



TCP J07222683+6220548: A New AM CVn Type System with Infrequent Outbursts

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Abstract

We present the discovery of TCP J07222683+6220548, a new ultracompact binary system of the AM CVn type. This system was first identified displaying a $\Delta V = 7.6$ mag outburst on 2025-01-20.9416 UTC by the New Milky Way wide-field survey for transients and later independently detected by ASAS-SN and ZTF. The outburst peaked at $V_{\max} = 12.45$ and lasted for seven days, followed by a series of rebrightenings. No previous outbursts are found in archival data. Positive superhumps with a period of 0.032546 ± 0.000084 day (46.87 ± 0.12 minutes), barely detectable during the main outburst, became clearly visible during the first rebrightening that lasted from day 18 to day 24 after the initial outburst. No convincing change in the superhump period was detected. Dense time-series photometry follow-up by a pair of 0.5 m INASAN robotic telescopes, together with VSNET and AAVSO observers, was essential for identifying TCP J07222683+6220548 as an AM CVn system and triggering confirmation spectroscopy with the 2.5 m CMO SAI telescope. Some outbursting AM CVn systems lacking such detailed follow-up may remain unrecognized among the newly discovered cataclysmic variable candidates.

Key words: (stars:) white dwarfs – (stars:) novae, cataclysmic variables – stars: dwarf novae – stars: individual (TCP J07222683+6220548)

1. Introduction

The AM Canum Venaticorum (AM CVn) stars are a rare class of ultracompact binary systems consisting of a white dwarf accreting helium-rich material from a degenerate or semi-degenerate companion (Warner 1995c; Solheim 2010). The nature of this companion (the donor star) can be either a low-mass white dwarf (fully degenerate supported by electron degeneracy pressure), or a helium-rich star that is only partially degenerate. In the latter case, the star's core is degenerate but its outer layers still experience some thermal pressure support. These remarkable binary systems have extremely short orbital periods ranging from ~ 5 to ~ 70 minutes, significantly below the ~ 80 minute period

minimum of hydrogen-rich cataclysmic variables (e.g., Tutukov et al. 1985; Gänsicke et al. 2009). The spectra of AM CVn stars are characterized by the presence of helium lines and a notable absence of hydrogen, reflecting the evolved nature of the donor star.

Currently, about 70 confirmed and candidate AM CVn systems are known (Liu et al. 2022), with the expectation that there is a large undiscovered population (Ramsay et al. 2018). The AM CVn population can be divided into subgroups based on their orbital periods and accretion behavior (Bildsten et al. 2006). Systems with periods below ~ 10 minutes likely undergo direct impact accretion without forming a disk. Those with periods between ~ 10 and 20 minutes maintain stable hot

accretion disks and show steady emission. The intermediate period systems (~ 20 to $\gtrsim 45$ minutes) experience dwarf nova-like outbursts where their brightness increases by 3–5 mag for days to weeks. Like hydrogen-rich dwarf novae, these outbursts occur when the accretion disk switches between faint (low-viscosity, low-accretion-rate) and bright (high-viscosity, high-accretion-rate) states (Kotko & Lasota 2012), but the instability arises from helium rather than hydrogen ionization (Smak 1983; Kotko et al. 2012; Hameury 2020; Jordan et al. 2024). The longest period systems typically have cool, stable disks, although some exceptions are known.

The formation channels and evolution of AM CVn binaries remain subjects of active research (Shen 2015; Green et al. 2018; Green 2019; Liu et al. 2021; Belloni & Schreiber 2023; Sarkar et al. 2023). They may form through three possible routes: from detached double white dwarf binaries that survive the onset of mass transfer, from binaries with helium star donors, or from evolved cataclysmic variables that have lost their hydrogen. Accumulation of the accreted helium-rich material on the surface of the primary white dwarf should eventually lead to a helium nova (Kato et al. 1989; Iben & Tutukov 1991; Yoon & Langer 2004). AM CVn stars are also potential progenitors of normal Type Ia and sub-luminous Ia supernovae (Bildsten et al. 2007; Solheim 2010; Deshmukh et al. 2024). AM CVn systems may be related to R Coronae Borealis stars as their progenitors (Solheim 1996) or by being an alternative outcome of common envelope evolution of a pair of white dwarfs (Webbink 1984; Solheim 1996).

AM CVn binaries are expected to be strong sources of low-frequency gravitational waves (Lipunov & Postnov 1987; Chen et al. 2022; Liu et al. 2022), detectable by future space-based gravitational-wave observatories such as Laser Interferometer Space Antenna (LISA; Amaro-Seoane et al. 2023) and TianQin (Mei et al. 2021) missions. The known AM CVn systems will serve as guaranteed verification sources for LISA, while the mission may potentially discover many more such systems through their gravitational wave emission (Kupfer et al. 2018).

Increasing the sample of known AM CVn stars, particularly those showing outbursts, is crucial for several reasons. First, it helps constrain their space density and better understand their formation channels. Second, outbursting systems provide opportunities to study the physics of helium accretion disks and the mechanisms driving their outbursts. Third, a larger sample improves our ability to characterize the low-frequency gravitational wave background that will be important for future space-based gravitational wave detectors.

In this paper, we report the discovery and follow-up observations of a new AM CVn system identified through its outburst activity. The paper is organized as follows: Section 2 describes the discovery technique and follow-up observations, Section 3 puts the newly discovered system in the context of other AM CVn stars and Section 4 summarizes our findings.

2. Observations and Analysis

2.1. NMW Survey Discovery

The New Milky Way survey¹⁶ (NMW; Sokolovsky et al. 2014) aims to rapidly detect bright Galactic transients including classical novae, dwarf novae, flare stars, young stellar object FUor/EXor outbursts (for reviews see Audard et al. 2014; Hartmann et al. 2016) and the brightest microlensing events (e.g., Wyrzykowski et al. 2020) in anticipation of more exotic transients such as a luminous red nova (Tylenda et al. 2011; Kochanek et al. 2014; Addison et al. 2022), a helium nova (Ashok & Banerjee 2003; Nyamai et al. 2021) and ultimately the next Galactic supernova (Adams et al. 2013). The ambition of the survey is to inform the community of the appearance of an astrophysically interesting transient over the minimal possible time.

The NMW survey operates two wide-field CCD cameras: unfiltered monochrome ST-8300M and STL-11000M attached to identical Canon 135 mm $f/2.0$ telephoto lenses and installed on computer-controlled HEQ5 Pro mounts. The two cameras have the field of view (pixel scale) of 7.7×5.8 ($8''.35 \text{ pix}^{-1}$) and $15^\circ \times 10^\circ$ ($13''.8 \text{ pix}^{-1}$), respectively. The cameras are housed in the rolling-roof pavilion at the Astrovert astrofarm¹⁷ in Nizhnii Arkhyz, Karachay-Cherkessia, Russia. The entire sky visible from the observing site is divided into a set of overlapping fields. Three 20 s exposures of each field are taken with dithering to aid in distinguishing celestial objects (fixed relative to the stars) from image artifacts (fixed relative to the chip). The transient detection pipeline is based on the VAST code (Sokolovsky & Lebedev 2018). It does not utilize the computationally expensive image subtraction and instead relies on matching the lists of sources detected on reference and second-epoch images. Apart from the images' limiting magnitude (around 14 mag on a moonless night), detection efficiency is limited by transient blending with surrounding stars. Insert-and-recovery simulations demonstrate the system has about an 80% (99%) chance of detecting a 13 mag (10 mag) transient in a low Galactic latitude field. After human vetting, the identified new transients are reported via the CBAT "Transient Objects Confirmation Page" (TOCP)¹⁸ with the exception of UV Ceti type flaring red dwarfs and other non-cataclysmic variable stars that are reported directly to the AAVSO International Variable Star Index (VSX; Watson et al. 2006).

