

Finding Planets: Exoplanet Validation Using Overlapping Data from TESS And K2

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ABSTRACT: Hidden from plain sight, vast archives of exoplanet data remain to be analyzed. TESS and K2 data are the vast majority of these archives. The overlap between these missions can be used to detect and validate exoplanets by cross-referencing transit signals. We predict that exoplanets can be validated if stars observed in these missions show consistent transit dips in their light curves. For our methods and materials, each candidate star was selected using the NASA Exoplanet Archive by retrieving its TIC ID. Using Python in Jupyter Notebook, the required packages were installed. The light curves were downloaded, detrended with Wotan, and analyzed with the Transit Least Squares (TLS) algorithm. Folded and binned transits were analyzed and checked for odd-even transits and secondary eclipses. Candidate 1 showed consistent transits with no secondary eclipses and a high SNR, supporting a hot Jupiter-sized planet, while Candidate 2 displayed consistent U-shaped transits but required further validation. Our hypothesis was supported, as the overlapped TESS and K2 transit signals reliably indicated a planetary candidate (Candidate 1), while Candidate 2 showed promising signs but required further confirmation. These results demonstrate that publicly available TESS and K2 data can be effectively used for validating exoplanet candidates.

KEYWORDS: Physics, Astrophysics, Exoplanet Detection, Transit Photometry, Exoplanet Validation, Planet Validation, TESS, TLS.

■ Introduction

To discover extraterrestrial life and Earth-like planets, our search must begin with the identification of exoplanets – a crucial foundation. One method of exoplanet detection is transit photometry,¹ which occurs when an exoplanet passes in front of its star, causing a measurable dip in the star's brightness. Other detection methods include direct imaging and gravitational microlensing.^{2,3} Transit photometry is used for large surveys because it can monitor thousands of stars simultaneously,⁴ whereas direct imaging is limited to widely separated planets.

To continue the exploration of exoplanets, the K2 mission⁵ was launched as a successor to the Kepler mission.⁶ The K2 further enhanced the discovery of exoplanets, with approximately 700 planet candidates identified.⁷ After the K2 mission, NASA launched the Transiting Exoplanet Survey Satellite (TESS) mission.⁸ TESS and K2 have been successful in observing common planet systems, providing abundant exoplanet and light curve data. By using overlapping observations from these two missions, we can perform independent checks on the detected transit signals.

Several studies have validated exoplanets using overlapping TESS and K2 light curves,^{9,10} with many more awaiting confirmation. This empirical paper investigates the transit dip in the light curves of stars to validate an exoplanet. It is based on the hypothesis that exoplanets can be confirmed if stars observed in both TESS and K2 show consistent transit dips in their light curves.

■ Methods

Candidate stars were selected from the NASA Exoplanet Archive using their TIC IDs, filtered for targets observed by both TESS and K2. All data handling and analysis were performed in Python using Jupyter Notebook. Then we utilised available packages for light curve extraction, detrending, and transit detection.

TESS light curves were downloaded and detrended using Wotan, which applies a smoothing algorithm to isolate transit signals from stellar variability and instrumental trends. The detrended light curves are then analyzed with the Transit Least Squares (TLS) algorithm, which models realistic transit shapes and is particularly sensitive to small, short-period planets. Transit events were visualized by phase-folding and binning the light curves, and checked for odd-even depth differences and secondary eclipses to rule out potential eclipsing binaries.

For the K2 targets, the pixel-level data were downloaded and processed to extract light curves. Pixel-Level Decorrelation (PLD) was applied to remove systematic trends from K2's variable pointing, followed by Wotan detrending to flatten the light curves. TLS analysis was then conducted, and the resulting light curves were folded and binned. Finally, the TESS and K2 results were compared by overlapping the folded light curves to verify the presence of consistent transit signals across both missions.

