The Past 8 Billion Years of Red Galaxy Growth

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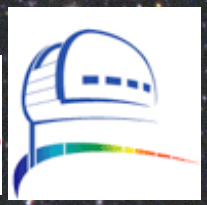
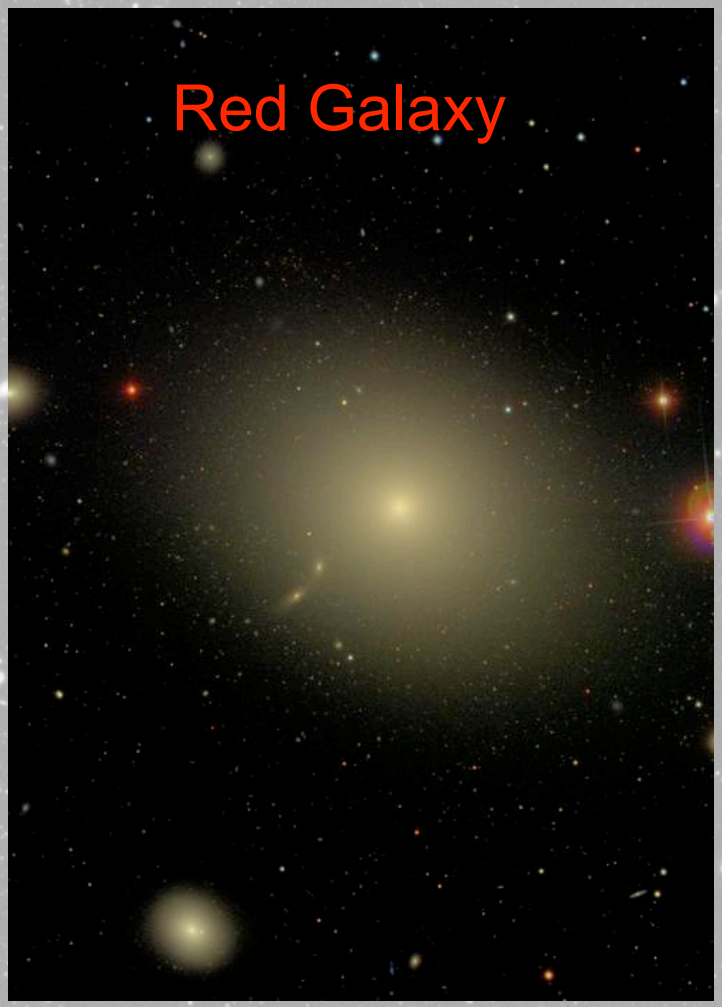
(Monash)

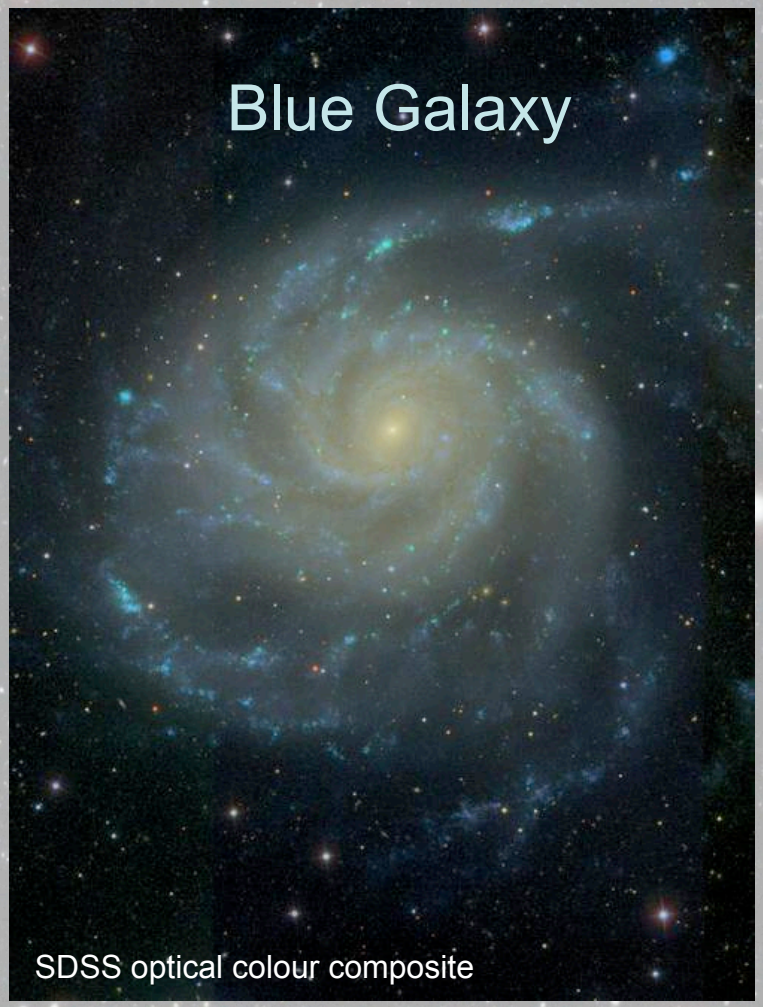
Zheng Zheng, Martin White, Buell Jannuzi, Arjun Dey, Kate Brand,
Mark Brodwin, Peter Eisenhardt, Andrew Benson, Darren Croton…

