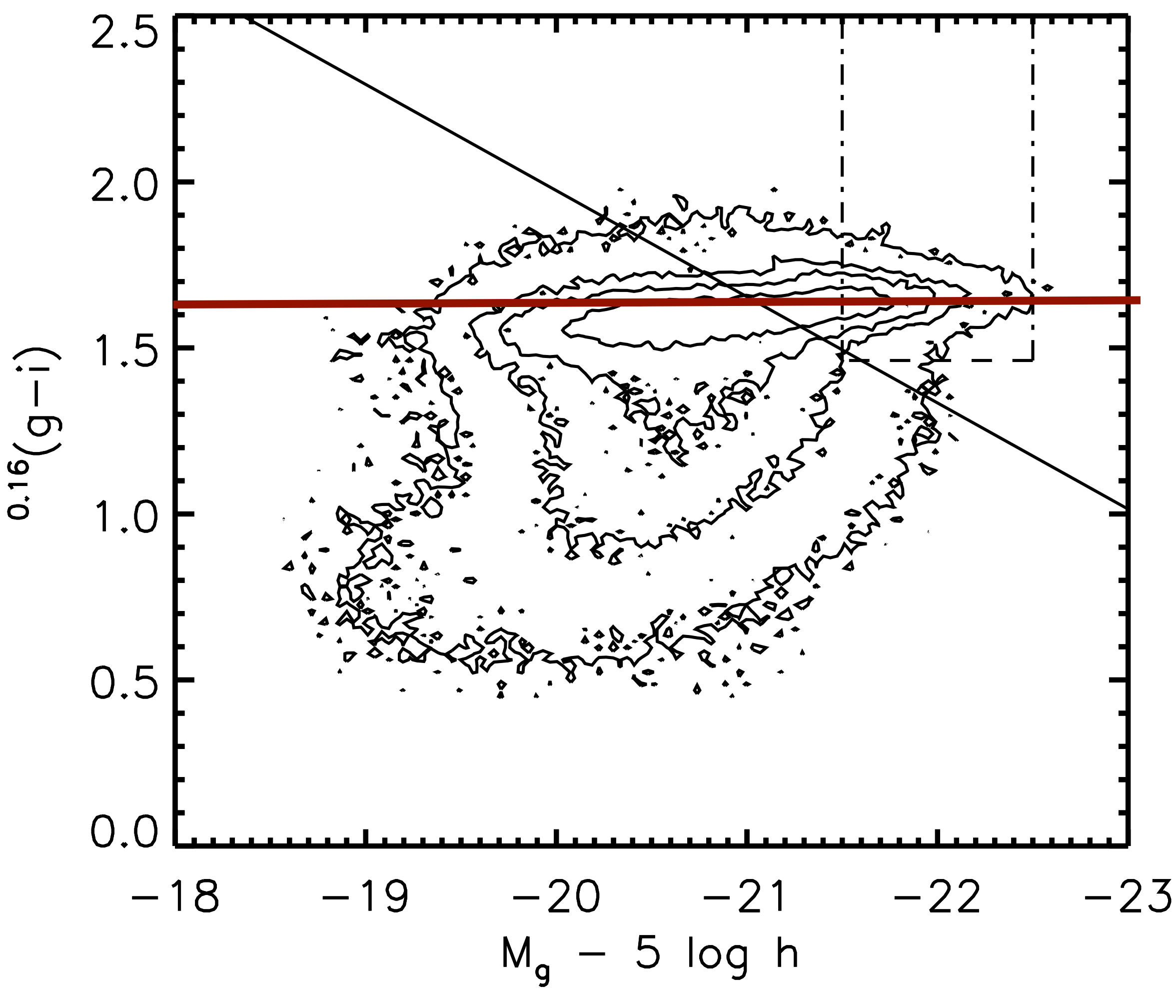
Constraining the Evolution of the Most Massive Galaxies Since z~1

Richard Cool
University of Arizona

Daniel Eisenstein (Arizona)
SDSS Collaboration

- Massive Red Galaxies Offer Convenient Probes of Cosmology to z=1
  - Efficiently selected relatively clean from blue galaxy contamination
  - Luminous -- only moderate imaging / spectroscopic depths needed to observe even to z~1 but large volumes are required to collect statistical samples of the rare objects

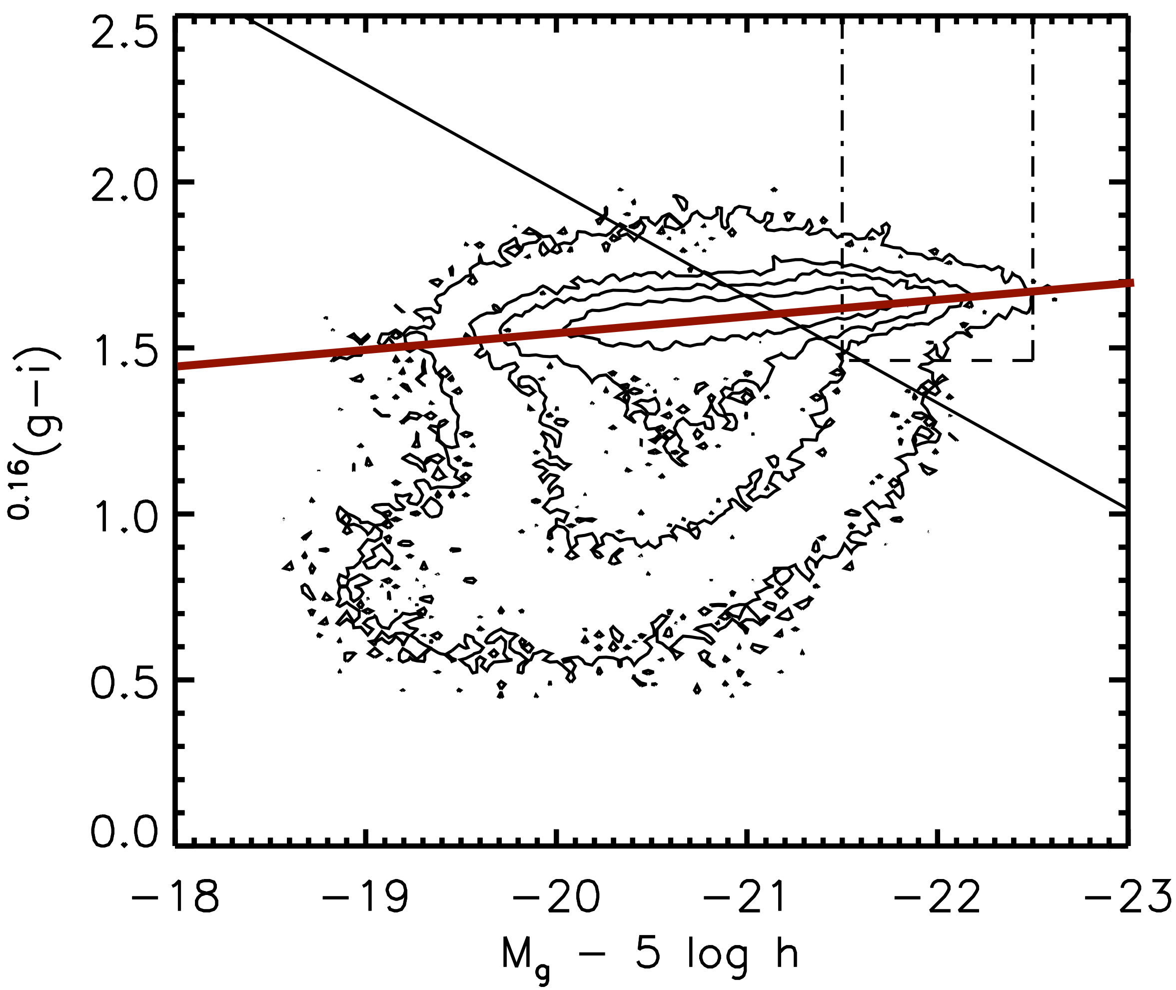
- Massive Galaxies are the endpoints of the hierarchical merging process
  - Measurements of their growth and evolution are quite sensitive to the details of the merging rates and feedback processes
- If we want to use these galaxies as cosmological probes, it is important to understand their empirical evolution
  - Goal : Using large samples of massive red galaxies, directly constrain the epoch of star formation and era of stellar assembly in the most massive galaxies



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)



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Zeropoint - Mean Star Formation History of Galaxies

