Astronomy 210

This Class (Lecture 36):

Black Holes

Stardial 2 is available

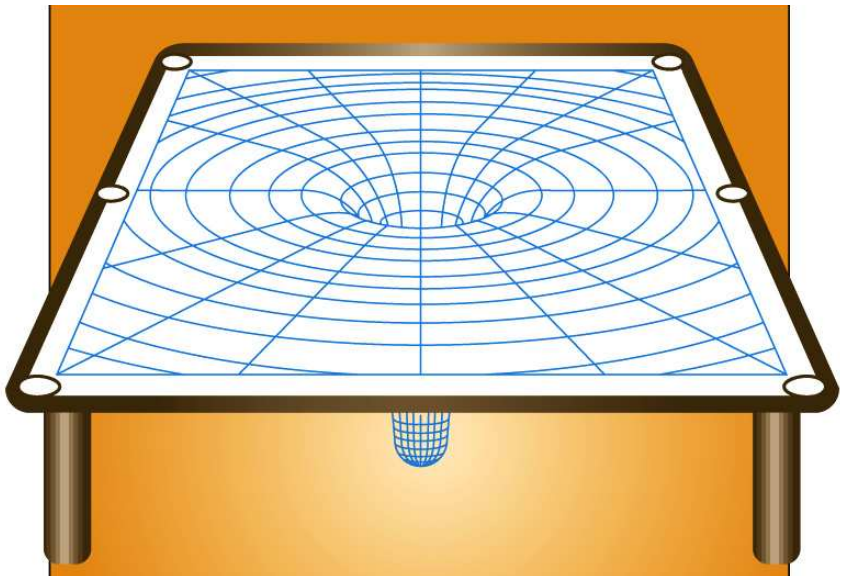
Next Class:

The Milky Way Galaxy

Outline

- Gravitational waves.
- Moving Out– The Milkyway!
- Dust plays an important role in the Disk of the Galaxy.
- 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 rotation curve.

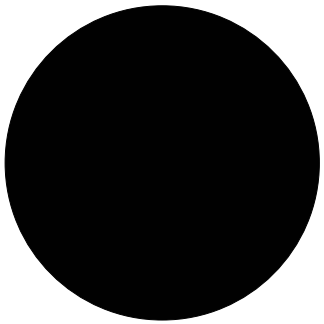
Curved Space

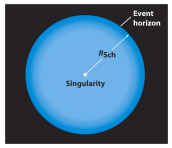


Black Holes Are Very Simple

They can have only

- Mass
- Electric charge
- Rotation (spin)

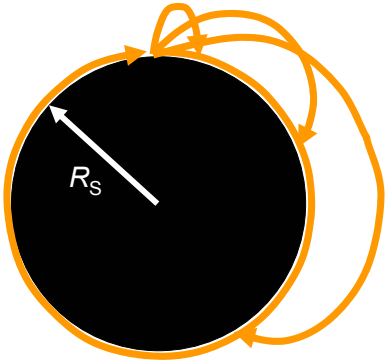




Black Hole

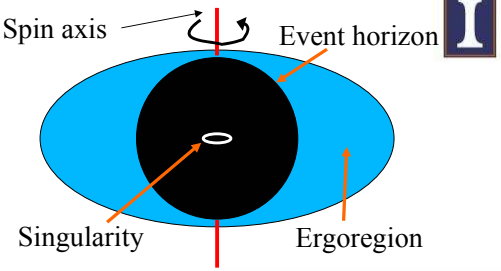
- The Schwarzschild radius
- More massive black hole = larger the event horizon
  - $R_{Sch} = 3\ (M/M_{\odot})$ km
  - If object's mass in radius < R_{Sch} then it's a BH
  - For Earth $R_{Sch} = 1$cm
- The radius of no return
- Cosmic roach hotel

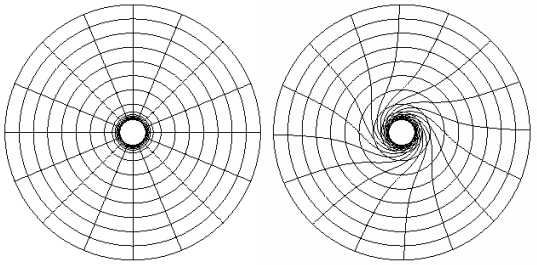
$$R_{Sch} = \frac{2GM}{c^2}$$



Rotating Black Holes

- First studied by Roy Kerr in the early 1960s
- Region just outside horizon where you are dragged along by spacetime
- Can't stand still in ergoregion without falling in
- Singularity is a torus

