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PHOTOMETRIC VARIABILITY OF DO LEO BASED ON TESS DATA

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Abstract. *This article presents a photometric analysis of the cataclysmic variable star DO Leo. The main focus is on TESS observational data, in particular sector 72. The main focus of this work is the analysis of TESS data. This work investigates the TESS light curve of DO Leo obtained in Sector 72, which has not been previously analyzed in detail. This data set allows us to examine cycle-to-cycle variability and characteristic photometric modulation. The analysis reveals pronounced short-period variability with a period of approximately 5.6 hours, consistent with the previously reported orbital period of DO Leo. At the same time, cycle-to-cycle amplitude variations were identified, indicating that the shape of the light curve and the depth of the modulation vary. To further estimate the period, the Lomb–Scargle method was applied, confirming the derived period. Bootstrap resampling was used to estimate the period uncertainty. Ultimately, the obtained results confirm the nature of DO Leo and highlight the importance of this object for studying instability processes in cataclysmic variable stars.*

Keywords: CVS, eclipsing binary systems, photometric variability, light curves, TESS.

1. Introduction

Cataclysmic variables (CVs) are interacting binary systems in which one of the components, a white dwarf, accretes matter from a low-mass companion orbiting it. The observed variability of such systems is due to several physical processes, such as instability of the accretion disk, magnetic control of the mass flux in magnetic systems, and thermonuclear flares on the surface of a white dwarf in novae [1].

In the evolution of cataclysmic variables, special attention is paid to the relationship between the observed variability and the accretion regime, the evolution of the orbital period due to the loss of angular momentum. Great importance is still attached to the problem of period discontinuity and the discrepancy between the theoretically predicted and observed spatial density of such systems [2].

In recent studies of eclipsing cataclysmic variables, it has been noted that their variability is influenced by changes in the structure of the accretion flow and the physical condition of the disk, as well as changes in the rate of mass transfer. For example, in the work of Kara et al. [3] analysis of the AY Psc system of the Z Cam type showed that the rate of mass transfer varies between different states, which affects changes in the accretion disk. Similarly, Medina Rodriguez et al. [4], observing the VY Scl SDSS J154453.60+255348.8 type system, found that the photometric behavior depends on the accretion regime, while the accretion disk is present in the high state and more suppressed in the low state. It can be concluded that the observed variability is due not only to orbital motion in the binary system, but also to changes in the accreting flow.

Recent TESS observations have significantly expanded the possibilities for studying cataclysmic variables due to the availability of long and nearly continuous light curves. Bruch [5] demonstrated the effectiveness of TESS data for detecting periodic variability and determining or refining orbital periods in

cataclysmic variables. Ellaqany et al. [6] analyzed TESS photometry of eclipsing CVs to determine orbital periods and eclipse epochs and to investigate possible orbital-period changes. More recently, Dağ et al. [7] performed a systematic analysis of TESS observations of a large sample of cataclysmic variables and candidates using Lomb–Scargle periodograms to identify coherent periodic signals. These studies demonstrate the effectiveness of TESS photometry for investigating orbital and short-term variability in cataclysmic systems.

One of the most prominent representatives of the CVs class is DO Leo (TIC 61285257). In the work of Abbott et al. [8], spectroscopic and photometric analysis showed that the observed eclipse is approximately $1^m.5$ deep and the period ≈ 5.63 hours. More recently, Subebekova et al. [9] included DO Leo in a catalog of eclipsing cataclysmic variables based on TESS observations, reporting an orbital period of approximately 5.62 hours. The DO Leo spectrum contains emission lines of hydrogen, He I, and a pronounced He II-line $\lambda 4686$, which indicates a high degree of gas ionization and makes this object particularly interesting from the point of view of its classification [8]. According to modern Gaia DR3 data, DO Leo has a brightness of $G \approx 16.87$ and a parallax of about 0.805 ± 0.075 wt, which corresponds to a distance of 1.18 ± 0.10 kpc [2]. Additional opportunities for studying this object are provided by the TESS (Transiting Exoplanet Survey Satellite) observations, which provide continuous photometric time series suitable for studying the stability of periodic signals and the detailed shape of the light curve [10].

In this paper, the photometric variability of DO Leo is analyzed using TESS data, with a focus on Sector 72. The aim of this study is to characterize short-term modulation, evaluate its cycle-to-cycle stability, and investigate variations in the shape and amplitude of the light curve.

