The History of the Universe in 200 Words or Less

Quantum fluctuation. Inflation. Expansion. Strong nuclear interaction. Particle-antiparticle annihilation. Deuterium and helium production. Density perturbations. Recombination. Blackbody radiation. Local contraction. Cluster formation. Reionization? Violent relaxation. Virialization. Biased galaxy formation? Turbulent fragmentation. Contraction. Ionization. Compression. Opaque hydrogen. Massive star formation. Deuterium ignition. Hydrogen fusion. Hydrogen depletion. Core contraction. Envelope expansion. Helium fusion. Carbon, oxygen, and silicon fusion. Iron production. Implosion. Supernova explosion. Metals injection. Star formation. Supernova explosions. Star formation. Condensation. Planetesimal accretion. Planetary differentiation. Crust solidification. Volatile gas expulsion. Water condensation. Water dissociation. Ozone production. Ultraviolet absorption. Photosynthetic unicellular organisms. Oxidation. Mutation. Natural selection and evolution. Respiration. Cell differentiation. Sexual reproduction. Fossilization. Land exploration. Dinosaur extinction. Mammal expansion. Glaciation. Homo sapiens manifestation. Animal domestication. Food surplus production. Civilization! Innovation. Exploration. Religion. Warring nations. Empire creation and destruction. Exploration. Colonization. Taxation without representation. Revolution. Constitution. Election. Expansion. Industrialization. Rebellion. Emancipation Proclamation. Invention. Mass production. Urbanization. Immigration. World conflagration. League of Nations. Suffrage extension. Depression. World conflagration. Fission explosions. United Nations. Space exploration. Assassinations. Lunar excursions. Resignation. Computerization. World Trade Organization. Terrorism. Internet expansion. Reunification. Dissolution. World-Wide Web creation. Composition. Extrapolation?

Astronomy 330

This class (Lecture 9):

Exoplanets
Paige Malec

Next Class:

Moon Origins
Ilana Strauss

HW 3 is due Thursday!

Music: *Planet of Sound*– Pixies

HW 2

- Timothy Garbaciak
  http://www.doomsdayguide.org/Video/page_061.htm
- Mark Rivera
  http://www.proofofalienlife.com

Presentations

- Paige Malec
  Mythbusters: Spock Edition

Outline

- Today we estimate f_p maybe.. Or at least get close
- Exoplanets – they are all over the place.

Groups

Last Tuesday, we discussed the origins of the elements for life. Last Thursday, you struggled to explain it. So, let's try again. In a short paragraph, explain to your science major friends how HONC (the elements of life) were created.

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

So, Why would Spock Care?

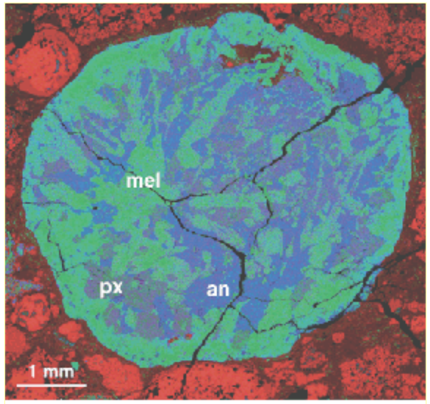
If we are to suppose that ET life will be based on a planet orbiting a star, then we need to know

- – How did our solar system form?
- – How rare is it?
- – Is our solar system unusual?

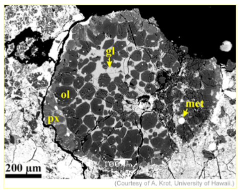
http://homepage.smc.edu/balm_simon/images/astro%205/spock.jpg

The Earliest Pre-Solar Dust Grains

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



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

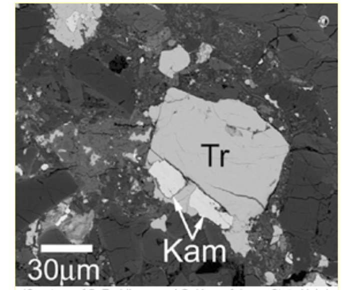


Formed 4,700,000,000 years ago

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.)

