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SDSS J093537.46+161950.8: A high-mass transfer CV below the period gap

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We present Transiting Exoplanet Survey Satellite (TESS) observations of a cataclysmic variable (CV) SDSS J093537.46+161950.8. The TESS light curve reveals eclipse-like features and confirms the previously reported orbital period of 0.06406(1) d. In addition, it shows previously unknown modulations with periods of 0.06584(2) d and 2.36(2) d, corresponding to the positive superhump and disc-precession periods, respectively. These periodicities likely arise from the prograde precession of an eccentric accretion disc. The system's stable long-term brightness, lack of outbursts, absolute magnitude, and spectral properties imply that it is unlikely to be an SU UMa-type dwarf nova. It may instead belong to the group of high mass-transfer CVs below the period gap, either a nova-like system or a high-luminosity intermediate polar.

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1. Introduction

SDSS J093537.46+161950.8 (hereafter J0935) is a cataclysmic variable (CV) in which a white dwarf (WD) accretes material from a low-mass main sequence star via Roche lobe overflow (Warner [1]). CVs with highly magnetized WDs ($\sim 10^{6-9}$ G), the accretion disc is either fully (Cropper [2], e.g. known as AM Herculis; a polar) or partially (Patterson [3], e.g., known as DQ Herculis; an intermediate polar (IP)) disrupted. Among non-magnetic CVs (WD magnetic field $<10^{6-9}$ G), the nova-like subclasses are distinguished by their lack of eruptive activity, as they have not exhibited either nova or dwarf nova outbursts. Their comparatively high mass-transfer rates sustain fully ionised accretion discs, which inhibit the disc-instability mechanism responsible for such eruptions Osaki [4]. In contrast, dwarf novae, a subclass of CVs, display recurrent outbursts on timescales ranging from days to years, driven by thermal instabilities within their accretion discs, a process that depends strongly on the mass-transfer rate. Within the dwarf nova class, The SU UMa subclass, located below the 2–3 h orbital period gap, displays both normal and superoutbursts. The thermal–tidal instability (TTI) model, which couples thermal and tidal effects, provides the leading explanation for these superoutbursts and their associated supercycles (Osaki [5, 6]). During superoutbursts, SU UMa stars exhibit superhumps that arise from the beat period between orbital motion and disc precession (Osaki [6], Vogt [7], Wood et al. [8]). However, superhumps observed in non-outbursting systems are often referred to as permanent superhumps (Patterson [9]).

Szkody et al. [10] identified J0935 as a CV based on the detection of Balmer and helium emission lines in its SDSS spectrum, and suggested that its strong He II (λ 4686 Å) emission indicates it might host a magnetic WD or be an old nova. Southworth et al. [11] later found eclipses and measured an orbital period of 0.0640591 d but could not clarify its classification. Hardy et al. [12] obtained a high-speed ULTRACAM light curve and reported that it may resemble that of the polar HU Aqr. Recently, Joshi et al. [13] analyzed J0935, along with two other CVs, using continuous, long-baseline, high-cadence optical photometric data from the Transiting Exoplanet Survey Satellite (TESS; Ricker et al. [14]). In that work, we presented the detailed results of three superhumping CVs; in this proceeding, we focus on J0935, and provide a concise summary of its key characteristics.

2. Observations and Data Reduction

J0935 was observed by TESS from 2023 November 11 (16:22:10.6) to 2023 December 07 (02:01:44.5) with a cadence of 120 s, for a total duration of 25.4 days in Sector 72. The data are publicly available from the Mikulski Archive for Space Telescopes (MAST). [1]. TESS consists of four cameras, each with a field of view of 24 × 24 degrees^2, which are aligned to cover 24×96-degree^2 strips of the sky (see Ricker et al. [14], for details). The TESS bandpass extends from 600 to 1000 nm, with an effective wavelength of 800 nm. Data points with anomalous events, identified by non-zero QUALITY flags in the FITS file headers, were excluded from our analysis, and Simple Aperture Photometry (SAP) fluxes were used.