■ Results

Candidate 1 TESS analysis:

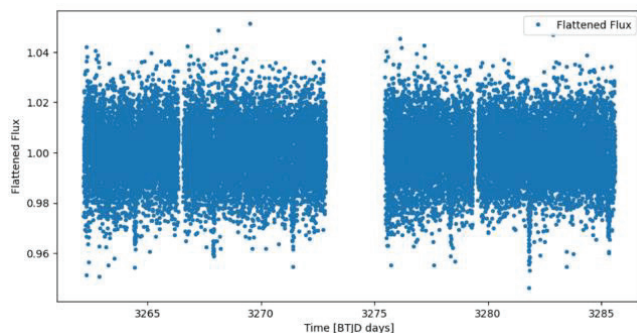


Figure 1: The detrended light curve, where the blue points represent the raw photometric data, spread across the graph. The vertical scatter in the blue points indicates the natural variability and noise present in the raw observations, while the extraneous signals demonstrate the reveal of potential transit features.

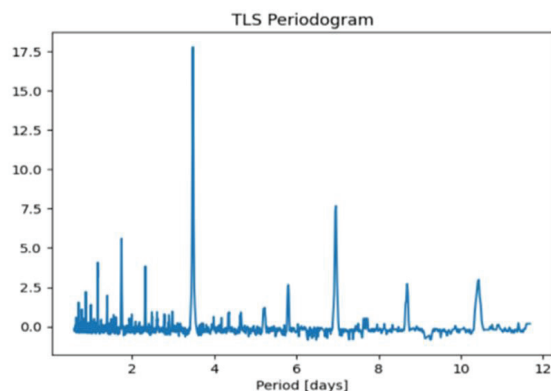


Figure 2: The detrended light curve was analysed using the Transit Least Squares (TLS) algorithm.

TLS models the light curve using realistic transit shapes rather than simple box-shaped signals, which is done by the Box-Least Squares (BLS) method (Figure 2), making it more sensitive to short periods, which can potentially be transits, which are typical of exoplanets. TLS identified these parameters: period = 3.47698 days, transit time (T_0) = 3264.4360 BJD, transit depth = 0.984%, and a transit duration of 0.156 days. These values represent the strongest periodic transit signal in the light curve and provide quantitative information for further analysis.

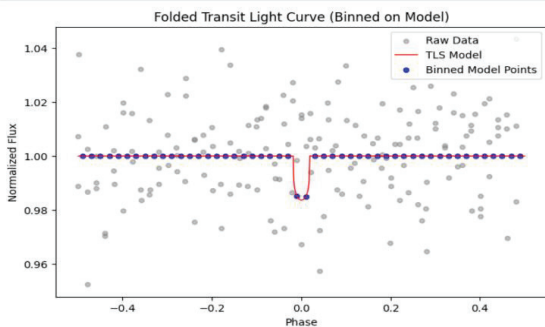


Figure 3: The light curve was folded and binned to improve the signal-to-noise ratio and visualize the transit more clearly.

The raw data points in grey are plotted across all observed phases (Figure 3), while the TLS model is shown as a continuous red line, flat except for the U-shaped dip at phase 0.0, corresponding to the planetary transit. The evenly spaced blue binned points represent averaged flux values within each phase bin, demonstrating the underlying transit signal more clearly against the noise. This allows for an easier analysis of transit depth, duration, and shape while reducing scatter from random variations.

Odd and even transits were also examined separately. The analysis yielded an odd transit depth of 0.01011 and an even transit depth of 0.01151, resulting in a difference of -0.00140 between the odd and even transits, which is almost negligible and indicates the consistent transit depths. This helps rule out the possibility of an eclipsing binary. Additionally, the root mean square was measured at 0.00800, corresponding to an approximate signal-to-noise ratio (SNR) of 122.96, showing a robust detection. A search for secondary eclipses near phase 0.5 revealed no significant signal – only at 0.0 –, further supporting that the observed transit is likely planetary in nature.

Candidate 1 K2 analysis:

For the cross-reference of the K2 mission, we downloaded the K2 target pixel file for Candidate 1, which was done from the Jupyter notebook. From this, the light curve was also downloaded and then processed through pixel-level decorrelation (PLD) to remove systematic instrumental noise. After PLD, the light curve was further detrended using Wotan to remove long-term stellar variability for extra confirmation. This ensured that the light curve was ready for TLS.

