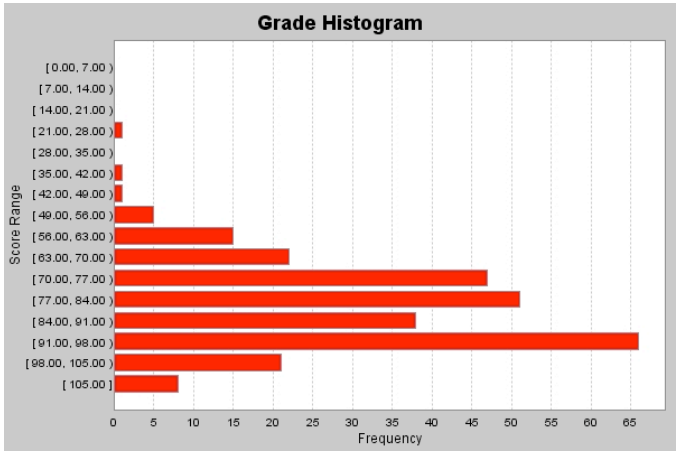
Exam 2

- Good results.
- Average of 82.4%
- Median of 83.5%
- Almost exactly like Exam 1

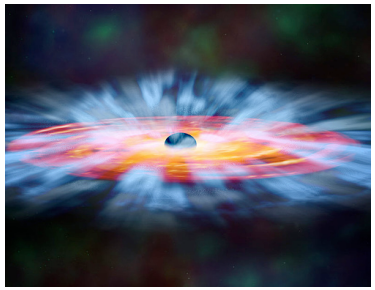


Outline

- Micro Black Holes
  - Death to us all?
- The structure of the Milky Way (a collection of stars, nebulae, dust, stellar corpses, planets..)
  - The disk
  - The halo
  - The bulge
  - The spiral arms
- How we orbit the Galactic center.

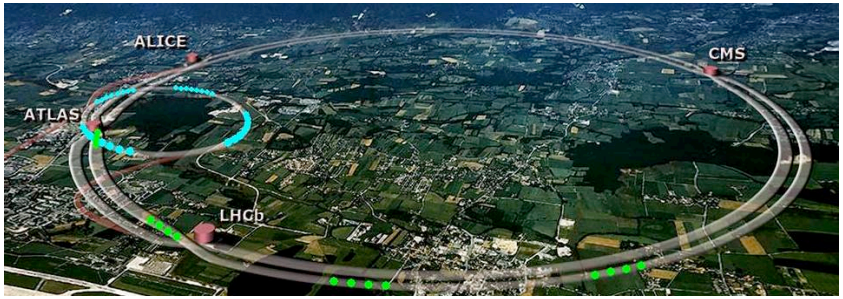
Micro-Black Holes?

- You don't need a lot of mass to make a black hole, just high density.
- What about very low mass black holes?
- Primordial black holes have never been seen, but if a few ton black hole hits the Earth, it is about as bad as a 10 solar mass back hole.
- Smash together nuclear particles at high speed and you perhaps can get high enough densities.



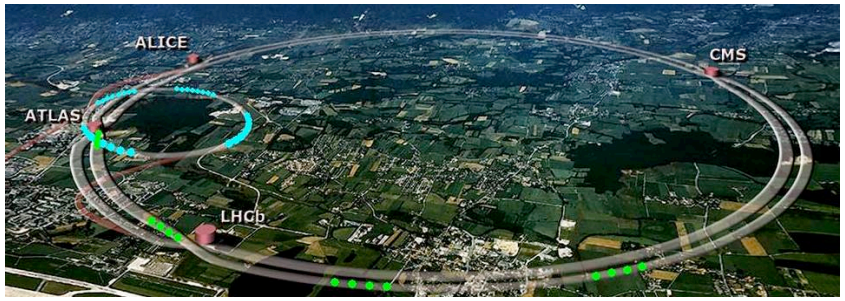
Man-Made Micro-Black Holes?

- What if we make our own?
- The Large Hadron Collider (LHC) near Geneva might be able to make them.
- Takes protons and accelerate them to 99.99% the speed of light, then crash the protons together.



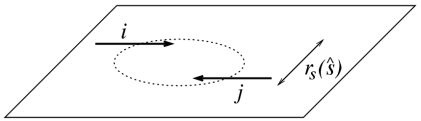
Man Made Micro-Black Holes?

- When the particles smash together new particles are created sometimes, which quickly decay
- Main point of the LHC is to look for the Higgs Boson, which is theoretically expected to be responsible for mass.



Black Holes

- If two particles pass close enough with enough energy, they might form a microscopic black hole

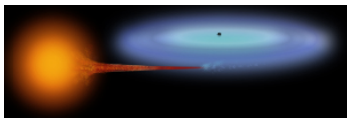


- For 3 spatial dimensions, gravity is too weak for this to happen. But with extra dimensions, gravity becomes stronger, micro black holes can be created in particle collisions!

