Acta Polytechnica CTU Proceedings **2**(1): 273–276, 2015 doi: 10.14311/APP.2015.02.0273

The UBV Color Evolution of Classical and Symbiotic Novae

I. Hachisu[1], M. Kato[2]

[1] *Department of Earth Science and Astronomy, College of Arts and Sciences, The University of Tokyo, Komaba, Meguro-ku, Tokyo 153-8902, Japan*

[2] *Department of Astronomy, Keio University, Hiyoshi, Kouhoku-ku, Yokohama 223-8521, Japan*

Corresponding author: hachisu@ea.c.u-tokyo.ac.jp

Abstract

We identified a general course of classical nova outbursts in the $B-V$ vs. $U-B$ diagram. It has been reported that novae show spectra similar to A–F supergiants near optical light maximum. However, they do not follow the supergiant sequence in the color-color diagram, neither the blackbody nor the main-sequence sequence. Instead, we found that novae evolve along a new sequence in the pre-maximum and near-maximum phases, which we call the nova-giant sequence. This sequence is parallel to but $\Delta(U-B) \approx -0.2$ mag bluer than the supergiant sequence. After optical maximum, its color quickly evolves back blueward along the same nova-giant sequence and reaches the point of free-free emission ($B-V=-0.03$, $U-B=-0.97$) and stays there for a while, which is coincident with the intersection of the blackbody sequence and the nova-giant sequence. Then the color evolves leftward (blueward in $B-V$ but almost constant in $U-B$) due mainly to development of strong emission lines. This is the general course of nova outbursts in the color-color diagram, which is deduced from eight well-observed novae including various speed classes. For a nova with unknown extinction, we can determine a reliable value of the color excess by matching the observed track of the target nova with this general course. This is a new and convenient method for obtaining color excesses of classical novae. Using this method, we redetermined the color excesses of nineteen well-observed novae.

Keywords: cataclysmic variables - novae - individual: FH Ser, PU Vul, PW Vul, V1500 Cyg, V723 Cas.

1 Introduction

A classical nova is a thermonuclear runaway event on a mass-accreting white dwarf (WD) in a binary. Despite of their overall similarity, optical light curves of novae have a wide variety of timescales and shapes. Recently, Hachisu & Kato (2006) found that, in terms of free-free emission, the optical and infrared (IR) light curves of several novae follow a similar decline law. Moreover, the time-normalized light curves were found to be independent of the WD mass, chemical composition of ejecta, and wavelength. They called it the universal decline law. Evolution of colors is another challenging subject that attracts many researchers, who attempted to find a general behavior among various types of novae. For example, Duerbeck & Seitter (1979) discussed that color evolutions of six novae are remarkably similar in the intrinsic $(B-V)_0$ versus $(U-B)_0$ color-color diagram independently of their different nova speed classes. van den Bergh & Younger (1987) derived general trends of color evolutions in nova light curves, i.e., $(B-V)_0 = 0.23 \pm 0.06$ at optical maximum and $(B-V)_0 = -0.02 \pm 0.04$ at t_2, where t_m ($m = 2$ or 3) is the days during which a nova decays by m-th magnitude from its optical maximum and $(B-V)_0$ is the intrinsic $B-V$ color of the nova. These two relations, however, often show large deviations from the values obtained by other methods. Miroshnichenko (1988) found a stabilization stage of novae in the $B-V$ and $U-B$ color evolutions soon after optical maximum and that this stage showed a general trend of $(B-V)_0 = -0.11 \pm 0.02$. He derived extinctions, $E(B-V)$, of 23 novae assuming that all novae have the same intrinsic $(B-V)_0$ color at the stabilization stage, i.e., $E(B-V) = (B-V)_{\rm ss} - (B-V)_0 = (B-V)_{\rm ss} + 0.11$, where $(B-V)_{\rm ss}$ is the observed $B-V$ color at the stabilization stage. This method looks powerful but sometimes results in a large difference from the true value.

According to Hachisu & Kato's (2006) universal decline law, optical fluxes in the UBV bands could be dominated by free-free emission. If it is the case, its color is simply estimated to be $(B-V)_0 = 0.13$ and $(U-B)_0 = -0.82$ for the optically thin free-free emission ($F_\nu \propto \nu^0$), or to be $(B-V)_0 = -0.03$ and $(U-B)_0 = -0.97$ for the optically thick free-free emission ($F_\nu \propto \nu^{2/3}$, see, e.g., Wright & Barlow 1975), where F_ν is the flux at the frequency ν. The latter value of $(B-V)_0 = -0.03$ is close to $(B-V)_0 = -0.02 \pm 0.04$

at t_2 derived by van den Bergh & Younger (1987). However, many novae do not keep these pivot points but further evolves blueward.

