Novae and Helium Novae As Bright EUV Sources

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I present theoretical light curves of novae and helium novae in EUV and visible bands derived from optically thick wind theory. The EUV light curves are very useful in determining the white dwarf mass and the distance to the star. Helium novae are bright EUV sources but much less luminous in the optical. Identification of helium novae will be observational evidence for the growth of the white dwarf, which will eventually become a Type Ia supernova. A semi-detached system may be a new progenitor model of Type Ia supernovae, which is a very bright EUV source with a faint optical counterpart.

1. Classical Nova

Novae are a thermonuclear runaway event on a white dwarf of a close binary system. A hydrogen shell flash on the white dwarf causes an outburst in which the star quickly brightens up and the hydrogen-rich envelope greatly extends. Most of the envelope is eventually blown off. In the H-R diagram, the star moves from the lower left part (accreting white dwarf) to the upper right (red giant region), undergoing strong mass loss. After the optical luminosity peak, the star moves blueward on the horizontal track with constant bolometric luminosity.

The evolutional track of the decay phase of classical novae is shown in Figure 1 (for more details see Kato & Hachisu 1994). The timescale of such a decay phase of classical novae is summarized in Table 1. The optically thick wind mass loss (the dashed part) lasts until the effective temperature exceeds $2-3\times10^5$ K. After that the star continuously moves leftward until it reaches the turning point where the hydrogen burning extinguishes around the point of maximum effective temperature in Figure 1. As the EUV and soft X-ray luminosity quickly drop around this point, the total duration in Table 1 gives the turn off time of EUV and soft X-ray after the optical maximum. Then the star returns to the pre-outburst magnitude.

Soft X-ray emission from GQ Mus has been observed to drop in 1993. Its turn off time of 9 yrs indicates the white dwarf mass of 0.68 $M_\odot$ from this table. This value is consistent with the value 0.5–0.6 $M_\odot$ obtained by the light curve analysis (Kato 1995b).

Theoretical light curves are calculated using the optically thick wind theory (Kato 1983; Kato & Hachisu 1994) which is so far the only method in reproducing nova light curves. Figure 2 shows the light curve fitting for classical nova V1668 Cyg (Nova Cyg 1978). Theoretical light curves of massive white dwarfs show a rapid evolution because of the small envelope mass. Both the optical and UV data show a good agreement with the model of a 1.0 $M_\odot$ white dwarf. The distance to the star can also be estimated from the comparison between observed apparent magnitude and the theoretical absolute magnitude and turns out to be 2.9 kpc (UV) and 3 kpc (optical). The theoretical expansion velocity at the photosphere is also consistent with *IUE* data. Details are published by Kato (1994) and Kato & Hachisu (1994).

The thick, solid curve starts at t = 780 days and is the EUV light curve (100–912 Å)

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TABLE 1. X-ray turn-off time of classical novae

$M_{\rm WD}$ ($M_\odot$)	t (wind) (yr)	t (static) (yr)	t (total) (yr)
1.33	0.11	0.038	0.148
1.2	0.26	0.15	0.41
1.1	0.39	0.34	0.73
1.0	0.61	0.74	1.35
0.9	0.87	1.4	2.27
0.8	1.4	2.7	4.1
0.7	2.4	5.3	7.7
0.6	4.0	8.9	12.9
0.5	7.4	16.8	24.2

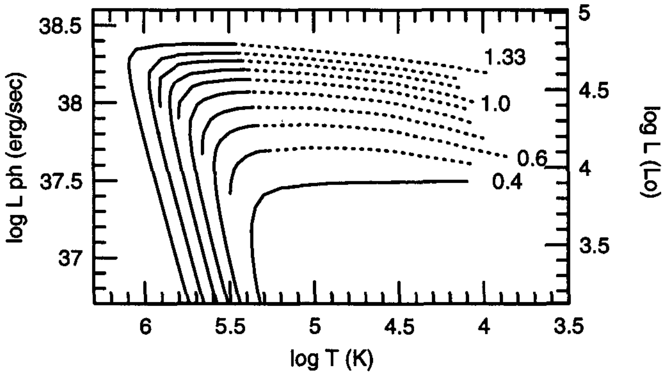

FIGURE 1. The evolutionary tracks of the decay phase of classical novae are plotted in the theoretical H-R diagram. Each curve corresponds to different white dwarf mass, i.e., 1.33 $M_\odot$, 1.2 $M_\odot$, 1.1$M_\odot$, 1.0 $M_\odot$, 0.9 $M_\odot$, 0.8 $M_\odot$, 0.7 $M_\odot$, 0.6 $M_\odot$, 0.5 $M_\odot$, and 0.4 $M_\odot$. Dashed part of the curve denotes the wind phase.

expected for 1.0 $M_\odot$ white dwarf model. This curve shows that the classical nova is a bright EUV source and becomes bright after the optical magnitude begins to decrease. This is because the effective temperature increases with time, and the wavelength at the spectral maximum shifts from the optical to the UV and EUV region. As the EUV curve has a different shape from the others, observational data will be useful in determining the white dwarf mass and the distance to the star with high accuracy.

