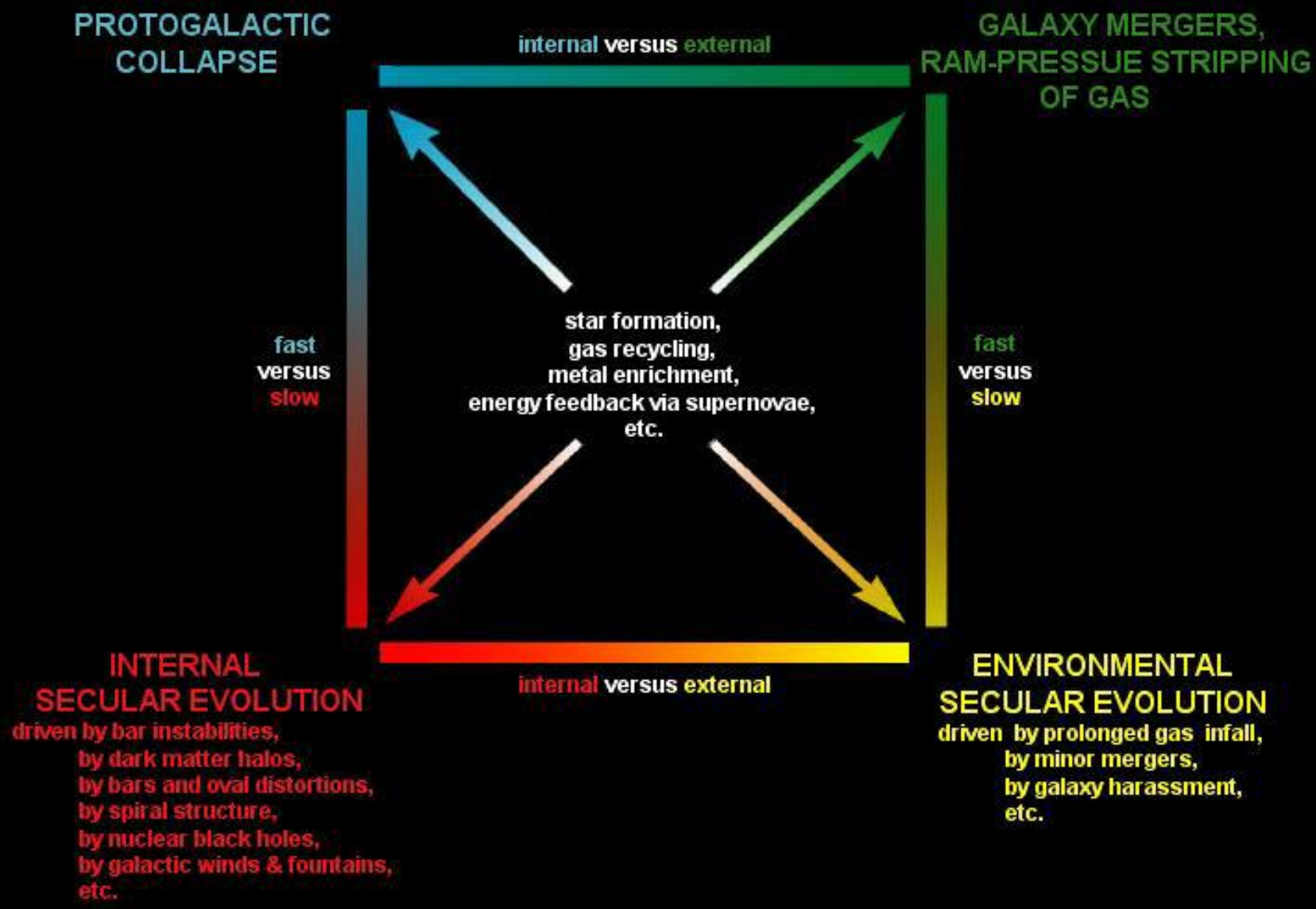
Galaxy Evolution and Environment

A short (and biased) introduction

Angela Iovino GEE2 – Milano 7-9 Nov 2011

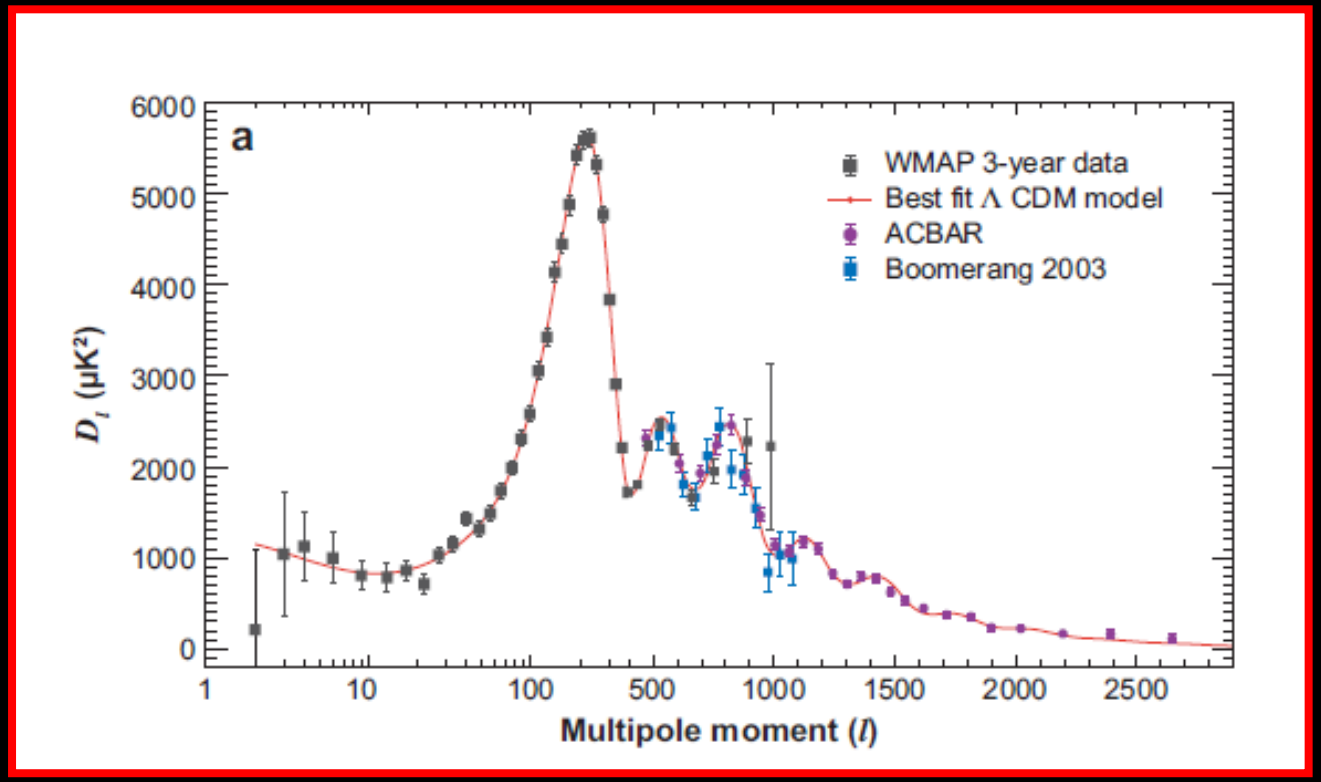


(Kormendy 1982)

30 years after ...

what are the news ??

ΛCDM cosmology is firmly in place



from review paper of Frieman, Turner, Huterer, 2008

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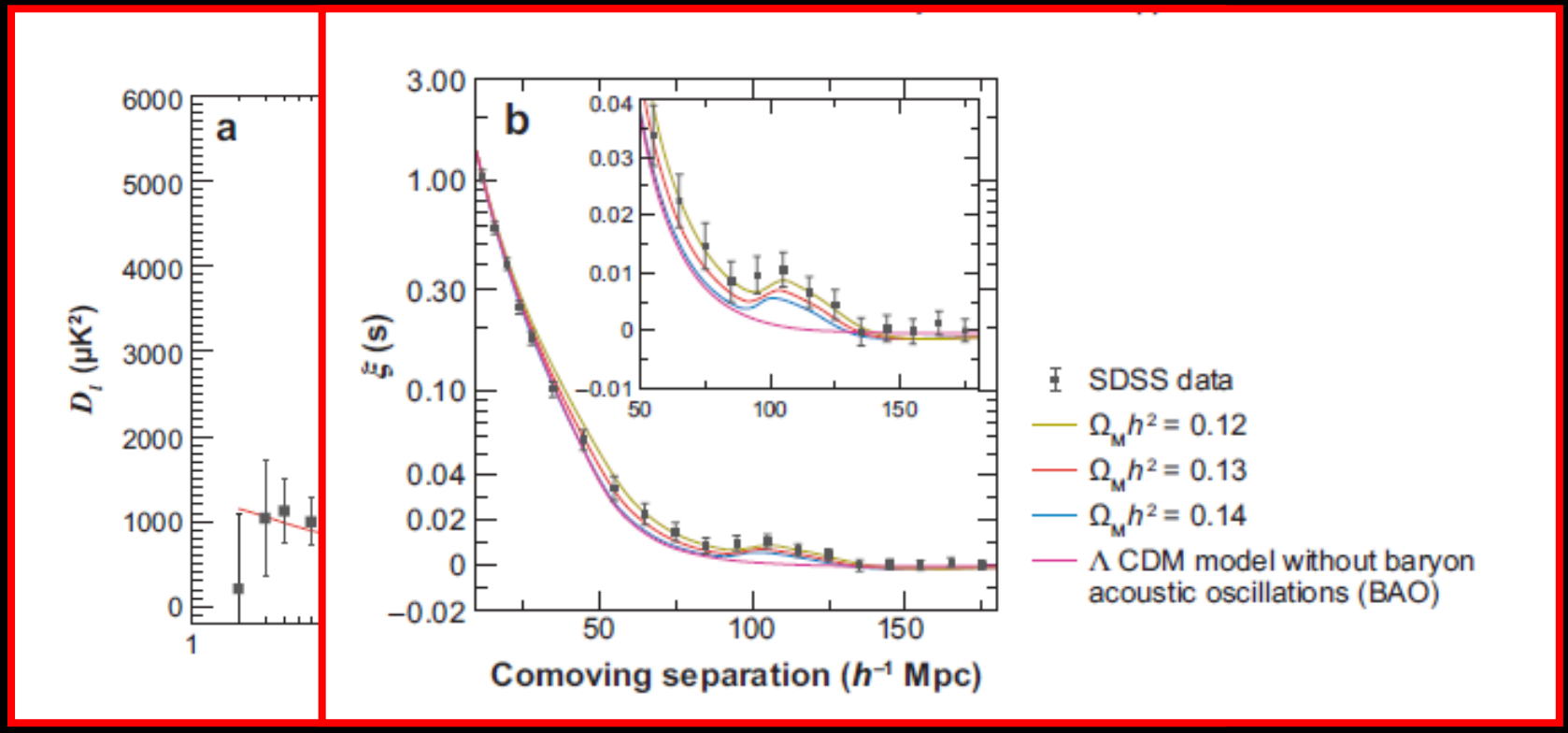

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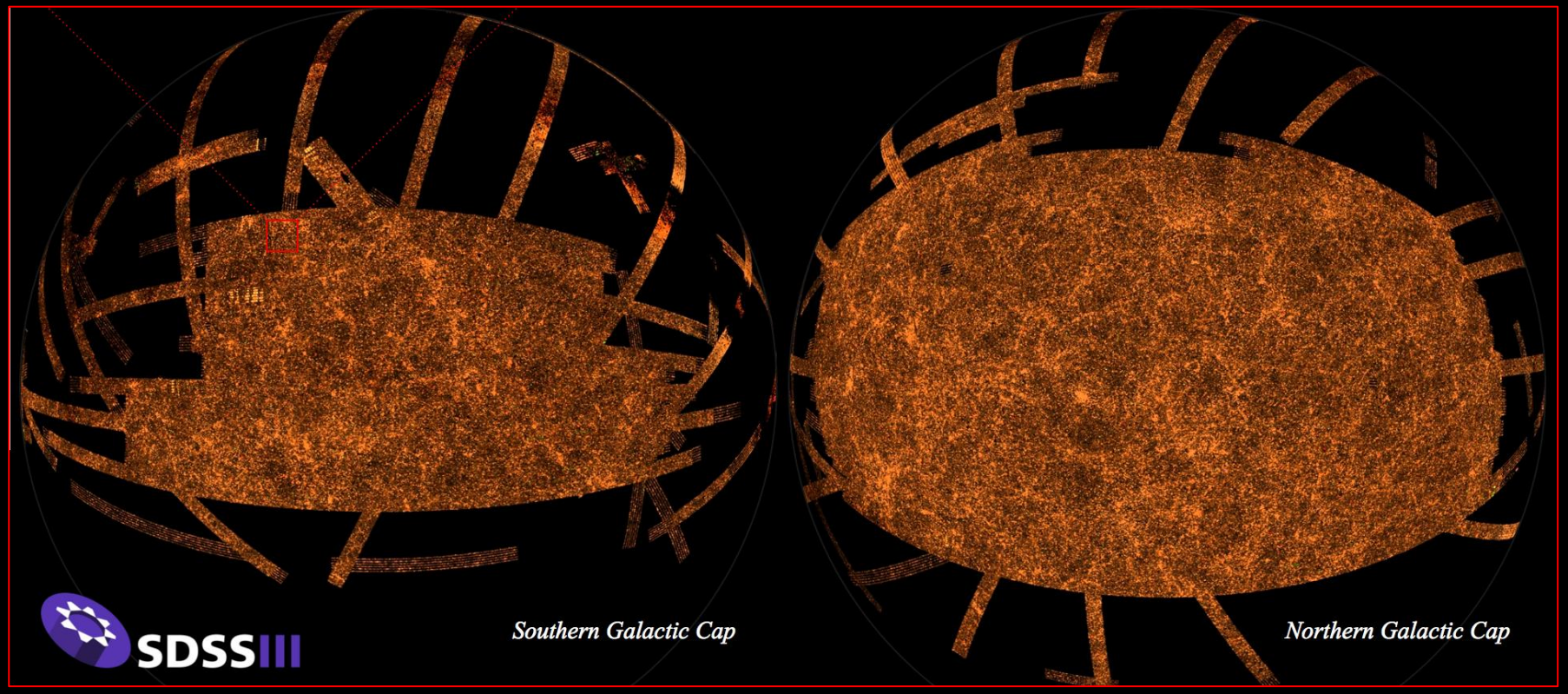
ΛCDM cosmology is firmly in place

Wealth of info for millions of low-z galaxies



ΛCDM cosmology is firmly in place

Wealth of info for millions of low-z galaxies

New observations of high-z universe

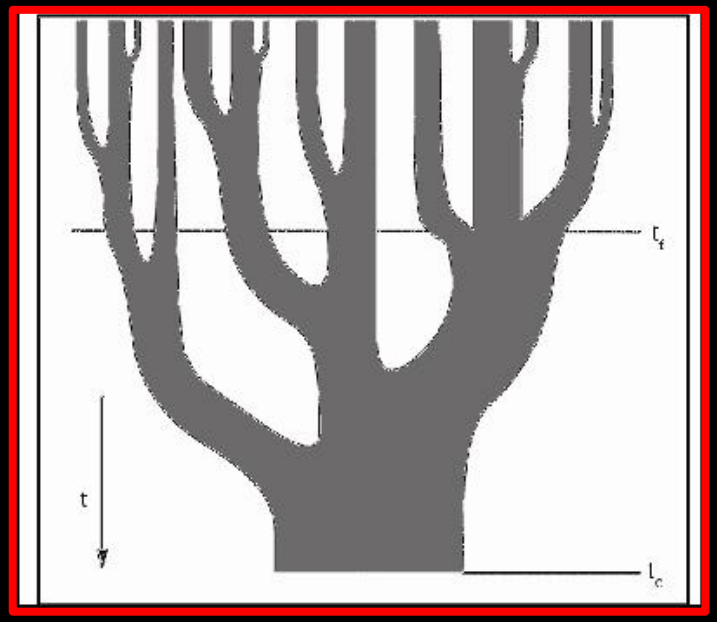
30 years after ...

