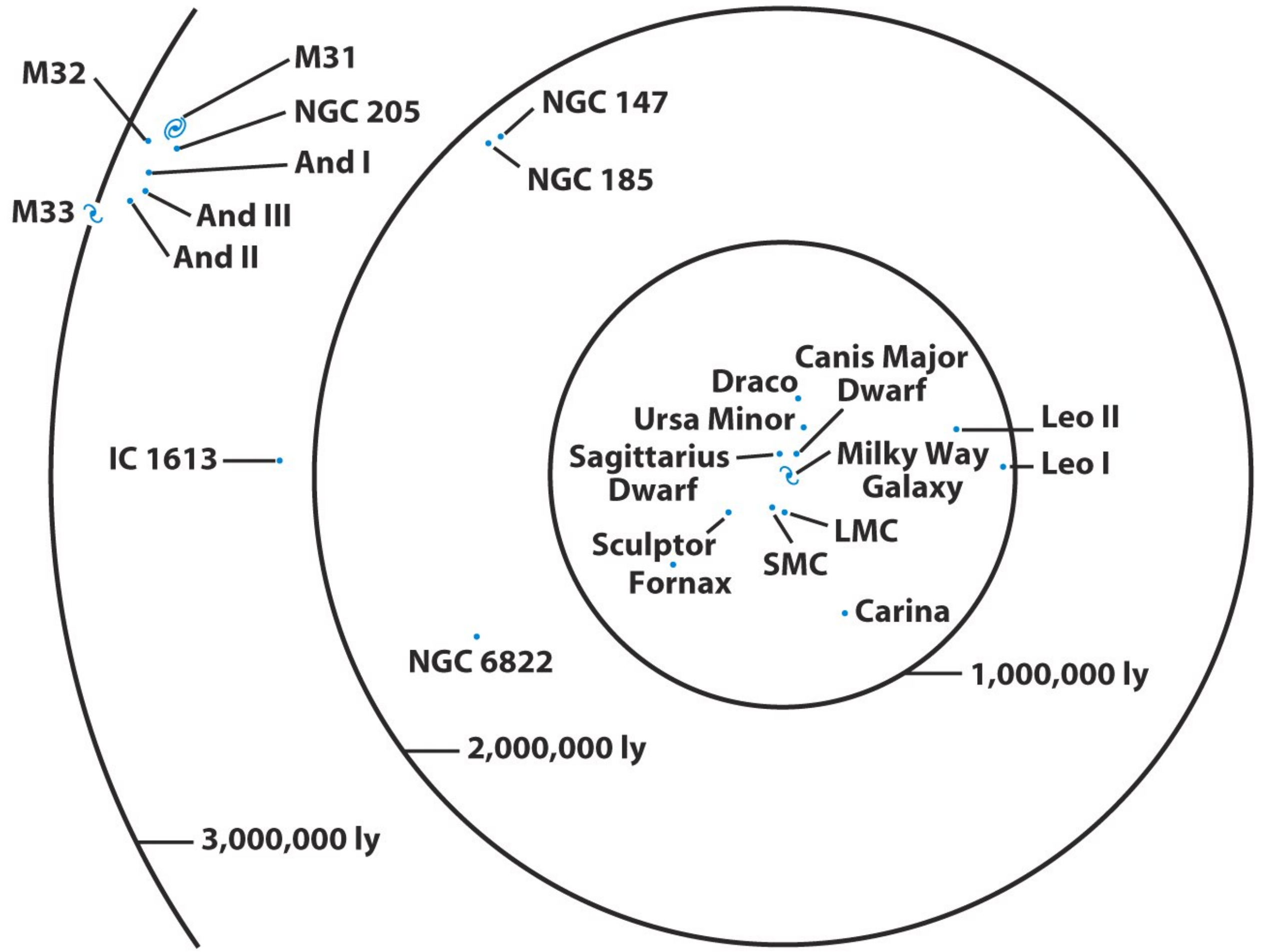
Clusters and Groups of Galaxies

- Groups and clusters
- The Local Group
- Clusters: spatial distribution and dynamics
- Clusters: other components
- Clusters versus groups
- Morphology versus density

