Analysis of Searching for Another Earth in Universe-Habitability for Exoplanet

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Abstract: The search for habitable exoplanets has been quite a hot discussion over the past decades, driven by the natural curiosity of human to know the universe and to look for a second habitat. This study evaluates the possibility of discovering Earth-like exoplanets by generalizing the current findings of exoplanets, synthesizing knowledge on habitability parameters, detecting methods both commonly-used, "classical" ones like transit and new emerging ones like artificial intelligence, and searching results of habitable exoplanets. The study also focuses on the habitable zones of exoplanets, and analyses on popular candidates for habitability like TRAPPIST-1e, Proxima Centauri b and Kepler-452b by comparing their features to the parameters of exoplanets. It is also stated clear that there are persisting challenges in the search for another Earth in technological aspect and knowledge aspect. To put in a nutshell, this essay tries to analyse the possibility to find an Earth-like planets which can carry humanity as well as lays the groundwork for future space detections and further understanding of universe.

1 INTRODUCTION

There has been an on-going puzzle about the place in the universe. The firm and television industry made thousands of movies on imaginary livings outside the solar system to fascinate generations after generations on searching for exoplanets which are habitable for holding lives, even for mankind. Due to the natural urge for knowing the unknown in humanity, explorations of exoplanets became a phenomenal activity and a topic of conversation and research in various fields of study on different levels (Howell, 2020). The searching of exoplanets started since the last century, and over the years, the number of exoplanets discovered augmented significantly. Beginning in 1992 with the discovery of a planet with a relatively small mass, there are all together thousands of exoplanets found now in 2025. Thus, the discovery of exoplanets can be considered as "a triumph of ingenuity in observational astronomy" (Wilkinson, 2016).

Discovering exoplanets made great contributions to the understanding of planetary formation. Theories evolved through studying systems of exoplanets, such as core accretion, revealing dynamic processes including planetary migration which is driven by gravitational forces that reshape systems over a period. Simultaneously, the discoveries point out a possibility for life since increasing numbers of exoplanets have been "found at larger distances", "temperate for having liquid water", and are "habitable for life" (Lee, 2018). Therefore, the searching for exoplanets plays a crucial role in the exploration of another earth-like planet which will be discussed in later content.

Over the past decade, the search for exoplanets has refreshed the understanding of planetary systems beyond Solar System. The Kepler mission which is launched in 2009, succeeded to identify more than 4,000 confirmed exoplanets, with a significant fraction among them that reside in the habitable zone of their host star (Fressin, et al., 2013). This statistical result verified prevalence of small exoplanets, which have a radius between one to four times of Earth's, challenging previous doubts on the diversity of planetary system.

In 2018, NASA's Transiting Exoplanet Survey Satellite, also known as TESS, extended research for exoplanets by conducting a survey on about 85% of the sky and detected thousands of new exoplanets in the habitable zone, including planets close to bright, nearby stars. Notable discoveries of TESS include a super-Earth, a planet more massive than Earth yet

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lighter than ice giants, in the Pi Mensae system as well as a rocky planet in the habitable zone of the M-dwarf TOI-700 (Huang, et al., 2018; Gilbert, et al., 2020). These findings highlighted the potential of Earth-like worlds to exist in different stellar environments.

