Publ. Astron. Obs. Belgrade No. 107 (2025), 13 - 20 *Invited Lecture*
http://doi.org/10.69646/14sbac02p

ARE THE DWARF NOVAE OUTBURSTS ABSENT IN VY SCL-TYPE STARS LOW STATES?

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Abstract. Low states light curves of VY Scl type systems show rises with amplitudes 35 mag. Despite the accepted belief that this type of star does not exhibit outbursts similar to the dwarf novae (DNe) one, their amplitudes, shapes and periods are similar to DNe with the same orbital periods. MV Lyr, TT Ari and KR Aur show periodicities in the range 200-400 d, but second maximum in power spectra also occurs around 850-1000 d.

The estimation of the change of mass loss via coronal mass ejections during the solar activity cycle can vary more than 5 times. The red dwarfs magnetic cycles with duration of years can explain the reduced mass transfer and long deep states in VY Scl variables.

1. INTRODUCTION

Cataclysmic variables (CVs) are evolved semi-contact close binary systems containing usually white dwarf and a donor of mass – a red dwarf. In rare cases, the donor may be a slightly evolved main sequence (MS) star, giant, or other white dwarf. Depending on the strength of the magnetic field of the white dwarf, systems can be magnetic or non-magnetic and the accreting matter falls through L1 via an accretion disk or accretion columns onto the primary star. According to the light curves, they are divided into different types and subtypes – novae (Ne), recurrent novae (RNe), dwarf novae (DNe) and novae-like (NLs) stars.

DNe are stars that show periodic bursts with an amplitude of 2–6 magnitudes at intervals from days to several years due to thermal-viscous instability of the disk. NLs, in contrast, are stars with a high accretion rate and a hot stable bright disk. VY Scl type stars (or anti-dwarf novae) are their subclass, which due to reduction or cessation of the accretion rate from the secondary star fall into low states with an amplitude of 2–6 mag, lasting several months to years. These low states are perceived to be occasional. Low states are also observed in other types of CVs – AM Her type (polars – systems without disk), intermediate polars (IP), DNe. It is accepted that due to magnetic properties of the secondary star mass transfer $\dot{M}$ impedes or stops completely. These components are low mass, almost fully convective stars with powerful magnetic field and they could produce 10^3–10^4 mass loss rate more than Sun via stellar wind, flares and coronal mass ejections (CMEs) (Mullan, 1996).

A possible physical mechanism of the mass transfer decrease was given by Livio and Pringle (1994) – magnetic spots on the surface of the secondary near L1 can prevent Roche-lobe overflow. Bianchini (1990) proposed another explanation – solar-like cycles of the secondaries can cause radius variations $\Delta R/R \sim 10^{-4}$ and the shrink can reduce mass transfer $\dot{M}$ too. Other mechanisms like tidal instability, irradiation effects on the secondary star etc. can affect mass transfer in the binaries.

The typical $\dot{M}$ in NLs is $\sim 10^{-8}$–10^{-9} $M_\odot$/yr. In DNe $\dot{M}$ is smaller, $\sim 10^{-11}$ (up to 10^{-10}) $M_\odot$/yr. At low state of VY Scl type stars reduced mass transfer is estimated to be similar to the DNe ones and the theoretical calculations show that the mass in their disks is enough to start up and sustain dwarf nova eruptions. Although the low state brightness of stars shows rise and decline, it is assumed in the literature that such eruptions are not observed. Leach et al. (1999) and Hameury and Lasota (2002) assumed that the disc instability outbursts can be suppressed by hot white dwarf (T∼40 000 K) or by the magnetic field on the white dwarf with a strength comparable to the values in IPs.

In this study we compare some properties of the observed outbursts in low states in MV Lyr, TT Ari and KR Aur to the dwarf novae ones. The analogy with the solar activity at different phases of the Sun's magnetic cycle could explain the existence of low states in cataclysmic variables and the observed mass accretion rate drop values.

2. DATA AND DATA ANALYSIS

The study of low states is difficult because of the low brightness of the objects. Only in the last 20–30 years, with the development of observation techniques they become available for observation by many amateur organizations such as the AAVSO[1]. We used AAVSO light curves in visual and Johnson's V band for MV Lyr, TT Ari and KR Aur.

For data extracting, selecting and plotting we use the AAVSO multi-platform VStar (Benn, 2012). The periodogram analysis was performed by Date Compensated Discrete Fourier Transform (DC DFT) method implemented in VStar period analyser routine.

