Causes of density-morphology relation

→ mergers, tidal interactions can convert
spirals → E, S0

Mergers operate more efficiently in galaxy groups
than in more massive clusters

Q Why?

→ Galaxy clusters (& richer groups) contain
dense, hot intercluster gas. Ram-pressure
stripping can remove cold gas from galaxies
entering the cluster.

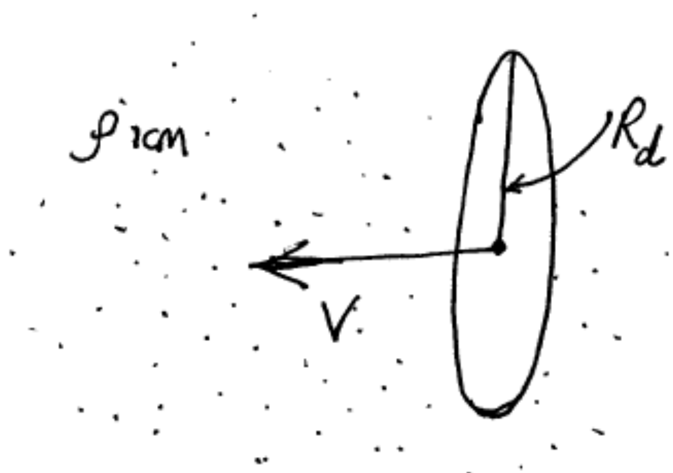
Ram pressure stripping

Mo, van den Bosch & White
Ch 12.5.3

Disk galaxy, radius R_d, moves thru intra-cluster medium which has density ρ_{ICM}.

Has velocity V.

Assume the velocity vector is $\perp$ to disk (ie wind is face-on to disk)



In unit time, disk will sweep up mass

$$\pi R_d^2 \rho_{ICM} V$$ of the ICM.

If the ICM wind is stopped by the galaxy's interstellar medium,

momentum transferred to disk in unit time is

$$\pi R_d^2 \rho_{ICM} V^2$$

Since force is $\frac{dp}{dt}$ (momentum), we only need to divide by the area of the disk to get the ram pressure

$$P_{ram} = \rho_{ICM} V^2$$

Gas will be stripped if the ram pressure is greater than the force per unit area binding it to the disk.

Assume that galaxy ISM has mean surface density Σ_{ISM} and the mean mass (surface density) of the galaxy is Σ_* (usually stars dominate)

