



Stochastic Optical Variability and an rms–Flux Relation in the Intermediate Polar EP240309a

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Abstract

Magnetic cataclysmic variables provide a natural laboratory for studying how accretion interacts with compact-object magnetospheres and generates stochastic variability. We present an optical variability study of the intermediate-polar candidate EP240309a, an Einstein Probe X-ray transient, using BOOTES photometry, high-cadence TESS light curves, and a Southern Astrophysical Research (SOAR)/Goodman optical spectrum. Previous studies found a white-dwarf spin period of 3.97 minutes ($P_{\text{spin}} \simeq 238$ s) and an orbital period of $P_{\text{orb}} = 3.7614(4)$ hr. Power spectral densities from the BOOTES data are consistent with single power laws with slopes $\alpha \simeq 1.2$ – 1.8 , with no statistically significant evidence for a bend across the sampled frequency range. Using red-noise simulations and injection–recovery tests, we place one-sided constraints on any putative break frequency, which translate, under standard dynamical identifications, into an upper limit on the magnetospheric radius of $R_m \lesssim \text{few} \times 10^{10}$ cm for $M_{\text{WD}} = 0.8 M_{\odot}$. In the TESS data, we detect a linear rms–flux relation on hour timescales in three high-cadence sectors, while two other sectors do not show a robust detection, indicating epoch-dependent rms–flux behavior. The SOAR spectrum shows Balmer and He II emission lines with FWHM ≈ 1000 – 1600 km s^{−1}; under a Keplerian interpretation, these imply characteristic radii of $r \approx (0.9$ – $3.4) \times 10^{10}$ cm, broadly comparable to the timing-based constraints. Overall, the data provide conservative, order-of-magnitude radius constraints consistent with accretion onto a magnetic white dwarf, but they do not establish the detailed accretion geometry or exclude stream-fed or mixed accretion scenarios.

Unified Astronomy Thesaurus concepts: Cataclysmic variable stars (203); DQ Herculis stars (407); Stellar accretion disks (1579); White dwarf stars (1799); Time series analysis (1916); Photometry (1234); Lomb-Scargle periodogram (1959); Magnetic fields (994)

Materials only available in the online version of record: data behind figure

1. Introduction

Magnetic cataclysmic variables (mCVs) are accreting white-dwarf binaries in which a megagauss-level magnetic field channels the flow and can truncate the inner disk. Intermediate polars (IPs) represent the disk-dominated end of the mCV family and are prolific X-ray emitters owing to accretion shocks and reprocessing (e.g., J. Patterson 1984; B. Warner 1995;

C. Hellier 1997). Large-area surveys have expanded the IP census and enabled population studies from soft to hard X-rays (J. Brunschweiler et al. 2009; H. Brunner et al. 2022). In parallel, high-cadence optical monitoring shows that many cataclysmic variables (CVs) exhibit red-noise flickering and, in a growing number of cases, a linear rms–flux relation interpreted as the imprint of inward-propagating accretion-rate fluctuations in a stratified disk (e.g., P. Uttley & I. M. McHardy 2001; P. Uttley et al. 2005; S. Scaringi et al. 2012; A. Bruch 2021, 2022).

The Einstein Probe mission recently reported the transient EP J115415.8–501810 (hereafter EP240309a), detected at

$t_{\text{trig}} = 2024 \text{ March } 9 \text{ 01:44:59 UTC}$ (Z. X. Ling et al. 2024). Unless otherwise stated, times are referenced to t_{trig} . Follow-up studies have classified it as an IP candidate and established key coherent periods from long baselines: an orbital modulation near 3.762 hr in TESS photometry and a white-dwarf spin near 3.97 minutes in high-speed ground-based data (S. B. Potter et al. 2024; S. Wu et al. 2025; Y. Xiao et al. 2025). These results secure the basic system parameters and motivate a deeper look at its stochastic optical variability and rms–flux/power spectral density (PSD) behavior as complementary probes of the accretion flow.

In this work we combine multnight BOOTES optical light curves, TESS light curves, and an optical spectrum on the Southern Astrophysical Research (SOAR) Telescope to place EP240309a in the broader framework of accretion-driven variability. Our goals are threefold: (i) to establish and assess the robustness of a linear rms–flux relation on timescales of hours using space-based photometry, in which the rms variability amplitude is approximately proportional to the mean flux; (ii) to quantify the broadband PSD of the longest ground-based runs and assess whether the data require a characteristic frequency (e.g., a bend or break) once narrow spin/beat/orbital components are accounted for; and (iii) to use deconvolved Balmer and He II line widths to obtain order-of-magnitude constraints on characteristic radii in the disk and compare them with limits implied by the timing analysis. Taken together, these measurements connect phenomenological timing diagnostics with simple spectroscopic estimates of the dynamical scale in an IP. The main purpose of the present work is therefore not to revisit the basic classification of EP240309a, but rather to provide a complementary characterization of its stochastic optical variability, to test whether the rms–flux behavior is persistent across multiple TESS epochs, and to place correspondingly conservative constraints on the accretion geometry.

As a consistency check, we searched the BOOTES light curves for the published spin and orbital periods using Lomb–Scargle (LS; N. R. Lomb 1976) and phase-dispersion minimization (PDM; R. F. Stellingwerf 1978). Owing to the few-hour nightly windows and strong red noise, no independent significant detections are obtained; the BOOTES data are therefore consistent with, but do not improve upon, the TESS-based timing solution. We thus adopt the published periods for narrow-line prewhitening prior to continuum PSD modeling.

The paper is organized as follows. Section 2 describes the BOOTES and SOAR observations and reductions, and summarizes the TESS data products. Section 3 outlines the analysis workflow for prewhitening, PSD estimation and model comparisons, red-noise surrogate tests, and rms–flux measurements. Section 4 presents the light curves, optical spectroscopic results, periodicity checks, PSD analysis, and the TESS rms–flux relation. Section 5 interprets these findings in terms of stochastic accretion variability in mCVs and discusses conservative, order-of-magnitude radius constraints derived from timing and line-width diagnostics, emphasizing that they provide consistency checks rather than a proof of disk-fed accretion or magnetospheric truncation. Section 6 summarizes our main conclusions.

