THE UBV COLOR EVOLUTION OF CLASSICAL NOVAE. II. COLOR–MAGNITUDE DIAGRAM

IZUMI HACHISU1 AND MARIKO KATO2
1 Department of Earth Science and Astronomy, College of Arts and Sciences, The University of Tokyo, 3-8-1 Komaba, Meguro-ku, Tokyo 153-8902, Japan; hachisu@ea.c.u-tokyo.ac.jp
2 Department of Astronomy, Keio University, Hiyoshi, Kouhoku-ku, Yokohama 223-8521, Japan

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ABSTRACT

We have examined the outburst tracks of 40 novae in the color–magnitude diagram (intrinsic $B - V$ color versus absolute $V$ magnitude). After reaching the optical maximum, each nova generally evolves toward blue from the upper right to the lower left and then turns back toward the right. The 40 tracks are categorized into one of six templates: very fast nova V1500 Cyg; fast novae V1668 Cyg, V1974 Cyg, and LV Vul; moderately fast nova FH Ser; and very slow nova PU Vul. These templates are located from the left (blue) to the right (red) in this order, depending on the envelope mass and nova speed class. A bluer nova has a less massive envelope and faster nova speed class. In novae with multiple peaks, the track of the first decay is more red than that of the second (or third) decay, because a large part of the envelope mass had already been ejected during the first peak. Thus, our newly obtained tracks in the color–magnitude diagram provide useful information to understand the physics of classical novae. We also found that the absolute magnitude at the beginning of the nebular phase is almost similar among various novae. We are able to determine the absolute magnitude (or distance modulus) by fitting the track of a target nova to the same classification of a nova with a known distance. This method for determining nova distance has been applied to some recurrent novae, and their distances have been recalculated.

Key words: novae, cataclysmic variables – stars: individual (FH Ser, LV Vul, PU Vul, V1500 Cyg) – stars: winds, outflows

1. INTRODUCTION

A classical nova is a thermonuclear runaway event triggered by unstable hydrogen burning on a mass-accreting white dwarf (WD) in a binary. After an outburst begins, the hydrogen-rich envelope expands to red giant size and ejects mass. The nova brightens up in the optical. After maximum expansion of the pseudo-photosphere, it begins to shrink owing to mass ejection. The mass ejection process is well described by the optically thick wind theory (e.g., Kato & Hachisu 1994; Hachisu & Kato 2006). The optical brightness decays, and subsequently the ultraviolet (UV) emission dominates the spectrum. Finally, the supersoft X-ray emission increases. The nova outburst ends when the hydrogen shell burning is extinguished.

Several groups proposed various time-scaling laws to identify a common pattern among the nova light curves (see, e.g., Hachisu et al. 2008a, for a summary). Hachisu & Kato (2006) found a similarity in the optical and near-infrared (NIR) light curves and calculated time-normalized light curves in terms of free–free emission, which are independent of the WD mass, chemical composition of the ejecta, and wavelength. They called it “the universal decline law.” This decline law was examined in a number of classical novae (Hachisu et al. 2006, 2007, 2008a; Hachisu & Kato 2007, 2009, 2010, 2015, 2016; Kato et al. 2009; Kato & Hachisu 2012). Based on the universal decline law, the maximum-magnitude versus rate-of-decline (MMRD) law was theoretically derived for classical novae (Hachisu & Kato 2010, 2015, 2016). To summarize, nova optical and NIR light curves can be explained theoretically in terms of free–free emission based on the optically thick winds (Kato & Hachisu 1994).

The evolution of colors was also studied by many researchers (see, e.g., Duerbeck & Seitter 1979; van den Bergh & Younger 1987; Miroshnichenko 1988). If the optical fluxes in the $UBV$ bands are dominated by free–free emission as derived by Hachisu & Kato (2006), its color is simply estimated to be $(B - V)_0 = +0.13$ and $(U - B)_0 = -0.82$ for optically thick free–free ($F_\nu \propto \nu^0$) emission, or to be $(B - V)_0 = -0.03$ and $(U - B)_0 = -0.97$ for optically thick free–free ($F_\nu \propto \nu^{2/3}$) emission (Wright & Barlow 1975). Here $F_\nu$ is the flux at the frequency $\nu$, and $(B - V)_0$ and $(U - B)_0$ are the intrinsic colors of $B - V$ and $U - B$, respectively. However, the nova $B - V$ color does not always stay long at these points but evolves further toward blue.

Hachisu & Kato (2014, hereafter Paper I) examined the color–color evolutions for a number of novae and identified a general course of classical nova outbursts in the $B - V$ versus $U - B$ color–color diagram. Matching the observed track of a target nova with this general course, they obtained the color excess of the nova. This is a new way to determine the color excess of a nova. A part of the extinctions thus obtained are summarized in Table 1.

In the present paper, we examine whether there is also a general track of novae in the color–magnitude diagram. To obtain the intrinsic colors and absolute magnitudes of novae, we need to know the color excess (or extinction) for each nova. For this purpose, we used the results obtained in Paper I. The present paper is organized as follows. In Section 2, we examine the color–magnitude evolutions of 10 well-observed novae, i.e., V1668 Cyg, LV Vul, FH Ser, PW Vul, V1500 Cyg, V1974 Cyg, PU Vul, V723 Cas, HR Del, and V5558 Sgr. Using these data, we deduce six templates of outburst tracks in the color–magnitude diagram. In Section 3, we apply these templates to 30 novae and try to identify general trends of novae. Table 1 lists the object name, outburst year, color excess, distance modulus in the $V$ band, and distance of each nova, including our target novae. Discussion and conclusions follow in Sections 4 and 5, respectively.


In this section, we study 10 well-observed novae, V1668 Cyg, LV Vul, FH Ser, PW Vul, V1500 Cyg, V1974 Cyg, PU Vul, V723 Cas, HR Del, and V5558 Sgr, in this order. These 10 novae were examined in detail in Paper I based on the color–magnitude diagram. Here we examine each nova in the color–magnitude diagram.

2.1. V1668 Cyg 1978

Figure 1 shows (a) the \( V \), \( y \), and UV 1455 Å light curves, (b) \( B - V \), and (c) \( (U - B)_0 \) color evolutions of V1668 Cyg. Here \((B - V)_0\) and \((U - B)_0\) are the dereddened colors of \( B - V \) and \( U - B \), i.e.,

\[
(B - V)_0 = (B - V) - E(B - V),
\]

\[
(U - B)_0 = (U - B) - 0.64E(B - V),
\]

where the factor of 0.64 is taken from Rieke & Lebofsky (1985). The UV 1455 Å band is designed to represent continuum flux of UV light (a narrow 20 Å width band at the center of 1455 Å; Cassatella et al. 2002). The \( UBV \) data of V1668 Cyg are taken from Duerbeck et al. (1980) and Kolotilov (1980), whereas the \( BV \) data are from Mallama & Skillman (1979) and the \( y \) data are from Gallagher et al. (1980). The \( V \) light curve of V1668 Cyg has \( t_2 = 12.2 \) days and \( t_3 = 24.3 \) days (Mallama & Skillman 1979). Hachisu & Kato (2016) reanalyzed the light curves of V1668 Cyg on the basis of model light curves, including the effects of both free–free
revised the color–color diagram (Figure 2(a)) and conclude that the reddening value of $E(B - V) = 0.30$ is still consistent with the general tracks of novae (solid green lines).

Next, we examine the combination of the revised values of $E(B - V) = 0.30$ and $\mu_V = (m - M)_V = 14.6$ in the distance–reddening relation for V1668 Cyg, whose galactic coordinates are $(l, b) = (90^\circ:8373, -6^\circ:7598)$. Figure 2(b) shows various distance–reddening relations for V1668 Cyg. Marshall et al. (2006) published a three-dimensional extinction map of our galaxy in the direction of $-100^\circ:0 \leq l \leq 100^\circ:0$ and $-10^\circ:0 \leq b \leq +10^\circ:0$ with grids of $\Delta l = 0^\circ:25$ and $\Delta b = 0^\circ:25$, where $(l, b)$ are the galactic coordinates. Their results are shown by four directions close to V1668 Cyg. We also plot the result given by Slovak & Vogt (1979) (filled red circles). Recently, Green et al. (2015) published data for the galactic extinction map, which covers a wider range of the galactic coordinates (over three-quarters of the sky) with much finer grids of $3^\circ/4 - 13^\circ/7$ and a maximum distance resolution of 25%. Their values of $E(B - V)$ could have an error of 0.05–0.1 mag compared with other two-dimensional dust extinction maps. We added Green et al.’s distance–reddening line (the best fitted of their examples) as the thick solid black line in Figure 2(b).

We also added our results of the model light-curve fits of the $V$ (solid blue lines) and UV 1455 Å (solid magenta lines) bands to Figure 2(b). These relations are calculated as follows: Figure 1(a) shows the theoretical light curve taken from Hachisu & Kato (2016), who calculated nova model light curves for various chemical compositions and WD masses based on free–free emission plus photospheric emission. The solid blue line shows the $V$ model light curve of a 0.98 $M_\odot$ WD with the chemical composition of “CO nova 3” (Hachisu & Kato 2016). Here we adopt their value $(m - M)_V = 14.6$ for V1668 Cyg. Then, the distance–reddening relation is calculated from

$$ (m - M)_V = 5 \log (d/10 \text{ pc}) + 3.1 E(B - V),$$

(3)


together with $(m - M)_V = 14.6 \pm 0.1$. We plot Equation (3) by the blue thick solid line flanked with thin solid blue lines in Figure 2(b). Hachisu & Kato (2016) also calculated the narrowband UV 1455 Å flux (Cassatella et al. 2002) for the same WD model on the basis of blackbody emission, which is shown in Figure 1(a) by the solid red line. Fitting our model with the observed fluxes, we also obtain a distance–reddening relation

$$ 2.5 \log \left( F_\lambda^{\text{obs}} / F_\lambda^{\text{mod}} \right) = R_\lambda E(B - V) + 5 \log \left( \frac{d}{10 \text{ kpc}} \right),$$

(4)

where $F_\lambda^{\text{mod}}$ is the model flux at the distance of $d = 10$ kpc, $F_\lambda^{\text{obs}}$ is the observed flux, the absorption is calculated from $A_\lambda = R_\lambda E(B - V)$, and $R_\lambda = 8.3$ for $\lambda = 1455$ Å (Seaton 1979). For V1668 Cyg, $F_{1455}^{\text{obs}} = 4.0$ and $F_{1455}^{\text{mod}} = 11.75$ in units of $10^{-12}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$ at the upper bound of Figure 1(a). This distance–reddening relation is plotted by the magenta lines with a $\sim 10\%$ flux 1σ error in Figure 2(b). All the above trends consistently cross each other at $d \approx 5.4$ kpc and $E(B - V) \approx 0.30$ as shown in Figure 2(b).

V1668 Cyg is located much below the galactic plane because its galactic coordinates are $(l, b) = (90^\circ:8373, -6^\circ:7598)$. It is far from the galactic plane ($-z > 0.6$ kpc) and much below emission and photospheric emission. They redetermined the reddening as $E(B - V) = 0.30 \pm 0.05$ and the distance modulus in the $V$ band as $\mu_V = (m - M)_V = 14.6 \pm 0.1$.

Adopting their value of $E(B - V) = 0.30$, we plot the color–color diagram of V1668 Cyg in Figure 2(a). Because the reddening of V1668 Cyg was updated to $E(B - V) = 0.30$ in Hachisu & Kato (2016) from $E(B - V) = 0.35$ in Paper I, we...
the galactic matter distribution (e.g., \( z \sim 125 \) pc; Marshall et al. 2006) for a distance of \( d \sim 5.4 \) kpc. Therefore, the extinction for V1668 Cyg should be close to the galactic dust extinction (two-dimensional map). The NASA/IPAC Galactic dust absorption map, which is based on the data of Schlafly & Finkbeiner (2011), gives \( E(B-V) = 0.29 \pm 0.02 \) for V1668 Cyg. Thus, we confirmed that the adopted value of \( E(B-V) = 0.30 \) is reasonable. Our distance and reddening estimates appear in Table 1.

Using the new value of \( E(B-V) = 0.30 \) together with \( (m-M)_V = 14.6 \), we plot the color–magnitude diagram of V1668 Cyg in Figure 3(a). The two horizontal solid lines indicate stages at the V maximum, \( m_{V,\text{max}} \), and 2 mag below the V maximum, \( m_{V,\text{max}} + 2 \). After the optical maximum (\( m_V \approx 6 \)), V1668 Cyg goes down almost along the line of \( (B-V)_0 = -0.03 \), which is the intrinsic \( B-V \) color of optically thick free–free emission (Hachisu & Kato 2014). This is consistent with the theoretical light curve of Figure 1(a), in which the flux of free–free emission dominates the photospheric emission. An optically thin dust shell formed at \( m_V \sim 10.5 \) (Gehrz et al. 1980) as indicated by an arrow. After that, V1668 Cyg entered the nebular phase about 4 mag below the maximum (e.g., Klare et al. 1980). It moves rightward, i.e., toward red, around/after the start of the nebular phase and then turns to the left, i.e., toward blue. The position of this turning point is denoted by the large open red square at \( M_V = -4.19 \) and \( (B-V)_0 = +0.02 \). We define a template of the color–magnitude track for V1668 Cyg by a thick solid green line in Figure 3(a). The orbital period of 3.32 hr was detected by Kaluzny (1990). Table 2 lists the position \((B-V)_0, M_V\) of the turning point in the color–magnitude diagram, distance modulus in the V band, orbital period (if it is known), and type of the track in the color–magnitude diagram on the basis of our classification introduced later in Section 2.11.

Figure 3(b) compares the V1668 Cyg track with other well-observed novae, V1500 Cyg (thick solid green line), V1974 Cyg (thick solid cyan line), F H Ser (thick solid magenta line), and PU Vul (thick solid blue line), the data of which are taken from later sections corresponding to each nova. These novae follow a similar path, but their tracks are located from left to right depending on the nova speed class, i.e., \( t_1 = 2.4, 12.2, 17, 42, \) and \( \geq 1500 \) days for V1500 Cyg, V1668 Cyg, V1974 Cyg, F H Ser, and PU Vul, respectively, except for the nebular phase. We also added a two-headed arrow, which shows Equation (5). We discuss these properties later in Section 2.12.

2.2. LV Vul 1968\#1

The reddening for LV Vul was estimated to be \( E(B-V) = 0.60 \pm 0.05 \) by matching the observed color–color track with the general course of novae (Hachisu & Kato 2014). Figure 4 shows the V, \( (B-V)_0 \), and \( (U-B)_0 \) evolutions of LV Vul. The \( (B-V)_0 \) and \( (U-B)_0 \) colors are dereddened with \( E(B-V) = 0.60 \). The UBV data are taken from Fernie (1969), Dorschner et al. (1969), Abuladze (1969), and Grygar (1969). The BV data are taken from Quast (1968) and Tempest (1972). In Figure 4(b), the B – V data of Dorschner et al. (1969) are 0.05 mag redder than the other data, so we shifted them toward blue by 0.05 mag. LV Vul reached its optical maximum at \( m_{V,\text{max}} = 4.7 \) on UT 1968 April 17. The V light curve of LV Vul has \( t_2 = 20.2 \) days and \( t_3 = 37 \) days (Tempest 1972).

We plot the color–color diagram of LV Vul in Figure 5(a), using the data shown in Figures 4(b) and (c). Andrillat et al. (1986) recorded a spectrum at the premaximum phase, and it showed a spectrum of an F-type supergiant star. Therefore, we expect that the early color evolution of LV Vul follows the nova-giant sequence in the color–color diagram. We confirm that the adopted value of \( E(B-V) = 0.60 \) is reasonable because the observed track of LV Vul is located on the general course of novae (solid green lines) especially on the nova-giant sequence.
Hachisu & Kato (2006) found that nova light curves follow a universal decline law when free–free emission dominates the spectrum. Using the universal decline law, Hachisu & Kato (2010) derived that if two nova light curves overlap each other after one of them is squeezed/stretched by a factor of \( f_v (t = t' \times f_v) \) in the direction of time, one nova brightness of \( (m_v', t') \) is related to the other nova brightness of \( (m_v, t) \) as \( m_v = m_v' + 2.5 \log f_v \). Using this result and the calibrated nova light curves, we are able to estimate the absolute magnitude of a target nova. They called this method the “time-stretching method.”

Hachisu & Kato (2014) estimated the absolute magnitude of LV Vul as \( (m - M)_V = 11.9 \), using the time-stretching method. Then the distance is calculated to be \( d = 1.0 \) kpc for \( E(B - V) = 0.60 \), which is consistent with \( d = 0.92 \pm 0.08 \) kpc obtained by Slavin et al. (1995) from the expansion parallax method. We plot the various distance-reddening relations for LV Vul, \((l, b) = (63^\circ 3024, +0^\circ 8464)\),
in Figure 5(b). Our set of $E(B - V) = 0.60$ and $d = 1.0$ kpc is located in a different area than the relations of both Marshall et al. (2006) and Green et al. (2015). Our result is roughly midway between theirs. We also plot the results of Hakkila et al. (1997). Their distance–reddening relation is roughly consistent with our set of $E(B - V) = 0.60$ and $d = 1.0$ kpc.

Adopting $E(B - V) = 0.60$ and $(m - M)_V = 11.9$, we plot the color–magnitude diagram of LV Vul in Figure 6(a). After the optical maximum, LV Vul goes down almost along the line of $(B - V)_0 = -0.03$. This is similar to the trend in V1668 Cyg. After that, the track of LV Vul departs into two tracks at $m_V = 8.2$ (denoted by an open blue circle at $M_V = 8.2 - 11.9 = -3.7$) in the color–magnitude diagram of Figure 6(a). This reason will be clarified below shortly after the explanation of the nebular phase.

The start of the nebular phase is identified by the first clear appearance of the nebular emission lines of $[O\text{ III}]$ (or $[Ne\text{ III}]$) stronger than the permitted lines. LV Vul had already entered the nebular phase on June 20 at $m_V = 8.2$ (Hutchings 1970a). Thus, we specify the onset of the nebular phase at $m_V = 8.2$ when the track departed into two tracks (solid black and magenta lines) at the large open blue circle in Figure 6(a). The presence of two tracks is due to the strong emission lines of $[O\text{ III}]$ contributing to the blue edge of the $V$ filter. Because the response of each $V$ filter differs slightly at the shorter wavelength edge of the $V$ passband, the resultant $V$ magnitude and color index $B - V$ are significantly different among the different $V$ filters. After the nebular phase started at $m_V = 8.2$ (M$_V = -3.7$), this difference becomes more and more significant as shown in Figures 4(a) and (b). Here one group (solid magenta line) consists of Abuladze (1969), Dorschner et al. (1969), and Grygar (1969) and the other (solid black line) consists of Quast (1968), Fernie (1969), and Tempesti (1972). These two trends began to depart at $m_V = 8.2$ ($M_V = -3.7$) in the color–magnitude diagram of Figure 6(a). We also specify a turning (cusp) point at $(B - V)_0 = -0.01$ and $M_V = -3.77$ (a large open red square) for the data of Abuladze (1969) as shown in Figure 6(a).

Figure 6(b) compares the track of LV Vul with those of V1500 Cyg (thick solid green line) and PU Vul (thick solid blue line) in the color–magnitude diagram. The track of LV Vul ($t_2 = 20.2$ days) is between V1500 Cyg ($t_2 = 2.4$ days) and PU Vul ($t_2 > 1500$ days). The tracks are located from left to right in the order of nova speed class. This is the same trend as that of Figure 3(b), as mentioned in the previous section (Section 2.1).
& Kato (2014) determined the reddening to be $E(B-V) = 0.60$ and the distance modulus to be $(m-M)_V = 11.7$. Using the same data as those in Figure 2 of Hachisu & Kato (2014), which showed the $V, (B-V)_0$, and $(U-B)_0$ evolutions of FH Ser, we plotted the color–magnitude diagram of FH Ser in Figure 7(a). We adopted the same reddening and distance modulus as Hachisu & Kato (2014). The $UBV$ data are taken from Osawa (1970), filled red circles, Borra & Andersen (1970, open magenta diamonds), and Burkhead et al. (1971, open blue squares). The $B-V$ color of Borra & Andersen (1970) is systematically $\sim 0.2$ mag bluer than the others, while their $V$ and $U-B$ data are reasonably consistent with the others. Therefore, we shifted Borra & Andersen’s $B-V$ data $0.2$ mag redder (see also Figure 2 of Hachisu & Kato 2014). Connecting main observational points in the color–magnitude diagram, we define a template track (thick solid green line) for FH Ser in Figure 7(a).

Figure 7(a) also shows stages at the $V$ maximum, $m_{V,\text{max}}$, and $2$ mag below the $V$ maximum, $m_{V,\text{max}} + 2$, by the thin horizontal solid lines. FH Ser first rises in the color–magnitude diagram and then turns to the right. It goes toward red up to $(B-V)_0 \approx +0.60$ at point A in Figure 7(a). Then, it turns back to the left, toward blue, and reaches maximum at $m_V = 4.4 (M_V = 4.4 - 11.7 = -7.3)$. Subsequently, it declines along the template track from point B to D through C. After point D, the nova suddenly darkened owing to formation of an optically thick dust shell. We consider the start of the dust blackout (large open red square) to be $(B-V)_0 = +0.05$ and $M_V = -4.48$ as shown in Figure 7(a).

Figure 8(a) compares the color–magnitude diagram of FH Ser with those of V1668 Cyg (thin solid green lines), PW Vul (thin solid blue lines), and PU Vul (thick solid blue lines), which are analyzed in Sections 2.1, 2.4, and 2.7, respectively. The location of FH Ser ($t_2 = 42$ days) is between those of V1668 Cyg ($t_2 = 12.2$ days) and PU Vul ($t_2 \gtrsim 1500$ days). V1668 Cyg declines vertically along $(B-V)_0 = -0.03$ (see, e.g., Hachisu & Kato 2014, 2016), which is the color of optically thick free–free emission calculated from $F_\nu \propto \nu^{7/3}$, whereas PU Vul goes down along $(B-V)_0 = +0.13$ (see, e.g., Hachisu & Kato 2014), the color of optically thin free–free emission calculated from $F_\nu \propto \nu^{2}$. If we shift the track of V1668 Cyg toward red by $\Delta(B-V) = 0.12$ mag as shown by the thick solid orange line with black points, it overlaps with that of FH Ser between $M_V \sim -6.5$ and $M_V \sim -4$.

We examine the combination of $E(B-V) = 0.60$ and $(m-M)_V = 11.7$ in the distance–reddening relation for FH Ser, $(l, b) = (32^\circ 9090, +5^\circ 7860)$. Figure 9(a) shows various distance–reddening relations for FH Ser. We show those given by Marshall et al. (2006), $(l, b) = (32^\circ 75, 5^\circ 75)$ (open red squares), $(33^\circ 00, 5^\circ 75)$ (filled green squares), $(32^\circ 75, 6^\circ 00)$ (blue asterisks), and $(33^\circ 00, 6^\circ 00)$ (open magenta circles). The closest one is that of the filled green squares. The solid blue line represents the relation of $(m-M)_V = 11.7$, crossing the trend of the filled green squares of Marshall et al. at $d \approx 0.93$ kpc and $E(B-V) \approx 0.60$. This point is consistent with our adopted values. This figure is essentially the same as Figure 3 of Hachisu & Kato (2014), but we added the distance–reddening relation (solid black line) given by Green et al. (2015). Green et al.’s relation is located at a slightly lower position than that.

2.3. FH Ser 1970

FH Ser shows a dust blackout. The $V$ light curve of FH Ser has $t_2 = 42$ days and $t_3 = 59$ days (e.g., Downes & Duerbeck 2000). The light curves of FH Ser were already analyzed in Paper I based mainly on the color–color evolution. Hachisu

Figure 6. Same as Figure 3, but for LV Vul. (a) The thick solid black and magenta lines denote a template track for LV Vul. The large open blue circle indicates the bifurcation point of these two tracks. (b) Comparison of LV Vul with other well-observed novae, V1500 Cyg (thick solid green line) and PU Vul (thick solid blue line). The two-headed black arrow represents Equation (5) from Section 2.12, and the two-headed red arrow shows a line 0.6 mag below the black one, i.e., Equation (6) from Section 2.12.

The two-headed black arrow in Figure 6(b) is located 0.6 mag above the trend of the LV Vul track just after the nebular phase started. Thus, we define another line by the two-headed red arrow in the same figure. The two-headed black arrow is defined by Equation (5), and the two-headed red arrow is defined by Equation (6), both of which will be discussed later in Section 2.12. Their physical meaning will be clarified there.
of Marshall et al. Considering the ambiguity of Green et al.’s relation (see Section 2.1), we may conclude that the combination of $E(B - V) = 0.60$ and $d = 0.93$ kpc is still reasonably consistent with these distance–reddening relations.

2.4. PW Vul 1984#1

The light curves of the moderately fast nova PW Vul were studied in detail by Hachisu & Kato (2014, 2015). They determined the distance modulus to be $(m - M)_V = 13.0$ and the reddening to be $E(B - V) = 0.55$. Figure 7(b) shows the outburst track of PW Vul in the color–magnitude diagram, the data of which are taken from Noskova et al. (1985, open blue squares), Kolotilov & Noskova (1986, open magenta diamonds), and Robb & Scarfe (1995, filled red circles). We define a template track by a thick solid green line for PW Vul almost along Robb & Scarfe’s observation in Figure 7(b).

The V light curve of PW Vul shows a wavy structure in the early decline phase (see, e.g., Figure 6 of Paper I). The brightness drops to $m_V = 8.7$ immediately after the V maximum ($m_{V,max} = 6.4$). Then it goes up to $m_V = 7.5$ and repeats oscillations with smaller amplitudes of brightness. The smoothed V light curve of PW Vul has $t_2 = 82$ days and $t_3 = 126$ days (e.g., Downes & Duerbeck 2000). PW Vul moves clockwise in the color–magnitude diagram during this first brightness drop just after the V maximum, the movement direction of which is indicated by red arrows in Figure 7(b).
This clockwise movement is different from the usual nova decline, like in Figure 7(a), and we will discuss it in more detail in Sections 2.10 and 2.11.

