50 years of galaxy evolution

- A perspective
- Using stellar masses and ESO/VLT
- Looking forward

Bird's-eye view of galaxy evolution

70s:

- Dark matter
- Structure of galaxies + Tully-Fisher, Faber Jackson

Low z

80s:

- Large scale structure/clusters and hot gas
- Flows
- Mergers (including IRAS Ulirgs)
- Lensing
- Galaxy structure and gastrophysics

Mostly low z

90s:

- Large scale structure
- Galaxy evolution
  - Z=0 to z=1 CFRS
  - Z=3: Lyman Breaks
  - Z=5 and above
- Evolution of clusters (Xray + optical)
- Super massive Black Holes

10000s of z

Z>5 !

2000s:

- SDSS
- Major surveys – quantify galaxy evolution
- Mass selected samples + serious models

100000s of z

Z > 8 !

What was ESOs contribution ?

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ESO for the Public > Science with ESO Telescopes > Top 10 Discoveries

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- Science with ESO Telescopes
  - **Top 10 Discoveries**
  - Exoplanets
  - Very Old Stars
  - Black Hole at the Galactic Centre
  - Gamma-Ray Bursts
  - Science Archive
- Events, Exhibitions & Campaigns
- Outreach
- Products
- Relations with Industry
- Working at ESO
- ESO in your Language

ESO Top 10 Astronomical Discoveries

1. Stars orbiting the Milky Way black hole
2. Accelerating Universe
3. First Image of an Exoplanet
4. Gamma-ray bursts – the connections with supernovae
5. Cosmic temperature independently measured
6. Oldest star known in the Milky Way
7. Flares from the supermassive black hole at the center of the Milk
8. Direct measurements of the spectra of exoplanets and their atmo
9. Richest planetary system
10. Milky Way stellar motions

Some highly cited ESO papers on galaxies/galaxy evolution

1980s

Lauberts 1982, Lauberts Valentijn 1989, ESO/Uppsala survey (including surface photometry (567, 436)

- Shaver et al. 1983 The galactic abundance gradient (735)

- Prevot, Lequeux, et al. 1984, The typical interstellar extinction in the Small Magellanic Cloud (309)

1990s (z>0.0001)

Caon, Capaccioli, D'Onofrio 1993, On the Shape of the Light Profiles of Early Type Galaxies (414)

Jorgensen, Franx, Kjaergaard et al. 1996, The Fundamental Plane for cluster E and S0 galaxies (393)

Bergeron & Boisse, 1991, A sample of galaxies giving rise to Mg II quasar absorption systems (356)

Rosati et al, 1998, The ROSAT Deep Cluster Survey: The X-Ray Luminosity Function Out to z=0.8 (355)

2000s

CDFS, Goods, Cosmos, VVDS survey papers (multi wavelength, multi-observatory)

Bell et al, 2004, Nearly 5000 Distant Early-Type Galaxies in COMBO-17: A Red Sequence and Its Evolution since z=1 (618)

Thomas et al 2005, The Epochs of Early-Type Galaxy Formation as a Function of Environment (597)

Haring, Rix 2004, On the Black Hole Mass-Bulge Mass Relation(573)

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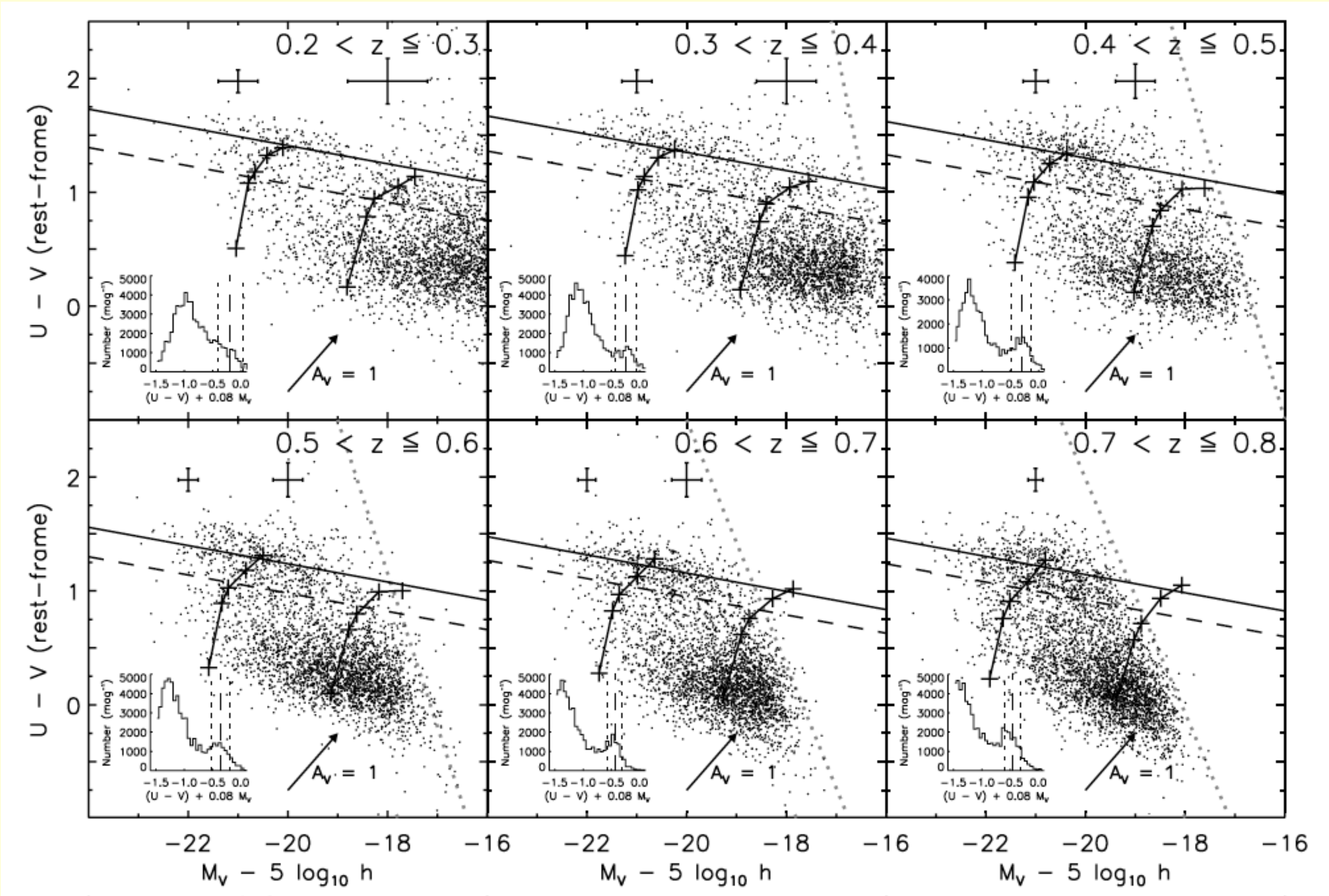
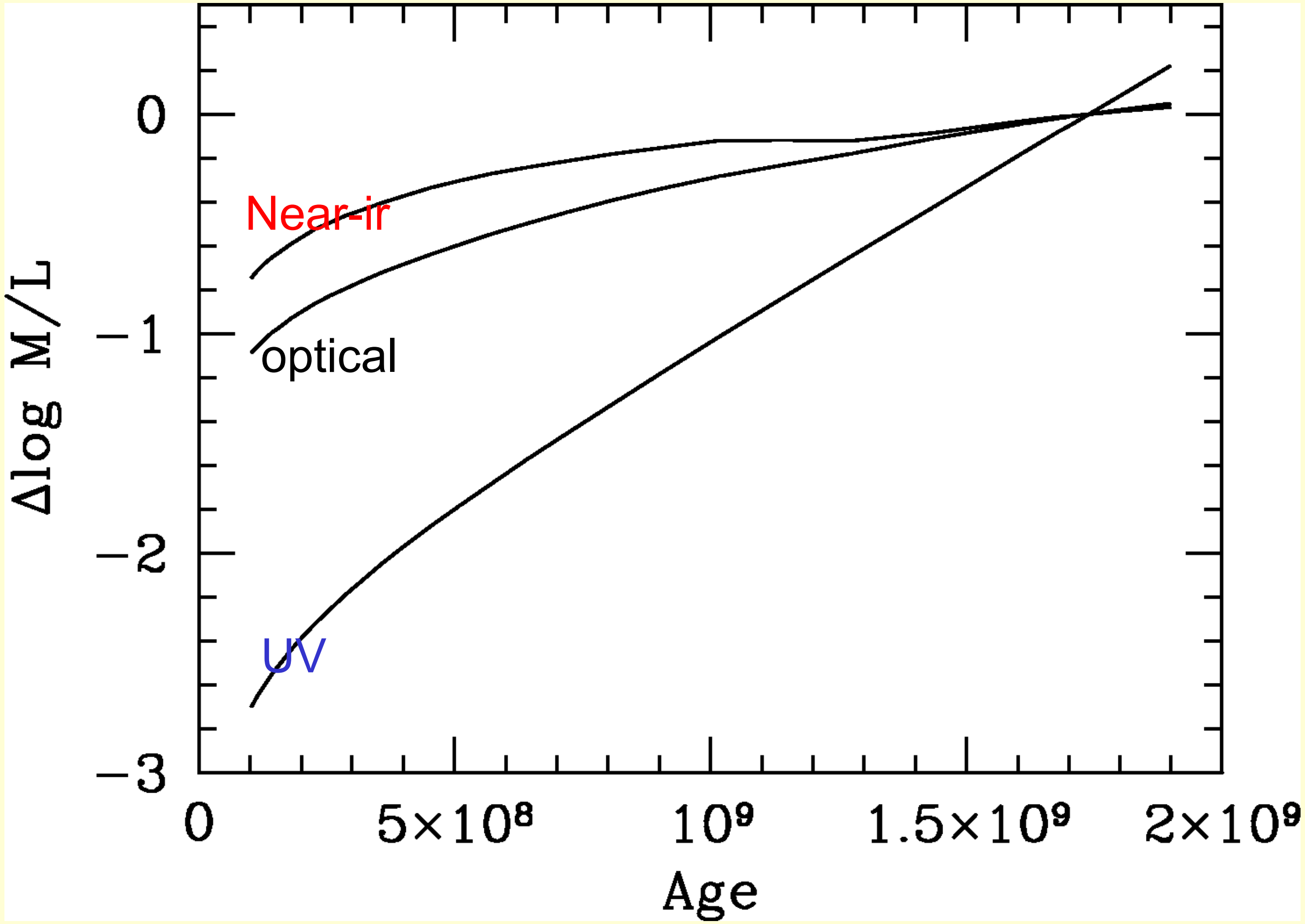
Combo-17: 2.2m imaging, with medium band filters