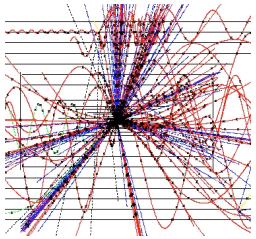
http://www.youtube.com/watch?v=BXzugu39pKM

Black Hole Evaporation

- "Normal" black holes:
  - Mass: $M_{BH} \sim M_{sun}$
  - Size: kilometer
  - Temperature: 0.01 K
  - Lifetime: ~ nearly forever



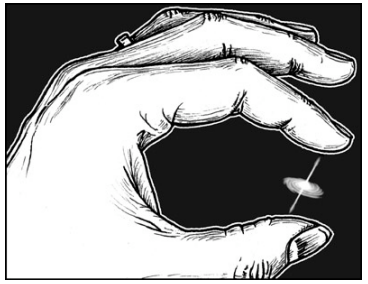
- Micro black holes:
  - Mass: $M_{BH} \sim 1000\ M_{proton}$
  - Size: 10^{-18} m
  - Temperature: 10^{16} K
  - ***Lifetime: 10^{-27} s***



They explode!

Cosmic Rays

- Cosmic rays hit the Earth, Sun, etc with 5x higher energies.
- If black hole can be created, they have been already, and we're still here.

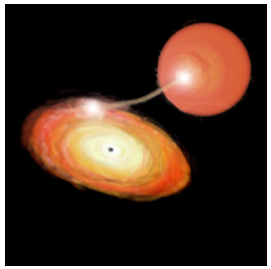


- In fact, LHC black holes would have high velocities, and probably leave the Earth before too much damage.
- Cosmic ray created BHs should have some low velocities ones.

http://www.thedailyshow.com/watch/thu-april-30-2009/large-hadron-collider

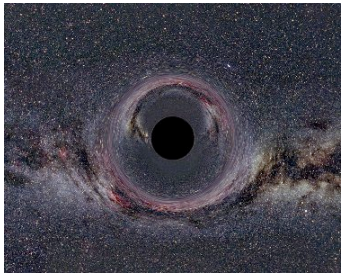
Other Compact Objects?

- There are a lot of white dwarfs or other non-black hole compact objects in the Galaxy.
- Still not very likely to interact with one.
- Collision is very unlikely, but could eject us or destroy the Sun.
- Very, Very unlikely, but probably more likely than a black hole.



Mitigation

- None or very little warning for some objects.
- For some objects much more warning.
- Try to play general relativity engineer?
- Can we predict accurately enough the orbits?
- Leave the Solar System.



Imagine

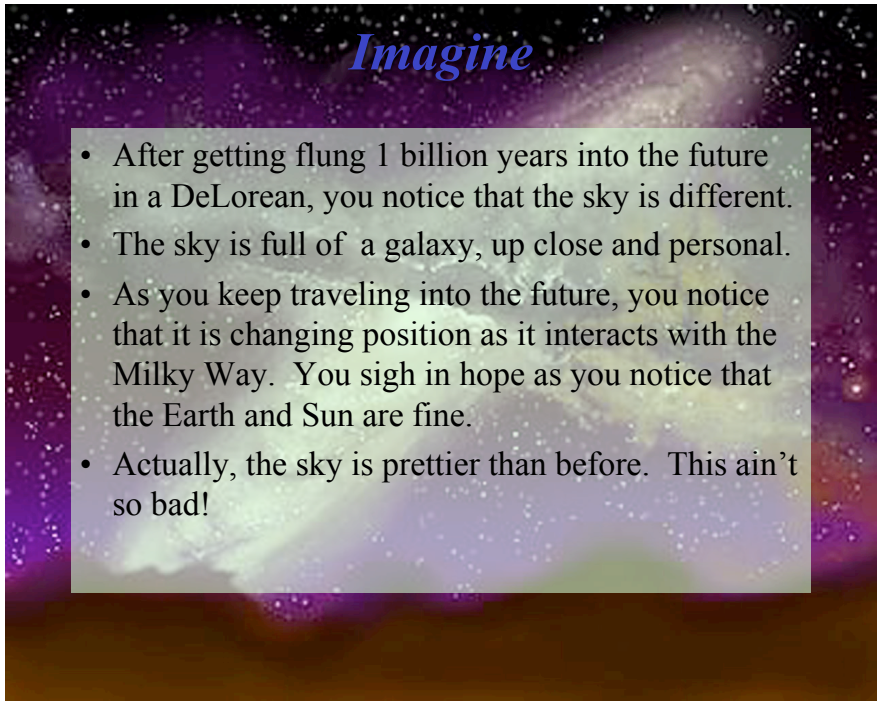
- An amateur astronomer trying to see Uranus is the first to notice. It's in the wrong place!
- Later, Jupiter is in the wrong place, then Mars!
- Even the Sun has moved!
- What is happening?! Oh, the Earth has moved.
- Panic spreads as scientist realize that a compact object has entered the Solar System and its mass is throwing off the orbits!
- Once the orbit was fixed for the object, telescopes looked for the object, but nothing– a black hole!

