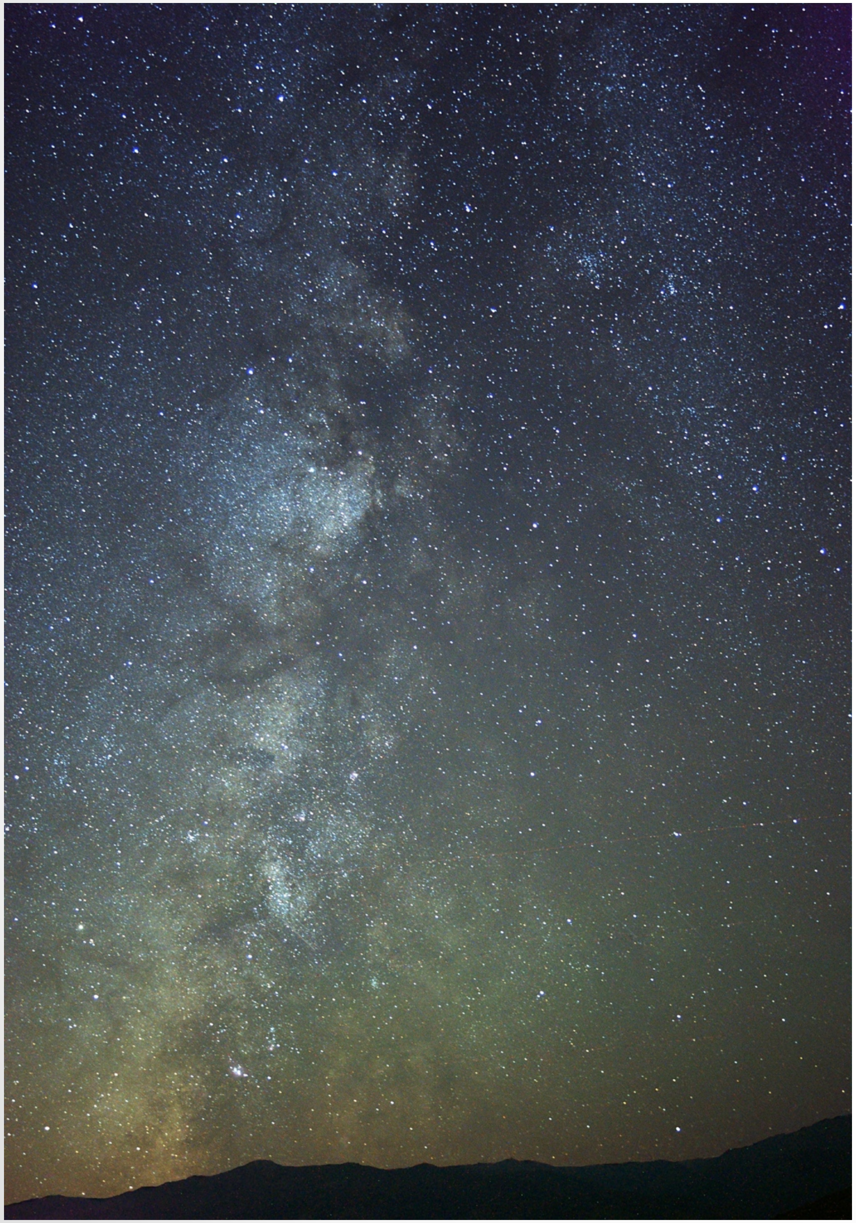
The Milky Way



Latin “via lactea”, similar in other European languages

“Silver River” in Chinese and many other East Asian languages

The “milky” appearance is stars that are unresolved (blended together) by your eyes

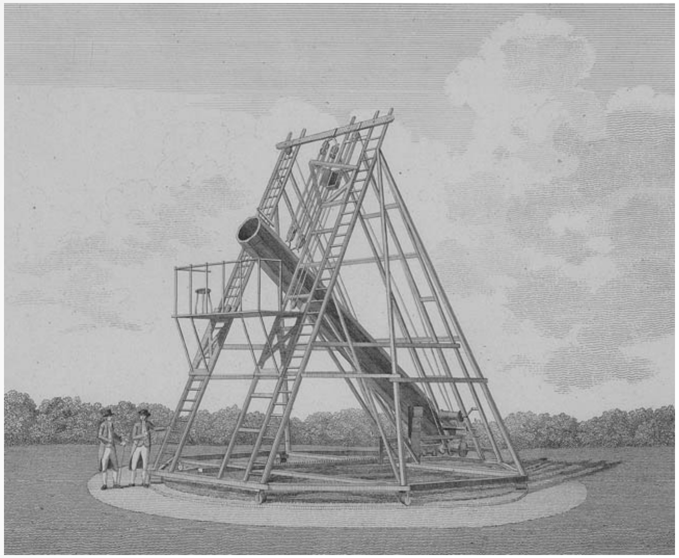
One of the discoveries of Galileo 400 years ago when he first used a telescope to observe the sky was that the Milky Way was resolved into thousands of stars

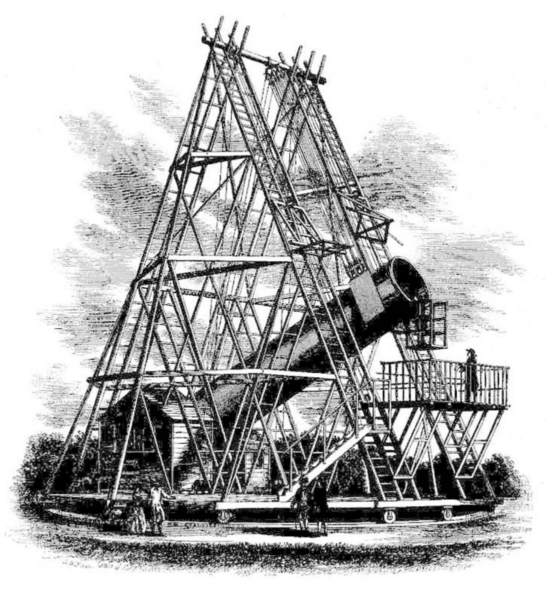
We now know that there are around 10^{11} stars in the Milky Way Galaxy

Short History of Understanding the Milky Way Galaxy

Galileo using his 1" telescope was the first to discover the "Milky Way" was composed of individual stars.

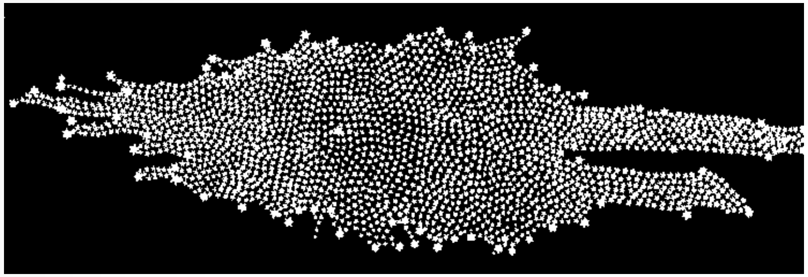
Next 300 years: star counts





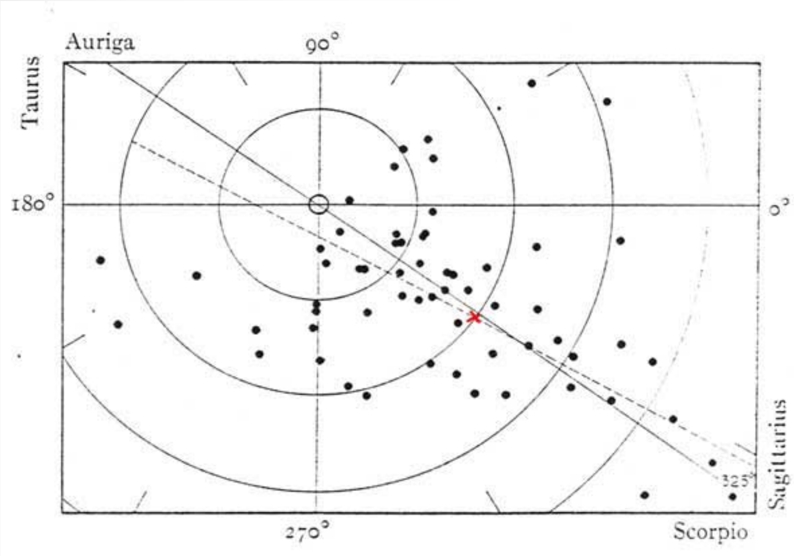
- Star counts were popular and a sense of the stellar system the Sun was a part of started to grow
- But, no knowledge of obscuring dust and no way to get distances to stars

Galactic Model 1781



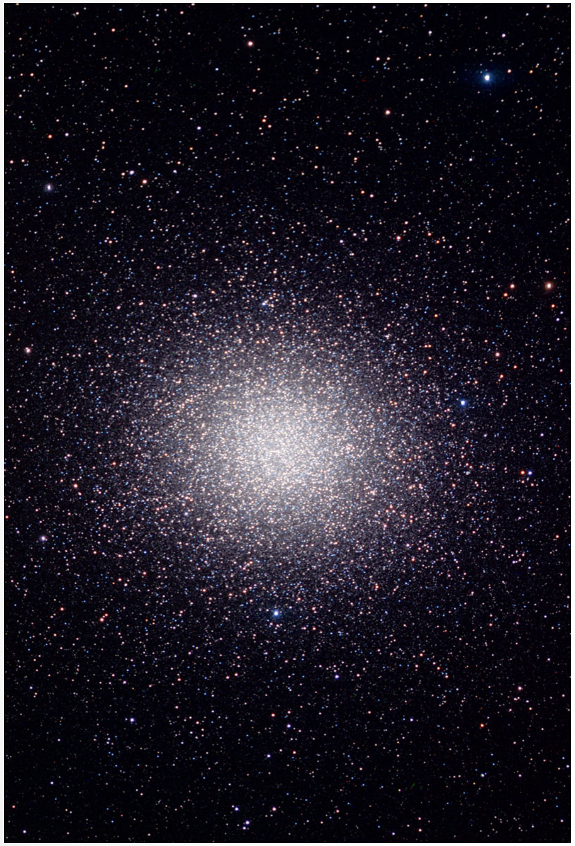
- William and Caroline Herschel built telescopes, observed the sky and made a map of the Galaxy that was the standard for 100 years

Major Progress: 1900-1920



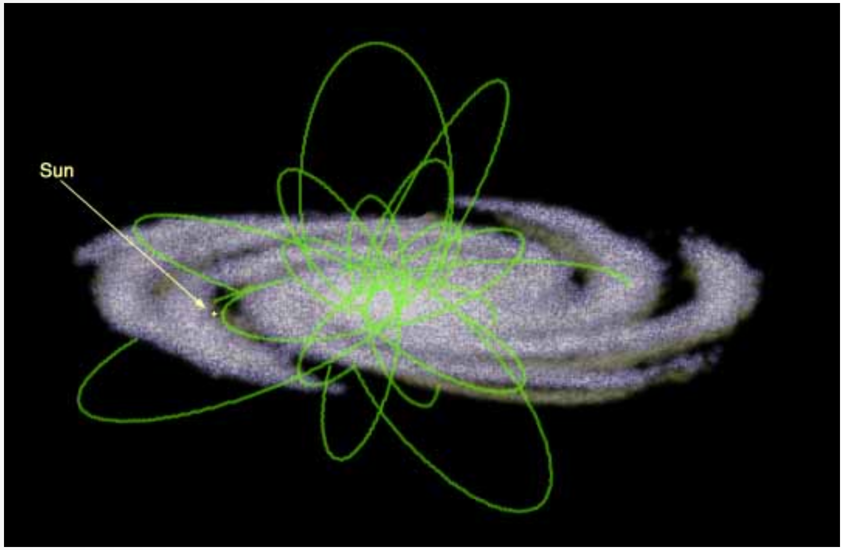
- The distance scale to stars was established via parallax measures and use of variable stars
- The presence of dust was inferred
- Harvard Astronomer Harlow Shapley determined the Galaxy was a factor of 100 larger than previously thought
- The solar system was far from the center

Globular Clusters



- Key to establishing the size of Galaxy was studies of Globular Clusters
- Gravitational bound groups of up to 10^6 stars (very visible)
- 150 in the Galaxy
- Distributed in a large spherical halo around the Galaxy
- Old (12 billion years) and deficient in chemical elements

Globular Clusters



- Distribution is in a halo and the "kinematics" are those of a hot gas
- Low chemical abundances of the stars and "plunging" orbit suggest that the globular clusters were formed very early in the history of the Galaxy

An Obscure Topic: Dust

Early attempts to understand the structure of the Galaxy were challenged by the presence of dust: carbon and silicate grains that block optical light. Preferentially in the disk, bulge and center of the Galaxy.


John P. Gleason
Milky Way Galaxy


Sombrero Galaxy • M104
Hubble Heritage
NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC03-28

Dust in Galaxies

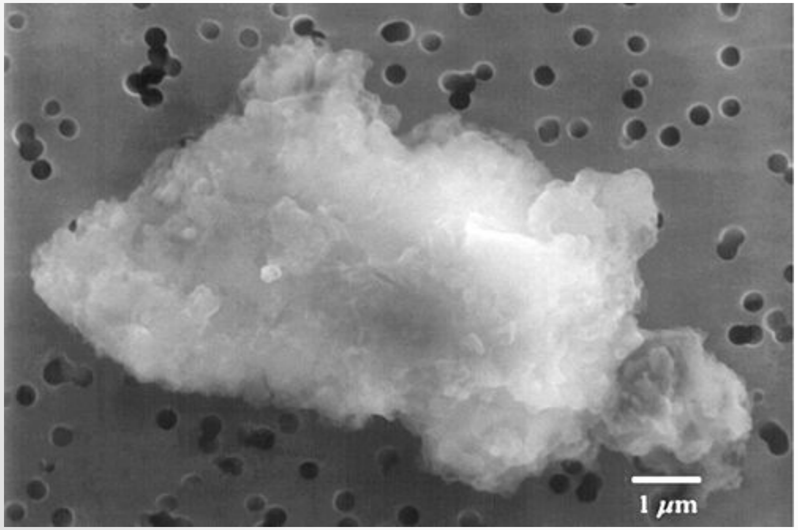
Dust grains are much larger than molecules or atoms: 0.1 - 10 microns.
About the same size as the wavelengths of visible light: your eyes see best at wavelengths near 0.5 microns.

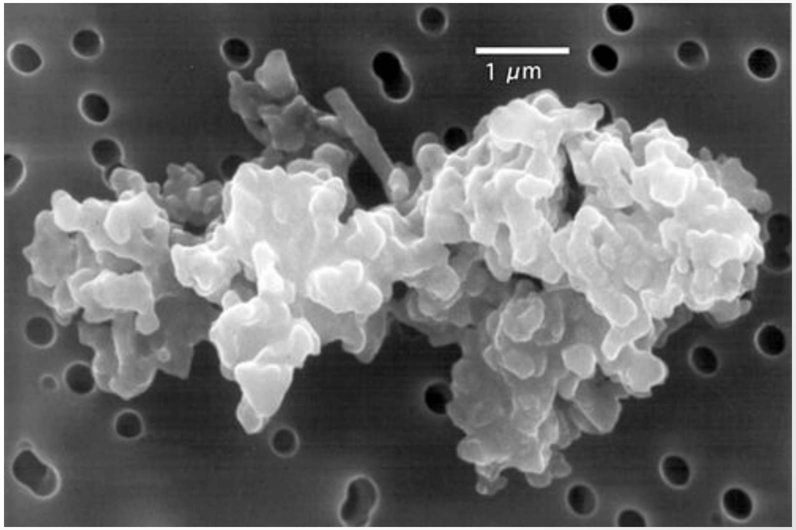
Dust grains are opaque and dense, so they absorb radiation.

Dust grains absorb light best if its wavelength is smaller than the dust.

