Evolution of massive galaxies

Jesse vd Sande, Daniel Szomoru, Moein Mosleh, Rachel Bezanson, Shannon Patel, Stijn Wuyts, Rik Williams, Ryan Quadri, Simone Weinmann, Danilo Marchesini, Mariska Kriek, Ivo Labbe, Gabe Brammer, Kate Whitaker, Tomer Tal, Adam Muzzin, Natascha Forster Schreiber, Garth Illingworth, Hans-Walter Rix, Arjen van der Wel, Pieter van Dokkum, MF

- What is a stellar mass ?
- evolution massive galaxies
- Linking progenitors and descendants

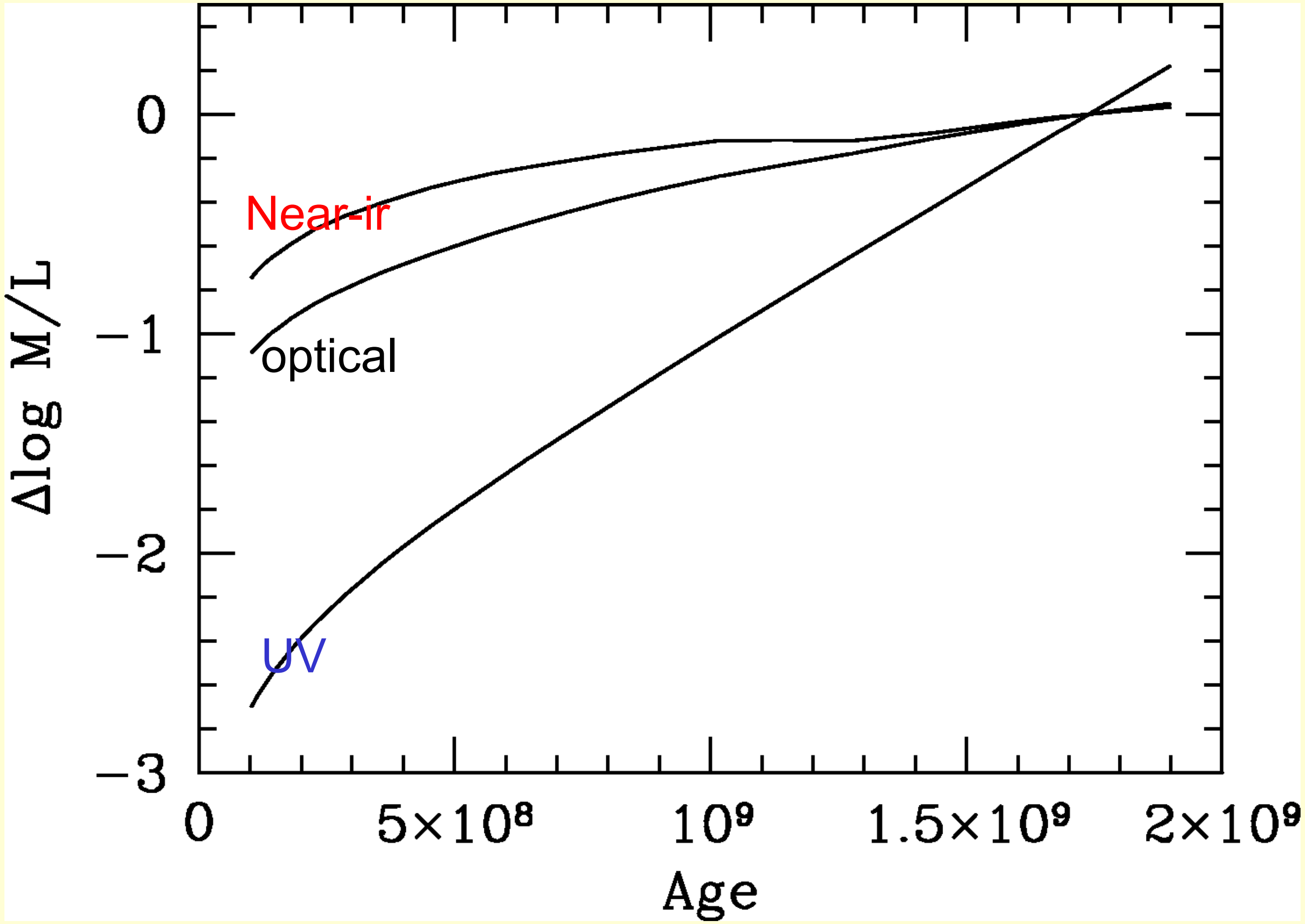
Introduction – what does it mean – massive ?

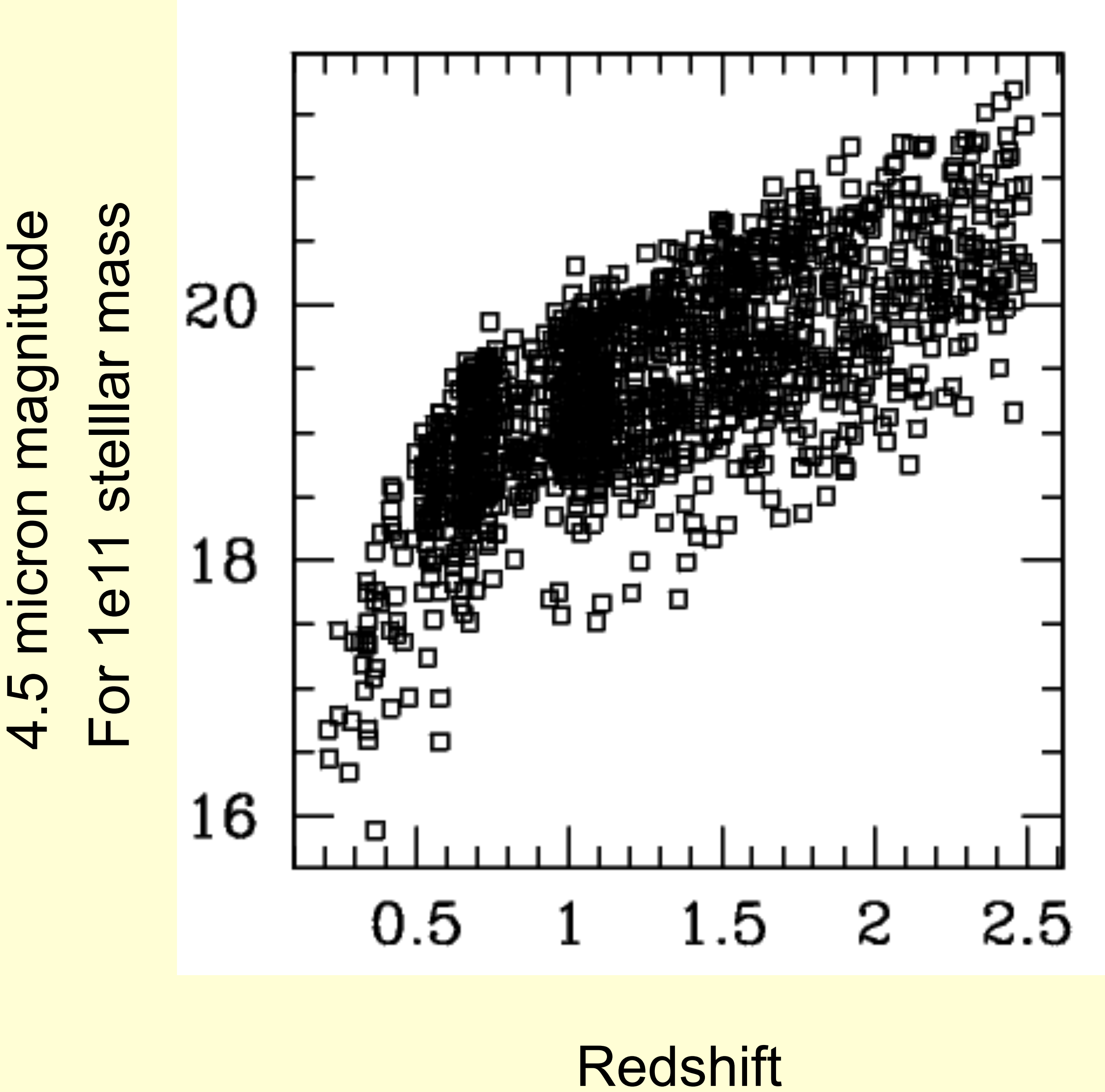
Typically, meant is “high stellar mass”

- Do we have any stellar masses ?
- How do you measure stellar masses anyway ?

Why bother using stellar masses ?

Before 2000, most analyses based on luminosities

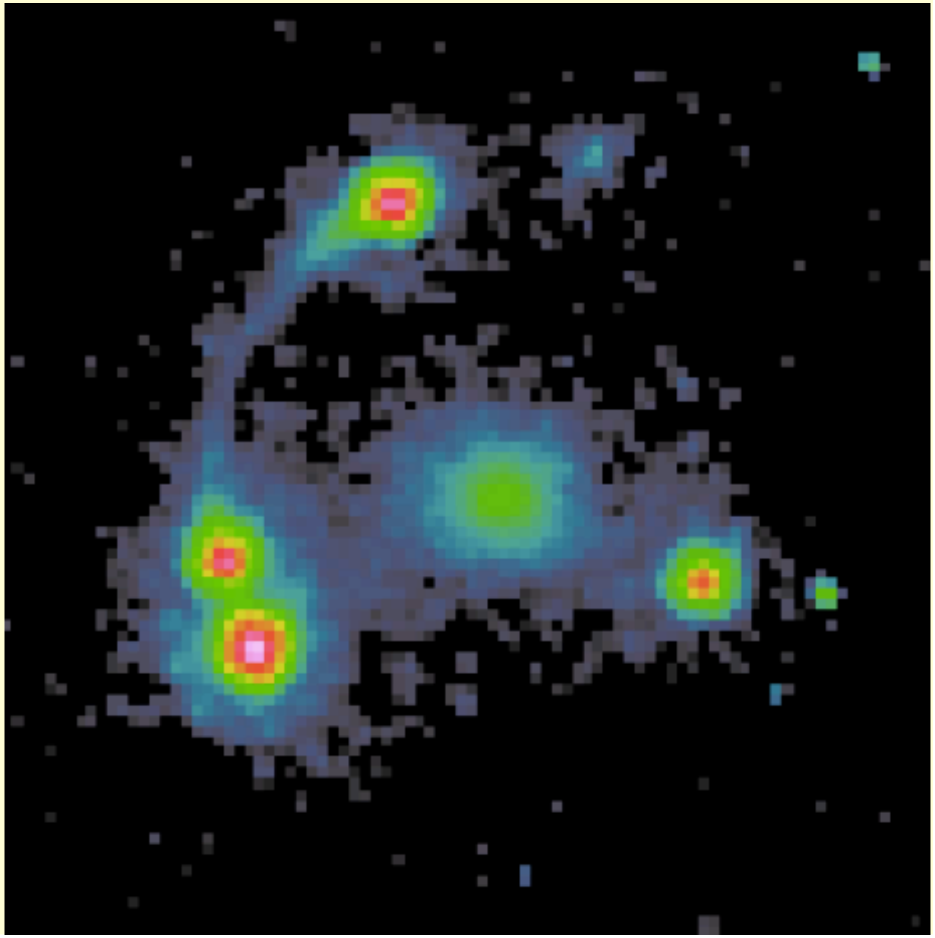



4.5 micron magnitude
For 1e11 stellar mass
20
18
16
0.5
1
1.5
2
2.5
Redshift

Have we measured any stellar masses ?

We only have a stellar mass for the Milky Way – where we can count the stars

Extragalactic: micro-lensing
(for “real” astronomers)



or …

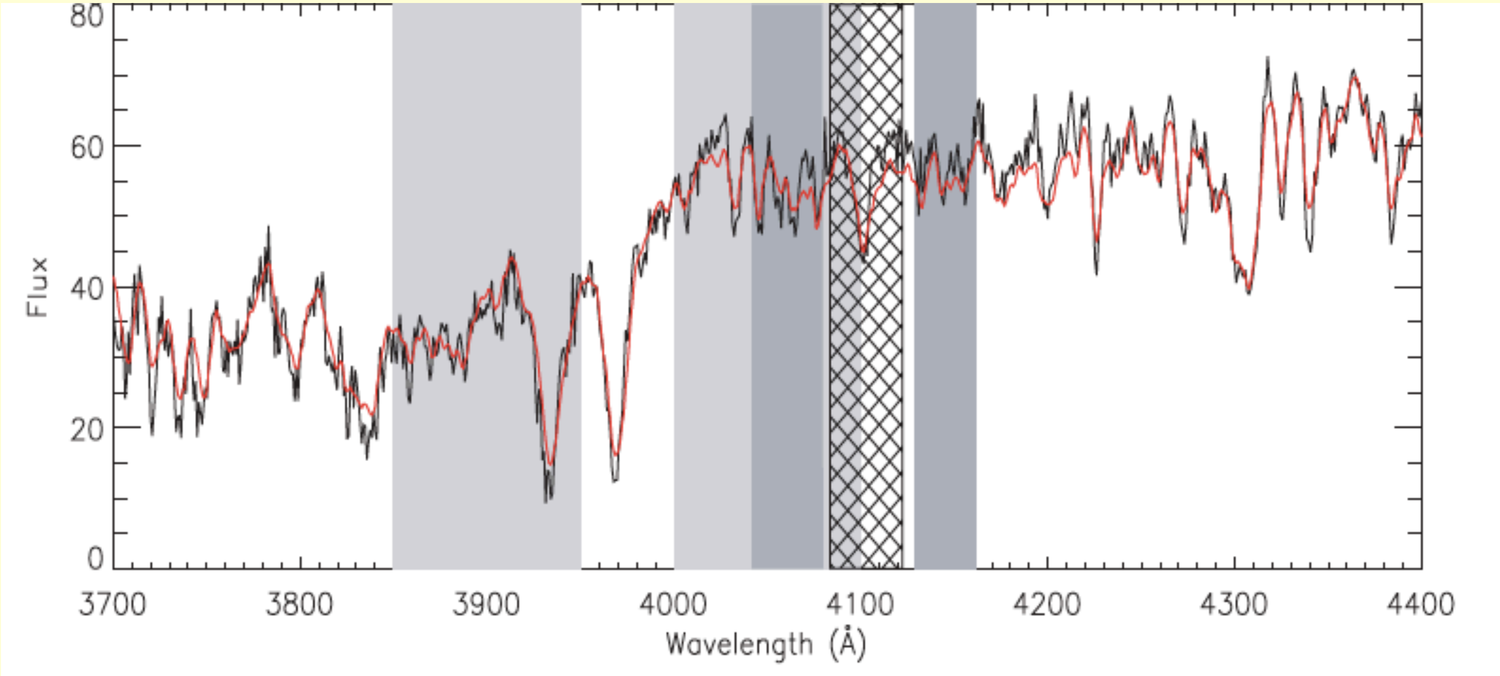
Have we measured any stellar masses ?

