Clusters of galaxies

Most galaxies belong to some larger bound structure. Conventionally consider **groups** and **clusters**, with characteristic properties:

<table>
<thead>
<tr>
<th></th>
<th>Groups</th>
<th>Clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core radius</td>
<td>250 h⁻¹ kpc</td>
<td>250 h⁻¹ kpc</td>
</tr>
<tr>
<td>Median radius</td>
<td>0.7 h⁻¹ Mpc</td>
<td>3 h⁻¹ Mpc</td>
</tr>
<tr>
<td>Velocity dispersion (line of sight)</td>
<td>150 km s⁻¹</td>
<td>800 km s⁻¹</td>
</tr>
</tbody>
</table>

(h is Hubble’s constant in units of 100 km s⁻¹ Mpc⁻¹)

Roughly, consider a group to possess a handful to tens of bright galaxies, while a cluster may have several hundred galaxies.

**ASTR 3830: Spring 2004**
A1689 imaged with ACS on HST
Why are clusters interesting?

Observationally:
• Large number of galaxies at the same distance
• Most dramatic place to look for environmental effects on galaxy formation and evolution

Theoretically:
• `Largest bound structures in the Universe’. Time for a galaxy to cross a cluster is:

\[ t_{cross} \sim 10^{10} \frac{d}{10 \text{ Mpc}} \frac{v}{1000 \text{ km s}^{-1}} \text{ yr} \]

...galaxies on the outskirts of a cluster have only made ~ a few orbits of the cluster.
• ‘Fair sample of the Universe’. Deep potential well of a rich cluster retains gas at $T \sim 10^8$ K. Expect that the ratio:

$$f = \frac{M_{\text{baryons}}}{M_{\text{total}}}$$

where $M_{\text{baryons}}$ is the mass of stars and gas, and $M_{\text{total}}$ is the mass of stars, gas, and dark matter. This ratio roughly represents the global value.

• Rare objects, formed from the most overdense peaks in the initial density field. Implies that their number density (number per Mpc$^3$) is a sensitive function of the amplitude of the initial fluctuations.
Surveys for galaxy clusters

Galaxy clusters contain galaxies, hot gas, and dark matter. Can survey for each of these components using observations in different wavebands:

**Optical**

Look for an overdensity of galaxies in patches on the sky

Can use color information (clusters contain many elliptical galaxies, which are red) to help

Disadvantages: vulnerable to projection effects, rich cluster in the optical may not have especially high mass
Abell clusters

Catalog of galaxy clusters compiled by George Abell from visual inspection of sky survey plates.

Selection criteria:

• **Richness.** Let $m_3$ be the magnitude of the third brightest galaxy in a group or cluster. Require at least 50 galaxies with magnitudes between $m_3$ and $m_3 + 2$.

• **Compactness.** The > 50 members must be enclosed within a circle of radius $1.5 \, h^{-1} \, \text{Mpc}$.

Original catalog contained $\sim 2700$ clusters. Error rate was around 10%.
X-ray

Galaxy clusters contain hot gas, which radiates X-ray radiation due to bremsstrahlung.

Advantage: bremsstrahlung scales with density and temperature as $n^2T^{1/2}$ - i.e. *quadratically* in the density. **Much less** vulnerable to accidental line-of-sight projection effects.

Disadvantage: still not detecting clusters based on mass.
Sunyaev-Zeldovich effect

Distortion of the microwave background due to photons scattering off electrons in the cluster. Measures:

\[ n_e dl \]

Mass weighted measure, though of gas not dark matter.

Gravitational lensing

Detect clusters from the distortion of background galaxy images as light passes through the cluster. Measures the total mass

But very difficult - not yet used as a survey technique
Mass estimates

Simplest mass estimate for clusters uses the observed properties + the Virial Theorem. For a system in equilibrium with kinetic energy $K$ and potential energy $W$:

$$2K + W = 0$$

This gives:

$$M \approx \frac{2R}{G} \approx 2 \times 10^{14} \frac{R}{10^{3} \text{kms}^{-1}} \frac{R}{1 \text{Mpc}} \frac{M_{\text{sun}}}{M}$$

Very approximate - but right order of magnitude. Rich cluster has a mass of $\sim 10^{15}$ Solar masses

Can also measure mass using X-ray observations and gravitational lensing.
Classification of clusters

Can classify clusters of galaxies according to (i) **richness**, and (ii) **morphology**. No morphological scheme enjoys same support as Hubble’s tuning fork diagram for galaxies. Example:

**Rood and Sastry scheme**

Importance: some clusters have cD galaxies. Expect a range of morphologies because clusters are young, merging systems…