HACK AN EXOPLANET

Becoming a Space Detective

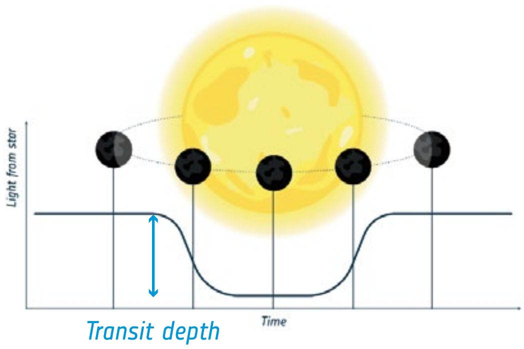
Your mission is to analyse Cheops data of the exoplanets **KELT-3b, TOI-560c, K2-141 b & c** and complete the missing information in their case files.

Through its science missions ESA is searching for the answer to the biggest questions of our time, such as the mysteries of our Universe, the understanding of our Solar System and the search for habitable planets or life outside our home planet.

In these challenges you will join scientists in the search for these answers and help them understand these mysterious alien worlds.

Exoplanets: the basics

Cheops' mission is to observe known exoplanets and characterise them by looking at the dip of stellar light caused by the planets' transit of their host stars.
Cheops observed the two mysterious exoplanets, **KELT-3b** and **TOI-560c** in January 2023.
Cheops observed another exoplanet system, **K2-141 b & c**, in September 2023.



Exoplanets are difficult to detect, as the signal received from them is small in comparison to the much larger signal coming from their bigger, brighter host stars. One of the methods to detect exoplanets is **transit photometry**.

The exoplanet is detected by measuring a dimming in the light coming from the star when the exoplanet passes in between the star and the telescope, this is called an **exoplanet transit**. A **light curve** is the measurement of the light of the star over a period of time. See to the left the representation of the dip in a light curve of a star during an exoplanet transit, also called transit depth.

ALLESFITTER

Astronomers use specific software tools to analyse the data and fit mathematical models. You can access one of the tools astronomers use to analyse these exoplanets: **hackanexoplanet.esa.int/allesfitter**

TARGET 1 - Complete the missing pieces of information in the KELT-3b case file

KELT-3b

KELT-3b CASE FILE

Fast Facts:

TYPE

Hot Jupiter

RADIUS OF THE PLANET

MASS OF THE PLANET

617 M_{EARTH}

ORBITAL PERIOD

DISTANCE TO HOST STAR

BULK DENSITY

DISCOVERED

2012 by the KELT survey

CHARACTERISTICS

puffy and gaseous

COMPOSITION

EQUILIBRIUM TEMPERATURE

1543°C

Known as **KELT-3b**, the third exoplanet found by the KELT survey, this exoplanet is unlike anything we have seen in our Solar System.

Cheops observed this mysterious exoplanet on the **22 January 2023** at **23:20 CET**. By analysing the data, we have discovered that KELT-3b is...

In comparison to the planets in the Solar System, KELT-3b...

KELT-3 is a sun like star 690 light years away from Earth in the Leo constellation. KELT-3 is slightly bigger than our Sun.

Mass of the star = **1.96 ± 0.50** M_{Sun}

Radius of the star = **1.70 ± 0.12** R_{Sun}

TARGET 2 - Complete the missing pieces of information in the TOI-560c case file

TOI- 560c CASE FILE

Fast Facts:

TYPE

Mini-Neptune

RADIUS OF THE PLANET

MASS OF THE PLANET

$9.70\,M_{EARTH}$

ORBITAL PERIOD

DISTANCE TO HOST STAR

BULK DENSITY

DISCOVERED

2021 by the TESS survey

CHARACTERISTICS

Neptune-like

COMPOSITION

EQUILIBRIUM TEMPERATURE

225°C

Compared to KELT-3b, TOI-560c is almost tropical, though it is still hundreds of degrees Celsius warmer than the Earth.

