Astronomy 122

This Class (Lecture 14):

Star Formation

Next Class:

Stellar Evolution:
When I grow up

Midterm Next Week!
(March 6^{th})

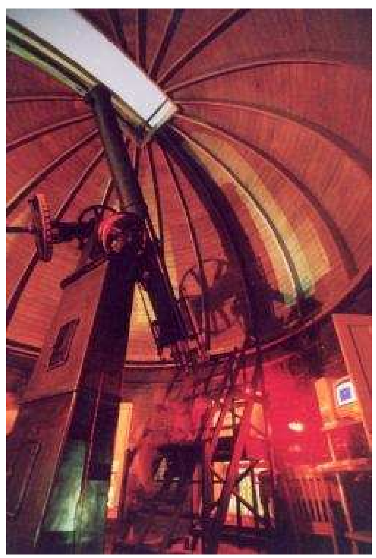
Music: *Princes of the Universe* – Queen

Midterm

- 50 min exam in this classroom
- Will cover material up to and including star formation
- 40 multiple choice questions.
- Exam will have 105 points graded out of 100 (i.e. extra credit)
- You may bring normal-sized sheet with notes on each side.
- Expect a study guide to be posted on class webpage at least by weekend.

Night Observing

- Last night was clear!
- Make-up dates added to list!
  - March 3-4^{th}: Monday-Tuesday
- Don't wait until last minute (never know about Illinois weather)!
- Observing sessions are from 7:30pm-9:30pm (allow 45 mins to complete)

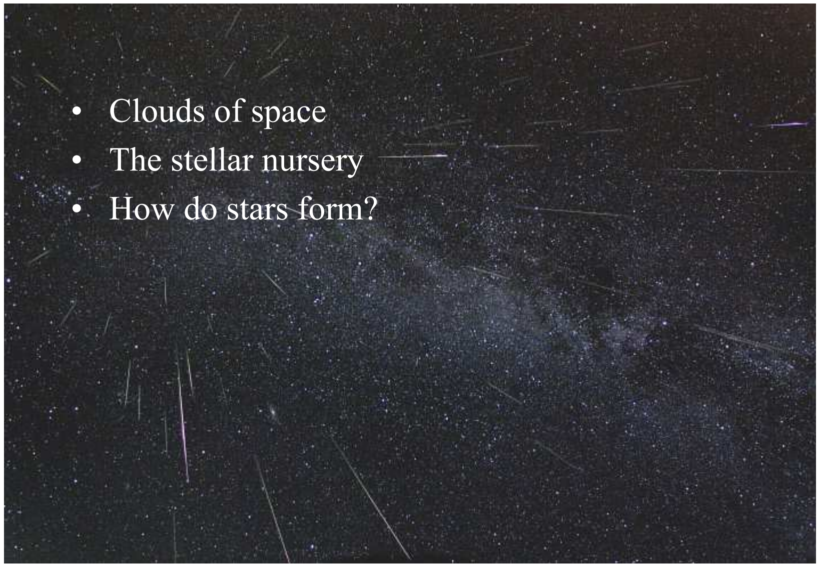


Jill Tarter

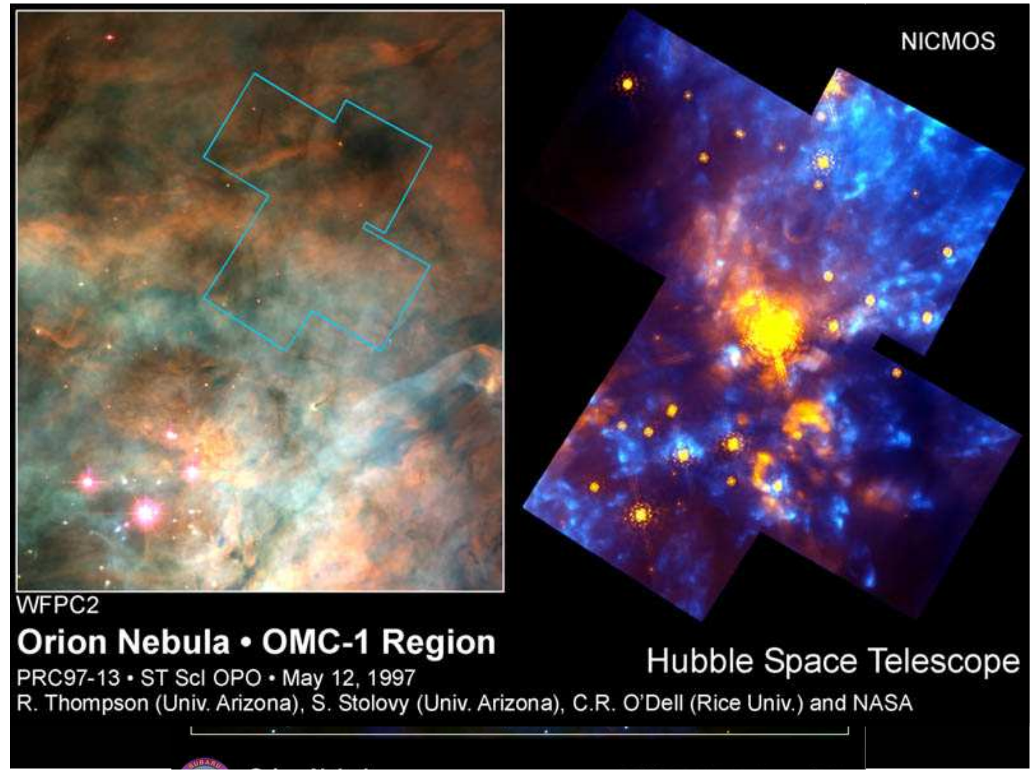
- Director of SETI
- Giving a talk on the Allen Telescope Array for SETI on Thursday at 1600 (4pm!) in 141 Loomis.