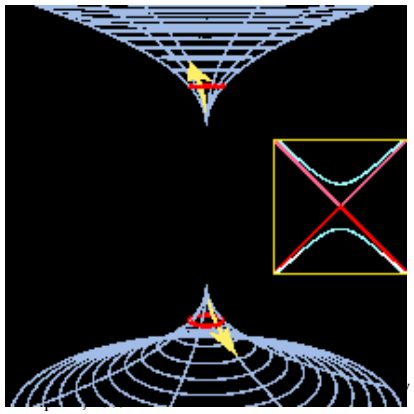




No rotation Maximum rotation

Wormholes

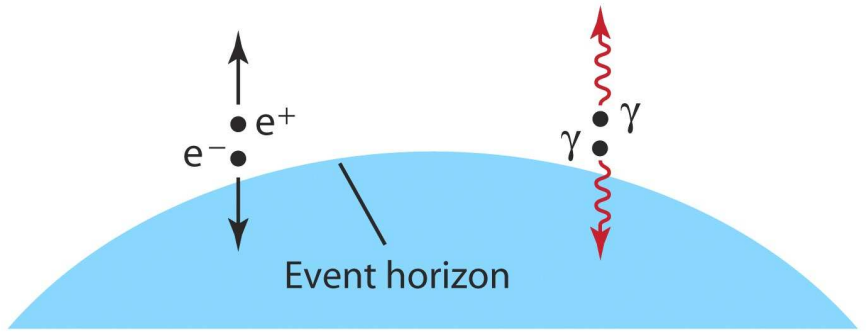
- Tunnel to another universe, or another part of our own?
- **No:**
  - Wormhole throat is unstable, and pinches off
  - Once you fall through one horizon, you can't come out through another
- **Also:** Stellar collapse to a black hole does not produce a wormhole
- **So:** mathematically allowed, but unphysical in general relativity

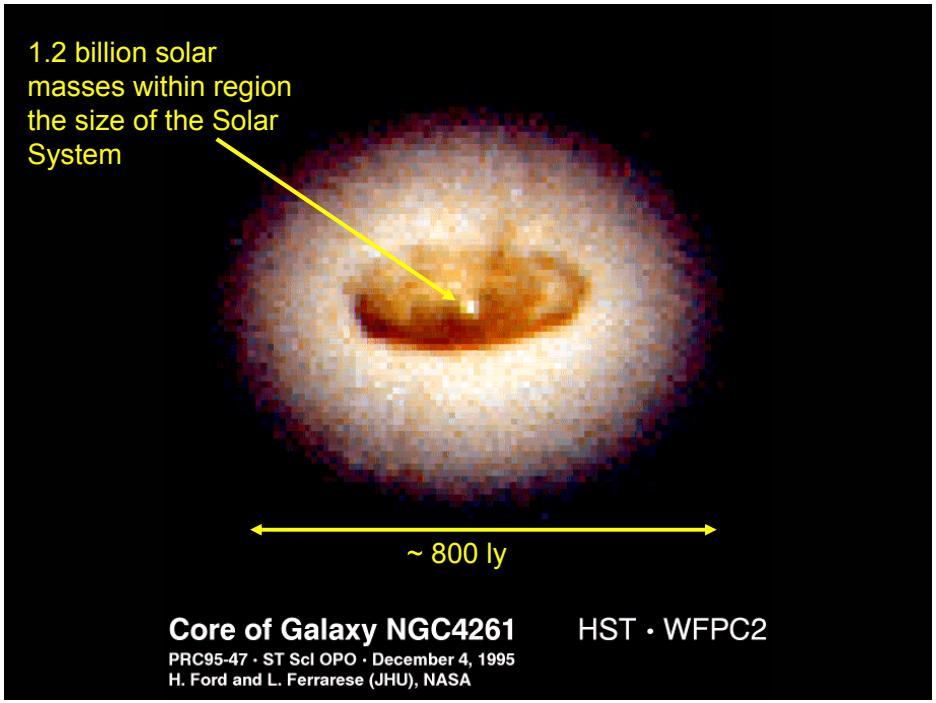


Sorry… not any time soon

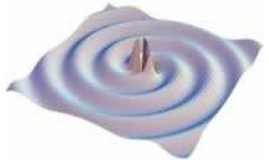
Hawking Radiation

- Black holes are not truly black!
- Quantum mechanical effects near event horizon cause them to produce blackbody radiation
- Temperature **increases** as mass **decreases**
- Too dim/cool to see for stellar-mass black holes