The 12.8 mag transient TCP J07222683+6220548 (referred as J0722 in the following) was found in the NMW images obtained on 2025-01-20.9416 UTC ($t_0 = \text{JD } 2460696.4416$). No objects brighter than $CV = 14.5$ are visible in the previous NMW image of the field obtained ten days earlier on 2025-01-

¹⁶ <https://scan.sai.msu.ru/nmw/>

¹⁷ <https://astrovert.ru/astrofarm/>

¹⁸ <http://www.cbat.eps.harvard.edu/unconf/tocp.html>

Table 1
J0722 Magnitudes and Extinction

Filter	Observed	Extinction	Absolute
$V_{\max}$	12.45 ± 0.01	0.30	$3.4^{+0.7}_{-0.9}$
$V_{\min}$	20.06 ± 0.03	0.30	11.0
g	19.98 ± 0.02	0.35	10.8
r	20.12 ± 0.02	0.25	11.1
G	20.01 ± 0.01	0.27	10.9
BP	20.00 ± 0.06	0.33	10.9
RP	20.01 ± 0.09	0.20	11.0

10.9233. The All-Sky Automated Survey for Supernovae (ASAS-SN; Shappee et al. 2014; Kochanek et al. 2017) independently discovered J0722 36 hr later on 2025-01-22.46, naming it ASASSN-25aj. The latest ASAS-SN observation of the field was on 2025-01-20.3957 (13 hr prior to the NMW detection) showing no object brighter than $g=17$. The transient was also identified as an anomaly among the Zwicky Transient Facility (ZTF; Masci et al. 2019) transients by Lima et al. (2025) and designated ZTF25aacfjde.

2.2. Gaia Counterpart, Distance and Extinction

A blue source, Gaia DR3 1087501559186713472 (07:22:27.05915 +62:20:56.7450 Equinox = J2000.0 at Epoch = J2000, $BP = 20.00 \pm 0.06$, $RP = 20.01 \pm 0.09$, $Plx = 1.96 \pm 0.53$ mas, $PM = 9.9$ mas yr⁻¹; Gaia Collaboration et al. 2023), is located 2.5'' from the measured position of the transient, within the few-arcsecond astrometric uncertainty of the discovery observations (8.35 pix⁻¹ image scale). Despite the large pixel scale, the identification is unambiguous as this is a relatively uncrowded field. The second-closest Gaia Data Release 3 (DR3) source is located 36'' away from the discovery position. The second-closest Pan-STARRS1 (Chambers et al. 2016) source is 20'' away. The matching source also clearly stands out in both Pan-STARRS1 and DSS2 (Lasker et al. 1996) color images as having much bluer color compared to field stars. The follow-up astrometric measurements reported by K. Yoshimoto via the TOCP confirm the Gaia source identification.

The Gaia parallax corresponds to the geometric distance of 575^{+304}_{-153} pc with 68% uncertainties according to Bailer-Jones et al. (2021). Table 1 lists the observed and absolute peak and minimum magnitudes of J0722 together with the extinction corrections. The corrections were derived using the MWDUST package (Bovy et al. 2016) that combines 3D dust maps of Drimmel et al. (2003), Marshall et al. (2006), Green et al. (2019). The same extinction values are predicted for the whole 68% range of distances. The uncertainty in absolute magnitude is dominated by the uncertainty in distance, and so applies equally to all bands. The minimum V band magnitude, $V_{\min}$,

was color-transformed from Pan-STARRS1 g and r band photometry using the relation from (Tonry et al. 2012)

$$V = 0.474 * (g - r) + 0.006 + r. \quad (1)$$

We have used the extinction coefficients from Table 2 of Casagrande & Vandenberg (2018) to compute the extinction in Gaia bands from $E(B - V)$ provided by MWDUST.

2.3. Spectroscopy with the 2.5 m CMO SAI Telescope

Spectroscopic observations of J0722 were performed with the 2.5 m telescope at the Caucasian Mountain Observatory (CMO) of the Sternberg Astronomical Institute of Lomonosov Moscow State University (SAI MSU; Shatsky et al. 2020) using the Transient Double-beam Spectrograph (TDS; Potanin et al. 2020). We used a 1'' slit width, which provides resolving power of 1300 in the blue channel (3550–5700 Å) and 2400 in the red channel (5700–7450 Å) of the spectrograph. The spectra were obtained on 2025-02-10.9578 (total exposure time was 600 s) and 2025-02-13.8017 (total exposure time was 3600 s) during the rebrightening, as demonstrated in Figure 1. The spectra were flux calibrated with A0V comparison stars, but due to light losses on the narrow slit, the flux may be offset by a constant factor.

The spectrum (Figure 2) shows a blue continuum with prominent broad absorption lines of He I. Notably, the spectrum lacks the Balmer hydrogen lines. The He II 4687 Å emission is also present. The list of He lines was obtained from the NIST Atomic Spectra Database (Kramida et al. 2024).

Such a spectrum is typical for an AM CVn system in outburst (e.g., Ramsay et al. 2010; Levitan et al. 2013). Similar to hydrogen-abundant dwarf novae (Idan et al. 2010), AM CVn systems show an absorption spectrum while in outburst and an emission line spectrum in quiescence. Painter et al. (2024) in their figure 5 present spectral evolution of the AM CVn system ASASSN-21br from outburst to quiescence, illustrating the transition from helium absorption to an emission dominated spectrum (see also Roelofs et al. 2007; Levitan et al. 2011).

2.4. Photometry

Time series photometry of J0722 was performed using multiple small telescopes described below. The results were shared via the AAVSO International Database (Kloppenborg 2025), the Variable Star Observers League in Japan (VSOLJ) database¹⁹ and the vsnet-alert mailing list. These targeted observations were complemented with more sparsely-sampled survey data to better trace the overall shape of the lightcurve prior to and during the outburst.

