https://doi.org/10.70882/8hfc1k08

SCIENCE FORUM (JOURNAL OF PURE AND APPLIED SCIENCES) 26, (5 Special) (2026), 320 - 329

Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: https://atbuscienceforum.com.ng/index.php/jpas

Exoplanet Detection Methods, Diversity, and the Search for Habitable Worlds

Imad Kamil Zayer

Physics Department, College of Science, Wasit University

Abstract

An exoplanet is a planet which is orbiting a star other than the Sun. Exoplanet research has grown quickly since the first exoplanet was discovered around a star like the Sun in 1995. In the NASA Exoplanet Archive, as of 15 October 2026, there were 6,451 exoplanets confirmed, with over 1,000 of those being found by the Transiting Exoplanet Survey Satellite (TESS). This review discusses the main approaches employed to discover these worlds and illustrates how various techniques are involved in the discovery and study of these worlds. It also explores planetary diversity, understanding of planetary atmosphere and the concept of the habitable zone, which plays a crucial role in the discussion of potentially life-sustaining planetary environments. These topics together give a picture of what an exoplanet is, and how it can be judged for its potential habitability. The review also concludes that future space missions and better spectroscopic observations will be needed to explore planetary atmosphere, create a more complete picture of distant worlds and evaluate the potential of some exoplanets for being habitable, a view they acknowledge is limited by existing evidence.

Keywords

Exoplanets;
Transit Photometry;
Radial Velocity;
Microlensing;
Direct Imaging;
Habitable Zone;
Atmospheric Characterization;
Astrobiology.

EISSN: 3156-5190 (Online)
ISSN: 1119-4618 (Print)
JPAS
Faculty of Science, ATBU Bauchi

Corresponding Author: Imad Kamil Zayer, Physics Department, College of Science, Wasit University. Email: ealrobeiy@uowasit.edu.iq

© 2026 Faculty of Science, ATBU Bauchi. All rights reserved

1. Introduction

In astronomy, extrasolar planets are planets that orbit stars other than the Sun, and the physical processes that link these planets and the star they orbit (OpenStax, 2022). Throughout most history planets around the Solar System were merely theories; present-day, thousands of planets beyond the Solar System have been confirmed based on ground and space-based observations (NASA Exoplanet Archive 2026a, 2026b).

The first discovery of planets orbiting a pulsar was made in 1992 (Wolszczan & Frail, 1992) and the discovery of the planet orbiting 51 Pegasi in 1995 (Mayor & Queloz, 1995) demonstrated that giant planets can orbit a Sun-like star very close (Wolszczan & Frail, 1992; Mayor & Queloz, 1995). The resulting findings were found to conflict with the previous models of planet formation, which had been mostly related to the planetary architecture of the Solar System (Raymond & Morbidelli, 2022).

As of this writing there are over 6000 known planets beyond the Solar System, and the Milky Way is thought to contain billions of planets (NASA, 2023, 2026b). This is a lot, and so raises the big question: how often do planets form? What makes planets of all kinds? What are the conditions necessary for a planet to be able to sustain liquid water and life? (NASA, 2020a, 2021).

This review addresses three questions:

- What are some means of observing exoplanets and what have they taught us about their characteristics?
- What are the types of planets discovered and what do these tell us about the formation of planets?
- How to determine the habitability of exoplanets?

2. Detection Methods

Measuring a planet's brightness is challenging due to the relative brightness of the host star, and the faintness of the exoplanet. All the most common forms of detection are indirect, such as the periodic dimming, Doppler shifts, gravitational lensing and timing changes (Perryman, 2018; Seager, 2010; Gaudi, 2012).

2.1 Transit Photometry

The transit method is based on the observation of a small dimming of the stellar light, during its passage across the stellar disk as seen by the observers on Earth. The ratio of planetary to stellar radius is the most important factor in determining the transit depth, and the time between transits is used to determine the orbital period (Perryman, 2018; Charbonneau et al., 2000). With the radius of the star known the radius of the planet can be determined, and with mass, density and composition constraints (ESA, 2019; Perryman, 2018).