Imagine

- A black hole coming right at us at 500 miles/sec.
- As it gets closer tidal effects– floods, earthquakes, and tsunamis.
- As the 10 solar mass black hole reaches 7 million miles away, its gravitational pull equals that of Earth, everything on Earth is weightless.
- Then, the pull of the black hole is more than Earth.
- As the Earth gets shredded, you try to remember what Leslie said about black holes!

Top 10 Ways Astronomy Can Kill you or your Descendents

6. Rogue compact objects–White Dwarfs/Black Holes.
   Black Holes don't suck, but if they hit you it sucks.
7. Galaxy Collisions.
   Milky Way vs. Andromeda.



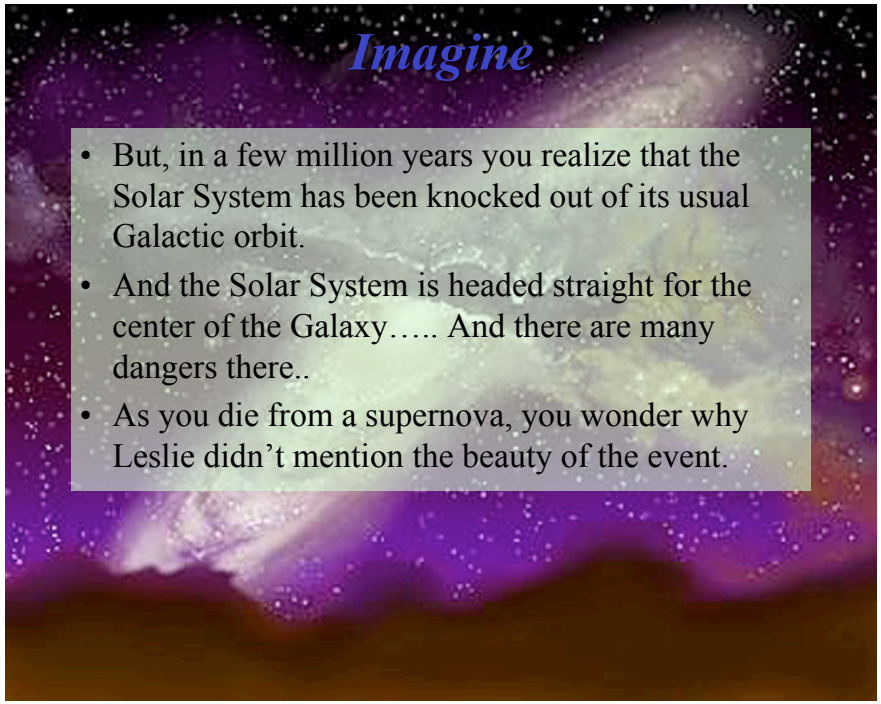
Top 10 Ways Astronomy Can Kill you or your Descendents

7. Galaxy Collisions.
   Milky Way vs. Andromeda.

Our sibling galaxy Andromeda is heading right for us, on a collisions course at 120 miles/second! In about 2 billion years, they will collide. Train wreck!

Remember Galaxies mostly empty space, so stars will not impact.

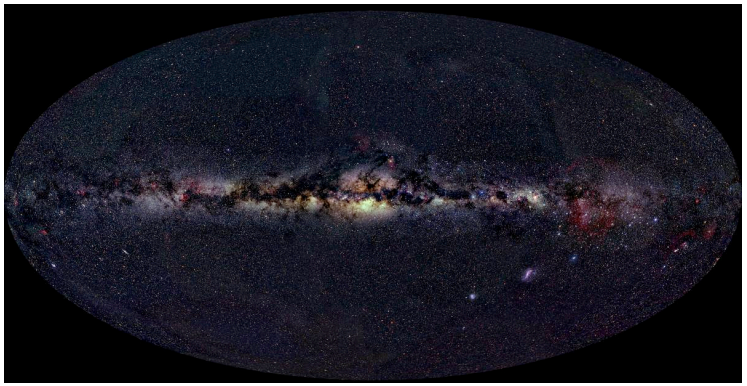
http://www.youtube.com/watch?v=dJRc37D2ZZY
http://www.youtube.com/watch?v=jexMl2SO6_I



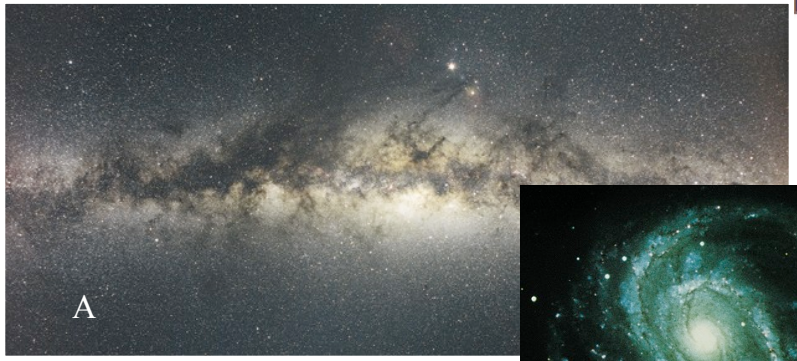
The Milky Way

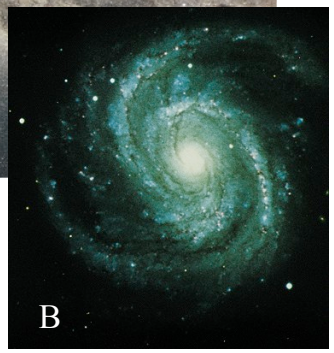
The Milky Way

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



Which is a picture of the Milky Way?