2. Observations

We monitored EP240309a from 2024 March 21 (UTC 22:47) to March 25 (UTC 07:07) in Clear (unfiltered) mode

and report magnitudes calibrated onto an R -band scale with a nominal 30 s cadence (30 s exposures for most runs; 180 s exposures on the first night). Observations were taken with two 0.6 m Ritchey–Chrétien telescopes in the BOOTES network (see A. J. Castro-Tirado 2023 for a recent overview): BOOTES-6 (B6; Boyden Astronomical Observatory, South Africa) and BOOTES-7 (B7; San Pedro de Atacama, Chile). Both use Andor iXon X3 electron-multiplying CCD (EMCCD) 888 cameras (1024×1024 pix; 0.6 pix^{-1}), cooled to $-50.0^\circ\text{C} \pm 0.1^\circ\text{C}$.

Standard reduction was applied with custom Python routines based on the *astropy*, *numpy*, *scipy*, and *matplotlib* packages, following the standard BOOTES EMCCD procedures (e.g., A. J. Castro-Tirado et al. 1999; Y.-D. Hu et al. 2023): bias subtraction (median stacks of zero-second frames), twilight-flat correction, and source detection on the reduced images. Aperture photometry used a 5 pixel circular aperture with a 7–9 pixel background annulus. Photometric zero-points were tied to Gaia Data Release 3 field stars via a flux-weighted fit with 1.5σ outlier rejection (Gaia Collaboration et al. 2023). Because the BOOTES frames were obtained in Clear (unfiltered) mode, we place the differential photometry onto an R -band magnitude scale through the same field-star calibration. Uncertainties combine photon and background noise, CCD read noise, and the zero-point scatter; typical per-point uncertainties are 0.01–0.03 mag. We obtained several BOOTES time-series runs between 2024 March 21–25 with cadences spanning approximately 50–335 s depending on the exposure time and overheads (Table 1); individual runs lasted up to ~ 6.0 hr, and we use the longest sequence as our primary dataset for the detailed PSD analysis, since its long, nearly continuous coverage provides the best frequency resolution and signal-to-noise ratio, whereas the shorter runs mainly serve as consistency checks.

2.1. SOAR/Goodman Spectroscopy

We obtained a SOAR/Goodman long-slit spectrum of EP240309a (J. C. Clemens et al. 2004) with a 450 s exposure, using the 400_SYZY grating, a $1''0$ slit, and 2×2 on-chip binning, at an air mass of $\simeq 1.24$. The data were reduced with the PYEIT Python package (J. X. Prochaska et al. 2020a, 2020b), following its standard long-slit workflow, including standard detector-level processing and overscan correction, and were subsequently flux-calibrated with the spectrophotometric standard EG 21 and corrected for telluric absorption. From the arc quality assurance products we measure a dispersion of $\simeq 2.0 \text{ \AA pix}^{-1}$ and arc-line widths of $\text{FWHM}_\lambda \approx 6 \text{ \AA}$, implying a resolving power of $R \sim 700\text{--}1100$ across our wavelength range, with higher R toward the red.

2.2. TESS Data Products and Light-curve Extraction

For the space-based optical variability analysis, we used calibrated TESS (G. R. Ricker et al. 2015) full-frame image (FFI) cutouts retrieved from MAST with the TESSCUT service, which provides target-pixel-style cutouts generated with ASTROCUT. We then used LIGHTKURVE to perform aperture photometry on the cutout pixel data and to extract light curves at the native FFI cadence of each sector. Cadences flagged as poor quality in the FFI products and measurements with nonfinite flux values were removed. The same extraction aperture and filtering procedure were applied to all sectors to

Table 1
Log of BOOTES Observations

Telescope	Start (UTC)	End (UTC)	Filter	Exposure (s)	N	Duration (hr)	Cadence (s)
BOOTES-6	2024-03-21 22:47:28	2024-03-21 23:34:43	Clear	180	11	0.7876	335.1
BOOTES-6	2024-03-22 21:01:15	2024-03-23 02:59:06	Clear	30	114	5.9642	64.4
BOOTES-7	2024-03-22 08:39:43	2024-03-22 09:59:35	Clear	30	77	1.3311	48.0
BOOTES-7	2024-03-23 01:01:10	2024-03-23 06:28:33	Clear	30	267	5.4564	52.0
BOOTES-6	2024-03-24 19:27:15	2024-03-24 23:59:56	Clear	30	214	4.5446	63.8
BOOTES-7	2024-03-25 01:11:15	2024-03-25 07:07:06	Clear	30	318	5.9308	54.0

Note. Columns show the UTC time range, filter, exposure time, and number of photometric points used in Figure 1. t_0 is the start time of each run.

ensure a uniform dataset for the subsequent timing and rms–flux analyses. Times are given in BTJD ($\text{BJD}_{\text{TDB}} - 2457000$).

3. Methods

3.1. Light-curve Preparation

For the stochastic-variability analysis we start from the calibrated BOOTES light curves described in Section 2. We remove nondetections, obvious outliers (e.g., cosmic-ray events), and duplicated time stamps. Unless stated otherwise, each light curve is median-normalized and mean-subtracted before computing PSDs and rms–flux statistics.

To suppress leakage from known coherent modulations into the broadband continuum, we prewhiten the spin, beat, and orbital fundamentals and their first harmonics using fixed published frequencies. We emphasize that this step targets only narrow-line components and does not impose or enhance any continuum break.

Specifically, we fit and subtract a fixed-frequency multi-sinusoid model,

$$x(t) = c_0 + \sum_{j \in \{\text{spin, beat, orb}\}} \sum_{h=1}^2 [a_{j,h} \cos(2\pi h f_j t) + b_{j,h} \sin(2\pi h f_j t)], \quad (1)$$

where $x(t)$ is the median-normalized light curve, and f_{spin} , f_{orb} , and $f_{\text{beat}} \equiv f_{\text{spin}} - f_{\text{orb}}$ are fixed to reported values (S. B. Potter et al. 2024). PSDs are computed from the residuals after subtracting the best-fitting model.

For TESS, we retrieve FFI cutouts via MAST TESScut (astrocut; C. E. Brasseur et al. 2019) and extract simple aperture photometry light curves using lightcurve (e.g., Lightcurve Collaboration 2018). We remove NaNs and retain only cadences with $\text{QUALITY} = 0$. Time stamps are in BJD_{TDB} ; any constant offset applied for plotting is purely cosmetic and does not affect the analysis. EP240309a is covered in Sectors 10, 37, 64, 90, 99, and 100.

