Astronomy 210

This Class (Lecture 37):

The Milky Way Galaxy

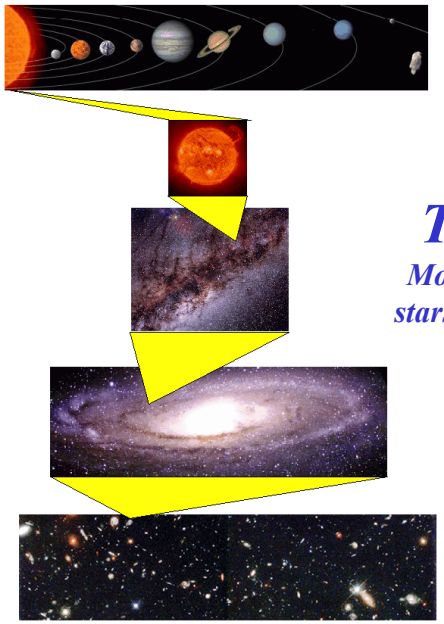
Stardial 2 due Friday

Next Class:

Galaxies, Structure of the Universe

Outline

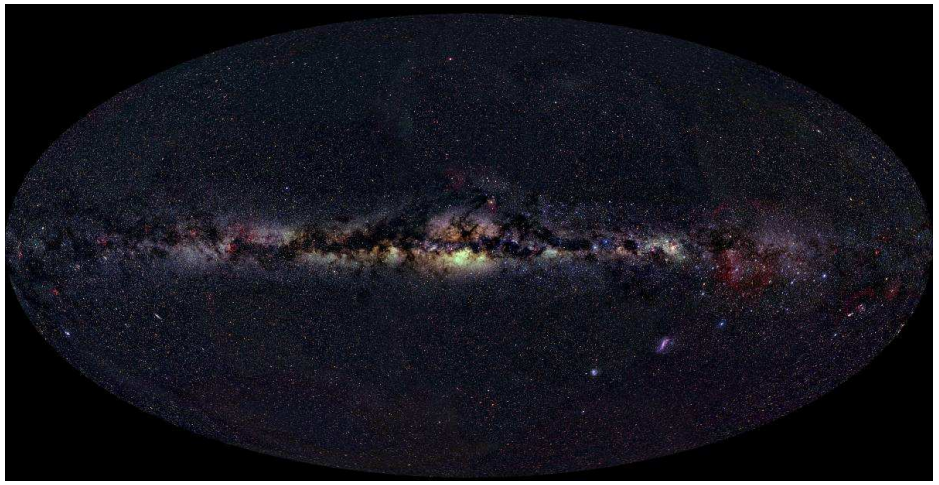
- The Milkyway
  - Globular clusters, Galactic nucleus, Nuclear bulge, Spiral Arms and the Disk
- We rotate around the center of the Galaxy.
- There is something fishy about the MW rotation curve.
- Other Galaxies, other rooms
- Recycling centers of the Universe
- Is everyone's rotation curves full of halibut?



Astronomy: The Big Picture

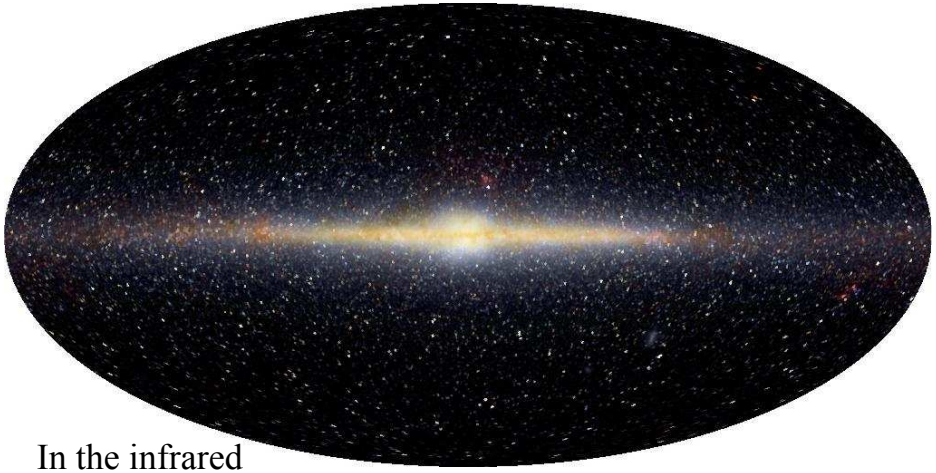
Moving from the birth/death of stars to a better understanding of the Galaxy!

The Milky Way



http://home.arcor-online.de/axel.mellinger/mwpan_aitoff.html

What is it?

