No.95 Mar. 2022

ISSN 0917-2211

Variable Star Bulletin

V476 Cyg (Nova Cyg 1920) is currently a dwarf nova — first such an object in the period gap?

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Received 2022 Mar. 11

Abstract

V476 Cyg (Nova Cyg 1920) is a bright, fast nova reaching a photographic magnitude of 2.0. Using the Zwicky Transient Facility (ZTF) public database, I found that this nova is currently a dwarf nova with a cycle length of ∼24 d. Compared to other classical novae currently in dwarf nova-type states, outbursts of V476 Cyg are rapidly rising and short with durations of a few days. Based on the AAVSO observations, this nova was probably already in the dwarf nova-type phase in 2016, 96 years after the nova eruption. I found a possible orbital period of 0.1018002(6) d using the ZTF data, which would place the object in the period gap. This supposed short orbital period appears to explain the features and faint absolute magnitudes of the observed dwarf nova outbursts. If this period is confirmed, V476 Cyg is a classical nova with the shortest orbital period with distinct dwarf nova outbursts and in which a nova eruption was recorded in the modern era. I also compared with the outburst properties with V446 Her (Nova Her 1960), which currently shows SS Cyg-type outbursts. The transition to the dwarf nova-phase in V476 Cyg occurred much earlier (∼100 yr) than what has been supposed (∼1000 yr) for classical novae below the period gap. V476 Cyg would not only provide an ideal laboratory of the behavior of an irradiated accretion disk in which tidal instability is expected to work, but also an ideal laboratory of the effect of a massive white dwarf on dwarf nova outbursts.

1 Introduction

V476 Cyg was discovered as a bright Galactic nova by Denning (1920). The visual peak magnitude by Denning (1920) was 2.2 on 1920 August 23. Photographic observations showed relatively slow rise from 7.0 mag to the peak (2.0 mag) which took place in 7 d (Campbell 1932). This nova was a fast nova with t_2=16.5 d (Duerbeck 1987) or t_2=6 d (Strope et al. 2010). The nova was classified as a D-class one with a weak dust dip in the light curve by Strope et al. (2010). Leslie Peltier described that the post-nova could be sometimes glimpsed in his autobiographical *Starlight Nights* (Peltier 1965)[1]. He indeed followed this nova since its maximum in 1920 (when he was at an age of 20) and saw it around 16 mag or slightly below it between 1961 and 1972 according to the AAVSO International Database[2]. Ringwald et al. (1996a) reported a low-resolution spectrum at V=17.33. Shara et al. (1986) reported a magnitude of V ∼18.7 and Ringwald et al. (1996a) suspected that either there were significant flux errors in Shara et al. (1986) or the nova was variable on a short time-scale. Ringwald et al. (1996a) discussed that wiggles in the spectrum of V476 Cyg might be a signature of a dwarf nova.

[1]I read this story in the book translated to Japanese (Peltier 1985).
[2]<http://www.aavso.org/data-download>.

2 V476 Cyg as a dwarf nova

Using the Zwicky Transient Facility (ZTF: Masci et al. 2019) public data[3], I found that this object is currently a dwarf nova (T. Kato on 2020 March 5, vsnet-chat 8457[4]) [for general information of cataclysmic variables and dwarf novae, see e.g. Warner (1995)]. Here I report on this object using the ZTF data up to the end of 2021. The light curve is shown in figure 1. I must note, however, neither all outbursts were detected nor all outbursts were detected at their peaks by ZTF. The quiescent brightness varied relatively strongly, and the object was bright in 2019 August–September (BJD 2458700–2458760). During this bright phase, there was a outburst starting on BJD 2458718 (2019 August 22; figure 2), which had a shoulder [or referred to as an embedded precursor by Cannizzo (2012)] and the peak brightness (r ∼16.5 and g ∼16.6) was brighter than the other outbursts. There were equally bright outbursts in 2018 September, peaking on BJD 2458386 (first panel of figure 1) and in 2020 June, peaking on BJD 2459010 (third panel of 1). The former outburst apparently had a shoulder as in the 2019 August one.

The color was $g - r$=+0.1 at outburst peak, while it was redder ($g - r \sim +0.5$) in quiescence. This was probably due to the presence of a close, physically unrelated, companion star Gaia EDR3 2089624258068065152 with a Gaia magnitude G=19.07 (Gaia Collaboration et al. 2021).

