Astronomy 230

Section 1– MWF 1400-1450

106 B6 Eng Hall

This Class (Lecture 8):

Nature of the Solar System

Extrasolar planets

HW2 due on Sept 20th

Next Class:

Habitable Planets

Music: *Planet of Sound* – Pixies

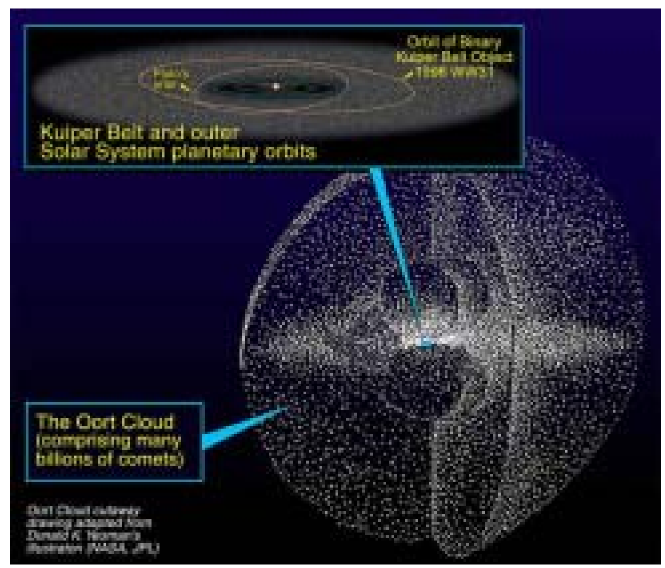
Outline

- How did our Solar System form?
- Extrasolar planets: watch them wobble.
- Not exactly what we expected.
- What to expect in the future.
- What is f_p?

Data: Planet's Dance

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

Data: Kuiper Belt



Data:
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

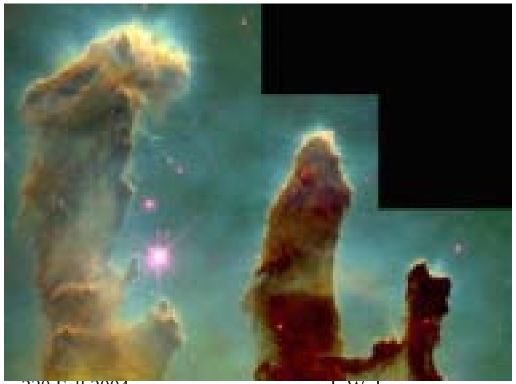
Age of Solar System is probably around 4.6 billion years old

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 last class.



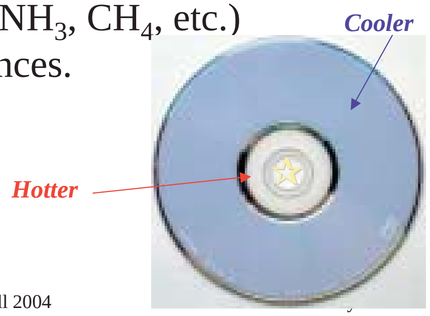
The Early Solar System

- 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 giants.
    - 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

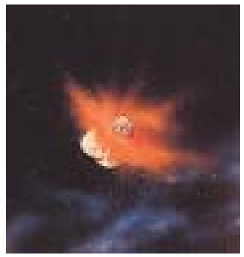
- As the star forms, the inner region of the disk gets much hotter than the outer regions, creating a temperature gradient.
- The inner part of the disk had a higher density than the outer regions.
- Icy mantles of dust grains (NH_3, CH_4, etc.) evaporated at varying distances.



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



What it might have looked like.

http://eeyore.astro.uiuc.edu/~lwl/classes/astro100/fall03/Lectures/solarsystemform.mov

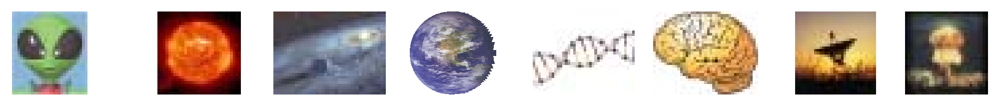
What Are We Looking For?

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: # of advanced civilizations we can contact
- R_*: Rate of star formation
- 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

25

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 effect of gravity.
- Star pulls on planet,
- Newton 3rd Law: But planet pulls on star with equal & opposite force
- Planet lighter, wobbles a lot (called orbits)
- But star must wobble 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.

