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The symbiotic binary ZZ CMi: Intranight variability and suggested outbursting nature

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Abstract

We present photometric and spectral observations of the symbiotic star ZZ CMi. We detect intranight variability—flickering and smooth variations in U band. The amplitude of the flickering is about 0.10 – 0.20 mag in U band. In the B band, the variability is lower, with amplitude ≤ 0.03 mag. We also detect variability in the $H\alpha$ and $H\beta$ emission lines, and find an indication for outflow with velocity of about 120–150 km/s. The results indicate that ZZ CMi is an accretion-powered symbiotic containing an M4-M6 III cool component with a white dwarf resembling recurrent novae and jet-ejecting symbiotic stars.

KEYWORD

stars: binaries: symbiotic – white dwarf – accretion, accretion disks – stars: individual: ZZ CMi

1 | INTRODUCTION

The symbiotic stars are interacting binaries with long orbital periods in the range from 100 days to more than 100 years. They consist of an evolved red or yellow giant transferring mass to a hot compact object (Mikołajewska 2012). The mass donor is a giant or supergiant of spectral class G-K-M. If the giant is an asymptotic giant branch star, the system usually is a strong infrared source. More than 250 Galactic symbiotic systems are known (Akras et al. 2019; Merc et al. 2019). Only a handful of them displays flickering activity (which is variability on a timescale of $\sim$ 10 min with amplitude $\sim$ 0.2 magnitude)—RS Oph, T CrB, MWC 560, Z And, V2116 Oph, CH Cyg, RT Cru, o Cet, V407 Cyg, V648 Car, and EF Aql. The last two were identified as flickering sources during the last decade: V648 Car (Angeloni et al. 2012) and EF Aql (Zamanov et al. 2017).

ZZ CMi (BD+09 1633) is not a well-understood object. Sanford (1947) classified it as an M6 star, noted the presence of variable $H\alpha$ emission, and shell-type absorption in $H\alpha$ giving a velocity of −40 km/s. Iijima (1984) noted the

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presence of high-excitation [Ne III] and [O III] emission lines on the objective prism spectra in 1982 and 1983 and classified it as a symbiotic star. Bopp (1984) pointed that ZZ CMi displays significant changes in emission lines and has spectroscopic and photometric characteristics similar to the symbiotic star EG And—weak emission lines and no IR excess. The orbital period of ZZ CMi seems to be about 440 days (Wiecek et al. 2010).

Here, we report optical photometry of ZZ CMi and detection of flickering in the Johnson U band. We also report a few spectra and find variability in the emission lines.

2 | OBSERVATIONS

CCD photometry[1] was obtained with the 60 cm telescope and the 50/70 cm Schmidt telescope of the Rozhen National Astronomical Observatory (NAO), Bulgaria and 1.23 m telescope of the Calar Alto observatory, Spain. The journal of the CCD photometry is given in Table 1. As comparison stars, we used TYC 764-474-1 (V 9.826, B 10.061, U 10.17) and TYC 763-411-1 (V 10.481, B 10.563, U 10.67). The check stars were TYC 764-314-1 and TYC 763-890-1. In addition, we have five optical spectra[2] of ZZ CMi secured with the ESpeRo Echelle spectrograph (Bonev et al. 2017) on the 2.0 m RCC telescope of Rozhen NAO (Table 2).

3 | RESULTS

3.1 | Intranight photometric variability

The results of our photometric observations are summarized in Table 1. Part of them is plotted in Figures 1 and 2.

For four runs, we measure the *SD* of ZZ CMi and ∼ 15 other stars in the field and plot it in Figure 2. The *SD* is calculated as

$$\sigma_{rms} = \sqrt{\frac{1}{N_{pts} - 1} \sum_i (m_i - \overline{m})^2}, \tag{1}$$

where $\overline{m}$ is the average magnitude in the run, N_{pts} is the number of the data points. σ_{rms} calculated in this way includes the variability of the star (if it exists) and the measurement errors. For non-variable stars, it represents the precision of the photometry. The *SD* for ZZ CMi (σ_{ZZ}) and *SD* of non-variable star (σ_{nv}) with similar brightness are given in the last column of Table 1. The results from photometric observations are:

1. Flickering variability is clearly visible in our observations in U band from November 19, 2011 (Figure 1a), November 9, 2020, (Figure 1c), and January 20, 2021. The amplitude is 0.27 mag, 0.13 mag, and 0.13 mag, respectively.
2. A decrease of the brightness in U band of 0.1 mag for 2 hr is visible in the observations on October 23, 2019, and October 24, 2019 (Figure 2). The simultaneous observations in these two nights do not indicate similar changes in the B band. It is likely that the red giant is the dominating source in the B band (Section 3.3).
3. In the observations from January 18, 2020 (Figure 1b), flickering is not clearly visible. The root-mean-square (Figure 3b) indicates that it exists; however, its amplitude is comparable with the observational errors.

The root mean square (rms) deviation of ZZ CMi is 2–5 times larger than that expected from observational errors, indicating that ZZ CMi is variable on a timescale of ∼ 1 hr. The presence of flickering in U band with the observed amplitude strongly suggests that the hot component is a white dwarf (see section 4.1 in Sokoloski & Bildsten 2010).

3.2 | Variability of the emission lines

In Table 2 are given the following parameters measured on our spectra—the equivalent width (EW) of $H\alpha$, the radial velocity of the central dip, the radial velocities of the blue and red peaks of $H\alpha$, the EW of $H\beta$, the radial velocities of the blue and red peaks of $H\beta$, and the radial velocity of the red giant. The accuracy of the EW is about ±5% and that of the velocity ±1 km s^{-1}. The EW($H\alpha$) is about −9 Å, which is similar to that of the recurrent nova T CrB in 1999 (Zamanov et al. 2005). Perhaps most intriguing is the profile of $H\alpha$ on December 30, 2017, which is of P Cyg type. The absorption has centrum at −85 km/s and extends to −145 ± 5 km s^{-1}. This indicates an outflow with velocity of about 120–150 km/s.

3.3 | System parameters

3.3.1 | Interstellar reddening E(B-V)

In our spectra, no signs of the diffuse interstellar bands at 5,780 Å, 5,797 Å, and 6,613 Å are visible, which implies that the interstellar reddening to ZZ CMi is low. The

[1] The photometric data are available as supporting online material at https://onlinelibrary.wiley.com/doi/10.1002/asna.202113975 or upon request to the authors.

[2] The spectra are available as supporting online material at https://onlinelibrary.wiley.com/doi/10.1002/asna.202113975 or upon request to the authors.