The Kepler mission tracked over 150,000 stars, and found thousands of planet candidates (Borucki et al., 2010). TESS used this approach to systematically survey bright stars for the entire sky, for detailed follow-up studies (Ricker et al., 2015). ESA's CHEOPS mission is an Earth- or Neptune-size planet photometer of known host planets (ESA, 2019, 2026).

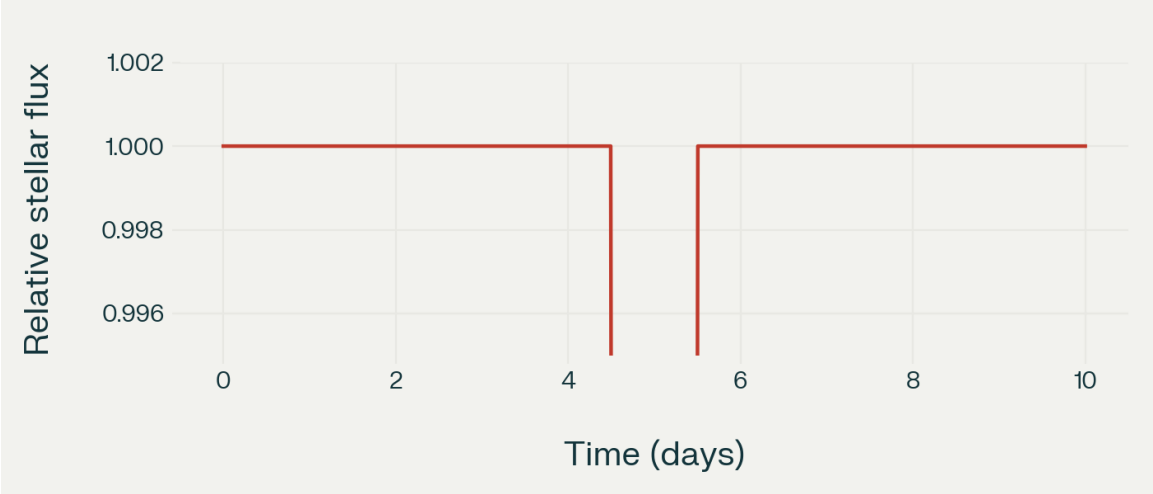


Figure 1. Schematic transit light curve. The brief decrease in brightness occurs when a planet passes in front of its host star (Perryman, 2018; Charbonneau et al., 2000).

2.2 Radial Velocity

Using the radial velocity method, Doppler effects in the spectral lines of stars due to the gravitational effect of a planetary orbiting companion can be measured. The amplitude and period give some minimum mass and period of the planet (Perryman, 2018, Seager, 2010, Mayor & Queloz, 1995).

It is an approach that led to the discovery of 51 Pegasi b, the first planetary system with planets orbiting a Sun-like star (Mayor & Queloz, 1995). Radial velocity is best for massive planets on short-period orbits, but is less sensitive to planets with low masses on longer-period orbits (Perryman, 2018; Seager, 2010).

