Star Formation in Field Galaxies since z=1

A quiescent, mass-dependent history

Kai Noeske, CfA

KITP, 18 Sept 2007

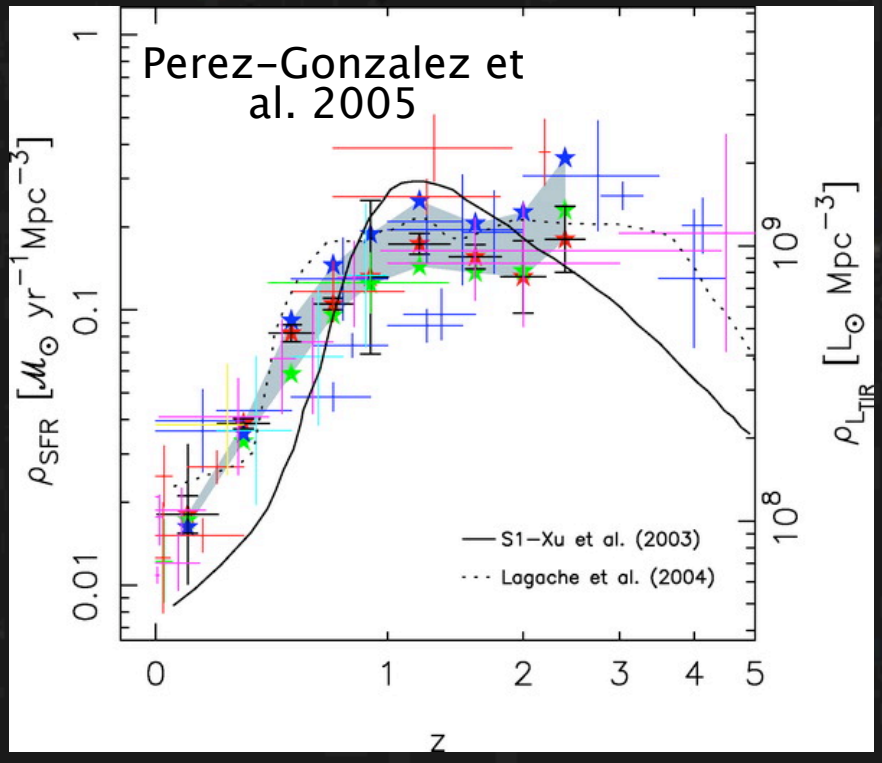
... and thanks so much for inviting!!!

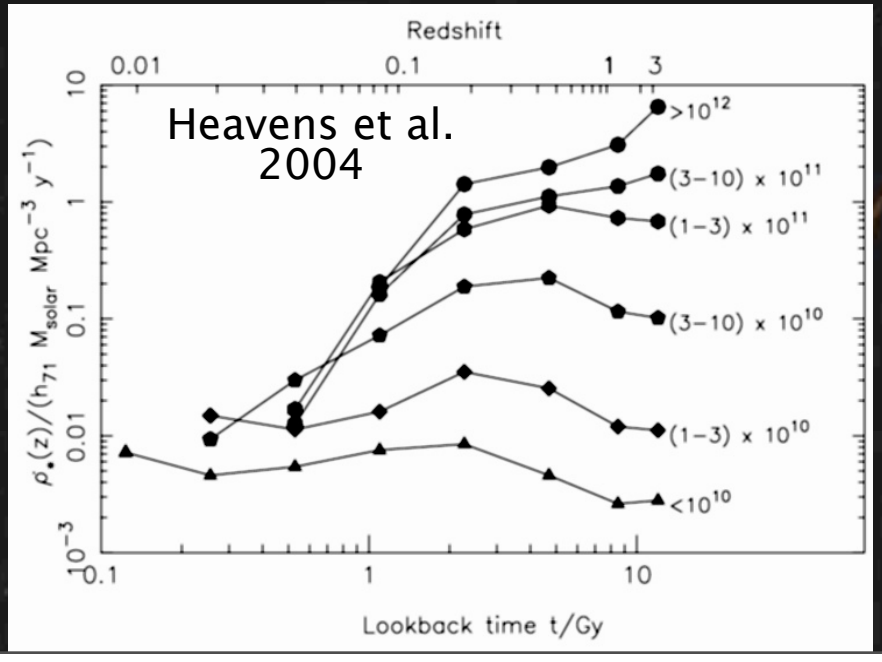
AEGIS
All-wavelength Extended Groth strip International Survey

CfA

I. Why bother?

Star formation since z~1





Co-moving star formation rate density declined by ~x10

proposed: driven by increase of glaxy merger rate with z

Bell et al. 2005

Mass dependence:

massive galaxies formed bulk of stellar and early, less massive galaxies formed on longer timescales

Understanding star formation on galaxy-wide scales

(evolution of light and chemistry in the Universe,

illuminates DM, the evolution of clustering, cosmology, etc.)

Theory:

- no complete understanding on small scales,
- gas dynamics: cooling/accretion, feedback, winds, ...
- CPU /resolution limits in 'true' cosmological simulations
- semi-empirical treatment (Schmidt Law or similar);

efficiency, feedback, timescales, etc. at z>>0?

Observations:

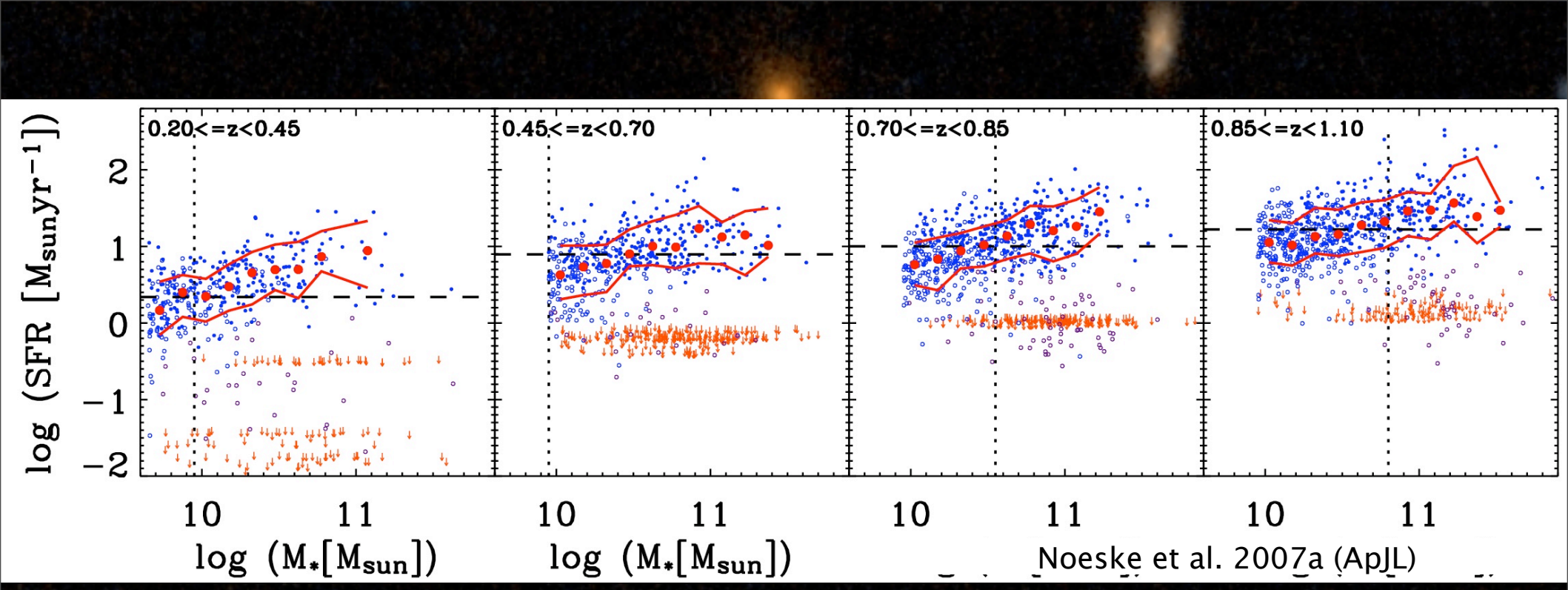
rapidly improving, but still no comprehensive picture at z>>0:

Starbursts? Mass dependence?

