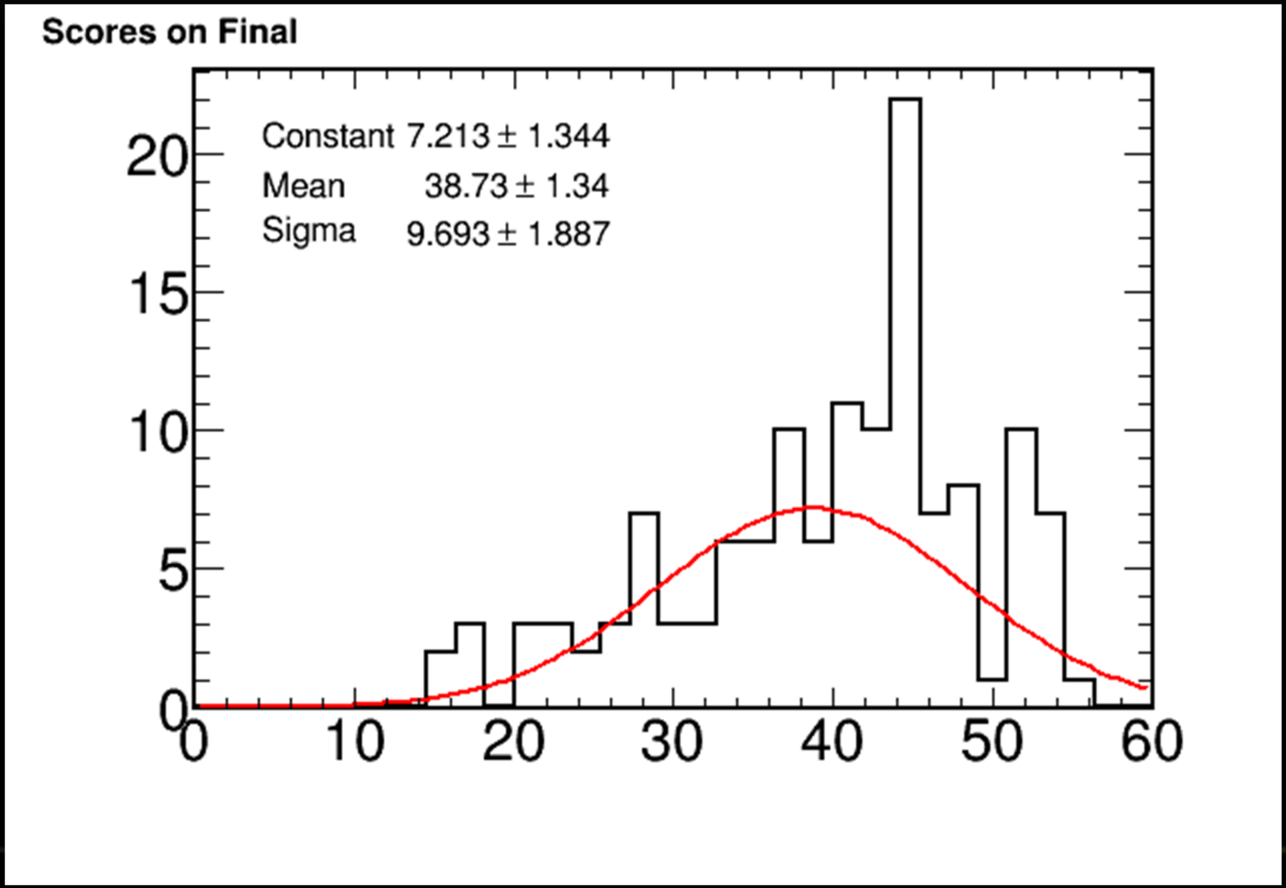
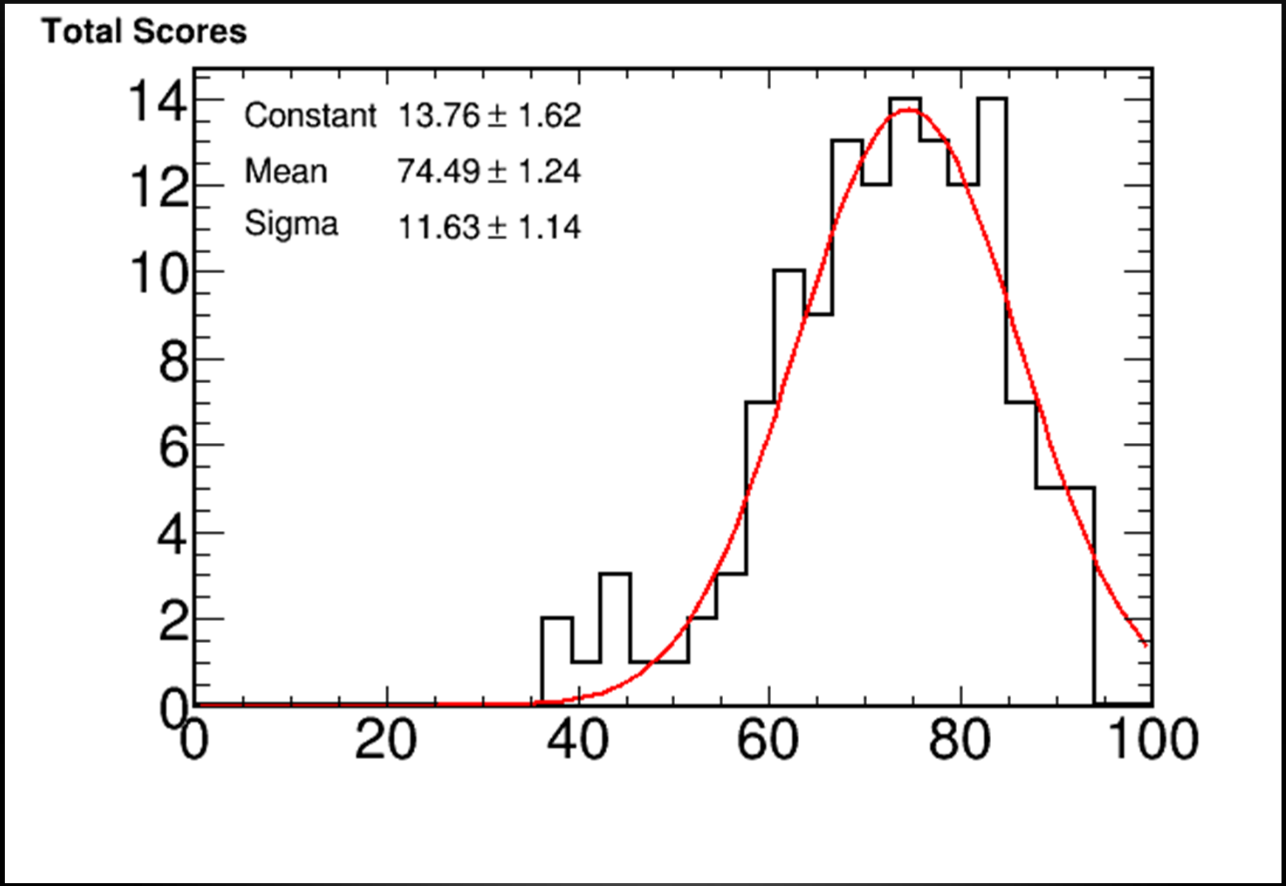
# TEST 3 SCORES (OUT OF 60)



# TOTAL SCORES AFTER TEST 3




I didn’t have the “show the letter grade” option turned on when I sent the email.
If you don’t know what your overall letter grade is at this point, please check again.

# OUR GALAXY

## Ch.15


Milky way seen over monument Valley
Photo by Wally Pacholka

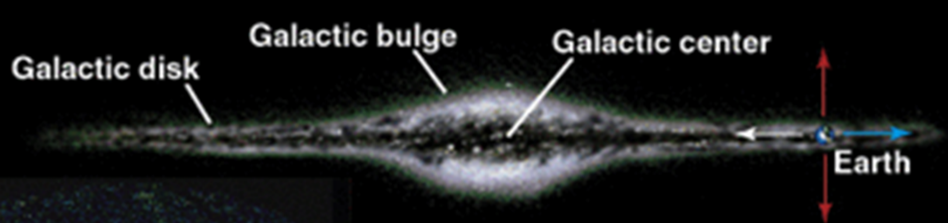
# WHAT WE SEE

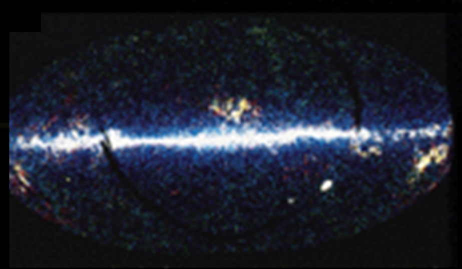
Image of the Southern Sky, Milky Way, and Comet Hyakutake by Gordon Garradd

- A band of many stars across the sky
- So many that all the fainter ones we can't see individually add up to a haze
- A sight which is the most obvious casualty of light pollution

