Astronomy 330

This class (Lecture 10):

Origin of the Moon
Ilana Strauss

Next Class:

Our Planet
Scott Huber
Thomas Hymel

HW 3 is due tonight!

Music: *3rd Planet* – Modest Mouse

HW 2

- Alex Bara
  http://userpages.bright.net/~phobia/main.htm
- Margaret Sharp
  http://hubpages.com/hub/Proof-that-UFOs-Exist---And-the-Government-Knows

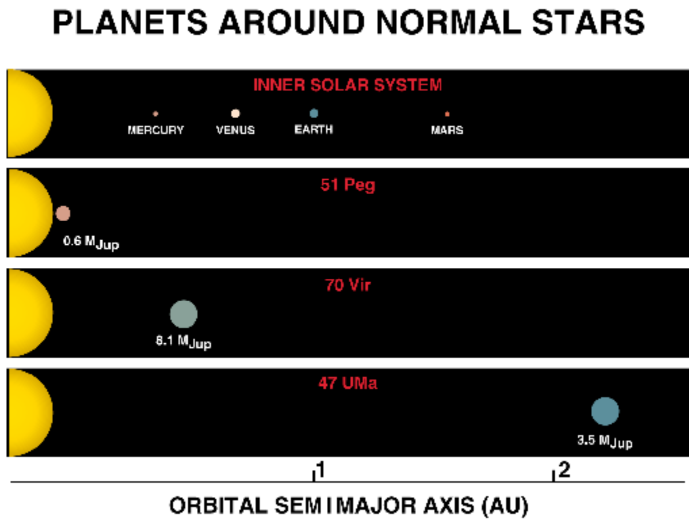
Presentations

- Ilana Strauss
  Futurama Aliens

Outline

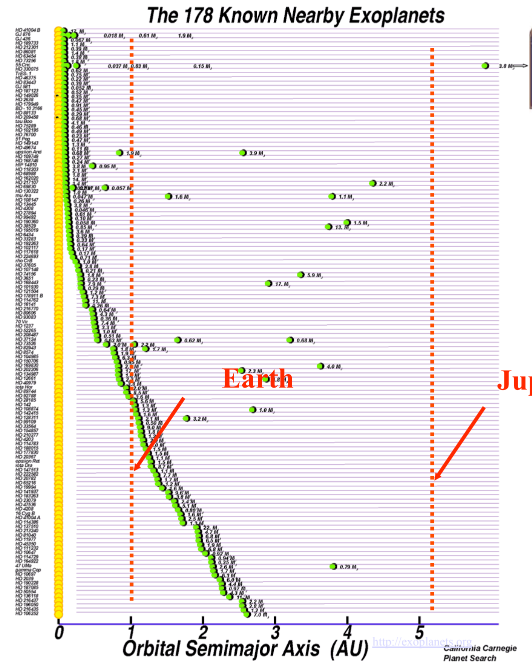
- f_p
- N_e – two terms required
- What's up with the Earth?

Early Discovery-- 1996



Hear all about it.

As of today, there are over 500 planets with radial velocities (wobbles)

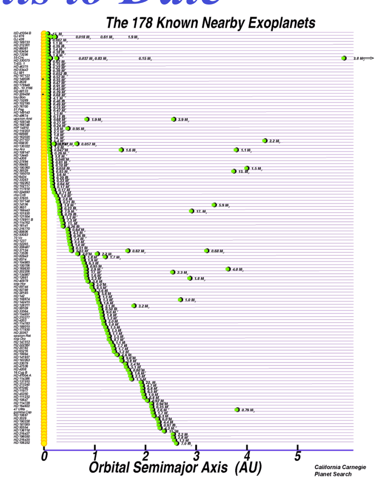


Exoplanets: Velocity Results to Date

Over 500 planets detected so far

- More than 25 times the number in our Solar System!

- By measuring the wobble variation:
  - With time, gives the planet distance: Kepler's 3rd law
  - The orbital speed of the star gives masses: the bigger the wobble amplitude, the heavier the planet



Velocity: Results to Date

More than 53 multi-planet systems.

