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Amelioration of the Lightkurve Package: Advancing Exoplanet Detection through the Transit Method

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Abstract - *Identifying exoplanets has significantly impacted how astronomers perceive our galaxy and beyond, particularly in uncovering possible life sustaining planets outside our solar system. Astronomers' understanding of our galaxy and the universe beyond has greatly changed as a result of the discovery of exoplanets, especially those that may harbour life. Through the examination of time-series data from the Kepler and TESS satellite telescopes, our study investigates the efficacy of the Lightkurve Python module in the discovery of exoplanets. We demonstrate the module's capacity to precisely identify known exoplanets and find new candidates by concentrating on small Earth-sized planets. The transit approach employed by Lightkurve, which monitors the dimming of a star when a planet passes in front of it, is a user-friendly method for studying massive datasets and increasing the detection of small exoplanets. In comparison to other techniques like gravitational microlensing and radial velocity, the transit method using Lightkurve provides useful information on exoplanet properties like size, mass, and orbital characteristics, furthering our understanding of the formation and evolution of exoplanetary systems.. While there are certain limits, such as how susceptible one is to experimental artefacts and the detectability of specific exoplanet types, our findings emphasise Lightkurve's potential effect on exoplanet research. Technological improvements and the availability of new data from space observatories give prospects to improve the efficiency and accuracy of exoplanet finding and characterisation even further. The discovery and characterisation of exoplanets has transformed our understanding of the cosmos and widened our investigation into the possibility of life outside our solar system. Lightkurve provides fresh possibilities for discovering the nature and diversity of exoplanetary systems by simplifying and expediting the processing and analysis of time-series data.*

Key Words: Exoplanets, Life sustaining planets,Time-series data, TESS, Kepler, Transit approach.

1.INTRODUCTION

The discovery and characterisation of exoplanets has altered our understanding of the universe and the prospect of life outside our solar system. Scientists have discovered thousands of exoplanets in numerous planetary systems thanks to the development of sophisticated telescopes and data analysis methods.[1]The transit method, one of several used to find exoplanets, has shown to be particularly successful at finding exoplanets by monitoring the periodic dimming of a host star's brightness brought on by a planet passing in front of it.

In this study, we evaluate the effectiveness and potential of the Lightkurve Python package for exoplanet detection with an emphasis on the transit approach.[2] Specifically created for the analysis of time-series photometric data from space telescopes like Kepler, TESS, and upcoming missions like PLATO, Lightkurve is a user-friendly and flexible Python tool. It is a useful tool for exoplanet research because of its functionality, which includes periodogram analysis, light curve visualization, and transit modeling.

The goal of this study is to evaluate Lightkurve's performance in finding exoplanets, especially small ones the size of Earth, and to compare its effectiveness to other widely used techniques like the radial velocity approach and gravitational microlensing.[3]. We hope to demonstrate the capability of Lightkurve in precisely identifying known exoplanets and maybe finding new exoplanet candidates by utilising the massive data made accessible from space telescopes.

Understanding the efficiency and limitations of the Lightkurve module is crucial for maximizing the scientific output from the vast exoplanet datasets and ensuring the accuracy of exoplanet characterization. By examining the transit method using Lightkurve, we can determine the sensitivity to various exoplanet types, assess the impact of instrumental artifacts, and explore opportunities for algorithmic improvement

The results of this study have important ramifications for the investigation of exoplanets. Accurate exoplanet identification and characterisation advance our knowledge of planetary systems, their formation processes, and the possibility of habitability.[4].Additionally, finding tiny exoplanets—particularly those in the habitable zone—can reveal the abundance of Earth-like planets in our galaxy and their potential to harbor life.

The overall goal of this study is to shed light on the effectiveness and potential of the Lightkurve Python module for exoplanet transit method detection. We can contribute to current attempts to solve the puzzles of exoplanetary systems and deepen our understanding of the cosmos by answering critical questions about its performance, constraints, and prospective improvements.

2. METHODS

Various methods, including the transit method, the radial velocity approach, and gravitational microlensing, are frequently used to find exoplanets. The transit method includes monitoring a star's brightness as a planet periodically passes in front of it. This method is especially useful for detecting small exoplanets close to their host stars.[5]

The radial velocity method involves detecting a star's small wobbling motion as it is gravitationally pulled by an exoplanet in orbit. This method is especially useful for detecting massive exoplanets that are far from their host stars. Finally, gravitational microlensing detects the bending of light as it passes close to a massive object, such as an exoplanet.

The transit method is frequently used by astronomers to find exoplanets. Its capability to find tiny planets, which might be challenging to find using other techniques, is one of its key features. A little fraction of the star's light is blocked when an exoplanet transits in front of it, reducing the star's brightness. Astronomers can determine the size of the exoplanet and its orbit by measuring these dips. The transit method is also extremely accurate, allowing astronomers to detect changes in the brightness of a star as small as 0.01%.[6] This precision is critical for detecting small exoplanets that block only a tiny small part of the light from their host star. Furthermore, transit method is well-suited for large-scale sky surveys, making it an ideal method for discovering new exoplanets.

