Analysis of Extra-Planet Searching Approaches: Radial Velocity, Transit and AI Algorithm Detection

Yunjie Ruan
Shanghai Hongkou Secondary School Affiliated to Shanghai Normal University, Shanghai, China

Keywords: Transit, Radial Velocity, AI Detection, Habitability, Extraterrestrial Life.

Abstract: With the advancement of human exploration of the universe, the detection of exoplanets has become one of the core areas in astronomy. The search for exoplanets and potential signs of life holds critical significance for understanding galactic systems across the cosmos and the origins of life. This study analyses the current mainstream detection methods, including the transit method, radial velocity method, and Artificial Intelligence-based (AI-based) detection algorithms. It elaborates on their principles, technical advantages, limitations, and major research achievements to date. According to the analysis, the transit method is highly sensitive to the orbital inclination of planetary systems. While it can accurately determine a planet's radius, it is unable to provide continuous long-term observations of radial velocity. The radial velocity method can estimate planetary mass but is primarily effective for detecting massive planets in close proximity to their host stars. Due to significant interference from stellar activity, this method poses considerable challenges in practice. In contrast, Artificial Intelligence (AI) algorithms leverage deep learning to integrate multiple data sources, enabling improved identification and analysis, thereby substantially enhancing detection accuracy. These findings contribute to the development of an intelligent astronomical observation system that integrates multiple technologies, thereby advancing scientific research in exoplanet detection.

1 INTRODUCTION

In the research history of exploring exoplanets, the earliest was in 1988 when Canadian astronomers discovered a Jupiter-like planet orbiting the star gamma Cephei A, but it was not confirmed at that time. Later in 1995, there was a major breakthrough when Swiss astronomers discovered 51 Pegasi b, which is a widely recognized exoplanet and also opened a new era of exoplanet exploration (Mayor & Queloz, 1995). Subsequently, various methods such as the transit method, radial velocity method, and microlensing method have continued to develop. Researchers worldwide have utilized advanced detection equipment and employed highly skilled personnel to conduct in-depth studies.

Up to now, people have discovered more than five thousand exoplanets, and there are still several thousand candidates waiting to be confirmed. Researching exoplanets can not only improve the entire theoretical system of planetary formation, allowing people to understand the formation conditions and evolutionary processes of different planetary systems, but also explore planets within the habitable zone of stars, searching for various signs of life (Charles, 2020). All of these can deepen people's understanding of the universe and satisfy their strong curiosity about the universe from ancient times to the present (Wang, 2022). The full text focuses on three detection methods: the transit method, radial velocity method, and AI algorithm method. Incorporating recent remarkable technological advancements, this paper will propose an integrated approach combining these three research methodologies.

In 2022, the total number of confirmed exoplanetary systems reached 5,000. In September of that year, astronomers announced the discovery of a new type of exoplanet orbiting a relatively close red dwarf, observed by National Aeronautics and Space Administration (NASA) Transiting Exoplanet Survey Satellite (TESS). Additionally, a scorching exoplanet named TOI-1075b was discovered, one of the largest "super-Earths" found to date with a surface temperature of 1,050°C. Astronomers also detected metallic barium in the atmospheres of two hot exoplanets, WASP-76b and WASP-121b, the heaviest element ever identified in exoplanetary atmospheres (Polanski, et al., 2024).

Ruan, Y.
Analysis of Extra-Planet Searching Approaches: Radial Velocity, Transit and AI Algorithm Detection.
DOI: 10.5220/0013825900004708

In *Proceedings of the 2nd International Conference on Innovations in Applied Mathematics, Physics, and Astronomy (IAMPA 2025)*, pages 364-368
ISBN: 978-989-758-774-0

In 2023, scientists made significant discoveries. The James Webb Space Telescope confirmed the presence of heavy elements like carbon and oxygen in the atmosphere of the distant exoplanet HD 149026b, differing from the hydrogen- and helium-dominated atmospheres of gas giants in the Solar System. NASA's TESS discovered a gas giant named TOI-4600c with an orbital period of 482.82 days, the longest "year" among TESS-discovered planets, and a surface temperature of -78°C. A rare planetary system, HD 110067, was also found, featuring six tightly orbiting "sub-Neptunes."

