Astronomy 230
Section 1– MWF 1400-1450
106 B6 Eng Hall

This Class (Lecture 6):

Star Formation

Oral Presentation Decisions By Feb 6th!

Next Class:

Planet Formation

Outline

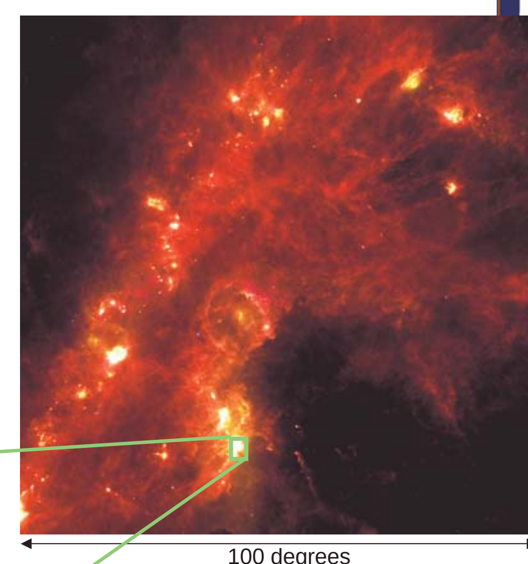
- Star formation is ongoing.
- Stars form in dense molecular clouds.
- The cores collapse, and often fragment, forming multiple young stars.
- The young stars are embedded and enshrouded in dust.
- Protostars have circumstellar disks and jets that influence their environment.

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 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.

Giant Molecular Clouds

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



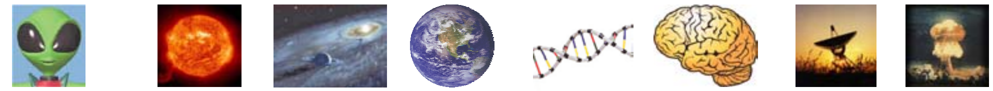
Infrared image from *IRAS*

3 Lessons of Interstellar Molecules

- Molecules with as many as 13 atoms have evolved in places other than Earth.
  - In our Galaxy and beyond.
  - Hard thing is getting the lab data for searching for more complicated molecules.
  - Evidence for polycyclic aromatic hydrocarbons (PAHs) links of carbon atoms with hydrogen on the outside is found in space.
  - Also found in the exhaust of cars and may play a role in early life.
- Dominance of carbon in interstellar chemistry. So perhaps carbon based life forms is not just Earth chauvinism.
- Study of these in space illustrates the problems of molecules getting more and more complex and not being destroyed by UV light. That's why they were not expected

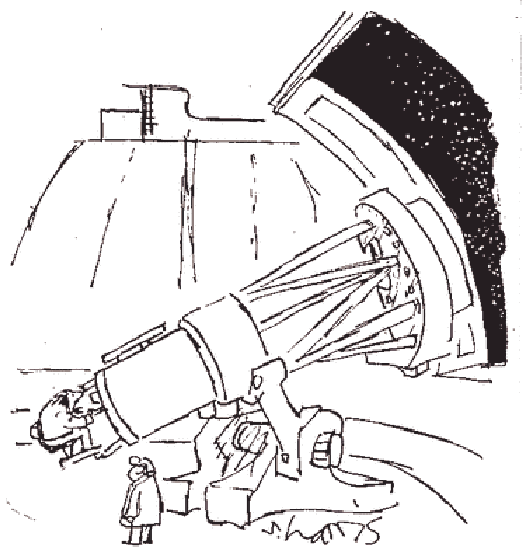
Drake Equation

Frank Drake



$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact	Rate of formation of Sun-like stars	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations



'Let's see, now ... picking up where we left off ... one billion, sixty-two million, thirty thousand, four hundred and thirteen ... one billion, sixty-two million, thirty thousand, four hundred and fourteen ... "

Counting Stars

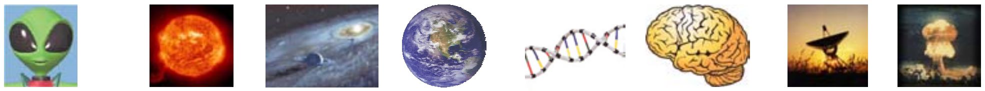
Estimate of R_*:
The Rate of formation of Sun-like stars