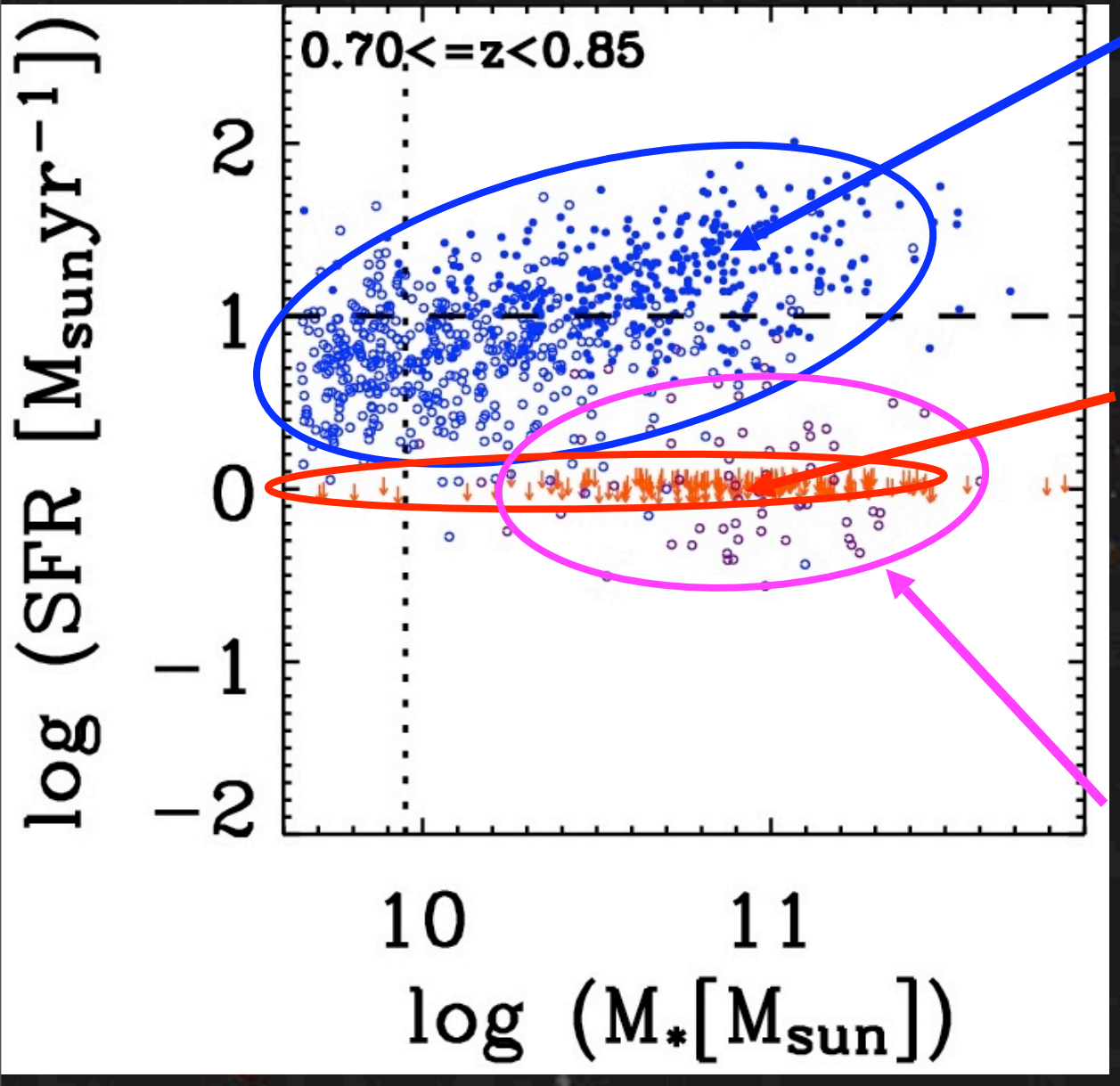
II. New deep multiwavelength surveys: a more complete view

The All-Wavelength Extended Groth Strip International Survey

- DEEP2:Keck /DEIMOS spectra: ~10,000 precision redshifts, galaxy kinematics
- HST V,I (700 sq arcmin-2xGOODS)
- Very deep:
  - Spitzer (IRAC, MIPS)
  - GALEX (NUV, FUV)
  - Chandra ACIS
  - VLA 20cm
- Ground-based deep U- to K-imaging
- aegis.ucolick.org
- Release Aug 2007, ApJ special issue & press releases out


0.20<=z<0.45
0.45<=z<0.70
0.70<=z<0.85
0.85<=z<1.10
log (SFR [M_sun yr^-1])
log (M*[M_sun])
Noeske et al. 2007a (ApJL)

A more detailed view of star formation properties



1) Fiducial star-forming galaxies:
24μm sources, or
blue emission line galaxies
(~2/3 of sample)

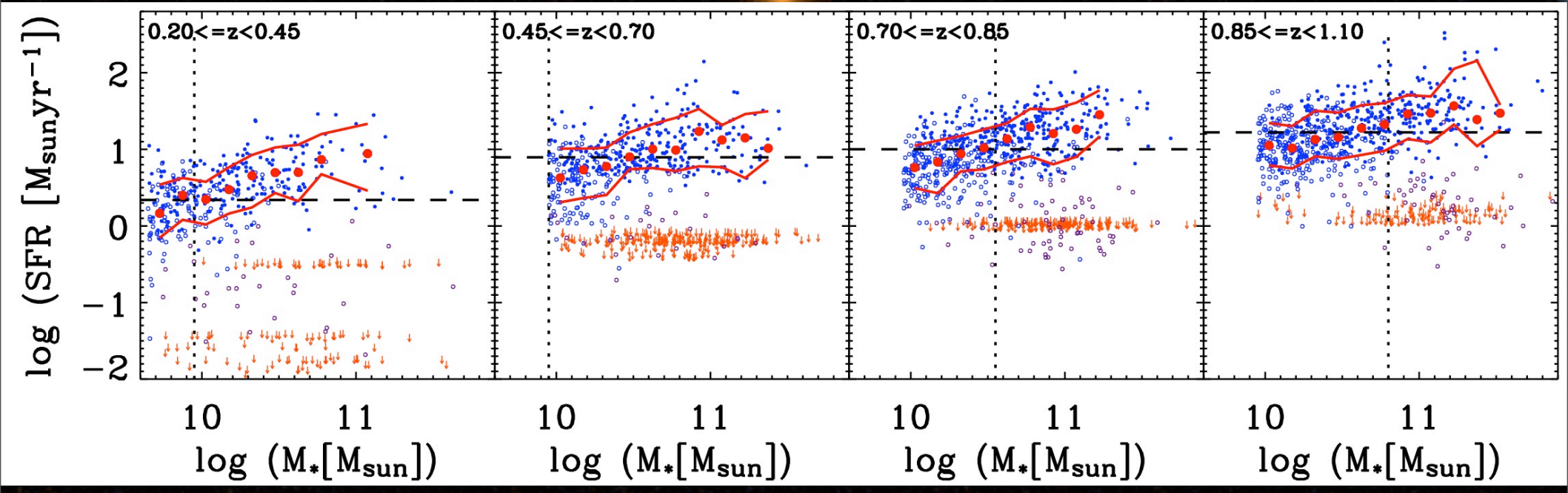
2) Galaxies not detected in 24μm or emission lines:
red sequence, early-types
not significantly star-forming
(~1/3 of sample)

3) Galaxies with no detection in 24μm, but weak emission lines:
red sequence, 2/3 early-types
large fraction LINERs/AGN ;
(<20% of sample)

III. The "Main Sequence" of star-forming galaxies

and how it tells us how SF mostly happened

“Main Sequence” of star-forming galaxies



The majority of star-forming galaxies form a defined sequence with a limited range of SFR at a given stellar mass and redshift.