Slope - Chemical Enrichment History

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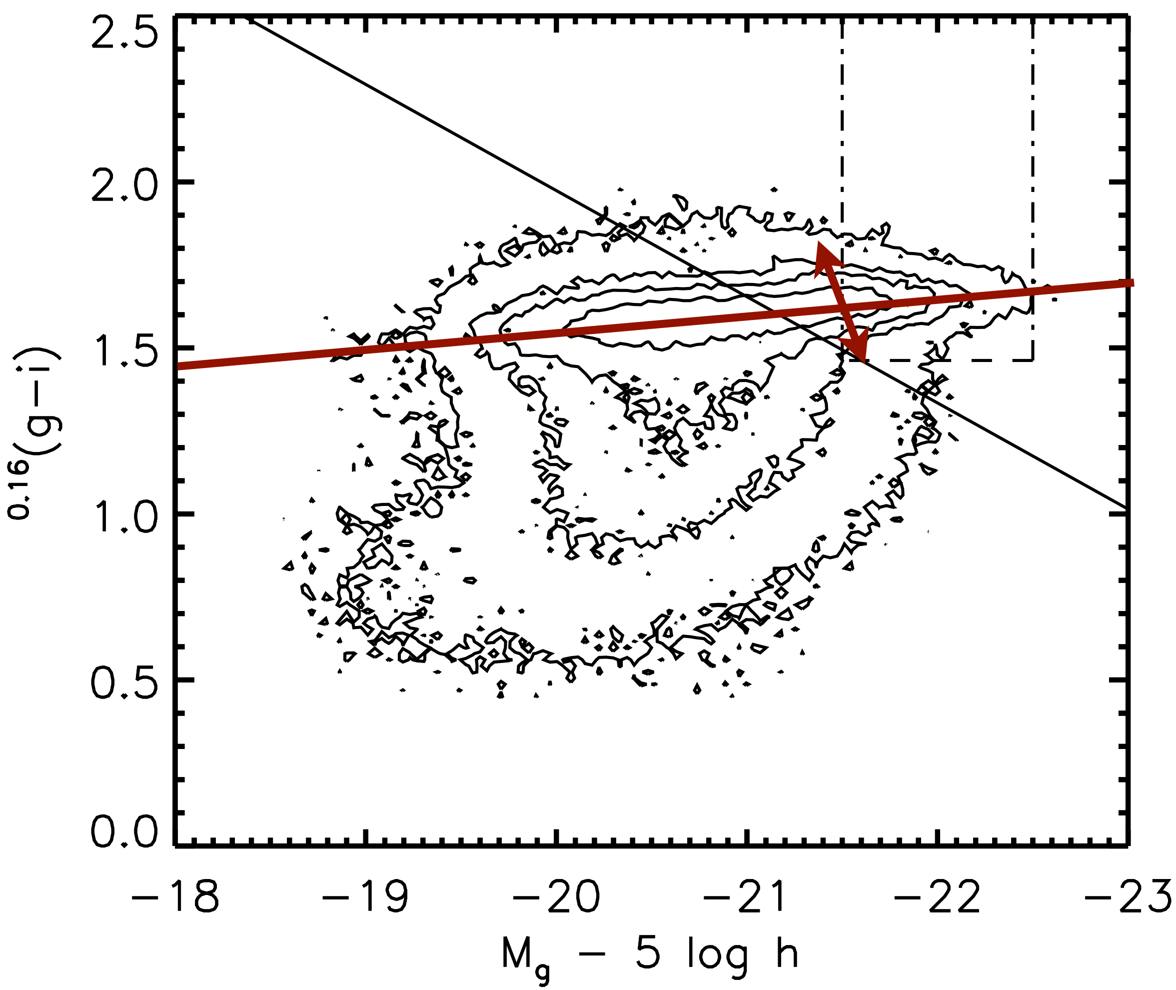

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Zeropoint - Mean Star Formation History of Galaxies

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

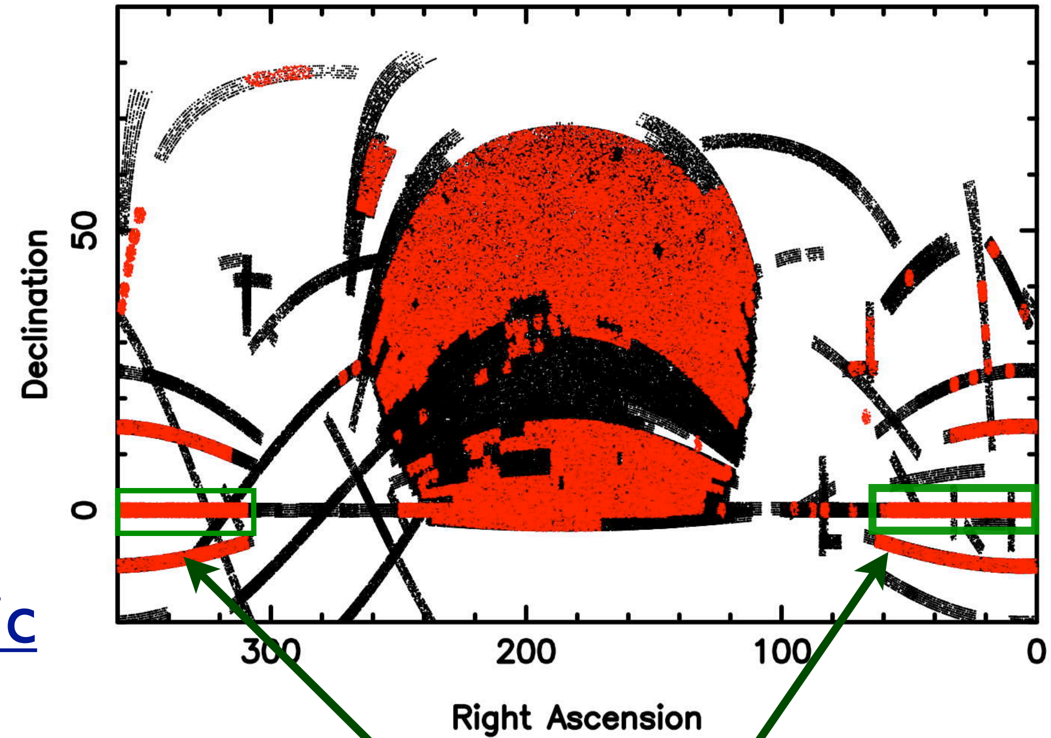
Cool et al. 2006 - AJ 131, 736 (astro-ph/0510301)

Sloan Digital Sky Survey (SDSS):

Imaging : 8400 deg^2

Spectra : 6900 deg^2

981,000 galaxy redshifts



Two complementary Spectroscopic Galaxy Samples:

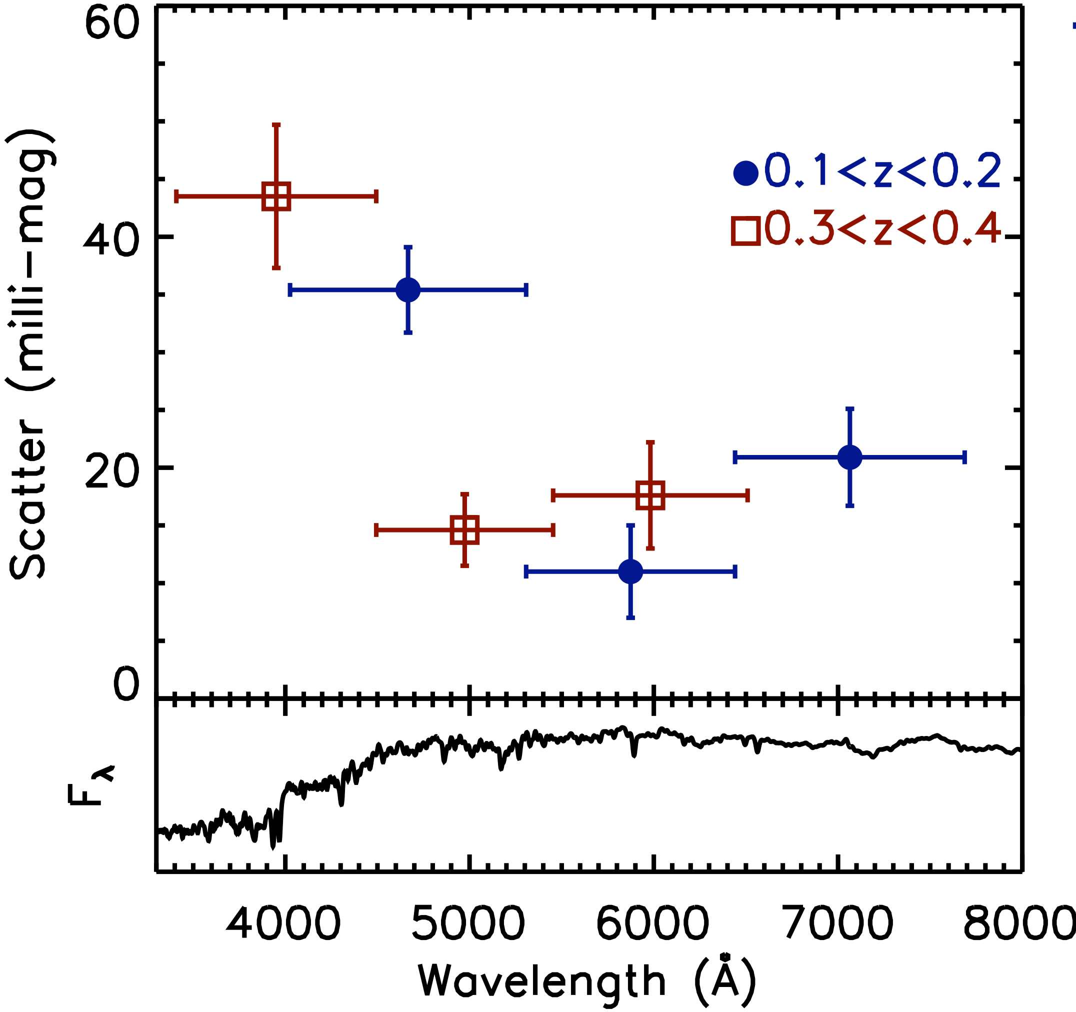
MAIN galaxy Sample:
flux-limited r < 17.77

