Astronomy 330

<u>This class (Lecture 10):</u>

Star Formation

<u>Next Class:</u>

Exoplanets

Exam 1 next Thursday!

Music: *3rd Planet* – Modest Mouse

Exam 1

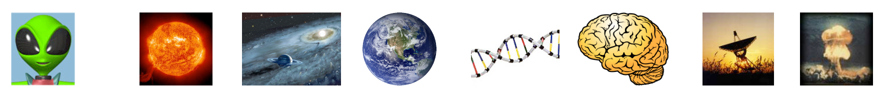
- Next Thursday in this room.
- Tuesday, class decided on 35 MC questions, plus two extra credit questions.
  - Maximum score is 105 counted out of 100 points.
- You can bring 1 sheet of paper with notes
  - Printed, scribbled, whatever, I don't care.
- Will cover material up to and including today's lecture.
- Major resources are lectures, in-class questions and homework.

Outline

- To better understand f_p, we need to explain how our Solar System formed.
- Planet's motions are special
- Explained by a circumstellar disk
  - Common around known young stars

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 in our Galaxy today	Star formation rate	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
	9 stars/ yr	? systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

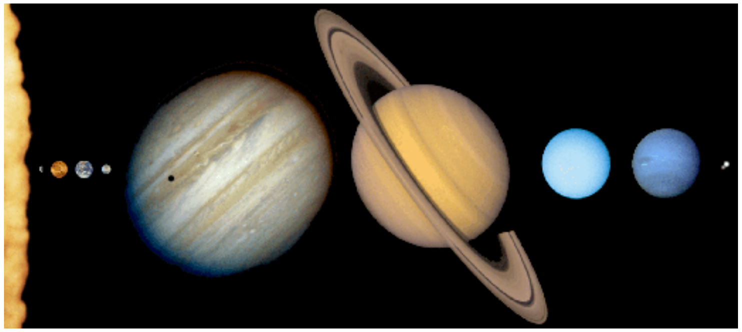
What is the origin of the Solar System?

- Explain present-day Solar System data.
- Predict results of new Solar System data.
- Should explain and predict data from other stars!

What are clues to solar system origins?

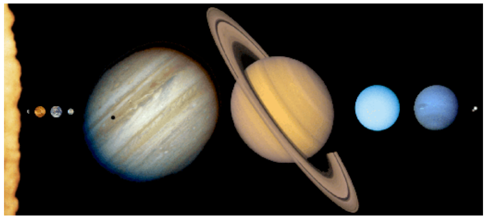
Some Facts of the Solar System

- We have 8 or 9 planets.
- So perhaps the average extrasolar system has about 10 planets (rounded off).



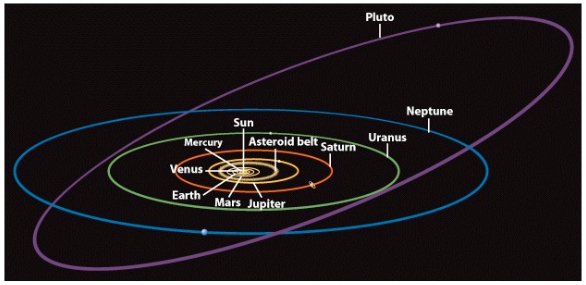
Some Facts of the Solar System

- Mass of solar system
  - 99.85% in the Sun (planets have 98% of ang. mom.)
  - Outer planets more massive than the inner ones
  - Jupiter is more than twice as massive as the rest of the planetary system combined!
- The inner planets are rocky and the outer planets are gaseous



