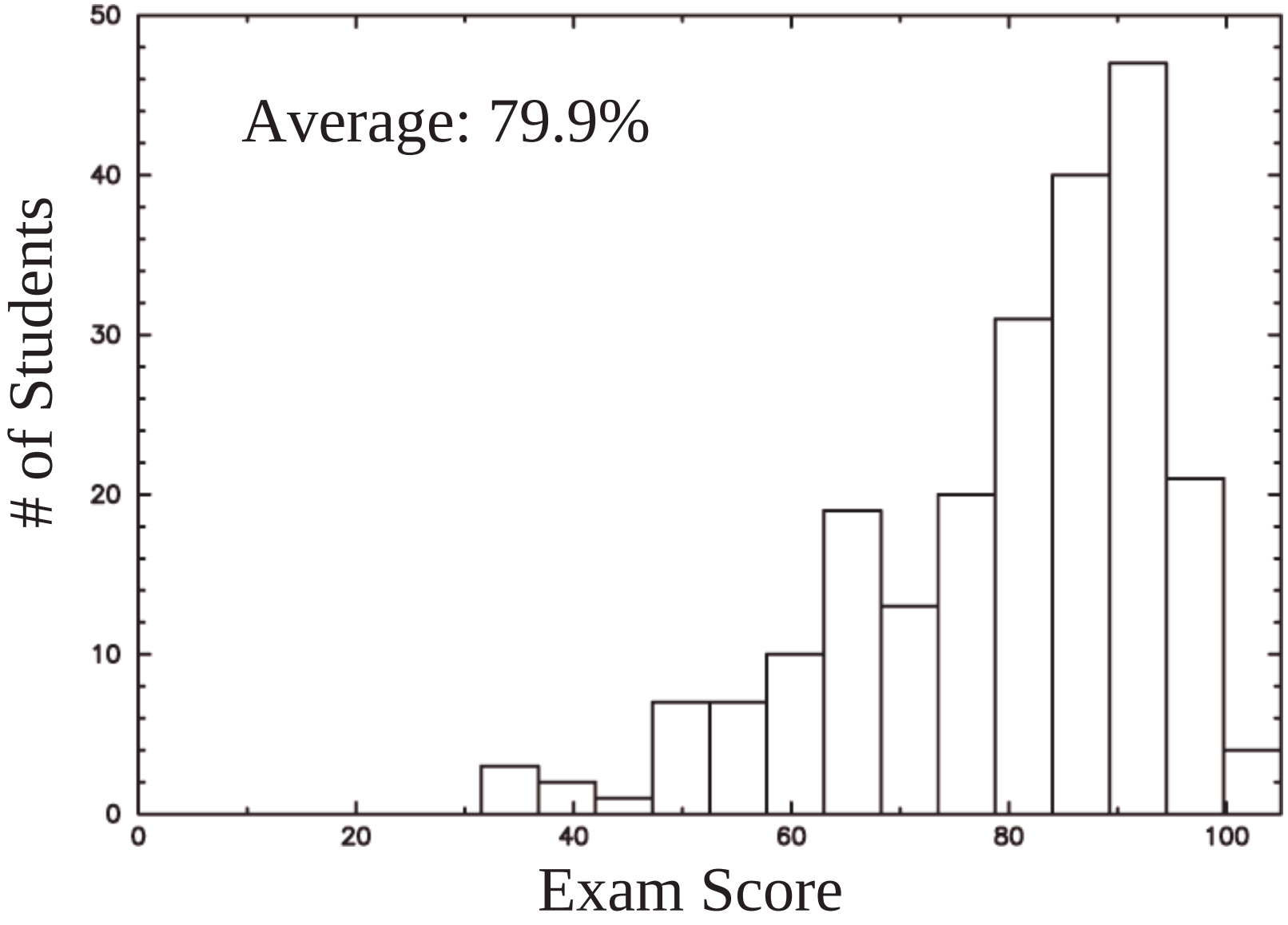
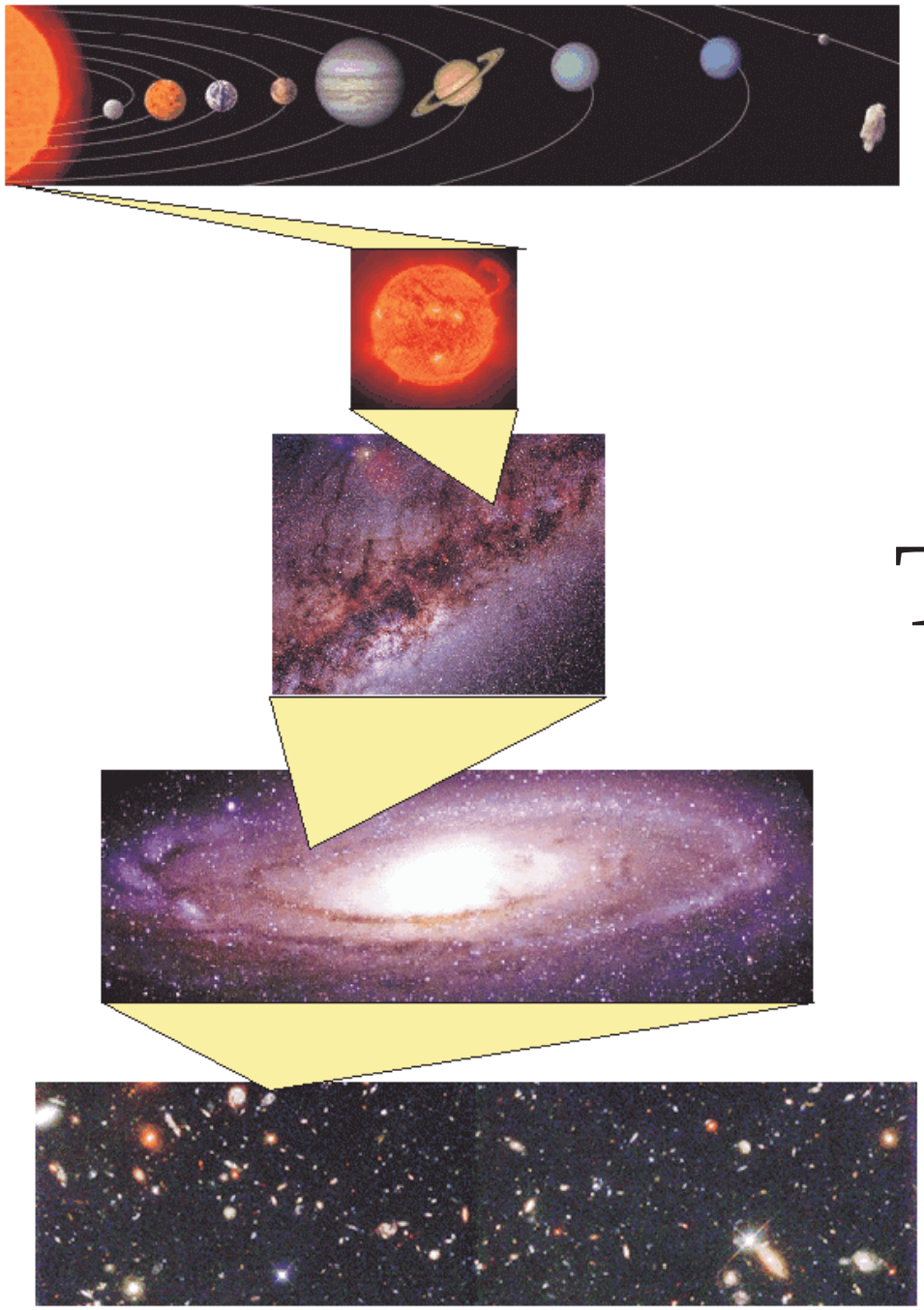
- Next week is Thanksgiving Break.
- No homework until you get back.
- On Friday…
- Exam 2 Grades are posted.
- Nighttime observing should be posted by Friday.

Exam 2


Average: 79.9%
# of Students
Exam Score
0
10
20
30
40
50
0
20
40
60
80
100

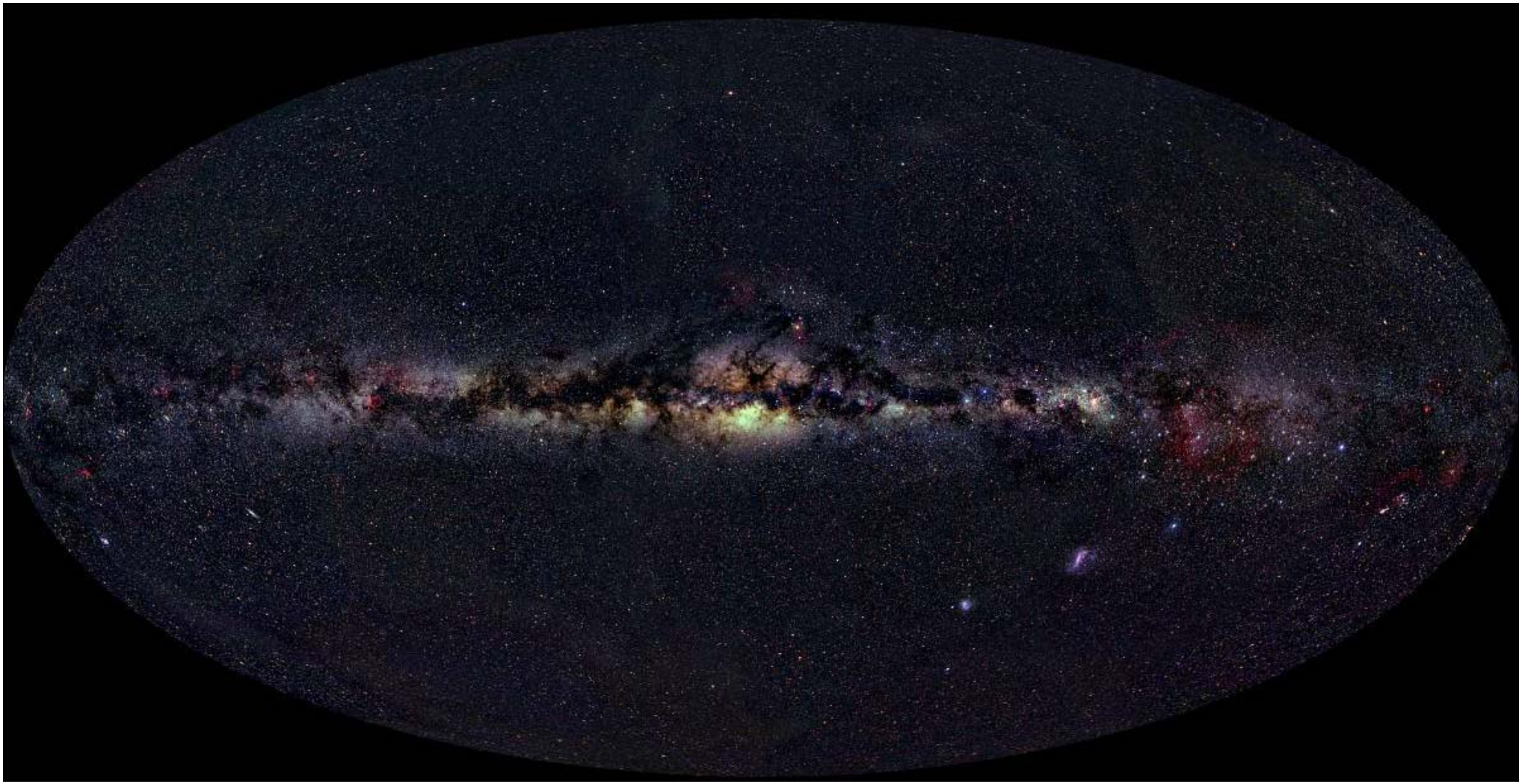
Outline

- The Milkyway Galaxy– what is it?
- Early studies put us at the center of the Universe. Wrong!
- Dust plays an important role in the Disk of the Galaxy.
- What are those weird spiral nebulae?
- 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.
  - Dark Matter!



