Astronomy 230

TR 1300-1420

134 Astronomy Building

This class (Lecture 6):

Star Formation

Next Class:

Origin of planets

HW 2 is due Thursday.

Sept 13:
Darcy Barron
Margaret Hutton:

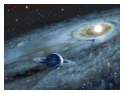
Music: *Black Hole Sun* – Soundgarden

Drake Equation

The class's first estimate is

Frank Drake








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

# 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
	15 stars/ yr	systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

Presentations

- Will be treated like a real scientific talk.
- I will keep you to 10 minutes with 5 minutes of questions.
- Any speculative claims *MUST* have a scientific reference source.
  - Can't just claim that monkeys live on the Moon.

Presentations

- Can give presentation in any format you want.
- Over last few semesters:
  - 95% powerpoint (**CAREFUL** if it is Apple)
  - 2% talking with pics from webpages
  - 2% dedicated webpage
  - 1% overhead slides
- If presentation is electronic
  - Email me evening before
  - Or, on netfiles, email me URL location BEFORE class
  - Or, bring in burned CD (present to me BEFORE class)

Oral Presentation

1. How relevant is the general topic to this class (e.g. search for extraterrestrial life)?
2. How interesting is the topic for the general class audience?
3. Rate the extent of the speakers knowledge on the topic?
4. Rate the quality of the overall presentation?
5. Does the research use enough solid scientific basis?

These questions are rated 1-10 out of 10 scale by your peers!

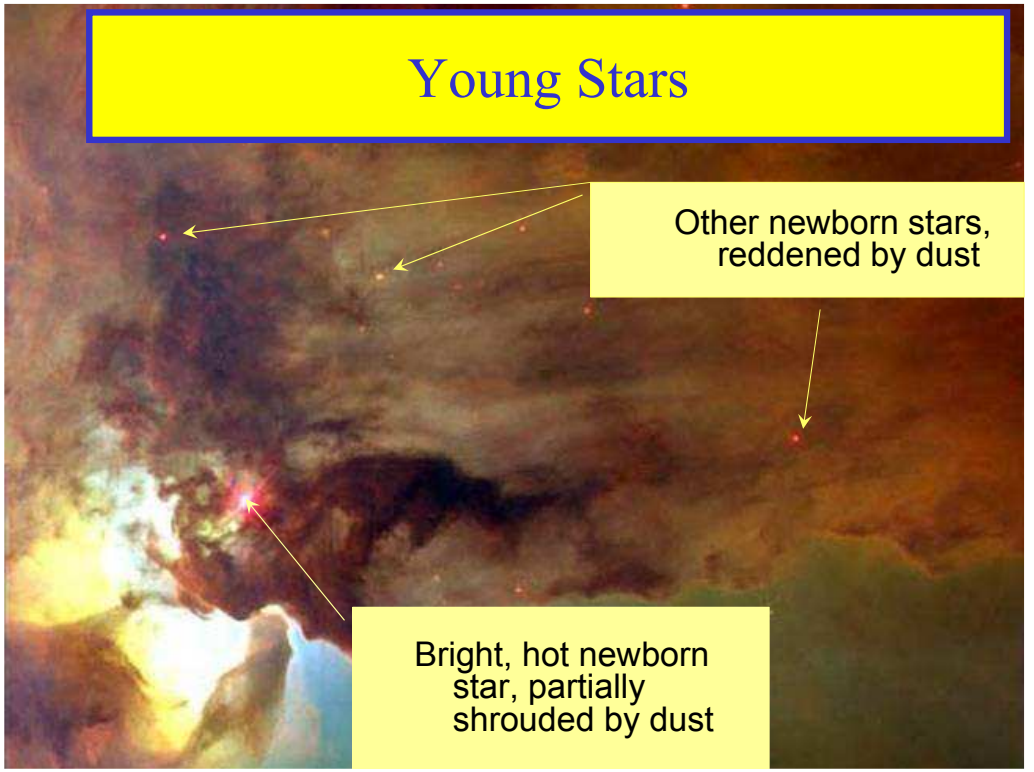
Outline

- From molecular clouds to baby stars– protostars.
- Star formation requires a circumstellar disk that is often seen around young stars.
- The origin of the Solar system also requires a disk of material in which dust clumped, forming planetesimals, then planets.
- Planets are different due to distance away from Sun..

How Do We Know that Stars Form in Molecular Clouds ?

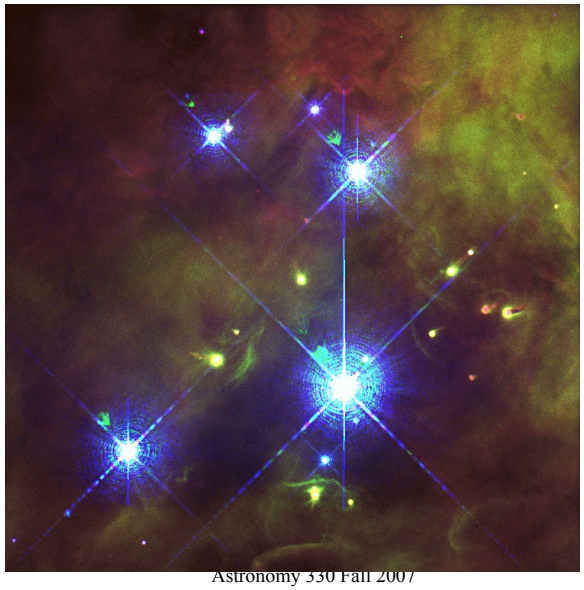
- Young stars are seen near molecular clouds.
- In infrared light, we can see into the deeper regions of clouds, and see clusters of young stars with circumstellar material (dust and gas) surrounding them.
- Stars are continuously being formed in our galaxy.

