Lecture XI: Environmental effects on galaxies in clusters.

(main reference: Boselli & Gavazzi 2006)

Astrophysics of Galaxies 2019-2020

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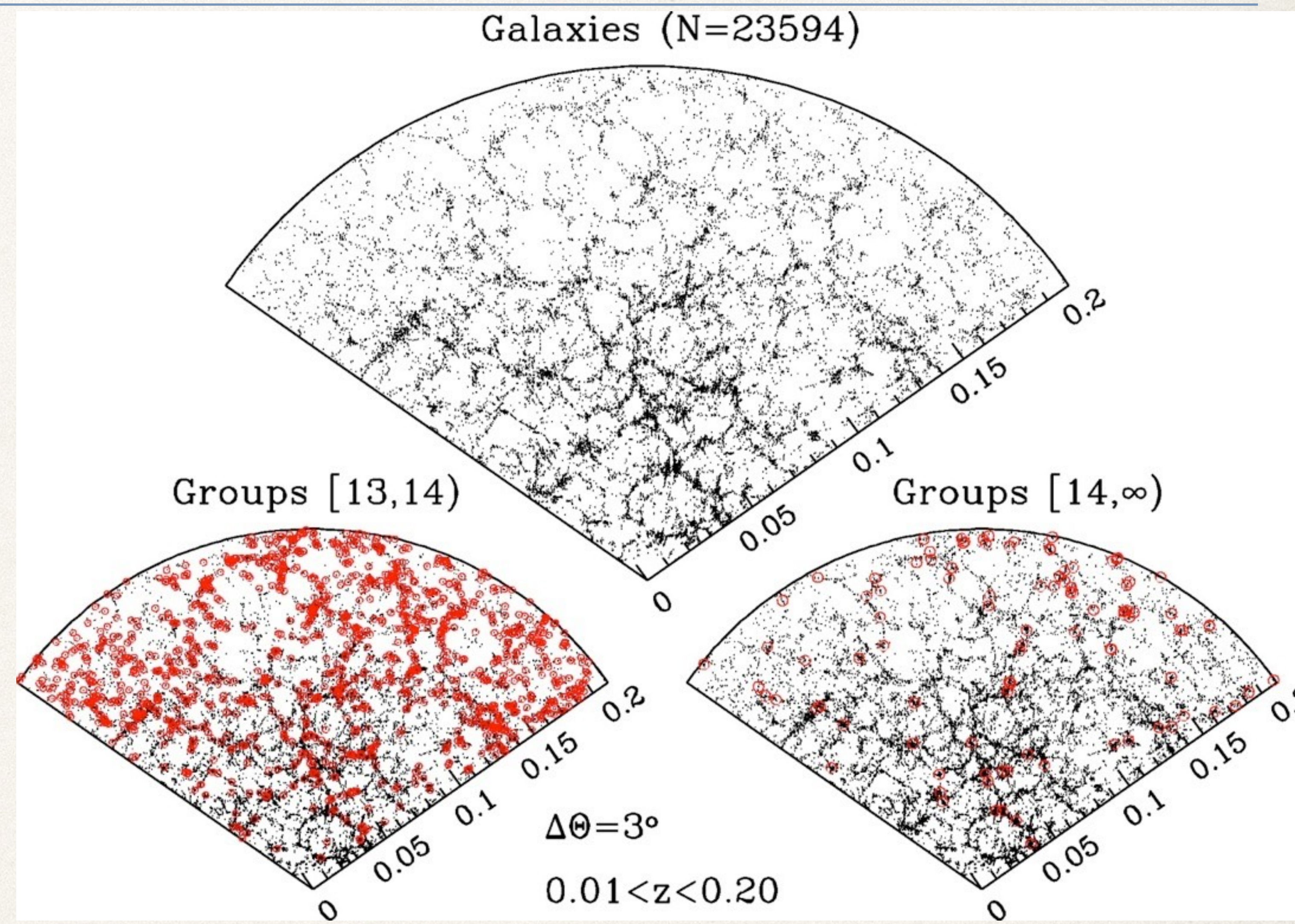
Cosmic web and galaxy clustering

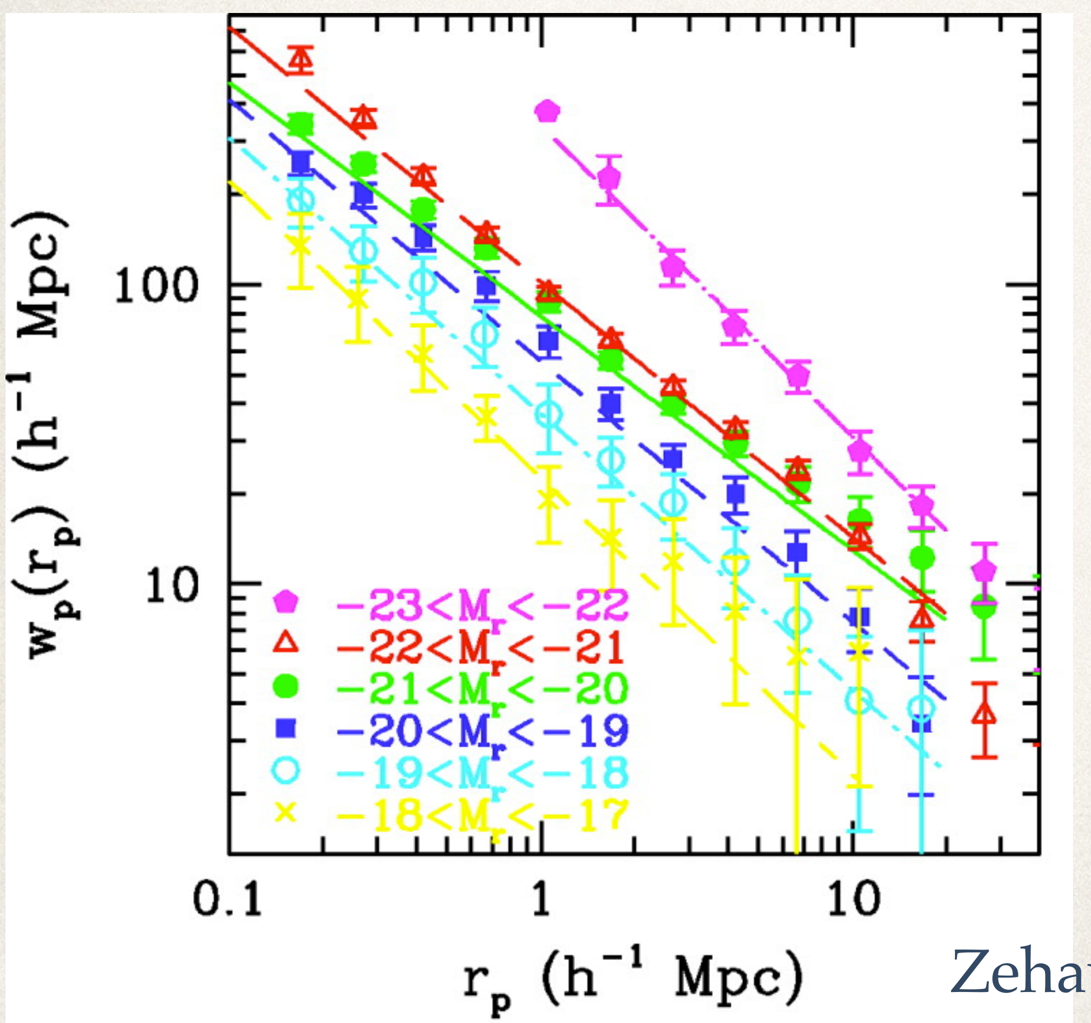
Yang et al. (2007, SDSS Group catalog)



- 2-point correlation function

$$dP = n[1+\xi(r)]dV.$$

$$dP = \mathcal{N}[1+w(\theta)]d\Omega,$$ projected



Zehavi et al. (2005)

$$\xi(r) = \left(\frac{r}{5.77h^{-1}\mathrm{Mpc}}\right)^{-1.80}$$ 3D real space

What is environment?

see Muldrew et al. (2011)

- Halo properties
  - mass, concentration
- Local density
- Large scale density
- Different methods:
  - Neighbors $\sigma_n = \frac{n}{\pi r_n^2}$
  - Aperture $\delta \equiv \frac{\delta\rho}{\rho} = \frac{N_g - \bar{N}_g}{\bar{N}_g}$
  - Multiscale analysis with annuli (probes different physical regimes: core, halo, outskirts, infall regions...)

Num.	Method	Author
	Neighbours	
1	Third nearest neighbour	Muldrew
2	Projected Voronoi	Podgorzec & Gray
3	Mean fourth and fifth nearest neighbours	Baldry[1]
4	Five-neighbour cylinder	Li[2]
5	Seventh projected nearest neighbour	Ann
6	10-neighbour Bayesian metric	Cowan[3]
7	20-neighbour smooth density	Choi & Park[4]
8	64-neighbour smooth density	Pearce
	Aperture	
9	$1\,h^{-1}$ Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Grützbauch & Conselice[5]
10	$2\,h^{-1}$ Mpc ($\pm 500\,\mathrm{km\,s^{-1}}$)	Gallazzi[6]
11	$2\,h^{-1}$ Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Grützbauch & Conselice
12	$2\,h^{-1}$ Mpc ($\pm 6000\,\mathrm{km\,s^{-1}}$)	Gallazzi[6]
13	$5\,h^{-1}$ Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Grützbauch & Conselice
14	$8\,h^{-1}$ Mpc spherical	Croton[7]
	Annulus	
15	0.5–1.0 h^{-1} Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
16	0.5–2.0 h^{-1} Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
17	0.5–3.0 h^{-1} Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
18	1.0–2.0 h^{-1} Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
19	1.0–3.0 h^{-1} Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]
20	2.0–3.0 h^{-1} Mpc ($\pm 1000\,\mathrm{km\,s^{-1}}$)	Wilman & Zibetti[8]

Central vs. satellite galaxies

- Galaxies are born in their own DM halo
- Halos grow hierarchically
    - some galaxies merge with the central one of the main halo
    - some are accreted as satellites (likely dissolving their own DM halo in the main halo)
- Central and satellites experience different kind of interactions with the environment
- New approach: large spectroscopic surveys required!