Gravitational force in disk is approx $2\pi G \Sigma_*$

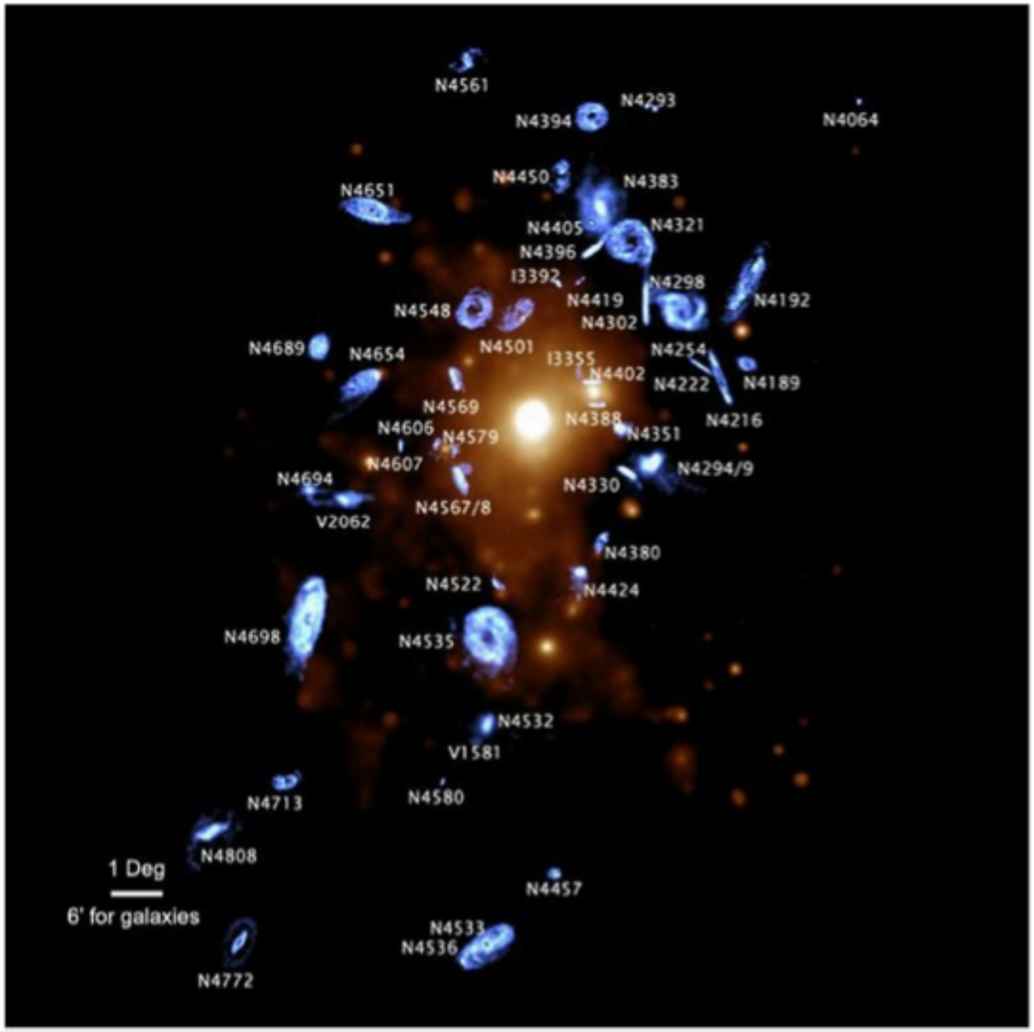
So grav. force per unit area is $2\pi G \Sigma_* \Sigma_{ISM}$

Stripping will happen if

$$\rho_{ICM} V^2 > 2\pi G \Sigma_* \Sigma_{ISM}$$

(ram pressure) (binding force)