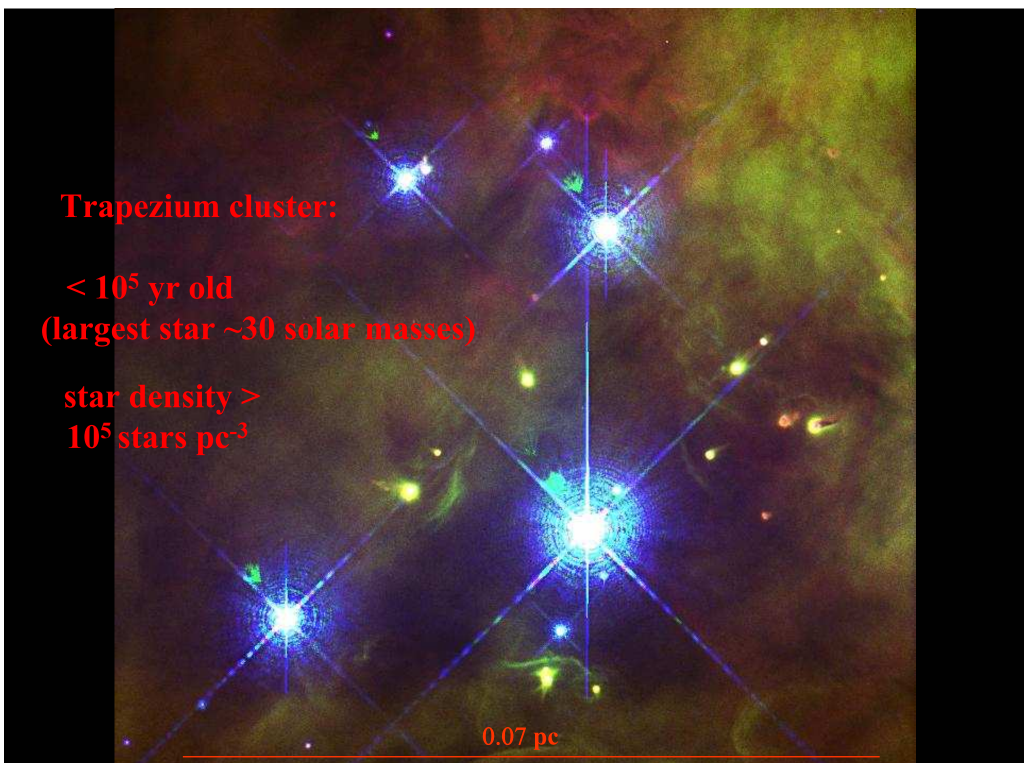
John Todd / AP

Outline



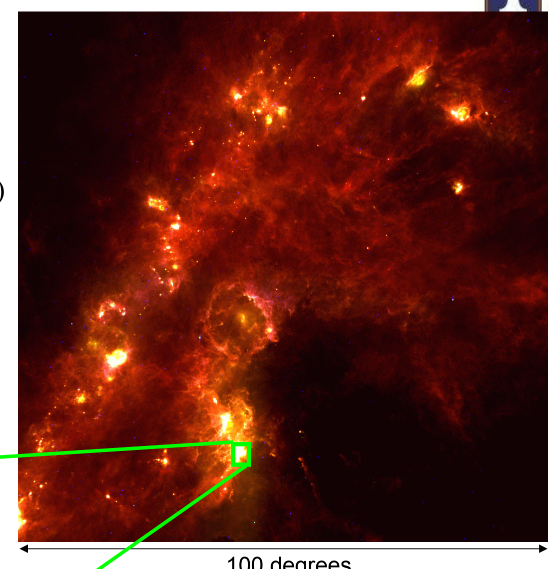
- Clouds of space
- The stellar nursery
- How do stars form?





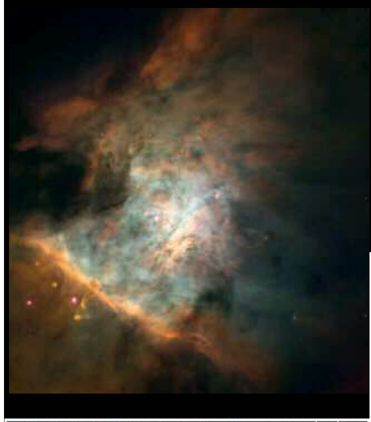
Giant Molecular Clouds

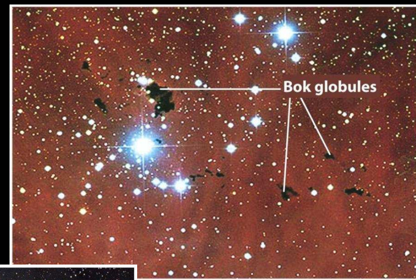
- Cool: < 100 K
- Dense: $10^2 – 10^5$ H_2 molecules/cm^3 (still less dense than our best vacuum)
- Huge: 30 – 300 lyrs across, $10^5 – 10^6$ solar masses
- CO molecular emission & dust emission trace structure