There were also CCD observations in the AAVSO International Database between 2016 and 2019. Short outbursts can be recognized by comparing with the ZTF data (figure 3). The AAVSO observations were unfiltered CCD ones obtained by HKEB (K. Hills, UK). At least a few outbursts recorded by ZTF were also recorded by AAVSO CCD observations. There was a bright outburst on 2017 February 14 (unfiltered CCD magnitude 15.3). The dwarf nova state should have started before 2016. Although there were some CCD observations with significant variations in 2007, the data were not sufficient to identify them as dwarf nova outbursts.

3 Nova in the period gap?

The mean outburst interval derived from the best recorded part (BJD 2459300–2459510) was 24.1(1.4) d. The durations of most these outbursts were short (2–3 d), suggesting that V476 Cyg has a relatively short orbital period. There was time-resolved photometry by ZTF on one night (figure 4). This run suggests a period of ∼0.10 d. With the help of this candidate period, I analyzed the ZTF data in quiescence (figure 5) using phase dispersion minimization (PDM: Stellingwerf 1978) analysis after removing the global trends by locally-weighted polynomial regression (LOWESS: Cleveland 1979). The error was estimated by methods of Fernie (1989) and Kato et al. (2010). Although this period looks like the orbital period, it might come from the physically unrelated companion star and needs to be confirmed by further observations. If this period is the orbital period of V476 Cyg, this object is in the period gap. This period appears to be consistent with the outburst behavior mostly showing short outbursts. The brightest dwarf nova outburst in the ZTF data had M_V=+5.5 using A_V=0.7 (Schaefer 2018) and the Gaia parallax (Gaia Collaboration et al. 2021). This is relatively faint among dwarf novae (see e.g. Warner 1987) and appears to be consistent with a short orbital period. Kato (2022) showed that WZ Sge stars start showing superhumps at M_V=+5.4. The present result of V476 Cyg is comparable to this value.

The borders of the period gap is somewhat variable depending the authors. I use the range 0.090–0.13 d based on equation (17) in Knigge et al. (2011). Well-established novae in the period gap include IM Nor (recurrent nova) (Woudt and Warner 2003; Patterson et al. 2022), V Per (Shafter and Abbott 1989; Shafter and Misselt 2006), QU Vul (Shafter et al. 1995), V597 Pup (Warner and Woudt 2009), and some more borderline or less established cases. None of these object shows dwarf nova-type outbursts.

4 Novae showing dwarf nova outbursts after the eruption

There are well-established classical novae which currently show dwarf nova-type outbursts. I summarized them in table 1. There have been many references for GK Per and I only listed a few of them. It might be worth noting that Robinson (1975) already reported dwarf nova-like outbursts for V446 Her before the nova eruption. This phenomenon may have been similar to the reported case in Mróz et al. (2016). V446 Her currently shows dwarf

[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>.

[4]<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-chat/8457>.