These different trends of nova color evolutions may represent different sides of the true color evolution which we do not yet fully understand observationally or theoretically. The aim of this presentation is to find a general path of nova color evolutions as Duerbeck & Seitter (1979) tried to find about thirty years ago. First we examine the color evolutions of slow and fast novae, FH Ser, PW Vul, V1500 Cyg, V1668 Cyg, V1974 Cyg, PU Vul, HR Del, and V723 Cas. We found that the tracks of color-color evolutions of these slow/fast novae are common. Then we redetermined the reddening of nineteen novae by fitting the color evolution of a target nova with the common path in the color-color diagram. Thus, we propose a new method for estimating the color excess.

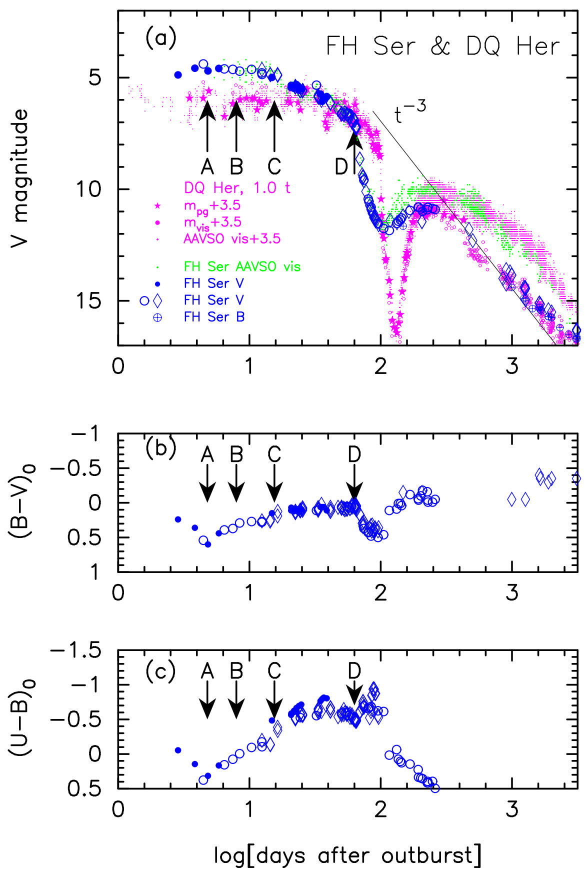

Figure 1: Light and color curves of FH Ser

2 Nova-giant Sequence in the Color-color Diagram

The first example of our analysis is the moderately fast nova FH Ser. The V, $(B-V)_0$, and $(U-B)_0$ light curves of FH Ser are plotted in Figure 1. FH Ser showed a gradual optical decay with $t_2 = 41$ and $t_3 = 62$ days followed by a sudden drop of the brightness due to dust shell formation about 2.8 mag below the optical maximum. The $(B-V)_0$ vs. $(U-B)_0$ color-color evolution is plotted in Figure 2 (see Hachisu & Kato 2014 for more detail). The reddening toward FH Ser was obtained by Kodaira (1970) to be $E(B-V) = 0.6$ from the MMRD relation and interstellar reddening relation. Della Valle et al. (1997) obtained $E(B-V) = 0.82$ from the color at optical maximum, i.e., $E(B-V) = (B-V)_{\rm max} - (B-V)_{0,\rm max} = 1.05 - 0.23 = 0.82$, $E(B-V) = 0.61$ from the line ratio of $\mathrm{H}\alpha/\mathrm{H}\beta = 5.7$, and $E(B-V) = 0.5$ from the equivalent width of Na I $\lambda5890$. Then, della Valle et al. (1997) adopted an averaged value of $E(B-V) = 0.64 \pm 0.16$. Since Kodaira's $E(B-V) = 0.60$ and della Valle et al.'s $E(B-V) = 0.61$ from the line ratio of $\mathrm{H}\alpha/\mathrm{H}\beta$ are coincident with each other, we use $E(B-V) = 0.60$ in the present paper and confirm below that this value is reasonable.