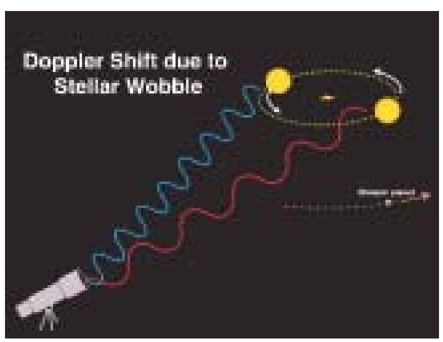
Star Wobble: Radial Velocity

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

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

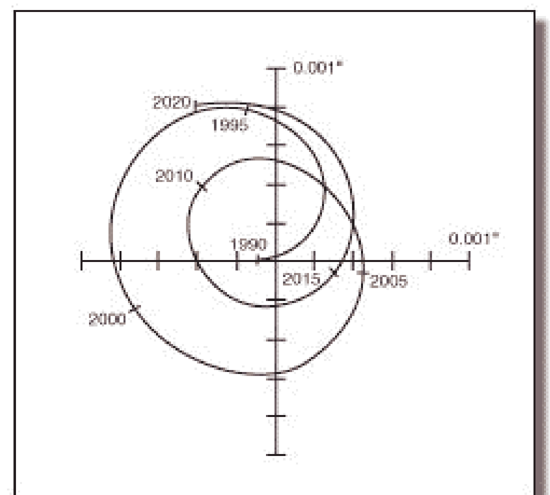
http://www.howstuffworks.com/planet-hunting2.htm



The Sun's Wobble

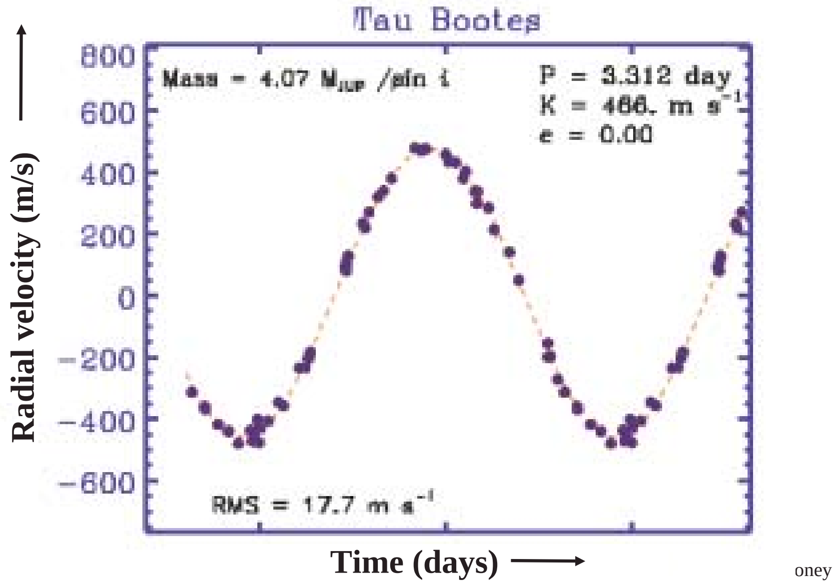
Astrometric displacement of the Sun due to Jupiter (and other planets) as at it would be observed from 10 parsecs, or about 33 light-years.

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



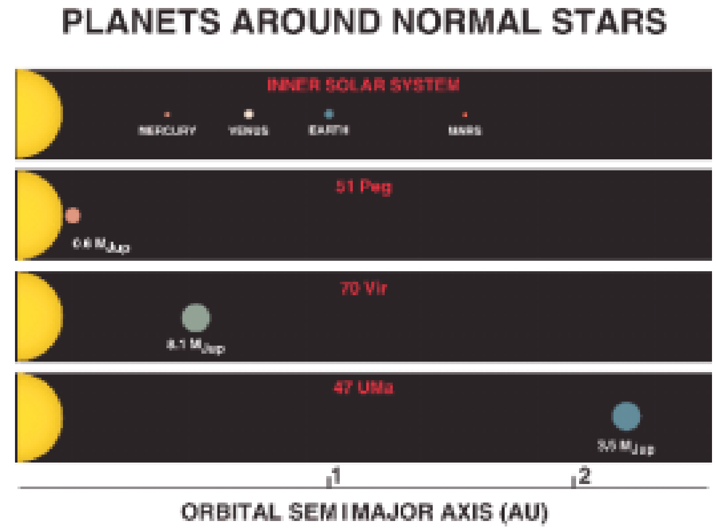
http://planetquest.jpl.nasa.gov/Keck/astro_tech.html

Radial Velocity Shifts: Planets around other Stars?