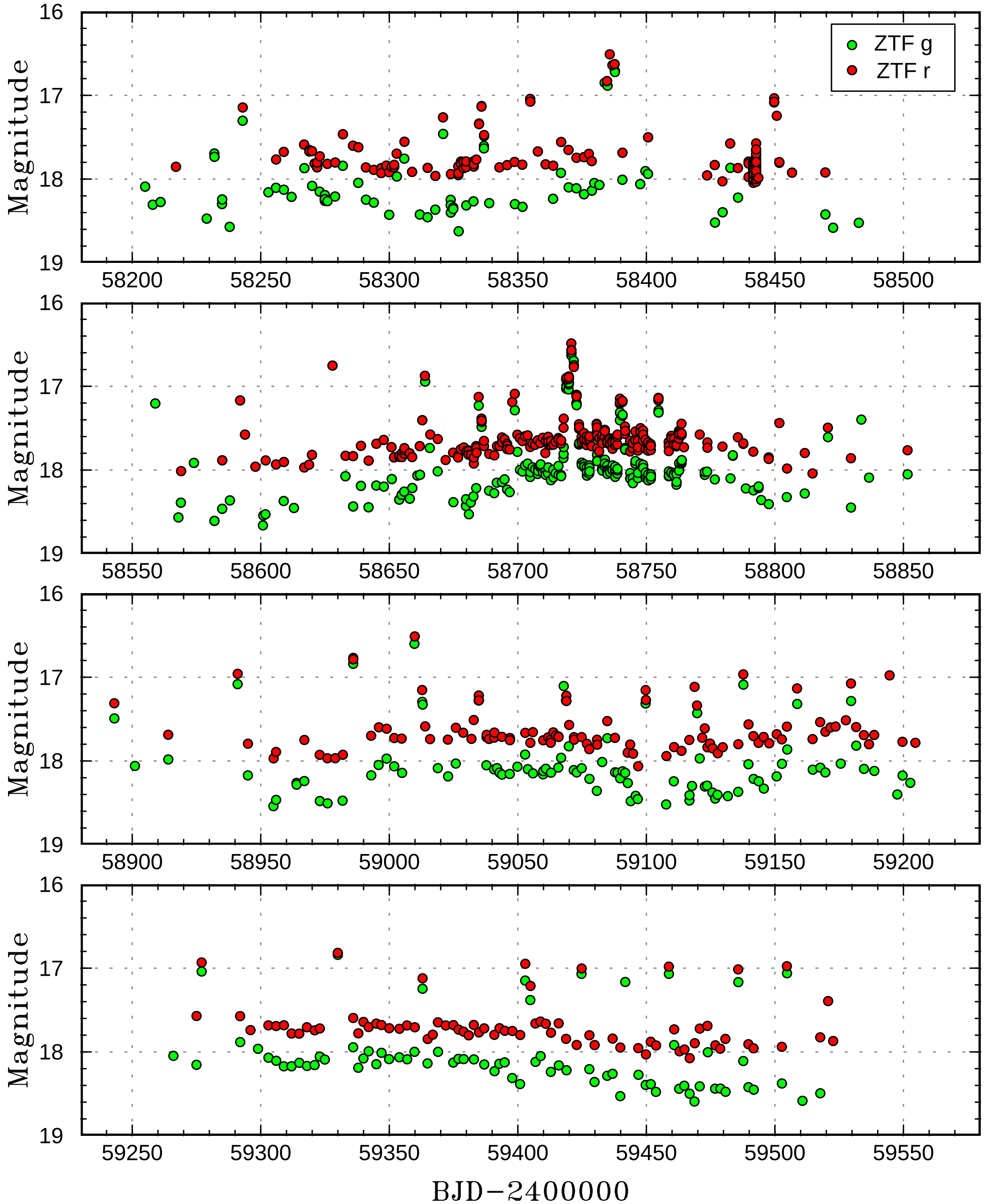

Figure 1: ZTF light curve of V476 Cyg.

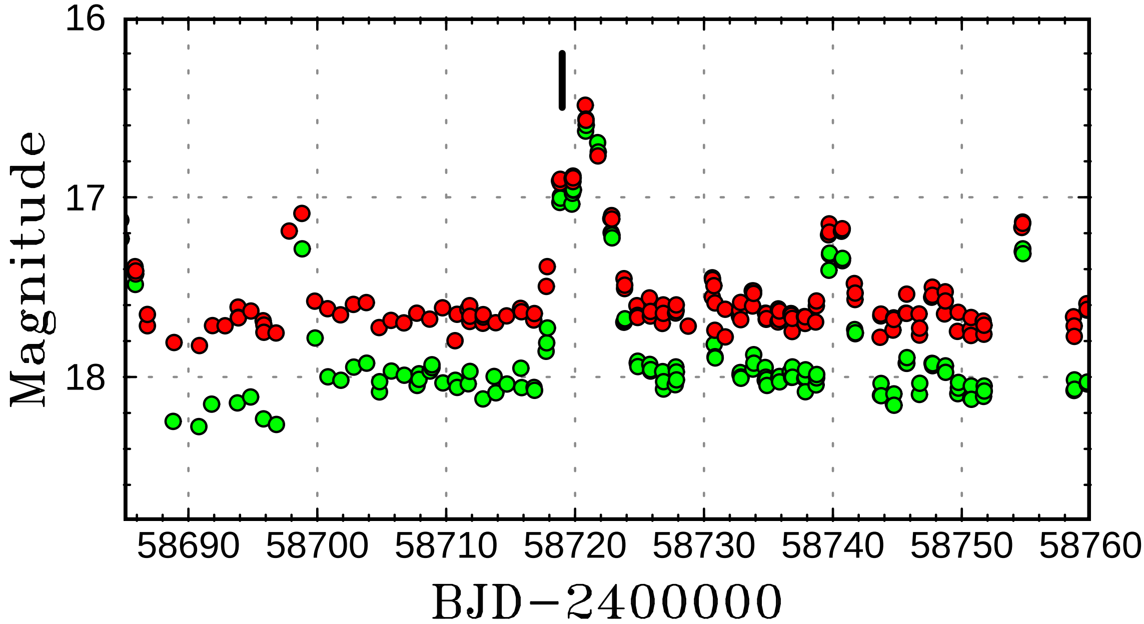

Figure 2: ZTF light curve of V476 Cyg. Enlargement of the bright state in 2019 August–September. The tick represents a shoulder in the bright outburst. The symbols are the same as in figure 1.

