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On the orbital period of the dwarf nova CW Mon

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Abstract

CW Mon is a relatively bright and nearby SS Cyg-type dwarf nova frequently used in detailed analysis of cataclysmic variables and statistical studies. Using Transiting Exoplanet Survey Satellite (TESS) observations, we found that the orbital period is different from what has been adopted. Using the combined data (TESS, the Zwicky Transient Facility data and VSNET campaigns), we updated the period to be 0.19346802(4) d. The previously adopted period of 0.1766 d turned out to be its 2-day alias, probably introduced by a confusion between the two maxima/minima of the ellipsoidal variations. We confirmed that the object showed grazing eclipses during the 2016 and 2002 outbursts, and also in quiescence before and after the 2016 outburst. These eclipses were not necessarily always present and were not remarkable during some past outbursts and in the TESS data. The presence/absence of eclipses may be related to the disk radius or the brightness of the outer part of the disk. A 37-min quasi-period oscillation (QPO) signal was reported during the 2002 outburst. Combined with a recent report of the detection of QPOs around the peaks of long outbursts of a dwarf nova, we suspect that such QPOs during long outbursts may have been excited when the accretion disk reaches the maximum radius, the tidal truncation radius as being a possibility.

CW Mon is a relatively bright and nearby (∼330 pc, Gaia Collaboration et al. 2021) SS Cyg-type dwarf nova. The orbital period of this object was assumed to be 0.1766 d in Kato et al. (2003) based on a preliminary period of 0.176 d and the possible detection of grazing eclipses by Szkody and Mateo (1986). This period was listed in Ritter and Kolb (2003) and in AAVSO VSX (Watson et al. 2006),[1] and has widely been referenced (e.g., Warner 2004; Pretorius and Knigge 2008; Harrison 2016; Hause et al. 2017; Dubus et al. 2018).

One of the authors (TK) found a period different from this using Transiting Exoplanet Survey Satellite (TESS) observations (Ricker et al. 2015)[2] in quiescence between 2020 December 18 and 2021 January 13. These observations started ∼10 d after fading of the 2020 November–December outburst. No further outburst was recorded by 2021 May 4 [The data sources of the long-term behavior were the All-Sky Automated Survey for Supernovae (ASAS-SN: Shappee et al. 2014), the Asteroid Terrestrial-impact Last Alert System (ATLAS: Tonry et al. 2018) forced photometry (Shingles et al. 2021), the Zwicky Transient Facility (ZTF: Masci et al. 2019)[3] and observations reported to VSOLJ and VSNET (Kato et al. 2004)]. The presence of the orbital variation was already visible to the eyes in the TESS light curve. After removing the global trend by locally-weighted

[1]<https://www.aavso.org/vsx/index.php?view=detail.top&oid=18951>.

[2]<https://tess.mit.edu/observations/>. The full light-curve is available at the Mikulski Archive for Space Telescope (MAST, <http://archive.stsci.edu/>).

[3]The ZTF data can be obtained from IRSA <https://irsa.ipac.caltech.edu/Missions/ztf.html> using the interface <https://irsa.ipac.caltech.edu/docs/program_interface/ztf_api.html> or using a wrapper of the above IRSA API <https://github.com/MickaelRigault/ztfquery>.