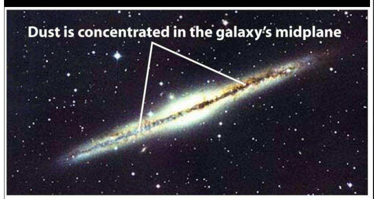


Infrared image from *IRAS*

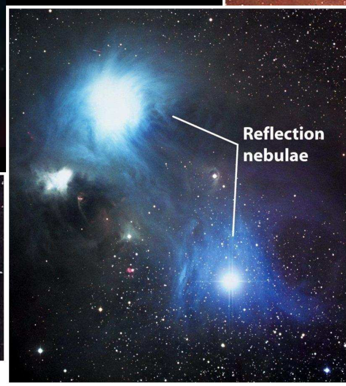
Interstellar Clouds

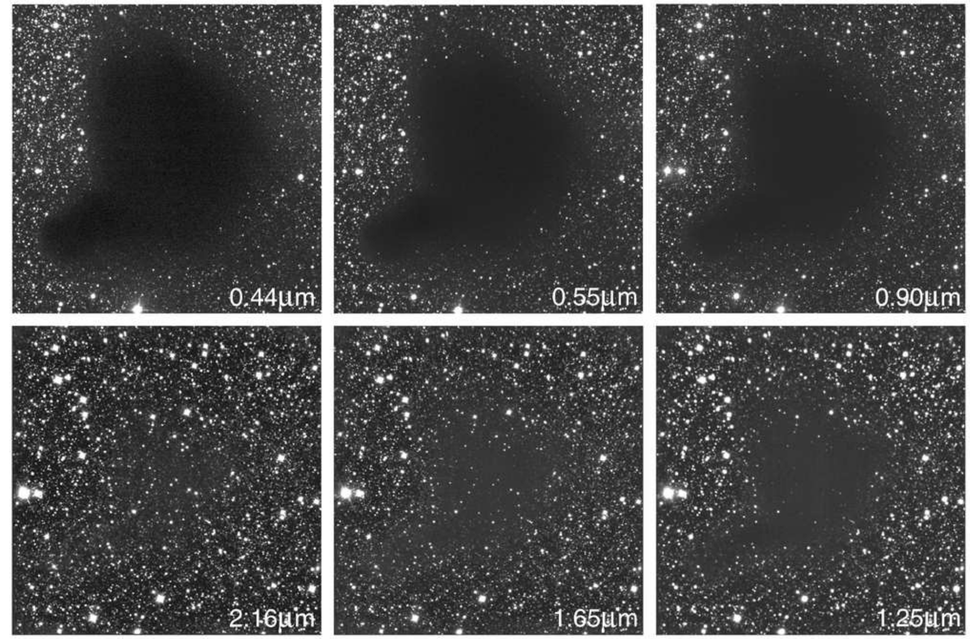






We see spiral galaxy NGC 891 nearly edge-on



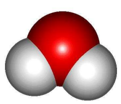


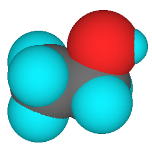
The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

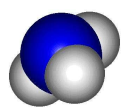
ESO PR Photo 29b/99 (2 July 1999)

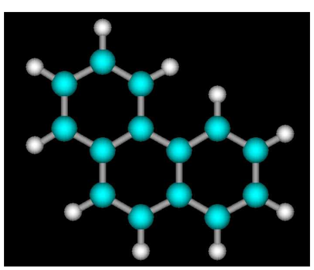
Other Things Besides Hydrogen in Molecular Clouds

- Molecules (i.e. still mostly H_2)
  - 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 (~1%)
  - Silicates, sometimes ice-coated
  - Soot molecules

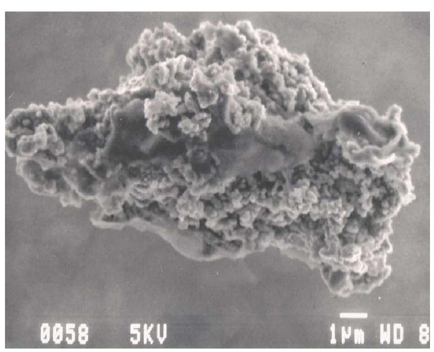








Polycyclic aromatic hydrocarbons (PAH)

