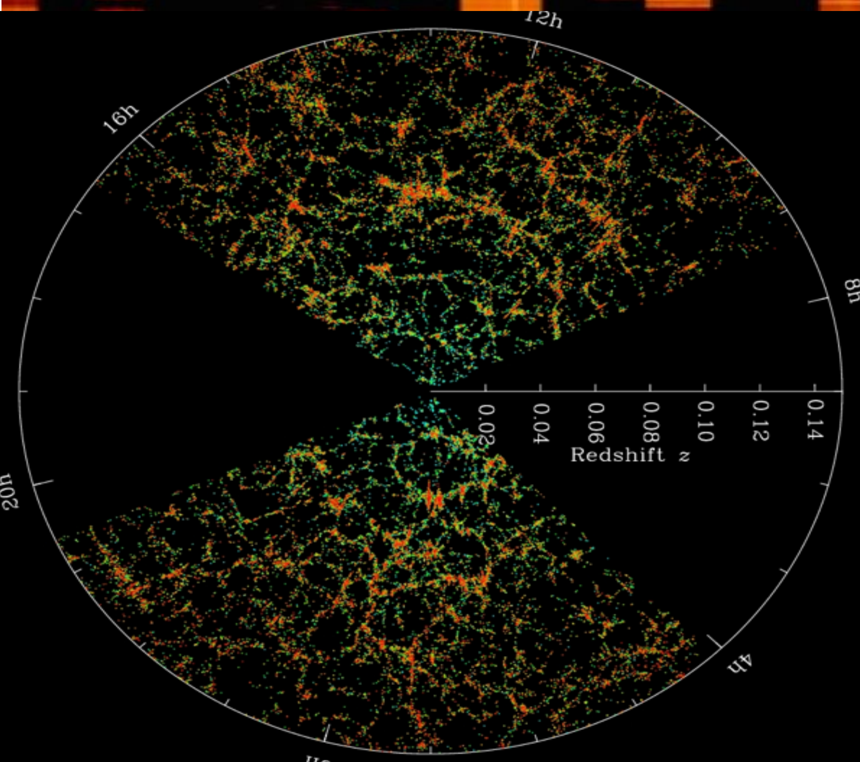
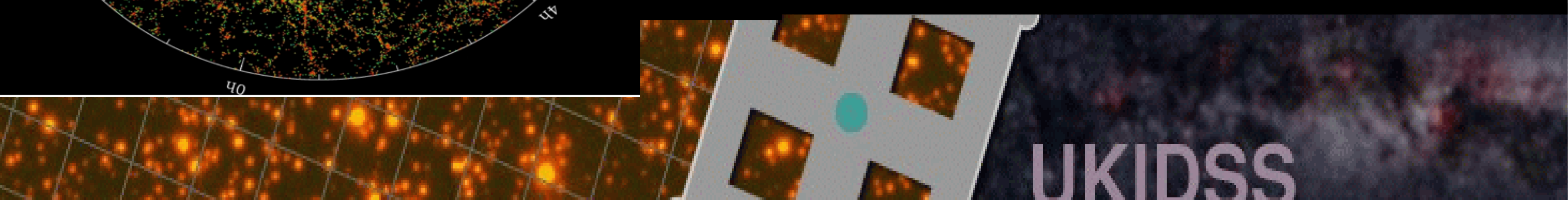
THE ASSEMBLY OF GALAXIES

(an attempt at a review)



A HUGE WEALTH OF NEW DATA

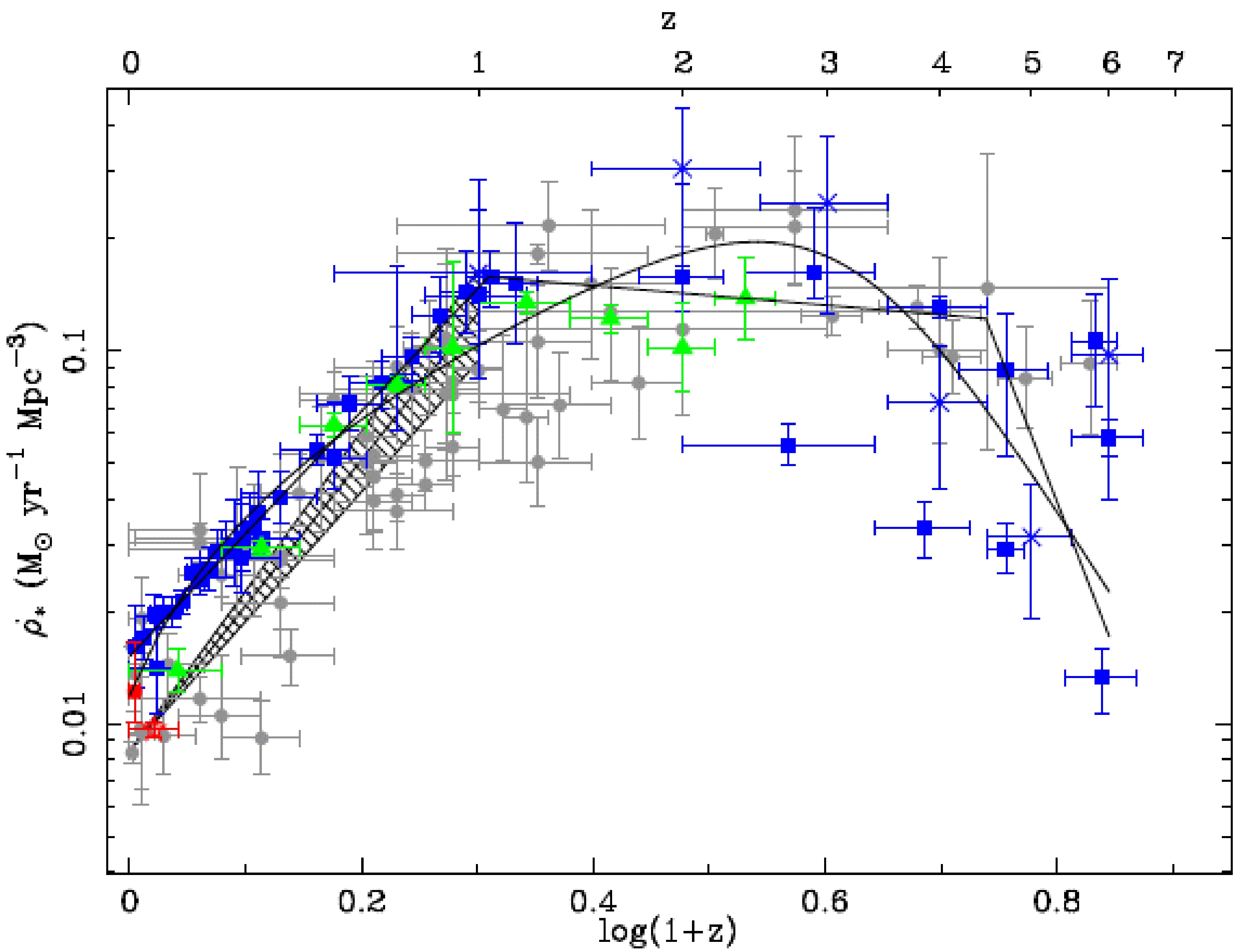


1) MAIN EMPIRICAL RESULTS

2) COMPARISON WITH MODELS

3) WAYS FORWARD

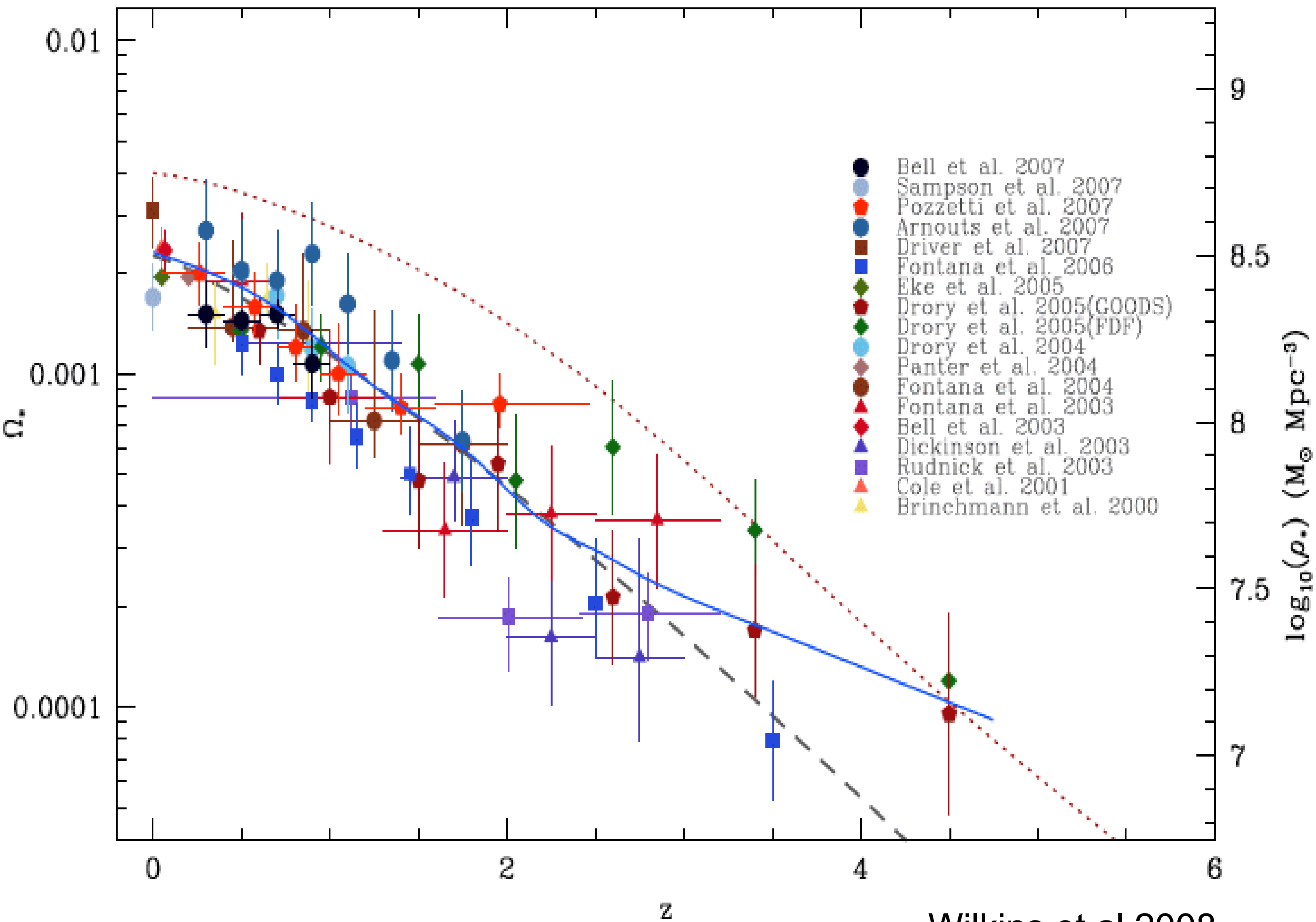
INTEGRATED QUANTITIES



Hopkins & Beacom 2006

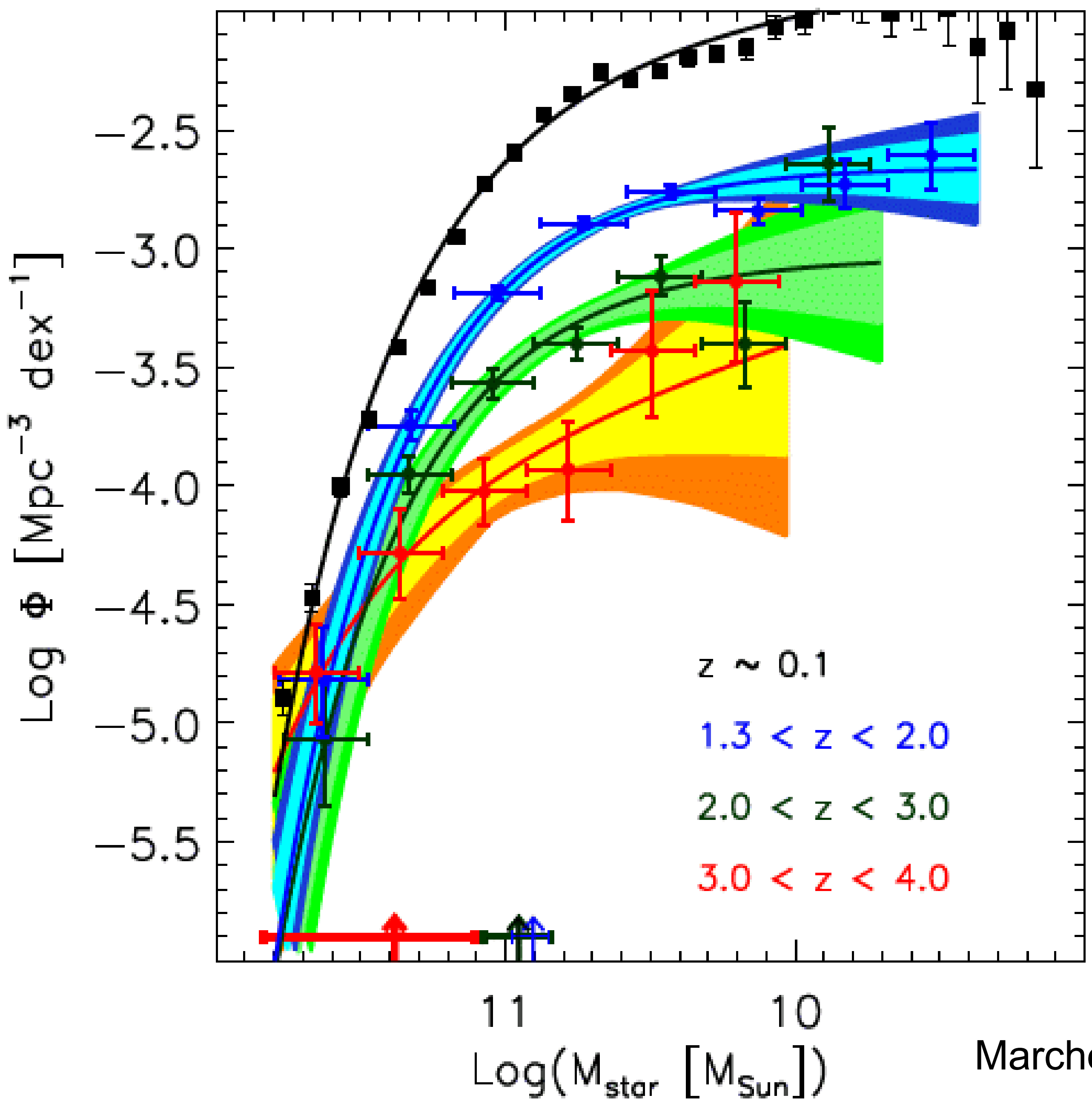
Integrated SFR density (z) > Stellar mass formed (z)

Reasons: Systematic problems with SFR indicators?, IMF?



