Planet Transit Project Report

Introduction and Background

A planetary transit is the passage of a relatively small body i.e. a planet across the disk of a larger body i.e. a star. For example, in our solar system occasionally Venus and Mercury line up between the Earth and the Sun as seen in Figure 1. The first transit observed was by French astronomer Gassendi of Mercury in 1631.

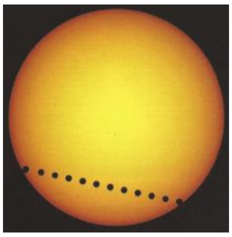

Figure 1 – An image of the transit of Venus that took place on 8th June 2004.

Planetary transits are important as they can be used as a method to discover exoplanets, albeit in a slightly different way.
Currently, the technology does not exist to directly observe exoplanets, which is why adopting this method (and other methods) is key to achieving data which can prove their existence and determine their properties.

The following outline a number of indirect methods used to determine the existence of exoplanets:

1. **Astrometry** – Measures the slight wobble in the otherwise straight-line path of a parent star across the sky. It is the gravitational tug of massive planets that is believed to cause these tiny wobbles. Although this is the oldest method used, it cannot convincingly confirm the existence of exoplanets as well as any of their properties.

2. **Radial Velocity** – Similarly, radial velocity measures the wobble induced by a parent star. The gravitational tug of massive planets would cause a small but measurable periodic Doppler shift in a star's spectral lines. The Sun-like star 51 Pegasi, 50 light years away, was reported to show slight radial velocity variations in 1995. These variations are attributed to the first confirmed extrasolar planet. Other properties such as the atmospheric composition of exoplanets can be analysed using this method. However, the disadvantage of this method is that smaller Earth-sized planets are more difficult to discover as they have a much lesser influence on tugging the star to make it wobble.

3. **Gravitational microlensing** – Measures the light amplification by the candidate visible star. If a faint star is along our line of sight to a brighter, more distant star, its gravitational field would act as a lens to amplify the bright starlight. Planets orbiting the intervening star would cause a tiny change in the light amplification. Although the chance of this event is slim, it is a method that is possible to detect earth-sized exoplanets.

4. **Transits** – Also known as photometry, it is based upon measuring the light output of the candidate visible star. A planet that moves directly in front of its star along our line of sight would cause a slight dip in brightness. This dip in brightness indicates the presence of exoplanets. The advantages of using this method are that it can be used to determine

numerous properties of the exoplanet such as its size, mass, temperature, density. The disadvantages are that in order to view a planet transit, a planet must be perfectly aligned from the viewer's vantage point, and the chance of this happening is around 0.47%.

Target and Dataset

The aim of the project was to use observational data from the fully robotic Liverpool Telescope to validate the existence of an exoplanet orbiting around the Hat-P-5 star.

The data was obtained from the Liverpool Telescope (LT) using the RISE instrument, which is a fast-readout camera developed in collaboration with the Queens University Belfast for the precision measurement of transiting exoplanet timing.

Around 100 images were given over a period of 4.5 hours encompassing the whole of the transit. Finding the brightness of the Hat-P-5 star using the LT Imaging software for each image can enable to create a transit curve using Microsoft Excel.

Method of Analysis

The coordinates of the target star, Hat-P-5 were found using SIMBAD, then the coordinates were used to find an image centralised on Hat-P-5 on the website STScI via DSS form.

This image was compared with the data provided by the observations of the Liverpool Telescope of Hat-P-5 to find which star on the data pattern was actually Hat-P-5.

Once Hat-P-5 was located, the data was analysed using the LT Image program, which gave each time frame, and the brightness of the star that we were looking at. From this data a transit pattern was expected to be seen; however the data was far too scattered and disordered to produce a suitable graph, and it was far from the transit pattern we were expecting.

Then in order to find a suitable graph pattern, we considered the effects that the atmospheric conditions would have had on the light collected by the telescope, so the results were collected from a second star in the region, and these were divided by the results corresponding to the results from Hat-P-5 with the same time frames.