# WHAT IS THIS BAND?

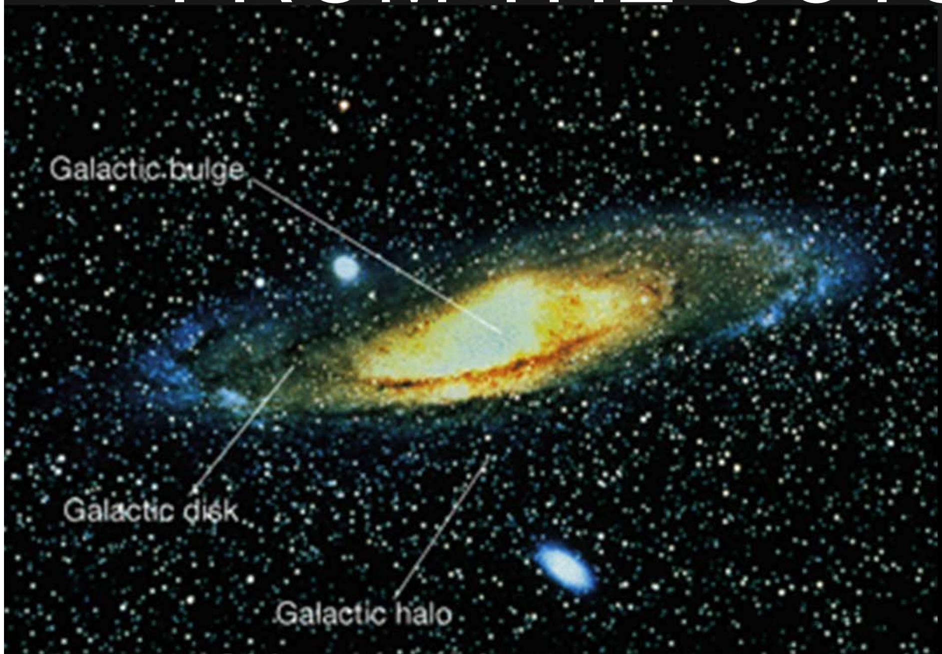
- Many many stars – the Sun is one of a few hundred billion neighbors
- This is the view we would get if sitting in a disk of stars
  - Only a few thousand ly thick
- Bulge is in direction of Sagittarius



IR view of dust in disk of Milky Way

# FROM THE OUTSIDE




- Other galaxies we see which are similar to our own

M31, Andromeda

NGC 891

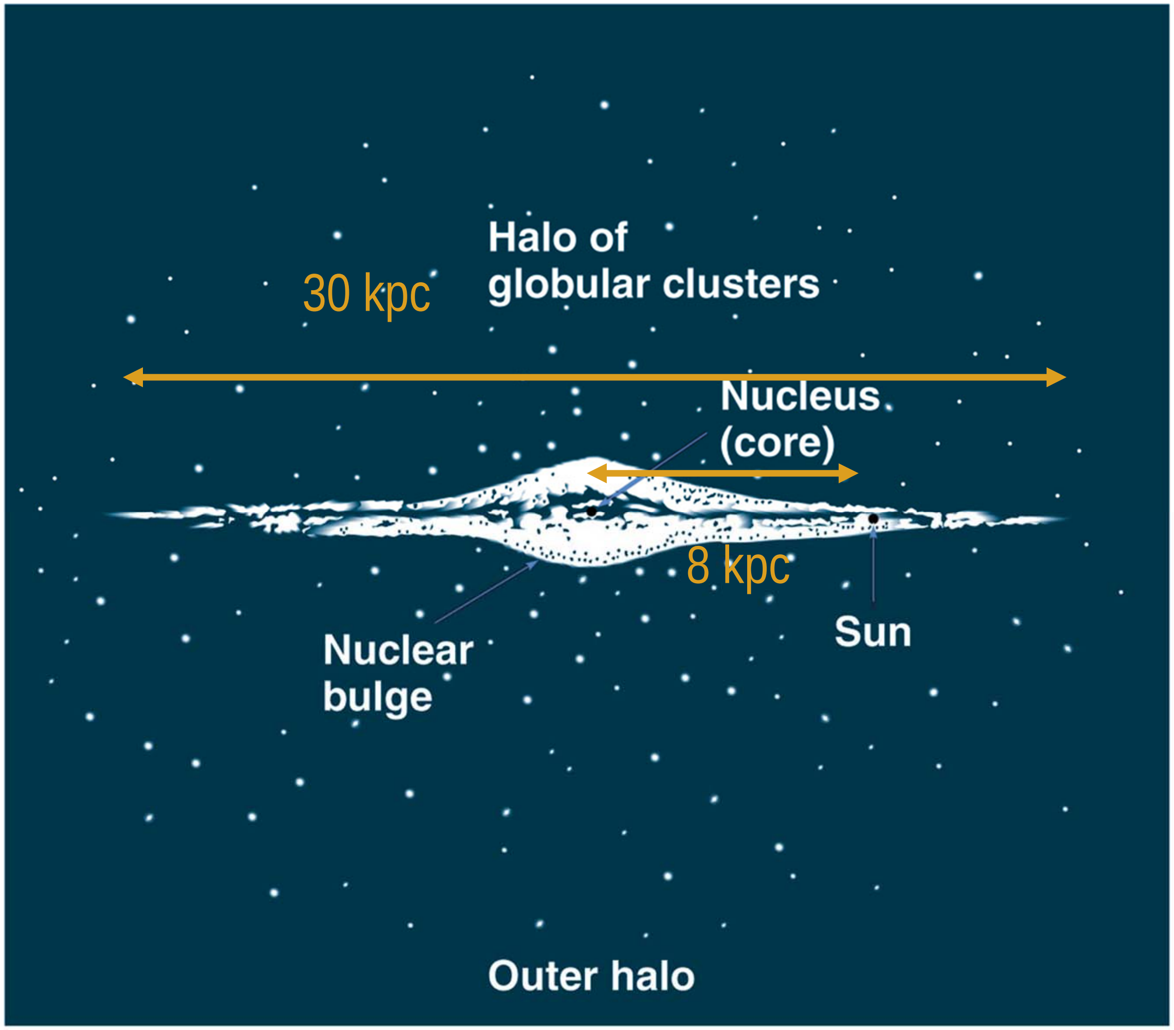
NGC 6744

# GLOBULAR CLUSTERS

M80, by F. R. Ferraro & M. Shara with the HST

- Spherical groups of very many stars
  - They stick together
  - Many stars very close
- Formed a very long time ago
- Hundreds of thousands of stars
- Outside the plane of the galaxy – but part of our galaxy, they are not other galaxies
  - Determined by mapping their positions

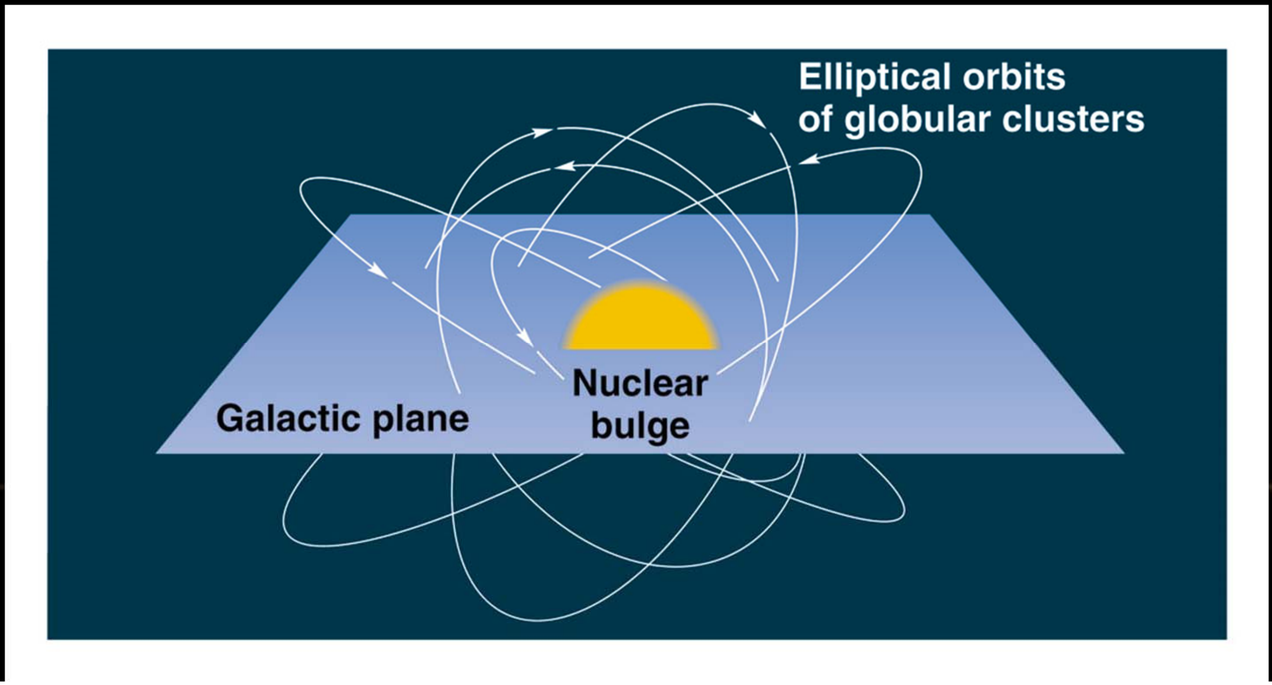
# HALO




- Globular Clusters form a "Halo" around the more familiar galactic shape
  - Other galaxies have them too
- We map their locations, they center around our galaxy's center

# ORBITING

- Not just centered
- But actually orbiting the center of mass of the galaxy
- Discovered by measuring their radial velocities via the Doppler shift



