Stars, Galaxies & the Universe
Lecture Outline

Our Milky Way Galaxy

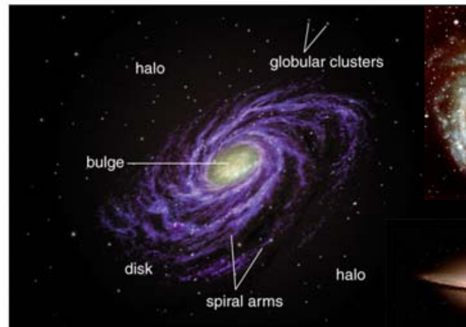
(1) Components
  - HII regions, Dust Nebulae, Atomic Gas

(2) Shape & Size

(3) Rotation of the Galaxy

(4) Spiral Arms of the Milky Way

A galaxy is a collection of 100 billion stars!



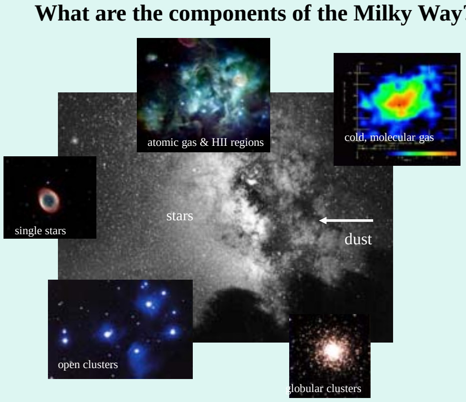
The Sun lives in the Galactic suburbs
At ~24,000 light years from the Galaxy's center

The Sun's place in the Milky Way Galaxy

- The Sun is just one of ~100 billion stars that are associated together in our Galaxy
- The stars and star clusters in a Galaxy are "bound" to the Galaxy by gravitational forces

  - stars, gas rotate around the Galaxy much like the planets rotate around Sun

What are the components of the Milky Way?



The components of the Milky Way ISM:

1. HII regions

2. Regions of Dust and Reflection Nebula

3. Atomic Clouds

1. HII Regions

Rosette Nebula

• same basic composition as stars - hydrogen

• **main difference: density**

density = atoms/volume
also mass/volume

• **mass = 100-10,000 times mass of Sun**

but spread out over many light years

• **size = 1-100 pc across (or ~3-300 light years)**

1. HII Regions

The Pelican nebula in Cygnus

<u>typical density of nebulae</u>

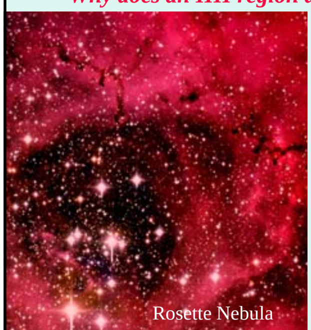
1000's atoms per cubic centimeter

<u>density of air</u> – "almost nothing"

10^{19} atoms per cubic centimeter

1. HII Regions

Why does an HII region appear red in color?

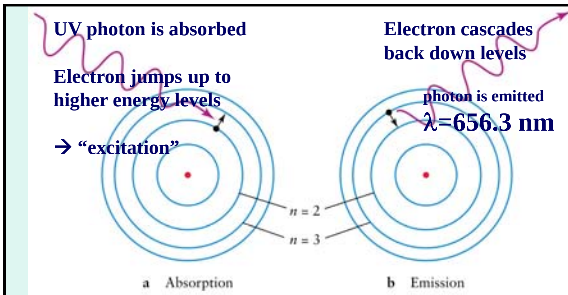


Rosette Nebula

• hydrogen gas cloud near very hot (O + B types) stars → 10,000 – 50,000 K

• these stars emit mostly UV photons (very hot!)

• hydrogen atoms absorb the UV photons and become "excited"



→ a photon is emitted at 656.3 nm – red visible light

2. Regions of Dust: Dust Nebulae

• concentrations of cold hydrogen and microscopic *dust* particles

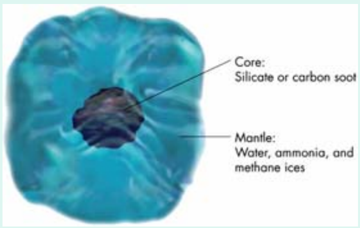
• how cold? ~10-100 K (hydrogen is a molecule)

• the main observed property of a dark nebula **is that it is dark – it absorbs surrounding radiation**

2. Regions of Dust: Dust Nebulae

2. Regions of Dust: Dust Nebulae

What does an interstellar "dust grain" look like?