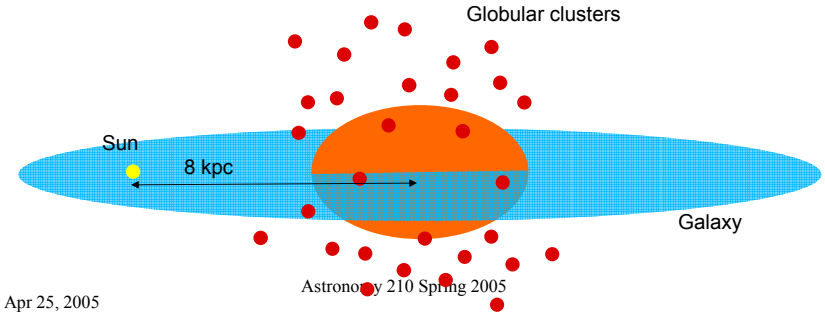


In the infrared

http://antwrp.gsfc.nasa.gov/apod/image/0001/milkyway_cobe_big.jpg

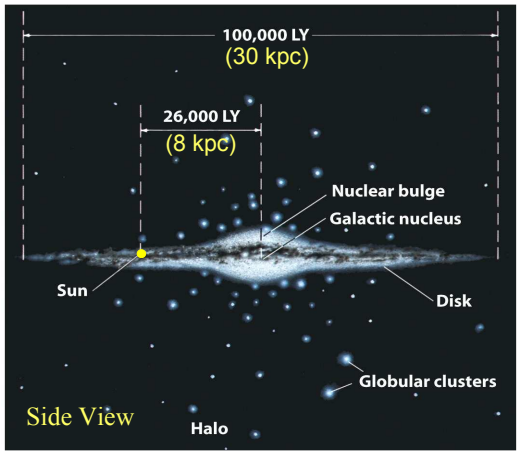
Our Place

- Shapley showed that we are not the center of the Galaxy in the 1920s.
  - **2nd Copernican revolution!**
- All of the globular clusters are orbiting around a point in Sagittarius– 26000 lyrs or 8000 parsecs away.
- That must be the center of our Galaxy.



The Structure of Our Galaxy

- Disk
  - All kinds of stars, many younger
  - Open clusters
  - Gas and dust
- Halo
  - Old, red dwarfs and giants
  - Little gas and dust
  - Globular clusters
- Bulge
  - Mixture of halo and disk



The Disk

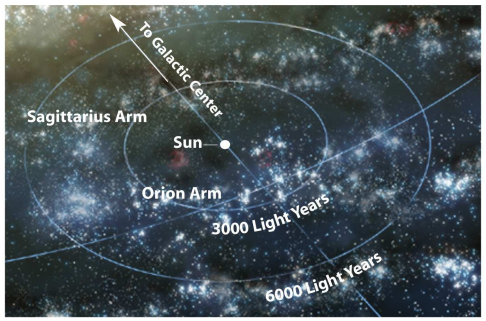
- The disk of our Galaxy contains most of its visible mass
  - 90% of the Galaxy's stars
- Its where "the action" occurs
  - Star formation, nebulae, etc..
- Relatively thin
  - 700 parsecs thick vs. 30,000 parsecs across

Spiral Arms?

- Other disk galaxies show spiral arms
  - Made of O- & B-type stars, diffuse nebulae, and giant molecular clouds
- How do we know our Galaxy has them?
- It's the problem of not seeing the forest for the trees

Hints of Spiral Arms

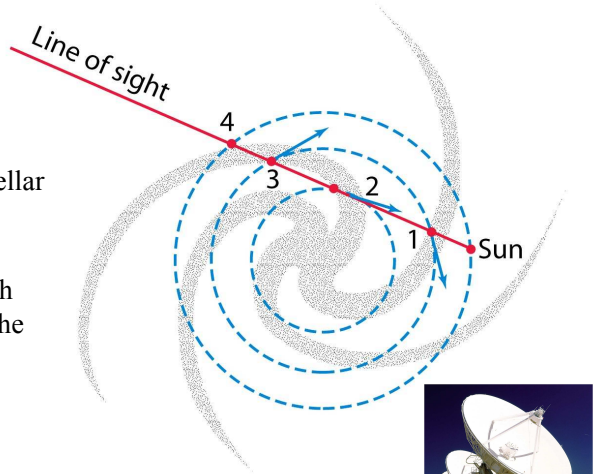
- We plot the locations of nearby O- and B-type stars in our Galaxy
- Find the stars are arranged in arms
- Our Sun is in-between spiral arms



- But we can't see beyond a few thousand light years
- What about the rest of the Galaxy?

Seeing the Galaxy in Hydrogen Emission

- Look for 21-cm wavelength photons
  - Emitted by interstellar hydrogen – most abundant stuff!
  - Easily pass through gas & dust along the way
  - Map the Galaxy!

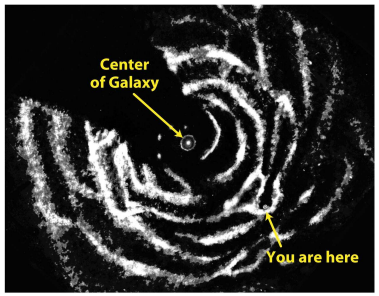


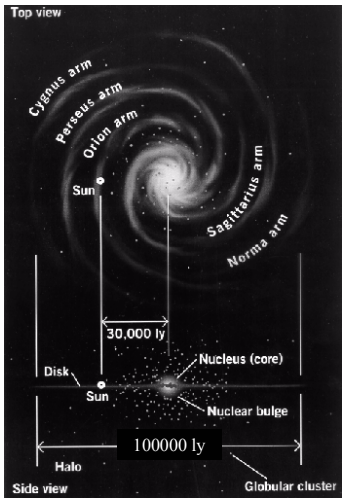
Visible and Radio

M83

The Galaxy's Spiral Arms

- The 21-cm radio emission shows the spiral arms (below)
- We find five main arms in the Galaxy (right)