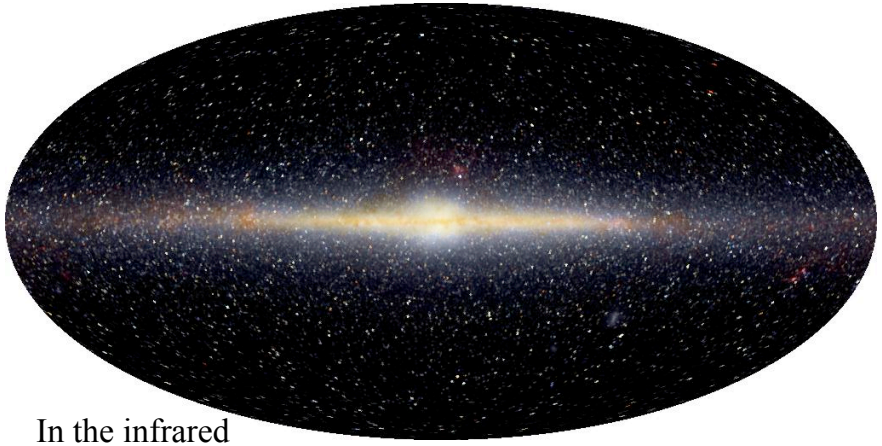


A is what we see from Earth inside the Milky Way. *B* is what the Milky Way "might" look like if we were far away looking back at our own galaxy from some other galaxy

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

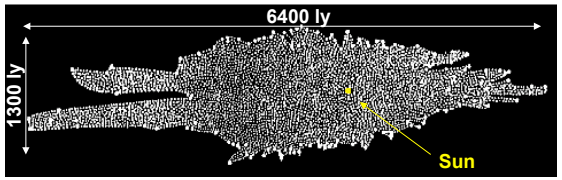
What is it?



In the infrared

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

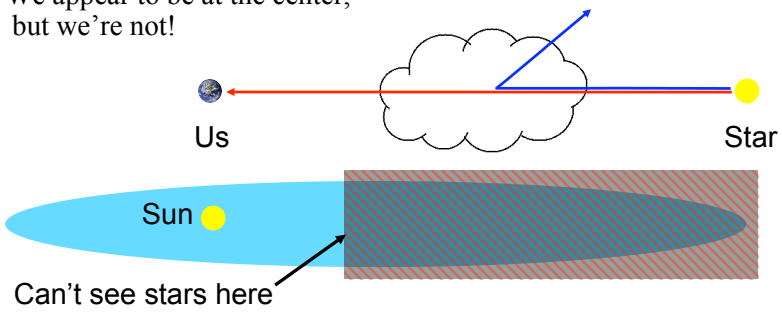
The Discovery of the Milky Way!



- The number of stars were counted in all directions from the Sun by William Herschel (the guy who discovered Uranus) and his sister Caroline
- They assumed that all stars have the same brightness **– Bad assumption!** and that space is completely transparent **– Nope!**
- They concluded that the Sun is at the center of the Universe

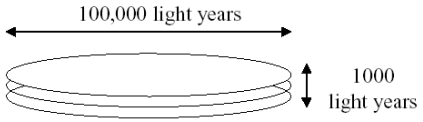
The Importance of Being Earnestly Dust

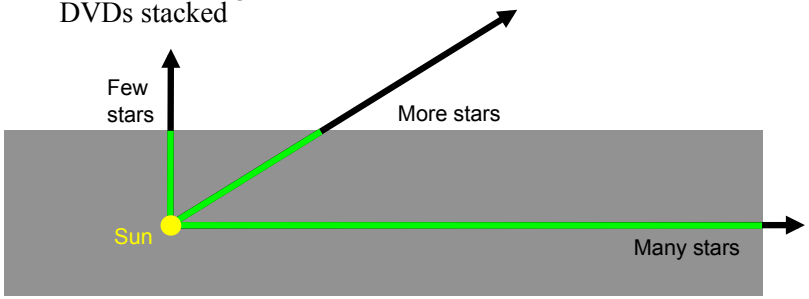
- There is clearly dust in the Milky Way disk. How does dust effect the measurement?
  - Makes stars dimmer and redder
- There is more dust toward Galaxy center.
- Consequence: Under-estimation in the number of stars in one direction
- We appear to be at the center, but we're not!



But, We Are in a Disk of Stars!

