



Discovering Planets Around Other “Suns”

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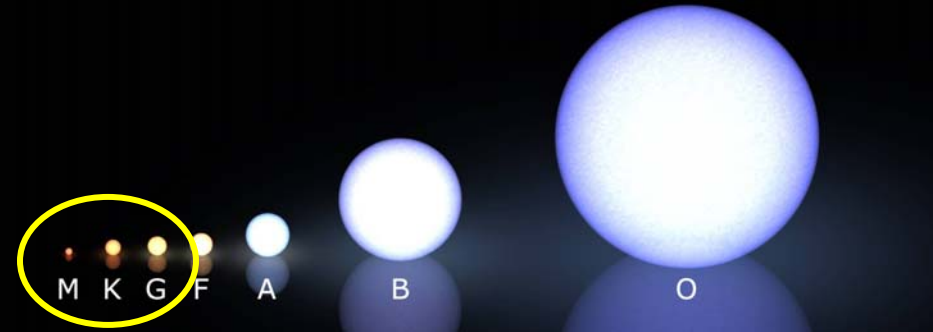
Extra-Solar (EXO) - PLANETS

- ***Planets around other stars***
- ***About 1700 planets now confirmed***
- ***Most orbit near star – very hot***
- ***Others very Jupiter-like***
- ***100 are earth-size (< 1.25 Re)***
- ***Made of: carbon, iron, rock, water, gas***
- ***Why are astronomers interested ?***

Is there life in the Galaxy ?



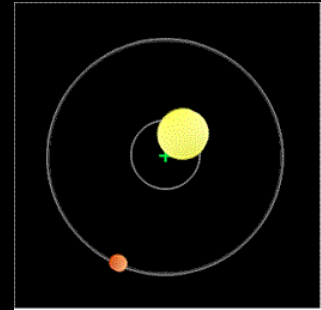
Types of stars



- *Sun is a “G-type” star*
- *70% of stars are “M-dwarfs” @ 0.25 solar mass*
- *So, our solar system is already a minority*
- *On average, every star has a planet*
- *There are 200,000,000,000 stars in Milky Way*

Exoplanet Detection

➤ *Wobble Method - 500*



➤ *Transit Method (Kepler) >2700 candidates*



Kepler Planet Observatory, 2009

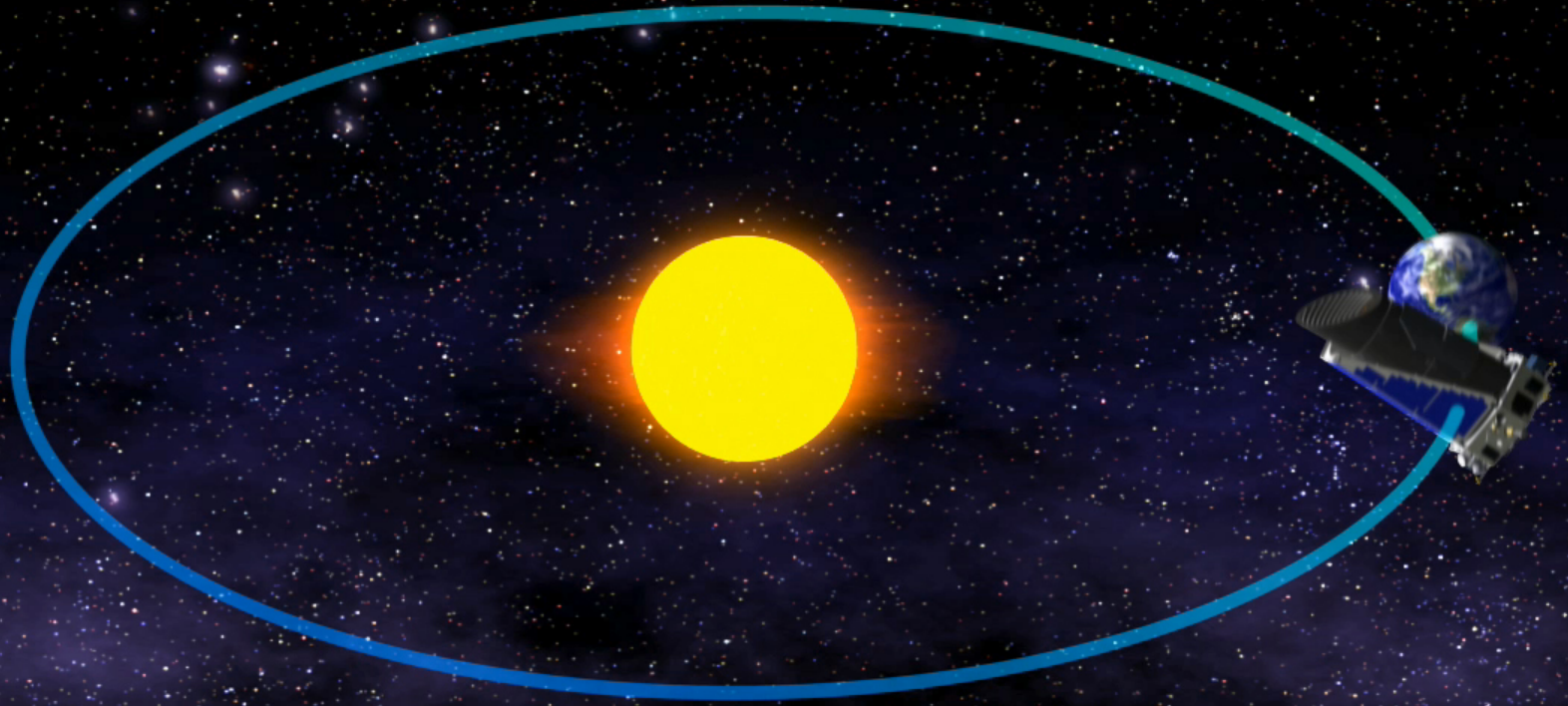
(after Johannes Kepler, ca 1600)

