# Astronomy 330

This class (Lecture 7):

Molecules

Next Class:

Star Formation

**HW 3 due Sunday.**

Music: *Supernova*– Liz Phair

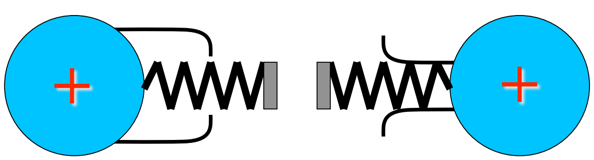


# Outline

- Sneaky little neutrinos (proof of fusion)
- C and O for the first time (1st gen of stars)
- N for the first time (2nd gen of stars)
- Molecules are for lovers!

## Why Nuclear Fusion Doesn't Occur in Your Coffee

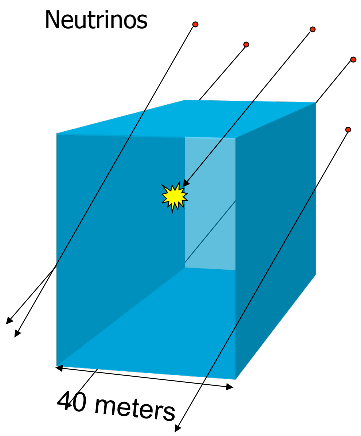
- Fusion requires:
  - High enough temperature (> 5 million K)
  - High enough density
  - Enough time

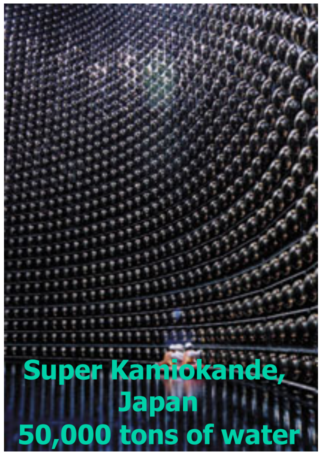


# Sneaky Little Neutrinos

- The Sun's nuclear fusion produces a particle called a *neutrino*
- Matter is almost transparent to neutrinos
- On average, it would take a block of lead over a quarter of a light-year long to stop one
- Roughly 1 billion pass through every square centimeter of you every second!

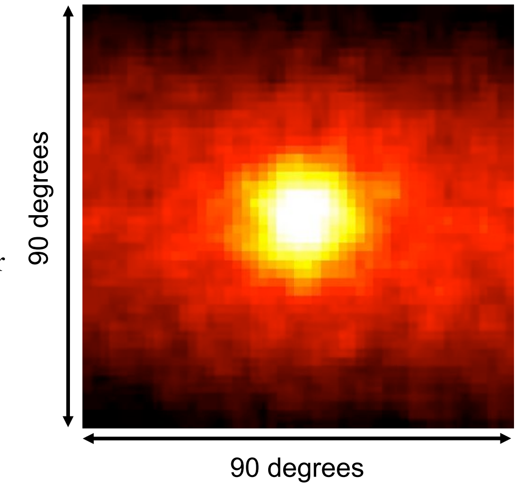
# Detecting Neutrinos




# The Sun in Neutrinos

- **Confirmation** that nuclear fusion is happening in the Sun's core
- 500 days of data
- As they can only be produced by nuclear processes, our energy source concept must be fundamental




# Cosmic Gall

**NEUTRINOS, they are very small.**
**They have no charge and have no mass**
**And do not interact at all.**
**The earth is just a silly ball**
**To them, through which they simply pass,**
**Like dustmaids down a drafty hall**
**Or photons through a sheet of glass.**
**They snub the most exquisite gas,**
**Ignore the most substantial wall,**
**Cold shoulder steel and sounding brass,**
**Insult the stallion in his stall,**
**And scorning barriers of class,**
**Infiltrate you and me! Like tall**
**and painless guillotines, they fall**
**Down through our heads into the grass.**
**At night, they enter at Nepal**
**and pierce the lover and his lass**
**From underneath the bed-you call**
**It wonderful; I call it crass.**

very little
hardly

- *Telephone Poles and Other Poems*, John Updike, Knopf, 1960

# How much Gas do we have left?

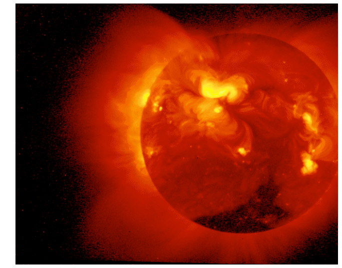
- Total energy available is easily calculated by mass of hydrogen in Sun and energy released by each hydrogen conversion.
- We only have about 5 billion years left!