Planetary Orbits

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

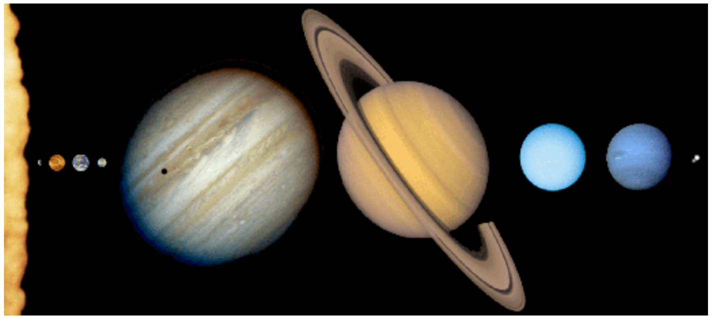


- There are some exceptions
- Venus, Uranus, and Pluto <u>rotate</u> clockwise (orbits are still clockwise)
- Some moons orbit backwards

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

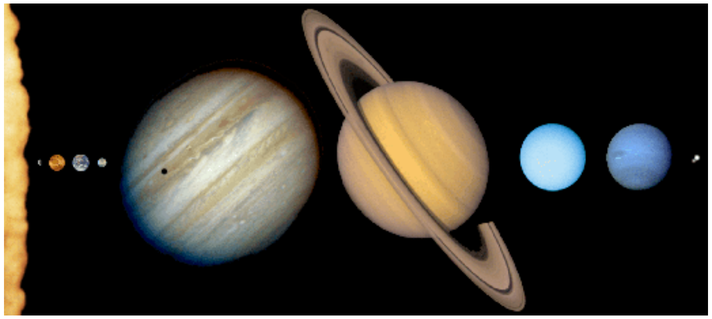
Some Facts of the Solar System

- Outer planets more massive than inner planets.
- The inner planets are rocky and the outer planets are gaseous.



Some Facts of the Solar System

- Numerous collisions occurred in the early Solar System
  - Origin of Moon, Lunar craters, Uranus's obit, and Pluto
- Planets are not evenly spaced– factors of 1.5 to 2.
  - Sun/Saturn distance is 2x Sun/Jupiter distance
  - Sun/Mars distance is 1.5x Sun/Earth distance



What is the Age of the Solar System?

- Earth: oldest rocks are 4.4 billion yrs
- Moon: oldest rocks are 4.5 billion yrs
- Mars: oldest rocks are 4.5 billion yrs
- Meteorites: oldest are 4.6 billion yrs
- Sun: models estimate an age of 4.5 billion yrs

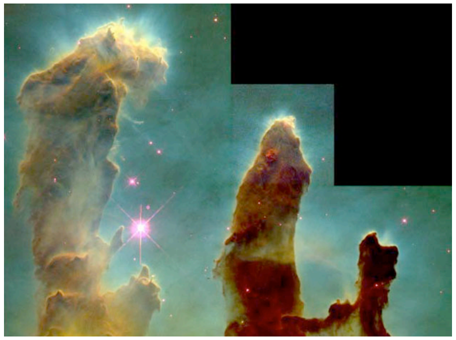
- **Age of Solar System is probably around 4.6 billion years old**

Origin of Solar System: Solar Nebula Theory

"***nebula***" = cloud

Gravitational Collapse

- The basic idea was put forth by Immanuel Kant (the philosopher)– Solar System came from a Gas Nebula.
- 4.6 billion years ago: a slowly spinning ball of gas, dust, and ice with a composition of mostly hydrogen and helium formed the early Solar System.
- This matches nearly exactly with the modern idea of star formation.

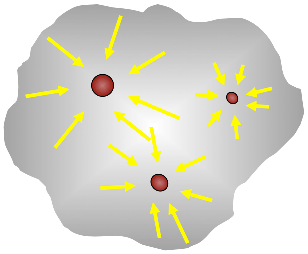


Gravitational Contraction

- As we discussed for the first stars, 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



Making a Flattened Object

- 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.

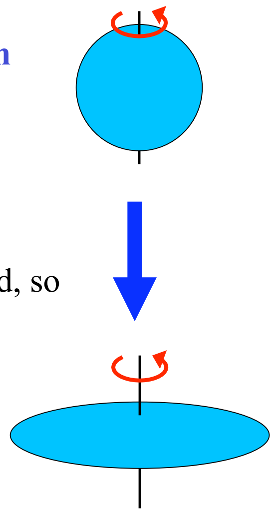
Angular momentum is a single, *constant* number = *conserved*!

