The Transit Method for Exoplanet Detection

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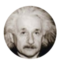

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ABSTRACT

The transit method, one of a number of methods used to discover exoplanets, detects a periodic decrease (or dip) in a star's light flux which indicates a transit of a planet in front of the star as seen from the observer's point of view. This method has by far surpassed all other methods of exoplanet detection in terms of the number of planets discovered and as such, it represents our best option for finding earth-like planets with our current technological capabilities. Furthermore, this method allows for determining the composition of the planet's atmosphere by studying the high-resolution stellar spectrum of the light from the star that passes through the upper atmosphere of the planet. A summary of the concept of the method is given alongside some of the results that its use has yielded.

INTRODUCTION

In the search for extrasolar planets, many methods such as Imaging, Radial Velocity, and Gravitational Lensing have been employed but the transit method also known as transit photometry has been mankind's most effective tool as it is responsible for the discovery of 1189 of the 1822 planets that have currently been confirmed! (NASA Exoplanet Archive). In order to discover planets using this method, the brightness of stars are monitored in the hopes of observing a periodic "dip" in the light flux of the star which would suggest that a planet has transited between the observer's field of vision and the star. The period and depth of the transits observed allow for the calculation of the orbit and size of the planet in question using Kepler's third law of planetary motion. The more pronounced the depth of the dip, the bigger the planet, and the wider the dip, the longer the transit time.

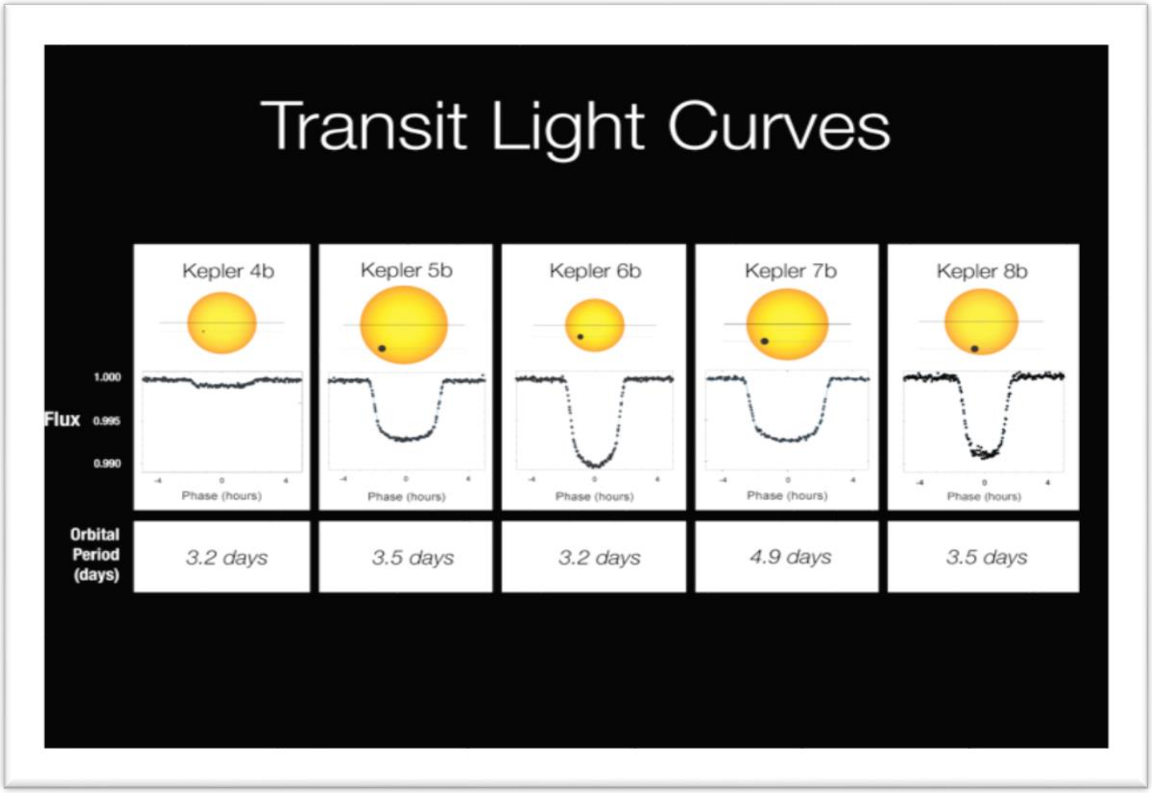


Figure 1. Depth and width of light curves

The objective of this essay is shed light on the workings of the Transit method, as well as its advantages and disadvantages as compared to the other methods being used to find extrasolar planets.