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



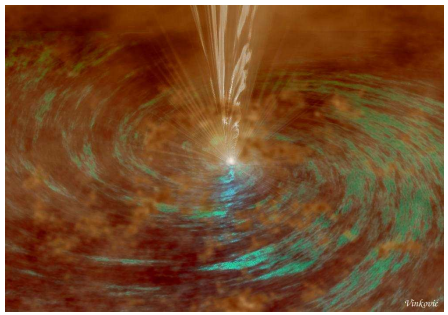
The Birthplace of Stars

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



The Trapezium

Star Formation



Stars are born in cold, dense interstellar clouds

- Cold gas
- Dust grains

Star formation is probably triggered by

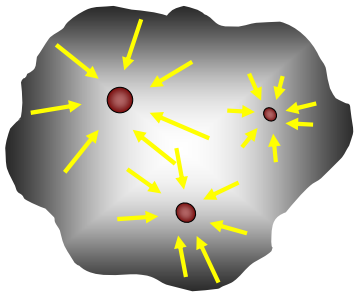
- Cloud turbulence
- Collision with another cloud
- Nearby supernova explosion
- Nearby hot star wind
- Disturbance from the Galaxy

Gravitational Contraction

- As we discussed for the first stars, the gravity of the gas and dust clumps 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

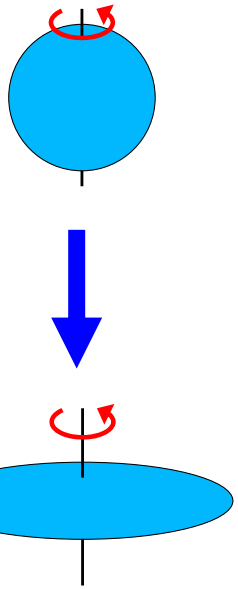
Move closer to axis → speed up!

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

When Doves Cry and Stars Form

Solar nebula competition:
Gravity vs Angular Momentum

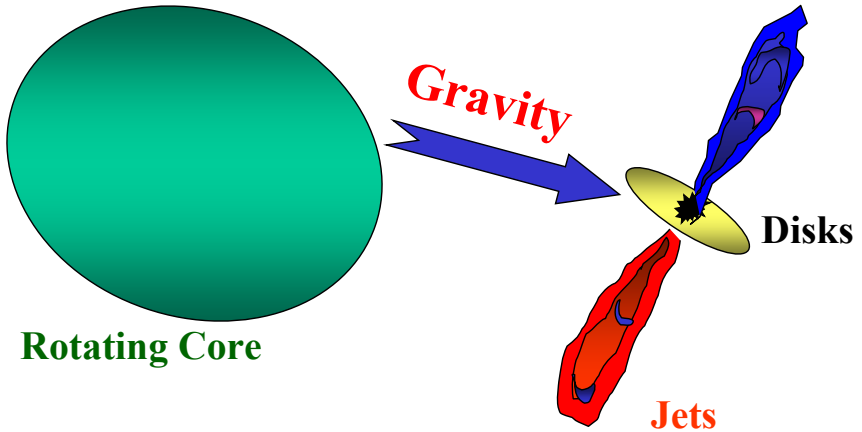
- If fall perpendicular to spin axis
  Needs to speed up
  → resistance centrifugal force
- If fall parallel to spin axis
  same speed, so no resistance
  → forms ***protoplanetary disk***



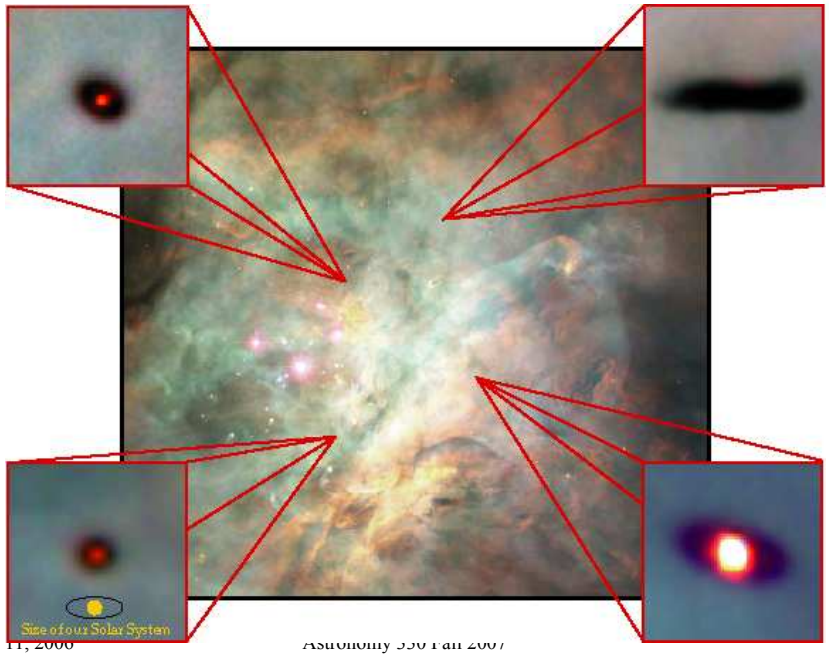
  – Origin of planet's orbits!
  – Organizes spins along initial spin axis

