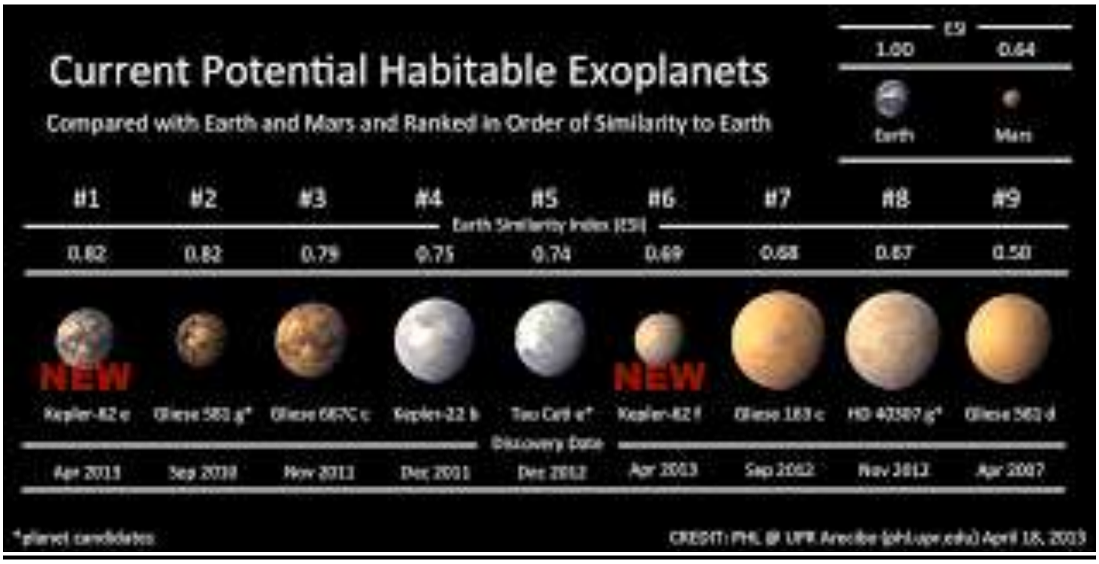
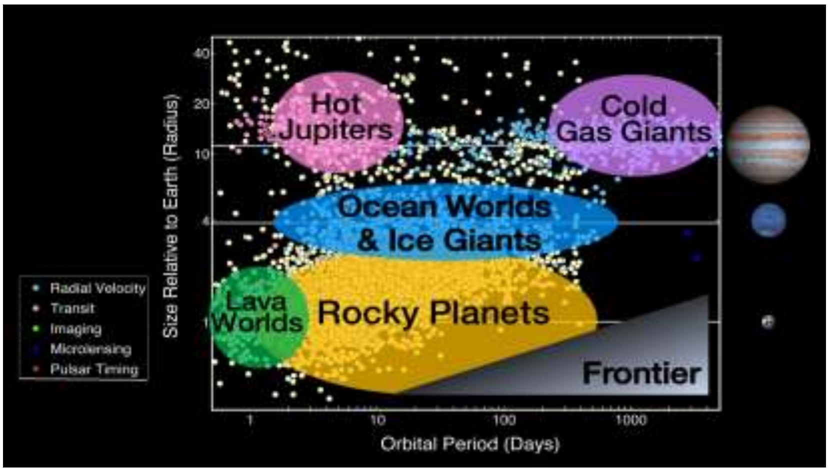
<u>**Exoplanets**</u>



An exoplanet, or an extrasolar planet, is a planet which orbits any star other than our Sun – so one which is not within our Solar System. The observational study of extrosolar planet was first announced in 1995 by Michel Mayor and Didier Queloz with the discovery that planet orbits an 8 billion year old star called 51 Pegasus, 42 light years away with the Milky Way. The suspected planet takes just four days to orbit 51 Pegasus. It has a surface temperature around 1000°C and a mass about 0.5 the mass of Jupiter.

One year later, seven other extrasolar planets were identified. Among them, 47 Ursa Major has a planet with a surface temperature estimated to be around that of Mars (–90 to –20°C), and the 70 Virginis planet has a surface temperature estimated at about 70–160°C. The latter is the first known extrasolar planet whose temperature might allow the presence of liquid water. At present 4,141 exoplanets have been detected and confirmed. These exoplanets and exoplanet systems are of extreme interest as they provide insights into planet formation and evolution, as well as a number of exotic types of planets that are not found in our solar system. They may support life.