Photometry of J0722 was performed using two robotic telescopes operated by the Institute of Astronomy of the

¹⁹ <http://vsolj.cetus-net.org/index.html>

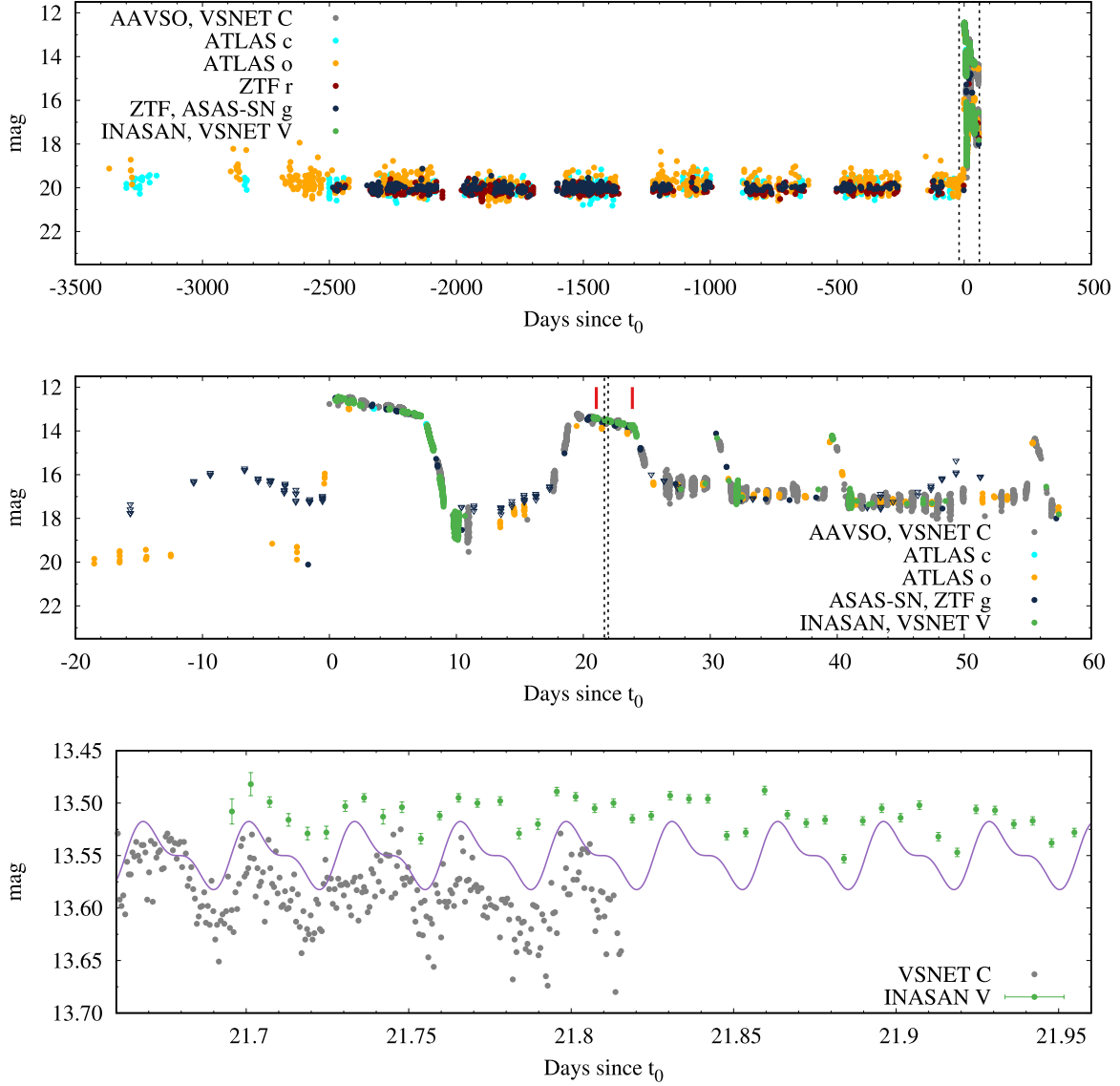


Figure 1. The lightcurve of J0722 combining V -band photometry from INASAN Terskol and Kislovodsk telescopes (Section 2.4) with V -band and unfiltered CV -band measurements collected by VSNET and AAVSO observers (including CV photometry from the two NMW cameras), ASAS-SN g , ATLAS o (orange) and c (cyan), and ZTF g and r data. The top panel shows the complete combined lightcurve with the vertical dashed lines indicating the outburst plotted in the middle panel. The vertical dashed lines in the middle panel indicate time range of the bottom plot that presents an example section of the lightcurve where superhumps are visible (Section 3.2). The purple curve approximates the superhump shape as a sum of two sine waves, one with a period from Equation (3) and the peak-to-middle amplitude of 0.025 mag and the other with twice that period and half the amplitude (see Figure 4), it is plotted to guide the eye. The outburst plot (middle panel) includes ASAS-SN g upper limits (triangles) along with the positive detections (filled circles). Vertical red bars mark the times of spectroscopic observations described in Section 2.3.

Russian Academy of Sciences (INASAN). These instruments are based on Ritchey–Chrétien Astrosib RC 500 telescopes with the aperture 0.5 m and focal ratio $f/8$. The telescopes are operated using a dedicated control system designed to enable both remote and fully automatic observations (Naroenkov & Nalivkin 2019). The system implements continuous real time monitoring of weather conditions and astronomical alerts—notifications of newly discovered transient events such as

gamma-ray bursts (GRBs). A centralized observation planning optimizes the distribution of observing tasks between the telescopes. Observations of J0722 during its main outburst were carried out using a robotic telescope installed at Terskol Observatory of INASAN (Tarasenkov & Naroenkov 2024) in the V band. Photometric monitoring was conducted every clear night in automatic mode. The object’s high northern declination allowed continuous observation throughout the night.

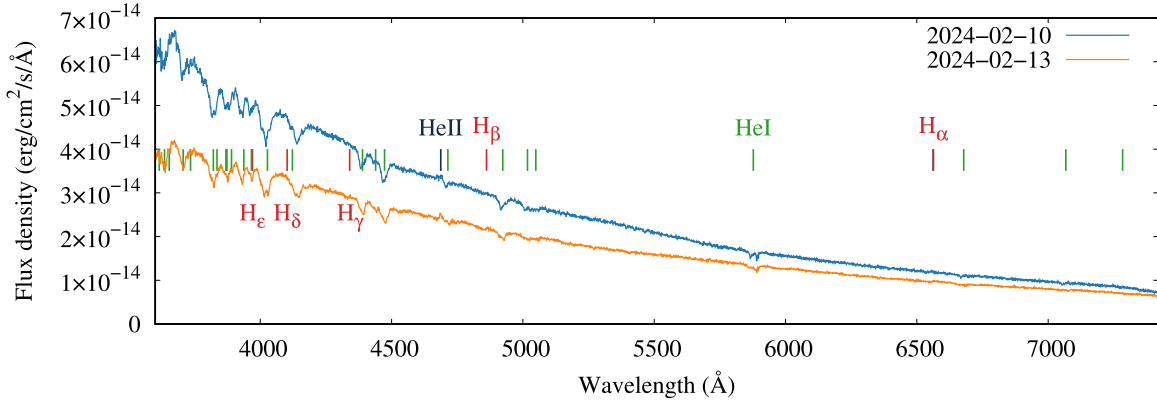


Figure 2. The spectra of J0722 obtained with the 2.5 m SAI MSU telescope during the rebrightening. The green and dark blue marks show the locations of prominent He I and He II lines, respectively. The red marks indicate the expected location of Balmer lines.

During rebrightening, we performed photometry of J0722 in *BVRI* bands using a similar 0.5 m Astrosib RC 500 robotic telescope of INASAN Kislovodsk Observatory (Naroenkov et al. 2024). Both telescopes are equipped with a filter wheel with Johnson *UBVRI* filters. The telescope at the Kislovodsk Observatory is equipped with a ZWO ASI6200MM Pro CMOS camera, while the telescope at the Terskol Observatory uses a FLI ProLine 16803 CCD camera. Aperture photometry was performed using ASTROIMAGEJ software (Collins et al. 2017). The photometric aperture size was adjusted to match changes in seeing during image processing. Stars from the APASS catalog (Henden et al. 2012), which are close to J0722, were used as comparison.

