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Study of the low-amplitude Z Cam star IX Vel

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Abstract

IX Vel has been considered as one of the prototypical novalike cataclysmic variables with thermally stable accretion disks. Using All-Sky Automated Survey (ASAS-3) and All-Sky Automated Survey for Supernovae (ASAS-SN) observations, I found that IX Vel is a low-amplitude dwarf nova showing standstills. This object has been re-classified as a Z Cam-type dwarf nova. This conclusion is consistent with the mass-transfer rate using the Gaia parallax which places the object near the lower limit of the thermal stability. Using two-dimensional Least Absolute Shrinkage and Selection Operator (Lasso), I found that the cycle lengths of dwarf nova outbursts varied between 13 and 20 d. Analysis of the ASAS-3 data suggested that the cycle lengths are shorter and the amplitudes are smaller when the system is bright. Standstills occurred when the system was bright. These results support the idea that a subtle variation in the mass-transfer rate from the secondary causes transitions between outbursting state and standstills in Z Cam stars.

1 Introduction

Despite its apparent brightness (V ∼9.5), IX Vel (=CD−48°3636 = CPD−48°1577) has been relatively new to the field of cataclysmic variables (CVs) [for general information of cataclysmic variables and dwarf novae, see e.g. Warner (1995)]. This object was spectroscopically identified as a UX UMa-type novalike CV by Garrison et al. (1984). Eggen and Niemela (1984) performed radial-velocity observations and obtained a possible orbital period (0.1220 d, which was not a correct value). Wargau et al. (1983) obtained a better orbital period of 0.187(3) d. Although Wargau et al. (1983) reported the similarity of the spectrum of IX Vel with that of the Z Cam star HL CMa, the lack of outbursts in the archival plates suggested a novalike variable. This reference was the first to classify IX Vel by long-term photometric history. The modern binary parameters (orbital period = 0.193927 d) were determined by Beuermann and Thomas (1990); Kubiak et al. (1999); Linnell et al. (2007).

Using the data in All-Sky Automated Survey (ASAS-3: Pojmański 2002), I found in 2018 that IX Vel is a low-amplitude Z Cam star (vsnet-chat 8199).[1] In this paper, I report analysis of IX Vel as a dwarf nova.

2 Results

2.1 Overall light curve

The light curve based on the ASAS-3 data is shown in figure 1. Most of the time, this object showed low-amplitude (up to 0.5 mag) quasi-cyclic variations. The object, however, showed standstills such as BJD 2453030–2453080 and 2454500–2454620. The light curve based on the All-Sky Automated Survey for Supernovae (ASAS-SN:

[1] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-chat/8199>.

Shappee et al. 2014; Kochanek et al. 2017) is shown in figure 2. Although some g-band observations of the ASAS-SN data were apparently affected by saturation (particularly after BJD 2459300 when there were a number of measurements below 10.0 mag), the overall variations are composed of phases of low-amplitude, quasi-cyclic variations and standstills as in the ASAS-3 data. The presence of standstills are more apparent in the ASAS-SN data (such as BJD 2457630–2457690 and BJD 2458440–2458630; the amplitudes in more recent data were also small, but this may have been affected by saturation). The overall features are sufficient to classify IX Vel as a Z Cam star.

2.2 Analysis of dwarf nova-type outbursts using two-dimensional Lasso

I used two-dimensional Least Absolute Shrinkage and Selection Operator (Lasso) method (Kato and Uemura 2012; Kato 2021) to study the variation of cycle lengths in the dwarf nova phases. The result for the ASAS-3 data is shown in figure 3. I used the window size and shift value of 200 d and 10 d, respectively. I had to use a relatively large window size due to the limited sampling rate of observations. During the interval BJD 2453400–2454300, dwarf nova-type variations were most apparent at frequencies 0.056–0.062 c/d, corresponding to cycle lengths of 16–18 d. The cycle lengths of dwarf nova-type variations varied fairly strongly, and they were around frequencies 0.071–0.078 c/d, corresponding to cycle lengths of 13–14 d in the interval BJD 2453000–2453200. During the latter interval, the signal in the two-dimensional Lasso spectrum was weaker compared to the former interval, which can be also seen as smaller amplitudes in the upper panel of the figure.

