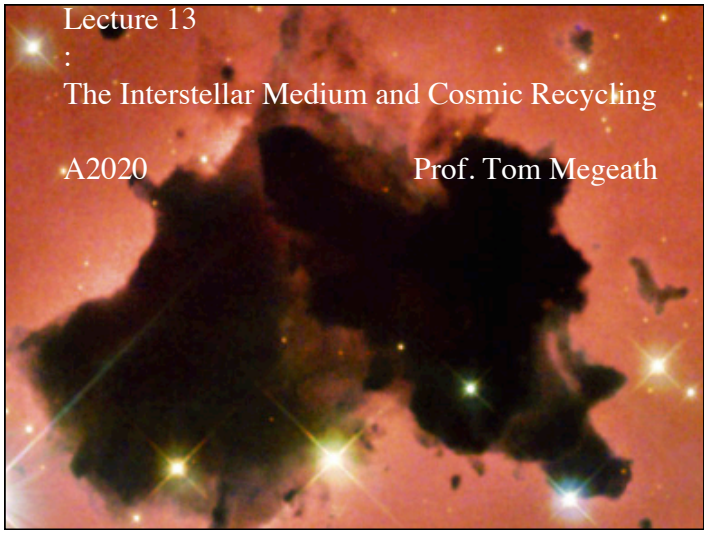
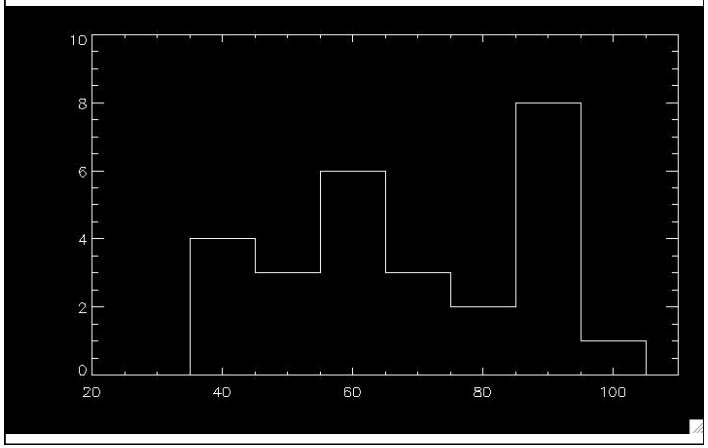
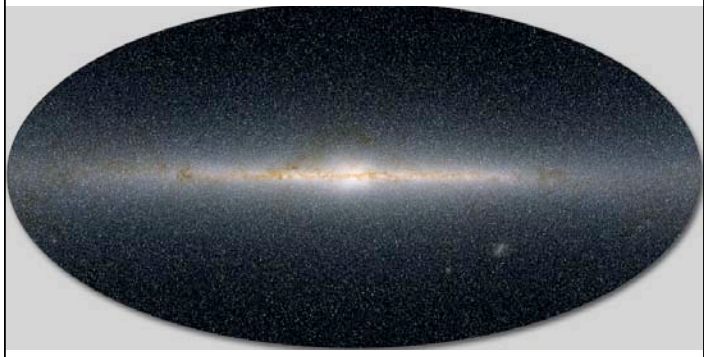


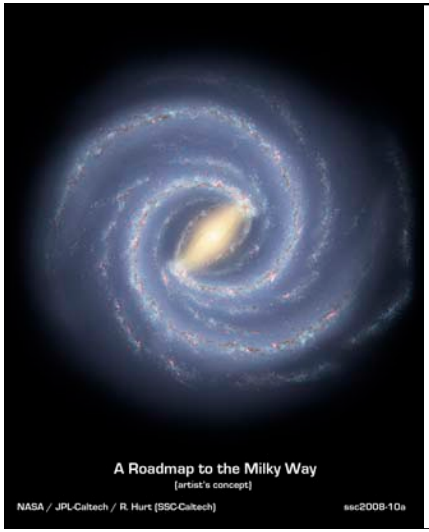
Midterm Results



The Milky Way in the Infrared



View from the Earth: *Edge On*
Infrared light penetrates the clouds and shows the entire galaxy



The Milk Way from Above (artist conception)

The Milky Way appears to have a bar and four spiral arms. Star formation and hot blue stars concentrated in arms.

