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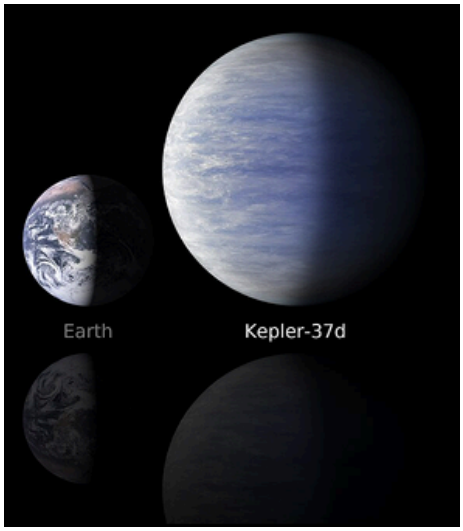
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Defining Exoplanetary Systems

An exoplanet, also known as an extrasolar planet, is any planet located outside the Solar System. The first confirmed detection was in 1992 around a pulsar and the first detection around a main sequence star (star similar to our Sun) was in 1995. As of 2026, there are 6,445 confirmed exoplanets in 4,834 planetary systems with 1,070 systems having more than just one planet. About 1 in 5 Sun-like stars is estimated to have an Earth-sized planet in the habitable zone. Assuming 200 billion stars in the Milky Way, there may be more than 11 billion potentially habitable planets in our Galaxy.

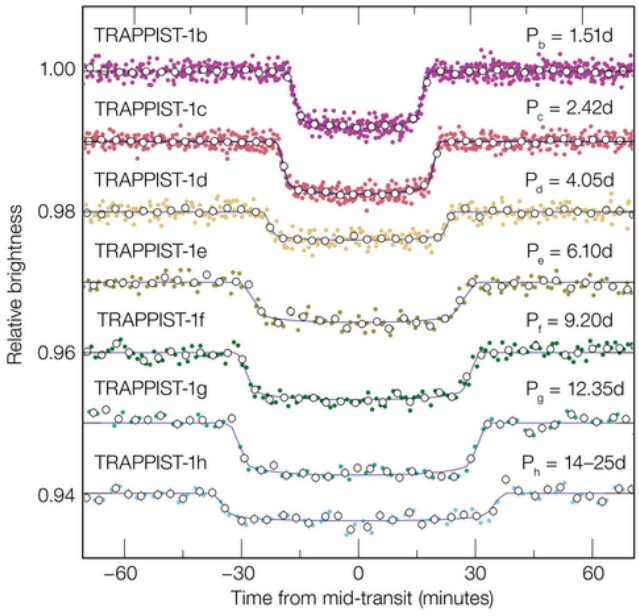


Kepler-37d compared to Earth

Methods: Transit Photometry

Many methods are employed in the search for exoplanets. The most well-known ones are transit photometry and Doppler spectroscopy. Both of these methods favour detection of large planets near their star, rather than planets further from the parent star such as is the case in our Solar System. Case in point, an Earth-sized planet orbiting a Sun-like star would cause a 0.008% dip in brightness, making such planets rather difficult to detect.

As a planet transits its host star, it will block a portion of the light incoming from the star. This state of incident light can be plotted against time to construct a light curve. From the relative change of luminosity and the duration of the decrease, the planet's approximate size and distance from its star can be reconstructed.



Another major disadvantage connected with using transit photometry is the fact that the orbit of the planet has to be almost perfectly aligned from the observer's vantage point. An orbit not perfectly in line-of-sight is simply not visible to the observer.

