

# EXOPLANETS

## I. What is an Exoplanet?

### What is a Planet?

International Astronomical Union (IAU) definition: A "planet" is a celestial body that

1. is in orbit around the Sun,
2. has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and
3. has cleared the neighbourhood around its orbit.

Eight planets : Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

### What is an Exoplanet?

IAU has proposed a working definition according to which an exoplanet

1. has a mass below the limiting mass for thermonuclear fusion of deuterium ( $\approx 13$  Jupiter masses for solar metallicity), and
2. has mass above the mass required for a planet in our Solar System, and
3. is in orbit around a star or a stellar remnant

## IV. Early Milestones in Exoplanets Exploration:

### First Published Discovery to Receive Subsequent Confirmation:

**Published:** 1988 **Confirmed:** 2003  
**Scientists:** Campbell, Walker and Yang  
**Telescope:** Canada-France-Hawaii 3.6 m Telescope, Hawaii  
**Discovery:** Planet around Gamma Cephei, a binary star system 45 light years away

### The First Ever Declaration of Detection (False Alarm):

**Year:** 1991 **Retraction:** 1992  
**Scientists:** M. Bailes, Andrew Lyne and S.L. Shemar  
**Telescope:** Lovell Telescope, England  
**Claim:** Discovery of a planet in orbit around the pulsar PSR 1829-10.

### First Definitive Detection (around a pulsar [see III B]):

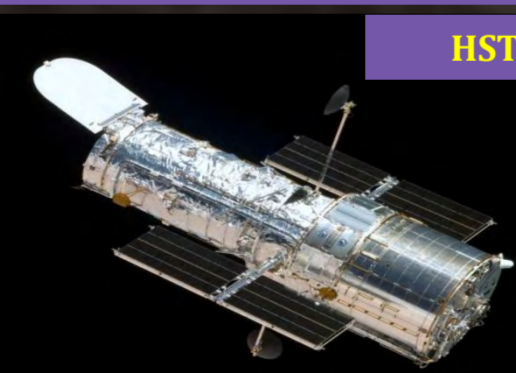
**Year:** 1992 **Confirmation:** 1994  
**Scientists:** Aleksander Wolszczan and Dale Frail  
**Telescope:** Arecibo Observatory, Puerto Rico  
**Discovery:** Two Earth-Mass planets orbiting the pulsar PSRB 1257+12

### First planet to be discovered around a normal (sun-like) star:

**Year:** 1995 **Confirmation:** 1995  
**Scientists:** M. Mayor and D. Queloz  
**Telescope:** Haute-Provence Observatory, France  
**Discovery:** Jupiter-mass planet around the sun-like star 51 Pegasi, in an orbit smaller than that of Mercury

## VI. Some Programs & Telescopes

1. Kepler Space Mission (see section VII)
2. CoRoT Space Mission
3. Hubble Space Telescope (HST)
4. EPICs for Very Large Telescope (VLT), ESO, Chile (1.8m)
5. European Extremely Large Telescope (EELT)(39.2m, 4.2m)
6. **PRL Advanced Radial-velocity All-sky Search (PARAS), Mt. Abu**
7. Gemini Planet Imager for Gemini Space Telescope, Hawaii & Chile(8.1m)
8. Subaru Telescope, Mt. Kea, Hawaii(Japan)(8.2m)
9. Palomar Observatory,
  - i. Hale Telescope(5.1m)
  - ii. 48-inch Samuel Oschin Telescope
  - iii. The 60-inch Telescope



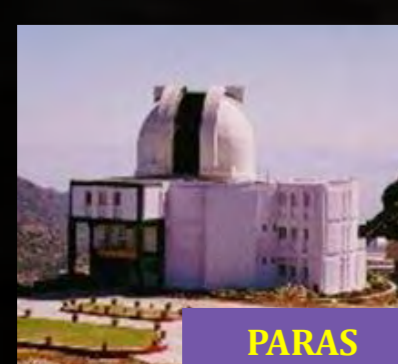
HST



Hale



48" S-O



PARAS



Gemini



Subaru

## II. Finding Exoplanets: Not So Easy

It is difficult to detect the outer planets in our solar system itself! This is because:

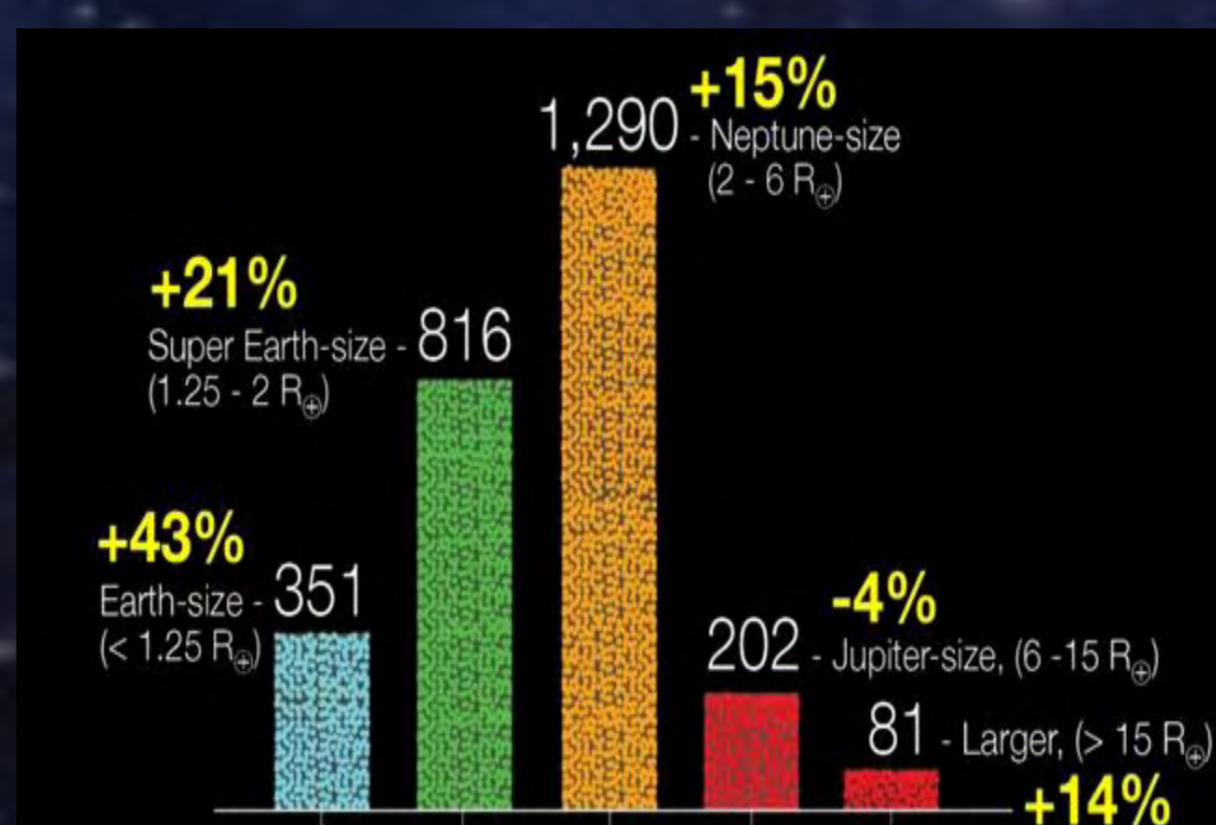
1. The outer planets are very faint due to their distance from the sun.
2. Again, due to their distance from the sun, they move very slowly.

Exoplanets are, of course, even more difficult to detect since

1. They are extremely far away and are very faint compared to stars. Imagine trying to detect a dot as thick as a strand of spider web from a distance of 100 km, just using the light from a 10 W bulb 1 m away from the strand.
2. Since telescopes are never perfect, there will always be some blurring. The blurring of the image of the star, extremely bright compared to the planet, can wash out the image of the planet.