The Interstellar Medium

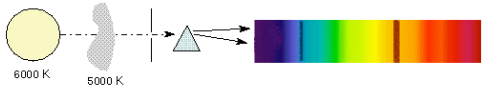
The space between the stars is not empty, but filled with a very low density of matter in the form of:

- Atomic hydrogen
- Ionized hydrogen
- Molecular Hydrogen
- Cosmic Rays
- Dust grains
- Many other molecules (water, carbon monoxide, formaldehyde, methanol, etc)
- Organic molecules like polycyclic aromatic hydrocarbons

Remainder of the Lecture

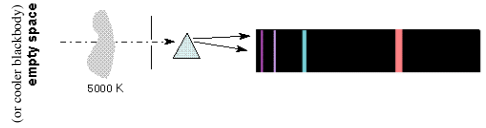
1. How we observe and study the interstellar medium
2. The multiwavelength Milky Way
3. Cosmic Recycling

How do we know the gas is there?
Review: Kirchoff Laws



Foreground gas cooler, absorption

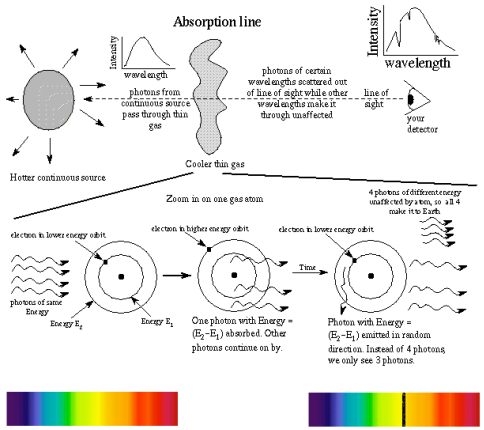
Type of spectrum seen depends on the temperature of the thin gas **relative to** the background. TOP: thin gas is *cooler* so **absorption lines** are seen. BOTTOM: thin gas is *hotter* so **emission lines** are seen.



Absorbing gas hotter, emission lines (and blackbody)

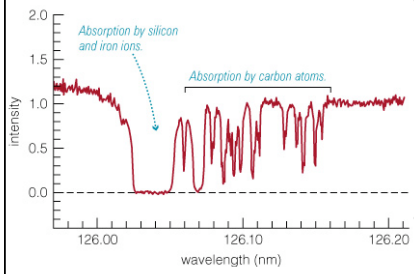
If foreground gas and emitting blackbody the same temperature: perfect blackbody (no lines)

Picture from Nick Strobel's astronomy notes: www.astronomynotes.com



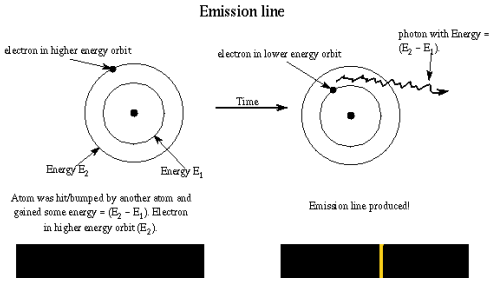
Picture from Nick Strobel's astronomy notes: www.astronomynotes.com

Observing the ISM through Absorption Lines

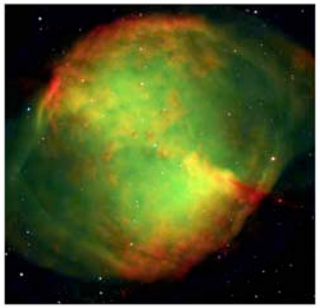


- We can determine the composition of interstellar gas from its absorption lines in the spectra of stars
- 70% H, 28% He, 2% heavier elements in our region of Milky Way

Emission Lines



Emission Line Nebula M27



Planetary Nebula NGC 6853 (M 27) - VLT UT1+FORS1

Emitted by atoms and ions in planetary and HII regions.

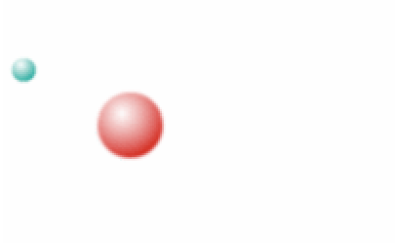
Planetary Nebula M27

Green: Ionized Oxygen
Red: Hydrogen

Gas ionized by central white dwarf

Observing Ionized Gas: Bremstrahlung

Created when electrons fly by protons.
Depending on temperature, Bremstrahlung can emit any wavelength, from radio to X-ray or visible wavelengths.
Typical temperature of gas 10,000 to 1 million Kelvin

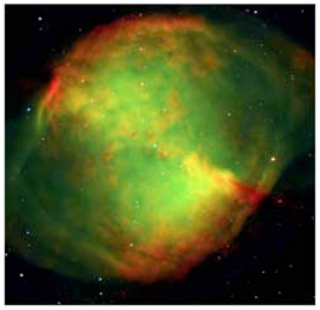


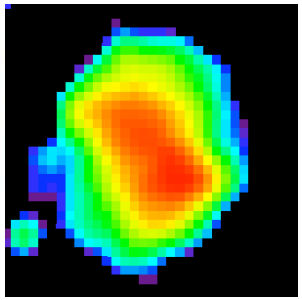
http://www.nrao.edu/whatisra/mechanisms.shtml