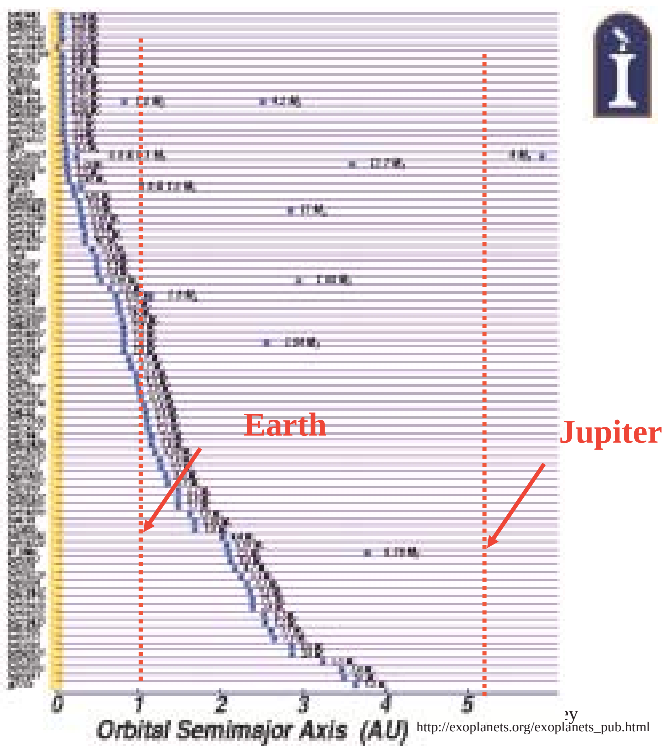


Early Discovery-- 1996

Hear all about it.



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

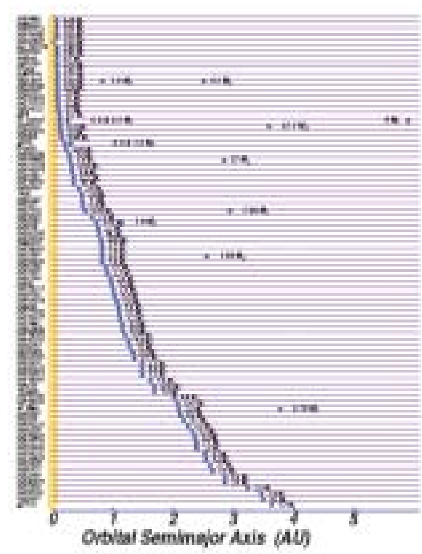


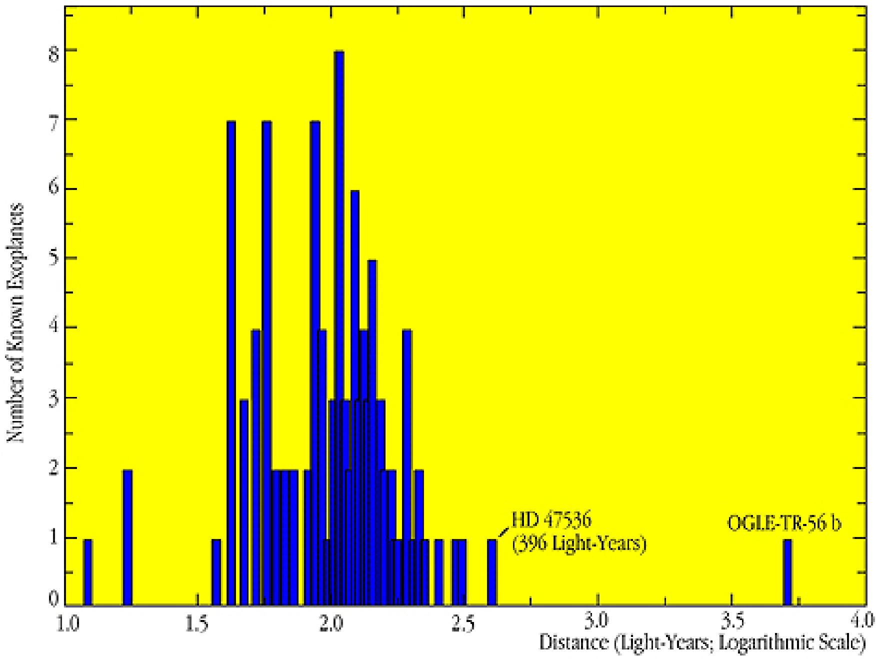
http://exoplanets.org/exoplanets_pub.html

Exoplanets: *Results to Date*

Over 118 planets detected so far
- More than 10 times the number in our Solar System!

