Massive Galaxies, the Mean SED, and the Stellar Mass Density at z<3

Gregory Rudnick (NOAO, Tucson)

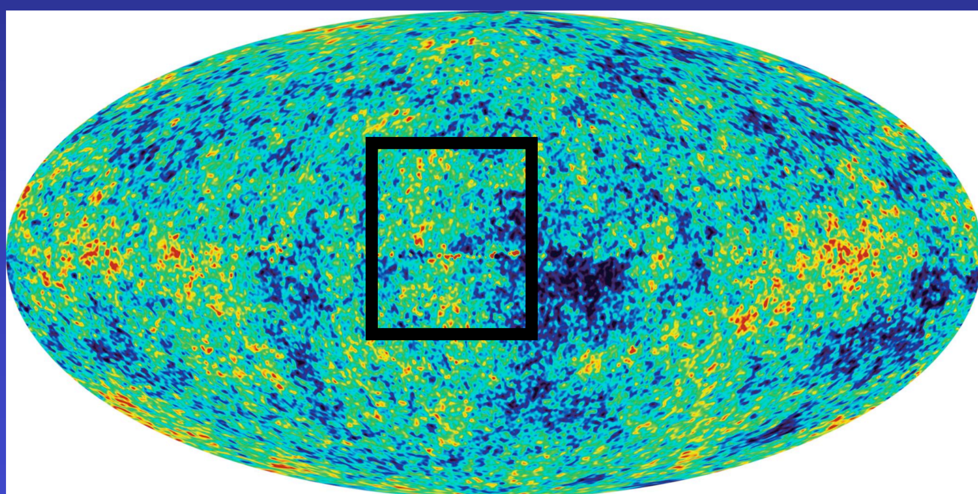
- Introduction
- Characteristics of massive high redshift galaxies
- Mean properties of luminous galaxies
- Evolution in stellar mass density

National Optical Astronomy Observatory

Science Questions

- What is the evolution in the stellar populations of galaxies as an ensemble?
- How did stellar mass in galaxies accumulate over time?
- At each redshift, what kind of galaxies dominated the stellar mass density?

How do Galaxies Grow?



- The initial conditions are well known.
- The dark matter paradigm is well developed.
- The growth of DM halos can be traced via simulations.

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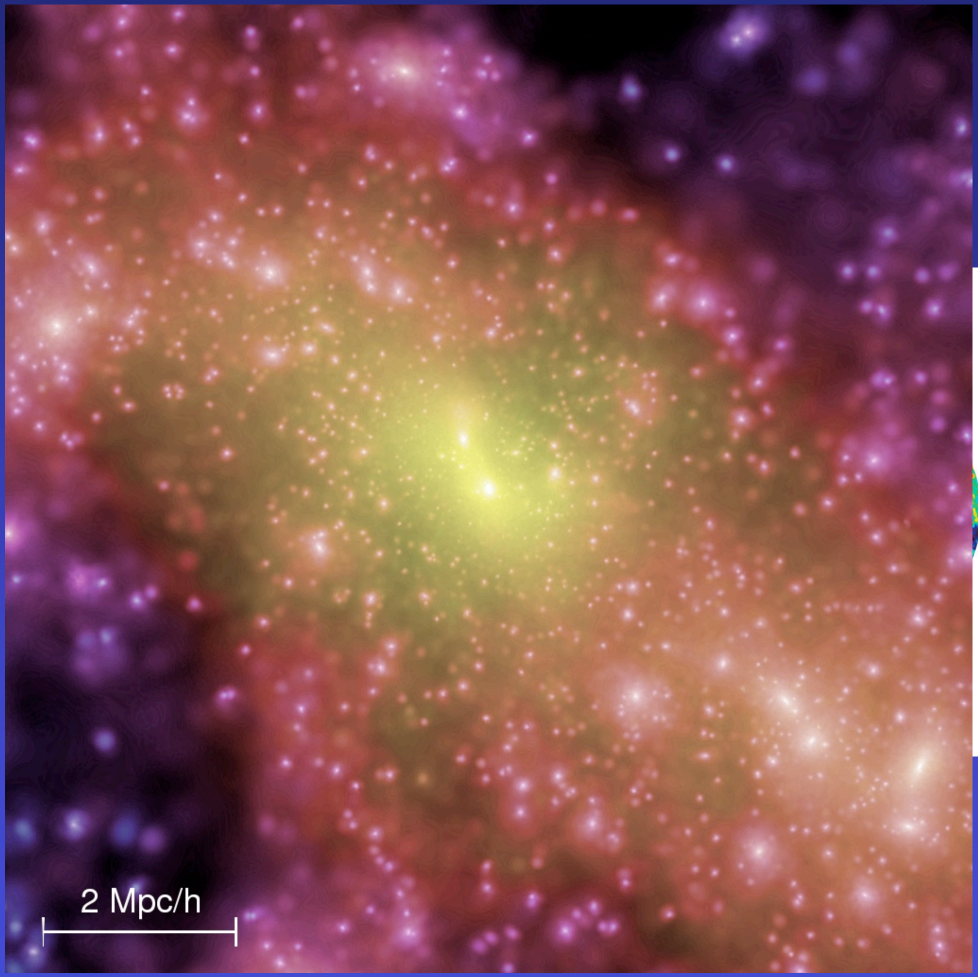

simulation by volker springel

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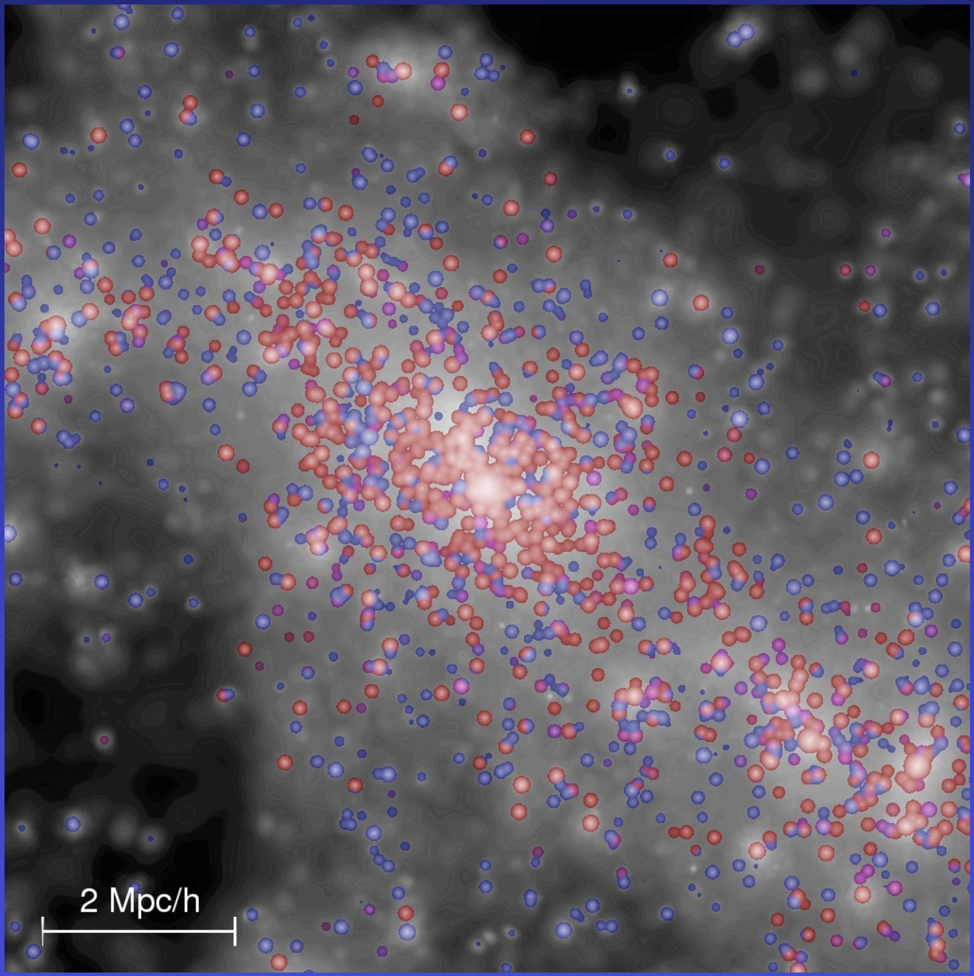
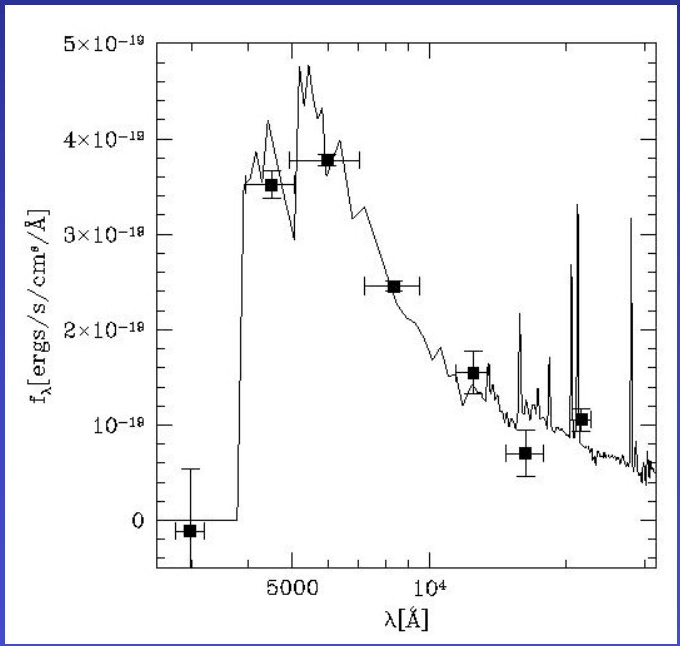


