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Letter

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Optical spectroscopic monitoring of the symbiotic star MWC 560 before and after the 2018 unpredicted brightening

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Abstract

MWC 560 (V694 Mon) is classified as a symbiotic binary consisting of a white dwarf and an M5III red giant. In this object, a very-high-speed component, thought to be a jet, has been reported in the hydrogen Balmer line. We have been conducting long-term spectroscopic monitoring since the brightening in 2016 February. An irregular rebrightening was reported by Goranskij et al. (2018, Astronomer's Telegram, 12227), who also showed that the high-velocity absorption component was not seen on 2018 November 16. Our low-resolution spectroscopic observations showed no high-velocity absorption component on 2018 November 14, and wide emission lines in Balmer line region (Hα, Hβ). However, high-resolution spectroscopy revealed the presence of slow, weak absorbing components and an emission wing on 2018 December 25. MWC 560 began to brighten in 2018 November, and it is gradually brightening as of 2020 April 14. For the absorption component, we propose a shell expansion of a classical symbiotic nova that occurred in 2016. During the 2018 brightening a new emission wing with $v_{\mathrm{FWHM}} \approx 700\,\mathrm{km\,s^{-1}}$ was confirmed, which could be triggered by disk instability like a dwarf nova. This paper summarizes the results of long-term monitoring observations and the recent changes in MWC 560.

Key words: binaries: symbiotic — novae, cataclysmic variables — stars: individual (MWC 560)

1 Introduction

MWC 560 (V694 Mon) is a symbiotic star discovered by Merrill and Burwell (1943). Tomov et al. (1990) observed a complex profile in the hydrogen Balmer line (Hβ), and found that it fluctuated on a time scale of several days. The brightness of MWC 560 was 9.65 mag, and the P Cygni profile was observed in its emission line. The maximum outflow velocity was about $-6000\,\mathrm{km\,s^{-1}}$. This object was presumed to have ejected the jet in the line of sight. According to Tomov and Kolev (1997) in the observing season months after the 1990 outburst peak, the outflow was very slow at velocities from -130 to $-320\,\mathrm{km\,s^{-1}}$. After that, a velocity component of -1580 to $-2140\,\mathrm{km\,s^{-1}}$ was observed (e.g., Kondratyeva & Rspaev 2012).

Photometric observations were performed by many observers and professional astronomers. Doroshenko, Goranskij, and Efimov 1993 investigated a periodic component in the light curve of MWC 560. Gromadzki et al. (2007) examined the evolutionary stage of the red giant star by near-infrared photometric observations, and they proposed that the low-temperature star of MWC 560 is in the TP AGB-phase. Figure 1 shows the V-band light curve of MWC 560 from 1990 to 2020 as reported to AAVSO (the American Association of Variable Star Observers). The first brightening and three recent brightening events investigated in this paper are labeled as (i) 1990, (ii) 2016, (iii) 2018, and (iv) 2019.

Long and short periods were reported for MWC 560. The long period of 1860–1930 d would be the orbital period of this binary (e.g., Doroshenko et al. 1993). The short period of 331–340 d would be the pulsation period or the ellipsoidal variation of the red giant (e.g., Gromadzki et al. 2007). If the light curve is related to the orbital period of 1930 d, the next brightening event would be observed in 2021. However, in 2018 November, irregular brightening was reported by Goranskij et al. (2018). Additionally, Munari et al. (2016) discussed the periods, and the orbital period is not well established. The purpose of this study is to elucidate the cause of this irregular brightening based on our low- and high-dispersion optical spectral monitoring.

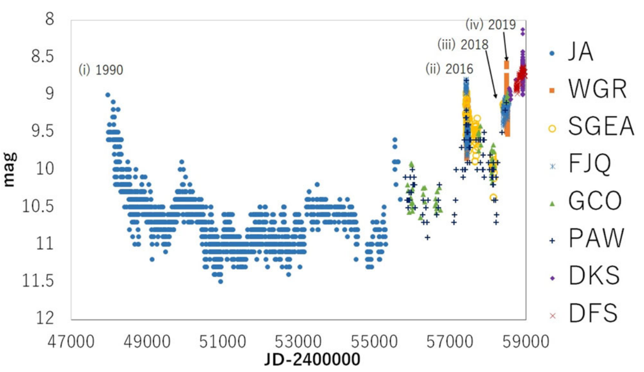

Fig. 1. Light curve of MWC 560 from 1990 April 5 to 2020 September 1 as reported to AAVSO. The data are color coded by observers: Albert Jones (blue circles), Gray Walker (orange square), Geoffrey Stone (yellow ring), James Foster (blue asterisk), Carlo Gualdoni (green triangle), Alan Plummer (blue plus sign), Shawn Dvorak (purple diamond), and Sjoerd Dufoer (red cross). (Color online)