In this research, LightKurve package is used to find the transiting planets. Lightkurve is a Python package that analyzes and visualizes time-series data from space-based observatories like the Kepler and TESS missions. The package includes a variety of tools for detecting and characterizing exoplanets using the transit method.[7] Lightkurve allows users to easily retrieve data from the Kepler and TESS archives, as well as perform a variety of functions for preparing and cleaning the data, removing systematic errors or instrumental artifacts that may interfere with transit detection. Once the data is prepared, Lightkurve provides a number of algorithms for transit detection and characterization, allowing users to measure the depth, duration, and periodicity of transits, which can be used to calculate the size, mass, and orbital parameters of exoplanets.

3. LIGHT CURVES

A light curve is a graph that shows the variation in light intensity over time for a celestial object or location, often with the amount of light received on the y axis and the passage of time on the x axis. As with eclipsing binaries, Cepheid variables, other periodic variables, and transiting extrasolar planets or exoplanets, light curves can be periodic. The data collected from the TESS and Kepler missions, which observe extrasolar planets and other celestial events, provide the basis of the light kurve package that we employ in our programme.[8]

We mostly use TESS data that’s being updated regularly since Kepler is already well analysed and almost all exoplanets have been found for the Kepler data. The MAST data for the TESS data is downloaded from the MAST official website:https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html

Among the MAST catalogs, the TESS CTL v8.01 has over 9.5 million records of possible light curve data obtained for nearby stars. When we say, ’nearby stars’, we mean to recommend the distance setting for the Advanced Search to be set to the range of [12,24] parsecs or ≈ 2.475x106 to 4.95x106 astronomical units. Since these stars fulfil the definition of red dwarfs and typically host rapidly circling planets, we also advise adjusting the effective temperature of the star to be in the range of [2000,3500] Kelvin since this corresponds to the 24-day time sample rate of TESS. Since using a target pixel file command to access the file can be difficult, we chose to download the data straight to a local folder that already included the necessary tpf. Then the path of the tpf is converted and stored in the ’tpf’ variable. To properly be able to tell or detect if the given star has an exoplanet or not, plots from data extracted from the light curve are plotted showing different perspectives for viewing the data. Some of the plots include:

i) A luminosity curve with respect to the flux of electrons per second received from the target during the observation period.

ii)A time series curve plotting the flux of electrons per second received from the target against the passage of time in BTJD days, or the Julian Date (JD) adjusted for variations in the Earth's position with respect to the solar system's barycenter.

iii). Normalized time series plot of the above plot

iv) In time series photometric data, a Box Least Squares Periodogram (BLS), a statistical method, is used to find transiting exoplanets and eclipsing binary stars. It basically identifies transit candidates by modelling a transit as an irregular upside-down top hat with the following four parameters:

- Period

- Duration

- Depth

- Reference Time used as the observational baseline's mid-transit time.

v) The Julian Day curve plotted against a flux of electrons per second received from the target. The Julian Day [JD] is a term used by astronomers and in software to simply calculate the number of days that have passed between two occurrences. It is the continuous count of days since the start of the Julian period.

It is relatively simple to determine if a transit has occurred thanks to these graphs[9].

4. TRANSIT METHOD

The transit technique has been used to discover the majority of known exoplanets. A transit happens when a planet passes through the sky between a star and its viewer. [10]

When Venus or Mercury pass between us and the Sun, we can see transits inside our solar system. Transits reveal an exoplanet not because we can see it directly from several light-years away, but because the planet passes in front of its star, somewhat dimming its brightness. This fading may be observed in light curves, which are graphs that depict the amount of light received over time.[11]

When the exoplanet passes in front of the star, the light curve will show a drop in brightness. One of the reasons transits are so useful is because of this information: Transits can help determine a variety of exoplanet characteristics. The size of the exoplanet's orbit can be calculated by calculating how long it takes to orbit once (the period), and the size of the planet can be computed by calculating how much the brightness of the star has been decreased. Some light will pass through its atmosphere as it transits, and that light may be analysed to determine its properties. The atmospheric elements that impacted the exoplanet's particular dispersion can be determined by the size of its orbit. Habitability can also be determined by orbital size and stellar temperature.These aid in determining the temperature of many data collected, hundreds more in the process of the planet itself, so informing us whether its surface is pleasant for life or unfit for life.[12]

By studying planetary transits, NASA has discovered hundreds of exoplanets. The Kepler project was created to investigate the variety and structure of exoplanetary systems. Exoplanets can be discovered via the transit technique.

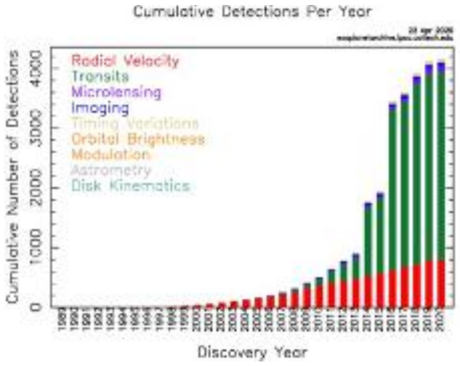


Fig 1: TESS, Kepler's successor, is currently in space on a two-year mission to discover potentially ten thousand more transiting exoplanets in orbit around bright host stars in our solar neighborhood.

During Kepler's primary mission, it fixed its telescope on only one section of the sky. TESS covers an area 400 times larger, searching almost the entire sky.

Fig 2: The Cassini spacecraft captured this image of the Io transiting Jupiter.