2. Observations and data analysis.

Photometric data used in this work were obtained with TESS. Sector 72 was selected, and SPOC data for TIC 61285257 (DO Leo) with a frequency of 200s was used. This sector has not been analyzed before and the choice is due to the presence of a homogeneous and almost continuous time series suitable for studying the short-term photometric variability of an object. The data was uploaded and initially processed using the Barbara A. Mikulski Archive for Space Telescopes (MAST) [11] and the *lightcurve* package in the Python environment. The processing also included removing invalid values (NaN) and normalizing the flow for further analysis. To study the object, the light curve of sector 72 was divided into local maxima and minima. Since the observed signal contains both relatively deep brightness dips and smaller local modulations, using all the identified minima would introduce an additional error in determining the cycle. Therefore, local minima located close to the maxima were used to determine individual cycles. This provides a more uniform description of the signal in a short time interval by suppressing false long intervals caused by deeper minima, that is, large drops in brightness. The cycle was determined by the distance between successive local minima.

For additional verification, an independent search was performed for the period along the light curve for sector 72 using the Lomb-Scargle method. The uncertainty of the Lomb-Scargle period was estimated using an initial resampling procedure that was applied to the original time series. In each implementation, the light curve was resampled and replaced. And the final period was taken as the median of the resulting deviation of this distribution.

3. Results

At the first stage, the TESS light curve for DO Leo in sector 72 was studied. Figure 1 shows that the observed signal has a complex structure and represents a short-period component of variability. Since the purpose of this analysis was to trace local short-period modulation, only the last minima were used to determine individual cycles of variability. This avoids misidentification of cycles caused by deep drops in brightness. Based on the identified maxima and selected local minima, the light curve was divided into cycles. The boundaries of individual cycles were determined by minima associated with short-period modulation.

After dividing the light curve of DO Leo into cycles, a period was determined for each cycle and is presented in Figure 2. Looking at the figure, it is clear that the periods fluctuate around a single average value about 5.6 hours. However, slight deviations are also observed in the first and last approximately ten cycles. These deviations may be attributed to variations in the light curve itself and to changes in the orbital motion of the system from cycle to cycle. This indicates the presence of repetitive modulation, a constant short-term component in the variability of the system.

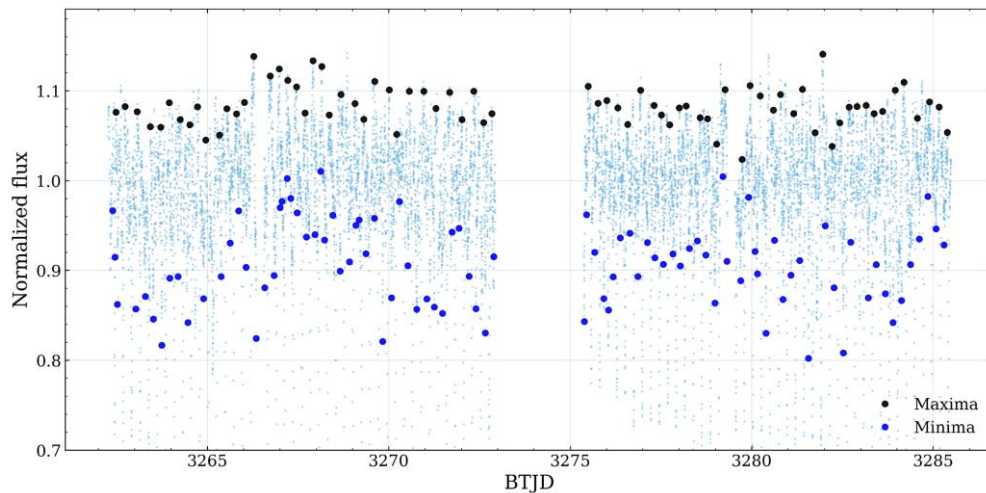


Fig. 1. The light curve of DO Leo in sector 72. The black dots correspond to the maxima, while blue dots - to the minima. BTJD = BJD - 2457000.

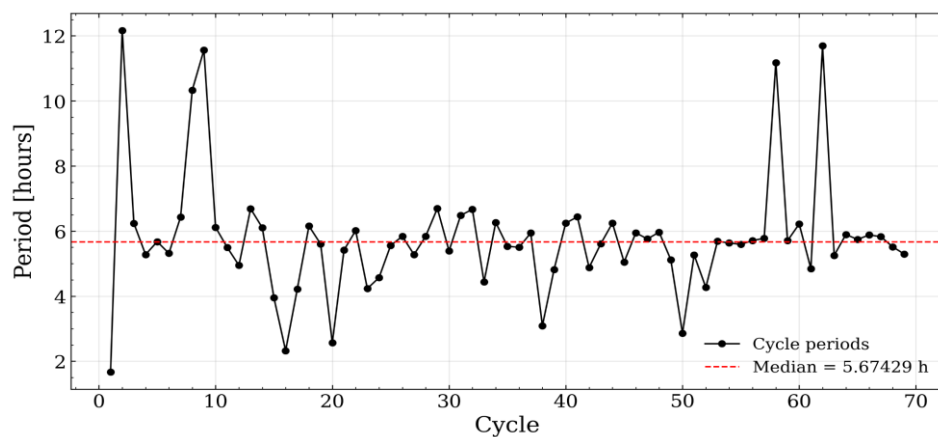


Fig. 2. Dependence of the period on the cycle. The red dashed line indicates the average value of the period ~ 5.6 h.