The Protostar Stage

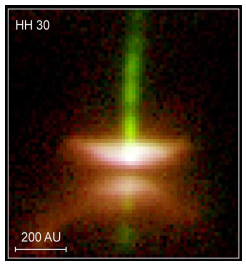
Gravity, Spin, & Magnetic Fields

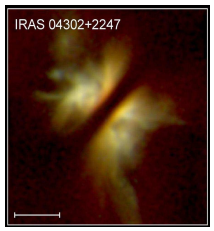


Disks around Young Stars are Common

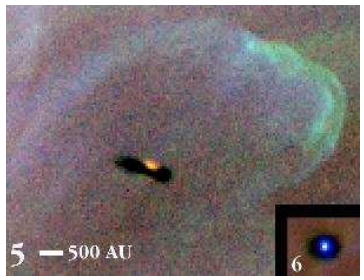


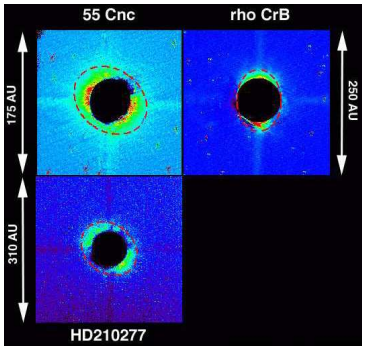
And Disks around Young Stars are Common



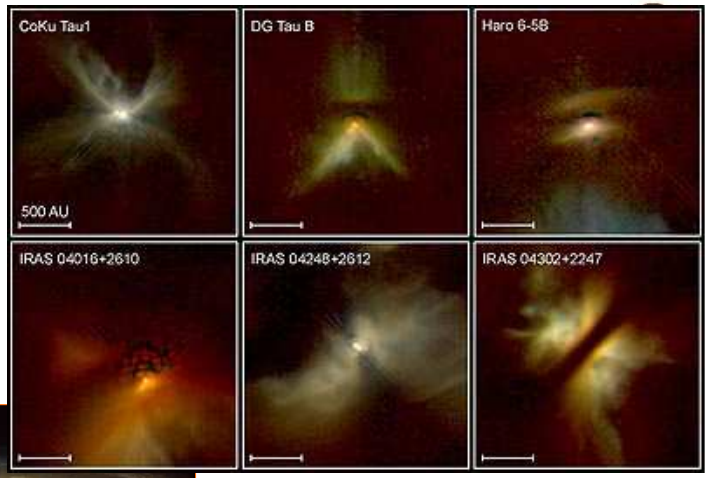


http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm



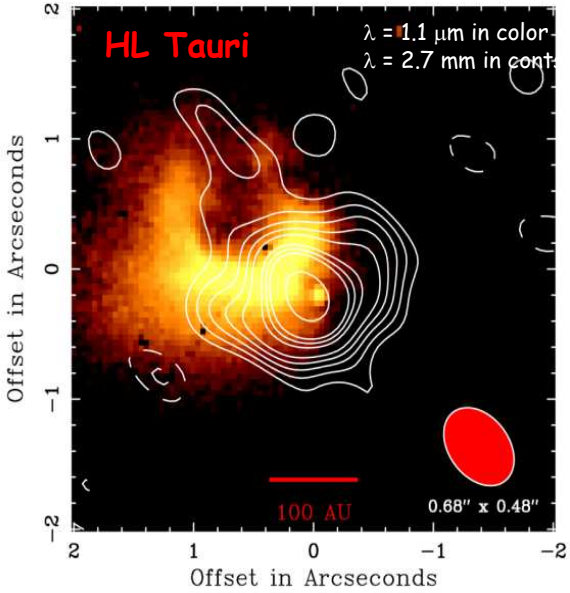


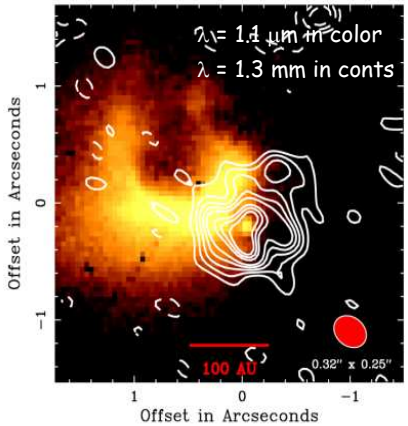
Disks have been imaged with HST's infrared camera



Young stars are surrounded by dense disks of gas and dust

Tracing the Bulk Material

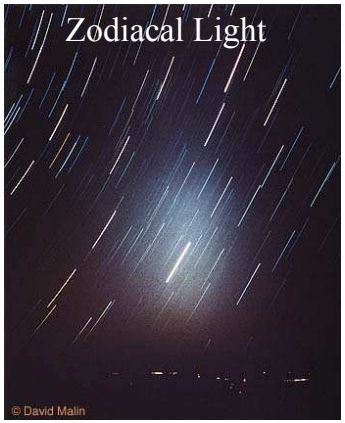


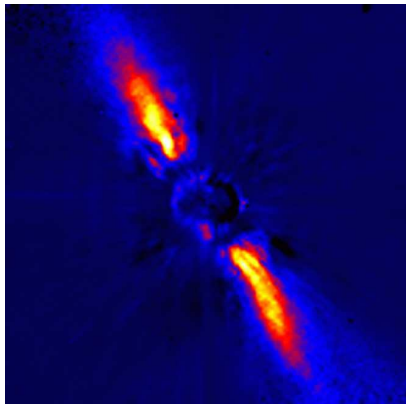


Stapelfeldt et al. 1995; Looney et al. 2000

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.

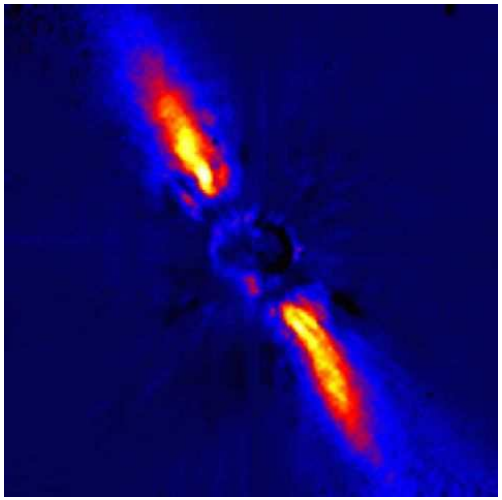


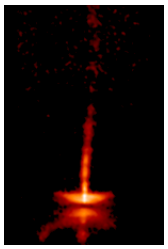


http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html
http://antwrp.gsfc.nasa.gov/apod/ap970826.html

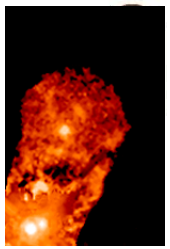
Disks Around Young Stars

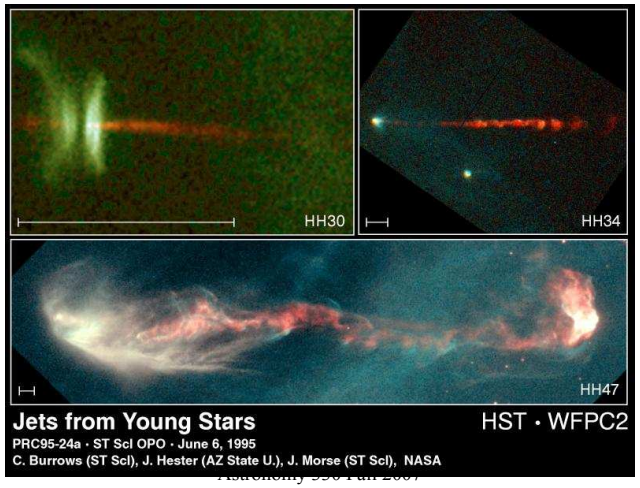
- Many (> 50%) of newborn stars surrounded by a disk of material!
- Disks thick, blocks light
  - Enough material to make planets
  - Agrees with Solar Nebula theory!

