What has the Sloan Digital Sky Survey taught us about galaxies?

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some common species ...

(Barred examples)
brightest cluster galaxies slightly differ from gEs (Bernardi, Lauer, Desroches)

cE galaxies

warped disks

... and some rarer species

1000 km/s outflows (Tremonti et al)

mergers (McIntosh, Allam, etc)

ring galaxies
Broad-band galaxy properties

<table>
<thead>
<tr>
<th>luminosity</th>
<th>color</th>
<th>Sersic n</th>
<th>size</th>
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<tbody>
<tr>
<td>$M_r-5\log_{10}h$</td>
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<td>$n$</td>
<td>$r_{50} (h^{-1} \text{ kpc})$</td>
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<tr>
<td>$-18$</td>
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The diagram illustrates the distribution of galaxy properties across different luminosity, color, Sersic index, and size ranges.
## Broad-band galaxy properties

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Broad-band galaxy properties

- Luminosity
- Color
- Sersic $n$
- Size

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Contour plots and histograms illustrating the distribution of galaxy properties.
Broad-band galaxy properties

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The figure shows the distribution of galaxy properties across different ranges.
log stellar mass

metal-rich outflows (and low specific star-formation rates) at low mass?

but of course there’s more ...

more detailed photometric analysis: color-gradients (Park & Choi)
S0 galaxies

E galaxies

BCG/cD galaxies

\[ M_r - 5 \log_{10} h \]

\[ g - r \]

\[ n \]

\[ r_{50} \ (h^{-1} \text{ kpc}) \]
Sc/Sd galaxies

Sb galaxies

Sa galaxies
field galaxies ($r > 1$ Mpc from big cluster)
cluster fringe galaxies
(0.4 < r < 1 Mpc from big cluster)
cluster core galaxies
($r < 0.4$ Mpc from big cluster)
Processes affecting colors and magnitudes

“quenching” due to ram pressure, starvation, AGNi, gas depletion

ongoing star-formation

“dry” mergers

FAINT  BRIGHT
What have we learned about these processes and the effect of environment on galaxy formation?

1. What properties does a galaxy’s surroundings affect? 
*changes early-type fraction, but not properties of early and late classes* 
(Park et al. 2007 has most thorough investigation of this effect) 

2. On what time scales does the influence of environment act? 
*relatively slowly (> 1 Gyr) --- slower than ram pressure stripping* 

3. What features about the environment matter? 
*only the host halo -- except maybe for the central galaxy* 
*matters even at low density, not a “cluster” phenomenon -- ditto exception!*

4. Are the effects different for central galaxies than for satellites? 
*affects central luminosity; affects satellite age*
Early-type fraction changes; galaxy scaling relations don’t

Park et al. (2007) -- color magnitude diagram
Early-type fraction changes; galaxy scaling relations don’t

*Park et al. (2007) -- Faber-Jackson relationship*
Early-type fraction changes; galaxy scaling relations don’t

Bernardi et al. (2006) -- Fundamental Plane
Early-type fraction changes; galaxy scaling relations don’t

Pizagno et al. (2006) -- Tully-Fisher

- Geha et al. (2006)
- Pizagno et al. (2006)

$\rho > 1 \, h^{-1} \text{ Mpc}$

$0.5 < \rho < 1 \, h^{-1} \text{ Mpc}$

$\rho < 0.5 \, h^{-1} \text{ Mpc}$

$\log_{10} V_{\text{max}}$

$M_r - 5 \log_{10} h$

$-12$ $-14$ $-16$ $-18$ $-20$ $-22$
The time-scale of transformation due to environment is slow

Kauffmann et al (2004): distribution of D4000 and current star-formation rate independent of environment
The time-scale of transformation due to environment is slow

Quintero et al (2004): post-starburst, K+A galaxies, are rare objects.

Hogg et al (2006): K+A fraction is only weakly related to environment
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Hogg et al (2006): K+A fraction is only weakly related to environment
1. Sort by # of galaxies $M < -18.5$, $d < 0.5$ Mpc:
   a. $N = 0$
   b. $1 < N < 6$ (Local Groupish)
   c. $N > 6$

2. Even at low densities, relative numbers of red and blue galaxies change with environment

3. Location of red sequence and blue sequence weak function of environment (Balogh et al. 2003; Baldry et al. 2004; Hogg et al. 2004)
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3. Location of red sequence and blue sequence weak function of environment \cite{Balogh2003, Baldry2004, Hogg2004}
Only the local halo matters ...

