Astronomy 330

This class (Lecture 11):
What is f_p?
Eric Gobst
Suharsh Sivakumar

Next Class:
Life in the Solar System

HW 4 is due tonight!

Music: *Jesus Came From Outta Space*– Supergrass

HW 2

- Kira Bonk
  http://www.ufodigest.com/news/0308/ascension.html
- Matthew Tenpas
  http://morphman.hubpages.com/hub/Alien-Artifacts-Discovered-Under-Crop-Circles

Presentations

- Eric Gobst
  If the moon were made of ribs, and what the heck the other planets are made of
- Suharsh Sivakumar
  Evolution of Intelligence

Outline

- Transit Studies (Kepler)
  - Small planets are common
- Estimate f_p?

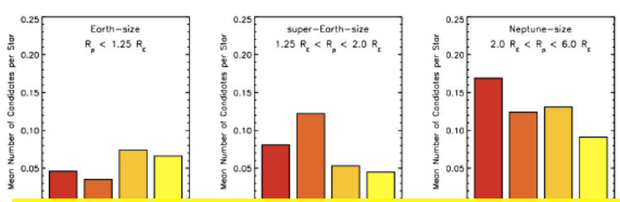
Finding Planets

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

Kepler Mission

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

Kepler Status

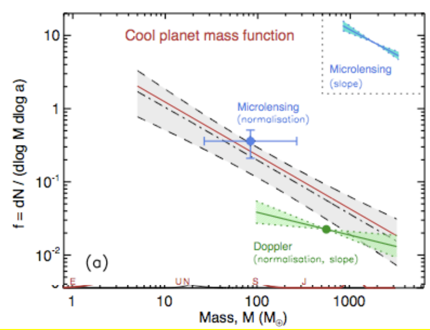


The Kepler team estimated that at least 5.4% of all stars host Earth-like planets and that at least 17% of all stars have planets.

Others using the Kepler data estimated 1.4 to 2.7% of all sun-like stars are expected to have earth-like planets within the habitable zones of their stars-- or two billion Earths in the Milky Way!

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

Kepler Status



Another team used Kepler and other data (micro-lensing) to estimate that on average every star in the Galaxy has 1.6 planets.

That means f_p = 100%!

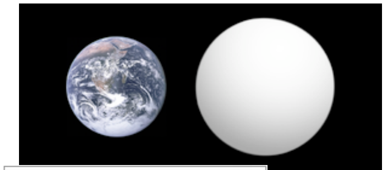
http://arxiv.org/pdf/1202.0903v1.pdf

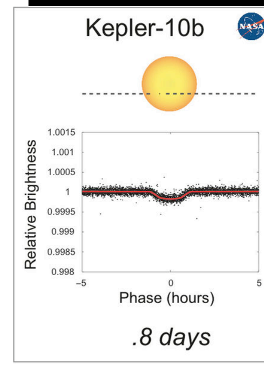
Kepler Status

Still remember, we are only looking locally.

Kepler-10b

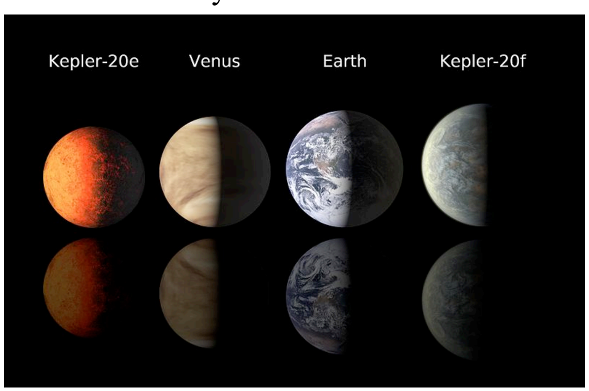
- First confirmed rocky exoplanet, Jan 2011
- Smallest confirmed planet yet, only 1.4 Earth diameters.
- 4.6 Earth masses
- Orbits freaky close— 20 hours (0.017 AU)!
- Hot!
  - 1833 K– melt iron.