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 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

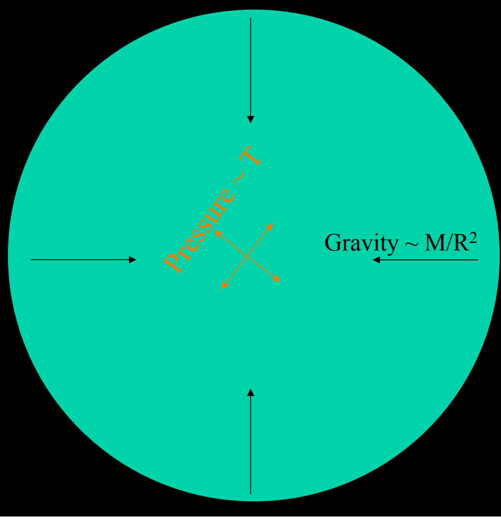
Prenatal Stars

- A star's life begins in darkness….
- in an optically thick molecular cloud in space.
- Shielded by dust and gas from galactic starlight and cosmic rays, the cloud cools
- In the densest clumps of molecular gas, gravity overcomes internal pressure: clumps contract

Prenatal Stars

- Deeply embedded inside molecular clouds (high density in space = ultrahigh vacuum in lab)
- Very young – 10,000 to 100,000 years old!(still cute and cuddly)
- Just a ball of dust and gas (1-10 million years until it burns hydrogen to helium– main sequence), shaped by gravity.

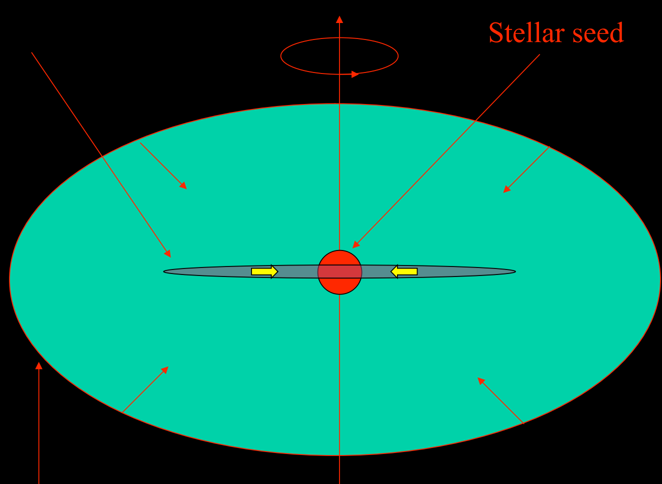
A Collapsing Molecular Clump



Prenatal Stars

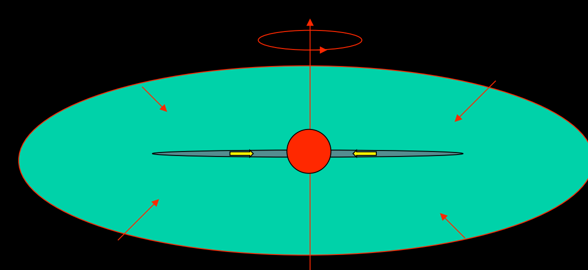
- A star's life also begins with rotation….
- A result of tidal encounters among clumps or Galactic rotation
- Spinning, collapsing clumps produce:
  - a *flattened envelope* from which material flows toward a ….
  - *circumstellar disk*, through which material flows toward a….
  - central, prestellar core (a "*stellar seed*")