Katoomba, June 2008





Old stars
The most massive galaxies
Central black holes

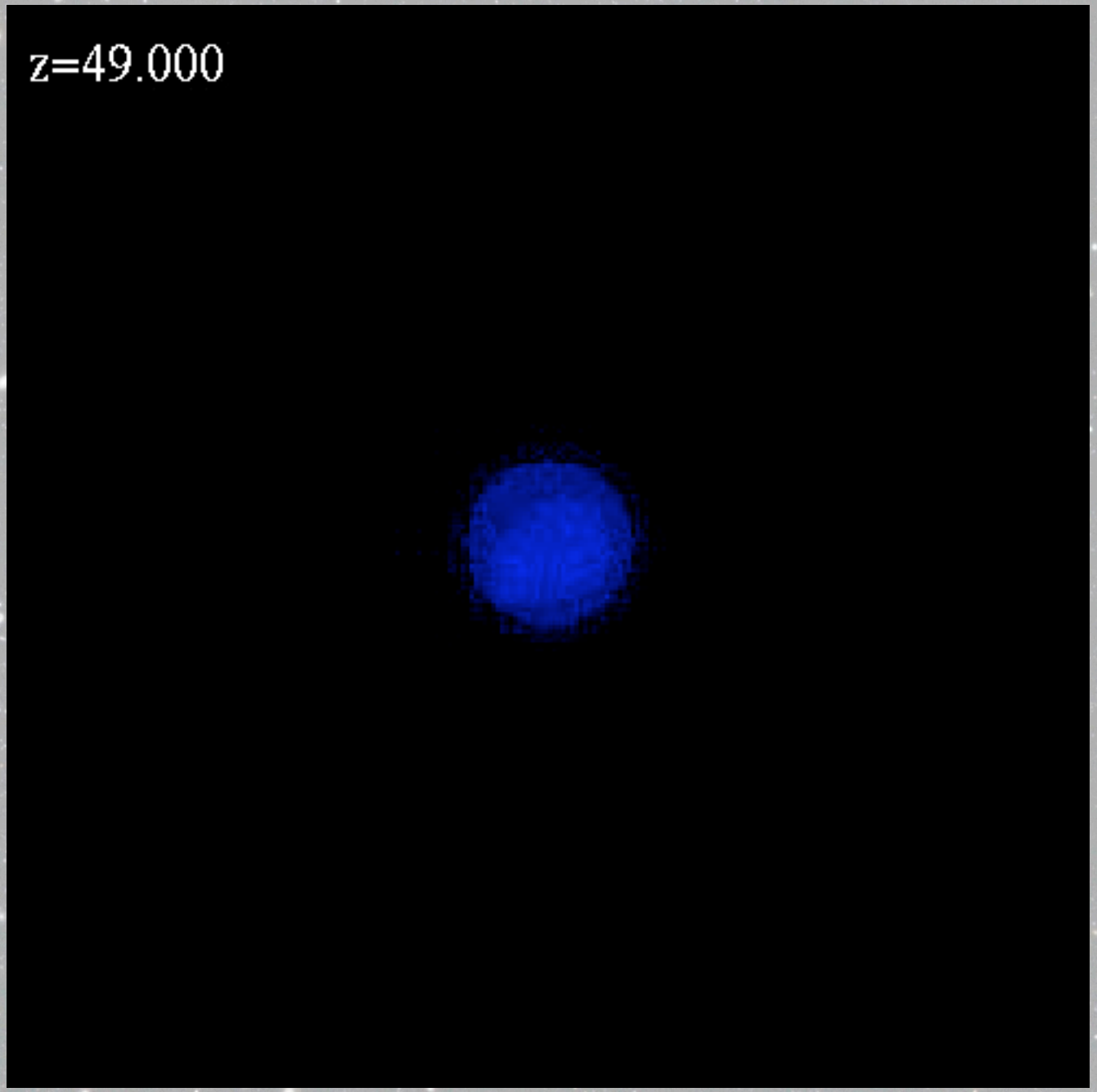


Still forming stars
Most numerous galaxies

Red Galaxies

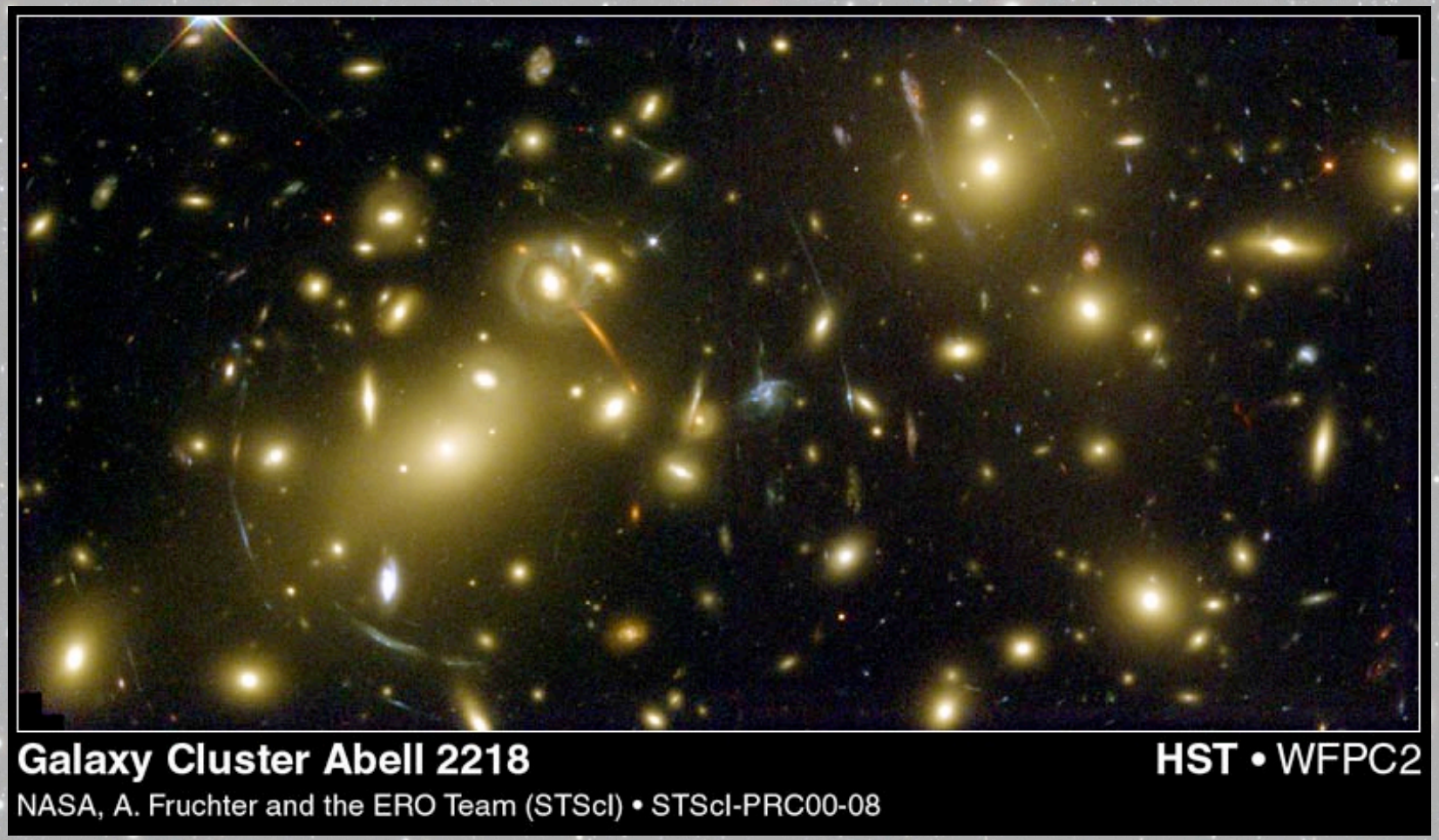
- Excellent for tests of galaxy formation models.
  - Contain ~50% of the stars at low redshift.
  - Include the most massive low redshift galaxies.
  - Little growth from recent star formation.
  - Low rates of star formation (AGN feedback?).

Image stolen from SDSS

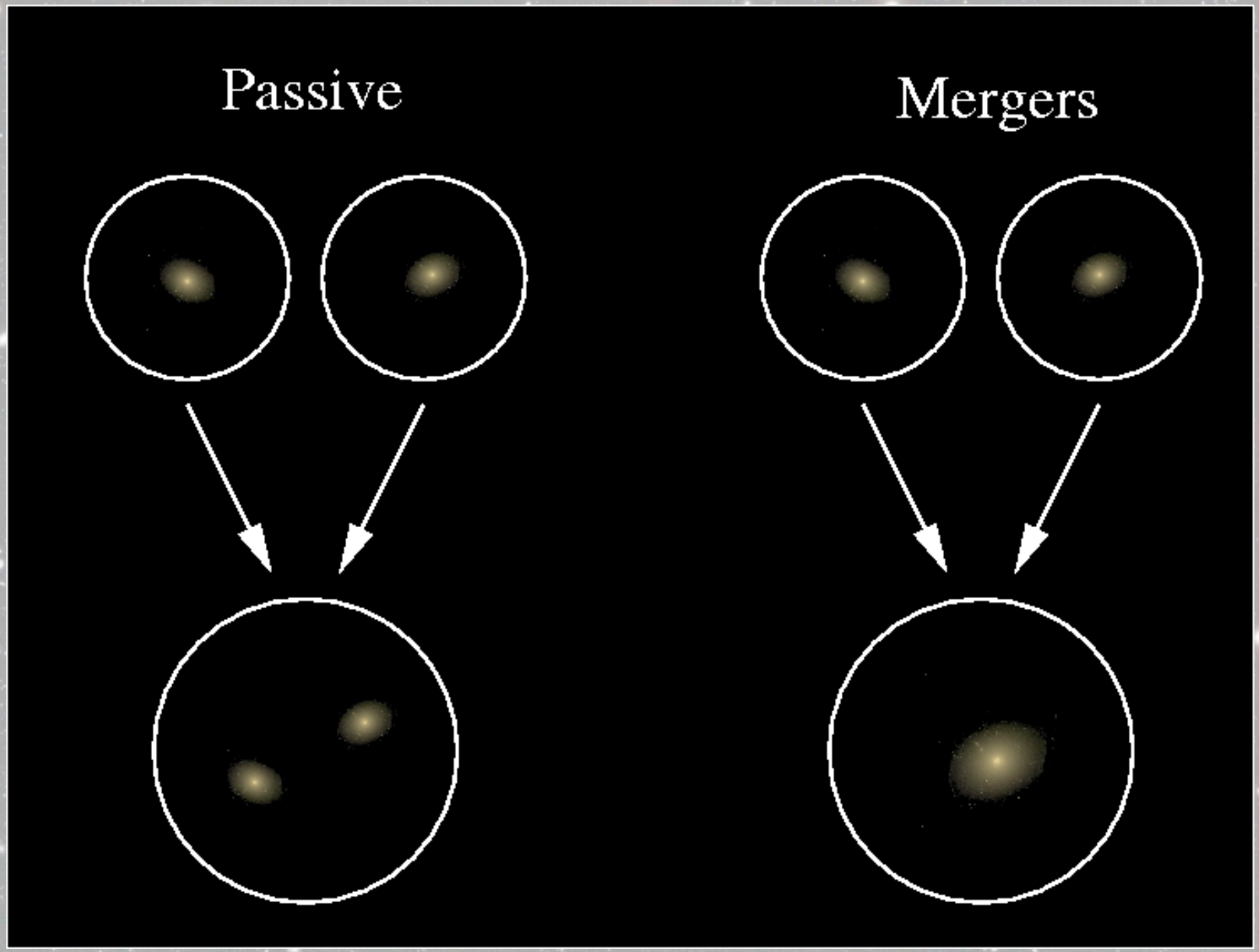


Dark matter only sim. of of ~10^{15} solar masses

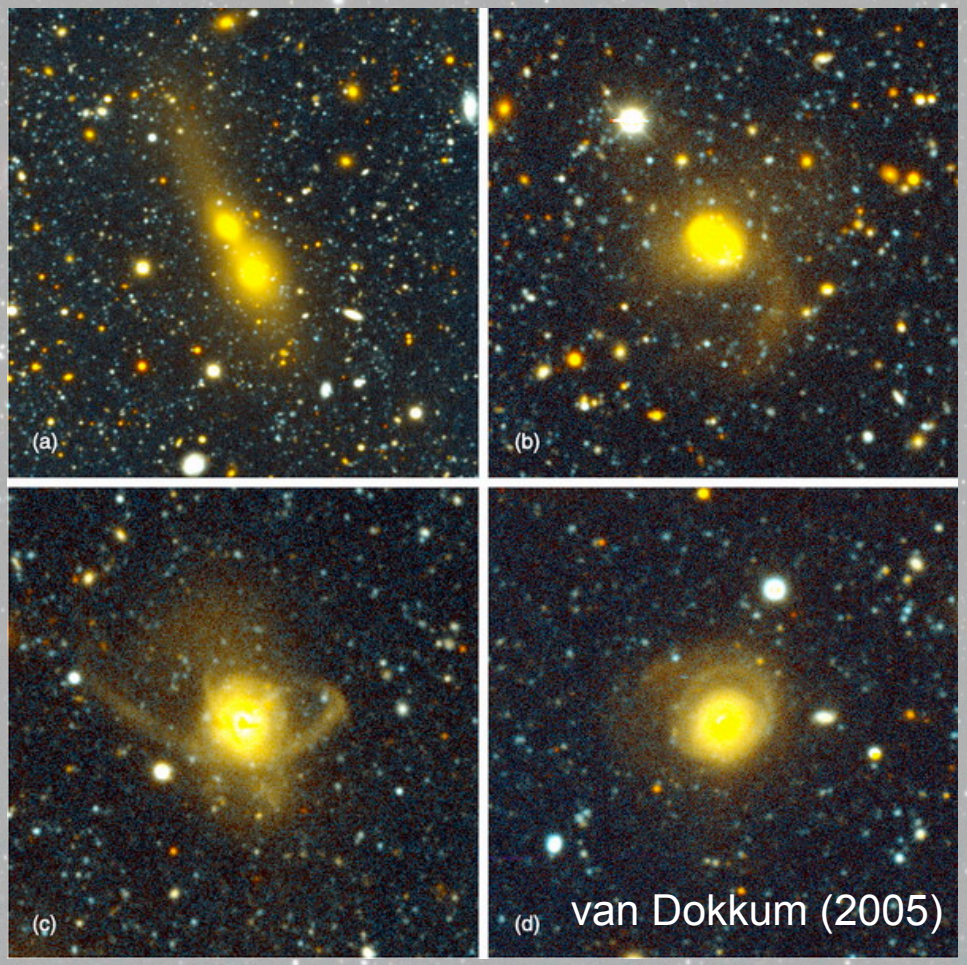
Durham Institute for Computational Cosmology



- Galaxies contain dark matter, gas and stars.
- Galaxies can reside within substructures of dark matter.
- Tidal stripping, gas pressure, cooling, star formation, heating.
- Simulations & models produce varying histories.