Astronomy: The Big Picture

The Milky Way

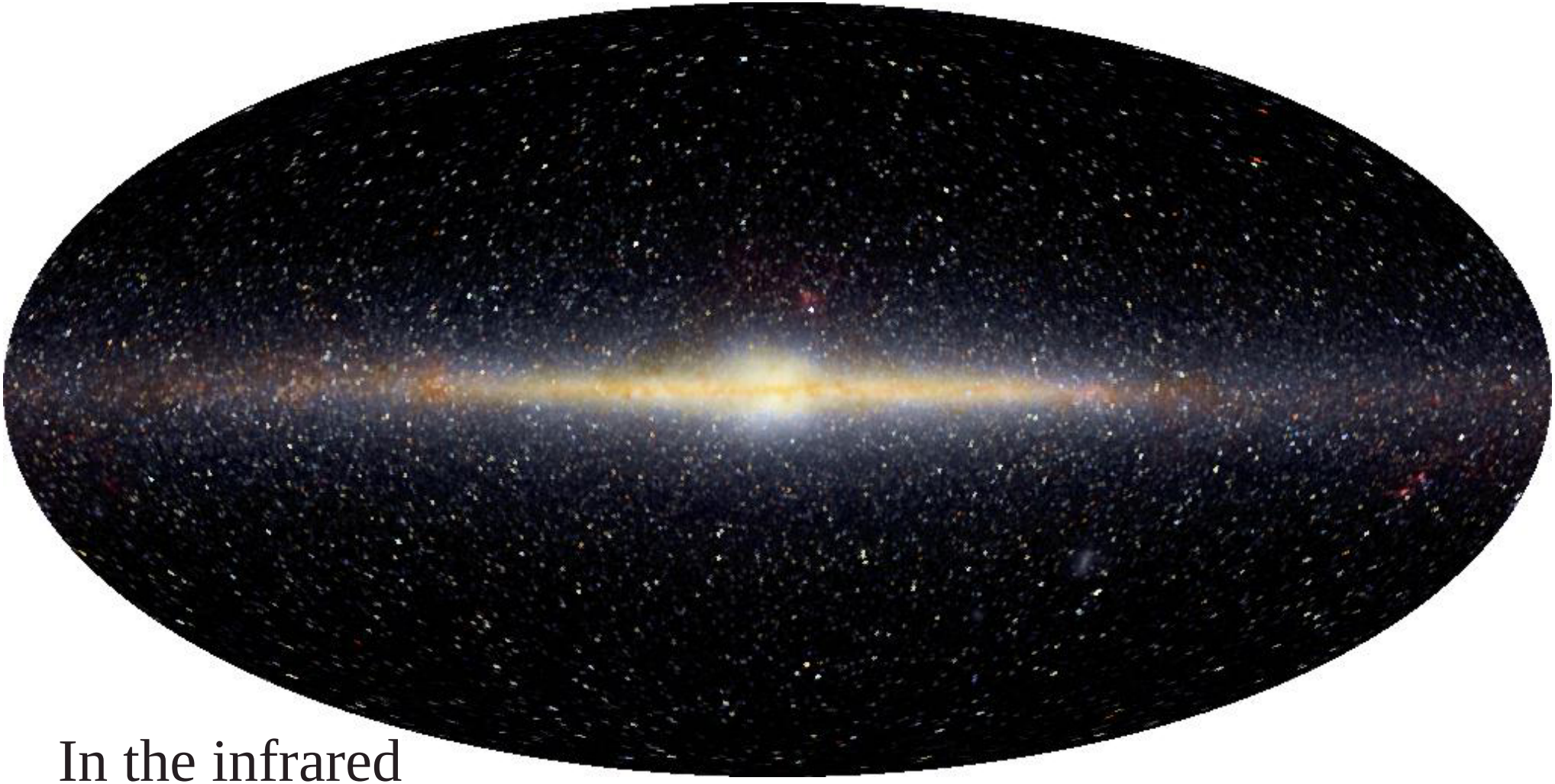


http://home.arcor-online.de/axel.mellinger/mwpan_aitoff.html

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

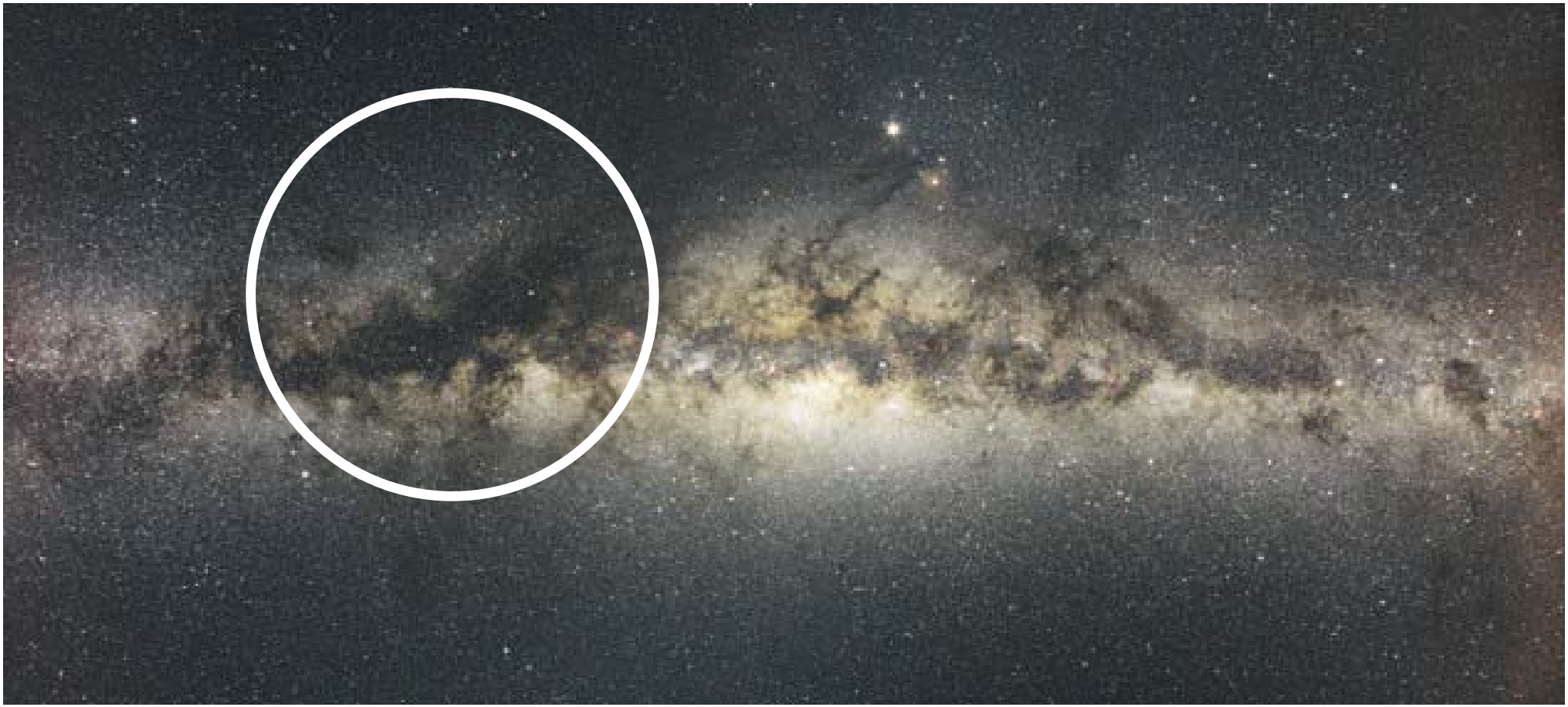
What is it?



In the infrared

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

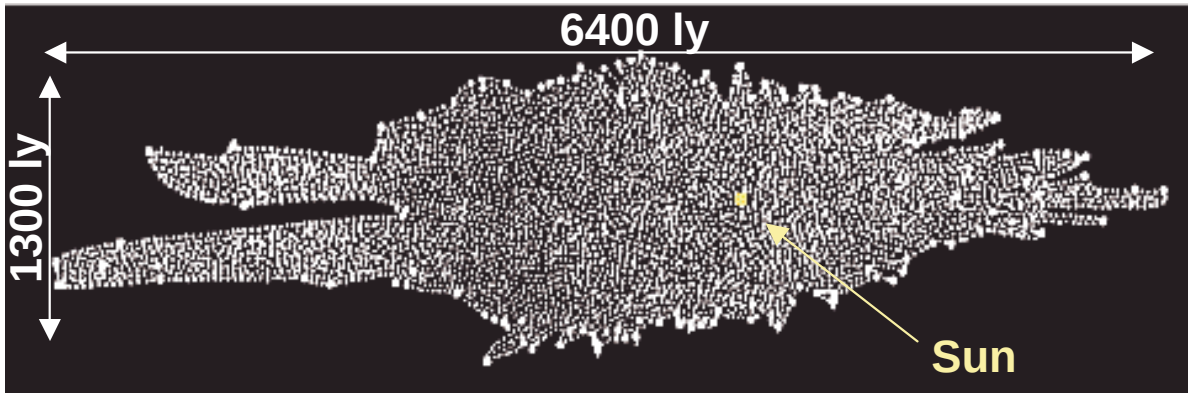
The Milky Way is made of all the stars in our galaxy– about 400 billion. All the stars you can see in the sky are in our Galaxy.