Similar to planets in our solar system, exoplanets also have various sizes and compositions. Types of exoplanets are discussed as:

1. **Gas Giants**: All planets with masses exceeding 10 Earth masses are called gas giants. These planets probably have a small rocky core, but they are mainly composed of hydrogen and helium. Gas giants are planets similar to Jupiter, Saturn, Uranus, and Neptune. Roughly 25 percent of all discovered exoplanets are gas giants.

2. **Hot Jupiters**: Hot Jupiters are gas giants that either formed very close to their host star or formed farther out and “migrated” inward. It means if multiple planets are orbiting a star, they will interact with their gravity and exchange their energy. This exchange of energy causes the orbit expands or shrinks. A hot Jupiter is a gas giant that orbits its host star in a very close orbit (0.015 - 0.5 AU), hence it's a high-temperature variant of a gas giant. Such type of exoplanets can only form beyond the frost line (snow line). Beyond the frost line the hydrogen compounds such as water and ammonia have the condensed form, solid pieces that are available for accretion into bigger planets. Hence all hot Jupiters must have formed beyond the snow line and subsequently migrated to a closer orbit. As such, they are extremely hot (with high temperatures as 2400 K), and are the most common type of exoplanet found; about 50 percent of all discovered exoplanets are Hot Jupiters. This is due to the

fact that those exoplanets which are close to their host star and very large are easy to detect and Hot Jupiters have both properties.

3. **Water World (Ocean Planets):** Water worlds are exoplanets that have enough water to completely cover the entire surface of the planet with oceans. These planets actually formed from debris rich in ice further from their host star. As they migrated inward, the water melted and covered the planet in a giant ocean. Ice giants (like Neptune in our solar system) can become as water worlds as they have to migrate from further outside to a closer orbit in the habitable zone. This phenomenon is called planetary migration. The other extreme is a desert planet; a planet without any surface water. Such planets are quite common too.

4. **Rocky Planets:** Rockey planets are those which have solid planetary surface and mainly composed of heavier metals like silicon, oxygen and other metals. All such type of exoplanets is formed without any significant atmosphere. During the planet's formation the light and volatile gases were blown away by the stellar wind of the host star. But due to some activities, like outgassing from volcano activities, delivery of frozen gases and water by comet impacts, a dense atmosphere formed slowly and provided that it’s mass is sufficiently strong to gravitationally bind the atmosphere. A strong magnetic field also helps to preserve the atmosphere since it protects the planet from stellar winds.

5. **Super-Earths:** Super-Earths are potentially rocky planets that have a mass greater than the Earth. Super-Earths are planets of between 1 and about 10 Earth masses. Super earth means larger than our Earth. They might be more suitable for life than our Earth. Super earths with the composition of hydrogen and helium are of low densities and those with water and silicon are of high densities. Super-Earths of up to 1.5 Earth radii are likely to be ocean planets or rocky planets with a thin atmosphere.

6. **Exo-Earths:** Exo-Earths are planets just like the Earth. They have a similar mass, radius, and temperature to the Earth, orbiting within the "habitable zone" of their host stars. Only a very small number of Exo-Earth candidates have been discovered as they are the hardest type of planet to discover.

7. **Chthonian Planets:** Chthonian Planets are planets that used to be gas giants but migrated so close to their host star that their atmosphere was stripped away leaving only a rocky core. Due to their similarities, some Super Earths may actually be Chthonian Planets.

8. **Rough Planets:** Rogue planets (or nomad planets or orphan planets) are planets without a central star. They are free floating throughout our galaxy. Since there is no star around them, they are dark and very difficult to detect. At least 200 to 400 billion rogue planets are now floating through the Milky Way. Rogue planets can be in all sizes from small rocky planets to huge gas giants, but since they are very difficult to detect so all the rogue planets discovered up to now (such as, CFBDSIR 2149-0403) have been huge gas giants. They can be directly imaged especially in infrared or they can be detected via micro-lensing.

Methods of detection of Exoplanets

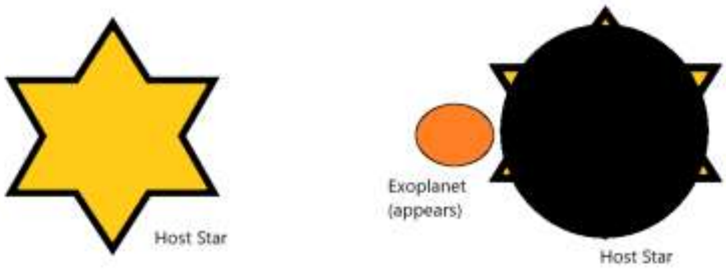
Detection of exoplanets is a very difficult task because they are far away from our solar system. Stars are vastly brighter and more massive than planets, and most stars are far enough away that the planets are lost in the glare. There are five methods of detection of exoplanets.