SFR ~±0.3 dex (1σ)

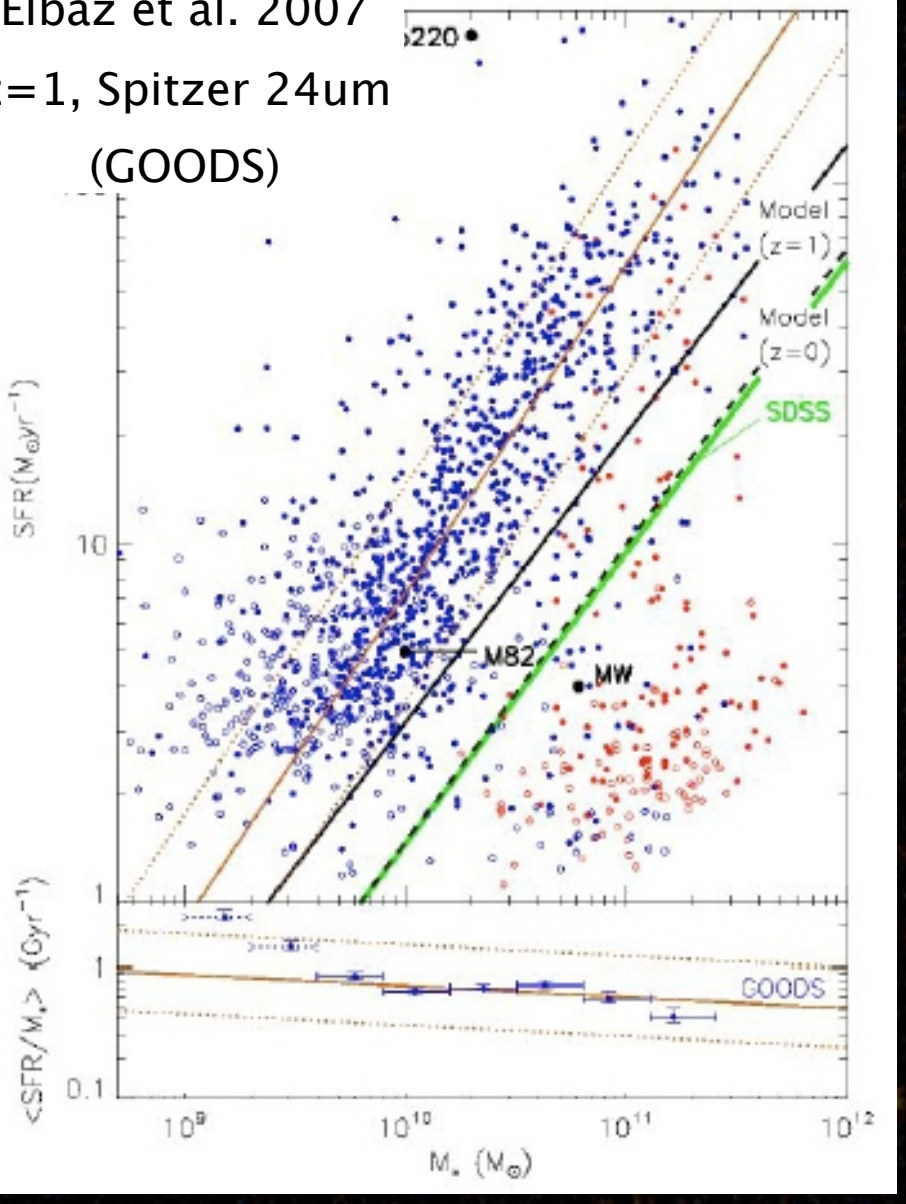
“Normal” star-forming galaxies,

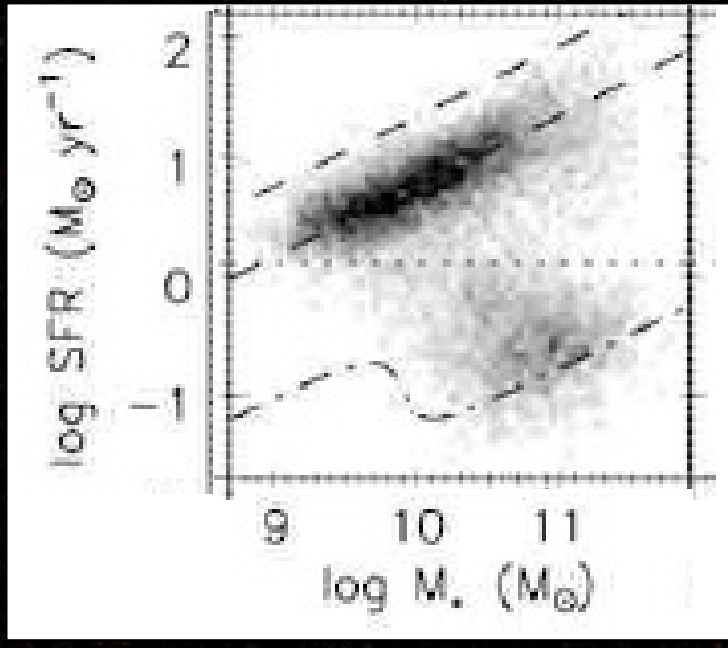
– prior to quenching of star formation – ?

“Main Sequence” found to z>~1 for different tracers of SFR, stellar mass larger mass range

Elbaz et al. 2007

z=1, Spitzer 24um (GOODS)