The middle panel of the figure shows the trend of the light curve obtained by locally-weighted polynomial regression (LOWESS: Cleveland 1979). This demonstrates a positive correlation between the brightness trend and the frequency of the dwarf nova-type variations. When the system was bright, there was a tendency that the cycle lengths were shorter and the amplitudes were smaller. It is also apparent from the figure that standstills occurred when the system was bright. It was a slight pity that the two-dimensional Lasso spectrum was rather fragmentary due to the presence of observational gaps. It looks likely that the cycle lengths would have been longer when the system was faint around BJD 2452300, but the lack of the data prevented me from drawing a conclusion.

The same type of analysis for the ASAS-SN data is shown in figure 4. In order to avoid the effect of saturation, I used only V data. Readers should keep in mind that the entire time interval of the figure is much shorter than the ASAS-3 data (figure 3). Thanks to the higher sampling rate of the ASAS-SN observations, I could use a smaller window size and shift value of 130 d and 5 d, respectively.

In the upper panel of the figure, the dwarf nova-type variations are clearly seen after BJD 2457700. The frequencies varied between 0.05 c/d (corresponding to a cycle length of 20 d) to 0.075 c/d (13 d). In contrast to the ASAS-3 data, this variation of the frequencies does not look like to positively correlate with the trend of the light curve. This result is based on a relatively short segment of data (700 d, compared to 2900 d in the ASAS-3 data) and needs to be treated with caution. I consider that the result from the ASAS-3 data is more reliable in discussing the correlation.

3 Discussion

The mechanism of transition between outbursting state and standstills in Z Cam stars is not still well understood. There has been a consensus that a subtle variation in the mass-transfer rate from the secondary causes transitions between outbursting state and standstills (Meyer and Meyer-Hofmeister 1983). This mechanism implies that the mean brightness during standstills is brighter than during outbursting state. In four of five "classical" Z Cam stars studied by Honeycutt et al. (1998), the standstills were as bright as or brighter (by 0.2 mag in some systems) than the mean brightness during outbursting states. The unusual standstills of SY Cnc were reported to be fainter than the mean brightness during outbursting intervals (Honeycutt et al. 1998). Whether standstills in Z Cam stars are universally brighter than outbursting states still needs to be investigated. As I have shown, the ASAS-3 data of IX Vel indeed show this tendency and this would be an additional support to the idea by Meyer and Meyer-Hofmeister (1983).

In the case of IX Vel, the mass-transfer rate appears to be close to the limit of thermal instability and when the mass-transfer rate is slightly below the critical value, dwarf nova-type outbursts occur. The mass-transfer rate, however, is only slightly below the critical value and only the outer part of the disk is thermally unstable (or the cooling wave cannot easily reach deeper into the inner region of the disk). This explains why the amplitudes of dwarf nova-type outbursts in IX Vel are so small. According to Dubus et al. (2018), the mass-transfer rate of

