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^+ Regions, & Gas
- Sites of recent star formation

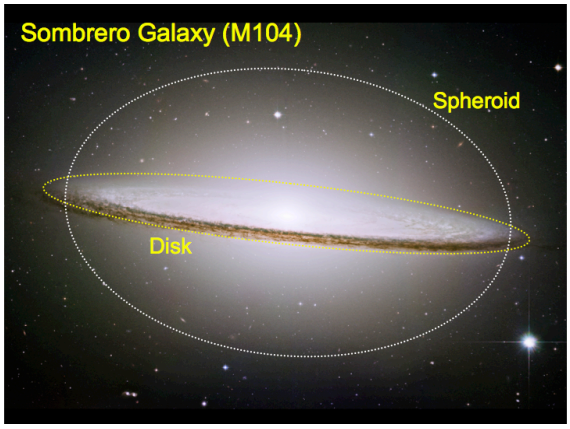
Spiral Galaxies
The Milky Way and Andromeda are examples of *Spiral Galaxies*

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-$10^{12}M_{Sun}$
- Diameter: 5-50 kpc
- Luminosity: 10^8-10^{11} L_{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
- Globluar 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:

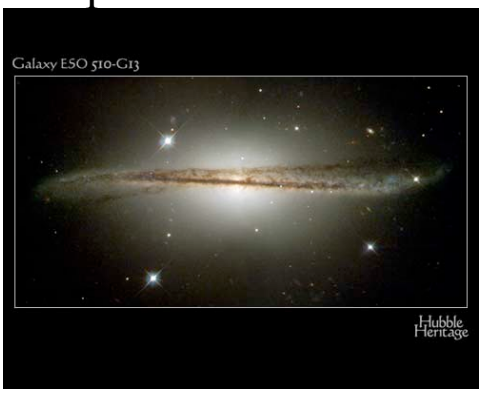
- Bar rotates as a unit (solid body rotation)
- Spiral arms emerge where the bar ends

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

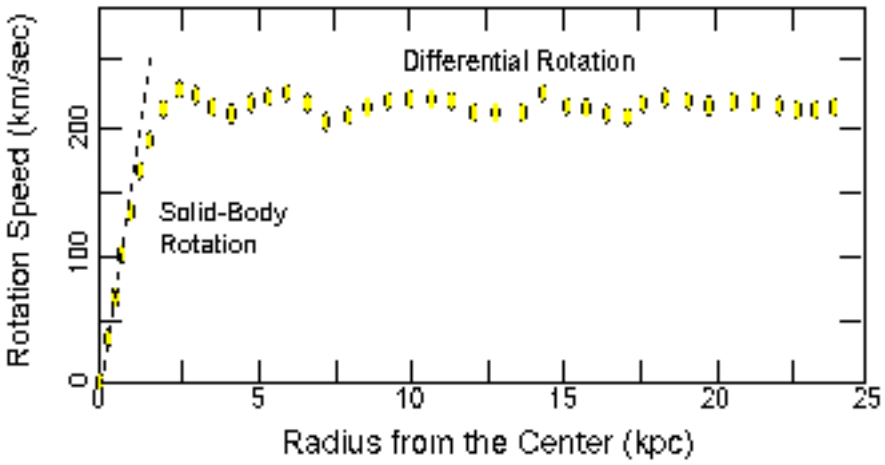
Orbital speed **increases** with radius

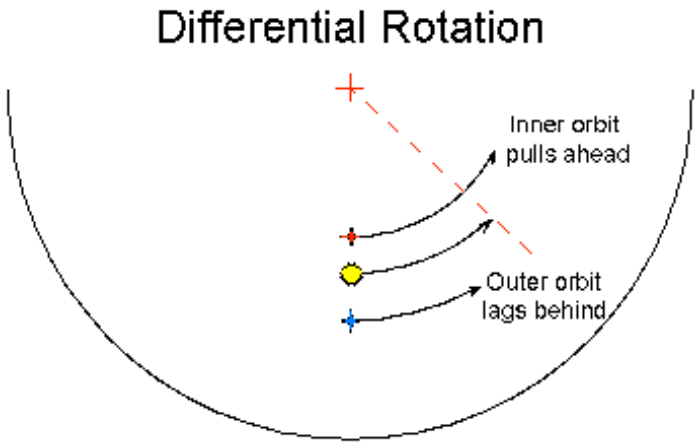
Orbit period is **constant**

Outer Parts: Differential Rotation

Orbital speed is nearly **constant** with radius

Orbital period **increases** with radius





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=$9 \times 10^{10} M_{Sun}$ inside R=8kpc

Gas Cloud in Outer Disk:

R=16kpc, V_{rot}=275 km/sec
Gives M=$2.8 \times 10^{11} M_{Sun}$ 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

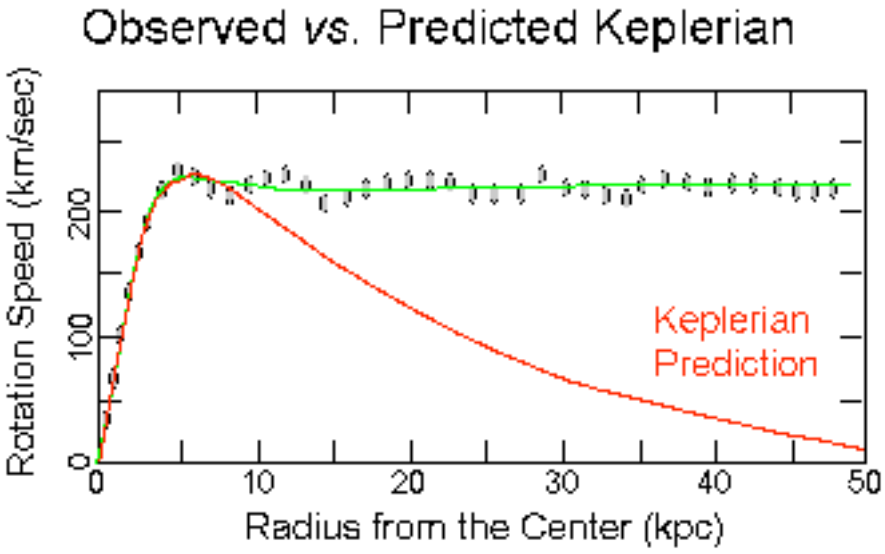
Most of the stars are in the inner 10 kpc
If stars provided all of its mass, we expect

Rotation speed should rise to a **maximum** in the inner parts
Then **fall steadily** with radius outside R~10 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^{o} 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?