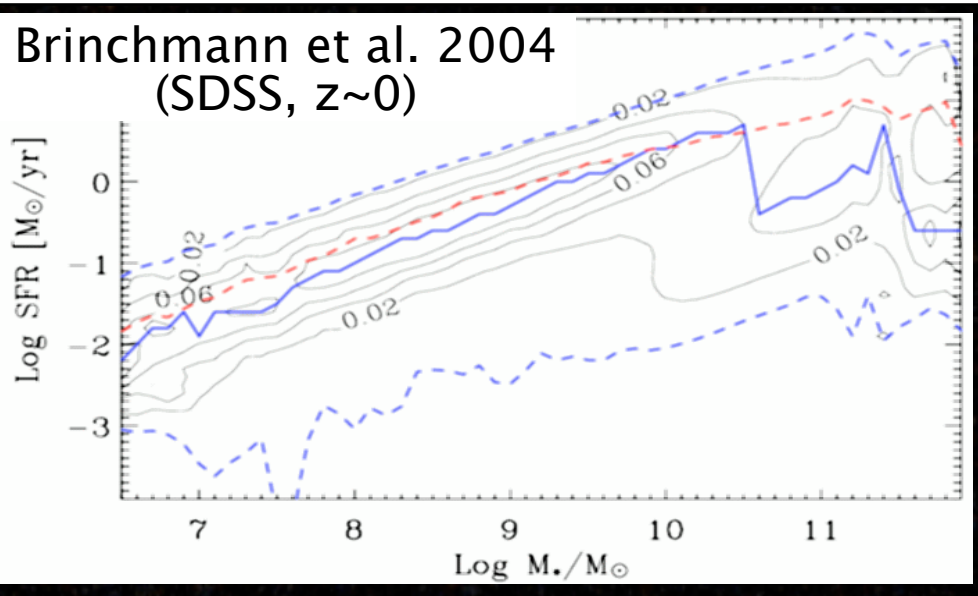




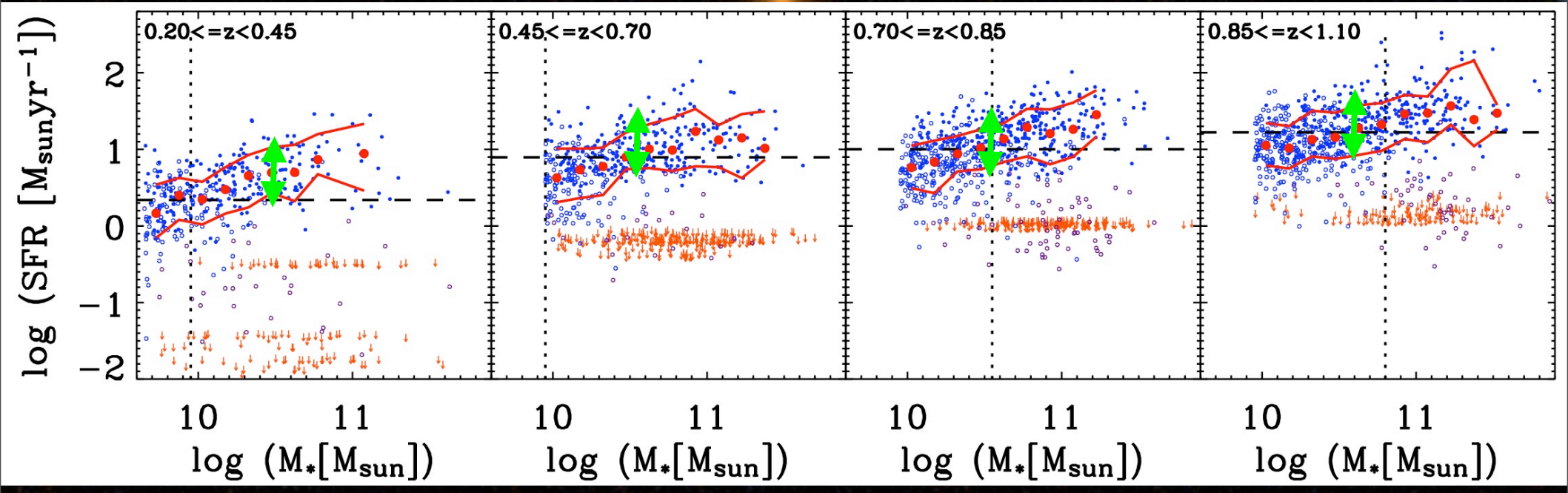
Zamojski et al. 2007

z=0.7, GALEX/ COSMOS

Brinchmann et al. 2004 (SDSS, z~0)



A defined Main Sequence with similar range of SFR to z~1:



1) Limit on the amplitude of SFR variations/starbursts:

Galaxies are 2/3 of the time

within a factor of ~2

of their average SFR at that z

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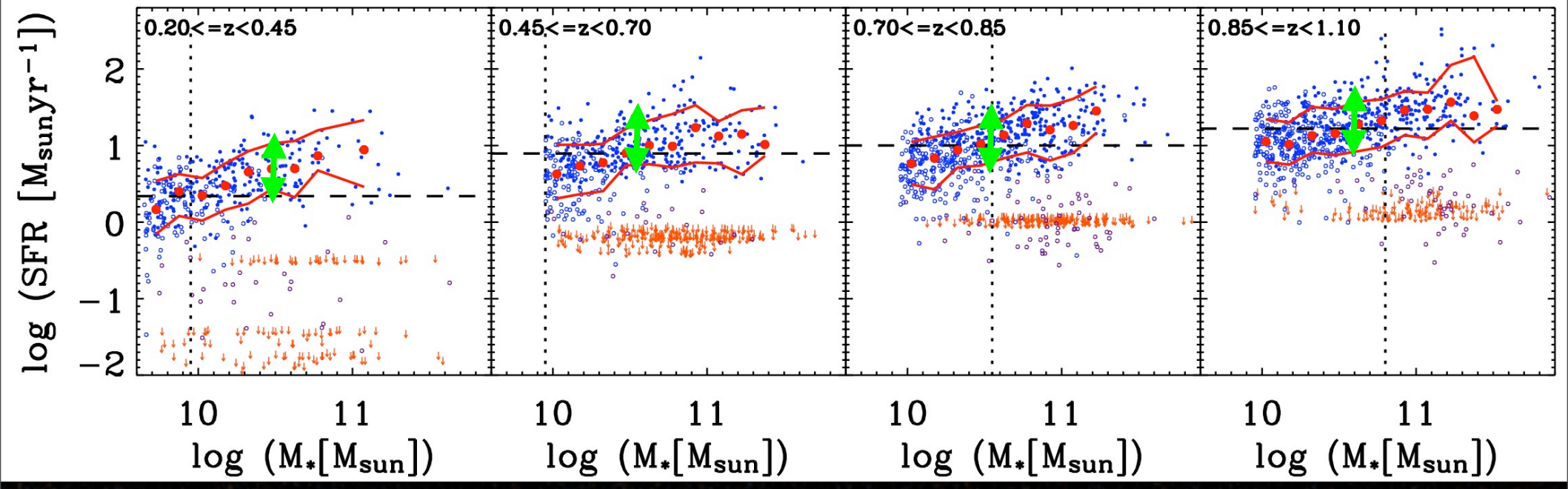
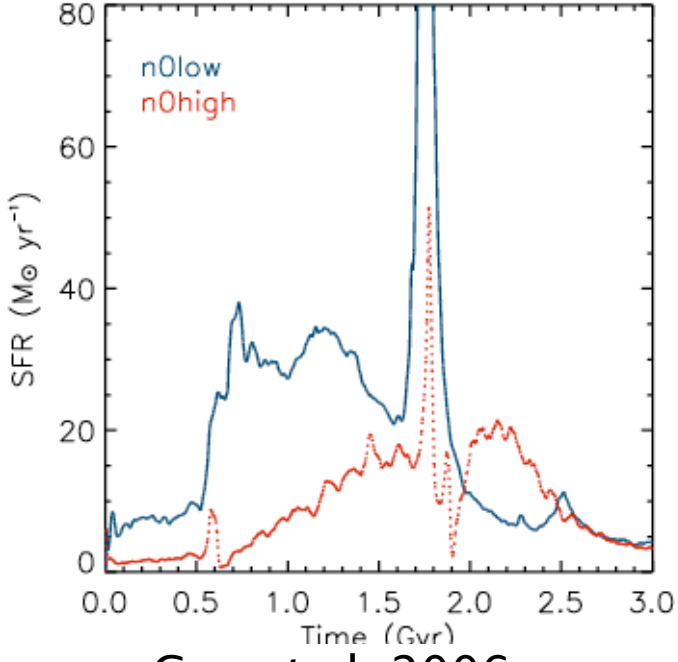