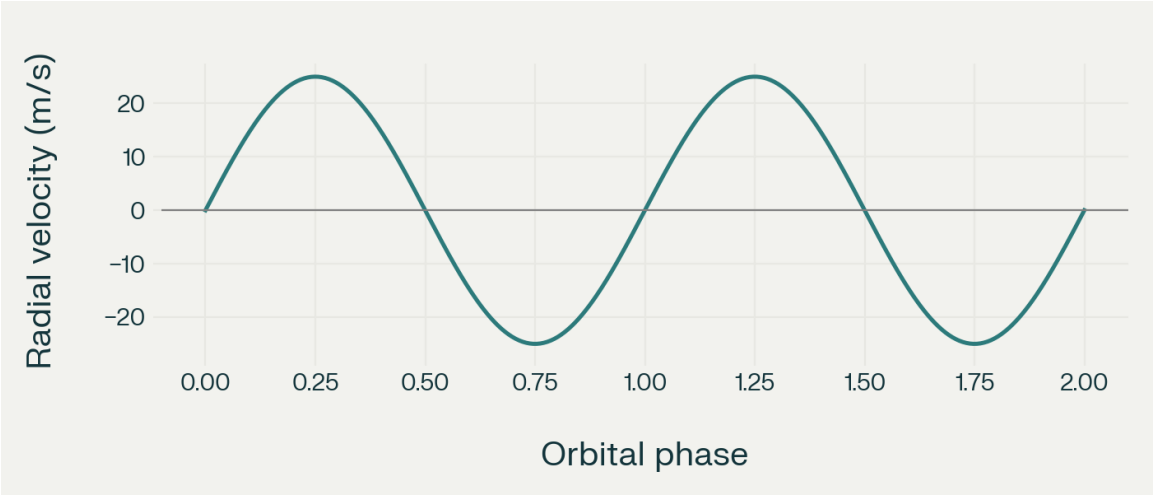


Figure 2. Schematic radial-velocity curve. The star's periodic motion produces alternating blueshifts and redshifts (Perryman, 2018; Seager, 2010).

2.3 Gravitational Microlensing

Gravitational microlensing is a temporary magnification of the light from a more distant background star by the gravity of a foreground star. A planet orbiting the foreground star can create an

additional short-lived anomaly in the light curve (Perryman, 2018; Gaudi, 2012).

The sensitivity of microlensing is such that it can detect planets more than several kiloparsecs away from the Earth, and it is sensitive to planets at large orbital separations. Most of the time, though, the alignment occurs only once and is hard to follow up with characterization (Perryman, 2018; Gaudi, 2012).

2.4 Direct Imaging

Direct imaging involves using coronagraphs, adaptive optics and high-contrast imaging systems to isolate the light from the planets from the light of the star. Young, massive planets in wide orbits are best suited for this method due to the fact that planets are still warm from their formation and they emit strongly in infrared wavelengths (Perryman, 2018; Gaudi, 2012; NASA, 2020b).

Direct imaging allows planet brightness, color, orbit and in some cases atmosphere properties to be measured. However, it is still biased, in favor of large planets located far from their star, over earth-like planets orbiting closer to their star (Perryman, 2018; NASA, 2020b).

2.5 Astrometry and Timing Methods

Astrometry involves measuring the minute change in the position of a star as a result of a planet orbiting it. While it is challenging, it can deliver true planetary masses and orientations to the orbit, alongside radial-velocity measurements (Perryman, 2018; NASA, 2020b).

Timing methods are used to identify periodic time shifts in the arrival times of pulsar pulses or eclipses in a compact binary system. Pulsar-timing variations (Wolszczan & Frail, 1992) were used to detect the first extrasolar planets around a pulsar. The following techniques are used for special systems, but show that planets can form in extreme environments (Perryman, 2018; Wolszczan & Frail, 1992).