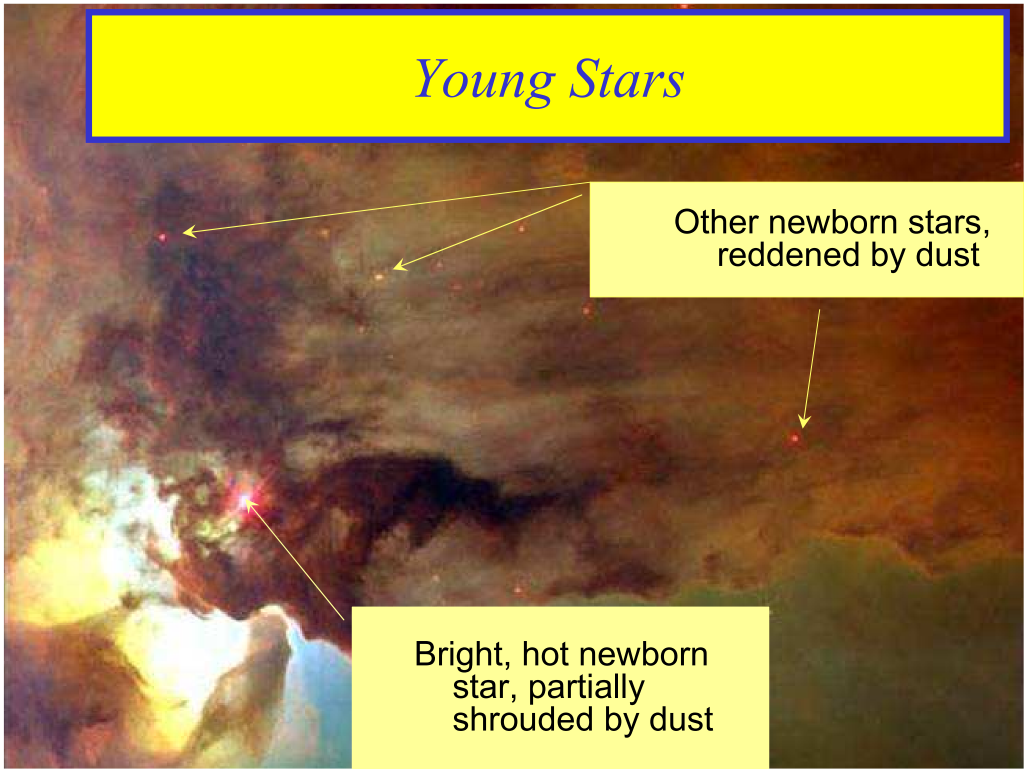


Dust particle (interplanetary)

How Do We Know that Stars Form in Molecular Clouds ?

- 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.

http://antwrp.gsfc.nasa.gov/apod/ap030630.html



Question

Where do stars form?

a) In the local theater scene
b) Inside of molecular clouds
c) Inside of other stars
d) During supernova explosions
e) We don’t know

Water Power?

- Does a bottle of water have any stored energy? Can it do work?

The water has potential energy. It wants to flow downhill. If I pour it out, the conservation of energy tell us that it must turn that potential energy into kinetic energy (velocity). The water wants to reach the center of the Earth. This is how we get hydro energy from dams.

Gas powered

- Similar to my bottle of water, these initial gas clumps want to reach the center of their clump-ness.
- The center gets hotter and hotter. The gravitational energy potential turns into heat (same as velocity actually).
- It is a run-away feature (or snowballing), the more mass at the center, the more mass that wants to be at the center.
- The center of these clumps gets hotter and denser.

http://www.rob-clarkson.com/duff-brewery/snowball/04.jpg

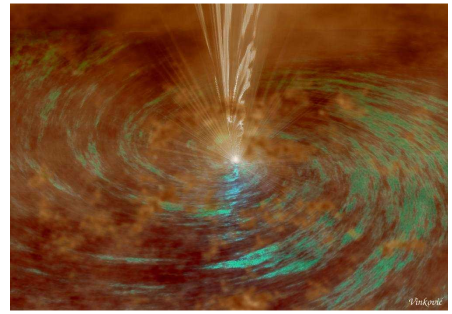
Solar Nebula Theory

- In these clouds are small clumps that become gravitationally unstable
- The gas and dust has mass (thus gravity)
- Gravity pulls it toward the center – contracts!

Gravity follows the inverse square law, so closer = stronger. Once it falls in a little, it gets pulled in more.

RUNAWAY GRAVITY!

Star Formation



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

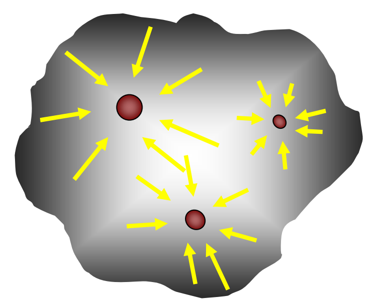
Star formation is probably triggered by
- Cloud turbulence
- Collision with another cloud
- Nearby supernova explosion
- Nearby hot star wind
- Disturbance from the Galaxy

Gravitational Contraction

- The gravity of the gas and dust clumps push 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.

http://www.birthingthefuture.com/AllAboutBirth/americanway.php

Cloud Contraction



But..

- Not all mass falls in directly (radially). Why?

- All gas has a small spin that preferentially causes the formation of a flattened structure
  – time for an interlude.

http://homepages.igrin.co.nz/moerewa/Pages/

Interlude: Angular Momentum

Spinning or orbiting objects in a closed system have angular momentum.

Keep same dist. to axis → velocity same

Move closer to axis → speed up!

