Astronomy 150:
Killer Skies

This Class (Lecture 6):
The Origin of Rocks in Space

Next Class:
The Atmosphere and Meteors

HW1 and HW2 due on ~~Monday~~ Tuesday night.

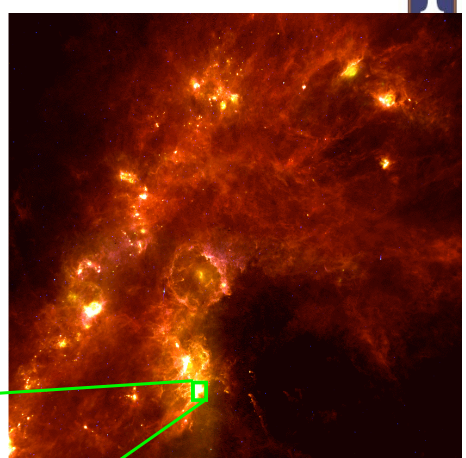
Music: *The Day Lassie Went to the Moon* – Camper van Beethoven

Outline

- Star Formation– so where did the rocks come from
- Why was there so much trash left over?

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
- Mostly molecular hydrogen
- CO molecular emission & dust emission trace structure

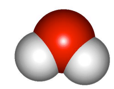


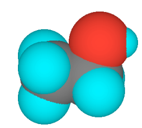
100 degrees

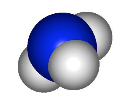
Infrared image from *IRAS*

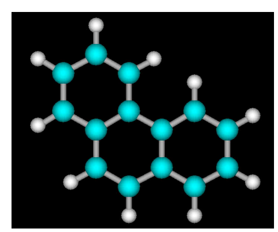
Other Things Besides Hydrogen in Molecular Clouds (~1%)

- 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

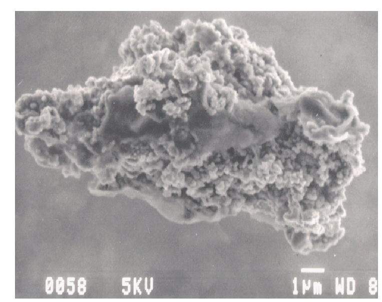








Polycyclic aromatic hydrocarbons (PAH)



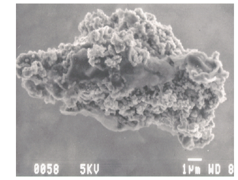
Dust particle (interplanetary)

Question

Molecular clouds, where stars form, are <u>mostly</u> made up out of

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

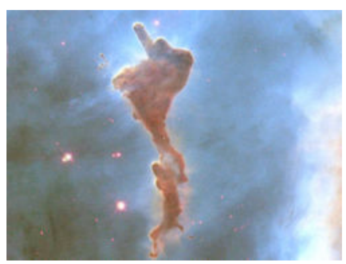
In Dust We Trust



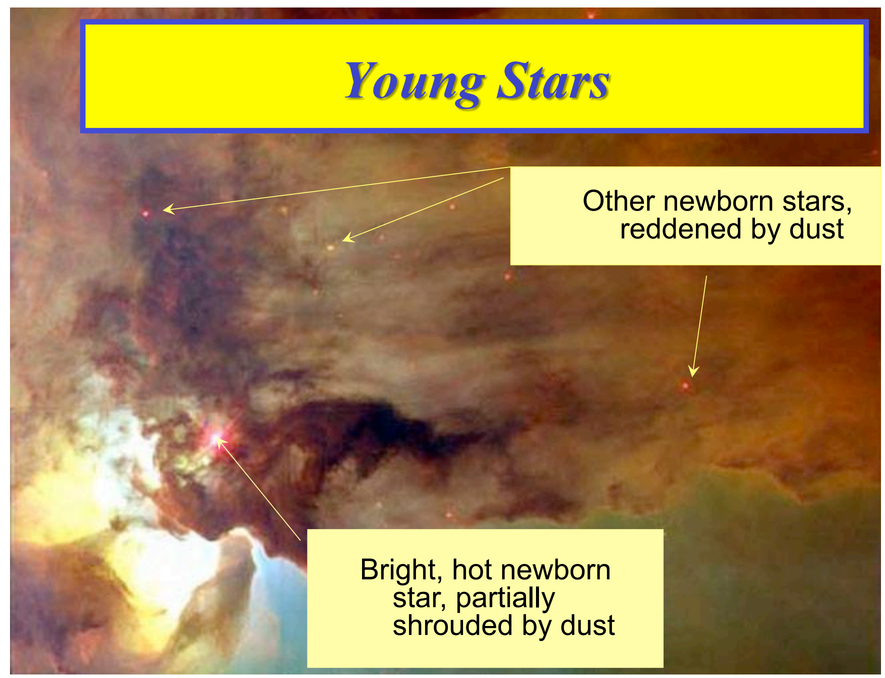
- Small (< 1 micron), solid particles in space
- Two types:
  - Primarily carbon (sort of like what we call soot)
  - Silicates, minerals of silicon and oxygen (sort of like what we call dust)
- Produced in material flowing from old stars, but mixed in space.
- Some of the micrometeorites could be primordial interstellar dust!
- But too small to be death rocks.