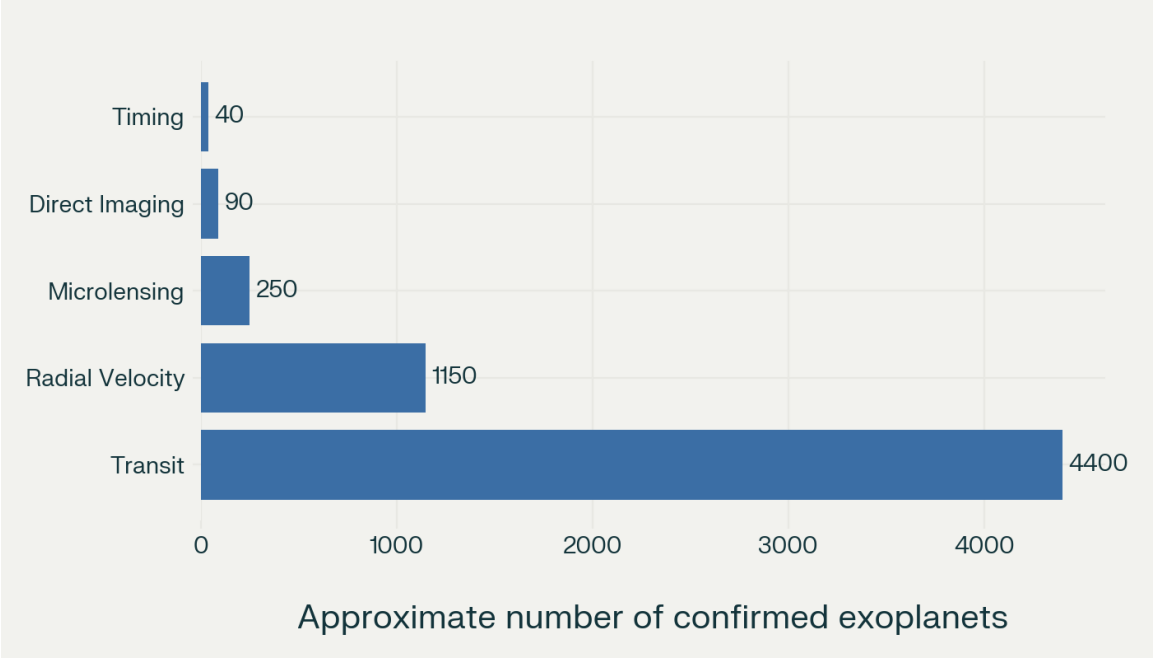


Figure 3. Approximate relative contribution of major exoplanet detection methods. Transit photometry and radial velocity account for most confirmed discoveries; values are illustrative (NASA Exoplanet Archive, 2026a; Perryman, 2018; Ricker et al., 2015).

Table 1. Comparison of Exoplanet Detection Methods

Method	Observable signal	Best suited for	Main measurements	Main limitation
Transit photometry	Periodic decrease in stellar brightness	Close-in planets with edge-on orbits	Radius, orbital period, atmosphere	Requires favorable orbital alignment
Radial velocity	Doppler shifts in stellar spectra	Massive close-in planets	Minimum mass, orbital period	Difficult for small, long-period planets
Microlensing	Temporary magnification of background starlight	Distant and wide-orbit planets	Mass ratio, projected separation	Usually non-repeatable
Direct imaging	Light from the planet itself	Young, massive, wide-orbit planets	Brightness, orbit, atmosphere	Low sensitivity to Earth-like planets
Astrometry	Small positional motion of the star	Nearby systems	True mass and orbit	Extremely small signals
Timing methods	Variations in pulse or eclipse timing	Pulsars and compact binaries	Planet mass and orbit	Limited to special systems

3. Exoplanet Diversity and Classification

The Solar System is far from representative in the world of exoplanets. These are generally terrestrial planets, super-Earths, mini-Neptunes, gas giants and hot Jupiters (Raymond & Morbidelli, 2022; Fulton et al., 2017). Some systems have planets with orbital periods and sizes that are not found in the Solar System, indicating that formation and migration can yield a variety of outcomes (Raymond & Morbidelli, 2022; Fulton et al., 2017).

Hot Jupiters are Jupiter-mass planets that orbit very close to their stars, and were unexpected because the snow line (Mayor & Queloz, 1995) was thought to be a limit on the formation of giant planets. (Raymond & Morbidelli, 2022) Super-Earths and mini-Neptunes are also very popular, but there are no planets in the Solar System of this size (Fulton et al., 2017; NASA, n.d.-a).

