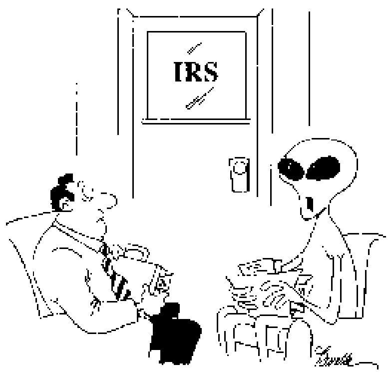
Astronomy 230

TR 1300-1420

134 Astronomy Building



"Oh, sure, the government denies our existence...until tax time."

This class (Lecture 7):

Origin of planets

Next Class:

Nature of Solar Systems
Edward Espiritu &
Aylin Selcukoglu

HW 2 is due today.

Sept 21:
Natalaya Sholomyansky &
Rebecca Wright:

Music: *Planet of Sound* – Pixies

Outline

- Extrasolar planets: watch them wobble.
- Not exactly what we expected.
- What to expect in the future.
- What is f_p?
- The formation of the Earth– atmosphere and oceans.

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.

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?

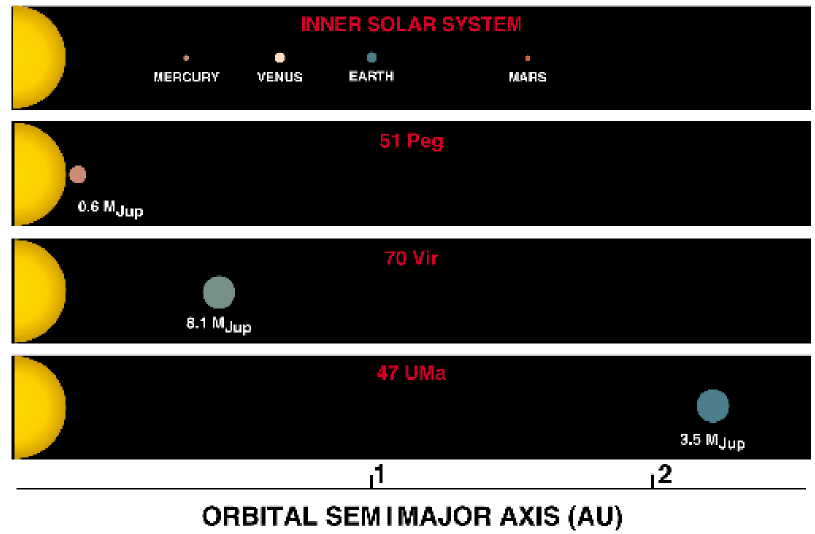
Hard to find!

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

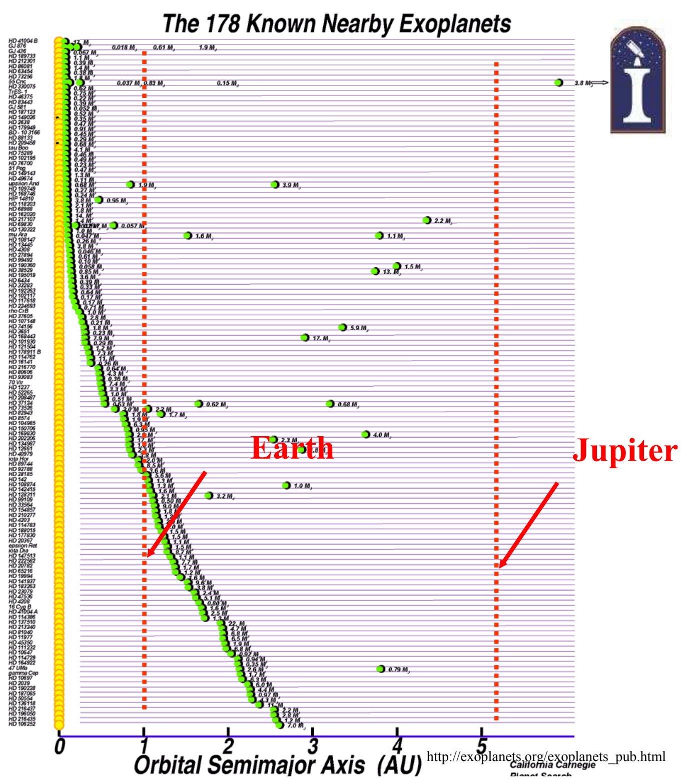
Early Discovery-- 1996

PLANETS AROUND NORMAL STARS

Hear all about it.



As of now, there are at least 178 planets around nearby stars.



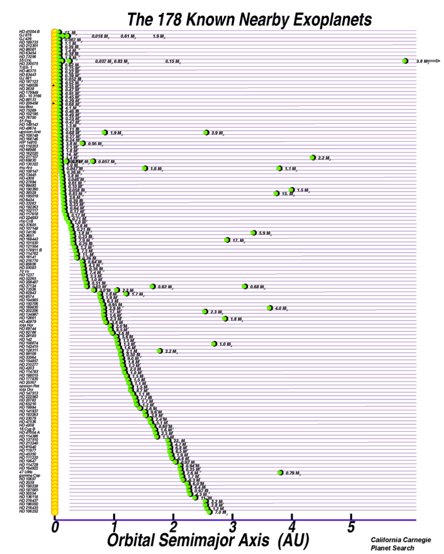
http://exoplanets.org/exoplanets_pub.html