# WHAT ABOUT THE STARS?

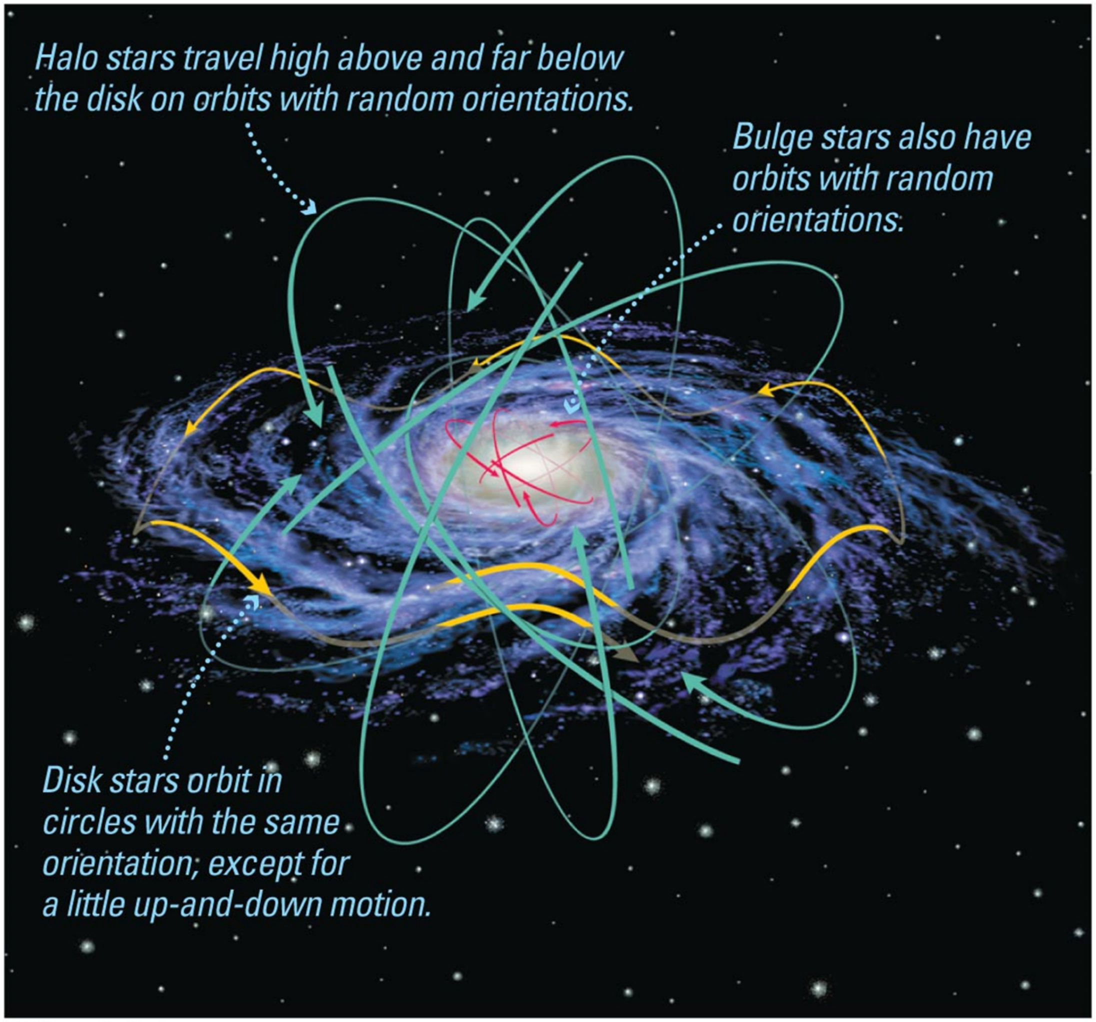



Fig.15.2

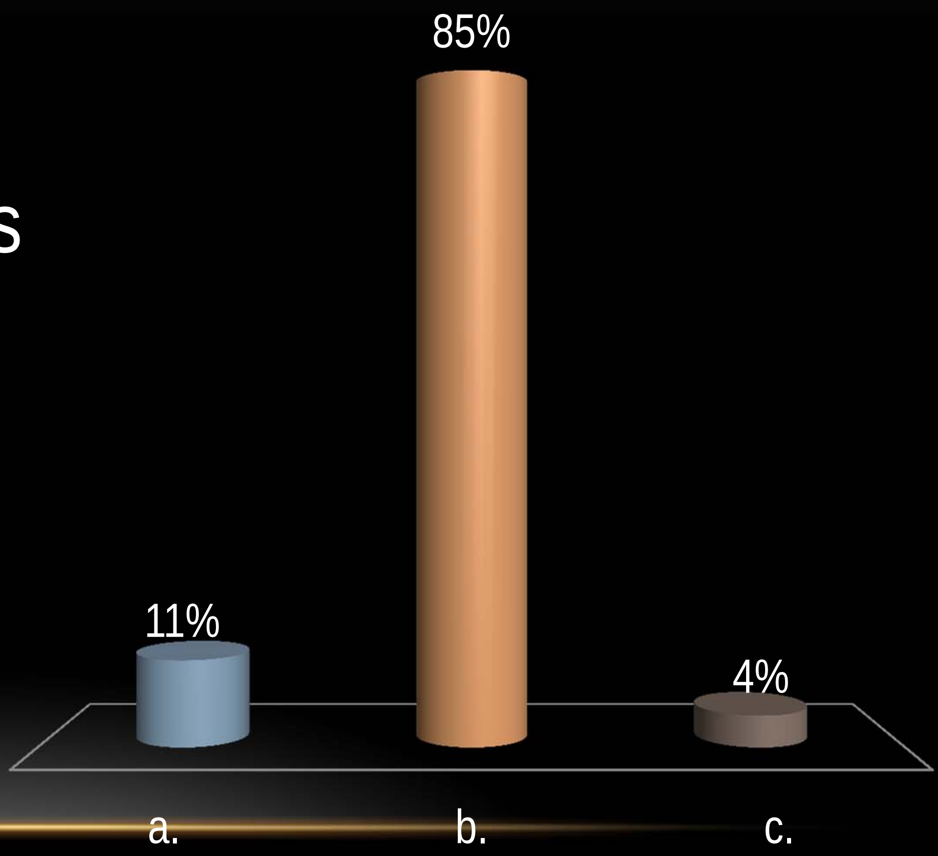
- Halo stars are on their own, but orbit like globular clusters
- Disk stars go around like kids on a carousel
- Bulge stars buzz around the very middle

# WHY DO ORBITS OF DISK STARS BOB UP AND DOWN?

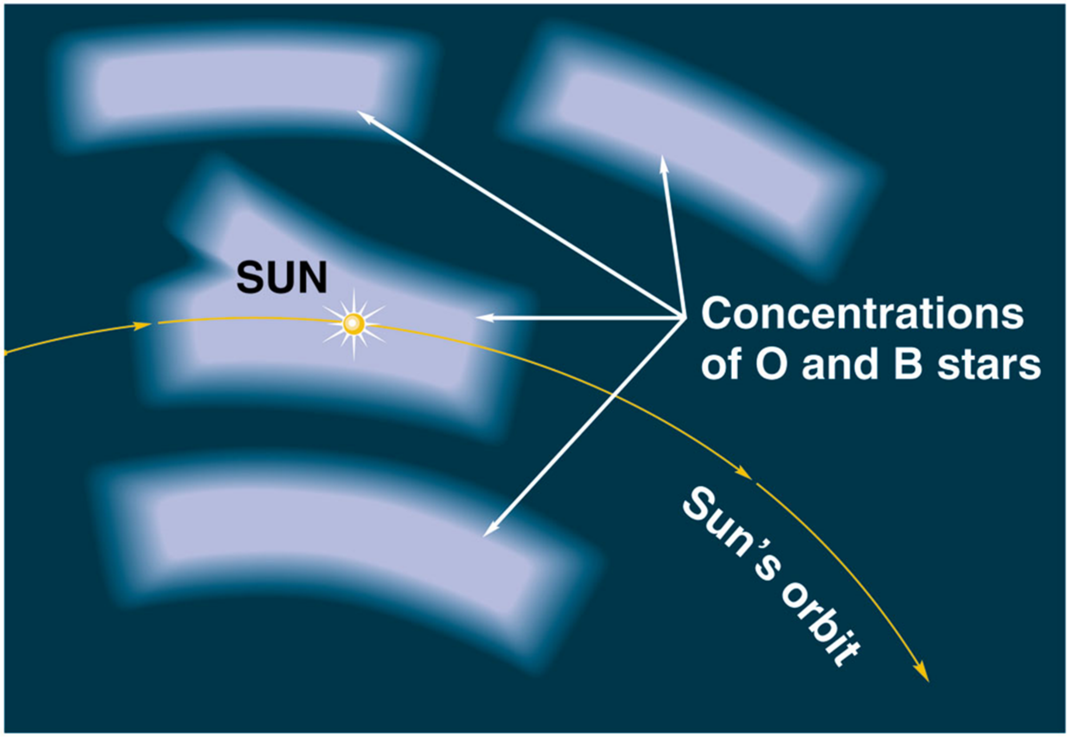
a. They're stuck to the interstellar medium.

b. The gravity of disk stars pulls them toward the disk.

c. Halo stars knock them back into the disk.