ADVANTAGES AND DISADVANTAGES OF THE TRANSIT METHOD

There are various methods used to detect exoplanets and they all have their merits as well as shortcomings. As a result of this, two or more methods are often used in conjunction with one another in order to combine the merits of the methods used to obtain certain results. Compared to the other methods, the transit method has a good number of unique advantages.

One of the strengths of the transit method is that it allows for the calculation of the radius of the orbiting planet as well as the transit time, the radius of its orbit around the star using Kepler's laws and the components of its atmosphere, granted that the radius and light flux of the host star is known.

The relationship between the radius of the star and the radius of the transiting planet is determined from transit depth measurement and is represented by Equation 1, where F is the flux of the star in question.

$$\frac{\Delta F_{star}}{F_{star}} = \left(\frac{R_{planet}}{R_{star}}\right)^2 \quad \textit{Equation 1}$$

This relationship provides a convenient way to determine the radius of the observed planet. The depth of the transit is linearly proportional to the size of the planet.

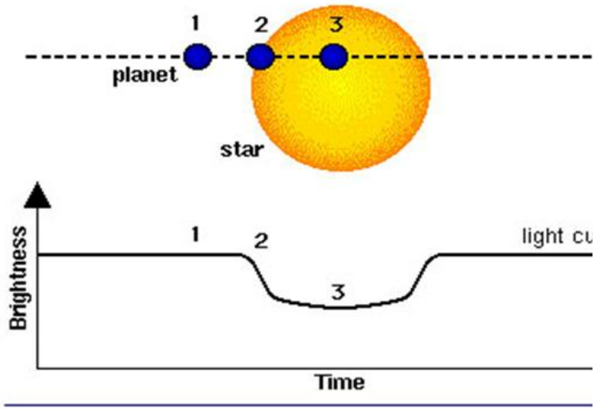


Figure 2. Transiting planet

The duration of the transit is given by the expression,

$$\tau = \frac{P}{\pi}\left(\frac{R_S \cos\delta + R_p}{a}\right) \quad \text{Equation 2}$$

where P is the orbital period, δ is the stellar latitude of trajectory (angle), a is the orbital radius, R_s is the radius of the star, and R_p is the radius of the planet.

The third and perhaps the most important capability of the transit method, is the ability to determine a planet's atmospheric composition. The starlight passing through the planet's atmosphere is absorbed to different degrees at different wavelengths. Monitoring the depth of the transit at different wavelengths allows for the recreation of the absorption spectrum and thus deducing the composition of the atmosphere.

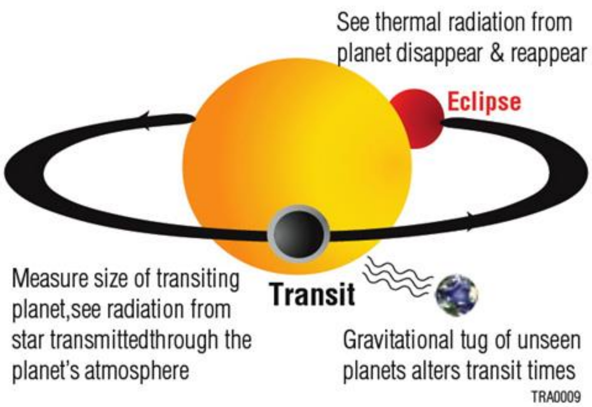


Figure 3.

This is very important because the composition of the atmosphere could tell us if the planet can sustain liquid water as well as other necessities for life (as we know it) such as oxygen and ozone in the atmosphere.

Furthermore, when combined with the radial velocity method, the transit method gives a relatively good estimate of the planet's mass by observing the luminosity of the planet's star in order to determine its mass (the star's mass), and then observing the Doppler shift of the star which is essentially a result of the gravitational pulls of the star and the planet on each other.

Despite all these advantages, the transit method does have a few disadvantages. The first of which is that the nature of the method allows for many false positives and as such, a lot of data needs to be processed to obtain information about exoplanets. More importantly, in order for a transit to be observed, it must occur between the star in question and the line of sight of the observer. This means that unlike the radial velocity method for instance, if the planet cannot be seen in front of the star from our point of view, the planet is essentially invisible to the observer using that method. This is inconvenience is depicted in Figure 2.

