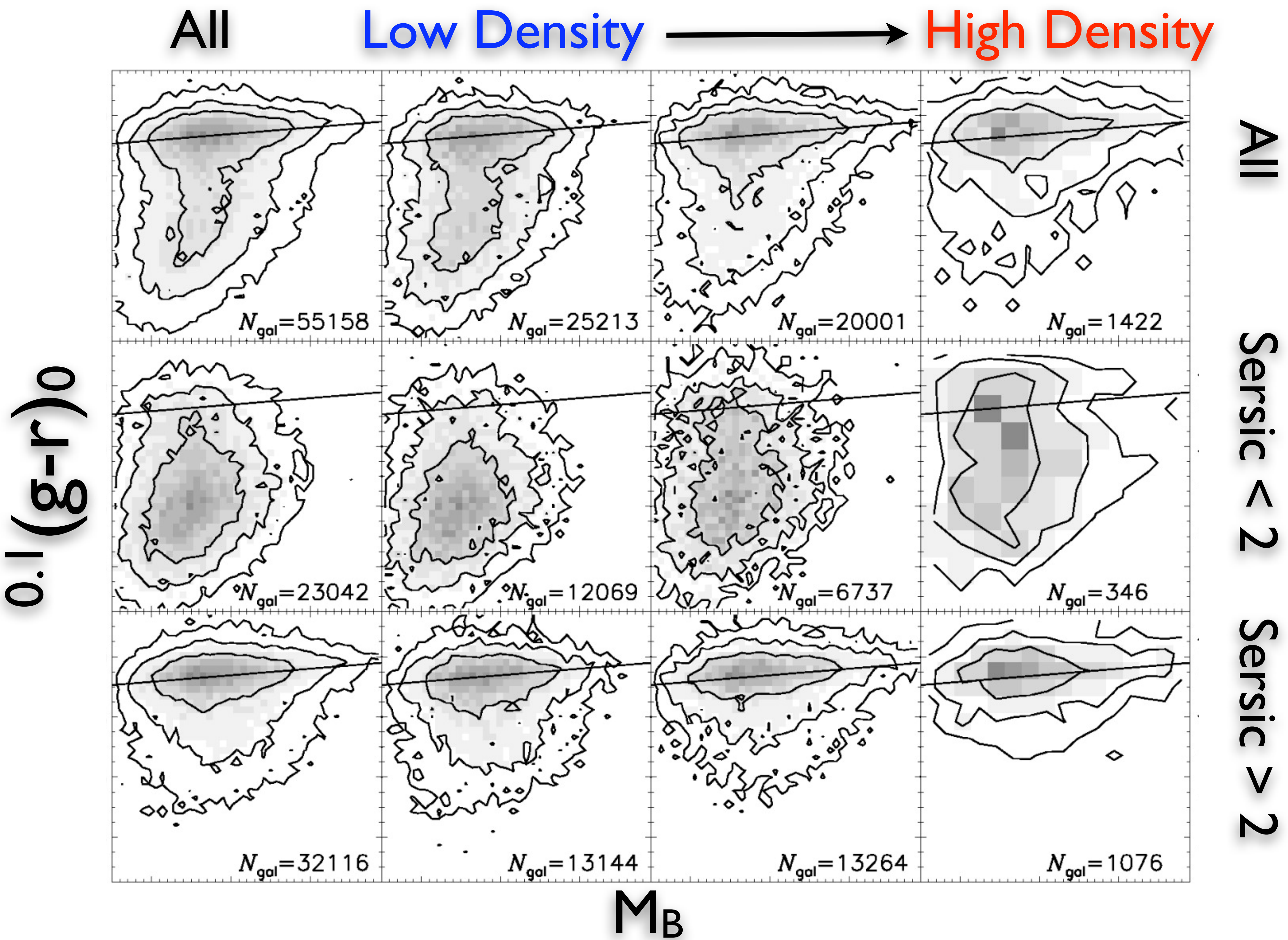
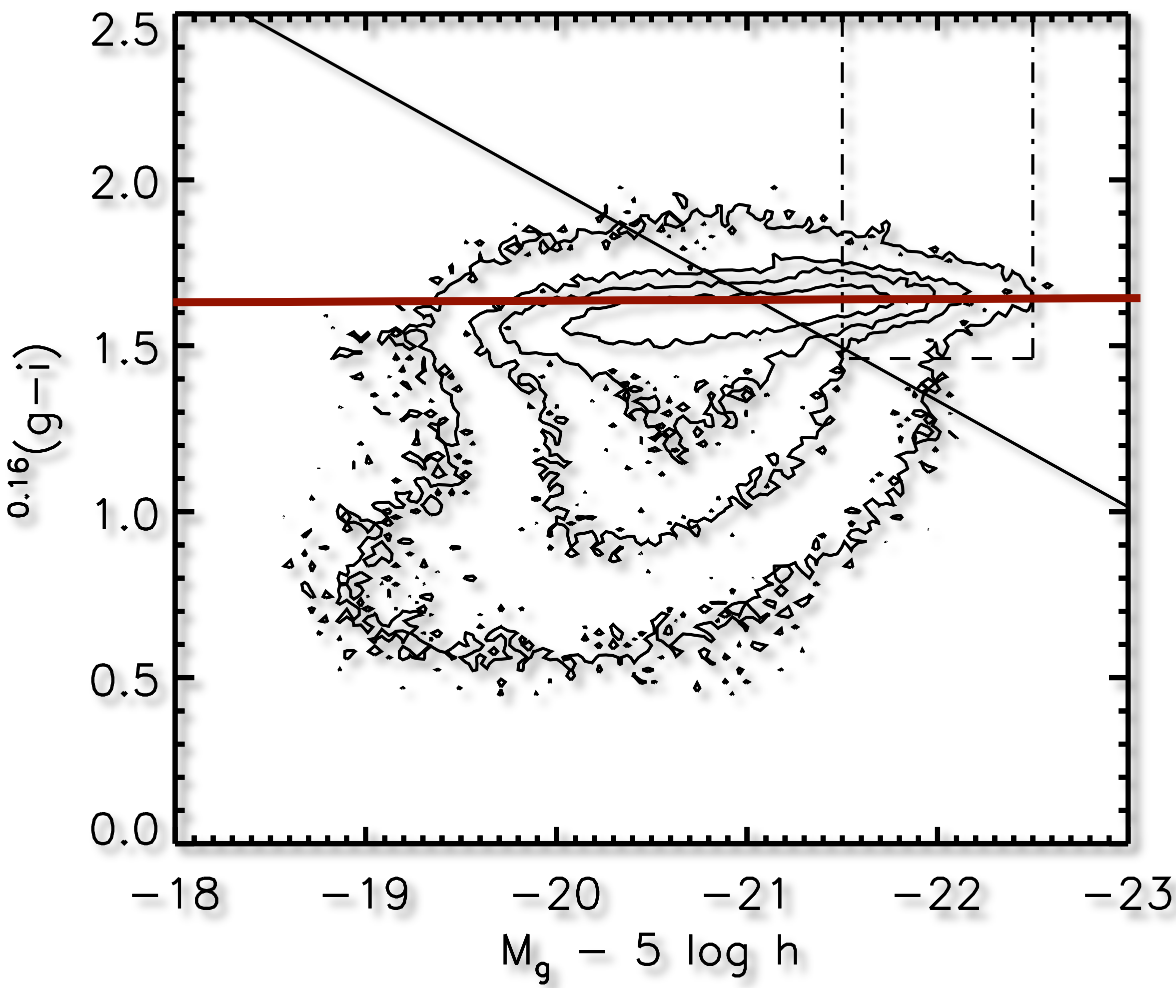
Constraining the Evolution of the Most Massive Galaxies Since z~1