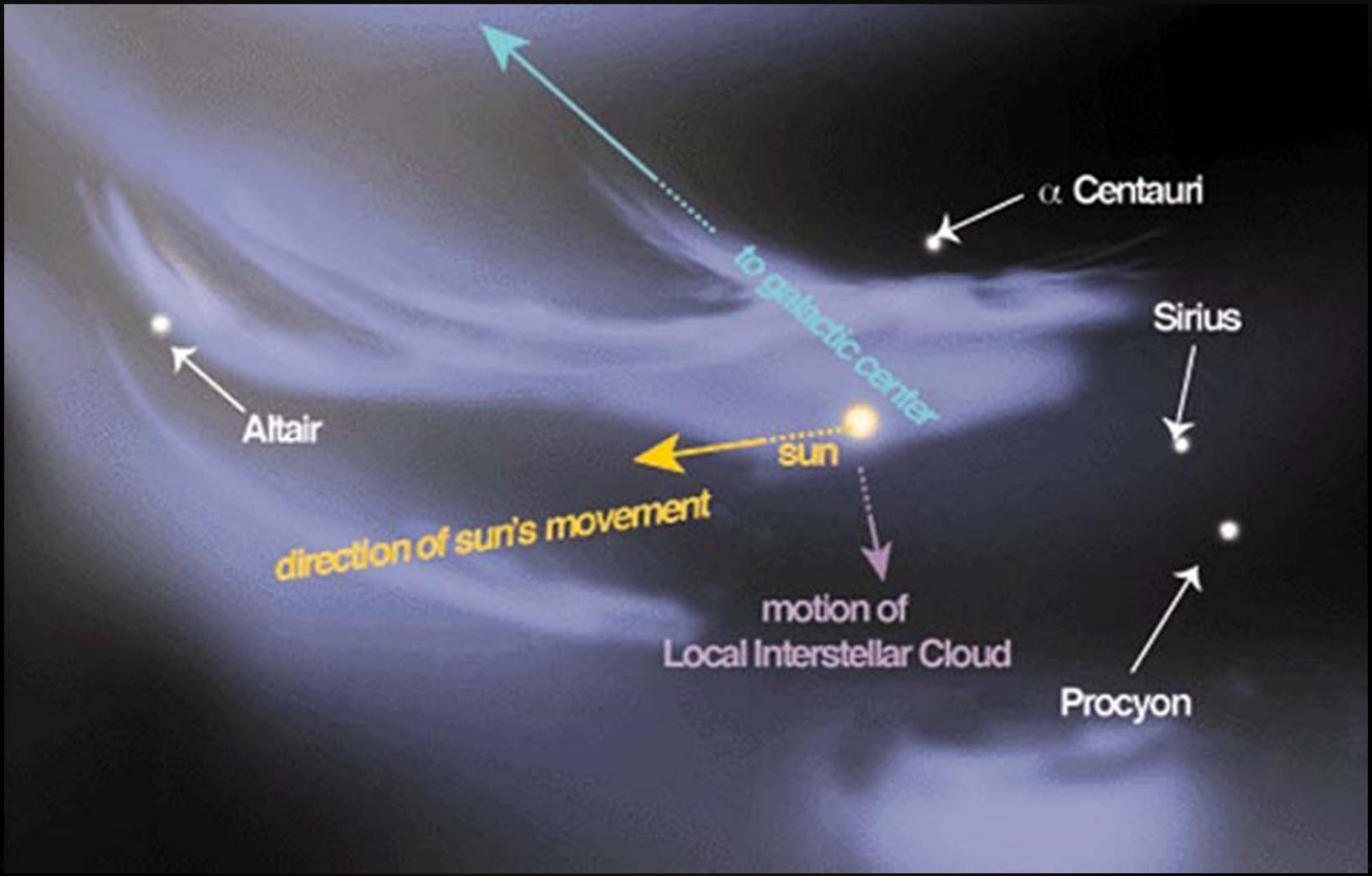


# OUR NEIGHBORHOOD, ORBIT



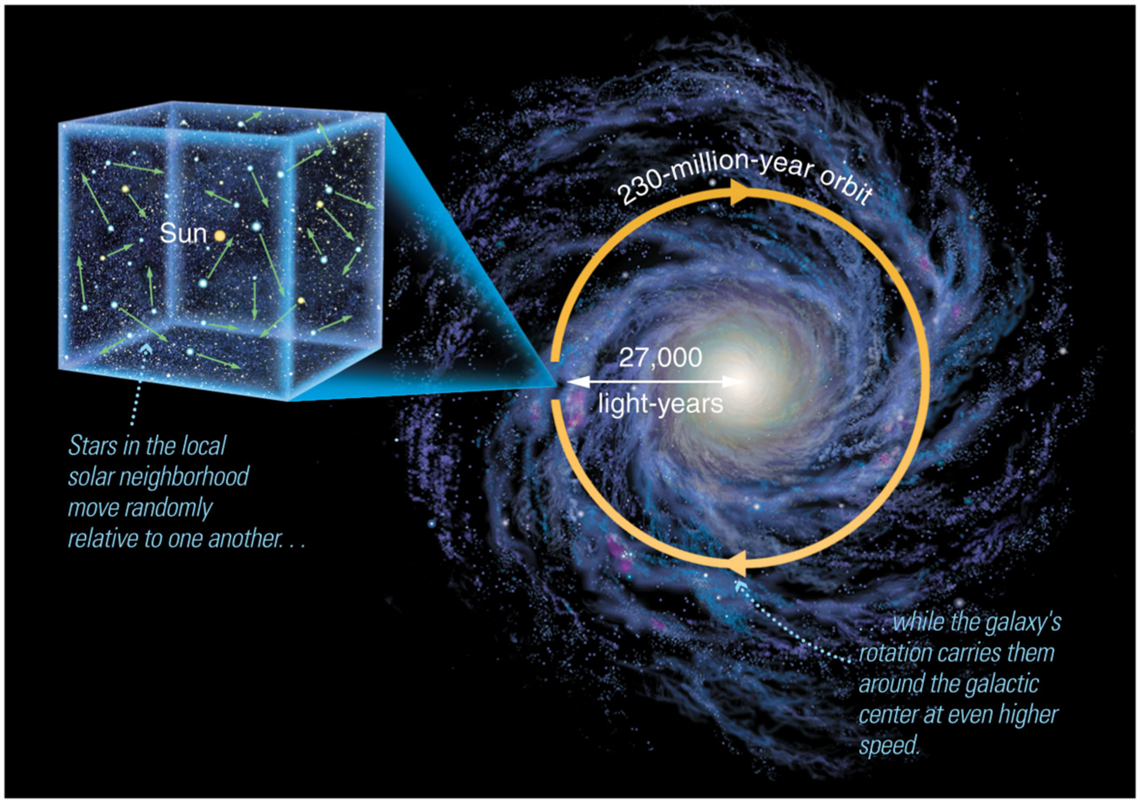

- Make a 3D map of the nearest few thousand ly
- We see bright stars forming what are apparently parts of spiral arms
- The Sun orbits the center of the galaxy once per 230 million years