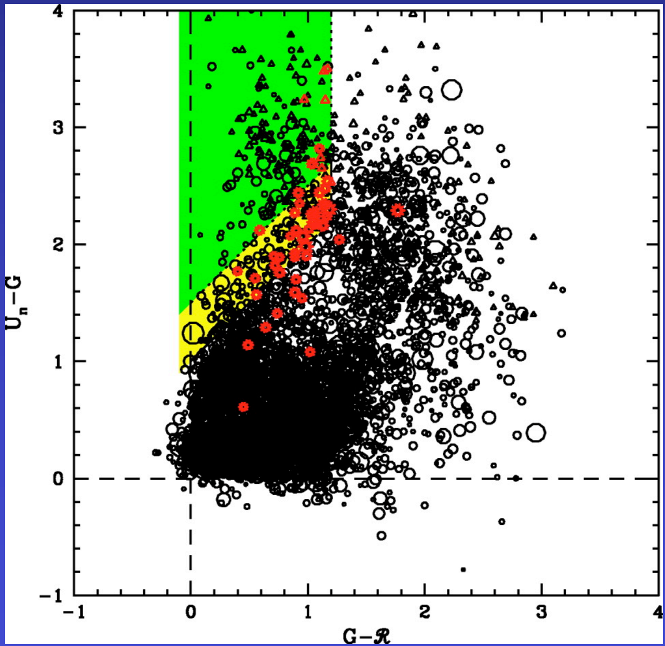
- The initial conditions are well known.
- The dark matter paradigm is well developed.
- The growth of DM halos can be traced via simulations.
- Add baryonic (gastrophysics) physics to DM simulation, e.g.:
- star formation, cooling, feedback from SF, feedback from an AGN
- From DM to observables!!
- But, physics are very uncertain and observational constraints are crucial

Finding high redshift galaxies

•Historically selected in the optical => redshifted rest-frame UV

(e.g. Steidel et al. 1996, Madau et al. 1996)



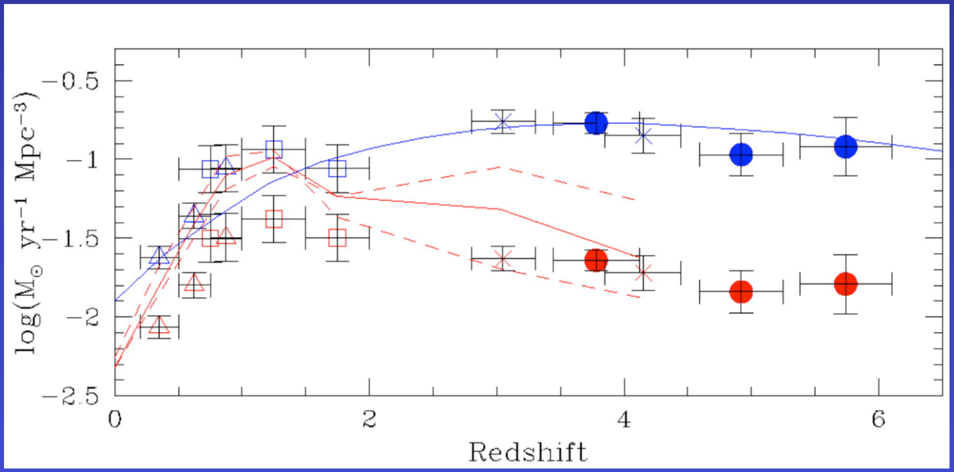


steidel et al. (2003)

•UV selected galaxies are relatively unobscured and vigorously star-forming

Observing the buildup of stellar mass

- One method is to measure the SFR(z)
- Select galaxies in UV and convert UV light to SFR
  - assume IMF + dust



Giavalisco et al. 2004

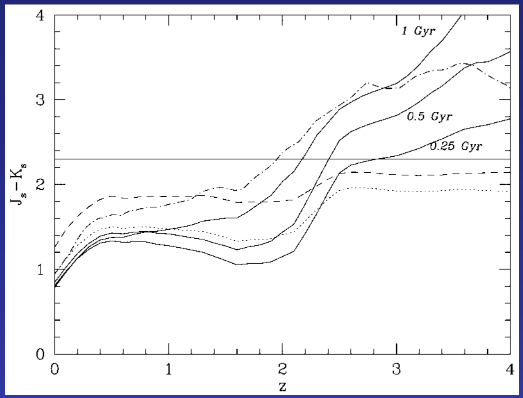
- Dust extinction is important, but uncertain
- Misses contribution from heavily obscured galaxies, e.g. Sub-mm galaxies

An Alternative: Tracing the Stellar Mass Build-up Directly

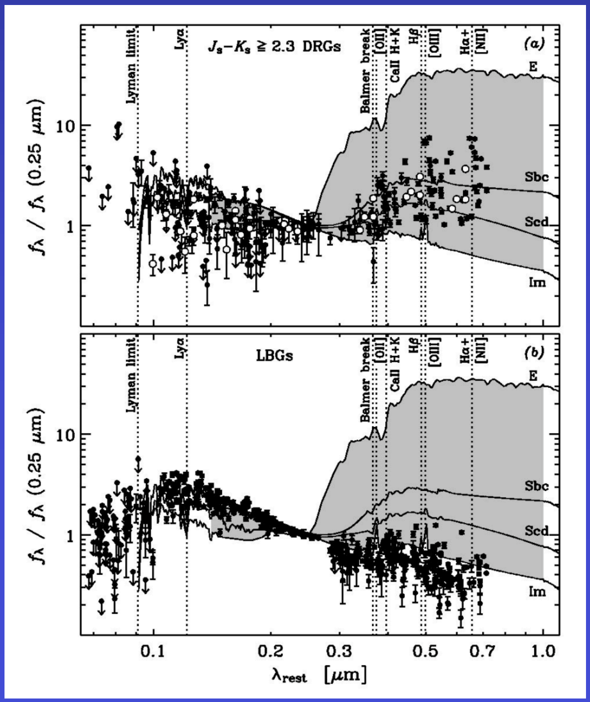
- Need observations in rest-frame optical/NIR
- Measures "older" light
- More sensitive to lower mass stars
    - less IMF dependence
- Less affected by extinction
    - Must observe in near-IR/MIR

What have deep NIR surveys told us about the galaxy population at high redshift?

