The Transit Method

If the orbit of an exoplanet is oriented so that we are looking at the edge of the orbital plane from Earth, the total brightness of the central star will periodically decrease by a small amount. The planet then regularly moves in front of the star disk and darkens it somewhat. From these fluctuations in brightness, a variety of conclusions can be drawn about the physical properties of the planet.

Task 1:

The fluctuations in the brightness of the star's light can be recorded with the help of telescopes and extremely sensitive sensors if you observe the star long enough. However, measurements with earthbound telescopes have the disadvantage that the air movements of the atmosphere worsen the results. Most of the "transit planets" were therefore detected with the help of special satellites.

Find out about the COROT, KEPLER, and TESS satellites on the internet, and summarise their main characteristics in your own words.

Task 2: Simulated brightness curves

a) A small computer programme "Transit.exe" should help you to understand the origin and shape of typical brightness curves (transit curves)[1]. Start the programme "Transit.exe", and familiarise yourself with its functions.

b) Describe in words and with sketches (or take over clipboard diagrams) what influence the size of the exoplanet and its position with respect to the star have on the brightness curve. Then investigate and explain to what extent the appearance of the star disk (edge darkening) changes the brightness curve.

c) The brightness curve of the star TrES-1 has a special feature. The dip in the curve occurred because the planet apparently passed a sunspot (star spot) during its transit in front of the stellar disc. Recreate such a situation with the help of the simulation.

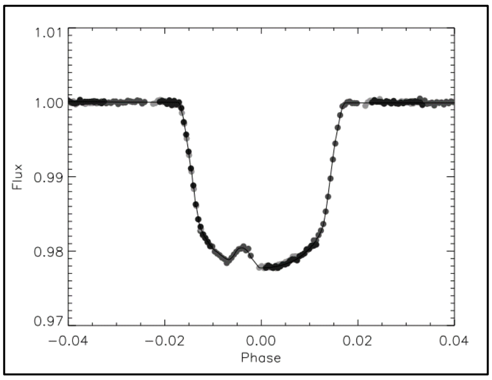

Fig. 1: Brightness curve of the star TrES-1. Source https://arxiv.org/abs/0812.1799v1

[1] http://mabo-physik.de/transitmethode.html

d) The depth of the brightness dip during a transit provides information about the diametre (or radius) of the exoplanet. The following applies: The loss of brightness corresponds to the relation between the area of the planetary disk and the area of the stellar disk (i.e. $\Delta H = \frac{A_{Planet}}{A_{Star}}$).

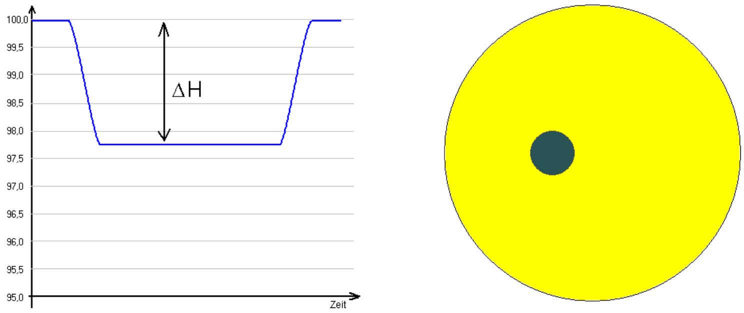

Fig. 2. Source: M. Borchardt

Using this and the formula for the area of a circle, derive the following formula for the radius of the exoplanet $r_{Planet} = r_{Star} \cdot \sqrt{\Delta H}$.

Remark:
As you can see from the formula, knowledge of the brightness dip alone is not enough. You also need the radius of the star. However, this is usually known from other investigations (e.g. stellar spectrum).

Task 3: Real brightness curves

In the appendix, you will find the brightness curves of two exoplanets. With the help of these curves, determine the radii (or diametres) of these exoplanets.

To help you, a step by step example is given below. This is the light curve of the exoplanet *Corot-1 b* (Fig. 3).

First of all, a comment on the notation: In the natural sciences, it is customary to indicate differences or discrepancies of a quantity with the Greek letter Δ. ΔH (pronounced: delta H) thus means the difference in brightness.

Example:

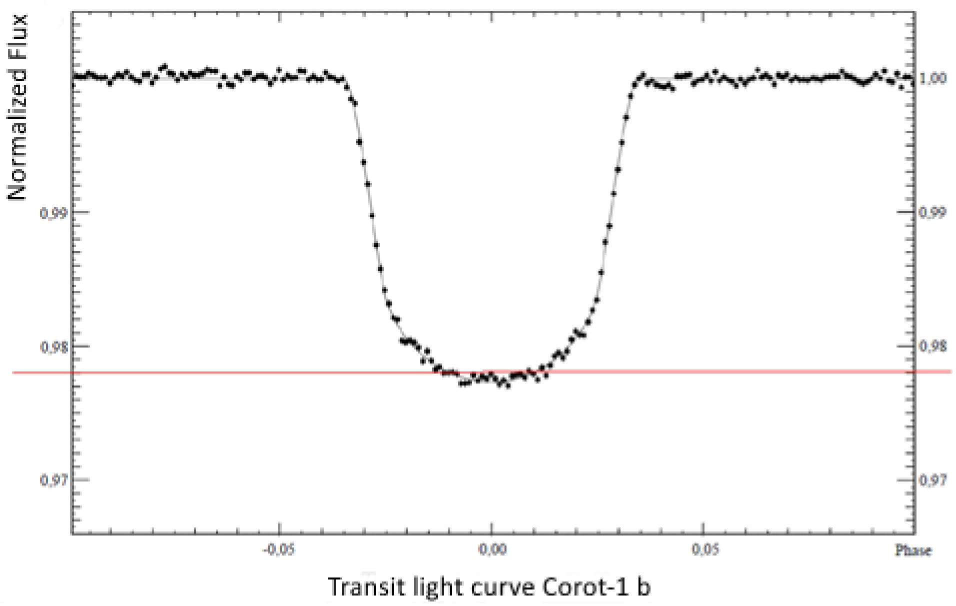

Fig. 3: Light curve of the exoplanet Corot-1b. Source: https://arxiv.org/pdf/0803.3202.pdf