http://skeptically.org/sitebuildercontent/sitebuilderpictures/.pond/suv-econ-gas-pump.jpg.w300h294.jpg

# Think-Pair-Share

If we could sustain fusion in the lab we could meet humankind's energy needs nearly forever! Why is it so difficult to achieve this, when stars do it every day?

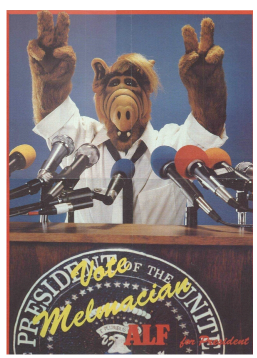
# Nuclear Fusion in the First Stars



- Core $T$ > 10 million K
  - Violent collisions
  - $e^-$ stripped from atoms (ionized)
  - Nuclei collide, react
    - They get close enough that the nuclear strong force takes over.
- Thru series (chain) of reactions
- 4 protons ⇨ helium (2p,2n) nucleus + energy
- **Fusion:** light nuclei combine ⇨ heavier nuclei

# Alf Doesn't Care?

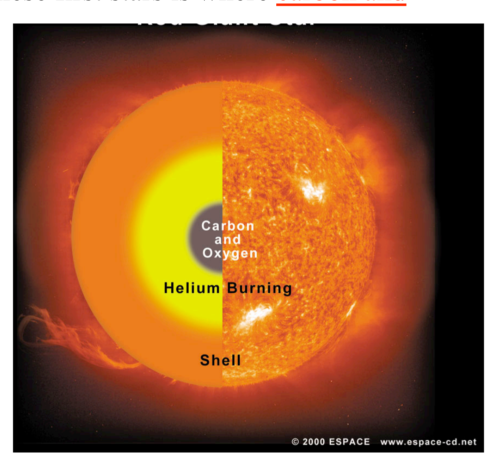
- A star in hydrostatic equilibrium will not shrink or swell.
- It will maintain constant size, density, and temperature for more than a million years!
- At this point, the star is called a main sequence star.
- If stars were not constant, what effect would that have on life on orbiting planets. Ultraviolet light variations?




http://alf.disim.com/photos/photoposter.htm

# The First Stars

- In the cores of the first stars, it gets hot enough for nuclear fusion.
- In the internal furnace of these first stars is where carbon and oxygen are created for the first time in the Universe.
- Higher density and temperature of the red giant phase allows for the creation of sulfur, phosphorous, silicon, and finally iron.



# Question

The rocky planets that formed around the first stars would have been?

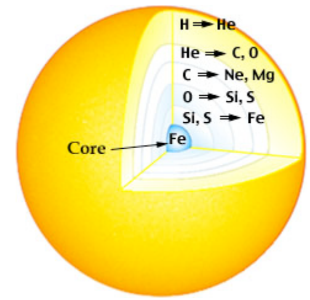
a) A perfect place to raise a family.
b) Devoid of the molecules necessary for life .
c) Too close to the massive star to have life.
d) Inhabited by truly alien creatures.
e) Trick question. There would not have been any rocky planets.

