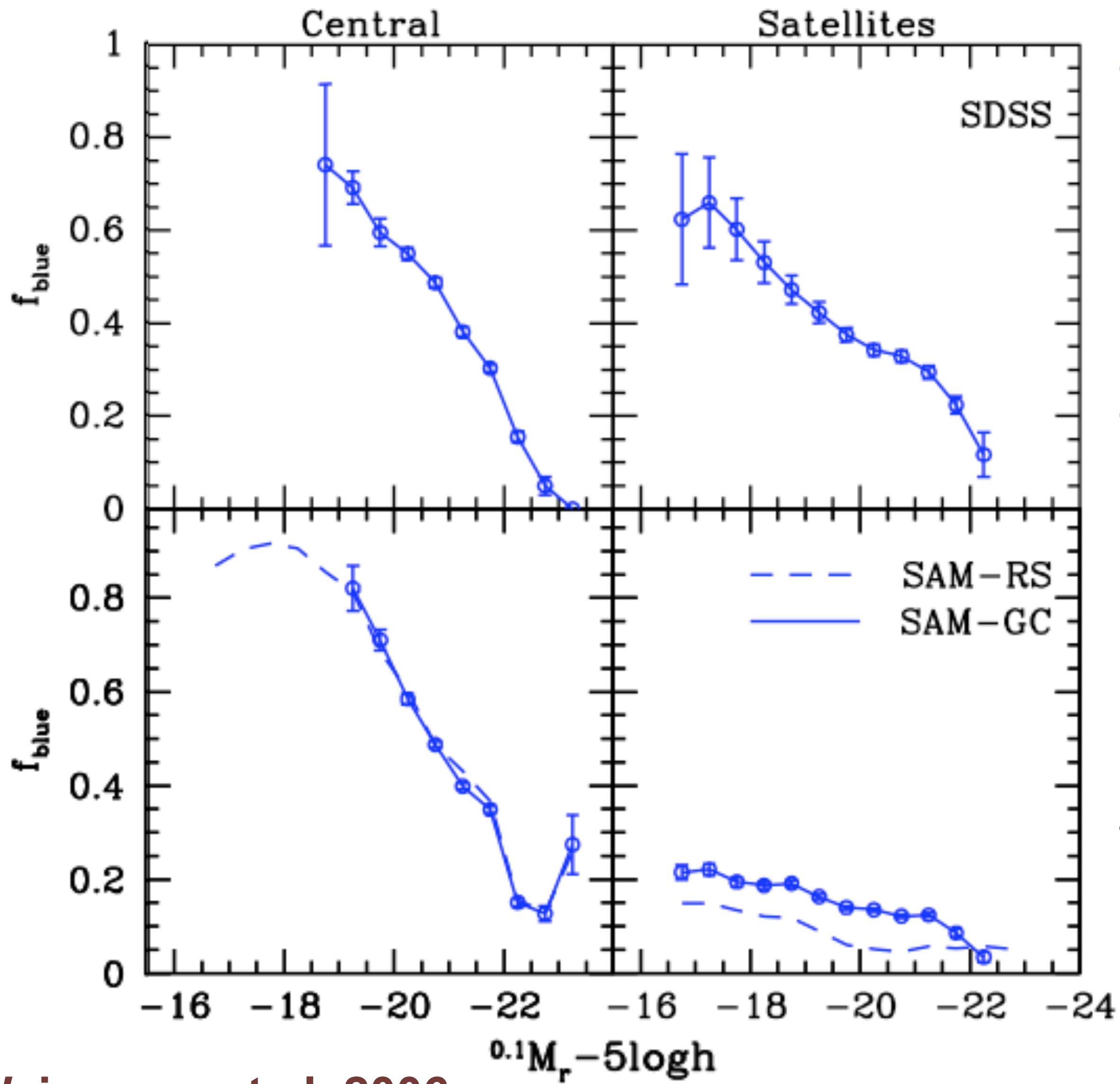
Very rapid and positive reaction from the entire astronomical community (large number of papers published based on Millennium DB).

The output of a semi-analytic model



De Lucia & Blaizot 2007

Over-quenching of satellite galaxies



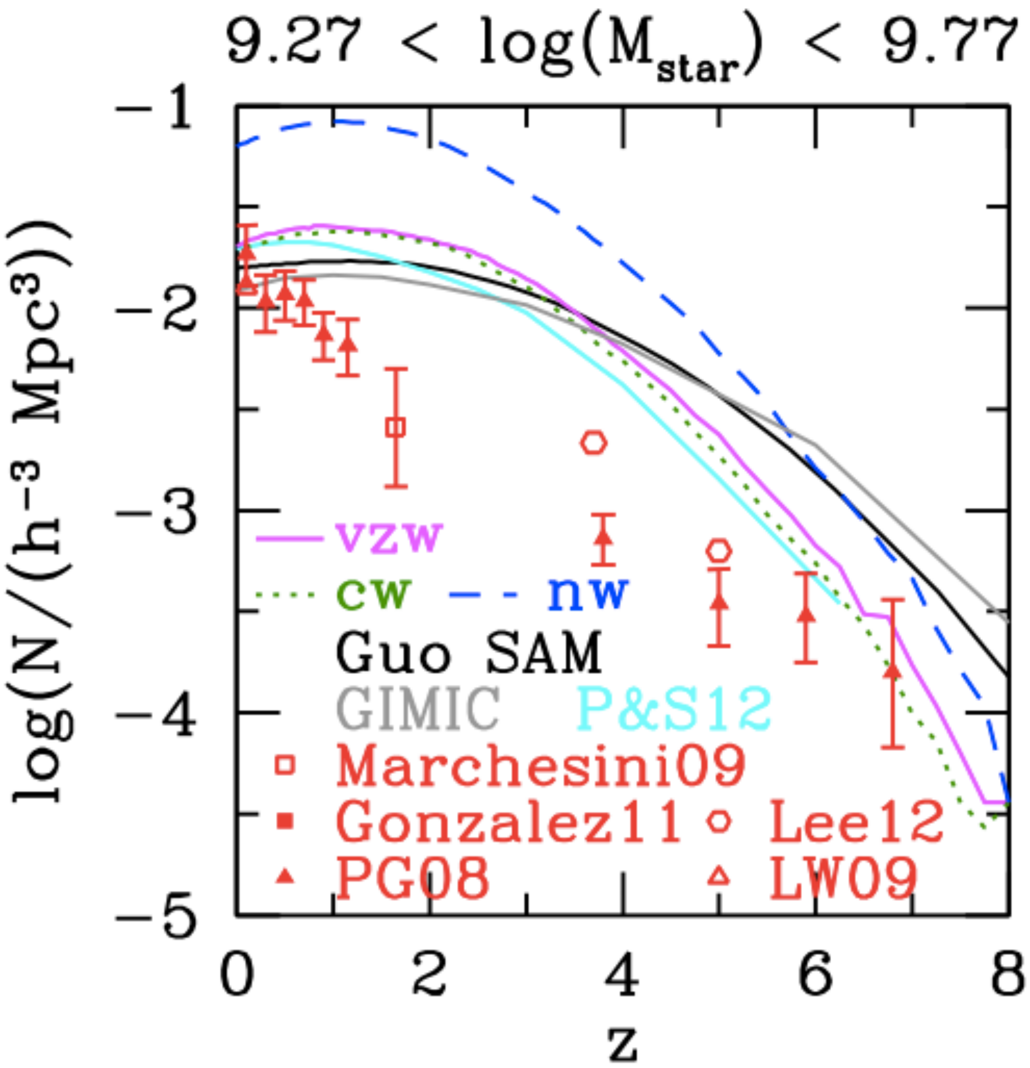
Weinmann et al. 2006

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"?

An excess of low-mass galaxies



Weinmann et al. 2012

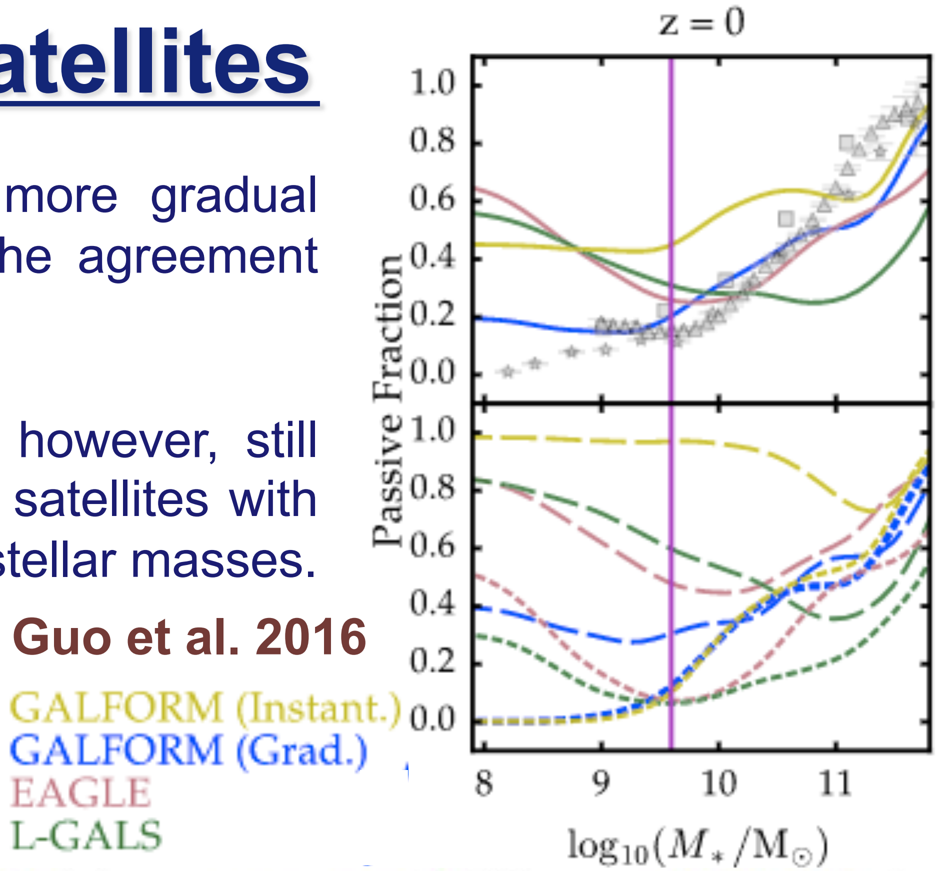
Number density of low-mass galaxies predicted by different models (and hydro-sims) with different implementations of stellar feedback is larger than observational estimates at z>0 (z=0 point is often "fine-tuned").

In this mass range, the mass growth of galaxies follow the growth of their parent haloes closely.
A mechanism is required to break this parallelism (feedback obvious culprit - but not as currently modeled).

Improved treatment of satellites

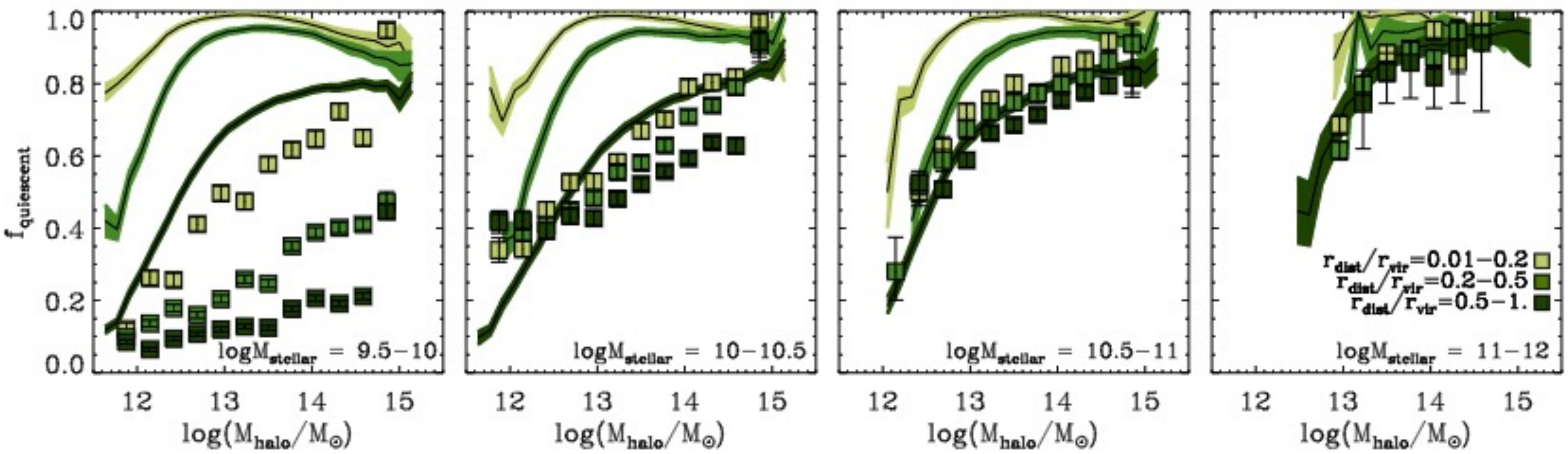
Modified treatment of satellites (a more gradual stripping of the hot gas) improves the agreement with data.