Note: Jupiter is 318 times the mass of Earth or

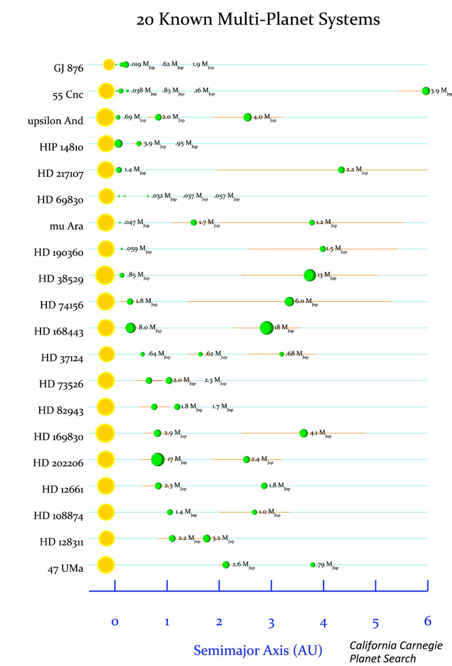
$M_E = 0.003\ M_J$

$M_J = 0.001\ M_{Sun}$

$M_{red\ dwarf} = 80\ M_J$

$M_{brown\ dwarf} = 18\ M_J$

$Period_J = 12$ years

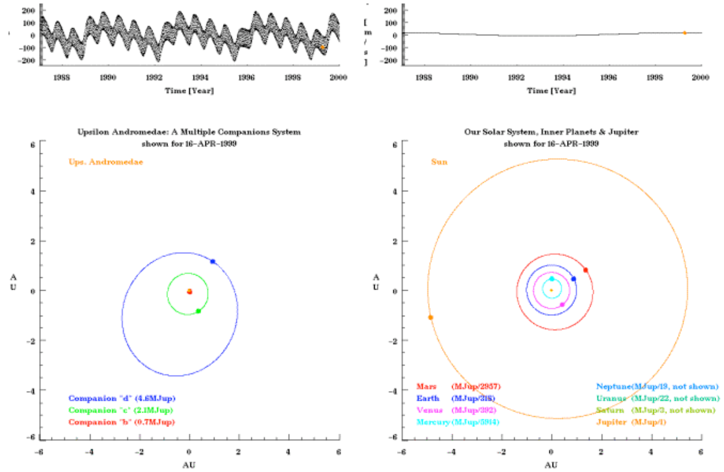


Other Planets, Other Stars

47 Ursae Majoris System– 51 light years away (near the Big Dipper). 13 years of data has shown 2 planets– 1 Jupiter like and 1 Saturn like.

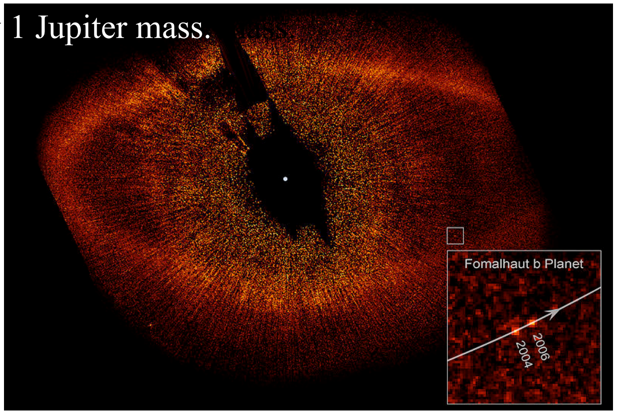
Wow! Among the most similar to our own system

Detecting the Our Wobble



Imaging: Fomalhaut

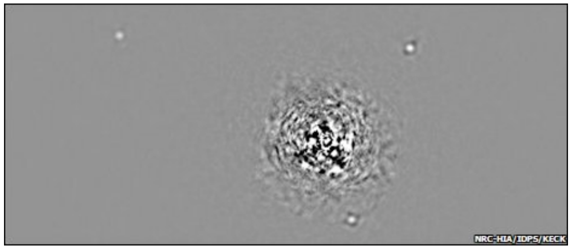
- First planet imaged in visible light
- Orbits at 115 AU!
- Probably 1 Jupiter mass.



http://hubblesite.org/newscenter/archive/releases/2008/39/image/

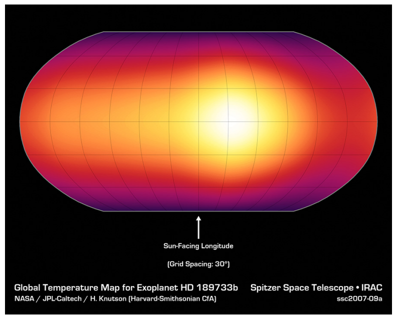
Imaging: HR 8799

- First detection of exoplanet in IR.
- Three planet system
  - 10 M_J (24 AU)
  - 10 M_J (38 AU)
  - 7 M_J (68 AU)



Exoplanet Weather

- Transiting Planet: HD 189733 b (orbit of 0.03AU)
- Surface temp estimated by Spitzer
- Atmosphere has water vapor and methane!
- Surface temp of 1000 K.