- By measuring the wobble variation:
  - With time, gives the planet distance
  - The bigger the wobble, the heavier the planet

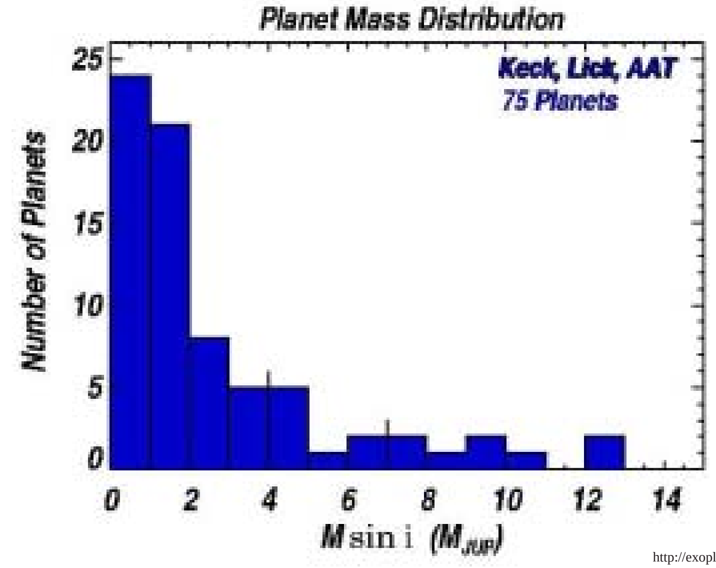




Distribution of Exoplanet Distances

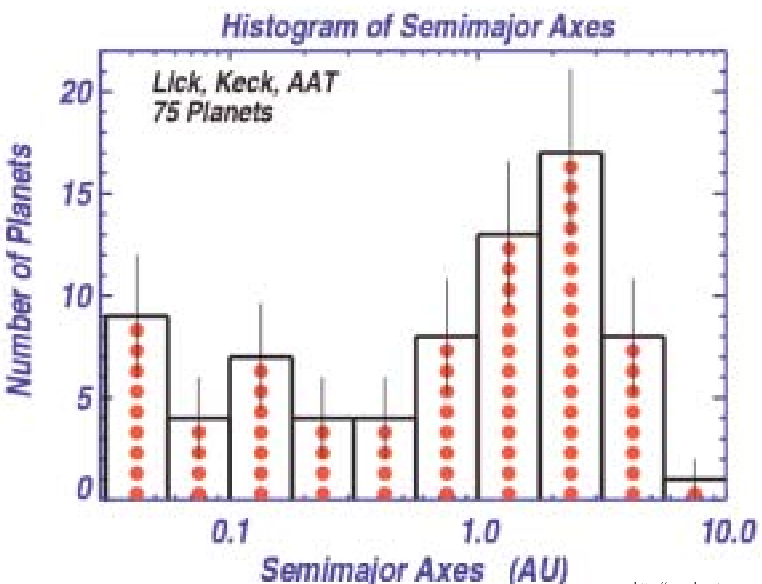
ESO PR Photo 05d/03 (22 January 2003)

