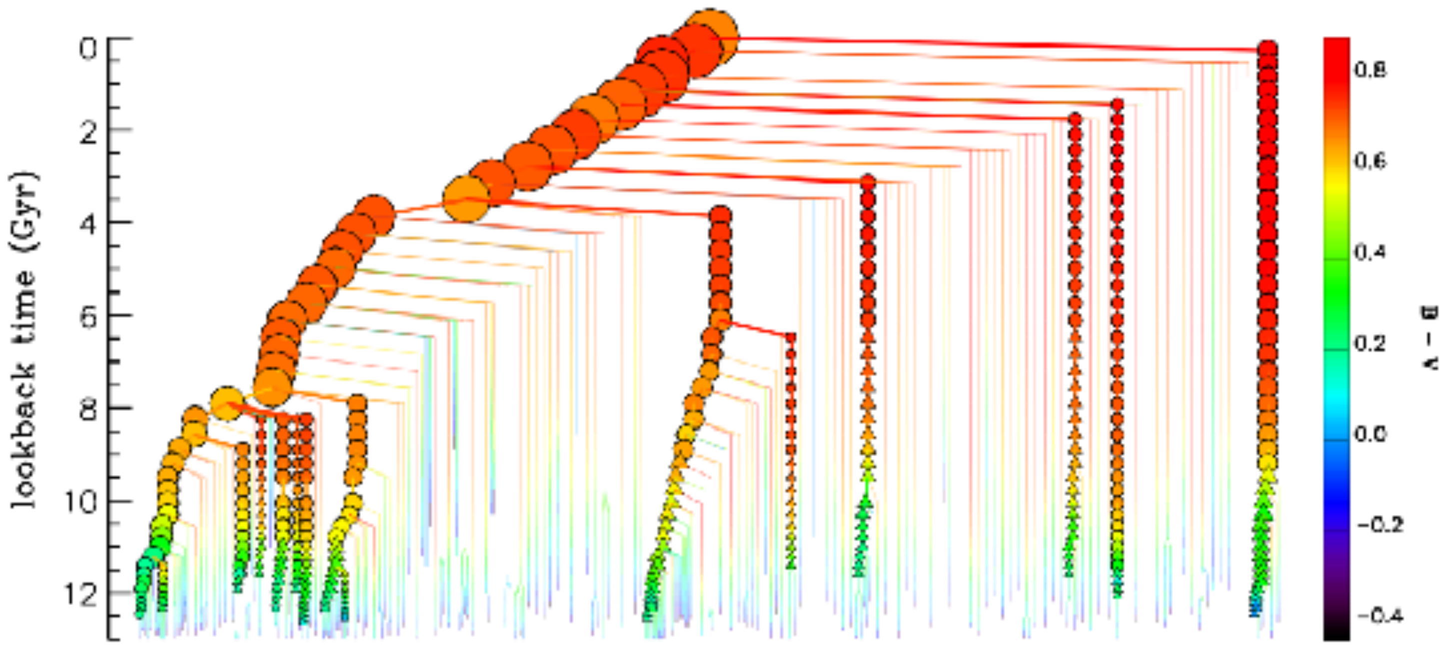
Witnessing the onset of environmental quenching at z~1-2. Results from 3D-HST

Matteo Fossati
USM/MPE Munich

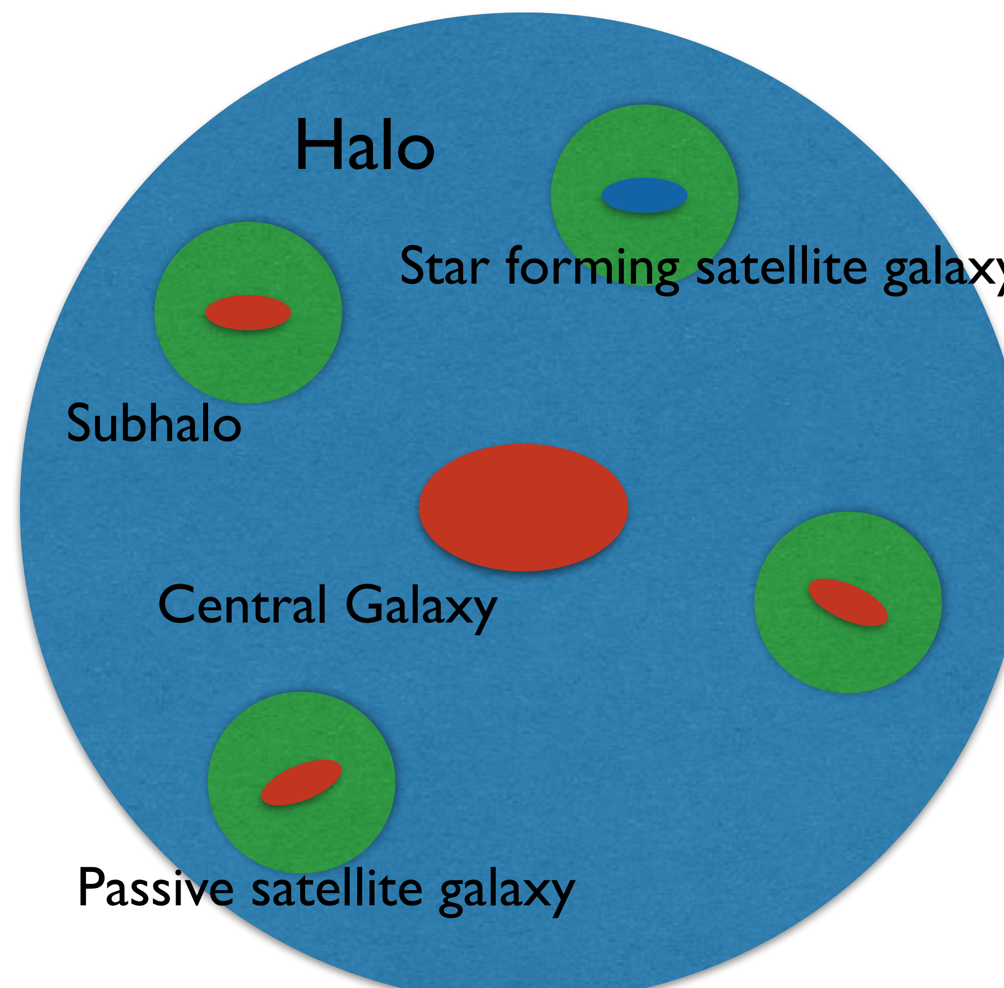
with D.Wilman, J.T. Mendel, R. Saglia, A. Beifiori, A. Galametz, R. Bender, N.M. Forster Schreiber, R. Genzel, P. Van Dokkum, & KMOS3D team

Paris - 15 December 2016

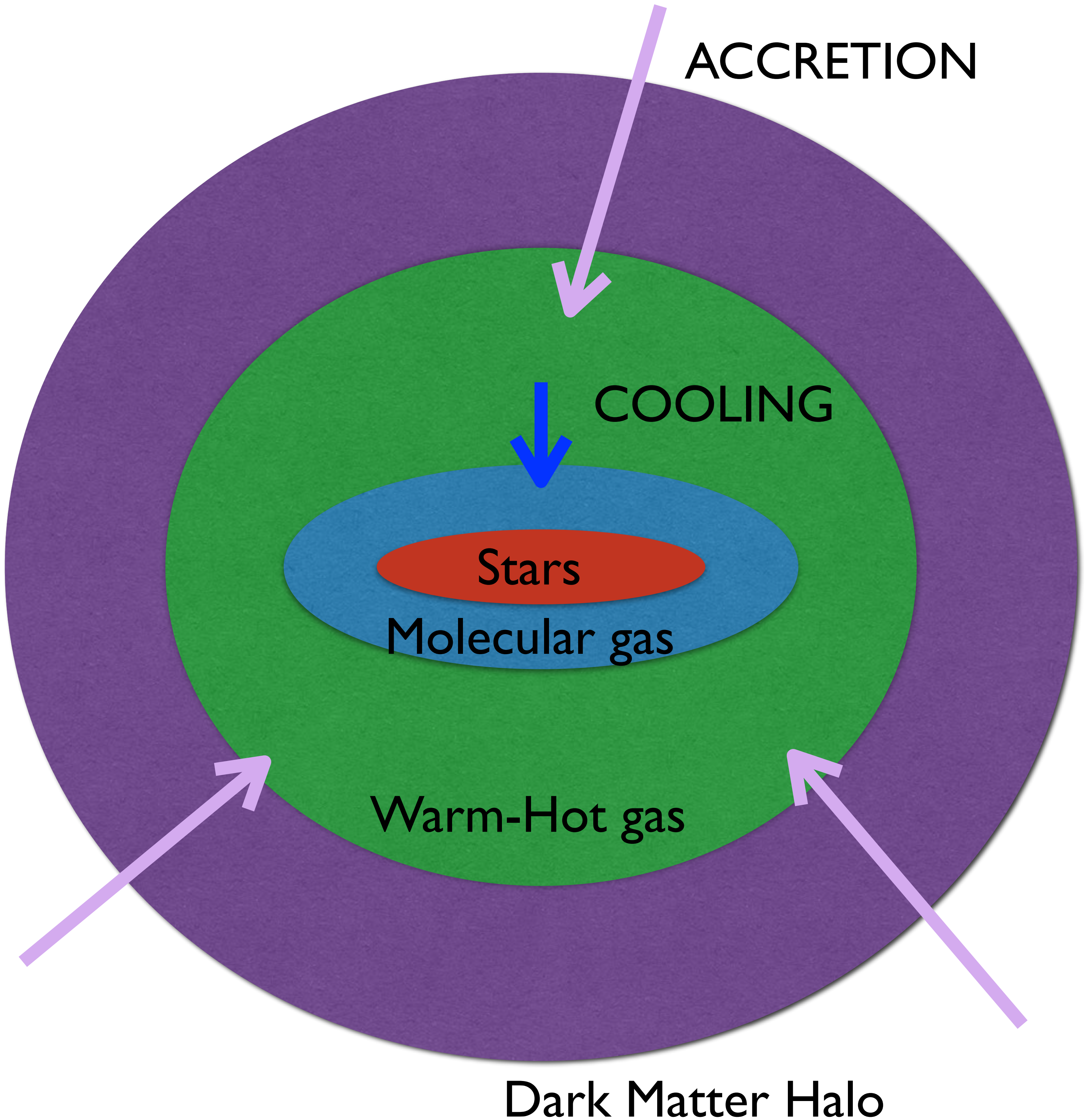
The build-up of a hierarchical Universe



Merger tree from Millennium simulation



Zooming-in on a galaxy



Properties characterizing galaxies:

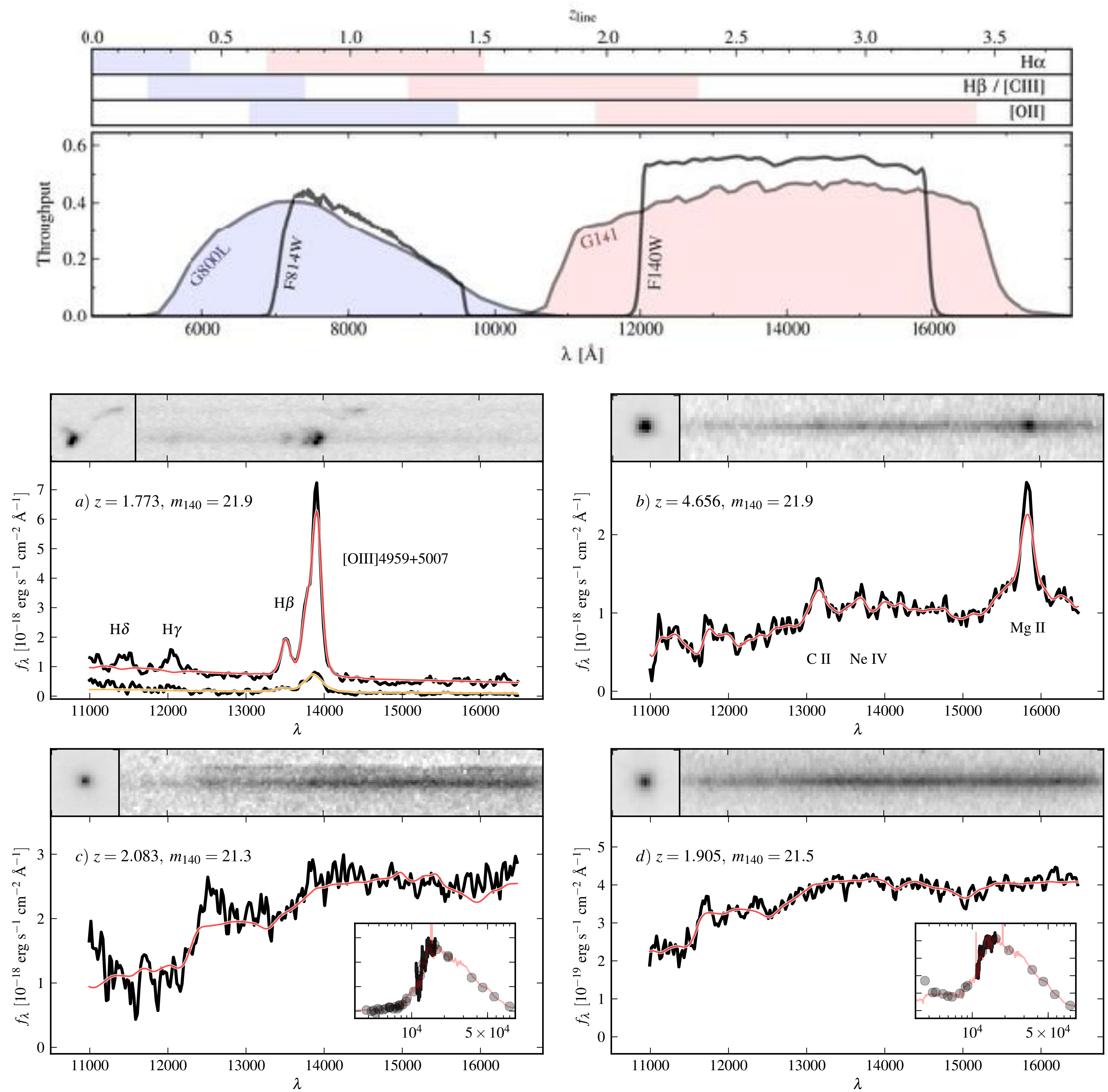
- Central/satellite
- Halo Mass
- Stellar Mass
- Star Formation Rate (Colors)
- Gas masses (various phases)
- Redshift