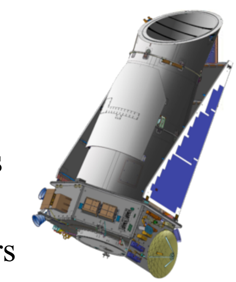
Kepler Mission

- Launched March 7, 2009
- Probing planet transits toward 145,000 main sequence stars (10 square degs)

Kepler Mission

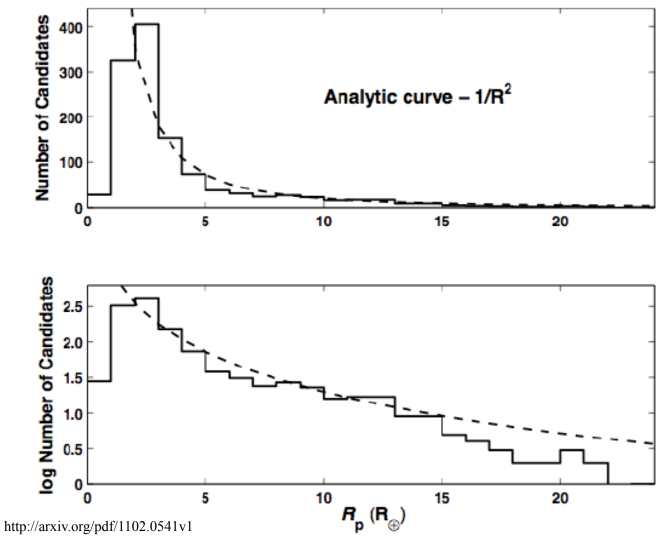
- Looking for small intensity dips in stars
- Must have planet block some of the star's light
- Playing probability game as random orbits must intersect our line of sight
  - For Earth, the chance of this happening is 0.465%.
  - If ALL stars have Earths, would see 678 Earths
- But, Kepler group won't call objects candidates until they see the dip three times.. not yet enough time for Earth's at 1 AU.

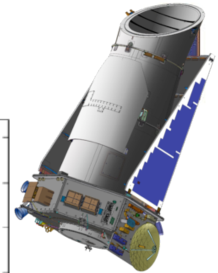
Kepler Status



- First major release is the first 4 months of data
- 1235 planet candidates around 997 stars
  - 68 Earth-sized
  - 54 planets in the habitable zone
  - Habitable zone is the region around a star where water is likely to be a liquid.
- Candidates because 90% confidence currently. Will improve with time.

Kepler Status

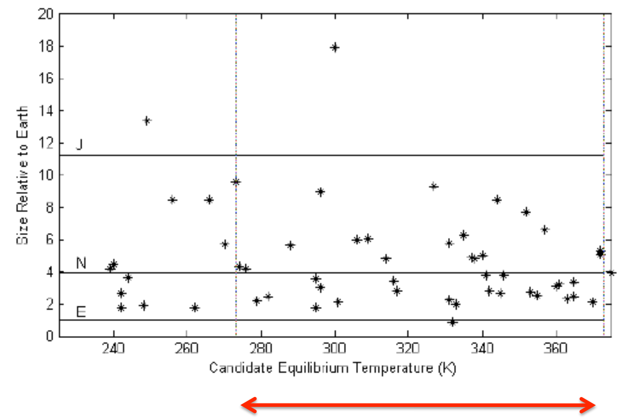




Unlike radial velocity sources, smaller planets are more common in Kepler data.

http://arxiv.org/pdf/1102.0541v1

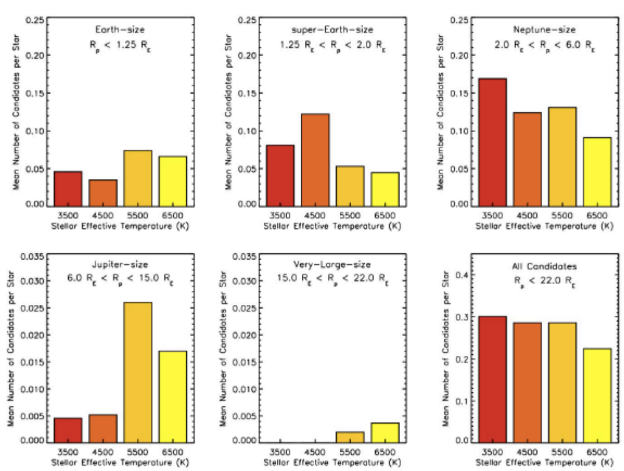
Kepler Status



Many sources in the habitable zone

http://arxiv.org/pdf/1102.0541v1

Kepler Status



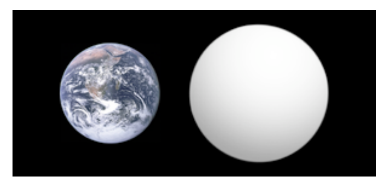
First scientific estimate of f_p ever!
= 34%

