Mass-Dependent Delays in Galaxy Formation

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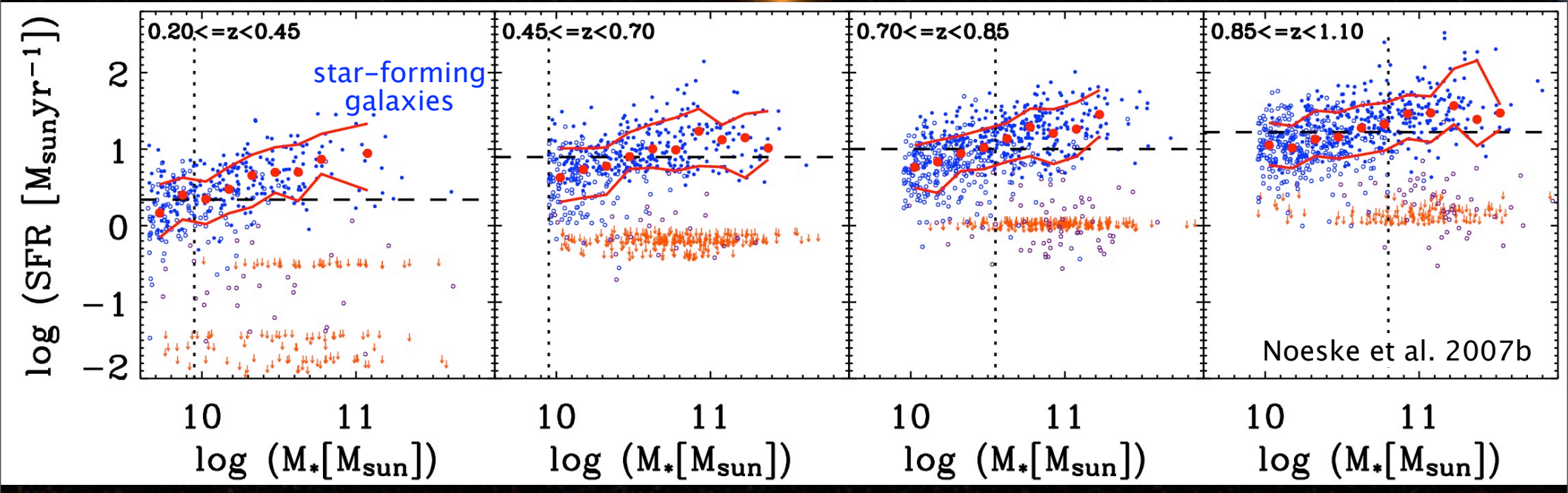
and the AEGIS collaboration

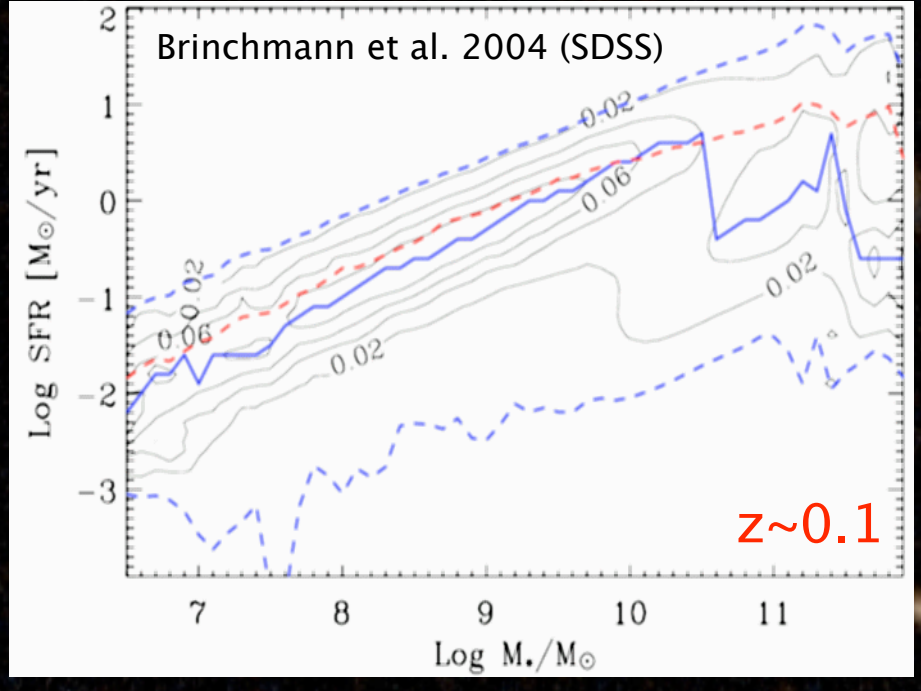
"The First Two Billion Years of Galaxy Formation"
Aspen, February 11, 2008