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

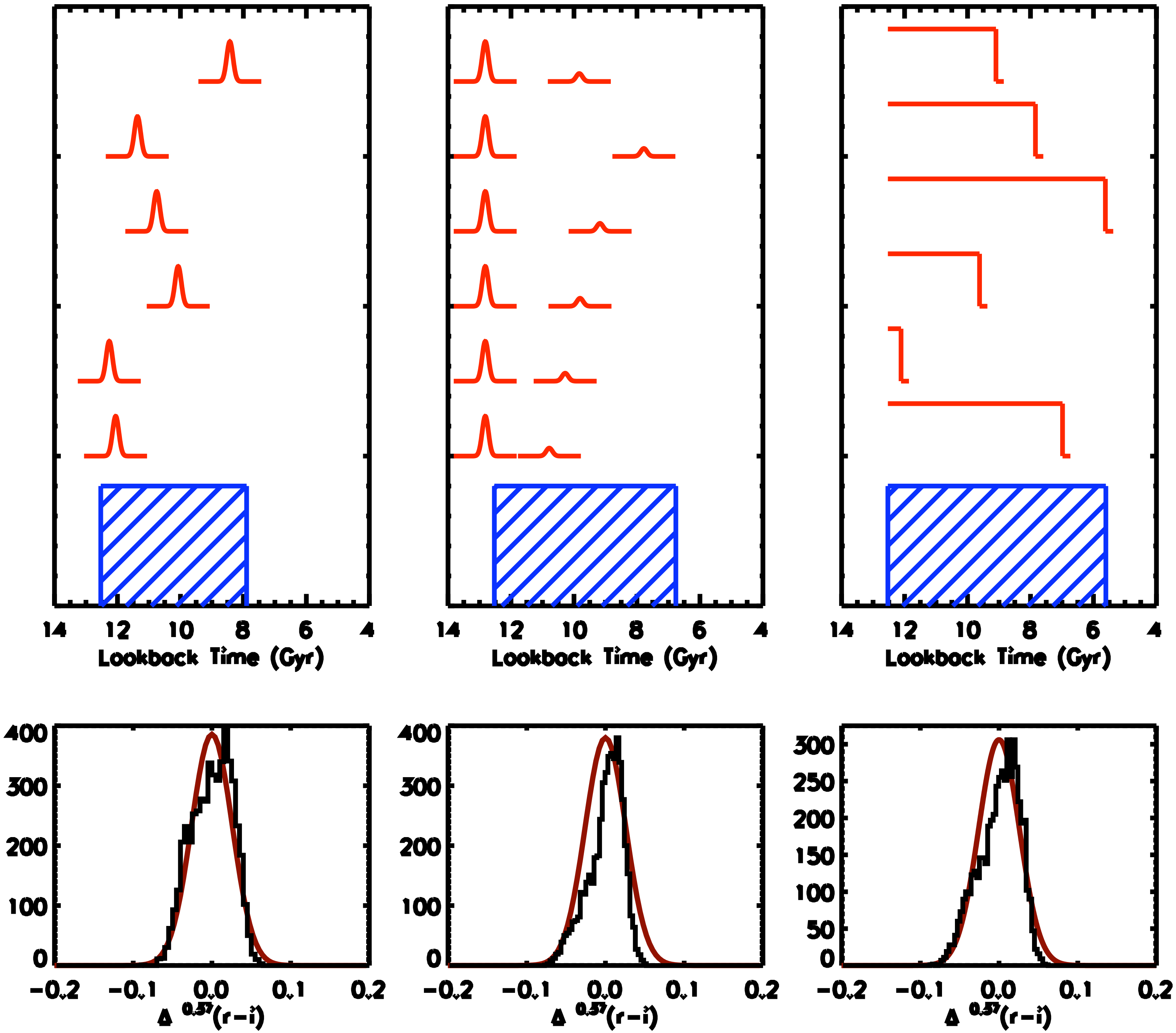


Massive early-type **field** galaxies show small scatter in all optical colors

Bluest bands show factor of 2 higher dispersion

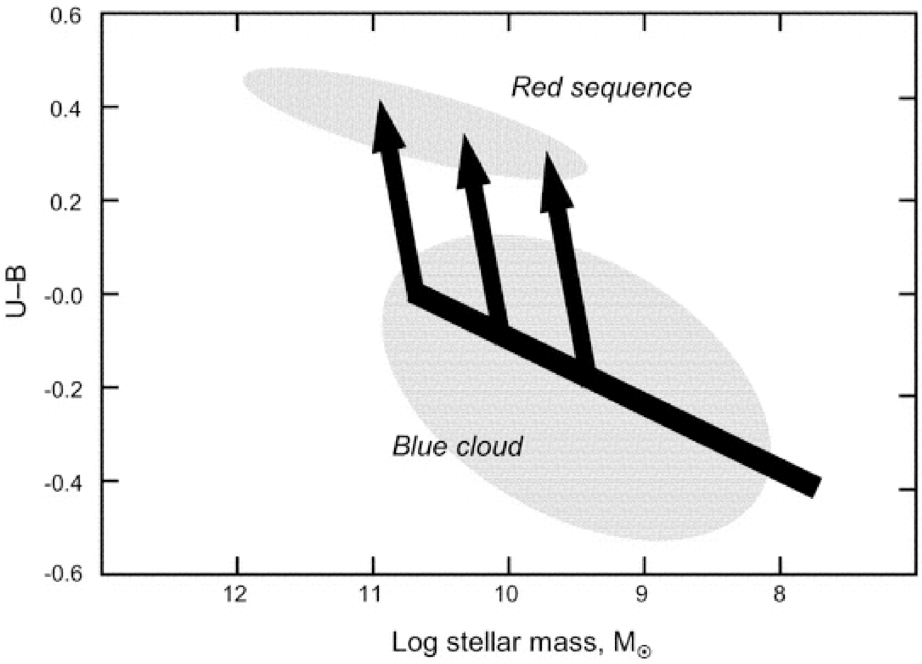
Galaxies in dense environments have 11% smaller scatter than field galaxies

Little diversity in star formation histories of massive early-types



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

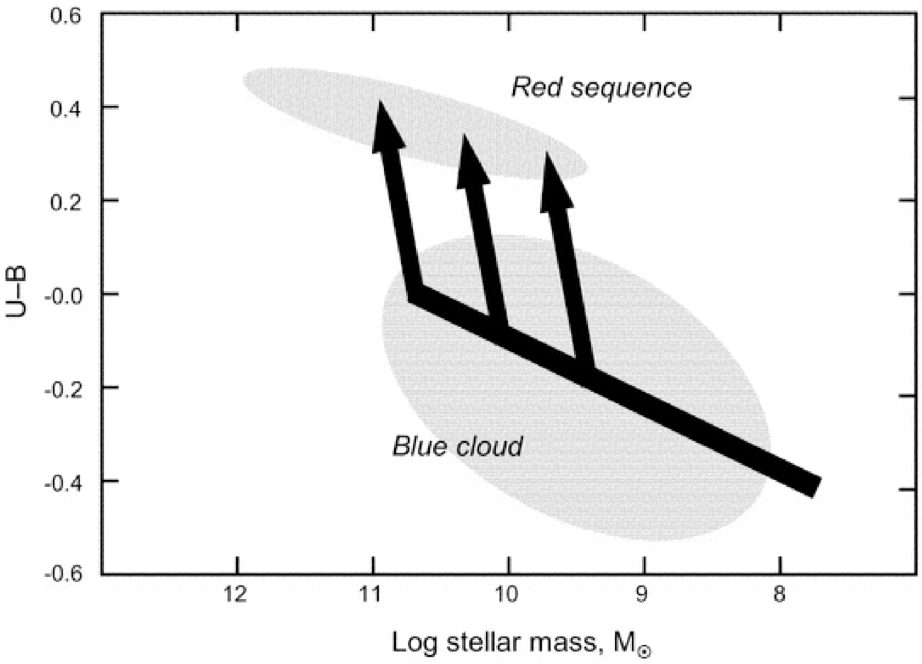
What kind of mergers are important for massive galaxies?