Photometric observations of J0722 were performed at Andromeda observatory in Mol, Belgium using a Carbon tube C14 Edge HD 0.36 m telescope at *f*/7 and a QHY600M CMOS camera with Astrodon photometric filters. Aperture photometry was performed with LesvePhotometry software²⁰ using AAVSO sequence comparison stars.

J0722 was observed using with a 0.3 m *f*/4 Newtonian telescope and QHY IC 8300 CCD remotely operated with INDI²¹ and Ekos/Kstars. Image processing was done by gcx²² software and aperture photometry was performed by IRAF (Tody 1986) under Linux.

J0722 was also observed with a 0.3 m Schmidt–Cassegrain telescope equipped with an unfiltered ZWO ASI294MM Pro CMOS camera. The source was also observed using a 0.2 m Schmidt–Cassegrain telescope with an unfiltered ATIK383L CCD camera. The images from these two telescopes were measured using Muniwin 2.1.36.²³

The observations of J0722 were also performed using a 0.36 m Schmidt–Cassegrain telescope (focal length 3950 mm,

f/11) equipped with an FLI ML1001E CCD camera and a set of Johnson-Cousins filters. MIRA Pro 64 software was used for photometry.

To better track the long-term evolution of the lightcurve, we supplement the targeted observations collected with the telescopes described above with unfiltered CV band photometry collected by the two wide-field NMW cameras (Section 2.1). The photometry was also extracted from the ASAS-SN Sky Patrol (Shappee et al. 2014; Kochanek et al. 2017) (*Vg* bands), ZTF (*gr* bands) Public Data Release 23 (covering time interval from 2018 March to 2023 June) accessed via the SNAD VIEWER²⁴ (Malanchev et al. 2023) together with ZTF outburst photometry obtained through the LASAIR broker²⁵ (Williams et al. 2024) and ATLAS (*c cyan* and *o orange* bands; Tonry et al. 2018; Smith et al. 2020) surveys. The ASAS-SN and ATLAS measurements were extracted from original (not difference) images using forced photometry at the Gaia DR3 position of the host system (Section 2.2). The long-term lightcurve of J0722 is presented in Figure 1.

3. Results and Discussion

3.1. Overall Shape of the Lightcurve

The combined lightcurve of J0722 (Figure 1) displays a single outburst in 2025. The lightcurve spans 9 yr with positive detections at quiescence by ZTF and ATLAS and 13 yr with ASAS-SN upper limits. The seasonal gaps in the lightcurve (smallest for the ASAS-SN data) are typically about 100 days long. If a previous outburst happened less than 13 yr ago, in order to be completely missed it would have to start after the start of a seasonal gap and end before the end of that gap. Taking the outburst duration together with the first rebrightening to be 25 days (see the discussion below and Figure 1), the

²⁰ <http://www.dppobservatory.net/astroprograms/LesvePhotometryDownloadPage.php>

²¹ <https://www.indilib.org/>

²² <https://gcx.sourceforge.net/>

²³ <https://c-munipack.sourceforge.net/>

²⁴ <https://ztf.snad.space/>

²⁵ <https://lasair-ztf.lsst.ac.uk/objects/ZTF25aacfjde/>

Table 2
Outburst Parameters

Outburst	Rise Rate (mag day ⁻¹)	Plateau Rate (mag day ⁻¹)	Decline Rate (mag day ⁻¹)	Plateau Duration (day)	Peak (mag)
Main	-7.8	0.128	2.1	6.7	12.45
1st Rebrightening	-3.5	0.123	2.0	4.6	13.22

effective gap length becomes 75 days, corresponding to a 20% chance of missing a single outburst and a 4% chance of missing two outbursts occurring at random times over the past 13 yr. If we also consider the post-outburst decline lasting >60 days when the system was ~ 2 mag brighter than in quiescence (a difference that should have been easily visible in the ATLAS and ZTF photometry), this further reduces the probability of completely missing an outburst over the last decade. We conclude that outbursts in J0722 are likely rare.

The pre-outburst ZTF and ATLAS lightcurve does not show any obvious variability. Specifically, there seems to be no pre-outburst brightening in contrast to what was observed in another AM CVn system ASASSN-21au by Rivera Sandoval et al. (2022). The season-to-season variations hinted by the ATLAS lightcurve of J0722 are probably of an instrumental origin as the changes do not match between *c* and *o* bands and are not seen in ZTF *gr* photometry.

The 2025 outburst of J0722 is characterized by a fast rise at a rate of 7.8 mag day^{-1} ($0.325 \text{ mag hr}^{-1}$), estimated from the comparison of ATLAS photometry during the lightcurve rise and the NMW discovery photometry. The total outburst amplitude is $\Delta V = 7.6 \text{ mag}$. Such fast rise and high amplitude are typical for dwarf novae (e.g., Ridden-Harper et al. 2019). After peaking some time between the NMW discovery at t_0 and the next NMW observation 11 hr later, J0722 begins a linear (in magnitudes as a function of time) decline at a rate of $0.128 \text{ mag day}^{-1}$. This slow decline continues until $t_0 + 7.2$ days and by $t_0 + 7.7$ days changes to a rapid 2.1 mag day^{-1} decline. The decline stops about 1.25 mag above the median quiescence level by $t_0 + 10$ days. According to ATLAS photometry, by $t_0 + 13$ days it changes to a gradual rise of 0.3 mag day^{-1} , that around $t_0 + 18$ days turns into a more rapid rise toward a rebrightening. The rise to the rebrightening is happening at a rate 3.5 mag day^{-1} , considerably slower than the rise toward the main outburst. The rebrightening is characterized by a decline rate of $0.123 \text{ mag day}^{-1}$, similar to that of the main outburst. The end of the rebrightening at $t_0 + 24.1$ days is well constrained by the INASAN-Kislovodsk photometry. The rapid 2.0 mag day^{-1} post-rebrightening decline stops 3.3 mag above quiescence. At least three short-lived rebrightenings follow at $t_0 + 30$ days, $t_0 + 39$ days and $t_0 + 55$ days. Table 2 summarizes the properties of the main outburst and the first rebrightening.

The magnitude change rates quoted in Table 2 were obtained by robust linear fitting (implemented in the GNU Scientific Library; Gough 2009) to the relevant sections of the color-combined lightcurve. We do not report fitting uncertainties as the true uncertainties are dominated by the lightcurve sampling (at what times observations are available), the accuracy of color correction for the overall lightcurve (where the same color regardless of magnitude is assumed), and the validity of linear approximation to the actual lightcurve shape. Comparison with weighted linear fits and fits including or excluding individual points suggests that the magnitude change rates are typically constrained to within 20% by the available data.

The difference in rise times (rates of brightening) between outbursts of an individual dwarf nova are often interpreted as the difference between the “outside-in” and “inside-out” outbursts (Cannizzo et al. 1986; Buat-Ménard et al. 2001; Kotko et al. 2012; Jordan et al. 2024). The fastest rise is attributed to an “outside-in” outburst: the thermal instability begins at the outer edge of the accretion disk and propagates inward. The slower rise is expected for an “inside-out” outburst, where the inner part of the accretion disk is the first to transition to the ionized state, with the heating/ionization wave propagating to progressively larger disk radii. The decay time (rate) is expected to be the same for both “outside-in” and “inside-out” outbursts, as the cooling wave always moves from the outer region of the disk to the inner (Section 3.5.4.1 of Warner 1995a). Comparing this to the observed rise and decline rates listed in Table 2, we suggest that the main outburst might have been of the “outside-in” type, while the first rebrightening was an “inside-out” outburst.