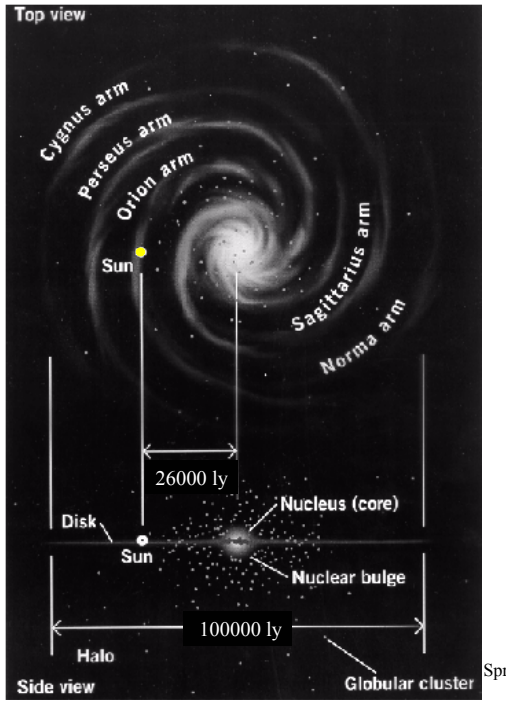
The Galactic Halo

- Our Galaxy's disk is surrounded by a spherical halo of stars & globular clusters
  - Red dwarfs and red giants – old stars
  - Only about 2% the number of stars in the disk
- There is some structure to the halo
  - Denser towards the center
  - Two sets of globular clusters
    - Outer clusters – older, spherical distribution
    - Inner clusters – slightly younger (but still old), flattened spherical distribution

The Bulge

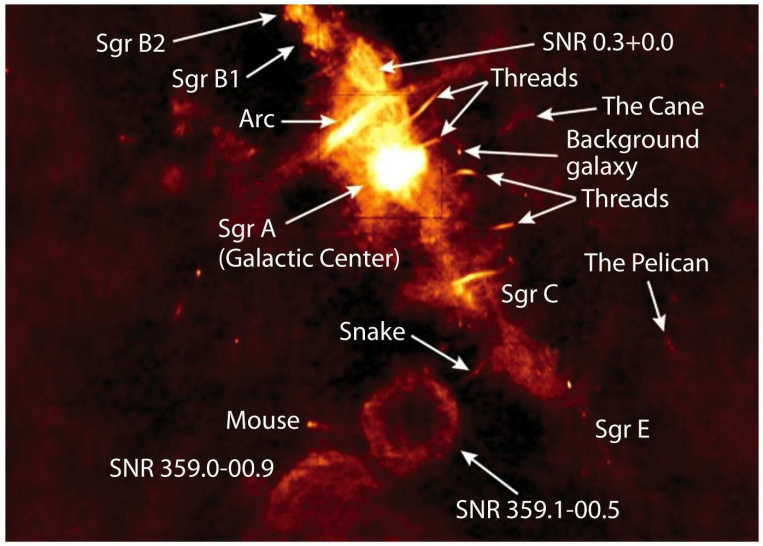
- The region where the disk and the halo merge
  - About 2,000 pc across
  - Contains about 10% of the Galaxy's stars

- Mix of primarily old stars, but also contains some young stars and gas & dust
- Like an extension of both the disk and halo



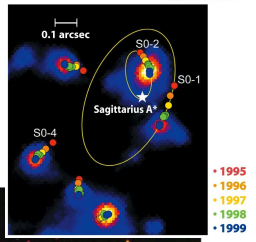
Our Galaxy

The Center of Our Galaxy

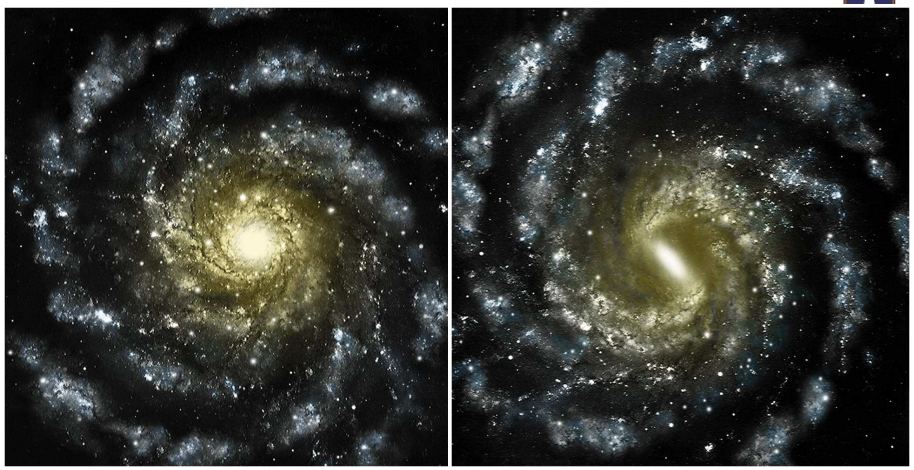


The Galactic Nucleus

- Buried in the center of the bulge
- 8,000 pc away
- Incredibly dense region of stars and gas



Do Galaxies Spin?



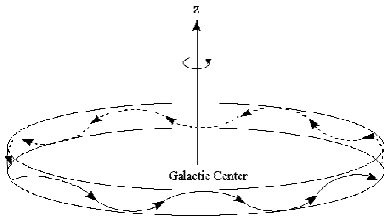
Spiral galaxies really suggest it. BTW, our Galaxy probably looks more like the right galaxy.

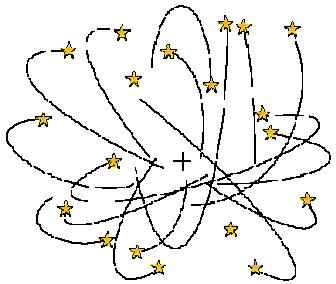
Rotation of the Galaxy

- Similar to the planets orbiting the Sun, the stars and gas of the Galaxy orbit the nucleus
- How does the Galaxy rotate?
- Like a CD? DVD?
- How about disk vs. halo?
- Measure Doppler shifts to find out.