Richard Cool
University of Arizona

Daniel Eisenstein (Arizona)
SDSS Collaboration



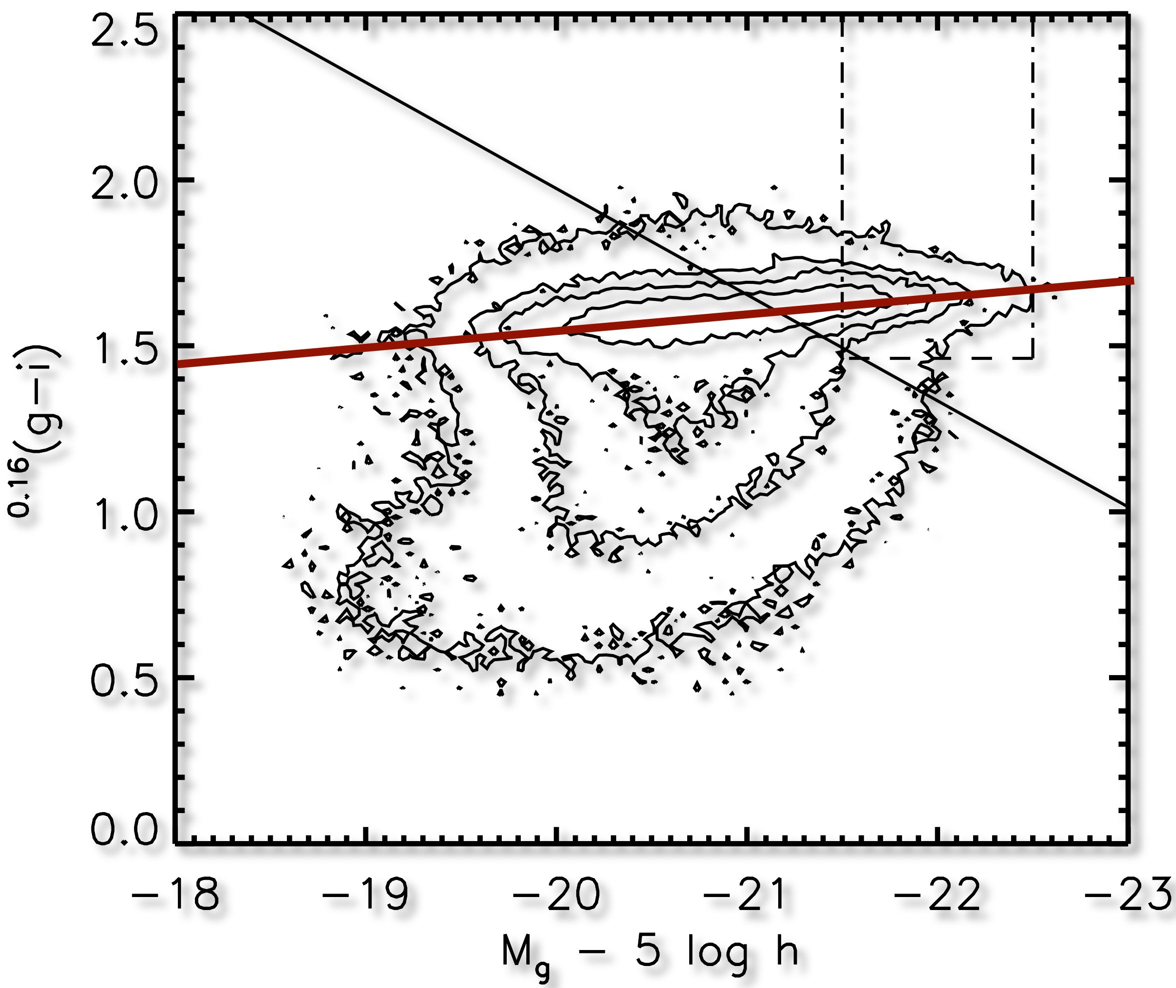
Hogg et al 2004



The red-sequence is encoded with a great deal of evolutionary information

Zeropoint - Mean Star Formation History of Galaxies

Cool et al. 2006 - AJ 131, 736 (astro-ph/0510301)

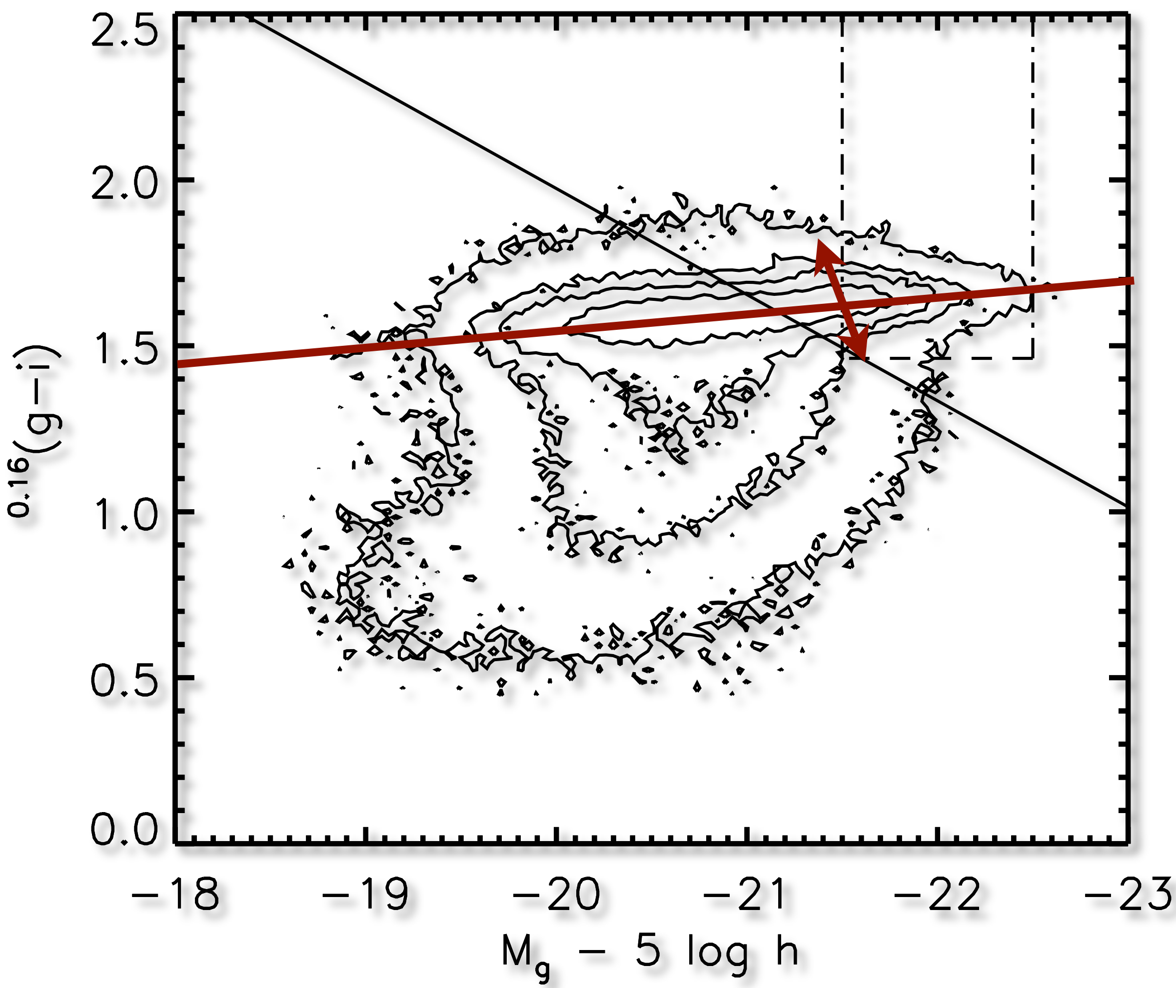


The red-sequence is encoded with a great deal of evolutionary information

Zeropoint - Mean Star Formation History of Galaxies

Slope - Chemical Enrichment History

Cool et al. 2006 - AJ 131, 736 (astro-ph/0510301)



The red-sequence is encoded with a great deal of evolutionary information

Zeropoint - Mean Star Formation History of Galaxies

Slope - Chemical Enrichment History

Dispersion - Variation on the Star Formation Histories

To constrain dispersion, you need a large spectroscopic galaxy survey with homogeneous, accurate, photometry

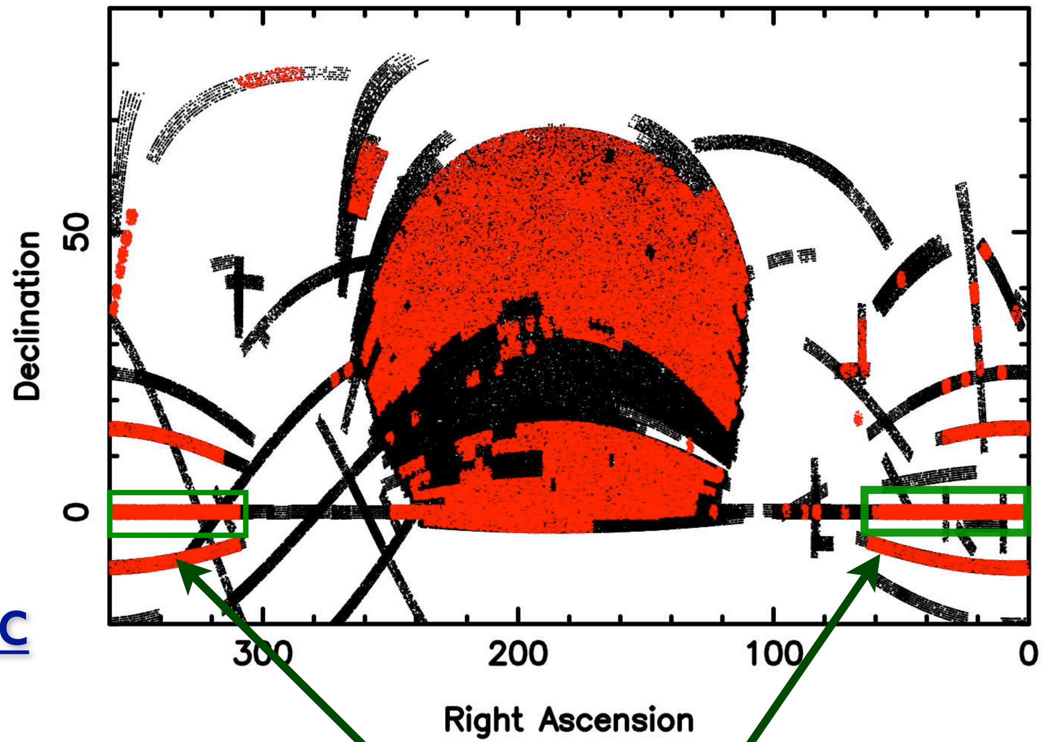
Cool et al. 2006 - AJ 131, 736 (astro-ph/0510301)

Sloan Digital Sky Survey (SDSS):