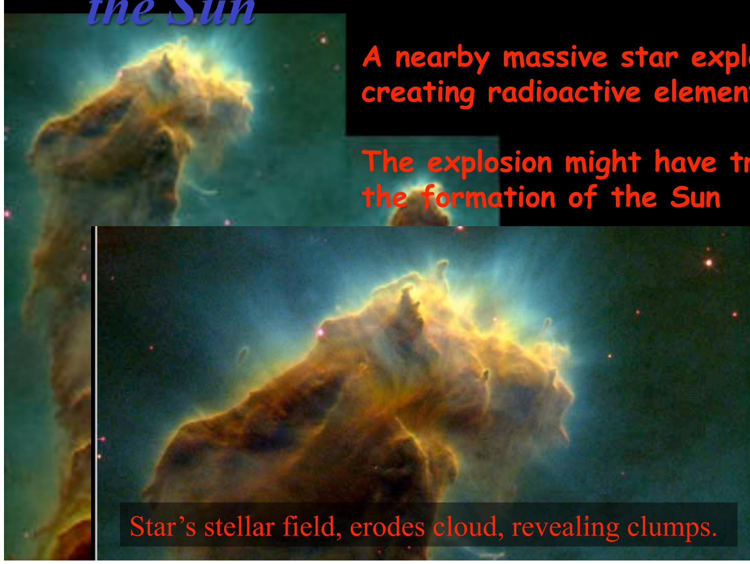
Half life 1.5 million years

The Birth of the Sun

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

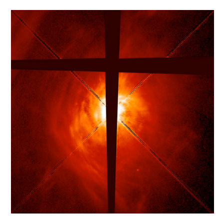
A nearby massive star exploded, creating radioactive elements

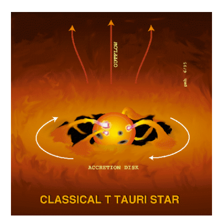
The explosion might have triggered the formation of the Sun



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

On to the Main Sequence: A Star is Born!





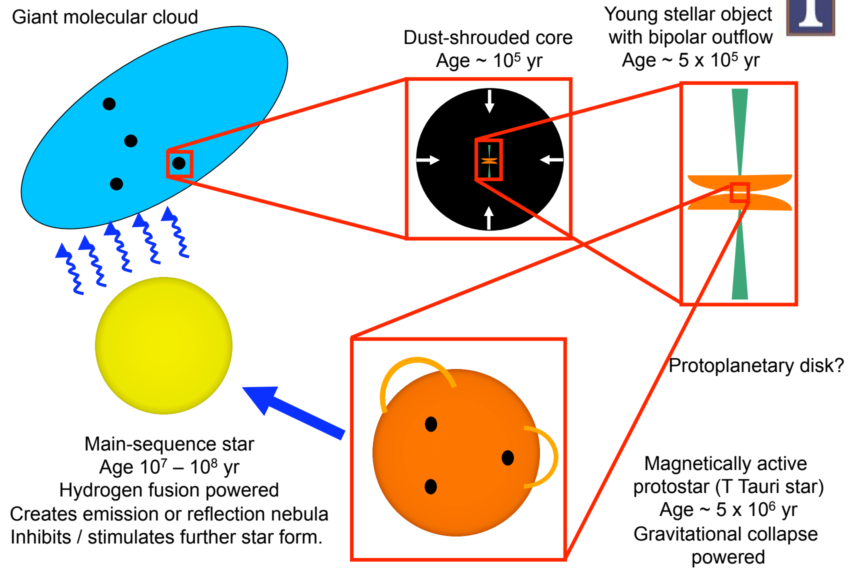
- For 1 solar mass star, process takes about 10 million years
- Density increase, temperature increases until fusion can occur.
  - Blows away most of its natal circumstellar material.
  - Becomes a hydrogen burning star
  - http://www.youtube.com/watch?v=jhYEQgLW5NM
  - http://www.youtube.com/watch?v=mZL7VBmeFxY&feature=related

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.

