**Modern Methods of Exoplanet Detection**

1. **Motivation**

Ever sinceWolszczan and Frai made the first definitive discovery of exoplanets in 1992, astronomers have been looking for ways to make other such discoveries. The primary reason being our solar system is just one of many such planetary systems that exist in the universe and analyzing these exoplanets in turn helps in understanding our solar system and its planets better. It enhances our understanding of the various trends in planet formation around different stars and make comparisons to our solar system in order to determine if the existence of a planet like Earth was just a fluke or are there other worlds where similar conditions can be achieved for life to prosper.

Over the years, the exoplanet detection methods have progressed leaps and bounds and today we have over 4000 confirmed detected exoplanets [NASA, 2022], all of which have enhanced our knowledge about the Universe as a whole. However, not all of these methods work all the time and sometimes require very specific conditions for orientation of planet’s orbit, planet’s distance from the star or even the thermal emission of the planet. Which is why it is important to understand the caveats associated with these detection methods to minimize selection bias.

1. **Methods**

In this report the physics behind the three main methods of exoplanet detection: (1) Radial Velocity, (2) Transits and (3) Direct Imaging are discussed in detail along with estimates about the limits of today’s cutting-edge technology and if it was our solar system being observed, would Jupiter be detected as an exoplanet around the Sun.

* 1. **Radial Velocity**

This technique involves finding the relation between the radial velocity of an object in orbit and its mass assuming 2-body Keplerian motion (Seager). The equations below explain said relation:

--- (1)

--- (2)

Here *P* refers to the planet’s period of revolution around the star, *a* is the semi-major axis of the orbit, *G* is the universal gravitation constant, *M\** is the mass of the star, *Mp* is the mass of the orbiting planet, *vp* the orbital speed of the planet and *i* is the angle of inclination of the orbit from our plane of view. Equation (1) is Kepler’s third law and can be used to derive Equation (2) which gives the value if the planet’s redial velocity signal, also called the RV semi-amplitude (*K*) (Seager). Usually, the angle of inclination is unknown and therefore a measurement of: *Mp sin (i)* is made and an estimate of the ‘minimum planet mass’ is made. The state-of-the-art detection is currently the most suitable for detecting planets around unevolved-G, late-K and M stars due to the smaller noise signal and low mass of these stars amplifying the RV signals of the orbiting planets. Insert detection limit value

* 1. **Transits**

This method of observation relies on the principle of eclipses that Dr. Joshua Winn defines as “the obscuration of one celestial body by another” (Seager). The most important requirement to effectively use this technique is that the inclination of the planet’s orbit around the star needs to be ‘near edge-on’. Below are some important equations needed to make calculations using this technique:

--- (3)

--- (4) --- (5)

In equation (3), *PTransit* represents the probability of a transit being detected, *Rp­*, *R\** and *a* once again represent the radii of the planet and star respectively and the semi-major axis of the orbit. The ratio of the cross-sectional areas of the planet and star are given in equation (4) with *f* being called the depth of transit. This depth of transit is the important quantity that must be significant enough for the state-of-the-art detectors to measure. It heavily favors large planets (comparable to Jupiter) with short revolution periods (of the order of a few days). Insert detection limit

* 1. **Direct Imaging**

This detection method involves directly observing the planet around a star by artificially suppressing the light from the central star using techniques such as a rectangular mask coronagraph or angular differential imaging. Direct Imaging heavily favors young, hot, self-luminous planets as their high temperature gives them a strong detectable flux and ‘Their large distances from their planet stars makes them easier to see in the halo of atmospherically or instrumentally scattered star light’ (Seager). Below are the important equations for this technique:

--- (6)

--- (7)

--- (8)

Here, *fR* is the starlight reflected by the planet and is directly related to the albedo (*A*). Equation (7) shows the Planck function which is a measure of the thermal emission of a body and depends on the Planck’s constant (*h*), speed of light (*c*), frequency (*v*), Boltzmann constant (*kB*) and temperature (*T*). Assuming that both the star and the planet emit thermal emission, equation (8) shows the Star-Planet contrast and its relation to *Tp* and *T\** which are the temperatures of the planet and the star respectively. Insert detection limit

1. **Results**

For the purposes of this project, the special case of a Jupiter-like planet around a sun-like star was chosen to better understand the limitations and capabilities of the state-of-the-art detection equipment for the three methods discussed in the previous section.

1. **Conclusion**

**References:**

**https://exoplanets.nasa.gov/faq/6/how-many-exoplanets-are-there/**