Using (stellar masses) for galaxy evolution

Before 2000, most analyses based on luminosities



Using (stellar masses) for galaxy evolution

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

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

or …

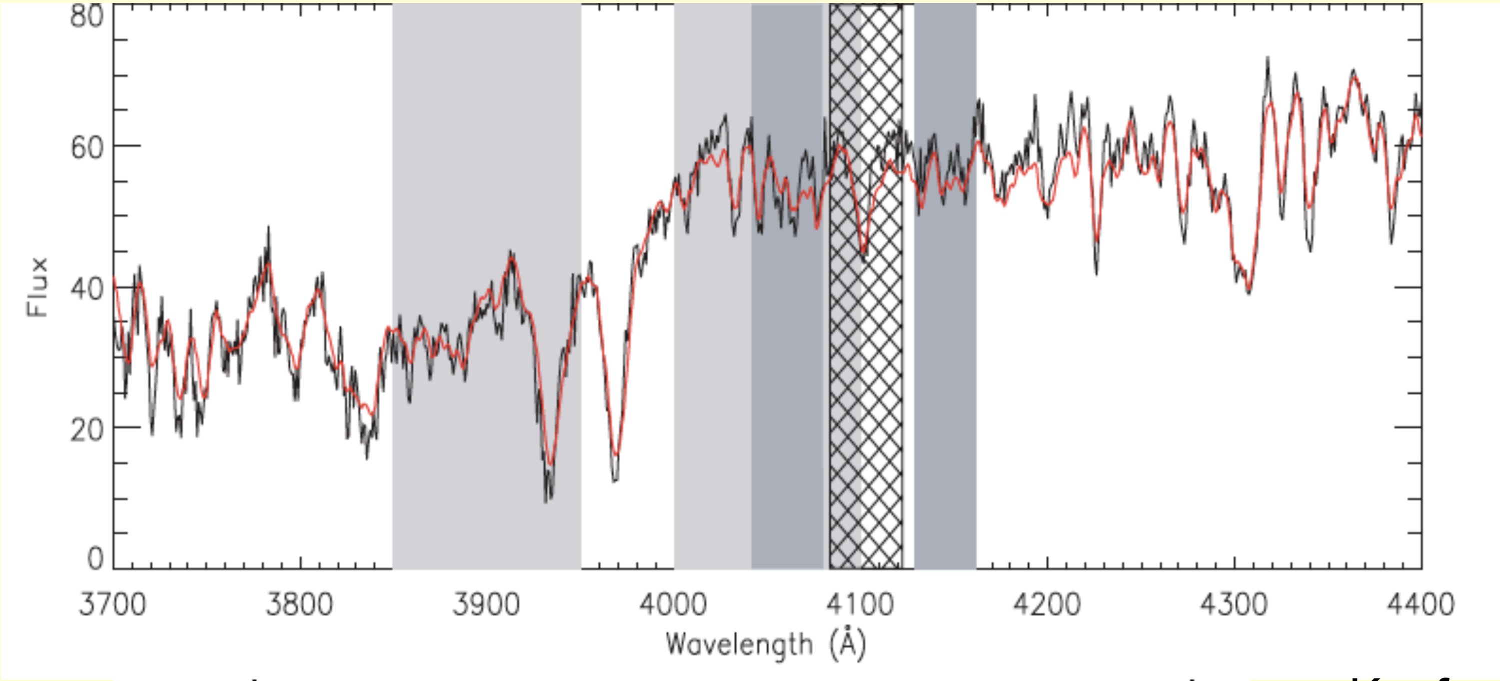
Using (stellar masses) for galaxy evolution

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

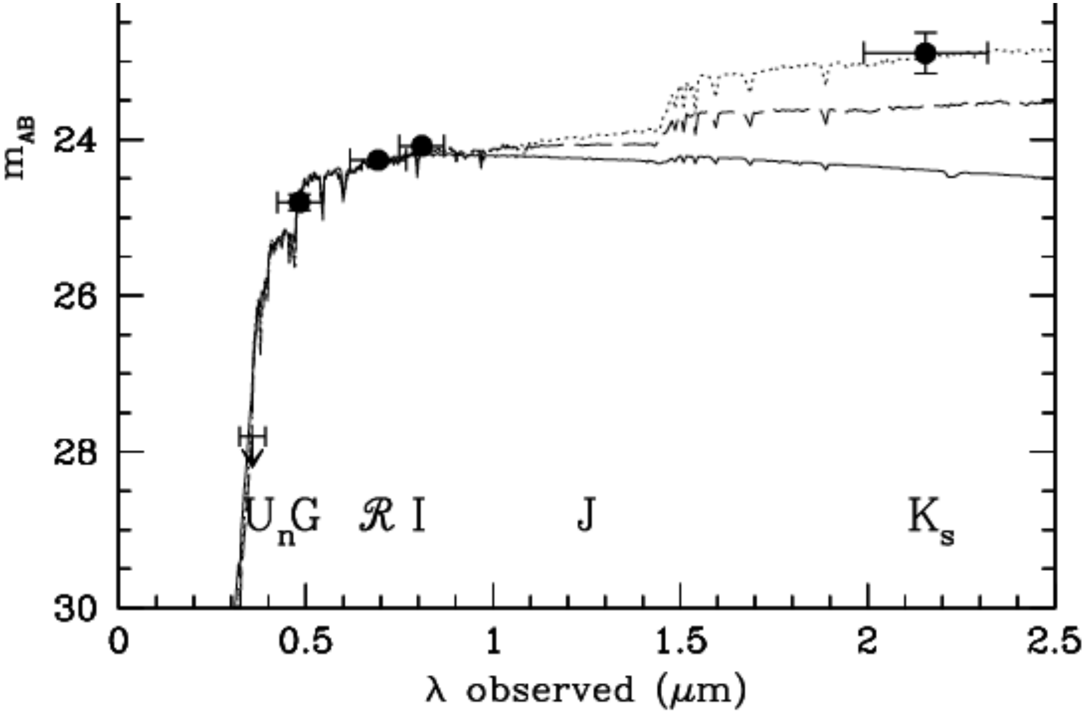
Extragalactic: micro-lensing (for "real" astronomers)

or …

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

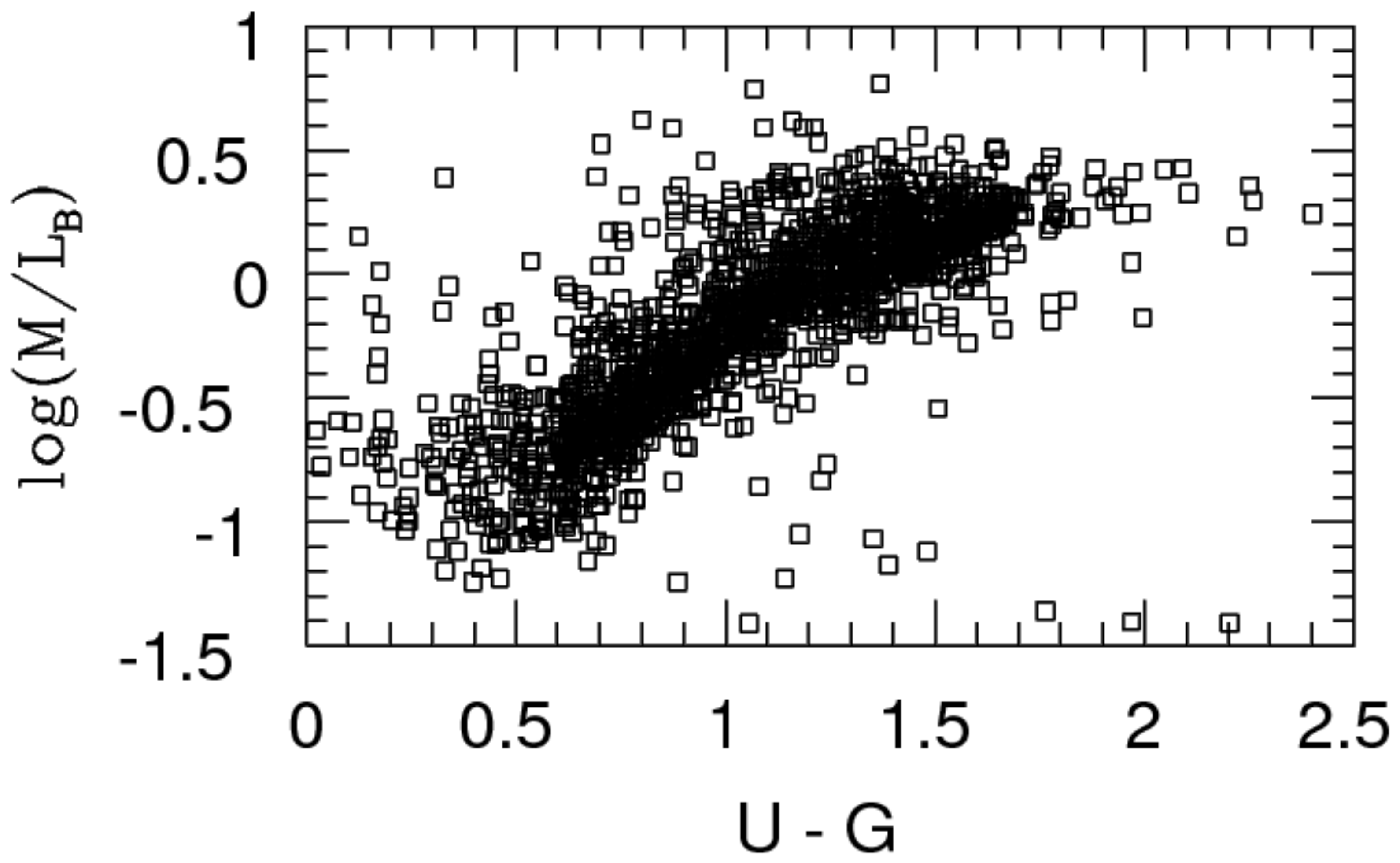


Kaufmann et al. 03



Shapley et al. 01

The saving grace:



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

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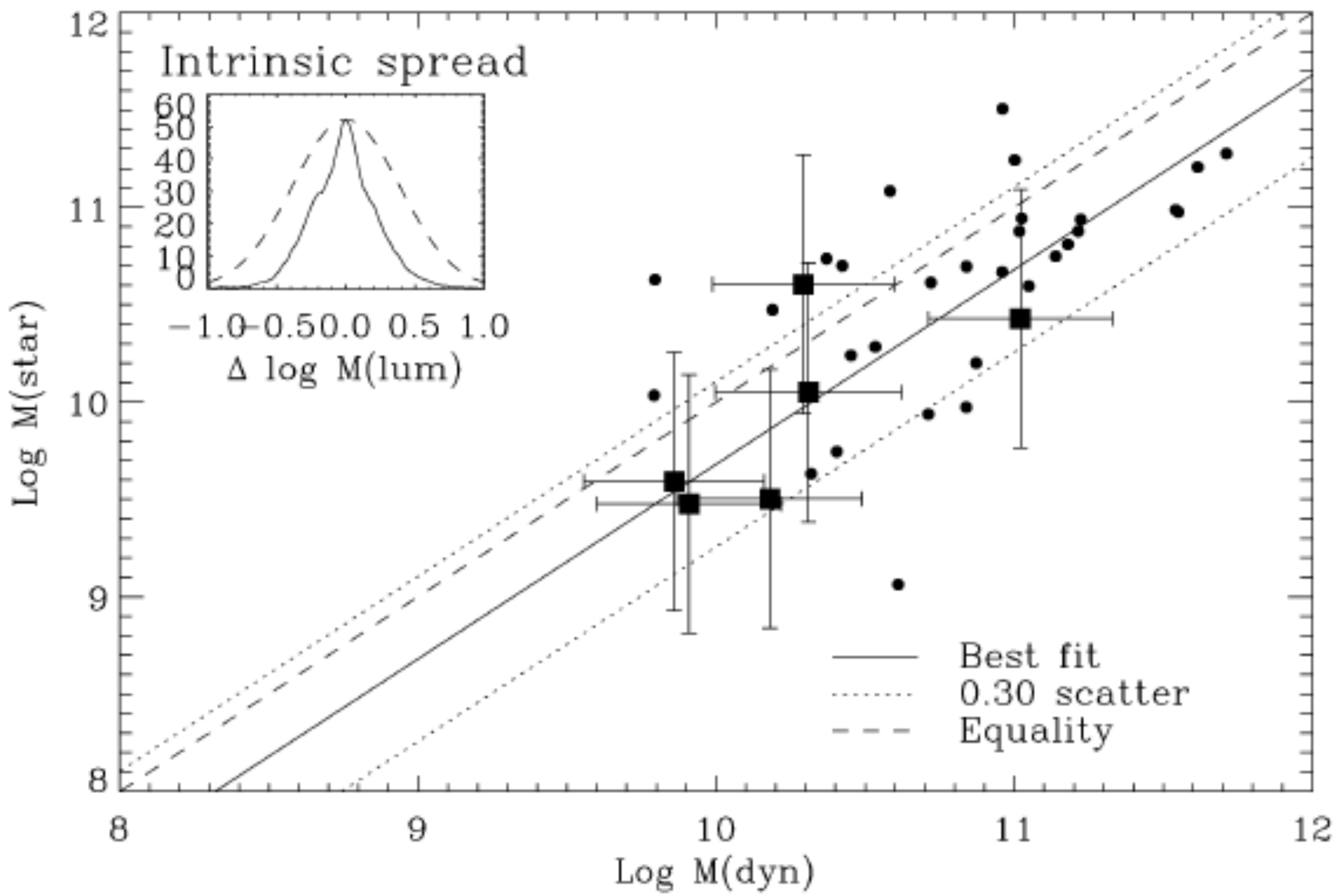
ABSTRACT