Bremstrahlung from M27

Emission Line

Bremstrahlung

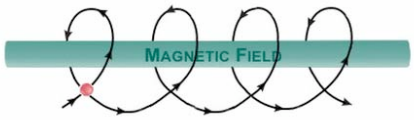




Planetary Nebula NGC 6853 (M 27) - VLT UT1+FORS1

Observing Ionized Gas: Synchroton Radiation

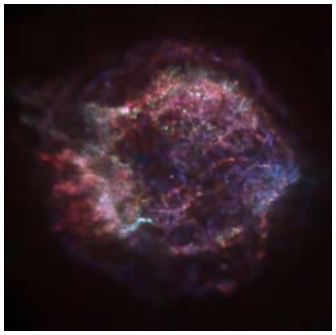
Magnetic fields are present in the Galaxy, when electrons move throught these fields, they produce synchrotron radiation. Often produced in Supernova remnants

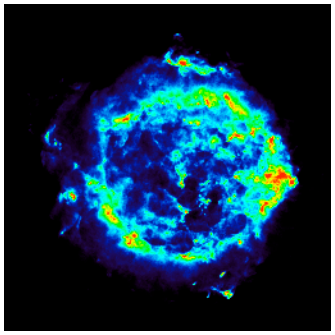


Supernova Remnant Cassiopeia A

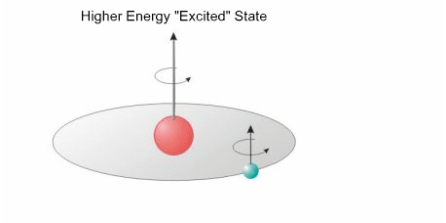
X-ray (emission line, bremstrahlung, synchrotron)

Radio map (VLA), synchrotron





Observing a radio emission line from atomic hydrogen: The 21 cm line (1428 MHz)

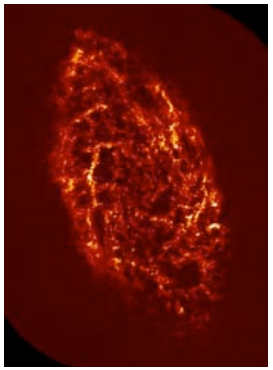


http://www.nrao.edu/whatisra/mechanisms.shtml

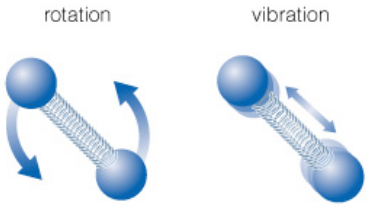
21 cm emission in the galaxy M33

Visible Light

21 cm



Emission from Molecules



Rotation produce radio wavelength rotation.

Vibrations produce infrared radiation.

Most clouds to cold for vibrations.

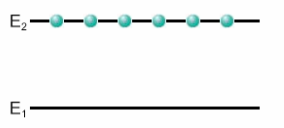
Need polar molecules, like CO (carbon monoxide).

Most common molecule, H_2, is not polar and is hard to detect

Molecular Clouds in Our Galaxy

Image Courtesy of Tom Dame

Interstellar Masers



Monochromatic: light all of a single wavelength and in phase.

Molecules seen with masers:

H_2O (water), H_2CO (formadehyde), NH_3 (ammonia), SiO (silicon monoxide), OH (Hydroxyl), HCN (Hydrogen Cyanide)

LASER: Light Amplified by Stimulated Emission of Radiation

MASER: Microwave Amplified by Stimulated Emission of Radiation

MASERS occur naturally in giant stars, molecular clouds, and disks around black holes in other galaxies

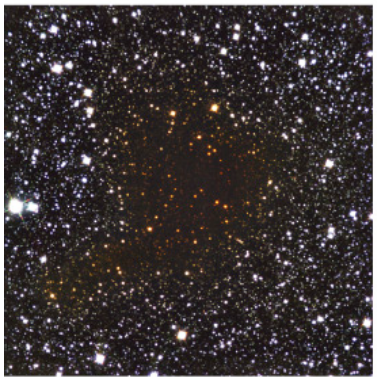
Dust in the Milky Way Galaxy

Image Courtesy of Tom Dame

Interstellar Dust

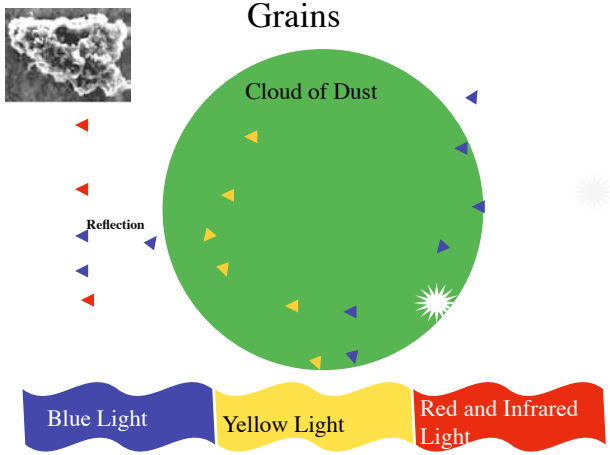
- Tiny solid particles of *interstellar dust* block our view of stars on the other side of a cloud
- Particles are < 1 micrometer in size and made of elements like C, O, Si, and Fe