We only have a stellar mass for the Milky Way – where we can count the stars

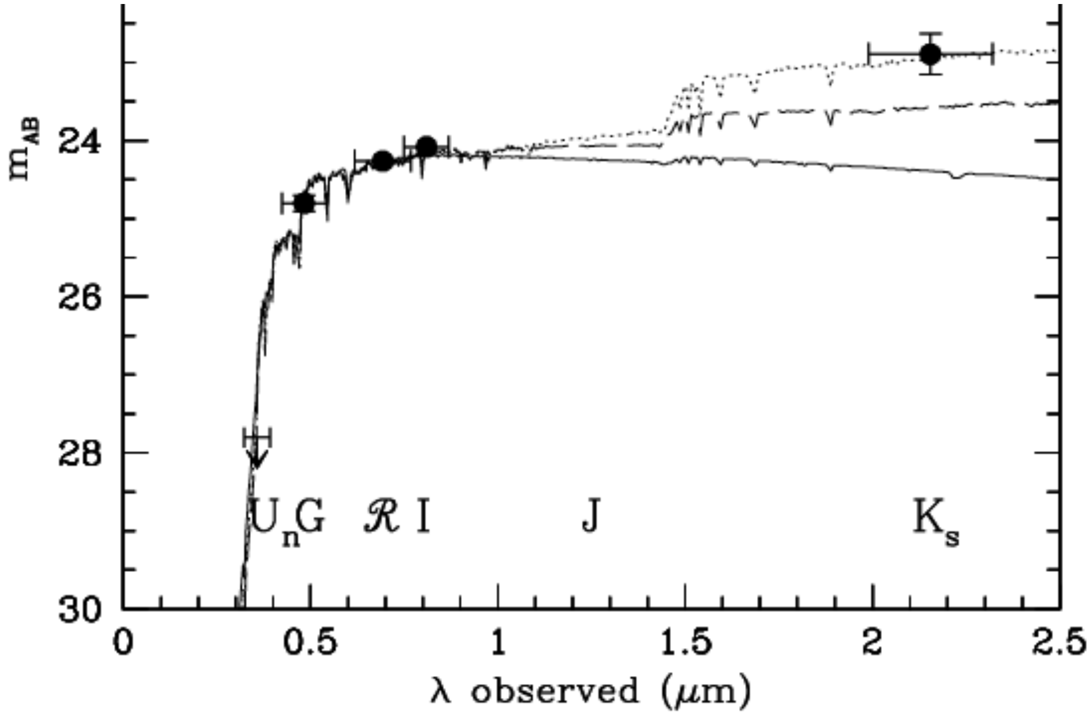
Extragalactic: micro-lensing (for “real” astronomers)

or …

Modeling … (IMF, stellar population model, metallicities, star formation, history, extinction curve, distribution of dust and stars, emission lines …)

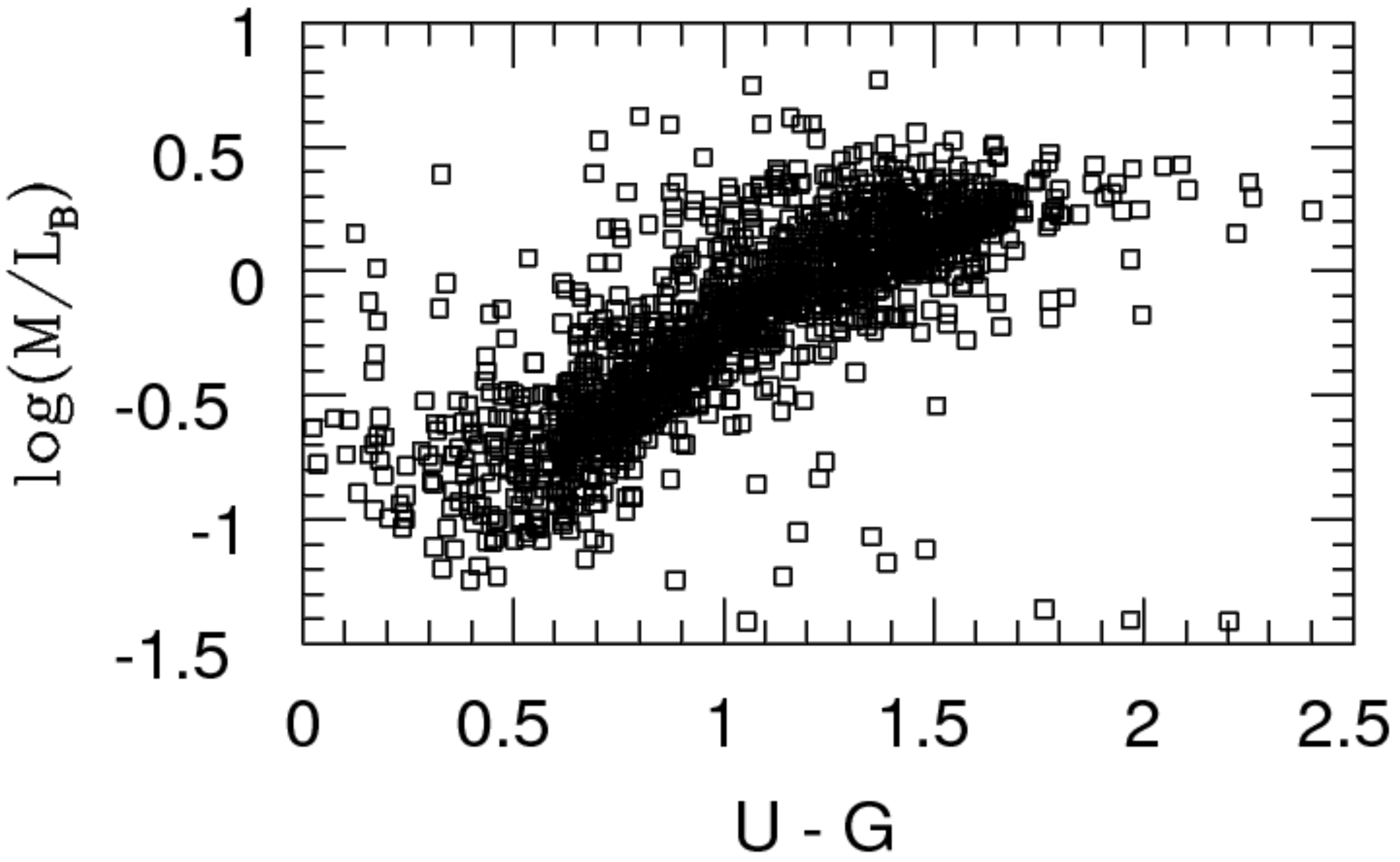


Kaufmann et al. 03



Shapley et al. 01

The saving grace:



THE MASS ASSEMBLY AND STAR FORMATION CHARACTERISTICS OF FIELD GALAXIES OF KNOWN MORPHOLOGY

JARLE BRINCHMANN[1]

AND

RICHARD S. ELLIS[2]

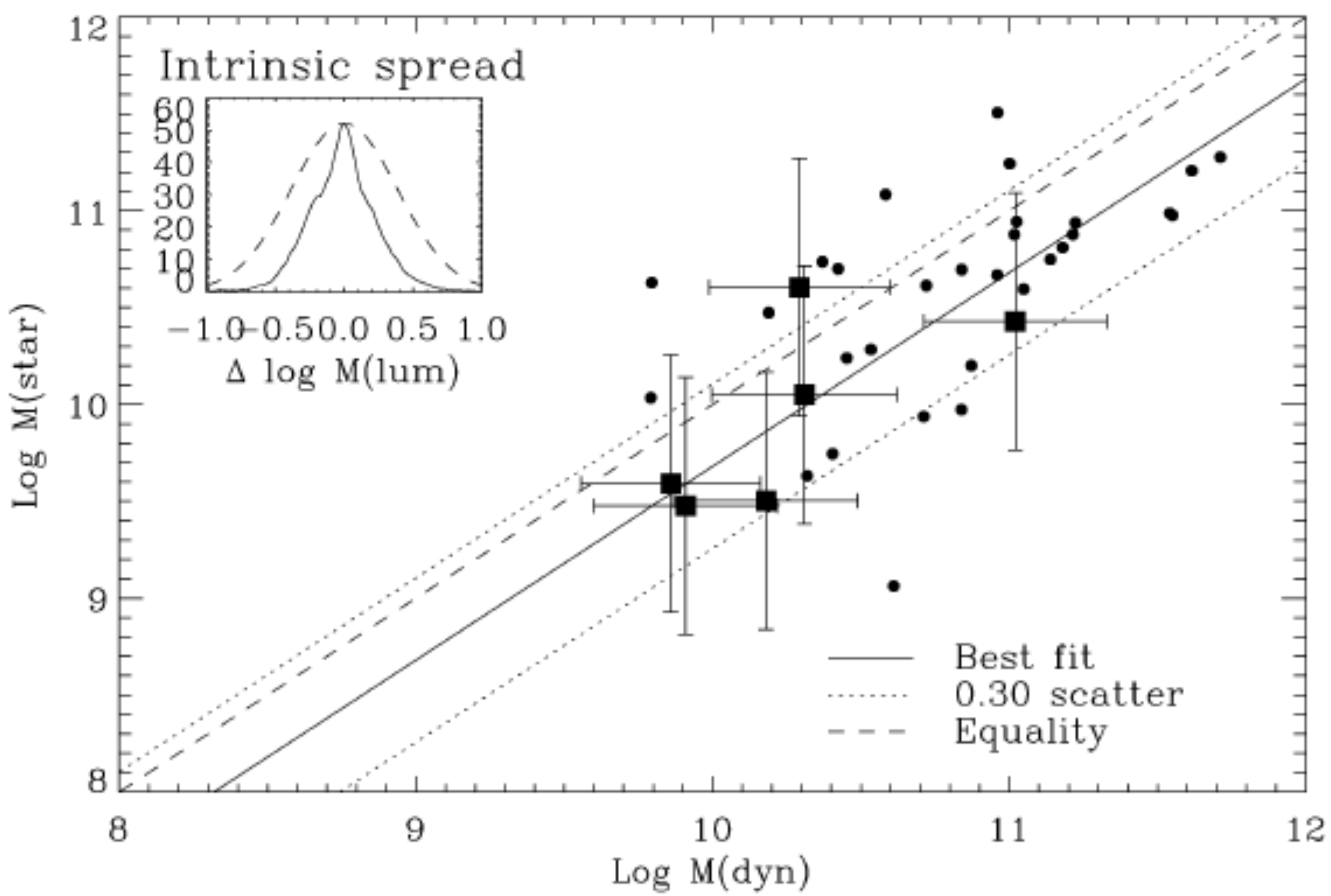
Institute of Astronomy, Cambridge University, Cambridge, England, UK

Received 2000 March 28; accepted 2000 May 5; published 2000 June 19

ABSTRACT

We discuss a new method for inferring the stellar mass of a distant galaxy of known redshift based on the combination of a near-IR luminosity and multiband optical photometry. The typical uncertainty for field galaxies with $I < 22$ in the redshift range $0 < z < 1$ is a factor of 2. We apply this method to a newly constructed sample of 321 field galaxies with redshifts and *Hubble Space Telescope* morphologies enabling us to construct the stellar mass density associated with various morphologies as a function of redshift. We find a marked decline with time in the stellar mass associated with peculiar galaxies accompanied by a modest rise in that observed for elliptical galaxies. The result suggests that peculiar galaxies decline in abundance because they transform and merge into regular systems. The star formation rate per unit stellar mass indicates that massive systems completed the bulk of their star formation before redshift 1, whereas dwarf galaxies continue to undergo major episodes of activity until the present epoch.

Subject headings: galaxies: evolution — galaxies: fundamental parameters — galaxies: stellar content



Intrinsic spread
60
50
40
30
20
10
0
−1.0−0.50.0 0.5 1.0
Δ log M(lum)
12
11
10
9
8
Log M(star)
8
9
10
11
12
Log M(dyn)
Best fit
0.30 scatter
Equality

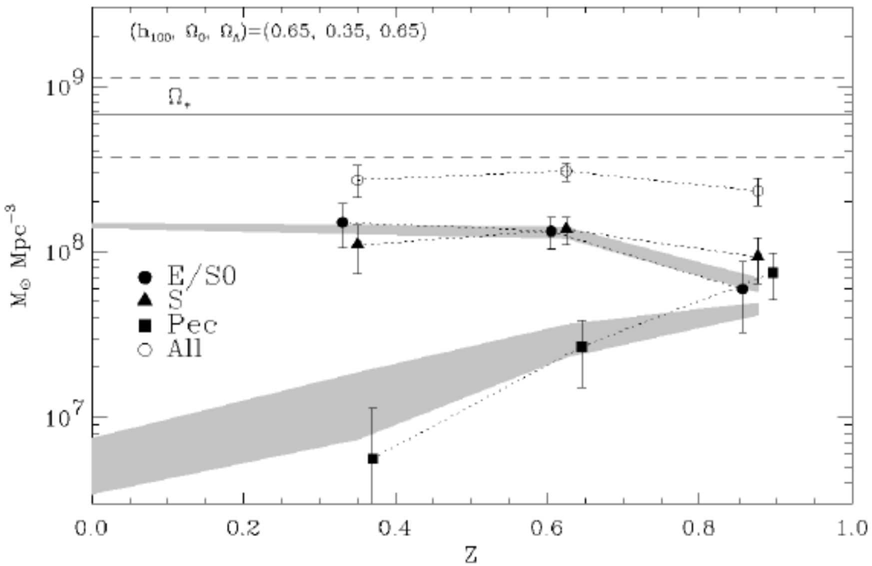


FIG. 2.—Integrated stellar mass density for galaxies with $10.5 < \log M_{star} < 11.6$ as a function of redshift and visual morphology. The shaded regions show the predictions of the mass density in peculiar and elliptical galaxies from the simple merging models described in the text.