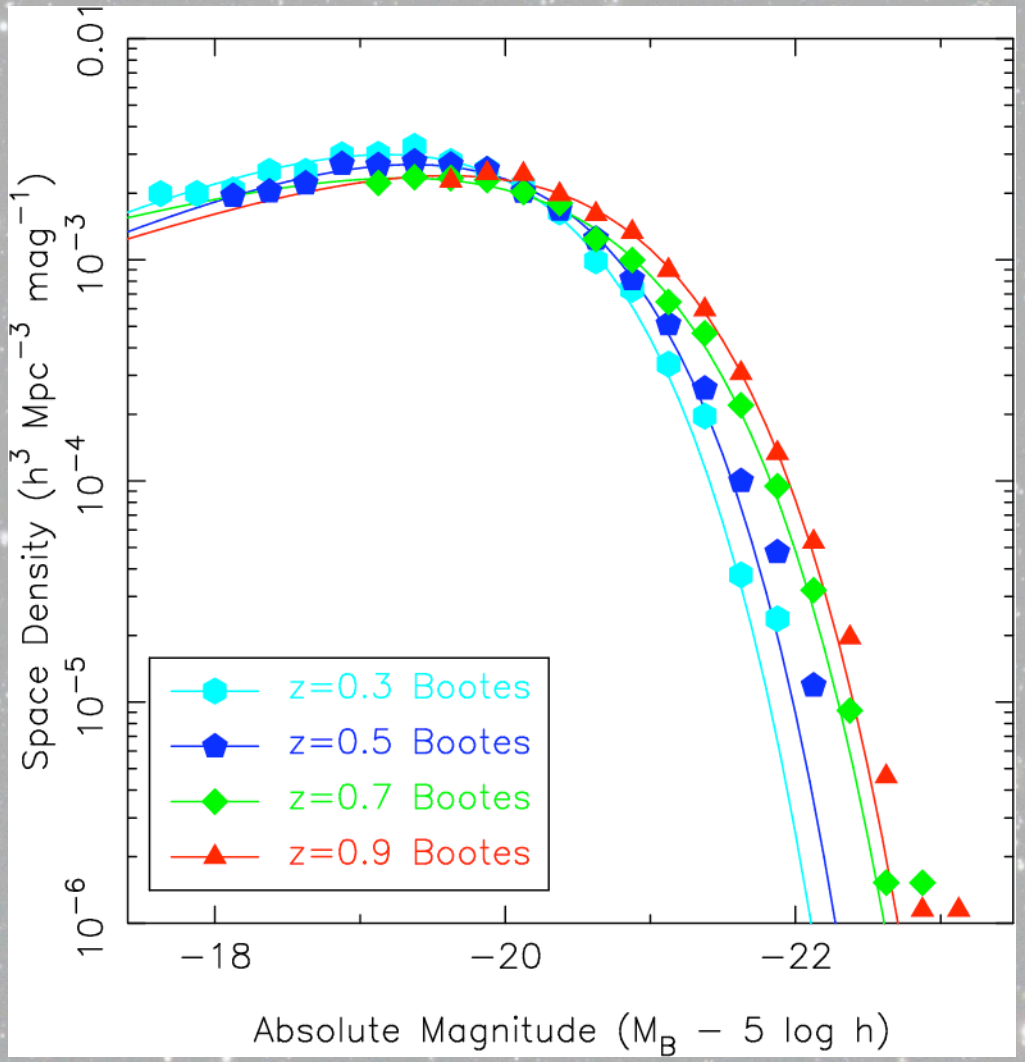

Passive
Mergers

Merging Galaxies



One can argue about the rate of growth…

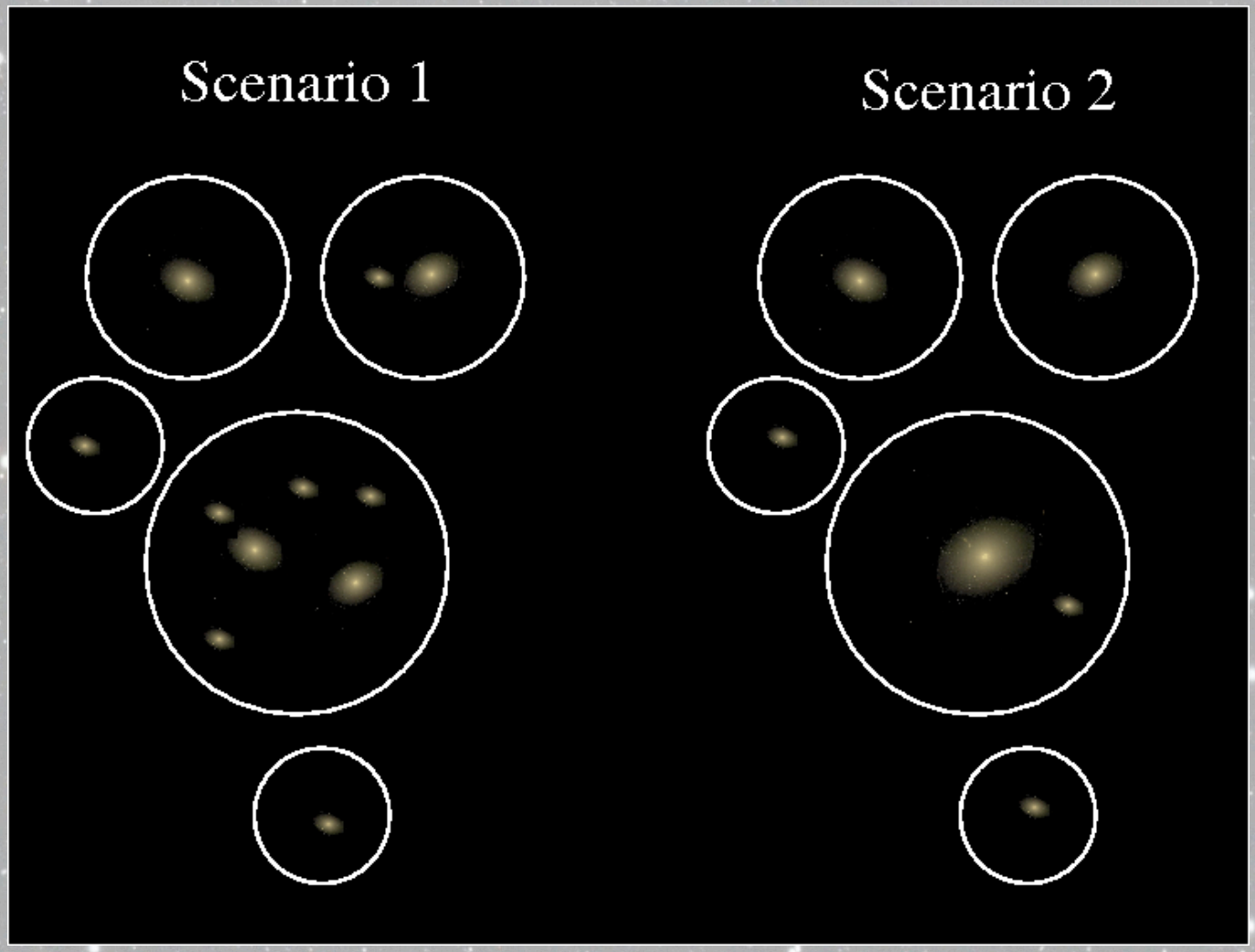
Red Galaxy Luminosity Function



We see the fading/aging of stellar populations.

The evolution of the luminosity function is not dominated by growth via merging.

Brown et al. (2007)

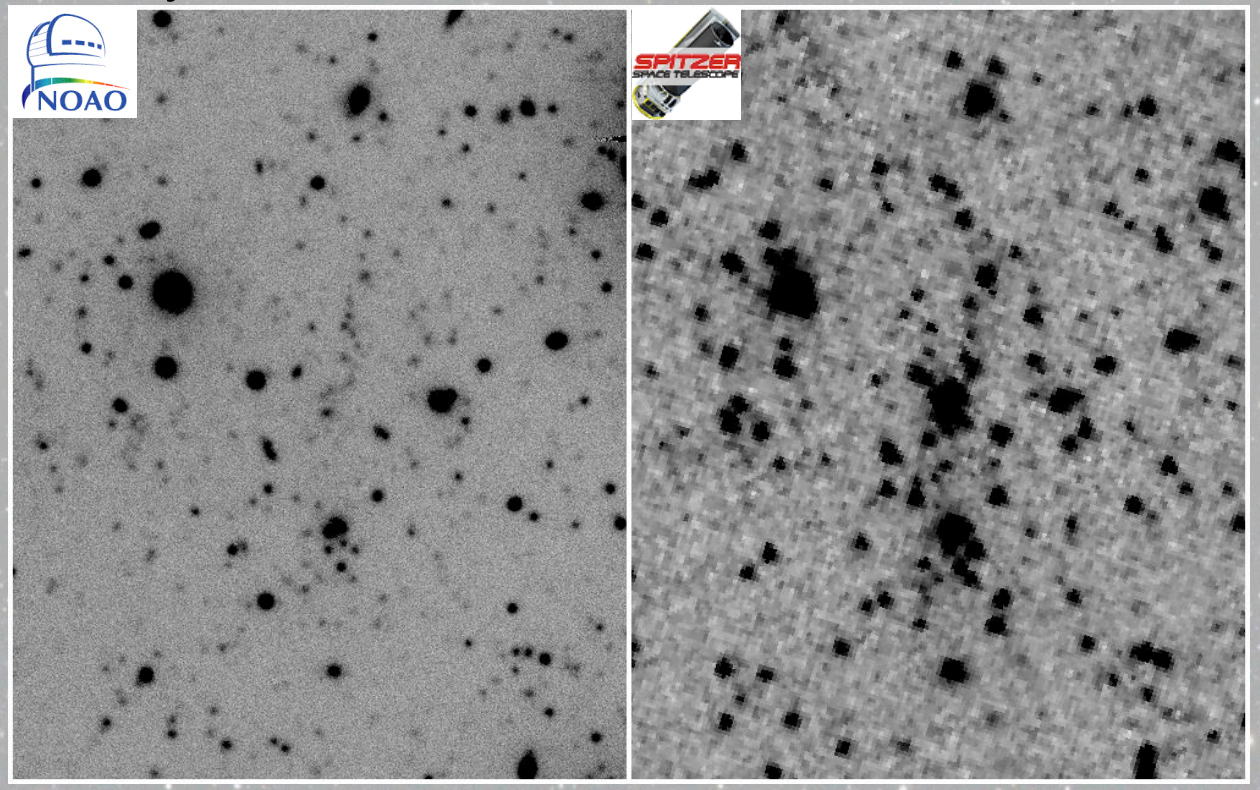


The space density & clustering of DM halos are known.
The space density & clustering of galaxies will vary with the galaxy formation scenario.