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

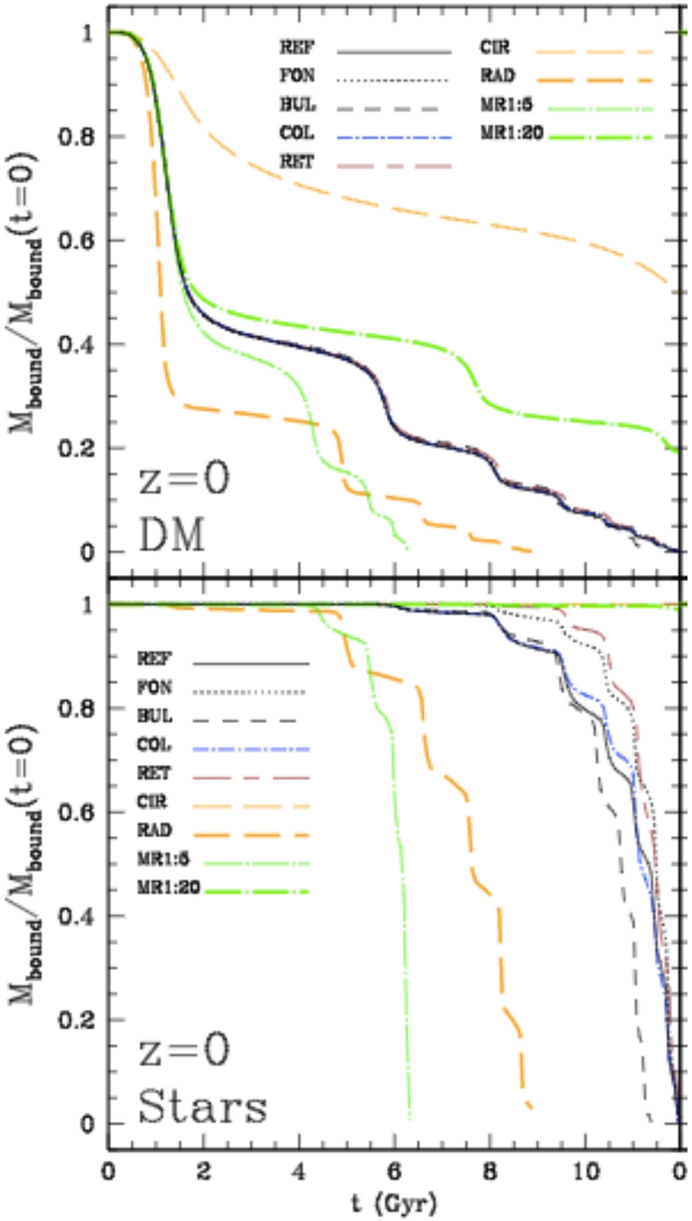


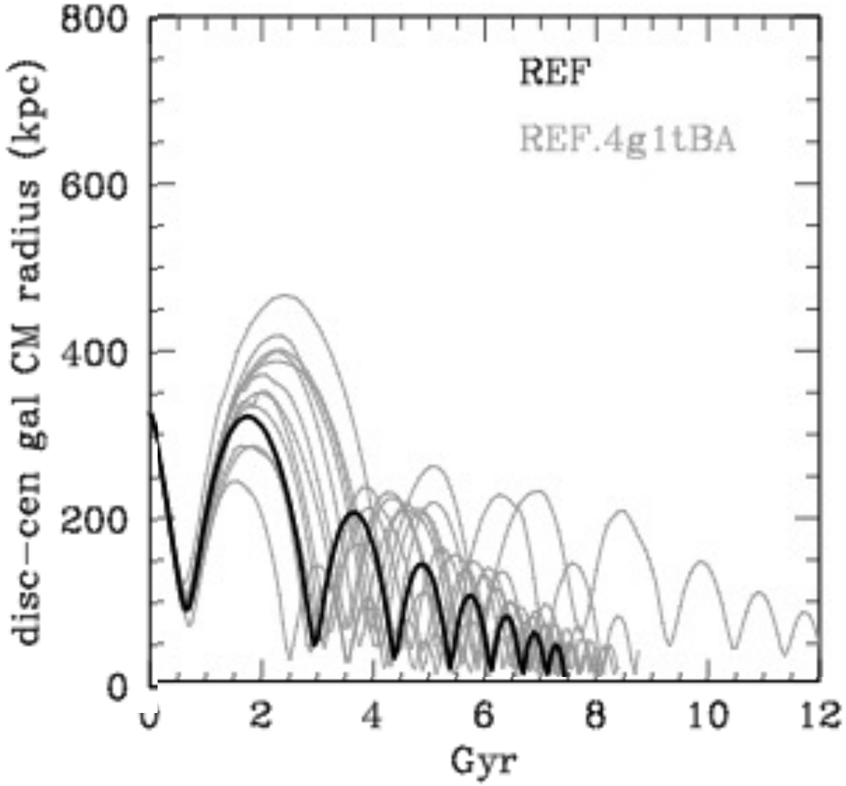
Guo et al. 2016

Hirschmann et al. 2014



Stripping (disruption) and merging times





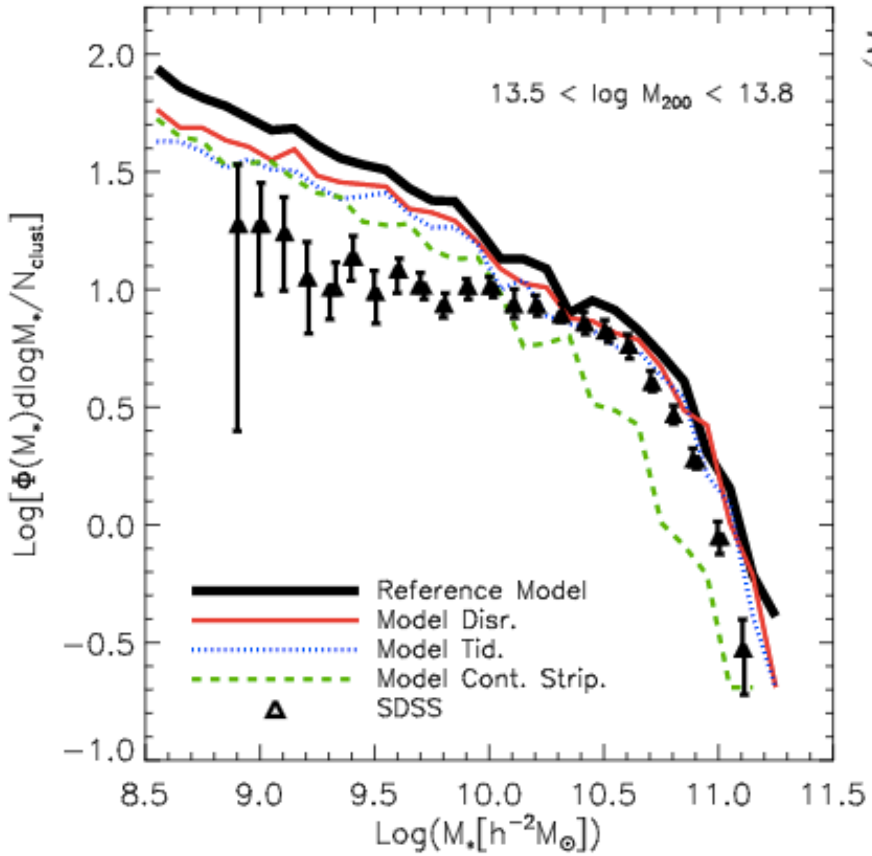
Stellar stripping starts only after dark matter has been significantly reduced; depends strongly on the orbit of the satellite (unsurprising) and on presence of other galaxies (often neglected).

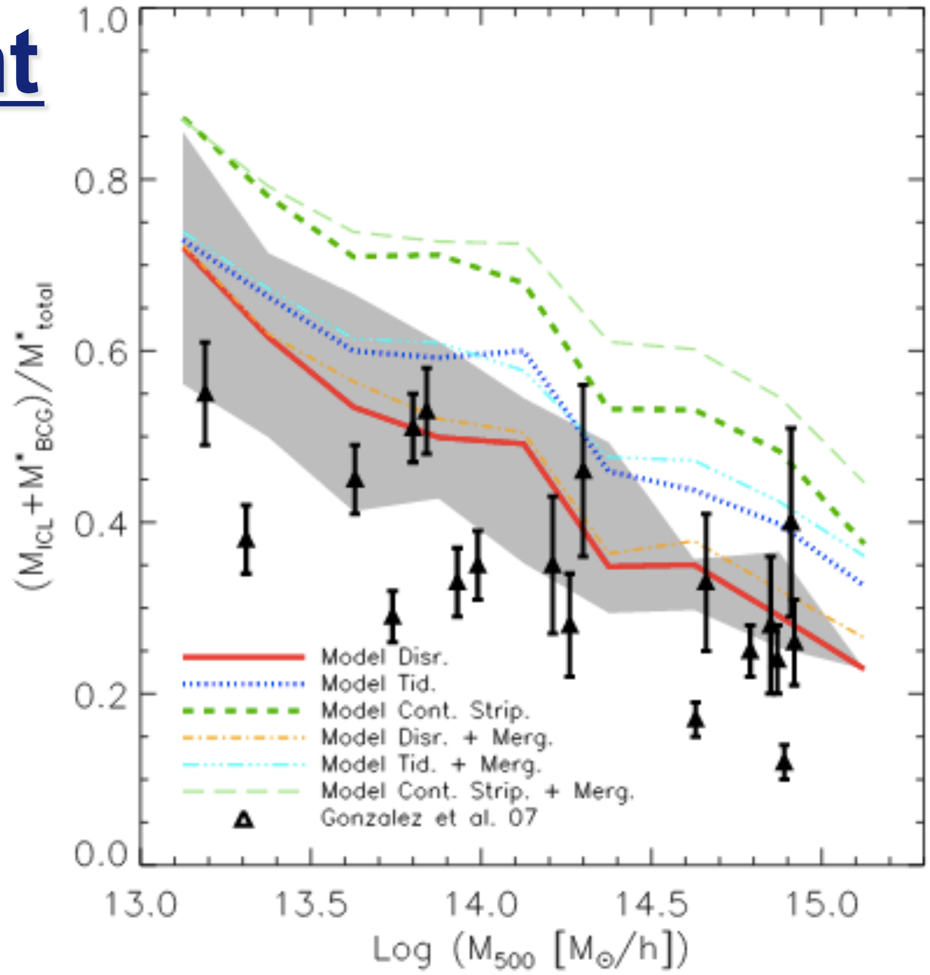
Villalobos et al. 2012, 2014

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..

