SFR and dust obscuration a z~2: galaxies at the dawn of downsizing

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with

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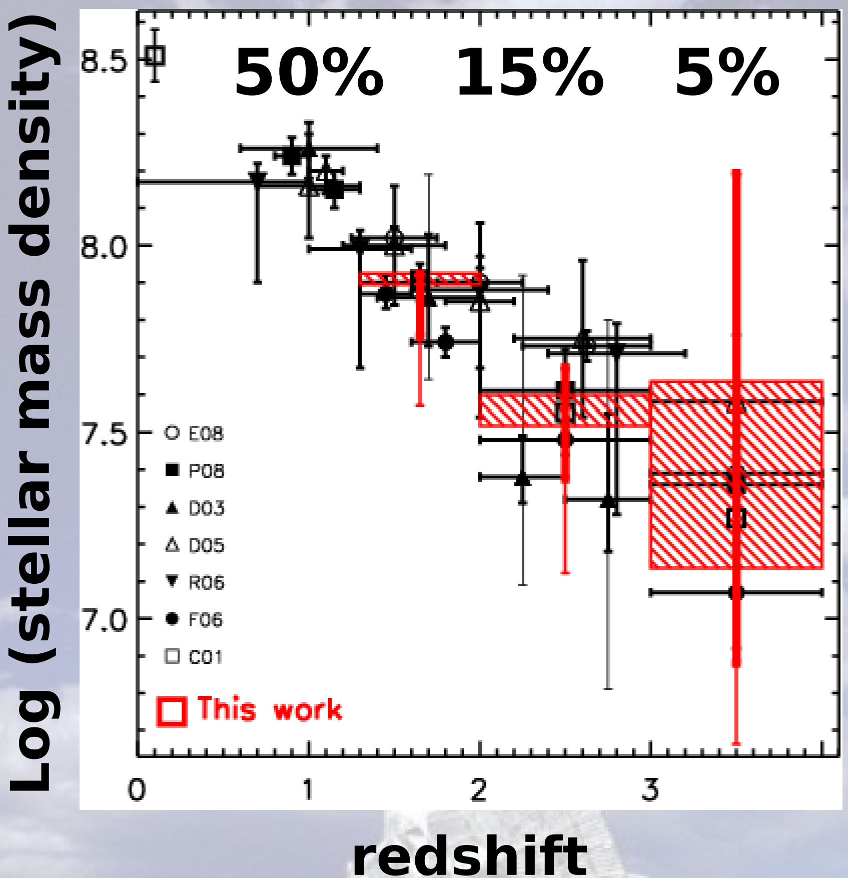
and the COSMOS team

When and how galaxies formed

The growth of stellar mass in the Universe



(Marchesini et al., 2009)

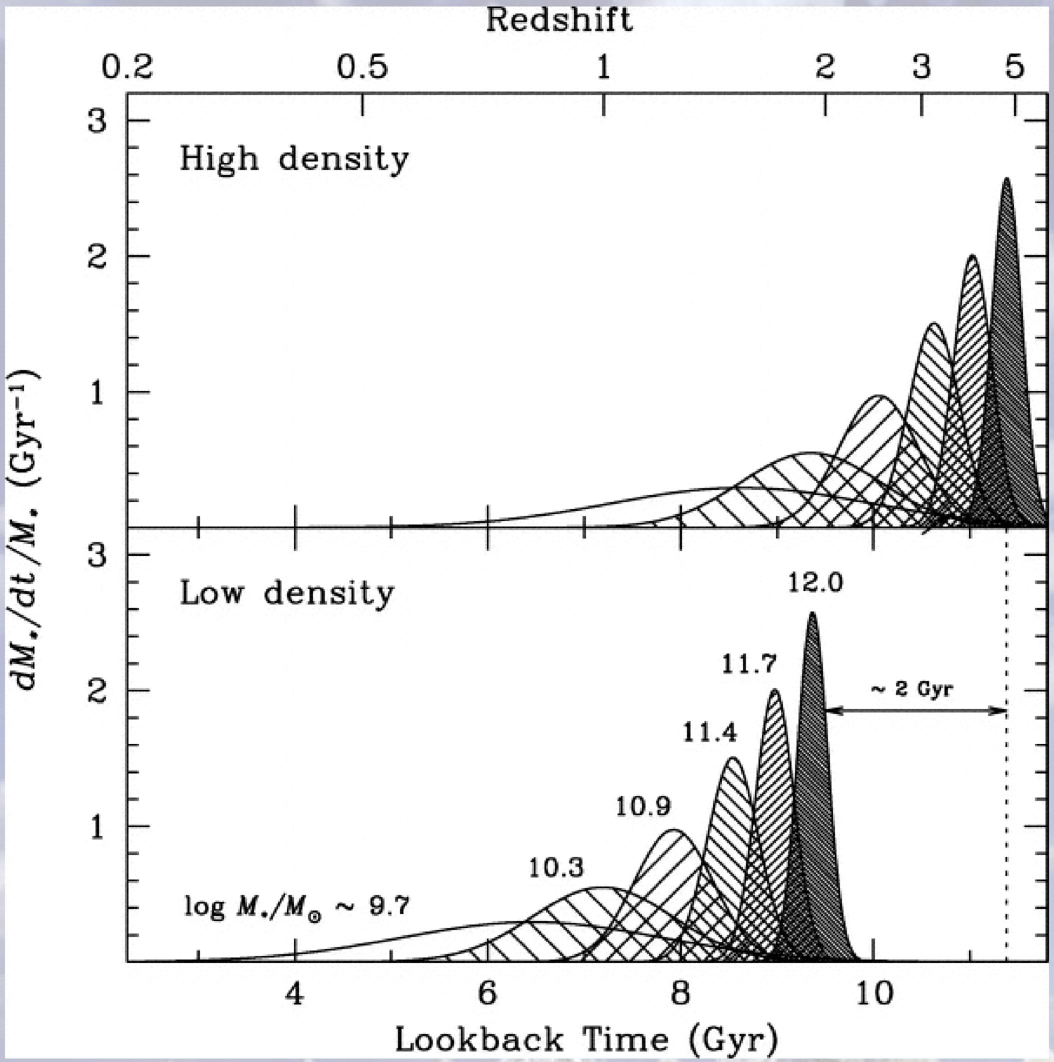
Broad consensus on the evolution of the galaxy stellar mass function up to high redshift

About 45% of the present day stellar mass has been produced in about 3.6 Gyrs at $1 < z < 3$

The remaining 50% has formed in the last 7.5 Gyrs at $1 < z < 0$

When and how galaxies formed

The downsizing scenario



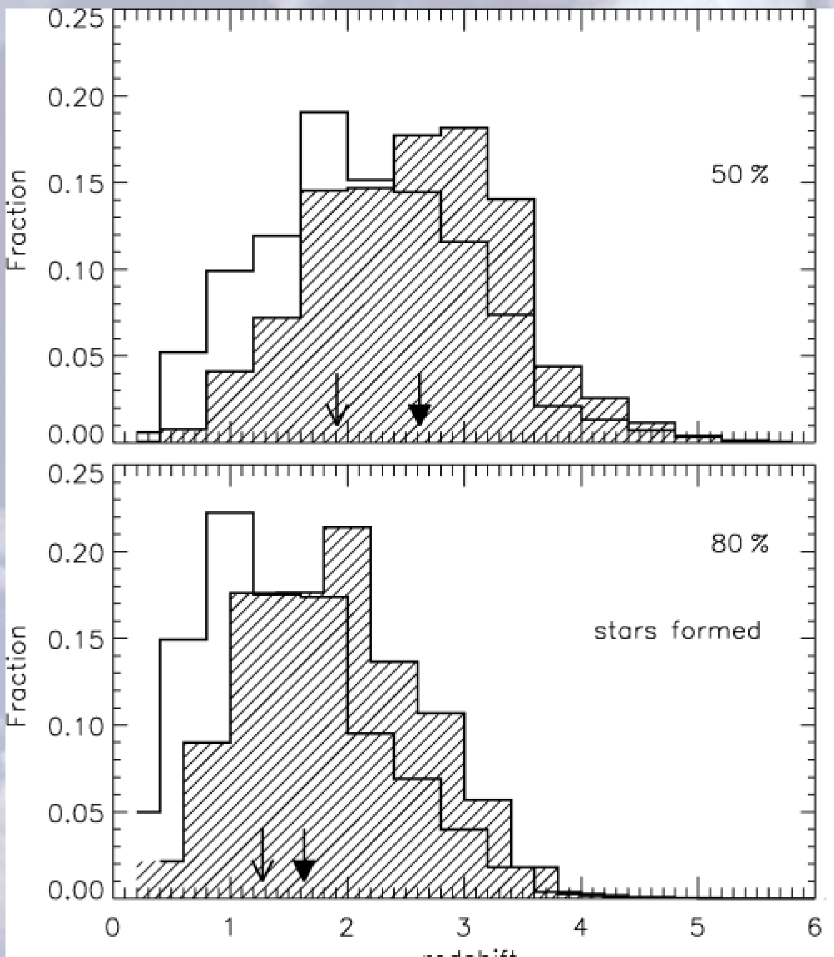
(Thomas et al., 2005)

"... galaxy formation took place in "downsizing", with more massive galaxies forming at higher redshift." (Cowie et. al., 1996)

Is that a problem for hierachical models of galaxy formation ?

When and how galaxies formed

The downsizing scenario in a hierarchical Universe



(De Lucia et al., 2006)

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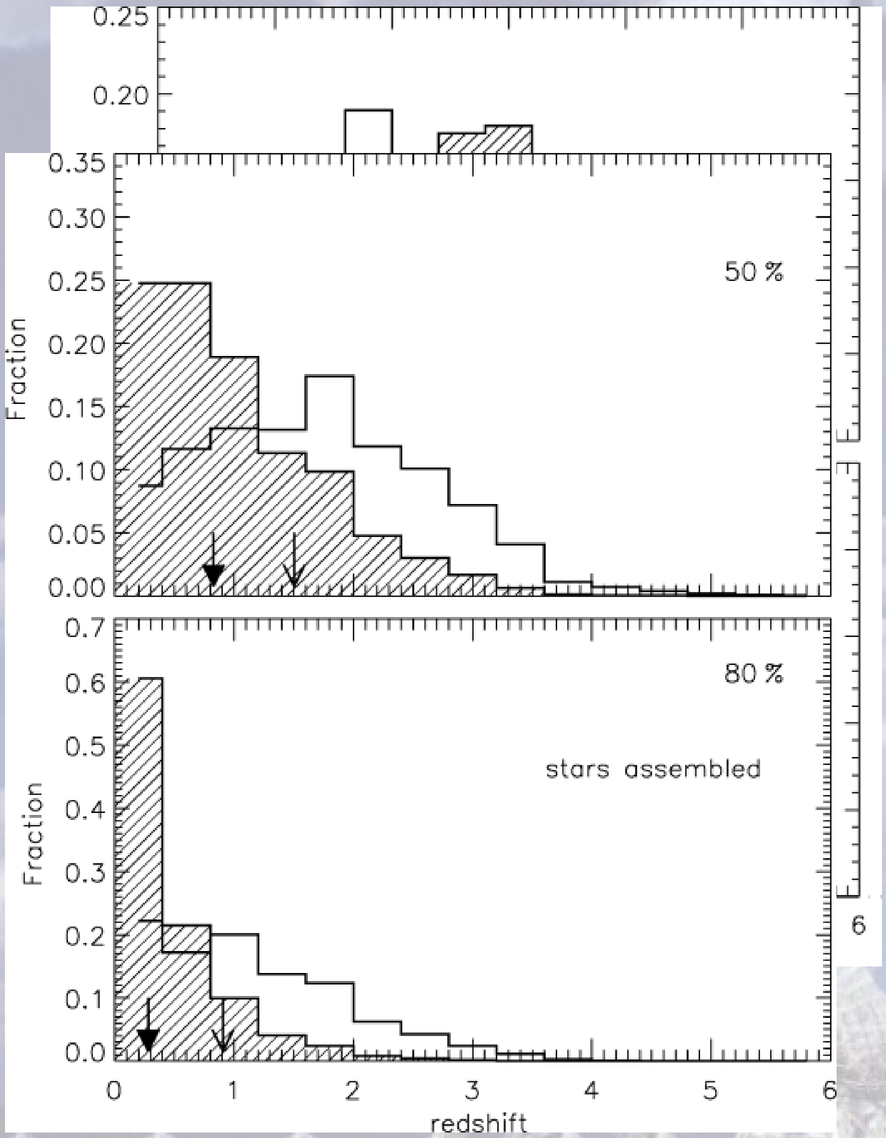
Star formation happens in downsizing

but ...

