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Astrophysics of symbiotic stars with small telescopes

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Abstract. Symbiotic stars comprise a cool giant and a white dwarf (WD) on, typically, a few years orbit. The white dwarf accretes from the giant's wind, heats up to $1 - 2 \times 10^5$ K, ionizes the circumbinary environment, and is subject to occasional outbursts. The presence of physically different sources of radiation and particles in the system, diversing extremely in temperatures, produces a complex composite spectrum from X-rays to radio wavelengths. In my presentation I will introduce some main points of the research of symbiotic stars based on the multicolour photometry carried out by small telescopes of the Astronomical Institute of the Slovak Academy of Sciences.

Key words: Stars: binaries: symbiotic – Techniques: photometric

1. Introduction

The symbiotic stars (SS) represent the extremum of the interacting binary star classification. Merrill (1950) first gave the name symbiotic, because of the simultaneous presence of spectral features indicating two very distinct temperature regimes – that of a late-type stellar photosphere with characteristic molecular absorptions, superimposed upon which are emission lines of high excitation/ionization. The attribute *symbiotic* was then adopted to denote this class of objects.

At present, the SSs are understood as interacting binary systems consisting of a cool giant and a WD. Typical orbital periods are between 1 and 3 years, but can be significantly larger. There are two principal processes of interaction: (i) Mass loss from the cool giant in the form of a wind, which represents the primary condition for appearance of the symbiotic phenomenon. (ii) Accretion of a part of the giant's wind by its compact companion. This process generates a very hot ($T_{\rm h} \approx 10^5$ K) and luminous ($L_{\rm h} \approx 10^2 - 10^4\,L_{\odot}$) source of radiation, which ionizes a fraction of the neutral wind from the giant giving rise to *nebular* emission. As a result the spectrum of SSs consists of three basic components of radiation – two stellar and one nebular. This general view on the nature of SSs was originally found out by, e.g., Boyarchuk (1967), Allen (1984), Seaquist et al. (1984), Kenyon (1986) and Nussbaumer & Vogel (1987).

The hot WD's radiation dominates the supersoft X-rays and the far-UV, while the nebular radiation is best indicated at the near-UV/optical and the

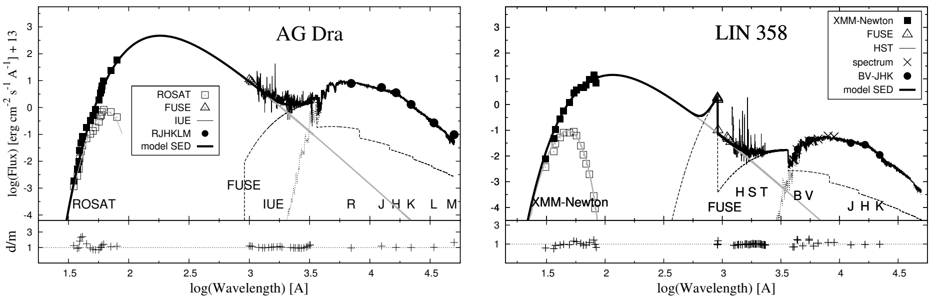

Figure 1. A comparison of the measured and modelled SED (see the legend) of the symbiotic binaries AG Dra and LIN 358. The gray, dashed and dotted lines denote components of radiation from the burning WD, nebula and giant, respectively (adapted from Skopal (2014)).

radio domain. Contribution from the giant dominates usually the optical/near-IR. Figure 1 demonstrates this type of the spectral energy distribution (SED) for the classical SS AG Dra and the symbiotic X-ray binary LIN 358.

The complexity of the total spectrum of SSs provokes the question, whether the multicolour optical photometry of SSs by small telescopes can considerably contribute to understanding of their nature. To answer this principal question, I will introduce some examples demonstrating the impact of photometric measurements to the research of these enigmatic objects. In particular, I discuss fundamental types of variations in the light curves (LCs) of SSs that reflect most closely their nature – the orbitally-related wave-like variation and eclipses.

2. Monitoring – examples of LCs of symbiotic binaries

Throughout the optical, the light contributions from different sources of radiation rival each other (see Fig. 1), producing a spectrum whose color indices differ significantly from those of standard stars. Therefore the LCs of SSs have a complex profile, often having an unexpected variation. Here I show examples of Z And and BF Cyg.

