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A PREDICTION OF SUPERSOFT X-RAY PHASE OF CLASSICAL NOVA V5583 SAGITTARII

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ABSTRACT

We have observed the fast nova V5583 Sagittarii with five B, V, y, R_C, and I_C bands, and found that these multi-band light curves are almost identical with those of V382 Vel 1999 until at least ~ 100 days after outburst. A supersoft X-ray phase of V382 Vel was detected with *BeppoSAX* about six months after outburst. V5583 Sgr outbursted a few days ago the discovery on 2009 August 6.5 UT near its optical peak. From a complete resemblance between these two nova light curves, we expect a supersoft X-ray phase of V5583 Sgr six months after outburst. Detection of supersoft X-ray turn-on/turnoff dates strongly constrain the evolution of a nova and, as a result, mass range of the WD. For a timely observation of a supersoft X-ray phase of V5583 Sgr, we have calculated nova outburst evolution based on the optically thick wind theory, which predicts the supersoft X-ray phase: it will most probably start between days 100 and 140 and continue until days 200 – 240 after outburst. We strongly recommend multiple observations during 2009 December, and 2010 January, February, and March to detect the turn-on and turnoff times of the supersoft X-ray phase of V5583 Sgr.

Subject headings: binaries: close — novae, cataclysmic variables — stars: individual (V382 Velorum, V5583 Sagittarii) — white dwarfs — X-rays: stars

1. INTRODUCTION

Classical novae are a thermonuclear runaway event on a white dwarf (WD) in a binary system, in which the WD accretes hydrogen-rich matter from the companion star. When the accreted matter reaches a critical value, hydrogen at the bottom of the WD envelope ignites to trigger a shell flash. Just after the nova outburst, the envelope on the WD rapidly expands to a giant size and optically thick winds blow. Then the photosphere gradually shrinks whereas the total luminosity is almost constant during the outburst. Thus, the photospheric temperature $T_{\rm ph}$ increases with time. The main emitting wavelength region moves from optical to ultraviolet and finally to supersoft X-ray (e.g., Kato & Hachisu 1994).

Thus, classical novae become a transient supersoft X-ray source in a later phase of the outburst, but their X-ray detections are rather rare mainly because of sparse observing time of X-ray satellites (e.g., Krautter et al. 1996; Orio et al. 2001a; Ness et al. 2007a). If the turn-on/turnoff dates of the supersoft X-ray are detected, we are able to constrain the evolution of hydrogen shell-burning on the WD and, as a result, the mass range of the WD (e.g., Hachisu & Kato 2006, 2009, 2010; Hachisu et al. 2007). Therefore detection of a supersoft X-ray phase of a nova provides us with rich information on the WD.

V5583 Sgr is a fast classical nova, discovered on 2009 August 6.5 UT by K. Nishiyama and F. Kabashima at mag ~ 7.7 (Nishiyama et al. 2009). Their survey frames on July 22.5 and 29.6 UT showed nothing at this position (limiting mag 12.7), and nothing is visible on Digitized Sky Survey images. The ASAS3V images showed $V = 7.78$ on August 6.2 UT (Nishiyama et al. 2009).

We started multi-band photometric observation of V5583 Sgr from one day after the discovery, i.e., from August 7.5 UT. To our surprise, the observed multi-band light curves are almost identical with those of V382 Vel, which is also a fast classical nova outbursted in 1999. A supersoft X-ray phase of V382 Vel was clearly detected with the X-ray satellite *BeppoSAX* about six months after the outburst. From the perfect resemblance between these two novae, we expect a supersoft X-ray phase of V5583 Sgr similar to that of V382 Vel. In this Letter, we have calculated a supersoft X-ray phase for V5583 Sgr, and predict turn-on/turnoff dates for timely detection.

In the next section (Section 2), we briefly describe our multi-band photometric observation of V5583 Sgr. Section 3 introduces our model of nova light curves based on the optically thick wind theory and summarizes numerical results for prediction of a supersoft X-ray phase. Discussion follows in Section 4.

