Astronomy 230
Section 1– MWF 1400-1450
106 B6 Eng Hall

<u>This Class (Lecture 8):</u>

Nature of the Solar System

<u>Oral Presentation Decisions!</u>

<u>Deadline is Today!!!</u>

<u>Next Class:</u>

Habitable Planets

Outline

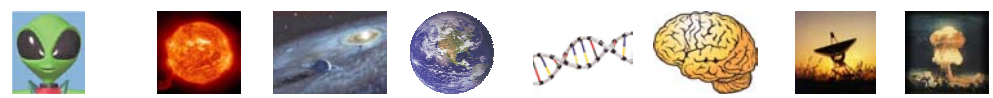
- Extrasolar planets
- Watch them wobble.
- Not exactly what we expected.
- What to expect in the future.
- What is f_p?
- Formation of the Moon.
- Hot Earth! Hot Earth!

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?

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*	fp	ne	fl	fi	fc	L
# of advanced civilizations we can contact	Rate of formation of Sun-like stars	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

10

Test Of Exoplanets

Planets around other stars
= extrasolar planets = ***"exoplanets"***

Hard to find!

Cannot just look at star
- planet lost in glare
  The Earth is 1 billion times fainter than the Sun!!!!!

Can use Newton's laws
- Gravity: Star pulls on planet,
- Newton 3rd Law: But planet pulls on star with equal & opposite force
- Planet lighter, moves faster
- But star must move too!

Finding Planets

1. Radial Velocity
2. Astrometry
3. Transit Method
4. Optical Detection

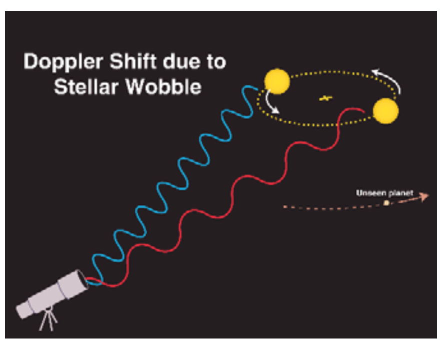
To date no extrasolar planet has been detected directly. Remember that planets in our Solar System are bright because they reflect light from the Sun.

Star Wobble

Newton's 3rd Law:
- *Both* planet *and star* move
- Both orbits fixed around the "center of gravity"

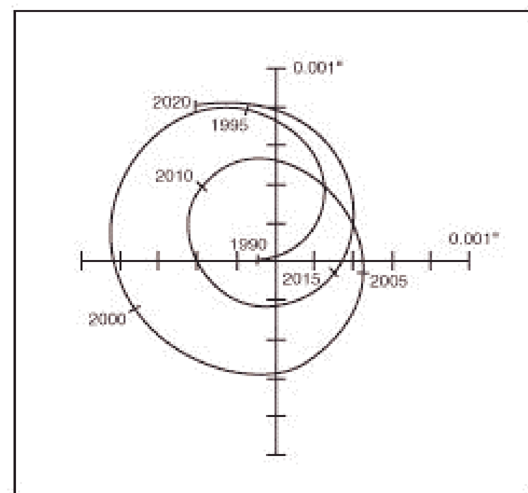
http://www.howstuffworks.com/planet-hunting2.htm

- Star's period? Place your bets…
  – Same as planet
- Star movement too small to see
  – Moves in small, tight circle
  – But "wobble" in star speed detected!



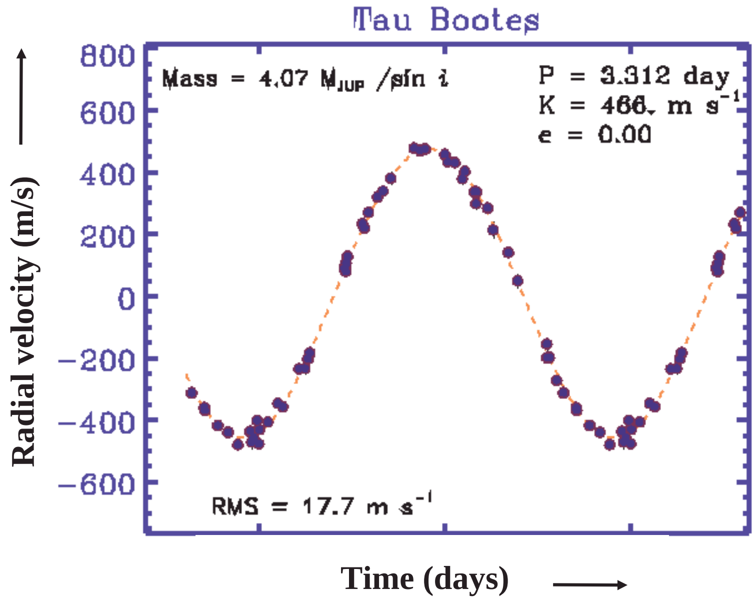
The Sun's Wobble

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.



