

# Variable Star Bulletin

## WFI J161953.3+031909: eclipsing ER UMa-type and Z Cam-type star in the period gap

Taichi Kato<sup>1</sup>

*tkato@kusastro.kyoto-u.ac.jp*

<sup>1</sup> Department of Astronomy, Kyoto University, Sakyo-ku, Kyoto 606-8502, Japan

Received 2022 Mar. 13

### Abstract

WFI J161953.3+031909 was considered to be an eclipsing novalike object in the period gap. Using the Zwicky Transient Facility (ZTF) public database, I found that this object is the first eclipsing Z Cam star in the period gap, and is also most likely an ER UMa star with supercycles of 60–80 d. The longest outburst (most likely a superoutburst) comprised 35–46% of the supercycle in the extreme case. If superhumps are confirmed, this becomes the second object showing both ER UMa and Z Cam states after NY Ser. These objects have anomalously high mass-transfer rates despite that they are in the period gap. I refined the orbital period to be 0.099419808(8) d. We can expect to learn from WFI J161953.3+031909 using eclipses what is actually happening in the ER UMa-type and Z Cam-type disk. I also provide a revised classification of an eclipsing IW And star for BMAM-V383 = IPHAS J200822.55+300341.6 by detecting an IW And-type standstill.

## 1 Introduction

WFI J161953.3+031909 was discovered by Rau et al. (2006) during a wide-field search for orphan afterglows of gamma-ray bursts (GRBs). The object showed sudden brightening by 2.4 mag between 1999 June 14 and June 19. Although Rau et al. (2006) described that the object decayed over 50–90 d before returning to quiescence, this figure was based on very sparse observations (see their figure 5). Rau et al. (2006) suggested it to be dwarf nova. Based on detections of 9 X-ray photons with ROSAT, they derived a high  $L_X/L_{\text{opt}}=0.6$  and was considered to be consistent with an SU UMa star referring to Verbunt et al. (1997). Rau et al. (2006) derived a distance of order of a few hundred parsec based on this X-ray observation.

Rau et al. (2007) studied this object in more detail in 2006 and found it to be an eclipsing binary with a period of 0.099041(9) d. Rau et al. (2007) also detected strong Balmer and He I emission lines. Rau et al. (2007) also attributed a broad feature as a Bowen blend, although there was no feature of He II emission, which should be present when the Bowen blend is present. Rau et al. (2007) interpreted that WFI J161953.3+031909 has a low mass-transfer rate expected for an object in the period gap based on the absence of an orbital hump or the asymmetry in the eclipse. Based on this interpretation, Rau et al. (2007) concluded that the “outburst” detected in 1999 (Rau et al. 2006) represented the mean out-of-eclipse brightness rather than a dwarf nova-type outburst and that the faint ( $R=19.9$ ) observations corresponded to eclipses. Rau et al. (2007) concluded that there was no evidence for a dwarf nova outburst in this system and corrected  $L_X/L_{\text{opt}}$  to be  $\sim 0.1$  using the out-of-eclipse brightness rather than what had been considered to be quiescence.

Based on the classification by Rau et al. (2007), the AAVSO Variable Star Index (Watson et al. 2006) classified this object to be an eclipsing novalike object (at the time of this writing on 2022 March 13), although it

was apparently inconsistent with the low mass-transfer rate as stated by Rau et al. (2007). This object was also detected as a transient Gaia19cwd<sup>1</sup> by the Gaia Photometric Science Alerts Team. The light curve on the page of Gaia19cwd showed scattered magnitudes between 17.0 and 20.0, but the type of variability is not apparent due to the sparse coverage

## 2 ZTF light curve

Using the Zwicky Transient Facility (ZTF: Masci et al. 2019) public data<sup>2</sup>, I found that this object was in a standstill at least between 2021 February and September (T. Kato on 2022 March 13, vsnet-chat 9014<sup>3</sup>). Considering that this object is an eclipsing cataclysmic variable in the period gap, this finding is surprising. I here analyze the data in more details.

