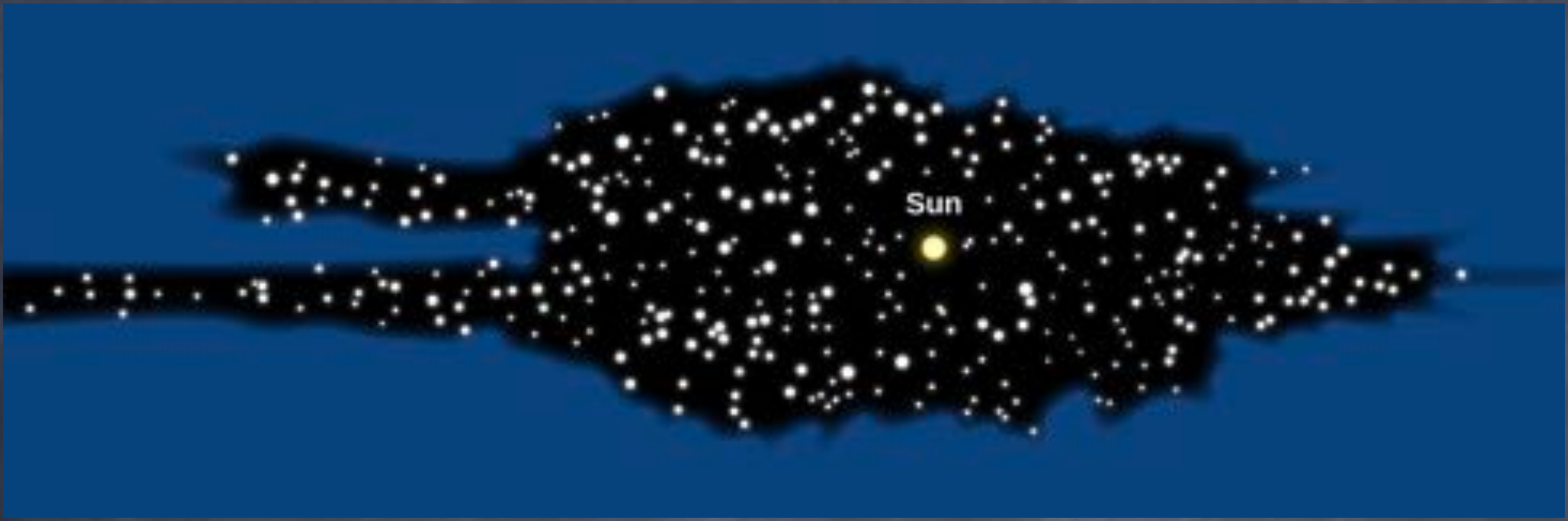
The Milky Way

Chapter 25

The Milky Way can be seen in a dark sky.
It is the gas and stars of our own galaxy.

The Milky Way

- The Milky Way can easily be seen by the naked eye on a dark night, but what it is was not clear unit rather recently.
- Copernicus led modern astronomy to make the Sun and not the Earth the center of our solar system. But most people then thought the Sun was also the center of the Universe.
- The place of our Sun in the Universe was not clear until people started exploring the nature of our galaxy.

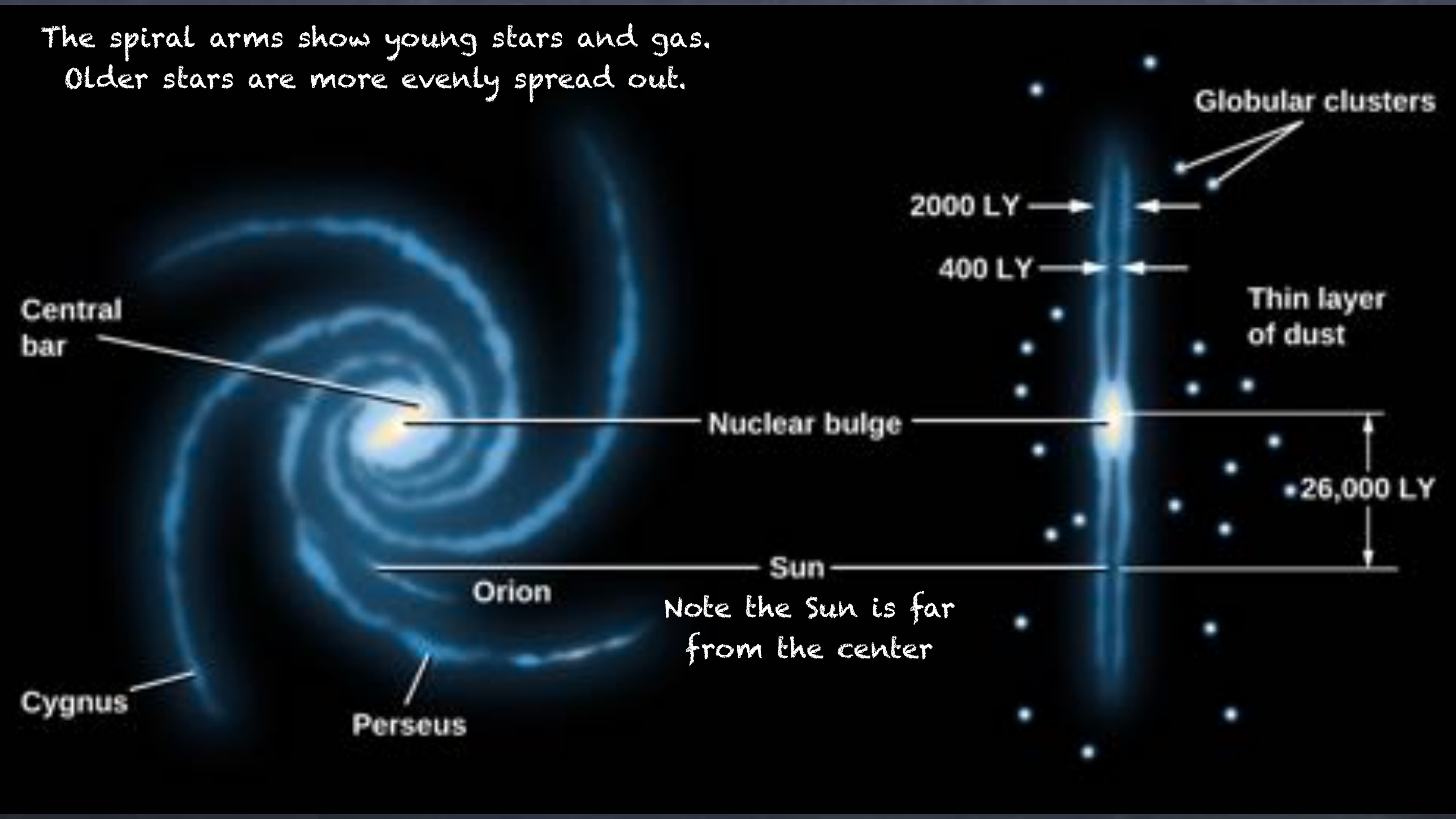


Herschel was the first person to try and map out our galaxy by counting the number of stars in different directions. The above image is what he found. He concluded that stars were distributed in a disk like structure and that the Sun was near the center. The disk like structure can be associated with the Milky Way we see in the sky. However, he didn't know about dust so didn't realize he was only mapping out the local area.