Imaging : 8400 deg^2

Spectra : 6900 deg^2

981,000 galaxy redshifts



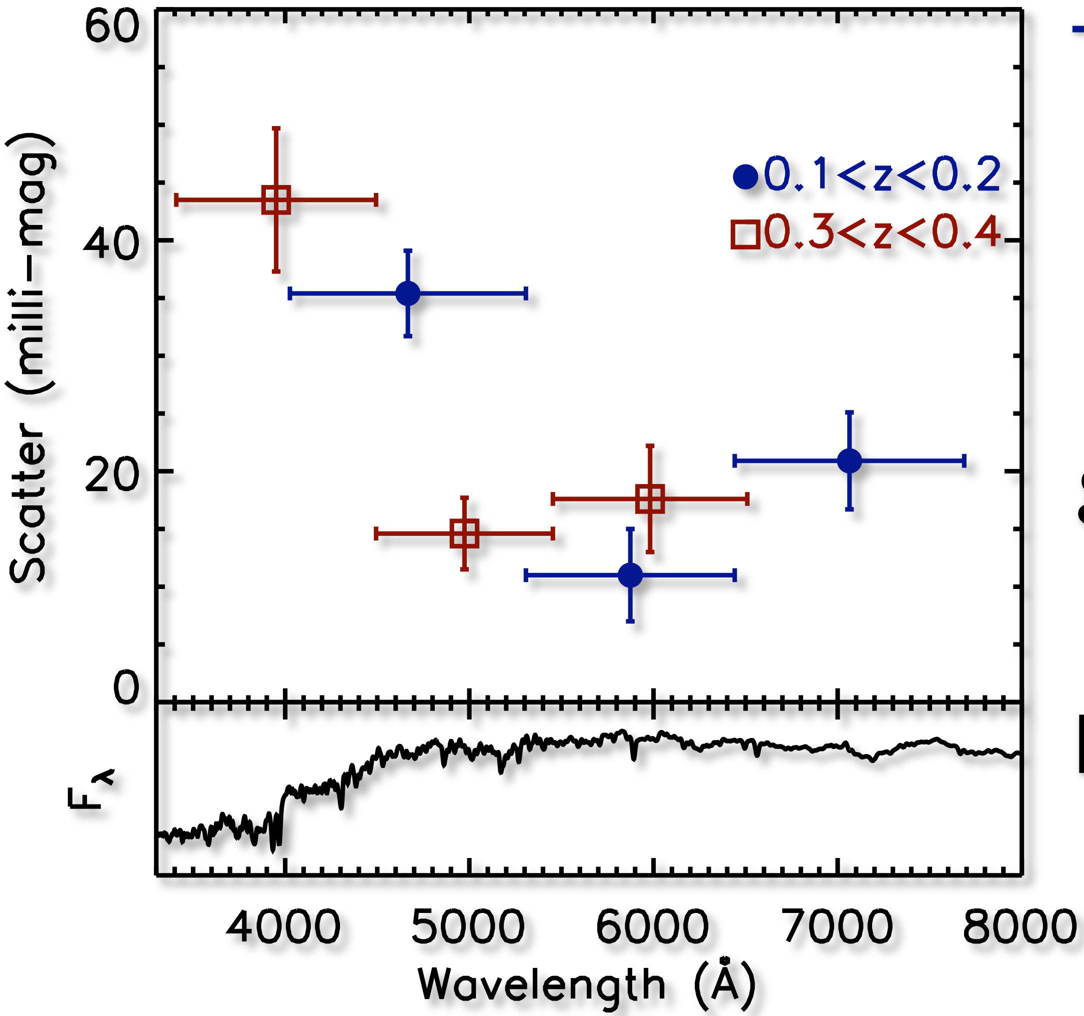
Two complementary Spectroscopic Galaxy Samples:

MAIN galaxy Sample:
flux-limited r < 17.77

Luminous Red Galaxy Sample (LRG) :
color-selected r < 19.2

SDSS Southern Survey:

Repeated imaging of 270 deg2 stripe on southern equator



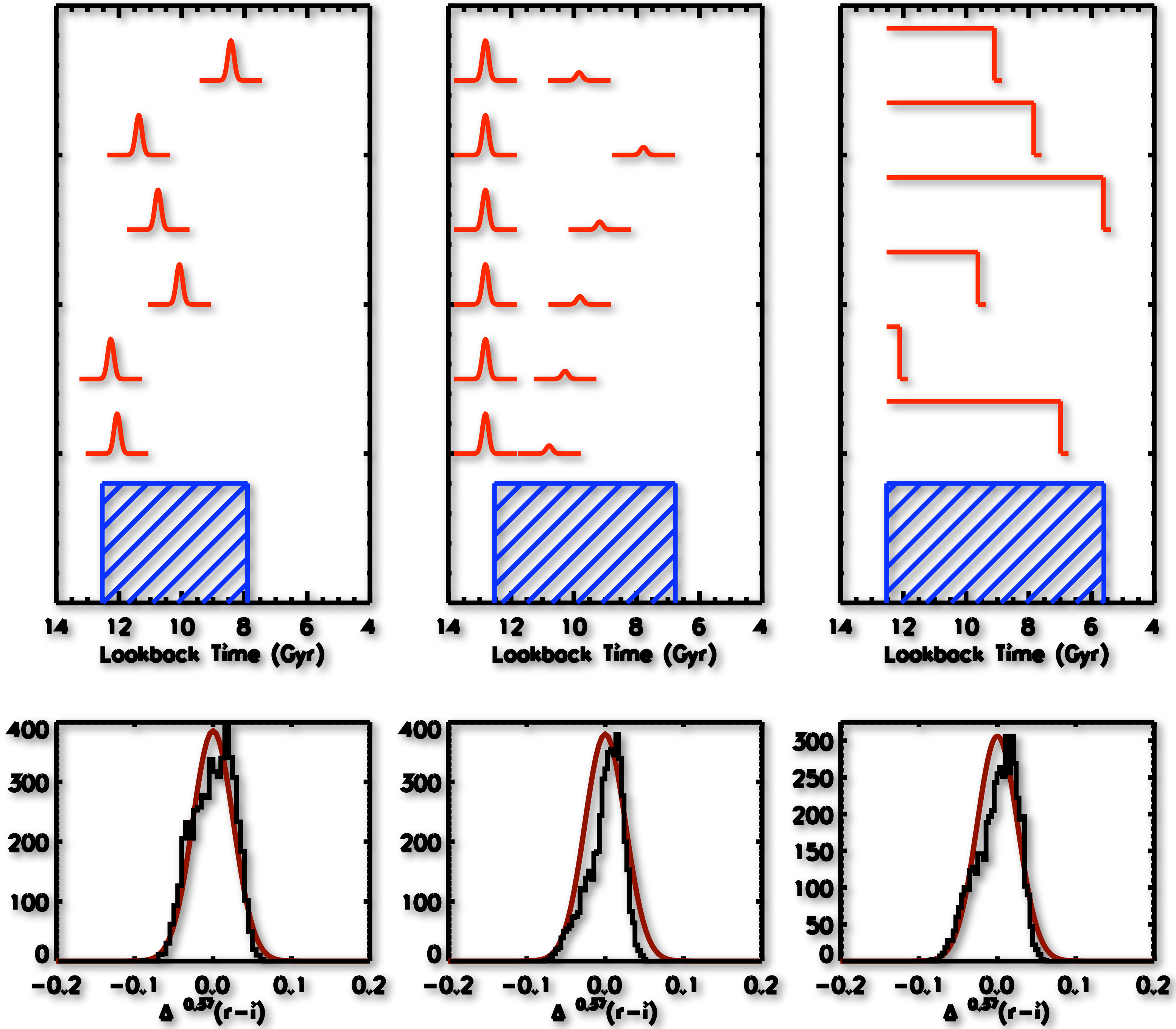
The Scatter Around of the Red-Sequence for Very Massive Galaxies

Massive early-type **field** galaxies show small scatter in all optical colors

Bluest bands show factor of 2 higher dispersion

Galaxies in dense environments have 11% smaller scatter than field galaxies

Little diversity in star formation histories of massive early-types



$z_{end} \sim 1.1$ $z_{end} \sim 0.84$ $z_{end} \sim 0.62$

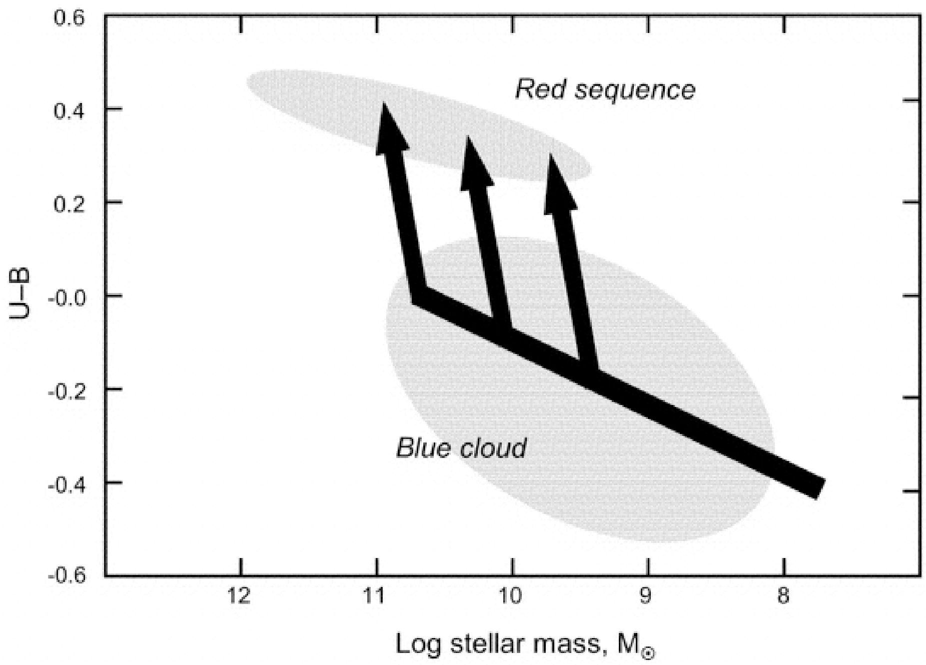
- What do we know?
  - Massive galaxies reside on the red-sequence - not many very massive blue galaxies in the local universe
  - Concentrated Morphologies - close to $r^{1/4}$ isophotes
  - Red Colors - old stellar populations

- What don't we know?
  - Why do massive galaxies all have red colors today - what made them stop forming their stars?
  - How old are these galaxies and how old are their stars?
  - Did the stars form long before the galaxy assembled or in situ?

- What do we know?
  - Massive galaxies reside on the red-sequence - not many very massive blue galaxies in the local universe
  - Concentrated Morphologies - close to $r^{1/4}$ isophotes
  - Red Colors - old stellar populations

- What don't we know?
  - Why do massive galaxies all have red colors today - what made them stop forming their stars?
  - How old are these galaxies and how old are their stars?
  - Did the stars form long before the galaxy assembled or in situ?