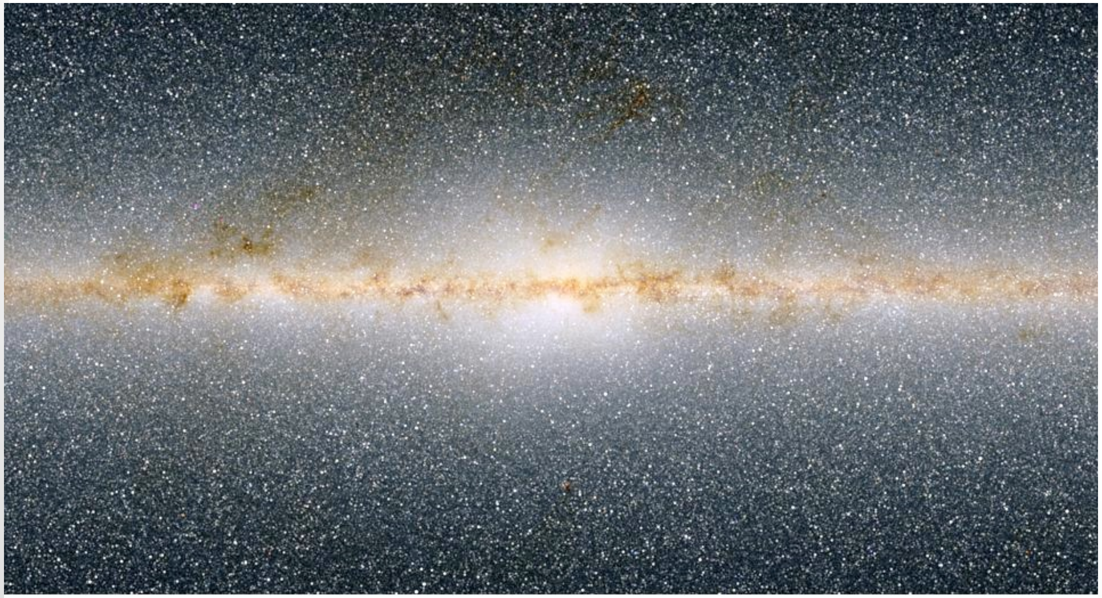
→ Light with shorter wavelengths (bluer) absorbed better

→ Dust blocks visible light. Dust blocks blue light the most.





Central part of the Milky Way in visible light



Same central part of the Milky Way in IR light. Note how much less the dust affects the image.

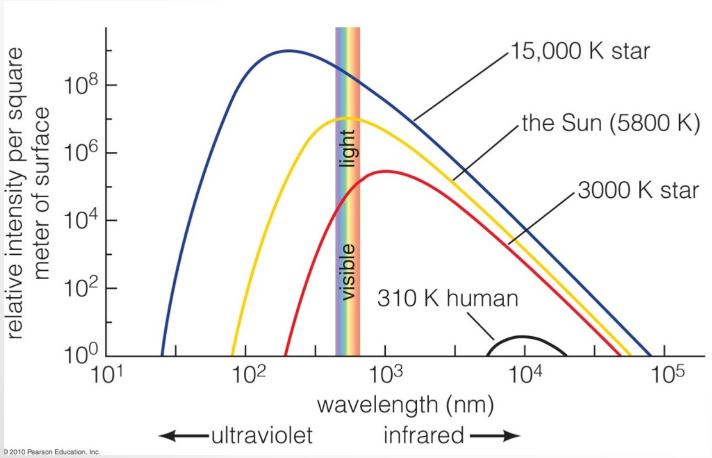
Dust and radiation

Energetic blue photons absorbed by dust and heat it. But dust grains are (relatively) big, with many atoms. A few blue photons doesn't add all that much kinetic energy (= heat)

Most dust is cool: the dust re-radiates the energy at longer (redder) wavelengths.

Even though dust is only about 1% of the interstellar medium of the Galaxy, it has a large effect

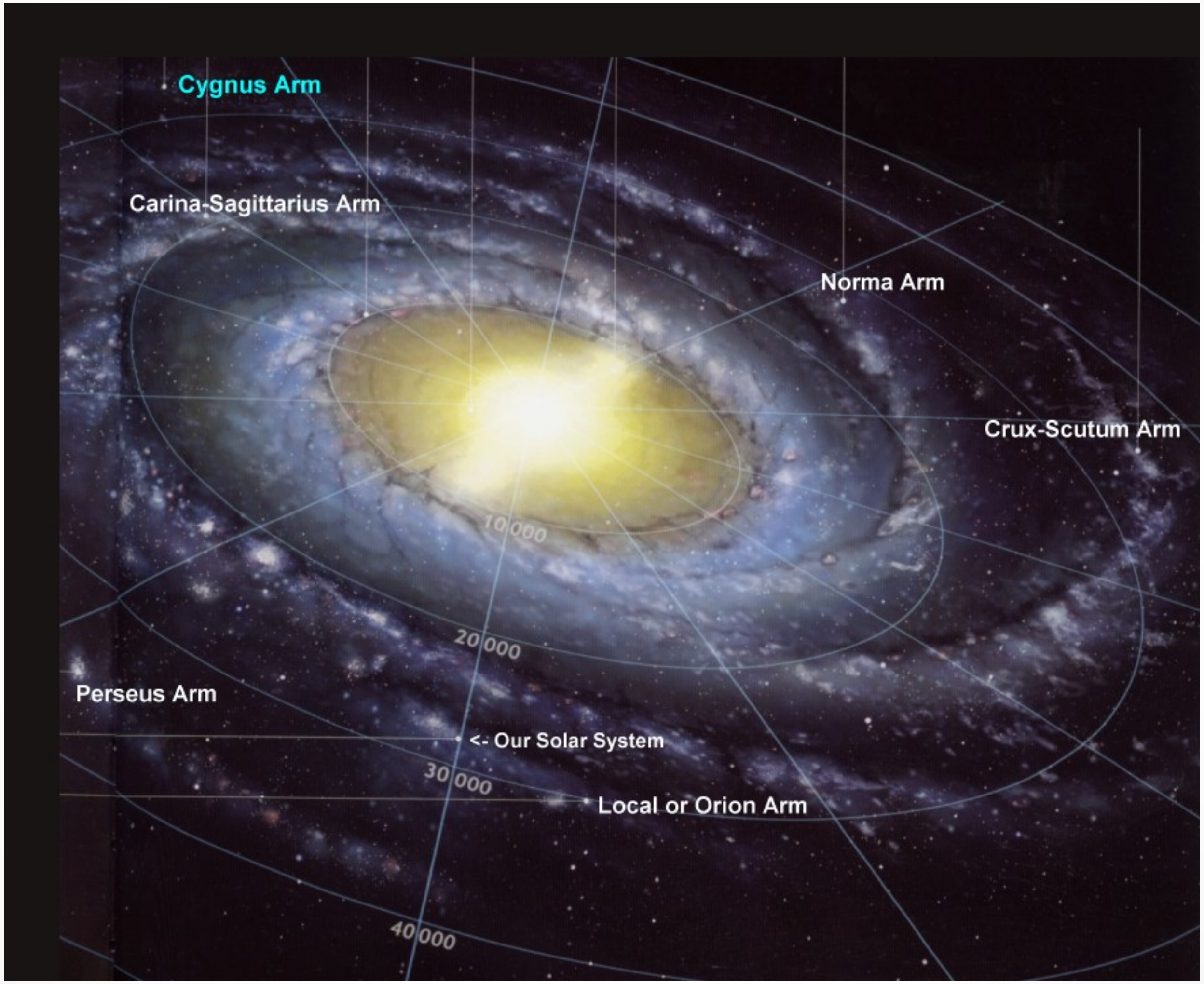
Remember Wein's law: peak wavelength depends on temperature.



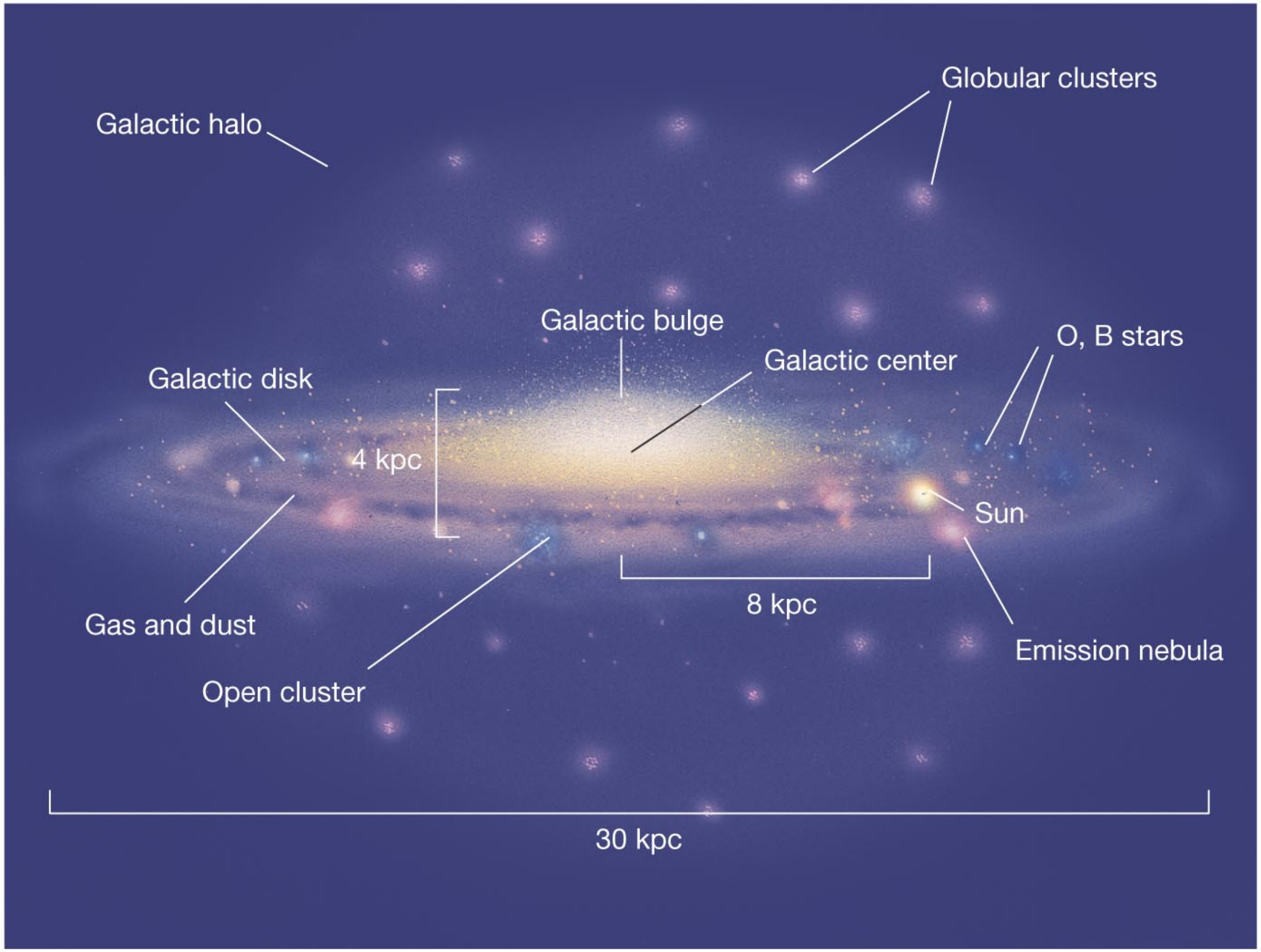
Milky Way Galaxy

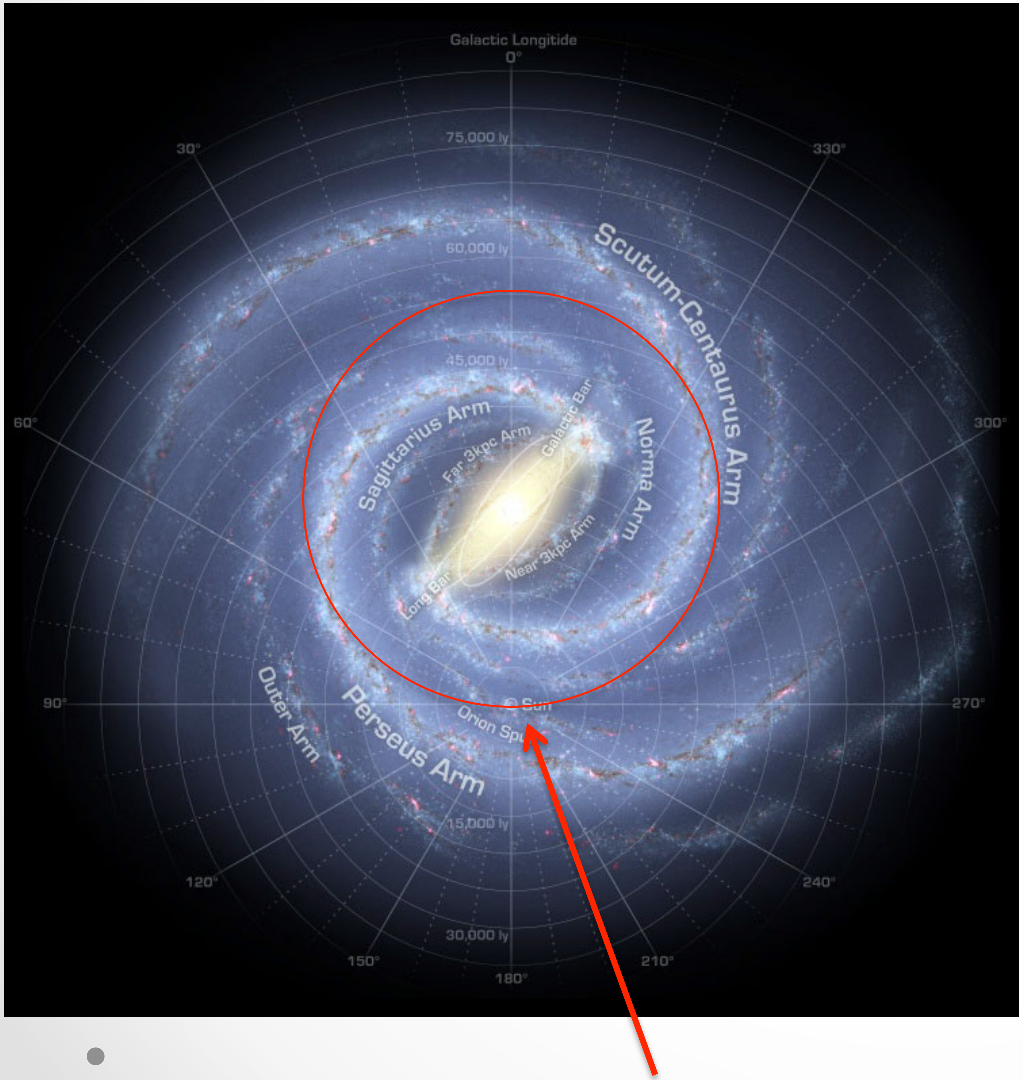
Stars	3×10^{11}
Planets	4×10^{11}
Gas	20% by mass
Disk diameter	120,000 LY
Age	12.5×10^{9} years

