The Growth of Galaxies Through the Peak of their Star Formation Activity @ z~2 and the role of environment

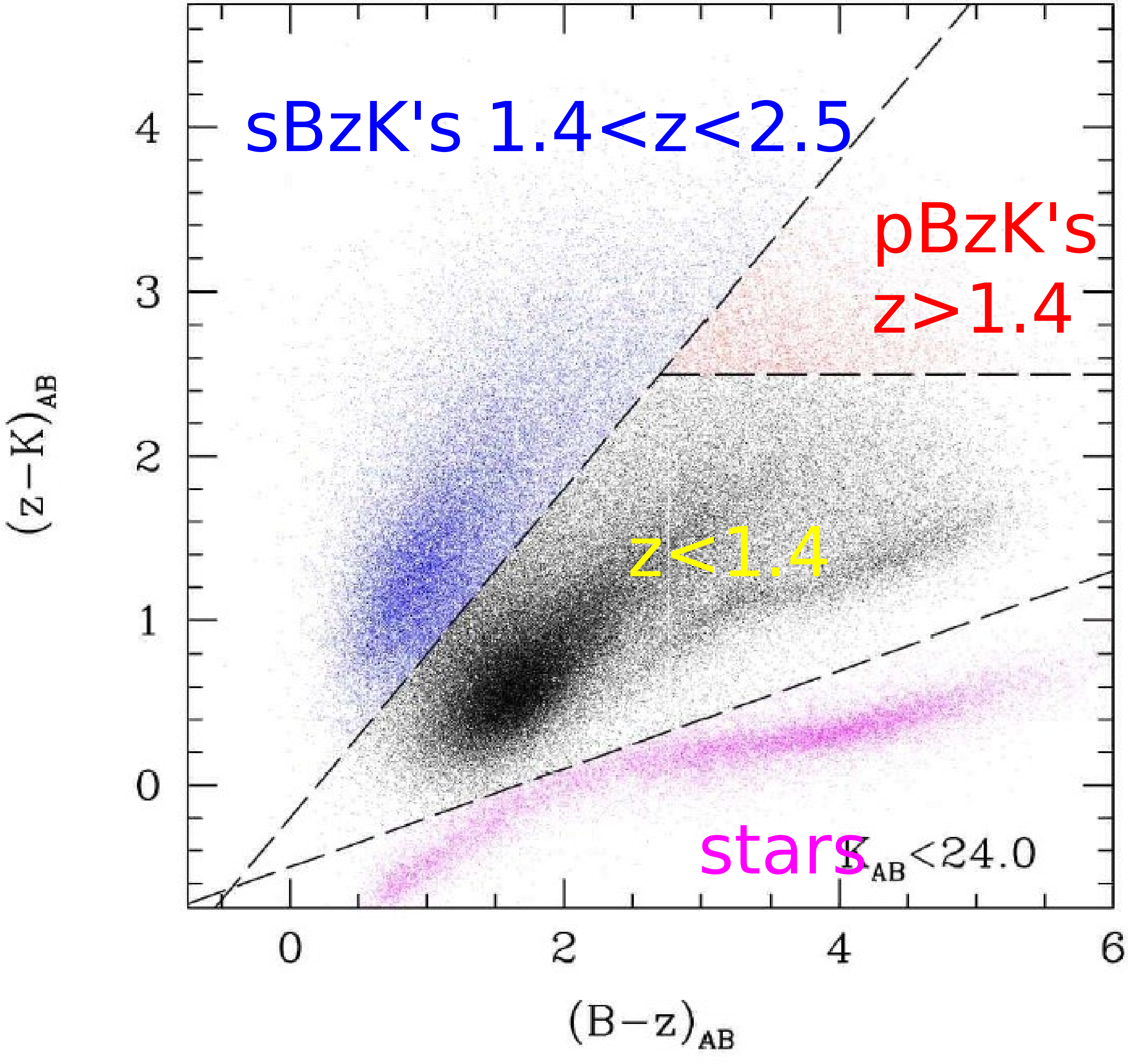
Outline:

- Selection of galaxies at $1.4<z<2.5$
- SFRs, Masses, Extinction
- The growth of Galaxies and how to feed it
- A conjecture on the orgin of the differentiation of galaxies into passive ellipticals and starforming spirals
- Environment, at last