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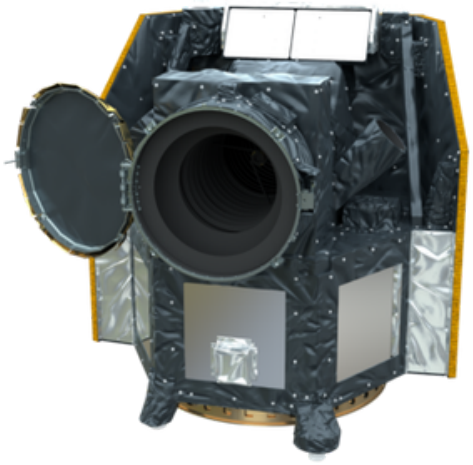
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ESA's Exoplanet Fleet

CHEOPS

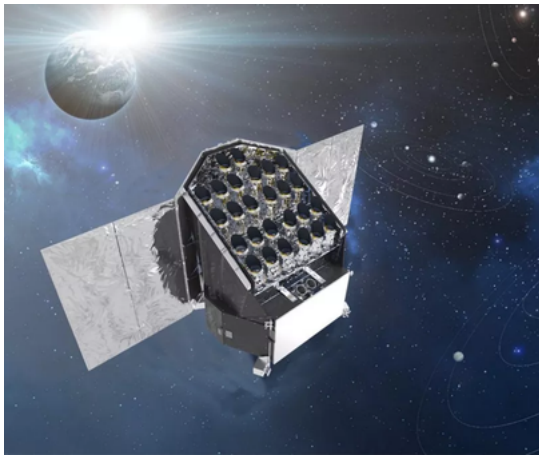
CHEOPS, standing for Characterising Exoplanets Satellite, is a European space telescope. Its objective is to determine the size of known exoplanets, which will allow the estimation of their mass, density, composition and formation. Launched on 18 December 2019, it is the first Small-class mission in ESA's Cosmic Vision science programme. The small satellite features an optical Ritchey–Chrétien telescope with an aperture of 30 cm, mounted on a standard small satellite platform. It was placed into a Sun-synchronous orbit of about 700 km altitude.



CHEOPS: ESA artist impression

PLATO

PLATO, standing for Planetary Transits and Oscillations of stars, is a space telescope under development by the European Space Agency for launch in March 2027. It is the third mission in the Cosmic Vision programme, like CHEOPS. It is named after the Greek philosopher Plato. The mission goals are to search for planetary transits across up to a million stars and to, ideally, discover rocky exoplanets around yellow dwarf stars in the habitable zone, where liquid water could exist. A secondary objective is to study stellar oscillations and seismic activity of stars to characterise them.



PLATO: ESA artist impression

Can you explain the term "habitable zone"?

Write here...

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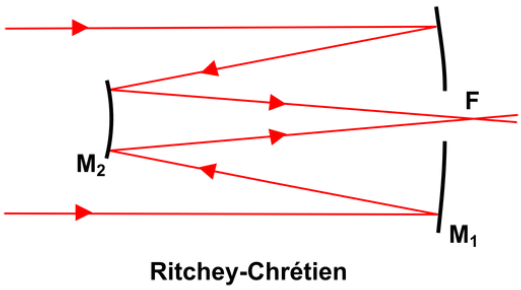
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What you need to know about...

Ritchey–Chrétien telescope

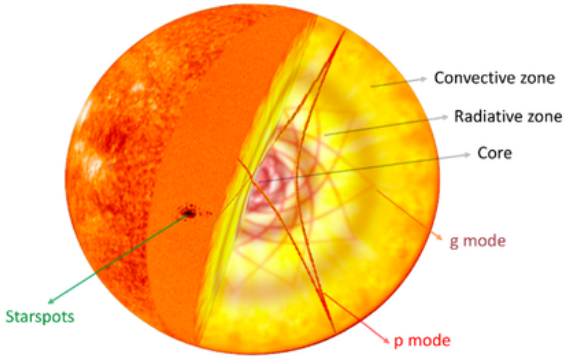
Also known as an RCT, it is a specialised variant of the Cassegrain telescope that has a hyperbolic primary mirror and hyperbolic secondary mirror. If that explains nothing, all you need to know is that it is the most frequently used telescope in professional astronomy and some eminent examples include the Hubble Space Telescope in space, and the ESO Very Large Telescope in Chile.



Ritchey-Chrétien

Stellar oscillations and asteroseismology

Stellar oscillations refer to the periodic vibrations occurring within stars, and asteroseismology is a specific branch focused on these oscillations in the Sun (and other stars). These oscillations are generated by sound waves originating from the Sun's convective zone, where hot gas rises and cool gas sinks, creating a dynamic environment. By examining the Doppler shifts in the spectrum of sunlight, scientists can observe the oscillations of different points on the stars' surface, revealing a constant state of vibration akin to a ringing bell.