Nowadays six investigative tools are used to spot hidden exoplanets.

- Direct detection
  - Imaging
- Indirect detection
  - Radial velocity

- Astrometry
- Pulsar timing
- Transit Method
- Gravitational Microlensing

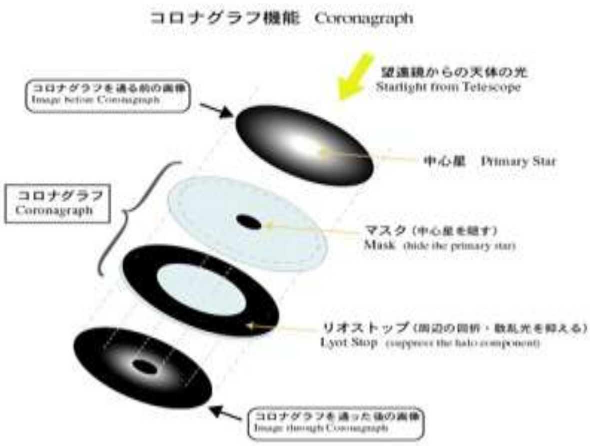
1. Imaging

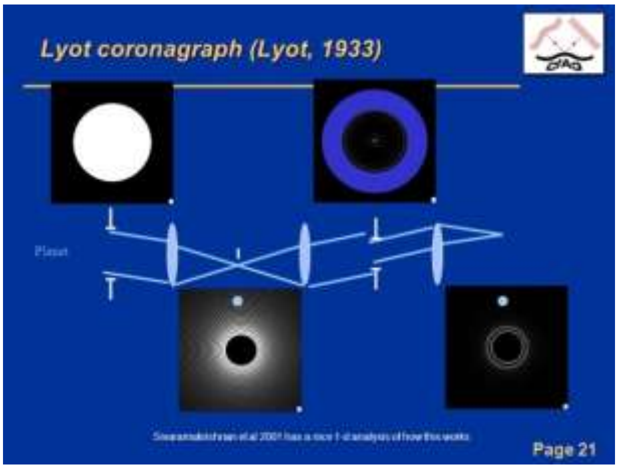


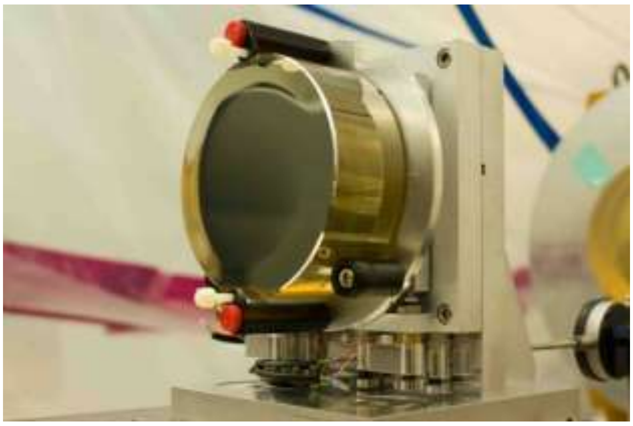
This is the toughest way to detect an exoplanet. This is because the host star has very high brightness in comparison to its companion planet. The planet can only be exposed by dimming the starlight so as that it can be observed in the shadow of the star.

There are two methods to decrease the starlight:

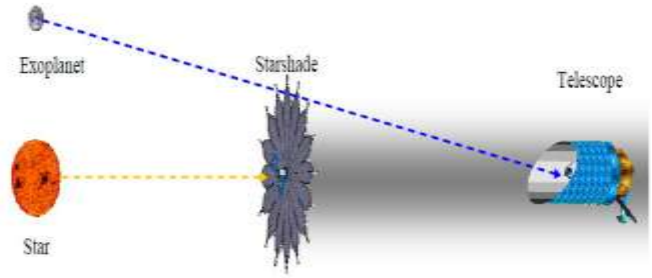
I. **Coronography:** In this method a device is used in the telescope to block the starlight before it reaches to the telescope’s detector. A coronograph that masks the bright central core of the star, leaving only the corona, the outer plasma region of the star’s atmosphere, visible and so allowing any nearby planets to shine through.