The Milky Way

- Using radio and infrared observations we can now map out the Milky Way in good detail. We find that the Milky Way has a number of components:
  - Disk - most of the galaxy is a disk about 100,000 lyrs across and 2,000 lyrs thick. The youngest stars and gas is found within 100 lyrs of the mid plane. The ISM is about 15% the mass of the stars. There are spiral arms in the disk
  - Bulge - in the center of the disk (inner 10,000 lyrs) stars are found in a bulge which is longer in one direction. The bulge also contains a bar.
  - Stellar Halo - The are also stars that are found in a spherical halo around the galaxy. This is only a small fraction of the mass, but extends out to much farther distances, 200,000 lyrs or more. The globular clusters are found out here.

The spiral arms show young stars and gas.
Older stars are more evenly spread out.



Note the Sun is far from the center

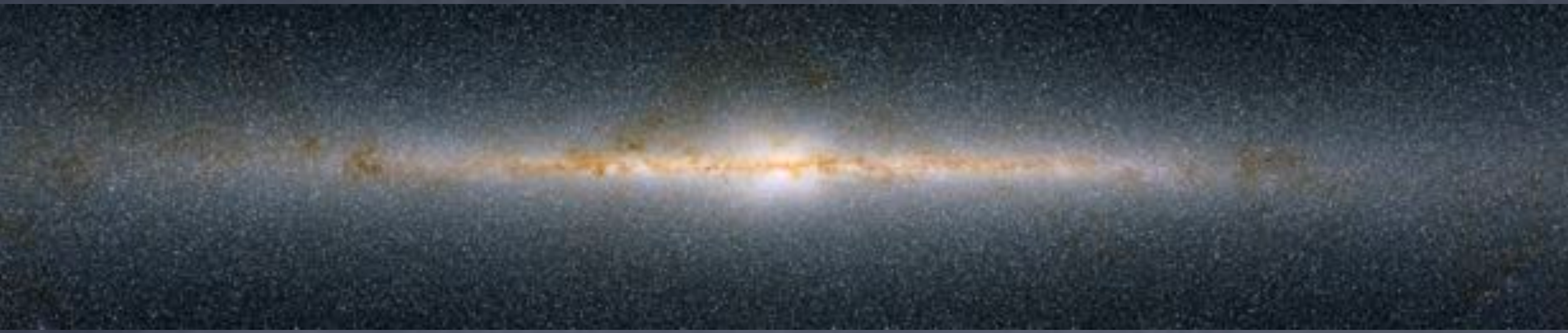
Spiral Galaxies

- Our understanding of our own Milky Way is largely based on observing other spiral galaxies and inferring that we should be similar.
- We still are less certain about many aspects of the Milky Way than other galaxies because we are inside it and that makes it much harder to see.

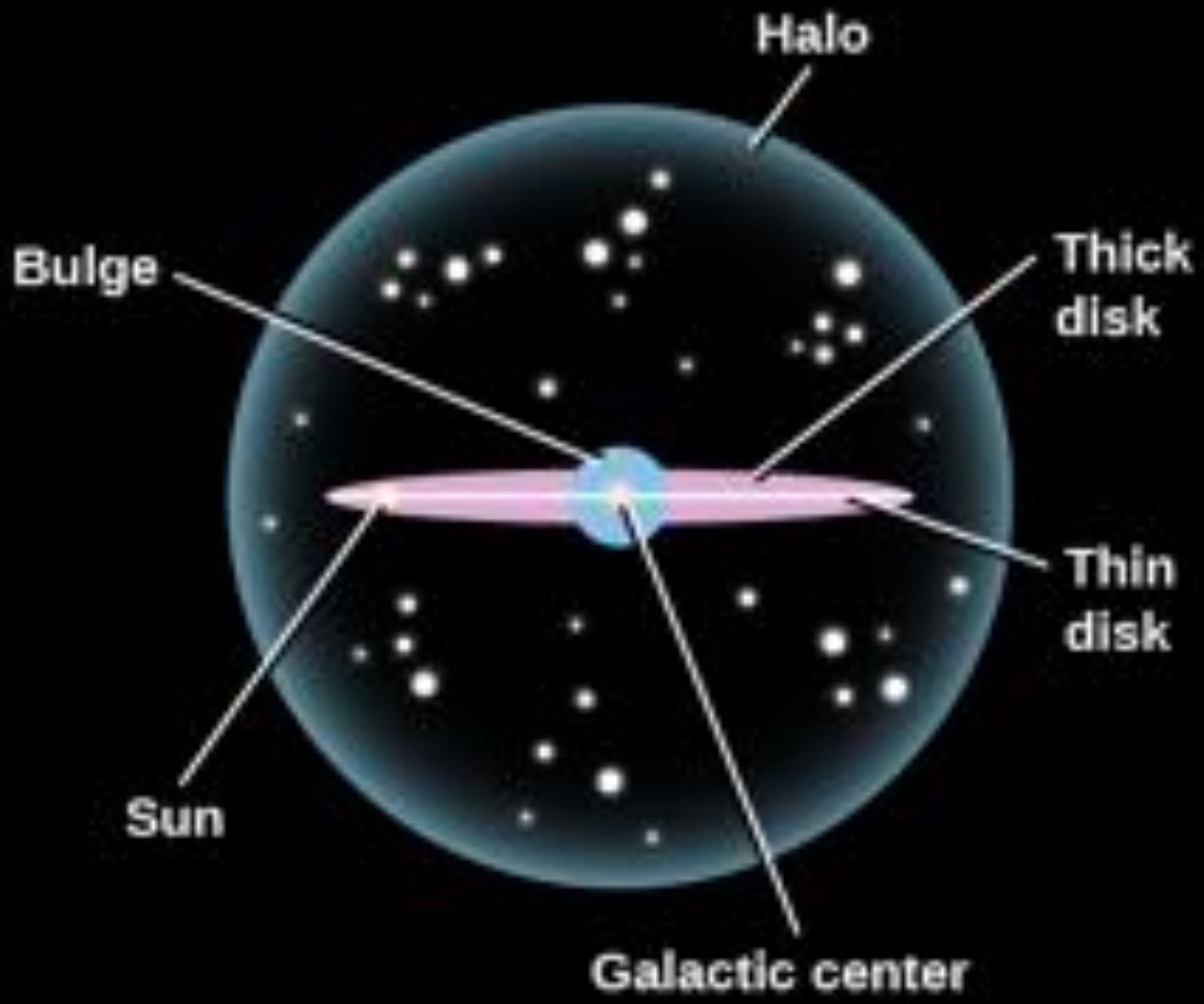
Other galaxies that the Milky Way probably resembles

(a)

(b)



The bulge is very hard to see because it contains a lot of gas and dust. It is best to look in the infrared, like the above image, but you can still clearly see the dust lanes. We make guesses as to the nature of the Milky Way's bulge based on other galaxies, but its mass and size are still pretty uncertain.