Alvio Renzini, GEE 2009

Based on GOODS & COSMOS Databases

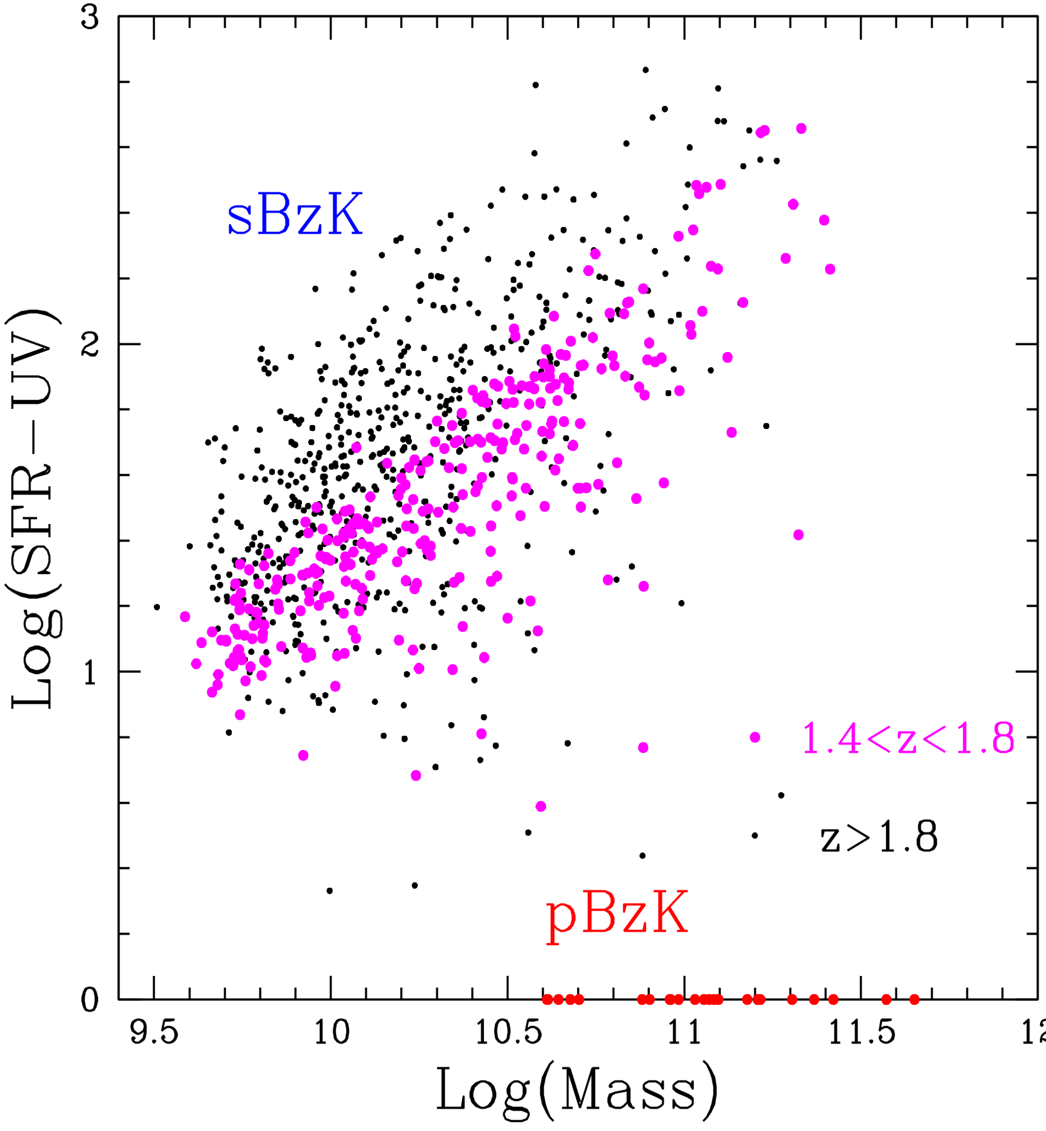
BzK-Selected Galaxies near the Peak of Their Mass Groth, Nuclear Activity and Morphological Differentiation



COSMOS Field,
McCracken et al. 2009

Today: first some results from the GOODS-South field, using the database of Daddi et al. 2007

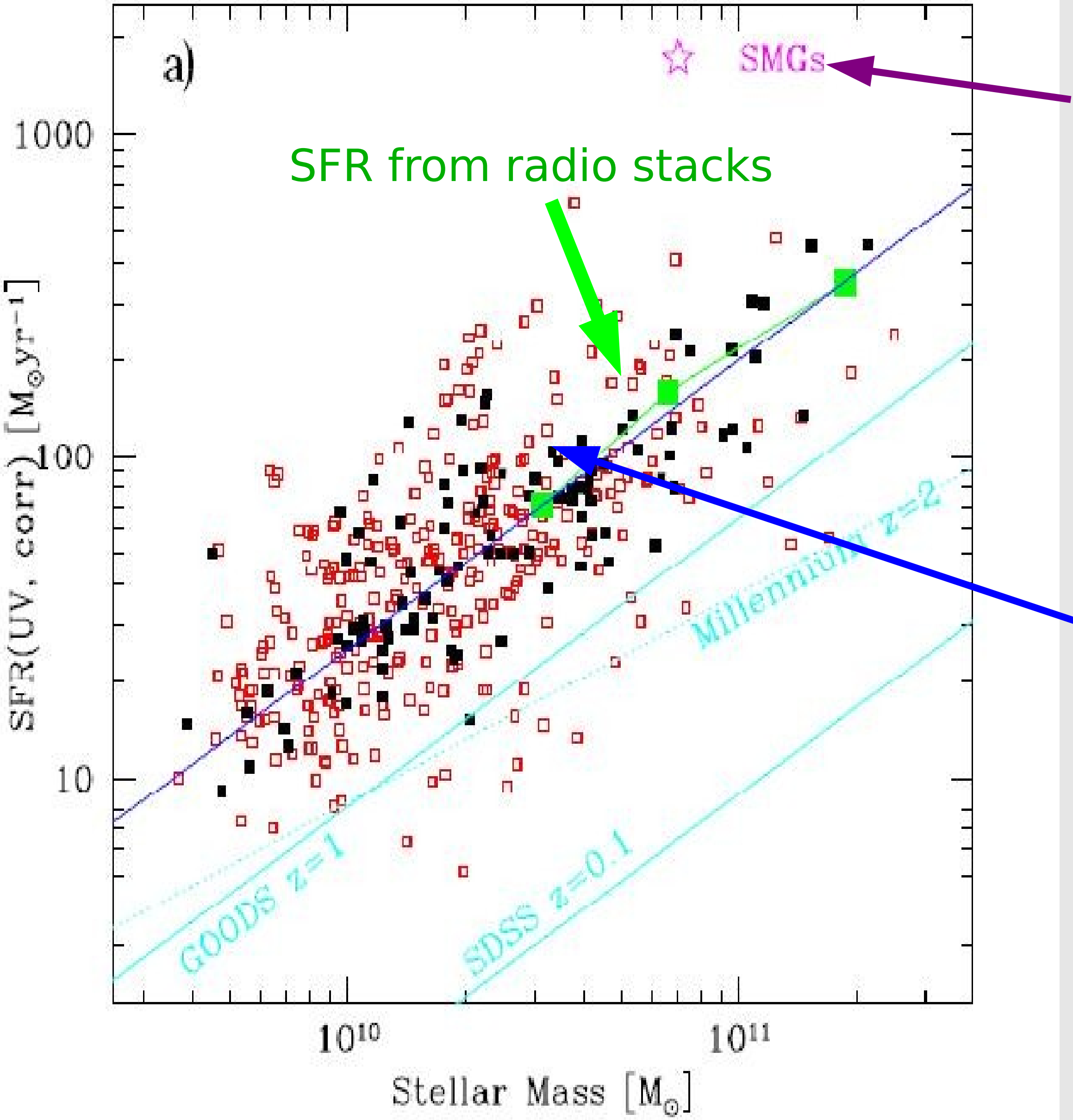
SFR vs Mass for ~1000 BzK Galaxies in the GOODS-South Field



SFR from rest-frame UV + extinction correction (Calzetti Law)

All mass & SFR data from Daddi et al. 2007!