NIR selected Distant Red Galaxies (DRGs)



Franx et al. (2003)

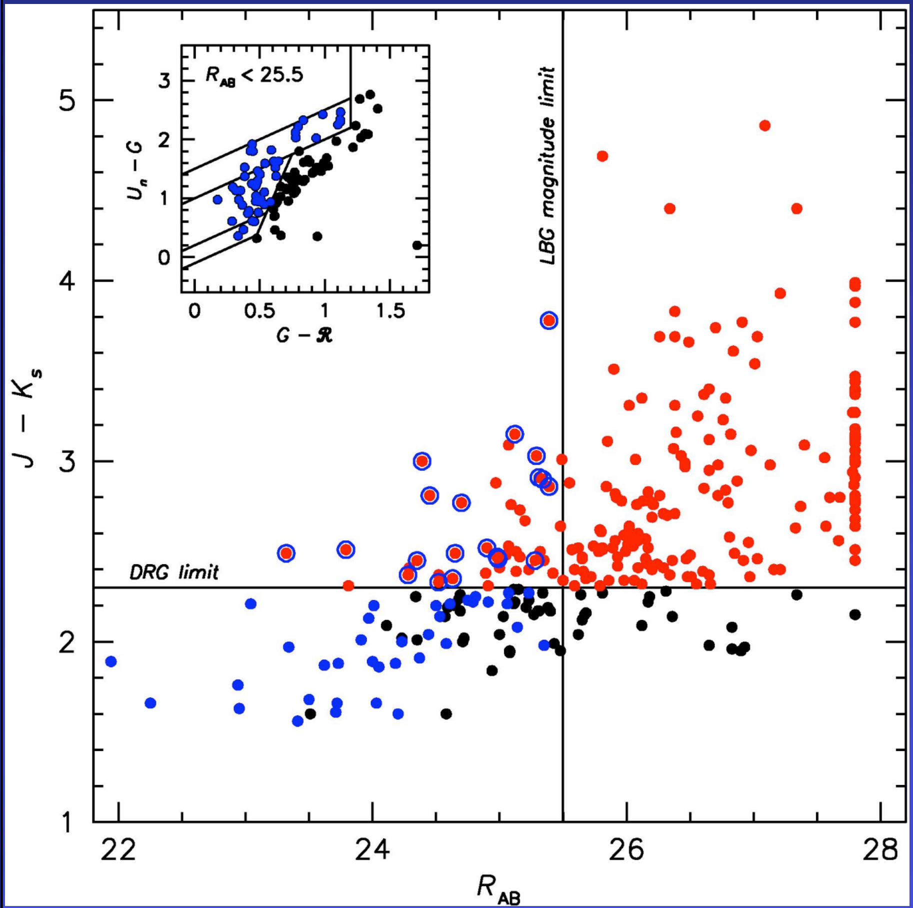


Discovered by Faint InfraRed Extragalactic Survey (FIRES)
GR
Ivo Labbè, OCIW, Pasadena
Natascha Förster Schreiber, MPE, Garching
Marijn Franx, Leiden
Pieter van Dokkum, Yale
Hans-Walter Rix, Heidelberg

- Lyman Break Galaxies don't have colors of normal galaxies
- DRGs have colors of local galaxies and have large rest-frame optical breaks

Förster Schreiber et al. (2004)

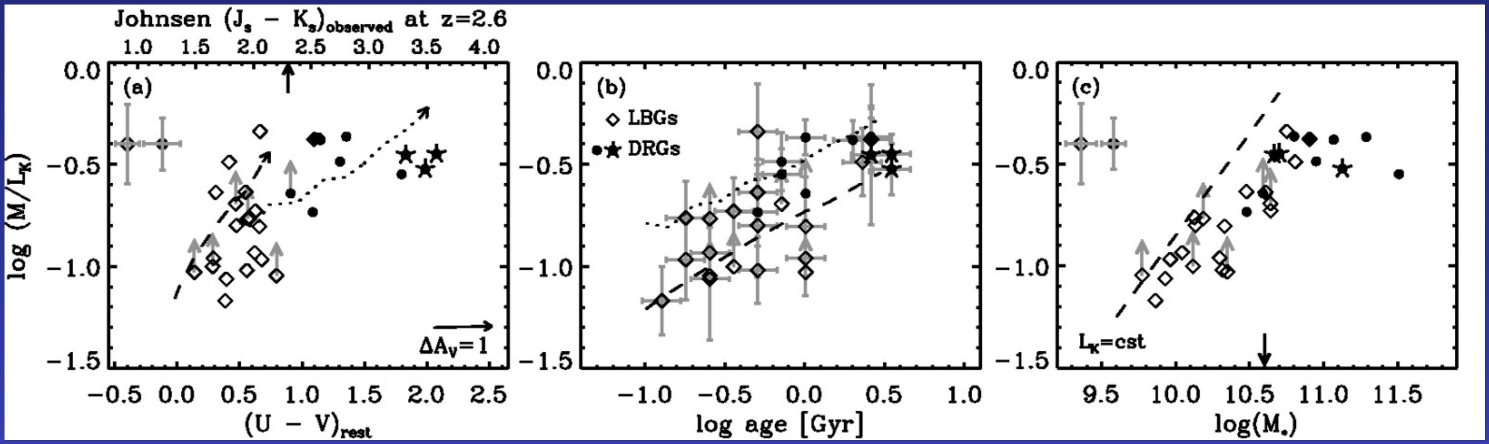
The most common massive galaxy at 2<z<3



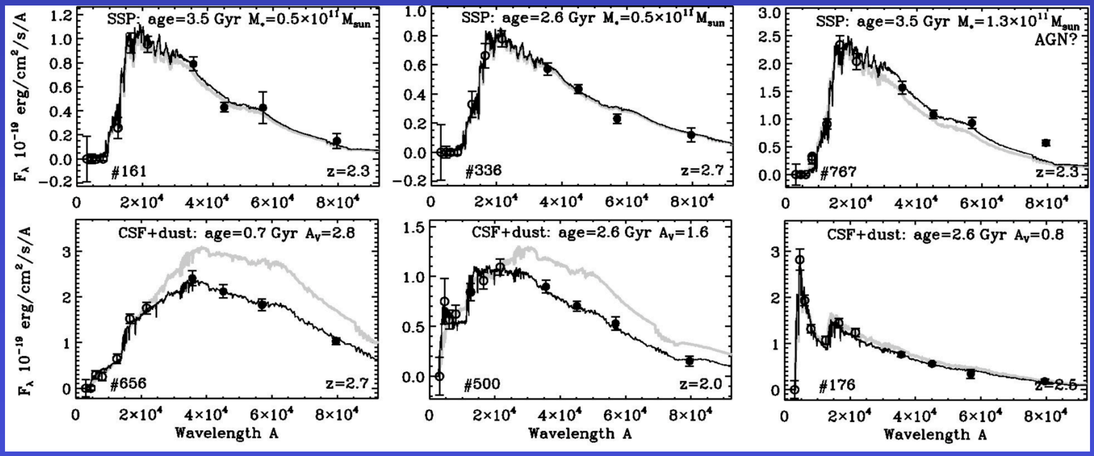
van Dokkum et al. (2006)

- $M > 10^{11} M_{solar}$ (Salpeter IMF)
- Complementary to UV selected samples
    - only 10% overlap with UV-selected samples (e.g. Reddy et al. 2005)
    - too faint in optical