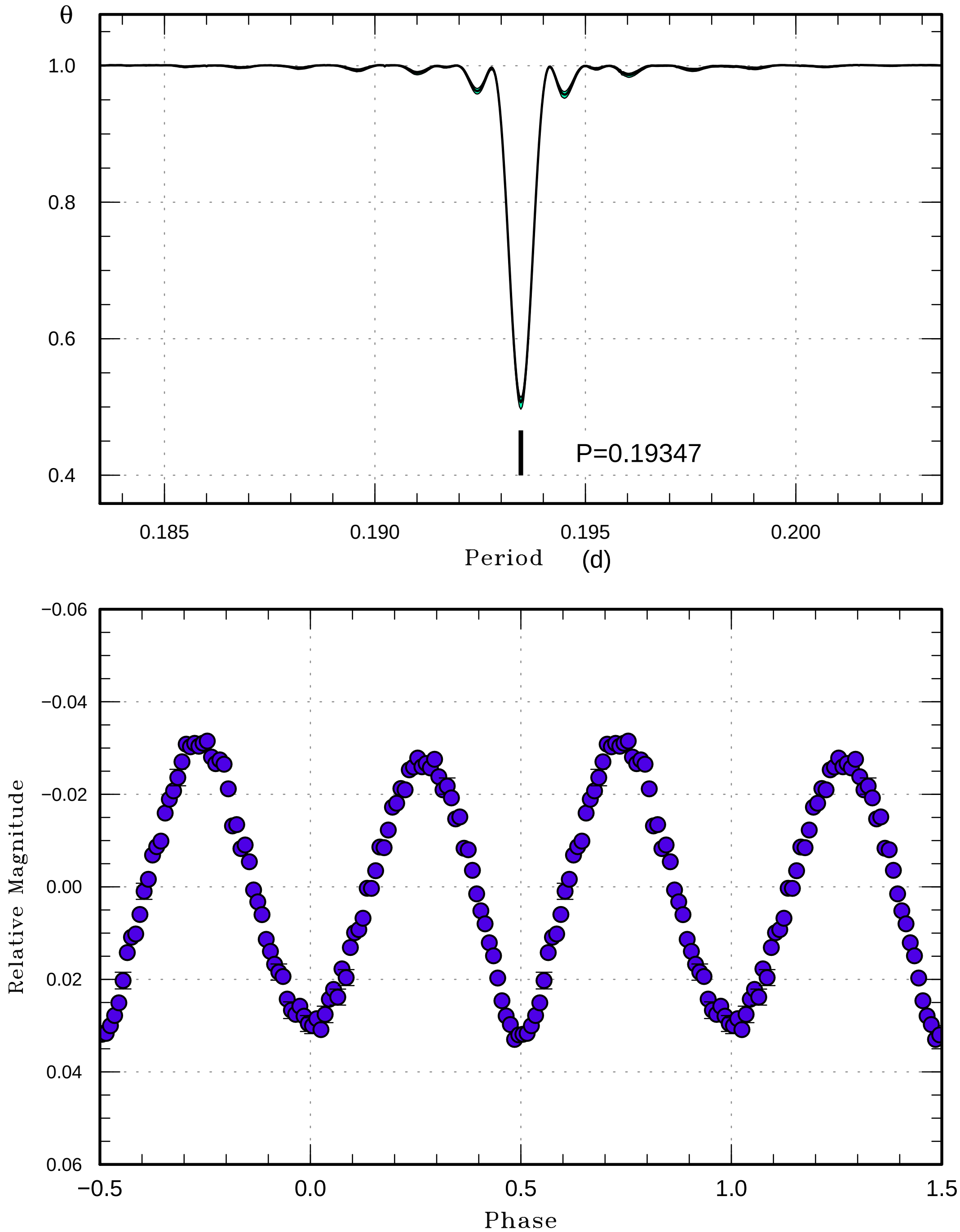

Figure 1: Period analysis of the TESS data in quiescence. (Upper): PDM analysis. The bootstrap result using randomly contain 50% of observations is shown as a form of 90% confidence intervals in the resultant θ statistics. (Lower): Phase plot. The zero phase (likely inferior conjunction of the secondary) is BJD 2459214.651.

polynomial regression (LOWESS: Cleveland 1979), a phase dispersion minimization (PDM, Stellingwerf 1978) analysis yielded an orbital period (figure 1) having a period of 0.193467(4) d with its error determined by the methods of Fernie (1989) and Kato et al. (2010). The zero orbital phase (BJD 2459214.651) was chosen as the shallower minimum of the ellipsoidal variations, which likely corresponds to the inferior conjunction of the secondary reflecting the effect of gravitational darkening. The amplitudes of the ellipsoidal variations were small in the TESS data due to contamination of nearby stars. This period could not be detected in the ATLAS forced photometry data (2145 measurements). A PDM analysis of the ZTF data (quiescent parts only, after removing the trends by LOWESS) detected a period of 0.193468(1) d (figure 2) (due to the large scatter in the individual data, we only show a phase-averaged light curve of the combined g+r data). This light curve appears to show an orbital hump.