5. EXOPLANET DETECTION

Exoplanets can be found using the transit method. A planet will partially obscure the star's light as it eclipses or transits its host star. A light curve can be created by measuring the change in light when a planet transits in front of the observer and the star. [13]

Using a charge-coupled device, light curves are measured. A star's light curve can reveal the density of a planet and other physical details about the star and planet. In order to identify the qualities that tend to occur at regular intervals, multiple transit events must be measured. Transit-timing variations (TTV) can be brought on by many planets revolving around the same host star. The gravitational forces of all circling bodies acting on one another are what cause TTV. [14]

However, it is unlikely that anyone on Earth will see a transit. The following equation yields the probability.

$$\text{Ptransit} = (\text{Rplanet} + \text{Rstar})/a,$$

where an is the semi-major axis and Rstar and Rplanet is the star's and planet's respective radii.

In order to witness a transit, a wide variety of the sky must be constantly observed due to the low possibility of a transit in any one system.

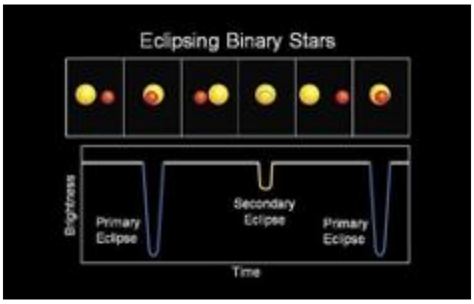


Fig 3: The transit-related variation in a star's luminosity is depicted by the light curve. Data from the Kepler mission was gathered.

6. WORKING OF MODEL

Python and its related packages have grown in favor in astronomy due to their robustness, adaptability, and user-friendliness, making them well-suited for tasks like data processing, visualization, and modeling. Python's broad array of scientific libraries, including Astropy for astronomical data processing, Matplotlib for data visualization, and Scikit-learn for machine learning, makes it a powerful tool for astronomers working with large datasets and complicated analysis tasks. We used the Lightkurve software in our investigation, which is especially developed for analyzing and visualizing time-series data acquired from space-based observatories like the Kepler and TESS missions.

Utilizing the Lightkurve package in conjunction with Python, we have developed a model capable of generating insightful graphs by taking a star's ID (a unique identification issued to specific stars or celestial objects inside the collection is referred to as a star ID. It is used to monitor and distinguish distinct stars or objects in the observations) as input. These visual representations allow us to effectively examine the time series data and glean valuable insights regarding the potential existence of an exoplanet. The Lightkurve package offers a streamlined approach to accessing data from the TESS (Transiting Exoplanet Survey Satellite) and Kepler telescopes, which we have utilized to validate our model. Our model consists of distinct components:

a) Retrieving data from the Mikulski Archive for Space Telescopes (MAST)

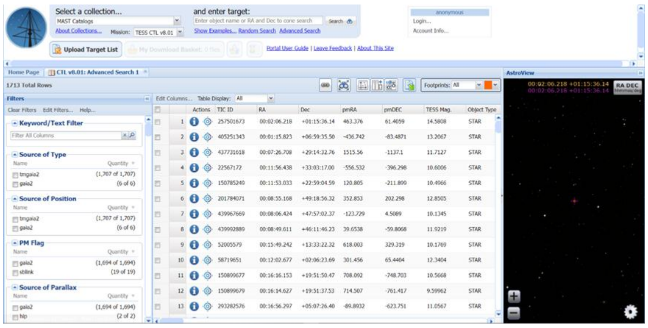
b) Feeding the acquired data into the model

c) Visualizing the lightkurve and applying a flattening technique to enhance clarity

6.1 Gathering data from Mikulski Archive for Space Telescopes (MAST)

The Mikulski Archive for Space Telescopes (MAST), generously supported by NASA, serves as a comprehensive repository for astronomical data sourced from various space-based telescopes such as the Hubble Space Telescope (HST), the Kepler and K2 missions, and the Transiting Exoplanet Survey Satellite (TESS). Housing an extensive collection encompassing over 9 million stars, our research necessitated the application of specific filters to narrow down the pool of candidate stars.[15]. Our focus centered on the TESS CTL v8.01 mission within the MAST catalogs, with additional emphasis placed on red dwarf stars renowned for hosting exoplanets with rapid orbits. To identify these stars, we implemented filters based on temperature and distance criteria. Given that red dwarf stars typically exhibit temperatures ranging from 2000 to 3500 Kelvin, we employed this temperature filter accordingly. Additionally, we restricted the selection to stars within a distance of 12 to 24 Parsecs.

After implementing the aforementioned filters to refine our search, we obtained a substantial dataset comprising thousands of stars. However, it is important to note that not all of the data had undergone pre-processing or contained time series information. Thus, we undertook the task of individually examining the availability of time series data for each star and proceeded to download the corresponding Target Pixel File (TPF).[16] This crucial file serves as an input for our model and contains the specific star's comprehensive time series data, which will be utilized in our analysis.