Because BOOTES nightly windows are short and fragmented, ground-based period searches are strongly affected by aliases and red-noise leakage (Section 4.2). Throughout, we therefore adopt the published TESS-based spin and orbital periods for prewhitening and interpretation.

3.2. Power Spectral Density Analysis

We compute PSDs in fractional $\text{rms}^2 \text{Hz}^{-1}$ units using Welch’s method with 50% overlap (P. D. Welch 1967). Each cleaned light curve is interpolated onto a uniform

grid with cadence Δt (median positive time step), then median-normalized and mean-removed. Continuum fits are performed over a predefined frequency band (given in the figure captions), typically $f_{\text{low}} \simeq 1/(3T_{\text{span}})$ and $f_{\text{high}} \lesssim 0.5f_{\text{Nyq}}$ with $f_{\text{Nyq}} = 1/(2\Delta t)$. We fit two alternative continuum models in $\log_{10} P$ – $\log_{10} f$ space: a single power law (SPL) and a bending power law (BPL),

$$P_{\text{SPL}}(f) = A f^{-\alpha}, \quad P_{\text{BPL}}(f) = A \left(\frac{f}{f_b} \right)^{-\alpha_{\text{low}}} \left[1 + \left(\frac{f}{f_b} \right)^{(\alpha_{\text{high}} - \alpha_{\text{low}})} \right]^{-1}. \quad (2)$$

3.3. Model Selection and One-sided Constraints

We compare SPL and BPL fits using the Akaike/Bayesian information criteria (AIC/BIC) (least squares in $\log_{10} P$ with a Gaussian likelihood), defining $\Delta \text{IC} \equiv \text{IC}(\text{SPL}) - \text{IC}(\text{BPL})$. To guard against spurious bends from red noise, we test the SPL null with Monte Carlo surrogates generated following J. Timmer & M. Koenig (1995). We claim a bend only when information criteria and the red-noise test consistently favor the BPL; otherwise we report one-sided lower limits on f_b from injection–recovery simulations, which translate (under $f_b \sim f_K(R_{\text{in}})$) into conservative upper bounds on a characteristic inner radius (e.g., M. Revnivtsev et al. 2009; S. Scaringi et al. 2012).

3.4. TESS rms–Flux Relation

For each TESS sector we compute rms–flux relations using nonoverlapping 0.75/1.0/1.5 hr windows. The mean flux is measured from the median-normalized light curve; the rms is computed from residuals after subtracting a linear trend within each window. We fit $\text{rms} = a\langle F \rangle + b$ and estimate slope uncertainties via bootstrap resampling (median and 16th–84th percentiles) (e.g., P. Uttley et al. 2005; S. Scaringi et al. 2012).

3.5. Spectroscopy: Deconvolved Line Widths and Radius Mapping

Instrumental-broadening corrections are applied in quadrature but are negligible for the very broad Balmer and He II lines considered here and do not affect our results. To express the observed widths as a characteristic velocity scale, we adopt a fiducial white-dwarf mass $M_{\text{WD}} = 0.8 M_{\odot}$ (e.g., A. F. Pala et al. 2022) and a representative inclination $i = 60^\circ$ (with a systematic envelope for $i \in [45^\circ, 75^\circ]$). We convert between

