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Spectroscopic observations of the symbiotic recurrent nova V407 Cygni

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Abstract. The symbiotic star V407 Cyg performed a large amplitude outburst in March 2010. The time for two magnitudes decline was 6.1 day and the colour at two magnitudes below maximum was (B−V)=0.59 ± 0.03. The absolute maximum luminosity $M_V = -8.9$ mag and the interstellar extinction E(B−V)=0.61 ± 0.05 are derived with these results. The distance to the object is estimated to be about 7 kpc. The coronal emission lines [Fe X] 6374 and [Ar XI] 6919 emerged and grew rapidly in intensity about 20 days after light maximum. The other forbidden lines [O I], [O III], [N II], and [Fe II] strengthened suddenly about 50 days after light maximum. The super-soft X-ray flux and the intensities of the coronal emission lines showed nearly contemporaneous variations. On the other hand, the intensities of the emission lines of highly photo-ionized ions, which were related to the temperature of the white dwarf, varied with different manners. These results suggest that the super-soft X-rays were not due to the thermal radiation of the white dwarf at least in the phase of their maximum flux, but were more probably due to the collisional shock front of the ejecta with the circumstellar envelope. The helium abundance in the ejecta is estimated to be N(He)=0.20 ± 0.03.

Key words. Stars: individual – V407 Cyg – Stars: novae, cataclysmic variables

1. Introduction

V407 Cyg has been classified as a symbiotic star, because composite spectra were observed (Merrill & Burwell 1950; Herbig 1960). A semi-regular light variation with a period of about 750 days was known (Meinunger 1966; Munari et al. 1990; Kolotilov et al. 1998; Kiziloglu & Kiziloglu 2010). This object performed a large amplitude outburst in March 2010 (Maehara 2010), which resembled to those of classical novae. Thus, this object is now classified as a recurrent nova with a red giant secondary (Munari et al. 2011; Shore et al. 2011), that is, a member of the subclass of recurrent novae consists of T CrB, RS Oph, V745 Sco etc. We will call them as symbiotic recurrent novae, because they are indeed symbiotic stars in the quiet stage. In this paper, some topics on the outburst of V407 Cyg in 2010 are reported.

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2. Light curve and the distance

The V and visual magnitudes and (B−V) colour collected in the VSNET are plotted in Fig. 1. The results of a single observer with the code name Mhh are used to minimize the personal effects.

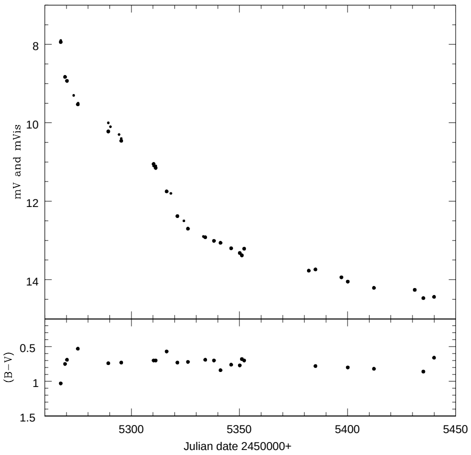

Fig. 1. The V (large dots) and visual (small dots) magnitudes and (B−V) of V407 Cyg.

The light maximum was 6.8 mag of the unfiltered CCD band at 2010 March 10.81 U.T. (Nishiyama & Kabashima 2010). We determine this as time zero with a Julian date 2455266.31. The first V band photometry was made one day after and obtained m_V=7.94 mag at March 11.85 U.T. (Maehara 2010). We estimated the V magnitude at maximum to have been m_V=7.2 mag with an extrapolation of the light curve.

This object faded by two magnitudes during 6.1 day, and the colour at two magnitudes below maximum was (B−V)=0.59 ± 0.03 (Fig. 1). The absolute magnitude at light maximum is estimated to be M_V = −8.9 mag using the formula of Della Valle & Livio (1995). van den Bergh & Younger (1987) found that classical novae have roughly same colours at two magnitudes below maxima, of which average is $(B-V)_0$ = −0.02 ± 0.04. Thus, the interstellar extinction to this object is likely E(B−V)=0.61 ± 0.05. This result agrees with that of Munari et al. (1990), E(B−V)=0.57, in the limit of the error, while Shore et al. (2011) found a lower value E(B−V)=0.45 ± 0.09 in the analyses for the diffuse interstellar absorption bands. The effects of the interstellar extinction are corrected by E(B−V)=0.6 in this paper.