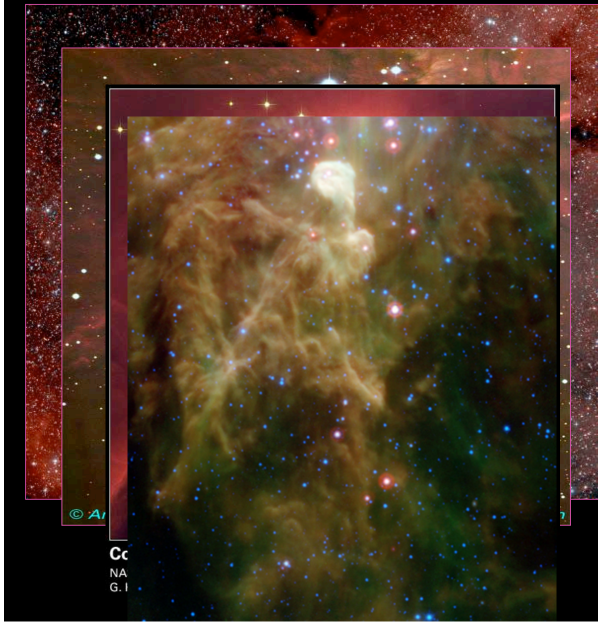
How Do We Know that Stars Form in Molecular Clouds ?

- 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

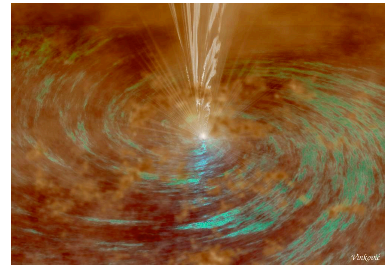




The Cone Nebula

A Star Forming Region

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

Question

Stars are born

a) in molecular clouds.
b) in supernovae.
c) in black holes.
d) on Broadway.
e) in empty space.

Water Power?

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

A) Yes
B) No

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, the initial gas clumps in molecular clouds 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.

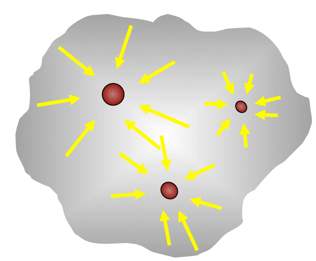
http://www.rob-clarkson.com/duff-brewery/snowball/04.jpg

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 closed system have angular momentum.

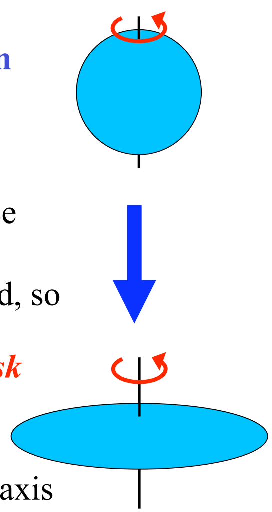
Angular momentum is a single, *constant* number = *conserved*!

Keep same dist. to axis → velocity same

Move closer to axis → speed up!