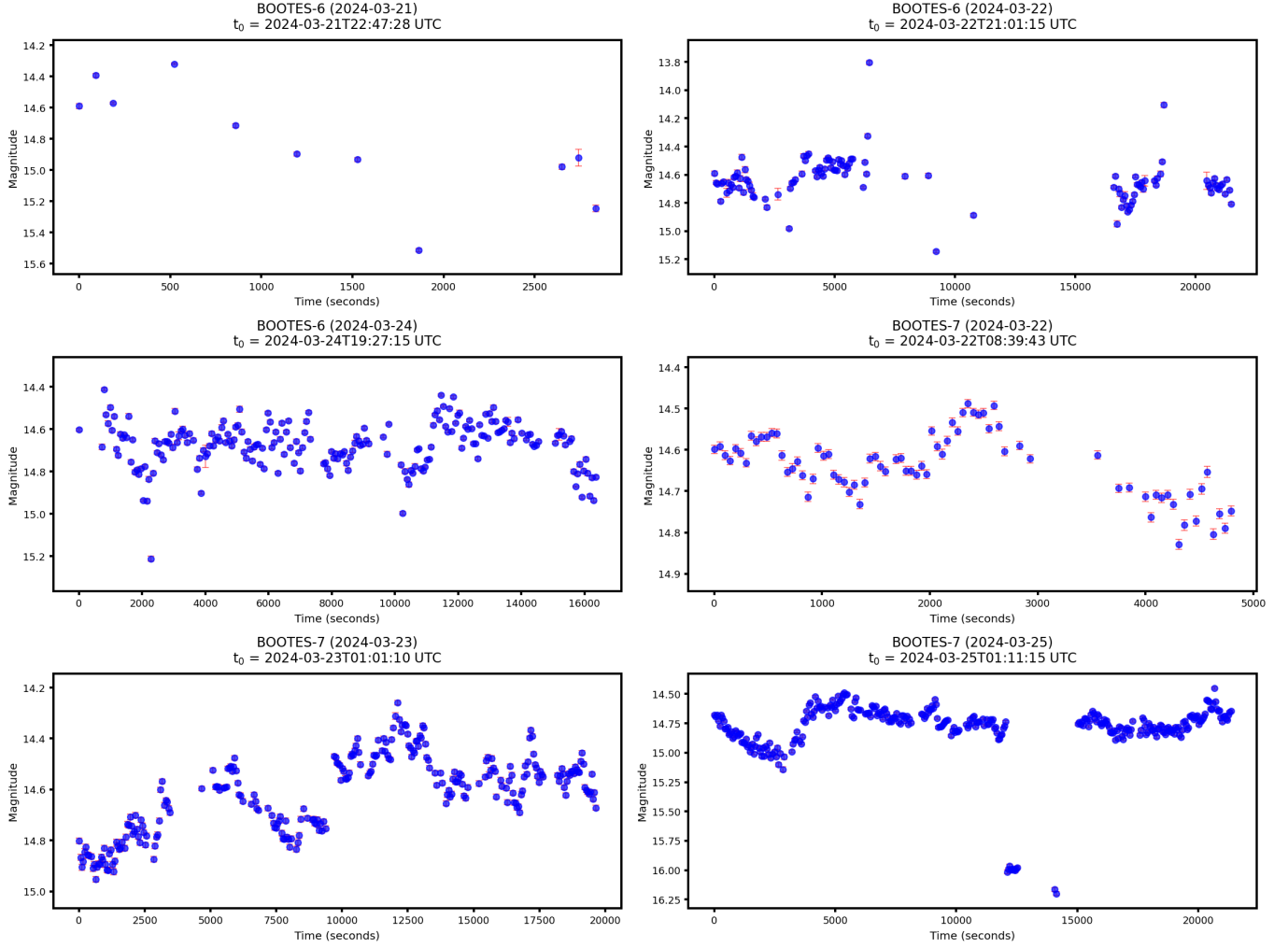


Figure 1. BOOTES-6 and BOOTES-7 optical light curves of EP240309a from 2024 March 21 to 25. Each panel shows one night of differential photometry, with time measured from the start of that night’s observations on the horizontal axis and magnitude on the vertical axis. The corresponding reference time t_0 (i.e., $t = 0$) is indicated in each panel in UTC. Blue points indicate individual measurements and red bars show the total photometric uncertainty (Section 2). All nights display pronounced variability on minute-to-minute timescales on top of modest night-to-night changes in mean brightness.

(The data used to create this figure are available in the [online article](#).)

mass and radius using the zero-temperature mass–radius relation of M. Nauenberg (1972). If one formally interprets a deconvolved velocity width v_{FWHM} as tracing rotation, a characteristic Keplerian radius is

$$r \simeq \frac{GM_{\text{WD}}}{\left[\frac{v_{\text{FWHM}}}{2 \sin i}\right]^2}. \quad (3)$$

However, as discussed in Section 4.5, $H\beta$ can be multi-component and phase dependent, so the optical line profiles need not arise purely from a steady Keplerian disk. Because our single-epoch profiles are broadly single peaked (preventing a peak-separation measurement), any mapping from v_{FWHM} to r is model dependent and should be regarded only as an order-of-magnitude characteristic scale, not a measurement of a disk radius. Nondisk broadening (e.g., stream/curtain/wind or turbulence) would tend to increase v_{FWHM} and thus bias the formal r low; accordingly, we do not use Equation (3) to claim disk-fed accretion or to place quantitative constraints on the magnetospheric truncation radius R_{m} .

4. Results

4.1. Light Curves

The BOOTES-6 and BOOTES-7 light curves (Figure 1) provide six nights of coverage over the interval 2024 March 21–25, with individual continuous segments ranging from ~ 0.7 to ~ 6.0 hr (Table 1). The bulk of the measurements fall in the range $14.3 \lesssim R \lesssim 15.6$ mag (Figure 1), with a few isolated points outside this interval; night-averaged levels differ by at most a few tenths of a magnitude, while all nights show strong variability on timescales of minutes and longer, i.e., broadband flickering commonly seen in accreting CVs. Such variability is not unique to disk accretion and can also arise in stream-fed or curtain-dominated geometries, so the BOOTES light curves alone do not discriminate the accretion mode.

4.2. Periodicity Checks

Because the nightly windows are short and the light curves are dominated by red-noise flickering, period searches in the combined, cleaned BOOTES dataset (913 points over a time

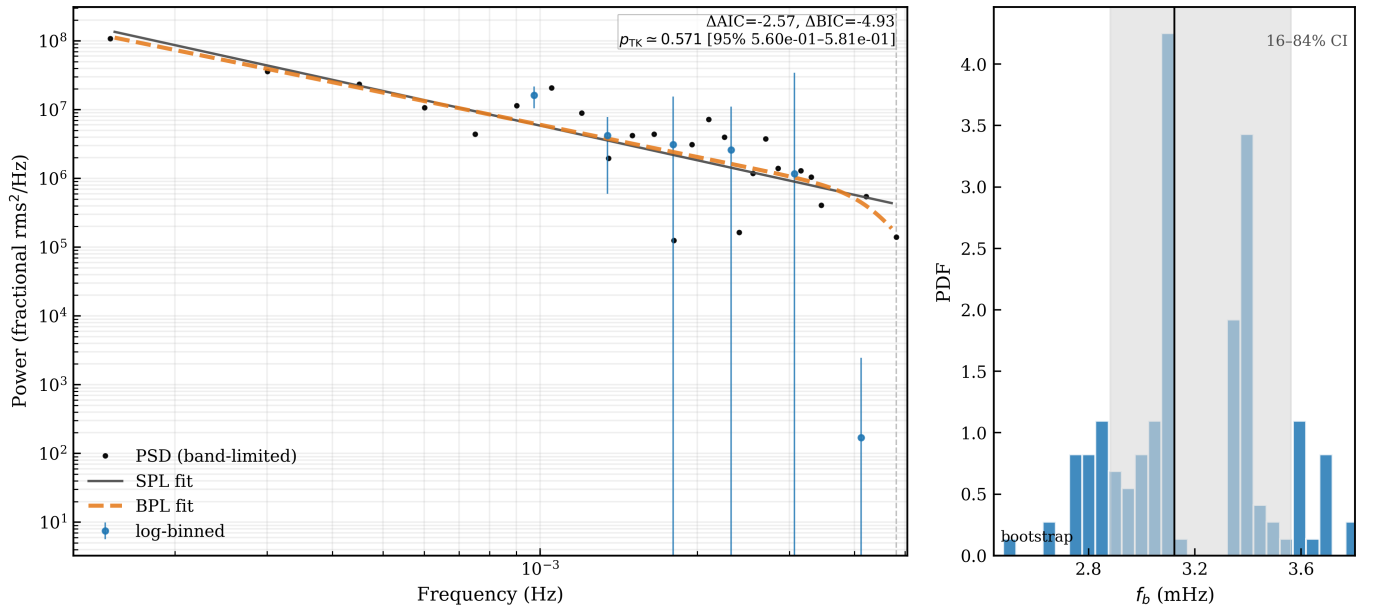


Figure 2. Full-night BOOTES PSD (fractional $\text{rms}^2 \text{ Hz}^{-1}$) for the longest sequence, with the adopted analysis band and best-fitting SPL/BPL continua overplotted. The SPL continuum is mildly preferred over the BPL and TK simulations do not reject the SPL null hypothesis, so no bend is claimed within the sampled frequency range.

baseline of 58.1 hr) recover only low-significance candidate features rather than independently significant periodicities. Using standard LS and PDM analyses over 0.5–5.0 hr, we find an LS peak at 2.0300 hr and a PDM minimum at 3.5345 hr, but red-noise surrogate tests give $\text{FAP} > 0.05$ for both. The 2.0300 hr LS peak is consistent with the 24 hr sampling alias of the previously reported harmonic at $P_{\text{orb}}/2 = 1.8807$ hr, and the 3.5345 hr feature is likewise compatible with a daily-window alias. We therefore interpret these signals as low-significance aliases rather than true detections. The BOOTES data are thus consistent with the published TESS-based orbital and spin periods (S. B. Potter et al. 2024; Y. Xiao et al. 2025), but do not provide additional timing constraints, so we adopt the published periods for narrow-line prewhitening prior to continuum PSD modeling.

