DETECTION OF EXOPLANETS BY TRANSIT METHOD

Our proposal is to show an example of exercise for secondary pupils. It’s based on the detection of exoplanets by transit method and could be a brilliant way to pupils to have an idea of scientific work in astronomy and astrophysics.

There are a sample of images of a planet HD 189733b* obtained by the space telescope Spitzer**. We will extract data from these images and use a software to handle and analyse it with Excel graph.

The idea is to understand the transit and how it can be underlined by the results from images data.

SYNOPSIS

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What is an exoplanet (extrasolar planet)?
Roughly, it’s a planet orbiting a star, outside the solar system. Until December 2008, 335 exoplanets have been detected. Their wide variety leads to their classification by mass, nature, size, etc. The detection of exoplanets is hard because of the huge distance between the observer and the planet. Nevertheless, there are different methods of detection and the most effective ones are:

- **radial velocity**: the first method used to detect an exoplanet (by M. Mayor and D. Queloz in 1995) and it’s still the most efficient one. It enables to find information about mass of the planet. On the site of EU-HOU, you can find an high-school level exercise about the detection of exoplanets by this method.

- **the transit**: complementary to the radial velocity method. It reveals the luminosity variation of the star when the planet passes in front of it. Moreover, the radius of the planet can be determined with this method; hence its classification.
INSTRUCTION FOR THE SOFTWARE SALSAJ

The software for image and data handling: SalsaJ

It’s an ordinary program in which we can work on images from SPITZER. The goal is to analyse the luminosity of stars and find information concerning the existence of planets orbiting them.

1st step: Start up the software and open images
Open the software ‘SalsaJ’.
Click the button to open files:

Then click the 20 files one by one and click ‘horizontal mosaic’ by right-click in the desktop toolbar:

We can visualize the whole images at once:
2nd step: Handle the images
Click ‘Luminosity/contrast...’ from ‘Adjustment’ of ‘Image’:

Adjust the second bar ‘Maximum’ to obtain clearer image of three stars:
We can visualize all of the 20 images:

3\textsuperscript{rd} step: Get photometric measures

Open ‘Photometry parameters’ from ‘Analysis’ and settle the parameters as the following:

- Coordonnées du centre de l'étoile: Auto/Manuel
- Rayon auto (FWHM)/Rayon = 2(-Rayon étoile)
- Ciel: Rayon manuel
- Rayon de l'étoile: Rayon auto (FWHM)/Rayon manuel
Open ‘Photometry’ from ‘Analysis’ and move the cursor to the star in order to get the value of its luminosity:

Do the same for all images and for each star. We can number the three stars as the following:

Therefore, at the end we have 60 measurements of luminosity.
ANALYSIS OF THE DATA BY EXCEL

Plot the graph of luminosity variation and identify the signal of a transit
The software EXCEL is useful to plot its graph.

1st step: Put up the measurements on an Excel paper.
‘Select all’ in the photometry window and transfer the measurements to an Excel paper:

<table>
<thead>
<tr>
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<th>STAR 1</th>
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<th>STAR 3</th>
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Comment: decimal numbers are insignificant, as the scale of the luminosity is in the order of $10^4$ and the measurements are not very precise. Therefore, use the function ‘Convert...’ from ‘Data’ to get integer values.

2nd step: Draw the graph of the luminosity variation
As the scale is different for these stars, we start off with plotting the graph for each star. We use the function ‘Graphics...’ in ‘Insert’ and we choose a type from standard types as the following:
After clicking ‘Next’, delete two other graph to get only one graph:
Repeat it for each star and we can access to three graph:

3rd step: Analyse the signal between the stars
We notice a particularity in the form of the luminosity variation of the Star 1 which is obviously different from the two others. Indeed, we note that the fall of intensity is maintained for a certain length of time which is a property of the transit of a planet in front its star. However, the intensity of the Stars 2 & 3 is more or less constant and varies around a medium value.
Graph comparison

In the scientist’s view, it is necessary to show the particularity of the star 1 by looking at its graph with the two others in the same scale. As the scale is largely different between the three graphs, the method of normalization is required. With Excel, we can directly get the normalized results using the mathematic function of Excel.

1st step: Get the normalized values

We add another column for each star for the normalized values.

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By using ‘Functions...’ from ‘Insert’ we calculate the average of the measurements. Then we get the normalized values by entering in the cell the subtraction of the initial value with the average value.

2nd step: Superpose the three new graphs

In the same way as detailed before, we can draw these graphs in the same sheet. We can, therefore, compare them with one another and notice the signal resulted by the transit.
While the graphs of Stars 2 & 3 are characterized by relatively small variations of the intensity, the graph of Star 1 is marked by a specific drop of the intensity spread in a certain period of time.

3rd step: Add more details in the graphs
It is important to note the errors induced by several factors. We can calculate them using ‘standard deviation’ from Excel functions.

For Star 1, we calculate the value of standard deviation by using ‘Functions...’ from ‘Insert’. Nevertheless, we only consider the first values (1 to 8) of the serial because of the particular fall of the intensity.
For Stars 2 & 3, we can put the error bar from the average calculated between the standard deviations of them.

Point the cursor on the plot and by right-clicking, choose ‘Serial data format...’. In the ‘Error bar Y’ field, enter in the cells of ‘personal error bar’ the value divided into two for upper and lower parts of the error bar.
INTERPRETATION OF THE RESULTS: HIGHLIGHT ON THE TRANSIT

Corresponding the lack of luminosity ("photometric transit depth") to the transit

During a transit there are four "contacts", when the circumference of the planet touches the circumference of the star at a single point.

1) **First contact**: the planet is entirely outside the star, moving inward

![Diagram showing the first contact](image1)

2) **Second contact**: the planet is entirely inside the star, moving further inward

![Diagram showing the second contact](image2)
3) **Third contact**: the planet is entirely inside the star, moving outward

4) **Fourth contact**: the planet is entirely outside the star, moving outward
*Exoplanet HD 189733b*

The exoplanet orbiting the star HD 189733 was discovered on October 5, 2005 by transit method in France. The planet is classified as a hot Jupiter class Jovian planet, orbiting very close with a short period of 2.2 days. It’s approximately 63 light-years away in the constellation of Vulpecula (the Fox).

http://apod.nasa.gov/apod/ap080321.html

Its location is indicated in this deep (wide-angle) image of the sky centered on the northern constellation of Cygnus.

And the physical characteristics of this planet are defined by:
- mass: 1.13 $M_J$
- radius: 1.138 $R_J$
- surface gravity: 21.2 m/s²
- temperature: 1117K

**The instrument of exoplanets detection: the SPITZER telescope**

The Spitzer Space Telescope (formerly SIRTF, the Space Infrared Telescope Facility) was launched into space from Cape Canaveral, Florida on 25 August 2003. It’s the largest infrared telescope (0.85-meter) ever launched into space with highly sensitive instruments and it detects the infrared energy, or heat, radiated by objects in space between wavelengths of 3 and 180 microns (1 micron is one-millionth of a meter).
Spitzer will be the final mission in NASA's Great Observatories Program which is a family of four orbiting observatories, each observing the Universe in a different kind of light: the Hubble Space Telescope HST (visible and infrared), Compton Gamma-Ray Observatory CGRO (gamma rays), and the Chandra X-Ray Observatory CXO (X-rays).