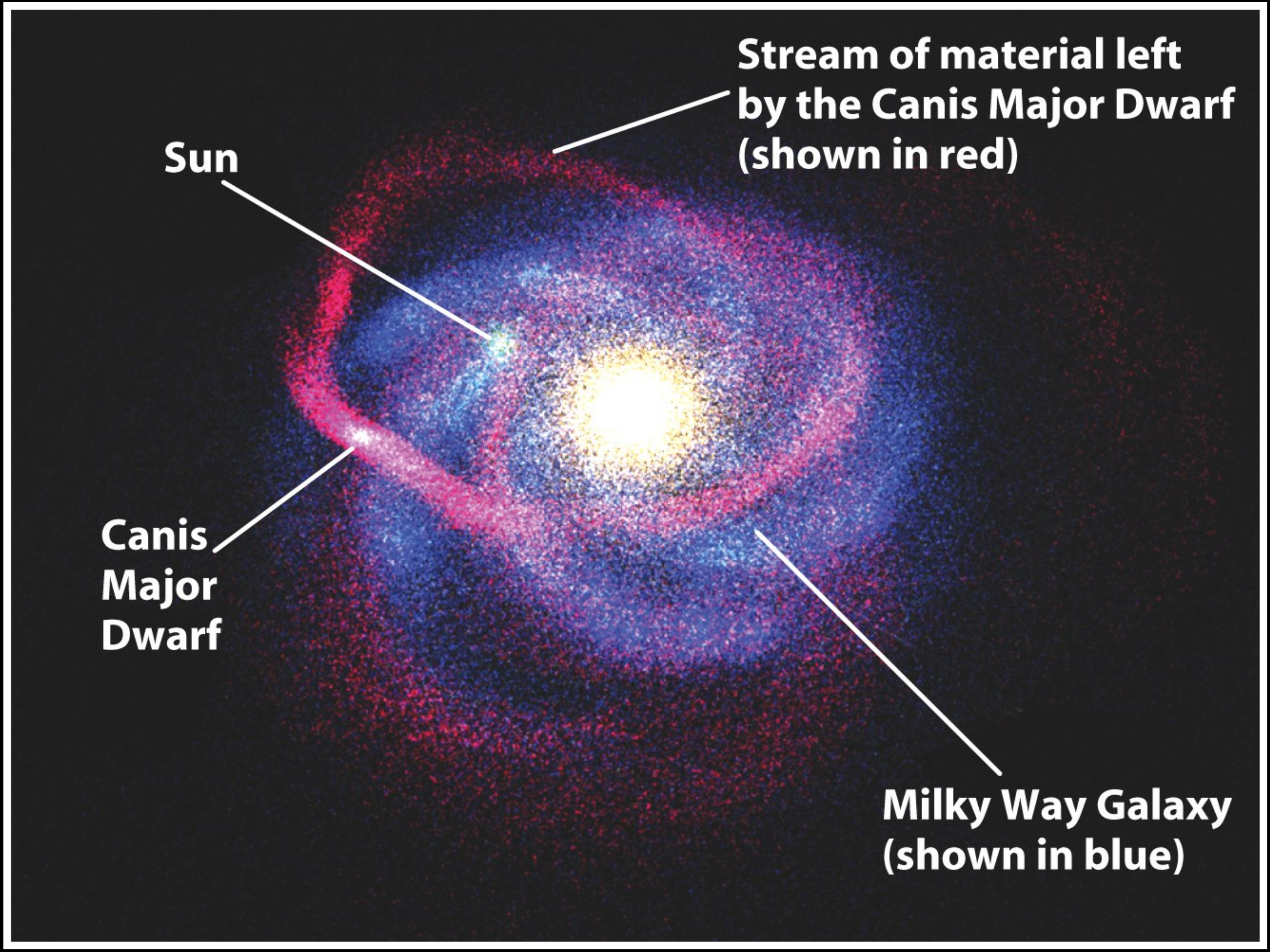
Groups and Clusters

- Galaxies are found in collections ranging from an individual, isolated galaxies to massive clusters with many thousands of members.
- Groups are usually defined as containing fewer than about 50 galaxies within a volume about 1 Mpc across, cluster are more than 50 galaxies typically spread across a larger volume.
- Many nearby galaxies that are members of the “Local Group” are very small and dim and would be impossible to detect even at distances of a few Mpc. Thus, strict counting of all the galaxies in a group/cluster is not feasible. Typically a “group” will have several galaxies with stellar luminosities similar to the Milky Way and a larger, but poorly determined number of smaller galaxies.

Our Galaxy is a member of the "Local Group"



- MW, M31, M33 are spirals and have similar size.
- Others are dwarfs, spheroidal or irregular, and tend to be clustered near large galaxies.
- Compact high velocity clouds (CHVCs) were briefly thought to be gas clouds with masses of dwarf galaxies, but later found to be low mass and within ~100 kpc of MW.


Stream of material left
by the Canis Major Dwarf
(shown in red)
Sun
Canis
Major
Dwarf
Milky Way Galaxy
(shown in blue)

