Astronomy 330

This class (Lecture 10):

Exoplanets 2
Braden Anderson
Jennifer Bora

Next Class:

Origin of the Moon
Eric Gobst
Suharsh Sivakumar

HW 4 is due Thursday!

Music: *3rd Planet* – Modest Mouse

HW 2

- Ryan Ruddell
  http://www.cropcircleresearch.com/index2.html
- Neel Lawande
  http://www.paranormalhaze.com/5-pieces-of-evidence-that-suggests-intelligent-alien-life-exists/

Presentations

- Braden Anderson
  Roswell
- Jennifer Bora
  Alien Language

Outline

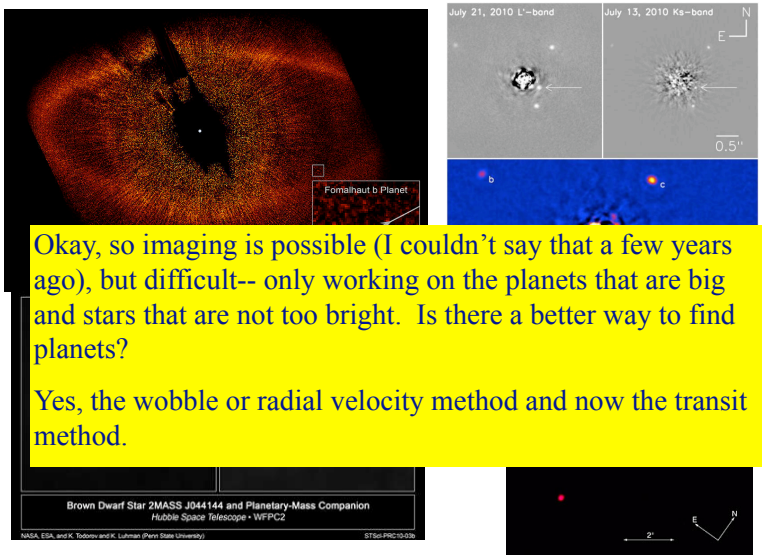
- Exoplanets – they are all over the place.
- Radial Velocity studies (wobble method)
- Transit Studies (Kepler)
- Estimate f_p?

Finding Planets

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

Only a few planets have been detected directly in the optical and IR. Remember that planets in our Solar System seem bright because they reflect light from the Sun in the visible.

We have imaged some Exoplanets

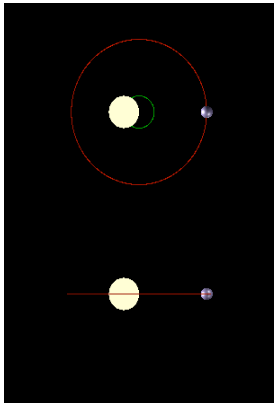


Okay, so imaging is possible (I couldn't say that a few years ago), but difficult-- only working on the planets that are big and stars that are not too bright. Is there a better way to find planets?

Yes, the wobble or radial velocity method and now the transit method.

Wobbling Stars

- Planet's gravity "tugs" the parent star
- As planet orbits the star, the tugs make the star "wobble"



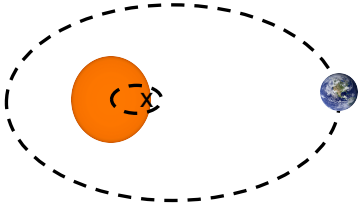
Star and planet each orbit around their mutual center of mass

Star Wobble: Radial Velocity

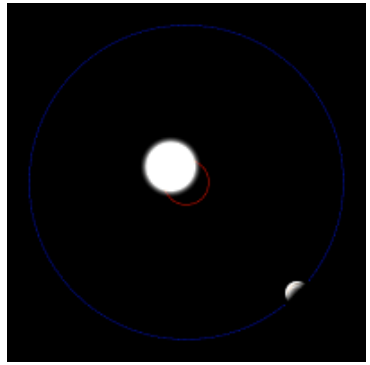
Newton's 3rd Law:

- *Both* planet *and star* move
- Both orbits fixed around the "center of gravity"