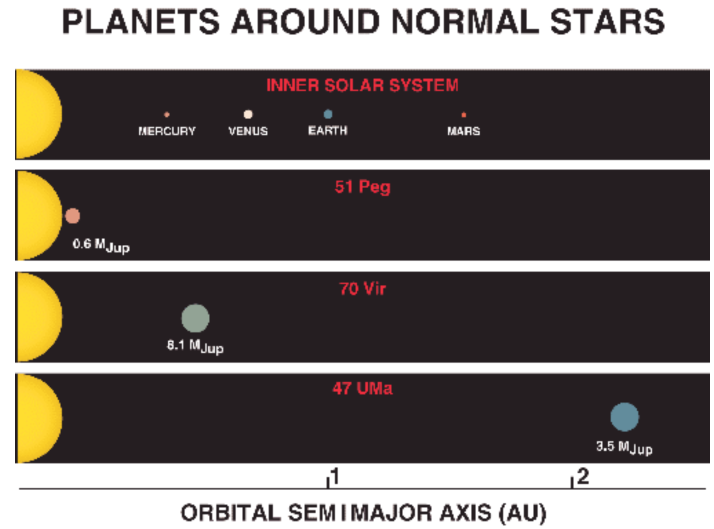
http://planetquest.jpl.nasa.gov/Keck/astro_tech.html

Planets around other Stars?

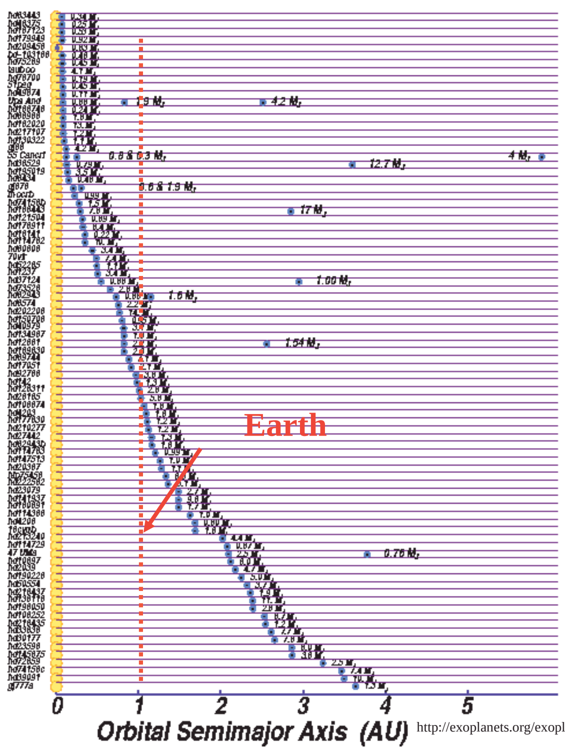


Early Discovery-- 1996

Hear all about it.



As of Jan, there are at least 118 planets around other nearby Stars.



