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Orbital period of the IW And-type star ST Cha

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Abstract

We analyzed TESS data of the IW And-type dwarf nova ST Cha during ordinary dwarf nova states. We have identified an orbital period of 0.285360(1) d. The object was reported to be eclipsing in the past using the data obtained in the 1970s, which is not in agreement with the present data. Despite the constant mean brightness, the strength of the orbital signal varied significantly, suggesting that the strength of the orbital signal does not always reflect the mass-transfer rate. During an outburst with a shoulder, we did not find evidence of humps recurring with a period longer than the orbital period which were recorded in V363 Lyr. This finding strengthens the idea that V363 Lyr is an unusual object. We found that the strength of the orbital signal increased after an outburst with a shoulder. This outburst may have changed the state of the disk and the hot spot became more apparent. Such a change in the disk may have triggered a transition from an ordinary dwarf nova-type state to an IW And-type state and this possibility would require further examination.

1 Introduction

IW And stars are a subgroup of Z Cam type dwarf novae [or general information of dwarf novae, see e.g. Warner (1995)]. Z Cam stars are characterized by the presence of standstills in addition to ordinary dwarf nova-type outbursts. Standstills in Z Cam stars usually occur after outbursts and end with fading (see e.g. Szkody and Mattei 1984). In IW And stars, outbursts and standstills sometimes occur regularly (IW And-type state) and the light curves are characterized by brightening from a standstill (or standstill-like phase) sometimes followed by a deep dip (Simonsen 2011; Kato 2019). Accretion disks of the dwarf novae of this type are considered to be near the thermal stability (see e.g. Kimura et al. 2020).

After recognition of the initial two prototypical objects, IW And and V513 Cas (Simonsen 2011), ST Cha was the third object of this group (Simonsen et al. 2014; Kato 2019). Kato and Hambsch (2021) studied ground-based time-resolved photometry to characterize the outburst pattern of this object and found that the brightness level of the shoulders (or embedded precursors) during long outbursts is the same as the ones when the object started brightening at the end of standstills.

In this paper, we identified the orbital period of this object using the Transiting Exoplanet Survey Satellite (TESS) observations[1]. The full light-curve is available at the Mikulski Archive for Space Telescope (MAST[2]).

2 Observations

The TESS spacecraft observed ST Cha at a two-minutes cadence during two segments: between 2019 April 24 and 2019 June 18 (segment 1) and between 2021 April 29 and 2021 June 24 (segment 2). We used simple-aperture-

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photometry (SAP) data. The zero point of the TESS data is rather arbitrary and these magnitudes should be regarded as relative ones rather than zero-point calibrated ones. These segments contained ordinary dwarf nova states and not IW And-type states [see Kato and Hambsch (2021) for a light curve containing both states].

Examples of TESS light curves are shown in figure 1. The upper panel shows a long outburst with a shoulder in the segment 1. The lower panel shows a short segment (from the segment 2) in which orbital variations were directly visible. See also upper panels of figures 2 and 3 for the entire TESS observations.

3 Results and Analysis

3.1 Orbital period

We made period analysis using Phase Dispersion Minimization (PDM, Stellingwerf 1978) after removing the trends of outbursts by locally-weighted polynomial regression (LOWESS: Cleveland 1979). The errors of periods by the PDM method were estimated by the methods of Fernie (1989) and Kato et al. (2010). Both segments 1 and 2 yielded almost the same periods [0.28533(3) d for the segment 1 and 0.28533(1) d for the segment 2]. The signals were very stable and we identified this period as the orbital one.

The result of PDM analysis after combination of the two segments is shown in figure 4. A period of 0.285360(1) d, 1σ and 3σ different from the periods obtained from the segments 1 and 2, respectively, has been identified as the most likely orbital period by this study.

3.2 Eclipses in the past?

The orbital period of ST Cha was suggested to be 0.285 d by Steiner et al. (1988), who analyzed photometric data by Mauder and Sosna (1975) and concluded that ST Cha is an eclipsing binary with a period of 6.85 hours (=0.285 d) allowing possibilities of aliases of $P = 1.9975/(2n + 1)$ hours, where $n = 0, 1, 2, \ldots$. Combined with a low-resolution spectrum, Steiner et al. (1988) concluded that ST Cha is either an optically selected low-mass X-ray binary (LMXB) or a novalike cataclysmic variable. The TESS observations, however, did not show any sign of eclipses and the orbital variations were in low amplitudes ($\sim$0.02 mag). Such low-amplitude variations would have been difficult to detect by photographic observations by Mauder and Sosna (1975) and the identity of the periods obtained by this and our studies is likely a chance coincidence, unless ST Cha was an eclipsing binary in the past which stopped to be eclipsing (such a case may not be unthinkable; there are 10 systems among classical eclipsing binaries, see e.g. Zasche and Paschke 2012).