Exoplanets: Results to Date

Over 178 planets detected so far

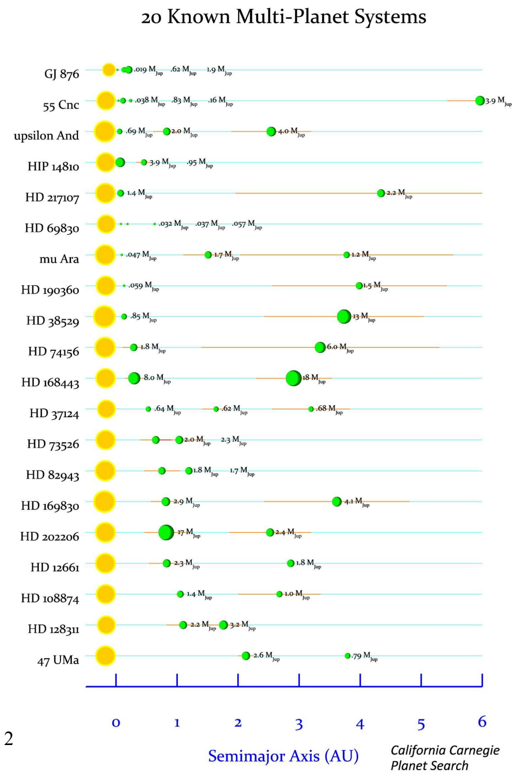
- More than 17 times the number in our Solar System!

- 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

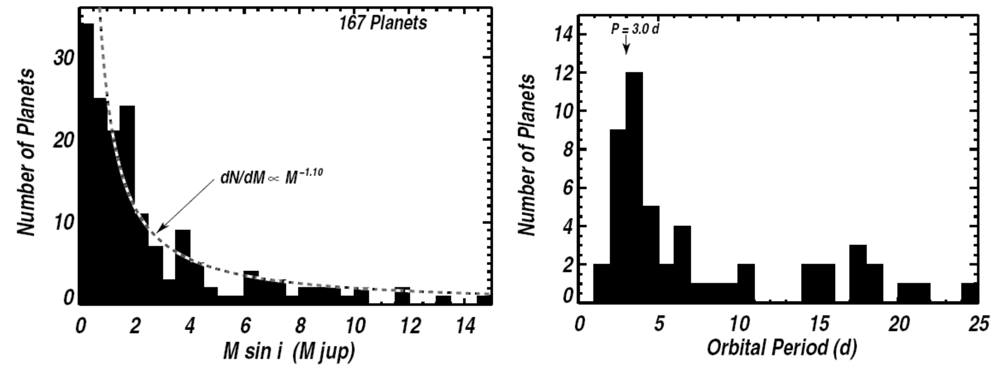


Exoplanets: Results to Date

At least 20 multi-planet systems!



Masses/Periods of Extrasolar Planets



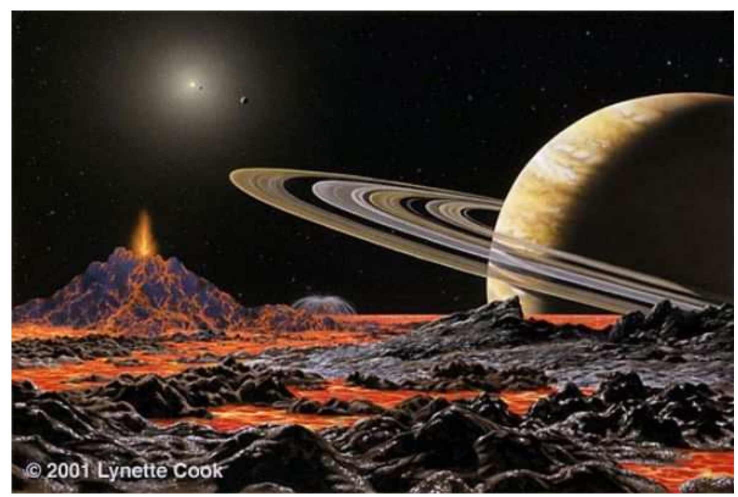
http://exoplanets.org

List

http://exoplanets.org/planet_table.shtml

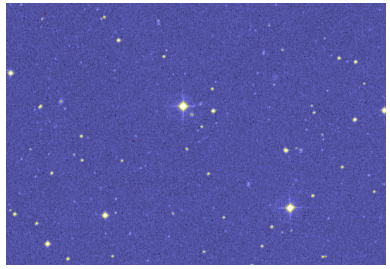
Other Planets, Other Stars

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.

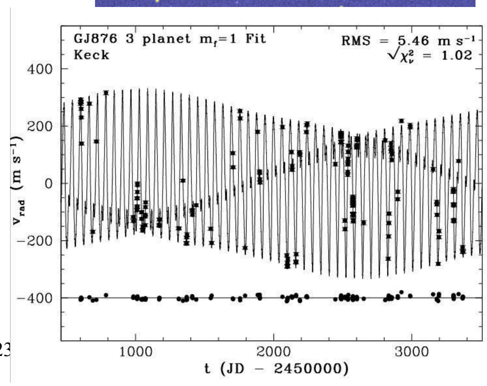


Wow! Among the most similar to our own system

The Lowest Mass to Date



GJ 876 – a Red Dwarf that is 15 light years away (in Aquarius). Has three planets! 2 Jupiter-like and one that is 6-8 Earth masses! But all are inside 1 AU!