Table 2. Major Exoplanet Types

Type	Approximate size or mass	Typical characteristics
Terrestrial planet	Rocky, Earth-sized or smaller	Solid surface possible; may retain an atmosphere
Super-Earth	Larger than Earth, smaller than Neptune	Rocky or volatile-rich composition
Mini-Neptune	Between Earth and Neptune	Thick gas envelope likely

	in size	
Gas giant	Jupiter- or Saturn-like	Mostly hydrogen and helium
Hot Jupiter	Jupiter-sized, close-in orbit	High temperature and short period
Circumbinary planet	Orbits two stars	Complex orbital dynamics
Rogue planet	Not bound to a star	Drifts through interstellar space

The distribution of planet sizes shows that planets between Earth and Neptune are particularly prevalent, although observational bias makes smaller planet and longer orbital period planets more difficult to find (Borucki et al., 2010; Ricker et al., 2015; Fulton et al., 2017). These biases need to be corrected when estimating the true abundance of Earth-like planets (Borucki et al., 2010; Fulton et al., 2017).

4. Atmospheric Characterization

The characterization of the Earth's atmosphere is the next step after discovery and is a large undertaking as well. A tiny amount of starlight goes through the atmosphere of the planet and produces special features in the spectrum that provide clues to what the atmosphere is composed of (NASA, 2025a, 2025b; NASA, 2022).

Transmission spectroscopy is one method that the James Webb Space Telescope will use to detect water vapor, carbon dioxide, methane, and sulfur dioxide in exoplanet atmospheres (NASA, 2025a, 2025b, 2022). The researchers compare the spectrum of the star on the transit with the spectrum taken off the transit and the difference in the wavelengths is what is absorbed by the planet's atmosphere (NASA, 2025a, 2022).

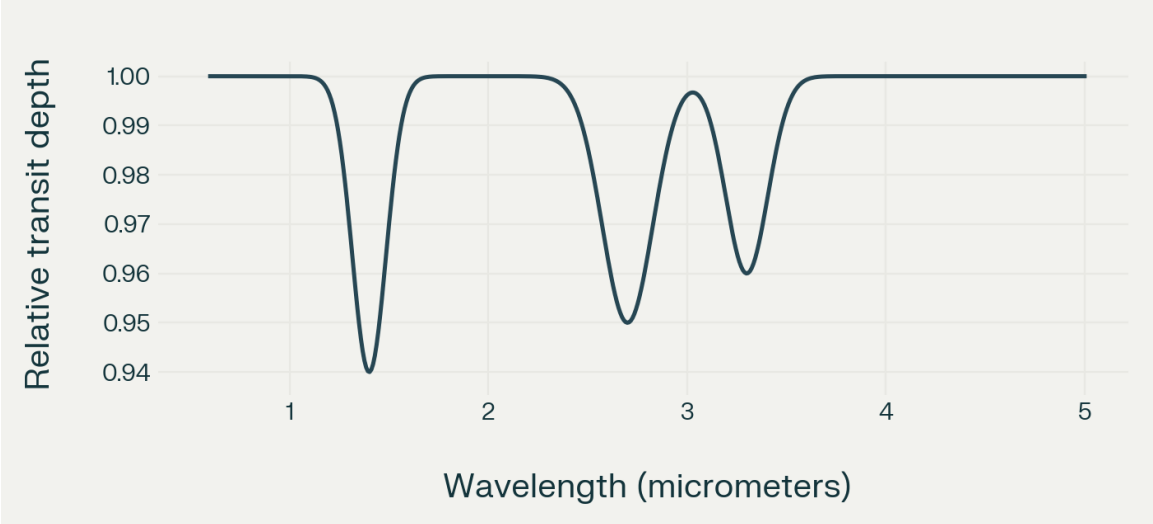


Figure 4. Schematic transmission spectrum. Dips at particular wavelengths represent absorption by atmospheric molecules (NASA, 2025a, 2025b, 2022).

Observations in the atmosphere can help limit the temperature, the presence of clouds, the composition (metallicity) of the atmosphere, and the photochemical processes. But the presence of a single molecule does not prove that life exists, as many molecules can be created biologically or non-biologically (NASA, 2020c, 2021; Seager, 2019). Researchers are thus looking for mixtures of gases and conditions that don't lend themselves to a non-biological explanation (NASA, 2020c; Seager, 2019).