1) Limit on the amplitude of SFR variations/starbursts:

Galaxies are 2/3 of the time
within a factor of ~2
of their average SFR at that z
(limit to effect of mergers on SFR,
constrains feedback in simulations)



Cox et al. 2006

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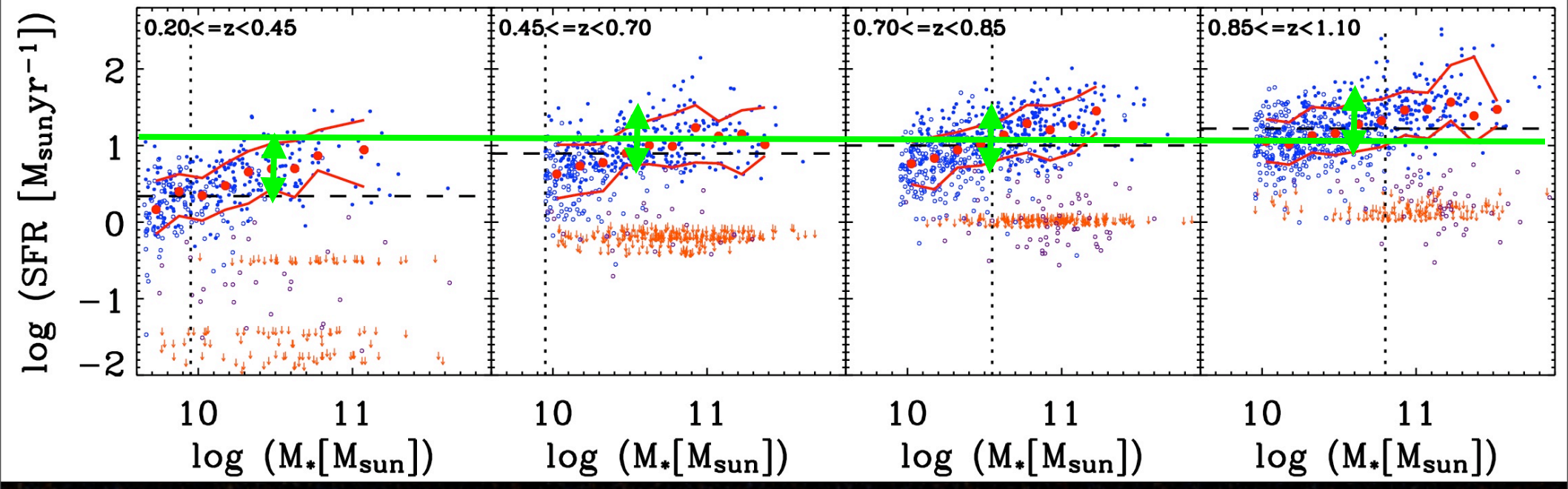


1) Limit on the amplitude of SFR variations/starbursts:

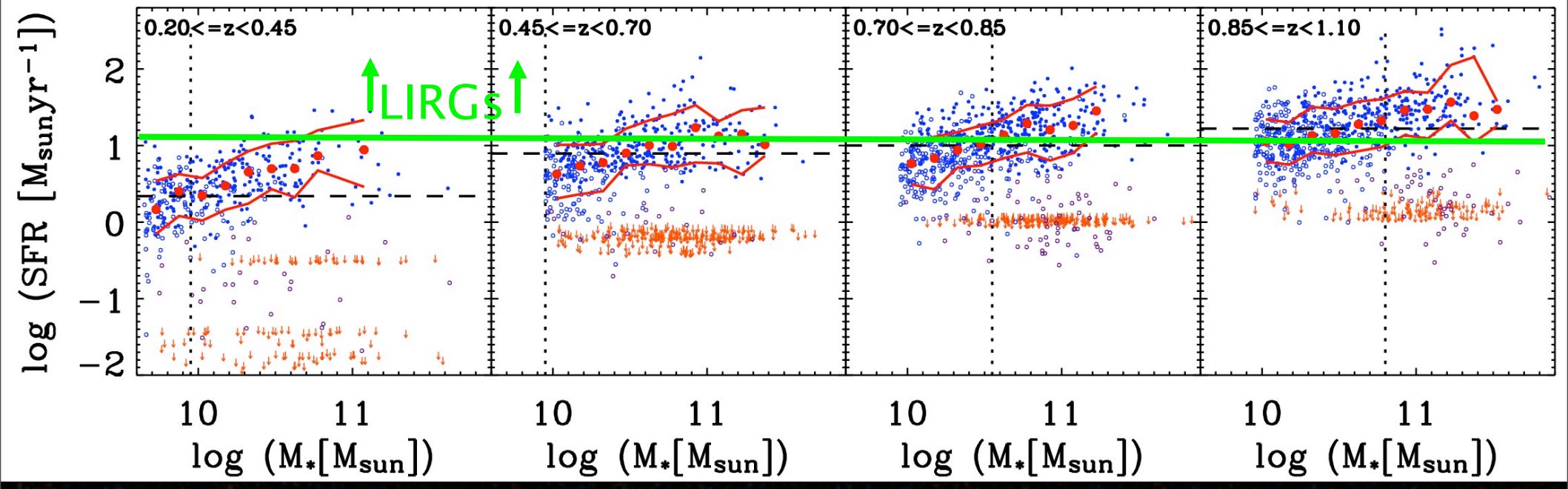
Galaxies are 2/3 of the time within a factor of ~2 of their average SFR at that z (® limit to effect of mergers on SF)

2) Range of log(SFR) constant to z~1,

MS ZP evolves with z:

dominant mode of SF since z~1 is apparently a gradual decrease of SFR, not evolving role of starbursts

A defined Main Sequence with similar range of SFR to z~1:



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2) Range of log(SFR) constant to z~1:
dominant mode of SF since z~1 is apparently a gradual decrease of SFR, not evolving role of starbursts

3) LIRGs at z~1 are massive galaxies in their normal high SFR, not strong starbursts like local LIRGs