Kepler's Laws of Planetary Motion (later proven by Newton ca 1700)



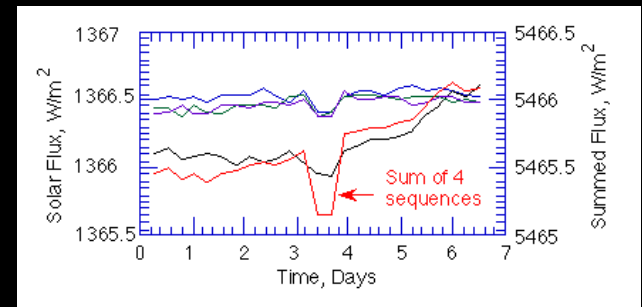
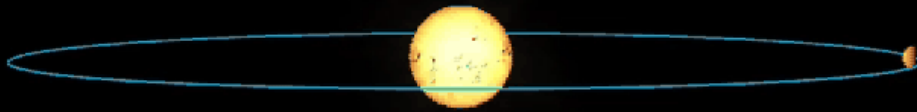
- **Planets move in ellipses with the Sun at one focus.**
- **The radius vector describes equal areas in equal times. (The Second Law)**
- **The squares of the periods are to each other as the cubes of the mean distances.**

Kepler Earth-trailing Solar Orbit

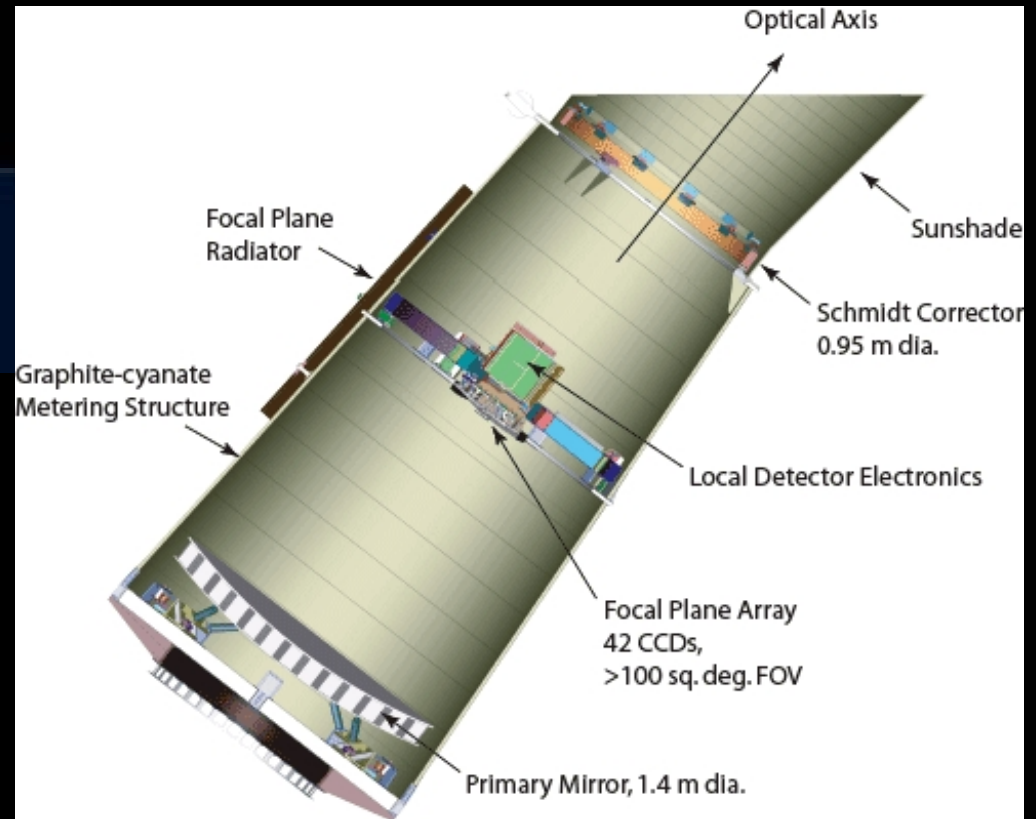
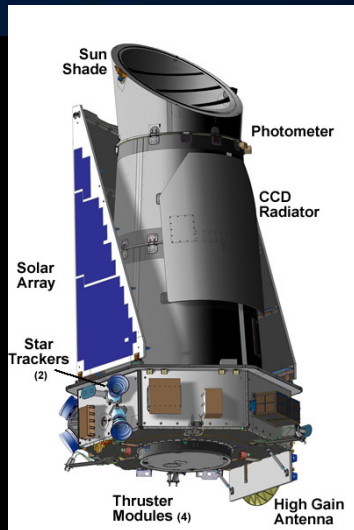


Transits

Kepler relies on multiple transits. They can vary considerably.

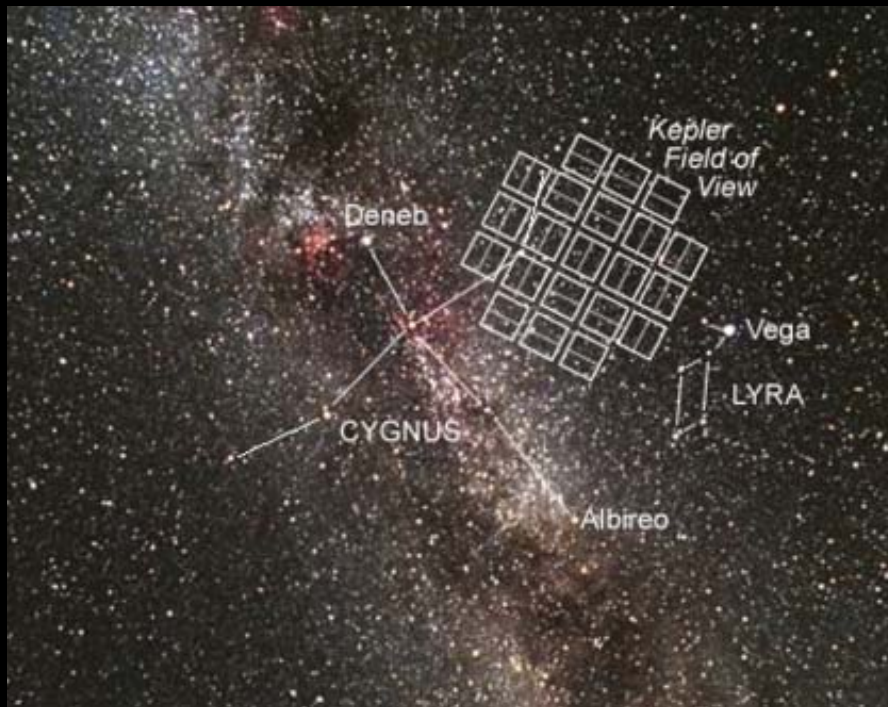


Kepler Planet-Hunter Array (2009)



