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Studying symbiotic stars and classical nova outbursts with small telescopes

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Abstract. Symbiotic stars are the widest interacting binaries, whose orbital periods are of the order of years, or even more, while cataclysmic variables are interacting binaries with periods of a few hours. Both systems comprise a white dwarf as the accretor, and undergo unpredictable outbursts. Using the multi-colour photometry and optical spectroscopy obtained with small telescopes, I present examples of the white dwarf outburst in a cataclysmic variable, the classical nova V339 Del, and that in the symbiotic star AG Peg. In this way I highlight importance of observations of bright outbursts using small telescopes.
Key words: stars: binaries: symbiotic – novae, cataclysmic variables – individual: V339 Del, AG Peg

1. Introduction

Symbiotic stars (SSs) and cataclysmic variables (CVs) are interacting binary systems, in which the accretor is a white dwarf (WD). In the former the donor is a red giant, while in the latter an evolved main sequence star. Orbital periods are extremely different, being typically of the order of years for SSs, but only of a few hours for CVs. The red giant in SSs underfills its Roche lobe with a factor of ~ 0.5 (e.g. Mürset & Schmid, 1999), whereas the evolved dwarf donor in CVs fills its Roche lobe. As a result, the WD in SSs accretes from the wind of the giant, while in CVs the accretion runs via the Roche-lobe overflow. A review of CVs can be found in the monograph of Warner (1995) and that on SSs in Kenyon (1986).

A common feature of these types of interacting binaries are their unpredictable outbursts observed on a very different and variable time-scale. The so-called classical nova (CN) outbursts of CVs are characterized by a large brightness amplitude of ~7–15 mag, whereas the so-called Z And-type outbursts of SSs are as low as $\sim 1 - 3$ mag in the optical. CN outbursts are caused by the explosive thermonuclear fusion of hydrogen to helium on the WD surface, when the pressure at the base of the accreted matter exerts the critical value (e.g. Bode & Evans, 2008, for a review). In most cases the CN events result from accretion onto the WD at rates of $\sim 10^{-11} - 10^{-8}\,M_\odot\,\mathrm{yr}^{-1}$, which gives the recurrence time of their explosions usually much longer than the human life (Yaron et al., 2005). The energy output from the accreting WD in SSs can be generated by two different mechanisms. The observed hot component luminosity of $\sim 10^0 - 10^2\,L_\odot$ can be powered solely by the accretion process onto a WD (e.g. EG And, 4 Dra, SU Lyn, see Skopal, 2005a; Mukai et al., 2016), while in other cases, luminosities of a few times $10^3\,L_\odot$ (e.g. Muerset et al., 1991; Skopal, 2005b) are believed to be caused by stable hydrogen nuclear burning on the WD surface (e.g. Paczynski & Rudak, 1980). The latter requires accretion onto a low mass WD at $\sim 10^{-8} - 10^{-7}\,M_\odot\,\mathrm{yr}^{-1}$ (e.g. Shen & Bildsten, 2007).

The nature of outbursts of accreting WDs in SSs is not yet unambiguously established. The low luminosity *accretion powered* WDs could increase their energy output due to transient accretion phenomena connected with a disk instability, as in dwarf novae. Here an example can be a ∼1 mag brightening of Z And in 1997 (see Sokoloski et al., 2006) and/or the erratic activity of the symbiotic star CH Cyg (e.g. Mikolajewska et al., 1988). For the luminous *nuclearly powered* WDs in SSs, the event of outburst can result from an increase in the accretion rate above the level sustaining the stable burning, which leads to blowing optically thick wind from the WD (Hachisu et al., 1996) and the luminosity can increase to the Eddington limit. The wind converts a fraction of the hot WD's radiation to the optical in the form of nebular emission, which causes a brightening in the light curve we indicate as the outburst. In this way, Skopal et al. (2017) explained the recent 2015 outburst of AG Peg.

In this contribution I present examples of the accreting WD outburst in a CV, the classical nova V339 Del (Nova Del 2013), and that in the symbiotic binary AG Peg. This work is based on the optical multicolour photometry and spectroscopy obtained solely with small telescopes collected mostly by amateur astronomers. In this way I demonstrate how such the observations carried out with a high cadence can contribute to worthy science.