The entire ZTF light curve is shown in figure 1. The object was initially in dwarf nova-type state (in 2018–2020). After BJD 2459260 (2021 February), it entered a well-defined, long standstill. The object is now confirmed to be a Z Cam star [for general information of cataclysmic variables and dwarf novae, see e.g. Warner (1995)] in the period gap. There is only another known Z Cam star in the period gap (NY Ser, Kato et al. 2019), which will be discussed later. WFI J161953.3+031909 is the first eclipsing Z Cam star in the period gap. There is (yet) no indication of the IW And-type phenomenon in this object [see e.g. Simonsen (2011); Kato (2019) for IW And-type stars].

## 3 Orbital period

Due to the presence of both dwarf nova-type variations and eclipses, and due to the sparse sampling, period analysis of the ZTF data is rather difficult. I smoothed  $g$ ,  $r$  and  $i$  observations separately by locally-weighted polynomial regression (LOWESS: Cleveland 1979) using global smoothing parameters of  $f=0.05$  to reduce the effect of dwarf nova outbursts. I then combined them into a single data set and performed phase dispersion minimization (PDM: Stellingwerf 1978) analysis. The upper panel of figure 2 shows the result of the PDM analysis. There was no signal other the indicated one around the period by Rau et al. (2007). The orbital period was refined using the Markov-Chain Monte Carlo (MCMC)-based method introduced in Kato et al. (2010). The resultant ephemeris is

$$\text{Min(BJD)} = 2458790.81347(4) + 0.099419808(8)E. \quad (1)$$

The averaged orbital light curve based on this ephemeris is shown in the lower panel of figure 2. Note that this light curve contains observations in all states (dwarf nova outbursts, quiescence and standstill). The result, however, is very similar to the one in Rau et al. (2007) without a pronounced orbital hump.

Since Rau et al. (2007) reported no variations outside the eclipses on seven epochs in 2006 May, it was likely Rau et al. (2007) observed the object during a standstill similar to the one in 2021. The brightness ( $R=17.4\text{--}17.8$ ) outside the eclipses also supports this idea. I cannot, however, perfectly exclude a possibility that they observed the object during the late phase of a superoutburst when superhumps became less apparent. In either case, the object was observed when the accretion disk was hot. This explains why there was no pronounced orbital hump, on the contrary to the explanation by Rau et al. (2007) considering a low mass-transfer rate. By looking back using the ephemeris (1), the epoch listed in Rau et al. (2007) was offset by  $\sim 0.17$  phase. I did not attempt to link the ephemerides since the orbital period in this study was derived from observation far from ideal to determine the period and the actual error may be much larger than the nominal one shown in equation (1).

## 4 WFI J161953.3+031909 as a likely ER UMa star

During the dwarf nova-type state in 2018–2020, WFI J161953.3+031909 showed long outbursts, which are marked with vertical ticks in figure 1. Considering the short orbital period, these long outbursts must have been super-outbursts of an SU UMa star. The longest outburst (the first one in the second panel of figure 1) lasted at least

<sup>1</sup><http://gsaweb.ast.cam.ac.uk/alerts/alert/Gaia19cwd/>.

<sup>2</sup>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](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>.

<sup>3</sup><http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-chat/8457>.