Wilkins et al 2008

Evolution of the Stellar Mass Function: "anti-hierarchical" growth of galaxies



Marchesini et al 2009

COLOUR/ STELLAR MASS BIMODALITY

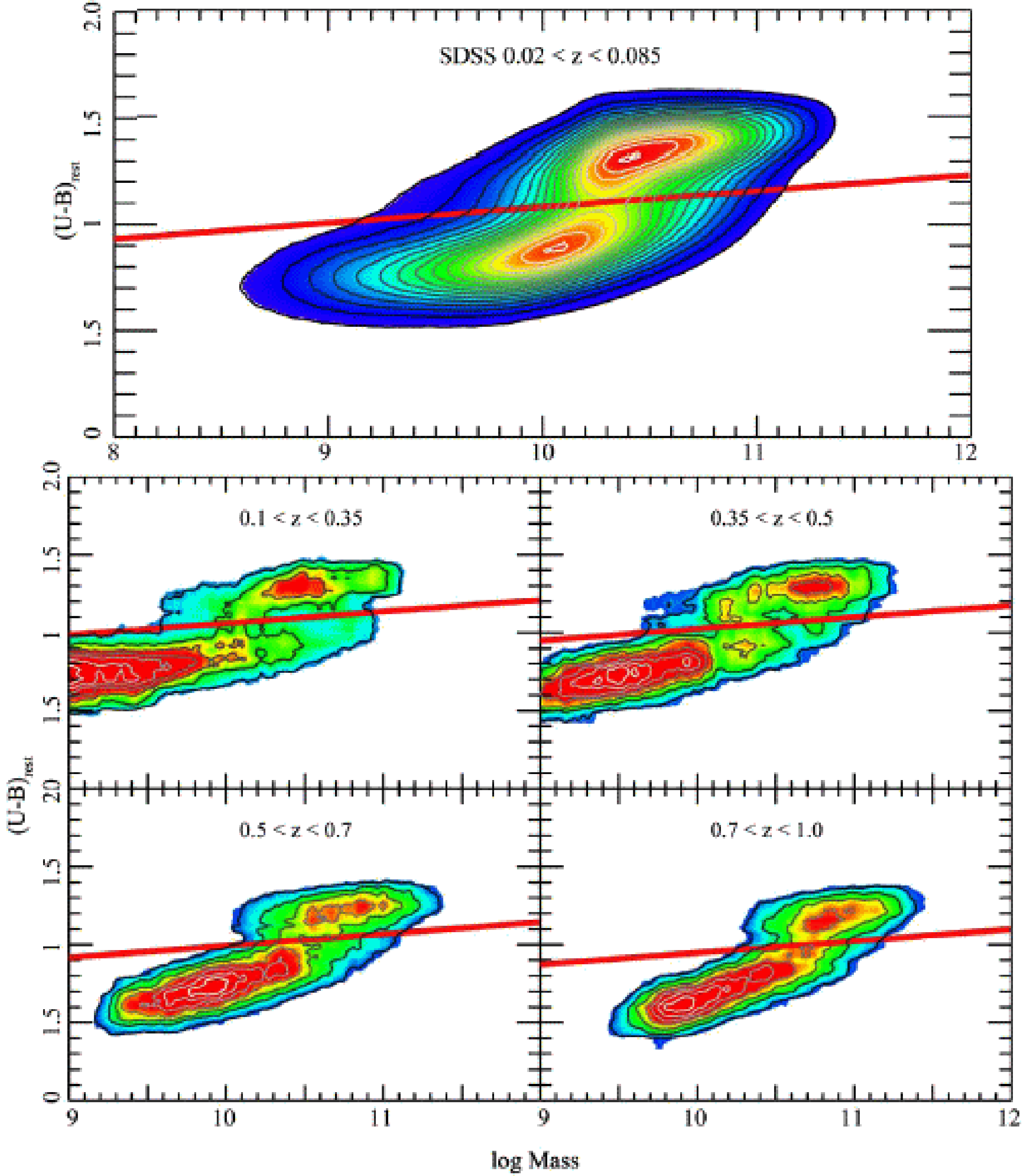
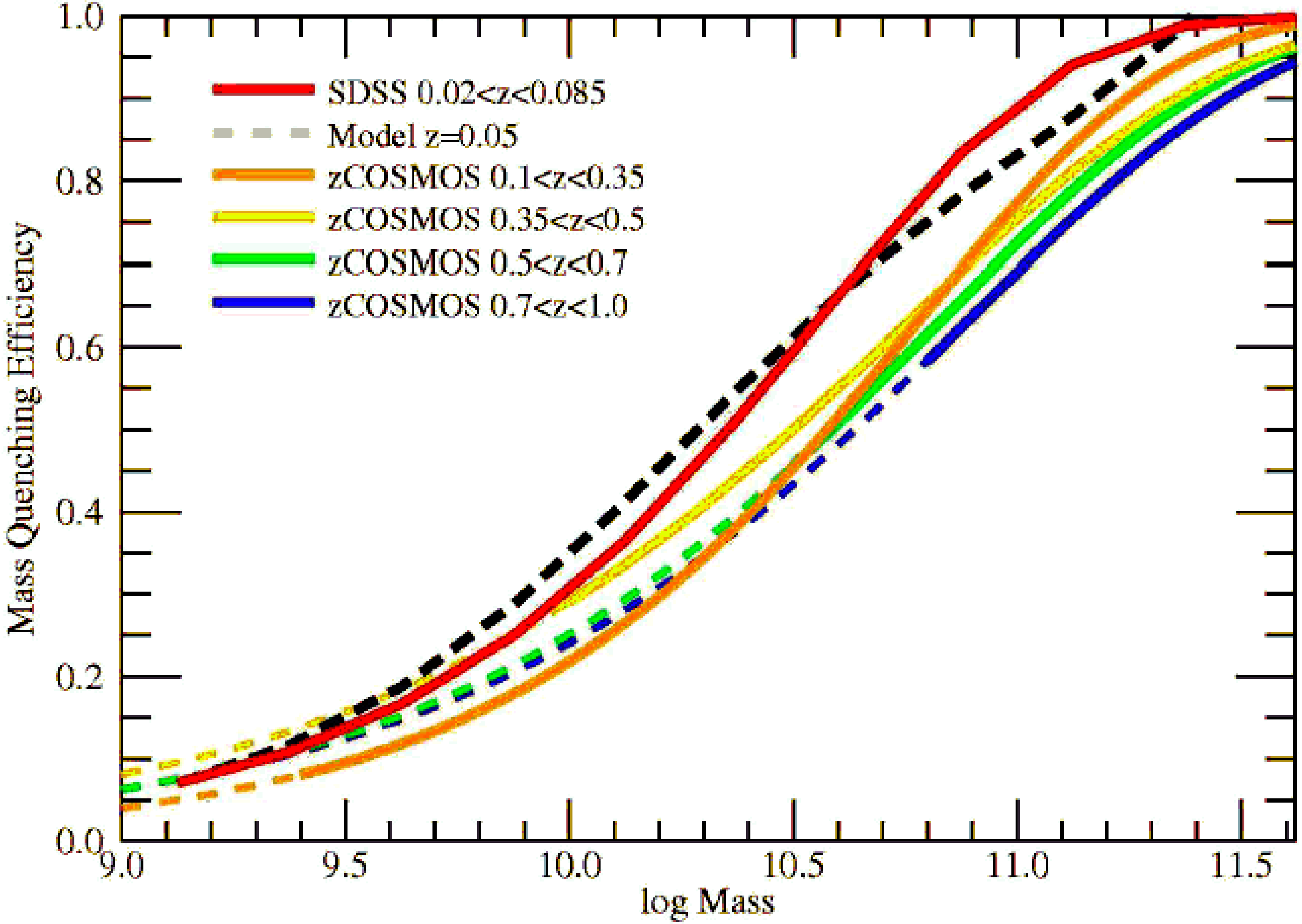


Fig 4: Color distributions in SDSS (upper) and zCOSMOS at different redshifts (lower panels) with the dividing line used to split galaxies into red and blue.

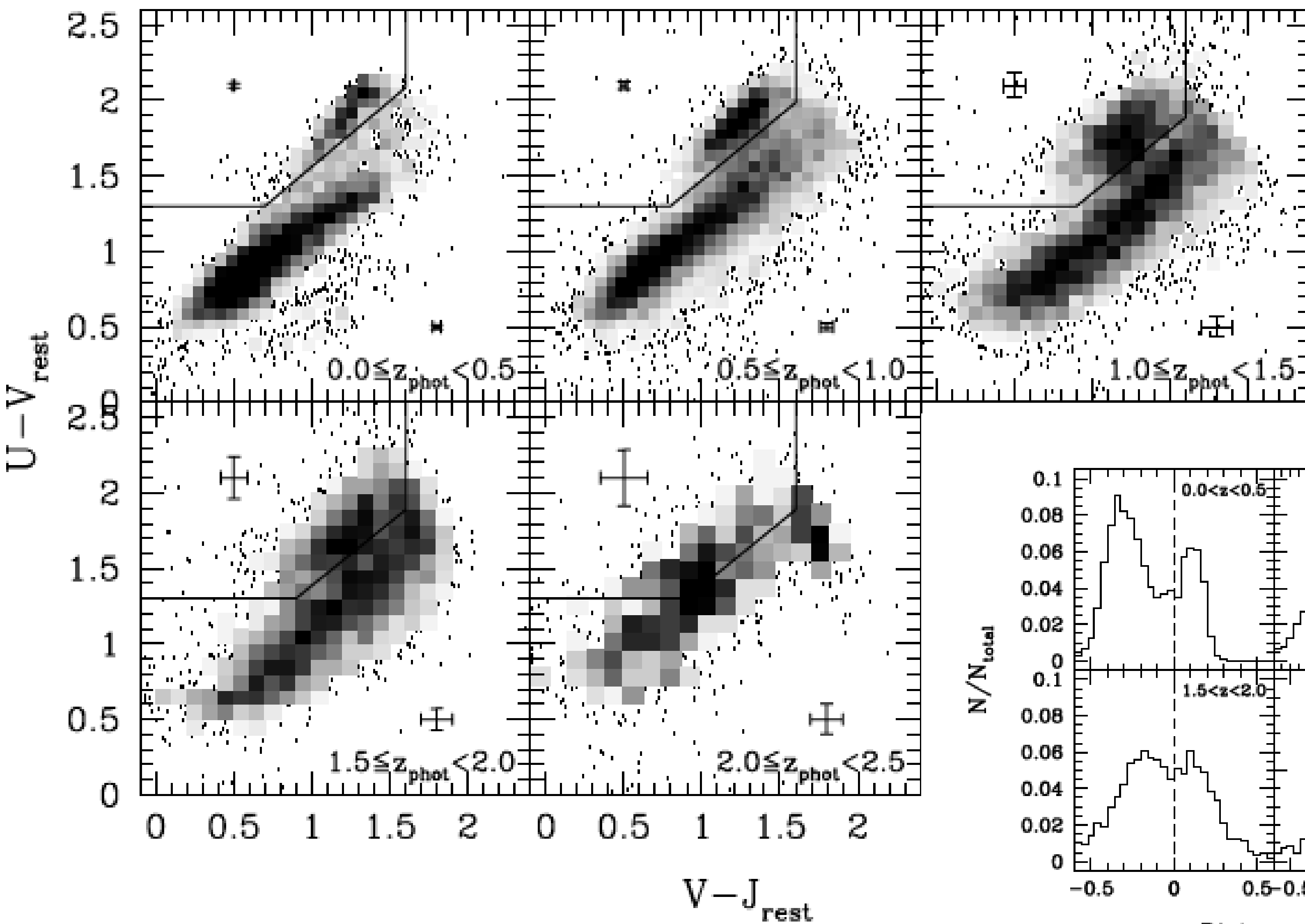
Peng et al 2010

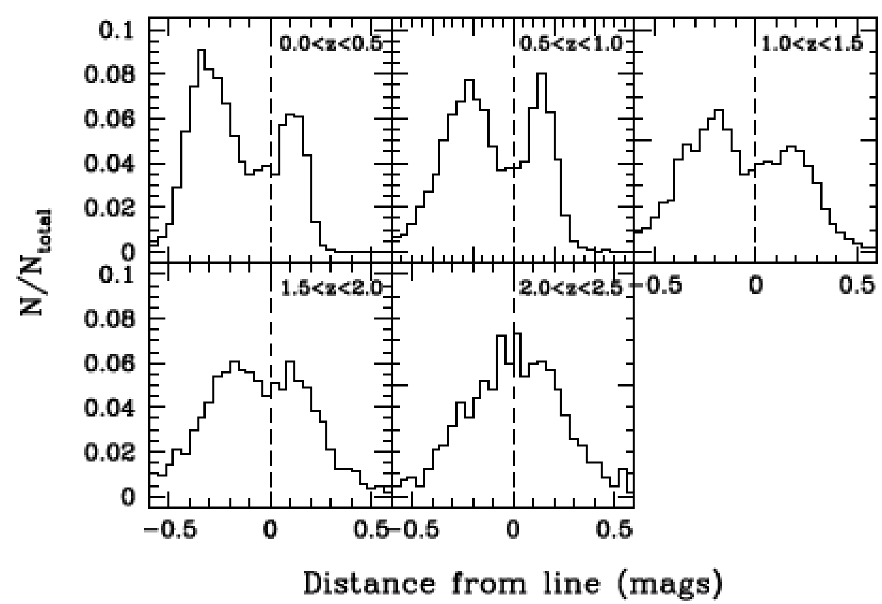
Very weak evolution in the massscale at which galaxies are “quenched”