Still a lower limit though.

http://arxiv.org/pdf/1102.0541v1

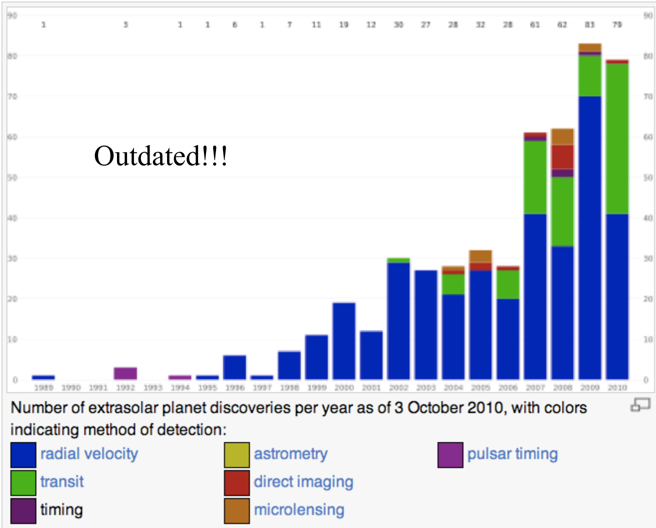
Kepler-10b

- First confirmed rocky exoplanet
- Smallest confirmed planet yet, only 1.4 Earth diameters.
- 4.6 Earth masses
- Orbits freaky close—20 hours (0.017 AU)!
- Hot!
  - 1833 K– melt iron.



http://en.wikipedia.org/wiki/Kepler-10b

Discover!



Number of extrasolar planet discoveries per year as of 3 October 2010, with colors indicating method of detection:

http://en.wikipedia.org/wiki/List_of_extrasolar_planets

Lists

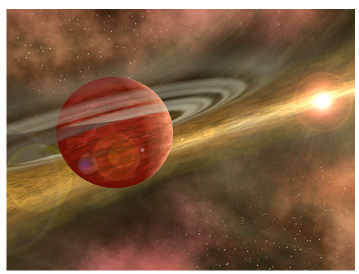
http://exoplanets.org/

[http://en.wikipedia.org/wiki /List_of_extrasolar_planets](http://en.wikipedia.org/wiki/List_of_extrasolar_planets)

Results to Date

No surprise

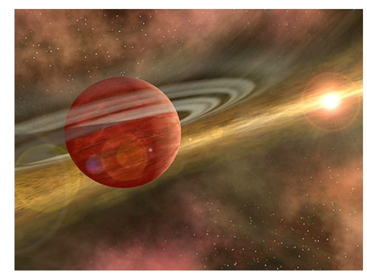
- ✓ Planets are common
- ✓ There are rocky planets and gas giants



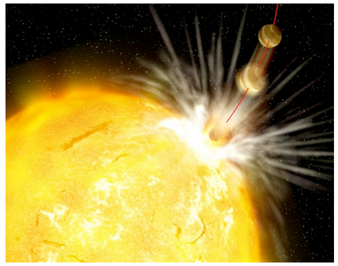
Results to Date

Big surprises

- ? Many periods are short– *a few days!*
- ? Many massive planets are very near their stars!
- ? τ Bootes' planet is 3.6 times Jupiter's mass, but it's orbit smaller than Mercury's!
- ? If a Jupiter-like planet formed close in, perhaps that prevents terrestrial planets from forming.



Exoplanets: Implications



Solar Nebula **Theory**:
- Giant planets born far from star

Exoplanet Data:
- Giant planets found very close

Theory is *incomplete/wrong*!

New questions:
? Who is normal: Them or us?
? Are giant planets born close in?
? Are some giant planets born far out, move in?
"planet swallowing"!?!