4.3. Power Spectral Density

Figure 2 shows the PSD of the longest BOOTES sequence and the best-fitting continuum models. The SPL continuum is mildly preferred over the BPL ($\Delta\text{AIC} = -2.57$, $\Delta\text{BIC} = -4.93$), and TK red-noise simulations matched to the best-fitting SPL do not reject the SPL null ($p_{\text{TK}} \approx 0.57$). We therefore do not claim evidence for a bend in the sampled frequency range.

We convert this nondetection into one-sided lower limits on the bend frequency f_b from injection–recovery simulations (fiducial strict convention):

$$\begin{aligned} \text{UL}_{95\%} &= 0.395 \text{ mHz}, \\ \text{UL}_{90\%} &= 0.334 \text{ mHz}. \end{aligned}$$

In the remainder of the paper we adopt $\text{UL}_{90\%}$ as the fiducial constraint, implying conservative upper bounds on a characteristic inner scale; if one adopts the standard dynamical identifications, these can be expressed as upper bounds on R_m under the adopted mappings. For $M_{\text{WD}} = 0.8 M_{\odot}$, we obtain $R_m/R_{\text{WD}} \lesssim 41.4$ (dynamical) and $\lesssim 30.6$ (freefall), adopting

$R_{\text{WD}} \simeq 7.0 \times 10^8$ cm from the zero-temperature mass–radius relation of M. Nauenberg (1972).

As a consistency check, SPL fits to individual BOOTES nights within the common cross-night analysis band yield mutually consistent slopes and are not used for physical inference.

4.4. TESS rms–Flux Relation

We test for a linear rms–flux relation on hour timescales (e.g., P. Uttley et al. 2005; S. Scaringi et al. 2012). Using the same extraction and filtering across sectors, we find clear positive linear trends in Sectors 37, 64, and 99, whereas Sectors 90 and 100 do not show a robust detection. Sector 10 provides no valid high-cadence segments at these window sizes and is excluded.

For the fiducial 1 hr windows, the Pearson coefficients are $r_P = 0.336$ ($p_P = 1.3 \times 10^{-16}$; $N_{\text{seg}} = 572$) in Sector 37, $r_P = 0.195$ ($p_P = 9.2 \times 10^{-7}$; $N_{\text{seg}} = 624$) in Sector 64, $r_P = 0.271$ ($p_P = 2.4 \times 10^{-9}$; $N_{\text{seg}} = 470$) in Sector 99, $r_P = -0.0158$ ($p_P = 0.689$; $N_{\text{seg}} = 642$) in Sector 90, and $r_P = 0.0302$ ($p_P = 0.46$; $N_{\text{seg}} = 609$) in Sector 100. We treat r_P as descriptive; the primary effect size is the bootstrapped linear slope.

At 1 hr, the bootstrap-median slopes are $a_{50} = 4.34 \times 10^{-4}$ for Sector 37, 2.55×10^{-3} for Sector 64, and 3.93×10^{-3} for Sector 99, with confidence intervals that remain positive, while Sector 100 gives $a_{50} = 1.95 \times 10^{-2}$ but with an interval spanning zero. The positive trend also persists across 0.75/1.0/1.5 hr windows in Sectors 37, 64, and 99, whereas Sectors 90 and 100 remain state-dependent nondetections in our dataset.

Using the same fixed-aperture extraction and $\text{QUALITY} = 0$ filtering, the median aperture-summed flux levels are $\bar{F}_{37} = 9572$, $\bar{F}_{64} = 9786$, and $\bar{F}_{99} = 9584$, whereas Sectors 90 and 100 are both consistent with zero in the same extracted units ($\bar{F}_{90} = -1.33$, $\bar{F}_{100} = 0.051$). We therefore do not interpret Sectors 90/100 as straightforward absolute-brightness