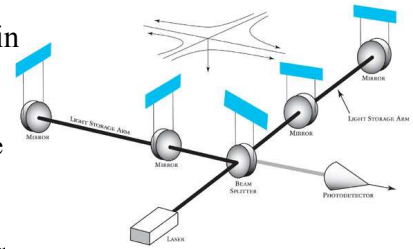




Grav Waves

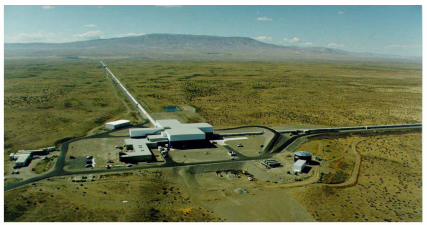


- Ripples in spacetime!
- Similar to EM radiation
- Recall rubber sheet analogy: if disturb, launch waves
- Larger disturbance ⇒ bigger waves
- Emitted in dynamic, strong gravity systems: neutron stars in pairs (binaries)
  - Orbit ⇒ emit gravity waves ⇒ lose energy ⇒ fall in ⇒ decrease period P



http://www.ligo.caltech.edu/LIGO_web/PR/scripts/facts.html

The Search



Four interferometers contribute data to LSC analyses:

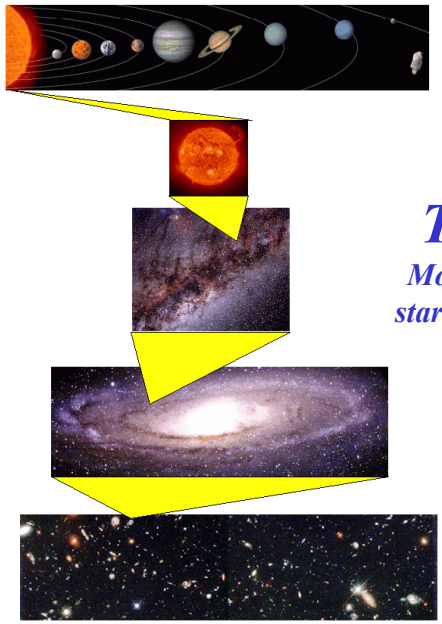
•4 km and 2 km interferometers at LIGO Hanford Observatory

•4 km interferometer at LIGO Livingston Observatory

•GEO600

N.B.: No GEO data available for S2, but back on air for S3.

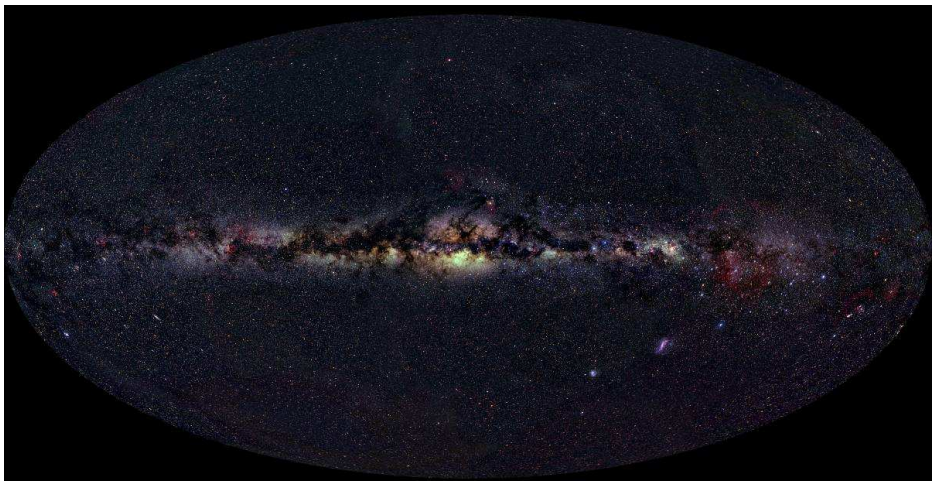
LIGO-G040300-00-Z http://sciencebulletins.amnh.org/astro/f/gravity.20041101/index.php *22 July 2004*