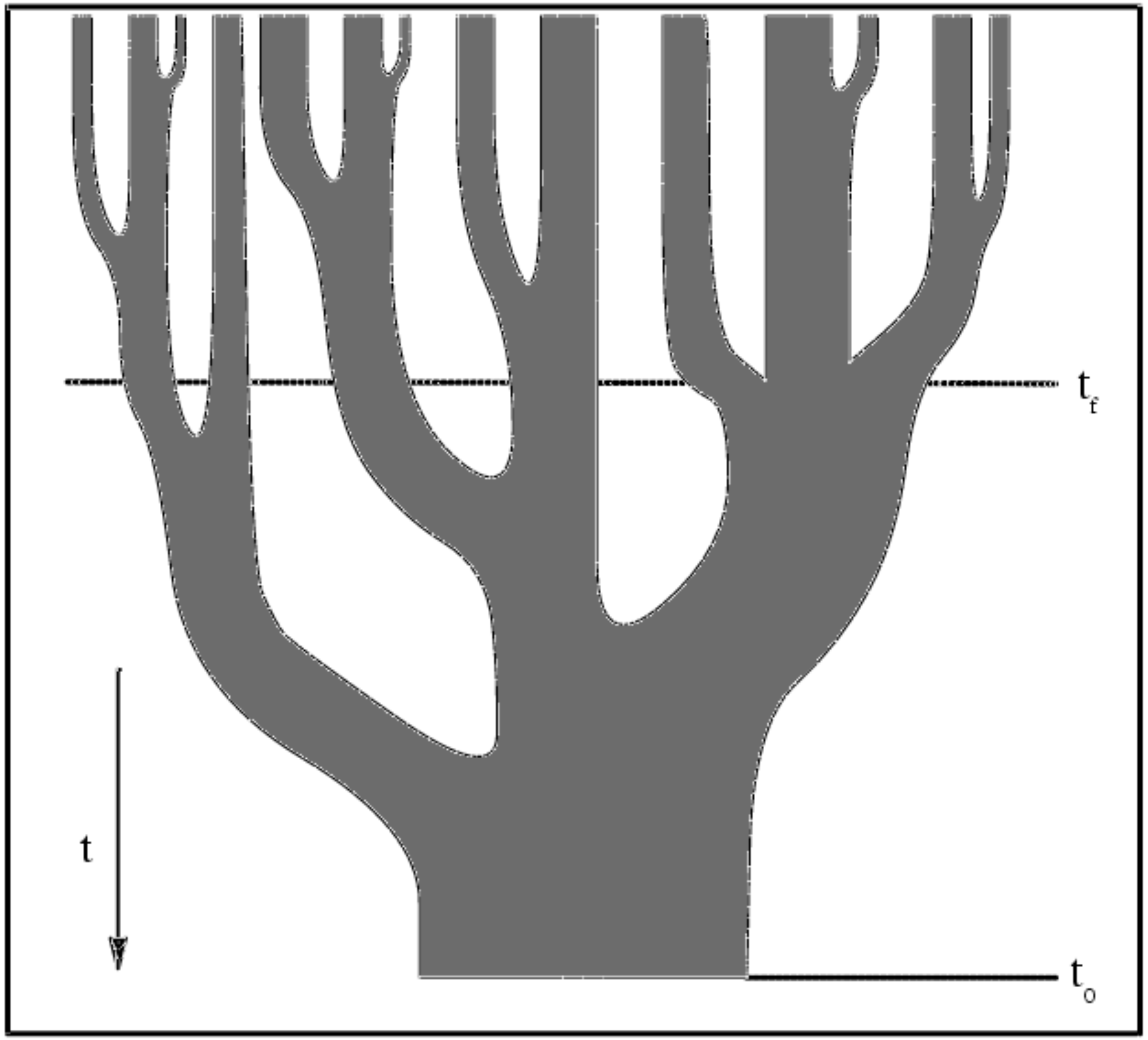
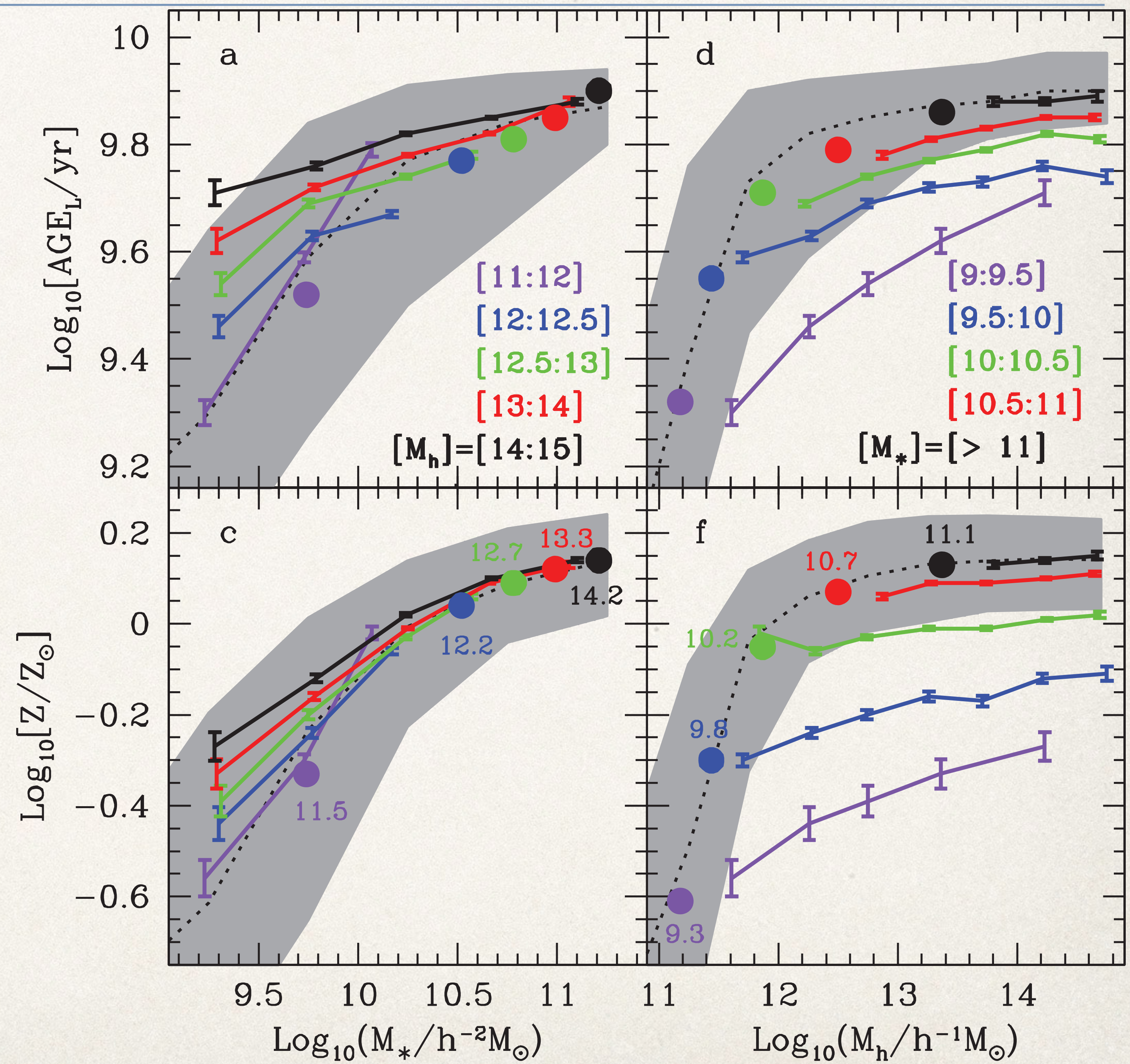


Figure 6. A schematic representation of a "merger tree" depicting the growth of a halo as the result of a series of mergers. Time increases from top to bottom in this figure and the widths of the branches of the tree represent the masses of the individual parent halos. Slicing through the tree horizontally gives the distribution of masses in the parent halos at a given time. The present time t_0 and the formation time t_f are marked by horizontal lines, where the formation time is defined as the time at which a parent halo containing in excess of half of the mass of the final halo was first created.

Lacey & Cole (1996)

Systematic differences between satellite and central galaxies

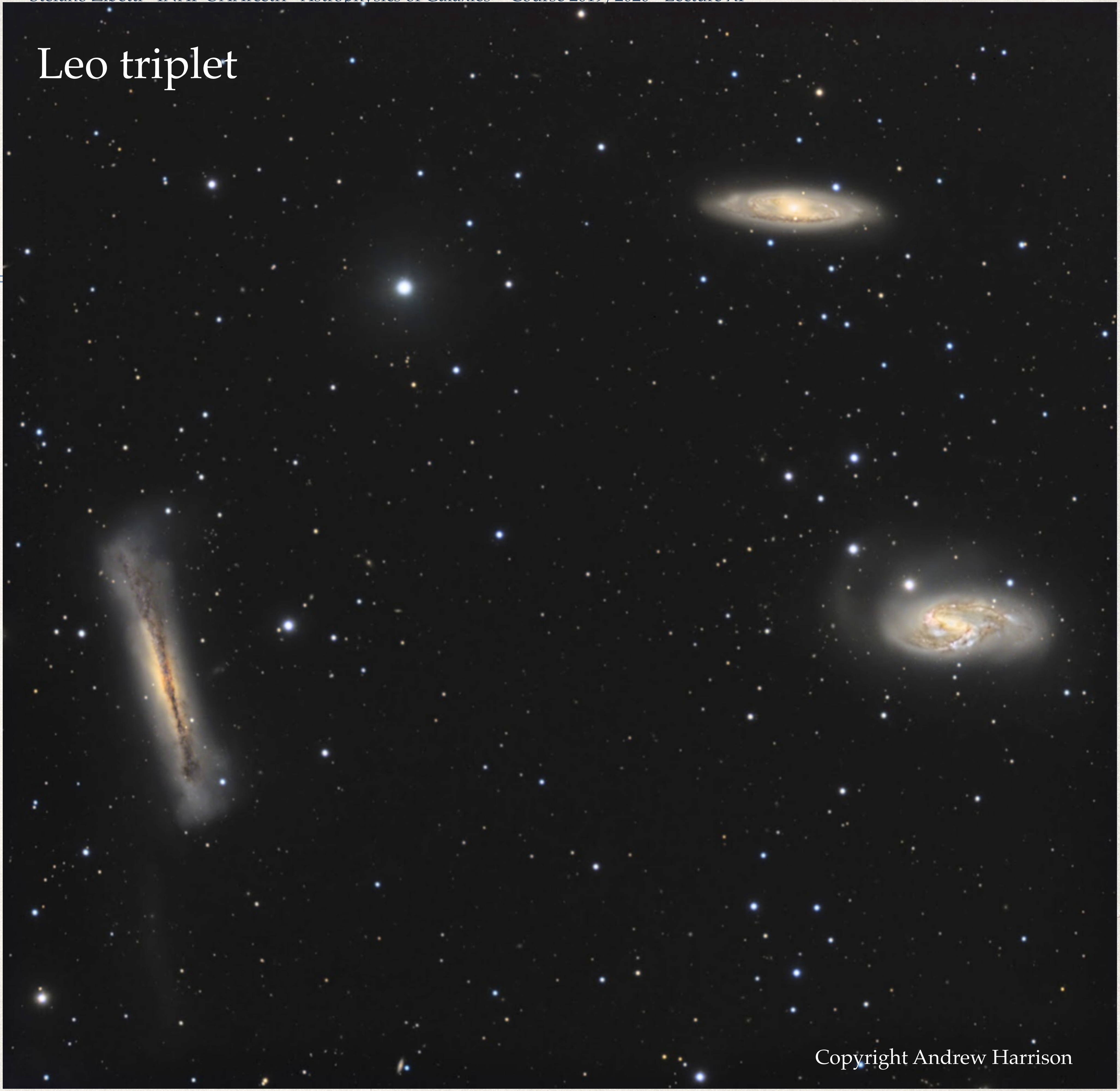
- Easily seen after the main dependence on stellar mass is removed
- Satellite galaxies systematically differ from central galaxies at given stellar mass, being older and more metal rich (more for more massive halos)
- Less massive galaxies suffer much more from the environmental effects



Pasquali, Gallazzi et al. (2010)

The morphology-density relation

A small group



A cluster ~10^{14} $M_{\odot}$: Virgo

A BIG cluster ~10^{15} $M_{\odot}$: Coma

The morphology-density relation

Dressler (1980)

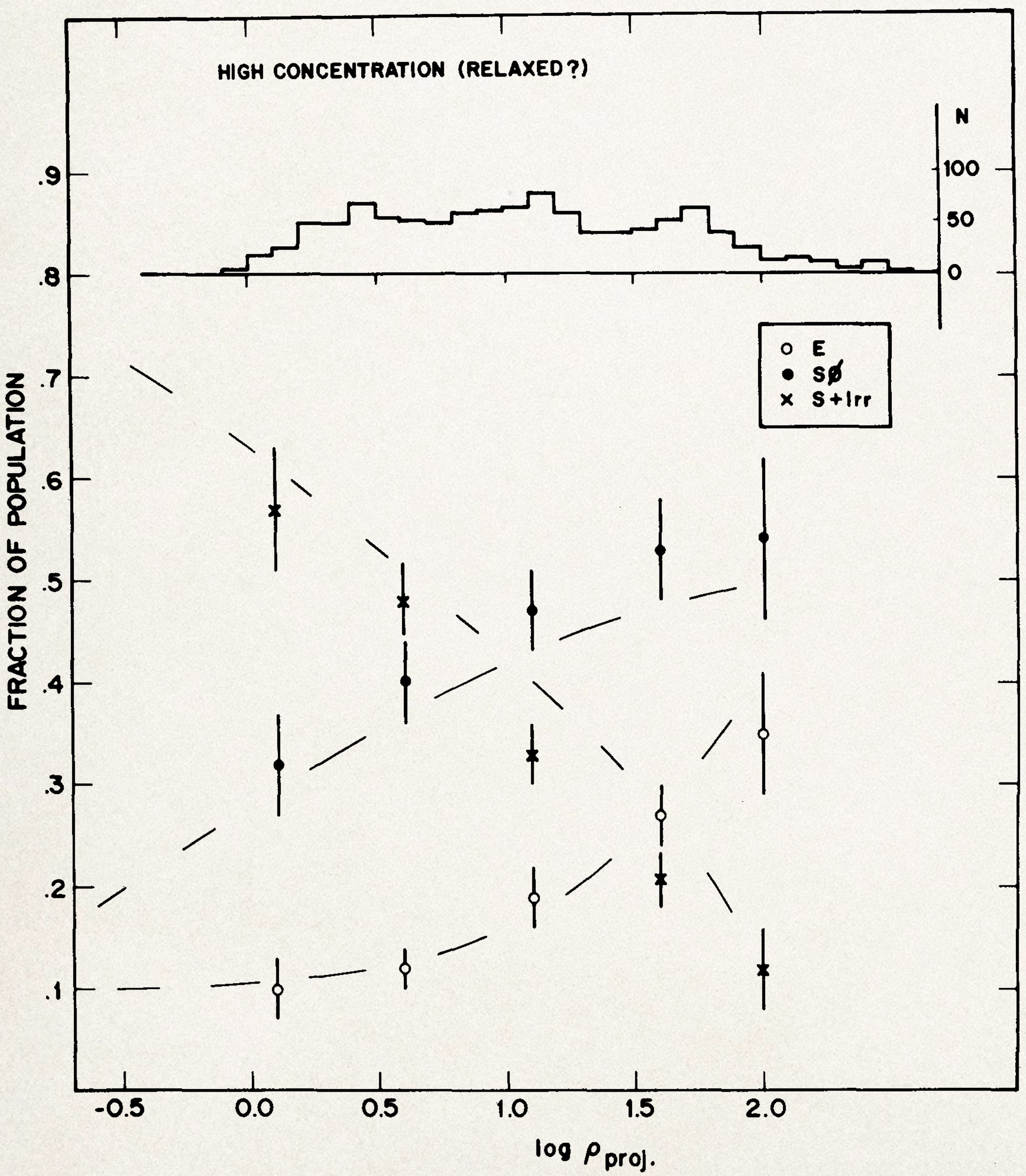


FIG. 8.—High-concentration clusters (A151, A539, A957, A1656, A1913, A2040, A2063, 0247−31, 0428+53, 1842−63).