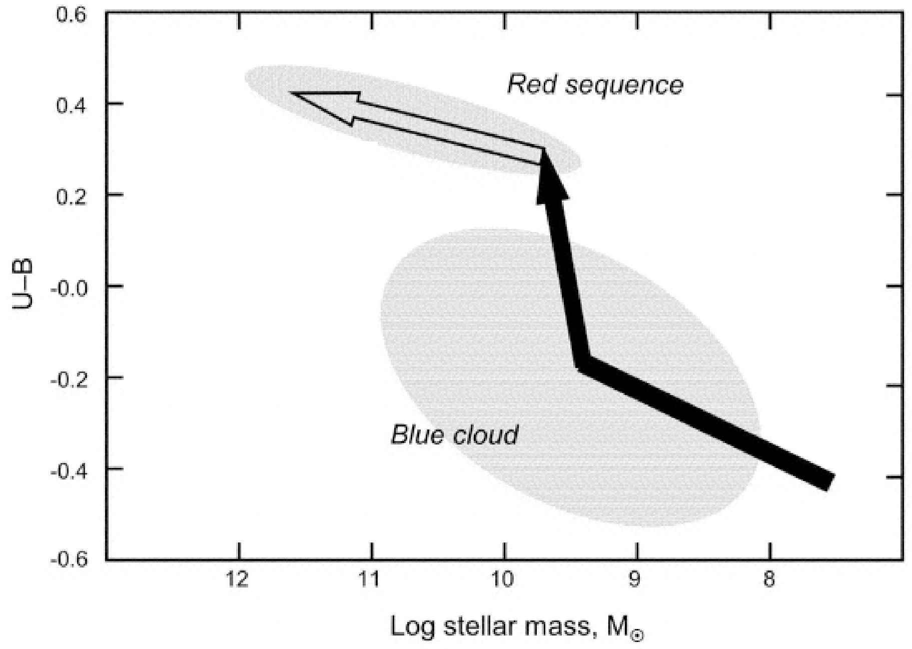


Galaxies grow through gas-rich mergers then fade

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

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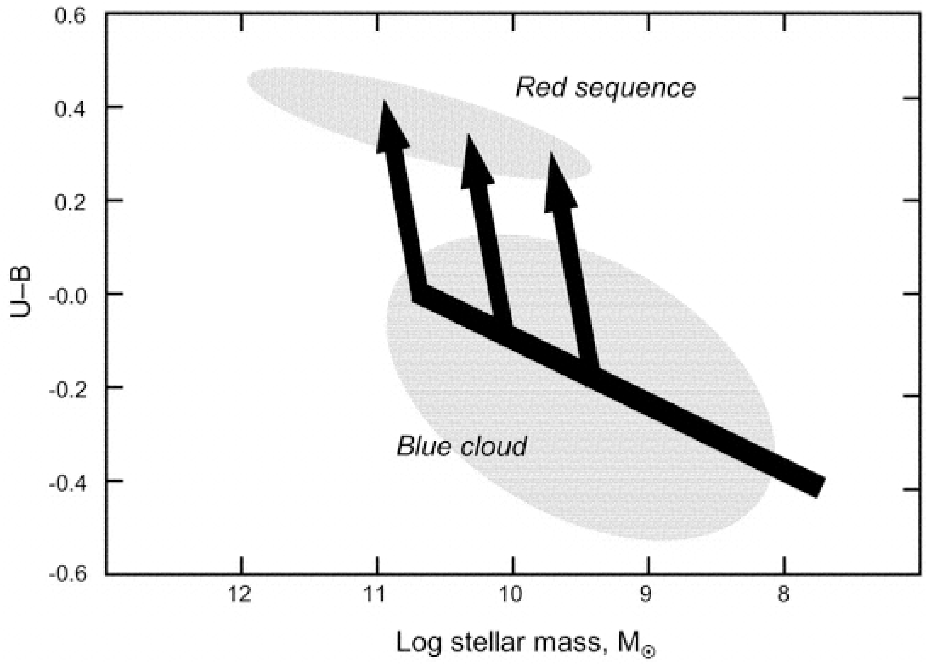
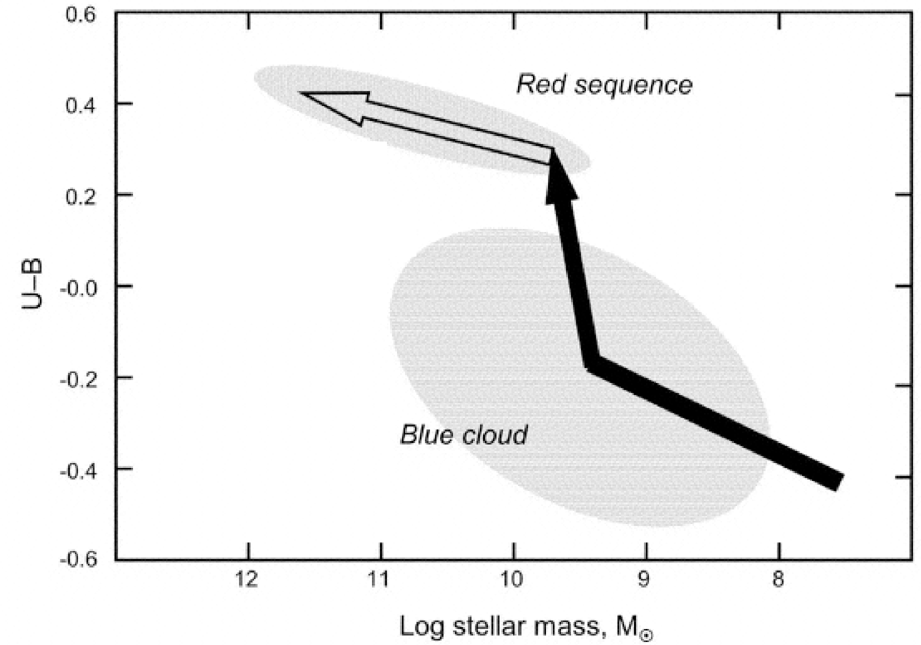
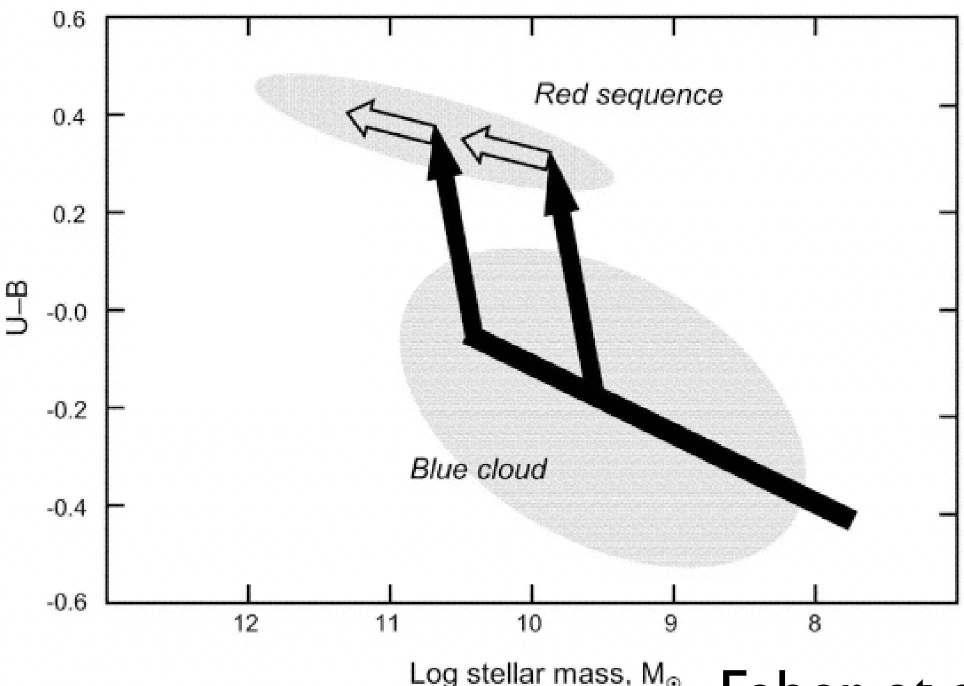






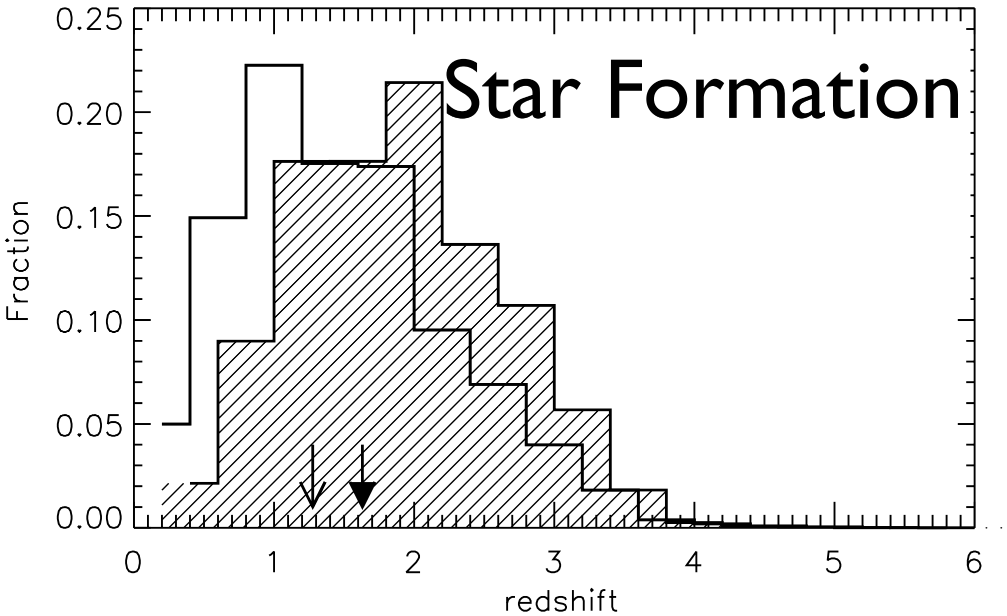
Faber et al 2006

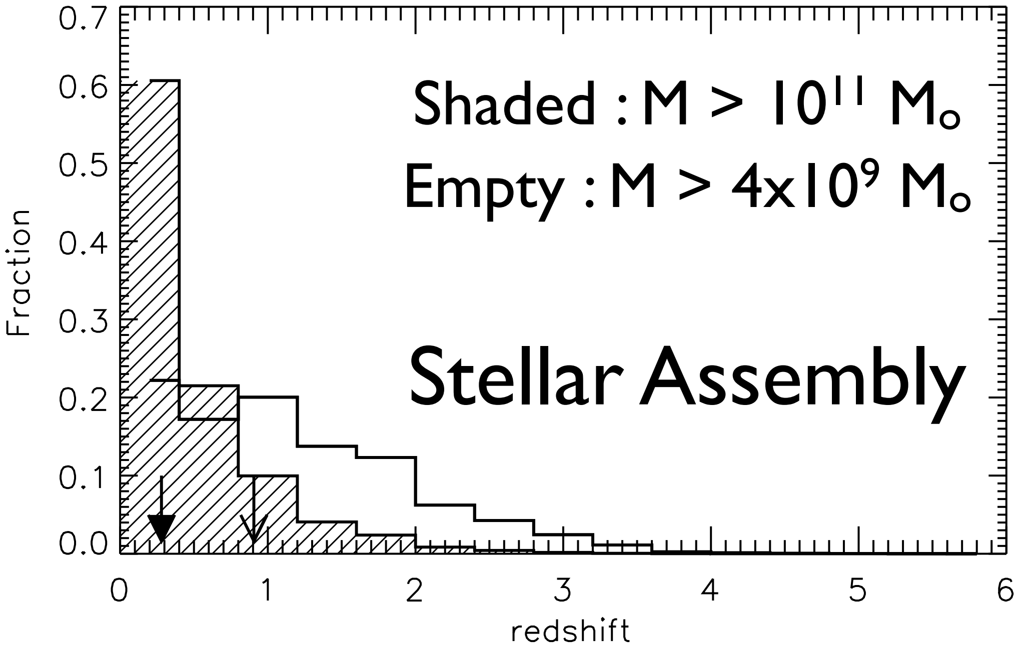
Galaxies grow through gas-rich mergers then fade

