In and Out the Main Sequence of Starforming Galaxies

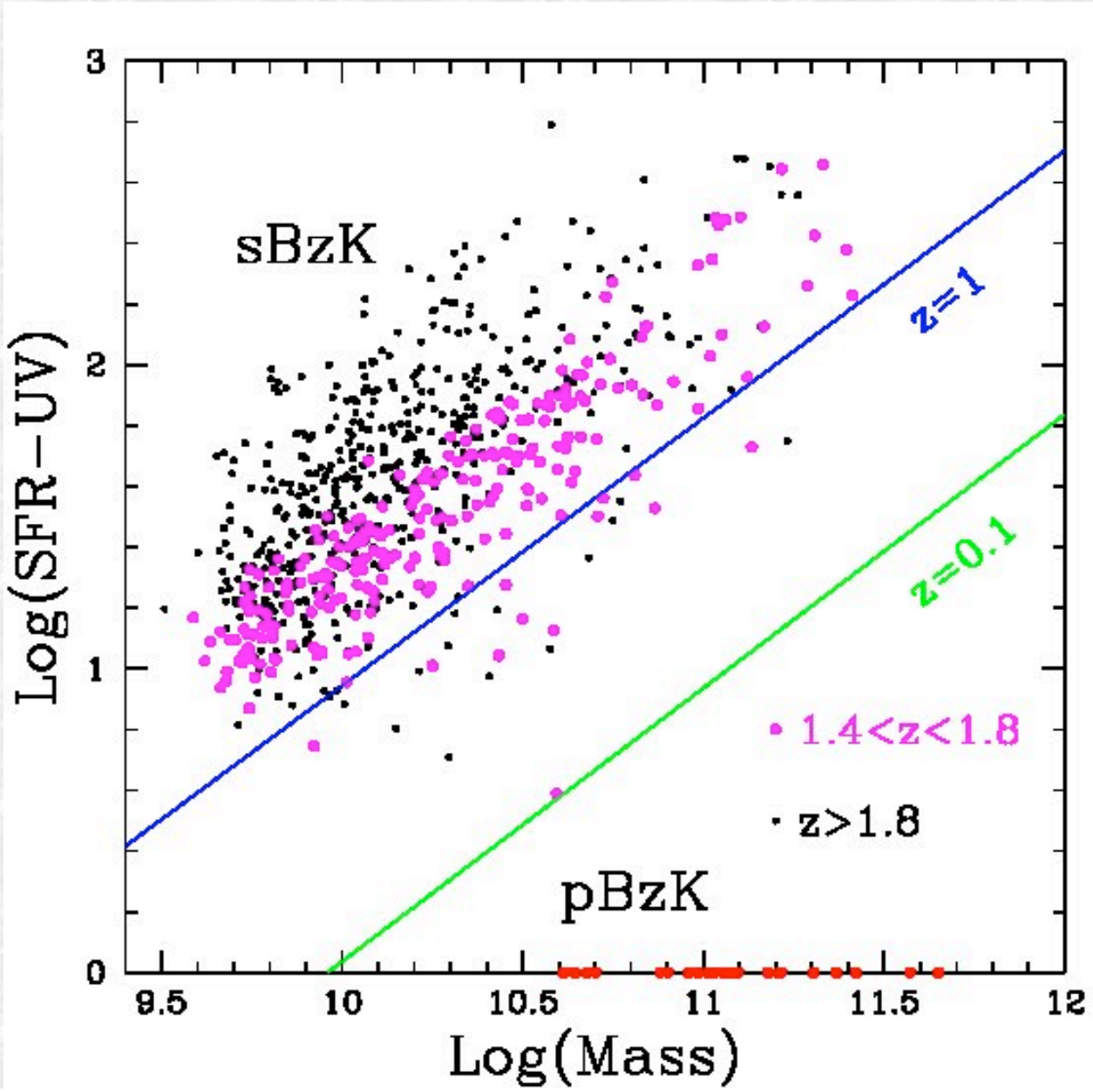
("Liers" and Outliers)

Outline:

- The Main Sequence at Low and High Redshift
- What it means for the growth of galaxies
- The Outliers: * red dusty starbursting galaxies
  * red & dead (quenched) galaxies
- Herschel looking at COSMOS & GOODS fields
- The relative role of starbursts and quasi-steady SFR in the mass growth of galaxies

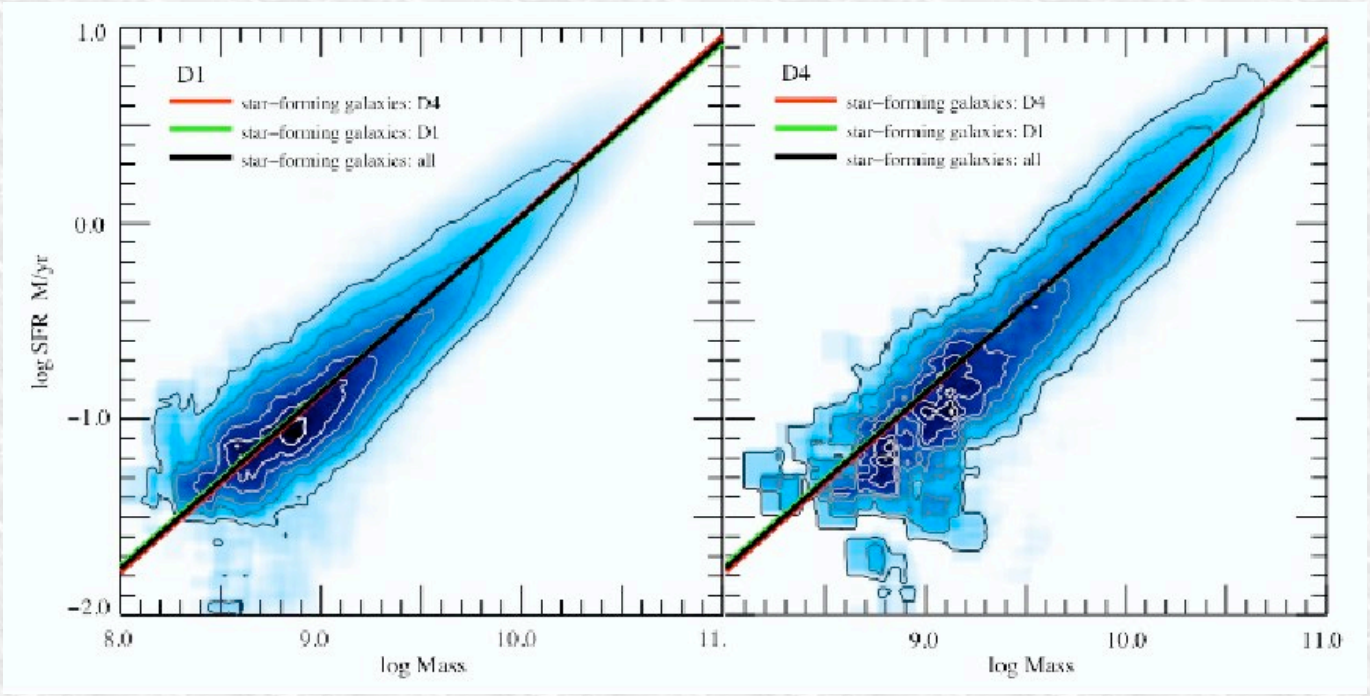
Alvio Renzini, IPMU, May 13, 2012

The Main Sequence of Starforming galaxies At 1.4 < z < 2.5

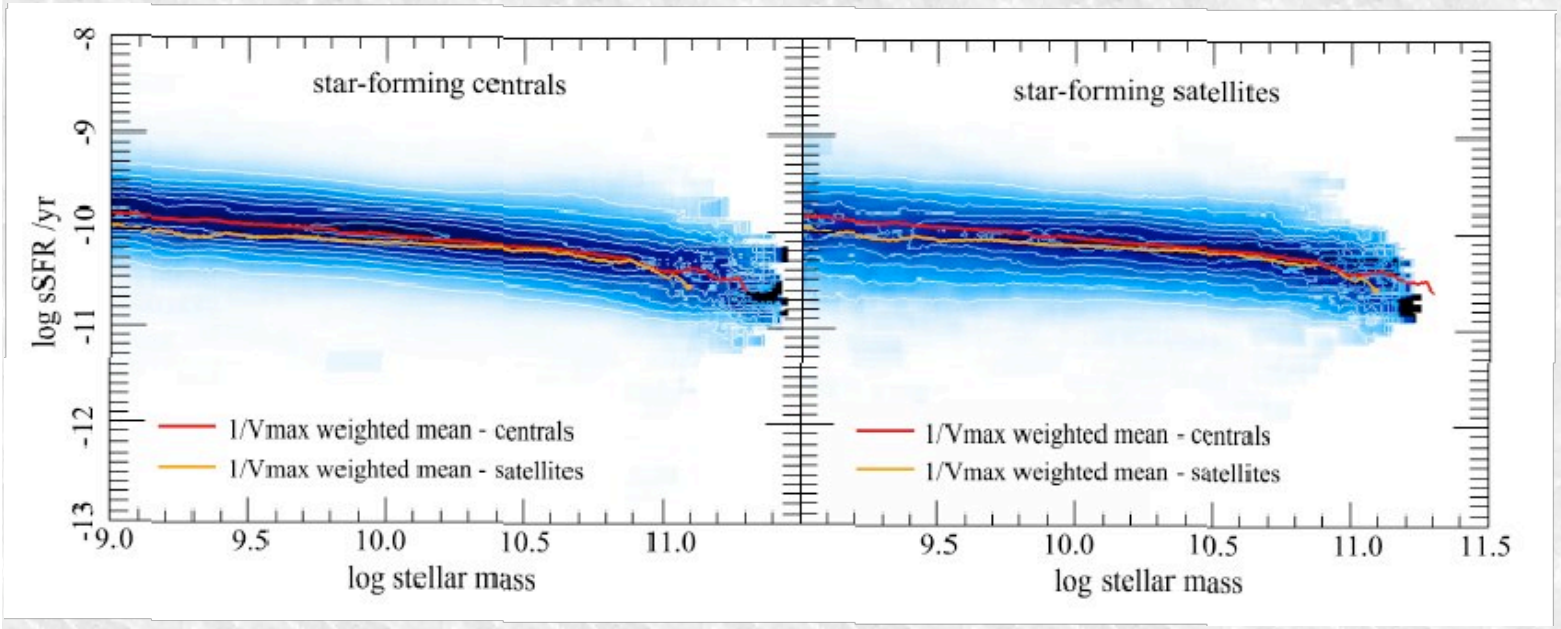


From Daddi et al. (2007)