still open problems

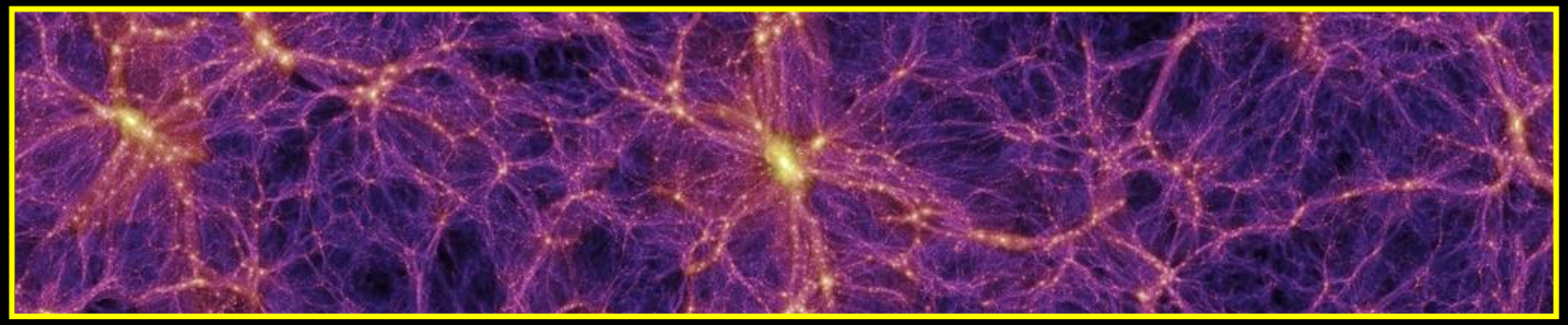
ΛCDM cosmology is firmly in place

We know very well how to build with N-body simulations the evolution of the Dark matter universe.

Hierarchical evolution of cosmic structures

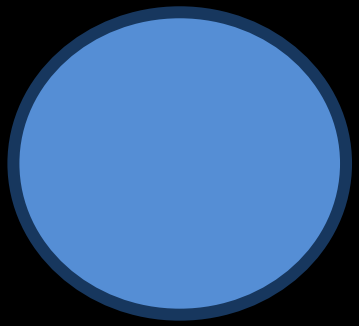


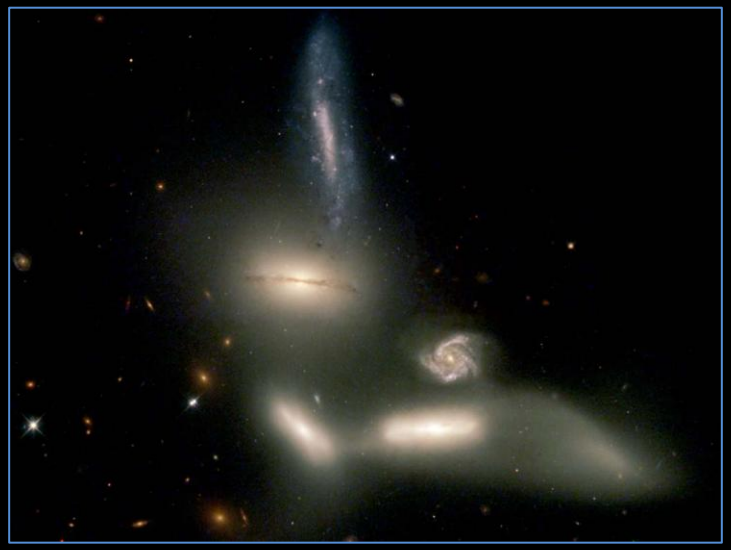
Millennium Simulations



Volume: 500 h^{-2} Mpc on a side
Uses more than ten billion particles to represent the dark matter.

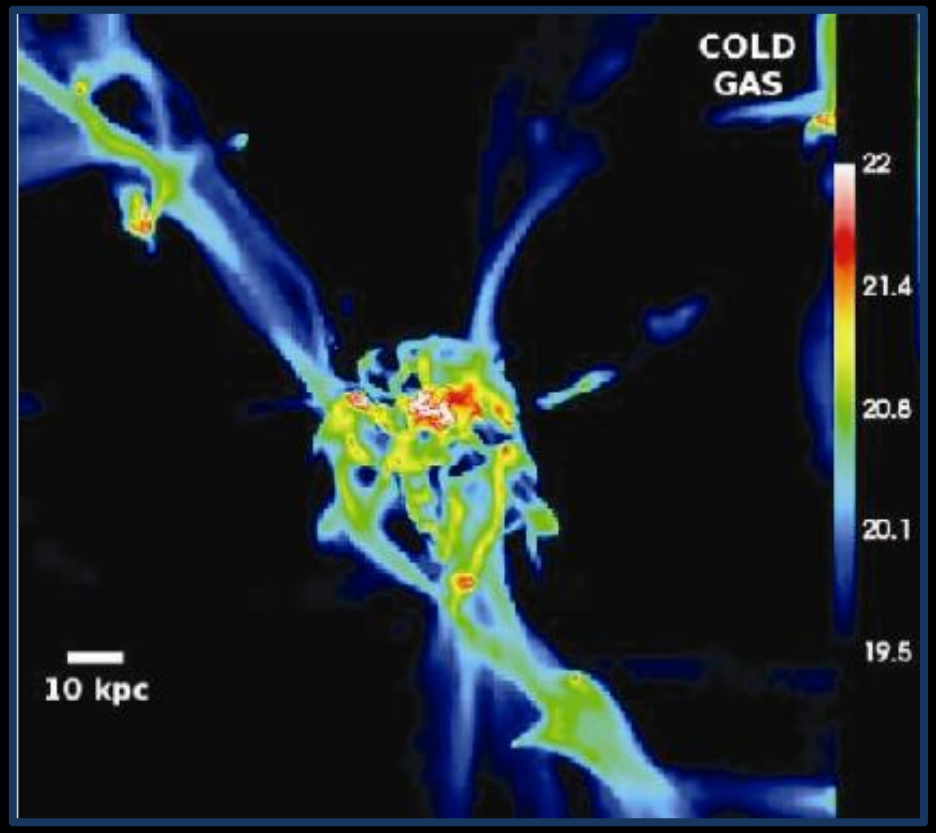
Dark matter halos are only the 'cradles' of galaxy formation





Enter in the realm of gastro-physics (Richard Bond)

Need to include both gas accretion and gas removal by various physical mechanisms, possibly operating in different ways in different environments



Two key facts about galaxy formation:

- efficiency of galaxy formation is low
- efficiency of galaxy formation is not the same in halos of different mass

Eke et al 2006, Yang et al 2005

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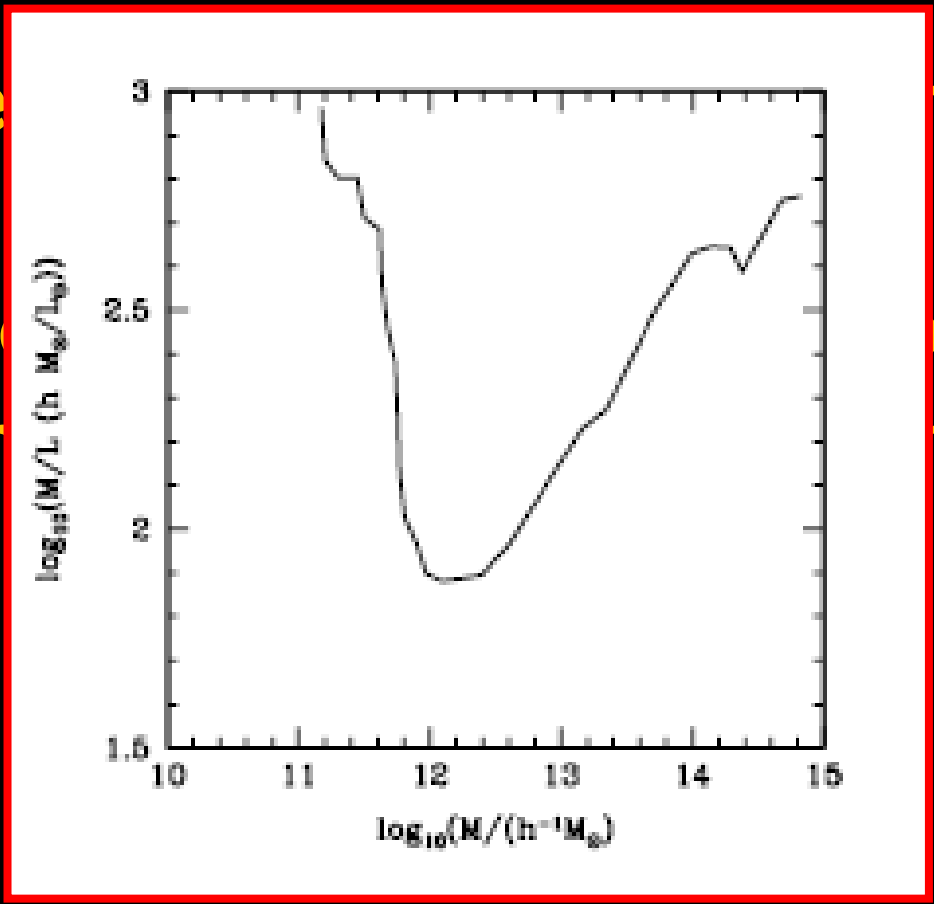
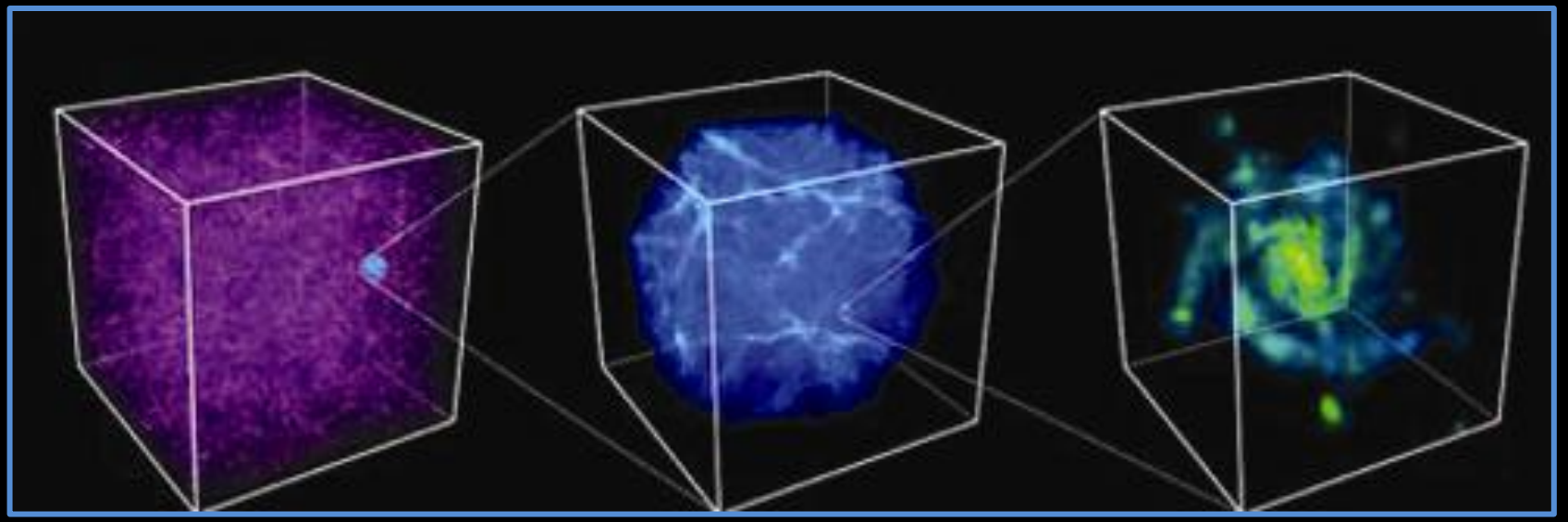
- efficie … is low
- effici … on is not the sam … mass



Eke et al 2006, Yang et al 2005

Still open problem

How to link the observed properties of luminous galaxies to those of dark matter halos in which they reside?



Crain et al 2009

Achievements

Halo mass function varies in different environments: more massive halos form in denser regions

Stars in massive galaxies at z = 0 have mostly formed by z = 1-2, while those in smaller galaxies form at later times

Correct predictions for mass functions in local and distant universe

Still there is quite a lot of complexity involved and unknown physics to explore

Need to keep a tight connection with observations (a two ways process!)

News from low-z galaxies

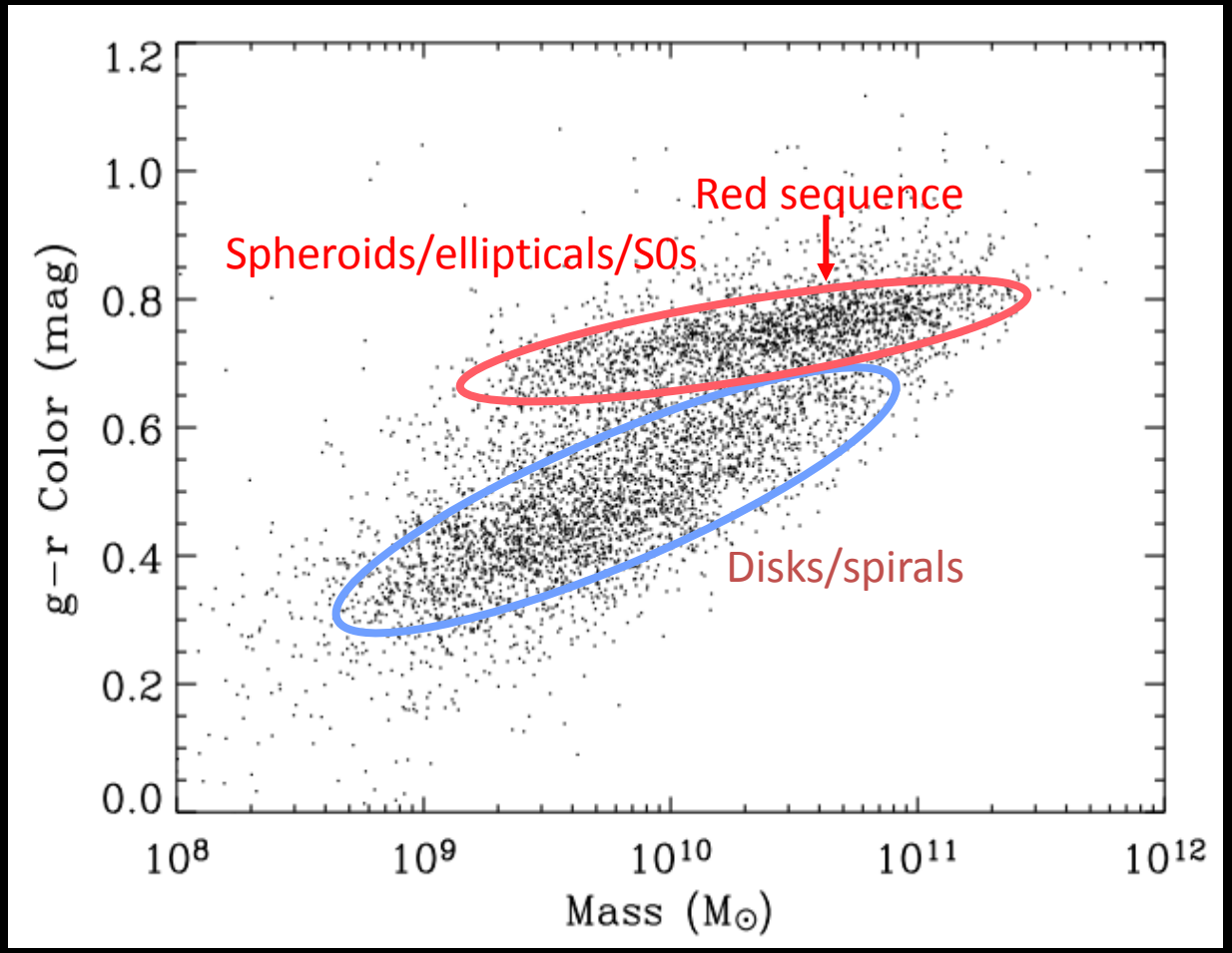
Striking Bimodality

Any property that can be used to characterize a galaxy shows some correlation with its stellar mass