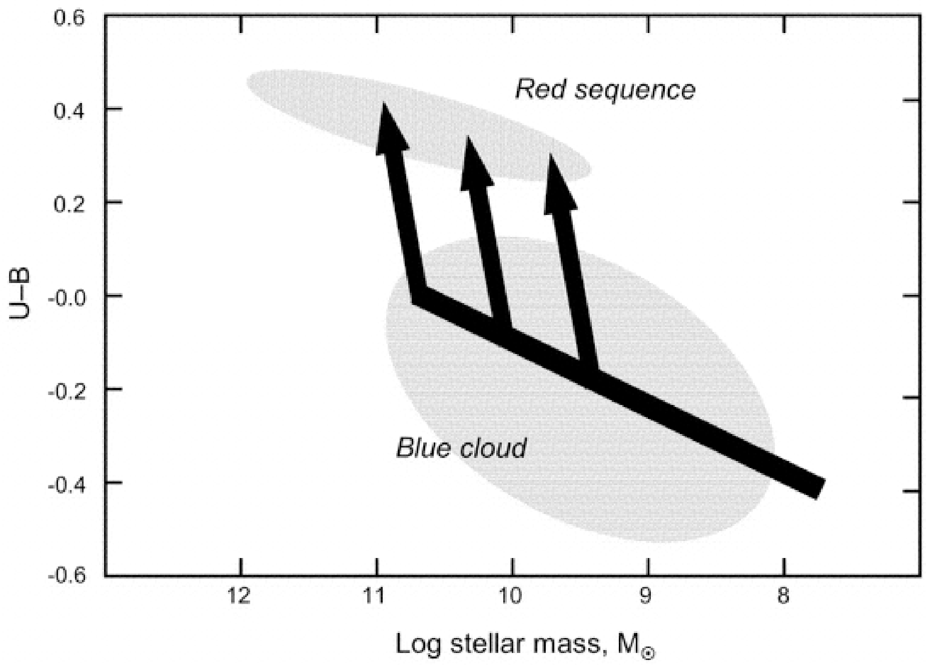
What kind of mergers are important for massive galaxies?

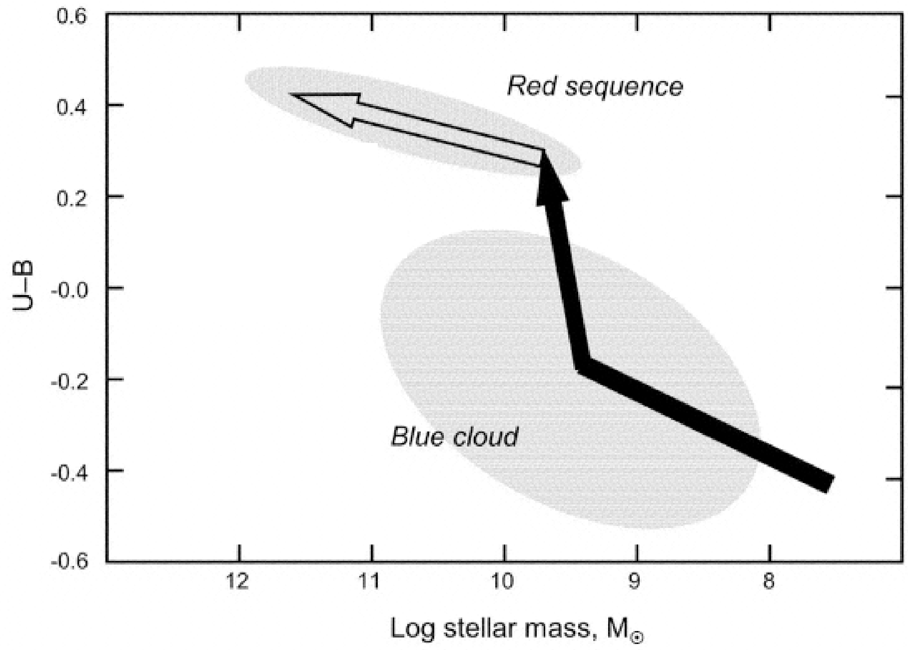


Galaxies grow through gas-rich mergers then fade

Faber et al 2006

What kind of mergers are important for massive galaxies?



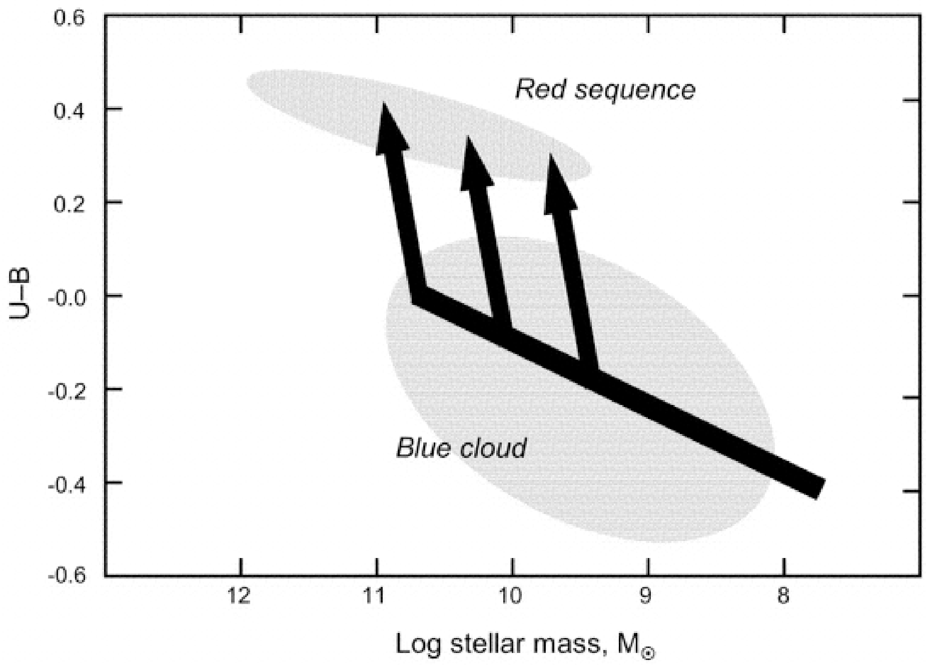


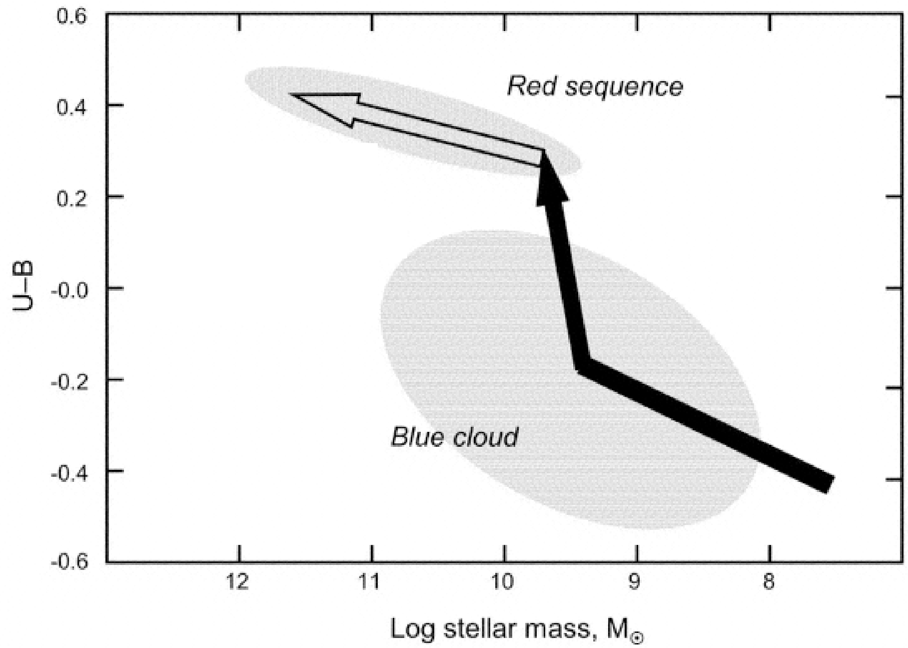
Galaxies grow through gas-rich mergers then fade

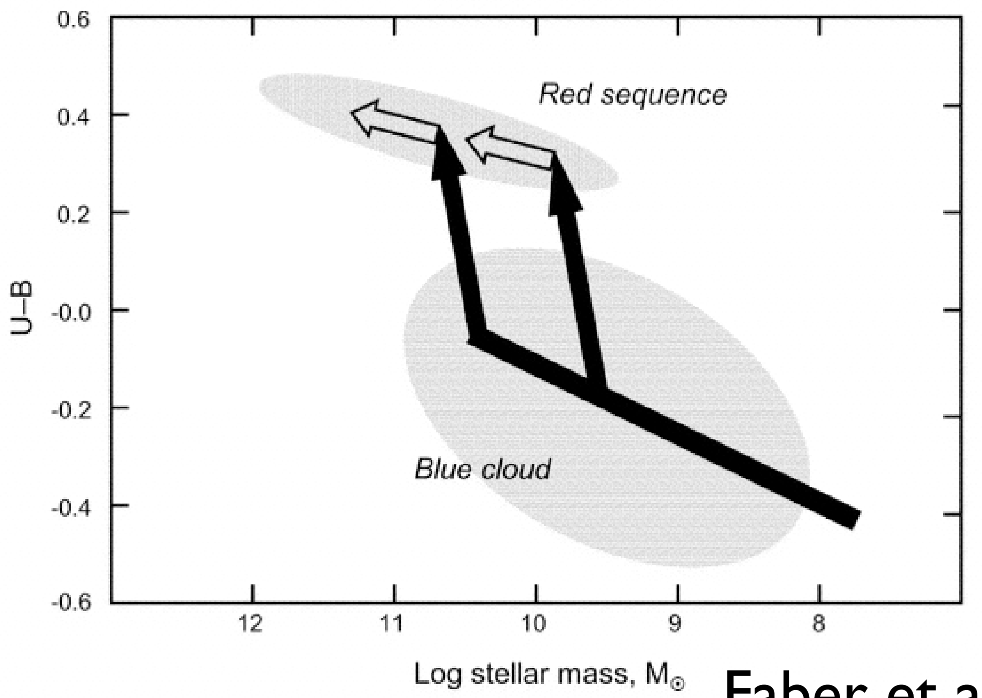
Galaxies form their stars early and then merge without star formation

Faber et al 2006

What kind of mergers are important for massive galaxies?