Milky Way Galaxy Structure



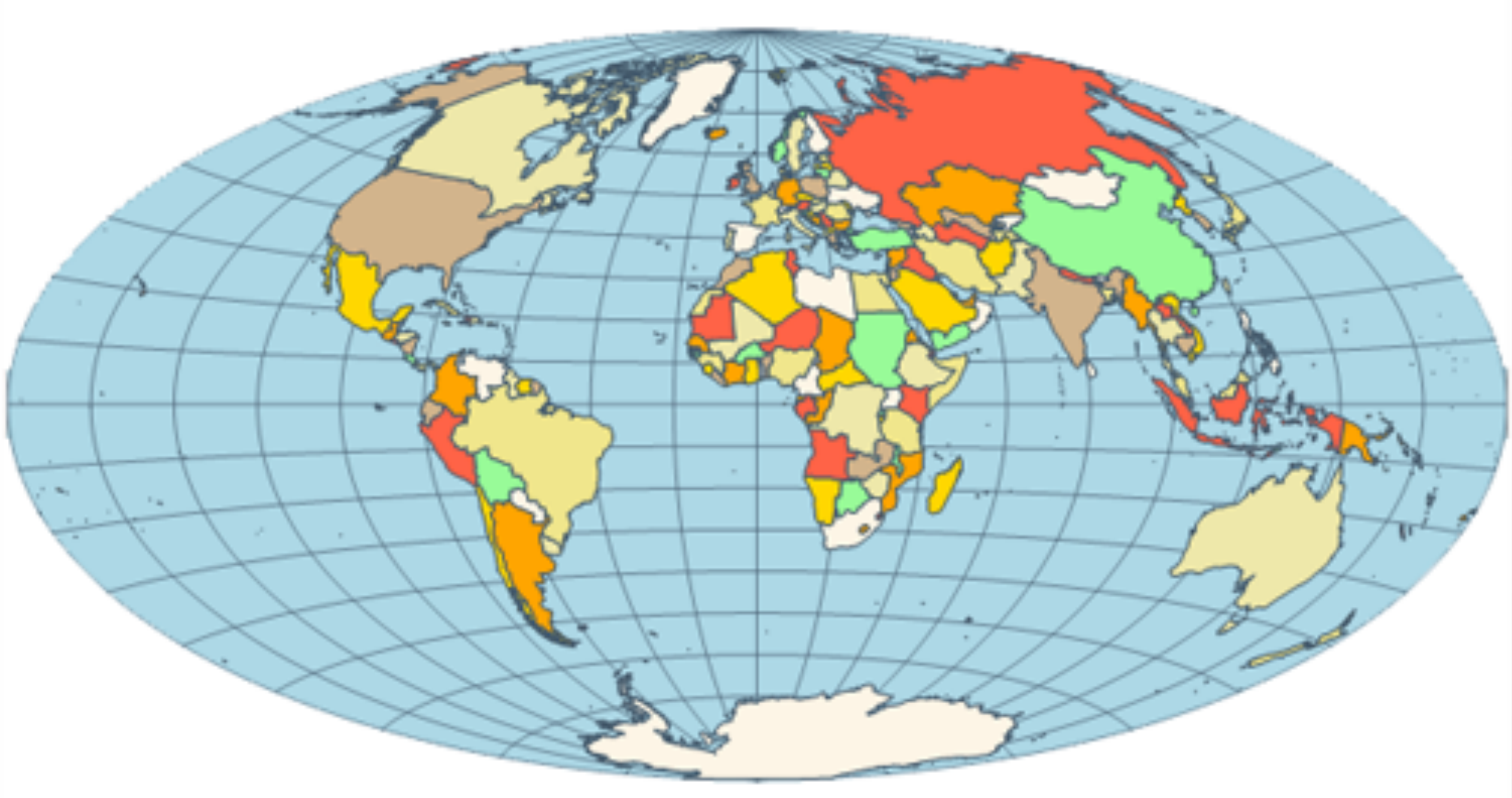
Milky Way Structure II





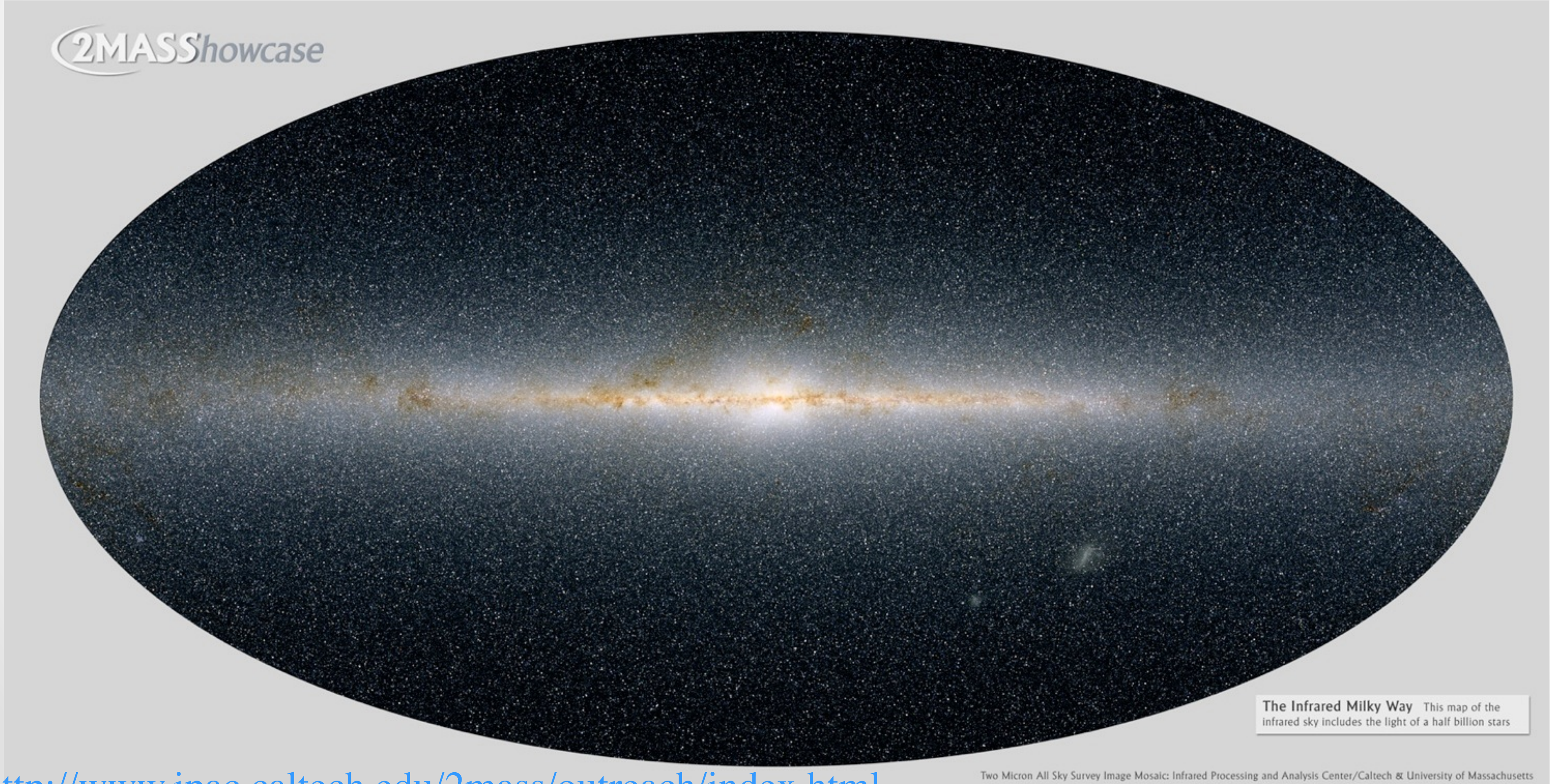
- The Sun is in the Galactic disk and orbits the center of the Galaxy once every 240 million years
- 220 km/second wrt the Galactic Center
- Interesting question: why don't the arms wind up tightly after just a few rotation periods?

Aitoff projection: “unwrapping” a sphere to show its entire surface on a flat plane (like a piece of paper or a projector)



The Milky Way Galaxy: infrared view

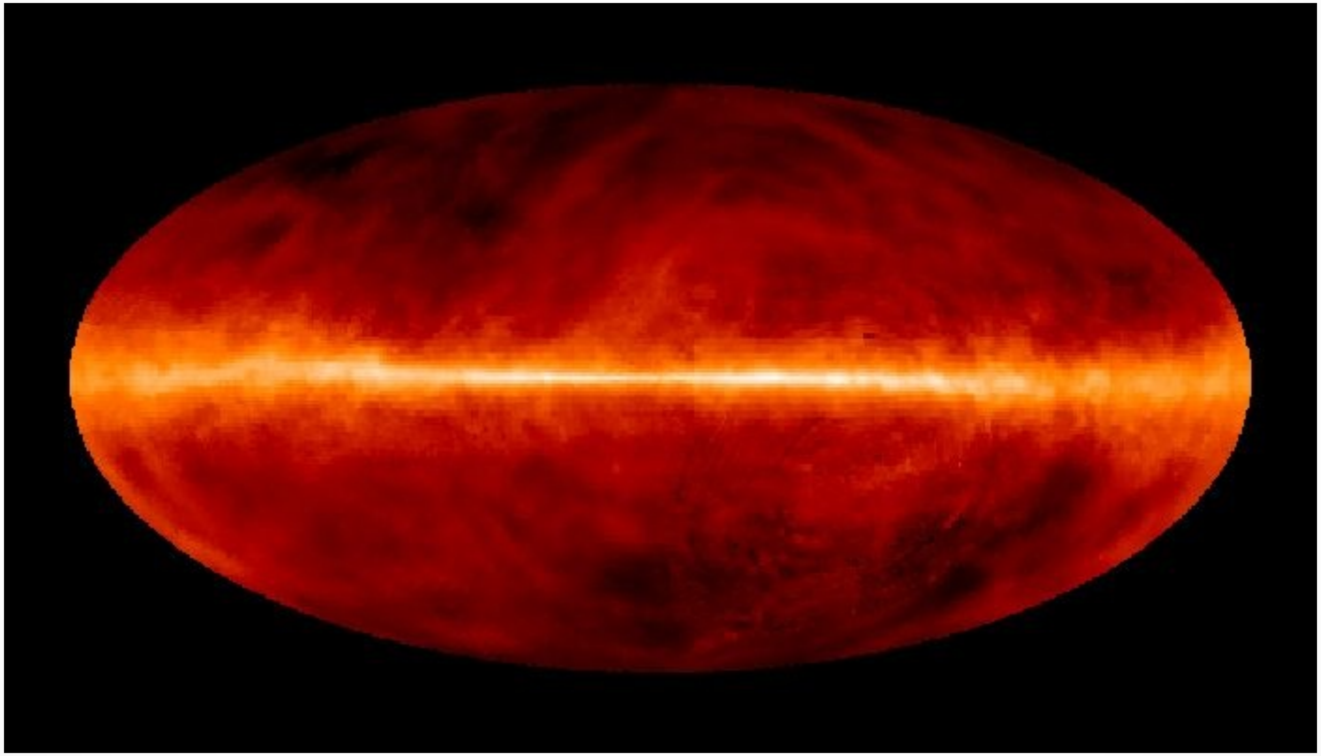
Aitoff projection, from the 2MASS survey. A map made from real data! Images taken at wavelengths 1-2.2 microns.



http://www.ipac.caltech.edu/2mass/outreach/index.html

The Milky Way: Gas Content

Map (Aitoff projection) of emission from H atoms in the Galaxy
Brightness = gas density



Spread through space, far from most stars. So very cold: not a lot of energy input from stars.

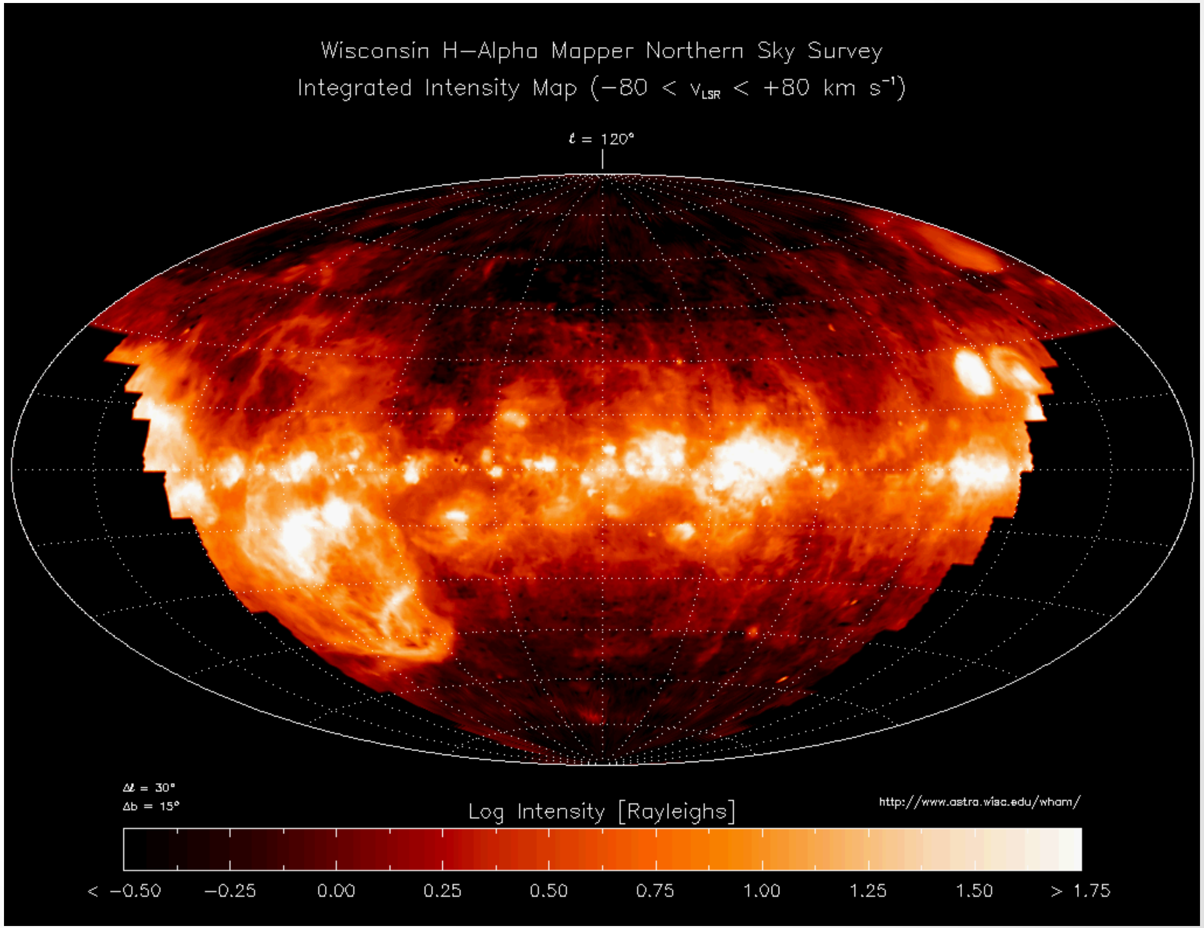
Wavelength of emission is 21 cm, frequency 1420 MHz

Gas is transparent, get emission line spectrum.