Anyway: Planets are common!
✓ Good news in search for life elsewhere...maybe

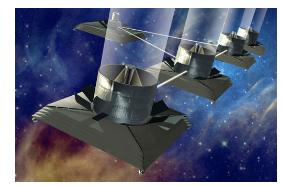
What Are We Looking For?
General Predictions of Solar Nebula Theory

☺ Are interstellar dust clouds common? ***Yes!***
☺ Do young stars have disks? ***Yes!***
? Are the smaller planets near the star?
Not always
? Are massive planets farther away?
Not always

Important Caveat

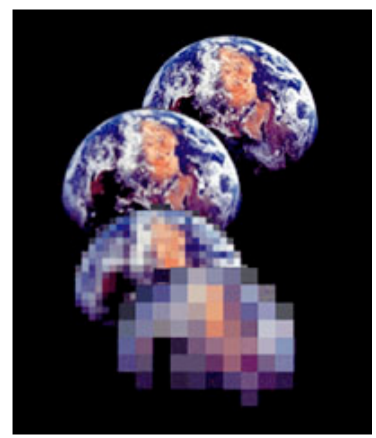
- Our current observations of extrasolar planets do **not** exclude planetary systems like our solar system to be common
- Current instruments are most sensitive to larger planets close to their stars
  - Big planet - big wobble or more transit signal
  - Close planet - fast wobble or easier to confirm time-wise
- We only have a little over 10 years of wobble data – 1 orbit's worth for Jupiter
- Kepler data release is only 4 months of data!
- Even with all the caveats, we have a lower limit for fp of 34%!

A Future Mission?



The goal of imaging an Earth-like planet.

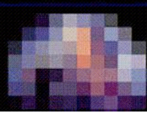
5 platforms of 4 eight meter interferometer in space.



http://spider.ipac.caltech.edu/staff/jarrett/talks/LiU/origins/openhouse30.html

A Future Mission

Pixel / Diameter	Pixel size @ planet (km)	Image		Interferometer Requirements: Collecting Area	Baseline
400	32		IR Visible	144 km² 1,296 km²	100,000 km 5,000 km
100	128		IR Visible	0.64 km² 5.76 km²	24,000 km 1,200 km

Pixel / Diameter	Pixel size @ planet (km)	Image		Interferometer Requirements: Collecting Area	Baseline
25	510		IR Visible	1,024 m² 9,216 m²	6,000 km 303 km
10	1276		IR Visible	64 m² 576 m²	2,4km 120 km

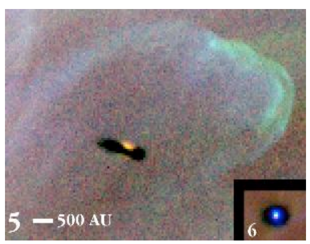
Disks in Binary Systems

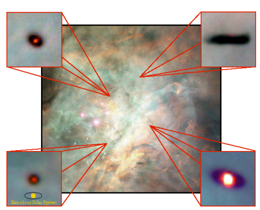
- >60% of all stars are in binary or multiple systems.
- We do see circumstellar disks in binary systems
- We do see exoplanets in binary systems.

- But we also see effects of the binary on the disk.
  - Still unclear how large of an effect.

Now, for f_p

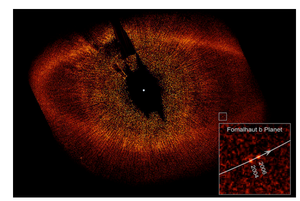
- About 2/3 of all stars are in multiple systems.
  - Is this good or bad?
- Disks around stars are very common, even most binary systems have them.
- Hard to think of a formation scenario without a disk at some point– single or binary system.
- Disk formation matches our solar system parameters.
- We know of many brown dwarfs, so maybe some planets do not form around stars.
  - There might be free-floating planets, but…

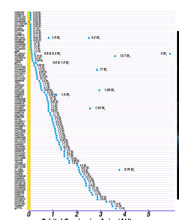


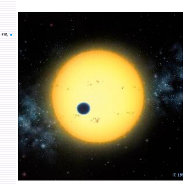


Now, for f_p

- Extrasolar planet searches so far give about $f_p \sim 0.34$!!!!!!
- Maximum is 1 and lower limit is probably around 0.30.
- A high fraction assumes that the disks often form a planet or planets of some kind.
- A low fraction assumes that even if there are disks, planets do not form.
- <u>This is not Earth-like planets, just a planet or many planets.</u>