2 Observations and data analysis

2.1 Low-resolution spectroscopic observations

We obtained 79 optical spectra with two telescopes: the Okayama University of Science Observatory 28 cm telescope and the Funao Observatory 36 cm telescope. Each telescope is equipped with an SBIG spectroscope DSS-7 and an SBIG CCD camera (ST-402 or ST-1603). The wavelength range covers 3800–7800 Å, with a spectral resolution of $R = 400$. The exposure time is between 20 s and 60 s. The data reduction was performed using the Bespec free software package (developed by Bisei observatory researcher K. Kawabata). The observation log is presented in table 1.

2.2 High-resolution spectroscopic observations

We obtained 11 optical spectra by using HIDES (HIgh Dispersion Echelle Spectrograph; Izumiura 1999) with a fiber feeding system (Kambe et al. 2013) on the 188 cm telescope at the Okayama branch of the Subaru Telescope of the National Astronomical Observatory of Japan (NAOJ). HIDES is a cross-dispersed echelle spectrometer currently with a mosaic of three 2k × 4k CCDs at its focal plane, which enables simultaneous coverage of the wavelength range 3800–7600 Å, and provides a spectral resolution of $R = 50000$ for the combination of a 100 μm core fiber and an image slicer for it. Each exposure time was 300 s. The wavelength calibration for each echelle spectrum was done using a thorium–argon lamp before and after the science spectrum. The data reduction was performed using

Table 1. Observation log.

Observation season	Number of observations
2016/3/26–2016/5/12	10 nights
2016/10/10–2017/4/14	17 nights
2017/11/25–2018/4/8	43 nights
2018/11/14–2019/4/3	7 nights
2019/11/21–2020/1/21	2 nights

Table 2. Observation log for HIDES.

Year	Observational date
2018	12/25, 12/29
2019	1/3, 1/8, 1/12, 1/21, 1/27

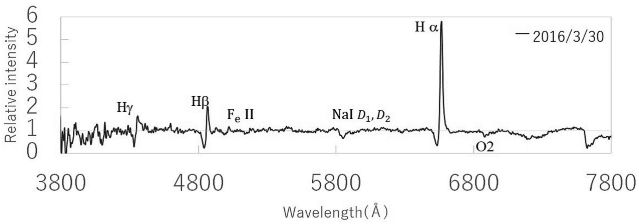

Fig. 2. Spectrum on 2016 March 30, observed at Okayama University of Science Observatory during the brightening in 2016. The wavelength range is from 3800 to 7800 Å. The vertical axis is relative intensity.

the IRAF package. The HIDES observation log is shown in table 2.

3 Results

3.1 Optical low-resolution spectra

Figure 2 shows the spectrum obtained by using a low-dispersion spectrometer at Okayama University of Science Observatory at the time of brightening in 2016. In this paper, we normalize the continua of the spectra to unity. In the obtained spectrum, the hydrogen Balmer lines (Hα, Hβ, and Hγ) with a P Cygni profile and the emission line of Fe II were mainly seen.

As shown in figure 3, the spectrum gradually changes. The data for 2017 November 25 showed a clear high-velocity absorption component, but on 2018 April 8 (middle), the absorption line was slightly shallower. The high-velocity absorption component disappeared in the spectrum on 2018 November 14 (top). Such a change was reported by Goranskij et al. (2018); in the spectrum of 2017 November 25, hydrogen Balmer lines with weak high-velocity absorption components were observed, but in the spectrum of 2018 November 16, no high-velocity absorption components are seen. The asymmetric Balmer line profile was described as a broad emission line shoulder.

3.2 Optical high-resolution spectra

After the disappearance of high-velocity absorption components, we made follow-up observations using HIDES on the Okayama 188 cm telescope. Figure 4 shows five spectra around Hα from 2018 December 25 to 2019 January 27 (the time series is from bottom to top). From this result, it was found that a low-velocity absorption component was confirmed at around 6560 Å, and its absorption line depth was shallower.