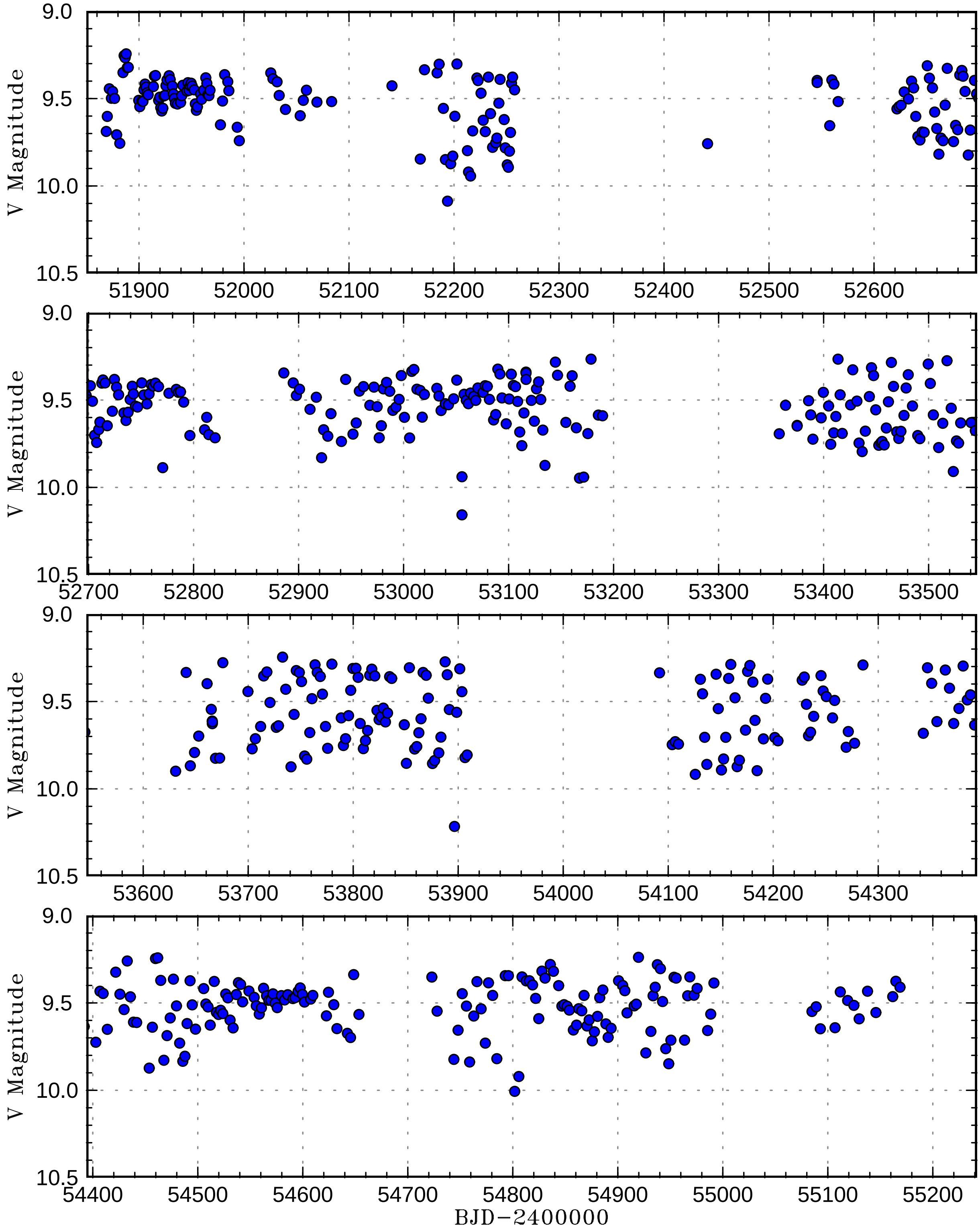

Figure 1: Light curve of IX Vel using the ASAS-3 database.