Data from SOHO/LASCO CDAW catalog[2] were used for the calculations of the occurrence rate and the mass lose due to the observed CMEs at different solar activity states in 1996 – 2020.

3. RESULTS

3. 1. OUTBURSTS DURING LONG LOW STATES IN VY SCL VARIABLES AND DWARF NOVAE ERUPTIONS

VY scl type stars in rare occasions show peculiar very long deep states up to ∼10 years. A few of them, e.g., MV Lyr, KR Aur and TT Ari, repeated several times such low states. Many authors noticed their erratic behavior with sudden drops and rises. For instance, Fig. 1 shows the long-term light curve of MV Lyr. Shugarov and Pavlenko (1998) revealed 3 types of outbursts in low state with amplitudes 1 to 4 mag and duration from few days to 200 days and always the brightness was fainter than the one in the high state. The upper rows of Figures 2 and 3 give more detailed picture of MV Lyr behavior at the minima in 1995–2003 (Min1) and 2007–2015 (Min2).

[1] `https://www.aavso.org/`

[2] `https://cdaw.gsfc.nasa.gov`

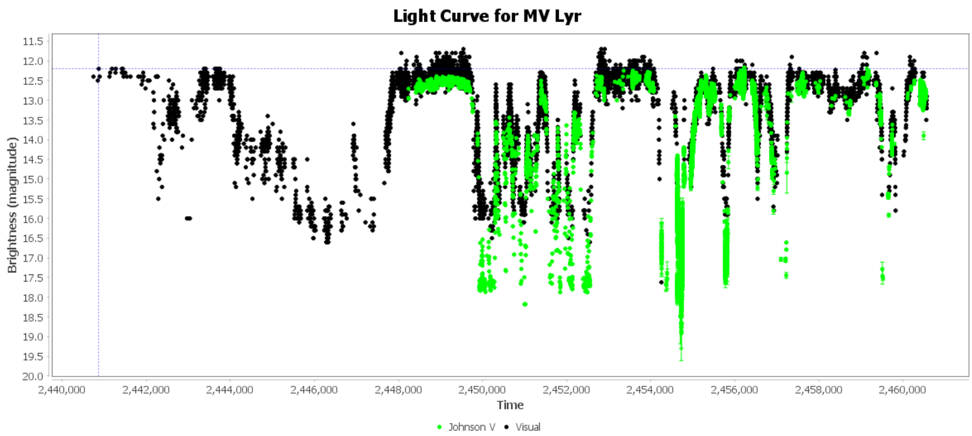

Figure 1: Long-term light curve of MV Lyr from 1971 to 2024 in Visual and V band.

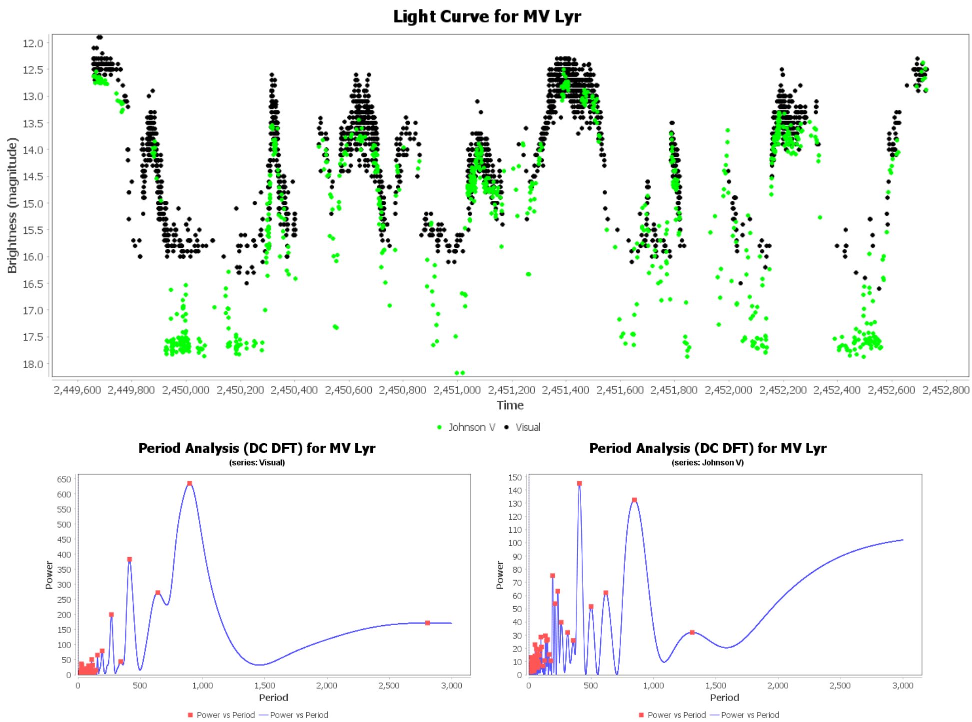

Figure 2: Upper plot: Low state of MV Lyr from 1995 to 2003. Lower plots: Power spectra in Visual (left) and V band (right).