In 2024, a research team led by Professor Dong Subo from the Department of Astronomy at Peking University's School of Physics reported a new exoplanet, Gaia22dkvLb, through follow-up photometric observations of a microlensing event alerted by the Gaia satellite. This planet has a mass 0.6 times that of Jupiter and orbits its host star at approximately 1.4 astronomical units. The host star is the brightest ever found for a microlensing-detected planet, offering potential for measuring the planet's orbital eccentricity and other parameters via high-precision radial velocity methods, as well as searching for additional planets within its orbit to study the overall architecture of the planetary system (Rojas-Ayala, 2023).

In subsequent sections, this study will introduce each detection method along with its fundamental principles, describe the relevant instrumentation and equipment used and present significant detection results from recent years. Through comparative analysis of outcomes from different methods, the study will synthesize these three approaches before concluding with future research prospects.

2 DESCRIPTIONS OF PLANET SEARCHING

To detect exoplanets, it is essential to determine their fundamental planetary parameters, including mass, diameter, and orbital period. Equally crucial is the investigation of atmospheric characteristics to assess potential biosignatures, e.g., the presence of water (H_2O), carbon monoxide (CO), and carbon dioxide (CO_2) along with the identification of various elemental compositions.

The specific process involves first determining whether planets exist around the star, then measuring the planet's orbital period, semi-major axis, eccentricity, etc. This study uses these known parameters to evaluate the physical properties of planets, estimate their mass, radius, density, etc. Subsequently, researchers observe whether atmospheric components exist and search for signs of life. Finally, they evaluate whether the planet lies within the star's habitable zone.

Furthermore, evaluating planetary habitability constitutes a critical component of exoplanet research. The detection of liquid water and elements essential for biological metabolism or replication provides key evidence for potential extraterrestrial life. Current mainstream exoplanet detection methodologies include, i.e., Transit method, Radial velocity method (Deng & Tang, 2024), Astrometry, Gravitational microlensing, Direct imaging (Chauvin, 2023).

3 RADIAL VELOCITY

The radial velocity method is also called the wobble method. Its principle is to detect exoplanets by measuring changes in the star's motion speed toward or away from Earth. Academically, it relies on gravitational interaction planets orbiting stars form a binary system, and while planets orbit the center of mass in large orbits with wide ranges, the star actually exhibits small wobbles.

Furthermore, when the star moves away from the planet, its spectral lines shift toward the red end (i.e., wavelength becomes longer); when the star moves toward the planet, its spectral lines shift toward the blue end (i.e., wavelength becomes shorter). Through long-term monitoring of these stellar spectral shifts, one can calculate the periodic amplitude of velocity changes. This allows us to deduce the planet's existence and estimate parameters such as its mass or orbital radius.

Otherwise, for the radial velocity method, there are two types of high-precision detection instruments. One is the High Accuracy Radial Velocity Planet Searcher (HARPS), and the other is the High-Resolution Echelle Spectrometer (HIRES). Through complex mathematical calculations based on Kepler's laws and Newton's law of gravitation, researchers can conclude that:

$$v \propto \frac{GMp\sin i}{P\sqrt{GM_*}} \tag{1}$$

where i is one of the planet's orbital inclinations and G is the gravitational constant.

Swiss astronomers detected a star in Pegasus using the radial velocity method and observed an oscillation every 4.23 days. Through data points and fundamental principles, they calculated that there is a planet close to Jupiter's size located 4 million miles away from this star (Mayor, & Queloz, 1995).

In recent years, while there are higher-precision detection methods available, as one of the earlier methods that has successfully detected multiple exoplanets, it is still widely used and has its own advantages and limitations. It can quickly detect low-mass planets, but due to unknown orbital period data, scientists need to conduct long-term observations. Moreover, it is easily affected by stellar activity interference and cannot directly measure planetary radius. This method is one of the classical means for detecting exoplanets and is often used in combination with the transit method.