The distance to this object is estimated to be about 7 kpc, where the interstellar absorption is A_V = 3.1×E(B−V)=1.86 mag. This distance is much larger than those reported in the previous works, e.g., 2.7 kpc by Munari et al. (1990) or 1.9 kpc by Kolotilov et al. (1998). These small distances were derived under the assumptions that the cool component in this object was a Mira variable and the light variation with the period of about 750 days was owing to its pulsation. Herbig (1960) reported that only Hδ was in emission among the hydrogen Balmer lines in his spectrum. Therefore, the cool component is likely a pulsating variable star. It is, however, not sure whether the light variation with the period of about 750 days was really owing to its pulsation. If the light variation is owing to the pulsation, the irregular Balmer decline do appear every 750 days, which is not confirmed yet. The light variation of a long period binary system with mass transfer is sometimes confused with that of a Mira variable. Further spectroscopic and photometric observations are needed.

3. Spectral evolution

Low resolution spectra $\lambda/\Delta\lambda \cong 1000$ were obtained with a Boller & Chivens grating spectrograph mounted on the 122 cm telescope at Asiago Astrophysical Observatory. High resolution spectra $\lambda/\Delta\lambda \cong 10000$ were obtained with a Reosc Echelle spectrograph mounted on the 182 cm telescope at the Mount Ekar station of the Astronomical Observatory of Padova. The spectra were reduced using the standard tasks of NOAO IRAF package at Asiago Observatory. A log of the observations is given in Table 1.

3.1. Intensities of selected emission lines

Intensities of selected emission lines relative to Hβ=100 observed on April 9 and May 18 are given in Table 2. The intensities of the coronal emission lines and the super-soft X-ray flux were nearly maxima on the former date, while the maximum intensities of the emission lines of highly photo-ionized ions, He II, O IV, and

Table 1. Log of spectroscopic observations.

Date 2010	UT	JD	Inst.	Range nm
March 14	4:30	5269.7	B&C	456-697
March 15	4:18	5270.7	”	”
March 15	4:30	”	”	345-583
March 16	4:15	5271.7	”	”
March 16	4:35	”	”	490-730
March 24	4:21	5279.7	Ech	435-612
March 28	4:05	5283.7	B&C	534-775
April 2	3:29	5288.7	”	340-578
April 2	4:12	”	”	540-780
April 6	3:47	5292.7	”	340-578
April 6	4:00	”	”	530-773
April 8	4:02	5294.7	”	445-696
April 9	3:42	5295.7	”	461-702
April 22	3:33	5308.7	Ech	435-612
April 30	1:47	5316.6	”	”
May 7	2:59	5323.6	”	516-685
May 18	1:55	5334.6	B&C	445-685
May 23	2:01	5339.6	Ech	493-665

JD: Julian date – 2450000.
UT: Universal time at start of exposure.

[Fe VII], were observed on the latter date. The results on the other dates will be reported in a forth coming paper. The effects of the interstellar extinction are corrected by E(B−V)=0.6. The errors in the intensities are about ±10%, but the errors in those of [Fe X] 6374 are large, because it was blended with the emission lines of Si II 6373, [O I] 6364, and Fe II 6369. In particular, its error on May 18 is large as indicated by an error bar in Fig. 2, because it was blended with the much stronger emission line of [O I] 6364. The values with larger errors are denoted by a colon.

The intensities of selected emission lines relative to Hβ=100 are plotted in Figs. 2 and 3. As seen in Fig. 1, there was a bend on the light curve about 50 days after light maximum. The vertical broken lines in Figs. 2 and 3 indicate the date of the bend.

As seen in Fig. 2, the coronal emission lines [Fe X] 6374 and [Ar XI] 6919 emerged and grew rapidly in intensity about 20 days after light maximum (JD2455286). On the other hand, the emission lines of the highly photoionized ions O IV 6106 and [Fe VII] 6085 grew in intensity about 50 days after light maximum. The emission line of He II 4686 showed a nearly linear growth in intensity. The intensities of the other forbidden lines are shown in Fig. 3. These lines started strengthen

Table 2. Intensities of selected emission lines relative to Hβ = 100 corrected by E(B−V)=0.6.