- We are about to start the topic of star formation and planet formation, but really the field is not well developed to estimate R_*.
- Instead take the total number of stars in the galaxy and divide by how long it took those stars to form.

$$R_* = \frac{10^{11}\,stars}{10^{10}\,years} = 10\,\frac{stars}{year}$$

Drake Equation

Frank Drake



$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

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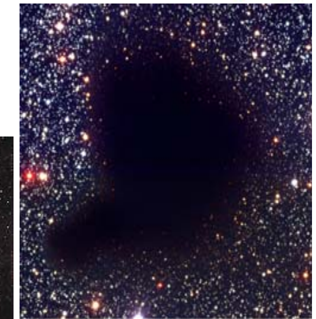
~10

Interstellar Clouds

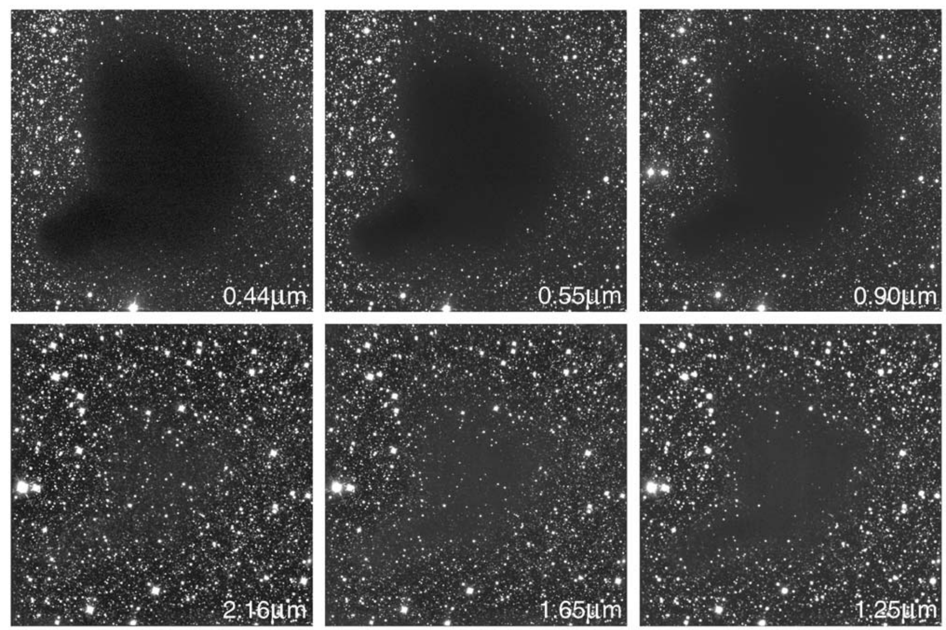


http://www.seds.org/messier/more/oricloud.html

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



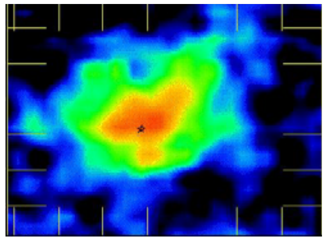
The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

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

The Importance of being a Molecular Cloud

- Different than the clouds that formed the First Stars
- Stars form in cold, dense molecular clouds (normally starless)
  - Colder, as molecules and dust easily emit in the radio and infrared.
  - Thus, clumps more easily, as the material is cold, forming regions of high density.
- Formation of more complex molecules
  - Density allows for more collisions, interactions, formation of molecules
  - *Maybe formed biological compounds?*