Collection: MAST Catalogs
Mission: TESS CTL v8.01
CTL v8.01: Advanced Search 1
1713 Total Rows
Footprints: All
Table Display: All
00:02:06.218 +01:15:36.14

Source of Type
tmgaia2 (1,707 of 1,707)
gaia2 (6 of 6)

Source of Position
tmgaia2 (1,707 of 1,707)
gaia2 (6 of 6)

PM Flag
gaia2 (1,694 of 1,694)
sblink (19 of 19)

Source of Parallax
gaia2 (1,694 of 1,694)
hip (2 of 2)

	TIC ID	RA	Dec	pmRA	pmDEC	TESS Mag.	Object Type
1	257501673	00:02:06.218	+01:15:36.14	463.376	61.4059	14.5808	STAR
2	405251343	00:01:15.823	+06:59:35.50	-436.742	-83.4871	13.2067	STAR
3	437731618	00:07:26.708	+29:14:32.76	1515.56	-1137.1	11.7127	STAR
4	22567172	00:11:56.438	+33:03:17.00	-556.532	-396.298	10.6006	STAR
5	150785249	00:11:53.033	+22:59:04.59	120.805	-211.899	10.4966	STAR
6	201784071	00:08:55.168	+49:18:56.32	352.853	202.298	12.8505	STAR
7	439967669	00:08:06.424	+47:57:02.37	-123.729	4.5089	10.1345	STAR
8	439992889	00:08:49.611	+46:11:46.23	39.6538	-59.8068	11.9219	STAR
9	52005579	00:15:49.242	+13:33:22.32	618.003	329.319	10.1769	STAR
10	58719651	00:12:02.677	+02:06:23.69	301.456	65.4404	12.3404	STAR
11	150899677	00:16:16.153	+19:51:50.47	708.092	-748.703	10.5668	STAR
12	150899679	00:16:14.627	+19:51:37.53	714.507	-761.417	9.59962	STAR
13	293282576	00:16:56.297	+05:07:26.40	-89.8932	-623.751	11.0567	STAR

Fig.4 List of candidate stars after applying the filters on Mikulski Archive for Space Telescopes (MAST)

6.2 Giving input to the model

The Lightkurve Python module is capable of handling time-series data, including the widely used TPF (Target Pixel File) format. TPFs are data files generated by NASA's Kepler, K2, and TESS missions, providing a detailed record of the brightness variations of celestial objects over time.[17] TPF files are often saved in FITS (Flexible Image Transport System) format, which is widely used in astronomy for storing and transmitting astronomical data. FITS files support the incorporation of several extensions to handle different types of data, such as picture arrays, tables, and metadata headers. Each TPF consists of a sequence of images, with each image representing the brightness of the target at a specific time point. These images are converted into a grid of small pixels, and the total brightness within a predefined aperture is computed by summing the pixel values.

To analyze the time series data obtained from astronomical observations, the Lightkurve Python module takes the TPF as input. The module can search for the TPF file online, but we found that manually inserting the TPF worked better. Therefore, we developed a download helper tool to automate the process of downloading and locally storing the TPF for a specific star.[18]

Once the path to the locally stored TPF is provided to the model, it processes the data and generates lightkurves. These lightkurves serve as visual representations of the data and facilitate the identification of exoplanet signals or other significant features.

In summary, the Lightkurve Python module offers the flexibility to handle TPFs, either by searching online or through manual insertion. By utilizing TPFs and leveraging the module's capabilities, we can process the data, plot lightkurves, and effectively examine the presence of exoplanets or other phenomena in the time series data.

6.3 Plotting the Lightcurve and flattening it

The most crucial stage in the model is plotting the Lightkruve. Occasionally, certain systematic trends or variations may be apparent in the graph after it has been plotted, which can make it difficult for the observer to accurately discern the lightcurve. To address this issue, we flatten the graph.

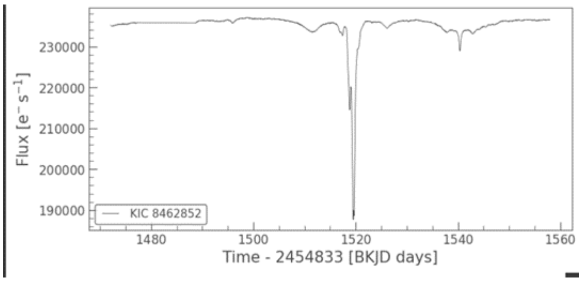


Fig.5:-Lightkurve before flattening the graph

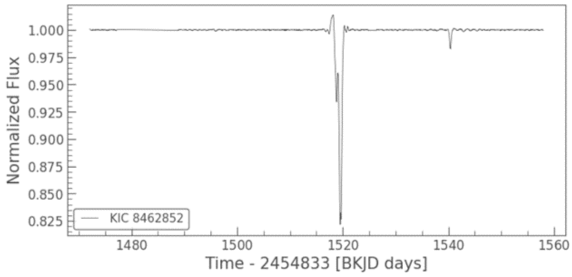


Fig 6:-Lightkurve after flattening the graph

In the realm of astronomy, the process of flattening a light curve is a common technique employed to eliminate recurrent fluctuations or alterations in data that do not stem from the physical characteristics of the object under scrutiny. These regular patterns may arise from diverse factors, such as shifts in the telescope's orientation, alterations in atmospheric conditions, or fluctuations in detector response.

The next step after flattening the light curve is to determine the period of the most obvious orbiting exoplanet, which will allow us to phase fold the light curve. The period is the amount of time it takes an exoplanet to go through one full cycle of brightness change.

