SCIOLY .ORG

Astronomy/Exoplanets

Exoplanets, or extra-solar planets, are planets orbiting stars outside of Earth's solar system. **Exoplanets** is one of the topics for the 2024 Astronomy event, the others being Stellar Evolution and Star Formation.

Contents

Detection of Exoplanets

In the equations below, the subscript s denotes the star, and the subscript e denotes the exoplanet. R denotes the radius of the object, and M denotes the mass of the object.

Transit

The transit method uses the light blocked from the parent star by the host planet to determine various properties of the star and planet. When a planet comes across the plane of the star in the point of view of the Earth, the light given by the star will encounter a brief dip then flatten out before then coming back up to the mean value. This dip, called the transit depth, can be used to calculate the radius of the planet by comparing it with the radius of the star which can be determined through other means and the equation

$$\frac{\Delta F}{F_0} = \frac{R_p^2}{R_s^2},$$

where ΔF is the change in flux or brightness of the star, and F_0 is the original flux.

One important factor is the likelihood of transit in terms of the properties of the star. This also determines how likely it is to find a certain kind of exoplanet. The bigger the planet, the more likely the transit can happen which should make sense: the bigger the planet, the more area it covers in the sky and more importantly on the star itself, increasing the likelihood of a transit. The bigger the orbit, the less likely the transit can happen due to the inclination of the orbit. With a smaller orbital radius, there exists a greater range of inclinations that can result in a transit regardless of the size of the planet. However, with a larger orbital radius, there exists a lower range of inclination possibly resulting in a transit.

As of September 2023, the transit method has discovered the largest number of exoplanets (about 3/4 of the total known exoplanets), particularly due to the Kepler/K2 and TESS (Transiting Exoplanet Survey Satellite) missions.

Radial Velocity

Radial velocity, also known as **Doppler spectroscopy**, detects exoplanets by measuring Doppler shifts in the spectrum of the parent star. As of September 2023, about 19% of exoplanets were detected using radial velocity.

The velocity and period of the planet's orbit and the mass of the planet can be calculated after measurements with Radial Velocity. First, if the mass of the star M_s is not given, calculate it by plotting it on the H-R diagram. If the velocity of the star is not given, calculate it using the Doppler shift formula $\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$, where λ_0 is the average of the highest and lowest wavelength and $\Delta\lambda$ is the difference between the highest and the average wavelengths.

Find the period P of the star's orbit from the radial velocity measurements. Then, use the general form $\frac{r^3}{P^2} = \frac{GM_s}{4\pi^2}$ of Kepler's Third Law, where r is the length of the semi-major axis of the planet's orbit. Alternatively, one can use the specific form $\frac{r^3}{P^2} = M_s$ where r is in AU, P is in years and M_s is in solar masses.

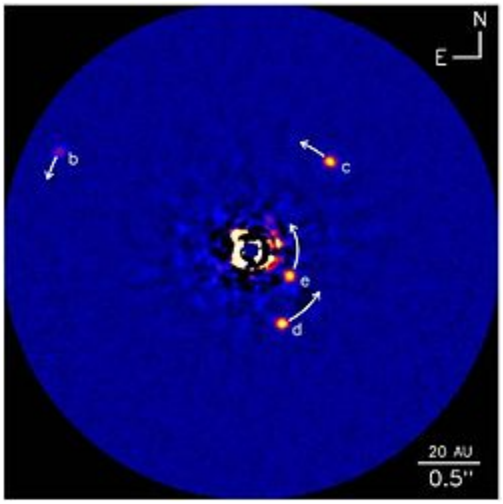
Find the velocity of the planet using $v_p = \frac{2\pi r}{P}$. Finally, find the mass of the planet using $m_s v_s = m_e v_e$.

This calculation gives us the minimum mass of the planet. The measured velocity of the star is less than its true velocity if the orbital plane is not perpendicular to the sky.Let α denote the orbital inclination (https://en.wikipedia.org/wiki/Orbital_inclination#Exoplanets_and_multiple_star_systems), then the true velocity of the star and true mass of the planet is given by $v_{s,\,\text{true}} = \frac{v_s}{\sin\alpha}, M_{e,\text{true}} = \frac{M_e}{\sin\alpha}$.

When an exoplanet transits the parent star, the inclination α is very close to 90 degrees. Therefore, the calculation based on radial velocity is close to its true mass.

Direct Imaging

Direct imaging detects exoplanets by resolving the exoplanet from the star in an image. is usually very difficult, because planets are much fainter than their parent stars. The coronoagraph is used to block the light from the star so the planets can be resolved. Most direct imaged exoplanets are relatively close to the Earth, widely separated from its parent star, and are especially large and hot. Images are made in the infrared, where the radiation from the planet is the strongest.



Direct Image of four planets around the star HR 8799.

Types of Exoplanets

Gas Giant

Planets composed mainly of hydrogen and helium. They may possibly have rocky or icy cores. They have masses greater than 10 Earth masses.