Ground-based follow-up observations and archival data analysis further enriched human's knowledge of "candidates" of another Earth. For instance, radial velocity measurements, which will be introduced in detail in the later essay, confirmed the masses of TESS candidates, and distinguished gaseous giants from rocky bodies. In addition, atmospheric studies using the Hubble and Spitzer space telescopes implied that there is water vapor and clouds in the atmosphere of sub-Neptune, although the definite biological signature of them remains elusive. Human also witnessed a paradigm shift toward characterizing planetary populations and distribution in researches done in this decade. Analyses revealed that nearly every star hosts at least one planet, and compact multi-planet systems are common. These insights have revolutionized previous theories on planetary formation and abundance of potentially habitable worlds in the universe. For further development in the future, there are upcoming missions such as the James Webb Space Telescope which promise to depict exoplanet atmospheres in unprecedently reached detail, while other large-scale surveys aim to catalog Earth simulations. The discoveries in the past ten years established a foundation for settling the big problem of humanity mentioned above. Given the Earth's finite resources, space colonization is an alternative that human must attach attention to. This paper will evaluate the feasibility of discovering an Earth-like planets—planets with conditions akin to Earth and can support human life. Human must be aware of such research, which is vital not just for a specific field of study, but for securing humanity's future and preparing for the ultimate time when Earth can no longer sustain human.

To be specific, the following study will successively elaborate on the definition and features of habitable planets, the approach and results on searching for habitable exo-planets, and the limitations of the current methodology and technology.

2 HABITABILITY PARAMETERS

In order to find an exoplanet that can carry human life, it must be first identified clearly that what such a planet is like. The ability of a planet that is able to support activities of "at least one know organism" is called habitability (Cockell, et al., 2016). Here, this study must state clearly the difference between an earth-like planet and a habitable planet, since they are not necessarily the same, and that there's no affiliation between the two concepts. Earth-like planets, for example Kepler-452b, are rocky celestial bodies with an earth-like size in habitable zones, while habitable planets can broadly support life, with even non-earth environments such as Europa's subsurface ocean. An Earth-like planet doesn't mean it's habitable (like Venus).

Searches for habitable planets often focus on identifying whether the physical and environmental condition on the planet fits into the parameter of sustaining life. These conditions, involving the planet's gravitational strength and atmospheric composition, as well as topographical activity and climate stability—together determine whether a planet can provide a habitable environment, like maintaining liquid water, protective environments, and biochemical processes. While Earth is the main reference for habitability, new findings, like underground oceans on icy moons or other places filled with methane, are making us to now and then question what a habitable environment could be like. These discoveries show that life might exist in environments one never imagined before.

One standard included in the key parameters for habitability is the gravity. Surface gravity number of a planet normally ranges between 0.3 to 1.5 times Earth's gravity. If it's too weak, as on Mars, atmospheric loss will accelerate, resulting in extreme difference in temperature of day and nights. By the contrary, an excessively strong gravity on much larger planets might decrease biological complexity. Simultaneously, rotation rate is also an important factor of habitability since it influences climate. To be specific, extremely fast rotation, such as Jupiter's 9.9-hour day, brings violent storms, whereas slow rotation, taking Venus's 243-day cycle as an example, creates significant temperature contrasts. Last but not least, a feasible atmosphere ranges from 0.1 to 10 times Earth's pressure, with gases like CO_2, O_2, and N_2, along with other protective characteristics like ozone layers or magnetic fields to shield the surface against harmful radiation.

Temperature, on the other hand, depends on a planet's position within the habitable zone, which is defined as that range of area around a star where water can exist in liquid form. The Earth orbits within the Sun's habitable zone, for instance. Yet, even within this zone, factors like atmosphere composition and greenhouse effects can modify thermal conditions at a large extent. Venus, though lying close to the inner edge of the Sun's habitable zone, experiences a runaway greenhouse effect and has surface temperatures exceeding 450°C, attributed by its thick CO_2 atmosphere.

Atmospheric composition is another determinant of habitability. Oxygen or chemical imbalance might suggest livings, while CO_2 is able to ensure heat and liquid water on the planet. However, more research on "the interior dynamics and evolution of the solid planet" and its relationship with the atmosphere, and this includes pursuing "experimental and modelling constraints on the interactions between the atmosphere and interior over long time scales" (Kane & Gelino, 2012).

3 PLANET SEARCHING APPROACHES

Searching for exoplanets revolutionized human's knowledge of the universe above them, using both established and common techniques and innovative ones which are developed in recent years. Below, the essay would list some of these approaches that had helped human detect exoplanets, and these methodologies play a crucial role in the possibility to find another Earth in the planetary system.