5. The Habitable Zone

The Goldilocks zone, or habitable zone, is the region around a star in which a planet has the potential to have liquid water on its surface, provided that the orbiting planet has an atmosphere that is appropriate for maintaining these conditions (NASA, 2020a; Kasting et al., 1993). The boundaries are based on luminosity and temperature of the star; they are further away from hot, luminous stars and nearer to cool, low-mass stars (NASA, 2020a; Kasting et al., 1993).

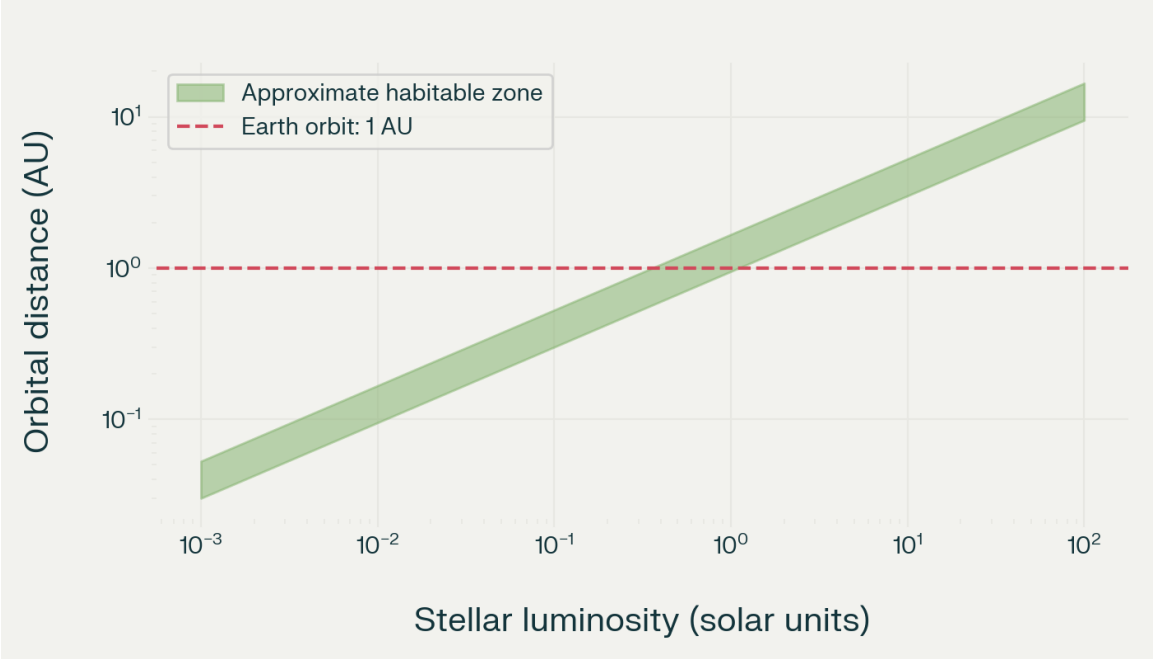


Figure 5. Schematic habitable zone as a function of stellar luminosity. More luminous stars have habitable zones at larger orbital distances (NASA, 2020a; Kasting et al., 1993).

The habitable zone can be used to determine targets but it is not an indicator of habitability. The planet must also have enough atmospheric pressure, a stable climate, water, radiation protection, and carbon and other cycling geological processes (NASA, 2020a, 2020c, 2021).

There are opportunities and threats in red-dwarf systems. Although they're near the star where planets are easier to see, planets in their habitable zones may suffer from the effects of strong flares from their star and lose their atmospheres (NASA, 2020c, 2021; ESA, n.d.). Planets with orbits in the habitable zone around Sun-like stars orbit over a longer time and the transit signal is weaker (Kasting et al., 1993; ESA, n.d.).