2. Recurrent Novae

A recurrent nova is also a thermonuclear runaway event on a massive white dwarf. It brightens within a few days and fades in the optical with a short decline time of 10 days to several months. The outburst repeats every few decades. No heavy element enhancement has been reported.

The example of light curve fitting of recurrent novae, U Sco, is shown in Figure 3. The best fit curves for U Sco are the models of mass $M_{\rm WD} \sim 1.38\ M_\odot$ with heavy element abundance $0.01 < Z < 0.03$ as shown in this figure. Very similar results are also obtained

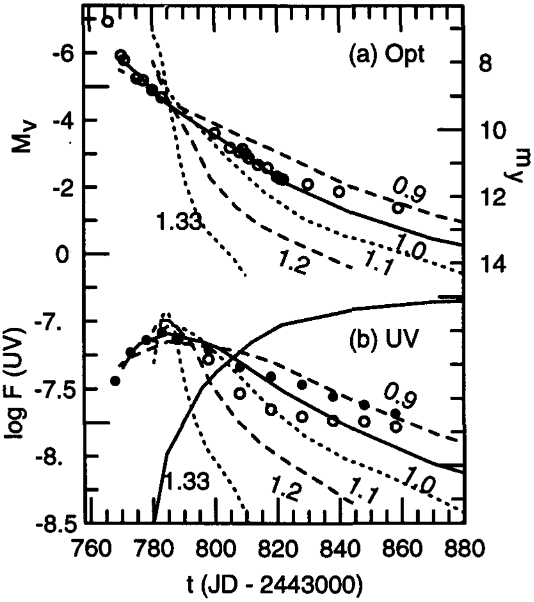

FIGURE 2. Theoretical and observational light curves for the decay phase of classical novae. Theoretical ones are denoted by lines. White dwarf mass is attached to each curve. (a) Optical light curves. The left ordinate shows the absolute visual magnitude for the theoretical curves. Observational data of Nova Cygni 1978 (Gallagher et al. 1980) are shown by open circles. Its apparent y-magnitude is written on the right ordinate. (b) UV light curves. Open circles denote the UV flux (1140–3290 Å) and filled circles do the summation of the UV and IR fluxes (> 12000 Å) in the unit of erg cm^{-2} s^{-1} (Stickland et al. 1981). Theoretical UV flux, $F = L_{\mathrm{UV}}/4\pi D^2$, is also shown by lines, where D is the distance to the star and assumed to be 2.88 kpc. The solid curve rising at $t = 780$ days is the EUV light curve (100–912 Å) for 1.0 $M_\odot$ model.

in V394 CrA and T CrB, and $1.35 \leq M_{\mathrm{WD}} \leq 1.38\ M_\odot$ with $0.004 < Z < 0.02$ for V745 Sco (Kato 1995b). These white dwarf masses are near the Chandrasekhar limit and very close to the critical mass, i.e., 1.38 $M_\odot$, for accreting hot white dwarfs to become a Type Ia supernova or a neutron star triggered by accretion-induced collapse.

As recurrent novae decline almost linearly, fitting of the theoretical light curves have an ambiguity. Multiwavelength observations, such as EUV or FUV, are very helpful for accurate fitting of light curves to estimate the parameters such as the distance to the star.

3. He Nova—As an Evidence of Mass-Growing WD

When a part of the accreted matter remains after the hydrogen shell flash, the white dwarf develops a helium layer under the hydrogen burning zone. This helium layer will grow in each hydrogen shell flash. When the mass of the helium layer reaches a critical value, an unstable helium burning triggers a nova-like phenomenon.