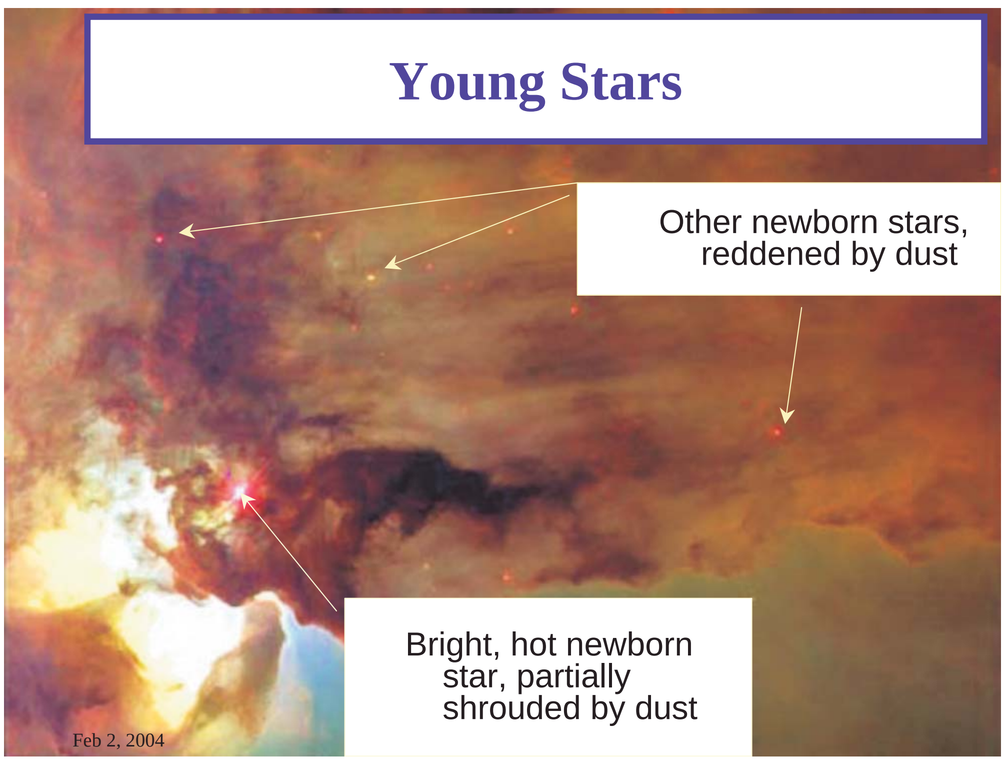
$C^{18}O$ emission from L483

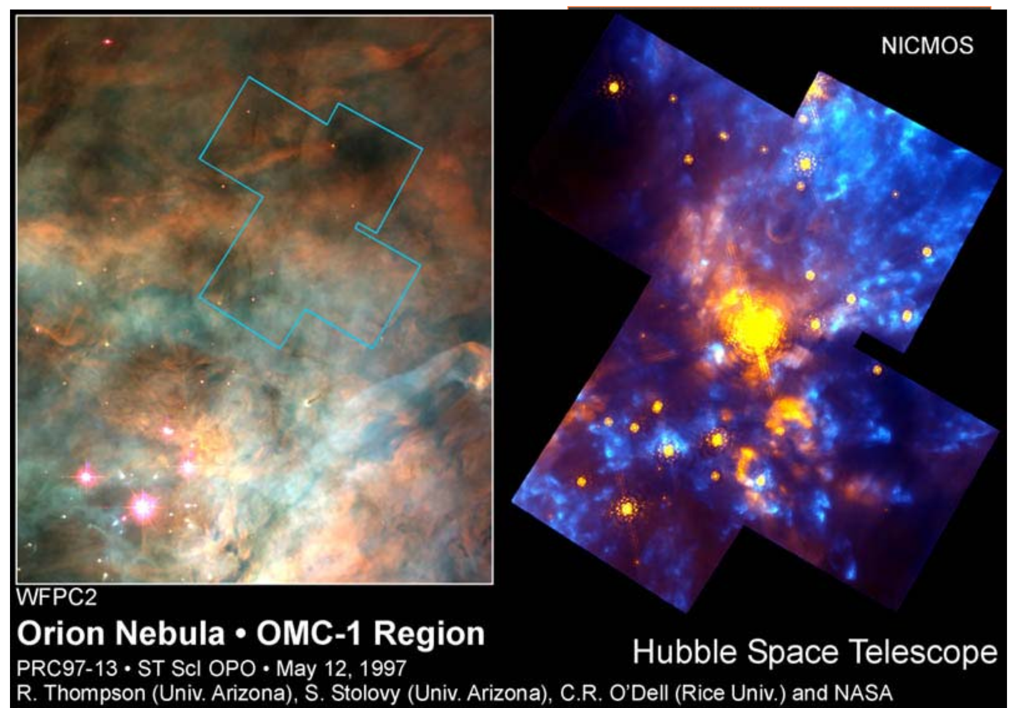


How do we know?