http://exoplanets.org/exoplanets_pub.html

Exoplanets: *Results to Date*

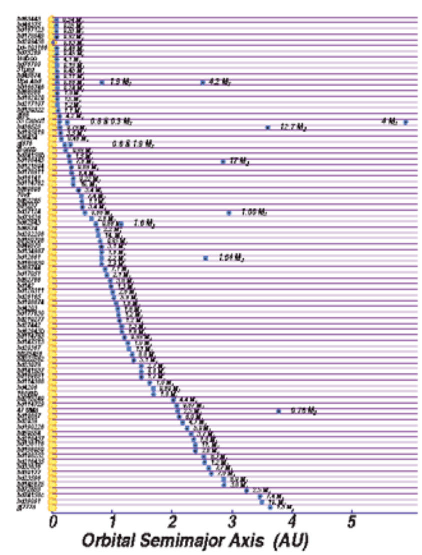
Over 118 planets detected so far

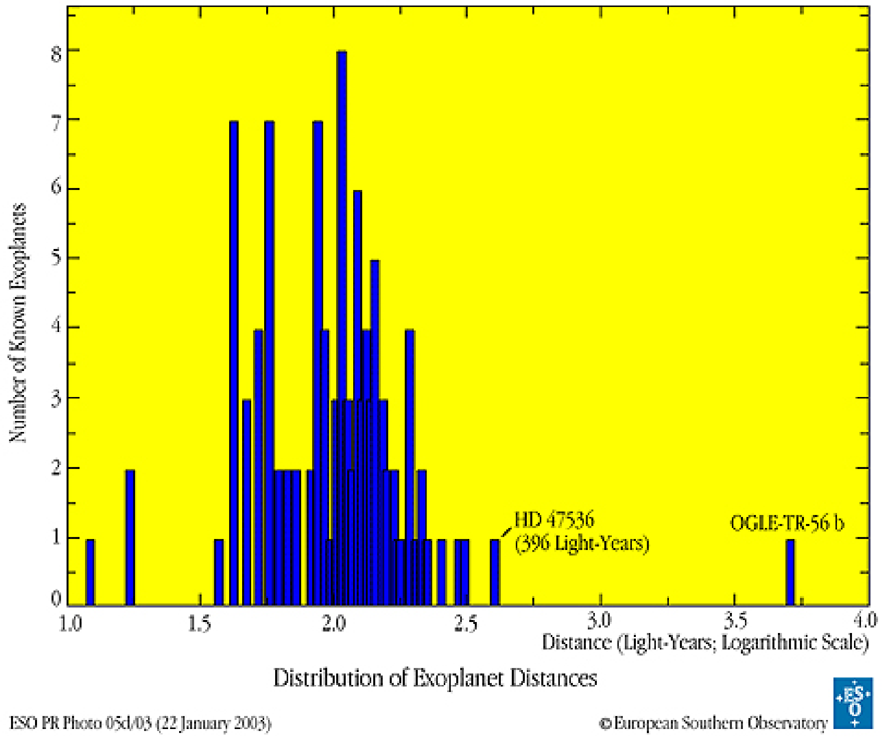
- More than 10 times the number in our Solar System!

- Measure $P_{star} = P_{planet}$

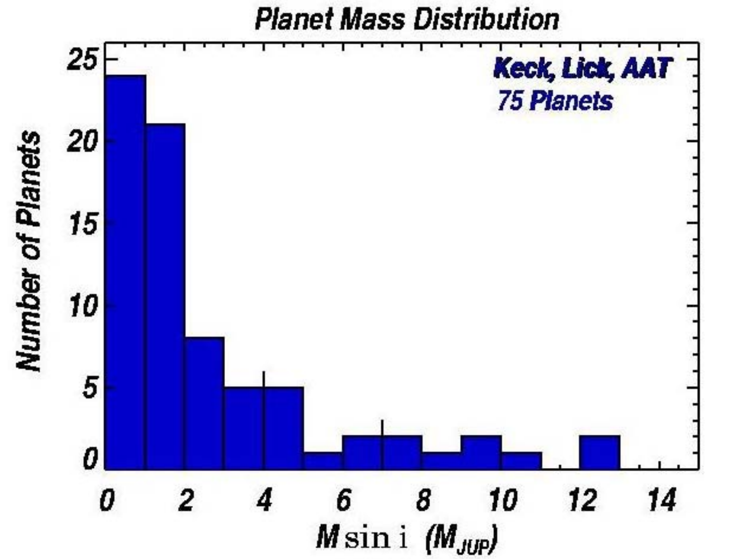
  Kepler/Newton give:
  - Planet distance $P^2 = a^3$
  - Note: Get distance w/o directly measuring it!