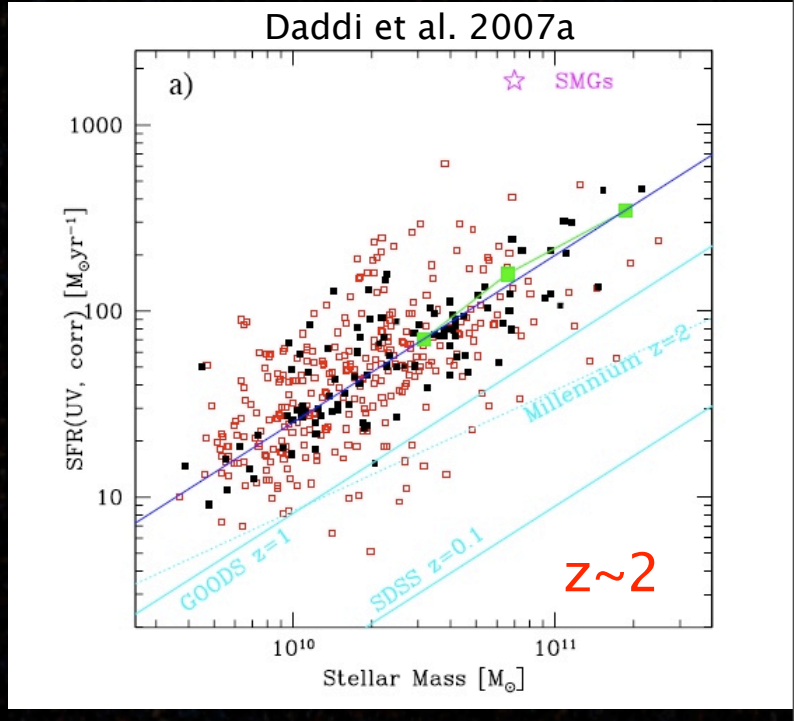
Deep Multi-Wavelength surveys allow for the first time to trace the history of star formation and stellar mass assembly to z>2

http://aegis.ucolick.org

The Star Formation Rate–Stellar Mass Relation("Main Sequence")







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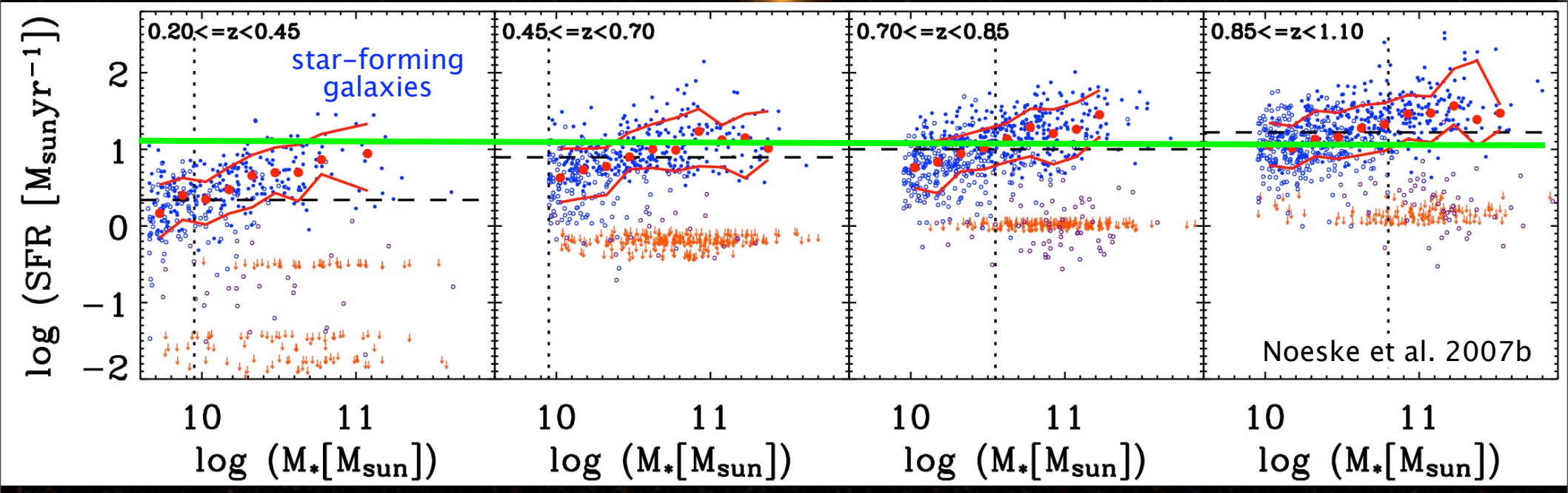


1) Star-forming galaxies form a defined relation:

SFR – stellar mass out to z>2.