The SFR-M* relation in the local Universe



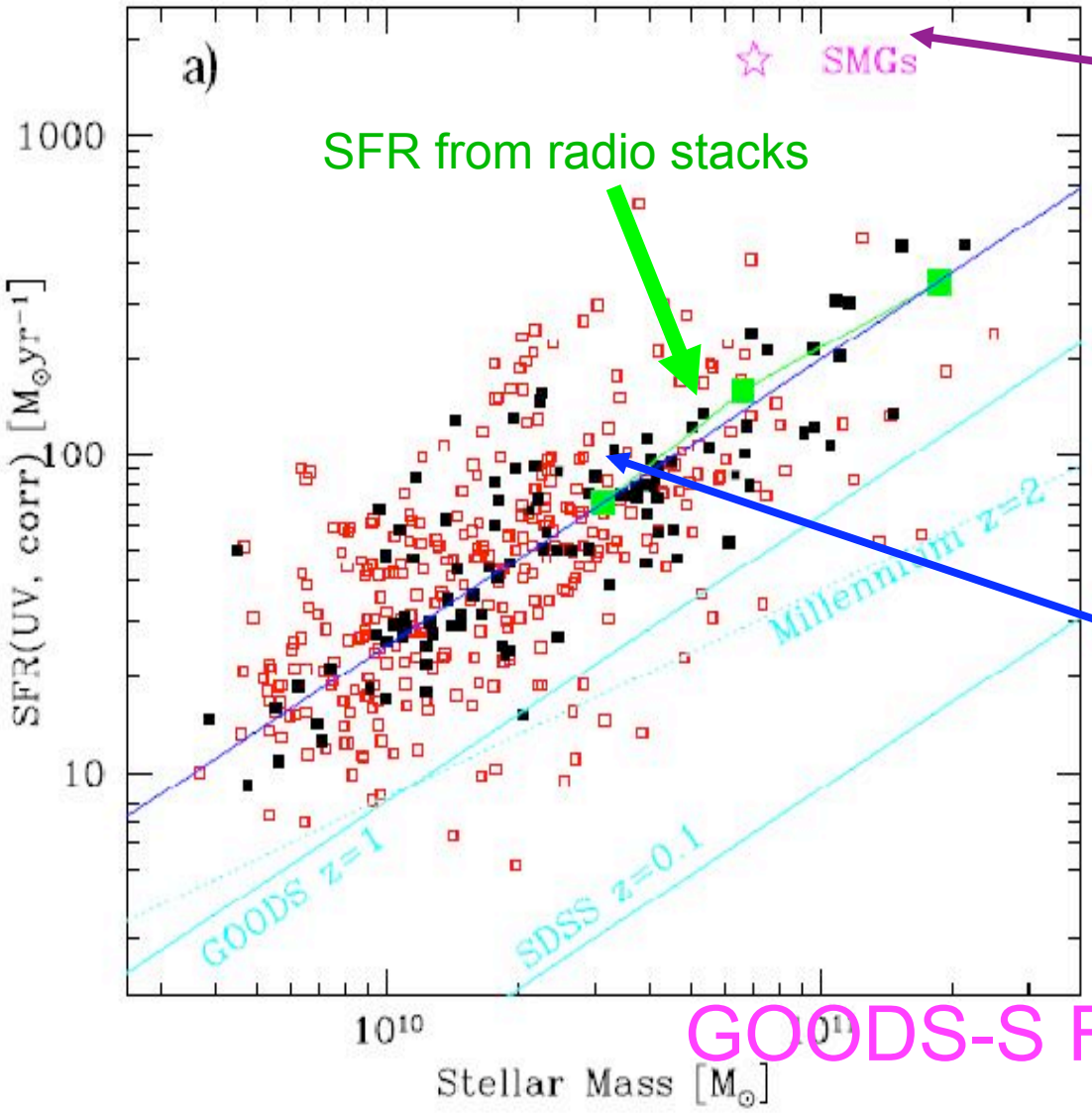
From SDSS data, SFR from Hα, Peng et al (2010)



Peng et al. (2011)

Starbursts or just High SFR at z~2?

SMGs may be the real, major-merger driven, starburst galaxies

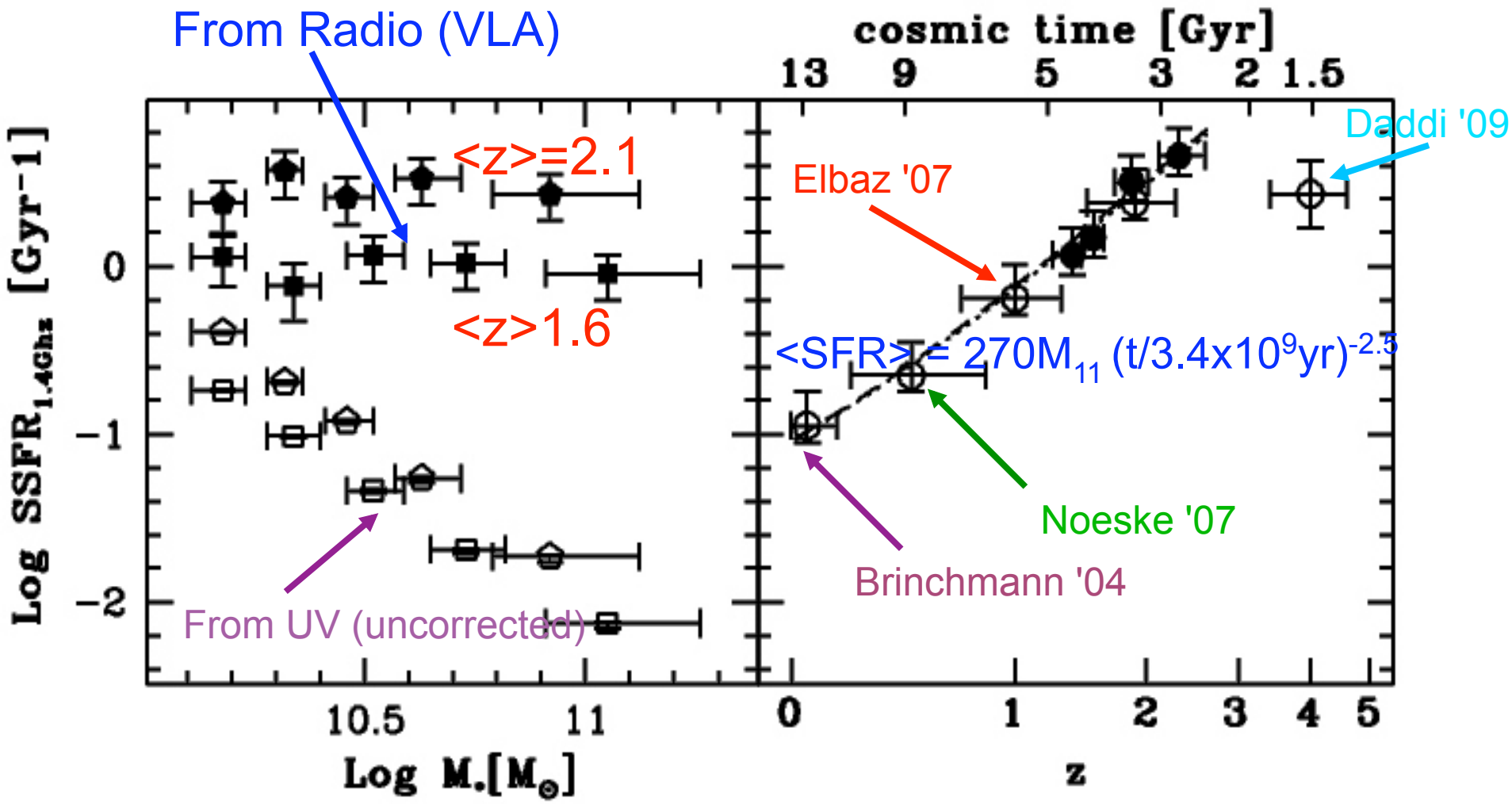


SFR $\propto$ ~$M^{0.9+/-0.1}$ with Very small dispersion!!
No starbursting galaxies!
just galaxies with high SFR, continuously fed by cold-stream accretion!

GOODS-S Field: Daddi et al. 2007

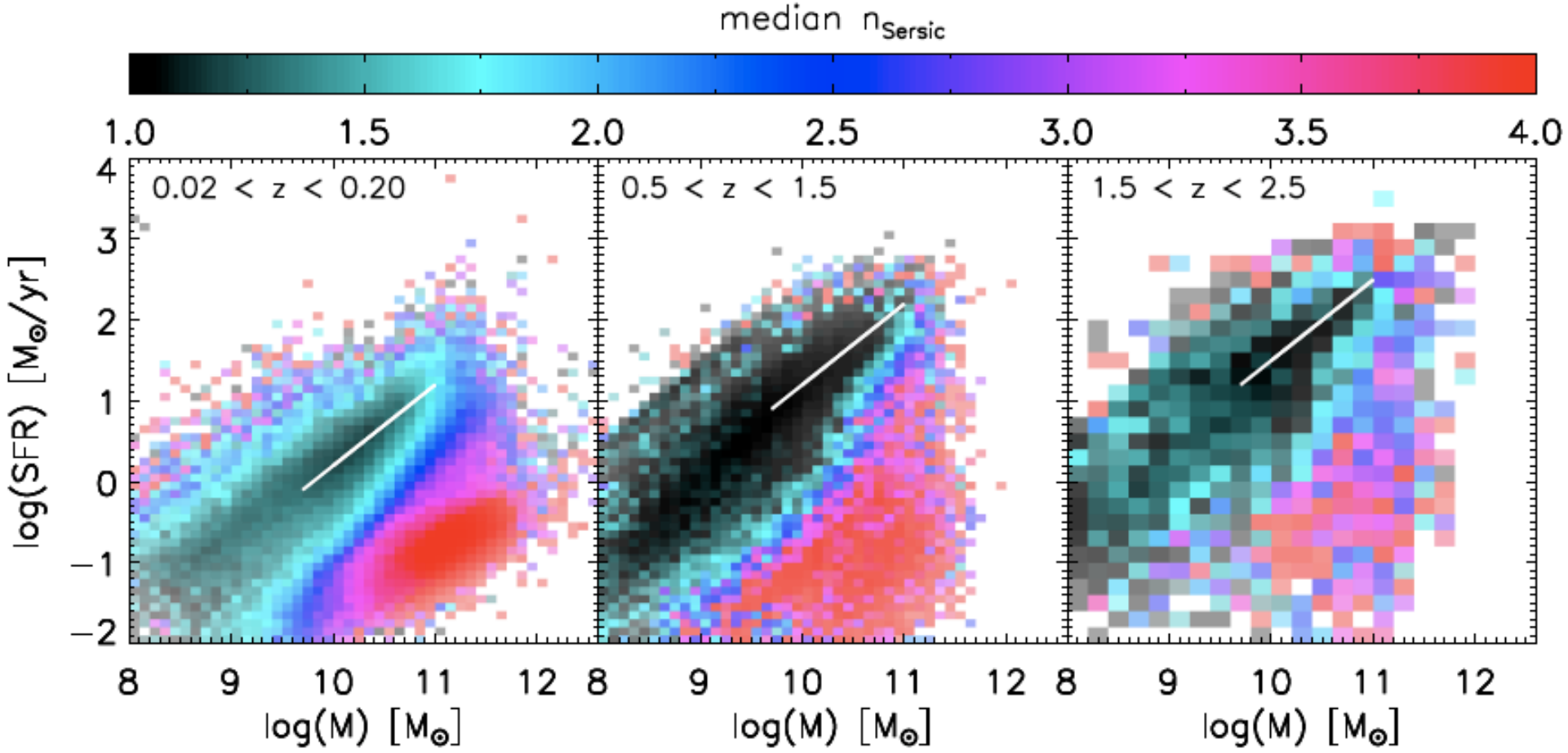
SFRs of sBzKs in COSMOS from stacked 1.4 GHz flux

Pannella et al.