2. OBSERVATION

Optical observation was started one day after the discovery (Nishiyama et al. 2009). Each observer and their observational details are listed in Table 1. Maehara started observa-

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TABLE 1
OBSERVATIONS

name of observer	location	telescope aperture	observed bands	No. of obs. nights
Kiyota	Mayhill, USA	30cm	B, V, R_c, I_c	8
Kiyota	Moorook, Australia	25cm	B, V, R_c, I_c	6
Maehara	Kyoto, Japan	25cm	B, V, y, R_c, I_c	23

tion on August 7 and obtained 23 nights data for five bands of B, V, y, R_C, and I_C (until 2009 November 3). Kiyota obtained four bands of B, V, R_C, and I_C for 14 nights starting from 2009 August 8 (until 2009 October 18). The magnitudes of this object were measured by using the local standard star, HD 321237 with $V = 11.683$ and $B-V = +0.198$ (Kiyota) from AAVSO (the American Association of Variable Star Observers), or TYC 7395-2150-1 with $V = 9.80$ and $B-V = +0.50$ (Maehara) from Tycho catalog.

Our observational results are plotted in Figure 1 for four bands of B, V, R_C, and I_C of V5583 Sgr together with the B, V, R, and I light curves of V382 Vel. We have added other observational points available in VSOLJ (the Variable Star Observing League of Japan) and AAVSO archives. It is very clear that these two nova light curves are almost identical with each other. Here we assume that the outburst day of V5583 Sgr is $t_{\rm OB}$ =JD 2455048.0 (2009 August 4.5 UT).

From the almost complete resemblance between these two novae, we can deduce various features of the classical nova V5583 Sgr. (1) V5583 Sgr is probably a neon nova because V382 Vel was identified as a neon nova (Woodward et al. 1999). (2) The chemical composition of nova ejecta is similar to that of V382 Vel obtained by Shore et al. (2003) and Augusto & Diaz (2003). (3) A supersoft X-ray phase will be detected about six months after the outburst similarly to the V382 Vel case (Orio et al. 2002). (4) The interstellar extinction is calculated to be $E(B-V) = 0.33$ from

$$\begin{aligned} & [E(B-V)]_{\rm V5583\ Sgr} - [E(B-V)]_{\rm V382\ Vel} \\ & = [(B-V)-(B-V)_0]_{\rm V5583\ Sgr} - [(B-V)-(B-V)_0]_{\rm V382\ Vel} \\ & = (B)_{\rm V5583\ Sgr} - (B)_{\rm V382\ Vel} + (V)_{\rm V5583\ Sgr} - (V)_{\rm V382\ Vel} \\ & = 4.83 - 4.7 = 0.13 \end{aligned} \tag{1}$$

together with $E(B-V) = 0.2$ for V382 Vel (Shore et al. 2003). Here we assume that the intrinsic color of $(B-V)_0$ is the same between V5583 Sgr and V382 Vel. (5) The distance modulus of V5583 Sgr is estimated from the comparison between the two nova brightnesses. Since the distance modulus of V382 Vel is already known to be $(m-M)_V = 11.5 \pm 0.1$ (Hachisu & Kato 2010) and the difference between the two nova brightnesses is $\Delta V = 4.7$ from Figure 1b, we obtain $(m-M)_V = 16.2 \pm 0.1$ for V5583 Sgr. (6) Therefore the distance to V5583 Sgr is estimated to be $d \sim 11 \pm 1$ kpc from $(m-M)_V = 5 \log(d/10) + A_V$ and $A_V = 3.1 E(B-V) = 1.0$. These values are summarized in Table 2.

