The Exploration of Exoplanets Based on The Transit Method

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Abstract. Up to now, the vast majority of discovered exoplanets have been detected by an important detection method called "transit" technology, which discovers the exoplanets based on observing and determining through repeated weakening phenomena on the light spot generated during planetary orbit transit. By adopting this technique, A wide variety of exoplanets have been discovered, and extremely satisfactory results have been achieved. In the paper, mainly with the light curve (LC) data obtained from TESS (Transiting Exoplanet Survey Satellite), it's analyzed using Lightkurve, a newly developed Python open-source library. By choosing specific regions of interest to extract LCs, performing many sophisticated processes and steps, doing detailed transit seeking work, then extracting parameters related to transiting planets from the process, and finding potential candidate planet transits eventually, and verifying the effective performance of all steps, successfully detecting a number of potentially good planets from various samples. In addition, the paper also found that even at present, the most modern method of planetary detection will have the crucial difficult problem, how to distinguish between genuine occultations occurring as planet orbits and light spot weakening events on stars and noises from instruments or noise produced in some way. The reliable and accurate approach proposed here to treat data could be used to assist and increase the probability of future planetary discovery.

Keywords: Exoplanets; Transit Method; TESS; Light Curves; Data Analysis.

1. Introduction

Nowadays, the search for and discovery of exoplanets is among the most frontier, hot, and significant questions facing the whole area of astronomy. Involving an extremely important question: are humans the only intelligent beings in the universe? At the same time, looking for other planetary worlds is also an effective way of discovering the origin and diversity of planetary systems. To proceed with such work, NASA's Kepler project continuously monitors roughly 150,000 stars fixed in the sky for a few years till it goes offline from 2009 to 2018 and made many discoveries of exoplanet candidates with great contributions to increase human understanding about different types of planets [1]. In the meanwhile, to make even better efforts and efforts to transit searching planet detection by space telescope, NASA launched in 2018 the Transiting Exoplanet Survey Satellite, i.e. TESS, which will completely scan the whole sky area to look for many planet hosts with some planets around bright stars and provides an avalanche amount of astronomical data including useful ones for exoplanet future discovery and characterization such as planet’s atmosphere studies [2]. Then it released catalogues regularly with new and updated information about exoplanet candidates [3]. As a matter of fact, the transit method has become one of the most popular and effective techniques for detecting exoplanets, but some unresolved problems still exist (there are some difficulties, such as false positive signals). Example(s) of the former phenomenon was that, when a certain astronomer observe an exoplanet system, trying out by transit detecting methods, the observation might meet some eclipsing double stars that would cause artificial appearing of signals similar to possible exoplanets, or other incorrect instrumental effects may cause strange planetary transit signals suspected of existence in the system Fressin et al [4].

However, there is a particularly difficult thing when looking for potential terrestrial planets near active stars is to applying the right algorithms to extract some real planet transit signals (i.e., signs) amidst complicated noises from other places (sources) and from inside our own solar system, for instance [5].

Based on this, this paper uses TESS light curves available in the open field and performs data analysis with Python toolkit Lightkurve to search and identify suspicious transit signals, explains the technical principles of the transit method through specific cases, reveals the difficulties and difficulties in the actual signal verification, provides an inspiration for future, more accurate planetary searches.

2. Research Methods

One method among all the exoplanet searching methods have become one of the most efficient one: the transit method (the planet transits in front of a luminous star so brightness dims): when the host stars of planet planets are observed from Earth, once planets are orbiting around their host stars, there would be transiting planets to gradually move into the telescope field of view (i.e., planetary transits are seen in front of its brightness) then planetary light is slightly reduced and goes down slowly (called dark light, dimming) and bright again as they move across in front of the host stars during orbital periods in a few consecutive hours or days or even a whole year depending on the orbital distances, then telescope observations can easily catch onto them and hence tell us that there must be planets there not only and not at least determining many physical parameters, e.g., planet's radius, planetary distance, orbital period, orbital inclination, etc.

To systematically search for possible planetary signals, this study utilized publicly available observational data from the Transiting Exoplanet Survey Satellite (TESS) [1]. The analysis specifically focused on the Full Frame Image (FFI) data from Sectors 27 to 35, which cover observations conducted between July 2020 and June 2021. These sectors include observations spanning mid-2020 to mid-2021, with high integrity and continuity of the data. The targets of this study mainly refer to G-type and K-type stars in the TOI list of TESS: these stars have moderate surface temperatures (approximately 5,000-6,000 K for G-type stars and 3,900-5,000 K for K-type stars) and are key target candidates to search for planets that can host life. The data processing is the most basic part of the work: this paper downloaded "Target Pixel File" in the Mikulski Archive for Space Telescopes (MAST) by the institute named “Space Telescope Science Institute” (STScI), with its TPF files containing star data of each pixel of the object field within the period of observed observations; then calibrated and preprocessed TPF according to standards, which included steps such as subtracting background noise (the noise from other background stars needs to be eliminated before analysis, thus being subtracted off the brightness level corresponding to the pixels of the original background) and flat fielding correction (due to the differences between the instrumental cameras on different positions on the chip, this kind of deviation should be corrected by means of relative standardization so as to reduce effects of instrumental problems on the results); extracted light curves from preprocessed and calculated pixel file of the target stars, i.e., time sequence stellar brightness variation curve (Lightkurve provides functions for extracting stellar brightness light curve: extract_lightcurve());

Noise and Trend Removal — The activities of a star itself, such as solar flares and cycles, are related to the Sunspot cycle, even minor shifts of the instrument can cause variations in light curves unrelated to planet signals. This study used methods such as Self Flat Fielding (SFF) to “smooth” these noises, making the potential “transits” more apparent to the human eye. After we obtain so-called “clean light curves,” the following step is still not simple: detecting transit signals with the BLS algorithm.