The results showed that the second star followed a similar brightness pattern to our target star, eliminating the atmospheric conditions and possible cloud layers that were affecting these brightness patterns.

Once the brightness for each of the 100 images of Hat-P-5 for the 4.5 hour duration were altered by eradicating the atmospheric conditions; they were accounted for and revised in Excel, and a more convincing transit curve was created from these restructured results.

Results

We needed the transit curve to not only deduce that an object was passing in front of the target star, but to deduce what the passing object is.

As you can see from Figure 1, the flux of Hat-P-5 and the flux of the comparison star follow very similar decreasing patterns, suggesting that both stars are being affected by the same thing, which we figured was the atmospheric conditions of Earth, or even clouds. But it also shows that there is a dip in the graph of the Hat-P-5 star, indicating the passing of an object. So when we eliminated the limiting conditions, we arrived at a new set of results that gave the graph of Figure 2.

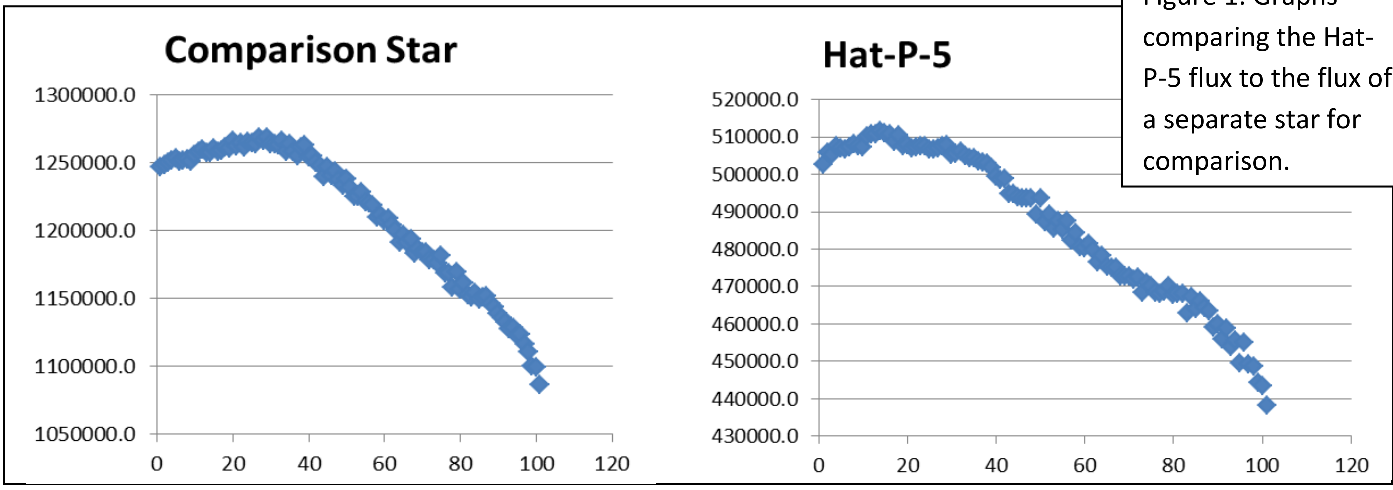

Figure 1. Graphs comparing the Hat-P-5 flux to the flux of a separate star for comparison.

From Figure 2, you can now clearly see that there is a dip in the flux that the Hat-P-5 emits, visibly indicating that an object is involved in a transit of the star. Now that the transit curve has an obvious dip in the middle, we can now use this to determine a number of properties about the passing object that we believe to be an Exo Planet. For example, with the use of a simple formula, we could find the radius of the object, thus determining that the object is in fact an Exo Planet and not a star.