- Wobble speed gives planet mass

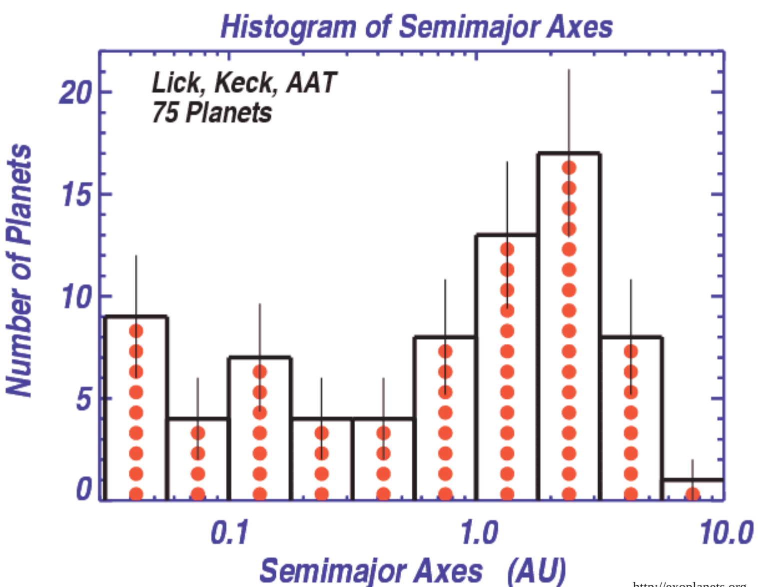




Masses



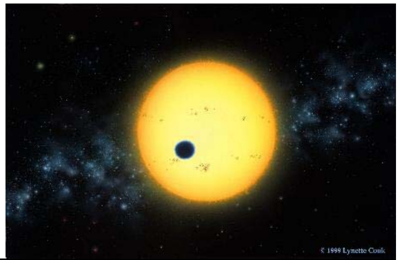
Semi-Major Axes

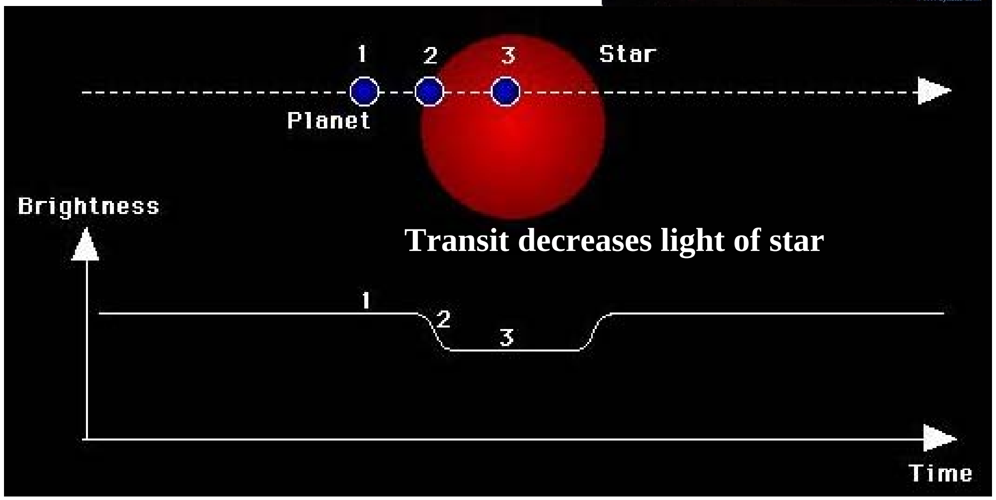


List

http://exoplanets.org/planet_table.shtml

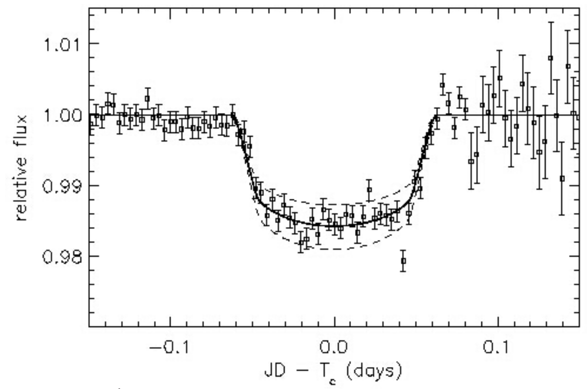
Planet Transits





Transits

- http://www.howstuffworks.com/planet-hunting2.htm
- A few solid detections.



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!

Exoplanets: *Results to Date*

No Surprise:

- ✓ New planets are massive
- ✓ Why? Needed to get big wobble
- ✓ If not massive, we could not have found them

Big Surprise:

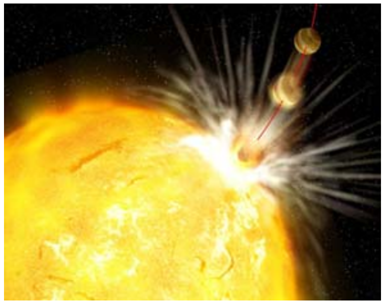
- ? Period of few days--whip around stars
- ? Most planets are very near stars!
- ? Example: tau Boo is 3.6 x Jupiter mass, but closer than Mercury's orbit!
- ? If an Jupiter like planet formed close in, perhaps that prevents terrestrial planets from forming.

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!***
- ? Are massive planets farther away?
  - ***Not most of the ones found so far!***

Exoplanets: Implications



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

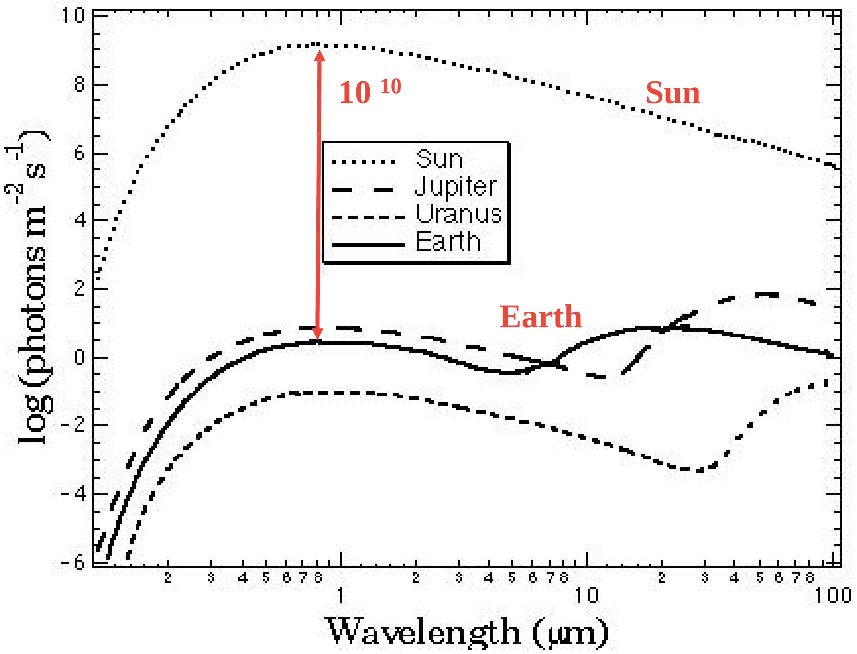
Exoplanet Data:
- Giant planets found very close