- Young stars are seen near molecular clouds.
- In infrared light, we can see into the deeper regions of clouds, and see clusters of young stars with circumstellar material (dust and gas) surrounding them.
- Stars are continuously being formed in our galaxy.

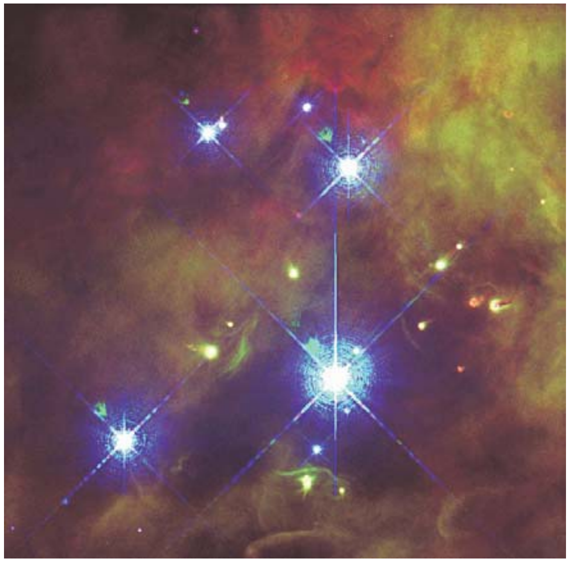
Young Stars





The Birthplace of Stars

- Young stars often are seen in clusters
- Very young stars are also associated with clouds of gas (nebulae)



The Trapezium

Lifecycle of a Star

- Star formation
  - Take a giant molecular cloud core with its associated gravity and wait for 10^4 to 10^6 years.
- Main sequence life (depends on mass!)
  - Few x 10^6 years to more than age of Universe
  - Thermonuclear burning of H to He
- Death
  - Exhaust hydrogen
  - Red giant / supergiant or supernova
  - White dwarfs, neutron stars, black holes

Stellar Middle Age

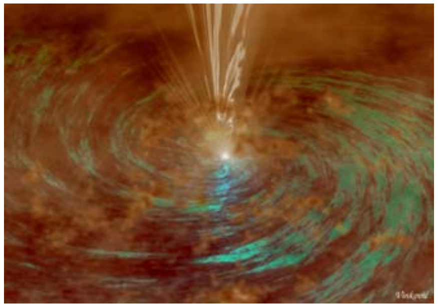
Stars like the Sun

Massive stars

Stars

- The fundamental building blocks of the Universe.
- High mass stars are 8 to 100 solar masses
  - Short lived: 10^6 to 10^7 years
  - Luminous: 10^3 to 10^6 L_{sun}
  - Powers the interstellar medium– input of energy
- Intermediate Stars are 2 to 8 solar masses
- Low mass stars are 0.4 to 2 solar masses
  - Long Lived: >10^9 years
  - Good for planets, good for life.
  - Not so luminous: 0.001 to 10 L_{sun}

Star Formation



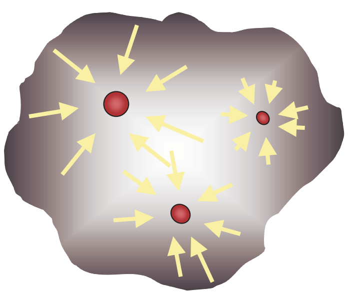
Stars are born in cold, dense interstellar clouds
- Cold gas
- Dust grains

Star formation is probably triggered by
- Cloud turbulence
- Collision with another cloud
- Nearby supernova explosion
- Nearby hot star wind
- Disturbance from the Galaxy

Gravitational Contraction

- As we discussed for the first stars, the gravity of the gas and dust clumps pushes the clumps together, but there is some resistance from pressure and magnetic fields to collapse.
- Probably as the cloud core collapses, it fragments into blobs that collapse into individual stars.
- Cloud becomes denser and denser until gravity wins, and the clumps collapse under their own mass– a protostar.
- This process is slower than for the first stars where the clumps were much more massive.
- As the collapse proceeds the molecules and dust emit light, keeping the temperature of the core low.

Cloud Contraction



But..

- Not all mass falls in directly. Why?
- All gas has a small spin that preferentially causes the formation of a flattened structure – time for an interlude.