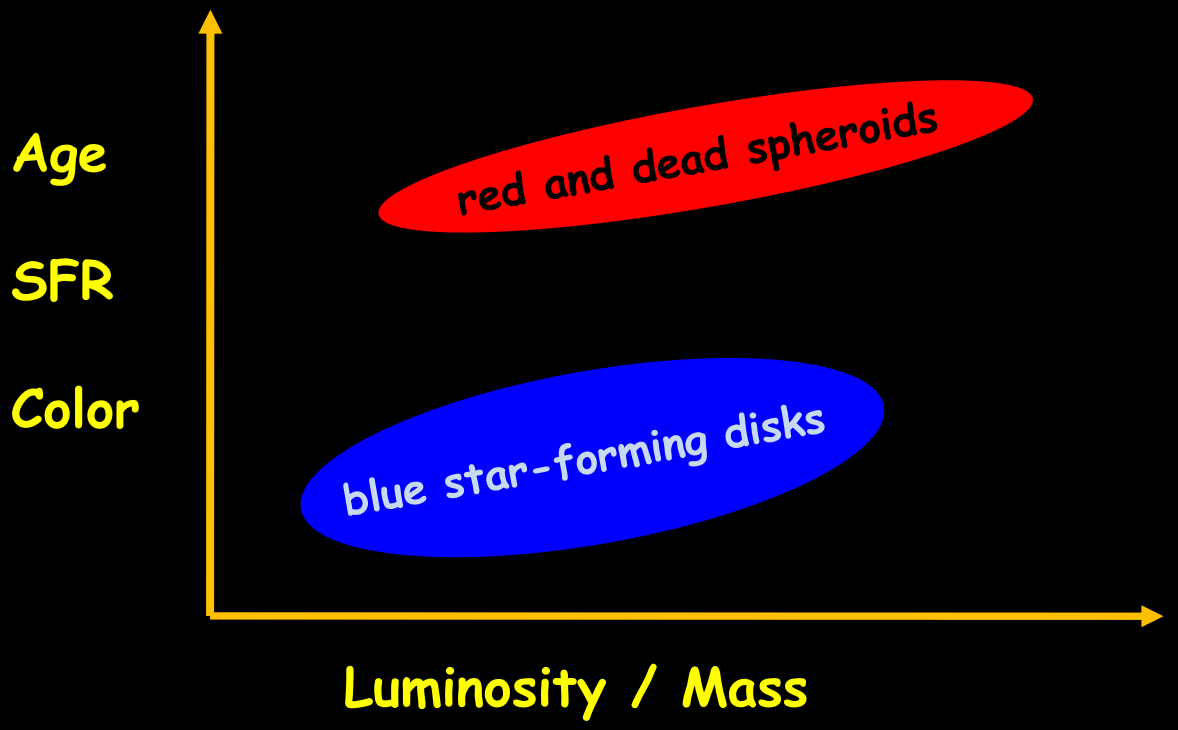
Striking Bimodality

Red

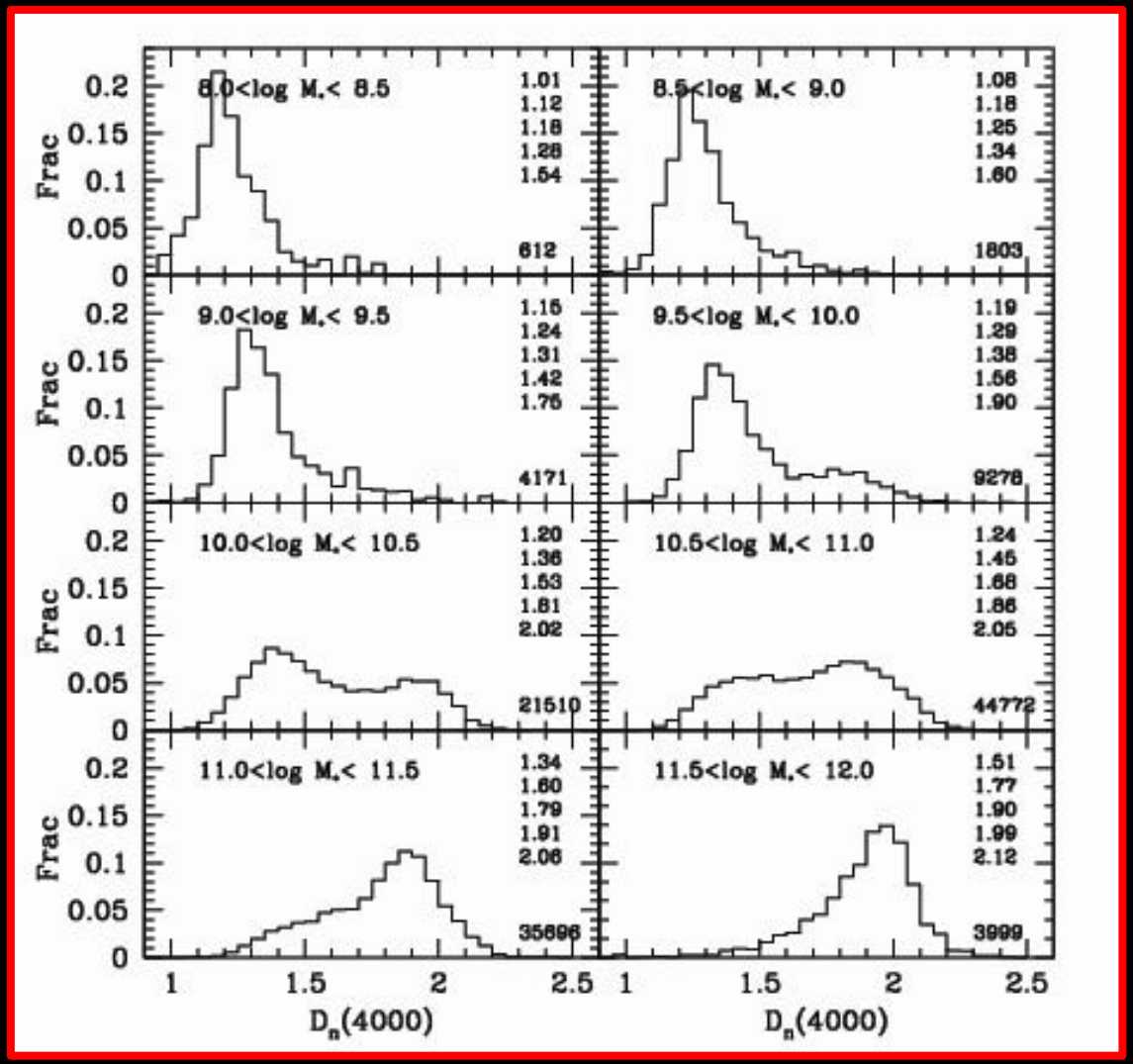
Blue



Striking Bimodality



Striking Bimodality
Strong correlation with galaxy stellar mass



Kauffmann et al. , 2003

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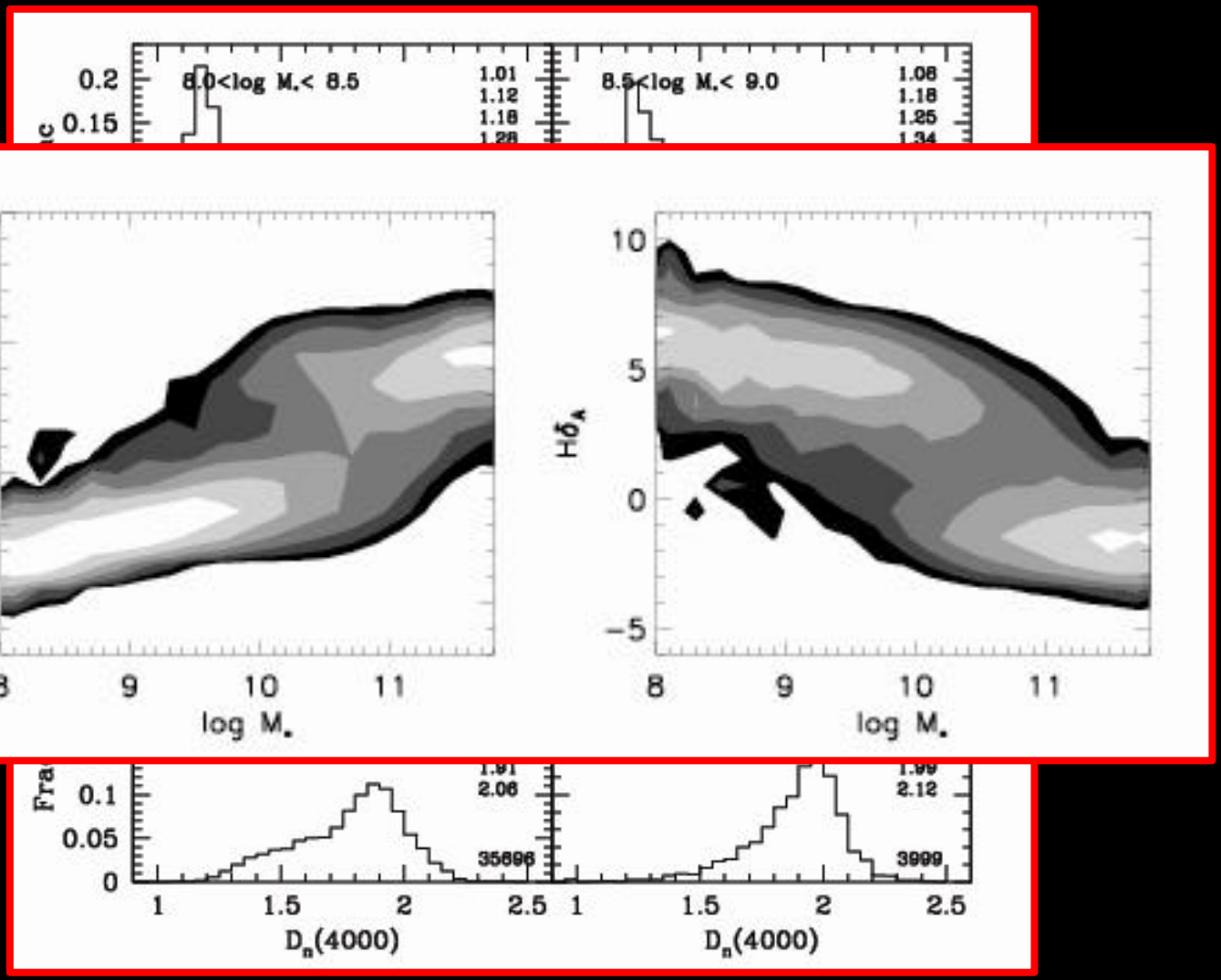