IV. Size matters: mass dependence of SF histories

today

billions of years ago

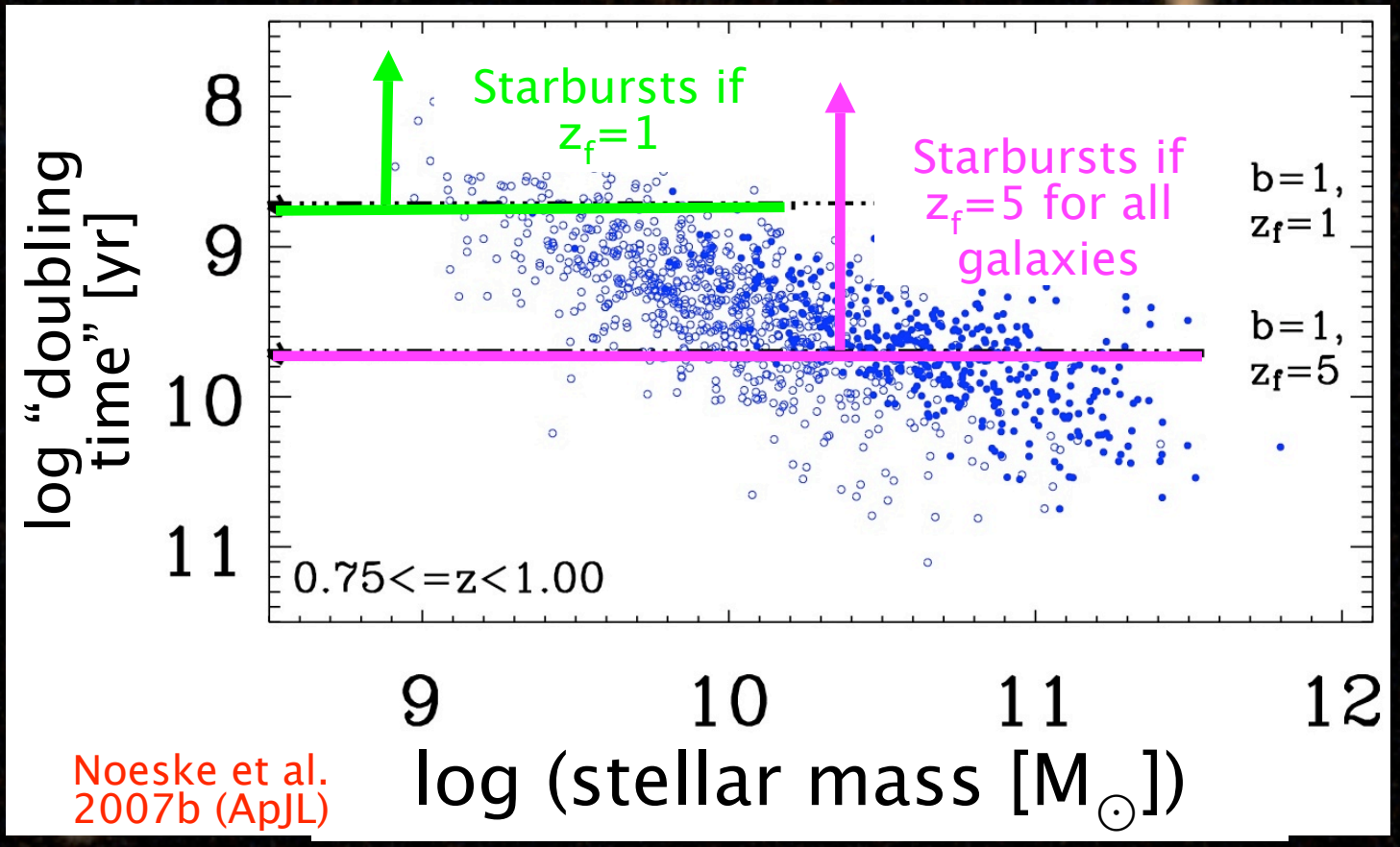
rapid star
birth & gas
consumption

slow star
birth & gas
consumption

big galaxies

(image: Driver 1998)

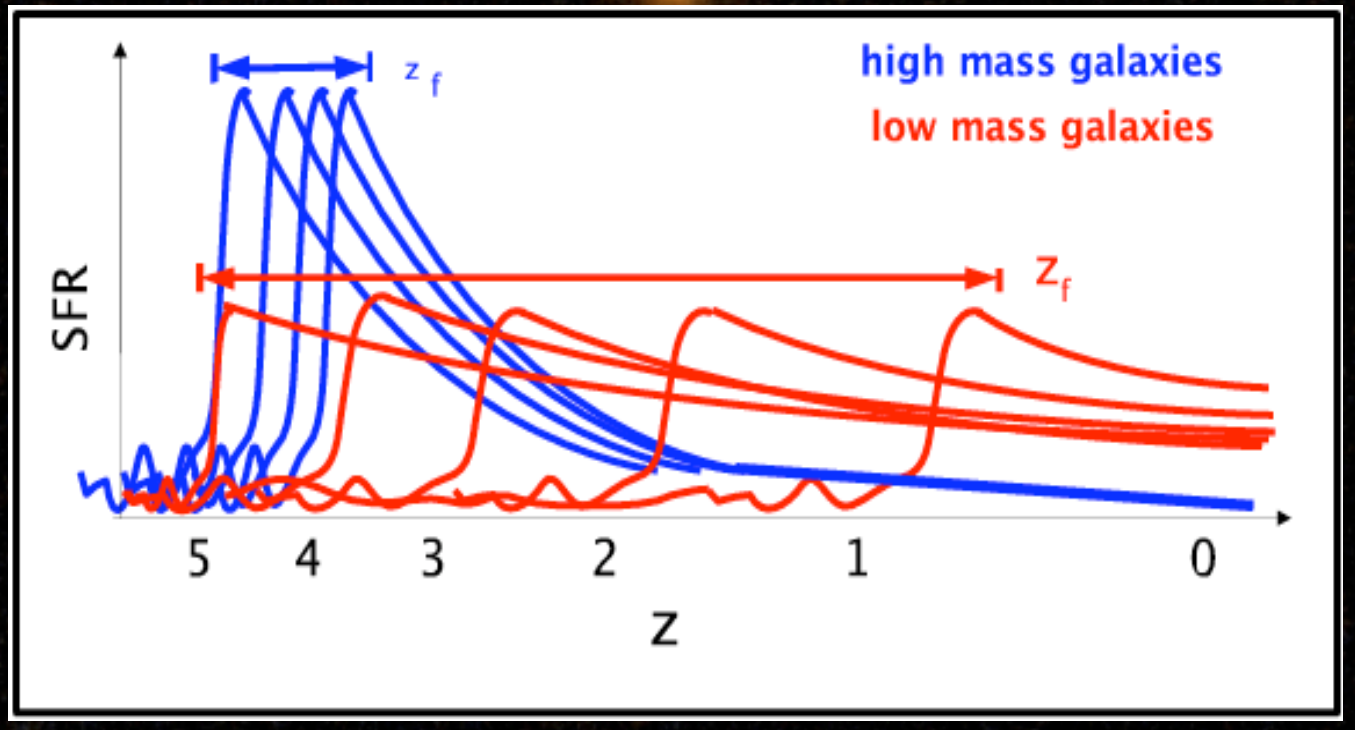
small galaxies



Assumption of old age for all galaxies: $t_d << t_{Univ}$,
simultaneous starbursts for >50% of galaxies at $<10^{10} M_\odot$, z=1

Implausible, and inconsistent with gradual decline of SFR

only alternative: delayed onset of major star formation
in part of less massive galaxies: $t_d \sim t_{Univ}$



