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Research on the Methods of Exoplanet Detection and Discussion on Correlations and Flaws

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Abstract. The search for exoplanets, particularly Earth-like planets, has garnered significant attention as potential second homes for human beings. Highlights of the urgency of finding alternative habitable planets due to the dire consequences of global warming and climate change on Earth. This underscores the importance of exoplanet research and the potential it holds for humanity's future. This paper delves into the two fundamental methods used in the discovery of exoplanets include the transit method and the radial velocity method, accompanied by illustrative calculations. It further endeavors to establish a correlation between the observational data obtained through the transit method and the conditions that Earth-like planets might possess. Additionally, the paper acknowledges certain limitations and shortcomings that could compromise the accuracy of these two methods. Ultimately, the paper concludes that Earth-like planets, characterized by similar temperatures and compositions, tend to adhere to specific relationships in terms of their radii and masses. Overall, this paper contributes to the ongoing effort to find suitable habitable planets beyond the solar system, addressing both the methodologies and challenges associated with this exciting field of research.

Keywords: Transit method, exoplanet, planet composition, planetary properties, radial velocity.

1. Introduction

The planet's delicate balance hangs perilously in the balance, threatened by the relentless forces of global warming, the melting of glaciers, the relentless rise of sea levels, the devastating impacts of deforestation, and the pervasive presence of plastic waste. The quest for extrasolar planets has risen to the forefront of scientific discourse, becoming a beacon of hope for humanity's future.

The advent of the Kepler telescope has opened up more possibilities for the search for exoplanets. In the past decade, thousands of exoplanets far away from the solar system were discovered by Kepler telescope, to a sum of 2773 confirmed [1]. Some of the exoplanets detected by the Kepler telescope have been proven to have possibilities of living on due to the existence of rocky surfaces (k2-22b) [2]. The k2-18b planet is also widely studied and was proven to have water vapour, clouds, and carbon dioxide [3]. Such findings are exciting and important in both giving people roads for further study and increasing expectations for successfully finding an Earth-like planet.

By the Kepler telescope and methods such as transit and atmospheric transmission spectrum, scientists have been able to study the orbit and the atmosphere components of the planet and by the calculation of radial velocity, the mass density can be figured out to get a more detailed components information of the plane. For example, the k2-18b planet has an orbital period of 32.940045±0.000010 days, radius of 2.610±0.087 (R⊕), orbital radius of 0.15910+0.00046-0.00047Au and mass of 8.63±1.35 (M⊕). However, with all the k2 planets' data shown, rarely do people try to find out the relation between some of its data such as the orbital radius and mass density, which indeed have some relation between the two of that. By finding out the relation between many of the data, it will make it easier for astronomers to work on planets with a greater possibility of having lives. Relations may also be able to give further inductions on exoplanets and their suitableness of having Earth-like climate.

There are two common methods of detecting and finding out information. The radial velocity method and the transit method. The radial velocity methods can be affected by many factors such as global oscillation (The amplitudes of these variations are of order meters per second, and decrease with increasing surface gravity and stellar magnetic activity) [4]. Many of the observations and findings are done by these two methods, Wei Zhu introduces the use of radial velocity. In his research, they have devised a versatile approach that effectively accounts for the incompleteness in surveys and enables us to reconstruct the inherent distribution of planetary multiplicities. This method ensures that the limitations in observational data, which may lead to missing or underrepresented planets, are adequately considered, allowing them to gain a more accurate picture of how planets are distributed around stars in the universe [5]. The popular K2 mission uses the transit method to discover and identify targets in exoplanets.

This paper delves into the intricacies of deriving data and crafting graphs through the transit and radial velocity methods, to uncover the intricate relationship between planetary components, orbital radius, surface temperature, and planet radius. It is crucial to acknowledge that, despite their prowess, these methods are not without their flaws, as they can be susceptible to various external factors.