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

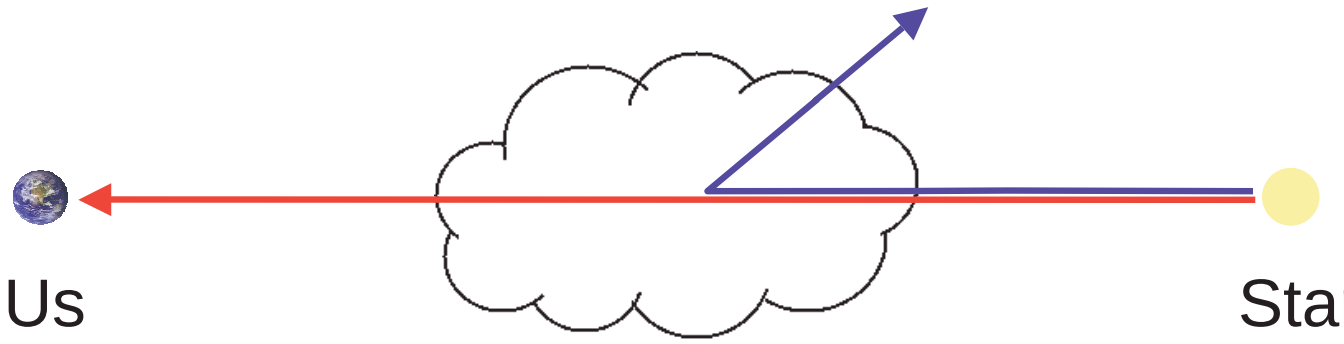
We Are in a Disk of Stars!

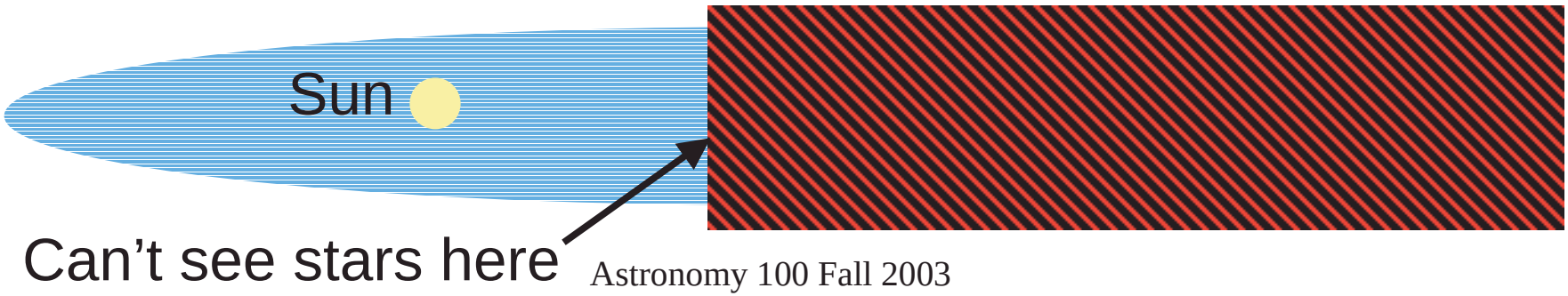
- The number of stars were counted in all directions from the Sun by William Herschel and his sister Caroline.
- They assumed that all stars have the same brightness and that space is completely transparent. Wrong!
- They concluded that the Sun is at the center of the Universe. Wrong.



The Importance of Being Earnestly Dust

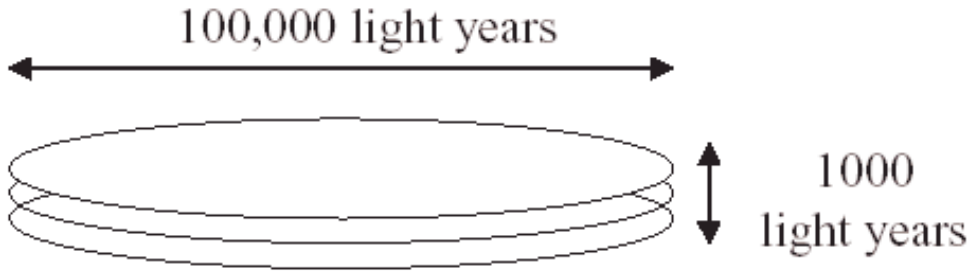
- There is dust in the disk of the Milky Way– it's easily seen. How does this dust effect the measurement?
  - Makes stars dimmer and redder
- There is more dust toward the center of the Galaxy
- Consequence: Underestimation in the number of stars in one direction– looks like we are center.

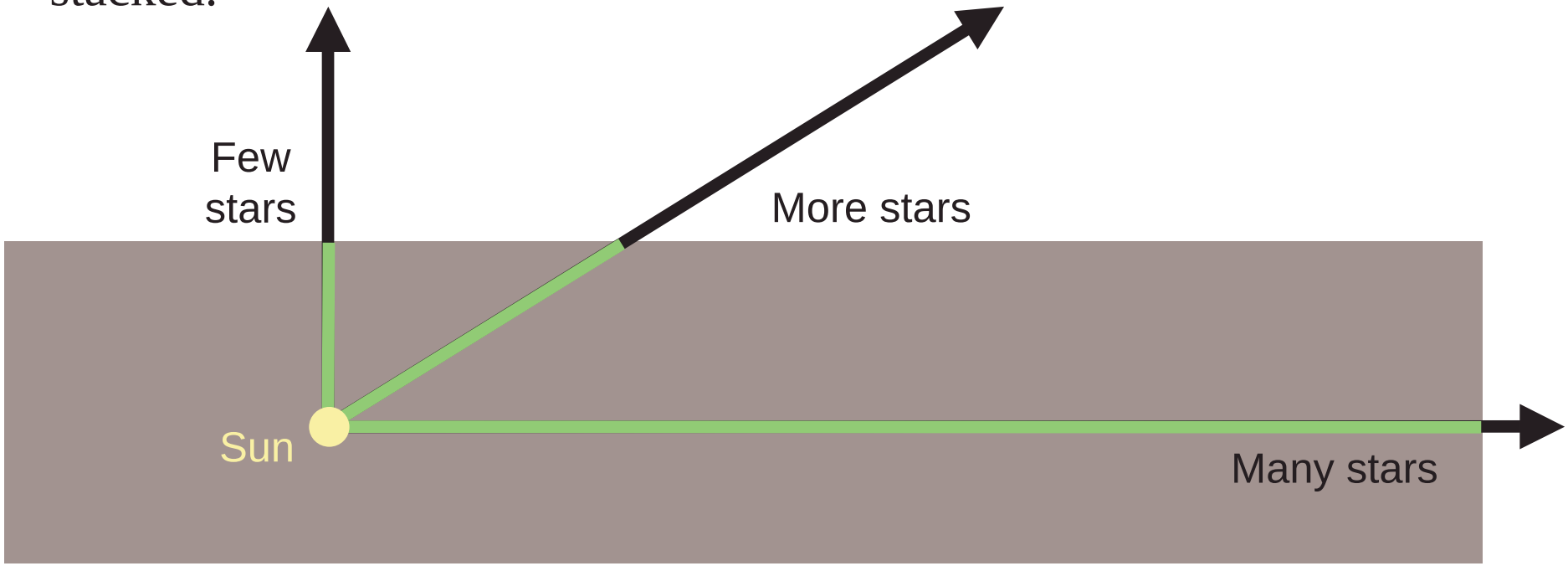




We Are in a Disk of Stars!

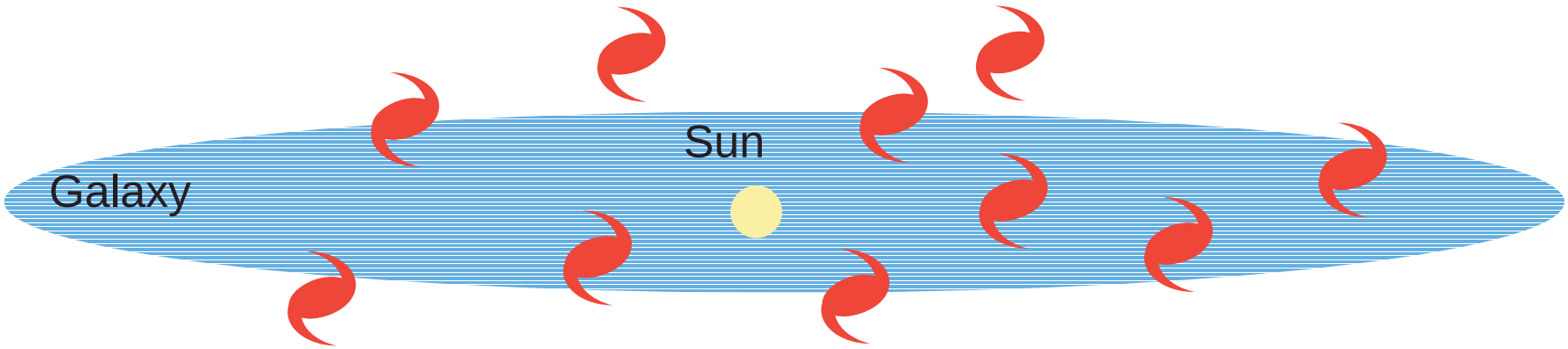
But they were correct in determining that the distribution of stars in the Milky Way is in a thin disk. The Milky Way is very thin in comparison to its diameter– imagine 3 CDs stacked.