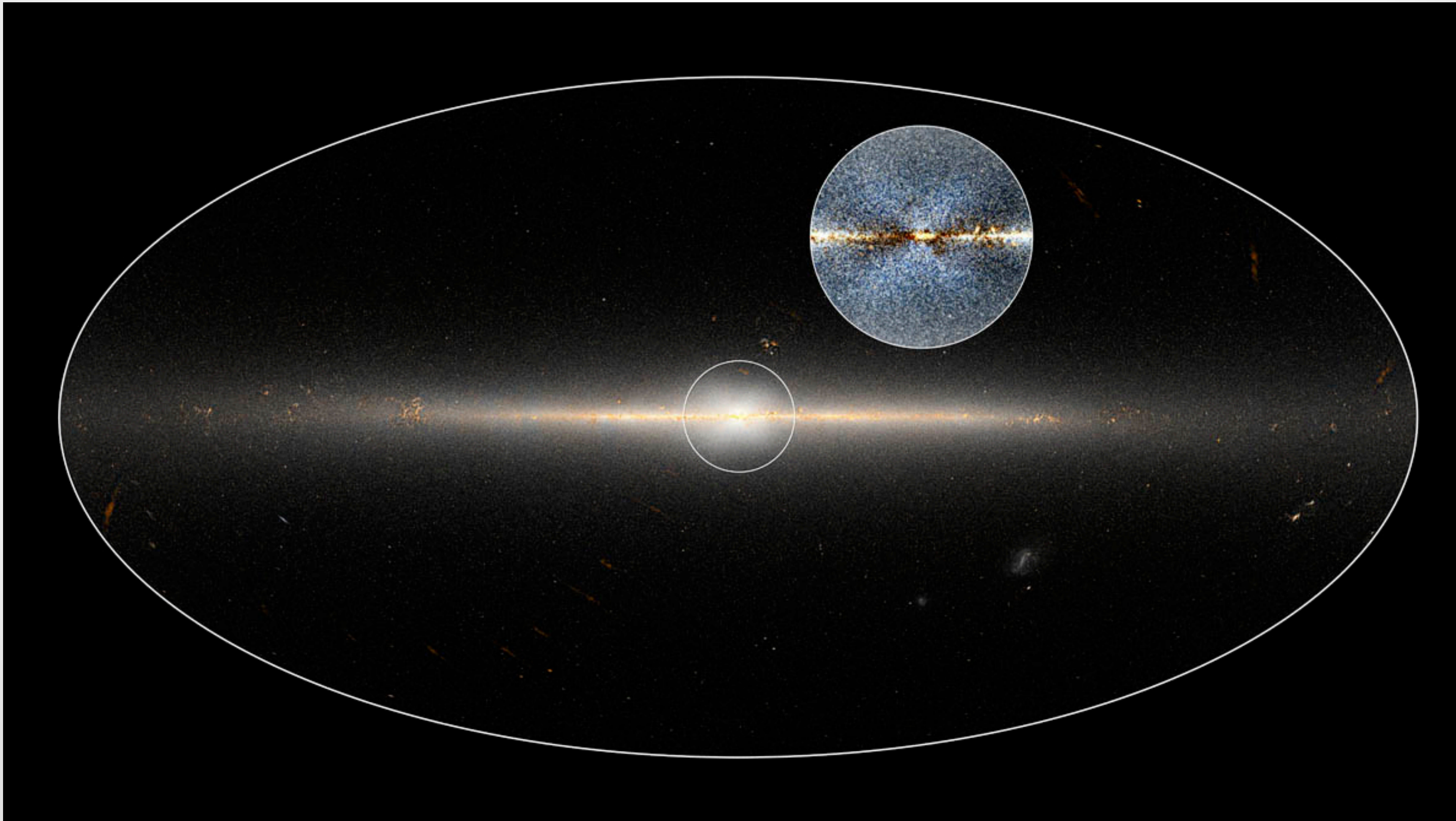
Map (Aitoff projection) of emission from ionized H atoms.
These are atoms that were illuminated with very energetic photons.
Enough energy to overcome the electromagnetic force that holds the electron and proton together to make an H atom.

Where to do photons that energetic come from? What color are those photons? What makes photons that energetic?

Hot, transparent gas:
temperature 10,000 K



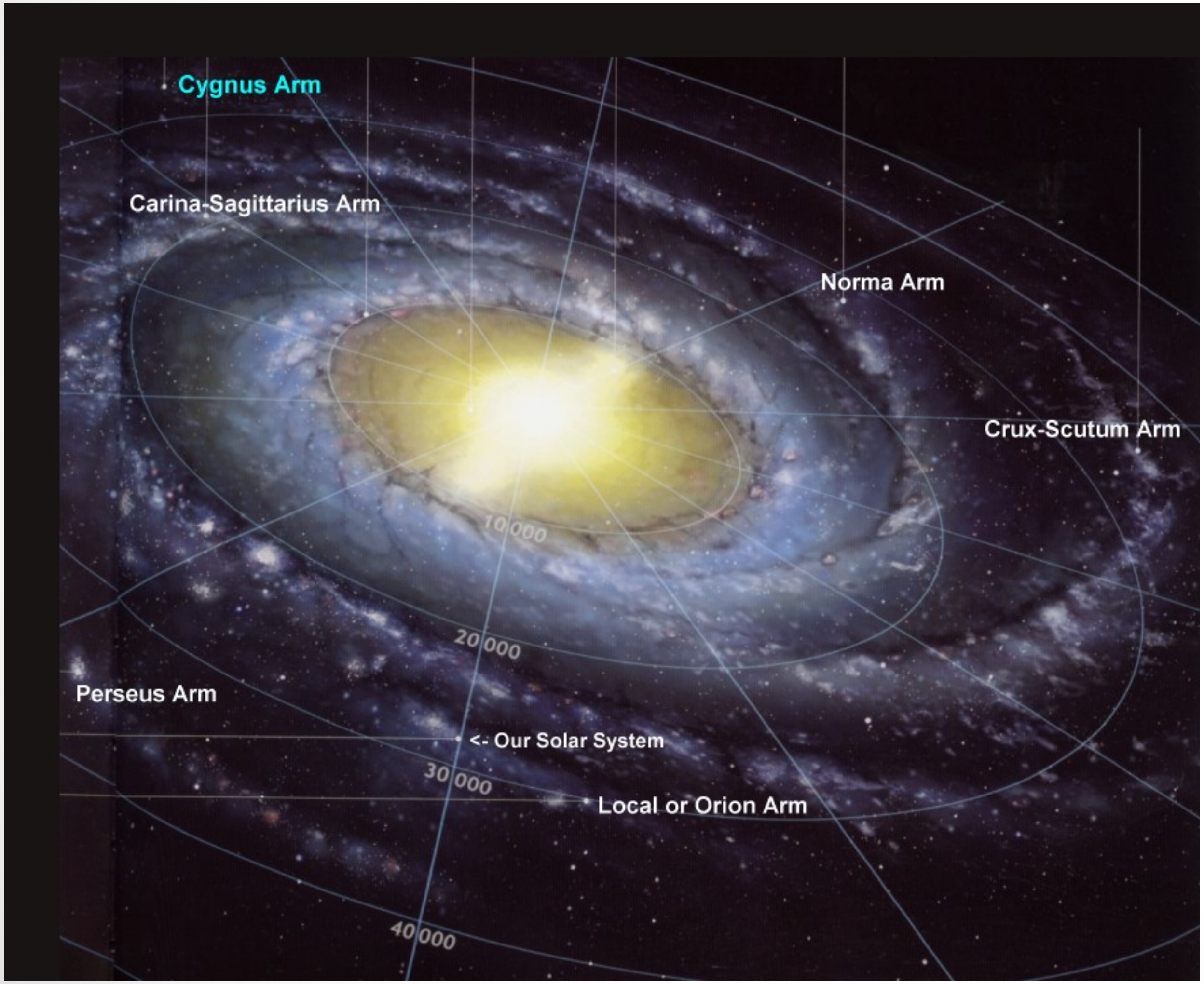
Galaxy disk



Galaxy disk

- Flattened and very thin compared to its diameter or the halo of the galaxy
  - Diameter of the disk: 100,000 light-years
  - “thickness” of the disk ~300-1000 light-years
- Contains most of the Galaxy’s:
  - Cool gas
  - Dust
  - Young stars

Milky Way Galaxy Disk

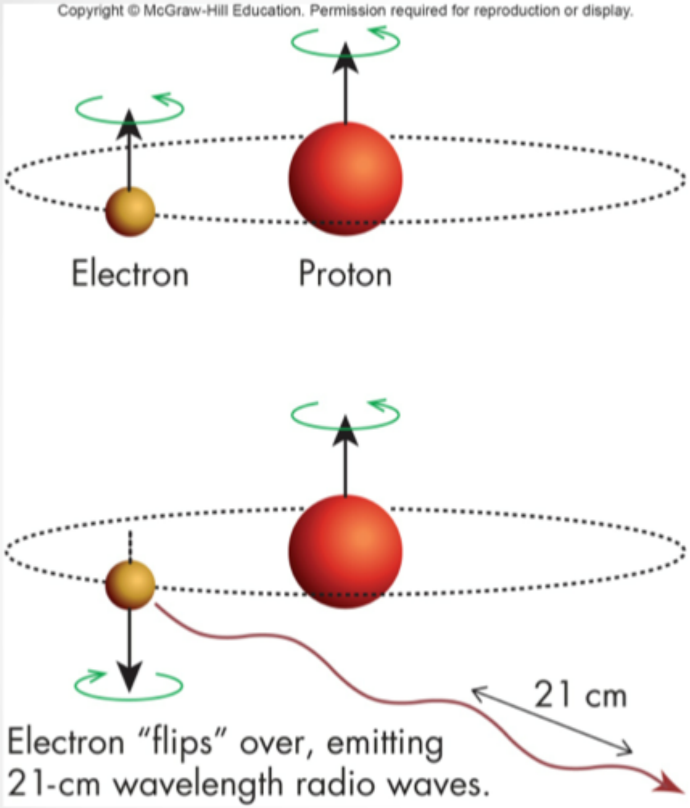


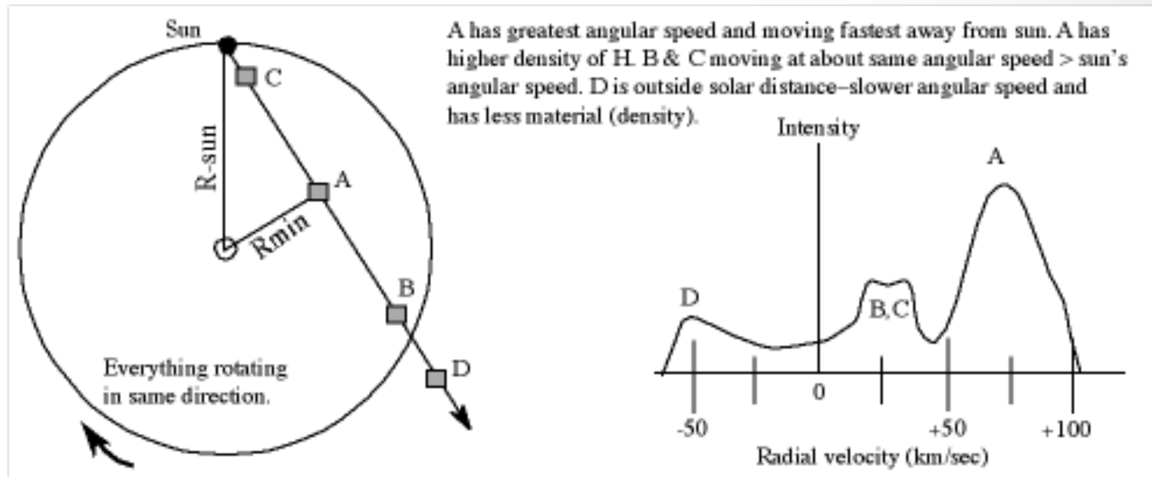
The spiral arms are contained in the disk

It is not so easy to know that

Because all the dust is in the plane it makes it hard to count stars as a function of distance even at infrared wavelengths

Hydrogen atom
1 proton, 1 electron

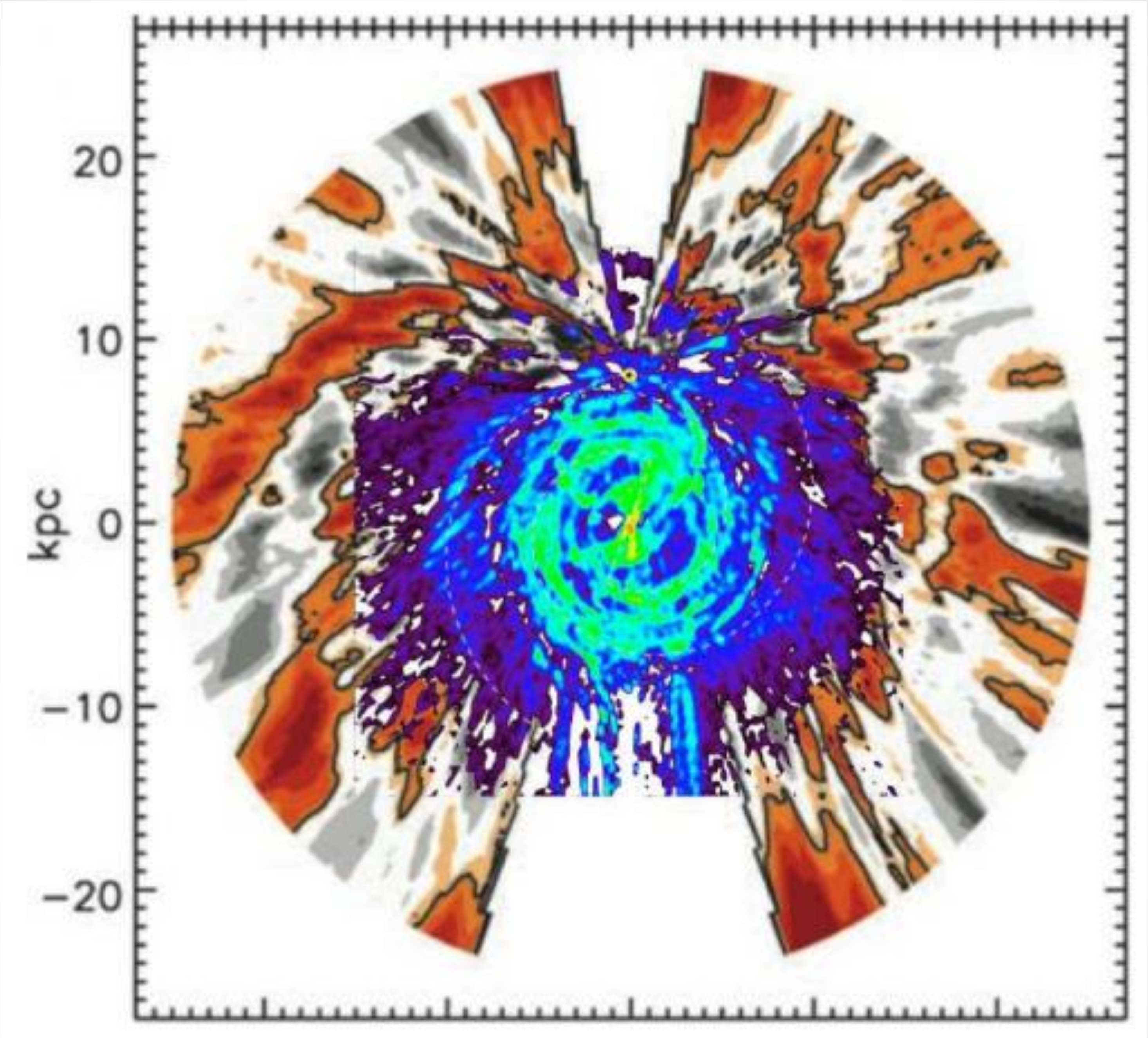




Four clouds all in the same direction. Use doppler shifts to distinguish one cloud from the other. Use the rotation curve to convert the doppler shifts of each cloud to distances from the center of the Galaxy. Do this for other directions to build up a map of the Galaxy strip by strip.

Get an emission-line spectrum from cool hydrogen

use Doppler shift to measure speed of gas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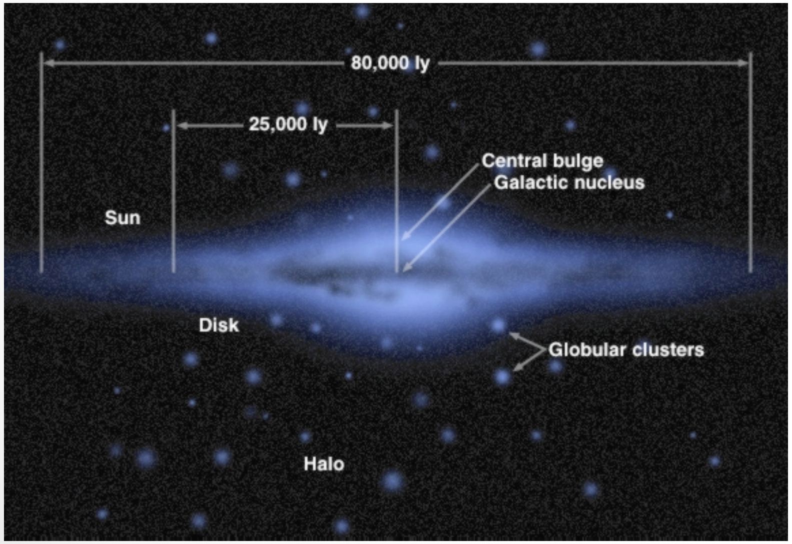
Galactic Bulge



- There is another major component of the Galaxy which is called the Galactic Bulge.
- Also composed of old (12 billion years old) stars, but in the case of the bulge, primarily the same chemical abundances for stars as the Sun

Galactic Halo

- Disk and spiral arms are embedded in the halo
- Componets of the halo are ndividual stars with large space motions and low chemical abundances
- Globular clusters
- Dwarf galaxies

Galactic Halo

- Globular Clusters are collections of up to millions of stars all gravitationally bound to the cluster and orbiting the Galaxy
- Dwarf galaxies are similar in many was to the globulars
- All the evidence is that the stars in the Halo or old: 12 billion years or so.