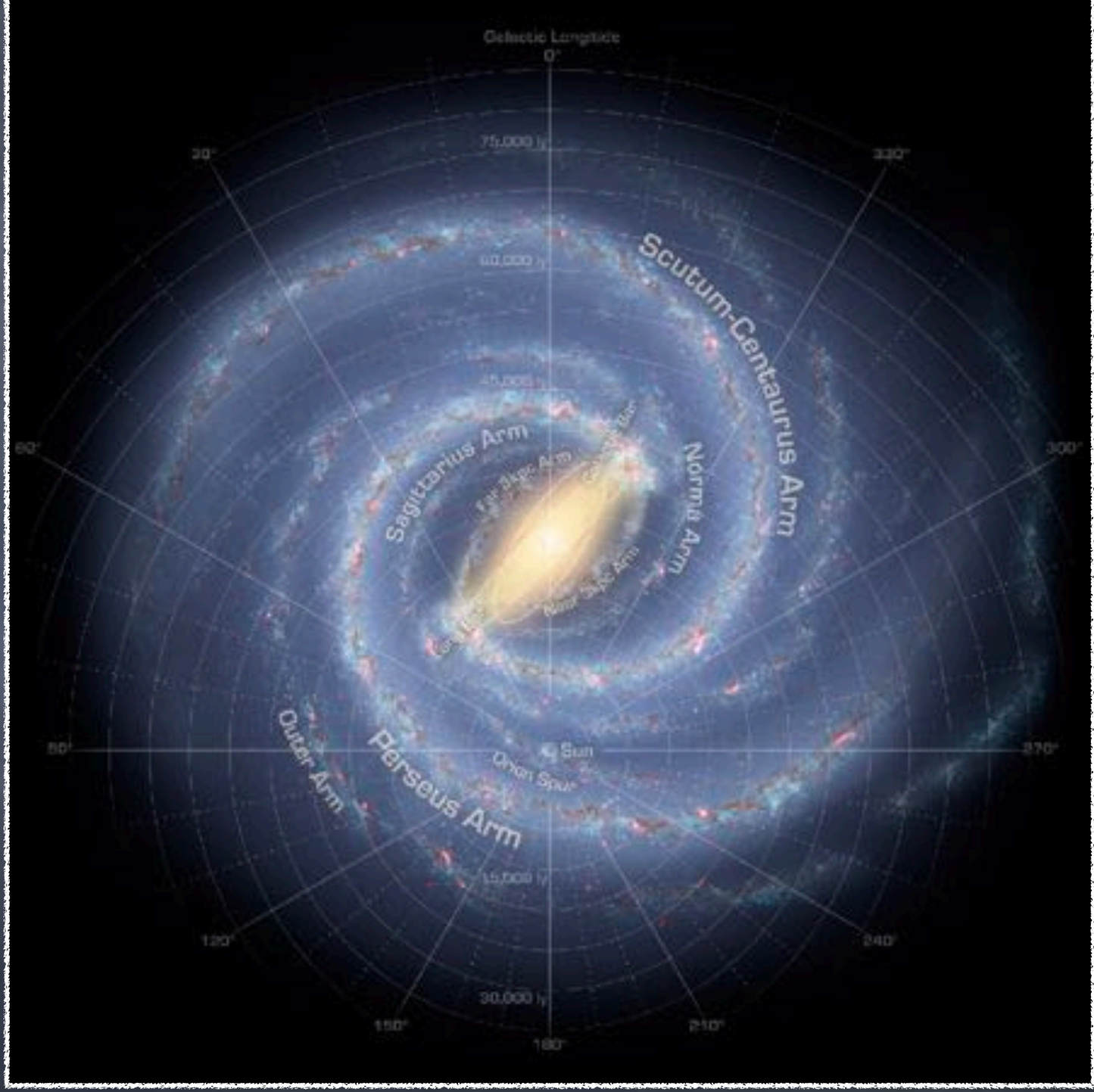

Halo
Bulge
Thick disk
Thin disk
Sun
Galactic center

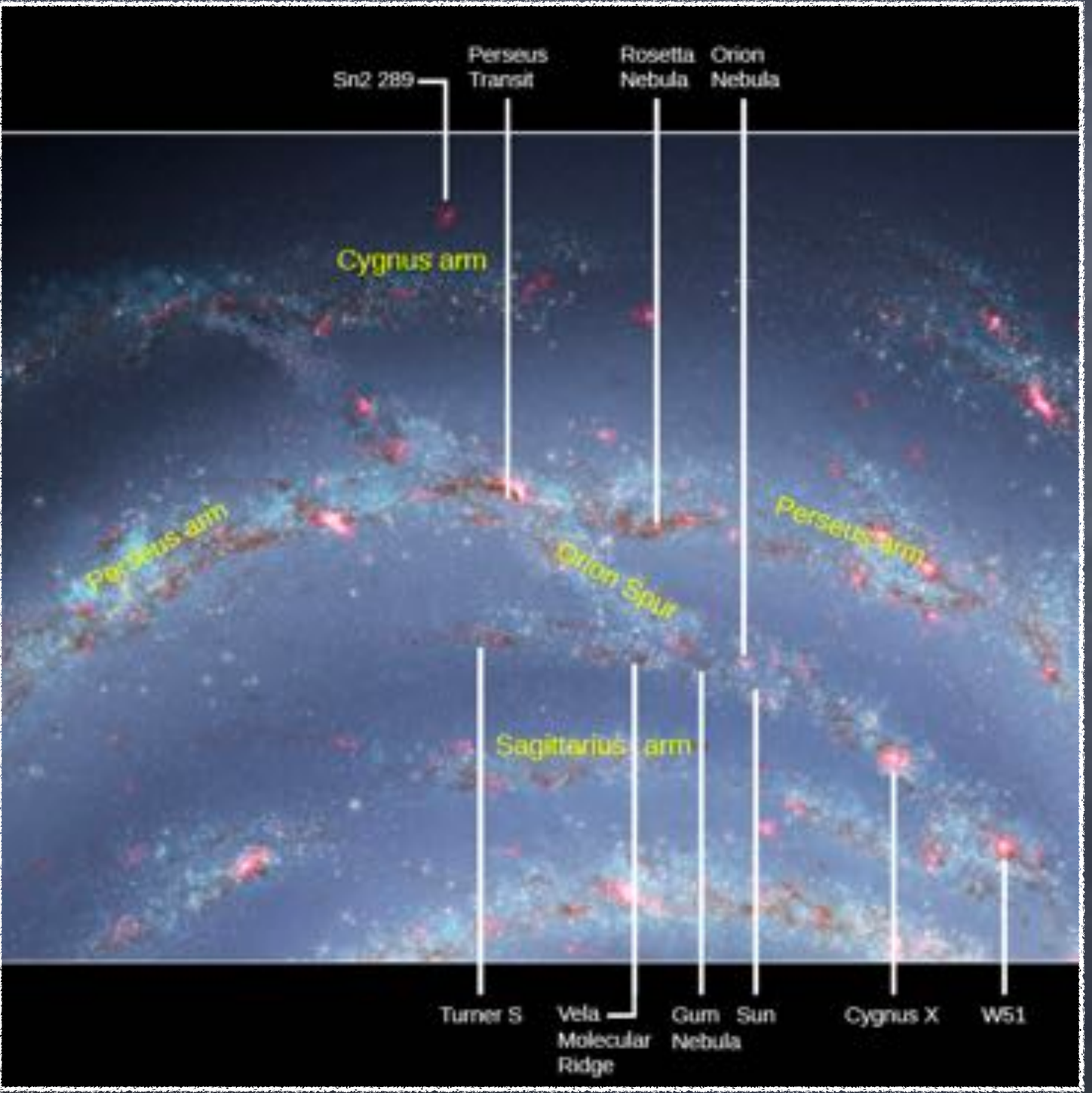
Properties of the Milky Way

Property	Thin Disk	Thick Disk	Stellar Halo
Stellar Mass	4×10^{10} M_{sun}	4×10^{8} M_{sun}	10^{10} M_{sun}
Luminosity	3×10^{10} M_{sun}	3×10^{8} M_{sun}	8×10^{8} L_{sun}
Typical age of stars	1 million to 10 billion years	11 billion years	13 billion years
Heavier elements abundance	High	Intermediate	Very Low
Rotation	High	Intermediate	Very Low