The same period was detected from the data obtained during and around the 2016 October outburst (observer: FJH). The phase-averaged light curve (figure 3) in quiescence before and after the outburst indicates the presence of an eclipse and an orbital hump. This finding apparently reinforces the presence of grazing eclipses reported during the 2002 outburst (Kato et al. 2003). Using all the data (TESS, ZTF and the 2016 VSNET campaign) between 2002 and 2022, we obtained a refined ephemeris of:

$$\mathrm{Min(BJD)} = 2459214.651 + 0.19346802(4)E. \quad (1)$$

Using this ephemeris, the corrected figure corresponding to figure 4 in Kato et al. (2003) is shown in figure 4. Although the disappearance of an eclipse on the second night during the 2002 outburst was likely due to the usage of an incorrect orbital period, not the change in the disk radius suggested in Kato et al. (2003), this could not be directly confirmed due to the absence of the data on the second night around the expected eclipse. The two periods of 0.1766 d and 0.19346802 d are in the relation of 2-day alias, which was probably introduced by a confusion between the two maxima/minima of the ellipsoidal variations by Szkody and Mateo (1986). The same figure for the 2016 outburst is shown in figure 5. Eclipses were also present. The available data seem to confirm that CW Mon is a grazing eclipser both in outburst and in quiescence, at least in quiescence before and after the 2016 outburst. The eclipse signature in the TESS data was less apparent than in 2016. Although there were some observations during other outbursts in 2005 (Hiroyuki Maehara), 2008 (Seiichiro Kiyota) and 2010 (S. Kiyota), the results were not as clear as in 2016. An eclipse-like signal was possibly present at the expected phase on two nights, but absent in one night in 2005. The data were insufficient in 2008 and the eclipse signature was apparently absent in 2010 in one night covering this phase. These observations were relatively short and did not cover much of outbursts (and they did not record quiescence before and after the outburst) as in 2016, and we feel it difficult to draw a firm conclusion. It is possible that the eclipse signature is missing during some outbursts. The 2002 and 2016 outbursts had a "shoulder", or an embedded precursor (Cannizzo 2012), sometimes seen in long outbursts of dwarf novae above the period gap and the disk was probably large during such outbursts. In other outbursts, either the size of the disk may have not been sufficient or the outer part of the disk may have not been bright enough to show detectable eclipses. This interpretation may be tested by observations of future observations of different types of outbursts.

Regarding the possible signal of an intermediate polar (Kato et al. 2003), Pretorius and Knigge (2008) did not detect a coherent pulsation nor a spectroscopic signature of a magnetized white dwarf. Warner (2004) classified the reported 37-min signal as quasi-periodic oscillations (QPOs). There has been increasing evidence that short-term variations are excited around a shoulder (or an embedded precursor). For example, quite recently, Sun et al. (2023) reported enhancement of QPO signals near the long outburst top light curves in HS 2325+8205 = NSV 14581 using the TESS data. These outbursts had a shoulder. Similar enhancement of short-term variations (an orbital or a superhump signal) during a shoulder of a long outburst was also reported in V363 Lyr (Kato 2021) using the Kepler data. The QPOs observed in CW Mon might have been related to these phenomena, and may be related to excitation of short-term variations when the accretion disk reaches the maximum radius, the tidal truncation radius as being a possibility.