# Iron – The End of the Road

- "Burning" heavier and heavier atoms in the fusion process
- Each stage faster than the last
- After iron - no fuel left!
  - It requires energy to produce heavier atoms

| Stage | Temperature | Duration |
|---|---|---|
| H fusion | 40 million K | 7 million yr |
| He fusion | 200 million K | 500,000 yr |
| C fusion | 600 million K | 600 yr |
| Ne fusion | 1.2 billion K | 1 yr |
| O fusion | 1.5 billion K | 6 mo |
| Si fusion | 2.7 billion K | 1 day |

Values for a $25M_{Sun}$ star

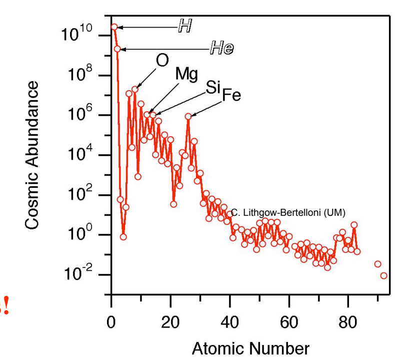



# Supernova!

http://www.spacetelescope.org/images/screen/heic0609c.jpg

# Making Heavy Elements

- The star goes supernova and explodes. Some of C, O, P, S, Si, and Fe get carried away. At this point, even heavier elements can be made.
- During the explosion, energy-consuming fusion reactions are possible
- These by-products are *blasted* into space (>90% of star)
- Supernovae provide much of the building blocks for planets… and us!
- **We are recycled supernova debris!**
- **We are Star stuff.**

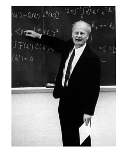



Delenn, B5

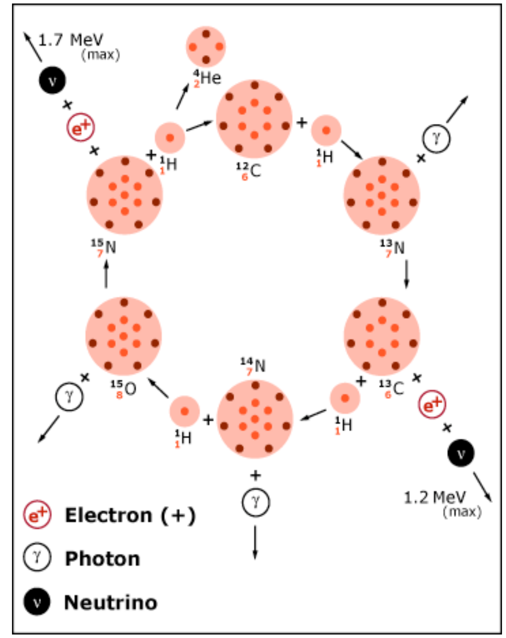
# CNO-ing

- Now the Universe has some C and O laying around, it can use it.
- In the next generation of stars, the CNO cycle can be used in the fusion process.
- It is more efficient in stars slightly more massive than the Sun.
- Remember the Sun mostly uses proton-proton fusion.

# The CNO Cycle



Hans Bethe



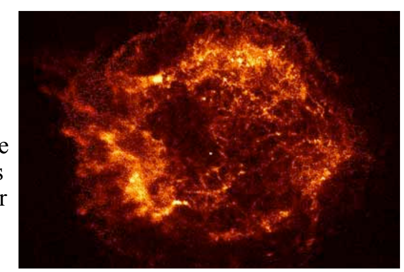

# The Second Generation

- The first stars blew up their new elements into the proto-galaxy.
- Now, the second stars form in the ashes of the first.
- With C and N, the 2nd generation can form helium through the CNO cycle, in which most of the Universe's nitrogen is created.
- The 2nd generation also eventually explodes blowing nitrogen and the other elements into the galaxy.

A supernova in a nearby galaxy. A single star exploding can be brighter than millions of stars in the nucleus.

# The Next Stars

- The new atomic elements from the 1st and 2nd stars are spread out into the galaxy.
- The Sun must be at least a 3rd generation star as we have **nitrogen** in abundance.
- Indeed, the percentage of heavier elements is larger toward the center of the galaxy, where the first generation of stars probably formed. (Seen in ours and other galaxies.)
- **Again, we are star stuff.**
- Keep in mind that this is all from the nuclear strong force– fusion.



The Chandra x-ray observatory has shown that the CasA supernova has flung calcium, iron, and silicon into space.