Rosino & Iijima (1987) reported that the nova entered the nebular phase at 1985\textsuperscript{mid-January} (at $m_V = 9.8$) as indicated in Figure 7(b). This onset corresponds to the large open red square on the track, i.e., $M_V = -3.32$ and $(B-V)_0 = -0.39$. The track of PW Vul shows a small bend globally and a tiny zigzag motion locally near this point. A possible orbital period of 5.13 hr was detected by Hacke (1987).

Figure 8(b) shows the position of PW Vul among the tracks of other novae. We also plot two-headed black and red arrows represented by Equations (5) and (6), respectively. The onset of the nebular phase (large open red square) is located on the two-headed red arrow. The track of PW Vul is very close to that of LV Vul except for the early clockwise circle. We regard PW Vul as the same type of nova as LV Vul in the color–magnitude diagram.

This trend is the same as in Section 2.1. Note that the $t_2$ time of PW Vul is much longer than $t_2 = 20.2$ days of LV Vul. The reason is that the early $V$ light curve of PW Vul has a wavy structure with a large amplitude of the $V$ magnitude and the $t_2$ time could not
represent the intrinsic nova speed class. On the other hand, other novae (V1500 Cyg, V1668 Cyg, LV Vul, FH Ser, and PU Vul) show smooth declines, and their $t_2$ times could show their intrinsic nova speed class.

We check the combination of $E(B-V) = 0.55$ and $(m-M)_V = 13.0$ in the distance–reddening relation for PW Vul, $(l, b) = (61^\circ.0983, +5^\circ.1967)$. Figure 9(b) shows various distance–reddening relations for PW Vul. Marshall et al.’s (2006) relations are plotted in four directions close to PW Vul: $(l, b) = (61^\circ.00, 5^\circ.00)$ (open red squares), $(61^\circ.25, 5^\circ.00)$ (filled green squares), $(61^\circ.00, 5^\circ.25)$ (blue asterisks), and $(61^\circ.25, 5^\circ.25)$ (open magenta circles). The closest one is that of blue asterisks. We also add Green et al.’s (2015) relation (thick solid black line).

Hachisu & Kato (2015) calculated model $V$ and UV 1455 Å light curves for various WD masses and chemical compositions of the hydrogen-rich envelope and obtained a best-fit model for a 0.83 $M_\odot$ WD with the chemical composition of CO nova 4 (see Figure 10 of Hachisu & Kato 2015). Their UV 1455 Å fit, together with Equation (4), is plotted by a solid magenta line. The $V$ light-curve fit is the same as our value of $(m-M)_V = 13.0$. This relation is plotted by a solid blue line.

The three trends, UV 1455 Å fit, $E(B-V) = 0.55$, and $(m-M)_V = 13.0$, consistently cross at the point $E(B-V) \approx 0.55$ and $d \approx 1.8$ kpc, but this cross point is not consistent with the trends of Marshall et al. and Green et al. If we adopt $d = 1.8$ kpc, we obtain $E(B-V) \approx 0.42$ from Marshall et al.’s relation of blue asterisks. This value is consistent with $E(B-V) = 0.43 \pm 0.02$ calculated from the NASA/IPAC dust map in the direction of PW Vul. Thus, our set of $E(B-V) = 0.55$ and $(m-M)_V = 13.0$ is not consistent with the trends of the 3D dust map.

Therefore, we again discuss previous reddening estimates pinpointing PW Vul. The reddening of PW Vul was estimated
as $E(B-V) = A_V/3.1 = (1.78 \pm 0.05)/3.1 = 0.57 \pm 0.02$
from the Balmer/ Paschen line ratios by Williams et al. (1996),
$E(B-V) = 0.58 \pm 0.06$ from the He II 1640/4686 ratio
by André et al. (1991), $E(B-V) = 0.55 \pm 0.1$ from the
interstellar absorption feature at 2200 Å by André et al.
(1991), and $E(B-V) = 0.60 \pm 0.06$ according to Saizar
et al. (1991) from the He II 1640/4686 ratio. The simple
arithmetic mean of these four values is
$E(B-V) = 0.57 \pm 0.1$. The distance to PW Vul
was estimated to be $d = 1.8 \pm 0.05$ kpc by Downes & Duerbeck
(2000) from the expansion parallax method. We plot this by
horizontal black lines in Figure 9(b). Then the distance modulus
in the $V$ band is calculated to be $(m-M)_V = 5\log(1800/10) + 3.1 \times 0.57 = 13.04$. Our
combination of $d = 1.8$ kpc and $(m-M)_V = 13.0$ is consisten-
t with these estimates. The reddening trend of Marshall
et al.’s blue asterisks suggests a large deviation from the other
three trends by $\Delta E(B-V) \approx 0.1$, suggesting that the redden-
ing distribution has a patchy structure in this direction and a
further deviation of $\Delta E(B-V) \sim 0.1$ may be possible. Thus,
we use the set of $E(B-V) \approx 0.55$ and $d \approx 1.8$ kpc in this paper.

2.5. V1500 Cyg 1975

V1500 Cyg was identified as a neon nova by Ferland &
Shields (1978a, 1978b). The $V$ light curve shows a very
rapid decline with $t_2 = 2.4$ days and $t_3 = 3.7$ days (e.g.,
Downes & Duerbeck 2000). The orbital period of 3.35 hr
was detected by Tempesti (1975). We already analyzed the
nova light curves in Paper I, and we determined the reddening
to be $E(B-V) = 0.45 \pm 0.05$ and the distance modulus to be
$(m-M)_V = 12.3 \pm 0.1$. Adopting their values of
$E(B-V) = 0.45$ and $(m-M)_V = 12.3$, we plot the color–
magnitude diagram of V1500 Cyg in Figure 7(c), the data of
which are taken from Arkhipova & Zaitseva (1976), Pfau
(1976), Kiselev & Narizhnaia (1977), and Williamson (1977).

The spectrum energy distribution changed from blackbody
emission during the first 3 days to thermal bremsstrahlung
emission on day $\approx 4 - 5$ (Gallagher & Ney 1976; Ennis
et al. 1977). Thus, we conclude that the nova enters a free–free
emission phase about 5 days after the outburst. Optically thin
free–free emission ($F_\nu \propto \nu^2$) yields $(B-V)_0 = +0.13$,
whereas optically thick free–free emission ($F_\nu \propto \nu^{2/3}$) gives
$(B-V)_0 = -0.03$, both of which are indicated in Figure 7(c).

In Figure 7(c), different observers obtained different tracks.
The data of Pfau (1976) are $\sim 0.2$ mag bluer than that of the
solid green line based mainly on the data of Kiselev &
Narizhnaia (1977). This difference is partly attributed to the
slight difference in the response of each color filter, which is
sensitive to strong emission lines on the edge and eventually
makes the nova color significantly different among the
observers. We define a template track of V1500 Cyg by the
thick solid green line, which is based mainly on the data taken
from Kiselev & Narizhnaia (1977).

The first feature of the nebular, forbidden lines of [O \text{II}] and
[Ne \text{II}] appeared on 1975 September 8, at $m_V = 6.1$, and their
intensities steadily increased and reached that of Hβ on October
12.9, at $m_V = 7.9$ (e.g., Woszczyk et al. 1975). We specify that
the nebular phase started around October 13.0–14.0, that is,
$M_V = m_V - (m-M)_V = 7.9 - 12.3 = -4.4$. The two
tracks of Williamson (1977) and Pfau (1976) began to diverge
at $M_V = m_V - (m-M)_V = 6.1 - 12.3 = -6.2$ as shown in
Figure 7(c). This is due to the contribution of strong emission
lines of [O \text{III}] close to the blue edge of the $V$ filter. After the
nebular phase started at $M_V \sim -4.4$, this difference develops
more and more. The strong emission lines of [O \text{II}] eventually
made the nova color evolution turn to the right for the three
cases of Williamson (1977), Arkhipova & Zaitseva (1976),
and Kiselev & Narizhnaia (1977) near the cusp (or zigzag) point
denoted by a large open red square. This position is
$M_V = -3.83$ ($m_V = 8.5$) and $(B-V)_0 = -0.47$ based on the
data (filled red circles) of Arkhipova & Zaitseva (1976).

Figure 8(c) shows the position of V1500 Cyg among other
well-observed novae. The track of V1500 Cyg is located on the
bluest side in the color–magnitude diagram. The onset of the
nebular phase (large open red square) is located on this two-
headed arrow.

The distance to V1500 Cyg was discussed by many authors
(see Paper I). We obtained the set of $E(B-V) = 0.45$ and
$(m-M)_V = 12.3$ in Paper I. Figure 9(c) shows various
distance–reddening relations toward V1500 Cyg, that is,
$(l, b) = (89^\circ\!8233, -0^\circ\!0720)$. We add Marshall et al.’s
(2006) relations for four directions close to V1500 Cyg, that is,
$(l, b) = (89^\circ\!75, 0^\circ\!00)$ (open red squares), $(90^\circ\!00, 0^\circ\!00)$
(filled green squares), $(89^\circ\!75, -0^\circ\!25)$ (blue asterisks), and
$(90^\circ\!00, -0^\circ\!25)$ (open magenta circles). We further add the
relations of Hakkila et al. (1997) and Green et al. (2015). Green
et al.’s relation gives $d = 1.5$ kpc for $E(B-V) = 0.45$.

We also plot the two relations $(m-M)_V = 12.3$ (solid blue
line) and $E(B-V) = 0.45$ (vertical solid red line), which are
taken from Hachisu & Kato (2014). These two relations and
Green et al.’s relation cross each other at the same point of
$d \approx 1.5$ kpc and $E(B-V) \approx 0.45$, consistent with the
distance estimate of $d = 1.5 \pm 0.1$ kpc by the expansion
parallax method. This strongly supports the Hachisu & Kato
(2014) set of $(m-M)_V = 12.3$ and $E(B-V) = 0.45$.

2.6. V1974 Cyg 1992

V1974 Cyg was identified as a neon nova by Hayward et al.
(1992). The $V$ light curve shows a fast decline with $t_2 = 17$ days and $t_3 = 37$ days (e.g., Downes & Duerbeck
2000). The orbital period of 1.95 hr was detected by De Young &
Schmidt (1994). Paper I and Hachisu & Kato (2016) already
analyzed the nova light curves on the basis of the universal decline law and determined the reddening
as $E(B-V) = 0.30 \pm 0.05$ and the distance modulus as
$(m-M)_V = 12.2 \pm 0.1$. Adopting their values of
$E(B-V) = 0.30$ and $(m-M)_V = 12.2$, we plot the color–
magnitude diagram of V1974 Cyg in Figure 7(d). The observational data are taken from Chochol et al. (1993) and
IAU Circular Nos. 5455, 5457, 5459, 5460, 5463, 5467, 5475,
5479, 5482, 5487, 5490, 5520, 5526, 5537, 5552, 5571, and
5598. We define a template track of V1974 Cyg by the thick
solid green line, based mainly on the data of Chochol et al.
(1993).

The nova entered the nebular phase on April 20 at $m_V = 8.1$
(Rafanelli et al. 1995), as indicated by an arrow in Figure 7(d).
The position is denoted by a large open red square at
$M_V = -4.02$ and $(B-V)_0 = -0.21$. This point is taken from
the observational points of Chochol et al. (1993) and
corresponds to a cusp on the track. We list the values at the
cusp in Table 2. We add the epoch when the supersoft X-ray
source (SSS) phase started at $m_V = 9.7$ about 250 days after the
outburst (Krautter et al. 1996).
Figure 8(d) compares the position of V1974 Cyg with other well-observed novae. The track of V1974 Cyg is located between those of V1500 Cyg and FH Ser. The data of V1974 Cyg taken from IAU Circulars (filled red circles) scatter slightly, and their blue edge (blue side bound) coincides with the template track of V1500 Cyg, whereas their red side edge almost coincides with the template track of FH Ser. We shift the track of V1500 Cyg toward red by $\Delta(B - V) = 0.12$ mag and plot it by a thin solid black line, which overlaps with that of V1974 Cyg between $M_V = -8$ and $M_V = -4$. The onset of the nebular phase (large open red square) is located on the two-headed black arrow.

Figure 9(d) shows various distance–reddening relations for V1974 Cyg. $(l, b) = (89^\circ1338, 7^\circ8193)$. We plot our distance modulus of $(m - M)_V = 12.2$ by a thick solid blue line and the UV 1455 Å light curve fit by a thick solid magenta line (Hachisu & Kato 2016). We added Chochol et al.’s distance value as $d = 1.8 \pm 0.1$ kpc (horizontal straight solid line flanked by thin lines). Marshall et al.’s (2006) relations are given for $(l, b) = (89^600, 7^775)$ (open red squares), $(89^625, 7^775)$ (filled green squares), $(89^600, 8^700)$ (blue asterisks), and $(89^625, 8^700)$ (open magenta circles). We also add Green et al.’s (2015) relation by a thick solid black line. These trends almost cross at the same point of $E(B - V) \approx 0.30$ and $d \approx 1.8$ kpc. This agreement strongly supports our set of $(m - M)_V = 12.2$ and $E(B - V) = 0.30$.

2.7. PU Vul 1979

PU Vul is a symbiotic nova with an orbital period of 13.46 yr (e.g., Kato et al. 2012). Figure 10(a) shows various distance–reddening relations for PU Vul, $(l, b) = (62^6573, -8^5317)$. Kato et al. (2012) examined the distance–reddening relation for PU Vul with several different methods and determined the reddening as $E(B - V) = 0.30$, the apparent distance modulus in the $V$ band as $(m - M)_V = 14.3$, and the distance as $d = 4.7$ kpc. We plot these results in Figure 10(a) by the vertical solid red line, solid blue line, and horizontal black line, respectively. Hachisu & Kato (2014) reanalyzed the light curve and color–color evolution of PU Vul and reached the same conclusion, i.e., $E(B - V) = 0.30$ and $(m - M)_V = 14.3$. The NASA/IPAC galactic dust absorption map gives $E(B - V) = 0.29 \pm 0.01$ in the direction toward PU Vul. We also add Marshall et al.’s (2006) and Green et al.’s (2015) distance–reddening relations to Figure 10(a). Green et al.’s trend consistently crosses our solid lines at $d = 4.7$ kpc and $E(B - V) = 0.30$, which supports the values of $E(B - V) = 0.30$ and $(m - M)_V = 14.3$.

Figure 11(a) shows the color–magnitude track of PU Vul and the template track of LV Vul (thick solid magenta line). Here we use $E(B - V) = 0.30$ and $(m - M)_V = 14.3$ for PU Vul. The solid green line represents the track of LV Vul, but is shifted toward red by $\Delta(B - V) = 0.2$. The data of the small open orange circles are taken from Shugarov et al. (2012). The other data of small filled red circles are taken from various sources but are the same as in Figures 16 and 17 of Paper I. We define a template track of PU Vul by a thick solid blue line. The numbers 1–5 attached to large open black squares on the solid blue line correspond to the stages 1–5 of PU Vul as defined in Figure 15 of Paper I. The figure also shows the stages at the $V$ maximum, $(m_V)_{\text{max}}$, and 2 mag below the $V$ maximum, $(m_V)_{\text{max}} + 2$, by thin horizontal solid lines. It is remarkable that the green shifted LV Vul track almost coincides with the PU Vul track except for the flat optical peak of PU Vul (see Figure 15 of Paper I for the $V$ light curve of PU Vul).

Vogel & Nussbaumer (1992) reported that a distinct nebular spectrum emerged between 1989 September ($m_V \approx 10.4$, $M_V \approx -3.9$) and 1990 November ($m_V \approx 10.6$, $M_V \approx -3.7$). We consider this to be the nova entering the nebular phase at $m_V \approx 10.5$ ($M_V \approx -3.8$), which is denoted by an arrow in Figure 11(a). Here we specify this onset point by a large open red square at $(B - V)_0 = +0.20$ and $M_V = -3.80$. The onset of the nebular phase (large open red square) is located on the two-headed red arrow. This position accidentally coincides with the onset point of the nebular phase on the green shifted LV Vul track as shown in Figure 6(a).

2.8. V723 Cas 1995

V723 Cas is a very slow nova with an orbital period of 16.64 hr (Goranskij et al. 2000). Figure 10(b) shows various distance–reddening relations for V723 Cas, $(l, b) = (124^69606, -8^80686)$. The NASA/IPAC galactic dust absorption map gives $E(B - V) = 0.34 \pm 0.01$ in the direction toward V723 Cas. We plot the distance–reddening relation given by Green et al. (2015) by a solid black line, the apparent distance modulus in the $V$ band of $(m - M)_V = 14.0$ (Hachisu & Kato 2015) by a solid blue line, the reddening of $E(B - V) = 0.35 \pm 0.05$ from Paper I by a vertical solid red line flanked with dashed red lines, the distance of $d = 3.85^{+0.23}_{-0.21}$ kpc from the expansion parallax method (Lyke & Campbell 2009) by a horizontal solid black line flanked with dashed lines, and the UV 1455 Å model light-curve fit (Hachisu & Kato 2015) by a solid magenta line. All these trends cross each other at $E(B - V) \approx 0.35$ and $d \approx 3.85$ kpc. Therefore, we adopt $E(B - V) = 0.35$ and $(m - M)_V = 5 \log(3850/10) + 3.1 \times 0.35 = 14.0$ for V723 Cas after Hachisu & Kato (2015).

Figure 11(b) shows the color–magnitude track of V723 Cas. The data of V723 Cas are taken from Chochol & Pröll-a (1997). The solid green line represents the LV Vul track shifted toward red by $\Delta(B - V) = 0.2$. The PU Vul and green shifted LV Vul tracks are remarkably similar to that of V723 Cas except for the flaring pulses around optical maximum of $M_V = -7$ to $-6$. See Figures 19–21 of Paper I for the $V$ light curve and color curves.

The onset of the nebular phase was detected by Iijima (2006) between 1997 May 30 and July 1, at $m_V \approx 11.3$, as shown in Figure 11(b). We specify the point $(B - V)_0 = -0.17$ and $M_V = -2.83$ from the observational data in Figure 11(b) and denote it by a large open red square. The start of the nebular phase is slightly below the line of the two-headed red arrow.

2.9. HR Del 1967

HR Del is a very slow nova with an orbital period of 5.14 hr (Bruch 1982; Kürster & Barwig 1988). The light-curve shape is very similar to that of V723 Cas and V5558 Sgr (see, e.g., Figures 19–21 of Paper I). Figure 10(c) shows several distance–reddening relations, the apparent distance modulus in the $V$ band of $(m - M)_V = 10.4$ (Hachisu & Kato 2015), the reddening of $E(B - V) = 0.15 \pm 0.03$ (Verbunt 1987), and the distance of $d = 0.97 \pm 0.07$ kpc (Harman & O’Brien 2003). We also add Green et al.’s (2015) relation. All the trends consistently cross at $E(B - V) \approx 0.12$ and $d \approx 1.0$ kpc. The NASA/IPAC galactic dust absorption map also gives
$E(B - V) = 0.112 \pm 0.006$ in the direction toward HR Del, $(l, b) = (63.24304, -13.9721)$. Therefore, we adopt $E(B - V) = 0.12$ and $(m - M)_V = 10.4$ for HR Del.

Figure 11(c) shows the color–magnitude track of HR Del. The data of HR Del are taken from O’Connell (1968), Mannery (1970), Barnes & Evans (1970), and Onderlička & Vetešník (1968). The track of HR Del is very similar to that of PU Vul except for the flaring pulses around the optical peak of HR Del. The track of HR Del also follows the green LV Vul track shifted toward red by $\Delta(B - V) = 0.2$.

The start of the nebular phase was identified by Hutchings (1970b) at $(B - V)_0 = -0.02$ and $M_b = -3.59$, which is indicated by a large open red square in Figure 11(c). The track of HR Del departs into two branches at this point, depending on the different filter responses of various observers, just as for LV Vul. One of them turns to the right (toward red) when the nebular phase started. This departing point accidentally coincides with that of the green shifted LV Vul track. The start of the nebular phase is almost on the line of the two-headed red arrow.

### 2.10. V5558 Sgr 2007

V5558 Sgr is a very slow nova. Its light-curve shape is very similar to that of V723 Cas and HR Del (see, e.g., Figures 19–21 of Paper I). Figure 10(d) shows various distance–reddening relations for V5558 Sgr, $(l, b) = (11.6107, -0.2067)$. This figure is the same as Figure 24 of Paper I, but we added Green et al.’s (2015) relation. All the trends consistently cross at...
$E(B-V) \approx 0.70$ and $d \approx 2.2$ kpc. Therefore, we adopt $E(B-V) = 0.70$ and $(m-M)_V = 13.9$, the same values as in Paper I.

Figure 11(d) shows the color–magnitude track of V5558 Sgr. The data of V5558 Sgr are taken from the archives of the American Association of Variable Star Observers (AAVSO; filled red circles), the Variable Star Observers League of Japan (VSOLJ; filled red circles), and SMARTS\(^4\) (Walter et al. 2012; filled blue squares).

The track of V5558 Sgr is very similar to that of PU Vul, except for the flaring pulses around the optical peak. We connect the track of V5558 Sgr by a thin solid red line during the first flaring pulse around the optical maximum. Also, we connect the track during the second flaring pulse by a thin solid black line. The first flaring pulse shows a clockwise movement in the color–magnitude diagram. This clockwise behavior is very similar to that of PW Vul in Figure 7(b). This clockwise movement, however, is very large in V5558 Sgr. It rises vertically along $(B-V)_0 \sim 0.2$ up to the maximum brightness $(m_V \sim 6.5, M_V \sim -7.4)$, then turns to the right (toward red) up to $(B-V)_0 \sim 0.6$, and then goes down to $M_V \sim -5.8$, coinciding with the flat maximum brightness of PU Vul. This large clockwise circular movement in the color–magnitude diagram is very different from the usual tracks of novae such as FH Ser and LV Vul. The track of the second flaring pulse follows that of the first flaring pulse in the rising phase but does not go toward red. It loops on the blue side of the first flaring pulse. The third and fourth flaring pulses follow the second phase.

\(^4\) http://www.astro.sunysb.edu/fwalter/SMARTS/NovaAtlas/
flaring pulse, and these tracks almost overlap the track of the second flaring pulse. They are very similar to the loop of PW Vul in Figure 7(b).

The start of the nebular phase was identified by Poggiani (2012) at \((B - V)_0 = -0.16\) and \(M_V = -3.46\), which is denoted by a large open red square in Figure 11(d). The track of V5558 Sgr departs into two branches at this point, depending on the different filter responses of various observers just as in LV Vul and HR Del. One of them turns to the right (toward red) when the nebular phase started. The start of the nebular phase is located on the line of the two-headed red arrow.

2.11. Categorization of Color–Magnitude Tracks

It is clear that there is no single track common to all novae in the color–magnitude diagram. This is in contrast to the general track in the color–color diagram. In Paper I, we found that, in the color–color diagram, novae generally go down along the nova-giant sequence in the pre-maximum phase and then come back after the optical maximum as shown in Figure 2(a) (see also Figures 4 and 8 of Paper I). Fast novae tend to have short excursions, and slow novae tend to have long journeys to their peaks along the nova-giant sequence.

Figure 12 collects the templates of the color–magnitude diagrams for the very fast nova V1500 Cyg; fast novae V1668 Cyg, V1974 Cyg, and LV Vul; moderately fast nova FH Ser; and symbiotic (very slow) nova PU Vul. Because we excluded novae such as PW Vul, which shows oscillatory behavior around the optical peak, all six of these novae show smooth declines from their optical peaks. The behaviors of these six novae in the color–magnitude diagram are summarized as follows: (1) After the optical peak, each nova generally evolves toward blue from the upper right to the lower left along similar but different tracks. (2) Each track is located from the left (blue) to right (red) depending on the nova speed class, i.e., \(r_2 = 2.4, 12.2, 17, 20.4, 42, \text{ and } \gtrsim 1500\) days for V1500 Cyg, V1668 Cyg, V1974 Cyg, LV Vul, FH Ser, and PU Vul, respectively. Thus, we propose six templates of smooth decline nova tracks, i.e., V1500 Cyg, V1668 Cyg, V1974 Cyg, LV Vul, FH Ser, and PU Vul.

In the previous subsections, we examined the behaviors of 10 novae in the color–magnitude diagram. The LV Vul track almost overlaps that of PW Vul except for the early pulse (a loop). The track of PU Vul almost overlaps those of V723 Cas, HR Del, and V5558 Sgr except for the early pulses (loops). We may call PW Vul an LV Vul type track because the track of PW Vul is very close to the template of LV Vul. We also call V723 Cas, HR Del, and V5558 Sgr PU Vul type tracks. Thus, we define six types of nova tracks in the color–magnitude diagram, i.e., the V1500 Cyg, V1668 Cyg, V1974 Cyg, LV Vul, FH Ser, and PU Vul types.

These six template novae are further grouped into three families by their similarities. The track of V1500 Cyg overlaps that of V1974 Cyg if we shift it by \(\Delta(B - V) = 0.12\) mag toward red, as shown in Figure 8(d). V1668 Cyg shows a shallow dust blackout, while FH Ser shows a deep dust blackout. The track of V1668 Cyg is \(\Delta(B - V) = 0.12\) mag bluer than that of FH Ser, as shown in Figure 8(a). The track of LV Vul (PW Vul) almost overlaps those of PU Vul, V723 Cas, HR Del, and V5558 Sgr, if we shift it by \(\Delta(B - V) = 0.2\) mag toward red. Thus, we may categorize these 10 novae into three families, i.e., V1500 Cyg, V1668 Cyg, and LV Vul families. The V1500 Cyg family includes V1500 Cyg and V1974 Cyg, the V1668 Cyg family includes V1668 Cyg and FH Ser, and the LV Vul family includes LV Vul, PW Vul, PU Vul, V723 Cas, HR Del, and V5558 Sgr.
2.12. Characteristic Properties of Color–Magnitude Tracks

If optically thick free–free emission \((E_c \propto \nu^{2/3})\) dominates the spectrum of a nova, its color should be \((B - V)_0 = -0.03\) (Paper I), the color of which is indicated by a vertical thin solid red line in Figure 12. If the spectrum is of optically thin free–free emission \((E_c \propto \nu^0)\), its color is \((B - V)_0 = +0.13\) (not shown in Figure 12). V1668 Cyg and LV Vul almost follows the line of \((B - V)_0 = -0.03\), while V1500 Cyg and V1974 Cyg cross this line and move further toward blue. This is due to emission-line effects (see Figure 10 and discussion of Paper I). In the later phase, these novae turn to the right (toward red) owing to the contribution of [O iii] lines to the blue edge of the \(V\) filter. Therefore, this excursion toward red could be prominent in the nebular phase. We have already marked the beginning of the nebular phase in each figure. For V1500 Cyg and V1974 Cyg, the start of the nebular phase agrees with the clear cusp in the color–magnitude track as indicated by the large open red squares. For V1668 Cyg, we also found a cusp (not clear, but a slight cusp) on the track as shown in Figure 3. For LV Vul, we found that the track departs into two branches at the onset of the nebular phase, depending on the different response of each \(V\) filter, especially on the blue edge of the response function. For the other novae, we already specify the onset of the nebular phase on their tracks if it was detected and reported in the literature.

