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Exoplanet Detection of the Kepler Space Telescope through the Transit Method

Helin Yang

Guangzhou Foreign Language School, Guangzhou, Guangdong, 511455, China

liaixia@ldy.edu.rs

Abstract. With the exploitation of resources and environmental pollution, the Earth has suffered countless damages. As a result, there are more and more environmental problems such as the greenhouse effect and desertification. People only have one home, one Earth, so if the Earth becomes extinct, people will not exist anymore. Therefore, people need to repair and protect the planet. Humans have tried many ways to protect the Earth, but some damage is irreversible. Thus, to find another home and save mankind long after, scientists began to detect some potentially habitable exoplanets. In 2009, the National Aeronautics and Space Administration (NASA) launched the Kepler Space Telescope (KST) to detect exoplanets through the transit method. Surprisingly, it did find several exoplanets that are similar to Earth in some aspects. Unfortunately, with current technology, people can't get there. This paper is going to introduce the KST, the transit method, and several potentially habitable exoplanets.

Keywords: Kepler Space Telescope, transit method, exoplanets.

1. Introduction

Nowadays, the environment of the Earth is getting worse and worse because of human activities. Even though every environmental problems happens in different places, their reaches are global. Moreover, environmental problems like deforestation, air pollution, and the crisis of water resources have penetrated every aspect of human life. More severely, some environmental problems even give rise to international political struggle. Humans are facing a variety of environmental problems. To be specific, the pollution of water resources, air pollution, atmospheric pollution, water and soil loss, soil erosion, and so on. Air pollution claimed the lives of 8.1 million people in 2021, and it was the cause of almost 700,000 deaths among children under the age of five, or 15% of all child deaths worldwide. The alarming fact is that hazardous levels of PM2.5 pollution are experienced by 99% of the world's population.[1]. Those environmental problems further lead to more serious problems like global warming, and many animals lose their homes. Therefore, humans are worried about whether they will be the next. So it is important to find solutions to the environmental problems. There are some possible ways like energy conservation and emission reduction or afforestation. But they can not solve the problems fundamentally. With the development of technology, scientists came up with a new idea, which is "Interstellar Migration". In general terms, scientists need use some advanced technologies to detect any planets which have some similar properties to the Earth. In the solar system, the only planet with the potential to colonize might be Mars. Mars and Earth are located within a habitable zone [2]. Also, Mars has a thin atmosphere, which is abundant in dust aerosols and covers a dry surface. Unfortunately, people can't ignore the insurmountable problems, like the extreme temperature differences and scarce water. Besides, the substantial uncertainties that exist in the interpretation of the Martian ionosphere are impossible to be completely solved without more data [3]. Therefore, scientists have to look beyond the solar system. Finding some exoplanets that resemble Earth is important, regardless of whether humans can go there with existing technology. National Aeronautics and Space Administration (NASA) launched the Kepler Space Telescope (KST) into orbit on March 6, 2009. Using the transit approach, hundreds of exoplanets were found in nine years. Fortunately, a small percentage of them are kind of like the Earth, for example, Kepler-22b, Kepler-438b, Kepler-442b, et al. (in no particular order).

This paper is going to discuss the KST, transit method and a small number of the exoplanets with the potential to colonize, gives readers a glimpse into exoplanet detection.

2. Introduction of KST

The KST is the world's first spacecraft designed to detect Earth-like exoplanets. During its mission, the KST would observe the numerous star systems in the Cygnus and Lyra constellations. The orbit of the KST can be described as "Heliocentric Orbit Trailing Earth", in simple terms, this is the orbit in which a spacecraft follows the Earth around the sun while maintaining a certain distance and gradually moving away from the Earth. This orbit allows the spacecraft to operate independently of the Earth's orbit, thus avoiding the periodic occlusion of the Earth, moon, and sun and enabling continuous space observations. This kind of orbit contains a lot of preponderance, to be specific, Earth's trailing heliocentric orbit avoids gravitational perturbations and the inherent torque that may be encountered in Earth's orbit, providing a more stable observation platform for the telescope. Besides, because it is far from the ecliptic plane, sunlight does not leak into the photometer, and the observation areas of Cygnus and Lyra are not obscured by objects in the Kuiper Belt or the asteroid belt, therefore improving the observation efficiency. Furthermore, this orbit places the stars that KST detected toward the galactic disk and at a distance similar to that of the solar system from the galactic center, which has significant ramifications for research into the composition of the Milky Way and the planets' distribution. To make sure the telescope can follow the Earth, the orbital period is about 372.5 days. Starting from 2009, the KST has detected thousands of exoplanets. In 2013, the KST's reaction wheel suffered a major failure, causing it to be unable to properly set the direction, and the observation work stopped. Finally, in 2018, the KST was officially decommissioned after running out of fuel.