TABLE 1 Photometric observations of ZZ CMi

Date	Telescope	Band	UT start-end	Frames	m_{av}	Merr	Variability	σ_{ZZ}/σ_{nv}
February 11, 2011	60 cm Roz	B	23:29–00:33	71 × 30 s	11.52	0.004	No	0.013/0.011
		V	23:31–00:33	72 × 10 s	10.23	0.004	No	0.012/0.012
November 19, 2011	60 cm Roz	U	22:26–02:58	262 × 60 s	11.29	0.011	Yes, $\Delta U = 0.27$ mag	0.054/0.012
December 29, 2011	60 cm Roz	B	23:40–00:52	120 × 30 s	11.71	0.010	No	0.025/0.025
January 1, 2012	60 cm Roz	U	22:24–02:08	217 × 60 s	12.00	0.023	No (not good data)	0.030/0.028
January 2, 2019	60 cm Roz	V	23:03–02:36	400 × 30 s	10.55	0.003	No	0.005/0.005
October 22, 2019	2.0 m	V	23:27–01:23	277 × 3 s	10.10	0.008	No	0.010/0.010
October 23, 2019	50/70 cm Roz	U	00:20–03:47	115 × 60 s	11.78	0.009	Yes, $\Delta U = 0.15$ mag	0.027/0.011
		B	00:21–03:48	115 × 15 s	11.64	0.006	No	0.010/0.009
October 24, 2019	50/70 cm Roz	U	23:27–03:33	115 × 60 s	11.76	0.008	Yes, $\Delta U = 0.17$ mag	0.0435/0.0089
		B	23:27–03:32	115 × 60 s	11.66	0.007	No	0.010/0.010
December 11, 2019	123 cm	B	00:02–02:31	62 × 10 s	11.42	0.005	No	0.0081/0.0074
	Calar Alto	V	00:02–02:32	65 × 5 s	9.98	0.003	No	0.026/0.020
		U	00:06–02:28	58 × 60 s	12.39	0.009	Yes?, $\Delta U \approx 0.04$ mag	0.0141/0.0076
January 2, 2020	50/70 cm Roz	U	22:10–00:40	95 × 60 s	11.70	0.008	Yes, $\Delta U = 0.10$ mag	0.015/0.008
		B	22:10–00:40	97 × 10 s	11.61	0.006	Yes?, $\Delta B \approx 0.02$ mag	0.0093/0.0079
January 18, 2020	50/70 cm Roz	U	21:17–23:47	115 × 60 s	11.60	0.006	Yes?, $\Delta U \approx 0.04$ mag	0.011/0.006
February 2, 2020	50/70 cm Roz	U	21:15–22:16	100 × 30 s	11.43	0.015	No $\Delta U < 0.04$ mag	0.016/0.016
November 9, 2020	50/70 cm Roz	U	00:58–03:55	151 × 60 s	11.40	0.005	Yes, $\Delta U = 0.13$ mag	0.0269/0.0070
January 20, 2021	60 cm Roz	U	22:12–01:22	127 × 60 s	11.87	0.007	Yes, $\Delta U = 0.13$ mag	0.0304/0.0075
		B	22:13–01:23	127 × 60 s	10.98	0.004	Yes?, $\Delta B \approx 0.03$ mag	0.007/0.005

Note: In the table are given date, telescope, band, UT start-end, number of the frames and exposure time, average magnitude, typical observational error (merr), variability, and σ_{ZZ}/σ_{nv}.

TABLE 2 Spectral observations of ZZ CMi obtained with the 2.0 m telescope of Rozhen NAO

Date of observation (hh:mm)	Exp-time (min)	$H\alpha$ EW (Å)	$H\alpha$ V_r(abs) km s^{-1}	$H\alpha$ V_r(blue) km s^{-1}	$H\alpha$ V_r(red) km s^{-1}	$H\beta$ EW (Å)	$H\beta$ V_r(blue) km s^{-1}	$H\beta$ V_r(red) km s^{-1}	Red Giant km s^{-1}
December 31, 2017 00:49	60	−9.1	−85.5		+15.3	−4.43		3.3	−1.3
December 5, 2019 22:09	60	−9.2	−18.4	−67.4	+28.2	−2.59	−69.8	27.3	2.0
December 6, 2019 21:26	60	−10.1	−18.7	−68.1	+28.6	−2.23	−68.7	25.0	2.1
January 4, 2020 01:33	60	−8.9	−17.1	−62.1	+29.9	−5.13	−75.3	30.7	5.5
January 16, 2020 22:20	60	−8.8	−18.2	−59.9	+31.2	−4.14	−77.3	34.4	5.4

Note: In the table are given date of observation, exposure time (exp-time), parameters of $H\alpha$ line, parameters of $H\beta$ line, and radial velocity of the red giant.

upper limit of the expected reddening is E(B-V) ≤ 0.04. This upper limit is set from our spectra as well as from the interstellar reddening through the Milky Way calculated by IRSA: Galactic Reddening and Extinction Calculator in the NASA/IPAC Extragalactic Database.