3. MODEL LIGHT CURVES AND SUPERSOFT X-RAY PHASE

The decay phase of novae can be followed by a sequence of steady-state solutions (e.g., Kato & Hachisu 1994). Using the same method and numerical techniques as in Kato & Hachisu (1994), we have followed evolutions of novae by connecting steady state solutions along the decreasing envelope-mass sequence. The mass of the hydrogen-rich envelope is decreasing due to wind mass-loss and nuclear burning. We solve a set of equations, consisting of the continuity, equation of motion, radiative diffusion, and conservation of energy, from the bottom of the hydrogen-rich envelope through the photosphere assuming spherical symmetry. Winds are accelerated deep inside the photosphere so that they are called "optically thick winds."

TABLE 2
PHYSICAL PROPERTIES OF V5583 SGR

subject	symbol		present work
nova type	...	...	neon nova
extinction	$E(B-V)$	...	0.33
absorption in V-band	A_V	...	1.0
distance modulus	$(m-M)_V$	...	16.2 ± 0.1
distance	d	...	11 ± 1 kpc
WD mass	$M_{\rm WD}$	...	$1.23 \pm 0.05\ M_\odot$
supersoft X-ray on	$t_{\rm X-on}$	...	120 ± 20 days
supersoft X-ray off	$t_{\rm X-off}$	...	220 ± 20 days

We have calculated nova light curves of V5583 Sgr in the same way as for V382 Vel (Hachisu & Kato 2010). Supersoft X-ray light curves are calculated assuming blackbody spectrum with the photospheric temperature, $T_{\rm ph}$, for the energy range of 0.2–0.6 keV (see, e.g., Hachisu & Kato 2009). The UV 1455Å band is also useful to follow nova evolutions and to determine WD masses (e.g., Cassatella et al. 2002; Hachisu & Kato 2006, 2010; Kato et al. 2009), although they are not available both for V382 Vel and V5583 Sgr.

For optical and near IR light curves, flux at the frequency ν is estimated from free-free emission spectrum, Equation (9) of Hachisu & Kato (2006), i.e.,

$$F_\nu \propto \frac{\dot{M}_{\rm wind}^2}{v_{\rm ph}^2 R_{\rm ph}}, \tag{2}$$

during the optically thick wind phase, where $\dot{M}_{\rm wind}$ is the wind mass-loss rate, $v_{\rm ph}$ the wind velocity at the photosphere, and $R_{\rm ph}$ the photospheric radius, all of which are taken from our optically thick wind solutions. After the optically thick wind stops, the total mass of the ejecta remains constant in time. The flux from such homologously expanding ejecta is estimated from Equation (19) of Hachisu & Kato (2006), i.e.,

$$F_\nu \propto t^{-3}, \tag{3}$$

where t is the time after the outburst.

We assume that the chemical composition of hydrogen-rich envelope is similar to that of V382 Vel and adopt a set of $X = 0.55$, $Y = 0.30$, $Z = 0.02$, $X_{\rm CNO} = 0.10$, $X_{\rm Ne} = 0.03$, based on the composition analyses for V382 Vel by Shore et al. (2003) and by Augusto & Diaz (2003) (see Table 1 of Hachisu & Kato 2006). We plot our model free-free and X-ray light curves in Figure 2. Hachisu & Kato (2010) estimated the WD mass of V382 Vel to be $M_{\rm WD} = 1.23 \pm 0.05\ M_\odot$ and the supersoft X-ray turn-on/off times of $t_{\rm X-on} \sim 120$ days and $t_{\rm X-off} \sim 220$ days as shown in Figure 2 and as listed in Table 2. Errors come from ambiguity of the chemical composition.

Because the two nova light curves are almost identical, our light curve fitting of V5583 Sgr gives similar results. We obtain the supersoft X-ray phase of V5583 Sgr to be days 120–220, i.e., the supersoft X-ray phase lasts from early December of 2009 until mid March of 2010. Since the supersoft X-ray phase has already started in our estimate, urgent X-ray observation is required.

