Lecture 30: Groups and Clusters of Galaxies Section 26-6

Key Ideas

Galaxies often gather into *Groups & Clusters* The Milky Way is part of the *Local Group* Hierarchy of Structure Groups: 3 to 30 bright galaxies Clusters: > 30 (up to 1000's) of bright galaxies Superclusters: Clusters of Clusters Voids, Filaments, & Walls Properties of Clusters X-ray Gas in Clusters and Groups HI gas in Groups Morphology-Density Relation Dark Matter

Groups & Clusters of Galaxies

Most galaxies are found in groups & clusters

Basic Properties

- Groups: 3 to 30 bright galaxies
- Clusters: 30 to 300+ bright galaxies
- Sizes: 1-10 Mpc across (our Galaxy is ~50 kpc across)
- Often contain many more dwarf galaxies

~3000 clusters have been cataloged to date.

Just because there's some galaxies close together in the sky doesn't mean there has to be a cluster. They could be a chance superposition. They need to be at the same distance and gravitationally bound.

The Local Group

Group of > 45 galaxies including the Milky Way and Andromeda

- Size: ∼1 Mpc
- o 5 bright galaxies (M31, MW, M33, LMC, IC10)
- 3 spirals (MW, M31 & M33)
- \circ >23 ellipticals (4 dEs & >19 dSph)
- o 14 irregulars of various sizes

Total Mass $\sim 5 \times 10^{12} M_{Sun}$

Local Group diagram (see Figure 26-17). Note that many of the dEs and dSphs are close to M31 (=Andromeda) and the Milky Way.

Virgo Cluster

Nearest sizable cluster to the Local Group

Relatively loose cluster, centered on two bright ellipticals: M87 & M84 <u>Properties</u>

- Distance: ~ 18 Mpc
- Size: ~2 Mpc
- o 2500 galaxies (mostly dwarfs)
- $\circ Mass: \sim 10^{14} \, M_{Sun}$

Rich Clusters

See Figure 26-16 for an example Contain 1000's of bright galaxies:

- Extend for 5-10 Mpc
- Masses up to 10^{15} M_{Sun}
- One or more giant Elliptical Galaxies at center
- Ellipticals found near the center
- Spirals found at the outskirts

10-20% of their mass is in the form of a very hot (10^7-10^8K) intracluster gas seen only at X-ray wavelengths.

Brightest Cluster Galaxies



The centers of clusters are usually dominated by one or two *giant ellipticals*. These ellipticals have more than 10x the mass of the Milky Way and are larger by themselves than the whole Local Group.

Gravity Pulls Galaxies Together

See movie of gravity pulling galaxies into a cluster from Tom Quinn at the University of Washington at hpcc.astro.washington.edu/faculty/trq/toden.mpeg

Note that the galaxies have formed long before they are pulled into the cluster. This movie shows what happens to the dark matter and stars, not the gas.

How to get Hot Gas

Heating by photons (light). The hottest stars can heat gas to 10,000K. Visible light produced! Makes ionized hydrogen.

In clusters, there is heating by collision and shocks Shocks can heat gas to millions of degrees. X-rays!

Note: X-ray spectrum is not a blackbody. The gas is not dense enough.

Gas Colliding as Cluster Forms

See movie of gravity pulling gas together, and gas colliding at hpcc.astro.washington.edu/faculty/trq/gas1_6_11.mpeg

As gravity pulls the galaxies together to form a cluster, the gas in those galaxies smashes into other gas. Shocks heat the gas.

X-ray Gas in Clusters

Rich clusters can have lots of matter in the hot X-ray gas.

X-ray gas can be used to find clusters and avoid chance alignments. If gravity hasn't pulled galaxies together, no collisions of gas and no X-rays.

The X-ray gas is not very dense. It has an emission line spectrum that can be used to study its composition.

X-ray Gas in Groups Example: Stephan's Quintet Groups can have some hot X-ray gas as well. Usually a much smaller fraction of the cluster mass and not all encompassing of the galaxies in the cluster.

Neutral Hydrogen in Groups See Figure 26-25.

Groups of galaxies can have lots of neutral hydrogen gas. If we observe the emission at 21-cm, we can make maps showing the distribution of gas in groups. These galaxies are definitely connected!

The Magellanic Stream

The Milky Way and its satellites, the LMC and SMC, are also connected by neutral hydrogen gas.

Morphology-Density Relation

Ellipticals are much more common in clusters than in the field. The richer the cluster, the more ellipticals and S0s.

Isolated bright galaxies Spirals (Sa-Sc) $\sim 80\%$ S0 $\sim 10\%$ E $\sim 10\%$ Bright galaxies in rich clusters Spirals (Sa-Sc) $\sim 10\%$ S0 $\sim 50\%$ E $\sim 40\%$

Almost certainly due to the environment of clusters. In clusters, galaxies interact, merge, and harass each other. Spirals find it hard to survive. (Next class will discuss more details of the processes).

Motions of Galaxies in Clusters

Just like binary stars orbit around their center of mass, or stars orbit around a galaxy, galaxies in a cluster will orbit around their cluster center.

We can measure these motions (at least the radial ones!) through the Doppler shift in the integrated light.

Speeds exceeding 1000 km/s relative to the cluster center.

Evidence for Dark Matter in Clusters of Galaxies

Many lines of evidence show the presence of dark matter in clusters. This is not surprising since the individual galaxies have dark matter. ~90% of the matter is dark.

Speeds of galaxies (velocity dispersion)
Galaxies are moving very fast. Dark matter is needed to keep them attached to the cluster.
Confinement of X-ray gas
Gas atoms very hot (=moving very fast). Dark matter needed to keep the gas attached to the cluster.

Gravitational Lensing (see General Relativity)

Superclusters

Cluster of Clusters

Properties:

- Sizes up to 50 Mpc
- \circ Masses of 10¹⁵ to 10¹⁶ M_{Sun}
- o 90-95% empty space (voids)
- Often long and filamentary in shape

Largest coherent (but not gravitationally bound yet) structures in the Universe

Local Supercluster See Figure 26-20

Roughly centered on the Virgo Cluster <u>Properties:</u>

- Size: ~20 Mpc
- \circ Mass: $10^{15} M_{Sun}$
- \circ Only ~5% of the volume is occupied by galaxies

The Local Group is located on the outskirts of the Local Supercluster, and falling into the Virgo Cluster

Voids, Filaments & Walls

The Universe looks foamy on the largest scales (see Figure 26-21, 22)

<u>Filaments:</u> Vast Chains of superclusters Occupy ~10% of the Universe <u>Voids:</u> Empty bubbles 25-50 Mpc in diameter 5x fewer galaxies than in superclusters

The "Great Wall" Sheet of superclusters: 150 Mpc long 60 Mpc "high" 5 Mpc thick

Mass is $\sim 2x10^{16}M_{Sun}$

One of the largest structures known in the Universe

Implications

The existence of "Large Scale Structure" tells us something about how galaxies are formed.

Large structures sculpted by gravity Concentrations of matter where galaxies form

Unanswered questions:

Why do galaxies form only in particular places? How "empty" are the voids?