3.3.2 | Red giant

GAIA DR2 (Bailer-Jones et al. 2018) gives a parallax 0.9686 ± 0.1097 mas, which means distance $d \approx 1030$ pc ($927 \leq d \leq 1165$ pc). ZZ CMi has V band magnitude in

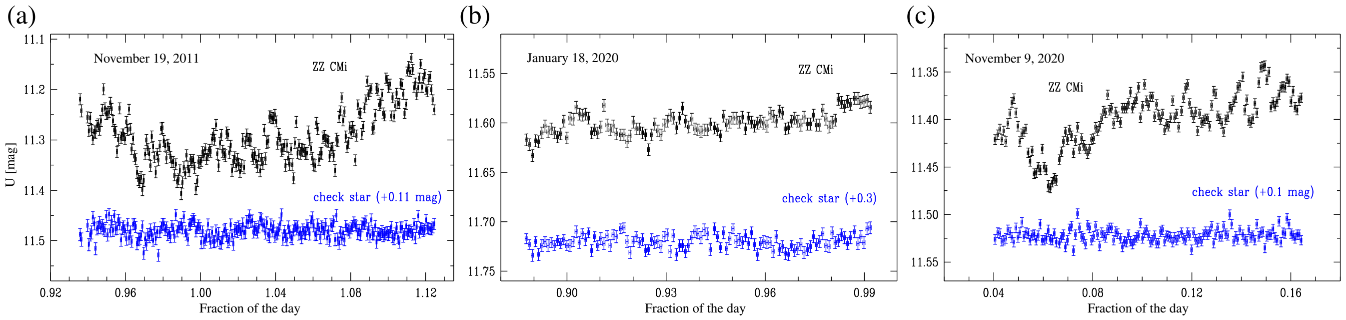

FIGURE 1 The symbiotic binary ZZ CMi—detection of flickering in Johnson U band on November 19, 2011, and November 9, 2020

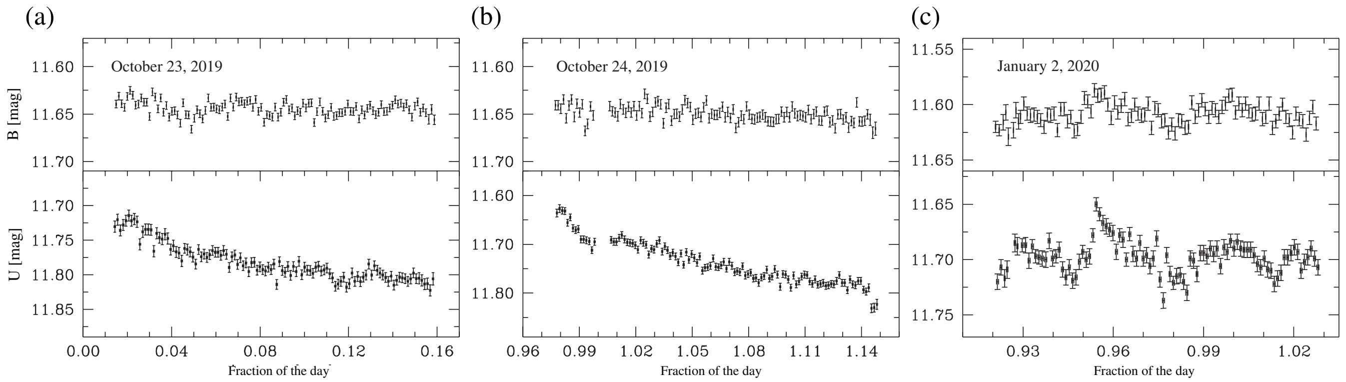

FIGURE 2 ZZ CMi—simultaneous U and B band observations. The intranight variability is clearly visible only in U band