Masses



http://exoplanets.org

Semi-Major Axes

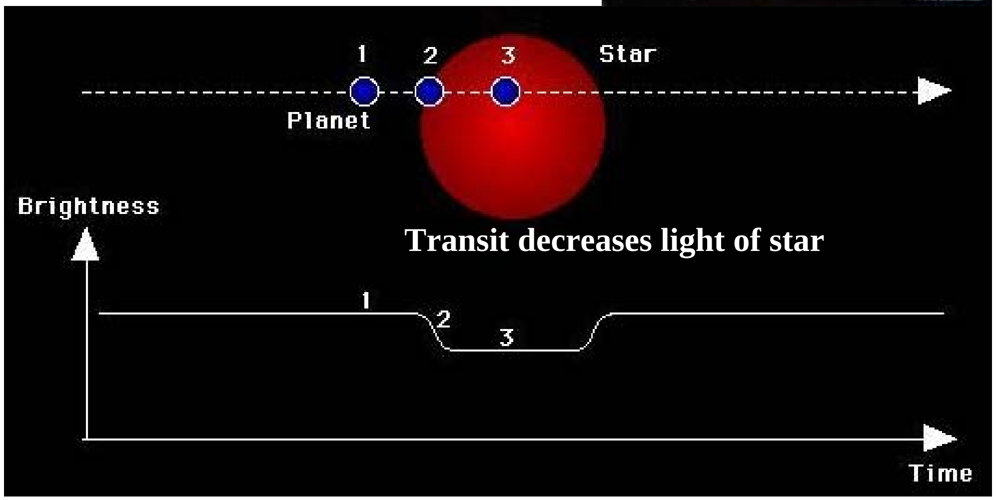


http://exoplanets.org

List

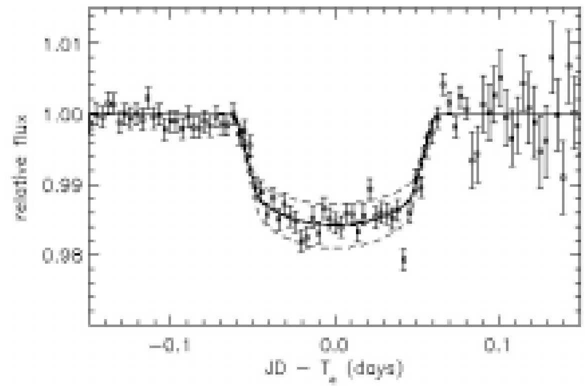
http://exoplanets.org/planet_table.shtml

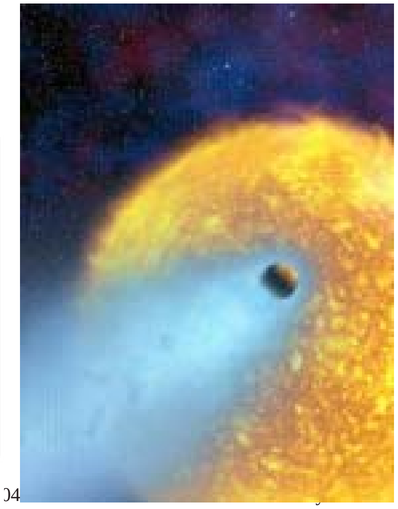
Planet Transits



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? Need massive planets to see the wobble
- ✓ If not massive, we could not have found them yet

Big Surprise:

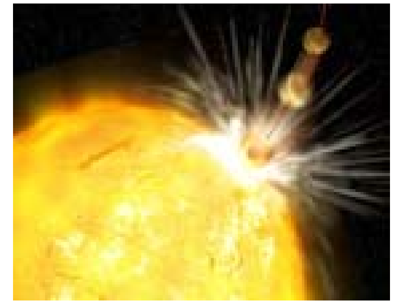
- ? Period of few days— whip around stars
- ? Most planets are very near stars!
- ? Example: tau Boo is 3.6 x Jupiter mass, but closer than Mercury's orbit!
- ? If a Jupiter-like planet formed close in, perhaps that prevents terrestrial planets from forming.

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

Exoplanets: Implications



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

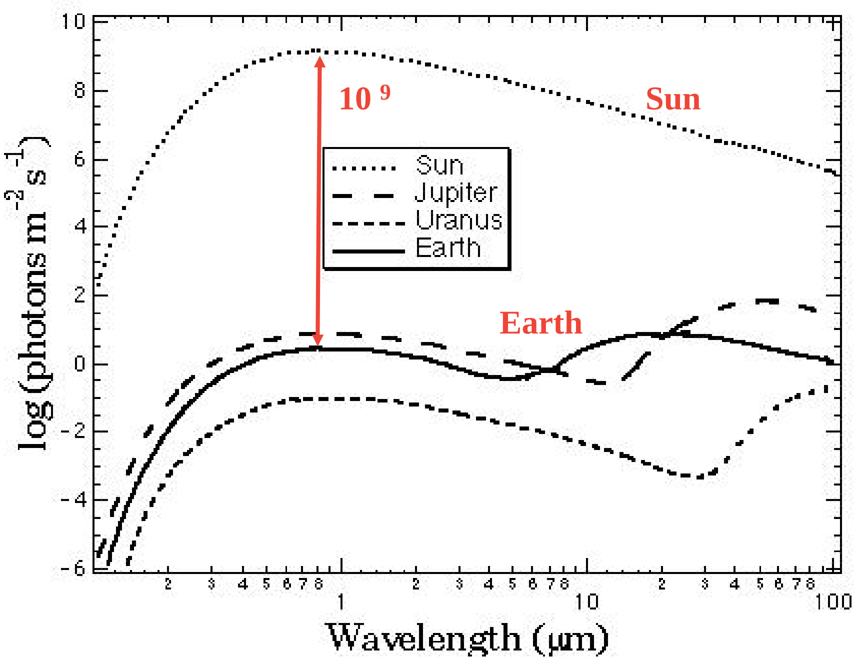
Exoplanet Data:
- Giant planets found very close