2. Observations

2.1. Classical nova V339 Del

Classical nova V339 Del (Nova Delphini 2013) was discovered by Koichi Itagaki on 2013 August 14.584 UT at a visual magnitude of ∼6.8 (Nakano et al., 2013). On Aug. 16.45 UT, after ∼1.85 days of its discovery, the nova peaked at $V \sim 4.43$ (Munari et al., 2013), and became to be an attractive target also for amateur astronomers that resulted in obtaining high-cadence photometric and spectroscopic observations in the optical. Figure 1 shows the AAVSO International Database[1] photometric observations in the B and I_C passbands. Optical spectroscopy for the purpose of this contribution was taken from the *Astronomical Ring for Access to Spectroscopy (ARAS)* database.[2] Here, the spectrum obtained by J. Guarro at the Santa Maria de Montmagastrell Observatory on

[1] https://www.aavso.org/data-download
[2] http://www.astrosurf.com/aras/Aras_DataBase/Novae/Nova-Del-2013.htm

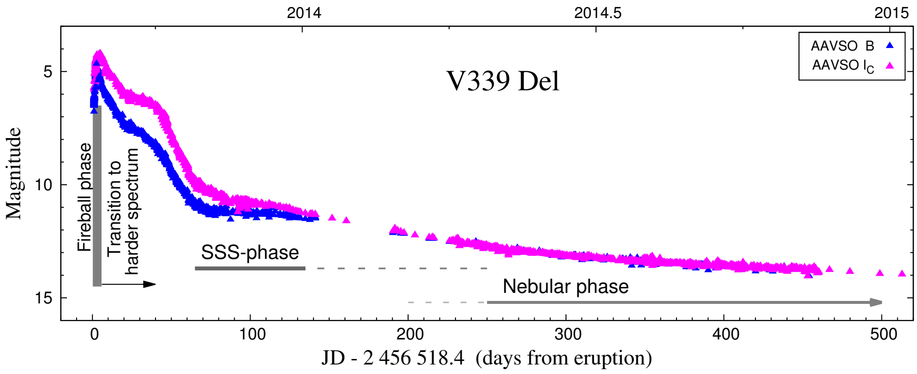

Figure 1. The B and $I_{\rm C}$ light curves of the nova V339 Del from its explosion (day 0) to day 520 of its life as collected in the AAVSO International Database. Basic phases of the nova evolution are designated by thick gray lines.

August 15.99, 2013, and that secured by M. Fujii at the Fujii Kurosaki Observatory with a 0.4 m telescope on September 13, 2013, were used. The spectra were described in detail by Skopal et al. (2014).

2.2. Symbiotic star AG Peg

AG Peg is a symbiotic binary comprising an M3 III giant (Mürset & Schmid, 1999) and a WD on an 818-d orbit (e.g. Fekel et al., 2000). It erupted around 1850, and rose in brightness from ~ 9 to ~ 6 mag around 1885 (Lundmark, 1921). Afterwards, AG Peg followed a gradual decline to around 2000. Such the evolution represents the slowest nova outburst ever recorded (Kenyon et al., 1993). From around 1997 to June 2015, AG Peg kept its brightness at a constant level, showing just pronounced wave-like orbitally-related variations (see Fig. 2). During June 2015, AG Peg experienced a new outburst (Waagen, 2015). The new outburst was monitored both photometrically and spectroscopically with a high cadence and also in the X-ray domain by the *Swift* satellite. It was found that the 2015 outburst was of the Z And-type (Ramsay et al., 2016; Tomov et al., 2016), during which the enhanced wind from the burning WD converted a fraction of its radiation to the nebular emission causing the observed 2 mag brightening in the light curve (Skopal et al., 2017).

Optical spectroscopy presented in this contribution was performed by K. Graham at his private station using a 0.25 m telescope on October 27, 2013, by U. Sollecchia at the private station in L′Aquila with a 0.20 m telescope on June 26, 2015 and by D. Boyd at the West Challow Observatory using a 0.28 m telescope. Spectra are available at the ARAS database and were described by Skopal et al. (2017).

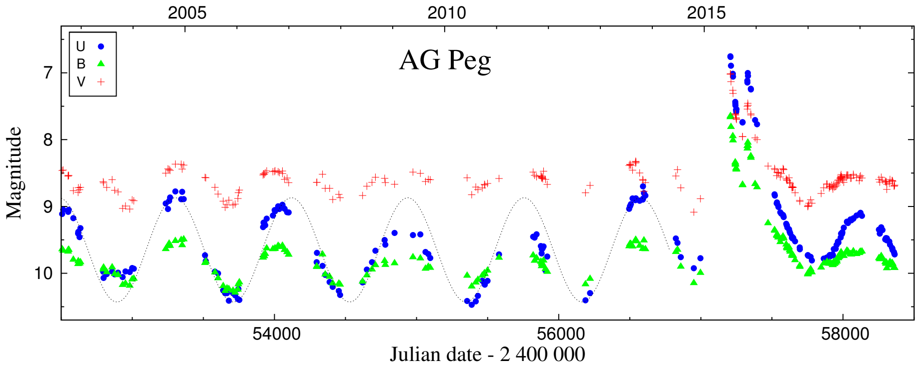

Figure 2. UBV light curves of AG Peg from 2003 to the present. During the quiescent phase the wave-like variation along the orbit is observed (the sine wave with the period of 818 days). Between June 2015 and June 2016, AG Peg showed a new outburst of the Z And-type. Data are from Skopal et al. (2012) and Sekeráš et al. (2019).