Dwarf novae light curves are also not strictly periodic. They show different lengths and shapes of the outbursts. DNe outbursts can be with fast or slow rise, short or long, normal or superoutburst with larger amplitude and duration. Figure 4 represents the behavior of a typical DN variable SS Cyg. Despite the different time scale quite a few similarities can be seen between the shapes of the outbursts of SS Cyg and MV Lyr at the first minimum (Min1). The next low state of MV Lyr was quite different in occurrence rate and amplitudes of outbursts.

The period analysis was performed for 5 MV Lyr low states, 2 for TT Ari and 3 for KR Aur. Figures 2 and 3 (lower rows) show power spectra for visual and Johnsons V filter observations for Min1 and Min2 respectively. Similar power spectra gives analogical periods for all 3 variables in the range 200–400 d, but second maximum occurs around 850–1000 d.

Many statistical studies were carried out for DNe systems parameters and their outbursts, e.g. Coppejans et al. (2016) and Otulakowska-Hypka et al. (2016). The orbital periods (P_{orb}) of VY Scl type variables (∼3.5–4 h) are longer than DNe P_{orb} (usually <2 h). For such P_{orb} the lower-limit on the outburst amplitude is in the range 2.5–3 mag and the upper-limit of the recurrence time is from 20–30 d to 1000 d. Probably the duty cycle value ∼0.6 is larger, but values ∼0.4 also exist, usually for DNe with larger P_{orb}.

Several empirical relations for DNe are valid for VY Scl type stars too. For instance in Min1 MV Lyr shows two types of outbursts: short (with amplitudes ∼4 mag and a period ∼250 d) and long (with amplitudes ∼5 mag and a period ∼800 d). The first type can be interpreted as normal outbursts and the second one – as superoubursts. In Min2, the system shows a different behavior that can be explained by entering in the superoutbursts regime without normal outbursts. That event may occur due to a higher mass accretion rate. These properties of low-state bursts led us to assume that their nature is similar to DNe eruptions.

3. 2. LOW STATES AND SOLAR MAGNETIC CYCLE

The Sun is our closest star and various parameters of its magnetic activity can be observed and measured easier than on other stars. Various space-borne instruments in the last 30 years improved the volume and accuracy of the collected solar data.

Prior to the space era, observations of the solar activity and sunspots have been carried out for about 400 years, while similar cycles were discovered for other stars about 40 years ago, including the late-type secondary components of various classes of cataclysmic stars, e.g., GK Per, TT Ari, SS Syg, etc. (Bianchini, 1990). The sunspot cycle is nearly 11 years long while solar-like stellar cycles last usually 3–20 (30) years, with a maximum of the distribution ∼6 years.

The mass loss rate of the Sun via solar wind is $\sim$2–3$\times10^{-14}$ $M_{\odot}$/yr and consists of almost constant component – thermal solar wind, and variable one – solar flares and CMEs. In the solar wind, CMEs component can contribute up to 15–20% of the mass loss rate. In the late type MS stars the magnetic activity is stronger and thermal winds can exceeded more than 1000 times the solar wind. CMEs in active dwarfs can contribute to larger part of the stellar mass loss.