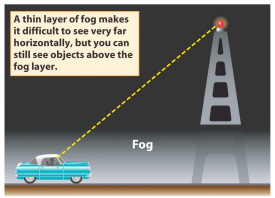
- But they were correct in determining that the distribution of stars in the Milky Way is in a thin disk
- The Milky Way is very thin in comparison to its diameter – imagine 3 DVDs stacked





How Do We Find the Center?

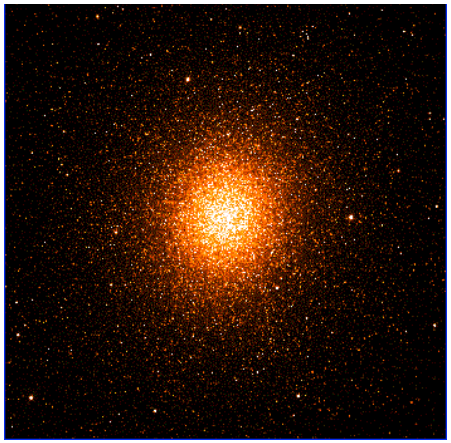
- If dust blocks our view, how do we find the center?
- We need to look outside of the disk!
  - Get around the dust
- A collection of relatively bright objects, outside the disk.



Determining your position in the fog

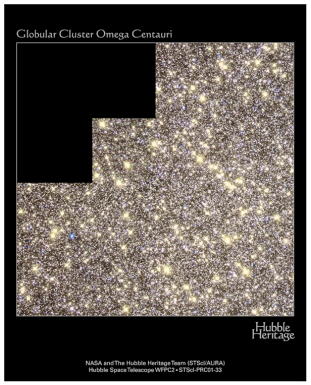
Globular Clusters

- 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.

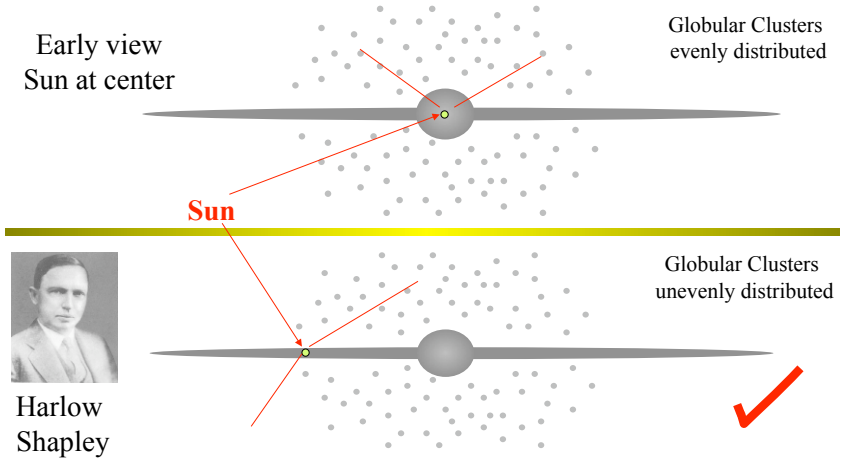


Globular Clusters

- Large groups of stars (about 150 in the MW)
- Old population of stars



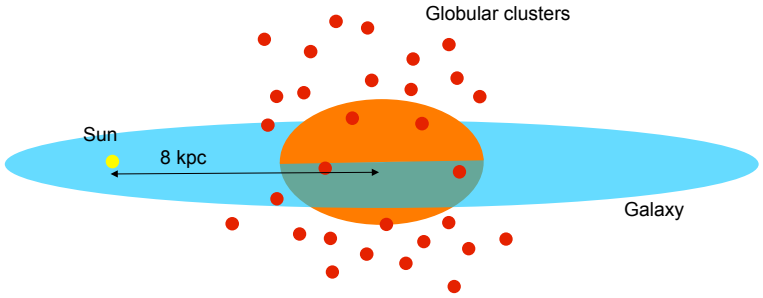
Finding Our Place!



Harlow
Shapley

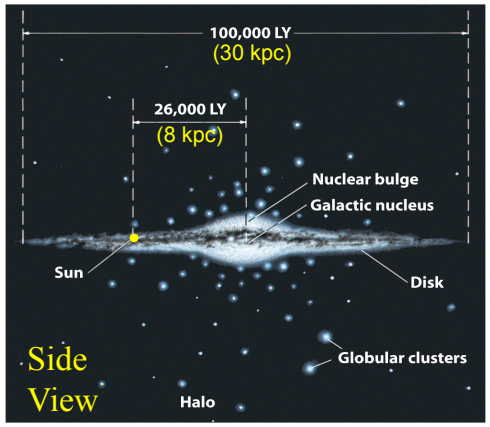
Our Place

- 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– 25,000 lyrs away.
- That must be the center of our Galaxy.



Our Galaxy

- Globular clusters– oldest stars
- Galactic nucleus– dense collection of stars (center of Galaxy)
- Nuclear bulge– mostly old stars, but very densely packed
- Spiral arms and the disk– mostly young stars and lots of dust
- Note position of the Sun, just over half way out.