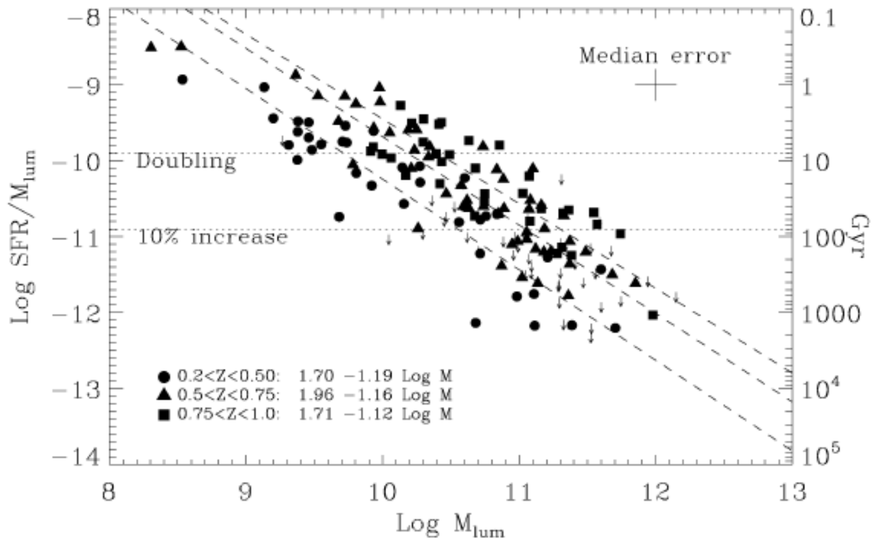
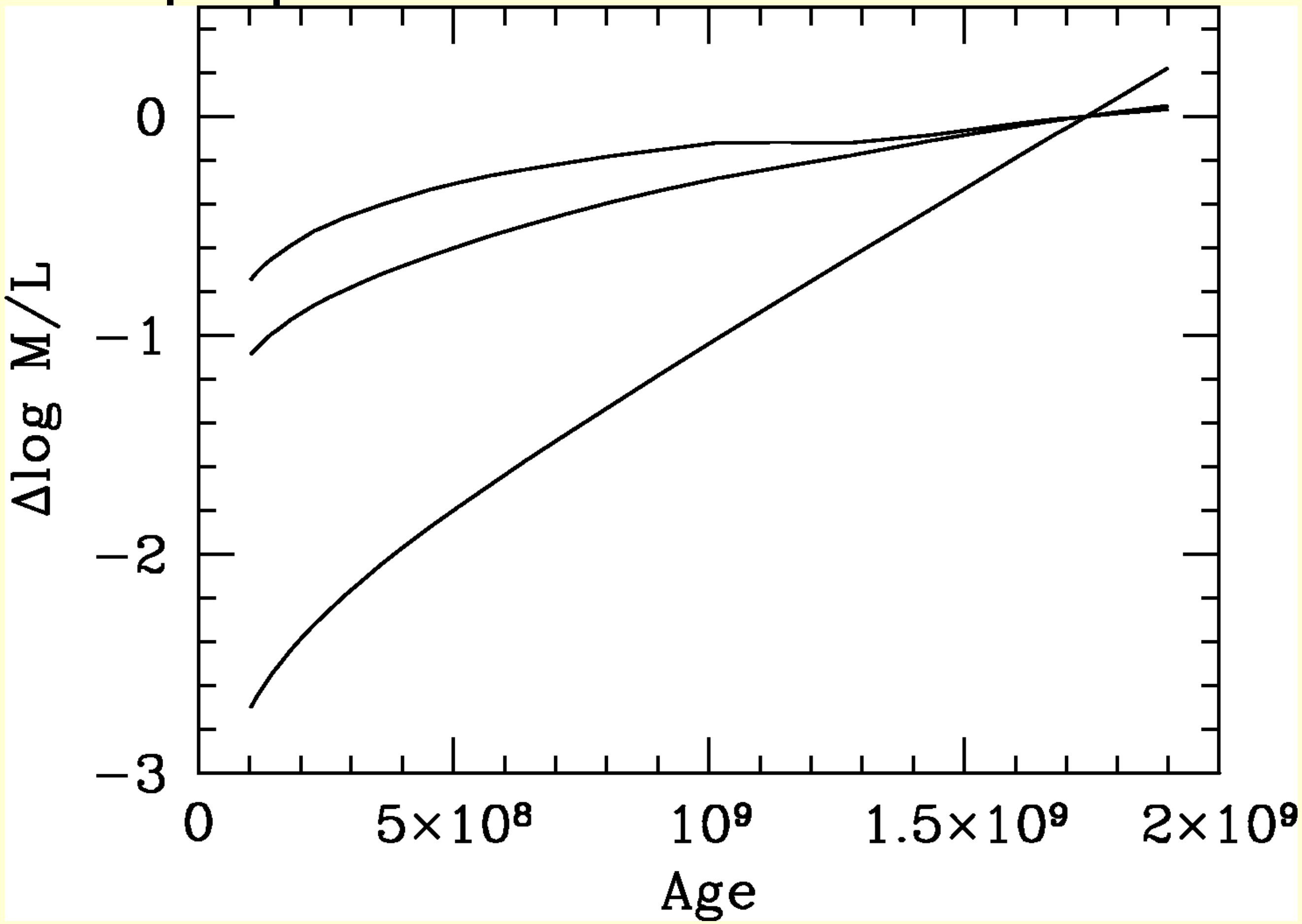


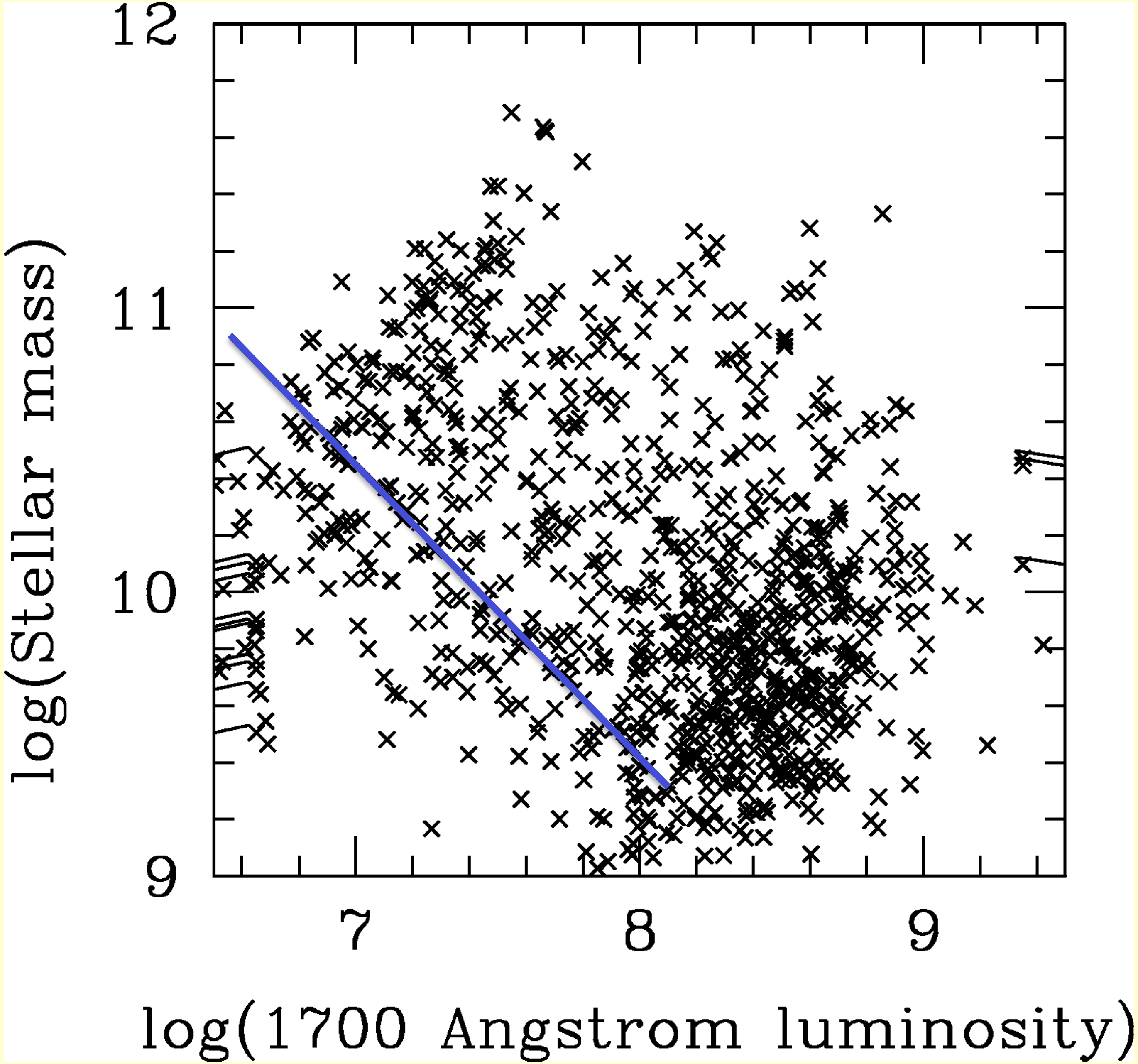
FIG. 3.—Specific star formation rate R for the galaxies in the sample. The three lines show orthogonal least-squares fit to the three redshift ranges indicated. The fit parameters are shown in the lower left corner. The right-hand panel shows the doubling time in Gyr, assuming constant star formation. Arrows show 2 σ upper limits for galaxies with no detected [O II] emission.

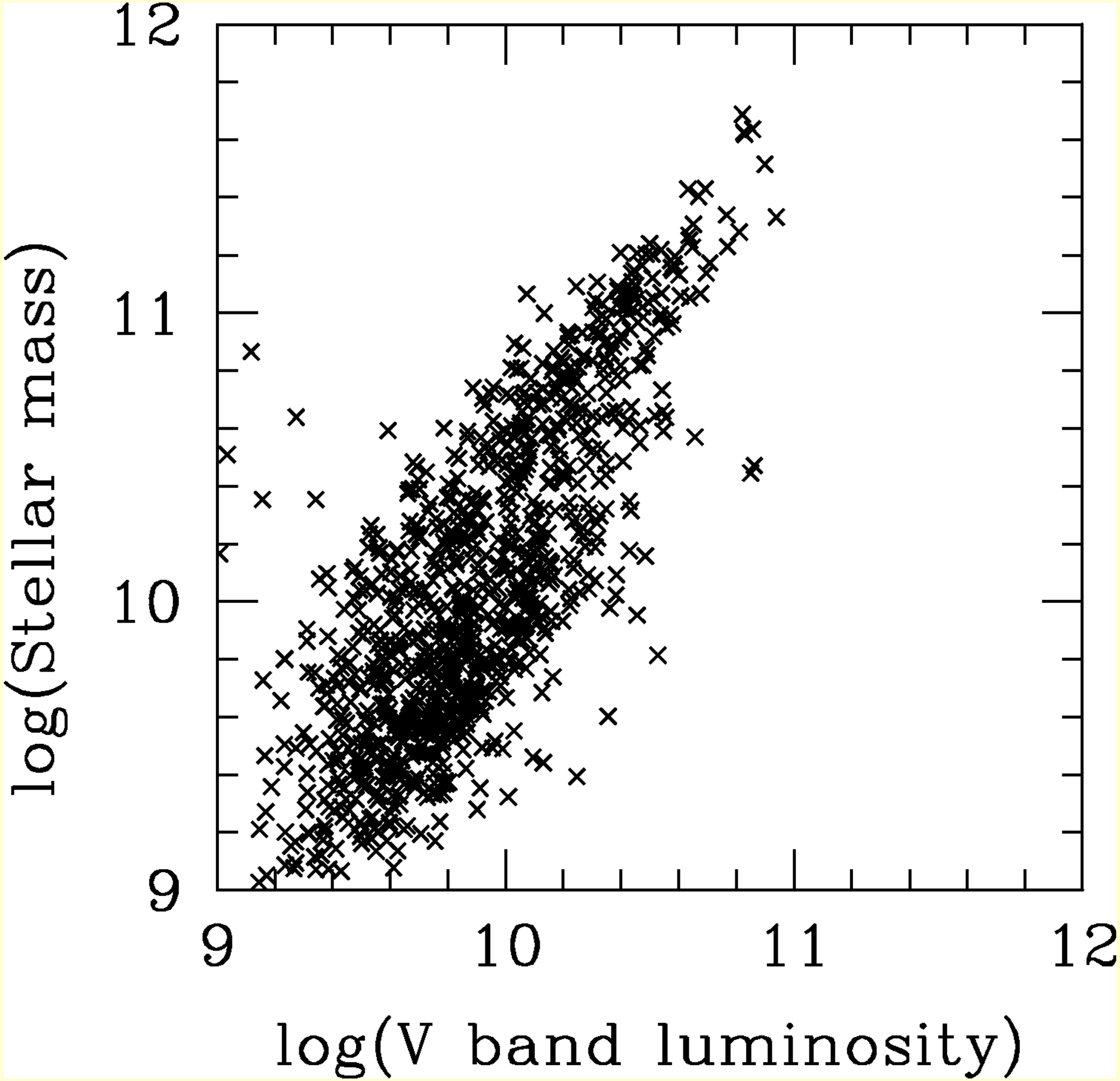
How do we get a mass selected sample at high redshift ?

We need a proper census



Z>2: selection in observed optical = rest-frame UV



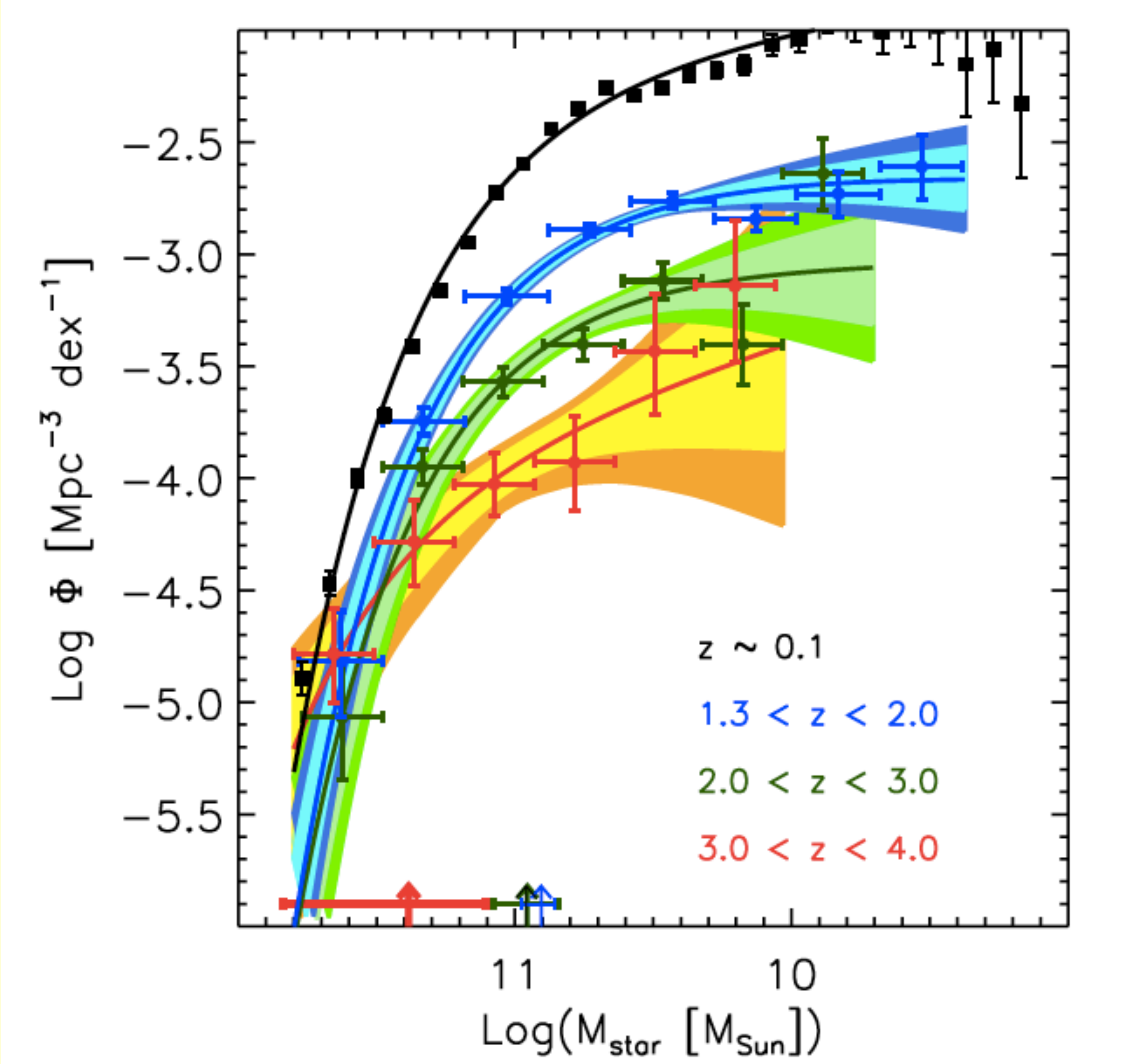

12
11
10
9
log(Stellar mass)
9
10
11
12
log(V band luminosity)