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Striking Bimodality
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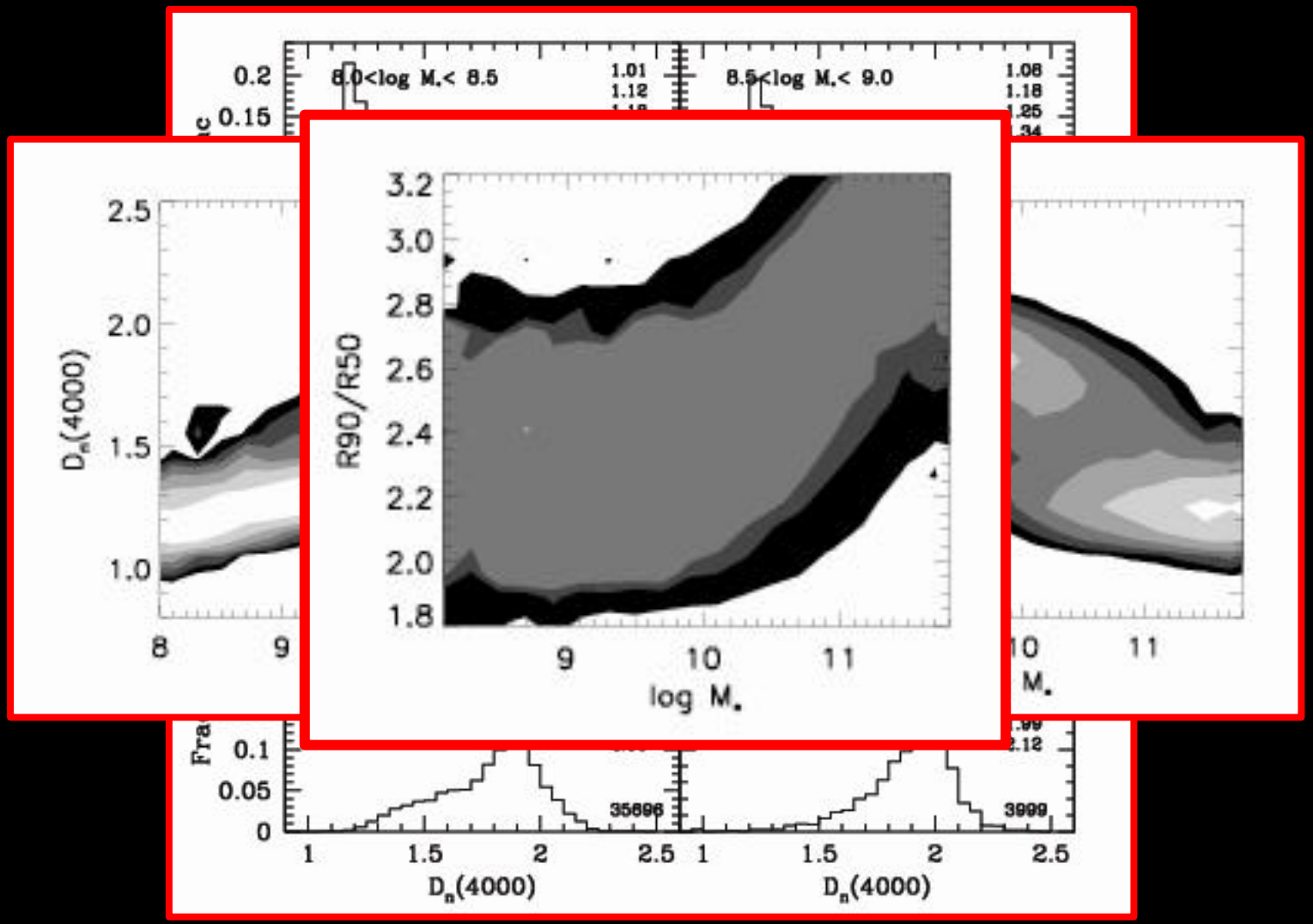
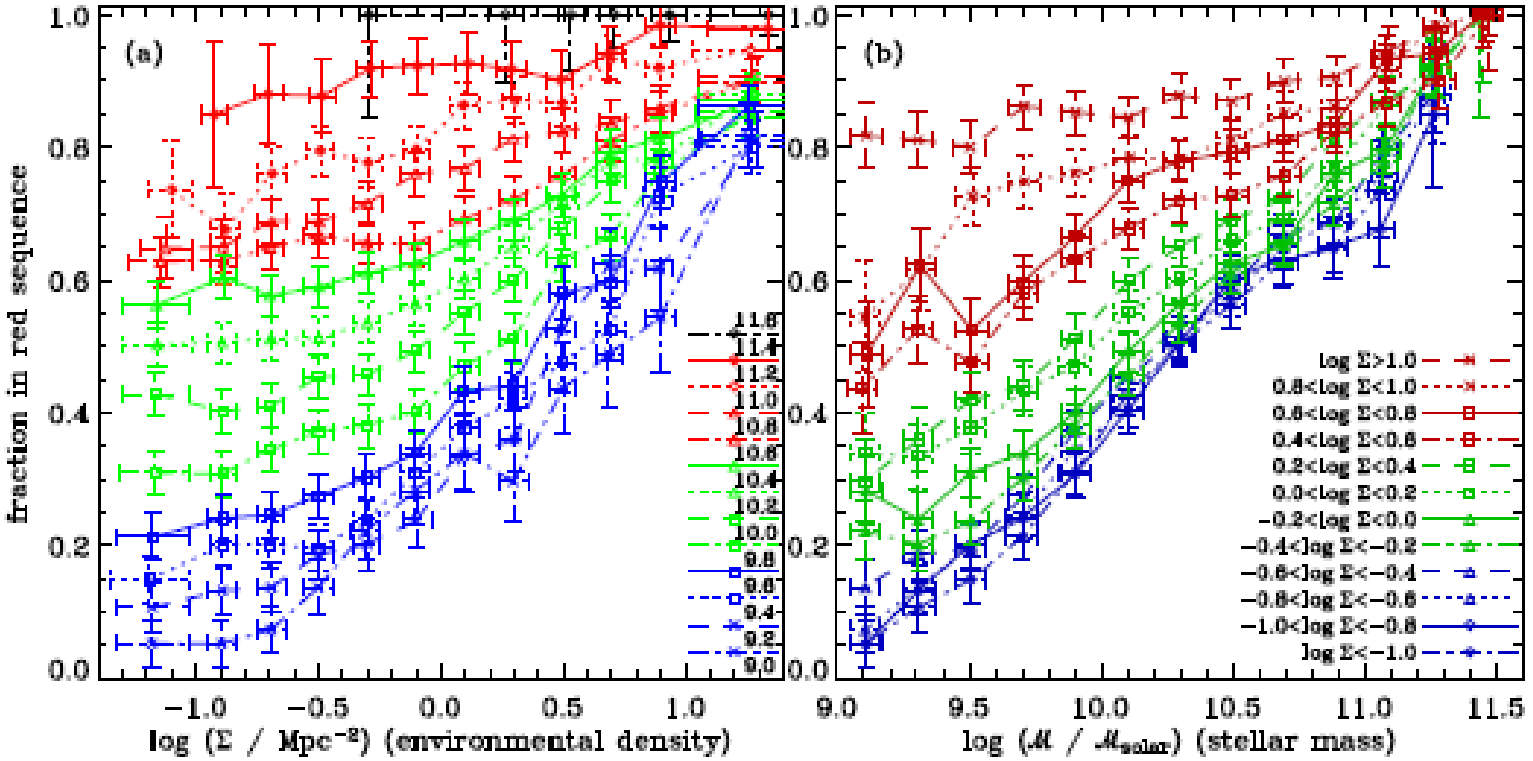


Kauffmann et al. , 2003

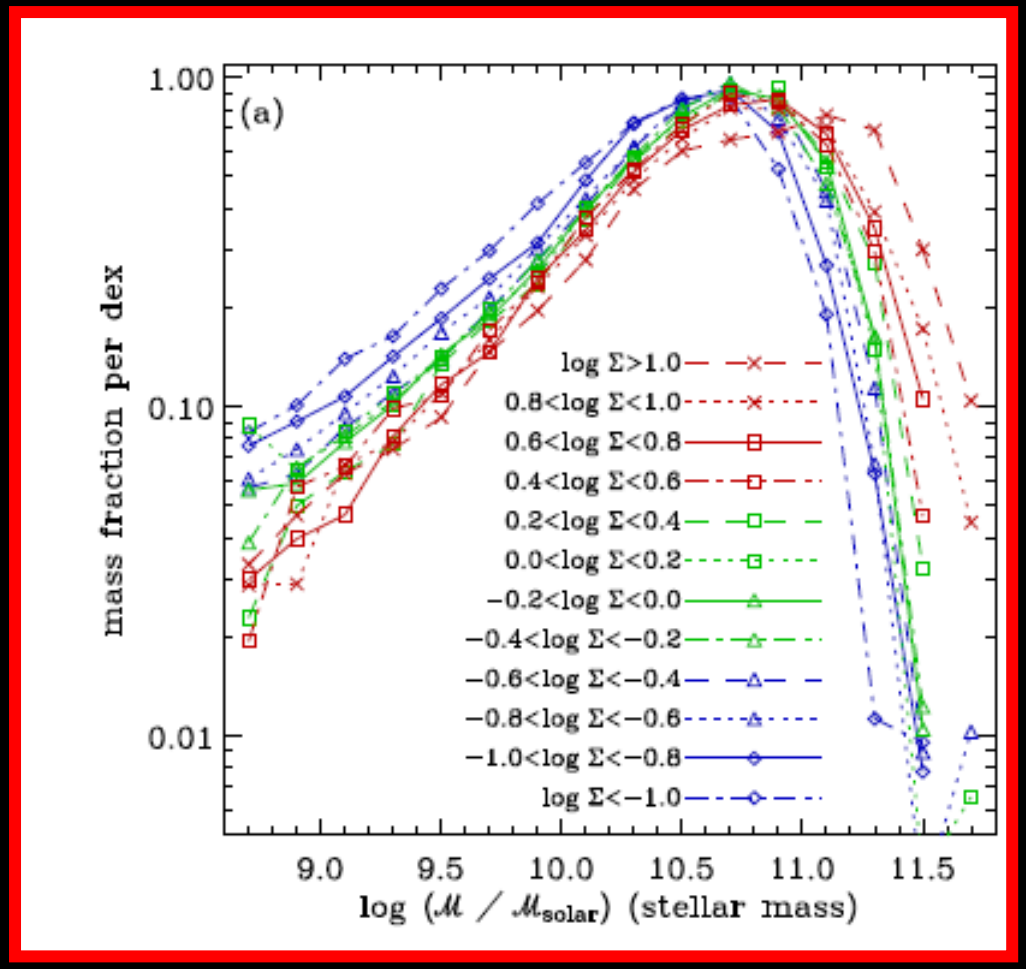
Striking Bimodality
Equally strong correlation with environment



Baldry et al. , 2006

Striking Bimodality

… and higher mass galaxies preferentially populate higher density regions



Baldry et al. , 2006

Stellar mass and environmental analysis need to be done separately (ie in bins of stellar mass / bins of environment) in order to determine their relative influence on galaxy population.

Subtle biases can affect the analysis whenever there is a sample of galaxies that contains a range of stellar masses !

As galaxy stellar mass is a key ingredient to predict galaxy properties it is better to select galaxy samples directly using mass (or a mass proxy)

A more economical way to select a galaxy sample that needs minimal trimming before use !

A closer look at the

BLUE CLOUD

For the star-forming galaxy population, the typical mean SF-rate depends only on mass and not on environment

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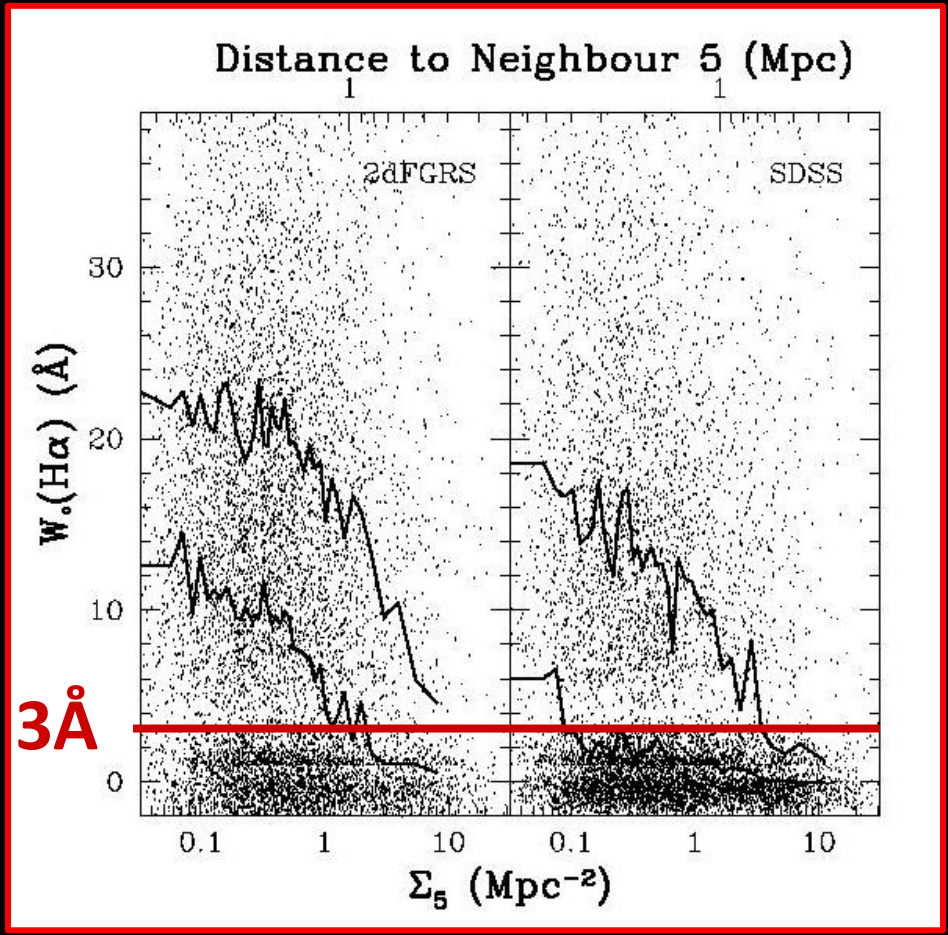

Balogh et al. 2004

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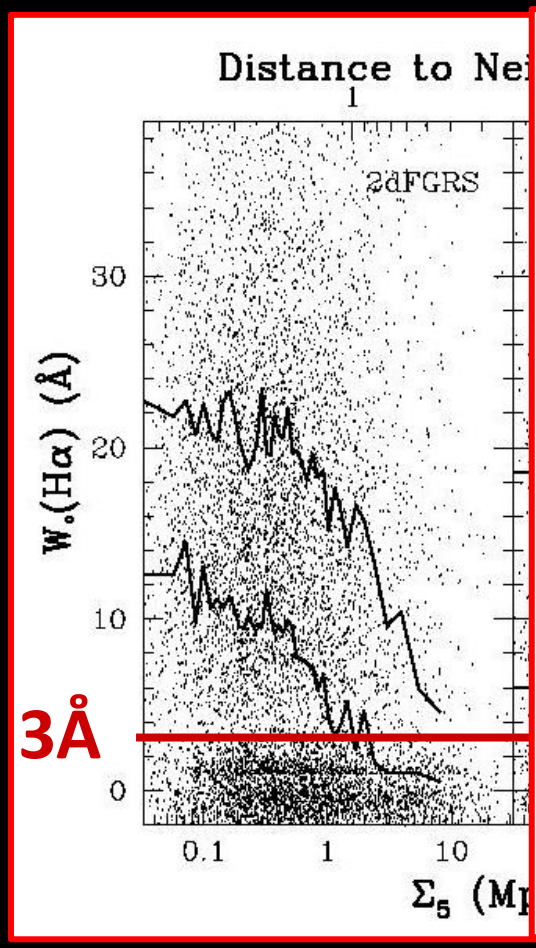