→ SIZES of DUST GRAINS: variety
- typically in the range of visible light ~500 nm across

2. Regions of Dust: Dust Nebulae

Regions that contain dust have two effects on starlight:

(1) ABSORPTION: Completely block starlight!

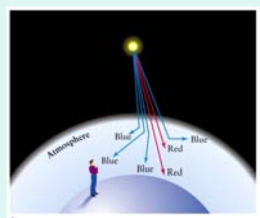
(2) SCATTERING and REDDENING: Partially block starlight (reduce its strength), and make starlight look redder than it would naturally be by scattering the blue light component!

→ Produce a reflection nebula
→ Cause interstellar redding

2. Regions of Dust: Dust Nebulae

Horsehead Nebula
Regions of blocked starlight

2. Regions of Dust: Scattering to make Reflection Nebulae

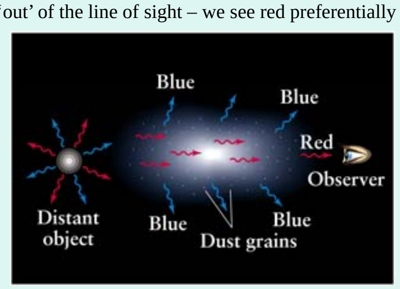


Dust preferentially scatters the
Blue light away from light path,
Creating a reflection nebula

Good example of this phenomena
In the Pleiades stellar cluster

2. Regions of Dust: Interstellar Reddening

• more distant objects appear "redder" than they are
• because the blue parts of their light is scattered 'out' of the line of sight – we see red preferentially



2. Regions of Dust: Dust Nebulae

Interstellar DUST – keeps our Galaxy dark!

• only 40% of light from a star 3000 ly away is seen by us

the other 60% is absorbed by dust

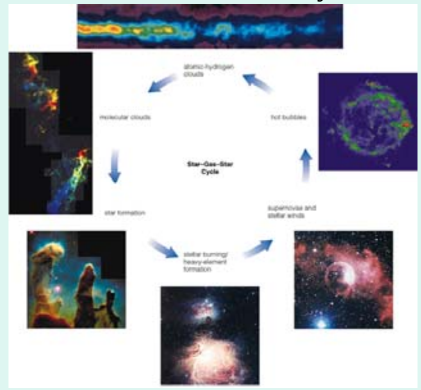
• only 16% of light from a star 15,000 ly away is seen by us!

→ *"Interstellar Extinction"*

Phases of the ISM

State of Gas	Primary Constituent	Approximate Temperature	Approximate Density (atoms per cm³)	Description
Hot bubbles	Ionized hydrogen	1,000,000 K	0.01	Pockets of gas heated by supernova shock waves
HII regions		10,000 K		
Warm atomic gas	Atomic hydrogen	10,000 K	1	Fills much of galactic disk
Cool atomic clouds	Atomic hydrogen	100 K	100	Intermediate stage of star–gas–star cycle
Molecular clouds	Molecular hydrogen	30 K	300	Regions of star formation
Molecular cloud cores	Molecular hydrogen	60 K	10,000	Star-forming clouds

The Star–Gas–Star Cycle



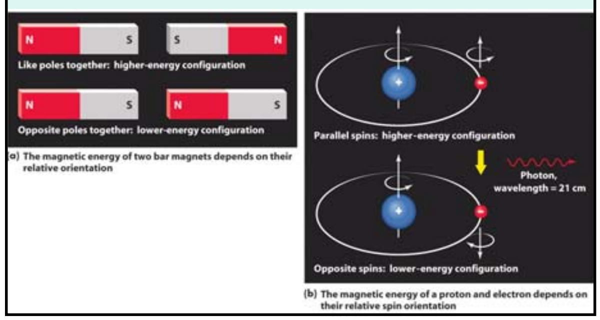
3 . Atomic Hydrogen Gas

Atomic Hydrogen in the Milky Way

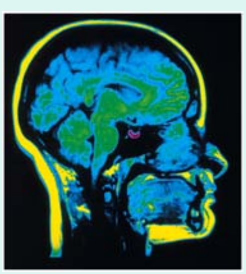
- In the cool ISM, ionized Hydrogen recombines with electrons.
  - neutral, atomic H is formed
- The Milky Way contains 5 billion $M_{\odot}$ of atomic H in two states:
  - large, tenuous, warm (10,000 K) clouds
  - small, dense, cool (100 K) clouds

3 . Atomic Hydrogen Gas: Detection!

