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Analysis the Approaches for Planet Searching and Detection

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Abstract:
As a matter of fact, investigating the unknown has always been a central theme in the advancement of human science especially in recent years. Contemporarily, cosmologists obviously have a passion for exploring exoplanets. In light of this, the purpose of this study is to examine a number of popular planet search techniques and provide an overview of their benefits, drawbacks, and range of applications. Specifically, by going over the direct imaging method, the astrometry approach, and the radio velocity method. The study discusses the state-of-the-art observation findings, present challenges, and future directions. Indeed, these studies are crucial to understanding planetary formation and dispersion across the universe, and they give humanity's study of the cosmos even more momentum according to the analysis. As a result, this work has significant scientific and practical implications, and the findings provide guidance for future research in planet searching. Overall, these results shed light on guiding further exploration for planet search.

Keywords: Planet search; astrometry; radial velocity.

1. Introduction

As the science of great antiquity, astronomy has deeply attracted and enchanted scientist to unearth its significance. The detection of exoplanet, a specific area of this mysterious territory, grasp researchers attention. Numerous methods have been used to find more than 4000 exoplanets , including direct imaging , gravitational microlensing , astrometry , and the radial velocity method . However, the transit approach has been used to find most verified exoplanets [1].

To search a portion of the Milky Way galaxy for Earth-sized planets orbiting stars outside the solar system, the National Aeronautics and Space Administration (NASA) launched the Kepler Space Telescope and its second survey programmed K2 in 2009 and 2014, respectively. As soon as the Kepler space survey's data were made public, the predation event observation method dominated the detection as the result of its unparalleled precision in photometry and pointing at the one millionth (ppm) scale [2]. NASA launched the successor of Kepler in April 2018, i.e., the Transiting Exoplanet Survey Satellite (TESS). It covers 85 per cent of the sky- a region that is 400 times larger than that covered by Kepler and produces about one million light curves every month. TESS observes stars that are 30-100 times brighter than those selected by the Kepler mission [1]. Aim to uncover thousands of exoplanets circling the sky's

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brightest dwarf stars by catching transits, as of August 2024, TESS has confirmed 542 exoplanets and thousands of candidates' exoplanets, encompassing the detection for bodies capable of supporting life [3]. Cosmologists have constructed many amazing methods to study exoplanets throughout the years, including as gravitational microlensing, direct imaging, and the radial velocity approach, which found the first exoplanets. The broad use of these detection techniques in both ground- and space-based exoplanet search missions has increased the understanding of the extrasolar worlds [3]. This study will be elaborated in five parts. The results obtained by some mainstream exoplanet detection methods will be introduced in Sec. 2. Then Sec. 3 will introduce in depth the principles of astrometry, direct imaging, and the radial velocity approach methods, related state-of-the-art instruments and results. In Sec. 4 and Sec. 5, this study discusses limitations of current detection schemes and future prospects and conclude.

2. Descriptions of Detection Approaches

Although there are still various proposed methods for searching exoplanets, the previous mainstream detection methods are still responsible for the vast majority of planetary detection. In 1995, radial velocity measurements resulted to the first reliable finding of an exoplanet. Since then, because to advancements in technology and observation, numerous exoplanets have been discovered via this technique. Transiting planets are also very important for exoplanet science, which examines light curves and periodograms. Because the planets' radii may be calculated from the star's periodic light dimming, information obtained during transits can be used to determine the sizes of the planets. The field of exoplanet research saw a significant shift by the end of 2023. As of currently, NASA claimed that around 4153 transiting planets were known to exist, with the Kepler space telescope having found almost 2778 of them [4]. Direct imaging, which uses images to identify exoplanets, gravitational microlensing, and astrometry, which measures a star's position in relation to the background sky, are other efficient techniques [4, 5].