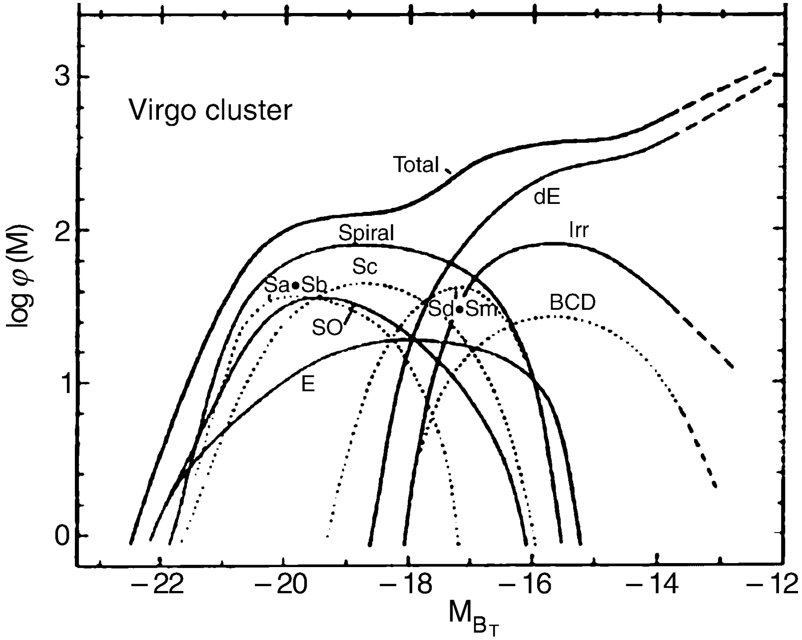
Nearby Groups and Clusters

- There are a number of other groups of galaxies that are neighbors to the local group, most have 2-4 large galaxies and are named for the largest galaxy.
- The M81 group contains M81, M82 (starburst), NGC 2403, and a number of smaller galaxies, currently 34 known (compare with "about 8" in textbook). Several of these galaxies are interacting (notably M82 and M81) and have active star formation.
- Closest cluster is the Virgo cluster at 16 Mpc, with 250 large galaxies that cover a patch about 8 degrees across on the sky. Virgo is an irregular cluster and has 3 "sub clumps".
- The closest massive cluster is Coma at a ~100 Mpc, with ~1000 large galaxies. Coma is a "regular" cluster (smooth galaxy distribution with no sub-clumps) and is classified as a "rich" cluster.

Clusters

- Most famous catalog is from Abell. Abell searched for groups of galaxies on photographic plates taken at the Palomar Observatory in the 1950s and covering declinations above -30º. Clusters are defined as 50 or more galaxies within a circle with radius 1.7'/*z* with magnitudes between m_3 and m_3+2 where m_3 is the magnitude of the third brightest galaxy in the cluster. Redshift was estimated assuming the 10^{th} brightest galaxy in every cluster has the same absolute magnitude. Clusters are ordered by RA and given a number, e.g. Abell 2218.
- The Abell catalog is neither complete (it misses some clusters that satisfy the selection criteria) nor reliable (*z* was not measured for individual galaxies, so some galaxies appear close together on the sky, but are at different distances – projection effects). Also, the list of cluster members is often incorrect because of projection effects.
- Abell defined a "richness class" based on the number of galaxies with magnitudes between m_3 and m_3+2.

Richness class R	N	Number in Abell's catalog
(0)	(30–49)	($\geq$ 1000)
1	50–79	1224
2	80–129	383
3	130–199	68
4	200–299	6
5	$\geq$ 300	1



Luminosity functions and morphology

- Compared to the field, clusters have fewer spirals and more ellipticals particularly at very high and very low luminosities.
- Unique to clusters are cD galaxies. These are the largest galaxies in both size and mass. Some cDs have multiple cores. cDs are thought to be formed by mergers.

- Clusters are classified as regular or irregular.
- Regular clusters tend to be richer, more dense particularly at the core, have cDs and mostly early-type galaxies, and are gravitationally relaxed.
- Irregular clusters have spirals, show substructure, are not gravitationally relaxed.

	S0	cD	E	dE	dSph
M_B	−17 to −22	−22 to −25	−15 to −23	−13 to −19	−8 to −15
$M(M_\odot)$	10^{10} to 10^{12}	10^{13} to 10^{14}	10^{8} to 10^{13}	10^{7} to 10^{9}	10^{7} to 10^{8}
D_{25} (kpc)	10–100	300–1000	1–200	1–10	0.1–0.5
$\langle M/L_B \rangle$	∼10	> 100	10–100	1–10	5–100
$\langle S_N \rangle$	∼5	∼15	∼5	4.8 ± 1.0	–

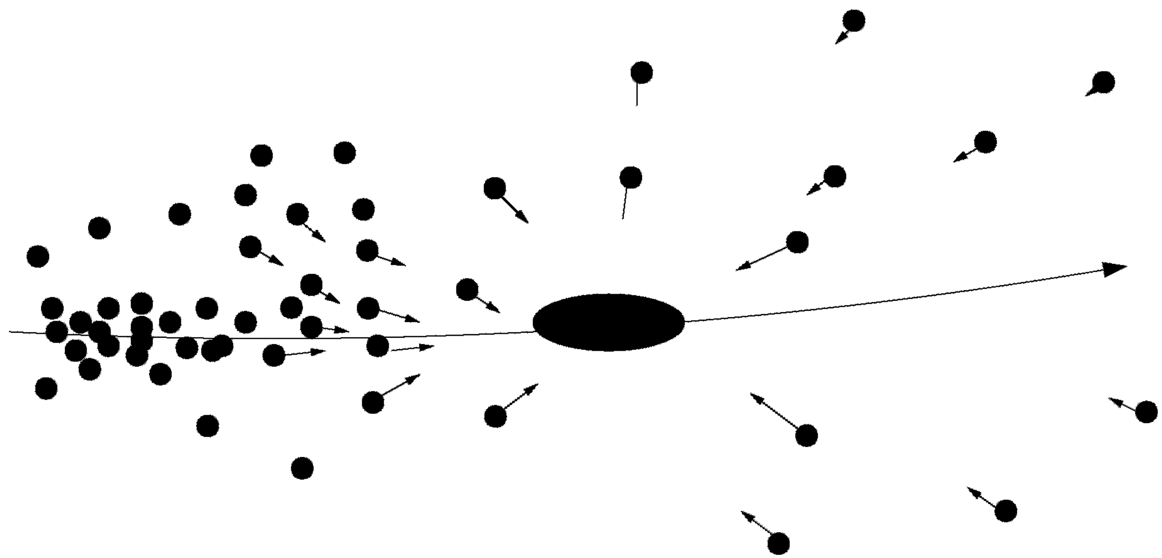
Spatial distributions and dynamics of clusters