The stellar activity on the secondary star can produce mass transfer bursts via CMEs or solar flares. In the light curves of the stars fast variations of the brightness were observed. In time-scales from seconds (minutes) to 1–2 hours such flare events

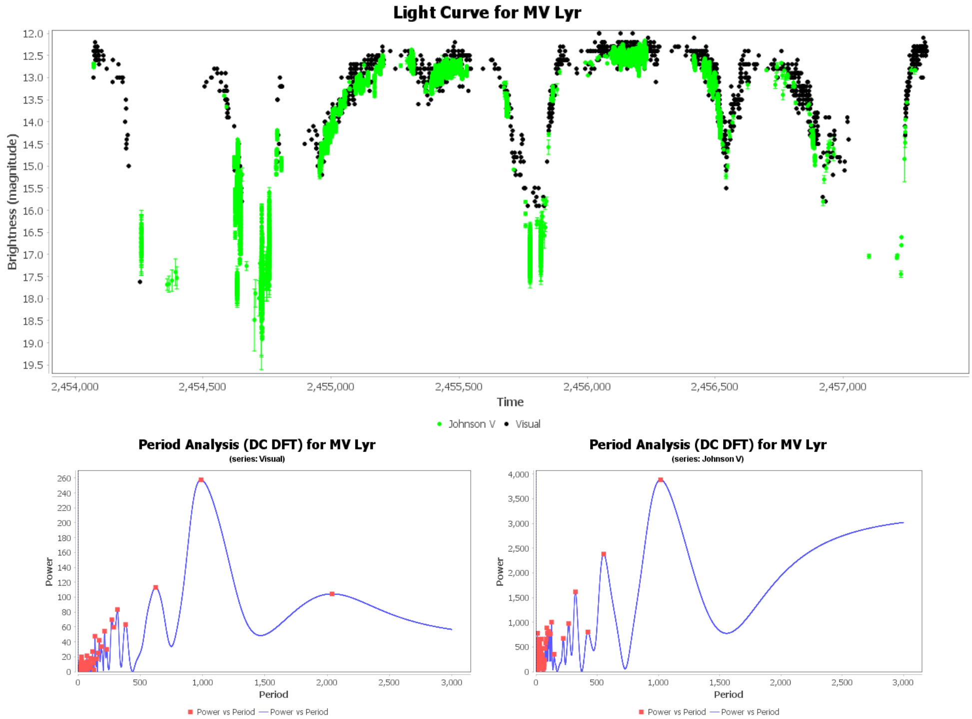

Figure 3: Upper plot: Low state of MV Lyr from 2007 to 2015. Lower plots: Power spectra in Visual (left) and V band (right).

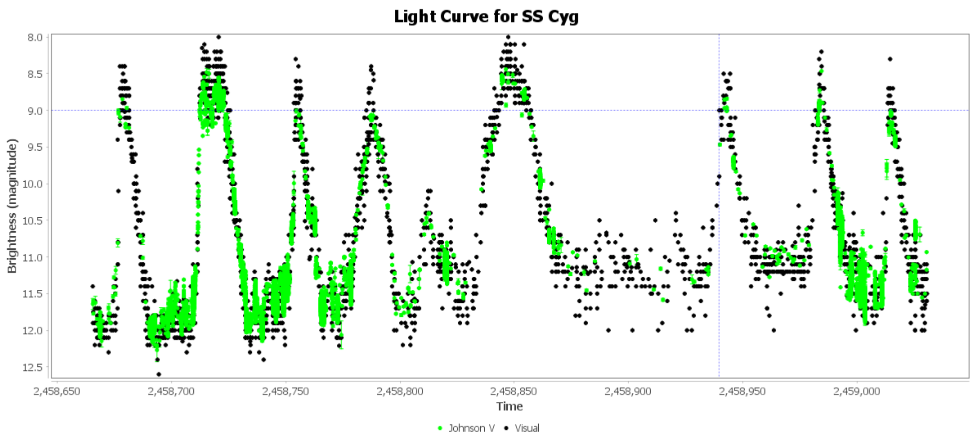

Figure 4: AAVSO light curve of SS Cyg (2019–2020).

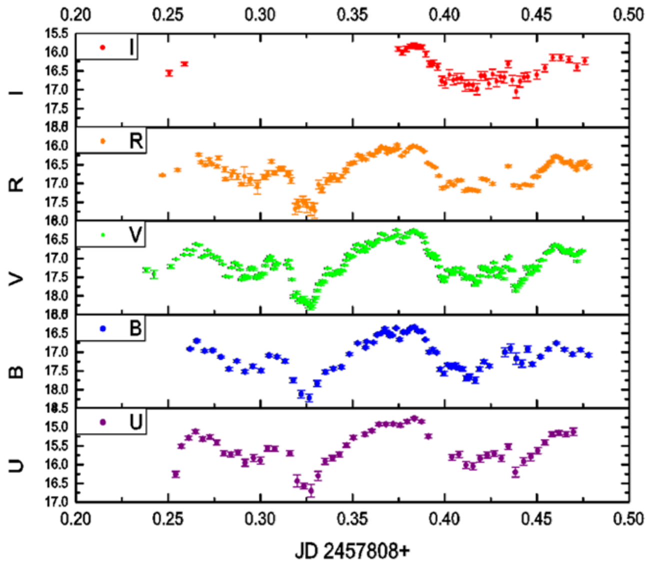

Figure 5: Multicolor simultaneous light curve of KR Aur received on 23.02.2017 using 4 telescopes in Bulgaria and Serbia (from Boeva et al, 2021a).