3. Approaches of Detection

3.1 Astrometry

Consistent development over the last century enhanced the accuracy of star position determinations, enabling the determination of stars' proper movements, parallax displacements resulting from Earth's rotation around the Sun, and orbital motion resulting from the gravitational attraction of star partners [5]. Astrometry,the exact measurements of the locations and motions of stars and other celestial entities,has also become more efficient and accurate.A reference frame is created and realized by observations of far-off objects, such quasars, in order to quantify these properties.The formation of absolute reference frames is made possible by surveys like as Gaia and the Very-long-baseline interferometry. This allows for the measurement of „absolute astrometry", also known as global astrometry, for celestial bodies. On the other hand, „relative astrometry," or the measurement of the relative movements between celestial bodies, is the main emphasis of facilities like FGS/HST and GRAVITY/VLTI. Relative astrometry measures the velocity of a target star in relation to a reference star, which is often a far-off star [6].

Imaging (e.g., HST Wide Field Camera), interferometry (e.g., GRAVITY/VLT), and drift scan (e.g., Gaia) are the three main astrometric methods. The Cerro Tololo Inter-American Observatory Parallax Investigation (CTIOPI) is an example of how imaging astrometry collects target pictures across several epochs to enable effective astrometric determination. By using interference patterns from telescopes or light channels, interferometric astrometry is able to provide finer celestial detail observation and better angular resolution. Drift-scan astrometry provides high precision astrometry that is directly related to temporal information by allowing stars to travel over the detector over time, in contrast to other approaches that follow stars [7].

By the end of 2023, astronomy had only found three exoplanets; two of them had masses of 2.26 and 5MJ, and one was a substellar partner with a mass 28 times that of Jupiter (28MJ). Details on these discoveries are available in the NASA exoplanet repository. With the 2013 launch of the Gaia satellite, astronomers have observed a dramatic change in their field. With accuracy of around 20–25 microarcseconds (μas) for stars at magnitude 15, Gaia is actively surveying over a billion stars at magnitudes up to V = 20–21. It is anticipated that this incredible improvement in accuracy will completely transform the knowledge of planetary systems. Thanks to gaia's extensive dataset, many thousand planetary systems with accurate planet masses and absolute orbits free of the sin i ambiguity, the uncertainty around the inclination angle of the planetary orbit, should be located. Furthermore, gaia will offer informative data on the co-planarity of planetary systems, shedding light on the arrangement and actions of several planets within a system [4]. A sketch is shown in Fig. 1 [8].

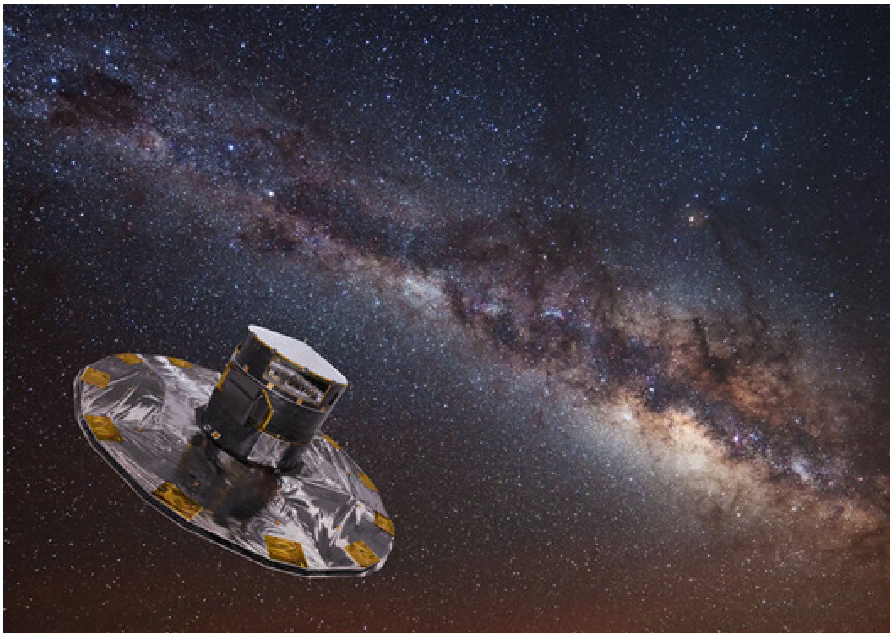

Fig. 1 Gaia mapping the stars of Milky Way [8].