Ram pressure stripping in Virgo

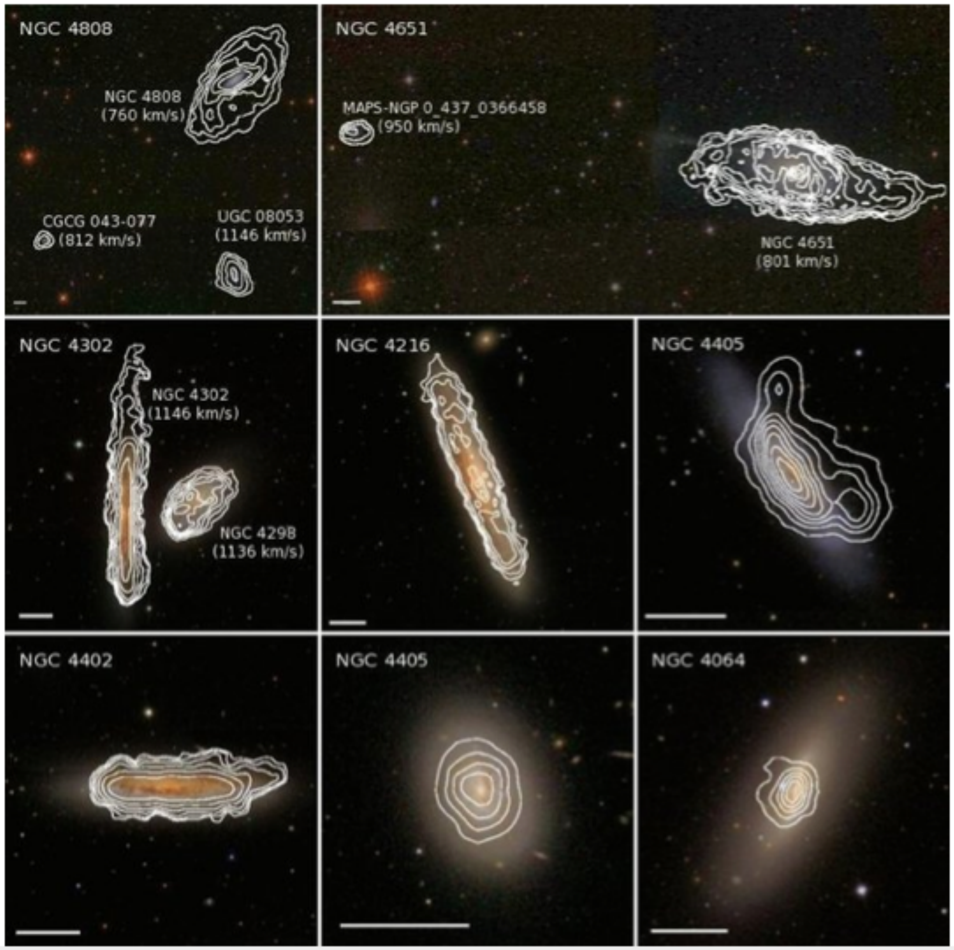


Reset

Figure 7. Composite image of the total H I images of the individual galaxies (in blue) overlaid on the *ROSAT* X-ray image (orange) by Böhringer et al. (1994). The galaxies are located at the proper position in the cluster but each H I image is magnified by a factor 10 to show the details of the H I distribution. The picture clearly shows how non-uniform the mass distribution in Virgo is, with enhanced X-ray emission from the three subclusters centered at the ellipticals, M87, M86, and M49.

Chung et al 2009

Gas morphology as stripping happens

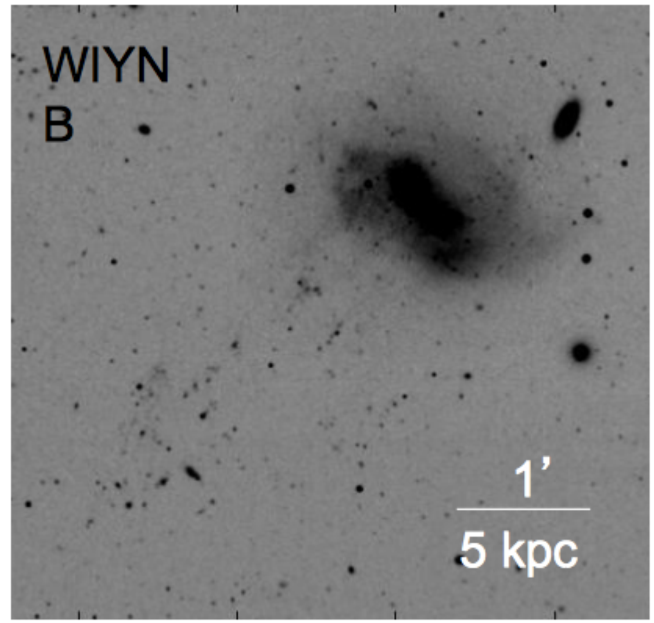


Reset

Figure 8. Examples of the different H I morphologies found in the survey. Total H I images are shown in white contours overlaid on the SDSS images. The thick white bar in the bottom-left corner indicates 1 arcmin in each panel. The top row shows examples of gas-rich galaxies in gas rich environments in the outskirts, the middle row shows galaxies at intermediate distances, while the bottom row shows examples of severely truncated H I disks at a range of projected distances from M87.