Table 3. Factors Affecting Exoplanet Habitability

Factor	Relevance to habitability
Orbital distance	Controls whether surface water can remain liquid
Stellar luminosity and type	Sets the location and width of the habitable zone
Planet mass and radius	Affects gravity, atmospheric retention, and interior evolution
Atmospheric composition	Regulates greenhouse warming and surface temperature
Water availability	Essential for life as currently understood
Magnetic field	May reduce atmospheric loss from stellar wind
Stellar activity	Flares and radiation can damage atmospheres
Orbital stability	Needed for long-term climate stability
Geological activity	Supports carbon cycling and long-term climate regulation

6. Current and Future Missions

Exoplanet science has gone through a revolution in space missions. Kepler showed that planets less than 10 Earth masses are very common, TESS will find planets orbiting bright nearby stars, and CHEOPS will accurately measure the size of known planets (ESA, 2019, 2026, Borucki et al., 2010, Ricker et al., 2015).

The ESA mission PLATO will look for rocky planets around Sun-like stars in the habitable zones, and will conduct stellar oscillations studies to further improve estimates of stellar properties (ESA, n.d.-a). The design of Ariel is to undertake a chemical census of a wide range of exoplanet atmospheres by transmission spectroscopy (ESA, 2023, n.d.-b).

The James Webb Space Telescope has already begun to deliver a wealth of atmospheric spectra, particularly of hot giant planets and sub-Neptunes (NASA, 2025a, 2025b, 2022). Future telescopes will expand these measurements to even smaller, cooler planets and even ones that resemble the Earth (NASA, 2020b; Seager, 2019; ESA, n.d.).

7. Challenges

While significant strides have been made, there are still several challenges to overcome (Perryman, 2018; NASA, 2020c; Borucki et al., 2010; NASA, 2020b):

The shallow transit signals for Earth-sized planets are extremely difficult to detect, requiring extremely stable photometry (Borucki et al., 2010; Ricker et al., 2015).

False transit-like signals may be generated by instrumental systematics and by stellar activity and eclipsing binaries (Perryman, 2018; Charbonneau et al., 2000).

The chief limitations of radial-velocity measurements are stellar jitter, and the time required to observe far-out orbits (Perryman, 2018; Seager, 2010).

The first challenge to be addressed by direct imaging is the huge brightness contrast between a star and a planet (Perryman, 2018; NASA, 2020b).

Ambiguous atmospheric biosignatures may arise due to abiotic processes which can generate the same gases (NASA, 2020c; Seager, 2019).

Surface habitability can be determined only by the location of the habitable zone (NASA, 2020a, 2020c, 2021).

8. Conclusion

The search for planets has confirmed that planets occur widely, in a range of types and around a diverse group of stars. Transit photometry and radial velocity have been the most successful methods, with most confirmed planets being found with these techniques, and microlensing, direct imaging, astrometry, and timing bring detection to systems which are not easily accessible with other techniques.

The concept of the habitable zone still plays a key role as it helps to locate the orbits where liquid water might be found on the surface of a planet. But the habitability requires a wider range of conditions such as the composition of the atmosphere, geological activity, the environment of the stars and climate stability. This will advance the science of characterizing exoplanet atmospheres and biologies into the future observatories.

References

Borucki, W. J., Koch, D., Basri, G., et al. (2010). Kepler planet-detection mission: Introduction and first results. Science, 327(5968), 977–980. https://doi.org/10.1126/science.1185402

Charbonneau, D., Brown, T. M., Latham, D. W., & Mayor, M. (2000). Detection of planetary transits across a Sun-like star. The Astrophysical Journal, 529(1), L45–L48. https://doi.org/10.1086/312457

European Space Agency. (2019). CHEOPS: ESA's first exoplanet mission. https://sci.esa.int/web/cheops/-/61088-cheops-esa-s-first-exoplanet-mission

European Space Agency. (n.d.-a). Exoplanets. https://www.esa.int/Science_Exploration/Space_Science/Exoplanets