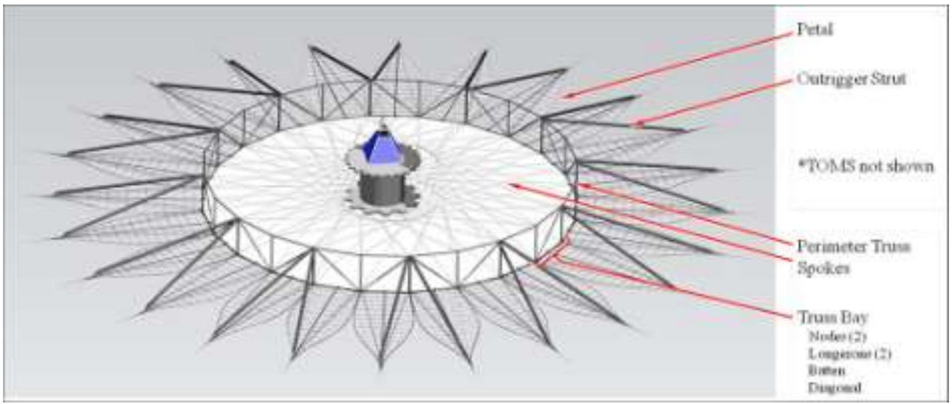






II. **Satrshade:** The starshade (also known as an external occulter) is a spacecraft that will enable telescopes in space to take pictures of planets orbiting faraway stars. The starshade is designed to fly in front of a telescope and block the immense glare from a star's light before it enters the telescope, allowing the planet's reflected light to pass through and be collected. To successfully achieve starlight blocking, the starshade must unfurl and expand in space to almost the size of a baseball diamond (34 m diameter). The starshade's razor-sharp petals redirect the effects of diffraction—the bending of starlight around the petal edges producing unwanted glare—and create a dark shadow for the trailing telescope to fly in.





Advantages:

- From the track of the planet over an orbital period, an accurate measurement of planet mass and orbital radius and shape can be made.
- In principle, this would permit the spectrum of the planet to be measured separately from the star, and thus its atmosphere to be unambiguously studied.

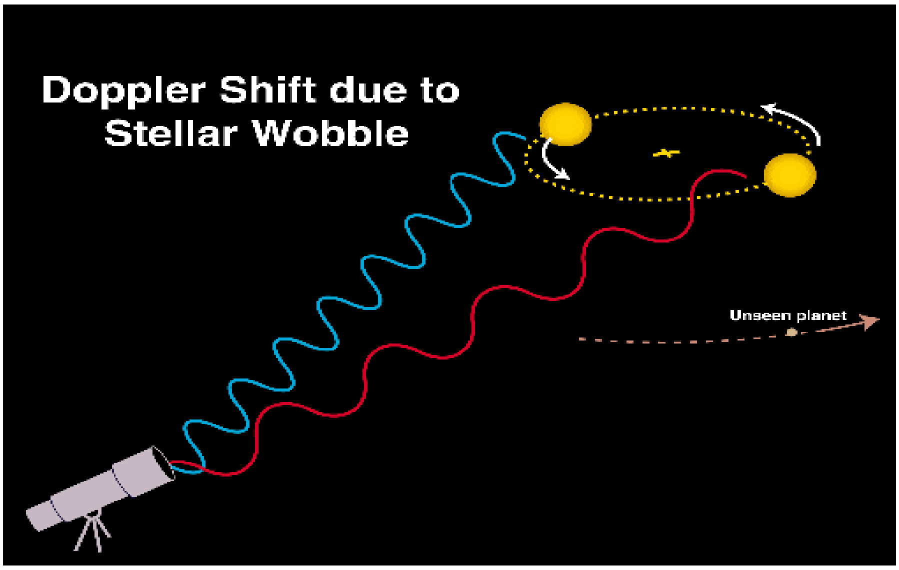
Disadvantages:

- Less number of exoplanets is detectable trough the existing telescopes.
- Larger and efficient telescopes which are useful for this method are very costly.