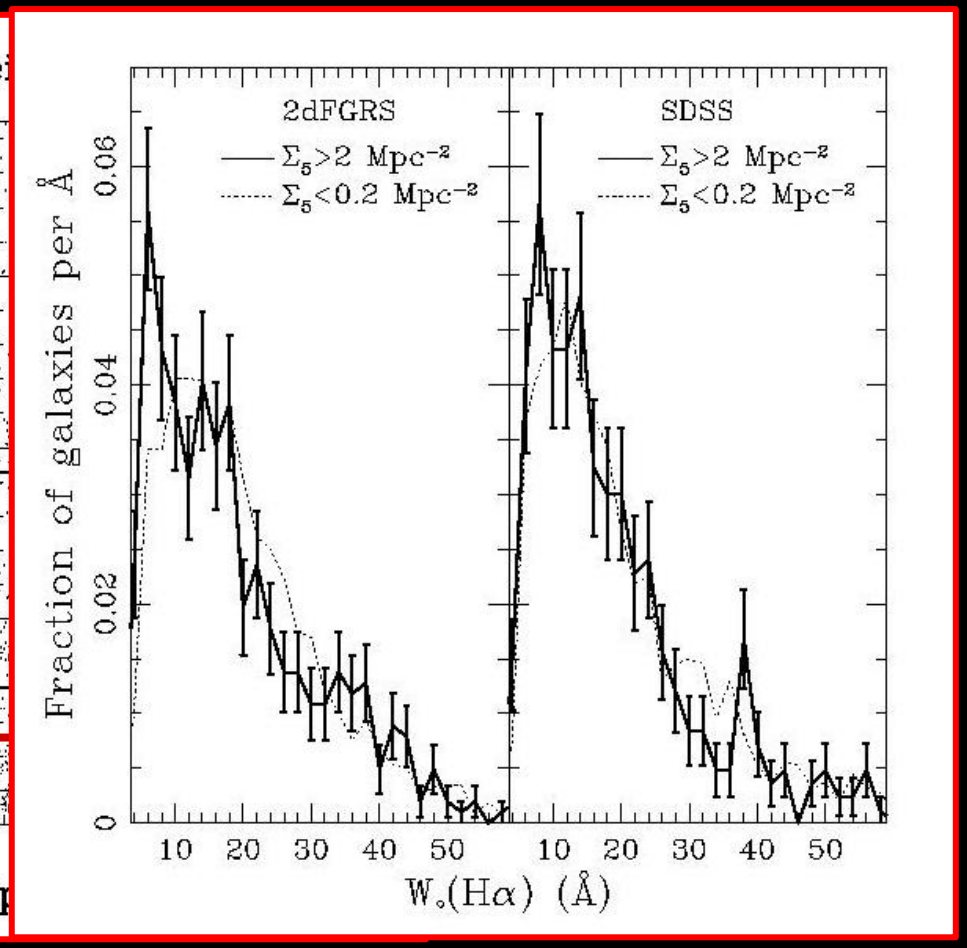

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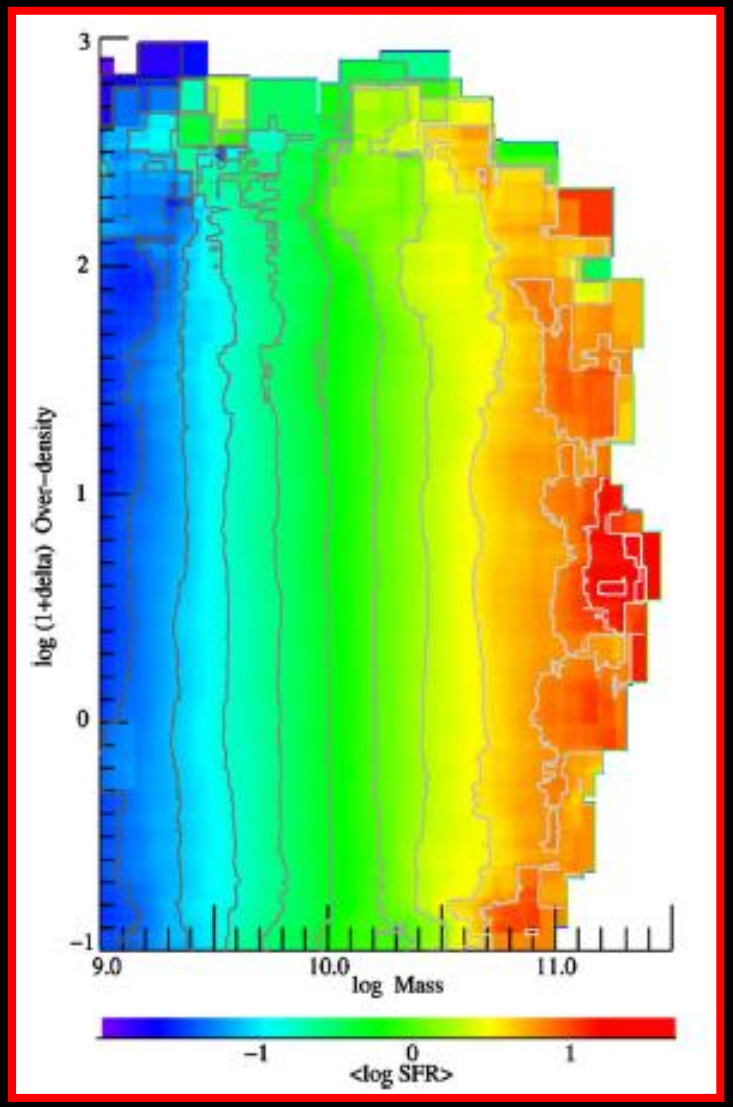

Peng et al. 2010

For the star-forming galaxy population, the typical mean SF-rate depends only on mass and not on environment

As a consequence also sSFR (per unit mass) does not depend on environment.

On the other hand sSFR has only a weak dependence on the galaxy stellar mass for star forming galaxies

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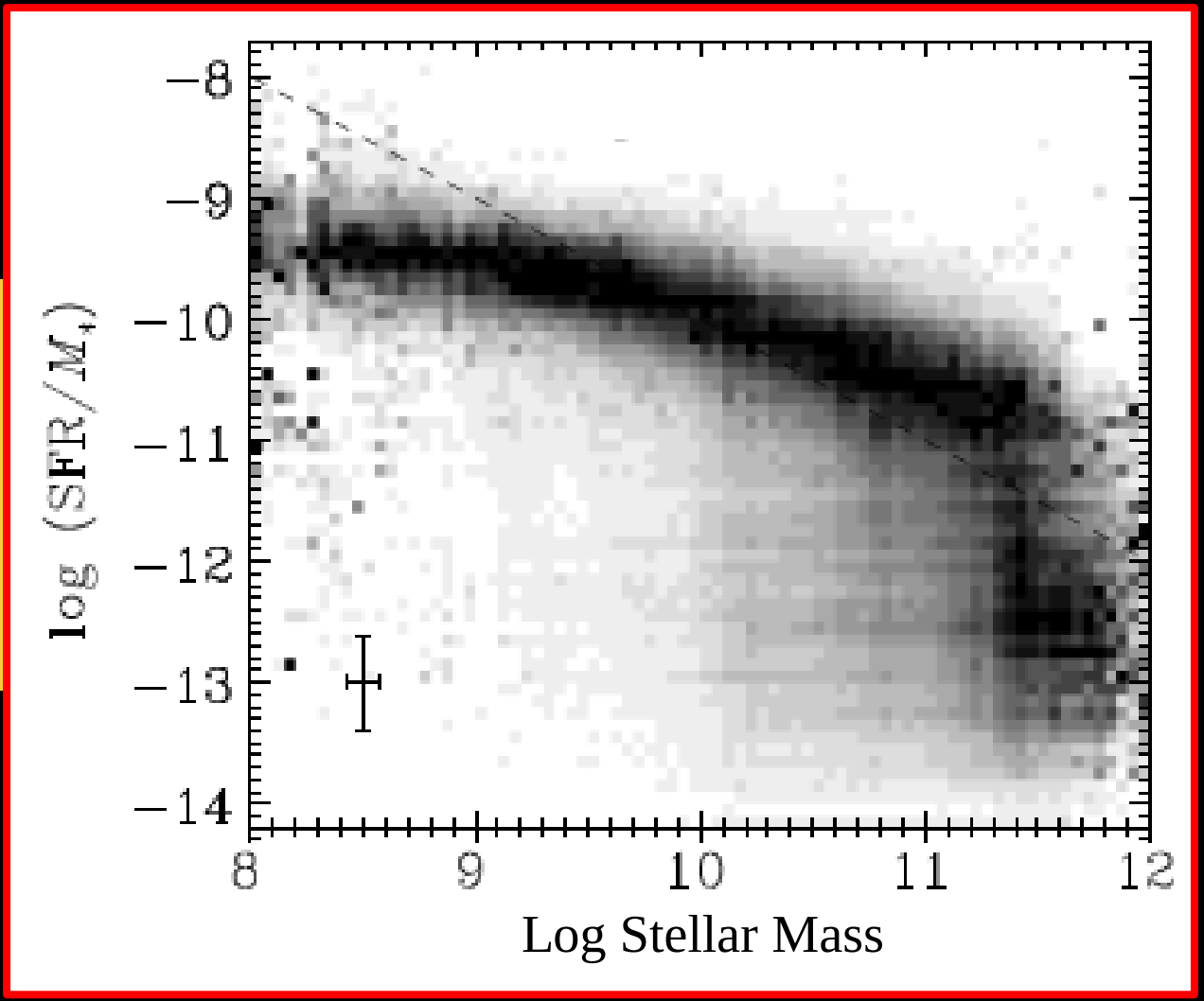
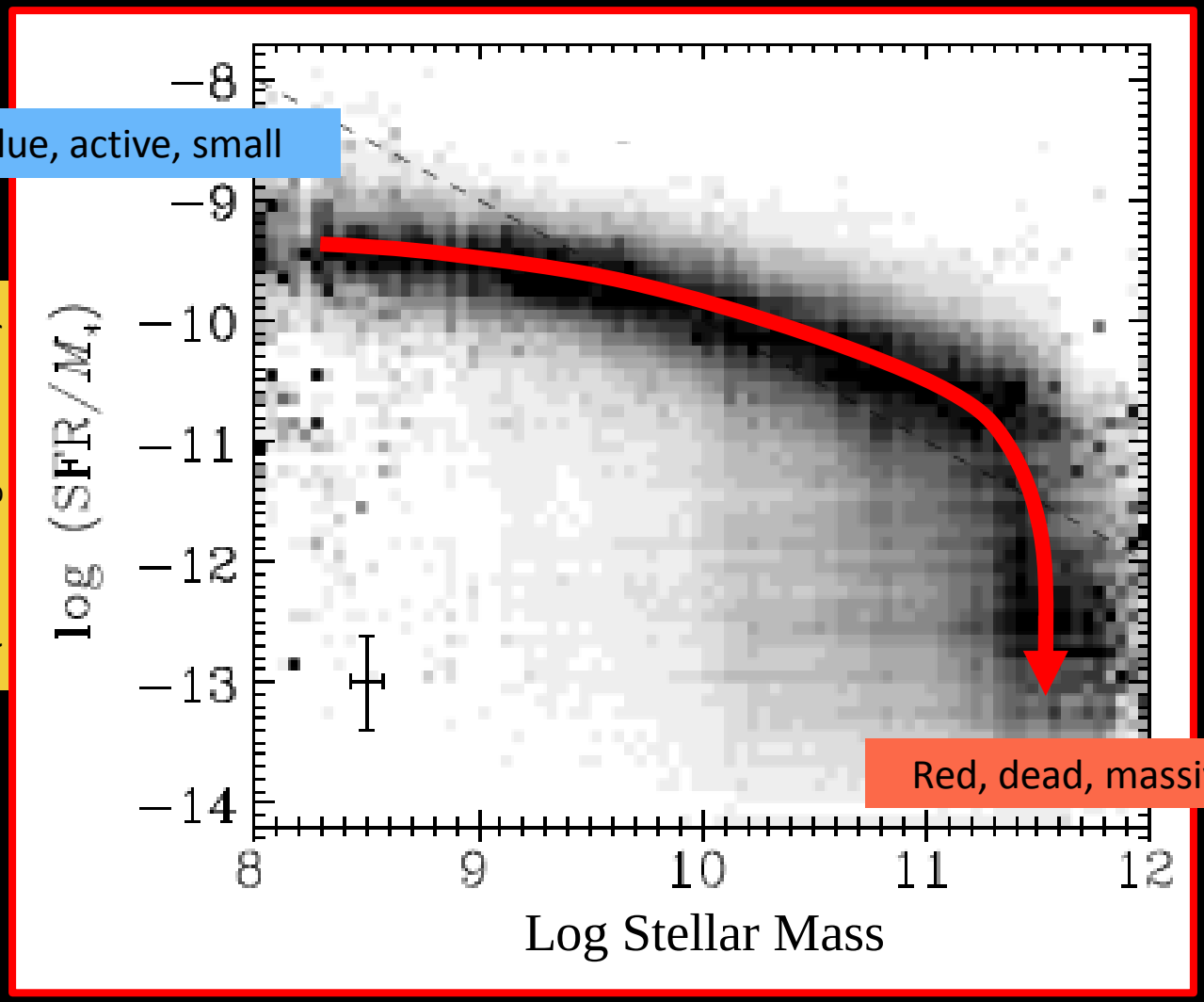
SSFR based on UV (reddening corrected)



Salim et al. 2007

On the other hand sSFR has only a weak dependence on the galaxy stellar mass for star forming galaxies



tight 'main sequence' of star-forming galaxies

Salim et al. 2007

A closer look at the

BLUE CLOUD

typical mean SF-rate
depends only on galaxy stellar mass
and not on environment

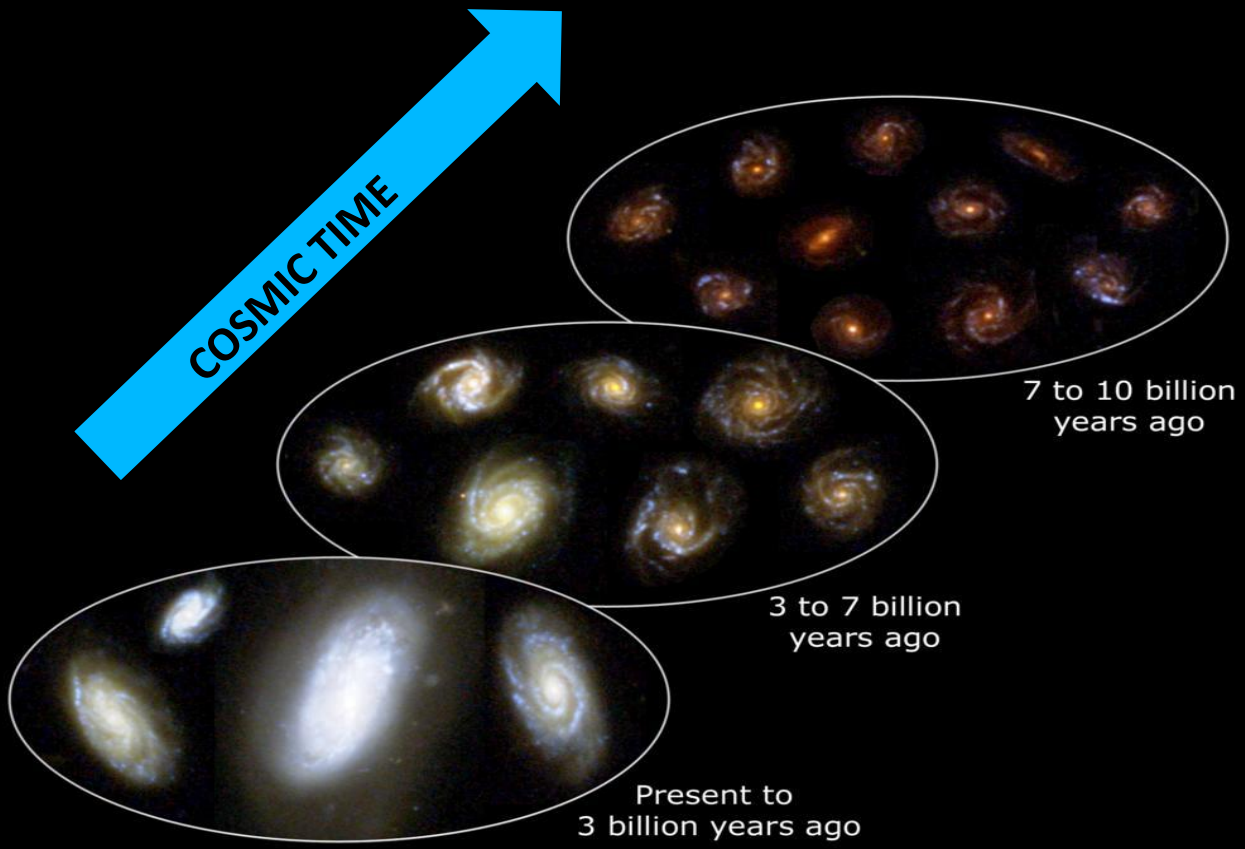
typical mean sSF-rate
depends weakly on the galaxy stellar mass
and not on environment

We are talking of global population properties that cannot be due to the relatively small percentage of galaxies that live in cluster cores today.