Figure 4 shows light curves of helium flashes. This light curve is similar to that of a typical nova, but the development is very slow. The optical magnitude drops in the

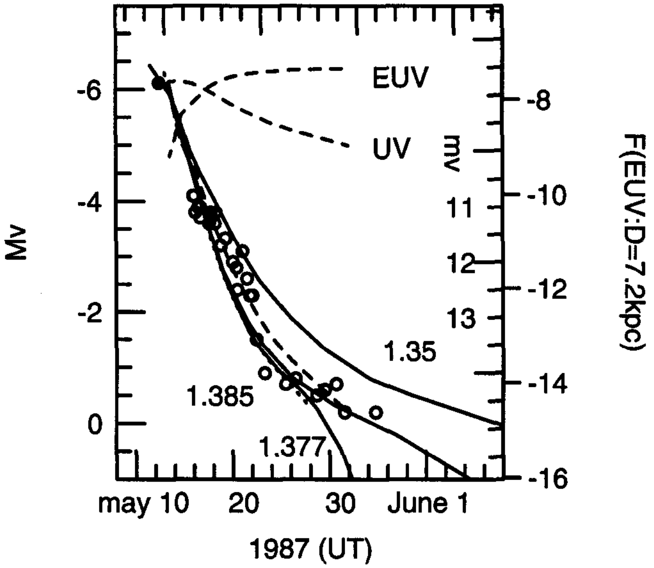

FIGURE 3. Light curve fittings of recurrent nova U Sco in 1987 outburst. Observational optical data are taken from Sekiguchi et al. (1988). These data are well fitted by theoretical models denoted by thick curves, i.e., 1.377 $M_\odot$ white dwarf with chemical comosition (X,Z) = (0.1, 0.01), (0.7, 0.02), (0.1, 0.02) and 1.385 $M_\odot$ with (0.1, 0.01). Dashed curves in the upper part of this figure denote theoretical light curves in EUV (100 – 912 Å) and UV (1200 – 2000 Å) bands of the best fitted model 1.377 $M_\odot$ with (0.1, 0.01).

later phase, but magnitudes of short wavelength are still large. In this phase, the helium nova will be observed as a very bright EUV source with a faint optical counterpart. The chemical composition of the star is highly hydrogen-deficient. Identification of such an object is very important, because it would connect recurrent novae to Type Ia supernovae (Kato 1995a), i.e., it will be the first observational evidence of mass-increasing white dwarfs which will eventually become Type Ia supernovae.

4. A New Model of Type Ia Supernovae

Hachisu & Kato (1995) proposed a new scenario of Type Ia supernovae. They considered a binary initially consisting of a white dwarf and a main-sequence star. When the secondary (main-sequence star) evolves toward the red-giant and fills its Roche lobe, mass transfer from the secondary begins. The mass transfer rate is high enough to cause a stable H burning at the WD surface. The optically-thick wind occurs at the surface of the WD envelope which takes the angular momentum, as well as mass, away from the binary. They followed the binary evolution for various sets of the binary parameters and found that binaries of initial mass ratio $q < 1.15$ experience stable mass transfer from the companion to the white dwarf, which can become a Type Ia supernova. This scenario predicts a progenitor of binaries consisting of an accreting hot white dwarf with an optically thick wind and a dwarf/semi-dwarf companion. Therefore, this progenitor

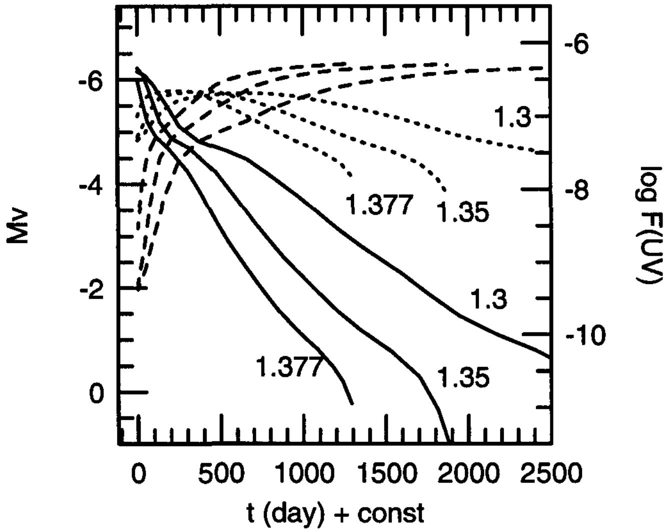

FIGURE 4. Optical, UV, and EUV light curves for He nova: dashed line is EUV (100 – 912 Å); solid line is optical; dotted line is FUV (912 – 2000 Å).

can be observed as a very bright EUV source whereas it is very faint in the optical band because its effective temperature is as high as $\log T \sim 5.2$. Observational identification is needed to examine this scenario.

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