Star Formation - Summary



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

Heavy Bombardment

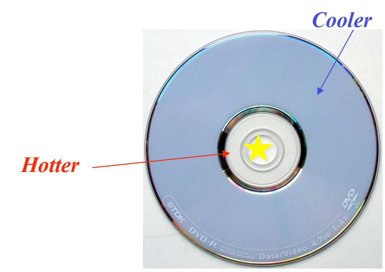
- There were billions of planetesimals in the early solar system
- Many collided with the young planets
  - Look at the Moon & Mercury!
  - Period of **heavy bombardment**
  - Lasted for about the first 800 million years of the Solar System
- Others were ejected from the solar system…

Fates of the Planetesimals

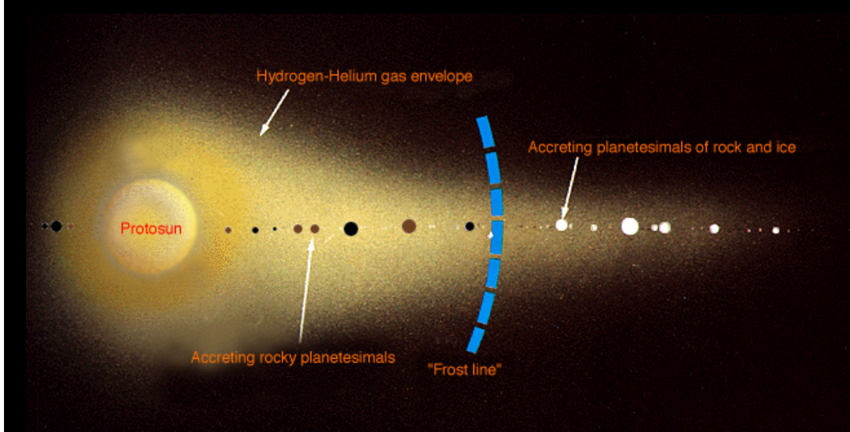
- Between Mars and Jupiter
  - Remain as the asteroids
- Near Jupiter & Saturn
  - Ejected from the solar system
- Near Uranus & Neptune
  - Ejected to the Oort Cloud
- Beyond Neptune
  - Remain in the Kuiper Belt

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?

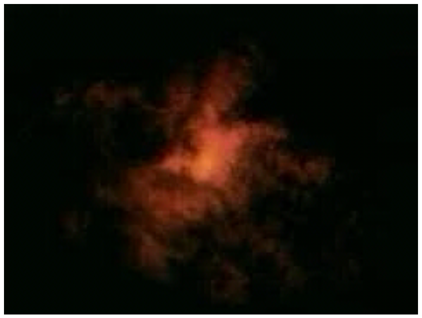


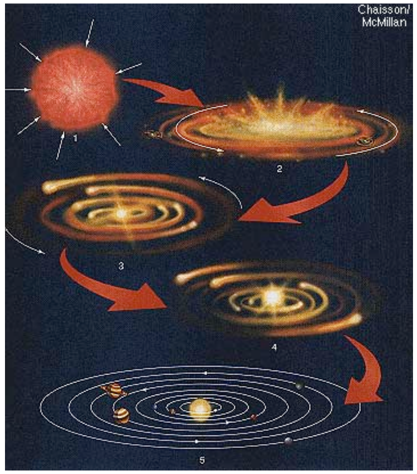
Temperature is the key factor!

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

Formation of the Solar System
4.6 billion years ago





Question

A star is born. Which of the following did not happen?

a) the nuclear strong force created gravitational instabilities.

b) a gas cloud clumped because of gravity and began to collapse.

c) a protoplanetary or circumstellar disk formed due to conservation of momentum.

d) an outflow or jet of material was ejected from the system.

e) fusion began due to heat and pressure.

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!

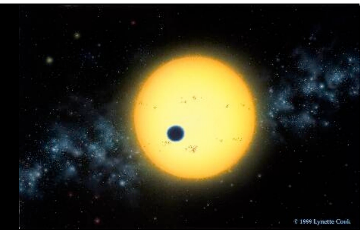
Reflected light from the Earth is 1 billion times fainter than the Sun!!!!!