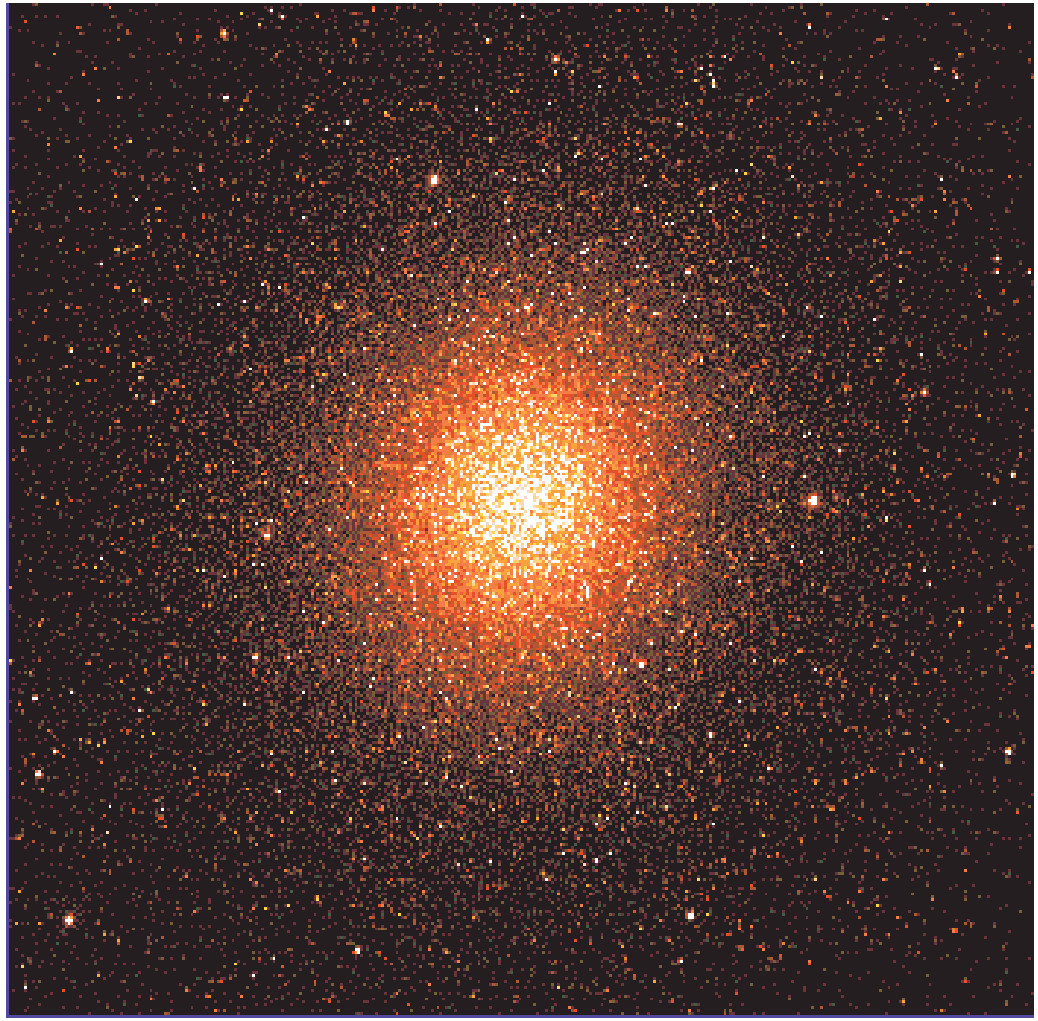
And those weird Spiral Nebulae?

- 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.



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

Early view
Sun at center

Globular Clusters
evenly distributed

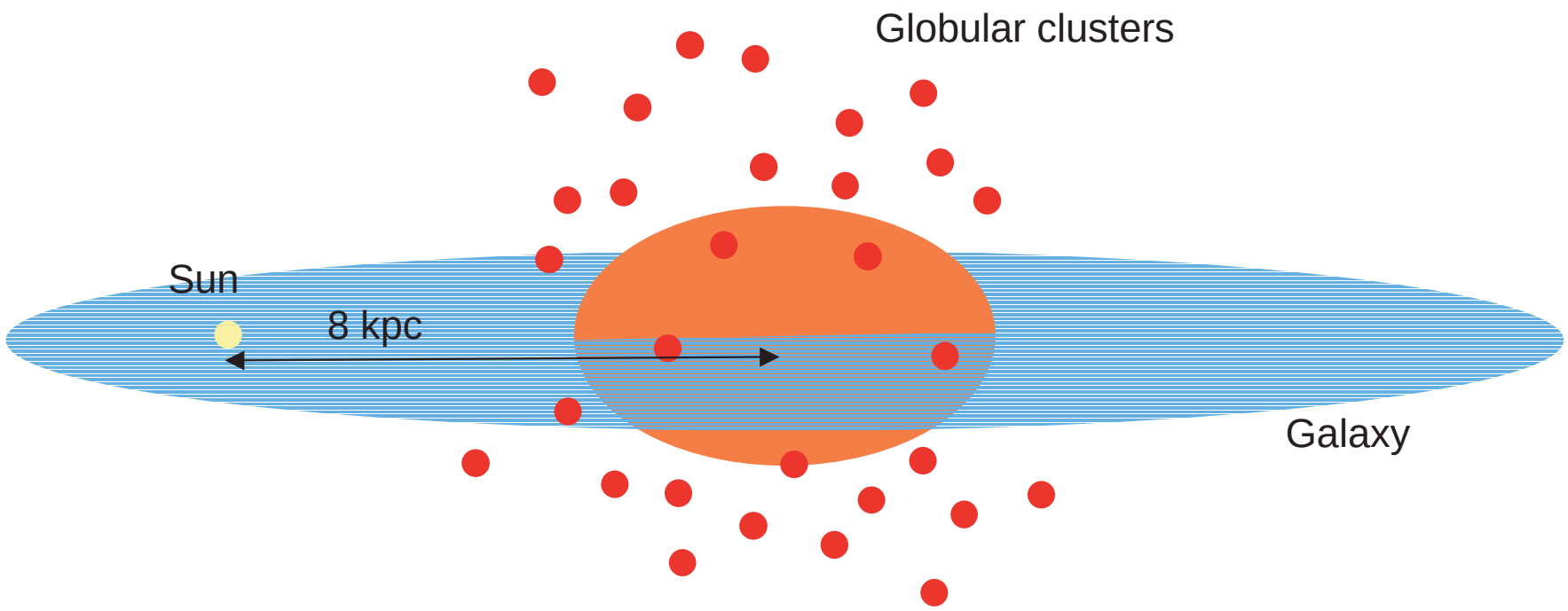
Sun

Globular Clusters
unevenly distributed

Harlow
Shapley

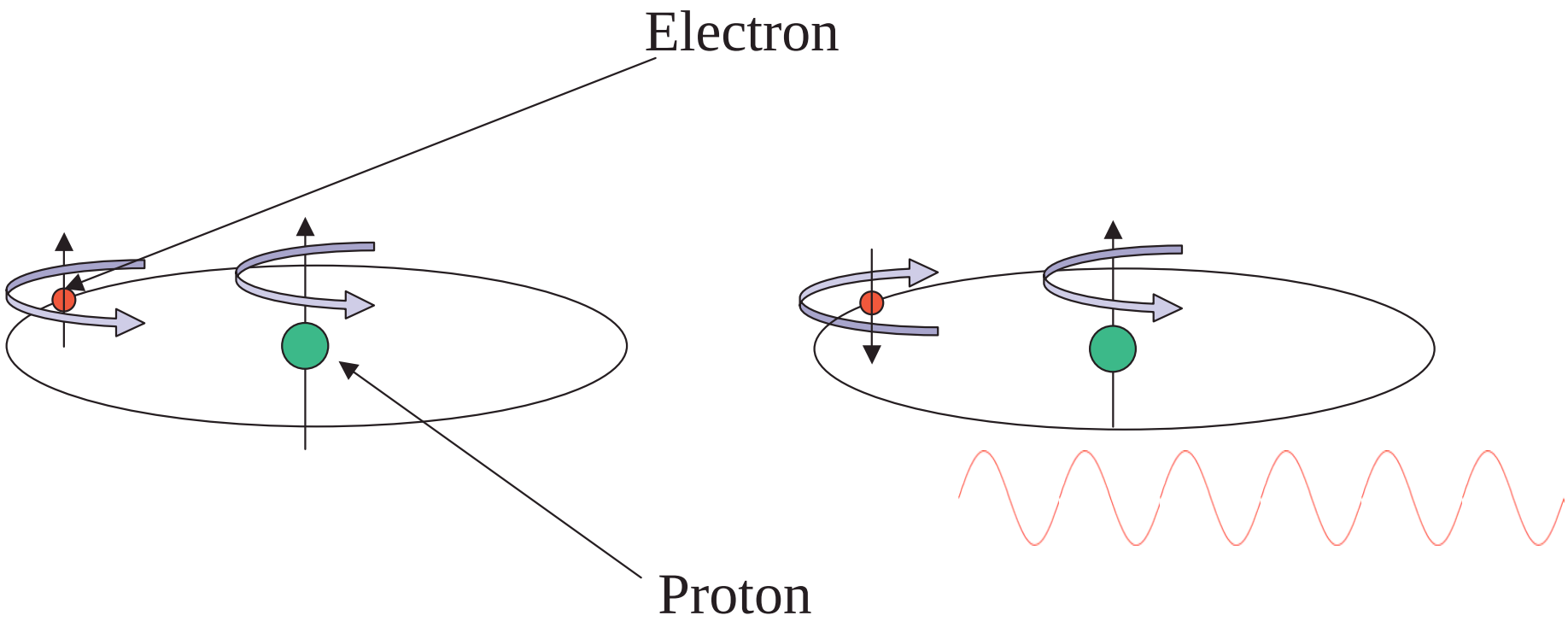
Our Place

- Shapley showed that we are not the center of the Galaxy in the 1920s.
- 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.



How to find out more?

The 21 cm emission line is the transition in the spin of the electron in hydrogen atoms. Long wavelength allows us to look though the dust.