Interlude: Angular Momentum

Spinning or orbiting objects in closed system have angular momentum.

Angular momentum is a single, *constant* number: =*conserved*!

Keep same dist. to axis → velocity same

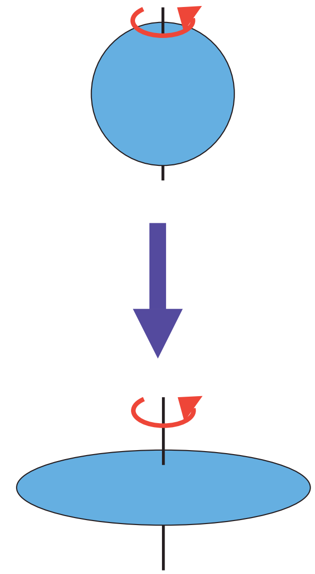
Move closer to axis → speed up!

Recall Kepler 2nd law – really due to angular momentum!

When Doves Cry and Stars Form

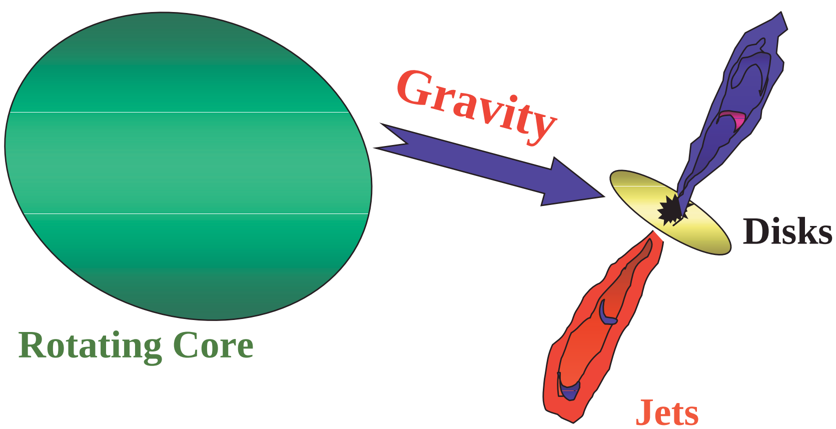
Solar nebula competition:
Gravity vs Angular Momentum

- If fall perpendicular to spin axis
  speed up → resistance
  centrifugal force
- If fall parallel to spin axis
  same speed, so no resistance
  → form ***protoplanetary disk***
  - Origin of ecliptic!
  - Organizes orbits in same direction
  - Organizes spins along initial spin axis