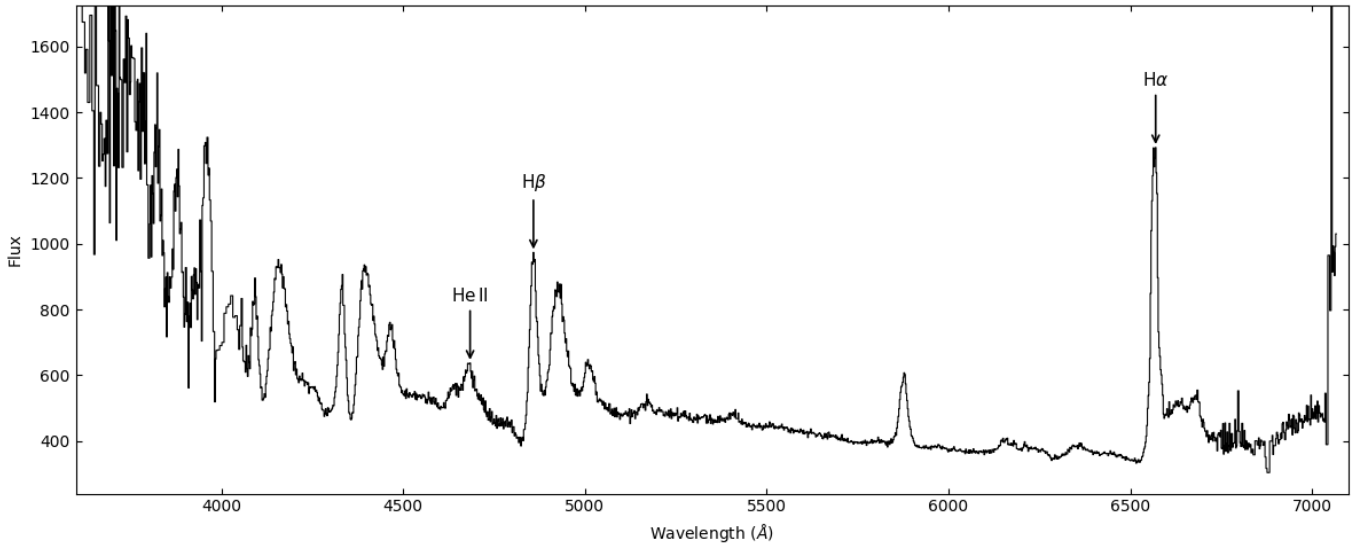


Figure 3. SOAR/Goodman optical spectrum of EP240309a at native sampling/resolution. Major emission features ($H\alpha$, $H\beta$, He II 4686) are marked. Broad low-contrast structures near ~ 4160 , ~ 4400 , and ~ 4940 Å are indicated and discussed in the text.

comparisons to Sectors 37/64/99; rather, they indicate that the rms–flux relation is not robustly detected in all epochs with the same pipeline.

4.5. Optical Spectroscopy

We obtained flux-calibrated SOAR/Goodman long-slit spectroscopy of EP240309a on 2024 March 25 (start 06:59 UTC; Figure 3) to document the spectral state contemporaneous with our 2024 March variability campaign. S. B. Potter et al. (2024) present Southern African Large Telescope/Robert Stobie Spectrograph (SALT-RSS) spectroscopy (low resolution, $R \sim 800$) obtained on 2024 March 19 with orbital-phase-resolved analysis and show that $H\beta$ comprises multiple components; therefore, the line profiles cannot be interpreted as arising purely from a steady Keplerian accretion disk. Here we use our single-epoch spectrum only for basic line-profile characterization and descriptive (velocity-scale) checks.

The wavelength solution and arc-line widths imply a characteristic instrumental FWHM of $\Delta\lambda \simeq 6.2$ Å (median arc FWHM $\simeq 3.11$ pix and dispersion $\simeq 2.0$ Å pix $^{-1}$), corresponding to $R \sim 670$ at 4160 Å, $R \sim 707$ at 4400 Å, $R \sim 805$ at 5000 Å, and $R \sim 1070$ near $H\alpha$. In addition to the prominent Balmer and He II emission, Figure 3 shows broad residual structures (bumps) around ~ 4160 , ~ 4400 , and ~ 4940 Å. These low-contrast broad bumps are not apparent in the 2024 March 19 SALT/RSS spectrum (S. B. Potter et al. 2024), plausibly because they are state-dependent and can be diluted or washed out by differences in the continuum level, signal-to-noise ratio (S/N), and spectral resolution and/or continuum normalization. To quantify these features in a reproducible manner, we fit a local linear pseudocontinuum in sidebands away from strong lines and measure the residual excess in a core window using the telluric-corrected 1D spectrum. For the three features, the residual peaks at $\approx (48\%, 78\%, 89\%)$ above the local pseudocontinuum with peak S/N $\approx (31, 48, 62)$, and remains highly significant when integrated over the core windows (S/N $\approx (122, 210, 258)$; EW $_{\text{pos}} \approx (19.8, 36.4, 38.7)$ Å, respectively). Given the single-epoch nature and modest resolution of our spectrum, we do not

attempt a unique identification of these weak broad structures here, but we report their presence and note that their contrast can plausibly vary with accretion state and continuum placement.

Deconvolved velocity widths cluster around $v_{\text{FWHM}} \sim (1\text{--}2) \times 10^3$ km s $^{-1}$ (Figure 4). The fitted centroid offsets v_γ are not consistent in sign across wavelength, indicating that line-by-line systematics (e.g., profile asymmetries/blends and residual wavelength-calibration zero-point errors) dominate over any single bulk velocity in this single-epoch spectrum. Balmer profiles show enhanced broad wings, most evident in $H\beta$ and $H\alpha$. To assess whether such wings bias our width measurements, we repeated the local fits allowing an additional broad component; the inferred core FWHM changes by $\lesssim 12\%$ ($H\beta$: -3.9% ; $H\alpha$: -11.5%) relative to single-Gaussian fits, i.e., within the systematic uncertainties of our line-profile characterization. The observed profiles are broadly single peaked with mild red-wing asymmetries, but any phase-dependent substructure would be smeared in this single-epoch spectrum. Accordingly, any line-width-based radius mapping should be interpreted only as an order-of-magnitude characteristic scale rather than as a precise geometric constraint.

5. Discussion

5.1. rms–Flux Behavior and Stochastic Variability

Our TESS analysis shows that the linear rms–flux relation in EP240309a is epoch dependent. Positive hour-timescale trends are detected in Sectors 37, 64, and 99, whereas Sectors 90 and 100 do not show a robust detection, and Sector 10 provides no valid high-cadence segments at the adopted window sizes (Section 4.4). We therefore interpret the nondetections as state-dependent absences of a measurable trend in our dataset, rather than as external control cases. Using the same fixed-aperture extraction and QUALITY = 0 filtering, Sectors 37/64/99 have similar positive median aperture-summed flux levels ($\bar{F}_{37} = 9572$, $\bar{F}_{64} = 9786$, $\bar{F}_{99} = 9584$), whereas Sectors 90/100 are consistent with zero in the same extracted units ($\bar{F}_{90} = -1.33$, $\bar{F}_{100} = 0.051$), so we do not interpret these sectors as straightforward absolute-brightness comparisons.