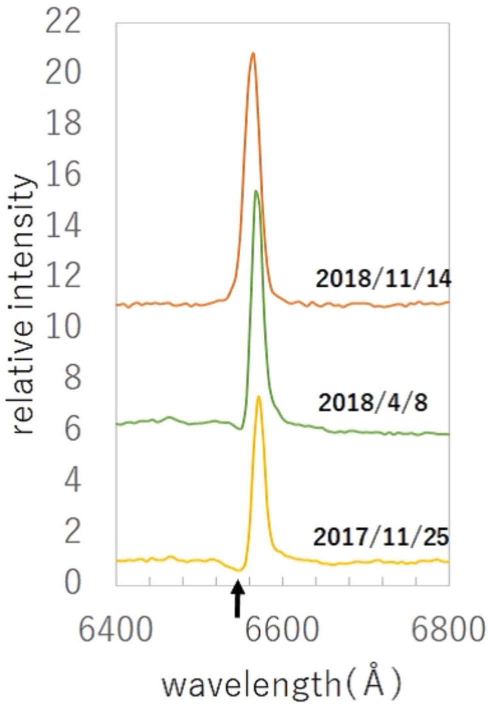

Fig. 3. Spectra for 2017 November 25 (bottom), 2018 April 8 (middle) and 2018 November 14 (top). The absorption line is denoted by an arrow. (Color online)

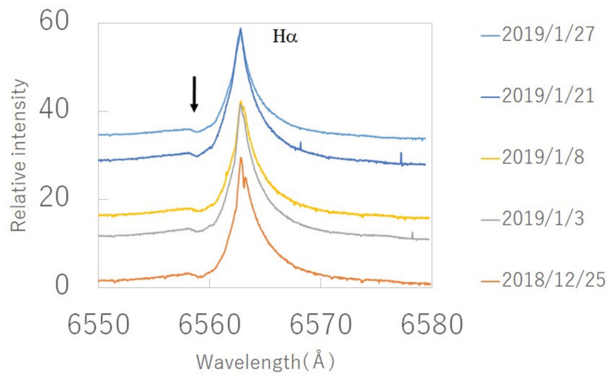

Fig. 4. Spectra obtained by high-dispersion spectroscopy. The spectra around Hα from 2018 December 25 to 2019 January 27 are shown. The wavelength range is 6550 to 6580 Å. The vertical axis is the relative intensity. The spectra were shifted with the elapsed days. The arrow denotes the absorption component. (Color online)

Figure 5 is an enlarged view of the Hα emission line on 2018 December 25. The velocity of the emission line peak was adjusted to 0 km s^{-1}. There seem to be three components in the Hα emission: a weak high-velocity component and a bright main component, and a blue absorption component. The weak high-velocity component is fitted by a Gauss curve of $v_{\rm FWHM} \approx 700$ km s^{-1} in figure 5. This weak component (wing) could be a new one from 2018

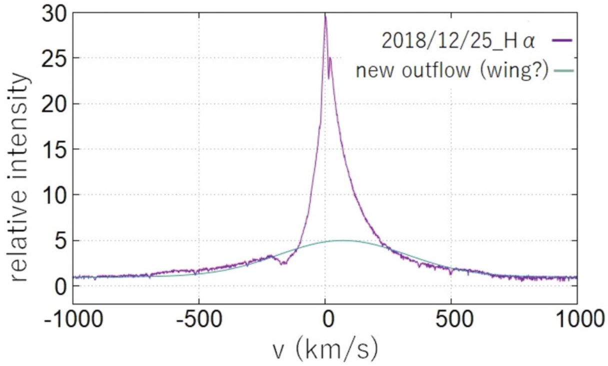

Fig. 5. Enlarged view of the Hα emission line on 2018 December 25 obtained by high-dispersion spectroscopy. The horizonal axis is velocity. The vertical axis is relative intensity. The purple line is the Hα line. The green line is the Gauss fitting for the Hα wing. (Color online)