[1] https://mast.stsci.edu/portal/Mashup/Clients/Mast/ Portal.html

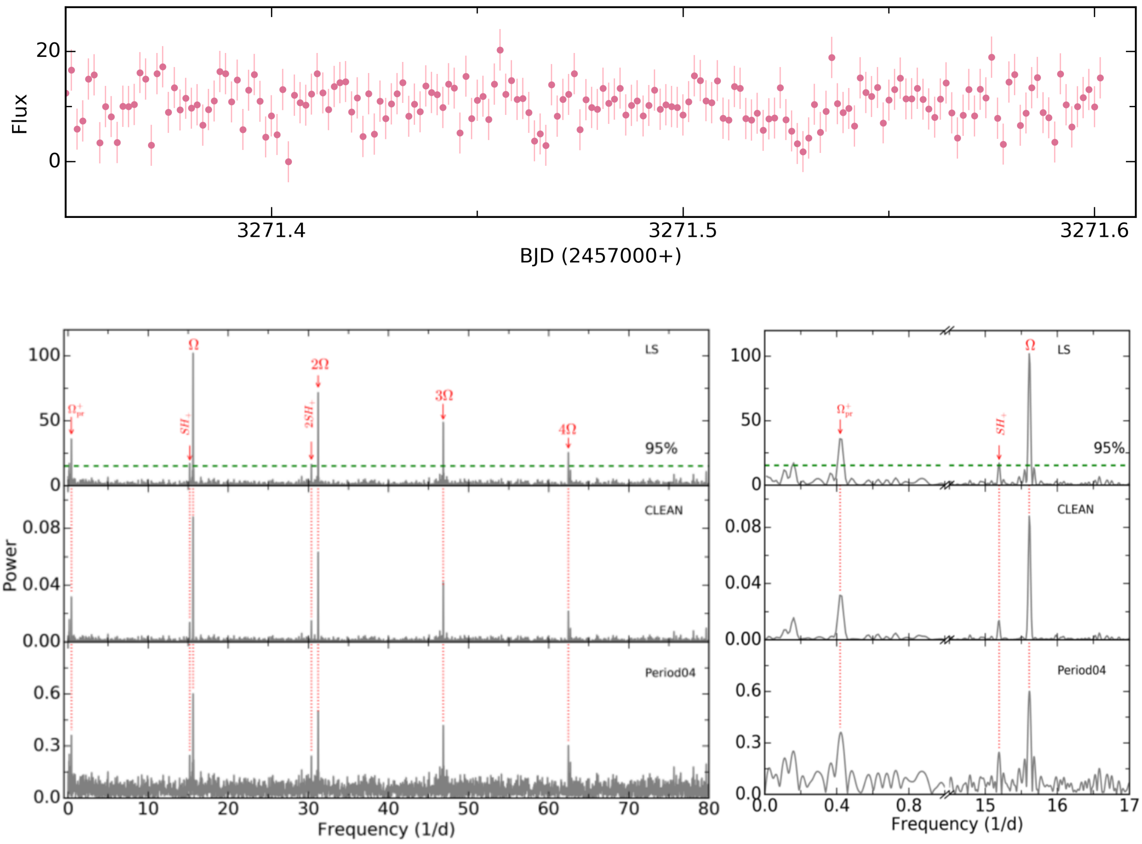

Figure 1: Top panel: a ~ 0.25 d segment of the TESS light curve of J0935, illustrating the eclipse-like pattern. Bottom panel: LS, CLEAN, and Period04 power spectra obtained from the combined total TESS data. The significant frequencies, determined at the 95% confidence level, corresponding to the orbital (P_{Ω}), superhump (P_{SH+}), and disc-precession ($P_{\Omega^+_{\rm pr}}$) periods, as well as the harmonics of the orbital and superhump signals, are distinctly marked.

3. Analysis and Results

We observed eclipse-like features in the TESS light curve of J0935 (see top panel of Figure 1), which are less pronounced than those reported by Southworth et al. [11]. Periodogram analyses were performed on the combined TESS data using the Lomb–Scargle, Period04, and CLEAN methods (Lomb [15], Scargle [16], Lenz et al. [17], Roberts et al. [18]), and the results are shown in the bottom panel of Figure 1. The most prominent peak corresponds to the orbital period (P_{Ω}) of 0.06406(1) d, with harmonics detected up to 4Ω. A secondary peak at 0.06584(2) d, approximately 3 % longer than the orbital period, is characteristic of the positive superhump ($P_{\rm SH+}$), and its harmonic ($P_{\rm 2SH+}$) is also visible. At lower frequencies, a strong peak at 2.36(2) d is detected, corresponding to the difference between the orbital and superhump frequencies, and can be interpreted as the disc-precession period ($P_{\Omega^+_{\rm pr}}$). A zoomed-in plot highlighting the orbital, positive superhump, and prograde disc-precession frequencies is shown on the right side of the bottom panel of Figure 1.