nova-type outburst typical for an SS Cyg star with long and short outbursts in the ZTF data (in contrast to the statement in Patterson et al. 2013: figure 6, see also the light curve in 1994 in Honeycutt et al. 1995). V392 Per was also a dwarf nova (Richter 1970) before the 2018 nova eruption (e.g. Munari et al. 2020), whose most recent slowly rising outburst was observed in 2016 February–April [detected by the VSOLJ observer Mitsutaka Hiraga and the AAVSO observer Carey Chiselbrook (cvnet-outburst message on 2016 February 28)]. BC Cas is currently in IW And-type state (Kato and Kojiguchi 2020) [see e.g. Simonsen (2011); Kato (2019) for IW And-type stars]. A recent light curve for X Ser is also present in Kimura et al. (2018). A discussion on V1017 Sgr can be also found in Salazar et al. (2017). The most recent dwarf nova-type outburst occurred in 2007. A outburst of V2109 Oph was detected by the Gaia satellite as Gaia21dza[5]. This outburst was a slowly rising one and the orbital period was suspected to be long (T. Kato, vsnet-alert 26178[6]).

BK Lyn was suggested to be the counterpart of the Chinese "guest star" in 101 A.D. (Hertzog 1986; Patterson et al. 2013) and showed a transient ER UMa-type phase in 2011–2012 (Patterson et al. 2013; Kato et al. 2013, 2014). This state had apparently started as early as in 2005 (Kato et al. 2013). The object is currently in novalike state and no dwarf nova outbursts are observed.

Although WY Sge (nova eruption in 1783) was once considered to be a dwarf nova (Shara et al. 1984), Naylor et al. (1992); Somers et al. (1996) pointed out that it is just an ordinary old nova. Modern ZTF observations do not show any sign of dwarf nova outbursts contrary to the expectation by the hibernation scenario (Shara et al. 1984, 1986). See also Vogt et al. (2018) for modern observations of WY Sge.

Although Vogt et al. (2018) listed old novae showing low-amplitude outburst (they referred to as stunted outbursts) in V841 Oph, V728 Sco, V1059 Sgr, V849 Oph, V363 Sgr, HS Pup and V2572 Sgr, the dwarf nova-type nature is not apparent from their light curves for most objects. I included only V728 Sco, which showed recurrent outbursts similar to dwarf novae by more than 1 mag, in the table.

Three of the objects in the table are long-period systems (orbital periods more than 1 d) and have evolved secondaries. It is understandable that a considerable fraction of this table is composed of such objects, since these objects have a large accretion disk and it is unstable to thermal instability even under mass-transfer rates typical for ordinary (short-period) novalike systems (Kim et al. 1992). Kim et al. (1992) predicted that outbursts in such systems are inside-out-type, approximately symmetric ones, which agree with the observations of these post-novae. This is apparently not the case for V476 Cyg. The outbursts in V476 Cyg rise rapidly and they are

[5] <http://gsaweb.ast.cam.ac.uk/alerts/alert/Gaia21dza/>.
[6] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/26178>.