When and how galaxies formed

The downsizing scenario in a hierarchical Universe



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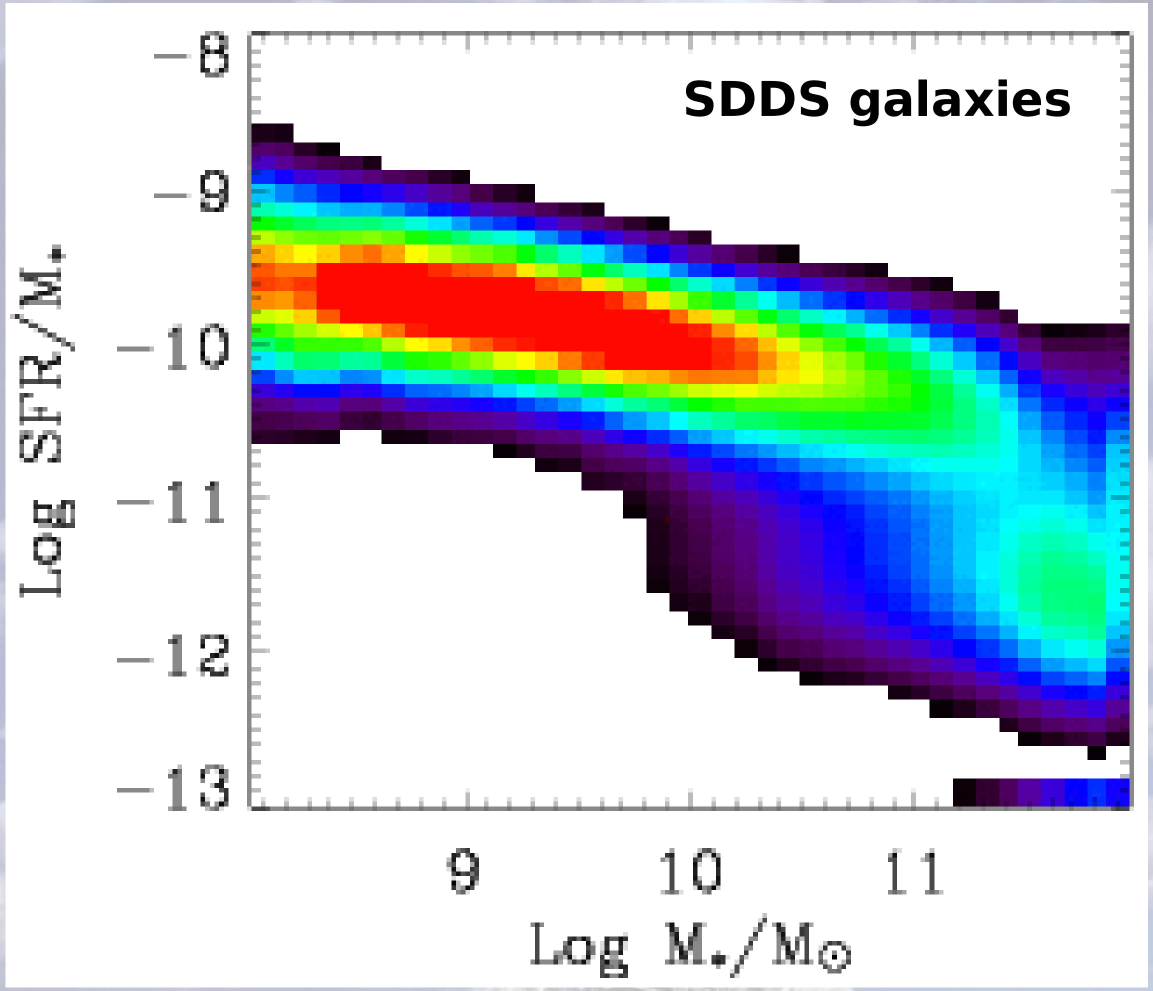
Star formation happens in downsizing

but

Galaxies form (hierarchically) upsizing

When and how galaxies formed

Specific star formation and downsizing



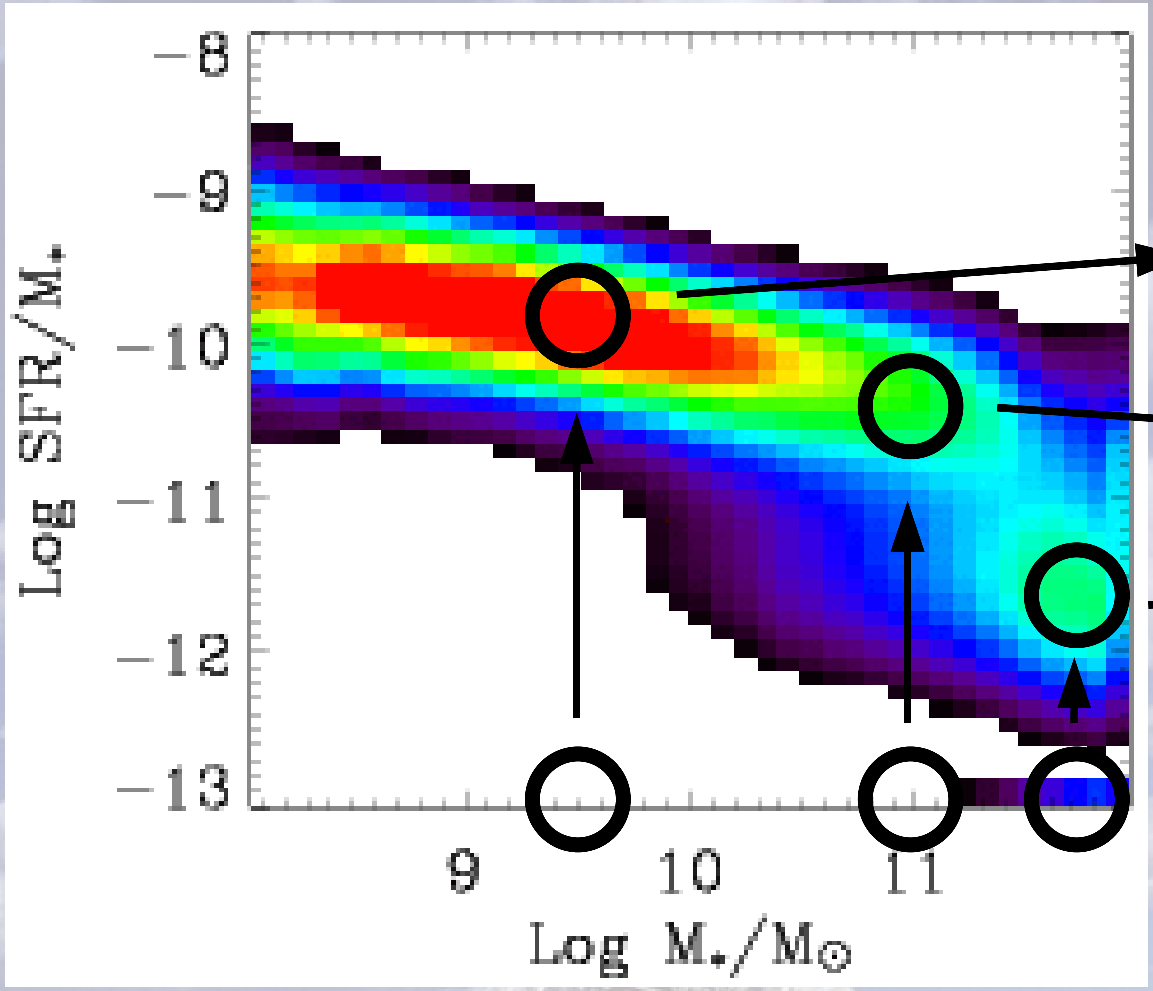
$$SSFR = SFR/M = \dot{M}/M$$

$$\Delta M/M \sim SSFR \times \Delta T$$

(Brinchmann et al., 2004)

When and how galaxies formed

Specific star formation and downsizing



ΔM/M in the last 2Gyrs:

$3x10^9$ M_o → 50%

10^{11} M_o → 8%

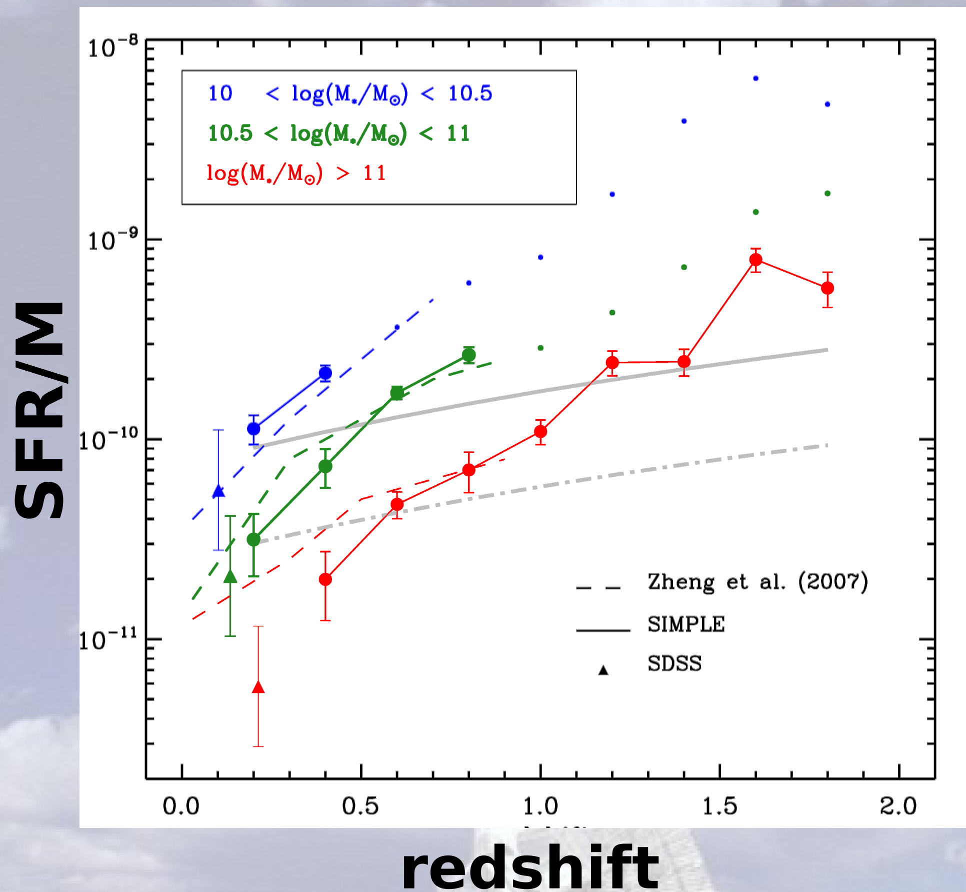
$7x10^{11}$ M_o → 0.05%

SSFR is the most favorite test for downsizing!