# MAP OF LOCAL GAS, MOTION




Map by Linda Huff & Priscilla Schiff

# WEIGHING THE GALAXY

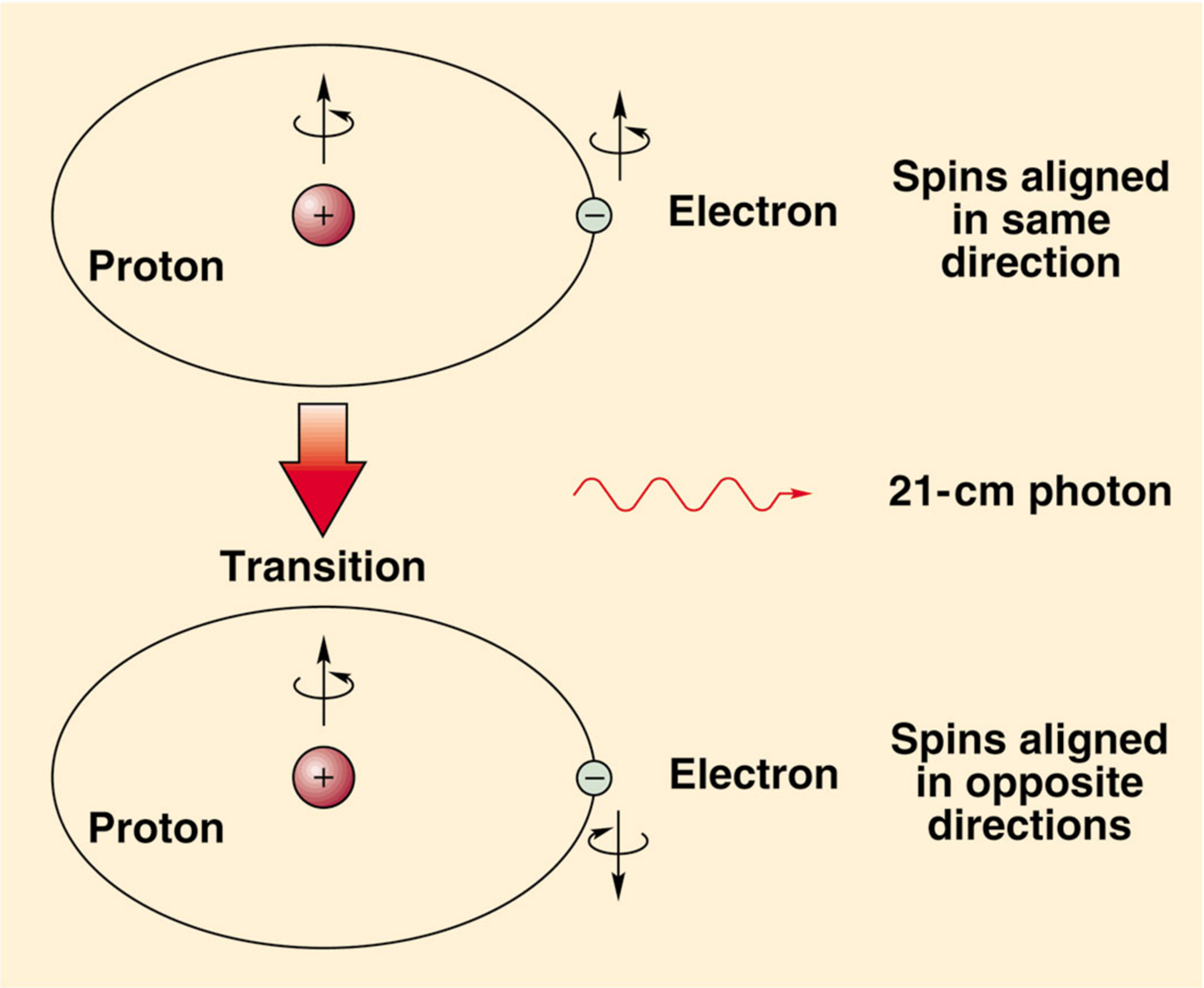



- We know galactic orbital distances and speeds for many stars
- We know how the force of gravity works
- Use this to calculate the mass of the galaxy inside the sun's orbit
  - 0.1 trillion $M_{\odot}$!
  - About 10% of this mass is visible as stars

# FUN ORBITAL FACTS

- The Sun is around 21 of “its years” old
  - *i.e.*, how many orbits about the galaxy has it made in 5 billion years?
- Moving at an orbital speed of ~220 km/h
- Currently headed towards Cygnus
- Figuring all this out was a big job – measure many star’s speeds, figure out our own speed, then subtract our own speed to see how the others stars orbit too

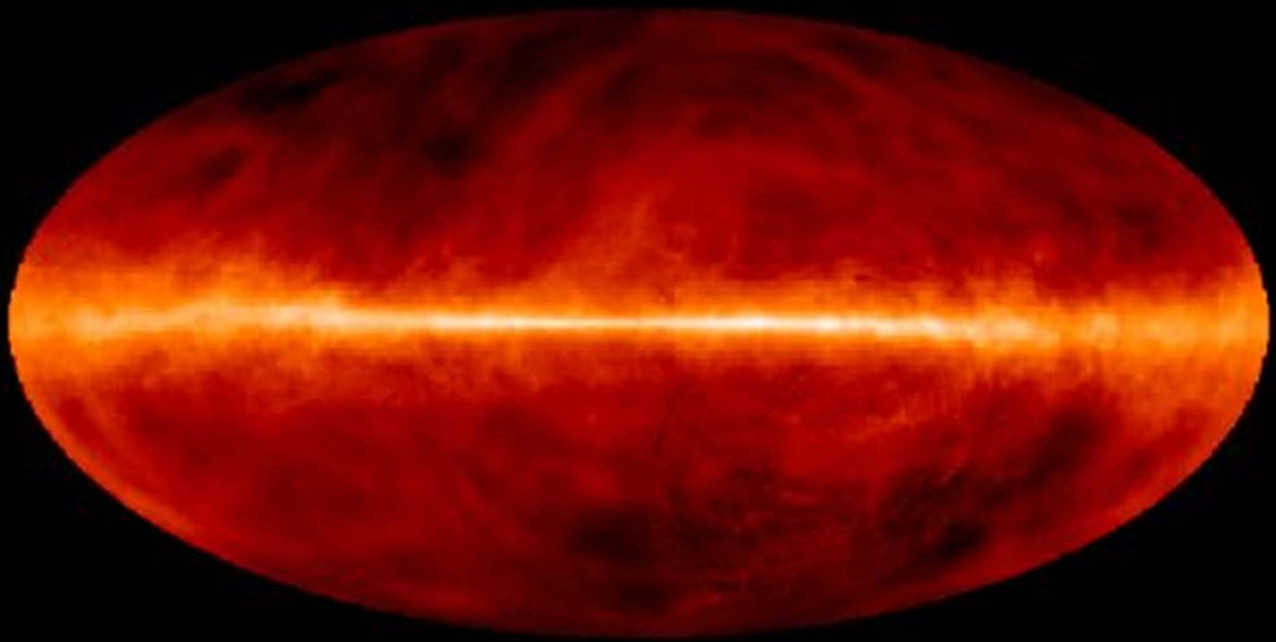
# SEEING MORE OF OUR GALAXY



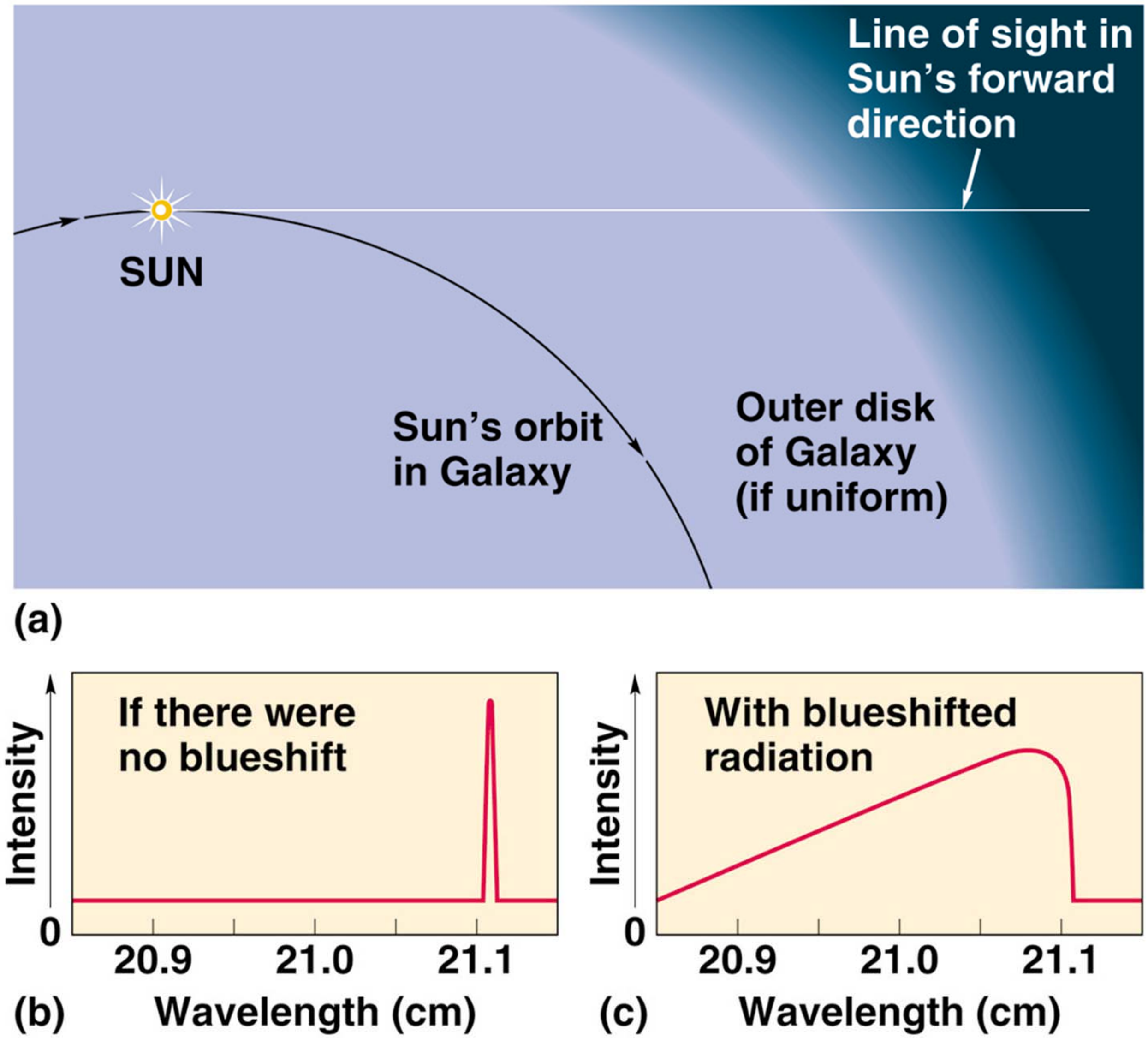

- With visible light, dust & gas block our view
  - Think of Orion's nebulae!
- But in the radio, we can look at simple Hydrogen, see right through the dust
- Radio emission process similar to an MRI

# THE SKY IN 21 CM RADIO

- We see the galactic disk, gas streamers
- By looking at the Doppler shift curves at each spot we can make a 3D Map