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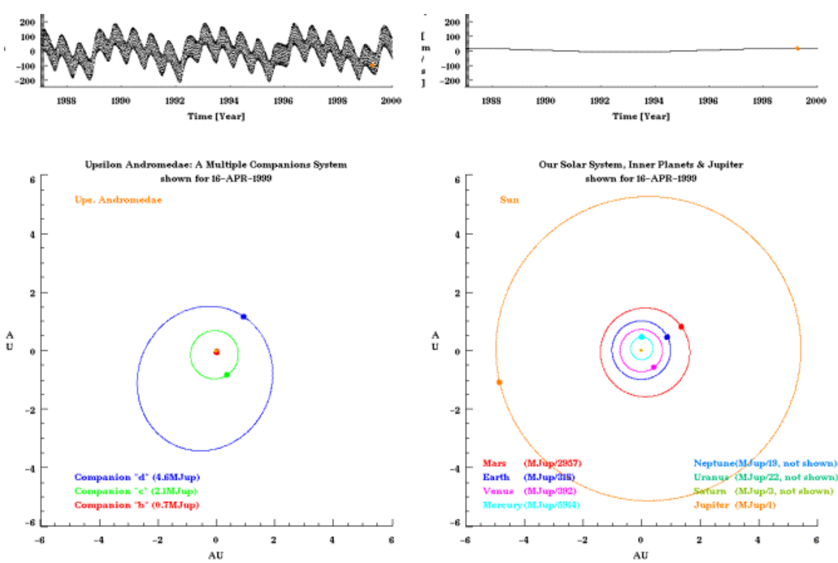
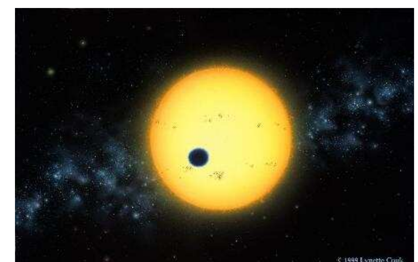
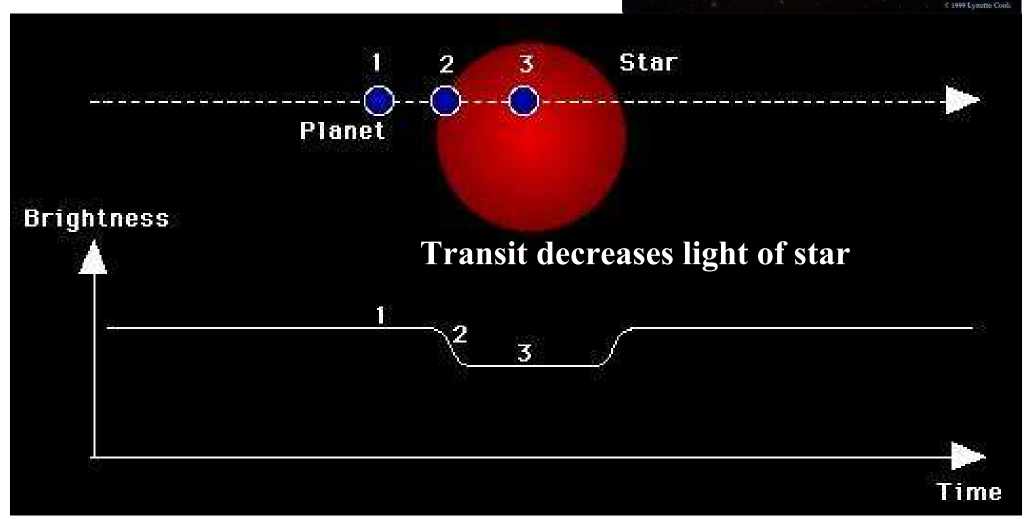
Detecting the Solar System



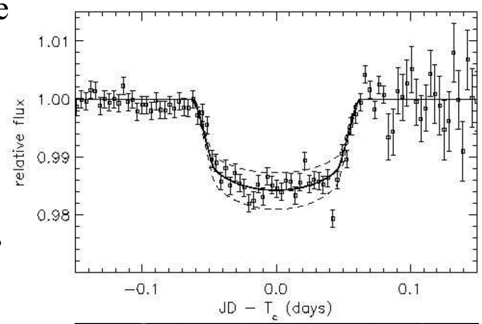
Planet Transits

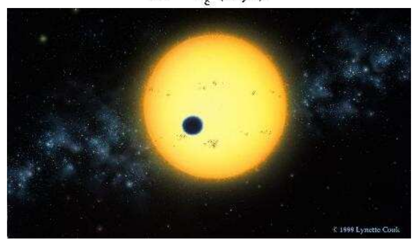


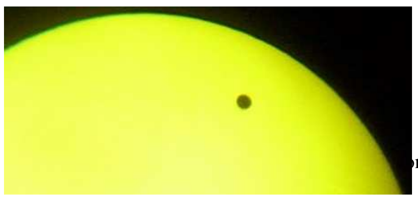


Transits

- 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

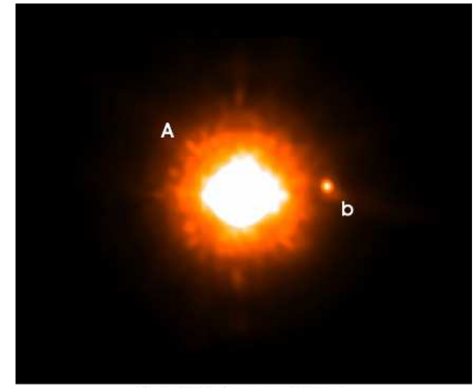






Direct Detection?

- The race is on to directly image a planet in the IR, it is still difficult to determine the stellar mass.
- Best example so far is an adaptive optic image from April, so planet or brown dwarf?

