The Evolution of Galaxy Morphologies in Clusters

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Marc Postman

& collaborators:

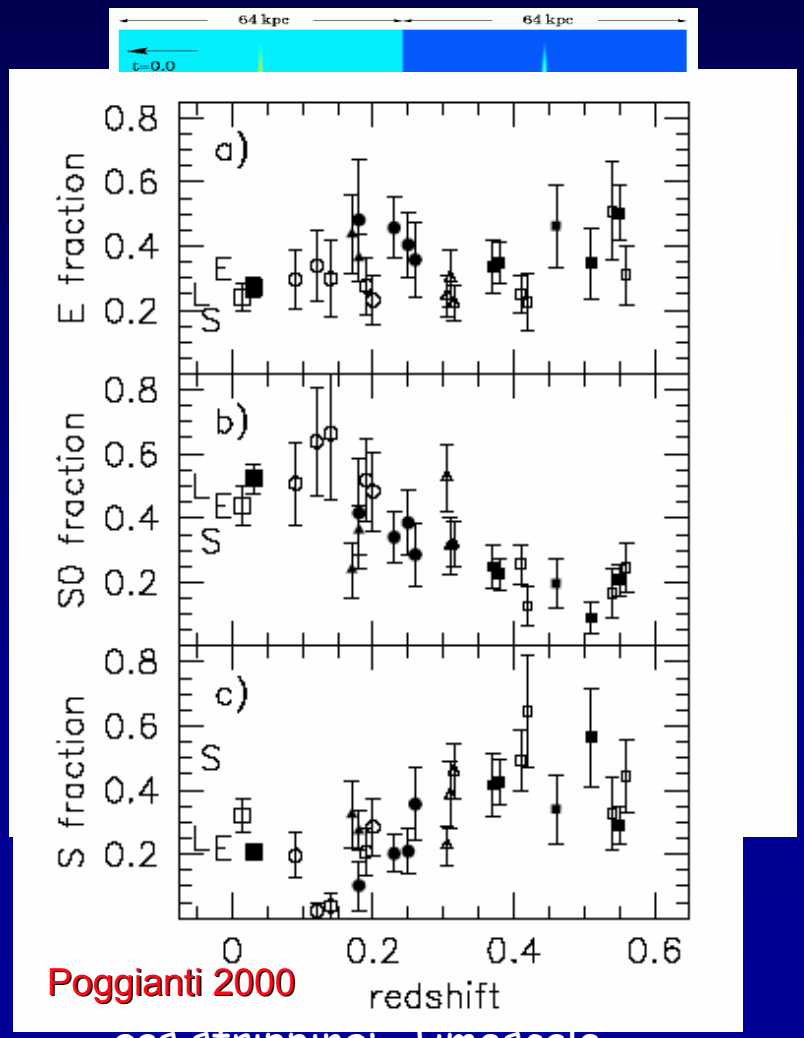
Frank Bartko
Txitxo Benitez
John Blakeslee
Nick Cross
Ricardo Demarco
Holland Ford
Marijn Franx
Tomo Goto
Brad Holden
Nicole Homeier
Garth Illingworth
Simona Mei
Piero Rosati
& the rest of the ACS IDT

Understanding the Origin of Morphological Differences in Galaxies

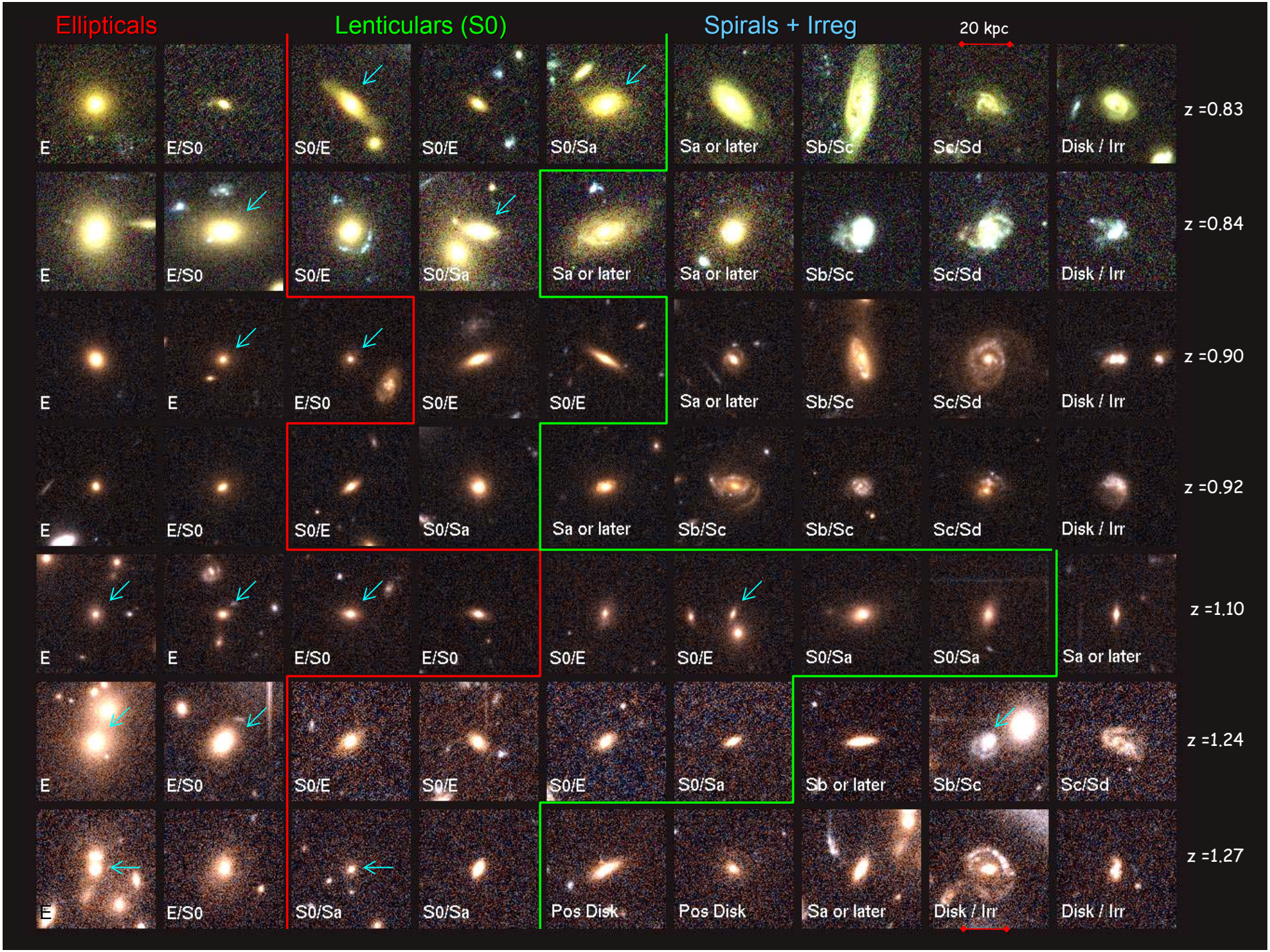
- Is the morphology - density relation (MDR) a fundamental relationship or is it a consequence of some other underlying correlation (e.g., galaxy mass - density relationship)?
  - Is the morphological population set mostly by environmental processes or initial conditions? Is the answer to this question dependent on galaxy mass?
  - When does the MDR get established?
  - How do the morph. populations of galaxies in clusters and the field vary with redshift?
  - The evolution in morphological composition as functions of radius, density, SFR, galaxy mass are powerful constraints on galaxy formation models.
  - What are the progenitors of current epoch S0 galaxies? Do mergers play an important role in morphological transformation of cluster galaxy populations?