2.1. Z Andromedae

Z And is considered a prototype of the class of SSs. The binary comprises a late-type, M4.5 III, giant and a WD on the 758-day orbit (e.g. Fekel et al. 2000). More than 100 years of monitoring Z And has shown the eruptive character of its LC. Typical brightening in the optical by a few magnitudes lasting for weeks to months are called as Z And-type of outbursts (e.g. Kenyon, 1986, and references therein). The top panel of Fig. 2 displays its UBV LCs since 1981.

They are characterized with the presence of the so-called *quiescent phases* (to 1984 and 1987 – 2000) and *active phases*, measured during 1985–86 and since 2000.

2.2. BF Cygni

BF Cyg is an eclipsing symbiotic binary with the orbital period of 757.2 d (Fekel et al. 2001). The cool component in the binary was classified as an M5 III giant (Mürset and Schmid, 1999). Its historical LC is characterized by the nova-like eruption in 1895 with superposed brightenings of the Z And-type (see Fig. 1 of Skopal et al. 1997). Bottom panel of Fig. 2 displays its UBV LCs since 1986. They cover the recent 1989-93 outburst with an eclipse effect, the wave-like variation during the following quiescent phase and the recent active phase, which started in August 2006.

These examples demonstrate that the LC-profiles of SSs are complex, often showing an unexpected variation. Nevertheless, during quiescent phases we can always recognize the wave-like variation, whose minima/maxima are separated approximately by the orbital period. During active phases, the LC profile is rather complex, differing from object to object. For systems with a high orbital inclination we can measure relatively narrow minima (eclipses) at the inferior conjunction of the giant.

3. The origin of the wave-like variability

To understand these types of variability, it is useful to compare the multicolour LCs with the disentangled composite spectrum in the visual domain. Figure 3 demonstrates this type of variability for two objects, BF Cyg and AG Dra. The minima and maxima occur at/around the inferior and superior conjunction of the giant, respectively. This variation is characterized with a large magnitude difference between the minimum and maximum, $\Delta m \sim 1 - 2$ mag, and we always measure $\Delta U > \Delta B > \Delta V$. This relationship can be understood with the aid of the SED throughout the UBV region. Figure 3 shows that the hot star contribution during quiescence can be neglected in the optical with respect to that from the nebula and the giant. As the contribution from the giant can be assumed to be constant along the orbital motion, the wave-like variability can be ascribed to the nebular emission. Indeed, Skopal (2001) found that a maximum/minimum of the nebular emission is observed around the conjunctions of the binary components, similarly as for the periodic wave-like variation of the photometric magnitudes. Then, the observed amplitude of the wave-like variation is proportional to the ratio of fluxes from the nebula and the giant. The orbitally-related variation in the nebular emission is only apparent. This implies that the nebular medium is in part optically thick and can be also attenuated by the extended neutral region of the wind from the giant. This causes different contributions of the nebula into the line of sight at different orbital phases.

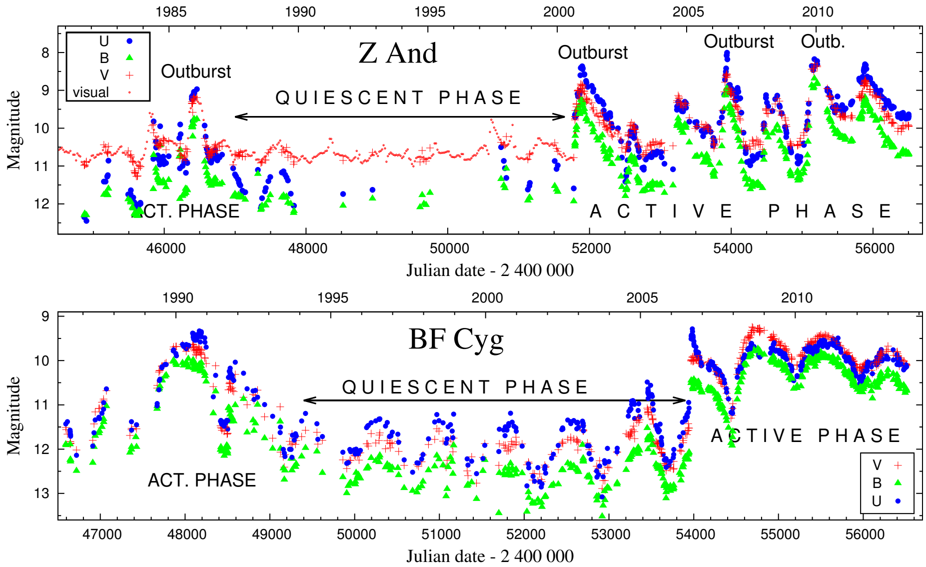

Figure 2. Examples of the UBV LCs of classical symbiotic stars Z And and BF Cyg. They show their basic behaviour during quiescent and active phases (see the text). Data were collected by Skopal et al. (2012).