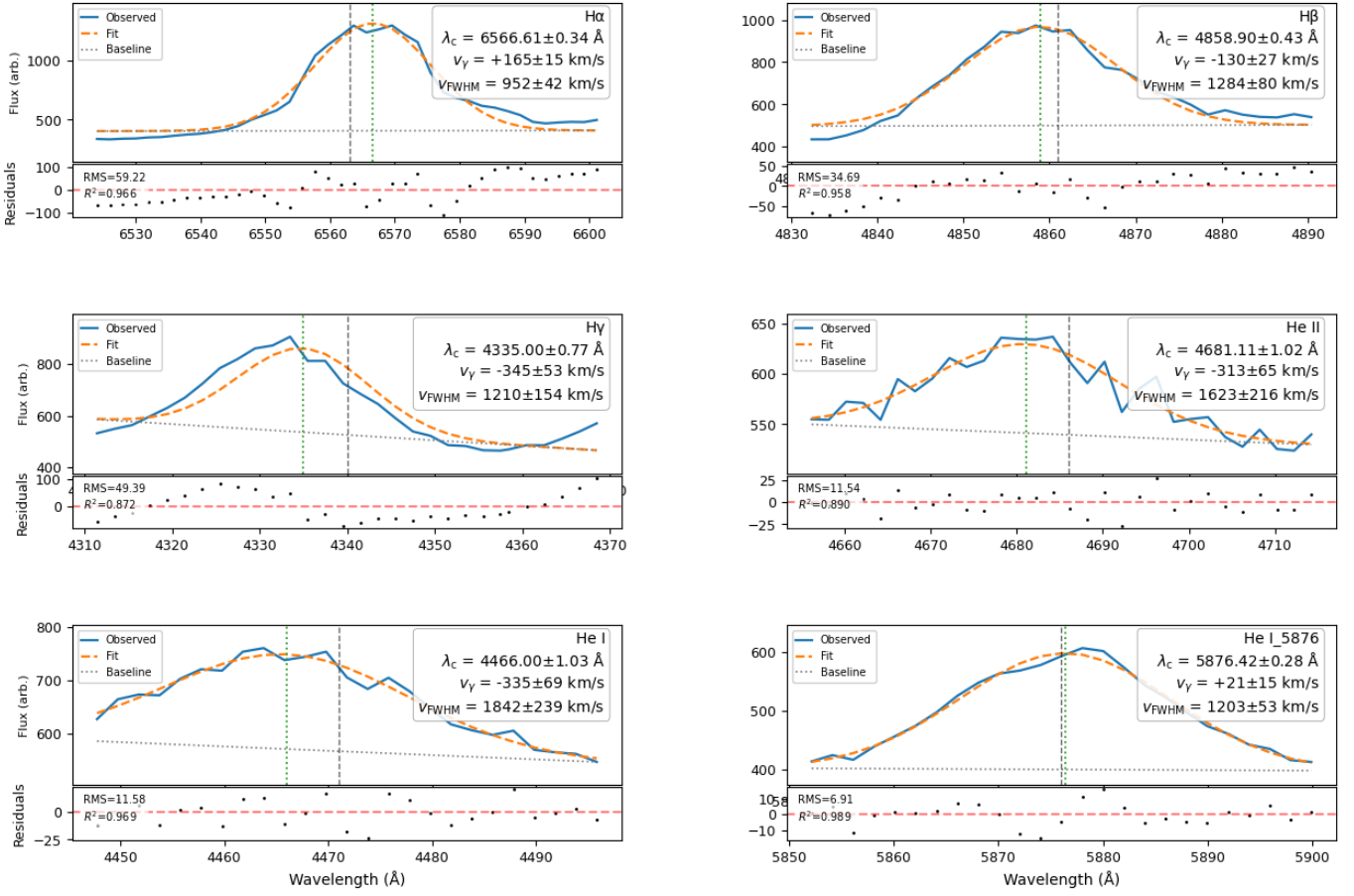


Figure 4. Example Gaussian + linear-baseline fits to six prominent emission lines used to estimate centroids and deconvolved widths. We annotate the fitted centroid λ_c and the corresponding apparent velocity offset $v_\gamma = c(\lambda_c/\lambda_0 - 1)$ in each panel; the annotated v_{FWHM} values are derived from deconvolved widths (see Section 3.5).

The detections in Sectors 37, 64, and 99 are consistent with multiplicative variability processes widely observed in accreting compact objects (e.g., P. Uttley et al. 2005; S. Scaringi et al. 2012). For the present data quality, a simple linear description is adequate; more flexible forms are not required by the information criteria and do not change the qualitative behavior. We therefore use the bootstrapped slope as the primary effect size and treat the Pearson statistics listed in Section 4.4 as descriptive diagnostics.

The rapid optical variability and PSD constraints further indicate broadband red-noise behavior typical of CVs: the fitted single-power-law indices span $\alpha \simeq 1.16 \pm 0.23$ to 1.78 ± 0.11 across nights (Section 4.3), consistent with stochastic accretion-driven flickering (e.g., Y. E. Lyubarskii 1997; P. Uttley et al. 2005; A. Bruch 2021). However, we do not detect a robust PSD bend in the sampled frequency range, so the timing analysis provides only one-sided lower limits on any putative bend frequency. Under standard dynamical identifications, these translate into conservative upper bounds on a characteristic inner scale and do not constitute evidence for a measured magnetospheric truncation radius or for disk-fed accretion in EP240309a.

Finally, the contemporaneous optical spectroscopy (Section 4.5) also cautions against overinterpreting the geometry: the available single-epoch, coadded spectrum does not provide phase-resolved kinematics, and published time-resolved spectra indicate that at least H β contains multiple

components. Any radius estimate based on deconvolved line widths should therefore be treated only as an order-of-magnitude check rather than as a quantitative constraint on the magnetospheric truncation radius.

5.2. Accretion-flow Geometry and the Magnetospheric Radius

EP240309a has $P_{\text{orb}} = 3.762$ hr and $P_{\text{spin}} = 3.97$ minutes, implying $P_{\text{spin}}/P_{\text{orb}} \approx 0.018$, within the range of IP candidates (e.g., J. Patterson 1994; B. Warner 1995; K. Mukai 2017). However, this timing ratio alone does not establish the detailed accretion geometry, so we treat EP240309a as an IP candidate.

Because we do not detect a robust PSD bend (Section 4.3), our timing analysis provides only one-sided constraints on a characteristic inner scale; under standard dynamical identifications, these may be expressed as conservative upper bounds on R_m . We therefore regard them as broad consistency checks rather than as evidence for a measured magnetospheric truncation radius.

For reference, the corotation radius is

$$R_{\text{co}} = \left(\frac{GM_{\text{WD}} P_{\text{spin}}^2}{4\pi^2} \right)^{1/3}. \quad (4)$$

Emission-line widths provide only an order-of-magnitude velocity-scale check: the available single-epoch, coadded

profiles lack phase-resolved kinematics, and published time-resolved spectroscopy shows multicomponent $H\beta$ structure.