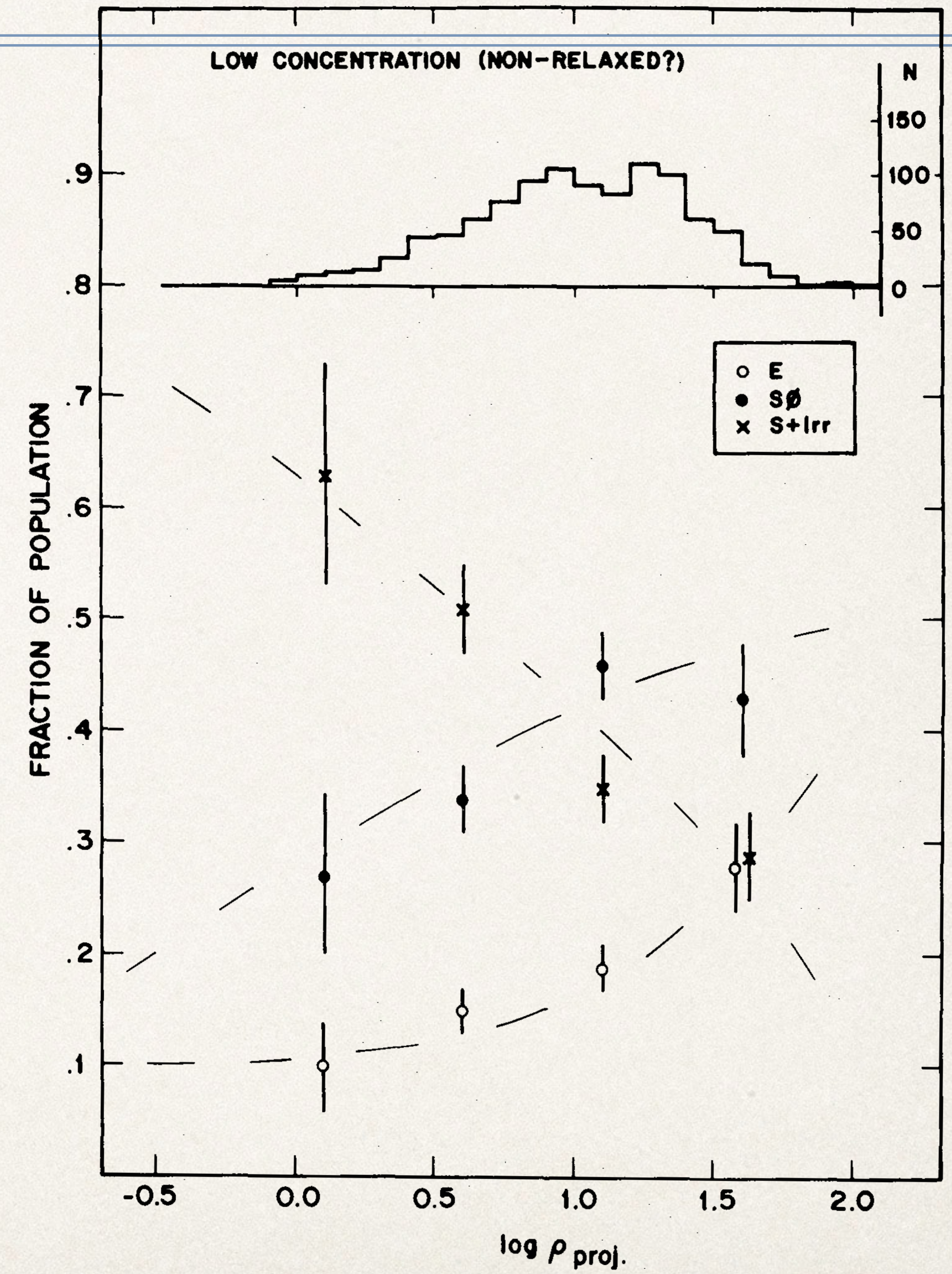
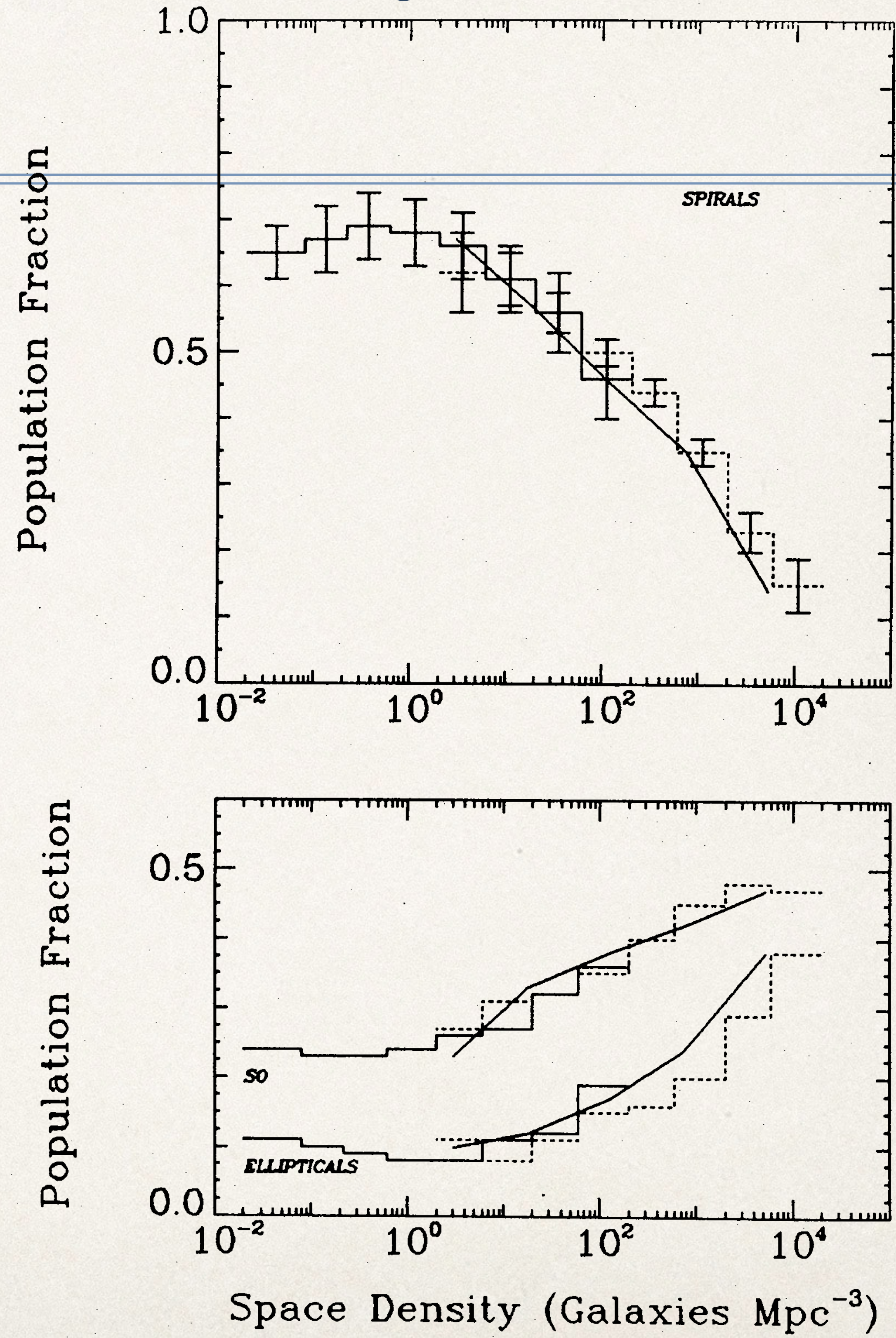


FIG. 9.—Low-concentration clusters (A76, A119, A168, A978, A979, A1644, A1736, A2151, 0030−50).