BIMODALITY PERSISTS OUT TO Z=2

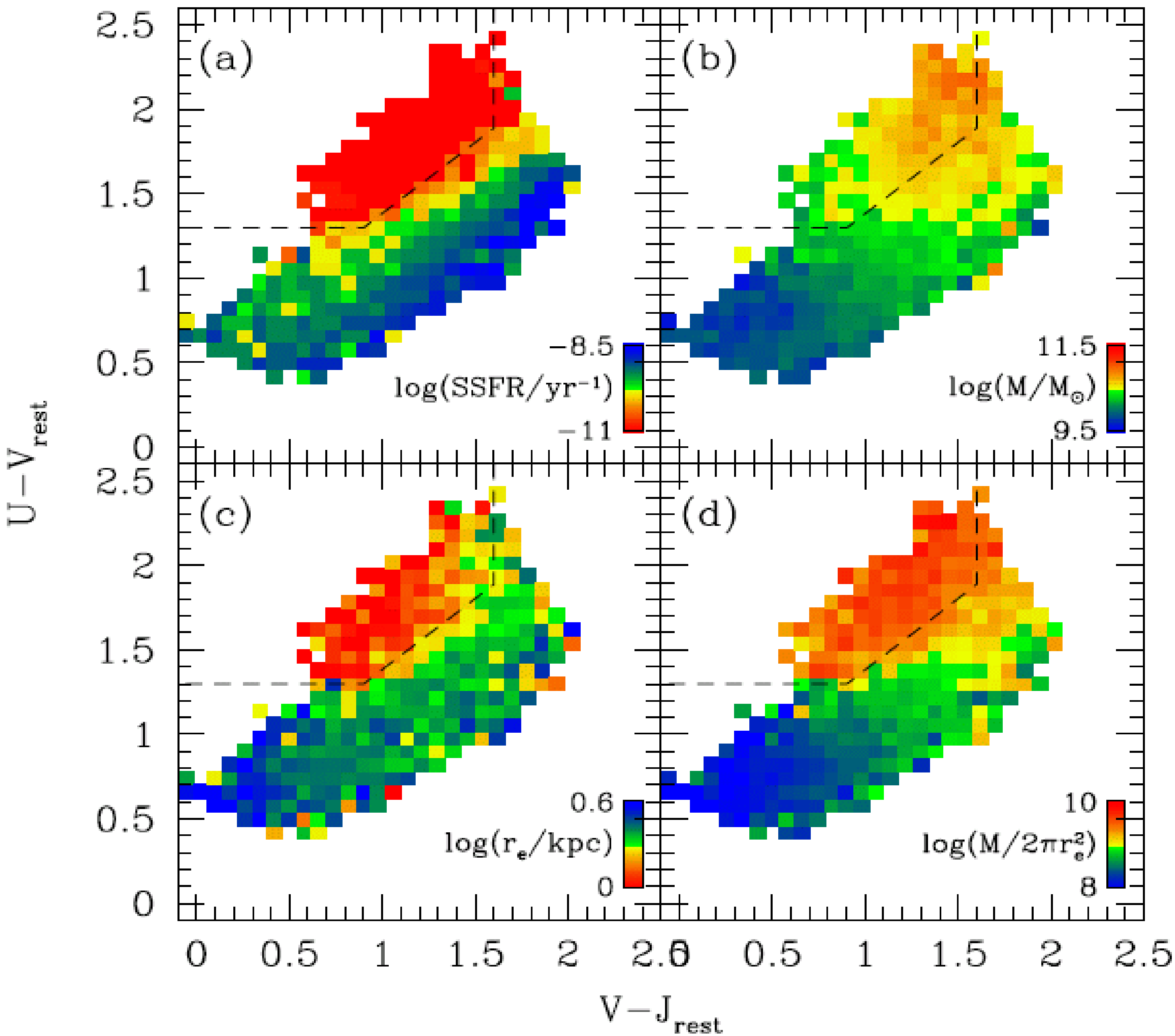
Williams et al 2008



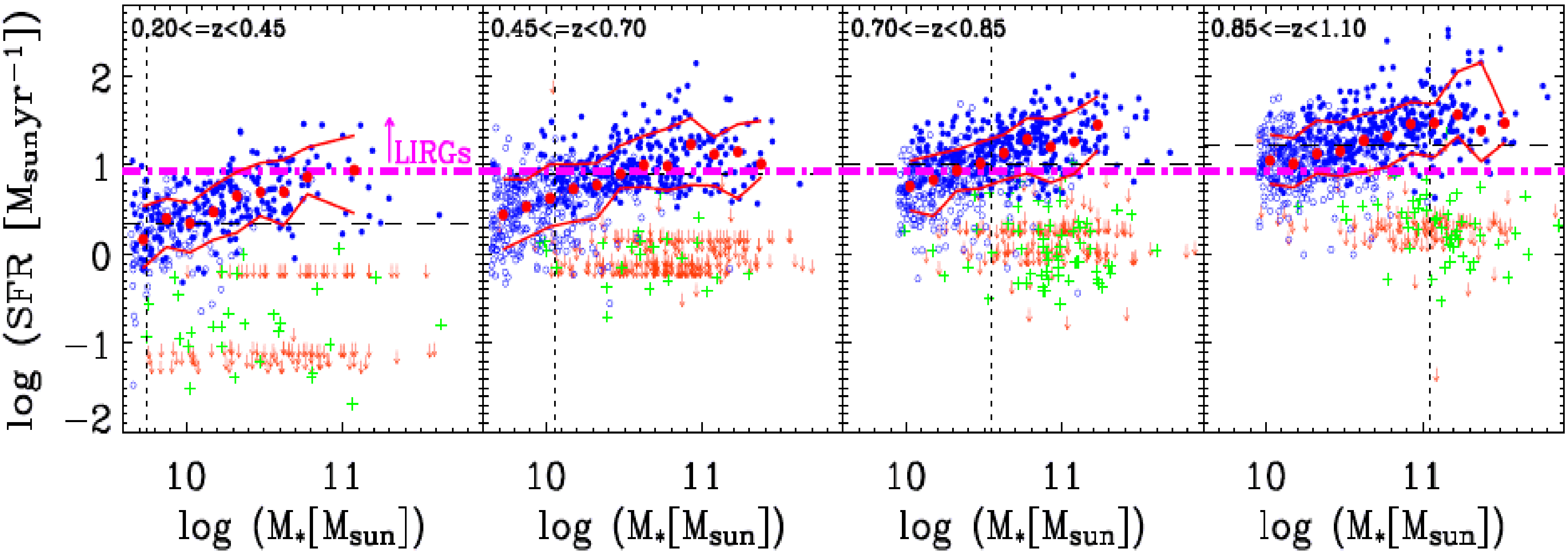


Galaxies at 1 < z < 2

Williams et al 2010



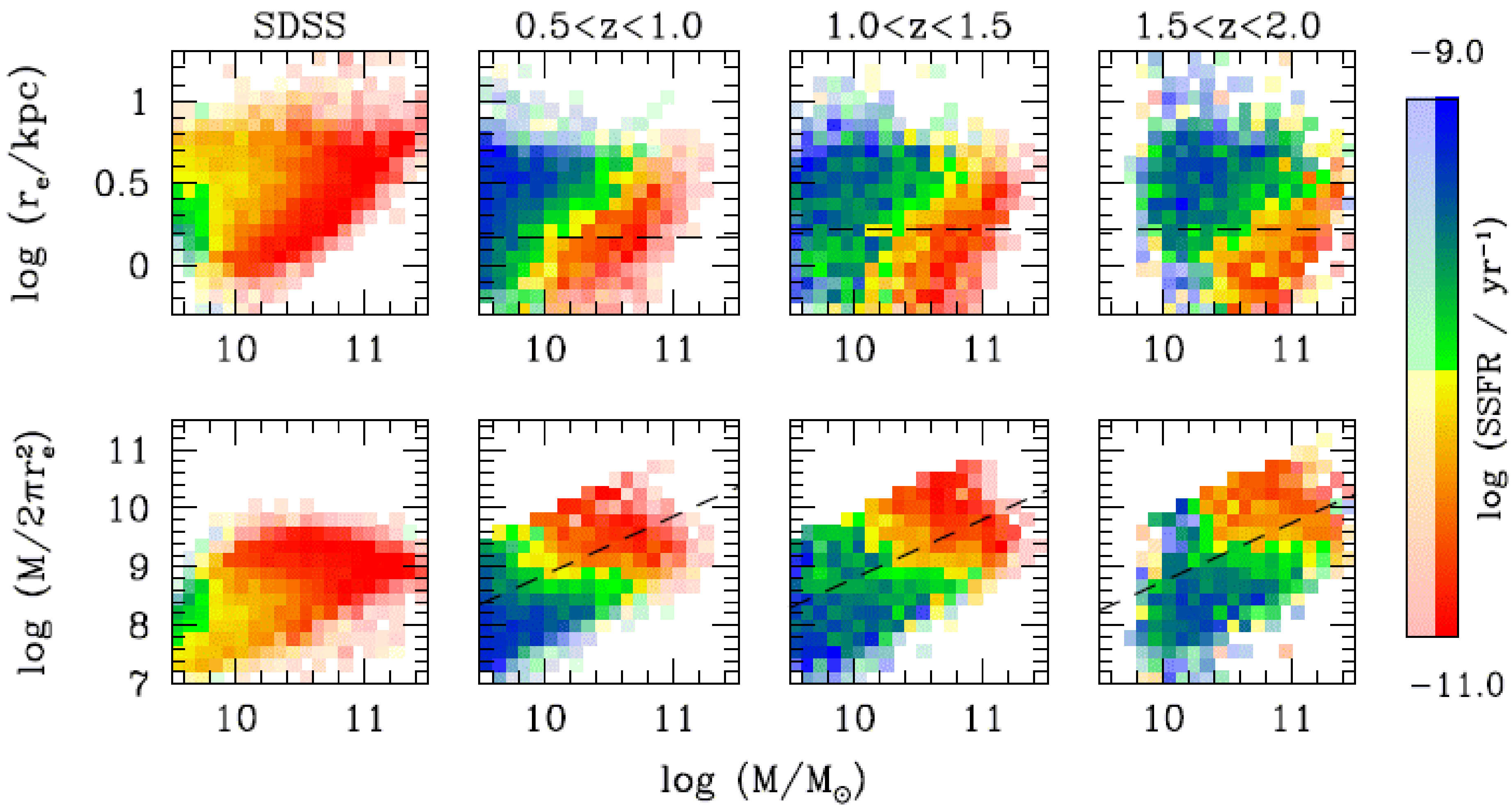
EVOLUTION OF GALAXIES ON THE BLUE SEQUENCE



Sequence remains tight (0.3 dex scatter), but evolves strongly in SFR amplitude

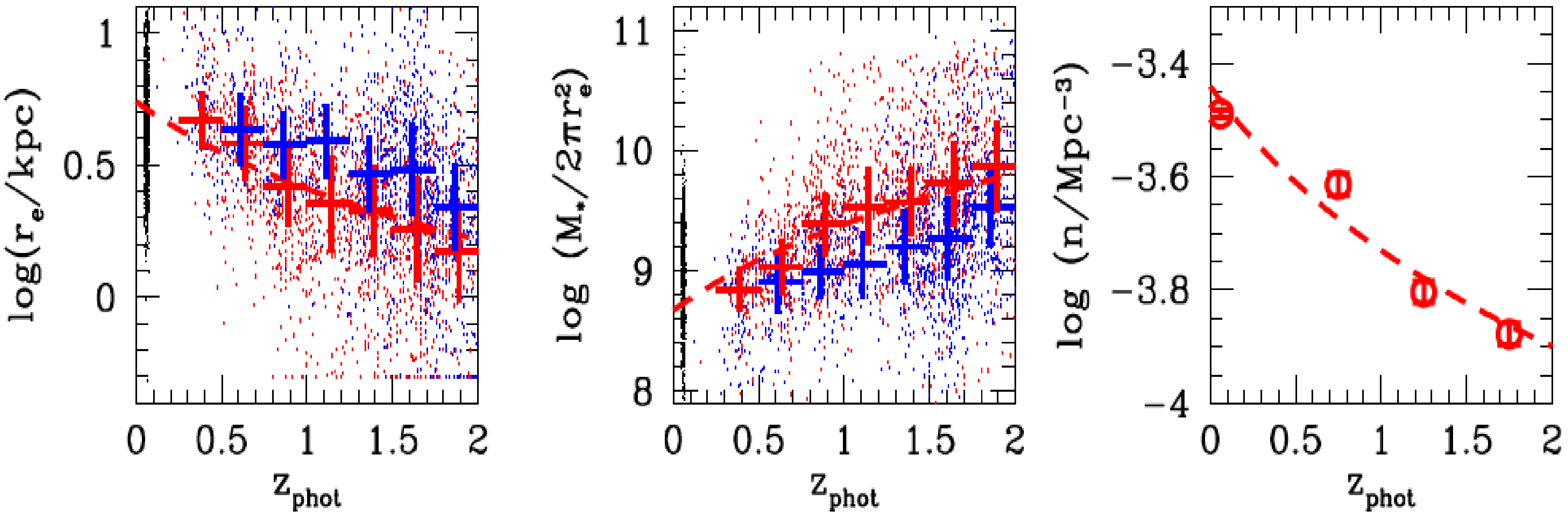
Noeske et al 2008

Strong Size/Density Evolution at Fixed Stellar Mass for Galaxies on the Red Sequence

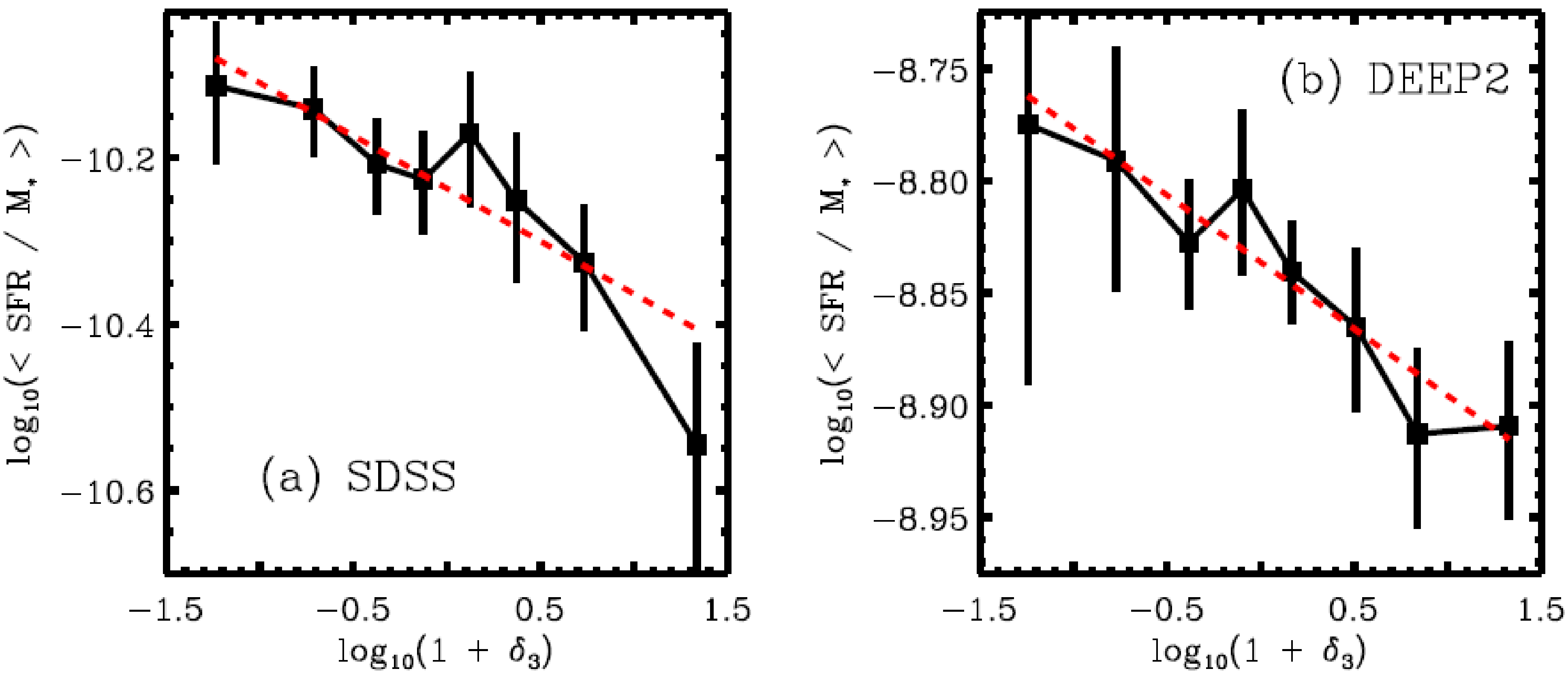


Williams et al 2010

Size evolution of Red and Blue Galaxies with log M*>10.8



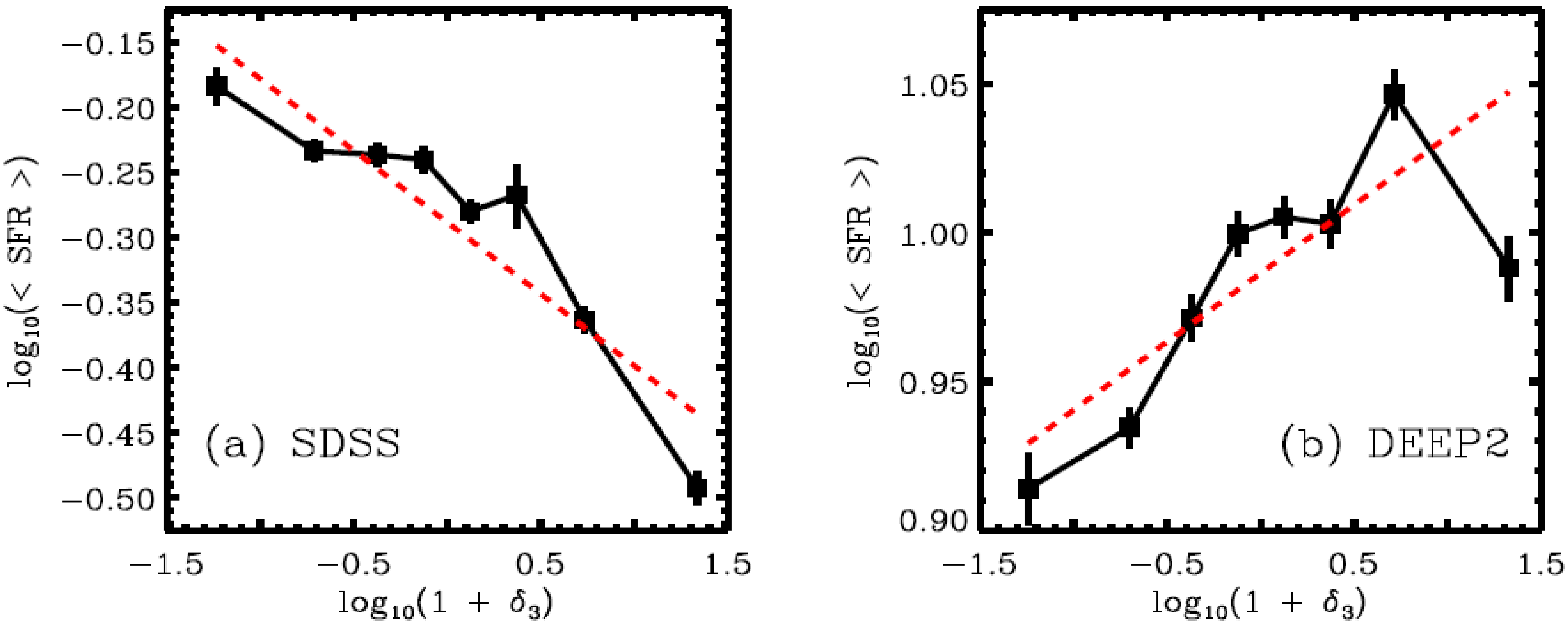
DEPENDENCE ON ENVIRONMENT:
relation between SSFR and enviroment does not change with redshift



Cooper et al 2008

DEPENDENCE ON ENVIRONMENT:

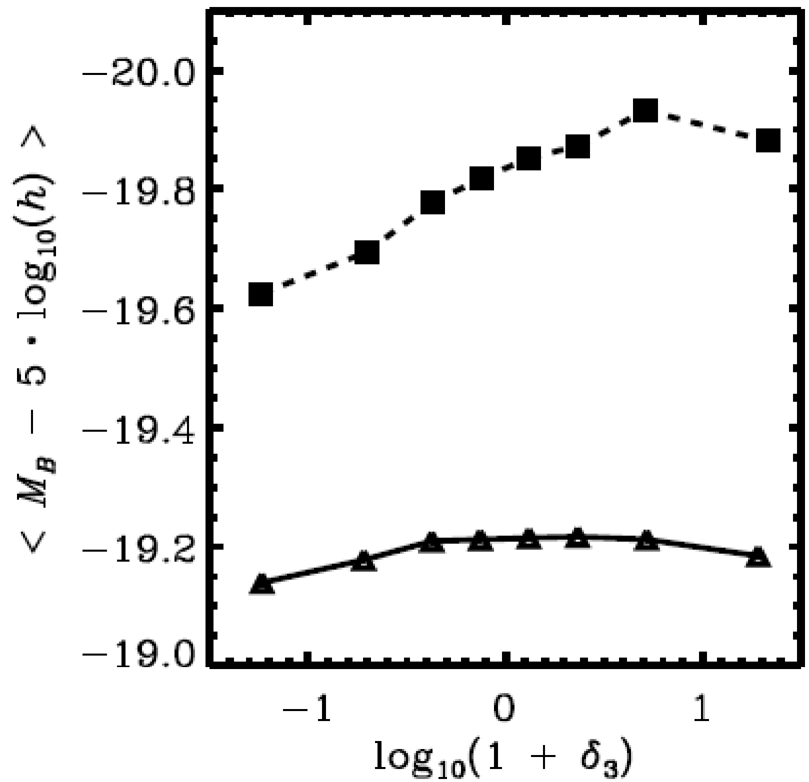
relation between average SFR and enviroment reverses!