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 are common!
- ✓ Good news in search for life elsewhere...maybe

It is a Hard Business

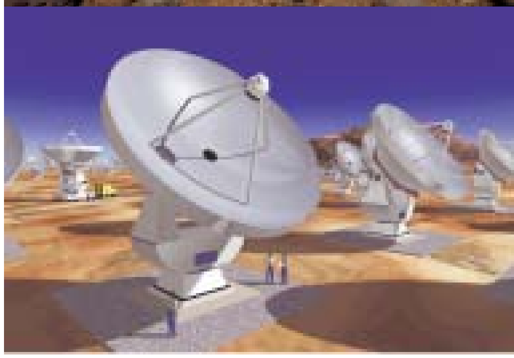


Future Projects

- 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. Imaging extrasolar Earths!!!!

ALMA -- 2010

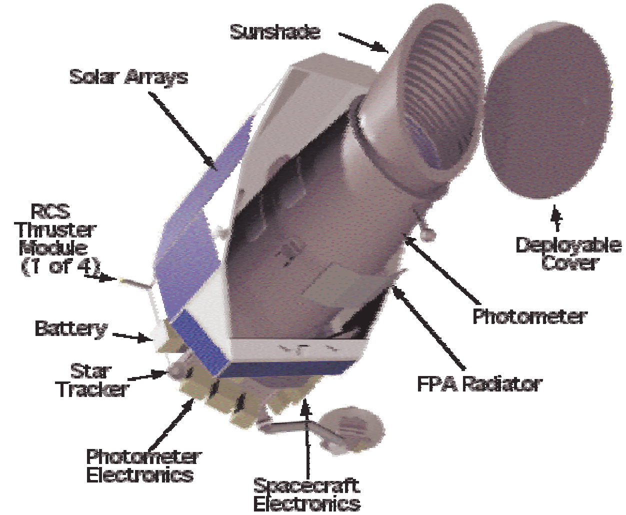
64 x 12 m @ 16,400 ft Chajnantor Chile



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.