Interstellar Reddening



- Long-wavelength infrared light passes through a cloud more easily than visible light
- Observations of infrared light reveal stars on the other side of the cloud

Absorption and Scattering by Dust Grains



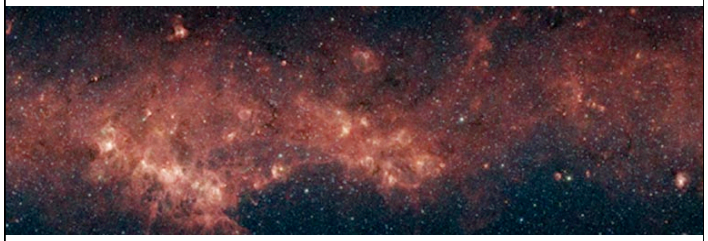
Reflection Nebulae

Very little dust: Pleiades

Lots of dust: Orion

When we see starlight scattered by dust grains, this is a reflection nebula.

Organics Molecules in Space

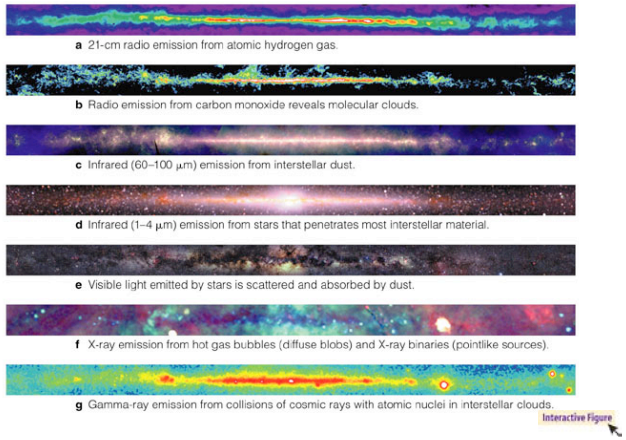


Polycyclic Aromatic Hydrocarbons, Formic Acid, Acetylene, Methanol, EthylAalcohol, and many more detected in molecular clouds.

Interstellar Medium has many components.

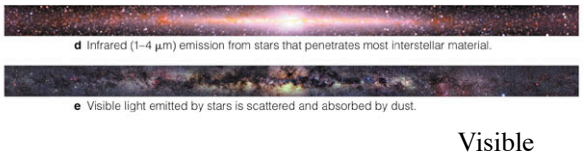
Molecular gas (20 K)
Cold atomic gas (100 K)
Hot atomic gas (10,000 K)
Ionized gas (10,000 - 1 million K)
Mixed in this is dust!!!

The Milky Way in Visible Light



We observe star-gas-star cycle operating in Milky Way's disk using many different wavelengths of light

Infrared

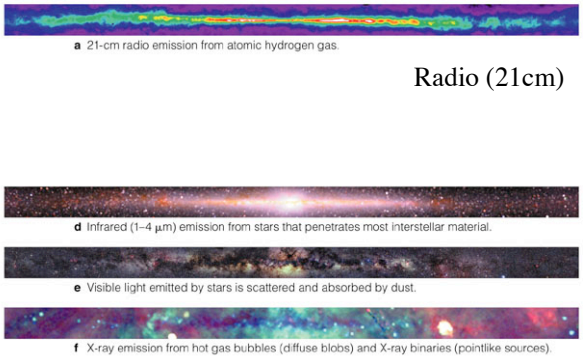


Visible

Infrared light reveals stars whose visible light is blocked by gas clouds

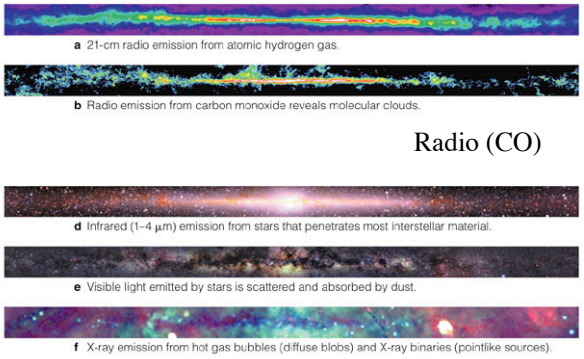
X-rays

X-rays are observed from hot gas above and below the Milky Way's disk

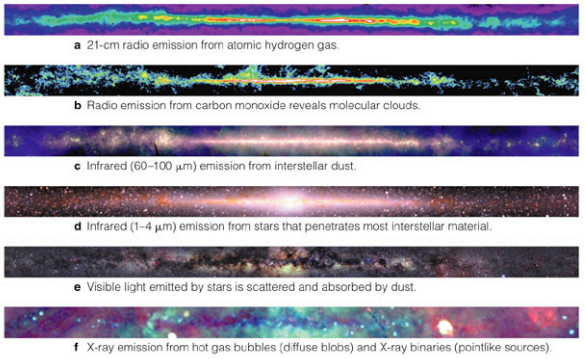


Radio (21cm)