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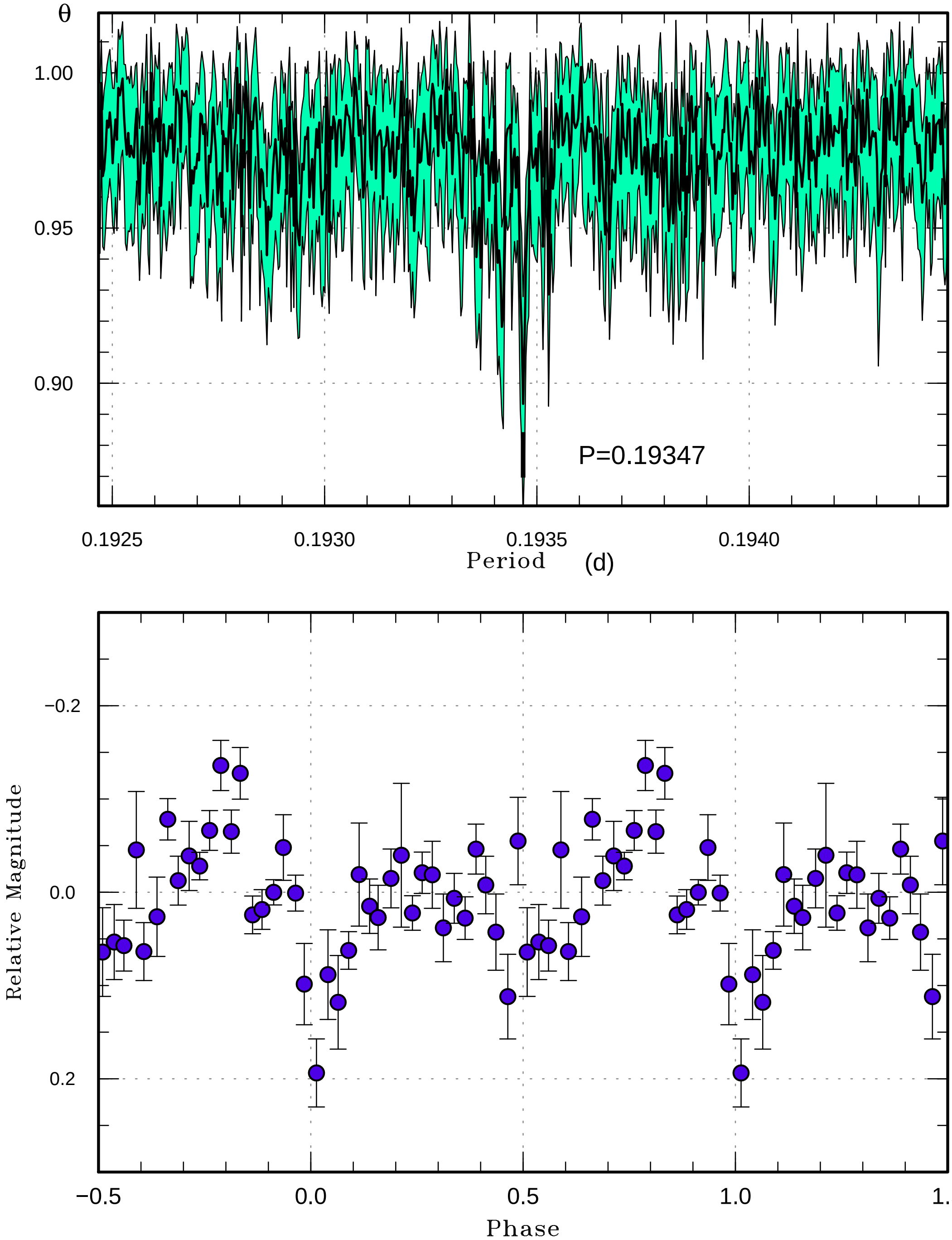

Figure 2: Period analysis of the ZTF data in quiescence. (Upper): PDM analysis. (Lower): Phase plot. The zero phase is the same as in figure 1.