Atomic Hydrogen emits 21 cm radio waves

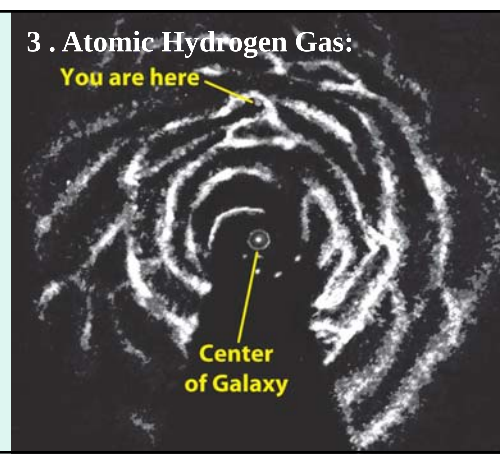


3 . Atomic Hydrogen Gas:



Same effect in other atoms is used to do magnetic resonance imaging (MRI)

3 . Atomic Hydrogen Gas:



What is the *shape* of the Milky Way Galaxy?

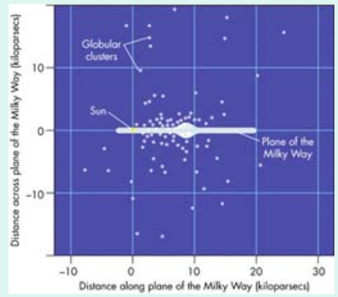
Early ideas of what the Milky Way shape is...

• Greeks wrote about shape of Milky Way

• Galileo wrote about "swarm of stars"

• W. Herschel in late 1780s concluded MW was a flattened disk of stars with Sun at center

Can find distances to globular clusters in Galaxy

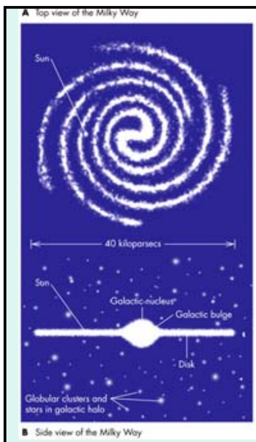


• 1915 Harlow Shapley found distances to ~100 globular clusters

• made a plot of
  → distribution of clusters
  → distances of clusters

• concentrated toward Sagittarius, about 25,000 ly away from the Sun

• Sun is at the edge of our Galaxy, far from the center!



Components of Galaxy:

• Nucleus
  ~25,000 ly from Sun

• Bulge
  spherical concentration of stars and star clusters

• Disk
  flattened distribution of stars; Sun is in the disk

• Halo
  distribution of star clusters outside of the disk/bulge

Regions of the Milky Way Galaxy

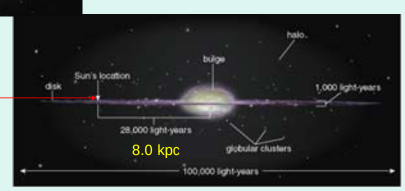
diameter of disk = 100,000 to 150,000 ly

thickness of disk ~ 1000 ly

number of stars ~ $2 \cdot 10^{11}$

Distance to sun from center ~ 25,000 ly

Sun is in disk, ~25,000 ly out from center



Distribution of HI emission in the Milky Way – Galactic coordinates

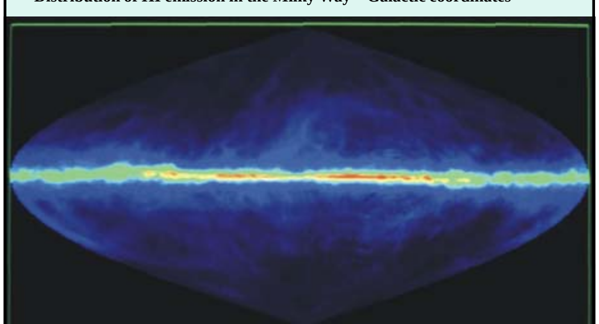
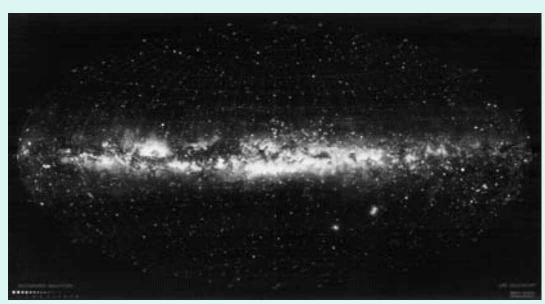
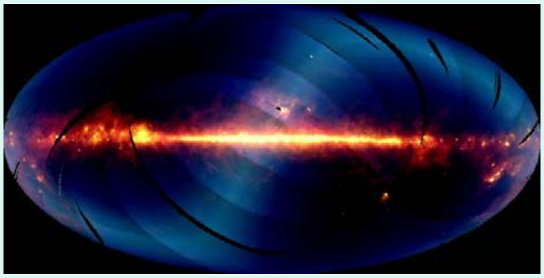