(Brinchmann et al., 2004)

When and how galaxies formed

The downsizing of cosmic star formation



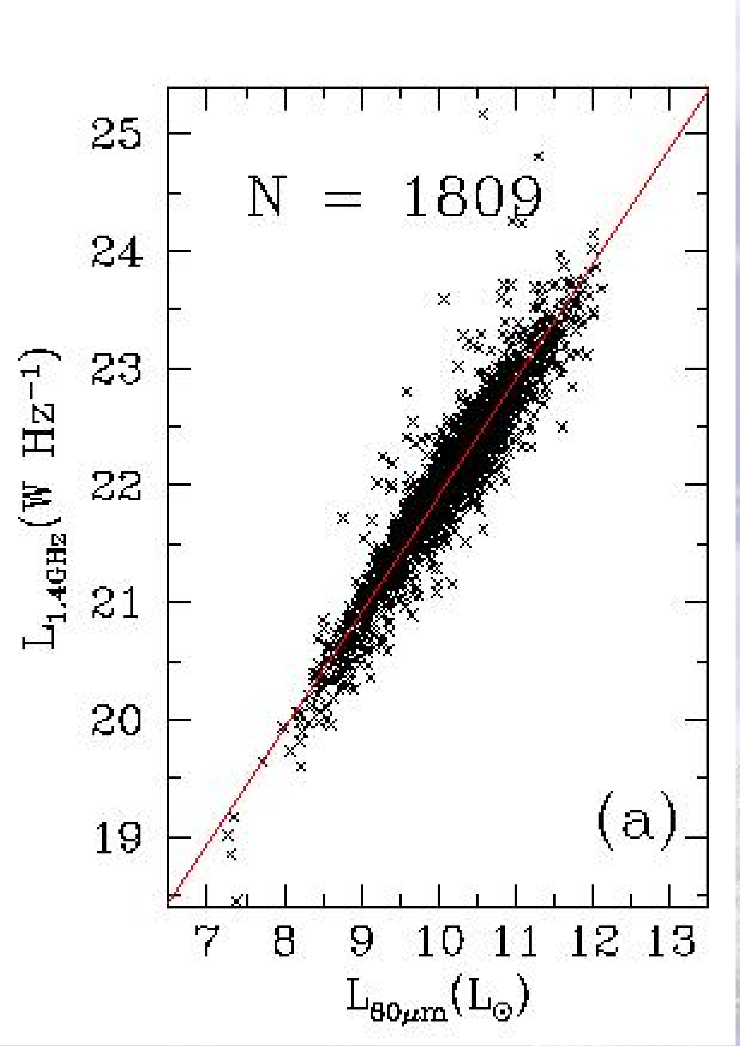
(Damen et al., 2009)

"The SSFR increases with z at a rate independent of mass"

"SSFRs of more massive galaxies are typically lower than those of less massive galaxies over the whole redshift range"

The downsizing pattern seems to be at work up to high redshift

Radio emission and SFR



(Yun et al., 2001)

SFR-FIR correlation (Kennicutt 1998)

x

Radio-FIR correlation (Yun et al, 2001; Bell 2003)

x

Radio interferometry has ~1 arcsec resolution

=

The ideal dust-unbiased SFR indicator

The VLA-COSMOS wide survey

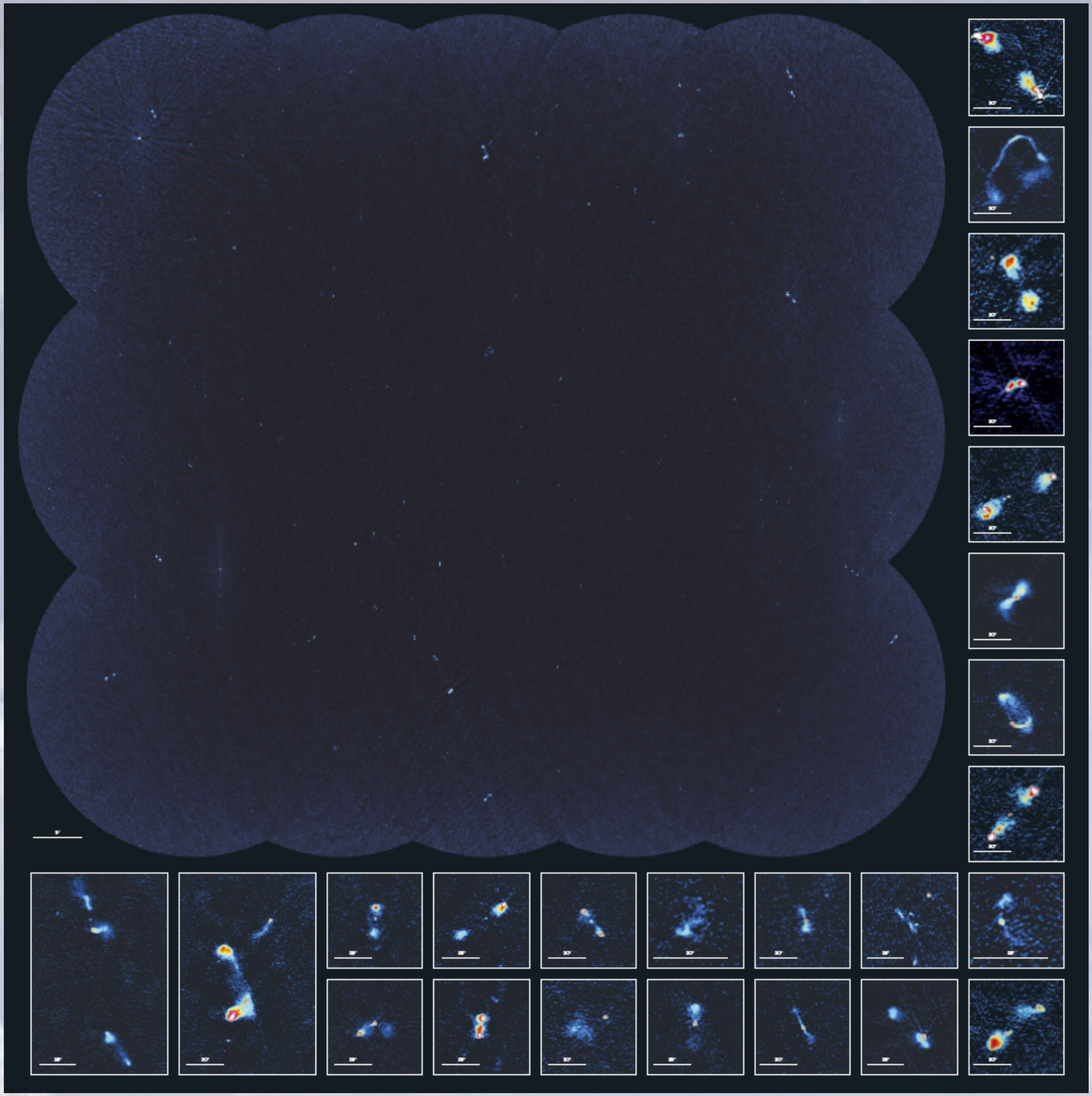
VLA Large Program

(P.I. Eva Shinnerer)

Full COSMOS field at 1.4 GHz

1.5'' resolution

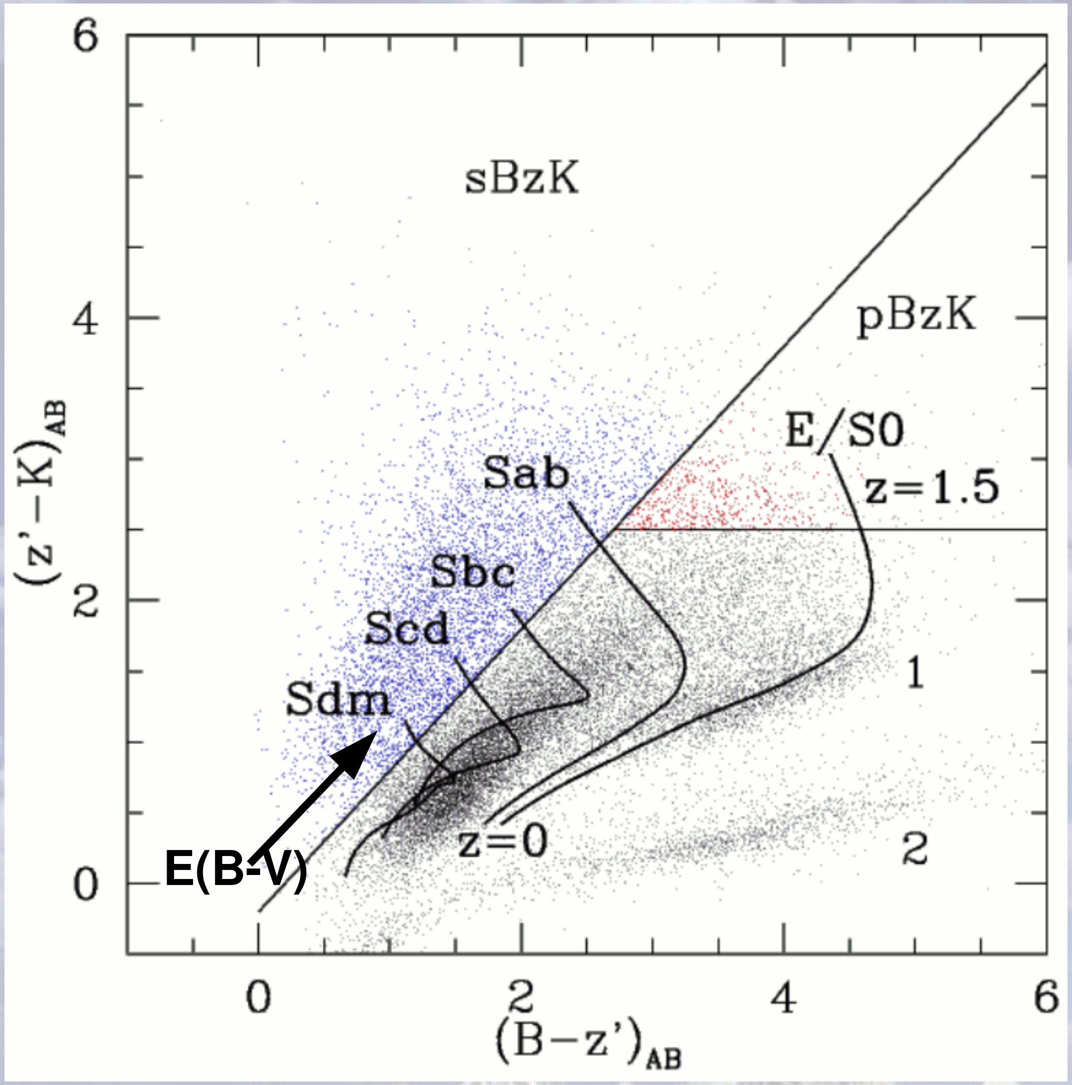
rms ~ 10 μ Jy



(Schinnerer et al., 2007)