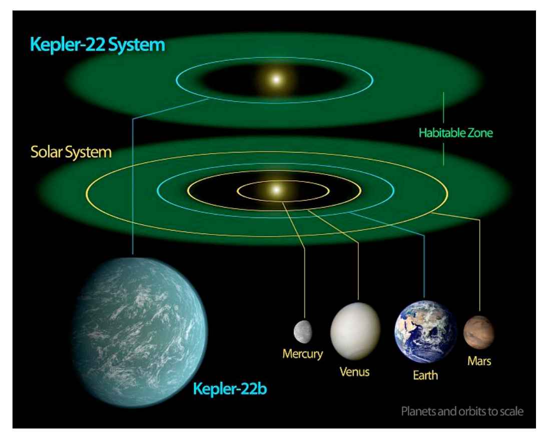
Kepler-20 e/f

- First confirmed Earth-sized exoplanets around Sun-like star, Dec 2011
- But orbits smaller than Mercury.
- Hot!
  - 1400 F
  - 800 F



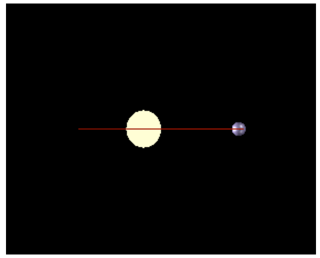
Kepler-22b

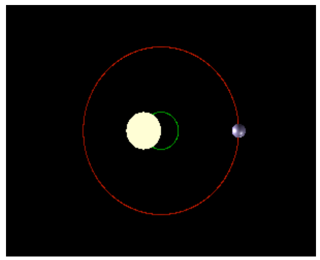
- First confirmed exoplanet in the habitable zone!!!
- Dec 2011
- 2.4 Earth radii
- Mass unknown
- 290 day orbit
- Rocky?
- Ocean planet?
- Venus-like?



Limitations of Doppler and Transit Methods

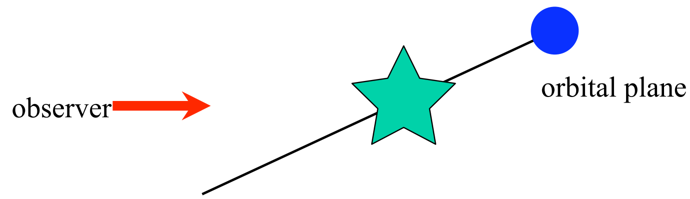
- In edge-on system (above)
  - Transits are possible
  - Doppler shift observed
  - Radial velocity is star's true motion
  - Doppler method gives planet mass
- In face-on system (below)
  - No transits, no Doppler shift



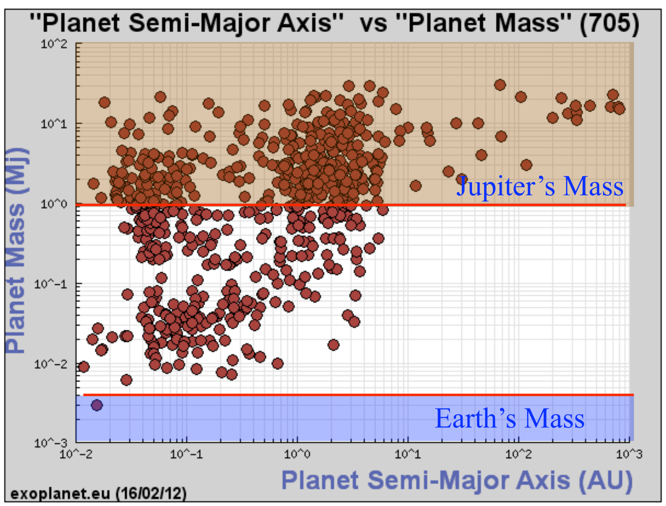


Limitations of Doppler and Transit Methods

- Inclined systems
- No transits observed
- Doppler shift is observed
  - Radial velocity less than star's true motion
  - Doppler method gives us a lower limit on planet mass