Chung et al 2009

Virgo dwarf IC3418: 1-sided tail of young stellar associations & linear streams

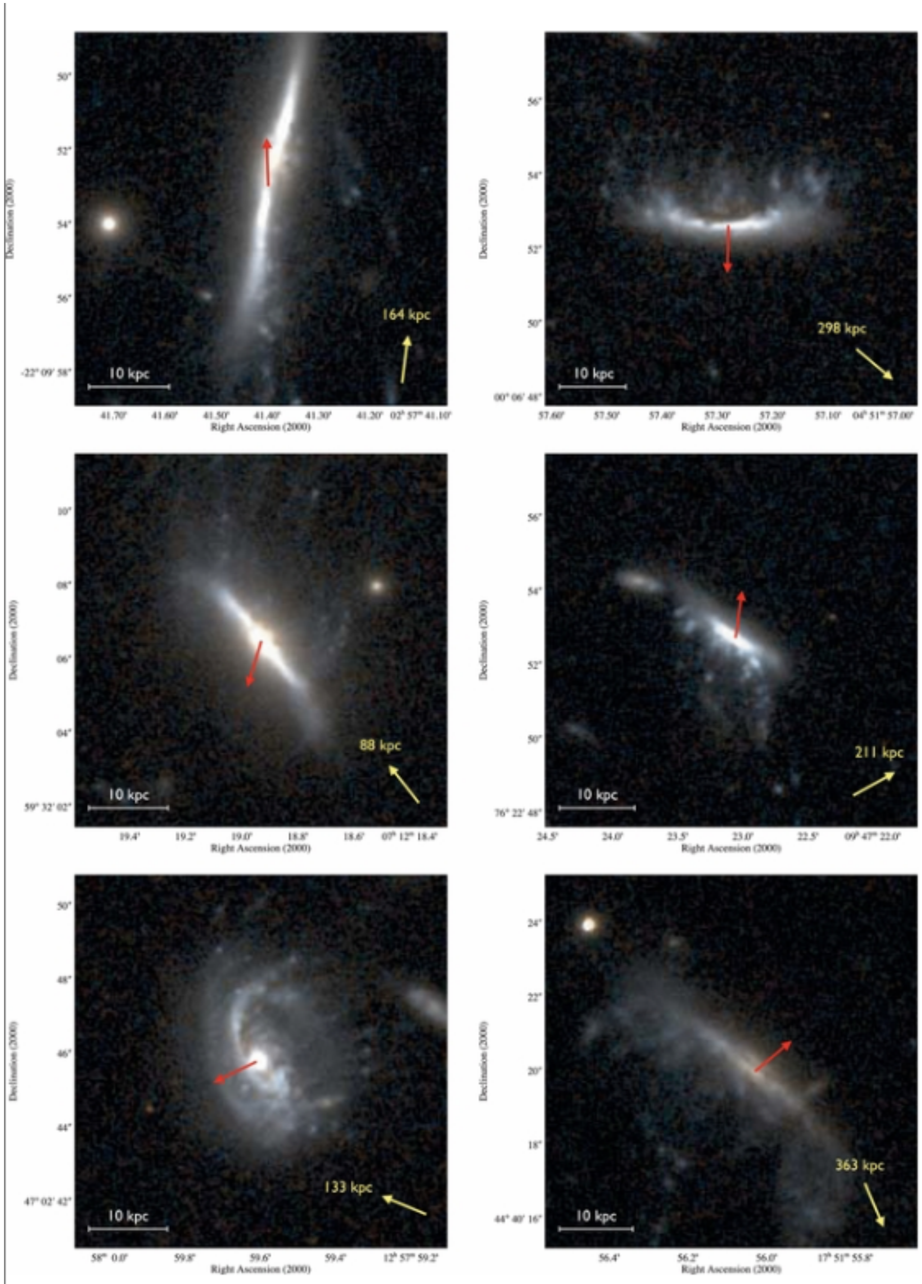


Chung+09; Hester+10; Fumagalli+11; Kenney+14

We are probably witnessing the transformation of a dwarf irregular galaxy into a dwarf elliptical galaxy by complete ram pressure stripping

Jeff Kenney (Yale)