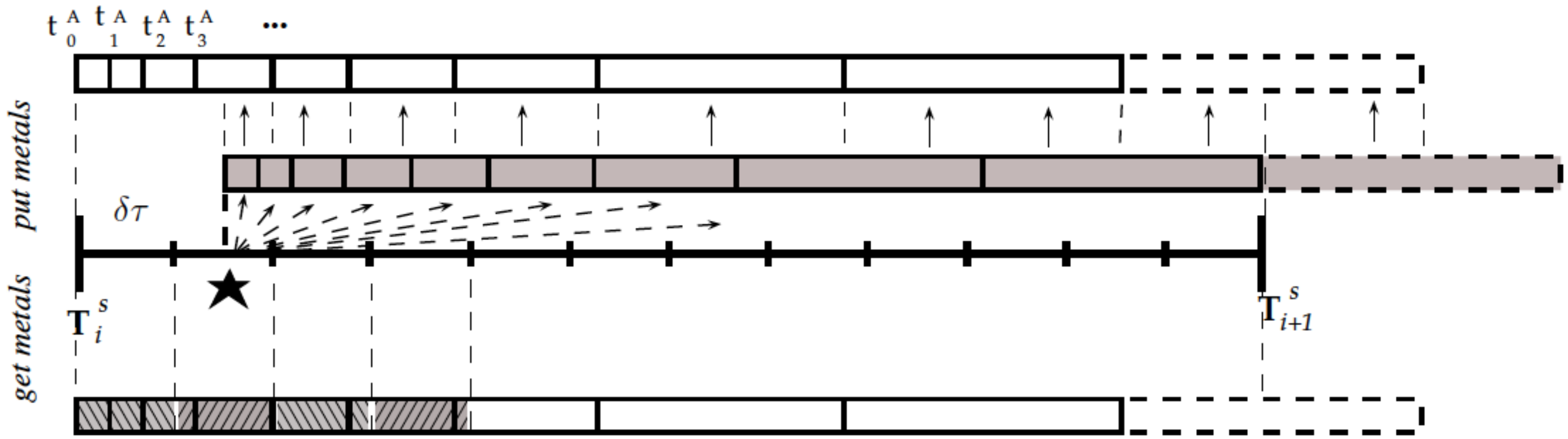
The development of GAEA

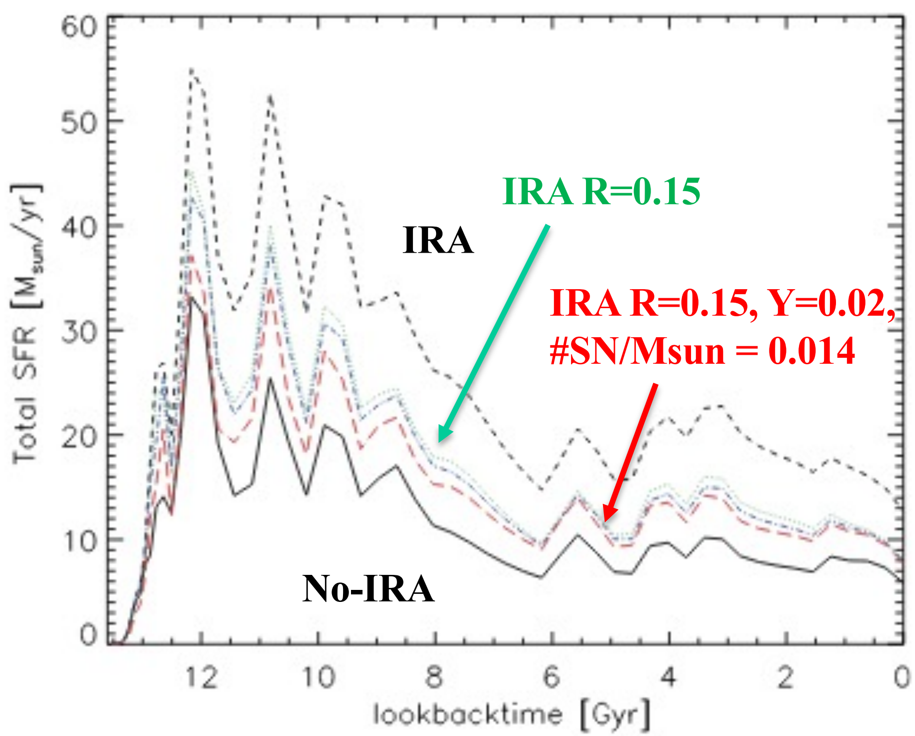
Two "fundamental" problems with satellites (wrong properties, wrong number densities). No "easy" solution with modifying the treatment of satellites. The overall treatment of star formation-feedback cycle can (and need) to be improved.

- ✓ Models still assume an instantaneous recycling approximation (late recycling of gas and metals can delay star formation and stellar feedback)
- ✓ Gas is treated as a single phase component (star formation correlated with molecular gas component, more difficult to strip in satellite galaxies)
- ✓ Current implementation of stellar feedback unable to break the parallelism between baryon and dark matter growth

Info and model outputs: **https://sites.google.com/inaf.it/gaea/**

Non-instantaneous approximation





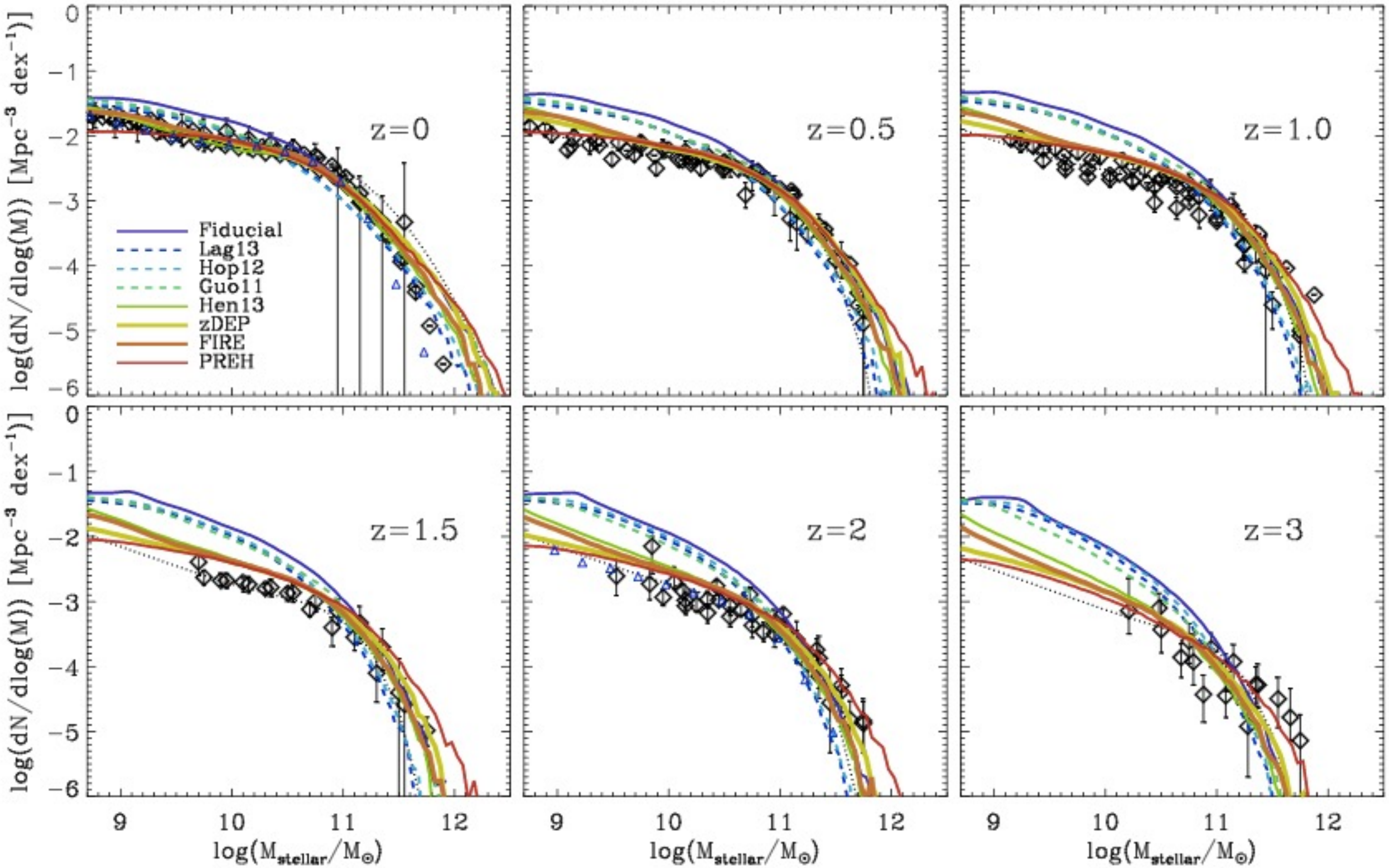
Instead of storing information about the past star formation history, we `project' the metals (and the gas and the energy) in the future.

Important consequences on the predicted star formation histories of galaxies (plus the chemical yield is no longer a free parameter)

De Lucia et al. 2014

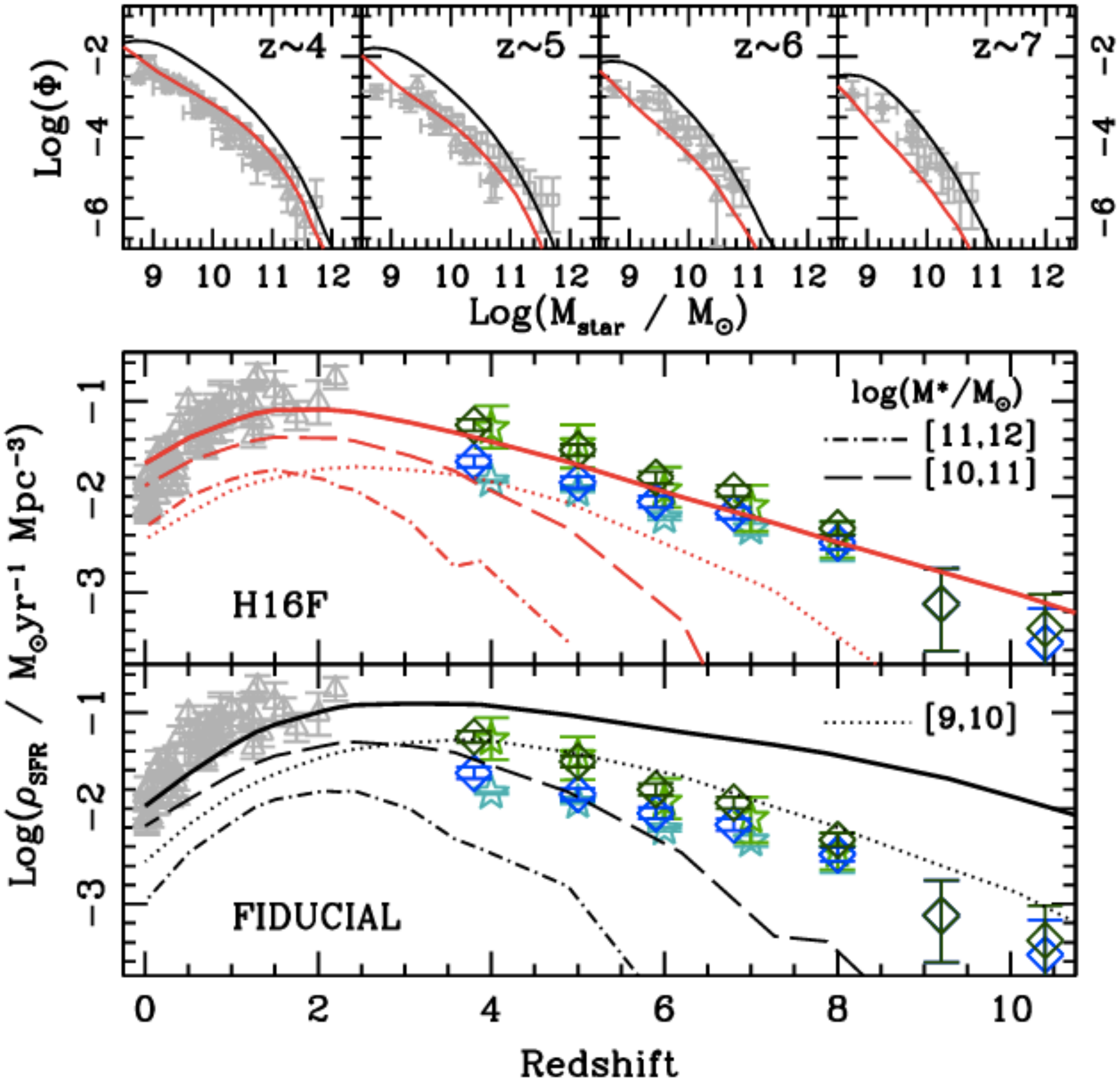
A different feedback scheme

*Hirschmann, De Lucia & Fontanot 2016



* Available at : https://apps.sciserver.org (contact us!)