In this way, we found that there is a special feature like a cusp, bifurcation, or sharp turning point on the track near the onset of the nebular phase. Such a cusp (sharp turning point) appears at \(M_V = -4\) for the three fast novae, V1668 Cyg, V1500 Cyg, and V1974 Cyg. An inflection appears also at \(M_V = -4\) for the symbiotic novae PU Vul and slow novae V723 Cas and PW Vul. We found that the positions of these cusps/inflections are located on the lines described by

\[
M_V = -0.7(B - V)_0 - 4.17 \\
\pm 0.1 \text{ (two–headed black arrow).} \tag{5}
\]

This line is plotted in Figure 12 by the two-headed black arrow, which is obtained simply by connecting the inflection of PU Vul and the turning point of V1500 Cyg. The \(1\sigma\) error of 0.1 mag comes from our entire analysis of the color–magnitude diagrams for 13 novae, which will be discussed later from Section 4.2.

For LV Vul, HR Del, and V5558 Sgr, on the other hand, the start of the nebular phase is close to the line of the two-headed red arrow in Figure 12, i.e.,

\[
M_V = -0.7(B - V)_0 - 3.57 \pm 0.2 \\
\text{(two–headed red arrow).} \tag{6}
\]

This line is 0.6 mag below the line of the two-headed black arrow. The \(1\sigma\) error of 0.2 mag comes from our entire analysis of the color–magnitude diagrams for 11 novae, which will be discussed later in Section 4.2. These two lines are empirically determined, so we do not have a theoretical justification yet.

If the positions of cusps/inflections are always located on Equation (5) or Equation (6), we are able to estimate the absolute magnitudes of novae by placing the observed cusp/inflection on the line of Equation (5) or Equation (6). This could be a new method for obtaining the absolute magnitude of novae.

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3. COLOR–MAGNITUDE DIAGRAMS FOR VARIOUS NOVAE

In this section, we further examine various novae in the color–magnitude diagram. We have collected data from the literature for as many novae as possible that have a sufficient number of data points (usually more than a few tens). We classify these 30 nova tracks into the previously discussed six types, i.e., V1500 Cyg, V1668 Cyg, V1974 Cyg, FH Ser, LV Vul, and PU Vul, and discuss their physical properties in the color–magnitude diagram. These 30 novae are examined in the order of discovery.

3.1. RS Oph (1958, 1985, 2006)

RS Oph is a recurrent nova with six recorded outbursts in 1898, 1933, 1958, 1967, 1985, and 2006. The orbital period of 456 days was obtained by Fekel et al. (2000). Figure 13 shows the \(V, (B - V)_0, \text{and (} U - B)_0 \) evolutions of RS Oph. The observed data of RS Oph are taken from Connelley & Sandage (1970) (filled red circles) for the 1958 outburst and from AAVSO (open red diamonds), VSOLJ (encircled magenta plus signs), SMARTS (blue stars), Sostero & Guido (2006a, 2006b) and Sostero et al. (2006) (filled blue triangles), and Hachisu et al. (2008b) (filled green squares; data are tabulated only in arXiv:0807.1240 for the 2006 outburst). The \(V\) light curve declined with \(t_2 = 6.8\) days and \(t_3 = 14\) days (Schaefuer 2010). In panel (b) of Figure 13, the \(B - V\) data of the 2006 outburst are systematically 0.1 mag redder than those of the 1958 outburst (Connelley & Sandage 1970), so we shifted the \(B - V\) data of the 2006 outburst by 0.1 mag up (toward blue) to match...
them with the $B - V$ data of Connelley & Sandage (1970). The $B - V$ data of SMARTS are shifted by 0.05 mag down (toward red), however.

In Paper I, we determined the color excess as
\[ E(B - V) = 0.65 \pm 0.05 \]
and the distance modulus as
\[ (m - M)_V = 12.8 \pm 0.2 \]
on the basis of the general track in the color–color diagram and the time-stretching method, respectively. Assuming that $E(B - V) = 0.65$, we plot the color–color evolution of RS Oph (1958) in Figure 14(b). This color–color track of RS Oph is the same as that in Figure 42 of Paper I, but we reanalyze the data along the color evolution in Figure 13 and confirmed that the color excess is
\[ E(B - V) = 0.65 \pm 0.05 \]
by matching the color–color track (filled red circles) with the general course of novae (green lines) in Figure 14(a).

The distance to RS Oph was already discussed in Paper I. We plot various distance–reddening relations in Figure 15(a). This figure is the same as Figure 34(a) of Paper I, but we added Green et al.'s (2015) relation (solid black line). Three lines of $(m - M)_V = 12.8$, UV 1455 Å fit, and $E(B - V) = 0.65$ cross consistently at $d \approx 1.4$ kpc. The cross point is midway between Marshall et al.'s (2006) and Green et al.'s (2015) relations. Thus, we confirmed the values in Paper I, i.e., $(m - M)_V = 12.8$, $E(B - V) = 0.65$, and $d \approx 1.4$ kpc.

Figure 16(a) shows the color–magnitude diagram of RS Oph. The track is very similar to that of V1668 Cyg in the early phase, but turns to the right and follows the right side of the LV Vul track in the later phase. The start of the nebular phase was identified from the 1985 outburst observed by Rosino & Iijima (1987) as shown in Figure 16(a). We specify the point as $(B - V)_0 = -0.12$ and $M_V = -3.29$ with a large open red square in the figure. The starting point of the nebular phase is on the two-headed red arrow, so we identify RS Oph as an LV Vul type rather than a V1668 Cyg type in the color–magnitude diagram as listed in Table 2. We add the epoch when the variable SSS phase started at $m_V = 9.1$, about 30 days after the outburst (Hachisu et al. 2008c; Osborne et al. 2011). The epoch when the stable SSS phase started at $m_V = 9.6$, about 45 days after the outburst, is coincident with the start of the nebular phase. The track of RS Oph follows the line of $(B - V)_0 = -0.03$ in the early phase, being consistent with optically thick free–free emission ($F_\nu \propto \nu^{2/3}$). After the
stable SSS phase started, it jumps to \((B - V)_0 = +0.13\) and stays there for a while (between \(M_V = -2.7\) and \(M_V = -1.7\)), being consistent with the optically thin free–free emission \((n_{\mu} F_0)\). When the stable SSS phase started, the ejecta had already become optically thin. This agreement supports our adopted values of \(E(B - V) = 0.65\).

### 3.2. V446 Her 1960

Figure 17 shows the \(V, (B - V)_0\), and \((U - B)_0\) evolutions of V446 Her. These light-curve data are the same as those in Figure 42 of Paper I, but we reanalyzed the data as mentioned below. The data are taken from Antal (1961), Bronkalla & Notni (1961), Knipe (1960), Ross (1960), and IAU Circular No. 1730. The orbital period of 4.97 hr was detected by Thorstensen & Taylor (2000). The \(B - V\) data of the IAU Circular, Knipe (1960), and Bronkalla & Notni (1961) are systematically 0.1 mag redder than those of Ross (1960), so we shift them by 0.1 mag toward blue. As a result, the \(B - V\) color curve becomes smooth as shown in Figure 17(b). We also shift the \(U - B\) data of the IAU Circular and Bronkalla & Notni (1961) by 0.1 mag toward blue, so the \(U - B\) color curve also becomes smooth as shown in Figure 17(c).

In Paper I, we determined the color excess as \(E(B - V) = 0.40 \pm 0.05\) on the basis of the general track in the color–color diagram and the distance modulus as \((m - M)_V = 11.7 \pm 0.2\) by the time-stretching method. The reanalyzed data give a consistent matching with the general tracks of novae in the color–color diagram of V446 Her as shown in Figure 14(c) for the same reddening value of \(E(B - V) = 0.40\) as in Paper I. We also plot various distance–reddening relations for V446 Her, \((l, b) = (45^{\circ}.4092, +4^{\circ}.7075)\), in Figure 15(b). This figure is the same as Figure 34(b) of Paper I, but we added Green et al.’s (2015) relation (solid black line). The lines cross consistently at the point of \(E(B - V) = 0.40\) and \(d = 1.23\) kpc. Thus, we confirmed the values of Paper I, i.e., \(E(B - V) = 0.40\), \((m - M)_V = 11.7\), and \(d = 1.2\) kpc.

Using \(E(B - V) = 0.40\) and \((m - M)_V = 11.7\), we plot the color–magnitude diagram of V446 Her in Figure 16(b). We
identified the start of the nebular phase as \( \sim 40 \) days after the outburst from Figure 11 of Meinel (1963), at which the forbidden lines of \([\text{O} \text{ III}]\) surpassed the permitted lines. This epoch corresponds to \( m_V = 7.6 \) \((M_V = -4.1)\) as shown in Figure 16(b). We assign the start of the nebular phase to the observational point \( m_V = -4.05 \) and \((B - V)_0 = -0.13\), denoted by a large open red square in Figure 16(b). The track of V446 Her goes almost vertically down along the line of \((B - V)_0 = -0.03\), similarly to V1668 Cyg in the early phase, and turns to the left (toward blue) near the onset of the nebular phase (large open red square), almost on the two-headed black arrow. Then the track turns to the right (toward red) below the two-headed red arrow. Because the start of the nebular phase is located on the two-headed black arrow, we regard V446 Her as a V1668 Cyg type in the color–magnitude diagram as listed in Table 2.

3.3. V533 Her 1963

Figure 18 shows the \( V, (B - V)_0, \) and \((U - B)_0\) evolutions of V533 Her, where the \( UBV \) data are taken from van Genderen (1963), Chincarini (1964), and Shen et al. (1964). The orbital period of 3.53 hr was obtained by Thorstensen & Taylor (2000). The data of this figure are the same as those in Figure 41 of Paper I, but we reanalyzed the data as mentioned below. The \( U - B \) data of Chincarini (1964) and van Genderen (1963) are systematically 0.3 mag redder than those of Shen et al.
so we shifted them up (toward blue) by 0.3 mag in Figure 18(c).

In Paper I, we determined the color excess as $E(B - V) = 0.05 \pm 0.05$ on the basis of the general track in the color–magnitude diagram, and the distance modulus$^5$ as $(m - M)_V = 10.8 \pm 0.2$ by the time-stretching method (see Paper I for other estimates of reddening and distance). The NASA/IPAC galactic dust absorption map gives $E(B - V) = 0.038 \pm 0.002$ in the direction toward V533 Her, $(l, b) = (69^\circ1887, +24^\circ2733)$. Here we adopt this smaller value of $E(B - V) = 0.038$ and plot the color–magnitude diagram of V533 Her in Figure 14(d), resulting in a better matching with the general tracks of novae.

We plot three distance–reddening relations in Figure 15(c). The lines of $(m - M)_V = 10.8$ and $E(B - V) = 0.038$ cross at $d = 1.36$ kpc, so we adopt $d = 1.36$ kpc as the distance to V533 Her. The distance was estimated also by Cohen (1985) to be $d \sim 1.32$ kpc from the expansion parallax method, together with the nebular expansion velocity of $v_{exp} = 1050$ km s$^{-1}$. Gill & O’Brien (2000) obtained $d = 1.25 \pm 0.30$ kpc, together with $v_{exp} = 850 \pm 150$ km s$^{-1}$.

Our distance of $d = 1.36$ kpc is consistent with the values given by both Cohen (1985) and Gill & O’Brien (2000). Green et al.’s (2015) distance–reddening relation is also consistent with the value of $E(B - V) = 0.038$.

$^5$ It should be noted that $(m - M)_V = 11.1$ in Table 2 of Paper I is a typographical error.

Figure 17. Same as Figure 1, but for V446 Her. The $(B - V)_0$ and $(U - B)_0$ are dereddened with $E(B - V) = 0.40$. In panel (b), the $B - V$ data of IAU Circular No. 1730, Knipe (1960), and Bronkalla & Notni (1961) are systematically shifted toward blue by 0.1 mag. In panel (c), the $U - B$ data of the IAU Circular and Bronkalla & Notni (1961) are also systematically shifted toward blue by 0.1 mag.

Figure 18. Same as Figure 17, but for V533 Her. The $(B - V)_0$ and $(U - B)_0$ are dereddened with $E(B - V) = 0.038$. In panel (c), the $U - B$ data of Chincarini (1964) and van Genderen (1963) are systematically shifted toward blue by 0.3 mag.

Adopting $E(B - V) = 0.038$ and $(m - M)_V = 10.8$, we plot the color–magnitude diagram in Figure 16(c). We added the $BV$ data (open magenta circles) of Kreiner et al. (1966). The nebular phase started around UT 1963 April 19 at $m_V = 7.2$ (Chincarini & Rosino 1964). After that, these three tracks branch off and diverge. In the nebular phase, the $[O iii]$ emission lines dominate the spectrum at the blue edge of the $V$ filter. Because the response of each $V$ filter is slightly different at the blue edge, the $[O iii]$ emission lines make a large difference in the $V$ magnitude among the observers. This can be seen clearly in Figures 3–5 of Kreiner et al. (1966), in which the $V$ magnitude of each observer started to branch off after UT 1963 April 10 (JD 2,438,129.5), while the $B$ magnitude was essentially the same among the observers. This is also shown clearly in Figures 18(a) and (b). In the color–magnitude diagram, there is a sharp (cusp) turning point on the data of Shen et al. (1964) at $M_V = -3.97$ and $(B - V)_0 = -0.40$. We identify V533 Her as a V1974 Cyg type in the color–magnitude diagram as listed in Table 2.

3.4. T Pyx (1966, 2011)

T Pyx is a recurrent nova with six recorded outbursts in 1890, 1902, 1920, 1944, 1966, and 2011. The orbital period of 1.83 hr was obtained by Uthas et al. (2010). Figure 19 shows the $V$, $(B - V)_0$, and $(U - B)_0$ evolutions of the 1966 and 2011 outbursts, where the $UBV$ data are taken from Eggen et al. (1967) and Landolt (1970) and the $BV$ data are taken from the SMARTS and AAVSO archives. We also added the X-ray light...
The curve of T Pyx taken from the Swift Web page\(^6\) (Evans et al. 2009).

We adopt the distance of 4.8 kpc after Sokoloski et al. (2013) and the extinction of \(E(B-V) = 0.25\) from Paper I (see Paper I for other estimates of the reddening and distance). Then, the distance modulus is \((m-M)_V = 14.2\) for \(E(B-V) = 0.25\) and \(d = 4.8\) kpc. Figure 20 compares four light curves of the novae, T Pyx, DQ Her, PW Vul, and NQ Vul. The timescales of these four novae are almost the same except for the early fluctuations in the optical maximum phase. The light curves of these four novae almost overlap each other in the later decline phase and decline as \(t^{-3}\) (thin solid black line) except for the period of dust blackout of DQ Her, where \(t\) is the time after the outburst. We obtained the following relation among them:

\[
(m - M)_{V,T\text{Pyx}} = 14.2 \\
= (m - M + \Delta V)_{V,DQ\text{Her}} \\
= 8.2 + (+6.0) = 14.2 \\
= (m - M + \Delta V)_{V,PW\text{Vul}} \\
= 13.0 + (+1.2) = 14.2 \\
= (m - M + \Delta V)_{V,NQ\text{Vul}} \\
= 13.6 + (+0.6) = 14.2, \tag{7}
\]

where \(\Delta V\) is the difference between the \(V\) light curve of T Pyx and that of a target nova. We shift the optical light curve of DQ Her down by \(\Delta V = 6.0\) mag, that of PW Vul down by \(\Delta V = 1.2\) mag, and that of NQ Vul down by \(\Delta V = 0.6\) mag against that of T Pyx. The distance of DQ Her was obtained with the trigonometric parallax method to be \(d = 386^{+13}_{-20}\) pc (Harrison et al. 2013). Adopting \(A_V = 3.1 \times E(B-V) = 0.31\) (Verbunt 1987), we obtain the distance modulus of DQ Her as \((m - M)_V = 8.24 \pm 0.18\). Thus, we use \((m - M)_V,DQ\text{Her} = 8.2\). We have already obtained \((m - M)_V,PW\text{Vul} = 13.0\) in Section 2.4 and \((m - M)_V,NQ\text{Vul} = 13.6\) in Section 3.6. The relations in Equation (7) strongly suggest that the overlapping region of the \(t^{-3}\) law has almost the same absolute brightness among novae having similar timescales, although the peak absolute brightnesses are different.

Using \((m - M)_V = 14.2\) and \(E(B-V) = 0.25\), we plot the color–magnitude diagram of T Pyx in Figure 16(d), where the data are taken from Landolt (1970) for the 1966 outburst and from the SMARTS and AAVSO archives for the 2011 outburst. The nebular phase started around UT 1967 March 12, at \(m_V \sim 9.6\) (Catchpole 1969), corresponding to the turning point of the track, denoted by a large open red square at \(M_V = -4.59\) and \((B-V)_0 = -0.56\). The track of T Pyx is located near that of V1974 Cyg in the early phase, turns gradually to the left (toward blue) over the track of V1500 Cyg, and then suddenly turns to the right (toward red) near the starting point of the nebular phase. We add the epoch when the SSS phase started at \(m_V = 10.8\) about 120 days after the outburst (Chomiuk et al. 2014). We identify T Pyx as a V1500 Cyg type in the color–magnitude diagram as tabulated in Table 2.

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\(^6\) http://www.swift.ac.uk/
almost follows that of PW Vul and LV Vul. Thus, we regard IV Cep as an LV Vul type in the color–magnitude diagram as listed in Table 2. Strong emission lines of [O III] appeared between UT 1971 September 12 and 22 (Rosino 1975), which is an indication of the nebular phase. We identify the start of the nebular phase at \((B - V)_0 = -0.37\) and \(M_V = -3.23\), denoted by a large open red square in Figure 23(a). This starting point is located on the line of the two-headed red arrow.

### 3.6. NQ Vul 1976

NQ Vul belongs to the dust blackout type novae like FH Ser. Figure 24 shows the \(V\), \((B - V)_0\), and \((U - B)_0\) evolutions of NQ Vul, where the \(UBV\) data are taken from Yamashita et al. (1977), Landolt (1977), Chambliss (1977), and Duerbeck & Seitter (1979) and the \(V\) and visual magnitudes are from di Paolantonio & Patriarca (1978) and the AAVSO archive, respectively. The data of this figure are the same as those in Figure 43 of Paper I, but we reanalyzed them as mentioned below. The \(B - V\) colors of Duerbeck & Seitter (1979) are systematically bluer by 0.05 mag and of Yamashita et al. (1977) are redder by 0.05 mag than the other data, so that we shift them down by 0.05 mag and up by 0.05 mag, respectively. The \(U - B\) colors of Duerbeck & Seitter (1979) and Yamashita et al. (1977) are systematically redder by 0.1 mag and bluer by 0.1 mag than the other data, so we shift them up by 0.1 mag and down by 0.1 mag, respectively. Using these color data, we fit the color–color evolution of NQ Vul with the general track of novae and obtain \(E(B - V) = 1.0 \pm 0.05\) as shown in Figure 22(b). We reanalyzed the color data but obtained the same result as that in Paper I.

Figure 25(a) shows various distance–reddening relations toward NQ Vul, \((l, b) = (55^\circ35352, +1^\circ2899)\). The data are the same as those in Figure 35(a) of Paper I, but we add Green et al.’s (2015) relation. Our lines \((m - M)_V = 13.6\) and \(E(B - V) = 1.0\) cross at the point \(d = 1.26\) kpc, and the cross point is midway between the distance reddening relations of Marshall et al. (2006) and Green et al. (2015). Thus, we confirmed the same values as in Paper I.

Using \((m - M)_V = 13.6\) and \(E(B - V) = 1.0\), we plot the color–magnitude diagram of NQ Vul in Figure 23(b). The track of NQ Vul is located closely to that of FH Ser (solid orange lines), although the data are scattered. The large variation in the early-phase data is partly due to a few pulsations on the \(V\) light curve in the pre-maximum phase. We can see two small brightenings before the optical maximum in Figure 24(a). The color–magnitude data obtained by Duerbeck & Seitter (1979), which are connected by a thin solid magenta line, show two clockwise movements that correspond to the two pulses before the optical maximum in Figure 23(b). The first clockwise looping is close to the track of FH Ser. The second clockwise movement departs from the track of FH Ser and then approaches the track of V1668 Cyg. Then, the track of NQ Vul reaches its peak and goes down between the tracks of V1668 Cyg and FH Ser after the optical maximum. The color of the track became bluer after a considerable part of the envelope mass was ejected during these early pulses. This strongly suggests that the bluer the nova color is, the smaller the envelope mass is. We regard NQ Vul as an FH Ser type in the color–magnitude diagram as listed in Table 2. The start of the dust blackout is denoted by a large open red square in Figure 23(b) at \((B - V)_0 = +0.01\) and \(M_V = -4.26\).
3.7. V1370 Aql 1982

V1370 Aql also shows a dust blackout, but its depth is much shallower than those of FH Ser and NQ Vul. Figure 26 depicts the V and visual, (B – V)0, and (U – B)0 evolutions of V1370 Aql, where the UBV data are very limited. We found only the data of Okazaki & Yamasaki (1986) and IAU Circular No. 3689 for the UBV data and Rosino et al. (1983) for the BV data in addition to the visual magnitudes from the AAVSO archive. The V light curve has \( t_2 = 8 \) days and \( t_3 = 13 \) days (e.g., Williams & Longmore 1984). V1370 Aql was identified as a neon nova by Snijders et al. (1987).

In Paper I, we determined the color excess as \( E(B - V) = 0.35 \pm 0.05 \) from the color–color diagram fit and the distance modulus as \( (m - M)_V = 15.2 \pm 0.2 \) by the time-stretching method relative to the distance modulus of V1668 Cyg (see Paper I for other estimates of reddening and distance). After that, Hachisu & Kato (2016) revised the distance modulus of V1668 Cyg including the photospheric emission in addition to the free–free emission. Therefore, we redefine the distance modulus of V1370 Aql based on the new estimate of the distance modulus of V1668 Cyg (see also Section 2.1).

Figure 27 shows a comparison of V1370 Aql with V1668 Cyg and OS And. We adopt the stretching factor as \( f_s = 1.12 \) and 1.58 for V1668 Cyg and OS And against V1370 Aql, respectively. These three nova light curves overlap each other. Then, the brightness difference is \( \Delta V = 2.0 \) mag for V1668 Cyg and \( \Delta V = 2.2 \) mag for OS And against that of V1370 Aql. Using the time-stretching method (see Section 2.2 for a short explanation of the time-stretching method), we obtain the distance modulus of V1370 Aql as

\[
(m - M)_{V, V1370 Aql} = \frac{(m - M)_{V, V1668 Cyg} - 2.5 \log 1.12}{14.6 + 2.0 - 0.12} - 16.48 = 14.8 + 2.2 - 0.50 = 16.50,
\]

where we use \( (m - M)_{V, V1668 Cyg} = 14.6 \) from Section 2.1 and \( (m - M)_{V, OS And} = 14.8 \) from Section 3.10. We adopt \( (m - M)_{V, V1370 Aql} = 16.5 \). Then, the distance is calculated to be \( d = 12 \) kpc for \( E(B - V) = 0.35 \).
Hachisu & Kato (2016) calculated the absolute magnitudes of model light curves of novae for various sets of chemical compositions. Adopting their chemical composition of CO nova 3, we obtained a best-fit $V$ light-curve model for a $\varepsilon_{M_0} = 0.95$ WD and plotted them in Figure 27(a). The fitting of the $V$ light curve gives a distance modulus of $-16.5$, being consistent with that obtained from the time-stretching method mentioned above. Therefore, we plot the distance–reddening relations of the $V$ light-curve fit calculated from Equation (3), together with $(m - M)_V = 16.5$ (solid blue line) and the UV 1455 Å light-curve fit calculated from Equation (4) (solid magenta line) in Figure 25(b). We added other distance–reddening relations for V1370 Aql, $(l, b) = (38^\circ.8126, -5^\circ.9465)$, in Figure 25(b), that is, the relations given by Marshall et al. (2006) and Green et al. (2015). The three trends of the distance–reddening relations, i.e., Marshall et al.’s and two distance moduli in the $V$ and UV 1455 Å band, cross each other at $E(B - V) = 0.35$ and $d \approx 12$ kpc, being consistent with our estimates for V1370 Aql. Green et al.’s (2015) relation deviates largely from our value of $E(B - V) \approx 0.35$.

Using $E(B - V) = 0.35$ and $(m - M)_V = 16.5$, we plot the color–magnitude diagram for V1370 Aql in Figure 23(c). The peak $V$ magnitude reaches as bright as $M_V = m_V - (m - M)_V = 6.5 - 16.5 = -10$. We plot the starting position of the dust blackout in the color–magnitude diagram by a large open blue square. V1370 Aql experienced a relatively shallow extinction.