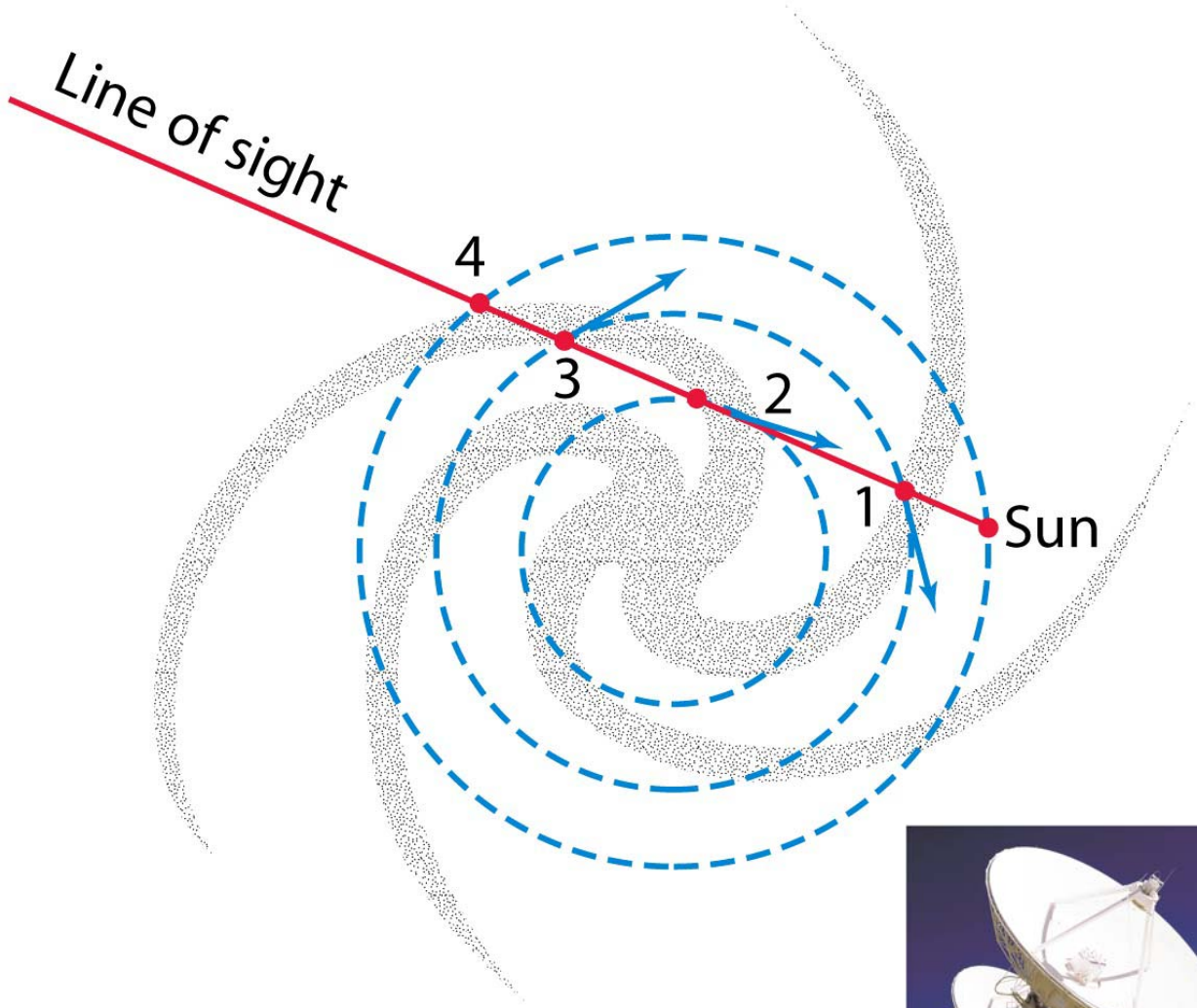


Higher Energy State

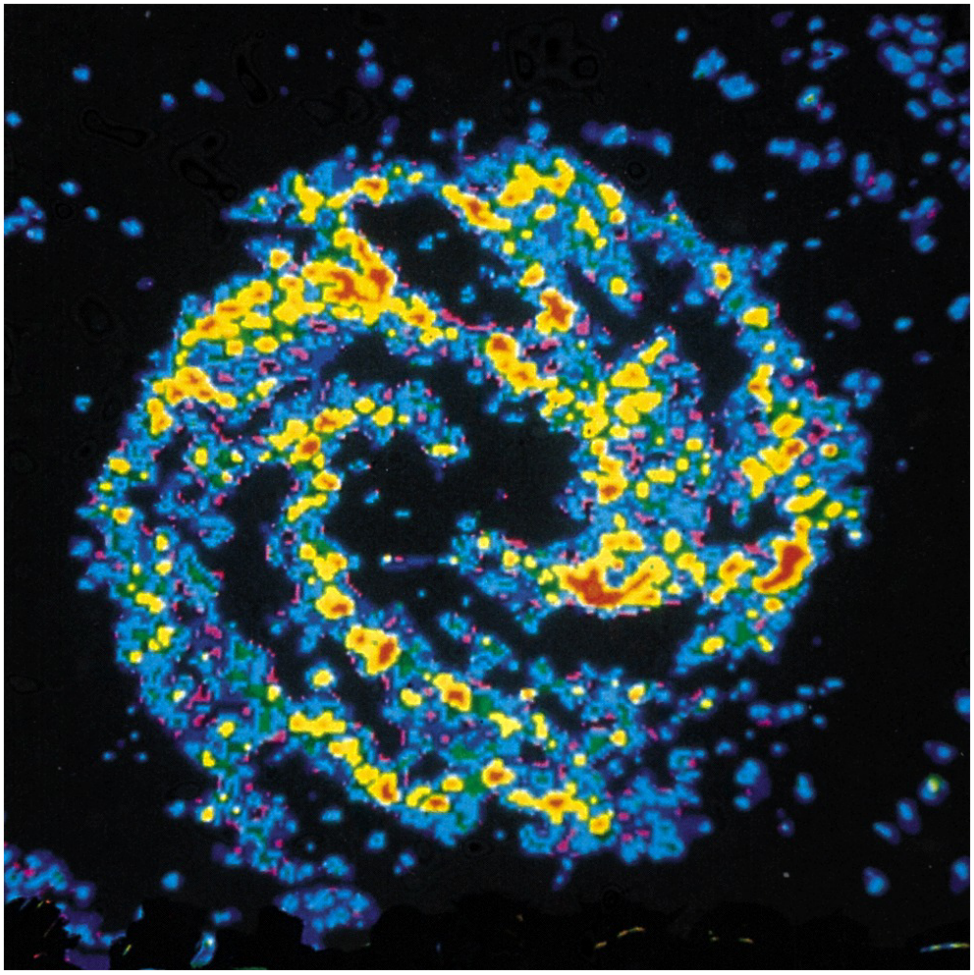
Lower Energy State
+ 21 cm photon

Hydrogen Emission

- Looking for 21-cm wavelengths of light
  - Emitted by interstellar hydrogen– most abundant
  - As we look along the disk of the Milky Way (from inside), we see 21-cm photons Doppler shifted varying amounts