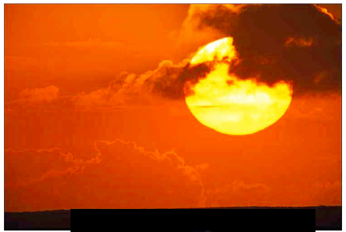
# Question

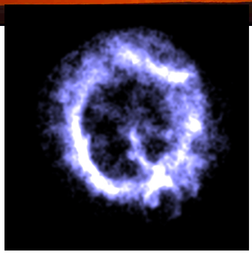
HONC is important for life. In which order did these elements first appear in the Universe?

a) H, O, N, C
b) All at once
c) H, C, O, N
d) N, O, H, C
e) C, O, N, H

# Star Stuff

- Now, we have the elements crucial to life in the Galaxy-- **HONC**.
- There are about 92 elements found in the Universe and about 20 more elements that have been created in laboratories (but decay quickly).
- The 92 elements were almost all made in the interiors of massive stars or during a supernova explosion.

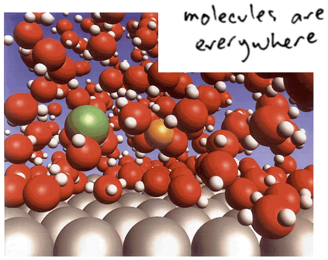




http://www.astronomyinfo.pwp.blueyonder.co.uk/starstuff.htm
http://antwrp.gsfc.nasa.gov/apod/ap991209.html

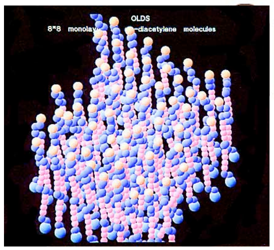
# Star Stuff and Earth Stuff


- Deep inside stars the electrons are stripped away, and only the nucleus (and the strong nuclear force) play roles.
- But, most of the important aspects of life depend on molecules. That involves electrons and the electromagnetic force that keeps the electron(s) with the nucleus.

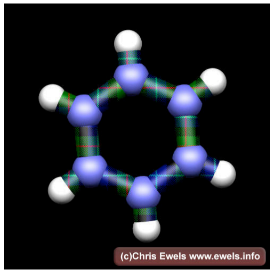



http://nanokids.rice.edu/explore.cfm
http://www.toothpastefordinner.com/archives-sum02.php
http://www.psc.edu/science/Voth/Voth.html

# Molecules



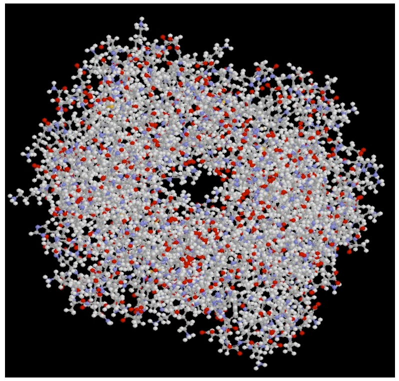

- Combination of 2 or more atoms such that they are bound together without their nuclei merging.
- Just like an atom is the smallest piece of an element, a molecule is the smallest piece of an compound.
- When dividing water, smallest division, before separation of hydrogen and oxygen.




http://www.ph.qmw.ac.uk/research_bk/theory.htm

# Molecules

- Wow! An enormous jump in complexity. There are only about 115 elements, but there are millions of known molecules and nearly infinite number of possibilities.
- Some of the key life molecules contain billions of atoms.

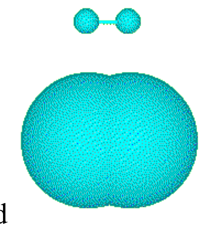


http://www.bris.ac.uk/Depts/Chemistry/MOTM/silly/sillymols.htm

http://www.steve.gb.com/science/molecules.html

# Example $H_2$

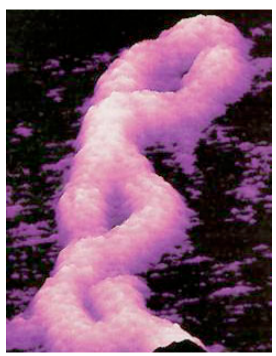
- $H_2$ is the simplest molecule– two hydrogen atoms.
- What does that mean?
  - There are 4 particles.
    - 2 protons of the 2 nuclei, which repel each other
    - 2 electrons of the 2 atoms, which repel each other
  - But
    - The electron of each atom will attract the other nucleus
- Although not obvious, the 2 attractive forces and 2 repulsion forces equal out.
- The electromagnetic force works for hydrogen, but there is no $He_2$.



