Lecture 28: Spiral Galaxies
Readings: Section 25-4, 25-5, and 26-3

Key Ideas:
Disk & Spheroid Components
  Old Stars in Spheroid
  Old & Young Stars in Disk
Rotation of the Disk:
  Differential Rotation Pattern
  Measurement of Galaxy Masses
  Dark Matter!
Spiral Arms:
  Outlined by O&B Stars, H\(^\text{+}\) Regions, & Gas
  Sites of recent star formation

Spiral Galaxies
The Milky Way and Andromeda are examples of Spiral Galaxies

Thin **Disk** of stars, gas and dust.
Thick **Spheroid** of stars with little gas or dust

All Spirals have disks of varying sizes.
The spheroids of spirals vary greatly in size.

Properties:
  Mass: \(10^9-10^{12} M_{\text{Sun}}\)
  Diameter: 5-50 kpc
  Luminosity: \(10^8-10^{11} L_{\text{Sun}}\)

Structure & Dynamics
  Disk + Spheroid
  Supported by relatively rapid rotation, but spheroid is puffed up by random motions
Spheroid Structure

**Bulge:** Where inner spheroid & disk merge  
- Many RR Lyrae stars  
- A little gas and dust  

**Halo:** sparse outer spheroid  
- Old metal-poor stars  
- Globular clusters  
- RRLyrae stars  
- Dark Matter important

Disk Structure

**Thick disk of Stars**  
- Mix of young & old stars  
- Open Clusters & loose Associations of stars  
- Cepheid Stars in young clusters

**Thin disk of Gas & Dust**  
- Mostly cool atomic H gas  
- Dusty Giant Molecular Hydrogen Clouds

NOTE: Gas & Stars act differently when they pass by. Stars rarely collide, gas collides and pancakes.

Type S: Ordinary Spirals

Classified by relative strength of the bulge & tightness of the spiral arms

**Types:** Sa, Sb, and Sc  
- Sa: strong bulge & tight, indistinct spiral arms  
- Sb: intermediate type  
- Sc: small bulge & loose, well-defined spiral arms
See Figure 26-4 for pictures of the types.

**Type SB: Barred Spirals**
Parallel group to the ordinary spirals:
   About as many barred as ordinary spirals.
Feature a strong central **stellar bar:**
   Bar rotates as a unit (solid body rotation)
   Spiral arms emerge where the bar ends
Same subclasses
   SBa, SBb, and SBc

See Figure 26-5 for pictures of the types.

**Warped Disks**

The distribution of gas in the Milky Way suggests our thin disk is warped too.

“Twanging” by passing galaxies likely responsible

**Rotation of the Disk**
Measure using the **Doppler Effect**
Stars:
   Doppler shifts of stellar absorption lines
Ionized Gas:
   Doppler shifts of emission lines from H\(^+\) regions
Atomic Hydrogen (H\(^0\)) Gas:
   Cold H clouds emit a **radio emission line** at a wavelength of 21-cm
   Can trace nearly the entire disk beyond where the stars have begun to thin out.
Rotation Curves
The disk rotates about the center of the galaxy

**Inner Parts: Solid-Body Rotation**
- Orbital speed **increases** with radius
- Orbit period is **constant**

**Outer Parts: Differential Rotation**
- Orbital speed is nearly **constant** with radius
- Orbital period **increases** with radius

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**Differential Rotation**

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**Measuring Masses of Galaxies**
Star or Gas cloud is held in its orbit by the gravity of the mass **interior** to its orbit.
Newton’s Gravity:

\[ M(R) = \frac{V_{rot}^2 R}{G} \]

M(R) = mass interior to radius R
V_{rot}=rotation speed

Example: Milky Way

Sun:
- R=8kpc, V_{rot}=220 km/sec
- Gives M=9\times10^{10}M_{\text{Sun}} inside R=8kpc

Gas Cloud in Outer Disk:
- R=16kpc, V_{rot}=275 km/sec
- Gives M=2.8\times10^{11}M_{\text{Sun}} inside R=16kpc

Measuring the rotation curves gives us a good way to measure the masses of Spiral Galaxies

**Galaxy Rotation Curves**

Spiral Galaxies rotate such that:
- Speed rises from the center to the inner disk
- Speed becomes constant (flat) in the outer disk

**Mass Distribution in Galaxies**

Most of the stars are in the inner 10 kpc
If stars provided all of its mass, we expect
- Rotation speed should rise to a **maximum** in the inner parts
  - Then **fall steadily** with radius outside R\sim10 \text{kpc}

But the rotation curve stays flat!
- Outer parts are rotating **faster** than expected

Need **more mass at large radii** than is observed in the stars and gas alone…
Dark Matter Halos

Question: What is the extra mass if it is not stars & gas?

Answer: Galaxies must have extended dark halos

Properties of Dark Halos:
- Contain ~90% of the galaxy’s mass
- More extended than the starlight component
- The orbits of satellite galaxies suggest halos may extend out as far as 200 kpc!

Spiral Arms

The spiral arms are regular, spiral-shaped patterns of hot stars, star clusters, gas & dust that cross the face of the disk.

Tracers
- O&B stars
- H\(^+\) Regions (star forming regions)
- Giant Molecular Clouds
- Hydrogen Gas and Dust Clouds

These are rarely found outside the arms

Sites of Active Star Formation

Sun takes ~200 Myr orbit Galaxy
- Sun lives for ~12 Gyr, so can make ~50 orbits

O&B Stars only live for ~10 Myr
Only move 10-20° before dying as supernovae
They won’t move very far from their birthplace before exploding as supernovae

We see O&B Stars and H\(^+\) regions strung along the spiral arms like “beads on a string”

**What are Spiral Arms?**
Spiral Arms are **Density Waves** that pass through the general disk of stars
Density Waves are a kind of orbital traffic jam
- Orbits crowd together in the arms
- Stars pile up and make the regions look brighter
- Gas clouds pile up, collide, fragment, and form new stars

O&B stars are born, ionize leftover gas (H\(^+\) regions), then die before moving far from the waves.

**Density Waves**
Density waves pass through the disk like water waves pass over the ocean.
- Stars move through the spiral arms
- Gas clouds try to move through, but some are induced to form stars (collision or compression)
Not sure how the waves are created:
- Tidal disturbance from a nearby companion?
- Excited by a stellar bar in the central regions?
Both mechanisms are possible?