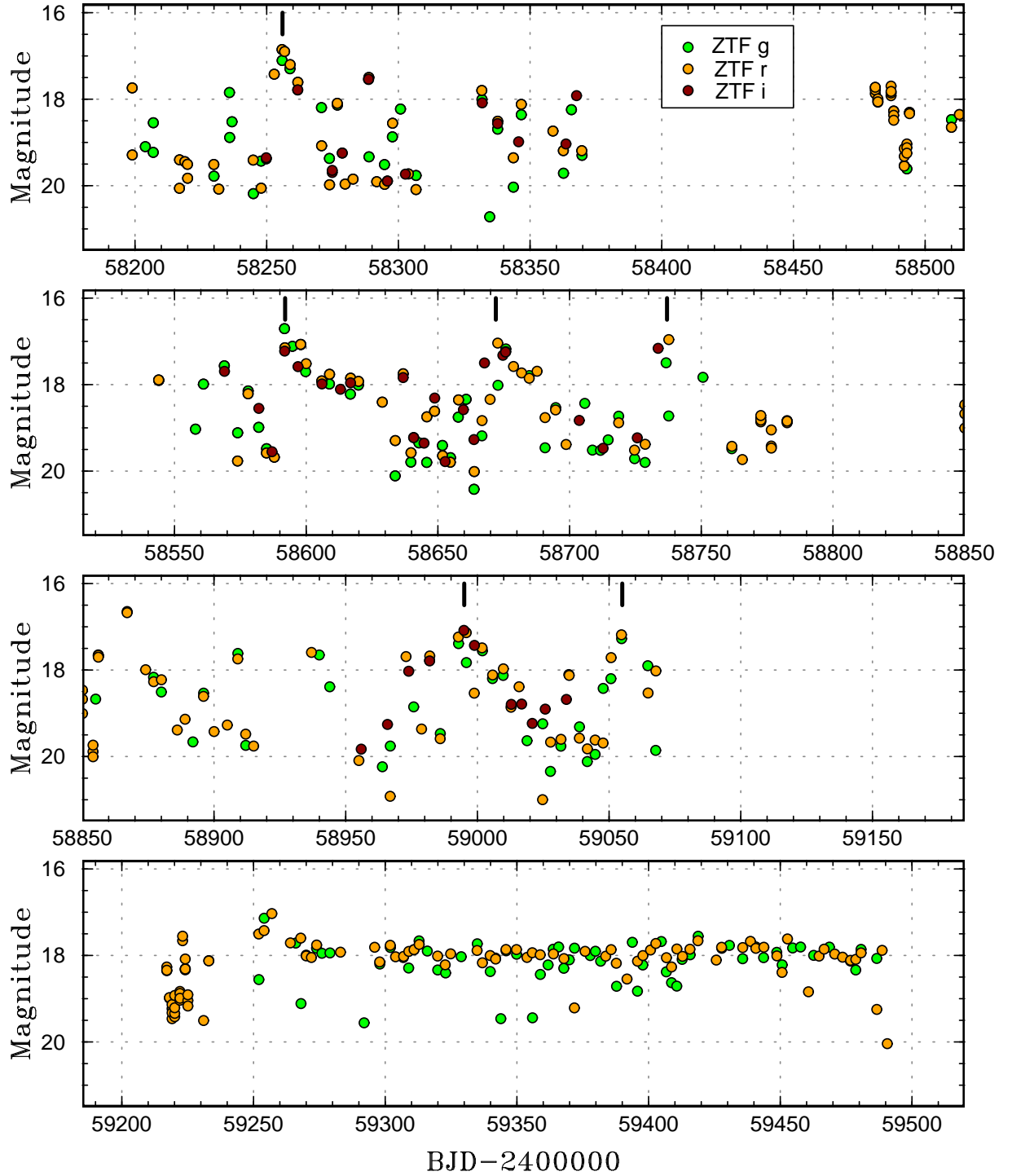


Figure 1: ZTF light curve of WFI J161953.3+031909. The object was initially in dwarf nova-type state. After BJD 2459260, it entered a well-defined, long standstill. The sporadic excursions to fainter magnitudes represent eclipses. The vertical ticks in the upper three panels represent likely superoutbursts.