When Doves Cry and Stars Form

Solar nebula competition:
Gravity vs Angular Momentum



- If fall perpendicular to spin axis
  Needs to speed up
  → resistance centrifugal force
- If fall parallel to spin axis same speed, so no resistance
  → forms ***protoplanetary disk***
  – Origin of planet's orbits!
  – Organizes spins along initial spin axis

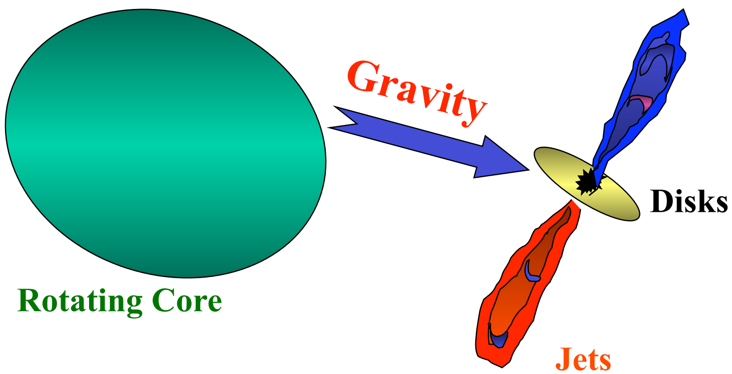
Question

Since in star formation a collapsing cloud is spinning, the cloud will form

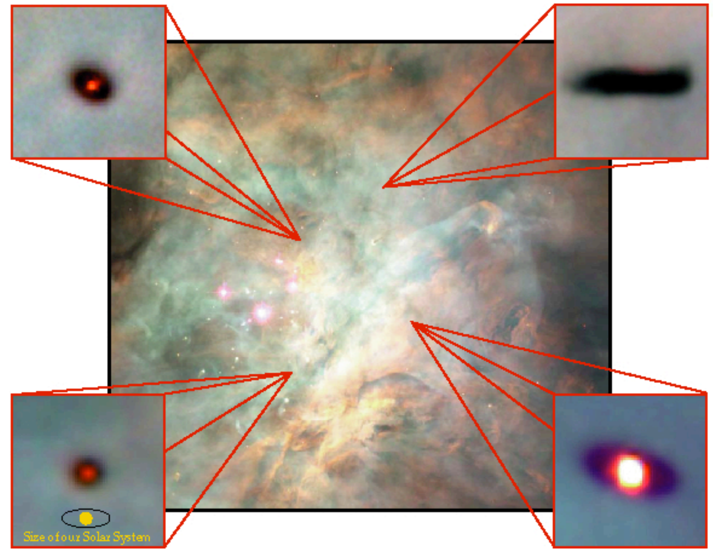
a) a spherical cloud
b) a star
c) a flattened disk
d) a planet
e) a galaxy

The Protostar Stage

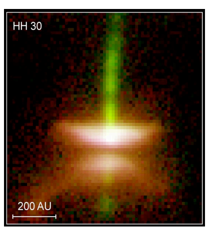
Gravity, Spin, & Magnetic Fields

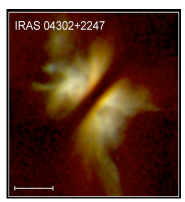


Disks around Young Stars are Common

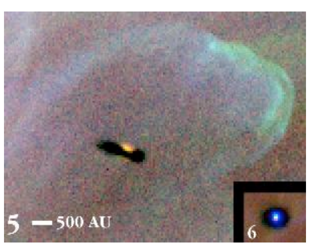


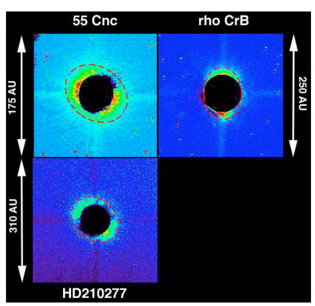
And Disks around Young Stars are Common



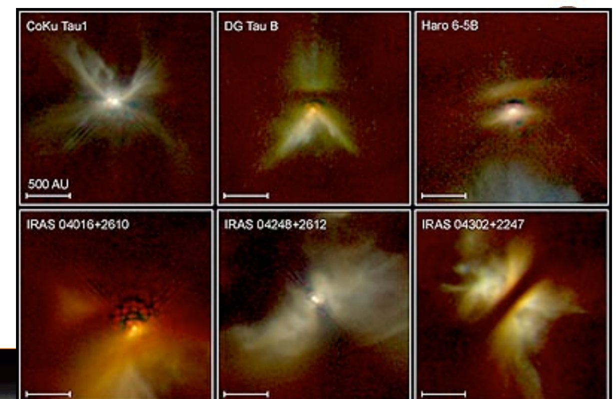


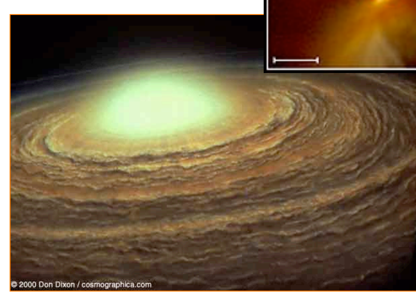
http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm