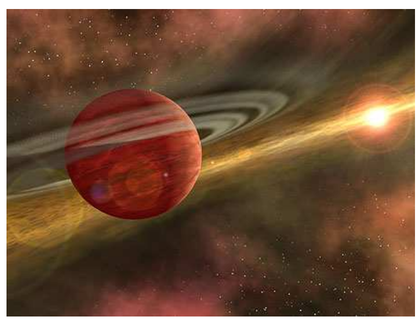


The Sub-Stellar Companion to GQ Lupi (NACO/VLT)

Results to Date

No surprise

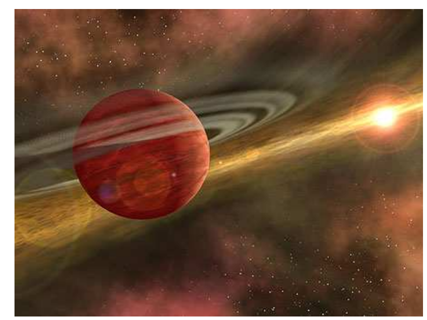
- ✓ New planets are massive
- ✓ Why? Big planets make a big wobble
- ✓ If not massive, we could not have found them
- ✓ About 3-5% of all stars have some type of planet.



Results to Date

Big surprises

- ? Most periods of only *a few days!*
- ? Most 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.



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?

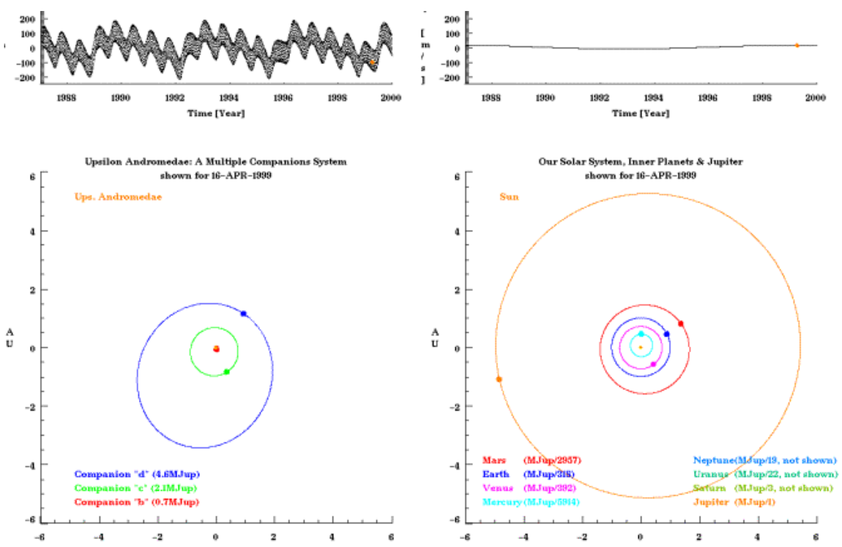
  Not the ones found so far! Haven't found smaller planets yet!
- ? Are massive planets farther away?

  Not most of the ones found so far!

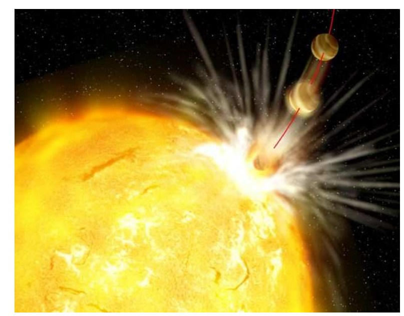
Important Caveat

- Our current observations of extrasolar planets do **not** exclude planetary systems like our solar system
- Current instruments are most sensitive to large planets close to their stars
  - – Big planet - big wobble
  - – Close planet - fast wobble
- We only have a little over 10 years of data – 1 orbit's worth for Jupiter
- To find solar-type systems, we need more sensitive equipment

Detecting the Solar System



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

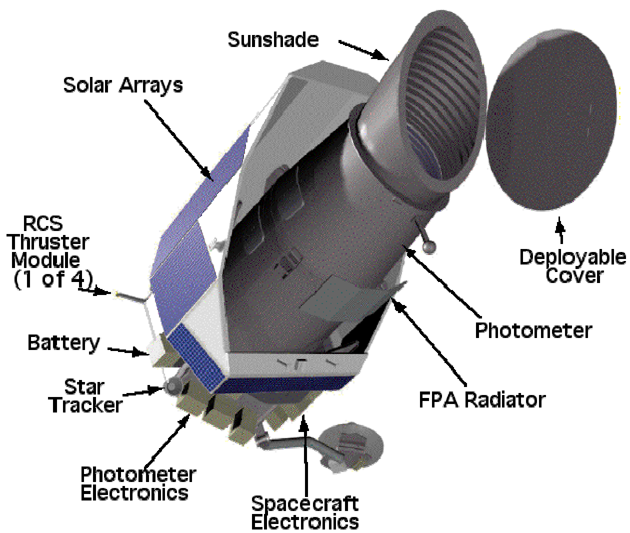
Future Projects

- Atacama Large Millimeter Array (ALMA): 2010
  - mm interferometer:
    direct detection of young gas giants
- Kepler: 2008
  – Planet Transits
- Next Generation Space Telescope
  James Webb Space Telescope (JWST): 2013
  - Direct imaging of forming gas giants?
- Space Interferometry Mission (SIM): 2015?
  - Astrometry
- Terrestrial Planet Finder (TPF): Mission 1: 2014
  - Coronagraph
  - IR interferometer
- Terrestrial Planet Finder (TPF): Mission 2: 2020
  – A large-baseline infrared interferometer. Imaging extrasolar Earths!!!!

Kepler

1.4 meter mirror, measuring accurate brightness of stars.

A terrestrial-sized Earth-like planet would dim the star's light by 1/10,000th – comparable to watching a gnat fly across the beam of a searchlight.