After that, an additional check was carried out to determine the period using the Lomb-Scargle method. Figure 3 shows a periodogram where a prominent peak indicates a period value of about 5.63 hours, which confirms the cycle-based analysis and the repeating signal.

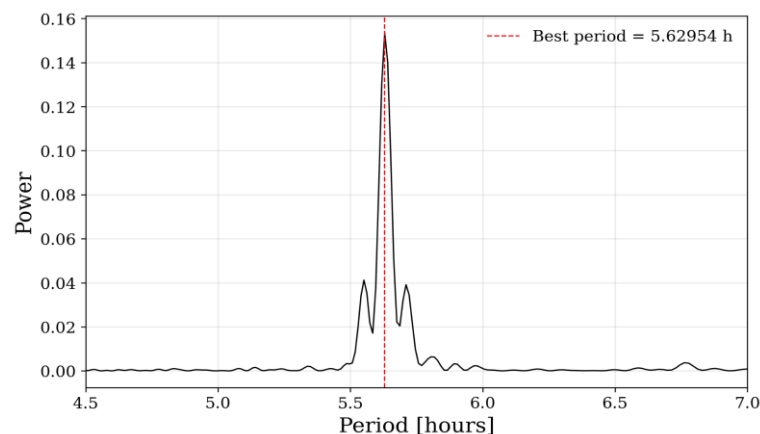


Fig. 3. Lomb-Scargle periodogram of DO Leo in sector 72.

However, it should be borne in mind that the two methods used should be considered as separate approaches, since the cycle-based method is sensitive to selected local minima, while the Lomb-Scargle method considers the complete structure of the light curve. The uncertainty of the period calculated by the

Lomb-Scargle method was determined using an initial re-sampling of the light curve. The resulting distribution of periods gives the total value of the period. This provides a reliable statistical estimate of the observed signal.

The results obtained were collected and presented in Table 1. The photometric variability of the object is non-permanent and may indicate changes in the light curve due to the contribution of components in the system. It may also be related to the geometry and physical component of the accreting substance.

Table 1. Comparison of periods of DO Leo with different methods.

Method	Period (h)
Cycle-based analysis	5.67
Lomb-Scargle	5.63
Bootstrap Lomb-Scargle	5.63 ± 0.001

At the next stage, each cycle was phased out, and Figure 4 shows the overall light curve. Superimposing the light curves on top of each other allows us to study the average shape of the modulation, and it can be seen that most of the data describes a certain profile of the light curve. This result indicates the presence of constant short-period modulation and is consistent with the results of the cycle analysis. A light curve with an average period of 5.6 hours was also highlighted.

At the same time, noticeable differences remain from cycle to cycle, both in amplitude and in the detailed shape of the profile. These deviations are expressed in changes in the depth of the minima, the height of the maxima, and minor phase-dependent distortions of the folded profiles. This behavior indicates that although the system exhibits repetitive short-term modulation, the detailed photometric response is not strictly stationary.