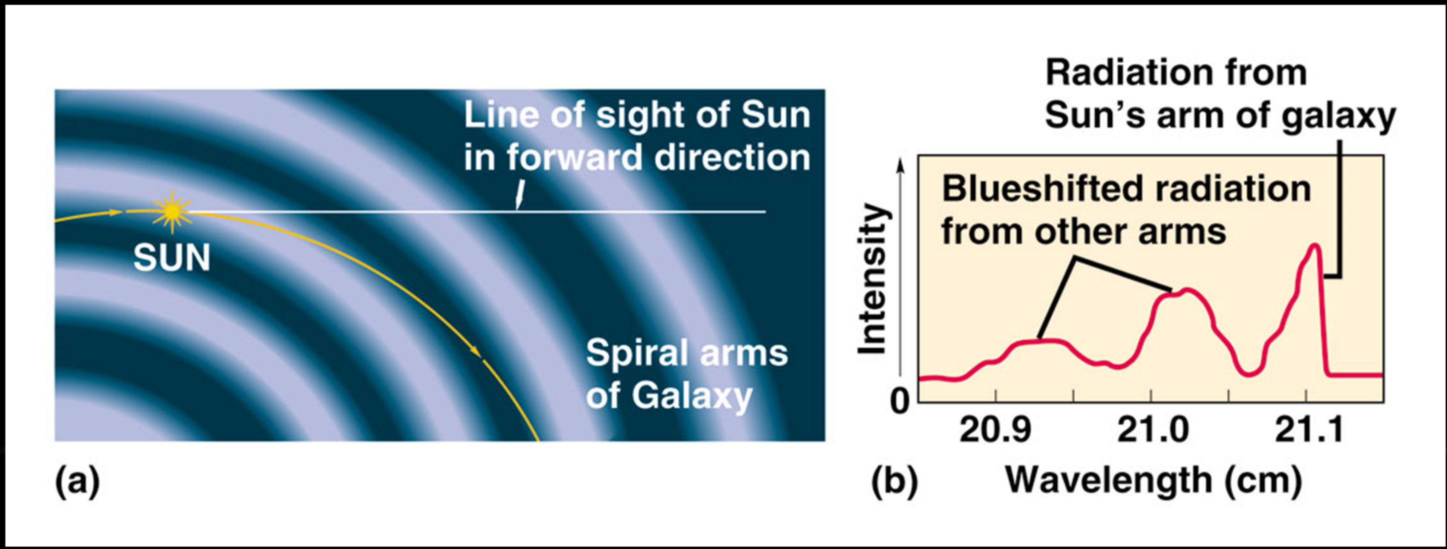
# EXTREMELY USEFUL FOR MAPPING




- Lets us measure our own orbit using the Doppler shift
- 21 cm radio line shifted as we move towards or away from gas
- Spread out because we are seeing many different areas of gas all at once

# HOW?

- We really see many arms of gas, not just a constant haze
- Looking through several spiral arms would produce this graph of blueshifts



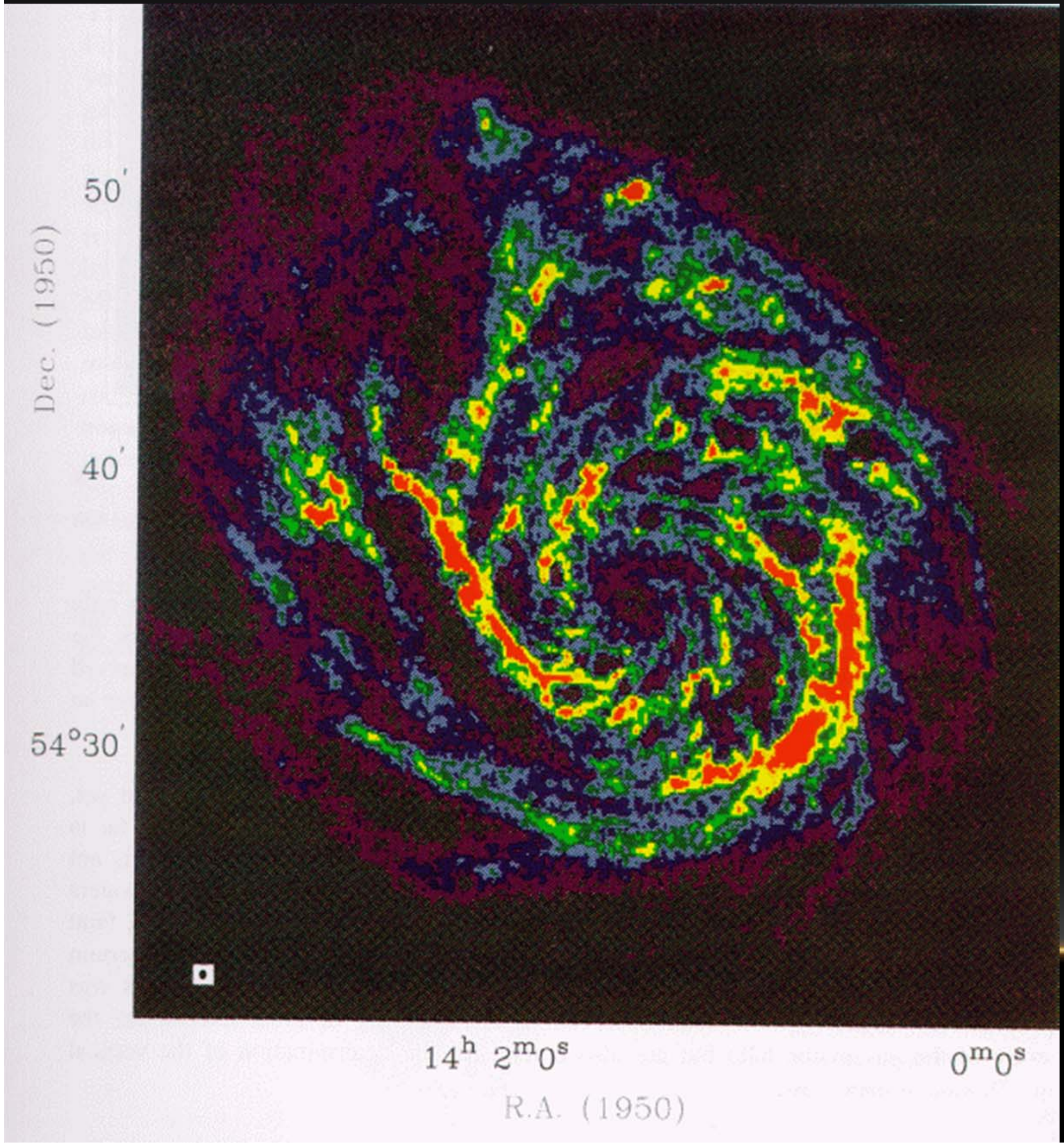
# A MILKY WAY MAP

Sun's Location

30 kpc

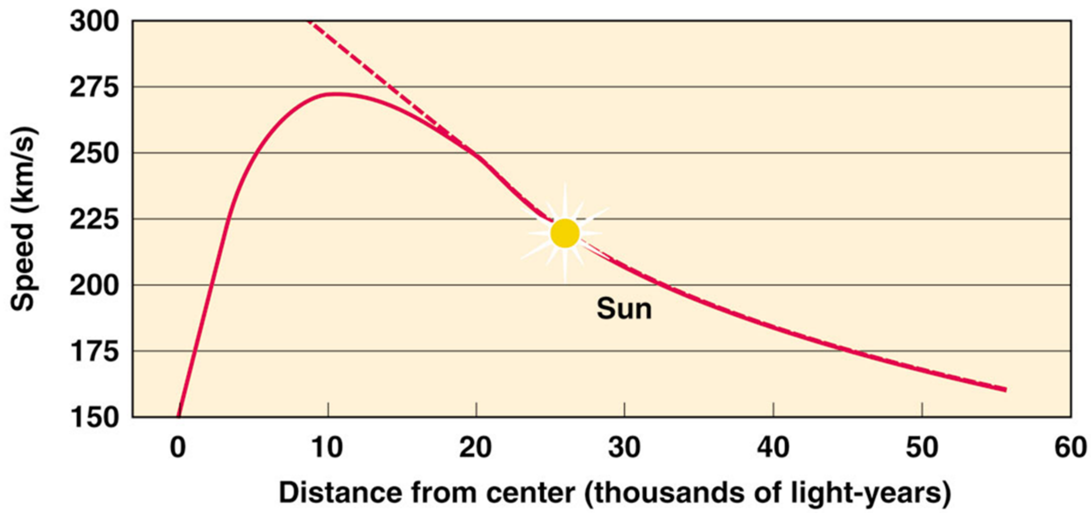
- Artist's depiction based on many surveys
  - Visual, 21cm, IR
- Note Spiral Arms, Central Bar
- Magellenic Clouds
  - Small, irregular dwarf galaxy satellites

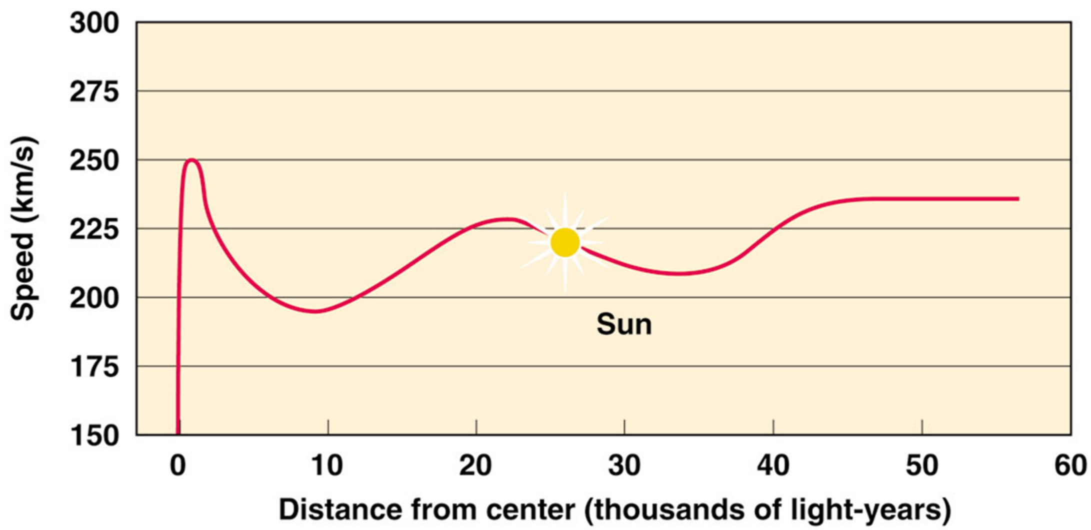
# 21 CM MAP OF M101




- Other galaxies have this radio emission too
- Comparisons of what we can see at different angles help to unravel things locally