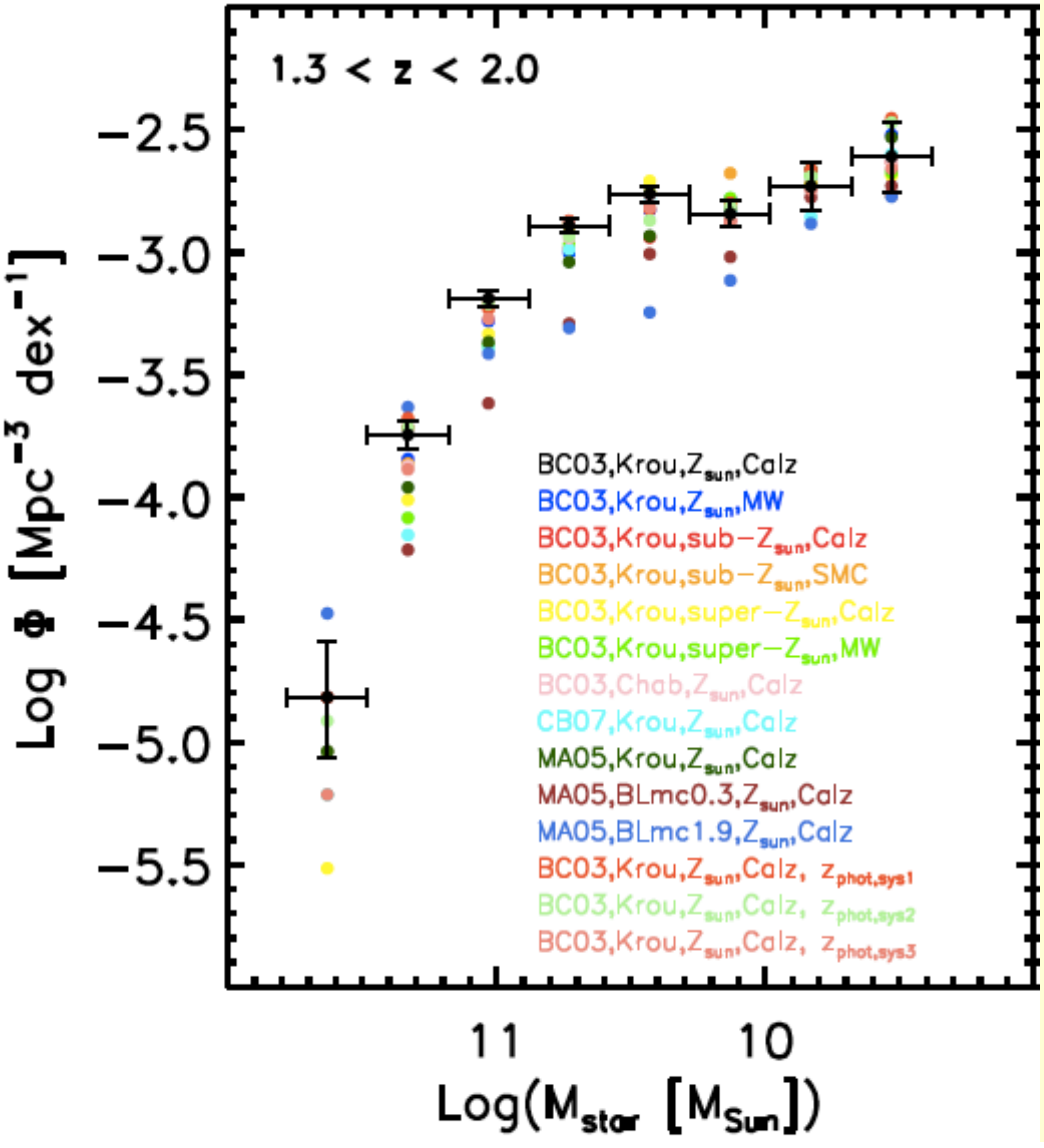
For a mass selected sample, we need rest-frame optical selected sample

Observed near-IR at z>1.5

- Many galaxies at z>2 very faint in optical
- Spectroscopic redshifts very hard to get
- 33

Next step, stellar mass functions





1.3 < z < 2.0
Log Φ [Mpc⁻³ dex⁻¹]
−2.5
−3.0
−3.5
−4.0
−4.5
−5.0
−5.5
11
10
Log(M_star [M_Sun])
BC03,Krou,Z_sun,Calz
BC03,Krou,Z_sun,MW
BC03,Krou,sub−Z_sun,Calz
BC03,Krou,sub−Z_sun,SMC
BC03,Krou,super−Z_sun,Calz
BC03,Krou,super−Z_sun,MW
BC03,Chab,Z_sun,Calz
CB07,Krou,Z_sun,Calz
MA05,Krou,Z_sun,Calz
MA05,BLmc0.3,Z_sun,Calz
MA05,BLmc1.9,Z_sun,Calz
BC03,Krou,Z_sun,Calz, z_phot,sys1
BC03,Krou,Z_sun,Calz, z_phot,sys2
BC03,Krou,Z_sun,Calz, z_phot,sys3

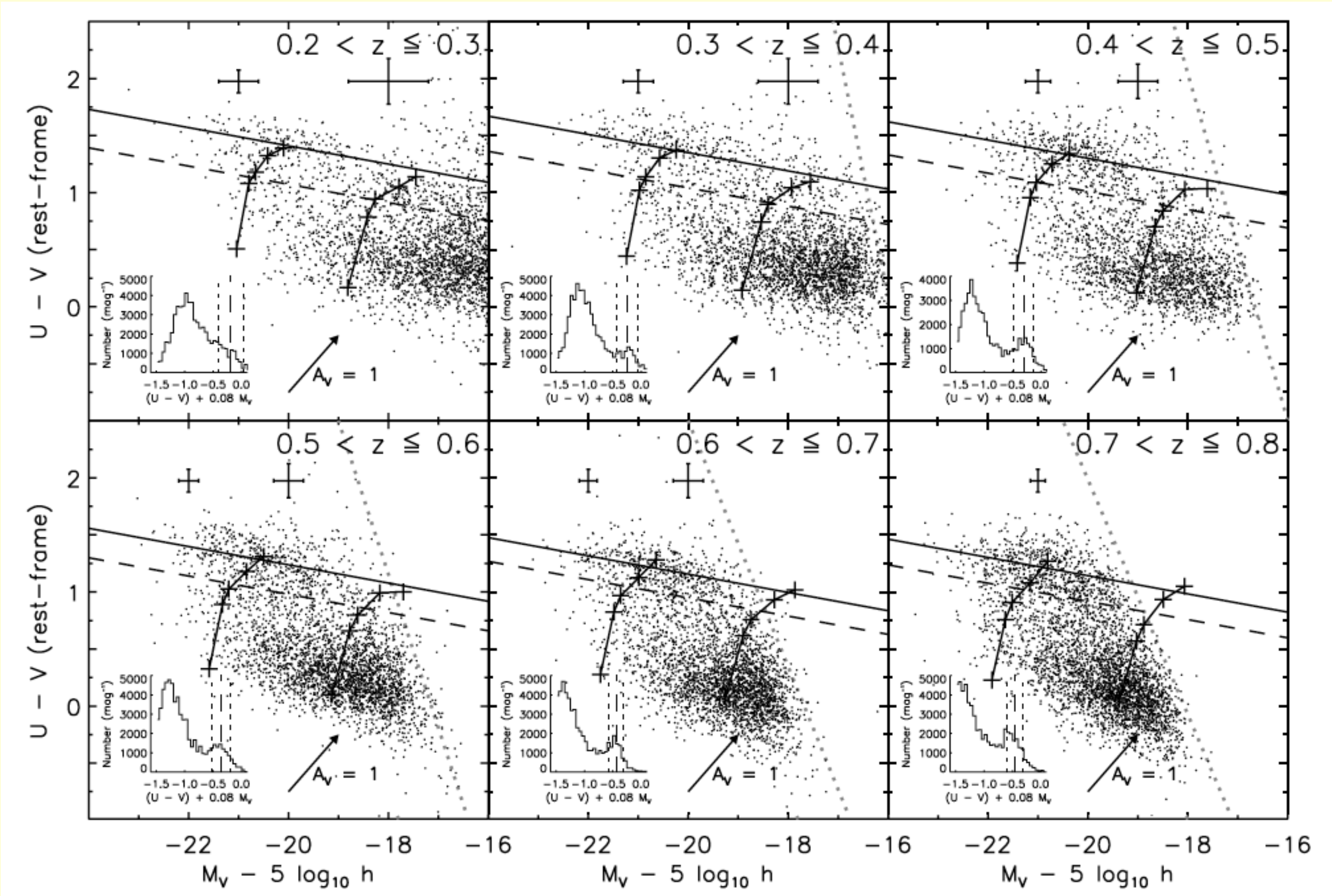
Overall results on stellar mass function

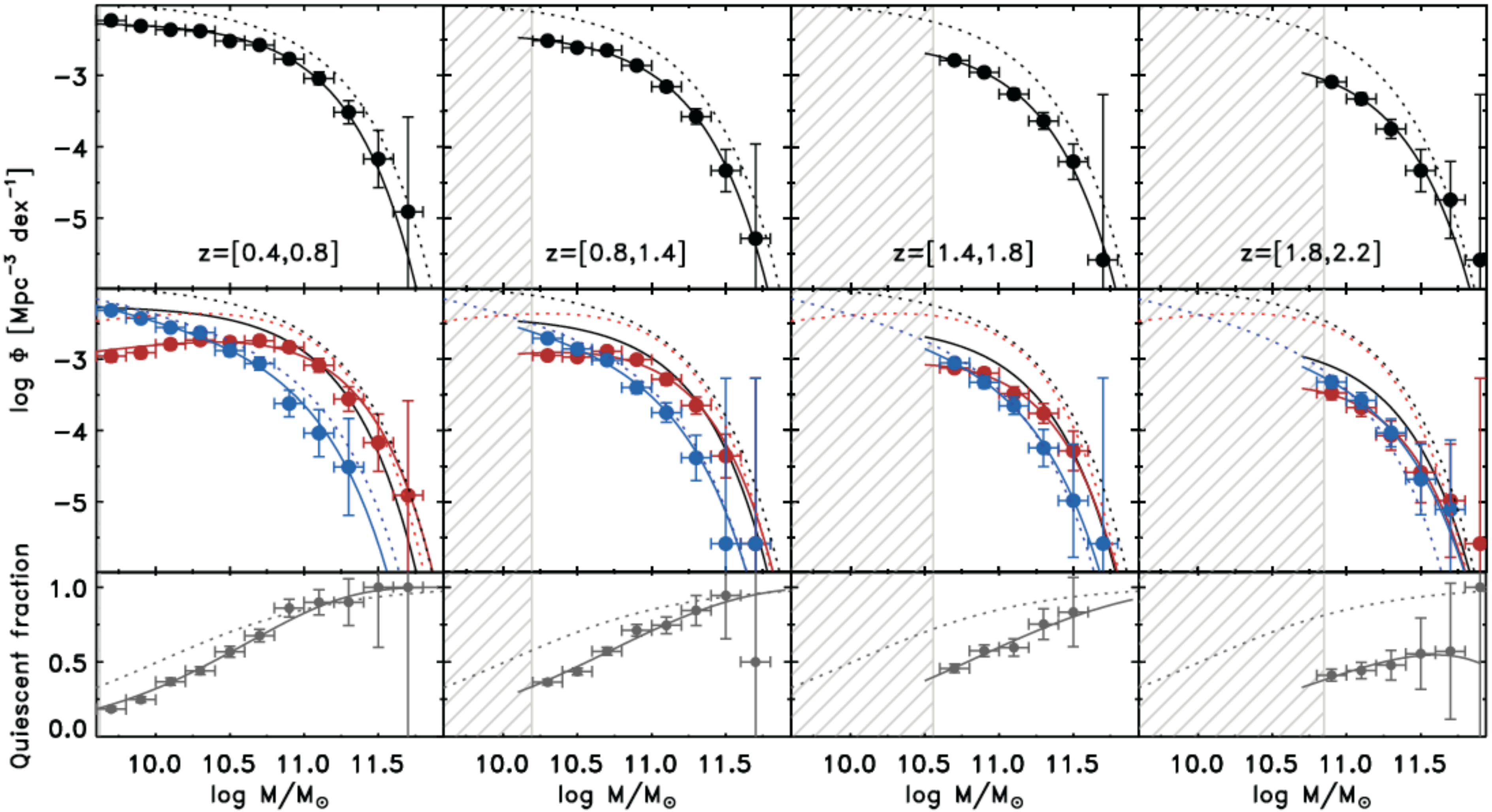
Rapid evolution at lower masses (1e10 Msun)

Much slower evolution at high redshift

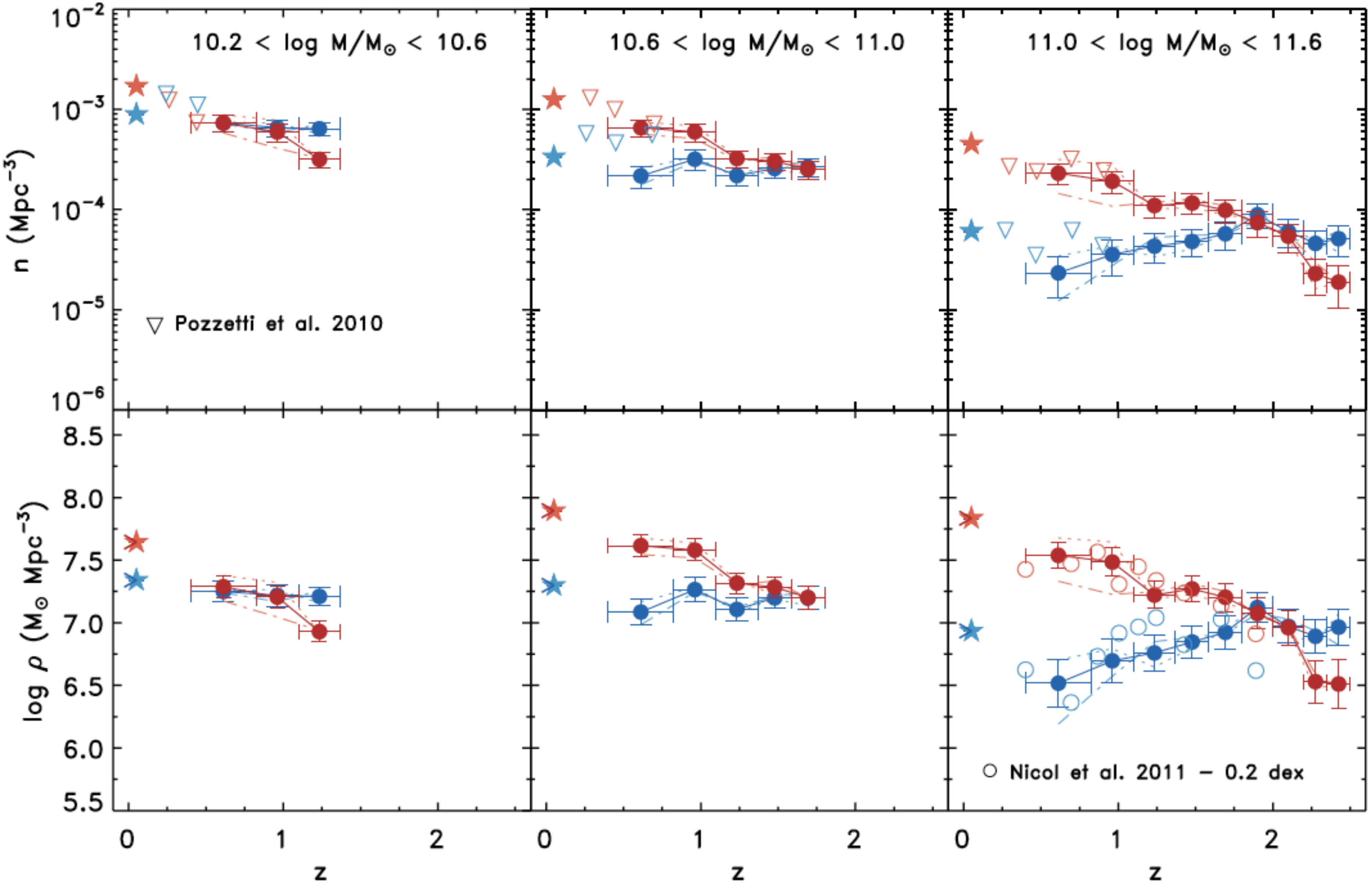
Bell et al, 2004, Nearly 5000 Distant Early-Type Galaxies in COMBO-17: A Red Sequence and Its Evolution since (618)