Disks have been imaged with HST's infrared camera

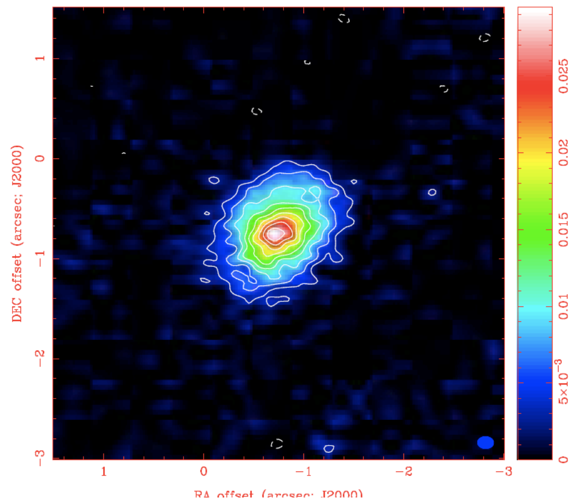




Young stars are surrounded by dense disks of gas and dust

Tracing the Bulk Material

HL Tauri



Interesting Question

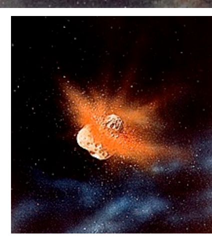
Leslie studies circumstellar disks. What is he actually observing?

a) The disks of Galaxies.
b) The disks around Black Holes.
c) The disks around protostars.
d) The disks around planets like Saturn.
e) The disks under nice beverages.

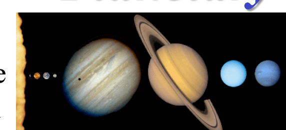
Planet Formation in the Disk

Heavy elements clump

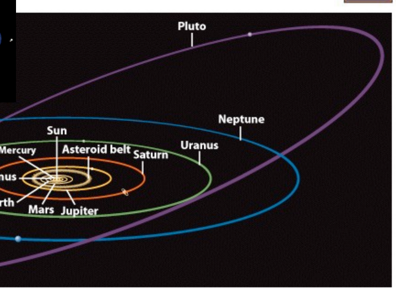
1. *Dust grains* collide, stick, and form planetesimals– about 10^{12} of them, sort of like asteroids! All orbit in the same direction and in the same plane.
2. Gravity Effects: Big planetesimals attract the smaller planetesimals. So, fewer and fewer of large objects (100's). Collisions build-up inner 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



Planetary Orbits



Most of the motions in the Solar System are counter clockwise in a flat system (pancake-like)

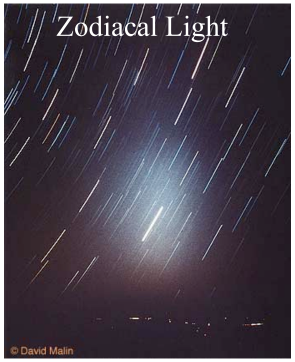


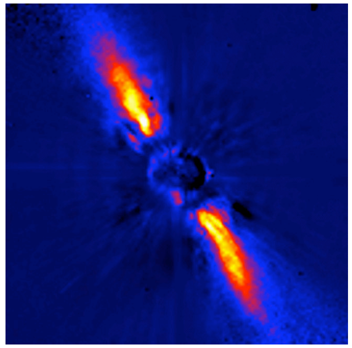
– There are some exceptions
– Venus, Uranus, and Pluto <u>rotate</u> clockwise (orbits are still clockwise)
– Some moons orbit backwards

http://janus.astro.umd.edu/javadir/orbits/ssv.html

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.