# MANY ORBITS



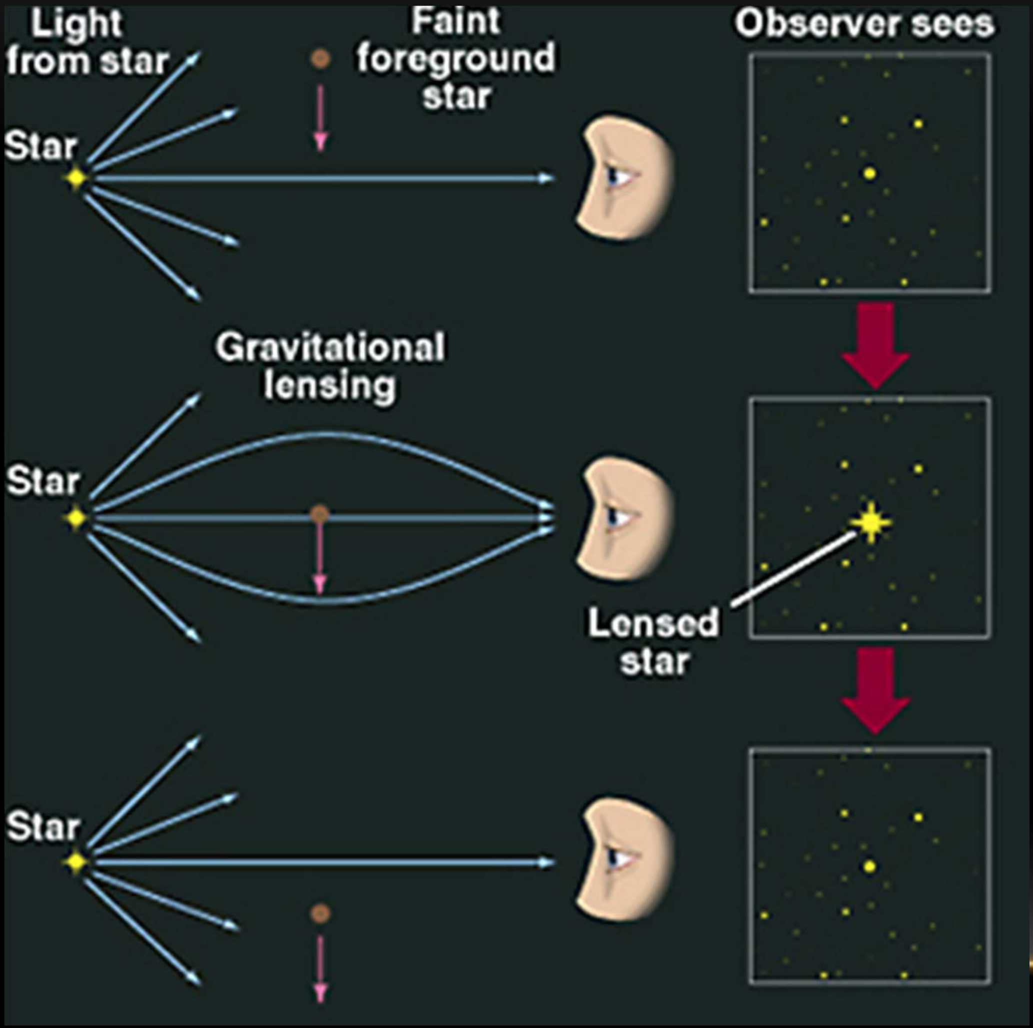




- Stars further out should go more slowly
  - Kepler's Law, top figure
- They don't!
  - Bottom figure
  - Can be explained by the presence in the Halo of a lot of mass we don't see
- The famous "Dark Matter" problem
  - More later

# STELLAR DARK MATTER?

- Is some of this unseen mass things like brown dwarfs or faint white dwarfs?
  - MACHOs (as opposed to sub-atomic WIMPs)
- Search for sudden temporary brightening of background stars as such an object gravitationally lenses it

# MICROLENSING




- Such gravitational lensing looked for by monitoring millions of stars
- Some events seen – but not enough to make up all the Dark Matter

# GALACTIC RECYCLING

- We talked about this to some extent when talking about Star Formation a chapter or two ago
- How does this fit into our Galaxy?

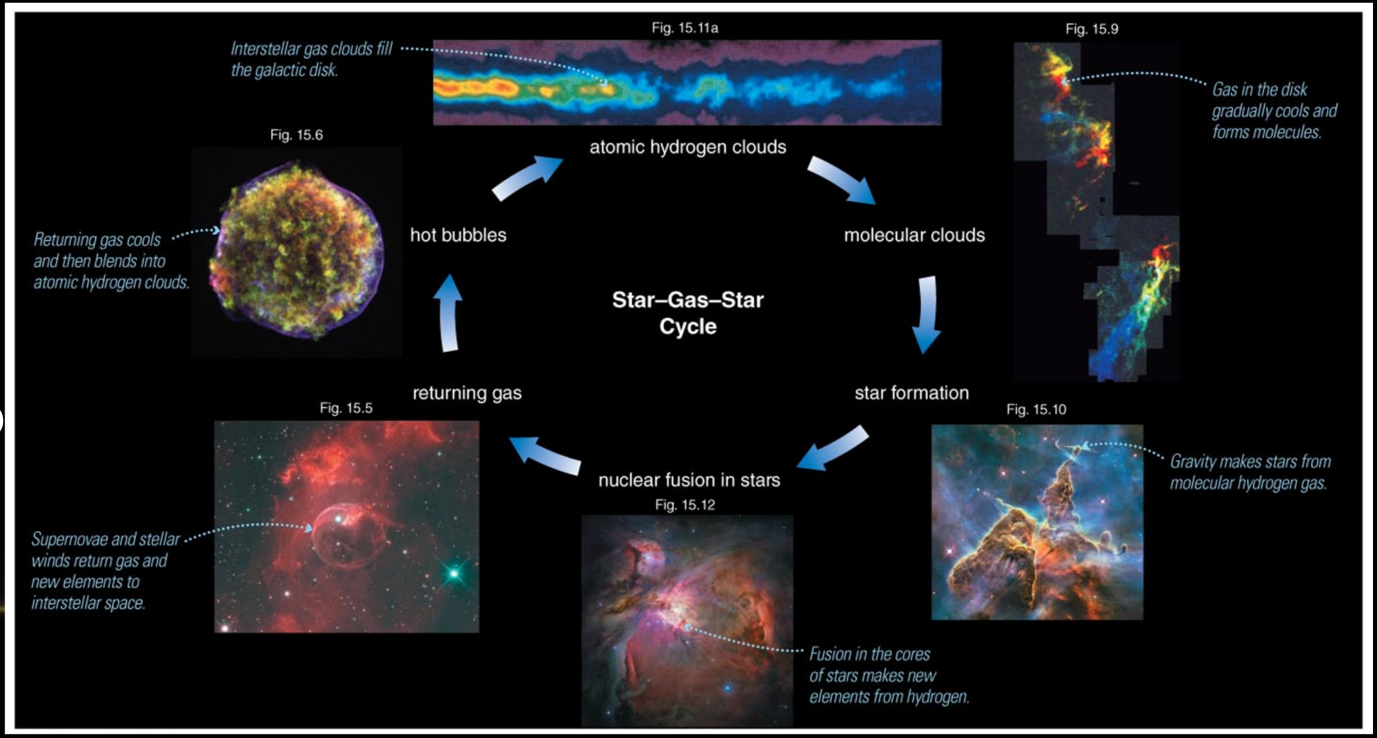



Fig.15.3

# STARS PUT GAS BACK

- Planetary Nebulae are the atmospheres of low-mass stars, mostly H and He, headed back into space leaving the burnt-out core of the star, now called a White Dwarf
- For a star like our sun, almost half its original mass gets put back

Fig.15.4

# … SOMETIMES WITH A BANG

- A supernova puts a lot of stuff back
  - Containing heavier elements made during the star's life and the explosion itself
- This young SN remnant as seen in X-rays shows the super-hot shock front as well as the somewhat cooler ejecta behind it
  - Whole thing is about 20ly across in the picture