The Dwarfs

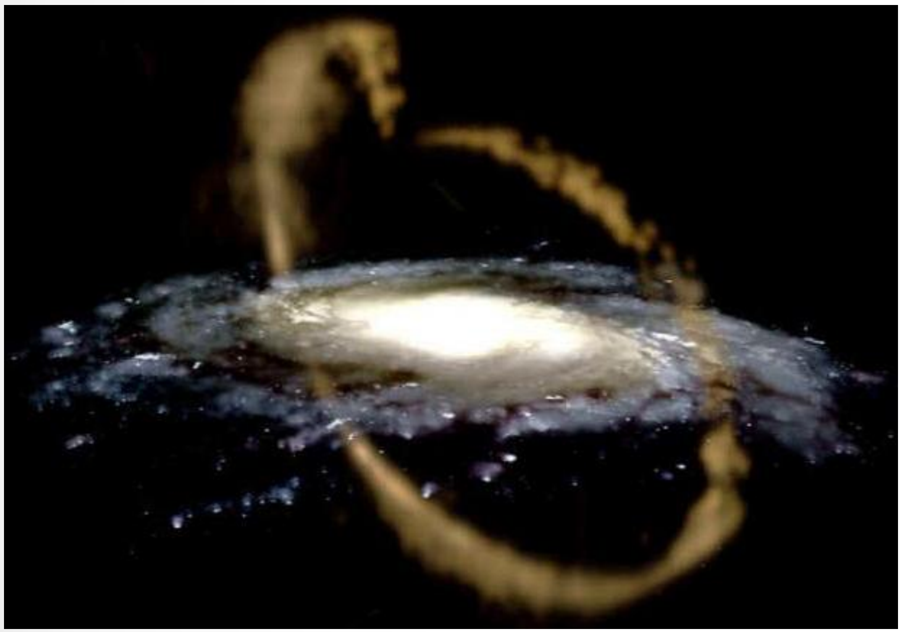
- There are 47 (and counting) dwarf galaxy companions to the Galaxy
- A few contain gas and are still forming stars
- Most are very faint, low luminosity, contain little or no gas and are composed of old stars

- Large and Small Magellanic Clouds are nearby Dwarf Irregular galaxies
- LMC is ~1/100th the mass of the Galaxy
- ~160,000 light-years distant
- Contains gas, young stars, old stars

Dwarf Spheroidals

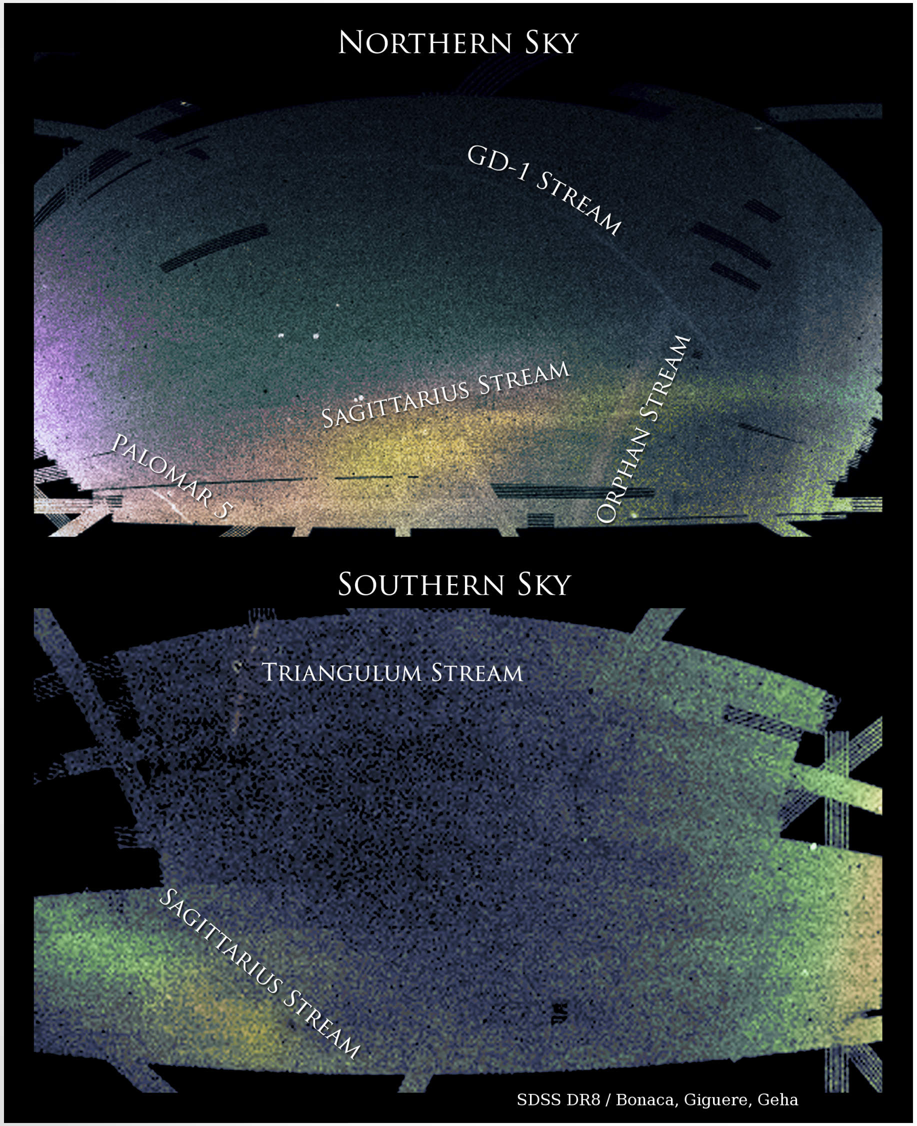
- Most of the Galactic dwarf galaxy companions are "dwarf spheroidal" galaxies
- No gas, old stars, very low luminosity
- Important for models of the formation of galaxies (later)

Galactic Cannibalism



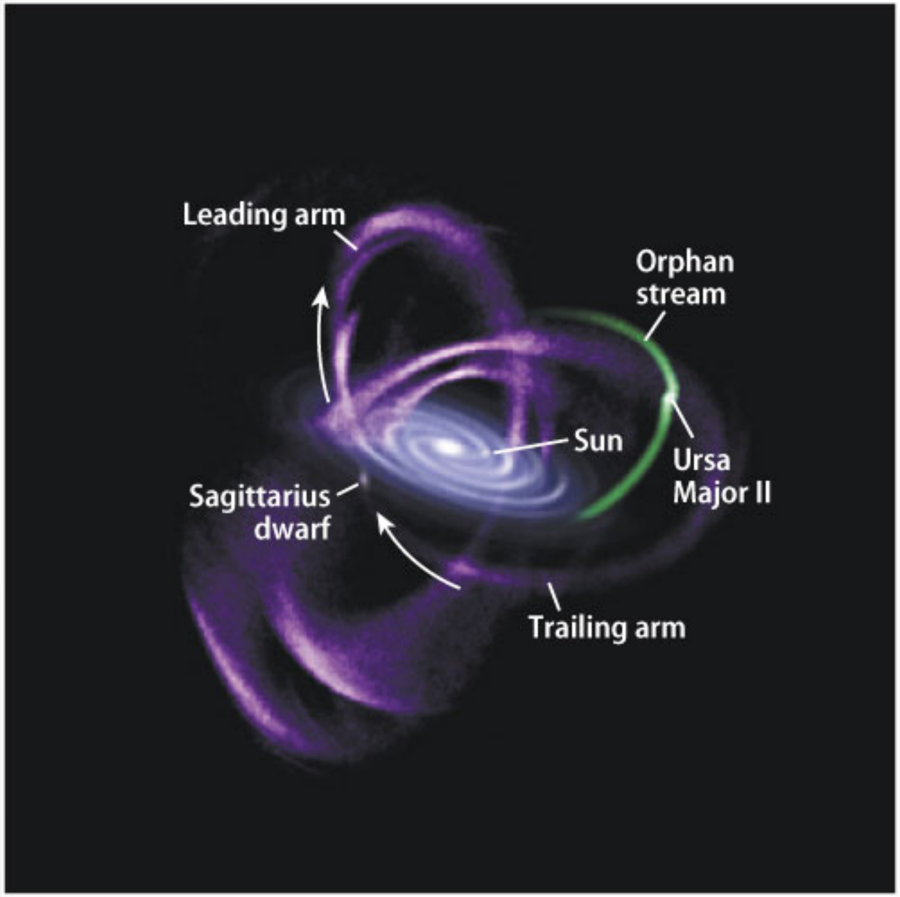
- A third class of companion galaxy is the Sagittarius dwarf which shows up as a "tidal stream"
- Dwarf galaxy in the process of being shredded by the gravitational field of the Galaxy
- Key to understanding how the halo formed

Tidal Streams



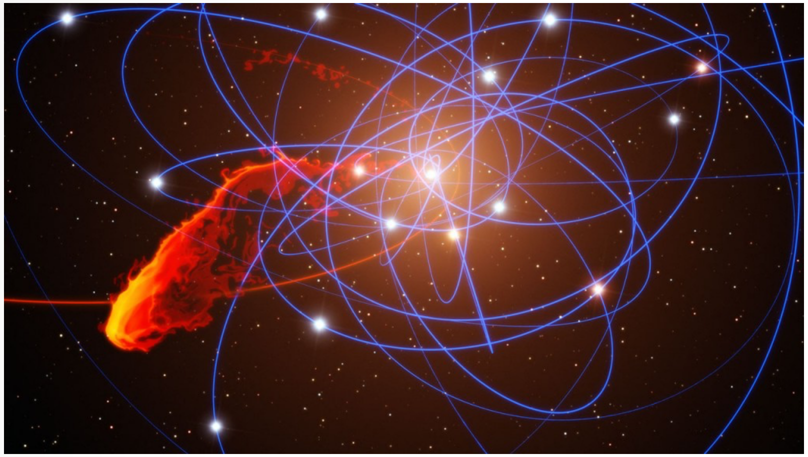
- When a dwarf galaxy or star cluster is tidally disrupted, the stars spread *along* the orbit (at near constant energy) and spread out *around* the stream according to the mass of the galaxy

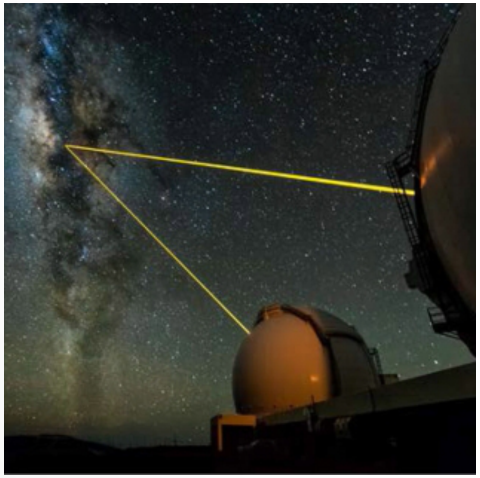
Tidal Streams



- The tidal streams can be very long lived and trace out the orbit of the shredded dwarf/cluster
- We can learn much about the gravitational potential of the Milky Way Galaxy by the behavior of the tidal streams.

Galactic Center





- The center of the galaxy is a special place with some wild processes going on and some wild astrophysical objects
- Will talk about this in a later lecture after you have learned about black holes

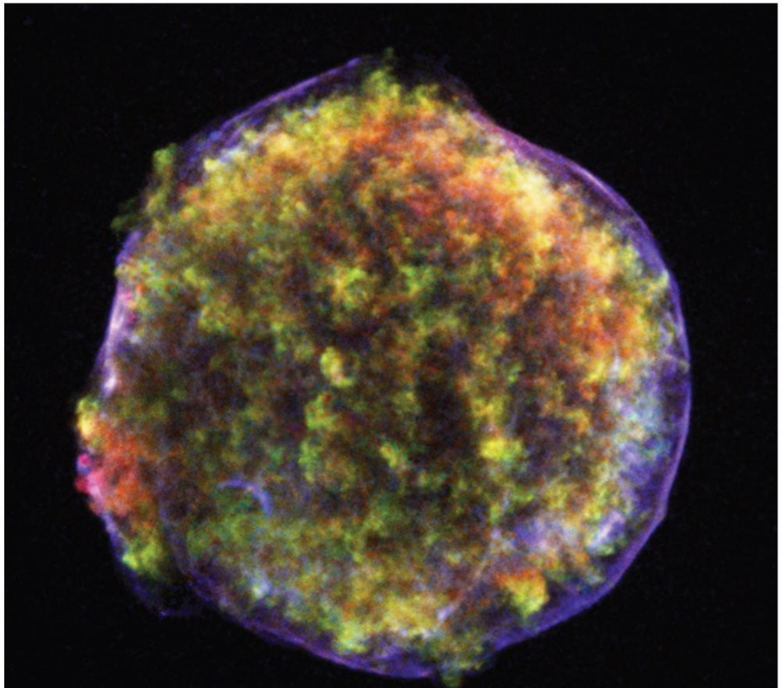
Evolution of the Galaxy

After the Big Bang, almost all atoms in the universe are in H gas. A little bit of He, even less of the other elements. The "raw material" for making galaxies.

Evolution of the universe to what we see today (stars, galaxies, planets, banana slugs, etc.) is all about turning H gas into other stuff

Some of that "raw material" is still around

Credit: Hubble Heritage Team (AURA / STScI / NASA)

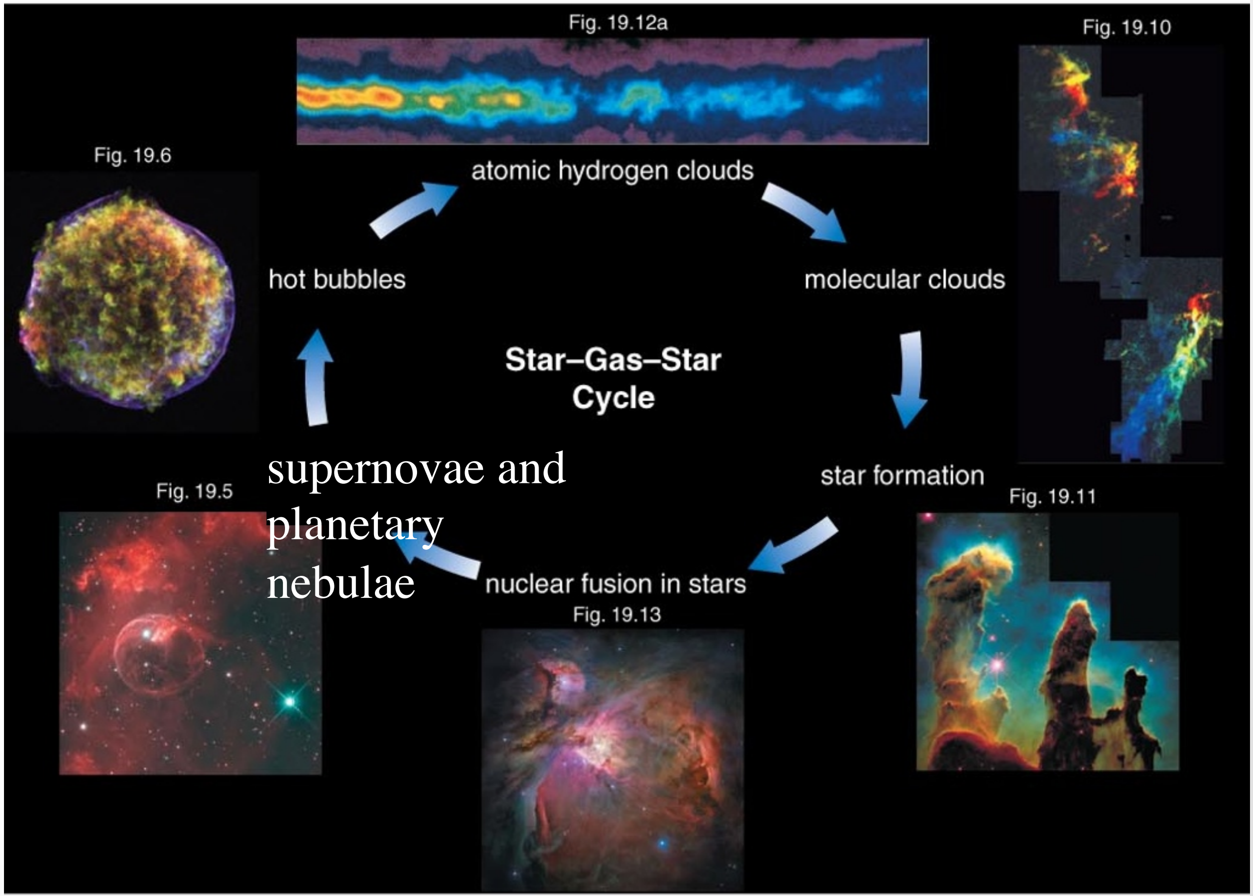


Some of it gets recycled to make new stuff

But different, no longer "raw" material: mix of elements is different thanks to nucleosynthesis