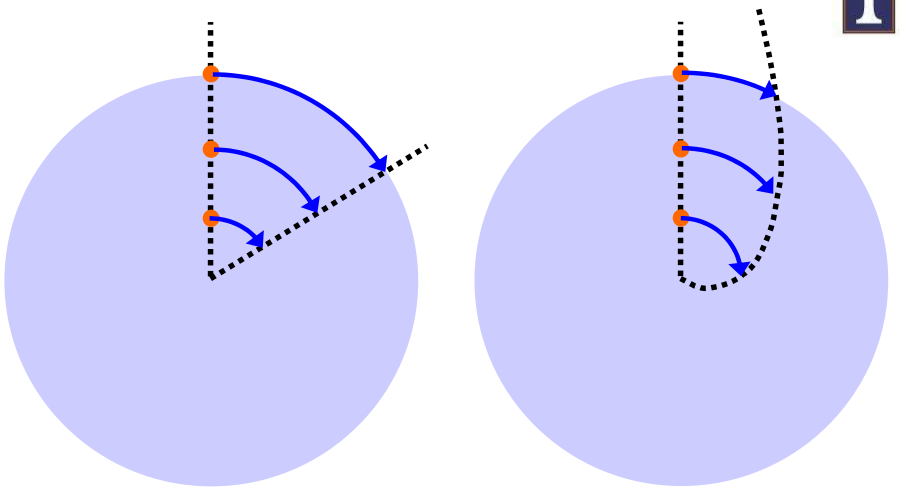
Rotation of the Galaxy

- Stars in the disk all orbit the Galaxy in the same direction
  - Stay in the disk (they may drift up and down)
  - Orbits roughly circular
- Stars in the halo and bulge orbit the Galactic nucleus randomly
  - No organization to the orbits
  - Many very elliptical orbits





Solid vs. Differential Rotation



Same angular speed (degrees per year)

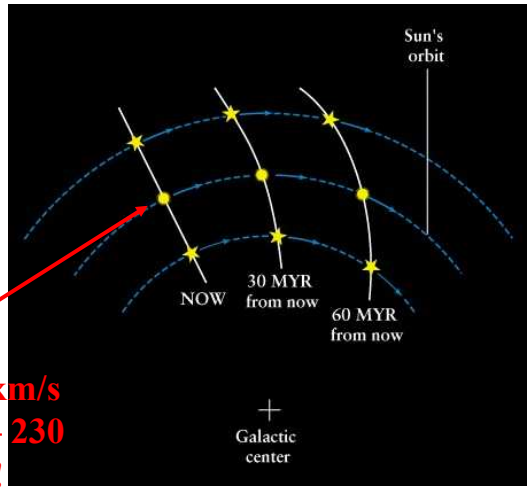
Same linear speed (parsecs per year)

Rotate on..

- Different than the solar system.
- In Solar System, the mass is centralized.
  - $V = 2\pi a / P$ and $P^2 = a^3$
  - So, $V \propto 1/a^{1/2}$
- For a galaxy, there is substantial mass at all radii, so the orbital velocities of stars and gas change differently with orbital radius in a galaxy than in the solar system.
- Using the Sun's orbital speed and Kepler's 3rd Law, we can calculate the mass of the Galaxy inside our orbit!
- Measure our movement with respect to the globular clusters.

Is the Solar System Moving Too?

Yes… the whole Galaxy has differential rotation– us included

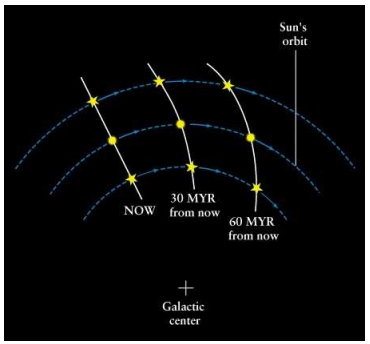


The Sun orbits at 220 km/s or about 500,000 mph– 230 million years per orbit!

Wow! That's fast!

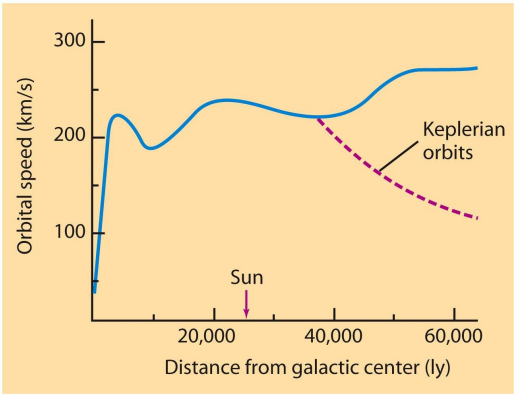
Stop and think about it.

- **That's traveling to Chicago in 1 second!**
- But MW is big!
- Only orbited 50 times!
- Last time the Sun was here, the dinosaurs were just starting out.
- ¼ way around, they were extinct!



The Rotation of the Galaxy

- Since we know our speed, we can measure the orbital speed of the other stars.
- v is constant from 2kpc out.



Velocities Are Odd.

- v ~ constant after 2 kpc
- Recall that

$$v_{circ} = \sqrt{\frac{GM}{R}}$$

- Can be used to get mass interior

$$M(r) = \frac{v_{circ}^2 R}{G}$$

Velocities Are Odd.