http://www.historyoftheuniverse.com/h2.html

# Molecule Benefits for Life

- Molecules can easily be broken apart, but are also stable.
- Flexibility in arrangement.
- Plethora of molecules.
- Electromagnetic force is much weaker than strong nuclear force, lower energies– lower temperatures.
- Perfect for life.



http://www.time.com/time/daily/special/genetics/

# Question

Life is based on molecules instead of atoms because

a) molecules are bigger than atoms.
b) there are many more molecular options than elements.
c) molecules survive better at high temperatures.
d) molecules survive better at low temperatures.
e) one word– ducks.

# How to Write Molecules

- We'll talk about $H_2$ or $CO_2$
- Or

Molecular Hydrogen

H-H

Single bond

Sharing 1 electron pair

Carbon Dioxide

O=C=O

Double bond

Sharing 2 electron pairs

http://www.gristmagazine.com/dogood/connections.asp

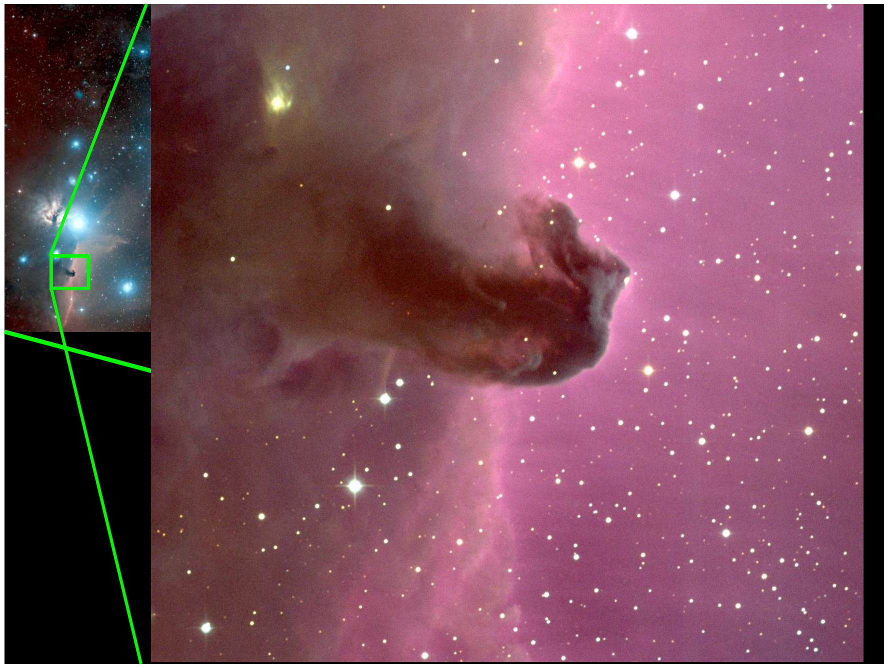
# Talkin' About a Revolution

- Molecules first showed up in space after enough heavy elements accumulated.
- There is **a lot** of interstellar molecular gas clouds in space.
- First complicated molecules found in space in 1968, and we have found even more over the last 20 years.
- They often emit light in the millimeter regime.