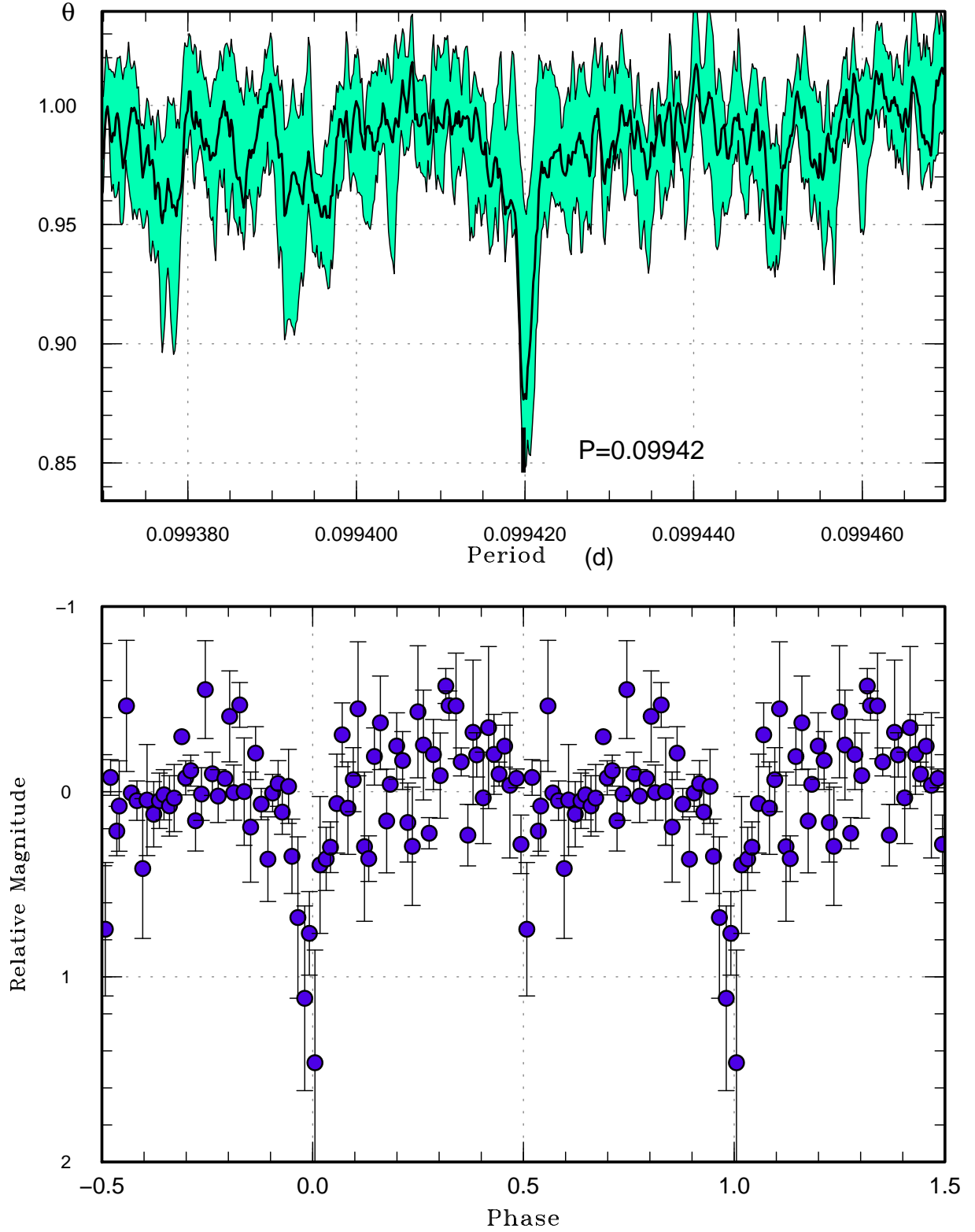


Figure 2: PDM analysis of WFI J161953.3+031909 using the ZTF data. (Upper): PDM analysis. (Lower): mean profile. The epoch and period were from the MCMC analysis.