- Star's period? Place your bets…
  - Same as planet



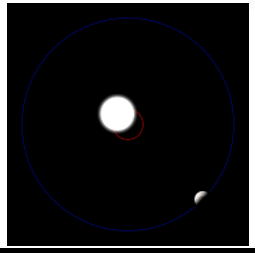
Greatly exaggerated

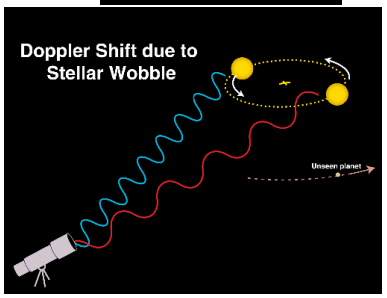


http://en.wikipedia.org/wiki/File:Planet_reflex_200.gif

Star Wobble: Radial Velocity

- Star movement too small to see
  - Moves in small, tight circle
  - But “wobble" in star speed detected!
  - The stellar spectrum is shifted red and blue as it moves towards us and away from us.





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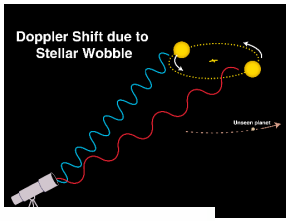
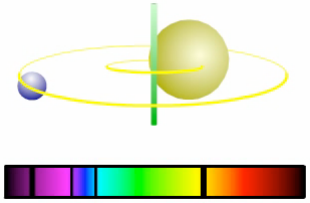
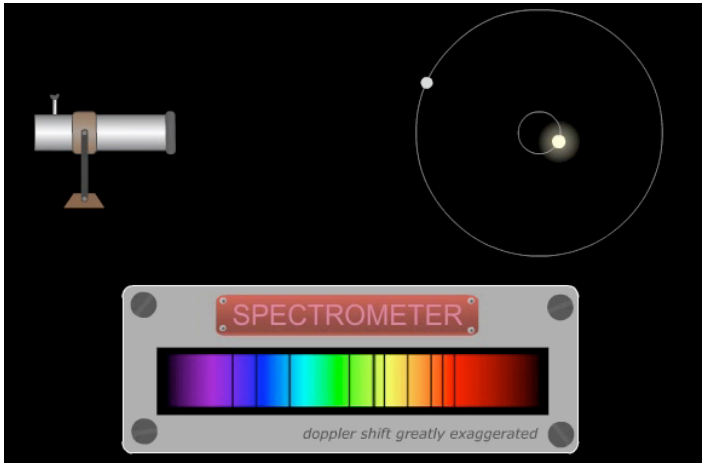


How Planet Hunting Works



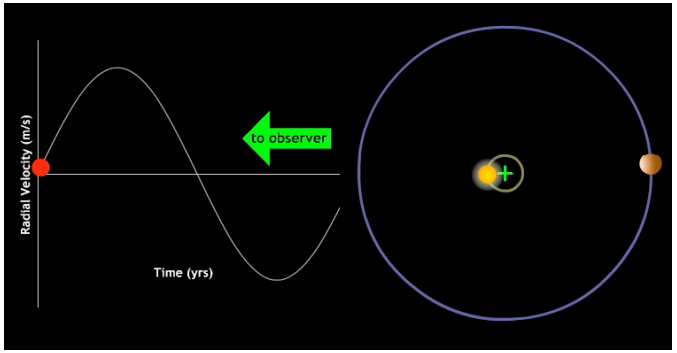
Star Wobble: Radial Velocity

- Need very sensitive spectrometers to measure the wobble.



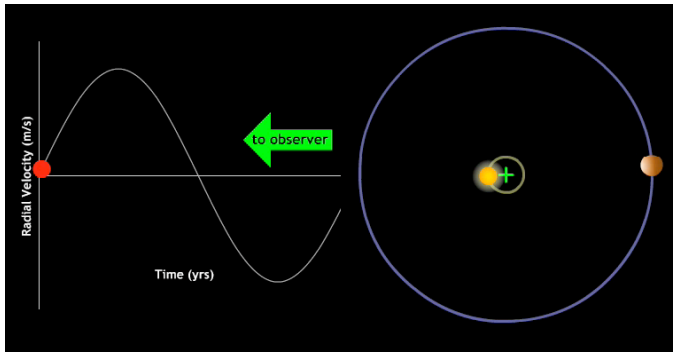
Star Wobble: Radial Velocity

- Observed wave form as the planet orbits the star.
  - Period depends on what?
  - Amplitude depends on what?