Hot Jupiters

Gas giants that orbit very close to their host star. Scientists believed Hot Jupiters formed farther away and migrated inward. Migration is a change in orbit due to interactions with a disk of gas or planetesimals. Hot Jupiters are found within .05-.5 AU of the host star. They are extremely hot, with temperatures as high as 2400 K. They were initially the most common type of exoplanet found because they are the easiest to detect (because they are huge and close to the host star), but as detection methods have improved smaller exoplanets and exoplanets farther from their host stars have been discovered as well.

Ice Giant

Composed primarily of volatile substances heavier than helium, such as oxygen, carbon, nitrogen, and sulfur. Ice giants have significantly less helium and hydrogen than gas giants and they are also smaller. Uranus and Neptune are ice giants. According to some planetary models, these two giant planets may have layers of superionic ice under relatively shallow hydrogen and helium atmospheres, which would explain their unusual magnetic fields.

Terrestrial Planet

Composed primarily of silicate minerals or metals.

Super-Earth

Defined exclusively by mass with upper and lower limits. Super Earths are ‘potentially’ rocky planets with up to 10 times the mass of Earth. The term ‘Super Earth’ simply refers to the mass of the planet and not to any planetary conditions, so some of these may actually be gas dwarfs. The Kepler Mission defined a Super-Earth as a planet bigger than Earth-like planets (.8-1.25 Earth radii), but smaller than mini-Neptunes (2-4 Earth radii).

Mini-Neptune

Also known as a **gas dwarf** or **transitional planet**. Mini-Neptunes are planets with a mass up to 10 Earth masses. They are less massive than Uranus and Neptune (shocker) and have thick hydrogen/helium atmospheres.

Pulsar Planet

A planet that orbits a pulsar, a rapidly rotating neutron star. Pulsar planets are discovered through anomalies in pulsar timing measurements. Pulsars rotate at a regular speed, so any bodies orbiting the pulsar will cause regular changes in its pulsation. The changes can be detected with precise timing measurements.

Goldilocks Planet

Planet that falls within star's habitable zone, which basically means it has the potential to support liquid water on its surface.

Rogue Planet

Also known as interstellar planet, nomad planet, free-floating planet, orphan planet, wandering planet or starless planet. A planet without a host star that orbits the galaxy directly.

Puffy Planet

A planet with a large radius but very low density. Puffy planets expand because they are being warmed from the inside out. This warming may be from the star's heat reaches the planet's core, or from stellar winds carrying ions and heat that reach deeper into the planet. The ions are attracted to the planet's magnetic field. Friction is generated by winds blowing past ions being held by the magnetic field, creating heat that will warm the planet from the inside and causing it to expand.

Chthonian Planet

The rocky core left behind when a hot Jupiter orbits too close to their star. The star's heat and extreme gravity can rip away the planet's water or atmosphere.

Water Worlds

An exoplanet completely covered in water. Simulations suggest that these planets formed from ice-rich debris further from their host star. As they migrated inward, the water melted and covered the planet in a giant ocean.

Temperature of Exoplanets

In calculation of temperature of exoplanets, the star is often assumed to be a blackbody. The exoplanet is assumed to reflect some of the radiation, have no heating from its core, and have emissivity close to 1.

Let the temperature of the exoplanet and the star be T_e and T_s, and the radius be R_e and R_s. They are separated by a distance of D. Then, by Stefan-Boltzmann Law, the radiation from the star and the exoplanet is

$$L_s = 4\pi R_s^2 \cdot \sigma T_s^4, \qquad L_e = 4\pi R_e^2 \cdot \sigma T_e^4,$$

where σ is the Stefan-Boltzmann constant.

Only a fraction of the star's radiation reaches the exoplanet, and only a fraction of those radiation is absorbed. The ratio of radiation that reaches the exoplanet is $\frac{\pi R_e^2}{4\pi D^2}$ by considering the sphere centered at the sun that crosses the exoplanet, and $1 - A$ of those is absorbed, where A is the Albedo (https://en.wikipedia.org/wiki/Albedo) of the planet. Therefore, $L_e = \frac{\pi R_e^2(1-A)}{4\pi D^2} L_s$.

Expanding L_e and L_s and simplifying, we find

$$T_e^4 = \frac{R_s^2 T_s^4 (1-A)}{4D^2}, \qquad T_e = \sqrt[4]{\frac{R_s^2 T_s^4 (1-A)}{4D^2}}.$$

For example, if both the sun and the Earth are assumed to be blackbodies ($A = 0$), the temperature of the Earth would be

$$\sqrt[4]{\frac{(7 \cdot 10^8 m)^2 (5778K)^4}{4(1\mathrm{AU})^2}} = 280K.$$

This equation can also be adjusted to account for the presence of an atmosphere with greenhouse gases, which gives a better prediction of temperature for some types of exoplanets.

External Links

- NASA Exoplanet Exploration Website (https://exoplanets.nasa.gov/) (Exoplanet information for the general public)
- NASA Exoplanet Archive (https://exoplanetarchive.ipac.caltech.edu/) (Database and exoplanet news)

- The Extrasolar Planets Encyclopaedia (http://exoplanet.eu/) (Another database)
- NASA Exoplanet Watch (https://exoplanets.nasa.gov/exoplanet-watch/resources/everything-exo/) (Collect and work with exoplanet data!)