It compared this BLS algorithm as an efficient and powerful kind of “Period-matching.” By selecting several thousand period-time combinations among possible orbital periods (set from 0.5 days to 20 days since our data has high sampling rates and good baselines such as the TESS satellite), it can screen signals matching that of “periodical brightness dimming with short duration.” Of course, not all the candidates generated by the above algorithm have true meanings. So, all the signals marked as possibly periodic need checking manually. One hand for checking signal shape: if the true event of stellar transits would produce a “symmetric U shape” on the bottom part of the light curve; another hand checking the phases of those signals with different periods, whether they can align themselves very accurately. Even the manual work seems traditional nowadays, but very necessary to delete some obvious signals which should be fake ones: e.g., sudden noise (glitch) of the instrument, a gap in a data point.

3. Results and Analysis

Using the above method, we found out 3 relatively credible planets from tremendous, massive data—the three all clearly had signal morphology matching transit ones and passed a simple morphological check preliminarily; we also rejected several similar candidates. Here are the results. Candidates (TOI Number) (Table 1).

Table 1. Here is the detailed information about the specific data of the three planets.

Planet	Orbital period (days)	Transit depth (ppm)	Duration (hours)	Speculated planet type
TOI 1233.01	7.56	2800	4.5	Hycean Neptune / Mini Neptune
TOI 1410.01	1.34	850	-	Ultra-short period planet
TOI 1693.01	18.80	520	-	Super earth

Case of False Positive Signal Exclusion:

The most typical false positive signal here comes from an eclipsing binary star; the bottom of its light curve is a sharp "V" shape (because when the two stars in the eclipsing binary system cross in front of each other, their brightness plunges quickly, and the bottom of the light curve is abrupt). In contrast to the "U" shaped light curves from planetary transits, by using this property of its light curves, it successfully removed this false positive signal. This case once again shows the importance of checking planet signals manually.

4. Discussion

Another important uncertainty of this study comes from the calculation method used to determine planetary parameters: The planetary radius derived in this study depends strongly on the reliability of the star's radius.

If the estimate of a stellar radius deviates by 10%, then the error in the calculation of planetary radius will be amplified as much, but the observation interval of the TESS data is 27 days (i.e., one observation sector), and we face natural obstacles when observing planets in long orbital periods (e.g., orbital period larger than 27 days). The problem could result in missing some habitable planets in the "temperate zone". Directions for further research optimization. To address the above issues, as well as considering existing trends in the research field, we expect the research could move forward from the following three aspects:

(1) Verification using other methods: For the selected candidates in this study, especially for those with weak signals like TOI 1693.01, follow-up verification can be performed using the radial velocity method to calculate planetary mass through Doppler shifting the star's spectra, and also high-resolution imaging technology—allowing observation of planet brightness without interference from background stars or galaxies—is the general international standard for upgrading "candidates" to "confirmed planets" [6]

(2) Machine learning-based algorithms for cross-checking: Facing an increasing flood of data (a single sector reaches terabyte scale), traditional manual screening of signals can hardly meet the needs. In the future, with machine learning algorithm assistance (e.g., convolutional neural network and random forest) in initial screening and removing false positives in datasets, researchers can use

limited resources in an effective way and focus efforts on what are considered scientifically more meaningful stars

Further observation and future identification: The main value of the stars and planets found in this study — especially the planet TOI 1233.01 orbiting the bright star — is that they will give us great opportunities to become the observation target of the next round of space telescopes. Ricker et al. once conceived of the first purpose of the TESS spacecraft during its design, saying that the core purpose of TESS is to draw a "treasure map of planets", which can be used as a basis for further study [7]. In the future, more powerful instruments, such as the James Webb Space Telescope (JWST), will observe the likes of this by using atmospheric transmission spectra; it will determine from the characteristics of light reflected by light from behind the atmosphere on planets whether there are any particular kinds of chemical substances, such as water and oxygen, thereby seeking the signs of alien life.

5. Conclusion

In conclusion, this study has successfully established a reproducible data processing pipeline based on the transit method, employing Lightkurve to analyze TESS Full Frame Image (FFI) data from Sectors 27–35. Three high-confidence exoplanet candidates have been identified and characterized: TOI 1233.01, a hot sub-Neptune orbiting a bright host star; TOI 1410.01, an ultra-short-period planet that serves as an ideal candidate for studies of tidal evolution; and TOI 1693.01, a potential super-Earth located within the temperate zone. These findings further demonstrate that the transit method remains one of the most promising approaches in contemporary exoplanet research.

The scientific value of planetary discovery in the Milky Way should not be assessed solely by quantitative growth—i.e., the increasing number of detected exoplanets—but also by the effectiveness with which the most promising candidates are selected for follow-up investigation. Future work will involve follow-up observations, including radial velocity measurements and atmospheric spectroscopy, to confirm the planetary nature of these candidates and to probe their atmospheric properties using complementary instrumentation. For instance, TOI 1233.01, validated in this study, may serve as a key observational target for advanced facilities such as the James Webb Space Telescope (JWST). Significant advances in the understanding of exoplanetary atmospheres may originate from such targets. The exploration of exoplanets remains an ongoing endeavor.

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