Out to the cosmic dawn



Our reference model reproduces nicely the measured galaxy mass function out to z~7 and the cosmic SFR out to z~10 (these data have NOT been used to `tune' the model).

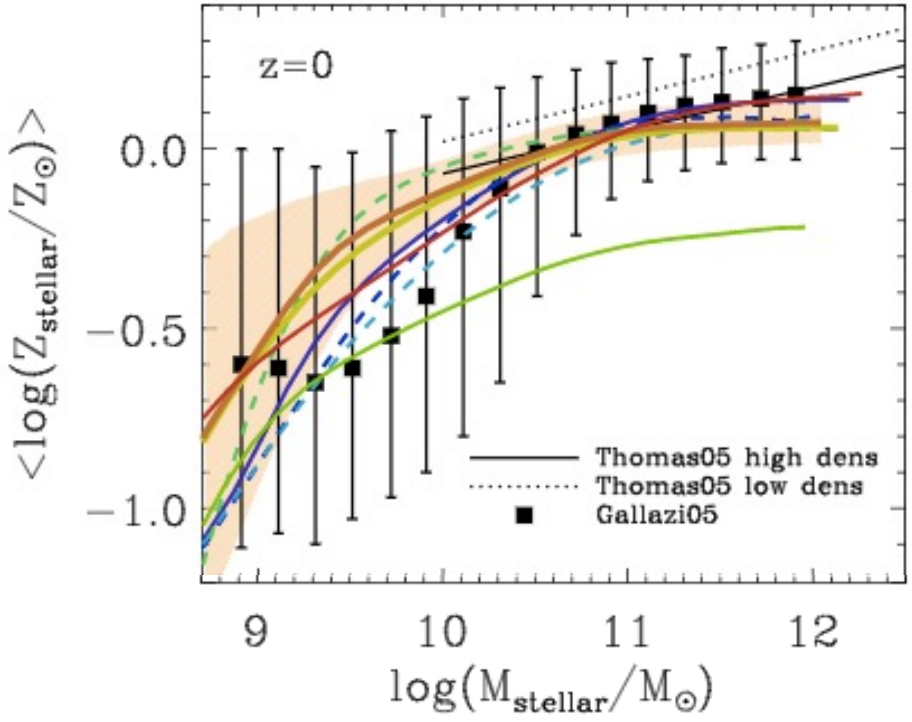
A decreasing (with increasing z) importance of dust attenuation is required to reproduce the measured UV luminosity functions

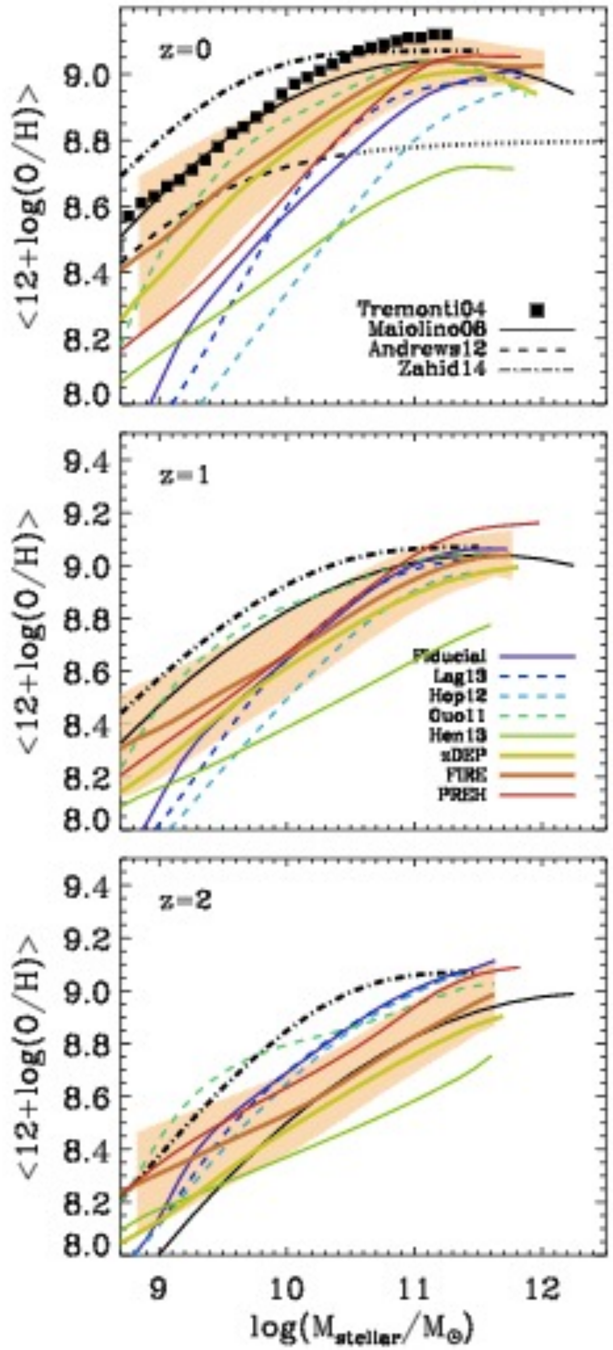
Fontanot et al. 2017

Metals in stars and gas

GAEA reproduces the observed mass-metallicity relations at z=0 and predicts an evolution of these as a function of z (qualitative agreement with data)

Results are robust against modifications of the chemical parameters (elemental yields, DTD of SNIa, IMF, etc.)

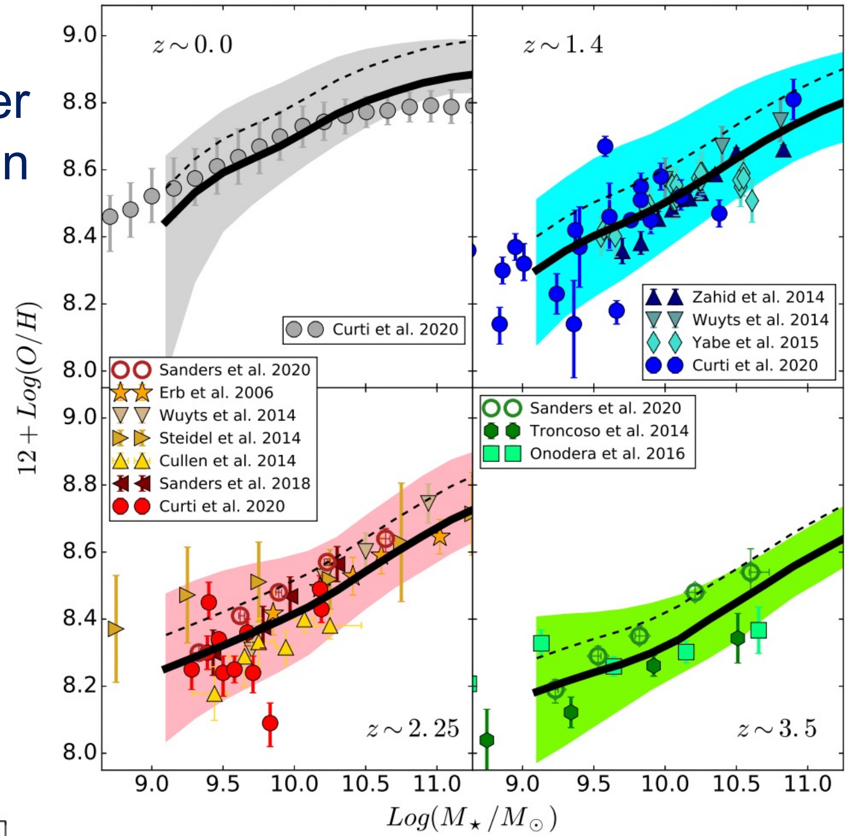




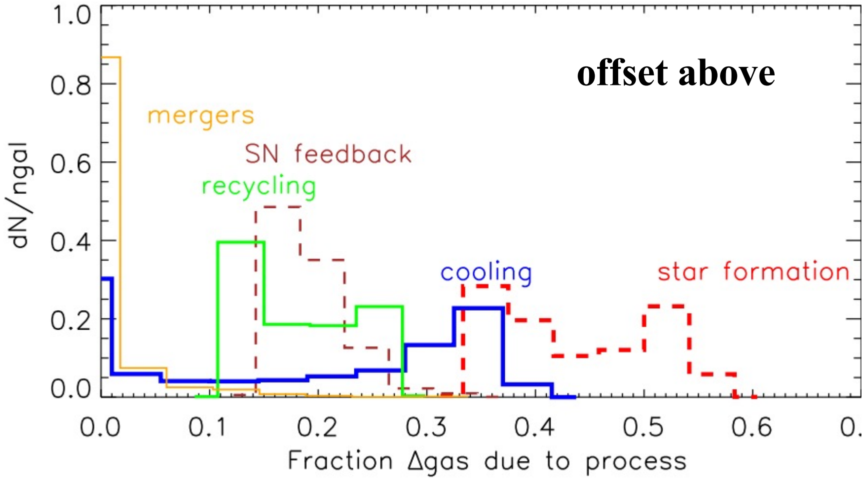
Hirschmann, De Lucia & Fontanot 2016

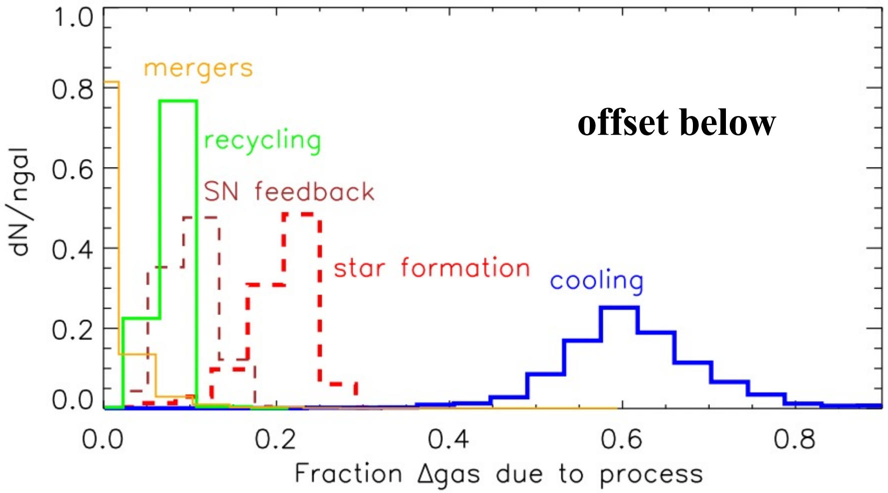
Origin of scaling relations

Fontanot et al. 2021



Cold gas (atomic) is the third parameter governing the scatter of the M-Z_{gas} relation at z=0, in agreement with data.