- The spatial distribution of regular clusters is often approximated as spherically symmetrical. The (observable) projected density distribution, $N(R)$, is then characterized by the central density, $N_0 = N(0)$, the core radius, r_C, where $N(r_C) = N_0/2$, and an outer radius where the cluster ends.
- The simplest model of the dynamics of regular clusters is the isothermal sphere: the cluster is a self-gravitating ideal gas. The galaxies are non-interacting with a Maxwell velocity distribution with a single temperature, thus, $(1/2)m\langle v^2\rangle = (3/2)kT$. The gas pressure, $P = nkT$, is balanced by the gravitational force. Assuming the central density has a finite value, ρ_0, and the density profile is flat at the center, one can solve for the density profile $\rho(r)$. One finds $\rho_0 = 9\sigma^2/4Gr_C^2$ and $\rho(r) \sim r^{-2}$ for large r, thus, the total mass diverges as $M(r) \sim r$ as needed to keep arbitrarily high velocity particles in the Maxwell distribution bound.
- Remove the divergence by introducing a cutoff in the velocity distribution, e.g. King models with $\rho(r) = \rho_0[1+(r/r_C)^2]^{-3/2}$ have logarithmic divergence.

Dynamics of clusters

- Crossing time $t_{cross} \sim R/\sigma \sim 1$ Mpc/1000 km/s ~ 1 Gyr << 14 Gyr. So, clusters are dynamically bound and have had several crossing over the age of the universe.
- Use virial theorem: $2E_k + E_p = 0$ where $E_k = (½) \Sigma\, m_i v_i^2$ and $E_p = -(½) \Sigma\, Gm_i m_j / r_{ij}$
- Define total mass $M = \Sigma\, m_i$, velocity dispersion $\langle v^2 \rangle = \Sigma\, m_i v_i^2 / M$, and gravitational radius $r_G = 2M^2 / \Sigma\, Gm_i m_j / r_{ij}$
- Then $E_k = (½) M \langle v^2 \rangle$ and $E_p = -GM^2/r_G$ thus $M = r_G \langle v^2 \rangle / G$
- Use projected quantities: $\langle v^2 \rangle = 3\sigma^2$ and $r_G = \pi R_G/2$ with $R_G = 2M^2/\Sigma\, Gm_i m_j / R_{ij}$
- Then $M = 3\pi R_G \sigma^2 / 2G = 1.1 \times 10^{15}\, M_{sun}$ for $R_G = 1$ Mpc and $\sigma = 1000$ km/s
- Cluster mass to light ratio ~ 200 M_{sun}/L_{sun}. This was first noted by Zwicky in 1933 based on analysis of the Coma cluster.
- Virial theorem is OK as long as galaxies trace total mass distribution, R_G is unchanged if all masses are multiplied by a common factor.
- Two body collisions are unimportant, so $\langle v^2 \rangle \sim m^0$ instead of $\sim 1/m$.