The outburst rise and decay rates should also depend on the accretion disk size, with longer rise and decay timescales found in systems with longer orbital periods and hence larger disks (Section 3.3.3.5 of Warner 1995a). For J0722, the first rebrightening, which is characterized by a slower rise, is unlikely to be associated with the accretion disk being larger than during the main outburst, which displayed a faster rise (Figure 1 and Table 2). The fainter peak magnitude of the rebrightening compared to the main outburst suggests that the disk reached a smaller maximum radius during the rebrightening.

The rebrightenings (sometimes referred to as “echo outbursts”) and the elevated (compared to pre-outburst time) brightness level between them may result from an enhanced mass transfer level from a secondary, heated by the accreting white dwarf during the outburst (Hameury & Lasota 2021).

An isolated outburst with a week-long plateau bracketed by the rapid rise and decline phases and followed by rebrightenings is typical for outbursting AM CVn type systems. However, similar lightcurve shapes are found among hydrogen-rich dwarf novae of WZ Sge type, as discussed in Section 3.3.

3.2. Periodic Modulation

After applying the heliocentric correction (e.g., Eastman et al. 2010) and detrending the V band lightcurve with a piecewise linear function (e.g., Sokolovsky et al. 2023) we performed a period search using multiple techniques: the Discrete Fourier Transform (DFT; Deeming 1975; Max-Moerbeck et al. 2014; Kankkunen et al. 2025), its Lomb-Scargle modification that allows for analytical computation of false alarm probability if the photometric measurements are affected by uncorrelated (white) Gaussian noise (Lomb 1976; Scargle 1982; Frescura et al. 2008; VanderPlas 2018), and the string-length method of Lafler & Kinman (1965) implemented in the codes WINEFK²⁶ (Goranskij 1976), VAST and the online period search tool.²⁷ We have analyzed separately the data collected during the main outburst (t_0 to $t_0 + 8$ days) and during the rebrightening ($t_0 + 20$ days to $t_0 + 24$ days). We considered a range of trial periods (frequencies) from 0.1 day (10 days^{-1}) to 0.01 days (100 days^{-1}), appropriate for WZ Sge dwarf novae located below the period gap (Kolb et al. 1998; Howell et al. 2001; Kato 2015). The period analysis results are presented in Figures 3 and 4.

The main outburst power spectrum (Figure 3, top left panel) shows a weak peak corresponding to a period of 0.016209 day (23.34 ± 0.03 minutes). The analytical false alarm probability for this peak in the Lomb-Scargle periodogram is 0.01 or 0.05, depending on the method used to estimate the number of independent frequencies, following the prescriptions of Schwarzenberg-Czerny (2003) and Horne & Baliunas (1986), respectively (see discussion in Frescura et al. 2008; VanderPlas 2018). We also estimate the false alarm probability of this peak using bootstrapping (e.g., Section 7.4.2.3 of VanderPlas 2018), obtaining a value of 0.04 after 10,000 iterations.

This peak is not associated with a spectral window feature or any known instrumental periodicity, nor does it result from their combination. The interaction between a sampling feature, appearing as a spectral window peak at frequency f_{sampling} , and an instrumental (or true astrophysical) signal at frequency

f_{signal} can produce alias peaks at frequencies

$$f_{\text{alias}} = |f_{\text{signal}} \pm n f_{\text{sampling}}|, \quad (2)$$

where n is an integer (e.g., VanderPlas 2018; Briegal et al. 2022). If no true periodic signal is present in the data but there is slow, irregular variability of astrophysical or instrumental origin, power from these variations may leak into higher frequencies (“red-noise leak”; e.g., Kankkunen et al. 2025). Aliasing can interact with this leakage, enhancing power at unexpected locations. One possible scenario is that this interaction generates a series of spurious periodogram peaks, with lower-frequency peaks being suppressed by lightcurve detrending. In such a case, the highest-frequency peak in the series may remain the strongest, obscuring the fact that it is part of a series of multiple peaks.

The peak in Figure 3, top left panel, corresponds to a sine wave peak-to-mean amplitude of 0.003 mag, which is not distinguishable in the phased lightcurve plot (Figure 3, top right panel). This peak is not visible in the Lafler-Kinman string-length periodogram.

All these considerations cast doubt on the reality of the periodic signal in the main outburst lightcurve. However, the tentative detection of this short-period signal motivated us to conduct spectroscopic observations of J0722 revealing it as an AM CVn system (Section 2.3). The presence of this periodic signal during the main outburst was confirmed with the analysis of Clear band photometry independently collected by VSNET observers (false alarm probability estimated from bootstrap and the analytical methods: $\ll 10^{-2}$).

The periodic signal becomes clearly visible during rebrightening (Figure 3, bottom panels) where a modulation with a period of $P = 0.032516 \pm 0.000178$ day (46.82 ± 0.26 minutes; twice the period found during the main outburst) and a peak-to-peak amplitude of 0.05 mag was observed. The larger period uncertainty compared to the one quoted above for the main outburst results from the quadratic relation between the period and its error (Equation (4)) and the shorter time baseline of INASAN-Kislovodsk V band photometry during the rebrightening plateau. The phased lightcurve (Figure 3, bottom right) shows two asymmetric humps per period. The peak at half that period, corresponding to the main outburst periodicity, is also clearly seen in the power spectrum (Figure 3, bottom left). We find no measurable difference between the modulation period during the main outburst (double the period corresponding to the periodogram peak in Figure 3, top left panel) and the rebrightening. Reassured by the absence of rapid period change, we combine all the V and Clear band data from the beginning to the end of the rebrightening to derive the best estimate of