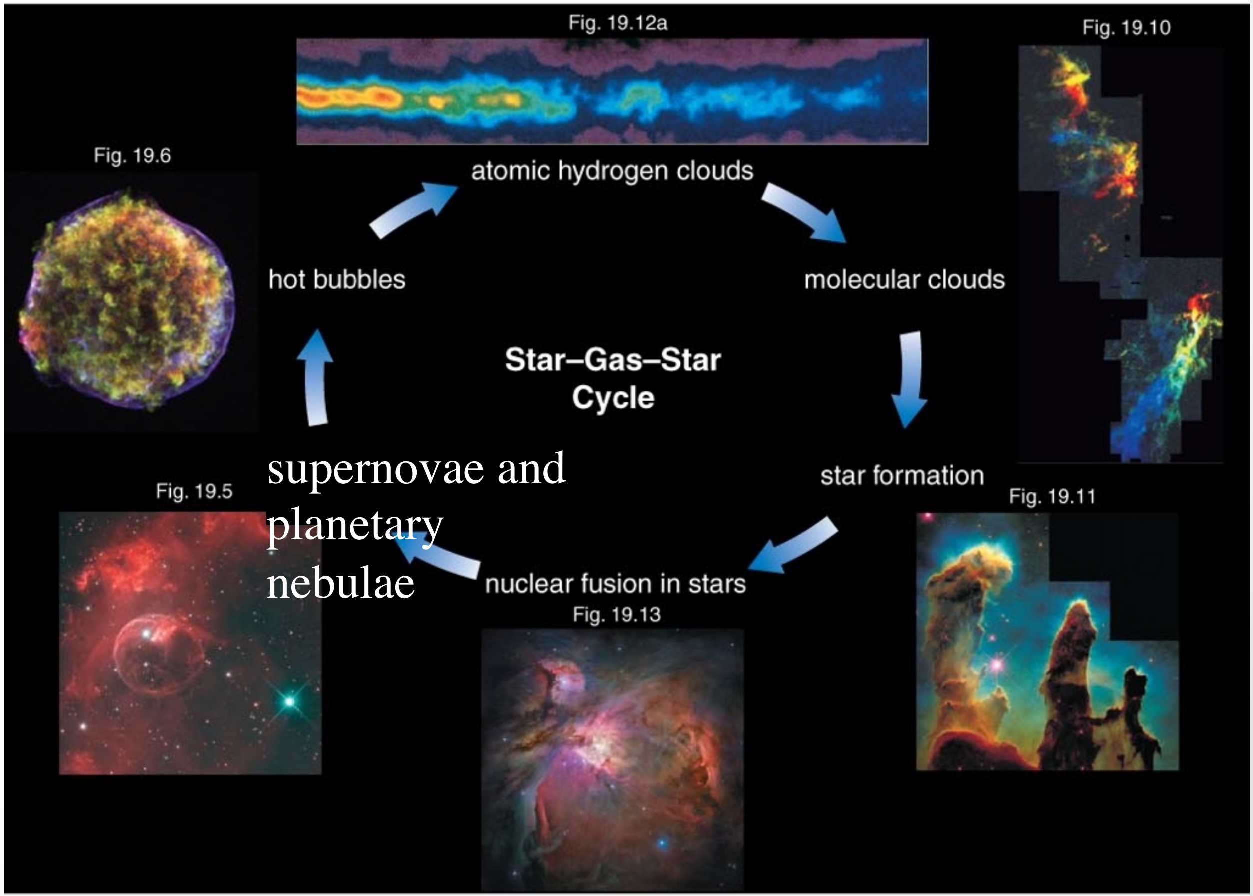
The Milky Way: Contents and Evolution

1. Start: H, He gas atoms in the galaxy (top of figure below)
2. Gas gets compressed (why/how? more later on spiral arms in the disk). Density rises: make dense and dusty molecular clouds.



The Milky Way: Contents and Evolution

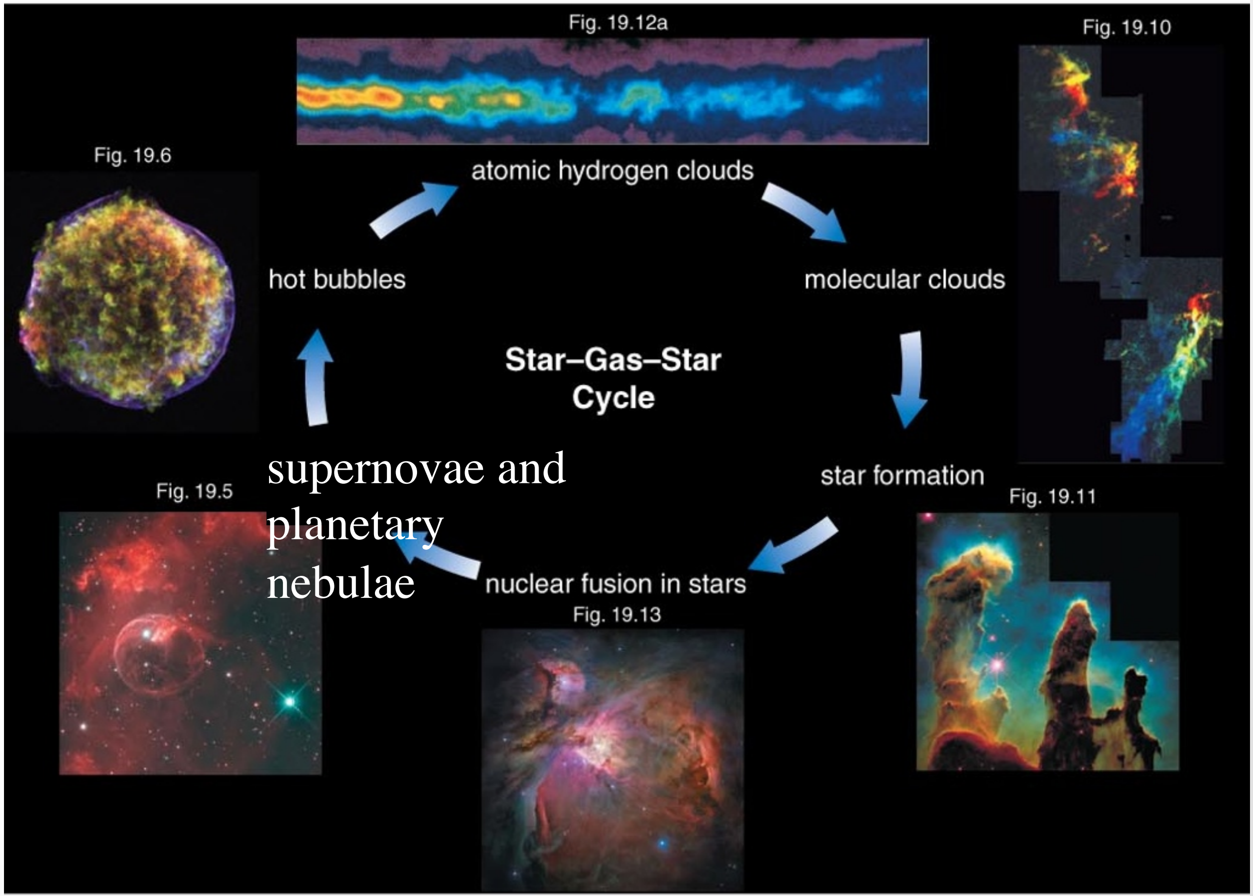
2. Gas gets compressed (why/how? more later on spiral arms in the disk). Density rises: make dense and dusty molecular clouds.
3. Gravity takes over: stars form



The Milky Way: Contents and Evolution

4. Stars fuse H, He into new elements
   Originally: 75% H
   25% He

   Now: 70% H
   28% He
   2% everything else (Ca, C, Si, ...)

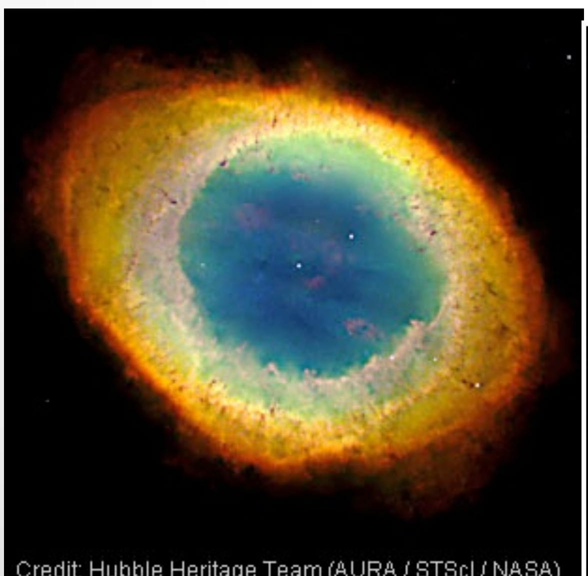


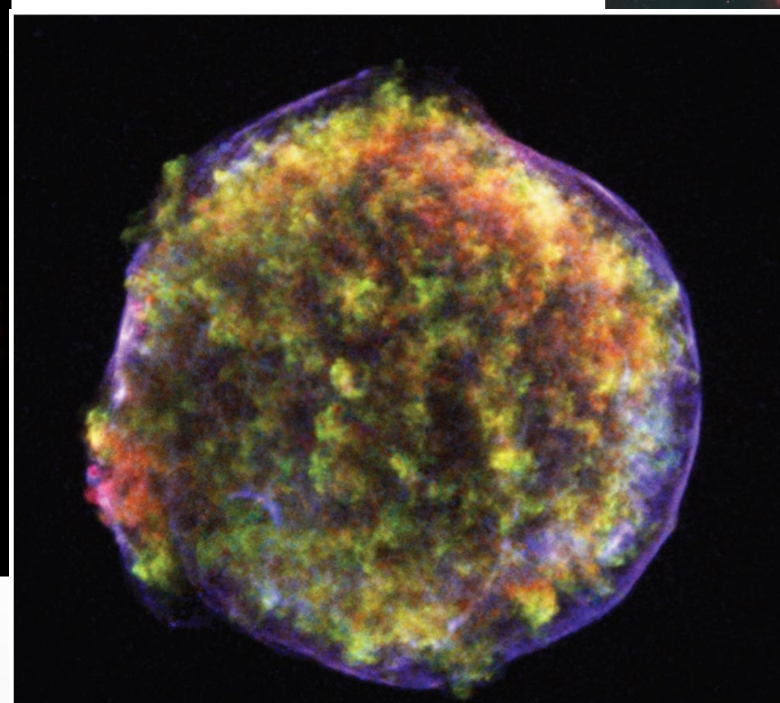
The Milky Way: Contents and Evolution

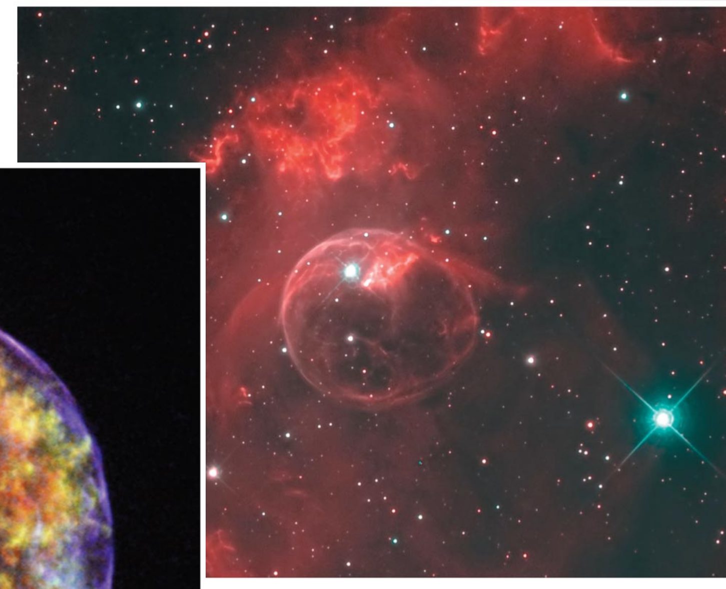
Low mass stars: lose outer layers (1/2 total mass) as Planetary Nebulae.

High mass stars and white dwarf binaries: end as Supernovae.
Eject mass, new elements back into the Galaxy.

Winds from planetary nebulae, energy of supernovae explosions also add kinetic energy: spread the new elements out into the Galaxy and mix up the gas.

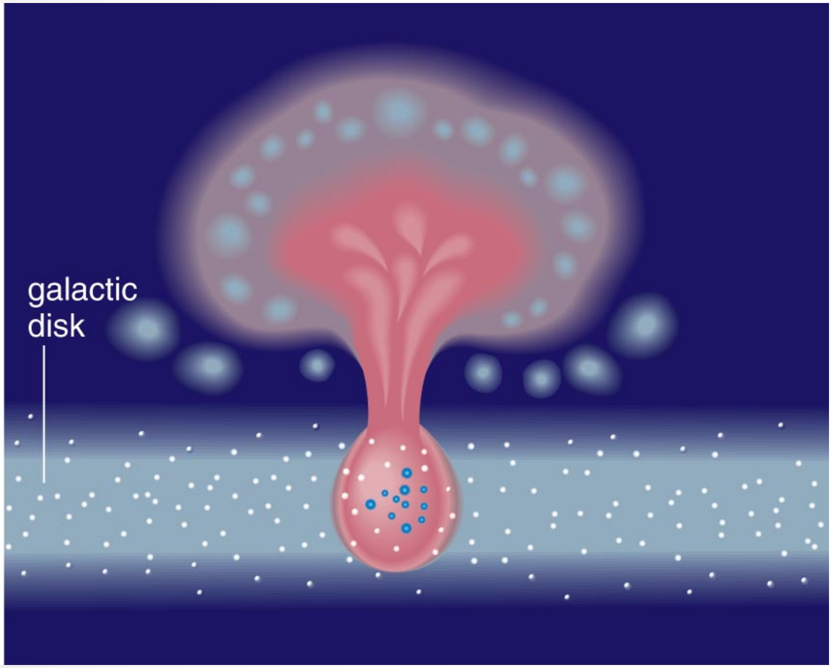




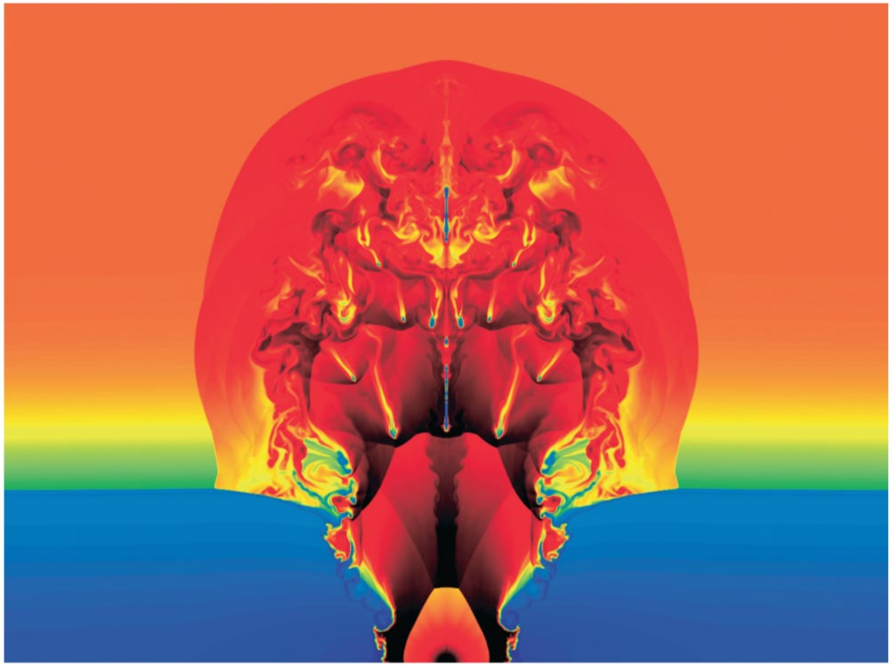


The Milky Way: Contents and Evolution

Lots of Supernovae together can input some serious kinetic energy. Gas can escape out of the disk.