Bootes Surveys

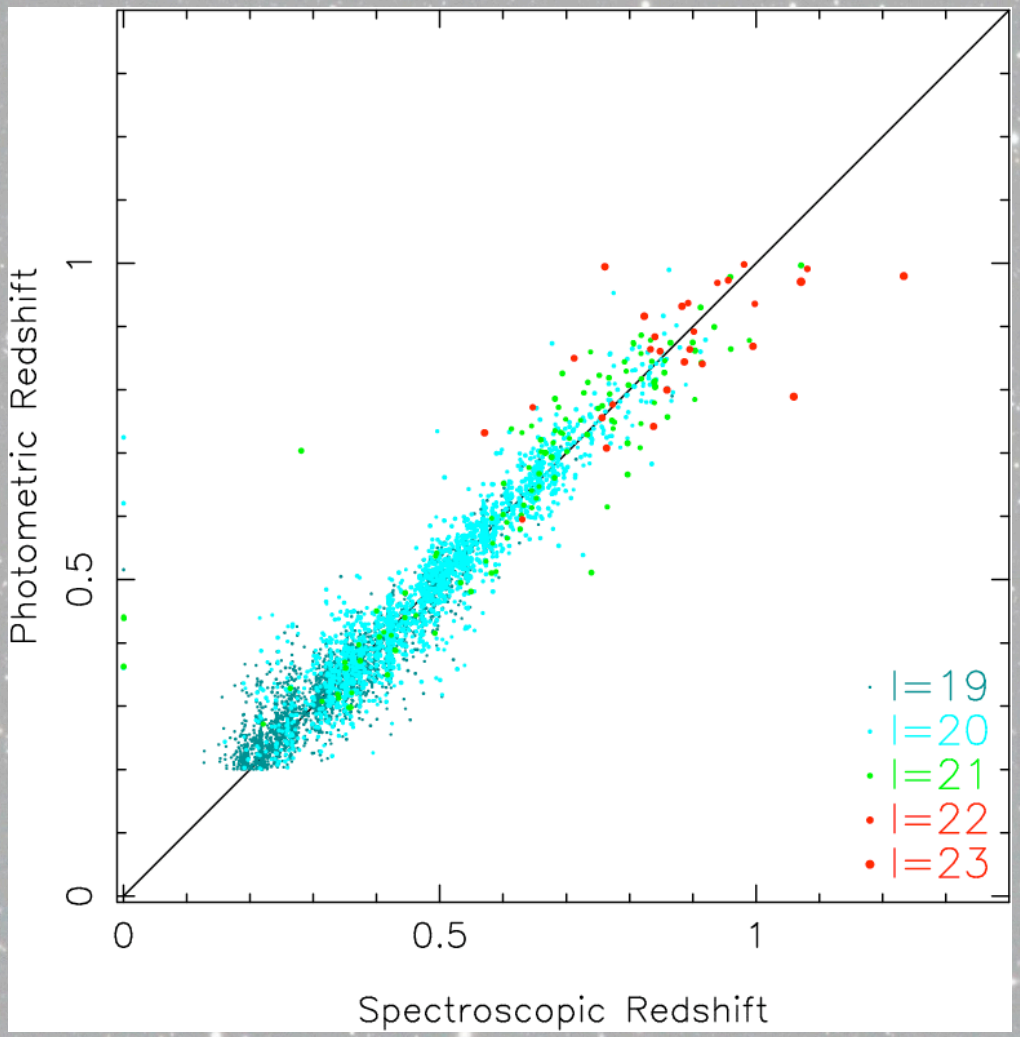
NOAO Deep Wide-field Survey
Spitzer IRAC Shallow Survey
AGES
Spitzer MIPS Bootes
Chandra Xbootes
FLAMEX
GALEX UV Survey
Westerbork
Very Large Array

9 deg^2 area
B_W~27, R~26, I~25



"Postage Stamps" of 0.02% of the survey

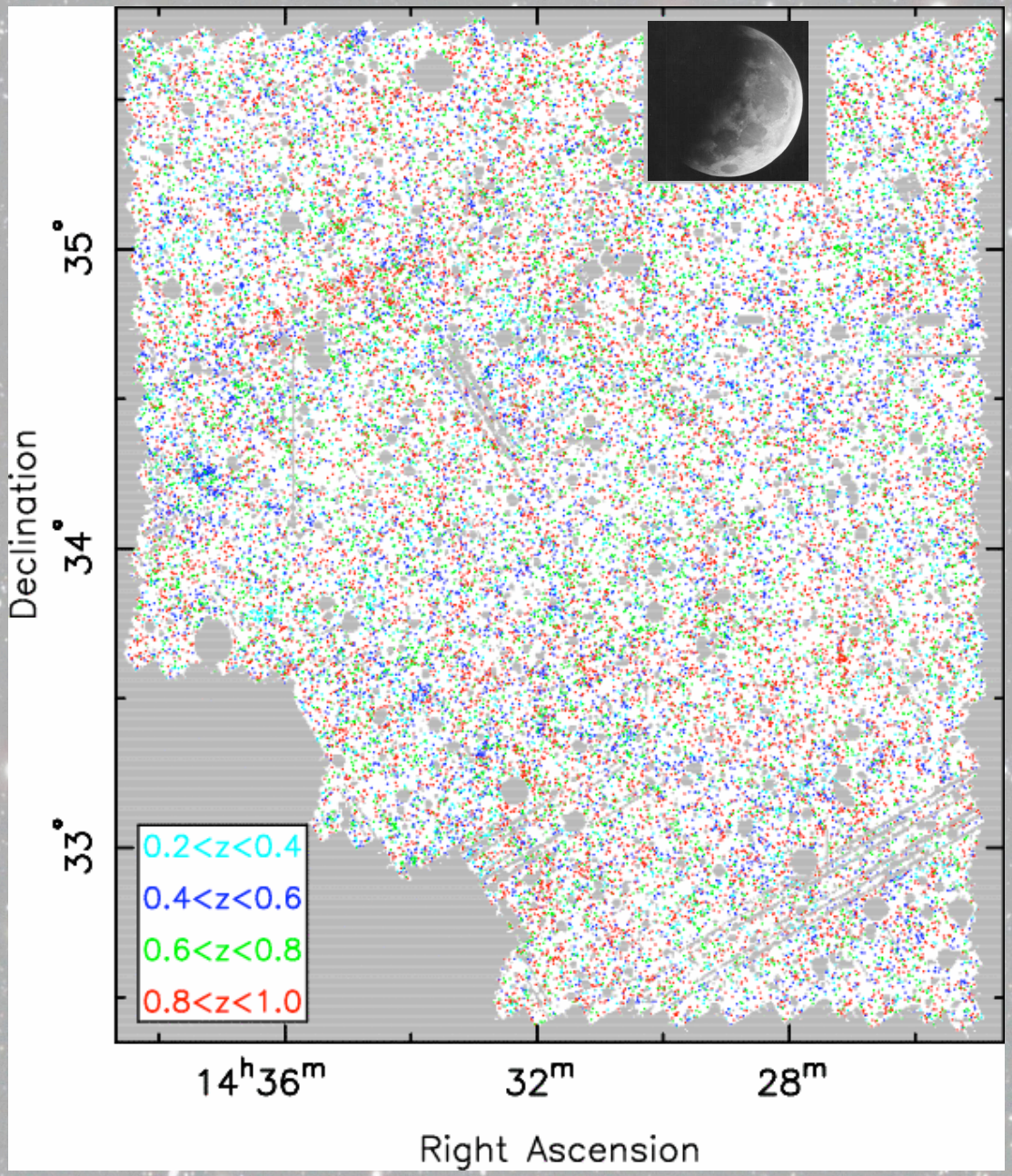
Photometric Redshifts



The Bootes surveys are larger than high redshift spectroscopic surveys.

Photo-zs accurate to +/-0.05 at I<22.

Luminosities & colours by fitting of model spectra.