Overall, the present data are consistent with accretion onto a magnetic white dwarf, but do not allow us to establish the detailed accretion geometry; in particular, they do not demonstrate disk truncation or distinguish robustly between disk-fed and stream-/curtain-dominated scenarios. Longer, less-windowed optical baselines together with contemporaneous time-resolved spectroscopy are required for stronger geometric constraints.

5.3. Transient Behavior and Implications for the IP Population

EP240309a was discovered as an X-ray transient by Einstein Probe; during our 2024 March monitoring its optical brightness spanned $\Delta R \simeq 1.3$ mag, but our BOOTES/TESS coverage does not capture a full rise/decay cycle and therefore cannot establish a classical dwarf-nova-like optical outburst evolution. In line with this, the ASAS-SN Sky Patrol photometry reported by S. B. Potter et al. (2024) is more consistent with a bimodal brightness distribution (i.e., state-dependent switching) than with well-sampled, discrete outburst rise-decay cycles.

Several mechanisms could drive transient episodes in mCVs (e.g., disk instabilities or gated accretion; J.-P. Lasota 2001; C. R. D'Angelo & H. C. Spruit 2010; S. Scaringi et al. 2017; G. Dubus & C. Babusiaux 2024), but the present data cannot distinguish among them. The observed flickering and epoch-dependent rms-flux behavior indicate stochastic variability, but not a specific trigger mechanism; discriminating among scenarios requires simultaneous X-ray/optical coverage through full transient cycles. EP240309a adds to the emerging sample of transient IP-like systems by showing red-noise optical variability and epoch-dependent rms-flux behavior consistent with accretion onto a magnetic white dwarf, while its detailed accretion geometry and transient trigger remain unconstrained. Longer multiwavelength monitoring is needed to assess recurrence and to place the source more robustly within the IP population.

6. Conclusions

We present multnight BOOTES optical photometry and a contemporaneous SOAR/Goodman spectrum of EP240309a, complemented by archival TESS photometry, to characterize its stochastic optical variability and to test for an rms-flux relation. The present data yield only conservative, one-sided constraints on a characteristic inner scale and do not establish the detailed accretion geometry; accordingly, we describe EP240309a as an IP candidate rather than a confirmed transient IP.

The BOOTES PSD of the best night is well described by a single power law and shows no compelling evidence for a bend in the sampled frequency range. Injection-recovery simulations yield strict one-sided lower limits on any bend frequency, which translate into order-of-magnitude constraints on a characteristic inner scale under standard dynamical identifications and subject to unknown system parameters. For $M_{WD} = 0.8 M_{\odot}$, these limits can be expressed (under standard dynamical identifications) as $R_m/R_{WD} \lesssim 41.4$ (dynamical) or $\lesssim 30.6$ (freefall).

Space-based data reveal a linear rms-flux relation on hour timescales in three high-cadence TESS sectors (37, 64, and 99), while Sectors 90 and 100 do not show a robust detection using

the same analysis pipeline, indicating that the rms-flux behavior is epoch dependent in EP240309a; Sector 10 is unusable for this test because no valid high-cadence segments are available at the adopted window sizes. For our fiducial 1 hr windows we obtain slopes $a = (4.43^{+0.86}_{-0.82}) \times 10^{-4}$ (Sector 37), $a = (2.55^{+0.62}_{-0.68}) \times 10^{-3}$ (Sector 64), and $a = (3.93^{+0.99}_{-0.94}) \times 10^{-3}$ (Sector 99), in units of fractional rms per unit mean flux. Together with the red-noise PSDs, these results are consistent with multiplicative variability processes, but do not by themselves identify the underlying accretion geometry.

The SOAR spectrum shows Balmer and He II emission with FWHM ≈ 1000 – 1600 km s $^{-1}$, with He II $\lambda 4686$ systematically broader than the Balmer lines. Given the inclination dependence of line-width-based radius estimates and published evidence for multicomponent Balmer-line structure, spectroscopy provides at most an order-of-magnitude cross-check rather than a quantitative geometric constraint. Future longer, contiguous high-cadence monitoring and coordinated X-ray/optical observations will be key to tightening inner-scale constraints and testing for state changes.

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Facilities: SOAR (Goodman), BOOTES, TESS

Software: Astropy (Astropy Collaboration et al. 2013, 2018, 2022), NumPy (C. R. Harris et al. 2020), SciPy (P. Virtanen et al. 2020), Matplotlib (J. D. Hunter 2007), Lightcurve (Lightcurve Collaboration 2018), Astrocute (C. E. Brasseur et al. 2019), PyPlot (J. X. Prochaska et al. 2020a, 2020b).

Data Availability

The BOOTES photometry is provided as machine-readable data behind Figure 1. The TESS time-series pixel cutouts used in this work were obtained from the calibrated FFIs via MAST. The underlying calibrated FFIs are available at MAST for Sectors 10 (STScI 2024a), 37 (STScI 2024b), 64 (STScI 2024c), 90 (STScI 2025), 99 (STScI 2026a), and 100 (STScI 2026b).

Appendix

Method-sensitivity Summaries

For brevity, we summarize representative sensitivity tests for the TESS rms-flux analysis as compact tables (Tables A1 and A2) of the bootstrap-median slope a_{50} under different quality-control settings. We include one robust positive-detection case and one non-robust-detection case at the fiducial 1 hr windows.

Table A1

Sensitivity Summary for the TESS rms-Flux Slope in Sector 64 (1 hr Windows)

σ -clip (per Segment)	Min. Points = 8	Min. Points = 10	Min. Points = 15
3.0	0.00264	0.00260	0.00264
2.5	0.00252	0.00252	0.00250
2.0	0.00255	0.00251	0.00254

Note. The table lists the bootstrap-median linear rms-flux slope a_{50} (in fractional rms per unit mean flux) obtained under different per-segment σ -clipping thresholds and minimum-number-of-points requirements.

Table A2

Sensitivity Summary for the TESS rms-Flux Slope in Sector 100 (1 hr Windows; Non-robust-detection Case)

σ -clip (per Segment)	Min. Points = 8	Min. Points = 10	Min. Points = 15
3.0	0.0315	0.0320	0.0324
2.5	0.0320	0.0284	0.0358
2.0	0.0196	0.0190	0.0226

Note. The table lists the bootstrap-median linear rms-flux slope a_{50} (in fractional rms per unit mean flux) obtained under different per-segment σ -clipping thresholds and minimum-number-of-points requirements.

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