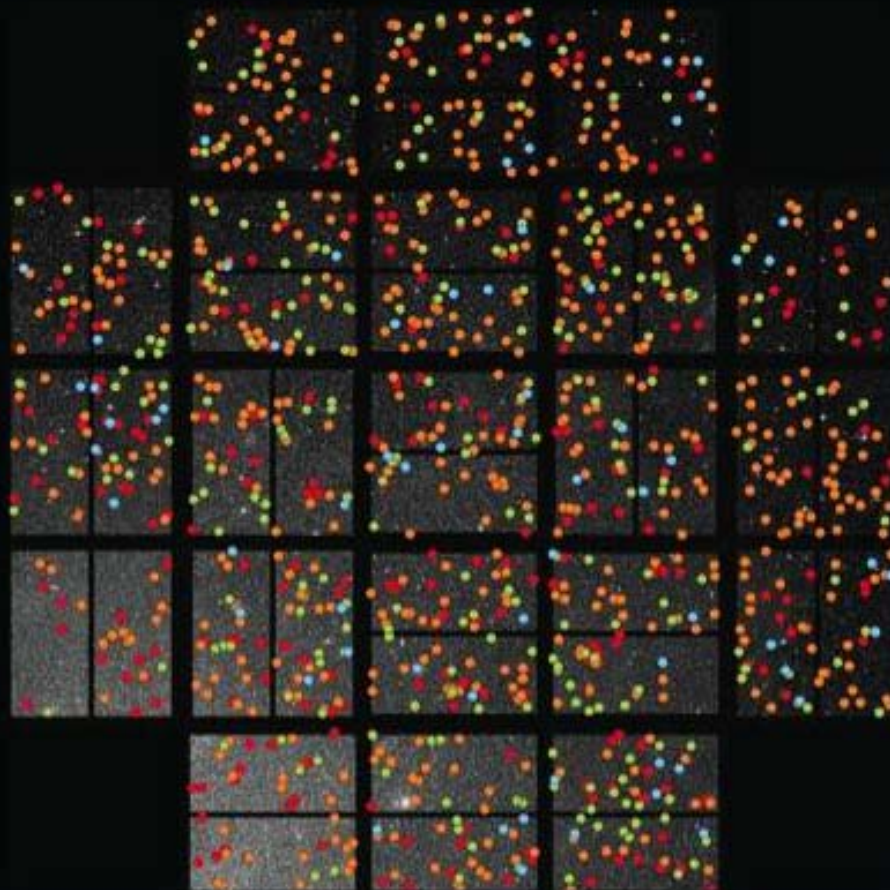
Kepler Field of View

- 12 deg
- 42 CCDs, 50x25mm @ 2200x1024 pix
- Staring at 150,000 stars
- Sensitivity: 0.0001 brightness dip
(earth-sun = 0.0001, Jupiter-sun = 0.01)



Locations of Kepler Planet Candidates

- Earth-size
- Super-Earth size
1.25 - 2.0 Earth-size
- Neptune-size
2.0 - 6.0 Earth-size
- Giant-planet size
6.0 - 22 Earth-size