RPS of massive spirals in massive clusters at z=0.3-0.4

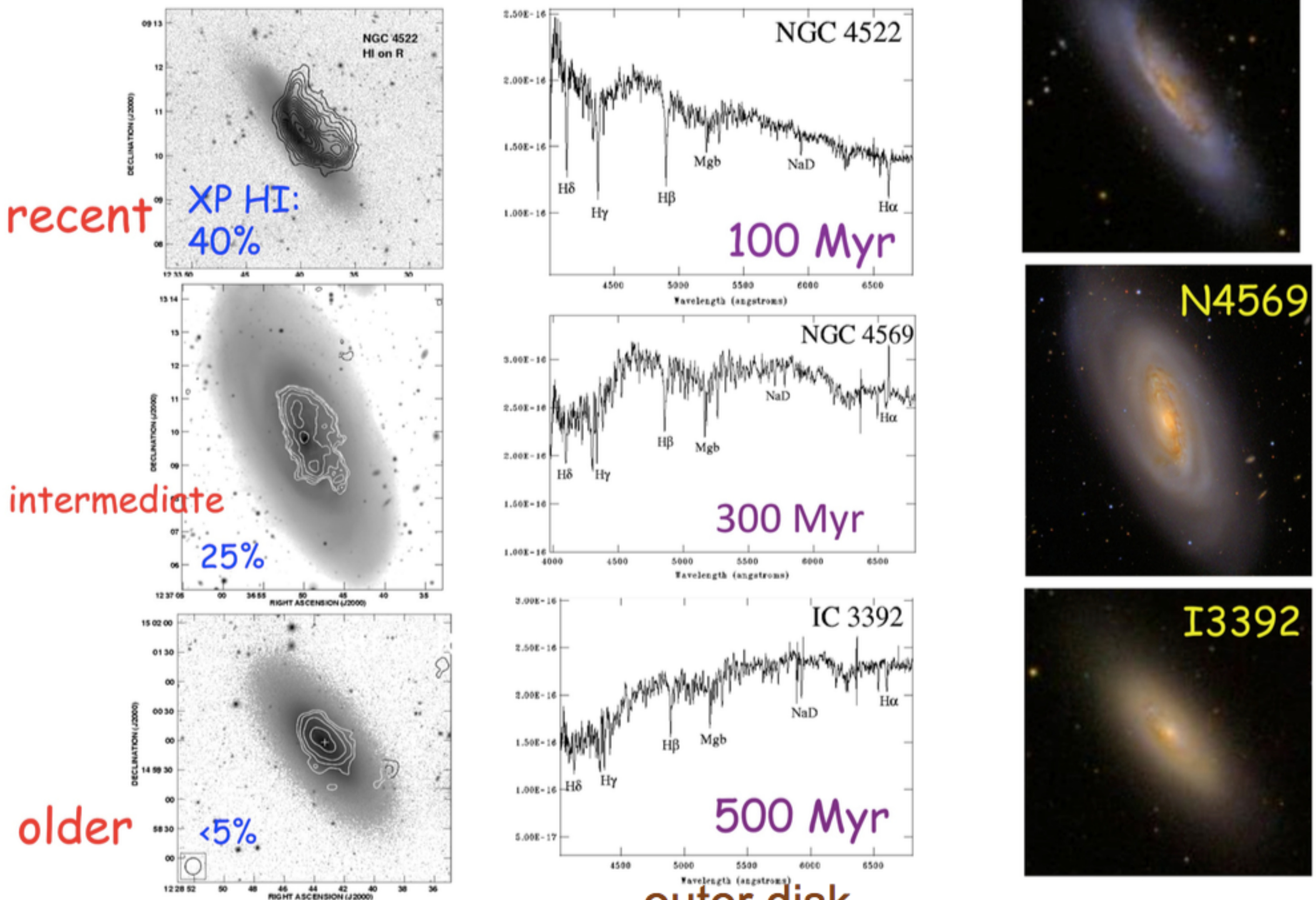


HST
F606+F814

Ebeling+2014

Jeff Kenney
(Yale)

Time Sequence of Stripping



HI on R

WIYN Optical spectra

SDSS Optical image

Jeff Kenney (Yale)

Summary: Ram Pressure Stripping does these things:

~completely strips dwarf galaxies in Virgo-like clusters

partially strips large spirals in Virgo-like ($M \sim 10^{14}$ M_{sun}) clusters

~completely strips massive galaxies during first infall Into Coma-like ($M \sim 10^{15}$ M_{sun}) clusters

~completely strips (small) dwarf satellite galaxies close enough to their (large) host galaxy

must be ***important starvation mechanism*** in high and medium density environments-- gas removed from outer galaxy or halo by r.p. will not settle to inner disk & form stars

Jeff Kenney (Yale)

What changes with environment?