Combo-17: 2.2m imaging, with medium band filters





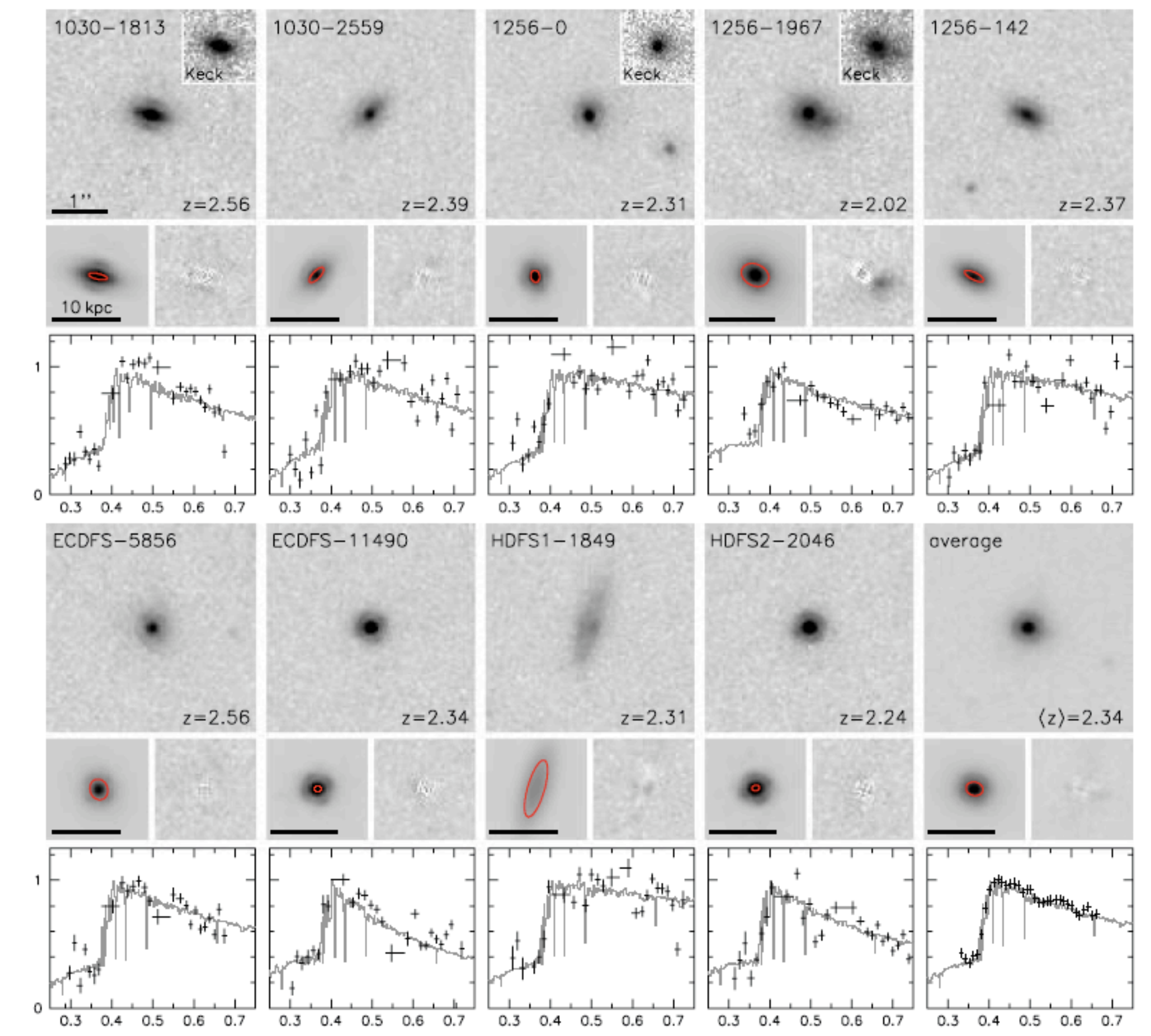
Brammer et 2011

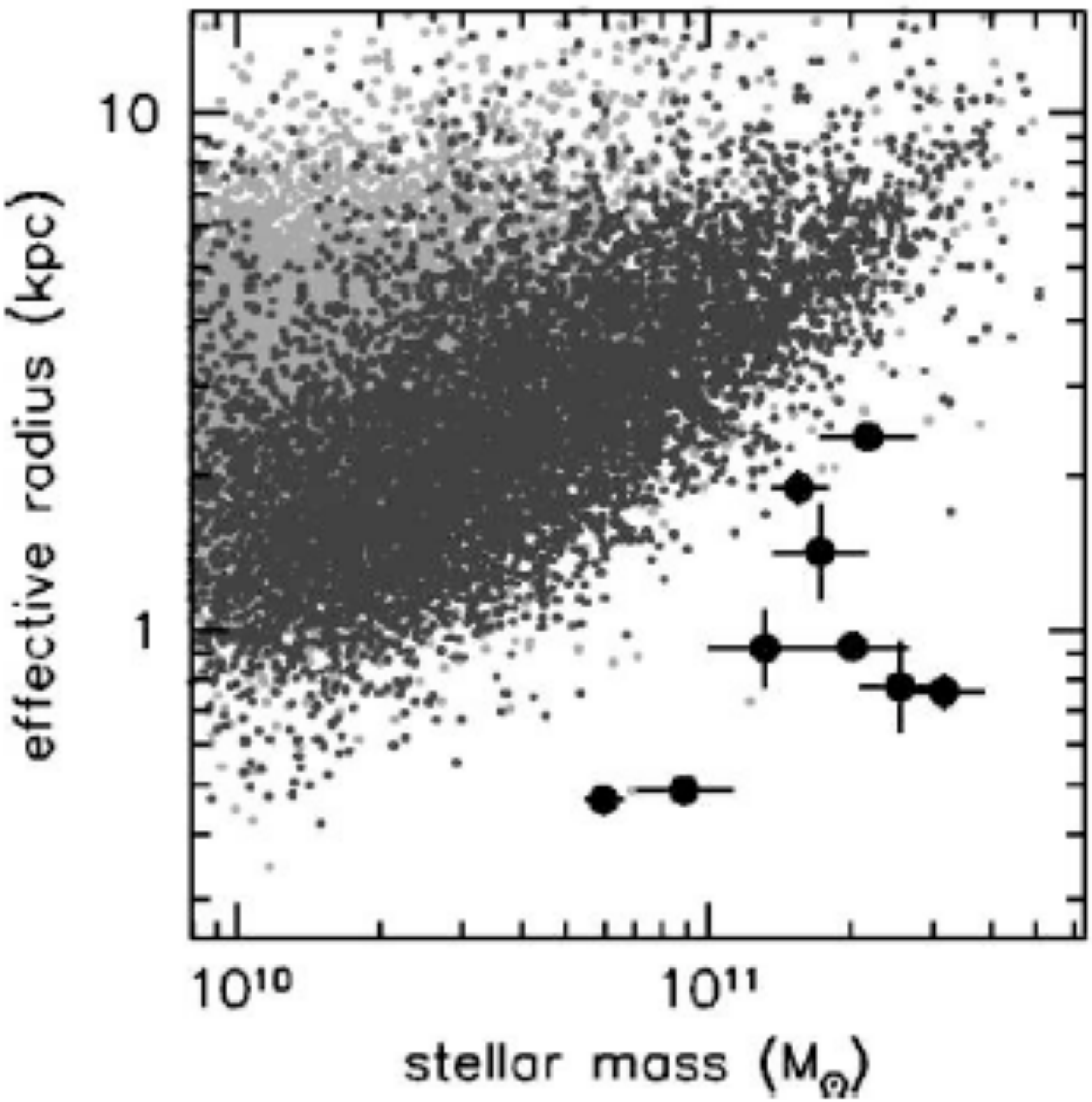

10.2 < log M/M⊙ < 10.6
10.6 < log M/M⊙ < 11.0
11.0 < log M/M⊙ < 11.6
▽ Pozzetti et al. 2010
○ Nicol et al. 2011 − 0.2 dex
n (Mpc^{-3})
log ρ (M⊙ Mpc^{-3})
z

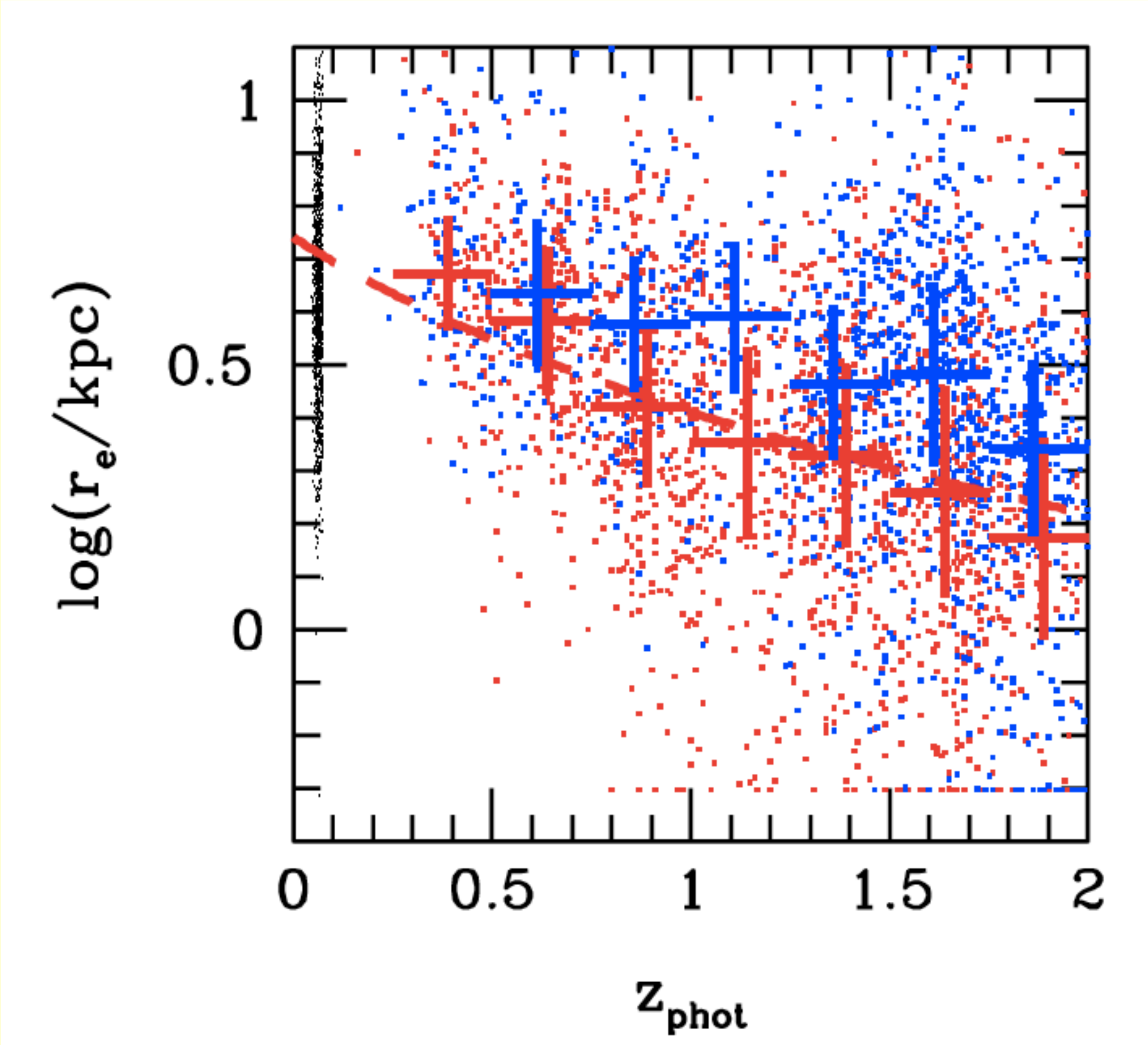
Main results

1) Slow evolution of mass function at massive end
2) Rapid evolution of density of quiescent galaxies
   + slow evolution for star forming galaxies

Size evolution

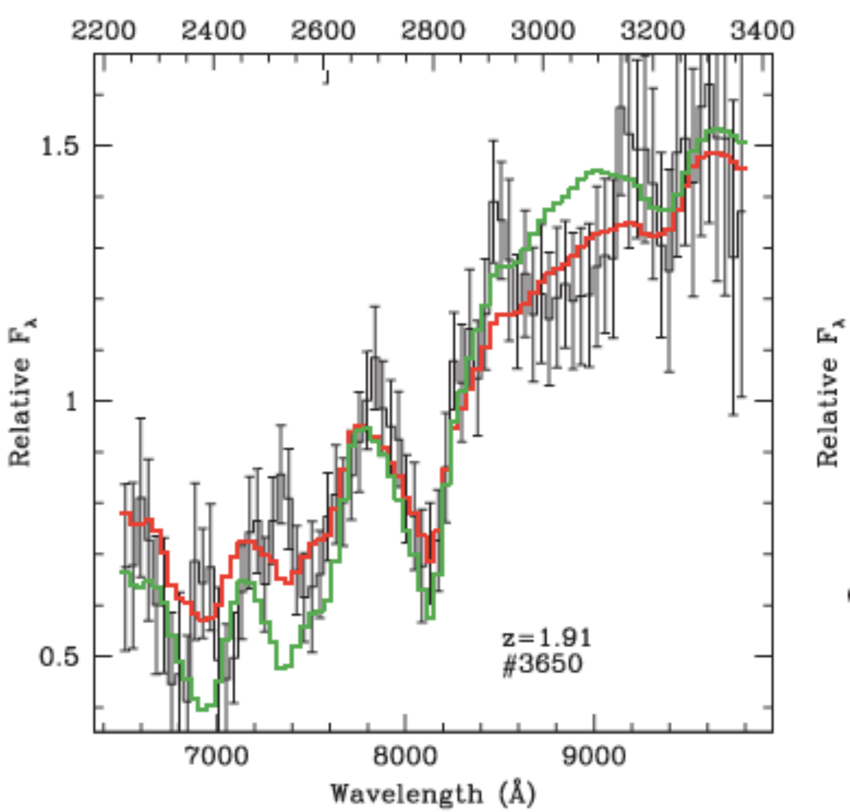



10
1
effective radius (kpc)
10¹⁰
10¹¹
stellar mass (M☉)