Detailed Characteristics

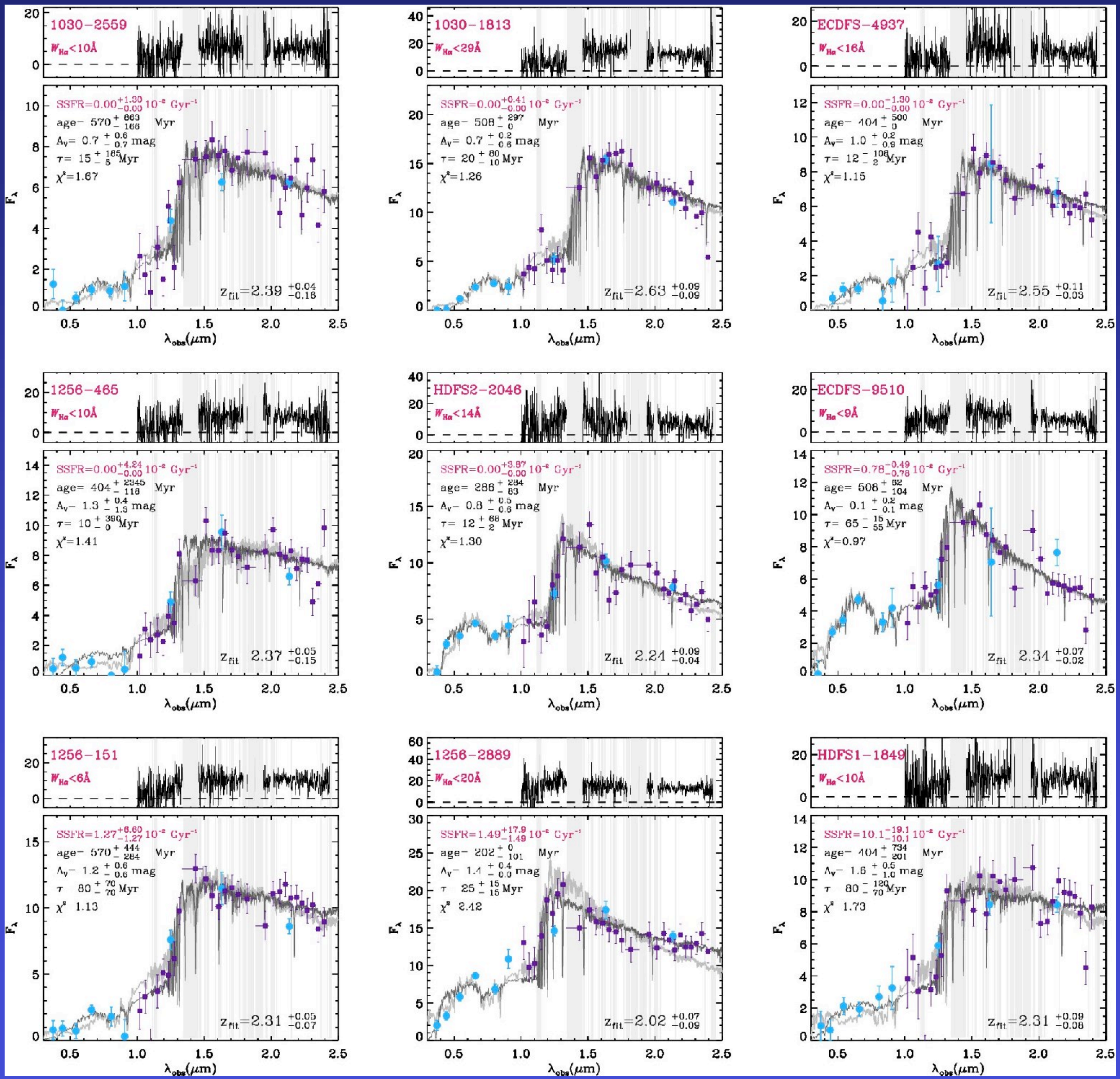


Labbé et al. (2005)

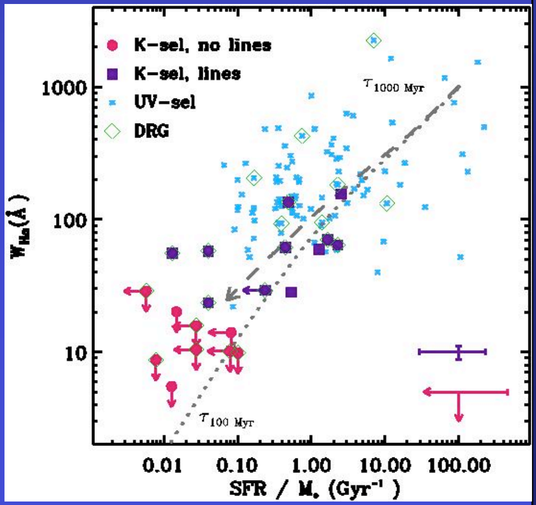


- More massive and older than UV-selected galaxies
- Some are consistent with being quiescent
  - confirmed by NIR spectroscopy (Kriek et al. 2006)

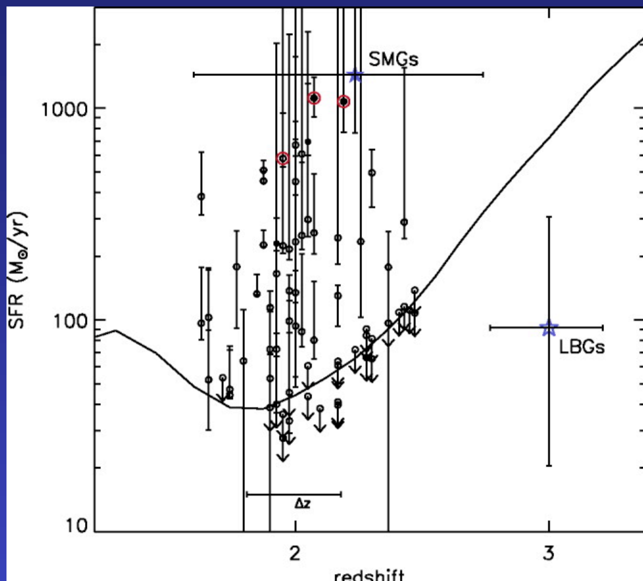
Queiscent Massive Galaxies



9 out of 20 K<19.7 galaxies at z~1 are quiescent.



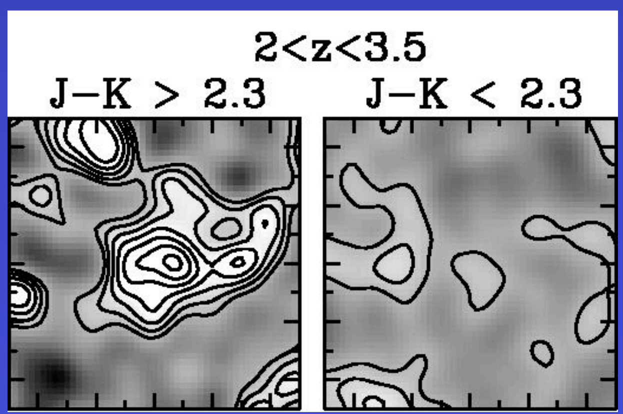
Massive Star Forming Galaxies



Webb et al. (2006)

Many DRGs have a high SFR

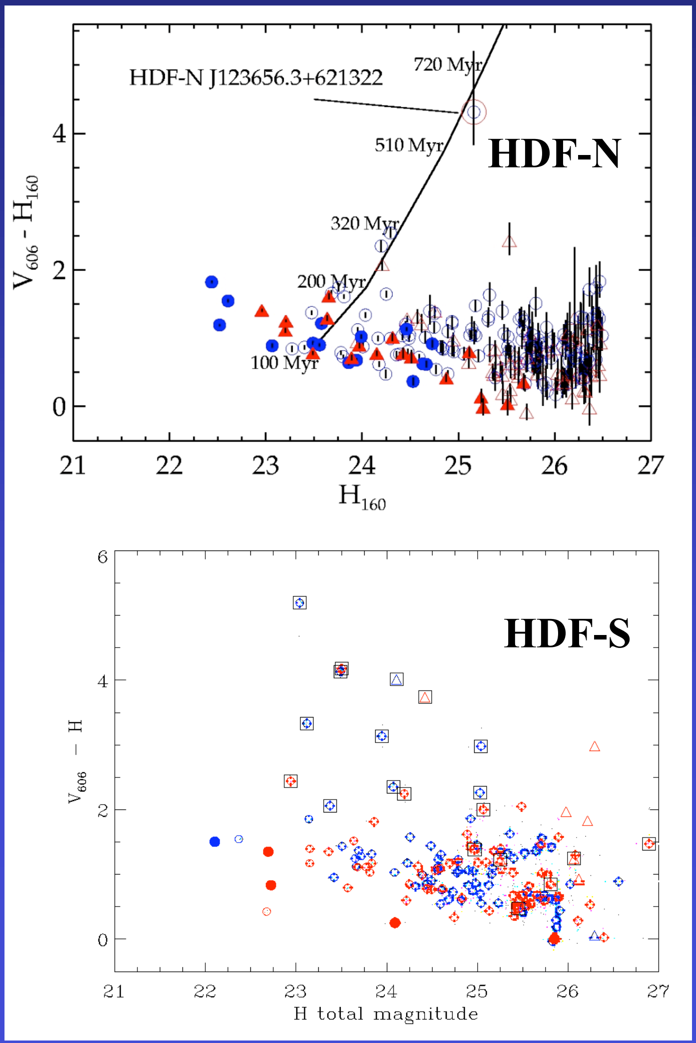
<~25% contamination from AGN (Papovich et al. 2006)



Knudsen et al. (2005)

More star formation than non-DRGS

Field-to-field Variance



Cosmic variance in this population is large.