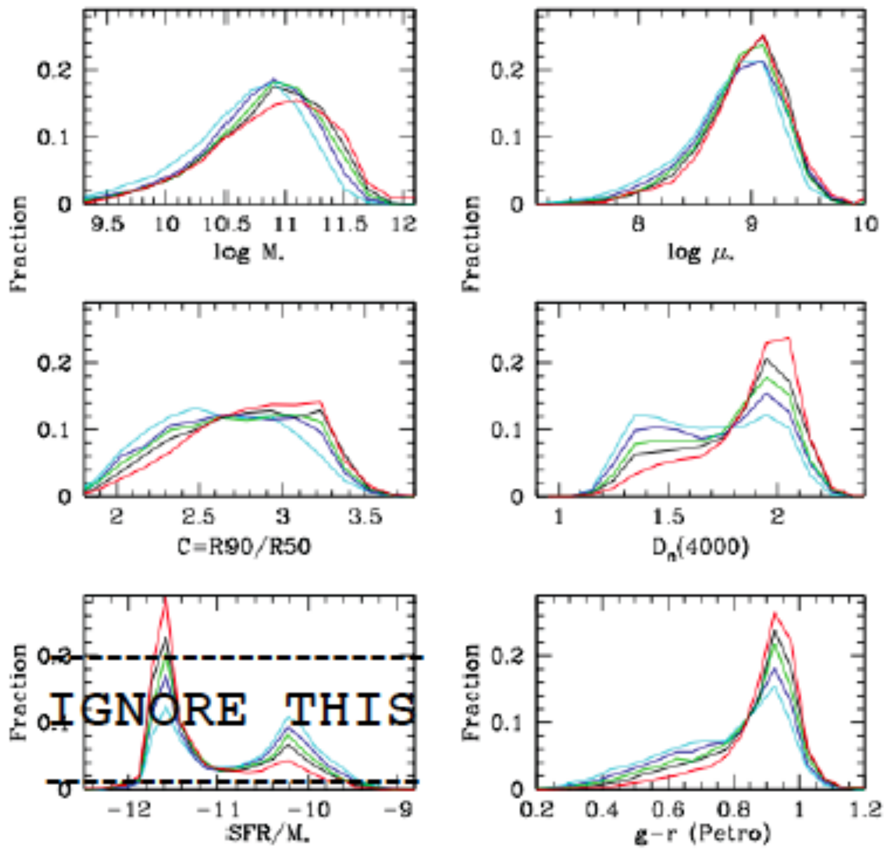


Figure 2. The fraction of the total stellar mass in the local Universe contained in galaxies as a function of log M_*, log μ_*, concentration index, $D_n(4000)$, SFR/M_* and $g-r$ colour (k-corrected to $z=0.1$). The different colour lines represent the different density bins as follows: cyan, 0 or 1 neighbour; blue, 2–3 neighbours; green, 4–6 neighbours; black, 7–11 neighbours; red, more than 12 neighbours.

low density cyan
high density red

Q: even in very low density environments, old/metal rich galaxies dominate (see Dn(4000) plot)
Doesn't this contradict the density/morphology relation? What is going on?

Kauffmann et al 2004

Malmquist effect:
the bane of astronomers' lives

- In a magnitude-limited sample, the more luminous objects will dominate because they can be detected to greater distances than the less luminous ones
- So red galaxies (statistically more luminous) dominate the SDSS sample

Kauffmann et al find:

STRONG correlations between star formation & environment over a large range of densities; cant just blame extreme places like centers of rich galaxy clusters.

less strong correlations between structural properties (how the stars & gas are arranged) and environment.

SDSS groups measure stellar mass of galaxy using spectrum & spec. synthesis to give M/L and L from redshift.