4 TRANSITS

The transit method, as one of the most classical methods, has recently made significant discoveries. Its detection principle is that when a planet passes through the disk of its parent star, a slight decrease in the star's visual brightness can be observed. However, the degree of dimming depends on the size of the planet itself and the size of the star. These brightness changes cannot be observed by the naked human eye, thus requiring long-term monitoring to analyze data such as the planet's size. For the transit method, there are two representative high-precision detection instruments: the Kepler Space Telescope and the TESS.

When a planetary transit occurs, telescopes can also analyze the starlight passing through the planet's atmosphere, which allows determination of the atmospheric composition. This enables the search for gases related to life. On April 17, 2024, a team of astronomers from the University of Cambridge published in The Astrophysical Journal Letters that they detected Dimethyl Sulfide(DMS) and Dimethyl Disulfide (DMDS) in the atmosphere of exoplanet K2-18b, compounds only produced in Earth's biological processes, also known as chemical fingerprints. This planet is located in the habitable zone of a red dwarf star 124 light-years away in the direction of Leo (Madhusudhan, et al., 2025). A typical measurement for the gas components is shown in Fig. 1. This currently represents the strongest evidence for extraterrestrial life, but this is not an official announcement and requires more observational verification.

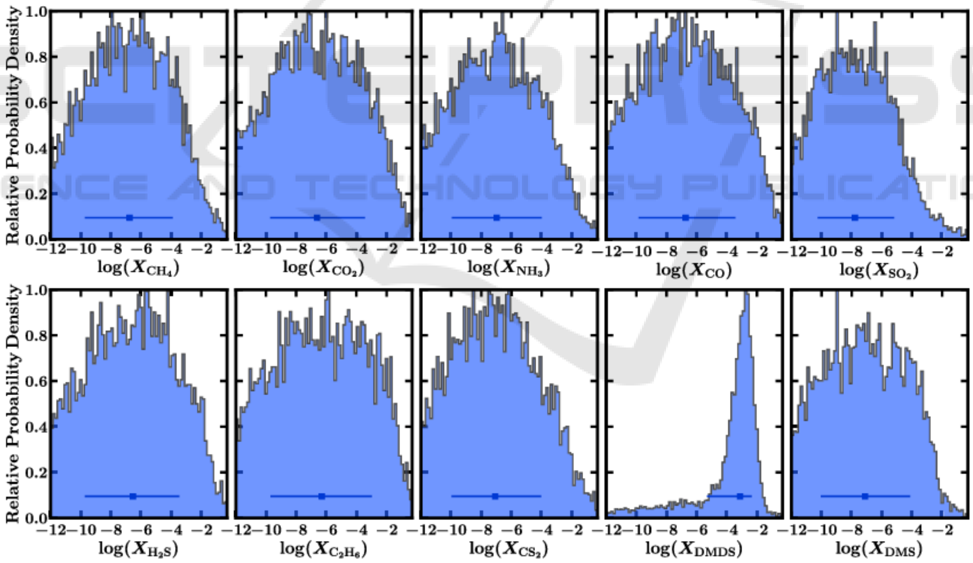

Figure 1: A typical analysis of the gas components (Madhusudhan, et al., 2025).

5 AI ALGORITHM DETECTION

In recent years, the AI team has gradually grown stronger. In the field of astronomy, the AI-driven intelligent exoplanet detection team has also been gradually introduced. For AI intelligent detection, its principle leans more toward letting AI conduct data learning, allowing it to learn from large amounts of known exoplanet data, then through deep learning algorithms master various phenomena and known methods to deduce periodic changes in stellar brightness, thereby calculating the probability of whether certain specific characteristic patterns are caused by planets. These data can all be provided to astronomers for further research.