(Generic mode of star formation in galaxies, prior to quenching of SF?)

2) Range of log(SFR) ~±0.3 dex (1σ) at all z:

starbursts had only a modest, barely evolving role out to z~2

3) Normalization evolves strongly with z:

evolution of SF since z~2 dominated by a gradual decrease of SFR

The picture of star formation since z<2
from deep multi-wavelengh surveys:

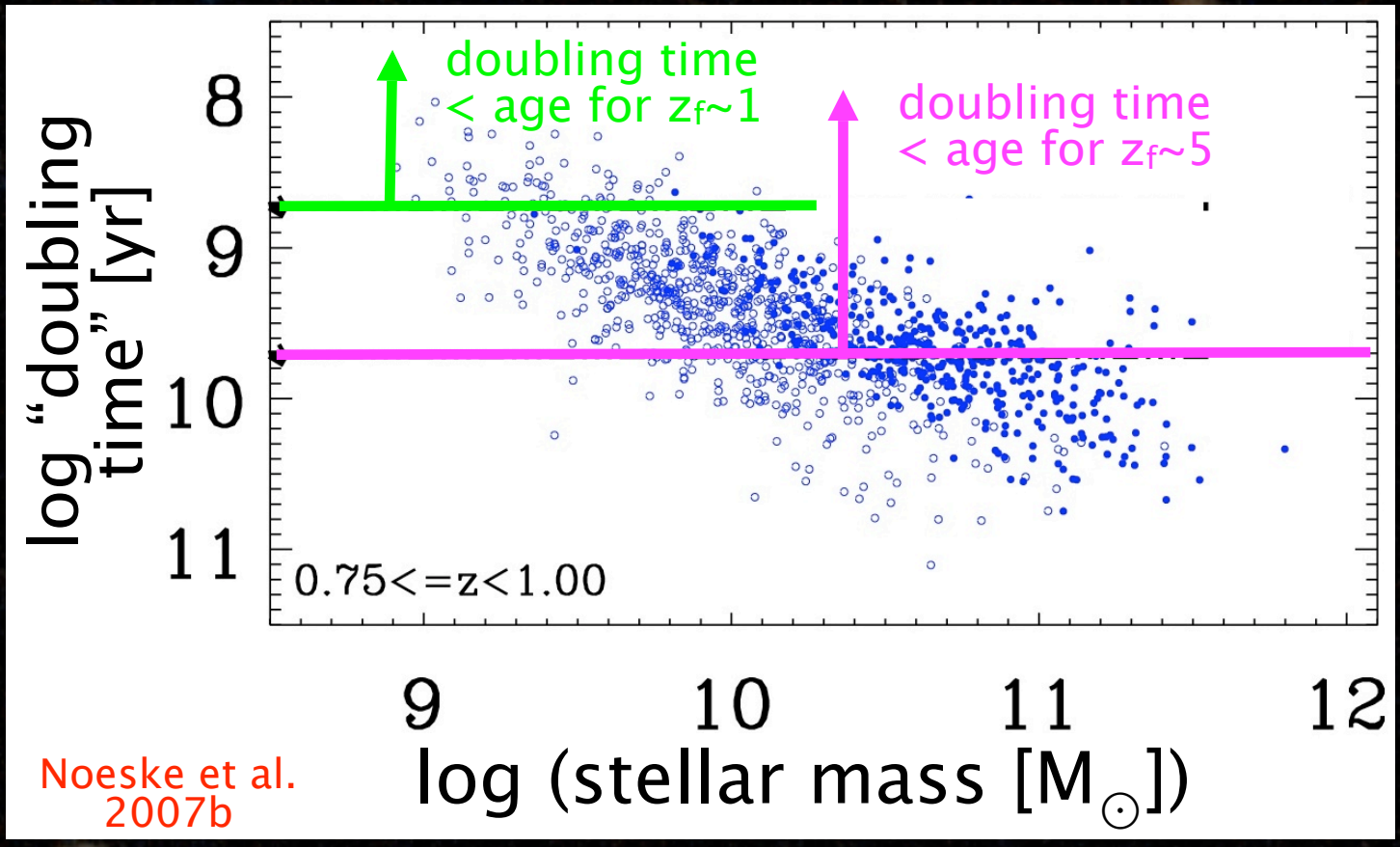
Mass-dependent, smooth, rather uneventful

Galaxies of similar mass had similar SF histories
(!pre-quenching!)