Figure 23. Same as Figure 16, but for (a) IV Cep, (b) NQ Vul, (c) V1370 Aql, and (d) GQ Mus. Solid magenta lines denote the template track of LV Vul in panels (a), (c), and (d). Thin solid green lines represent the track of PW Vul in panel (a), but that of V1668 Cyg in panels (b) and (c). In panel (b), thin solid orange lines denote the track of FH Ser. In panel (d), the solid cyan line denotes the track of V1974 Cyg, the thick solid orange line represents the track of V1500 Cyg, and green symbols correspond to T Pyx.
dust blackout. The $V$ magnitude was about $m_V \approx 11.2$ just before the dust blackout started as shown in Figure 26. This corresponds to $M_V = 11.2 - 16.5 = -5.3$. In the dust blackout type novae, their $B - V$ colors are almost constant before the dust blackout as shown in Figure 26(a). Therefore, we expect that $(B - V)_0 = -0.03$ at this epoch. This estimated point is indicated by a large open blue square in Figure 24(c). The color of $(B - V)_0 = -0.03$ is just the same as that of optically thick free-free emission. Rosino et al. (1983) concluded that [O m] had already developed in September and had been much stronger than $H\beta$. Therefore, we may conclude that the nova had already entered the nebular phase in 1982 August at $m_V \sim 14$. We identify the start of the nebular phase at $(B - V)_0 = -0.35$ and $M_V = -3.10$ and denote it by a large open red square in Figure 23(c). The track of V1370 Aql almost follows that of LV Vul in the later phase, and the starting point of the nebular phase is close to, but a bit lower than, the line of the two-headed red arrow. Therefore, we regard V1370 Aql as an LV Vul type in the color–magnitude diagram as listed in Table 2.

### 3.8. GQ Mus 1983

Figure 28 shows the V and visual, $(B - V)_b$, and $(U - B)_b$ evolutions of GQ Mus. The $UBV$ data of GQ Mus are taken from Whitelock et al. (1984) and IAU Circular Nos. 3766, 3771, and 3853. The $V$ data were observed with the fine error sensor (FES) monitor on board HUE, which are taken from the INES archive data sever.\(^7\) The visual photometric data are from the Royal Astronomical Society of New Zealand (RASNZ) and AAVSO (see Hachisu et al. 2008a, for more details). Krautter et al. (1984) estimated the peak brightness to be $m_{v,max} \approx 7.0$ (or $m_{v,max} < 7.3$). Hachisu et al. (2008a) adopted $m_{v,max} \approx 7.2$ after Warner (1995). GQ Mus declined with $t_2 = 15$ days and $t_3 = 40$ days (e.g., Warner 1995). The orbital period of 1.43 hr was detected by Diaz & Steiner (1989).

Paper I and Hachisu & Kato (2015) analyzed the light curve of GQ Mus and determined the reddening as $E(B - V) = 0.45 \pm 0.05$ from the color–diagram fit and the distance modulus in the $V$ band as $(m - M)_V = 15.7 \pm 0.2$ by the time-stretching method (see Paper I and Hachisu & Kato 2015 for details). Here we adopt $E(B - V) = 0.45$ and $(m - M)_V = 15.7$ for GQ Mus after Paper I and Hachisu & Kato (2015).

Using $E(B - V) = 0.45$ and $(m - M)_V = 15.7$, we plot the color–magnitude diagram of GQ Mus in Figure 23(d). We superpose the data of T Pyx (green symbols) on the figure. These two tracks almost overlap each other in the middle part of the tracks. We regard GQ Mus as a V1500 Cyg type in the color–magnitude diagram as listed in Table 2, because T Pyx was identified as a V1500 Cyg type. The nova entered the nebular phase no later than UT 1983 March 4, at $m_V \approx 10.2$ (Drechsel et al. 1984), which is denoted by an arrow in Figure 23(d), i.e., near the point of $M_V = -5.70$ and $(B - V)_0 = -0.25$. This starting point of the nebular phase is much (~1.7 mag) above the line of the two-headed black arrow.

### 3.9. QU Vul 1984#2

Figure 29 shows the V and visual, $(B - V)_b$, and $(U - B)_b$ evolutions of QU Vul. The $UBV$ data of QU Vul are taken from IAU Circular No. 4033, Kolotilov & Shenavrin (1988), Bergner et al. (1988), and Rosino et al. (1992). The visual data are taken from the AAVSO archive. The $B - V$ colors of Rosino et al. (1992) are systematically bluer by 0.1 mag, so we shift them down by 0.1 mag in Figure 29(b). Gehrz et al. (1985) identified QU Vul as a neon nova, and Shafter et al. (1995) detected the orbital period of 2.68 hr.

Paper I and Hachisu & Kato (2016) analyzed the light curve of QU Vul and determined the reddening as $E(B - V) = 0.55 \pm 0.05$ from the color–diagram fit and the distance modulus in the $V$ band as $(m - M)_V = 13.6 \pm 0.2$ by the time-stretching method (see Paper I and Hachisu & Kato 2016 for other estimates of reddening and distance). Assuming $E(B - V) = 0.55$, we plot the color–diagram fit of QU Vul in Figure 22(c). This figure is the same as Figure 31(c) of Paper I, but we reanalyzed the color data as mentioned above in Figure 29(b). The color–diagram evolution is consistent with the general tracks of novae. Therefore, we adopt $E(B - V) = 0.55$ for QU Vul.

We plot various distance–reddening relations for QU Vul, $(l, b) = (68^\circ 5108, -6^\circ 0263)$, in Figure 25(c). The thick solid blue line denotes $(m - M)_V = 13.6$. The solid magenta line is the relation calculated from the model UV 1455 Å light-curve fitting of a 0.96 $M_\odot$ WD model with the chemical composition of Ne nova 3 (Hachisu & Kato 2016). We also plot the four distance–reddening relations of Marshall et al. (2006). The solid black line is Green et al.‘s (2015) relation. These distance–reddening relations cross consistently at/near the point of $d = 2.4$ kpc and $E(B - V) = 0.55$. Thus, we adopt a

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\(^7\) http://sdc.cab.inta-csic.es/ines/index2.html
set of $E(B-V) = 0.55$, $d = 2.4$ kpc, and $(m-M)_V = 13.6$ for QU Vul after Hachisu & Kato (2016).

Adopting $E(B-V) = 0.55$ and $(m-M)_V = 13.6$, we plot the color–magnitude diagram of QU Vul in Figure 30(a). The track of QU Vul roughly overlaps with that of V1974 Cyg, so we regard QU Vul as a V1974 Cyg type in the color–magnitude diagram as listed in Table 2. The nova entered the nebular phase in 1985 April at $m_V \approx 9.7$ (Rosino & Iijima 1987; Rosino et al. 1992) as denoted by an arrow in the figure. We obtain the starting position of the nebular phase at $M_V = -4.01$ and $(B-V)_0 = -0.31$ as denoted by a large open red square. This point is located on the line of the two-headed black arrow. Then the track once made an excursion toward blue up to $(B-V)_0 \sim -1.0$, followed by the final excursion toward red.

3.10. OS And 1986

Figure 31 shows the visual and $V$, $(B-V)_0$, and $(U-B)_0$ light curves in Figure 27, but on a logarithmic timescale. The $UBV$ data of OS And are taken from Kikuchi et al. (1988), Ohmori & Kaga (1987), and IAU Circular Nos. 4306, 4342, and 4452.

In Paper I, we determined the reddening as $E(B-V) = 0.15 \pm 0.05$ from the color–color diagram fit and the distance modulus in the $V$ band as $(m-M)_V = 14.7 \pm 0.2$ by the time-stretching method (see Paper I for other estimates of reddening and distance). We reanalyzed the time-stretching method for V1668 Cyg, V1370 Aql, and OS And in Equation (8) because the distance modulus of V1668 Cyg was revised in Hachisu & Kato (2016). The new distance modulus of OS And is $(m-M)_V = 14.8 \pm 0.2$. Then the distance is calculated to be $d = 7.3$ kpc for $E(B-V) = 0.15$.

We fit our model light curves with the OS And observation, i.e., $V$ and UV 1455 Å light curves. We adopt a 1.05 $M_\odot$ WD model of the CO nova 3 chemical composition (Hachisu & Kato 2016). This model fits well both the $V$ and UV 1455 Å light curves as shown in Figure 27(a). Here we plot the three model light curves for V1370 Aql (0.95 $M_\odot$), V1668 Cyg...
Figure 26. Same as Figure 17, but for V1370 Aql. We dereddened \((B - V)_0\) and \((U - B)_0\) colors with \(E(B-V) = 0.35\).

Figure 27. Comparison of V1370 Aql (green symbols) with V1668 Cyg (blue symbols) and OS And (red symbols). In panel (a), we add a 0.95 M\(_\odot\) WD model with the chemical composition of CO nova 3 (Hachisu & Kato 2016) for the V (thin solid blue line) and UV 1455 Å (thin solid red line) light curves.

Figure 28. Same as Figure 17, but for GQ Mus. We dereddened \((B - V)_0\) and \((U - B)_0\) colors with \(E(B-V) = 0.45\).

Figure 29. Same as Figure 17, but for QU Vul. We dereddened \((B - V)_0\) and \((U - B)_0\) colors with \(E(B-V) = 0.55\).
0.98 \, M_\odot), \text{ and OS And (1.05 \, M_\odot) with appropriate time-stretching factors depicted in the figure. The solid blue/red lines are almost the same for V1370 Aql, V1668 Cyg, and OS And, because these model light curves have a universal shape. The \( V \) light-curve fit gives a relation of \((m - M)_V = 14.8\) for OS And. We plot the distance–reddening relations in Figure 25(d), i.e., the lines for \((m - M)_V = 14.8\) (solid blue line), given by Green et al. (2015) (solid black line), and the UV 1455 Å model light-curve fit (a 1.05 \, M_\odot WD model with the chemical composition of CO nova 3). These lines cross at/near the point of \( d = 7.3 \, \text{kpc} \) and \( E(B - V) = 0.15 \). Therefore, we adopt \((m - M)_V = 14.8\) and \( E(B - V) = 0.15 \) in this paper.

Using \( E(B - V) = 0.15 \) and \((m - M)_V = 14.8\), we plot the color–magnitude diagram of OS And in Figure 30(b). The track denoted by open blue squares (data from IAU Circumars) is close to that of FH Ser (solid orange lines), while that denoted by filled red circles (data from Kikuchi et al.) is close to that of V1668 Cyg. We regard OS And as a V1668 Cyg type in the color–magnitude diagram and list it in Table 2. The dust blackout starts at \( M_V = -4.59 \) and \((B - V)_0 = +0.14\), denoted by a large open red square.

3.11. QV Vul 1987

Figure 32 shows the visual and \( V, (B - V)_0, \) and \((U - B)_0\) evolutions of QV Vul. The \( UBV \) data are taken from Ohshima.
(1988) and IAU Circular Nos. 4493, 4511, and 4524, and the visual data are from the AAVSO archive. We shift the $B - V$ and $U - B$ data of IAU Circulars down by 0.1 and 0.2 mag, respectively, to match these data to those of Ohshima (1988). QV Vul is a dust blackout type moderately fast nova with $t_2 = 50$ days and $t_3 = 53$ days (Downes & Duerbeck 2000).

In Paper I, we determined the reddening as $E(B - V) = 0.60 \pm 0.05$ from the color–color diagram fit and the distance modulus in the $V$ band as $(m - M)_V = 14.0 \pm 0.2$ from the time-stretching method (see Paper I for other estimates of reddening and distance). Using $E(B - V) = 0.60$, we plot the color–color track of QV Vul in Figure 22(d). The figure is the same as Figure 32(a) of Paper I, but we added the data of IAU Circulars (open blue circles). The track of QV Vul is consistent with the general track of novae (solid green line), so we adopt $E(B - V) = 0.60$.

We plot various distance–reddening relations for QV Vul, $(l, b) = (53.38585, +6.9741)$, in Figure 33(a), i.e., Marshall et al.’s (2006) four relations, Green et al.’s (2015) relation, $E(B - V) = 0.60$, and $(m - M)_V = 14.0$. The various distance–reddening relations cross each other at $E(B - V) = 0.60$ and $d = 2.7$ kpc. Therefore, we adopt $E(B - V) = 0.60$ and $(m - M)_V = 14.0$ for QV Vul.

Using $(m - M)_V = 14.0$ and $E(B - V) = 0.60$, we plot the color–magnitude diagram of QV Vul in Figure 30(c). The track is similar to, but slightly bluer than, that of FH Ser. We regard QV Vul as an FH Ser type in the color–magnitude diagram. The dust blackout started at $m_V \approx 9.0$ as indicated by an arrow and large open red square at $(B - V)_0 = -0.03$ and $M_V = -5.0$.

### 3.12. V443 Sct 1989

Figure 34 shows the visual and $V$, $(B - V)_0$, and $(U - B)_0$ evolutions of V443 Sct. The $UBV$ data are taken from IAU Circular Nos. 4862, 4865, 4868, 4873, and 4902. The photographic magnitudes are taken from IAU Circulars Nos. 4862 and 4868. V443 Sct possibly reached 7.5 mag at maximum (Rosino et al. 1991). The visual magnitudes are from the AAVSO archive. The global shape of the light curve is similar to that of PW Vul (see Figure 52 of Paper I).

In Paper I, we determined the reddening as $E(B - V) = 0.40 \pm 0.05$ from the color–color diagram fit and the distance modulus in the $V$ band as $(m - M)_V = 15.5 \pm 0.2$ from the time-stretching method (see Paper I for other estimates of reddening and distance). Then, the distance is calculated to be $d = 7.1$ kpc for $E(B - V) = 0.40$. We plot various distance–reddening relations in Figure 33(b). The two lines of $(m - M)_V = 15.5$ cross at $d = 7.1$ kpc. On the other hand, Green et al.’s (2015) (solid black line) and Marshall et al.’s (2006) four relations cross the line of $(m - M)_V = 15.5$ at $E(B - V) \approx 0.64$ and $d \approx 5.2$ kpc. Rosino et al. (1991) estimated the reddening as $E(B - V) = 0.3$ from the He I line ratios. Anupama et al. (1992) obtained the reddening of $E(B - V) = 0.4$ from the Balmer/Paschen line ratios, being consistent with our value. Andréa et al. (1994) estimated the reddening as $E(B - V) = 0.30$ from the H and He recombination line ratios. Here we adopt $E(B - V) = 0.40$ and $(m - M)_V = 15.5$ because the $1 \sigma$ error of reddening is rather large for this direction in the Marshall et al. relations.

Using $E(B - V) = 0.40$ and $(m - M)_V = 15.5$, we plot the color–magnitude diagram of V443 Sct in Figure 30(d). The
track of V443 Sct is similar to that of PW Vul, which is an LV Vul type, although the number of data points is small. Thus, we regard V443 Sct as an LV Vul type as listed in Table 2. Rosino et al. (1991) reported that the nova had already entered the nebular phase in 1990 March after a period of seasonal invisibility. They also wrote that the nova was approaching the nebular phase in 1989 November. Therefore, we specify that the nova entered the nebular phase at $m_V \approx 12.0$, which is denoted by an arrow in Figure 30(d).

3.13. V1419 Aql 1993

Figure 35 shows the visual and $V$, $(B - V)_0$, and $(U - B)_0$ evolutions of V1419 Aql. The $UBV$ data are taken from Munari et al. (1994b) and IAU Circular Nos. 5794, 5802, 5807, and 5829. The visual magnitudes are from the AAVSO archive. V1419 Aql is a dust blackout type fast nova with $t_2 = 17$ days and $t_3 = 31$ days (Downes & Duerbeck 2000).

In Paper I, we determined the reddening as $E(B - V) = 0.50 \pm 0.05$ from the color–color diagram fit and the distance modulus in the $V$ band as $(m - M)_V = 14.6 \pm 0.2$ from the time-stretching method (see Paper I for other estimates of reddening and distance). Then, the distance is calculated to be $d = 4.1$ kpc for $(m - M)_V = 14.6$ and $E(B - V) = 0.50$. We plot various distance–reddening relations in Figure 33(c), which is the same as Figure 36(d) of Paper I, but we added Green et al.’s relation (solid black line). These trends, i.e., $(m - M)_V = 14.6$, $E(B - V) = 0.50$, Marshall et al.’s (2006), and Green et al.’s (2015), roughly cross each other at the point of $E(B - V) \approx 0.50$, $(m - M)_V \approx 14.6$, and $d \approx 4.1$ kpc, the same values as in Paper I.

Adopting $E(B - V) = 0.50$, we plot the color–color diagram of V1419 Aql in Figure 36(a). The figure is the same as Figure 32(c) of Paper I, but we added more data points from Munari et al. (1994b) and the track of V1668 Cyg (small open

Figure 33. Same as Figure 9, but for (a) QV Vul, (b) V443 Sct, (c) V1419 Aql, and (d) V705 Cas. The thick solid blue lines denote (a) $(m - M)_V = 14.0$, (b) $(m - M)_V = 15.5$, (c) $(m - M)_V = 14.6$, and (d) $(m - M)_V = 13.4$. The Astrophysical Journal Supplement Series, 223:21 (62pp), 2016 April Hachisu & Kato
magenta squares). The color–color evolution of V1419 Aql almost overlaps that of V1668 Cyg. This again confirms that our value of \( E(B - V) = 0.50 \pm 0.05 \) is reasonable.

Using \( E(B - V) = 0.50 \) and \( (m - M)_V = 14.6 \), we plot the color–magnitude diagram of V1419 Aql in Figure 37(a). The color–magnitude track of V1419 Aql is also very similar to that of V1668 Cyg except for the maximum brightness. The maximum brightness is close to those of LV Vul and FH Ser. We regard V1419 Aql as a V1668 Cyg type as listed in Table 2. In the color–magnitude diagram, the dust blackout started at \( (B - V)_0 = -0.13 \) and \( M_V = -3.85 \) (a large open red square).

3.14. V705 Cas 1993

Figure 38 shows the visual and \( V, (B - V)_0, \) and \( (U - B)_0 \) evolutions of V705 Cas. The \( UBV \) data are taken from Munari et al. (1994a), Hric et al. (1998), and IAU Circular Nos. 5905, 5912, 5914, 5920, 5928, 5929, 5945, and 5957. The visual data are from the AAVSO archive. V705 Cas is a dust blackout type nova with \( t_2 = 33 \) days and \( t_3 = 61 \) days (Hric et al. 1998). The orbital period of 5.47 hr was obtained by Retter & Leibowitz (1995).

Paper I and Hachisu & Kato (2015) determined the reddening as \( E(B - V) = 0.45 \pm 0.05 \) and the distance modulus in the \( V \) band as \( (m - M)_V = 13.4 \pm 0.1 \), both from the model light-curve fitting (see Paper I and Hachisu & Kato 2015 for other estimates of reddening and distance). We plot three distance–reddening relations in Figure 33(d). Hachisu & Kato (2015) fitted their model light curves of a 0.78 \( M_\odot \) WD of CO nova 4 chemical composition with the V705 Cas observation. The \( V \) light-curve fit gives \( (m - M)_V = 13.4 \), and the UV 1455 Å light-curve fit also yields that of the solid magenta line in Figure 33(d). The solid black line is the distance–reddening relation given by Green et al. (2015). These trends roughly cross each other at the point of \( d \approx 2.5 \) kpc, \( E(B - V) \approx 0.45 \), and \( (m - M)_V \approx 13.4 \). Therefore, we adopt \( E(B - V) = 0.45 \) and \( (m - M)_V = 13.4 \), the same as those in Paper I and Hachisu & Kato (2015).

Using \( E(B - V) = 0.45 \), we plot the color–color diagram of V705 Cas in Figure 36(b). Because the dust blackout started about 60 days after discovery, we plot only the data for \( t < 70 \) days. This figure is the same as Figure 32(d) of Paper I, but we reanalyzed the color data. The color–color evolution is consistent with the general track of novae (solid green lines). This again confirms our value of \( E(B - V) = 0.45 \pm 0.05 \).

Using \( E(B - V) = 0.45 \) and \( (m - M)_V = 13.4 \), we plot the color–magnitude diagram of V705 Cas in Figure 37(b). V705 Cas moves along a flat circle anticlockwise in the very early phase near maximum. After that, it follows the track of FH Ser and then goes along the track of V1668 Cyg. We regard V705 Cas as a V1668 Cyg type. The nova entered a dust blackout phase at the position of \( (B - V)_0 = -0.20 \) and \( M_V = -4.09 \).

3.15. V382 Vel 1999

Figure 39 shows the visual and \( V, (B - V)_0, \) and \( (U - B)_0 \) evolutions of V382 Vel. The \( UBV \) data are taken from IAU Circular Nos. 7176, 7179, 7196, 7209, 7216, 7226, 7232, and 7277. The visual magnitudes are taken from IAU Circulars and the AAVSO archive. V382 Vel was identified as a very fast neon nova (Woodward et al. 1999). The orbital period of 3.5 hr was detected by Balman et al. (2006).
In Paper I and Hachisu & Kato (2016), we determined the reddening as $E(B-V) = 0.15 \pm 0.05$ and the distance modulus in the $V$ band as $(m-M)_V = 11.5 \pm 0.1$, both from the model light-curve fitting (see Paper I and Hachisu & Kato 2016 for other estimates of reddening and distance). Using $E(B-V) = 0.15$ and $(m-M)_V = 11.5$, we plot the color–magnitude diagram of V382 Vel in Figure 37(c). The color–magnitude diagram of V382 Vel almost coincides with the track of V1974 Cyg. Therefore, we regard V382 Vel as a V1974 Cyg type in the color–magnitude diagram. The distance is calculated to be $d = 1.6$ kpc for $E(B-V) = 0.15$ and $(m-M)_V = 11.5$.

Della Valle et al. (2002) reported that the nebular phase started at least by the end of 1999 June, i.e., $\sim 40$ days after the optical maximum. We plot this phase $(M_V = m_V - (m-M)_V, \approx 7.4 - 11.5 = -4.1)$ by an arrow in Figure 37(c). Then we can specify the position of a cusp point to $(B-V)_0 = -0.29$ and $M_V = -4.04$ as denoted by a large open red square.

3.16. V1493 Aql 1999#1

This nova is not studied in Paper I. Figure 40 shows the visual and $V$, $(B-V)_0$, and $(U-B)_0$ evolutions of V1493 Aql. The $UBV$ data are taken from Bonifacio et al. (2000). The $BV$ data are from the VSOLJ archive and IAU Circular Nos. 7228, 7254, 7273, and 7313. The peak could be missed, so we may assume $m_{V,\text{max}} = 8.8$ for this nova. It quickly decayed with $t = 2$ days (Bonifacio et al. 2000) or with $t_2 = 7$ days and $t_3 = 24$ days (Venturini et al. 2004). Therefore, V1493 Aql belongs to the class of very fast novae. The light curve of V1493 Aql has a prominent secondary maximum about 50 days after the optical maximum (e.g., Bonifacio et al. 2000; Hachisu & Kato 2009). Dobrotka et al. (2006) obtained an orbital period of 3.74 hr. The observational period of the $U$ band is too short to derive $E(B-V)$ from the general course of nova tracks (Figure 40(c)). Therefore, we could not estimate the extinction from the color–color diagram of V1493 Aql. We show the $V$ light curve, $(B-V)_0$, and $(U-B)_0$ color evolutions in a.
logarithmic timescale in Figure 41 together with the three fast novae, V2275 Cyg, V382 Vel, and V1500 Cyg, which have similar decline rates.

The reddening for V1493 Aql was estimated as $E(B-V) = 0.33 \pm 0.1$ (Bonifacio et al. 2000) from the intrinsic $B-V$ color at $t_2$, to be $E(B-V) = 1.5$ (Arkhipova et al. 2002) from the Balmer decrement (mostly first Balmer lines), and to be $E(B-V) = 0.57 \pm 0.14$ (Venturini et al. 2004) from the dust reddening curve of Draine (1989). These three values are very different from each other. Therefore, we made a new estimate assuming that the intrinsic $B-V$ color of V1493 Aql is similar to those of V1500 Cyg, V382 Vel, and V1500 Cyg as shown in Figure 41(b). Then we obtain the color excess of $E(B-V) = 1.15 \pm 0.05$.

Using the time-stretching method as plotted in Figure 41(a), we obtain the apparent distance modulus in $V$ as follows:

$$ (m - M)_{V, V1493 Aql} = 17.7 $$

$$ = (m - M + \Delta V)_{V, V1500 Cyg} - 2.5 \log 1.0/1.0 $$

$$ = 12.3 + (+4.0 + 1.4) + 0.0 = 17.7 $$

$$ = (m - M + \Delta V)_{V, V382 Vel} - 2.5 \log 0.85/1.0 $$

$$ \approx 11.5 + (+4.6 + 1.4) + 0.18 = 17.68 $$

$$ = (m - M + \Delta V)_{V, V2275 Cyg} - 2.5 \log 1.0/1.0 $$

$$ = 16.3 + (+0.0 + 1.4) + 0.0 = 17.7, $$(9)

where we use $(m - M)_{V, V1500 Cyg} = 12.3$ from Section 2.5, $(m - M)_{V, V382 Vel} = 11.5$ from Section 3.15, and $(m - M)_{V, V2275 Cyg} = 16.3$ from Section 3.19. Therefore, we adopt $(m - M)_V = 17.7$ for V1493 Aql.

Figure 37. Same as Figure 16, but for (a) V1419 Aql, (b) V705 Cas, (c) V382 Vel, and (d) V1493 Aql. Thin solid magenta lines in panels (a) and (b) denote the tracks of LV Vul, but the track of V382 Vel in panel (d). Thin solid cyan lines in panels (a) and (b) denote the track of FH Ser. Thin solid blue lines represent the track of V1974 Cyg in panels (c) and (d).
Figure 42(a) shows various distance–reddening relations for V1493 Aql, \( \mu = 40.9080, \sigma = 2.1551 \). Here we plot four nearby directions calculated by Marshall et al. (2006), i.e., \( \mu = 45.75, \sigma = 2.25 \) denoted by open red squares, \( \mu = 46.00, \sigma = 2.25 \) by filled green squares, \( \mu = 45.75, \sigma = 2.00 \) by blue asterisks, and \( \mu = 46.00, \sigma = 2.00 \) by open magenta circles. We also plot the distance–reddening relation (solid black line) given by Green et al. (2015). The two lines of \( E(B - V) = 1.15 \) and \( m_M = 17.7 \) cross at the point \( d = 6.7 \) kpc and \( E(B - V) = 1.15 \). This position is consistent with the distance–reddening relation of Marshall et al. (2006) but deviates slightly from that of Green et al. (2015).