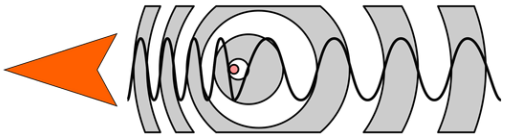


Sun-synchronous orbits

A nearly polar orbit around a planet in which the satellite passes over any given point of the planet's surface at the same local mean solar time. A Sun-synchronous orbit is useful for imaging, reconnaissance, and weather satellites, because every time that the satellite is overhead, the surface illumination angle on the planet underneath is nearly the same. For example, a satellite in Sun-synchronous orbit might ascend across the equator twelve times a day, each time at approximately 15:00 mean local time.

Doppler shift/effect

The change in the frequency or, equivalently, the period of a wave in relation to an observer who is moving relative to the source of the wave. The most famous example is the changing pitch of an approaching ambulance, in astronomy redshift is a commonly cited and important consequence.



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Exoplanet Light Curve Mystery

Core principles

Transit depth

$$\delta = \frac{\Delta I}{I} \approx \frac{R_P^2}{R_S^2}$$

Left side corresponds to the fractional reduction of stellar intensity (without units, usually expressed in scientific notation). On the right side R_P is the radius of the planet and R_S is the radius of the star, both in absolute units.

Kepler's Third Law

$$a^3 = \frac{GM_S T^2}{4\pi^2}$$

Interpret (you know this):

Write here...

Transit duration

$$\Delta t \approx \frac{T}{2\pi a} 2R_S$$

The duration of the transit is equal to the fraction on the right, where *a* has to be calculated from Kepler's Third Law.

Scientific notation
1.5 · 10⁻² = 1.5e-2
Regular number
0.015
Percentage
1.5%

Always assume SI (metric) units, unless advised otherwise. It is commendable to make general equations for desired outcomes first, and only then calculate for specific data.

Worked example

Fictional star ESERO-A1. A recurring drop of 1.5% every 3.2 days.
Quick Analysis:

- 1.5% depth is very large, meaning this planet must be a gas giant just like Jupiter
- An orbital period this brief indicates a very close orbit – classified as a Hot Jupiter

planet	T [yr]	Δt [hr]	$\Delta t/T$ [∅]	$\delta = \Delta I/I$ [∅]	p_{trans}
Mercury	2.41 · 10⁻¹	8.1 · 10⁰	38 · 10⁻⁴	1.2 · 10⁻⁵	1.19 · 10⁻²
Venus	6.15 · 10⁻¹	1.10 · 10¹	20 · 10⁻⁴	7.6 · 10⁻⁵	6.65 · 10⁻³
Earth	1.000 · 10⁰	1.30 · 10¹	15 · 10⁻⁴	8.4 · 10⁻⁵	4.70 · 10⁻³
Mars	1.880 · 10⁰	1.60 · 10¹	9.7 · 10⁻⁴	2.4 · 10⁻⁵	3.10 · 10⁻³
Jupiter	1.186 · 10¹	2.96 · 10¹	2.9 · 10⁻⁴	1.01 · 10⁻²	8.90 · 10⁻⁴
Neptune	1.648 · 10²	7.13 · 10¹	0.49 · 10⁻⁴	1.27 · 10⁻³	1.50 · 10⁻⁴

Table of data for selected Solar System planets (sourced from ETH Zürich)
Note: p_{trans} stands for probability of transit being observable using the transit method (correct alignment)

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Exoplanet Light Curve Mystery

Good at maths? Try finding a general solution (else solve numerically)

Solve for $R_P(T, \Delta t, \delta, M_S)$

Find concrete solutions with $M_S = 1.989 \cdot 10^{30}\ \mathrm{kg}$ $G = 6.67 \cdot 10^{-11}\ \mathrm{m^3 kg^{-1} s^{-2}}$