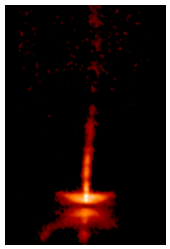




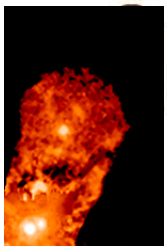
Protostellar Jets

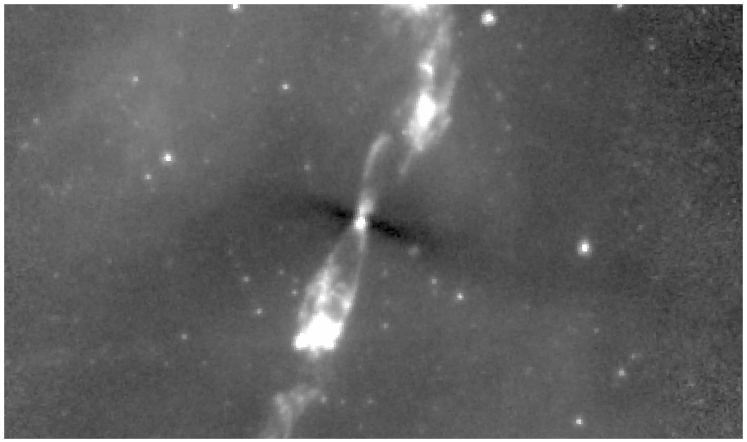




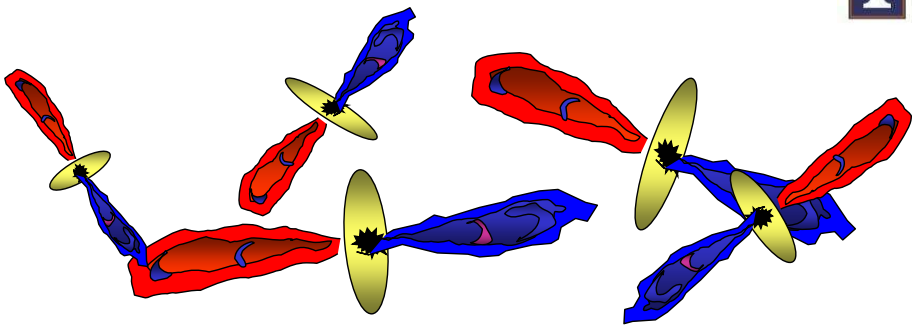


Protostellar Jets



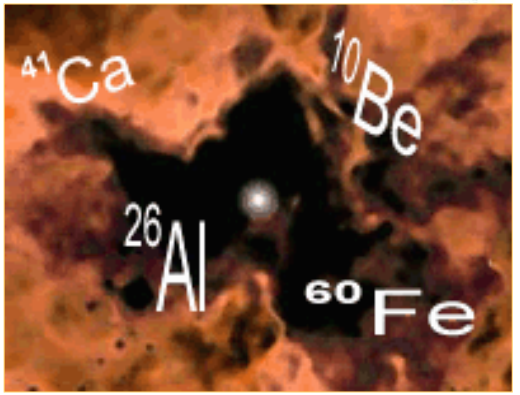


Young Stars in Groups



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

Isotopes in the Pre-Solar Nebula



- Supernova explosion also contain 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

→

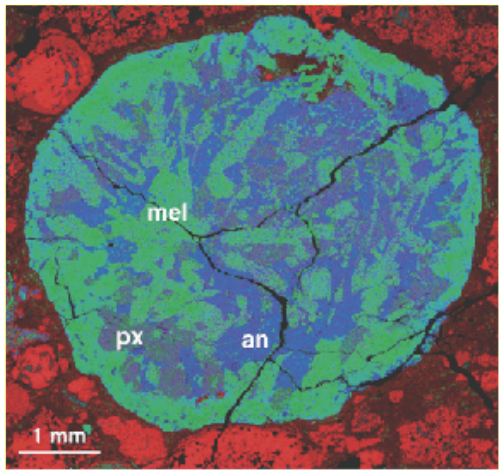
^{26}Magnesium
•12 protons
•14 neutrons

When we find an excess of ^{26}Mg, we know ^{26}Al must have been present

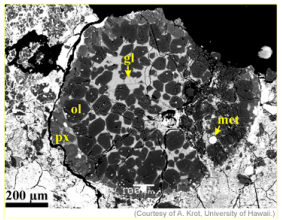
Half of the ^{26}Al decays each 740,000 years

The Earliest Pre-Solar Dust Grains

- Calcium-aluminum-rich inclusions (CAIs)
- Chondrules (grains found in primitive meteorites) also contain the "daughter products" of decayed ^{26}Al
- Chondrules formed about 2 million years AFTER the CAI rich inclusions



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



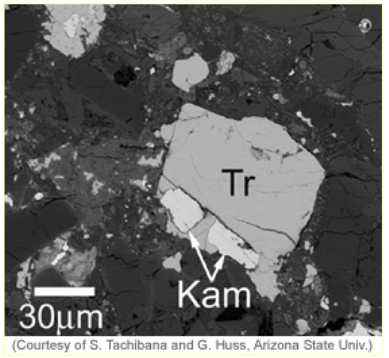
(Courtesy of A. Krot, University of Hawaii.)

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 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