4. DISCUSSION

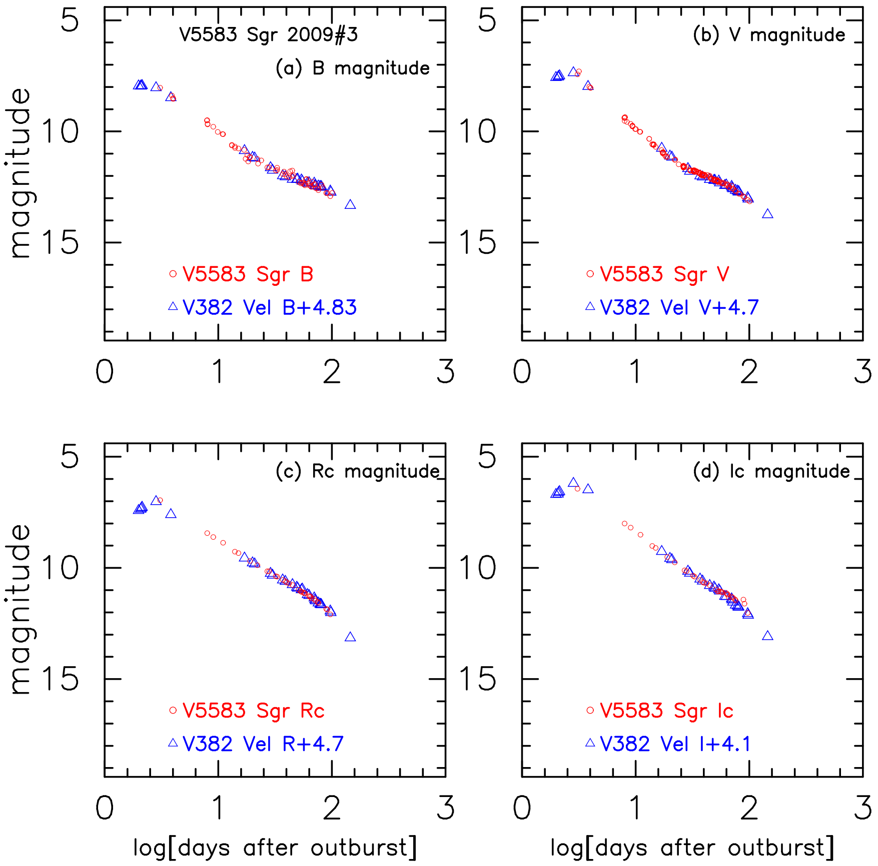

FIG. 1.— Our four multi-band (B, V, R_C, and I_C) optical light curves for V5583 Sgr together with those of V382 Vel 1999. Observational V382 Vel data of B, V, R, and I are taken from IAU Circulars 7176, 7179, 7196, 7209, 7216, 7226, 7232, 7238, and 7277. Here we assume the outburst day of $t_{\rm OB}$ =JD 2455048.0 (2009 August 4.5 UT) for V5583 Sgr, and $t_{\rm OB}$ =JD 2451319.0 (1999 May 20.5 UT) for V382 Vel (Hachisu & Kato 2010).

TABLE 3
DISTANCE AND ABSORPTION OF NOVAE[a]

object	...	$(m-M)_V$[b]	A_V	distance (kpc)	discovery satellite	ref.[c]
V1281 Sco 2007#2	...	17.8	2.17	13	Swift	1
V458 Vul 2007	...	17.0	1.86	11	Swift	2
V597 Pup 2007#1	...	16.9	0.93	16	Swift	3
V2467 Cyg 2007	...	16.3	4.65	2.2	Swift	4
V5116 Sgr 2005#2	...	16.2	0.81	12	XMM Newton	5
V5583 Sgr 2009#3	...	16.2	1.02	11	–	6
V574 Pup 2004	...	15.4	2.2	4.6	Swift	5
V4743 Sgr 2002#3	...	13.8	0.78	3.8	Chandra	7
V1494 Aql 1999#2	...	13.4	1.83	2.2	Chandra	8
V1974 Cyg 1992	...	12.3	1.00	1.8	ROSAT	9
V598 Pup 2007#2	...	11.7	0.27	2.1	XMM Newton	10
V382 Vel 1999	...	11.4	0.62	1.5	BeppoSAX	11