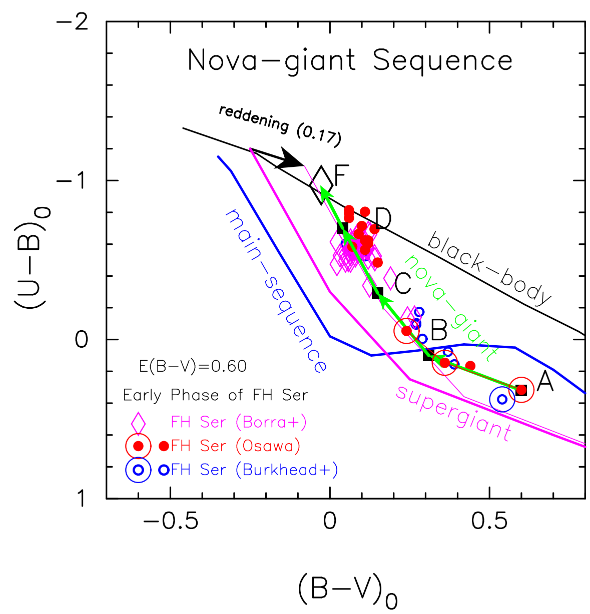

Figure 2: Color-color evolution of FH Ser

In Figure 2 we plot only the data before the dust blackout started about 70 days after the outburst. We also depict three known sequences, the blackbody, supergiant, and main-sequence sequence, the data of which are taken from Allen (1976). We also added a point, i.e., optically thick free-free emission spectra (open diamond denoted by F) of $F_\nu \propto \nu^{2/3}$. We have frequently seen in literature such a statement that nova spectra near maximum are similar to those of A–F type supergiants. However, the track of FH Ser in the color-color diagram does not follow the supergiant sequence as clearly shown in Figure 2. The shape of FH Ser track is very similar to that of the supergiant sequence but it locates about $\Delta(U-B) \approx -0.2$ mag bluer than the supergiant sequence. Therefore, we are forced to define a new sequence based on the data of FH Ser, which is designated by points A, B, C, D, and F from redder to bluer. These points correspond to epochs in Figure 1. In what follows, we will see that many novae evolve along this sequence when their photospheric spectra are similar to those of A–F type supergiants. Therefore, we call this track "the nova-giant sequence" after the supergiant sequence.

3 Common Paths of Novae in the Color-color Diagram

We have also studied color-color evolutions of the fast and slow novae, PW Vul, V1500 Cyg, V1668 Cyg, V1974 Cyg, PU Vul, HR Del, and V723 Cas, in the $(B-V)_0$ - $(U-B)_0$ diagram and showed that these well observed novae follow very similar evolutionary courses in the intrinsic color-color diagram as shown in Figure 3. We finally specified four templates, (1) the moderately fast nova FH Ser, a proto-type of the nova-giant sequence, (2) the slow nova PW Vul and the very fast nova V1500 Cyg, (3) the fast novae V1668 Cyg and V1974 Cyg, and (4) the symbiotic nova PU Vul, the very slow novae V723 Cas and HR Del. The tracks are characterized with several specified points (A, B, C, D, F, 0, 1, ..., 5, 4', 5', 4", and 5"). Figure 4(a) shows templates of these eight well observed novae.

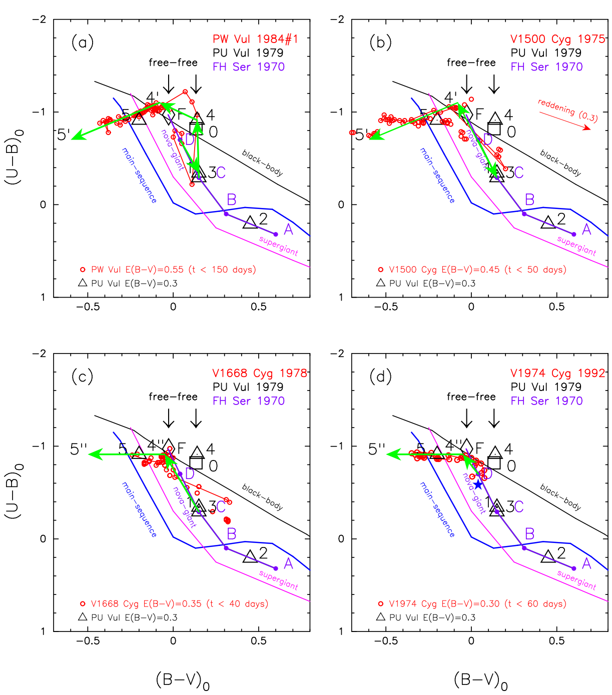

Figure 3: Several typical tracks of novae in the color-color diagram

Since these well observed eight novae follow the templates in Figure 4(a), we expect other novae also follow the same paths. In other words, if all novae follow this template, we are able to determine the color excess of a target nova by directly comparing its track in the color-color diagram with our general track in Figure 4(a).