The Disk

- The disk of our Galaxy contains most of its visible mass
  - 90% of the Galaxy's stars

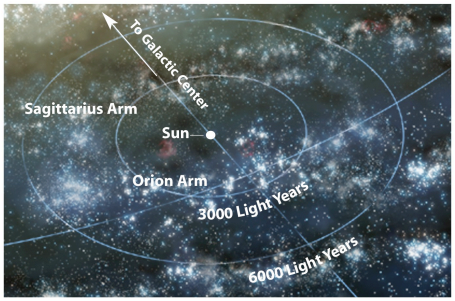
- It's where "the action" occurs
  - Star formation, nebulae, etc..
- Relatively thin
  - 1,000 lyrs thick vs. 100,000 lyrs across

Spiral Arms?

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

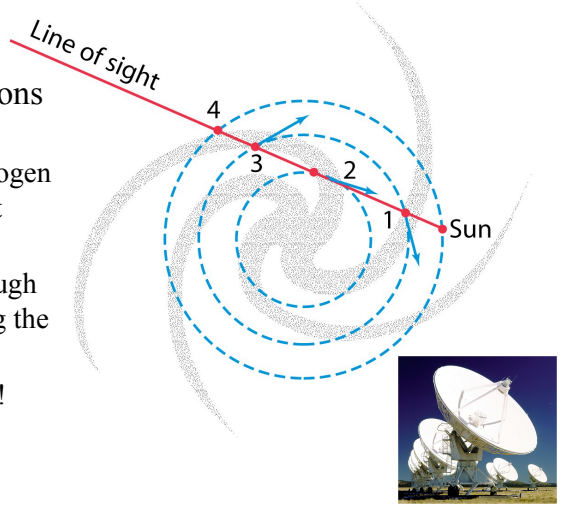
Hints of Spiral Arms

- 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
- What about the rest of the Galaxy?