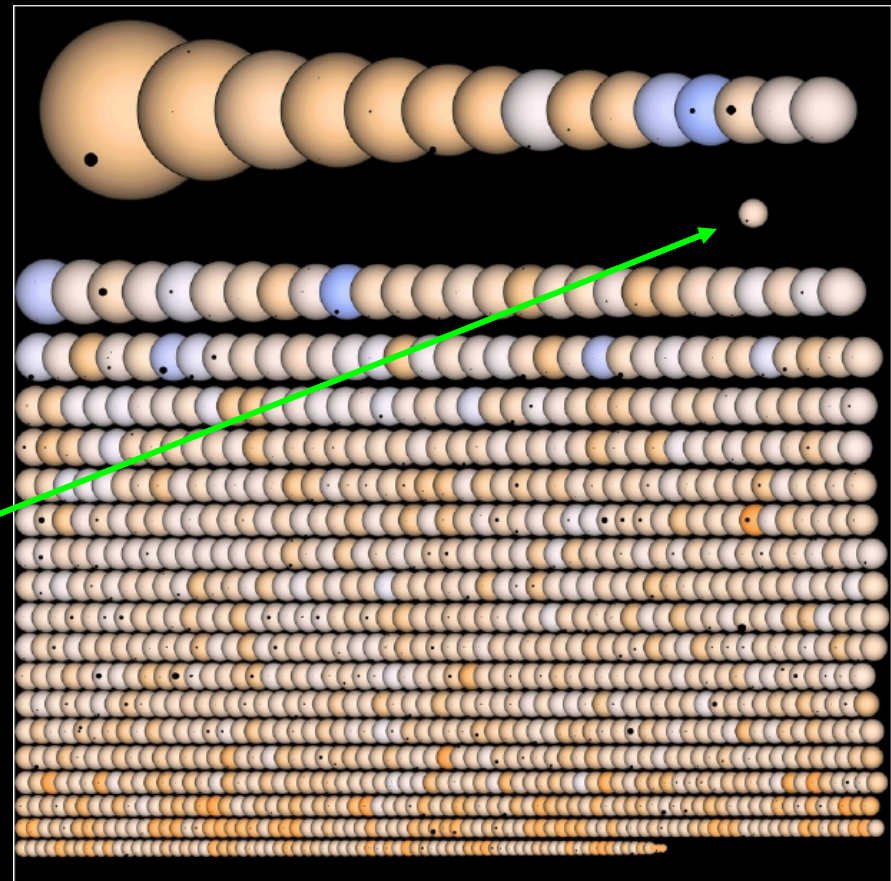
What has Kepler discovered ?

- Over 3500 candidates (Jan2013)
- 153 confirmed & counting (900 total conf).

- **Variety**

- 455 earth-size (1-1.25)
- 1050 super-earths (1.25-2)
- 70 in Goldilocks Zone
- 13 super-earths in Goldilocks zone

Sun & Jupiter



Kepler – Latest Planet Lineup



- ***Single stellar system***
< 20 day orbits
Hot planets close to star

Kepler -22b, 1st Super-earth in Habitable Zone (HZ)