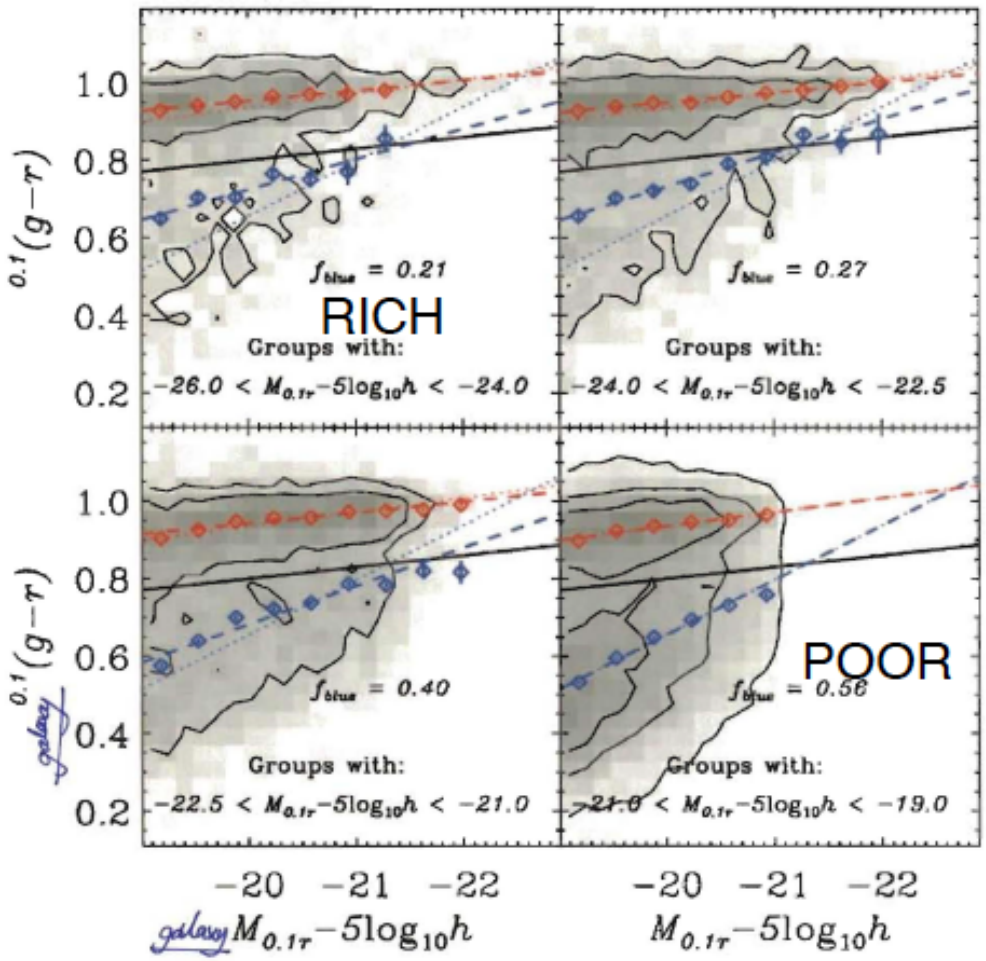
They find that stellar mass increases with density; and that many other properties correlate with mass.

Group environment: "pre-processing"

Large galaxy samples allow more sensitive investigations : what are the most fundamental quantities ?