1. Consider galaxies in groups of Blanton & Berlind (2006)

2. Define environment in two ways:
   a. host group luminosity
   b. density in surrounding 6<r<10 Mpc

3. Compare them:
   a. Larger groups: lower blue fraction
   b. But no correlation with larger scales

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1. At high mass, clusters with blue central galaxies are in denser regions than those with red central galaxies.

2. Younger central galaxies are in groups embedded in denser regions: halo assembly bias? (Wechsler et al. 2006; Gao et al. 2006)

... except maybe for central galaxies?
Satellite galaxy host masses relate primarily to their color: ram pressure stripping or starvation?
Central galaxy host masses related primarily to luminosity: dry mergers?

Mean group multiplicity vs. luminosity
Related to the sensitivity of the bright-end luminosity function cutoff to density: possibly driven by dry mergers onto BCGs? (e.g. Cooray & Milosavljevic 2005)

\[ \Phi(M_r - 5 \log_{10} h) \]

This paper (uncorrected)

Void LF (Hoyle et al. 2003)

Cluster LF (Popesso et al. 2004)
incredibly detailed statistics from SDSS: what is the common thread?

1. Overall, these results yield circumstantial evidence for the importance of the group-scale processes: so-called “pre-processing” of galaxies in groups before they enter clusters.

   a. local halo is the most important environmental parameter
   b. effects kick in even at very low densities (not “cluster” phenomena)
   c. scaling relations fixed across large range of densities

2. What about our mechanisms? what do these observations say?

   a. ram pressure stripping too fast, only in clusters
   b. starvation (denial of gas accretion) looks very likely
   c. effects due to merger history variation also possible (necessary?)
   d. mergers appear important to growth of largest galaxies

3. Small detectable deviations for normal galaxies; larger ones for BCGs and probably dwarf galaxies; but this is the basic picture for L* galaxies.
Merging galaxies
(1% of population)
1. Structure quantified here using the Sersic index

2. Sersic index and color both decline with distance from cluster center.

3. At fixed color, no dependence of Sersic index on distance.

4. Meanwhile, color depends on distance no matter what.

5. Note that in this formulation of the problem, unlike that of Blanton et al. (2005) or Kauffmann et al. (2004), intrinsic uncertainty in Sersic index matters very little.

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Quintero et al (2006)
Only the local halo matters ...

1. Consider galaxies in groups of Berlind et al. (2006)
2. Define environment in two ways:
   a. density in redshift space in $6<r<10$ Mpc annulus (projected)
   b. group luminosity and groupocentric distance
3. Compare them:
   a. Larger groups: low blue fraction
   b. Larger groups: dense environments
   c. Fixed group luminosity: no correlation of blue fraction with environment
4. Similar results: Kauffmann et al. (2004), Lewis et al. (2002)
Dependence on luminosity

1. Two sequences in color and absolute magnitude

2. How does environment vary among these galaxies?
   a. strong function of luminosity at high luminosity
   b. increasingly strong function of color at low luminosity
Dependence on luminosity

1. Two sequences in color and absolute magnitude

2. How does environment vary among these galaxies?
   a. *strong function of luminosity at high luminosity*
   b. *increasingly strong function of color at low luminosity*
Blue sequence: spirals
Sersic indices of red sequence

Red sequence

cD galaxy

giant elliptical

dE
“Interlopers” on the red sequence

S0/Sa galaxies

edge-on spirals
(Maller et al)

cE
Dependence on luminosity

1. At even lower luminosities this effect becomes even more striking.

2. Extremely sensitive dependence: only a tiny fraction of isolated dwarf galaxies are red.

3. Is an interaction with a large galaxy the only way star-formation can end in dwarf galaxies?

*dwarf galaxy sample from SDSS*

\[ M_r - 5 \log_{10} h > -16 \]
Evolution of environment trends

1. DEEP2 results show:
   a. at all redshifts some low density galaxies are red (but at 5% dust is a real issue)
   b. fraction of red galaxies in dense regions declines at higher redshift

2. Epoch of creation or assembly of red galaxies? (Is it long enough ago to be the former?)

3. To explore this change more fully we need much larger samples.