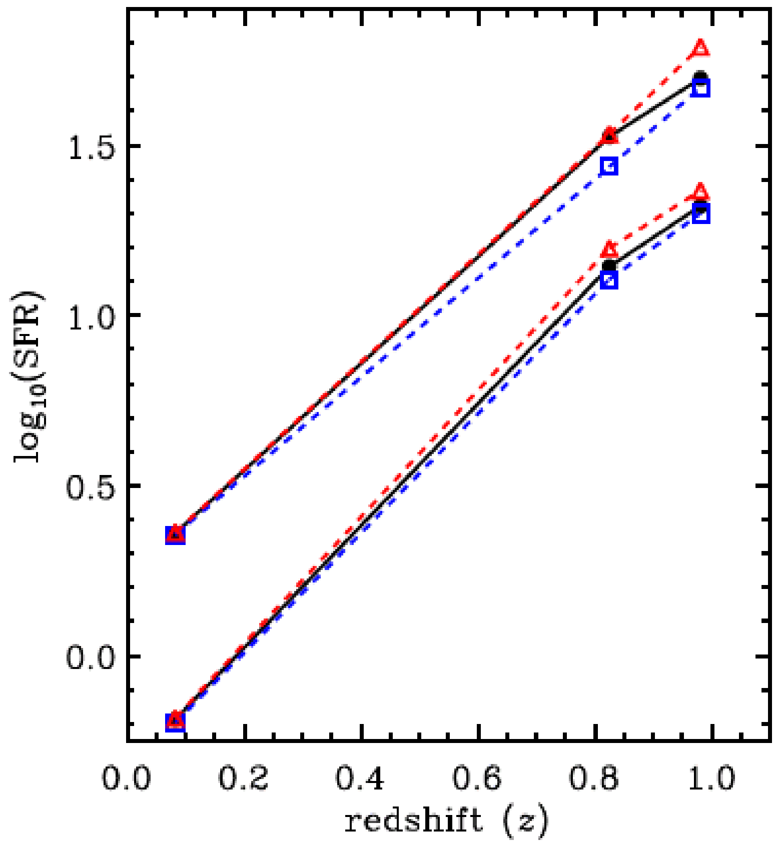


Cooper et al 2008

This is caused by the fact that there is a much stronger tendency for more luminous galaxies to be found in higher density regions at high redshifts.

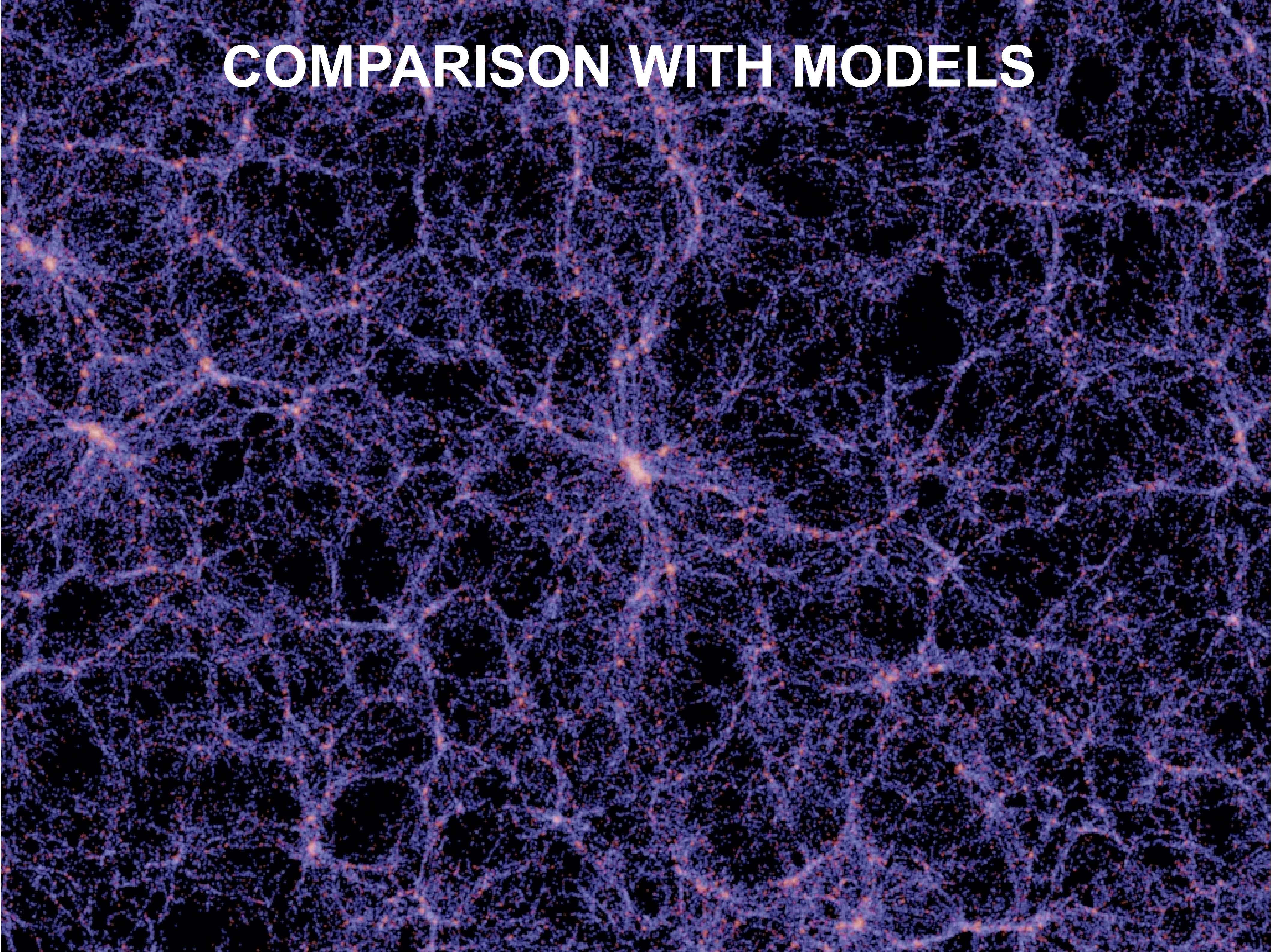
MAIN CONCLUSION:
evolution of SFR density depends very weakly on environment





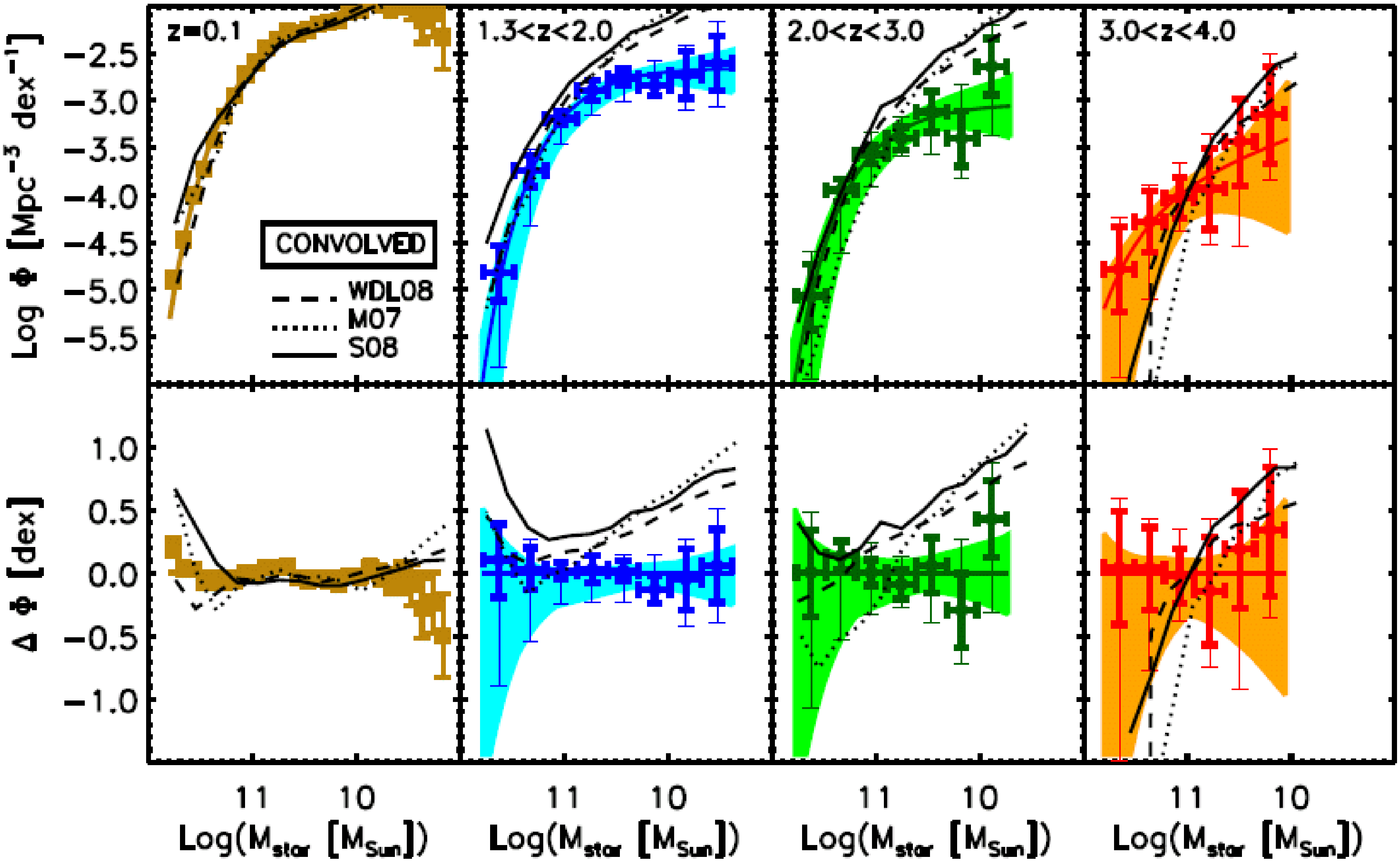
Cooper et al 2008

COMPARISON WITH MODELS

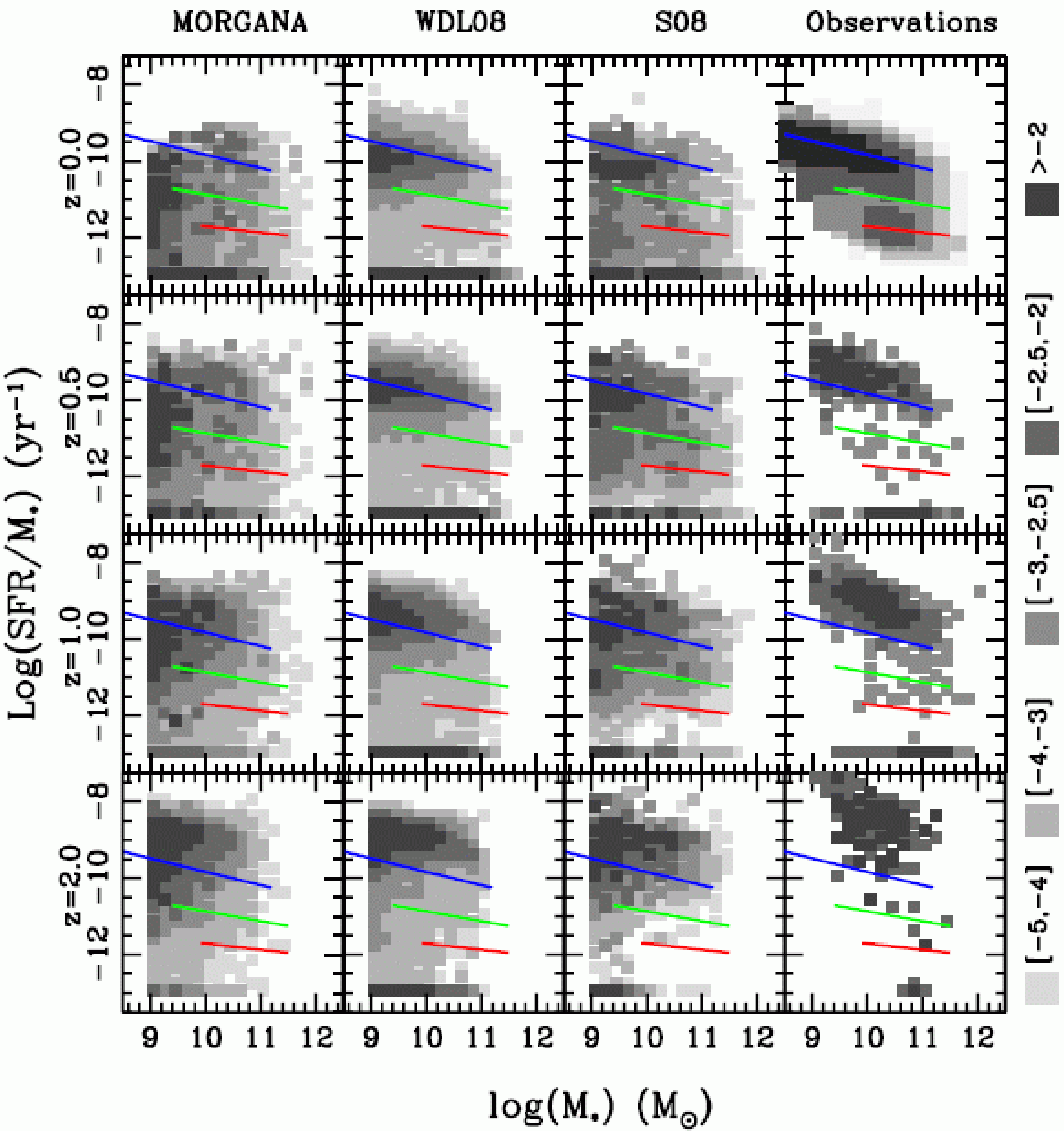


Not surprisingly, theoreticians have encountered considerable trouble when attempting to fit both the evolution of star formation and stellar mass with redshift .
(**We have seen that the DATA is not internally self-consistent !**)