The BzK COSMOS project

Chasing galaxies at z ~ 2 : the BzK selection technique



(Lane et al. 2007)

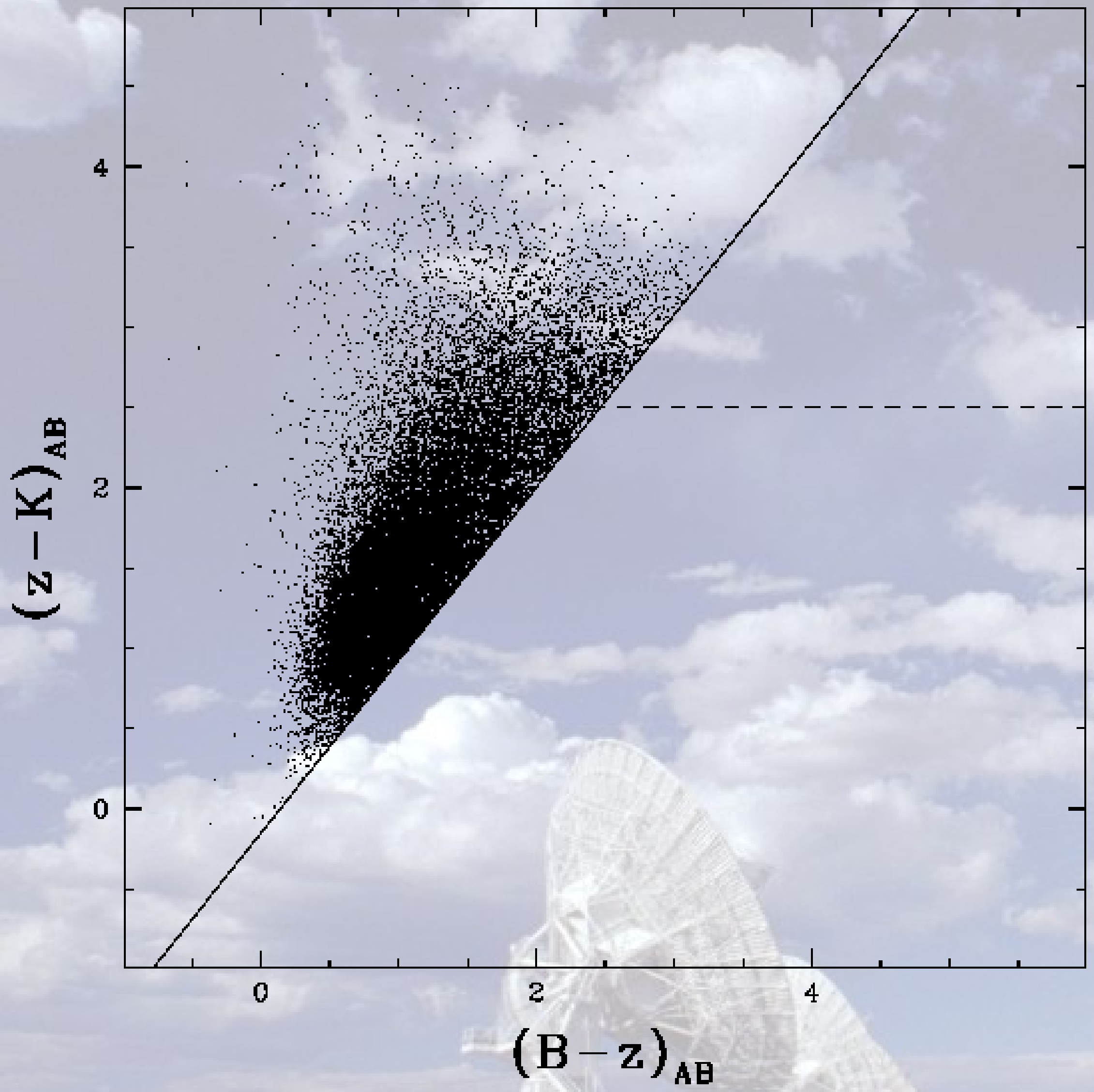
very simple

reddening independent

massive galaxies

high star formation rates

The BzK COSMOS project



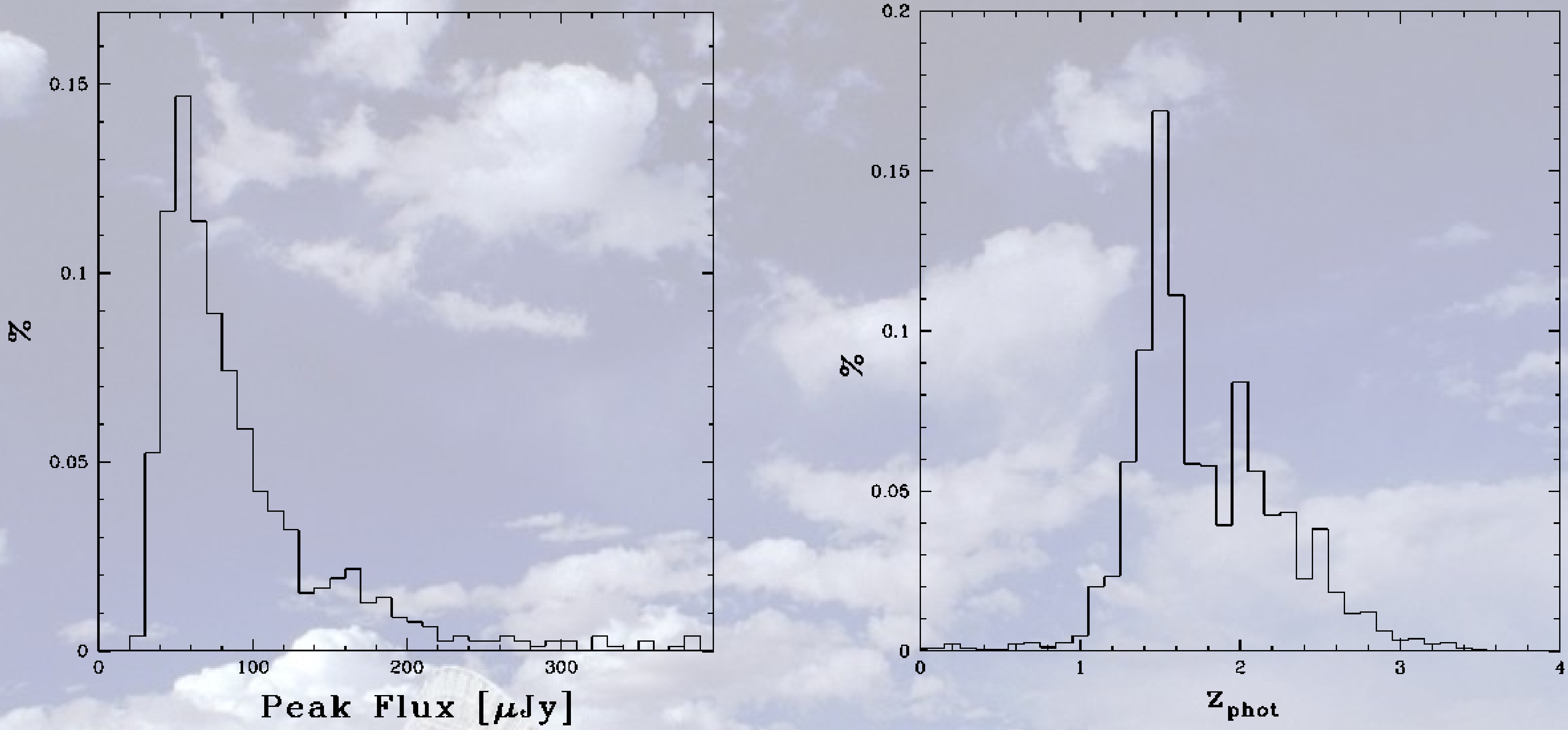
30125 sBzK galaxies

WIRCAM/CFHT K
(P.I. H. J. McCracken)

SuprimeCam/Subaru Bz
(COSMOS Legacy dataset)

$K_{AB} \sim 23$ mag

The BzK COSMOS project



Extremely effective selection of galaxies at 1.3 < z < 2.5

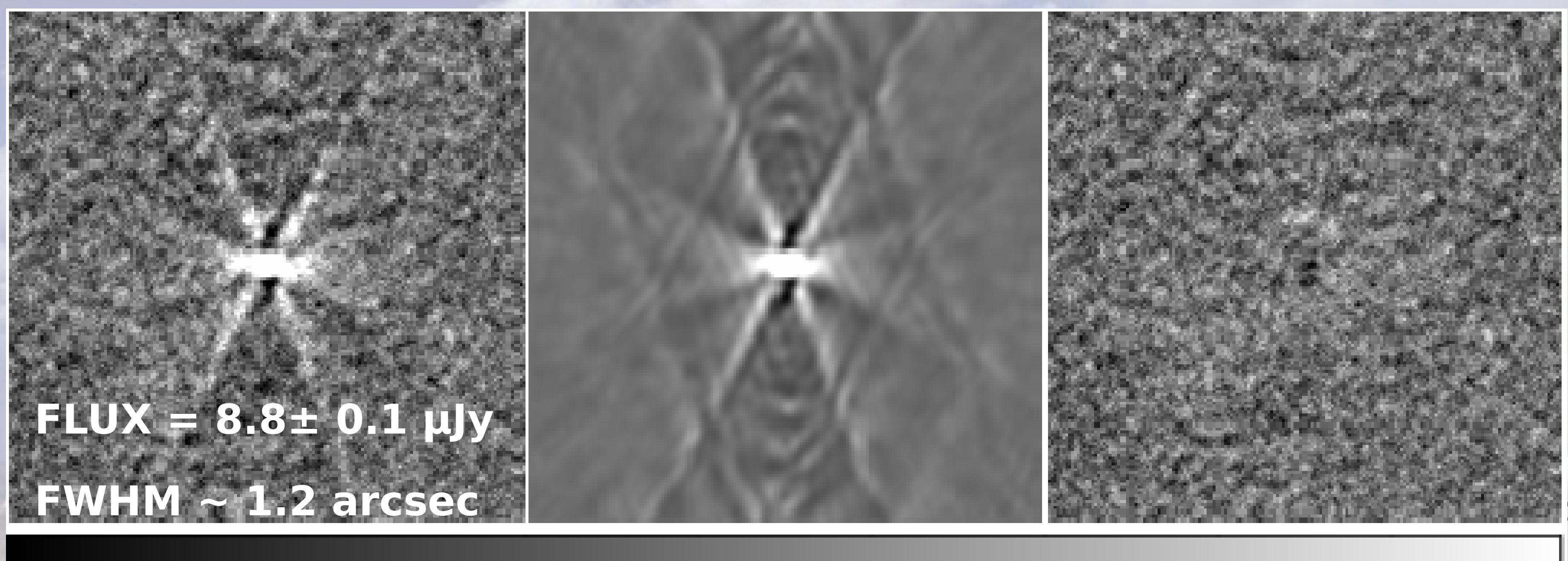
“Only” 616 objects (~2%) are 1.4 GHz detected