[a] supersoft X-ray on/off detected novae except V5583 Sgr

[b] distance modulus taken from Table 8 of Hachisu & Kato (2010)

[c] reference for A_V or $E(B-V)$, where we assume that A_V = $3.1E(B-V)$: 1-Russell et al. (2007a), 2-Wesson et al. (2008), 3-Ness et al. (2008c), 4-Mazuk et al. (2007), 5-Burlak (2008), 6-present work, 7-Vanlandingham et al. (2007), 8-Iijima & Esenoglu (2003), 9-Chochol et al. (1993), 10-Read et al. (2008), 11-Shore et al. (2003),

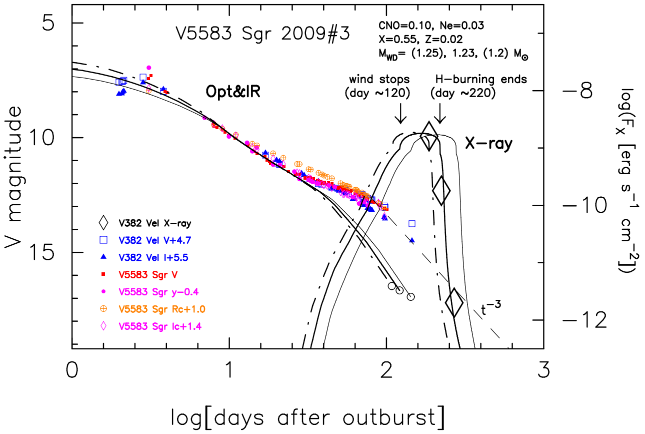

FIG. 2.— Optical and supersoft X-ray light curves for V5583 Sgr together with V382 Vel. We plot free-free emission model light curves (labeled "Opt&IR") and 0.2 – 0.6 keV supersoft X-ray fluxes (labeled "X-ray") of three WD mass models of $M_{\rm WD} = 1.25\,M_\odot$ (*thick dash-dotted line*), $1.23\,M_\odot$ (*thick solid line*), and $1.2\,M_\odot$ (*thin solid line*), for the envelope chemical composition of $X = 0.55$, $Y = 0.30$, $Z = 0.02$, $X_{\rm CNO} = 0.10$, $X_{\rm Ne} = 0.03$. We select the $1.23\,M_\odot$ WD as a best model reproducing the supersoft X-ray data of V382 Vel. The X-ray absorbed flux data (*large open diamonds*) of V382 Vel are taken from Orio et al. (2002) and Burwitz et al. (2002). Large open circles at the right edge of each free-free light curve correspond to the end epoch of an optically thick wind phase, during which the free-free flux is calculated by Equation (2).

The distance modulus of V5583 Sgr can also be estimated from the comparison with the absolute magnitude of free-free emission model light curves. Hachisu & Kato (2010) obtained the absolute magnitudes at the points denoted by open circles of model light curves, which correspond to the end of an optically thick wind phase. For the model of $1.23\,M_\odot$ WD, its absolute magnitude is $M_{\rm w} = 0.5$ (Hachisu & Kato 2010). This point corresponds to $m_{\rm w} = 16.7$ in Figure 2. Thus we have

$$(m-M)_V = m_{\rm w} - M_{\rm w} = 16.7 - 0.5 = 16.2. \qquad (4)$$

This value is consistent with $(m-M)_V = 16.2 \pm 0.1$ estimated with the difference between V382 Vel and V5583 Sgr in the previous section.

Supersoft X-rays are heavily absorbed by interstellar (or circumstellar) neutral hydrogen. Therefore the detection of supersoft X-rays depends not only on the distance (d) but also on the absorption (A_V). Table 3 lists 11 novae with a supersoft X-ray phase being detected in the order of decreasing distance modulus. The position of V5583 Sgr is mid of the list, that is, neither the distance nor the absorption is too large to be detected. We expect detection of supersoft X-rays from V5583 Sgr.

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