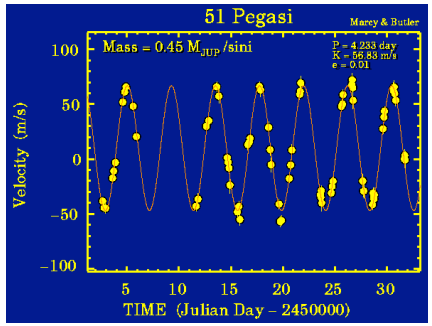
Star Wobble: Radial Velocity

- Observed wave form as the planet orbits the star.
  - Period depends on what? Orbital distance from star.
  - Amplitude depends on what? Mass of planet.



First extrasolar planet around a Sun-like star

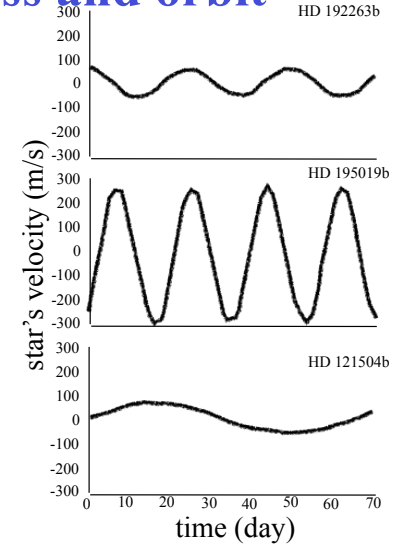
- Discovered in 1995 orbiting 51 Pegasi
  - Doppler shifts reveal a planet with 4.23 day orbital period
  - 0.5 M_{Jup} at 0.05 AU from its star!
- As of Feb 2012, 760 exoplanets are listed in the Extrasolar Planets Encyclopedia. http://exoplanet.eu/catalog.php



51 Pegasi b orbits it star every 4.23 days!

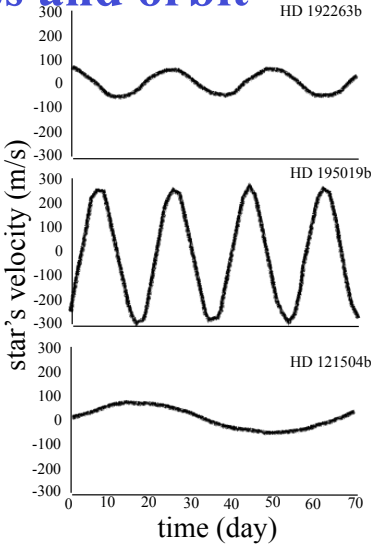
Doppler shift tells us about a planet's mass and orbit

- Top graph shows a 0.5 M_{Jup} planet in an orbit around a Sun-like star at 0.05 AU
- Middle graph - more massive planet (2 M_{jup}) in a 0.05 AU orbit
- Bottom graph - 0.5 M_{Jup} planet in more distant orbit

