Contrib. Astron. Obs. Skalnaté Pleso **43**, 282 – 289, (2014)

Cataclysmic variables and symbiotic stars – challenging targets for small telescopes

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Received: November 8, 2013; Accepted: December 23, 2013

Abstract. Cataclysmic variables and symbiotic stars are interacting binary stars hosting an accreting white dwarf as a primary component. Both types of stars display a variety of complex astrophysical phenomena that reveal themselves as a variability on many different time scales, from seconds to thousands of years. They are ideal targets for monitoring on metre-class telescopes, even in a poor astroclimate. Some examples of observations of symbiotic stars at Tartu Observatory, Estonia, are presented.

Key words: stars – stars: binaries: cataclysmic variables – stars: binaries: symbiotic

1. Introduction

Cataclysmic variables (CV) and symbiotic stars (SS) are interacting binary stars, both containing an accreting white dwarf (WD) primary. CVs are semi-detached close binary systems in which a WD is accreting material from a Roche-lobe-filling secondary (a main sequence star of a late spectral class or a brown dwarf). Orbital periods of CVs mostly lie between ~ 70 minutes and 7–8 hours, with a well-known period gap between 2 and 3 hours where a very small number of CVs is known. Orbital periods of AM CVn subtype CVs can be as short as about 10–20 minutes. When describing general characteristics of CVs here and below, we mostly refer to the monograph by Warner (1995) and some more recent overviews in conference proceedings (Giovanelli, Sabau-Graziati, 2012; Knigge, 2011).

CVs form a heterogeneous class of stars. They are classified into different types according to their variability and outburst characteristics. First, a rough classification into magnetic and non-magnetic CVs is made. While magnetic field strength $B \sim 10^5 - 10^6$ Gs is often considered as a dividing line between the two classes, it may be that actually the division is not that sharp, and magnetic field of the WD plays a certain role in the evolution and behaviour of virtually all CVs (Giovanelli, Sabau-Graziati, 2012; Sion, 2012). Non-magnetic CVs, in turn, are classified into following types and subtypes:

– classical novae;

– recurrent novae;

– dwarf novae (including subtypes of U Gem, Z Cam, SU UMa, and SS Cyg – stars);

– nova-like CVs (including subtypes of AM CVn, VY Scl, and SW Sex stars).

Magnetic CVs are usually divided to polars or AM Her stars and intermediate polars (DQ Her stars). Sometimes those stars are also considered as subtypes of nova-like CVs. In magnetic CVs the strong magnetic field channels the mass transfer from the red dwarf to the white dwarf so that the accretion disc does not form at all (polars) and accretion takes place through accretion columns, or the accretion disc is truncated in the inner regions (intermediate polars).

There are more than 1000 CVs known. The latest on-line update (RKcat7.20, 1 July 2013) of the catalogue by Ritter and Kolb (2003) lists 1094 CVs. The catalogue by Downes *et al.* (2001, on-line edition 2006) contains 1600 CVs. In addition, the Sloan Digital Sky Survey (SDSS) has discovered about 290 new CVs (Szkody *et al.*, 2011 and references therein). The Catalina Real-Time Transient Survey (CRTS) (Drake *et al.*, 2009) has discovered about 1000 CVs (including those discovered by SDSS).

Symbiotic stars (SS) are the widest interacting binary systems known. They also contain an accreting WD, but the secondary component is usually a red giant of spectral class M or a Mira type pulsating giant, in some cases a yellow giant of spectral class G or K. As a rule, the giant component in SSs does not fill its Roche lobe and accretion takes place from stellar wind. Both stars are embedded into a gaseous nebula that is partly ionized by the hot component. There is a fundamental difference between SSs containing a normal red (or yellow) giant and those with a Mira type cool component. The former are designated as type S (Stellar), their orbital periods are mostly between 200 and 2000 days, binary separation of the order 1–3 AU, and their nebulae are compact and dense ($10^8 - 10^9 \mathrm{cm}^{-3}$) (Belczyński *et al.*, 2000; Mikołajewska, 2012 and references therein). SSs with a Mira type cool component are designated as type D (Dusty). Their binary separation is of the order 20 AU, and orbital periods in tens of years (the only well known period is that of R Aqr, 44 years). Gaseous nebulae are extended and tenuous ($\sim 10^5 \mathrm{cm}^{-3}$), and the Mira is embedded into a dust envelope (with a temperature around 700–1000 K).