3D-HST a game changer survey at z=0.5-2.0

- 3DHST (PI P. Van Dokkum) grism spectroscopy in deep HST multi-band CANDELS fields.

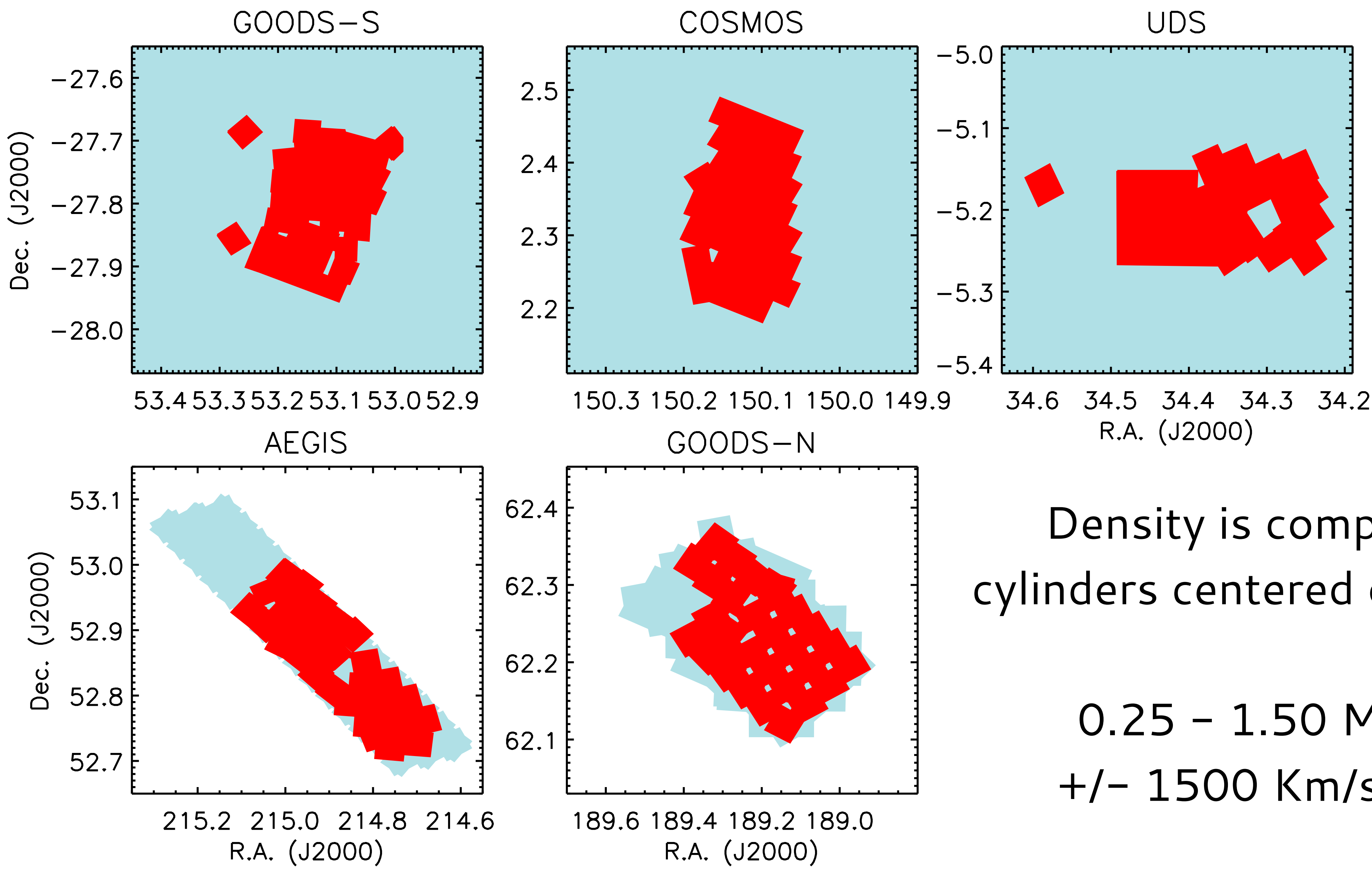
- Accurate redshifts (**σ** ~1000 km/s), especially for emission line galaxies but also using continuum features

- F140W<24 mag



Brammer et al. 2012, Momcheva et al. 2016

Computing galaxy densities



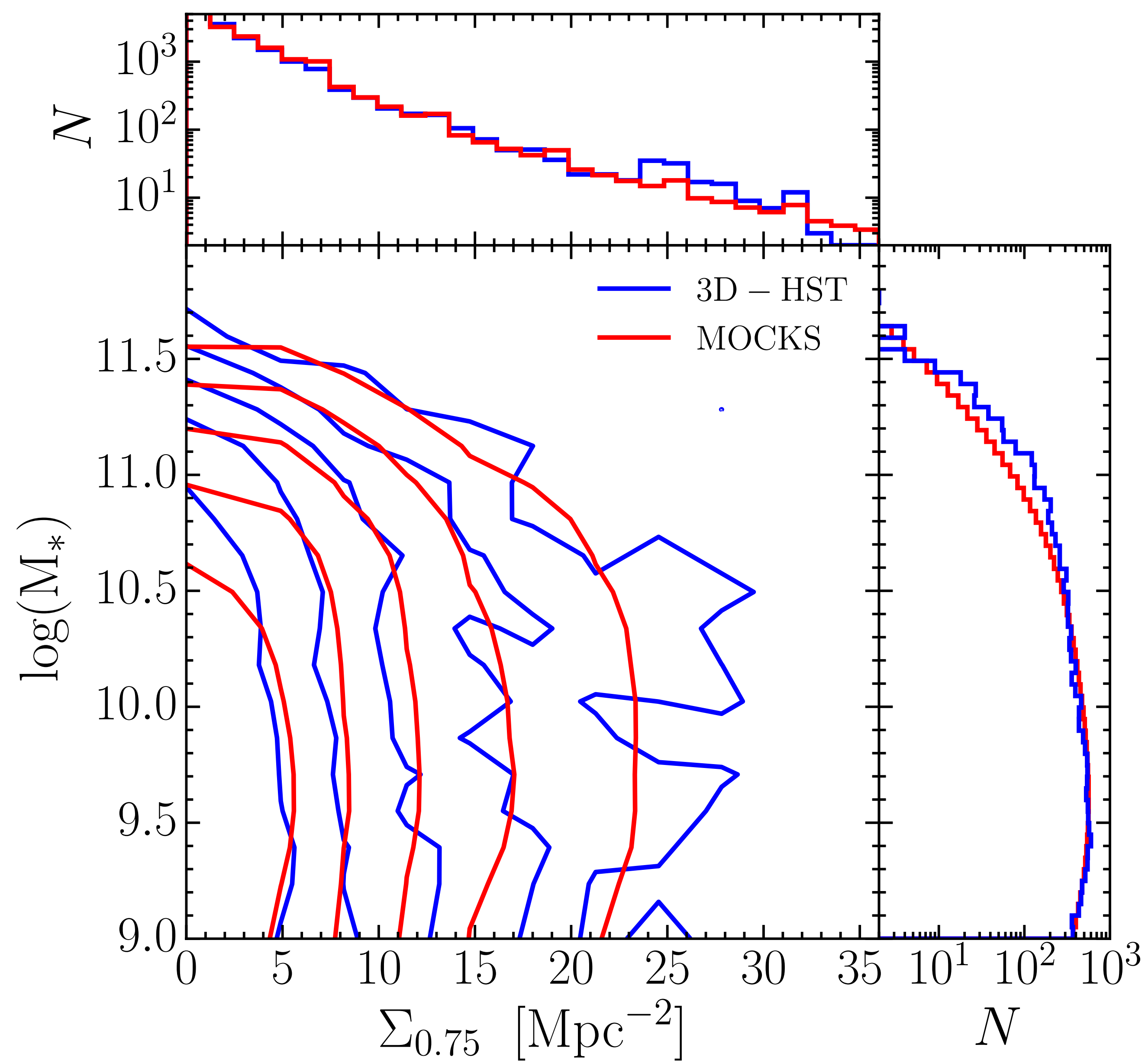
Density is computed within cylinders centered on each galaxy:

0.25 – 1.50 Mpc Radius
+/– 1500 Km/s in velocity

- Accurate edge corrections are applied using extended photometric catalogues (cyan)

Calibrating environment

- Density is not a physical parameter. We calibrate it into Halo Mass.
- We use lightcones from the Henriques+2015 SAM, selected and processed to reproduce the number density and redshift accuracy of 3D-HST.



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Observational sample

- Density (0.75 Mpc aperture)
- Stellar Mass
- Mass Rank (most massive in the aperture?)
- Redshift
- Redshfit accuracy

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- Density (0.75 Mpc aperture)
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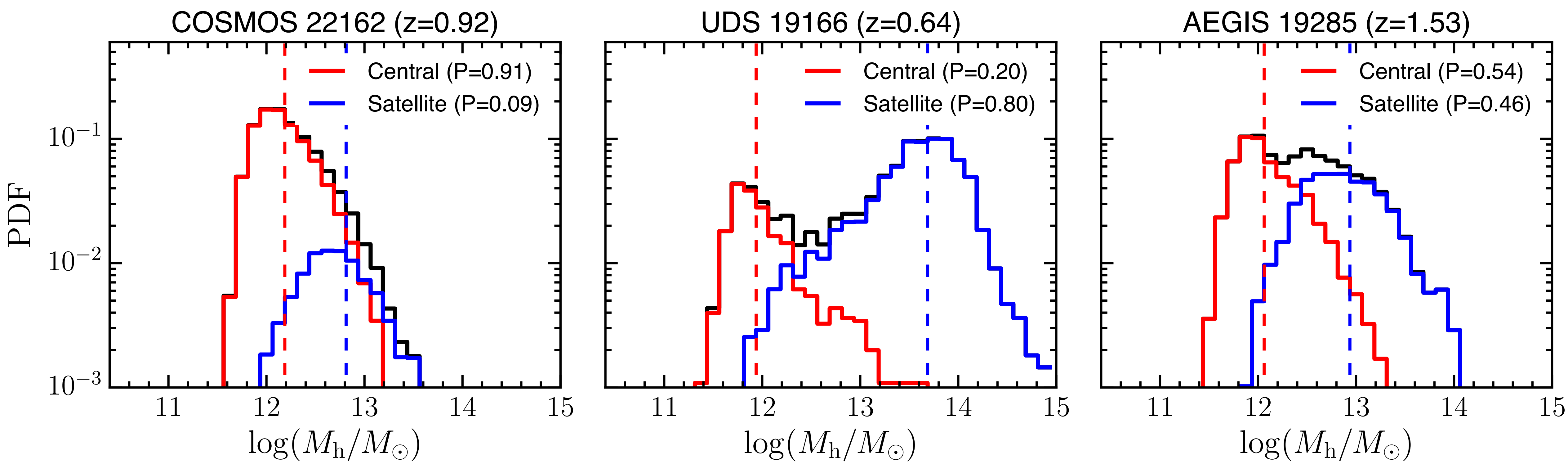
Mock sample