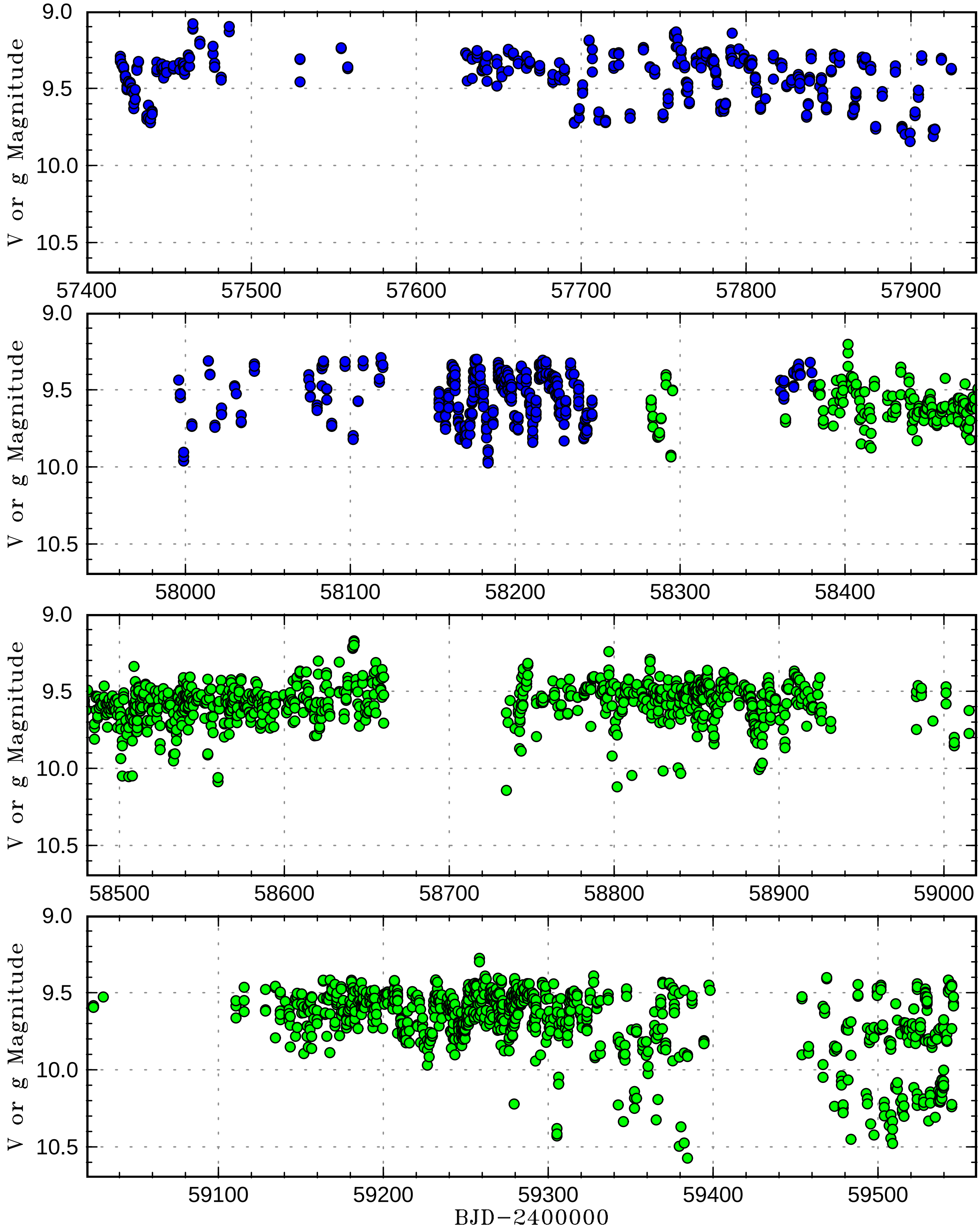

Figure 2: Light curve of IX Vel using the ASAS-SN database. Blue and green symbols represent V and g observations, respectively. Note that the scales are different from figure 1.