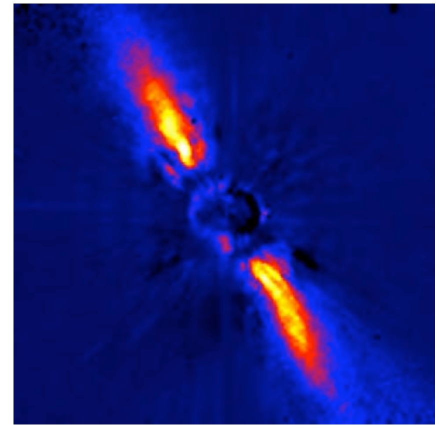


http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html

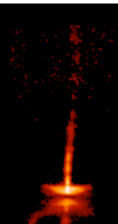
http://antwrp.gsfc.nasa.gov/apod/ap970826.html

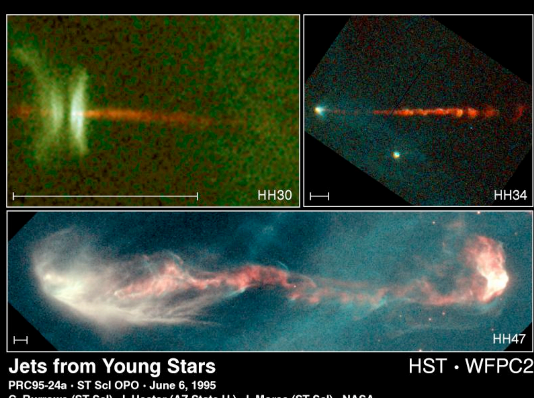
Disks Around Young Stars

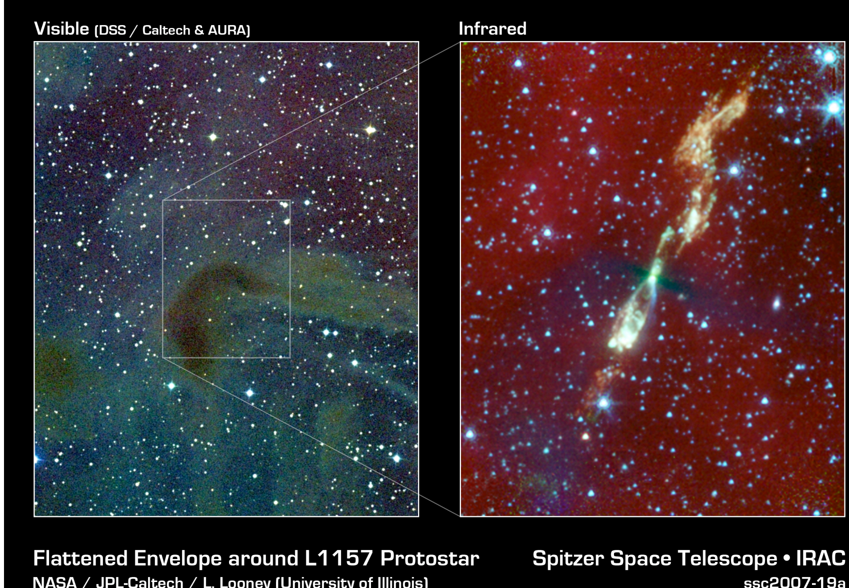
- Many (> 50%) of newborn stars surrounded by a disk of material!
- Disks thick, blocks light
  - Enough material to make planets
  - Agrees with Solar Nebula theory!