3.3 Strength of orbital signal and mass-transfer rate

We performed two-dimensional PDM analysis of the two segments (figures 5, 6) (see Kato 2021a). The orbital signal was persistently recorded during the segment 1, but was weak during the initial half of the segment 2. Although the strength of orbital humps is often considered to be an indicator the mass-transfer rate, this result suggests that it is not always the case since the mean brightness did not significantly varied during the segment 2. It may have been that the hot spot was sometimes not formed such as by stream overflow as suggested for SW Sex stars (Hellier 2000). There was no evidence of positive or negative superhumps.

3.4 Enhanced orbital signal after outburst with shoulder?

Kato (2021a) reported that humps recurring with a period slightly longer than the orbital one were recording by Kepler observations of the dwarf nova V363 Lyr during a long, bright outburst associated with a shoulder. The nature of these humps in V363 Lyr was inconclusive: (1) V363 Lyr may have an anomalously undermassive secondary and this object is an SU UMa star above the period gap or (2) The humps were a result of deformation of the disk at the tidal truncation radius. In the case of ST Cha, an outburst associated with a shoulder in the segment 1 did not show any sign of the humps similar to V363 Lyr. The case of V363 Lyr looks like to be special in that it showed brightness increase by 0.5 mag after the shoulder in contrast to ST Cha. After an outburst associated with a shoulder in the segment 2 (figure 6), however, the orbital signal became stronger. It may be that the outburst with a shoulder changed the state of the disk and the hot