Astronomy: The Big Picture

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

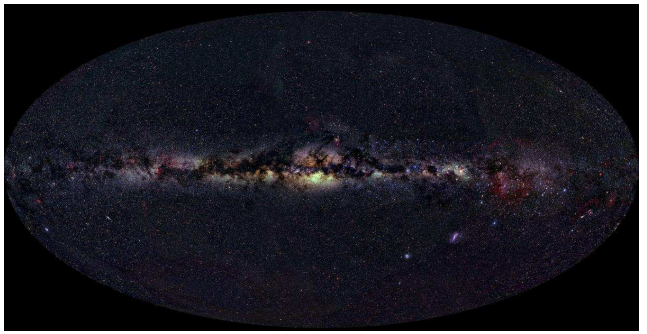
The Milky Way



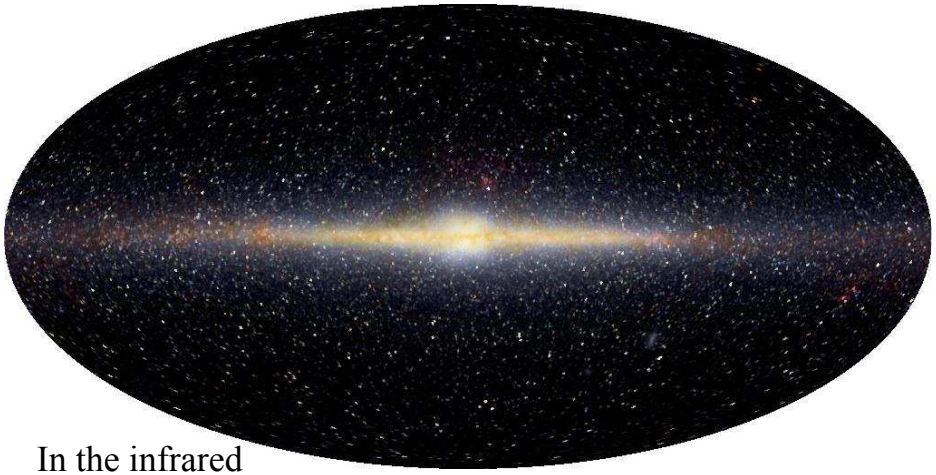
http://home.arcor-online.de/axel.mellinger/mwpan_aitoff.html

The Milky Way

- Our galaxy is a collection of stars, nebulae, molecular clouds, and stellar remnants
  - All bound together by gravity
  - Connected by the stellar evolution cycle



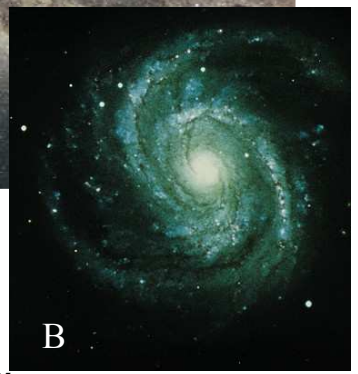
What is it?



In the infrared

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

Which is a picture of the Milky Way?



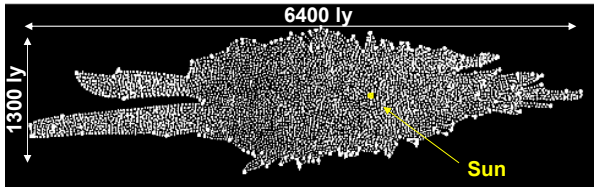
A is what we see from Earth inside the Milky Way. *B* is what the Milky Way "might" look like if we were far away looking back at our own galaxy from some other galaxy

The Milky Way is made of all the stars in our galaxy– about 100 billion. All the stars you can see in the sky are in our Galaxy.

Enormous clouds of dust obscure our view of most of the stars in our Galaxy

We Are in a Disk of Stars!

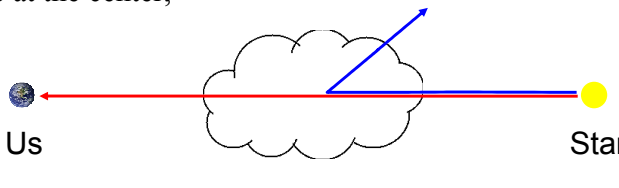
- The number of stars were counted in all directions from the Sun by Herschel (the guy who discovered Uranus) and his sister Caroline

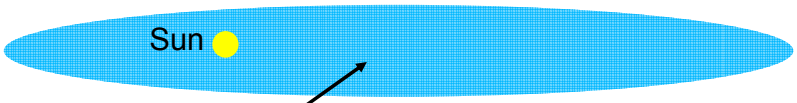


- They assumed that all stars have the same brightness and that space is completely transparent – **Bad assumption!**
- They concluded that the Sun is at the center of the Universe - **Nope!**

The Importance of Being Earnestly Dust

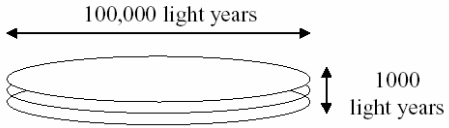
- There is clearly dust in the Milky Way disk. How does dust effect the measurement?
  - Makes stars dimmer and redder
- There is more dust toward Galaxy center.
- Consequence: Under-estimation in the number of stars in one direction
- We appear to be at the center, but we're not!