Using \( E(B - V) = 1.15 \) and \( m_M = 17.7 \), we plot the color–magnitude diagram of V1493 Aql in Figure 38(d). The nova was clearly in the nebular phase on UT 1999 September 16 at \( m_V \sim 15 \), i.e., about 65 days after the discovery (Arkhipova et al. 2002), while the nebular lines began to grow on UT 1999 August 4 \( m_V \sim 13 \). We could specify a possible start \( m_V \sim 14 \) of the nebular phase at the point \( (B - V)_0 = -0.35 \) and \( M_V = -3.78 \), which is denoted by a large open square in Figure 37(d).

Figure 38. Same as Figure 17, but for V705 Cas. We dereddened \( (B - V)_0 \) and \( (U - B)_0 \) colors with \( E(B - V) = 0.45 \).

Figure 39. Same as Figure 17, but for V382 Vel. We dereddened \( (B - V)_0 \) and \( (U - B)_0 \) colors with \( E(B - V) = 0.15 \).

Figure 40. Same as Figure 17, but for V1493 Aql. We dereddened \( (B - V)_0 \) and \( (U - B)_0 \) colors with \( E(B - V) = 1.15 \).

Figure 39(a) shows various distance–reddening relations for V1493 Aql, \( (l, b) = (45.9080, 2.1551) \). Here we plot four nearby directions calculated by Marshall et al. (2006), i.e., \( (l, b) = (45.75, 2.25) \) denoted by open red squares, \( (46.00, 2.25) \) by filled green squares, \( (45.75, 2.00) \) by blue asterisks, and \( (46.00, 2.00) \) by open magenta circles. We also plot the distance–reddening relation (solid black line) given by Green et al. (2015). The two lines of \( E(B - V) = 1.15 \) and \( m_M = 17.7 \) cross at the point \( d = 6.7 \) kpc and \( E(B - V) = 1.15 \). This position is consistent with the distance–reddening relation of Marshall et al. (2006) but deviates slightly from that of Green et al. (2015).

Using \( E(B - V) = 1.15 \) and \( m_M = 17.7 \), we plot the color–magnitude diagram of V1493 Aql in Figure 38(d). The track of V1493 Aql is located near the tracks of V382 Vel and V1974 Cyg. We regard V1493 Aql as a V1974 Cyg type in the color–magnitude diagram. The nova was clearly in the nebular phase on UT 1999 September 16 at \( m_V \sim 15 \), i.e., about 65 days after the discovery (Arkhipova et al. 2002), while the nebular lines began to grow on UT 1999 August 4 \( m_V \sim 13 \). We could specify a possible start \( m_V \sim 14 \) of the nebular phase at the point \( (B - V)_0 = -0.35 \) and \( M_V = -3.78 \), which is denoted by a large open square in Figure 38(d).

3.17. V1494 Aql 1999#2

This nova is not studied in Paper I. Figure 43 shows the visual and \( V \), \( (B - V)_0 \), and \( (U - B)_0 \) evolutions of V1494 Aql. The \( UBV \) data are taken from the VSNET archive. The \( BV \) data are from IAU Circulars Nos. 7324 and 7327.
visual data are from the AAVSO archive. V1494 Aql reached its maximum of $m_{V\text{,max}} = 4.0$ on UT 1999 December 3.4. V1494 Aql is a very fast nova with $t_2 = 6.6 \pm 0.5$ days and $t_3 = 16 \pm 0.5$ days (Kiss & Thomson 2000). The orbital period of 3.23 hr was detected by Rettter et al. (2000) and Barsukova & Goranskii (2003).

The reddening for V1494 Aql was estimated by Iijima & Esenoglu (2003) to be $E(B - V) = 0.6 \pm 0.1$ from the interstellar Na I D1 and D2 lines. We could not estimate the extinction from the color–color diagram of V1494 Aql because there is a large scatter in the $U - B$ data. Instead, we use Figure 44(b) and obtain $E(B - V) = 0.50 \pm 0.05$ assuming that the intrinsic $(B - V)_0$ color evolution of V1494 Aql is similar to those of the other color evolutions. This value is consistent with that obtained by Iijima & Esenoglu (2003).

Using the time-stretching method (see Figure 44(a)), we obtain

$$ (m - M)_{V, V1494 \text{ Aql}} = 13.1 $$

where we use $(m - M)_{V, V1500 \text{ Cyg}} = 12.3$ from Section 2.5, $(m - M)_{V, IV \text{ Cep}} = 14.7$ from Section 3.5, $(m - M)_{V, LV \text{ Vel}} = 11.9$ from Section 2.2, and $(m - M)_{V, V5114 \text{ Sgr}} = 16.5$ from Section 3.21. Because these values are consistent with each other, we adopt $(m - M)_V = 13.1$ for V1494 Aql.

Figure 42(b) shows various distance–reddening relations for V1494 Aql, $(l, b) = (40^\circ 9735, -4^\circ 7422)$. Here we plot the distance–reddening relations calculated by Marshall et al. (2006), i.e., for nearby directions, $(l, b) = (40^\circ 75, -4^\circ 50)$ denoted by open red squares, $(41^\circ 00, -4^\circ 50)$ by filled green squares, $(40^\circ 75, -4^\circ 75)$ by blue asterisks, and $(41^\circ 00, -4^\circ 75)$ by open magenta circles. The closest one is that denoted by open magenta circles. We also plot the distance–reddening relation (solid black line) given by Green et al. (2015). The two lines of $E(B - V) = 0.50$ and $(m - M)_V = 13.1$ cross at the distance of $d = 2.0$ kpc and $E(B - V) = 0.50$. This cross point is consistent with Marshall et al.’s relation, but slightly different from that of Green et al.

Using $E(B - V) = 0.50$ and $(m - M)_V = 13.1$, we plot the color–magnitude diagram of V1494 Aql in Figure 45(a). The track is very similar to that of V1500 Cyg in the middle part of the whole track. We regard V1494 Aql as a V1500 Cyg type in the color–magnitude diagram. The nebular phase started at least before the middle of 2000 April, i.e., around $m_V \approx 10$ (Iijima & Esenoglu 2003). We plot this phase by an arrow in Figure 45(a). However, there are no $B - V$ data around the starting point of the nebular phase.

3.18. V2274 Cyg 2001#1

Figure 46 shows the visual and $V, (B - V)_0$, and $(U - B)_0$ evolutions of V2274 Cyg. The $UBV$ data are taken from Voloshina & Metlova (2002b), and $V$ data are from the AAVSO archive and IAU Circular Nos. 7666 and 7668.

In Paper I, we determined the reddening as $E(B - V) = 1.35 \pm 0.10$ from the color–color diagram fit and the distance modulus in the $V$ band as $(m - M)_V = 18.7 \pm 0.2$ from the time-stretching method (see Paper I for other estimates of reddening and distance).

The light curve of V2274 Cyg is similar to those of FH Ser and NQ Vul, and these three nova light curves have similar decline trends just before the dust blackout as shown in Figure 47(a). From the time-stretching method, we obtain the apparent distance modulus of V2274 Cyg:

$$ (m - M)_{V, V2274 \text{ Cyg}} = (m - M + \Delta V)_{V, FH \text{ Ser}} - 2.5 \log 0.9 $$

$$ = 11.7 + (+1.9 + 5.0 + 0.11) = 18.71 $$

$$ = (m - M + \Delta V)_{V, NQ \text{ Vul}} - 2.5 \log 0.9 $$

$$ = 13.6 + (+0.0 + 5.0) + 0.11 = 18.71, $$

(11)

where we use $(m - M)_{V, FH \text{ Ser}} = 11.7$ from Section 2.3 and $(m - M)_{V, NQ \text{ Vul}} = 13.6$ from Section 3.6. We adopt this distance modulus of $(m - M)_{V, V2274 \text{ Cyg}} = 18.7$. The distance is estimated as $d = 8.0$ kpc for $E(B - V) = 1.35$.

Figure 42(c) shows various distance–reddening relations for V2274 Cyg, $(l, b) = (73^\circ 0415, +1^\circ 9910)$. This figure is the same as Figure 37(b) of Paper I, but we added the distance–reddening relations given by Green et al. (2015). The two lines of $E(B - V) = 1.35$ and $(m - M)_V = 18.7$ cross at the distance of $d = 8.0$ kpc, which is consistent with Marshall et al.’s and Green et al.’s relations.
Using $E(B-V) = 1.35$ and $(m-M)_V = 18.7$, we plot the color–magnitude diagram of V2274 Cyg in Figure 45(b). The track of V2274 Cyg is close to those of FH Ser and V1668 Cyg. We regard V2274 Cyg as a V1668 Cyg type in the color–magnitude diagram, because V2274 Cyg goes down along the track of V1668 Cyg.

3.19. V2275 Cyg 2001

This nova is not studied in Paper I. Figure 48 shows the visual and $V$, $(B-V)_0$, and $(U-B)_0$ evolutions of V2275 Cyg. The $V$ maximum is $m_{V,\text{max}} = 6.6$ (e.g., Sostero et al. 2001). Then it gradually declined with $t_2 = 2.9$ days and $t_3 = 7$ days (Kiss et al. 2002). The $V$ light curve of V2275 Cyg and its decay rate are very similar to those of V1500 Cyg. We could not estimate the extinction from the color–color diagram of V2275 Cyg because no $UBV$ data in the early phase are available. $UBV$ data were secured only in the nebular phase (Voloshina et al. 2002a). Balman (2005) suggested an orbital period of 7.55 hr from photometric orbital variations.

The $V$ light-curve shape and global timescale of V2275 Cyg are very similar to those of V1500 Cyg. Assuming that these two novae have the same brightness in the free–free emission phase, i.e., applying the time-stretching method to Figure 41(a), we obtain

\[ (m-M)_{V,V2275\text{Cyg}} = (m-M + \Delta V)_{V,V1500\text{Cyg}} = 12.3 + 4.0 = 16.3, \]

where we use $(m-M)_{V,V1500\text{Cyg}} = 12.3$ from Section 2.5. We adopt this value of $(m-M)_{V,V2275\text{Cyg}} = 16.3$ in the present paper.

Kiss et al. (2002) estimated the absolute magnitude at maximum to be $M_{V,\text{max}} = -9.7$ from the MMRD relations and other empirical relations together with $t_2 = 2.9 \pm 0.5$ days and $t_3 = 7 \pm 1$ days. Then we calculate the apparent distance modulus of $(m-M)_V = 6.6 - (-9.7) = 16.3$, being coincident with our value of $(m-M)_V = 16.3$.

Kiss et al. (2002) also discussed that V2275 Cyg closely resembles, in some respects, the well-studied very fast nova V1500 Cyg. Assuming that the intrinsic $B - V$ color is almost
the same for V2275 Cyg and V1500 Cyg, we determine the reddening to be $E(B - V) = 1.05 \pm 0.05$ by overlapping them as shown in Figure 41(b). This estimate is also consistent with the Kiss et al. value of $E(B - V) = 1.0 \pm 0.1$, obtained with a few interstellar absorption laws. We adopt $E(B - V) = 1.05 \pm 0.05$ in this paper.

Figure 42(d) shows various distance–reddening relations for V2275 Cyg. $(l, b) = (89^\circ 3710, +1^\circ 3905)$. Here we plot distance–reddening relations calculated by Marshall et al. (2006), i.e., four nearby directions, $(l, b) = (89^\circ 25, +1^\circ 25)$ denoted by open red squares, $(89^\circ 25, +1^\circ 50)$ by blue asterisks, and $(89^\circ 50, +1^\circ 50)$ by open magenta circles. The closest one is that denoted by blue asterisks. We also plot Green et al.’s (2015) distance–reddening relation in the same figure. These four trends, Marshall et al.’s (blue asterisks), Green et al.’s (solid black line), $(m - M)_V = 16.3$ (solid blue line), and $E(B - V) = 1.05$ (vertical solid black line), cross at the point $E(B - V) \approx 1.05$ and $d \approx 4.1$ kpc. Thus, we confirm that our estimates of $E(B - V) = 1.05$ and $(m - M)_V = 16.3$ are reasonable.

Using $E(B - V) = 1.05$ and $(m - M)_V = 16.3$, we plot the color–magnitude diagram of V2275 Cyg in Figure 45(c). The two nova tracks of V2275 Cyg and V1500 Cyg overlap each other in the color–magnitude diagram. Therefore, we regard V2275 Cyg as a V1500 Cyg type in the color–magnitude diagram.

3.20. V475 Sct 2003

Figure 49 shows the visual and $V, (B - V)_0,$ and $(U - B)_0$ evolutions of V475 Sct. The $UBV$ data are taken from Chochol et al. (2005), and $V$ and visual data are from IAU Circular Nos. 8190 and 8200 and the AAVSO archive.

In Paper I, we determined the reddening $E(B - V) = 0.55 \pm 0.10$ from the color–color diagram fit and the distance modulus in the $V$ band as $(m - M)_V = 15.6 \pm 0.2$ by assuming that the absolute magnitude of the light curve is the same for FH Ser and V475 Sct (see Paper I for other estimates of reddening and distance). To confirm this similarity, we plot the light curves of V475 Sct, FH Ser, PW Vul, and DQ Her in Figure 50, but we adopt $(m - M)_V = 15.4$ rather than the $(m - M)_V = 15.6$ of Paper I for V475 Sct. If we use $(m - M)_V = 15.4$, the absolute brightnesses of V475 Sct and FH Ser almost overlap.

Figure 51(a) shows various distance–reddening relations for V475 Sct, $(l, b) = (24^\circ 2015, -3^\circ 9466)$, i.e., the relations given by Marshall et al. (2006) and Green et al. (2015). Our new estimates of $(m - M)_V = 15.4$ and $E(B - V) = 0.55$ cross at $d = 5.5$ kpc, which is roughly consistent with trend of Marshall et al. but deviates from that of Green et al. Thus, we adopt $E(B - V) = 0.55$ and $(m - M)_V = 15.4$ in this paper.

The color–magnitude diagram of V475 Sct is plotted in Figure 45(d). The track is similar to that of FH Ser in the early phase but to that of V1668 Cyg in the later phase. We regard
V475 Sct as a V1668 Cyg type in the color–magnitude diagram. We specify a starting point of dust blackout, that is, $(B - V)_0 = -0.15$ and $M_V = -3.80$ denoted by a large open red square in Figure 45(d).

**3.21. V5114 Sgr 2004**

Figure 52 shows the visual and $V$, $(B - V)_0$, and $(U - B)_0$ evolutions of V5114 Sgr. The $UBV$ data are taken from Ederoclite et al. (2006), $BV$ data from the SMARTS archive and IAU Circular Nos. 8306 and 8310, and visual and $V$ data from the AAVSO archive.

In Paper I, we determined the reddening as $E(B - V) = 0.45 \pm 0.05$ from the color–color diagram fit and the distance modulus in the $V$ band as $(m - M)_V = 16.5 \pm 0.2$ from the time-stretching method (see Paper I for other estimates of reddening and distance). Then, the distance is calculated to be $d = 10.5$ kpc. Figure 51(b) shows various distance–reddening relations for V5114 Sgr, $(l, b) = (3^\circ9429, -6^\circ3121)$. This figure is the same as Figure 37(d) of Paper I, but we added the distance–reddening relation given by Green et al. (2015). The three trends, Marshall et al.’s trend, $(m - M)_V = 16.5$, and $E(B - V) = 0.45$, consistently cross at $d \sim 10.5$ kpc and $E(B - V) \sim 0.45$, although Green et al.’s relation deviates from this cross point. Thus, we adopt the same values of $(m - M)_V = 16.5$ and $E(B - V) = 0.45$ as those in Paper I.

Using $E(B - V) = 0.45$ and $(m - M)_V = 16.5$, we plot the color–magnitude diagram of V5114 Sgr in Figure 53(a). The track is close to those of V1500 Cyg (thick solid green line) and V1974 Cyg (thin solid blue line). This matching also supports our values of $E(B - V) = 0.45$ and $(m - M)_V = 16.5$. We regard V5114 Sgr as a V1974 Cyg type in the color–
magnitude diagram. We also specify a turning point of \( (B - V) = -0.50 \) and \( M_V = 3.92 \), which is denoted by a large open red square in Figure 53(a). The nebular phase started around 57 days after optical maximum, when the \([O\text{ III}] \) lines became stronger than the permitted lines (see Figure 3 of Ederoclite et al. 2006).

3.22. V2362 Cyg 2006

This nova is not studied in Paper I. Figure 54 shows the visual and \( V \), \((B - V)_0\), and \((U - B)_0\) evolutions of V2362 Cyg. The \( UBV \) data are taken from Munari et al. (2008b), and \( V \) and visual data are from the AAVSO and VSOLJ archives. V2362 Cyg reached \( m_{V, \text{max}} = 7.8 \) at optical maximum and then declined with \( t_1 = 9.0 \pm 0.5 \) days and \( t_3 = 21.0 \pm 0.5 \) days (Kimeswenger et al. 2008). For the first 60 days, the decline down to 12th magnitude is smooth and resembles a power-law decline. Then it rose up again to 10th magnitude (secondary maximum) about 240 days after the discovery, suddenly dropped to 13th magnitude in ∼20 days, followed by the formation of an optically thin dust shell (Arai et al. 2010), and again slowly declined resembling a power law before the secondary maximum (e.g., Kimeswenger et al. 2008). An orbital period of 1.58 hr was suggested by Balman et al. (2009).

The reddening of V2362 Cyg was obtained to be \( E(B - V) = (B - V)_{12} - (B - V)_{0,12} = 0.58 \pm 0.03 \) or \( -0.02 \pm 0.12 \) = 0.6 ± 0.1 (Kimeswenger et al. 2008), \( E(B - V) = 0.58 \pm 0.04 \) (Lynch et al. 2008b) from Ly\( \beta \) fluoresced \( O_1 \) lines, \( E(B - V) = 0.56 \) from the equivalent width of interstellar lines Na\( i \) D1 and D2, and \( E(B - V) = (B - V)_{12} - (B - V)_{0,12} \) from the equivalent width of interstellar lines in the direction toward V2362 Cyg. We dereddened \( E(B - V) = 1.35 \) from the equivalent width of interstellar lines. We also specify a turning point of \( (B - V) = -0.50 \) and \( M_V = 3.92 \), which is denoted by a large open red square in Figure 53(a). The nebular phase started around 57 days after optical maximum, when the \([O\text{ III}] \) lines became stronger than the permitted lines (see Figure 3 of Ederoclite et al. 2006).

\[
\begin{align*}
E(B - V) & = (B - V)_{12} - (B - V)_{0,12} = 0.58 \pm 0.03 \text{ or } -0.02 \pm 0.12 = 0.6 \pm 0.1 \text{ (Kimeswenger et al. 2008),} \\
E(B - V) & = 0.58 \pm 0.04 \text{ (Lynch et al. 2008b) from Ly\( \beta \) fluoresced \( O_1 \) lines,} \\
E(B - V) & = 0.56 \text{ from the equivalent width of interstellar lines Na\( i \) D1 and D2, and} \\
E(B - V) & = (B - V)_{12} - (B - V)_{0,12} \text{ from the equivalent width of interstellar lines in the direction toward V2362 Cyg. We dereddened } E(B - V) = 1.35 \text{ from the equivalent width of interstellar lines.}
\end{align*}
\]

Figure 47. Same as Figure 20, but for V2274 Cyg and V496 Sct. The light curves of FH Ser and NQ Vul are added for comparison. The data of V2274 Cyg are the same as those in Figure 46. The data of V496 Sct are the same as those in Figure 73.

\[
= 0.54 - (-0.02) = 0.56 \text{ (Munari et al. 2008b). The NASA/IPAC galactic dust absorption map gives } E(B - V) = 0.65 \pm 0.03 \text{ in the direction toward V2362 Cyg, } \begin{cases} l, b = (87\,^\circ 3724, -2\,^\circ 3574) \text{.} \end{cases}
\]

Because there are not enough \( U \) data in the first decline phase as shown in Figure 54(c), we cannot accurately determine the color excess from the general track fitting in the color–color diagram. Instead, we obtained \( E(B - V) = 0.60 \pm 0.05 \) by averaging the above four estimates. Assuming that \( E(B - V) = 0.60 \), we plot the \( (B - V)_0 \) and \((U - B)_0 \) color evolutions of V2362 Cyg in Figures 54(b) and (c), respectively, and in Figures 55(b) and (c) together with V1500 Cyg, V1668 Cyg, and V2468 Cyg. The color evolutions are similar to each other. Therefore, we adopt \( E(B - V) = 0.60 \pm 0.05 \) in this paper.

Using the time-stretching method (Figure 55(a)), we obtain the apparent distance modulus of V2362 Cyg,

\[
(m - M)_{V,V2362\,\text{Cyg}} = 15.9
\]

\[
= (m - M + \Delta V)_{V,V2468\,\text{Cyg}} - 2.5 \log 0.45/0.50 \\
\approx 15.6 + (-4.1 + 4.3) + 0.11 = 15.91 \\
= (m - M + \Delta V)_{V,V1500\,\text{Cyg}} - 2.5 \log 1.0/0.50 \\
\approx 12.3 + (-0.0 + 4.3) - 0.75 = 15.85 \\
= (m - M + \Delta V)_{V,V1668\,\text{Cyg}} - 2.5 \log 0.40/0.50 \\
\approx 14.6 + (-3.2 + 4.3) + 0.24 = 15.94,
\]

where we use \( (m - M)_{V,V2468\,\text{Cyg}} = 15.6 \) from Section 3.28, \( (m - M)_{V,V1500\,\text{Cyg}} = 12.3 \) from Section 2.5, and
We adopt $m_{V,1668\ Cyg} = 14.6$ from Section 2.1. We also estimated $m_{V,2362\ Cyg} = 15.9 \pm 0.2$ in this paper. Then the distance is estimated as $d = 6.4$ kpc from $m_{V} = 15.9$ and $E(B-V) = 0.60$. The distance to $V2362\ Cyg$ was also estimated by Kimeswenger et al. (2008) as $d = 7.5 \pm 2.5$ kpc from a simple average of the MMRD relation, $M_{V,15} = -5.44$ at 15 days after maximum, and an assumed luminosity at maximum (Bonifacio et al. 2000), and by Munari et al. (2008b) as $d = 7.2 \pm 0.2$ kpc from various methods including the MMRD and $M_{V,15}$ relations. Munari et al. (2008b) obtained the apparent distance modulus in the $V$ band as $m_{V} = 16.0$, which is consistent with our value of $m_{V} = 15.9 \pm 0.2$.

We plot the color–magnitude track of $V2362\ Cyg$ in Figure 53(b). The location of the color–magnitude track differs between the first and second peaks, which is interesting and very

Figure 48. Same as Figure 17, but for $V2275\ Cyg$. We dereddened $(B - V)_0$ and $(U - B)_0$ colors with $E(B-V) = 1.05$.

Figure 49. Same as Figure 17, but for $V475\ Sct$. We dereddened $(B - V)_0$ and $(U - B)_0$ colors with $E(B-V) = 0.55$.

Figure 50. Same as Figure 20, but for $V475\ Sct$. The sources of $V475\ Sct$ data are the same as those in Figure 49. Here we adopt $(m - M)_V = 15.4$, 13.0, 8.2, and 11.7 for $V475\ Sct$, $PW\ Vul$, $DQ\ Her$, and $FH\ Ser$, respectively.
suggestive. We depict the phase of the secondary maximum by open magenta circles in order to distinguish it from the first maximum (filled red circles). The track is close to that of FH Ser in the first decline phase and then moves to that of V1974 Cyg (or even to that of V1500 Cyg) during the secondary maximum phase (open magenta circles). Thus, we regard V2362 Cyg as a V1500 Cyg type in the color–magnitude diagram. This transition from an FH Ser type to a V1500 Cyg type between the first and second maxima shows that a massive mass ejection had occurred between the two peaks. FH Ser is located in the red side to V1500 Cyg because FH Ser had a more massive envelope. Thus, V2362 Cyg undergoes a transition from a redder track to a bluer after the massive mass ejection. We also point out that the movement in the color–magnitude diagram from the first to the second maxima is clockwise like in the track of PW Vul (see Figure 7(b)). We specify a turning point \((B - V)_0 = -0.51\) and \(M_V = -3.83\) by a large open red square as shown in Figure 53(b). This turning point corresponds to the beginning of the nebular phase. The nebular phase started around 250 days after the optical maximum (Munari et al. 2008b).

### 3.23. V1065 Cen 2007

This nova is not studied in Paper I. Figure 56 shows the visual and \(V\) and \((B - V)_0\) evolutions of V1065 Cen. The \(BV\) data are taken from the AAVSO archive, and \(V\) data are from the VSOLJ archive and IAU Circular Nos. 8800 and 8801. V1065 Cen reached \(m_V,max = 7.6 \pm 0.2\) at maximum on UT 2007 January 21. Then it smoothly declined with \(t_2 = 11\) days and \(t_1 = 26\) days (Helton et al. 2010). A shallow dust blackout started about 30 days after the optical maximum. V1065 Cen was identified as a neon nova by Helton et al. (2010).

The reddening for V1065 Cen was obtained as \(E(B - V) = 0.50 \pm 0.10\) (Helton et al. 2010) from an average of three estimates, i.e., \(E(B - V) = (B - V)_{max} - (B - V)_{0,max} = 0.52 \pm 0.04 - (0.23 \pm 0.06) = 0.29 \pm 0.07, E(B - V) = (B - V)_{0.2} - (B - V)_{0.02} = 0.41 \pm 0.05 - (-0.02 \pm 0.04) = 0.43 \pm 0.06, \) and \(E(B - V) = 0.79 \pm 0.01\) from the Balmer
decrement (Hα/Hβ). Helton et al. (2010) also estimated the apparent distance modulus in the V band as 
\((m - M)_V = 7.6 \pm 0.2 - (-8.6 \pm 0.5) = 16.2 \pm 0.6\) from the MMRD relation together with \(t_2 = 11\) days. This gives a distance of \(d = 8.7^{+2.1}_{-1.5}\) kpc. Assuming that the intrinsic \((B - V)_0\) color evolution of V1065 Cen is identical to that for similar types of novae, i.e., LV Vul, V1668 Cyg, V1419 Aql, and V496 Sco, we obtain 
\((B - V) = 0.45 \pm 0.05\) from Figure 57(b), which is consistent with the estimate of Helton et al.