²⁶ <http://www.vgoranskij.net/software/>

²⁷ <https://scan.sai.msu.ru/lk/>

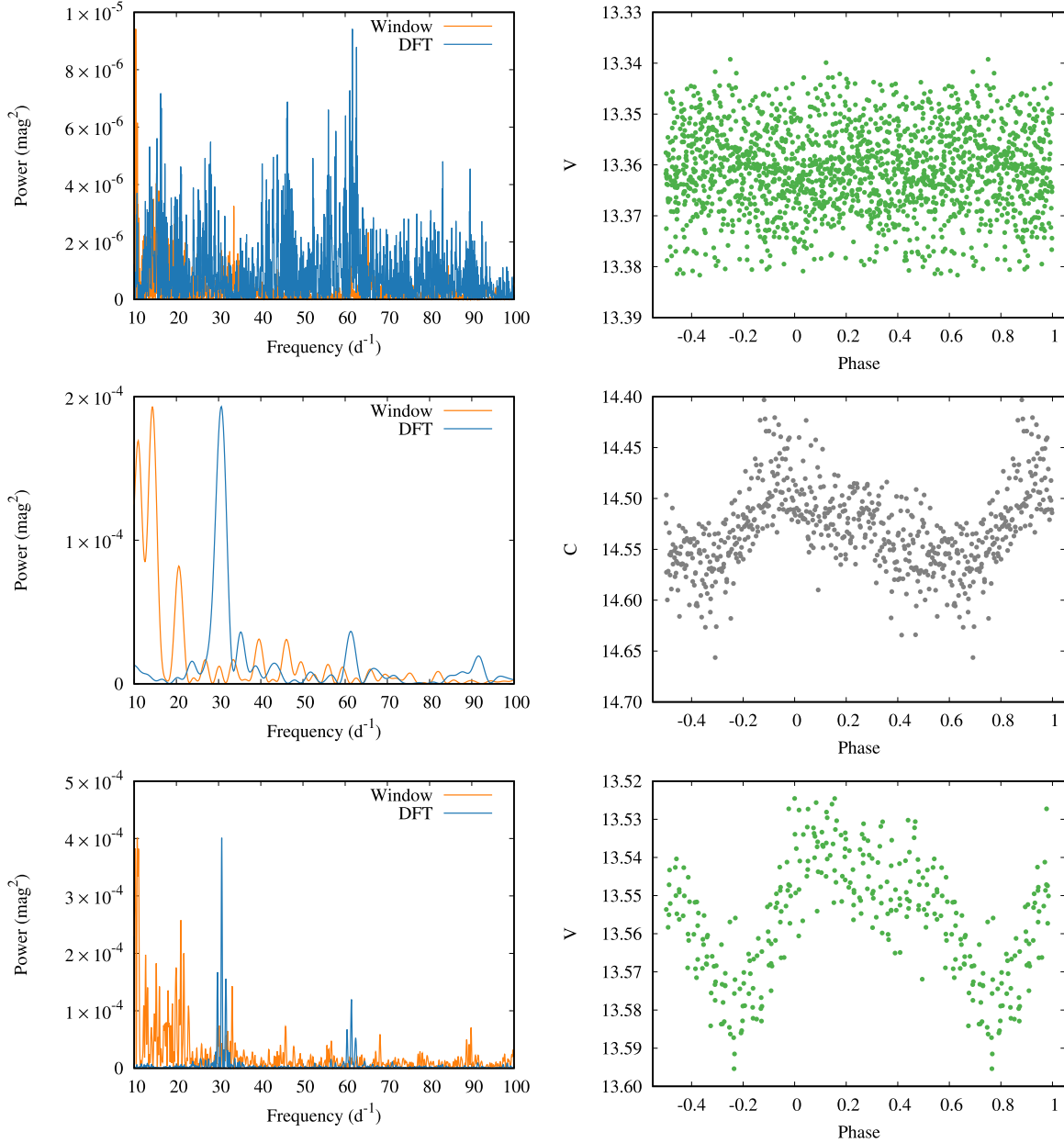


Figure 3. Power spectra with their corresponding spectral windows and phased lightcurves of J0722 during the main outburst (top panels; INASAN-Terskol; V filter), the rise to the rebrightening (middle panels; VSNET Hiroshi Itoh; Clear band) and during rebrightening (bottom panels). All lightcurves are phased with the light elements $HJD(TT) = 2460718.3052 + 0.032516 \times E$ corresponding to the highest peak in the rebrightening power spectrum (bottom left panel; INASAN-Kislovodsk; V filter).

the period (Figure 4)

$$P = 0.032546 \pm 0.000084 \text{ day } (46.87 \pm 0.12 \text{ minutes}). \quad (3)$$

We estimate the period uncertainty as

$$P_{\text{err}} = \Delta\phi P^2 / T, \quad (4)$$

where $\Delta\phi = 0.5$ is the phase shift between the first and the last points of the lightcurve that are separated by the time interval

T (see the discussion by Sokolovsky et al. 2022, of the relation between $\Delta\phi$, “periodogram oversampling factor” and the “natural” Rayleigh resolution). We note that while the choice of $\Delta\phi = 0.5$ (half-a-period shift) is often too conservative for a high signal-to-noise lightcurve, it is appropriate here given the low amplitude of the variations in J0722. To illustrate this, consider how different the phased lightcurve in Figure 3, bottom right would appear if some points were moved from

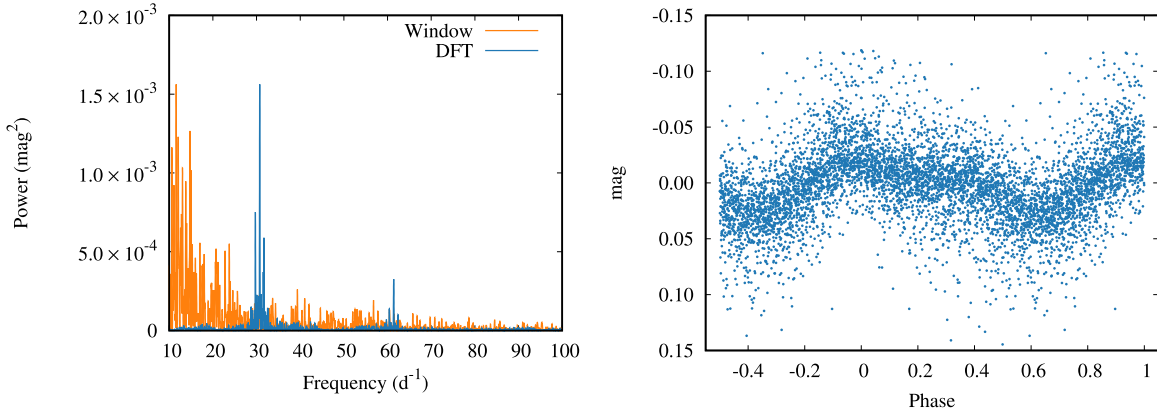


Figure 4. Power spectrum with its corresponding spectral window (left panel) and phased lightcurve of J0722 (right panel) during the rebrightening constructed by combining INASAN-Kislovodsk *BVR* and VSNET Clear band data. This data set combines the data presented in the middle and lower panels of Figure 3 with additional Clear band photometry. The lightcurve (right panel) is phased with the light elements $HJD(TT) = 2460721.0757 + 0.032546 \times E$ corresponding to the highest peak in the rebrightening power spectrum (left panel).

phase 0.0 to phase 0.5. We also note that P_{err} determined from Equation (4) characterizes the width of an individual periodogram peak while aliasing might inhibit one’s ability to choose the correct peak in a periodogram, further limiting the period determination accuracy.

We interpret the observed periodic modulation as positive superhumps—a type of photometric variation observed in some dwarf novae and related systems (e.g., Patterson et al. 2003; Kato et al. 2009, 2010, 2012, 2013; Bruch 2023; Sun et al. 2025). Positive superhumps are believed to arise from a tidal resonance in the accretion disk of the binary. As the accretion disk grows during a dwarf nova outburst, it may extend to the radius where the Keplerian motion in the disk is in a 3:1 resonance with the binary orbital motion. The disk becomes eccentric due to its tidal interaction with the donor star (Whitehurst 1988; Hirose & Osaki 1990; Whitehurst & King 1991). The superhump period is the beat (synodic) period between the short orbital period of the binary and the long period of disk apsidal precession—the orientation of the eccentric disk relative to the donor star repeats with this period (Foulkes et al. 2004). The tidal influence of the secondary on the distorted outer regions of the disk modulates energy dissipation in the disk with that period (Whitehurst 1988; O’Donoghue 1990). As the donor star passes the apocenter of the disk, two spiral arms are launched that travel inward into the disk and dissipate energy (Smith et al. 2007; Jordan et al. 2024). Alternatively, Simpson & Wood (1998) suggest that the modulated energy production is linked to the accretion disk oscillating between nearly circular and highly distorted shapes over the superhump period. Dwarf nova outbursts that display positive superhumps are referred to as “superoutbursts” (Warner 1995b).