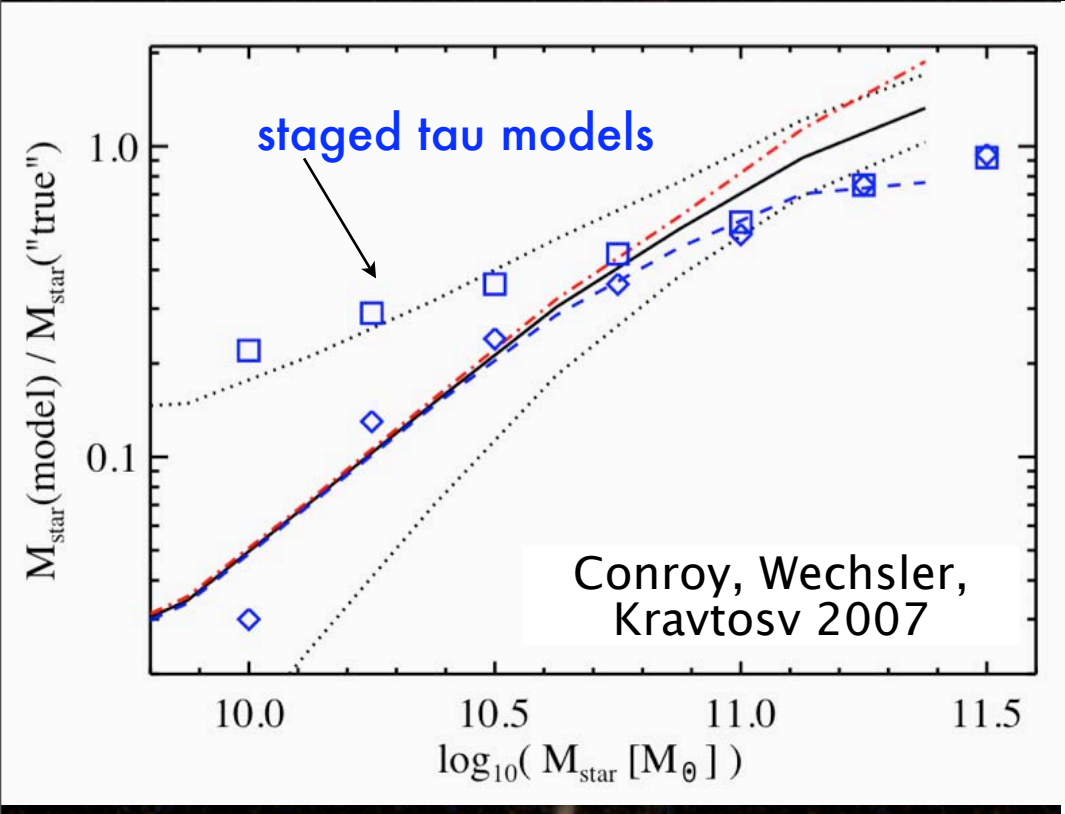
New concept:

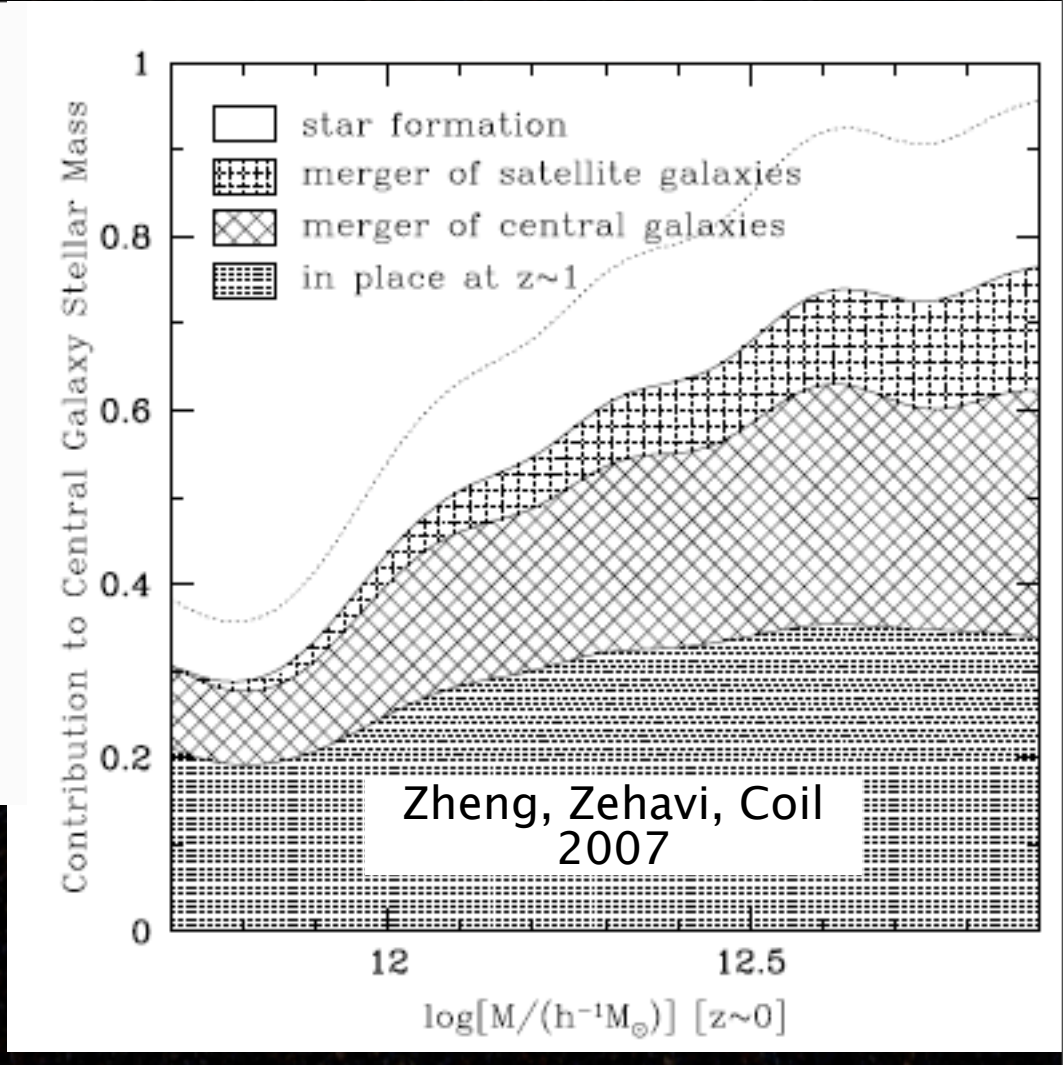
"Staged galaxy formation":

less massive galaxies start major SF on average later, with z_f more broadly distributed from high to low z

Today's low-mass galaxies (<10dex Msun at z=0) had only a small fraction of today's stellar mass at z~1