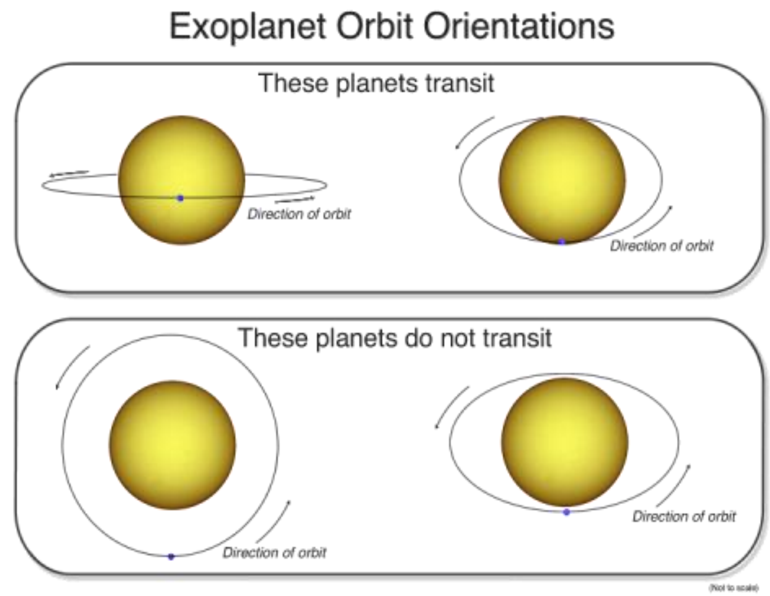
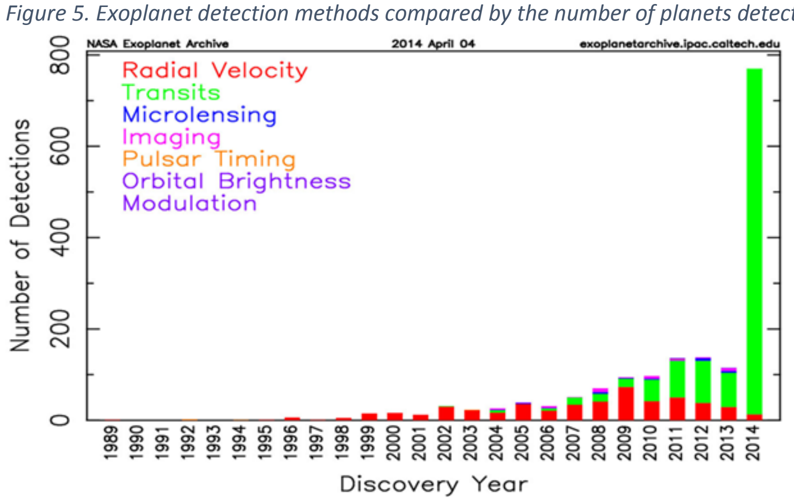


Figure 4. Point of view of transits

In spite of these disadvantages paired with the advantages of this method, the transit method has surpassed all other methods in terms of the number of confirmed exoplanets discovered. The last few years have seen a marginal increase in the number of planets discovered using the transit method, partly due to the contributions of the Kepler mission.

Figure 5. Exoplanet detection methods compared by the number of planets detected



ASTROPHYSICAL MIMICS

The mechanism through which the transit method works (observing the amount of light obstructed from a star) makes it susceptible to a high rate of false positives, due to the fact that not everything that appears to be a transiting planet is a transiting planet.

Many astrophysical false positives can mimic and exoplanetary transit. These astrophysical false positives are composed of various compositions of eclipsing binaries (hereafter EB) in which the companion star is gravitationally bound to the target star (EB in double or triple systems) or in the background or foreground within the photometric aperture of the instrument (Almenara et al. 2009). A transit of a small planet may also be explained by the transit of a larger planet orbiting a background star or a stellar companion of the target star. Fressin et al. (2013) have investigated the rate of each false positive scenario in the stellar population of the Kepler field. The authors find that most of false positives involve Neptune-size planets transiting companion stars of the target and mimicking earth-size ones.

There are a number of scenarios which could be mistake for a transit. Some of them are as follows: an eclipse of an FGK-type main sequence star by a low-mass star or a brown dwarf with a radius similar to that of Jupiter; an eclipse of a giant star by a main-sequence star; a grazing Eclipsing binary; an eclipse of a binary in the foreground or background aligned with the target star, as seen from the Earth; an eclipse of a binary bound with the target star; a transit of a planet on a star aligned with the target star, as seen from the Earth, in the foreground or background; a transit of a planet on a star physically bound with the target star; a transiting or occulting white dwarf. When the transit method is used in conjunction with the radial velocity method, the first three scenarios can be recognized as false positives. The others, however, require extensive investigation to discount. (A. Santerne, F. Fressin, R. F. Díaz, P. Figueira, J.-M. Almenara, N. C. Santos)

Failing to account for the possibility of astrophysical mimics could lead observers to obtain false results and data thus, it is important to account for them in the statistical analysis of exoplanet transit candidates.