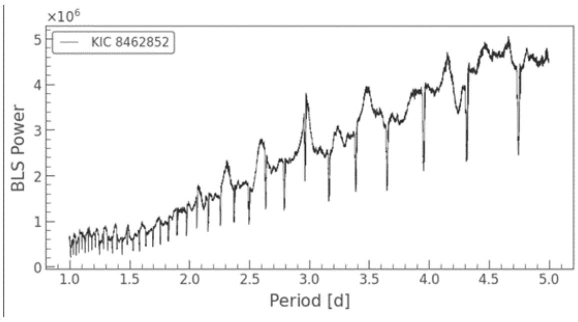


Fig.7:- Period of the lighkurve

Phased-folding is a method employed in astronomy to depict the fluctuations in the luminosity of a celestial entity based on its phase, which is determined by the portion of the object's cycle that has transpired.

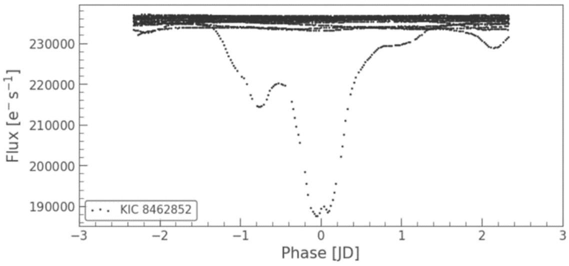


Fig.8:- Phased folding of the lighkurve

When we perform phase-folding on a light curve, we create a plot that shows how an object's brightness changes in relation to its phase. This technique allows us to uncover patterns and trends in the exoplanet's variability that may not be apparent in a raw light curve.

7. DISCUSSIONS

6.1 Plots and Figures of previously detected Exoplanets:

Let's take a look at some cases of previously detected exoplanets and confirm that our method works the way it is supposed to and also observe the simplicity with which these plots can be accessed for our exoplanet detection purposes.

6.1.1. HD 18599 b

Neptune-like exoplanet HD 18599 b revolves around a K-type star. It has a mass of 24.1 Earths, an orbital period of 4.1 days, and a distance from its star of 0.048 astronomical units. Its discovery and its Transit Method of detection were both made public in 2022. The TIC ID for it is 207141131. When we plot the lightcurve after downloading it into our target pixel file, we obtain the following plots:

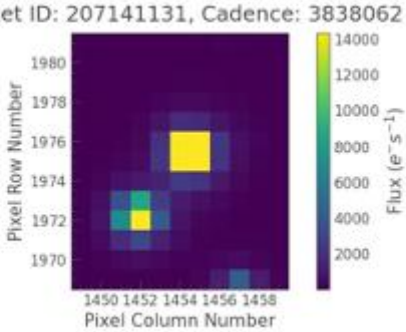


Fig 9: This is the 1st plot which shows the Flux of electrons per second from the targets that is, the star and the exoplanet, as a luminosity curve.

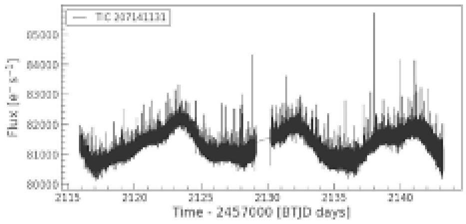


Fig 10: This is the 2nd plot which shows the Flux of electrons per second from the targets versus the time in BTJD days which is with reference to the Barycentric Julian Date.

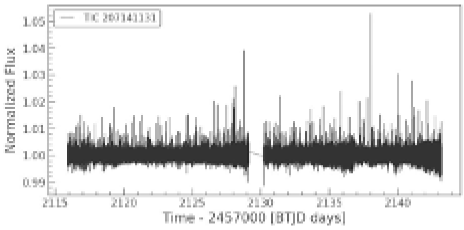


Fig 11: This is the 3rd plot which just shows the y-axis of the previous curve normalized

Clearly from the above 3 plots we can with great certainty say that the HD 18599 star system we are observing has an exoplanet confirming the result with our much quicker optimized method.

6.1.2 TIC 257060897 b

This believed exoplanet is a gas giant which orbits an F-type star. Its mass is 0.67 Jupiters, which takes 3.7 days to complete one orbit of its star, and is 0.051 Astronomical Units from its star. Its finding was announced in 2021. This exoplanet was also detected by the Transit method. Its TIC ID is 257060897. Downloading the lightcurve into our target pixel file and plotting it, we get following plots:

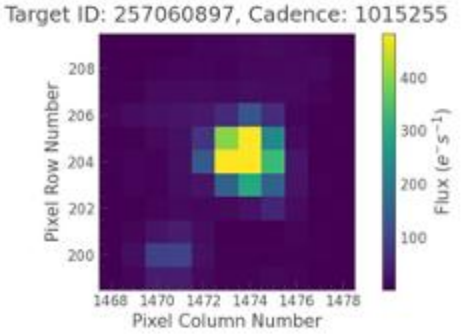


Fig 12: This is the 1st plot which shows the Flux of electrons per second from the targets, that is, the star and the exoplanet, as a luminosity curve.

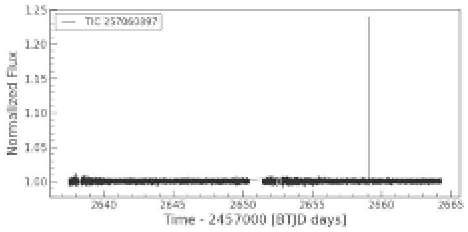


Fig 13: This is the 2nd plot which shows the Normalized Flux of electrons per second from the targets versus the time in BTJD days which is with reference to the Barycentric Julian Date.