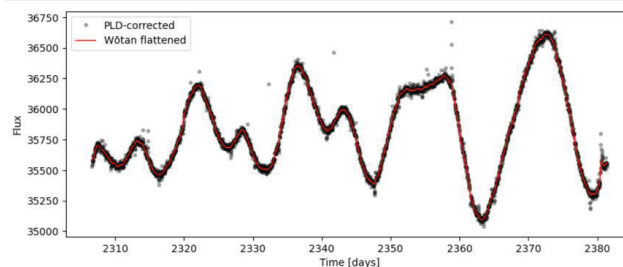


Figure 4: The detrended K2 light curve. The graph exhibits frequent fluctuations, which represent stellar variability and instrumental noise that remains after initial detrending. These ups and downs obscure the transit signal, making it difficult to visually identify transits without further processing.

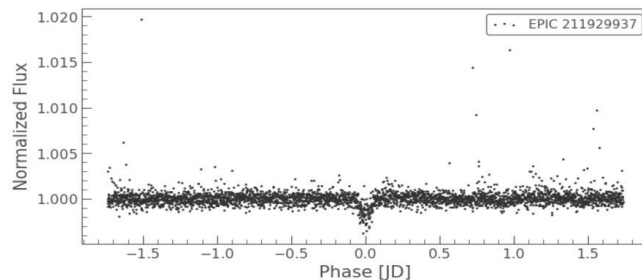


Figure 5: The K2 light curve after processing through PLD, Wotan detrending, TLS analysis, flattening, and phase-folding.

The K2 light curve was processed through PLD, Wotan, and TLS (Figure 5). The black dots are the binned flux points, mostly flat except for a clear dip at 0.0, which corresponds to the candidate's transit. TLS detected a best fit period of 3.4777 days – corresponding to both the NASA EXOPLANET ARCHIVE data and the earlier TESS analysis – with a transit depth of 0.998% and an SDE of 24.36, yielding an approximate SNR of 21.37. Odd-even transit analysis showed depths of 0.98855 and 0.99079, with a difference of -0.00224 , indicating no significant difference between consecutive transits. The secondary eclipse depth was measured at 1.00165, consistent with the absence of a secondary eclipse, suggesting the dip is unlikely to be an eclipsing binary.

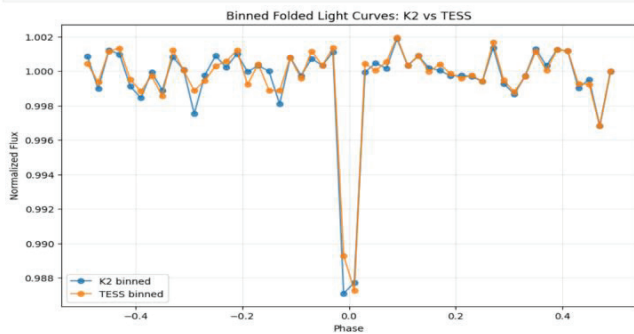


Figure 6: The folded and binned light curves of TESS (orange) and K2 (blue) overlapped.

The dip in phase 0.0 is visible, indicating that the transit signal is present in both TESS and K2 observations (Figure 6). While the K2 light curve exhibits more scatter and noise from 0.4 to 0.2, the alignment of the transit dips between TESS and K2 confirms the detection. This overlap provides strong evidence that the observed dips are likely caused by a planet transiting its host star.

Candidate 2 TESS analysis:

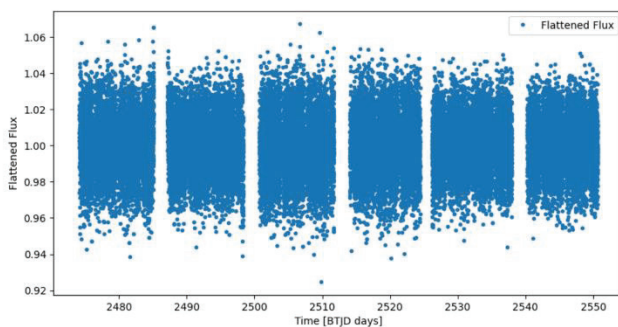


Figure 7: The light curve for Candidate 1 TESS was downloaded and detrended, producing the plot shown. The blue points represent the raw photometric data, while the detrended signal highlights potential transit events.