Forming the Star-Disk System



Going Full-Term

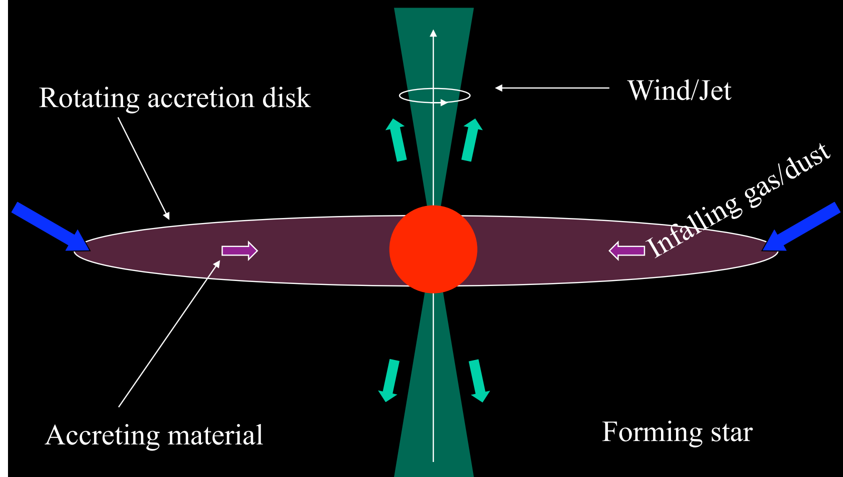
- Gas and dust transported to small scale:
  envelope ⟶ accretion disk ⟶ stellar seed
- Stellar mass builds up over time (~ 1-10 Myr)



Going Full-Term

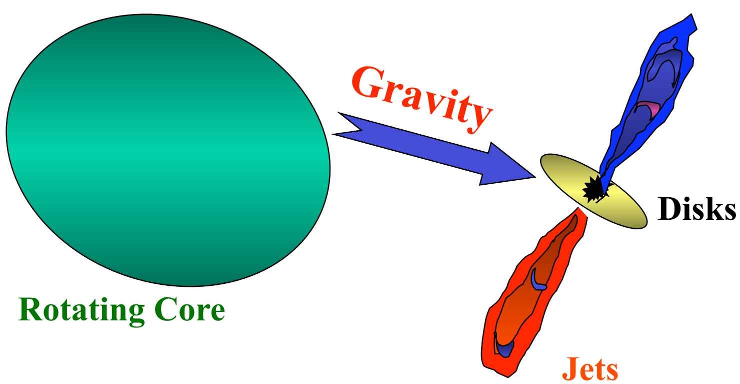
- Accreting material arises from regions that rotate
  - without a way of slowing down, the star will rotate so rapidly that material is flung off the equator
  - a star cannot reach ‘full-term’ without spin regulation
- Stellar winds and jets act as ‘rotation regulators’