Dynamical friction

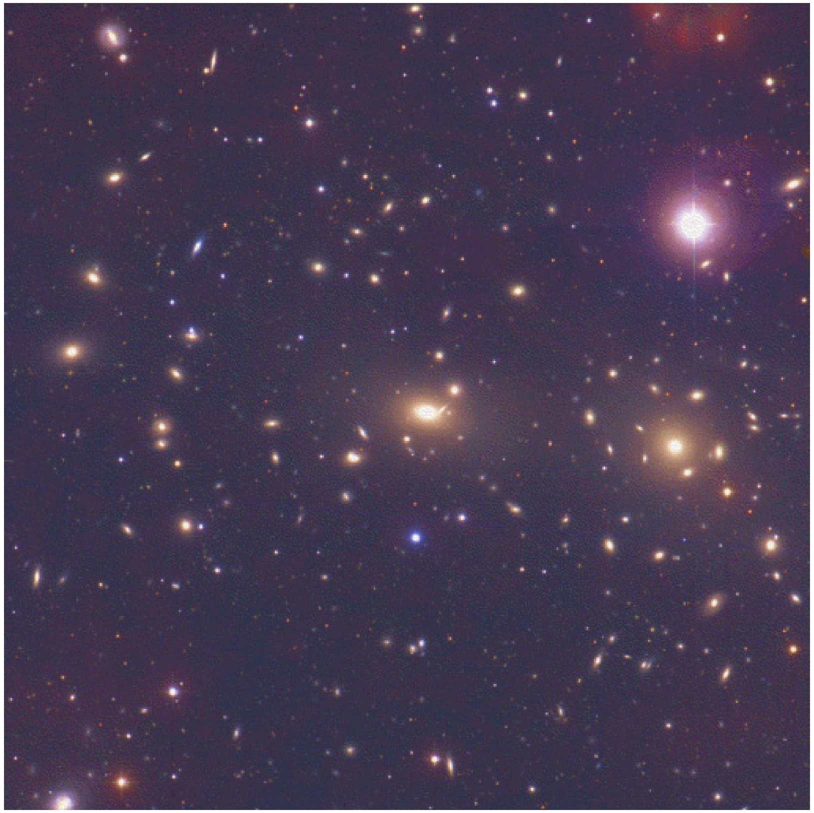


- When a massive particle moves through a collection of particles, the other particles are attracted to where the massive particle was in the past. This creates an over density behind the current position of the massive particle which slows it down.
- Dynamical friction: $d\mathbf{v}/dt \sim -m\rho\mathbf{v}/v^3$, causes massive galaxies to sink to the cluster center.
- Dynamical friction also occurs for stars and compact objects within galaxies or globular clusters. The same words are used for galaxy-galaxy interactions, such as the LMC with the MW, but then the process moves energy from the bulk motion of a galaxy into the motions of stars and gas within each galaxy.

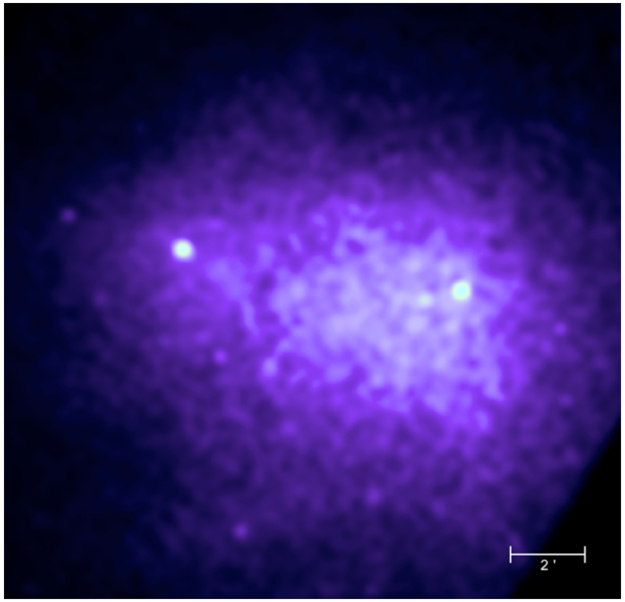
Other cluster components

- Intergalactic or "rogue" stars – stars not associated with a particular galaxy. Thought to be stars ejected in galaxy-galaxy interactions.
- Gas clouds – HI clouds with masses up to $10^8\ M_{\mathrm{Sun}}$ and dynamical masses up to $10^9\ M_{\mathrm{Sun}}$ with nothing in the visible/UV/IR bands, i.e. no stars. May be primordial gas clouds similar to those from which galaxies formed.
- Hot, 10^7- 10^8 K, X-ray emitting plasma – the dominant form of baryonic matter in most rich, regular clusters.

