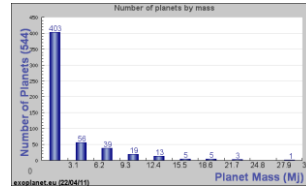


Extrasolar Planets

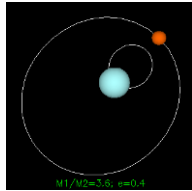
- Extrasolar/Exoplanets – beyond the SS!
- What is a planet vs a star?
 - Sort of opposite the 2006 debate
 - Does it have fusion (yes=star)
- Mass limit
 - $M < 0.013 M_{\odot}$, no fusion, planet
 - $0.013 M_{\odot} < M < 0.075 M_{\odot}$, brown dwarf (H^2)
 - $M > 0.075 M_{\odot}$, H fusion

- Jupiter = $0.00095 M_{\odot}$
- Use Jupiter's Mass (M_J)
 - $M < 14 M_J$, Planet
 - $14 M_J < M < 79 M_J$, brown dwarf
 - $M > 79 M_J$, a star



Detecting

- Why not just look for them?
 - Size difference
 - Illumination
- Gravitational Influence
 - Binary star analogy



Solve for binary star motion

- Center of mass relation

$$M_1 r_1 = M_2 r_2$$

- Kepler's Third Law

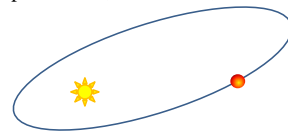
$$P^2 = \frac{(r_1 + r_2)^3}{(M_1 + M_2)}$$

And the first planets were discovered.....

- Around a pulsar?
 - PSR 1257+12
 - $b = 0.00007 M_J$
 - $c = 0.013 M_J$
 - $d = 0.012 M_J$
 - All within 0.46 AU of "star", $P < 100$ days
 - Not exactly what we had in mind...

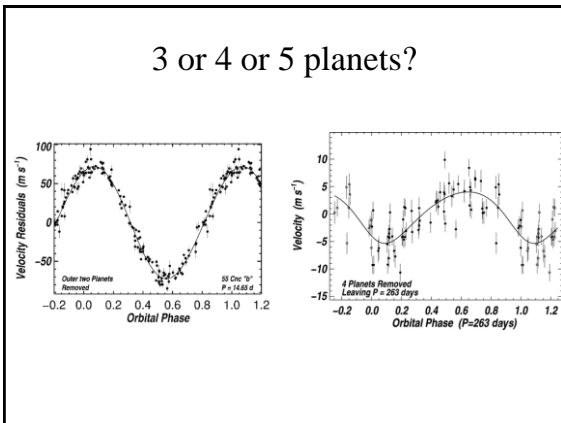
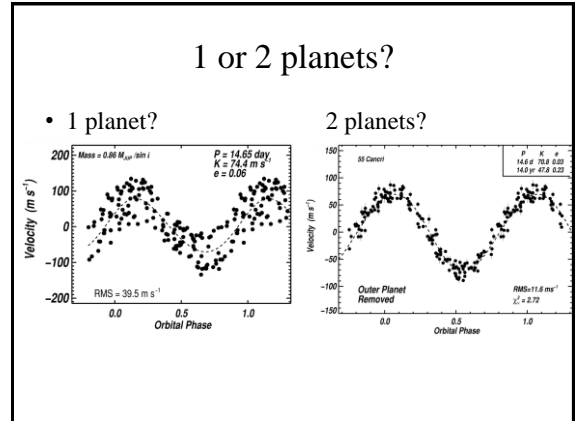
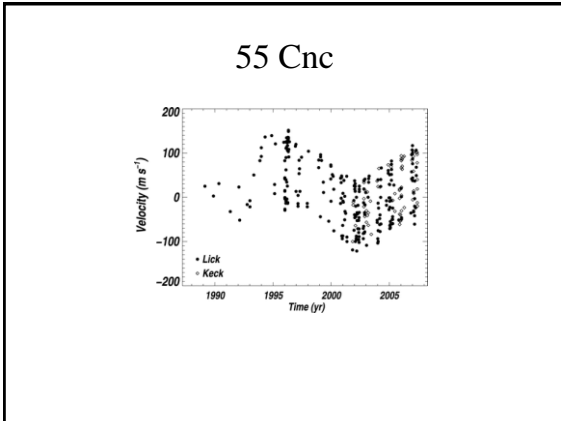
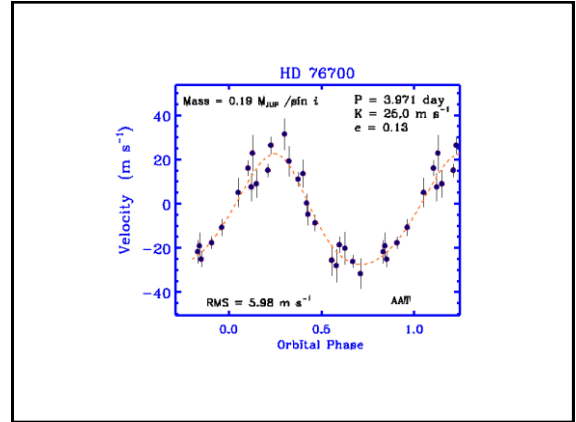
First discovery around "normal" star