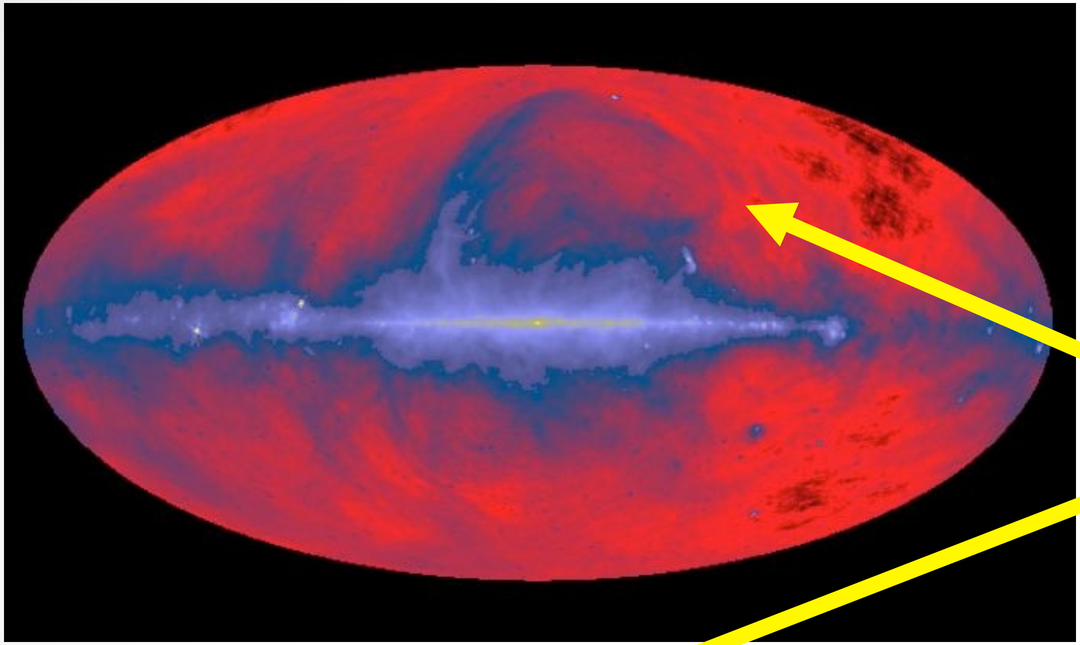


Cartoon: lots of massive stars close to each other in the disk. Many overlapping Supernovae bubbles give each other kinetic energy "boost", can escape out of the disk.

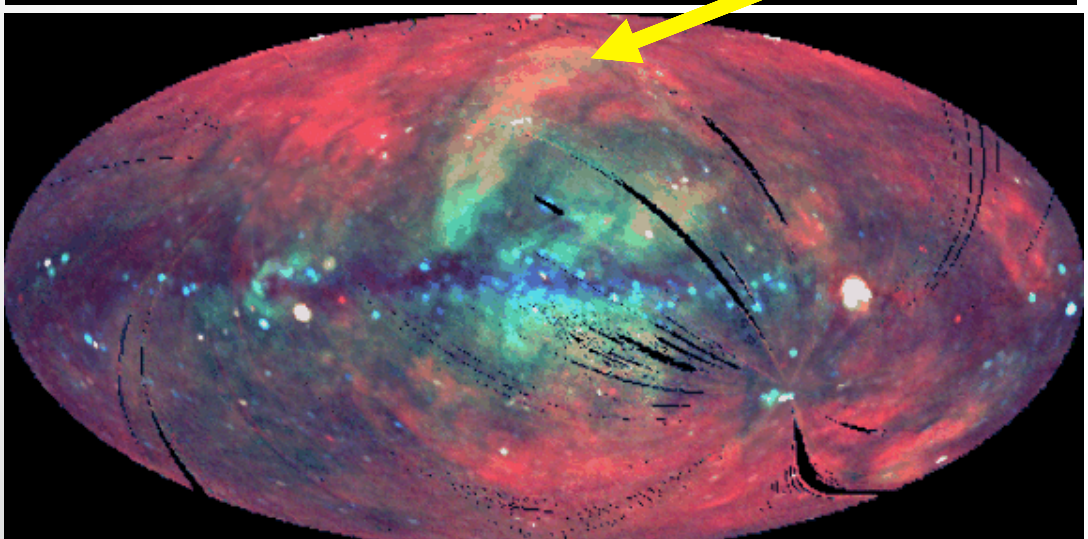


Computer simulation of an escaping bubble of hot, enriched gas.

The Milky Way: Contents and Evolution

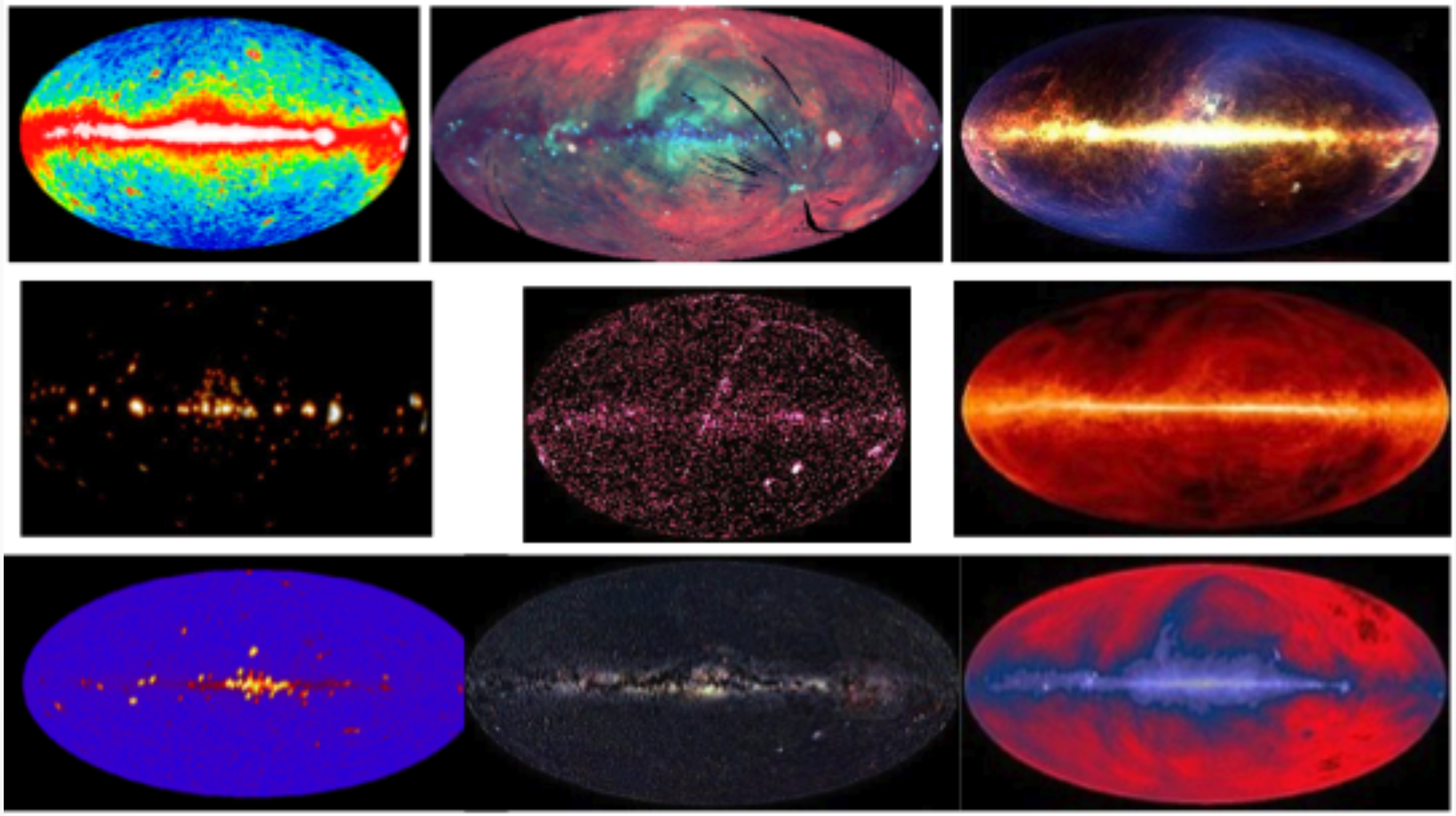


The Milky Way in long wavelength radio light (top)
and X-rays (bottom), both tracing hot gas from long-ago supernovae explosions.



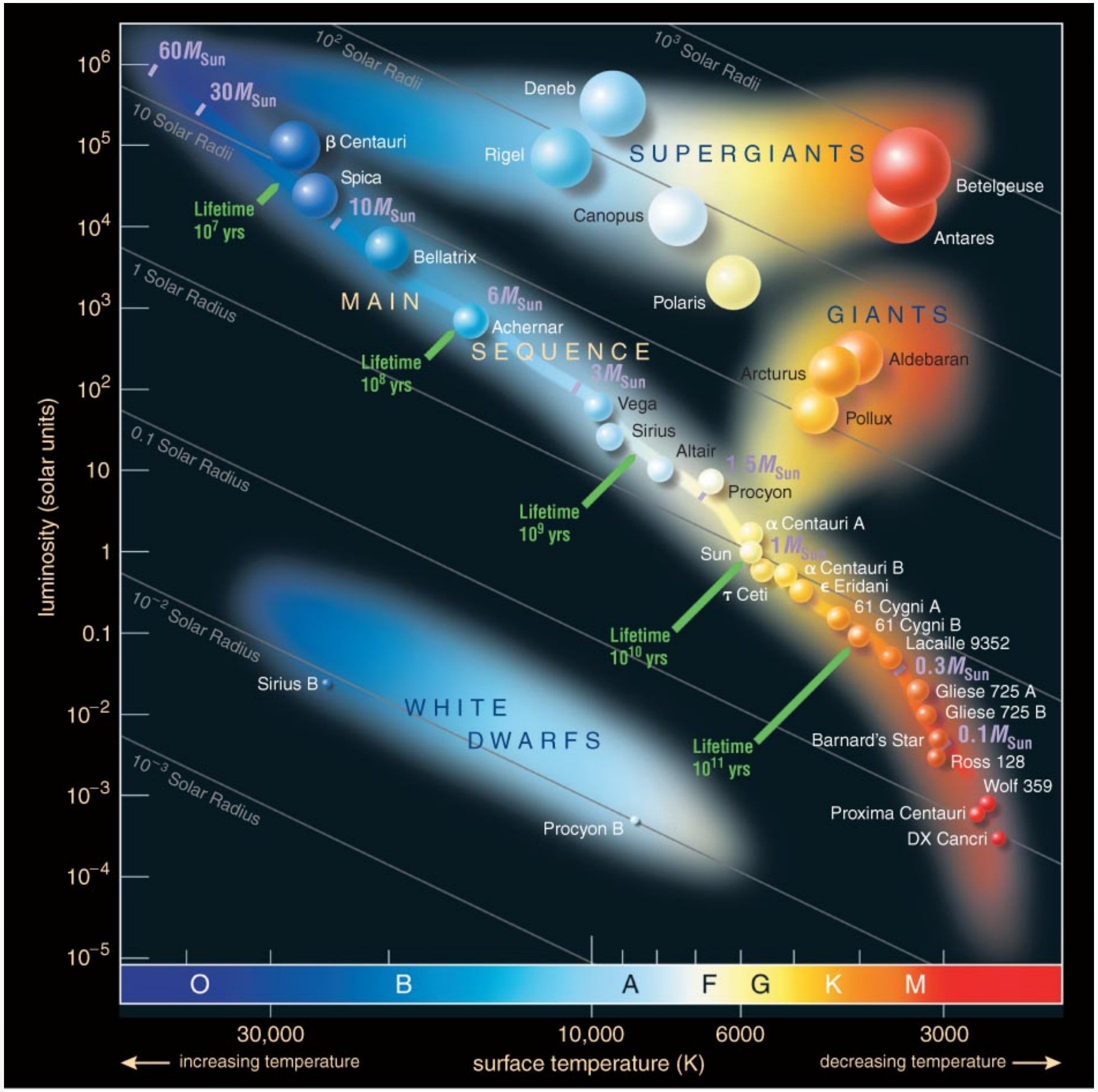
The Milky Way: What Does it Look Like?

Now, with 100 years of work and much better data:

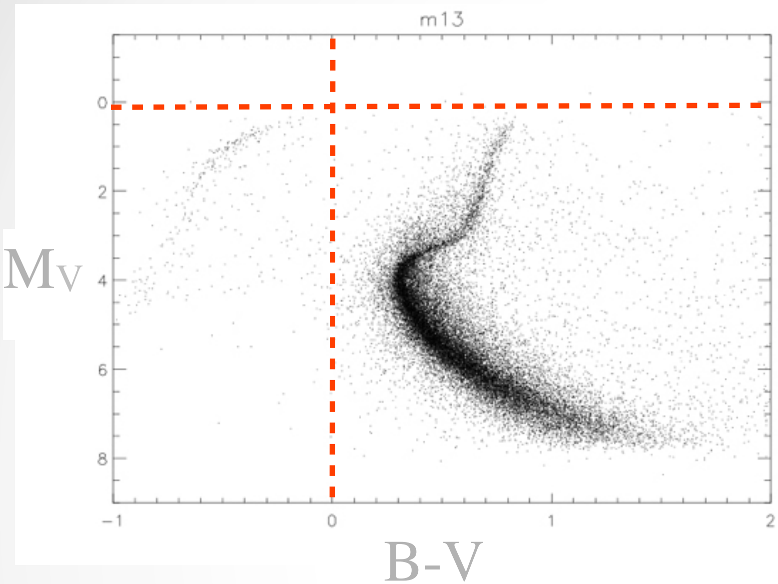


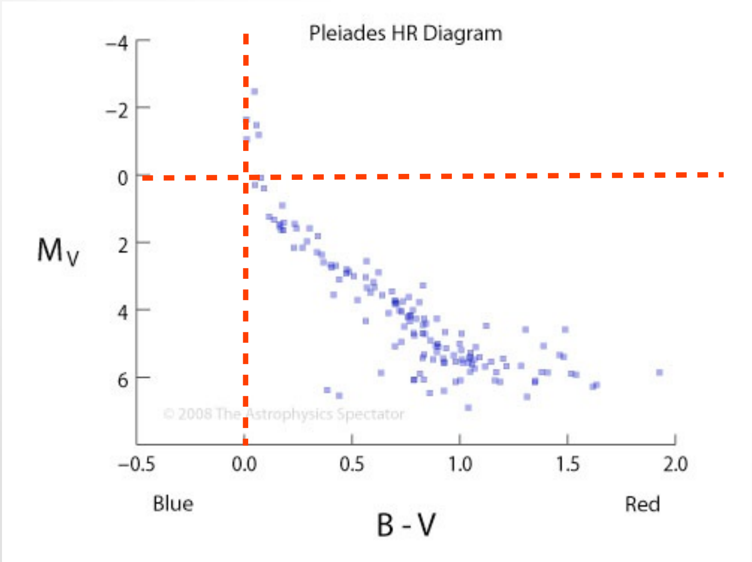
Gamma rays - diffuse | X-rays: hot gas | near-IR: hot dust (including solar system!)
Gamma rays - accreting stars | UV: hot, young massive stars | Short wavelength radio: H atoms
X-rays - accreting stars | Visible: stars | Long wave. radio: hot gas