## V. Exoplanets Statistics:

Most Distant: 21500 light years  
 Least Distant: 4.37 light years (around Alpha-Centauri)  
 Least Massive: 0.02  $M_{Earth}$   
 Largest Radius: 22.4  $R_{Earth}$   
 Smallest Radius: 0.57  $R_{Earth}$   
 Longest Year: 876 yrs  
 Shortest Year: 5.7768 hrs  
 Most Eccentric Orbit: 0.9349  
 Least Eccentric Orbit: 0.001  
 Longest Orbit : ~2740 light min  
 Smallest Orbit : ~0.05 light min  
 Least Dense: 80-180  $kg/m^3$   
 Most Dense: 23000  $kg/m^3$



Sizes of Kepler Exoplanet Candidates (see section VII for Kepler Mission)

No of Planetary Systems Detected: 676  
 Total no of confirmed Exoplanets: 859  
 Most No. of Confirmed Exoplanets around one star: 7

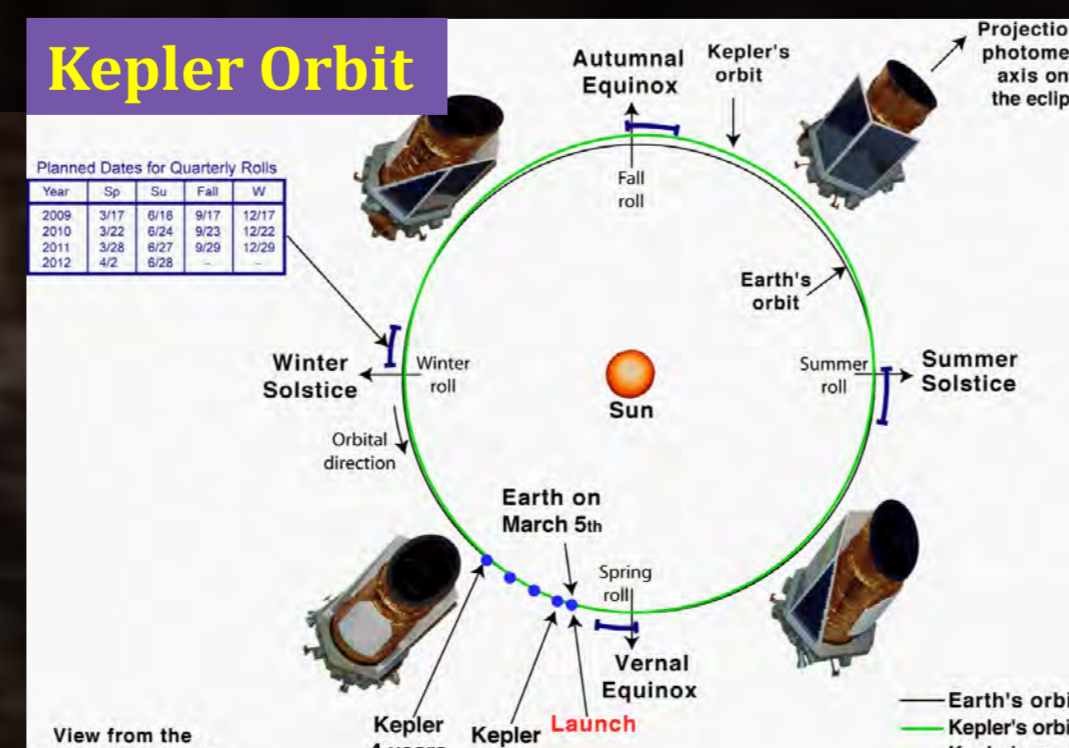
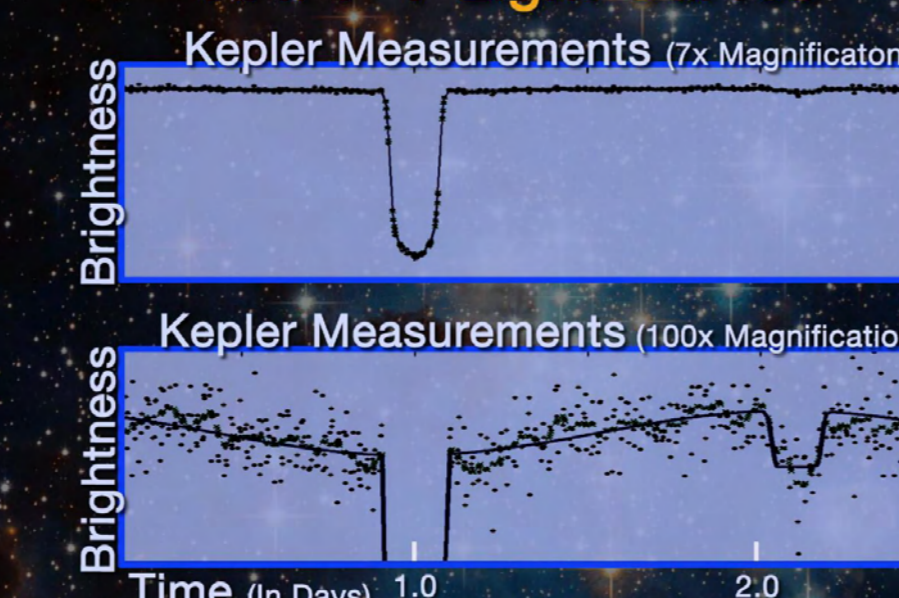
## VII. Kepler Space Mission