- GOODS-S is underdense by ~2 in number of massive z~2 galaxies

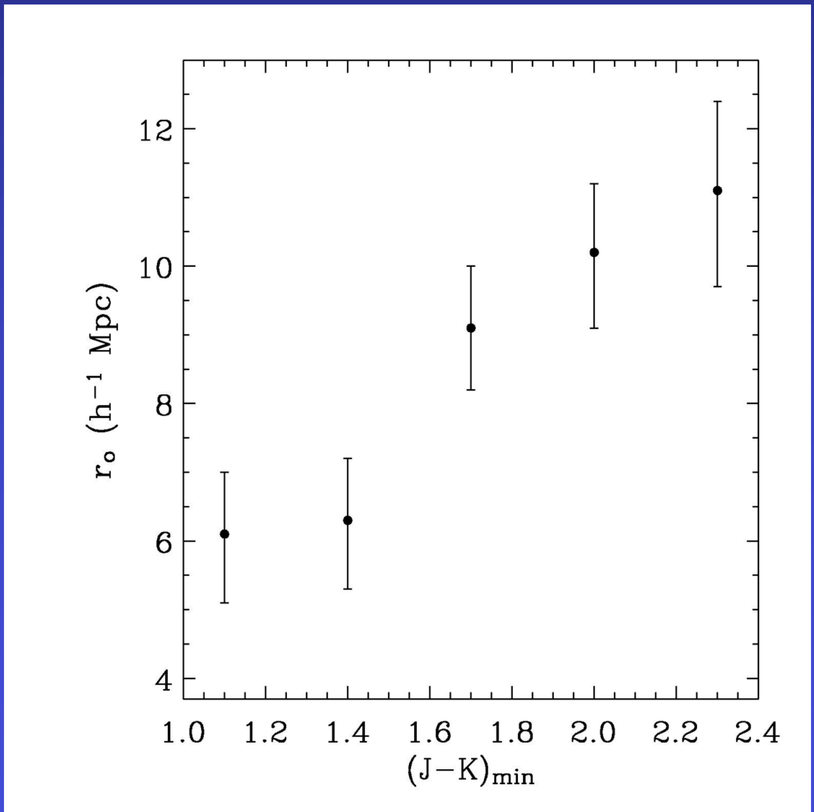
Multiple fields needed to measure their contribution to the mass density.

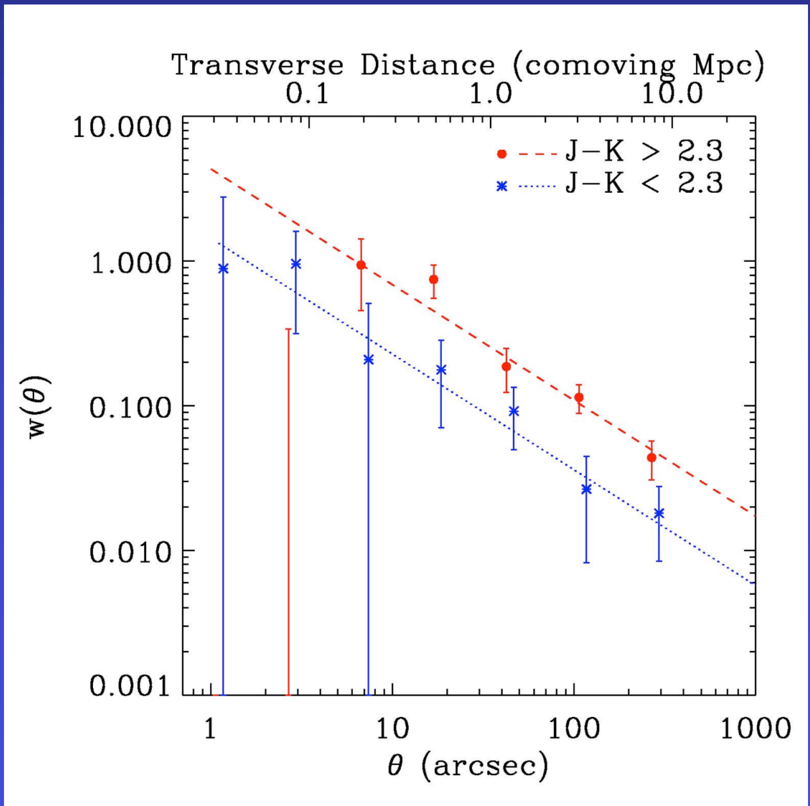
Labbé et al. (2003)

Clustering

Measured over 300 square arcminutes from MUSYC survey

DRGs are strongly clustered (Quadri et al. 2006)

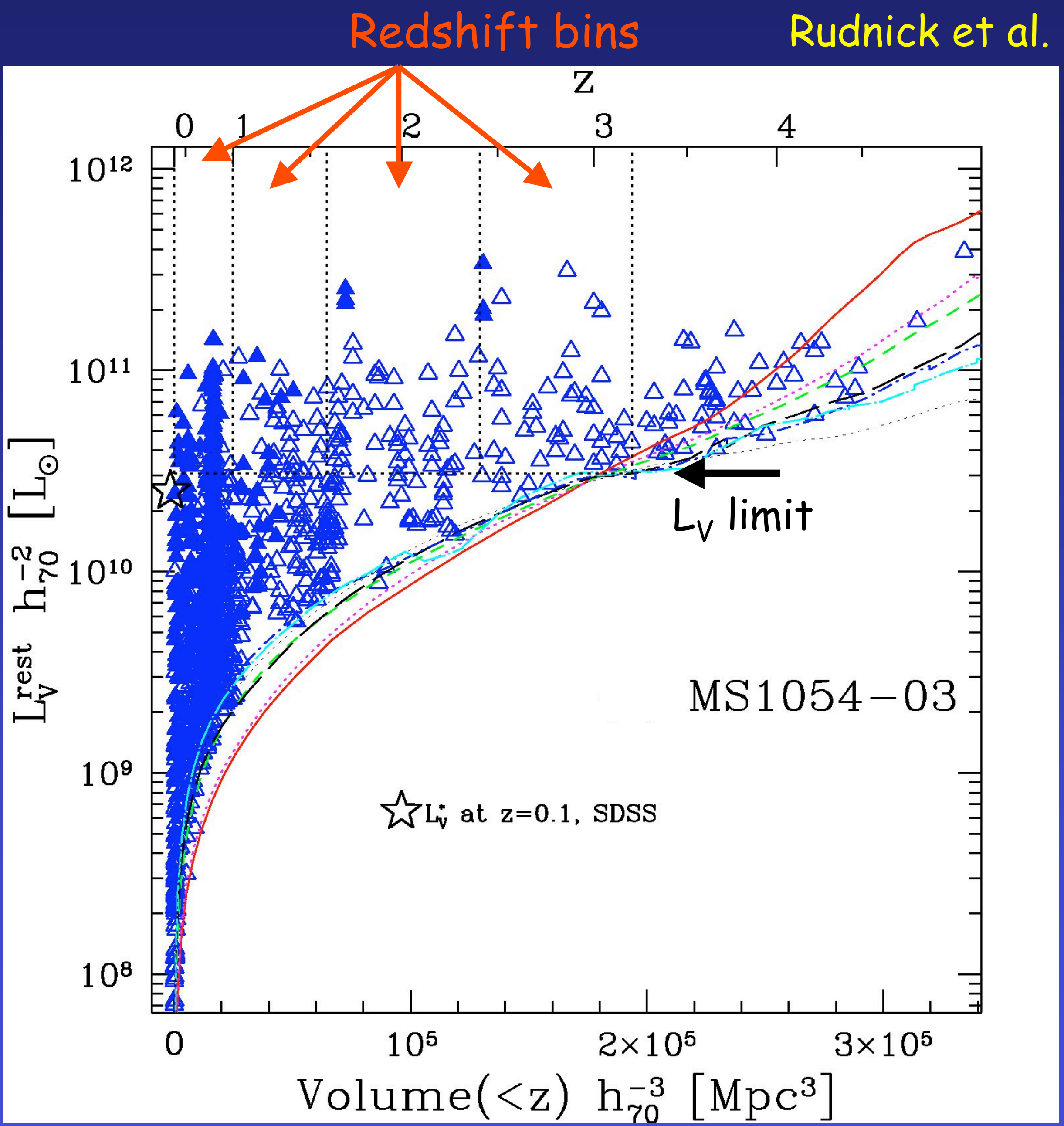




How to address Science Questions

- A comprehensive census of all stars
  - color selection is biased
- Control field-to-field variance
- Emphasize consistent comparison to theory