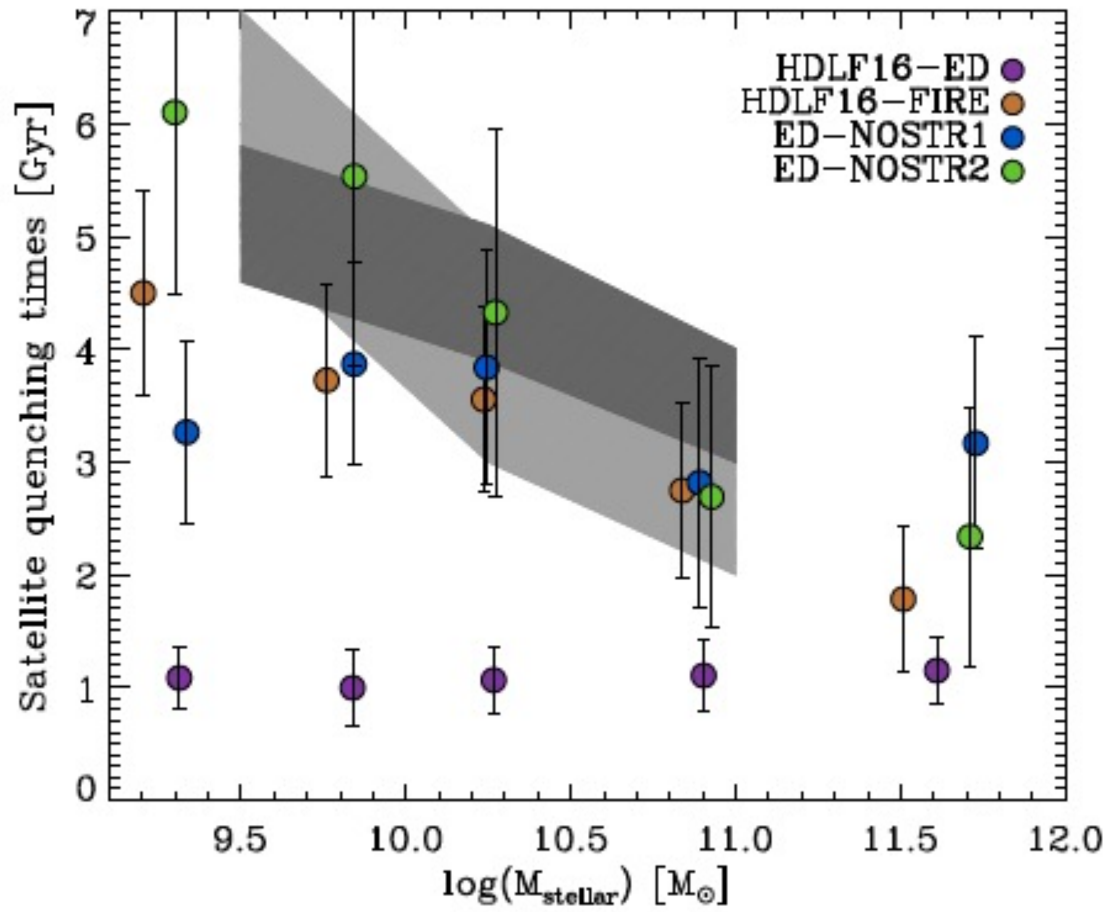




Scatter driven by fluctuations of the gas accretion rates: a decrease of gas supply leads to an increase of Z_{gas} due to star formation, an increase of available gas leads to Z_{gas} depletion.

De Lucia et al. 2020

Quenching time-scales



Modifications of “internal processes” can affect strongly the evolution of the satellite galaxies.

Old “fiducial” model gives very short quenching time-scales although it includes only “strangulation”.

No specific environmental process is needed other than strangulation (this is ok for at least the most massive galaxies)?

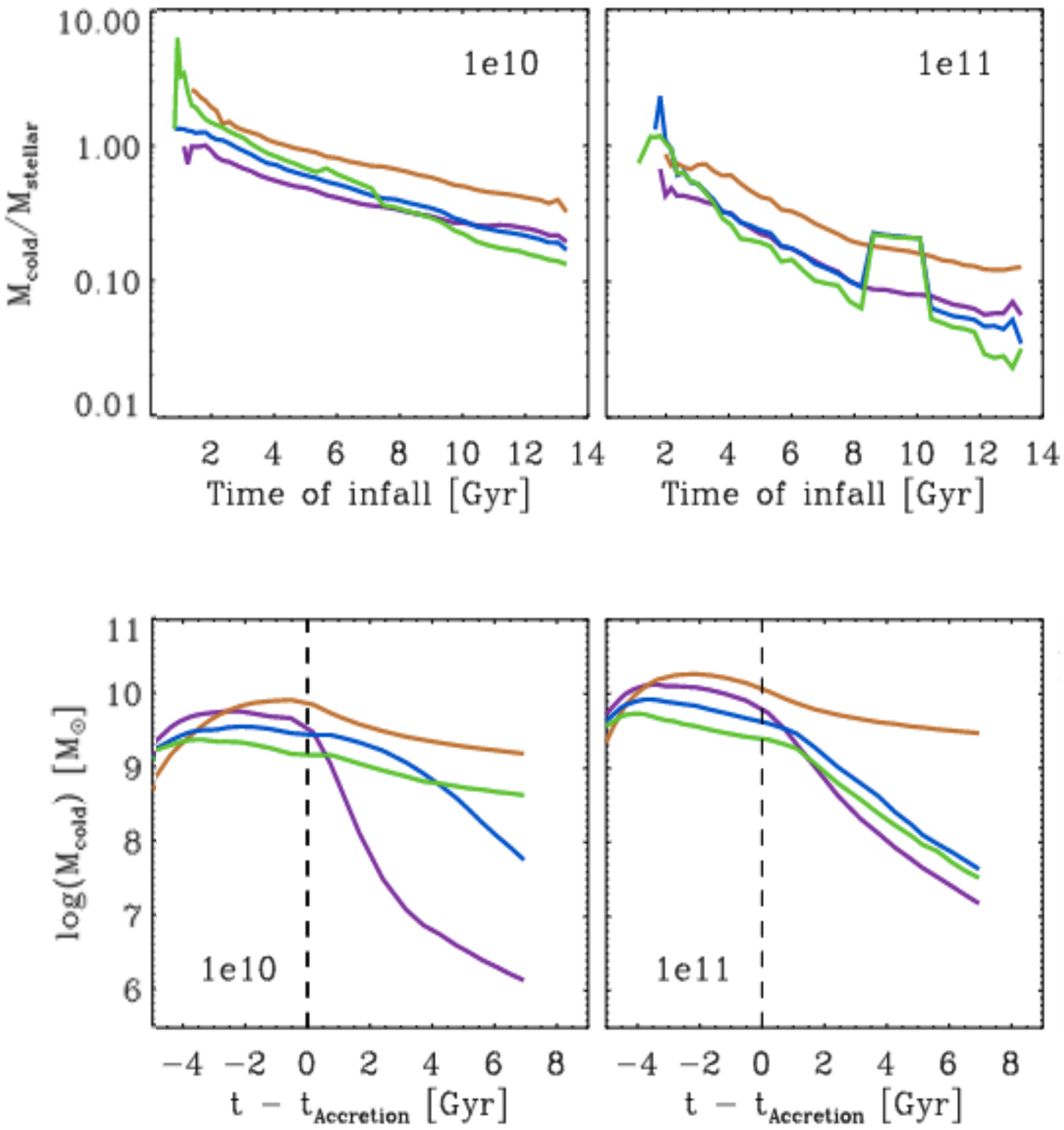
De Lucia et al. 2019

Why/how this works

In the reference GAEA, the quiescent fractions are in better agreement with data because:

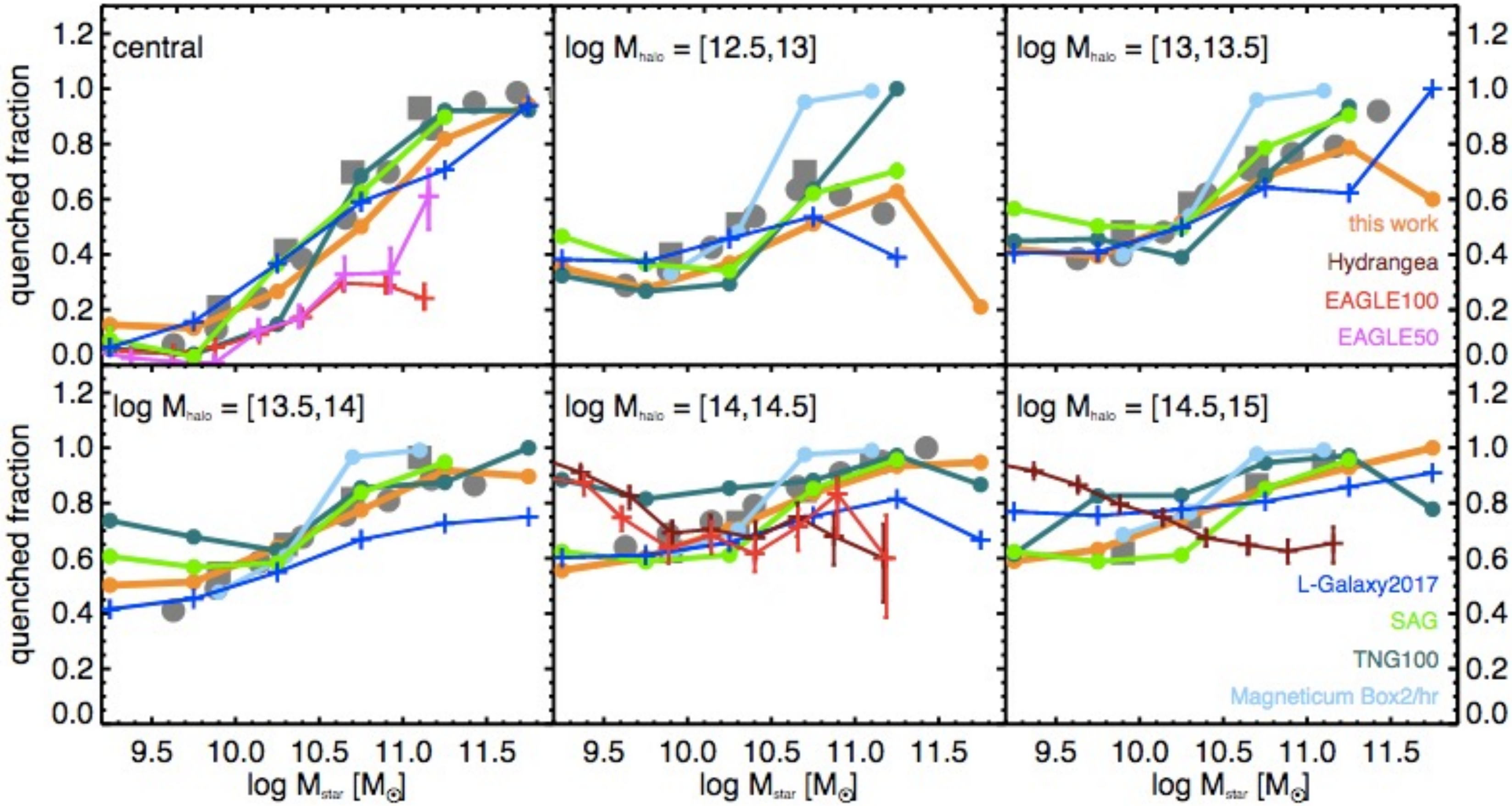
(i) Galaxies are generally more gas rich (and more star forming) at the time of accretion.

(i) rate at which gas is reheated and blown out is lower than in older scheme, so galaxies keep their star forming reservoir longer.