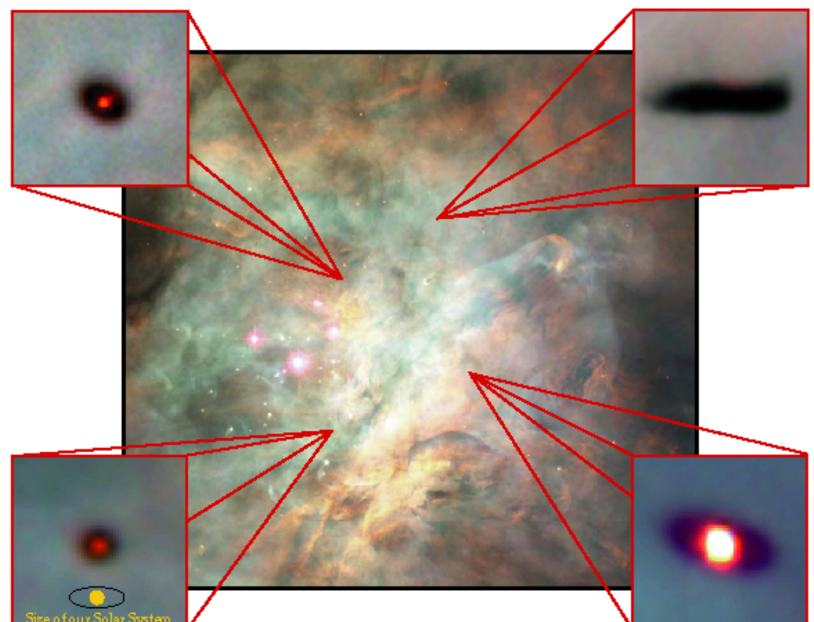


The Protostar Stage

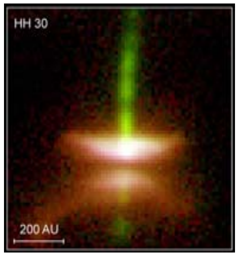
Gravity, Spin, & Magnetic Fields

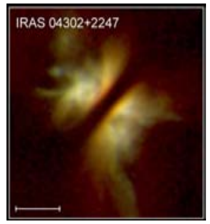


Disks around Young Stars are Common

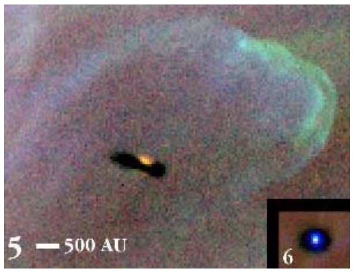


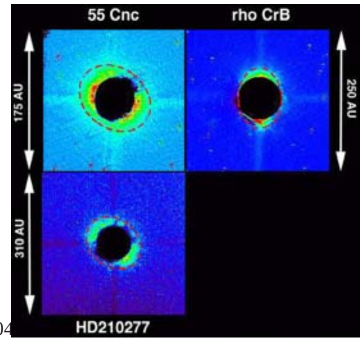
And Disks around Young Stars are Common



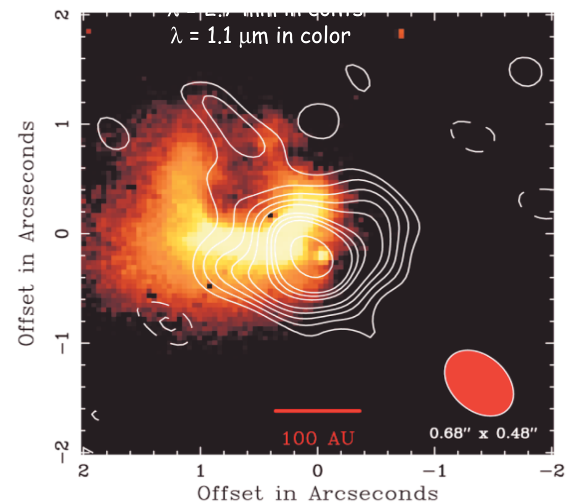


http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm



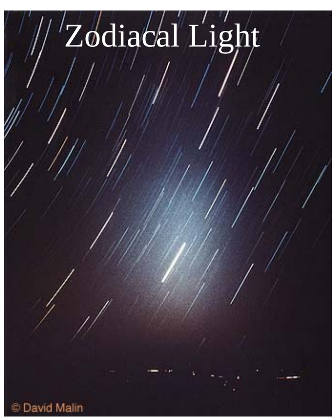


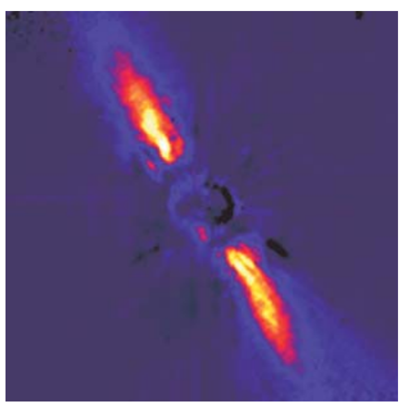
The Circumstellar Disk of HL Tauri



Do Fossil Disks Exist around other Stars?

- We see old disks around other stars (e.g. Vega and Beta Pictoris) as well as our own.

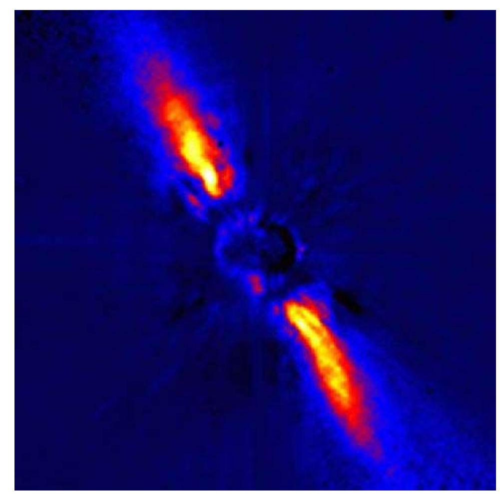




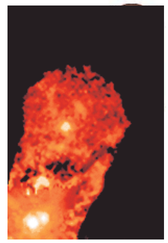
http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html
http://antwrp.gsfc.nasa.gov/apod/ap970826.html