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 common.
- ✓ good news in search for life elsewhere...maybe

It is a Hard Business

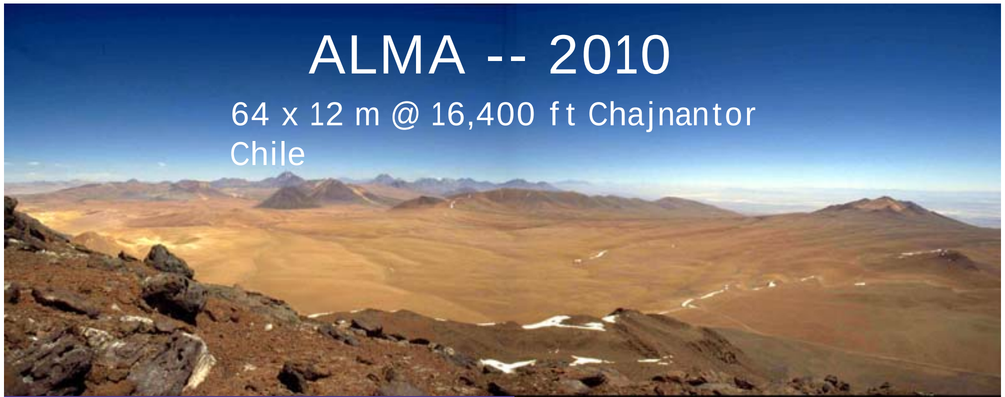


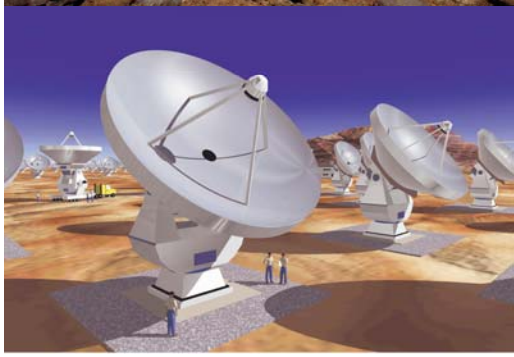
Future Projects

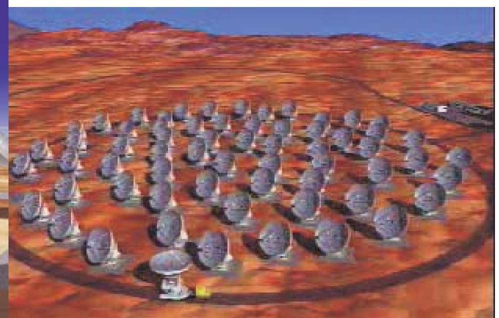
- Atacama Large Millimeter Array (ALMA): 2010
  - mm interferometer: direct detection of young gas giants
- Kepler: 2007
  - Planet Transits
- Next Generation Space Telescope
  - James Webb Space Telescope (JWST): 2011
  - Direct imaging of forming gas giants?
- Space Interferometry Mission (SIM): 2009
  - Astrometry
- Terrestrial Planet Finder (TPF): 2012
  - Coronagraph
  - IR interferometer
- Terrestrial Planet Imager (TPI): 2015
  - Either a visible band coronagraph or a large-baseline infrared interferometer

ALMA -- 2010

64 x 12 m @ 16,400 ft Chajnantor Chile



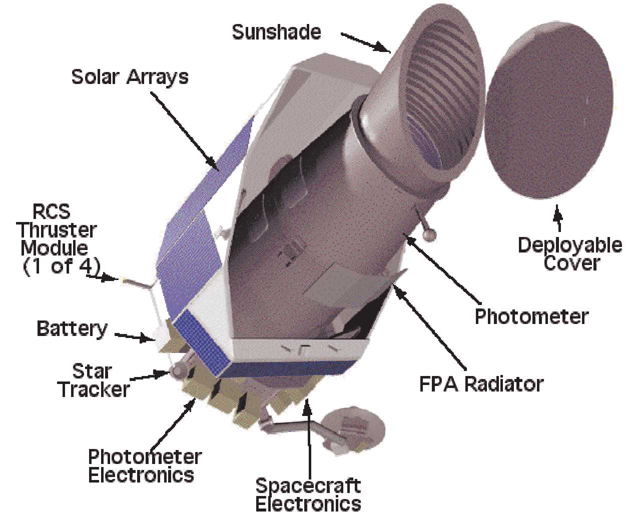




Kepler

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.