Problems appear to be worst for LOW MASS galaxies

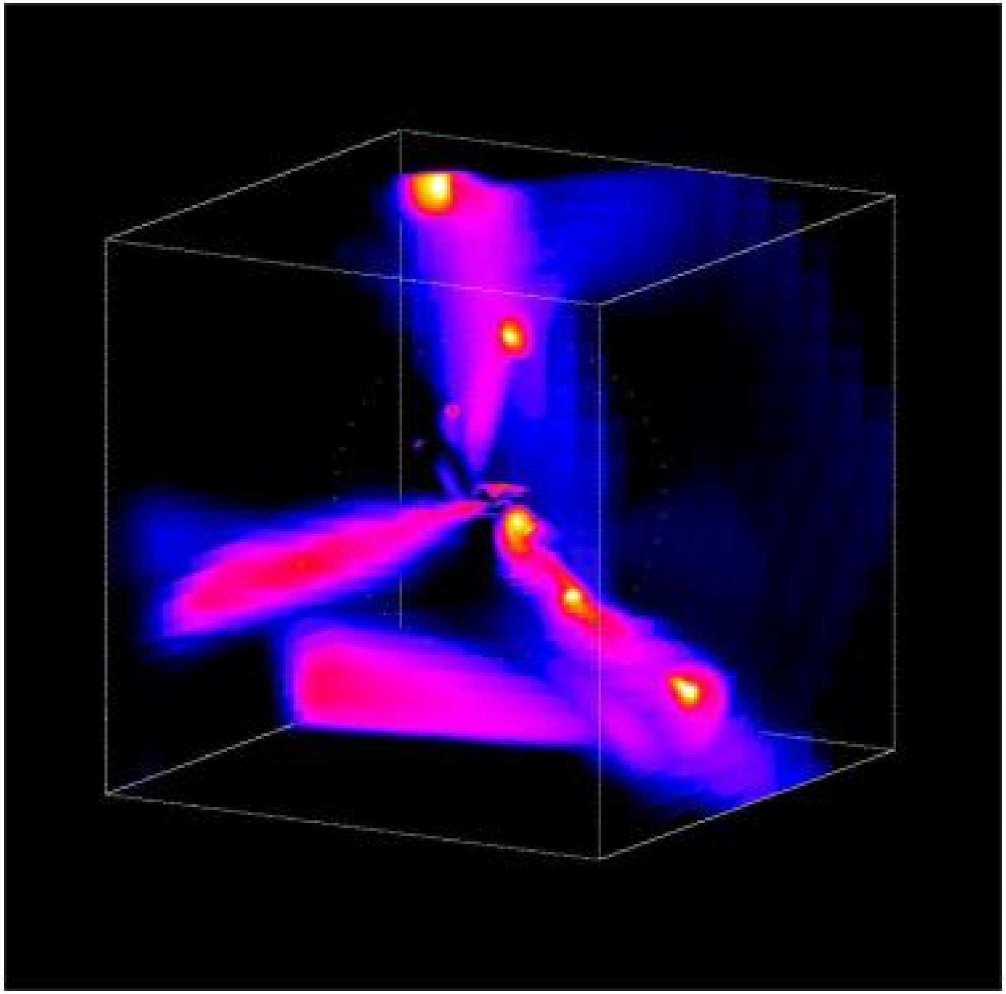


Marchesini et al 2009



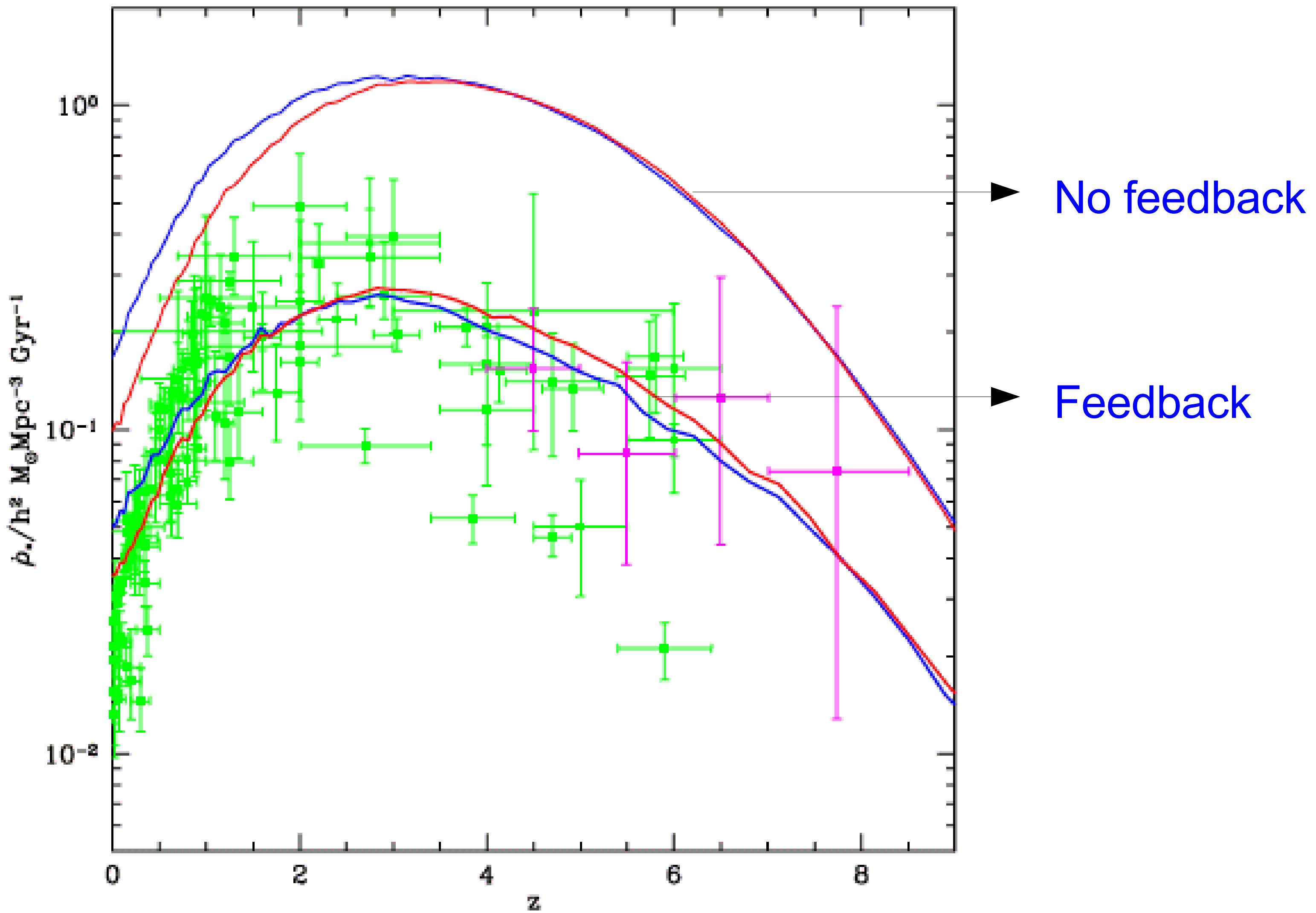
Fontanot et al
2009

What sets the star formation rates of galaxies on the blue sequence?

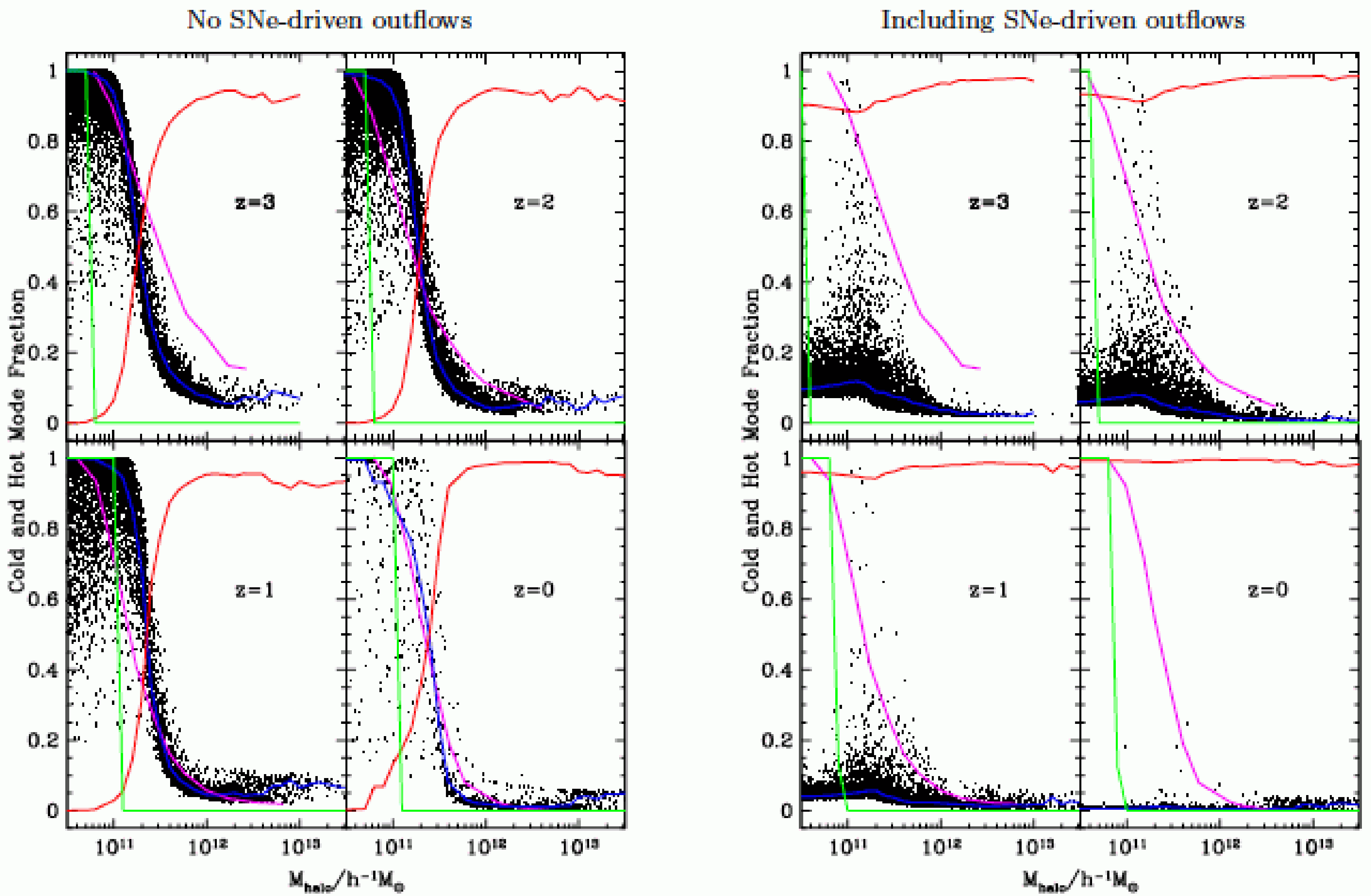


A lot of attention has been given to the role of cold gas **accretion** along filaments (so called "cold flows", e.g. Keres et al 2005, Dekel & Birnboim 2006)

In the absence of “feedback” from Supernovae, far too much gas will cool!



Benson & Bower 2010



Benson & Bower 2010

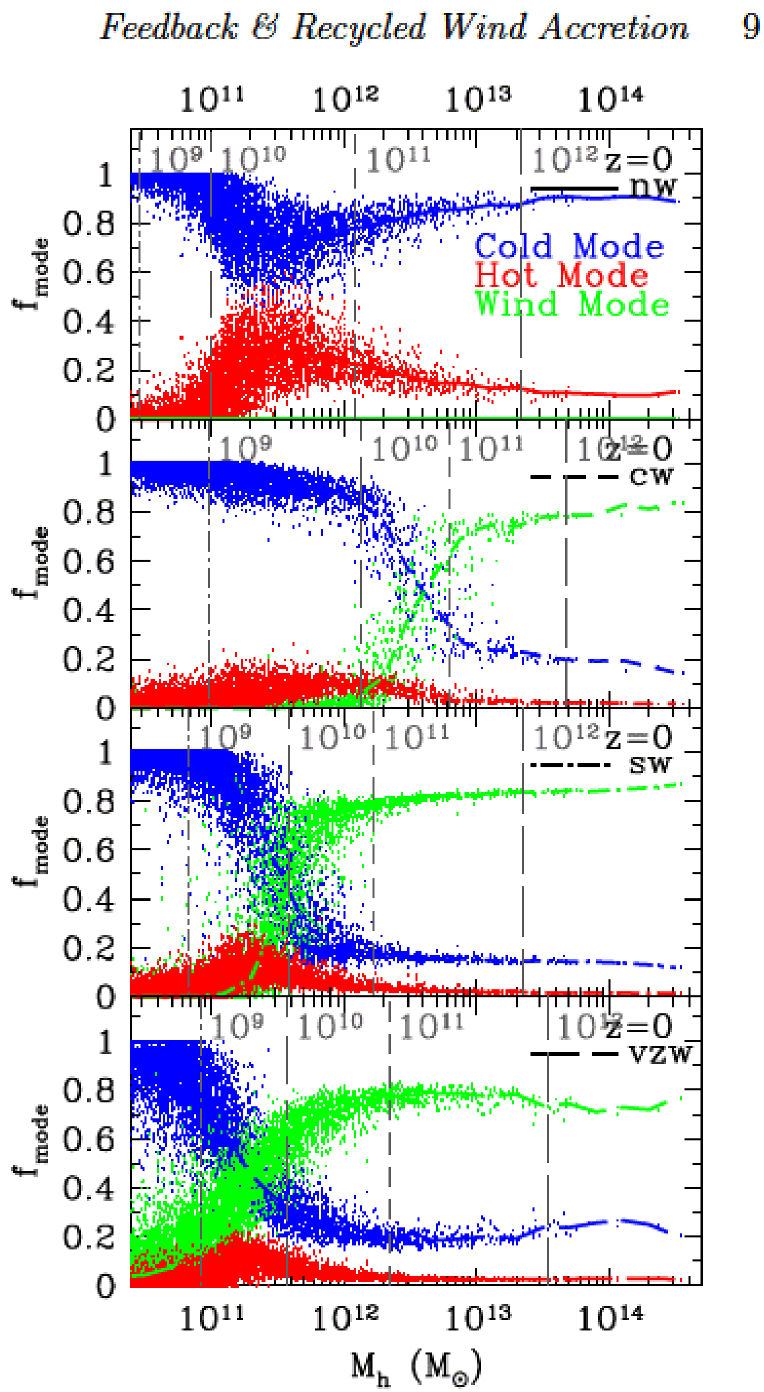


Figure 4. The fractional stellar mass of central galaxies assembled via the different modes as a function of halo mass. Coloured

Oppenheimer et al 2010 claim that accretion from recycled wind material can be the DOMINANT contributor to massive galaxies forming in high mass halos!

HOW DO WE EXPLAIN THE BIMODALITY?

WELL, QUENCHING IS A COOL WORD, BUT WHAT DOES IT MEAN?

Energy input from quasars regulates the growth and activity of black holes and their host galaxies

A Systematic Study of Radio-Induced X-ray Cavities in Clusters, Groups and Galaxies

Bursting and quenching in massive galaxies without major mergers or AGNs

Gravitational quenching in massive galaxies and clusters by clump accretion

Morphological quenching of star formation: making early-type galaxies red

The importance of satellite quenching for the build-up of the red sequence of present-day galaxies

Evolution of Sizes and Structure of Early-Type Galaxies:

the role of accretion via minor mergers

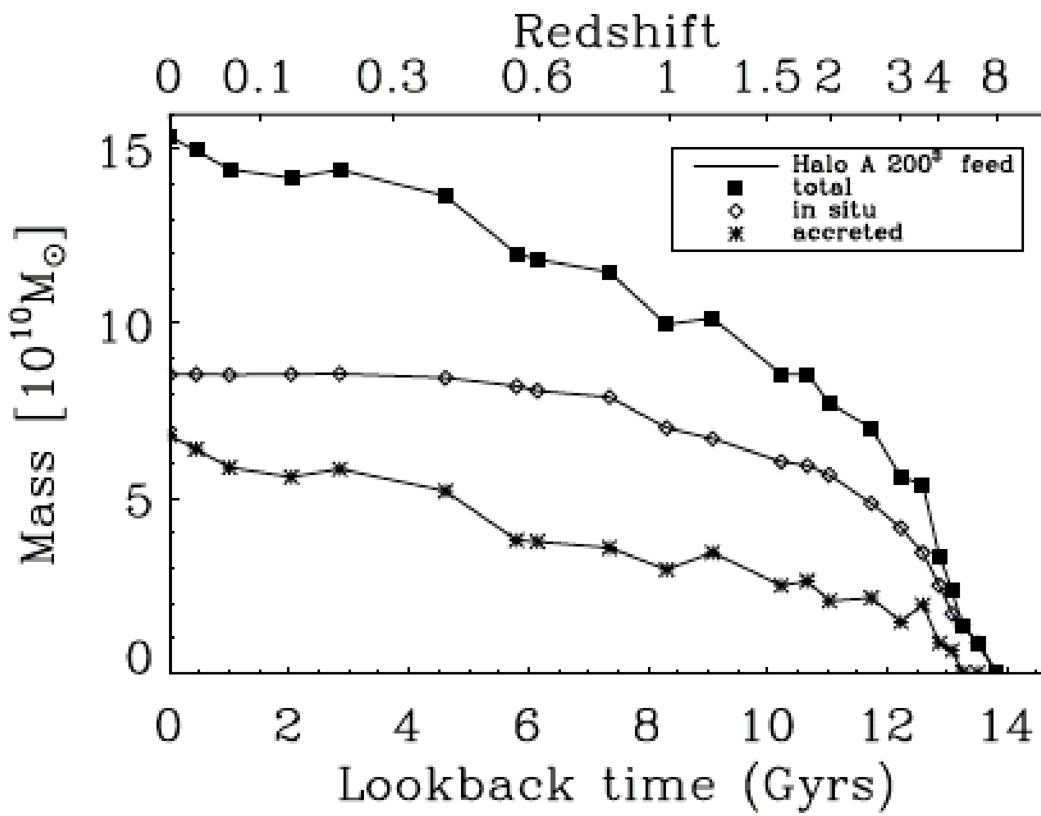
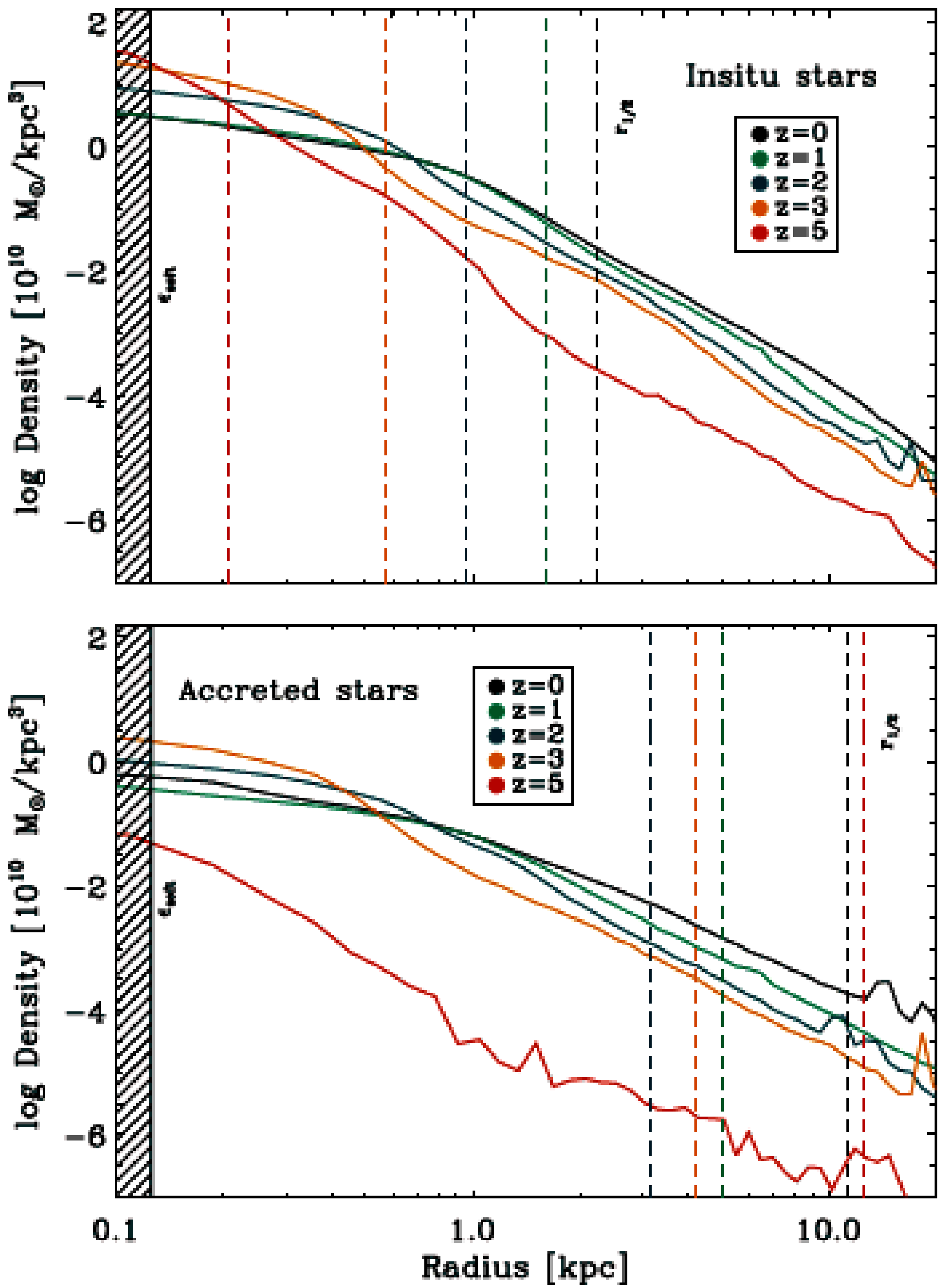


Figure 1. Mass assembly history of the stellar system (squares) separated into stars made in situ (open diamonds) in the galaxy and stars formed outside the galaxy that have been accreted (stars) later on. At high redshift ($z > 2$) the system assembles by the formation of in situ stars, at low redshift ($z < 1$) accretion is more dominant.