Protostellar Jets

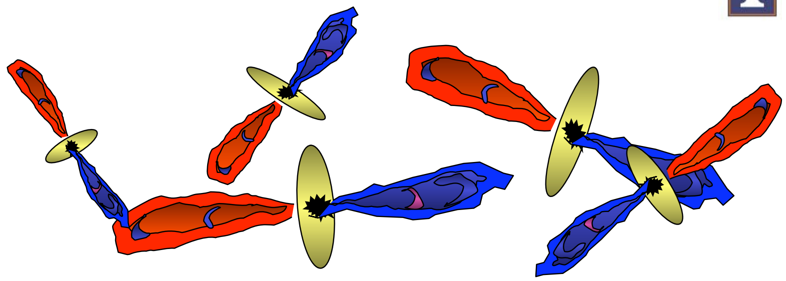






http://www.youtube.com/watch?v=Rm3Sj8qAaWg&NR=1

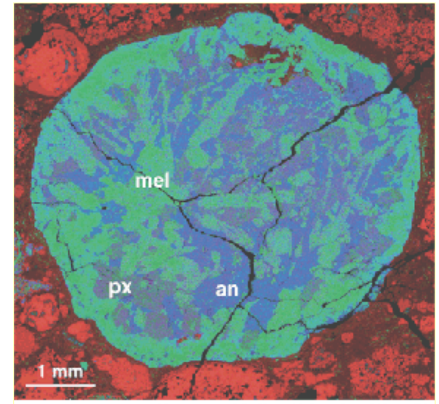
Young Stars in Groups



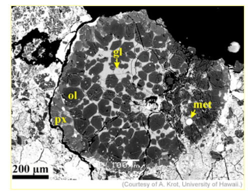
- Most stars are in multiple systems and clusters
- What about us?

The Earliest Pre-Solar Dust Grains

- Calcium-aluminum-rich inclusions (CAIs)
- Chondrules (grains found in primitive meteorites).



(Courtesy of A. Krot, University of Hawaii.)

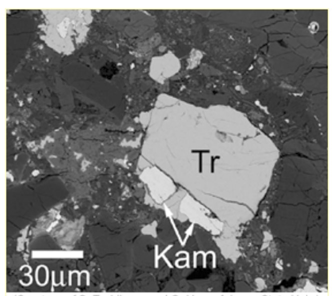


Formed 4,700,000,000 years ago

CAIs Once Contained ^{60}Fe

- Contain decay products of ^{26}Al and ^{60}**Fe**
- As seen by an excess of nickel
- Most likely produced by nearby supernova explosion!

- Can use the ensemble of all radioactive elements to estimate distance to the supernova
  - 0.1 to 1.6 pc away



(Courtesy of S. Tachibana and G. Huss, Arizona State Univ.)

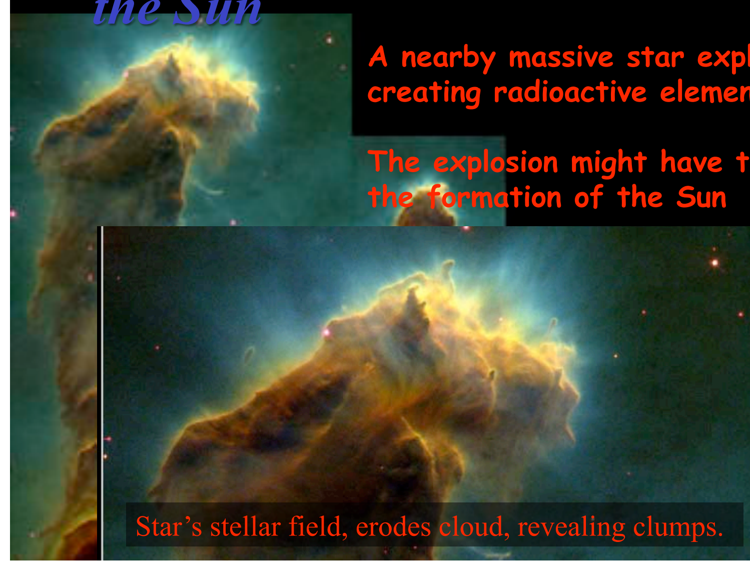
Half life 1.5 million years

The Birth of the Sun

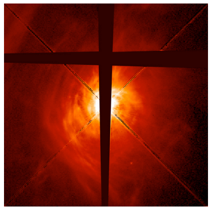
The Sun formed as part of a modest-sized cluster of stars

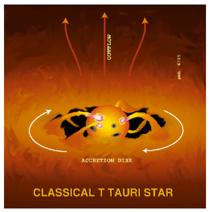
A nearby massive star exploded, creating radioactive elements

The explosion might have triggered the formation of the Sun



On to the Main Sequence: A Star is Born!





- For 1 solar mass star, process takes about 10 million years
- Density increase, temperature increases until fusion can occur.
  - Blows away most of its natal circumstellar material.
  - Becomes a hydrogen burning star
  - http://www.youtube.com/watch?v=jhYEQgLW5NM
  - http://www.youtube.com/watch?v=mZL7VBmeFxY&feature=related