-> late onset of major star formation





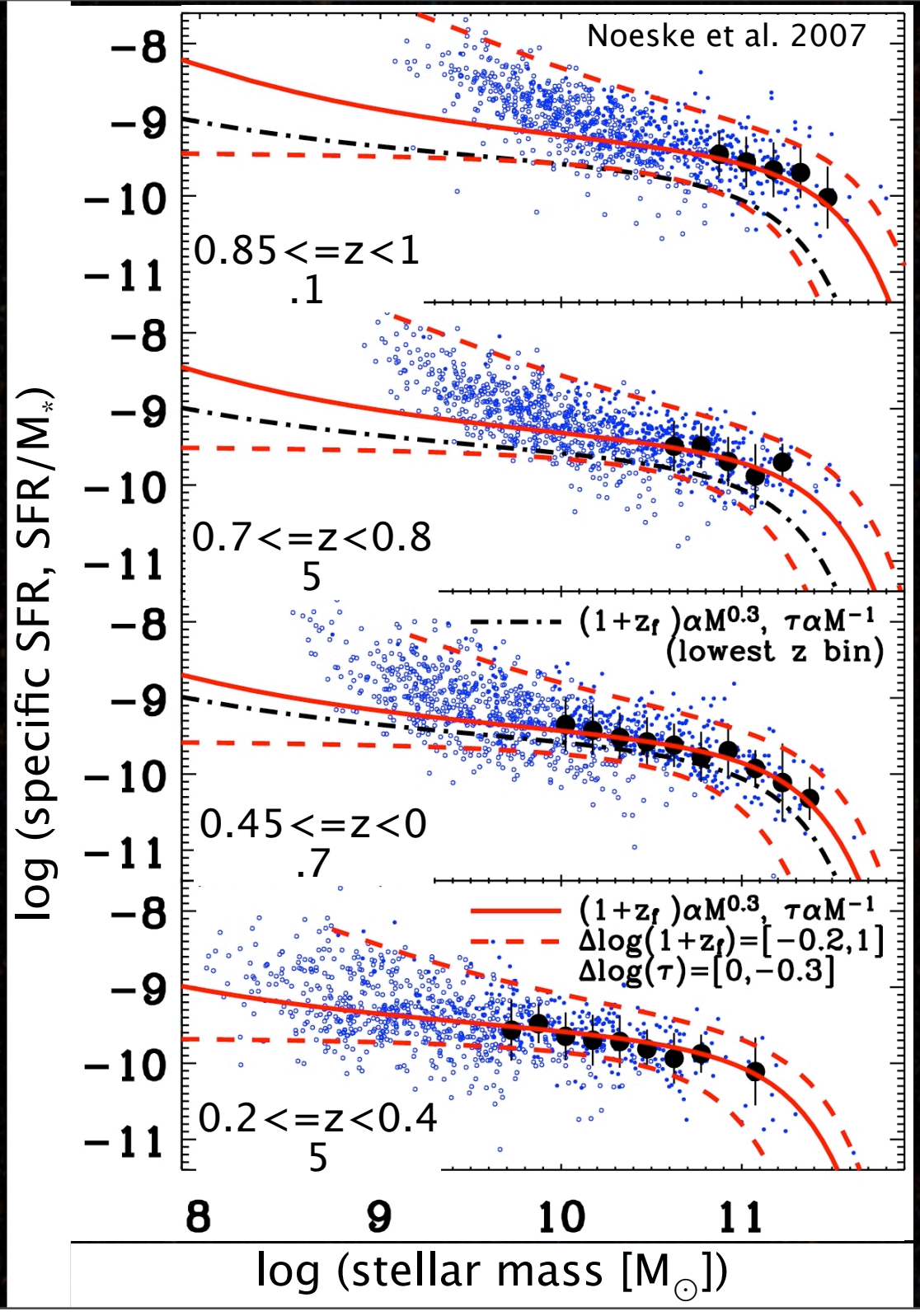
V. A parametrization model

What drives the dominant gradual decline of SFR since z~1?

Gradual processes like gas exhaustion?

A simple model to parametrize the mass-dependent evolution of SFR

along the star-forming sequence



Staged τ models: both τ and z_f mass-dependent

works

consistent, but no proof of, a gas depletion scenario

Summary:

(NOTE: star-forming field galaxies)

1) Main Sequence of SF galaxies, limited range of SFR at a given M,z.

2) Limits amplitude of starbursts, merger effects on SFR.

3) Gradual decline of SF, not starbursts, dominant since z~1;

4)LIRGs at z~1 are mostly normal SF galaxies, not extreme starbursts

- New picture: high SFR often not brief starbursts, but early, gas-rich phase of a galaxy -

3) mass-dependent τ models: model of SFR vs M, z over 2/3 t_H

4) New scenario: less massive galaxies have longer SF timescales, and a delayed onset of major star formation

→ 2 effects contributing to "downsizing": τ(M), z_f(M)

Prospects and future work

A new perspective to further our understanding of star formation:

Prior to quenching, star formation out ot z>1

follows a regular pattern

1) dominance of the same set of few physical processes?

3) A chance to identify the relevant physics

4) knowing normal SF: isolate effects of mergers, and quenching

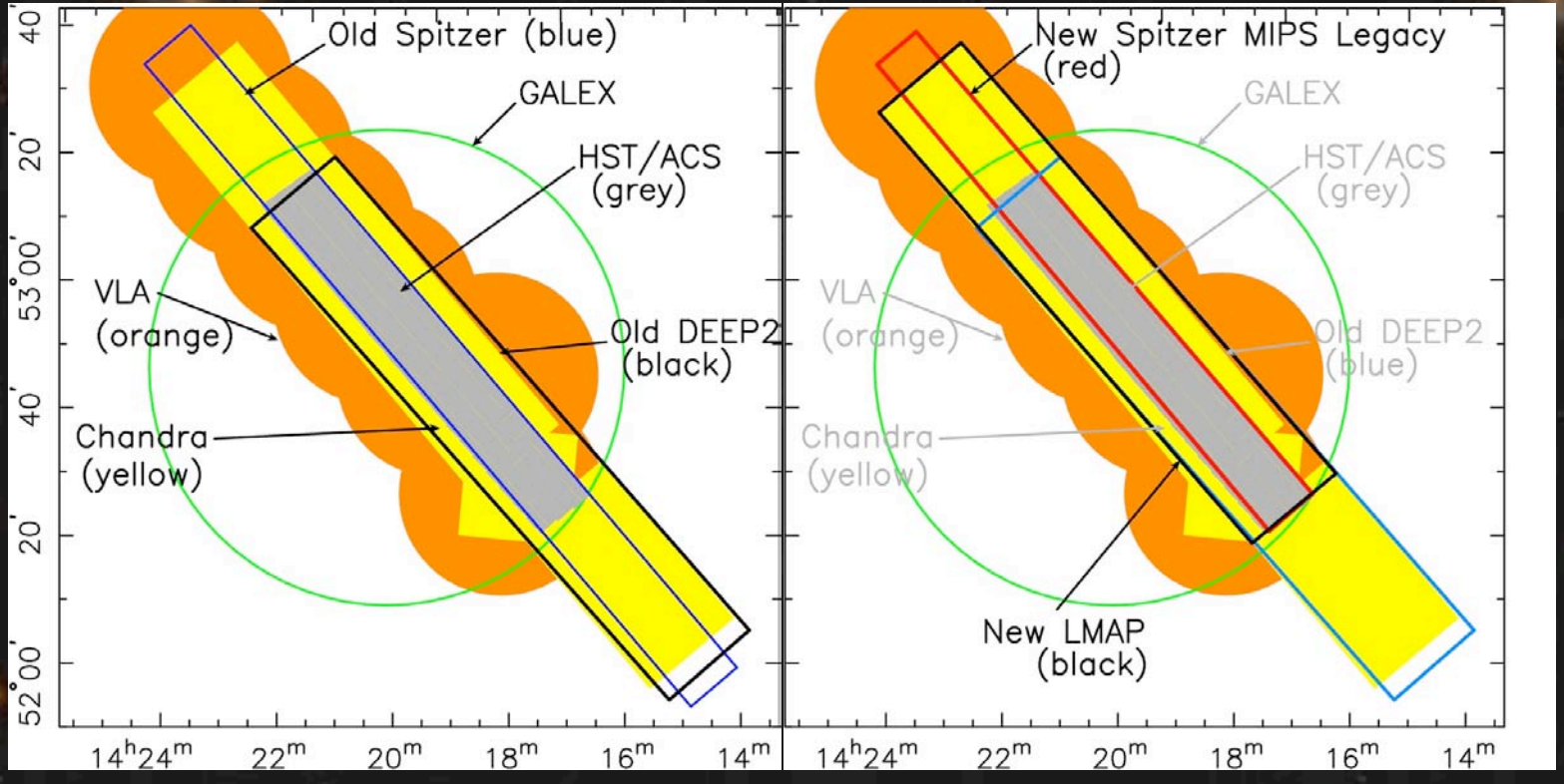
Outlook (1) : a new benchmark survey for SF, AGN, environments to z>1.5

GOODS, AEGIS : ~20,000 galaxies

MIPS Legacy survey (t_{exp}x12!) (in progress, PI M. Dickinson):

deep 24 and 70μm, robust SFR to z>2, and to low SFR at z<1

DEEP3 (4+ yr, KeckII/DEIMOS), proposed Faber/Noeske



Data vs Semi-Analytic Models: GOODS & Millenium

Elbaz et al. 2007