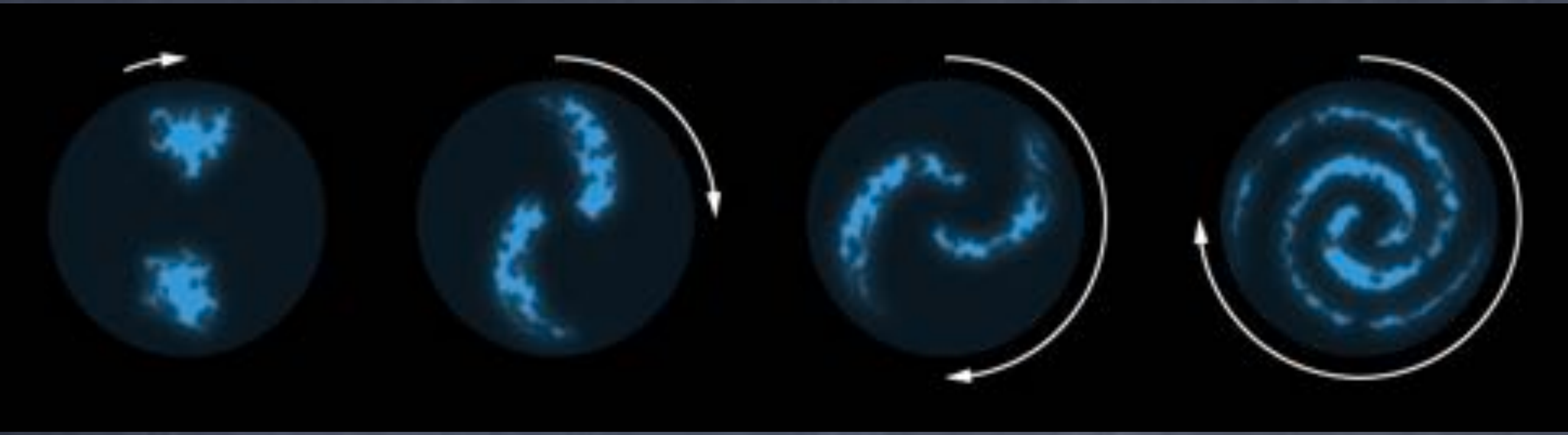
Spiral Arms

- The spiral arms in the Milky Way can best be mapped out in the 21cm line.
- The arms are most pronounced in gas and young stars. In the infrared which looks at all stars they can't really be seen.
- The arms are not a good indicator of the overall mass distribution.





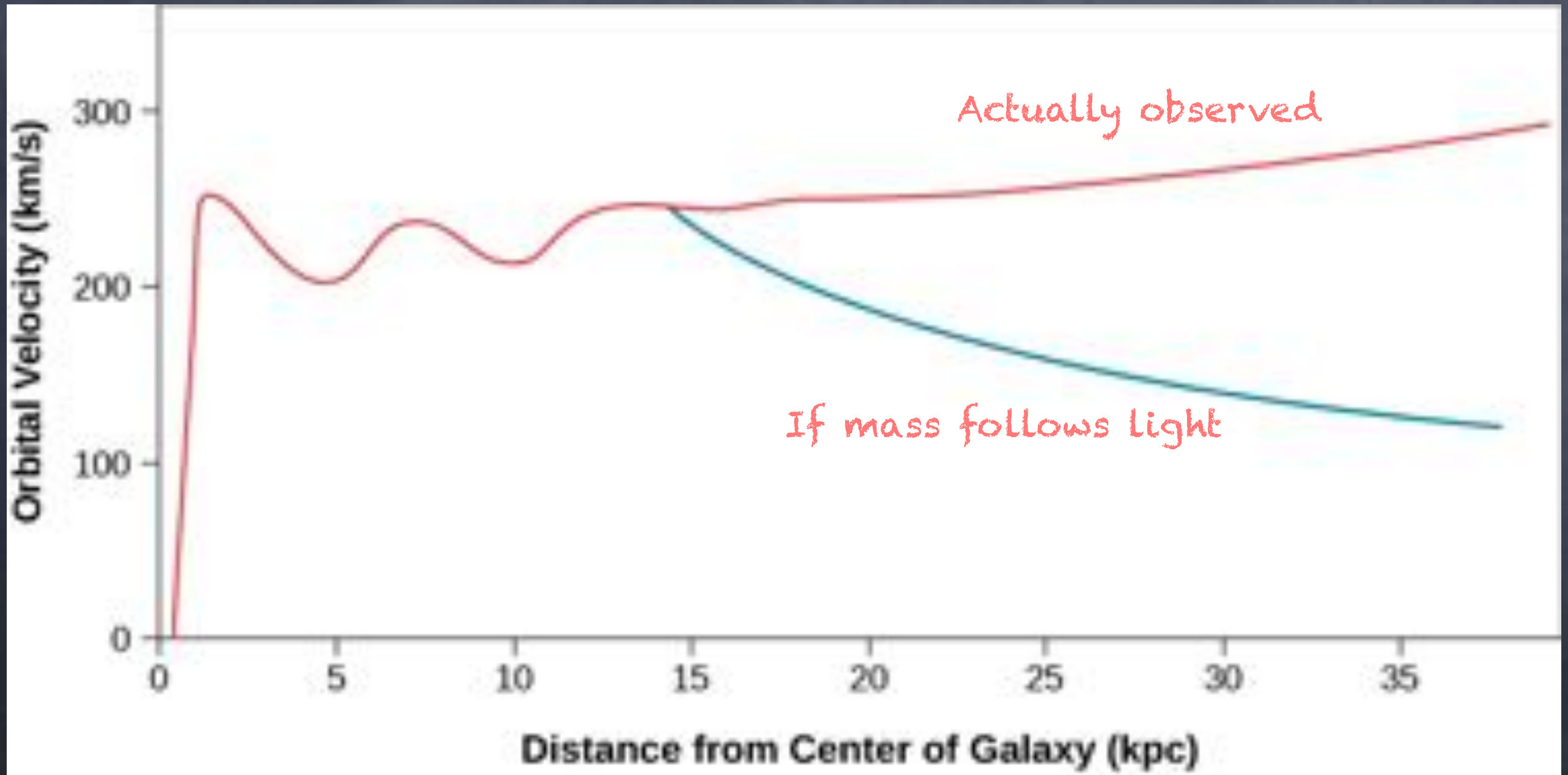
- The Sun is in a short spiral arm called the Orion Spur.
- The spur connects to larger spiral arms.
- This just currently happens to be the Sun's location as the spiral arms and Sun move around over time.



The spiral arms naturally form as an instability in the disk. Differential rotation wraps them up into a spiral. They only form in more massive disk galaxies. Thus they probably only formed a few billion years ago in the Milky Way.

Mass of the Milky Way

- We can measure the mass of a galaxy the same way we measured masses for planets and stars, find something in orbit.
- For a galaxy everything is in orbit so this is pretty easy to do. However, a galaxy is not a single point so we get a rotation curve, which shows the mass enclosed as a function of radius.
- When we compare to the light enclosed we find the surprising result that much of the mass of the galaxy is not visible.