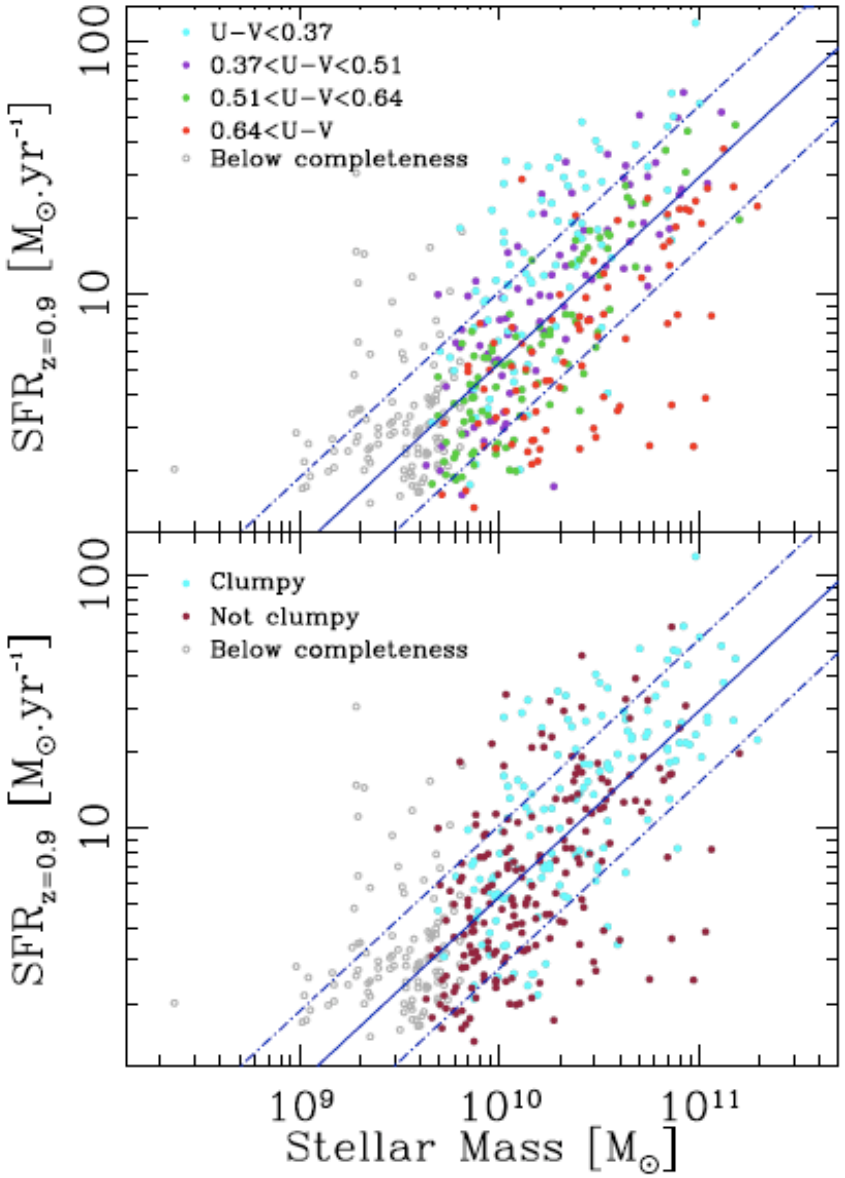
Main Sequence & Quenched Galaxies

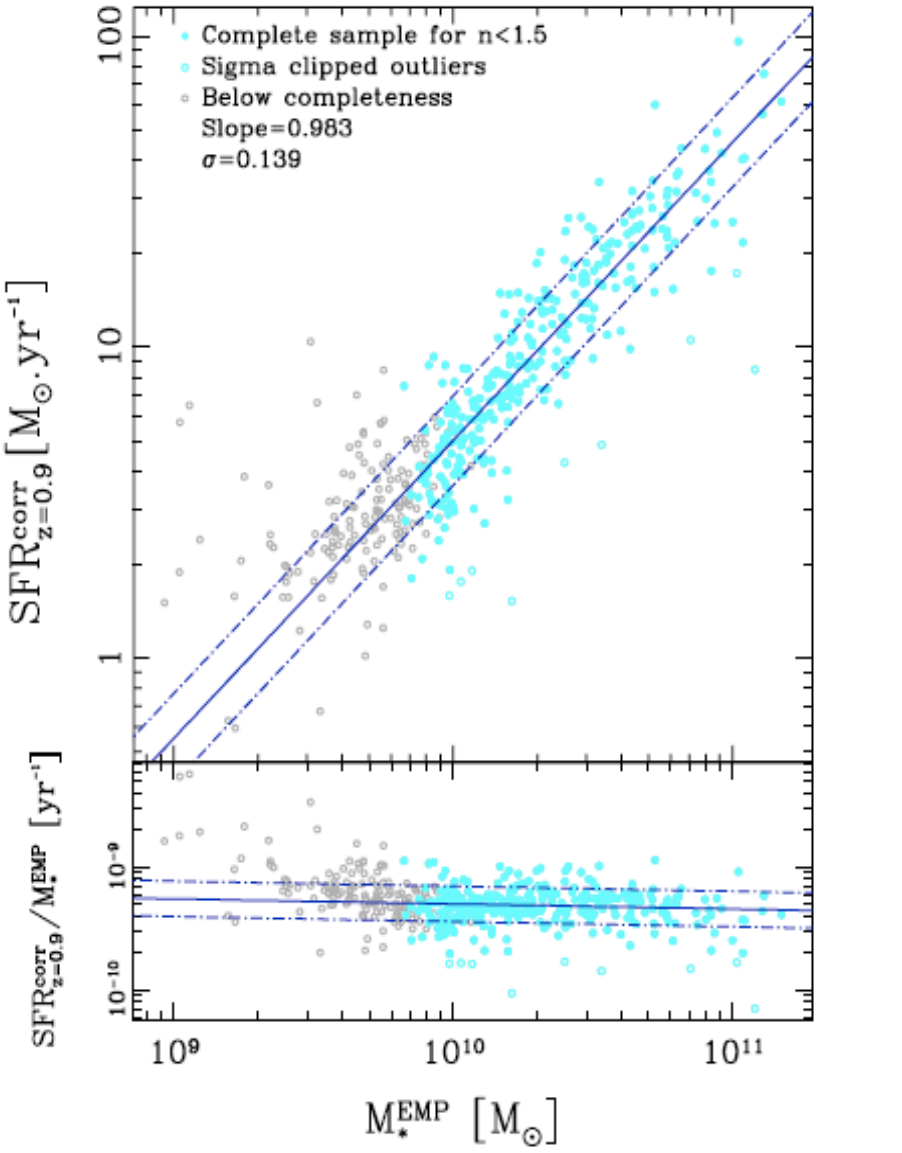
Wuyts et al. 2011



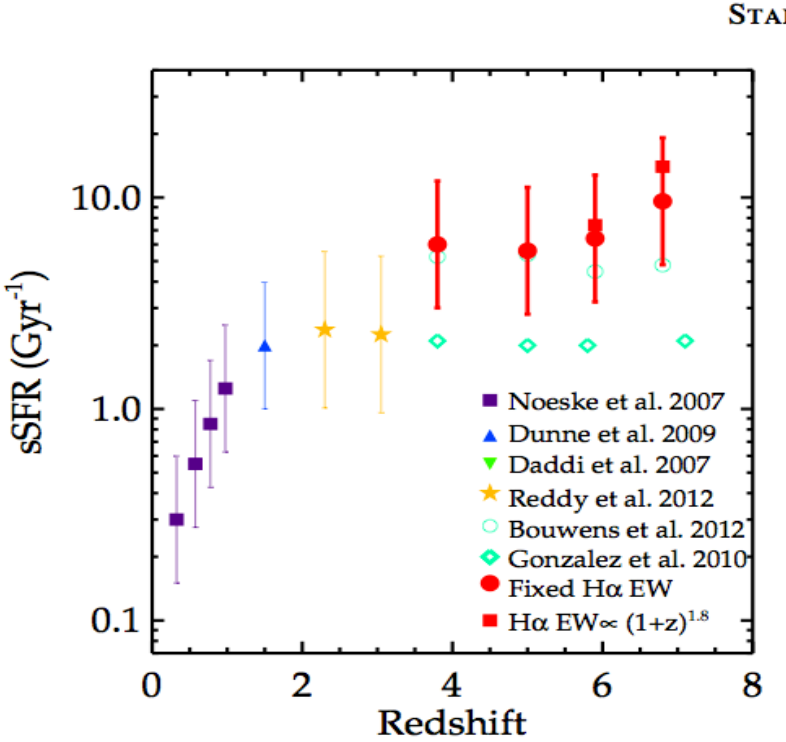
The intrinsic width of the MS at z~1

Salmi et al. 2012

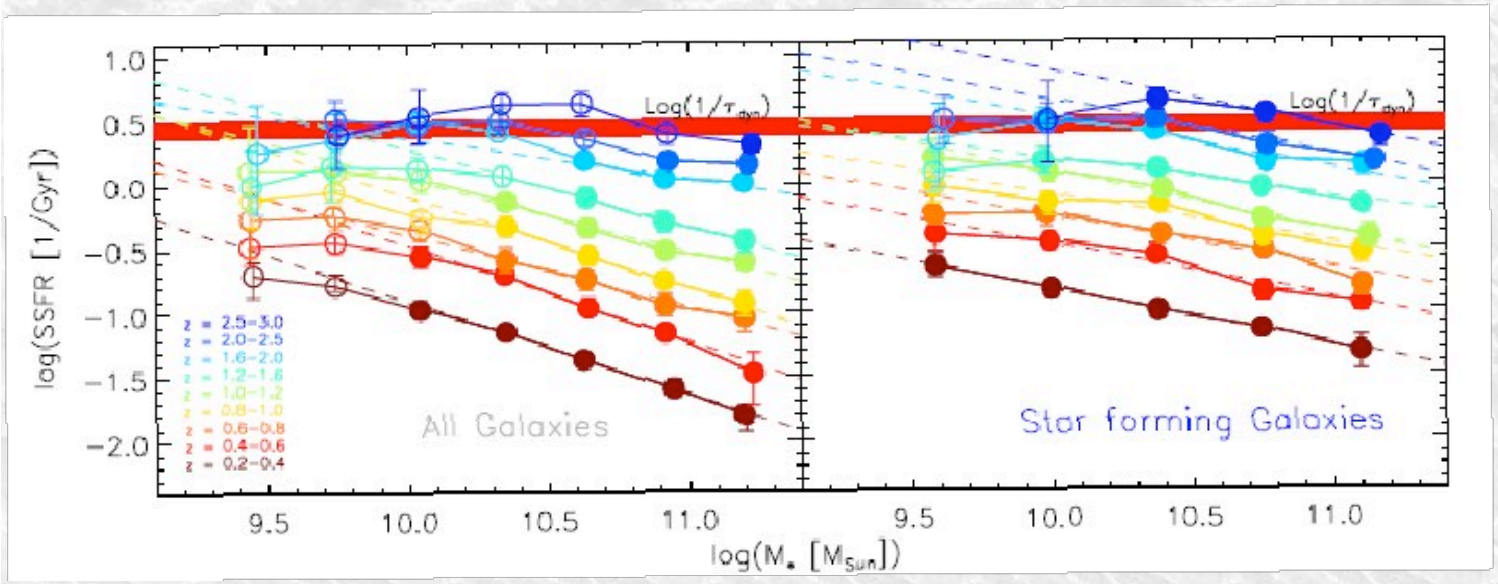




A Caveat: not all measurements of the SSFR agree ...