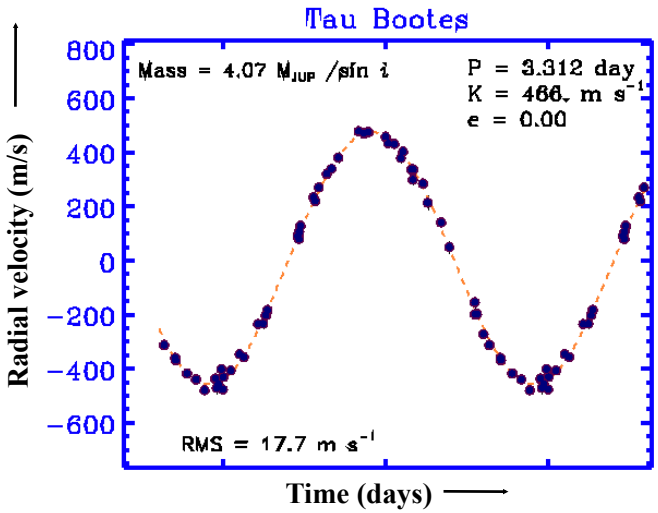


Doppler shift tells us about a planet's mass and orbit

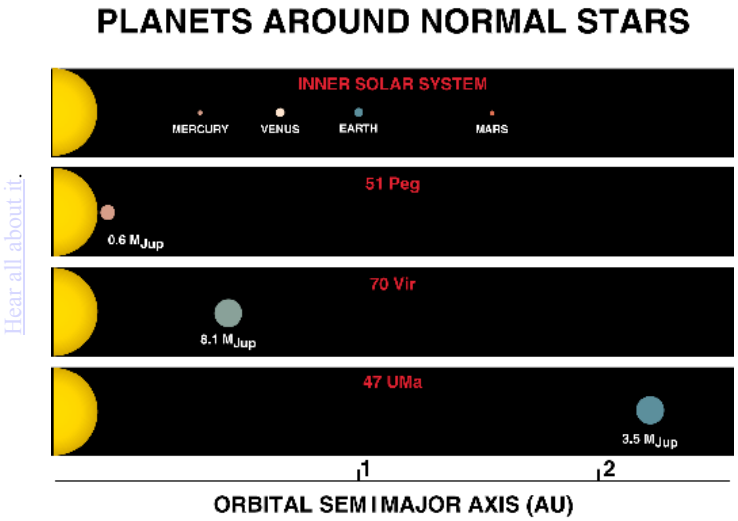
- The amplitude of the wobble tells us the planet's mass
- More massive planet in same orbit produces greater Doppler shift with same period around the star
- The period of the wobble tells us the radius of its orbit
- Same mass planet in a more distant orbit produces a smaller Doppler shift with a longer period.



Radial Velocity Shifts: Planets around other Stars?



Early Discovery-- 1996

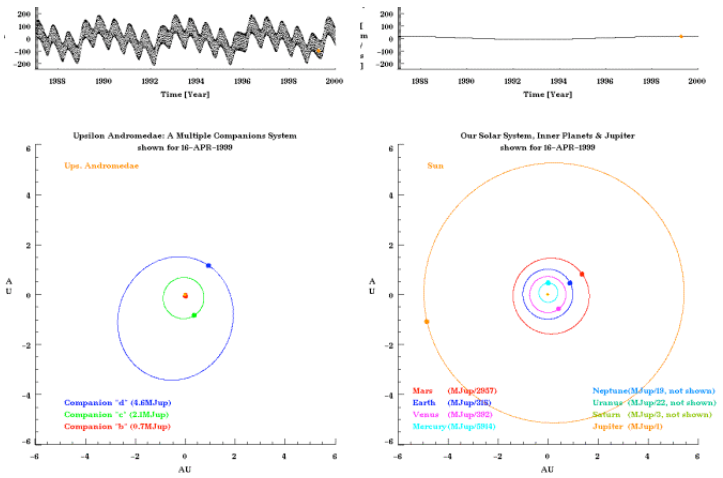


Hear all about it.

Selection Effect

- Big planets make big wobbles
  - Bigger Doppler shift
  - Easier to detect
- Close planets make fast wobbles
  - Shorter period of Doppler shift
  - Less time to observe a full orbital period
- Think about it...
  - Jupiter's orbital period ~12 years
  - Saturn's orbital period ~30 years
  - Detecting extrasolar planets for 15 years
  - Enough time for 1 Jupiter orbit, but not Saturn

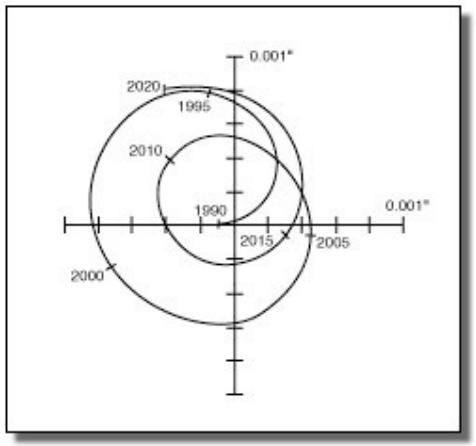
Detecting Our Wobble



The Sun's Wobble

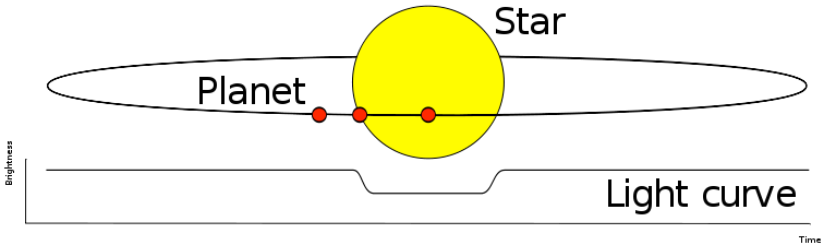
Astrometric displacement of the Sun due to Jupiter (and other planets) as at it would be observed from 10 parsecs, or about 33 light-years.