Building a Full-term Star

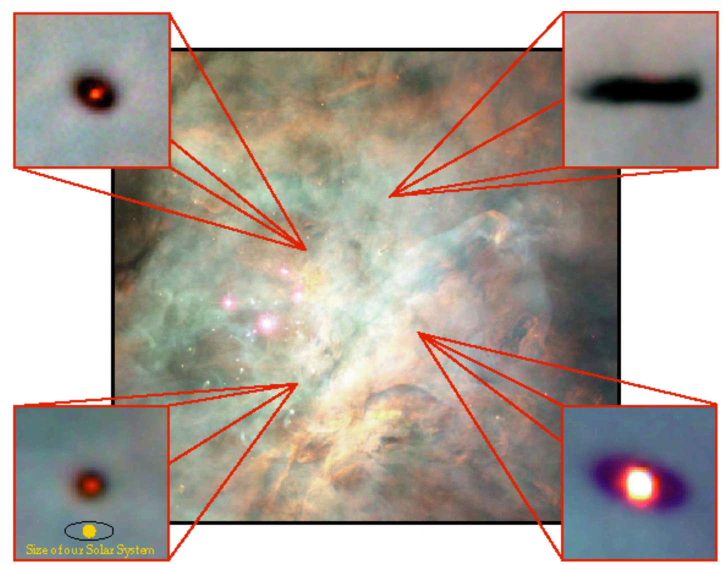


The Protostar Stage

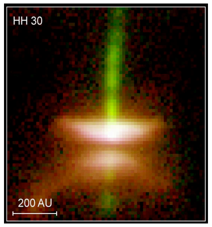
Gravity, Spin, & Magnetic Fields

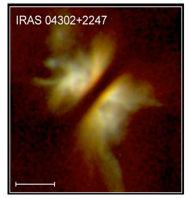


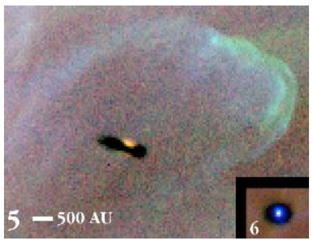
Disks around Young Stars are Common



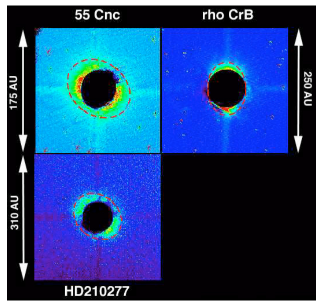
And Disks around Young Stars are Common



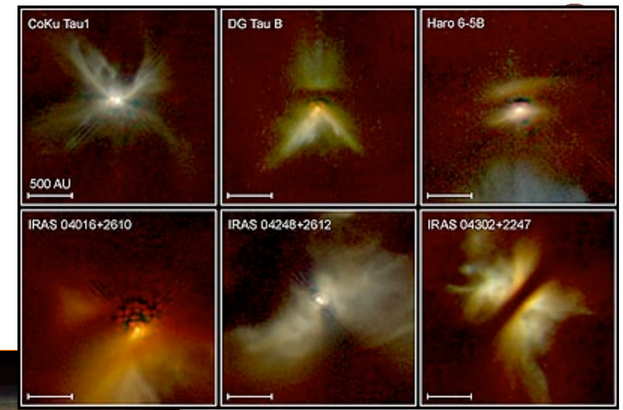


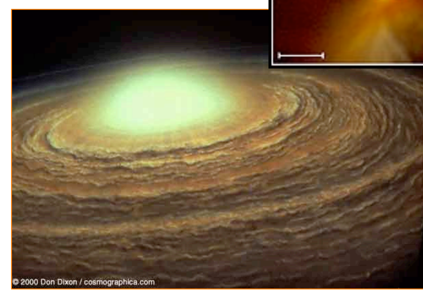


http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm



Disks have been imaged with HST's infrared camera

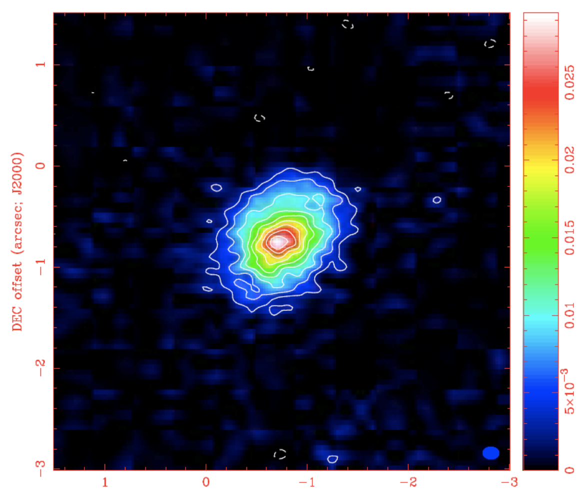




Young stars are surrounded by dense disks of gas and dust

Tracing the Bulk Material

HL Tauri



Looney et al. 2009

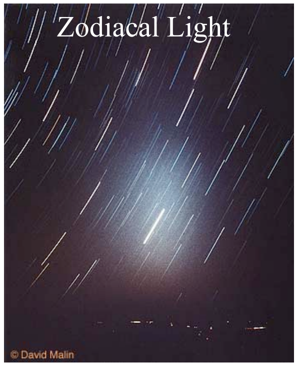
Interesting Question

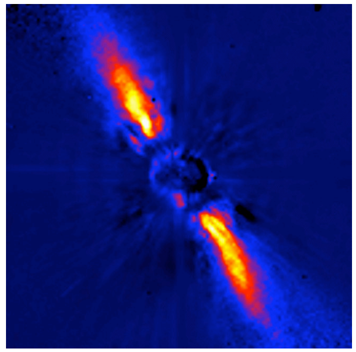
Leslie studies circumstellar disks. What is he actually observing?