Understanding the Origin of Morphological Differences in Galaxies

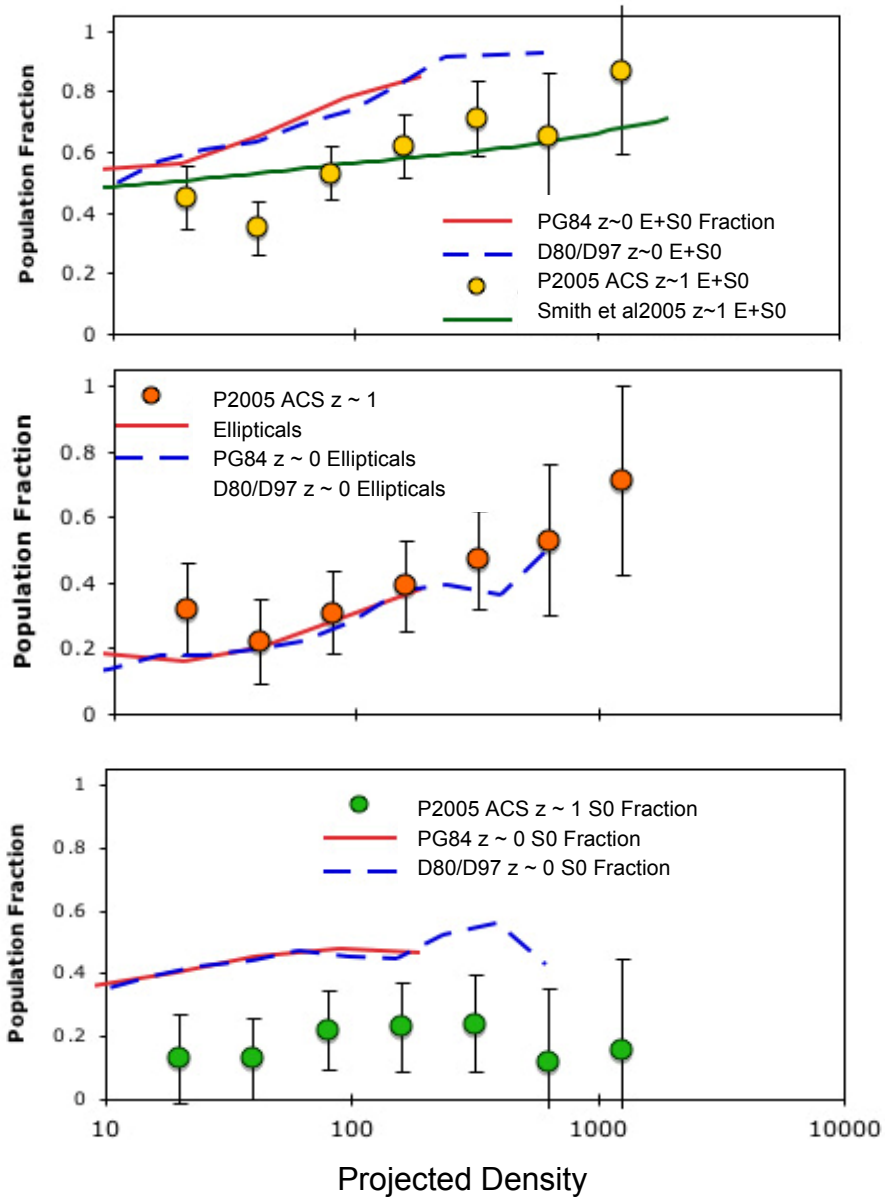
- What we knew prior to ACS on HST:
  - The relative fraction of galaxy morphologies depends on density (Dressler 1980, Postman & Geller 1984) and/or on clustocentric radius (Whitmore & Gilmore 1993)
  - Physical processes exist that can alter galaxy morphology on timescales much less than the current age of the universe: ram pressure, tidal disruption, mergers
  - Data suggested there is detectable evolution in the morphological composition of clusters over the past ~5 Gyrs: z~0.5 to the present epoch (Dressler et al 1997; Fasano et al. 2000; Treu et al. 2003).