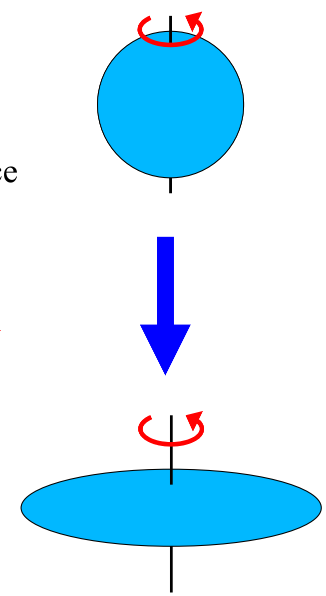
When Doves Cry and Stars Form

Solar nebula competition:
Gravity vs Angular Momentum

- If fall perpendicular to spin axis
  speed up → resistance centrifugal force

- If fall parallel to spin axis then
  same speed, so no resistance
  → forms ***protoplanetary disk***

  – Origin of ecliptic!
  – Organizes orbits in same direction
  – Organizes spins along initial spin axis



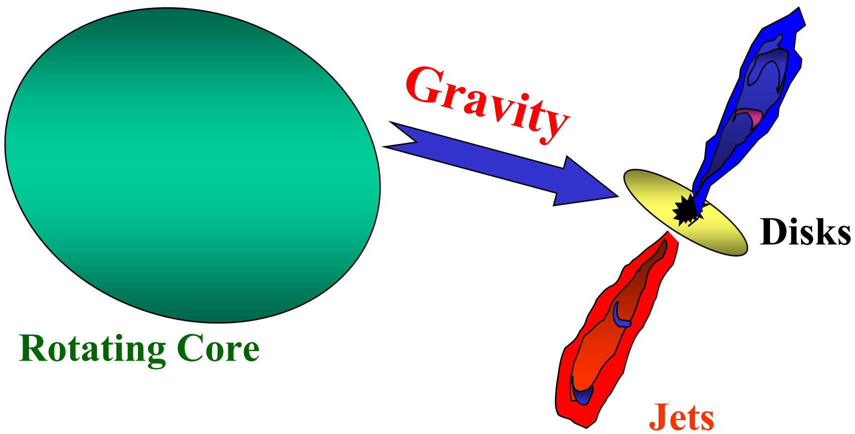
Question

Since a collapsing cloud is spinning, the cloud will form

a) a spherical cloud
b) a star
c) a flattened disk
d) a planet
e) a galaxy

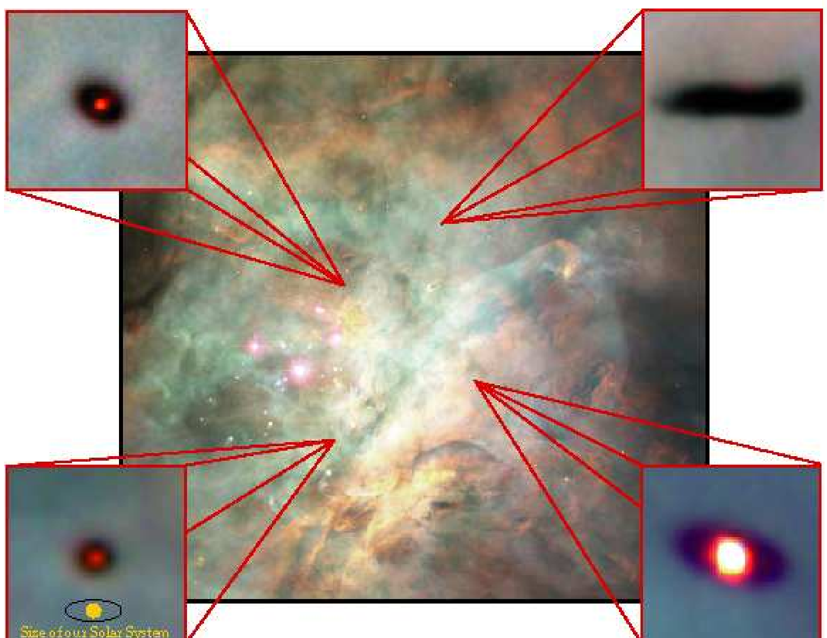
The Protostar Stage

Gravity, Spin, & Magnetic Fields

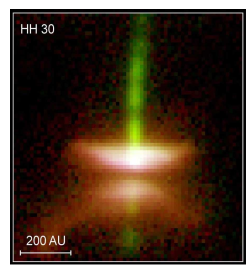


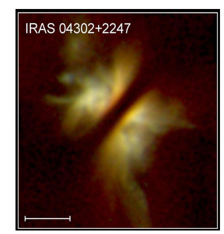