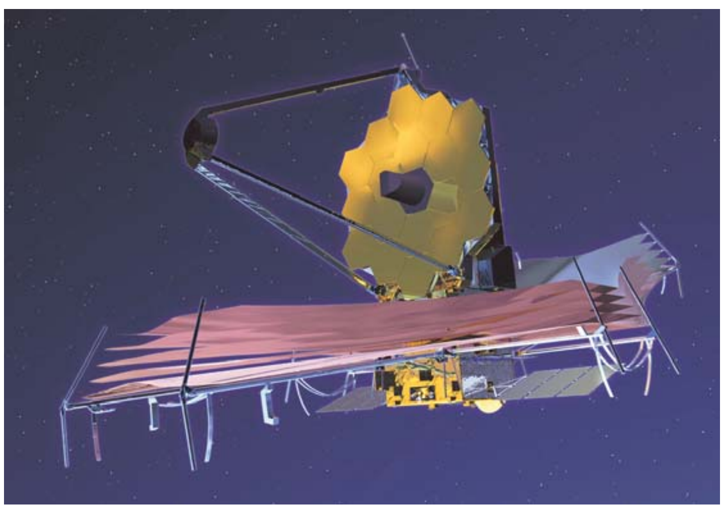


JWST

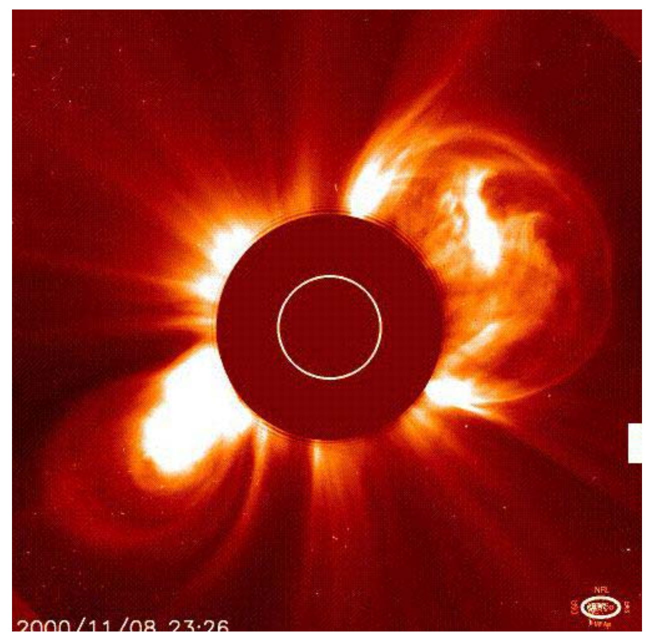
James Webb Space Telescope: Successor to HST

6.5 meter observatory

Working in the infrared with a coronagraph.



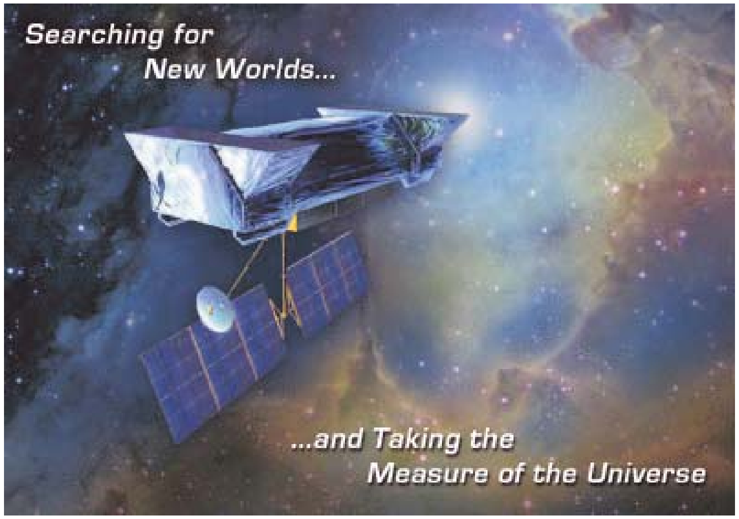
The Coronagraph Advantage



Space Interferometry Mission

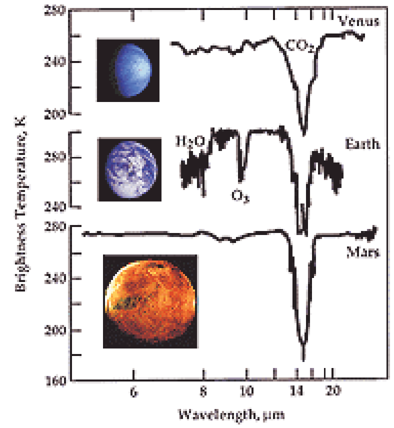
Accurately measure location of stars to micro-arcseconds.