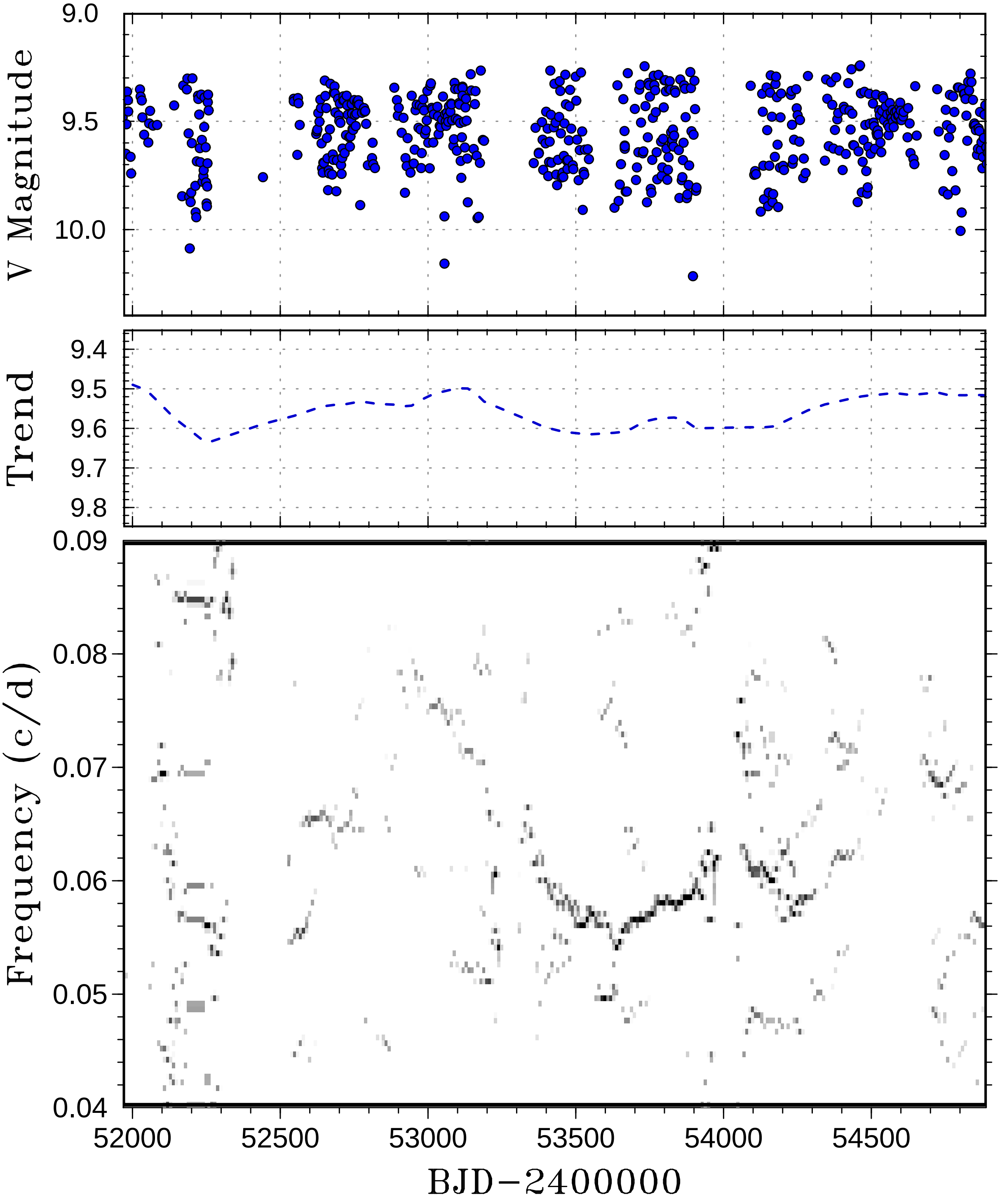

Figure 3: Period analysis of IX Vel using the ASAS-3 database. (Upper) Light curve. (Middle) Trend of the light curve using LOWESS. (Lower) Two-dimensional Lasso power spectrum. The window size and shift value are 200 d and 10 d, respectively.