Cheops observed this mysterious exoplanet on the **23 January 2023** at **13:12 CET**. By analysing this data we have discovered that TOI 560c is...

In comparison to the planets in the Solar System, TOI-560c...

TOI-560, also known as HD 73583, is a small orange-red star in the Hydra constellation, around 103 light years away from Earth.
TOI-560 is smaller and cooler than our Sun.
Besides TOI-560c, there is a second planet orbiting this star, TOI-560b.

Mass of the star = **$0.73 \pm 0.02\ M_{Sun}$**

Radius of the star = **$0.65 \pm 0.02\ R_{Sun}$**

TARGET 3 - Complete the missing pieces of information in the K2-141 b & c case file

esa

K2-141 b & c

K2-141 b & c CASE FILE

Fast Facts:	
K2-141b	**K2-141c**
TYPE	
RADIUS OF THE PLANET	
	$7.0\ R_{EARTH}$
MASS OF THE PLANET	
$4.97\ M_{EARTH}$	$< 8.0\ M_{EARTH}$
ORBITAL PERIOD	
	7.74850 days
DISTANCE TO HOST STAR	
BULK DENSITY	
DISCOVERED	
2018	
DETECTED BY	
Radial Velocity, Transit	
CHARACTERISTICS	
Rocky	Neptune-like
COMPOSITION	
EQUILIBRIUM TEMPERATURE	
~1830 °C	~422 °C

Cheops observed this mysterious exoplanet in **September 2023.** By analysing the Cheops data, my conclusions are...

Why is it not possible to calculate the radius of exoplanet K2-141c from the CHEOPS transit light curve of K2-141?

Why is it not possible to calculate the orbital period of K2-141c from the CHEOPS transit light curve of K2-141?

K2-141, is a small orange star, located 202 light years away, in the direction of the Pisces constellation. The K2-141 planetary system is composed of two exoplanets, **K2-141 b & c**.
K2-141c is a giant planet with a highly inclined orbit, causing it to only partially cover its star during transit, which results in a shallow transit dip. This is called grazing.

Mass of the star = $\mathbf{0.708 \pm 0.028\ M_{Sun}}$

Radius of the star = $\mathbf{0.681 \pm 0.018\ R_{Sun}}$

EXOPLANET INVESTIGATION MAP

esa

START HERE

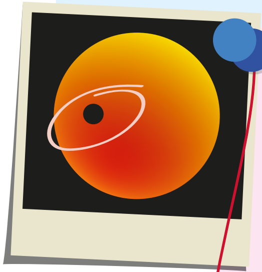
YOU ARE READY TO START YOUR INVESTIGATION!

USE THE ALLESFITTER TOOL TO ACCESS DATA COLLECTED BY THE CHEOPS SATELLITE AND ANALYSE THE MYSTERIOUS EXOPLANETS: KELT-3b, TOI-560c and K2-141 b & c

HOW ARE EXOPLANETS STUDIED?

Exoplanets are planets outside our own Solar System, orbiting a star other than our Sun.

Scientists use telescopes to detect their signatures.



THE SIZE OF THE EXOPLANET

The **depth** of the exoplanet transit is equivalent to the ratio of the area of the planet's disc and the area of the star's disc. By measuring the transit's depth and knowing the stellar radius *(R_s)* you can determine the **exoplanet's radius** *(R_p)*.

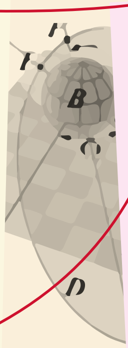
$$\text{transit depth} = \frac{\pi .\ R_p^2}{\pi .\ R_s^2} \quad \text{light from star out of transit}$$

HOW DOES YOUR ESTIMATE OF THE SIZE OF THE EXOPLANET COMPARE TO THE ALLESFITTER BEST MODEL FIT VALUE?