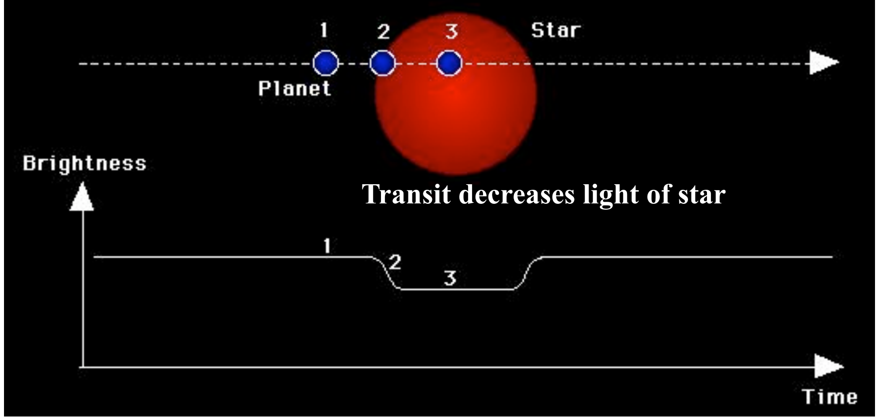
Finding Planets

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

Only a few planets have been detected directly in the optical and IR. Remember that planets in our Solar System seem bright because they reflect light from the Sun in the visible.

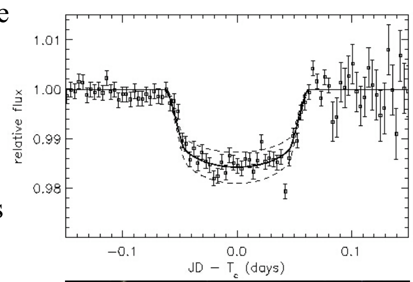
Planet Transits

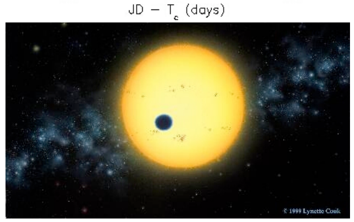




Transits

- The planet passes in front of the star– like Venus 2004.
- Can find planet radius
- Best chance of finding Earth-like planets
- Requires the extrasolar planet's orbital plane to be pointed at Earth
- http://www.howstuffworks.com/planet-hunting2.htm



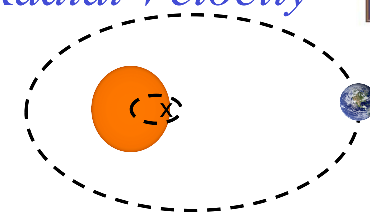


Star Wobble: Radial Velocity

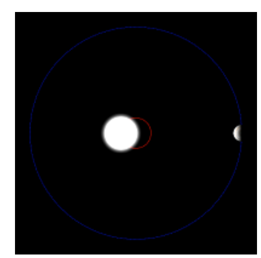
Newton's 3rd Law:

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

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



Greatly exaggerated

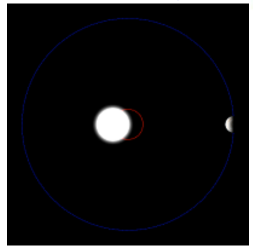


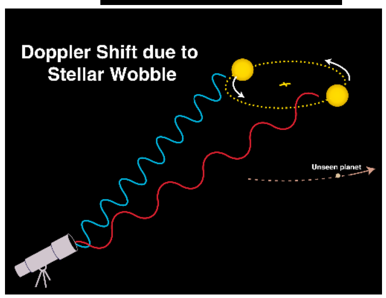
http://en.wikipedia.org/wiki/File:Planet_reflex_200.gif

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

Star Wobble: Radial Velocity

- Star movement too small to see
  - Moves in small, tight circle
  - But “wobble" in star speed detected!
  - The stellar spectrum is shifted red and blue as it moves towards us and away from us.





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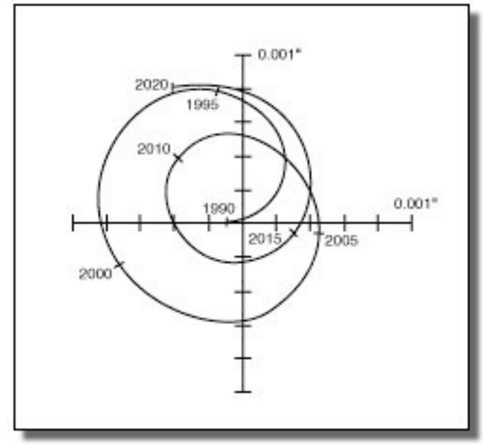
The Sun’s Wobble

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?