European Space Agency. (n.d.-b). CHEOPS. https://www.esa.int/Science_Exploration/Space_Science/Cheops

European Space Agency. (n.d.-c). PLATO: Revealing habitable worlds around Solar-like stars. https://sci.esa.int/web/plato

European Space Agency. (n.d.-d). Ariel. https://sci.esa.int/web/ariel

European Space Agency. (n.d.-e). Life on exoplanets? https://www.esa.int/Science_Exploration/Space_Science/Exoplanets/Life_on_exoplanets

Fulton, B. J., Petigura, E. A., Howard, A. W., et al. (2017). The California-Kepler Survey. III. A gap in the radius distribution of small planets. The Astronomical Journal, 154(3), Article 109. https://doi.org/10.3847/1538-3881/aa80eb

Gaudi, B. S. (2012). Microlensing surveys for exoplanets. Annual Review of Astronomy and Astrophysics, 50, 411–453. https://doi.org/10.1146/annurev-astro-081811-125518

Kasting, J. F., Whitmire, D. P., & Reynolds, R. T. (1993). Habitable zones around main sequence stars. Icarus, 101(1), 108–128. https://doi.org/10.1006/icar.1993.1010

Mayor, M., & Queloz, D. (1995). A Jupiter-mass companion to a solar-type star. Nature, 378, 355–359. https://doi.org/10.1038/378355a0

NASA. (n.d.-a). The habitable zone. https://science.nasa.gov/exoplanets/habitable-zone/

NASA. (n.d.-b). How we find and characterize exoplanets. https://science.nasa.gov/exoplanets/how-we-find-and-characterize/

NASA. (n.d.-c). Can we find life? https://science.nasa.gov/exoplanets/can-we-find-life/

NASA. (n.d.-d). Life in the universe: What are the odds? https://science.nasa.gov/universe/exoplanets/life-in-the-universe/what-are-the-odds/

NASA. (2022). Exoplanet WASP-39 b transmission spectra. https://science.nasa.gov/asset/webb/exoplanet-wasp-39-b-transmission-spectra/

NASA. (n.d.-e). Exoplanets. https://science.nasa.gov/exoplanets/

NASA. (n.d.-f). How will Webb study exoplanets? https://science.nasa.gov/mission/webb/science-overview/science-explainers/how-will-webb-study-exoplanets/

NASA. (n.d.-g). Webb's impact on exoplanet research. https://science.nasa.gov/mission/webb/science-overview/science-explainers/webbs-impact-on-exoplanet-research/

NASA Exoplanet Archive. (n.d.-a). Confirmed planets. California Institute of Technology. https://exoplanetarchive.ipac.caltech.edu/

NASA Exoplanet Archive. (n.d.-b). Exoplanet and candidate statistics. California Institute of Technology. https://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html

NASA. (n.d.-h). Super-Earths and mini-Neptunes. https://science.nasa.gov/exoplanets/

Fraknoi, A., Morrison, D., & Wolff, S. (2022). Astronomy 2e. OpenStax. https://openstax.org/details/books/astronomy-2e

Perryman, M. (2018). The exoplanet handbook (2nd ed.). Cambridge University Press. https://doi.org/10.1017/9781108304160

Raymond, S. N., & Morbidelli, A. (2022). Planet formation: Key mechanisms and global models. In Demographics of exoplanetary systems. Springer.

Ricker, G. R., Winn, J. N., Vanderspek, R., et al. (2015). Transiting Exoplanet Survey Satellite. Journal of Astronomical Telescopes, Instruments, and Systems, 1(1), Article 014003. https://doi.org/10.1117/1.JATIS.1.1.014003

Seager, S. (2010). Exoplanets. University of Arizona Press.

Seager, S. (2019). The search for signs of life on exoplanets. Science, 365(6459), eaax4350.

Wolszczan, A., & Frail, D. A. (1992). A planetary system around the millisecond pulsar PSR1257+12. Nature, 355, 145–147. https://doi.org/10.1038/355145a0