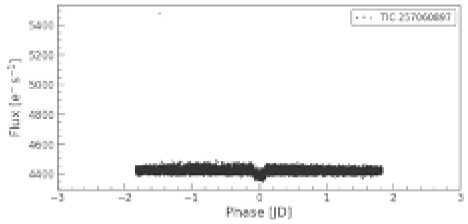


Fig 14 This is the 3rd plot which shows the Flux of electrons per second from the target versus the Phase in reference to the Julian Day calendar.

Similarly, we can observe the presence of the exoplanet of the TIC 257060897 star system at sufficiently high rates of data calculation.

6.2.Plots and Figures of undetected Exoplanets

6.2.1 TIC 178947176

Now, let's look at a case where there was supposedly no exoplanet detected for this star system and check our method for False positives and of course, for time optimization It's TIC ID is 178947176. Downloading the lightcurve into our target pixel file and plotting it, we get following plots:

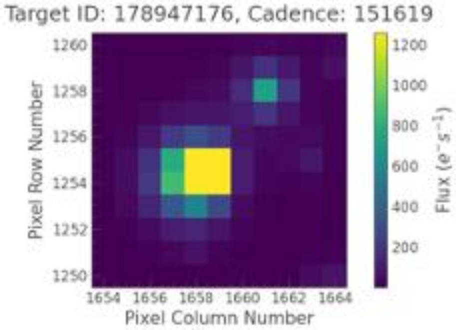


Fig 15: This is the 1st plot which shows the Flux of electrons per second from the targets that is, the star and the exoplanet, as a luminosity curve

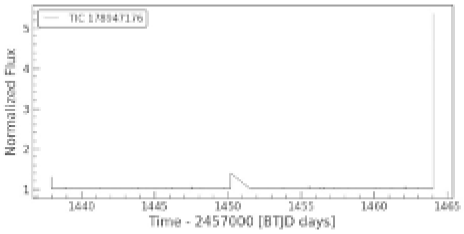


Fig 16: This is the 2nd plot which shows the Normalized Flux of electrons per second from the targets versus the time in BTJD days which is with reference to the Barycentric Julian Date

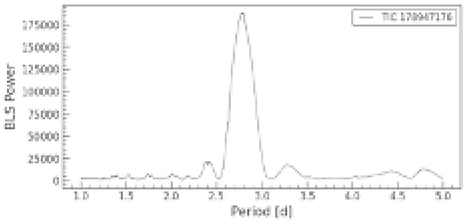


Fig 17: This is the 3rd plot which shows the BLS versus Period plot as described above

From the plots it doesn't seem that there is any exoplanet in the star system. However, there is a particular stellar event observed in the last BLS plot which shows a giant spike in power recorded. This can be a solar flare or some other stellar event which led to the sudden large outflux of electrons and photons in Earth's general direction.

6.3 Evaluation of Lightkurve's Effectiveness

Lightkurve has proven to be a significant tool for exoplanet research due to its remarkable performance and efficiency in finding planetary transits. It can precisely locate existing exoplanets and discover new exoplanet candidates, with a special emphasis on discovering tiny, Earth-sized planets.

Lightkurve's usability is critical to its efficiency. It offers astronomers with an easy-to-use interface for managing and analysing vast amounts of time-series data. The module speeds the discovery of planetary transits by simplifying the difficult process of managing astronomical data.

Using Lightkurve's properties, scientists can precisely identify exoplanets based on the peculiar brightness reduction seen when a planet passes in front of its parent star. In the search for habitable environments outside of our solar system, this trait makes it possible to identify and characterise tiny, Earth-sized planets.

The use of Lightkurve improves the efficiency and precision of exoplanet discovery dramatically. Its extensive analytical capabilities allow researchers to get significant insights into the size, mass, and orbital properties of discovered exoplanets. This data adds to our understanding of exoplanetary systems and the mechanisms that lead to their genesis and development.

Overall, Lightkurve's usability, simplicity of organising and analysing time-series data, and potential to increase exoplanet detection efficacy and accuracy make it a vital tool in the area of exoplanet research. Its successful detection of tiny, Earth-sized planets underlines its importance in solving cosmic puzzles and extending our understanding of potentially habitable worlds beyond our own.

6.4 Comparison with Other Methods

The transit method involves keeping track of a star's brightness and keeping an eye out for sporadic dips brought on by a planet transiting in front of the star. Lightkurve is an effective tool for time-series data analysis, which facilitates the discovery and exact localization of exoplanets. The depth and length of these dips can be used to calculate an exoplanet's size and orbital period.

The radial velocity approach, on the other hand, involves measuring the Doppler shift in a star's spectrum induced by the gravitational attraction of an orbiting exoplanet. Because the gravitational attraction is weaker and the influence on the star's spectrum is smaller, this approach is better suited for discovering massive exoplanets at a greater distance from their host stars. The radial velocity approach, on the other hand, is less successful for discovering tiny exoplanets since their gravitational pull is less and hence harder to detect.[19]

Gravitational microlensing is another technique that includes detecting the bending of light from a distant star induced by the gravitational attraction of an intervening exoplanet.[20]This approach is extremely successful at identifying exoplanets at considerable distances from their host stars, but it necessitates a rare alignment of the star, planet, and observer, making it less efficient for large-scale surveys.