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)
Log M(star)
Log M(dyn)
12
11
10
9
8
8
9
10
11
12
Best fit
0.30 scatter
Equality

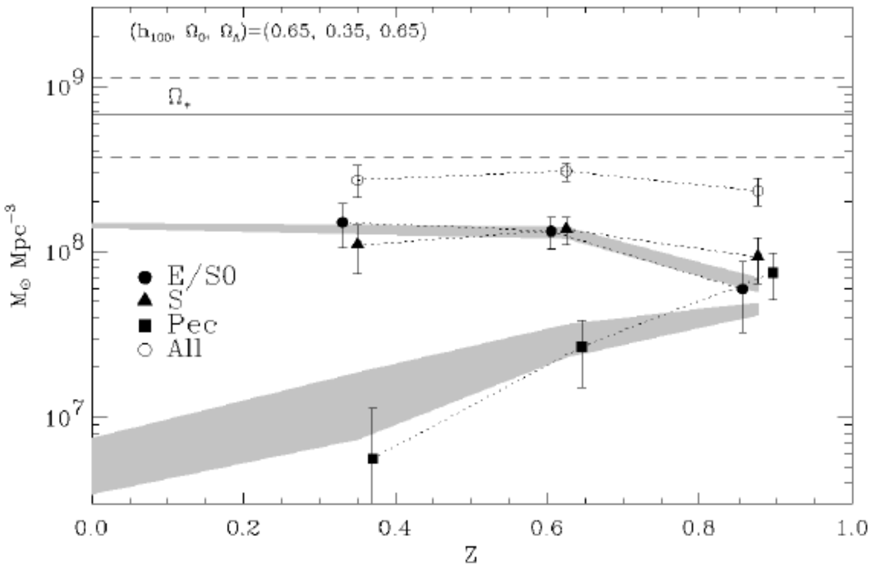


FIG. 2.—Integrated stellar mass density for galaxies with $10.5 < \log M_{\rm star} < 11.6$ as a function of redshift and visual morphology. The shaded regions show the predictions of the mass density in peculiar and elliptical galaxies from the simple merging models described in the text.

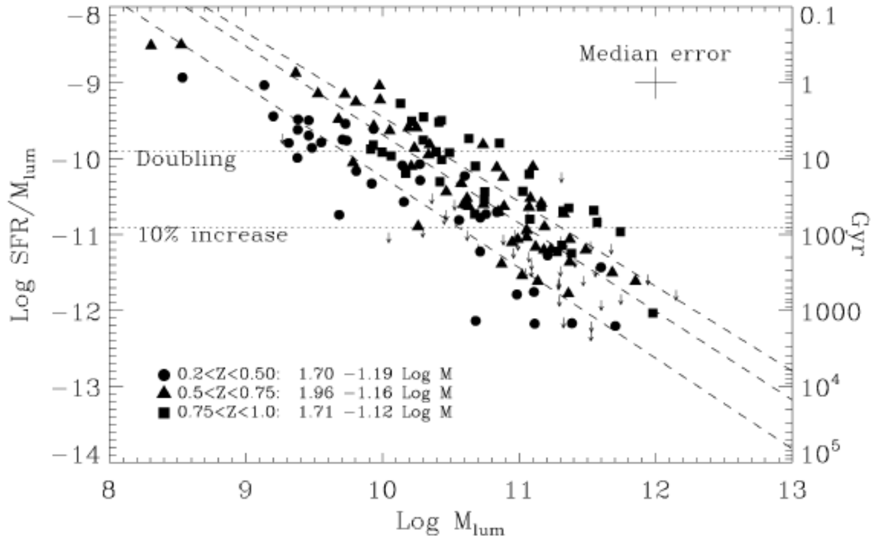


FIG. 3.—Specific star formation rate *R* for the galaxies in the sample. The three lines show orthogonal least-squares fit to the three redshift ranges indicated. The fit parameters are shown in the lower left corner. The right-hand panel shows the doubling time in Gyr, assuming constant star formation.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

Bell et al:

“When we account for the change in stellar mass-to-light ratio implied by the redshift evolution in red galaxy colors, the COMBO-17 data indicate an increase in stellar mass on the red sequence by a factor of 2 since z=1”.

Bell et al:

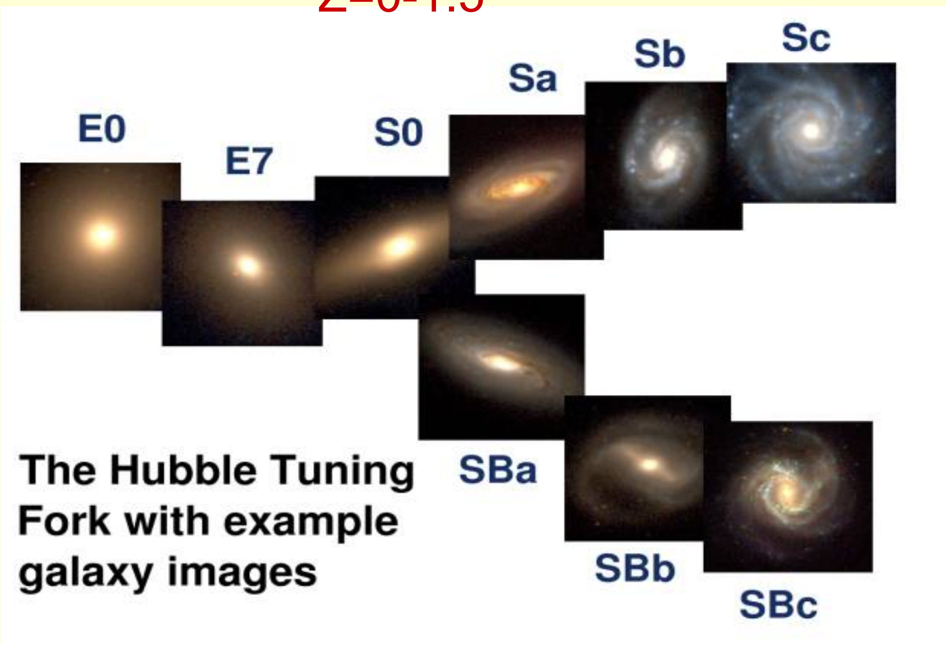
"When we account for the change in stellar mass-to-light ratio implied by the redshift evolution in red galaxy colors, the COMBO-17 data indicate an increase in stellar mass on the red sequence by a factor of 2 since z=1".

The mass in dead galaxies increases with time; the mass in star forming galaxies remains the same

Where does the VLT come in ?

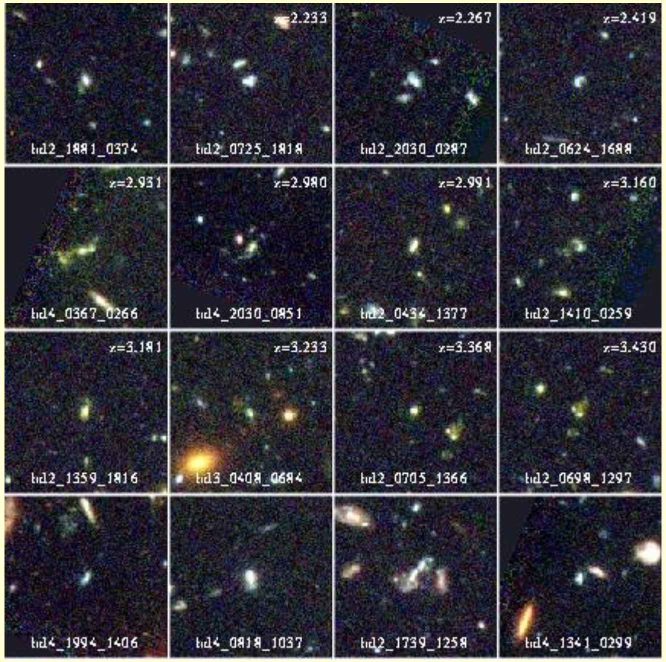
We knew about Lyman breaks, SFR(z), z=5 galaxies, Ly alpha emitters, etc