Another estimate of the SSFR from stacked radio data, Karim et al. (2011)



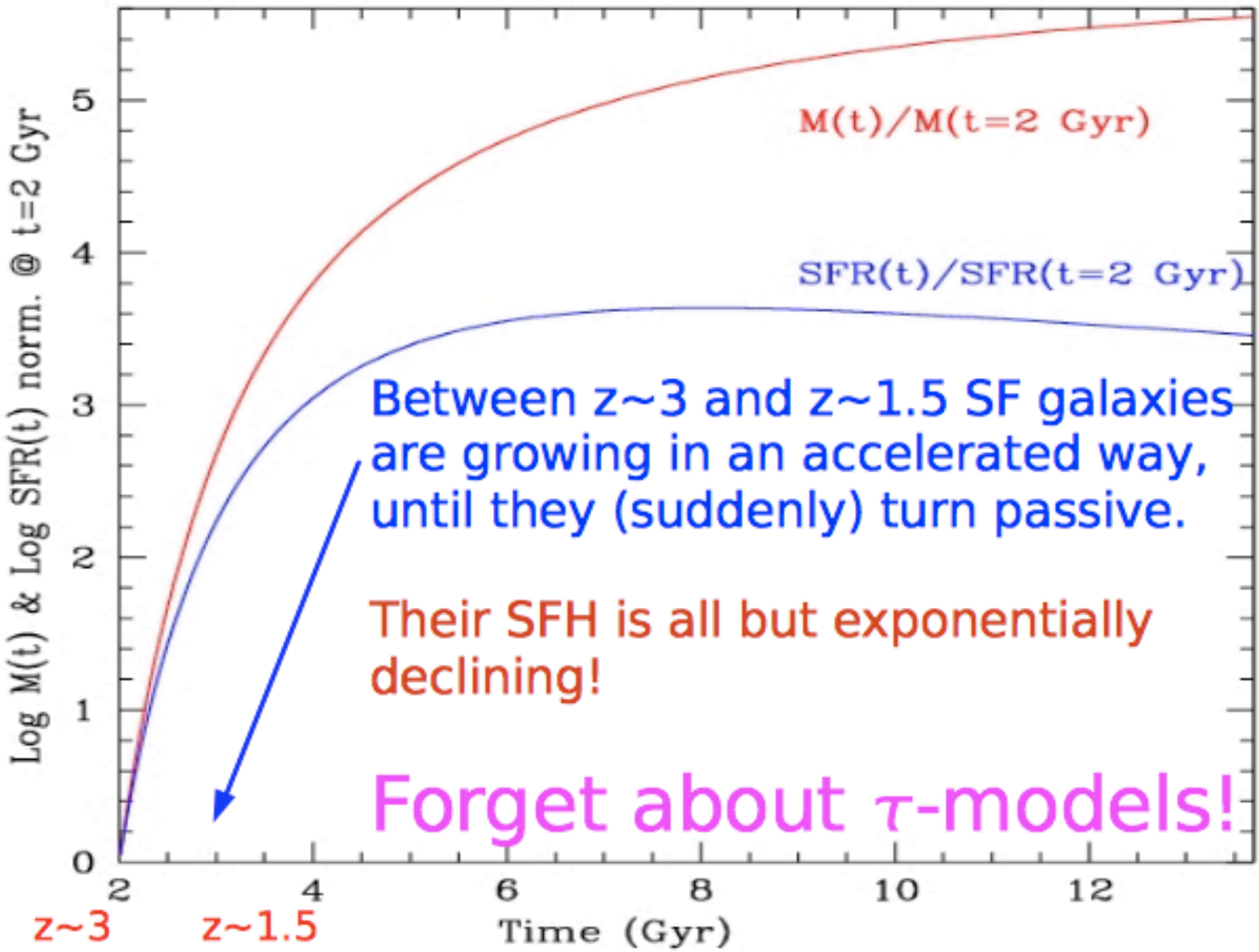
For galaxies on the MS we can legitimately integrate the Equation:

$$dM/dt = \langle SFR \rangle = \sim 270 \eta M_{11} (t/3.4 \times 10^9 yr)^{-2.5}$$

Where η is meant to take into account for the systematic error in the estimates of the SFR

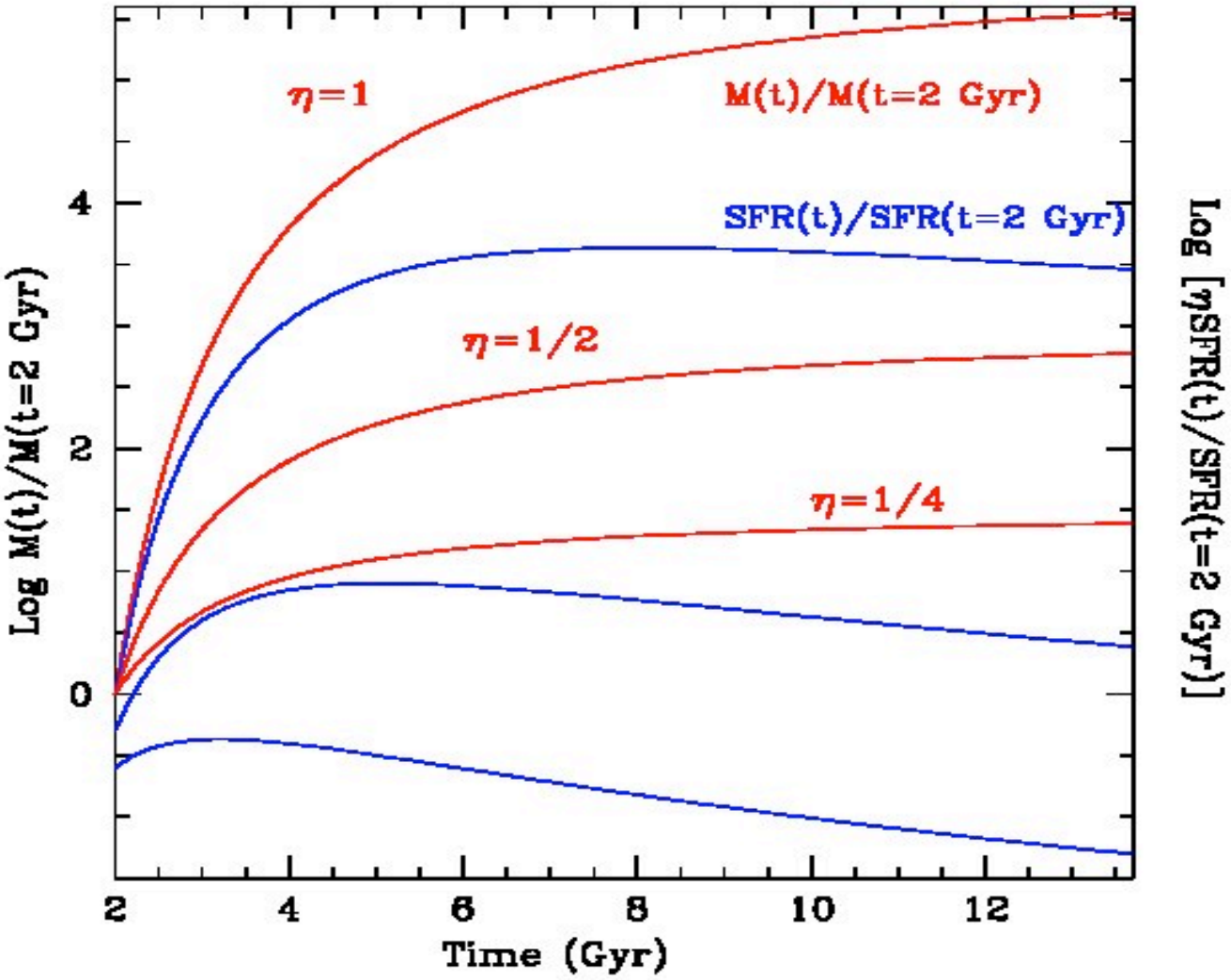
$$M(t) = M(t=2\ Gyr)\ \exp(12.53\eta)\ \exp(-38.26\ \eta\ t^{-1.5})$$

The mass Growth Factor


M(t)/M(t=2 Gyr)
SFR(t)/SFR(t=2 Gyr)
Between z~3 and z~1.5 SF galaxies are growing in an accelerated way, until they (suddenly) turn passive.
Their SFH is all but exponentially declining!
Forget about τ-models!
Log M(t) & Log SFR(t) norm. @ t=2 Gyr
Time (Gyr)
z~3
z~1.5
0
1
2
3
4
5
2
4
6
8
10
12

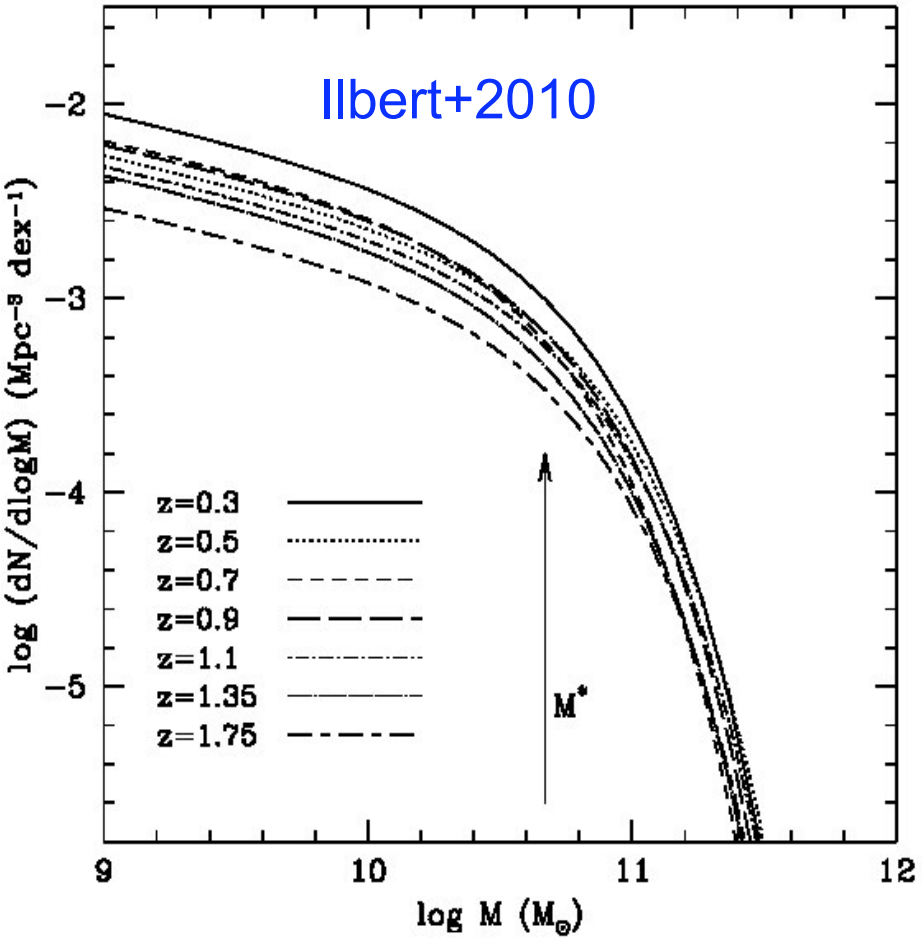
The actual growth of galaxies is EXTREMELY sensitive to the SFR