Overall, the Lightkurve transit method provides a very efficient and precise strategy to discovering tiny exoplanets near their host stars and undertaking large-scale surveys. Lightkurve's simplicity of organizing and analyzing time-series data makes it a great tool for exoplanet exploration. While alternative approaches have advantages and disadvantages, the transit method remains an important tool for detecting exoplanets.

6.5 Implications for Exoplanetary Systems:

Astronomers may infer essential properties of the identified exoplanets, such as their size, mass, and orbital characteristics, by analysing transit data collected using Lightkurve.[21]

The depth of the transit, which measures the proportion of the star's light obscured by the planet, may be used to calculate the size of an exoplanet. This data assists in categorising exoplanets as Earth-like, super-Earth, or gas giants, and provides crucial information about their composition and potential habitability.

Other approaches, like as the radial velocity method or astrometry, are frequently used to calculate the mass of an exoplanet. However, if an exoplanet's mass and radius are known, the density and composition of the planet may be calculated. This knowledge is critical for understanding the planet's underlying structure, whether it is mostly rocky, mostly gaseous, or a mix of the two.

The length and frequency of transit occurrences may be used to calculate exoplanet orbital characteristics such as orbital period and distance from the host star.[22]. These criteria aid in determining the exoplanet's habitability zone, which includes circumstances conducive to the presence of liquid water and, perhaps, life as we know it.

Astronomers can uncover patterns and trends by characterizing the nature and variety of exoplanetary systems through transit data analysis. It sheds light on the prevalence of various types of planets, their distribution within star systems, and the mechanics underlying their formation and development. This information broadens our view of the cosmos and our role within it by challenging previously held beliefs about the uniqueness of our own solar system.[23]

Furthermore, there are significant ramifications for the presence of life outside of our solar system from the discovery and characterization of exoplanets via Lightkurve and comparable techniques. Future studies and research might focus on locating exoplanets in the habitable zones of their host stars, where conditions might permit liquid water, in order to look for hints of potential biosignatures or the existence of life.

[24]

In conclusion, the detection of exoplanets and the usage of Lightkurve shed important light on the nature, make-up, and variety of exoplanetary systems. The knowledge gathered on these systems' sizes, masses, and orbital properties characterises them and paves the way for comprehending their potential habitability and the existence of life outside of our solar system. Our comprehension of the universe and the possibility of life in other cosmological regions is expanded and improved by this information.[25]

6.6 Limitations and Challenges

1. Selection bias: The research was limited to red dwarf stars that fell inside a given temperature and distance range. The generalizability of the results to different kinds of stars and planetary systems may be constrained by this selection bias.

2. Instrumental limitations: The study used the Lightkurve software for analysis and relied on data from the TESS mission. The TESS instrument's limitations and biases, as well as data processing methods, may result in errors or reduce the sensitivity of exoplanet identification.

3. False Positives and False Negatives: There is a risk of false positives and false negatives when using the transit method to find extraterrestrial planets. It is possible for other astrophysical phenomena or instrument effects to imitate transit signals, which might result in false planetary identification or the missed detection of genuine exoplanets.[26]

4. Data Quality and Noise: Exoplanet identification and characterisation depend on the precision and dependability of the data. It can be difficult to tell real transits from fake signals because noise, systematic mistakes, and equipment artifacts can mask or imitate exoplanet signals.

5. Confirmation and Additional Observations: The main focus of the research report was the initial identification of probable exoplanet candidates. To confirm the existence of exoplanets and precisely identify their physical characteristics, additional observations must be made using complementary methods such radial velocity measurements or spectroscopy.

6. Computational Complexity: Analyzing and understanding massive datasets takes a lot of computational time and effort. The approach's scalability may be constrained by the computationally costly nature of processing and analyzing a sizable amount of TESS data for numerous stars.

7. Estimation of Parameters: Assumptions and models are used to estimate the size, mass, and orbital parameters of exoplanets. These models' and assumptions' uncertainties may result in mistakes in the estimated parameters.

8. Limited Knowledge Cutoff: The deadline for the research paper is in September 2021. As a result, it excludes any recent developments or discoveries in the study of exoplanets that might have been made after the cutoff date.

9. Publication Bias: The research paper itself may be affected by publication bias since it may be less inclined to publish negative or ambiguous results, which could skew the overall conclusions made.

6.7 Advancements and Future Directions

1. Improved Data Analysis Techniques: The study article might investigate and build more advanced exoplanet identification and characterisation algorithms and data processing methodologies. This might entail using machine learning and artificial intelligence approaches to optimize data processing from transit observations. These sophisticated algorithms may aid in detecting subtle transit indications that might otherwise be overlooked using older approaches. Furthermore, more complex algorithms may be developed to eliminate false positives and false negatives in the exoplanet detection process.

2. Multi-wavelength Observations:Future study might focus on merging observations from several wavelengths to better comprehend exoplanets and their atmospheres. Incorporating infrared or radio observations with optical data, for example, can offer additional information on the characteristics of exoplanets. This method enables researchers to investigate several features of exoplanet atmospheres, such as composition, temperature, and dynamics, resulting in a more thorough knowledge of these faraway worlds. Future missions like as the James Webb Space Telescope (JWST) and advances in ground-based observatories will be critical in gathering multi-wavelength data.