- Density (0.75 Mpc aperture)
- Stellar Mass
- Mass Rank
- Redshift
- Redshfit accuracy
- Halo mass
- Central/satellite status

- For each 3D-HST galaxy we obtain a probability of being central/satellite (Pcen, Psat) and Halo mass PDFs given each type

Calibrating environment



Most likely central — Most likely satellite — Uncertain classification

Environment catalogue available at:

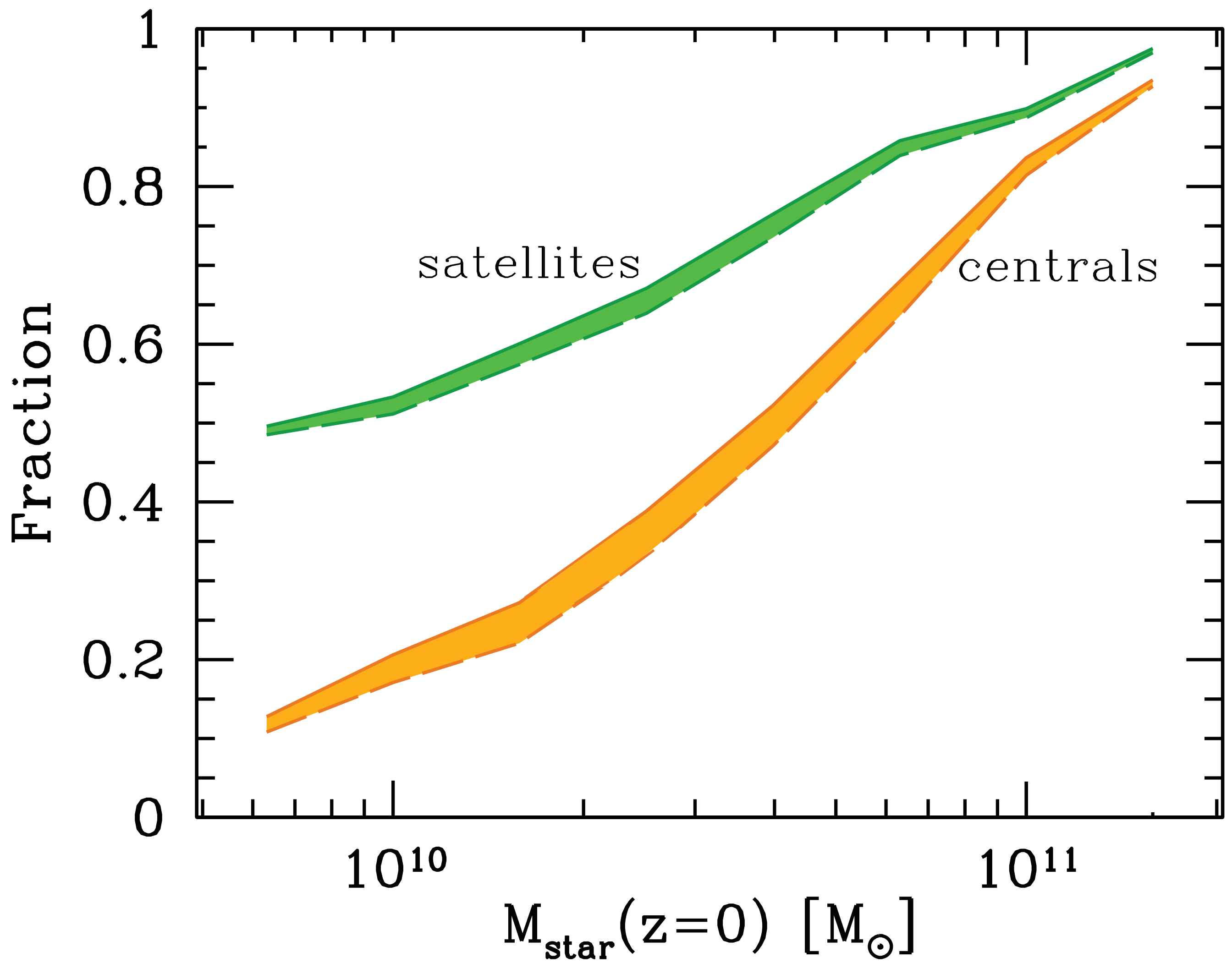
http://dx.doi.org/10.5281/zenodo.168056

What number (or fraction) of galaxies become passive as a direct result of their surrounding environments?

What is the main quenching mechanism? How long does it take for a satellite to be quenched?

Tracing evolution of the satellite population

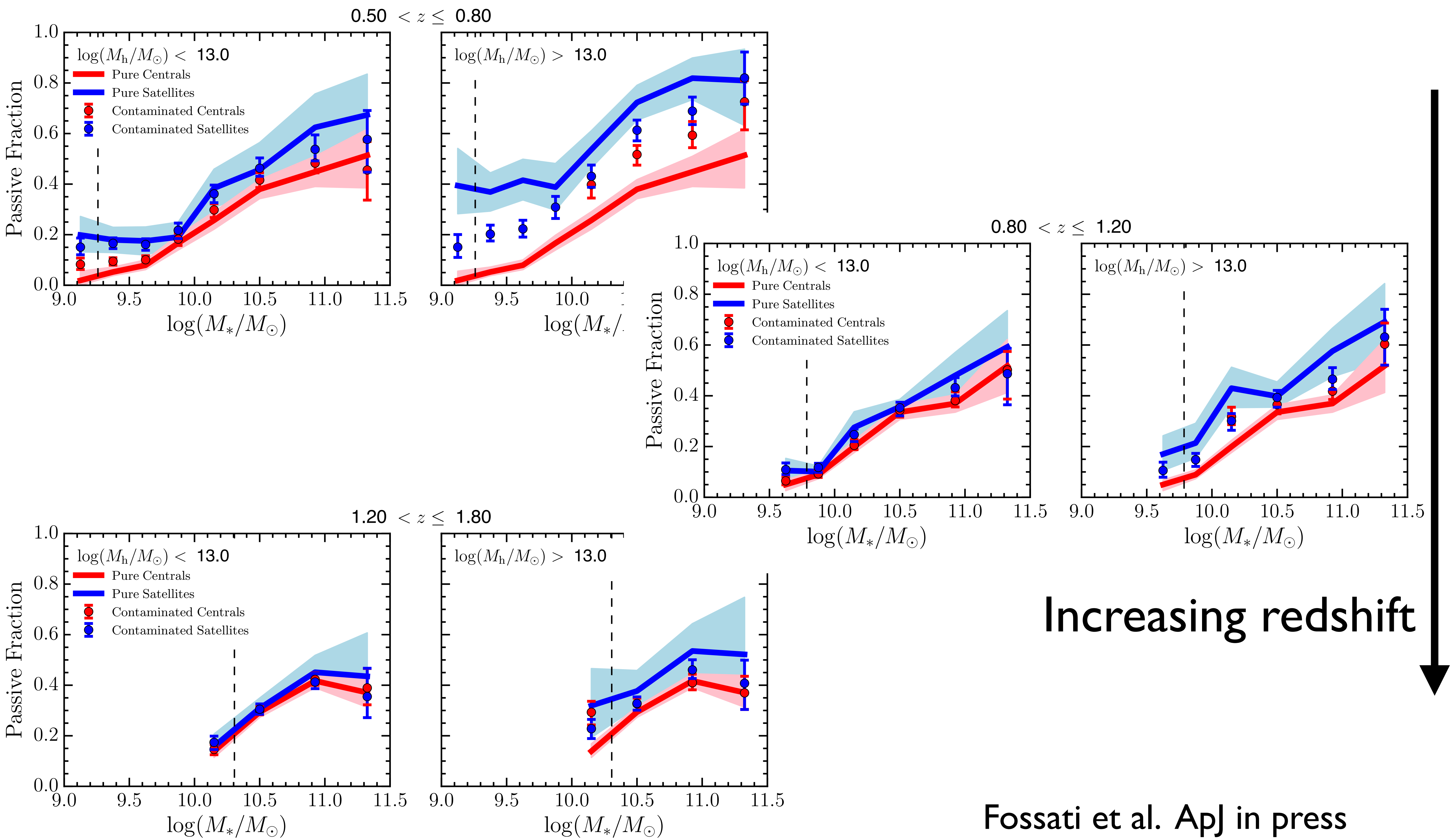
Locally, satellites are more likely to be passive than central galaxies at all stellar masses



Wetzel et al. 2013

Tracing evolution of the satellite population

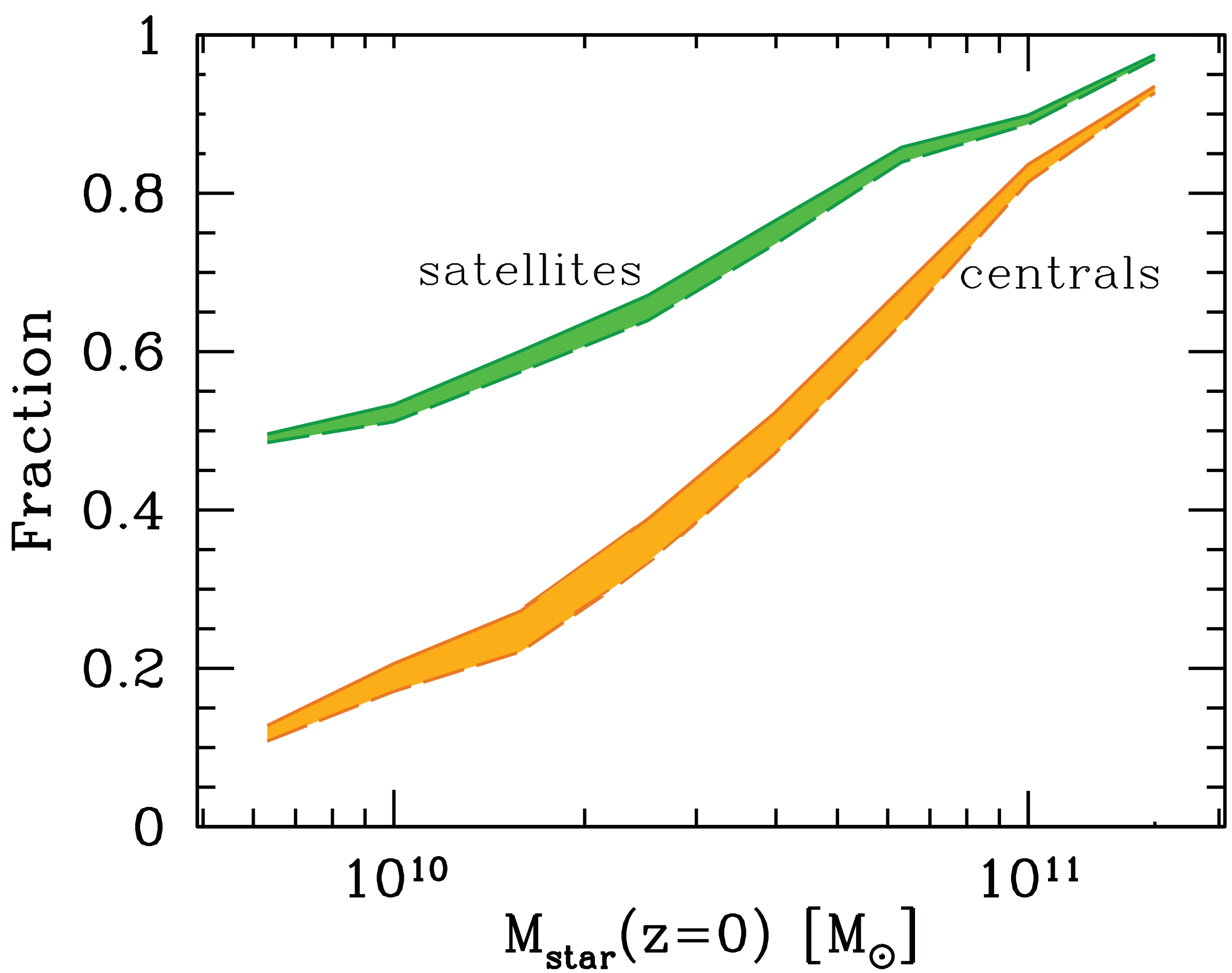
Satellites are more likely to be passive (in UVJ diagram) than central galaxies at all stellar masses over at least 10 billion years of cosmic time



Fossati et al. ApJ in press

Deconstructing the observed passive fraction

What is the excess probability that a galaxy is passive as a result of its environment?