The Orion Nebula

Disks around Young Stars are Common

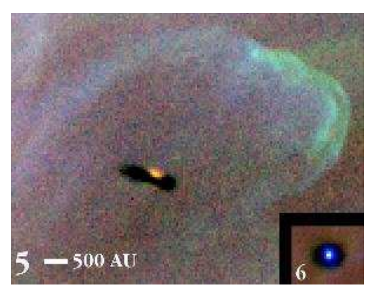


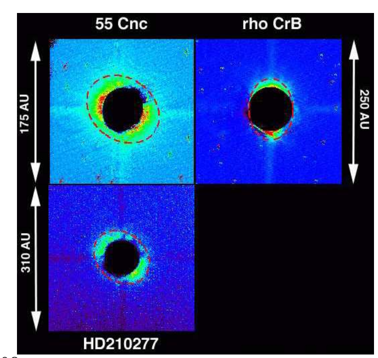
And Disks around Young Stars are Common



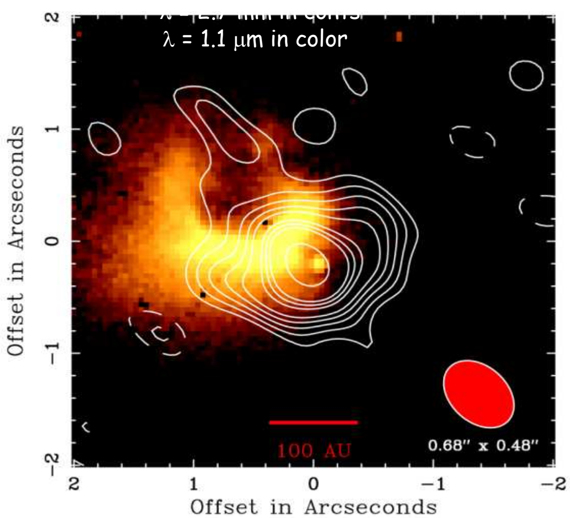


http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm



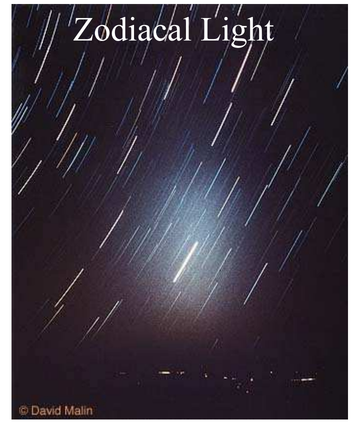


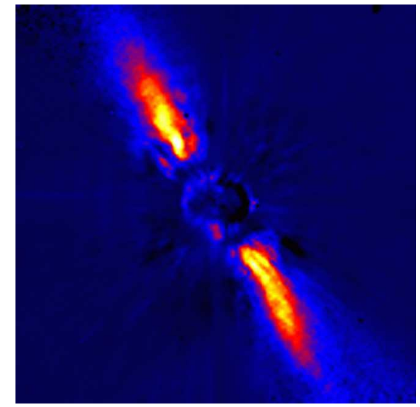
The Circumstellar Disk of HL Tauri



Do Fossil Disks Exist around other Stars?

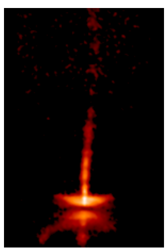
We see old disks around other stars (e.g. Vega and Beta Pictoris) as well as our own.

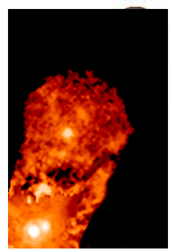


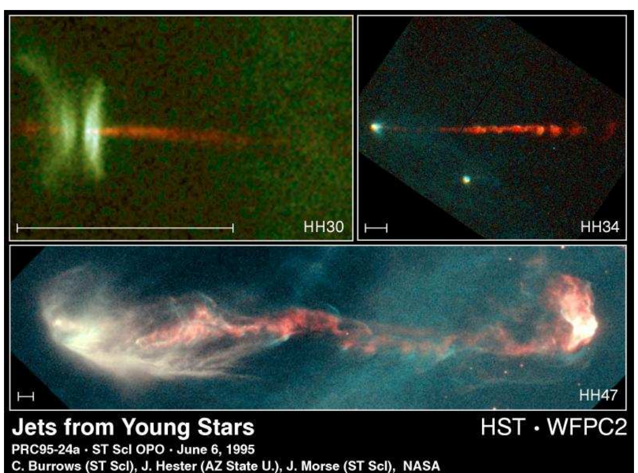


http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html
http://antwrp.gsfc.nasa.gov/apod/ap970826.html