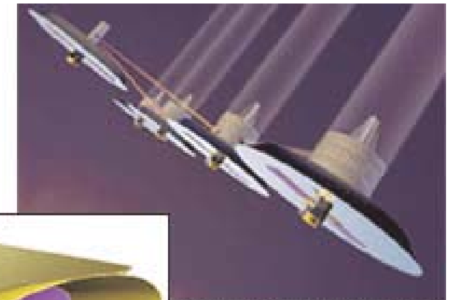
Need to know relative location of components to 50 pm.

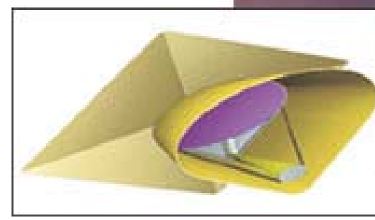


http://planetquest.jpl.nasa.gov/SIM/sim_index.html

Terrestrial Planet Finder





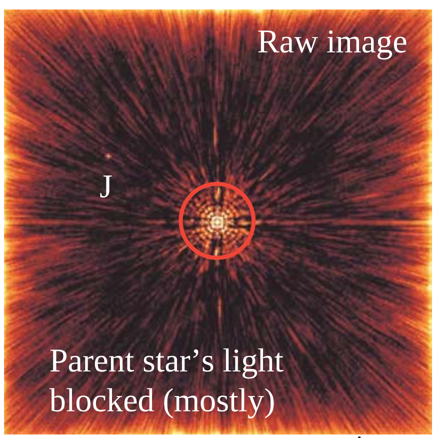


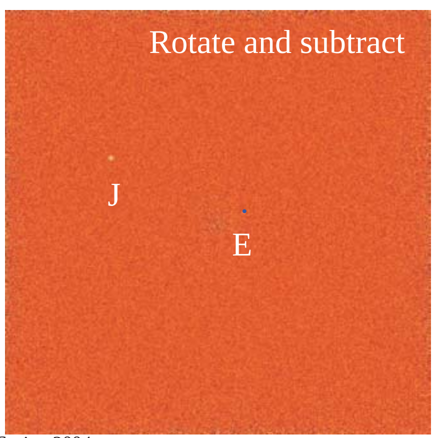
Terrestrial Planet Finder concepts include a coronagraph (left) and formation-flying interferometer (top)

TPF

Visual wavelength `coronagraph'

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





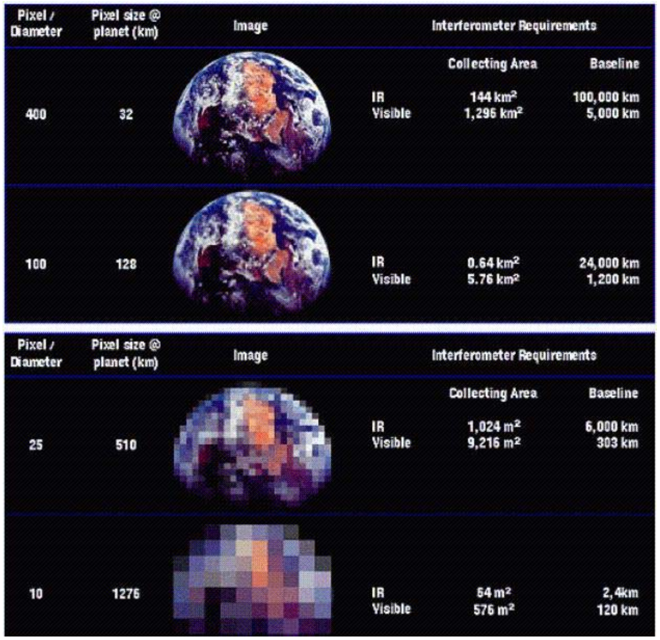
Terrestrial Planet Imager

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

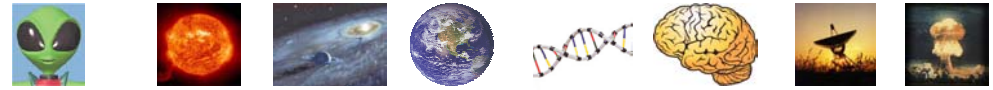
TPI -- Scales



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
25	510		IR Visible	1,024 m² 9,216 m²	6,000 km 303 km
10	1275		IR Visible	54 m² 576 m²	2,4km 120 km

Drake Equation

Frank Drake



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

- N: # of advanced civilizations we can contact
- R_*: Rate of formation of Sun-like stars
- f_p: Fraction of stars with planets
- n_e: # of Earthlike planets per system
- f_l: Fraction on which life arises
- f_i: Fraction that evolve intelligence
- f_c: Fraction that commun-icate
- L: Lifetime of advanced civilizations

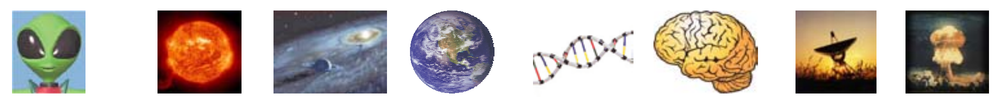
~10

Now, for f_p

- About 2/3 of all stars are in multiple systems.
- But disks around stars are very common, even some of the binary systems have them.
- We know of many brown dwarves, so maybe some planets may not form around stars.
  - There might be free-floating planets, but…
- 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 0.02. What number do you prefer?