Galaxies form their stars early and then merge without star formation

Some combination of the two

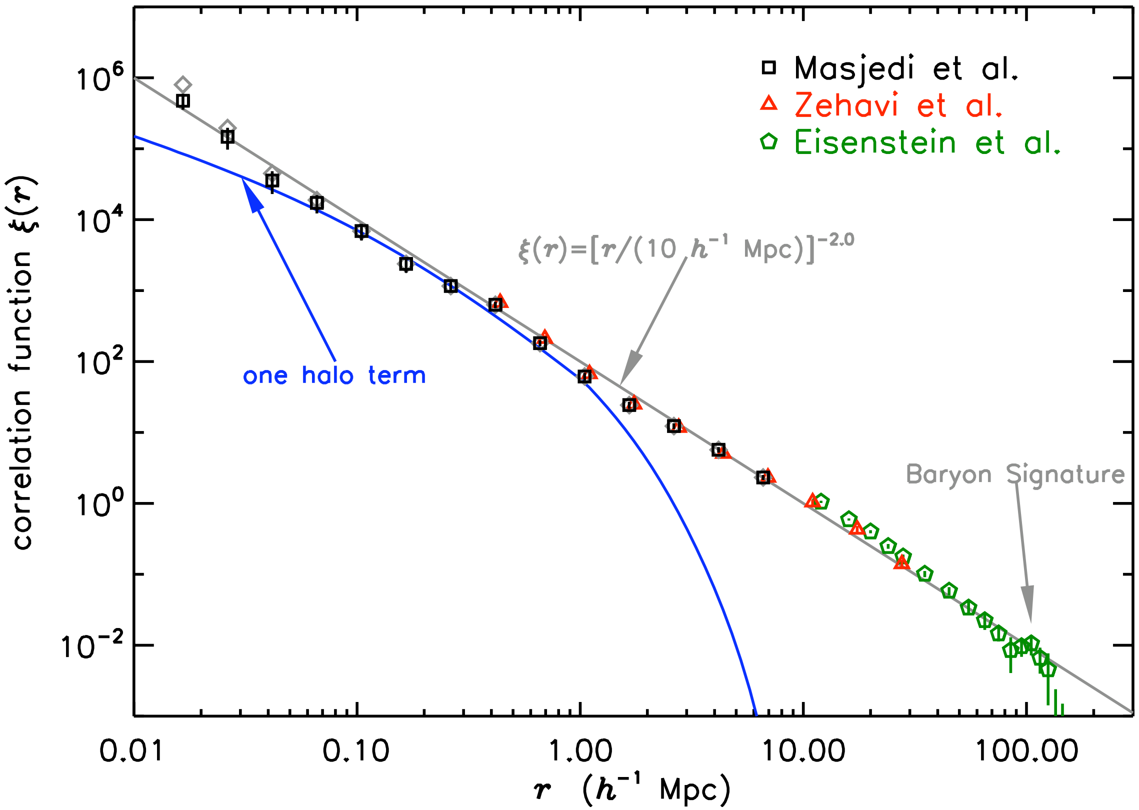
de Lucia et al 2006





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

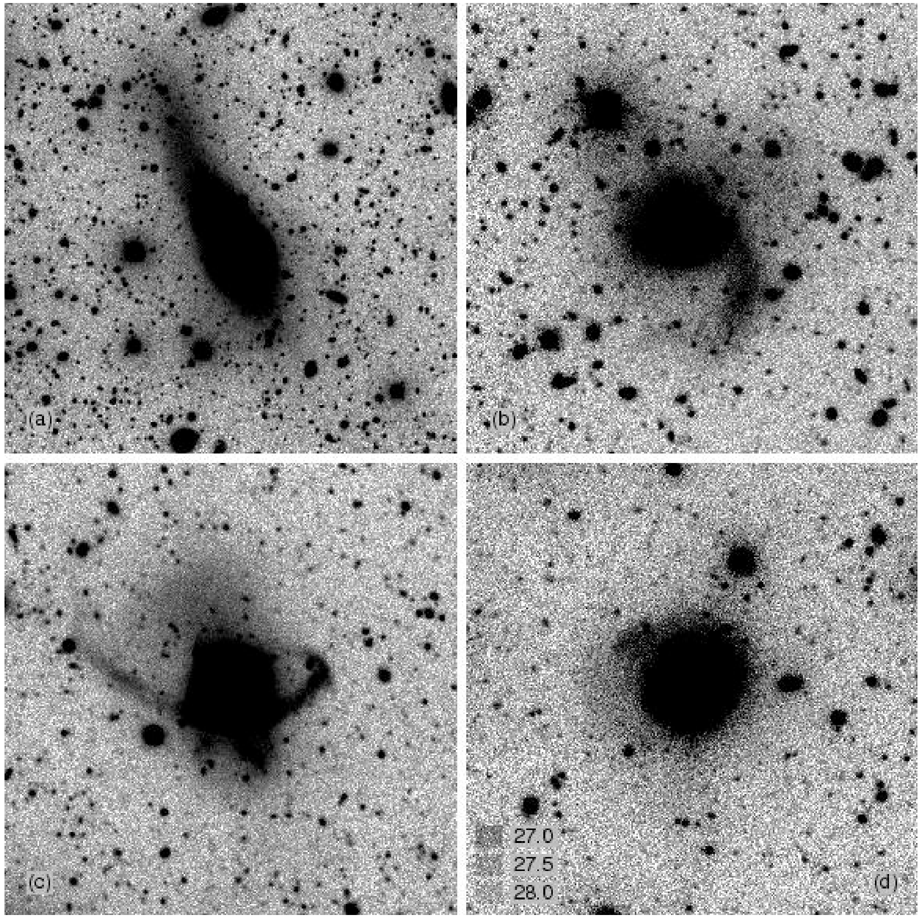
The most massive galaxies don't assemble until very late in these simulations, indicating that "dry" mergers must play a strong role at z<1



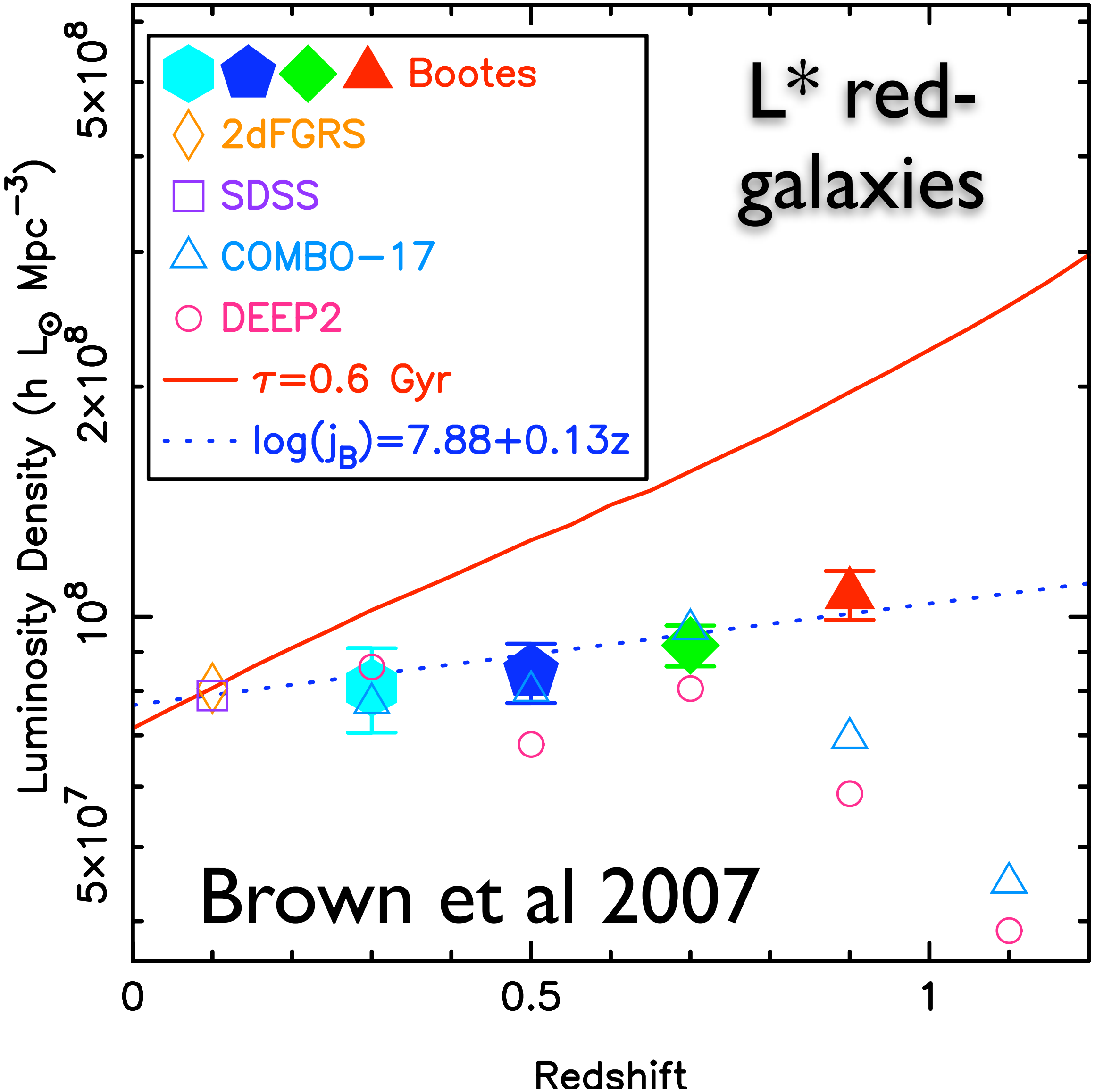
Observationally, estimates of the importance of dry mergers vary:

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:

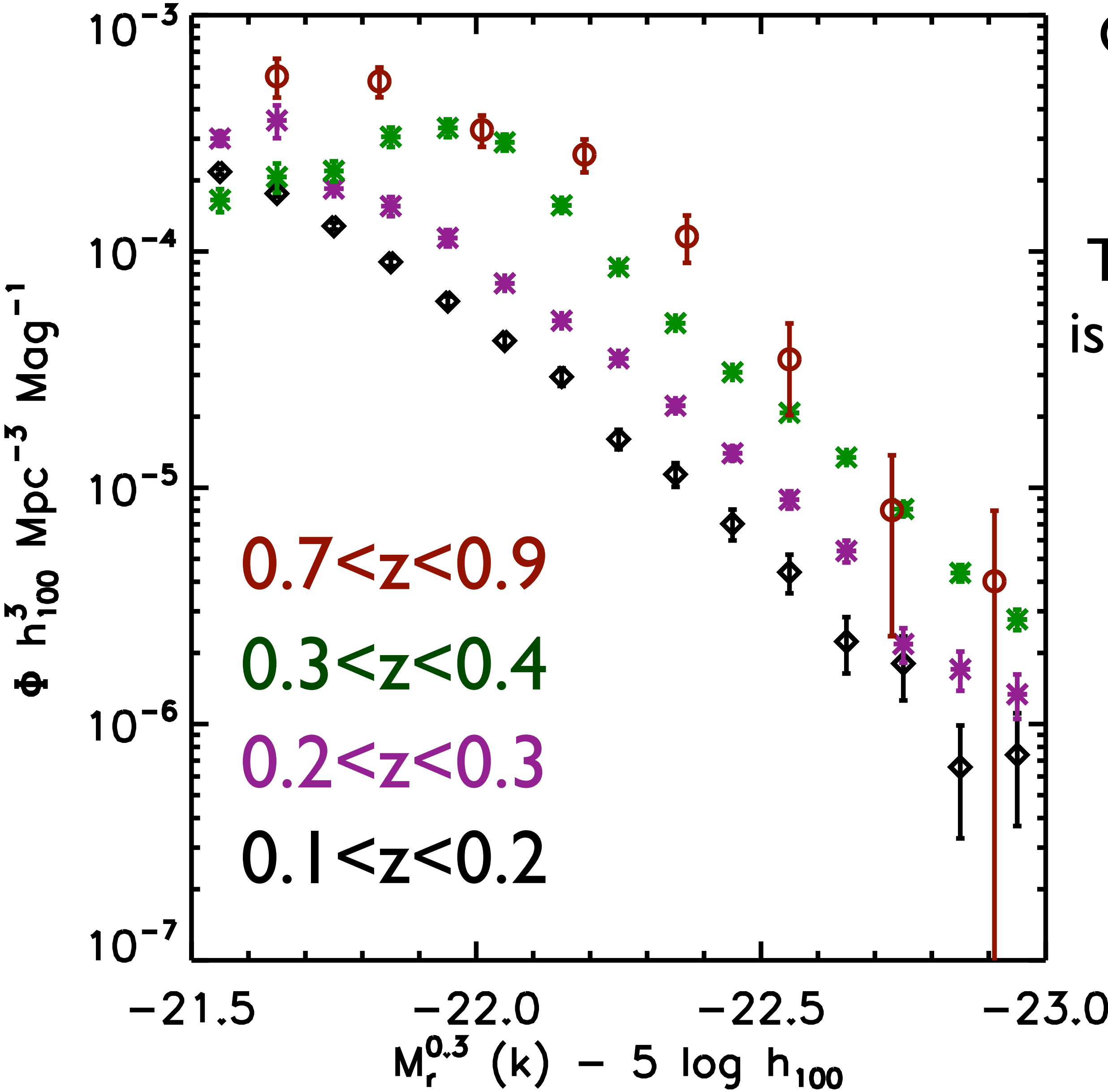
0.1 < z < 0.2 - Volume limited sample of Massive Early-Types from SDSS MAIN sample