KEPLER MISSION

The objective of the Kepler mission is primarily to search for planets in the habitable zones of a wide variety of stars as well as to determine the distribution, size and shapes of these planets and to determine the properties of those stars that possess planetary systems. The Kepler telescope employs the transit method to fulfill its directive of locating exoplanets. The telescope observes the light flux being received from stars and stores the received data, which is used to plot graphs of Light Flux vs Time (typically in units of days) such as those illustrated in figures 6 and 7.

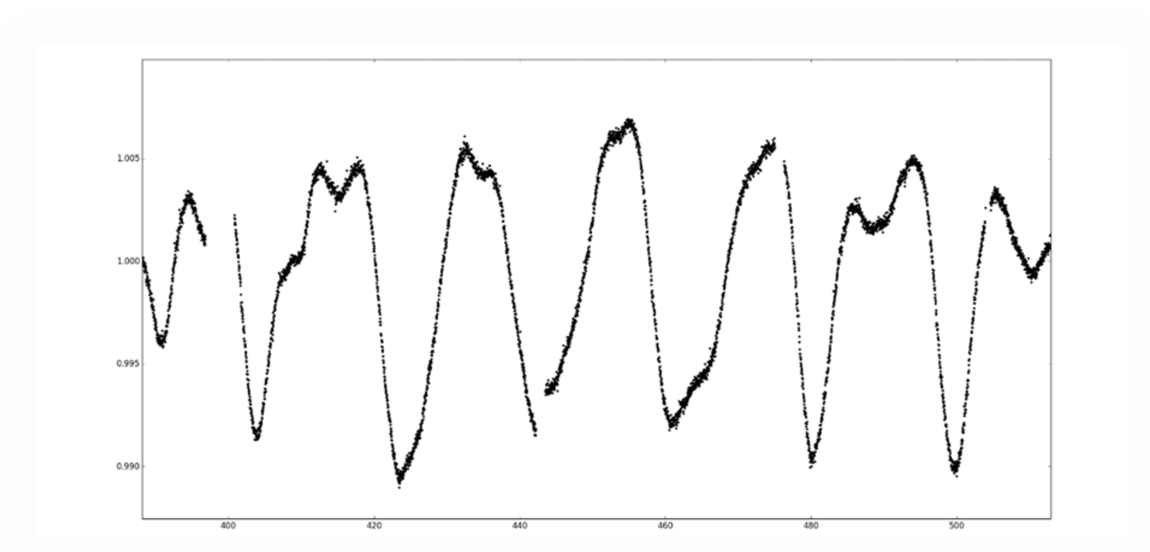


Figure 6. Kepler Light Curve of (Light) Flux vs. Time for Kepler-322 b (KOI 1820.02)

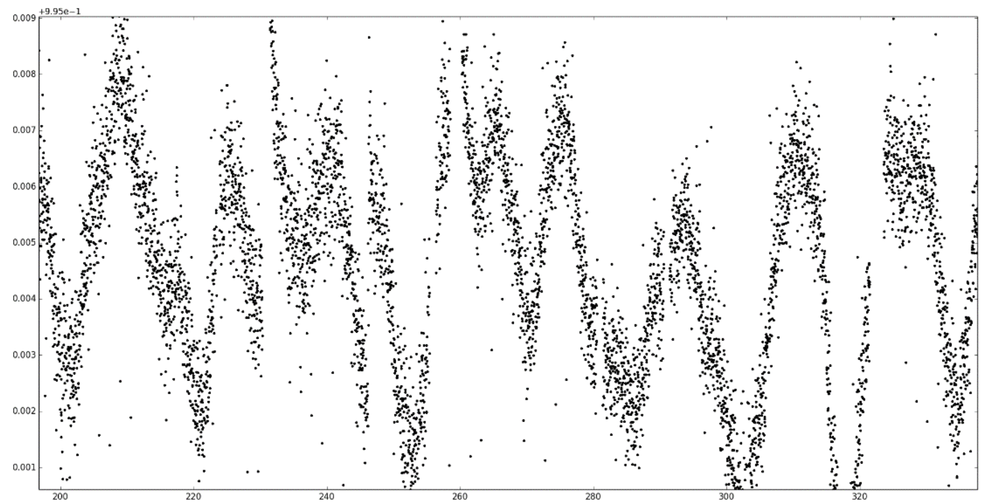


Figure 7. Kepler Light Curve of (Light) Flux vs. Time for Kepler-81 c (KOI 809.01)

These curves are often fitted to get more accurate information about the transits. For example, after fitting one period of the transit of KOI 809.01, there is a lot less background noise as can be seen in Figure 8.