2. **Radial Velocity Method:**

The radial velocity or "stellar wobble" method involves measuring the Doppler shift of the light from a particular star and seeing if it oscillates periodically between a red and blue shift. Both the star and the planet orbit around their common centre of mass and have their own gravitational force. Due to this gravitational force both experience a gravitational interaction. As it is well known that star will be massive and big so it contains high gravitational field whereas planet is small in size and has less gravity. But still it effects the gravitational field of star even if this effect is very less pronounced as star has on planet. It is the condition like tug of war. The gravity of planet causes the star to wobble a little bit. This wobbling of the star tells us about the presence of the planet, the number of the planets and their size.

The wobbling of the star can be observed by the Doppler shift. When the planet moves towards the observational point (or telescope) then the visible light from planet bunches up and looks more in blue (blueshift). Whereas when the planet moves away from the observational point (or telescope) then the visible light observed from planet stretched out and look more in red (redshift). Observation of this periodic change of colour in the spectrum signifies the presence of a planet around the star.



Advantages:

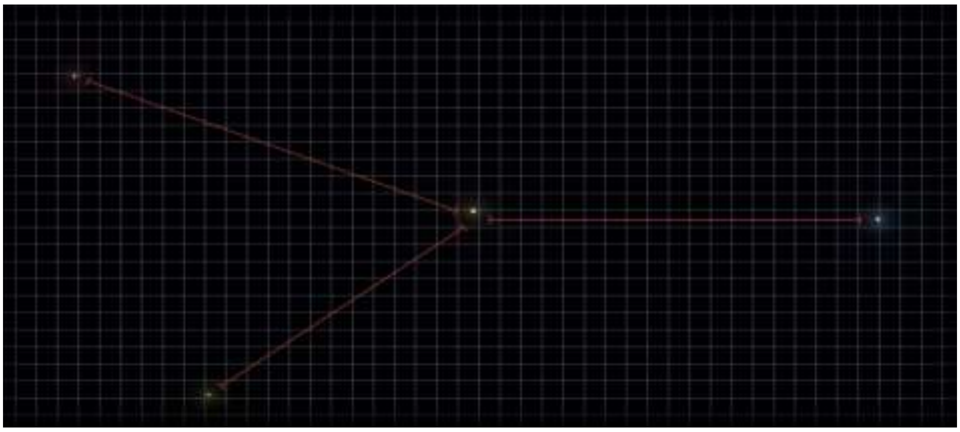
- From Doppler velocity observed over an orbital period, get planet mass and orbit shape and radius
- No need for high image contrast or resolved images
- Can detect many thousands with existing instruments and telescopes

Disadvantages:

- Since it does not involve detecting light from the planet, we cannot learn about the planet's surface, atmosphere, density, etc. from RV
- This method is good for cool stars like sun because hot stars do not have narrow spectrum.
- As the orbital inclination is not known hence the mass of the planet can't be detected directly. (Deviation~M_p)

3. **Astrometry:**

The astrometry method is similar to radial velocity tracking and is used to detect exoplanets by measuring the small regular perturbation in the position of a star due to its unseen companion. The star moves in a tiny circular orbit on the sky with a radius that depends on the mass of the planet and its distance from the star. This wobbling of the star can also be study as changes in star's apparent position in the sky. Astrometry is also a difficult way to detect an exoplanet because the star wobbles very minute distance and it's very tough to detect the wobble from planet, especially from small planets. So the movement of these stars can be track by taking a series of images of a star and some nearby stars. In these images the comparison of the distances between these reference stars and the wobbling star has been observed. If the target star has moved with respect to other stars then by analysing that movement the presence of exoplanet signifies. This method requires precise optics because our atmosphere distorts and bends light.



Advantages:

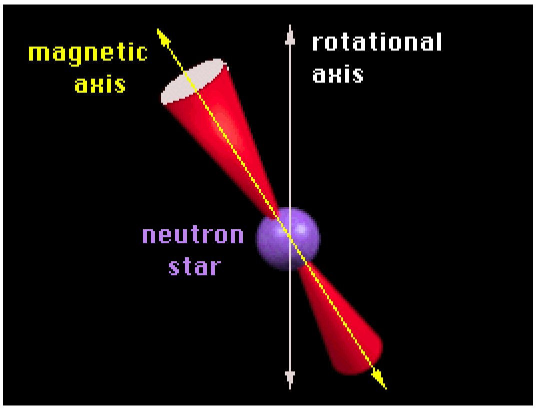
- This method does not depend on the distant planet being in near perfect alignment with the line of site from Earth, and it can therefore be applied to a far greater number of stars.
- It provides an accurate estimate of a planet's mass.
- Astrometry can actually detect relatively small planets orbiting far from their stars.