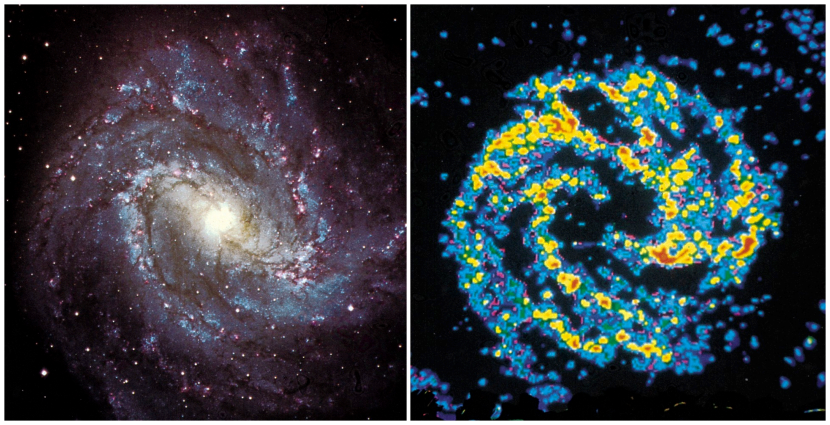


Seeing the Galaxy in Hydrogen Emission

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



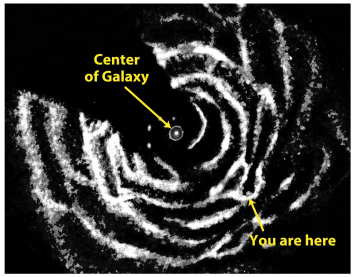
Visible and Radio

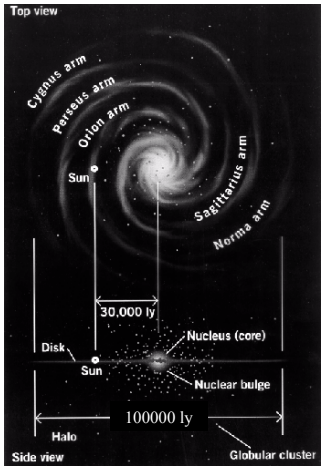


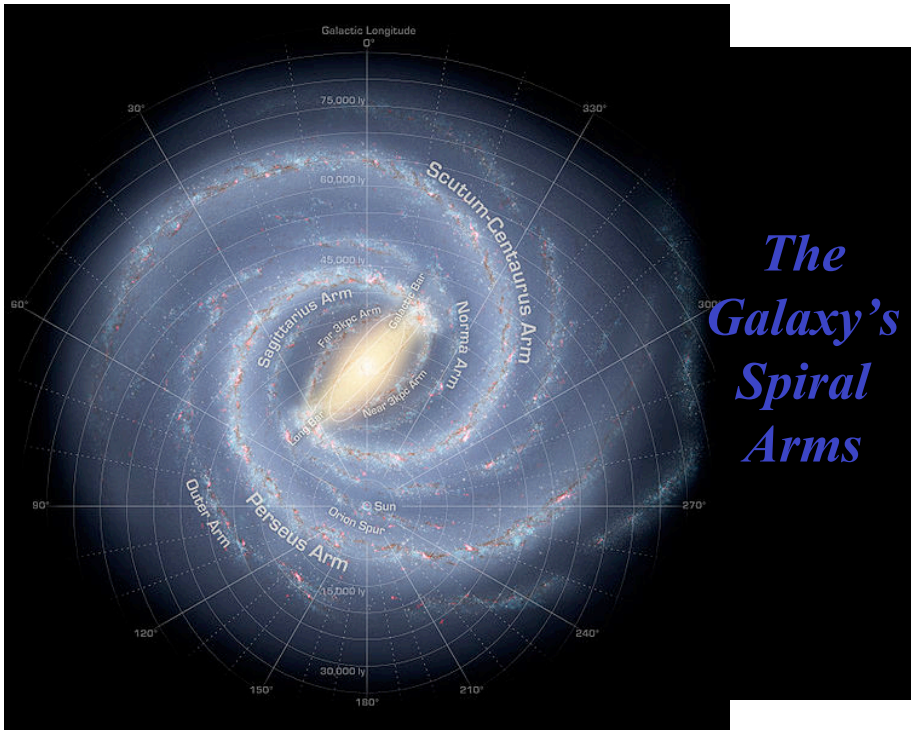
M83

The Galaxy's Spiral Arms

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

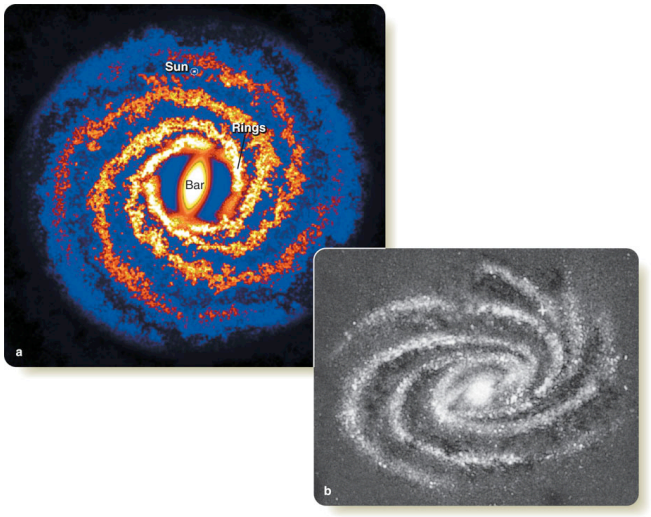






The Galaxy's Spiral Arms

The Galaxy's Spiral Arms



The Galactic Halo

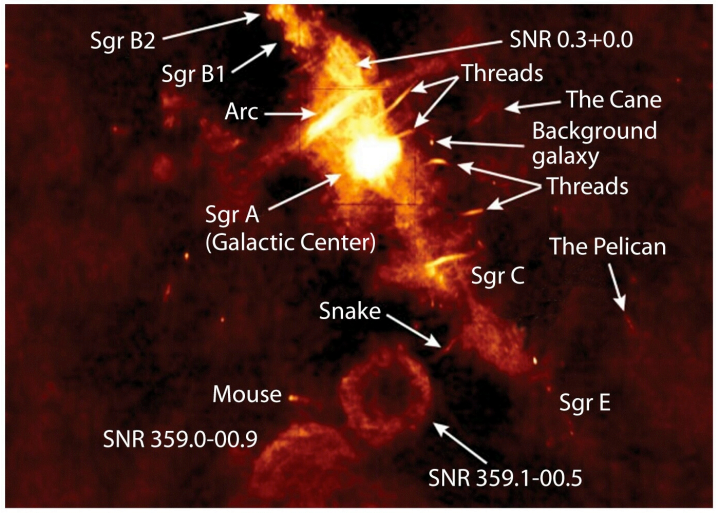
- Our Galaxy's disk is surrounded by a spherical halo of old stars & globular clusters
  - Red dwarfs and red giants – old stars
  - Only about 2% the number of stars in the disk

The Bulge

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

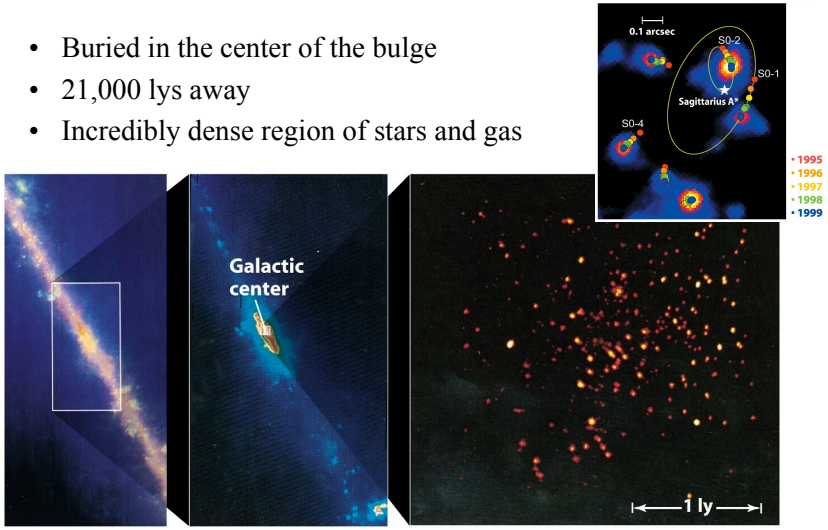
- Mix of primarily old stars, but also contains some young stars and gas & dust
- Like an extension of both the disk and halo