The SED in the optical suggests that the value of Δm depends also on the spectral classification of the giant in the binary. Systems containing a *yellow* giant produce $\Delta U/\Delta V >> 1$, because of a strong contribution from the giant into the V passband, while those with a red giant produce $\Delta U/\Delta V > 1$, because of a lower contribution of the giant in V with respect to the variable nebular component. Figure 3 depicts examples of such variability for the yellow symbiotic AG Dra (K7 III giant) and BF Cyg, which harbours an M5 III giant.

4. Eclipses during active phases

During active phases of systems with high orbital inclination, we often measure a narrow minimum (eclipse) at the position of the inferior conjunction of the cool component. Figure. 4 shows the significant difference in the minima profile as observed during the quiescent and active phase of AX Per and CI Cyg. This change is caused by a significant change in the ionization structure in symbiotic binaries during active phases, when a major fraction of the hot component radiation is located around the WD having the form of a flared optically thick disk-like structure (Skopal, 2005, Skopal et al. 2011, Cariková & Skopal, 2012). When viewing the system under a high inclination angle, the flared disk permanently occults the central hot star, while the matter above/below the disk

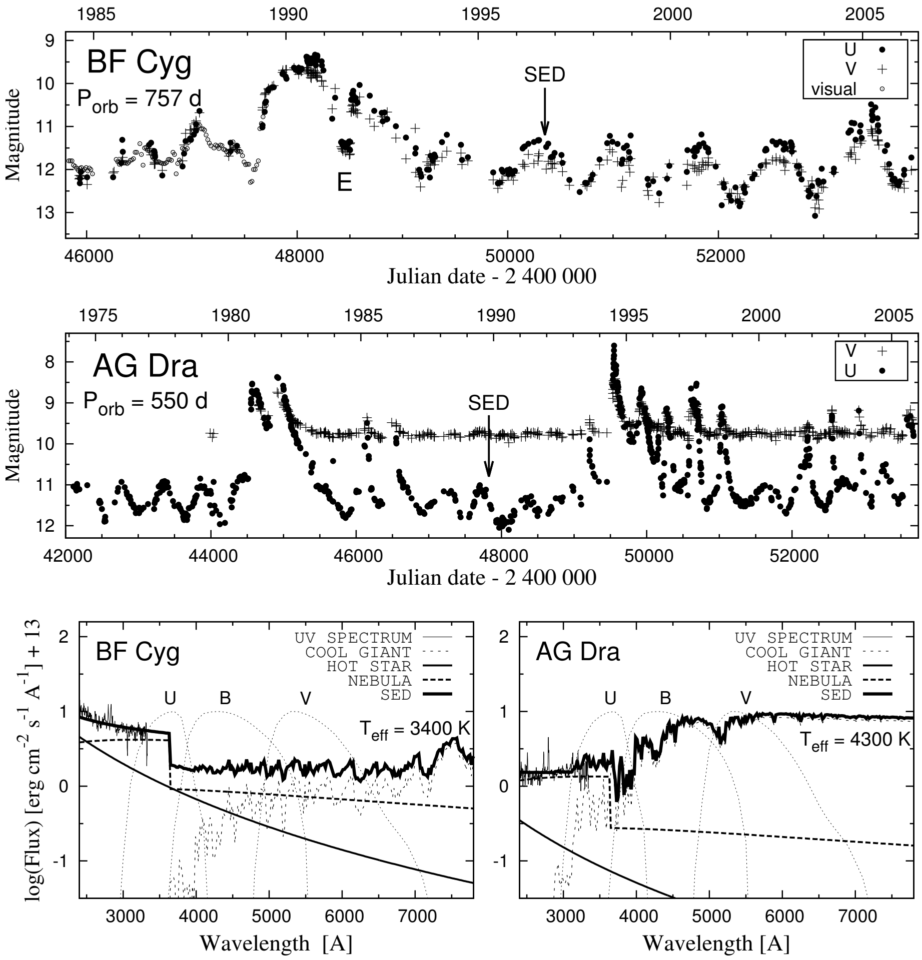

Figure 3. LCs of BF Cyg and AG Dra show a very different amplitude of the wave-like variation at different passbands. The SEDs of these objects throughout the UBV region explain the observed differences (see Skopal, 2008 in detail).

can be ionized by the hot central star. As a result, we observe the so-called two-temperature-type of the spectrum, that is characterized with a $1 - 2 \times 10^4$ K warm continuum, composed with a strong nebular emission contributing to both the continuum and the lines. As the nebula is only partially eclipsed, the colour indices during the totality differ significantly from those of a normal red giant. This provokes a question if the observed indices can be disentangled so to determine physical parameters of their contributors: the giant and the nebula.