# *The Interstellar Medium (ISM)*

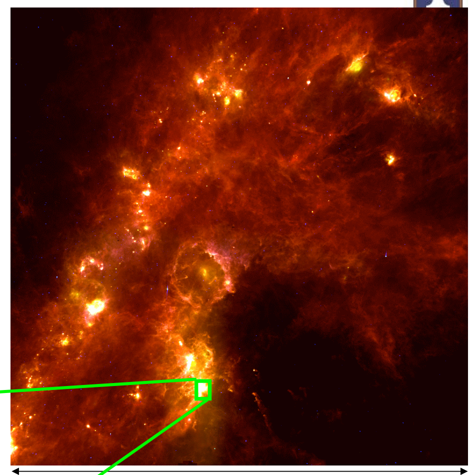
- Stuff between the stars in a galaxy.
- Sounds sort of boring, but
  - Actually very important
  - Features complex physical processes hidden in safe dust clouds
- Every star and planet, and maybe the molecules that led to life, were formed in the dust and gas of clouds.
- Exists as either
  - Diffuse Interstellar Clouds
  - Molecular Clouds

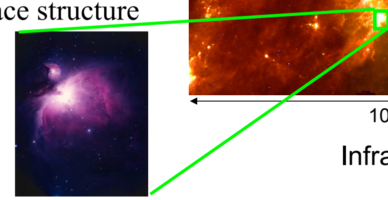
Keyhole Nebula



# Giant Molecular Clouds

- Cool: < 100 K
- Dense: $10^2 - 10^5$ $H_2$ molecules/cm$^3$
  (still less dense than our best vacuum)
- Huge: 30 – 300 lyrs across, $10^5 - 10^6$ solar masses
- CO molecular emission & dust emission trace structure