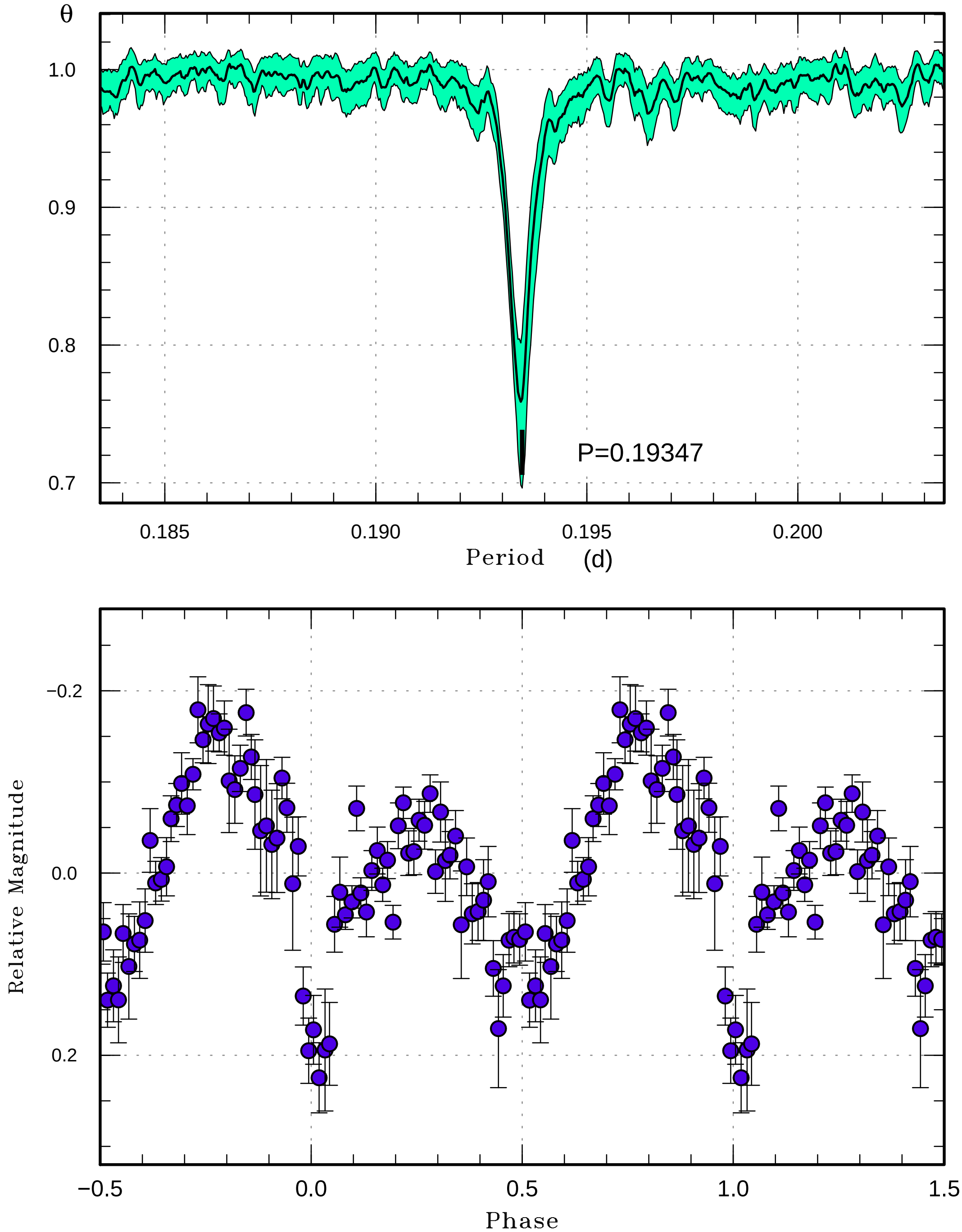

Figure 3: Period analysis of the data before and after the 2016 October outburst (BJD 2457669–2457671 and BJD 2457683–2457711). (Upper): PDM analysis. The vertical tick is given at the orbital period derived from the entire data discussed in this paper. (Lower): Phase plot. The zero phase is the same as in figure 1. An eclipse and an orbital hump are apparently seen.

