Exoplanets discovery methods:

Radial velocity:

The radial velocity method detects exoplanets by observing the gravitational effects of a planet on its host star. This involves three main observations: changes in the star’s radial velocity (its motion toward or away from Earth), which are detected through spectral shifts (blueshift and redshift); shifts in the star’s angular position in the sky due to the planet’s gravitational pull; and variations in the timing of periodic signals, like pulsar pulses, caused by the planet's influence. Since the first exoplanet discovery in 1995, this method has been used to detect 1,075 exoplanets by early 2024.

Transit method:

The transit method, first used in 1999 with the discovery of the "hot Jupiter" system HD 209458, detects exoplanets by observing periodic dimming of a star’s brightness as a planet passes in front of it. This discovery led to the monitoring of other systems found through radial velocity surveys, shifting the focus to finding transits. This method became crucial for identifying exoplanets, especially those not initially detected by radial velocity. Surveys from space and ground-based observatories began searching for planets solely using transit light curves, significantly expanding the number of discovered exoplanets. Transiting planets provide valuable information, such as planet sizes from light curve data and planetary mass and density when combined with radial velocity measurements. These factors offer insight into the planet’s composition. By 2023, nearly 4,153 transiting exoplanets had been found, with the Kepler space observatory responsible for discovering around 2,778 of them since it began operations in 2009. Ground-based surveys like HAT and WASP have also contributed to the discovery of bright, easily detectable transiting systems. Together, these discoveries have enriched our understanding of planetary diversity beyond our solar system.

Direct imaging method:

In modern exoplanet research, imaging involves detecting a planet as a distinct source of light, either from its thermal emission or reflected light from its star. This differs from resolving surface details or observing brightness variations caused by eclipses or reflected light. First imaging detections occurred in 2005, focusing on large, young, self-luminous planets in wide orbits, with notable examples including systems like β Pic, HR 8799, and Fomalhaut.Recent advancements in imaging technology, like VLT-SPHERE, Gemini-GPI, and Subaru-HiCIAO, have improved direct imaging capabilities, though these instruments mainly capture massive, young planets. Future 30–40-meter telescopes could enable imaging of planets using reflected starlight. However, imaging Earth-like planets remains a distant goal. Additionally, expanding imaging techniques to other wavelengths, such as radio and X-rays, could offer deeper insights into star-planet interactions, enhancing exoplanetary research.

Gravitational micro-lensing:

Gravitational microlensing, based on general relativity, involves using the gravitational field of a foreground object (the lens) to bend light from a distant background source. This technique distorts the source's image and can result in multiple visuals, depending on the alignment of the source, lens, and observer. Microlensing deals with unresolved images, while macrolensing produces multiple resolved images or "arcs." By 2023, 210 exoplanets had been discovered through microlensing, which is particularly effective for detecting planets in a specific mass and orbital range. Notable discoveries using microlensing include the first detection of a 4MJ planet in 2004, a 5M⊕ planet in 2006, and a two-planet system in 2008. In 2015, lens mass and microlens parallax were measured, and by 2018, evidence suggested the existence of free-floating planets. The technique offers a powerful and independent method for exoplanet exploration, especially in cases where other detection methods may struggle.

Astrometry:

Astrometry, the precise measurement of celestial objects' motions and positions, has long aimed to determine stellar parallaxes and proper movements, critical for understanding host stars. Modern astrometry seeks to detect the crosswise displacement of a host star caused by an orbiting planet’s gravity. While radial velocity measures the line-of-sight movement, astrometry focuses on this dynamic shift in the sky.

Historically, achieving high accuracy in astrometry has been challenging. Missions like Hipparcos and the Hubble Space Telescope achieved accuracies of about 1 milliarcsecond (mas), but this precision only slightly detected star displacements due to orbiting planets. By 2023, astrometry had discovered only three exoplanets, including two gas giants and a substellar object.

The field saw a significant advancement with the launch of the Gaia mission in 2013, which measures over a billion stars with an accuracy of 20–25 microarcseconds (μas) for stars with magnitude 15. Gaia is expected to revolutionize planetary system understanding by detecting thousands of planetary systems with accurate masses and orbits, free from inclination uncertainties. Additionally, Gaia will provide valuable insights into the co-planarity of planetary systems, improving knowledge of their configuration and behavior.