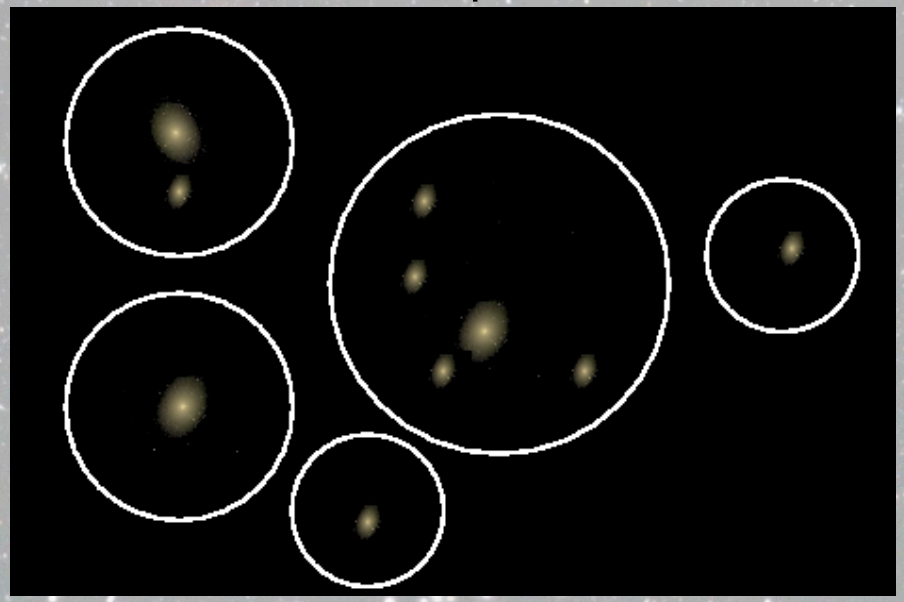


Brown et al. (2007),
ApJ, 654, 858

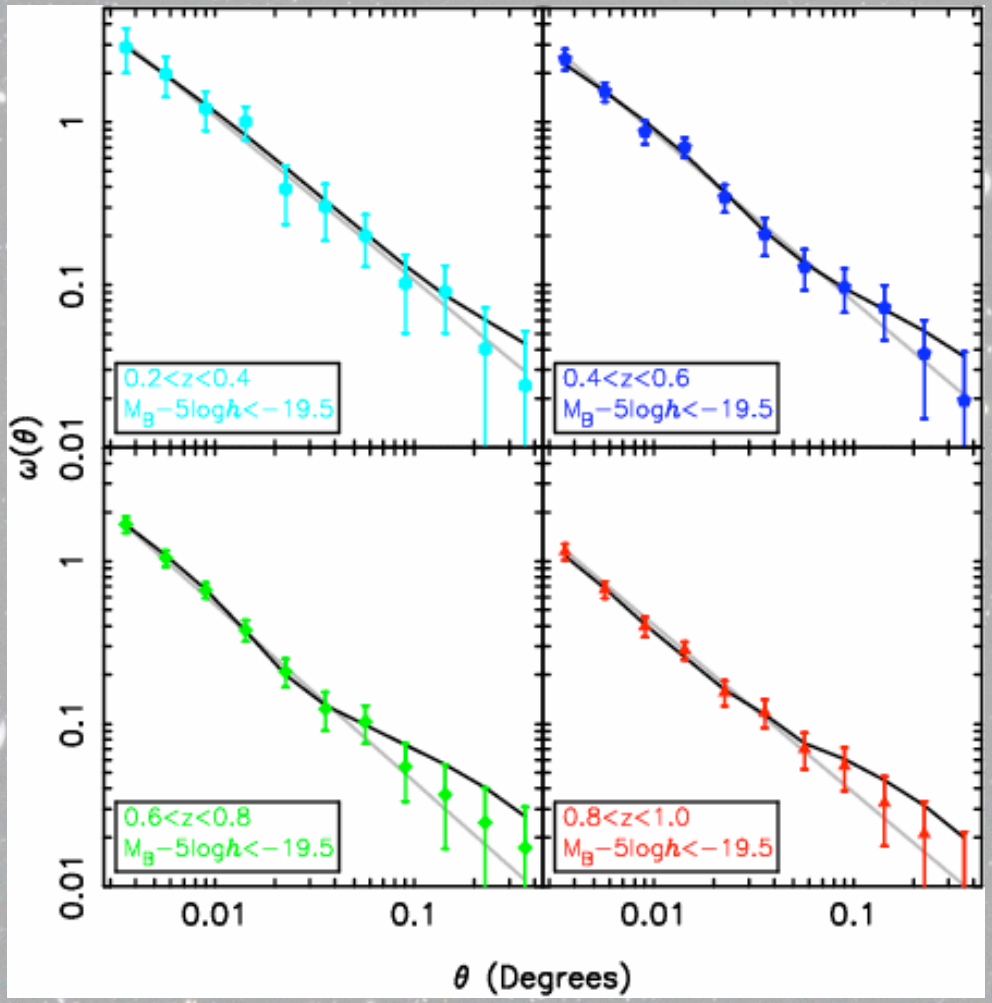
Brown et al. (2008)
ApJ in press
arXiv 0804.2293

Halo Occupation Distribution

- Models the number of galaxies per dark matter halo.
- Broken into a central and satellite galaxy components.
- Mean number of central galaxies per halo between 0 and 1.
- Central galaxy mass increases with halo mass.
- Mean number of satellites increases with halo mass.
- Assume satellites follow an NFW profile.



Connecting to Dark Matter

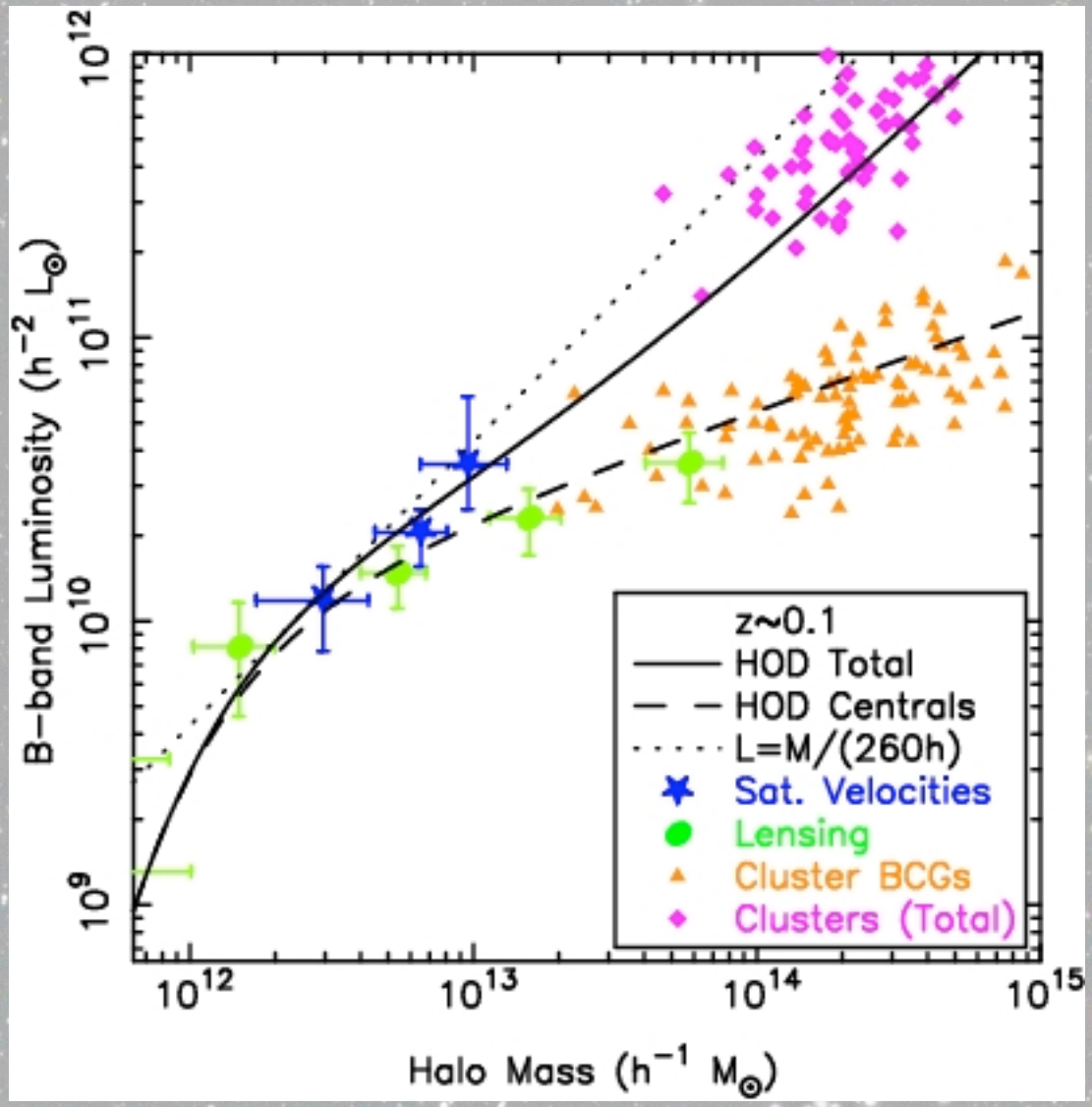


HOD constrained with…
1) Galaxy Space Density
2) Galaxy Clustering
3) Halo Mass Function
4) Halo Clustering
5) NFW profile

HOD matches our observations

Brown et al. (2008, arXiv 0804.2293)

Galaxy light in halos

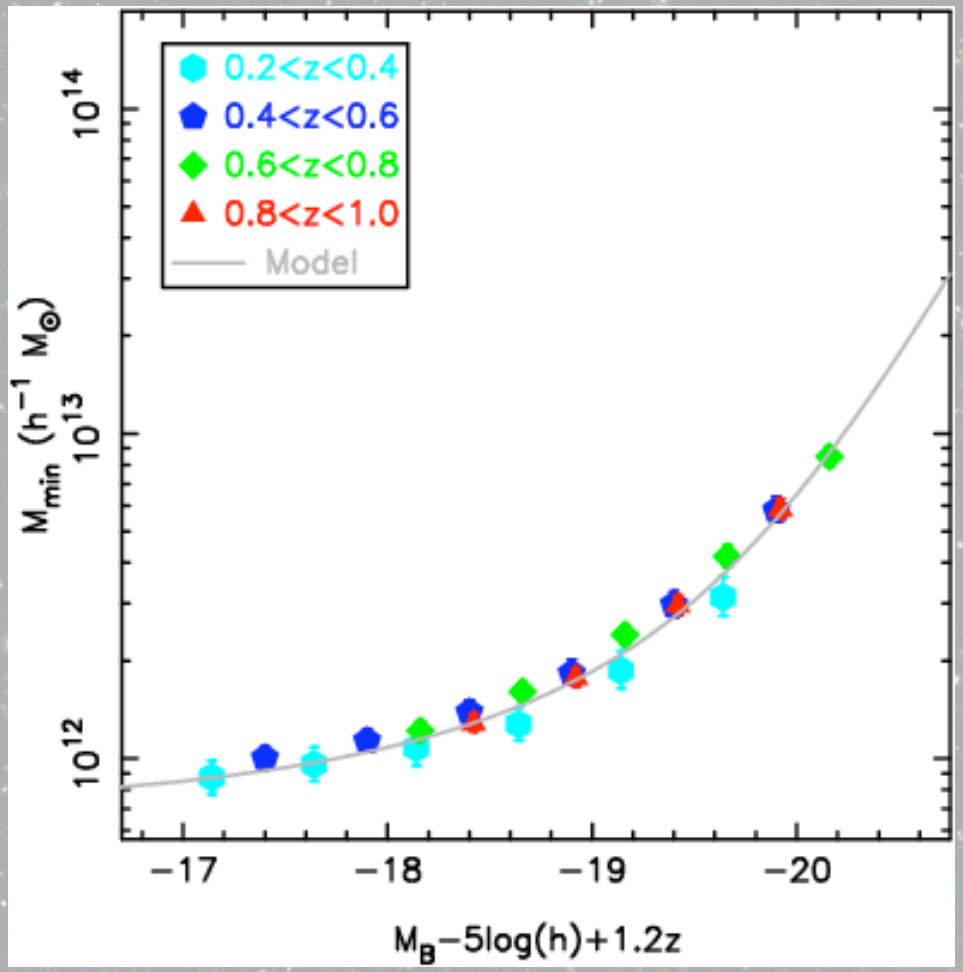


$$L_{cen} \propto M^{1/3}$$

Galaxy luminosity is weakly correlated with halo mass.

In massive halos most of the stellar mass is in satellite galaxies.