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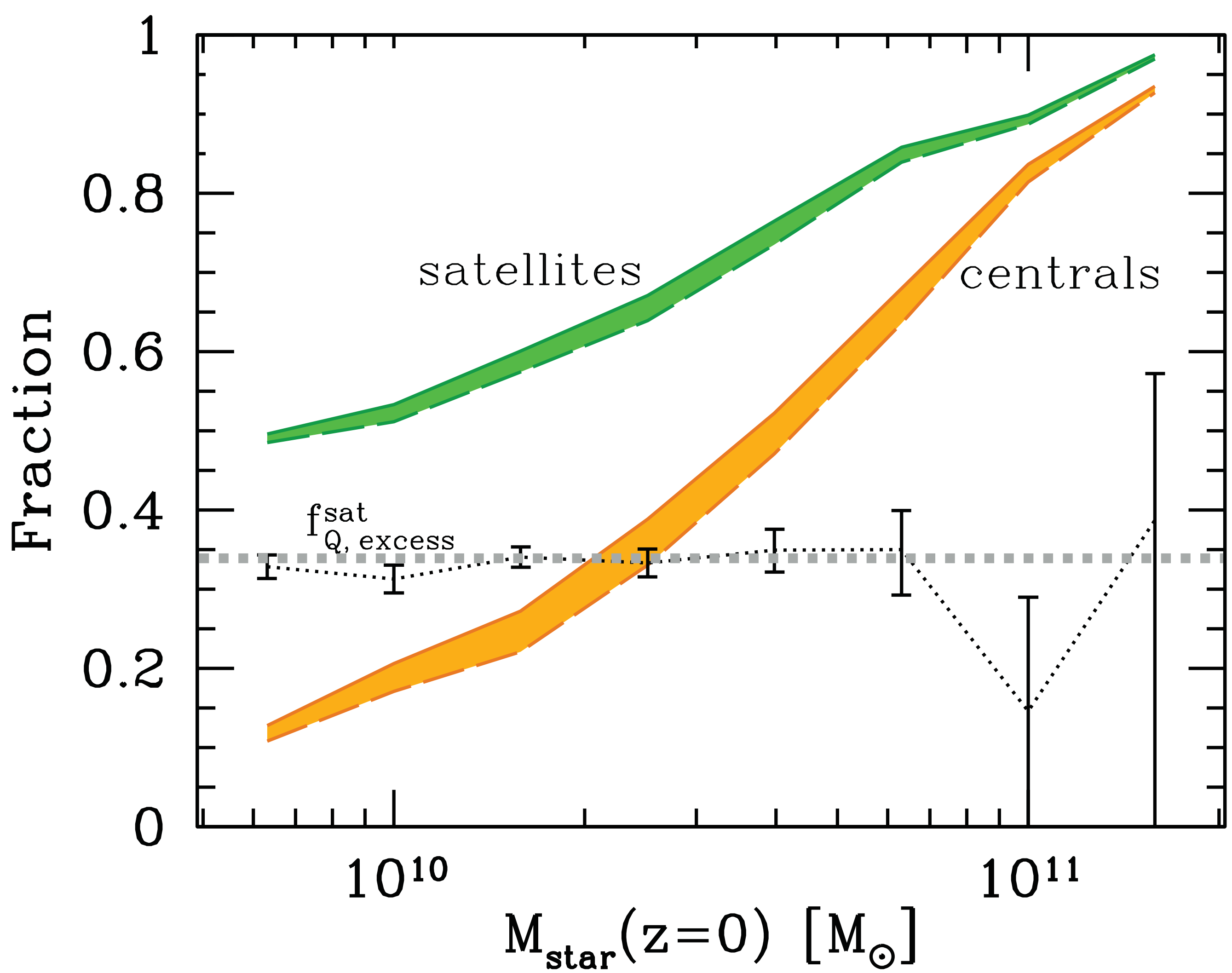


Fraction of passive centrals

Fraction of passive satellites

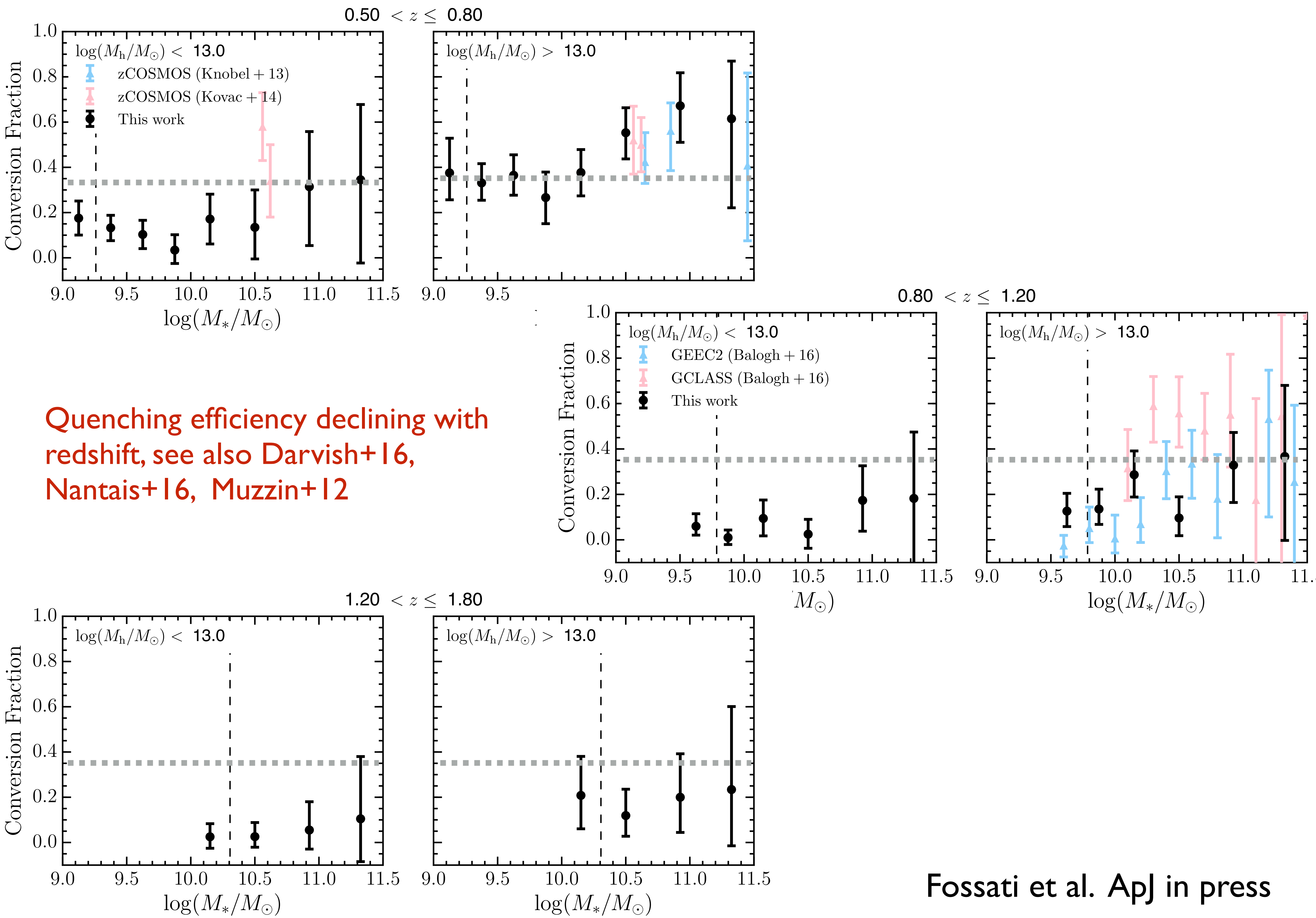
$$f^{sat}_{Q\ excess} = \frac{f^{sat}_{Q,\ now} - f^{cen}_{Q,\ now}}{f^{cen}_{A,\ now}}$$