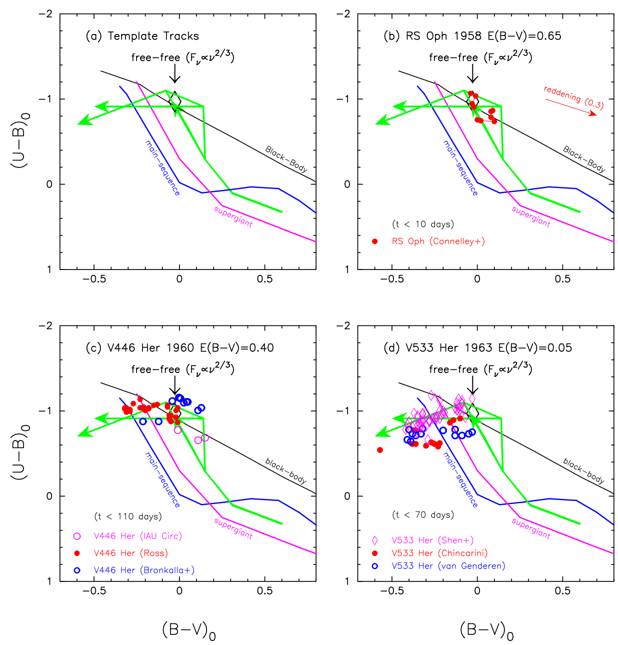

Figure 4: Color-color evolution of (a) template 8 novae, (b) RS Oph, (c) V446 Her, and (d) V533 Her.

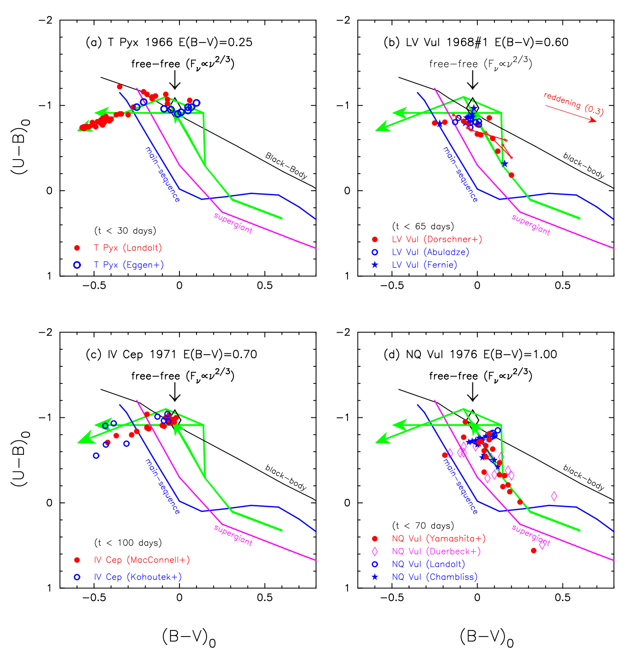

Figure 5: (a) T Pyx, (b) LV Vul, (c) IV Cep, and (d) NQ Vul.

4 Estimates of Extinctions toward Various Novae

We are able to determine color excesses of various novae using our general color-evolution tracks found in this work. We collected novae as many as possible from literature that have sufficient data points (usually more than ten). We assume that all novae follow the color-color evolution tracks in Figure 4(a). In order to obtain $E(B-V)$, we change $E(B-V)$ by steps of 0.05 to fit the observed track of a target nova with our general tracks in Figure 4(a).