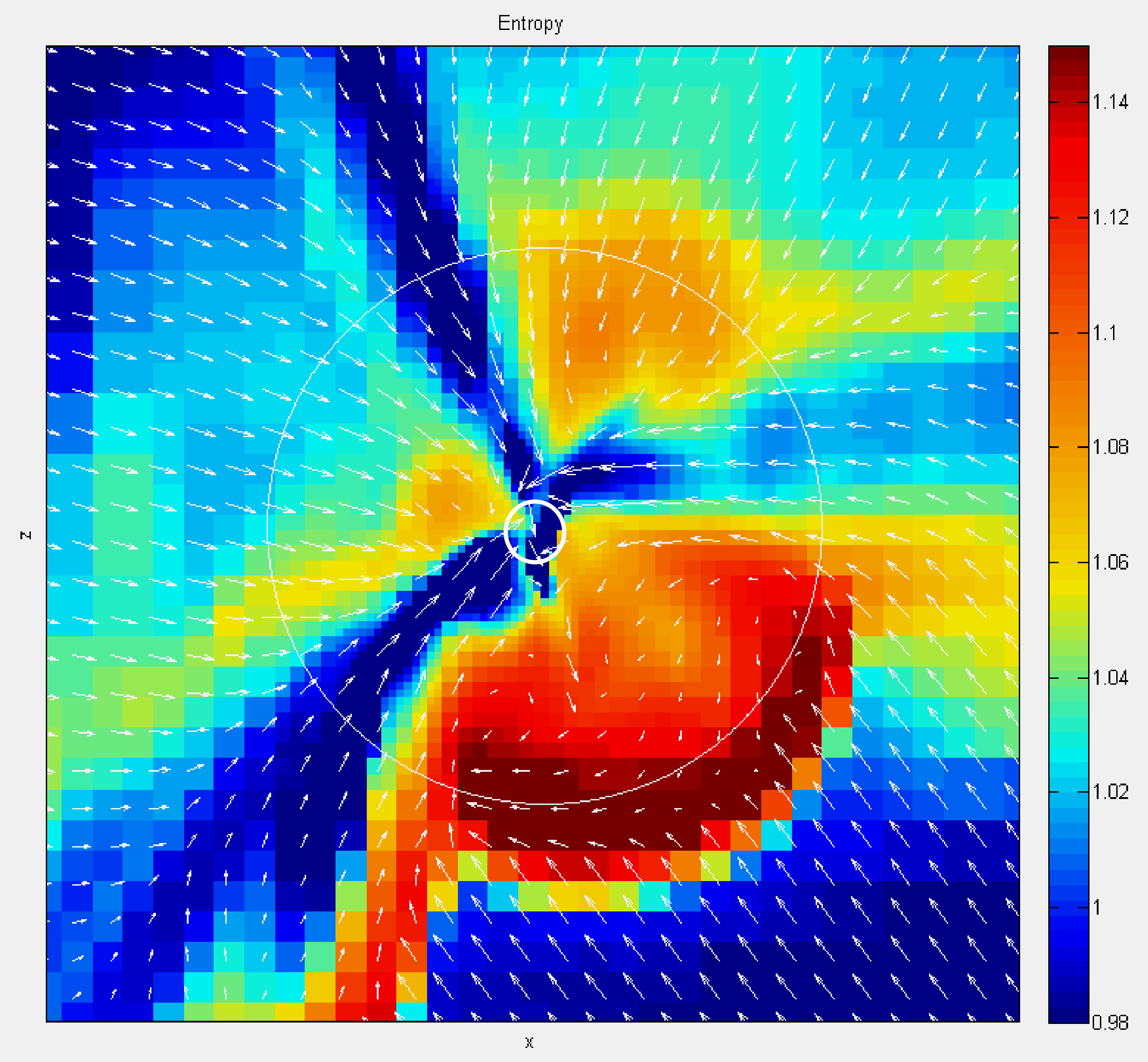
Starbursts or just High SFR?



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

$SFR \propto \sim M^{0.9+/-0.1}$ with very small dispersion!!!
No starbursting galaxies! just galaxies with high SFR, continuously fed by cold-stream accretion! (What's that?)

Feeding high rates of SF by cold streams in hydro-simulations



Not all gas is shock-heated to virial temperature (Binney 1977, PhD Thesis!! + 2004).