Halo Mass vs Stellar Mass

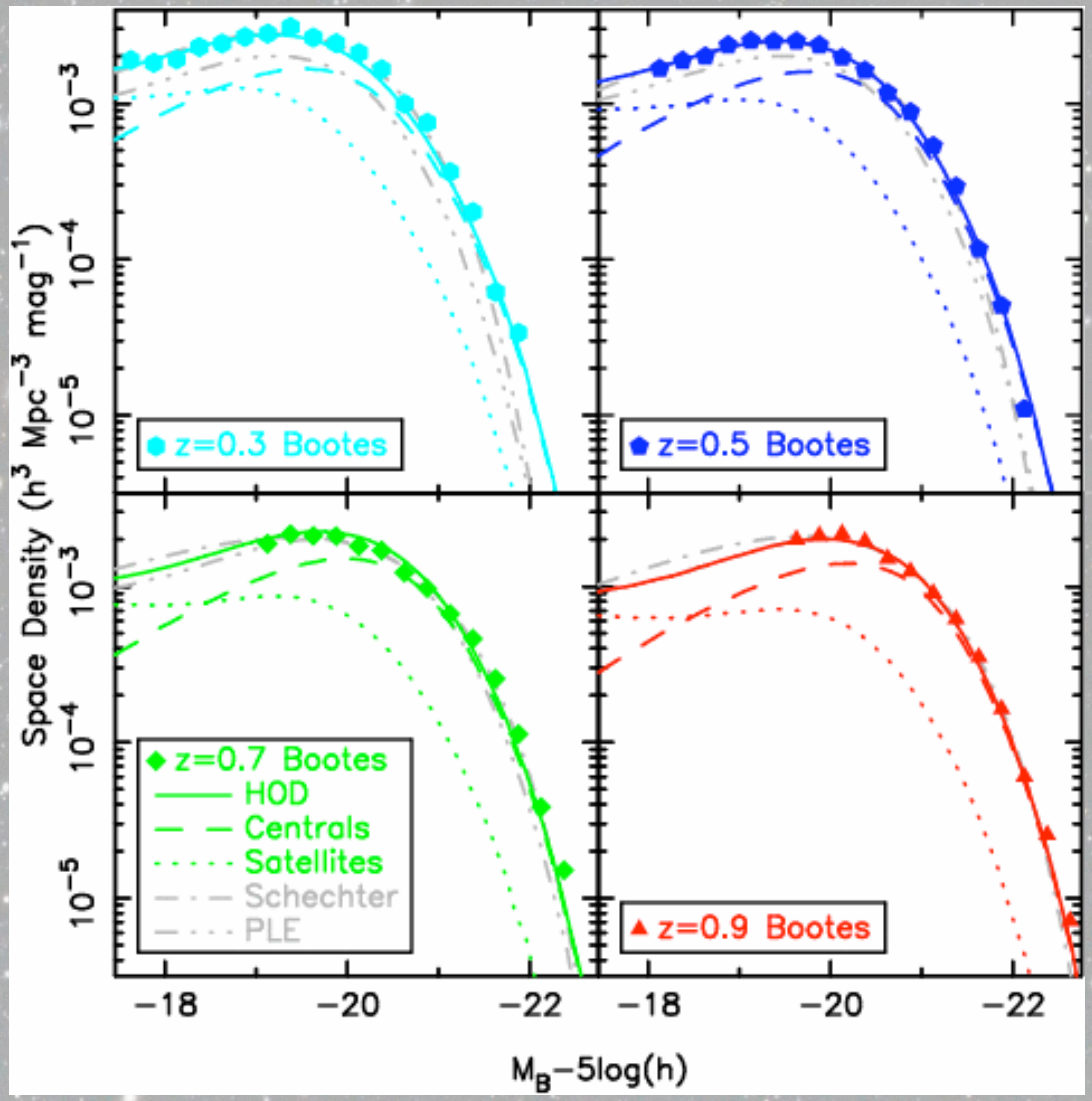


Minimum halo mass in which a galaxy can reside.

Galaxies occupy dark matter halos in the same way now as 8 Gyr ago.

Proxy for galaxy stellar mass

Luminosity Function



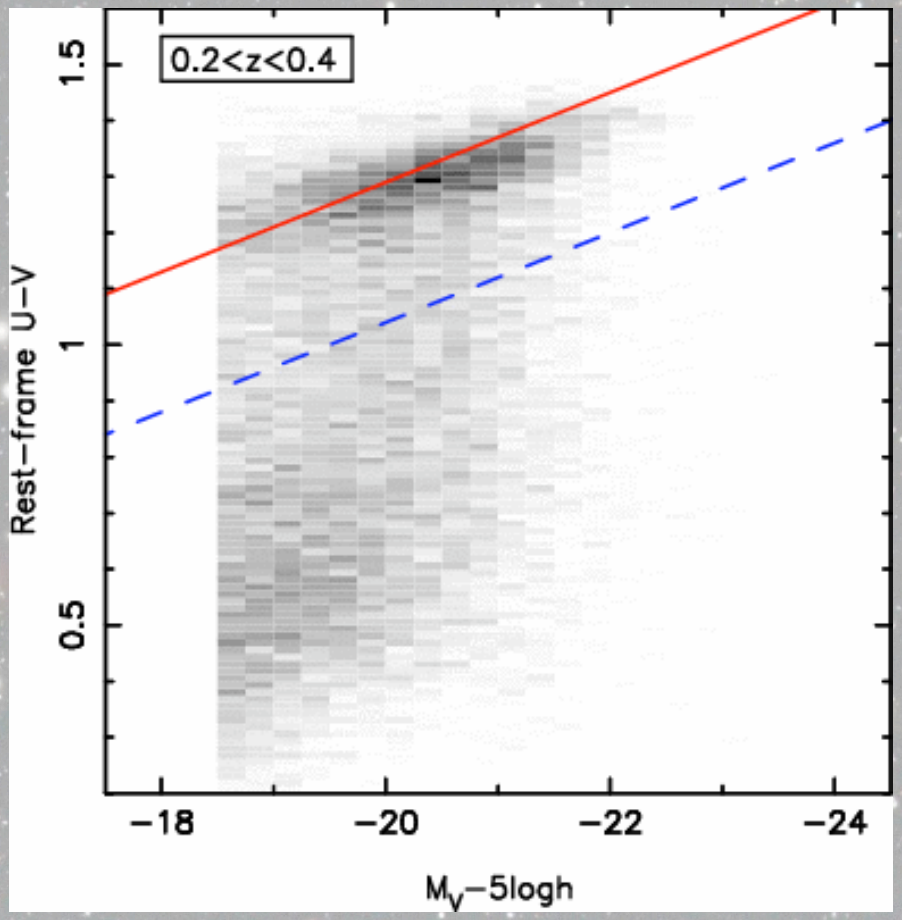
Summary

- The past 8 Gyr of Red Galaxy Growth:
  - Galaxies do grow via mergers.
  - Galaxies do not grow as rapidly as their DM halos.
  - All red (central) galaxies are in halos of $>10^{12}$ M_{sun}
  - Galaxies occupy halos now as they did 8 Gyr ago.

- Key Remaining questions...
  - What keeps star-formation turned off?
  - When were massive red galaxies assembled?