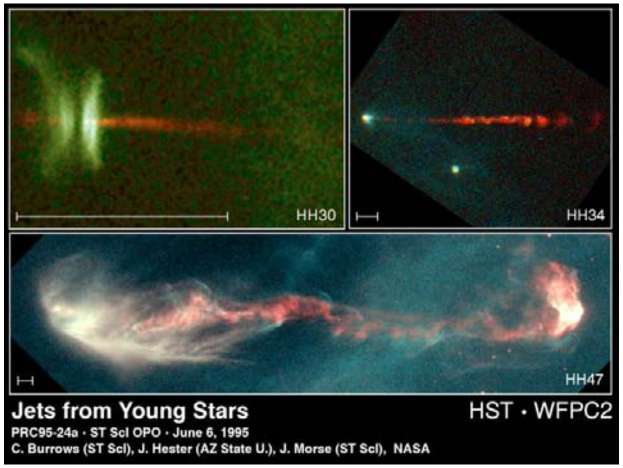
Disks Around Young Stars

- Many (> 50%) of newborn stars surrounded by a disk of material!
- Disks thick, blocks light
  - Enough material to make planets
  - Agrees with Solar Nebula theory!

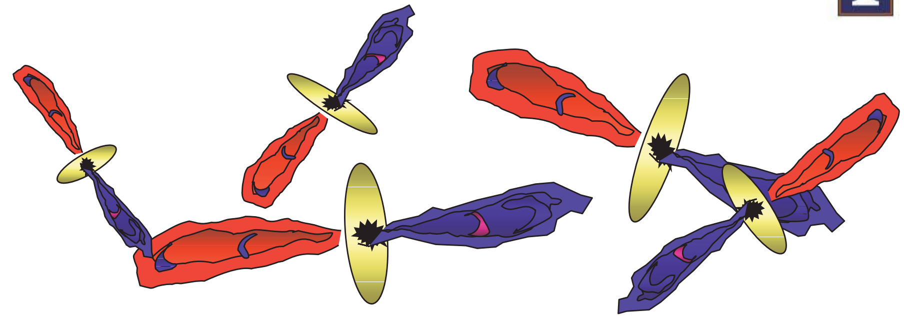


Protostellar Jets

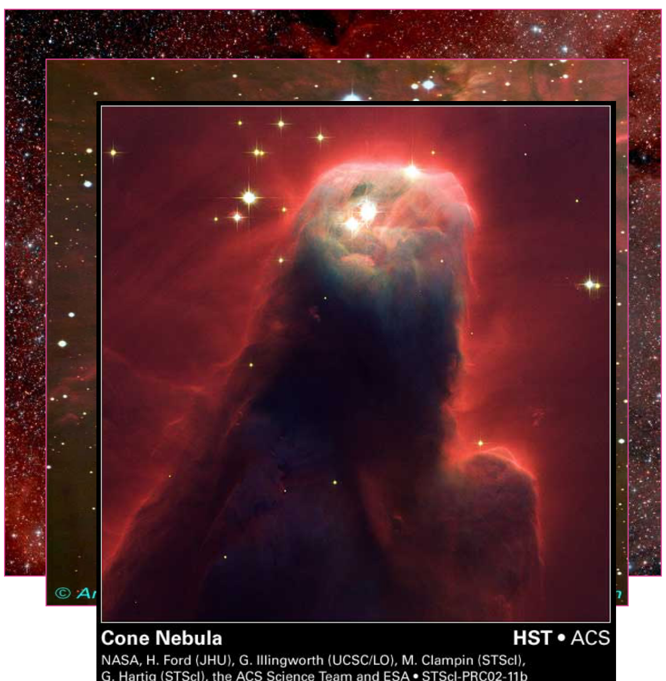




Young Stars in Groups



- Most stars are in multiple systems.
- How does this effect the protostars?
- How does this effect their planet formation?
- How does this effect the possibility of life on the *average* star?