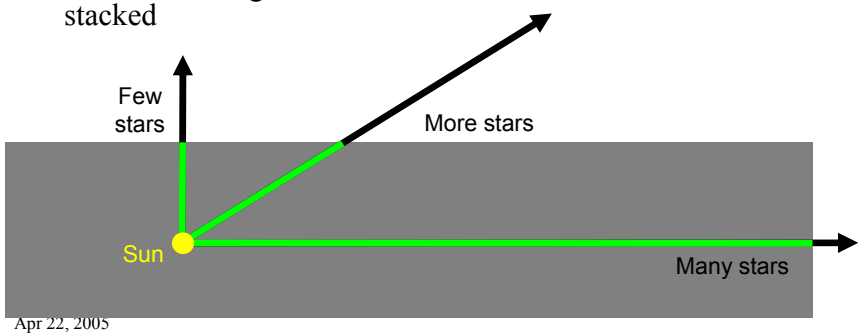




But, We Are in a Disk of Stars!

- But they were correct in determining that the distribution of stars in the Milky Way is in a thin disk
- The Milky Way is very thin in comparison to its diameter – imagine 3 CDs stacked



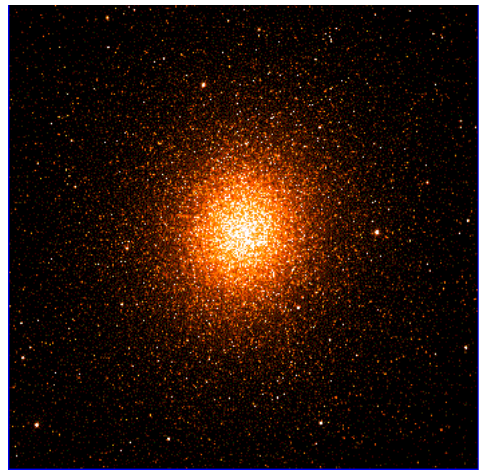


How Do We Find the Center?

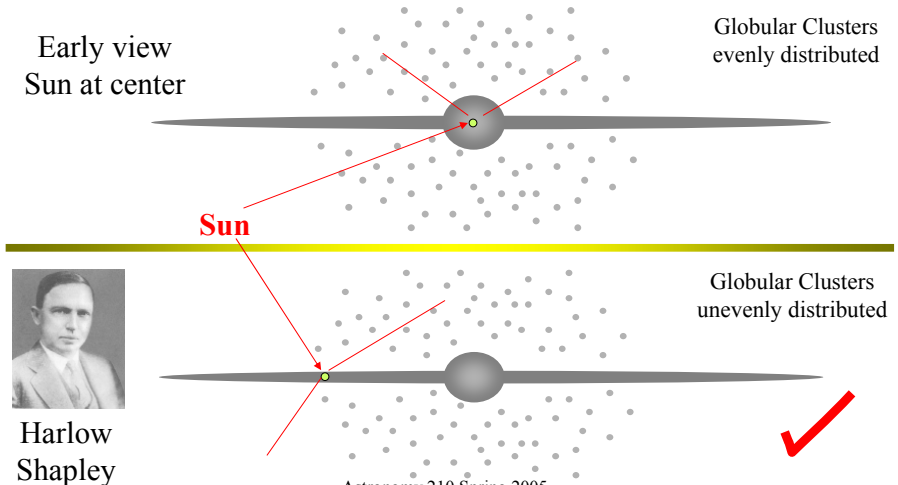
- If dust blocks our view, how do we find the center?
- We need to look outside of the disk!
  - Get around the dust
- A collection of relatively bright objects, outside the disk.

Globular Clusters

- Extremely regular, gravitationally bound groups of stars– very dense
- About 10^5 – 10^6 stars each
- HR diagram of these groups of stars show that they are very old– 10 billion years!
- Generally outside disk of the Galaxy
- About 150 known orbiting our Galaxy