According to NASA's data, the transit method has successfully detected more than 4000 exoplanets including Earth-sized candidates in habitable zones, significantly exceeding all other methods, and it is often employed by missions like Kepler Space Telescope and TESS. To be specific, this method detects planets by observing periodic dips in a star's brightness when another planet passes in front of it, and the depth of the light curve dip is correspondent to the planet's size relative to the star. Multiple transits would be able to confirm the planet's orbital period. Transit is highly efficient to studies of searching for exoplanets, indicated by the number of planets it found. However, it restraining stays clear: it is limited to short- to moderate-period orbits for signal frequency able for detection.

It's the second-most used technique and has detected more than 1000 exoplanets. This technique measures the Doppler shifts in a star's spectral lines caused by tis gravitational interactions with orbiting planets. By detecting these shifts, scientists can infer planetary mass and orbital periods. In fact, the method led to the first confirmed exoplanet, 51 Pegasi b, a hot Jupiter orbiting its host star in just 4.2 days. It limitations sate clear that while its highly effective for identifying massive planets close to their stars, it struggles with planets with lower mass and longer period.

Direct imaging focuses on emitting photons or photons reflected by planets by using coronagraphs to block stellar glare. The advantage of the method is that its most effective for searching for massive planets separate from their host stars in wide orbits. Noted examples include the JWST, also known as James Webb Space Telescope, which recently imaged the HR 8799 system and resolved four gas giants as well as analysed their atmospheric carbon dioxide signatures. A historic milestone was achieved in 2004 when Very Large Telescope (VLT) was employed at Paranal Observatory, Chile, to directly image 2M1207b as shown in Fig. 1, the first exoplanet confirmed via this method (Dai et al., 2021).

Gravitational microlensing can detect exoplanets by making use of the gravitational field of a foreground star or star-planet system as lens which could bend and amplify light from a background star, and it creates a temporary brightening. When a planet is present, it introduces detectable anomalies in the light curve like brief spikes or asymmetries. This method is most useful at finding low-mass planets (including Earth-sized), wide-orbit planets, and free-floating worlds, independent of the light emitted by the planet. Notable discoveries include OGLE-2003-BLG-235Lb: it is the first microlensing exoplanet in history.

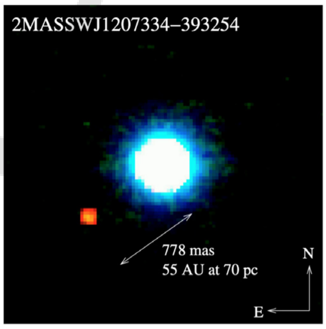

Figure 1: The CCD frame of 2M1207b (Dai et al., 2021).

The study introduces a novel approach to find exoplanets by using AI, specifically CNNs (convolutional neural networks), to solve the drawbacks of earlier methods like least-squares optimization and matched filtering. Traditional techniques are highly dependent on hand-coded metrics, struggling with noise and stellar variability, which set a barrier especially for Earth-sized planets with shallow transits. Researchers train a CNN on identifying simulated light curves and incorporating diverse planetary parameters like orbital periods and transit depths and use systematic noise to mimic stellar variability and instrumental effects. The CNN learns transit features directly from data, and avoids establishing dependence on predefined models. Compared to methods like support vector machines and box least-square, the CNN achieves much higher accuracy (which is about 99.7% in training and 91.5% in testing) and robustness in noisy conditions, particularly for signals near or below the noise floor. The CNN's performance stays stable even when it's applied to interpolated or incomplete data, demonstrating its ability to generalize. Validated on Kepler mission data, this approach successfully identifies known exoplanets and predicts their orbital periods by analysing phase-folded light curves. It's highlighted that the CNN is highly potential for future surveys like TESS and PLATO, in which automated, efficient processing of large datasets is essential (Pearson, et al., 2017).