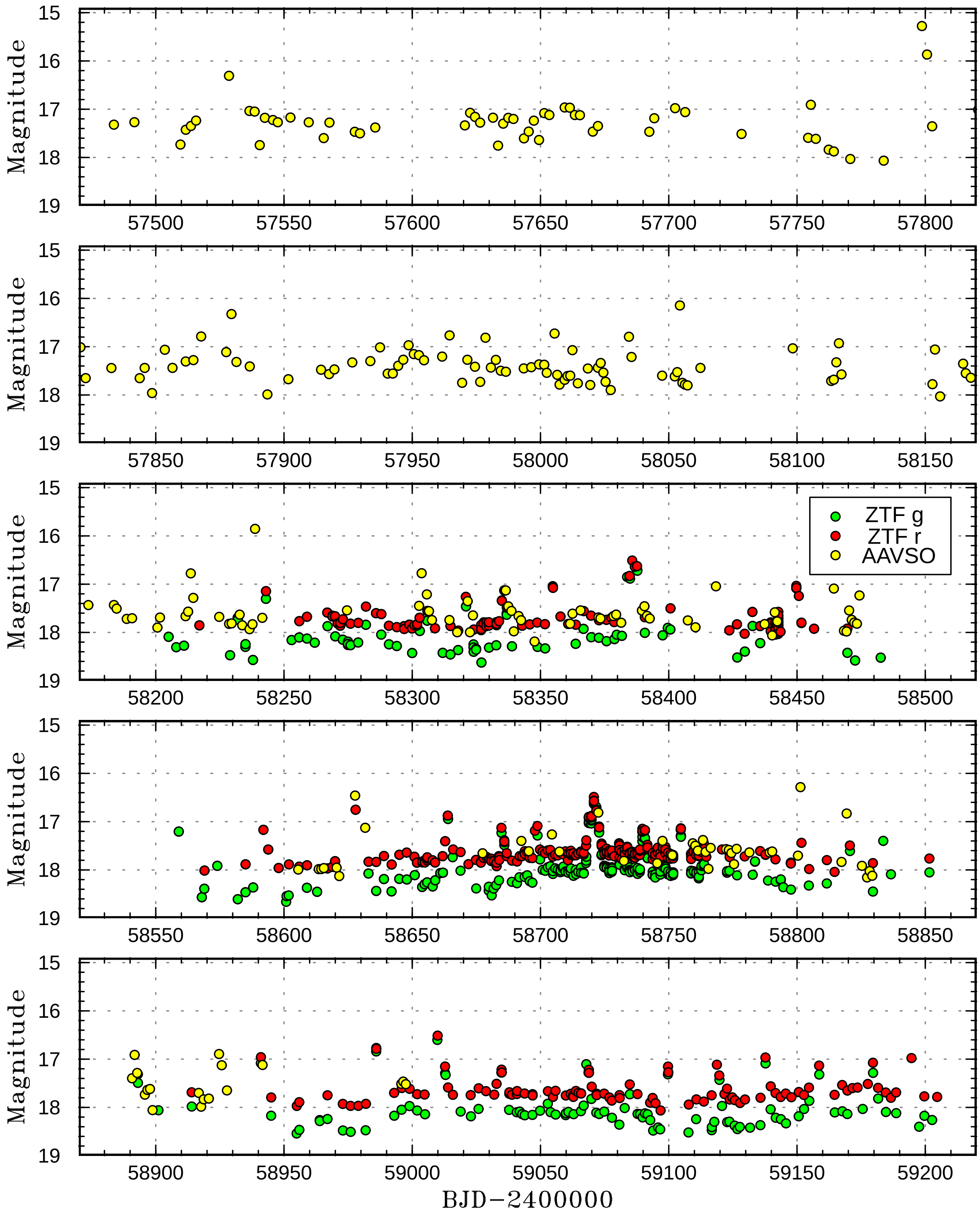

Figure 3: Combined ZTF and AAVSO light curve of V476 Cyg. The AAVSO observations were unfiltered CCD ones obtained by HKEB (K. Hills, UK). At least a few outbursts recorded by ZTF were also recorded by AAVSO CCD observations.