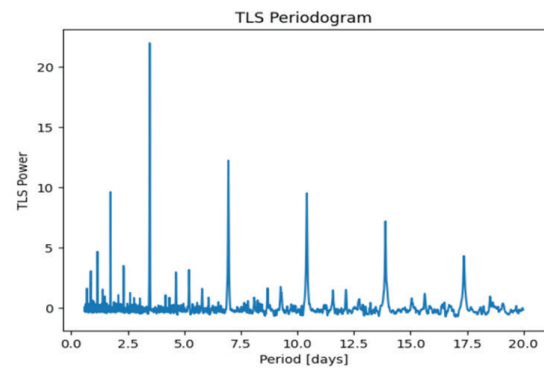


Figure 8: The detrended light curve was analysed using Transit Least Squares (TLS), producing the plot.

TLS identified a best-fit period of 3.472782 days, transit time (T_0) = 2476.24887 BJD - 2457000, transit depth = 0.988% (0.00988), and transit duration = 0.164 days (Figure 8). This algorithm models the light curve with transit shapes, allowing precise estimation of transit properties and providing a more sensitive detection than the BLS method.

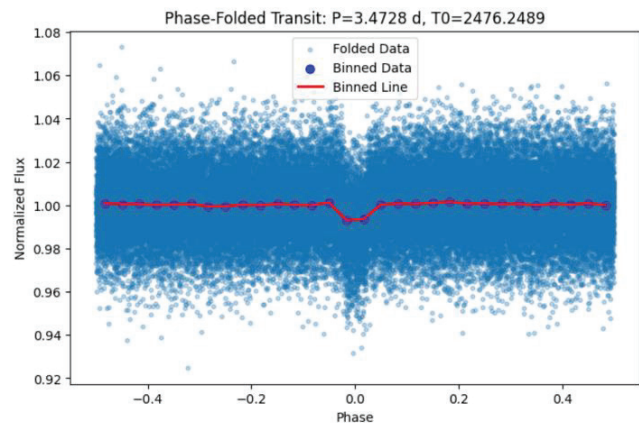


Figure 9: The light curve was then folded and binned to improve signal clarity and reduce scatter.

The red line represents the TLS transit model, which is flat except for the U-shaped dip at phase 0.0, corresponding to the transit (Figure 9). The evenly spaced dark blue points are phase-binned averages, which emphasise the transit signal over the noise, while the lighter blue raw data points show the original scatter.

Odd and even transits were compared to check for consistency. The odd transit depth was 0.00957 ± 0.00046 , and the even depth was 0.00941 ± 0.00048 , yielding an odd-even difference of 0.00017 ± 0.00066 (0.25σ). These results indicate uniform transit depths across consecutive events, ruling out strong eclipsing binary contamination. A secondary eclipse check near phase 0.5 measured a depth of 0.00021 ± 0.00045 , consistent with zero, supporting the interpretation of a planetary transit rather than a binary.

The transit model was fitted using `Batman + least_squares`, yielding a $R_p = 0.0882$, $a = 9.69$, inclination = 88.78° , $T_0 = 2476.24922$, and baseline = 0.99720. Derived planetary parameters include $R_p = 9.62 R_\oplus$, impact parameter $b = 0.21$, semi-major axis $a = 0.045$ AU, and equilibrium temperature

$T_{eq} = 1363$ K. The fit is stable and physically reasonable, showcasing a hot Jupiter-like exoplanet.

Candidate K2 analysis:

For Candidate 2, although the NASA Exoplanet Archive lists the target as observed by both TESS and K2, retrieving K2 data through Jupyter Notebook was unsuccessful. The K2 light curve could not be found or downloaded using the same methods applied to Candidate 1, which prevented any form of analysis. This may have arisen from several factors: it is possible that the candidate was included in the K2 catalog based on planned observations or preliminary data, but the processed light curves are not yet publicly available; alternatively, there may be inconsistencies in how the NASA Exoplanet Archive targets across missions. The inability to access K2 data for this candidate does not conclusively prove that the target was not observed by K2 or that the transit signal is absent in those sectors. It may simply reflect a limitation of the available data or the query method used. This highlights a limitation of the study, as independent verification of the transit signal from K2 - a key component of our cross-mission validation approach - could not be performed for Candidate 2.