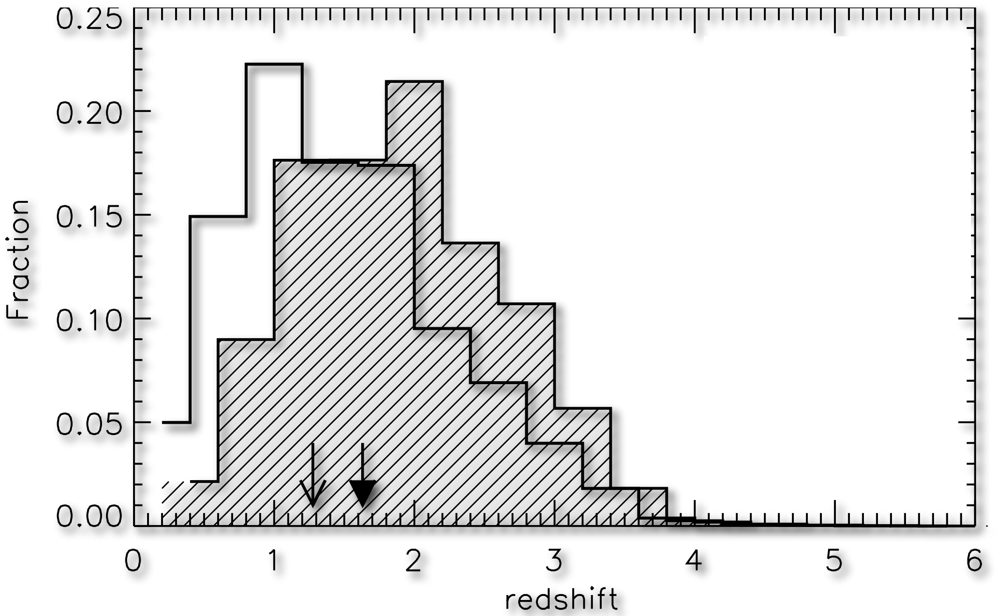
Faber et al 2006

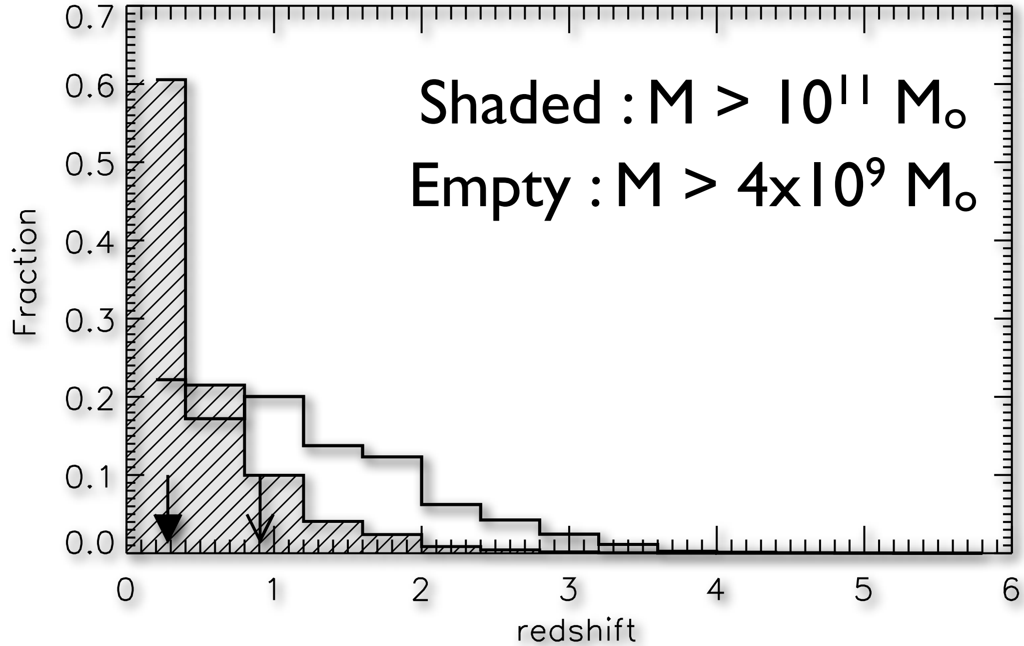
Galaxies grow through gas-rich mergers then fade

Galaxies form their stars early and then merge without star formation

Some combination of the two

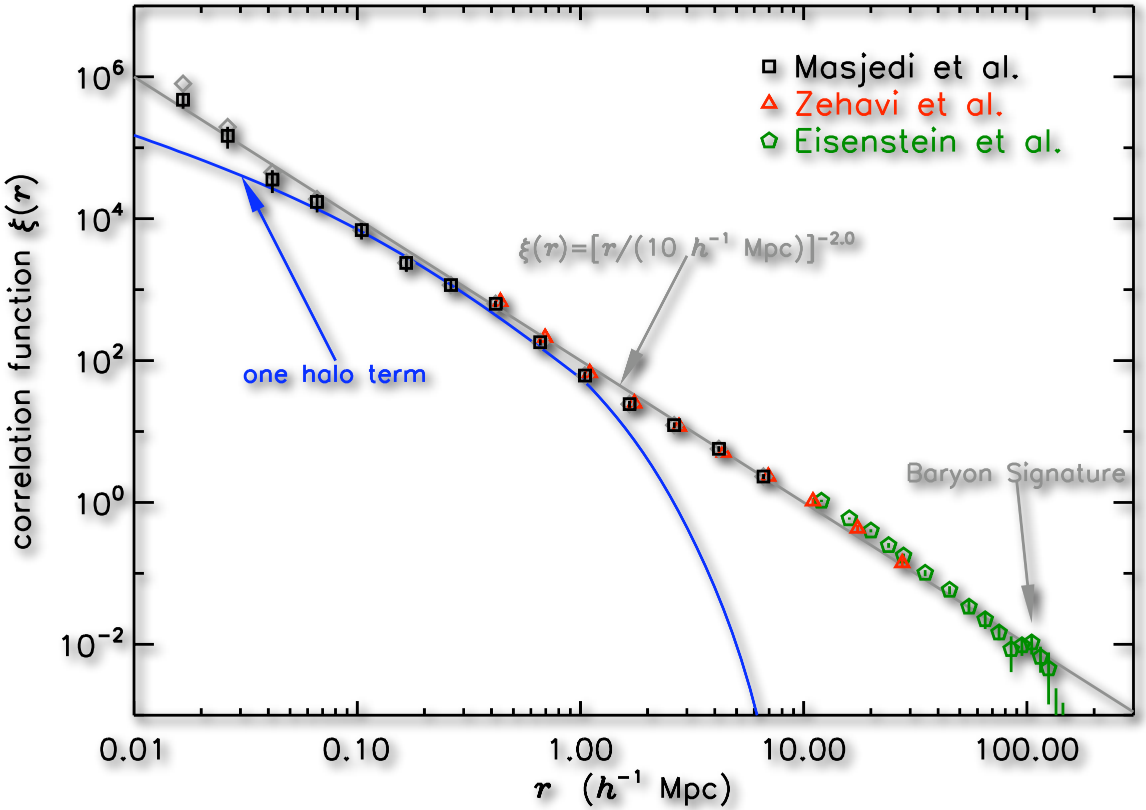
de Lucia et al 2006





Semi-Analytic models suggest that stars that reside in massive galaxies today are formed largely at z>1

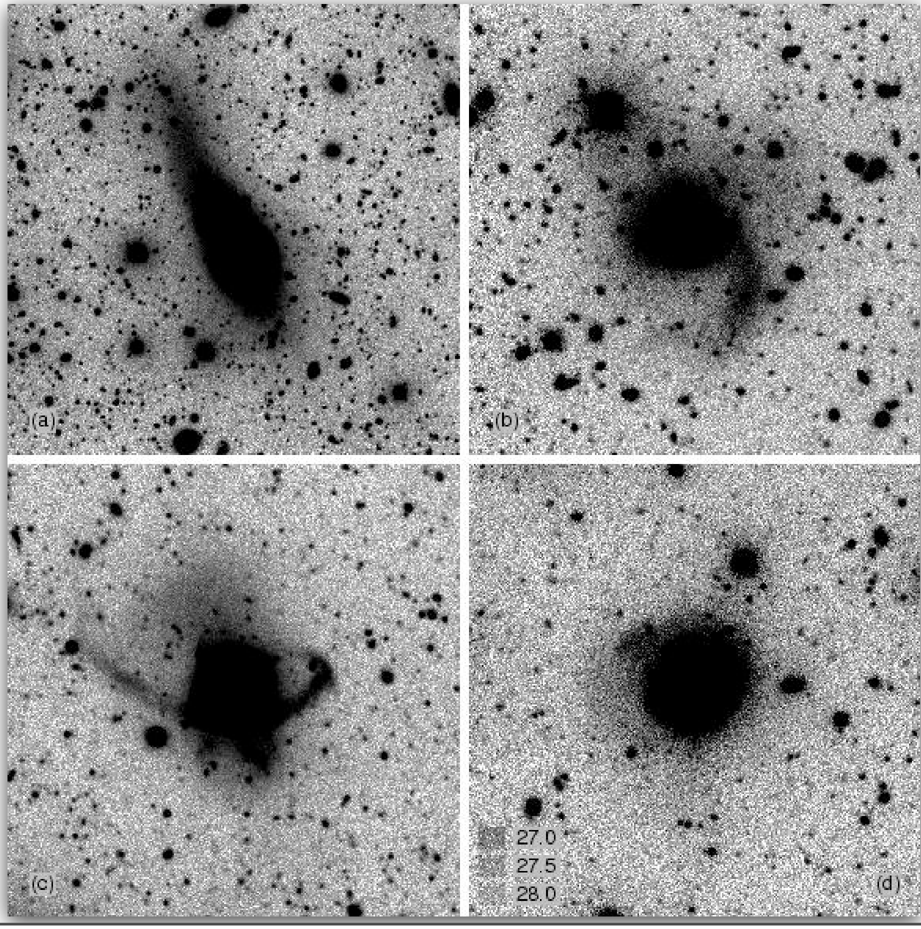
The most massive galaxies don't assemble until very late in these simulations, indicating that "dry" mergers must play a strong role at z<1