- Can be used to get mass interior

$$M(r) = \frac{v_{circ}^2 R}{G} \qquad M(8kpc) = 8\times10^{10} \text{ solar masses}$$

- And if v_{circ} is a constant, then $M \propto R$
- This means that there is more mass farther out

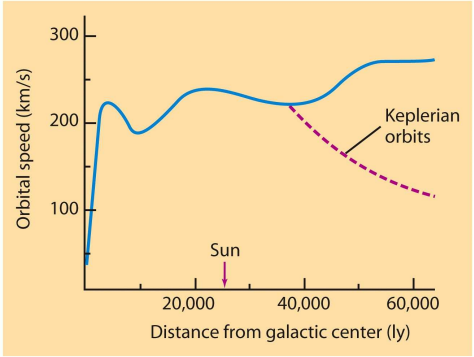
$$M(16kpc) = 2M(8kpc) = 1.6\times10^{11} \text{ solar masses}$$

- But once outside all visible matter, stars, gas, dust, the mass should be constant, then

$$v_{circ} = \sqrt{\frac{MG}{R}} \propto \frac{1}{\sqrt{R}}$$

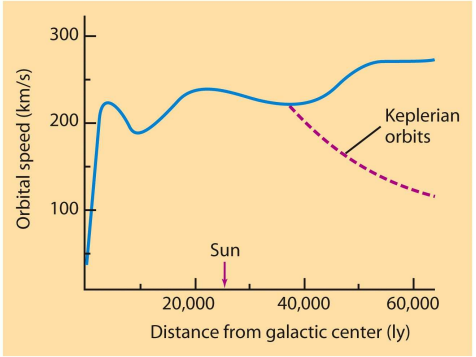
Whaa?

- Velocity does not drop off with stars, gas, or dust
- It is still constant, or even increasing
- There must be a lot of mass at farther radii that is not glowing at any wavelength.
- Dark Matter!



Rotation Curve Shows Hidden Mass

- The farther a star is from the center, the slower it should orbit
- Observations show that speed actually increases or is constant with distance from the center
- There must be **a lot** of mass in the outer parts of the Galaxy
- But only 20% of the Galaxy's light is outside the orbit of the Sun
- The mass in the outer part of the Galaxy is **dark**

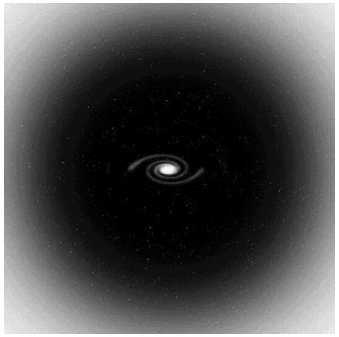


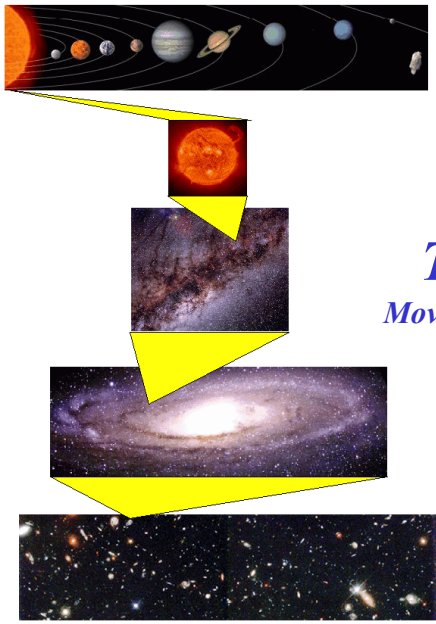
Dark Matter

- What is this dark matter?
- Must have mass and must not glow. To be precise, must be very dim.
- Dark matter is of unknown origins, although several hypotheses exist:

Dark Matter

- The dark matter in the Galaxy is in greatly extended halo
  - Up to 90% of the Galaxy's mass is dark matter!
  - Galaxy may have over a trillion solar masses total!





Astronomy: The Big Picture

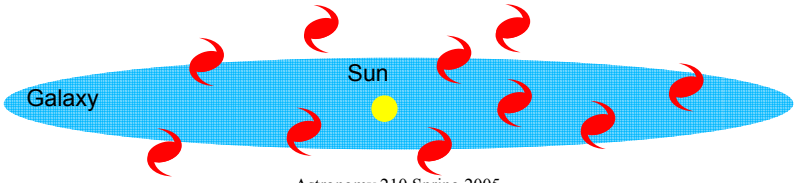
Moving from our Galaxy outward!

"Spiral Nebulae"

- Dim, diffuse "nebulae" with spiral patterns
- Spiral structures catalogued mid-1800s by Lord Rosse (Ireland)

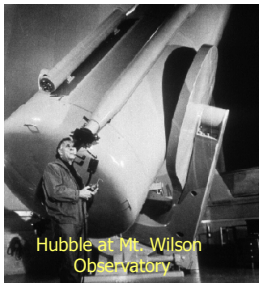
Those weird Spiral Nebulae?

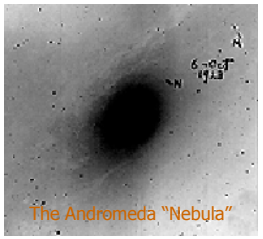
- Dim, diffuse, "interstellar" nebulae with spiral structure were seen in the 17th century.
- Some disagreement on what they were.
  - Kant: Our galaxy is a spiral "island universe" and the other spiral nebulae are the same and far away
  - Herschel and others: Milky Way is all there is in the Universe, and the spiral nebulae are nearby. More prevalent idea.



Edwin Hubble

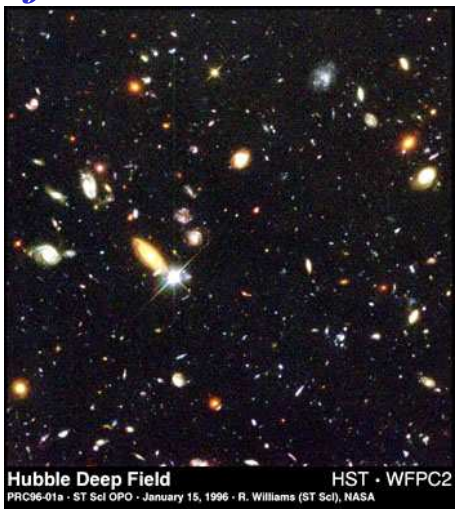
- In 1923, Hubble resolved M31, the Andromeda "Nebula", into stars
- If these stars were like the stars in our Galaxy, then M31 must be far away!
- Estimated the distance to M31 to be 300,000 parsecs (modern estimate is 700,000)
- Andromeda is an "island universe" like our own Galaxy.