Traditional methods like transit and radial velocity are still mainstream of exoplanet research, while innovative technique, including spanning radio astronomy, relativistic optics, and AI, are expanding frontiers in this field of study. Together, they enhance human's ability to look for Earth-like worlds and unravel planetary diversity. Future missions like the Habitable Worlds Observatory aim to synthesize these approaches and target atmospheric biosignatures and refining the cosmic context as well.

4 SEARCHING RESULTS

The first confirmed detection of an exoplanet in 1995, and since then the field of astronomy has experienced remarkable growth, with over 5,500 exoplanets having been identified until April 2025 according to NASA Exoplanet Archive. Early discoveries are mainly attentive on depicting of worlds beyond solar system, but recently there has been a shift toward identifying planets with potential habitability because of the natural curiosity towards finding another Earth mentioned before. This kind of exoplanets found must support Earth-like life, so that it had the possibility to provide humanity with a new habitat.

Defining Habitability: Key Parameters

Among all the exoplanets that scientists found, approximately 50-60 are located within their stars' habitable zones. These are potentially temperate worlds and they vary widely: some may have Earth-like surface temperatures which is 0–30°C if they hold atmospheres with greenhouse gases, and others orbit stars alike to the sun and might have stable climates, but with uncertain properties like gaseous or rocky. A large number of planets in habitable-zone orbit red dwarfs, who set challenges like tidal locking and stellar flares, and may affect climate stability. Future studies would focus on refining models of the unstable environments. The following passage would introduce some examples of the candidate exoplanets of "the second" Earth.

TRAPPIST-1 is 40 light-years away for Earth in the constellation Aquarius. It has gained wide notice as in 2017 seven exoplanets were announced to be found Earth-sized (Gillon, et al., 2017). Among the seven, TRAPPIST-1e, detected in 2016) orbits within the star's habitable zone, making it a competitive candidate for habitability. The red dwarf is an ultra-cool red dwarf, and is dramatically dimmer and cooler than the Sun so the habitability zone is shifted much closer to the star. TRAPPIST-1e's mass is of 0.69 Earth masses and its radius is of 0.91 Earth radii, demonstrating a rock composition similar to Earth.

Modelling shows that the star TRAPPIST-1e, under the assumption of a 1-bar nitrogen-oxygen atmosphere, has a stellar flux comparable to Earth (Wolf, et al., 2017). Not beyond that, the star's low luminosity determines the planet, however, to be most probably tidally locked, that is to say one hemisphere turns face to the star all the time, whereas the other is left in permanent darkness. Although such conditions could result in very sharp temperature differences, that would probably be prevented with the strong climate circulation which the latest models predict. As for characterization of the atmosphere, the planet's discovery is more challenging since the star is very faint. Planets with the same mass as Earth or heavier positively correspond with the conditions required for life. Several JWST missions are likely to address such topics.

Proxima Centauri b, another well-known exoplanet, is situated at a distance of 4.2 light-years from the Sun in 2016 and orbits a star named Proxima Centauri, which is the closest stellar companion to the solar system. Going in the same orbit with this M5.5V red dwarf, this planet is heavier than Earth (at least 1.07 times). Besides that, Proxima b is situated at the distance from the star that is at least an order of magnitude shorter (only 0.05 astronomical units), which means that the planet can complete an orbit around the star in 11.2 days. Being right under the star, Proxima b is subjected to acting tremendous stellar flares, which could at some point strip away its atmosphere. Nevertheless, probably Proxima b is superior to Earth: it has the same mass as Earth, is in the habitable zone, and is the primary ground for studies to find new habitable world.