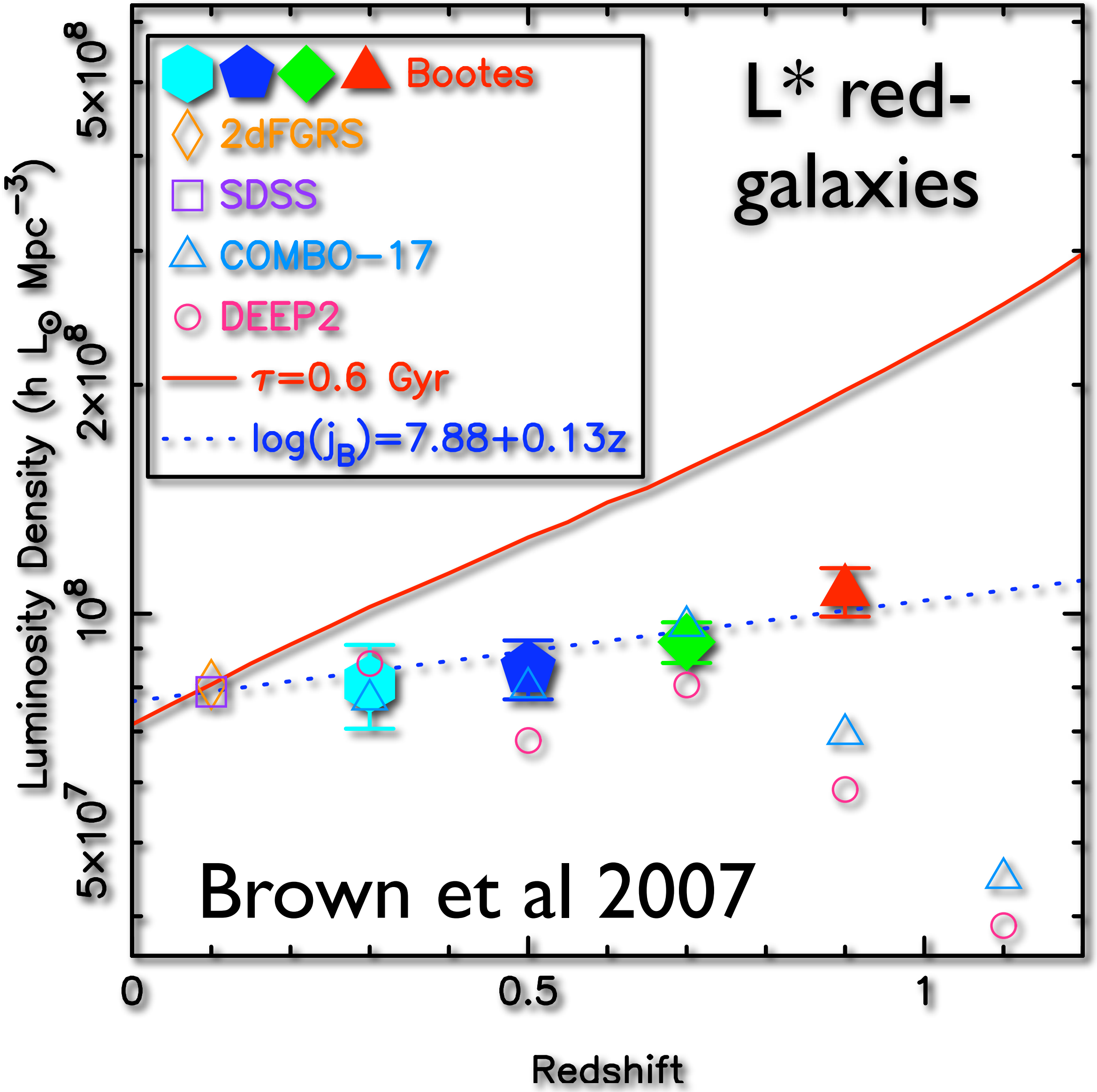
Observationally, estimates of the importance of dry mergers vary:

Masjedi et al. 2006 :

Small Scale Cluster of very massive galaxies limits rate to 1% Gyr^{-1}



van Dokkum 2005 : 35% of early-type galaxies have experienced a recent gas-poor merger



L* red galaxies have grown by a factor of 2-4 since z~1

Do massive galaxies evolve in the same manner or at a different rate?

Indications from NDWFS, COMBO-17, DEEP 2 and other surveys show little evolution in the massive galaxy population since z~1, but with limited samples of these very massive galaxies with spectroscopic redshifts

7 deg^2 of spectroscopy from MMT+Hectospec

600 galaxies at z>0.6

Large area limits uncertainty due to cosmic variance

Three Tiered Survey:

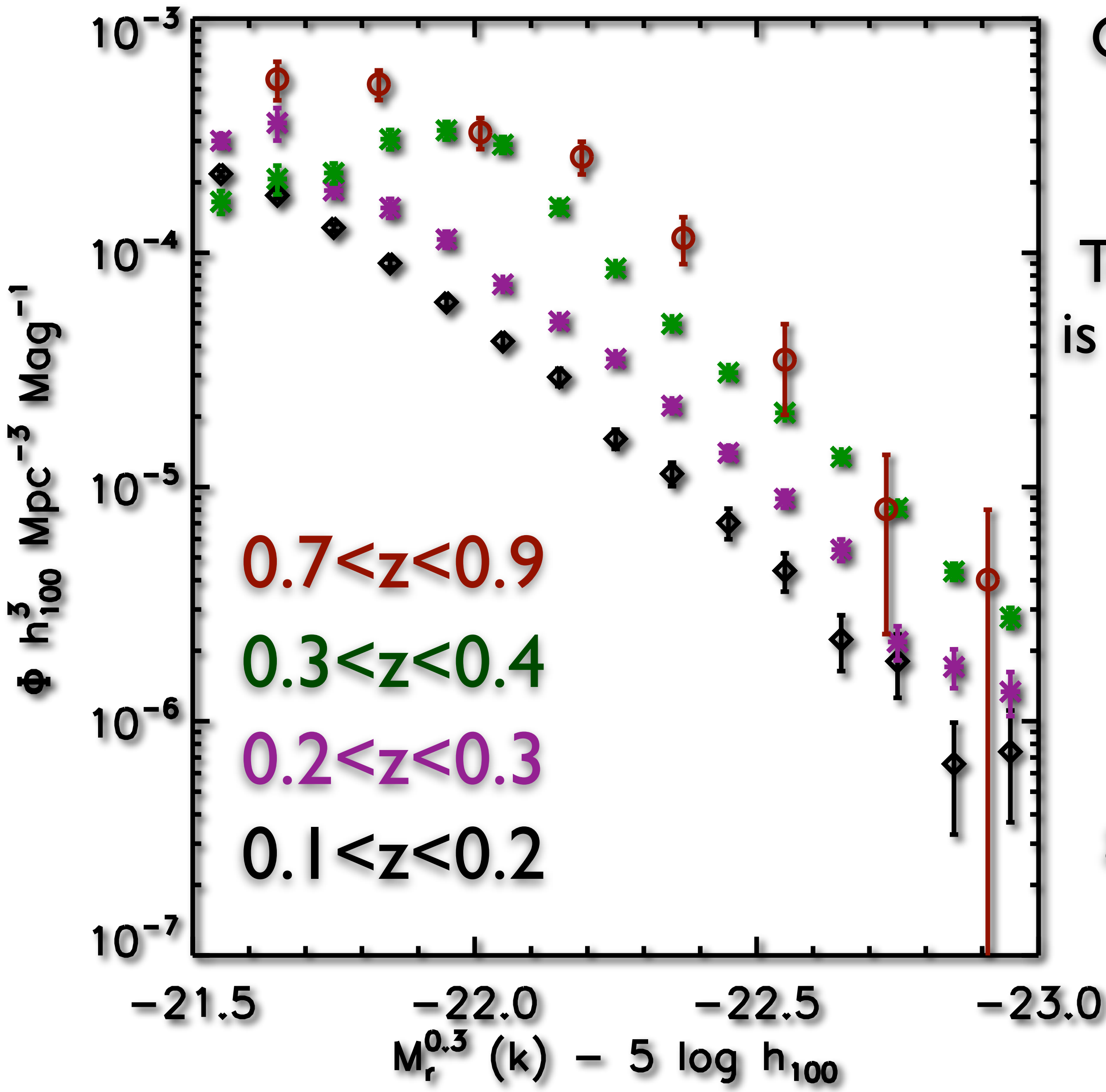
$0.1 < z < 0.2$ - Volume limited sample of Massive Early-Types from SDSS MAIN sample

$0.2 < z < 0.4$ - Luminous Red Galaxy Sample of SDSS

$0.7 < z < 0.9$ - New Spectroscopic Observations of Early-Type galaxies selected from deep SDSS coadded photometry