Using the time-stretching method (Figure 57(a)), we estimate the apparent distance modulus in the V band, i.e.,

\[
(m - M)_{V, V1065\text{Cen}} = 15.3
\]

\[
= (m - M) + \Delta V_{V, V1668\text{Cyg}} + 2.5 \log 10/1.0
\]

\[
\approx 14.6 + (+0.7 - 0.0) + 0.0 = 15.3
\]

\[
= (m - M) + \Delta V_{V, LV\text{Vul}} + 2.5 \log 10/1.0
\]

\[
= 11.9 + (+3.4 - 0.0) + 0.0 = 15.3
\]

\[
= (m - M) + \Delta V_{V, V1419\text{Aql}} + 2.5 \log 10/1.0
\]

\[
\approx 14.6 + (+0.7 - 0.0) + 0.0 = 15.3
\]

\[
= (m - M) + \Delta V_{V, V496\text{Sct}} + 2.5 \log 0.56/1.0
\]

\[
\approx 14.4 + (+1.6 - 0.0) - 0.625 = 15.375, \tag{14}
\]

where we use \((m - M)_{V, V1668\text{Cyg}} = 14.6\) from Section 2.1, \((m - M)_{V, LV\text{Vul}} = 1.19\) from Section 2.2, \((m - M)_{V, V1419\text{Aql}} = 14.6\) from Section 3.13, and \((m - M)_{V, V496\text{Sct}} = 14.4\) from Section 3.30. Then, we obtain the distance of \(d = 6.0\) kpc for 
\(E(B - V) = 0.45\) and \((m - M)_V = 15.3\).

Figure 51(d) shows various distance–reddening relations for V1065 Cen, \((l, b) = (293°3°841', +3°6130'). \) Here we plot the distance–reddening relation given by Marshall et al. (2006), i.e., four nearby directions, \((l, b) = (293°75', 3°75')\) denoted by open red squares, \((294°00', 3°75')\) by filled green squares, \((293°75', 3°50')\) by blue asterisks, and \((294°00', 3°50')\) by open magenta circles. The closest ones are those denoted by filled green squares and open magenta circles. Although these two relations differ for \(d \geq 3\) kpc, our values of \(d = 6.0\) kpc and \(E(B - V) = 0.45\) are midway between them. Thus, we think that our cross point is consistent with the relation of Marshall et al. The relation of Green et al. (2015) is not available for these galactic coordinates.

Using \(E(B - V) = 0.45\) and \((m - M)_V = 15.3\), we plot the color–magnitude diagram of V1065 Cen in Figure 53(c). The track of V1065 Cen almost follows that of LV Vul (solid magenta lines). Thus, we regard V1065 Cen as an LV Vul type in the color–magnitude diagram. This coincidence with LV Vul strongly supports our values of \((m - M)_V = 15.3\) and \(E(B - V) = 0.45\). We specify the starting point of dust blackout (Helton et al. 2010) at \((B - V)_0 = -0.06\) and \(M_V = -4.06\), denoted by a large open blue square in Figure 53(c). Helton et al. (2010) pointed out that the nova entered the early nebular phase at \(m_V \approx 12,\) about 70 days after maximum. We denote this phase by a large open red square, at \((B - V)_0 = -0.35\) and \(M_V = -3.42\). This point is close to the two-headed red arrow.

### 3.2.4. V1280 Sco 2007#1

This nova is not studied in Paper I. Figure 58 shows the V and Solar Mass Ejection Imager (SMEI) light curves and \((B - V)_0\) color evolution of V1280 Sco. The UBV data for QV Vul (Figure 32) are added for comparison. The SMEI data for V1280 Sco are from Hounsell et al. (2010), and the V data are from Naito et al. (2012). V1280 Sco reached \(m_{V, \text{max}} = 3.8\) at optical maximum on UT 2007 February 16.19 (Munari et al. 2007b). It experienced two major episodes of rebrightening peaking at UT February 16.15 and 19.18 (Hounsell et al. 2010). On UT February 26.4 its decline rate changed rapidly (e.g., Hounsell et al. 2010), indicating formation of an optically thick dust shell (Das et al. 2008).

The reddening for V1280 Sco was estimated by Das et al. (2008) as \(E(B - V) = A_V/R_V = 1.2/3.1 \approx 0.4\) from Marshall et al.‘s (2006) 3D dust map. The distance was obtained by Naito et al. (2012) as \(d = 1.1 \pm 0.5\) kpc from the expansion parallax of a dust shell (Chesneau et al. 2008) together with the expansion velocity of \(350 \pm 160\) km s\(^{-1}\).

In Figure 58(a), we shift the V light curve of QV Vul up by 3.0 mag to fit its peak with that of V1280 Sco. In the early phase of these outbursts, the brightness shows similar fluctuations (both the amplitude and period). Therefore, we expect that the peak brightness is the same for V1280 Sco and QV Vul. Then we obtain the apparent distance modulus of 
\((m - M)_{V, V1280\text{Sco}} = (m - M)_{V, QV\text{Vul}} = -3.0 = 14.0 - 3.0 = 11.0,\) where \((m - M)_{V, QV\text{Vul}} = 14.0\) was already obtained in Section 3.11. We also determined that \(E(B - V) = 0.35\) by assuming that the intrinsic \((B - V)_0\) color is the same for both V1280 Sco and QV Vul (see Figure 58(b)). Then the distance is calculated as \(d = 0.96\) kpc for \(E(B - V) = 0.35\) and \((m - M)_V = 11.0,\) being consistent with Naito et al.‘s estimate of \(d = 1.1 \pm 0.5\) kpc.
Figure 59 shows various distance–reddening relations for V1280 Sco. We plot Marshall et al.’s (2006) four relations, i.e., \((m - M)_V = 10.0\) denoted by open red squares, \((m - M)_V = 11.0\) by filled green squares, \((m - M)_V = 15.3\) by blue asterisks, and \((m - M)_V = 15.9\) by open magenta circles. The closer ones are those denoted by open red squares and filled green squares. The thick solid blue line indicates \(-M = 11.0\). These trends, i.e., Marshall et al.’s relations, \((m - M)_V = 11.0\), and \(E(B - V) = 0.35\) (vertical solid red line), cross at the point \(d \approx 0.96\) kpc and \(E(B - V) \approx 0.35\). Thus, we adopt \((m - M)_V = 11.0\) and \(E(B - V) = 0.35\).

Using \(E(B - V) = 0.35\) and \((m - M)_V = 11.0\), we plot the color–magnitude diagram of V1280 Sco in Figure 53(d). The track in the early phase looks similar to that of V705 Cas

Figure 53. Same as Figure 16, but for (a) V5114 Sgr, (b) V2362 Cyg, (c) V1065 Cen, and (d) V1280 Sco. Thick solid green lines represent the track of V1500 Cyg and thick solid blue lines the track of PU Vul. Thin solid blue lines denote the track of V1974 Cyg in panels (a) and (b), but that of V1668 Cyg in panels (c) and (d). Solid orange lines in panels (b) and (d) denote the track of FH Ser. Solid magenta lines in panel (c) represent the track of LV Vul.

3.25. V2467 Cyg 2007

This nova is not studied in Paper I. Figure 60 shows the V, \((B - V)_0\), and \((U - B)_0\) evolutions of V2467 Cyg. The UBV data of V2467 Cyg are taken from Tomov et al. (2007). BV data from the AAVSO archive, and V data from IAU Circular
Figure 54. Same as Figure 17, but for V2362 Cyg. We dereddened $B-V_0$ and $U-B_0$ colors with $E(B-V) = 0.60$.

Figure 55. Same as Figure 20, but for V2362 Cyg (filled red circles) and V2468 Cyg (filled blue triangles). We also add the light curves of V1500 Cyg (open magenta diamonds) and V1668 Cyg (filled green squares).

Figure 56. Same as Figure 17, but for V1065 Cen. We omit the $(U-B)_0$ color evolution because no $U$ observations are found in the literature. We dereddened $B-V_0$ with $E(B-V) = 0.45$.

Figure 57. Same as Figure 20, but for V1065 Cen (filled magenta squares) and V496 Sct (filled green stars). We also add the light curves of LV Vul (open black circles with plus sign), V1419 Aql (filled blue circles), and V1668 Cyg (open red diamonds).
No. 8821 and the AAVSO and VSOLJ archives. V2467 Cyg smoothly declines with \( r_2 = 7.6 \pm 3.0 \) days and \( r_3 = 14.6 \pm 3.5 \) days (e.g., Poggianti 2009). Then the \( V \) brightness shows some quasi-periodic oscillations with a period of 20–30 days and an amplitude of 0.7 mag during the transition phase as shown in Figure 60(a). These kinds of transition oscillations are similar to those of GK Per, V603 Aql, and V1494 Aql. The orbital period was estimated as \( P_{\text{orb}} = 3.83 \) hr (Shugarov et al. 2010). Swierzynski et al. (2010) suggested that V2467 Cyg is an intermediate polar with a spin period of 34.5 minutes.

The reddening and distance for V2467 Cyg were estimated as \( E(B - V) = 1.0 - 1.5 \) and \( d = 2 \) kpc, respectively (Steeghs et al. 2007), from the brightness and color of the progenitor, \( E(B - V) = 0.31 \) (Munari et al. 2007a) from the Na I D2 equivalent width, \( E(B - V) = 1.5 \) (Mazuk et al. 2007) from O I lines, and \( E(B - V) = 1.7 \) (Russell et al. 2007) from O I lines. In addition, the estimates \( E(B - V) = 1.16 \pm 0.12 \) and \( d = 2.6 - 3.6 \) kpc (Poggianti 2009) came from \( E(B - V) = (B - V)_{02} - (B - V)_{01} = 1.14 - (0.02 \pm 0.12) = 1.16 \pm 0.12 \) and the distance modulus of \( (m - M)_V = 15.9 - 16.5 \), derived from various empirical relations of nova light curves, and \( (m - M)_V = 16.4 \pm 0.2 \) and \( d = 2.2 \pm 0.2 \) kpc (Hachisu & Kato 2010) together with \( E(B - V) = 1.5 \) (Mazuk et al. 2007) from their free–free model light-curve fitting, and finally \( E(B - V) = 1.38 \pm 0.12 \) and \( d = 2.5 \pm 0.3 \) (Shugarov et al. 2010) from the absolute magnitude at maximum, \( B - V \) color relations, and interstellar extinction.

We are not able to estimate the color excess from fitting in the color–color diagram because the \( UBV \) data of V2467 Cyg obtained by Tomov et al. (2007) are for the transition oscillation phase and hence inappropriate for the general track of novae, i.e., too late to derive the reddening. Using the time-stretching method for the light curves in Figure 61(a), we obtain the distance modulus in the \( V \) band, i.e.,

\[
\begin{align*}
(m - M)_V, V2467 Cyg &= 16.2 \\
&= (m - M + \Delta V)_{V,V1668 Cyg} - 2.5 \log 1.0/1.0 \\
&\approx 14.6 + (-0.0 + 1.6) - 0.0 = 16.2 \\
&= (m - M + \Delta V)_{V,IV Cep} - 2.5 \log 0.80/1.0 \\
&\approx 14.7 + (-0.4 + 1.6) + 0.24 = 16.14 \\
&= (m - M + \Delta V)_{V,V2468 Cyg} - 2.5 \log 0.90/1.0 \\
&\approx 15.6 + (-1.1 + 1.6) + 0.11 = 16.21,
\end{align*}
\]

where we use \( (m - M)_V, V1668 Cyg = 14.6 \) from Section 2.1, \( (m - M)_V, IV Cep = 14.7 \) from Section 3.5, and \( (m - M)_V, V2468 Cyg = 15.6 \) from Section 3.28. Here we squeeze the times of V2467 Cyg, IV Cep, and V2468 Cyg by a factor of 1.0, 0.80, and 0.90 and shift the \( V \) light curves up by 1.6, 0.4, and 1.1 mag, respectively, against V1668 Cyg.

We also obtained \( E(B - V) = 1.40 \pm 0.05 \) by assuming that the intrinsic \( (B - V)_0 \) colors are similar among V2467 Cyg, V1668 Cyg, IV Cep, and V2468 Cyg as shown in Figure 61(b). Here we dereddened the \( B - V \) and \( U - B \) colors of V2467 Cyg with \( E(B - V) = 1.40 \).

Figure 59(b) shows various distance–reddening relations for V2467 Cyg, \((l, b) = (80^0.0690, +1^\circ.8417)\). Here we plot the distance–reddening relations given by Marshall et al. (2006), i.e., \((l, b) = (80^0.00, 2^\circ.00)\) denoted by open red squares, \((80^0.25, 2^\circ.00)\) by filled green squares, \((80^0.00, 1^\circ.75)\) by blue asterisks, and \((80^0.25, 1^\circ.75)\) by open magenta circles. The closer ones are those denoted by open red squares and blue asterisks. We also added the distance–reddening relation given by Green et al. (2015). These four trends, i.e., Marshall et al.’s relations, Green et al.’s relation (solid black line), \( (m - M)_V = 16.2 \) (thick solid blue line), and \( E(B - V) = 1.40 \) (vertical solid red line), cross consistently at the point of \( d \sim 2.4 \) kpc and \( E(B - V) \sim 1.40 \). Thus, we adopt \( E(B - V) = 1.40 \) and \( (m - M)_V = 16.2 \).

Using \( E(B - V) = 1.40 \) and \( (m - M)_V = 16.2 \), we plot the color–magnitude diagram of V2467 Cyg in Figure 62(a), as well as that of V1494 Aql (solid magenta line). The track of V2467 Cyg is very similar to those of V1500 Cyg and V1974 Cyg. Therefore, we regard V2467 Cyg as a V1974 Cyg type in the color–magnitude diagram. The nova entered the nebular phase at least on 2007 May 18, i.e., at \( m_V = 12.5 \) (Poggianti 2009). We specify a possible start of the nebular phase at the point of \( (B - V)_0 = -0.53 \) and \( M_V = -3.88 \) as indicated by a large open red square in Figure 62(a).

3.26. V2615 Oph 2007

This nova is not studied in Paper I. Figure 63 shows the visual and \( V \) and \( (B - V)_0 \) evolutions of V2615 Oph on a linear timescale. The \( BV \) data are taken from Munari et al. (2008a) and the AAVSO archive, \( V \) data are from IAU Circular No. 8824, and visual data are from the AAVSO archive.
V2615 Oph reached $m_{V,\text{max}} = 9.0$ at optical maximum on UT 2007 March 25.48 (Munari et al. 2008a). Then it displayed an oscillatory behavior like PW Vul and gradually declined with $t_2 = 26.5$ days and $t_3 = 48.5$ days (Munari et al. 2008a). A dust shell formed about 60 days after optical maximum to make a shallow dust blackout. The orbital period of 6.54 hr was detected by Mróz et al. (2015).

The reddening and distance for V2615 Oph were estimated as $E(B-V) = 1.0$–1.3 (Rudy et al. 2007) from OI lines, as $E(B-V) = 0.90$ and $d = 3.7 \pm 0.2$ kpc (Munari et al. 2008a) from an average of $E(B-V) = (B-V)_{\text{max}} - (B-V)_{0,\text{max}} = 1.12 \pm 0.06$ and $E(B-V) = (B-V)_{0,2} - (B-V)_{0,2} = 0.89 \pm 0.04$ and from $(m-M)_V = 15.7$ calculated by various empirical formulae including the MMRD and $M_{V,15}$ relations.

We plot the $V$ light curve and $B-V$ color evolution of V2615 Oph on a logarithmic timescale in Figure 64(a), as well as those of FH Ser, QV Vul, V705 Cas, and V475 Sct, because these light curves are very similar to each other. Since the timescales of these novae are almost the same, we regard that their brightnesses are the same as that of V2615 Oph. Then we obtain the apparent distance modulus of V2615 Oph as

$$(m-M)_V,\text{V2615 Oph} = 16.5$$

where we use $(m-M)_{V,\text{FH Ser}} = 11.7$ from Section 2.3, $(m-M)_{V,OV\text{ Vul}} = 14.0$ from Section 3.11, $(m-M)_{V,705\text{ Cas}} = 13.4$ from Section 3.14, and $(m-M)_{V,475\text{ Sct}} = 15.4$ from Section 3.20. We also obtained $E(B-V) = 0.95 \pm 0.05$ by assuming that the intrinsic $(B-V)_0$ color of
V2615 Oph is similar to those of FH Ser, QV Vul, and V705 Cas until the dust blackout started, as shown in Figure 64(b). The NASA/IPAC galactic dust absorption map gives \( E(B-V) = 0.87 \pm 0.02 \) in the direction toward V2615 Oph, being roughly consistent with our obtained value of \( E(B-V) = 0.95 \pm 0.05 \). Thus, we adopt \( E(B-V) = 0.95 \pm 0.05 \).

Figure 59(c) shows a plot of various distance–reddening relations for V2615 Oph, \((l, b) = (4^{\circ}1475, +3^{\circ}3015)\). Here we plot the distance–reddening relations given by Marshall et al. (2006), i.e., \((l, b) = (4^{\circ}00, 3^{\circ}25)\) denoted by open red squares, \((4^{\circ}25, 3^{\circ}25)\) by filled green squares, \((4^{\circ}00, 3^{\circ}50)\) by blue asterisks, and \((4^{\circ}25, 3^{\circ}50)\) by open magenta circles. The closest one is the one denoted by filled green squares. We also added the distance–reddening relation given by Green et al. (2015). These four trends, Marshall et al.’s relations, Green et al.’s relation (solid black line), \((m - M)_V = 16.5\) (thick solid blue line), and \( E(B-V) = 0.95 \) (vertical solid red line), consistently cross at \( d = 5.1 \) kpc.

Using \( E(B-V) = 0.95 \) and \((m - M)_V = 16.5\), we plot the color–magnitude diagram of V2615 Oph in Figure 62(b). The track of V2615 Oph is similar to that of FH Ser (solid orange lines) in the very early phase and then makes a loop clockwise near the track of LV Vul (solid magenta lines), corresponding to the oscillatory feature of the \( V \) light curve, and then goes down along the track of FH Ser. However, note that there are two different \( B - V \) color data sets in Munari et al. (2008a) from JD 2,454,220 to JD 2,454,250 as shown in Figure 63(b). Between \( M_V = -6 \) and \(-4\) in Figure 62(b), one goes down along the track of FH Ser, i.e., \((B - V)_0 \sim +0.06\), and the other goes down along that of LV Vul, i.e., \((B - V)_0 \sim -0.10\), until the dust blackout started. These two different \( B - V \) color data sets were obtained at two different observatories, so we suppose that the response functions of the \( V \) filters differ between them. After the recovery of the dust blackout, the V2615 Oph data follow those of LV Vul (magenta thick solid line). If we adopt the redder side data, we regard V2615 Oph as an FH Ser type in the color–magnitude diagram. A dust shell was formed when the brightness declined to \( m_V = 12.0 \) (Rudy et al. 2007) as indicated by a large open red square in Figure 62(b). We specify this starting point by \((B - V)_0 = -0.06\) and \( M_V = -4.58\).

3.27. V458 Vul 2007#1

This nova is not studied in Paper I. Figure 65 shows the \( V \) and \((B - V)_0 \) evolutions of V458 Vul on a linear timescale. The \( BV \) data are taken from IAU Circular No. 8863, CBET No. 1029, and the AAVSO archive. The \( V \) data are from VSOLJ, IAU Circular Nos. 8861 and 8899, and CBET Nos. 1029 and 1035. V458 Vul reached \( m_V, \text{max} = 8.1 \) at optical maximum on August 9.43 UT (Tarasova 2007). Subsequently, it underwent two major rebrightenings with an amplitude of 1 mag on August 13.5 and 19.5 UT. Then it declined with \( t_2 \approx 8 \) days and \( t_3 \approx 21 \) days (e.g., Wesson et al. 2008), showing small-amplitude fluctuations.

We also plot the light curve and color evolutions of V458 Vul on a logarithmic timescale in Figure 66 together with V443 Ser and PW Vul. The shape of the light curve and

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**Figure 60.** Same as Figure 17, but for V2467 Cyg. We dereddened \((B - V)_0\) and \((U - B)_0\) colors with \( E(B - V) = 1.40 \). The Astrophysical Journal Supplement Series, 223:21 (62pp), 2016 April HACHISU & KATO

**Figure 61.** Same as Figure 20, but for V2467 Cyg (open red circles with plus sign) and V2468 Cyg (filled blue stars). We also add the light curves of IV Cep (filled triangles) and V1668 Cyg (filled black squares).
The reddening for V458 Vul was obtained as $E(B-V) = 0.6$ (Lynch et al. 2007) from O I lines, as $E(B-V) = 0.55 \pm 0.12$ (Poggiani 2008) from $E(B-V) = (B-V)_{0} - (B-V)_{0,2} = 0.53 - (-0.02 \pm 0.12) = 0.55 \pm 0.12$, and as $E(B-V) = 0.63$ (Wesson et al. 2008) from the Balmer line ratio $H\alpha/H\beta$ of the southwest knot of the nebula associated with the nova. The NASA/IPAC galactic dust absorption map gives $E(B-V) = 0.54 \pm 0.03$ in the direction toward V458 Vul. We obtain the reddening of $E(B-V) = 0.50 \pm 0.05$ by assuming that the intrinsic $(B-V)_{0}$ color evolution of

\[(m-M)_{V, \text{V458 Vul}} = 15.3\]
\[(m-M)_{V, \text{V443 Sct}} = 15.5\]
\[(m-M)_{V, \text{PW Vul}} = 16.2\]

where we use $(m-M)_{V, \text{PW Vul}} = 13.0$ from Section 2.4 and $(m-M)_{V, \text{V443 Sct}} = 15.5$ from Section 3.12. Thus, we adopt $(m-M)_{V, \text{V458 Vul}} = 15.3$ in the present paper.

The color evolution of V458 Vul are similar to those of V443 Sct and PW Vul. In the figure, we stretch the time of V458 Vul by a factor of 2.0 and shift the $V$ light curve down by 1.0 mag in order to make them overlap. In Paper I, we determined the apparent distance modulus of V458 Vul as $m_M = 15.5$ by the time-stretching method. We reanalyzed the data and obtained $m_M = 15.3$ from Figure 66(a), i.e.,

\[(m-M)_{V, \text{V458 Vul}} = 15.3\]
\[(m-M)_{V, \text{V443 Sct}} = 15.5\]
\[(m-M)_{V, \text{PW Vul}} = 16.2\]

where we use $(m-M)_{V, \text{PW Vul}} = 13.0$ from Section 2.4 and $(m-M)_{V, \text{V443 Sct}} = 15.5$ from Section 3.12. Thus, we adopt $(m-M)_{V, \text{V458 Vul}} = 15.3$ in the present paper.

The reddening for V458 Vul was obtained as $E(B-V) = 0.6$ (Lynch et al. 2007) from O I lines, as $E(B-V) = 0.55 \pm 0.12$ (Poggiani 2008) from $E(B-V) = (B-V)_{0} - (B-V)_{0,2} = 0.53 - (-0.02 \pm 0.12) = 0.55 \pm 0.12$, and as $E(B-V) = 0.63$ (Wesson et al. 2008) from the Balmer line ratio $H\alpha/H\beta$ of the southwest knot of the nebula associated with the nova. The NASA/IPAC galactic dust absorption map gives $E(B-V) = 0.54 \pm 0.03$ in the direction toward V458 Vul. We obtain the reddening of $E(B-V) = 0.50 \pm 0.05$ by assuming that the intrinsic $(B-V)_{0}$ color evolution of V458 Vul are similar to those of V443 Sct and PW Vul. In the figure, we stretch the time of V458 Vul by a factor of 2.0 and shift the $V$ light curve down by 1.0 mag in order to make them overlap. In Paper I, we determined the apparent distance modulus of V458 Vul as $m_M = 15.5$ by the time-stretching method. We reanalyzed the data and obtained $m_M = 15.3$ from Figure 66(a), i.e.,

\[(m-M)_{V, \text{V458 Vul}} = 15.3\]
\[(m-M)_{V, \text{V443 Sct}} = 15.5\]
\[(m-M)_{V, \text{PW Vul}} = 16.2\]

where we use $(m-M)_{V, \text{PW Vul}} = 13.0$ from Section 2.4 and $(m-M)_{V, \text{V443 Sct}} = 15.5$ from Section 3.12. Thus, we adopt $(m-M)_{V, \text{V458 Vul}} = 15.3$ in the present paper.

The reddening for V458 Vul was obtained as $E(B-V) = 0.6$ (Lynch et al. 2007) from O I lines, as $E(B-V) = 0.55 \pm 0.12$ (Poggiani 2008) from $E(B-V) = (B-V)_{0} - (B-V)_{0,2} = 0.53 - (-0.02 \pm 0.12) = 0.55 \pm 0.12$, and as $E(B-V) = 0.63$ (Wesson et al. 2008) from the Balmer line ratio $H\alpha/H\beta$ of the southwest knot of the nebula associated with the nova. The NASA/IPAC galactic dust absorption map gives $E(B-V) = 0.54 \pm 0.03$ in the direction toward V458 Vul. We obtain the reddening of $E(B-V) = 0.50 \pm 0.05$ by assuming that the intrinsic $(B-V)_{0}$ color evolution of V458 Vul are similar to those of V443 Sct and PW Vul. In the figure, we stretch the time of V458 Vul by a factor of 2.0 and shift the $V$ light curve down by 1.0 mag in order to make them overlap. In Paper I, we determined the apparent distance modulus of V458 Vul as $m_M = 15.5$ by the time-stretching method. We reanalyzed the data and obtained $m_M = 15.3$ from Figure 66(a), i.e.,

\[(m-M)_{V, \text{V458 Vul}} = 15.3\]
\[(m-M)_{V, \text{V443 Sct}} = 15.5\]
\[(m-M)_{V, \text{PW Vul}} = 16.2\]

where we use $(m-M)_{V, \text{PW Vul}} = 13.0$ from Section 2.4 and $(m-M)_{V, \text{V443 Sct}} = 15.5$ from Section 3.12. Thus, we adopt $(m-M)_{V, \text{V458 Vul}} = 15.3$ in the present paper.