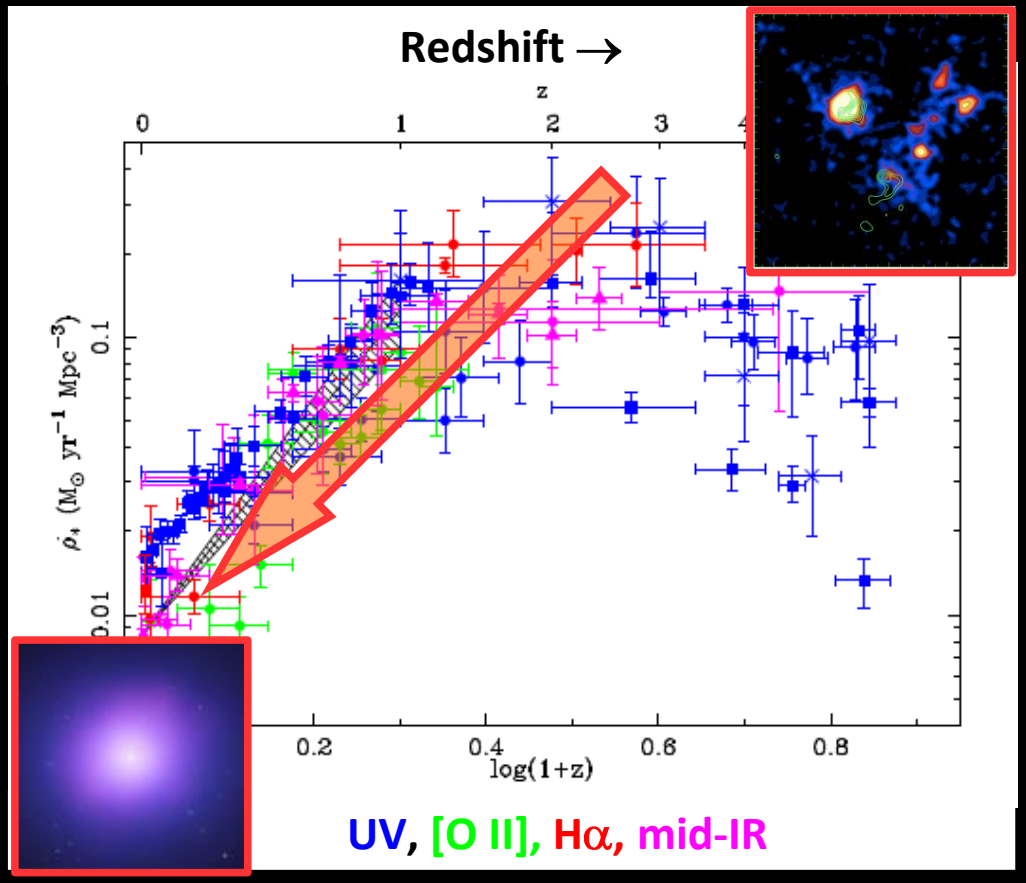
Evidence of trends with environment is not evidence of environment causing such trends

Galaxies in denser environments may simply have formed earlier → further evolved today

Need to add the TIME axis ....



Cosmic history of star formation

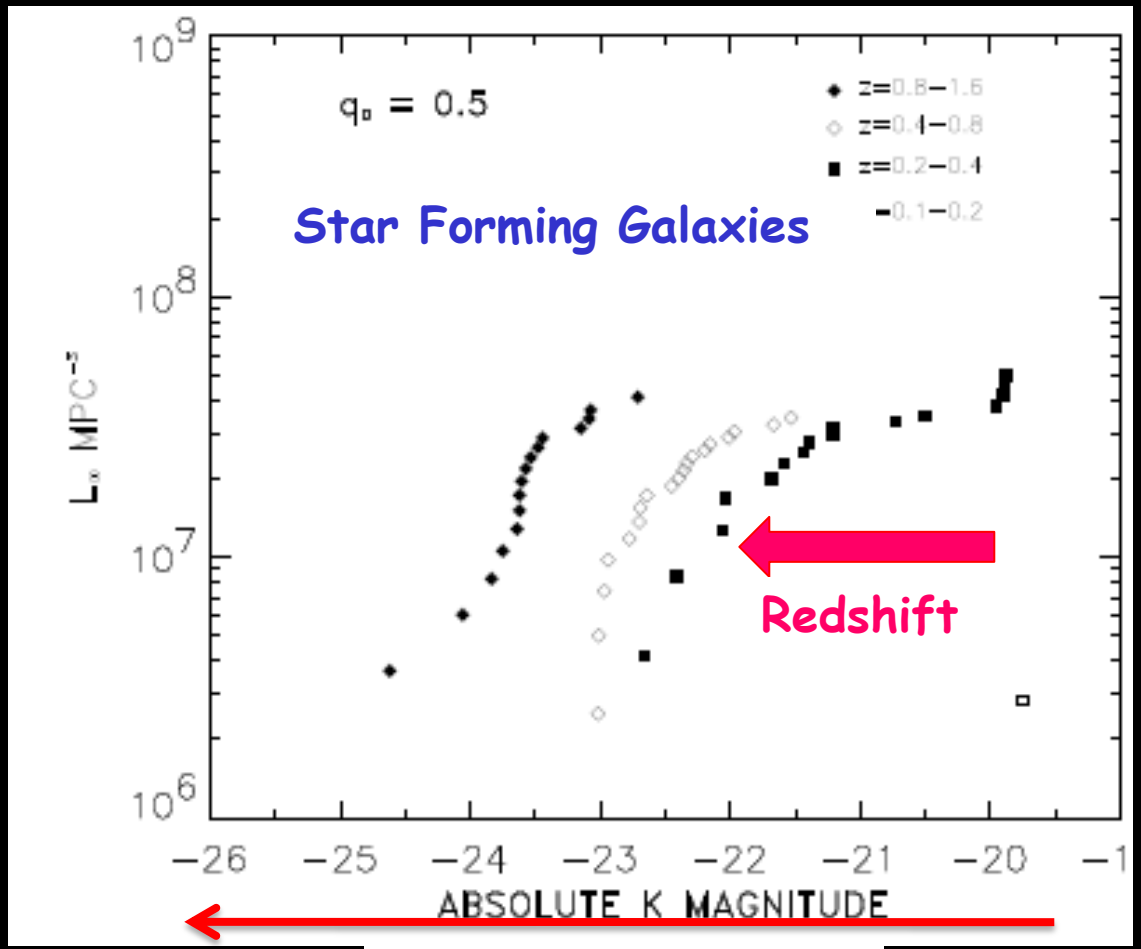


Hopkins (2004), Hopkins & Beacom (2006)

The Universe as a whole formed stars more actively in the past than today

Madau et al., 1996
Steidel et al., 1999

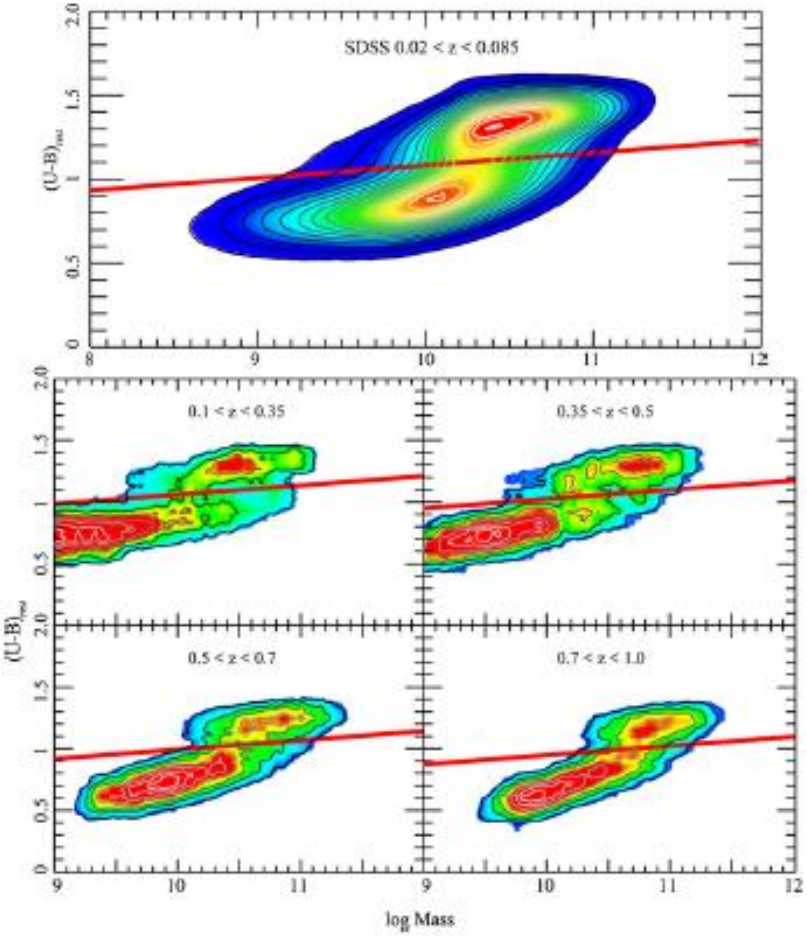
Downsizing



The sites of active star formation shift from high-mass galaxies at early times to lower mass systems at lower redshift

Cowie et al., 1996

Bimodality survives to highest z



Peng et al., 2010

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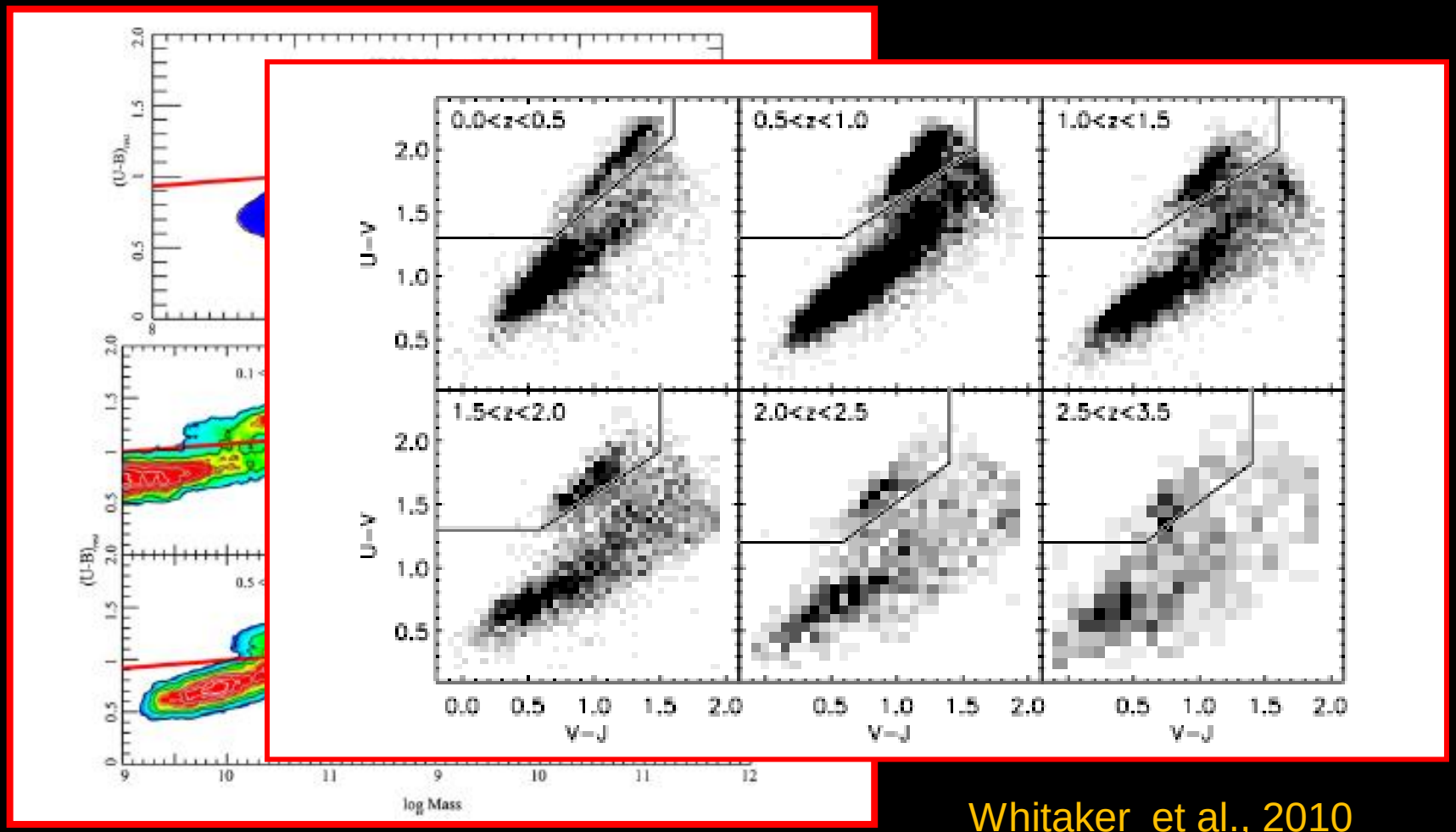

Peng et al., 2010

Whitaker et al., 2010

No clear indication of increase of transitional population

Any process that moves galaxies from the blue cloud to the red sequence should be fast (< 1.5-2 Gyrs) in order not to destroy bimodality

But not too fast to avoid over-populating the red sequence at low z!