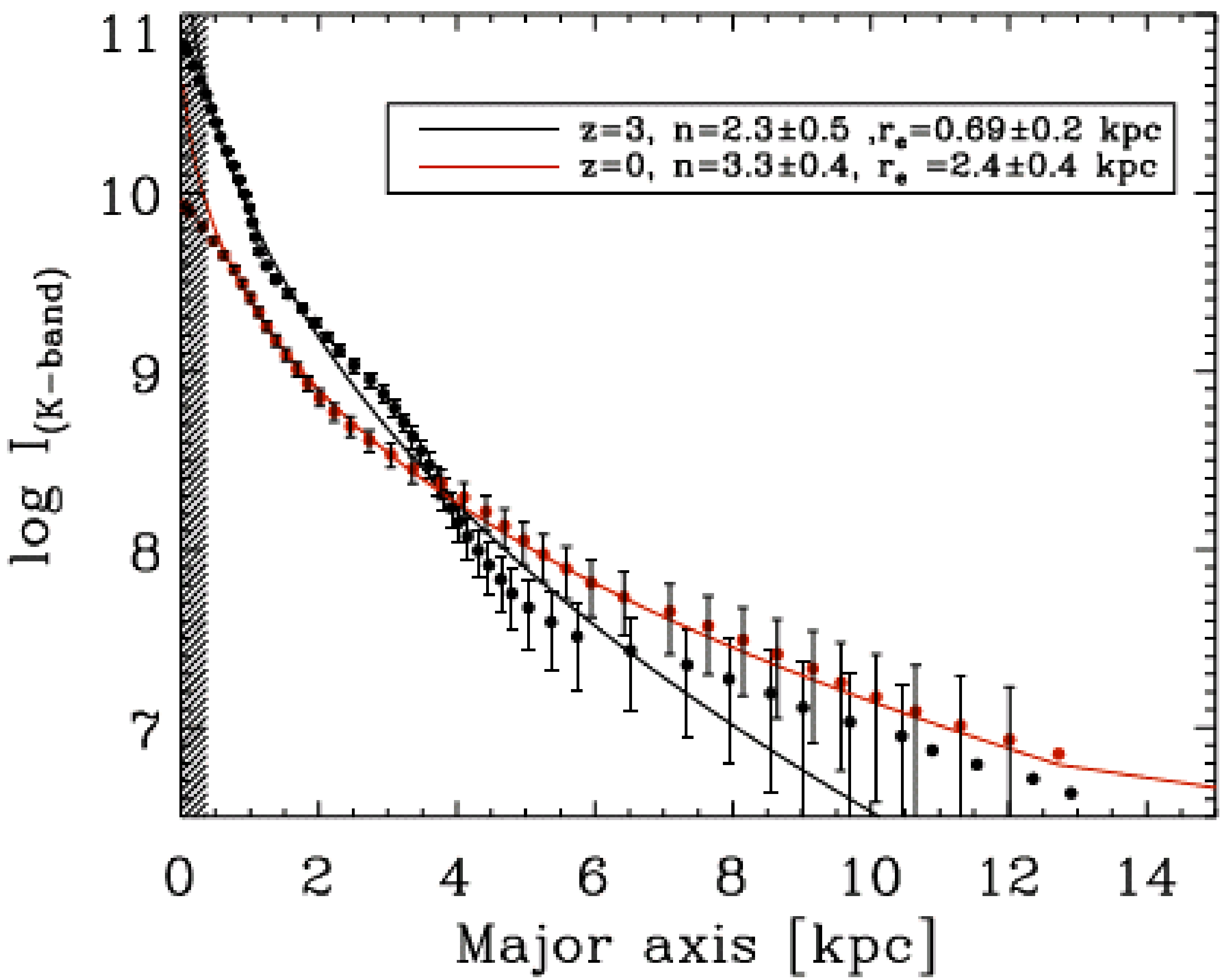
Naab et al 2009



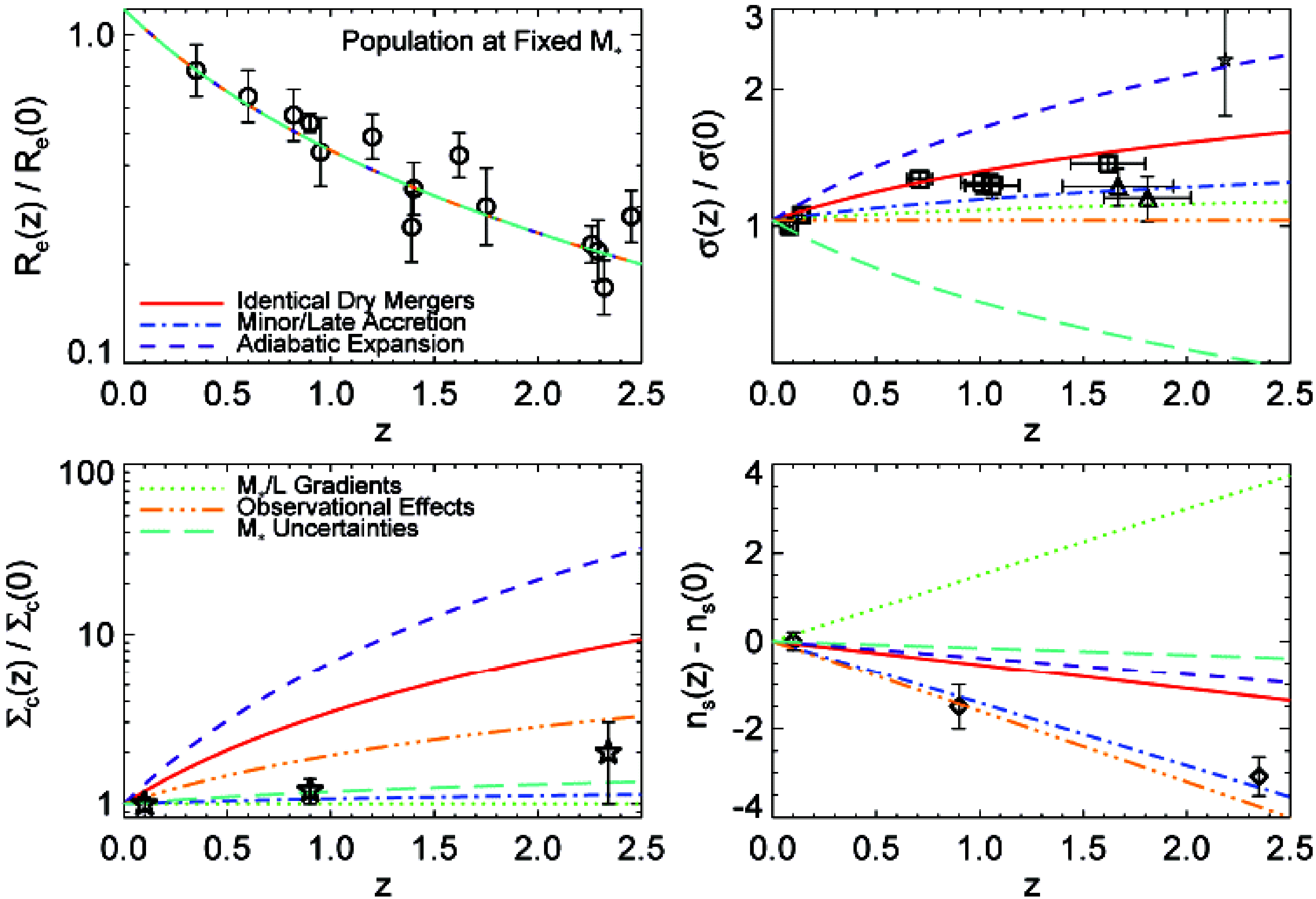
The stars formed "in situ" by gas flows at early times have a much more compact density profile than the stars that are accreted at late times in merging/accretion events.

Naab et al 2009

Predicted evolution in surface brightness profile from z=3 to z=0



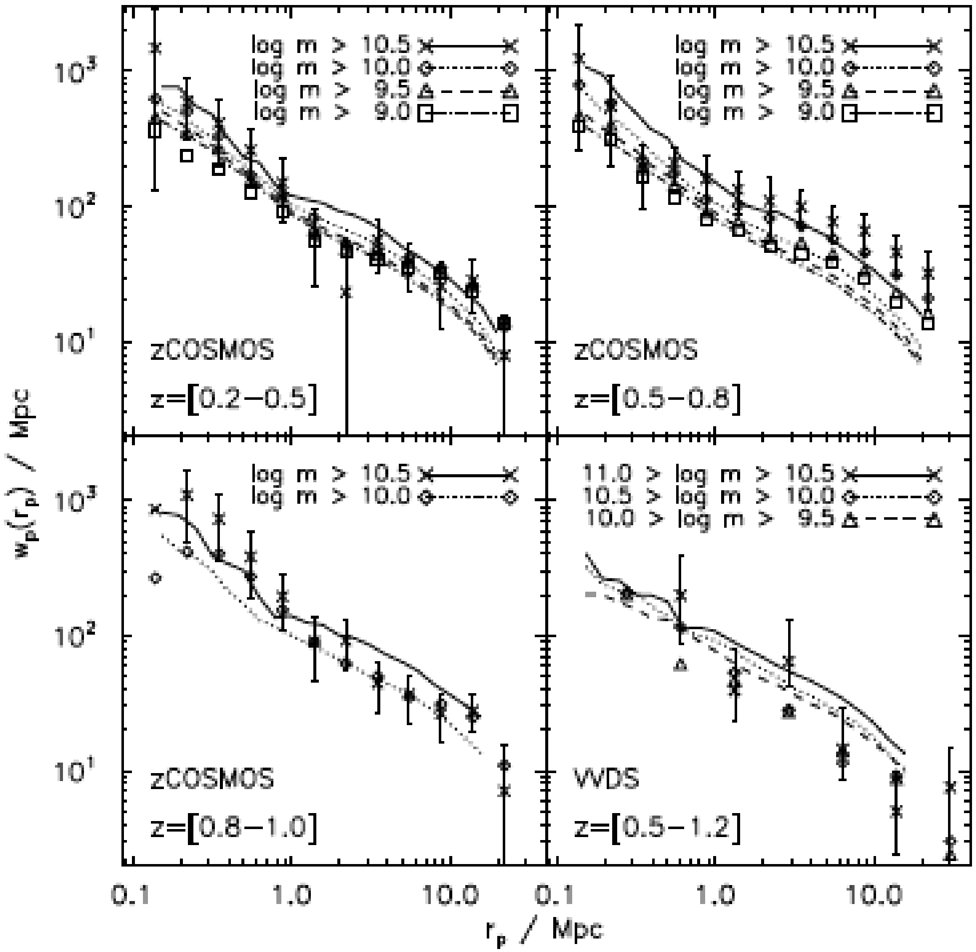
Hopkins (2010) empasizes that other structural quantities, e.g. Velocity dispersion, central surface density, Sersic index can be key in distinguishing between different scenarios.

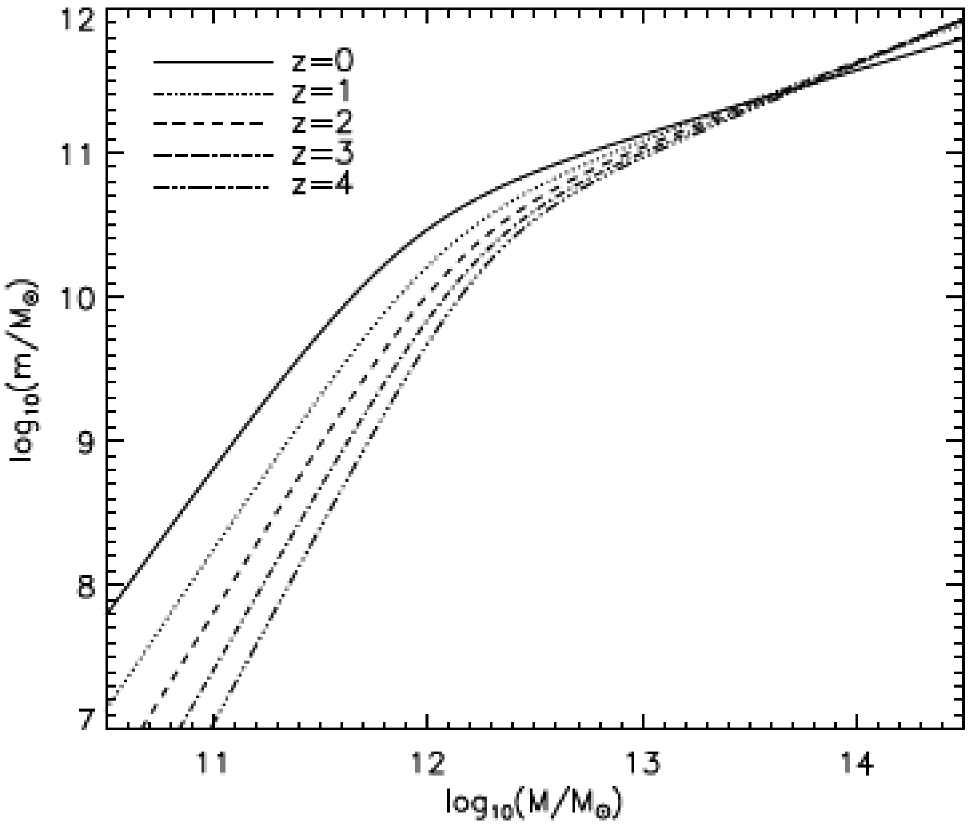


No consensus yet on whether or not the data can be explained within the framework of the “standard” galaxy formation paradigm.