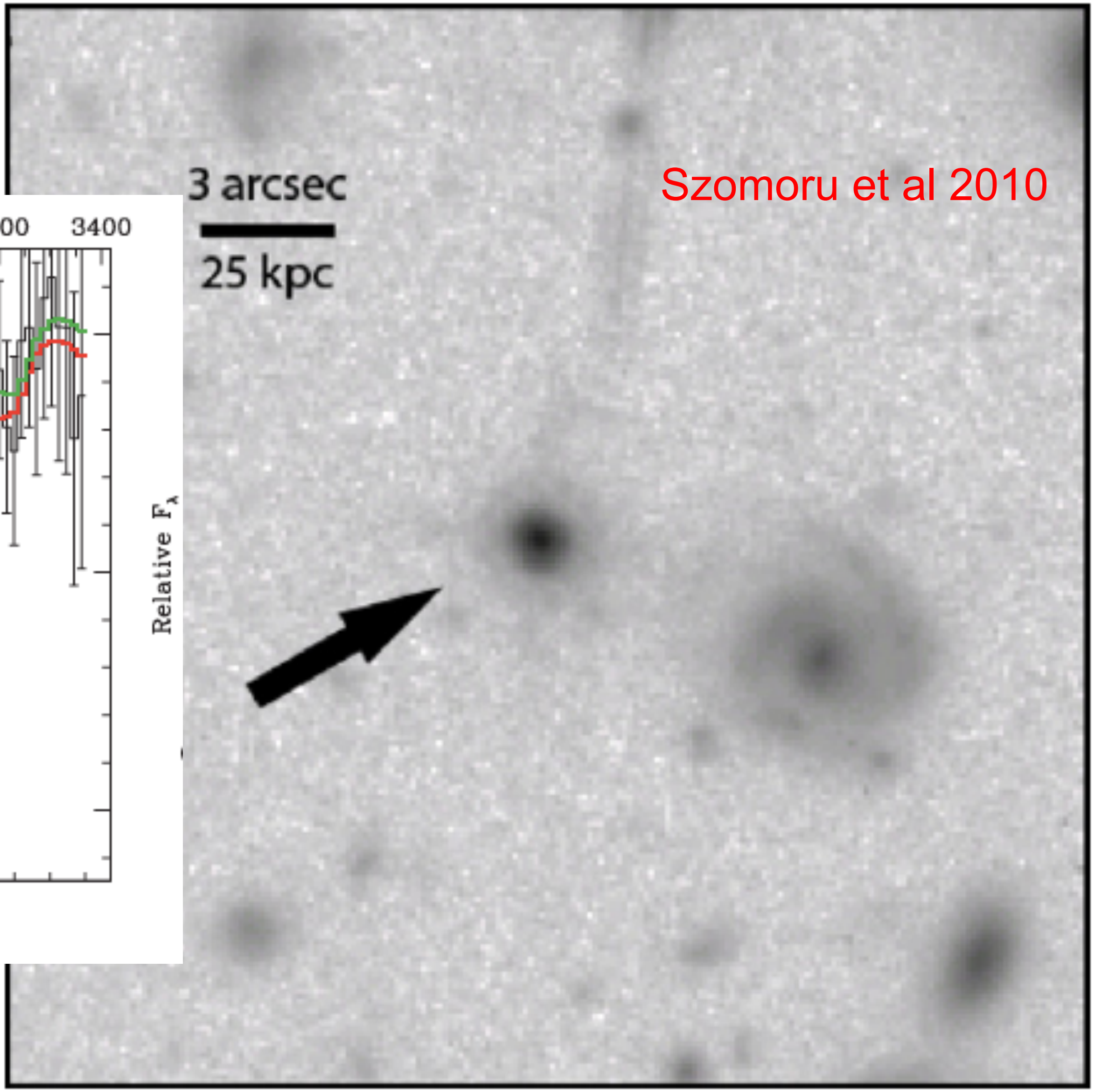


Williams et al 2010

Go to the UDF !

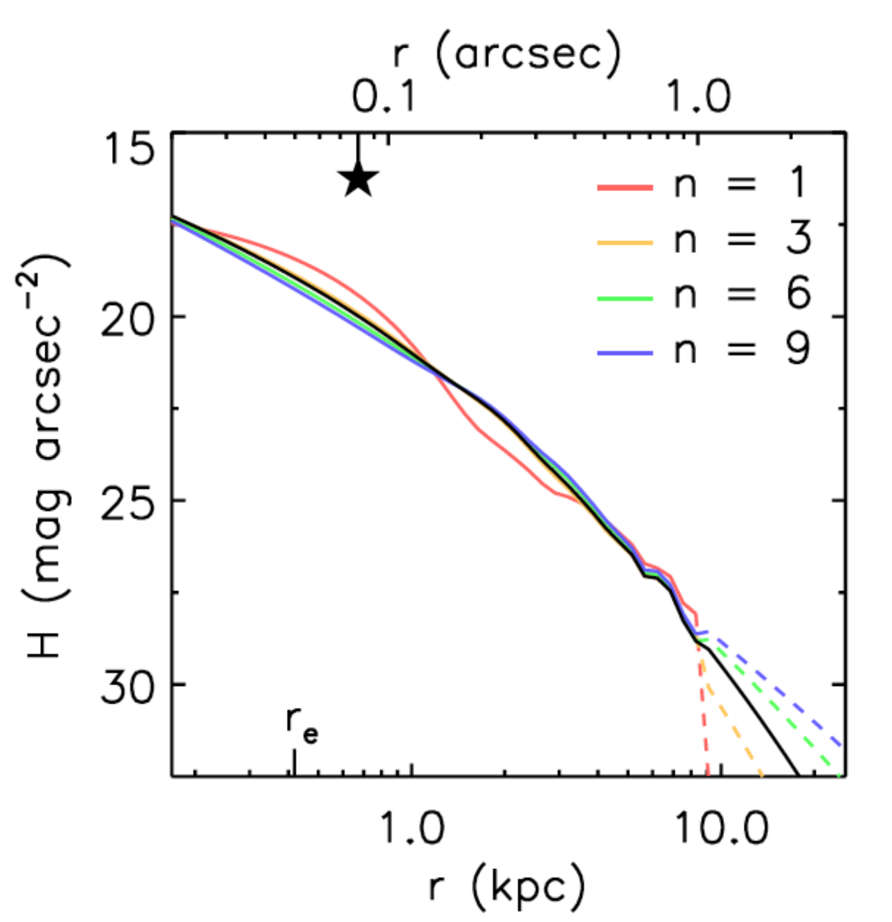


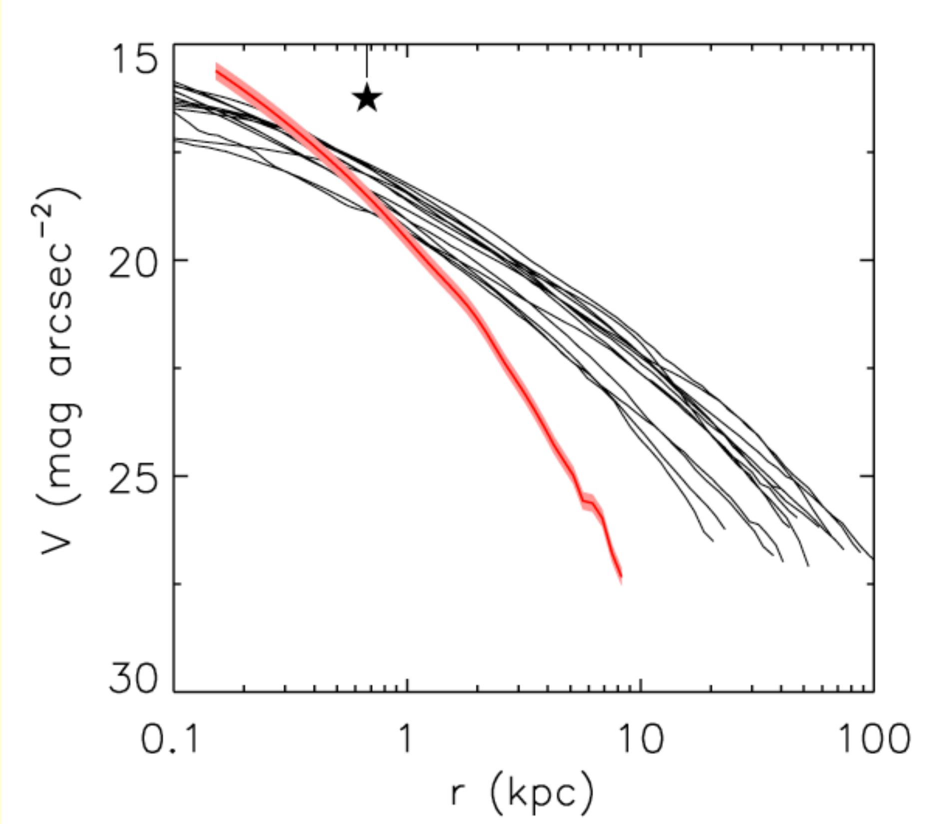
Daddi et al 2005



Szomoru et al 2010

UDF – very deep imaging

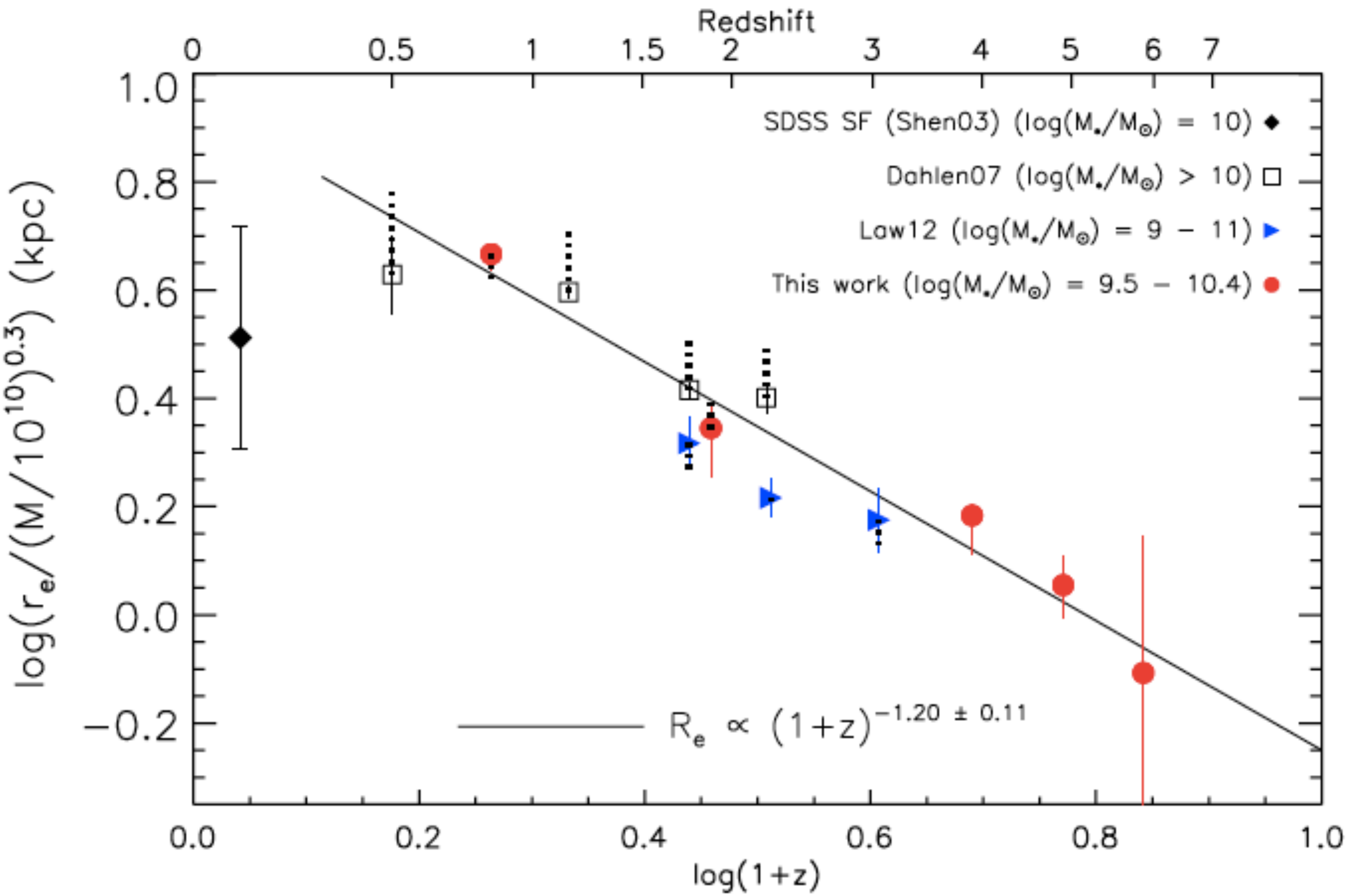




Szomoru et al 2010

Main results

1) Slow evolution of mass function at massive end
2) Rapid evolution of density of quiescent galaxies
   + slow evolution for star forming galaxies
3) Sizes of quiescent galaxies evolve very rapidly
   Re = 1/(1+z)



Redshift
0
0.5
1
1.5
2
3
4
5
6
7
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
log(r_e/(M/10^10)^0.3) (kpc)
SDSS SF (Shen03) (log(M*/M⊙) = 10)
Dahlen07 (log(M*/M⊙) > 10)
Law12 (log(M*/M⊙) = 9 − 11)
This work (log(M*/M⊙) = 9.5 − 10.4)
R_e ∝ (1+z)^−1.20 ± 0.11
0.0
0.2
0.4
0.6
0.8
1.0
log(1+z)

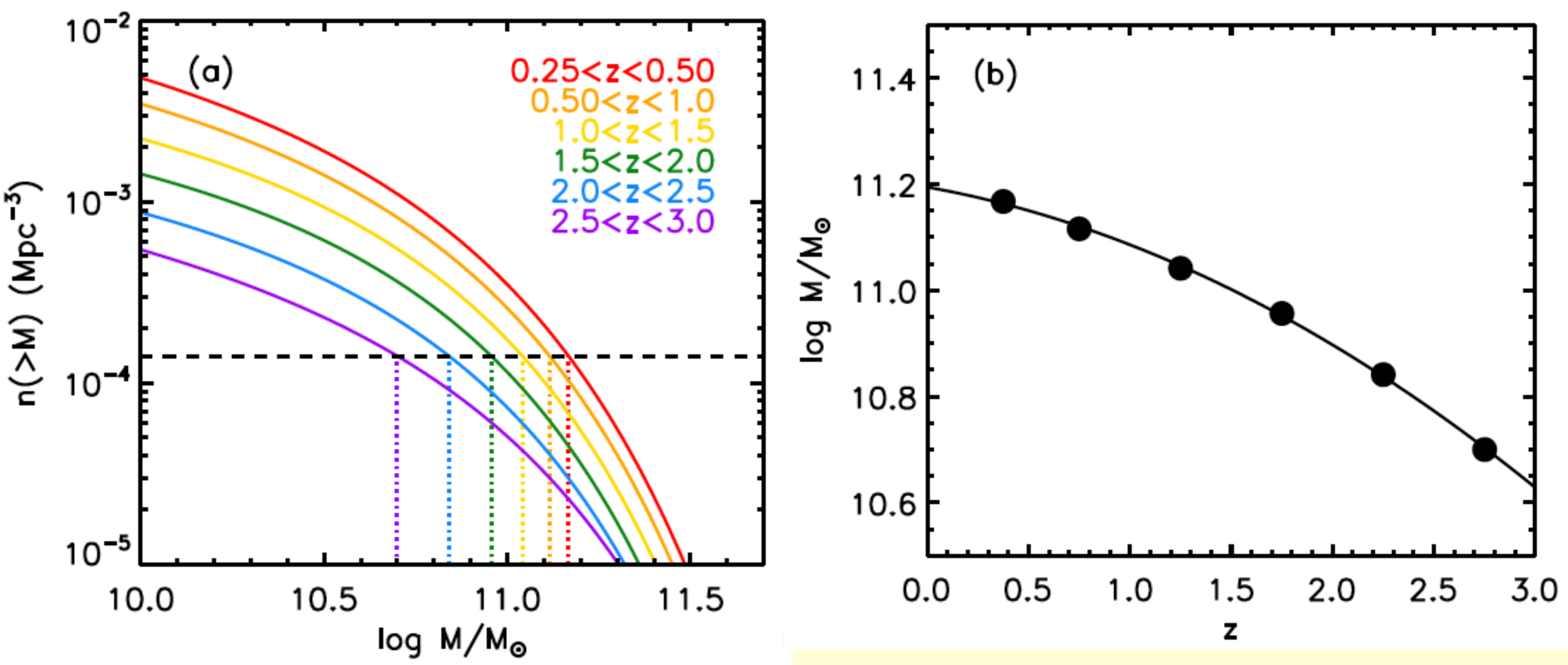
What is going on ?