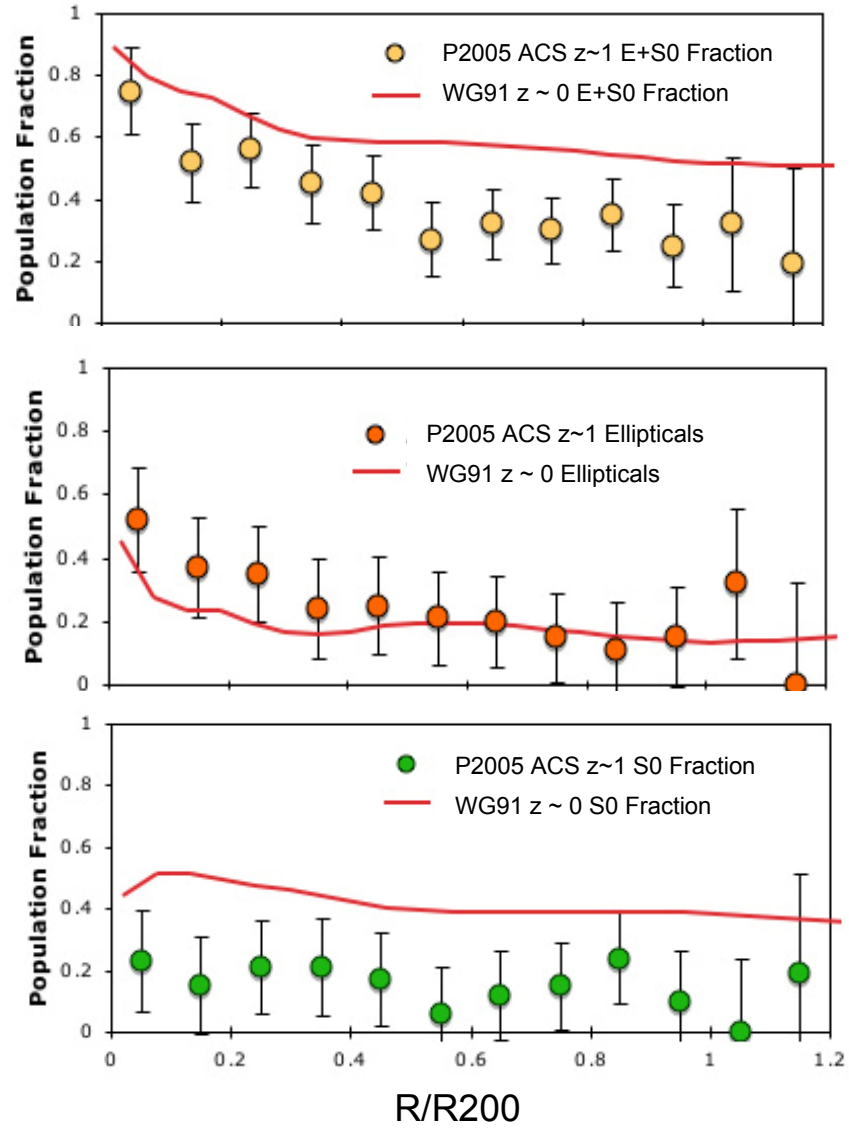
gas stripping; Timescale ~100 Myr

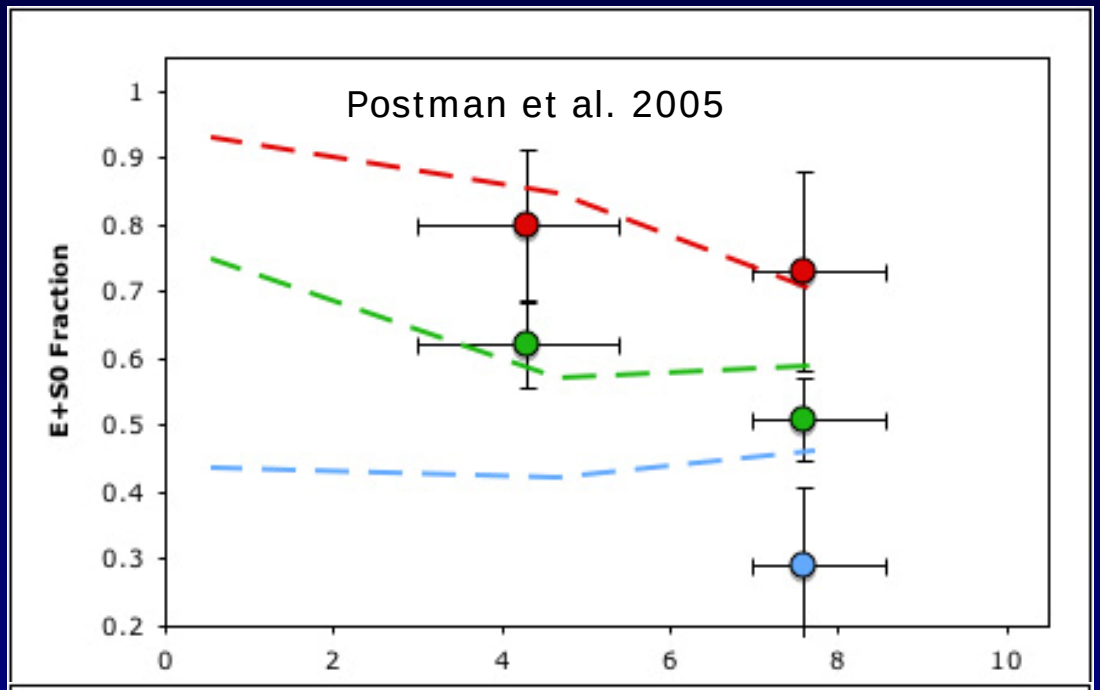

Ellipticals
Lenticulars (S0)
Spirals + Irreg
20 kpc
E
E/S0
S0/E
S0/E
S0/Sa
Sa or later
Sb/Sc
Sc/Sd
Disk / Irr
z =0.83
E
E/S0
S0/E
S0/Sa
Sa or later
Sa or later
Sb/Sc
Sc/Sd
Disk / Irr
z =0.84
E
E
E/S0
S0/E
S0/E
Sa or later
Sb/Sc
Sc/Sd
Disk / Irr
z =0.90
E
E/S0
S0/E
S0/Sa
Sa or later
Sb/Sc
Sb/Sc
Sc/Sd
Disk / Irr
z =0.92
E
E
E/S0
E/S0
S0/E
S0/E
S0/Sa
S0/Sa
Sa or later
z =1.10
E
E/S0
S0/E
S0/E
S0/E
S0/Sa
Sb or later
Sb/Sc
Sc/Sd
z =1.24
E
E/S0
S0/Sa
S0/Sa
Pos Disk
Pos Disk
Sa or later
Disk / Irr
Disk / Irr
z =1.27