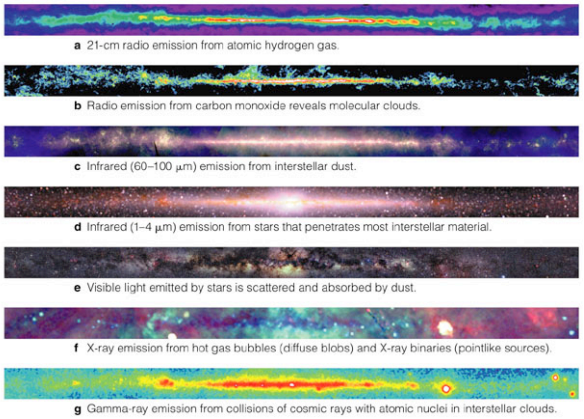
21-cm radio waves emitted by atomic hydrogen show where gas has cooled and settled into disk



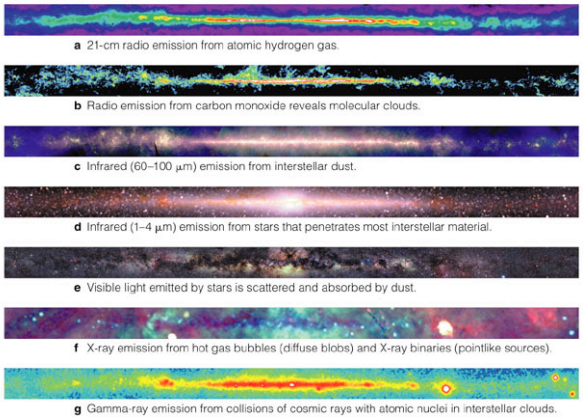
Radio waves from carbon monoxide (CO) show locations of molecular clouds



Long-wavelength infrared emission shows where young stars are heating dust grains



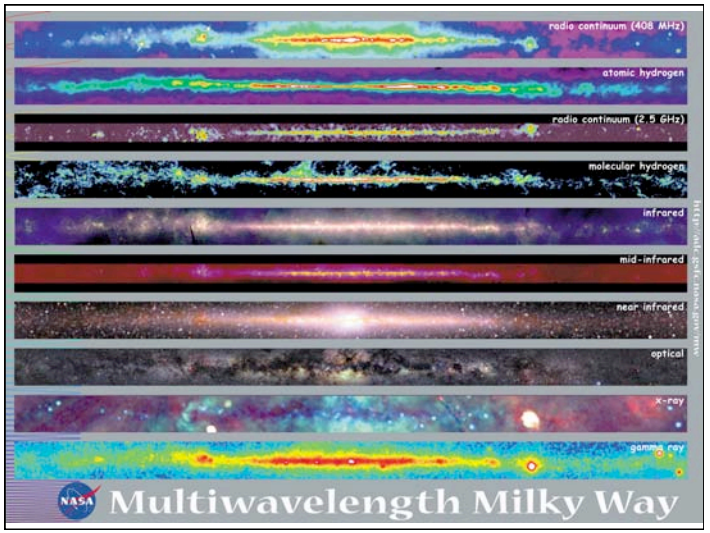
Gamma rays show where cosmic rays from supernovae collide with atomic nuclei in gas clouds



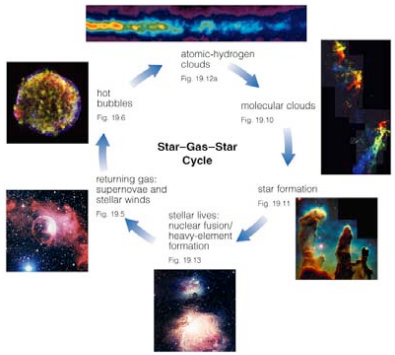
Gamma rays show where cosmic rays from supernovae collide with atomic nuclei in gas clouds

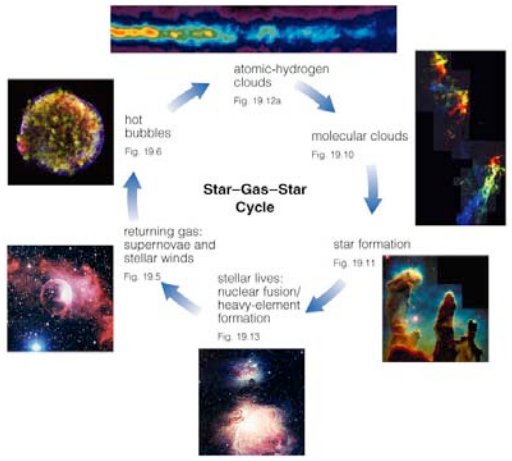
Interstellar Medium has many components.