Take away for this conference (I):
Shortly after the first 2 Billion years, galaxies had settled into this pattern

Of Not-So-Massive Galaxies and Denver Airport:

The First Two Billion Years of Delays

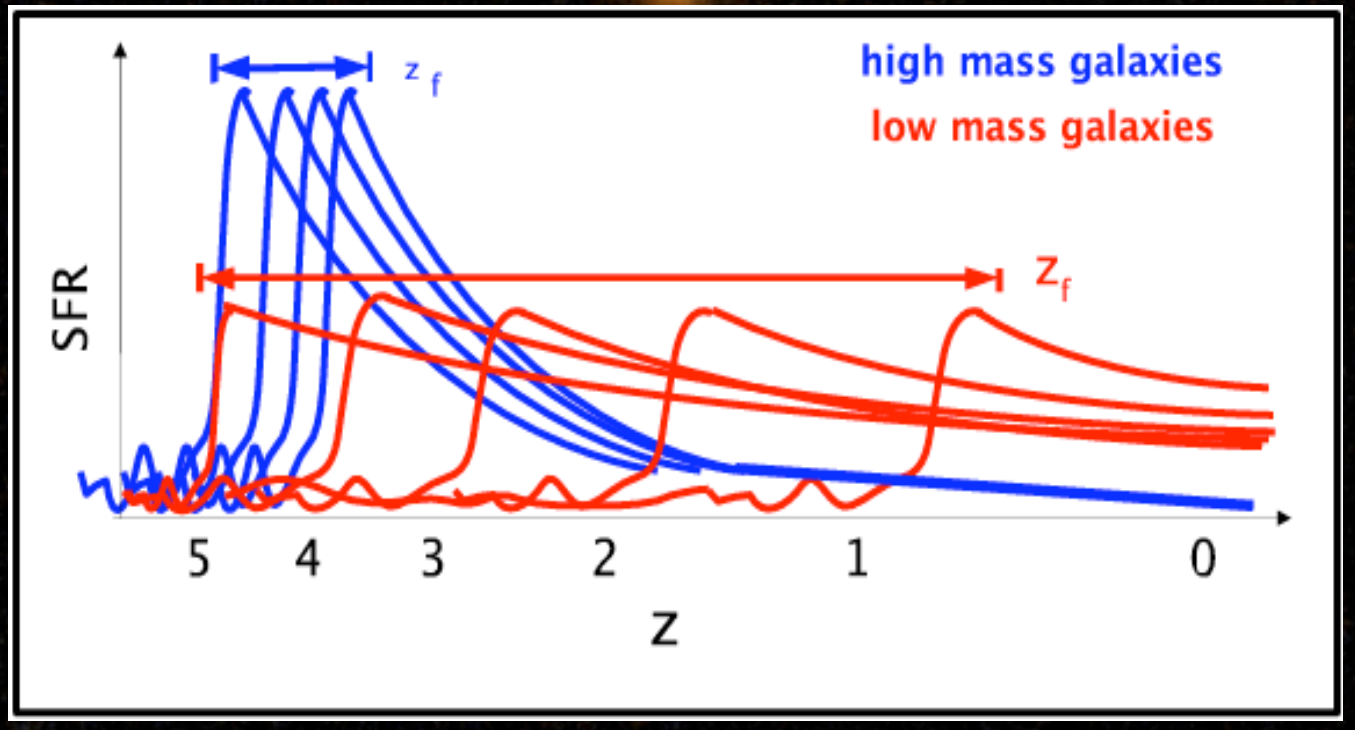


"Doubling Time Problem":

Given their SFR, low mass galaxies would produce their stellar mass in $t_d < t_H$:high SFR are not sustainable for ~t_H.

Simultaneous starbursts?
Not plausible, and inconsistent with gradual decline of SFR.

