TIME-SERIES ANALYSIS OF FV SCUTI WITH TESS: ECLIPSE DETECTION AND PERIOD EVOLUTION

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Cataclysmic variables (CVs) are binary star systems where a White Dwarf (WD) accretes matter from a donor star, and that accreted matter typically forms an accretion disk around the WD. Classical novae, a subclass of CVs, are distinguished by sudden outbursts resulting from thermonuclear runaways on the surface of the WD. FV Scuti (Nova Scuti 1960), a classical nova discovered in 1960, has a maximum visual magnitude of ~9.1 and faded by three magnitudes within approximately one month. Despite its historical detection, FV Sct has lacked a comprehensive modern investigation. Our study addresses this by analyzing Transiting Exoplanet Survey Satellite (TESS) light curves of FV Sct, specifically focusing on its quiescent behavior and orbital period evolution. TESS observed the system from June 18 to July 14, 2024, providing high-cadence (2-minute) photometric data. Following data reduction, which included detrending the light curve using the Locally Weighted Scatterplot Smoothing (LOWESS) method, we applied a Lomb-Scargle periodogram to determine the orbital period of the system, which is 7.33 hours. To assess period changes, we modeled primary eclipses and recorded the eclipsing time as observed time with inverted Gaussians fitting to the light curve and constructed an observed-minus-calculated (O-C) diagram. The quadratic fit in the O-C diagram yielded a period change rate of dP/dt = 2.474×10^{-7} days/day, indicating measurable orbital evolution potentially driven by angular momentum loss or mass transfer dynamics. These findings demonstrate FV Sct's ongoing activity in its post-nova phase and underscore TESS's value in long-term classical nova studies. Furthermore, the power density spectrum (PDS) reveals reduced high-frequency flickering, consistent with a cooler white dwarf, aligning with observations of other post-nova systems.

Keywords: classical nova, FV Sct, orbital period, TESS

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INTRODUCTION

Cataclysmic variables (CVs) are a type of variable star that exhibit changes in brightness over time. Classical novae are a subclass of CVs known for releasing dramatic amounts of energy. Classical novae are close binary systems composed of a White Dwarf (WD) and a main-sequence companion star. The companion star overfills its Roche lobe, causing matter to flow outward through the inner Lagrangian point to the WD. This process leads to the formation of an accretion disk around the WD. A fraction of this hydrogen-rich matter eventually accreted on the white dwarf's surface, where it's gradually compressed by additional accreted material. This compression heats the envelope of WD until conditions for a thermonuclear runaway (TNR) are met, triggering the nova outburst.

FV Scuti (Nova Scuti 1960) is a classical nova that erupted in the constellation Scutum. It was independently discovered by M. V. Savel'eva (1960). At its peak brightness, the nova reached a visual magnitude of approximately 9.1 and then exhibited a moderately fast decline, fading by three magnitudes in just over a month. (Nassau & Stephenson, 1961) Like typical classical novae, FV Scuti is a cataclysmic variable system where a white dwarf accretes material from a close binary companion. The thermonuclear runaway on the white dwarf's surface caused the sudden and dramatic increase in brightness. Despite its historical detection, FV Scuti hasn't been extensively studied in the modern era, and its quiescent properties remain poorly constrained.

METHODOLOGY

We acquired TESS observations for the FV Sct system from the Mikulski Archive for Space Telescopes (MAST), covering the period from June 18, 2024, to July 14, 2024. Tess provides 2-minute cadence photometric data, showing flux versus Barycentric Julian Date (BJD) for target CVs. After importing the data from the mast, the light curves undergo several processing steps. First, we remove any nan values. Next, we use a Locally Weighted Scatterplot Smoothing (LOWESS) method (Cleveland, 1979) to remove bright, long-term features from the photometric flux data. The LOWESS method convolves the light curve by fitting a sliding fraction of consecutive data points to the flux values, generating a smoothed value for each data point. This smoothed fit is then subtracted from the original flux to produce a 'detrended' residual light curve.

To determine the binary star's orbital period, we apply a Lomb-Scargle periodogram (VanderPlas, 2018) to the detrended light curve. Once we estimate the orbital period, we divide the observed light curve into chunks approximately one period wide. Each chunk should contain the primary and secondary eclipses of the system. We model the primary eclipse with an inverted Gaussian. From a sample chunk, we manually select two points within the eclipse portion of the light curve to derive an initial guess for the Full Width at Half Maximum (FWHM) and the eclipse center. Once the eclipse centers are derived, we extract them as Observed (O) eclipse times, which are essential for creating an O-C diagram.

After extracting the observed eclipse times (O), we calculate the predicted (C) eclipse times using the following equation:

$$C = T_0 + E\,P$$

Here, T_0 represents the initial time/epoch in the light curve, E is the cycle number of the eclipse, and P is the orbital period determined from the Lomb- Scargle periodogram. With both O and C values, we plot O−C versus the eclipse cycle number (E) and fit a quadratic fit to the data.

RESULTS AND DISCUSSION

Our analysis of TESS data for FV Scuti shows an orbital period of 0.305327 days, determined using the Lomb-Scargle method. Furthermore, the rate of orbital period change (dP/dt) derived from our O−C diagram is 2.474×10^{-7} days/day. This result provides crucial insight into the long-term behaviour of this classical nova system. A non-zero P′ suggests that the orbital period of FV Scuti is related to various physical processes at play, such as mass transfer variations, magnetic braking.