image courtesy of NRAO image gallery (http://www.nrao.edu/imagegallery)

When we look at the "Milky Way" we are seeing part of the disk of the Galaxy

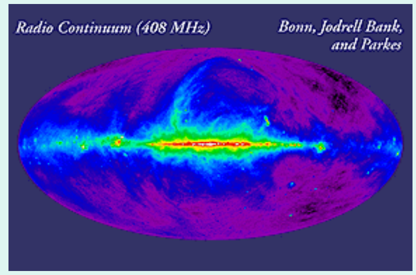


The disk of the Milky Way: an INFRARED image



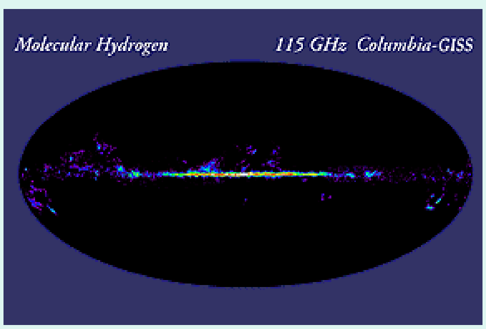
• this image shows dust glowing in the infrared

The disk of the Milky Way at RADIO wavelengths



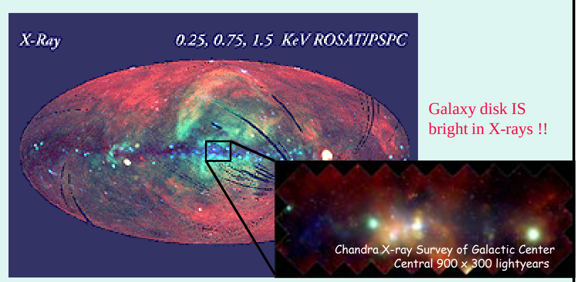
• radio continuum emission traces ionized gas, magnetic fields

The disk of the Milky Way at RADIO wavelengths:



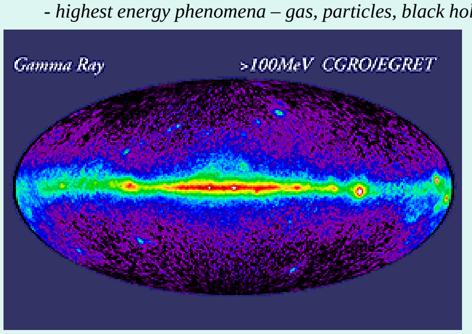
The disk of the Milky Way at X-RAY wavelengths:
- *highest energy phenomena*
- *emission from hot interstellar gas, X-ray binaries*

• some X-rays absorbed by gas in Galactic disk



Galaxy disk IS bright in X-rays !!

The disk of the Milky Way in GAMMA rays:
- *gamma ray detectors in orbit around Earth*
- *highest energy phenomena – gas, particles, black holes*



globular clusters in the bulge, halo

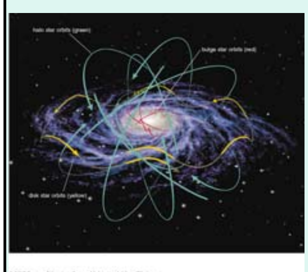
The Galactic Bulge & Halo regions:

- comprised mostly of globular clusters of stars
- REDDER/YELLOWER in visible light
  - globular cluster comprised of cooler stars
- stars in the disk are oldest in Galaxy
  - "redder" (cooler, lower mass, longer lifetimes)
  - they have fewer metals in their spectra
  - they probably formed when the Galaxy did
- no ionized, molecular gas
  - stars currently are not forming
- the globular clusters orbit the Galaxy at different angles (not in a flattened disk)