Rudnick et al. ApJ, in press



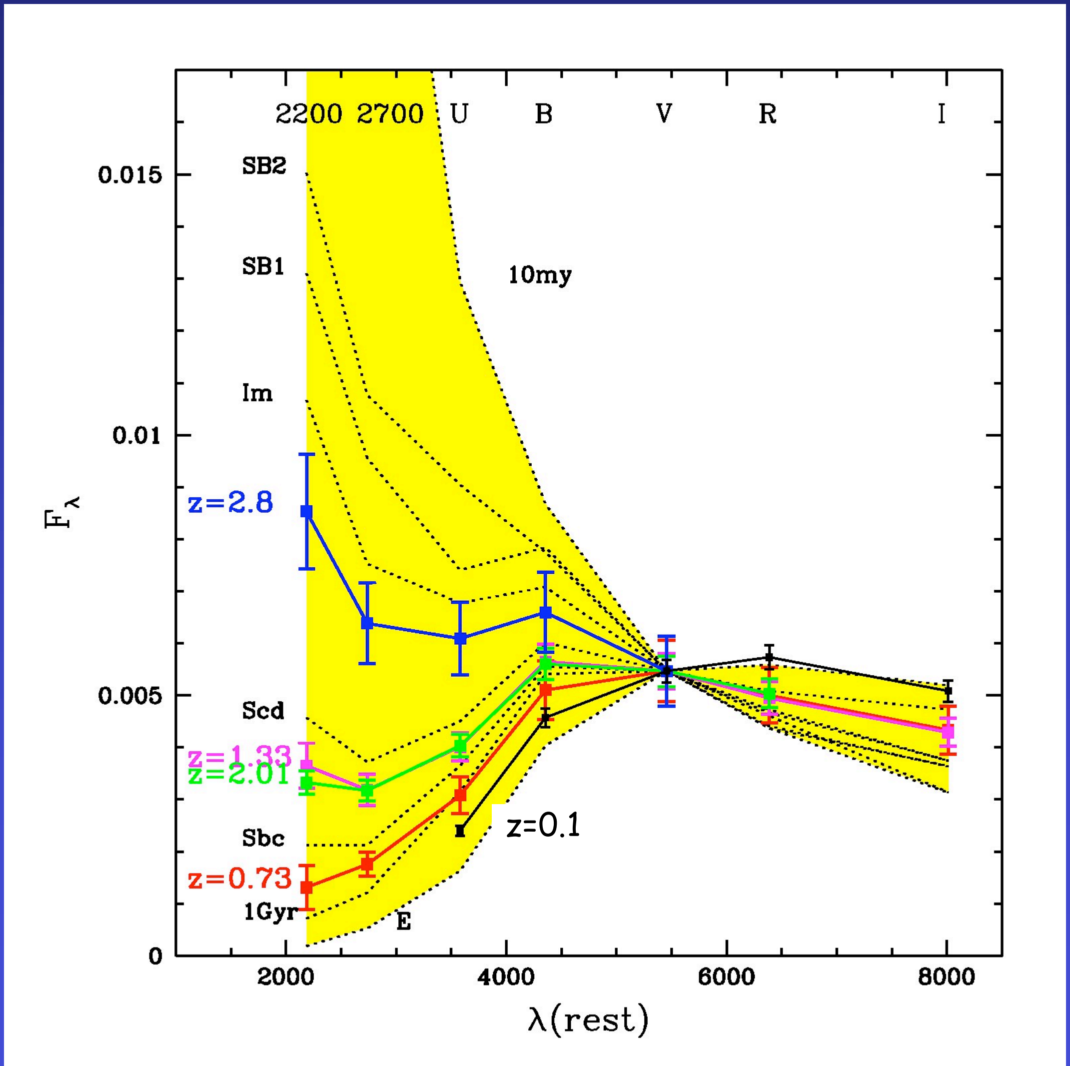
astro-ph/0606536

4 fields with deep Optical/NIR data

HDF-S
MS1054-03
GOODS-S
HDF-N

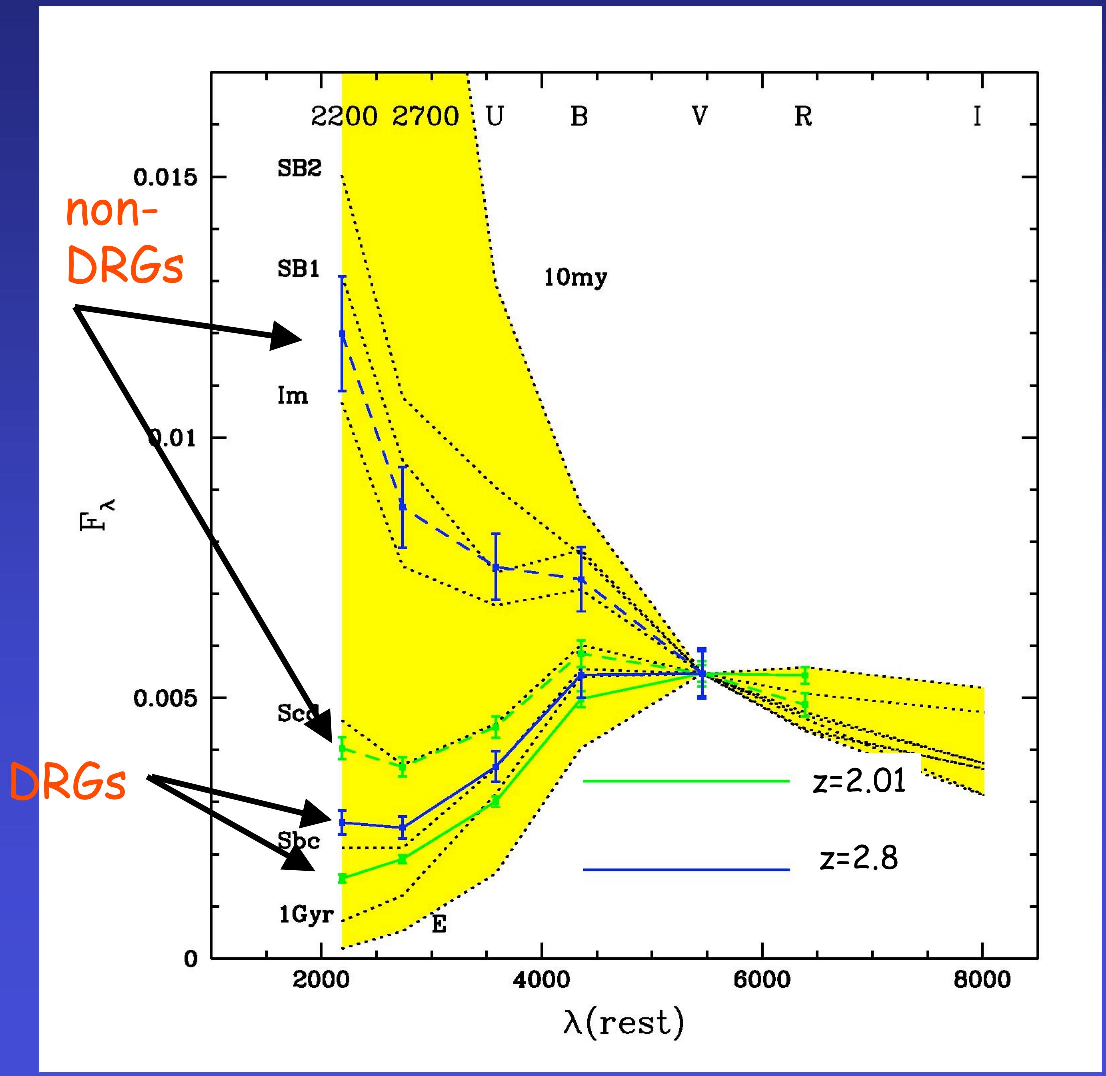
Calculate luminosity density in complete region