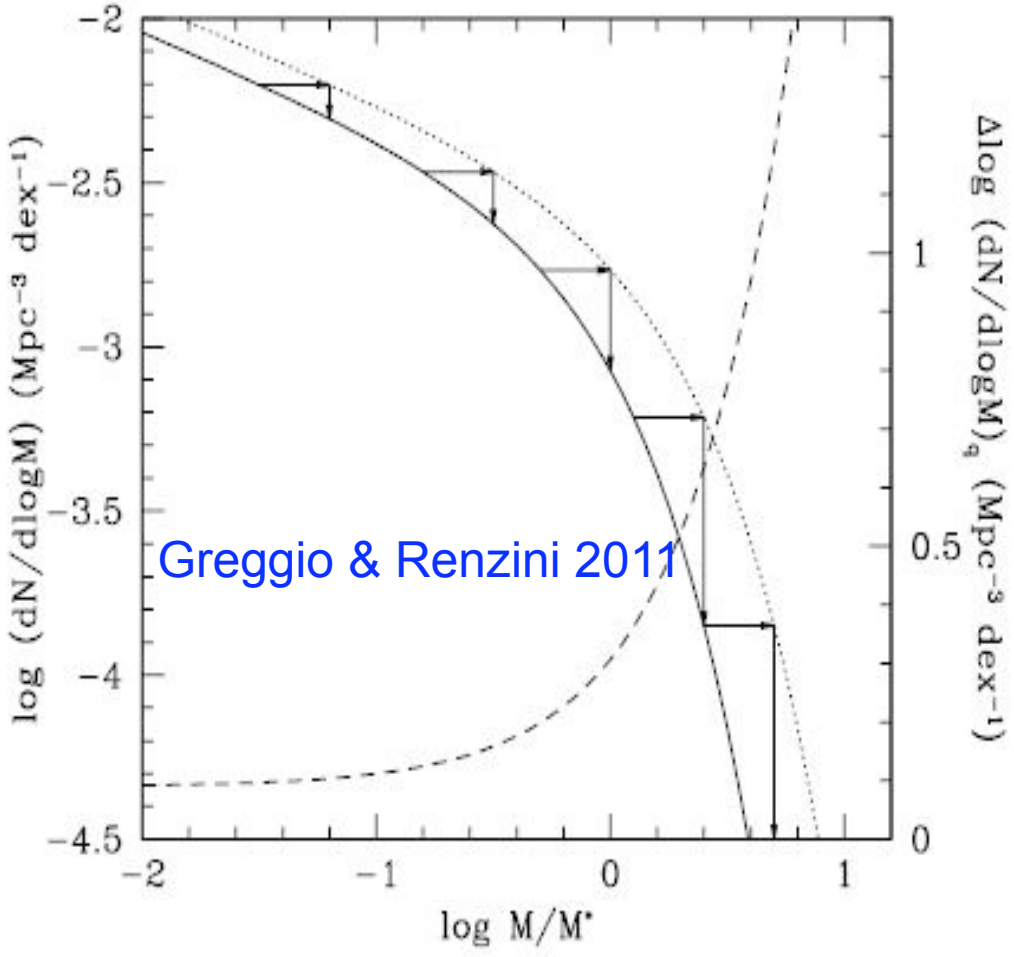
Renzini 2009



If you think, this goes a long way to explain why theoretical models Of galaxy evolution systematically fail

The mass grows very rapidly but the mass function very slowly: Quenching is unavoidable!



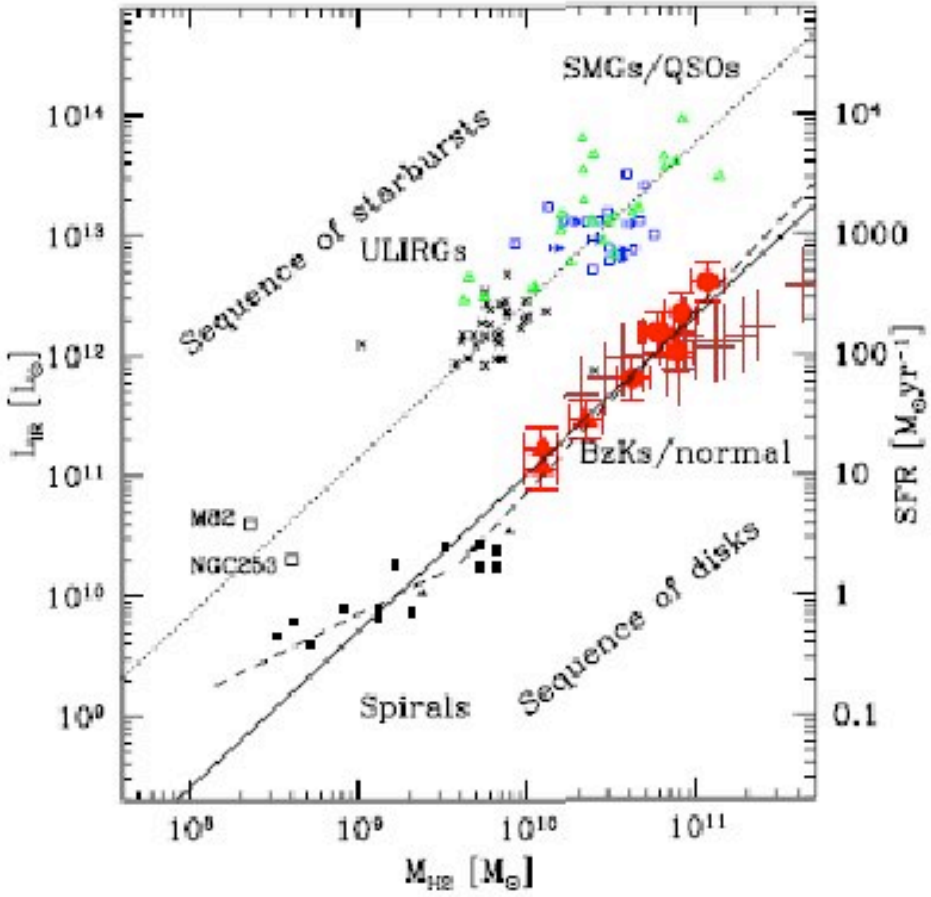


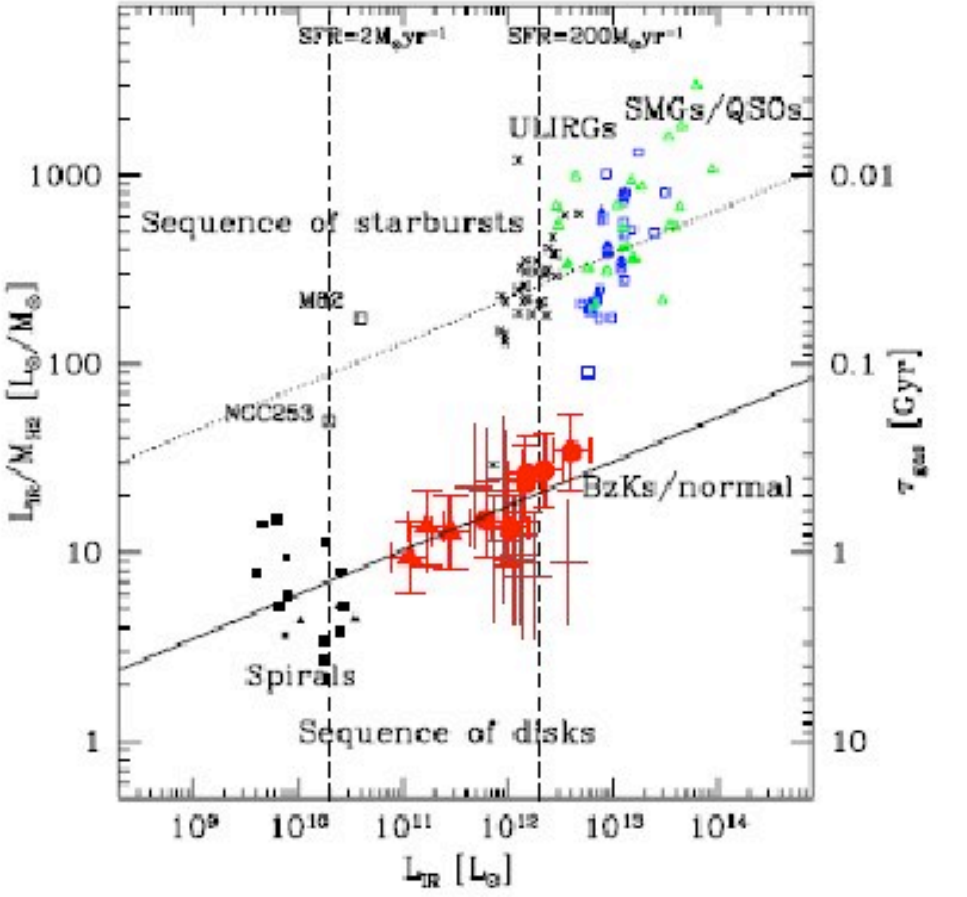
Summary of the first part

- Most galaxies form stars in a (quasi) steady fashion, hence lie on the "Main Sequence"
- As SFR ~ M*, the mass growth is initially (quasi) exponential
- Forget about "tau models"
- Quenching is inevitable
- Mass growth is extremely sensitive to SFR: theory will never ever be able to do the right job. Pure phenomenology pays better dividends (cf. Peng+2010, 2012: Lilly+2013)