Halo vs. Disk

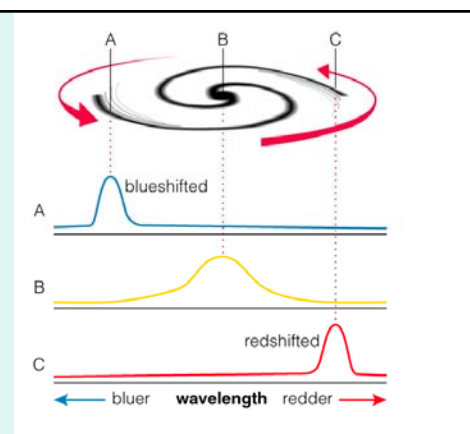
- Stars in the disk are relatively young.
  - fraction of heavy elements same as or greater than the Sun
  - plenty of high- and low-mass stars, blue and red
- Stars in the halo are old.
  - fraction of heavy elements much less than the Sun
  - mostly low-mass, red stars
- Stars in the halo must have formed early in the Milky Way Galaxy's history.
  - they formed at a time when few heavy elements existed
  - there is no ISM in the halo
  - star formation stopped long ago in the halo when all the gas flattened into the disk

Stellar Orbits in the Galaxy



- Stars in the disk all orbit the Galactic center:
  - in the same direction
  - in the same plane (like planets do)
  - they "bobble" up and down
    - this is due to gravitational pull from the disk
    - this gives the disk its thickness
- Stars in the bulge and halo all orbit the Galactic center:
  - in different directions
  - at various inclinations to the disk
  - they have higher velocities
    - they are not slowed by disk as they plunge through it
    - nearby example: *Barnard's Star*

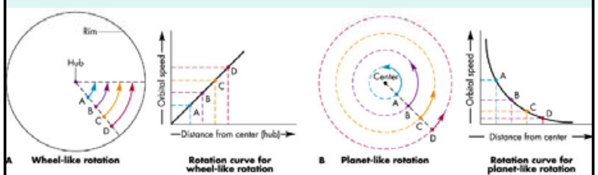
What lies at the edge of our Galaxy?



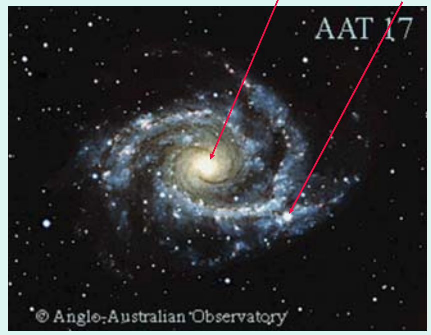
Two types of familiar rotation

1. wheel-like rotation: speed increases with distance

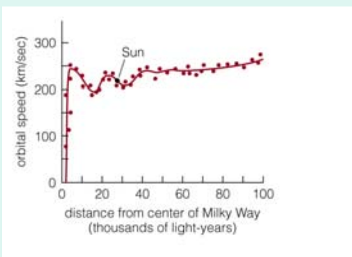
2. planet-like rotation: speed decreases with distance



These two types of rotation roughly correspond to the two regions of a galaxy: (1) bulge and (2) outer disk



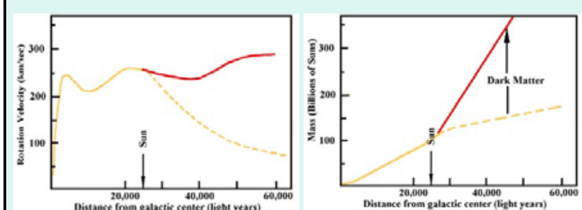
How does the rotation in the MW change with distance?



• it should rise at first (like wheel), then flattens, and finally decreases (like planetary-rotation)

• **but it does not fall off with distance – stays FLAT**

The rotation curve implies that there must be "dark matter" keeping the rotation curve FLAT

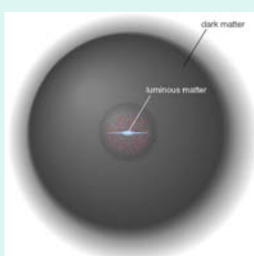


• what does this mean?
  → like finding out that Pluto, Mercury and the Earth all orbited the sun with an 88-day "year"
  → that the "edge" of our solar system is further out!
• our Galaxy must be full of material we can't see that has mass

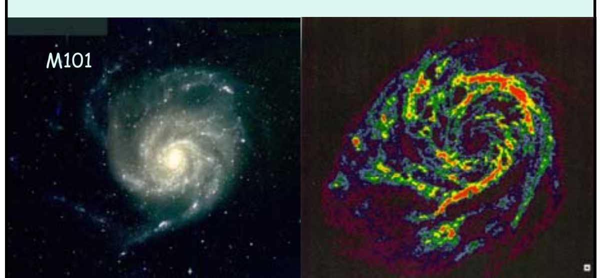
How to explain rotation curves?