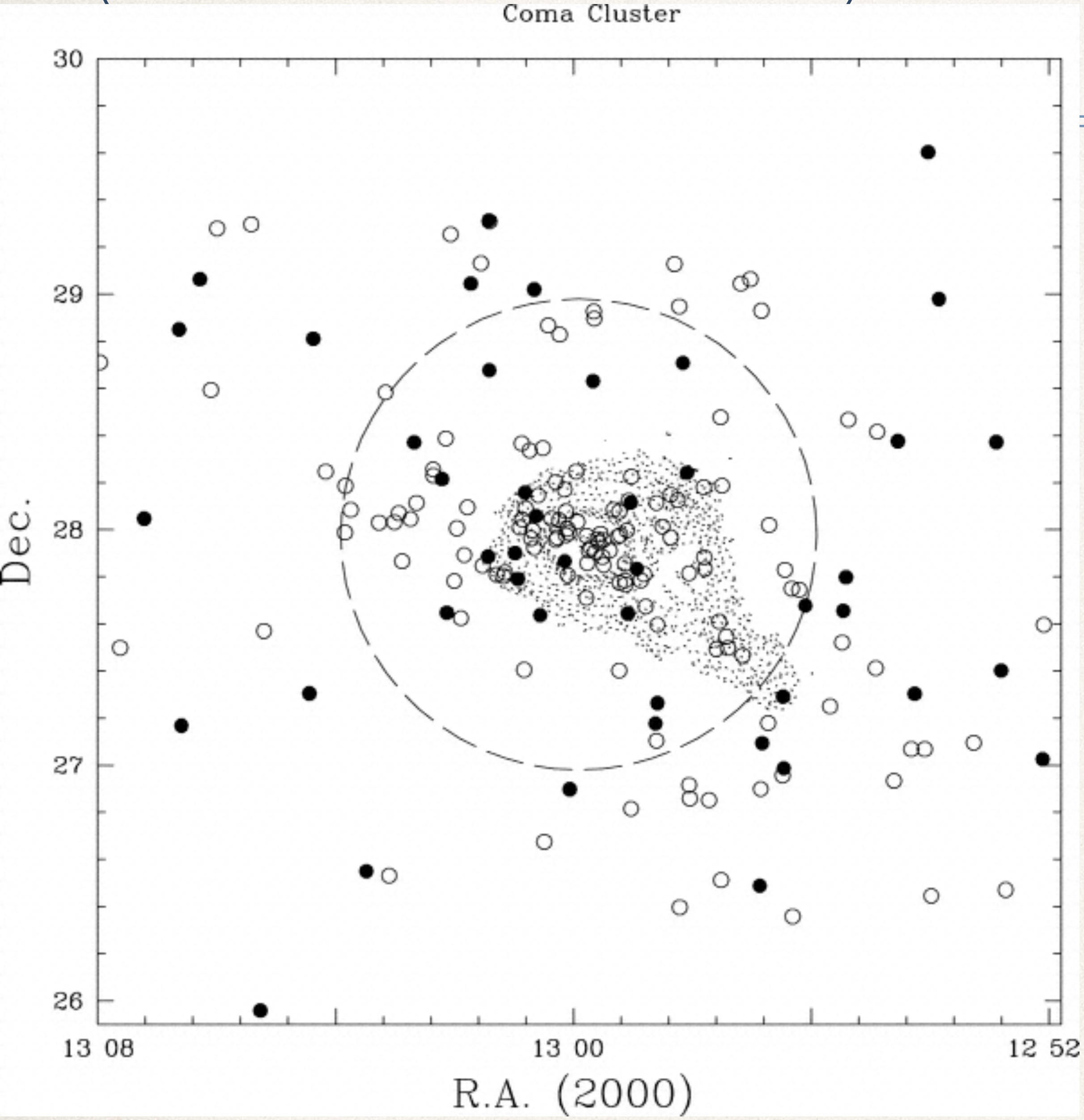
The morphology-density relation

- Over 6 orders of magnitude in density, covering field, groups and clusters

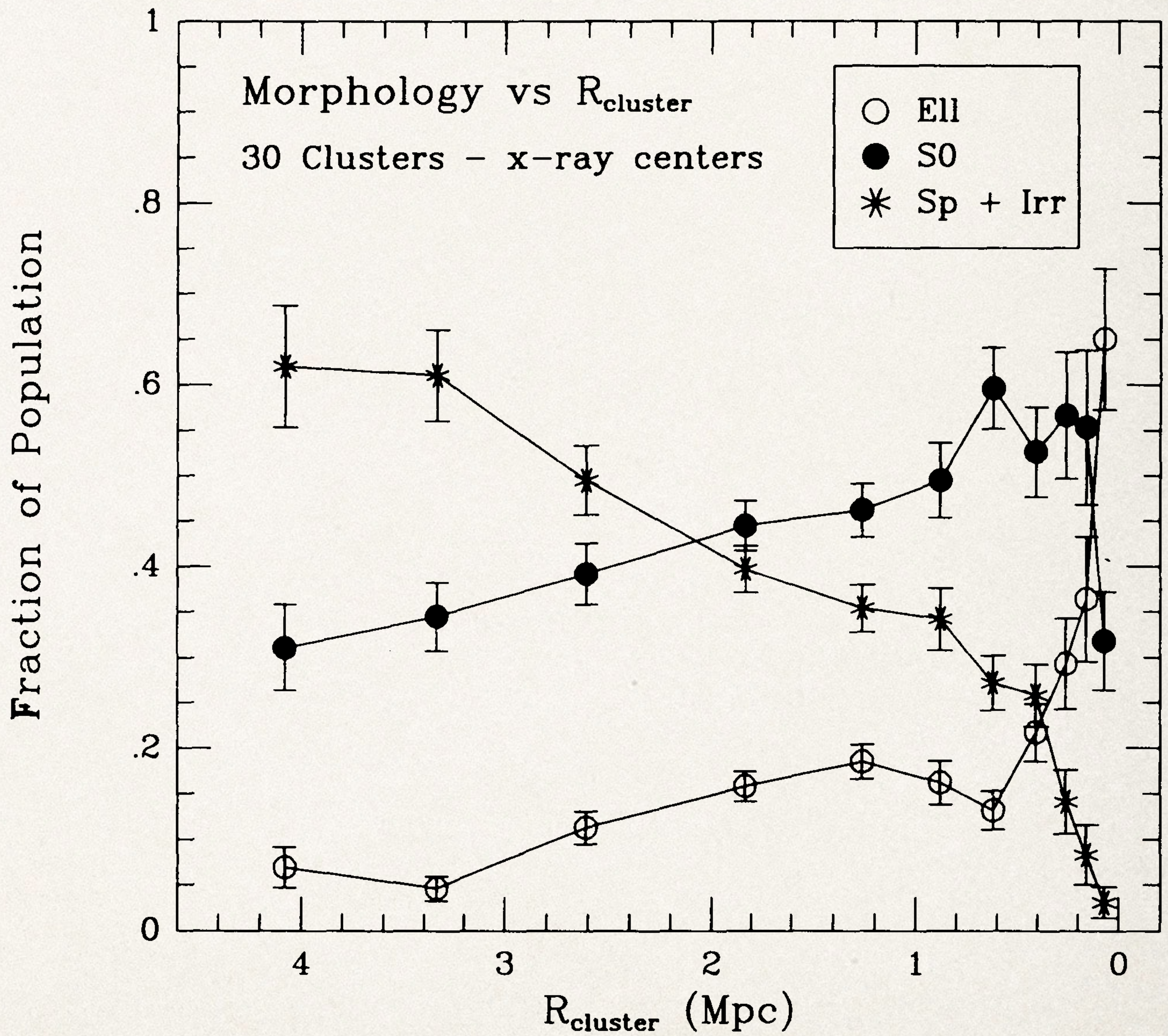


Postman & Geller (1984)

The morphology-radius relation (in clusters!)



Whitmore et al. (1993)



Celestial distribution of galaxies brighter than 15.7 from the Catalogue of Galaxies and of Clusters of Galaxies (Zwicky et al. 1968) in a 4 × 4 deg^2 box around the Coma Cluster. The 146 early−type (E+S0+S0a) galaxies (*open circles*) clearly mark the cluster density enhancement, whereas the 49 late−type (≥Sa) objects (including 10 unclassified spirals; *filled circles*) hardly trace the cluster. A 1° radius circle is traced about the X−ray center. The X−ray contours from *XMM−Newton* are superposed.

Boselli & Gavazzi (2006)

Morphology segregation

- Well established dependence of the fraction of morphological types on density (or clustercentric radius, which is largely correlated to density)

- Appears to “saturate” at large densities
- Fraction of spirals decreases further in more X-ray-luminous clusters
- Appearance of cluster-specific type: dE

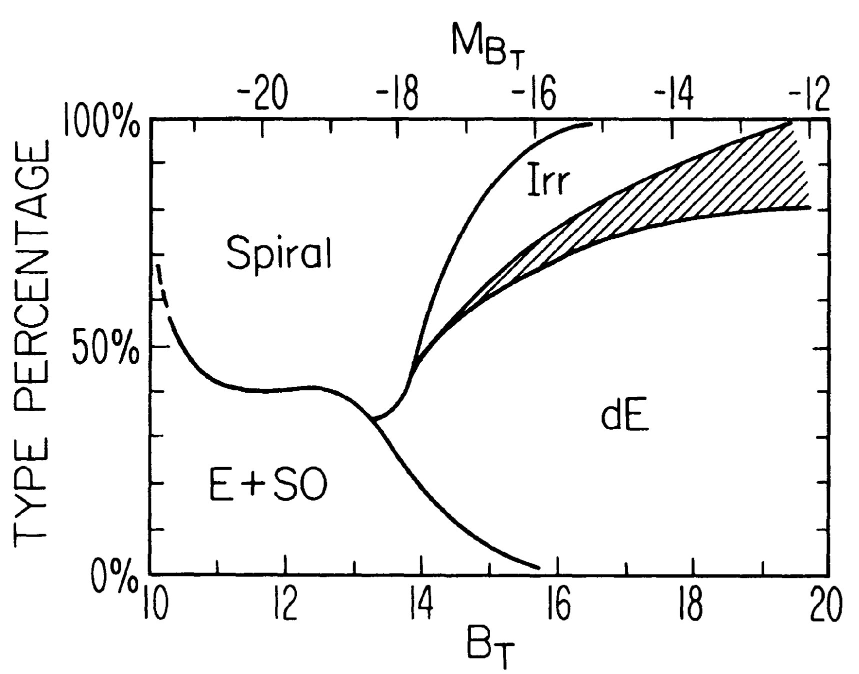
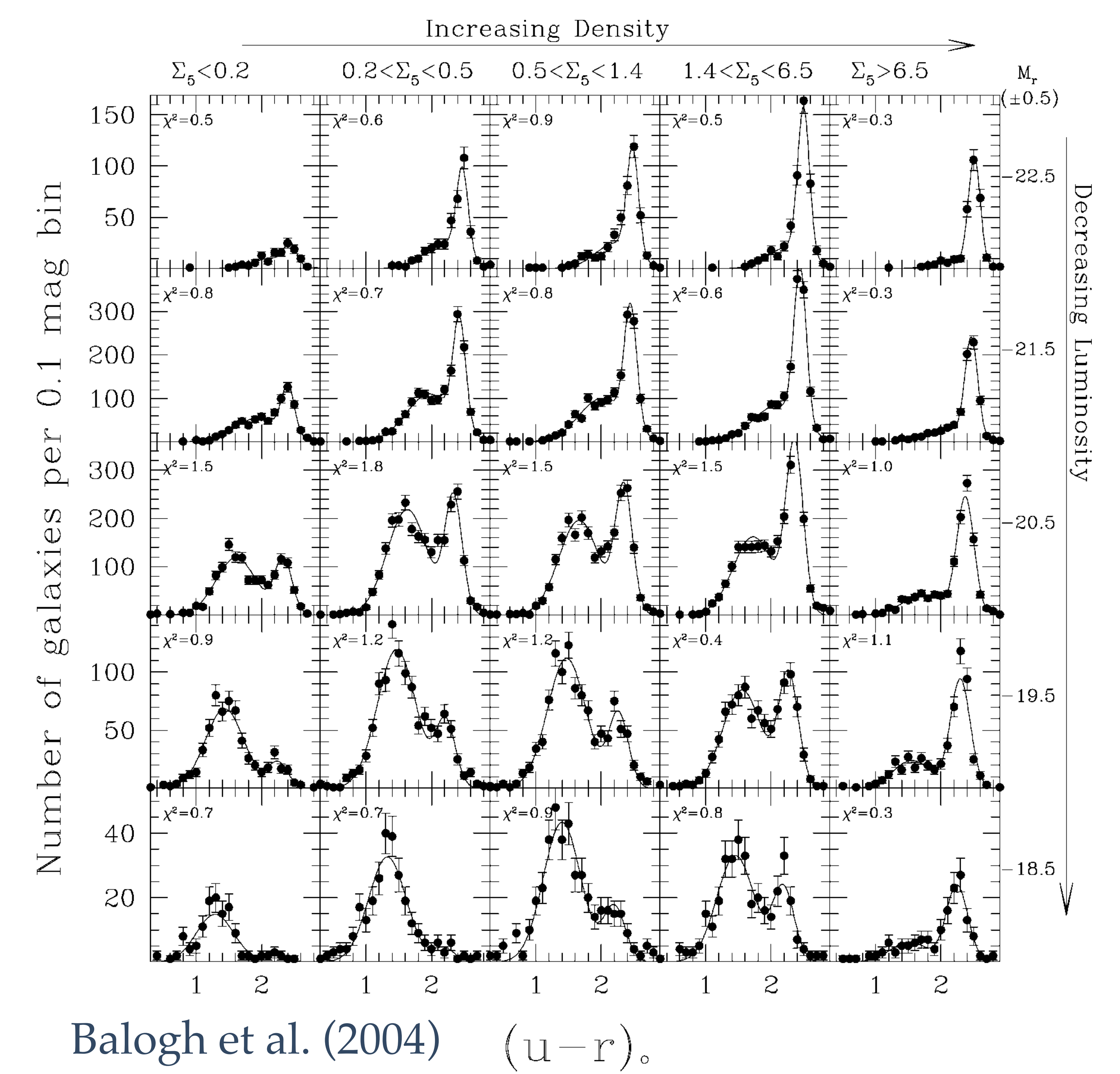


FIG. 22. Variation of the percentage of morphological types with absolute magnitude in the standard sample. The hatched area represents dwarf galaxies that are either hard to classify or are a real transition between the dE and the Im types.

Sandage, Binggeli & Tamman (1985)

The color density-relation



Balogh et al. (2004)

The SFR-density relation

Gómez et al. (2003, SDSS)

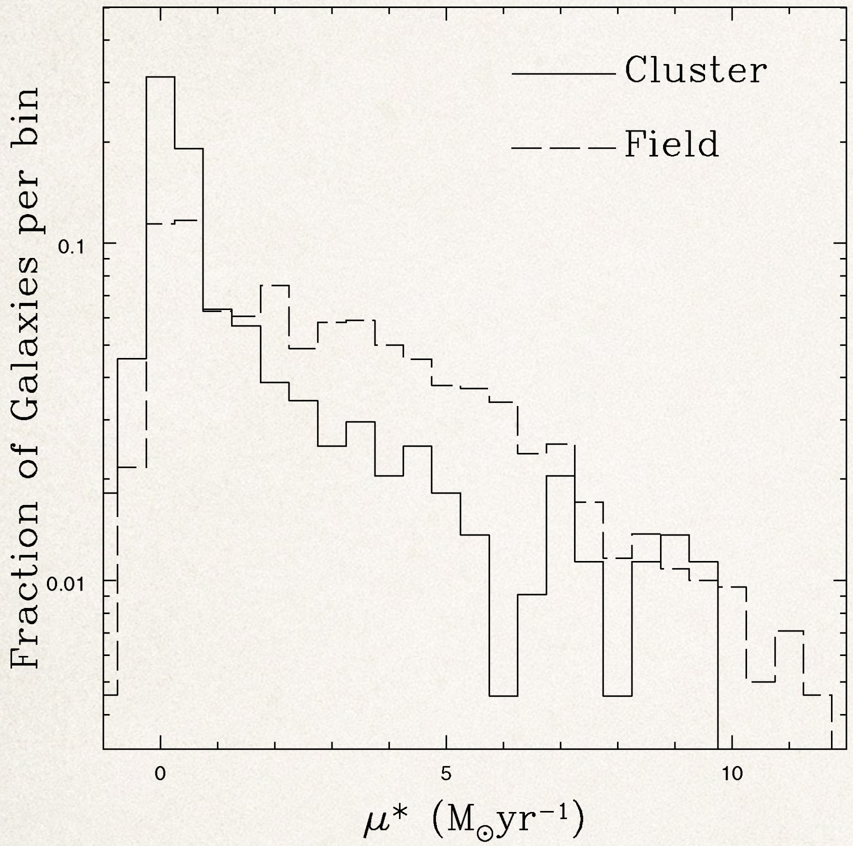
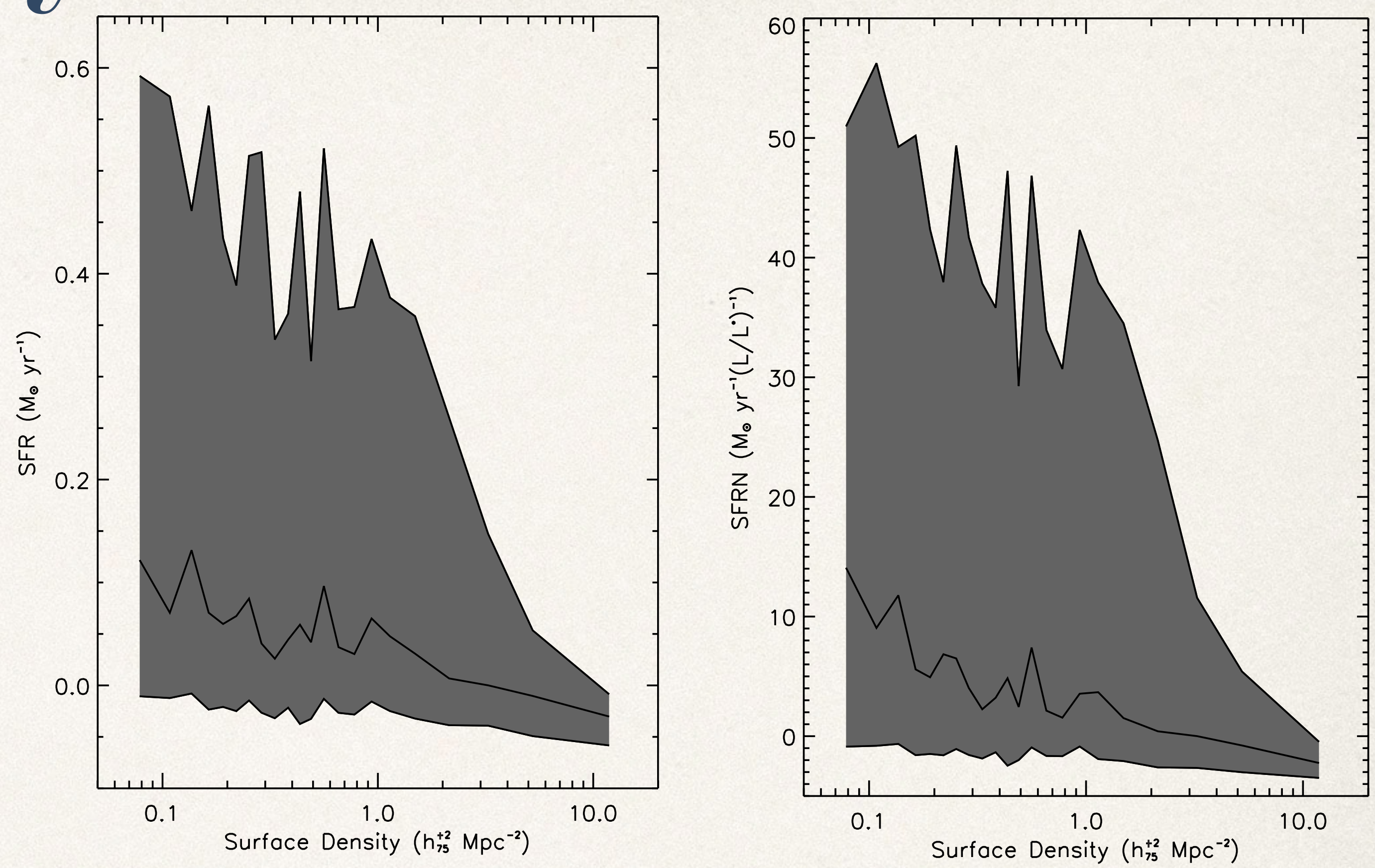
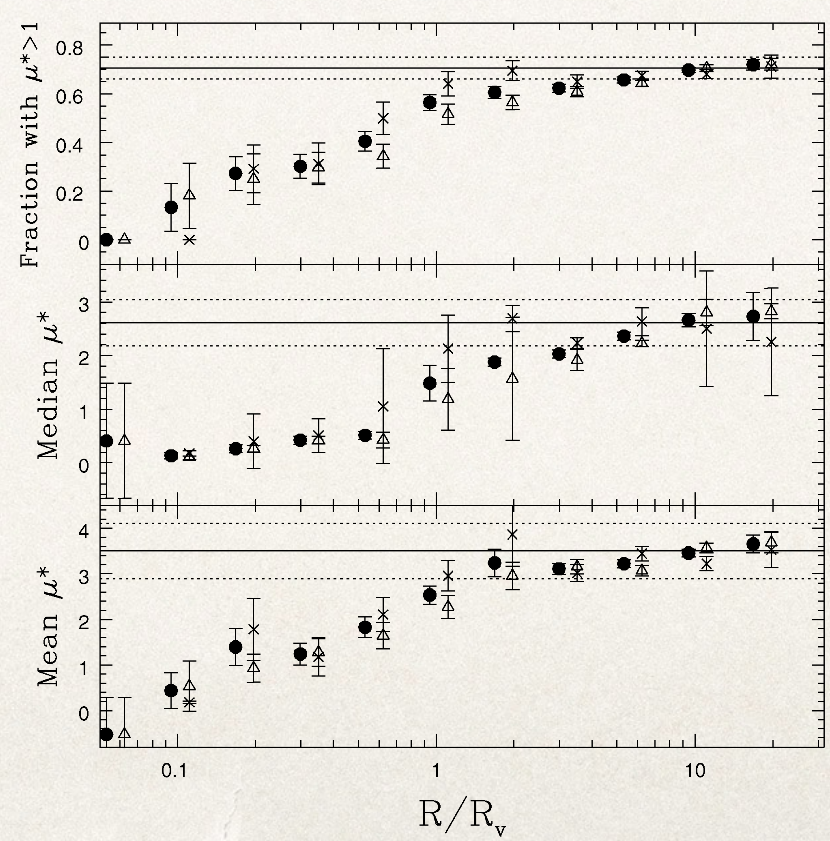