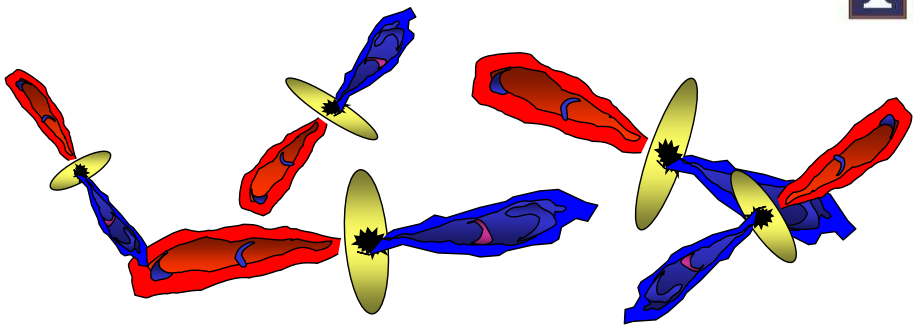
The Birth of the Sun

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

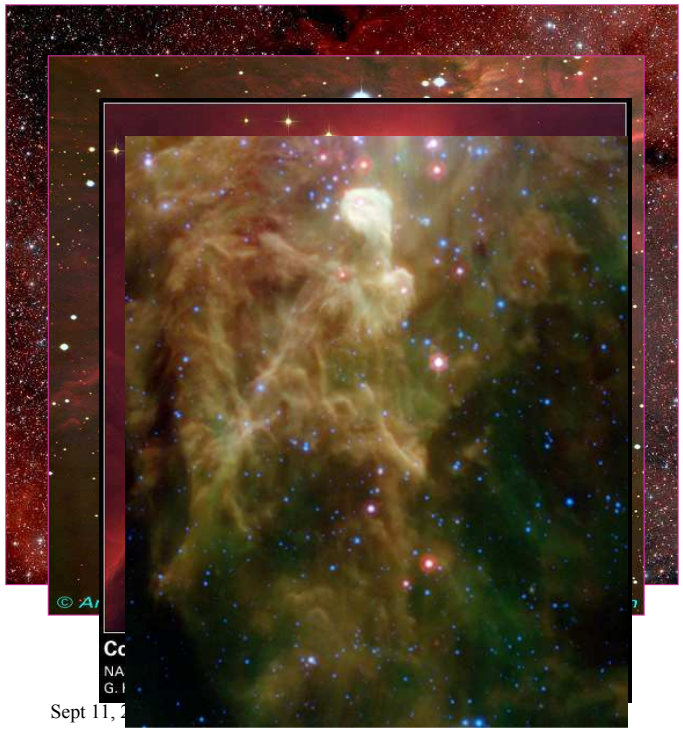
A nearby massive star exploded, creating radioactive elements

The explosion might have triggered the formation of the Sun

Young Stars in Groups

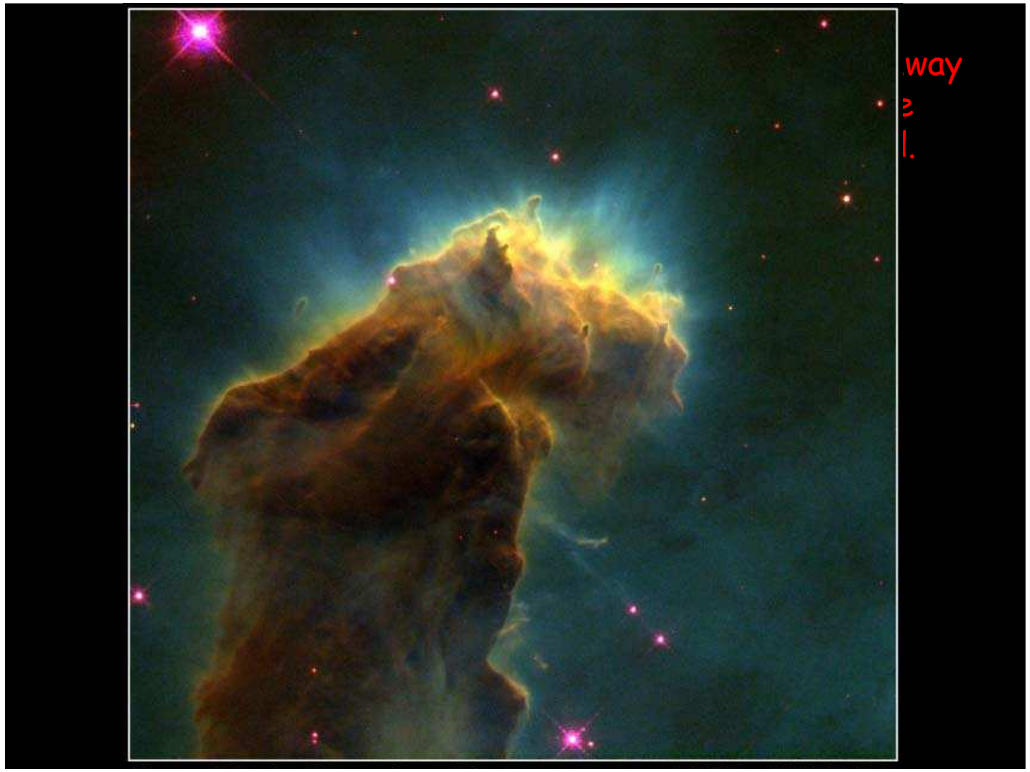


- Most stars are in multiple systems.
- How does this effect the protostars?
- How does this effect their planet formation?
- How does this effect the possibility of life on the *average* star?

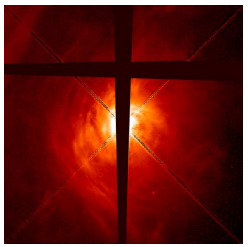


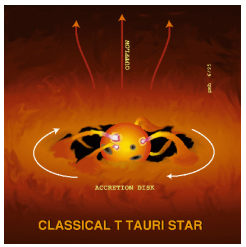
The Cone Nebula

A Star Forming Region



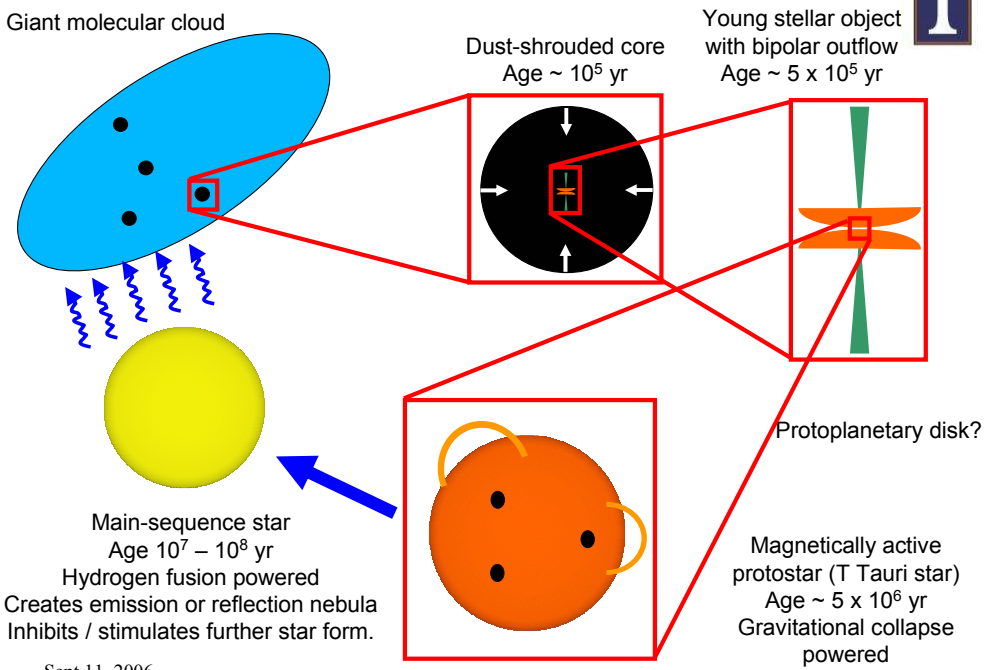
On to the Main Sequence: A Star is Born!