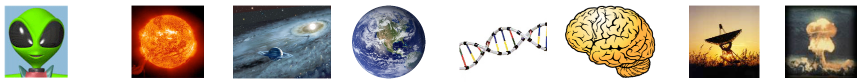




Drake Equation

Frank Drake

That's 9.75 planetary systems/year



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

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	0.65 systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

n_e

Complex term, so let's break it into two terms:

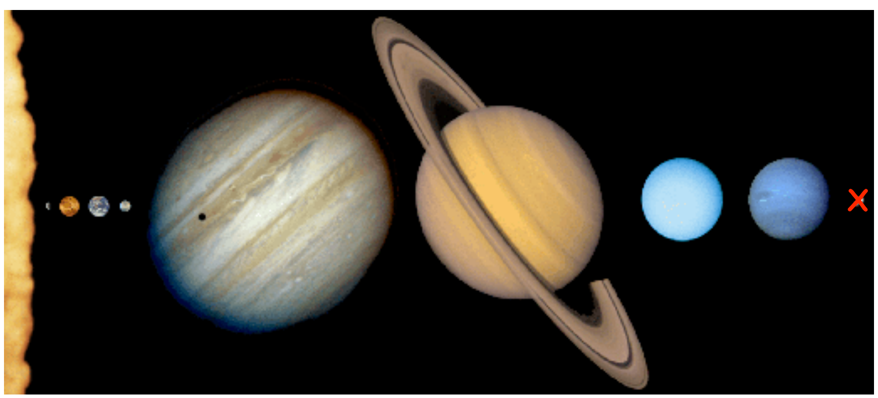
- n_p: number of planets suitable for life per planetary system
- f_s: fraction of stars whose properties are suitable for life to develop on one of its planets

$$n_e = n_p \times f_s$$

http://nike.cecs.csulb.edu/~kjlivio/Wallpapers/Planets%2001.jpg

Our Solar System

Terrestrial planets and Gas Giants… but how many are valid planets/moons for n_p?



Earth-Moon Comparison

Radius	6378 km	Radius	0.272 Earth
Surface gravity	9.8 m/s^2	Surface gravity	0.17 Earth
Mass	6.0x10^{24} kg	Mass	0.012 Earth
Distance to Sun	1.5x10^8 km	Distance to Earth	384,000 km
Year	365.2422 days	Orbital Period	27.3 days
Solar day	1 day	Solar day	27.3 days

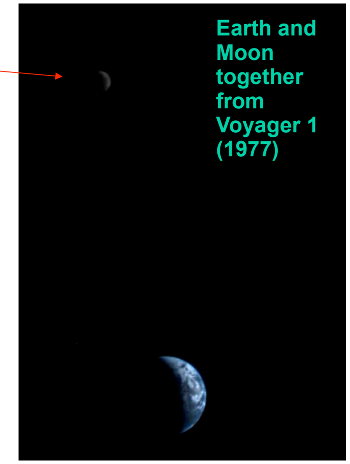
Formation of the Earth

- Earth formed from planetesimals in the circumstellar disk.
- Was hot and melted together.
- The biggest peculiarity, compared to the other planets, is the large moon.

A Double World

Why a “double world”?

- Most moons are tiny compared to the planet
  - The Moon is over 25% the diameter of Earth
  - Jupiter's biggest moons are about 3% the size of the planet
- The Moon is comparable to the terrestrial planets
  - About 70% the size of Mercury
  - Nearly the same density as Mars



The Moon

The Moon's surface is barren and dead

- No water, no air, some water ice.
- No life!!

Formation of the Moon: Smack

- Collision of Earth with a Mars-sized body early in the solar system’s history
- Iron-rich core of the impactor sank within Earth
- Earth’s rotation sped up
- Remaining ejecta thrown into orbit, coalesced into the Moon
- http://www.youtube.com/watch?v=ibV4MdN5wo0&feature=related

Why is this a good hypothesis?

- The Earth has a large iron core (differentiation), but the moon does not.
  - The debris blown out of collision came from the rocky mantles
  - The iron core of the impactor merged with the iron core of Earth
- Compare density of 5.5 g/cm^3 to 3.3 g/cm^3— the moon lacks iron.

http://www.flatrock.org.nz/topics/odds_and_oddities/assets/extreme_iron.jpg

Moon Impact on Life?

- Some think that our large Moon is very important for life on Earth.
  - Tides! Important to move water in and out of pools.
  - Stable Axial Tilt: 23.5 deg offset from the collision
  - Metals! Heavy elements at Earth's surface may be from core of impactor.

http://www.michaelbach.de/ot/sze_moon/index.html