SSs can also be classified on the basis of the variability and nature of their hot components. According to Munari (1994), one can distinguish the following types:

– classical symbiotic stars (Z And type): about 2–3 mag eruptions at irregular intervals (usually a few years);

– symbiotic novae: one about 6–12 mag outburst recorded;

– symbiotic recurrent novae: repeating outbursts ($\sim$ 2–10 mag) at about 10–100 years intervals;

– quiescent symbiotic stars: no outburst related brightness variations.

2. Physical phenomena to be studied in cataclysmic variables and symbiotic stars

While in a broad view the nature and behaviour of CVs and SSs is known and explainable in the framework of our present knowledge about interacting binary stars, there remain a lot of unexplained details and unknown relations. Both CVs and SSs are complex astrophysical laboratories where many interesting and sometimes unique phenomena can be studied.

One of the most significant common features of the both types of stars considered is **accretion**. In CVs the donor star is mostly a red dwarf of spectral class M, in rare cases a brown dwarf or white dwarf. In the standard model of CVs the red dwarf star fills its Roche lobe and matter is transferred to the WD companion through the Lagrangian point L_1 so that an **accretion disc** forms. While basic principles of disc accretion have been established since the seminal paper by Shakura and Sunyaev (1973), there are many open questions related to viscosity, angular momentum loss mechanisms, disc instability, etc. For example, dwarf nova outbursts are connected with the thermal instability of the disc (Cannizzo, 1993; Smak, 2002 and references therein), but it is still unclear whether the instability is caused by the variable mass transfer rate from the red dwarf or by intrinsic variations in the accretion disc. Another open question concerns the structure and radiation characteristics of the **hot spot** in the part of the accretion disc hit by the accretion stream. Of particular interest is the **boundary layer** – a geometrically narrow zone between the accretion disc and the surface of the WD where actually all or a significant part of the kinetic energy of the matter contained in the accretion disc must be radiated away.

SSs are much wider binary systems than CVs, but still interacting, due to great dimensions of red giants. However, it is generally believed that red giants in SSs do not fill their Roche lobe, but rather $R_{\rm g} \sim 0.5R_{\rm RL}$ (Mikołajewska, 2012; Mürset, Schmid, 1999). Accretion, most likely, takes place from stellar wind. On the other hand, ellipsoidal variations of light curves of many S-type SSs with orbital periods below ~ 1000 days are observed. The presence of tidally distorted red giants could facilitate accretion disc formation in SSs. Possible accretion disc formation is particularly interesting in connection with the so called combination nova model proposed by Sokoloski *et al.* (2006) for the prototypical symbiotic star Z And. An unstable accretion disk around the thermonuclear H-shell burning WD is a promising model to explain eruptions of the classical SSs and temporary ejection of bipolar jets in some outbursts, like it has been observed in the case of Z And (Burmeister, Leedjärv, 2007; Tarasova, Skopal, 2012).

The role of **magnetic fields** in both CVs and SSs is an important unsolved question. In polars or AM Her type CVs, the strong ($B \gtrsim 10^7$ Gs) magnetic field of the WD prevents the formation of accretion disc (as the Alfvén radius is greater than the circularization radius), and instead, channels the accreted matter to the WD surface via accretion columns. The WD rotation is synchronized with the orbital period which is usually a few hours (above the period gap). In intermediate polars or DQ Her type CVs, due to somewhat weaker magnetic field, the Alfvén radius is smaller than the circularization radius but greater than the WD radius. Thus, an accretion disk can form but its inner parts are disrupted at the Alfvén radius. Rotation of the WD is asynchronous with the binary period, $P_{\rm spin} \ll P_{\rm orb}$. The latter are rather below the period gap (≤ 2 hours).

The well-known **period gap** of CVs between 2 and 3 hours is not quite empty. An increasing number of SW Sex subtype CVs are found there (cf. Rodriguez-Gil *et al.*, 2007). This fact may indicate some kind of continuity between the intermediate polars and polars, with the SW Sex stars being a short evolutionary stage between these two types.