Actually observed
If mass follows light
Orbital Velocity (km/s)
300
200
100
0
0
5
10
15
20
25
30
35
Distance from Center of Galaxy (kpc)

Mass of the Milky Way

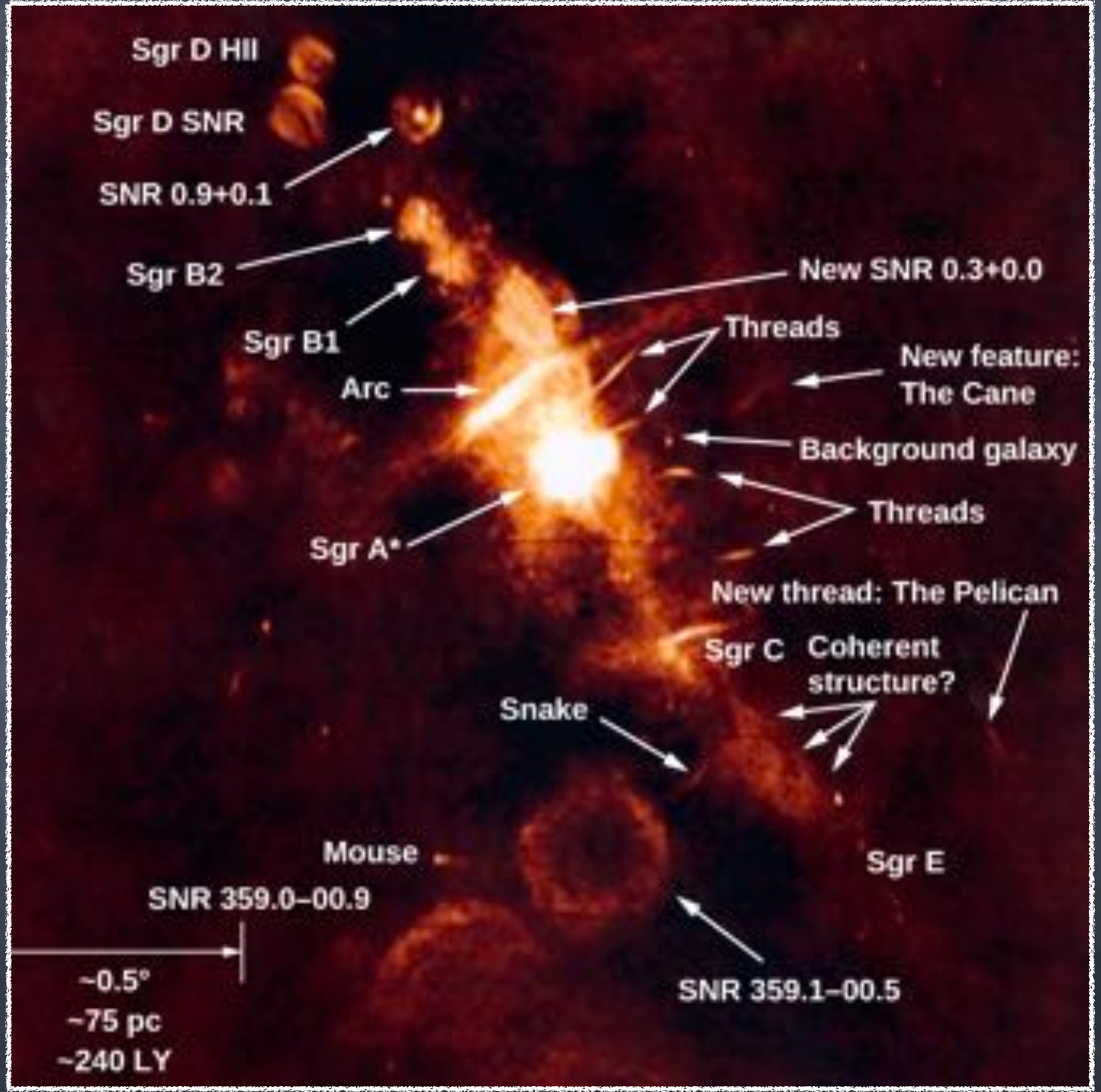
- Studies of the most distant objects orbiting the Milky Way give a mass of 2×10^{12} M_{sun} more than 20 times the mass in stars.
- This extra mass is called dark matter by astronomers which is misleading. It is not dark, it doesn't interact with electromagnetic radiation at all.
- This matter is most likely a different subatomic particle than the ones that are known. Which really means we have little idea of what it may be. But it is 95% of the mass in our own Milky Way.

Center of the Milky Way

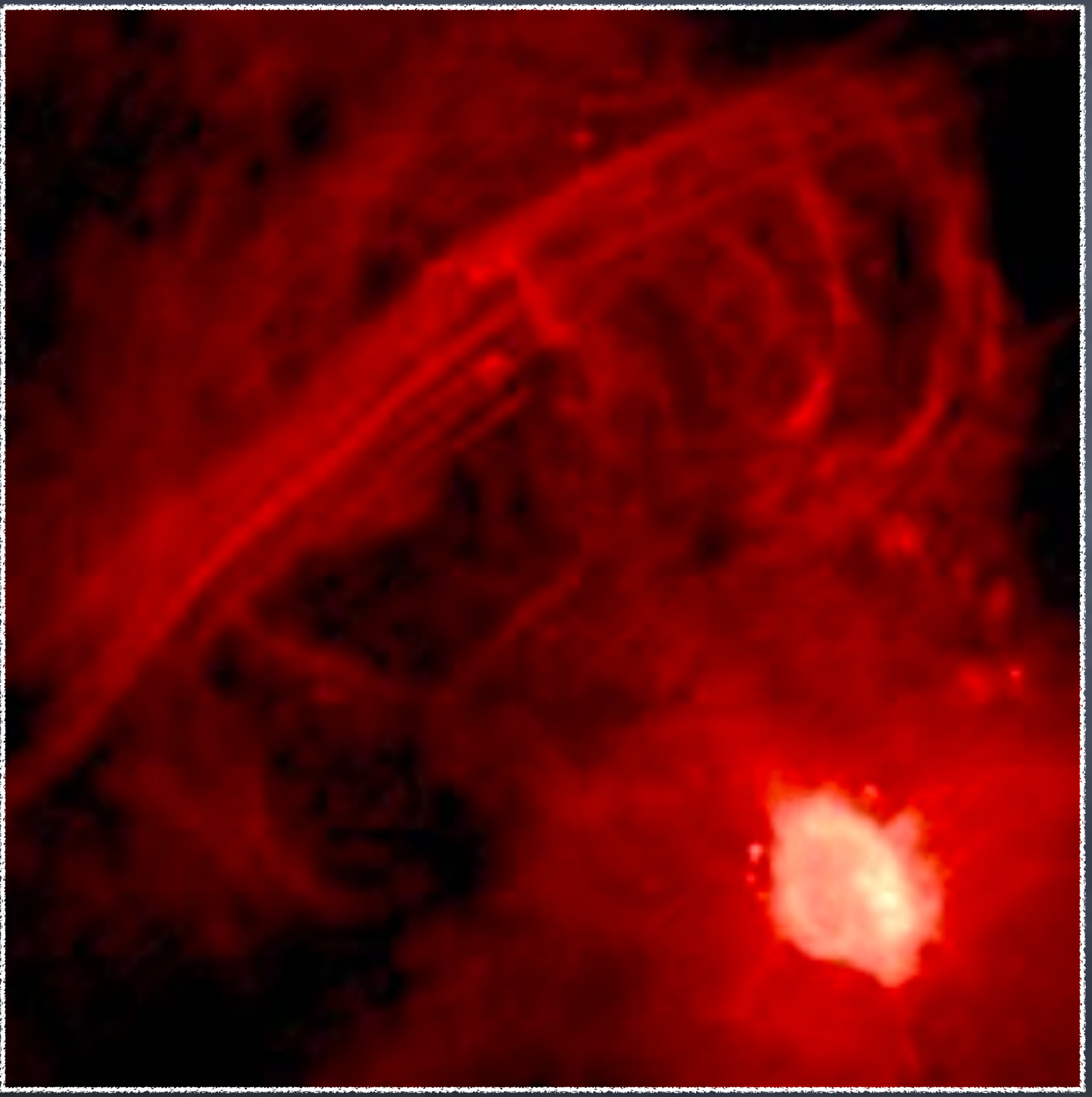
- At the center of the Milky Way lies a supermassive black hole, with a mass 4.6 million times that of the Sun.
- Discovering this black hole was not easy as the area is extremely obscured by dust. Visible light from this region is dimmed by a factor of a trillion.
- However, we can use other wavelengths to study the galactic center.