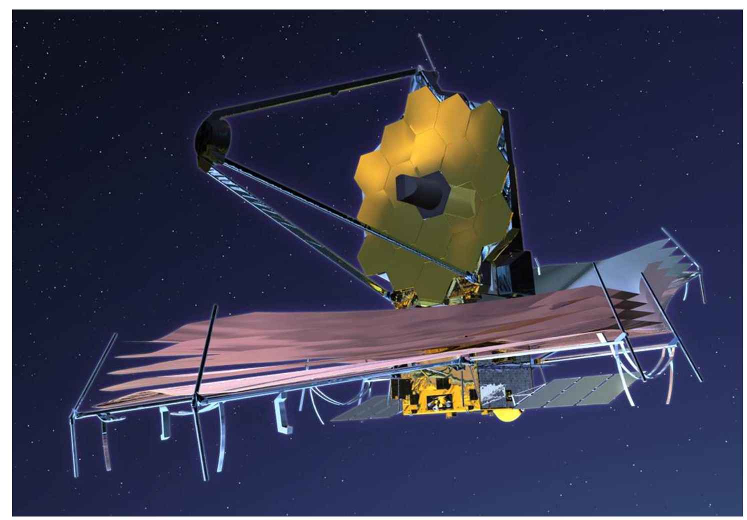


JWST

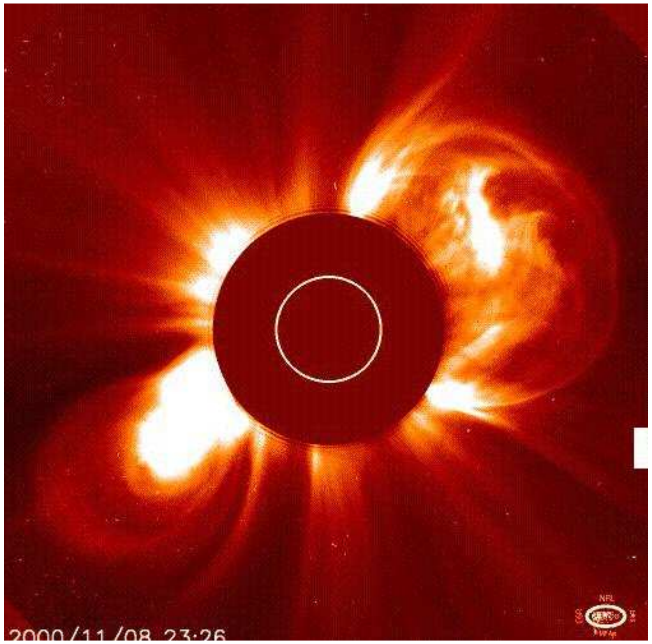
James Webb Space Telescope: Successor to HST

6.5 meter observatory

Working in the infrared with a coronagraph.



The Coronagraph Advantage



Space Interferometry Mission

Accurately measure location of stars to micro-arcseconds.

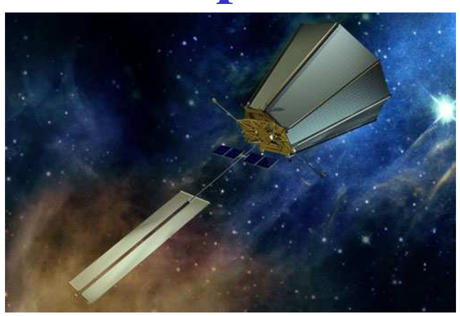
Need to know relative location of components to 50 pm.

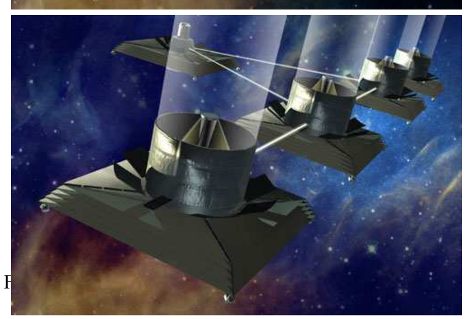
Funding in question.

http://planetquest.jpl.nasa.gov/SIM/sim_index.html

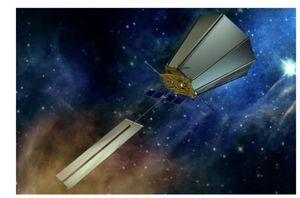
Terrestrial Planet Finder Mission: Two Telescopes

- Survey nearby stars looking for terrestrial-size planets in the "habitable zone”
- Follow up brightest candidates looking for atmospheric signatures, habitability, or life itself
- Then, the ultimate: image the little blue dots

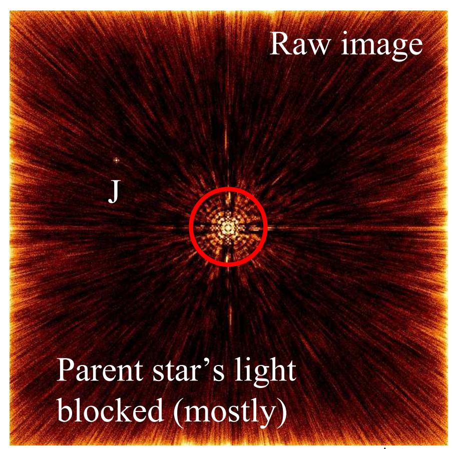


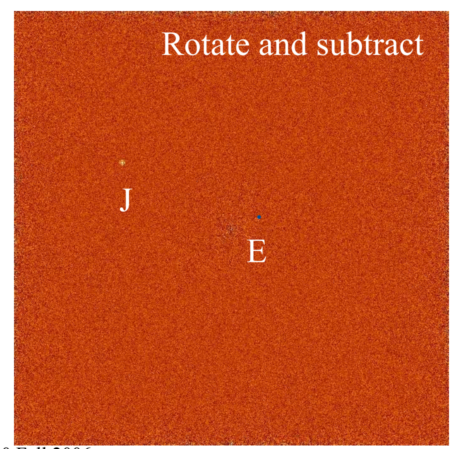


TPF

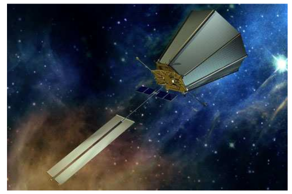


Visual wavelength `coronagraph’
- Find Earth-like planets
- Characterize their atmospheres, surfaces
- Search for bio-signatures of life (O_2, H_2O, etc)