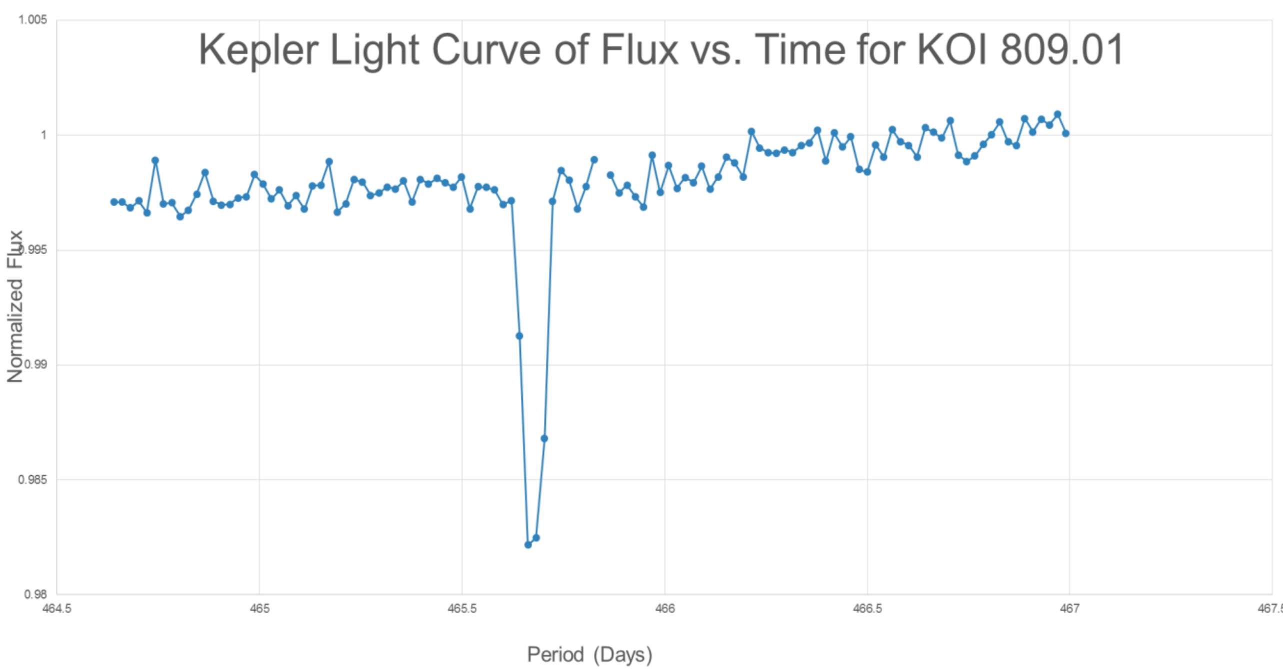


Figure 8. Graph of Light flux vs. Time (days) (fitted)

"The Kepler instrument is a specially designed 0.95-meter diameter telescope called a photometer or light meter. It has a very large field of view for an astronomical telescope 105 square degrees, which is comparable to the area of your hand held at arm's length. The fields of view of most telescopes are less than one square degree. Kepler needs the large field of view in order to observe the large number of stars. It stares at the same star field for the entire mission and continuously and simultaneously monitors the brightnesses of more than 100,000 stars for at least 3.5 years, the initial length of the mission, which can be extended." (NASA Ames Research Centre).

CONCLUSION

Considering the number of exoplanets discovered using the transit method in contrast to other methods, it is clear that the transit method is the most successful as well as one of the simplest of the methods. This method represents our most effective means of discovering exoplanets on a large scale at our current technical capabilities.

Furthermore, the ability to ascertain the components of a planet's atmosphere using this method, allows it to fulfill one of the primary reasons for searching for exoplanets, which is the search for extraterrestrial life. The detection of Oxygen and Ozone for instance in a planet's atmosphere suggests the presence of life (Léger, Pirre and Marceau, 1994), since biological reactions are needed to sustain the out-of-equilibrium chemical reactions that are producing these components.

The many advantages of the Transit method make it a most versatile one and even more so when paired with the radial velocity method. The two methods used in conjunction leave little to be wanted by an observer.

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