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.

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.

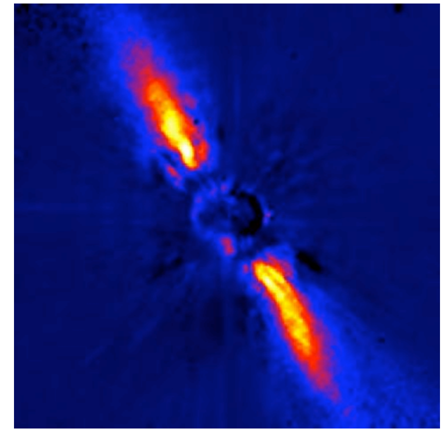




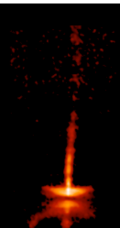
http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html
http://antwrp.gsfc.nasa.gov/apod/ap970826.html

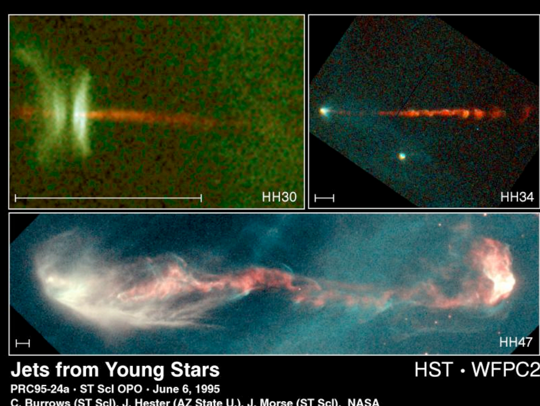
Disks Around Young Stars

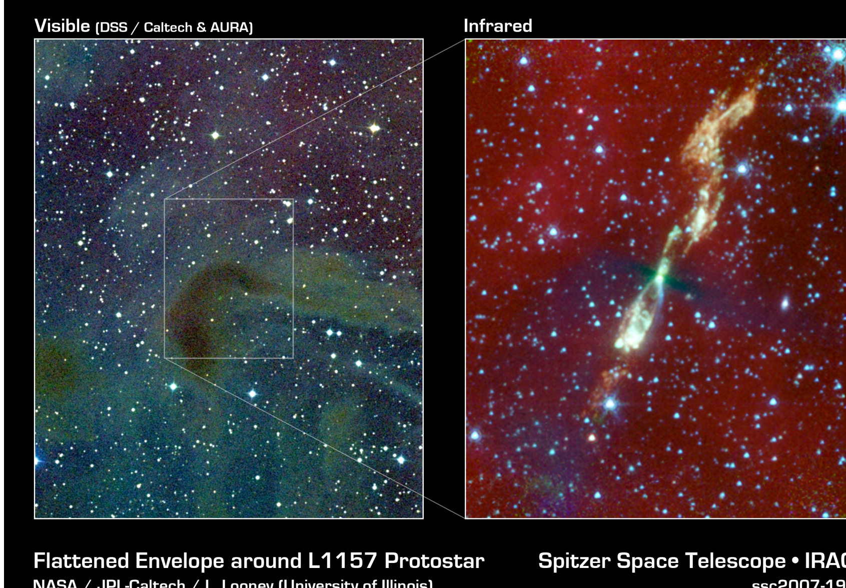
- Many (> 50%) of newborn stars surrounded by a disk of material!
- Disks thick, blocks light
  - Enough material to make planets
  - Agrees with Solar Nebula theory!