Z=0-1.5



The desert 1.5-2

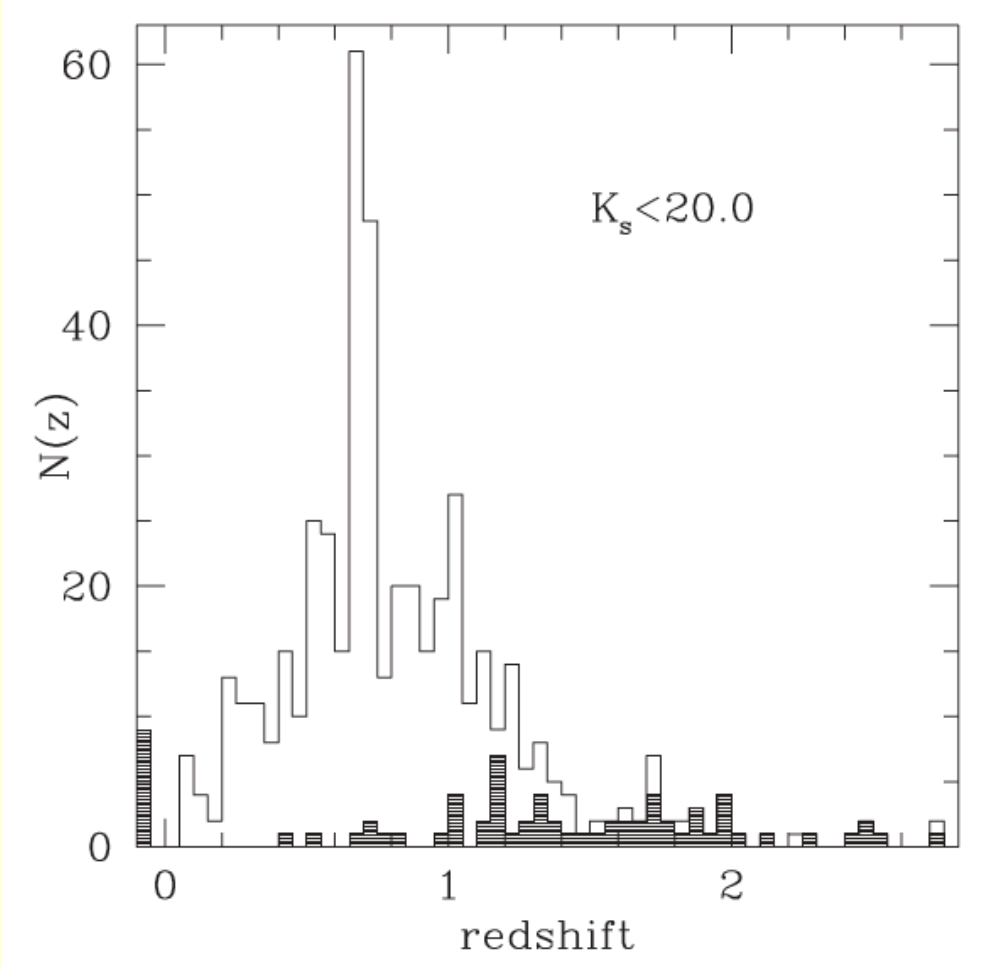
z=2-5



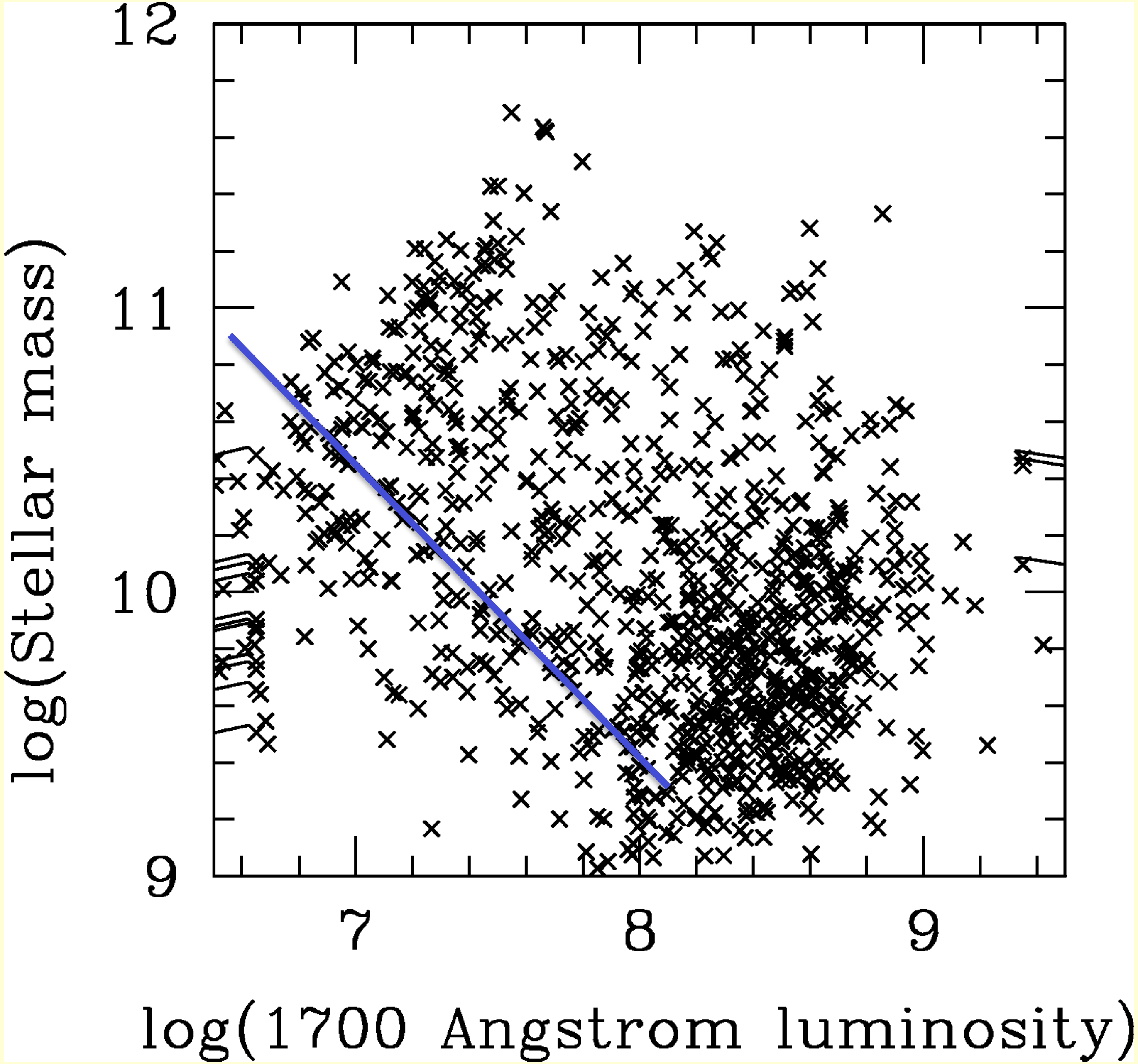
time

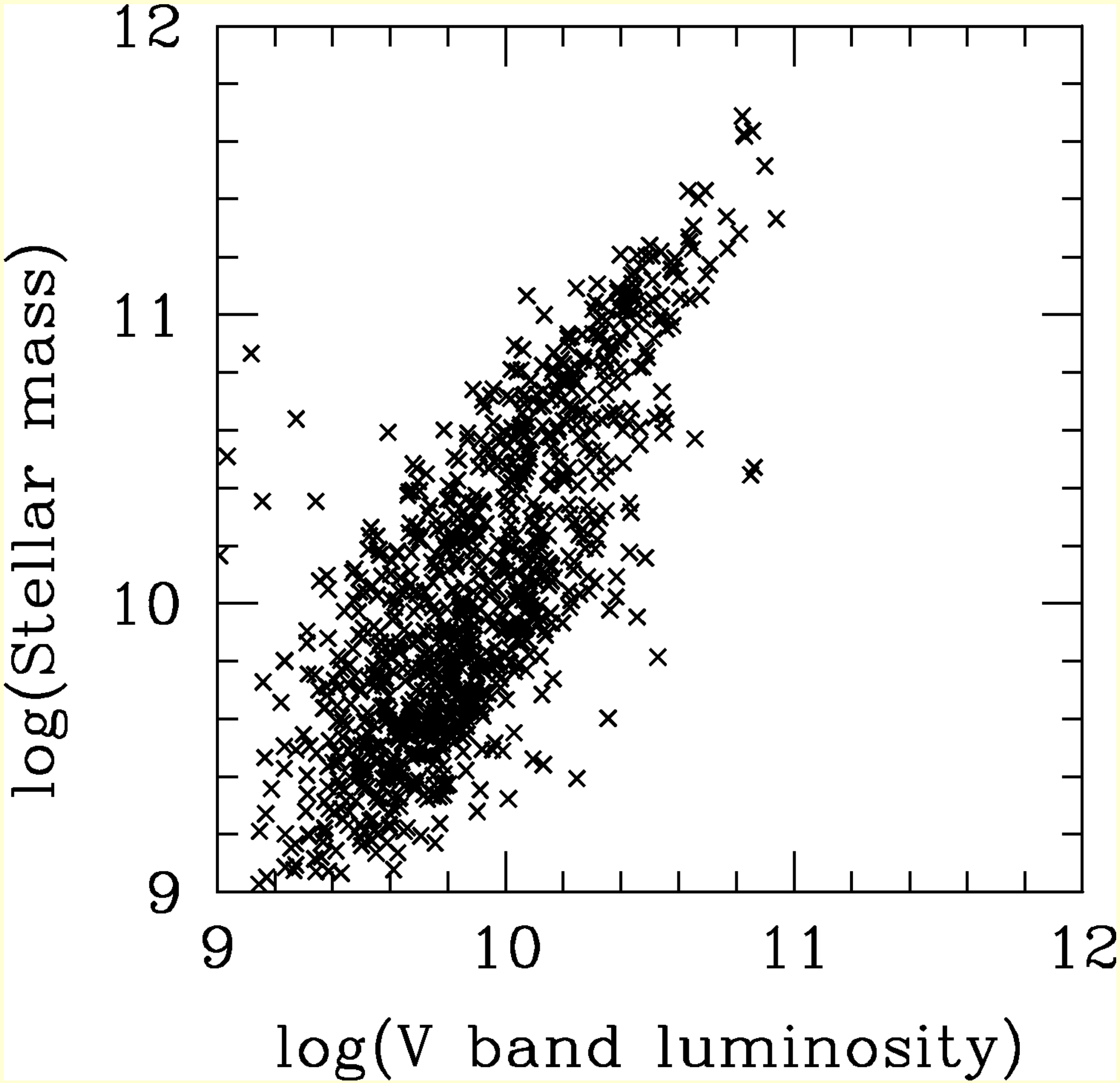
K20 survey (Cimatti et al)

Deep FORS spectroscopy on a K selected sample



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





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

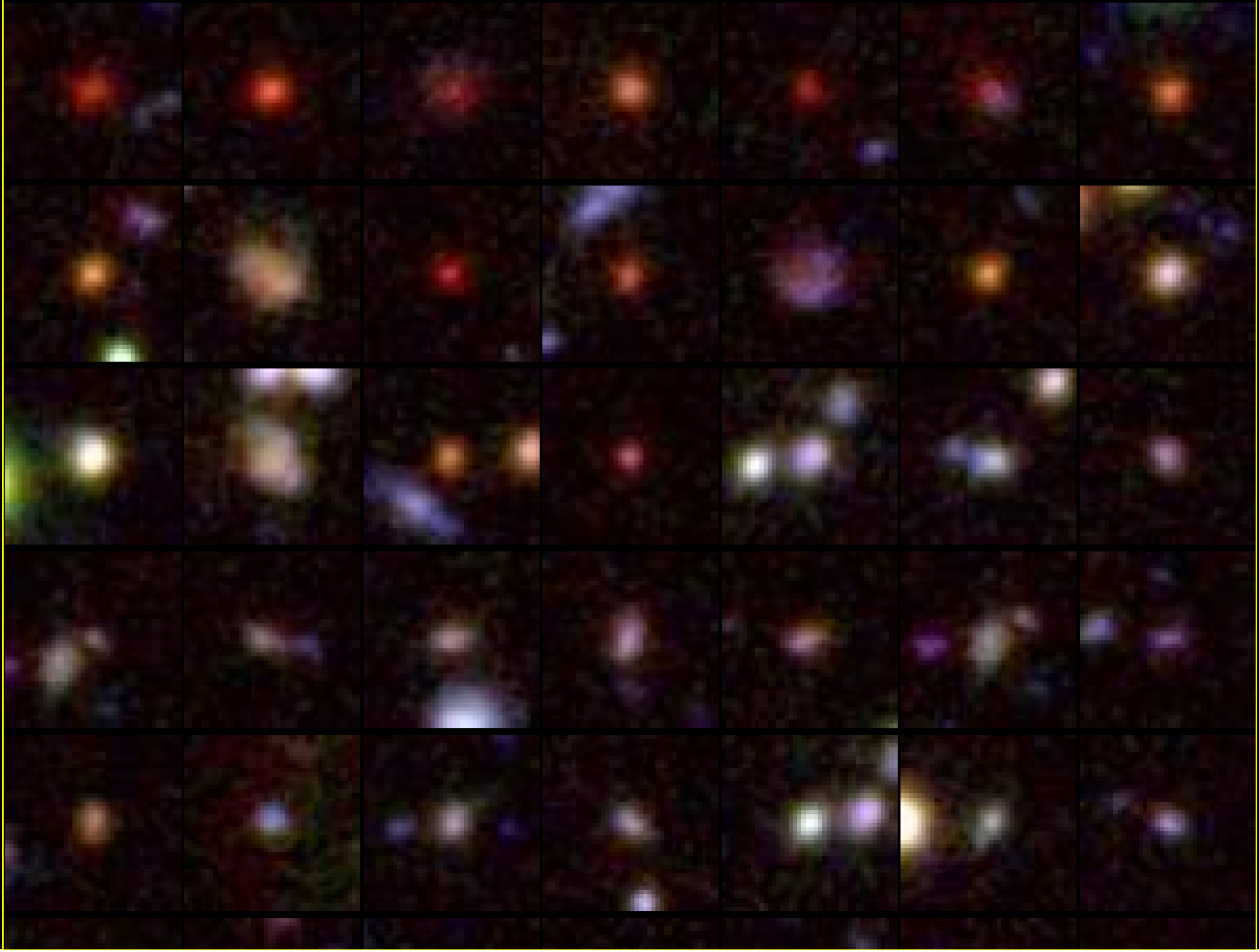
Need rest-frame optical selected samples at z>2