λ_{obs} Å	ID	A I(λ)	B I(λ)
4473	He I4471,[Fe II]4475		18.8
4490	Fe II 4489.2,4491.4		13.2
4583	Fe II 4583.8		23.6
4630	Fe II 4629.3	6.5	13.8
4640	N III 4640.6,41.9	5.8	10.0
4686	He II 4685.7	11.2	40.4
4815	[Fe II] 4814.6	1.4	19.8
4861	Hβ	100	100
4924	Fe II 4924,He I 4922	10.2	32.3
4959	[O III] 4958.9	1.7	28.3
5007	[O III] 5006.8	6.4	90.1
5018	Fe II 5018,He I 5016	12.6	48.1
5110	[Fe II] 5111.6,5108.0	0.6	10.6
5159	[Fe II] 5158.8	3.5	50.8
5274	[Fe II]5273,Fe II5276	6.9	40.5
5316	Fe II 5316.6	9.7	29.3
5334	[Fe II] 5333.7	1.5	18.9
5411	He II5412,[Fe II]5413	1.8	12.0
5526	[Fe II] 5527.3	0.6	14.8
5534	Fe II 5535,N II 5535	4.2	5.9
5756	[N II] 5754.8	5.7	91.8
5876	He I 5875.6	12.7	24.1
6087	[Fe VII] 6085.5	0.8:	6.0
6106	O IV 6105.9†	1.9	7.4
6300	[O I] 6300.2	3.1	70.2
6347	Si II 6347.1	3.3	4.5
6363	[O I] 6363.9	0.7:	25.2
6373	[Fe X] 6374.5	9.1	7.4:
6548	[N II] 6548.1		32.5
6563	Hα	1100	1580
6583	[N II] 6583.6		94.4
6667	[Ni II] 6668.2	0.3	5.2
6678	He I 6678.1	3.5	7.1
6916	[Ar XI] 6919	0.7	

A: 2010 April 9, JD2455295.7.
B: 2010 May 18, JD2455334.6.
†: The unidentified emission line at 6105.5Å in the catalog of Meinel et al. (1968) was identified as O IV 4s2P^0 – 4p2S at 6105.9Å by Iijima (2009).

suddenly about 50 days after light maximum (JD2455316).

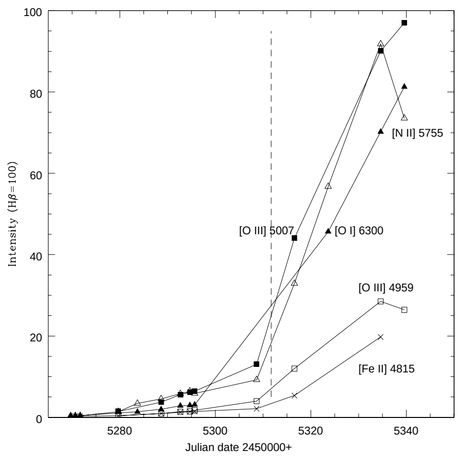

Fig. 3. Intensities of the emission lines of [O I] 6300 (solid triangle), [Fe II] 4815 (cross), [N II] 5755 (open triangle), [O III] 4959 (open square), and [O III] 5007 (solid square).

3.2. Super-soft X-rays

The super-soft X-ray flux of this object rapidly increased between the 10th and 20th days from light maximum, and its peak was found 30 days after light maximum (Shore et al. 2011). The super-soft X-ray flux and the intensities of the coronal emission lines showed nearly contemporaneous variations. On the other hand, the intensities of the emission lines of the highly photo-ionized ions He II, O IV, and [Fe VII] varied with clearly different manners (Fig. 2). The nearly contemporaneous variations of the super-soft X-rays and the coronal lines were observed also on the outburst of RS Oph in 2006 (Iijima 2009).