Protostellar Jets

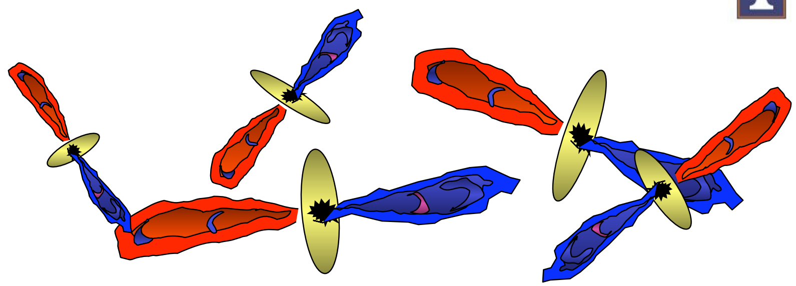






http://www.youtube.com/watch?v=Rm3Sj8qAaWg&NR=1

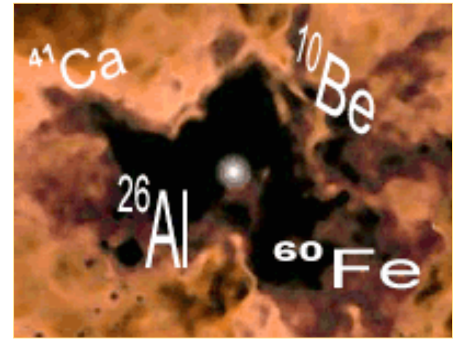
Young Stars in Groups



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

Isotopes in the Pre-Solar Nebula

- The Solar nebula had short-lived radioactive material (e.g. ^{26}Al or ^{60}Fe)
- Small mineral grains in meteorites contain evidence of this decayed material.
- The radioactive material decayed, and left rare forms of some elements in the rock



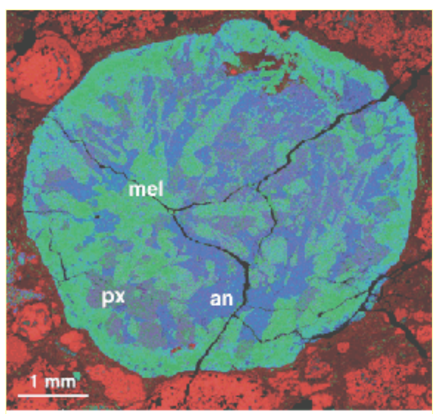
^{26}Aluminum
- 13 protons
- 13 neutrons

↓

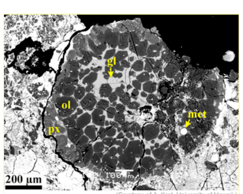
^{26}Magnesium
- 12 protons
- 14 neutrons

The Earliest Pre-Solar Dust Grains

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



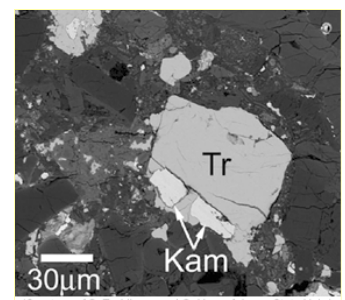
(Courtesy of A. Krot, University of Hawaii.)



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
- Can only be 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.)