Requires:

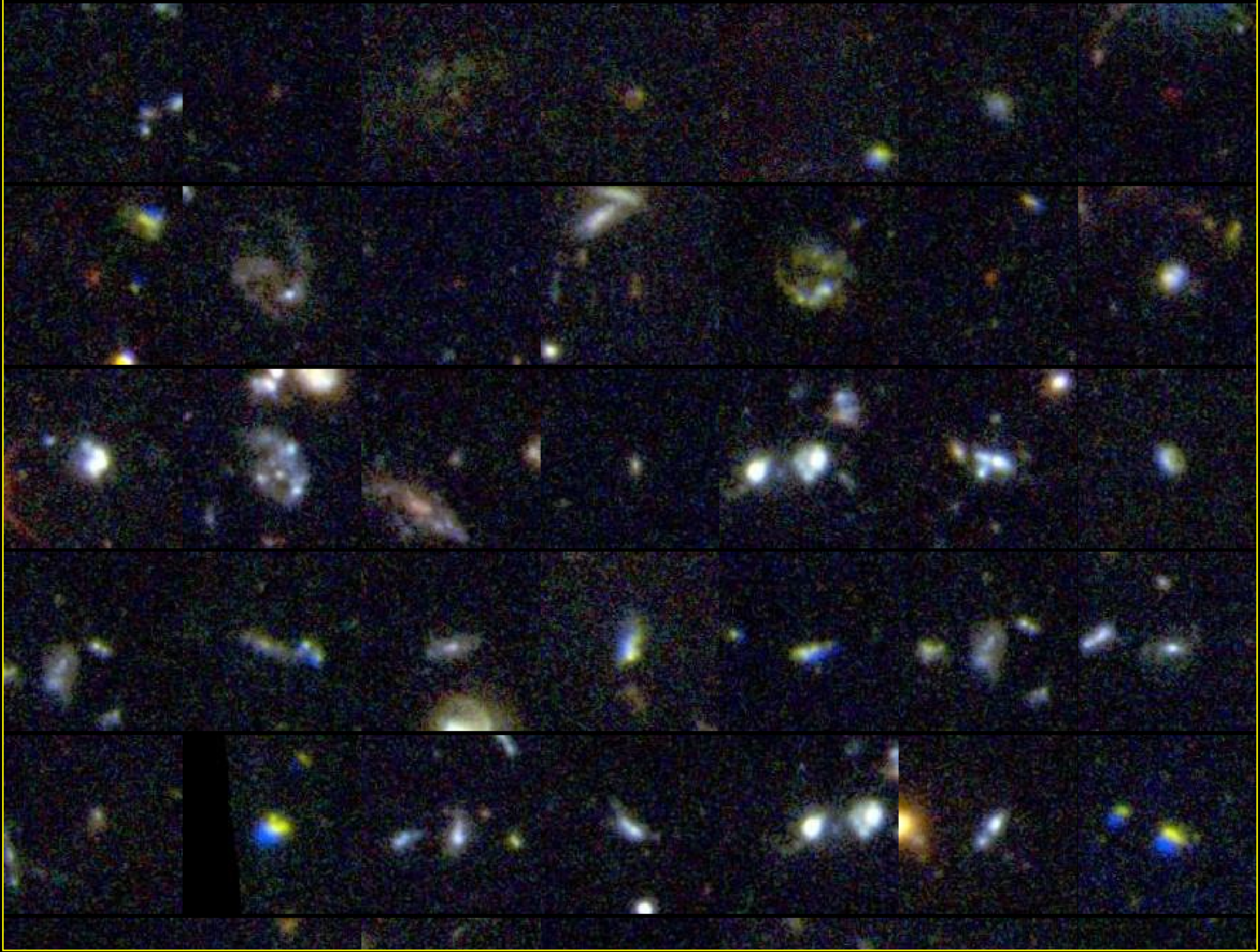
- Deep Near-IR imaging (ISAAC)
- Mostly photometric redshifts (multi-wavelength)