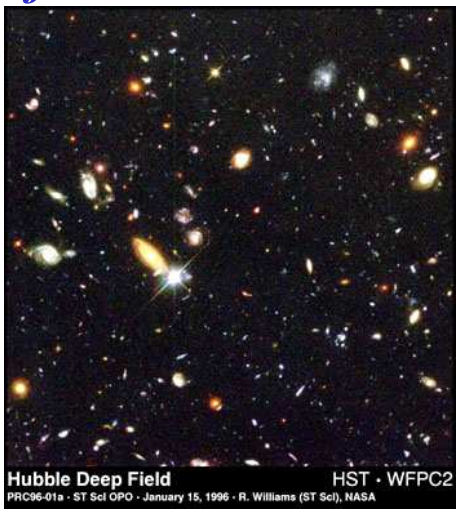
Galaxies – Fundamental "Ecosystems" of the Universe

- Galaxies "fill" universe.
- Typical separation ~ 10^6 pc or 1 Mpc
- Most distance is 1000's of Mpc away
- Galaxies are huge masses of stars
- Range in size from large (MW-like) to small "Dwarf"
  - 1 billion to 100's of billions of stars



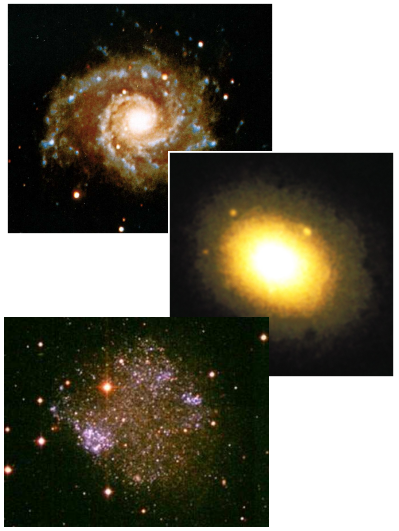
Galaxies – Fundamental "Ecosystems" of the Universe

- The cosmic engines that turn gas and recycles the gas the stars eject back
- In between no star formation occurs – "nothing happens" in intergalactic space.
- Can classify them



Classes of Galaxies

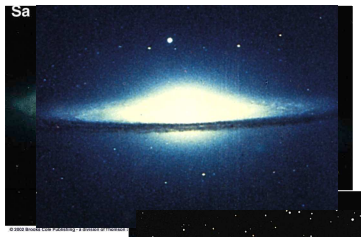
- **Spirals (S)**
  - Basic structure: disk and bulge
  - Medium to large galaxies
  - The disk has the young blue stars, while the bulge has older red stars
- **Ellipticals (E)**
  - Pure bulge, no disk component
  - Large range in sizes
  - All older red stars
- **Irregulars (Ir)**
  - Well… odd, irregular structure
  - Smaller galaxies
  - Mostly young blue stars



Galaxy Types: Overview

	Spirals	Ellipticals	Irregulars
Mass ($M_\odot$)	$10^9 – 10^{12}$	$10^5 – 10^{13}$	$10^8 – 10^{10}$
Luminosity ($L_\odot$)	$10^8 – 10^{10}$	$10^5 – 10^{11}$	$10^7 – 10^9$
Diameter (kpc)	5 - 200	1 - 200	1 - 10
Color	**Disk:** bluish-white **Bulge:** reddish - yellow	Reddish-yellow	Bluish-white

Spiral Galaxies



More bulge and tightly wound

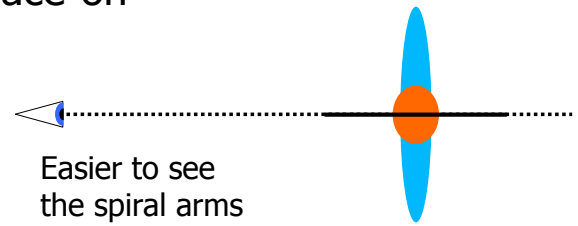
More disk and loosely wound

- Spirals are classified on the amount of bulge component (and how tightly the arms are wound)
- These are designated as Sa, Sb, Sc, in order of decreasing bulge

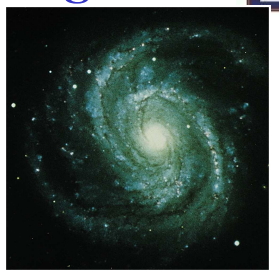
More disk means more ongoing star formation!

Effect of Viewing Angle

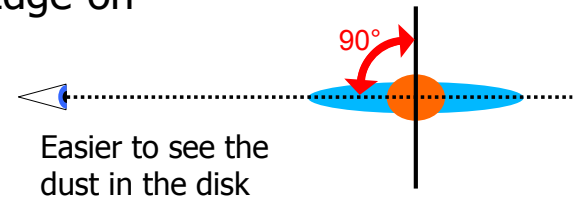
Face-on



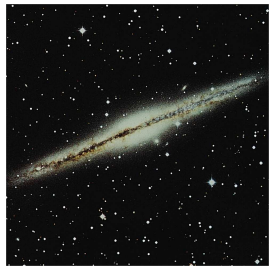
Easier to see the spiral arms



Edge-on

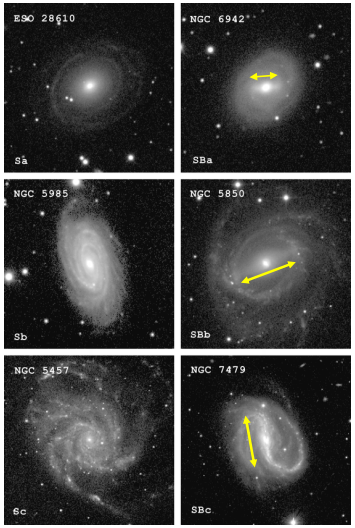


Easier to see the dust in the disk



Barred Spirals

- About 20% of spiral are *barred spirals*
- The spiral arms branch off from a straight bar of stars that passes through the central bulge
- They are designated with an "SB" rather than the usual "S" for spiral galaxies
- The classes of barred spirals are SBa, SBb, and SBc