The stacking analysis

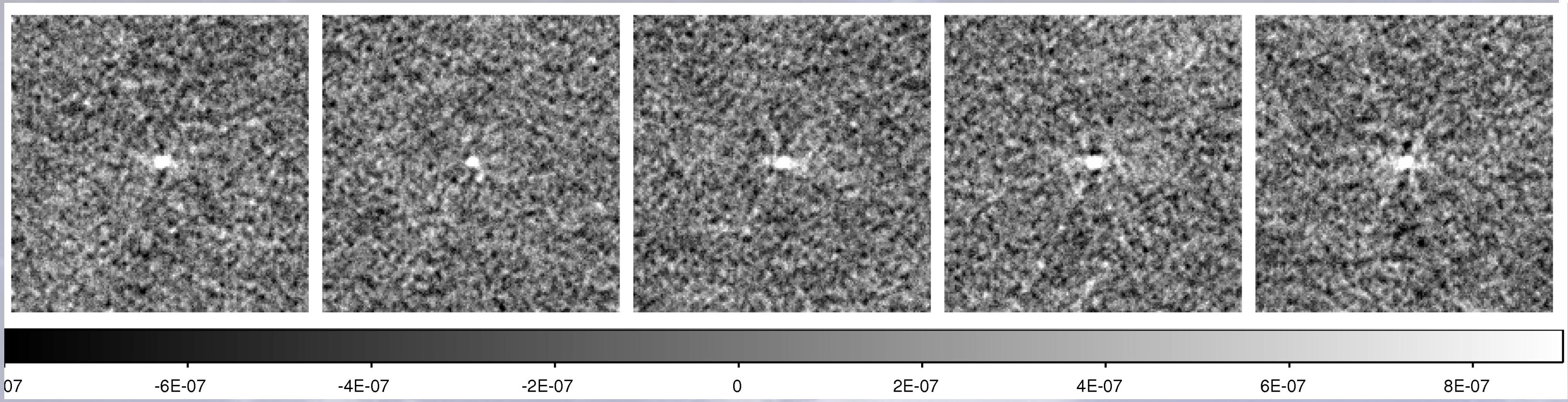
1.4 GHz median stacking:

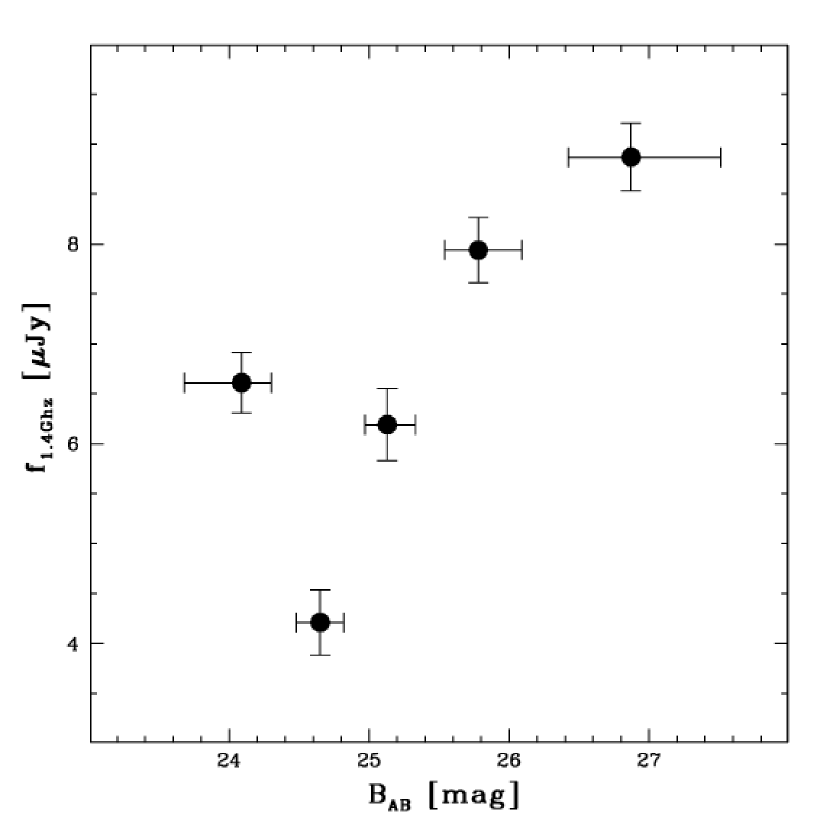
- more robust than mean against detections
- rms goes down by ~ $\sqrt{N}$ *i.e.* 0.1/0.3 μ Jy
- “normal” star forming galaxy at high z
- next generation arrays science case (SKA)

Stacked data **Model** **Residuals**



Radio stacks vs. B band mag

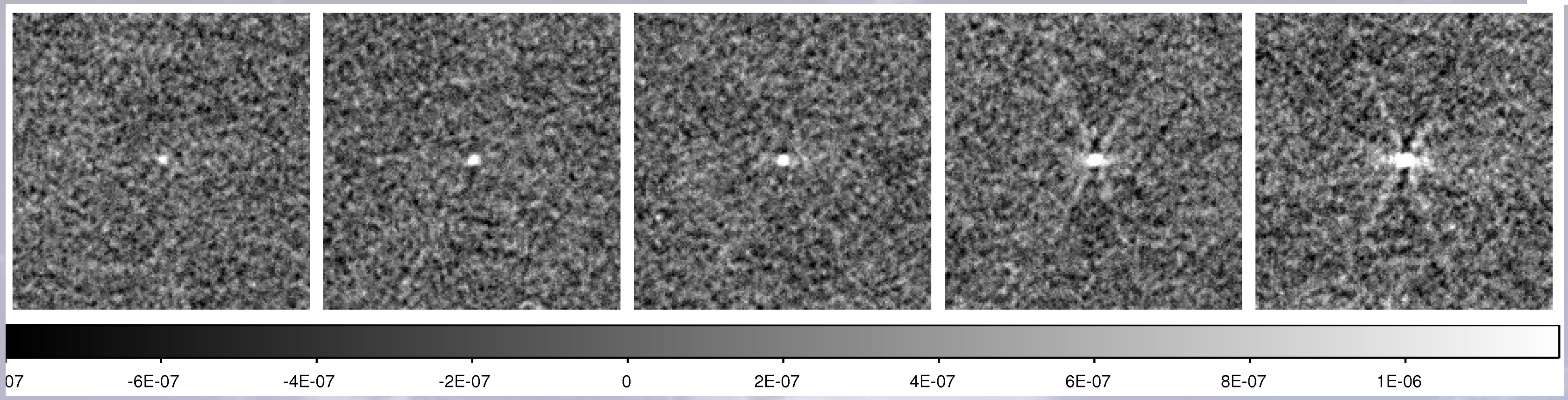


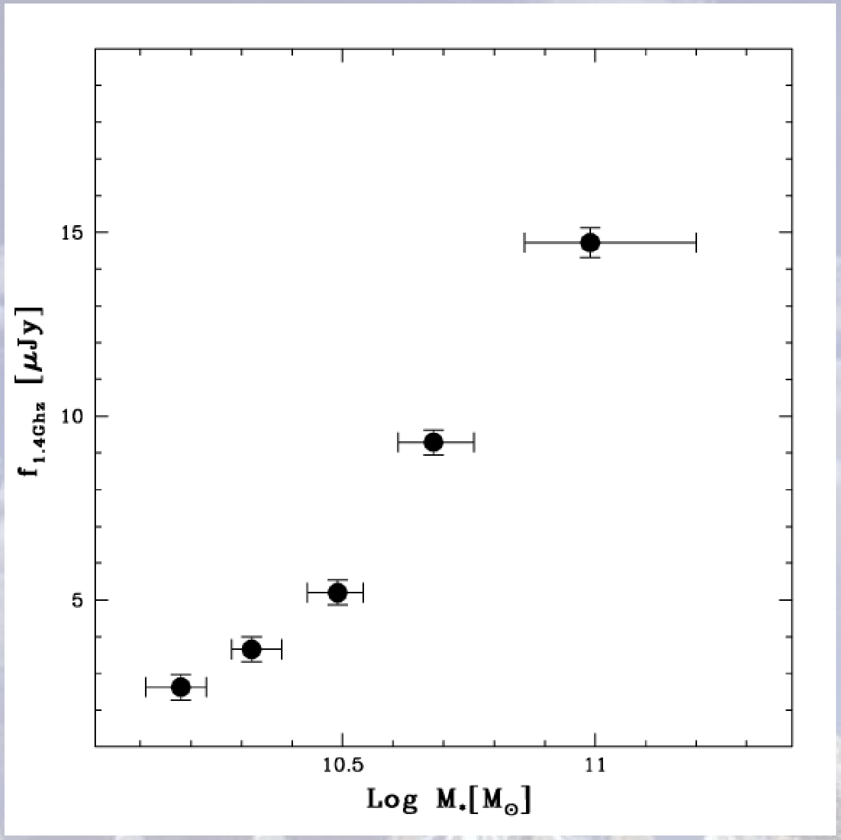


- observed UV restframe light (1500 Å) is poorly correlated with the ongoing star formation activity