Figure 5. The distribution of star formation rate per unit luminosity, in the cluster and field samples. The cluster sample is limited to galaxies within the virial radius.

Lewis et al. (2002, 2dF)



Negative tail due to stellar absorption



Clusters as evolutionary labs

- Environmental effects reach their maximum intensity
- Very high galaxy density
- Very high IGM density and temperature
- Evolution has proceeded extremely fast
- Probably not ideal for studying galaxy-galaxy interactions/mergers due to the very high velocity dispersion (~1000 km/s); smaller groups are better suited for this

The realm of dwarf galaxies

- Some process(es) heavily affect the structure of galaxies, to the point that a cluster-specific population of galaxies emerges: the dwarf ellipticals (dE)

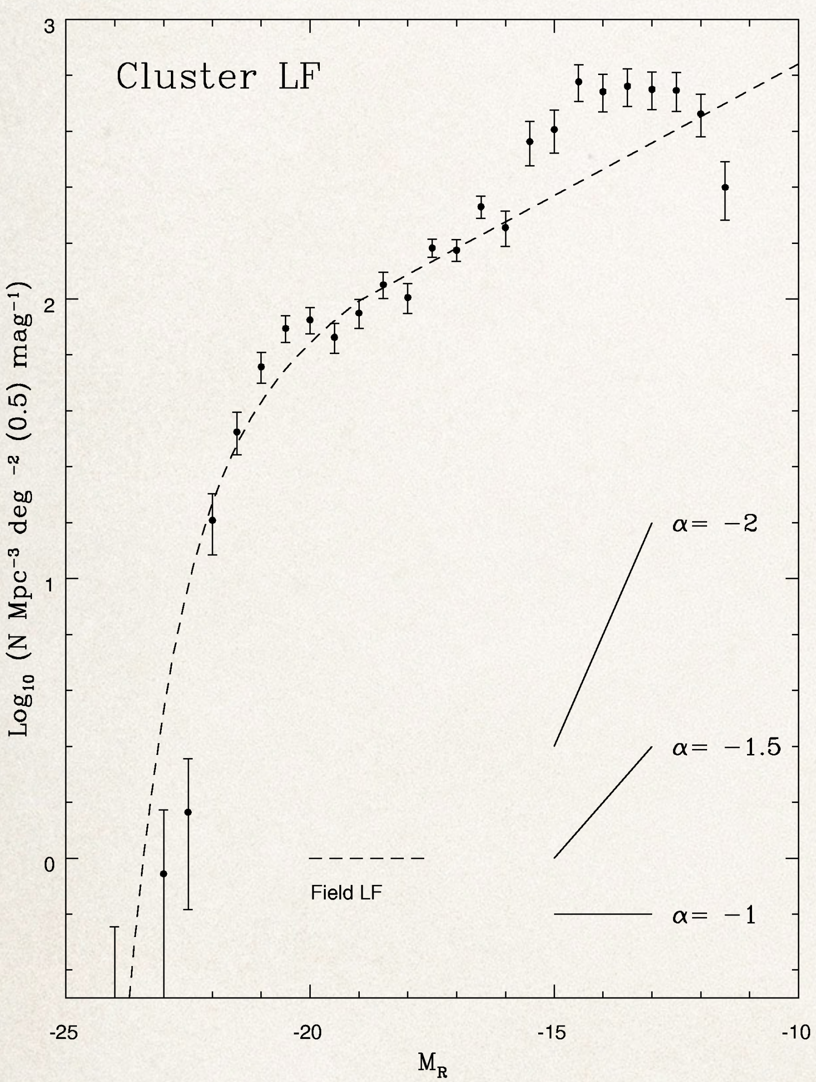


Figure 8. The galaxy cluster LF, computed as described as in the text. The normalization is arbitrarily chosen to be that appropriate for the Coma cluster at $M_R = -21$. The dashed line is the best-fitting field LF, which we approximate by a Schechter function with $M_R^* = -22.0$ and $\alpha^* = -1.28$ brightward of $M_R = -19$ and a power law with $\alpha = -1.24$ faintward of $M_R = -19$.

Trentham et al. (2005)

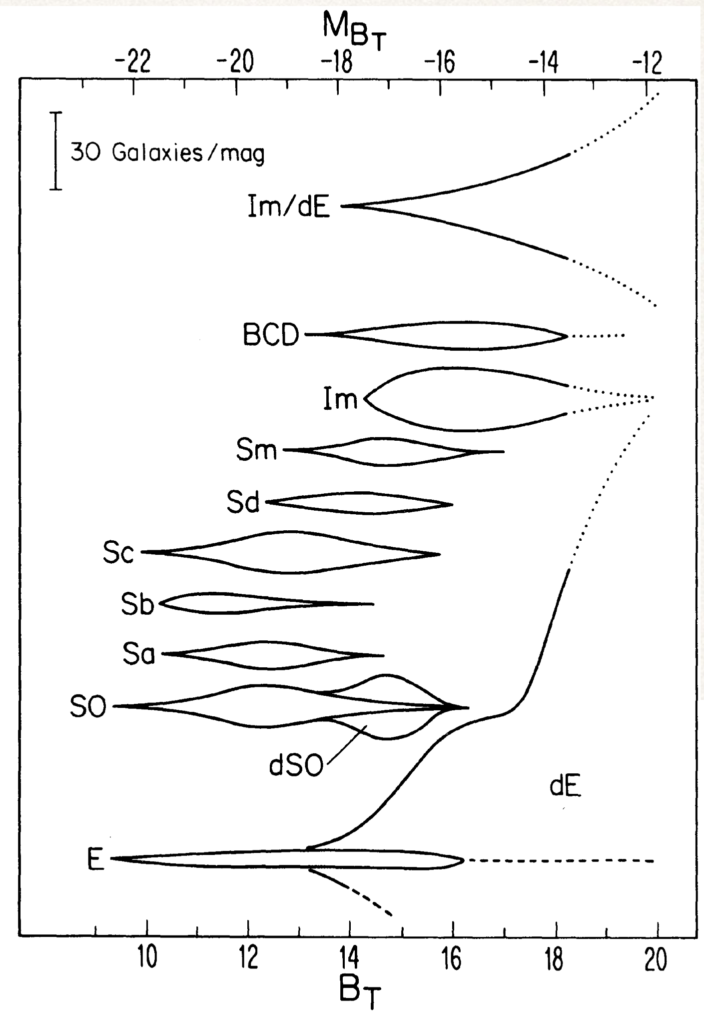


FIG. 21. Schematic $\phi(M)$ distributions for the main types. Closed figures show LF's that go to zero at both the bright and the faint ends. The two open figures for Im/dE and for dE show exponentially increasing LF's.

Credits Mihos (CWRU), Jerjen

Sandage, Binggeli & Tamman (1985)

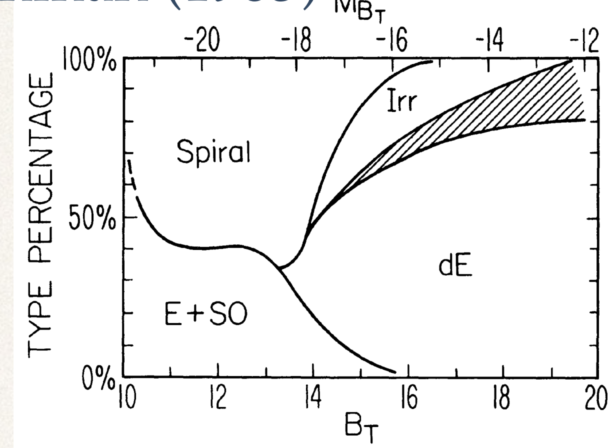
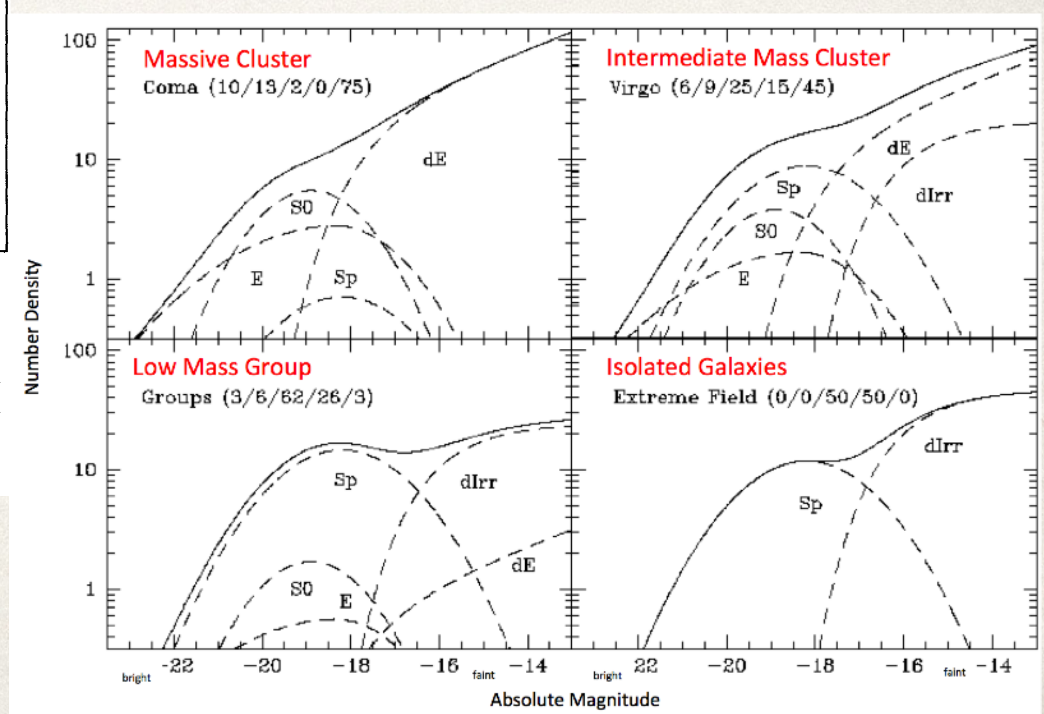


FIG. 22. Variation of the percentage of morphological types with absolute magnitude in the standard sample. The hatched area represents dwarf galaxies that are either hard to classify or are a real transition between the dE and the Im types.