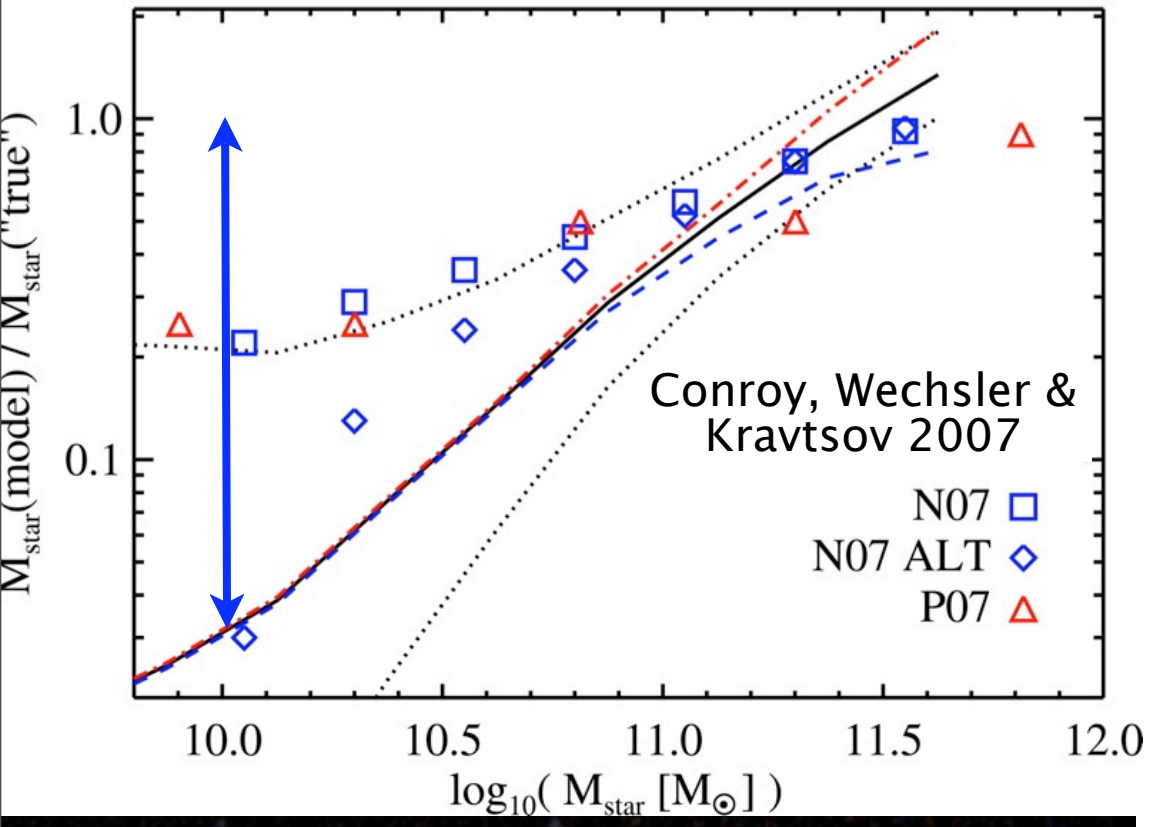
Only alternative: delayed onset of major star formation in many less massive galaxies