Sgr A*

- Looking in the radio we see there is plenty going on in the galactic center.
- In particular there is a very bright radio source Sgr A*.
- This radio emission comes from hot gas either heated by young stars or supernova blast waves.
- The thin threads are caused by strong magnetic fields.

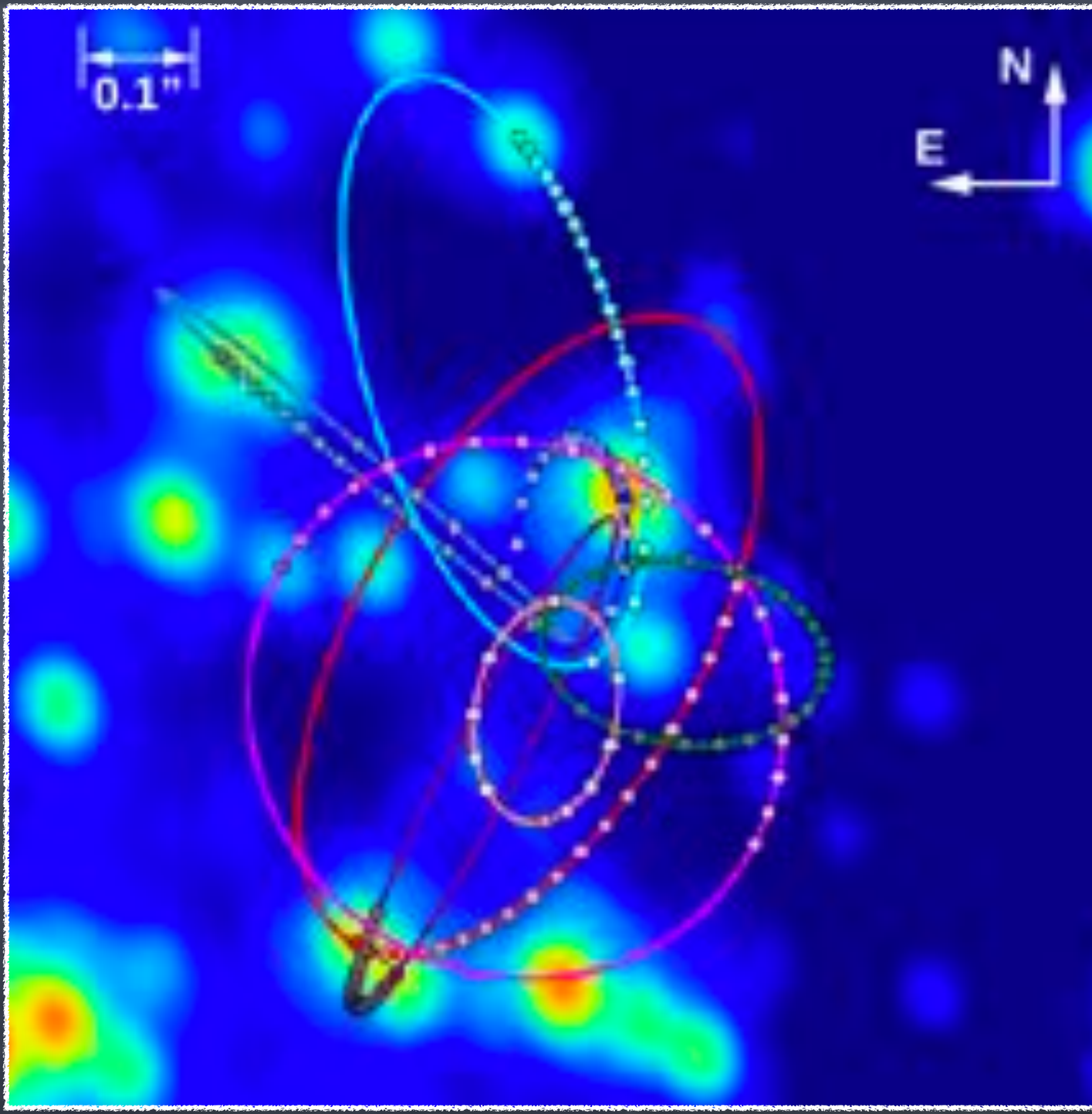


Zooming in and looking in the x-ray we see a lot of emission. The points are compact objects, white dwarfs, neutron stars or black holes. The diffuse 'haze' is gas at 10 million K. The hot gas is flowing away from the center.



- Zooming in even more but back to the radio we see a close up of Sgr A*.
- The rest of the emission is from hot (10 million K) gas.
- We suspect that Sgr A* is a supermassive black hole, because it is small and giving off lots of radiation.
- But to be sure we have to measure its mass.