Properties of late-type galaxies in clusters at z~0

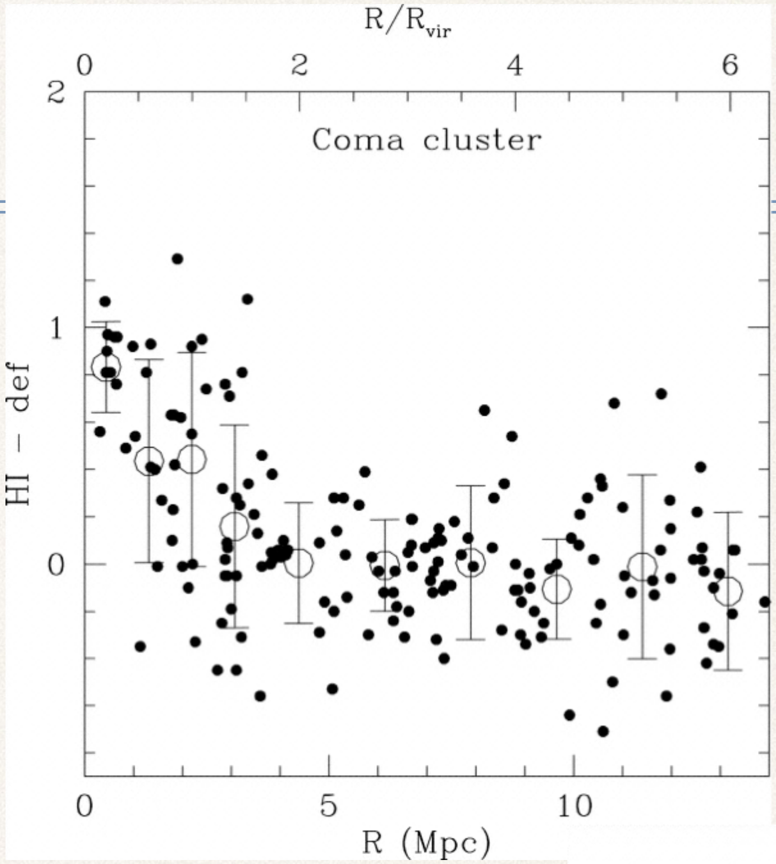
- Late-type galaxies are the most affected by the harsh cluster environment
- Most likely in the process of being transformed, but not fully transformed yet (since they retain the late-type morphology)
- Are they different from field late-types?
- What indications do they give about the transformation mechanisms?

HI properties

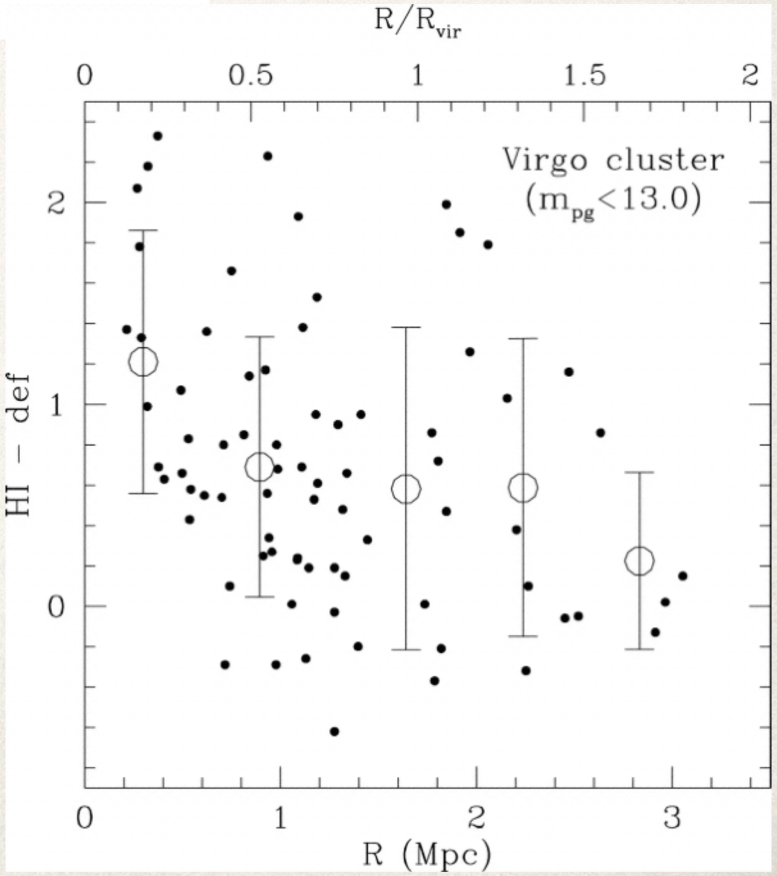
- In normal, isolated galaxies, the HI gas distribution extends beyond the optical disk
  - column densities ~10^{20} atoms cm^{-2} observed at ~1.8 times the optical diameter, with a relatively flat radial distribution that sometimes shows a central dip
- weakly bound and easy(ier) to remove than other components
- in fact, cluster galaxies have lower HI content than in field

HI properties

- HI deficiency parameter *def*(HI)= logarithmic difference between the observed HI mass and the expected value in isolated objects of similar morphological type and linear size (Haynes & Giovanelli, 1984)
- Galaxies with *def*(HI) ≤0.3 can be treated as unperturbed objects
- Large fraction of HI-deficient galaxies in clusters
  - typically display truncated or disturbed morphology



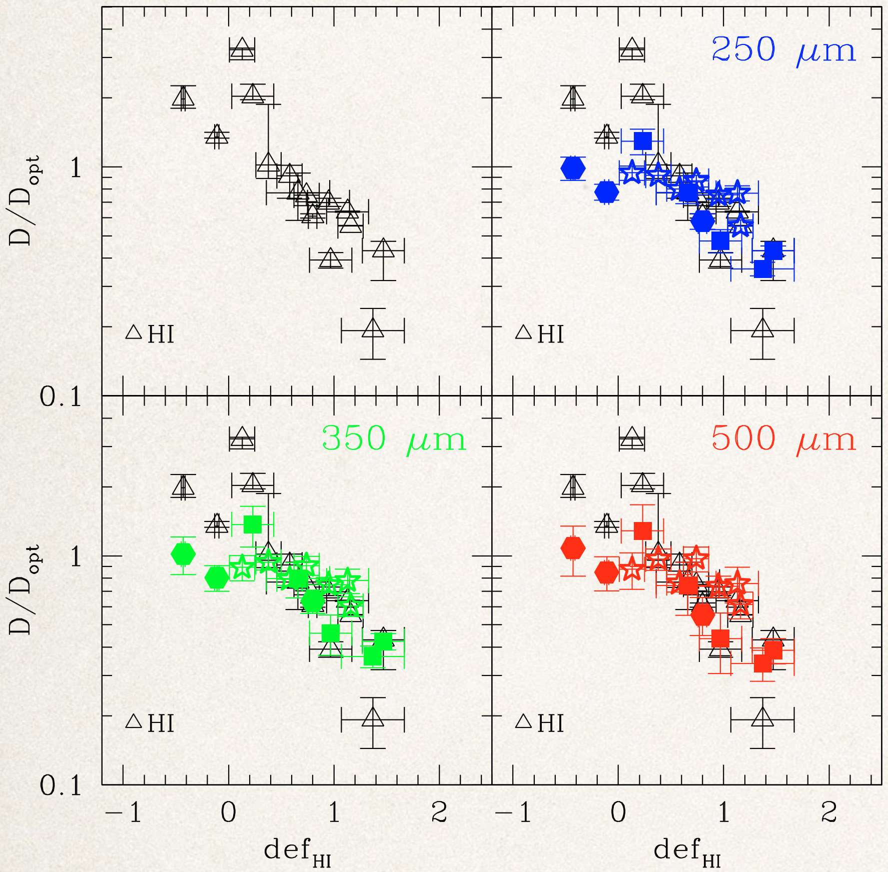
Boselli & Gavazzi (2006)

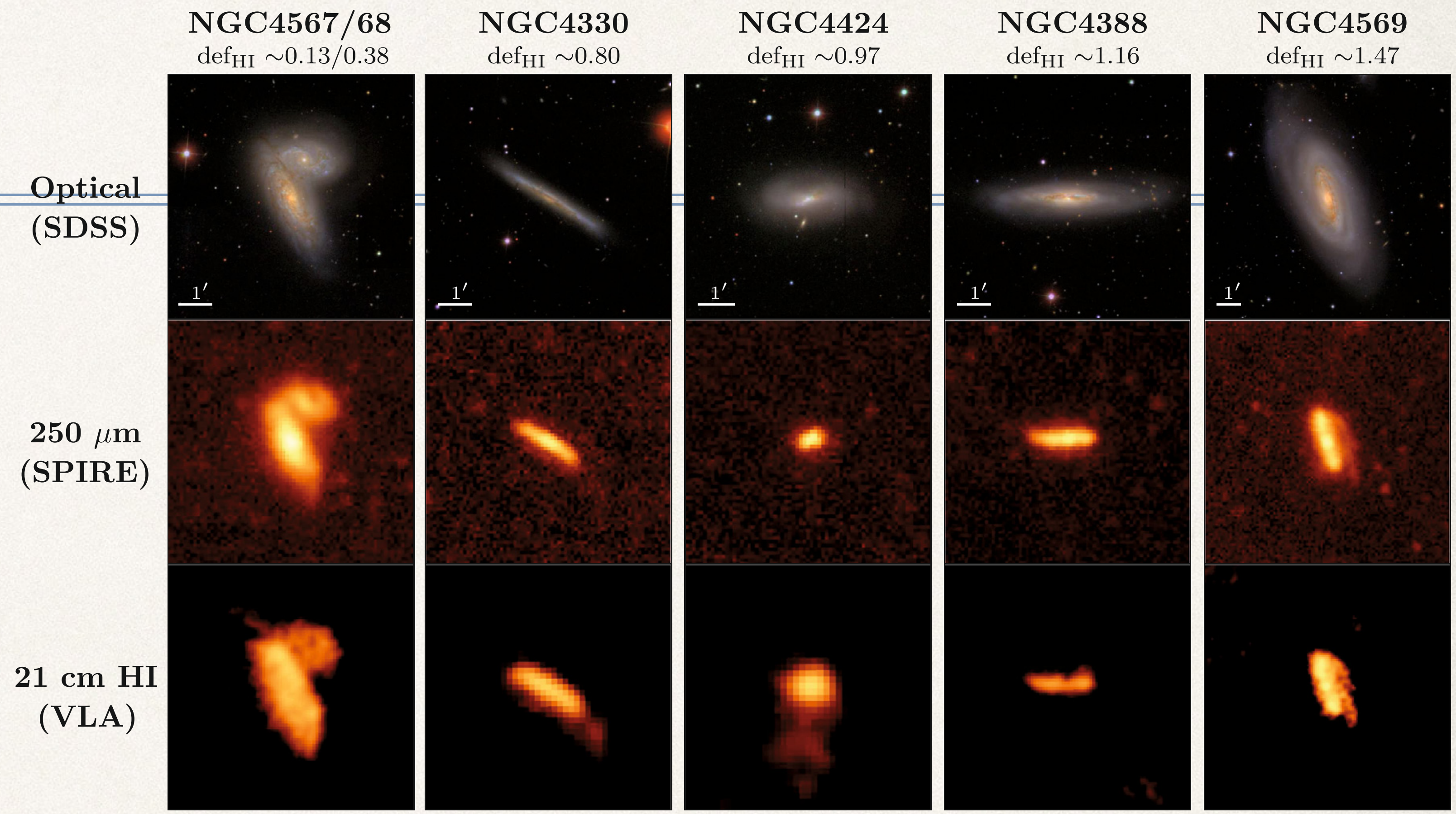


Molecular gas (H_2, CO)