- ✓ 10<sup>th</sup> mission in NASA's Discovery Program.
- ✓ Objective: Search for Earth-size habitable exoplanets.
- ✓ Advantage: Avoids atmospheric effects, hence, provides precise measurements (see graph of light curves below).
- ✓ Orbit: Earth-like, around sun with a period of 372 days
- ✓ Launched on March 9, 2009. Duration of the mission is expected to be about 7 to 8 years
- ✓ Surveying our neighbourhood in Milky way
- ✓ As per Jan. 2013, it has found 2740 likely candidates
- ✓ 105 of them have been confirmed by further studies
- ✓ Next space mission: Gaia. To be launched in August 2013



Kepler Telescope

### HAT-P-7 Light Curves



## III. Established Detection Techniques

### A. Radial Velocity

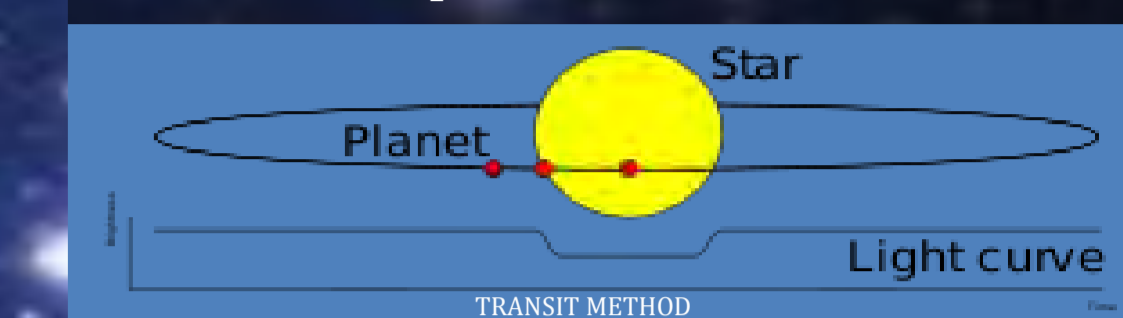
- ✓ A star with a planet moves in its own small orbit due to the planet's gravitational force.
- ✓ This results in variations in the speed with which the star moves toward or away from Earth (i.e. the star's radial velocity).
- ✓ The variations in radial velocity lead to variations in the frequency of light from the star (Doppler effect)
- ✓ The radial-velocity method of exoplanet detection involves measuring these variations in the frequency of light from the star in order to confirm the presence of the planet.

### B. Pulsar Timing

- ✓ A pulsar is a rotating neutron star: a small and highly dense remnant of an exploded star (supernova).
- ✓ Pulsars emit beams of electromagnetic radiation which we detect as extremely regular pulses as they rotate
- ✓ Since the rotation of a pulsar is very regular, slight changes in the timing of its observed pulses can be used to track the pulsar's motion.
- ✓ Thus, variations in the timing of the pulses can reveal the movements of the pulsar due to orbiting planets.

### C. Transit Method

- ✓ Planet crossing (or transiting) in front of its parent star decreases the observed light from the star.
- ✓ The amount the star dims is dependent on the relative sizes of the star and the planet.



### F. Orbital Phase Reflected Light Variation

- ✓ Short period giant planets in close orbits around their stars will undergo reflected light variations.
- ✓ This is because, like our Moon, they also go through phases from full to new and back again.
- ✓ Since telescopes cannot resolve the planet from the star, they see only the combined light.
- ✓ The brightness of the host star will seem to change over each orbit in a periodic manner.
- ✓ With high photometric precision, it is possible to detect a planet in transit across its star.
- ✓ Such Jupiter-sized planets are detectable by space telescopes such as the Kepler space observatory (see section VII).
- ✓ It is expected that in the long run, this method may find the most planets that will be discovered by the Kepler mission.