CONCLUSIONS/RECOMMENDATIONS

This study utilized TESS observations to investigate the cataclysmic variable FV Sct, a classical nova. Through meticulous data processing, including detrending with the LOWESS method, we determined the system's orbital period. Our lomb-scargle periodogram analysis yielded an orbital period of 0.305327 days or 7.33 hours. Furthermore, by constructing an O-C diagram and analyzing the deviations in eclipse timings, we derived an orbital period change rate dP/dt = 2.474×10^{-7} days/day.

This measured period change rate indicates that the orbital period of FV Sct is evolving, offering valuable insights into the dynamic processes occurring within this binary system. Such changes can be attributed to various phenomena, including mass transfer rate between the companion star and the WD, and angular momentum loss mechanisms like magnetic braking. The quantification of this period change, while associated with uncertainty, underscores the importance of high-cadence, long-baseline photometric observations, such as those provided by TESS.

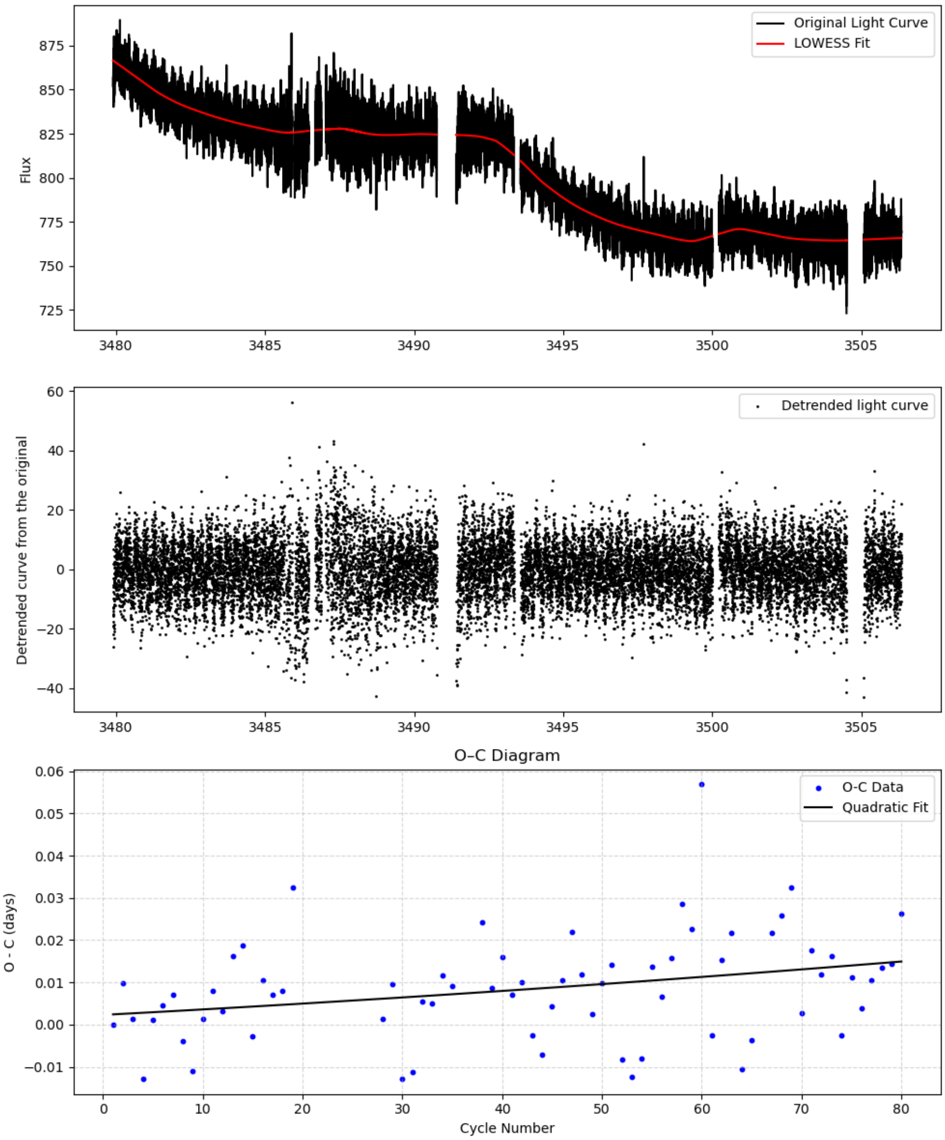

Figure 1: TESS Photometric Analysis of FV Sct. Top panel: Original light curve (black) with LOWESS detrending fit (red). Middle panel: Detrended light curve showing short-term variability. Bottom panel: O-C diagram illustrating the linear trend in eclipse timings, indicating orbital period change.

REFERENCES

Cleveland, W. S. (1979). Robust Locally Weighted Regression and Smoothing Scatterplots. *Journal of the American Statistical Association*, 829-836.

Nassau, J. J., & Stephenson, C. B. (1961). Nova Scuti 1960 and Nova Serpentis 1960. *Publications of the Astronomical Society of the Pacific*, 256.

Savel'eva, M. V. (1960). *astr. cire. U.S.S.R.*, 1.VanderPlas, J. T. (2018). Understanding the Lomb–Scargle Periodogram. *The Astrophysical Journal Supplement Series*, 28.