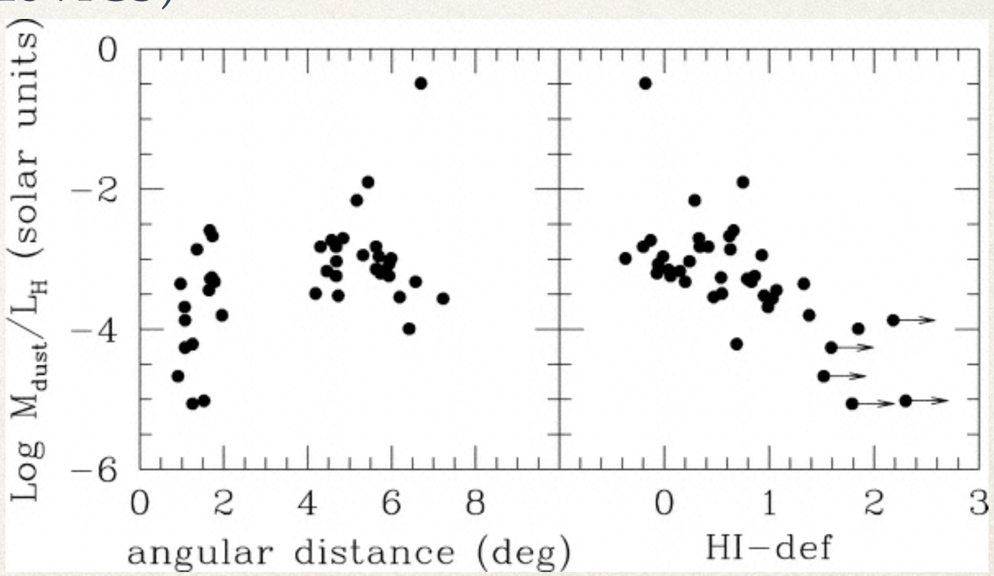
- ~15% of total gas, but directly related to SF
- Environmental effect on molecular gas, directly affect SF
- Molecular content of cluster late-types appears normal
  - molecular gas is much more bound than HI and not so extended: hard to remove

Dust





Cortese et al. (2010, HeViCS)

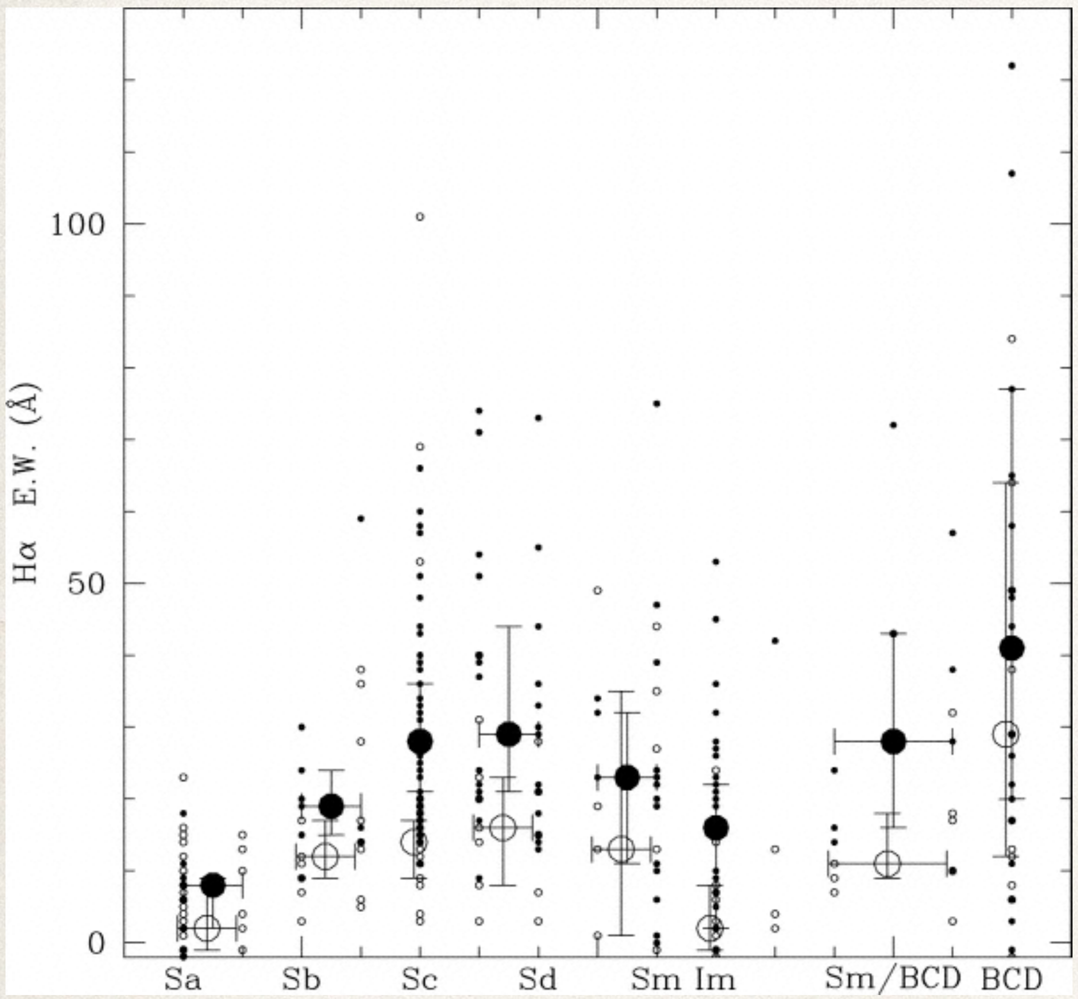


Boselli & Gavazzi (2006)

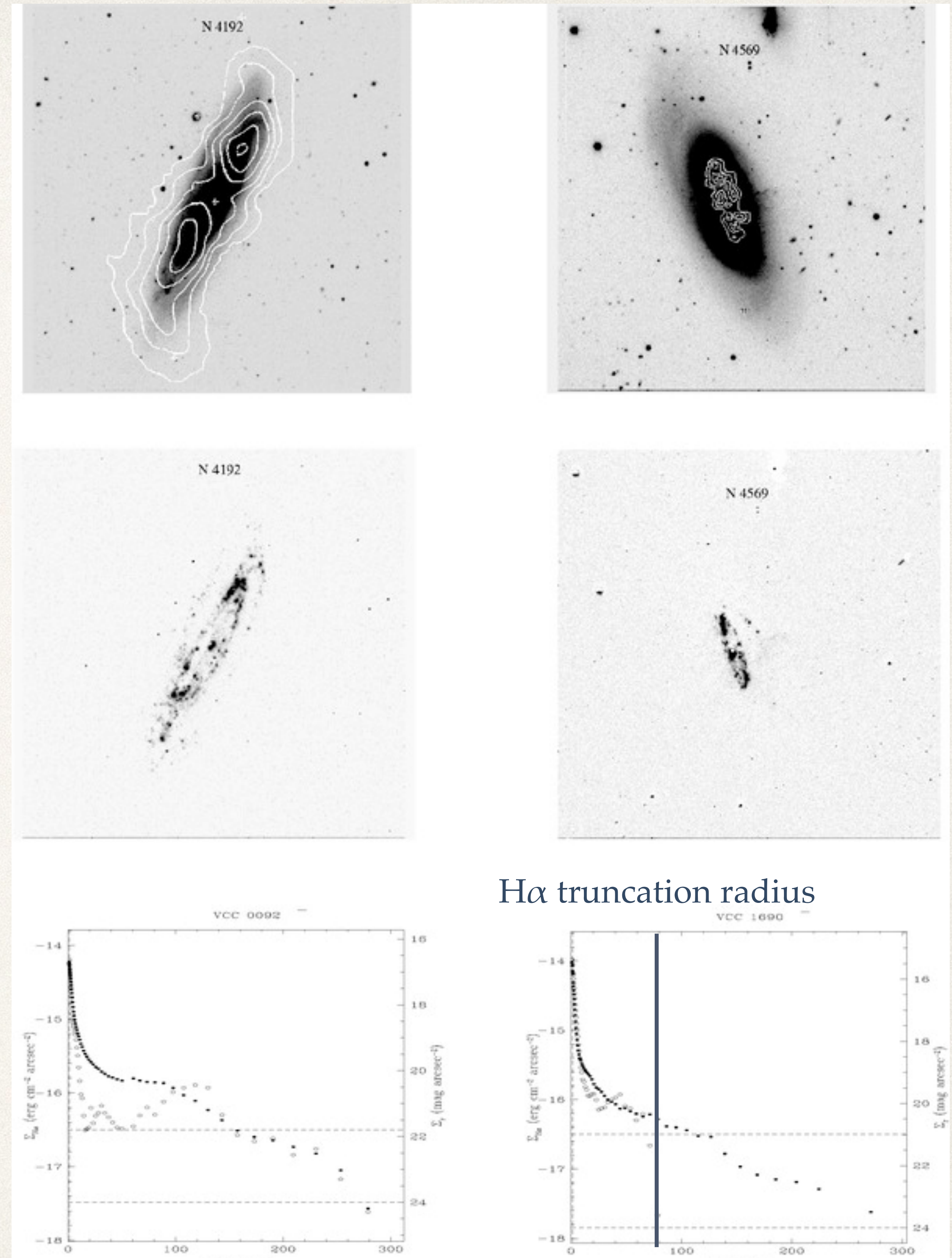
- Dust truncation follows HI truncation: dust and HI are swept together?

Star formation

- Fraction of star-forming vs properties of star-formation
- is the “mode” (intensity and/or spatial extent) of star formation modified in the cluster environment or is it just an on-off switch?



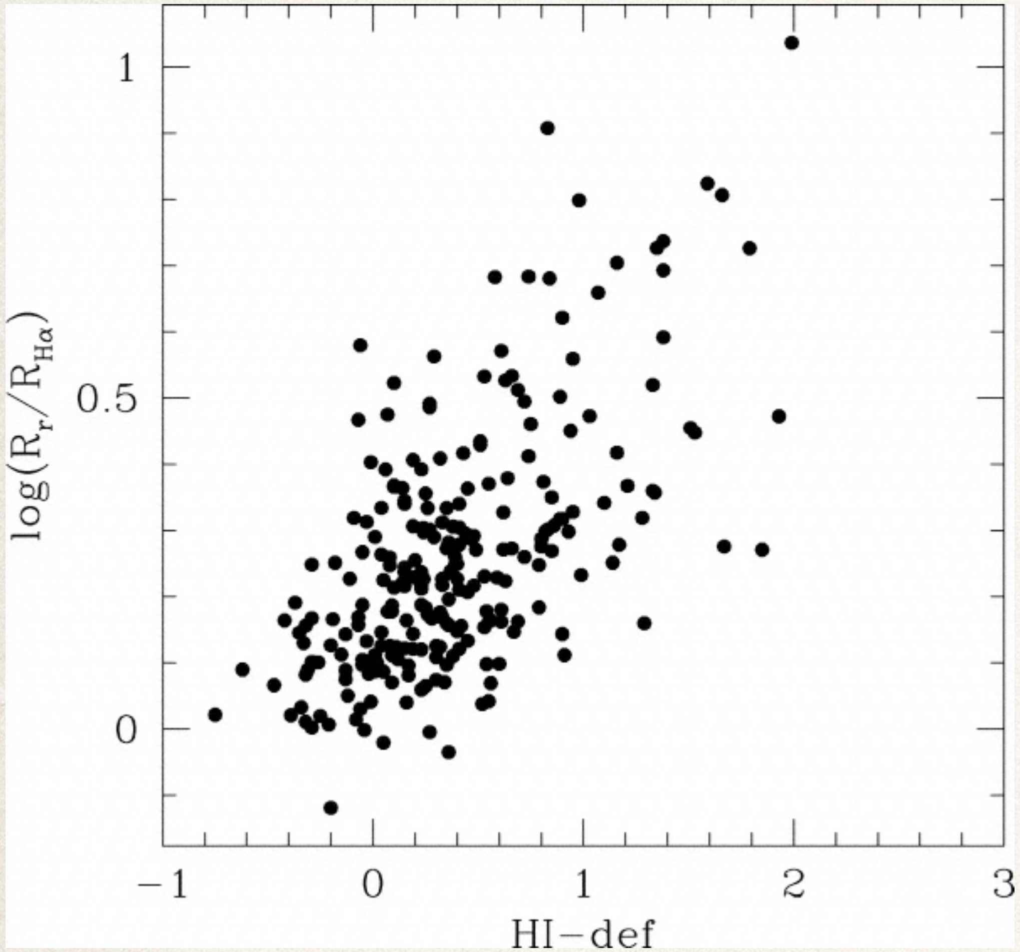
Distribution of individual Hα EW measurements in the Virgo Cluster along the Hubble sequence (*small circles*), and of the median Hα EW in bins of Hubble type. Large circles with error bars are drawn at the 25th and 75th percentiles of the distribution. Filled circles represent (unperturbed) objects, and open circles give (HI–deficient) galaxies