reach amplitudes 1–2 or more magnitudes and they are visible in the range from X-rays to radio wavelengths. The energy of the most powerful stellar flares is $\sim 10^{36}$–10^{37} erg (Schmitt et al., 2019).

Figure 5 presents 5 color observations of flare in KR Aur, received on 23.02.2017. The total energy of this flare is calculated to be $\sim 10^{36}$ erg, which value is close to the strongest observed flares (Boeva et al., 2021b). It is not clear if these bursts are flares on the secondary star or they represent sporadic accretion of blobs onto the white dwarf (Rodrguez-Gil et al., 2020).

There are many statistical studies of the occurrence rate of flares and CMEs with solar cycle phase. X-rays observations show ∼100 times increase of the number of flares during maximum of the solar activity compared to the minimum of the cycle (Aschwanden and Freeland, 2012). Lamy et al. (2019) reported 10–40 times more CMEs at solar maximum versus minimum. A correlation exists between occurrence rate of CMEs and total sunspot number however the total mass loss rate from the Sun through CMEs does not depend significantly on the strength of the cycle and the CMEs occurrence rate (Michalek et al., 2022). The fraction of mass loss due to CMEs vary from less than 1% at minimum to ∼10% at maximum.

The temporal evolution of mass loss rate of the secondaries in CVs during the solar-like cycle can affect mass transfer in the system. To study this we calculated the average CME number (N) and their mass (m) for three-month periods near maxima and minima of solar activity using CDAW catalog. The database contains 3 minima and 2 maxima from 1996 to 2020. Average mass (m) of CMEs (those with reported mass) and the total mass (M) are given in Table 1. We obtained 2.44 more events in maximum versus minimum, with 2.45 larger average mass, which provides 5 times more mass loss. The average total mass of CMEs varies slightly at maxima but at

Table 1: CMEs average number, average mass and overall mass at minimum and maximum of solar activity.

	N	m (g)	M (g)
Minima			
1996	120.33	5.79E+14	7.19E+16
2008/2009	61.00	8.37E+14	5.38E+16
2019/2020	44.67	2.59E+14	1.16E+16
average	75.33	5.58E+14	4.58E+16
Maxima			
2001	144.33	1.61E+15	2.09E+17
2014	224.00	1.13E+15	2.52E+17
average	184.17	1.37E+15	2.30E+17

minima it fluctuates around 6 times. The result can explain the decrease of mass transfer rate in the order of 1–2 magnitudes at VY Scl stars minima.

Solar cycles show long-term modulation too. The 11-year sunspot and 22-year magnetic cycles are well known but solar activity can vary significantly over the cycles length, shape and strength and also over longer periods. The amplitude of the solar cycle is modulated by the larger 100 (± 40) years Gleissberg cycle, but longer periodicities exist too (Biswas et al., 2023). Such long cycles can explain the different VY Scl type variables behavior even between adjacent low states.

4. CONCLUSIONS

The mass transfer never stops completely because of weak accretion rate due to the magnetic activity of the secondary. Long-term light curves of VY Scl type systems shows rises with amplitudes 3–5 mag, which durations and intervals between outbursts are similar to the dwarf novae eruptions. The detected periods for several systems are in agreement with empirical relations obtained for dwarf novae. The red dwarf magnetic cycles with duration of years can explain the reduced mass transfer and long deep states in VY Scl variables.

We estimated the increase in the mass loss via CMEs for the Sun by a factor of 5 (or more) during maximum versus minimum of the solar activity. Long-term modulations of solar-like cycles can cause different photometric behavior in the low states.

Acknowledgments

This work was supported by the Ministry of Science, Technological Development and Innovations of the Republic of Serbia through the Project contract No. 451-03-66/2024-03/200002.

The authors gratefully acknowledge the observing and financial grant support from the Institute of Astronomy with NAO – Bulgarian Academy of Sciences through the bilateral SANU-BAN joint research project *Astrometry and photometry of visual double and multiple stars.*

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