Red Galaxy Selection

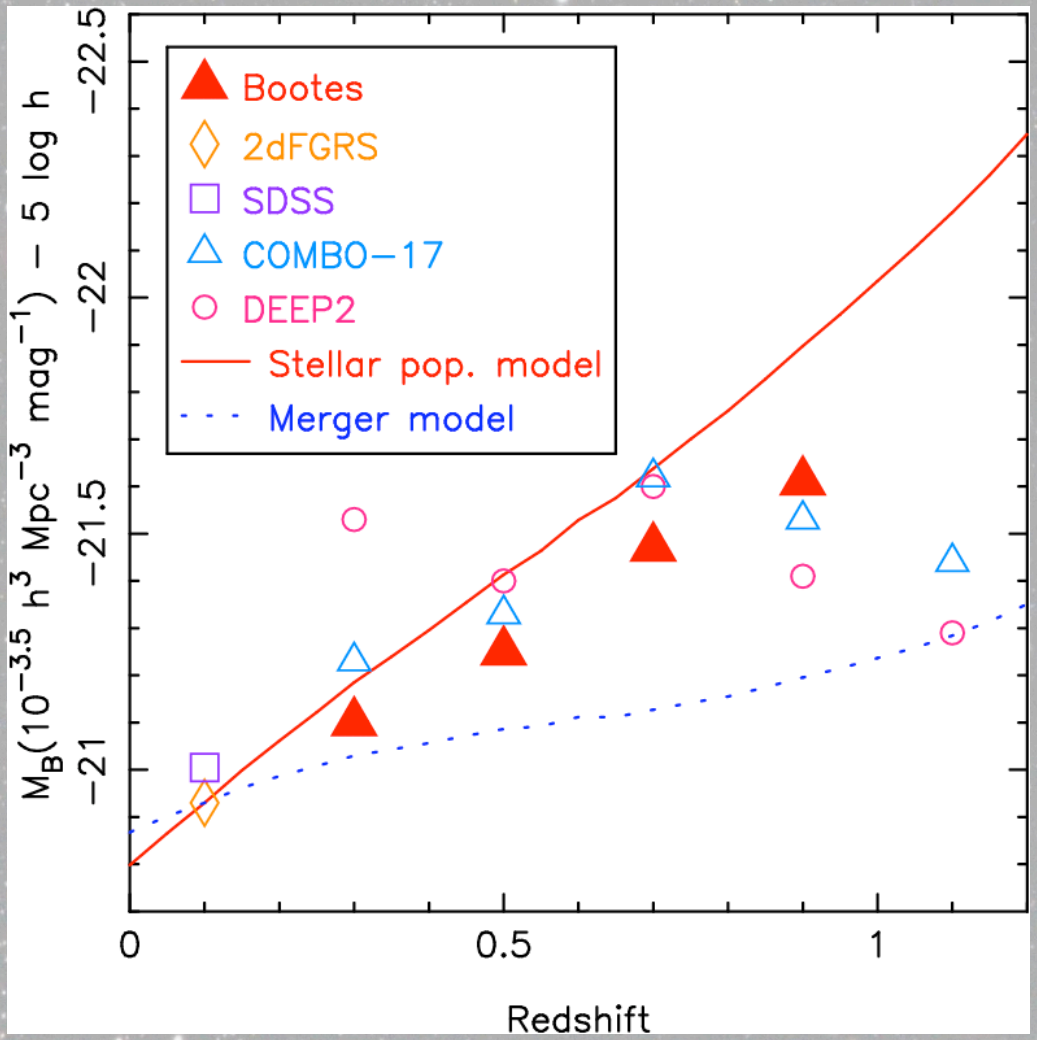
Colour



Luminosity

Selection criterion falls between the 2 galaxy populations

Massive Galaxies Grow Slowly

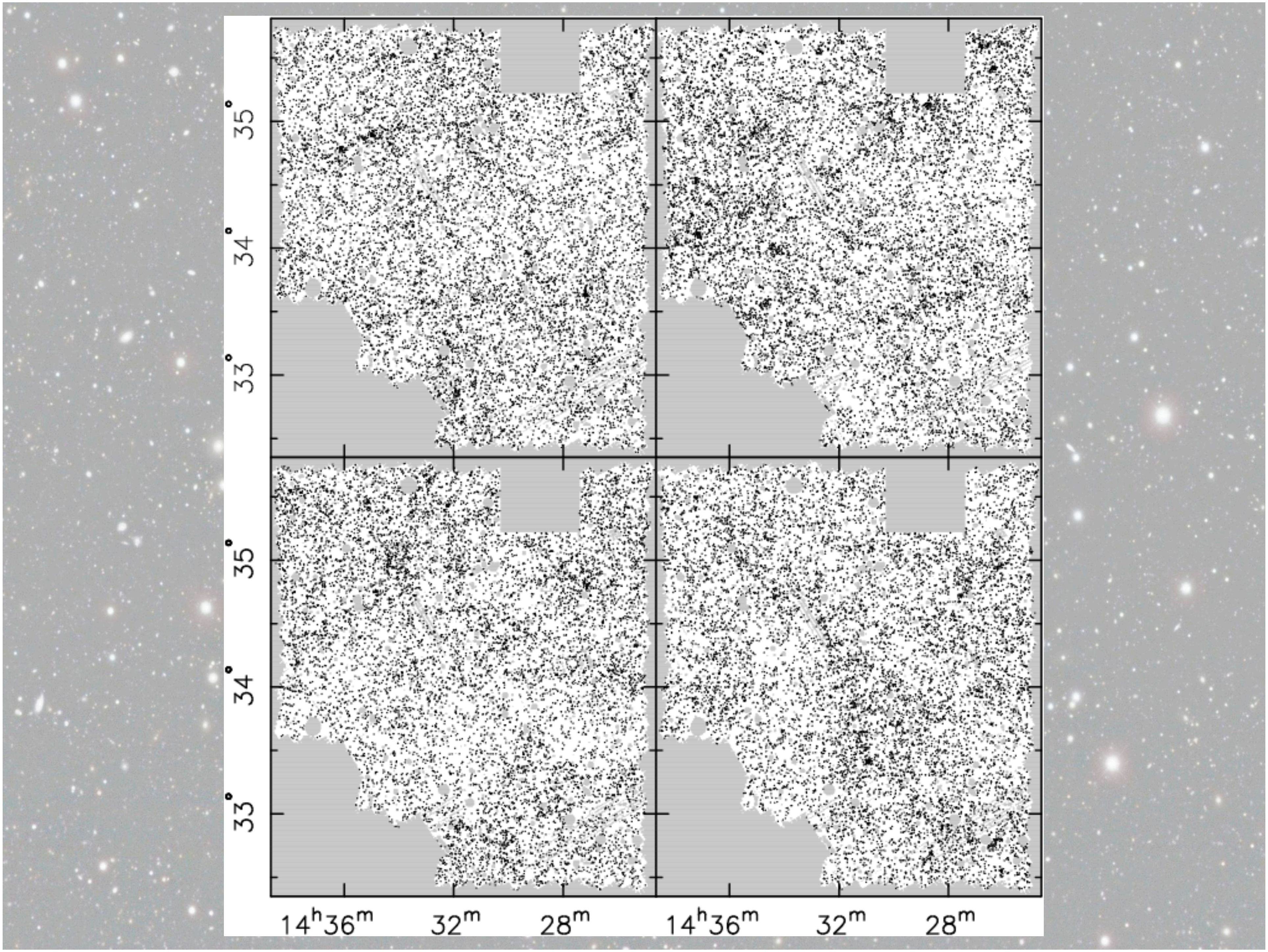


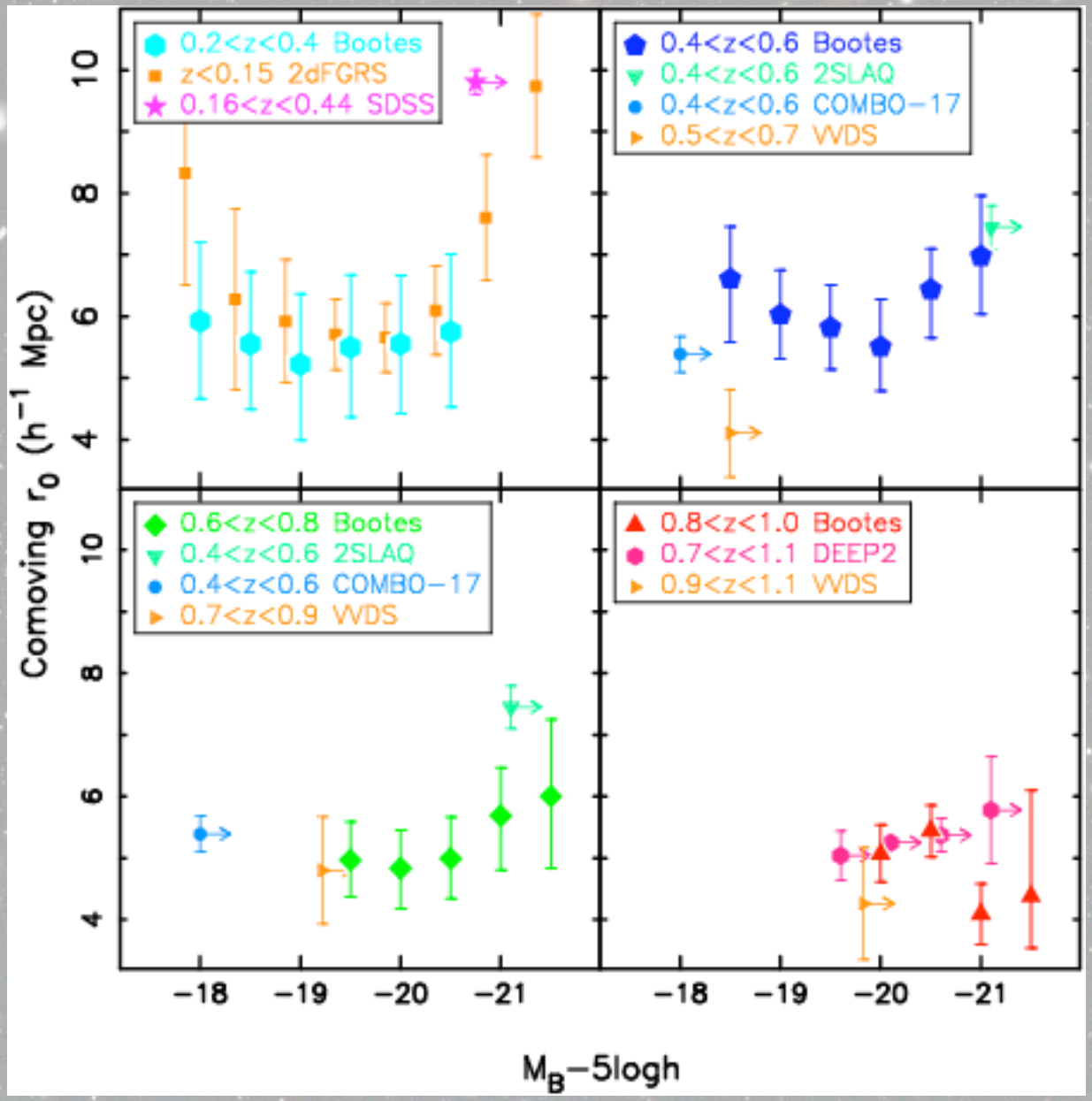
Fading differs from stellar pop. model.

Growth via mergers, but not rapid growth.

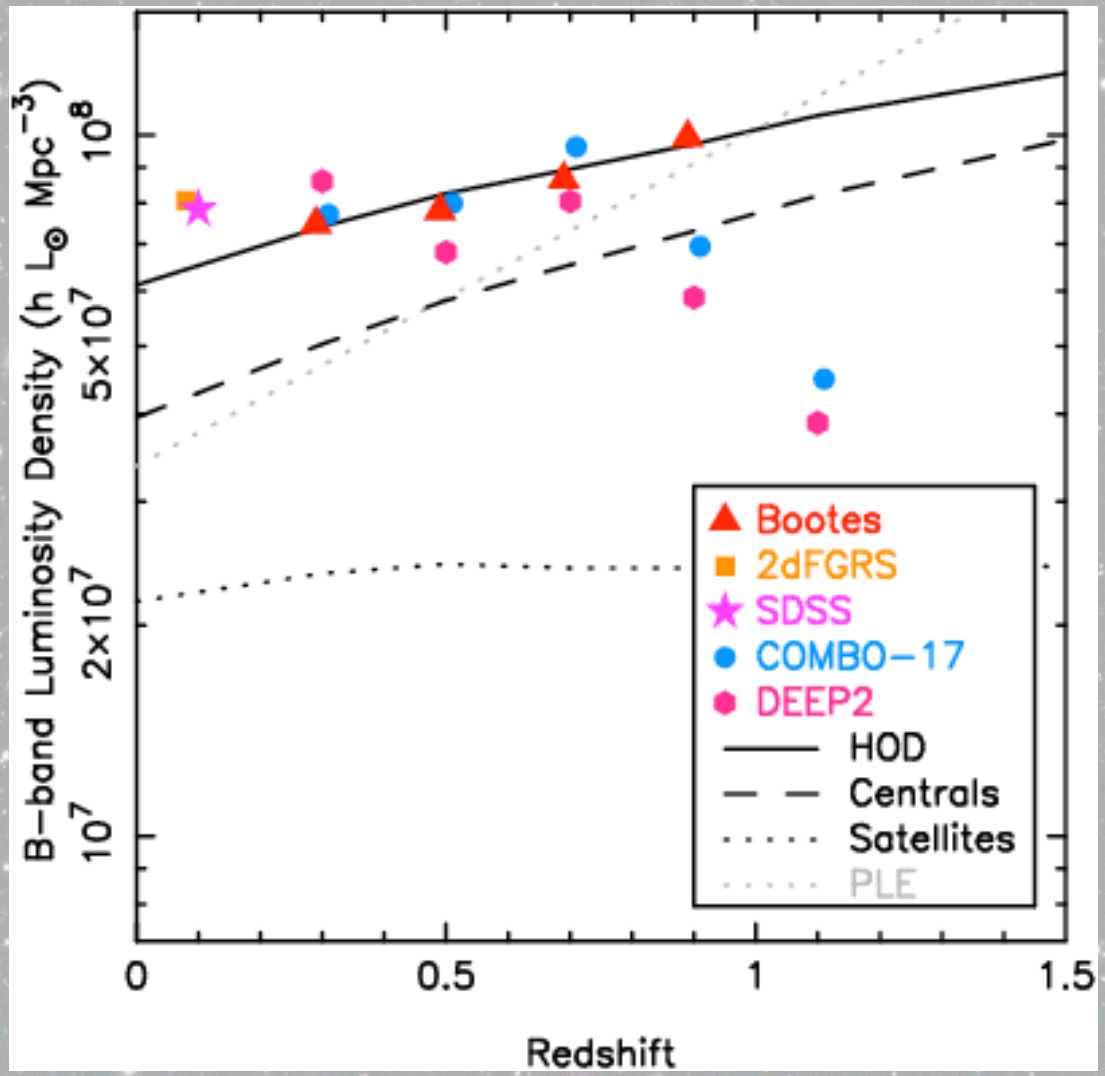
Why?