Star Formation and the Milky Way

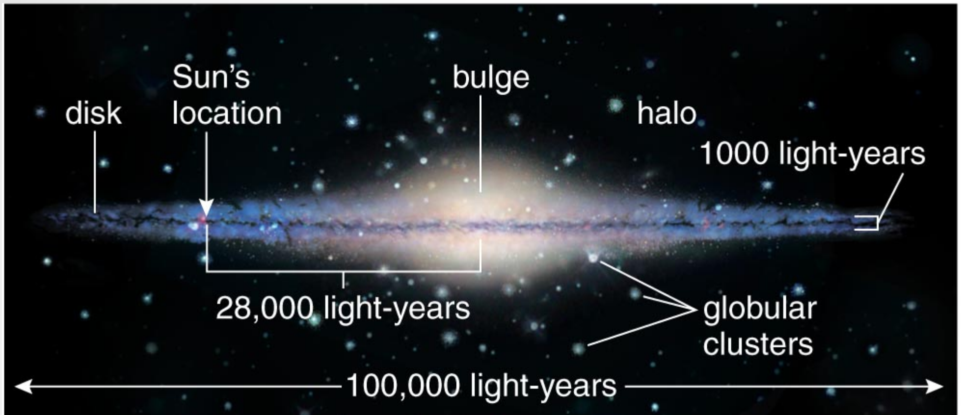


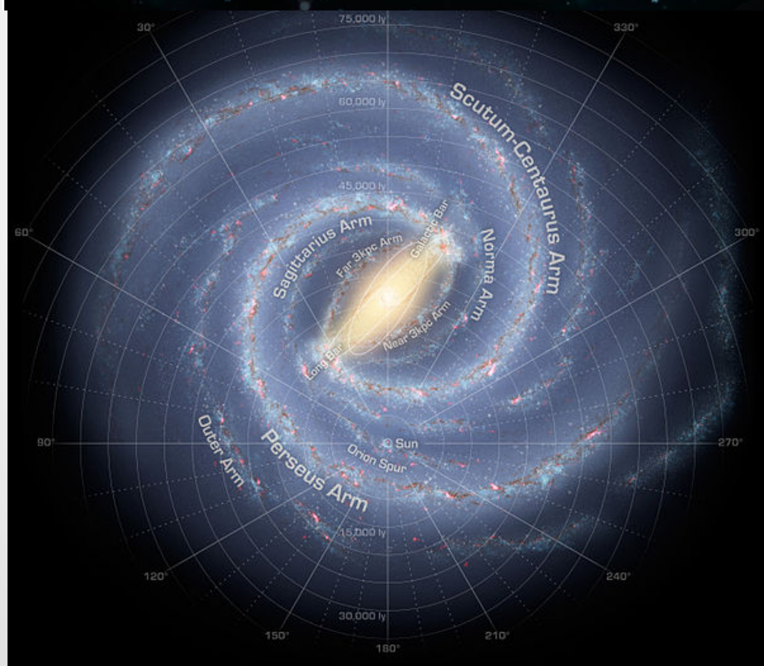
Star Formation and the Milky Way





The Milky Way: Contents and Evolution





All hot, massive, young stars are found only in the disk.

All the star formation and chemical processing takes place in the disk.

All the gas and dust is in the disk, too. (Coincidence?)

All stars in the halo, bulge and globular clusters are old. No gas and dust there.

Where stars live is related to where they formed and what happened to them after that.

This tells us about our galaxy:
1) What it looks like
2) How we think it formed

The Milky Way: Contents and Evolution

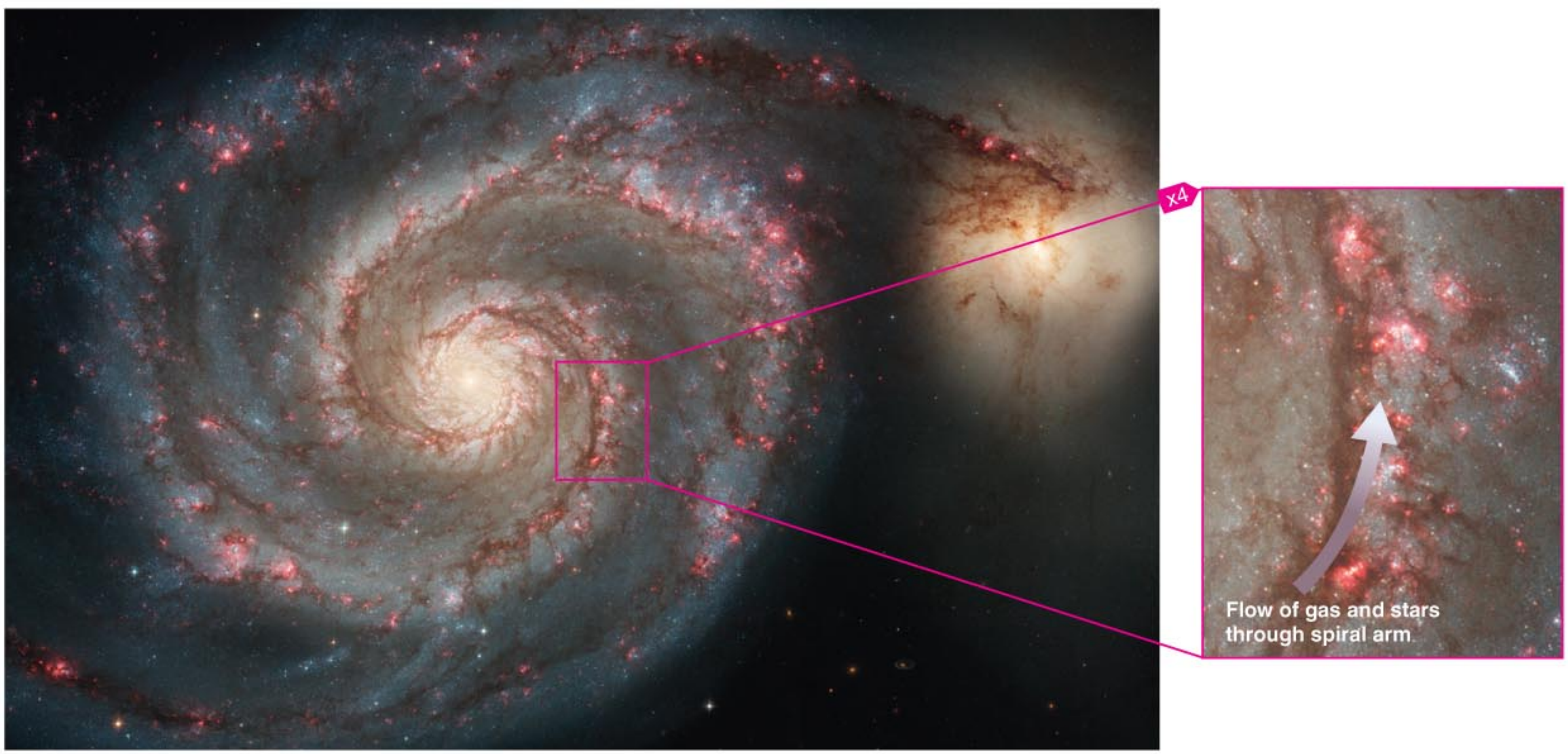
Spiral arms: regions of high density that rotate independently from the stars.

→ Stars and gas move through the spiral waves.

Gas gets compressed, makes molecular clouds and new stars.

Evidence: dust and youngest stars found close to spiral arms. Older stars farther away.

Oldest disk stars spread evenly through the galaxy.



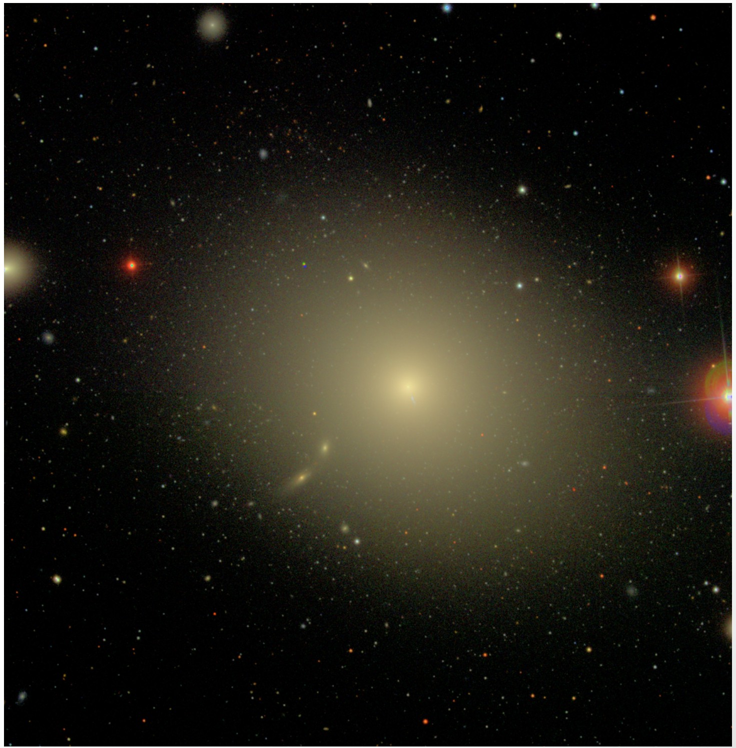
Star Formation and the Milky Way

To recap, our Galaxy:

1. Has a disk where most of the stars and almost all the gas and dust are.
2. Is forming stars from gas in the disk.
3. Has spiral arms. We think spiral arms have something to do with making star formation happen.

So, does our Galaxy look like:

or



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Star Formation and the Milky Way

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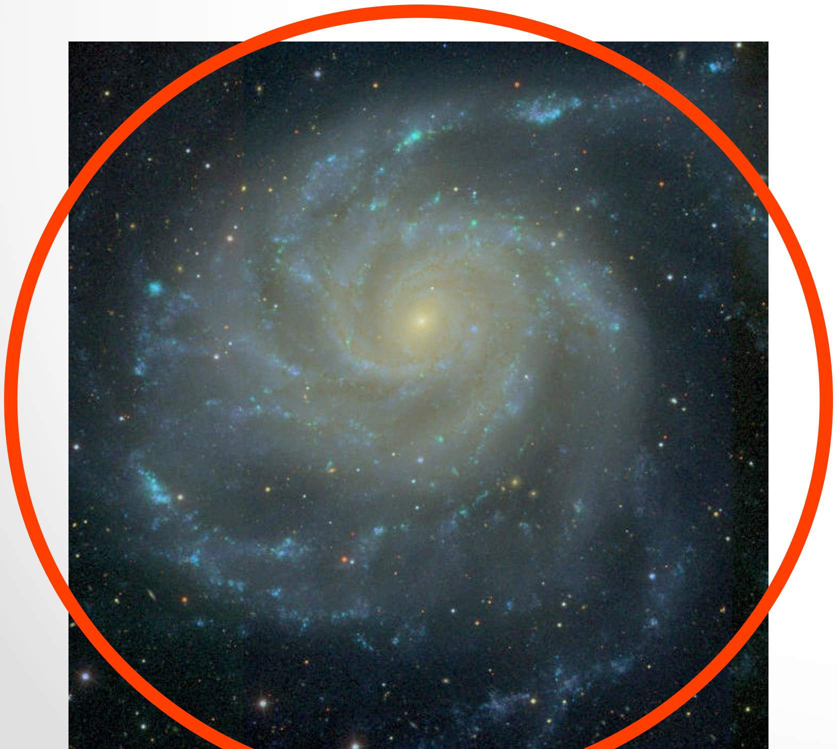
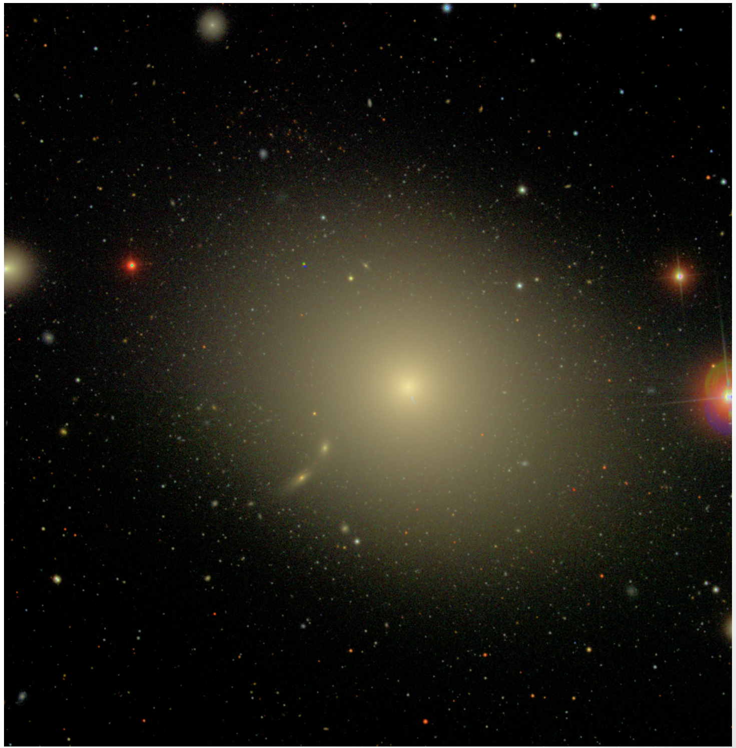


or



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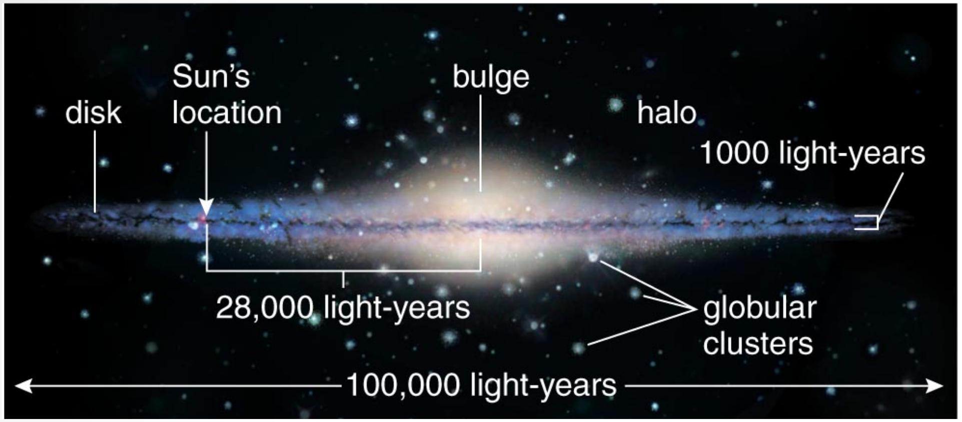
Milky Way: Where is this going?



Halo: Old, not very many stars, no young stars, no star formation going on now.

Disk: Younger, where all the gas and star formation action is at.

Age difference: infer Halo formed first and for some reason stopped forming stars

Star formation all in the disk today: infer that eventually, gas ends up only in the disk

At the current low star-formation rates and with known gas return fractions, in the next few billion years we will run out of fuel and the Galaxy will grow dimmer and cooler (and dimmer and cooler…)

The future of the Milky way

- Colder and darker will be interupted by
- Milky Way Galaxy and Andromeda Galaxy (M31) are approaching one another at 100 km/sec (68 miles/sec) and will “collide” in about four billion years.