As the accretion disk changes its radius over the course of a superoutburst, the positive superhump period changes (Lubow 1992). The superhumps pass through a number of

stages in their development over the course of an outburst (Kato et al. 2009; Kato & Osaki 2013). “Stage A” corresponds to the initial growth of the disk’s eccentricity—superhumps are just starting to appear (often after a short delay following the outburst onset) and have a relatively longer period (since the disk’s outer radius is maximal at this time). “Stage B” is the long, middle portion of the superoutburst where superhumps are fully developed; during this stage the superhump period often evolves slightly. “Stage C” refers to the tail end of the superoutburst and post-outburst phase, where the disk is contracting and the superhump signal weakens (Kato et al. 2012). An additional phenomenon called “early superhumps” is observed at the very beginning of a superoutburst. These are low-amplitude, double-peaked modulations at (or very near) the orbital period, appearing before the ordinary (positive) superhumps develop. Early superhumps are believed to result from a 2:1 resonance in the disk—an even more extreme tidal effect that can occur when the disk grows all the way out to where its orbital period is half the binary’s period (Kato et al. 2009; Tampo et al. 2023).

Isogai et al. (2019) reported the first detection of early superhumps in the AM CVn system NSV 1440 (36.33 minute orbital period). The outburst of NSV 1440 is similar to that of J0722: the first superoutburst with low-amplitude early superhumps (analogous to what we call “main outburst” in J0722) and the second superoutburst (our J0722 “rebrightening”) with ordinary superhumps that was followed by a series of short-lived rebrightenings. Superhumps during rebrightenings were also observed in a hydrogen-rich WZ Sge dwarf nova by Tampo et al. (2020). Comparison between J0722 and NSV 1440 suggests that what we observed during the main outburst might have been the early superhumps while the modulation during the rebrightening might be the fully-developed “Stage B” superhumps that in NSV 1440 had a period very close to that of the early superhumps. The lower

amplitude and difference in shape between the superhumps observed in the main outburst of J0722 and its rebrightening are consistent with this interpretation. The dominating half-period peak in the periodogram (Figure 3, top left) implies that the early superhumps had a shape of two identical waves per period, markedly different from the shape of superhumps during the rebrightening (Figure 3, bottom panel)—a pattern also found in hydrogen-rich dwarf novae (e.g., Figures 5 and 6 of Krushevska et al. 2024). The “Stage A” superhumps might have been missed due to insufficient coverage or somehow suppressed during the dip separating the main outburst from the rebrightening.

Kimura et al. (2016) discuss a superoutburst of a hydrogen-rich WZ Sge type dwarf nova being interrupted by a dip. They point out that the growth time of the 3:1 resonance tidal instability (responsible for the ordinary superhumps) is inversely proportional to the square of the binary’s mass ratio (Lubow 1991). For a sufficiently small mass ratio, the outburst might end by the cooling wave propagating in the accretion disk before the 3:1 resonance fully develops. Similarly to AM CVn systems NSV 1440 (Isogai et al. 2019) and likely J0722, the WZ Sge type dwarf nova ASASSN-15jd described by Kimura et al. (2016) showed the early superhumps before the dip interrupting the superoutburst and ordinary superhumps after recovering from the dip.

The prototype of the class, the AM CVn itself, is a non-outbursting system (its disk is in a permanently hot state) with an orbital period of 17 minutes that shows three types of photometric modulation simultaneously: the positive and negative superhumps, as well as the orbital modulation (Harvey et al. 1998; Skillman et al. 1999; Nelemans et al. 2001). Why is the periodic signal in J0722 a positive superhump rather than the orbital period or a negative superhump? The phased lightcurve shape featuring two asymmetric humps per cycle (Figure 4) is very typical for superhumps. The temporal evolution of the signal (Figure 3) aligns with superhump behavior: the modulation emerged weakly during the main outburst and increased in amplitude during the rebrightening. An orbital signal, by contrast, should persist independently of outburst state. The same is true for negative superhumps—another kind of variation attributed to a tilted accretion disk experiencing a nodal precession in a retrograde direction (Montgomery 2009; Thomas et al. 2010). The tilted geometry changes the way in which the accretion stream from the secondary star interacts with the disk. Instead of always striking the outer edge in a nearly constant geometry, the stream may alternatively pass over or under the disk, depositing kinetic energy at different annuli in a time-variable fashion. As a consequence, the observer sees brightness modulations with a period that is modestly shorter than the orbital period. Negative superhumps are typically present in quiescence and persist over a dwarf nova outburst cycle (e.g., Samsonov et al. 2010; Osaki & Kato 2013). In summary,

the periodic signal observed in J0722 is interpreted as positive superhumps rather than an orbital modulation or negative superhumps based on analogy with other well-studied AM CVn systems (O’Donoghue & Kilkenny 1989; Harrop-Allin 1996) where the orbital period is known from spectroscopy (Green et al. 2018) and eclipses (Breedt 2015).

3.3. Recognizing J0722 as an AM CVn

After the discovery of the outburst (Section 2.1) we initially assumed that J0722 is an ordinary (hydrogen-rich) dwarf nova of WZ Sge subtype. WZ Sge stars are characterized by rare (once in a decade or more) outbursts with a median amplitude of 7.7 mag (see Kato 2015, for a review). Such systems are often found in optical transient surveys, especially the ones aimed at finding classical novae (e.g., Pavlenko et al. 2019; Tampo et al. 2020; Soraisam et al. 2021; Kolbin et al. 2024; Krushevska et al. 2024). Before a definitive spectroscopic classification is available, WZ Sge systems can be distinguished from classical novae by their blue color, lower absolute magnitude (if Gaia parallax is available) and the appearance of superhumps in their lightcurves a few days after the eruption.

While the color and absolute magnitude of J0722 appeared consistent with expectations for a WZ Sge-type dwarf nova, the absence of evident superhumps with a typical dwarf nova period and the tentative detection of a shorter 23 minute periodicity (Section 3.2) suggested that J0722 might be something else. The presence of the short-period signal, the outburst amplitude and duration being shorter than those typically found in WZ Sge systems, and the overall similarity of J0722 to the recently studied AM CVn system ASASSN-21br (Painter et al. 2024) motivated us to conduct spectroscopic observations.