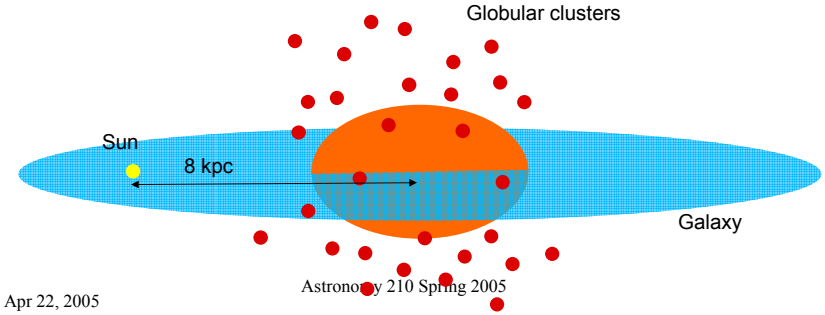


Finding Our Place



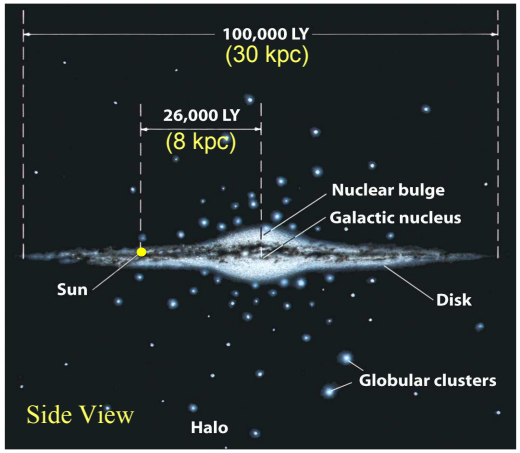
Our Place

- 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

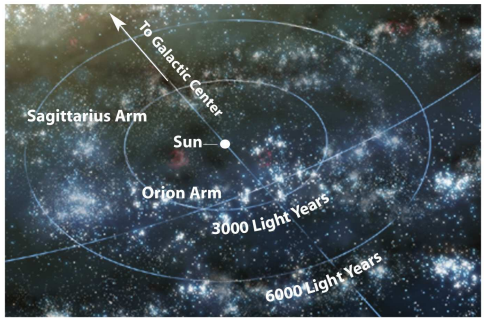
- The disk of our Galaxy contains most of its visible mass
  - 90% of the Galaxy's stars
- Its where "the action" occurs
  - Star formation, nebulae, etc..
- Relatively thin
  - 700 parsecs thick vs. 30,000 parsecs across

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

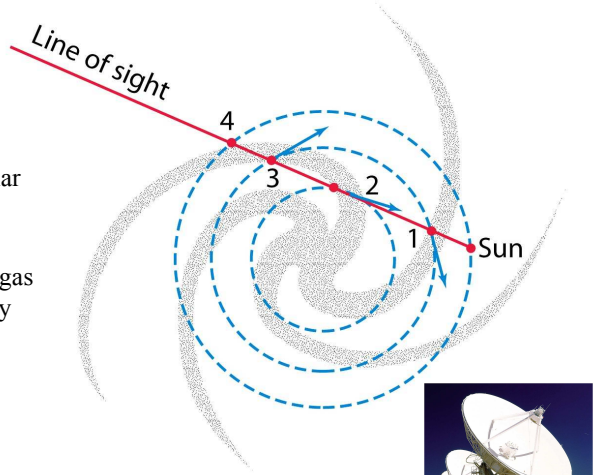
Hints of Spiral Arms

- 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?