ORBITAL PERIOD

The **orbital period**, *T*, of a planet is the time it takes the planet to complete one full orbit around its star. If multiple orbits of the same exoplanet are observed, then the time interval between the detected dips in the light curve is a direct measure of the orbital period of the planet.

WHEN WILL THE NEXT TRANSIT OF YOUR EXOPLANET BE?

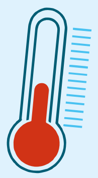


ORBITAL DISTANCE

Based on the orbital period, *T*, we can derive the **distance**, *d*, between the planet and the star, using **Kepler's Third Law**. Where G is the gravitational constant and M_{star} is the mass of the star.

$$T^2 = \left(\frac{4\pi^2}{GM_{star}}\right) d^3$$

HOW DOES THE ORBITAL DISTANCE CALCULATED USING KEPLER'S THIRD LAW COMPARE TO THE RESULT FROM THE ALLESFITTER BEST MODEL FIT VALUE?



TEMPERATURE

The **temperature** of a planet is mostly defined by its distance to its host star and by the presence of an atmosphere. An important factor to be considered for habitability is temperature. When a planet orbits a star at a distance where **liquid water** can be present, the planet is in the **habitable zone**.

DO YOU THINK YOUR EXOPLANET IS IN THE HABITABLE ZONE OF ITS HOST STAR?

COMPOSITION

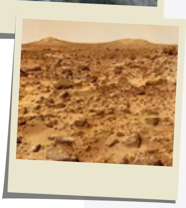
The **mass**, **M**, of an exoplanet cannot be determined from the transit method, but other methods like radial velocity can. When both the mass and radius of a planet are known, we can estimate the **bulk density**, ρ, and **composition** of the exoplanet.

$$\rho = \frac{M}{V}$$

Where **V** is the volume of the exoplanet. To calculate the volume of the planet, assume it is a perfect sphere:

$$V = \frac{4}{3}\pi R^3$$

WHAT IS THE BULK DENSITY OF YOUR EXOPLANET? WHAT DO YOU THINK ITS COMPOSITION IS?



COMPARISON

In our Solar System, planets are divided into two categories: **rocky** and **gaseous**. However, exoplanets can be very different from the neighbouring planets we are used to.

HOW DOES YOUR EXOPLANET COMPARE TO EARTH AND THE OTHER PLANETS IN THE SOLAR SYSTEM?

GLOSSARY

To solve the challenges, you will need some information about astronomical quantities and units. In astronomy measurements are often presented in exotic units. Many of these units relate to quantities that can be measured accurately like for example the sizes of some astronomical objects.

Astronomical Unit (au)
One astronomical unit is approximately the distance between the Earth and the Sun.
1 au = 149 597 870.7 km. A light year is significantly larger than an astronomical unit. 1 ly = 63 241 au.

Solar radii (R_{Sun})
One solar radius is equivalent to the radius of the Sun; this unit is useful when comparing stellar sizes.
1 R_{Sun} = 695 700 km.

Earth radii (R_{Earth})
Earth's radius is approximately 11 times smaller than the radius of Jupiter. 1 R_{Earth} = 6 378 km.

Mass of the Sun (M_{Sun})
The Sun is a medium size star with a mass 330 000 times larger than that of the Earth.
1 M_{Sun} = 1.9884×10^{30} kg.

Mass of the Earth (M_{Earth})
The Earth is the biggest of the rocky planets in our Solar System.
1 M_{Earth} = 5.9722×10^{24} kg.

Gravitational constant (G)
Is a constant used when calculating the gravitational
attraction between two objects. $G = 6.6743 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$.

Speed of light (c)
The speed of light is constant if in a vacuum, c = 299 792 458 m/s.

Year (y)
Although there are several different kinds of year, in astronomy *a year* refers to 365.25 days (31 557 600 seconds).

Light year (ly)
One light year is the distance that light travels during a year. 1 ly = 9 460 730 472 580.8 km.