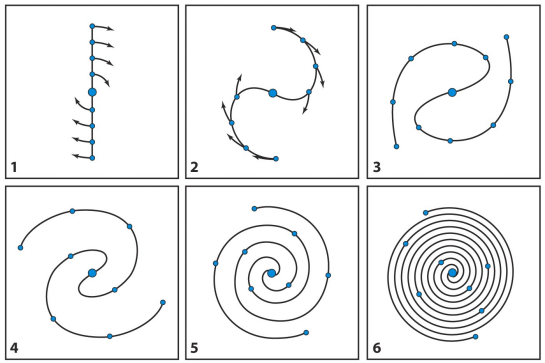


Why do we see Spiral Arms?

- They are easily seen as the arms contain numerous bright O and B stars that illuminate dust in the arms
- However, stars overall are evenly distributed throughout the disk

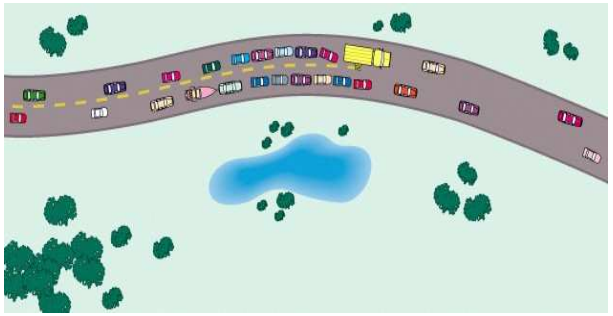
The Winding Problem

- If the arms are stationary, they should wind up and disappear
- This is not observed
- Spiral arms are **not** a permanent collection of stars
- Star, gas, and dust pass *through* the spiral arms



Density Waves

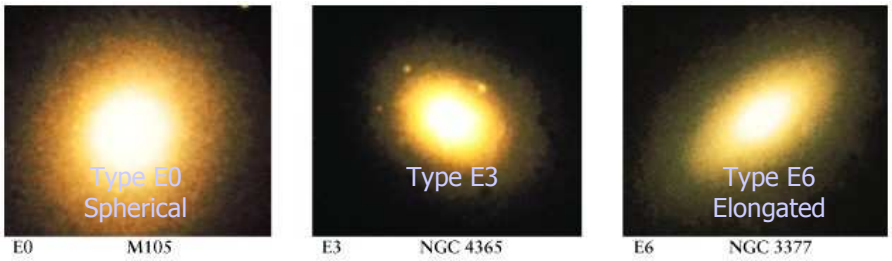
- Spiral arms are caused by waves in the gas and dust
  - Make the gas clump up
  - Like an interstellar traffic jam



- Increased density of gas and dust sparks formation of new O- and B-type stars that light up the spiral arm

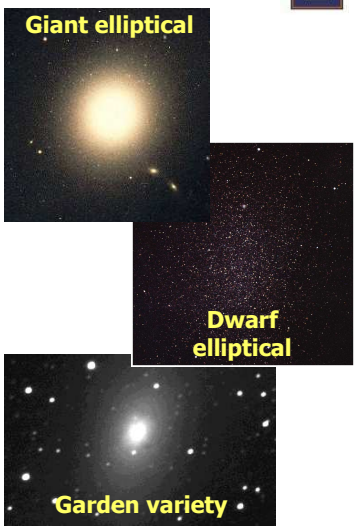
Elliptical Galaxies

- Like a spiral galaxy's bulge
  - Mostly old, redder stars, little gas and dust
  - No disk organization, stars on random orbits
- Classified by how elliptical they appear
  - E0 (spherical) to E7 (elongated)



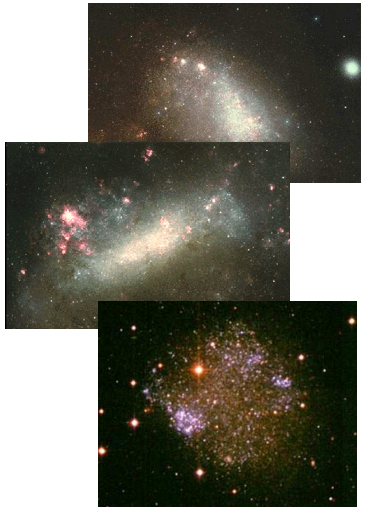
Varieties of Elliptical Galaxies

- Ellipticals come in a great range of masses
- The largest are *giant ellipticals*
  - Up to 100+ times more massive than the Milky Way
- The smallest are the *dwarf ellipticals*
  - 10,000 to a million times less massive than the Milky Way
  - Some only a few times larger than a globular cluster!
- Of course, there are also "garden variety" ellipticals
  - About 100 times smaller than to equal in size to the Milky Way