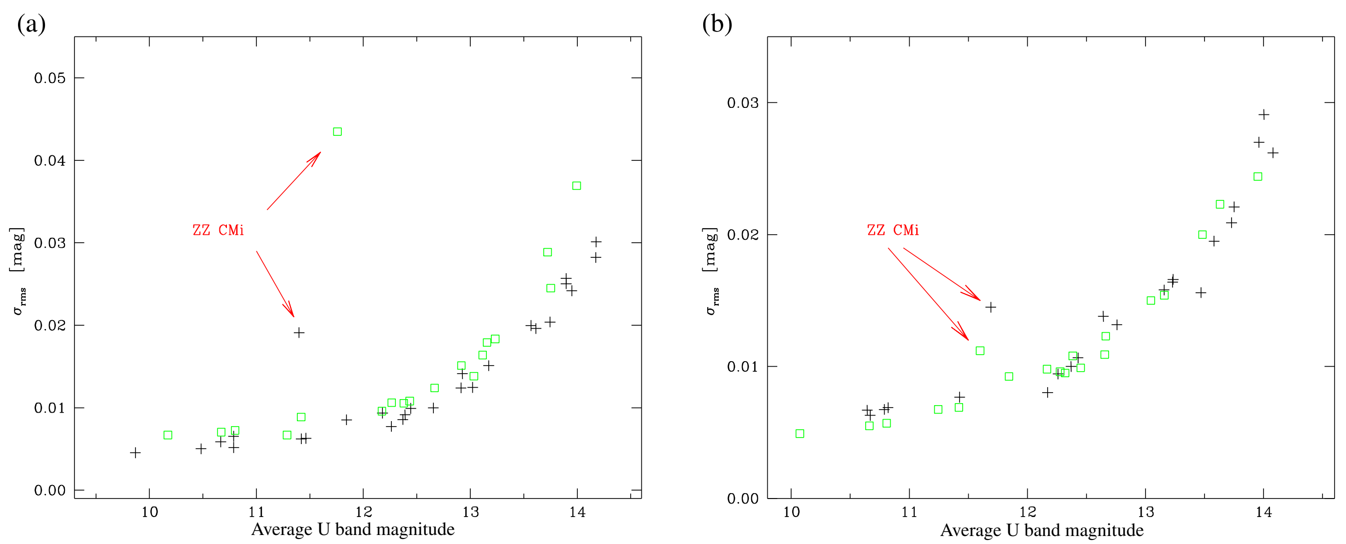

FIGURE 3 Root mean square deviation versus the average U-band magnitude. (a) The plus signs refer to the night November 9, 2020, and the squares to October 24, 2019. (b) The plus signs refer to the night 20,200,102 and the squares to January 18, 2020. The rms of ZZ CMi deviates from the behavior of the other stars, which indicates that it is variable during our observations

the range $9.5 \leq m_V \leq 10.5$. This gives absolute magnitude $-0.57 \leq M_V \leq 0.43$. SIMBAD gives M6I-IIep for ZZ CMi (Shenavrin et al. 2011). Taranova & Shenavrin (2001) suggest that the donor star is an M4.5-5 giant. For M5 stars, Straizys & Kuriliene (1981) give $M_V = -0.1$ for giants and M_V from -4.7 to -6.7 for supergiants. It means that the classification M4-6 III is more appropriate for the cool component of ZZ CMi.

It is worth noting that in a symbiotic binary a contribution to the V band from the accretion disk and the