28 d, and possibly 37 d. The intervals of successive superoutbursts in the second panel of figure 1 were 80 d and 65 d. The interval of the successive superoutburst in the third panel of figure 1 was 60 d. The shortness of the supercycle (interval between successive superoutbursts) and the long duration of superoutbursts (comprising 35–46% of the supercycle in the extreme case) are perfectly compatible with the traditional ER UMa-type classification [see Kato and Kunjaya 1995; Robertson et al. 1995; Patterson et al. 1995; for a review, see Kato et al. 1999]. Although BMAM-V383 = IPHAS J200822.55+300341.6 (Barentsen et al. 2014) is listed as an eclipsing ER UMa star in the AAVSO VSX (at the time of present writing), the slow fading rates from outbursts (figure 3; see also the light curve of the SS Cyg star CY Lyr in Kato et al. 2014) are incompatible with the ER UMa-type classification. This object showed a standstill in 2019 July–September with brightening at the end (figure 3) and it should be re-classified as an IW And star. Although its orbital period is not yet known, the figure<sup>4</sup> presented by Mariusz Bajer apparently shows a period longer than the period gap, compatible with an IW And star, but not with an ER UMa star. V4140 Sgr is the only known eclipsing ER UMa-like star (Kato et al. 2018). If superhumps are confirmed during superoutbursts of WFI J161953.3+031909, this will become the second case of eclipsing ER UMa stars.

If superhumps are confirmed (still not yet, but are very likely), WFI J161953.3+031909 is the third object showing both characteristics of Z Cam and SU UMa stars. The others are NY Ser in the period gap (Kato et al. 2019) and BO Cet, which is also an IW And star, above the period gap (Kato et al. 2021). NY Ser is particularly similar to WFI J161953.3+031909 in that both show frequent superoutbursts, which is a consequence of a high mass-transfer rate despite that they are in the period gap. At least two standstills in NY Ser were terminated by superoutbursts (Kato et al. 2019), which confirmed that the radius of an accretion disk can increase during standstills and this finding led to a working hypothesis that the IW And-type phenomenon is a manifestation of the increase in the disk radius during standstills (Kato et al. 2019; Kimura et al. 2020; M. Shibata et al. in preparation). In the case of WFI J161953.3+031909, we can directly determine the evolution of the structure of the disk by using eclipses. We can expect to learn from WFI J161953.3+031909 what is actually happening in the ER UMa-type and Z Cam-type disk, and potentially about the IW And-type disk if the star exhibits the IW And-type phenomenon in future.

## Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 21K03616. The author is grateful to the ZTF team for making their data available to the public. We are grateful to Naoto Kojiguchi for helping downloading the ZTF data. This research has made use of the AAVSO Variable Star Index and NASA’s Astrophysics Data System.

Based on observations obtained with the Samuel Oschin 48-inch Telescope at the Palomar Observatory as part of the Zwicky Transient Facility project. ZTF is supported by the National Science Foundation under Grant No. AST-1440341 and a collaboration including Caltech, IPAC, the Weizmann Institute for Science, the Oskar Klein Center at Stockholm University, the University of Maryland, the University of Washington, Deutsches Elektronen-Synchrotron and Humboldt University, Los Alamos National Laboratories, the TANGO Consortium of Taiwan, the University of Wisconsin at Milwaukee, and Lawrence Berkeley National Laboratories. Operations are conducted by COO, IPAC, and UW.

The ztfquery code was funded by the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (grant agreement n°759194 – USNAC, PI: Rigault).

We acknowledge ESA Gaia, DPAC and the Photometric Science Alerts Team (<http://gsaweb.ast.cam.ac.uk/alerts>).

## List of objects in this paper

IW And, Z Cam, SS Cyg, CY Lyr, NY Ser, V4140 Sgr, SU UMa, ER UMa, BMAM-V383, IPHAS J200822.55+300341.6, Gaia19cwd, WFI J161953.3+031909

---

<sup>4</sup><[https://www.aavso.org/vsx\\_docs/838271/3635/BMAM-V383%20View%20on%20eclipse.PNG](https://www.aavso.org/vsx_docs/838271/3635/BMAM-V383%20View%20on%20eclipse.PNG)>.