3. Transit method

3.1. Methods of Exoplanet Detection

Numerous techniques exist for the detection of exoplanets, including Microlensing, radial velocity method, and direct imaging. One of these is the transit system that KST employs. The transit method, on the whole, is an astronomical observation technique that uses the tiny dips in a star's brightness that occur when a planet passes in front of its parent star to deduce the planet's existence and characteristics. The observer, the planet, and the host star are nearly collinear in this method [4]. The transit method is capable of detecting planets of all sizes and types, including rocky Earth-like planets and giant gas giants. In addition, the information obtained through the transit method is abundant, by analyzing the pattern and duration of the luminosity change, it is possible to determine the planet's size, orbital period, and other basic parameters, and even infer the composition and properties of the planet's atmosphere. Last but not least, the transit method can be used as a preliminary screening method for planets and provide a basis for further research. It is worth mentioning that the transit method has several requirements for telescopes, for instance, high-precision observation equipment is needed to accurately measure the faint changes in a star's brightness. What's more, observations of the same star over a long period of time are required to confirm the periodicity of transit events.

3.2. Principle of Transit Method

The brightness of a blazing star first decreases when a planet passes in front of it, blocking some of the star's light. Thus, based on the telescope's observations, scientists are able to create a variety of graphs showing how brightness varies over time. "Light curve" is the name given to the curve in Fig. 1. The "transit" refers to the decrease in brightness that occurs when a planet moves in front of a star. By observing their transits, scientists can discover details about the sizes and orbits of other planets.

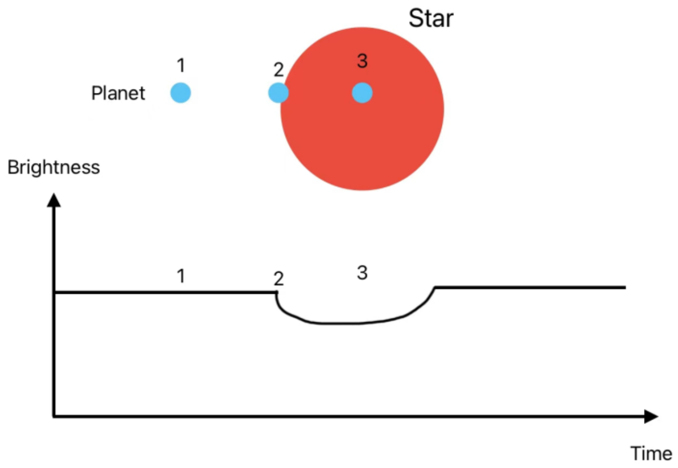

Fig. 1 an instance of Transit Light Curve (Photo/Picture credit: Original).

Due to the transit method, scientists can determine a planet's size. The amount of starlight blocked during a transit depends on the planet's size, with larger planets obscuring more light than smaller ones. Consequently, the light curve of a larger planet will exhibit a more pronounced dip, as illustrated in Fig. 2.

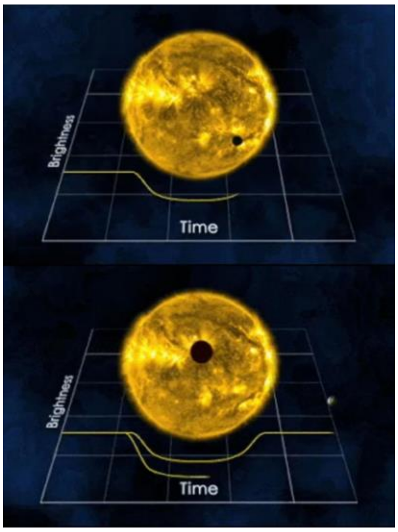

Fig. 2 different dips of planets of different sizes (Picture Credit: NASA).

However, to determine a planet's size, the transit depth alone is insufficient; scientists must also know the size of the host star. The curve's depth is influenced by the size of the star being transited (Fig. 3).

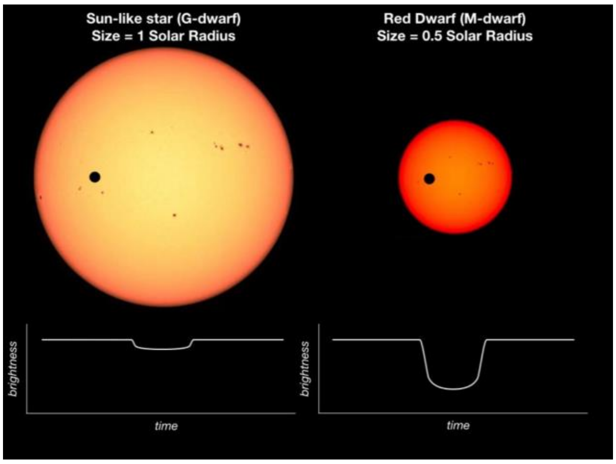

Fig. 3 A planet transiting a smaller star (right) generates a stronger transit signal compared to a planet of the same size transiting a larger star (left) [5].