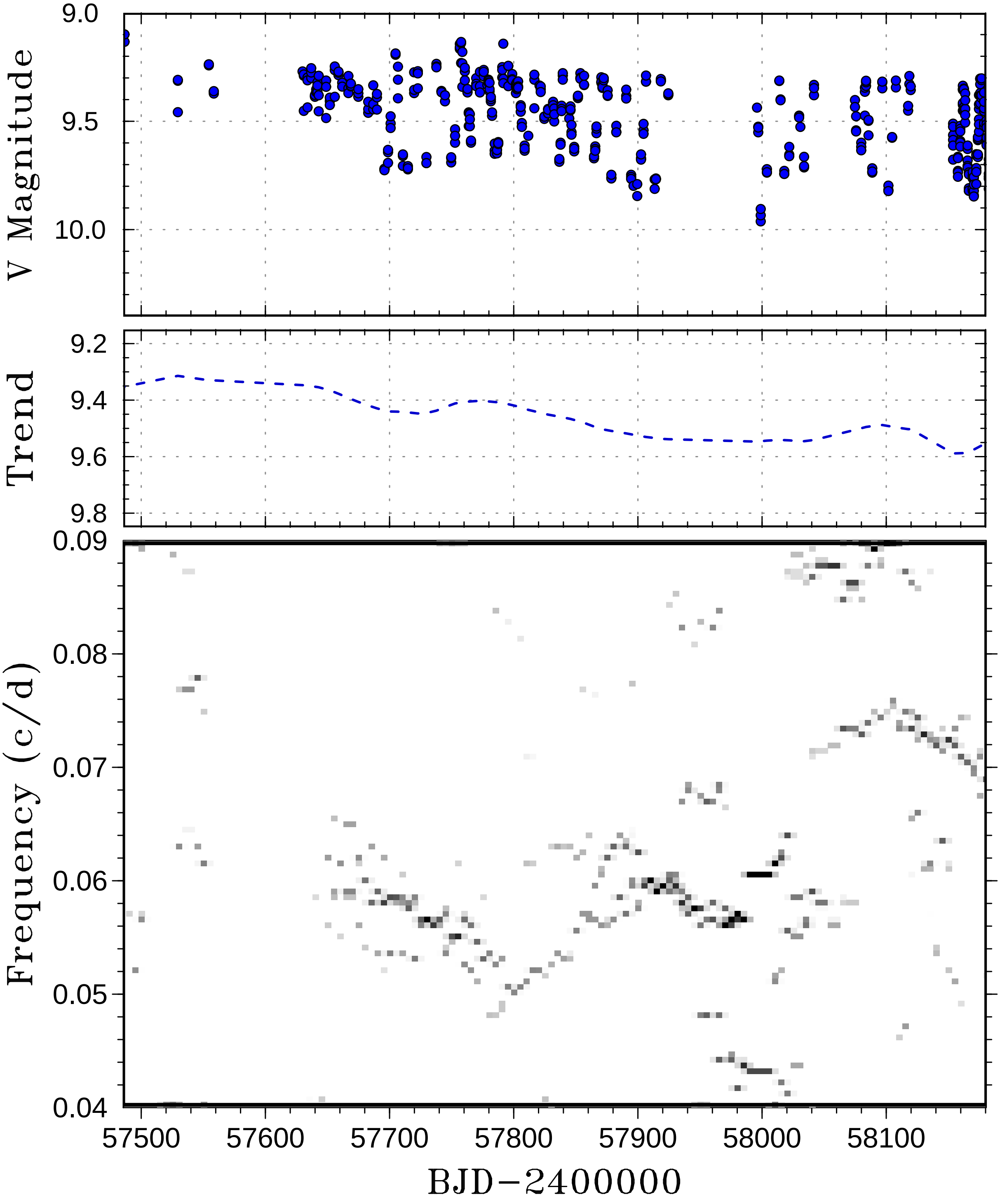

Figure 4: Period analysis of IX Vel using the ASAS-SN V data. (Upper) Light curve. (Middle) Trend of the light curve using LOWESS. (Lower) Two-dimensional Lasso power spectrum. The window size and shift value are 130 d and 5 d, respectively.

IX Vel using Gaia DR2 data (Gaia Collaboration et al. 2018)[2] is near the lower limit of the thermal stability and the above interpretation is consistent with the disk-instability theory.

Low-amplitude outbursts during standstills of "classical" Z Cam stars have also been documented, such as in Szkody and Mattei (1984); Kato (2001). These phenomena are likely the same as low-amplitude outbursts recorded in IX Vel.

Kimura et al. (2020) performed numerical simulations of dwarf nova outbursts (both in tilted and non-tilted disks) based on the thermal-viscous instability model (the simulation scheme was based on Ichikawa and Osaki 1992). In their simulations (figure 18 in Kimura et al. 2020), tilted disks are prone to thermal instability even under the condition of the mass-transfer rate high enough to keep the entire disk hot in a non-tilted disk. Their resultant light curve looks similar to that of IX Vel and it would be worth studying whether there is a signature of a disk tilt in this system.

The present observational knowledge of the behavior of the accretion disk near the border of the thermal instability might also be helpful in understanding the unusual behavior of IW And stars (Simonsen 2011; Hameury and Lasota 2014; Kato 2019; Kimura et al. 2020), which are also considered to have accretion disks near the border of the thermal instability.

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[2]The result is unchanged using Gaia EDR3 (Gaia Collaboration et al. 2021).

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