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cloud to the red seque
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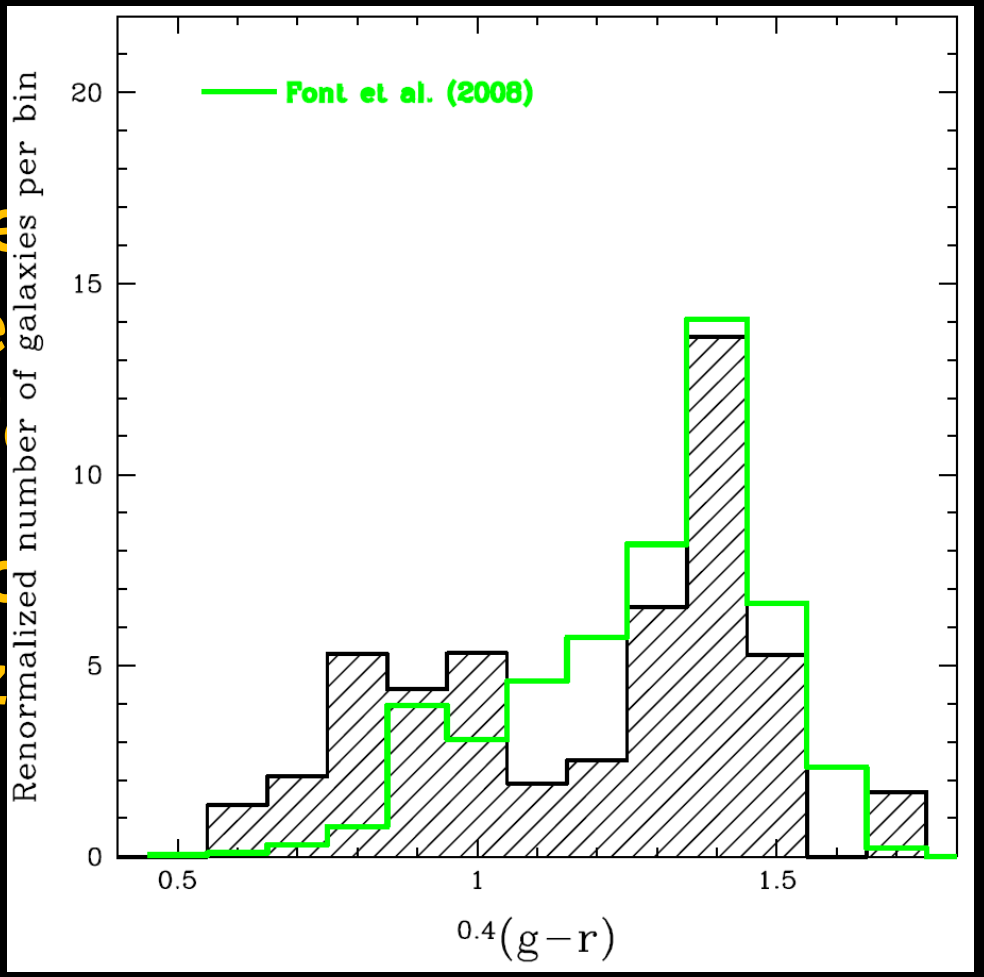
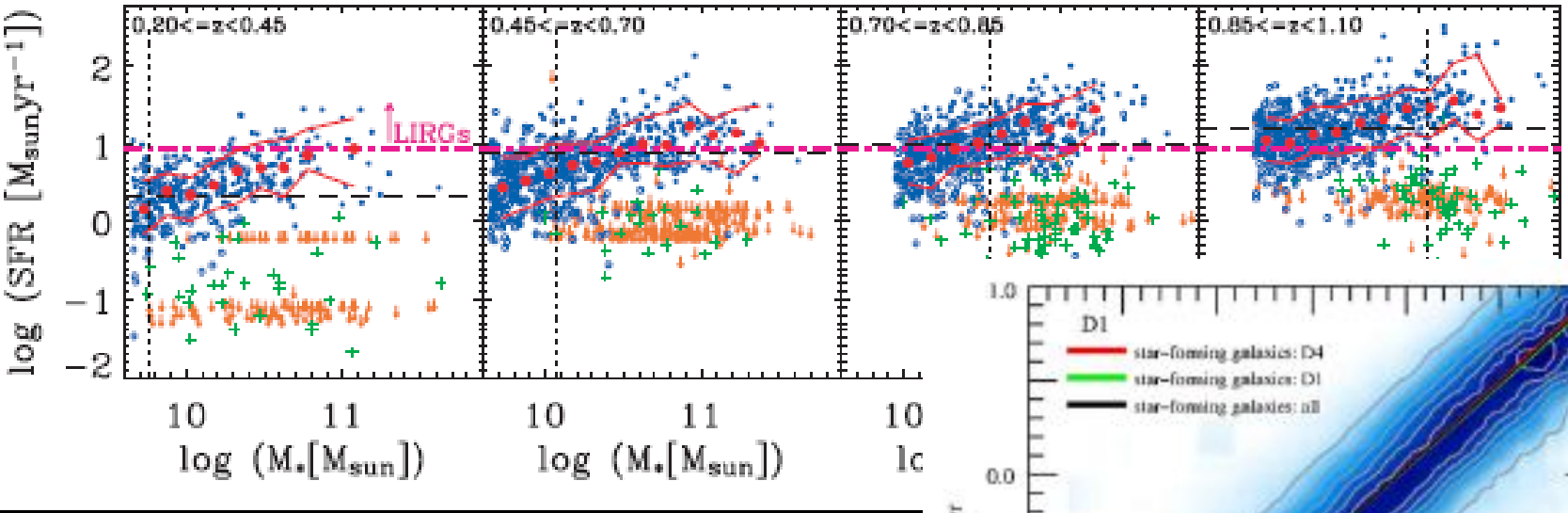
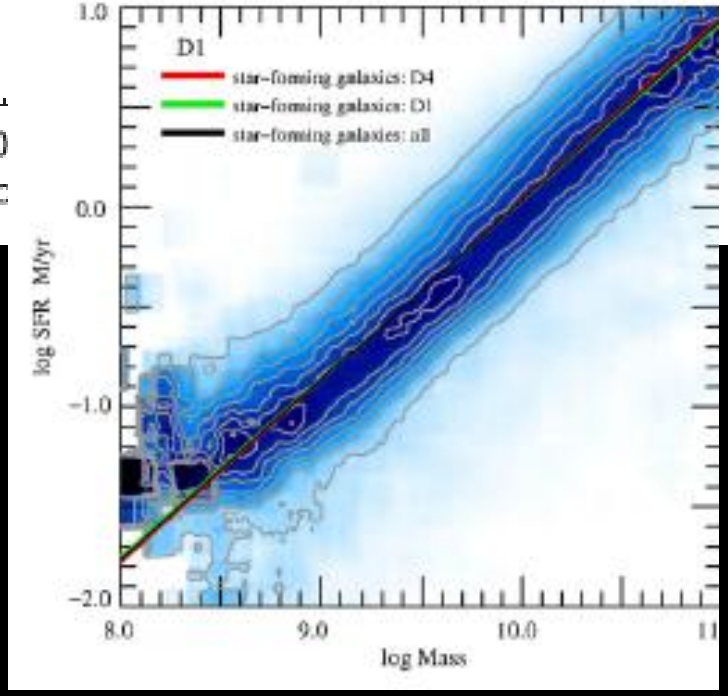


Balogh et al. (2009)

Main sequence of star forming galaxies survives at high-z



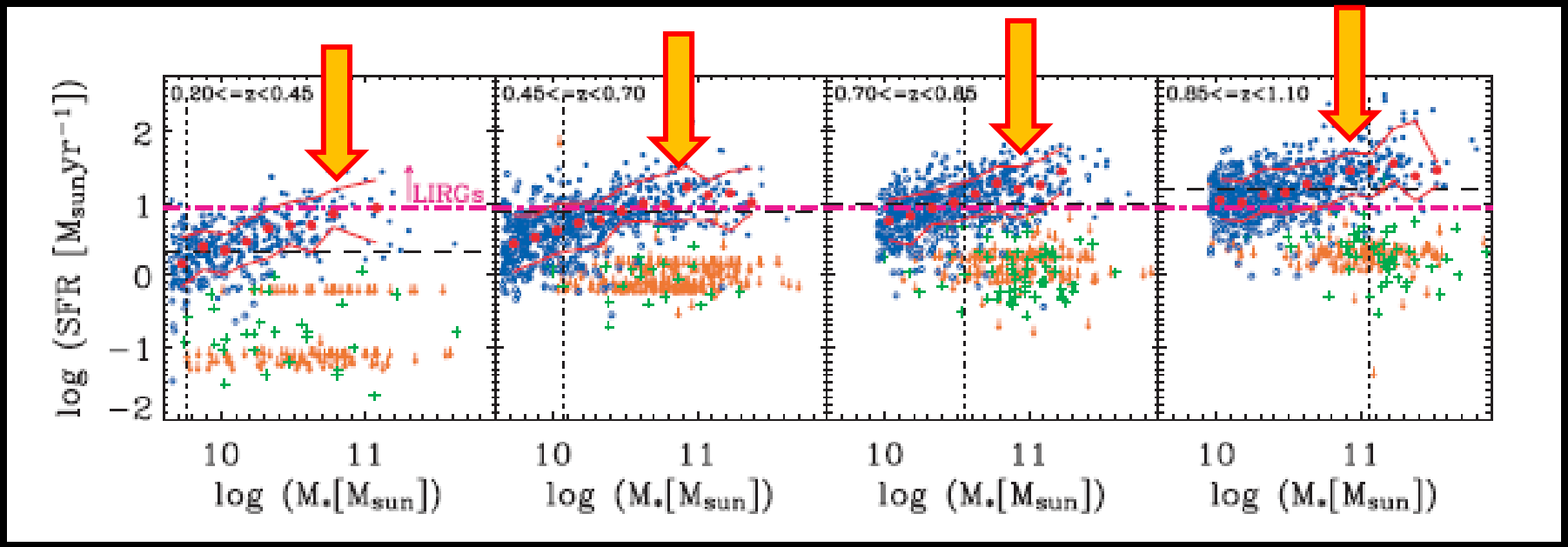
Noeske et al. (2007a)



SDSS Data

Peng et al., 2010

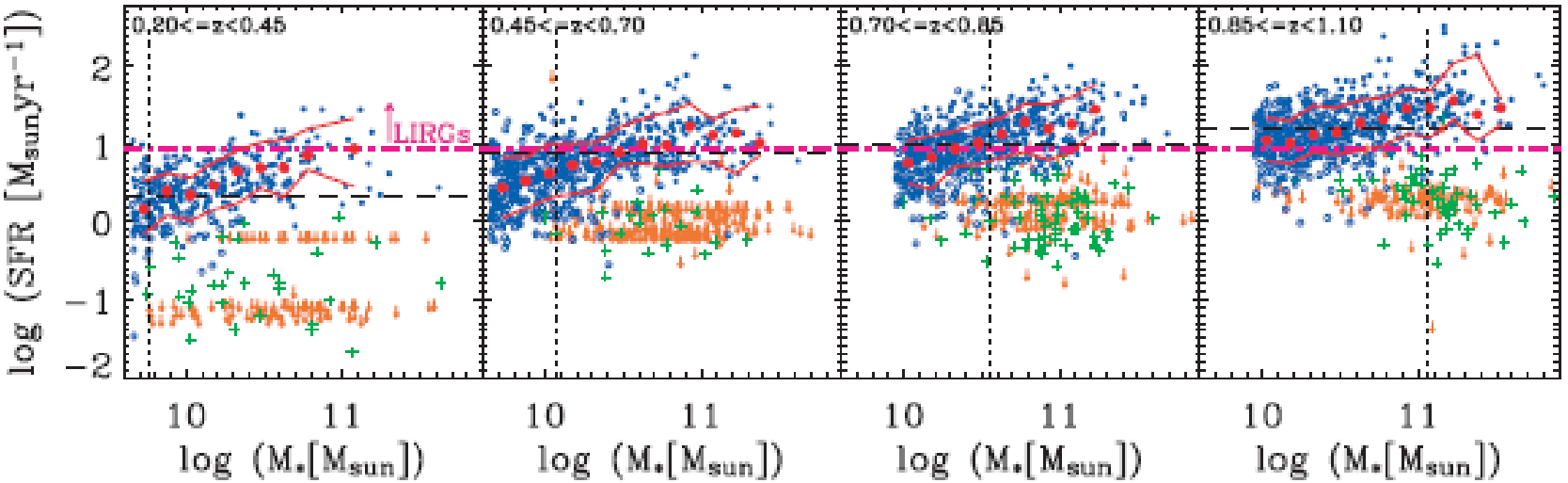
Main sequence of star forming galaxies survives at high-z



Noeske et al. (2007a)

Moving back in time we observe a steady increase in the SFR at a given galactic mass across the broad population of star forming galaxies → responsible for the evolution of the star formation rate density

Main sequence of star forming galaxies survives at high-z

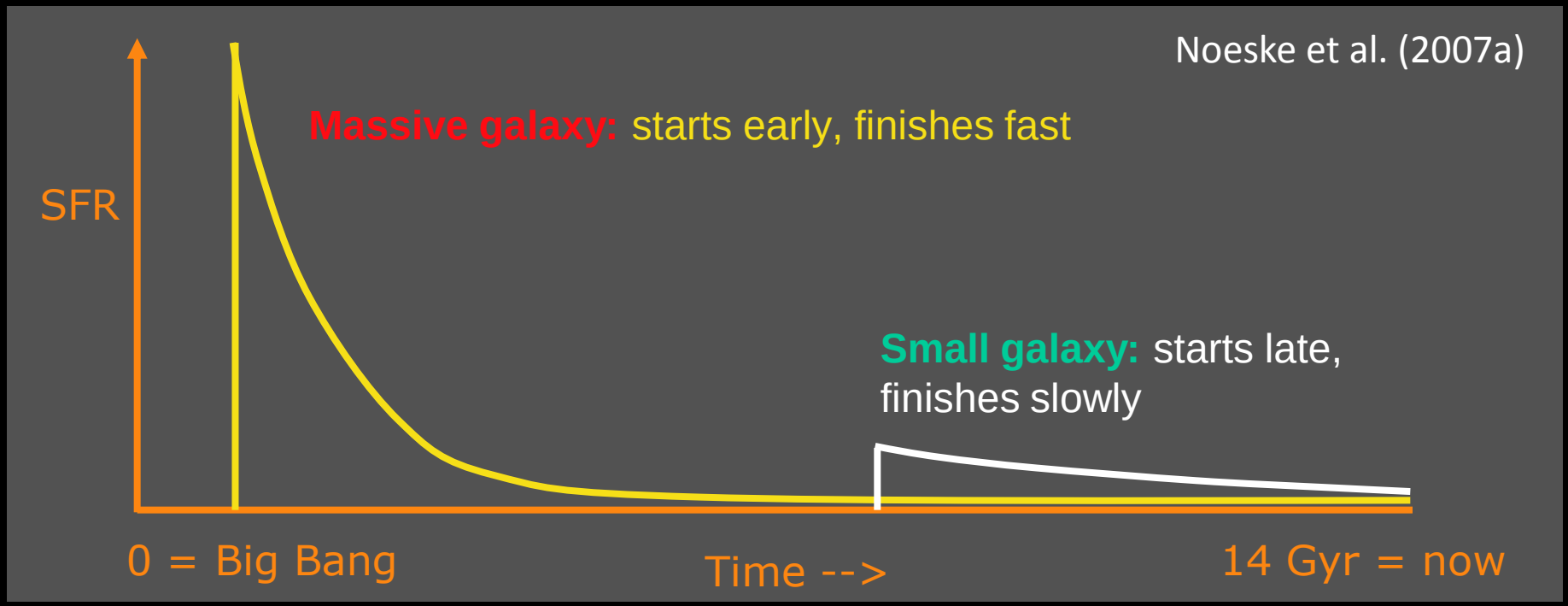


The dominant mode of the evolution of SF since z ~ 1 is apparently a gradual decline of the average SFR in most individual galaxies.

Evolution of the MS just due to gas exhaustion ?

So called Tau-model sequence:

- Star formation declines exponentially in each galaxy
- Bigger galaxies turn on sooner and decay faster



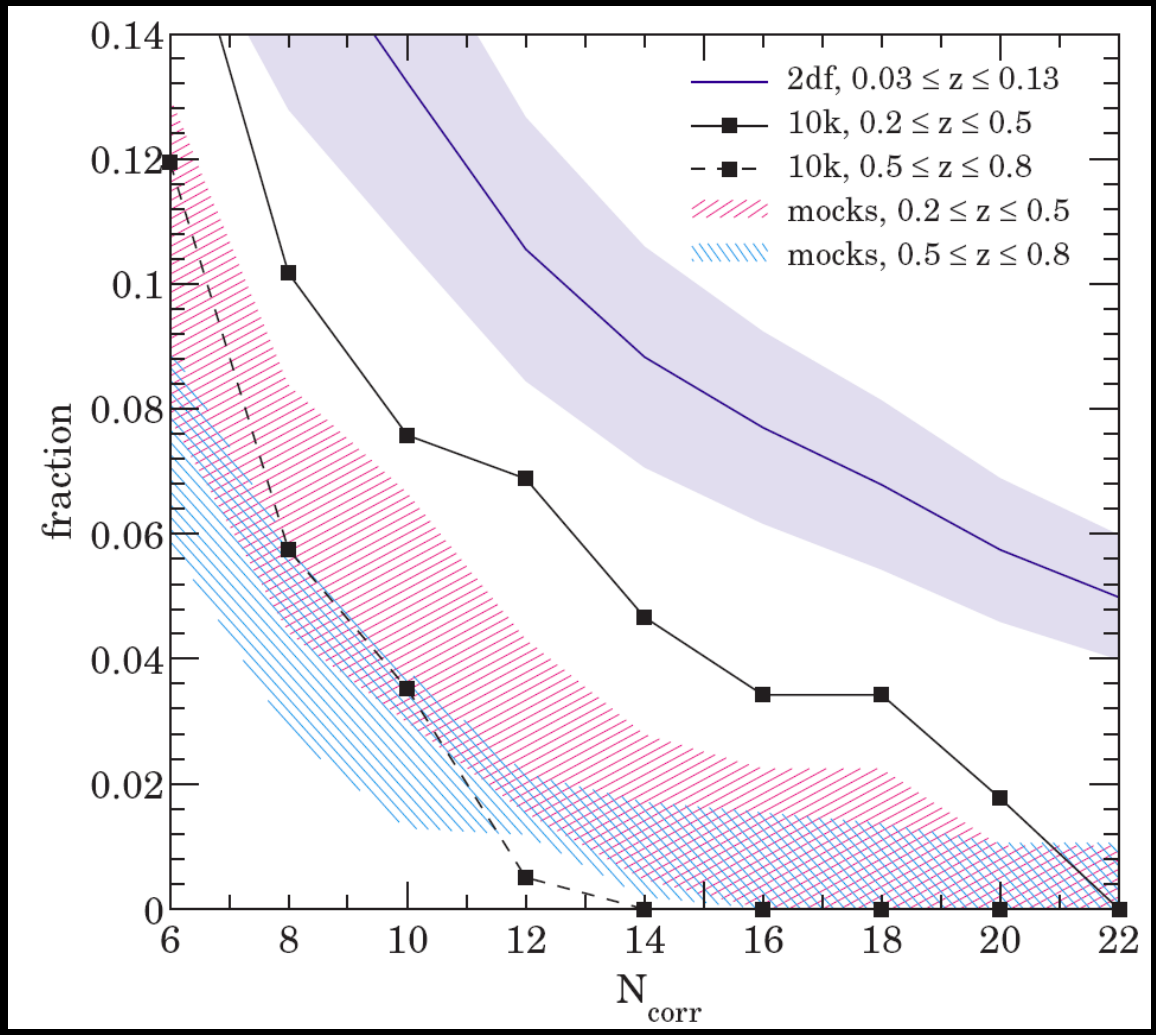
Questions

Which are the processes that regulate gas exhaustion?