2. Theoretical Basis

2.1. Method

There are two common methods of detecting and finding out information. The first one is the radial velocity method. The radial velocity method, also known as Doppler spectroscopy, is a technique used to detect exoplanets by observing variations in the velocity of a star. These variations are caused by the gravitational influence of an orbiting planet. As the planet orbits, it induces a small wobble in the star's motion, leading to periodic changes in the star's velocity along the line of sight. The Doppler shift infers that blueshift happens when planets move observer, causing a rise in the frequency, and redshift happens when planets move away from the observer, causing a fall in the frequency. By these calculation, data such as orbital period and mass will be gained.

The second method is the transit method. Dimming occurs when a planet passes in front of the star, relative to the observer's line of sight, temporarily blocking a small fraction of the star's light, dimming will be periodic so that the orbital period can be calculated. With the depth also calculated, many of the data will be derived, such as planet radius and orbital radius. The radial velocity methods can be affected by many factors such as global oscillation (The amplitudes of these variations are of order meters per second, and decrease with increasing surface gravity and stellar magnetic activity).

2.2. Example: WASP-151 b

Take the example of the WASP-151 b planet. From getting the periodical light intensity table from the data collected by the Kepler Telescope, it can get Figure 1 for the depth of the planet and star as well as the radius of the plane. Fig. 1 has the Radius of the star, depth, and Radius of the planet shown on the graph, while the Radius of the sun will remain unchanged, it can be out that there are some fluctuations between the depth and radius of the planet. The reasons for this will be discussed later in the context.

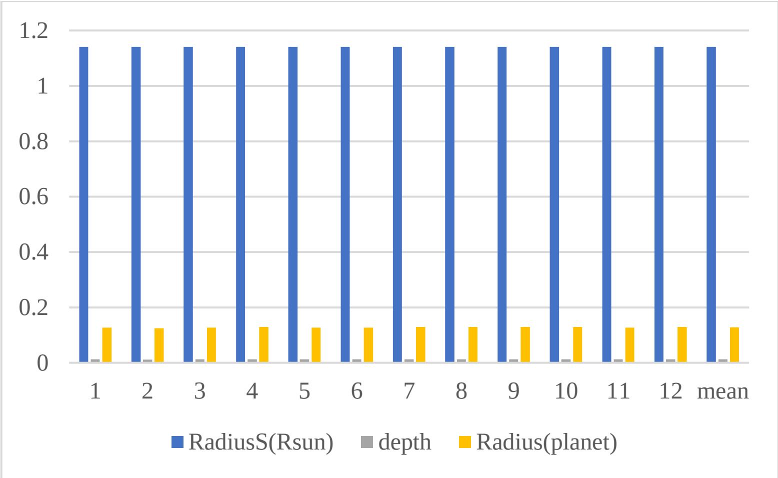

Fig. 1 Radius of WASP-151 b (Picture credit: Original).

Then from using the formula of The Kepler Third Law $a^3 = \frac{GMT^2}{4\pi^2}$, a is the distance between planet and star, T is the period of orbital motion of the planet, M is the mass of the Sun, the distance between the planet and the star can be known as G is a constant of 6.67×10^{-11}. For the planet of WASP-151 b, the distance will be 8.1×10^9 m. By using the formula of $v = \frac{2\pi a}{T}$, velocity of the planet can be also calculated. This is the basic way to decide some basic information of planets using the transit method. The radial velocity method is that to use the collected data of phase of orbit and radial velocity and to decide the periodical radial velocity. From the formula of $M_p = \frac{Radial\ velocity \times M_S^{\frac{2}{3}} \times T^{\frac{1}{3}}}{(2\pi G)^{\frac{1}{3}}}$, where Mp is the mass of the planet, Ms is the mass of the star, T is the period of the orbital motion of the planet and G is the constant of 6.67×10^{-11}. Then the mass of the planet can also be calculated. From these data calculated, it is possible to find some of the relations between them and may give some implications on what kinds of planets may be earth-like and have possibilities for surviving.