Fraction of star-forming centrals

~35 % of satellites became passive as a result of their environment

Wetzel et al. 2013

Evolution of the conversion fraction

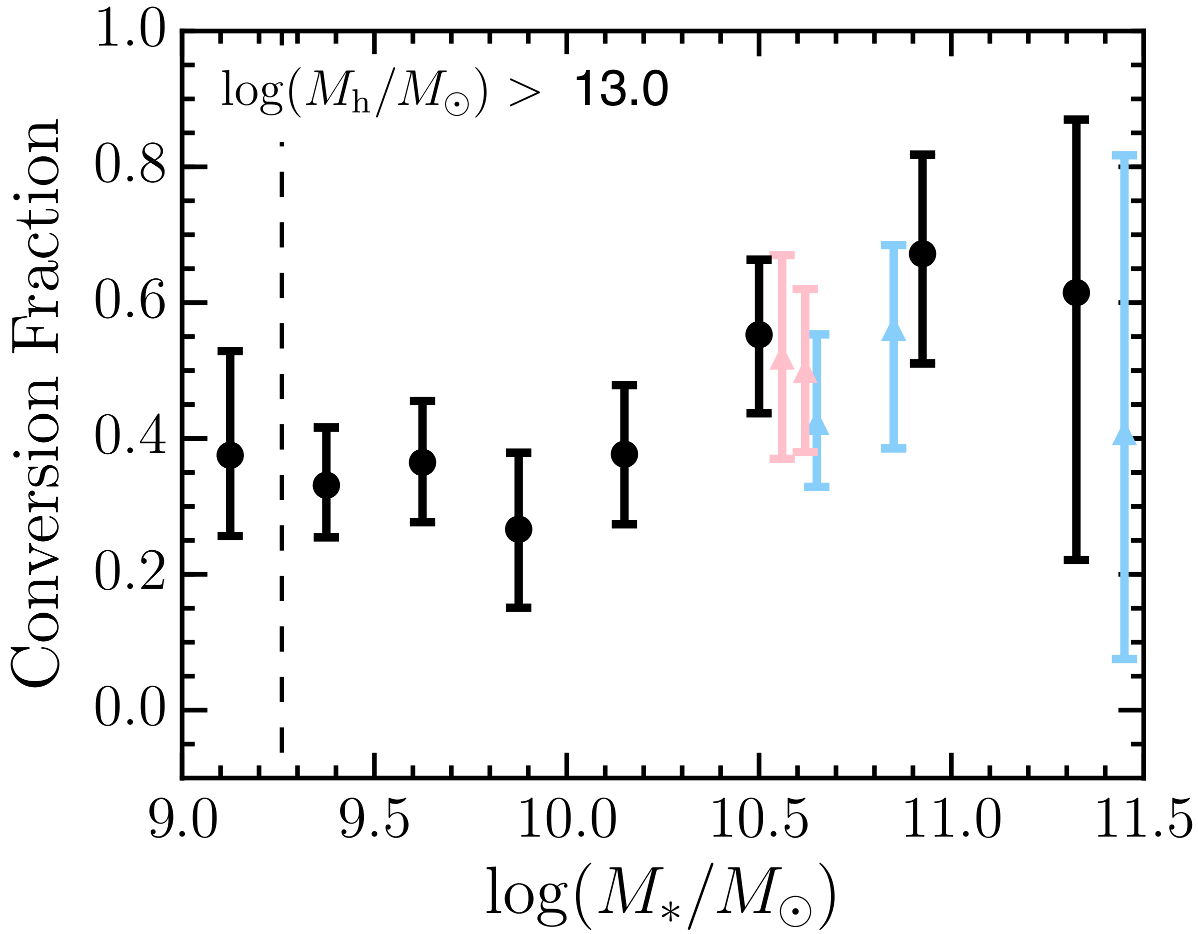


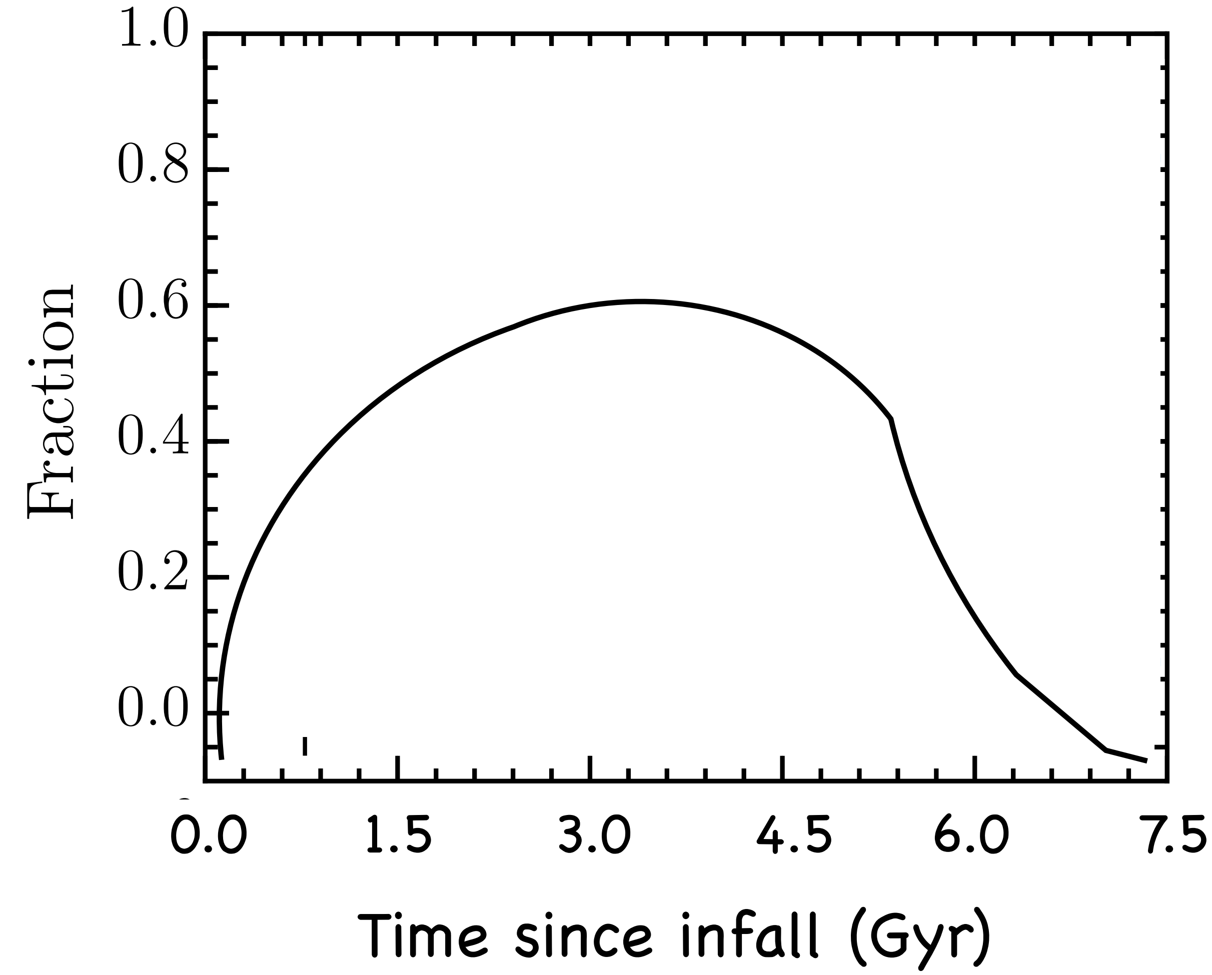
Quenching efficiency declining with redshift, see also Darvish+16, Nantais+16, Muzzin+12

Fossati et al. ApJ in press

From conversion fraction to quenching timescale

By assuming that the earliest accreted satellites also quench first, we can estimate how long it takes (on average) for galaxies to become passive





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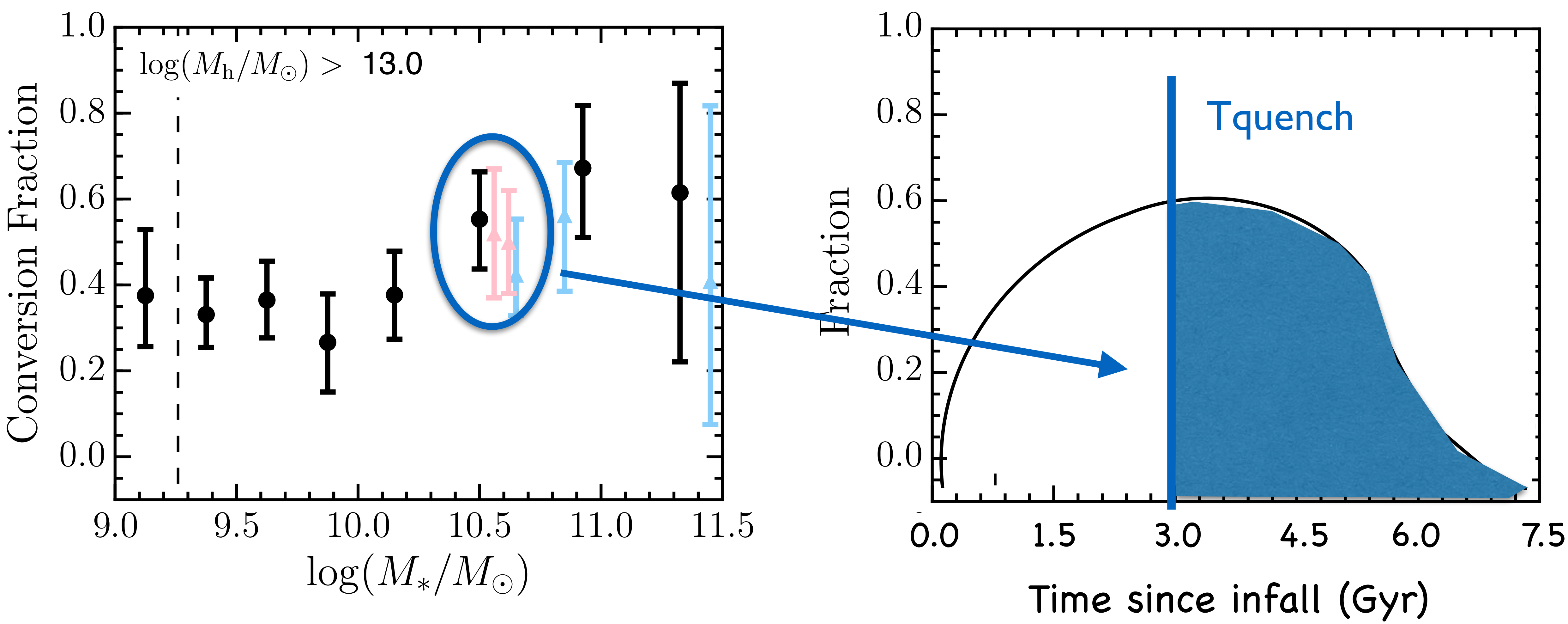
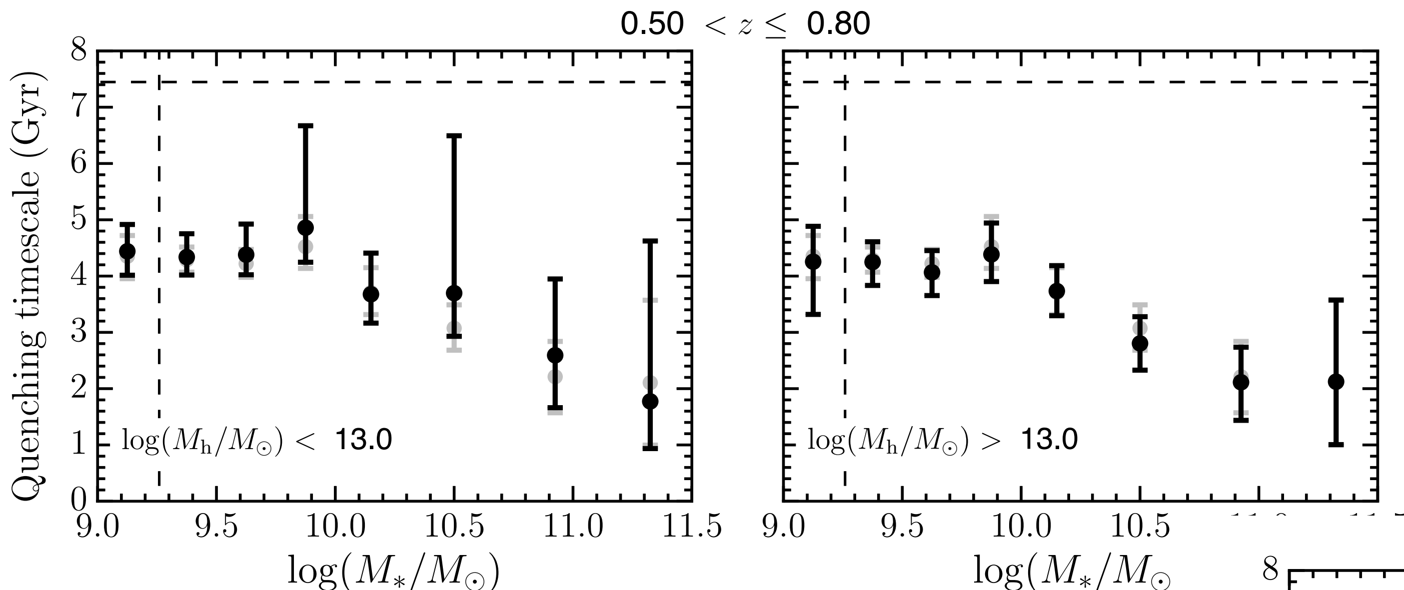
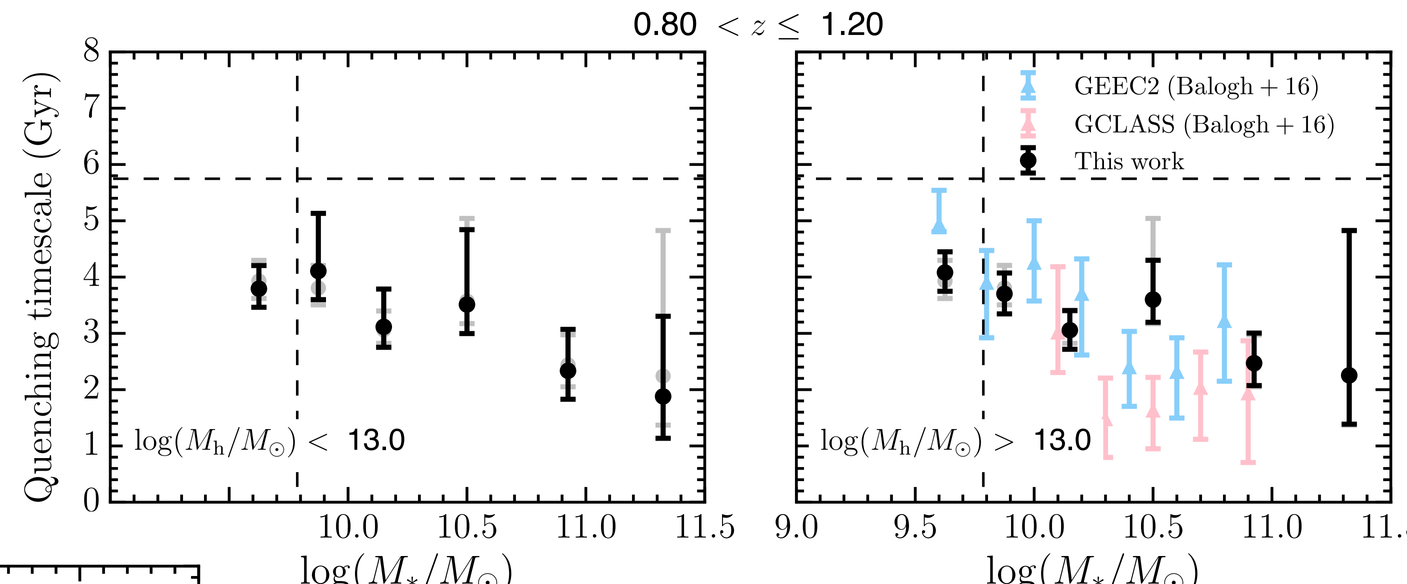