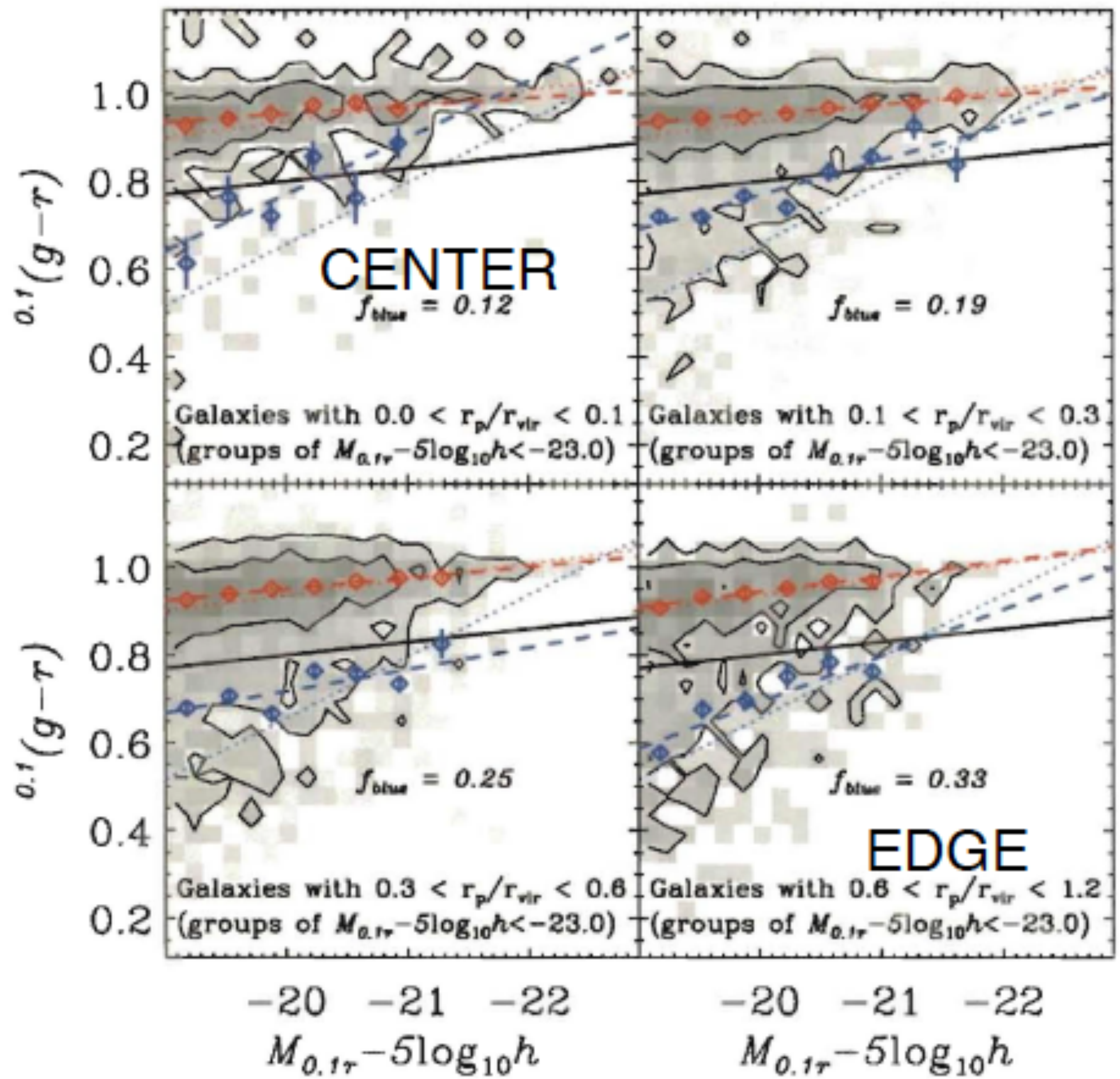
SDSS studies (Blanton & Berlind 07) show that group environment is very important : both luminosity of the group and position within the group

Effect of group luminosity on the color-magnitude distribution of galaxies. In each panel, the gray scale is related to number density of galaxies with a given color and absolute magnitude. The solid line is the same in each panel and represents our division between "red" and "blue." The fraction f_{blue} we consider blue by this criterion is listed in each panel. The dashed lines and diamonds are the fits to the red and blue sequences described in the text (the dotted lines are identical in each panel and equal to the dashed lines in the lowest luminosity set of groups). Each panel corresponds to groups of the listed range of total absolute magnitudes. As one goes from smaller to larger groups, the blue fraction decreases, although the positions of the red and blue sequences do not change much. Note that the cutoff seen on the right-hand side of the panels (most prominently in the $-21.0 < M_{0.1r} - 5\log_{10} h < -19.0$ panel in the lower right) is imposed by the lower limit on the absolute magnitude in each panel.



→ 0.1 superscripts remove effect of redshift (K correction)

Effect of groupocentric distance on the color-magnitude distribution, for high-luminosity groups. Similar to Fig. 1, but now concentrating on high-luminosity groups ($M_{0.1r}$ - 5 $\log_{10}$ h < -23) and dividing galaxies by the projected distance r_p from the center of the group relative to the virial radius r_{vir}. The dotted lines here are again the dotted lines for the low-luminosity set of groups.



Summary

Two major environmental processes which change galaxies from later types (spiral, irregular) to earlier types (elliptical, S0) are

-- mergers

-- ram pressure stripping

We expect mergers to be more effective in groups than clusters; ram pressure stripping depends on both the ICM density and galaxy velocity (richer environments have more of both) and on the galaxy mass