2.3. Correlation Between Planetary Properties

Firstly, one of the important factors in being able to survive is the temperature. Fig. 2 is a graph with the temperature of the planet on the Y-axis and the radius of the planet on the X-axis. The earth has an average temperature of 285K which means that searching for planets with similar temperature may be a good choices. From a range of 280-400k, by plotting a graph, it is obvious that most planets suiting this range has a rather small radius, most of them smaller than 0.5 radius of Jupiter.

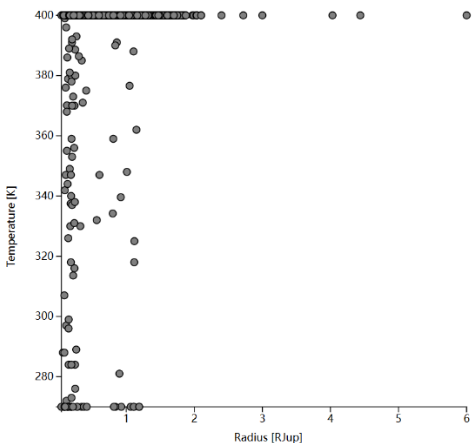

Fig. 2 Relation between planet radius and temperature (Picture credit: Original)

Fig. 3 is a graph with the temperature of the planet on the Y-axis and the mass of planet on the X-axis. The mass of a planet also has some relation with the temperature of the planet by plotting a graph of mass against temperature. Planets with temperatures between 280 and 400k are more likely to have a rather small mass, of less than 2-3 Jupiter mass.

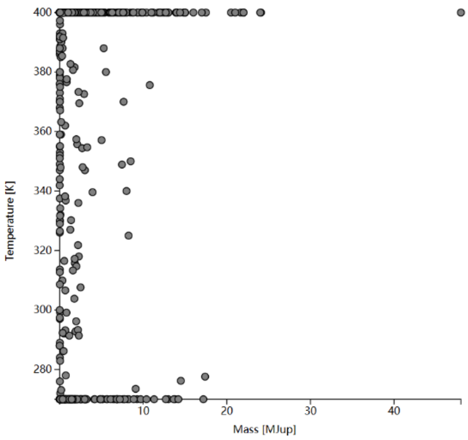

Fig. 3 The relation mass and temperature of planets (Picture credit: Original)

Exception exists such as the HD 202206 b planets, with a mass of 17.40 Jupiter mass and a temperature of 278k only [6]. Planet temperature can be affected by a number of factors including distance from stars, atmospheric composition, geological activity, orbital eccentricity and axial tilt and cloud cover. However, by finding relation between mass, radius and temperature, it may make it quicker to aim planets for further study.

2.4. Planetary Composition and Structure

Secondly, another important issue of being able to survive is the composition of the planet, including its surface and atmosphere. Methane, CO2, or water vapour are some of the gas compositions found in some planets such as WASP-39b. The analysis of the spectral features observed previously indicates a high degree of confidence in the attribution of sodium, potassium, and water vapour absorption. These detections are significant as they provide insight into the atmospheric composition of the observed object. Additionally, the suggestion that carbon dioxide (CO2) is responsible for the deep transit at 4.5 µm observed with the Spitzer Telescope is a plausible explanation [7]. Carbon dioxide absorption at this wavelength is a known characteristic, and its detection further supports the complexity and diversity of the object's atmosphere [7]. Despite the composition of atmosphere, the surface composition can be decided by the mass of the planet calculated using the radial velocity method. For example, rocky planets like Earth have an average density of 5155kgm^-3 while a gas giant such as Saturn only has an average density of 700kgm^-3. The measurements of a planet's mass and radius can offer valuable insights into its overall composition. In particular, the inclusion of(H) in a planet's makeup can have a significant impact on its radius for a given mass [8]. This is because hydrogen is a relatively light element, and its presence can lead to a more extended atmosphere and, consequently, a larger radius. Thus, by analyzing the mass and radius data of a planet, scientists can gain important clues about the abundance of hydrogen and other elements within its interior, providing a more comprehensive understanding of its bulk composition [8]. The mass-radius relation for a pure silicate (MgSiO3) composition then establishes the upper bound on a rocky planet's radius, while a pure Fe composition sets the lower bound. The majority of rocky entities are thought to reside in the middle of these two extremes, made up of silicate mantles and iron cores.