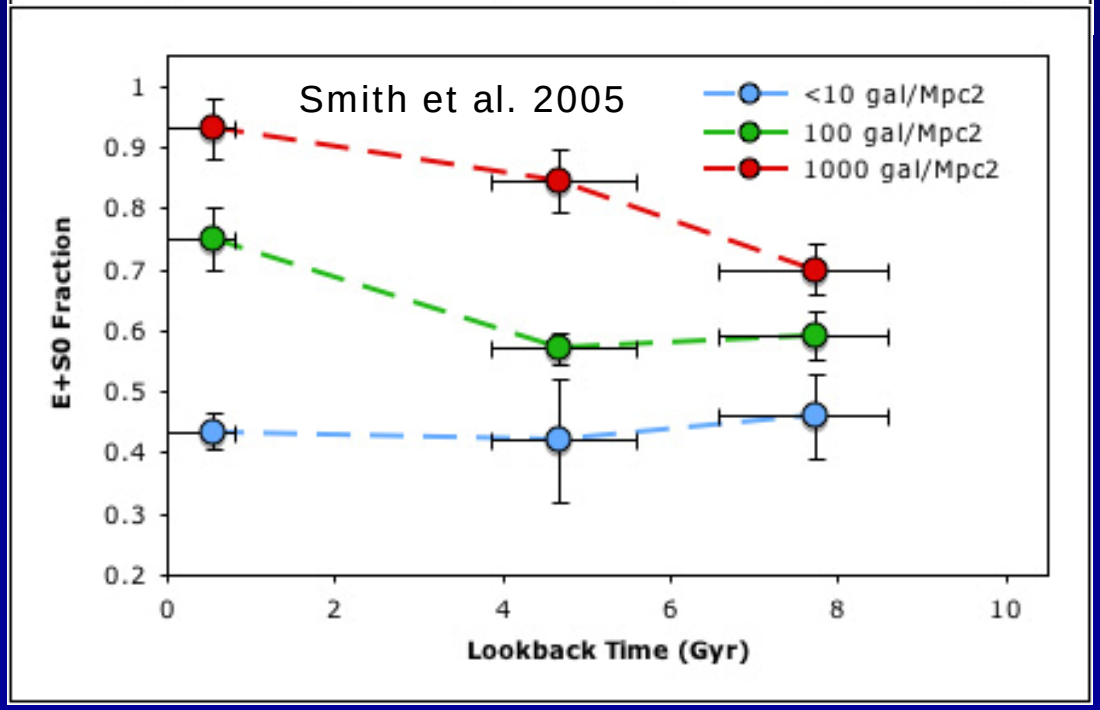
Morphology - Density Relation



Morphology - Radius Relation







Evolution in MDR

The increase in the early-type fraction with increasing density is less rapid at z~1 than at z~0. Consistent with environmentally driven transformation of late --> early types.

S0 fraction at z~1 is <50% of its z~0 value but consistent with its z~0.5 value (e.g., Dressler et al. 1997; Fasano et al. 2000; Treu et al. 2003)

No significant evolution seen in elliptical population fraction - density relation. Does not imply cosmic E pop doesn't increase with time, however.

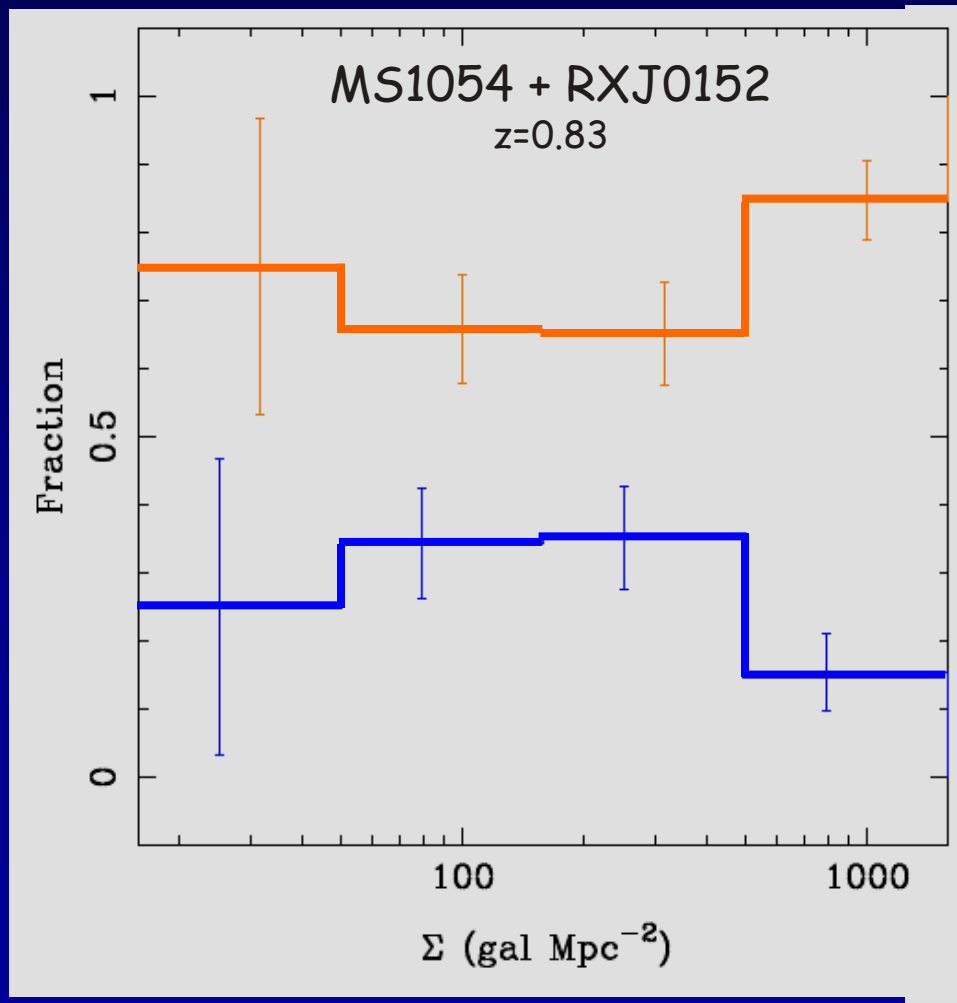
No significant evolution seen at low-density (Smith et al. 2005; Mobasher et al. 2006)