Coma cluster

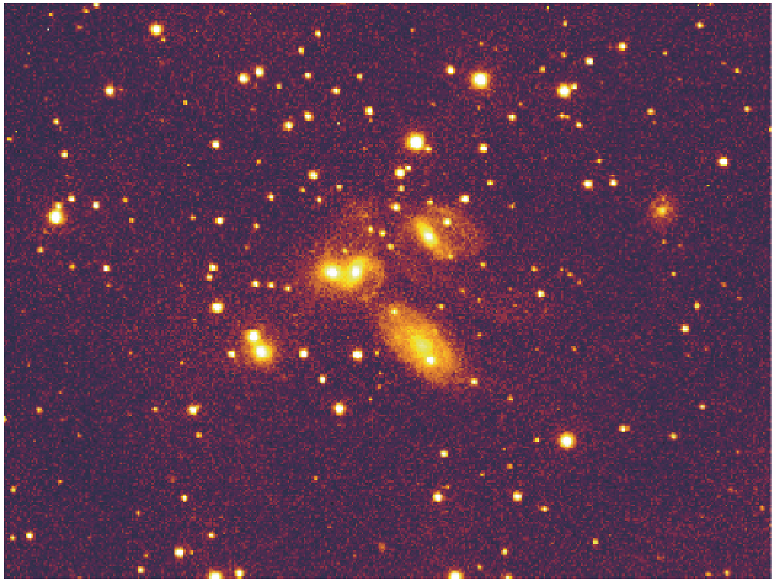


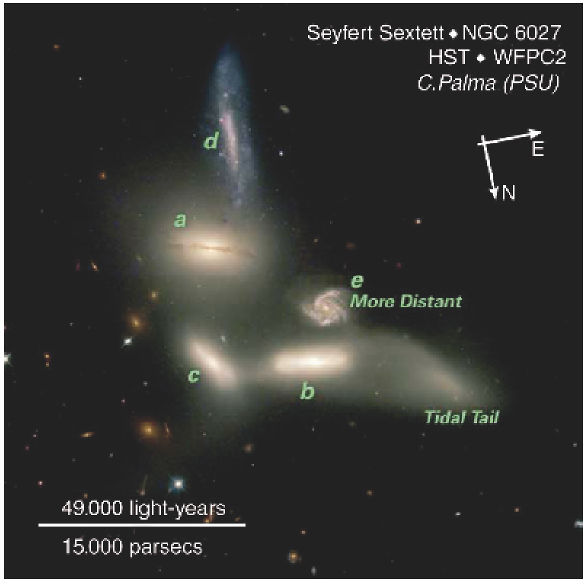
in X-rays



- X-ray emitting gas is at a temperatures of 10^7-10^8 K.
- Mass in X-ray emitting gas is often ~5 times mass in stars.