- counter intuitively: the faintest UV luminosity has the largest SFR

Radio stacks vs. Stellar Mass

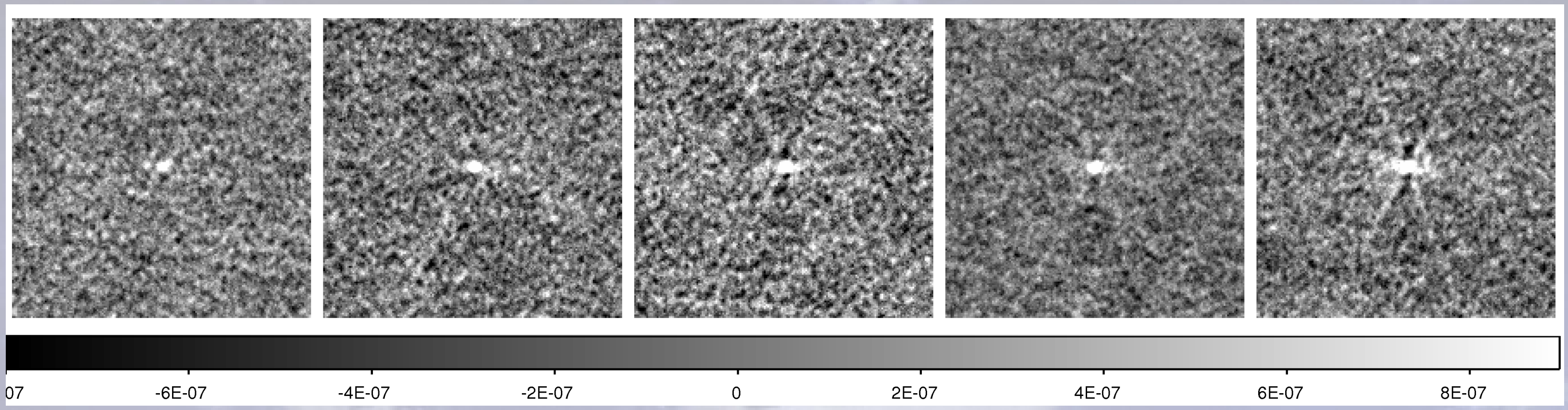


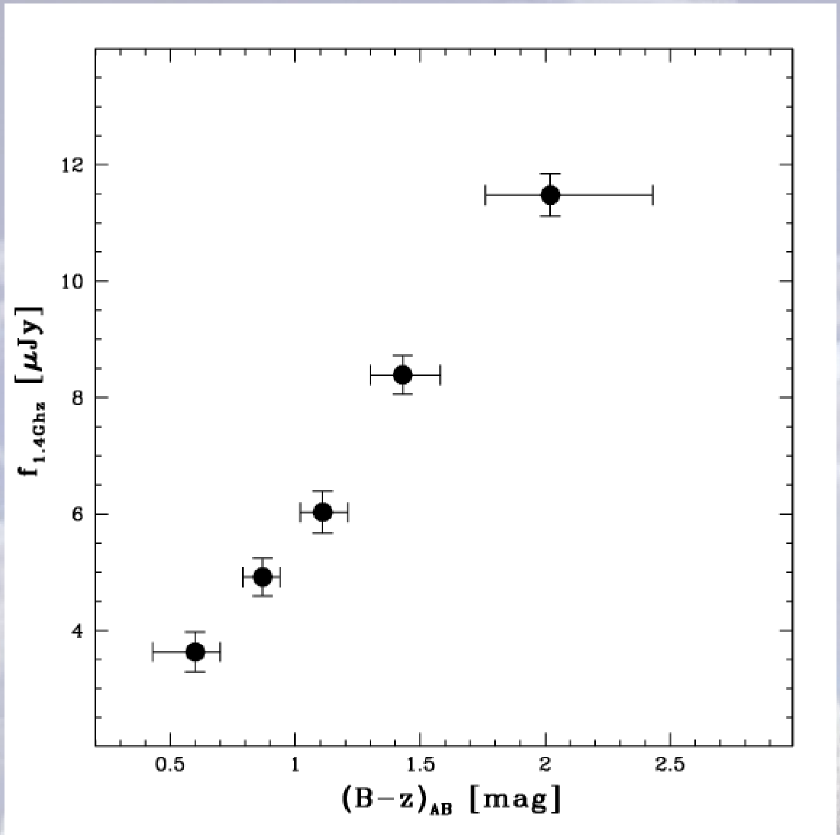


- Tight correlation between galaxy stellar mass and star formation

- Similarly to the local Universe: the higher the stellar mass, the more the star formation

Radio stacks vs. (B-z) color



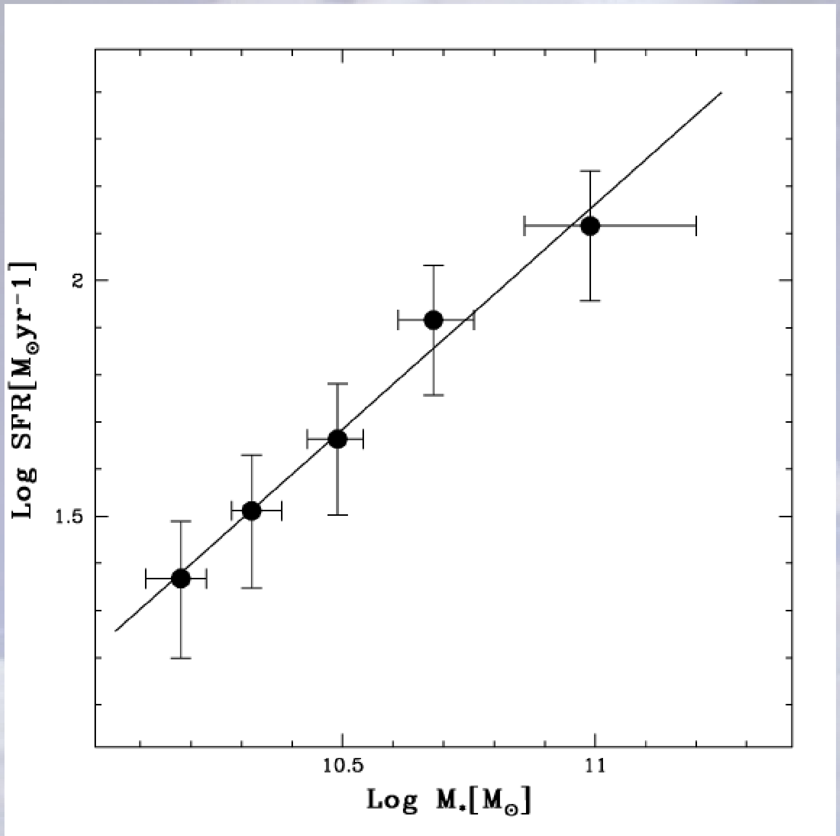


- Tight correlation between (B-z) color and star formation activity
- The observed (B-z) color of z~2 star forming galaxies is a measure of the UV slope, *i.e.* the dust content

Galaxies with higher SFRs are more dust extincted

Radio SFRs vs Stellar Mass

A linear relation is present at all redshifts probed and its slope is mildly increasing with redshift



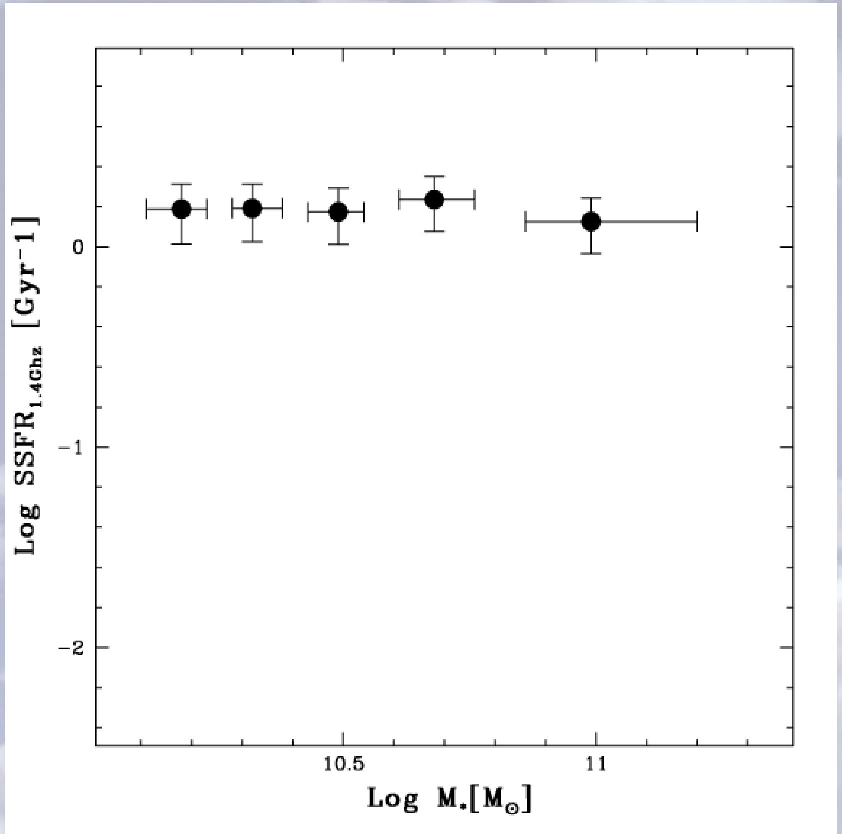
SDSS/AEGIS a = **0.7** @0/0.7

GOODS a = **0.9** @1

Log SFR = aLog M+c a = **0.95** @1.7

The evolution of the slope sets the time scales of galaxy evolution by tracing when galaxies enter their active stage as a function of mass

Radio SSFRs



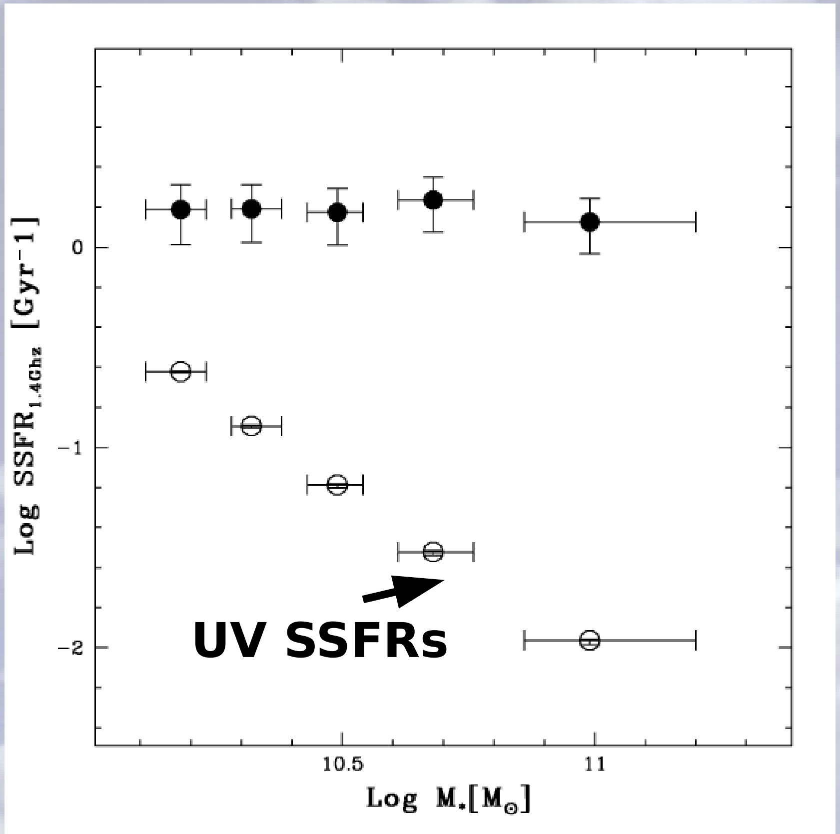
SSFR vs stellar mass is ~flat at z = 1.7