3. Flaws Which May Happen Using the Transit Method

The transit method can firstly be affected by the star variability, the brightness of the host star can change due to the stellar activity and sunspot which will cause fluctuations on the transit graph. Sometimes such an effect on the transit signal will make it hard to distinguish whether it is an actual planetary transit or the natural stellar variability.

Despite that, the detection of exoplanets, especially those belonging to the category of hot Jupiters, which are gas giants orbiting close to their host stars, has been greatly aided by the extended observation windows provided by space-based telescopes like Kepler and TESS. When these planets orbit around rapidly rotating massive stars, their transit signatures can become more elusive due to various factors, including precession. Precession, in this context, refers to the gradual change in the orientation of a planet's orbit over time, which can alter the timing and duration of transits as observed from Earth [9]. However, the extensive coverage and prolonged observation periods of Kepler and TESS have mitigated this challenge by increasing the chances of capturing transit events. Specifically, for certain regions of the sky, the combined observations from these missions have boosted the likelihood of detecting transits by a non-negligible margin, ranging from a few percentage points up to approximately 10% [9].

The method using radial velocity also has some flaws which may happen and reduce the accuracy of the method. The pursuit of extra-solar planets can be hindered by the inherent stellar radial velocity (RV) variability stemming from various stellar phenomena, such as pulsations and activity-related variations, like the rotation of starspots or their temporal evolution. Understanding the intrinsic stability of stars to the level of 1 ms-1 remains limited, but research has demonstrated a clear correlation between stellar RV variability and rotational broadening (Consequently, most extra-solar planetary search programs have imposed an empirical limit of $\mathrm{Vsini} = 4\mathrm{km}s^{-1}$to mitigate these effects [10].

4. Conclusion

This paper introduces the two methods in the detection of exoplanets, the transit method (where a planet crosses in front of its star, dimming its light slightly) and the radial velocity method (which measures the wobble caused by a planet's gravitational pull on its host star). These two methods are the main methods in the findings of exoplanets nowadays but still have some flaws that may be affecting the accuracy, such as the changing of the brightness of the host star or temporal evolutions as well as those caused by the high velocity of orbiting planets. Some relation between the temperature of the planet and the radius and mass of planets are also studied in the paper, giving the conclusion that planets with earth-like temperatures usually have rather small radii of below 0.5 Jupiter radius and 2 Jupiter mass. However, exceptions still exist due to the reason that temperature can be affected by several other factors.

As researchers delve deeper into the galaxy, the era of exoplanet discovery blossoms into a golden age. Telescopes and observatories, both terrestrial and space-based, have evolved, capable of detecting and characterizing thousands of planets outside the solar system with unprecedented precision. These include planets orbiting in the habitable zones of their parent stars, where temperatures are just right for liquid water to exist—a crucial ingredient for people to know it. The next step in the quest involves searching for evidence of life in these distant worlds. High-resolution spectrographs analyze the light emitted or reflected by exoplanets, searching for biosignatures—chemical compounds or patterns that indicate the presence of biological activity. From oxygen in the atmosphere to complex organic molecules, each discovery brings humans closer to confirming the existence of extraterrestrial life. The quest for another Earth is a testament to humanity's relentless curiosity and drive for exploration. It represents a future where science and technology have converged to unlock the secrets of the universe and fulfill the deepest desires for understanding and connection. As venture further into the cosmos, a commitment to preserving the wonder and diversity of the universe people call home.

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