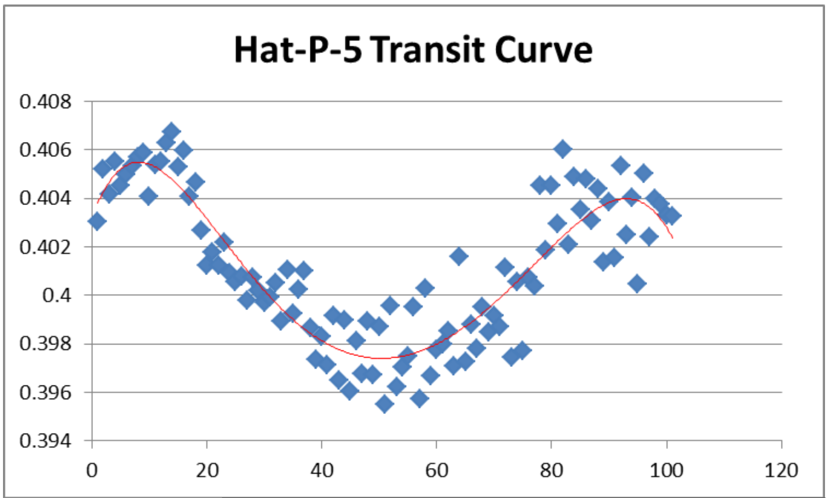

Figure 2. The Transit Curve for the Hat-P-5

We could manage this, as the flux of the star from Earth's perspective is equal to the circular area that we can see, so the change in the flux, divided by the maximum flux of the star cancels to give the object's radius squared over the star's radius squared. Which is equal to;

0.40475-0.3975 = 0.00725

0.00725÷0.40475 = 0.01791

Where 0.01791 multiplied by the radius of the star squared (6.588×10^11) is equal to the object's radius = 108621.5 km. Proving that the passing object is indeed a planet, as this radius is far too small for it to be a star.

Also, with the mass of the planet confirmed already, we could use Kepler's 3rd law to determine the distance of the planet from the star it orbits (a). The numbers that we used gave a value of 8.93×10^9 which proved to be a value that leads to a struggle when we were trying to calculate the inclination of the planet, due to it having an elliptical orbit. So instead we used the given value of the separation of 6.1×10^9.

Then with the value of the duration of the transit that we can read from Figure 2, which we determined as 3 hours, 2 minutes, we could work out the value for α as 0.274rad. Which we could then use to define the value for Ł as 8.33×10^8; where α is the transit angle and Ł is the perpendicular distance between the centre of the star and the centre of the planet, as the planet is just starting it's transit across the face of the star.

Next, we could use Pythagoras' Theorem to find a distance β - which is the distance from the vertical distance from the centre of the star to the centre of the planet as the planet's centre is directly above the star's centre – which would finally lead to using a simple geometric calculation using trigonometric ratios which gave:

$$\cos(i)=\beta/a$$

$$=\cos^{-1}(3.91\times10^{8}/601\times10^{9})$$

$$=86.3°$$

This value of 86.3° can be compared to the given value of inclination which is 86.75° (±0.44°)

Conclusion

Based on the results, it can be initially concluded that atmospheric distortion has a negative impact on observations and needed to be counteracted by surveying other stars.

It can also be confirmed that using LT Imaging to record the brightness of the star for each frame, and Microsoft Excel to tabulate and create a graph that shows a dip in brightness provides strong evidence that a planetary transit had occurred, verifying the existence of an exoplanet orbiting the HAT-P-5 star however it may be necessary to confirm this with another method other than planetary transit.

One of the major conclusions for this exoplanet existing was more strongly verified from the calculations that the radius of the intervening object across HAT-P-5 was too small to be a star (108621.5 km), hence it can only be determined as being a planet.

The final conclusion that can be drawn is that the planet orbiting the Hat-P-5 star is likely to have an elliptical orbit, as the value for the distance between the star and the planet that was calculated was quite a way from the given value, and that the inclination of the planet is around 86.3°.