### D. Gravitational Microlensing

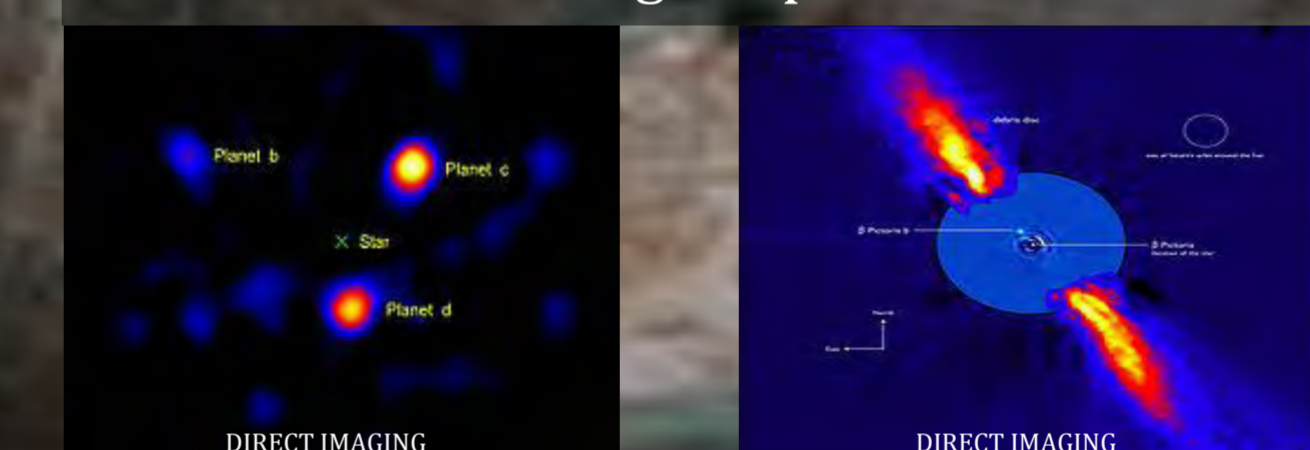
- ✓ Gravitational microlensing takes place when the gravitational field of one star acts like a lens and magnifies the light of a distant background star.
- ✓ Such an effect occurs only when the two stars are almost exactly aligned.
- ✓ If the lens star has a planet orbiting it, the gravitational field of the planet may cause small variations in the observed lensing effect.

### Gravitational Microlensing



### E. Direct Imaging

- ✓ Planets are extremely faint light sources compared to stars and what little light comes from them tends to be lost in the glare from their parent star.
- ✓ It is very difficult to detect them directly. It is easier to obtain images when the planet is especially large (considerably larger than Jupiter), widely separated from its parent star, and hot so that it emits intense infrared radiation.
- ✓ The images have then been made at infrared where the planet is brighter than it is at visible wavelengths.
- ✓ Coronagraphs are used to block light from the star while leaving the planet visible.



## VIII. Habitability: Can Exoplanets Sustain Life ???

NASA's suggested criteria: i) extended regions of liquid water, ii) conditions favourable for the assembly of complex organic molecules and, iii) energy sources to sustain metabolism.