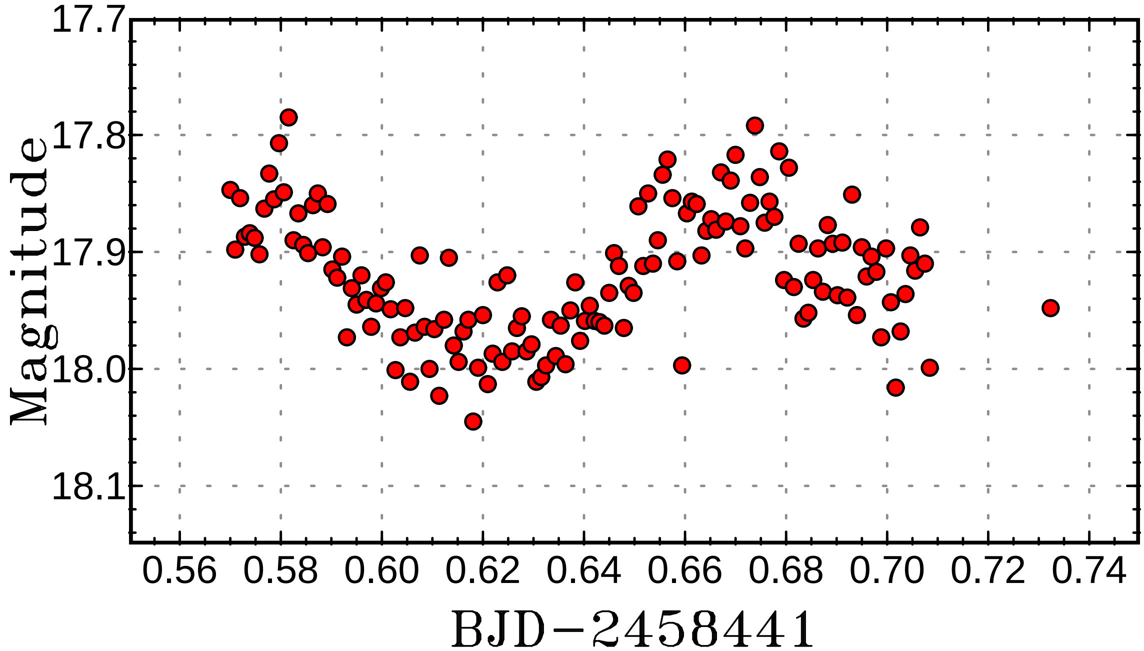

Figure 4: Short-term variation recorded in r-band time-resolved photometry by ZTF.

Table 1: Novae showing dwarf nova outbursts after the eruption

Object	Eruption	Orbital Period (d)	References
V728 Sco	1862	–	Vogt et al. (2018)
V606 Aql	1899	–	Kato and Kojiguchi (2021)
GK Per	1901	1.996803	Crampton et al. (1986); Bianchini et al. (1986); Šimon (2002)
X Ser	1903	1.478	Thorstensen and Taylor (2000); Šimon (2018)
V476 Cyg	1920	0.101800?	this paper
BC Cas	1929	–	Kato and Kojiguchi (2020)
V446 Her	1960	0.2070	Thorstensen and Taylor (2000); Honeycutt et al. (2011)
V2109 Oph	1969	–	vsnet-alert 26178
V1017 Sgr	1919	5.78629	Sekiguchi (1992); Webbink et al. (1987)
BK Lyn	101?	0.07498	Ringwald et al. (1996b); Patterson et al. (2013)