INFERENCES FROM CLUSTERING EVOLUTION

Moster et al 2010



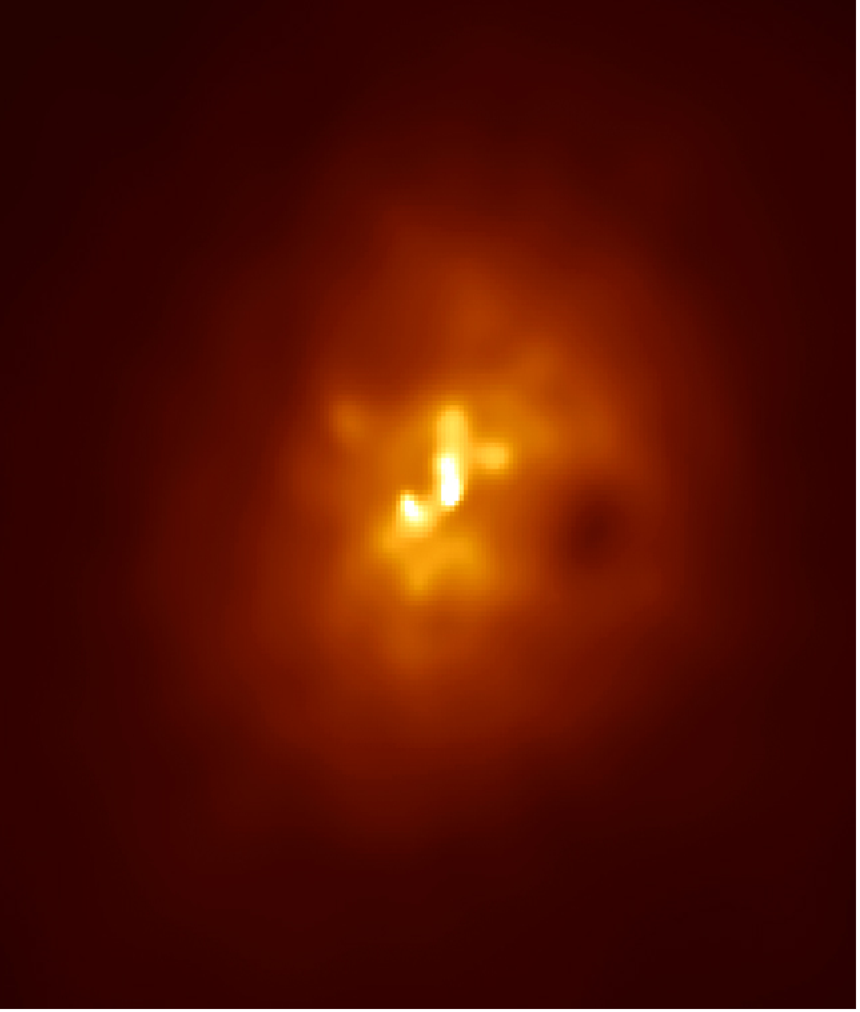


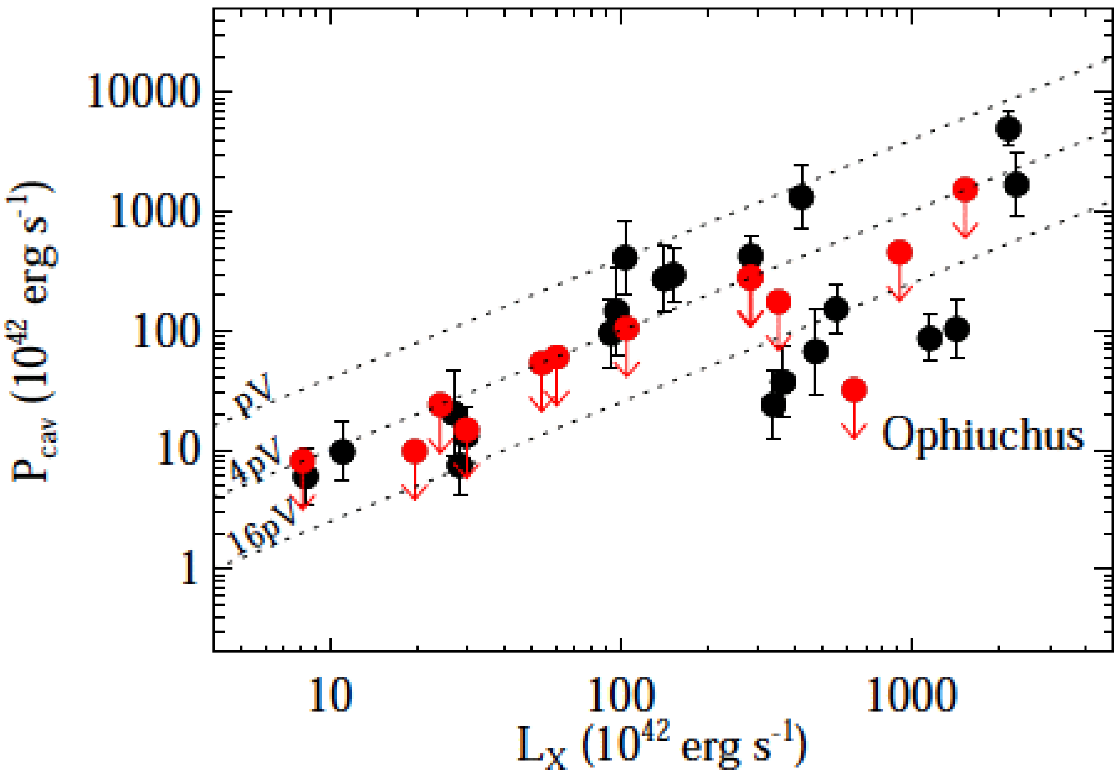
WAYS FORWARD

The goal is to use the observational material as directly as possible in order to identify the simplest things that are apparently *demanded* by the data and to define empirically based "laws" for the evolution of the population. We may then try to associate these clear evolutionary signatures with a dominant physical process, $\boxed{\text{but the causal connection cannot of course be proven}}$, and it is quite possible that some different set physical processes may conspire to mimic the same observed results.

Peng, Lilly et al 2010

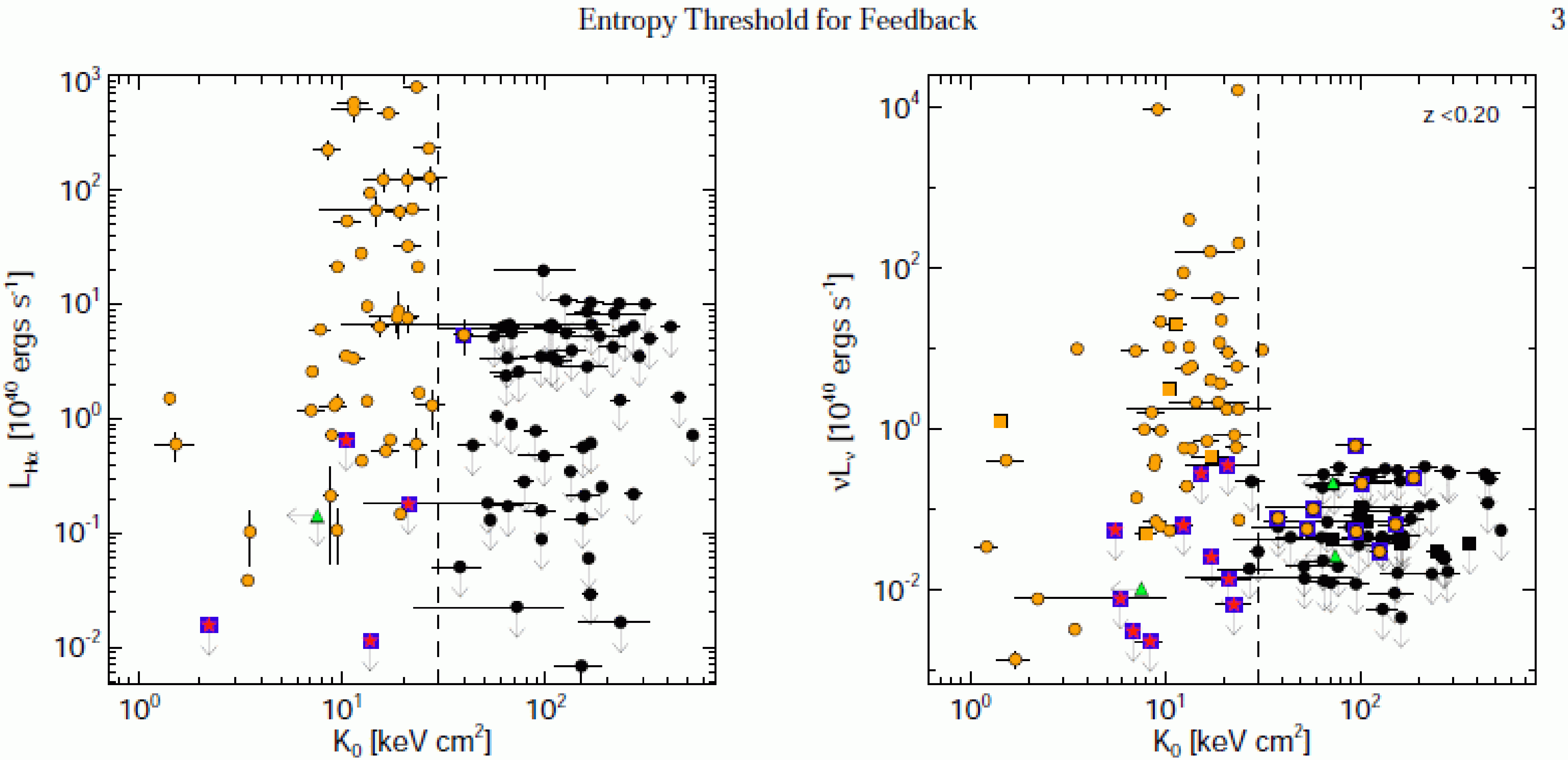
What we must do: observe both the stars and the gas in galaxies





Birzan et al 2009

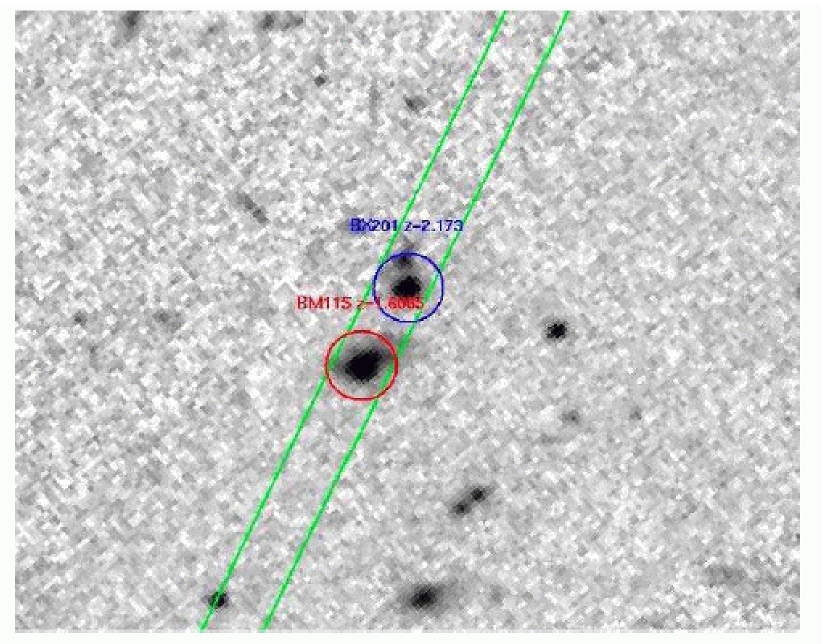
X-ray observations of the **hot gas in clusters** allow us to infer that the energy input into the ICM to create the observed cavities is sufficient to offset the cooling.



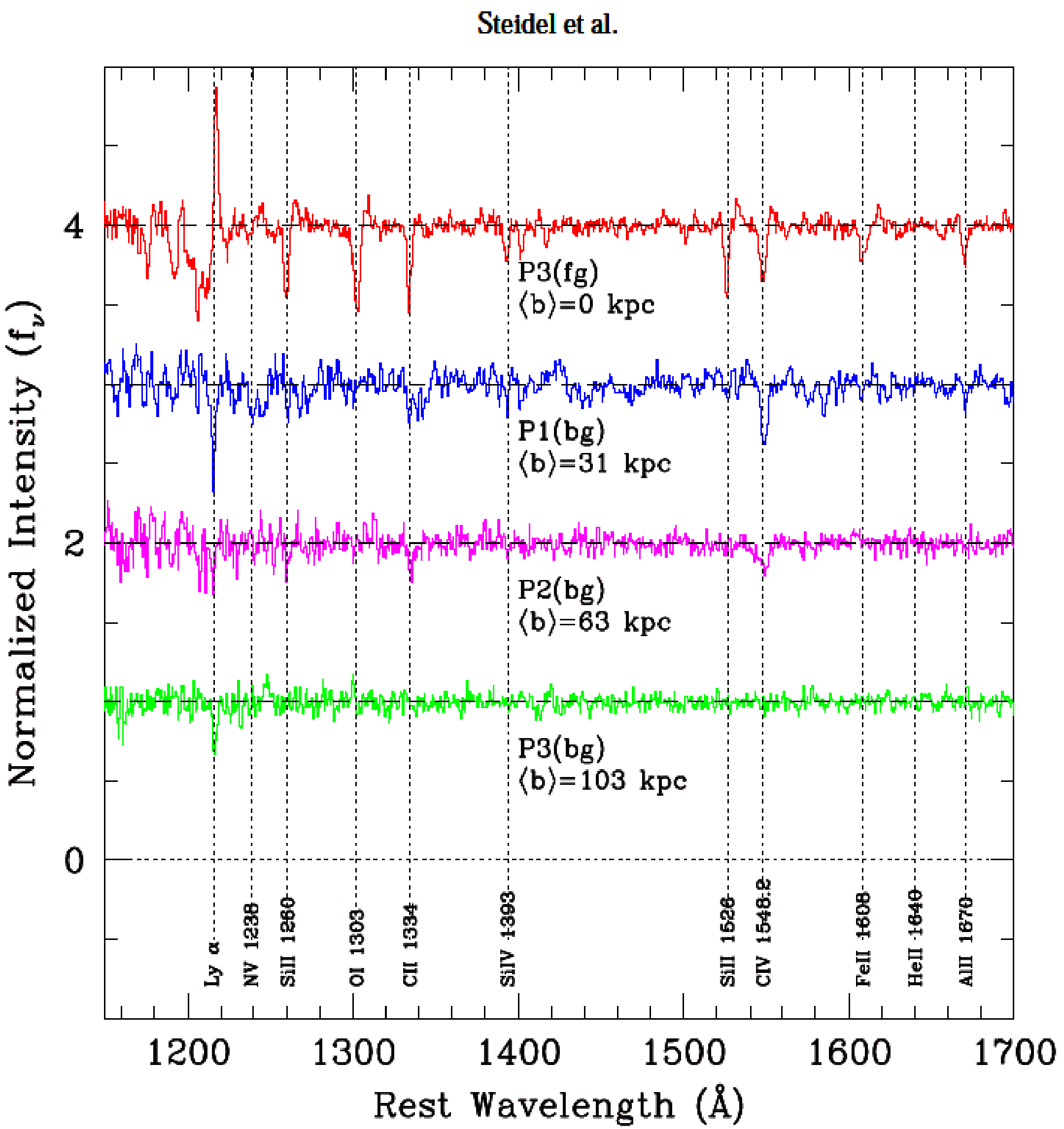
Cavagnolo et al 2009

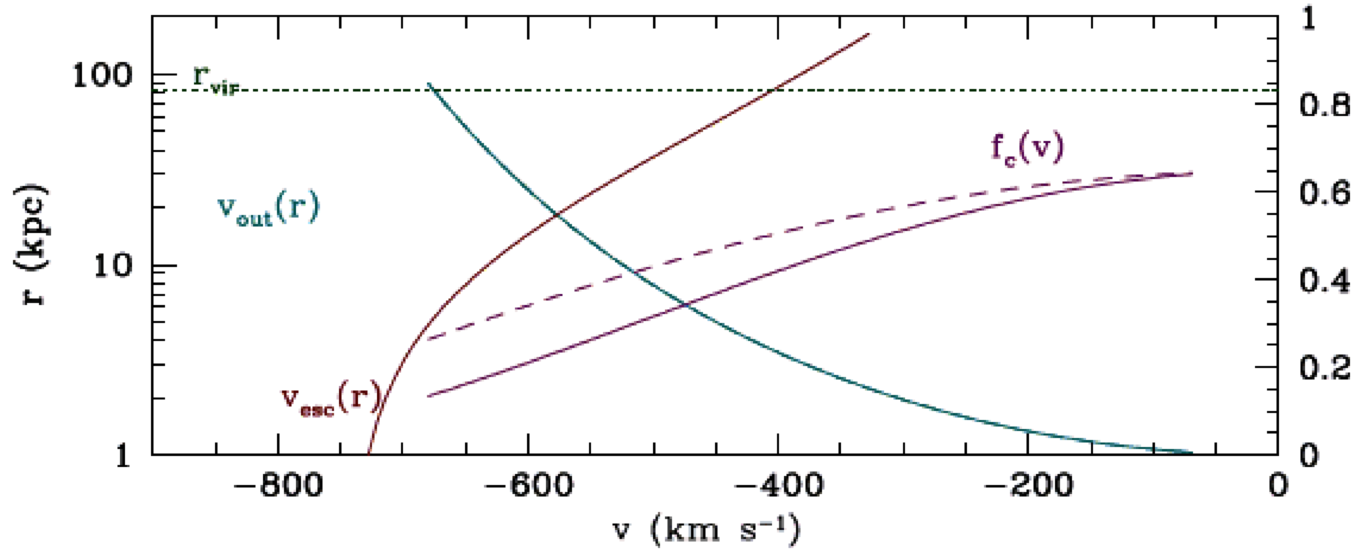
Only in clusters where the central entropy of the gas is below a certain critical value, does one see star formation and current radio AGN activity in the central cluster galaxy.