- 51 Peg b
- And many, many more....
- Mass determination
 - Depends on star's mass (from stellar physics)
 - Orbital parameters, inclination, eccentricity



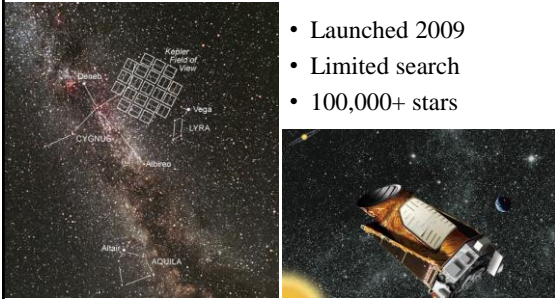
- A = amplitude of velocity (m/s)
- G = Constant
- P = Period (seconds)
- i = inclination ($>0^\circ$)
- e = eccentricity (0-1)
- M_* = mass of star (kg)
- M_p = mass of planet (kg)

$$A = \left(\frac{2\pi G}{P} \right)^{1/3} \frac{M_p \sin i}{(M_* + M_p)^{2/3}} \frac{1}{\sqrt{1 - e^2}}$$



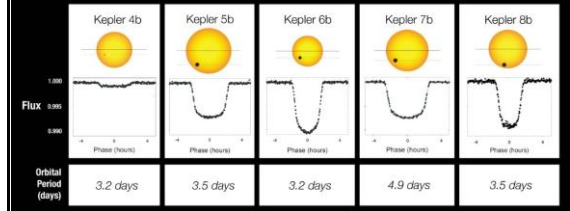
- ### Transits
- Passage of a planet in front of star
 - Requires small i value
 - Possible to detect?
 - Disk of Sun vs disk of planet (Sun vs Jupiter)
 - Jupiter disk = 0.01 Sun's disk (1%)
 - Blocks 1% of Sun's light (0.02 magnitude change)

Kepler Mission

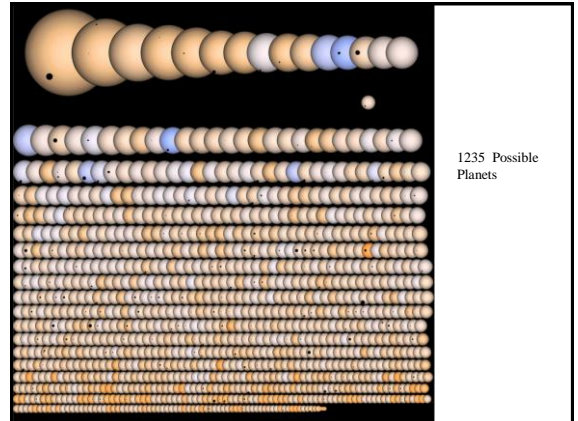
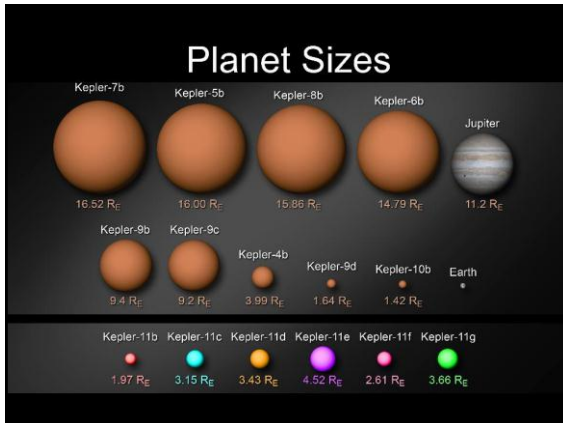


- Launched 2009
- Limited search
- 100,000+ stars

Transit Light Curves

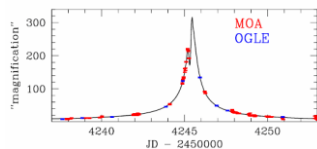


Planet Sizes



Microlensing

- Used to detect dark matter
- Looking for low mass stars, finding more



Habitable Zone

- Goldilocks Zone
- Water as a liquid
 - Function of spectral type
 - Inner boundary = $0.7 (L_*/L_{\odot})^{1/2}$
 - Outer boundary = $1.5 (L_*/L_{\odot})^{1/2}$

Why limit ourselves to “Normal” forms of life?

- Life discovered in extreme places
 - Hot springs/volcanic vents
 - Inside of rocks
 - In amber
 - Arid
 - Dark
 - Near vacuum
 - High pressure/low pressure

Is it worth our time to look?

Drake Equation

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

N - number of communicating civilizations

R_* - rate of star formation (stars/year)

f_p - fraction of stars with planets

n_e - number in HZ

f_l - fraction that have life

f_i - fraction that have intelligent life

f_c - fraction that have communicating life

L - length of time to communicate