Currently, the Shanghai Astronomical Observatory, with Professor Ge Jian leading an international team, has innovated a deep algorithm combining Graphics Processing Unit (GPU) phase folding and convolutional neural networks. From the stellar photometric data released by the Kepler telescope in 2017, they discovered five ultra-short-period planets. (Ni, 2024) In 2022, Google's ExoMiner neural network also screened Kepler telescope data and discovered 301 previously unknown exoplanets. (Valizadegan, et al. 2022)

Additionally, AI algorithms can be used to analyze the spectra of exoplanet atmospheres. AI algorithms can identify key molecules within them. For example, by analyzing spectra to search for water, methane and other molecules that may indicate the existence of life. Regarding the limitations of artificial intelligence algorithms in detecting exoplanets, it is impossible to determine whether there is any detection bias. But for the increasingly large artificial intelligence team, it has become the fastest and most convenient auxiliary tool in life. It can effectively assist astronomers in exploration, so it will be a very good method.

6 COMPARISON, LIMITATIONS AND PROSPECTS

From the entire article, the advantages and limitations of the three methods can be summarized as follows. The transit method can perform batch detection, it is suitable for detecting planets in the habitable zone of stars, and can directly measure planetary radius, but the sizes of both the star and planet need to be considered. The limitation is that it requires observation of at least one complete transit cycle, and since the cycle length cannot be predetermined, researchers need to conduct continuous observations. It cannot directly measure planetary mass.

On this basis, the radial velocity method can directly measure planetary mass. However, it is only highly sensitive to massive planets, its observation cost is very high, and it is easily affected by stellar activity. Finally, AI detection is highly efficient, can prcess complex data, reduce human errors, and uncover more hidden signals. However, its limitation is that it relies on extremely precise data and cannot make independent judgments.

On this basis, this study will propose combining these three scientific methods to complement each other. For planets suspected of having signs of life that have been discovered, the transit photometry method can be used first, followed by precise detection and calculation using artificial intelligence, and finally verified through the radial velocity method. This process can efficiently confirm planetary parameters and determine habitability (David, et al., 2014).

7 CONCLUSIONS

In summary, this is all my views and research on the three detection methods. Through analyzing the principles of each method and their currently observable developments, this research has conducted self-integration and proposed an innovative combination of these three different methods. Recently, more and more research achievements have been published, and people's techniques for exploring the universe are becoming increasingly refined. It is hoped that this can help promote development, enhance people's emphasis on cosmic technology research, and stimulate everyone's innovative consciousness.

REFERENCES

Charles, S. C., 2020 The eventful history and exciting future of astrobiology. News, 6.

Chauvin, G., 2023. Direct imaging of exoplanets: Legacy and prospects. Comptes Rendus. *Physique*, 24(S2), 129-150.

Deng, Z., Tang, Y., 2024. Searching Extra-Planet Based on Radial Velocity, Transit and Direct Imaging. I*AMPA International Conference on Innovations in Applied Mathematics, Physics and Astronomy*, 11.

Madhusudhan, N., Constantinou, S., Holmberg, M., Sarkar, S., Piette, A. A., Moses, J. I., 2025. New Constraints on DMS and DMDS in the Atmosphere of K2-18 b from JWST MIRI. *The Astrophysical Journal Letters*, 983(2), L40.

Mayor, M., Queloz, D., 1995. A Jupiter-mass companion to a solar-type star. *Nature*, 378(6555), 355-359.

Ni, S., (2024). With Innovative AI Technology, Scientists Discover 5 Ultra-Short-Period Planets. C*hina Science Daily*, 10, 21, 001.

Polanski, A. S., Lubin, J., Beard, C., et al., 2024. The TESS-Keck Survey. XX. 15 New TESS Planets and a Uniform RV Analysis of All Survey Targets. *The Astrophysical Journal Supplement Series*, 272(2), 32.

Rojas-Ayala, B., 2023. Twenty-five years of exoplanet discoveries: *The exoplanet hosts. Planetary Systems Now*, 71-95.

Valizadegan, H., Martinho, M. J., Wilkens, L. S., et al., 2022. ExoMiner: a highly accurate and explainable deep learning classifier that validates 301 new exoplanets. *The Astrophysical Journal*, 926(2), 120.

Wang, X., 2022, Exoplanets - Exploring the Starry Sea Beyond the Earth. *International Space Science Institute - Beijing*, 11.