spot may have become more apparent. Such a change in the disk may have triggered a transition from an ordinary dwarf nova-type state to an IW And-type state and this possibility would require further examination.
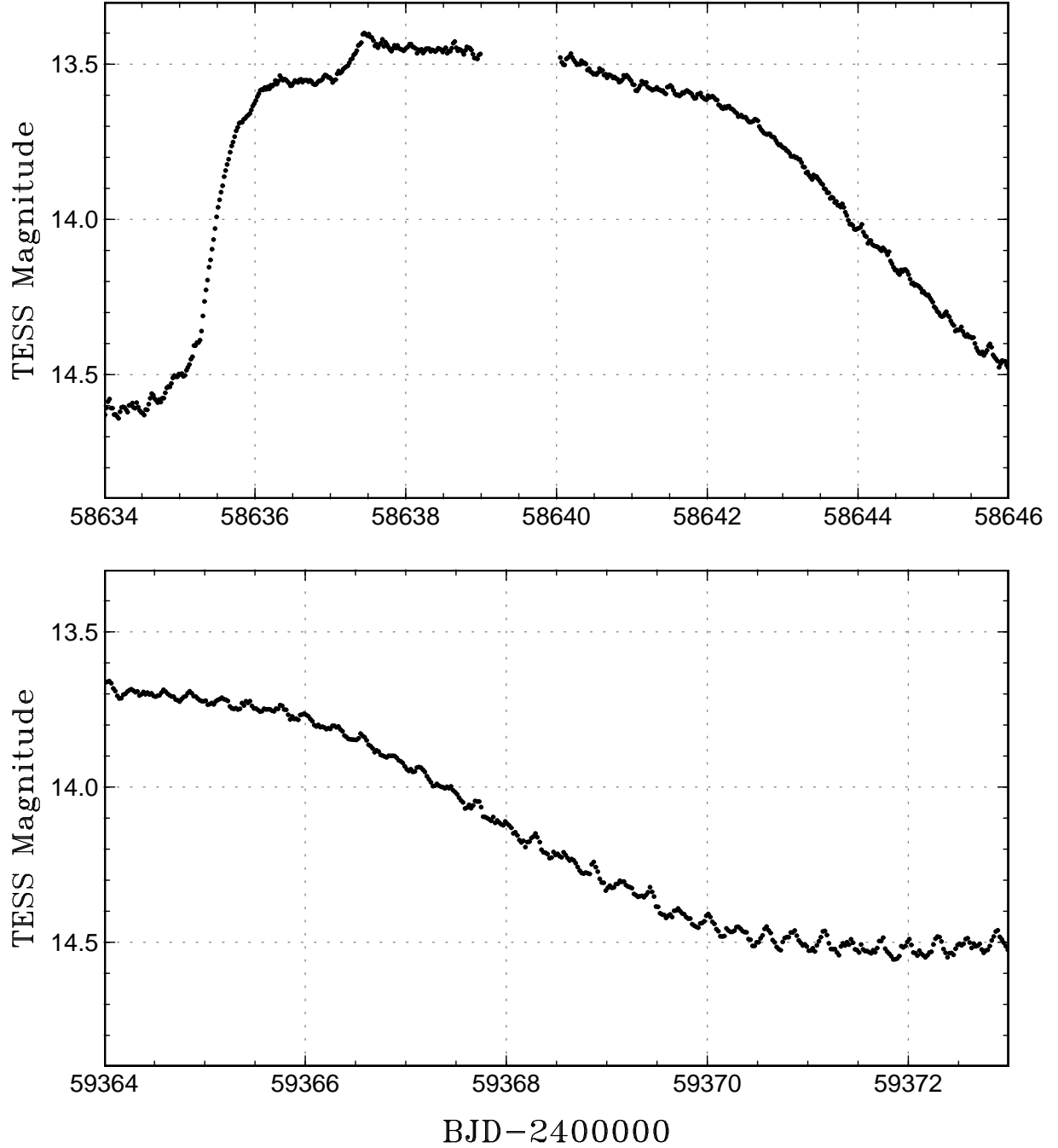
Figure 1: Examples of TESS light curves of ST Cha. The data were binned to 0.02 d for better visibility of variations. (Upper): Long outburst with a shoulder (or embedded precursor). (Lower): A short segment in which orbital variations were directly visible.
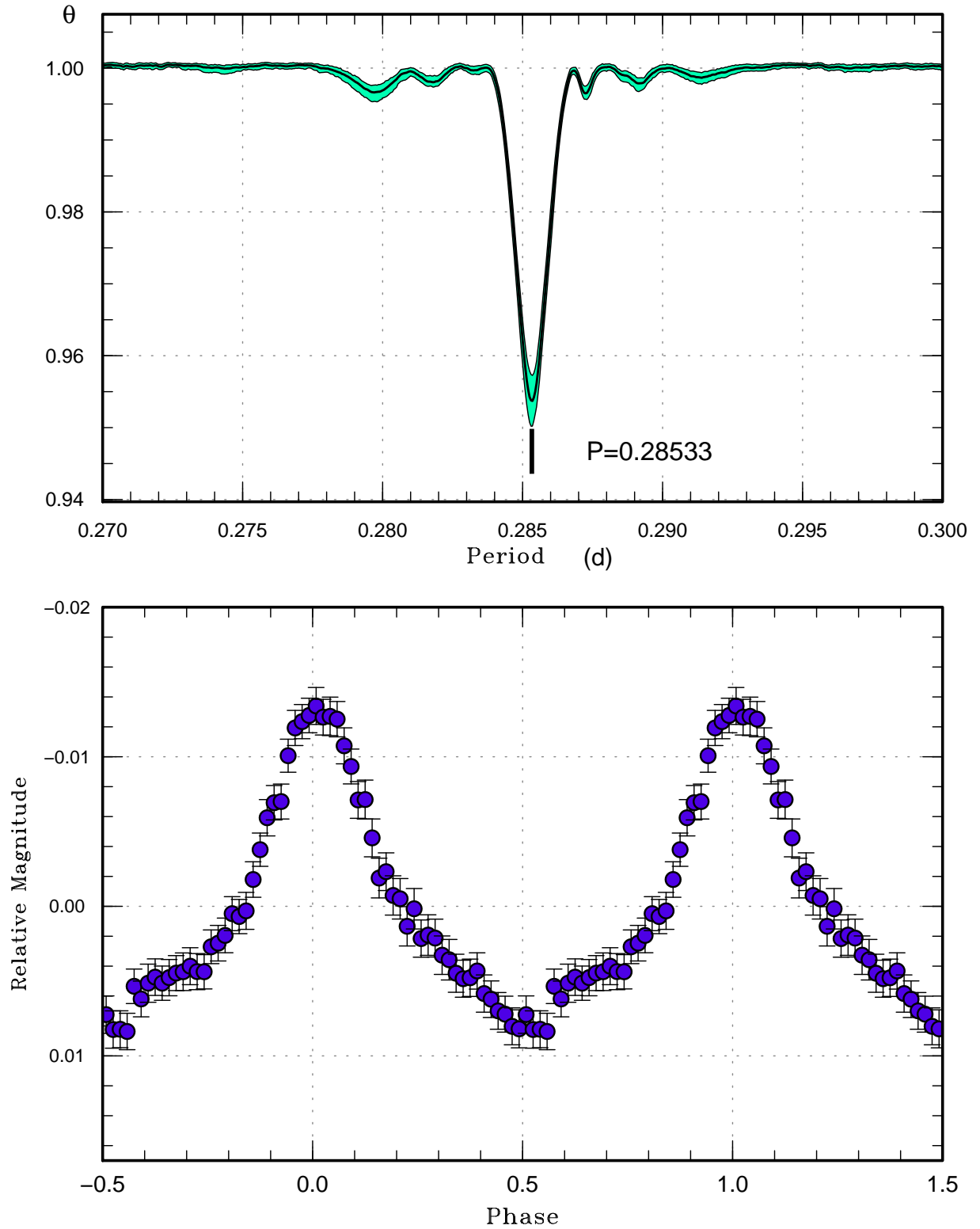