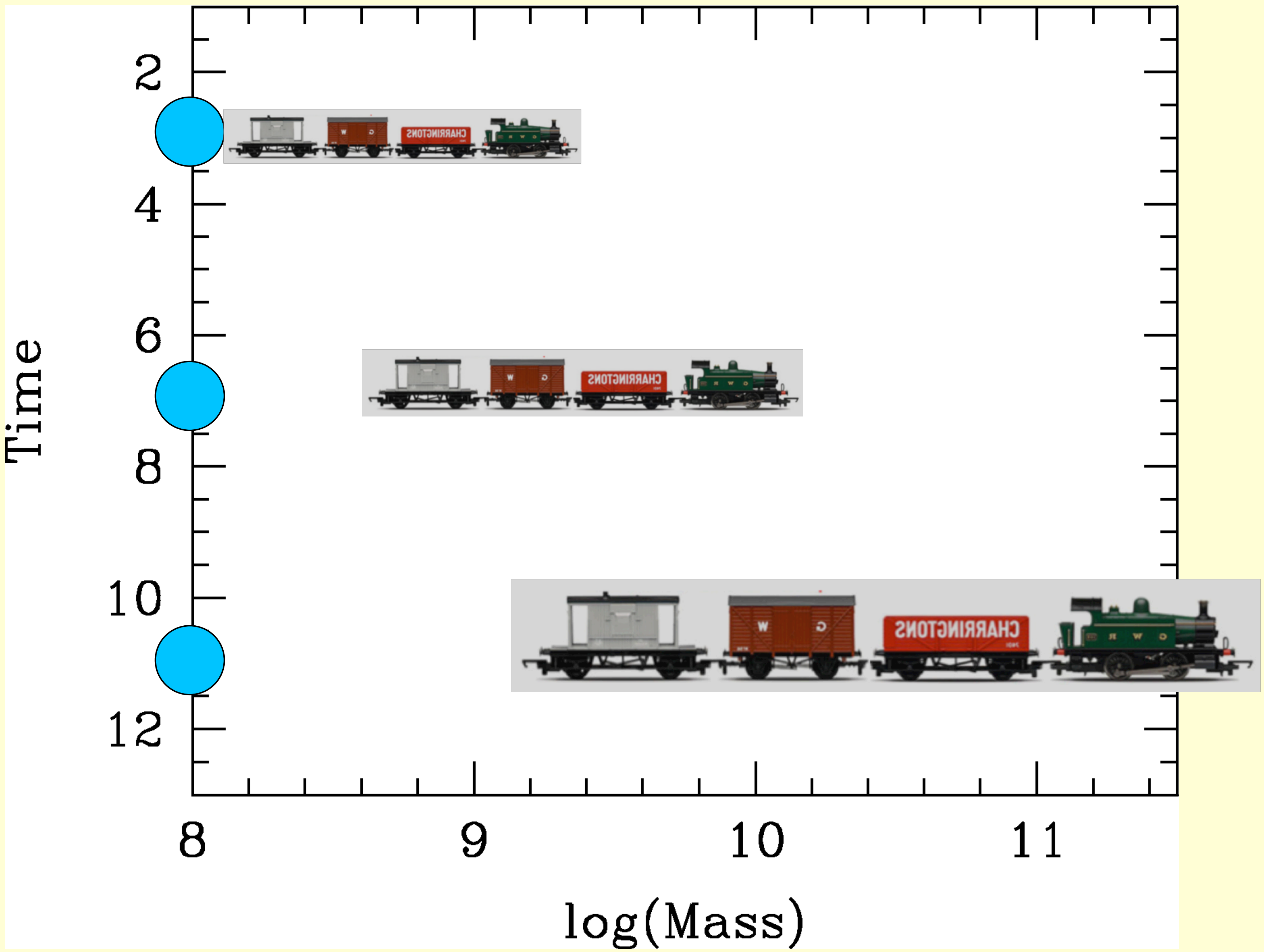
Typical massive galaxy

- Starts forming stars early (z>>2)
- After some time, slows down (driven by halo ? Merger ? Black hole ?)
- Gets added to the red sequence which slowly builds up with time

The Final Step

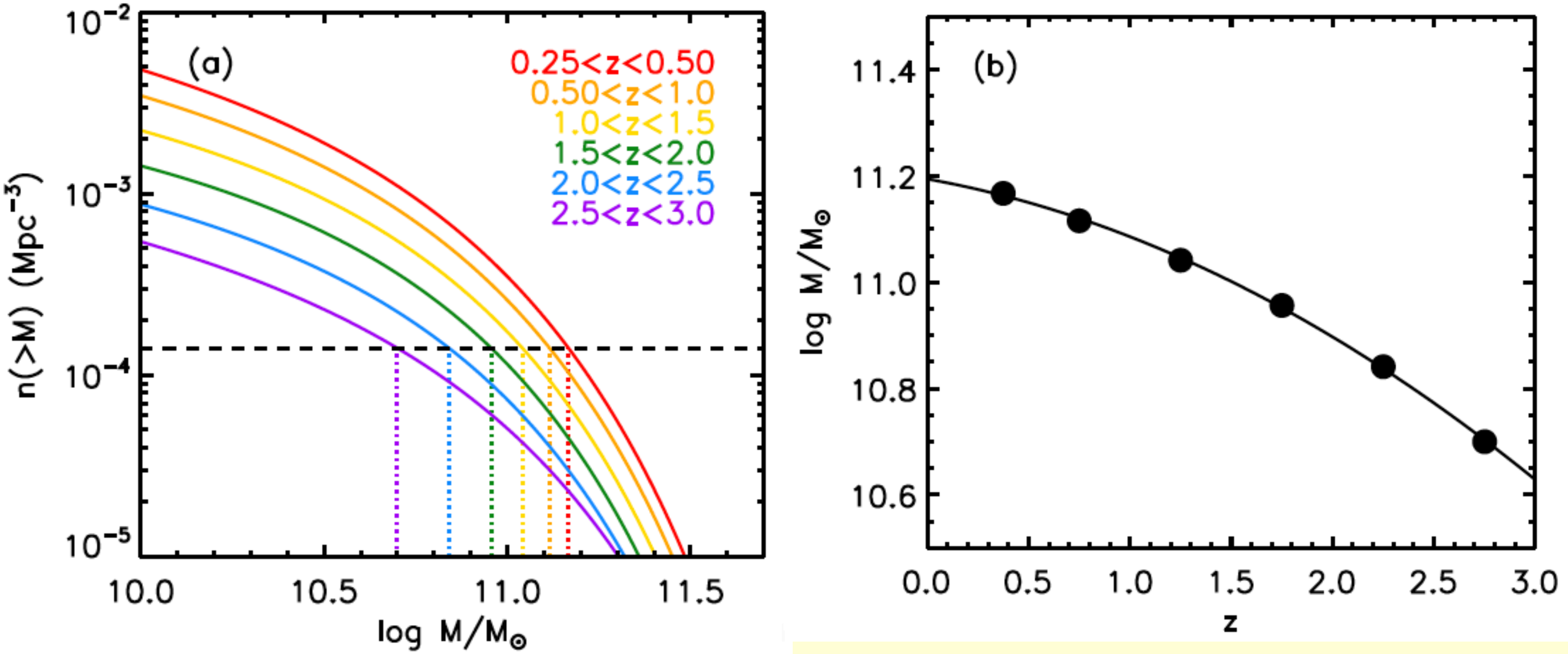
- Link galaxies by cumulative number density

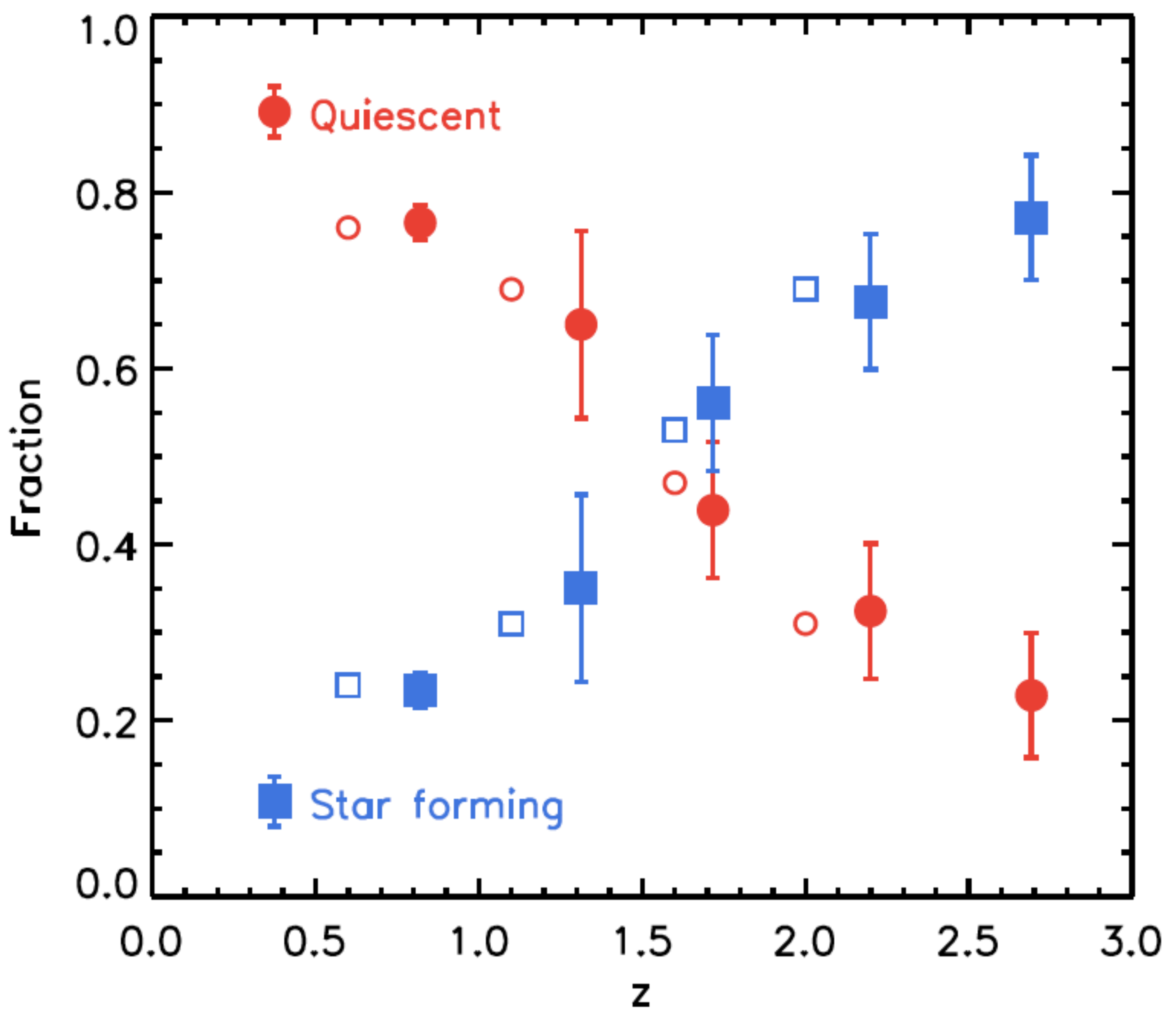


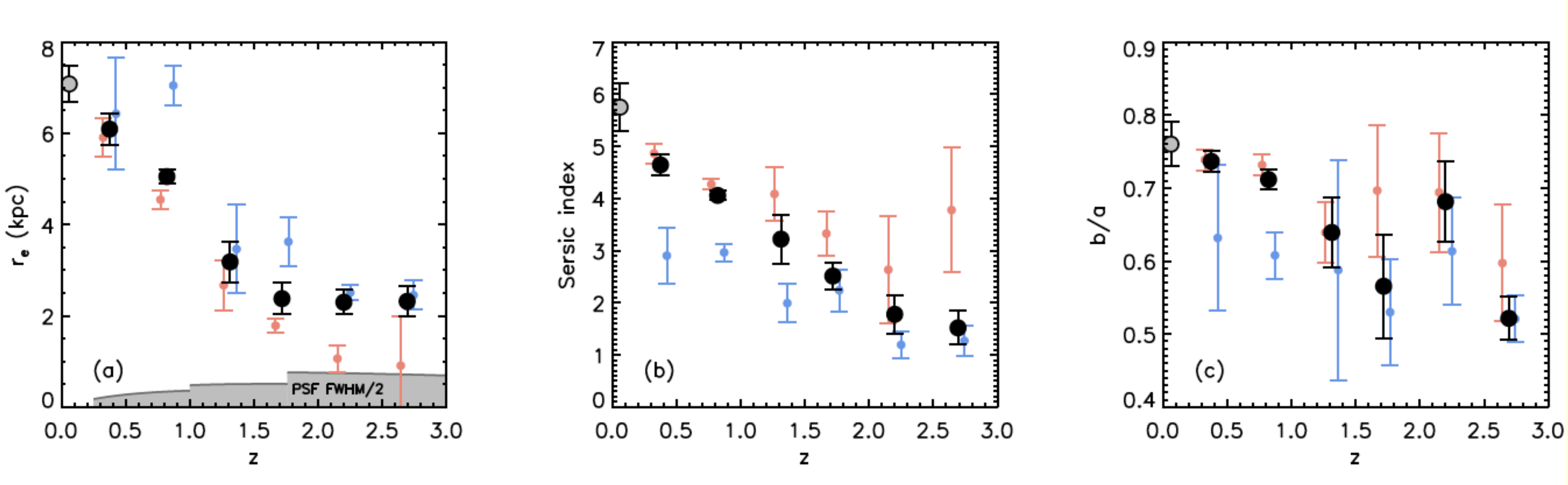

Time
2
4
6
8
10
12
8
9
10
11
log(Mass)