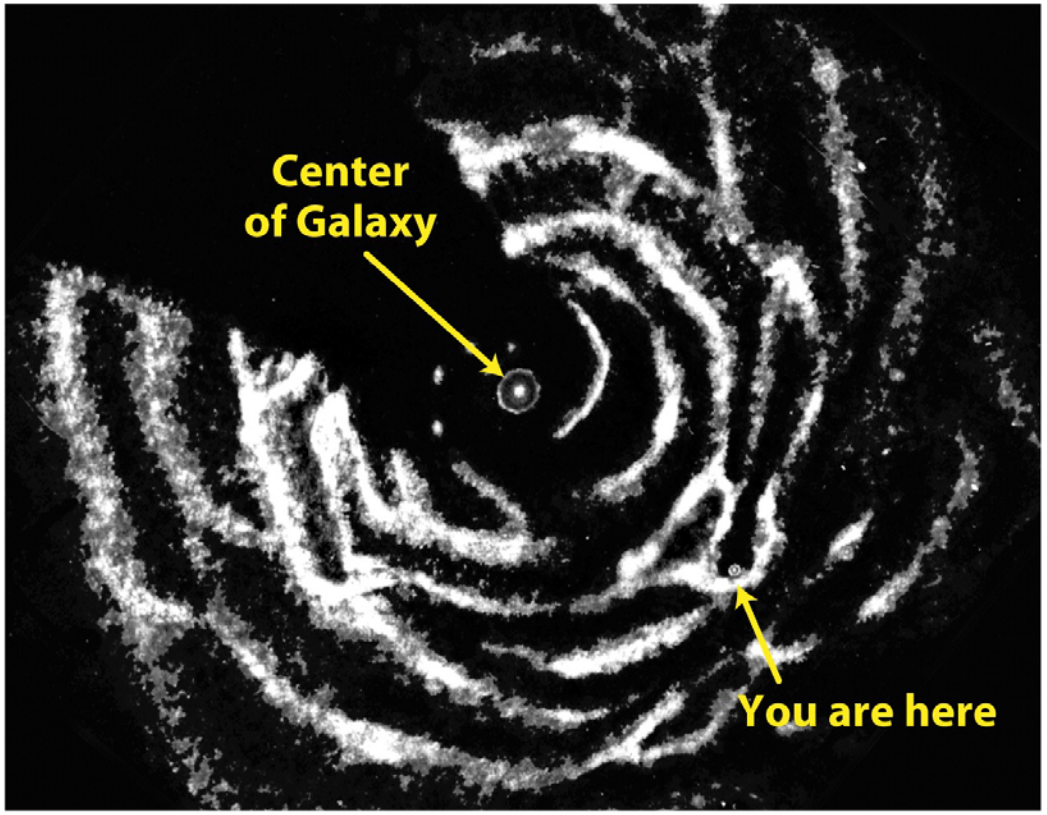


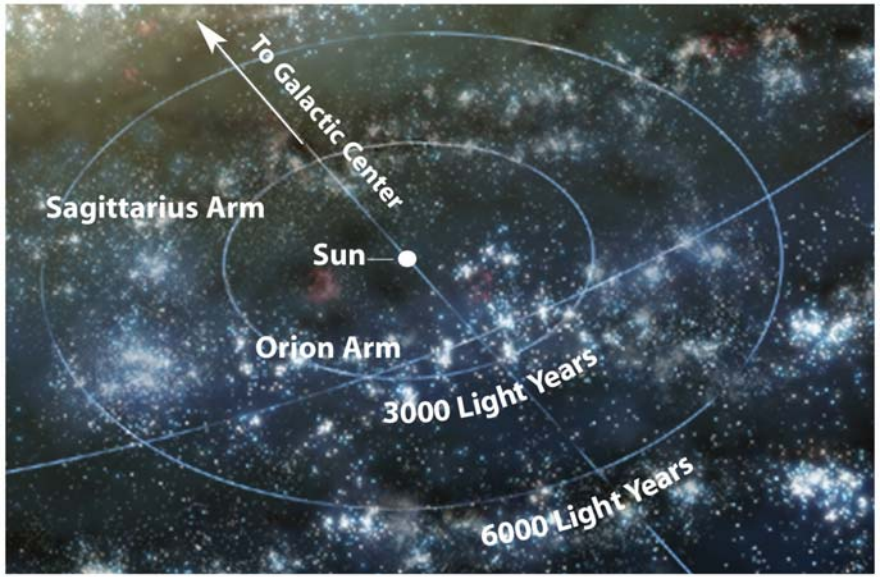
Visible and Radio



M83

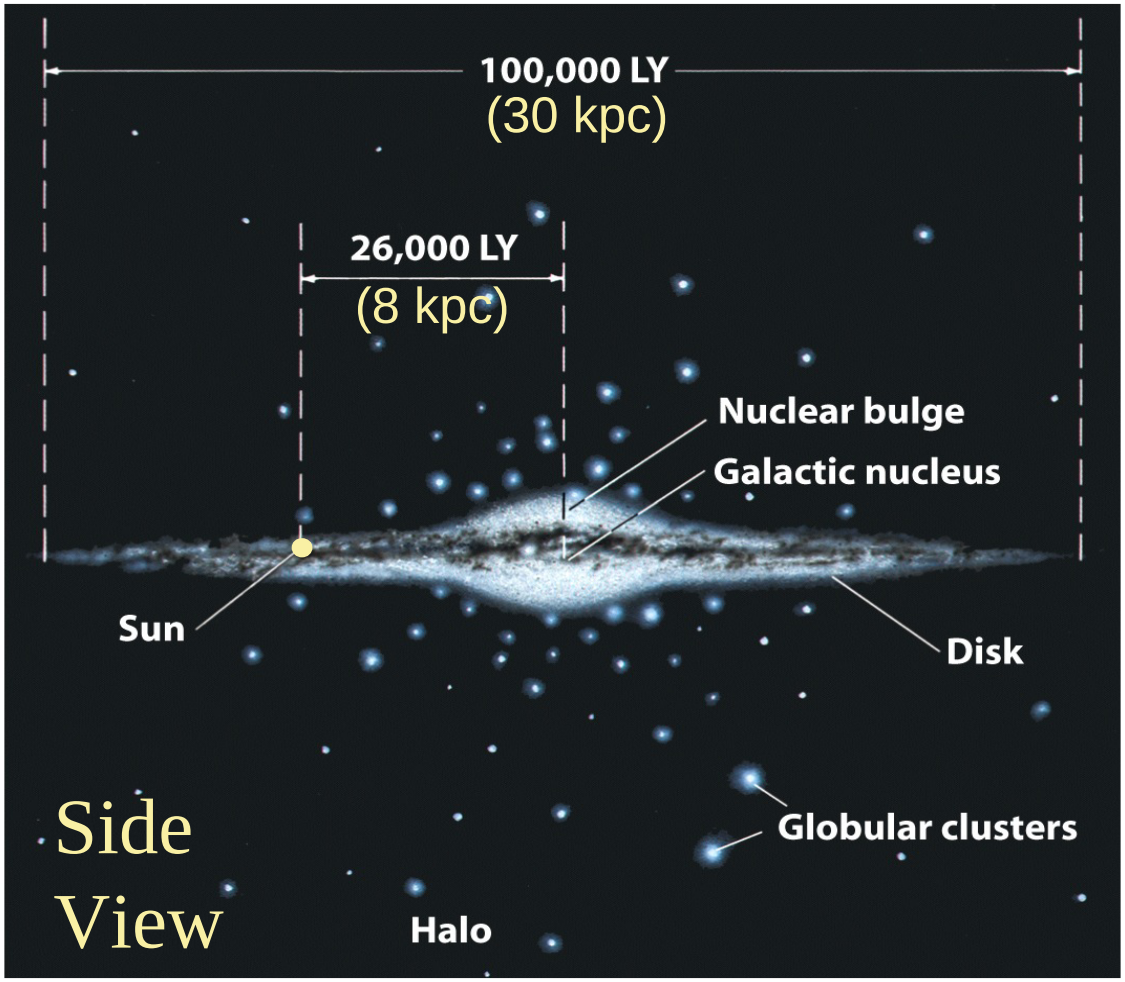
We see Spiral Arms– OK hints of

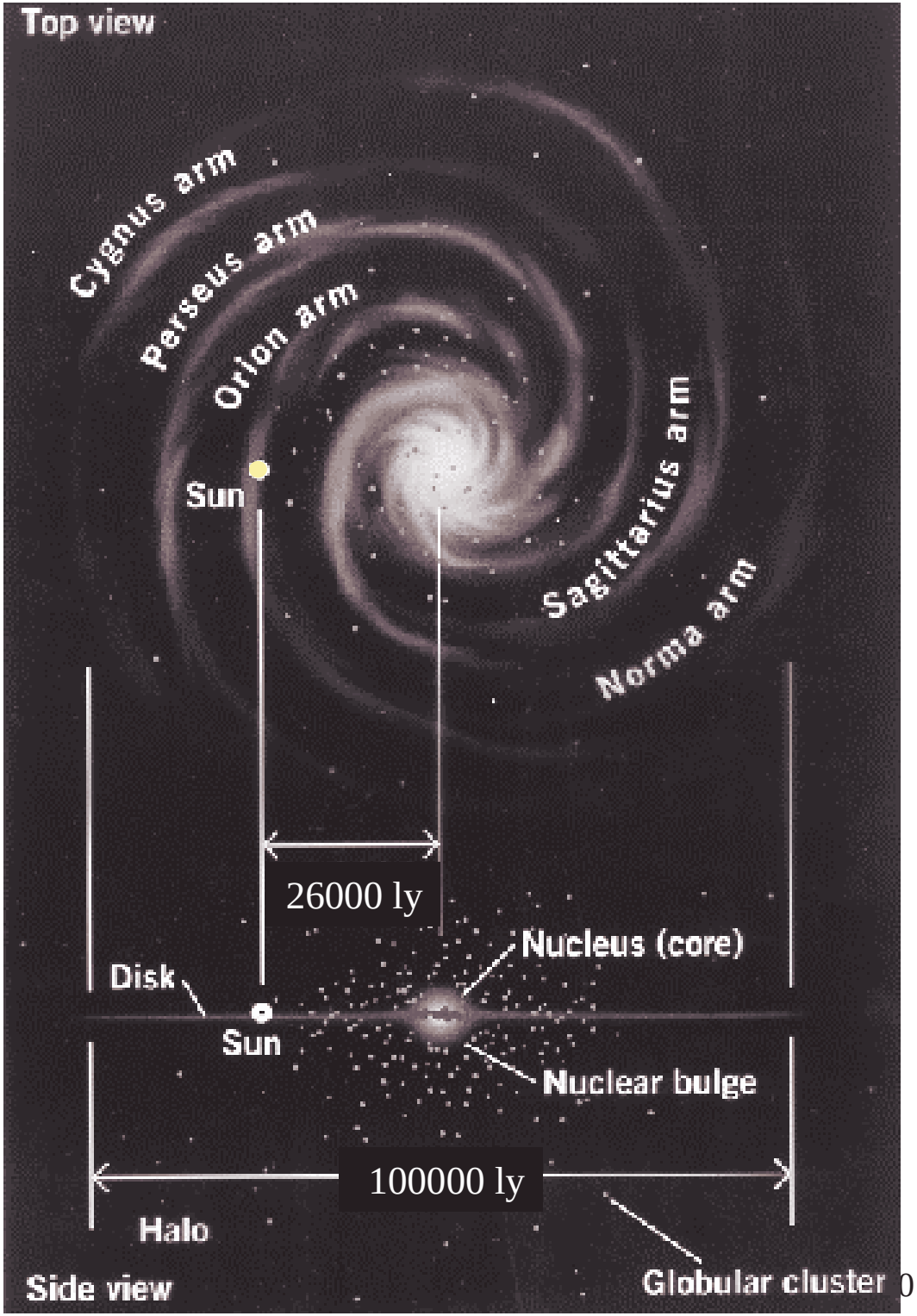




Our Galaxy

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

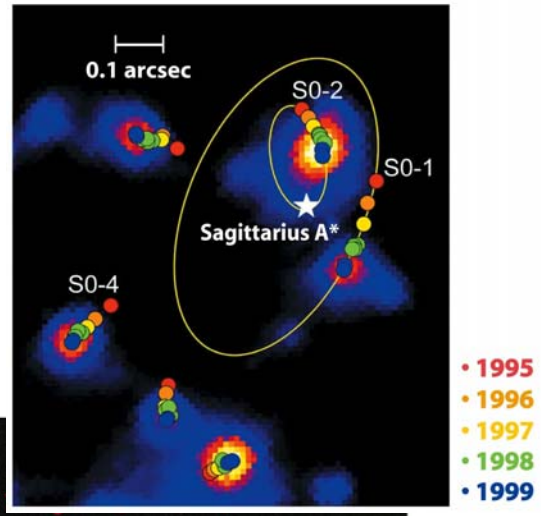


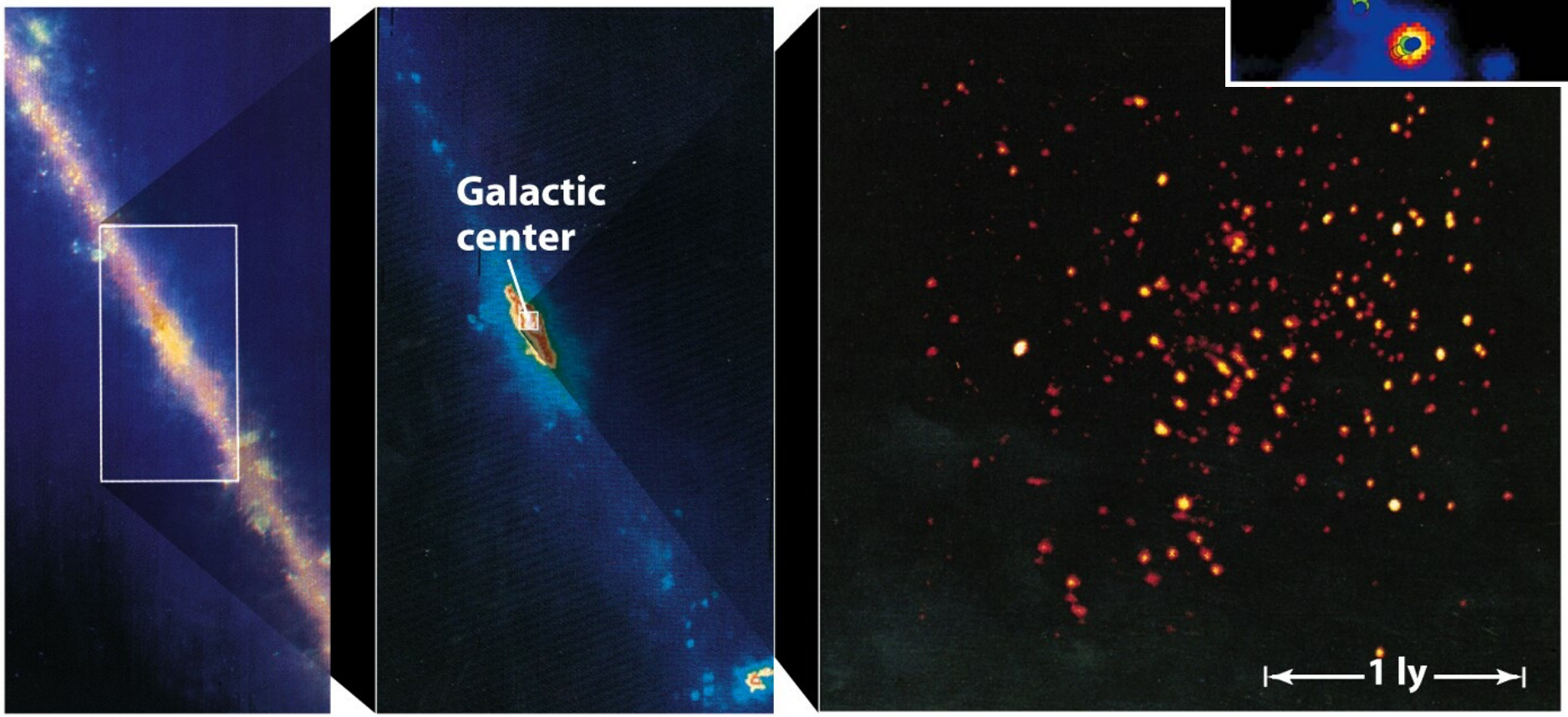

Top view
Cygnus arm
Perseus arm
Orion arm
Sagittarius arm
Norma arm
Sun
26000 ly
Nucleus (core)
Disk
Sun
Nuclear bulge
100000 ly
Halo
Side view
Globular cluster