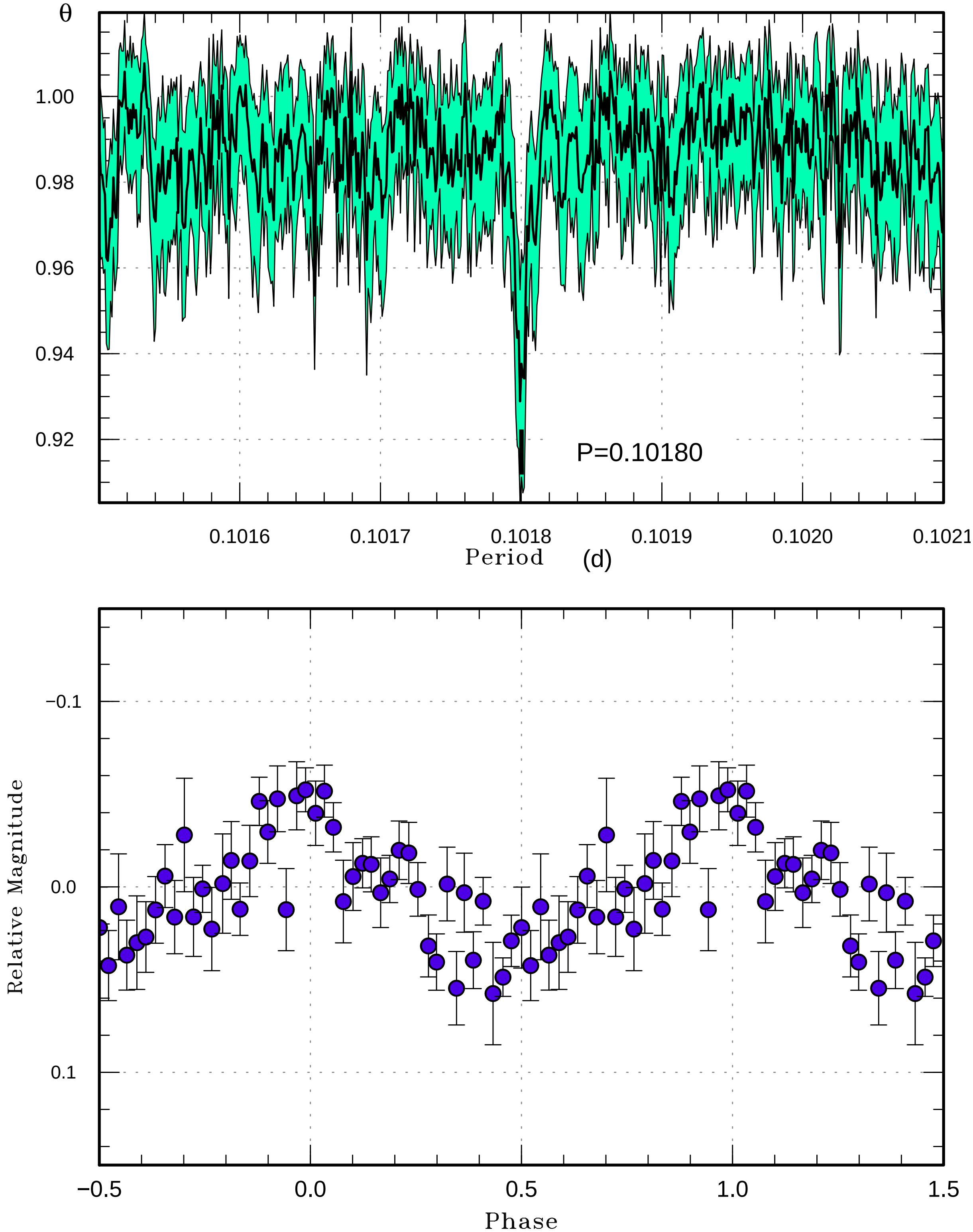

Figure 5: PDM analysis of V476 Cyg using the ZTF data in quiescence. (Upper): PDM analysis. A sharp signal at 0.1018002(6) d was detected. (Lower): mean profile.