The minimum of the curve is at a brightness of about 0.978 (in percent: $97.8\ \%$). The brightness dip is therefore: $\Delta H = 1 - 0.978 = 0.022$ (corresponds to $2.2\ \%$). From spectral studies of the star, it is known that it has a radius of $r_{Star} = 732{,}267\ \text{km}$.
This gives the radius of the exoplanet:
$r_{Planet} = r_{Star} \cdot \sqrt{\Delta H} = 732{,}267\ \text{km} \cdot \sqrt{0.022} = 108{,}613\ \text{km}$.

It is common to compare the radius of an exoplanet with the radius of the planet Jupiter. We therefore calculate: $\frac{r_{Planet}}{r_{Jupiter}} = \frac{108{,}613\ \text{km}}{71{,}492\ \text{km}} = 1.52$.

The result is: $r_{Planet} = 1.52 \cdot r_{Jupiter}$. Our exoplanet is thus about one and a half times the size of the planet Jupiter.

Now determine – as shown above – the size of the exoplanets *Kepler-5 b* and *Kepler-17 b* (see material in the appendix).

You can also simulate the brightness curves with the programme “Transit.exe”. Run these simulations, and print the results for your records.

Material for task 3:

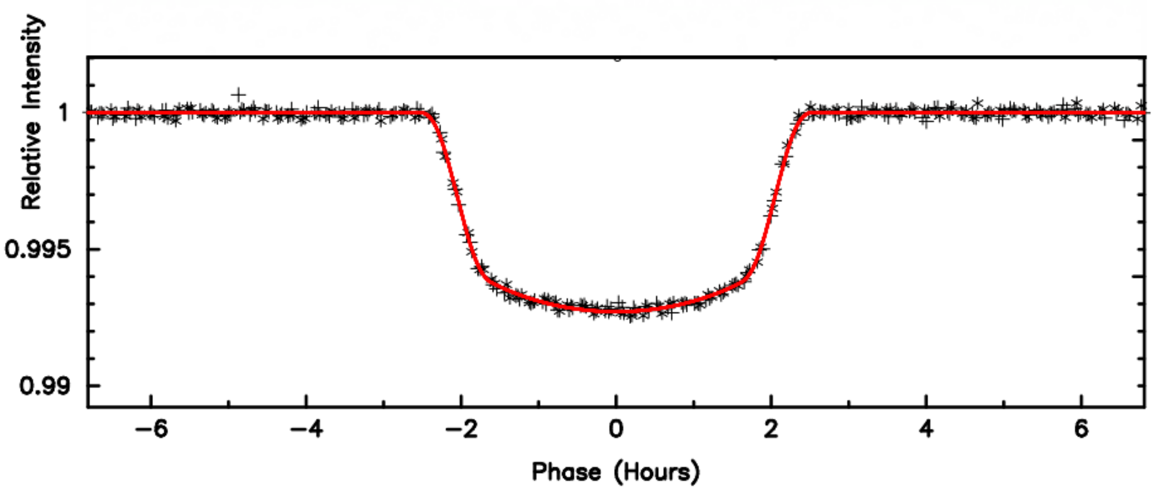

Fig. 4: Light curve of the star Kepler-5. Source: https://arxiv.org/abs/1001.0913v1

Radius of the star Kepler-5: $r_{Star} = 1{,}248{,}541\ km$

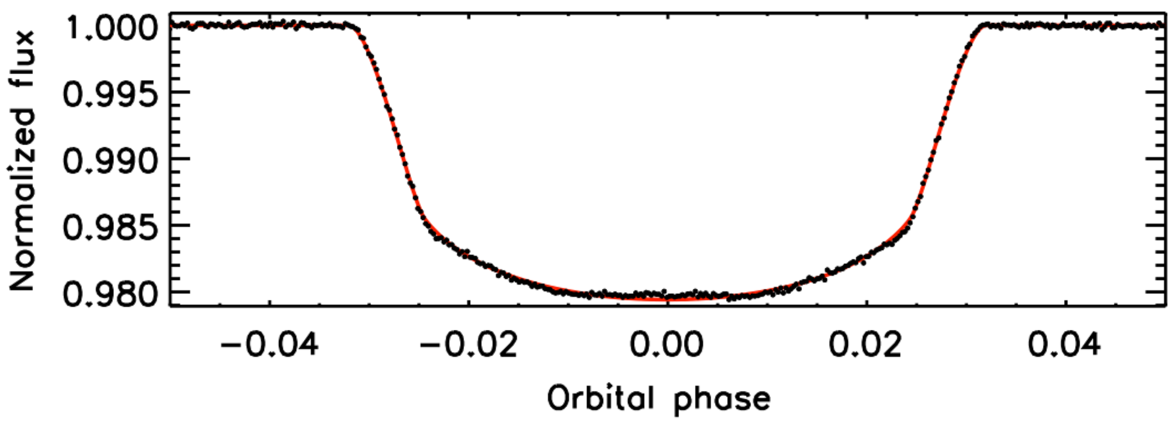

Fig. 5: Light curve of the star Kepler-17. Source: https://arxiv.org/abs/1107.5750v2

Radius of the star Kepler-17: $r_{Star} = 731{,}160\ km$