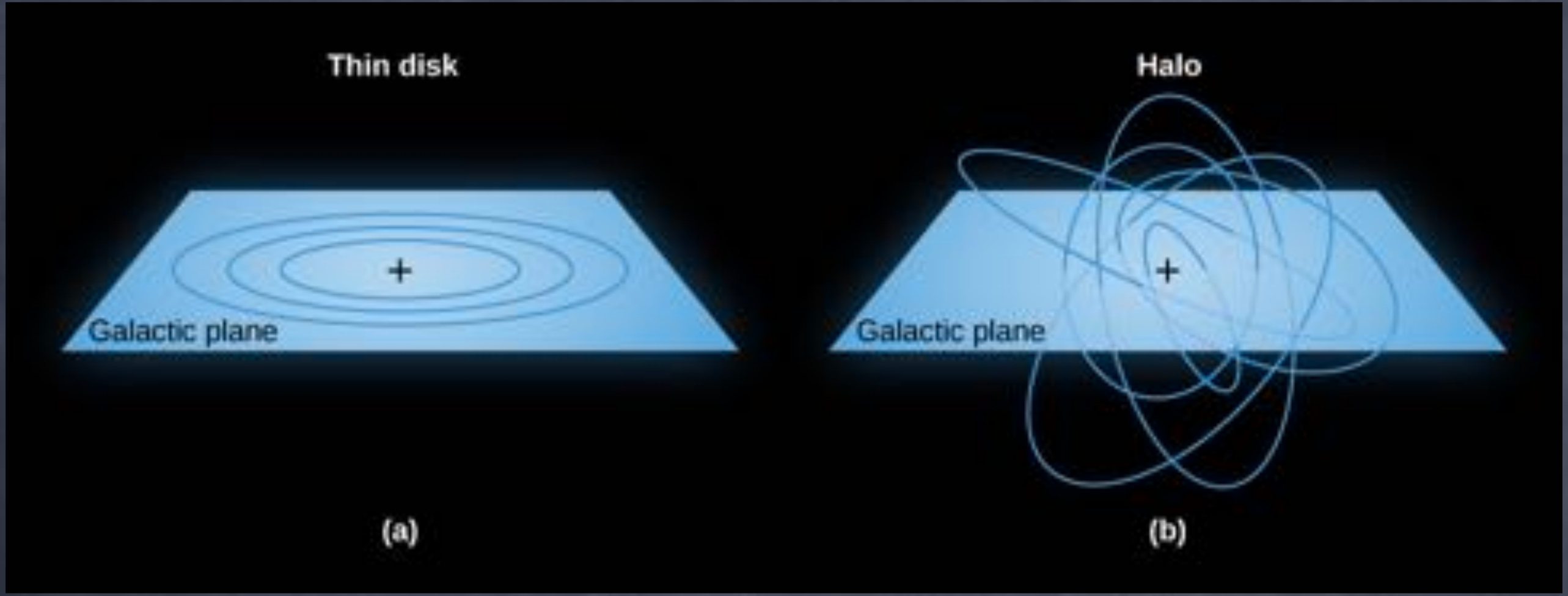
- This has been done by monitoring the motion of stars around the galactic center over many years.
- This must be done in the infrared, these stars can't be seen in visible wavelengths.
- From this we conclude that Sgr A* is a supermassive black hole with a mass of 4.6 million stellar masses.



https://www.youtube.com/watch?v=tMax0KgyZZU

Stellar Populations

- During WWII the astronomer Walter Baade noticed that the stars in our galaxy seemed to be of two different types.
- He cleverly named them population I and population II. Since astronomy never gets rid of bad names that is what they are still called today.
  - pop I - only found in the disk, nearly circular orbits, young stars, bluer, have heavier elements
  - pop II - found throughout the galaxy and in the halo, many on eccentric orbits, globular clusters, older stars, redder, very little heavier elements



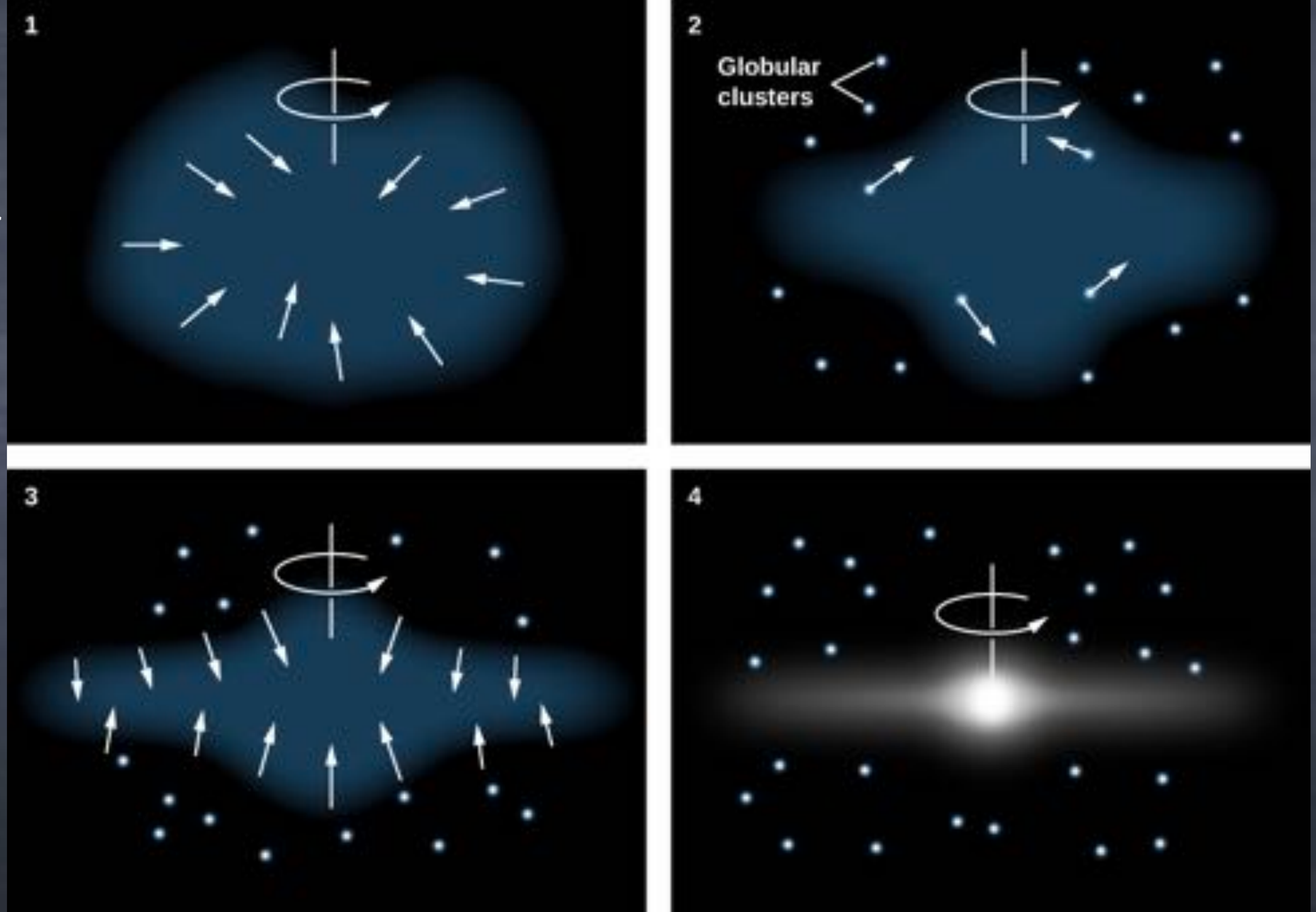
The overall trend is that stars found in the disk are younger, bluer and have more of the heavier elements while stars found in the halo are older, redder and have fewer of the heavier elements.