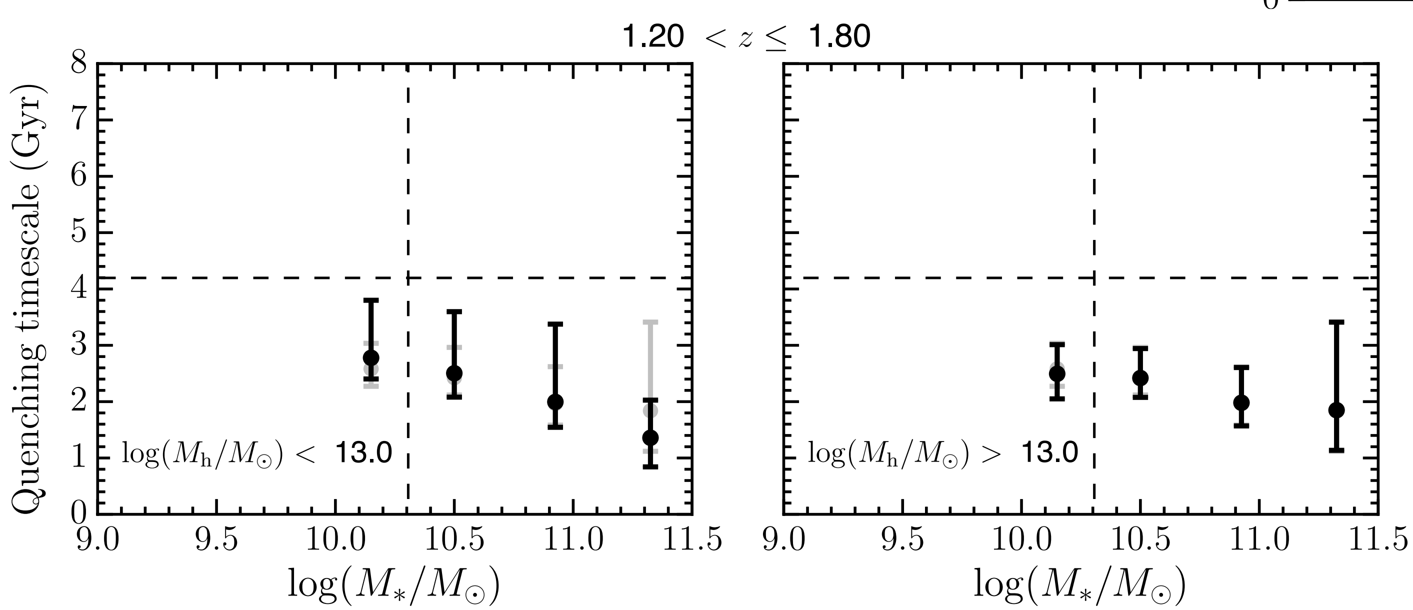
Quenching timescales are long!

Satellite galaxies continue forming stars for 2-5 Gyrs after infall



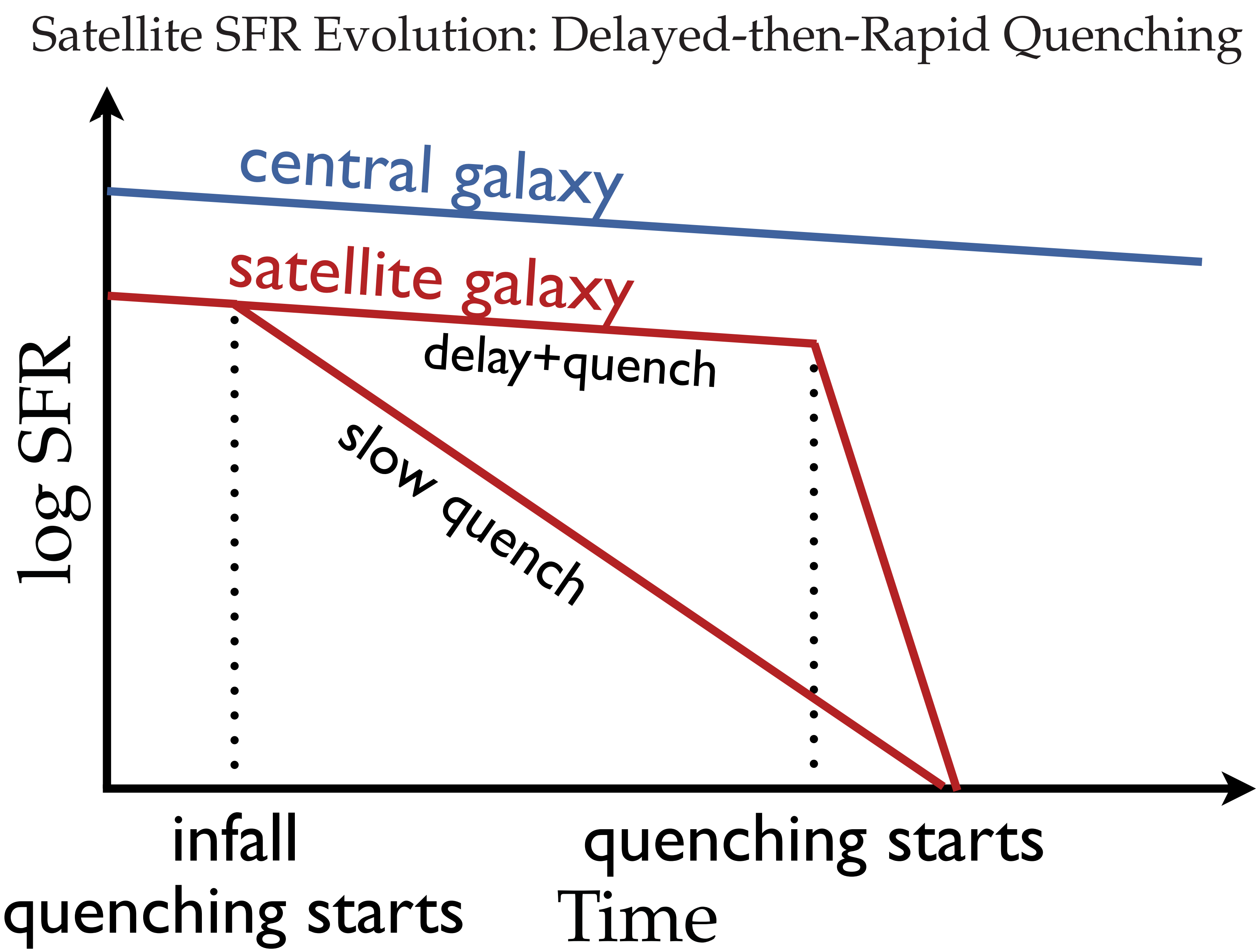
Quenching times are independent of halo mass disfavoring rapid removal of atomic+cold gas via dynamical processes





Fossati et al. ApJ in press

Reproducing observations with fast vs. slow

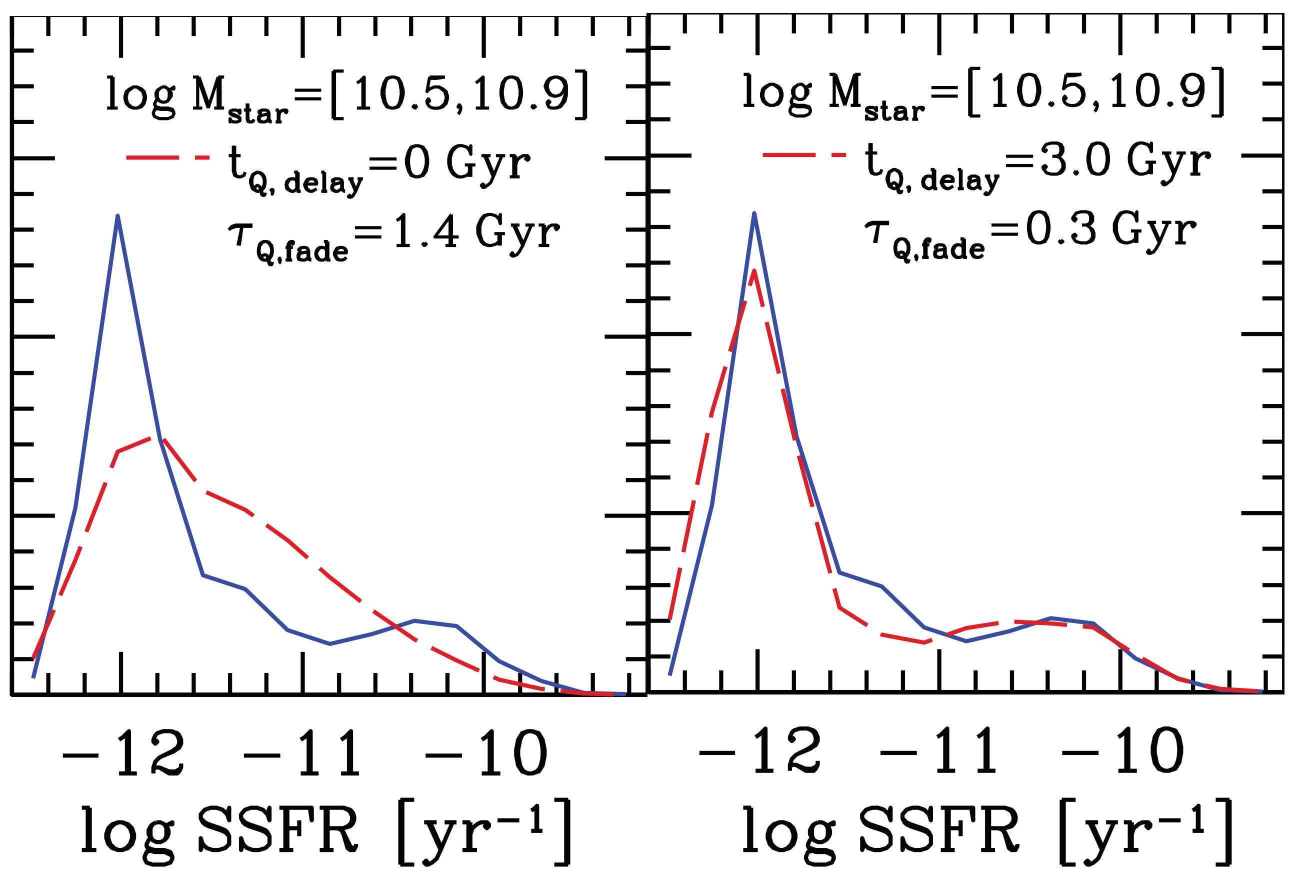


adapted from Wetzel et al. 2013

Delayed suppression of satellite star formation

Slow quenching over-produces "transition" galaxies

Mixed delay+quenching model



Wetzel et al. 2013

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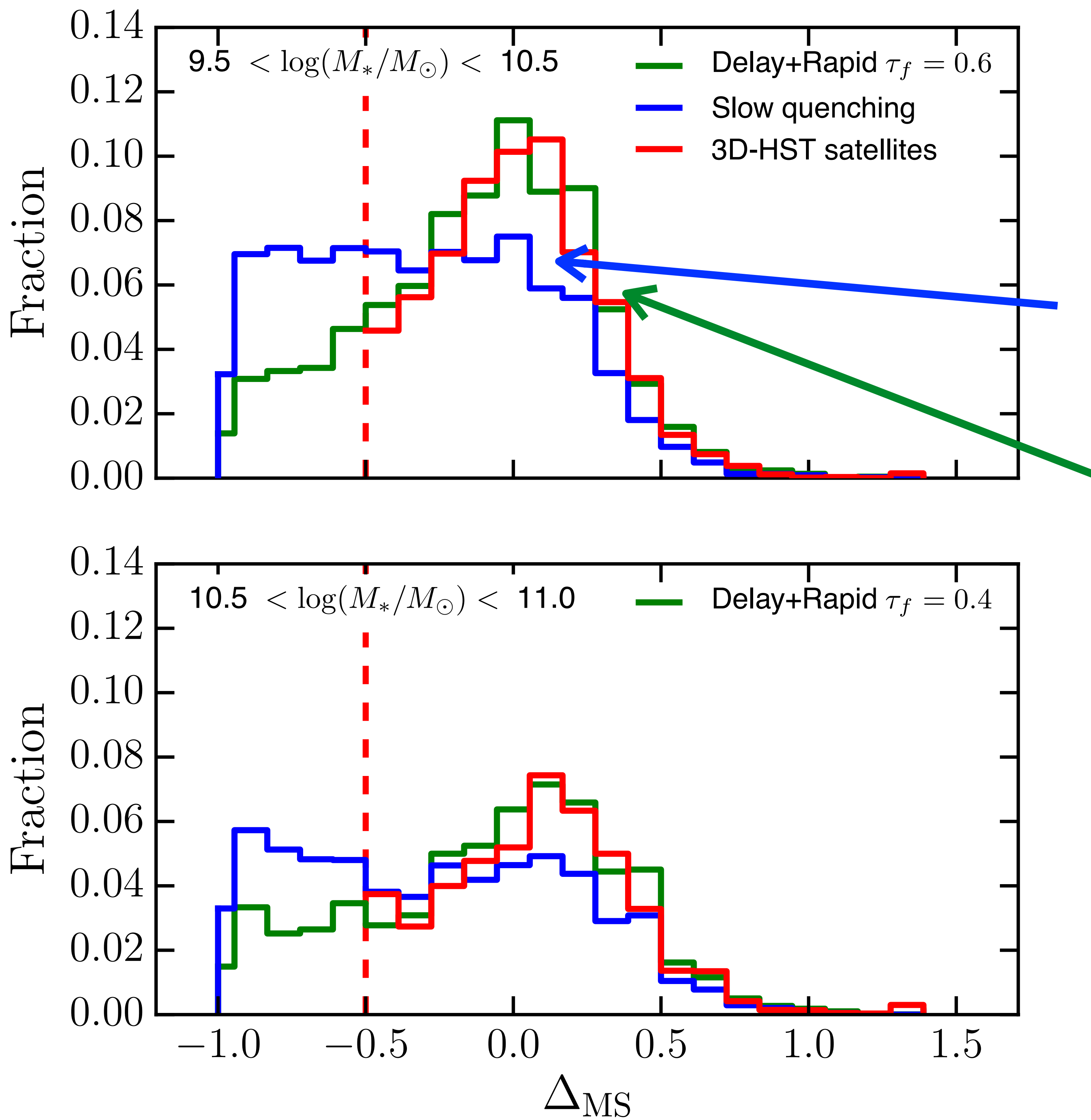


log(Offset from MS)