Cold Streams feed galaxies and sustain their SFR

Dekel et al. 2009

SFRs from Radio 1.4 Ghz VLA Data over the 2 sqdeg COSMOS Field

Pannella et al. 2009, ArXiv:0905.1674

Stacking 1.4 Ghz fluxes for ~34,000 sBzK galaxies, see photo-z's

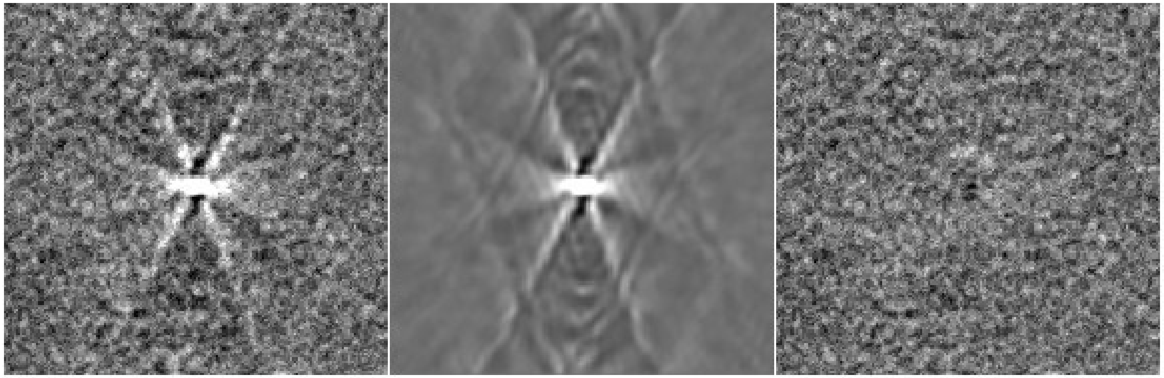
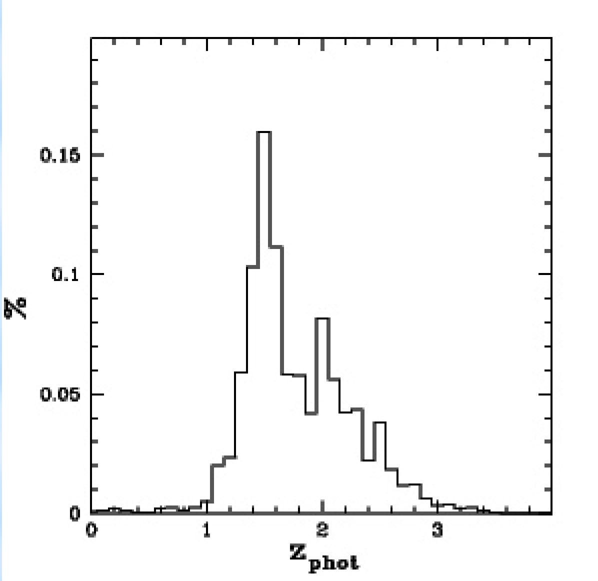
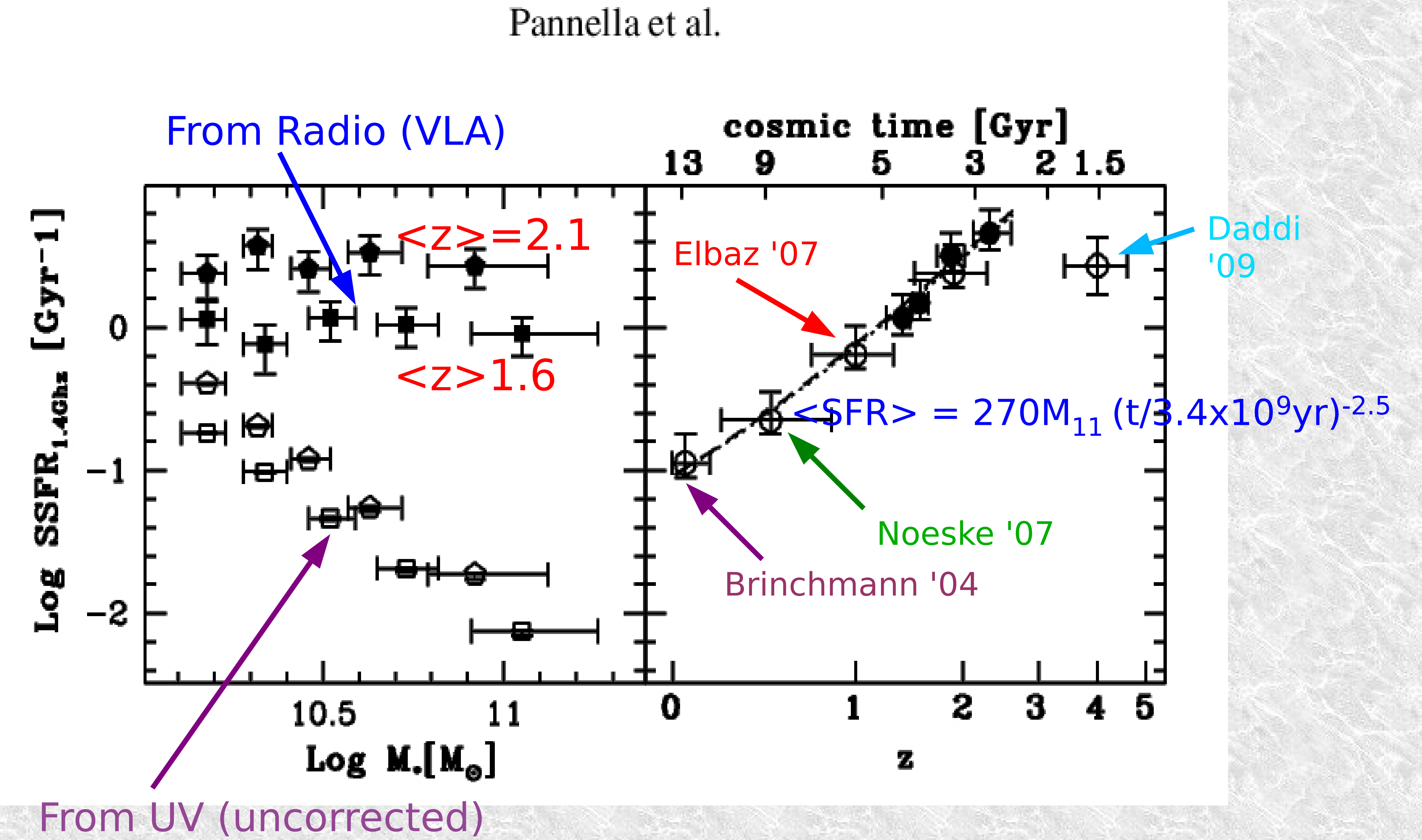


FIG. 2.— **Left:** Median stacking result of all the 34000 sBzK galaxies. **Middle:** Best fit dirty beam convolved Gaussian to the stacked data. The total flux recovered is 8.8±0.1μJy. **Right:** Residual image.