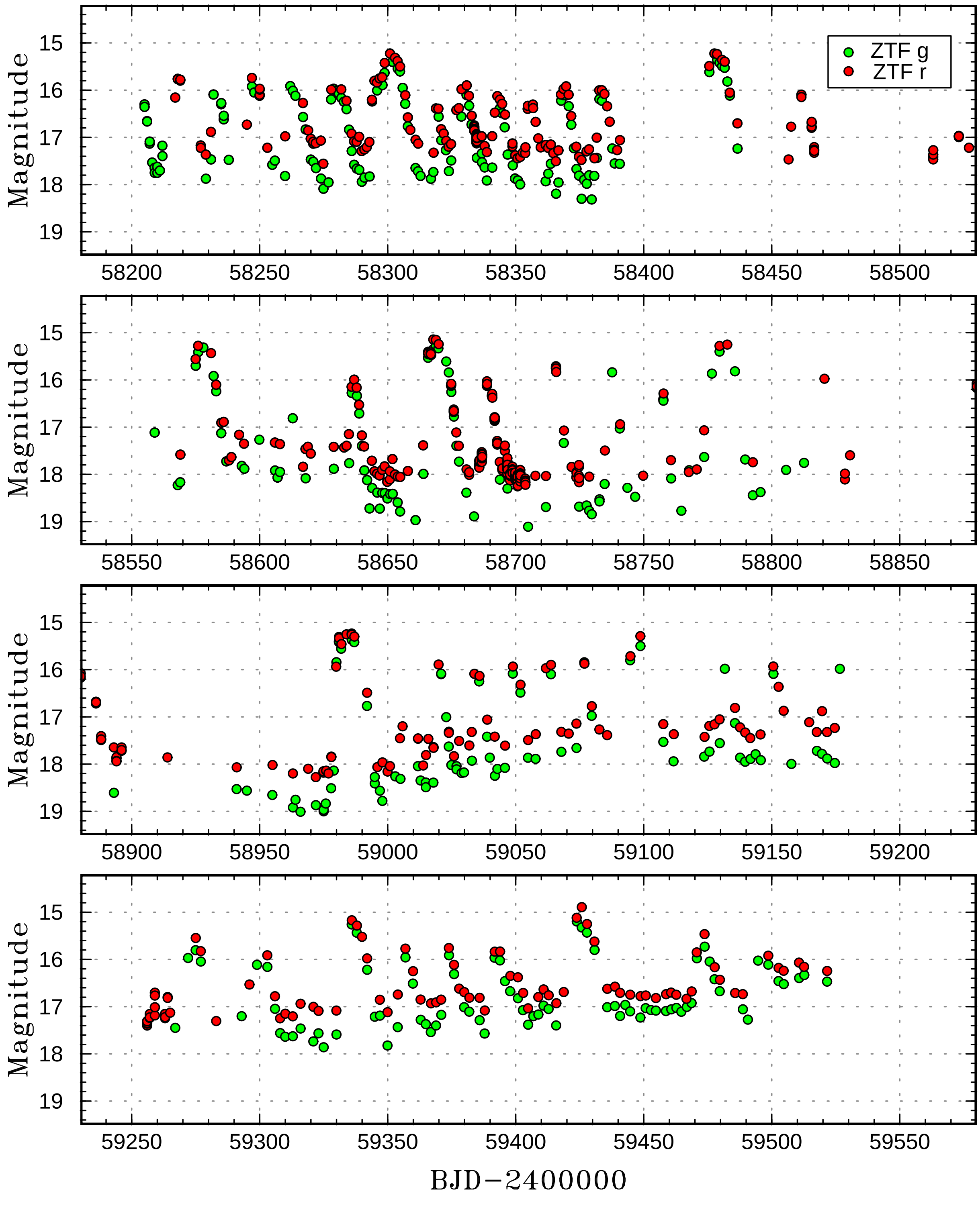

Figure 6: ZTF light curve of V446 Her. The current behavior is indistinguishable from that of ordinary SS Cyg-type dwarf novae. The BJD scale is the same as in figure 1 (V476 Cyg). One can easily see the shortness of outbursts in V476 Cyg.

apparently outside-in outbursts. If the suspected orbital period is correct, this behavior is consistent with the short-period nature. Among the table, the only confirmed short-period object is BK Lyn, whose dwarf nova-type phase was likely a transient phenomenon and the suspected nova eruption occurred nearly 2000 years ago. In this regard, the case of V476 Cyg with a long-lasting dwarf nova-type phase would be unique. Patterson et al. (2013) estimated that novae below the period gap show dwarf nova outbursts after the nova eruption when the white dwarf cools sufficiently after ∼1000 years. If the suspected orbital period of V476 Cyg is correct, this object can be an exception. The case of V476 Cyg may reflect the rapid evolution (with t_2=16.5 d or 6 d) of the nova eruption and rapid subsequent cooling.

5 Shoulder or failed superoutburst?

The nature of the shoulder in the dwarf nova-type outburst is not still clear. Cannizzo (2012) considered it to be similar to precursor outbursts in SU UMa-type superoutbursts. Kato and Hambsch (2021) suggested that it originates when the disk reaches the tidal truncation radius. In the special case of V363 Lyr, the outburst accompanied by a shoulder was 0.3–0.4 mag brighter than other outbursts and showed periodic modulations with a period slightly longer than the orbital period (Kato 2021). The nature of this variation is still unclear (Kato 2021). Compared to the light curves by Cannizzo (2012), such as that of SS Cyg, the case of V476 Cyg looks more similar to that of V363 Lyr. It would be worth performing time-resolved photometry during such outbursts to detect possible periodic signals as in V363 Lyr. Other shorter outbursts in V476 Cyg have variable peak brightness, although it was more constant at 17.0 mag in the late 2020 to the 2021 seasons (later part of the third panel and the fourth panel of figure 1). Considering the suspected orbital period in section 3, these outbursts with shoulders may be analogous to SU UMa-type superoutbursts [a "failed superoutburst" is also known in SU UMa stars, during which tidal instability is not sufficiently strong to produce a full superoutburst (Osaki and Kato 2013)], although the durations were much shorter.

Determination of the orbital period by radial-velocity studies is desired. Considering that many dwarf novae in the period gap have been identified as SU UMa stars [e.g. V1006 Cyg (Kato et al. 2016); MN Dra (Nogami et al. 2003; Pavlenko et al. 2010; Bąkowska et al. 2017); NY Ser (Pavlenko et al. 2014; Kato et al. 2019)], superoutbursts may be expected in V476 Cyg. Continued observations and timely time-resolved photometry would clarify the nature of dwarf nova outbursts in V476 Cyg. Since the object appears to be still declining from the 1920 nova eruption, this object would provide an ideal laboratory of the behavior of an irradiated accretion disk in which tidal instability is expected to work. This object would also be an ideal laboratory of the effect of a massive white dwarf on dwarf nova outbursts.

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 (Watson et al. 2006), the AAVSO International Database 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

V606 Aql, BC Cas, SS Cyg, V476 Cyg, V1006 Cyg, MN Dra, V446 Her, BK Lyn, V363 Lyr, IM Nor, V841 Oph, V849 Oph, V2109 Oph, V Per, GK Per, V392 Per, HS Pup, V597 Pup, V728 Sco, X Ser, NY Ser, WY Sge, WZ Sge, V363 Sgr, V1017 Sgr, V1059 Sgr, V2572 Sgr, SU UMa, ER UMa, QU Vul, Gaia21dza, Gaia EDR3 2089624258068065152

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