TPF



Visual wavelength `coronagraph'

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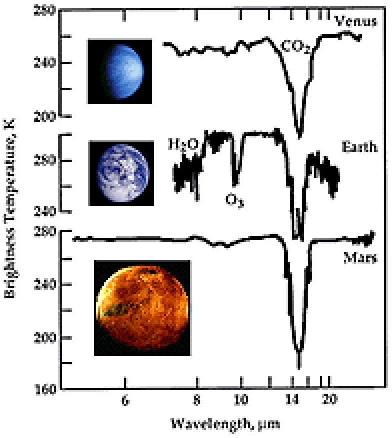
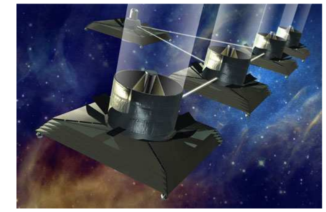


TPF: Step 2

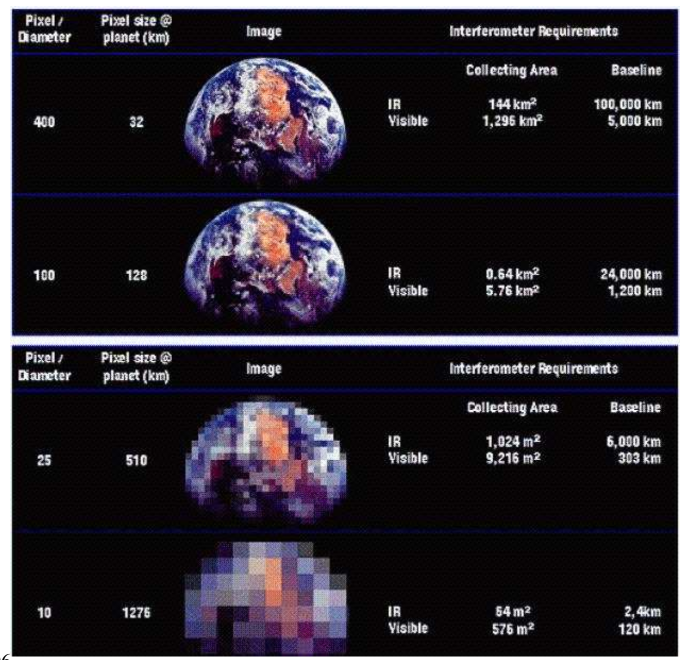


The goal of imaging an Earth-like planet.

5 platforms of 4 eight meter interferometer in space.

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

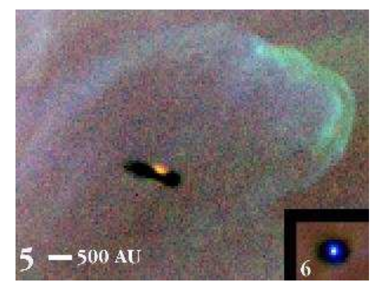
TPI -- Scales

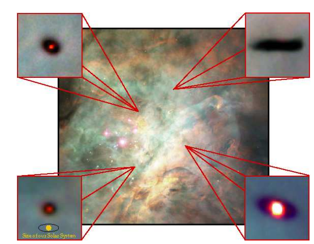


Pixel / Diameter	Pixel size @ planet (km)	Image	Interferometer Requirements	Collecting Area	Baseline
400	32		IR	144 km²	100,000 km
			Visible	1,296 km²	5,000 km
100	128		IR	0.64 km²	24,000 km
			Visible	5.76 km²	1,200 km
25	510		IR	1,024 m²	6,000 km
			Visible	9,216 m²	303 km
10	1276		IR	64 m²	2,4km
			Visible	576 m²	120 km

Now, for f_p

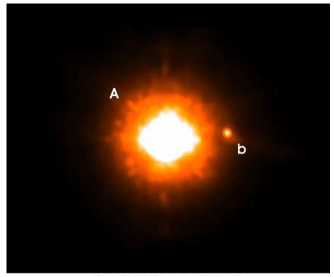
- About 2/3 of all stars are in multiple systems.
  - Is this good or bad?
- Disks around stars are very common, even most binary systems have them.
- Hard to think of a formation scenario without a disk at some point– single or binary system.
- Disk formation matches our solar system parameters.
- We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



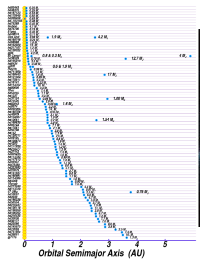


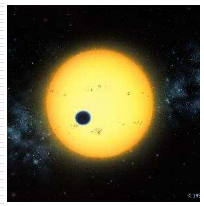
Now, for f_p

- Extrasolar planet searches so far give about $f_p \sim 0.03$, but not sensitive to lower mass systems.
- Maximum is 1 and lower limit is probably around 0.01.
- 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>



The Sub-Stellar Companion to GQ Lupi (NACO/VLT)





Drake Equation


Frank Drake

Earth Chauvinism?

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

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.