Disadvantages:

- It is very hard to detect an exoplanet through this method.
- This method will far less effective when applied to more distant objects.
- The astrometric measurements could be so sensitive that they might be affected by star spots-illusion that the star is wobbling.

4. **Pulsar Timing:**

The presence of a planet orbiting a star affects the timing of the regular signals emitted by the star itself. This phenomenon can be used to detect planets around a pulsar. Pulsars emit radio waves regularly as they rotate, creating a periodically pulsed beam, like a lighthouse. If an orbiting planet perturbs the motion of the star, then the timing of the beam is also affected, and this is how the first exoplanets were detected. The orbit as well as the mass of these planets can be observed by precisely measuring irregularities in the timing of the pulsars.



Advantages:

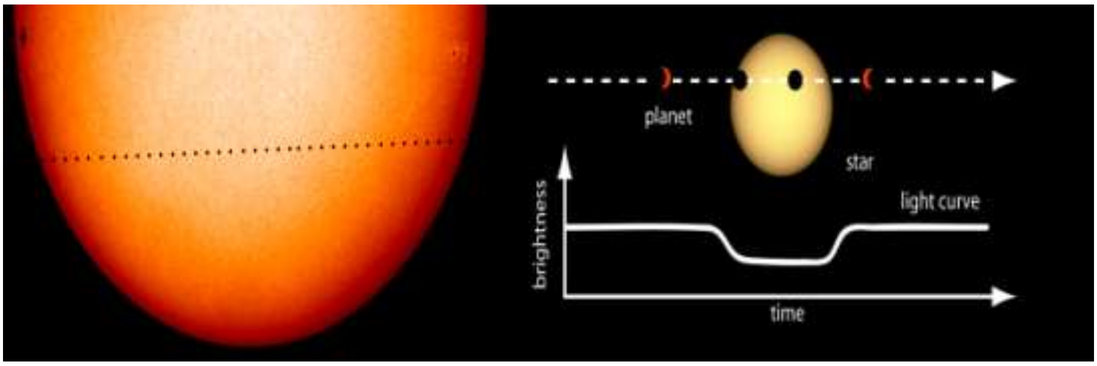
- This method is effective for planets having large orbits.
- It is virtually unaffected from stellar variability and activity effects.
- This method is very sensitive, cheap and detects small & low mass planets.

Disadvantages:

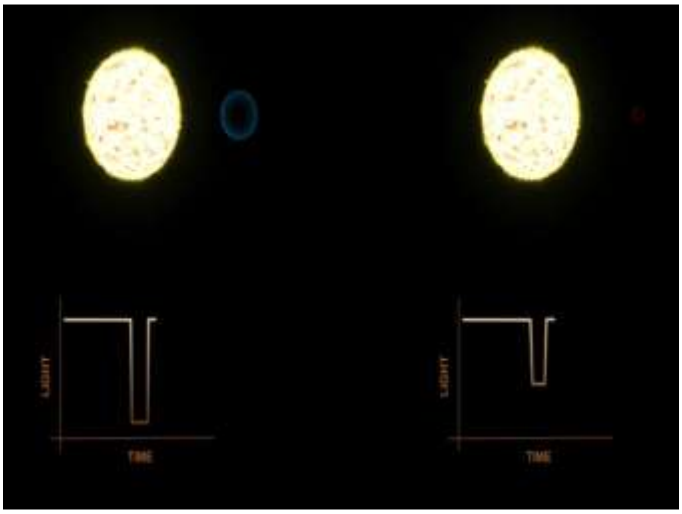
- It works only on pulsars which are very rare and weird.
- In a multiple system with planets of different sizes the astrometric signal would be dominated by the reflex motion induced by giant planets
- In any case, the signal expected for terrestrial-type planets is typically below the theoretical limits of positional error.