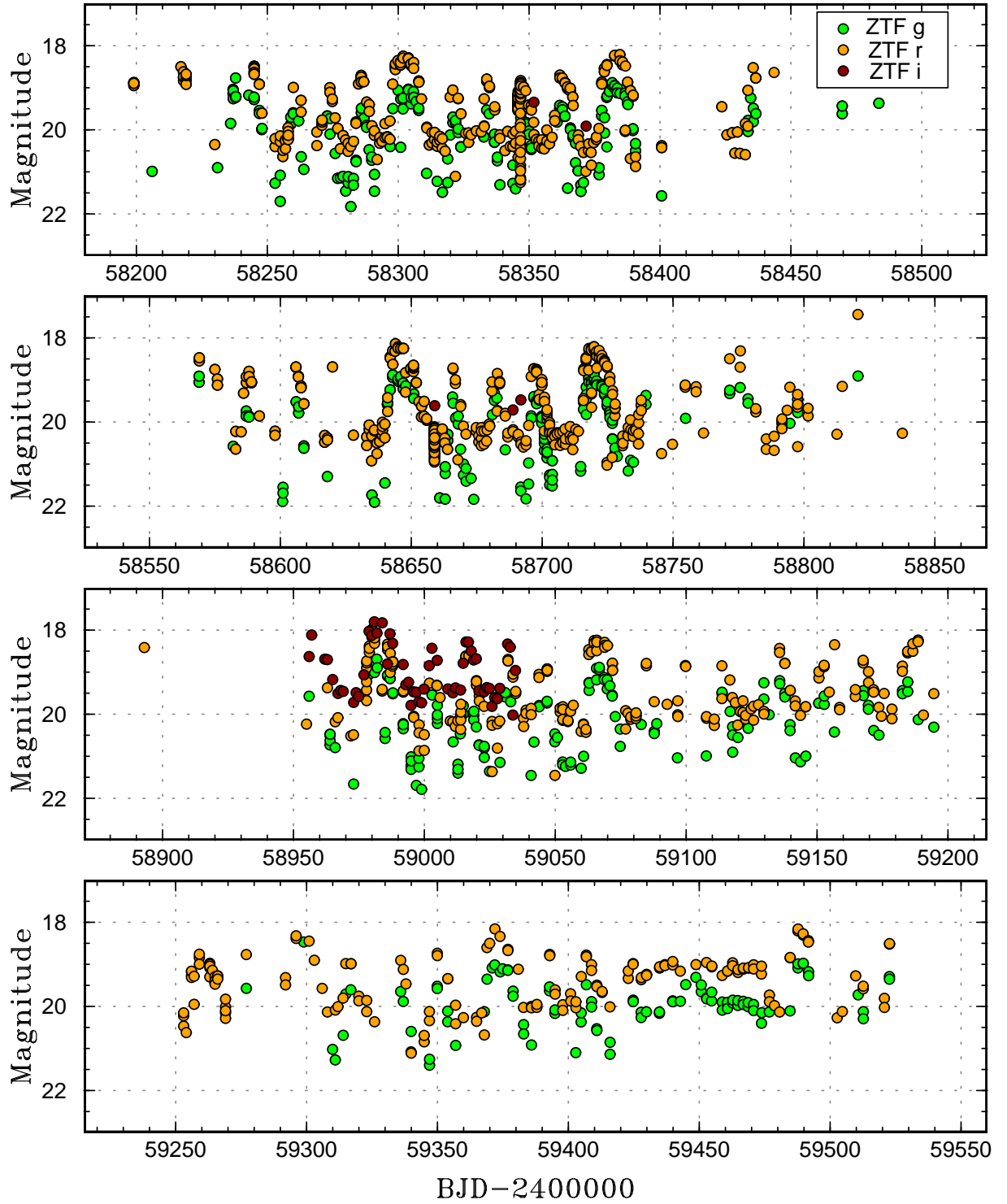


Figure 3: ZTF light curve of BMAM-V383 = IPHAS J200822.55+300341.6. The light curve is characterized by long and short outbursts, which are usually seen in SS Cyg stars. The presence of a standstill terminated by brightening (IW And-type phenomenon) is apparent in BJD 2459423–2459492.