Spectroscopic redshifts remove contamination from catastrophic photo-z failures

Evolution of Massive Galaxy Luminosity Function

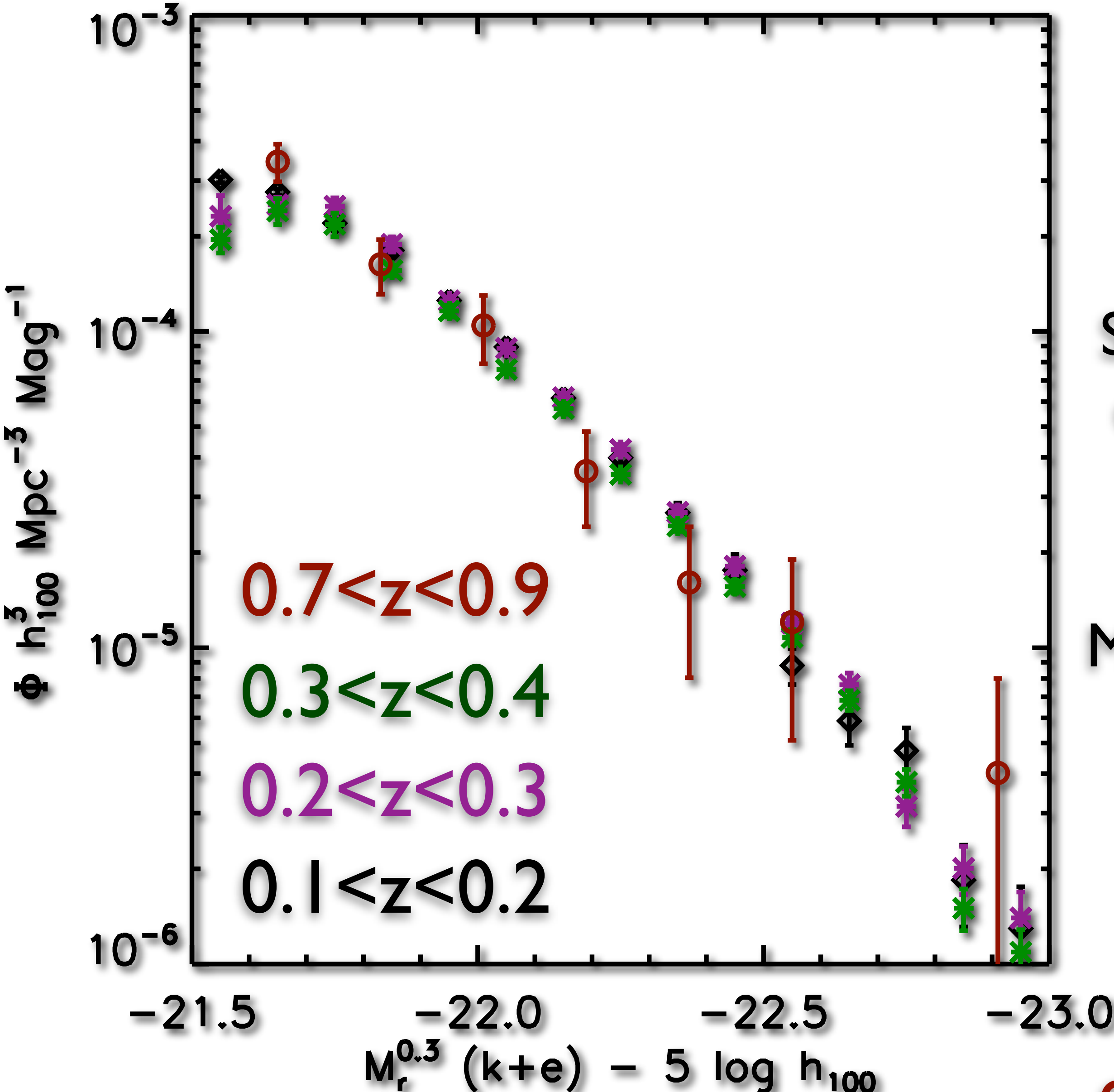


Characteristic brightening of galaxies to higher z

Turn-over at low-luminosities is due to the color-selection of these galaxies and not M*

So these galaxies have evolved, but how much of that is due to the passive fading of the stars in the galaxies and how much due to changing galaxy population?

Evolution-Corrected Luminosity Functions

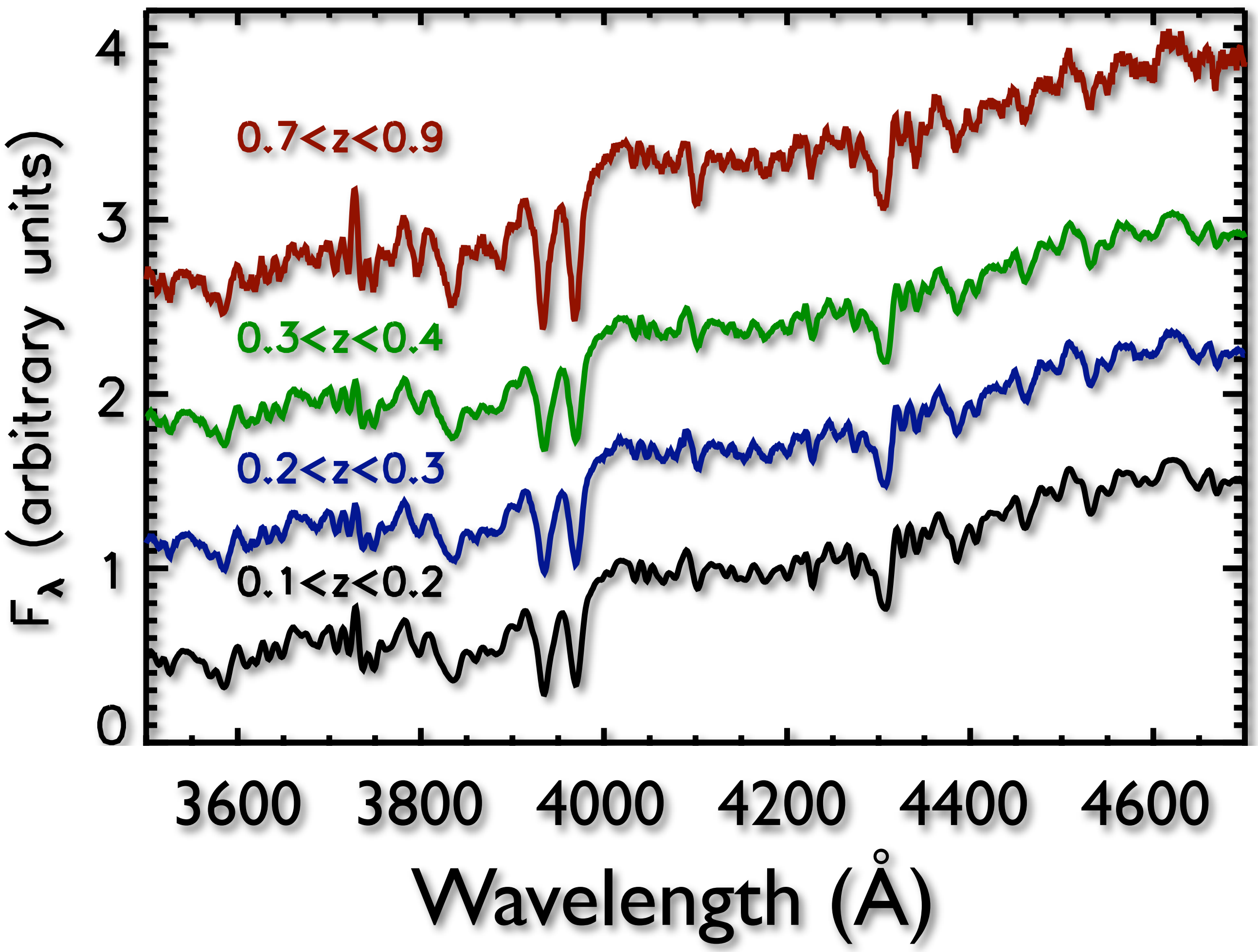


Little variation after the effects of passive evolution are included

Similar to that seen by Wake et al. 2006 at lower redshift

Merger rates > 10% are ruled out at 2-sigma

The population of massive galaxies has changed little since z~1

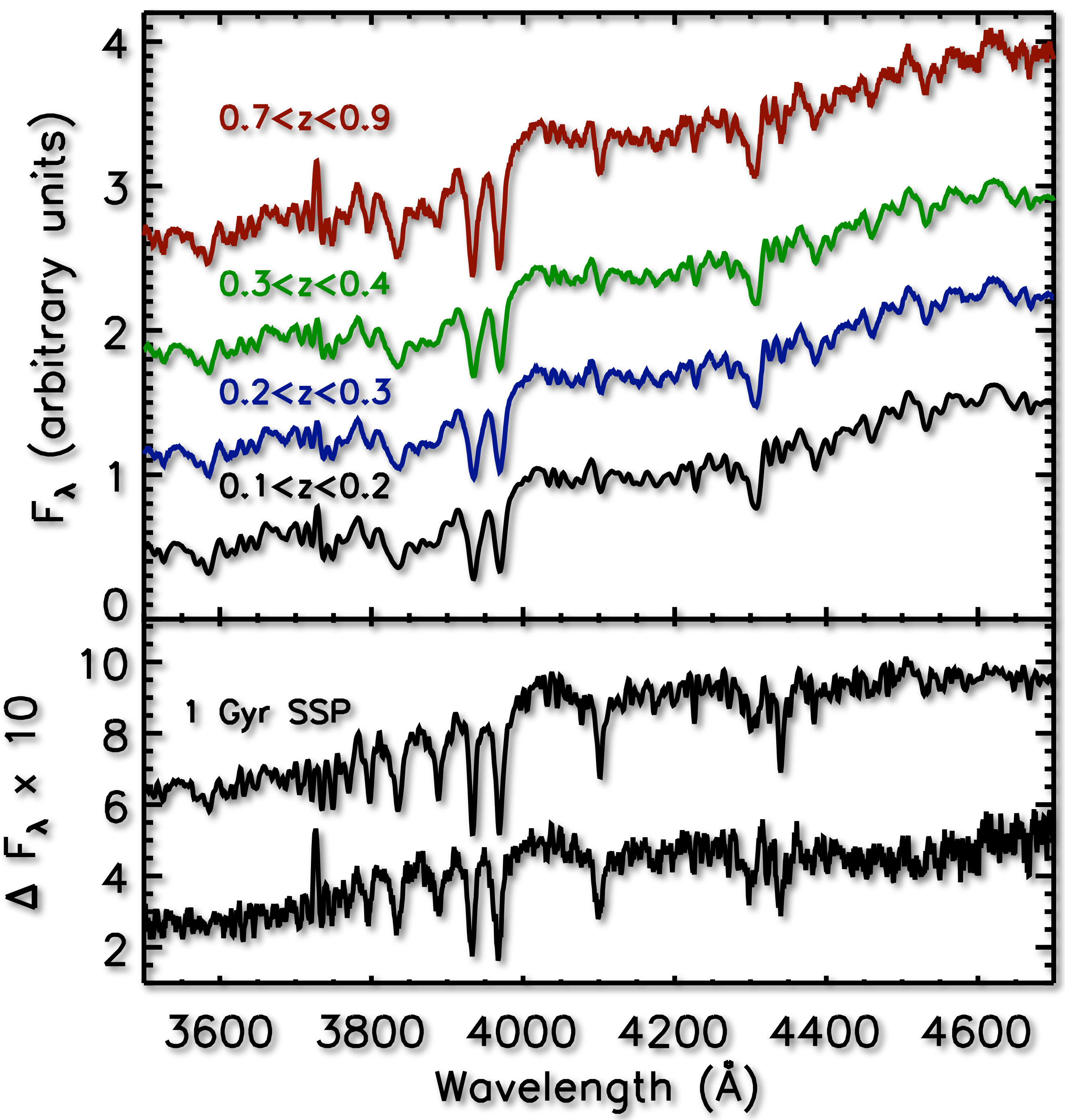


How have the average stellar populations changed since z~1?