The Final Step

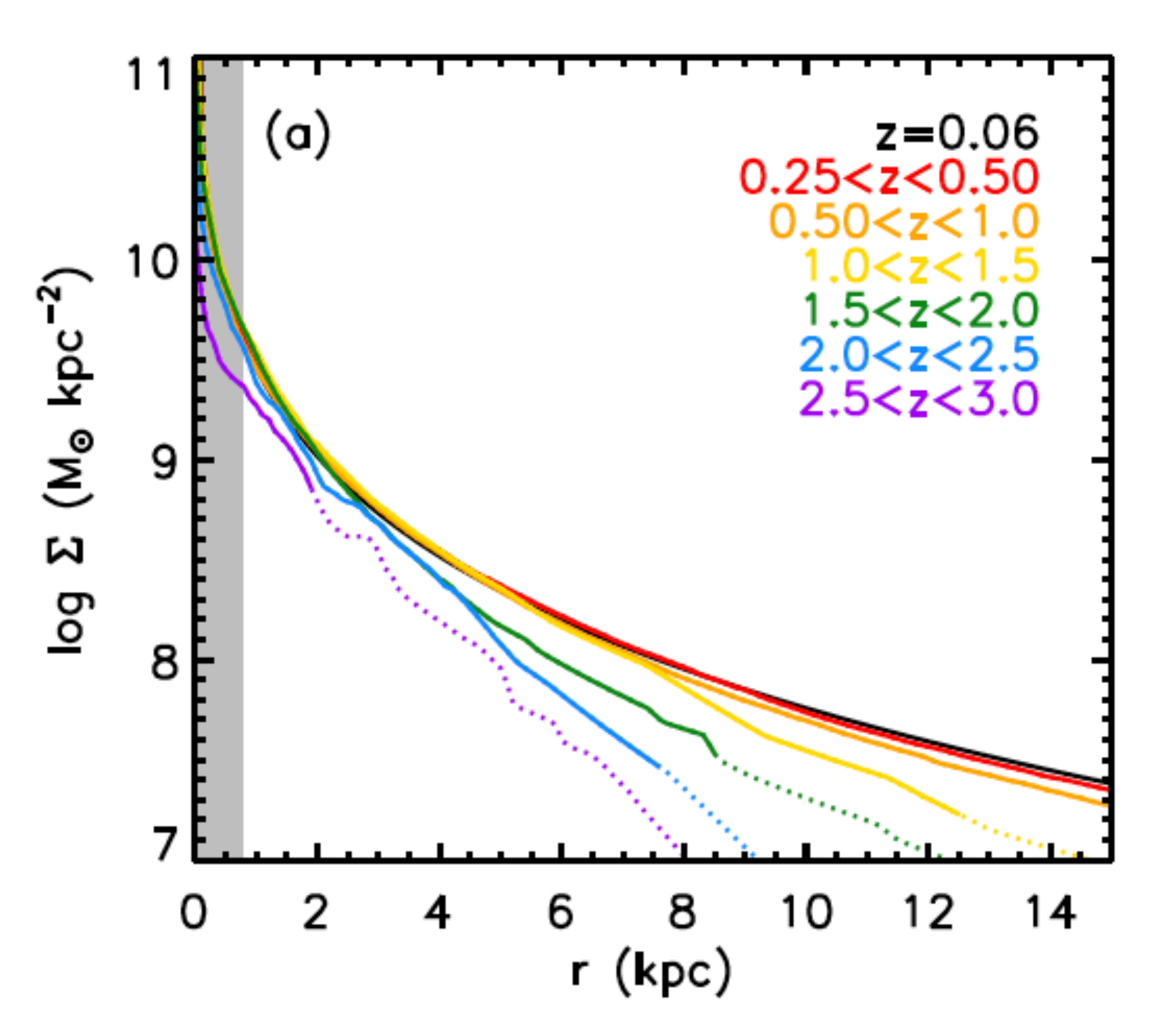
- Link galaxies by cumulative number density




Quiescent
Star forming
Fraction
z
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0



(a)
PSF FWHM/2
r_e (kpc)
z
(b)
Sersic index
z
(c)
b/a
z



Patel et al 12

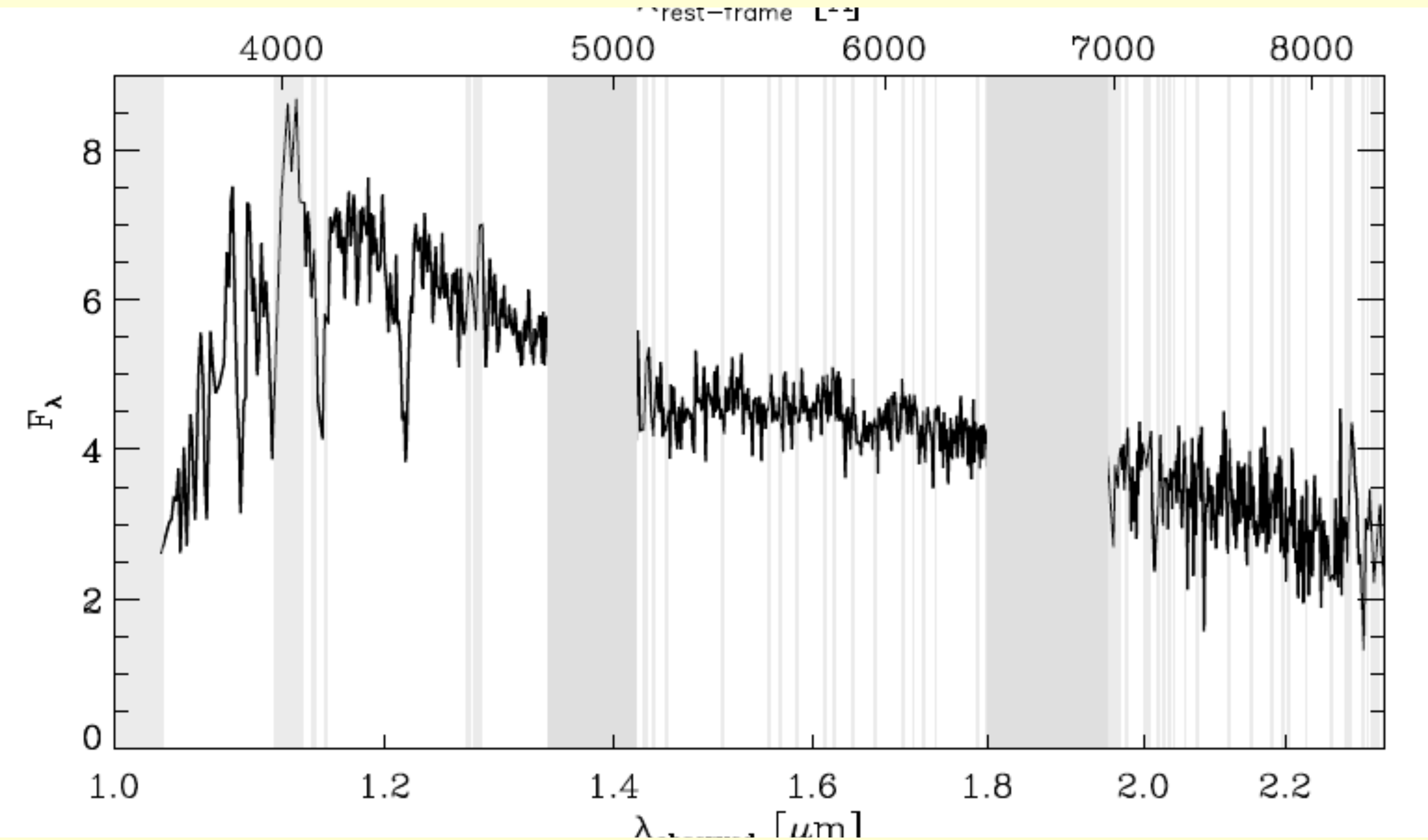
Main results

1) Slow evolution of mass function at massive end
2) Rapid evolution of density of quiescent galaxies + slow evolution for star forming galaxies -> Some process converts star forming galaxies to “dead” galaxies
3) Sizes of quiescent galaxies evolve very rapidly $Re = 1/(1+z)$
4) Galaxies build up “inside-out” – inner parts in place at high z.

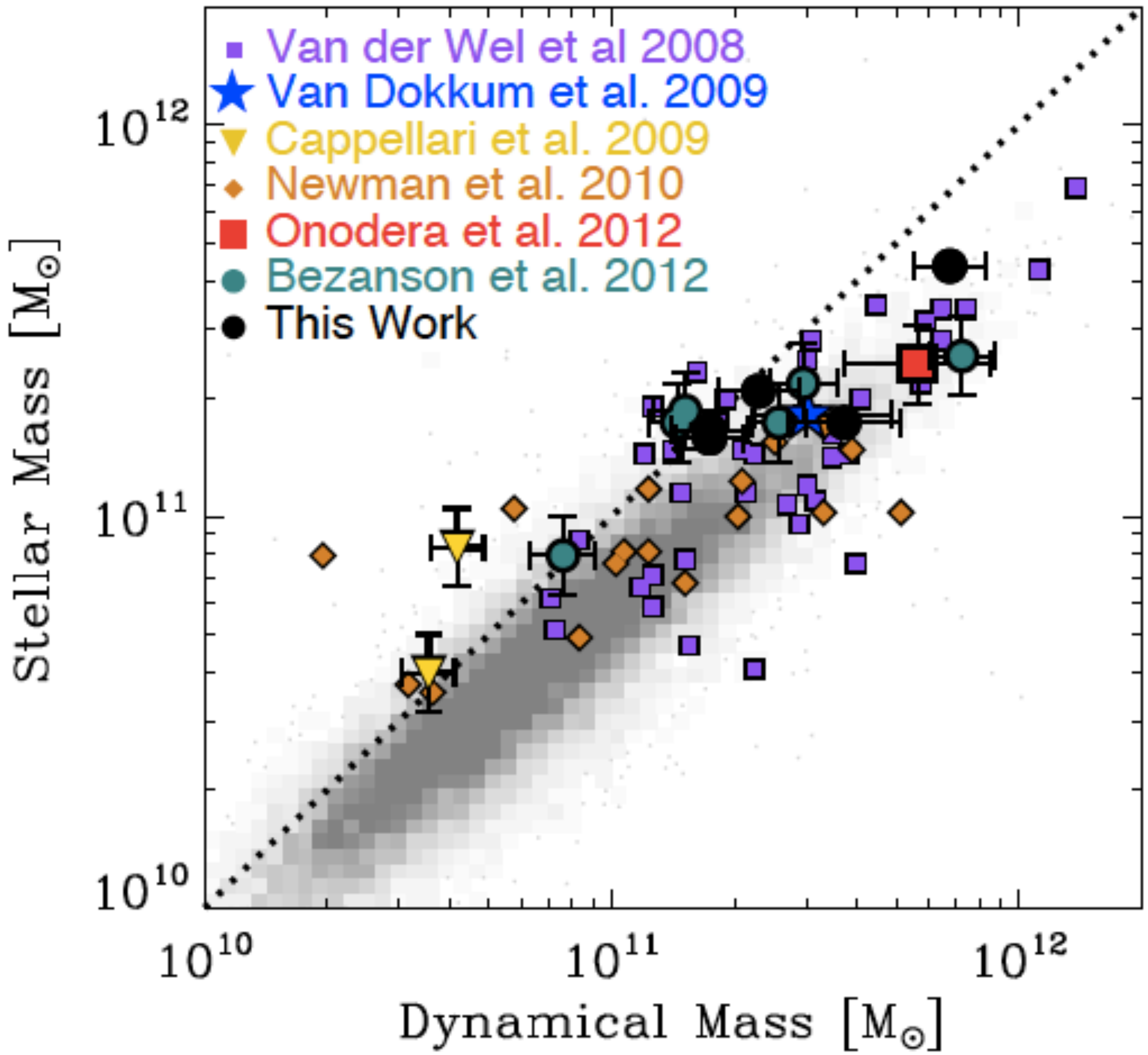
Why should we believe any of this ?

- Analyses depend strongly on “photometric redshifts” & stellar masses
- Spectroscopy required – in the Near-IR !

X Shooter spectrum of galaxy at z=1.8



Van de Sande 12



Van der Wel et al 2008
Van Dokkum et al. 2009
Cappellari et al. 2009
Newman et al. 2010
Onodera et al. 2012
Bezanson et al. 2012
This Work
Stellar Mass [$M_\odot$]
Dynamical Mass [$M_\odot$]
10^{10}
10^{11}
10^{12}

Open questions

1) What drives the formation

- Gas infall versus feedback

2) Why does star formation shut down ?

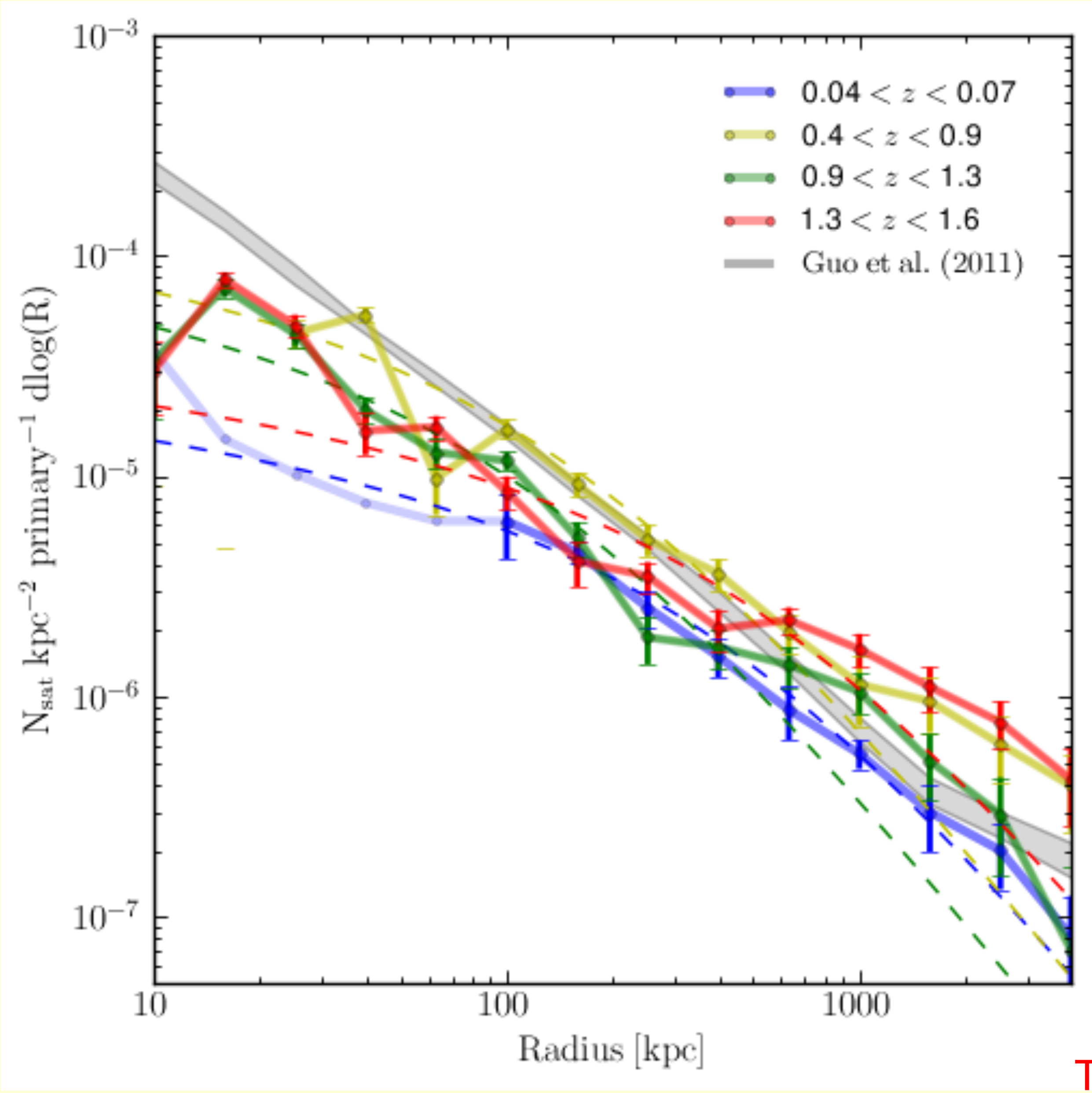
- Hot gas infall, black holes

Role of environment ?

3) How does growth since z=2.5 occur ?

merging ?

4) What process makes these very small systems?



10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
N_{sat} kpc^{-2} primary^{-1} dlog(R)
10
100
1000
Radius [kpc]
$0.04 < z < 0.07$
$0.4 < z < 0.9$
$0.9 < z < 1.3$
$1.3 < z < 1.6$
Guo et al. (2011)

Tal et al