Our Galaxy

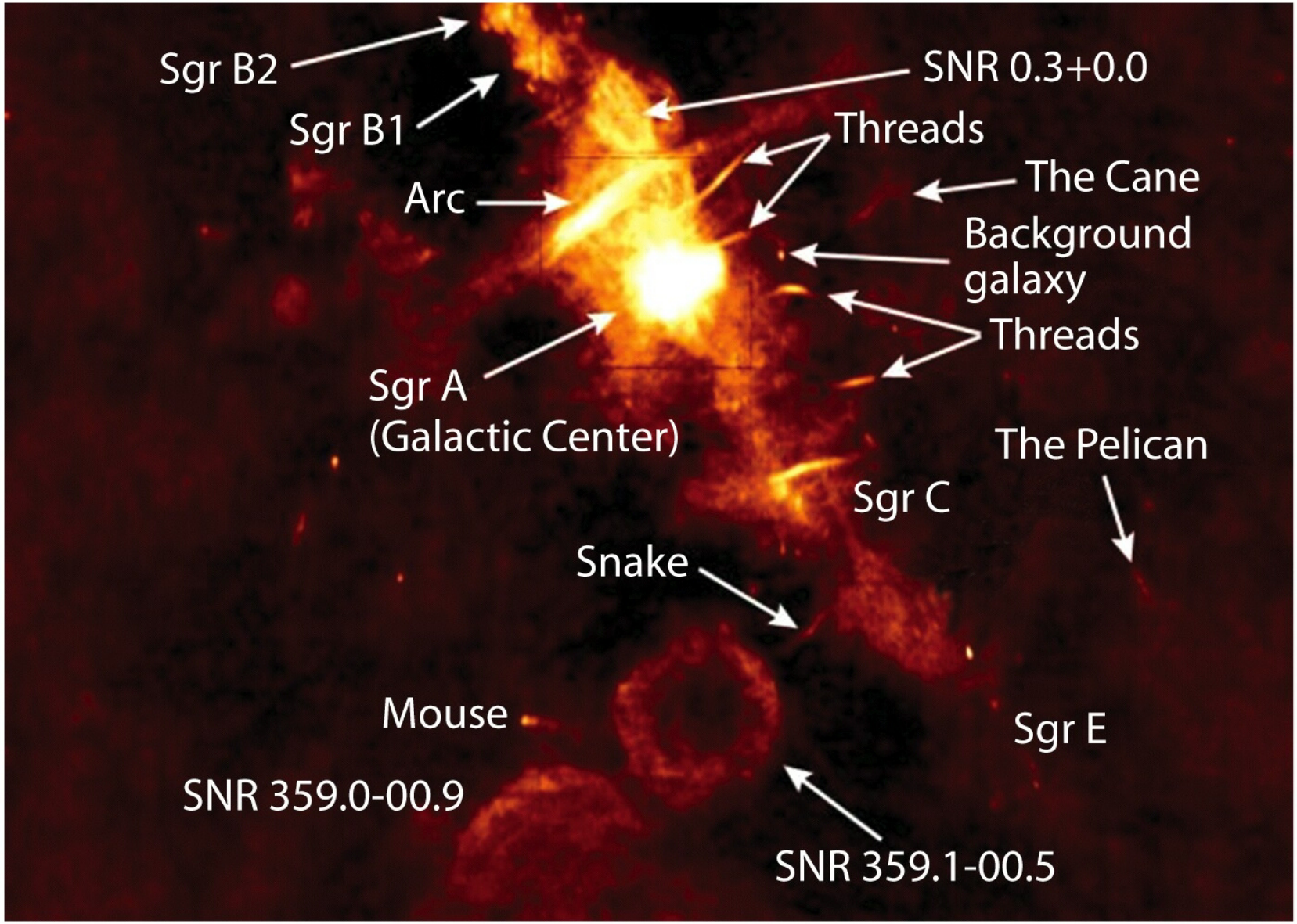
The Center of Our Galaxy

Lots of stars– and probably a massive blackhole.

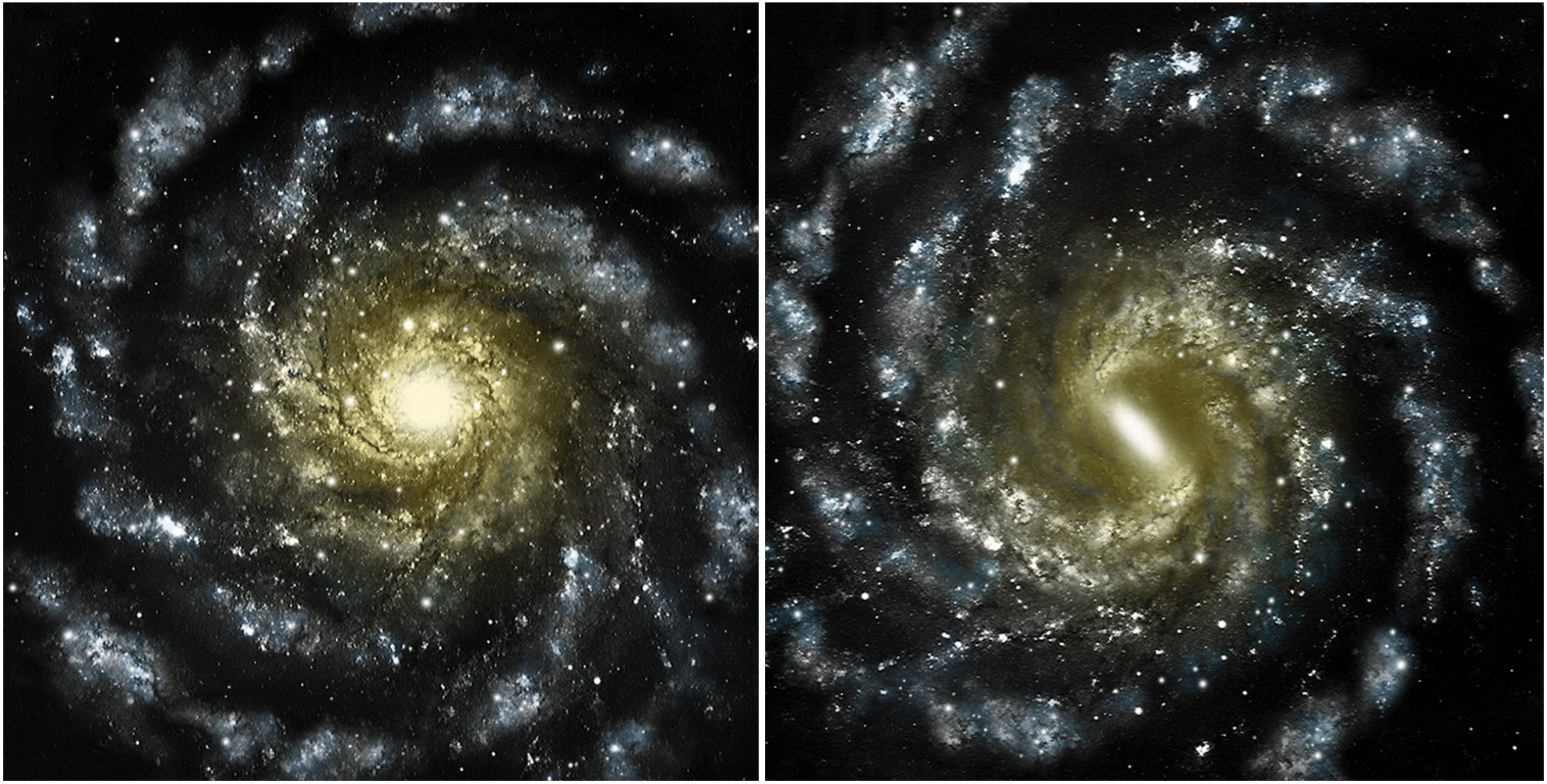




The Center of Our Galaxy

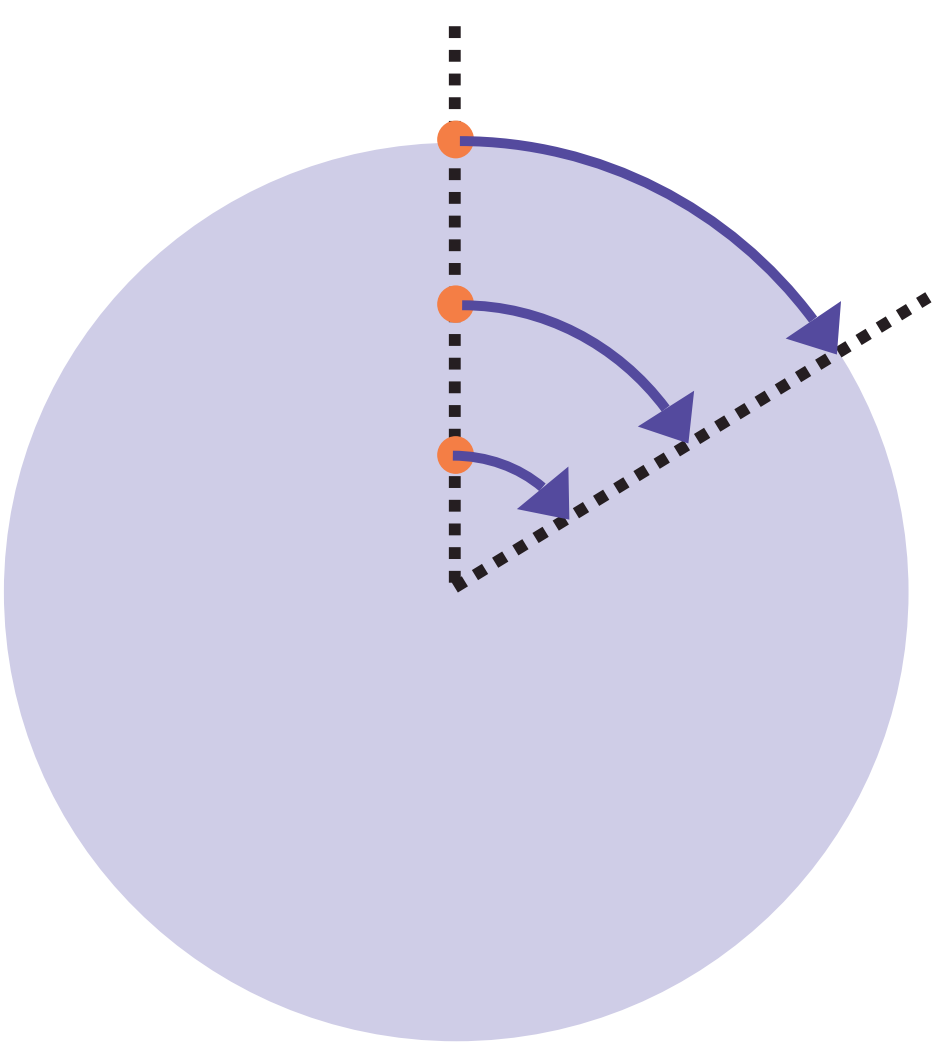


Do Galaxies Spin?