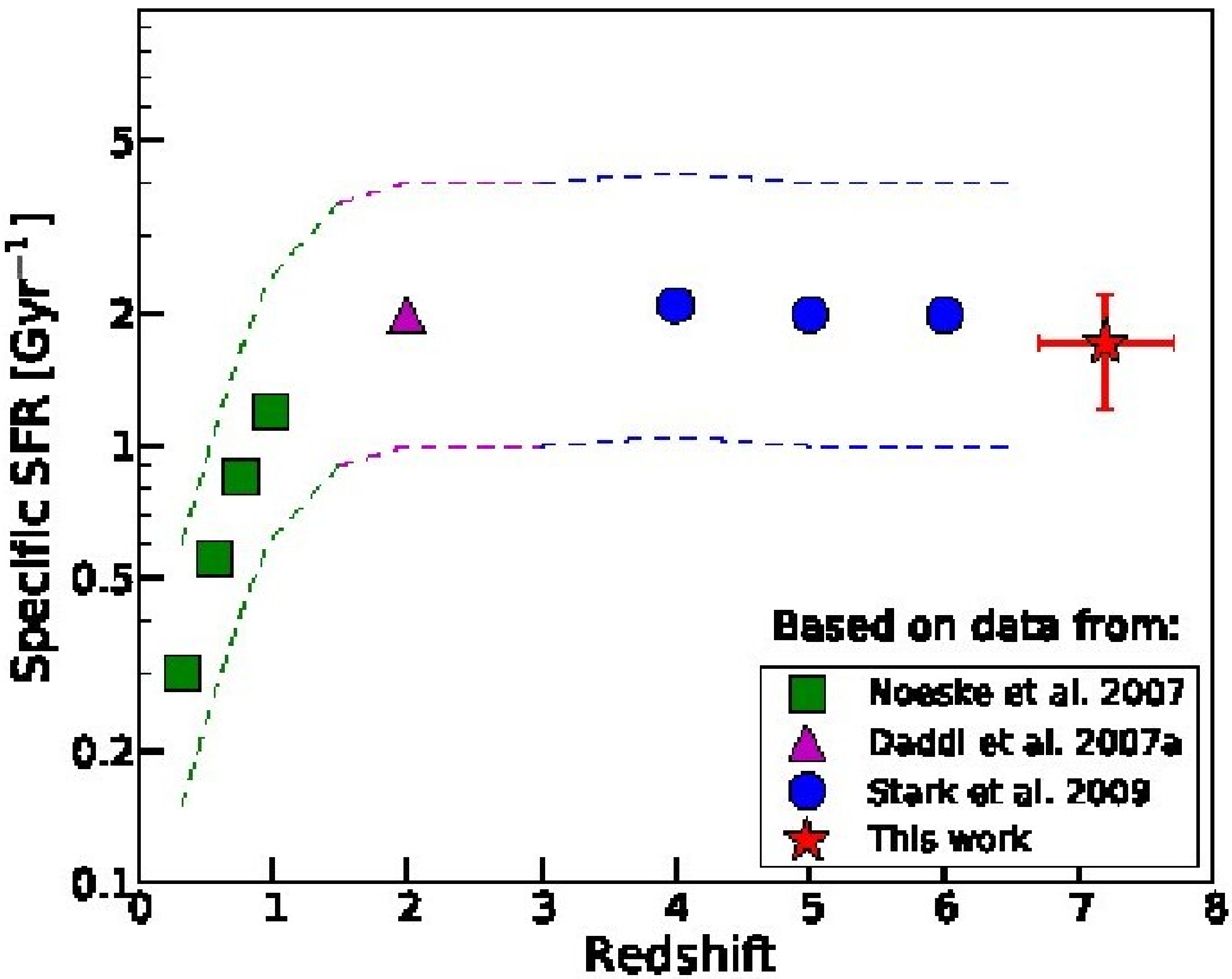


Then restricting to central 0.9 sqdeg with deep Chandra to exclude known AGNs

SFRs of sBzKs in COSMOS from stacked 1.4 Ghz flux



Gonzalez et al. 2009



Thus, we have an empirical SFR(M,t) which is closely followed by the vast majority of SF galaxies, from z~3 to z ~ 0

$\langle SFR \rangle = dM/dt = 270 M_{11} (t/3.4\times10^{9} yr)^{-2.5}$

The exceptions:

- Passive galaxies, with SFR ~ 0
- Starburst galaxies with SFR >> <SFR> (SMGs)
- Very, very few outliers

Hence, normal SF galaxies remain close to this relation from t~2 Gyr to t = 13.7 Gyr

For them we can legitimately integrate the Equation:

$$dM/dt = \mathbf{<SFR> \sim 270 M_{11} (t/3.4x10^9 yr)^{-2.5}}$$

Actually:

$$dM/dt = 270\eta\ M_{11}(t/3.4x10^9)^{-2.5}\ (M_\odot/yr)$$

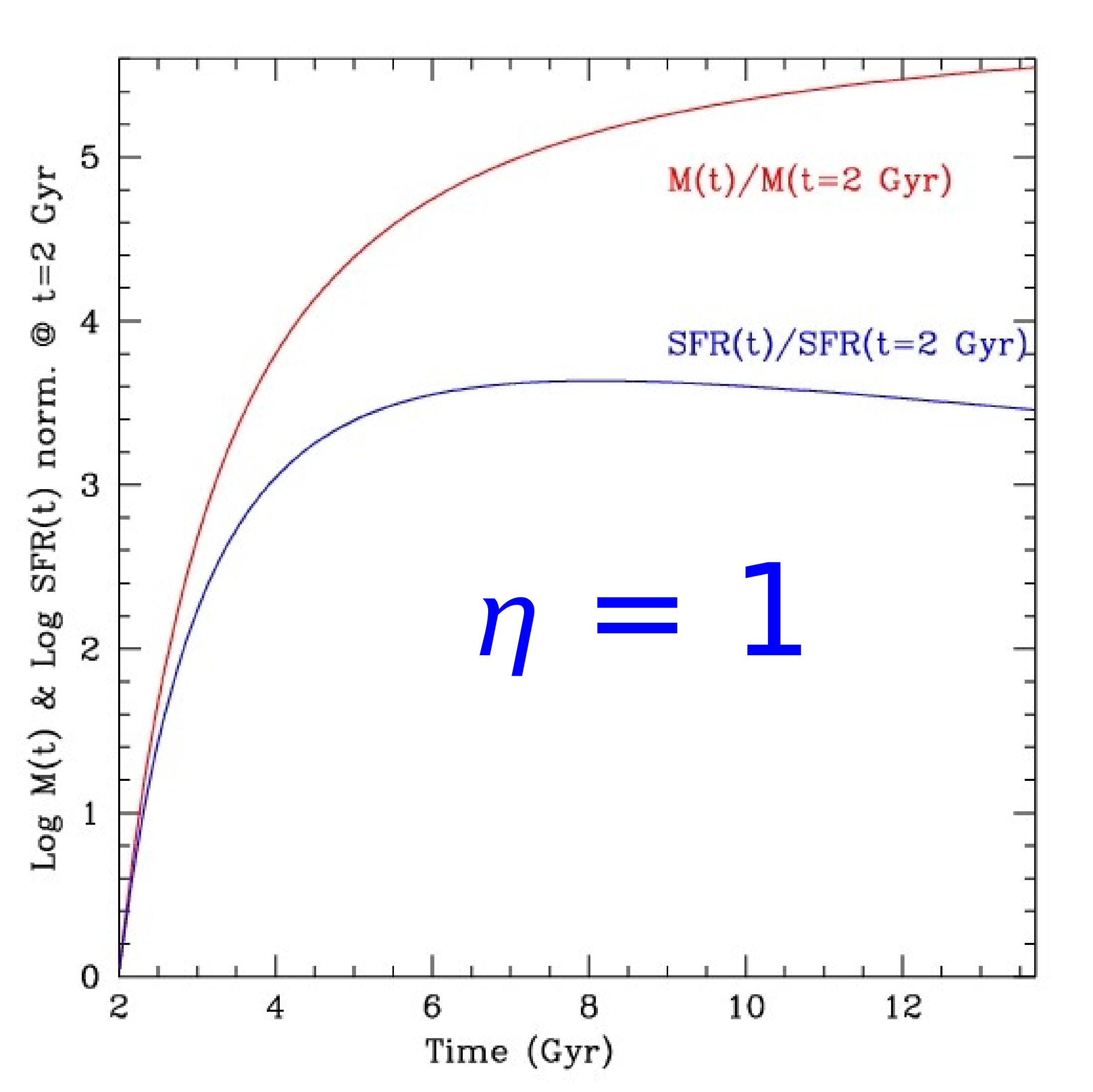
where η is meant to take into account for the systematic error in the estimates of the SFR, and more

$$M(t)=M(t=2\ Gyr)\ e^{13.53\eta}exp(-38.26\ \eta\ t^{-1.5})$$

The mass Growth Factor

The mass growth by SF alone (i.e. neglecting merging)

$\langle SFR \rangle = dM/dt = 270 M_{11} (t/3.4\times10^{9}yr)^{-2.5}$



With these SFRs galaxies would horribly overgrow!

Either our rates are wrong ... or something must happen:

We argue that what happens is that many galaxies turn passive hence stop growing.

But, not all galaxies that are SF at z~2—3 turn passive ellipticals! Many (most) galaxies remain SF out to z=0, without overgrowing!

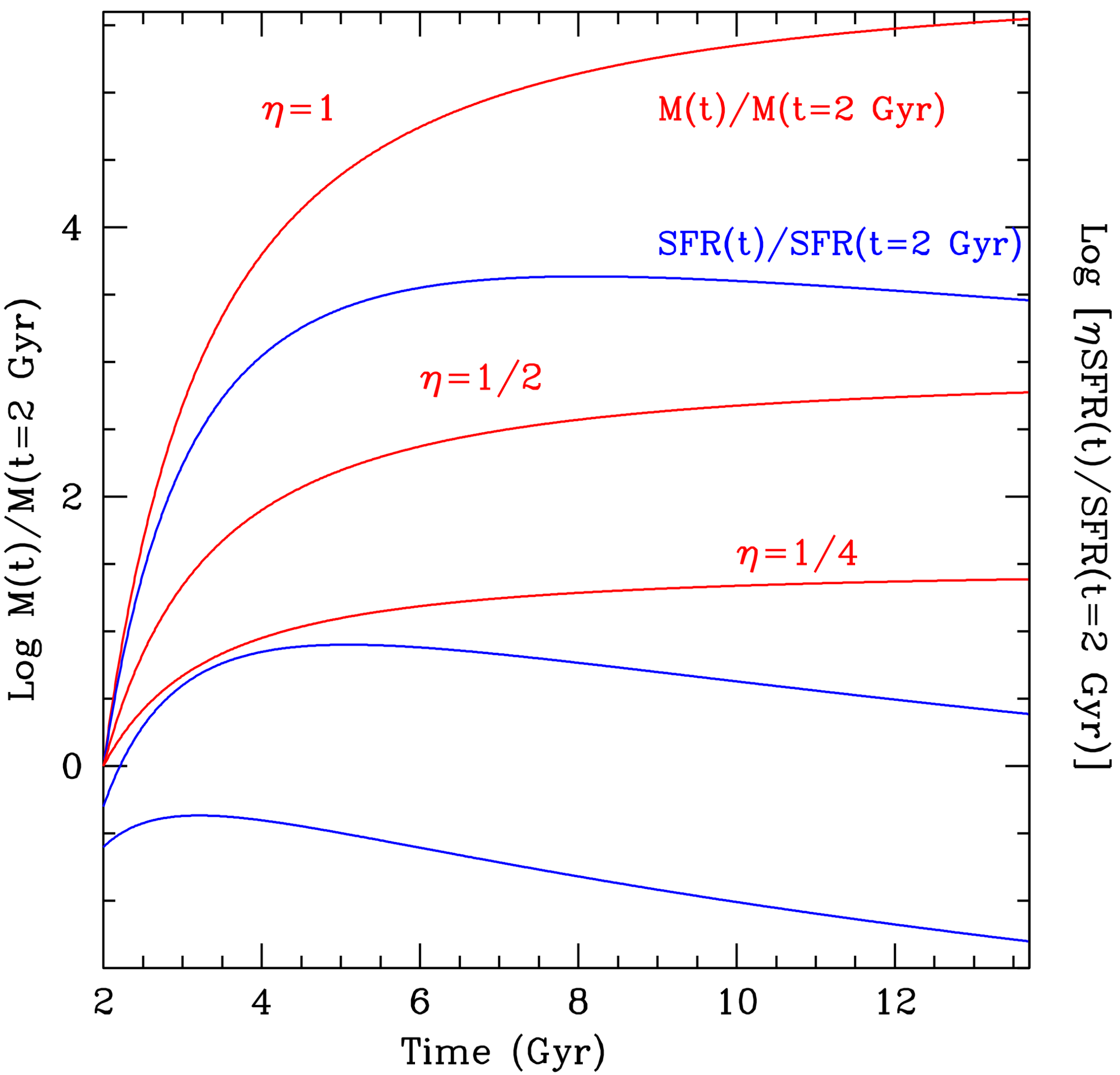
The “equation” <SFR> = f(M,t)

(with η =1)

cannot apply to all galaxies!!!