But pop fractions may be correlated with L_X

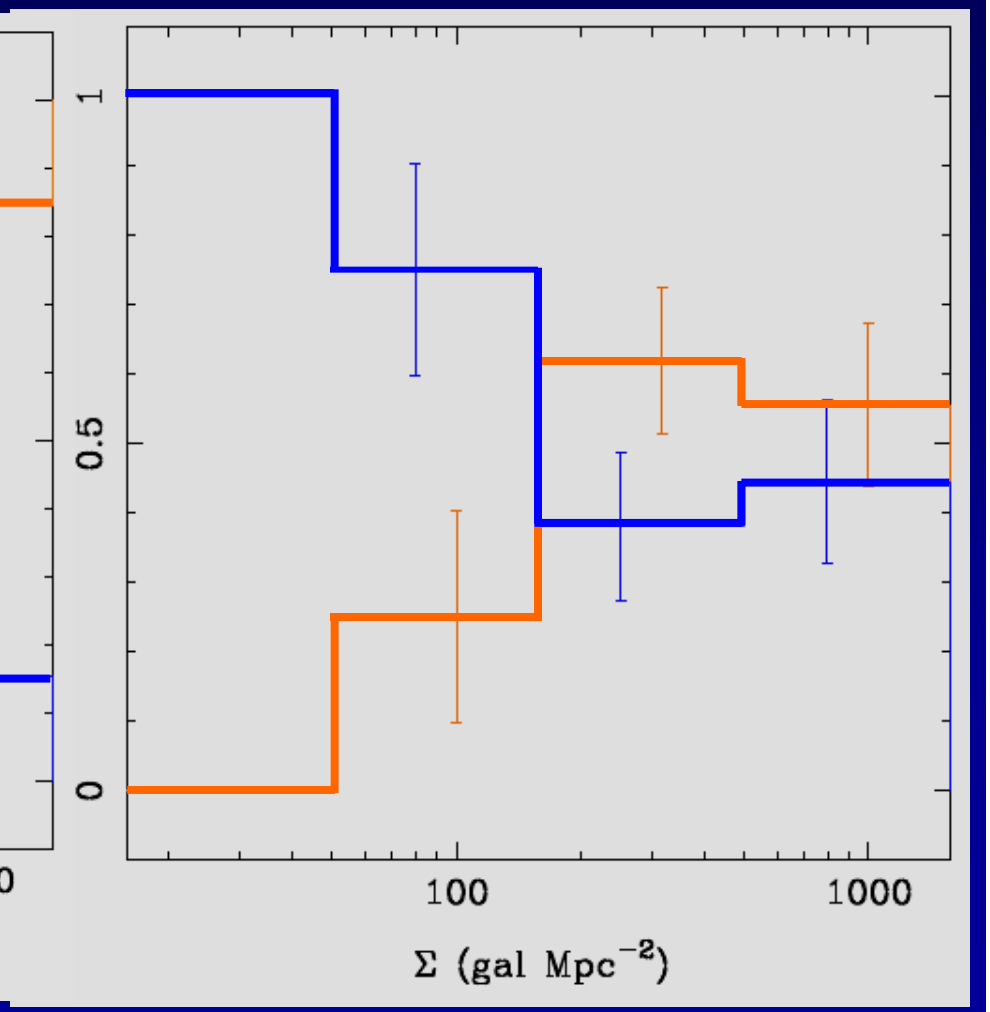
T - ∑ Relation vs. Galaxy Mass

HOLDEN ET AL. 2005, IN PREP.