De Lucia et al. 2019

Quiescent fractions in the local Universe

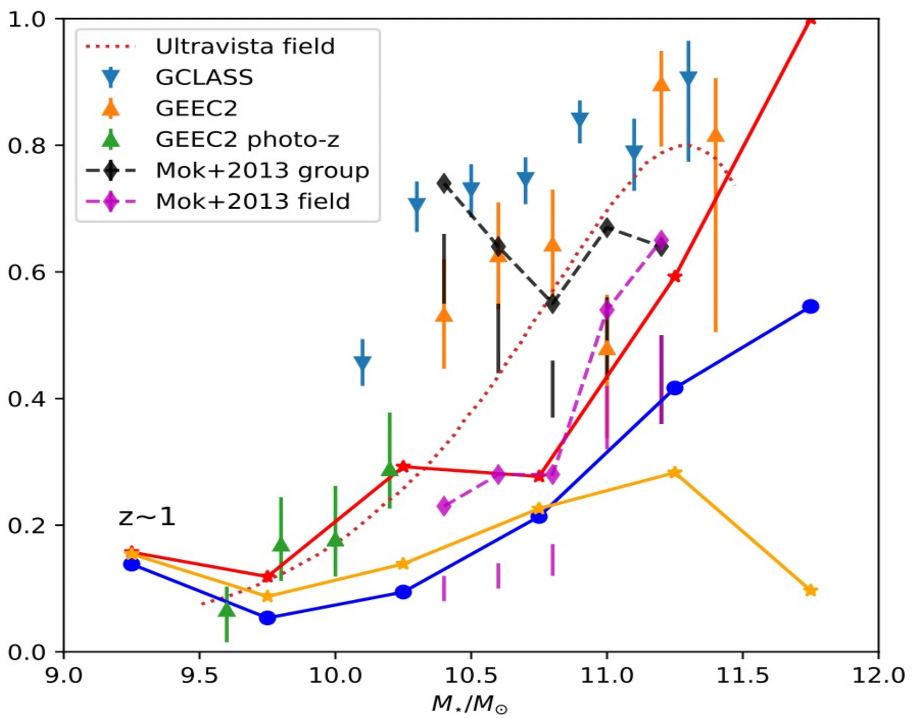


GAEA predictions in a context: no model/simulation provides a perfect match with available data at z~0. Our model performs quite well and can be used to make predictions to higher redshift.

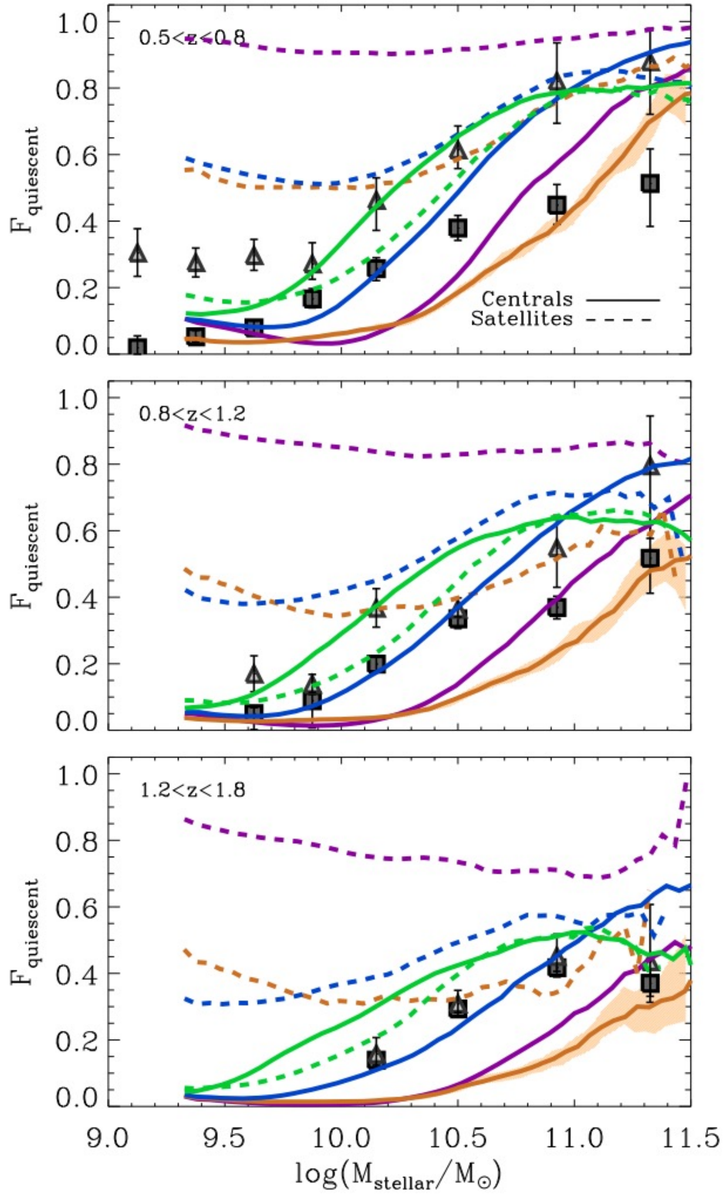
Xie et al. 2020

Quiescent fractions – high-z

De Lucia et al. 2019



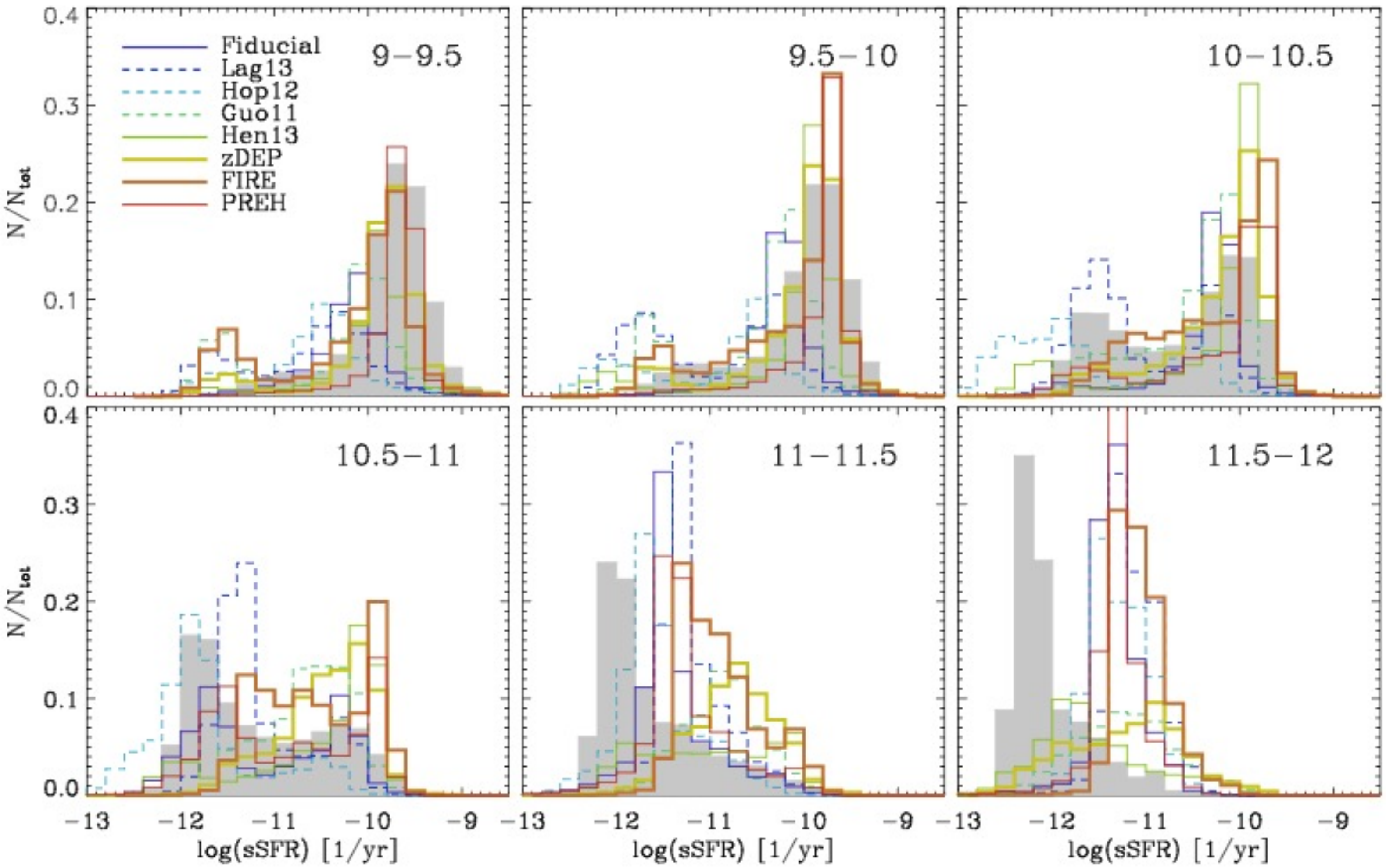
model by Xie et al. 2020



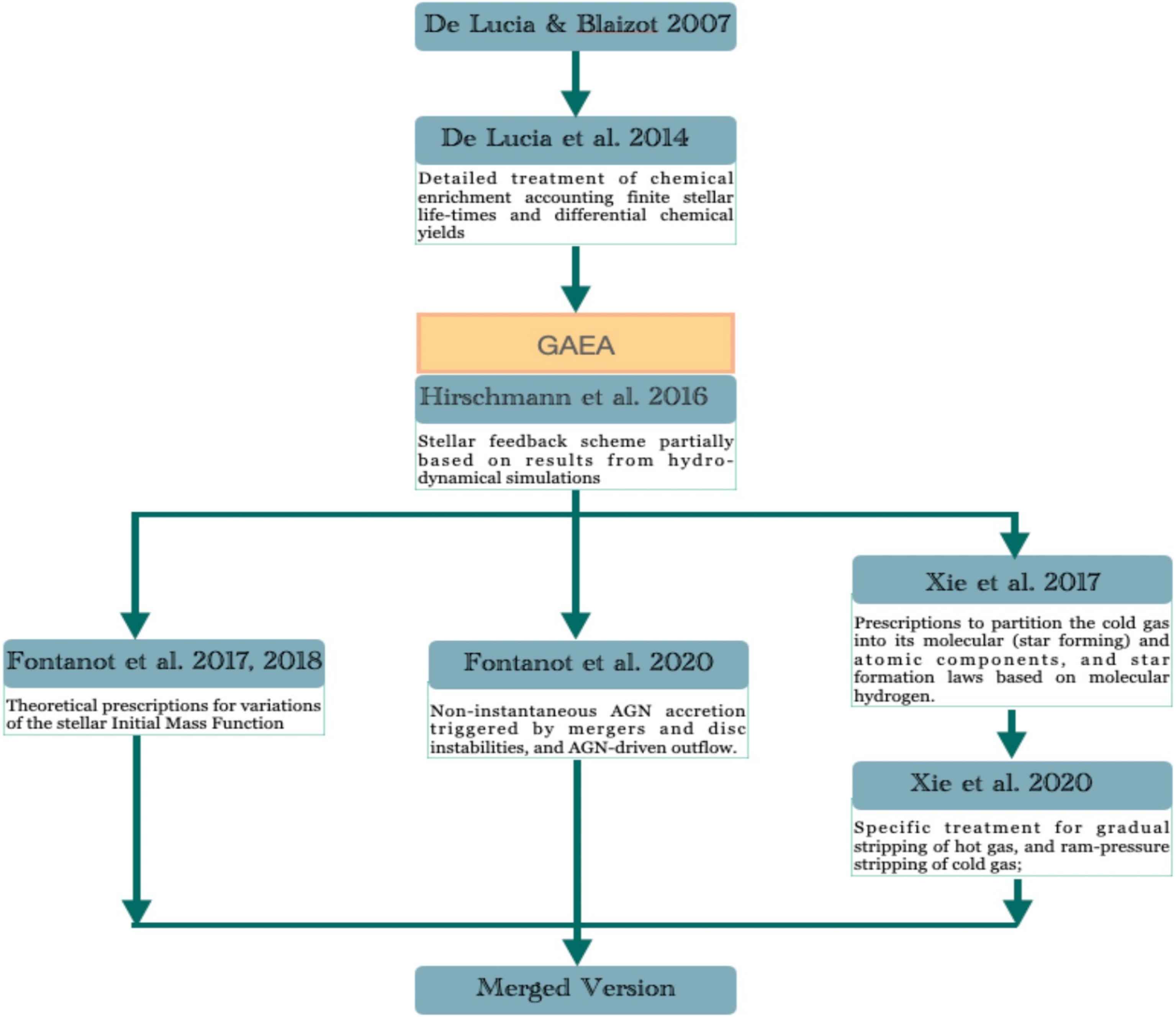
Our currently best model does not reproduce estimated quiescent fractions at z>0 and generally under-predicts the fraction passive galaxies at high-z.