4. Discussion and Conclusions

TESS observations of J0935 reveal a short orbital period of 0.06406(1) d with regular eclipses, consistent with results by Southworth et al. [11]. In addition, a previously unknown period of 0.06584(2) d which is about 3% longer than the orbital period is detected, indicating a positive superhump caused by the prograde precession of an eccentric accretion disc. The observed disc precession period of ∼ 2.36 d supports this interpretation.

From the period excess of the superhump period over the orbital period, and using Equation (8) of Patterson et al. [19], a mass ratio of ∼ 0.128 is estimated for J0935, which is comparable to those of other quiescent superhumping systems such as ER UMa and V1159 Ori. J0935's position in the mass ratio–orbital period diagram aligns with the standard CV evolutionary track (Knigge et al. [20]), suggesting that it is evolving normally toward shorter periods. Short-period CVs below the period gap are generally expected to have low mass-transfer rates and to exhibit dwarf nova outbursts, showing either normal or superoutbursts accompanied by superhumps. However, for J0935, despite the presence of superhumps, no outbursts have been detected in long-term monitoring data from ZTF, CRTS, AAVSO, or Gaia, implying a stable, high mass-transfer accretion disc. Positive superhumps in CVs below the period gap are typically short-lived and are closely associated with superoutbursts. In the framework of the TTI model, the tidal deformation of the accretion disc not only produces the positive superhumps but also enhances mass transport through the disc, leading to its rapid depletion. Therefore, the persistent presence of positive superhumps in J0935 implies that its donor star maintains a comparatively high mass-transfer rate, allowing the disc to remain deformed and stable outside of outburst phases.

Using the Gaia DR3 distance of ∼ 1530 pc from Bailer-Jones et al. [21] and an apparent magnitude of 18.73, J0935 has an absolute magnitude of approximately 7.8 and a colour of 0.28 mag. These values place it in a region between dwarf novae and nova-like systems, as represented in the colour–magnitude diagram of (Abril et al. [22], their Fig. 2), making it difficult to assign J0935 to any specific subtype. A comparison with the absolute magnitude versus orbital period relation from Mukai & Pretorius [23], which is primarily defined for intermediate Polars (IPs) but also includes tracks for dwarf novae in quiescence and outburst, leads to a similar ambiguity, with J0935 again located between the two regimes. However, J0935's eclipsing nature implies a high inclination, which can make the system appear 3−4 mag fainter than it would at an average inclination (Warner [24], Selvelli & Gilmozzi [25]). Correcting for this inclination effect shifts J0935 toward the region occupied by high–mass-transfer nova-likes/old novae/IPs in Abril et al. [22], and toward the high–mass-transfer (high-luminosity IPs and outbursting dwarf novae) zone in Mukai & Pretorius [23]. The presence of strong He II λ4686 Å emission may indicate magnetic accretion; however, high mass-transfer nova-likes have also been found to exhibit comparatively strong He II emission (e.g., Schmidtobreick [26]). Hence, it does not appear to be an unambiguous indicator of a magnetic WD. The detection of X-ray spin modulations will be required in the future to confirm (or rule out) its classification as an IP.

Altogether, although the presence of superhumps and a short orbital period usually points to an SU UMa-type classification, but the lack of outbursts in the long-term light curve, along with the spectral characteristics and absolute magnitude, suggests that J0935 is not an SU UMa-type dwarf nova. Instead, it may belong to the group of a high mass-transfer CV below the period gap possibly

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a rare nova-like variable or a high-luminosity IP. Its estimated mass ratio and orbital period place it on the standard CV evolutionary track. While systems below the period gap are generally expected to have low mass-transfer rates and show dwarf nova outbursts, J0935 appears to deviate from this behaviour. Its unusually high mass-transfer rate, which may be linked to past nova eruptions as proposed by Patterson et al. [27] for BK Lyn, makes it an intriguing target for follow-up studies, as such objects are in contradiction to what is expected from our understanding of CV evolution.

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