Drake Equation

Frank Drake



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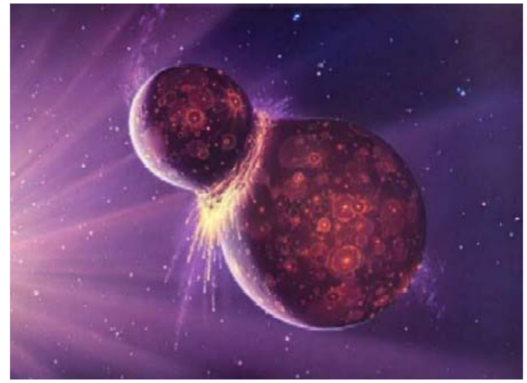
~10 ?

Formation of the Earth

- Focus on the formation of the Earth, including its atmosphere and oceans.
- The one peculiarity is the large moon.

Smack!

- Collision of Earth with Mars-size planetesimal early in history
- Core of planetesimal sank within Earth
- Earth rotation sped up
- Remaining ejecta thrown into orbit sufficient to coalesce into Moon



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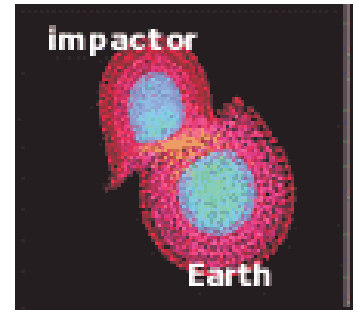
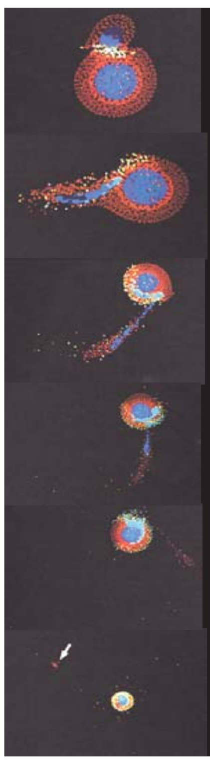


A.G.W. Cameron
Computer simulation



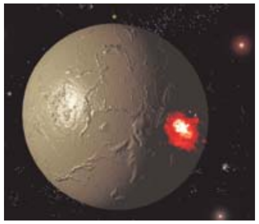
Large-Impact Hypothesis

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 iron-depleted, rocky mantles. The iron core of the impactor melted on impact and merged with the iron core of Earth, according to computer models.
- Compare density of 5.5 g/cm^3 to 3.3 g/cm^3-- the moon lacks iron.

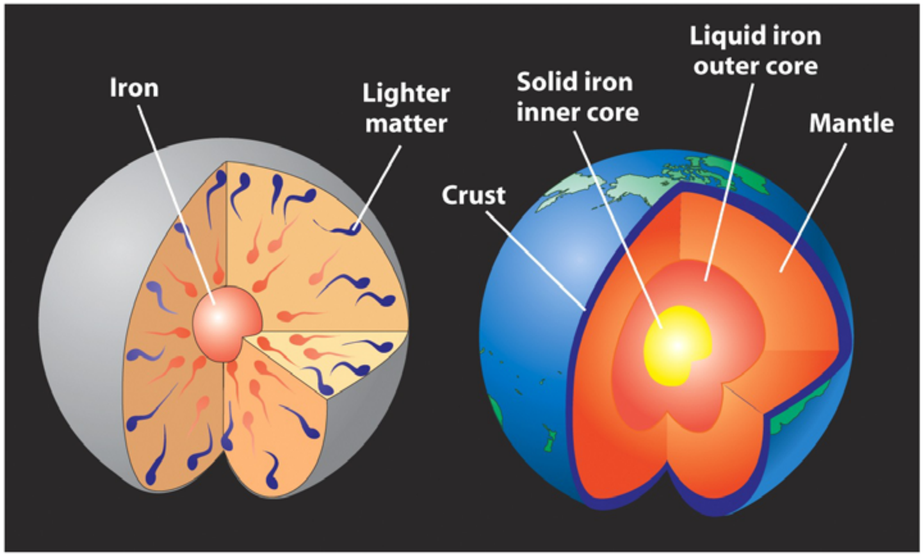
Implications

- 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 goes through a period of differentiation.



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

Planetary Differentiation



In Hawaii