Molecular gas (20 K)
- seen in CO maps -
Cold atomic gas (100 K)
Hot atomic gas (10,000 K)
- both seen in 21 cm maps -
Ionized gas (10,000 - 1 million K)
-seen in radio continuum and X-ray maps-
Mixed in this is dust - seen in dust absorption



How is gas recycled in our galaxy?

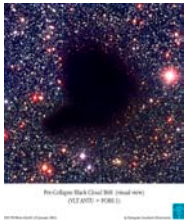




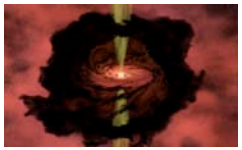
Star-gas-star cycle

Recycles gas from old stars into new star systems

Steps of Star Formation

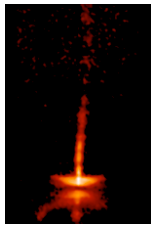


Molecular Cloud



Protostar

300,000 years



Star with disk

Not to scale!

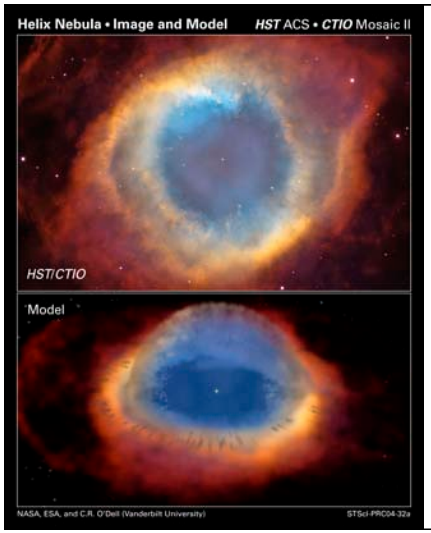
Low-Mass Star Summary

1. Main Sequence: H fuses to He in core
2. Red Giant: H fuses to He in shell around He core
3. Helium Core Burning: He fuses to C in core while H fuses to He in shell
4. Double Shell Burning: H and He both fuse in shells
5. Planetary Nebula leaves white dwarf behind

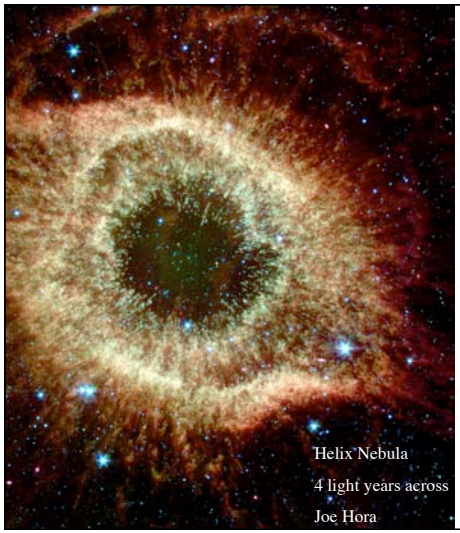
Planetary Nebulae

- Double-shell burning ends with a pulse that ejects the H and He into space as a *planetary nebula*
- The core left behind becomes a white dwarf

Binary Stars and Planetary Nebula



Model of the Helix Nebula



Enrichment of ISM by low to intermediate mass stars:

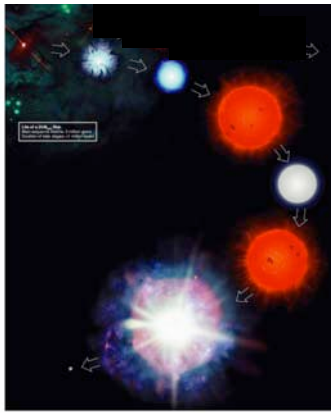
Planetary Nebulae

End point of low and intermediate mass stars

Can contain 40% of the mass.

Contain newly created Carbon, Nitrogen and Oxygen.

Dust and molecules are found in outer reaches of nebula

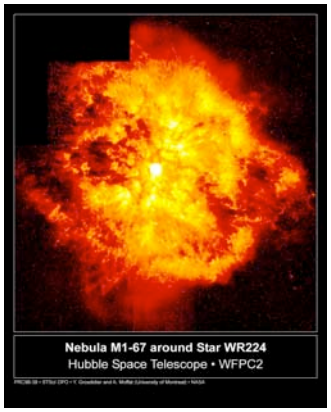


Not to scale!