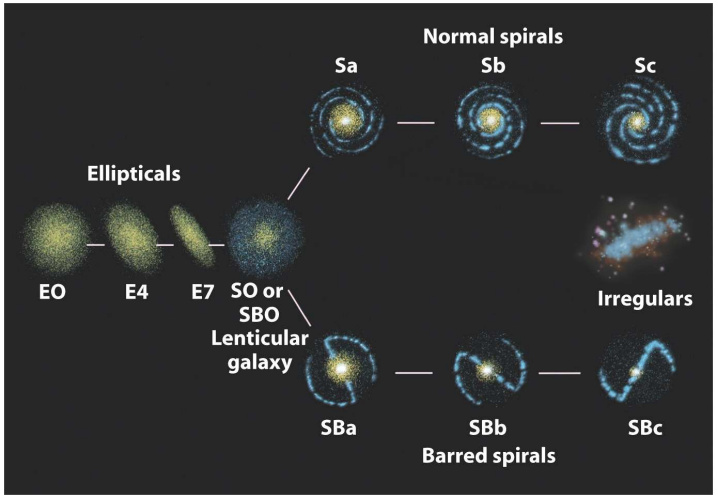


Irregular Galaxies

- Chaotic systems of stars
- Prominent examples: The Magellanic Clouds
  - Two of the Milky Way's satellite galaxies
- Generally smaller galaxies
  - Thousands to tens of times smaller than the Milky Way
- Chaotic systems of stars
  - No disk, no elliptical structure
- Dominated by young, blue stars



Hubble's "Tuning Fork" Classification Scheme

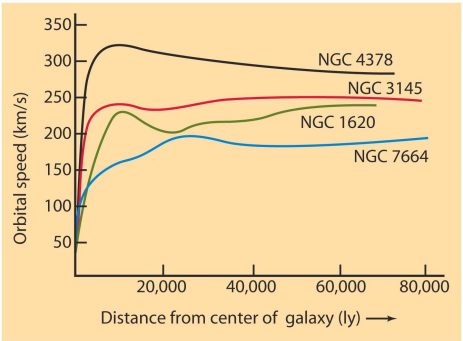


What Type of Galaxy is the Milky Way?

- The Milky Way is a spiral galaxy
  - Probably type **Sb**
- It might be a barred spiral!
  - Type **SBb?**

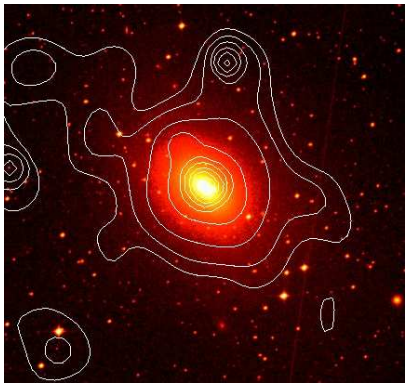
Masses of Galaxies

- As with the Milky Way, we measure the speed of a galaxy's rotation
  - Use Kepler's 3rd Law to calculate mass
- Like the Milky Way, other galaxies have a *flat rotation curve*
- Indicates a halo of **dark matter**



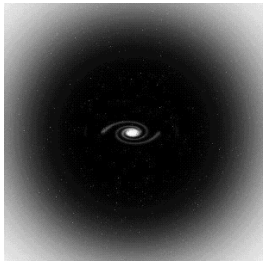
X-Ray Halos

- Some galaxies show a halo of X-ray emitting gas
  - Hot! - Millions of degrees in temperature
- Not much mass in the gas itself
- Its existence indicates a powerful gravitational field
  - Over ten times the mass found in the galaxy's stars
  - Again, **dark matter**!



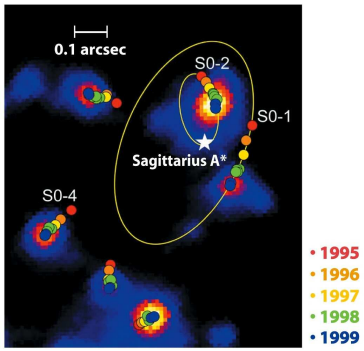
Dark Matter

- Dark matter fills the Universe!!!!
- Normal matter makes up less than 10% of the Universe
- Dark matter is spherically distributed all around galaxies in a huge halo.



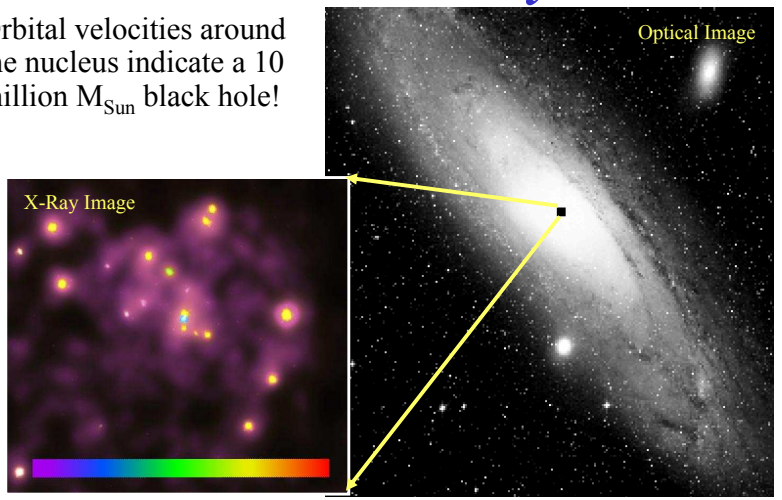
Galactic Nuclei

- Rapid orbits of radio sources around the Milky Way's center indicate a 2.5 million solar mass black hole at its nucleus!
- Do other galaxies show evidence for such supermassive black holes as well?



Nucleus of the Andromeda Galaxy

- Orbital velocities around the nucleus indicate a 10 million M_{Sun} black hole!



M87's Central Monster

- Jet of M87
- 5000 light-year blow-torch!
- Probably from the disk of the black hole at the center
- 3 billion solar masses!