Volume Averaged rest-frame SED of Luminous Galaxies



Color of the Universe is consistent with morphologically normal nearby galaxies

Volume Averaged rest-frame SED of Luminous Galaxies

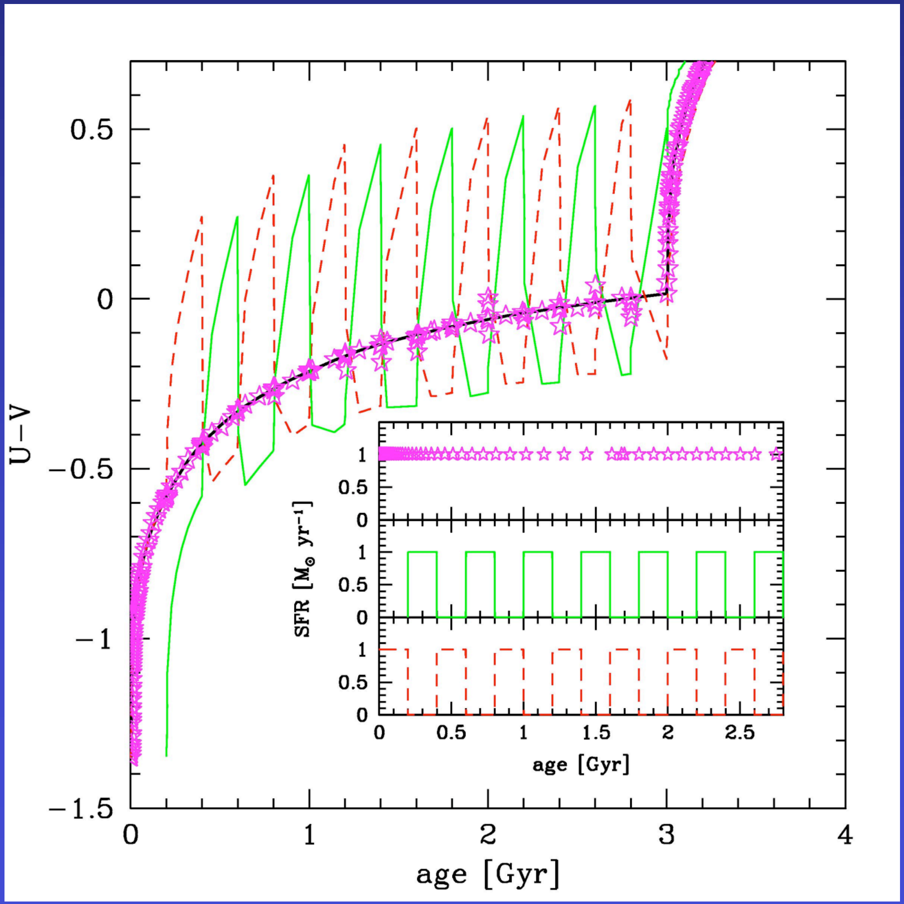


Color of the Universe is consistent with morphologically normal nearby galaxies

Split by J-K color

DRGs are redder at all wavelengths

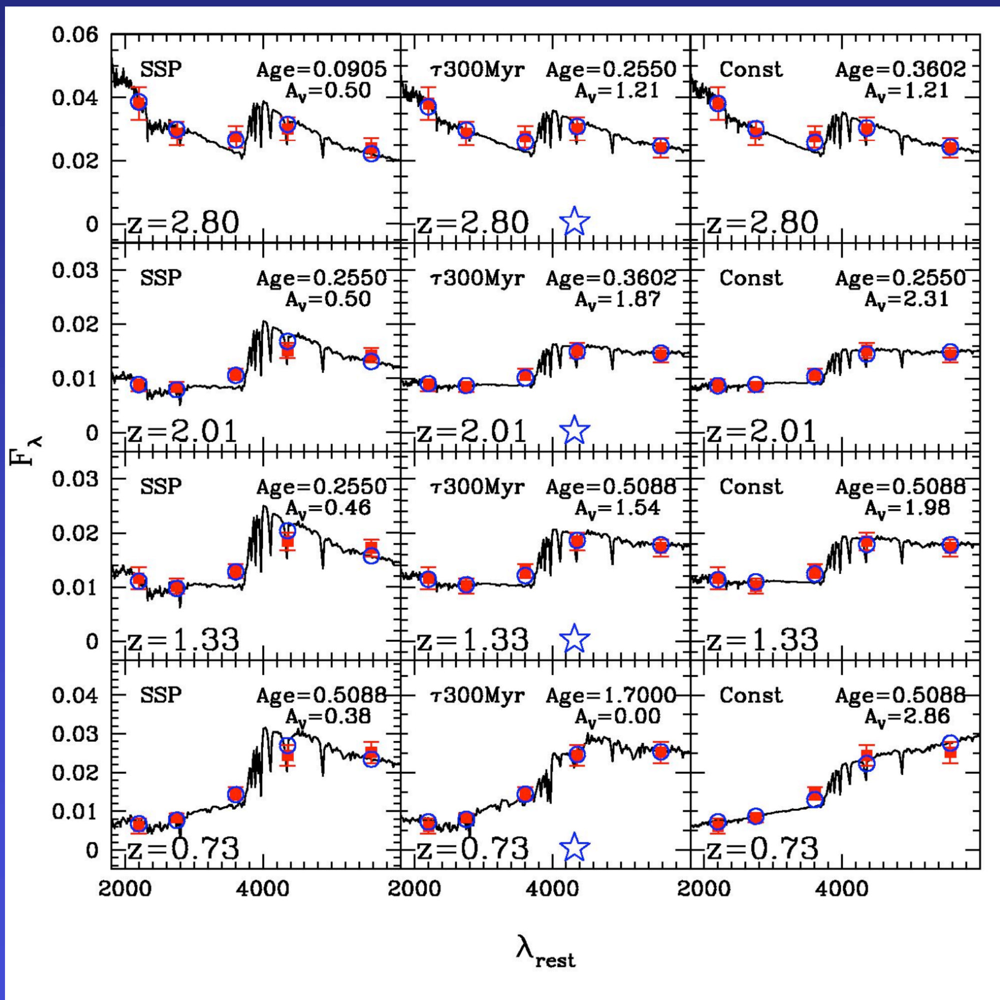
The benefits of averaging



Modeling the Mean SED

SSP τ=300Myr CSF

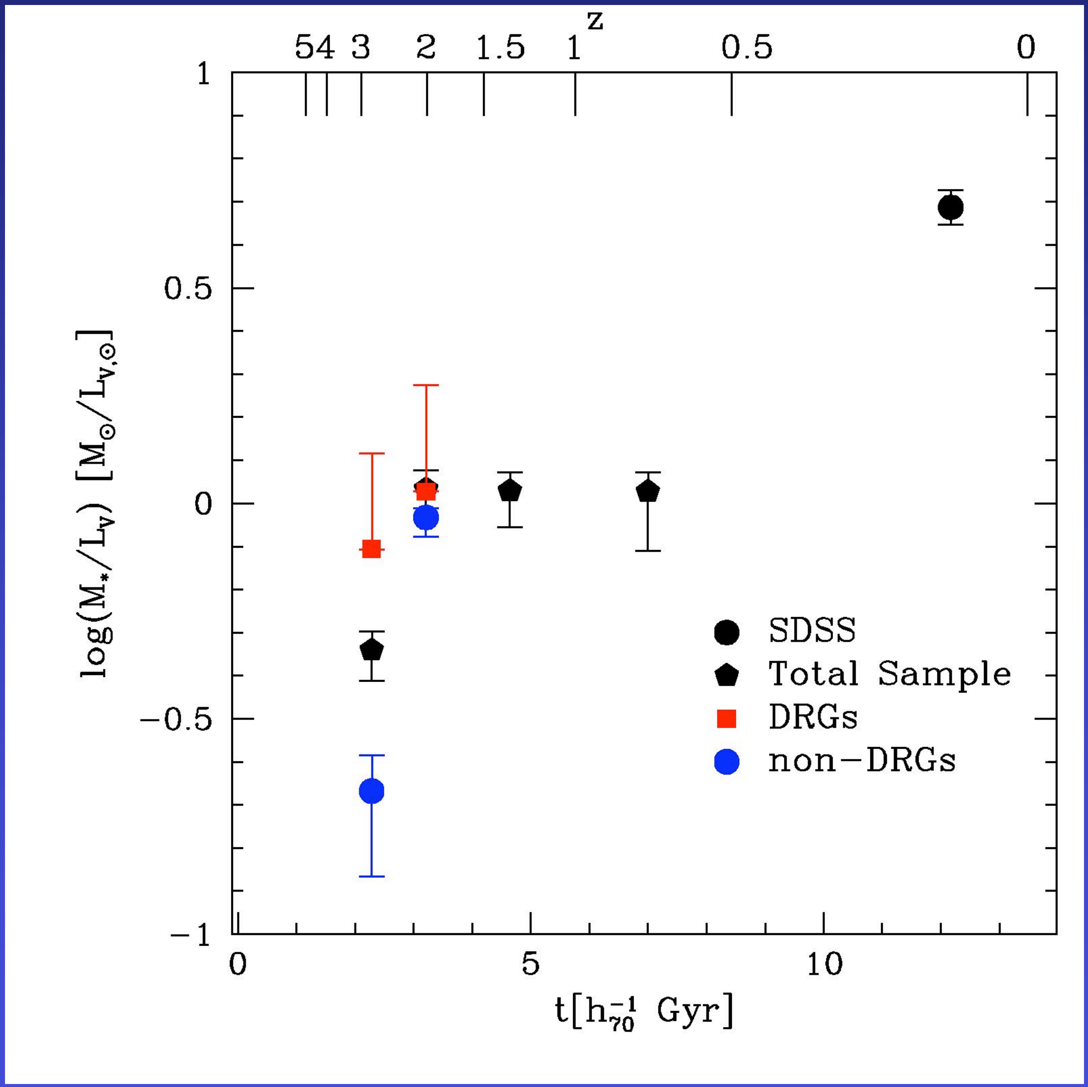
redshift



Mean SED is well fit by simple models at all redshifts

Strength of Breaks increasing with decreasing redshift

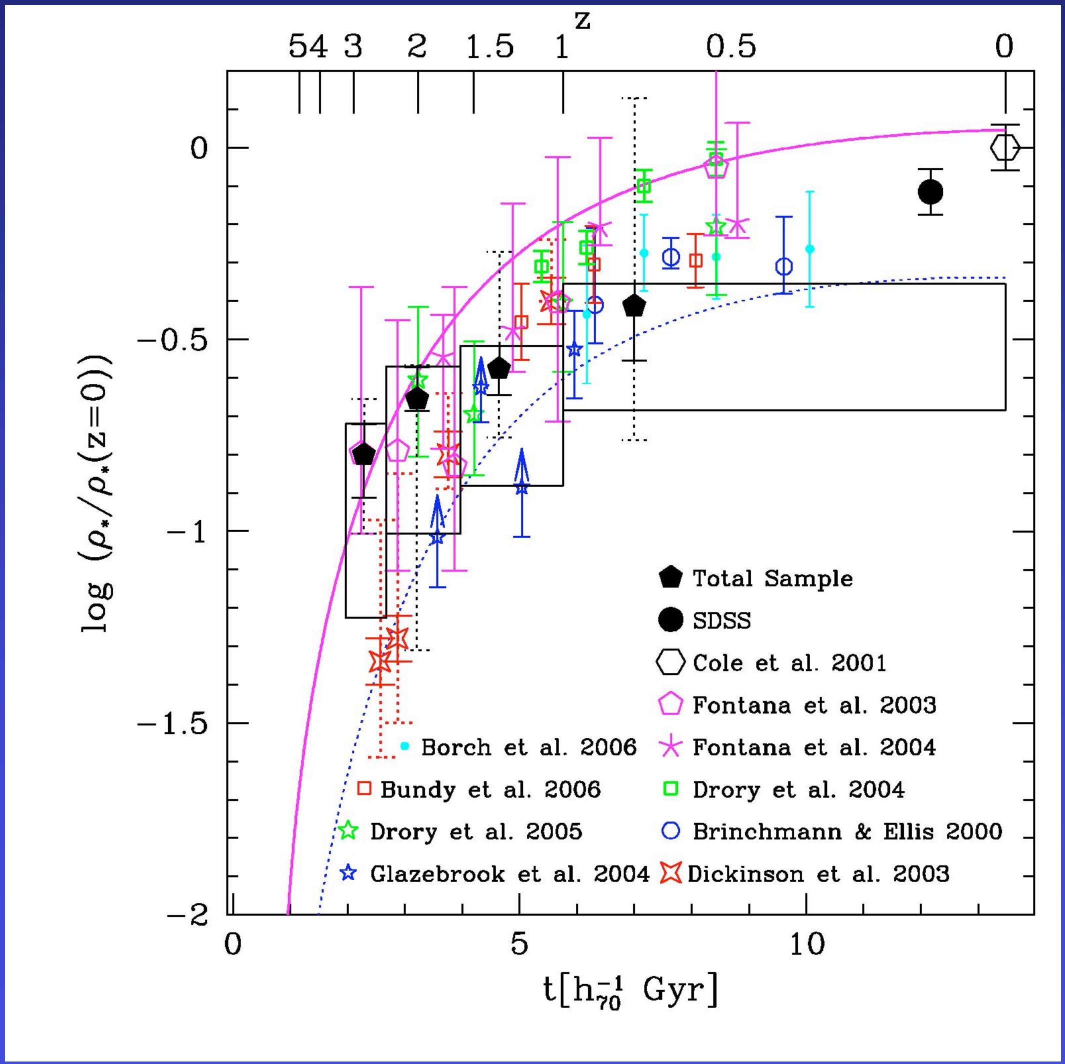
Evolution in $\langle M/L_V \rangle$



$\langle M/L_V \rangle$ declines by a factor of ~10

DRGs have higher M/L than non-DRGs