The reddening for V458 Vul was obtained as $E(B-V) = 0.6$ (Lynch et al. 2007) from O I lines, as $E(B-V) = 0.55 \pm 0.12$ (Poggiani 2008) from $E(B-V) = (B-V)_{0} - (B-V)_{0,2} = 0.53 - (-0.02 \pm 0.12) = 0.55 \pm 0.12$, and as $E(B-V) = 0.63$ (Wesson et al. 2008) from the Balmer line ratio $H\alpha/H\beta$ of the southwest knot of the nebula associated with the nova. The NASA/IPAC galactic dust absorption map gives $E(B-V) = 0.54 \pm 0.03$ in the direction toward V458 Vul. We obtain the reddening of $E(B-V) = 0.50 \pm 0.05$ by assuming that the intrinsic $(B-V)_{0}$ color evolution of V458 Vul are similar to those of V443 Sct and PW Vul. In the figure, we stretch the time of V458 Vul by a factor of 2.0 and shift the $V$ light curve down by 1.0 mag in order to make them overlap. In Paper I, we determined the apparent distance modulus of V458 Vul as $m_M = 15.5$ by the time-stretching method. We reanalyzed the data and obtained $m_M = 15.3$ from Figure 66(a), i.e.,

\[(m-M)_{V, \text{V458 Vul}} = 15.3\]
\[(m-M)_{V, \text{V443 Sct}} = 15.5\]
\[(m-M)_{V, \text{PW Vul}} = 16.2\]

where we use $(m-M)_{V, \text{PW Vul}} = 13.0$ from Section 2.4 and $(m-M)_{V, \text{V443 Sct}} = 15.5$ from Section 3.12. Thus, we adopt $(m-M)_{V, \text{V458 Vul}} = 15.3$ in the present paper.

The reddening for V458 Vul was obtained as $E(B-V) = 0.6$ (Lynch et al. 2007) from O I lines, as $E(B-V) = 0.55 \pm 0.12$ (Poggiani 2008) from $E(B-V) = (B-V)_{0} - (B-V)_{0,2} = 0.53 - (-0.02 \pm 0.12) = 0.55 \pm 0.12$, and as $E(B-V) = 0.63$ (Wesson et al. 2008) from the Balmer line ratio $H\alpha/H\beta$ of the southwest knot of the nebula associated with the nova. The NASA/IPAC galactic dust absorption map gives $E(B-V) = 0.54 \pm 0.03$ in the direction toward V458 Vul. We obtain the reddening of $E(B-V) = 0.50 \pm 0.05$ by assuming that the intrinsic $(B-V)_{0}$ color evolution of
V458 Vul is similar to that of PW Vul as shown in Figure 66(b). Then the distance is calculated as 
\[ d = 5.6 \text{ kpc} \]
for \( E(B-V) = 0.50 \) and \( (m-M)_V = 15.3 \).

The distance to V458 Vul was obtained as \( d = 6.7-10.3 \text{ kpc} \) (Poggiani 2008) from various MMRD relations for \( t_2 = 7 \pm 2 \) days and \( t_3 = 15 \pm 2 \) days and \( M_{V,15} \) magnitude, and \( d = 13 \text{ kpc} \) (Wesson et al. 2008) from the MMRD relation, galactic rotation, and light echo time of nearby nebula.
associated with the nova. It is well known that the MMRD and $M_{\epsilon,15}$ relations represent statistical tendencies and do not give correct brightness for individual novae. Roy et al. (2012) claimed that the nova could be as close as $d \sim 6.5$ kpc or more from an analysis of the H I cloud associated with the nova.

Figure 59(d) shows various distance–reddening relations for V458 Vul, $(l, b) = (58^\circ 6331, -3^\circ 6171)$. Here we plot the distance–reddening relations given by Marshall et al. (2006), i.e., $(l, b) = (58^\circ 50, -3^\circ 50)$ denoted by open red squares, $(58^\circ 75, -3^\circ 50)$ by filled green squares, $(58^\circ 50, -3^\circ 75)$ by blue asterisks, and $(58^\circ 75, -3^\circ 75)$ by open magenta circles. The closer ones are those denoted by filled green squares and open magenta circles. We also plot the distance–reddening relation given by Green et al. (2015). These trends cross consistently at the point $E(B-V) = 0.50$ and $d = 5.6$ kpc.

Assuming $E(B-V) = 0.50$ and $(m-M)_V = 15.3$, we plot the color–magnitude diagram of V458 Vul in Figure 62(c). The basic part of the track is close to that of PU Vul (thick solid blue lines). Therefore, we regard V458 Vul as a PU Vul type. This is consistent with the fact that these types of novae, including RR Pic, V723 Cas, HR Del, and V5558 Sgr, have multiple peaks (or flares) in the very early phase (see Kato & Hachisu 2009, 2011, for the reason behind multiple flaring pulses). We connect the first maximum by red lines, second by blue lines, and third by black lines. V458 Vul moves clockwise in the color–magnitude diagram during these three pulses (Figure 65) as indicated by blue arrows. This is very similar to that of V5558 Sgr in Figure 11(d).

Finally, we revisit the model light-curve analysis of V458 Vul, which was analyzed in our previous paper (Hachisu & Kato 2010). After that study, the end of the supersoft X-ray phase of V458 Vul was reported (e.g., Schwarz et al. 2011), which enables us to determine the WD mass more accurately. Our new model light curves are presented in Figure 67. The details of our numerical methods are described in Hachisu & Kato (2016). We add calculated supersoft X-ray fluxes together with the observational X-ray data (filled blue stars for the hard X-ray phase and blue plus signs for the soft X-ray phase). The X-ray count rates are taken from the Swift Web page. We think that the steep rise in the X-ray flux near 380 days after the outburst corresponds to the epoch when the optically thick winds stopped (see, e.g., Hachisu & Kato 2010). The optical and NIR light curves of free–free emission depend mainly on the WD mass and weakly on the chemical composition of the envelope. For the chemical composition $X = 0.55$, $Y = 0.30$, $X_{\text{CNO}} = 0.10$, $X_e = 0.03$, and $Z = 0.02$ (Ne nova 2) for a typical neon nova, we have a best-fit model with $M_{\text{WD}} = 1.0 M_\odot$ (black thick solid line) among 0.95, 1.0, and 1.05 $M_\odot$ WDs as shown in Figure 67(a). If we assume $X = 0.55$, $Y = 0.23$, $X_{\text{CNO}} = 0.20$, and $Z = 0.02$ (CO nova 4) for a typical carbon–oxygen nova, on the other hand, we have a best-fit model with $M_{\text{WD}} = 0.95 M_\odot$ among 0.9, 0.95, and 1.0 $M_\odot$ WDs as shown in Figure 67(b).

Our previous model was $M_{\text{WD}} = 0.95 M_\odot$ for the chemical composition of Ne nova 2 (see Figure 27 of Hachisu & Kato 2010) or $M_{\text{WD}} = 0.93 M_\odot$ for the chemical composition of CO nova 4 (see Figure 26 of Hachisu & Kato 2010). The $V$ light curve was fitted with the free–free emission model light curve, and it gave a distance modulus of $(m-M)_V = 17.0$ (see Equation (86) of Hachisu & Kato 2010). Here we revised this fitting using new estimates of the WD mass, 1.0 and 0.95 $M_\odot$ for Ne nova 2 and CO nova 4, respectively, and new distance modulus, $(m-M)_V = 15.3$, as shown in Figures 67(a) and (b). This is consistent with the end of hydrogen shell burning. We included the contribution from the photospheric emission (blackbody approximation) in the V light-curve model in addition to the free–free emission (see, e.g., Hachisu & Kato 2015).

Hard X-rays from novae are considered to originate from internal shocks in the ejecta (e.g., Mukai & Ishida 2001) or shocks between the ejecta and circumstellar matter that is fed by the cool wind from a red giant companion (e.g., Sokoloski et al. 2006). Hachisu & Kato (2010) claimed that the hard X-ray emission from V458 Vul comes from the shock between the ejecta and the companion. If that is the case, we may observe hard X-rays when the companion appears out of the optically thick nova envelope. We again examine this possibility. The orbital period of V458 Vul was first reported as $P_{\text{orb}} = 0.589$ days by Goranskij et al. (2008), but was later revised to $P_{\text{orb}} = 0.0681$ days by Rodriguez-Gil et al. (2011). Assuming that the companion is a 0.6 $M_\odot$ CO core (e.g., Wesson et al. 2008), we obtain a separation of 0.82 $R_\odot$ for the
primary of $M_{\text{WD}} = 1.0 \, M_{\odot}$. Then the emergence time of the secondary from the optically thick nova envelope is recalculated as $\sim 80$ days after the outburst based on our new nova models. This emergence time of the companion is coincident with the start of the hard X-ray (filled blue stars) increase.

3.28. V2468 Cyg 2008#1

This nova is not studied in Paper I. Figure 68 shows the visual, $V$, and $y$ light curves and $(B - V)_0$ color evolution for V2468 Cyg. We dereddened $(B - V)_0$ color with $E(B - V) = 0.75$.

![Figure 68](image)

Figure 68. (a) $V$ and $y$ bands and visual light curves and (b) $(B - V)_0$ color evolution for V2468 Cyg. We dereddened $(B - V)_0$ color with $E(B - V) = 0.75$.

The reddening for V2468 Cyg was obtained as $E(B - V) = 0.77$ (Rudy et al. 2008b) from OI lines, $E(B - V) = 0.80$ (Iijima & Naito 2011) from hydrogen column density, $E(B - V) = 0.8$ (Schwarz et al. 2009) from Balmer decrements, $E(B - V) = 0.79 \pm 0.01$ (Chochol et al. 2012) from a simple average of $E(B - V) = 0.78$ from $E(B - V) = (B - V)_{\odot} - (B - V)_{\odot} = 0.76 \pm (-0.02 \pm 0.04) = 0.78$, $E(B - V) = 0.77$ from OI lines (Rudy et al. 2008b), $E(B - V) = 0.8$ from the Balmer decrements (Schwarz et al. 2009), and $E(B - V) = 0.80$ from the hydrogen column density (Iijima & Naito 2011). These values are all consistent with each other, so we adopt $E(B - V) = 0.75 \pm 0.05$ in this paper.

The distance to V2468 Cyg was estimated mainly with the MMRD relations. Iijima & Naito (2011) estimated $(m - M)_V = m_{V,\text{max}} - M_V = 7.3 - (-8.8 \pm 0.3) = 16.1 \pm 0.3$ from $t_2 = 7.8 \pm 0.5$ days (della Valle & Livio 1995) and calculated $d = 5.5 \pm 0.8$ kpc for $E(B - V) = 0.8 \pm 0.1$, Chochol et al. (2012) also obtained $(m - M)_V = m_{V,\text{max}} - M_V = 7.57 - (-8.7 \pm 0.07) = 16.27 \pm 0.07$ for $t_2 = 9$ days and $t_3 = 22$ days (della Valle & Livio 1995; Downes & Duerbeck 2000) and $d = 5.4 \pm 0.4$ kpc for $E(B - V) = 0.79 \pm 0.01$.

In Paper I, we obtained the distance modulus of $(m - M)_V = 15.6$ for V2468 Cyg by the time-stretching method. We confirmed this result of Paper I in Figure 55(a) and Equation (13), and also in Figure 61(a) and Equation (15). Assuming that the $(B - V)_0$ colors of V2468 Cyg, V1500 Cyg, V1668 Cyg, IV Cep, V2362 Cyg, and V2467 Cyg are very similar to each other, we obtain the color excess of V2468 Cyg $E(B - V) = 0.75 \pm 0.05$ as shown in Figures 55(b) and 61(b). This estimate is consistent with the previous results mentioned above.

Figure 69(a) shows various distance–reddening relations for V2468 Cyg, $(l, b) = (66.7^\circ 8084, +0.2^\circ 2455)$. Here we plot the relations given by Marshall et al. (2006), i.e., $(l, b) = (66.7^\circ 75, 0.0^\circ 00)$ denoted by open red squares, $(67.0^\circ 00, 0.0^\circ 00)$ by filled green squares, $(66.7^\circ 75, 0.0^\circ 25)$ by blue asterisks, and $(67.0^\circ 00, 0.0^\circ 25)$ by open magenta circles. The closest one is denoted by blue asterisks. We also plot the distance–reddening relation given by Green et al. (2015). These distance–reddening relations cross at the same point, i.e., at the cross point of the two lines, $(m - M)_V = 15.6$ (thick solid blue line) and $E(B - V) = 0.75$ (vertical solid red line). The distance is calculated as $d = 4.5$ kpc for $E(B - V) = 0.75$ and $(m - M)_V = 15.6$.

Using $E(B - V) = 0.75$ and $(m - M)_V = 15.6$, we plot the color–magnitude diagram of V2468 Cyg in Figure 62(d). The track of V2468 Cyg is similar to that of V1500 Cyg (thick solid green line). Therefore, we regard V2468 Cyg as a V1500 Cyg type in the color–magnitude diagram. The nova entered the nebular phase on UT 2008 July 8, about 125 days after the outburst, i.e., at $m_V = 12.2$ (Iijima & Naito 2011) as indicated by the large open red square at $(B - V)_0 = -0.38$ and $M_V = -3.80$ in Figure 62(d).

3.29. V2491 Cyg 2008#2

This nova is not studied in Paper I. Figure 70 shows the $y$, $V$, and visual light curves and $(B - V)_0$ color evolution of V2491 Cyg. This nova reached $m_{V,\text{max}} = 7.45 \pm 0.05$ at optical maximum on UT 2008 April 11.37 (Munari et al. 2011). Then it declined with $t_2 = 4.8$ days, but rose again to $m_V = 9.5$ about 15 days after maximum, which is the secondary maximum similar to those of V1493 Aql (Figure 40) and V2362 Cyg (Figure 54). Hachisu & Kato (2009) proposed a mechanism for the secondary maximum on the basis of a strong magnetic field on the WD. Although Page et al. (2010) discussed various X-ray properties of V2491 Cyg against a strong magnetic field, recently Zemko et al. (2015) found a 38-minute periodicity and a possibility of a soft intermediate polar.

The reddening for V2491 Cyg was obtained as $E(B - V) = 0.3$ (Lynch et al. 2008a) from OI lines, which was revised by Rudy et al. (2008a) to be $E(B - V) = 0.43$ from the OI lines at 0.84 and 1.13 $\mu$m, and $E(B - V) = 0.23 \pm 0.01$ (Munari et al. 2011) from an average of $E(B - V) = 0.24$ from NaI A5889.953 line profiles, $E(B - V) = (B - V)_{\text{max}} - (B - V)_{\text{max}} = 0.46 - (0.23 \pm 0.06) = 0.23 \pm 0.06$, and $E(B - V) = (B - V)_{\text{max}} - (B - V)_{\text{max}} = 0.20 - (-0.02 \pm 0.04) = 0.22 \pm 0.04$. The distance modulus and distance of V2491 Cyg were estimated by Munari et al. (2011) as $(m - M)_V = m_{V,\text{max}} - M_V = 7.45 - (-9.06) = 16.51$ from the MMRD relation (Cohen 1988).
together with $t_2 = 4.8$, and then derived as $d = 14$ kpc. In this paper, we adopt $E(B-V) = 0.23$ after Munari et al. because the $(B-V)_0$ color dereddened with $E(B-V) = 0.23$ almost overlaps the other color evolution curves of V1500 Cyg and V1668 Cyg as seen in Figure 71(b).

Using the time-stretching method (Figure 71(a)), we obtain the distance modulus of V2491 Cyg in the $V$ band, 

$$(m - M)_V = 16.5,$$ 

$$= (m - M + \Delta V)_V,V_{V1500\,\text{Cyg}} - 2.5 \log 1.0/1.41,$$ 

$$\approx 12.3 + (+0.0 + 3.8) + 0.37 = 16.47,$$ 

$$= (m - M + \Delta V)_V,V_{V1668\,\text{Cyg}} - 2.5 \log 0.54/1.41,$$ 

$$\approx 14.6 + (-2.9 + 3.8) + 1.04 = 16.54,$$  

(18)

where we use the apparent distance moduli of $(m - M)_V,V_{V1500\,\text{Cyg}} = 12.3$ from Section 2.5 and $(m - M)_V,V_{V1668\,\text{Cyg}} = 14.6$ from Section 2.1.

Figure 69(b) shows various distance–reddening relations for V2491 Cyg, $(i, b) = (67^\circ 2287, +4^\circ 3531)$. We plot the distance–reddening relations given by Marshall et al. (2006),
i.e., \((l, b) = (67^\circ 00, 4^\circ 25)\) denoted by open red squares, \((67^\circ 25, 4^\circ 25)\) by filled green squares, \((67^\circ 00, 4^\circ 50)\) by blue asterisks, and \((67^\circ 25, 4^\circ 50)\) by open magenta circles. The closest one is that denoted by filled green squares. We also plot the distance–reddening relation given by Green et al. (2015). The extinction denoted by filled green squares nicely matches the value of \(E(B-V) = 0.23\). The NASA/IPAC galactic dust absorption map gives \(E(B-V) = 0.48 \pm 0.03\) in the direction toward V2491 Cyg, being consistent with Green et al.’s relation. However, such large values of the reddening are inconsistent with those mentioned above. We obtain the cross point of the two trends, i.e., \((m-M)_V = 16.5\) (thick solid blue line) and \(E(B-V) = 0.23\) (vertical solid red line), i.e., \(d = 14\) kpc at \(E(B-V) = 0.23\).

Using \(E(B-V) = 0.23\) and \((m-M)_V = 16.5\), we plot the color–magnitude diagram of V2491 Cyg in Figure 72(a). V2491 Cyg is located very close to the track of V1500 Cyg. This similarity supports that our adopted values of \(E(B-V) = 0.23\) and \((m-M)_V = 16.5\) (\(d = 14\) kpc) are reasonable. Therefore, we regard V2491 Cyg as a V1500 Cyg type in the color–magnitude diagram. It is interesting that V1500 Cyg is also a strong magnetic system, a polar (Stockman et al. 1988). The nova possibly entered the nebular phase around \(~30\) days after maximum at \(m_V = 12.5\) (e.g., Munari et al. 2011; Tarasova 2014). We specify the turning point \(m_V \approx 12.5\) and \(B-V = -0.28\), i.e., \(M_V \approx -4.0\) and \((B-V)_0 = -0.51\), denoted by a large open red square in Figure 72(a) and tabulated in Table 2. We add the epoch when the SSS phase started at \(m_V = 13.0\), about \(40\) days after the outburst (Page et al. 2010).

3.30. V496 Sct 2009

This nova is not studied in Paper I. Figure 73 shows the visual and \(B - V\) evolutions of V496 Sct on a linear timescale. This nova reached \(m_{V, \text{max}} = 7.07\) at optical maximum on UT 2009 November 18.716 (Raj et al. 2012). Then it declined with \(t_2 = 59 \pm 5\) days. There is lack of data between 2009 mid-December (JD 2,455,180) and early 2010 February (JD 2,455,220) owing to a solar conjunction of V496 Sct. The \(BV\) data are taken from Raj et al. (2012) (filled red circles) and the SMARTS archive (magenta stars), while the visual (green dots) and \(V\) (open blue circles) data are from the AAVSO archive. It showed a shallow dip of dust shell formation about \(90\) days after optical maximum (e.g., Raj et al. 2012). Figure 73 has no \(U - B\) color data because we could not find any \(U\)-band observation in the literature.

The reddening for V496 Sct was obtained by Raj et al. (2012) as \(E(B-V) = (B-V)_{\text{max}} - (B-V)_0 = 0.797 \pm 0.014 - (0.23 \pm 0.06) = 0.57 \pm 0.06\) from the intrinsic \(B - V\) color at maximum and \(E(B-V) = 0.65\) from interstellar Na I line profile. They also estimated the distance modulus as \((m-M)_V = m_{V, \text{max}} - M_{V, \text{max}} = 7.07 - (-7.0 \pm 0.2) = 14.1\) from the MMRD relation (della Valle & Livio 1995) together with \(t_2 = 59\) and then derived \(d = 2.9 \pm 0.3\) kpc.

Using the time-stretching method, we have already obtained \((m-M)_V = 14.4\) as shown in Figure 57(a) together with Equation (14). The overall behavior of the V496 Sct \(V\) light curve is similar to those of FH Ser and NQ Vul as shown in Figure 47(a). Using the time-stretching method, we estimate the distance modulus as

\[
(m-M)_V,\text{V496 Sct} = 14.4
\]

\[
= (m-M + \Delta V)_{V,\text{FH Ser}} - 2.5 \log 0.7
\]

\[
= 11.7 + (+1.9 + 0.4) + 0.39 = 14.39
\]

\[
= (m-M + \Delta V)_{V,\text{NQ Vul}} - 2.5 \log 0.7
\]

\[
= 13.6 + (+0.0 + 0.4) + 0.39 = 14.39,
\]

where we use \((m-M)_V,\text{FH Ser} = 11.7\) from Section 2.3 and \((m-M)_V,\text{NQ Vul} = 13.6\) from Section 3.6. The reddening is also estimated by assuming that the intrinsic \(B - V\) color of V496 Sct is the same as those of FH Ser and NQ Vul. We obtain \(E(B-V) = 0.50 \pm 0.05\), as shown in Figures 47(b) and 57(b). We adopt \(E(B-V) = 0.50\) and \((m-M)_V = 14.4\). Then the distance is calculated to be \(d = 3.7\) kpc.

Figure 69(c) shows various distance–reddening relations for V496 Sct, \((l, b) = (25^\circ 2838, -1^\circ 7678)\). We plot the distance–reddening relation given by Marshall et al. (2006), i.e., \((l, b) = (25^\circ 25, -1^\circ 75)\) denoted by open red squares, \((25^\circ 50, -1^\circ 75)\) by filled green squares, \((25^\circ 25, -2^\circ 00)\) by blue asterisks, and \((25^\circ 50, -2^\circ 00)\) by open magenta circles. The closest one is the one denoted by open red squares. We also plot the distance–reddening relation given by Green et al. (2015). Marshall et al.’s distance–reddening relation, denoted by open red squares, crosses consistently our extinction of \(E(B-V) \approx 0.50\) at \(d = 3.7\) kpc.

Using \(E(B-V) = 0.50\) and \((m-M)_V = 14.4\), we plot the color–magnitude diagram of V496 Sct in Figure 72(a). The track of V496 Sct is very similar to that of LV Vul. This confirms that our values of \(E(B-V) = 0.50\) and \((m-M)_V = 14.4\) are reasonable. Therefore, we regard
The dust blackout started $\sim 90$ days after the outburst at $m_V = 9.9$ (e.g., Raj et al. 2012). We denote the start of the dust blackout by a large open blue square. The nebular phase possibly started $\sim 130$ days after the outburst at $m_V = 11.2$ (e.g., Raj et al. 2012). We specify it by a large open red square on the track, i.e., $(B - V)_0 = -0.35$ and $M_V = -3.26$.

4. DISCUSSION

4.1. Categorization of Nova Tracks

4.1.1. V496 Sct as an LV Vul type in the color–magnitude diagram.

V496 Sct as an LV Vul type in the color–magnitude diagram. The dust blackout started $\sim 90$ days after the outburst at $m_V = 9.9$ (e.g., Raj et al. 2012). We denote the start of the dust blackout by a large open blue square. The nebular phase possibly started $\sim 130$ days after the outburst at $m_V = 11.2$ (e.g., Raj et al. 2012). We specify it by a large open red square on the track, i.e., $(B - V)_0 = -0.35$ and $M_V = -3.26$.

4. DISCUSSION

4.1. Categorization of Nova Tracks

Figure 12 depicts the color–magnitude tracks of six templates, from left to right: V1500 Cyg (thick solid green), V1668 Cyg (magenta), V1974 Cyg (sky blue), LV Vul (black), FH Ser (orange), and PU Vul (blue). We have collected 40 nova tracks in the color–magnitude diagram (Figures 3, 6, 7, 11, 16, 23, 30, 37, 45, 53, 62, and 72), compared them with the template tracks in Figure 12, and categorized them into one of the six as listed in Table 2. The V1500 Cyg type includes eight novae, i.e., V1500 Cyg, T Pyx, GQ Mus, V1494 Aql, V2275 Cyg, V2362 Cyg, V2468 Cyg, and V2491 Cyg, mainly fast novae. The V1974 Cyg type includes seven novae, i.e., V1974 Cyg, V2467 Cyg, V533 Her, QU Vul, V1493 Aql, V382 Vel, and V5114 Sgr. The V1668 Cyg type includes eight novae, i.e., V1668 Cyg, V446 Her, OS And, V705 Cas, V1419 Aql, V2274 Cyg,
V475 Sct, and V1280 Sco. The FH Ser type includes four dust formation novae, i.e., FH Ser, NQ Vul, QV Vul, and V2615 Oph. The LV Vul type includes eight novae, i.e., LV Vul, RS Oph, PW Vul, IV Cep, V443 Sct, V1370 Aql, V1065 Cen, and V496 Sct. The PU Vul type includes five novae, i.e., PU Vul, HR Del, V723 Cas, V5558 Sgr, and V458 Vul. Some of these novae show a hybrid signature, e.g., V1065 Cen evolved along the path of V1668 Cyg in the early phase until ~-M$_{4V}$ and then followed LV Vul as shown in Figure 53 (c). In this paper, therefore, we put V1065 Cen into the LV Vul type, although V1065 Cen underwent a shallow dust blackout like V1668 Cyg.

The different B − V color position of each track in the color–magnitude diagram can be understood as a difference in the envelope mass. In general, novae on the bluer side have smaller envelope masses. For example, the V1500 Cyg and V1974 Cyg types differ in the B − V color as shown in Figure 74 (a). This color difference originates from the difference in the envelope mass, i.e., V1500 Cyg has a less massive envelope and evolves more rapidly (e.g., M$_{env}$ = 0.53 × 10$^{-5}$M$_{⊙}$ for a 1.2 M$_{⊙}$ WD model of V1500 Cyg versus M$_{env}$ = 1.2 × 10$^{-5}$M$_{⊙}$ for a 0.98 M$_{⊙}$ WD model of V1974 Cyg in Hachisu & Kato 2016). A good example of this difference can be seen in the track of V2362 Cyg. In the early decline phase, V2362 Cyg evolves downward along the track of FH Ser until M$_{V}$ ∼ −4, as depicted by filled red circles in Figure 53 (b). After that, the V magnitude rises up to the secondary maximum (M$_{V}$ ∼ −6) and sharply drops down to M$_{V}$ ∼ −2, as depicted by open magenta circles. A large amount of envelope mass was lost during this secondary maximum (Munari et al. 2008b). The position of the secondary maximum in the color–magnitude diagram is about 0.2 mag bluer than that of the first maximum. This track shift toward blue is caused by the loss of envelope mass.