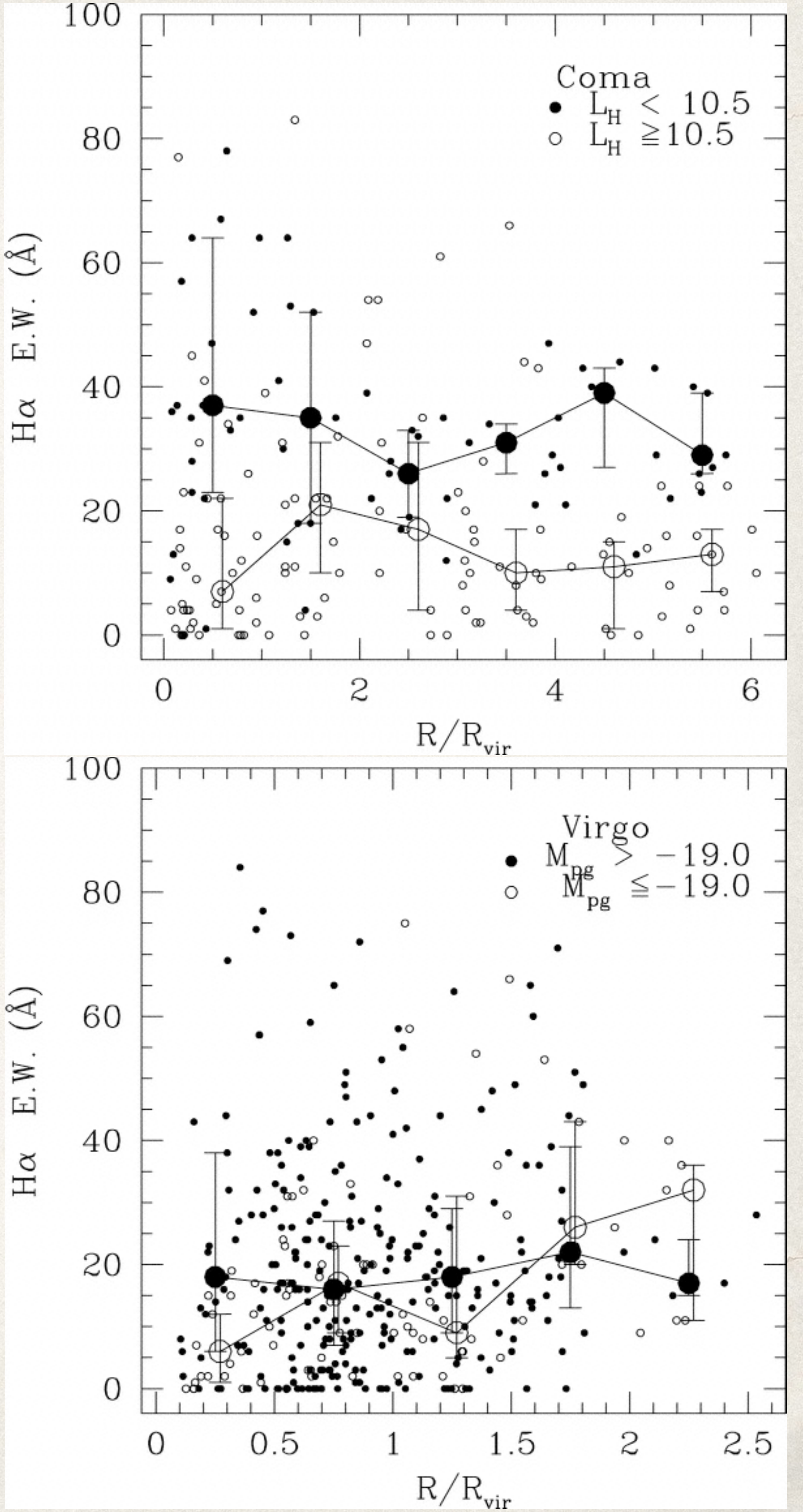
Top row, *r*−band continuum images with superposed HI isophotal contours adapted from Cayatte et al. (1990); *middle*, Hα NET images; *bottom*, *r* and Hα (NET) surface brightness profiles (*filled and open circles, respectively*) for two galaxies in the Virgo Cluster: the normal VCC 92 (NGC 4192) and the deficient VCC 1690 (NGC 4569).

Hα (i.e. SFR) truncation correlates with def(HI)

Ratio of the optical to Hα radius vs. the HI deficiency of late−type galaxies in the Virgo Cluster. The Hα isophotal radius is computed within $10^{-16.5}$ ergs cm^{-2} s^{-1} Å^{-1} arcsec^{-2}, and the *r*−band isophotal radius is within 24 mag arcsec^{-2} (Gavazzi et al. 2006).

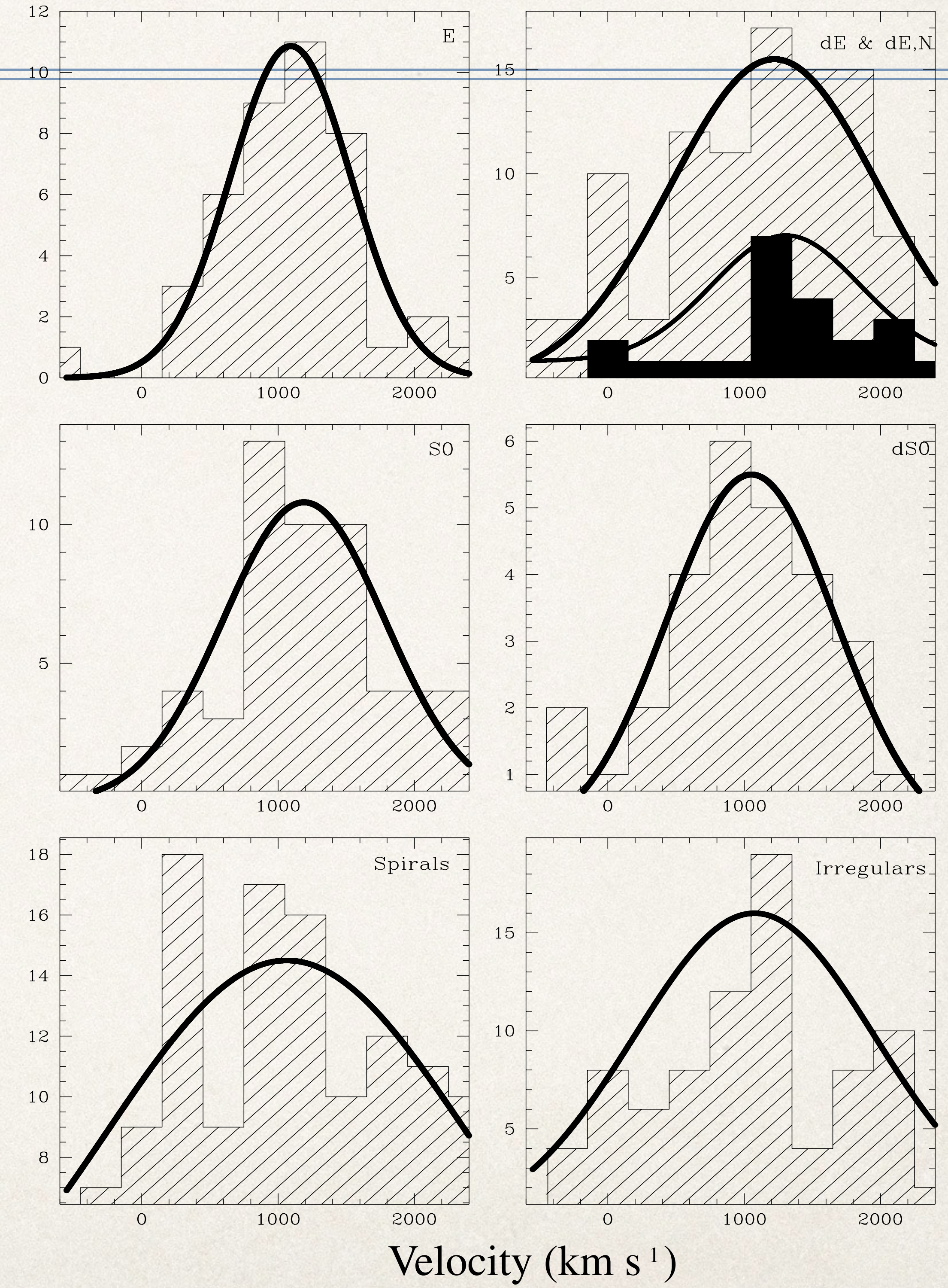


A radial dependence within 1Mpc?



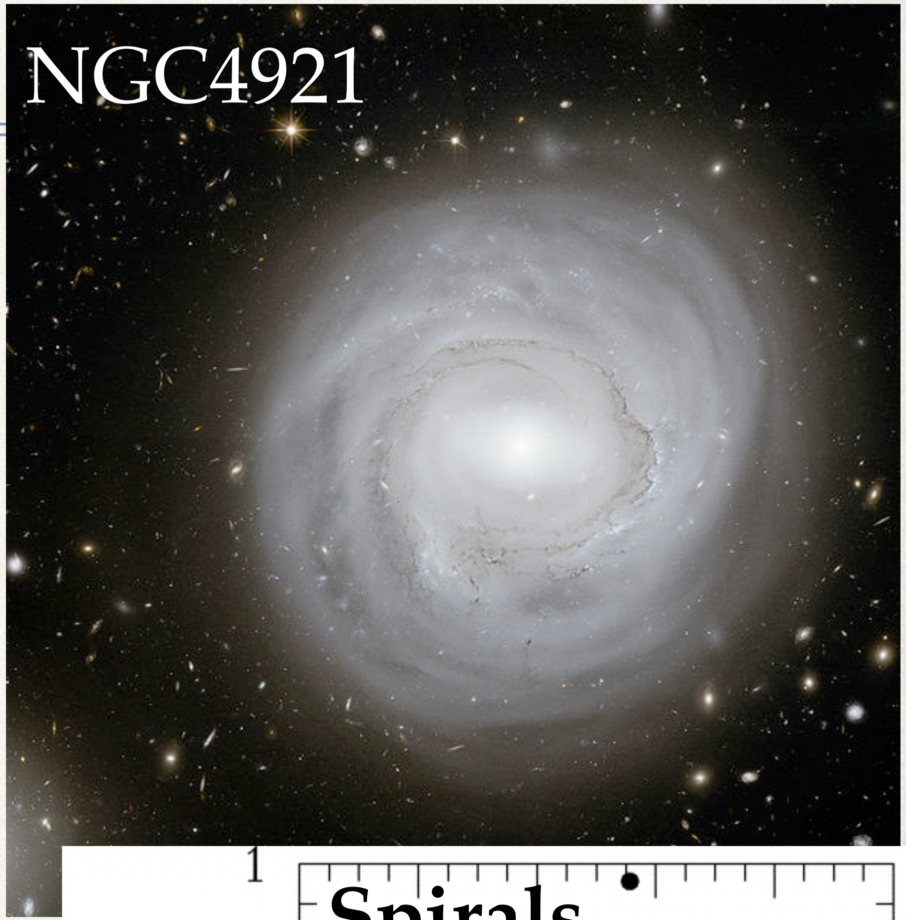
Morphological segregation in velocity

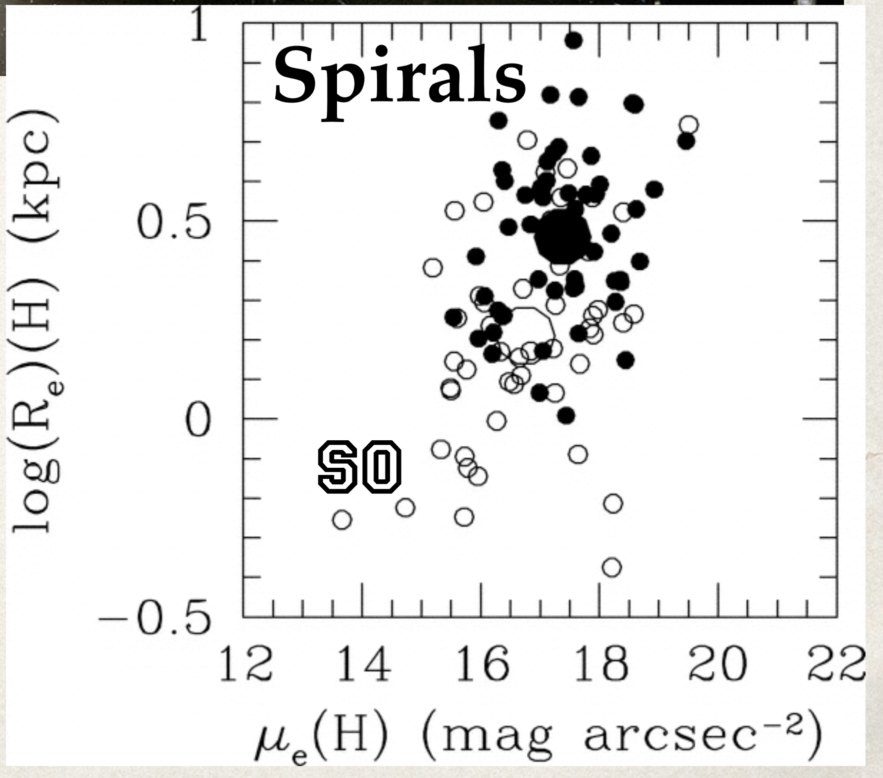
- The late-type populations in clusters displays broader velocity distribution than ETG (reminiscent also of the broader spatial distribution) [e.g. Biviano+1997; Binggeli+1987,1993; Conselice+2001; Colless&Dunn 1996]
    - LTGs not yet fully virialized?
    - dE's similar to Spirals



Anaemic and fading spirals

- "Anaemic" spirals (van den Bergh 1976)
  - low arm-interarm contrast
  - gas poor, low SF activity
  - redder colors than spirals, but similar B/T
  - inhabit cluster outskirts (Goto et al. 2003)
- Result from removing gas from normal spirals?
- Link in the transformation from Spirals to S0's?
  - Unlikely: present day Spirals are structurally different from S0





Conclusions

- Galaxy transformations in clusters are VERY COMPLEX
- Result from a number of mechanisms involving dynamics and hydrodynamics of multiple phases
- Interactions with the IGM appear to dominate the transformation of late type galaxies in present day clusters, but the efficiency of such mechanisms is very inter-dependent on all the other mechanisms