Observed ρ* Evolution

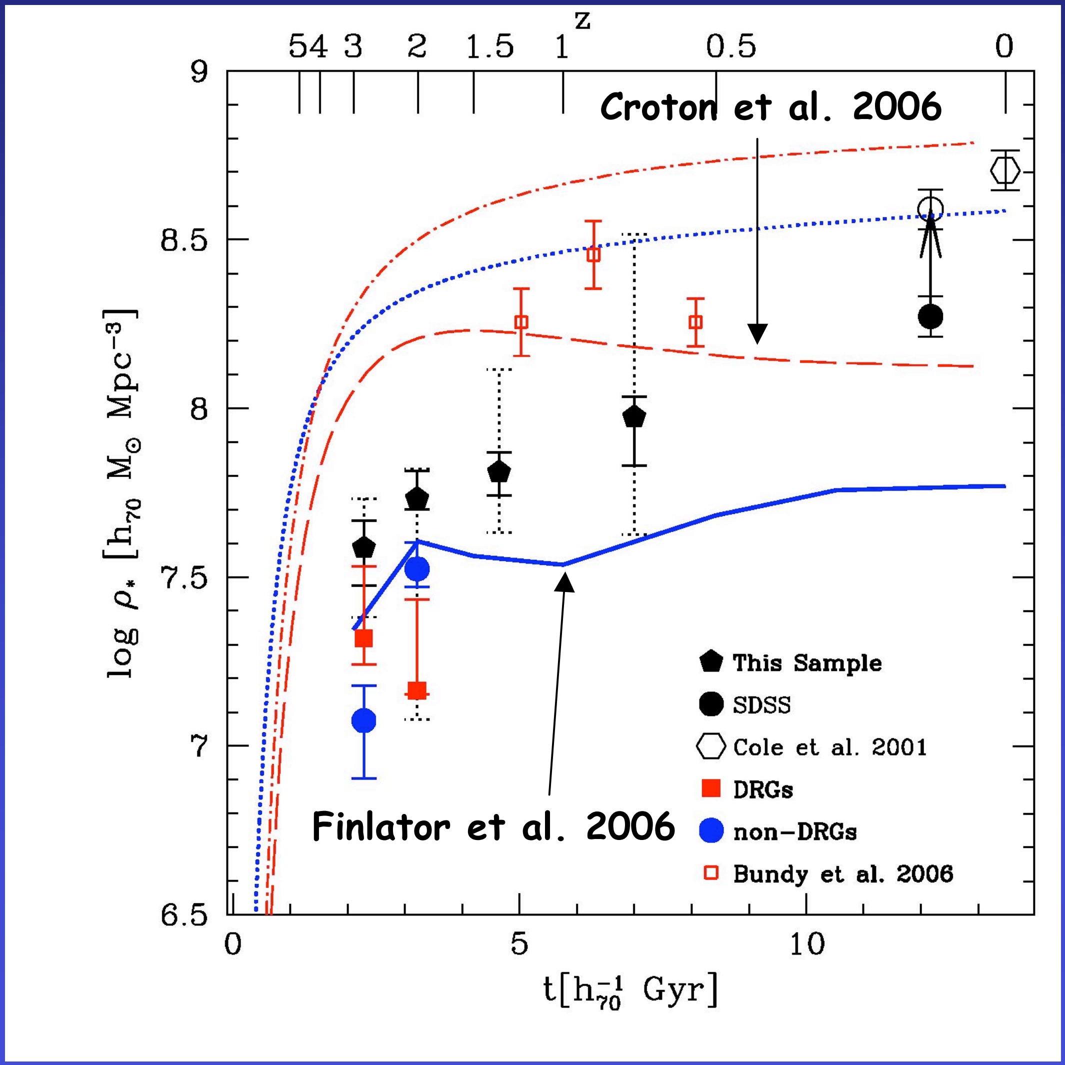


density increase by factor of ~4-10 from z=3 to 0

Still large field-to-field variations

rough agreement with integral of SFR(z) (from UV)

Comparison with Models



DRGs contribute significantly to stellar mass budget at 1.6<z<3

Perform consistent comparison with models

Model predictions are in poor agreement even when observational selection is applied

Conclusions

- Volume averaged SED evolves monotonically to redder colors from $z = 3$ to 0.
- Mean SED at all redshifts is consistent with morphologically normal local galaxies.
- Total mass density increases by ~4-10 from $z = 3$ to 0
- UV-selected samples miss ~50% of mass in luminous galaxies
- Consistently compared models fail to match observations.