High luminosity and temperature of the hot components of SSs is considered to originate from **thermonuclear burning** in a thin hydrogen shell on the surface of the WD. However, this concept encounters difficulties to explain the time scales and amplitudes of the classical SS outbursts. On the other hand, more or less collimated **bipolar jets** have been detected in about 10 SSs (Leedjärv, 2004), most recently in BF Cyg (Skopal *et al.*, 2013). The standard model for ejection of collimated bipolar jets includes an accretion disc as an important ingredient (cf. Livio, 1999). So, the nature and energy source of the hot components of SSs is not unanimously clear, the combination nova models, like that mentioned above for Z And (Sokoloski *et al.*, 2006) should be kept in mind. At the same time, a natural question could arise, why there are no jets observed in CVs. Non-detection, however, does not necessarily mean complete absence of jets. Recently, Körding *et al.* (2008) have found evidence for jets from radio observations of the dwarf nova SS Cyg. Another paper by Körding *et al.* (2011) claims a tentative detection of radio jets in the nova-like CV V3885 Sgr. If jets really exist in CVs, they are a transient phenomenon, like also in SSs, understanding their appearance needs a thorough exploration of the time domain. In general, interplay between thermonuclear burning, accretion discs and bipolar jets in CVs and SSs is an exciting field for further studies.

SSs are for a long time considered as potential precursors of **supernovae type Ia** (Munari, Renzini, 1992; Munari, 1994; Mikołajewska, 2012, 2013). An accreting WD is a promising candidate to gain enough mass to reach the Chandrasekhar limit, provided that its mass is high enough. In this respect, some recurrent novae (RS Oph, T CrB) seem to be the most likely candidates for SN Ia precursors, but other types of SSs cannot be excluded. Detailed studies of the balance between the really accreted matter and that lost by the WD (as stellar winds, jets etc.) are needed to clarify the role and contribution of SSs into the total number of SNe Ia.

3. Variability of cataclysmic variables and symbiotic stars

All CVs and SSs are variable stars. Variability reveals itself in practically all wavelength regions and on many different time scales. Below we present some examples of the time scales of variability, most of which are relevant for observations with small telescopes:

Seconds to (tens of) minutes – flickering in CVs and (only a few) SSs. Most likely, short-time scale flickering with an amplitude of a few hundredths or tenths of stellar magnitude originates in the inner regions of the accretion disc and/or boundary layer.

Tens of minutes to hours – orbital motion in CVs, occurence of superhumps in dwarf novae light curves.

Days to (tens of) years – recurrence of dwarf nova outbursts, superoutbursts, magnetic phenomena in magnetic CVs, spectral variations in SSs.

Hundreds of days to years – orbital motion in S-type SSs.

Years to decades – outbursts of classical SSs.

Decades – recurrent nova outbursts, orbital motion in D-type SSs.

Hundreds to thousands of years (?) – symbiotic nova outbursts.

Thousands to tens of thousands of years – recurrence of classical nova outbursts.

Tartu Observatory (Estonia) has the 1.5-meter reflector telescope AZT-12 as its main observing instrument. Being equipped with the Cassegrain focus spectrograph, it is used mostly for spectroscopic monitoring of variable stars. The 0.6-m Zeiss-600 telescope and the 0.3-m robotic PlaneWave telescope are used for photometric observations.

As examples of the monitoring and its results, we can mention the symbiotic stars CH Cyg (Burmeister, Leedjärv, 2009), AG Dra (Leedjärv *et al.*, 2004; Leedjärv, Burmeister, 2012), and Z And (Burmeister, Leedjärv, 2007). In Fig. 1 we show variability of the non-typical symbiotic star CH Cyg: the U light curve together with the Hα profiles at selected dates. Fig. 2 demonstrates long-term variability of the yellow symbiotic star AG Dra.

4. Relevance of CVs and SSs for small telescopes

Most of CVs and SSs are variable on "human" time scales. This makes them attractive objects for monitoring. As many of them are bright objects (the brightest SSs have $V \sim 7$ mag and CVs ~ 10 mag), they are ideal targets for metre-class telescopes. Due to short orbital periods, one or several orbital cycles of CVs can be observed during one night. Variability on long time scales, on the other hand, does not require high time cadence, and so, the telescopes in poor astroclimate might also be useful (like it is in Tartu Observatory, for instance).