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



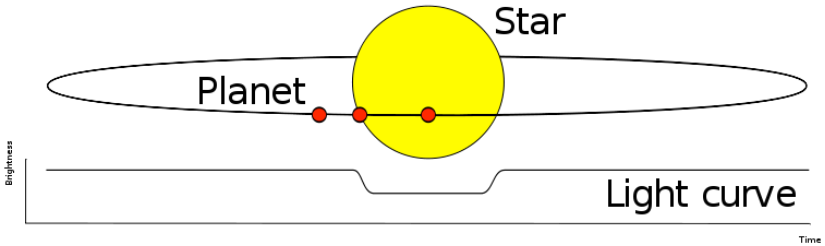
http://planetquest.jpl.nasa.gov/Keck/astro_tech.html

Detecting Planets via Transits



The effect on the observed brightness when a planet passes in front of the parent star

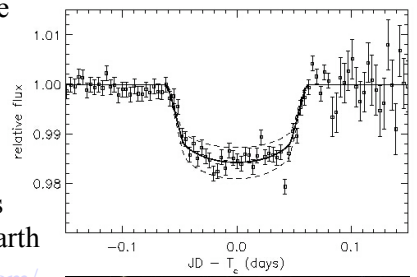
Detecting Planets via Transits

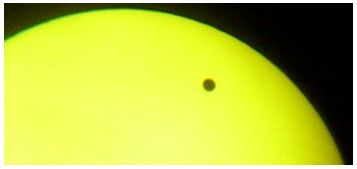


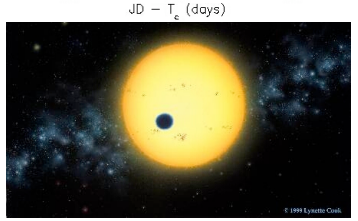
Look for regular dips in the brightness of a star as a large planet passes, or transits, in front of it. Requires the extrasolar planet's orbital plane to be pointed right at Earth.

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://science.howstuffworks.com/planet-hunting1.htm

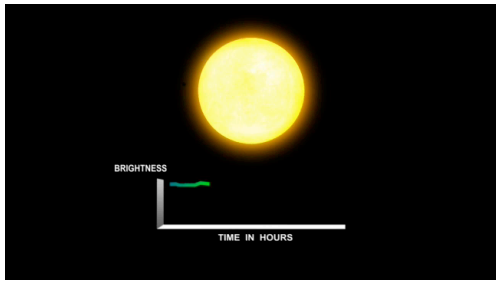






Transits are the best chance to find Earth-like planets

- Fraction of starlight blocked tells us planet's size
- Time between transits gives us orbit period
- A Jupiter-sized planet transiting a Sun-like star would cause a 1% brightness drop
- Best method to find Earth-like planets



Earth-sized planet would cause a 0.01% drop in brightness (1 in 10,000), but best instruments can measure 1 in 50,000 drop in brightness!

Kepler Mission

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

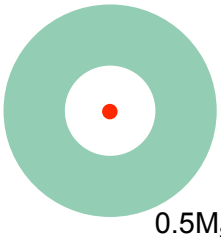
Kepler Mission

- Looking for small intensity dips in stars
- Must have planet block some of the star's light
- Playing probability game as random orbits must intersect our line of sight
  - For Earth, the chance of this happening is 0.465%.
  - If ALL stars have Earths, would see 678 Earths
- But, Kepler group won't call objects candidates until they see the dip three times.. not yet enough time for Earth's at 1 AU.

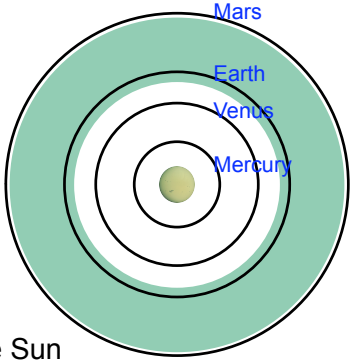
Planets in the Habitable Zone: Would be nice for life