The Cone Nebula

A Star Forming Region

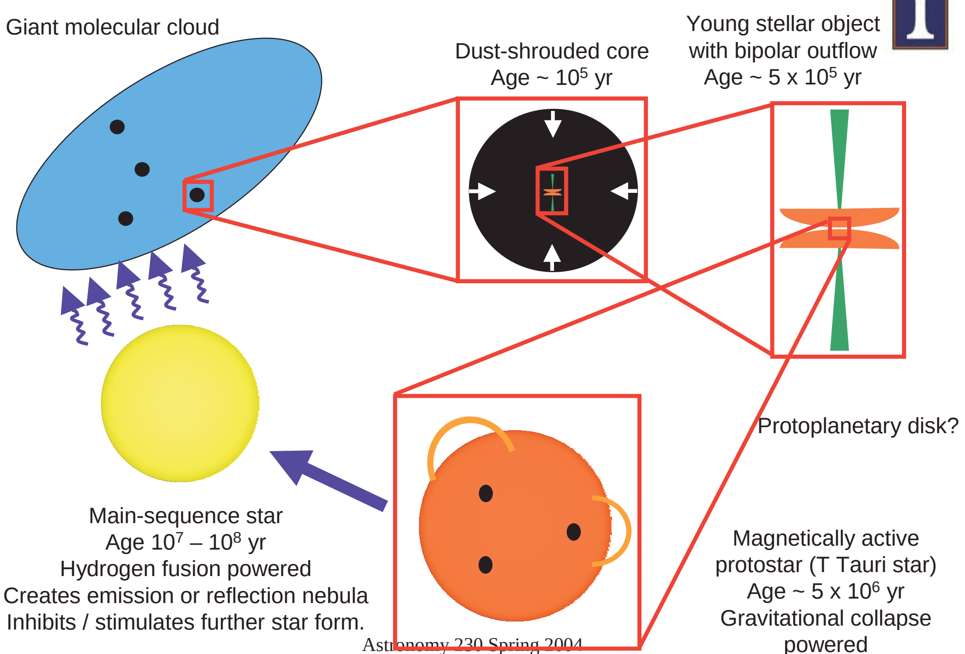
The Protostar Archetype: T Tauri

http://www.astrosurf.com/jwisn/ttauri.htm

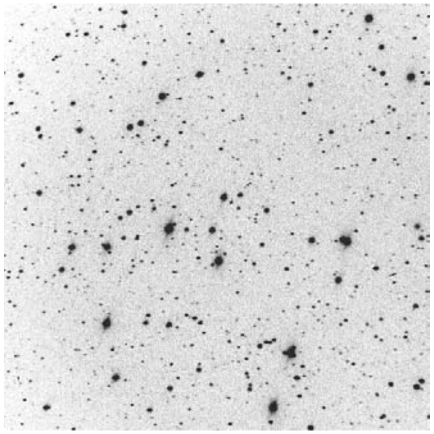
On to the Main Sequence: A Star is Born!

- Density increase, temperature increases until fusion can occur.
  - Blows away most of its natal circumstellar material.
  - Becomes a star on the main sequence of the HR diagram,
  - For low mass stars, this whole process can take 10^6 years.
  - Expect to see a large number of embedded protostars.

Star Formation - Summary

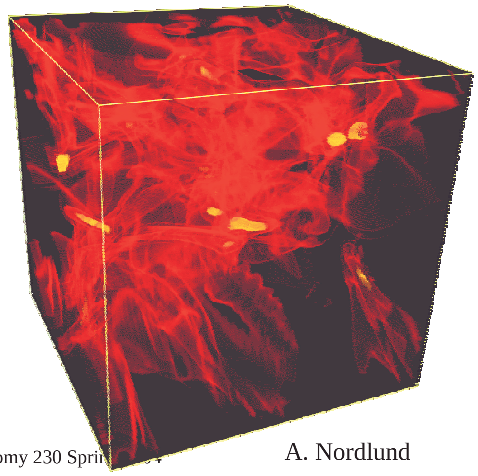


Stars Ages and ETs



Some outstanding Star Formation Issues

- Why do the cores collapse, but not the entire molecular cloud?
- What sets the sizes of cores, and hence masses of stars?
- What determines how stars cluster, group together, or form multiple systems?



A. Nordlund