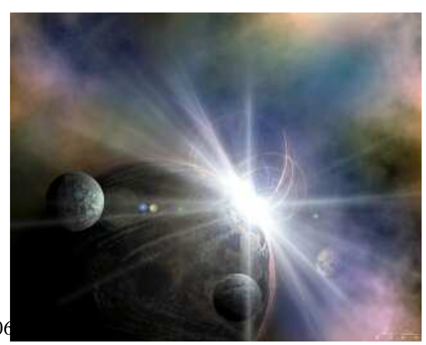
n_e

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



Earth-Moon Comparison

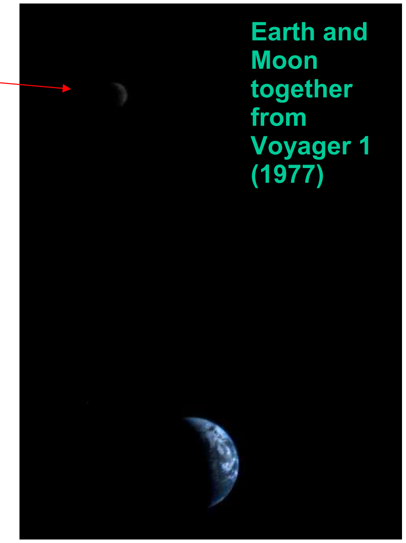
Radius	6378 km	Radius	0.272 Earth
Surface gravity	9.8 m/s^2	Surface gravity	0.17 Earth
Mass	6.0×10^{24} kg	Mass	0.012 Earth
Distance to Sun	1.5×10^{8} km	Distance to Earth	384,000 km
Year	365.2422 days	Orbital Period	27.3 days
Solar day	1 day	Solar day	27.3 days

Formation of the Earth

- Focus on the formation of the Earth, including its atmosphere and oceans.
- Earth formed from planetesimals from 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

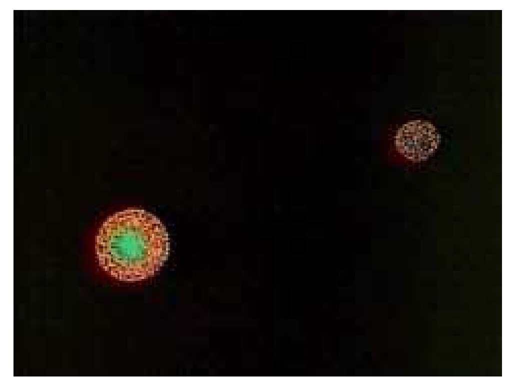


The Moon

The Moon's surface is barren and dead
- No water, no air
- 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



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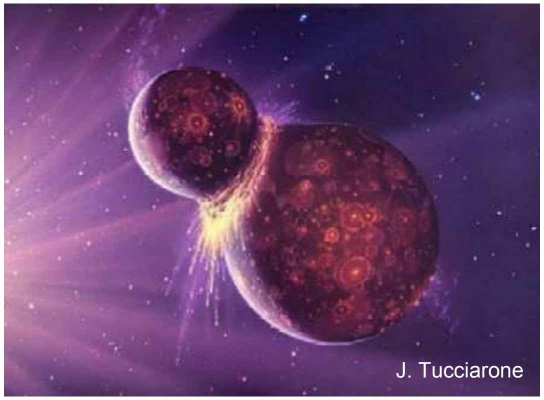


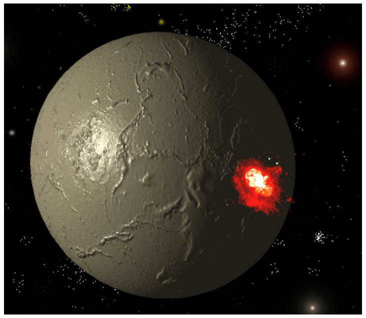
Why is this a good hypothesis?

- 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

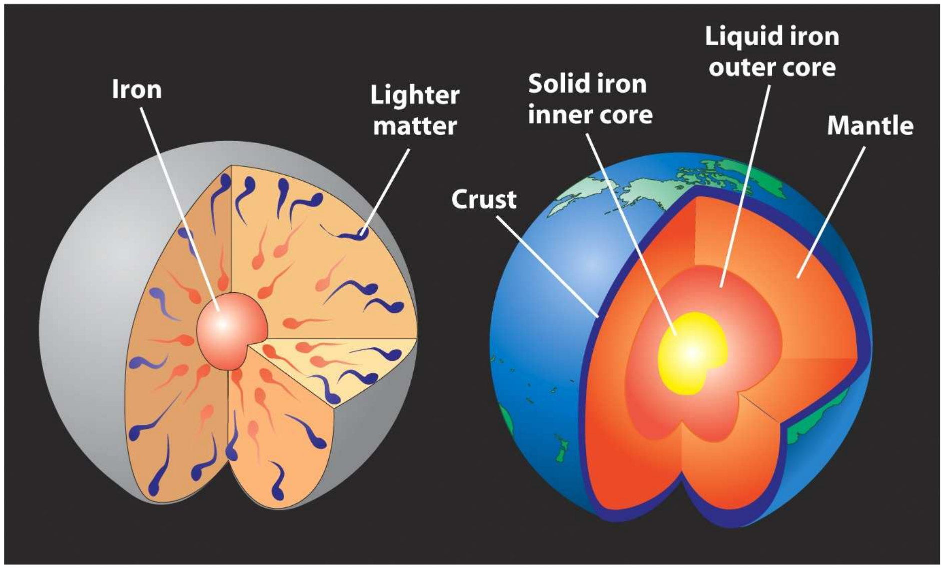
Implications

- **Hot, hot, hot.** Even if the moon theory is incorrect, other smaller bodies were playing havoc on the surface.
- When they impact, they release kinetic energy and gravitational potential.
- In addition, some of the decaying radioactive elements heated up the Earth– stored supernova energy!
- The planetesimals melt, and the Earth went through a period of differentiation.