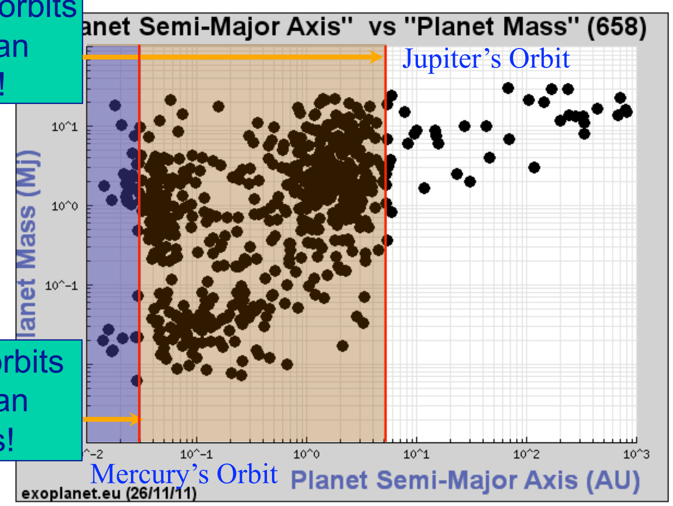


Most detected planets have more mass than Jupiter!



Most detected planets have orbits smaller than Jupiter's!

Many have orbits smaller than Mercury's!

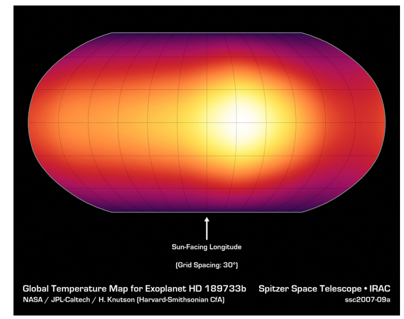


Planetary Good News

- Planets are common
- It looks like something like 2% of all Sun-like stars have Earth-like planets!
  - High mass stars don't life long enough for life anyway
  - Very low-mass stars, the planet has to be too close to be in the habitable zone
- Very good news for life in the Galaxy and the Universe

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.



Lists

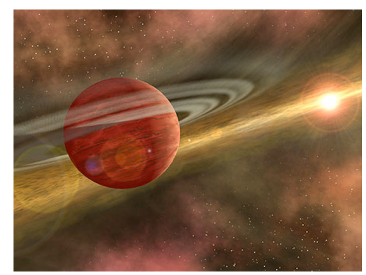
http://exoplanets.org/

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

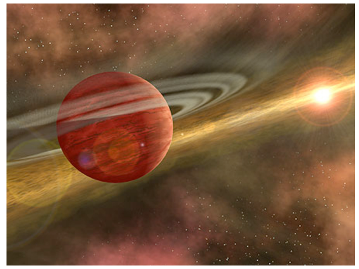
Results to Date

No surprise

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



Results to Date



Big surprises

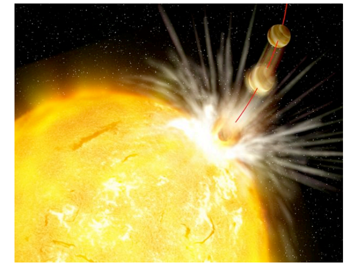
? Many periods are short–
a few days!

? 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

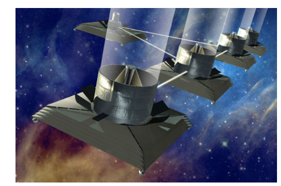
☺ Are interstellar dust clouds common? ***Yes!***

☺ Do young stars have disks? ***Yes!***

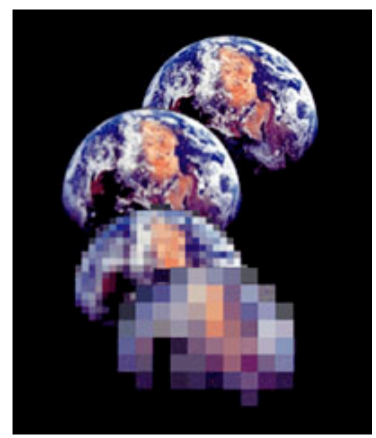
? Are the smaller planets near the star?
Not always

? Are massive planets farther away?
Not always

A Future Mission?