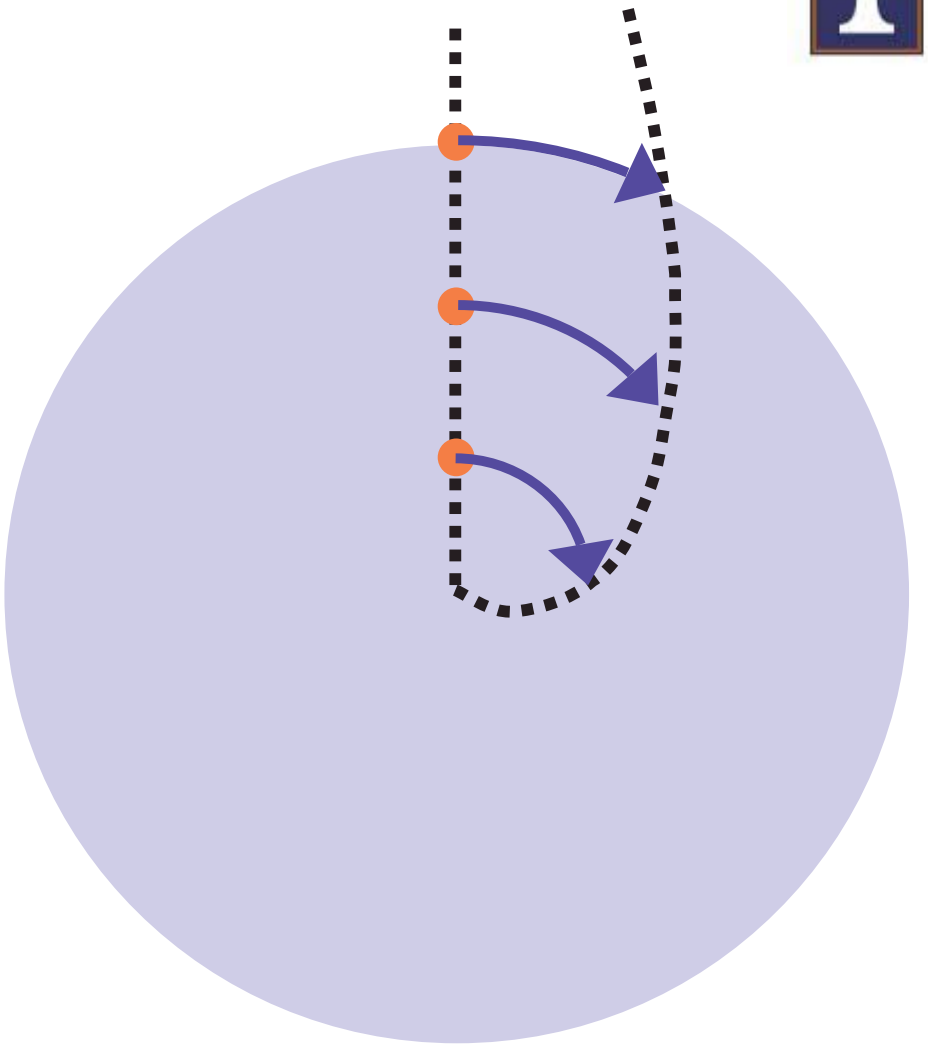


Spiral galaxies really suggest it. How? Like a CD?
Our Galaxy probably looks more like the right galaxy.

Differential Rotation



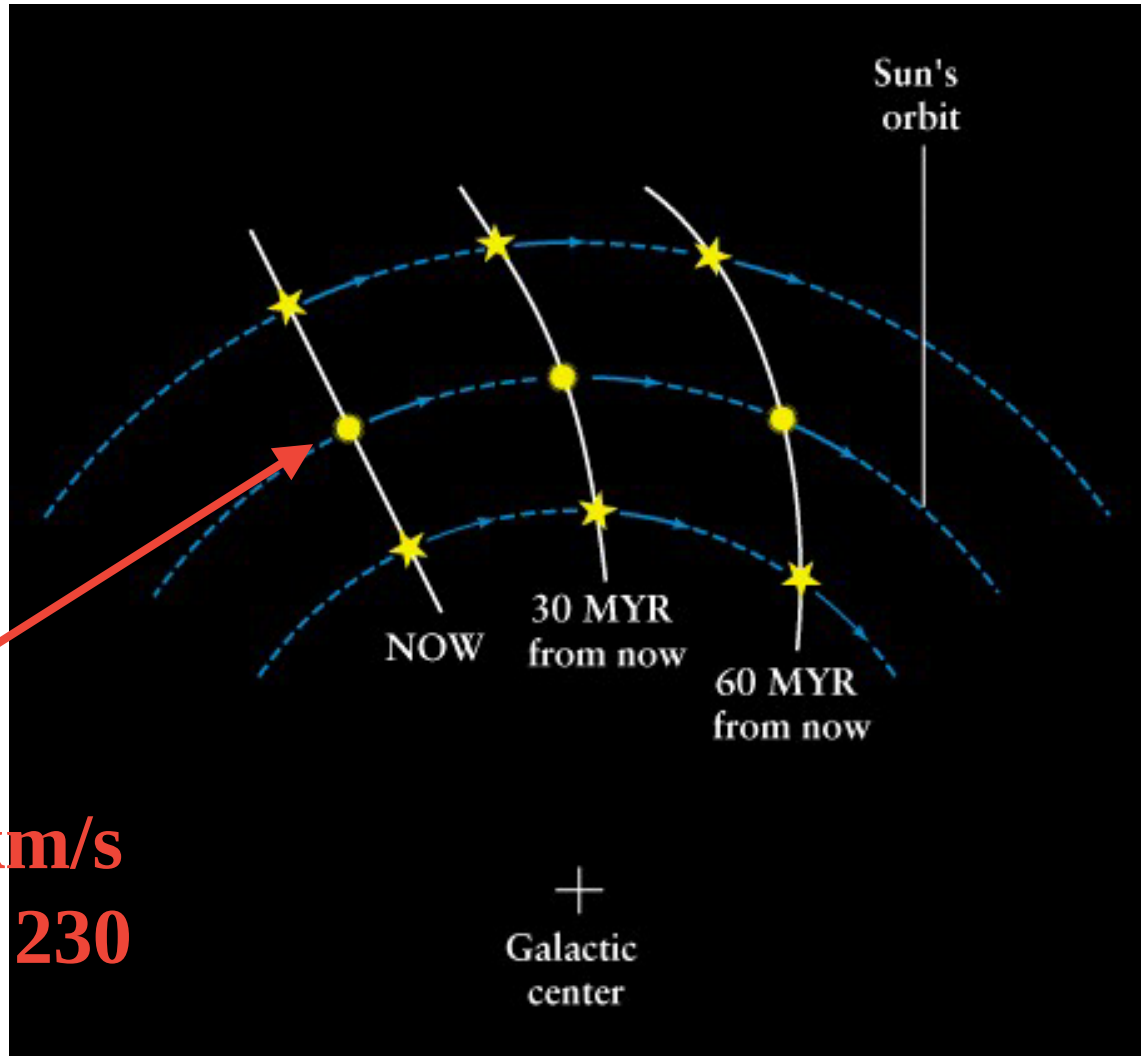
Same angular speed
(degrees per year)



Same linear speed
(parsecs per year)

Is the Solar System Moving Too?

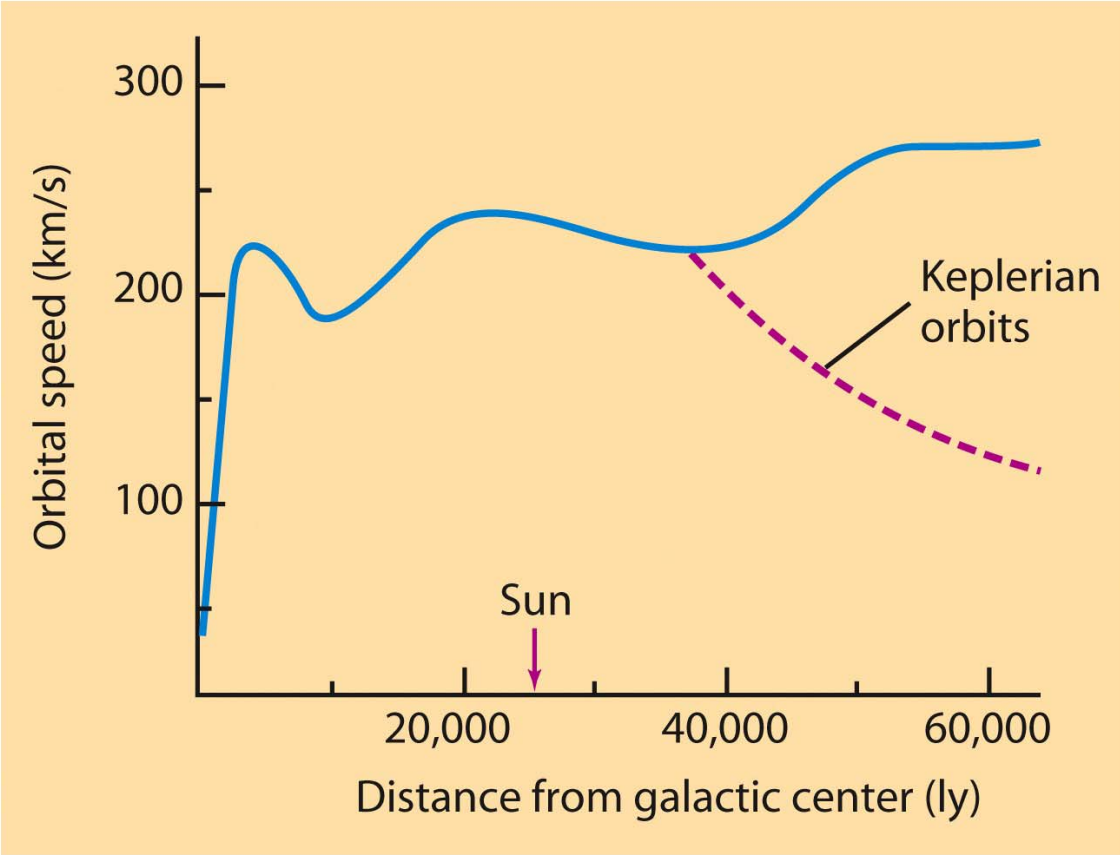
Yes… the whole Galaxy has differential rotation– us included



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

The Rotation of the Galaxy

- Using our rate of motion, we can use Kepler's 2nd Law to calculate the mass of the Galaxy inside our Orbit.
- 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.



The Rotation of the Galaxy

- According to Kepler's 3rd Law, 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 is mass outside of the Galaxy that is dark!
- In fact, 90% of the mass of the entire Galaxy (>10^{12} solar masses) is Dark Matter!