■ Discussion

The K2 and TESS were designed to identify different star territories. TESS emerged as a successor to the Kepler 2 (K2) mission, aiming to identify additional planets. This provides a valuable opportunity to explore common ground with the previous findings of K2.

The validation process conducted in this project followed a conventional exoplanet analysis workflow using detrending, transit search, and cross-verification across missions. Light curves were flattened with *Wotan*, transit signals were extracted using the Transit Least Squares (TLS) algorithm, and consistency between TESS and K2 periods was used as the main indicator of a genuine planetary signal.

We hypothesized that if stars observed in the K2 and TESS missions show consistent transit dips in their light curves, these dips can indicate a planetary candidate. During the study of the two candidates, this hypothesis was partially completed. We used the transit least squares algorithm to explore the identification of planet candidates. TLS has been used to successfully identify small planets.¹¹

Other studies have implemented the method of validation through larger validation, such as scaling K2.V,12, which also relied on detrending and TLS-based searches to find consistent periodic dips across multiple campaigns. Similarly, *VaTEST III*¹³ validated 8 potential super-earths from TESS data using pre-processing and signal modelling techniques. However, these studies extended their validation process by estimating false-positive probabilities and performing posterior distributions. They also performed Bayesian fits to refine planetary parameters. Our approach achieved empirical agreement across missions, but fell short of statistical validation. This means that our methods align well with previous studies, but differ in the depth of analysis.

A limitation of this investigation is the absence of advanced validation algorithms that could be used to confirm the status of our candidates. These algorithms would help quantify uncertainty and false-positive probabilities. One of these is *VESPA*, which helps assess whether a signal is more likely to be a planet or an astrophysical false positive. Studies such as *Scaling K2 V12* utilised *VESPA* to calculate a formal false-positive probability, thereby strengthening the credibility of their planet candidates. Similarly, the use of MCMC methods, as implemented through the *emcee* package, enables the derivation of posterior distributions for parameters such as planet radius and orbital period. This paper¹⁴ demonstrated how Bayesian fitting improved parameter precision and reduced degeneracy in multi-planet systems. The lack of these approaches in my analysis limited the statistical confidence of the results. Future work incorporating these techniques would not only refine parameter estimates but also provide quantitative validation aligned with professional standards.

The TESS light curve displayed clear and statistically significant transit dips consistent with a planetary signal, while the K2 light curve exhibited a sine-wave trend that complicated visual identification of the transit signal. For Candidate 1, the TESS analysis revealed high-value periodicity, characterised by a U-shaped transit consistent with a planetary radius of $9.62 R_{\oplus}$, and no detectable secondary eclipses, which reinforces the likelihood of a hot Jupiter-sized exoplanet. The high signal-to-noise ratio (122.96) further supports the statistical significance of the detection.

For Candidate 2, although the light curve exhibited consistent U-shaped transits and negligible secondary eclipses, the slightly lower transit depth and higher noise underscore the need for additional confirmation. Although advanced statistical tools were not applied, cross-mission light curve comparisons provide valuable preliminary evidence for exoplanet candidacy.

A notable limitation of this study is the quality of K2 data, including instrumental noise and shorter observational windows, which may have contributed to less clear transit signals. Future studies could incorporate transit timing variation analysis or more sophisticated modelling to refine candidate validation.

Overall, this investigation demonstrates the potential of available TESS and K2 archives for exoplanet validation. Consistent transit signals across multiple datasets, combined with high SNR and the absence of secondary eclipses, provide strong evidence for planetary candidates.

■ Conclusion

This study analysed archival TESS and K2 light curves to validate exoplanet candidates through transit photometry. Candidate 1 displayed consistent findings to support a hot Jupiter-sized exoplanet. Candidate 2 showed promising transit signals but requires additional validation. These findings demonstrate that careful analysis of overlapping light curves from multiple missions can provide strong preliminary evidence for exoplanet validation. By providing a cross-check, this paper strengthens the reliability of planet validation and contributes to expanding the catalogue of confirmed exoplanets.

The archival data can provide a rich source for research, paving the way for large-scale studies.

Our limitations include K2 instrumental noise and shorter observational windows, which can obscure transit signals. Future work could extend this approach to additional candidates, incorporate TTV analysis, and apply advanced statistical validation tools to refine candidate confirmation.

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