Distribution of sSFR (colours)

Hirschmann, De Lucia & Fontanot 2016

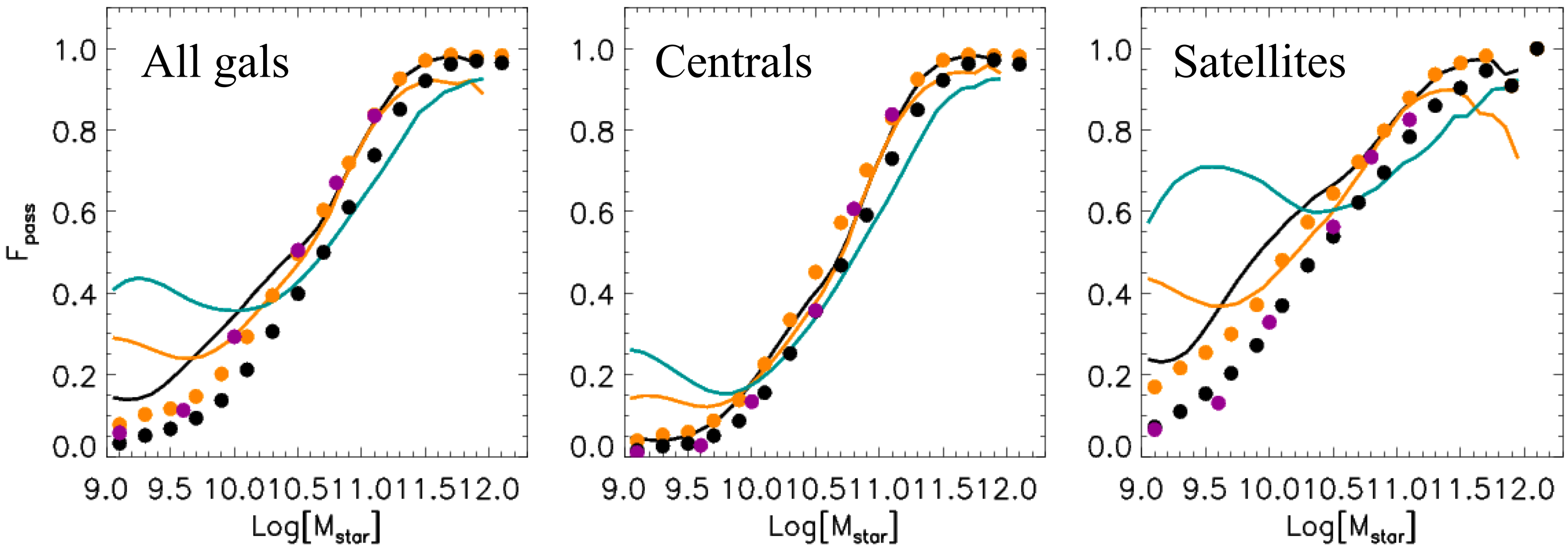


Massive galaxies are too active; bimodality not well pronounced. Simple modifications of AGN feedback do not improve the situation (**Fontanot et al. 2020**)


De Lucia & Blaizot 2007
De Lucia et al. 2014
Detailed treatment of chemical enrichment accounting finite stellar life-times and differential chemical yields
GAEA
Hirschmann et al. 2016
Stellar feedback scheme partially based on results from hydro-dynamical simulations
Fontanot et al. 2017, 2018
Theoretical prescriptions for variations of the stellar Initial Mass Function
Fontanot et al. 2020
Non-instantaneous AGN accretion triggered by mergers and disc instabilities, and AGN-driven outflow.
Xie et al. 2017
Prescriptions to partition the cold gas into its molecular (star forming) and atomic components, and star formation laws based on molecular hydrogen.
Xie et al. 2020
Specific treatment for gradual stripping of hot gas, and ram-pressure stripping of cold gas;
Merged Version

Quiescent fractions in the local Universe

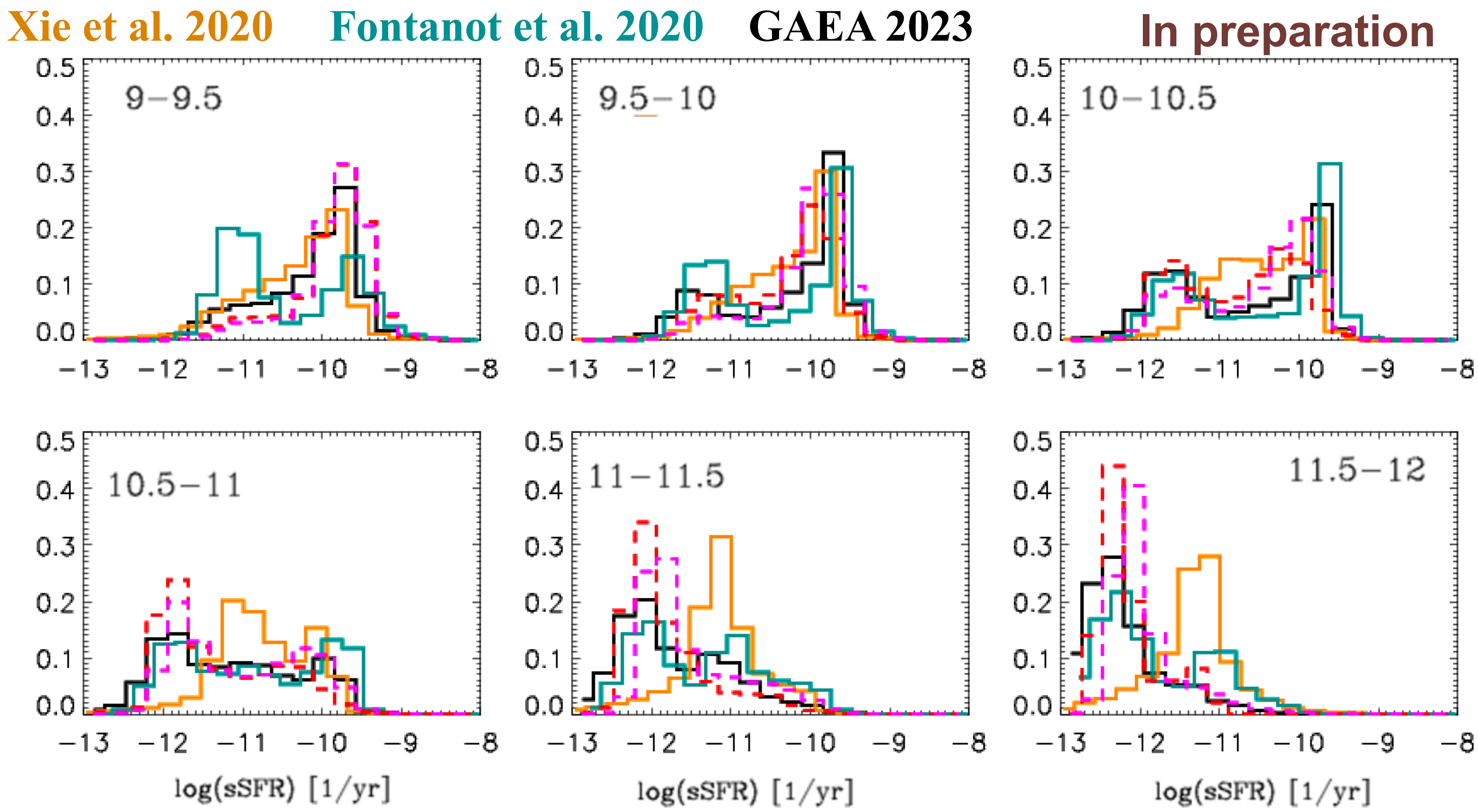
Xie et al. 2020 Fontanot et al. 2020 GAEA 2023 **In preparation**



Merging our updated model for AGN feedback and cold gas partition maintain (actually improves) the overall agreement between model predictions and observational estimates of passive fractions in the local Universe.

To be done: check what happens at low masses with MillenniumII, make comparison as a function of halo mass.

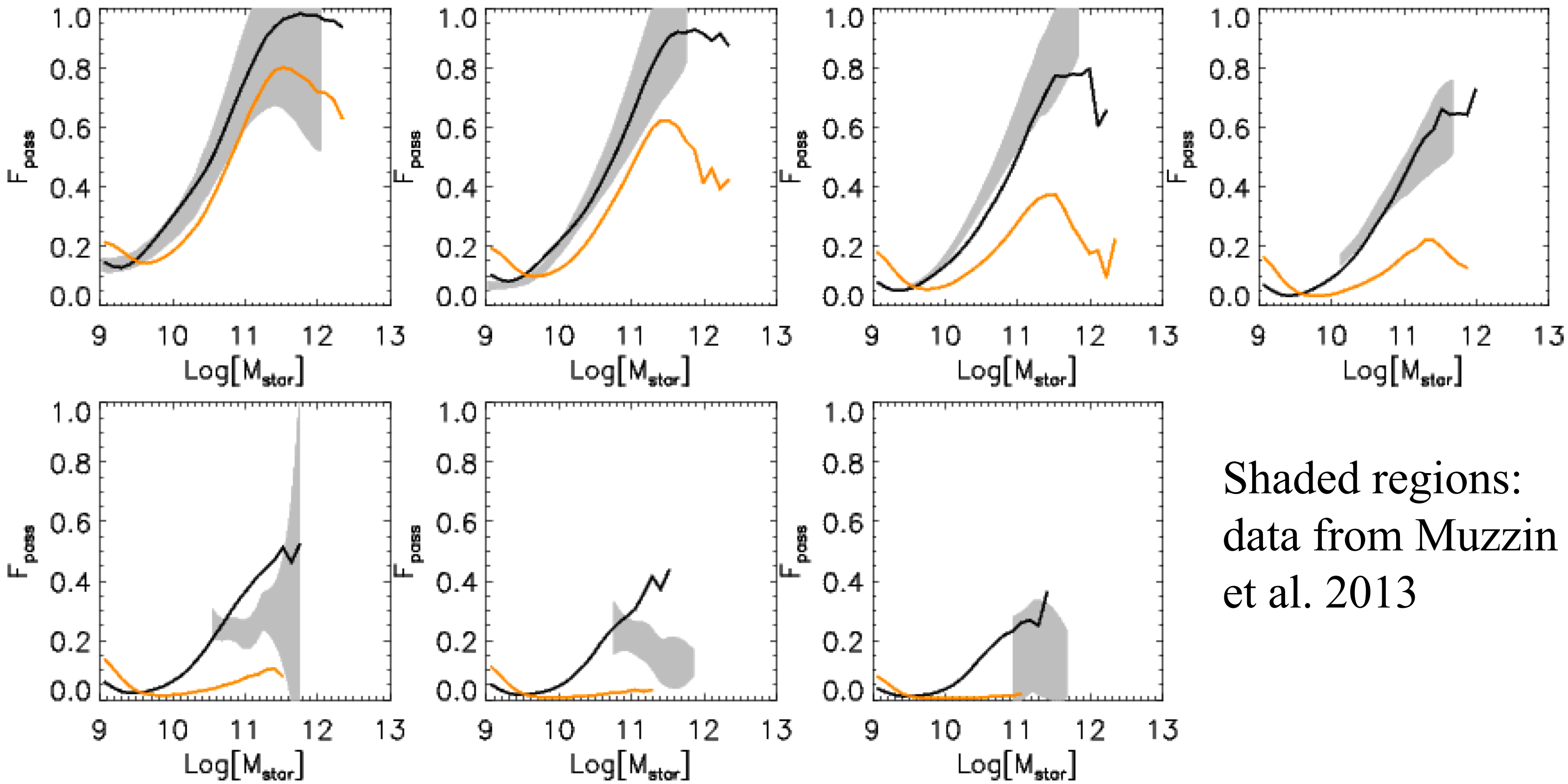
Distribution of sSFR



To be done: check if galaxies at very low sSFR are treated in a consistent way in data and model samples.