The Center of Our Galaxy



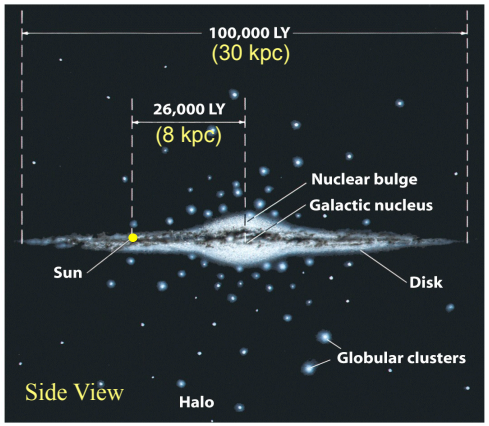
The Galactic Nucleus

- Buried in the center of the bulge
- 21,000 lys away
- Incredibly dense region of stars and gas

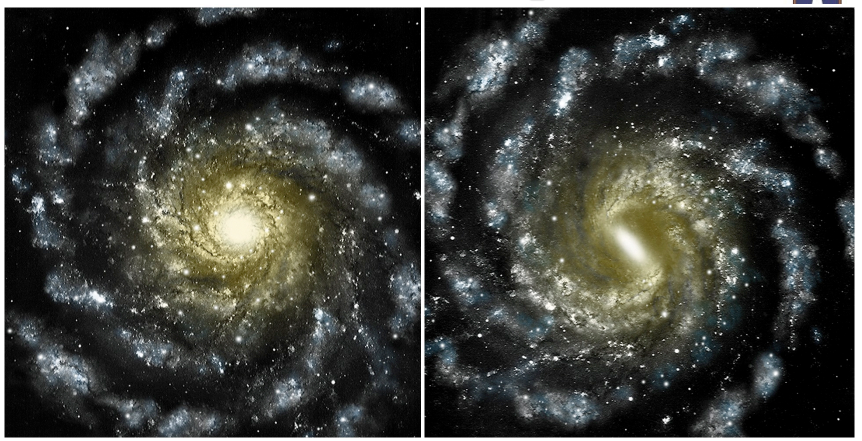


The Structure of Our Galaxy

- 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



Do Galaxies Spin?



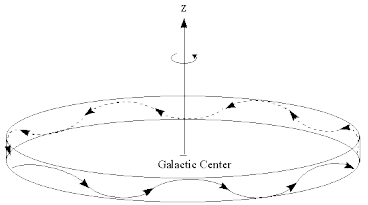
Spiral galaxies really suggest it. Our Galaxy probably looks more like the right galaxy.

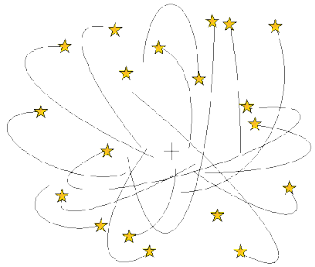
Rotation of the Galaxy

- Similar to the planets orbiting the Sun, the stars and gas of the Galaxy orbit the nucleus
- How does the Galaxy rotate?
- Like a DVD?

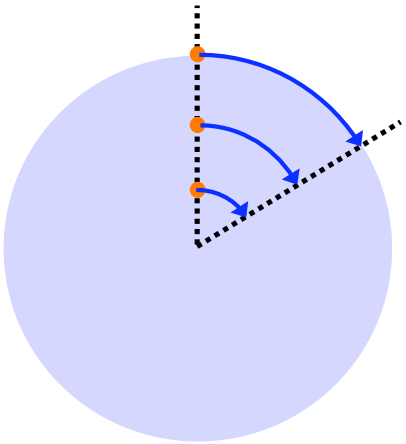
Rotation of the Galaxy

- 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

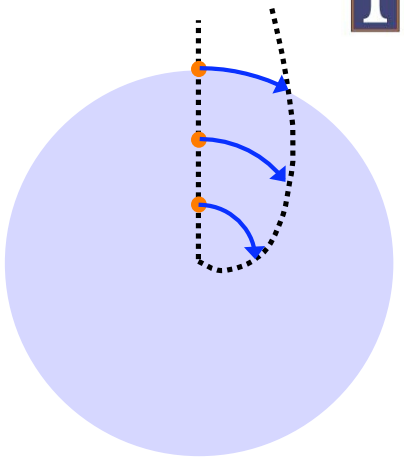




Solid vs. Differential Rotation



Same angular speed
(degrees per year)



Same linear speed
(parsecs per year)