The Milky Way Galaxy
Lecture 21

Lecture Topics
- The Galaxy: What is it?
  - Historical context
  - Importance of interstellar extinction
  - A few photos
- Components of the Milky Way
  - Disk, bulge, and halo
  - Atomic, molecular, and ionized gas
The Galaxy: What is it?

- Galaxy derives from the Greek word *galaktikos* which means milky white.
  - “River of Milk” from horizon to horizon
  - The word “Galaxy” (capitalized) is used to refer to our own galaxy, the Milky Way.
- Today we know this band of light is composed of countless numbers of individual stars and that we are among them.
- We’re far out from the center of a thin disk.
Historical Perspective

- In the early part of the 20th century, Kapteyn (~1920) counted stars to discern the shape of the Galaxy?
- Used spectral types to get $M_V$ and the distance modulus to derive the locations of the stars (the stellar distribution).
- Doing this it appears that we are near the center of an elliptical distribution of stars!

How it looks to us.

- Doing this it appears that we are near the center of an elliptical distribution of stars!
Why is the naïve view wrong?

- But we know that the Galaxy is a thin disk and we are near the edge.
- So a model with us at the center is not correct.
- What is wrong?

Interstellar extinction

The Milky Way in Sagittarius

Patchiness due to dust extinction
Interstellar Extinction

- There are dust particles in interstellar space. (~0.1 μm in size)
- They absorb and scatter light strongly in the UV and visible.
  - Stars appear dimmer and hence appear further away than they really are.
  - We can only see stars to about 1 to 2 kpc away in the visible.

The True Picture

- In the early 1920s, Harlow Shapley deduced the correct size and shape of the Milky Way using variables in globular clusters.

Globular clusters in the halo.
Thin Disk
The View Today

- Unlike the visible spectrum, infrared and radio wavelengths allow us to see through the dust.
- We can directly see the shape of the Milky Way.

Whole galactic plane in visible

Again, patchiness due to dust extinction
Whole galactic plane in Near-Infrared (2MASS)

Near-IR shows stars in the galaxy. Less extinction than visible

Infrared view penetrates dust

Infrared View
Whole galactic plane in Far-Infrared (IRAS)

Galactic plane and star formation regions show up in Far-IR

Whole galactic plane in Radio Continuum

Radio shows regions of star formation and supernova remnants
The Milky Way

- The Milky Way is ~12-15 kpc in radius
  - The Sun is ~8.5 kpc from the center.
- The MW has two primary constituents:
  - Stars
  - Gas and dust which are collectively known as the Interstellar Medium (ISM).
- The ISM comprises only ~ 1-3 % of the mass of the galaxy.
Schematic of the Milky Way

The Galactic Disk
- A very thin “pancake” of stars (Pop I)
  - Radius ~ 15 kpc
  - Thickness: 100 pc (O-stars) to 350 pc (M-stars)
- Spiral arms are present
  - long spiral features containing very young stars, star clusters, gas and dust
- Nearly all of ISM in the disk
Galaxy M51 showing spiral arms

- Lots of gas and dust in the spiral arms
- Young stars
  - O, B stars are present

Spiral Arm Details

- Wave patterns occur in the disk of the Galaxy.
- These “spiral density waves” trigger star formation.

Young blue stars are found on outer edge of spiral arm

Ionization nebulae arise where newly forming blue stars are ionizing gas clouds
Spherical Component

- Two components of Pop II stars:
  - **Halo** - spherical distribution of stars and Globular clusters. Halo radius ~ 5-10 kpc.
  - **Bulge** - dense swarm of stars centered on the Galactic center.
    - Bulge radius ~1.5 kpc, height ~0.7 kpc
- Very little gas and dust.
- Randomly tipped elliptical orbits

Schematic of orbital motion in Milky Way

- Halo and bulge orbits are randomly tipped and elliptical.
- Disk orbits are more circular but oscillate up and down in the disk.
Gas and Dust in the Galaxy

- Two major reservoirs of gas and dust
  - **Atomic gas** - mainly HI atoms which can be seen in the 21-cm line.
  - **Molecular Gas** - mainly H₂ molecules which are traced by CO molecules, since H₂ is difficult to detect.
- A small amount (~3%) of the ISM is found in ionized gas regions.

<table>
<thead>
<tr>
<th>State of Gas</th>
<th>Primary Constituent</th>
<th>Approx. Temperature</th>
<th>Approx. Density (atoms/cm³)</th>
<th>Description</th>
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<tbody>
<tr>
<td>Hot Bubbles</td>
<td>Ionized hydrogen</td>
<td>1,000,000 K</td>
<td>0.01</td>
<td>Pockets of gas heated by supernova shock waves</td>
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<tr>
<td>Warm atomic gas</td>
<td>Atomic hydrogen</td>
<td>10,000 K</td>
<td>1</td>
<td>Fills much of galactic plane</td>
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<tr>
<td>Cool atomic gas</td>
<td>Atomic hydrogen</td>
<td>100 K</td>
<td>100</td>
<td>Intermediate stage of star-gas-star cycle</td>
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<tr>
<td>Molecular clouds</td>
<td>Molecular hydrogen</td>
<td>30 K</td>
<td>300</td>
<td>Regions of star formation</td>
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<tr>
<td>Molecular cloud cores</td>
<td>Molecular hydrogen</td>
<td>60 K</td>
<td>10,000</td>
<td>Star-forming clouds</td>
</tr>
</tbody>
</table>
Ionized gas components

- Consist of
  - Supernova remnants (SNR)
  - Planetary nebula
  - HII regions
- SNR and Planetary Nebulae inject “heavy” elements into the ISM.
- SNR “stir up” the ISM.

X-ray view of Tycho’s supernova remnant (7500 lyr away, 20 lyr across)

Ring Nebula (M57)

Butterfly Nebula
Atomic Gas

- Flattened pancake
  - Radius > 20 kpc.
  - Height ~ 250 pc in center, 1 kpc at 20 kpc
- Mass ~ $3 \times 10^9 \, M_{\text{sun}}$, ~2/3 outside the orbit of the Sun around the Galactic Center.
- Distorted appearance at the fringes of the Galaxy. Interaction with LMC, SMC?

Schematic of the atomic gas distribution

M_{\text{gas}} \sim 3 \times 10^9 \, M_{\text{sun}}

warp in the disk

250 pc

20 kpc

Sun

Galactic Center

1 kpc
Molecular Gas

- Molecular “Ring”
  - from 4-8 kpc and concentration on GC
  - Thickness ~ 120 pc.
- Giant Molecular Clouds (GMCs):
  - Size ~ 10 - 50 pc, Mass ~ $10^3 - 10^6 M_{\text{sun}}$
  - Stars form in cores of GMCs.
- Mass ~ $3 \times 10^9 M_{\text{sun}}$, ~2/3 inside the orbit of the Sun around the Galactic Center

The molecular gas distribution

M ~ $2 \times 10^8 M_{\text{sun}}$ for GC clouds

Total mass of molecular gas ~ $3 \times 10^9 M_{\text{sun}}$