Mass selected galaxies $z \approx 2.5$

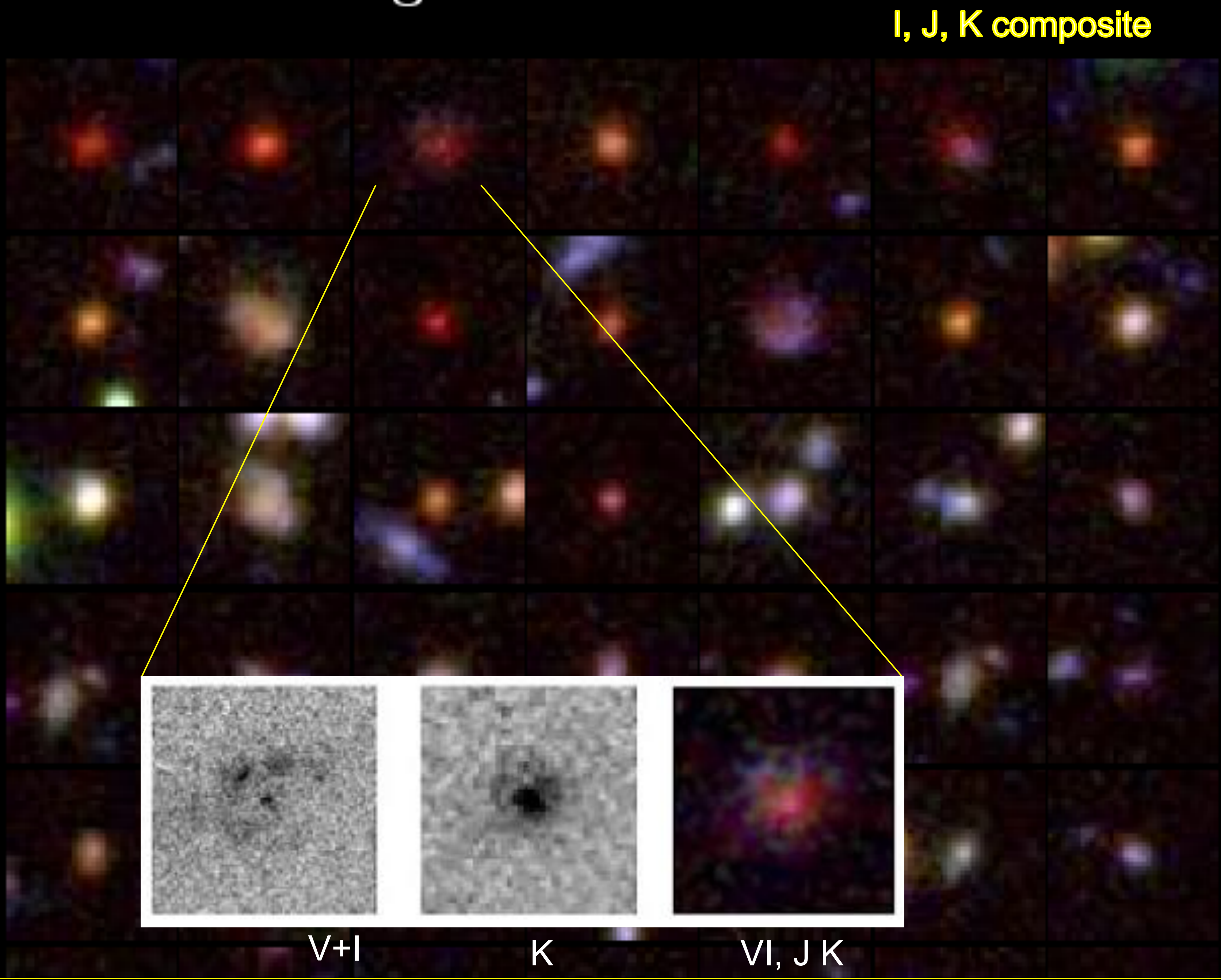
I, J, K composite



Mass selected galaxies $z \approx 2.5$



Mass selected galaxies $z \approx 2.5$

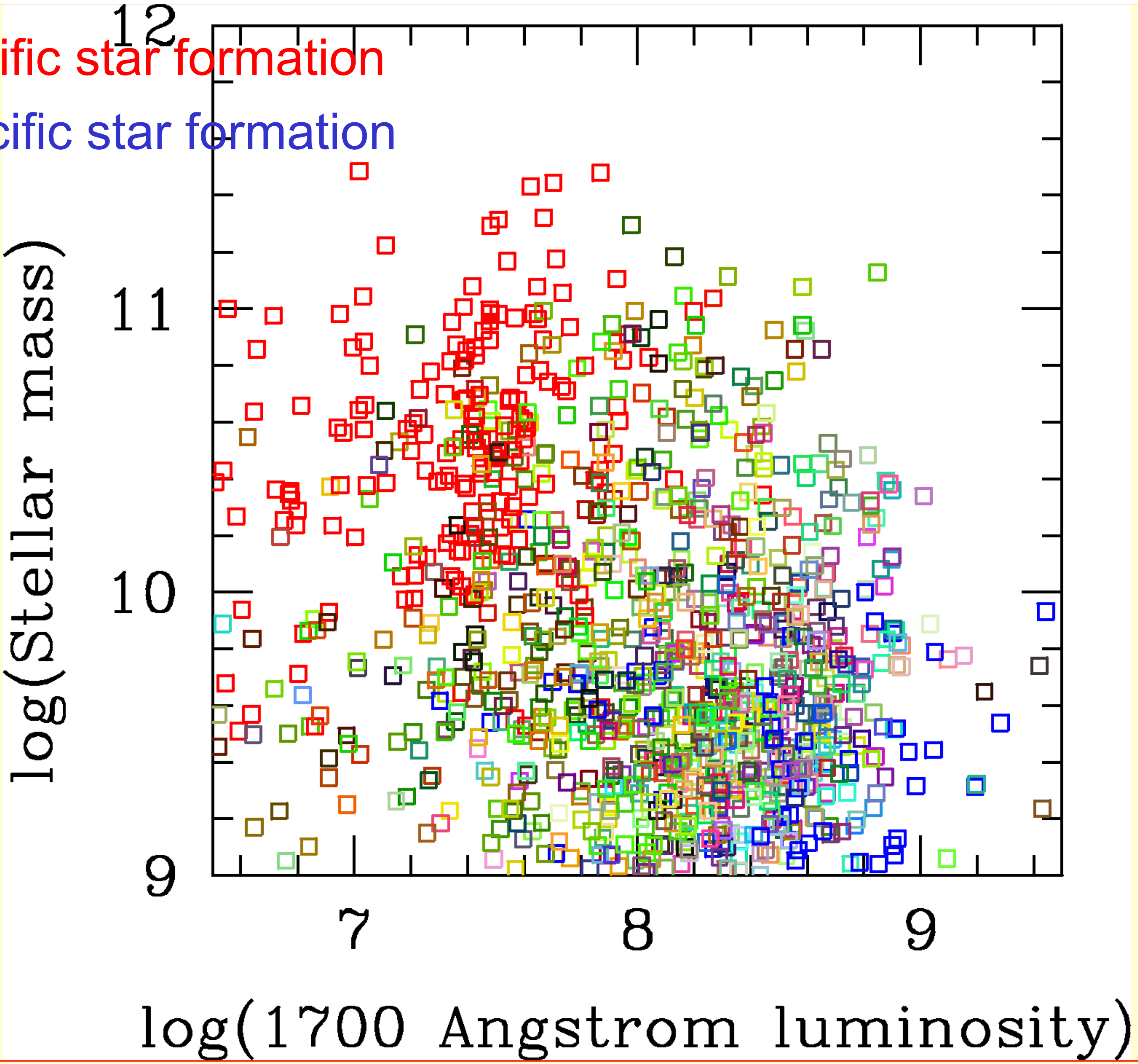


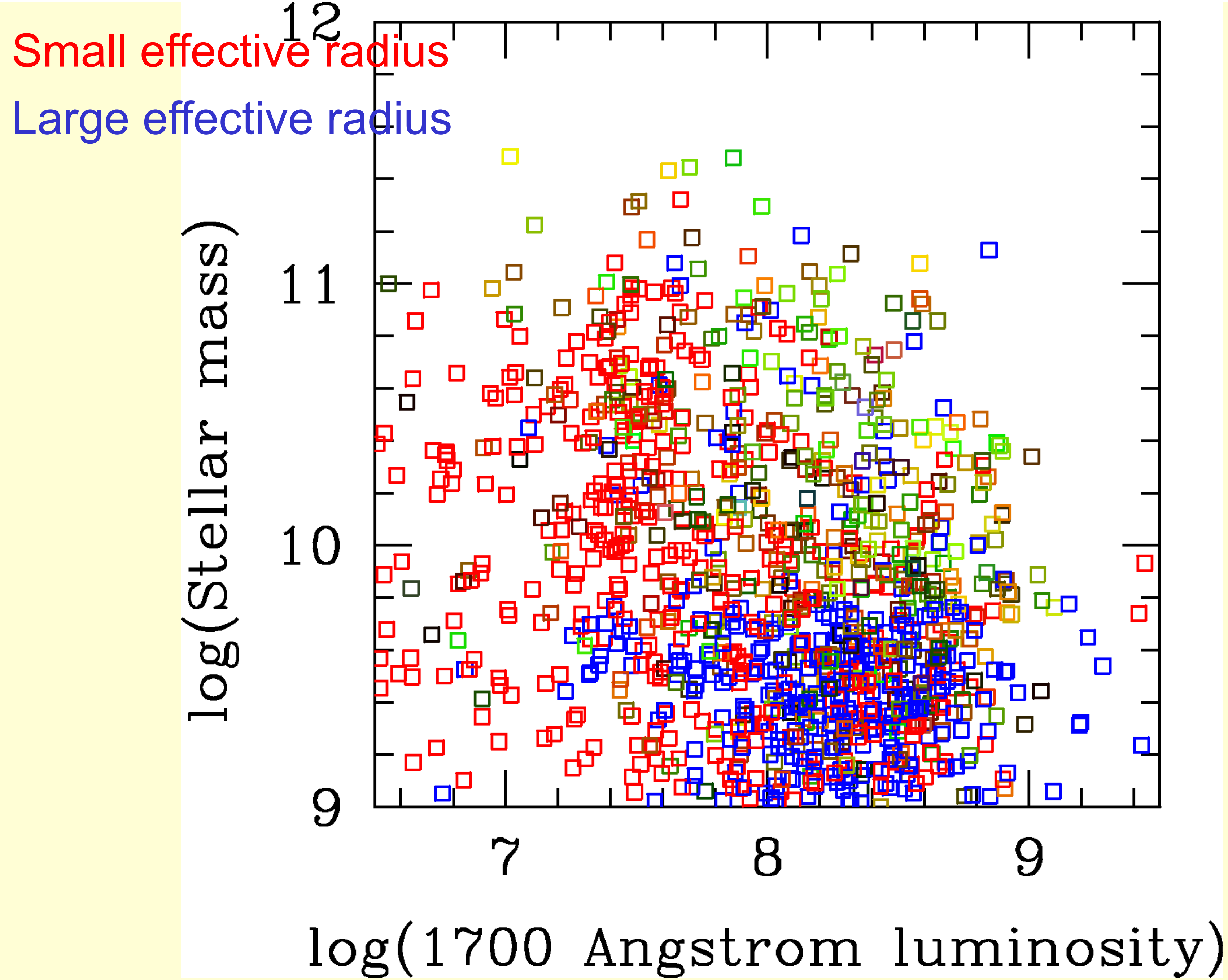
Z>2 universe selected in the restframe optical

- Massive galaxy population dominated by red galaxies – just like the nearby universe ("bulges", disks, "early-types")
- Most too faint for spectroscopic follow-up

Low specific star formation

High specific star formation




Small effective radius
Large effective radius
12
11
10
9
log(Stellar mass)
7
8
9
log(1700 Angstrom luminosity)

2 surprises

- Dead galaxies evolve strongly since $z=1$
- Red & star forming and red & dead galaxies exist at $z=2$ and above

Surprise #3

- Massive galaxies with very low star formation exist at $z>2$ – but they are very small !

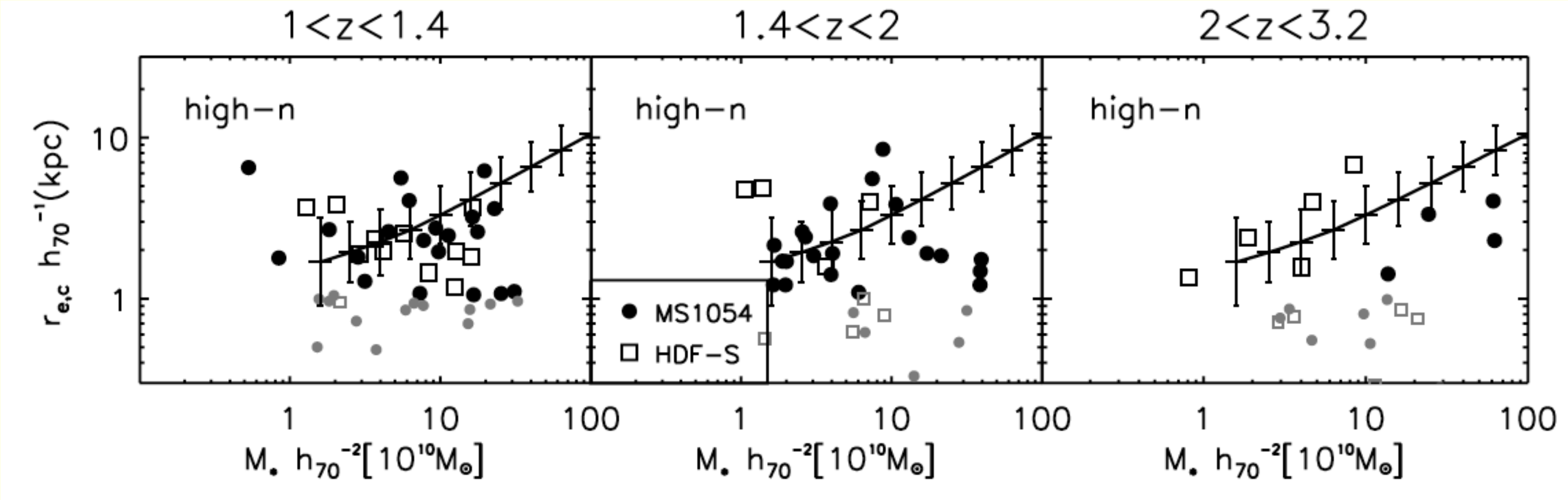
Daddi et al 2005

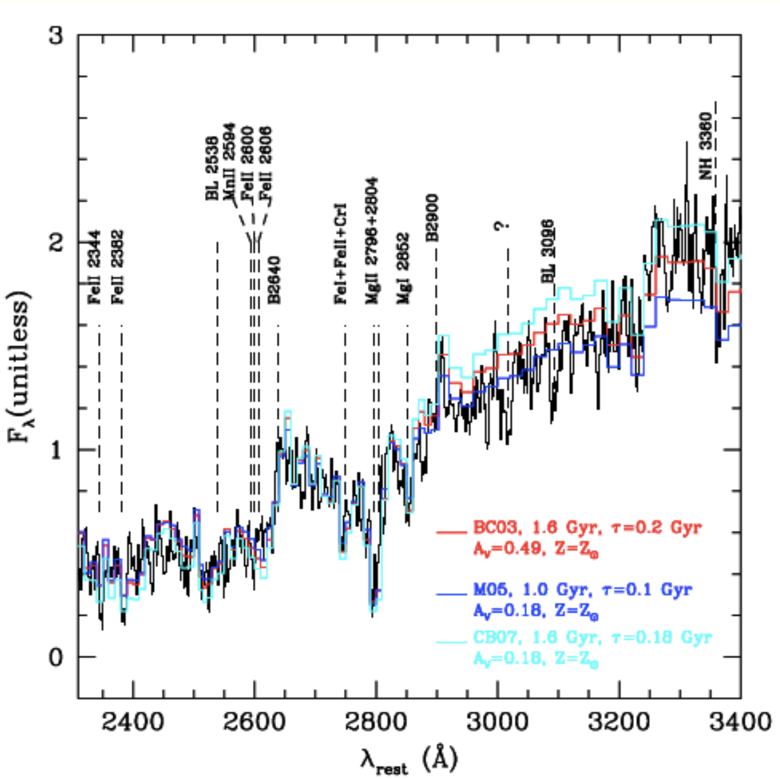
Trujillo et al 2004,06

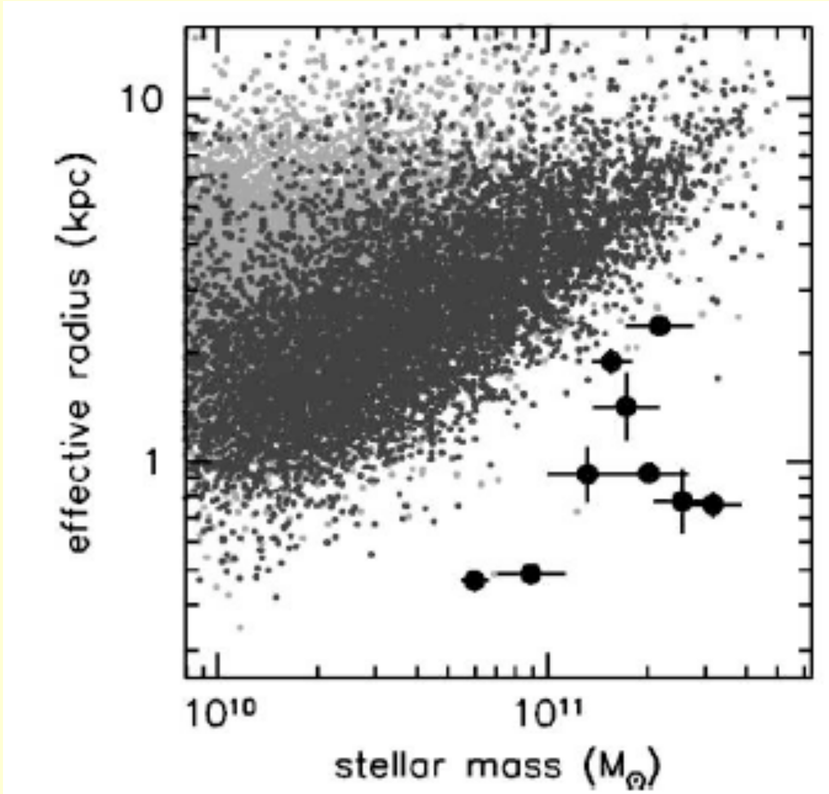
Franx et al 2008

Van Dokkum et al 2008

Cimatti et al 2008


1<z<1.4
1.4<z<2
2<z<3.2
high−n
MS1054
HDF−S
r_e,c h_70^-1 (kpc)
M_* h_70^-2 [10^10 M_⊙]