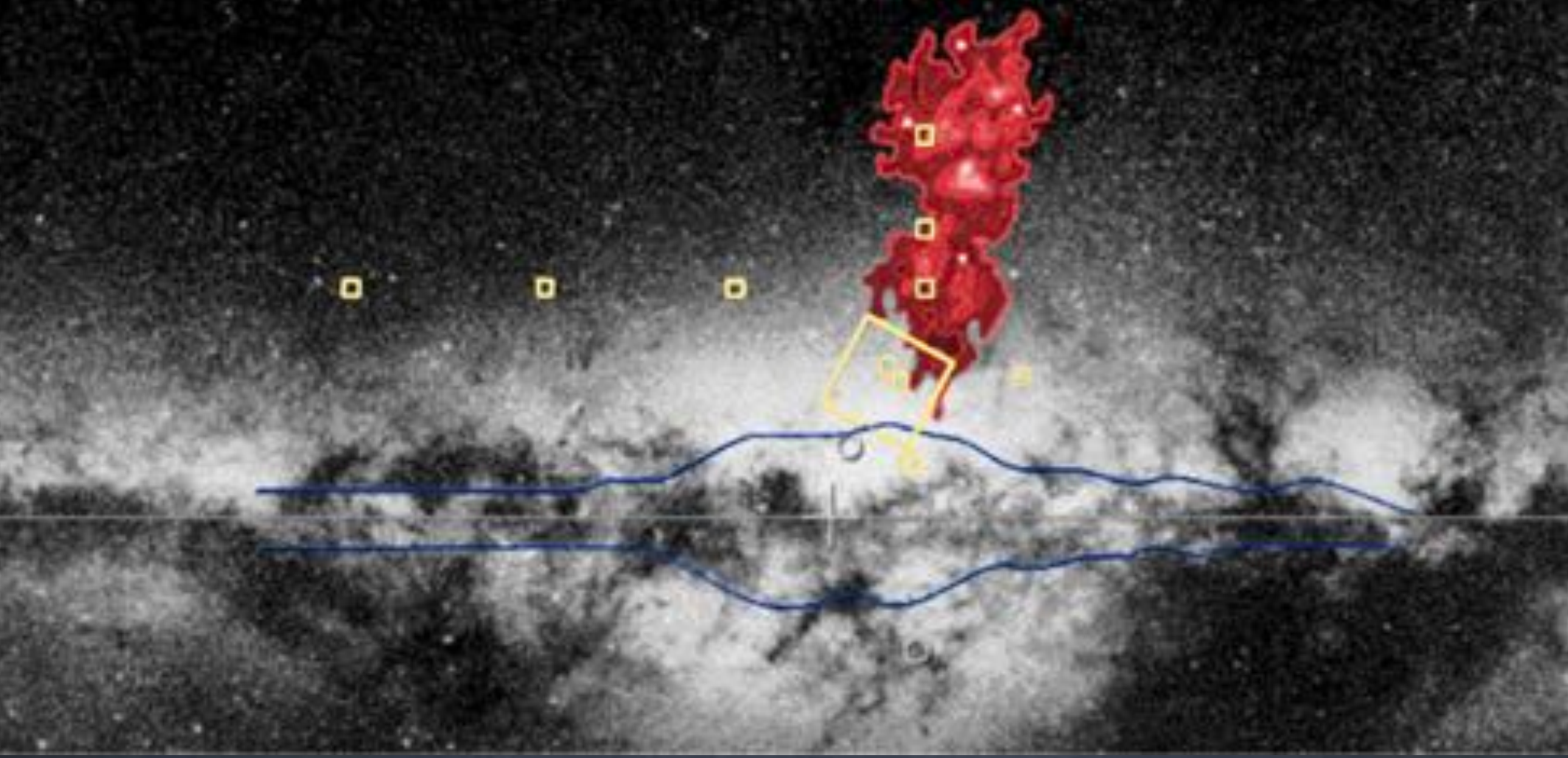
Looking at our nearest large neighbor, the Andromeda Galaxy (M31) we see blue stars at the outer edge of the disk while the majority of stars in the halo are red. The disk itself is obscured by dust so hard to tell, but the bulge is white.

Formation of the Galaxy

- The different stellar populations give us insight into the formation of the Milky Way.
- Stars in the halo, including the globular clusters are the oldest and formed before supernova increased the heavy element abundances in the gas.
- Stars in the disk are the youngest, their gas was enriched and they continue to orbit in a disk.

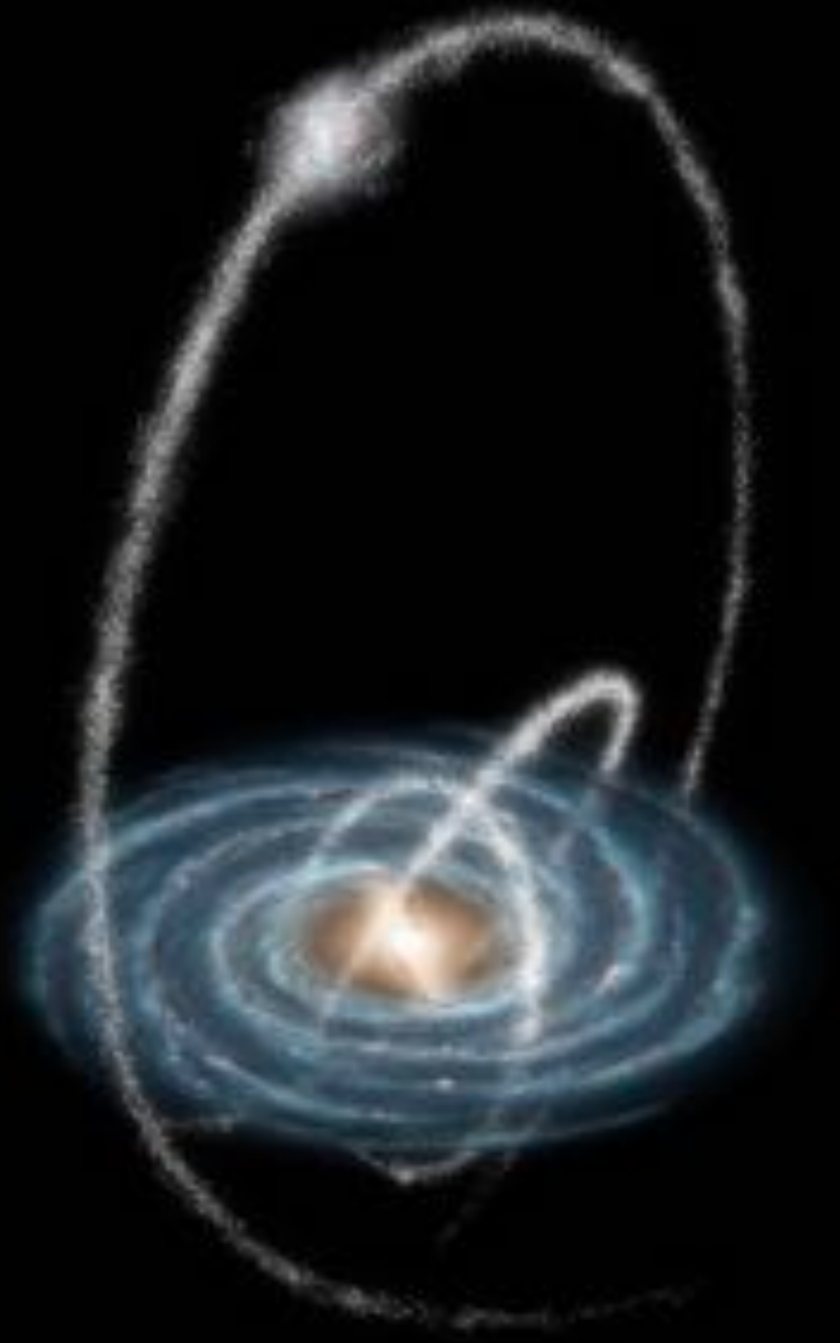
Monolithic collapse is an old model for the formation of the Galaxy where we start with a giant spherical cloud of gas. Stars originally form far away and thus have spherical orbits. The cloud collapses and then rotates. And today young stars form in the disk. However, model is not correct.





That is because we now know the galaxy is built by mergers like the one you see here. The small Sagittarius dwarf galaxy (in red) is merging with the Milky Way.

We now know that much of the stellar halo was formed as stars were stripped from galaxies that merged with the Milky Way.



Globular clusters might be the remnants of long ago mergers, or maybe not. Their origin is still a mystery.

A merger with the Andromeda galaxy is the future for our galaxy. The Milky Way will be gone and the sky will look different, but Earth will probably be just fine.

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