5. **Transit Method:**

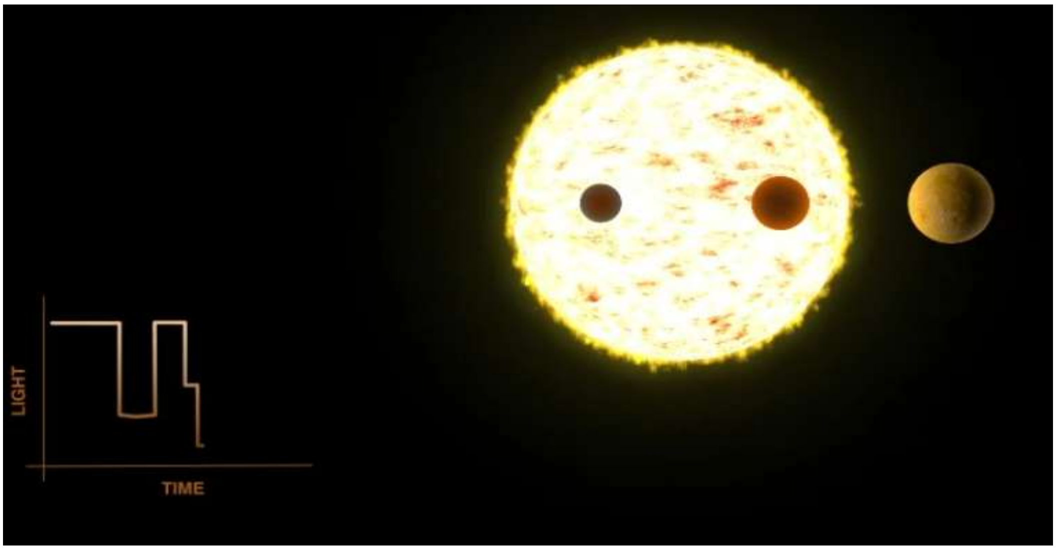
   When a planet passes directly between star and observer, it dims star's light by measurable amount. The transit method measures the drop in brightness when a planet transits in front of the star (as seen from Earth). With this method we can only find a minor fraction of the existing exoplanets and its star have to be perfectly aligned in order to observe an exoplanet's transit. In a graphical representation a dip will be observed when planet passes to the star. If there are multiple planets then multiple dips according to their size and passing time will be observed. The small size planet will produce tiny dip and a large planet will give a long dip.



Single planet orbits around the star and a dip in the starlight is found when planet transit to star.



Two planets of different sizes are orbiting around the star. Large planet shows large dip and small planet shows small dip in the starlight during transit of planet to its star.



Multiple planets with different sizes are orbiting around the star.

Advantages:

- The dip in star's luminosity during transit is directly proportionate to the size of planet.
- Planet's mass can also be observed by including the radial velocity data with transit data.
- The atmosphere and temperature of the planet can be studied through this method.

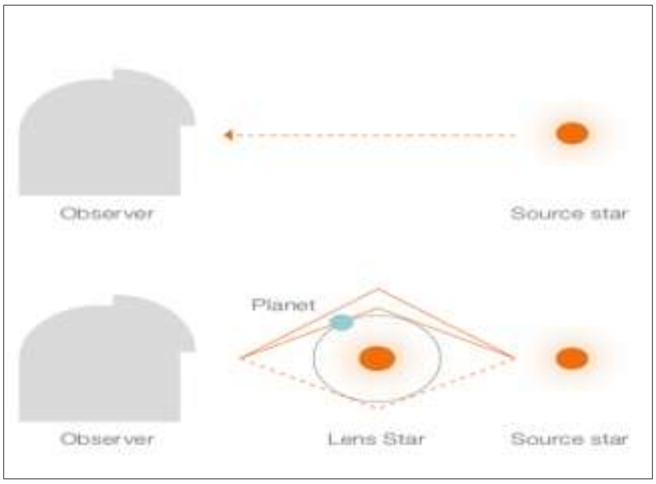
Disadvantages:

- The planet must pass directly between it's star and Earth.
- Binary Star and Planet are difficult to separate by this method.
- Transit time is very small in comparison to its orbiting time so to establish the presence of the planet it is required to take repeated transits occurring at regular intervals.