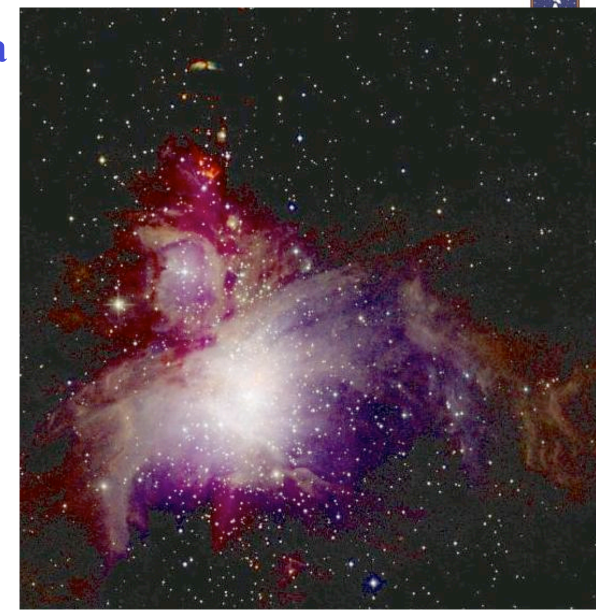



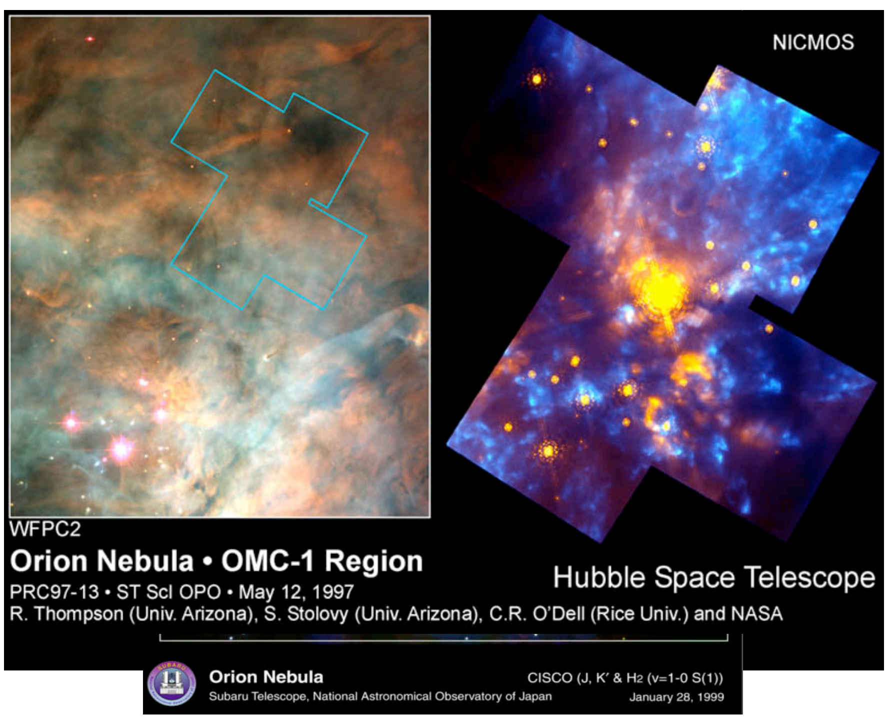
Infrared image from *IRAS*

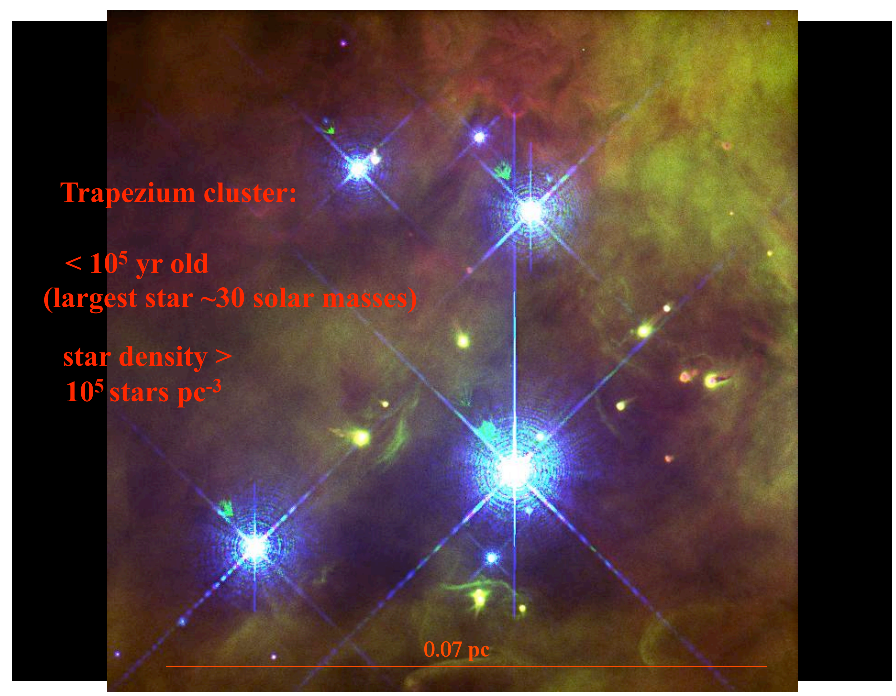
# Orion Nebula

**(near infrared)**

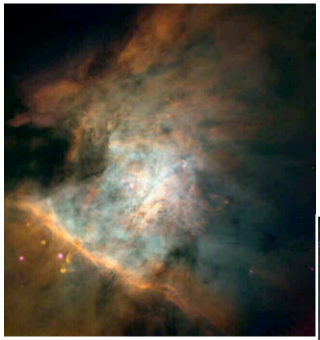
**Nearest massive star forming region with a large molecular cloud associated (distance of 1500 lys)**