Exoplanet Target	Orbital Period	Transit Duration	Relative Depth
Exoplanet A	3.50 days	2.75 hours	$1.5 \cdot 10^{-2}$
Exoplanet B	12.00 days	4.35 hours	$1.25 \cdot 10^{-3}$
Exoplanet C	5.00 days	3.10 hours	$1.23 \cdot 10^{-5}$

Solve and interpret data for exoplanets
(by hand or preferably calculator)

Reference
Mercury – 2,440 km
Earth – 6,371 km
Neptune – 24,622 km
Jupiter – 71,492 km

Exoplanet Target	Radius	Interpretation
Exoplanet A		
Exoplanet B		
Exoplanet C		

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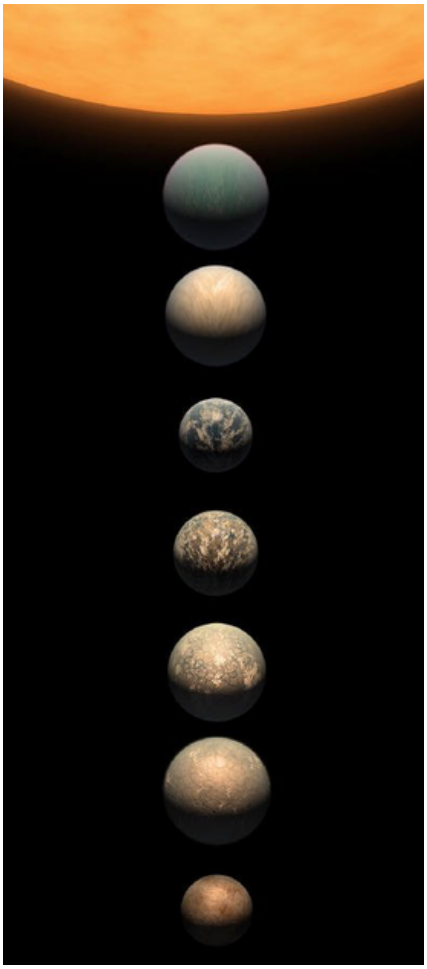
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Dictionary

- extrasolar [ekstrəˈsəʊlə] - extrasolární, mimo Sluneční s.
- pulsar [pʌlsɑː] - pulsar
- habitable zone [ˈhæbɪtəbl zəʊn] - obyvatelná zóna
- incident (light) [ˈɪnsɪdənt (laɪt)] - dopadající (světlo)
- plotted [plɒtɪd] - vynesený (do grafu), zaznamenaný
- approximate [əˈprɒksɪmət] - přibližný, orientační
- to align [tə əˈlaɪn] - zarovnat, vyrovnat (do jedné přímky)
- observer [əbˈzɜːvə] - pozorovatel
- vantage point [vɑːntɪdʒ pɔɪnt] - pozorovací stanoviště, úhel pohledu
- determine [dɪˈtɜːmɪn] - určit, stanovit
- estimation [estɪˈmeɪʃn] - odhad
- composition [kɒmpəˈzɪʃn] - složení, skladba
- oscillation [ɒsɪˈleɪʃn] - oscilace, kmitání
- seismic [ˈsaɪzmɪk] - seismický
- stellar [ˈstelə] - hvězdný
- notation [nəʊˈteɪʃn] - zápis, notace, označení
- transit [trænzɪt] - tranzit, přechod (vesmírného tělesa)
- unless [ənˈles] - pokud ne, ledaže
- to advise [tə ədˈvaɪz] - poradit, doporučit
- commendable [kəˈmendəbl] - chvályhodný, obdivuhodný
- brief [briːf] - stručný, krátký
- reconnaissance (rɪˈkɒnɪsns) - průzkum, pozorování
- illuminance (ɪˈluːmɪnəns) - osvětlenost, intenzita (veličina)



TRAPPIST-1 – artist impression via JPL NASA

Takeaways

- exoplanets (= extrasolar planets) are planets located outside our System
- first exoplanet – 1992, now 6445 exoplanets
- most commonly used method – transit photometry

What do you remember about ESA missions in the search for exoplanets?