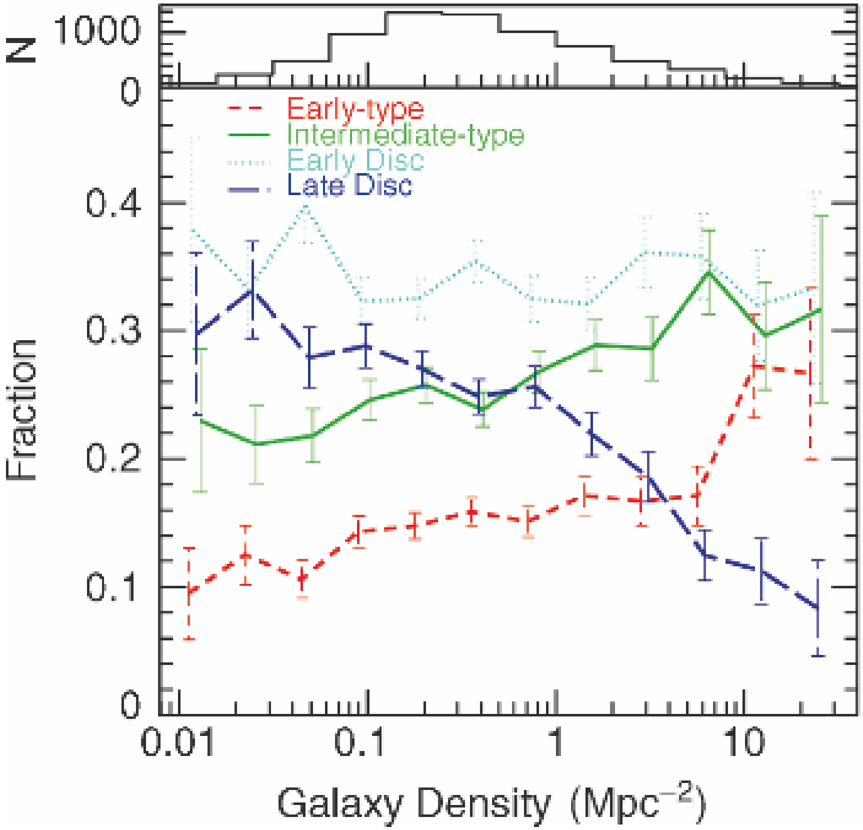
Clusters versus groups

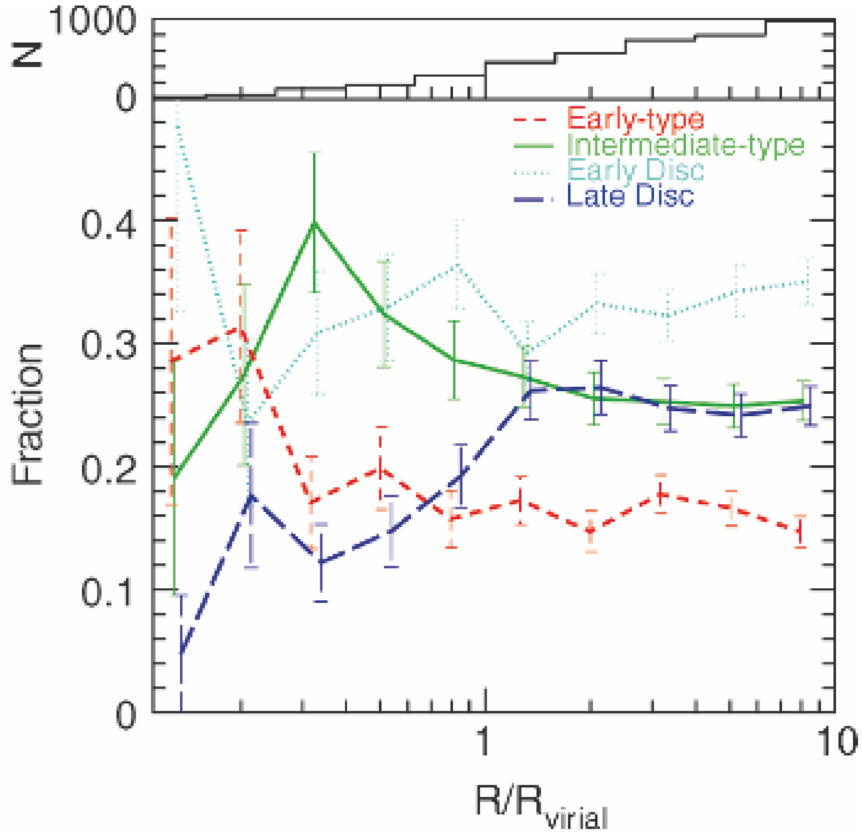




- Clusters and groups form a continuum that ranges from isolated galaxies to the richest groups.
- Loose groups like the Local Group have little interaction at the group level (but do have interactions between the larger galaxies and their satellites) and little or no X-ray emitting gas associated with the group as a whole.
- Compact groups, which are physically more compact and have higher velocity dispersions ~ 300 km/s, do have strong interactions between large galaxies in the group and often have hot, X-ray emitting gas.
- The dynamical lifetimes of many compact groups are shorter than the age of the universe. Thus, they must be currently forming, e.g. the Local group in a few billion years when the MW is interacting with M31 will be a compact group.