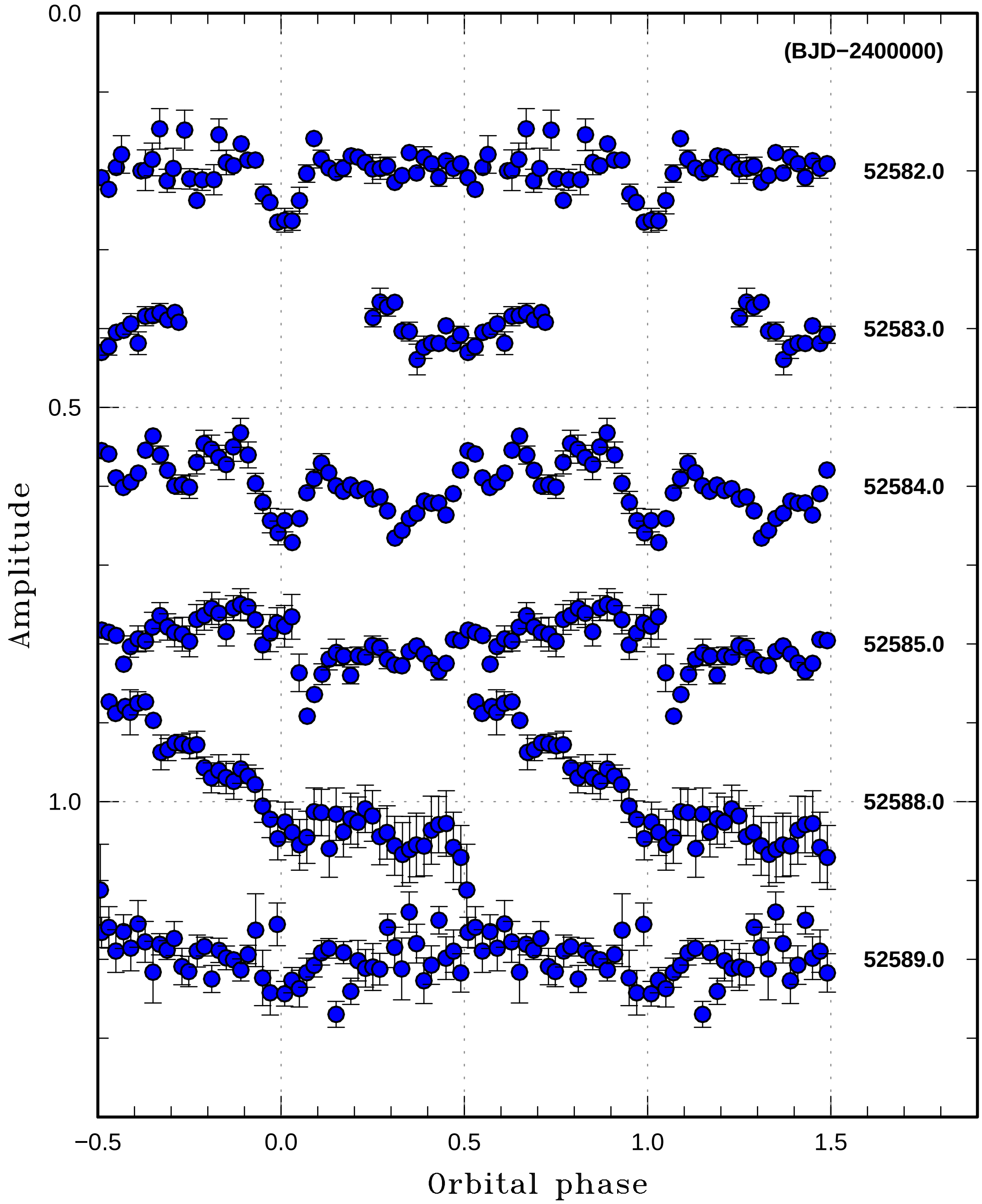

Figure 4: Nightly orbital profiles during the 2002 outburst using the correct orbital period. A discontinuity in the light curve of BJD 2452588.0 was an artificial one caused by two different observers giving different trends.