By means of a spectroscopic analysis, the atmosphere of the world has not been explored yet. However, there is theoretical implication if Proxima b has a lead shield and a thick atmosphere, it could keep enough gases so that there was liquid water on its surface. The article, which is dated back to 2020, and which also belongs to the residing in the original findings, simulated various climates of Proxima b and concluded that the atmosphere of that world must be composed predominantly of CO_2, otherwise the average surface temperature would range between the values of 0 and 40 degrees Celsius, which is optimal for supporting the existence of surface water. Consequently, fluctuations in stellar flares activity still pose a threat factor for Proxima b. On the other hand, it is much easier to monitor Proxima b compared to other exoplanets, since the distance and position let further investigations (Anglada-Escudé, et al., 2016).

Kepler-452b was initially discovered in 2015 (by the Kepler Space Telescope) and orbits a star of the G-type category at the distance of 1,800 light-years. This planet is 1.6 times bigger in its radius and estimated five times heavier than Earth, so it can be classified as a super-Earth. With 385 days of the orbital period, this planet is just touching slightly the sphere of the habitable zone of its star, so, it is getting 10% more energy from it. This possibility stands for the theory that it has liquid water on the surface, but its bigger size and mass give the hint that there is the dense atmosphere or the surface cover by ocean or sea. Super-Earths are no selecting criteria for habitability, however, the discovery of Kepler-452b and planets similar to it as a class of exoplanets indicates the tendency to search potentially habitable planets around the Sun-like stars. The planet is to Earth as humans are to the "good enough" planet, with which one has so much in common, from the respective orbital periods to the neighbouring states (of a government type), Planet Earth.

5 LIMITATIONS & PROSPECTS

It must be admitted that there are limitations rooted in rather narrow observations and inadequate assumptions. Most exoplanets, including those in habitable zones, are detected indirectly through methods like transit or radial velocity, so the data isn’t complete on aspects like surface conditions, atmospheric composition, and geological activity. Take TRAPPIST-1e and Proxima Centauri b for an example, although they are both candidates for habitability, they have close proximity to faint red dwarfs and intense stellar flares, and it hinders detailed characterization in atmosphere. On top of that, the definition of "habitability" is only generated dependent on Earth-like parameters such as liquid water, and an atmospheric construction of mainly nitrogen and oxygen, overlooking other exotic environments where human life might thrive.

In the future, progress must keep an eye on technology leaps and try to expand the knowledge of scientific frameworks. Missions like the James Webb Space Telescope make direct inspection of exoplanet atmospheres possible, and are capable of detecting biosignatures on planets like TRAPPIST-1e. Innovative, next-generation telescopes would be more precise in measuring planetary mass and radius as well as clarifying compositions of super-Earths like Kepler-452b. Meanwhile, astrobiology must evolve to move to consideration of broader habitability like subglacial oceans, radiation-tolerant ecosystems, or non-habitable-zone liquid water. Climate models and geological processes will better assess whether long-term habitability exist, which is better than static classifications on the habitable zone because it’s more dynamic and straight-forward. These advancements would help enhance the chance of finding a real second habitat for human.

6 CONCLUSIONS

In conclusion, this study analysed the viability of finding Earth-like exoplanets through continuously improving detection methods and habitability frameworks. Key findings include the discovery of 50–60 exoplanet candidates, in habitable zone, use examples including TRAPPIST-1e, which is tidally locked with potential atmospheric heat redistribution, Proxima Centauri b with atmospherically resilience in spite of stellar flares, and Kepler-452b, a super-Earth in a Sun-like system. What’s more, the essay demonstrates breakthroughs in detecting methods from transit to artificial intelligence which achieved more 90% accuracy. Yet, limitations such as incomplete atmospheric data and constrained concept of habitability parameter assumptions have acknowledged gaps in human’s current knowledge. Future missions like the JWST will prioritize solving problems of atmospheric biosignatures and improve habitability standard to more precisely identify habitable planets. This work not only refines humanity’s search for extraterrestrial life but also generalized and laid critical groundwork for sustainable interstellar colonization ahead, providing a trustable answer for both curiosity of human and the need to secure humanity's future beyond Earth.

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