Figure 2: Period analysis of the segment 1. (Upper): We analyzed 100 samples which randomly contain 50% of observations, and performed the PDM analysis for these samples. The bootstrap result is shown as a form of 90% confidence intervals in the resultant PDM θ statistics. (Lower): Orbital variation.
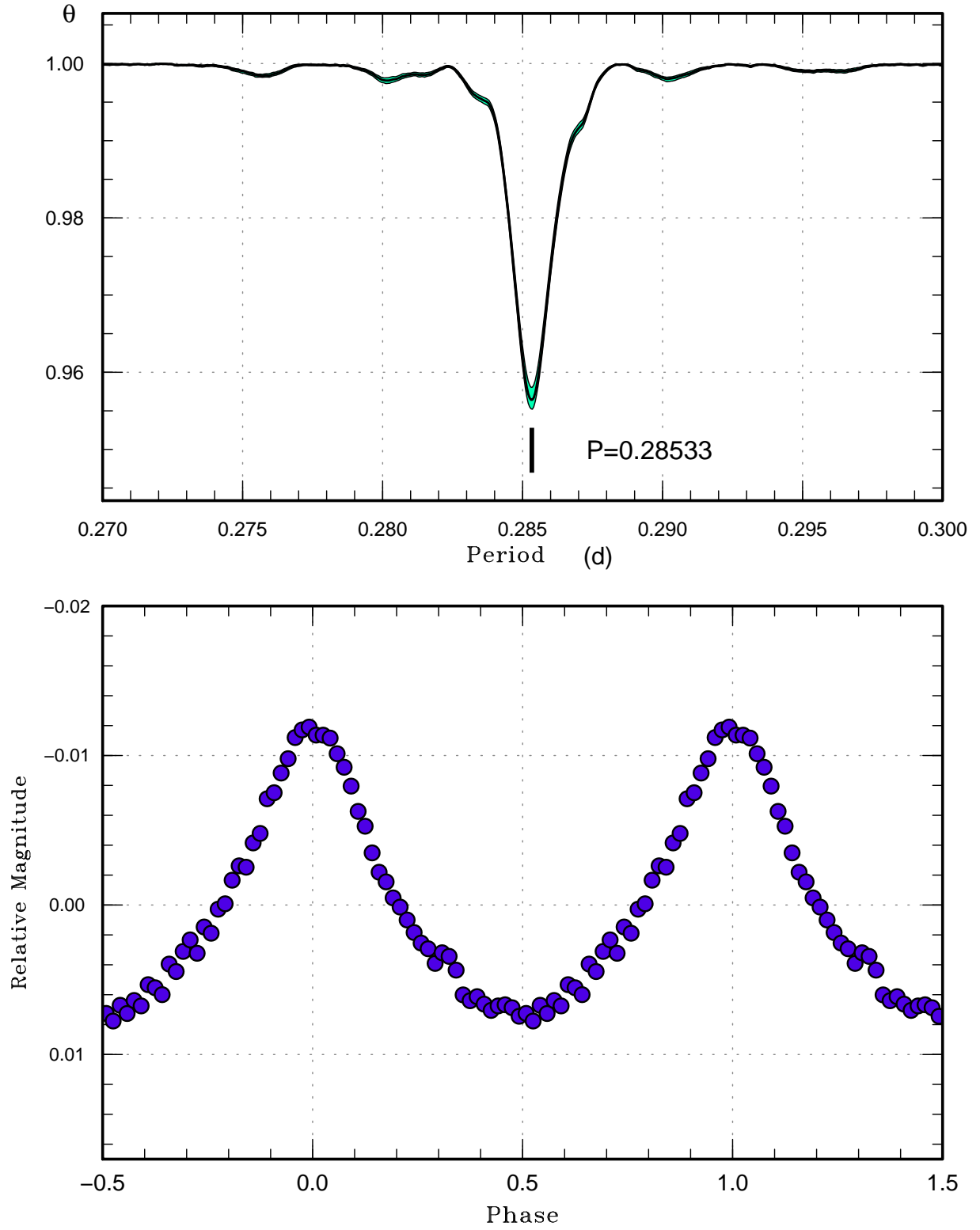
Figure 3: Period analysis of the segment 2. (Upper): PDM analysis. (Lower): Orbital variation.
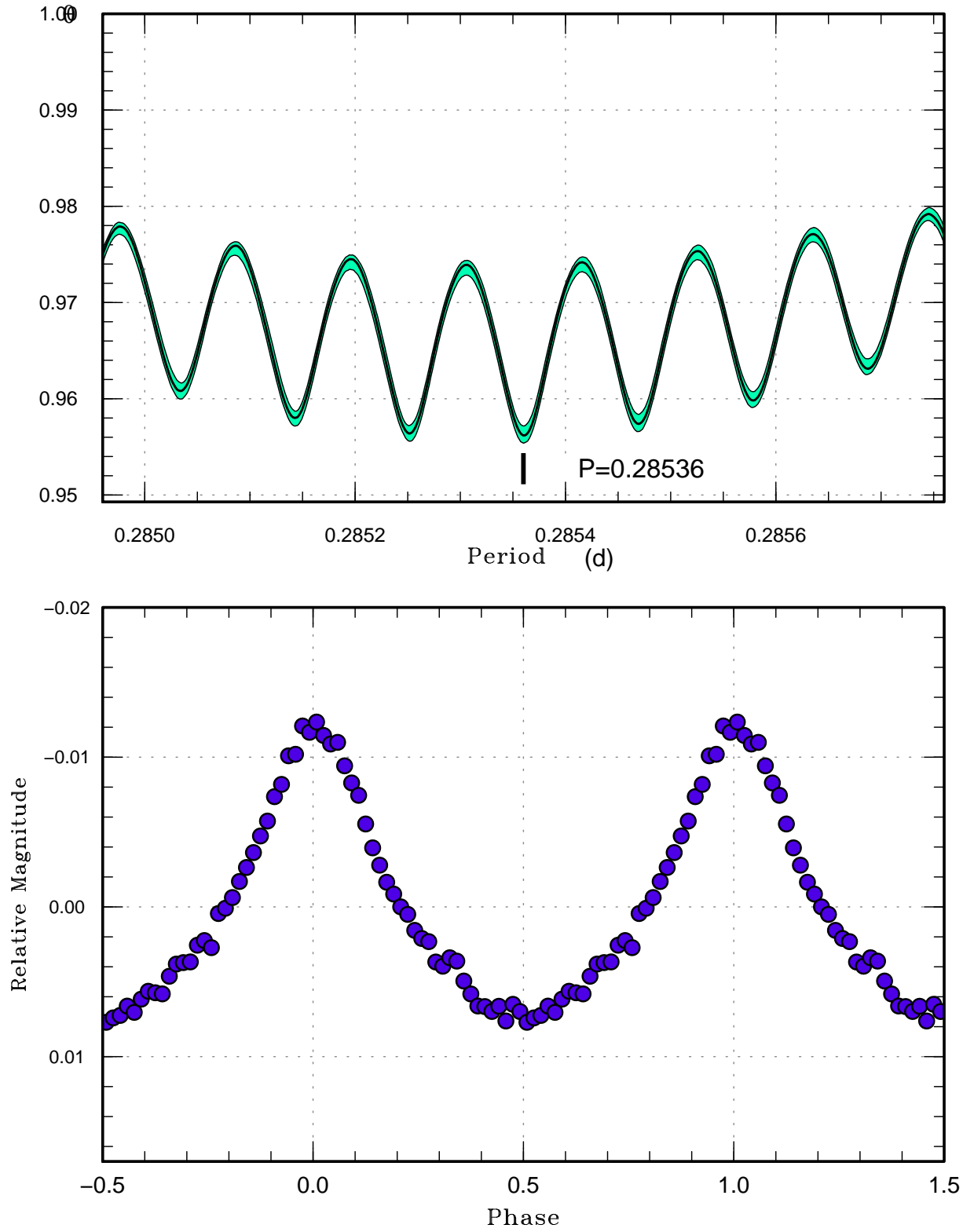
Figure 4: Period analysis of all the data. (Upper): PDM analysis. (Lower): Orbital variation.