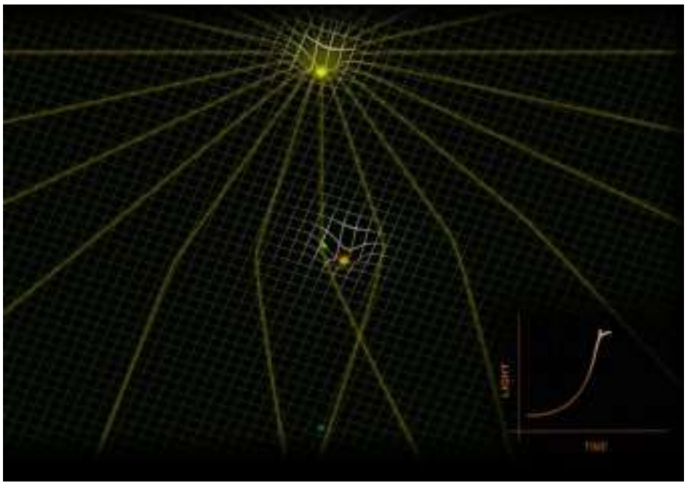
6. **Gravitational Microlensing:**

The gravitational pull of a large object will bend the light from distant objects and amplify it, acting like a magnifying lens. Light from a distant star is bent and focused by gravity as a planet passes between the star and earth i.e. when light from the background object travels towards Earth, its path is bent or warped as it bypasses any large foreground object that is aligned with the background light source. As the microlensing effect works on radiation from the background source, this technique can be used to study intervening objects that emit little or no light, such as black holes, or planets around distant stars. It happens when a star or planet's gravity focuses the light of another more distant star, in a way that makes it temporarily seem brighter. The rays of light from the more distant star bend around the exoplanet and then the exoplanet's star. A lensing event looks like a distant star that gets gradually brighter over the space for some time and then fades away. If a planet exists and lensed, it gives a blip of light during the brightening and dimming process.

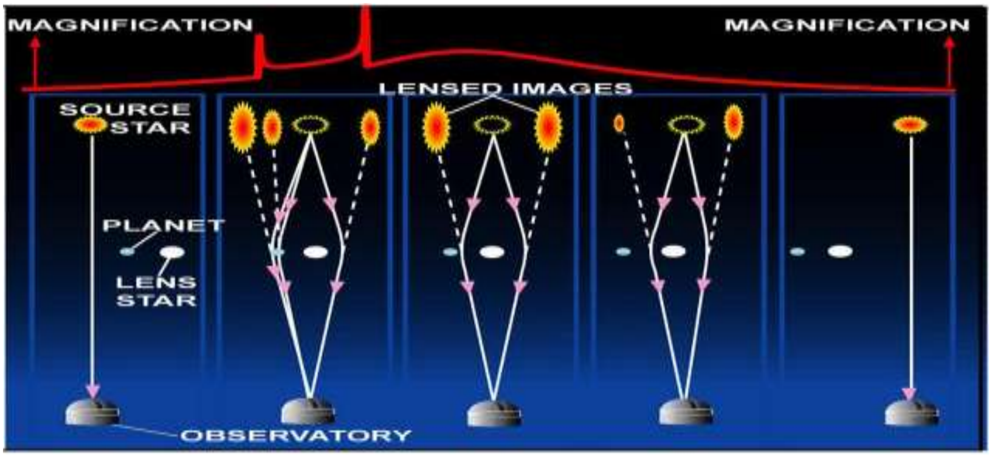
Suppose that the aligned foreground mass to be studied is a star that is hosting a planet and then the amplified light curve from the background source will contain an additional side peak. The size and shape of the secondary peak will depend on the mass and distance of the planet from the host star (see the image). The exoplanet OGLE 2003-BLG-235/MOA 2003-BLG-53 was the first planet discovered using this technique, in 2003. The disadvantage of the microlensing technique is that the effect happens only once, as it relies on a unique chance alignment of the foreground and background stars, and so measurements must be checked using other methods.



Bending of light due to presence of exoplanet and observed by gravitational microlensing



Blip in the brightness curve due to presence of another planet.



Advantages:

- This method is effective for the planets small in size and at very great distance (thousands of light years) from the earth.
- This method is also used for the plants which are at large distance from their host star.
- Like transit method, it also detects number of planets simultaneously.

Disadvantages:

- Unlike planets detected by other methods, which are associated with particular stars and can be observed repeatedly, planets observed by microlensing will never be observed again. This is because microlensing events are unique and do not repeat themselves.
- The planet detected by microlensing at the distance of thousands of light years is only by a rough approximation. So there are lots of possibilities of errors in the detection of planets at very far distance.
- Microlensing is dependent on rare and random event, i.e. the passage of one star precisely in front of another, as seen from Earth.

Reference Books:

1. **Complete Course in Astrobiology by Gerda Horneck and Petra Rettberg** file:///C:/Users/sony/Downloads/ebooksclub.org__Complete_Course_in_Astrobiology__Physics_Textbook_.pdf
2. **Astrochemistry from Astronomy to Astrobiology by Andrew M. Shaw** file:///C:/Users/sony/Downloads/_Astrochemistry-From-Astronomy%20to%20Astrobiology%20by%20Shaw.pdf
3. **Website:** www.nasa.gov.in