3.2 Radial Velocity Method

Up to the discovery of planets around pulsars, the existence of exoplanets, or planets outside the Solar System, was unknown [9]. With the discovery of 51 Peg b, a planet with a minimum mass of around 0.5 Jupiter that orbits a star similar to the Sun in 4.2 days, the scientific study of exoplanets gained momentum [9]. This study focuses on the radial velocity (RV) approach, which is the foundation for the identification of hundreds of exoplanets, including 51 Peg b. It operates on the following concept. The periodic reflex motion of a star that a planet orbits causes it to travel back and forth toward the observer at a certain velocity, or its RV. Through the Doppler effect, an observer can quantify a time series of RV by obtaining spectra of a particular star at several periods. The orbital eccentricity determines the form of the changes in RV, whose amplitude is proportional to the planetary mass.One of a planet‘s most basic characteristics is its mass. The combination of mass and radius, when measured independently using photometry, yields the density (which is crucial for describing the planet‘s interior structure) and the surface gravity, which is crucial for deciphering measurements of its atmosphere. Understanding eccentricity is crucial for comprehending how planetary systems originate, particularly in multiplanetary systems [9].

A planet orbiting a star causes both objects to rotate around a common center of mass, which causes a Doppler shift in the spectral lines of the star. The star‘s spectral lines undergo a redshift as it travels away from Earth. There is a blueshift when it approaches Earth. The presence and properties of planets may be ascertained by accurately measuring the frequency shifts seen in the spectral lines, which in turn infers fluctuations in the star‘s radial velocity. A high-resolution spectrometer is needed to measure the frequency shift of a star‘s spectral lines.

Several noteworthy typical outcomes have been obtained using the radial velocity approach. The finding of a sizable number of exoplanets is one of them. Scientists have found hundreds of exoplanets using the radial velocity approach, some of which are rocky planets like Earth. These findings have aided in improving the understanding of the universe‘s planets‘ origin, distribution, and development. One significant illustrative outcome is the identification of HD 209458 b through the use of the radial velocity approach. The honor of being the first exoplanet to be found with a mass comparable to Jupiter belongs to HD 209458 b. It revolves around HD 209458, a star. Due to its extremely tight orbit around its star, HD 209458 b has an exceptionally high surface temperature and may be losing material from its atmosphere, according to observations [10].

3.3 Direct Imaging

Distinguishing weak exoplanet light from the halo of brilliant, highly structured scattered starlight is necessary for direct imaging detections. The planet-to-star contrast ratio at a specific off-axis angular separation is the primary measure used to assess the detectability of extrasolar planets; the contrast ratio required for a detection varies with planet features. To generate profound raw contrasts, critical gear like as coronagraphs and AO (or, more

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broadly, wavefront control systems made of sensors and deformable mirrors) must first sharpen and then suppress scattered starlight. By using new methods of observation, post-processing algorithms can further eliminate leftover starlight, raising the feasible contrast ratios and enhancing the ability to discover planets.Surprisingly, in a few hours of telescope time, the direct imaging approach allows the capture of hundreds to thousands of spectroscopic datapoints on exoplanets. This abundance of data can significantly limit the atmospheric history of gas giant stars as a population as well as the temperature, clouds, chemistry, and gravity of individual planet [11].

Using the direct imaging method, numerous investigations have successfully found exoplanets in recent years, yielding numerous significant results. Using direct imaging, for example, Marois et al. achieved an amazing achievement by taking direct pictures of many planets orbiting HR 8799 [10]. The scientists were able to determine the planets‘ mass, orbital parameters, and even infer details about their atmospheric composition by closely examining these pictures. This finding has important ramifications for improving the understanding of the characteristics and evolutionary history of exoplanets. Furthermore, Currie et al. found a candidate planet around the deuterium-burning limiting mass of ROXs 42B using direct imaging [10]. The researchers also explored the principles of planet formation and evolution by deducing the planet‘s mass, temperature, and atmospheric composition by orbital analysis and spectral characterisation. This finding offers a crucial point of reference for the comprehension of the characteristics and beginnings of low-mass planets. These representative results show that the direct imaging approach has advanced the detection and analysis of exoplanets to a considerable degree. With continued technical progress, the direct imaging technique will help us solve more cosmic riddles and provide vital information that will help us better understand the origins, evolution, and possible habitability of celestial worlds.