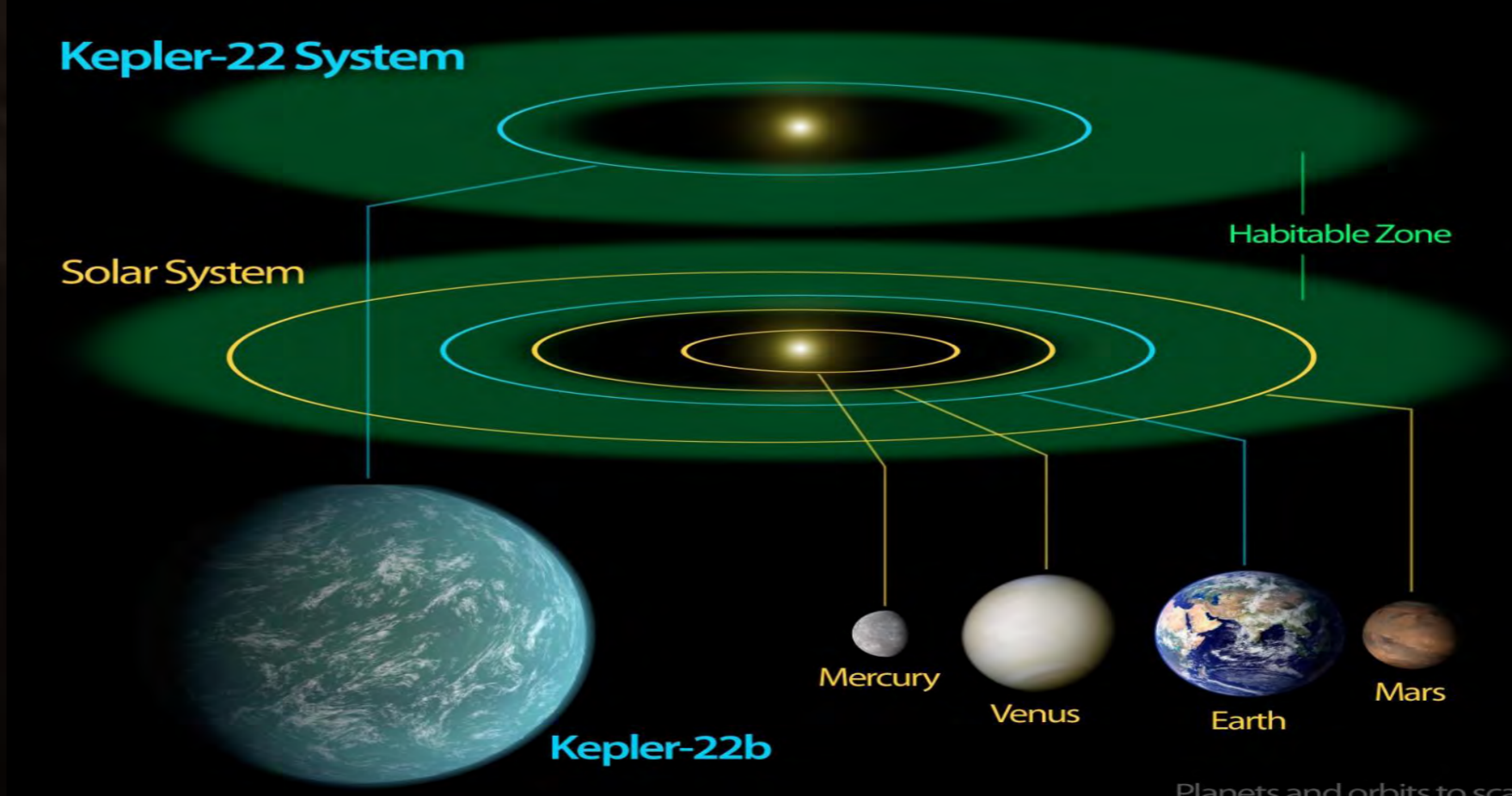
**Habitable Zone (HZ):** The region around a star where the temperature is such that a planet could have water in liquid state on its surface.

### Suitable Stars [HabStars]:

- (We have known 17000 of them from the Hipparcos Mission)
- ✓ Spectral Class: early F, G, Mid K (Sun : G)
- Photospheric Temp: 4000-7000K (Sun: 5777K)
- Life : Few billion years (Life can evolve)
- ✓ Low Variability in temperature and luminosity
- ✓ High Metallicity : High proportion of element other than H and He as it reflects in planets

### Suitable Planets: HabPlanet (Kepler has found 54 exos that may be in HZ)

- ✓ Terrestrial i.e. rocky
- ✓ Mass: Sufficient gravity to retain thick atmosphere and atmospheric pressure (liquid water)
- ✓ Radius: Sufficiently small surface to volume ratio to sustain geological activity and have a magnetic field
- ✓ Geochemistry and Metallicity: Rich in C, H, O, N and other elements thought to be necessary for life
- ✓ Orbit : Small eccentricity (small temperature fluctuations)
- ✓ Rotation: Tilted axis- moderate seasons, low precession
- ✓ Day-night cycle should not be too slow



An earth like satellite of a Jupiter like exoplanet in HZ is also considered as a potential candidate