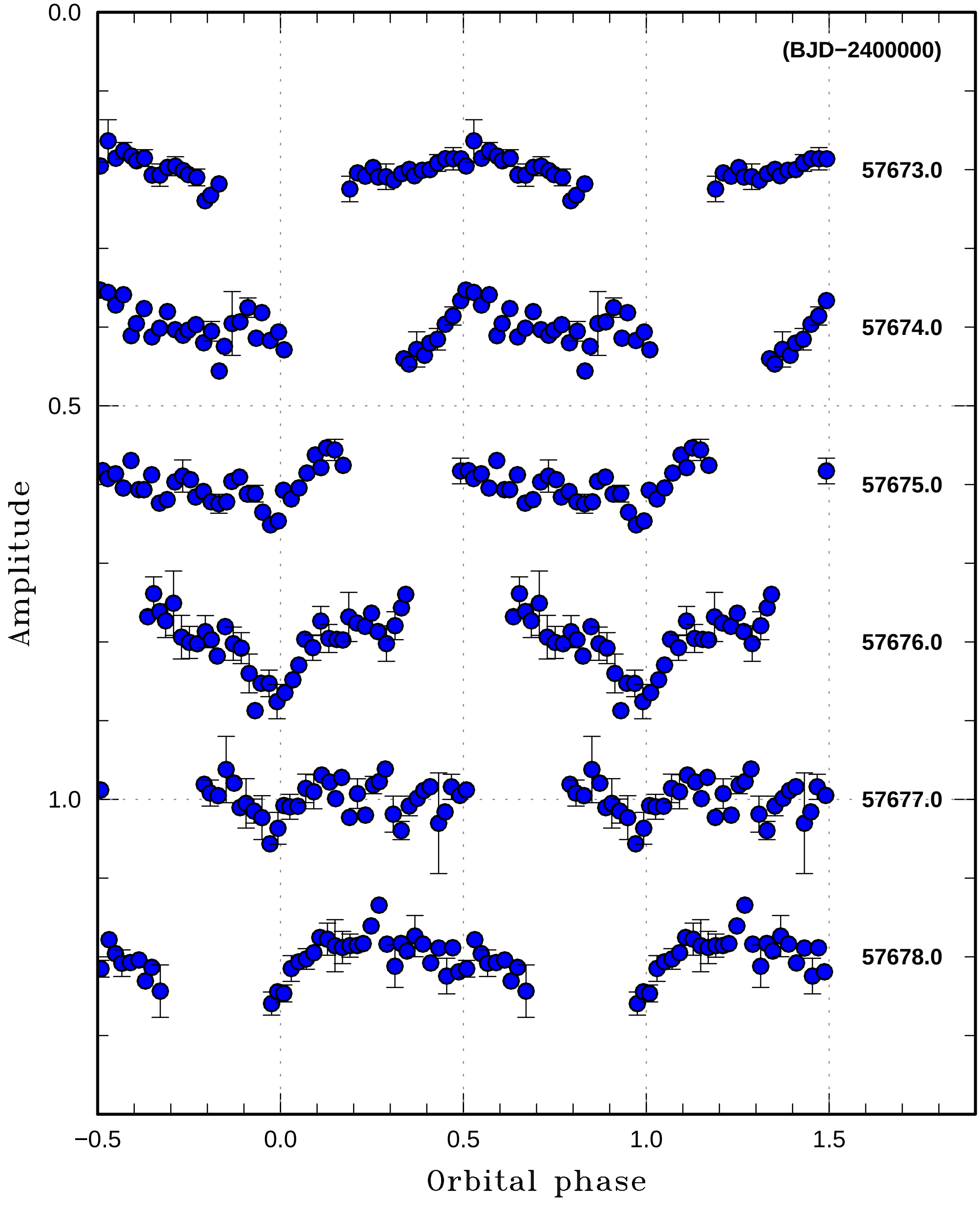

Figure 5: Nightly orbital profiles during the 2016 outburst. Eclipses were visible at least on the third to fifth nights.

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SS Cyg, V363 Lyr, CW Mon, NSV 14581, HS 2325+8205

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