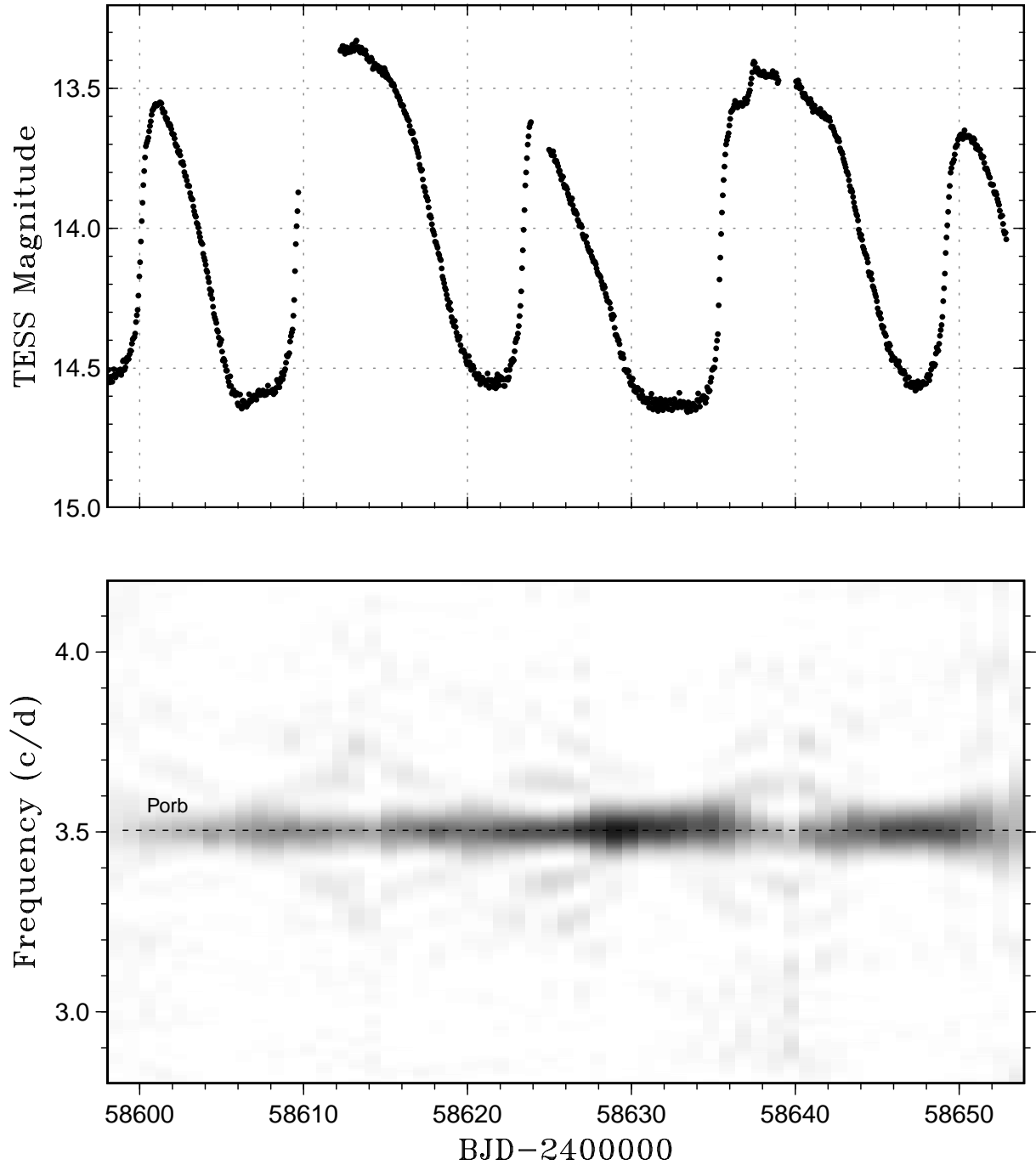
Figure 5: (Upper): TESS light curve of the segment 1. The data were binned to 0.05 d. (Lower): Two-dimensional PDM analysis. The width of the sliding window and the time step used are 10 d and 1 d, respectively. Dark colors represent signals (lower θ in the PDM statistics). The orbital signal was persistently recorded.
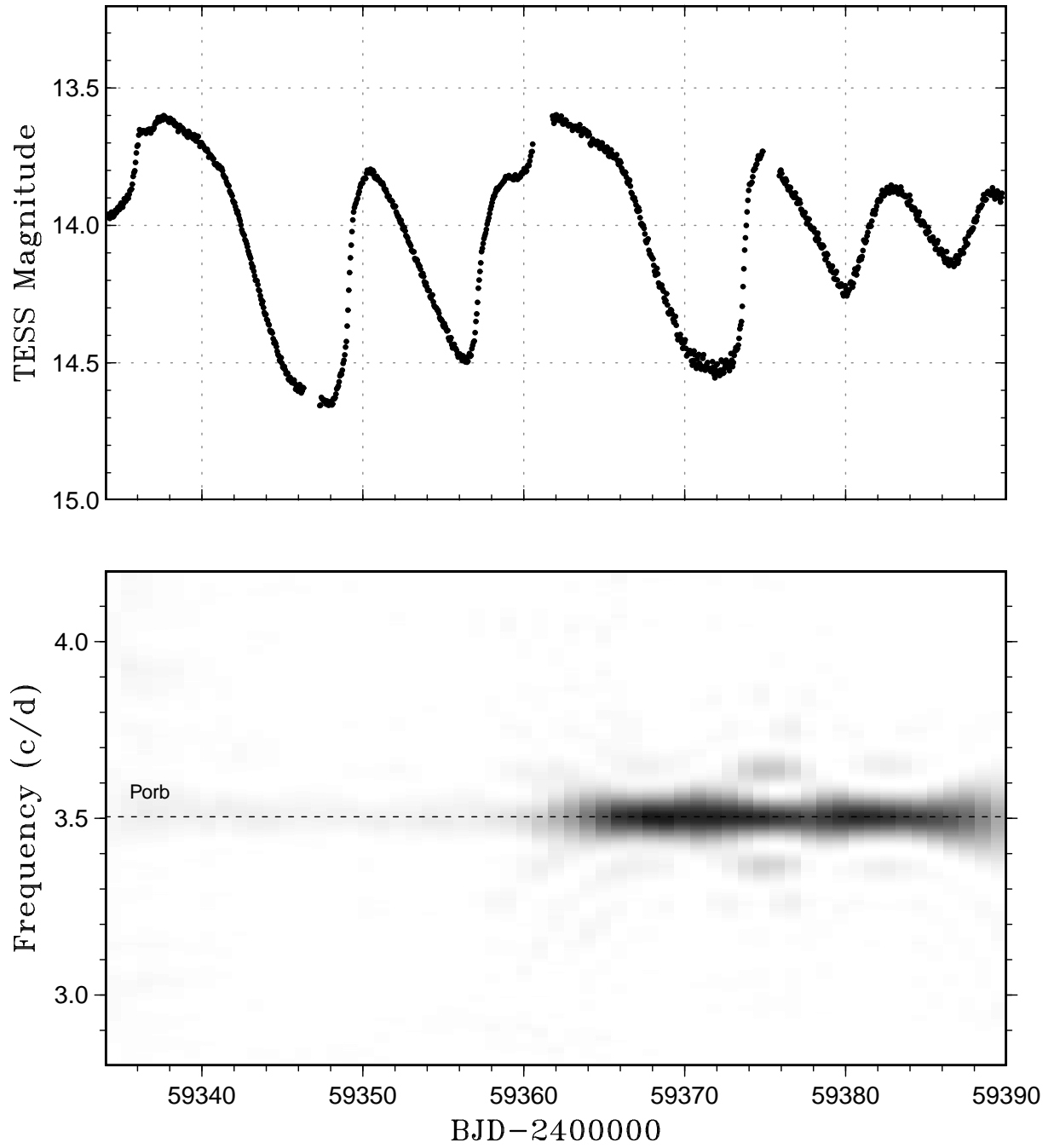
Figure 6: (Upper): TESS light curve of the segment 2. The data were binned to 0.05 d. (Lower): Two-dimensional PDM analysis. The strength of the orbital signal varied significantly.