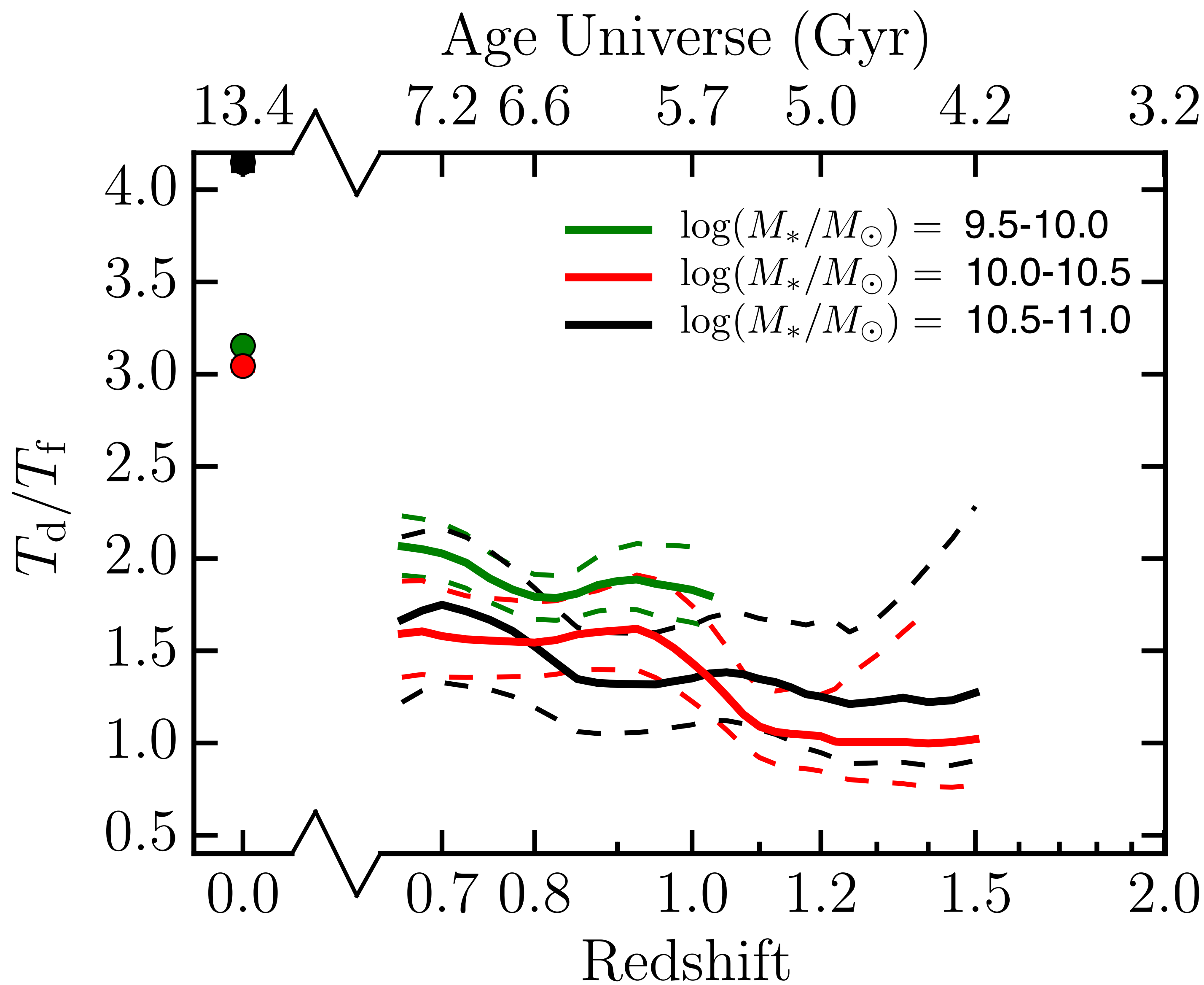
MS from Whitaker et al. 2014 using same 3D-HST dataset

Slow quenching over-produces "transition" galaxies

Mixed delay+quenching model fits satellite data (Red)

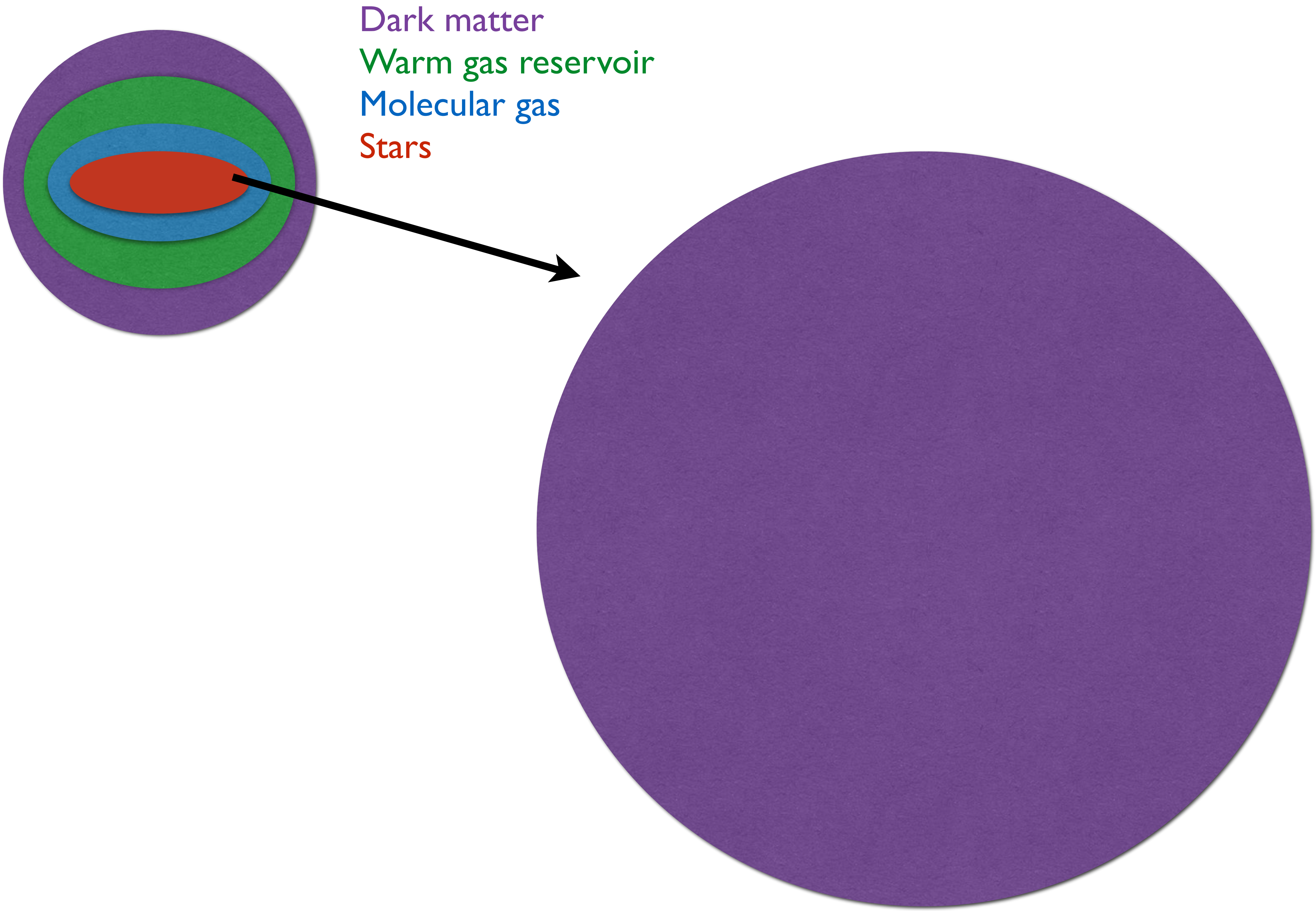
Fossati et al. ApJ in press

Delayed suppression of satellite star formation



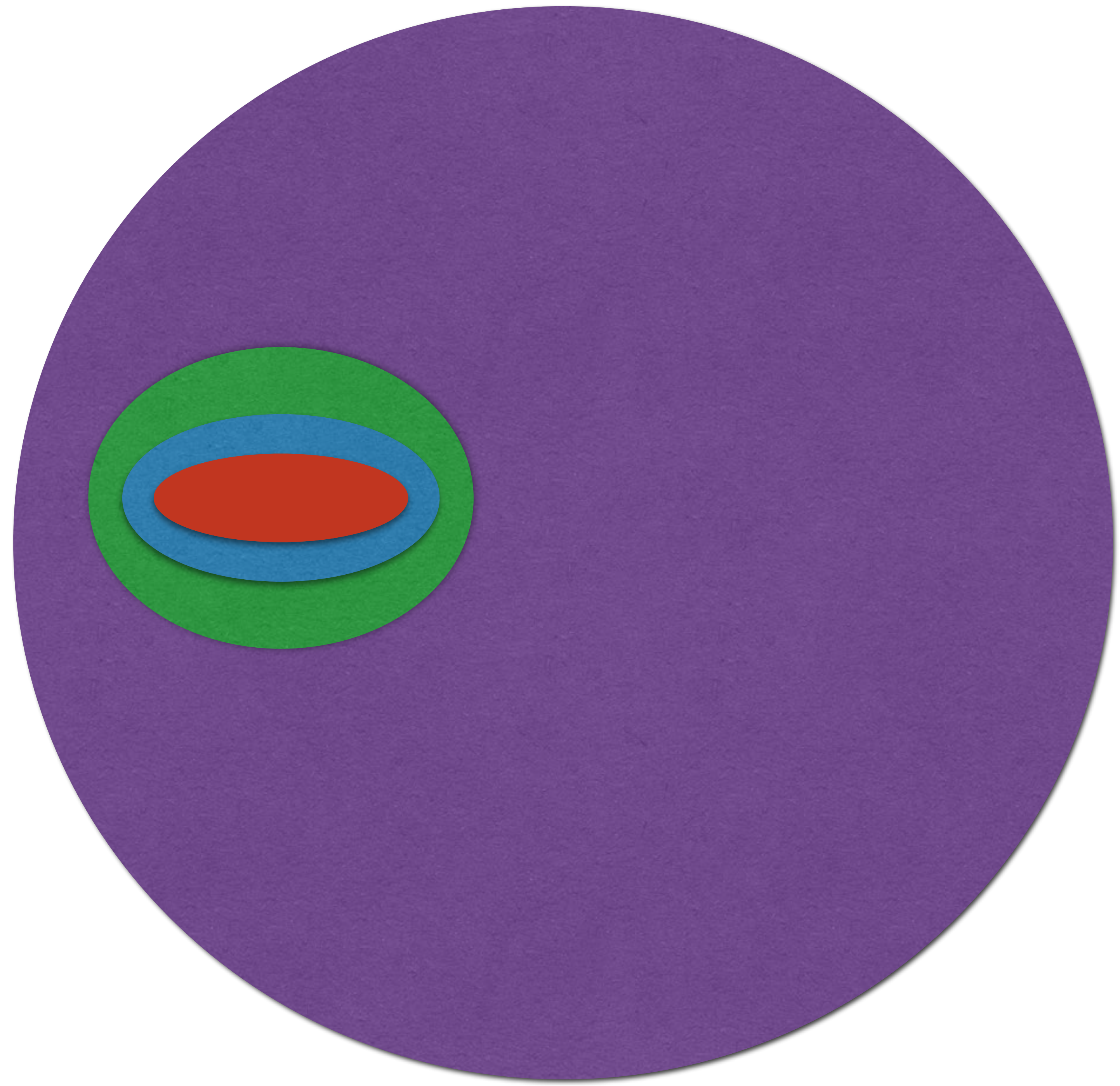
Long quenching times require a significant residual gas reservoir (not only molecular)