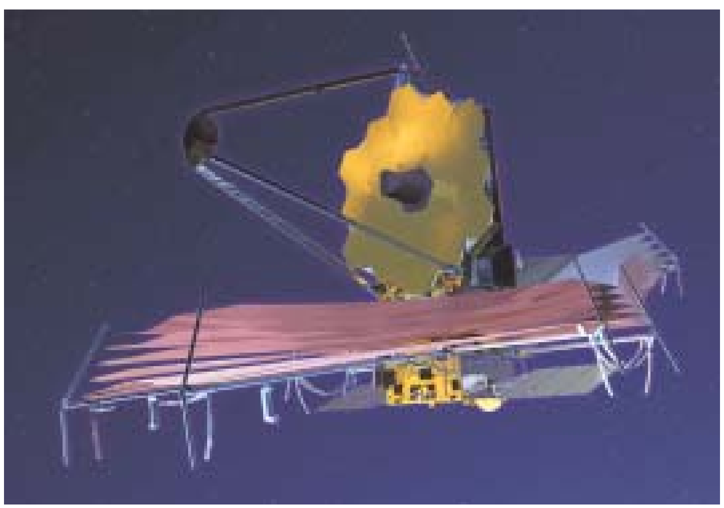


JWST

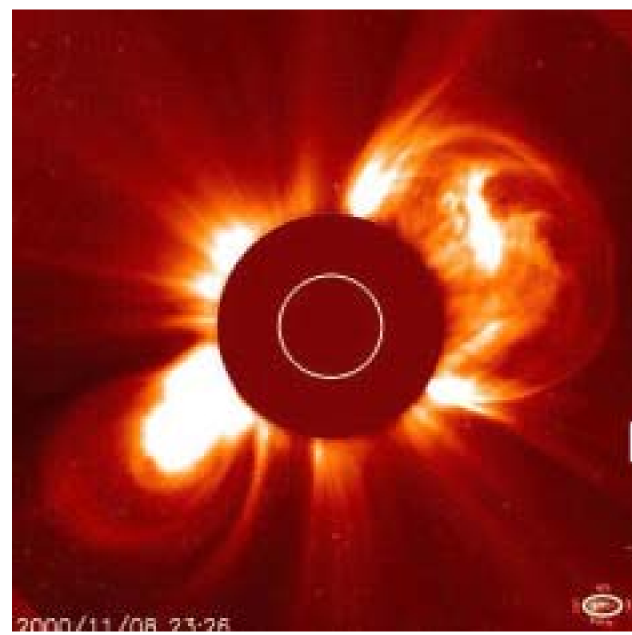
James Webb Space Telescope: Successor to HST

6.5 meter observatory

Working in the infrared with a coronagraph.



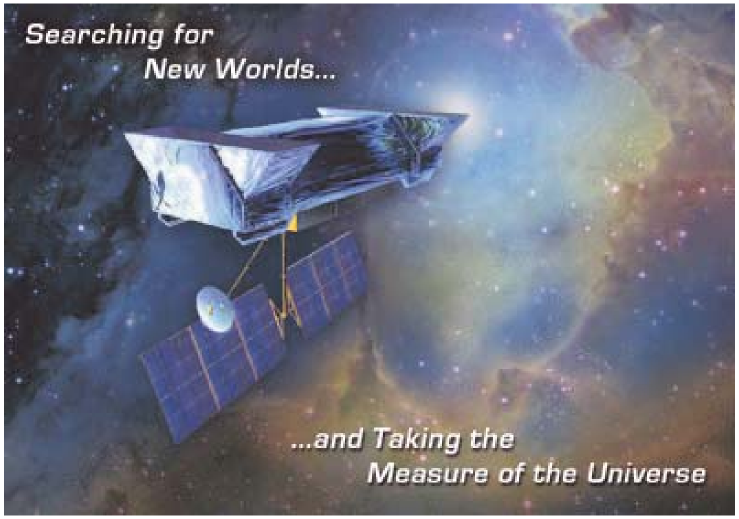
The Coronagraph Advantage



Space Interferometry Mission

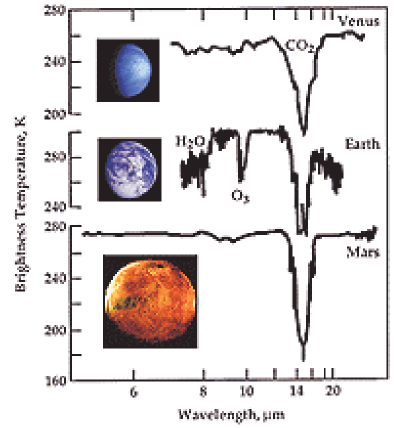
Accurately measure location of stars to micro-arcseconds.

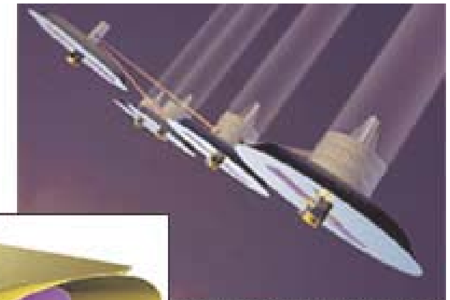
Need to know relative location of components to 50 pm.