Using general-purpose adaptive optics (AO) equipment at the site or space telescopes (like the Hubble Space Telescope), basic coronagraphs were used to capture the initial direct pictures and spectra of planet candidates [11]. Over the past ten years, advancement, explanation, and improvement of specialized extreme AO systems, combined with state-of-the-art coronagraphs and elegant after-processing methods, have made it possible to detect planets that are either fainter and less massive, or located at smaller angular separations that probe tighter orbits. Modifications to first-generation extreme AO systems and systems that are still in development will provide images of many exoplanets around the ice line . According to Spergel et al., the Coronagraphic Instrument on NASA‘s Roman Space Telescope (RomanCGI) may discover mature planets for the first time in reflected light.

Planned space missions and very large ground-based telescopes should make finding and verification of a livable, Earth-like exoplanet around a Sun-like star possible throughout the next twenty-five years. These research institutions are going to try to find biomarkers in systems including oxygen, water, and ozone. Their observations will offer the first evaluation of possible habitability surrounding stars with varying masses, revealing the actual environment in which life on Earth exists. In the last ten years, technological advancement, atmospheric characterisation, and demographic research on young Jovian planets have all contributed significantly to the achievement of this aim.

4. Limitation and Prospects

Planetary exploration has several current constrains, which are mainly the following. First, there are many technical obstacles that long-range planetary exploration missions must overcome. The great distances between planets cause delays and attenuation in signal transmission, which makes it difficult for real-time control and data acquisition. Second, an unstable energy supply can arise from solar panels during long-duration space missions due to the planets' unique environments, which include radiation and magnetic fields. Third, complex environments and extreme climatic conditions on planetary surfaces increase the requirements for the design and endurance of probes. Lastly, the high cost of planetary exploration missions restricts their further development. The amount of money and resources needed for current planetary exploration missions is frequently high, which could reduce the quantity and frequency of exploration missions.

Future planetary exploration, however, still has a lot of promise and opportunities. On the one hand, more sophisticated probes with improved autonomous navigation and data processing capabilities should be created as technology advances. For instance, planetary exploration missions will become more intelligent and effective with the development of autonomous robotic probes. However, new methods and technology will pave the way for further planetary exploration. For instance, samples of Martian rocks are anticipated to be returned to Earth by the Mars Sample Return Mission in order to advance research on the formation and development of planets.

5. Conclusion

Overall, this paper mainly introduces and analysis three exoplanet detection methods: astrometry method, radial velocity method and direct imaging methods. The exact measurement of stars' and other astronomical bodies' locations and motions is known as astrometry. Observations of far-off objects, like quasars, create and materialize a reference frame that is used to measure these attributes. For the purpose of creating absolute reference frames, surveys such as Gaia and Very Long Baseline Interferometry are used. The three main astrometric methods are drift scan (Gaia), interferometry (GRAVITY/VLT), and imaging (HST Wide Field Camera). Through the observation of star spectrum fluctuations, planets can be indirectly detected using the radial velocity approach. By detecting the Doppler shift in a star's spectrum, the approach deduces the existence and orbital characteristics of planets. This approach has shown to be a somewhat successful and dependable way to find big planets in close vicinity. By investigating the light that exoplanets release for themselves, the direct imaging approach finds them. This method requires a considerable angular separation and a suitably bright planetary light source. It makes it possible to obtain pictures that represent the planets and their physical features through data processing and analysis. Nevertheless, the difficulty of picking up dim planetary light against star glare limits the use of direct imaging. At last, this research discusses the limitations and future of this wonderful field. Most of the limitations are due to equipment and environment. As long as technology keeps developing, more advances in planetary exploration should be possible in the future. A few examples of new technology and methodologies that will further the understanding of the planetary universe are the creation of autonomous mechanical instruments, expeditions that bring back instances from the planet, and the organization and study of human lands on planets. The study concludes by summarizing and analyzing three methods in the field of planetary seeking. It also discusses future challenges and opportunities for planetary exploration. This will provide beneficial references for further research and analysis.

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