FeII 2344
FeII 2382
BL 2538
MnII 2584
FeII 2600
FeII 2606
B2640
FeI+FeII+CrI
MgII 2796+2804
MgI 2852
B2900
?
BL 3096
NH 3360
BC03, 1.6 Gyr, τ=0.2 Gyr
A_V=0.49, Z=Z_⊙
M05, 1.0 Gyr, τ=0.1 Gyr
A_V=0.18, Z=Z_⊙
CB07, 1.6 Gyr, τ=0.18 Gyr
A_V=0.18, Z=Z_⊙
F_λ (unitless)
λ_rest (Å)

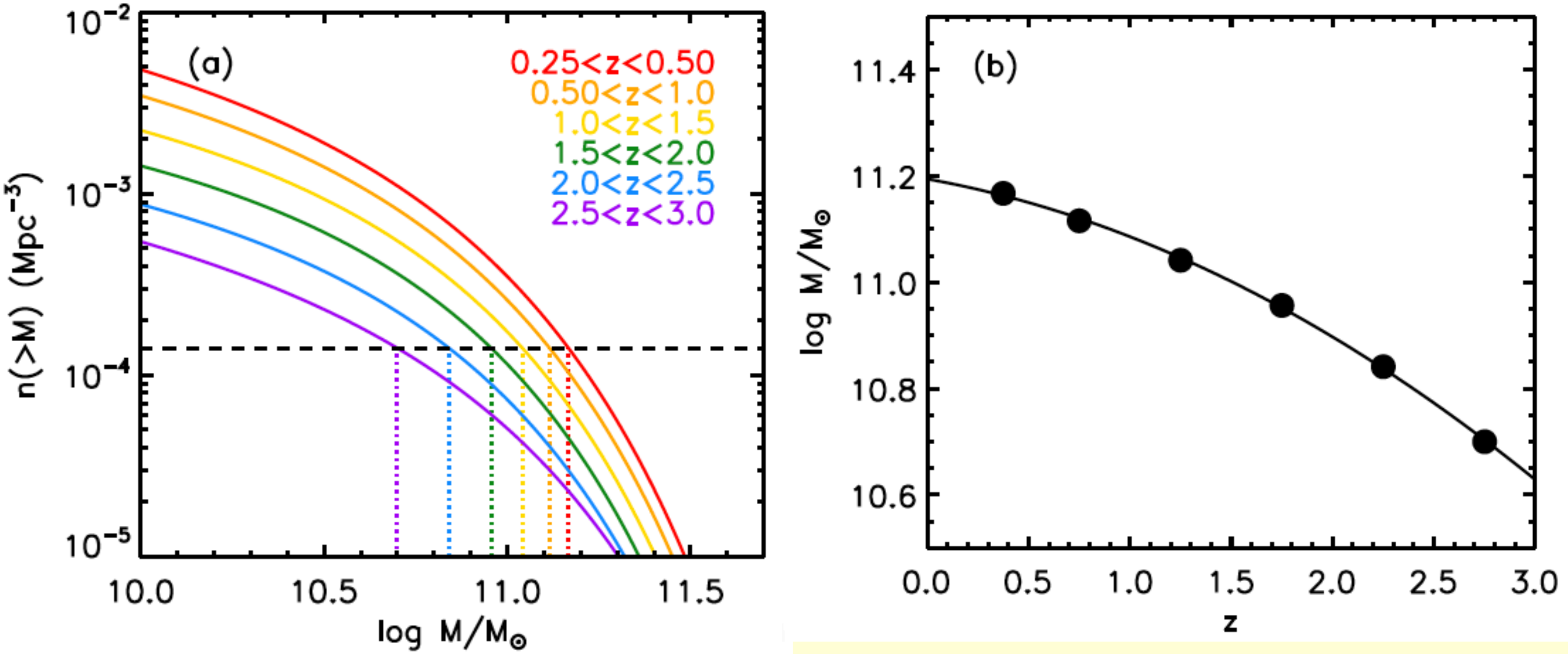

effective radius (kpc)
stellar mass (M_⊙)

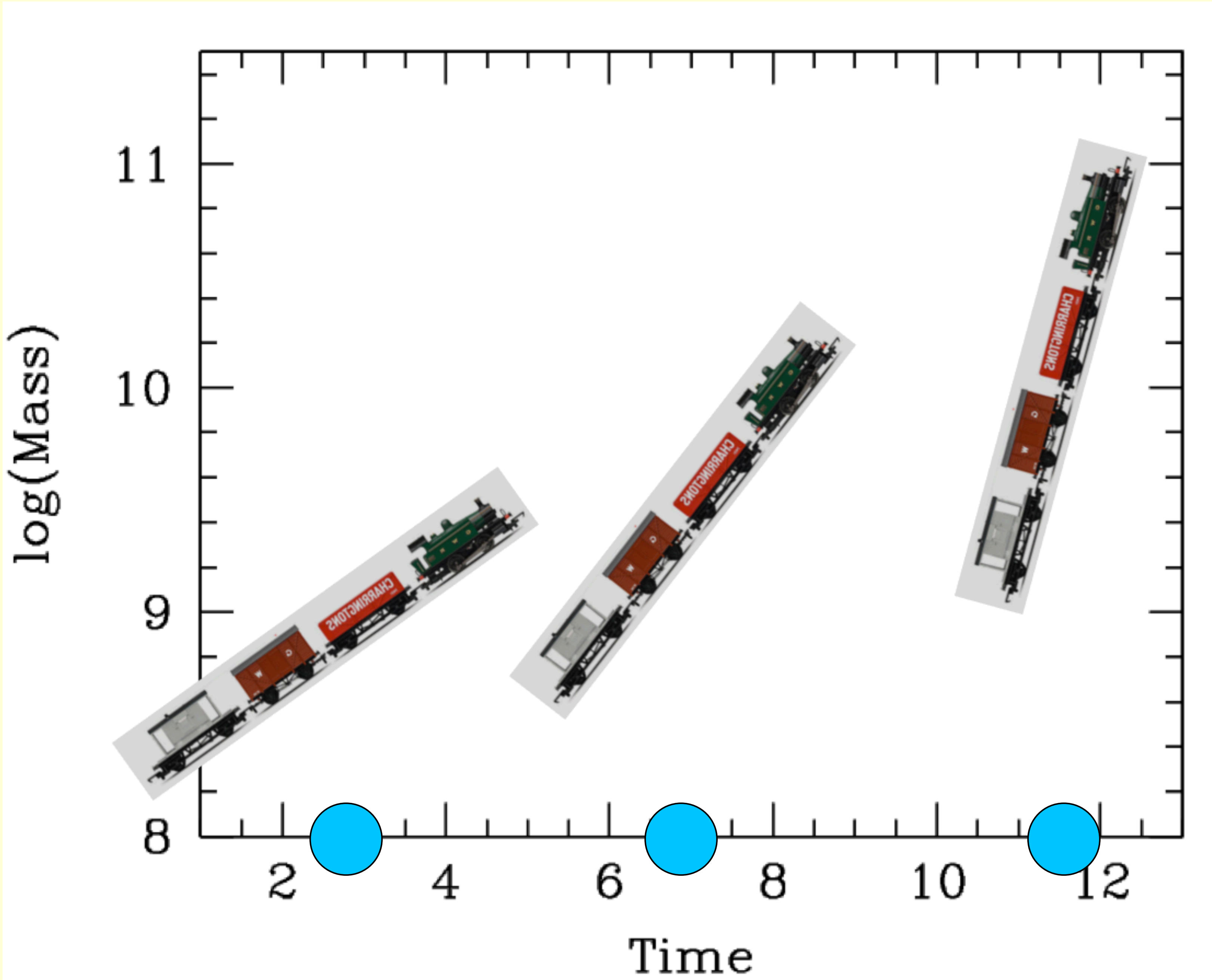
The dead galaxies that exist at z=2-4 are very different from those at z=0.

Galaxies have not read about passive evolution !