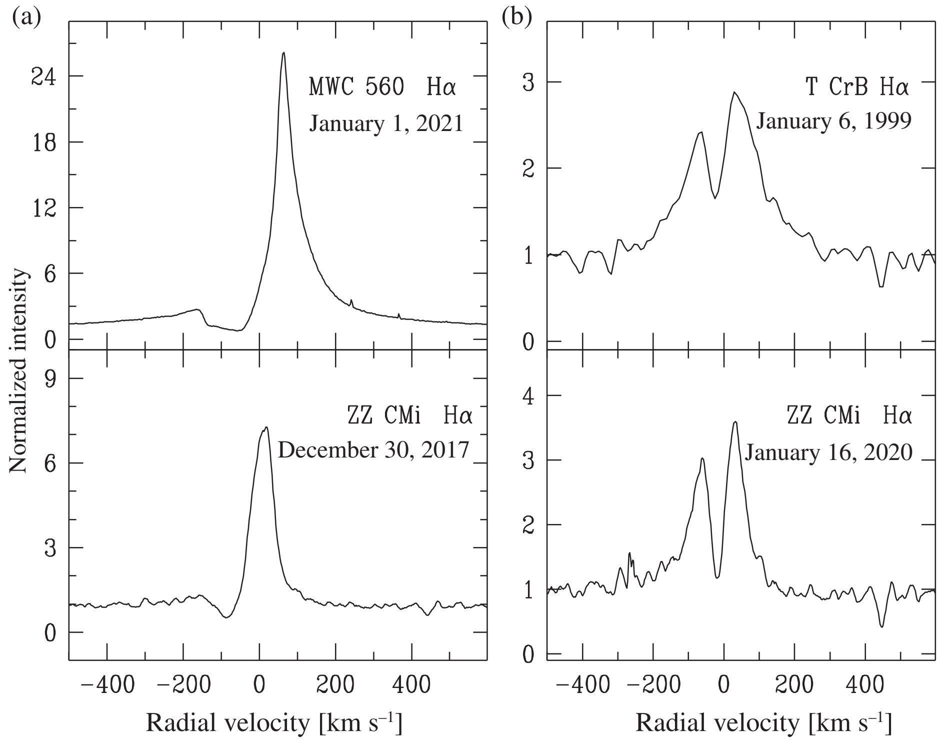

FIGURE 4 Comparison between the *Hα* emission lines of ZZ CMi, the jet-ejecting symbiotic star MWC 560 (a), and the recurrent nova TCrB (b)

nebula can be expected (Skopal 2005). However, in our observations, the flickering is not visible in V band, no [OIII] λ 5007 emission is detectable and the $H\alpha$ emission is weak. These suggest that the M giant is the dominating source in V band.

For an M6 giant, Houdashelt et al. (2000) gives U-V = 3.234 and B-V = 1.537. ZZ CMi has V band magnitude in the range $9.5 \le m_V \le 10.5$. This implies that the B band magnitude of the red giant is $11.0 \le m_B \le 12.0$ and its U band magnitude is $12.7 \le m_U \le 13.7$.

3.4 | Brightness in U band

For ZZ CMi the apparent magnitude in U band is in the range 11.15–12.3 mag. With $d \approx 1030$ pc and E(B-V) = 0, we estimate that the absolute U band magnitude lies in the range $-4.2 \le M_U \le -3.0$ mag.

For comparison, we can use the two symbiotic recurrent novae T CrB and RS Oph, the jet-ejecting symbiotic MWC 560 and the classical symbiotic stars AG Dra and Z And. For these objects, the long-term photometry is available in Sekeráš et al. (2019), Skopal et al. (1992, 1995, 2012), Tomov et al. (1996), and Zamanov & Zamanova (1997). For T CrB, the apparent magnitude in U band is in range $10.1 \le m_U \le 13.0$ mag. With GAIA parallax 1.213 ± 0.049 mas, and E(B-V) = 0.05 (Munari et al. 2016), we estimate $-4.7 \le M_U \le -1.8$ mag. For RS Oph, the apparent magnitude in U band is $10.1 \le m_U \le 13.0$ mag. With GAIA parallax 0.442 ± 0.053 mas and E(B-V) = 0.69 (Zamanov et al. 2018), we estimate $-8.8 \le M_U \le -6.6$ mag. For MWC 560, the apparent magnitude in U band is in the range $9.0 \le m_U \le 11.0$ mag. With GAIA parallax 0.3534 ± 0.1659 mas, and E(B-V) = 0.15 (Lucy et al. 2020) we estimate M_U from −9.0 to −7.0 mag. For AG Dra with GAIA parallax 0.3411 ± 0.0003 mas, apparent U band in the range $8.5 \le m_U \le 11.5$ (Leedjärv et al. 2004) and E(B-V) = 0.06 (Mikolajewska et al. 1995), we estimate $-9.2 \le M_U \le -6.2$ mag. For Z And with GAIA parallax 0.4866 ± 0.0005, apparent U band in the range $8 \le m_U \le 11$ and E(B-V) = 0.33 (Parimucha & Vaňko 2006), we estimate $-10.2 \le M_U \le -7.2$ mag.

This indicates that the luminosity of the hot component of ZZ CMi in U band is similar to that of T CrB.

4 | DISCUSSION

Rapid variability is a powerful tool to study the hot companions to cool red giants and asymptotic giant branch stars. The nature of the companion to Mira—the prototypical pulsating giant—has been a matter of debate for more than 20 years (Kastner & Soker 2004; Reimers & Cassatella 1985). The analysis of the rapid optical brightness variations in B band provided evidences that Mira B is a white dwarf (Sokoloski & Bildsten 2010). The observations of Y Gem show strong flickering in the UV continuum on timescales of 20 s, characteristic of an active accretion disk (Sahai et al. 2018). Rapid brightness variations can also be used to diagnose the state of the accretion disk—for example, CH Cyg (Sokoloski & Kenyon 2003).