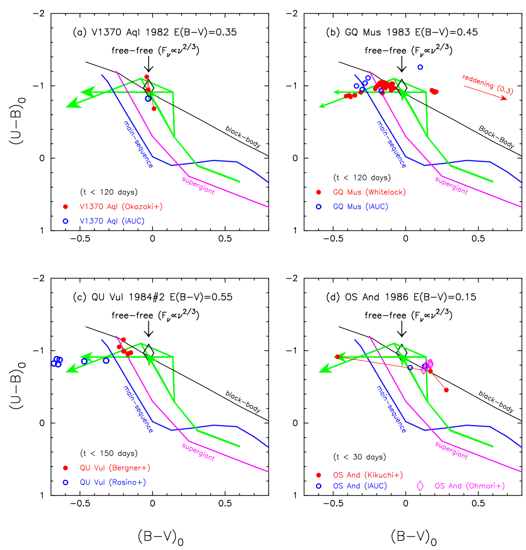

Figure 6: (a) V1370 Aql, (b) GQ Mus, (c) QU Vul, and (d) OS And.

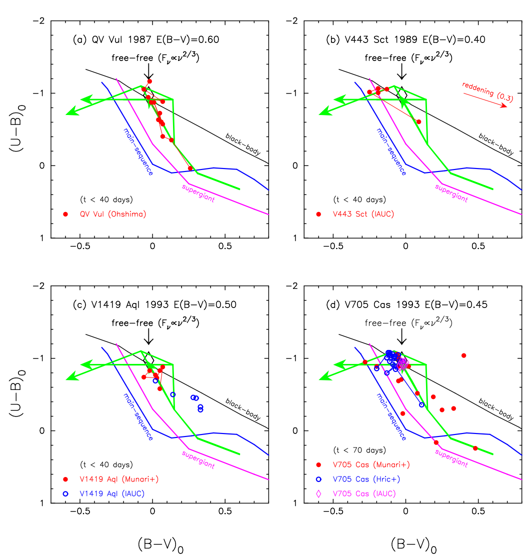

Figure 7: (a) QV Vul, (b) V443 Sct, (c) V1419 Aql, and (d) V705 Cas.

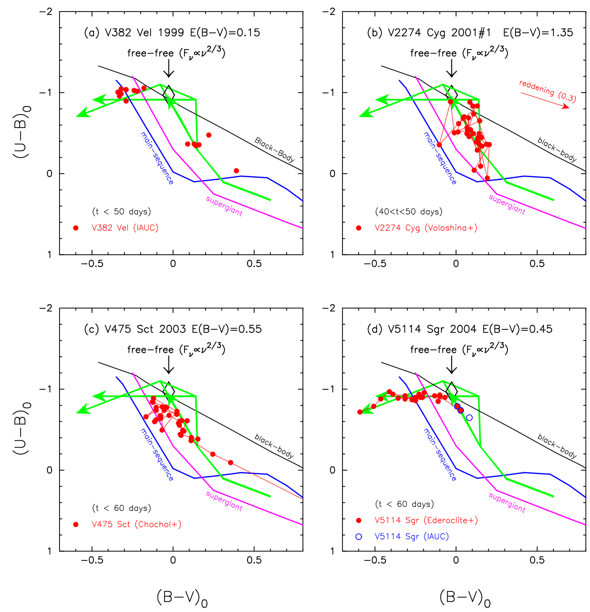

Figure 8: (a) V382 Vel, (b) V2274 Cyg, (c) V475 Sct, and (d) V5114 Sgr.

Figures 4, 5, 6, 7, and 8 show results of our analysis for 19 novae. Corresponding $E(B-V)$ excess is denoted in each panel (see Hachisu & Kato 2014, in detail).

References

[1] Allen, C. W. 1976, Astrophysical Quantities (3rd ed.; London: Athlone)

[2] della Valle, M., Gilmozzi, R., Bianchini, A., & Esenoglu, H. 1997, A&Ap, 325, 1151

[3] Duerbeck, H. W., & Seitter, W. C. 1979, A&Ap, 75, 297

[4] Hachisu, I., & Kato, M. 2006, ApJS, 167, 59 doi:10.1086/508063

[5] Hachisu, I., & Kato, M. 2014, ApJ, 785, 97 doi:10.1088/0004-637X/785/2/97

[6] Kodaira, K. 1970, PASJ, 22, 447

[7] Miroshnichenko, A. S. 1988, Soviet Astronomy, 32, 298

[8] van den Bergh, S., & Younger, P. F. 1987, A&Ap Suppl., 70, 125

[9] Wright, A. E., & Barlow, M. J. 1975, MNRAS, 70, 41 doi:10.1093/mnras/170.1.41