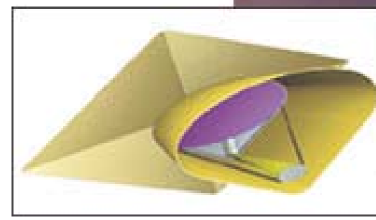


http://planetquest.jpl.nasa.gov/SIM/sim_index.html

Terrestrial Planet Finder





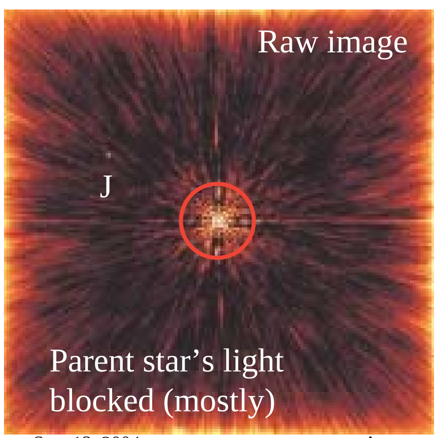


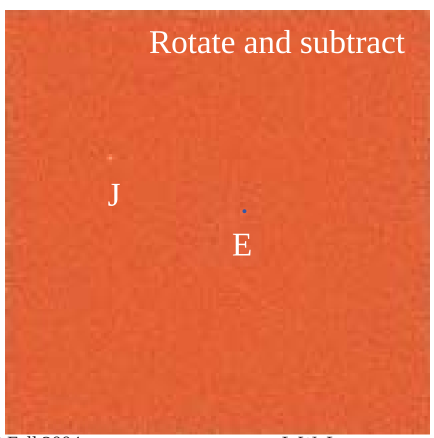
Terrestrial Planet Finder concepts include a coronagraph (left) and formation-flying interferometer (top)

TPF

Visual wavelength `coronagraph'

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

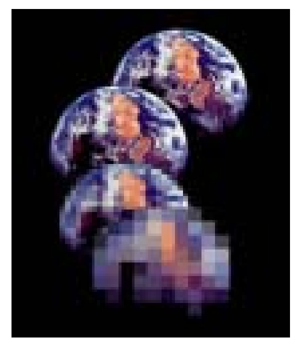


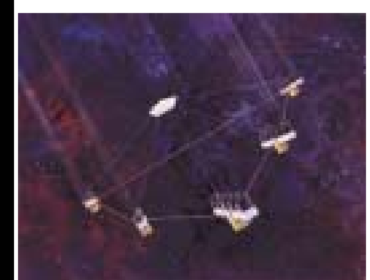


Terrestrial Planet Imager

The goal of imaging an Earth-like planet.

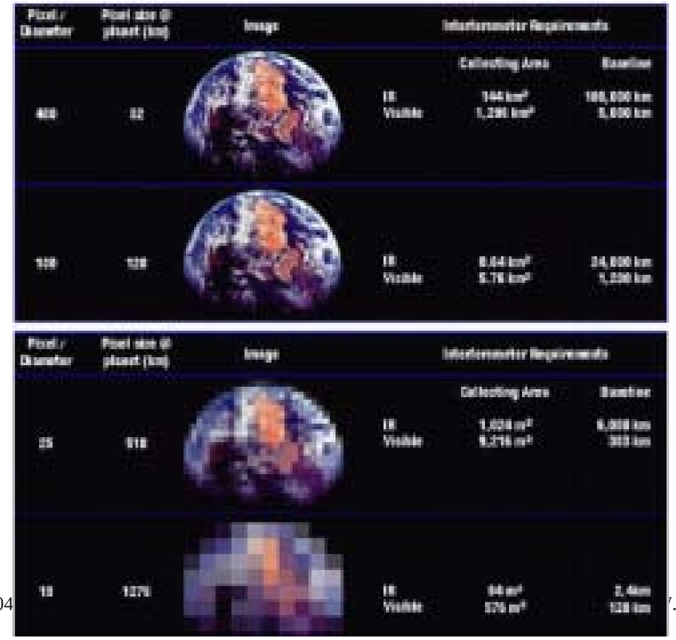
5 platforms of 4 eight meter interferometer in space.





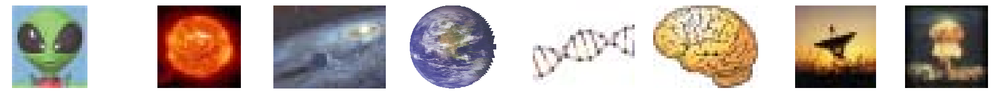
http://spider.ipac.caltech.edu/staff/jarrett/talks/LiU/origins/openhouse.html

TPI -- Scales



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	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
	25						

Now, for f_p

- About 2/3 of all stars are in multiple systems.
  - Is this good or bad?
- But disks around stars are very common, even many of the binary systems have them.
- Hard to think of a formation scenario without a disk at some point– single or binary system.
- Disk formation scenario matches our solar system parameters.

Now, for f_p

- We know of many brown dwarves, so maybe some planets do 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?
- A high fraction assumes that the disks often form planets.
- A low fraction assumes that even if there are disks, the planets do not form.
- This is not Earth-like planets, just planets.