What about environment?
Does it have a role to play in shutting down star formation?

Remember:
as cosmic time increases structure grows ...

Buildup of Structures

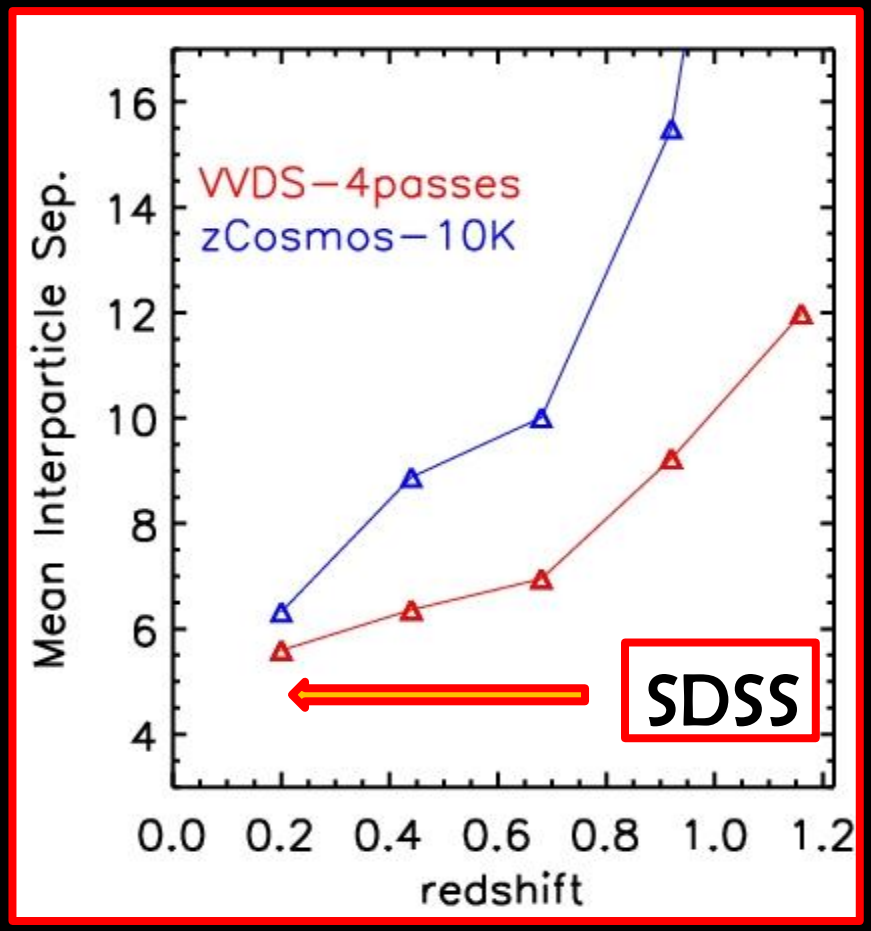


Knobel et al. (2009)

Smoking gun for environment in action

Search for evidence of faster rate of passive galaxies 'production' in denser environments. An effect superimposed to the general decline of the specific star formation rate of star-forming galaxies, possibly due to the decreasing supply of available gas.

Environment definition at high-z is not easy ...



Groups are adaptive by definition, allowing to reach smaller physical scales;

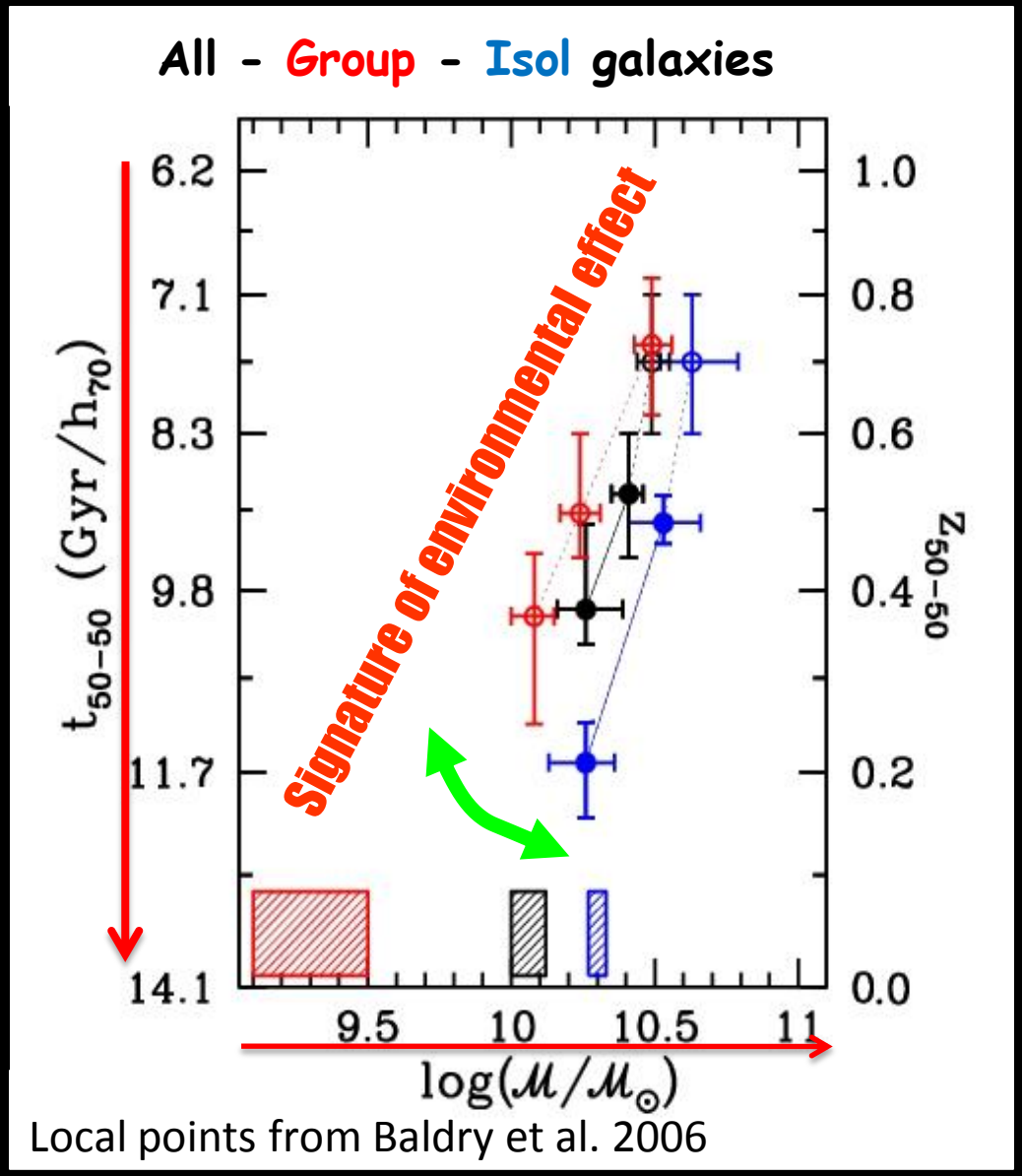
Groups are long lived structures (long timescales involved)

Environment definition at high-z is not easy …

Comparison with low-z is not trivial

Simulations can help

Smoking gun for environment in action

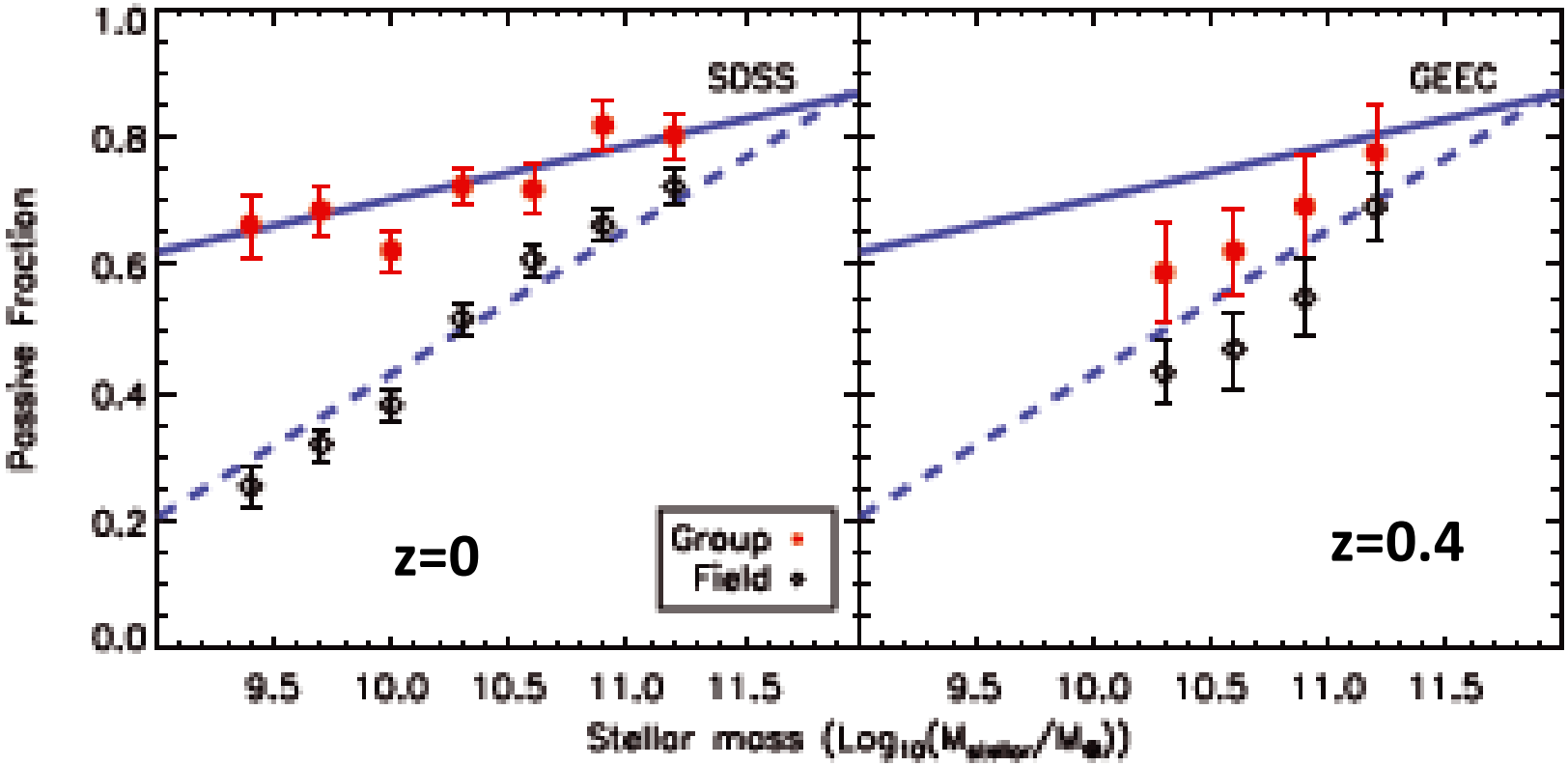


Local points from Baldry et al. 2006

The progressive speeding up in group environment of the color transition from blue to red galaxies cannot be interpreted using only *nature* mechanisms !

Iovino, Cucciati, Scodeggio et al, 2009

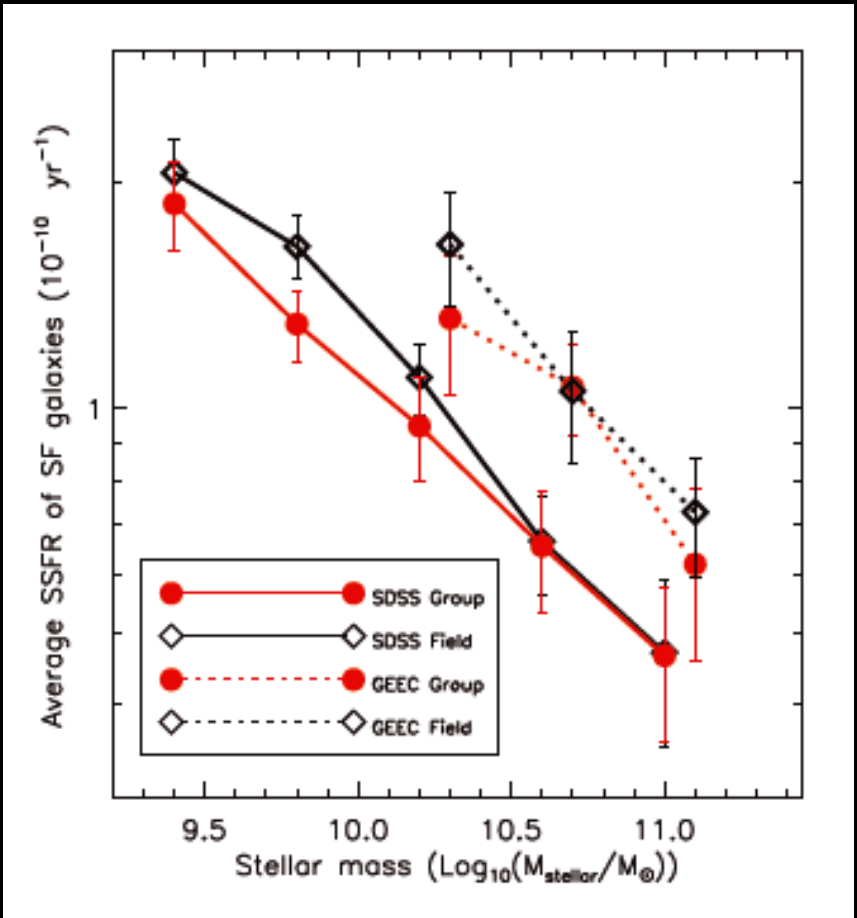
Smoking gun for environment in action



The progressive speeding up in group environment of the color transition from blue to red galaxies

McGee et al., 2011

Further evidence for fast transition



McGee et al., 2011

The average sSFR of star forming galaxies is very similar in groups and in field at both redshifts in any given mass bin

Galaxies must move quickly from SF to 'passive' ...

Open questions

Which are the physical mechanisms in groups ?

And those regulating SFR of field galaxies?

Where are the transitional galaxies?

Isolated galaxies may help ?

Explore radial trends in structures?

Link with simulations