3. Analysis and results

During the nuclearly powered outbursts of WDs in CVs and/or SSs, the ejected material reprocesses the inner radiation, originally produced by the nuclear fusion on the WD surface. Because the geometrical and optical properties of the ejecta vary with time, the observed spectrum will be a function of the outburst stage. Generally, at the Earth we can observe the radiation from the WD photosphere, $\theta^2_{\rm WD}\pi B_\lambda(T_{\rm BB})$, whose fraction can be converted to the nebular continuum, $k_{\rm N} \times \varepsilon_\lambda(T_{\rm e})$. In the case of a symbiotic star, an additional component is emitted by the cool giant, which is compared with an appropriate synthetic spectrum, $\mathcal{F}_\lambda(T_{\rm eff})$. As a result, the observed continuum can be expressed as

$$F(\lambda) = \theta^2_{\rm WD}\pi B_\lambda(T_{\rm BB}) + k_{\rm N} \times \varepsilon_\lambda(T_{\rm e}) + \mathcal{F}_\lambda(T_{\rm eff}), \tag{1}$$

where $\theta_{\rm WD} = R_{\rm WD}/d$ is the angular radius of the WD photosphere for the distance d. Fitting parameters are $\theta_{\rm WD}$, the blackbody temperature of the hot WD photosphere, $T_{\rm BB}$, the observed emission measure, $k_{\rm N}$, the electron temperature of the nebula, $T_{\rm e}$, and the effective temperature of the cool giant, $T_{\rm eff}$. The volume emission coefficient, $\varepsilon_\lambda(T_{\rm e})$, includes f–f and f–b transitions in the hydrogen plasma. A detailed description of modelling the composite spectrum (1) is given by Skopal (2005b).

3.1. Models SED of V339 Del

During the early stage of the nova evolution, called the 'fireball stage', the expanding shell redistributes the major part of the inner energetic photons into

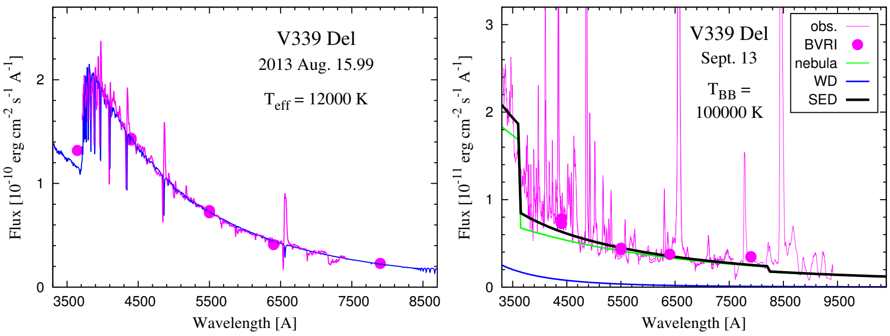

Figure 3. Observed (in magenta: spectrum and photometric flux-points) and models SED of V339 Del during the fireball stage (left) and the transition to harder spectrum (right). Observations were dereddened with $E_{\rm B-V} = 0.18$ mag (see Skopal et al., 2014).

the optical. The observed spectrum resembles that produced by a star of spectral type A to F. Accordingly, the spectrum of the nova can be compared with an atmospheric model, i.e., the first term in Eq. (1) is replaced by $\theta^2_{\rm WD}\,\mathcal{F}_\lambda(T_{\rm eff})$ and the nebular contribution can be neglected. The left panel of Fig. 3 shows the observed spectrum from the optical maximum compared with the atmospheric model calculated for the effective temperature of the WD photosphere of 12 000 K. Corresponding scaling, $\theta_{\rm WD} \sim 8.3 \times 10^{-10}$, gives the luminosity of $\sim 2.0 \times 10^{39} (d/4.5\,{\rm kpc})^2\,{\rm erg\,s^{-1}}$.