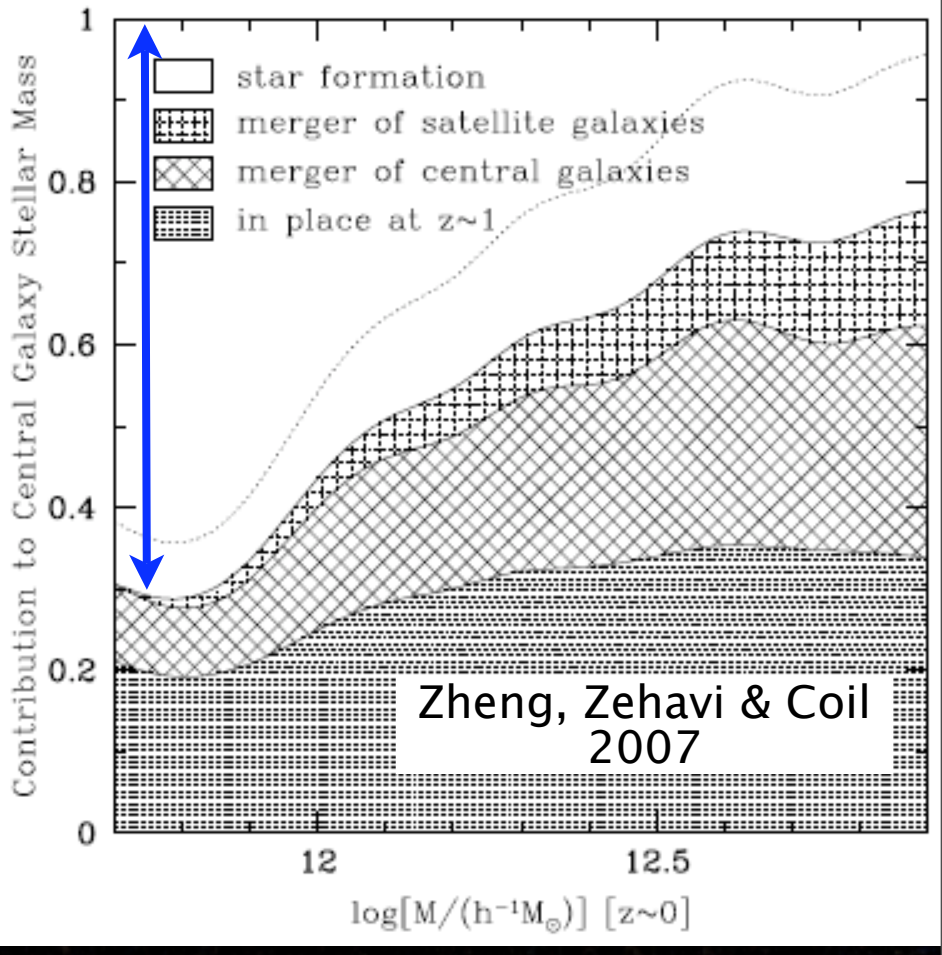


Less massive galaxies start major SF on average later:
Onset of SF (z_f) more broadly distributed from high to low z

("Staged galaxy formation")

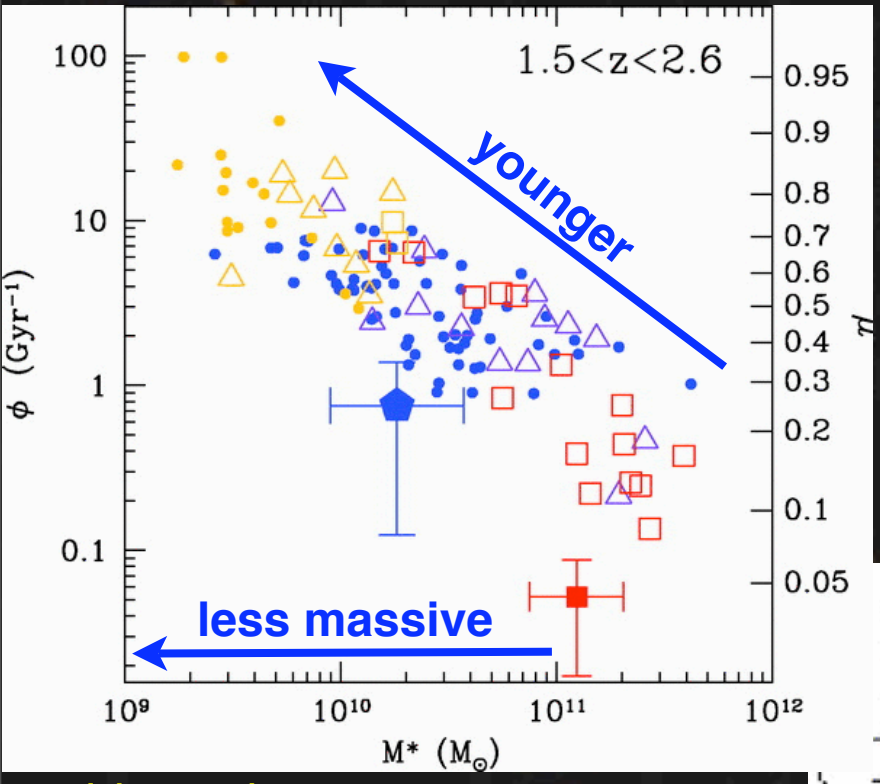
Independent evidence: combining cosmological simulations with stellar mass functions at z=0 and 1