Old stellar populations at each redshift

The difference spectrum between our highest and lowest redshift composite shows clear evidence of intermediate aged stars

1 Gyr stars are present in our z~0.8 massive galaxies



How have the average stellar populations changed since z~1?

Old stellar populations at each redshift

The difference spectrum between our highest and lowest redshift composite shows clear evidence of intermediate aged stars

1 Gyr stars are present in our z~0.8 massive galaxies

Conclusions

- The massive galaxy population has evolved little since z~0.9 beyond the passive fading of their stars
- Merger rates much larger than 10% since z~0.9 are heavily unfavored by our data. The most massive galaxies do not appear to assemble the bulk of their stars at late times.
- The mean spectrum of high-redshift massive galaxies show signs of recent activity on top of the old underlying population - the last epoch of star formation and assembly must have occurred within 1Gyr of z~0.9

PRIsm MUlti-object Survey (PRIMUS)

Motivation :

Large area photometric surveys such as SWIRE and COSMOS provide an enormous legacy to the community

Redshifts in these fields would maximize the scientific impact of these surveys and allow a wealth of investigations.

Goal :

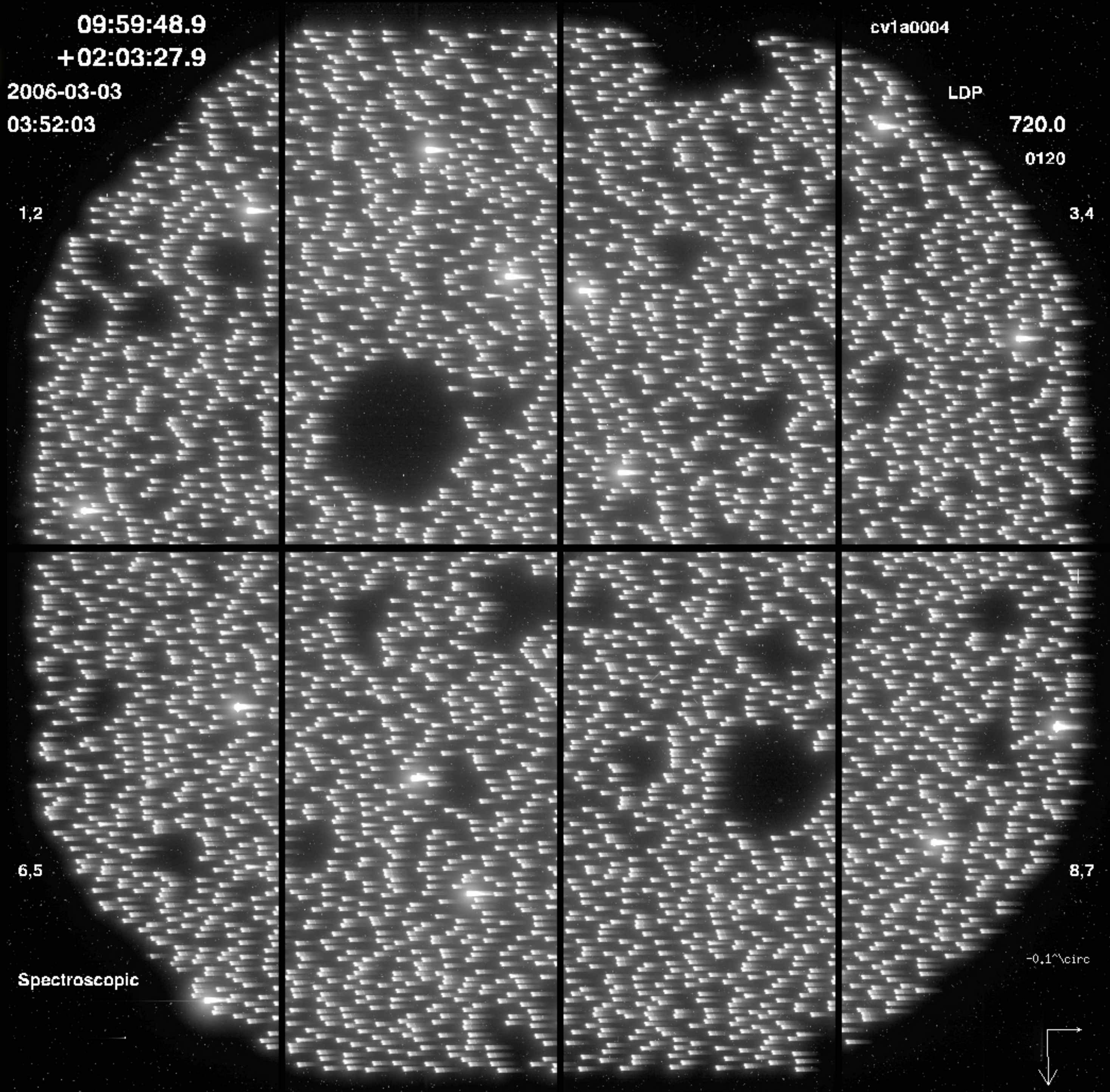
Collect 300,000 galaxy redshifts over 15 deg^2 in 2 years with a 6.5m telescope

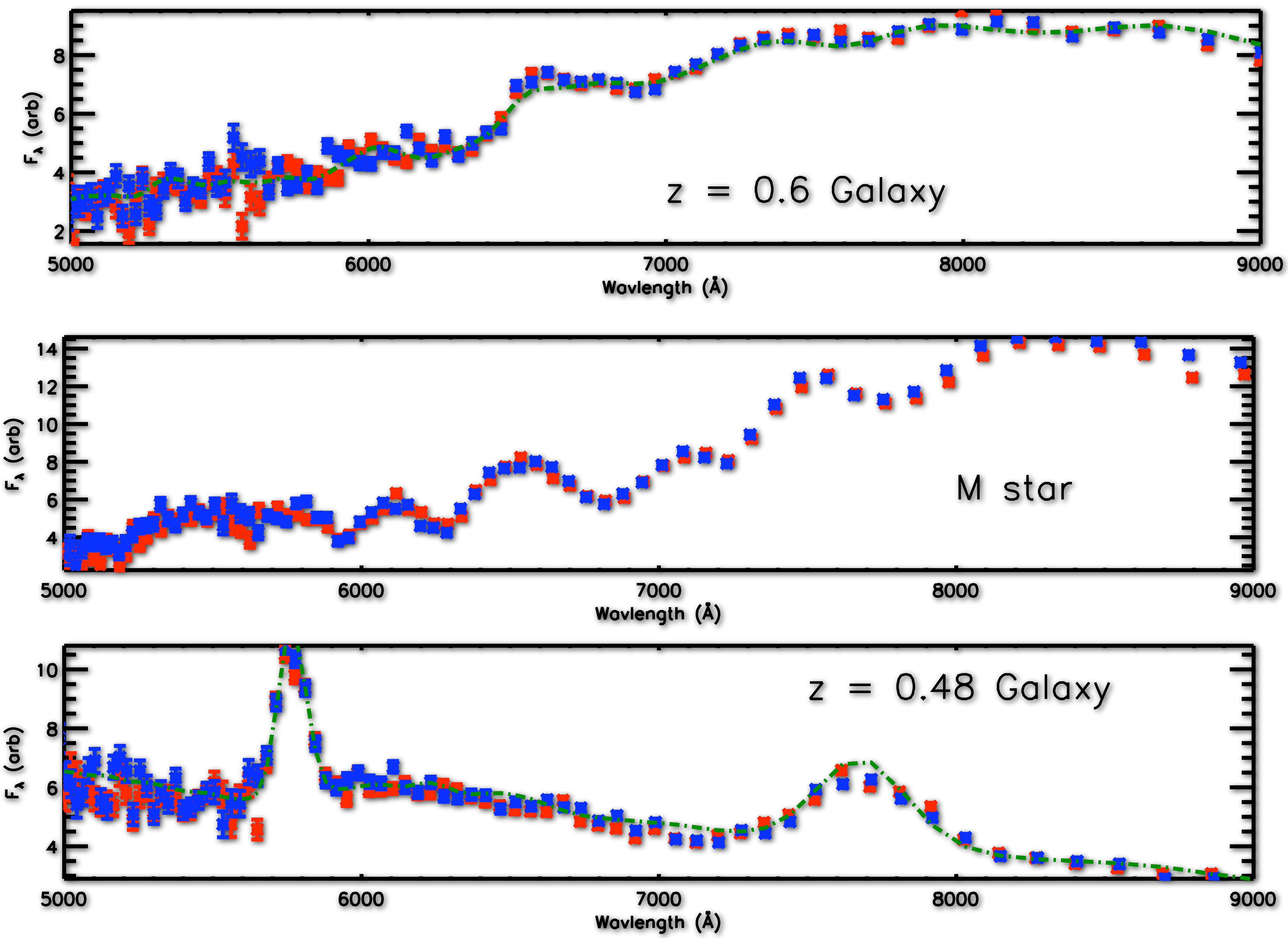
PRIMUS team : Mike Blanton, Adam Bolton, Scott Burles, Rebecca Burnstein, Alison Coil, Richard Cool, Daniel Eisenstein, David Hogg, Tim McKay

We have designed and commissioned a new prism for IMACS on Magellan

Trade resolution for more targets per slit mask

Multiplexing in the spectral direction allows for simultaneous observations of 3000 galaxies




z = 0.6 Galaxy
M star
z = 0.48 Galaxy
F_λ (arb)
Wavlength (Å)
5000
6000
7000
8000
9000

Current Status :

200,000 spectra in hand over 9 square degrees

6 square degrees of Spitzer imaging covered

More to come :

2007b - finish observations

100,000 more galaxies in 5.5 square degrees

Science using the largest faint galaxy redshift survey and the largest sample of Spitzer redshifts obtained to date