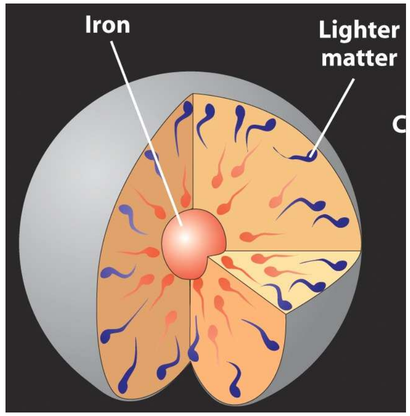
http://www.udel.edu/Biology/Wags/wagart/worldspage/impact.gif

Planetary Differentiation



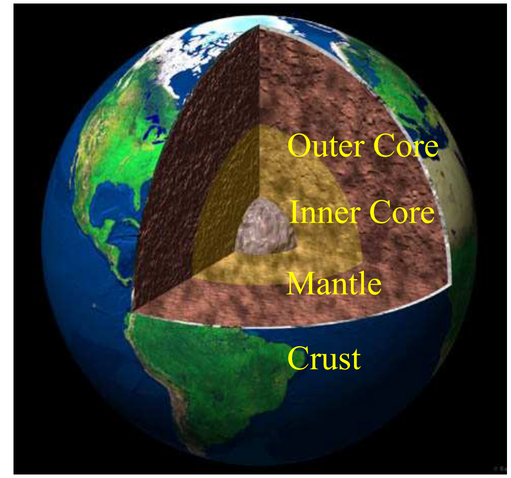
Differentiation

- Average density of Earth is 5.5 g/cm^3
- Average density on the surface is 3 g/cm^3
- So, something heavy must be inside
- When the Earth formed it was molten
  - Heavy materials (e.g. iron, nickel, gold) sank
  - Lighter materials (e.g. silicon, oxygen) floated to the top



Structure

- Luckily, not all of the iron sank to the center, else we would be still in the Stone Age.
- Core is made of 2 parts
  - inner core: solid, mostly Fe and Ni, very hot
  - outer core: liquid, mostly Fe and Ni, very hot, source of magnetic field
- Temperature increases as you go deeper. From around 290 K on surface to nearly 5000 K at center.
  - Heated by radioactive decay
  - Supernovae remnants



The Crust

- Outside layer of the Earth (includes oceans) that floats on top
  - About 50 km thick
  - Coldest layer – rocks are rigid
- Mostly silicate rocks
  - Made of lighter elements like silicon, oxygen, and aluminum
- Oxygen and water are abundant
- Excellent insulator
  - Keeps the Earth's geothermal heat inside!

In Hawaii

Earth's Surface

- 70% of the Earth's surface is covered with water
  - Ocean basins
  - Sea floors are young, none more than 200 million years old
- 30% is dry land – Continents
  - Mixture of young rocks and old rocks
  - Up to 4.2 billion years old

Geologically Active Surface

- The young rocks on the Earth's surface indicate it is geologically active
- Where do these rocks come from?
  - Volcanoes
  - Rift valleys
  - Oceanic ridges
- Air, water erode rocks
- **The surface is constantly changing**

Recycling Bio-elements

- From gravity and radioactivity, the core stays hot.
- This allows a persisting circulation of bioelements through continental drift— melting of the crust and re-release through volcanoes.
- Otherwise, certain elements might get locked into sediment layers– e.g. early sea life.
- Maybe planets being formed now, with less supernovae, would not have enough radioactivity to support continental drifts and volcanoes. (Idea of Peter Ward and Donald Brownlee.)

http://www.pahala-hawaii.com/j-page/image/activevolcanoe.jpg

The Earth's 1st Atmosphere

- The interior heat of the Earth helped with the Earth's early atmosphere.
- The inner disk had most gases blown away and the proto-Earth was not massive enough to capture these gases. And any impacts (e.g. the moon), would have blown the atmosphere away.
- Most favored scenario is that comets impacted that released – water (H_2O), carbon dioxide (CO_2), and Nitrogen (N_2) – the first atmosphere.
- The water condensed to form the oceans and much of the CO_2 was dissolved in the oceans and incorporated into sediments– such as calcium carbonate ($CaCO_3$).

http://www.fli-cam.com/images/comet-liner.jpg

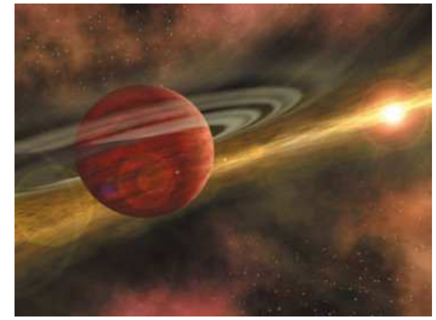
Our Atmosphere

- Rocks with ages greater than **2 million** years show that there was little or probably no oxygen in the Earth's atmosphere.
- The current composition: 78% nitrogen, 21% oxygen, and trace amounts of water, carbon dioxide, etc.
- Where did the oxygen come from?
- Cyanobacteria made it.
  - Life on Earth modifies the Earth's atmosphere.

http://www.uweb.ucsb.edu/~rixfury/conclusion.htm

This New Planet

- Mostly oceans and some solid land (all volcanic).
- Frequent impacts of remaining planetesimals (ending about 3.8 billion years ago).
- Impacts would have sterilized the young Earth– Mass extinctions and maybe vaporized oceans (more comets?).



This New Planet

- Impacts and volcanic activity created the continental landmasses.
- Little oxygen means no ozone layer–
  ultraviolet light on the surface.
- Along with lightning, radioactivity, and geothermal heat, provided energy for chemical reactions.