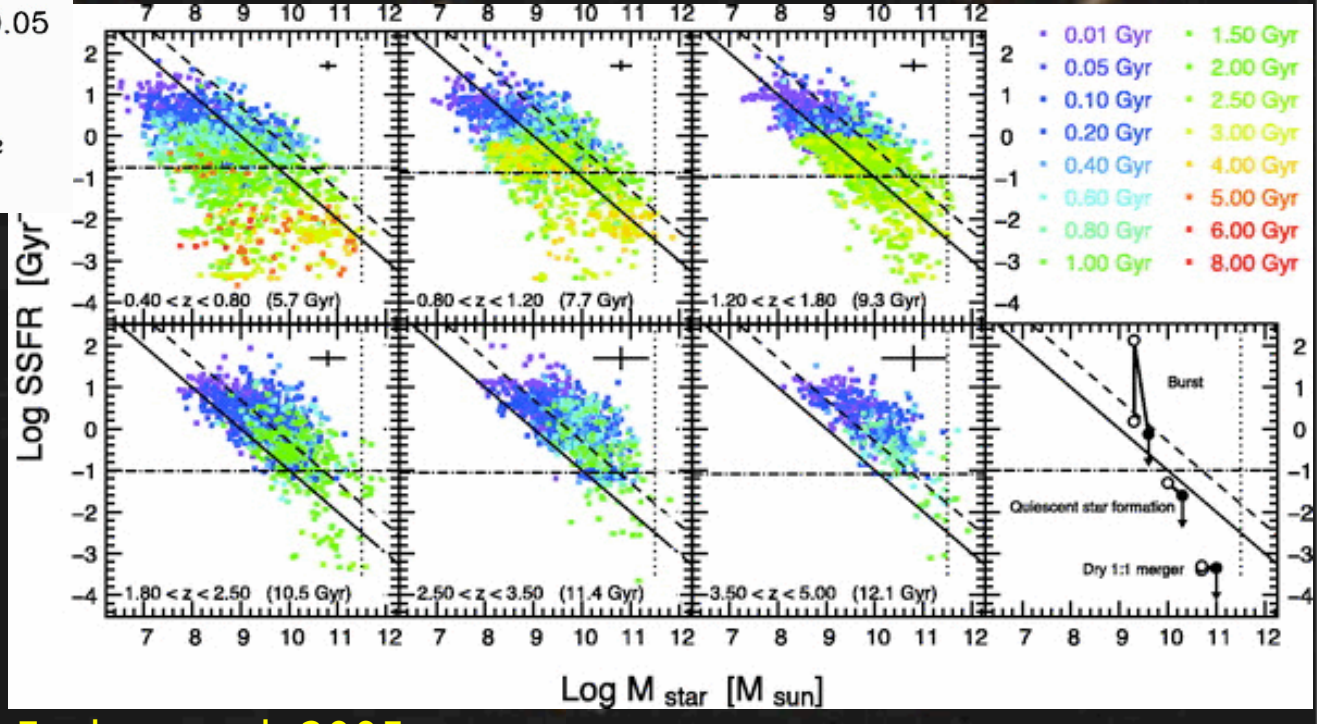


Today's low-mass galaxies (<10^{10} M_{sun})
formed more than 70-80% of their stellar mass since z~1
-> late onset of major star formation

Stellar populations of high z galaxies: more recent onset of SF in less massive galaxies



Reddy et al. 2006



Feulner et al. 2005

Possible Origin of mass-dependent delays?

1) Cosmological assembly history ?

Neistein et al. 2006: Observed Downsizing of SF with time requires baryonic processes that decouple the histories of star formation from those of halo assembly.

(Example: threshold halo mass for SF; needs to increase with z, and be >> M_{min} for HI cooling)

2) Current understanding of baryon physics?

Dave 2007: Current SAMs and hydro simulations do not reproduce the observed evolution of SFR.

Model SFR are too low at z~1 and z~2

(see also Elbaz et al. 2007, Daddi et al. 2007)

A delay in SF would help, but is hard to reconcile with physical understanding of gas accretion and star formation.

Tentative Conclusion:

Either our understanding of high z SFR is fundamentally wrong

(entirely possible - e.g. evolving IMF, Dave 2007),

Or we may not yet understand fundamental processes

(if LCDM correct, likely baryonic)