Galaxies are all in their active epoch

No downsizing shows up in these data

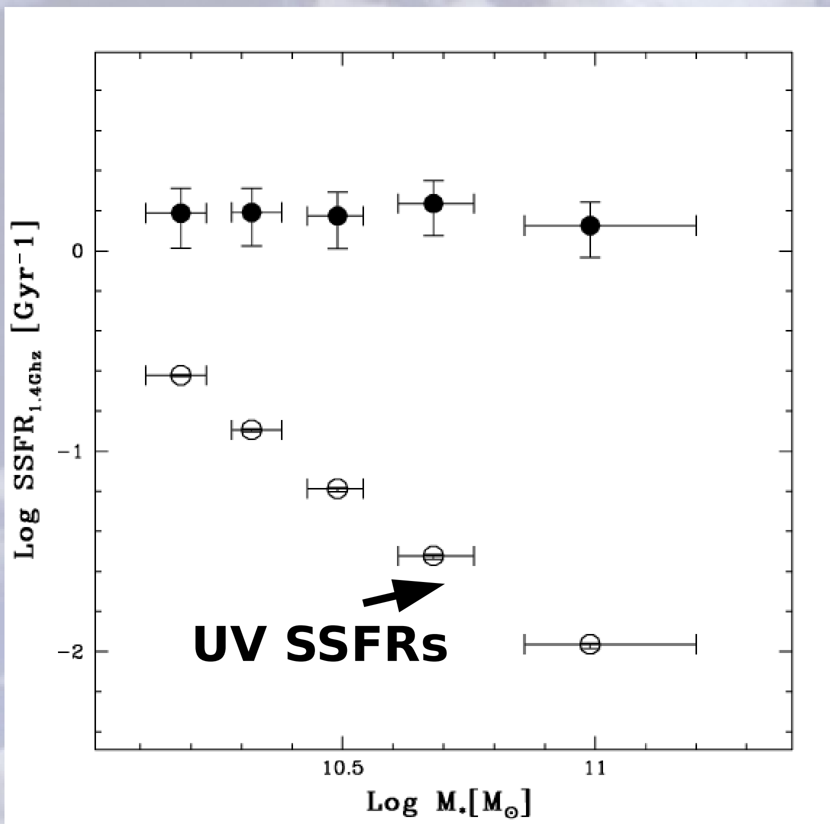
(see also Dunne et al., 2008)

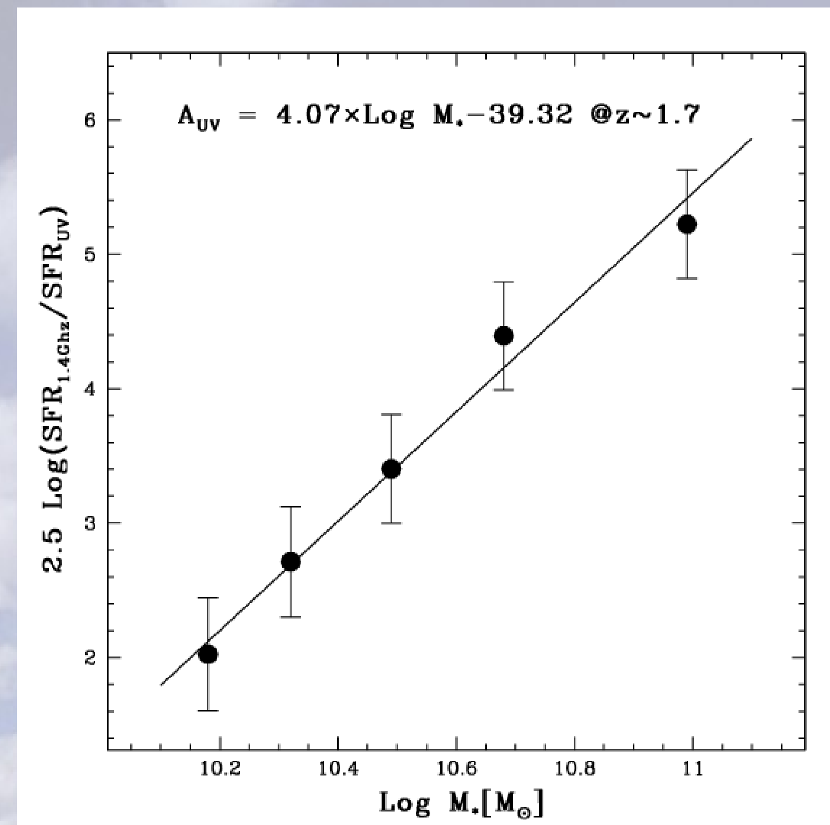
Radio vs UV SSFRs



Massive starburst galaxies are as red as ETGs

Radio vs UV SSFRs

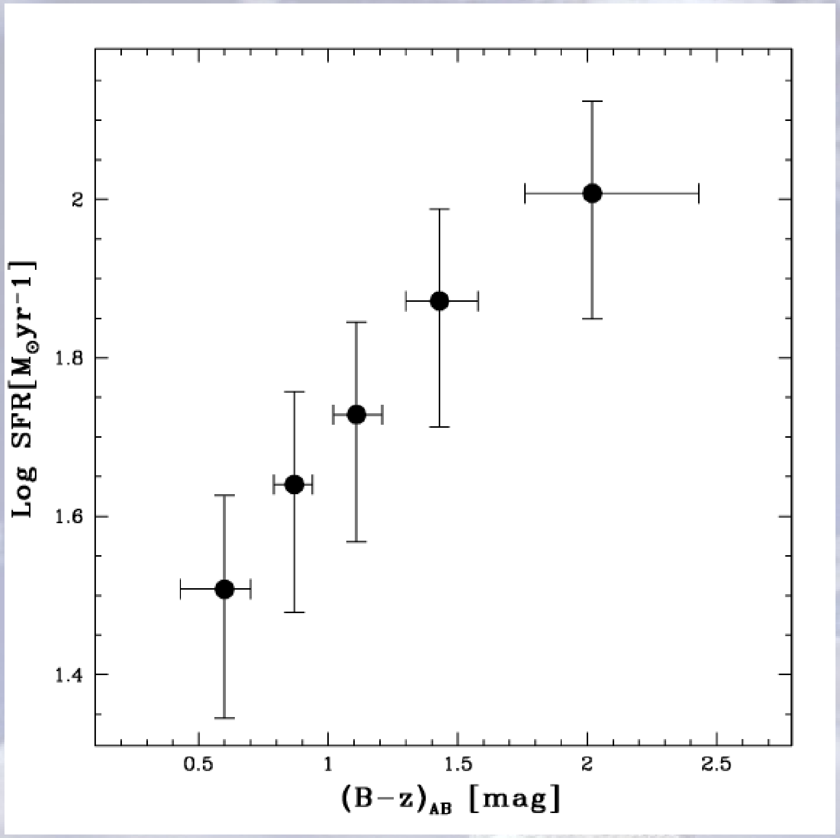




Massive starburst galaxies are as red as ETGs

A_{1500} is linearly proportional to Log M_*

Radio SFRs vs (B-z)



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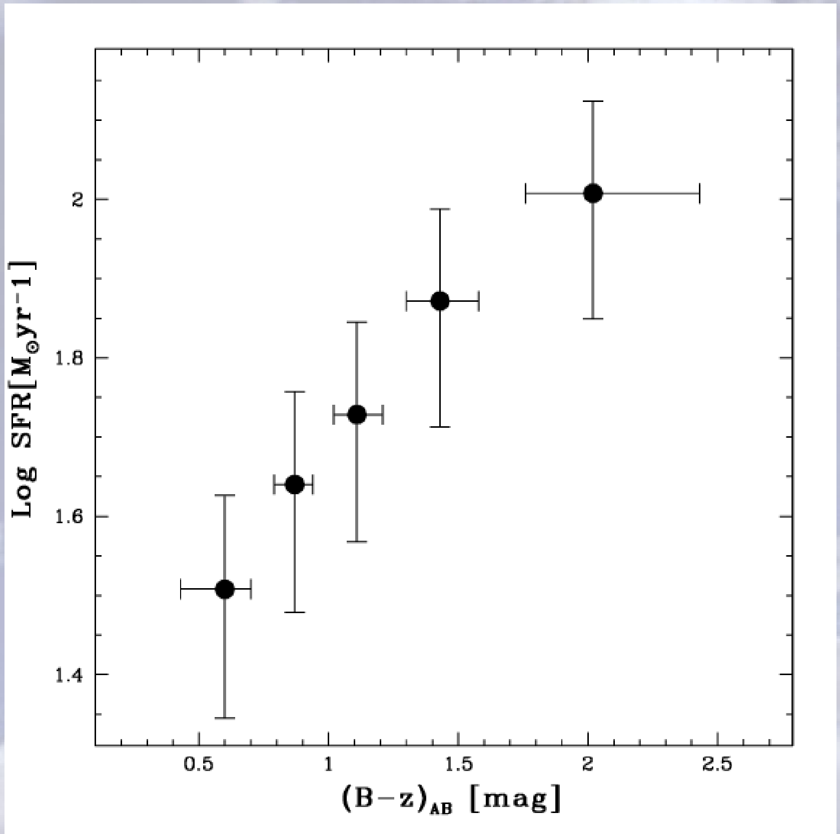
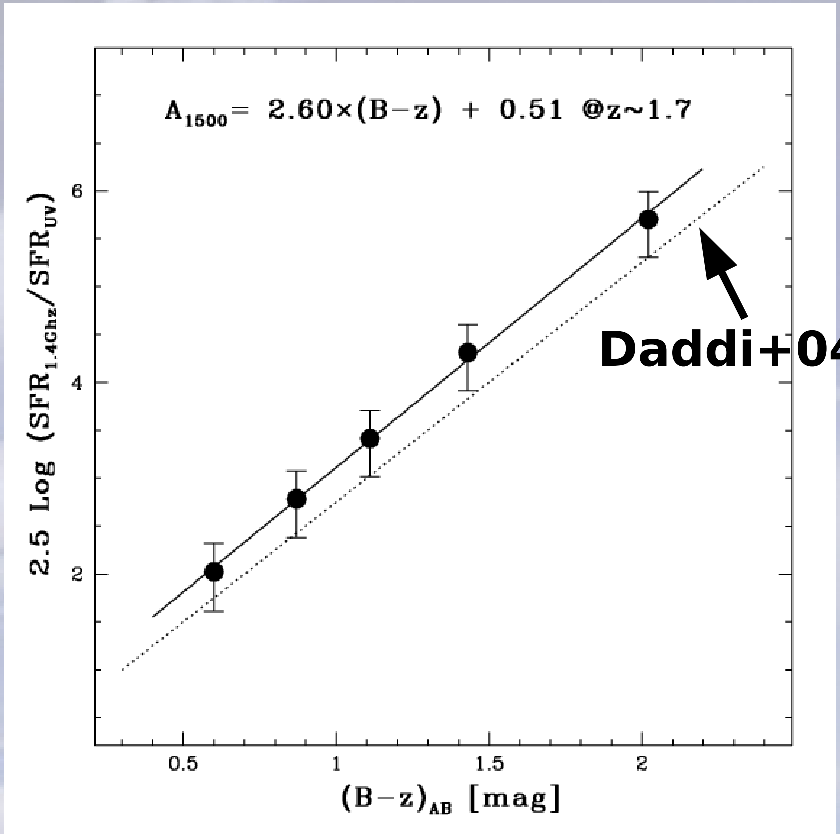
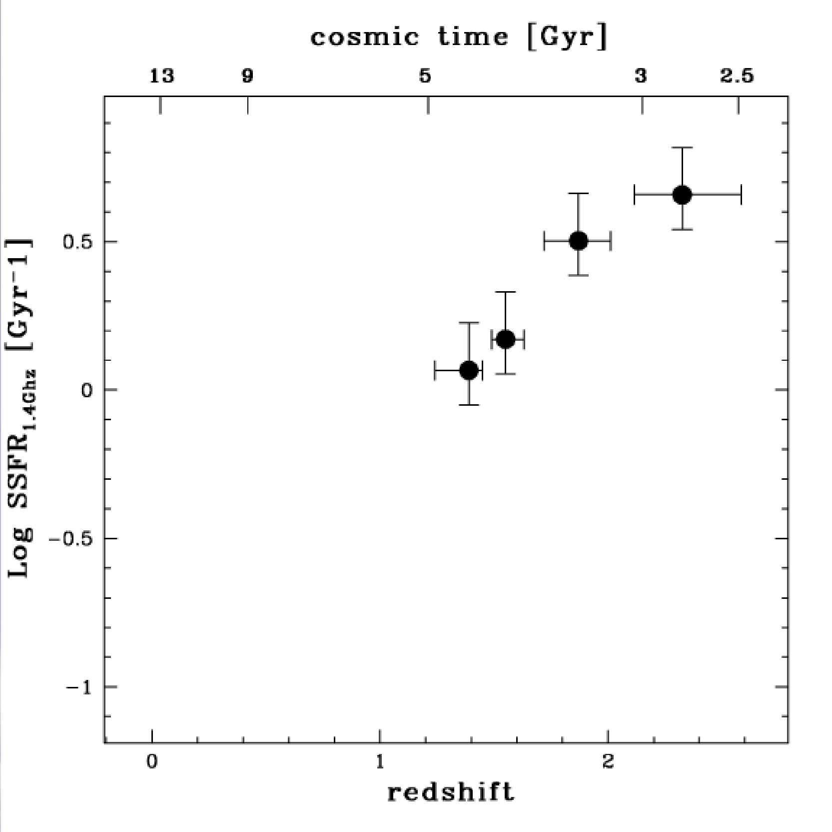