Distance from the star such that liquid water can exist on planet

Will depend on the star's temperature



$0.5M_{Sun}$ star

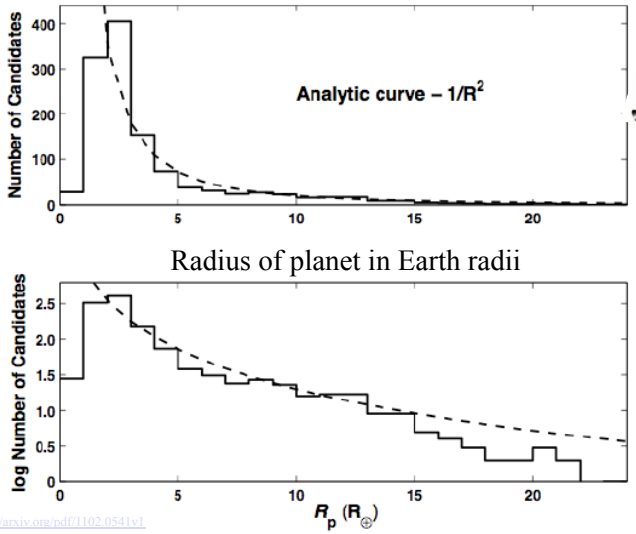


The Sun

Kepler Status

- First major release was early 2011 with another major release expected soon
- 2326 planet candidates
  - 207 Earth-sized
  - 48 planets in the habitable zone
  - Habitable zone is the region around a star where water is likely to be a liquid.
- Candidates because 90% confidence currently. Will improve with time.

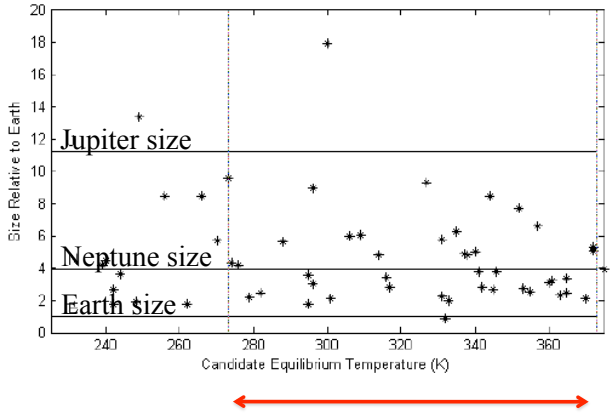
Kepler Status



Unlike radial velocity sources, smaller planets are more common in Kepler data.

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

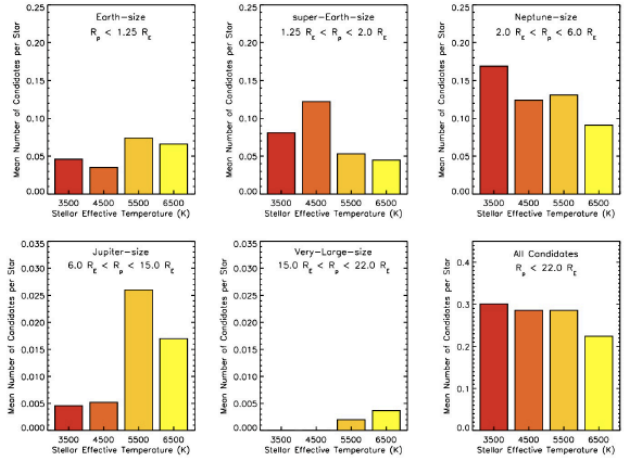
Kepler Status



Many candidate sources in the habitable zone

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

Kepler Status



First scientific estimate of f_p ever! = 34%

Still a lower limit though.

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

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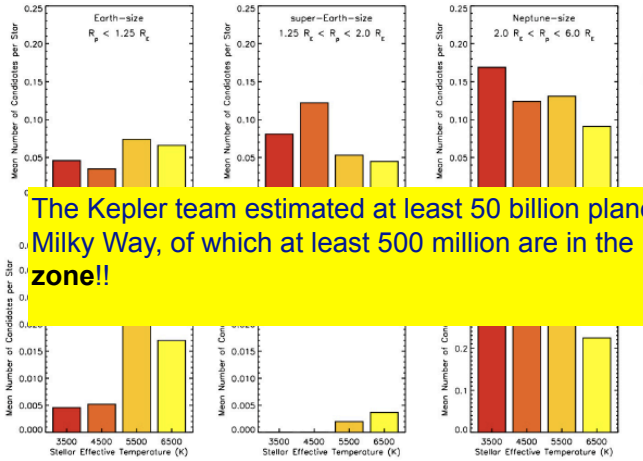

The Kepler team estimated at least 50 billion planets in the Milky Way, of which at least 500 million are in the **habitable zone**!!

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