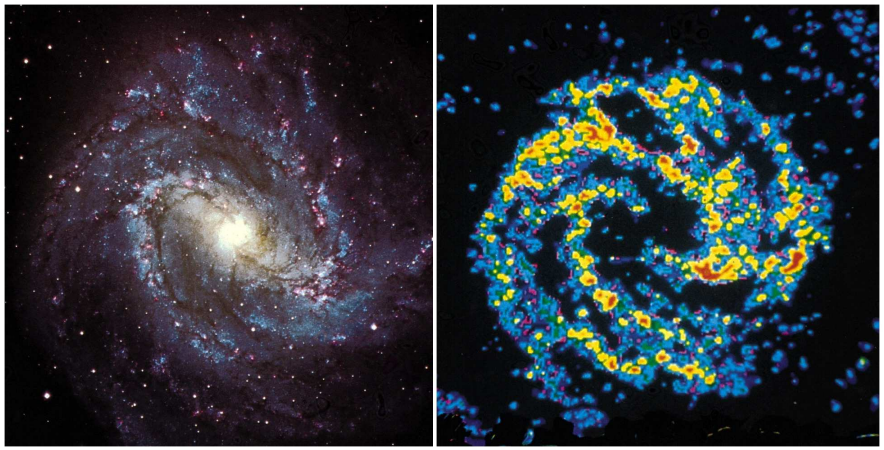


Seeing the Galaxy in Hydrogen Emission

- 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



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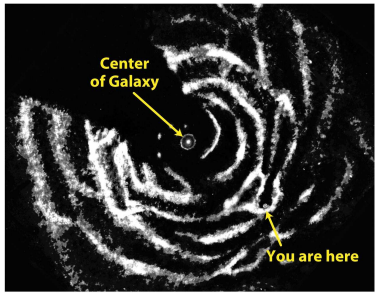
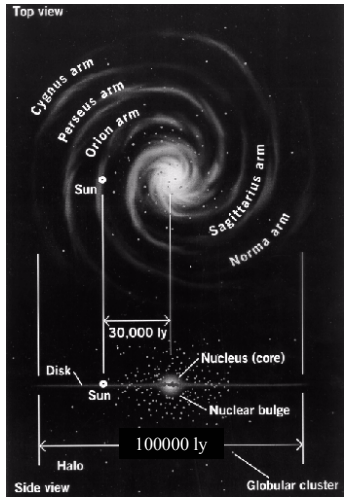
The Galaxy's Spiral Arms

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



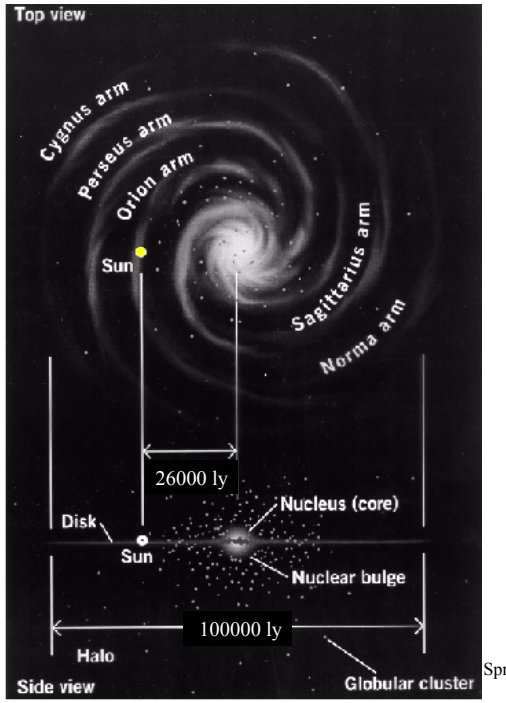


The Galactic Halo

- 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

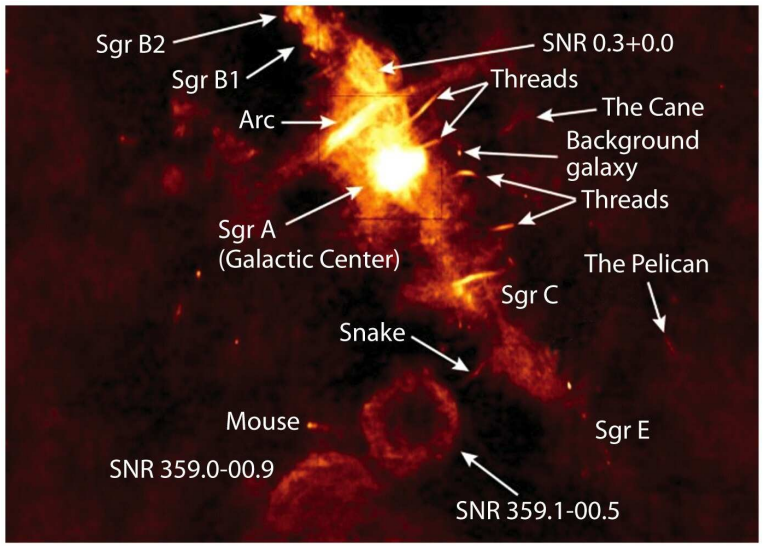
The Bulge

- 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



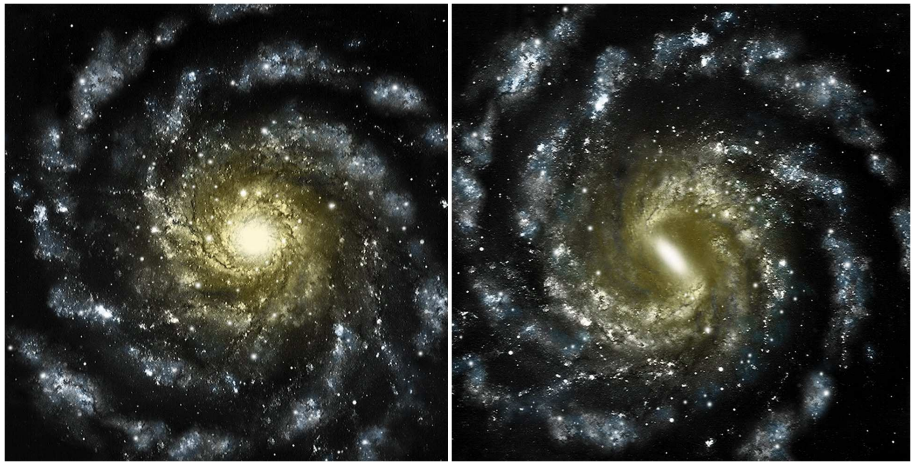
The Galactic Nucleus

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

Thought Question

Massive O-type stars are not found in the Galactic halo. What can we conclude from this?