Life Stages of High-Mass Star

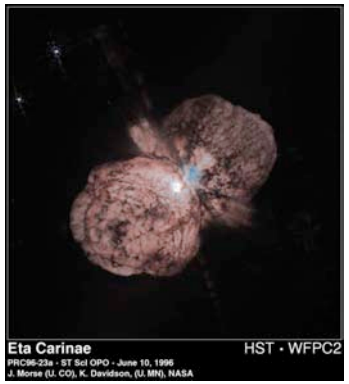
1. Main Sequence: H fuses to He in core
2. Red Supergiant: H fuses to He in shell around He core
3. Helium Core Burning: He fuses to C in core while H fuses to He in shell
4. Multiple Shell Burning: Many elements fuse in shells
5. Supernova leaves neutron star behind

Enrichment by High Mass Stars: Wolf Rayet Stars

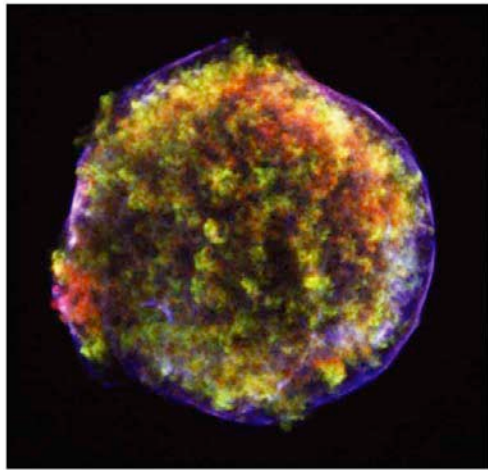


Evolved high mass stars with powerful winds, lose mass at 10^{-5} solar masses per year (10^{-14} for our sun), winds enriched in Helium, Nitrogen, Carbon and Oxygen. *Thus massive stars enrich ISM even before they supernova.*

Enrichment by High mass stars: Eta Carinae (a hypergiant)

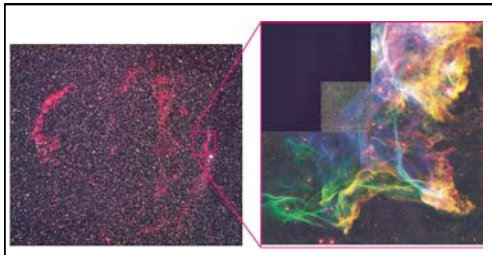


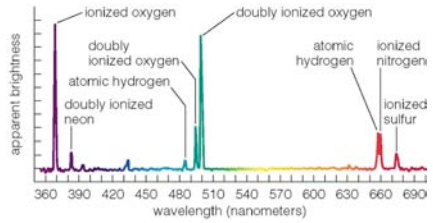
Hubble space telescope show star ejecting a cloud of gas and dust.



Enrichment by High Mass Stars: Supernovae

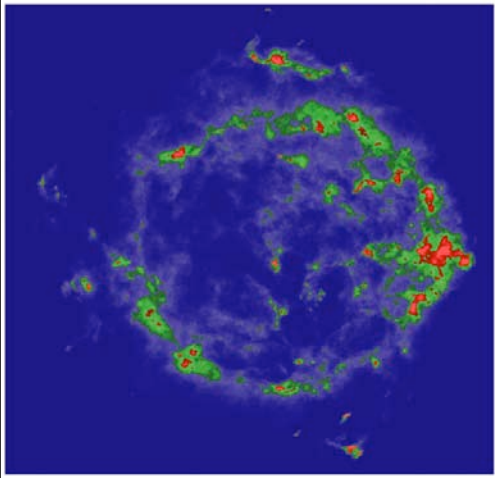
X-rays from hot gas in supernova remnants show emission lines from reveal newly-made heavy elements





Supernova remnant cools and begins to emit visible light as it expands

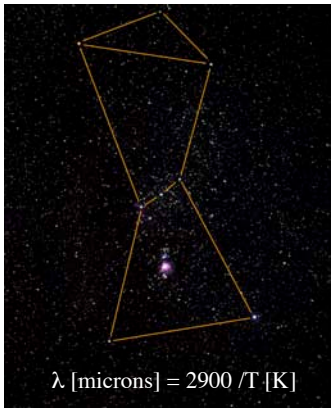
New elements made by supernova mix into interstellar medium

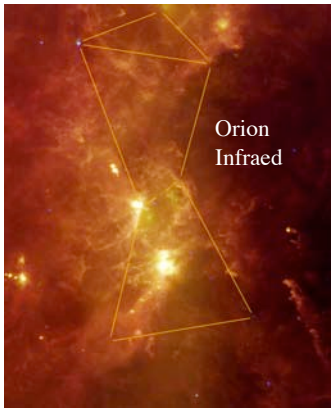


Radio emission in supernova remnants is from particles accelerated to near light speed

Cosmic rays probably come from supernovae

OB Association: High Mass Stars form in Associations with tens to hundreds of stars



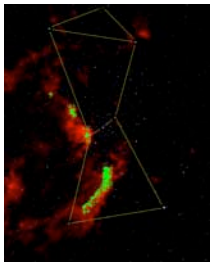


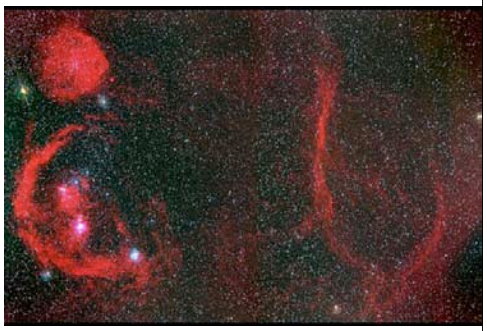
Superbubbles:

When 10 to 100 massive stars act together through winds and supernovae, sweeping up the surrounding gas in a bubble

N44 is the Large Magellenic cloud, a nearby galaxy

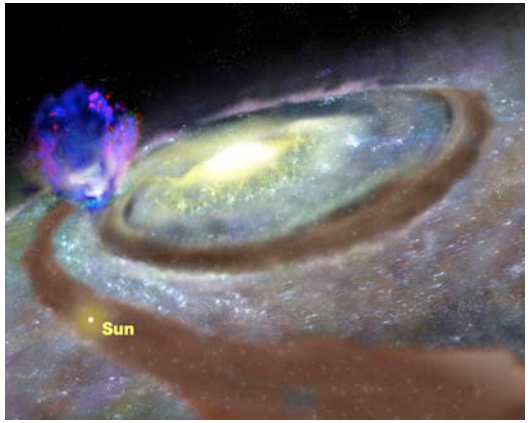
Eridanus Superbubble

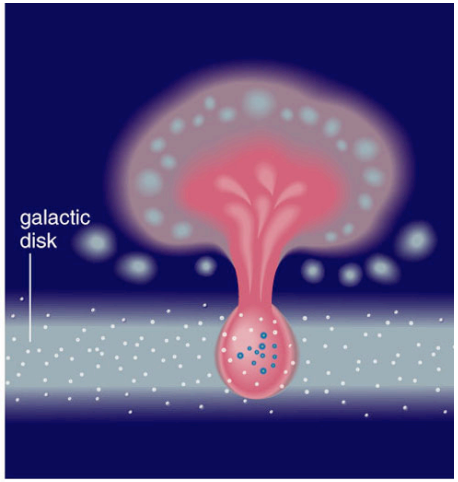




Red emission: hydrogen emission line

Galactic Fountains



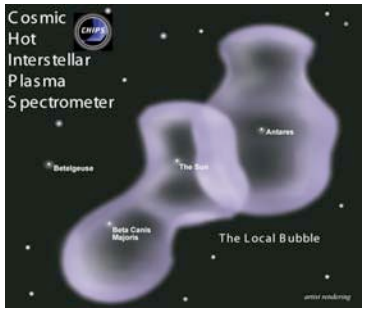


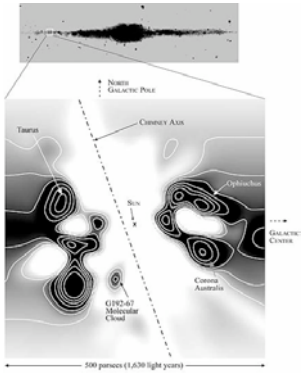
Multiple supernovae create huge hot bubbles that can blow out of disk

Gas clouds cooling in the halo can rain back down on disk

Galactic Fountains

The Local Bubble

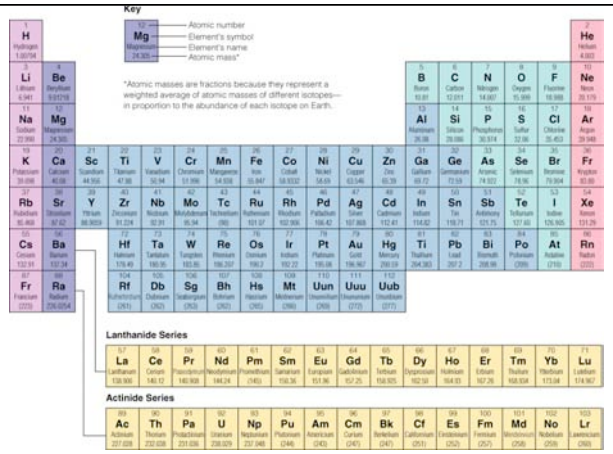




Summary of Galactic Recycling

Gas Cools

- Stars make new elements by fusion
- Dying stars expel gas and new elements, producing hot bubbles (~10^6 K)
- Hot gas cools, allowing atomic hydrogen clouds to form (~100-10,000 K)
- Superbubbles may sweep up and compress hydrogen clouds, creating molecular clouds.
- Spiral arms may also sweep up and compress hydrogen clouds, creating molecular clouds.
- Creation of dense clouds shields gas from UV photons from starlight permiting molecules to form, making molecular clouds (~30 K)
- Gravity forms new stars (and planets) in molecular clouds



Big Bang made 75% H, 25% He – stars make everything else

Overview

The Interstellar Medium

How gas and dust emit and absorb light in the ISM

What the ISM in our galaxy looks like at many wavelengths

Cosmic-Recycling:

Star formation - stellar evolution - winds, planetary nebula and supernova

High mass stars create bubbles and fountains in our galaxy.