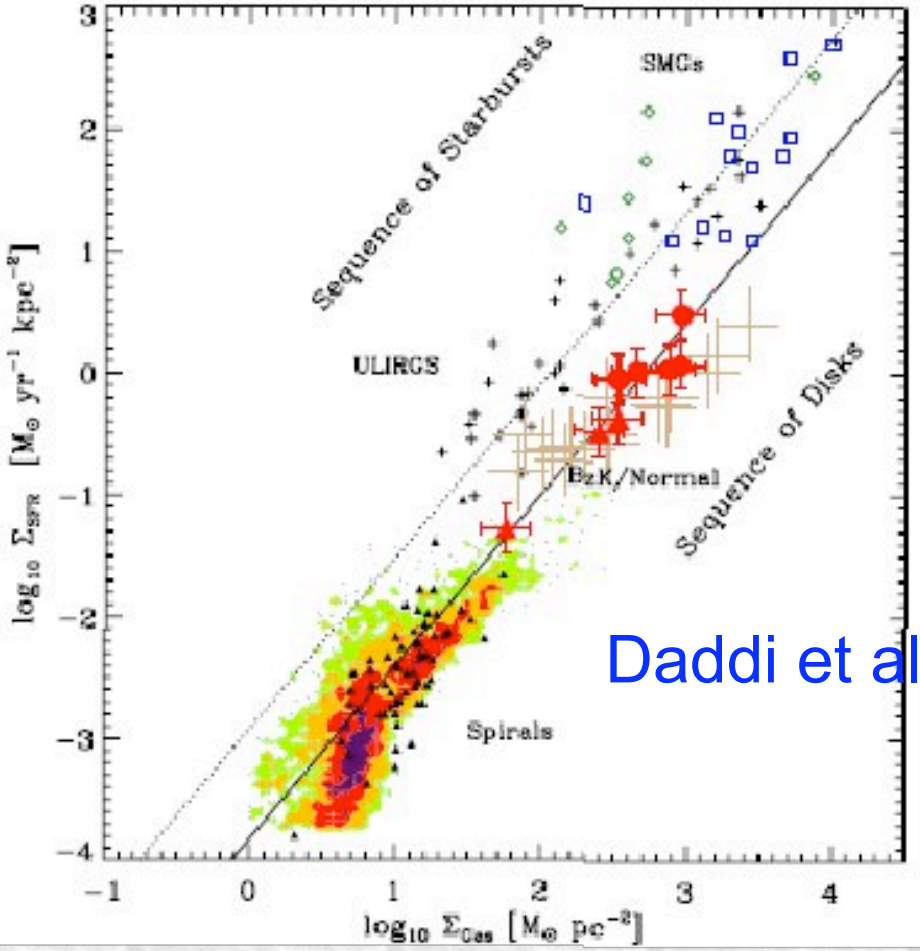
Not All SF Galaxies lie on the Main Sequence: The Two modes of star formation

Daddi et al. (2010)





Two regimes of star formation: quasi-steady on the main sequence, starbursts off of it



Daddi et al. 2010

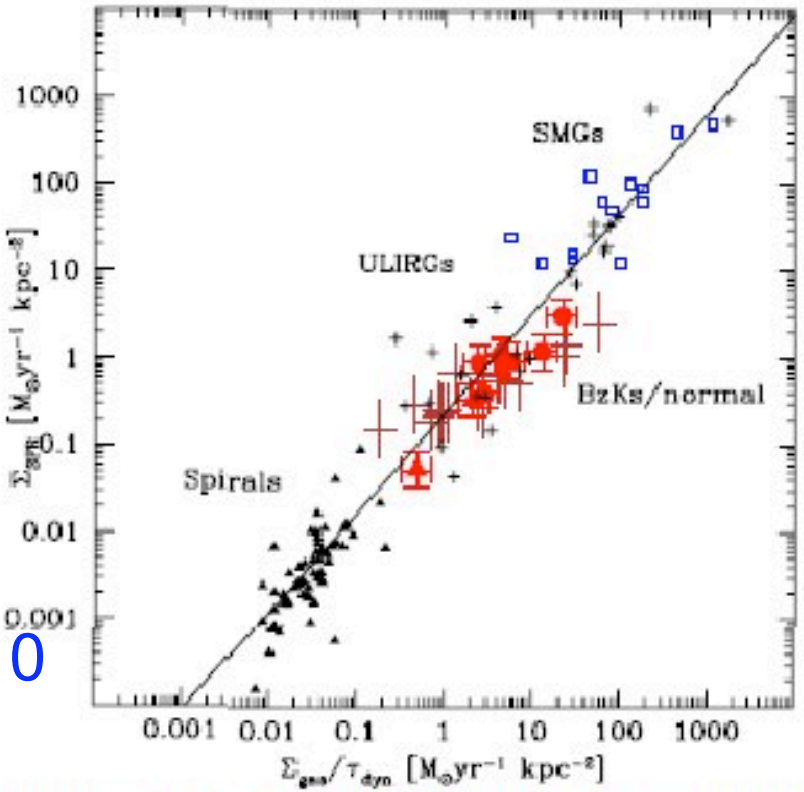


Figure 3. Same as Figure 2, but with the gas surface densities divided by the dynamical time. The best-fitting relation is given in Equation (3) and has a slope of 1.14.

(A color version of this figure is available in the online journal.)

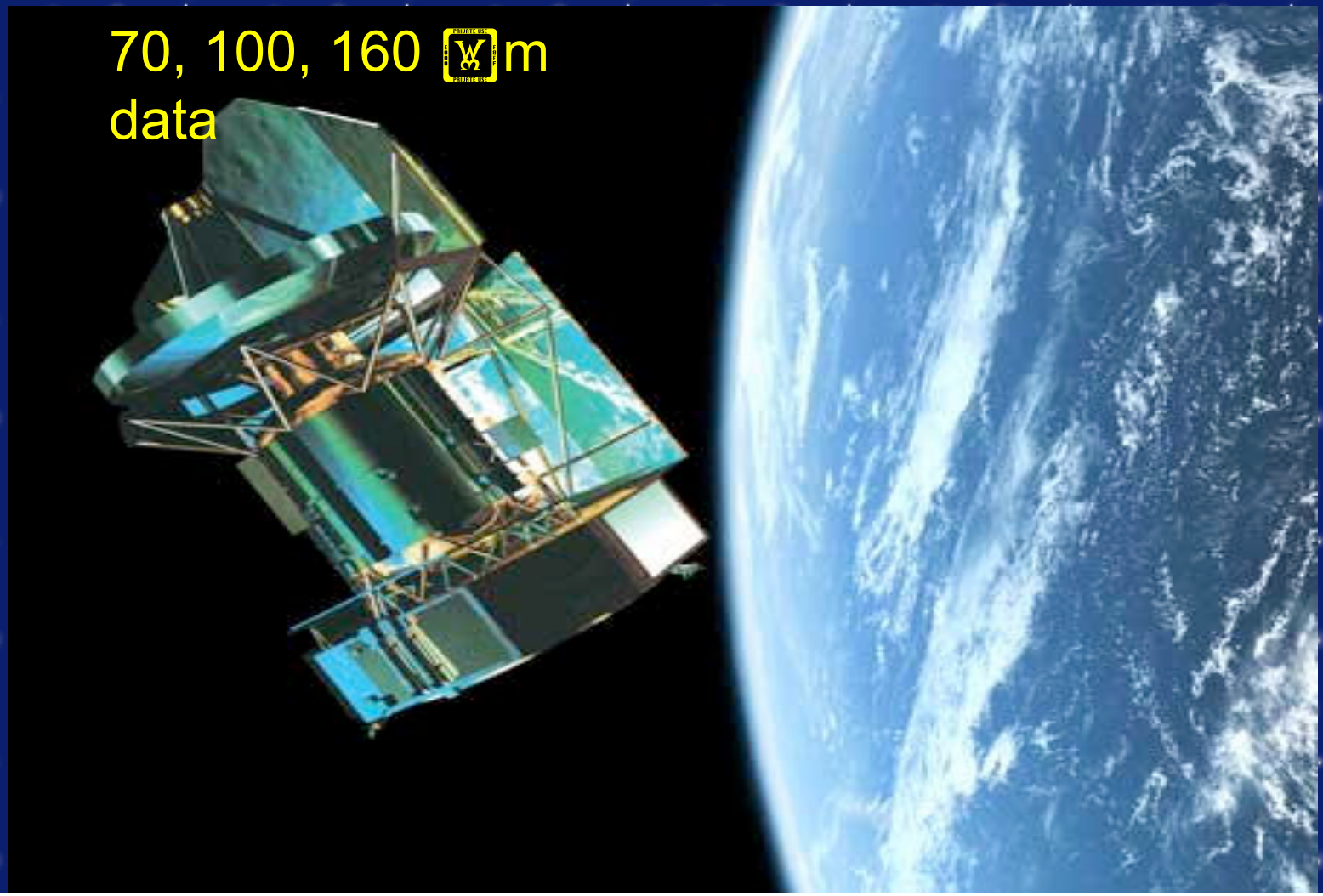
Two regimes of star formation: quasi-steady on the main sequence, starbursts off of it

Two Critical Questions:

Q1: what is the relative number of main sequence and starburst galaxies?

Q2: what is their relative contribution to the global, cosmic star formation rate density?

Answering with HERSCHEL/PACS Observations over the GOODS & COSMOS FIELDS



HERSCHEL/PACS Observations over the GOODS & COSMOS FIELDS

Rodighiero et al. (2011)