Figure 73. Same as Figure 56, but for V496 Sct. We dereddened (B − V)$_{0}$ color with E(B − V) = 0.50.

Figure 74. Starting points of the nebular phase or dust blackout on nova tracks in the color–magnitude diagram. (a) V1500 Cyg (thick solid green line) and V1974 Cyg (thin solid blue line) types, where the starting points of the nebular phase (filled red circles) of 13 novae are plotted. (b) V1668 Cyg (thin solid magenta lines) and FH Ser (thin solid orange lines) types, where the starting points of the nebular phase (filled red circles) of two novae and the starting points of the dust blackout (open blue circles) of nine novae are plotted. (c) LV Vul (solid magenta line) and PU Vul (thick solid blue line) types, where the starting points of the nebular phase (filled red circles) of 11 novae are plotted. The data of these points are tabulated in Table 2. The two-headed black arrows represent Equation (5), and the lower two-headed green arrows in panel (c) denote Equation (6).
The difference between the V1668 Cyg and FH Ser types shown in Figure 74(b) can also be understood as a difference in envelope mass. Both types have a dust formation episode, but the dust blackout is much shallower in the V1668 Cyg type than in the FH Ser type. This indicates that the envelope mass is more massive in the FH Ser type novae.

In PW Vul, a massive envelope could be ejected during the very early phase as represented by a large clockwise circle in the color–magnitude diagram (e.g., Kolotilov & Noskova 1986). After that, it follows a track similar to that of LV Vul in the mid- and late decline phase. Such a shift toward blue is also observed in the multiple peaks of V5558 Sgr (Figure 11(d)). This also suggests a large decrease in the envelope mass.

4.2. Absolute Magnitude at Nebular Phase

The color–magnitude diagram (H-R diagram) is an excellent tool for understanding the nature of stars (e.g., their evolution and absolute magnitudes), but it has not yet been widely applied to nova outbursts. In Paper I, we discussed a new way to estimate the distance to a nova. The method in Paper I was as follows: (1) determine $E(B - V)$ by fitting the color–color evolution of a target nova with the general course of novae; (2) choose a reference nova with known distance and extinction and compare it with our target nova; (3) obtain $(m - M)_V$ by the time-stretching method of light curves, i.e., using the relation $m_i = m_V - 2.5 \log f_i$ (Hachisu & Kato 2010); and (4) calculate the distance with Equation (3).

Here we propose another new method based on the type of nova tracks and the starting points of the nebular phase in the color–magnitude diagram. Figure 74 summarizes the positions of starting points of the nebular phase or dust blackout of each nova in the color–magnitude diagram. In the V1500 Cyg and V1974 Cyg type novae, i.e., the V1500 Cyg family, the gradual change toward blue in the very early phase ($M_V < -6$) corresponds to the continuum free–free emission phase of the nova spectrum. Then some emission lines become stronger in the $B$ band. The contribution of these emission lines causes an excursion toward blue between $-6 < M_V < -4$. After the turning point near $M_V \sim -4$, it went toward red owing to a large contribution of emission lines of $[O m]$ to the $V$ band. This turning point (or cusp) can be clearly identified in many of the V1500 Cyg family novae. We found that the start of the nebular phase almost coincides with the turning point (or cusp) and is already showing its position as a large red square in each color–magnitude diagram. We plot this turning point (or cusp) as an indication of the development of the nebular stage by filled red circles in Figure 74(a). These filled red circles are located on the two-headed black arrow of Equation (5) except for two novae, T Pyx and GQ Mus.

For the V1668 Cyg and FH Ser types of novae, i.e., the V1668 Cyg family, they often show a dust blackout at $M_V \sim -4.5$ before the above excursion toward red or blue. We plot the starting points of the dust blackout by open blue circles in Figure 74(b). They are rather scattered. On the other hand, we plot the starting points of the nebular phase by filled red circles for the two novae V1668 Cyg and V446 Her. These points are located on the two-headed arrow of Equation (5). The filled red circles in Figures 74(a) and (b) are located on the two-headed arrows represented by Equation (5) except for T Pyx and GQ Mus. Inversely, we obtain Equation (5) from these 13 red points, excluding T Pyx and GQ Mus.

The LV Vul and PU Vul type novae, i.e., the LV Vul family, have slightly different starting positions for the nebular phase. We plot also the starting points for the LV Vul family novae in Figure 74(c) by filled red circles. They are located on the two-headed green arrow represented by Equation (6), which is 0.6 mag below the two-headed black arrow represented by Equation (5). We obtained this lower line from these 11 red points in Figure 74(c).

In this way, we found the characteristic epochs corresponding to a certain magnitude given by Equation (5) or Equation (6). Using this property, we are able to obtain the absolute magnitude of the target nova by placing the starting point of the nebular phase on the line of Equation (5) or Equation (6) depending on the nova type. This is a new method for determining the absolute magnitude of a nova.

4.3. Application to Recurrent Novae

Using the color–magnitude diagram method summarized above in Section 4.2, we can estimate the absolute magnitudes of novae. This is essentially the same method as the main-sequence fitting or horizontal-branch fitting in the H-R diagram to estimate the distances to star clusters. In this subsection, we first confirm our method by applying it to the M31 1 yr recurrent nova, M31N 2008-12a, and then estimate the absolute magnitudes of three well-observed recurrent novae, CI Aql, U Sco, and V745 Sco.

4.3.1. M31N 2008-12a

The 1 yr recurrence period nova M31N 2008-12a is an excellent example of a recurrent nova because the distance and extinction are well determined (Darnley et al. 2015; Henze et al. 2015; Kato et al. 2015). The nova has $t_2 = 1.77$ days and $t_3 = 3.84$ days in the $V$ band (Darnley et al. 2015), being a very fast nova. Kato et al. (2015) concluded, on the basis of their multiwavelength light-curve model, that the WD mass is close to $1.38 M_\odot$. The distance to M31 is $d \approx 780$ kpc, and the extinction is $E(B - V) \approx 0.21$ toward the nova (e.g., Henze et al. 2015). Then the distance modulus is calculated to be $(m - M)_V = 25.1$.

Adopting $E(B - V) = 0.21$ and $(m - M)_V = 25.1$, we plot the color–magnitude diagram of M31N 2008-12a in Figures 72(c) and (d) by open black squares with connected solid black lines. The data for the 2014 outburst are taken from Darnley et al. (2015) and for the 2015 outburst from ATel Nos. 7974, 7965, 7967, 7969, 8033, 8029, and 8038. The peak brightness is about $M_V \approx -6.6$, much fainter than typical classical novae. Darnley et al. (2015) estimated that the peak brightness is $-6.8 < M_V < -6.3$. The nova almost goes down along the line of $(B - V)_0 = 0.03$ in the early phase, then turns to the left (toward blue) in the middle phase, and comes back to the right in the later phase. The turning point is not clearly identified but possibly located near the two-headed arrow. This supports our method of absolute magnitude determination discussed in the previous subsection (Section 4.2).

4.3.2. CI Aql

CI Aql is also a recurrent nova with recorded outbursts in 1917, 1941, and 2000. Schaefer (2001) proposed that CI Aql
could have an outburst every ~20 yr. Kiss et al. (2001) estimated the reddening of CI Aql \( E(B - V) = 0.85 \pm 0.3 \) from an average of various methods. Hachisu & Kato (2001), Hachisu et al. (2003), and Lederle & Kimeswenger (2003) derived \( E(B - V) \approx 1.0 \) based on their binary model light-curve fittings. Lynch et al. (2004) obtained \( E(B - V) = 1.5 \pm 0.1 \) from the O I line ratios. Iijima (2012) obtained \( E(B - V) = 0.92 \pm 0.15 \) from the equivalent widths of the diffuse interstellar absorption bands.

Figure 72(c) shows the data of CI Aql (filled red circles connected with a solid red line), taken from the VSOLJ archive (mainly from Kiyota’s data). Iijima (2012) found that CI Aql entered the nebular phase between UT 2000 May 31 and June 8 at \( m_V \approx 11.8 \). We identify a turning point (or cusp) at the starting point of the nebular phase, i.e., at the point \( (B - V)_0 = -0.52 \) and \( M_V = -3.84 \) (large open red square). Adopting \( E(B - V) = 1.0 \), we obtain the distance modulus in the V band from a fit with Equation (5). The derived distance modulus is \( (m - M)_V = 11.9 - (3.8) = 15.7 \) at the turning point. We can regard CI Aql as a V1500 Cyg type in the color–magnitude diagram, so the fit with Equation (5) is justified. We plot the track of V1500 Cyg by thick solid sky-blue lines and that of the recurrent nova T Pyx by green stars in Figure 72(c). The track of CI Aql almost follows these trends. This also confirms that our adopted values of \( E(B - V) = 1.0 \) and \( (m - M)_V = 15.7 \) are reasonable.

The distance is then calculated to be \( d \approx 3.3 \) kpc. This value is shorter than the ~5.0 kpc obtained by Schaefer (2010) from the MMRD relation (Downes & Duerbeck 2000), but longer than the value of \( d \sim 1.5 \) kpc estimated from the blackbody binary model light curves (Hachisu & Kato 2001; Hachisu et al. 2003; Lederle & Kimeswenger 2003) together with \( E(B - V) = 1.0 \). In general, one should not use the MMRD relations to obtain the maximum magnitudes of recurrent novae because they are faint objects as already discussed in our previous papers (Hachisu & Kato 2010, 2014, 2015, 2016). Sahman et al. (2013) obtained \( d = 1.3 \pm 0.2 \) kpc from the spectral type (F8IV) of the companion star together with Lynch et al.’s estimate of \( M_V = 4.6 \pm 0.5 \). If we adopt \( E(B - V) = 1.0 \) (\( A_V = 3.1 \)), Sahman et al.’s distance could be larger than \( d \gtrsim 2.6 \) kpc.

The set \( d = 3.3 \) kpc and \( E(B - V) = 1.0 \) is consistent with the distance–reddening relations for CI Aql, \( (l, b) = (31^\circ 6876, -0^\circ 8120) \), in Figure 69(d). Here we plot \( (m - M)_V = 15.7 \), \( E(B - V) = 1.0 \), and four nearby distance–reddening relations given by Marshall et al. (2006), i.e., \( (l, b) = (31^\circ 50, -0^\circ 75) \) denoted by open red squares, \( (31^\circ 75, -0^\circ 75) \) by filled green squares, \( (31^\circ 50, -1^\circ 00) \) by blue asterisks, and \( (31^\circ 75, -1^\circ 00) \) by open magenta circles. The closest one is that of the filled green squares. We also add the relation (solid black line) given by Green et al. (2015). These trends cross consistently at \( d \approx 3.3 \) kpc and \( E(B - V) \approx 1.0 \).

To summarize, the color–magnitude track of CI Aql almost overlaps with the tracks of T Pyx and V1500 Cyg, and its distance–reddening relation is consistent with the Marshall et al. relation. Thus, we may conclude that the set of \( E(B - V) = 1.0 \) and \( (m - M)_V = 15.7 \) (\( d \approx 3.3 \) kpc) is reasonable. We summarize the results in Table 3.

### 4.3.5. U Sco

U Sco is also a recurrent nova with 10 recorded outbursts, in 1863, 1906, 1917, 1936, 1945, 1969, 1979, 1987, 1999, and 2010, almost every 10 yr (Schaefer 2010). It is located at a high galactic latitude, \( (l, b) = (357^\circ 6686, +21^\circ 8686) \). Thus, it is far from the galactic plane (\( z > 1 \) kpc) if its distance is large enough (\( d \gtrsim 3 \) kpc), as suggested in the literature. Therefore, the extinction for U Sco should be close to the galactic dust extinction. The NASA/IPAC galactic dust absorption map gives \( E(B - V) = 0.32 \pm 0.04 \) for U Sco. Unfortunately, direct measurements of reddening show a scatter between 0.1 and 0.35 (e.g., Schaefer 2010). For example, Barlow et al. (1981) obtained two different absorptions toward U Sco in the 1979 outburst, \( E(B - V) \sim 0.2 \) from the line ratio of He II at an early phase of the outburst (~12 days after maximum) and \( E(B - V) \sim 0.35 \) from the Balmer line ratio at a late phase of the outburst (~33−34 days after maximum). The latter value is consistent with that of the galactic dust absorption map.

Adopting \( E(B - V) = 0.35 \), we plot the color–color diagram of the U Sco 2010 outburst in Figure 36(c). The \( B - V \) and \( U - B \) color data are taken from Pagnotta et al. (2015). The track of U Sco almost overlaps with the general track of novae (solid green lines) in the color–color diagram. Thus, we confidently determine the reddening of U Sco as \( E(B - V) = 0.35 \pm 0.05 \).

Figure 72(d) shows the color–magnitude diagram of U Sco. Here we adopt \( E(B - V) = 0.35 \) and then determine the distance modulus in the V band from the fit with Equation (5). We identify a turning point (or cusp) at the point \( (B - V)_0 = -0.64 \) and \( M_V = -3.72 \) (large open red square) as shown in Figure 72(d). The distance modulus is then calculated to be \( (m - M)_V = 12.3 - (3.7) = 16.0 \) at the turning point (large open red square). Then the peak is as bright as \( M_V = 7.5 - 16.0 = -8.5 \), about 0.5 mag brighter than the peaks of RS Oph and T Pyx (see Figures 16(a) and (d)), and 1.5 mag brighter than the peak of CI Aql (Figure 72(c)). After the turning point (large open red square), U Sco goes down further, crossing the two-headed arrow, and jumps to the left (toward blue) up to \( (B - V)_0 \sim -1.0 \). We neglect this bluest point in our determination of the turning point, because it could be affected by the first flare in the 2010 outburst (e.g., Schaefer 2011; Anupama et al. 2013; Maxwell et al. 2013; Pagnotta et al. 2015). Below \( M_V > -3.0 \), we suppose that the \( B \) and \( V \) magnitudes are affected by a large irradiated disk around the WD (e.g., Hachisu et al. 2000a) and, as a result, the \( B - V \) color is contaminated by the disk radiation. This is the reason why the color–magnitude track of U Sco stays at \( (B - V)_0 \sim -0.1 \) between \( -2.0 \lesssim M_V \lesssim -0.0 \). We added the epoch when the SSS phase started at \( M_V = 14.0 \), about 14 days after the outburst (Schaefer et al. 2011).

The distance to U Sco is calculated to be \( d = 9.6 \pm 0.6 \) kpc. This is larger than the \( d = 6 - 7 \) kpc calculated from the nova explosion/quiescent models of Hachisu et al. (2000a, 2000b). Assuming totality at mid-eclipse, Schaefer (2010) proposed a larger value of \( d = 12 \pm 2 \) kpc estimated from the spectral type (G5IV) of the companion star. We should note that a different spectral type (K2IV) of the companion was proposed by Anupama & Dewangan (2000). Anupama et al. (2013) revised their spectral type to K0 ~ K1. Mason et al. (2012) proposed that the spectral type of the secondary star is not earlier than F3 and not later than G, but concluded that they
Table 3
Physical Properties of Selected Recurrent Novae

| Object   | E(B − V) | (m − M)V | Distance (kpc) | M<sub>e,max</sub> | P<sub>orb</sub> (days) | RN Type<sup>a</sup> |
|----------|----------|----------|----------------|------------------|----------------------|---------------------|
| RS Oph   | 0.65     | 12.8     | 1.4            | −8.0             | 457<sup>b</sup>      | RS Oph             |
| T Pyx    | 0.25     | 14.2     | 4.8<sup>c</sup> | −7.9             | 0.076<sup>d</sup>    | T Pyx              |
| CI Aql   | 1.0      | 15.7     | 3.3            | −6.9             | 0.618<sup>e</sup>    | U Sco              |
| U Sco    | 0.35     | 16.0     | 9.6            | −8.5             | 1.23<sup>f</sup>     | U Sco              |
| V745 Sco | 0.70     | 16.6     | 7.8            | −7.9             | ...                  | RS Oph             |

Notes.
<sup>a</sup> Recurrent novae (RNe) are divided into three types, depending on the nature of the companion (or the orbital period), i.e., T Pyx (P<sub>orb</sub> ~ a few hours), U Sco (P<sub>orb</sub> ~ a day), and RS Oph (P<sub>orb</sub> ~ a few to several hundred days) types (e.g., Anupama 2008).

<sup>b</sup> Taken from Fekel et al. (2000).
<sup>c</sup> Taken from Sokoloski et al. (2013).
<sup>d</sup> Taken from Uthas et al. (2010).
<sup>e</sup> Taken from Mennickent & Honeycutt (1995).
<sup>f</sup> Taken from Schafer & Ringwald (1995).

cannot confidently exclude an early K spectral type for U Sco. Thus, we must be careful with the distance determination from only the spectral type of the secondary. We summarize our results in Table 3.

We added the B − V and U − B color evolution of T Pyx (1966) in Figure 36(c), shown by filled blue circles. The data are the same as those in Figure 30(a) of Paper I. The color–color evolutions of U Sco (2010) and T Pyx (1966) overlap each other. The color–magnitude track of U Sco (filled red circles connected by solid red line) in Figure 72(d) follows that of T Pyx (green stars) in the early phase. The color–color and color–magnitude evolutions of U Sco are very similar to those of T Pyx.

4.3.4. V745 Sco

V745 Sco is also a recurrent nova with three recorded outbursts, in 1937, 1989, and 2014. Figure 75 shows the V, supersoft X-ray count rate, (B − V)<sub>0</sub>, and (U − B)<sub>0</sub> evolutions of V745 Sco for the 1989 and 2014 outbursts. The UBV data of the 1989 outburst are taken from Sekiguchi et al. (1990), and the BV and X-ray data of the 2014 outburst are from Page et al. (2015). If the 2014 outburst is the same as the 1989 outburst, the V magnitude (open blue circles) of Sekiguchi et al. (1990) is systematically 0.3 mag brighter than those (filled red circles) of Page et al. (2015). Therefore, we shift the V magnitudes down by 0.3 mag and confirm that these two V light curves overlap each other as shown in Figure 75(a). Such a difference among observers was already discussed in our previous sections and attributed to slightly different responses of the V filters. When Sekiguchi et al. started UBV photometry about 4 days after the outburst, the SSS phase had just begun, indicating that the ejecta had already become optically thin. The spectra of the 1989 outburst show that the nebular [O III] lines had already developed at this time (e.g., Duerbeck 1989). If we shift Sekiguchi et al.’s V down by 0.3 mag, then Sekiguchi et al.’s (B − V)<sub>0</sub> data are consistently overlapping those of Page et al. as shown in Figure 75(b). The 2014 outburst shows t<sub>2</sub> = 2 days and t<sub>3</sub> = 4 days (e.g., Orio et al. 2014).

The galactic coordinates of V745 Sco are (l, b) = (357°3584, −3°9991). The NASA/IPAC galactic dust absorption map gives E(B − V) = 0.71 ± 0.02 for V745 Sco. Banerjee et al. (2014) suggested that the extinction for V745 Sco is E(B − V) = 0.70 on the basis of galactic dust extinction of Schlafly & Finkbeiner (2011) and Marshall et al. (2006). Orio et al. (2014) fitted the X-ray spectrum 10 days after the discovery of the 2014 outburst with a model spectrum and obtained the hydrogen column density of N<sub>H</sub> =
(6.9 ± 0.9) × 10^{21} \text{ cm}^{-2}. They suggested an extinction of \( E(B-V) \approx 1.0 \) from the relationship \( E(B-V) = N_{HI}/8.8 \times 10^{21} \text{ cm}^{-2} \) (Güver & Özel 2009). However, if we use the relation \( E(B-V) = N_{HI}/8.3 \times 10^{21} \) proposed by Liszt (2014), we obtain \( E(B-V) = 0.83 ± 0.1 \). Thus, we adopt \( E(B-V) = 0.70 ± 0.1 \), mainly from the results of Banerjee et al. (2014) and the NASA/IPAC galactic dust absorption map.

Adopting \( E(B-V) = 0.70 \), we plot the color–color diagram of V745 Sco in Figure 36(d). There are only six data (open magenta circles), but five of the six data are located at or near the point \( (B-V)_0 = +0.13 \) and \( (U-B)_0 = -0.87 \) denoted by the open black square labeled “free–free \((f_{e} \propto \nu^{0})\).” This point corresponds to the position of optically thin free–free emission (Paper I). These positions of the data in the color–color diagram are consistent with the fact that the ejecta had already been optically thin when these data were obtained. This supports our value of \( E(B-V) = 0.70 \).

Next, we estimate the distance to V745 Sco. The orbital period of \( P_{orb} = 510 ± 20 \text{ days} \) proposed by Schaefer (2009) is not confirmed by Mróz et al. (2014), so we do not use the method of distance estimate proposed by Schaefer (2009) based on the Roche lobe size. Mróz et al. (2014) detected semiregular pulsations of the red giant companion (with periods of 136.5 and 77.4 days). Thus, we use a distance estimating method for the pulsating red giant companion. There is a well-known relation between the pulsation period and its luminosity for Mira variables, which is applicable also to semiregular variables pulsating in the fundamental mode

\[
M_K = -3.51 \times (\log P(\text{day}) - 2.38) - 7.25, \tag{20}
\]

with an error of ~0.2 mag (Whitelock et al. 2008). For the fundamental 136.5-day pulsation, we get the absolute \( K \) magnitude of \( M_K = -6.39 ± 0.2 \). The average \( K \) mag is \( m_K = 8.33 \text{ mag} \) (Hoard et al. 2002), so we have

\[
(m - M)_K = 0.353 \times E(B-V) + 5 \log (d/1 \text{ kpc}) + 10, \tag{21}
\]

where we adopt the reddening law of \( A_K = 0.353 \times E(B-V) \) (Cardelli et al. 1989). We plot the distance–reddening relation (thick solid green line flanked with thin solid green lines),

\[
14.72 ± 0.2 = 0.353 \times E(B-V) + 5 \log (d/1 \text{ kpc}) + 10, \tag{22}
\]

in Figure 76(a). For a particular value of \( E(B-V) = 0.70 \), we get \( d = 7.8 ± 0.8 \text{ kpc} \). Then we have \( (m - M)_V = 16.6 \) for the distance modulus in the \( V \) band.

Using \( E(B-V) = 0.70 \) and \( (m - M)_V = 16.6 \), we plot the color–magnitude diagram of V745 Sco in Figure 76(b). The \( BV \) data of V745 Sco (2014) are taken from Page et al. (2015) (filled red circles connected with a red line), while the \( BV \) data of the 1989 outburst are from Sekiguchi et al. (1990) (open red circles). The track of V745 Sco follows the line of \( (B-V)_0 = -0.03 \) in the early phase (top two data points), being consistent with optically thick free–free emission \( (f_{e} \propto \nu^{2/3}) \). Then, it jumps to \( (B-V)_0 = +0.13 \) about 4 days after the outburst, being consistent with the optically thin free–free emission \( (f_{e} \propto \nu^{0}) \). The SSS phase started 4 days after the outburst, and the ejecta had already become optically thin at this time. After that, the track almost follows that of RS Oph until \( M_V \sim -2.5 \). This agreement supports our adopted values of \( E(B-V) = 0.70 \) and \( (m - M)_V = 16.6 \). We regard V745 Sco as an LV Vul type in the color–magnitude diagram. We summarize the results in Table 3.

5. CONCLUSIONS

In this series of papers, we have extensively examined \( UBV \) color–color and color–magnitude evolutions of classical novae and found several important properties. In Paper I, we
discussed the color–color evolution of novae and found the general track of novae in the color–color evolutions. Thus, we developed a way to determine the color excess $E(B-V)$ of a target nova by fitting its color evolution track with the general course in the color–color diagram. Using this new and convenient method, we redetermined the color excesses of 27 novae. In the present paper, we have focused on the color–magnitude diagram and identified some general trends in the color–magnitude evolutions of novae. Our results are summarized as follows:

1. We redetermined the color excesses of novae, mainly by the method of the general track in the color–color diagram and partly by other methods when sufficient $UBV$ data were not available.

2. Using the time-stretching method of nova light curves (Hachisu & Kato 2010), we estimated the distance modulus $(m-M)_V$ of a target nova. Thus, we determined the distance moduli and color excesses of 40 novae and plotted their tracks in the color–magnitude diagram.

3. We reduced 10 well-observed nova tracks into the six template tracks of V1500 Cyg, V1668 Cyg, V1974 Cyg, LV Vul, FH Ser, and PU Vul in the color–magnitude diagram (Figure 12). These six template tracks are almost parallel and spread out from bluer to redder in the order of nova speed class (from faster to slower). In other words, the order indicates the envelope mass (from less to more massive). A redder nova has a more massive envelope and belongs to a slower speed class. Based on these six template tracks, we categorized our 40 novae into six types as listed in Table 2.

4. We found a turning/cusp point, which corresponds to the onset of the nebular phase, on the track in the color–magnitude diagram. Such a turning point appears when the absolute $V$ magnitude fades to $M_V \sim -4$ (V1500 Cyg and V1974 Cyg types) or slightly below (LV Vul and PU Vul types). The positions of these points are expressed by Equation (5) with a standard deviation of $\sim 0.1$ mag for the V1500 Cyg and V1974 Cyg types and the V1668 Cyg and FH Ser types, or by Equation (6) with a standard deviation of $\sim 0.2$ mag for the LV Vul and PU Vul types.

5. Using this property, we can estimate the distance modulus of a nova by placing its turning/cusp point on the line of Equation (5) or Equation (6) depending on the type. This is a new method for obtaining the absolute magnitudes of novae.

6. We applied this method to three recurrent novae and redetermined their color excesses and absolute magnitudes.

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