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

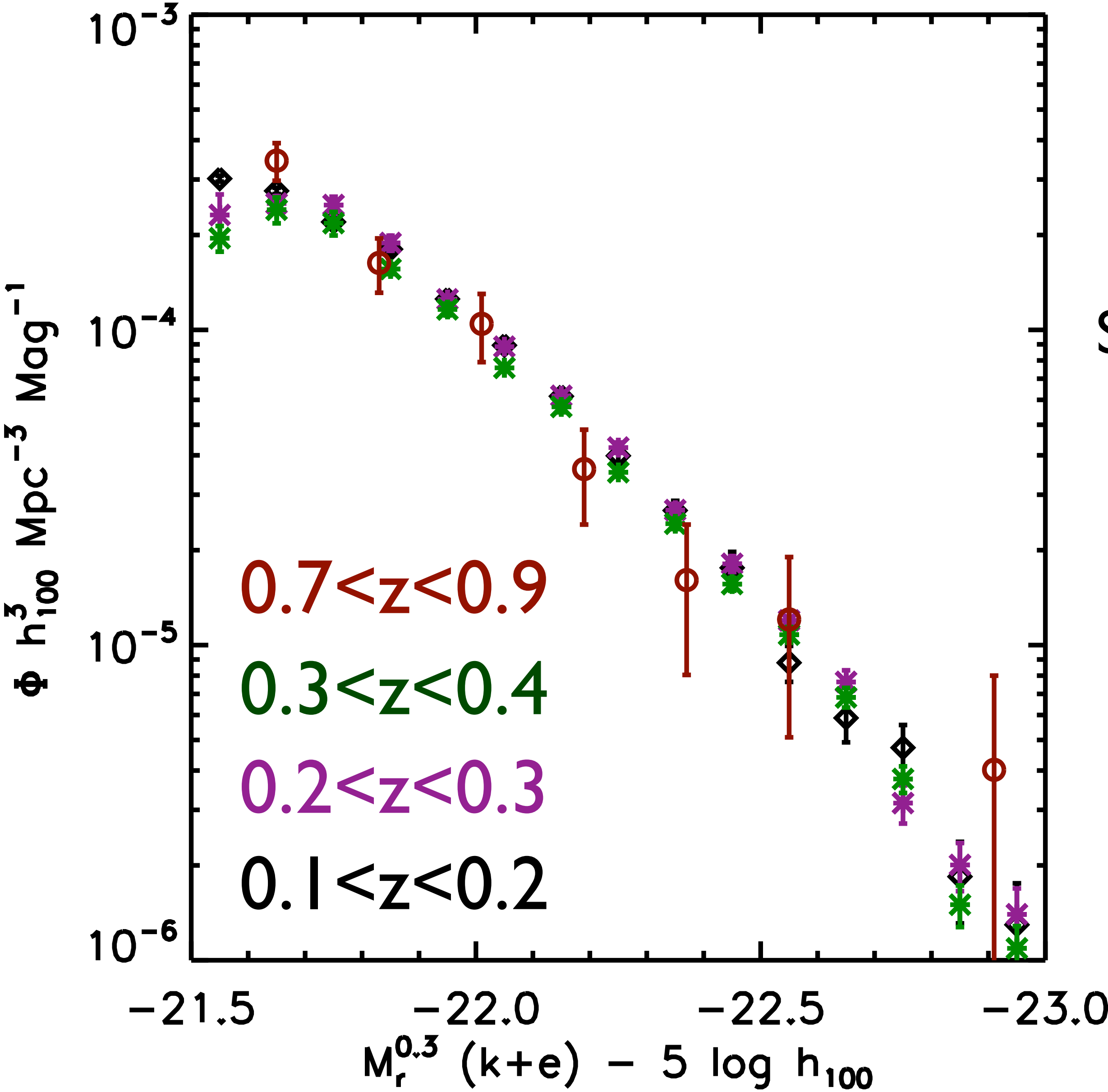


Characteristic brightening of galaxies to higher z

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

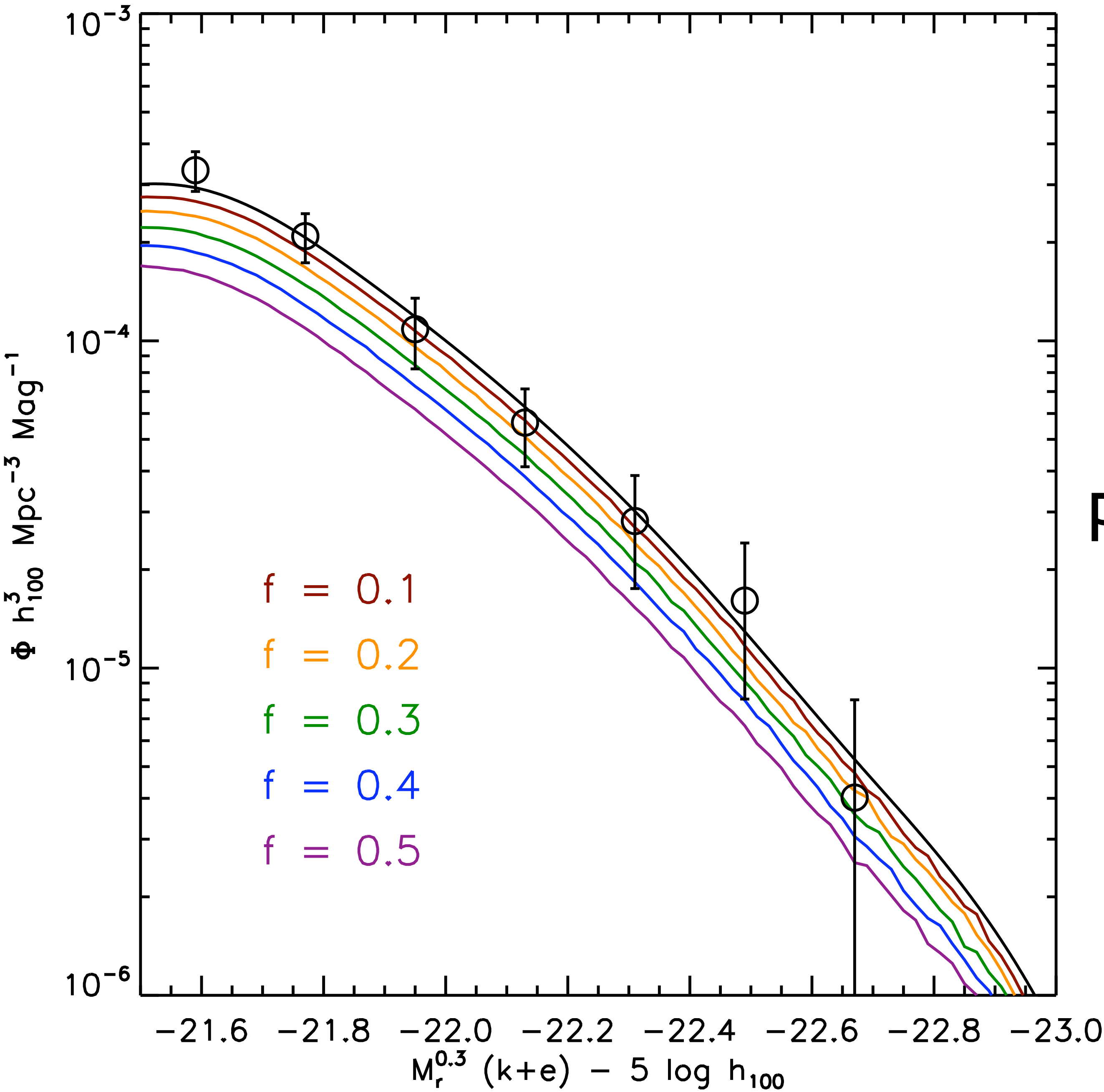
So these galaxies have evolved, but how much of that is due to the passive fading of the stars in the galaxies and how much due to changing galaxy population?

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 > 35% are ruled out with 90% confidence

More than 50% of the massive galaxy populations was fully in place by z=1

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

Conclusions

- The massive galaxy population has evolved little since z~0.9 beyond the passive fading of their stars
- Merger rates much larger than 40% 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.
- Observations at higher redshift and of more galaxies at intermediate redshifts are needed to quantify the small growth of these galaxies over the later half of cosmic history.

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 :

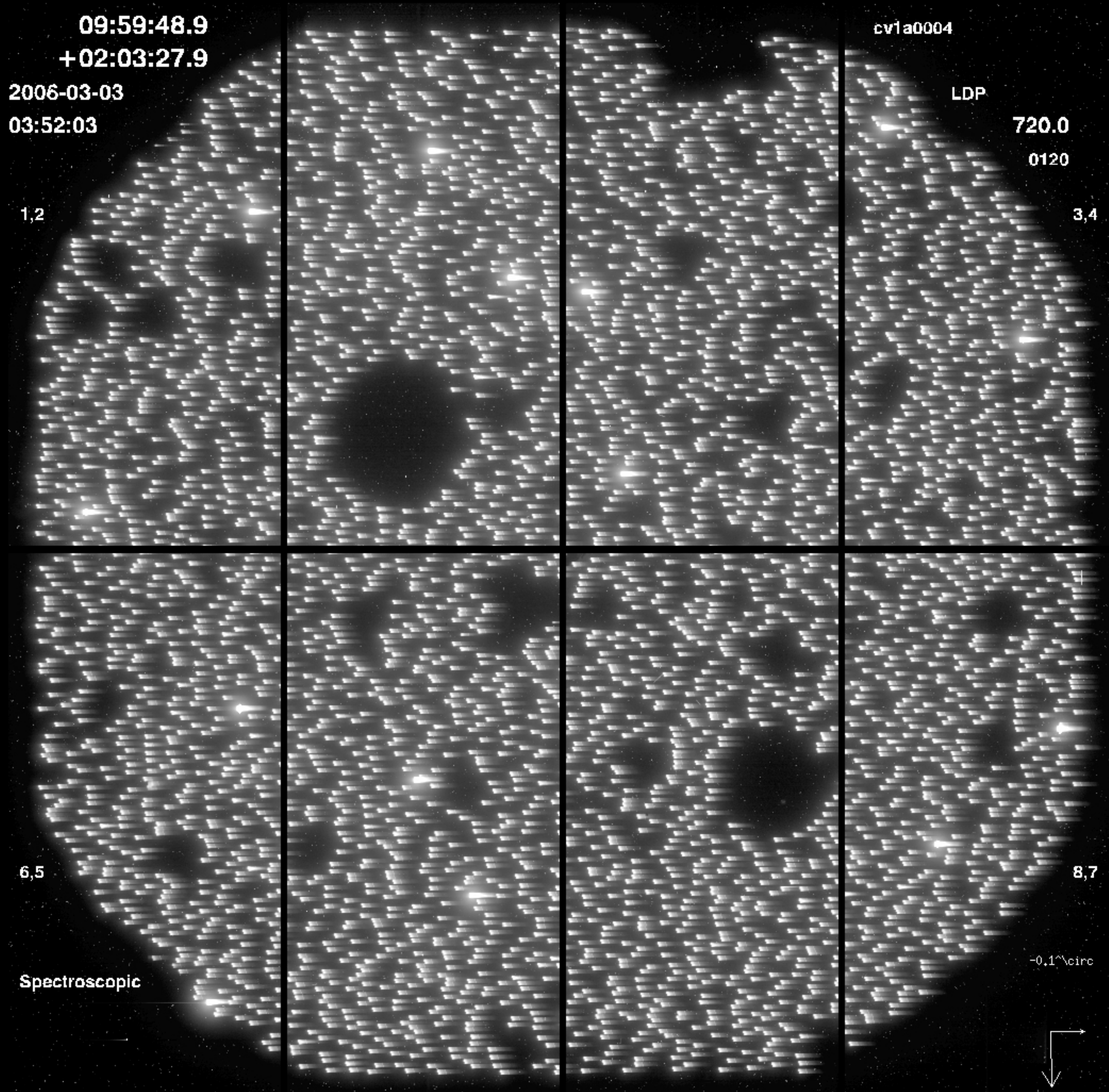
Collect 300,000 galaxy redshifts over 15 deg^2 in 2 years with a 6.5m telescope

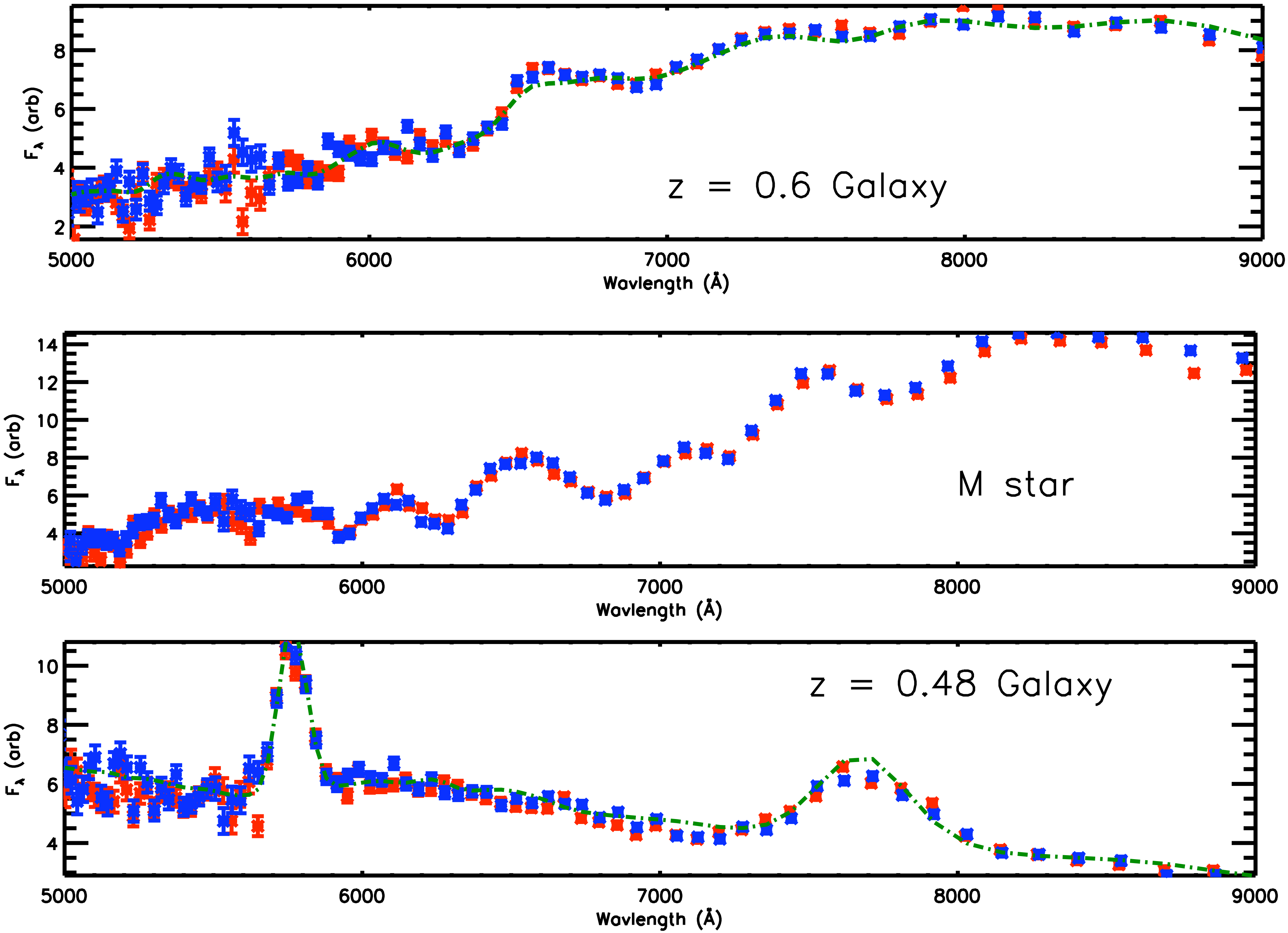
PRIMUS team : Mike Blanton, Adam Bolton, Scott Burles, Rebecca Bernstein, Alison Coil, Richard Cool, Daniel Eisenstein, David Hogg, Tim McKay