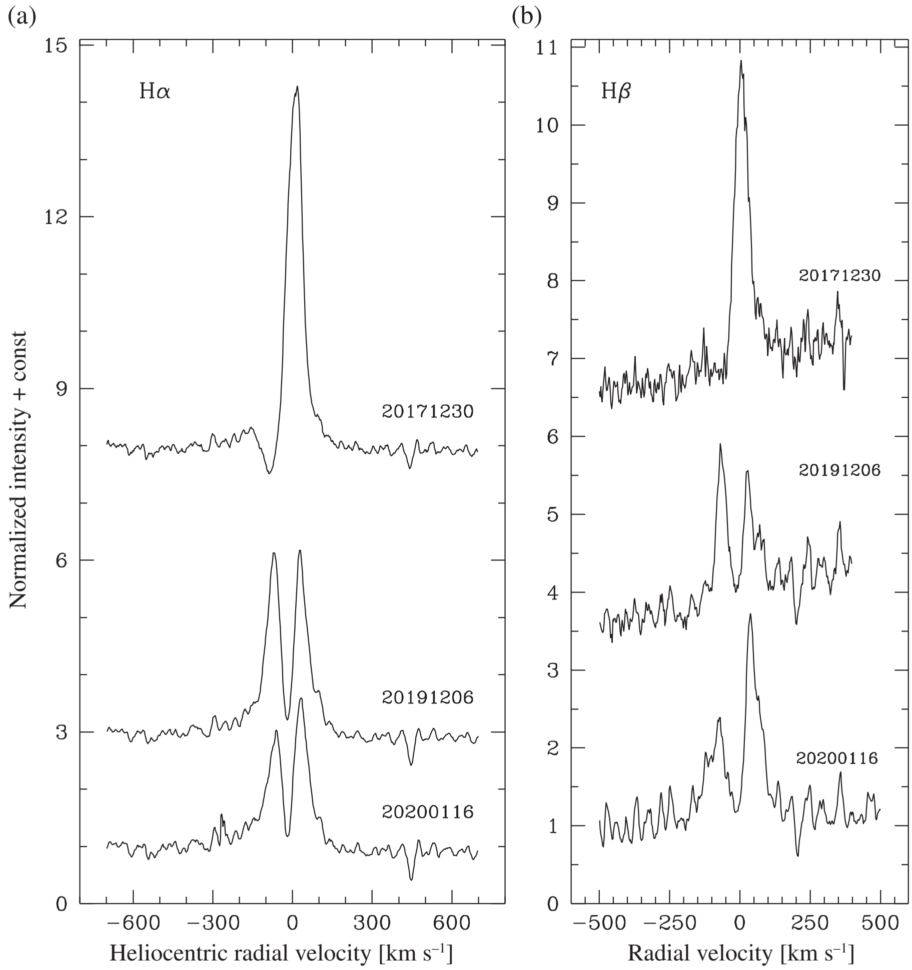

FIGURE 5 Variability of *Hα* and *Hβ* emission lines of the symbiotic star ZZ CMi

The first indication that ZZ CMi has intranight variability is given by Stoyanov (2012). These data and the new data presented here indicate that in ZZ CMi the flickering is difficult to detect in B band, because the amplitude of the intranight variability in B band is ≤ 0.04 mag. The intranight variability is visible in U band but sometimes with low amplitude. The searches for flickering by Dobrzycka et al. (1996) and Sokoloski et al. (2001) were performed in B band. Our results for ZZ CMi indicate that short time scale light variations in symbiotic binary stars have more chance to be detected in U and u′ bands. The smooth variation of the brightness of ZZ CMi on October 23, 2019, and October 24, 2019 (Figure 2) might be similar to the light curve of CH Cyg obtained on June 9, 1997 (see figure 1 of Sokoloski & Kenyon 2003), during which time the inner disk was probably disrupted.