The intensity ratio of He II 4686 to Hβ was 0.112 on April 9 (Table 2). The super-soft X-ray flux was nearly maximum at that time (Shore et al. 2011), but we have a surface temperature of the white dwarf roughly 100,000 K with this intensity ratio using the formula of Iijima (2006). This temperature seems to be too low to supply the observed super-soft X-ray flux. The intensity ratio of He II 4686 to Hβ increased after that time (Fig. 2), and the temperature of the white dwarf was about 140,000 K on May 18 (Table 2). The super-soft X-ray flux, however, decreased to about one-fourth during the same period (Shore et al. 2011). These results suggest that the super-soft X-rays unlikely due to the thermal radiation of the white dwarf at least in the phase of their maximum flux. The coronal emission lines and the super-soft X-rays were more probably due to the shock front owing to the collision of the ejecta with the circumstellar envelope.

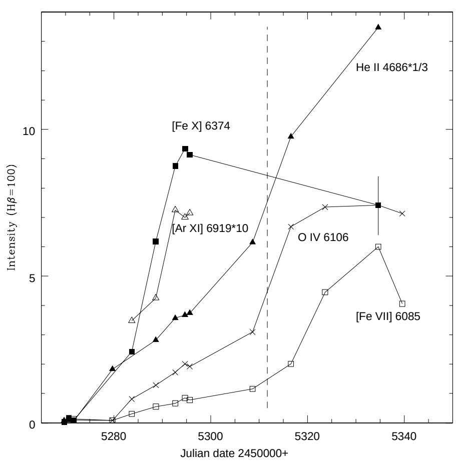

Fig. 2. Intensities of the emission lines of [Fe X] 6374 (solid square), [Ar XI] 6919 (open triangle), He II 4686 (solid triangle), O IV 6106 (cross), and [Fe VII] 6085 (open square). The intensity of [Fe X] 6374 at JD2455334.6, May 18, has a large error as indicated by an error bar. The vertical broken line indicates the date of the bend on the light curve.

When the bend was observed on the light curve (Fig. 1), the shock front on the ejecta likely reached the outer boundary of the circumstellar envelope. Thus, the density in the ejecta fell down according to the free expansion in the interstellar space, which resulted the rapid strengthening of the forbidden lines. The coronal lines and the super-soft X-rays faded probably as a result of the dissipation of the collisional shock front.

3.3. Outflow velocity

The full widths at half maxima of the emission lines of Hα and He I 5876 were about 1500 km s^{-1} five days after light maximum on the outburst of V407 Cyg. The widths of the same emission lines of RS Oph at the same phase on the outburst in 2006 were about 1800 km s^{-1} (Iijima 2009). The lower outflow velocity of V407 Cyg may have related to the scarce and rather weak coronal lines with respect to the rich coronal lines up to [Fe XIV] 5303 of RS Oph (Iijima 2009).

3.4. Nitrogen flash and helium abundance

The emission lines of N III appear and grow rapidly in intensity when classical novae fade by 3.5 mag from light maxima, which is called as *Nitrogen flash* (McLaughlin 1960). The intensity of the emission complex around 4640Å by N III lines exceeds that of Hβ in some novae. The luminosity of this object was roughly 3.5 mag below maximum on April 9 (Fig. 1). However, the intensity of the emission complex around 4640Å was only 5.8% of Hβ (Table 2). Its maximum intensity relative to Hβ was found on May 18 (Table 2), but it was 10% of Hβ even at that time. The lack of the nitrogen flash is a characteristic in the spectral evolution of this object.

The helium abundance in the ejecta is estimated to be N(He)=0.20 ± 0.03 with the intensities of the emission lines of He I 5876, 6678, and He II 4686 on May 18 (Table 2), where the formulae are given by Iijima (2006).

4. Discussion

MARGARITA HERNANZ: You mentioned "non thermal super-soft emission". Could you clarify what do you mean?

TAKASHI IIJIMA: The super-soft X-rays were unlikely due to the thermal radiation of the white dwarf, but were more probably emitted in the collisional shock front on the ejecta.

DMITRY BISIKALO: What are the gas velocities changed in the system during the outburst?

TAKASHI IIJIMA: The FWHM of Hβ are given by $3590 \times t^{-0.54}$ km s^{-1} in the first 30 days of the outburst, where t is the number of days from light maximum.

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