that delay or partially suppress SF

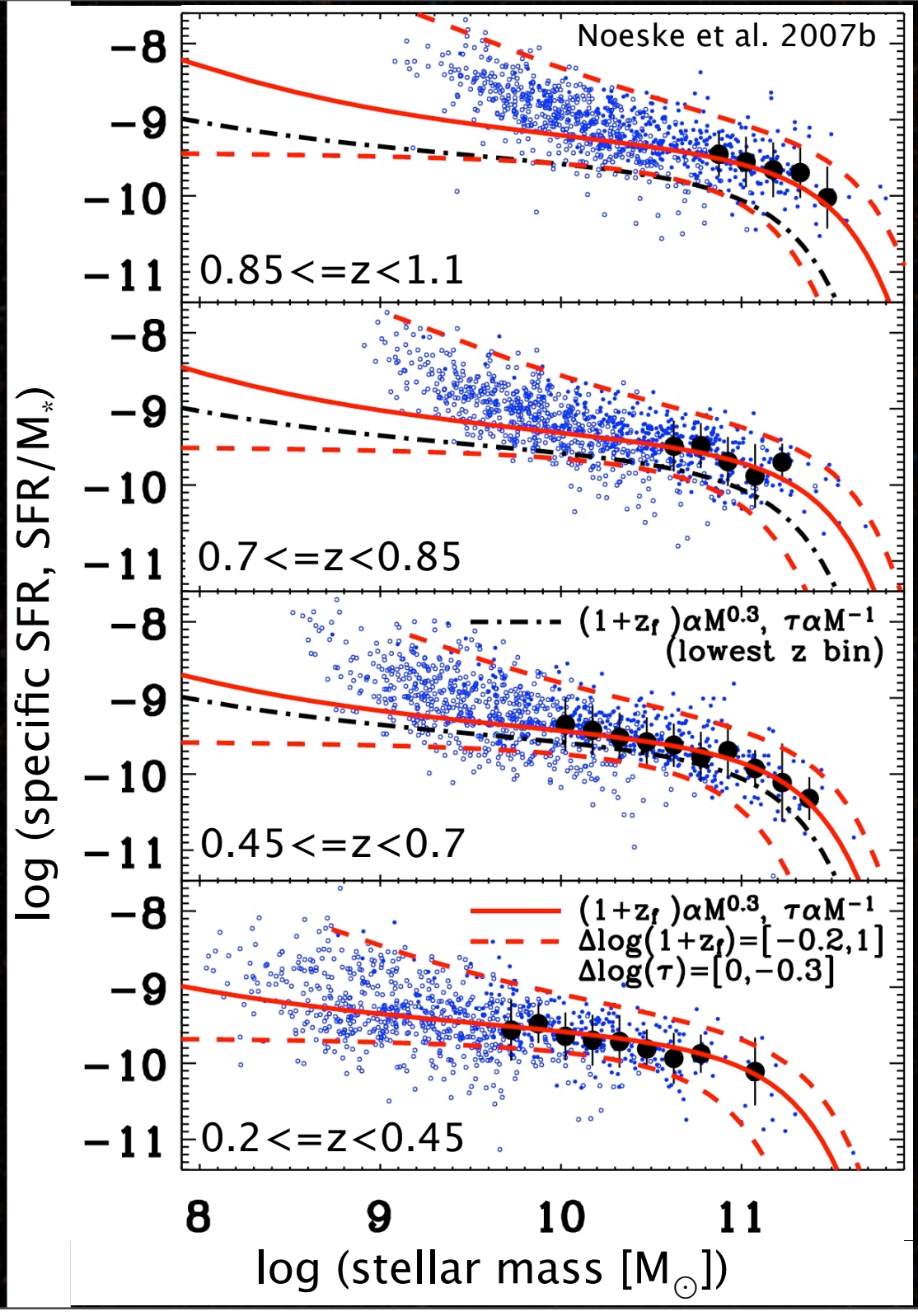
in a mass-dependent way

Note:

- common treatments of SN feedback: apparently not sufficient
- suppression of gas cooling by the UV background: works only for very low mass halos

-> Talk by A. Kravtsov

Observational constraints from the SFR–$M_{stellar}$ relation



AEGIS model of SF histories

Exponential SF histories

τ and z_f mass-dependent (power laws)

low mass galaxies form stars slower and start later

("Downsizing" needs 2 components!)

Parametrization tool, provides an average mass-dependent reference SF history

SFR-$M_{stellar}$ relation encodes mass-dependent clock of galaxy star formation

(similar MS in the HRD)

Observational calibration is tricky:
Depends on understanding of star formation rates at z>0.

In progress: quantify SFR-$M_{stellar}$ relation by combining SFR measures that are currently used in the community

-> bracket parameter space

Take away for this conference (II):

Evidence for a mass-dependent delay of major star formation in galaxies.

If our understanding of high z SFR is roughly correct, then we may be missing important physics that causes this delay.

During the first 2 Billion years, a considerable fraction of less massive galaxies were probably not or barely there.