Depending on the main source of the energy the symbiotics can be divided into two groups: (a) Symbiotics with steady nuclear burning, in which the mass accretion rate is high enough to maintain (fuel) steady nuclear burning; and (b) Accretion powered symbiotics, in which the mass accretion rate is below the limit of steady nuclear burning and the energy source is the accretion. The accretion-powered symbiotics can display recurrent nova outbursts—the best examples probably are RS Oph and T CrB (Anupama 2013) and collimated jets—for example, CH Cyg, MWC 560, and PN Sa 3-22 (Leedjarv 2004).

Flickering variability is a phenomenon typical for the cataclysmic variables (Bruch (1992) and references therein) and is also detected in the accretion-powered symbiotics. The only case when rapid variability is observed in a symbiotic with steady nuclear burning is the 22 min periodicity in Z And (Sokoloski & Bildsten 1999). This is probably due to the rotational period of a magnetic white dwarf, which somehow modulates the energy output of the nuclear burning.

Our expectations were that all the accretion-powered symbiotics should display flickering when the accretion disk is active. In accordance with these expectations, the flickering of the recurrent nova RS Oph disappeared after the nova outburst (Zamanov et al. 2006) and reappeared 240 days after it (Worters et al. 2007). The disappearance was in the low state when the accretion disk was destroyed by the nova outburst and the reappearance is a result of the resumption of the accretion. However, the disappearance of the optical flickering of CH Cyg (Sokoloski et al. 2010; Stoyanov et al. 2018) and of MWC 560 (Goranskij et al. 2018; Zamanov et al. 2020) in a bright state as well as the behavior of ZZ CMi indicate that there are different mechanisms that suppress the appearance of rapid optical fluctuations. These mechanisms might be (a) spherically symmetric accretion without the formation of an accretion disk or (b) the parts of disk where the flickering is generated are in a stable state, without fluctuations, although another mechanism might be at work.

In Figure 4 (a), we plot the $H\alpha$ emission line of ZZ CMi and the jet-ejecting symbiotic MWC 560. The $H\alpha$ emission line of ZZ CMi observed on December 30, 2017, resembles that of MWC 560 obtained recently. MWC 560 is a spectacular symbiotic having a jet along the line of sight (Tomov et al. 1990). The other spectra of ZZ CMi display double-peaked profiles of $H\alpha$ emission. This resembles those of T CrB in 1999 (Figure 4b) and can be considered coming from the accretion disk around the white dwarf. Another possible interpretation could be similar to that in Figure 3 by Tomov et al. (2013) and Figure 5 by Ikeda & Tamura (2004), where fitting with a few Gaussian components is applied.

ZZ CMi is also an X-ray active symbiotic from the β/δ-type (Luna et al. 2013), which means that there are two thermal X-ray components—soft and hard. The jet-ejecting symbiotic stars CH Cyg and MWC 560, which also display optical flickering are of the same X-ray type.

Inspection of the position of ZZ CMi in the NRAO VLA Sky Survey (Condon et al. 1998) reveals no radio source detection with a 3 sigma upper limit of 1.6 mJy at 20 cm. The 150 MHz radio sky survey with the Giant Metrewave Radio Telescope (Intema et al. 2017) also does not detect ZZ CMi with a 3 upper limit of 8 mJy. Future radio mapping with more sensitive interferometers would thus be desirable.

With the similarities between T CrB and ZZ CMi noted above, it may be worthwhile to look for long-term variability of the latter system in the photographic archives.

5 | CONCLUSIONS

We report detection of intranight brightness variations from the symbiotic star ZZ CMi. In three nights—November 19, 2011, November 9, 2020, and January 20, 2021—flickering with amplitude ≥ 0.12 mag in U band is observed. This is typical for accreting white dwarfs. On two other nights, a smooth trend (0.1 mag for 2 hr) in brightness is visible. The spectra indicate that an outflow with velocity ~ 120 km s^{-1} is present sometimes. In our opinion, ZZ CMi is an interesting object similar to outbursting sources that deserve more attention from observers.

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