But, let us explore other values of the parameter η

The mass and SFR evolution depend dramatically on the normalization (η)



- We would need to know η (the SFR) far better than a factor ~ 2 in order to predict the evolution
- Maybe Pannella et al. have overestimated SSFRs by a factor ~2 (i.e. η ~ ½ may be a better value)
- Not all galaxies have the same η!!

The amplification of small systematic differences in η takes place because upon integration η jumps from here

$$dM/dt = 270\,\eta\, M_{11}(t/3.4\mathrm{x}10^{9})^{-2.5}\ (M_{\odot}/yr)$$

to here on the exponential

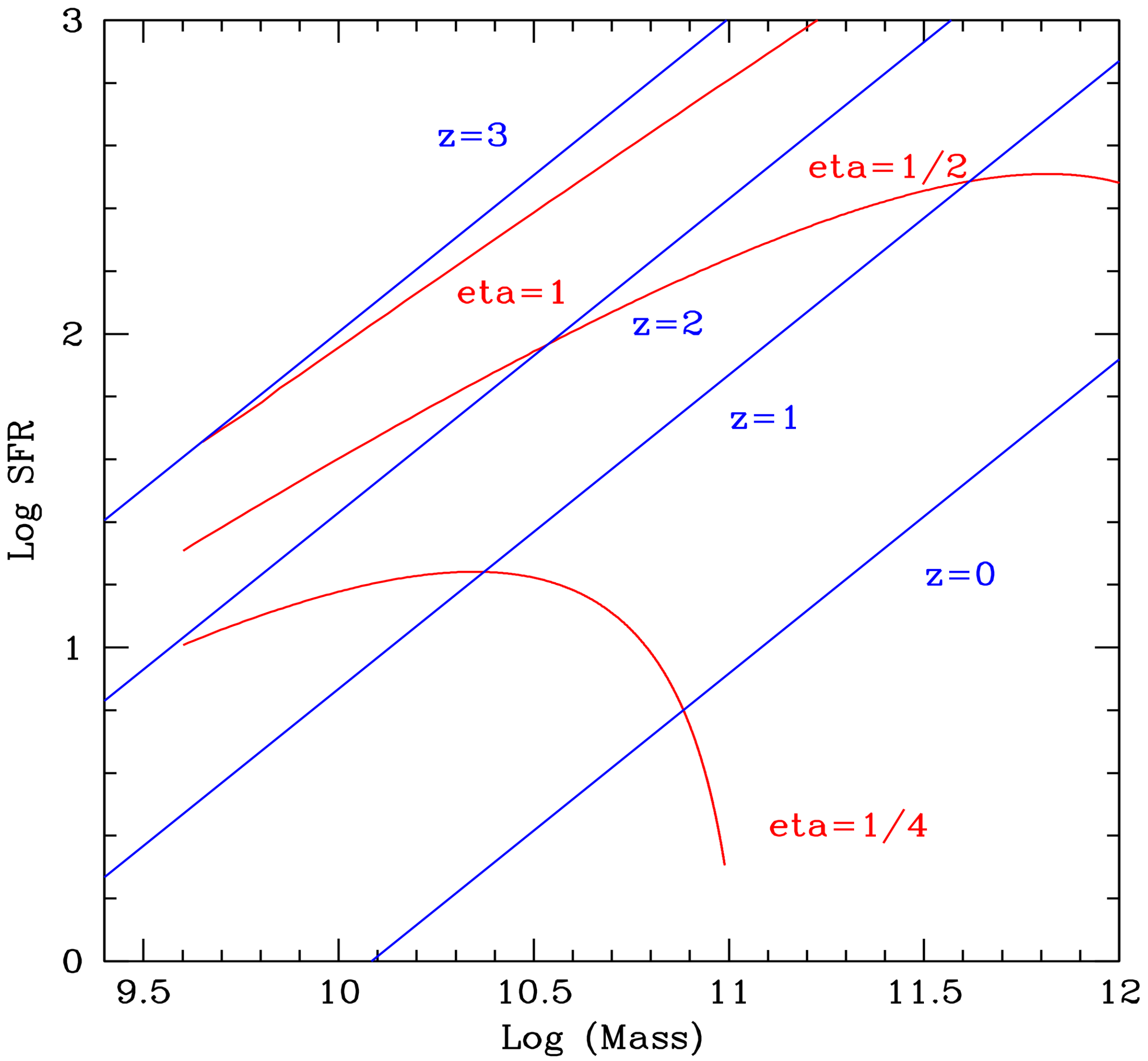
$$M(t)=M(t=2\ Gyr)\ e^{13.53\eta}\exp(-38.26\ \eta\ t^{-1.5})$$

a SSFR independent of mass works as an amplifier of small systematic differerences in the SSFR !

The conjecture (1)

- Galaxies with (time-averaged) η ~ above global average run into quasi-exponential mass growth, disks become unstable, clumps migrate to the center and a bulge/spheroid is formed, i.e., they become spheroid-dominated (ellipticals)
- Galaxies with (time-averaged) η ~ below global average avoid all that, and quietely keep forming stars to the present, i.e., they remain disk-dominated (spirals)

The evolution of 3 galaxies which start at z=3 (t=2 Gyr) with $M=4\times10^9\ M_\odot$ and 3 values of η



A difference by a factor of 2 in η makes a huge difference in the evolution.