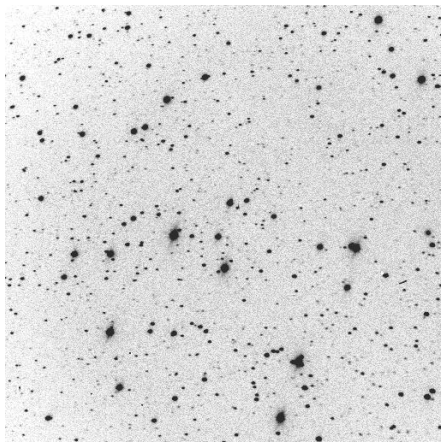


- Density increase, temperature increases until fusion can occur.
  - Blows away most of its natal circumstellar material.
  - Becomes a star on the main sequence of the HR diagram,
  - For low mass stars, this whole process can take a few 10^6 years.
  - Expect to see a large number of embedded protostars.

Star Formation - Summary



Stars Ages and ETs



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

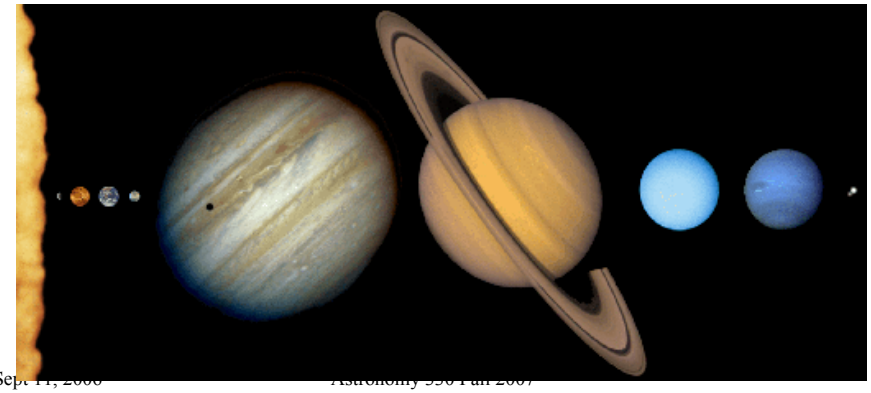
What is the origin of the Solar System?

- 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?

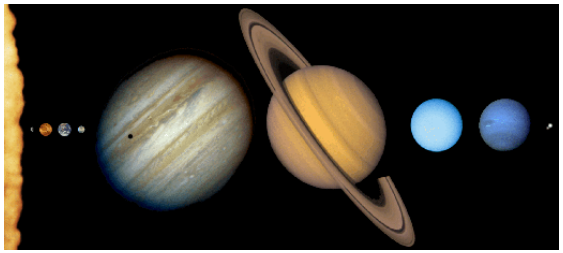
Some Facts of the Solar System

- We have 8 or 9 planets.
  - Pluto, an anomaly in many ways, probably a Kuiper object or moon of Neptune. Other Kuiper objects are being found.
- So perhaps the average extrasolar system has about 10 planets (rounded off).



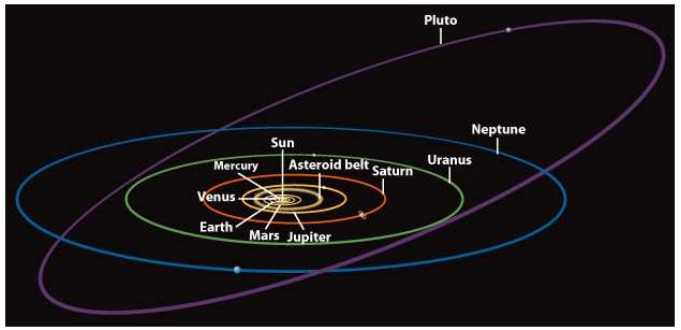
Some Facts of the Solar System

- 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)

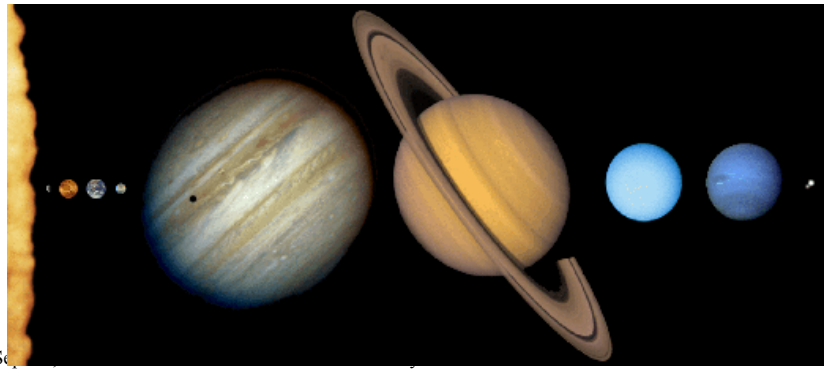


- There are some exceptions
- Venus, Uranus, and Pluto rotate clockwise (orbits are still clockwise)
- Some moons orbit backwards

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

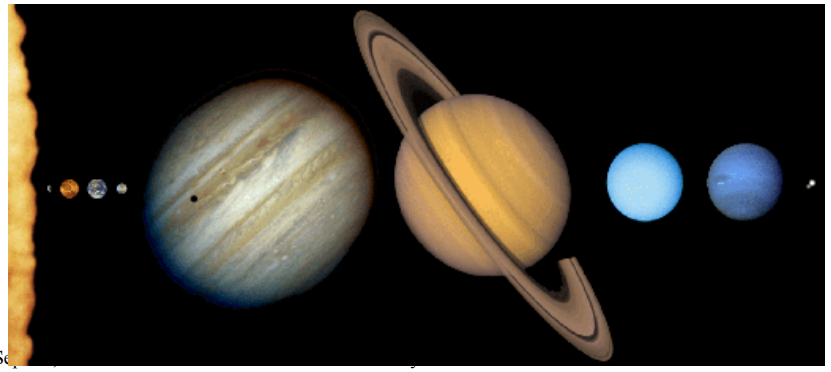
Some Facts of the Solar System

- 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

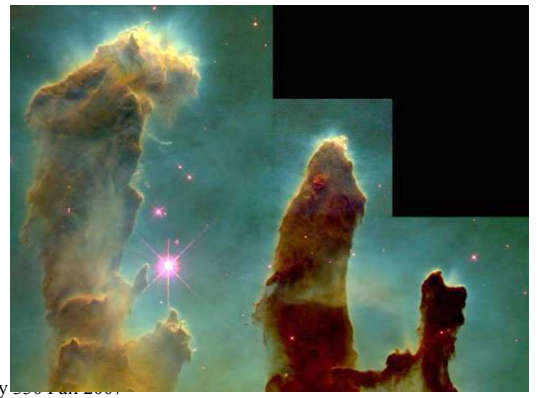
- **Age of Solar System is probably around 4.6 billion years old**

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 idea of star formation developed in class.