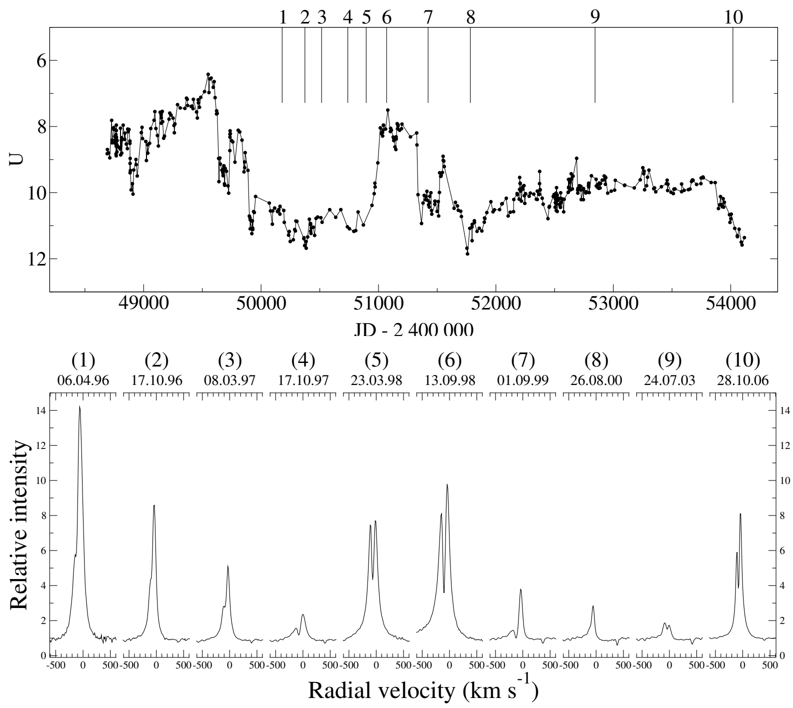

Figure 1. The U light curve of CH Cyg (upper panel) and examples of the Hα emission line profiles (lower panel) on the radial velocity scale for selected dates.

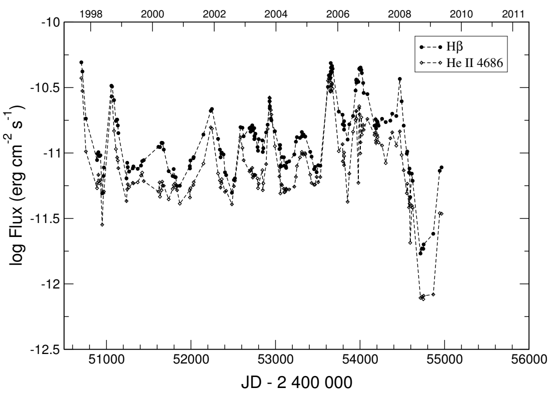

Figure 2. Variability of the absolute flux radiated in the emission lines of Hβ and He II λ 4686 in the spectrum of AG Dra.

Below we list some open questions in the studies of CVs and SSs into solving of which observations on small telescopes could contribute:

– What exactly is the interplay between magnetic braking and gravitational radiation, causing the period gap in the distribution of CVs?

– What is the physics of viscosity in accretion discs?

– What causes low states of polars as well as some nova-like systems with orbital periods between 3 and 4 hours?

– What is the actual number density and distribution of CVs in the Galaxy?

– What is the nature and mechanism of 2–3 mag outbursts of classical SSs?

– What is the role of RLOF and ellipsoidal variations in the mass transfer mechanism of SSs?

– Which SSs and under which conditions do emit collimated bipolar jets?

– Are SSs precursors of SNe Ia?

– What is the total number of SSs in the Galaxy?

5. Conclusions

When talking about observations on the metre-class telescopes, one implicitly assumes that those are performed mostly in the optical and/or near-infrared spectral regions. The interacting binary stars considered here actually emit radiation over the whole scale of electromagnetic waves. For example, X-ray and UV spectral regions are very important for disentangling the characteristics of hot regions: a boundary layer, a hot spot and accretion columns in CVs, H burning white dwarfs in SSs, colliding winds in SSs etc. Character of variability in other spectral regions might be quite different from that in optical/near-IR. The nature and behaviour of CVs and SSs can be fully understood only if all the available information across the whole electromagnetic spectrum is taken into account. Concluding, CVs and SSs are indeed challenging and important targets for metre-class telescopes but their observations should be considered in a wider context.

Acknowledgements. The author is thankful to the organizers of the conference for an invitation to give the talk on the above topic and for hospitality during the meeting. Participation in the conference was supported by the Estonian Ministry of Education and Research project SF0060030s08.

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