Brown et al. (2007), ApJ, 654, 858

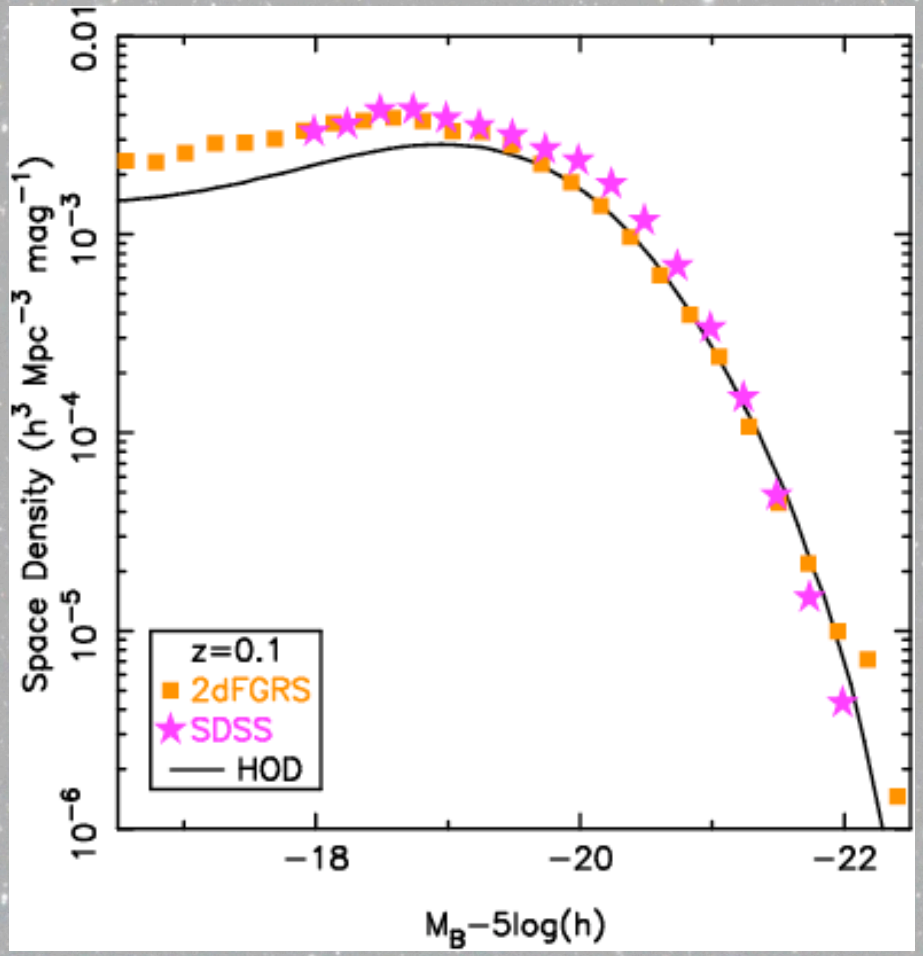

35°
34°
33°
14h36m
32m
28m

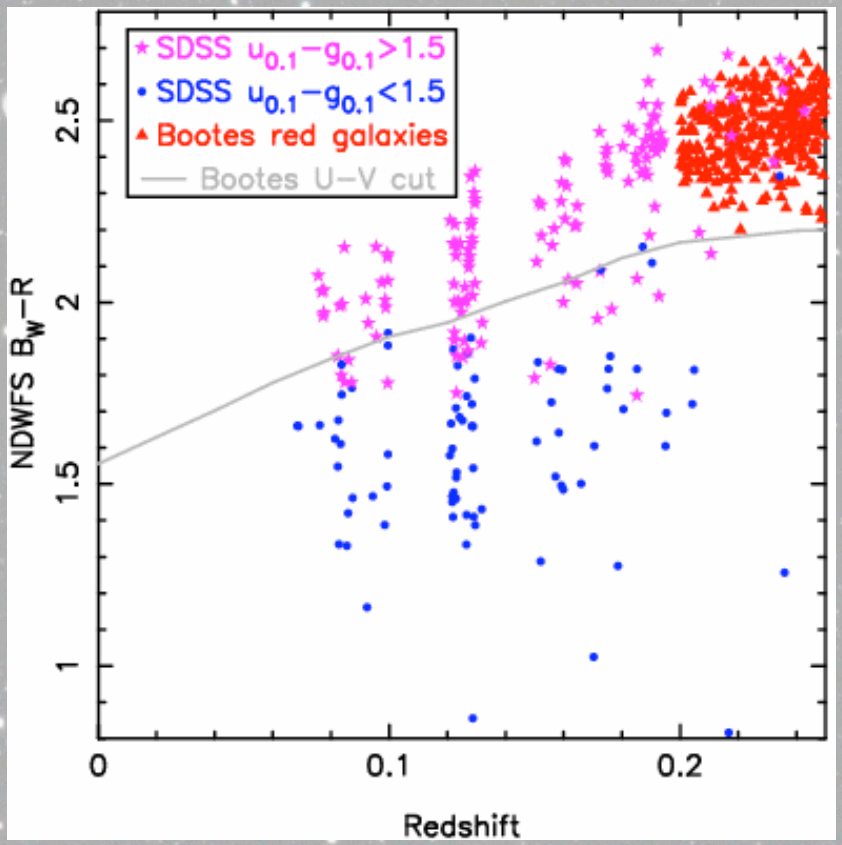

0.2<z<0.4 Bootes
z<0.15 2dFGRS
0.16<z<0.44 SDSS
0.4<z<0.6 Bootes
0.4<z<0.6 2SLAQ
0.4<z<0.6 COMBO−17
0.5<z<0.7 VVDS
0.6<z<0.8 Bootes
0.4<z<0.6 2SLAQ
0.4<z<0.6 COMBO−17
0.7<z<0.9 VVDS
0.8<z<1.0 Bootes
0.7<z<1.1 DEEP2
0.9<z<1.1 VVDS
Comoving r0 (h−1 Mpc)
MB−5logh
4
6
8
10
−18
−19
−20
−21

Luminosity Density

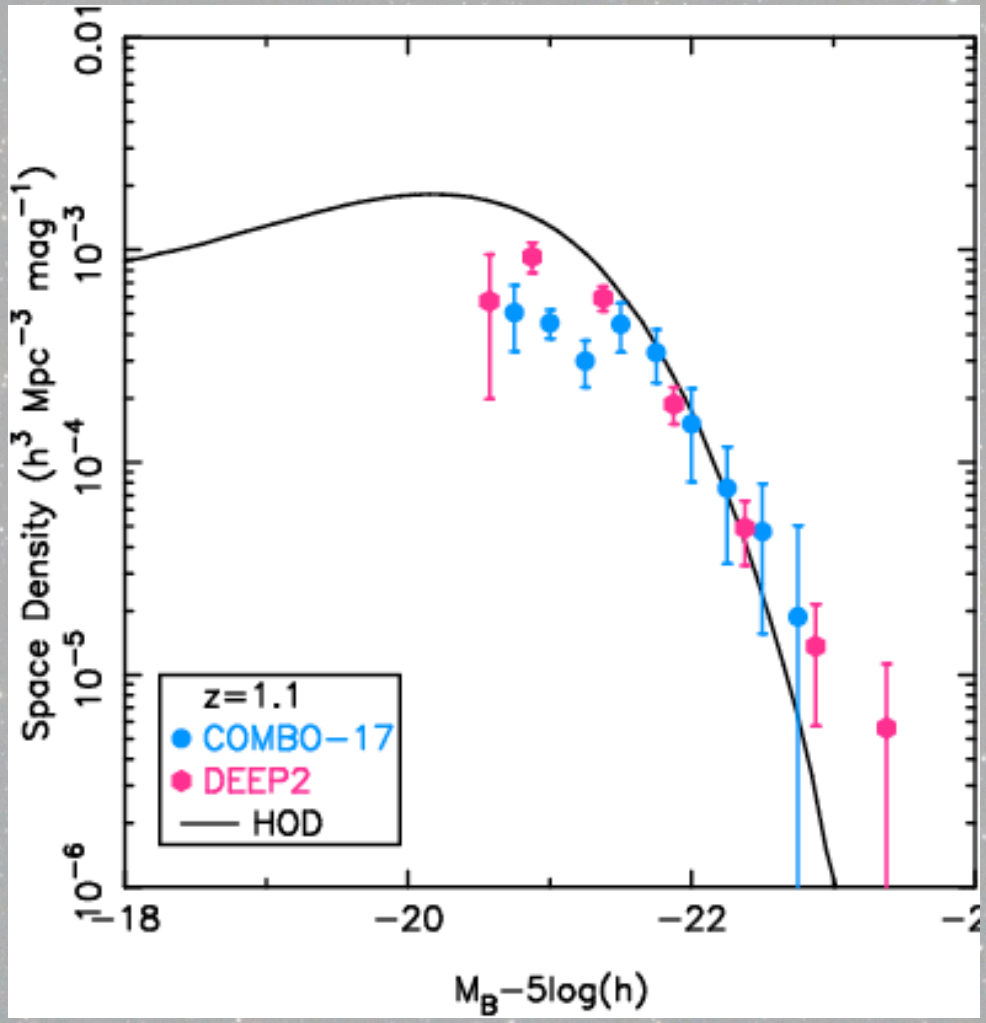


Low z LF


Space Density (h^3 Mpc^{-3} mag^{-1})
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
−18
−20
−22
M_B−5log(h)
z=0.1
2dFGRS
SDSS
HOD


SDSS $u_{0.1}-g_{0.1}>1.5$
SDSS $u_{0.1}-g_{0.1}<1.5$
Bootes red galaxies
Bootes U−V cut
NDWFS B_W-R
1
1.5
2
2.5
0
0.1
0.2
Redshift

High z LF


Space Density (h^3 Mpc^{-3} mag^{-1})
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
−18
−20
−22
M_B−5log(h)
z=1.1
COMBO−17
DEEP2
HOD