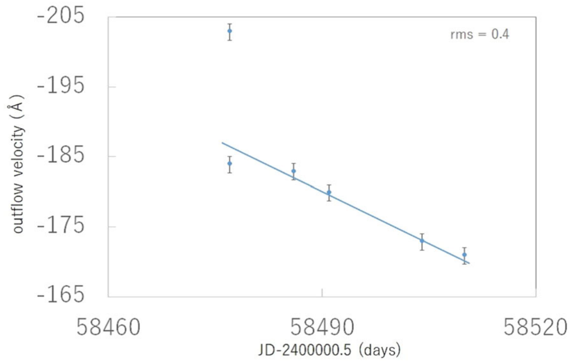

Fig. 7. Outflow velocity from 2018 December 25 to 2019 January 27 obtained from high-dispersion spectroscopic observations. Corresponds to (iv) in figure 6. The velocity slowed down by about 0.5 $\mathrm{km\,s^{-1}}$ per day. (Color online)

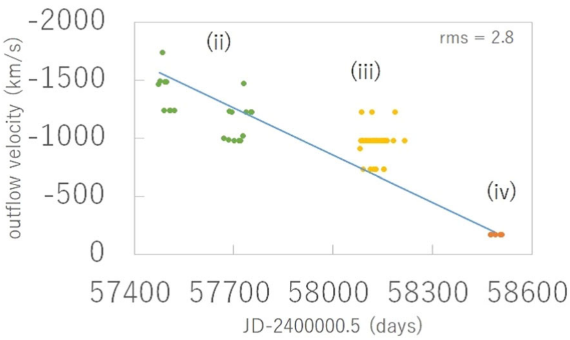

Fig. 6. Outflow velocity from 2016 March 26 to 2019 January 27. The velocities for (ii)–(iii) and (iv) are obtained by low- and high-resolution spectral observations, respectively. The point dispersion corresponds for (ii)–(iii) to the accuracy of the low resolution ($\Delta v \cong 250\,\mathrm{km\,s^{-1}}$). (Color online)

December. In addition, a double peak was seen in the spectrum only on 2018 December 25. Figure 6 shows the outflow velocity from 2016 to 2020, and a linear fitting was performed on the time variation of the velocity. The Roman numbers correspond to those in figure 1. We also use the term outflow velocity in the same way as previously (e.g., Iijima 2002), which is the difference between the absorption and emission peaks. The outflow velocities were (ii) about $-1400\,\mathrm{km\,s^{-1}}$ in 2016, (iii) about $-1000\,\mathrm{km\,s^{-1}}$ in 2018, and (iv) less than $-200\,\mathrm{km\,s}$ in 2019. It slowed down by about $1\,\mathrm{km\,s^{-1}}$ per day. Figure 7 shows the outflow velocity from 2018 December 25 to 2019 January 27. Both the velocities of the double peaks are plotted on 2018 December 25. Goranskij et al. (2018) also reported a similar low-velocity component in their 2018 November 16 spectrum.

4 Discussion

What caused the early 2016 and irregular 2018 brightening, and what is the origin of the slow outflow velocity? We focused on 2018 November, the brightest month in the history of the observation, the second brightest month in 2016 February, and the third in 1990.

MWC 560 showed an absorption line with a strong emission line of hydrogen in 1990 (Tomov et al. 1990). Its line profile suggested a strong outflow with velocity reaching $-6000\,\mathrm{km\,s^{-1}}$. Since the velocity of the absorption line was non-stationary, the jet must be in the direction of the line of sight. The outflow was very slow at -130 to $-320\,\mathrm{km\,s^{-1}}$ between 1990 December and 1991 March (Tomov & Kolev 1997). According to Zamanov et al. (2011), the optical flickering had disappeared between 1990 October and 1991 March. In 2016, MWC 560 became the second brightest in history, and the outflow velocity still decreased to $-1700\,\mathrm{km\,s^{-1}}$ (figure 6). The outflow gradually slowed down to $-1000\,\mathrm{km\,s^{-1}}$ in 2018 April. Until 2018 April, the high-velocity absorption component was constantly observed. However, after the observational season of this object, the spectrum changed at the beginning of the next season. The high-velocity absorption component became invisible with low-dispersion spectroscopic observations after 2018 November, and the bottom of the emission line showed a shoulder shape. On the other hand, a low-velocity absorption component was observed by the high-dispersion spectroscopic observations, which was too slow to resolve with low-dispersion spectroscopy. Goranskij et al. (2018) reported the disappearance of flickering in 2018 October, and Zamanov et al. (2019) indicated that the optical flickering was still missing on 2019 October 22. These are only the second times in the history of MWC 560 that flickering has been reported to disappear. The intense brightening and very slow absorption component in 1990 and 2016 might be related.