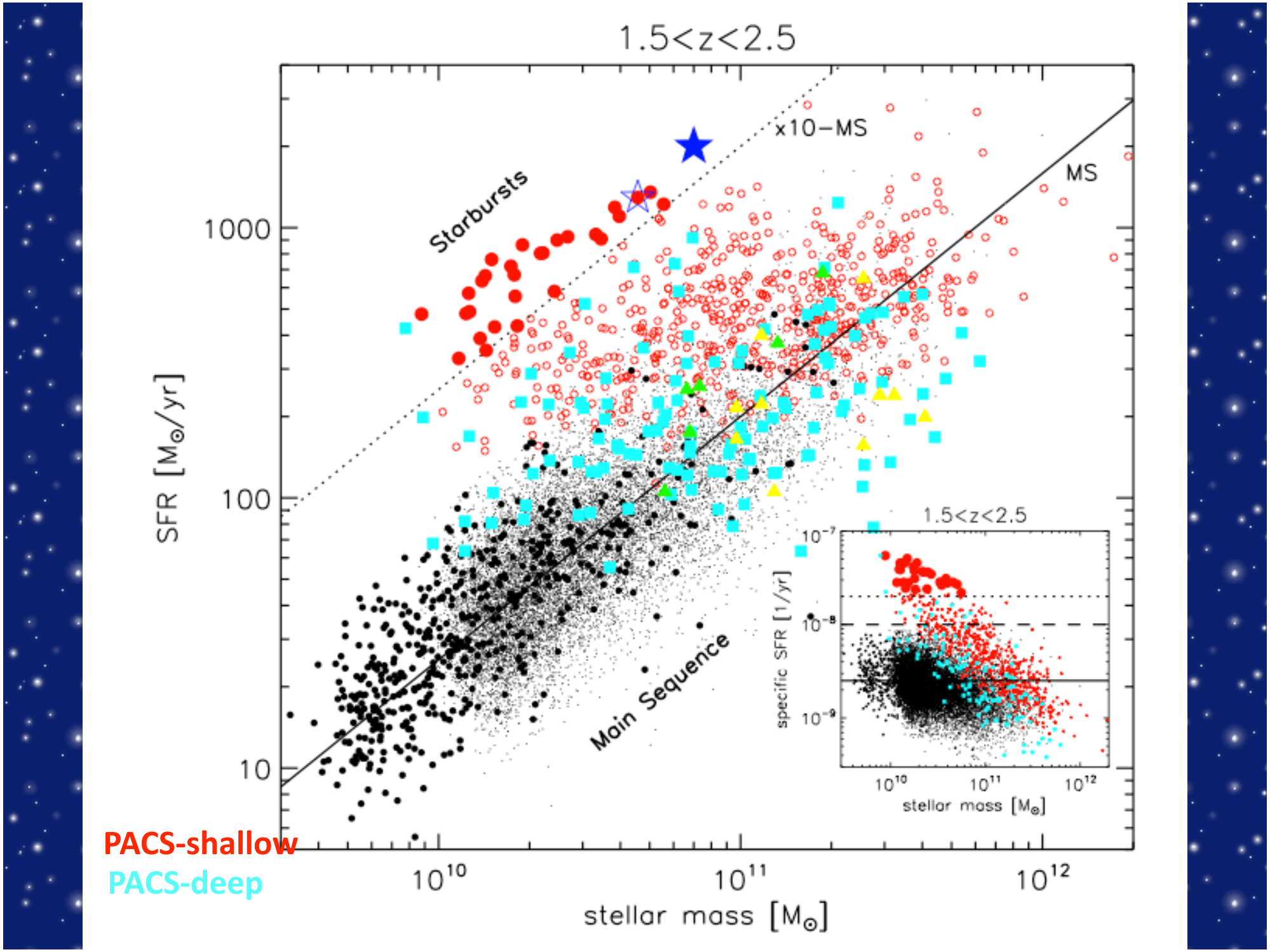
Data-sets used to fully sample the stellar mass – SFR plane:

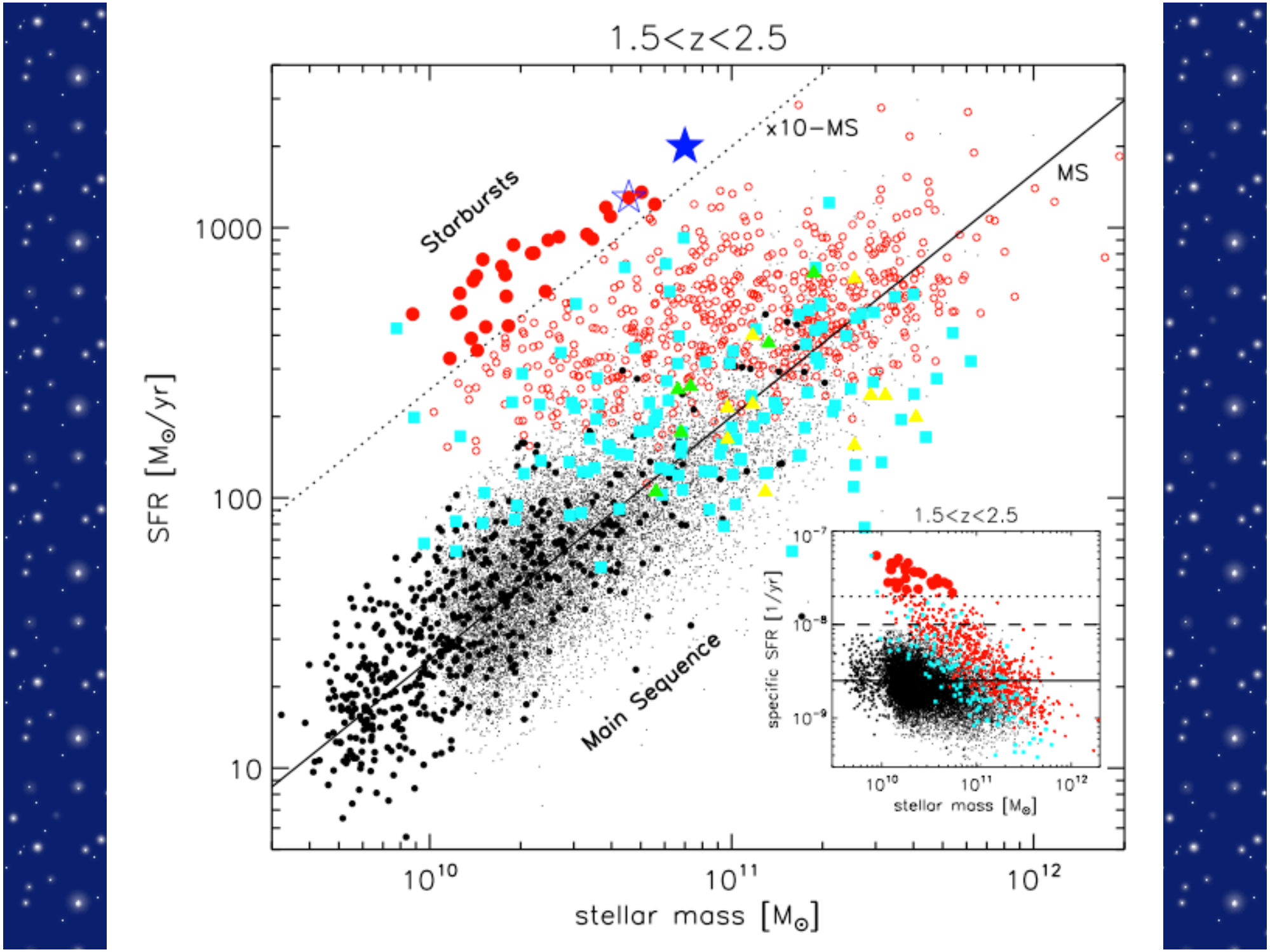
1. PACS 100μm and 160μm shallow source catalogs from PEP survey (Lutz et al. 2011) with Spitzer/MIPS 24μm prior positions + IRAC- selected 4.5 μm source catalog on the COSMOS field + multiwavelength photometry, spec & photo-z (Ilbert et al. 2010)

2. PACS 70, 100 and 160μm deeep PEP catalog in GOODS-S + multiwavelength photometry, spec & photo-z (Daddi et al. 2007)

3. BzK COSMOS catalog (McCracken et al. 2010)

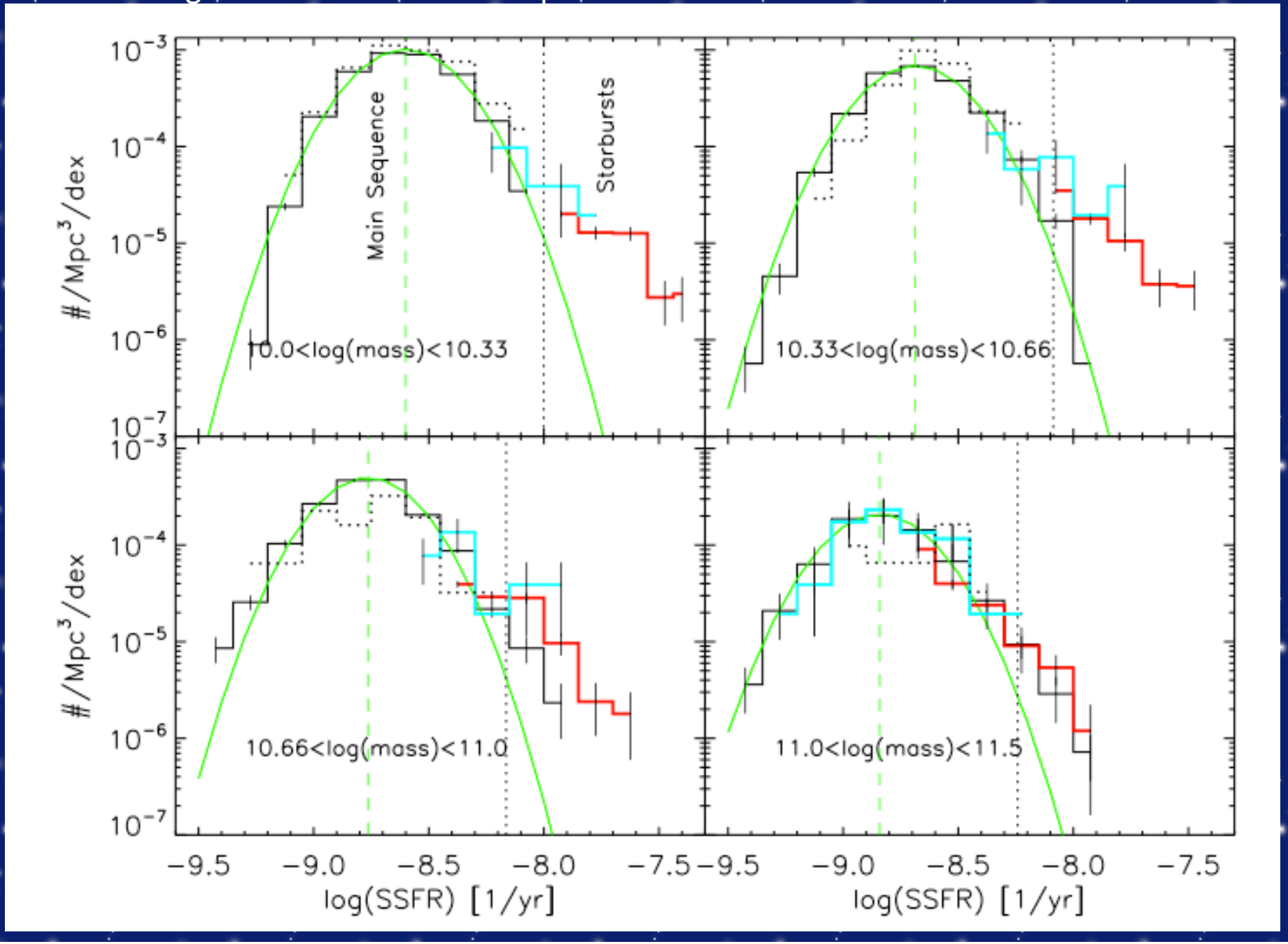
4. BzK GOODS-S catalog (Daddi et al. 2007)


1.5<z<2.5
x10−MS
MS
Starbursts
Main Sequence
SFR [M⊙/yr]
1000
100
10
10^10
10^11
10^12
stellar mass [M⊙]
PACS-shallow
PACS-deep
1.5<z<2.5
specific SFR [1/yr]
10^-7
10^-8
10^-9
10^10
10^11
10^12
stellar mass [M⊙]