Log(M) > 10.85

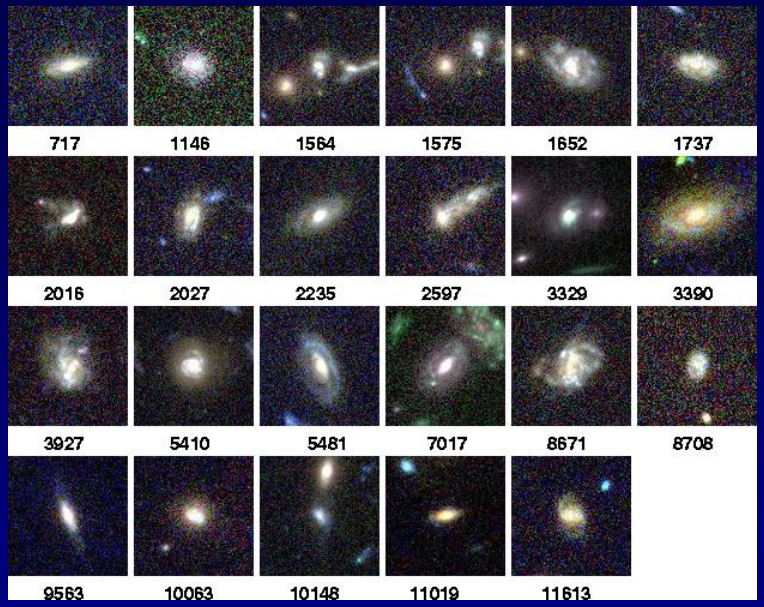


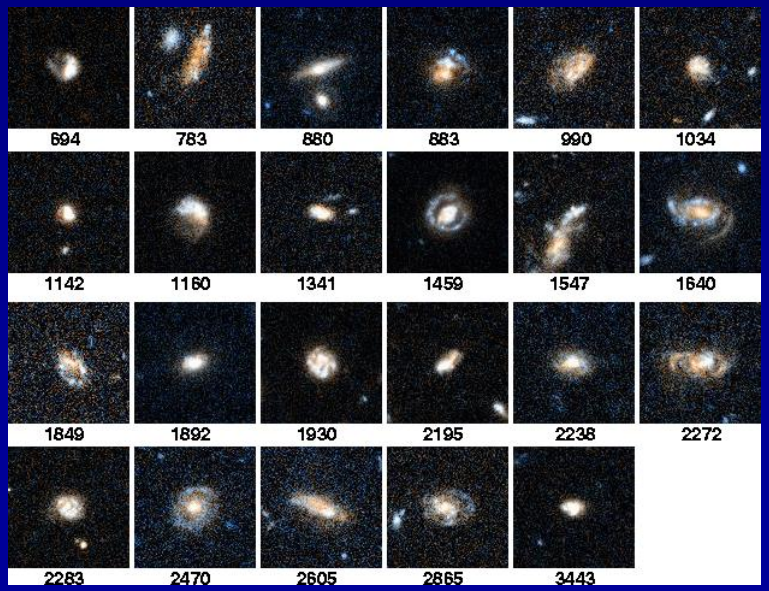
10.5 < Log(M) < 10.85

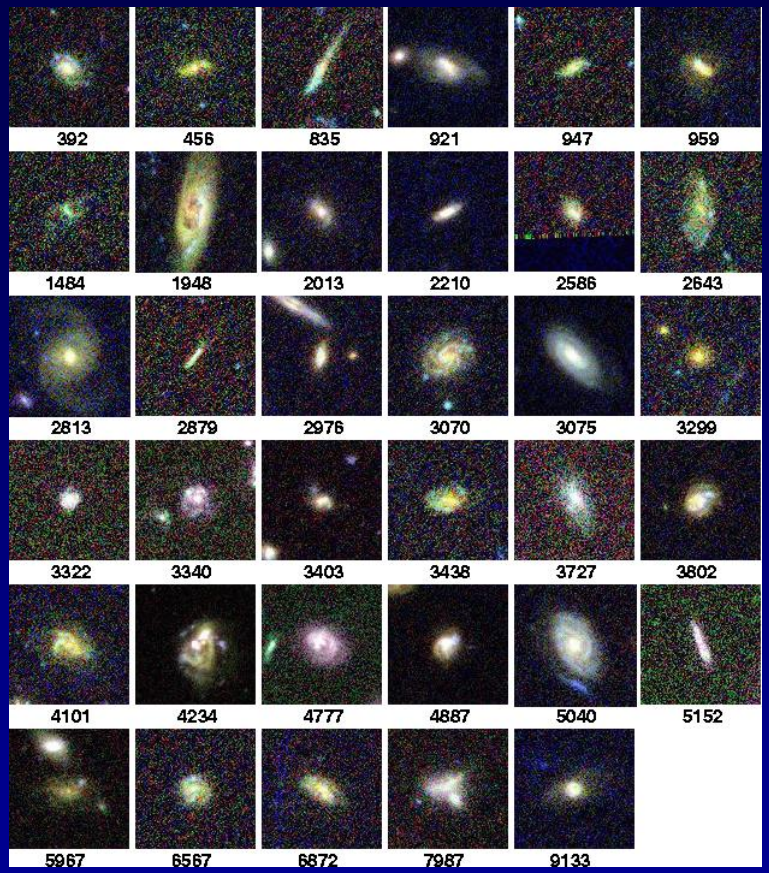


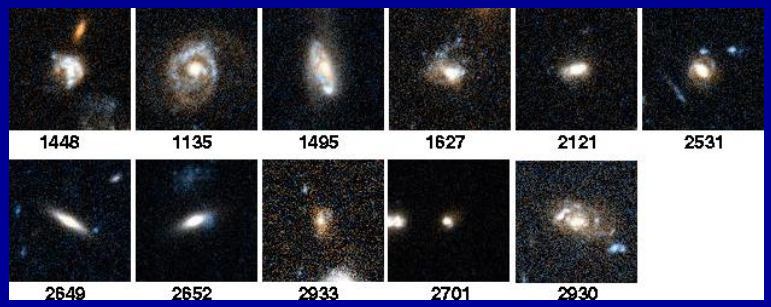
z ~ 1 Cluster Disk Galaxy Sample

Spectroscopically confirmed members with types Sa or later









z~1 Cluster Disk & SF Galaxy Properties

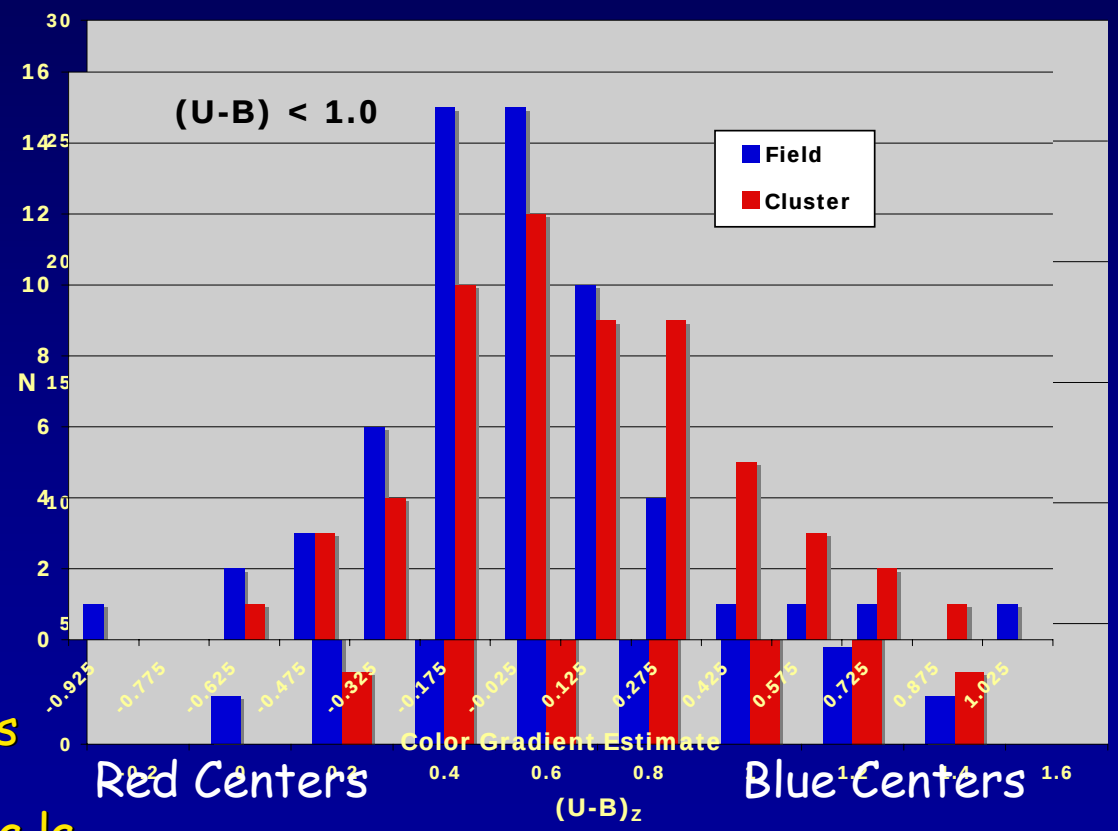
Homeier et al. 2005, Demarco et al. 2005, Homeier et al. 2005, in press.

- Cluster spirals are significantly redder their field counterparts
- But, their quantitative morphologies (C,A,S) are indistinguishable
- Sizes ($R_{1/2}$ or disk scale height) of cluster and field galaxies are similar

- Blue cluster disk galaxies show evidence (97% C.L.) for enhanced central star formation.