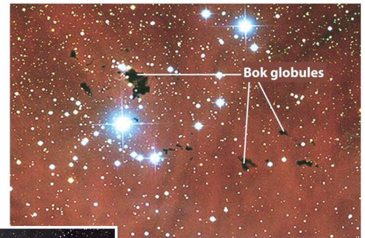


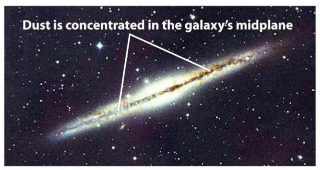


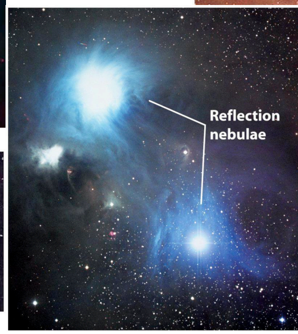
# Interstellar Clouds

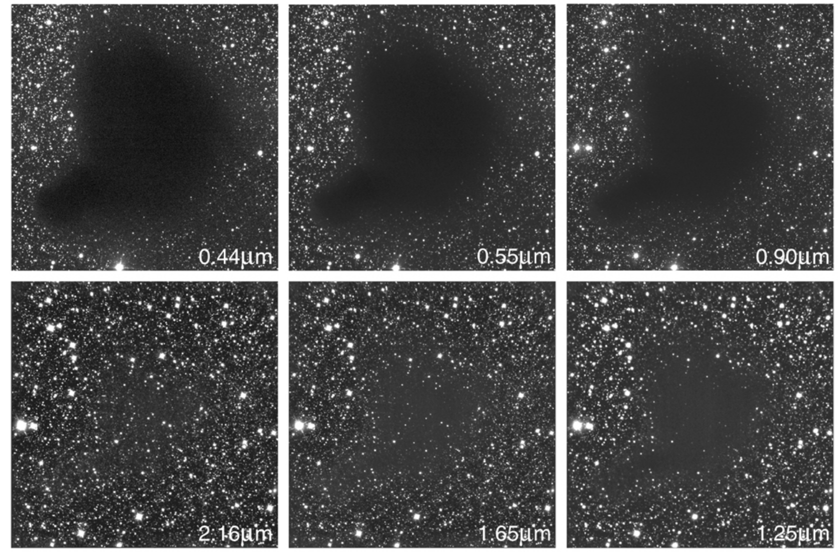





We see spiral galaxy NGC 891 nearly edge-on



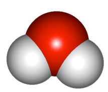

The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

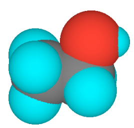
ESO PR Photo 29b/99 ( 2 July 1999 )

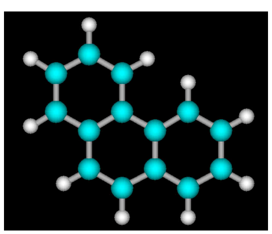


## Other Things Besides Hydrogen in Molecular Clouds

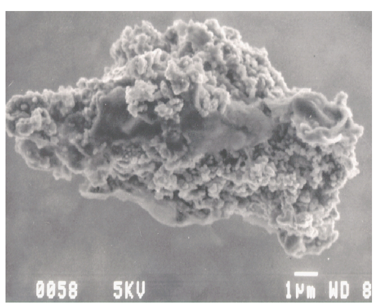
- Molecules (e.g.)
  - Carbon monoxide (CO)
  - Water ($H_2O$)
  - Ammonia ($NH_3$)
  - Formaldehyde ($H_2CO$)
  - Glycine ($NH_2CH_2COOH$)?
  - Ethyl alcohol ($CH_3CH_2OH$)
  - Acetic Acid ($CH_3COOH$)
  - Urea [$(NH_2)_2CO$]?
- Dust particles
  - Silicates, sometimes ice-coated
  - Soot molecules







Polycyclic aromatic hydrocarbons (PAH)

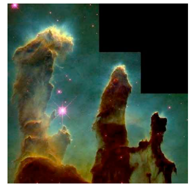



Dust particle (interplanetary)

# So?

- Complex molecules (>13 atoms) have evolved in places other than the Earth.
- Maybe there are more? The more complex molecules are harder to detect.
- Seen in other galaxies too.

# Molecular Clouds



- Interstellar clouds are important molecular factories.
- Analogous to clouds in our atmosphere
- Primarily molecular hydrogen (~93%) and atomic helium (~6%) with (~1%) heavy molecules– molecules or dust.
- $H_2$ is not good at emitting photons, so easier to see larger molecules emitting– especially CO (which tells the temperature of these clouds).
- Other molecules (mostly $H_2CO$, HCN, or CS) are used to derive estimates of density.

# Question

Molecular clouds, where stars form, are mostly made up out of

a) dust
b) a rich assortment of molecules that range from alcohol to urea
c) Hydrogen
d) water
e) $H_2$