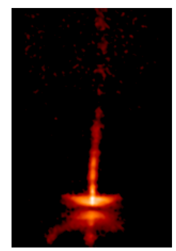
Protostellar Jets

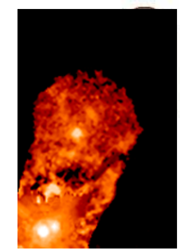


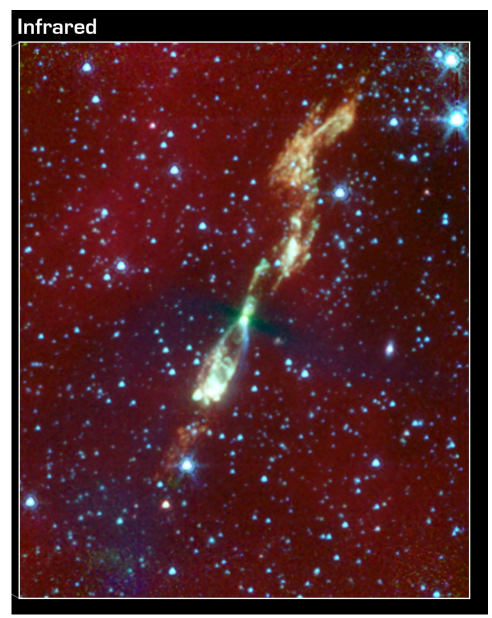


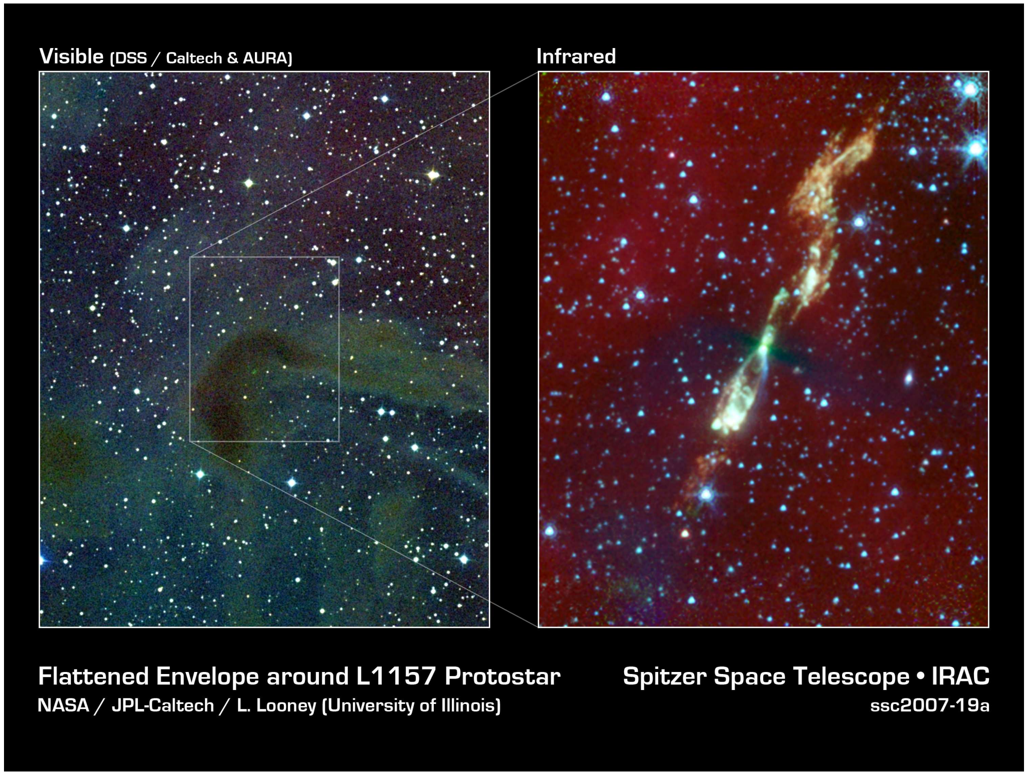


Protostellar Jets









The Movie

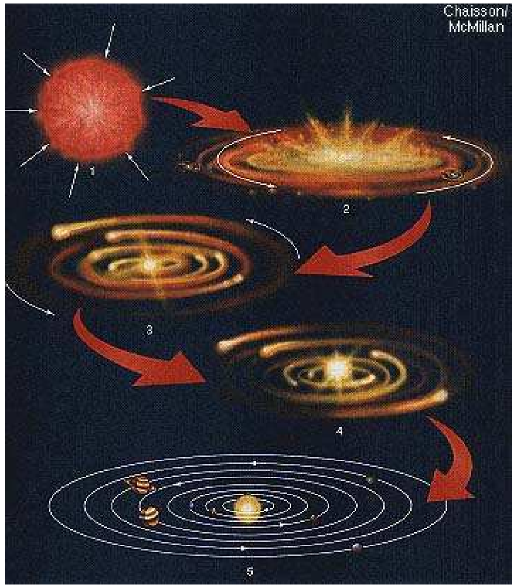
Questions

One of the weirdest things about star formation, where gas and dust are collapsing to form a star, is that

a) a disk is never formed
b) the star forms so fast
c) at the same time there are huge outflows
d) the molecular cloud determines the stellar mass
e) the star gets more massive with time

Formation of the Solar System 4.6 billion years ago

Clouds to Star and Planet Formation

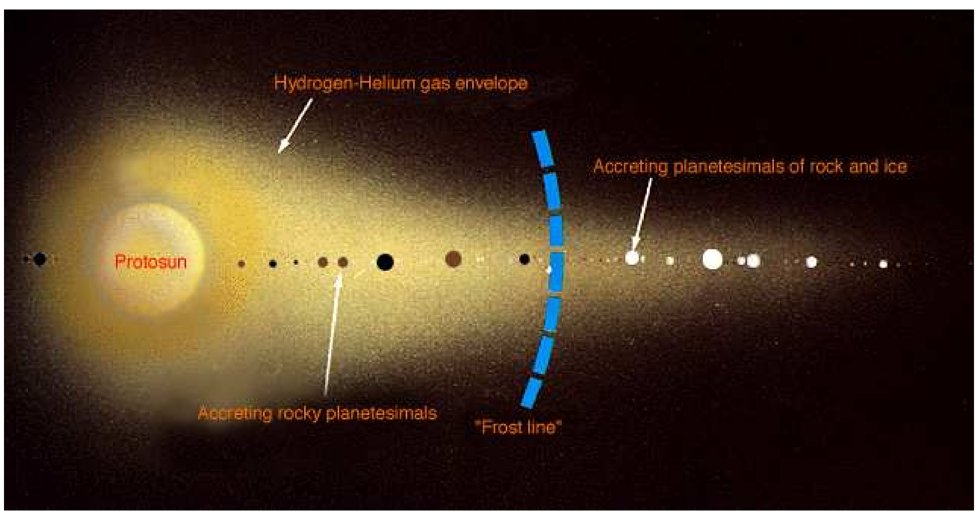


Planet Formation in the Disk

Heavy elements clump and then

1. *Dust grains* collide, stick, and form planetesimals– about 10^{12} of them, sort of like asteroids! All orbit in the same direction and in the same plane.
2. Gravity Effects: Big planetesimals attract the smaller planetesimals. So, fewer and fewer of large objects (100's). Collisions build-up inner planets and outer planet cores.
3. Collisions can also account for odd motions of Venus (backwards), Uranus (rotates on its side), and Pluto (high inclination of orbit). Proof of period of high collision evident on moon

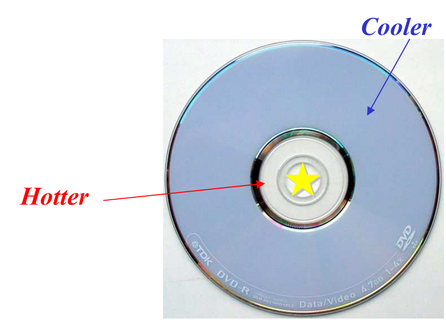
Why are the Planets so Different?