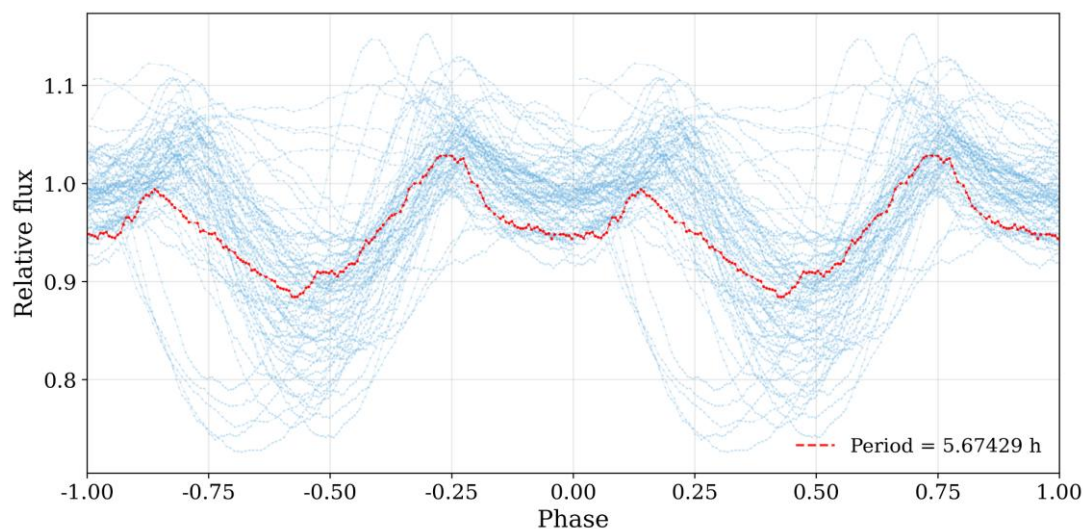


Fig. 4. The light curves of individual cycles of DO Leo.
The red dashed line highlights the modulation combined with a period of 5.67 h.

In addition, for each selected cycle, the oscillation amplitude was calculated as the difference between the maximum and neighboring minima. This analysis makes it possible to assess how stable the modulation depth changes from cycle to cycle. It also allows you to check whether its intensity remains constant.

The resulting amplitude value is shown in Figure 5. It is noticeable that the amplitude value between maxima and minima of the light curve fluctuates within a range of 0.18. These cycle-to-cycle variations exhibit pronounced modulation. This behavior is consistent with our findings, which show that despite the presence of a stable periodic component, the shape of the light curve of DO Leo and amplitude vary. That is, they do not remain strictly constant.

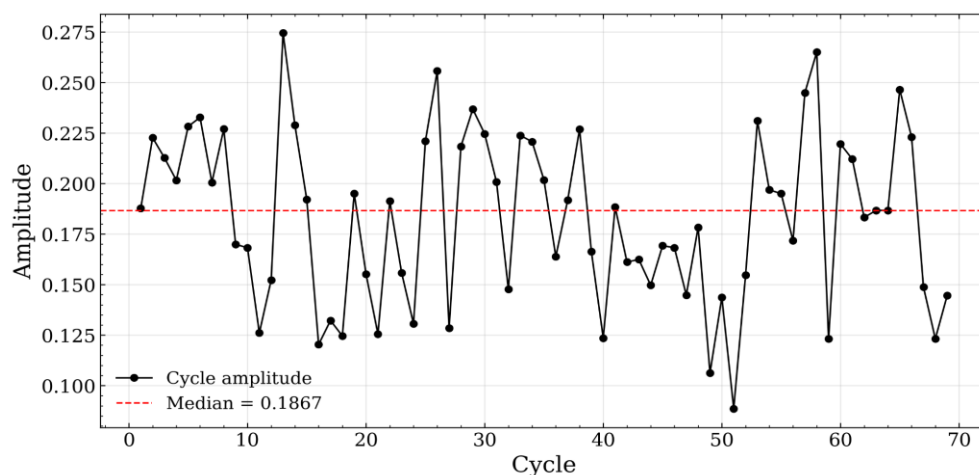


Fig. 5. Dependence of the amplitude on the sector cycle 72.
The red dashed line corresponds to the average value of 0.1867.

4. Conclusion

This work was based on an analysis of DO Leo photometric variability using TESS data. The main analysis was based on the determination of the period by cycles; an additional check was the Lomb-Scargle analysis. As a result, a persistent short-term modulation with a characteristic period of about 5.6 hours was detected. Repeated bootstrap resampling was used to estimate the uncertainty of the derived period.

The obtained light curves show that there is a general modulation scheme, but the shape and depth of the variability is not strictly constant. Therefore, the photometric behavior of the object is not strictly stable, but involves a change in amplitude from cycle to cycle. This confirms the assumption that the detected signal is at least partially related to the variability of the system's orbit.

With catastrophic variables, this behavior is naturally expected if the accretion disk evolves over time. In this context, cycle-based analysis, the Lomb-Scargle periodogram, and initial uncertainty estimates provide additional information about the repetitive and non-stationary components of the observed signal.

Taken together, these results indicate that the DO Leo variability is determined by the interaction between a recurring short-term component and unsteady processes most likely related to the accretion disk and its evolving structure.

Conflict of interest statement

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

CRediT author statement

Achkassova S.E.: Formal analysis, Software, Visualization, Writing - Original Draft; **Vaidman N.L.:** Conceptualization, Resources; **Khoklov S.A.:** Validation, Methodology, Project administration; **Agishev A.T.:** Investigation, Data curation, Writing - Review & Editing, Supervision; **Azhikenova A.S.:** Visualization, Investigation. The final manuscript was read and approved by all authors.

Statement on the use of Artificial Intelligence.

The authors declare that no artificial intelligence tools were used to generate scientific content, results, or conclusions of this article.

Data Availability Statement

The data that support the findings of this article are openly available.

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