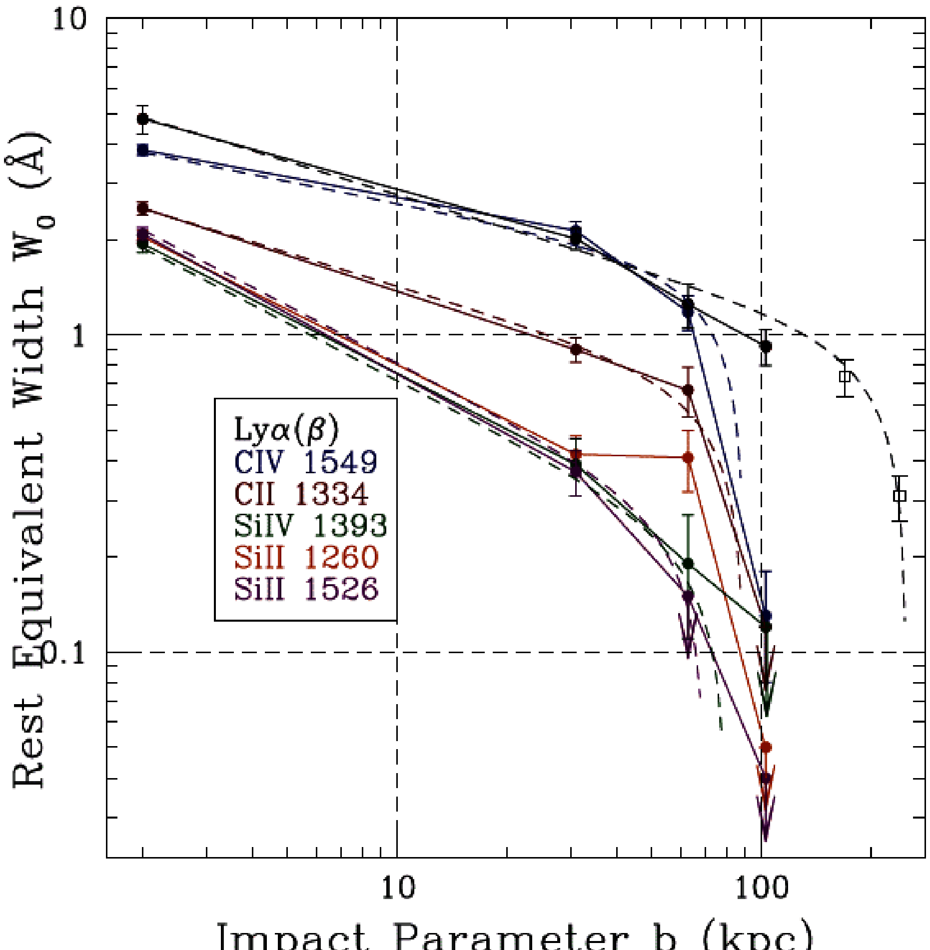
Study the **ionized gas surrounding galaxies** through interstellar absorption lines in the spectra of galaxy pairs



Steidel et al 2010



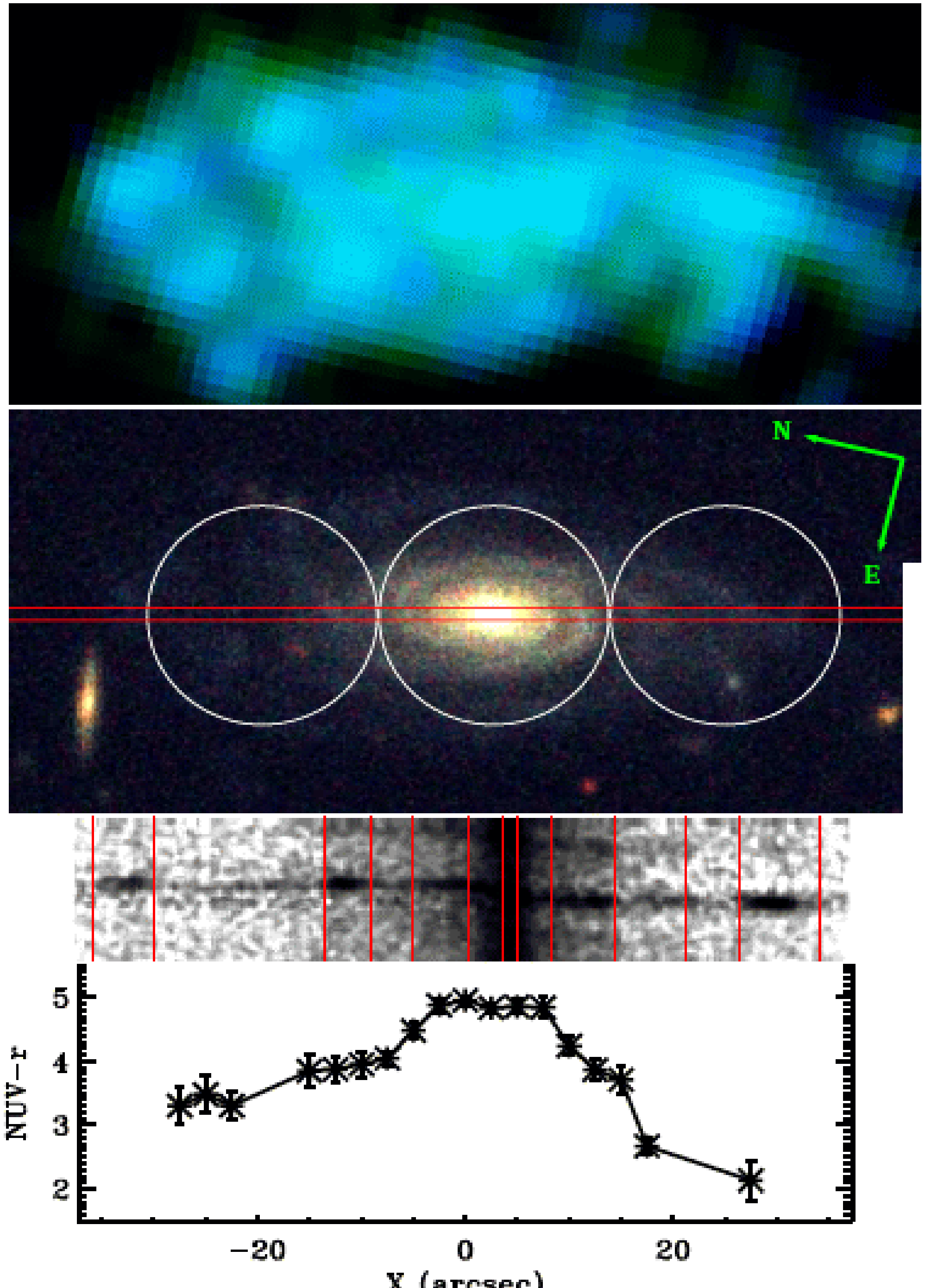




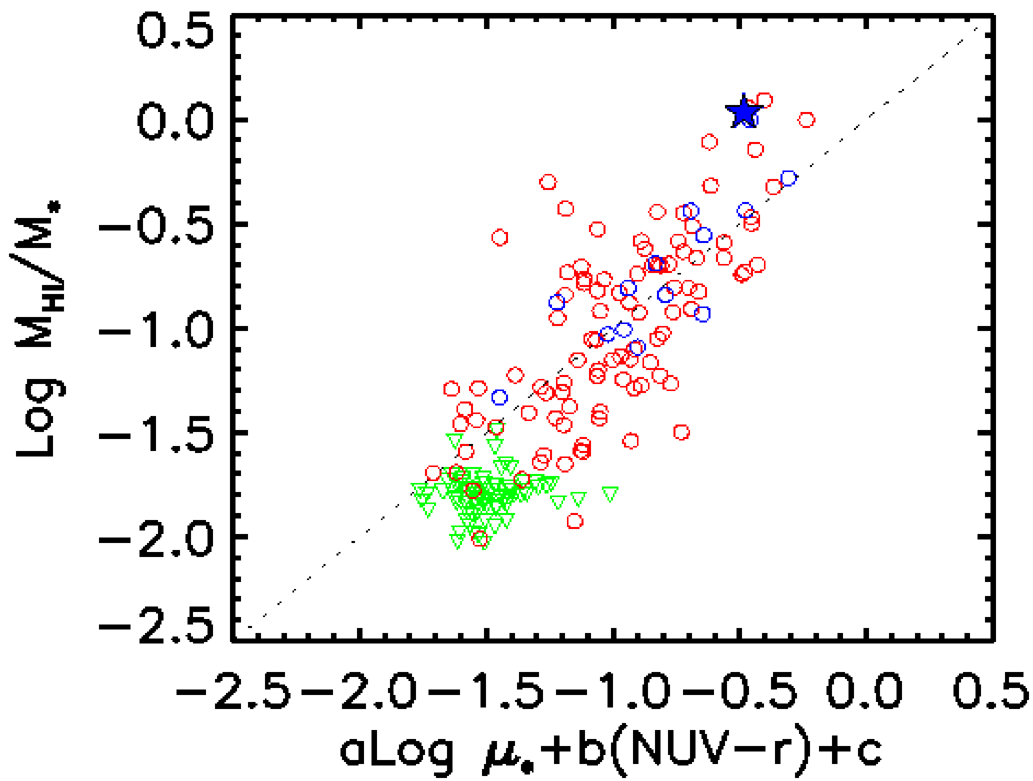
Clear evidence that ionized, metal-enriched gas is being ejected out of the dark matter halos of star-forming galaxies at high redshifts!

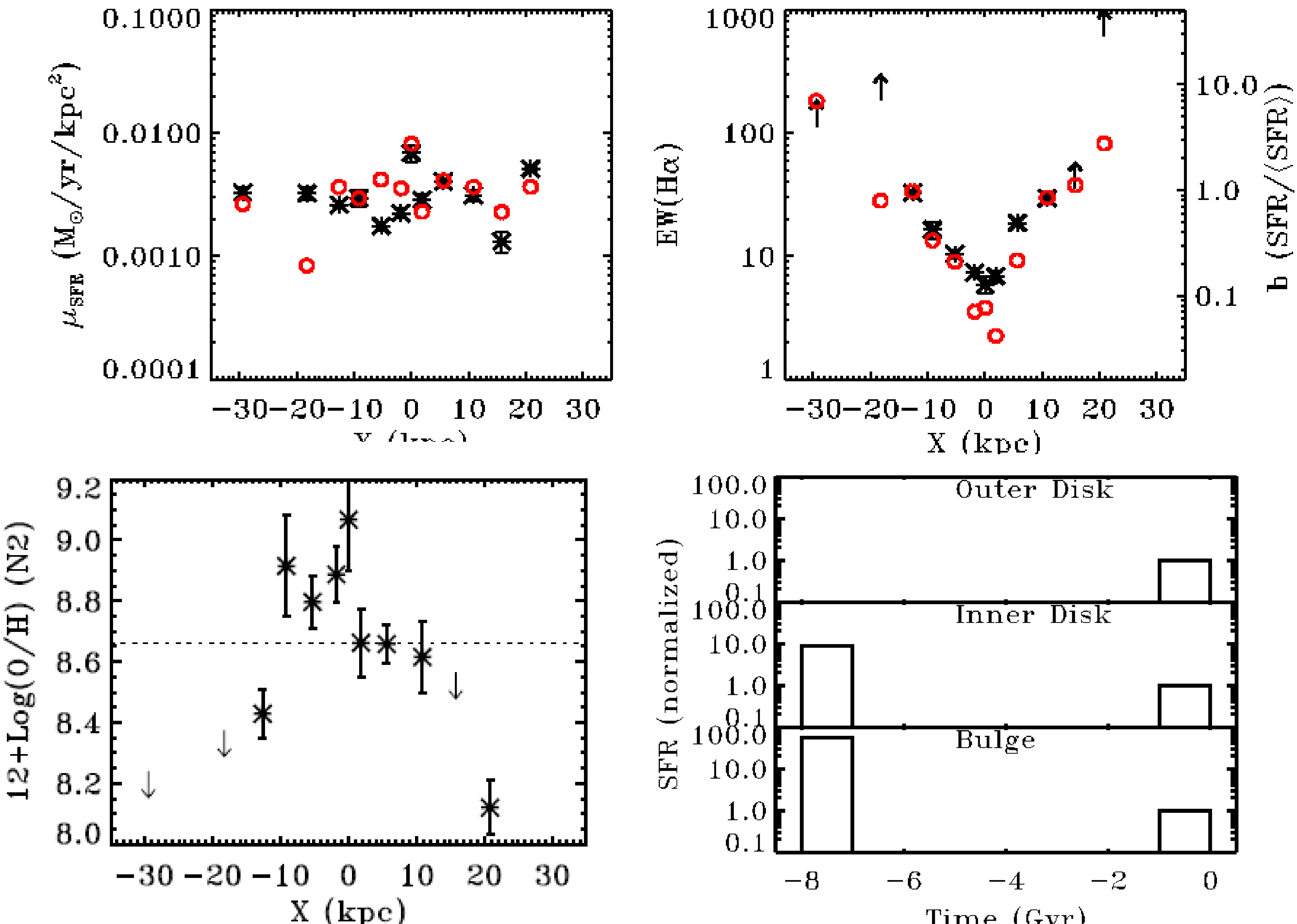
Steidel et al 2010

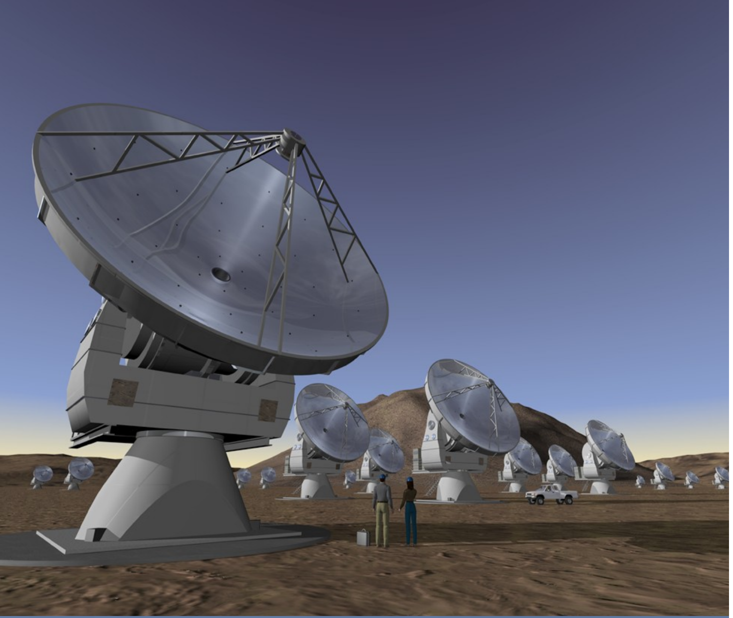
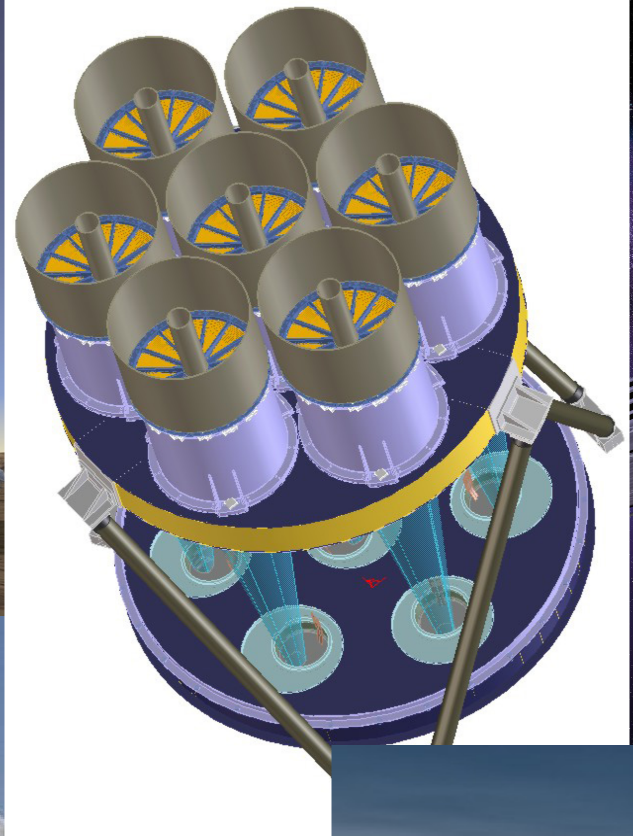
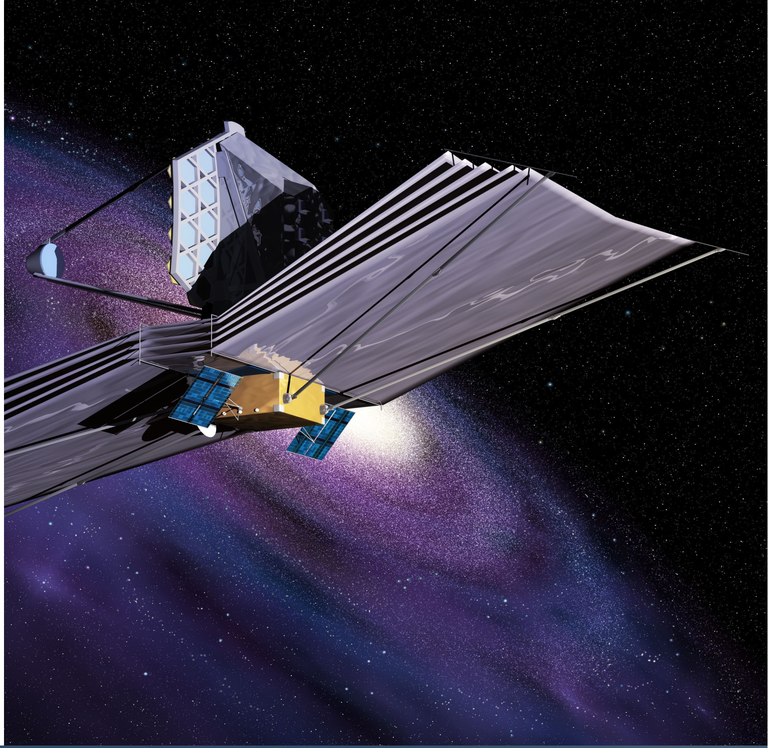
STUDY THE EFFECT OF COLD GAS ACCRETION ON THE ASSEMBLY OF GALAXIES



Moran et al 2010, in preparation




0.1000
0.0100
0.0010
0.0001
μ_{SFR} ($M_\odot$/yr/kpc^2)
−30 −20 −10 0 10 20 30
1000
100
10
1
EW(Hα)
10.0
1.0
0.1
b (SFR/⟨SFR⟩)
−30 −20 −10 0 10 20 30
X (kpc)
9.2
9.0
8.8
8.6
8.4
8.2
8.0
12+Log(O/H) (N2)
−30 −20 −10 0 10 20 30
X (kpc)
Outer Disk
Inner Disk
Bulge
100.0
10.0
1.0
0.1
SFR (normalized)
−8 −6 −4 −2 0
Time (Gyr)

THE WAY FORWARD