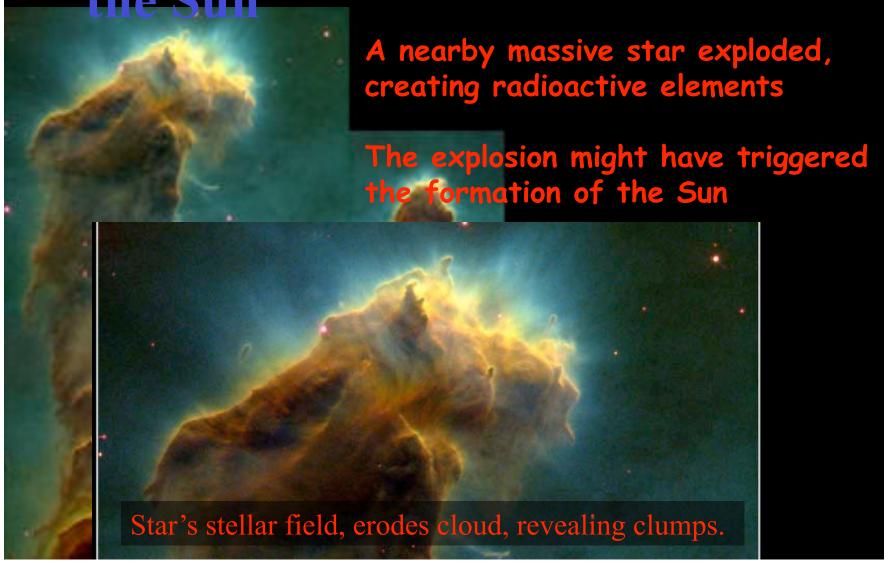
Half life 1.5 million years

The Birth of the Sun

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

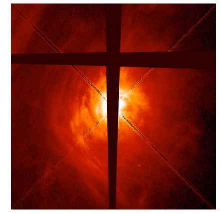
A nearby massive star exploded, creating radioactive elements

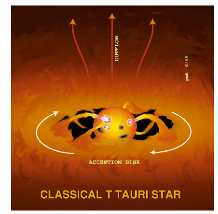
The explosion might have triggered the formation of the Sun



Star's stellar field, erodes cloud, revealing clumps.

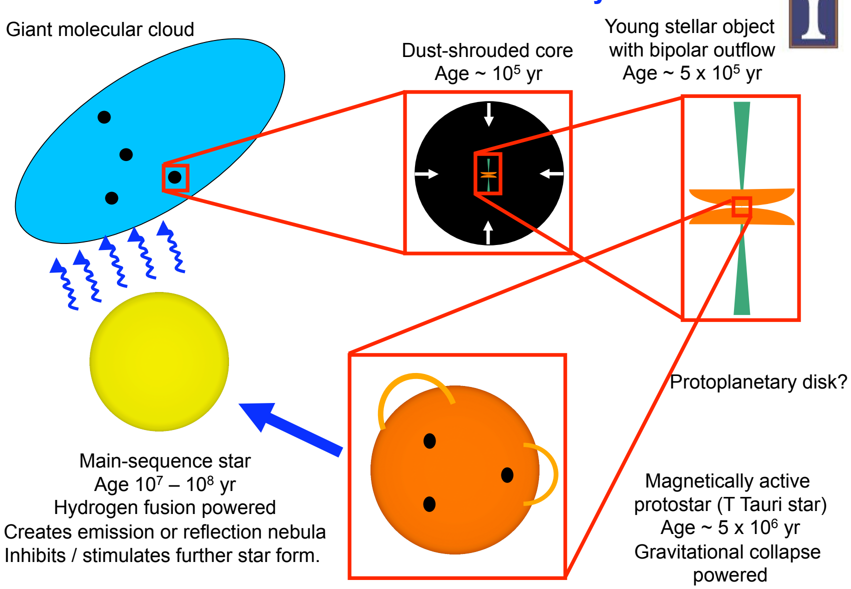
On to the Main Sequence: A Star is Born!





- 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.

Star Formation - Summary



So, Why would Spock Care?

- If we are to suppose that ET life will be based on a planet orbiting a star, then we need to know
  - How did our solar system form?
  - How rare is it?
  - Is our solar system unusual?

http://homepage.smc.edu/balm_simon/images/astro%205/spock.jpg

The Early Solar System

- A massive cloud of gas and dust
  - Seeded with elements from
    - Big Bang (hydrogen, helium, etc.)
    - Elements from planetary nebula pushed into space by red giant.
    - Elements blown from across galaxy by supernovae.

The cloud collapsed under its gravity and formed the circumstellar disk from which our solar system formed. Most theories for solar system formation require disks with masses of 0.01 to 1 solar masses.

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