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





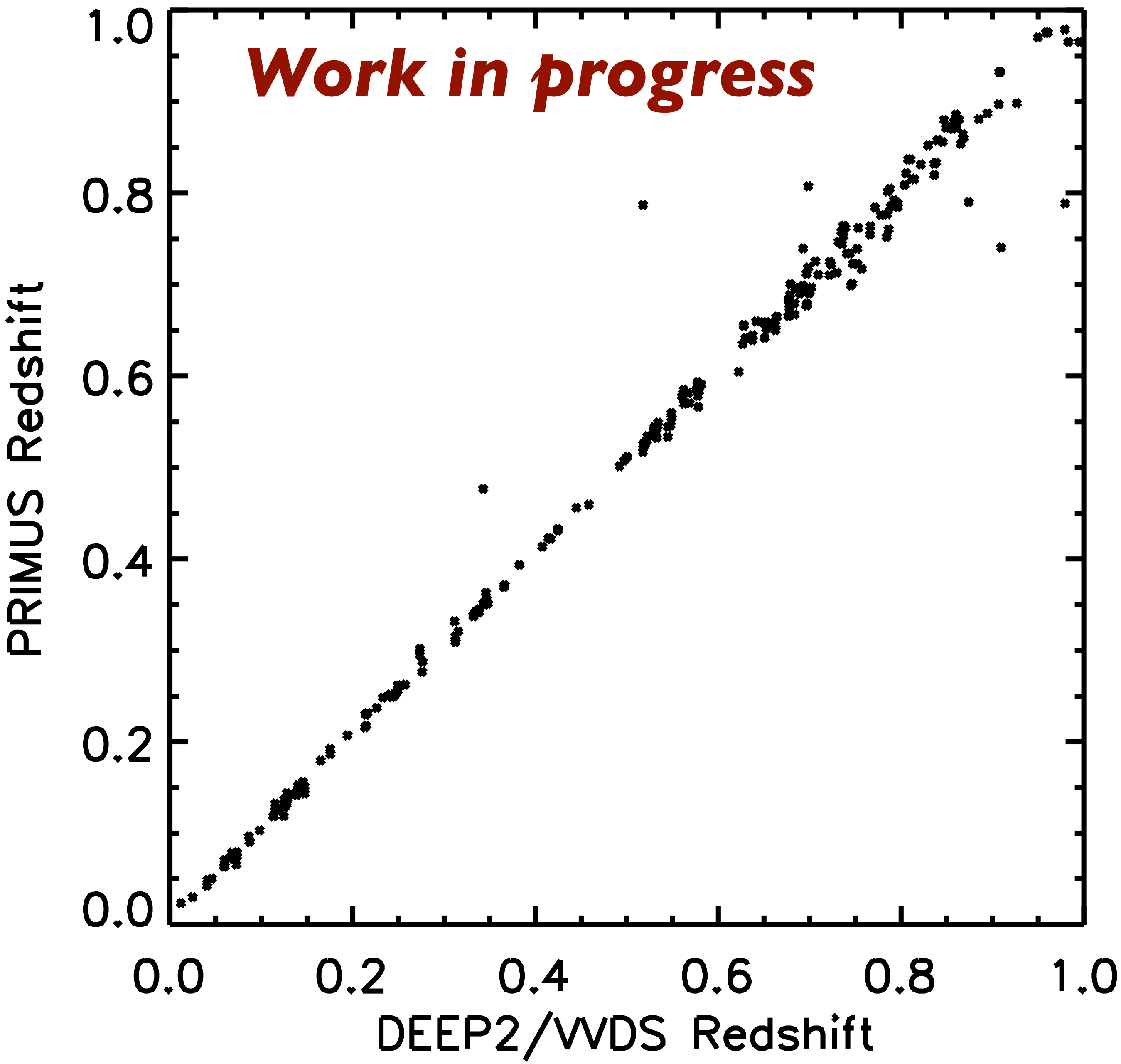
z = 0.6 Galaxy
M star
z = 0.48 Galaxy
Fλ (arb)
Wavlength (Å)
5000
6000
7000
8000
9000

Observations to be Completed in January

All data reduced with completely home-grown reduction package

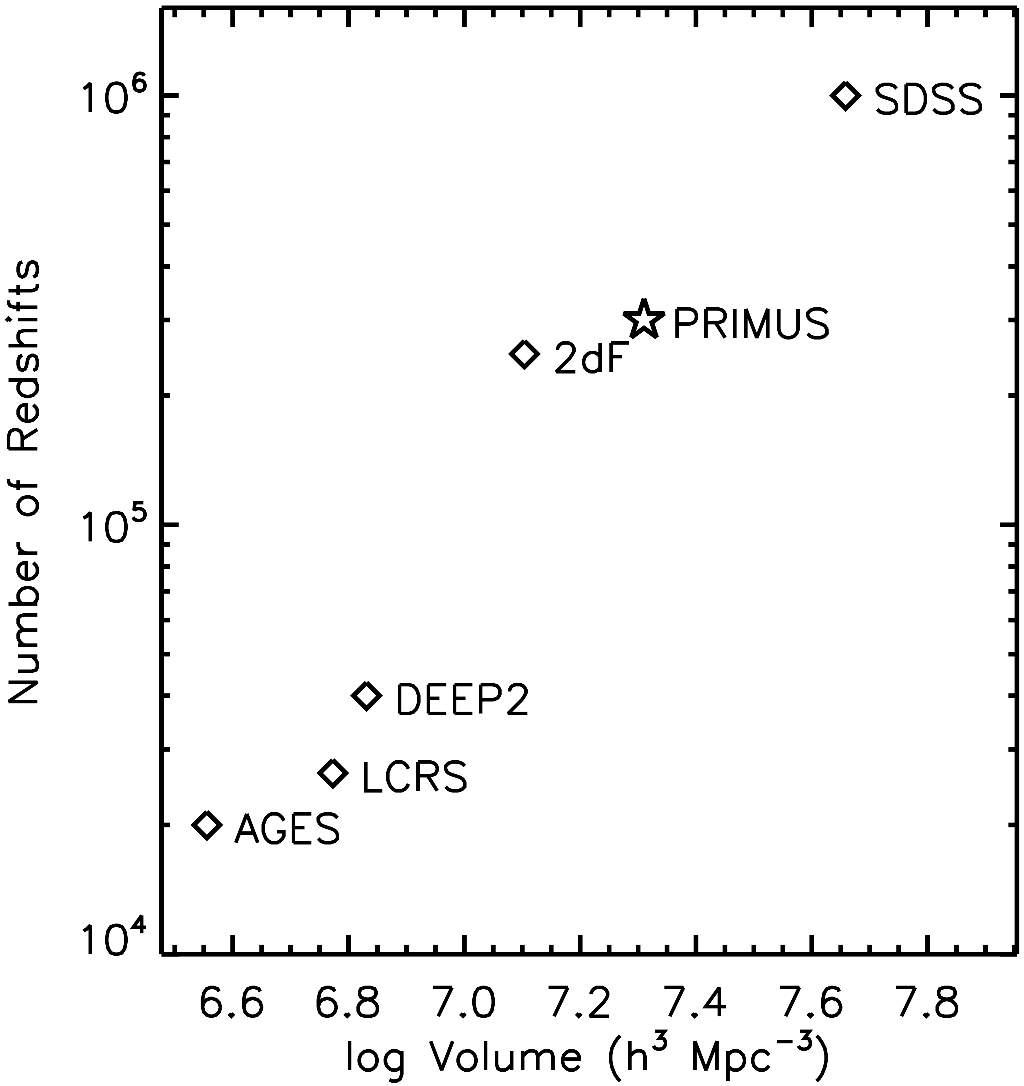
Currently obtain 1-1.5% redshifts with < 5% significant outliers

Several improvements to extractions and fitting will decrease outlier rate



- Primus surveys a uniquely large volume at intermediate redshifts with enough galaxies to subdivide by galaxy properties (galaxy type, environment, and stellar mass)
- We survey *all* galaxies (not just red or blue galaxies) and perform equally well for both

Probe factor of five more volume and and order of magnitude more redshifts than DEEP2



Comparable volumes to SDSS at z=0.1

Full Data Release Planned for Summer 2010

- Key Science goals

  - Provide a training set for photometric redshift codes at 0.2<z<1.0 - vital for future cosmological projects relying on photometric redshifts (Pan-STARRS, LSST, Dark Energy Survey)

  - Measure the co-evolution of stellar mass and star formation to understand the relative importance in situ star formation and growth through merging

  - Directly test AGN formation and evolutionary models by measuring the clustering strength of X-ray, IR, and optically selected AGNs

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