Do Galaxies Spin?



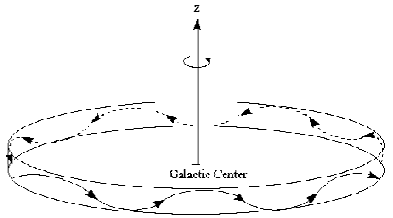
Spiral galaxies really suggest it. BTW, our Galaxy probably looks more like the right galaxy.

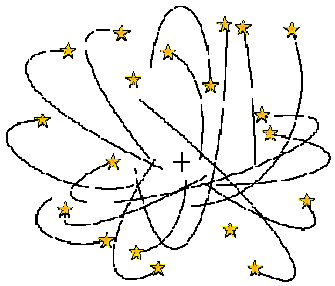
Rotation of the Galaxy

- 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.

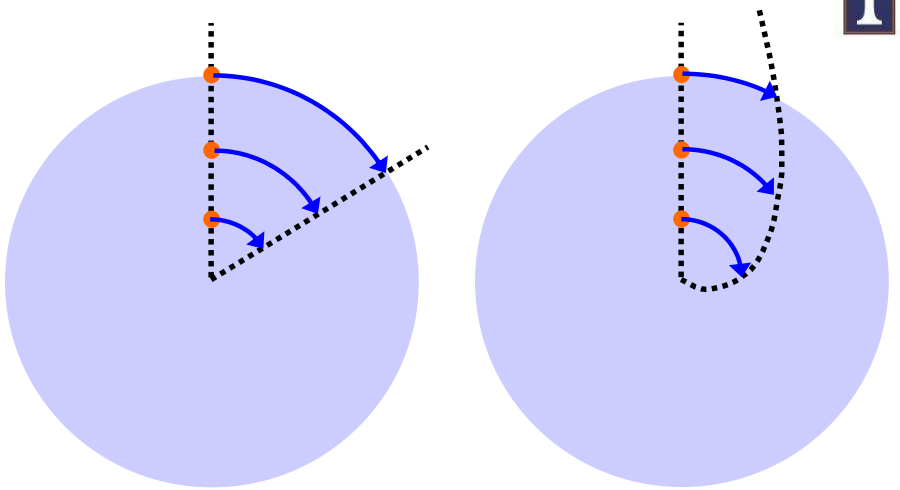
Rotation of the Galaxy

- 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)

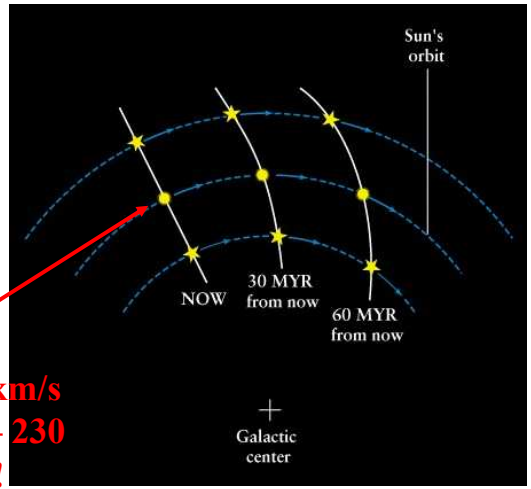
Same linear speed
(parsecs per year)

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

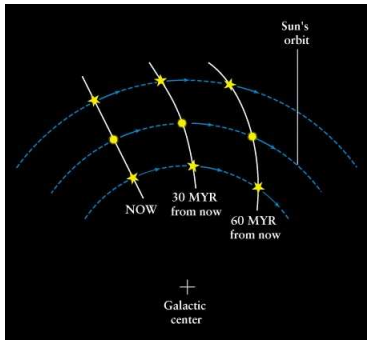


The Sun orbits at 220 km/s or about 500,000 mph– 230 million years per orbit!

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

- There is 10^{11} solar masses inside of our orbit.
- Since we know our speed, we can measure the orbital speed of the other stars.
- V is constant from 2kpc out.