Kepler-22 System

Solar System

Habitable Zone



Kepler-22b

Mercury



Venus

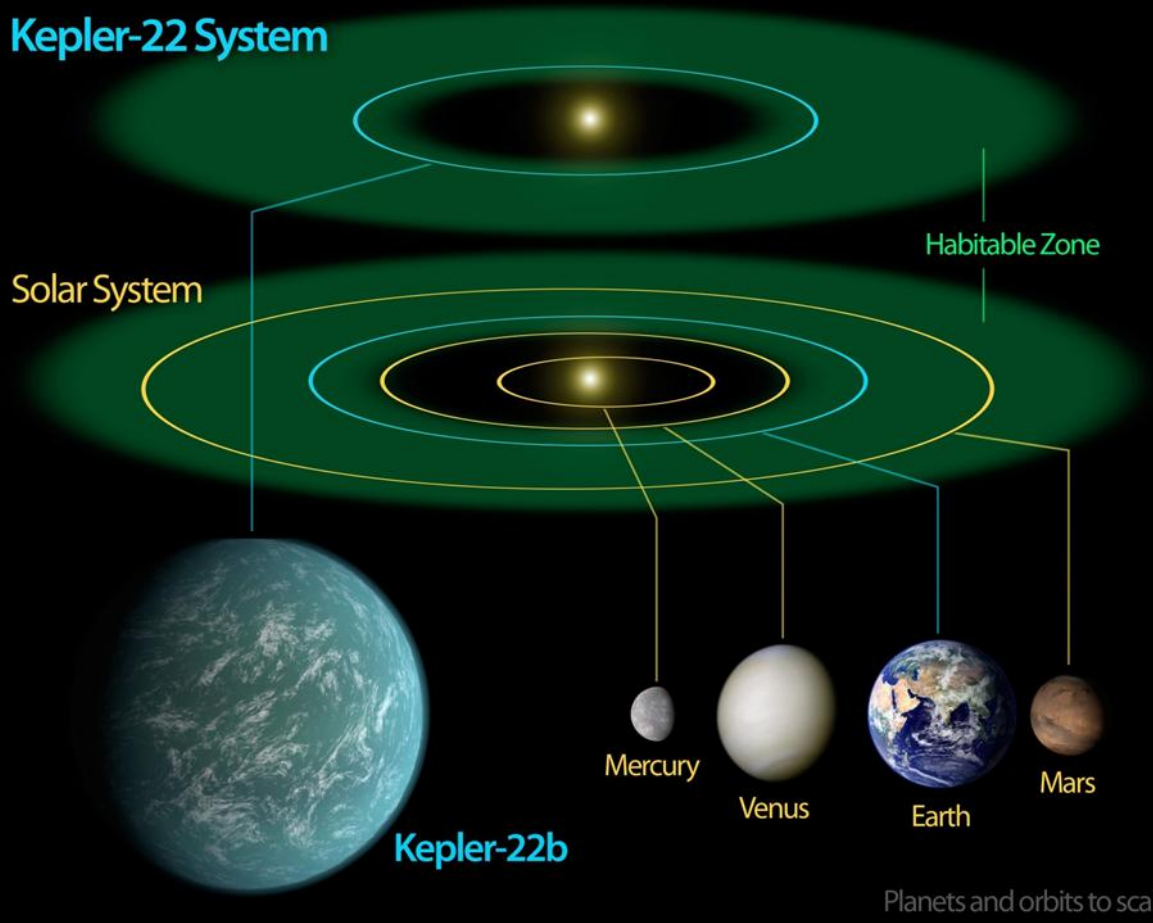


Earth



Mars

Planets and orbits to scale



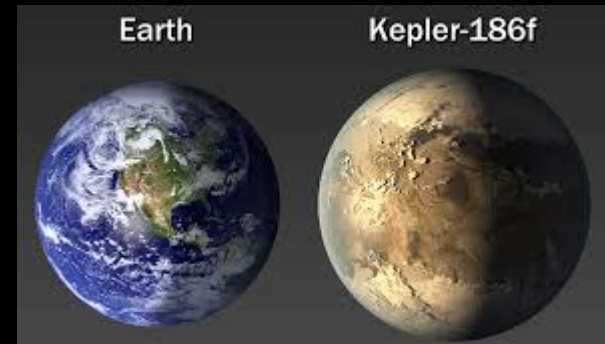
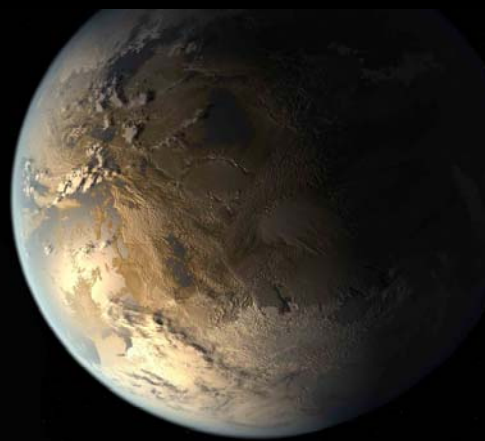
1st Earth-size Planet in HZ

Announced April, 2014

130 day orbit

Very close to earth –size (within 10%)

1/3 solar energy (noon brightness = 1 hr before sunset)



Statistics

- $3/7$ fraction earth/superearth planets
- $A = 1$ planet per star
- $B = 200,000,000,000$ stars
- $C = 3/700$...fraction earth/super-size in GZ
- $D =$...fraction of C that harbors life ???
- $E =$...fraction of D that is intelligent ???

earth planets in GZ = $A \times B \times C = 800,000,000$!!

with intelligent Life = $A \times B \times C \times D \times E = ?$

Kepler -10b

- 1.4 Earth-size***
- Closer than Mercury***
- 3000 F***



This is where your tax \$\$ go !