What is the Milky Way Galaxy, and how does it compare to other galaxies?
How do you define a galaxy?
What is the Local Group?
Do all galaxies have close neighbors?
What happens when galaxies collide?
A quick note on units...

- **Distances**: $1 \text{ kpc} = 3.08 \times 10^{19} \text{ meters}$
- **Mass**: $10^6 \text{ M}_\odot = 1.98 \times 10^{36} \text{ kg}$
- **Rates**: $100 \text{ km/s} \sim 100 \text{ kpc/Gyr}$
A close friend: Our Milky Way Galaxy

- An Sbc galaxy that is 30 kpc in diameter
Anatomy of the Milky Way

- $R_0 \sim 8$ kpc
- 200 billion stars
- $5 \times 10^{11} M_\odot$
- SFR $\sim 3$ $M_\odot$/yr
- Bulge $\sim 3$ kpc in diameter
A useful tool: Redshift

$$z = \frac{\lambda_{\text{obs}} - \lambda_0}{\lambda_0} = \frac{f_0 - f_{\text{obs}}}{f_{\text{obs}}}$$

- Measure the shift in a spectral line – $f_0$ is the rest frequency ($\lambda_0$ the rest wavelength)
- **Extragalactic objects** often identified by their $cz$ measurement.
- ALFALFA will cover $cz = -2000$ to $17000$ km/s
Expansion of the Universe

• Edwin Hubble (among others) showed the Universe was expanding!

• However, there are other factors to take into account in the local Universe – peculiar velocities! Deviations can be quite large depending on the galaxy, and whether it is part of a group or a field galaxy.

\[ cz = H_0 d \]
Around the Milky Way...
Around the Milky Way...
The Andromeda Galaxy

- Sb galaxy 770 kpc from the Milky Way.
- Larger, more luminous, with a larger disk scale length than the Milky Way – it even rotates faster at 260 km/s!
- At least 9 known satellite galaxies – dwarf elliptical and spheroidals!
The Andromeda Galaxy: GALEX
**M33**

- **Late-type spiral** galaxy \(~850\) kpc from the Milky Way and \(~200\) kpc from Andromeda
- Disk scale length is around 1.7 kpc, rotating around 120 km/s.
What are we missing!?!?!?!
What are we missing!?!?!?!

THE GAS!!!!!!!!!!!
M33

- Richer in HI gas than M31 or the Milky Way – VLA doppler image show movement of the HI gas towards and away.
- The HI disk extends out to 30 kpc, enough for M31 to cause tidal effects and warp the outer disk!
Galaxy Morphology
What do galaxies look like?

Well, it depends...
Galaxies across the spectrum

Radio Astronomy provides a crucial part of the picture!
<table>
<thead>
<tr>
<th>Galaxy Type</th>
<th>Hubble</th>
<th>de Vaucoulers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiral</td>
<td>S, Sa, Sb...</td>
<td>1 through 6</td>
</tr>
<tr>
<td>Elliptical</td>
<td>E</td>
<td>-6 through -4</td>
</tr>
<tr>
<td>Dwarf</td>
<td>dE, dSph</td>
<td></td>
</tr>
<tr>
<td>Lenticular</td>
<td>S0, SB0</td>
<td>-3, -2, -1</td>
</tr>
<tr>
<td>Irregular</td>
<td>Irr</td>
<td></td>
</tr>
</tbody>
</table>
Hubble’s Tuning Fork
Spiral Galaxies

- Thin disks
- Most have some form of a bar – arms will emanate from the ends of the bars
- Other classification:
  1. Relative importance of central luminous bulge and disk in overall light from the galaxy
  2. The tightness of the winding of the spiral arms
  3. Degree to which spiral arms are resolved into stars and individual HII regions
Dwarf Galaxies

- Smaller size than giant elliptical galaxies
- Lower surface brightness

M32

Sagittarius Dwarf
Irregular Galaxies

- LMC and SMC are satellite galaxies of our own – disrupted by gravitational interaction with the Milky Way…
Irregular Galaxies

- M82 – irregular starburst galaxy
- Star formation rate at 10 times the rate of our galaxy
- Chandra X-ray image reveals hot gas flowing out of the galaxy – hot spots indicate x-ray binary stars – some of the brightest known!
Elliptical Galaxies

- **Smooth** and very little structure; varying in shape
- Classified by EN where \( N = 10(1-b/a) \)
- Large populations in clusters.
- Little gas – don’t see spectral HI lines

M87
The Local Group

- The Local group has **41 members**, ranging from large spiral galaxies to small dwarf irregulars. Most galaxies are dwarf spheriodals...
The Local Group

- Giant spirals
- dSph (+dEII)
- dlrr
- dlrr/dSph
Galaxy Groups
Groups of galaxies

- Galaxies can be gravitationally bound to each other, and undergo interactions and collisions.
- Separations across intergalactic distances range from 50 kpc up to 1 Mpc.
- Groups are important physically because one can determine a dynamical mass for the system.
- ALFALFA science goals include studying the effects within the group environment –
  - What is the HI mass function – the mass density of a given environment?
  - How do unseen HI clouds/starless galaxies effect dynamics?
  - Are there unseen tidal remnants or debris?
  - What are sizes of HI disks?
Neighboring Galaxy Groups
Groups of galaxies

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution

21 cm HI Distribution
M83 Group
Extended HI Disk of a BCD

UGC 5288
Sdm:
M66 Group
M66 Group
Colliding Galaxies
Colliding Galaxies
Colliding Galaxies
Galaxy Clusters
Clusters of Galaxies

• Around half the galaxies in the Universe are found in clusters or groups.
• Cluster have a higher density than “loose” groups – brightest galaxies are S0s and ellipticals instead of spirals
• Abell Catalog contains 4073 rich clusters
• Gravity binds the members, as well as hot intracluster gas (seen in the X-ray)
Virgo Cluster

- \( cz \sim 1050 \text{ km/s} \)
- \( \Delta v \sim 1000 \text{ km/s} !! \)
- 1300 catalogued members!!
- Most galaxies are dwarfs
- Core radius \( \sim 500 \text{ kpc} \)
Coma Cluster

- At $cz = 6900$ km/s
- **Four times** the size of Virgo!!
- Core contains only ellipticals.
Fornax cluster

- $cz \approx 1400 \text{ km/s}$
Fornax Cluster – Xray view
Fornax – optical + radio
Hercules Cluster

$cz \sim 11,000 \text{ km/s}$
Perseus Cluster

cz \sim 5000 \text{ km/s}
Leo Cluster

• $cz \sim 6400 \text{ km/s}$
Centaurus Cluster

- $cz \sim 3000 \text{ km/s}$
- X-ray image shows gas expelled from the central member
Superclusters
The largest structures in The Universe
Local Supercluster
Pisces-Perseus Supercluster

Haynes & Giovanelli
The big picture

• 8800 galaxies from Springob, Haynes, Giovanelli, and Kent 2005!

• A large collection of HI in galaxies!
What to think about...

What kind of galaxy am I currently examining?
- Where and what kind of information can I find on this galaxy (or group)?
- What is the distance? Mass?
- What will new information obtained from YOUR observations tell you about the galaxy, its history, and even its future?

Your MOTIVATION – study the Universe with the world’s LARGEST telescope!