3.5 Are IW And-type states brighter than dwarf nova-type states?

We used All-Sky Automated Survey for Supernovae (ASAS-SN: Shappee et al. 2014; Kochanek et al. 2017) *g*-band observations to see whether IW And-type states are brighter than dwarf nova-type states. The method is the same as described in Kato (2021b) using LOWESS to obtain the trends (the trends were determined from fluxes, not magnitudes). The result in figure 7 did not show a strong tendency that the object was brighter during IW And-type states, although a very faint state (BJD 2458600–2458700) corresponded to a long-lasting dwarf nova-type state.

Acknowledgements

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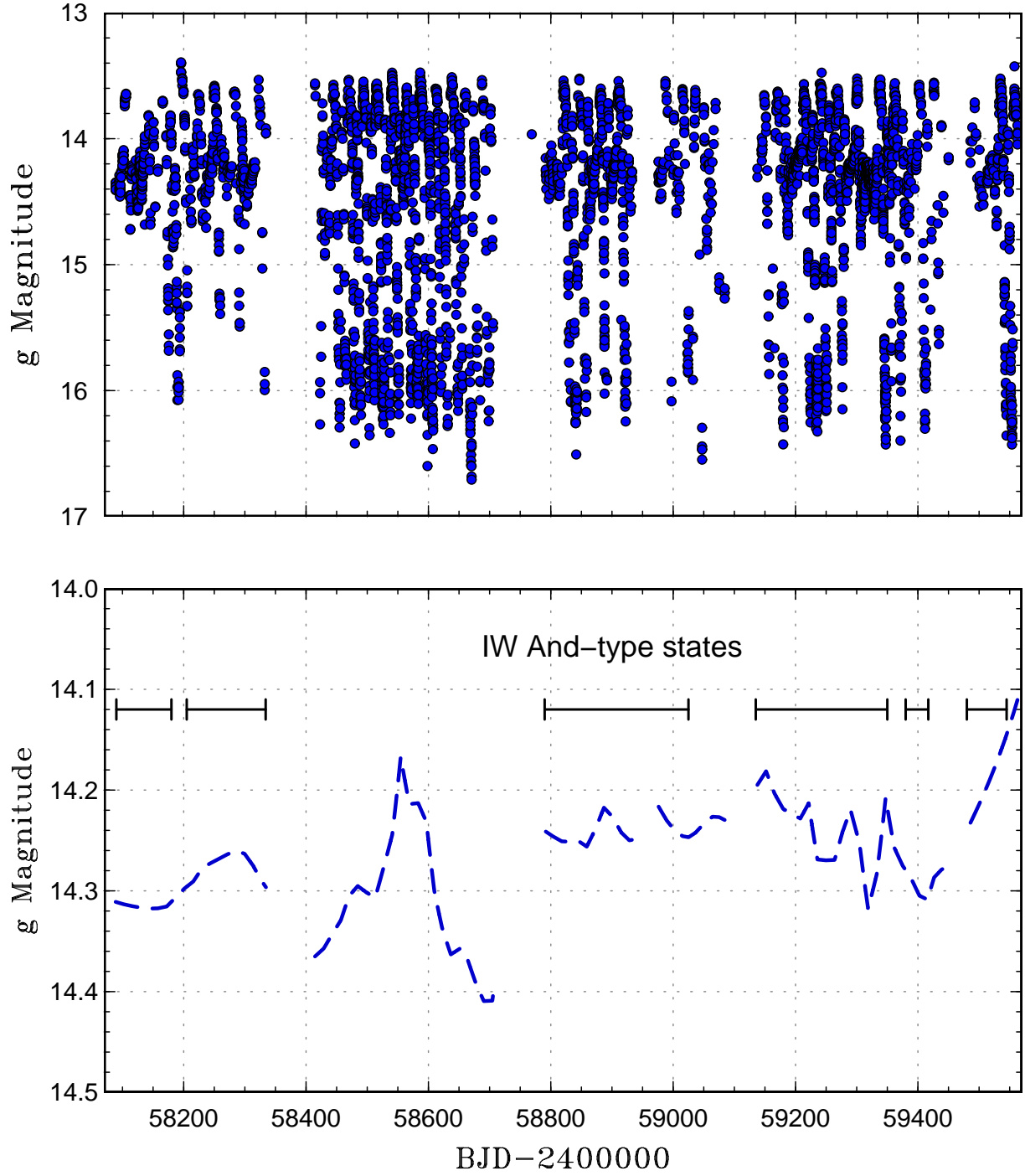
Figure 7: (Upper): ASAS-SN g-band light curve of ST Cha. (Lower): Trends determined by LOWESS. Horizontal marks represent IW And-type states.

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