A schematic picture for satellite quenching



A schematic picture for satellite quenching

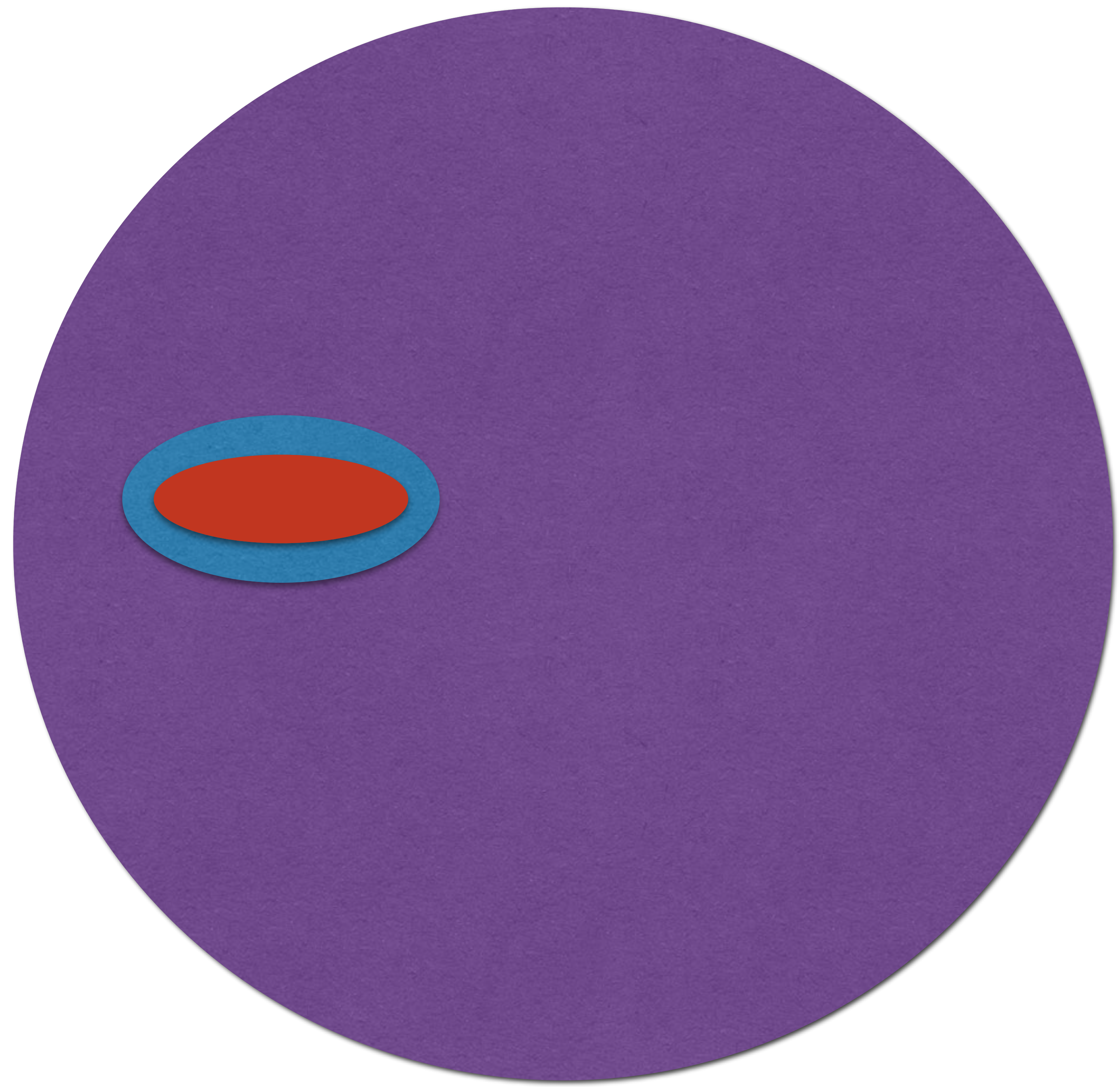
1. On infall, satellite galaxies lose their connection to the cosmic web, but retain significant gas reservoirs (both atomic and molecular)



A schematic picture for satellite quenching

1. On infall, satellite galaxies lose their connection to the cosmic web, but retain significant gas reservoirs (both atomic and molecular)

2. DELAY PHASE Over time, star formation slowly eats through the available molecular gas, which is replenished by cooling from the larger gas reservoir, depleting the overall gas supply but maintaining relatively "normal" star formation.



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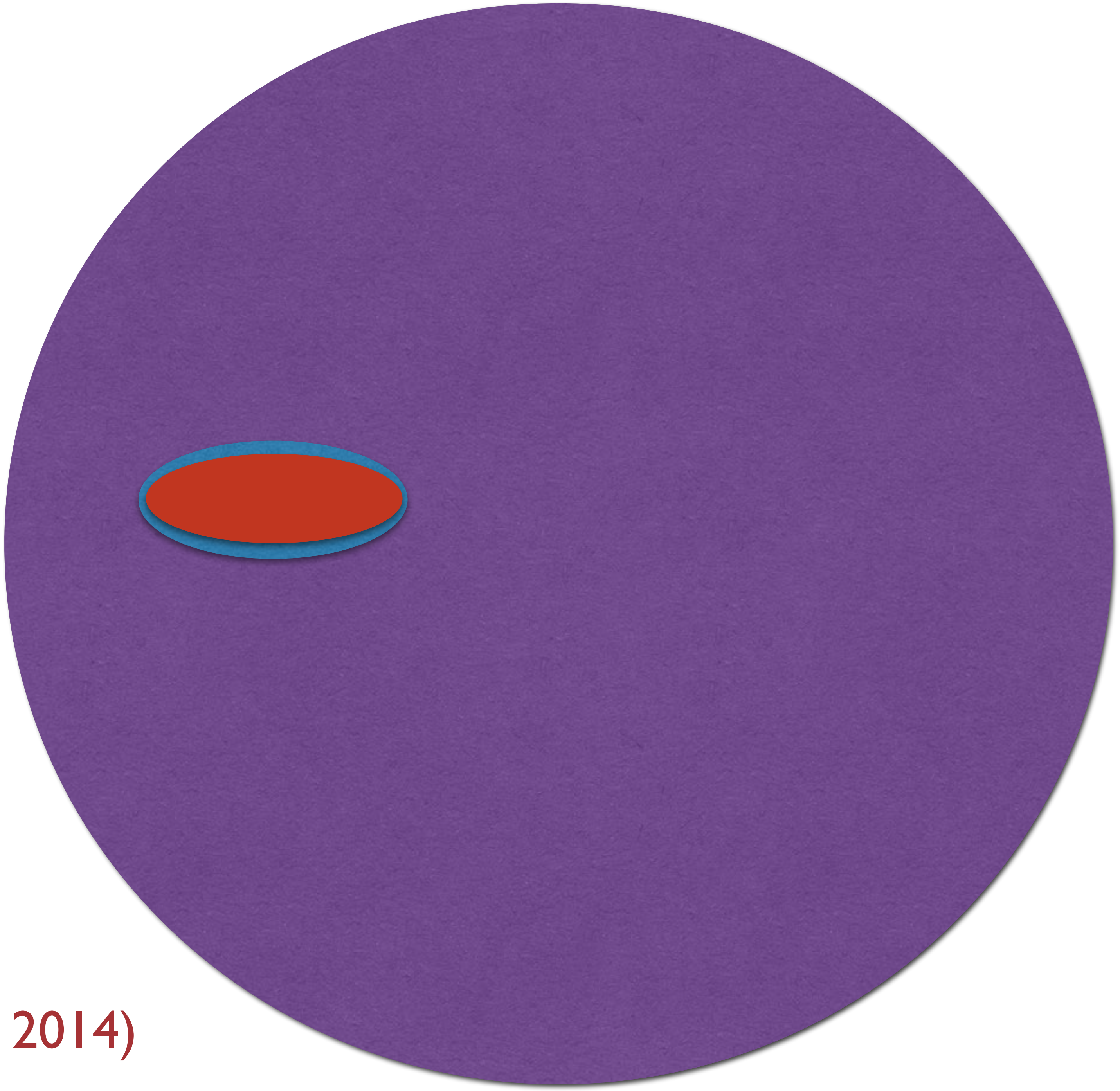
3. FADING PHASE Once only molecular gas remains, the star-formation rate starts to decline as molecular gas is used up, resulting in a fading of star formation on relatively short timescales

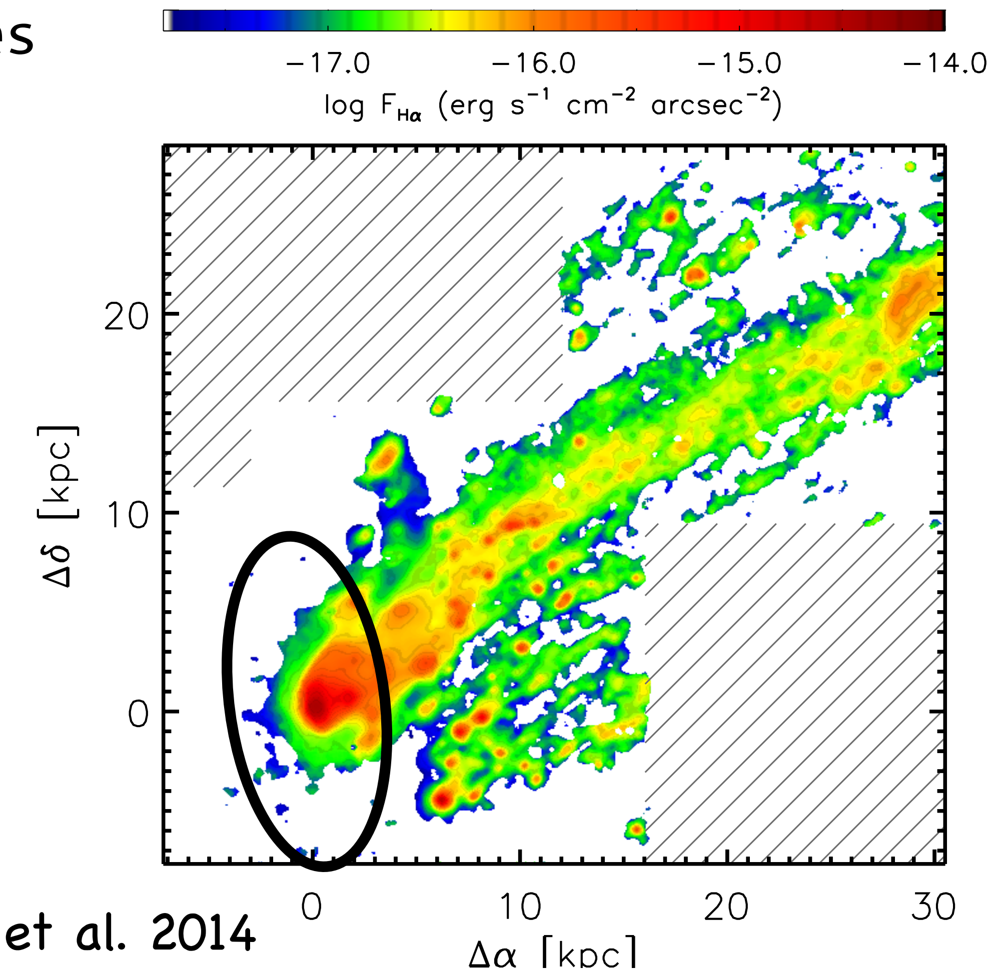


"overconsumption" model (McGee et al. 2014)

Conclusions and Reconciling to cluster observations

- Our data supports a scenario where satellite quenching is driven by exhaustion of a multiphase gas reservoir over a long quenching time. This holds up to z=1.5, above this redshift the quenching time is too long to produce a significant population of quenched satellites.

- How to reconcile with spectacular observations of rapid gas stripping in local clusters or statistical studies in high-z clusters? Despite being the most conspicuous environments, galaxy clusters are relatively rare, and probably not the dominant environment for most galaxies over their lifetimes



Fumagalli, MF et al. 2014

VESTIGE: a large program to observe environmental effects in Virgo

VESTIGE: A Virgo Environmental Survey Tracing Ionised Gas Emission

PI: Alessandro Boselli

Instrument: MegaPrime, 50 nights allocated.

VESTIGE will be a complete blind survey of the Virgo cluster within one virial radius from M87 and M49, the same sky region mapped by NGVS (104 deg^2; green footprint

Boselli, MF et al. 2016