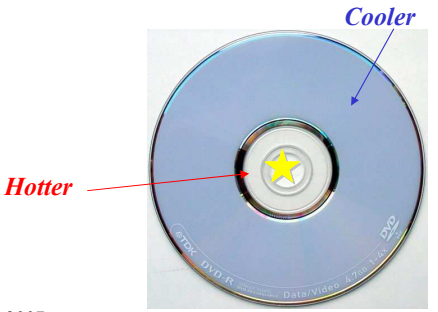
The Early Solar System

- 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.

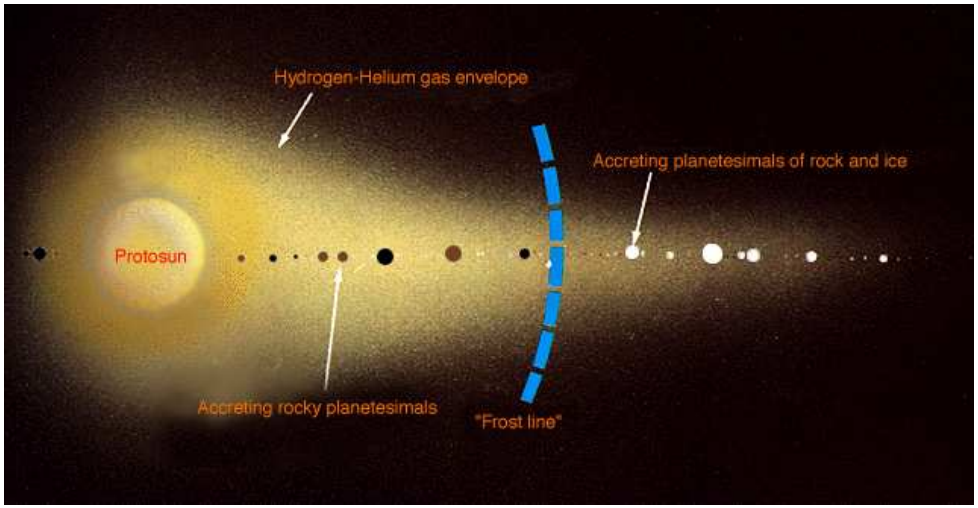
The cloud collapsed under its gravity and formed the circumstellar disk from which our solar system formed. Most theories for solar system formation require disks with masses of 0.01 to 1 solar masses.

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!

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…

Fates of the Planetesimals

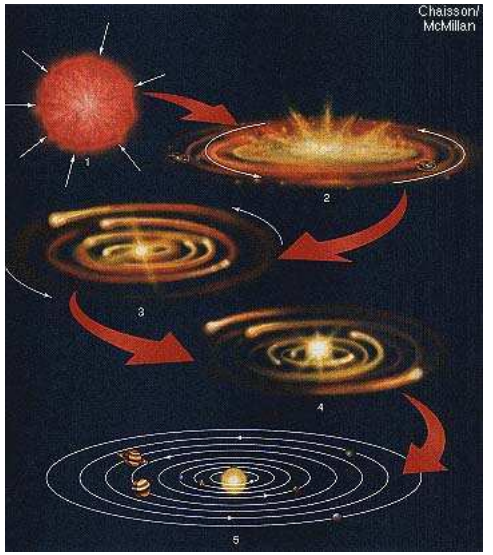
- Between Mars and Jupiter
  - Remain as the asteroids
- Near Jupiter & Saturn
  - Ejected from the solar system
- Near Uranus & Neptune
  - Ejected to the Oort Cloud
- Beyond Neptune
  - Remain in the Kuiper Belt

Planet Formation in the Disk

Heavy elements clump

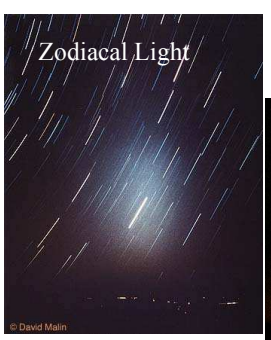
1. *Dust grains* collide, stick, and form planetesimals– about 10^{12} of them, sort of like asteroids! All orbit in the same direction and in the same plane.
2. Gravity Effects: Big planetesimals attract the smaller planetesimals. So, fewer and fewer of large objects (100's). Collisions build-up inner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

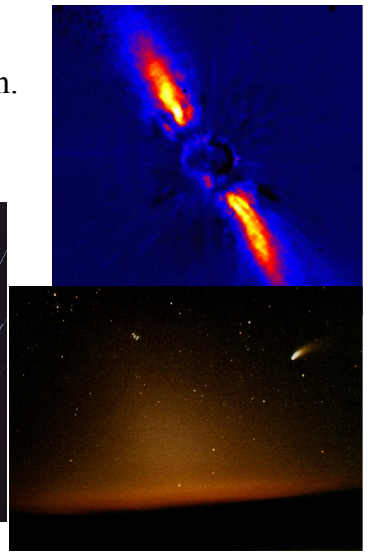
Formation of the Solar System 4.6 billion years ago



Fossil Disks Exist around other Stars?

- We see old disks around other stars (e.g. Vega and Beta Pictoris) as well as our own.
- Many (more than half!) of newborn stars surrounded by a disk of material!
- Disks are thick and dusty
  - Enough material to make planets
  - Agrees with the Solar Nebula theory!





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

What Are We Looking For?

General Predictions of Solar Nebula Theory

☺ Are interstellar dust clouds common? ***Yes!***

☺ Do young stars have disks? ***Yes!***

? Are the smaller planets near the star?