- Star forming cluster galaxies avoid densest regions. Most (~80%) are "normal" spirals. (a la Gisler 1978; Lewis et al. 2002; Gómez et al. 2003)

$$CGE = 10 \times \log (r_{red}/r_{blue})$$

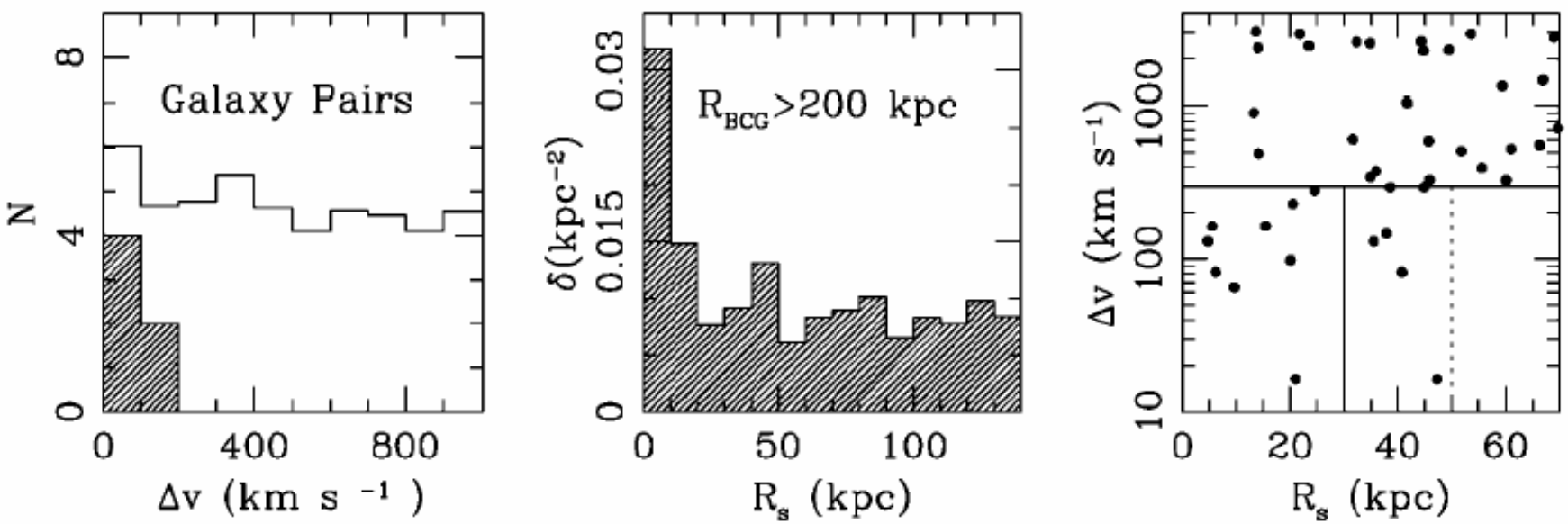


Close Pair Candidates

CL0152

MS1054

MS1054: A significent population of mergers
(van Dokkum et al. 2003 &Tran et al. 2005)

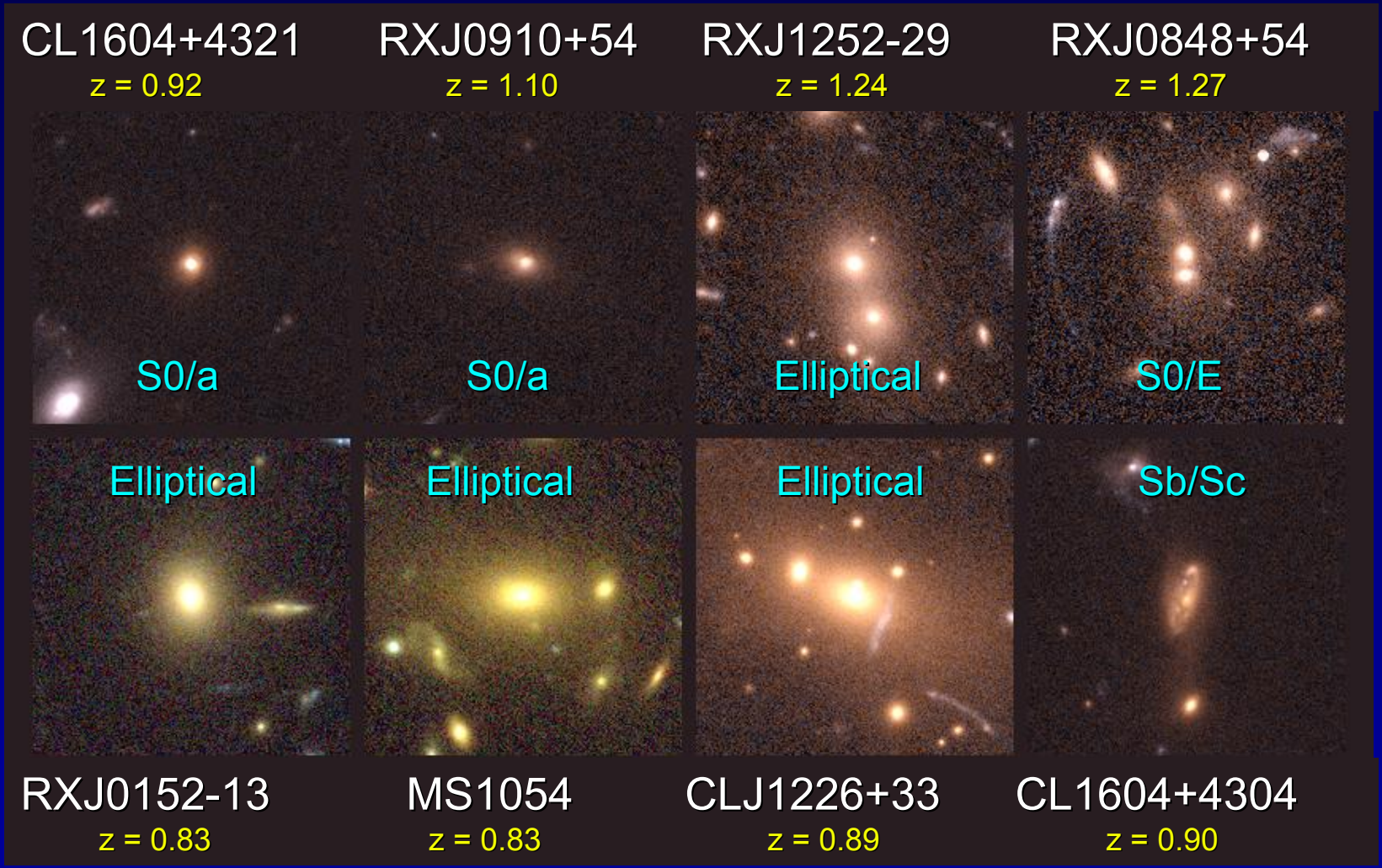


We find similar excesses in CL0152-1357 (z=0.83) and RXJ1252-2927 (z=1.24) but not in CL1226+33 (z=0.89) or any of our less massive (< few x 10^{14} M_{sol}) clusters.