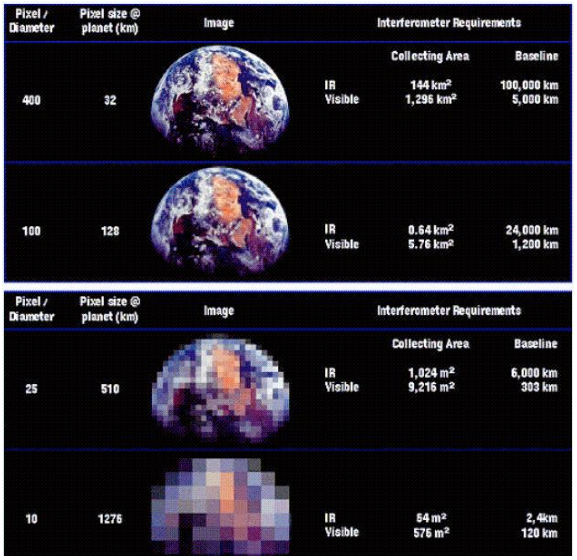
The goal of imaging an Earth-like planet.



5 platforms of 4 eight meter interferometer in space.

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

A Future Mission



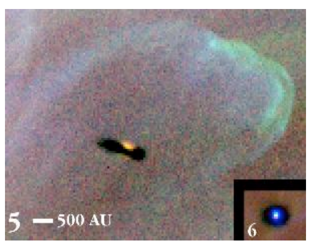
Pixel / Diameter	Pixel size @ planet (km)	Image		Interferometer Requirements: Collecting Area	Baseline
400	32		IR Visible	144 km² 1,296 km²	100,000 km 5,000 km
100	128		IR Visible	0.64 km² 5.76 km²	24,000 km 1,200 km
25	510		IR Visible	1,024 m² 9,216 m²	6,000 km 303 km
10	1276		IR Visible	64 m² 576 m²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

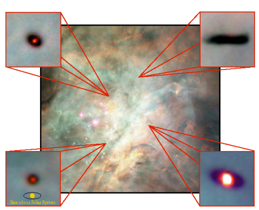
Disks in Binary Systems

- >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

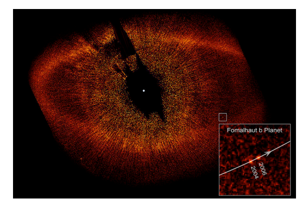
- About 2/3 of all stars are in multiple systems.
  - Is this good or bad?
- Disks around stars are very common, even most binary systems have them.
- Hard to think of a formation scenario without a disk at some point– single or binary system.
- Disk formation matches our solar system parameters.
- We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

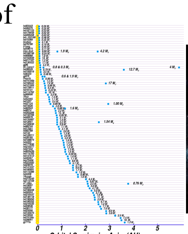


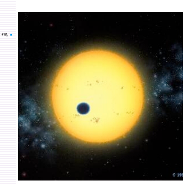


Now, for f_p

- Extrasolar planet searches so far give an absolute lower limit of about $f_p \sim 0.34$!
- Some estimates of total planets give an average of $f_p = 1$!!!!
- Maximum is 1 and lower limit is probably around 0.30.
- A high fraction also 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.
- f_p is not Earth-like planets, just a planet or many planets.



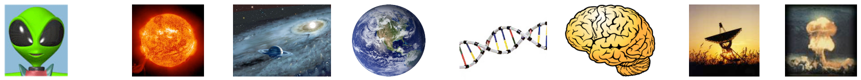




Drake Equation

Frank Drake

That's 16 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
	20 stars/yr	0.8 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