? Are massive planets farther away?

Test Of Exoplanets

Planets around other stars

= extrasolar planets = "***exoplanets***"

Would our solar system nebula formation theory account for other solar systems around other stars?

Hard to find!

Reflected light from the Earth is 1 billion times fainter than the Sun!!!!!

Finding Planets

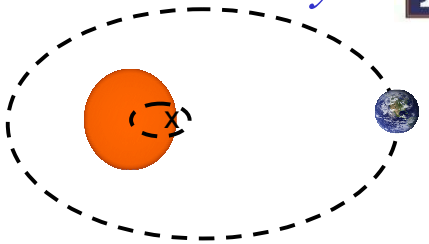
1. **Radial Velocity:** **Stars will wobble.**
2. Astrometry: See the stars move.
3. Transit Method: Occultation.
4. Optical Detection: Direct.

Arguable 2 extrasolar planets have been detected directly in the IR. Remember that planets in our Solar System seem bright because they reflect light from the Sun in the visible.

Star Wobble: Radial Velocity

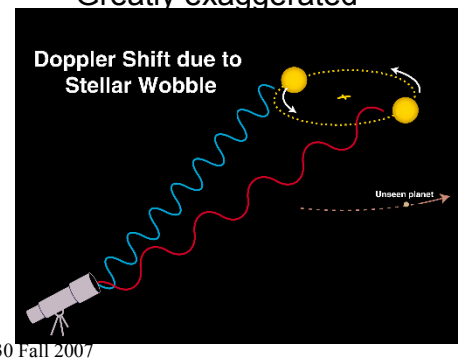
Newton's 3rd Law:

- *Both* planet *and star* move
- Both orbits fixed around the "center of gravity"



- Star's period? Place your bets…
  - Same as planet

Greatly exaggerated



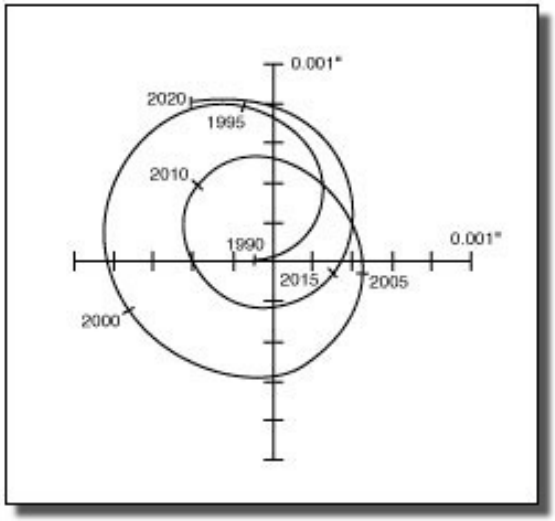
- Star movement too small to see
  - Moves in small, tight circle
  - But "wobble" in star speed detected!

http://www.howstuffworks.com/planet-hunting2.htm

The Sun's Wobble

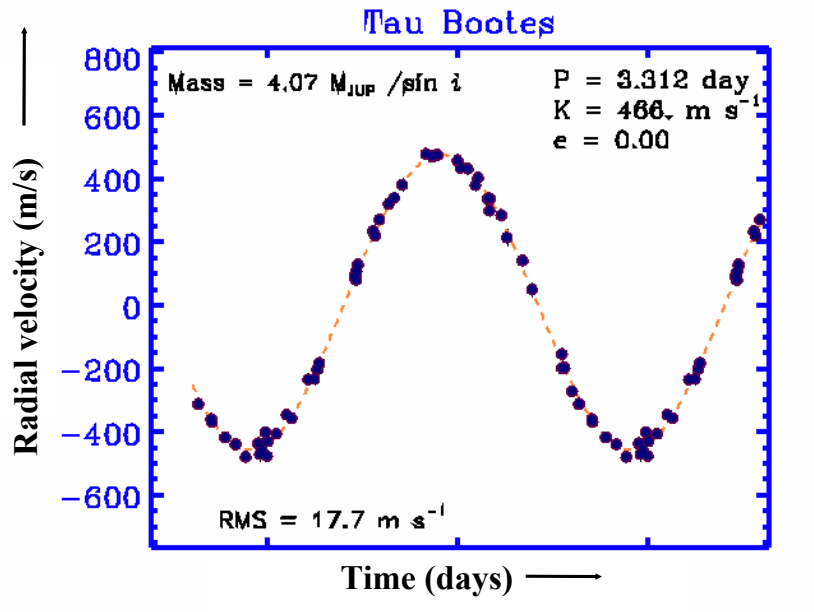
Astrometric displacement of the Sun due to Jupiter (and other planets) as at it would be observed from 10 parsecs, or about 33 light-years.

If we could observe this, we could derive the planetary systems– also called astrometry.

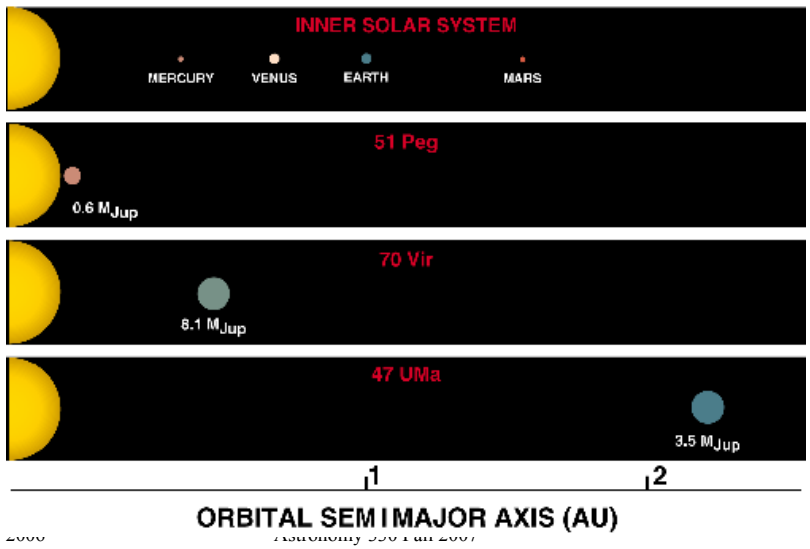


http://planetquest.jpl.nasa.gov/Keck/astro_tech.html

Radial Velocity Shifts: Planets around other Stars?



Early Discovery-- 1996



Hear all about it.