A_{1500} is a linear combination of Log M_* and (B-z)

The SSFR redshift evolution

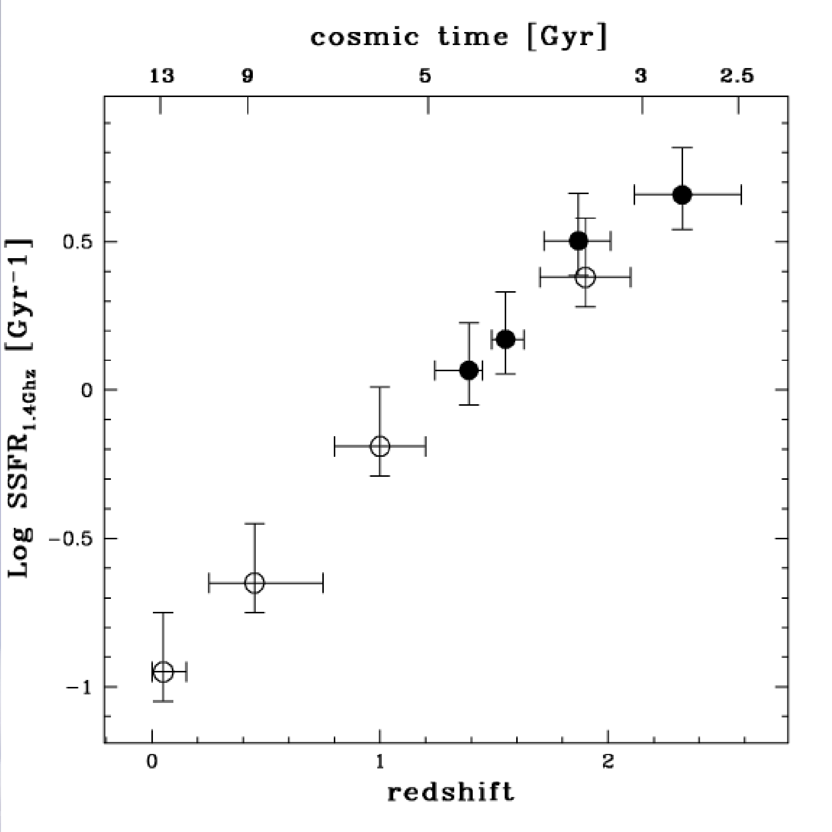


SSFR(M) is flat in 1.4 < z < 2.3

SSFR(z) decreases by a factor 4 in the redshift range 1.4 < z < 2.3

The mass growth of galaxies

The secular decline of SSFR with time



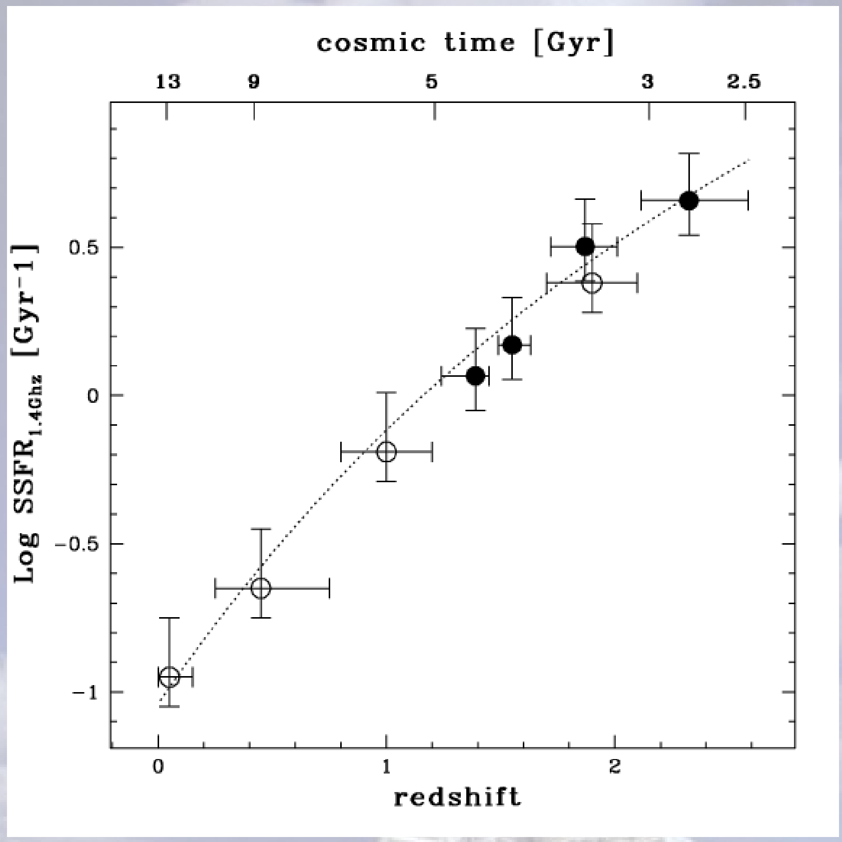
SSFR(M) is flat in 1.4 < z < 2.3

SSFR(z) decreases by a factor 4 in the redshift range 1.4 < z < 2.3

The decrease continues all the way down to the local Universe

The mass growth of galaxies

$$\langle SFR(M,t)\rangle \simeq 270\ (M/10^{11})\ (t/3.4)^{-2.5} = dM/dt$$



Galaxies cannot keep growing at the empirical average SFR!

If so, the mass of individual galaxies should increase by a factor ~6 between z=2 and z=1.6, a factor ~20 by z=1.3, and ~250 by z=0.

Clearly, galaxies don't grow that much!

The mass growth of galaxies

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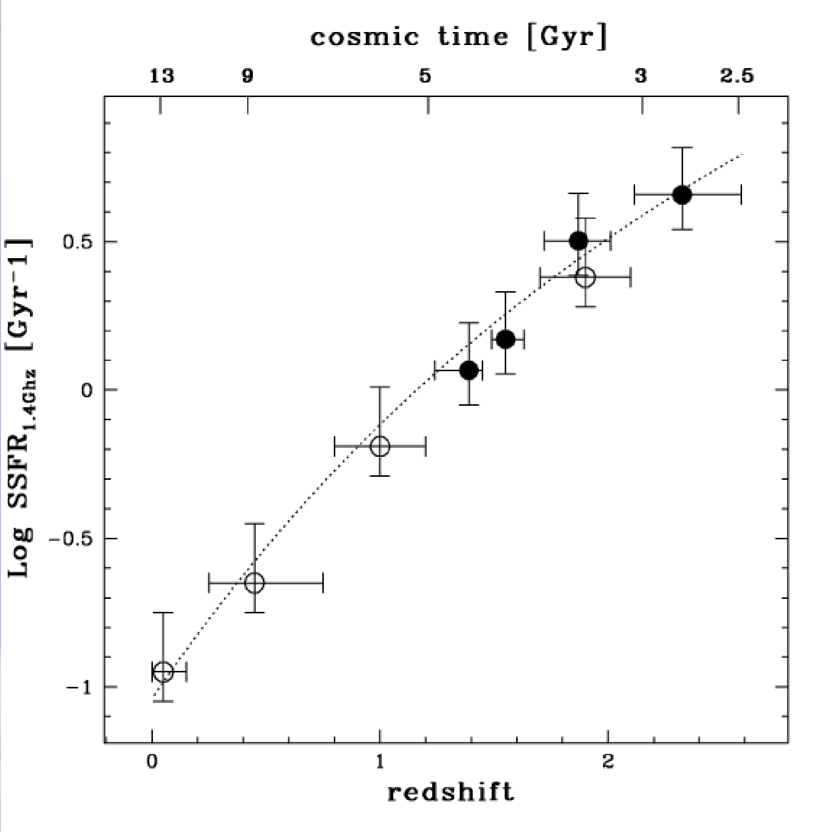

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Clearly, galaxies don't grow that much!

They turn passive
They do so in a “downsized” fashion

Conclusions

A universal dust attenuation correction does not apply

Dust attenuation is a function of galaxy stellar mass, with more massive galaxies being more heavily extincted

Galaxies have, at all masses, the same evolutionary timescales and a nearly exponential growth with time

An empirical mean SFR(M,t) well describes the data

The mass overgrowth is not happening because galaxies turn passive in a downsized fashion

This might be regarded as the “dawn of downsizing” for the star forming galaxy popolation at z~2