3.3. How to Measure the Radii

Eventually, the transit Depth is equal to the ratio between the planet's radius (P) and the star's radius (S) squared:

$$\text{Depth} = \left(\frac{P}{S}\right)^2 \tag{1}$$

So the S can be written as this formula:

$$P = S \times \sqrt{\text{Depth}} \tag{2}$$

NASA makes all data collected by the KST publicly available. Fig. 4 displays the Kepler light curve of HAT-P-7 b, an exoplanet classified as a hot Jupiter, which is among the easiest types of planets to detect [5].

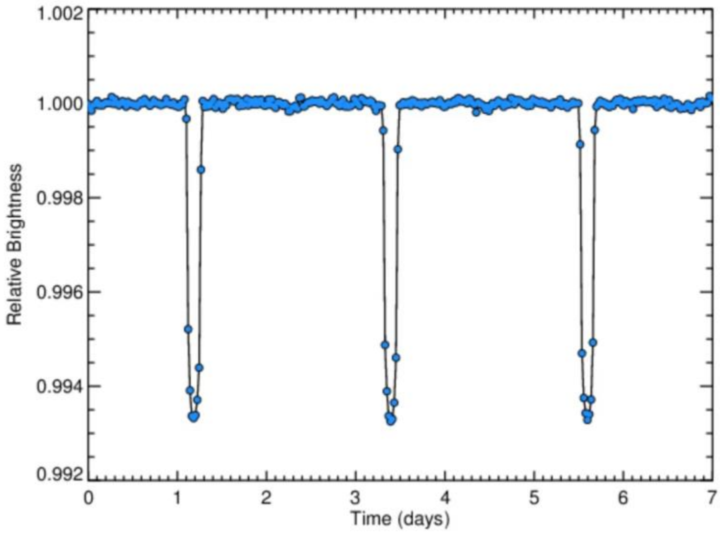

Fig. 4 The Kepler light curve of HAT-P-7 [5].

First, take note of the scale in Figure 4. The transit causes the flux to drop from 1.0 to around 0.994, a decrease of roughly 0.6%. By applying the planetary radius formula with Depth = 0.6% = 0.006 and S = 2 solar radii, the planetary radius P is calculated to be approximately 1.5 Jupiter radii [6]. Additionally, the time between two transits is known as the planet's "orbital period," or the length of its year. This demonstrates how effectively the transit method allows us to measure both the planet's radius and orbital period.

4. Results of Detection

Initially, only typical exoplanets were detected. To assess whether a planet is suitable for human habitation, the Earth Similarity Index (ESI) is calculated, factoring in radius, density, surface temperature, and escape velocity. The ESI ranges from 0 to 1, with planets scoring above 0.8 being considered highly Earth-like. For comparison, Mars has an ESI of 0.64 and Venus 0.78 [7]. The first Earth-like exoplanet discussed is Kepler-438b, with an ESI of 0.88. Discovered five years after the Kepler Space Telescope began operating, it is located in the habitable zone, where liquid water could exist. Kepler-438b is 12% larger than Earth, 475 light-years away, orbits its star in 35.2 Earth days, and receives 40% more stellar light than Earth. Despite its potential habitability, researchers from the University of Warwick discovered that frequent stellar flares might strip away its atmosphere, exposing the surface to harmful radiation and reducing the likelihood of life [7].

The next exoplanet, Kepler-452b (ESI=0.83), is 1.6 times Earth's diameter and 1,400 light-years away. It orbits a Sun-like star in 385 days, earning it the title "Earth 2.0." However, it is undergoing stellar changes that may have already evaporated any surface water [7]. Lastly, Kepler-22b is one of the most promising candidates, with a radius 2.4 times Earth's. It orbits a Sun-like star every 290 days and resides in the habitable zone, with an average surface temperature of about 21°C [8].

5. Conclusion

This paper first studies the KST and its working principle and mission. Afterwards, readers can understand how does the transit method work and how to measure the radius of an exoplanet through the transit light curve. Finally, the paper introduces three potentially habitable exoplanets. Through reading this paper, it can be found that the KST is one of the important tools for humans to explore the universe and search for extraterrestrial life, and its discovery and results have a profound impact on the astronomy community. Although people could find some exoplanets that humans might be able to live on, people can’t get there with current technology. If humans want to leave the solar system now, it will probably take tens of thousands of years, so Interstellar migration is still a long way off, the Earth is still the only home. Therefore, every single person needs to protect the environment. This could allow the planet to provide shelter for humans for longer, and scientists have a greater chance of inventing the tool that can take humans to their second home.

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