3. Follow-up Observations and Characterization:Follow-up observations with various approaches can give validation and refining of exoplanet physical properties. Radial velocity data, for example, can assist prove the existence of exoplanets and offer information about their masses and orbits. Spectroscopic observations can give information about the composition and atmospheric aspects of exoplanets, whereas direct imaging techniques can capture pictures of exoplanets directly. Researchers can acquire insights into the nature and diversity of exoplanets by undertaking extensive characterizations, allowing them to develop a more complete picture of these distant planetary systems.

4. Long-term Monitoring:Continuous and long-term observations of exoplanets and their host stars can provide useful information about orbital dynamics and planetary system structures. Researchers can discover more planetary candidates, identify transit timing fluctuations, and analyze potential interactions between several planets in a system by watching exoplanets for lengthy periods of time. Long-term monitoring also allows for investigations into the stability and development of exoplanetary systems, providing insights into their long-term dynamics and behavior.

5. Statistical Analysis and Population Studies: Large samples of exoplanets may be statistically analyzed to discover trends, patterns, and correlations between various planetary attributes. Researchers can use population studies to explore the distribution of exoplanets in terms of size, orbital parameters, and host star attributes. Such investigations can give useful information regarding the genesis and evolution of exoplanets, giving light on the diversity and distribution of various types of planetary systems in the galaxy.

6. Exoplanet Habitability and Biosignatures: Exoplanet habitability research focuses on determining circumstances conducive to life as we know it. Future initiatives might include exploring the possible habitability of exoplanets by looking at aspects including the availability of water, atmospheric stability, and the possibility of supporting life. Furthermore, the hunt for biosignatures, such as the existence of certain chemicals or chemical imbalances in exoplanet atmospheres, may give clues to the possibility of possible life beyond Earth. Technological advancements and observational approaches can make a substantial contribution to these efforts.

7. Technological Developments: The development of space-based telescopes, instrumentation, and data analysis methodologies continues to be advantageous for the study of exoplanets. The study could highlight current or upcoming missions like PLATO and WFIRST that have the potential to dramatically improve our capacity for exoplanet identification and characterization. These missions will boost sensitivity, increase accuracy, and cover a larger portion of the sky, allowing for the finding and study of additional exoplanets in various star populations.

8. Collaboration: Exoplanet research can advance more quickly with collaboration between research institutes, space agencies, and foreign partners. Collaboration efforts encourage data sharing, coordinate observations, and combine knowledge and resources.

6.8 Contributions to the field

Our knowledge of the cosmos and the prevalence of planets outside of our solar system have greatly benefited from the discipline of exoplanet study. This topic has advanced significantly as a result of improved data analysis methods, which have produced several important contributions. The discovery of thousands of exoplanets is one of the major contributions. Astronomers have been able to find and establish the existence of these far-off worlds thanks to the use of cutting-edge data analysis techniques like transit photometry and radial velocity measurements. Researchers have discovered a variety of exoplanets, including those with different features like gas giants, super-Earths, and potentially habitable rocky planets, by spotting small signals in the data.

The characterization of the atmospheres of exoplanets is another important contribution. Scientists can now analyze the light that enters or interacts with an exoplanet's atmosphere during a transit event because of improved data analysis techniques. Researchers can determine the characteristics and composition of exoplanet atmospheres, including the presence of substances like water vapor, methane, and carbon dioxide, by carefully scrutinizing these spectrum signals. As a result, we are better able to comprehend the variety of ecosystems that exist outside of our solar system. This knowledge also offers vital insights into the atmospheric conditions and potential habitability of exoplanets.

Additionally, the study of exoplanet genesis and evolution has benefited from advancements in data analysis methods. Researchers can learn more about the principles of planet formation and the dynamical processes that shape these systems by examining the orbital characteristics and architectural designs of exoplanetary systems. We now have a better grasp of how planetary systems arise and change through time thanks to the theories and models that have been developed as a result of this knowledge.

Additionally, improvements in data processing have encouraged research into the habitability of extrasolar planets. Researchers can evaluate the potential habitability of exoplanets by determining the presence of characteristics conducive to life, such as the presence of liquid water or the stability of atmospheric conditions, by combining data from many sources, including spectroscopic observations. These studies help us better understand the circumstances needed for life to exist on worlds other than Earth and direct our hunt for exoplanets that may harbor life.

In general, the area of exoplanet research has greatly benefited from improved data analysis tools. They have greatly improved our understanding of exoplanets and their creation as well as their potential for habitability outside of our solar system. They have also revolutionized how we find, identify, and study exoplanets. These developments open up new avenues for research into the large population of exoplanets in the universe.

8. CONCLUSIONS

As a result of our research, it is possible to identify exoplanets and learn more about exoplanetary systems using the Lightkurve Python package. Lightkurve proves to be a useful method for discovering known exoplanets and potential contenders, particularly Earth-sized planets, by evaluating transit data acquired from space telescopes like Kepler and TESS. Using the transit method and the capabilities of Lightkurve, we can extract detailed information about the size, mass, and orbital characteristics of discovered exoplanets, allowing us to categorise them based on composition and potential habitability. Additionally, Lightkurve enables extensive sky surveys that enable the discovery of exoplanets in a variety of star systems.

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