The previous observations and our own suggest that the following three types of outflow have been observed so far in MWC 560 (a schematic view is shown in figure 8):

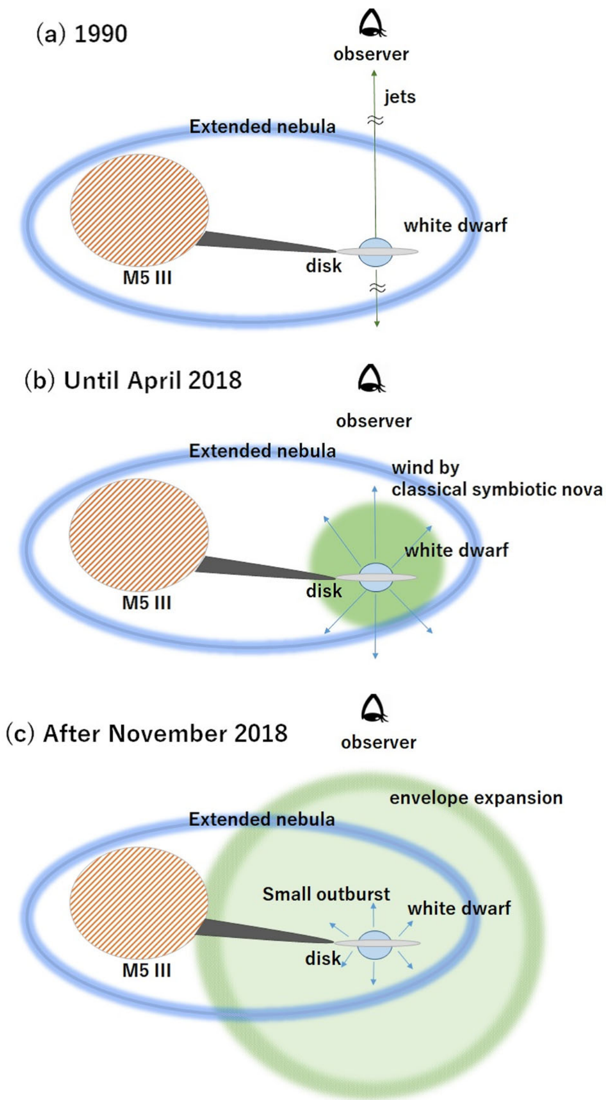

Fig. 8. Schematic view of the outflow for the last three periods of light intensification proposed from observations. (Color online)

(a) A fast outflow (jet) in the line-of-sight direction was observed during the 1990 brightening. The non-stationary P Cygni profile suggested jets (Tomov et al. 1992). (b) The outflow observed from the 2016 brightening, which brightened rapidly and gradually faded out over about two years as shown in figure 1, is considered to be a shell expansion due to a classical symbiotic nova, because the velocity of the absorption component was slowing down by about $1\,\mathrm{km\,s^{-1}}$ per day. (c) As described in subsection 3.2, a new emission wing was confirmed after 2018 November, and its v_{FWHM} is about $700\,\mathrm{km\,s^{-1}}$. It might be a new outflow component. On this phase, the previous absorption component was simultaneously observed.

Symbiotic stars can be divided into symbiotic novae and classical symbiotic novae based on their activity (Mikolajewska 2011). Symbiotic novae are thermonuclear novae in symbiotic binary stars. Classical symbiotic novae are caused by thermal pulses or shell flashes (Kenyon & Truran 1983) and disk instabilities for dwarf nova (Mikolajewska et al. 2002). We supposed that the 2016 outburst was a classical symbiotic nova triggered by disk instability, and the expanding shell formed. Shell ejections have also reported in classical symbiotic outburst. In addition, the 2018 outburst is thought to have been caused by a disk instability due to a temporary increase in mass transfer. The shell formed during the 2016 outburst had expanded to become optically thin at the time. These behaviors of MWC 560 resemble combined novae, which combine elements of dwarf and classical novae (Sokoloski et al. 2006). Thus, a unique phenomenon was captured at this time. It is necessary to pay attention to this object in the future.

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