3.4. Comparison with Other AM CVn Binaries

Peaking at $V_{\max} = 12.45$ (Table 1), J0722 is among the five brightest AM CVn outbursts ever observed along with ASASSN-14mv, ASASSN-14ei, SDSS J141118.31 +481257.6 and NSV 1440 (Ramsay et al. 2018). The peak absolute magnitude $M_V = 3.4^{+0.7}_{-0.9}$ is about 2 mag brighter than those displayed in Figure 3 of Ramsay et al. (2018). The unusually bright absolute magnitude during the outburst (while the quiescence magnitude is fairly typical) may be an indication that the accretion disk in J0722 is viewed almost face-on which maximizes its apparent brightness (Paczynski & Schwarzenberg-Czerny 1980; Patterson 2011). According to Equation (12) of Osaki & Meyer (2002), the amplitude of early superhumps is determined by the inclination of the system, with lower inclination resulting in smaller amplitude. Thus, the face-on interpretation is also consistent with the small amplitude of early superhumps observed in J0722 (Section 3.2). The intrinsic colors of J0722 at minimum are

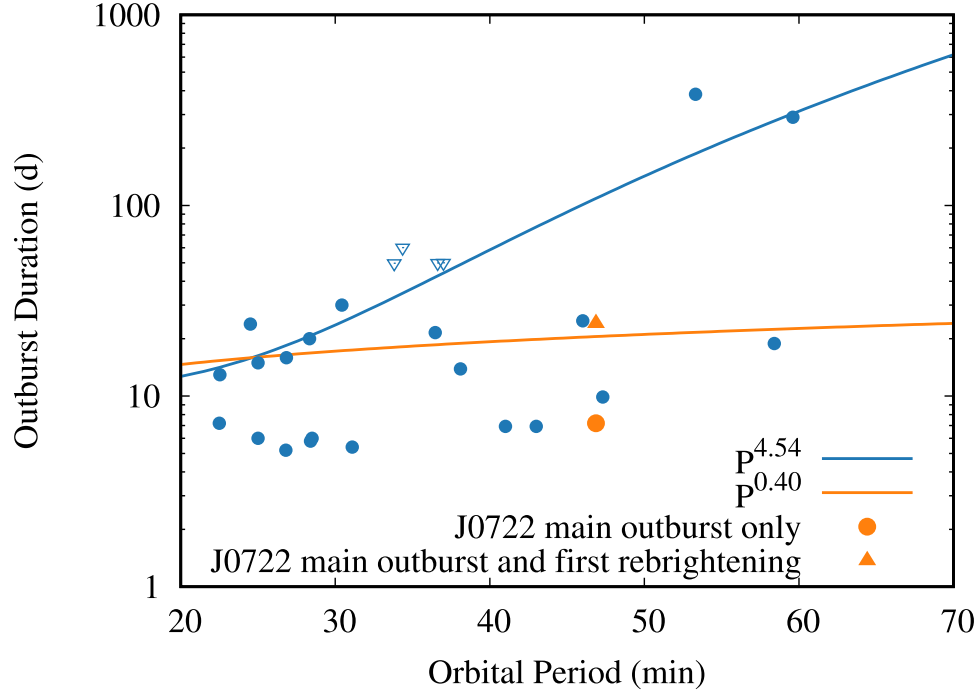


Figure 5. Outburst duration as a function of the orbital period for AM CVn stars from Cannizzo & Ramsay (2019), Pichardo Marciano et al. (2021), Rivera Sandoval et al. (2022), Painter et al. (2024). For systems where Cannizzo & Ramsay (2019) and Pichardo Marciano et al. (2021) give different outburst durations (KL Dra, CP Eri) both estimates are plotted as they are presumably based on different outbursts. Open triangles represent upper limits on the outburst duration. The top blue curve represents the empirical relation of Levitan et al. (2015). The bottom orange curve is the accretion disk limit cycle model of Cannizzo & Nelemans (2015), Cannizzo & Ramsay (2019).

$(g - r)_0 = -0.24$, $(BP - RP)_0 = -0.14$ (Table 1). The quiescent absolute magnitude and colors of J0722 are typical for AM CVn binaries (see Figure 7 of Rivera Sandoval et al. 2021).

The characteristic time over which matter moves radially through the accretion disk, the viscous timescale, may directly correspond to the duration of a superoutburst according to Cannizzo & Ramsay (2019), Hameury & Lasota (2021), while other authors suggested this may be the case for normal outbursts (Kotko et al. 2012; Pichardo Marciano et al. 2021). Following Levitan et al. (2015), Cannizzo & Ramsay (2019) and Pichardo Marciano et al. (2021), we consider the relation between the outburst duration and orbital period, putting J0722 on the plot (Figure 5) using its superhump period as the proxy for the orbital period. We indicate two locations of J0722 on the plot: one if only duration of the main outburst is considered and the other if the time between the start of the main outburst and the decline from the first rebrightening is taken as the outburst duration. A well-sampled long-duration lightcurve is needed to make this distinction (Pichardo Marciano et al. 2021). A confusion between the main outburst and a rebrightening may increase the scatter of outburst duration estimates in Figure 5. At least two other AM CVn systems, NSV 1440 (Isogai et al. 2019) and SDSS J141118.31+481257.6 (Cannizzo & Ramsay 2019; Rivera Sandoval &

Maccarone 2019), show the first rebrightening characterized by a long-lived plateau (resembling a superoutburst of a dwarf nova) followed by a series of short-lived rebrightenings (resembling ordinary dwarf nova outbursts). According to Cannizzo & Ramsay (2019), it is unclear if the first superoutburst-like rebrightening should be included in the outburst duration for the purposes of τ_{visc} estimation (Figure 5). Shorter-period AM CVn systems often show a lightcurve feature described as “dip” in their main outburst lightcurve (Ramsay et al. 2012; Duffy et al. 2021) which may be a less dramatic version of the fading that separates the main outburst from the first rebrightening in J0722, SDSS J141118.31+481257.6 and NSV 1440.

No X-ray source is associated with J0722. The Upper Limit Server²⁸ (Saxton & Gimeno 2011) provides a 2σ 0.2–2 keV ROSAT/PSPC upper limit of 0.026 cts s^{-1} from the survey (Voges et al. 1999, 2000; Boller et al. 2016) observations performed on 1990 September 15. The V band extinction, A_V , listed in Table 1 corresponds to the equivalent hydrogen absorbing column $N_H = 6.63 \times 10^{20} \text{ cm}^{-2}$ according to the Güver & Özel (2009) calibration. For this N_H value and a fiducial powerlaw spectrum with a photon index $\Gamma = 2$, the ROSAT/PSPC count rate upper limit corresponds to a

²⁸ <http://xmmuls.esac.esa.int/hilight/>

0.2–2 keV flux upper limit of $5 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$. The corresponding luminosity upper limit $L_X < 2 \times 10^{31} \text{ erg s}^{-1}$ is one order of magnitude above the average X-ray luminosity of AM CVn systems (Rodríguez et al. 2025), so the X-ray non-detection is not in tension with the AM CVn classification. However, a number of X-ray bright AM CVn systems have X-ray luminosities above the J0722 upper limit (Ramsay et al. 2006; Begari & Maccarone 2023). The X-ray flux of AM CVn systems may vary with time by a factor of a few (Ramsay et al. 2012; Rivera Sandoval & Maccarone 2019).

4. Conclusions

We report the discovery and spectroscopic confirmation of TCP J07222683+6220548, an AM CVn system that displayed a single $\Delta V = 7.6 \text{ mag}$ outburst followed by multiple rebrightenings in 2025 January–March. The overall shape and duration of the outburst are similar to those found in long-period AM CVn stars. A periodic modulation in the lightcurve, Equation (3), that is barely detectable during the main outburst and grows in peak-to-peak amplitude to 0.05 mag during the first rebrightening, is interpreted as positive superhumps (with two waves per period). No change in superhump period is observed over the course of their development. As few dwarf novae benefit from a detailed photometric and spectroscopic follow-up similar to the one performed for J0722, it is possible that some outbursting AM CVn systems remain unrecognized among dwarf novae candidates identified by surveys.

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