Temperature is the key factor!

Everyone Loves Disks

- As the star forms, the inner region of the disk gets much hotter than the outer regions, creating a temperature gradient.
- The inner part of the disk had a higher density than the outer regions.
- Icy mantles of dust grains (NH_3, CH_4, etc.) evaporated at varying distances.



Why are the Planets so Different?

- Temperature is the key factor
- Inner Solar System: Hot
  - Light gasses (H, He) and “ices” vaporized
  - Blown out of the inner solar system by the solar wind
  - Only heavy elements (iron & rock) left
- Outer Solar System: Cold
  - Too cold to evaporate ices to space
  - Rock & ice “seeds” grew large enough to pull gasses (H, He) onto themselves

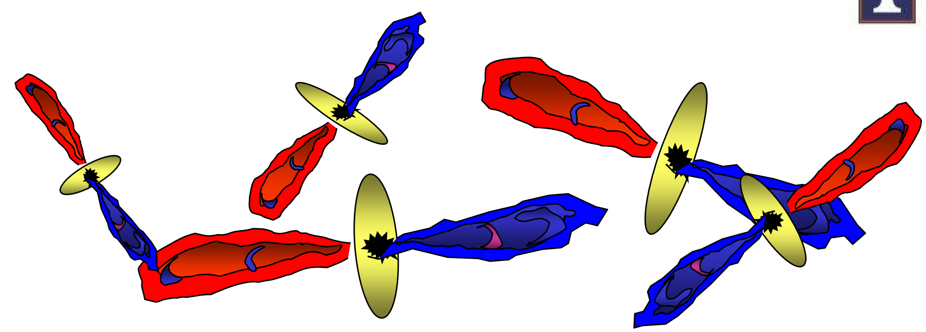
Heavy Bombardment

- There were billions of planetesimals in the early solar system
- Many collided with the young planets
  - Look at the Moon & Mercury!
  - Period of **heavy bombardment**
  - Lasted for about the first 800 million years of the Solar System
- Others were ejected from the solar system…

Earth’s Water Source?

- There are two ideas on where Earth’s water came from:
  - Released from within by volcanic vents
  - Brought to Earth by comets during the heavy bombardment

Young Stars in Groups



- Most stars are in multiple systems and clusters
- What about us?

The Birth of the Sun

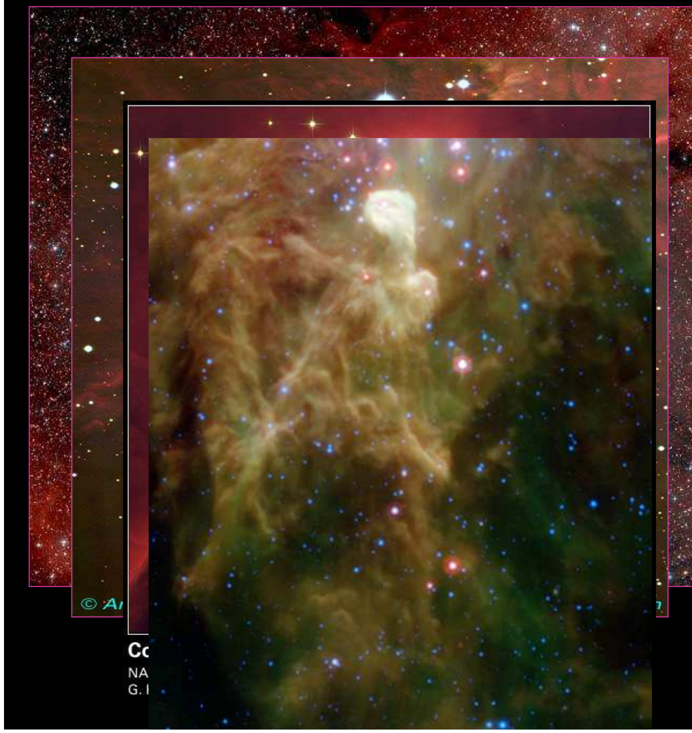
The Sun formed as part of a modest-sized cluster of stars

A nearby massive star exploded, creating radioactive elements

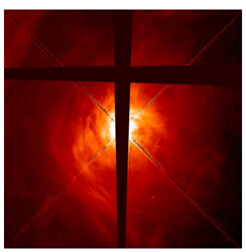
The explosion might have triggered the formation of the Sun

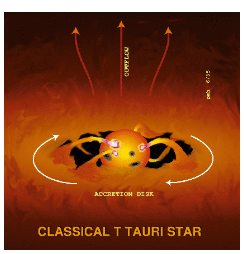
The Cone Nebula

A Star Forming Region



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 a few 10^6 years.
  - Expect to see a large number of embedded protostars.

Moving To the Main Sequence

- When a protostars first burns hydrogen into helium: it is a main sequence star!
- They start cold, move toward the left with gravitational energy (remember Jupiter again).
- Path to the main sequence is different depending on mass.