Bartko et al. 2006, in prep

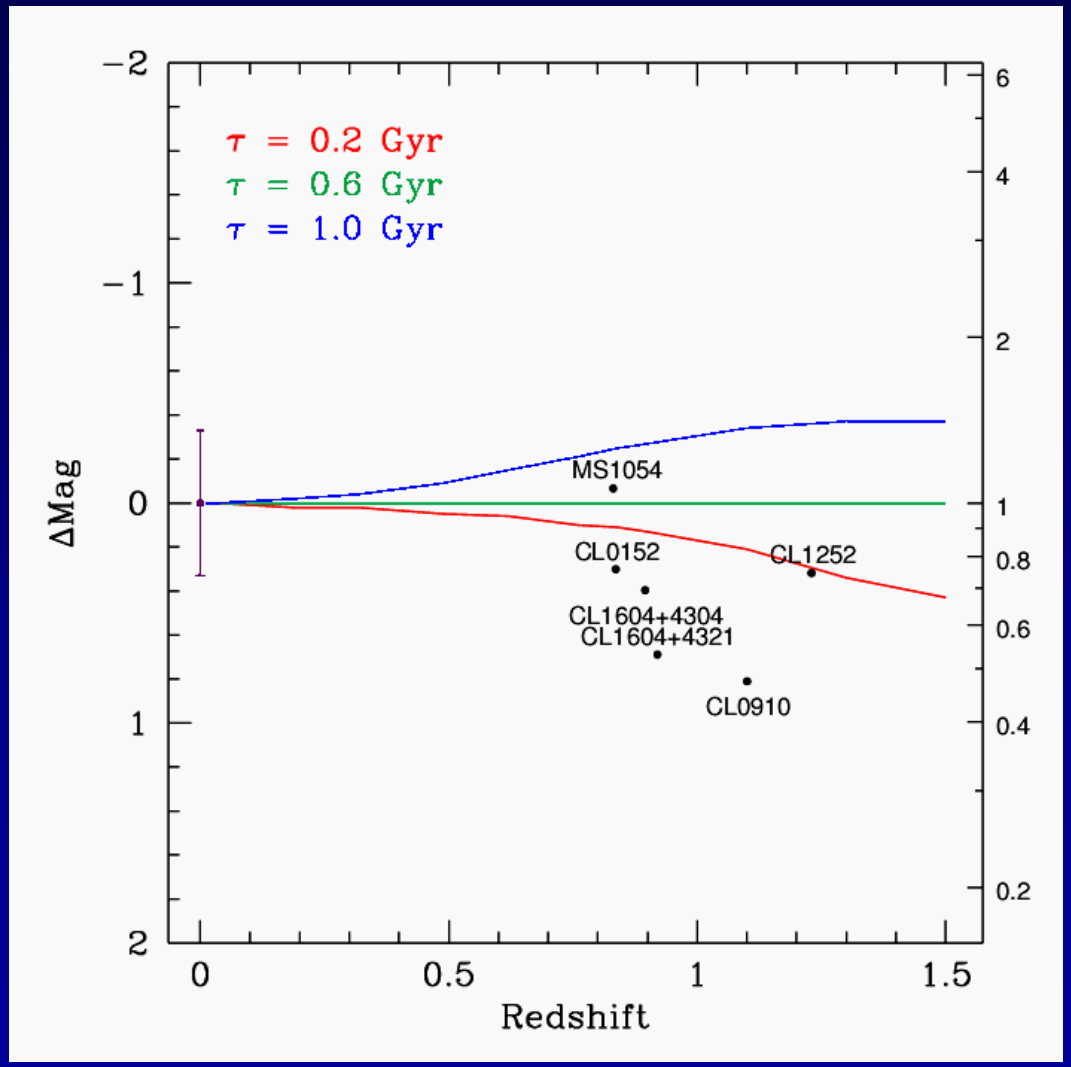
- Excess of red galaxy pairs appears to be a common (but not a universal) phenomenon associated with very dense environments at z ~ 1. It is not seen at lower z nor in less massive (<5 x 10^{14} solar masses) hi-z clusters. Caveat: small sample!
- Early type mergers confined to central regions. Late type merger fraction not strongly dependent on radius once beyond central 500 kpc or so.

Brightest Cluster Galaxies



BCG Luminosity Evolution

Postman et al. 2006, in prep.



z ~ 1 BCG exhibit a broader morphological distribution than their z=0 counterparts

M_2 - M_1 in the majority z~1 clusters is smaller (<0.35 mag) than that in ~85% of the z~0 rich Abell clusters

We thus expect many of these BCGs will undergo a doubling in mass by z~0.5 (e.g., RDCS1252-2927)

Implications for the Evolution of Cluster Galaxy Morphologies

- MDR is a fundamental relationship, not a simply consequence of mass-density relationship. But the formation of the most massive galaxies may be influenced by initial or large scale conditions.

- E and S0 populations likely have different formation histories. Up to 50% of S0's in high density regions could be in place by z~1. Work done at z ~ 0.5, shows a similar deficit of S0 galaxies (e.g., Dressler et al. 1997; Fasano et al. 2000). We are witnessing the "recent" build up of about half the cluster S0 population via the transformation of in-falling spiral galaxies.

- z ~ 1 Cluster spirals are not a "pristine" population - i.e., they already exhibit evidence for environmentally induced alteration of their stellar populations (relative to field galaxies at similar redshifts).

- However, a typical z=0 S0 is twice as massive as a typical z=1 cluster spiral. Additionally, z~1 BCGs show much more morphological and photometric variation than those at z=0. Many cannot be passively evolved to match current epoch BCG luminosities. Galaxy merging is likely an important process.