Quiescent fractions – high-z

Xie et al. 2020 **GAEA 2023** **In preparation**

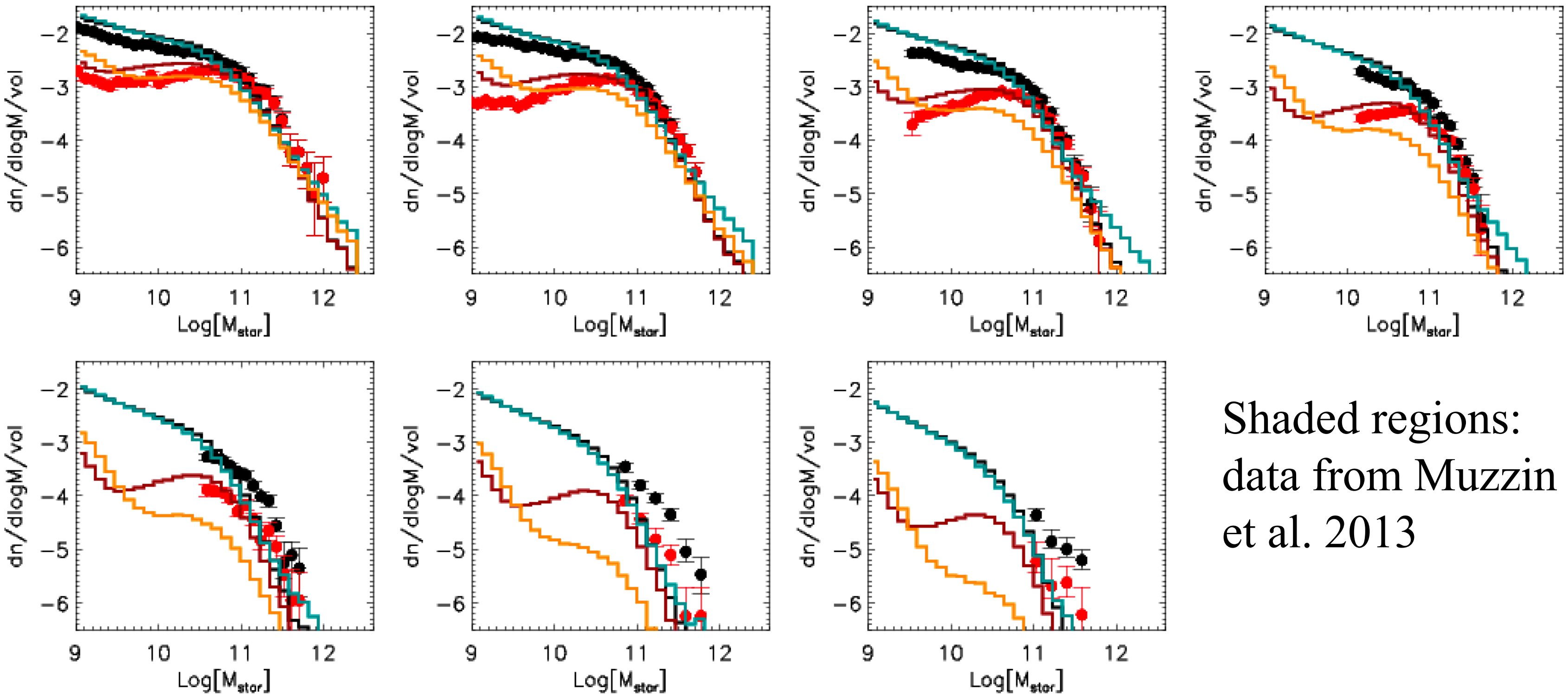


Shaded regions: data from Muzzin et al. 2013

To be done: add predictions from Fontanot et al; apply a colour-colour selection that is consistent with data.

Quiescent fractions – high-z

Xie et al. 2020 **GAEA 2023** **In preparation**



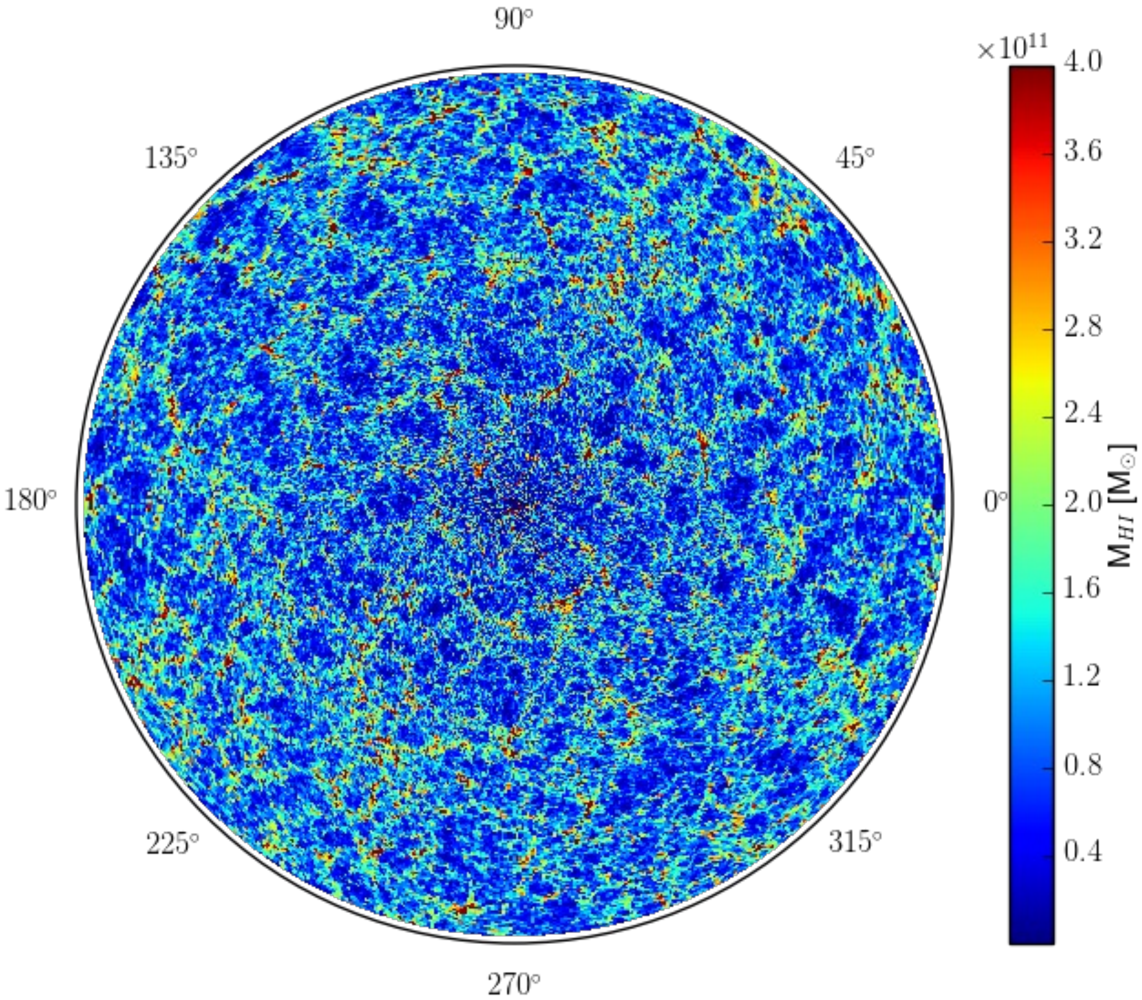
Shaded regions: data from Muzzin et al. 2013

To be done: add predictions from Fontanot et al; apply a colour-colour selection that is consistent with data; check trends for low-mass galaxies using MillenniumII

Ongoing/planned developments

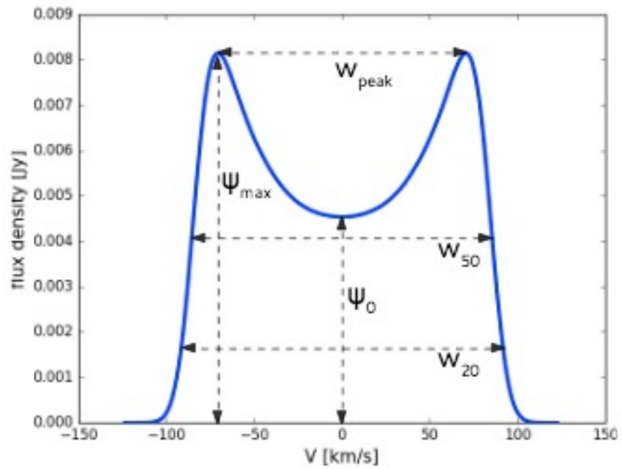
- ✓ Updated model for a variable stellar Initial Mass Function (see talk by Fabio).
- ✓ Explicit model for dust formation/destruction (starting hopefully after summer).
- ✓ Explicit model for 21cm line emission lines – ongoing activity within SKA cosmology science working group (see also talk by Marta).
- ✓ Merger trees based on P-Millennium (larger volume, resolution intermediate between Millennium I and II, updated cosmology) almost done. Preliminary results are promising.
- ✓ Coupling with PINOCCHIO merger trees working (see talk by Vieri).
- ✓ ….

Mock catalogues



Dedicated light-cones including HI and other physical/observable properties.

These can also be used for cross-correlation studies with galaxies samples based on different selections.

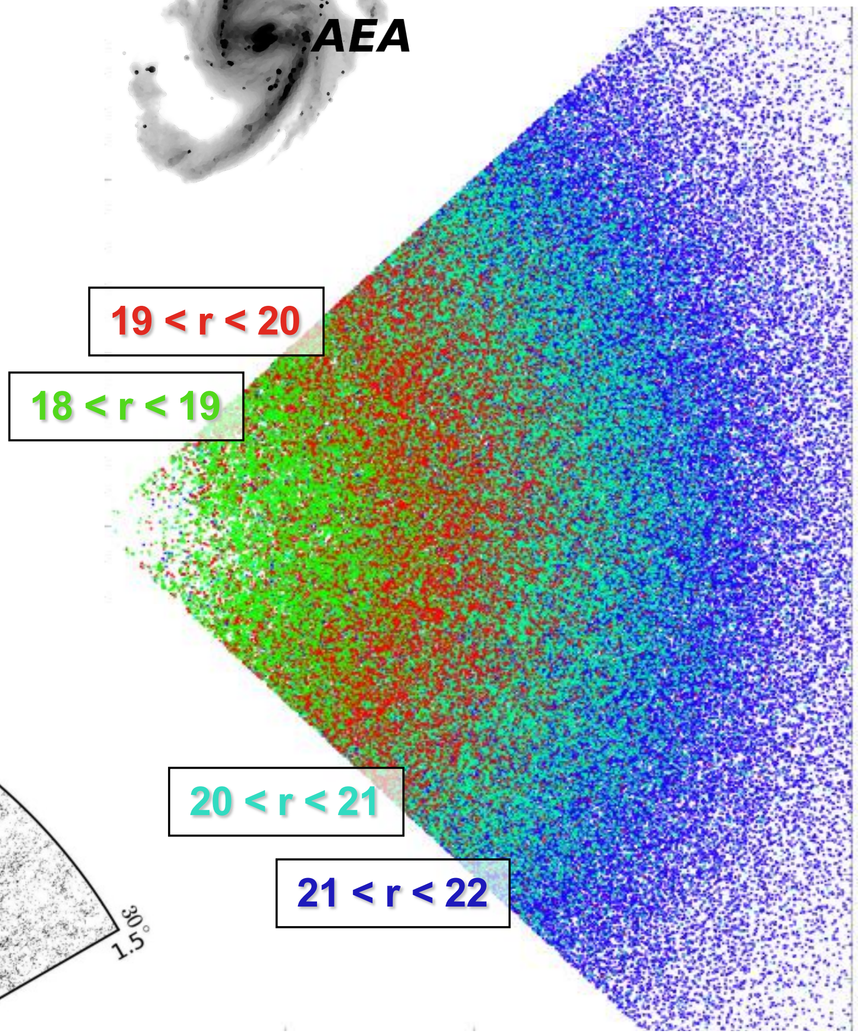


Anna Zoldan, PhD thesis

Large, deep, many mocks

Using approximate methods to create (many) large and deep light-cones of dark matter haloes (also based on alternative cosmologies) on the fly (no need to replicate simulated boxes).

Coupling to a semi-analytic model to populate haloes with galaxies.



PINOCCHIO