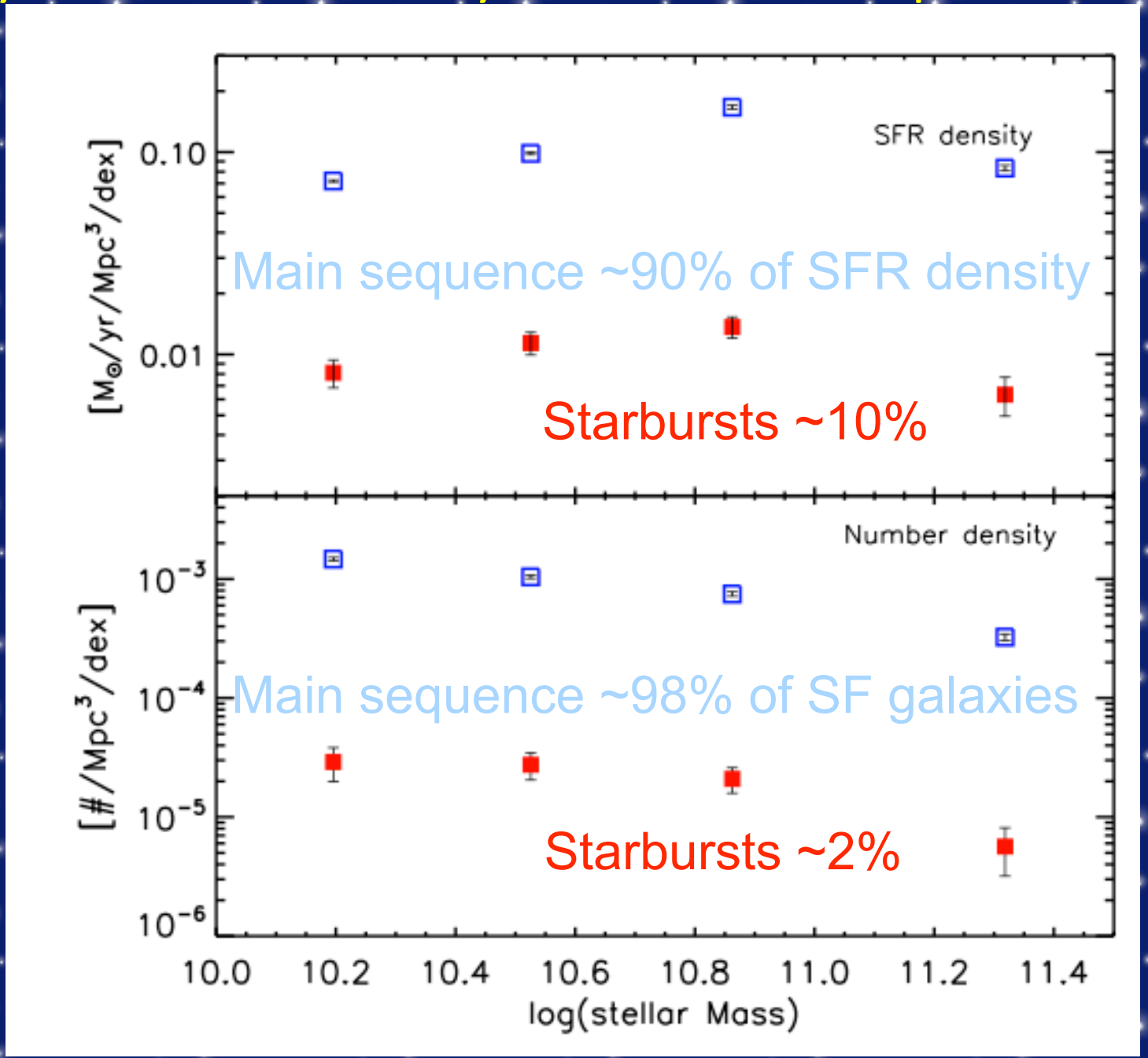

1.5<z<2.5
x10−MS
MS
Starbursts
Main Sequence
SFR [M⊙/yr]
1000
100
10
10^10
10^11
10^12
stellar mass [M⊙]
1.5<z<2.5
specific SFR [1/yr]
10^-7
10^-8
10^-9
10^10
10^11
10^12
stellar mass [M⊙]

Number densities as a function of mass and SSFR bins:

defining the ON & OFF main sequence loci

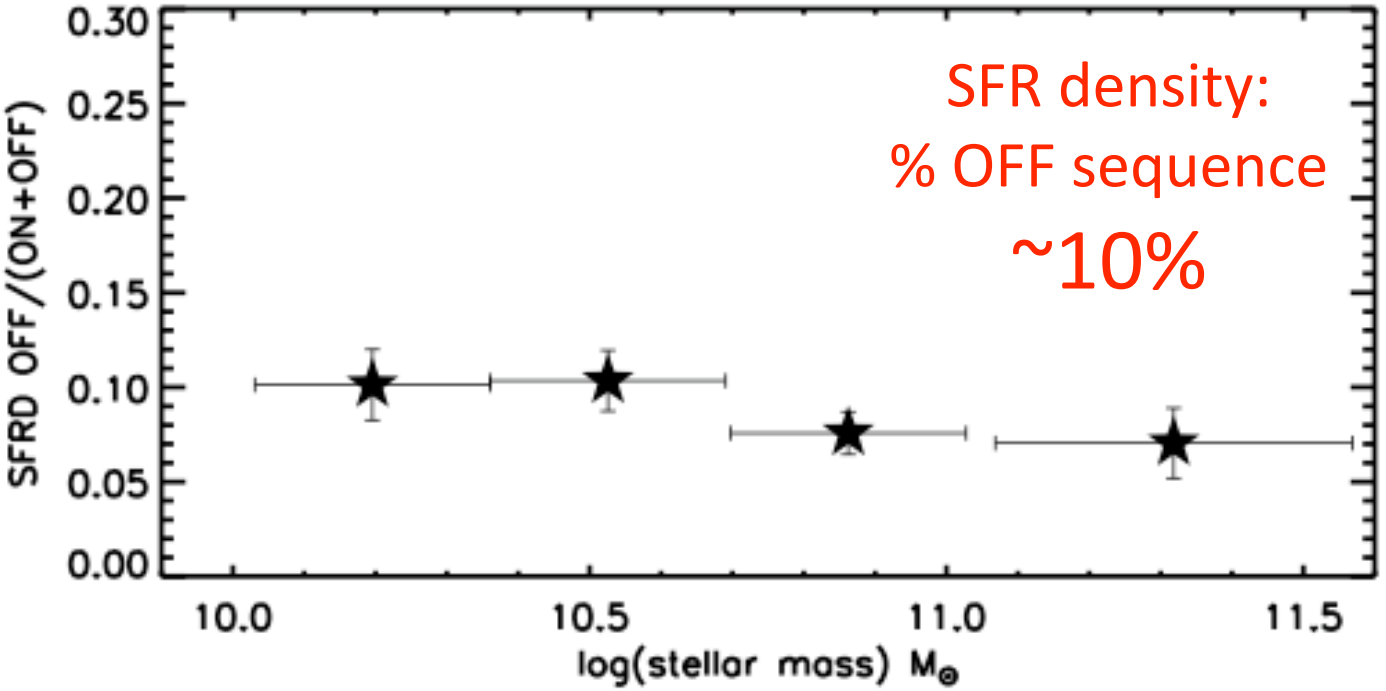


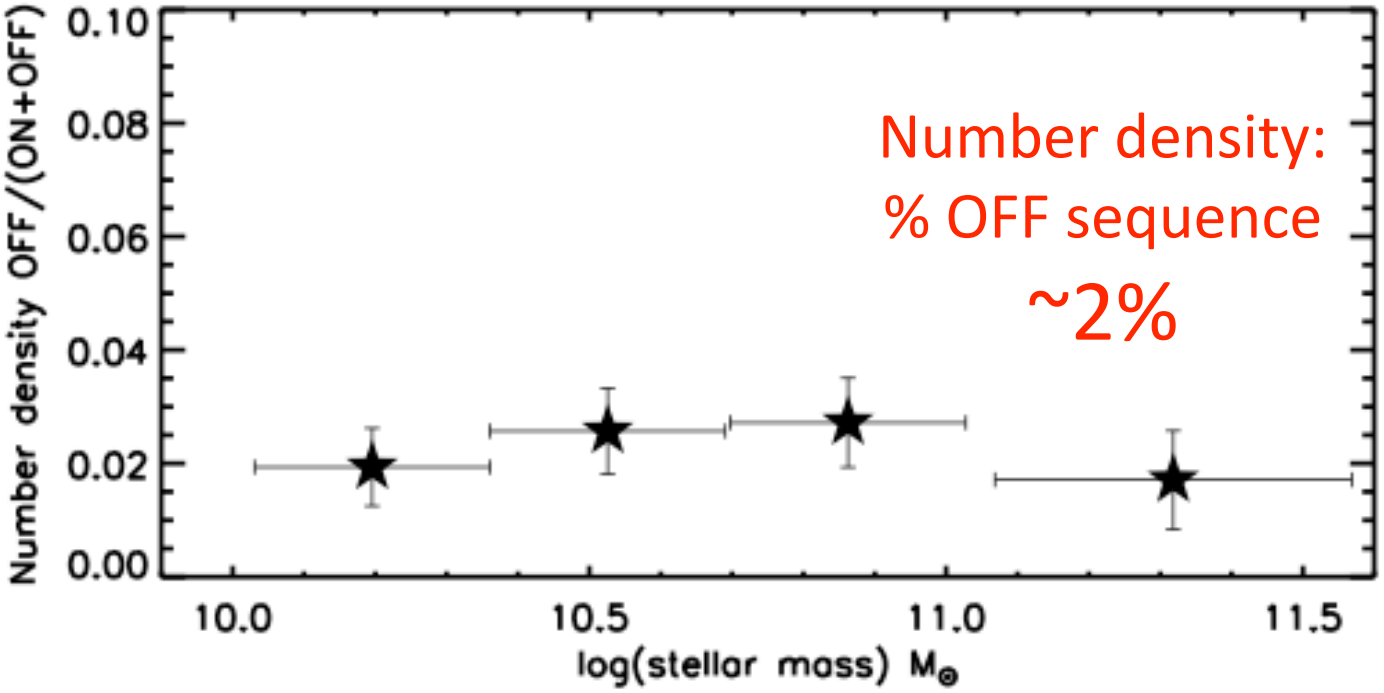
SFR density & Number density: ON and OFF sequence



SFR Density

Number Density





DUTY CYCLE ON/OFF the Main Sequence

The cosmic time elapsed within the $1.5 < z < 2.5$ redshift interval Is ~ 2 Gyr, thus observed galaxies within this interval have spent on average ~1 Gyr within it.

With only ~ 2% of the massive galaxies being OFF the main sequence on average each galaxy spends 20 Myr in the starburst mode.

This is actually much shorter than both the gas depletion timescale (~0.5 Gyr) and the dynamical time in starburst galaxies (~50-200 Myr, Daddi et al. 2010; Genzel et al. 2010).

Not all galaxies may experience a (meger-driven) starburst during these ~2 Gyr of cosmic time interval.

Summary of Part 2

- The merger-enhanced SFR phases are relatively unimportant for the stellar mass growth of z ~ 2 galaxies, and probably so at all redshifts given that z ~ 2 is the `prime time' for SMGs (Chapman et al. 2005).

- Still, going through a merging-driven starburst phase may be one way of turning star-forming galaxies into passive ellipticals.


Thank You!