Two possibilities to explain rotation curves:

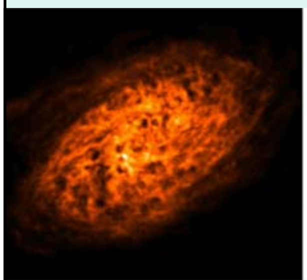
(1) we do not understand gravity on galaxy-size scales
(2) the velocities are caused by the gravitational attraction of unseen matter…called **dark matter**



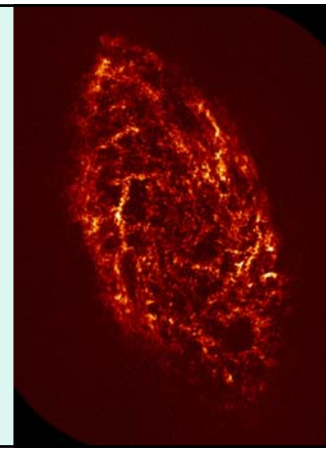
- If we trust our theory of gravity...
  - there may be 10-20 times more dark than luminous matter in our Galaxy
  - luminous matter is confined to the disk
  - dark matter is found in the halo and far beyond the luminous disk



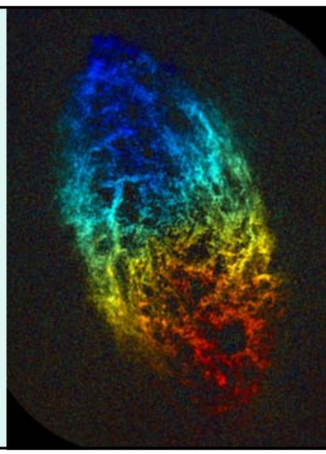
Distribution of HI emission in NGC 2403



Distribution of HI emission in M33



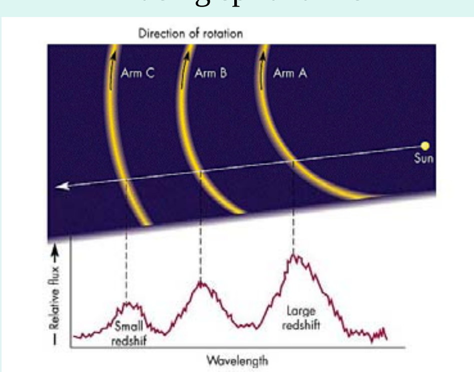
Distribution of HI emission in M33 – color represents velocity of HI line



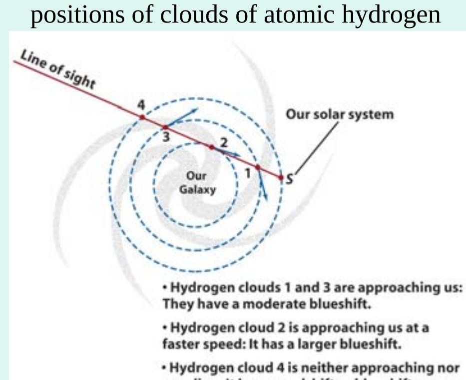
Spiral Structure

- The Galactic disk does not appear solid.
  - it has spiral arms, much like we see in other galaxies like M51
- These arms are not fixed strings of stars which revolve like the fins of a fan.
- They are caused by compression waves which propagate around the disk.
  - such waves increase the density of matter at their crests
  - we call them **density waves**
  - they revolve at a different speed than individual star orbit the Galactic center

Tracing spiral arms



Spiral arms can be traced from the positions of clouds of atomic hydrogen



Formation of the Milky Way Galaxy

→ Galaxy ~10 billion years old
(globular clusters in the bulge)
→ Halo may be older ~12 million yrs
→ Halo may have formed first from clouds
as well as already-formed clusters

Halo may be made up of stars and clouds