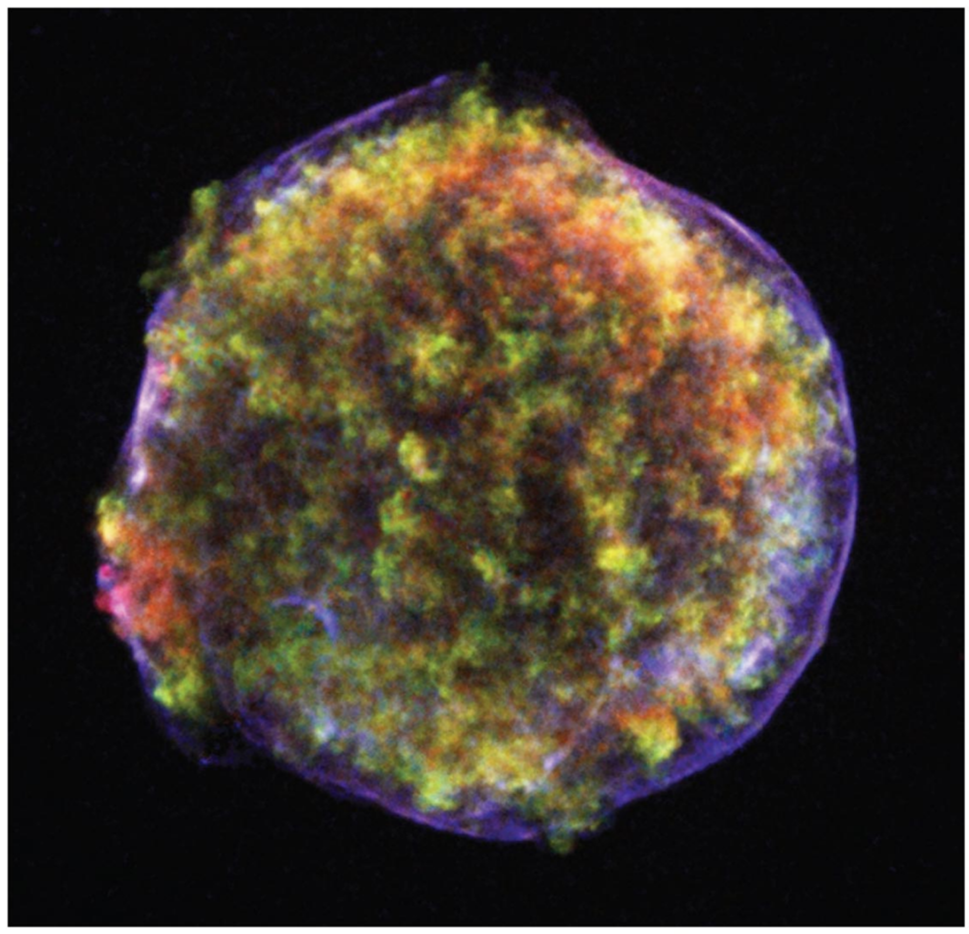


Fig.15.6

# BUBBLES

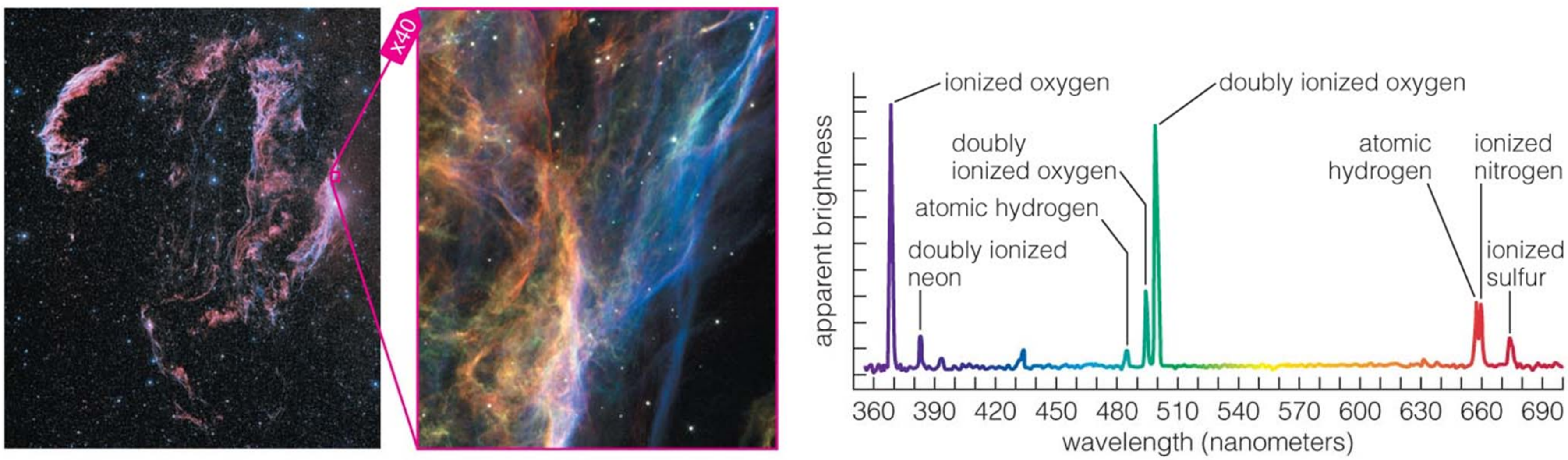
- As this expands and plows out a big sphere of space, it leaves a less-dense bubble behind
- Somewhat tamer bubbles are also made by bright hot stars and their strong stellar wind


Fig.15.5

# AN OLDER REMNANT

- The "Cygnus Loop" seen in visible light below is 130ly across

Fig.15.7




**a** This visible-light image shows the entire supernova remnant, which is about 130 light-years across and spans an angular width in our sky six times that of the full Moon.

**b** This Hubble Space Telescope image shows fine filamentary structure in a small piece of the remnant. The colors come from emission lines of the atoms and ions indicated in part c.

**c** A visible-light spectrum from the Cygnus Loop shows the strong emission lines that account for the distinct colors in the Hubble Space Telescope image.

# COSMIC RAYS

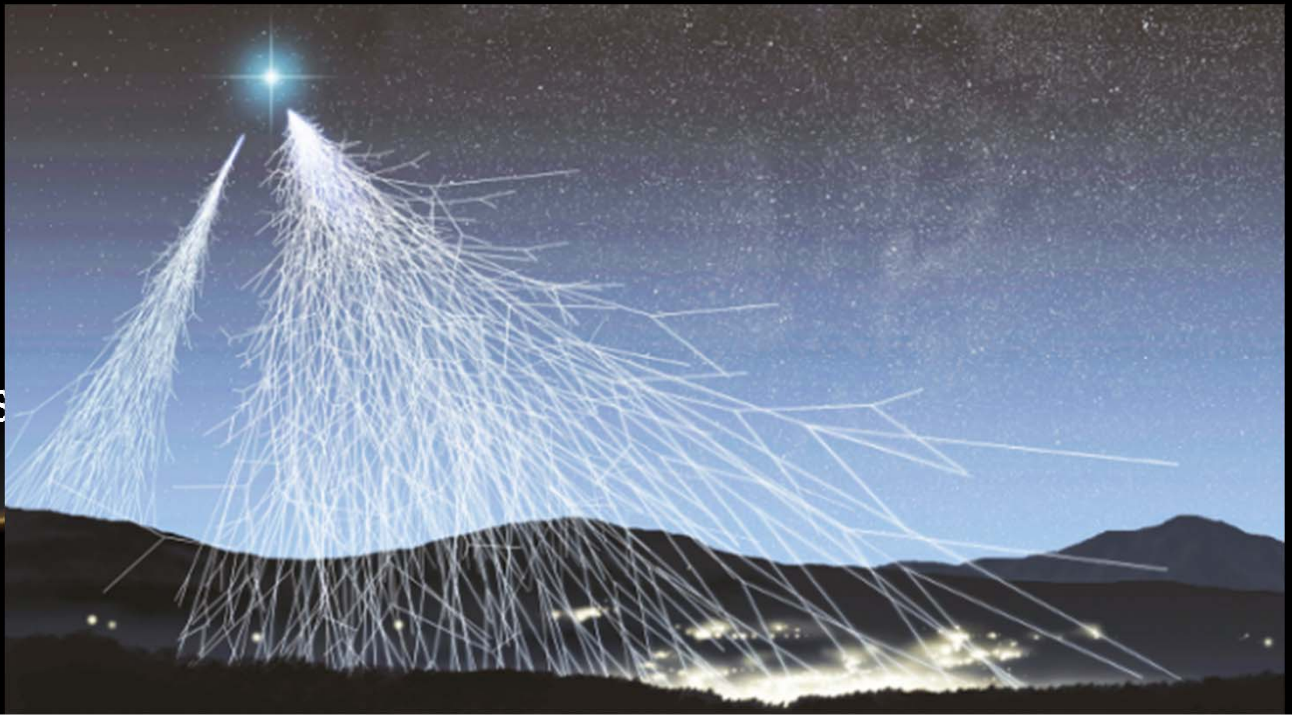
- Some particles get really clobbered by the shock front
- Get accelerated to very high energy by "Fermi Acceleration"
- When they hit earth, we call them "Cosmic Rays"

SN 1006 remnant
(NASA, ESA, & Zolt Levay)

Gamma ray signatures in SN remnants have confirmed this process, click here for a good youtube video on it

# COSMIC RAYS

- When these particles hit the atmosphere, they create a spray of secondary particles
  - Going through you right now at a rate of about one per head per second
- One of the larger sources of natural radiation you bask in
  - Gets larger if you fly a lot or live at higher altitudes



# UNDERGROUND


- So neutrino experiments go underground
  - The rock filters out a lot of the cosmic rays
- At Soudan, it's about one CR per head per week
  - Even deeper is better
  - Experiments now going to Homestake (South Dakota) and SNOLAB (Ontario)