During the transition to harder spectrum, the ejecta dilutes on the line of sight, the WD photosphere becomes hotter, shifts its maximum to shorter wavelengths and ionizes the outer material giving rise to the nebular emission. Therefore, to model the observed continuum we use the first two terms on the right-hand side of Eq. (1). The right panel of Fig. 3 shows an example of the optical spectrum and its model SED. The nebular continuum radiates at $T_{\rm e} \sim 40\,000$ K and strongly dominates the optical with a large emission measure of $\sim 3.0 \times 10^{62} (d/4.5\,{\rm kpc})^2\,{\rm cm^{-3}}$. However, a small contribution of the hot WD photosphere in the optical does not allow to determine its $T_{\rm BB}$.

3.2. Models SED of AG Peg

In the optical, the contribution from the hot WD in AG Peg (i.e., the first term on the right-hand side of Eq. (1)) is negligible with respect to those from the nebula and the cool giant. Therefore, the method is able to disentangle only these dominant contributions, i.e., to determine variables $k_{\rm N}$, $T_{\rm e}$ and the giant's spectral type. Fig. 4 shows examples of the optical spectrum from the quiescent phase and that from the very beginning of the 2015 outburst with their models SED. The nebular continuum dominated the optical immediately at the start of the outburst. A factor of ~12 increase of the emission measure, from ~0.75

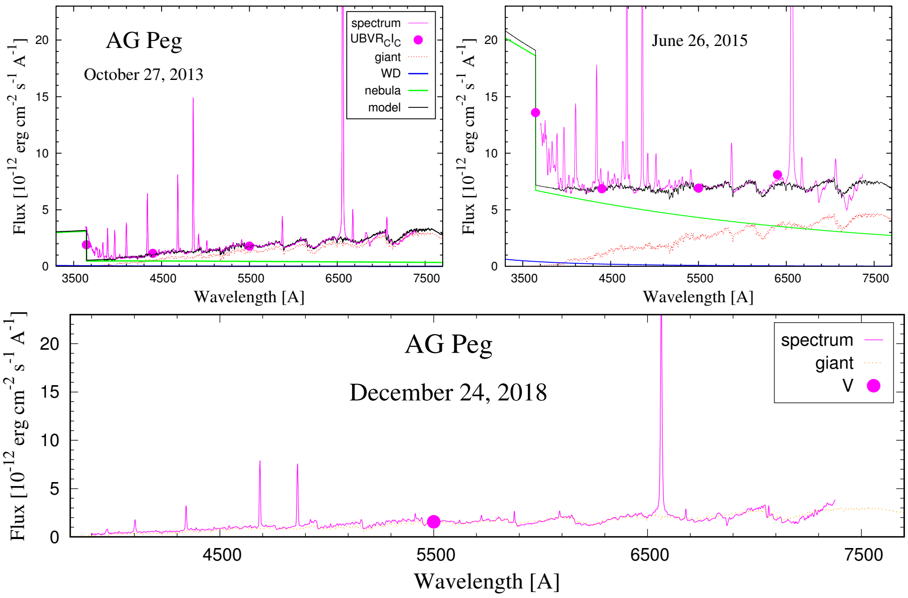

Figure 4. Examples of the AG Peg spectra (magenta) and their models SED (black) from the quiescence (left), the 2015 outburst (right) and 2018 quiescence (bottom). Observations were dereddened with $E_{\mathrm{B-V}} = 0.1$ mag (see Skopal et al., 2017).

to $\sim 9 \times 10^{60}\,(d/0.8\,\mathrm{kpc})^2\,\mathrm{cm}^{-3}$ at these dates corresponds to the observed brightening by ~2.7 mag (see Skopal et al., 2017, in detail).

4. Conclusion

In this contribution, using examples of the classical nova V339 Del (Nova Delphini 2013) and the symbiotic binary AG Peg, it was shown that bright explosions of accreting WDs in SSs and CVs represent very suitable targets for the science with small telescopes. The following points are relevant.

- An unpredictable sudden change in the brightness of these types of objects is exclusively discovered by photometric monitoring. A discovery of outbursts provides an alert for observation with other facilities (Sect. 2.2).
- Multicolour photometric measurements, when corrected for emission lines, define the continuum flux-points, which allow us to calibrate the spectra that are usually obtained in arbitrary units (Skopal, 2007, Figs. 3 and 4 here).
- High cadence of both photometric and spectroscopic observations as provided by AAVSO and ARAS databases allows a detailed mapping of usually fast events of outbursts (e.g., Fig. 9 of Skopal et al., 2017).

– Disentangling the composite spectra into its individual components of radiation allow us to determine the corresponding physical parameters (Sect. 3).

– Observations with small optical telescopes are useful to complement measurements in other wavelengths.

Accordingly, it is possible to conclude that photometric and spectroscopic observations of bright transients with small telescopes can contribute to worthy science.

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