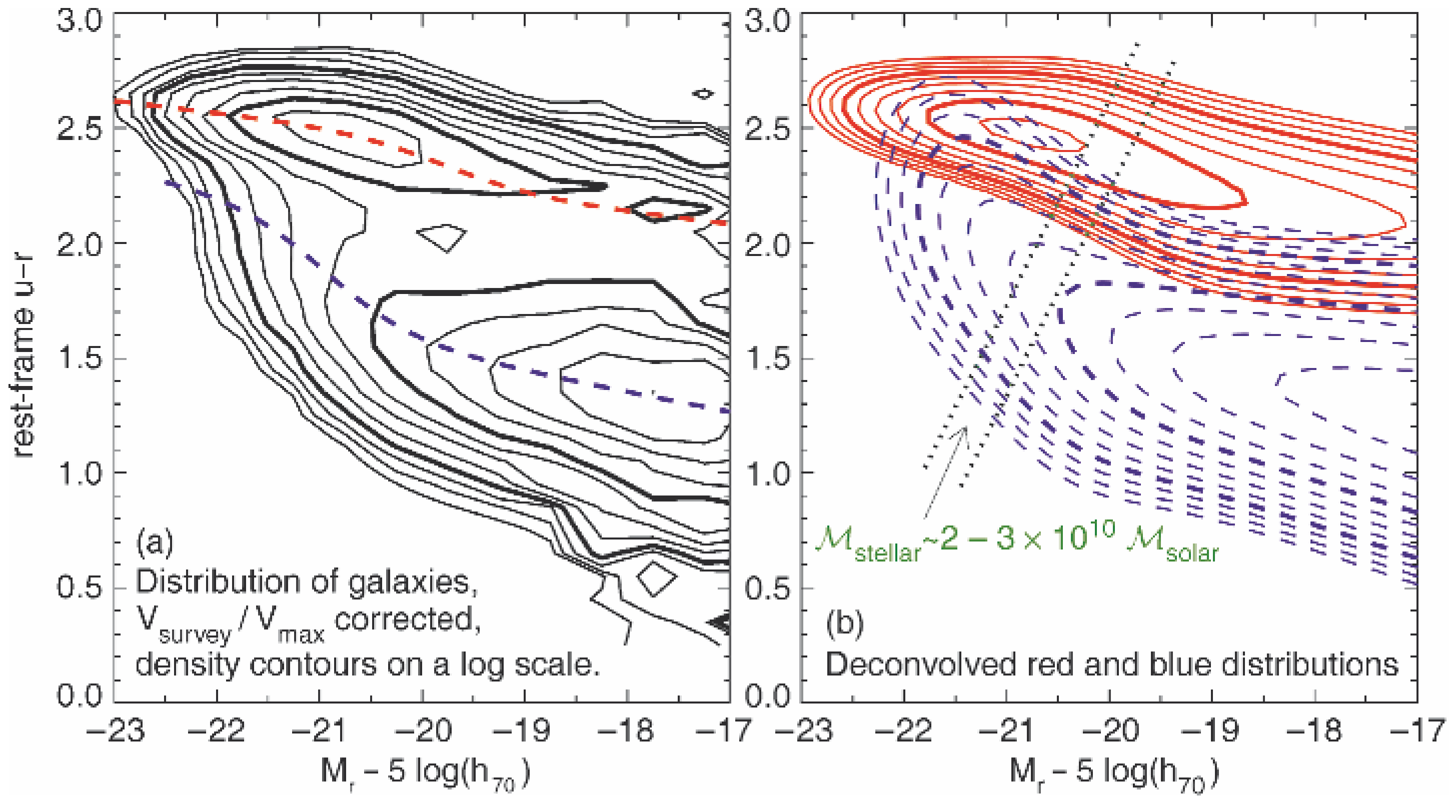
Morphology versus density





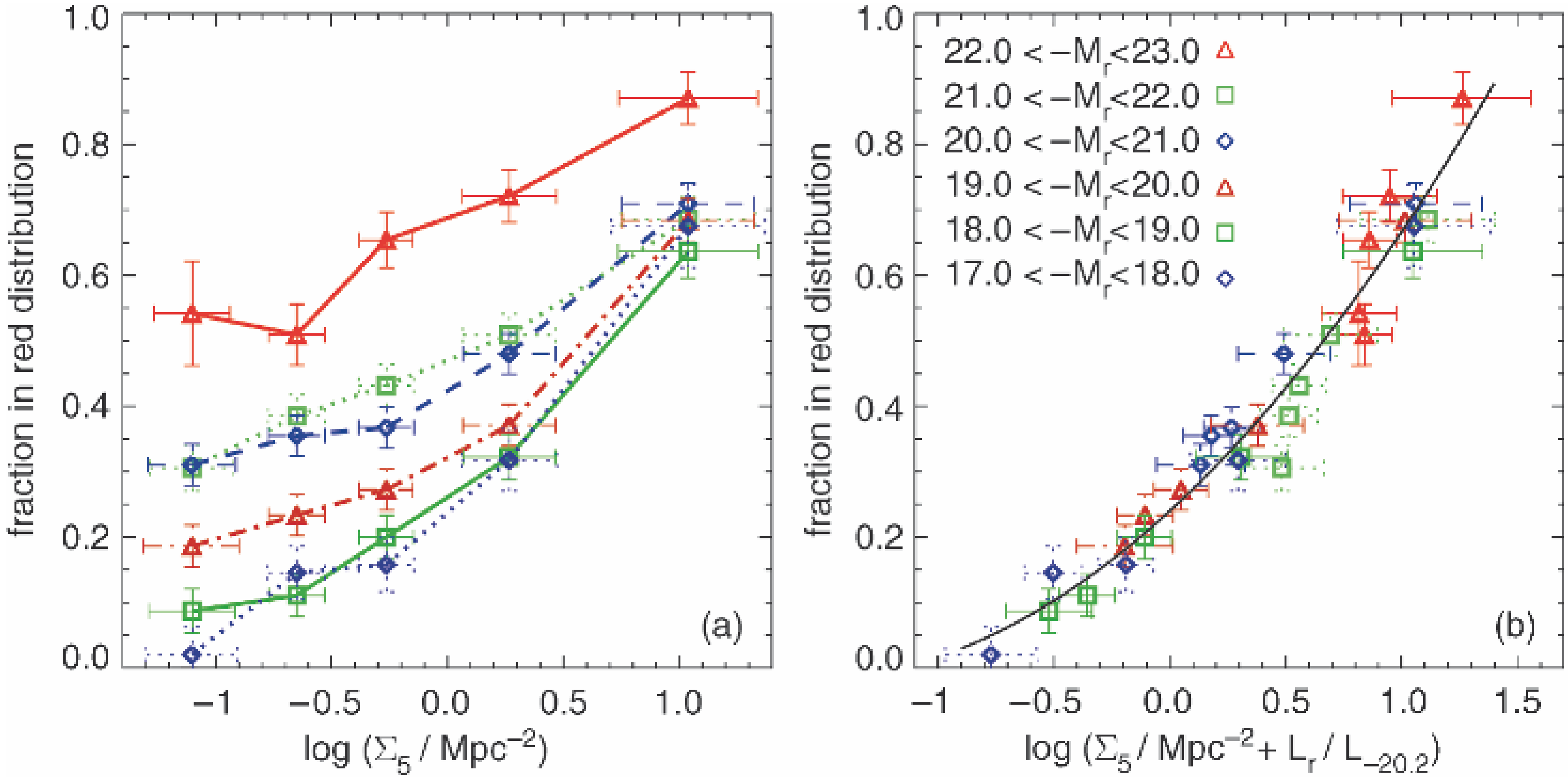
- Galaxy morphology is correlated with local density of galaxies and location in cluster
- Virial radius is radius at which mass density is 200 times critical density.
- This likely shows effect of interactions on galaxy evolution, but could be due to ram pressure striping removing gas from galaxies in dense regions.

Color-magnitude diagram



- Two distinct peaks in galaxy CMD: dim/blue versus bright/red.

Morphology versus density



- Using the quantitative red versus blue classification of galaxies and a combination of local galaxy density and galaxy luminosity, one finds a tight correlation.
- This sort of graph is a step towards precision studies of galaxy evolution. Direct interpretation of the correlation is not obvious, but models of galaxy evolution can be tested using this correlation.

For next class

- Read 6.3, 6.4, 6.6.
- Homework for chapter 6 is now on the class web site and is due Monday, October 15.
- First draft of project papers will be due on October 29. Papers should be in the style of the Astrophysical Journal. Grading for the first draft will mainly concentrate on the Introduction/background section. These should include a good discussion of the context and motivation for the paper (more extensive than many ApJ papers) with references to the literature.