The Final Step

- Link galaxies by cumulative number density

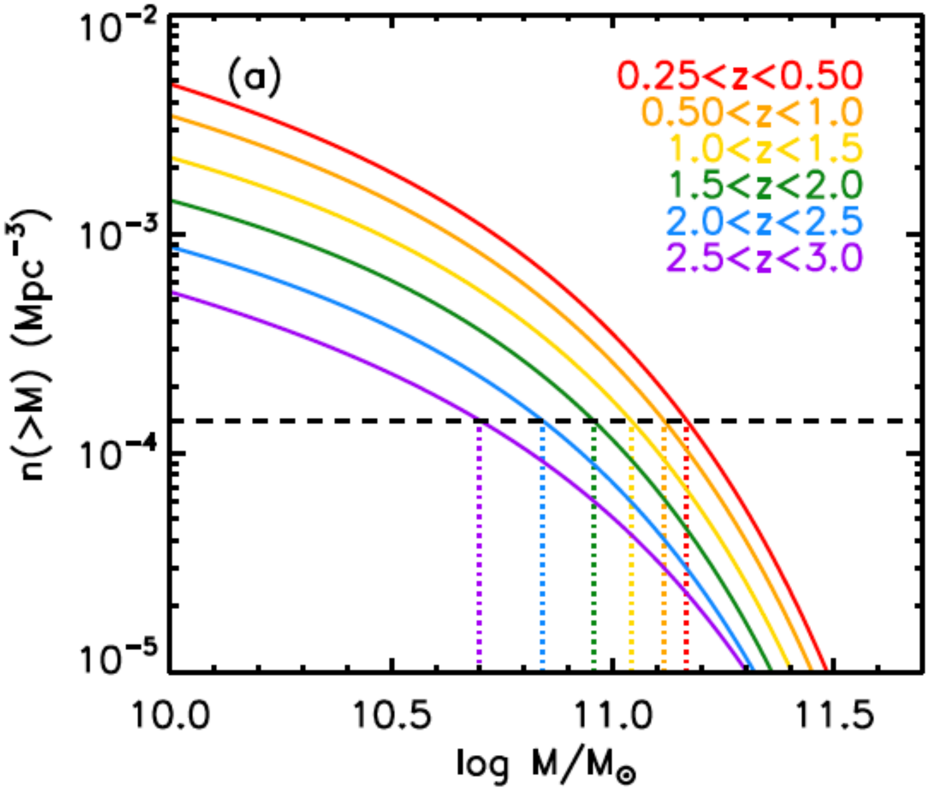


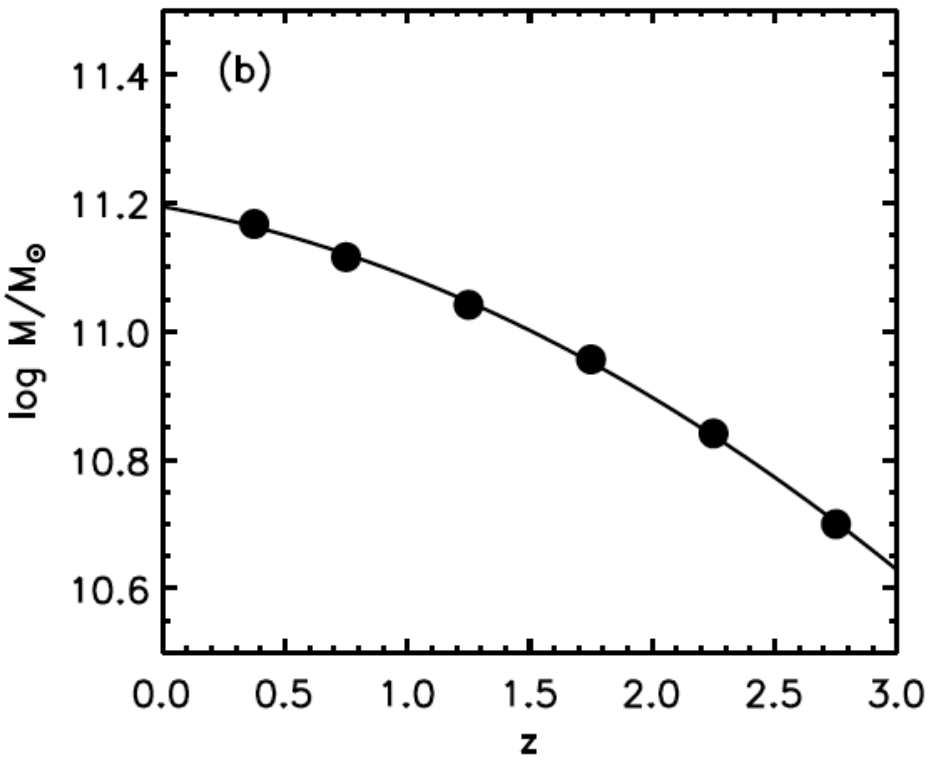


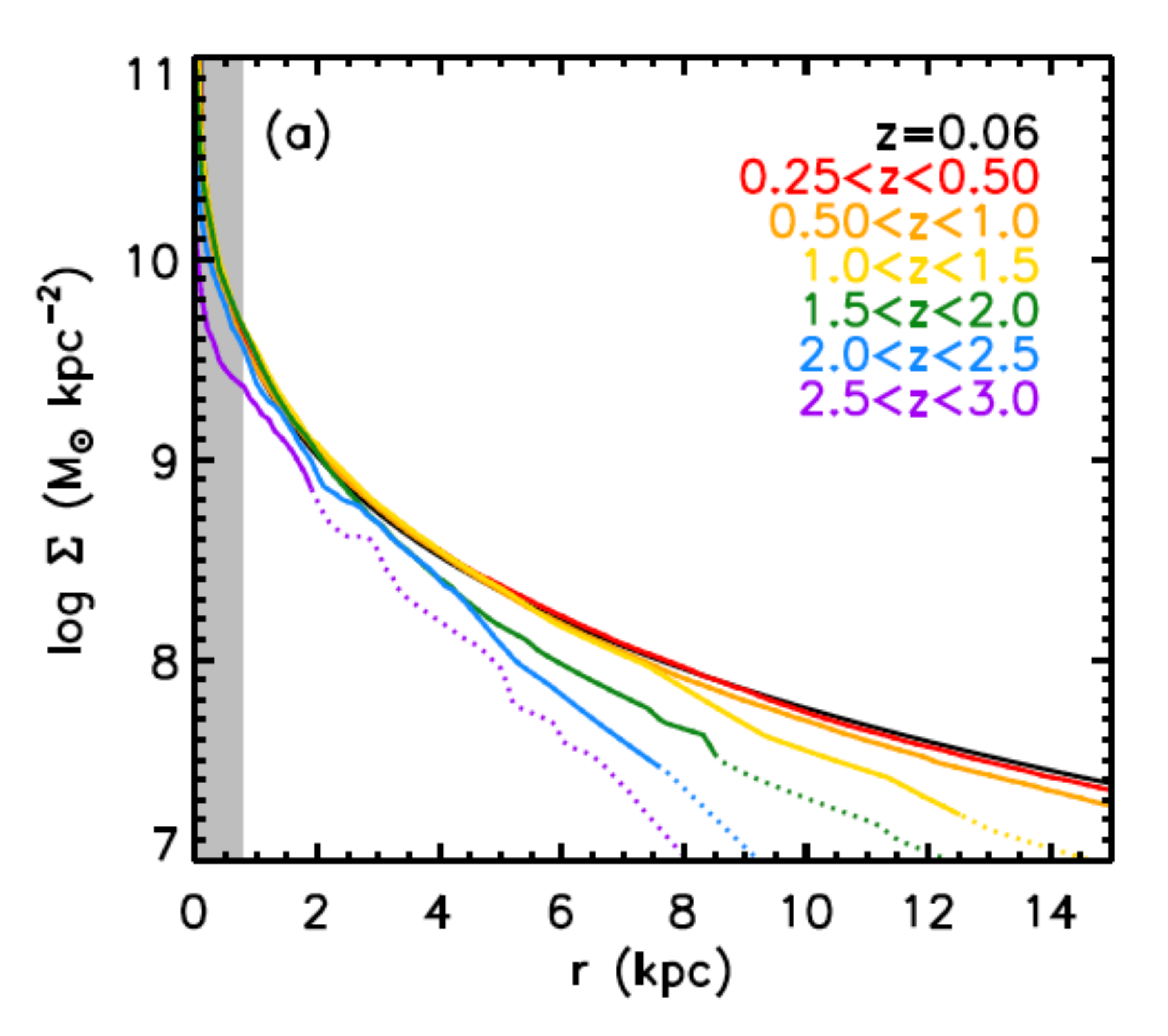
log(Mass)
11
10
9
8
2
4
6
8
10
12
Time

The Final Step

- Link galaxies by cumulative number density





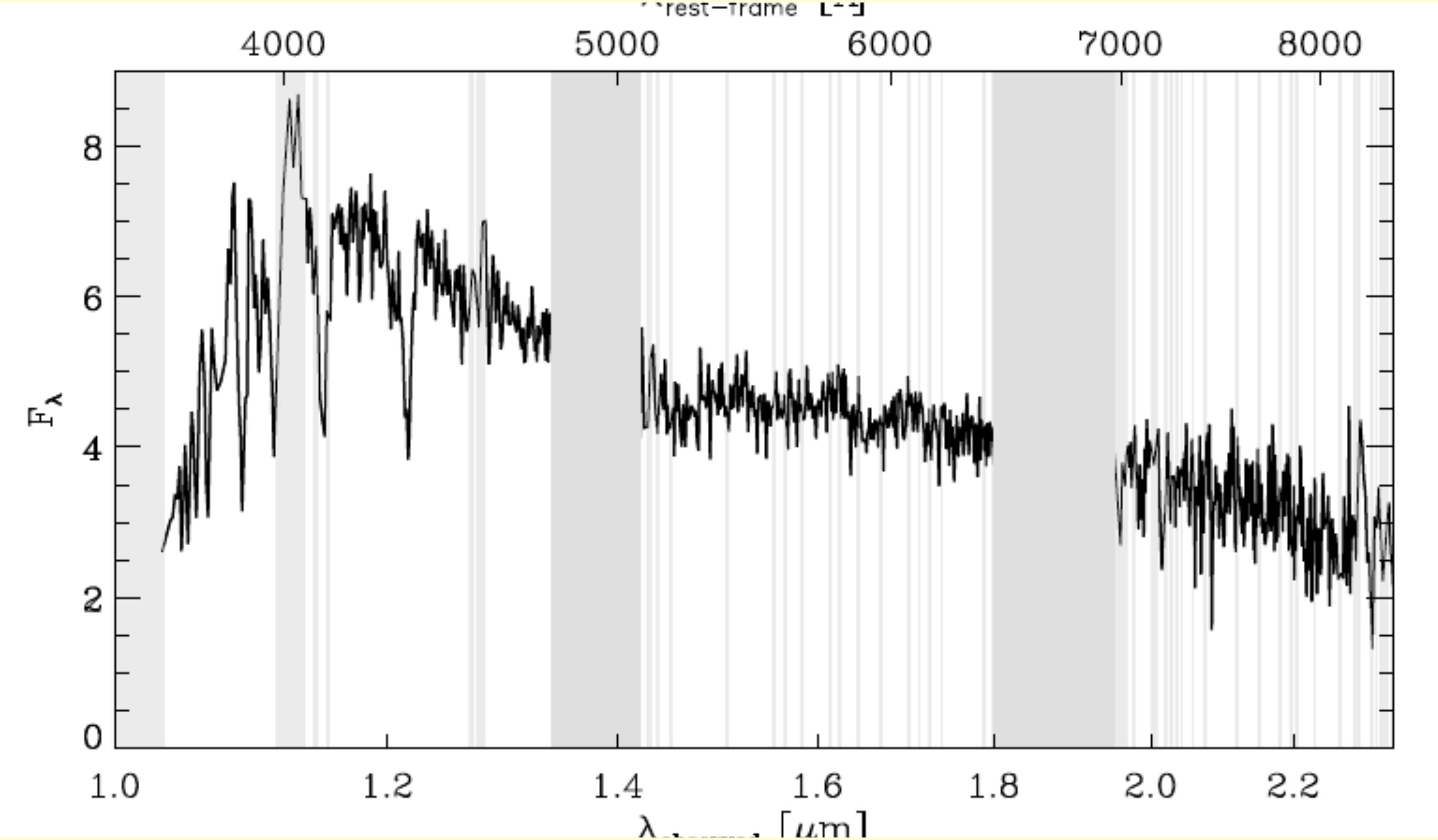


Patel et al 12

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

Lessons for the future

- In early days, ISAAC was truly innovative (image size, quality)
- Deep surveys (e.g., K20, Combo17, FIRES) made impact: depth and multiplex

Why were 8m-10m telescopes so succesfull ?

- Area only a factor of 4 gain !

Why were 8m-10m telescopes so succesfull ?

- Area only a factor of 4 gain !
- Throughput: factor 2-3
- Image quality: factor 2-4
- Multiplex: factor 4-50
- Total: factor 120-1500

Lessons for the future

- For ELT, the same will hold: area, throughput, multiplex, image quality, (wavelength coverage) are crucial

Lessons for the future:

- Synergy with other facilities crucial

Lessons for the future:

- Synergy with other facilities is crucial
- overlap ELT with JWST will be minimal
- VLT, Alma, Euclid

Happy Birthday !