## References

- Barentsen, G. et al. (2014) The second data release of the INT photometric H $\alpha$  survey of the northern Galactic plane (IPHAS DR2). *MNRAS* **444**, 3230
- Cleveland, W. S. (1979) Robust locally weighted regression and smoothing scatterplots. *J. Amer. Statist. Assoc.* **74**, 829
- Kato, T. (2019) Three Z Cam-type dwarf novae exhibiting IW And-type phenomenon. *PASJ* **71**, 20
- Kato, T., Hambusch, F.-J., & Cook, L. M. (2018) Detection of the supercycle in V4140 Sagittarii: First eclipsing ER Ursae Majoris-like object. *PASJ* **70**, L3
- Kato, T. et al. (2014) Survey of period variations of superhumps in SU UMa-type dwarf novae. V: The fifth year (2012–2013). *PASJ* **66**, 30
- Kato, T., & Kunjaya, C. (1995) Discovery of a peculiar SU UMa-type dwarf nova ER Ursae Majoris. *PASJ* **47**, 163
- Kato, T. et al. (2010) Survey of Period Variations of Superhumps in SU UMa-Type Dwarf Novae. II. The Second Year (2009–2010). *PASJ* **62**, 1525
- Kato, T., Nogami, D., Baba, H., Masuda, S., Matsumoto, K., & Kunjaya, C. (1999) in *Disk Instabilities in Close Binary Systems*, ed. S. Mineshige, & J. C. Wheeler (Tokyo: Universal Academy Press) p. 45
- Kato, T. et al. (2019) Discovery of standstills in the SU UMa-type dwarf nova NY Serpentis. *PASJ* **71**, L1
- Kato, T. et al. (2021) BO Ceti: Dwarf nova showing both IW And and SU UMa-type features. *PASJ* **73**, 1280
- Kimura, M., Osaki, Y., & Kato, T. (2020) KIC 9406652: A laboratory of the tilted disk in cataclysmic variable stars. *PASJ* **72**, 94
- Masci, F.-J. et al. (2019) The Zwicky Transient Facility: Data processing, products, and archive. *PASP* **131**, 018003
- Patterson, J., Jablonski, F., Koen, C., O'Donoghue, D., & Skillman, D. R. (1995) Superhumps in cataclysmic binaries. VIII. V1159 Orionis. *PASP* **107**, 1183
- Rau, A., Greiner, J., & Schwarz, R. (2006) Constraining the GRB collimation with a survey for orphan afterglows. *A&A* **449**, 79
- Rau, A. et al. (2007) The incidence of dwarf novae in large area transient searches. *ApJ* **664**, 474
- Robertson, J. W., Honeycutt, R. K., & Turner, G. W. (1995) RZ Leonis Minoris, PG 0943+521, and V1159 Orionis: Three cataclysmic variables with similar and unusual outburst behavior. *PASP* **107**, 443
- Simonsen, M. (2011) The Z CamPaign: Year 1. *J. American Assoc. Variable Star Obs.* **39**, 66
- Stellingwerf, R. F. (1978) Period determination using phase dispersion minimization. *ApJ* **224**, 953
- Verbunt, F., Bunk, W. H., Ritter, H., & Pfeffermann, E. (1997) Cataclysmic variables in the ROSAT PSPC All Sky Survey. *A&A* **327**, 602
- Warner, B. (1995) *Cataclysmic Variable Stars* (Cambridge: Cambridge University Press)
- Watson, C. L., Henden, A. A., & Price, A. (2006) The International Variable Star Index (VSX). *Society for Astronom. Sciences Ann. Symp.* **25**, 47



---

VSOLJ  
c/o Keiichi Saijo National Science Museum, Ueno-Park, Tokyo Japan

Editor Seiichiro Kiyota  
e-mail: [skiyotax@gmail.com](mailto:skiyotax@gmail.com)

---