If the global average of η=1, too many galaxies would run into runaway mass growth

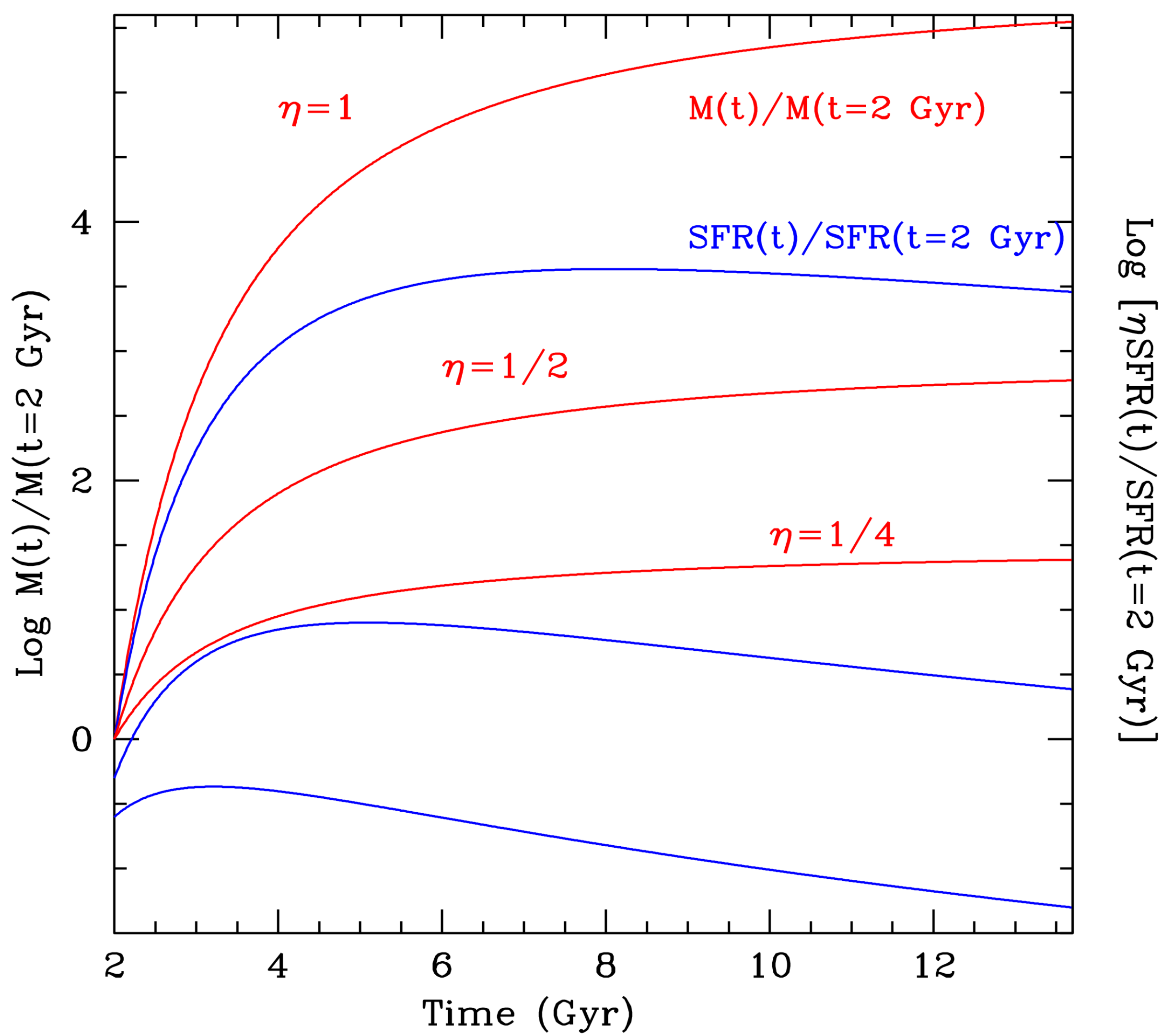
A global average $\eta \sim ½$ may result in a more fair proportion of ellipticals and spirals.

The conjecture (2)

- Why some galaxies should have systematically different η's from others?
- Well, difficult to imagine that η is a universal constant, i.e. That all galaxies follow exactly the same SFR(M,t) relation.
- Actually, the SSFR(t) certainly fluctuates up and down a factor of a few in the course of one's galaxy evolution (apart from merger-driven starbursts)
- And after all environment must matter, e.g. Galaxies in overdense regions have systematically higher (?) SSFRs compared to those in underdense regions
- This may help establishing the morphology-density relation (!?)

Differences in η are most important at early times

Note that most of the quasi-exponential growth takes place at the beginning, between t=2 and 3 Gyr (i.e. Between z~3 and z~2)



The Conjecture (3): Nature & Nurture in one formula

Nature (Mass matters!)

$$dM/dt = 270\,\eta\; M_{11}\,(t/3.4\times10^{9})^{-2.5}\;(M_{\odot}/yr)$$

Nurture:
the SSFR depends (slightly) on the local environment (overdense vs underdense regions)

Nurture:
the SSFR depends (strongly) on the global environment: the universe expands, baryons are shock-heated to high temperatures, cold streams dry out ...

Caveats and Open Ends

- The exponents of M and t in the "equation" may not be strictly 1 and -2.5, and may depend on redshift
- On top of this mergers must take place, hence this is only part of the story
- Downsizing in quenching star formation (massive galaxies turn passive first) does not follow naturally from this scenario (more physics is needed)
- What happens beyond $z=3$? i.e. In the first ~2 Gyr?

Summary

- Most SF galaxies at z<~3 follow a rather tight relation SFR(M,t)

- For them SSFR = SFR/M is flat with M

- This results in a dramatic amplification of (intially) small systematic differences in SFR, that may help understanding the dychotomy between passive spheroids (ellipticals) and starforming disks (spirals)
- ArXiv:0906.4628

La Frasetta Finale

- Riusciranno i nostri eroi di zCOSMOS a vedere se la SSFR a z~2 correla con l'environment? (local overdensity)
- Al momento, e per un bel po', sono gli unici in grado di provarci ...