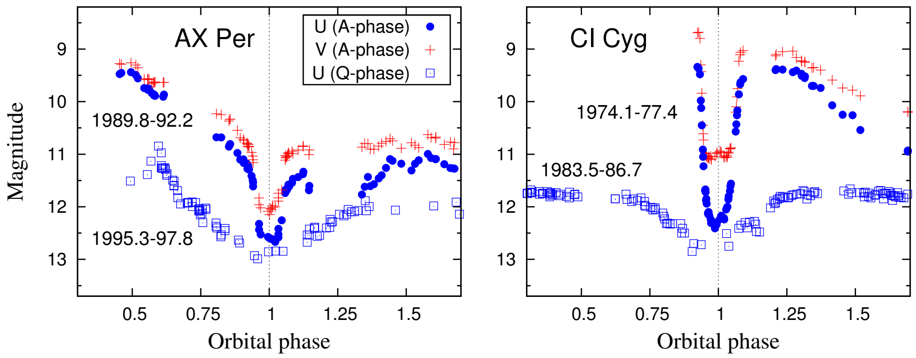

Figure 4. An example of narrow and broad minima observed during active and quiescent phases, respectively, of symbiotic stars AX Per and CI Cyg (see the text; figure adapted according to Skopal, 2008).

5. Physical parameters from UBV magnitudes

Assuming that the contribution from the hot stellar source can be neglected within the optical, Cariková and Skopal (2010) found that it is possible to disentangle the optical continuum, as defined by the UBV photometry, into its individual components of radiation. Their model is thus applicable for systems during the quiescent phase, when the Rayleigh-Jeans tail of the very hot WD is negligible with respect to contributions from the nebula and the giant in the optical (see e.g. SEDs in Fig. 3). During active phases, the model is applicable only during the total eclipse, when the light from the hot star and its disk-like pseudophotosphere is cut off from the spectrum. In the case of non-eclipsing systems, the optical light from the hot object can be neglected at any orbital phase.

The basis of the method is determination of three U, B, V flux-points of the the *true* continuum (i.e. dereddened and corrected for emission lines). Then comparing these fluxes with the model, which includes contributions from the nebula and the giant, one can determine the electron temperature and emission measure of the nebula, and the V magnitude of the giant. Model parameters are well comparable with those determined independently by another method. This approach thus provides a good estimate of the physical parameters of contributing sources of radiation into the optical on the basis of a simple UBV photometry. Figure 5 shows an example of the disentangled UBV magnitudes of AG Dra during its active and quiescent phase.

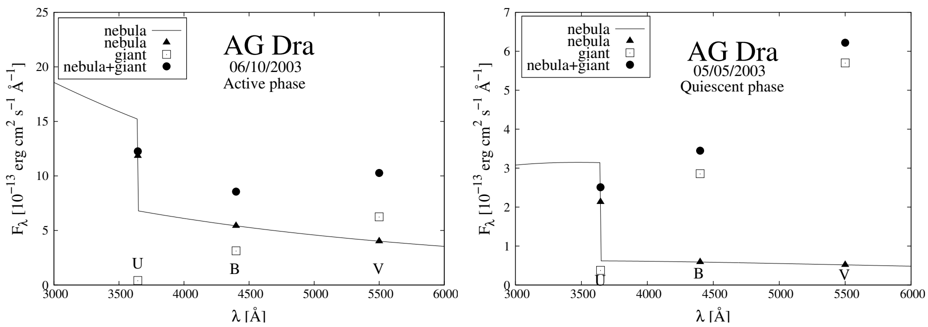

Figure 5. An example of the disentangled UBV magnitudes for AG Dra during the active (left) and quiescent (right) phase. Components from the nebula and the giant are denoted by symbols in the legend. The nebular continuum is drawn with a solid line (according to Cariková and Skopal, 2010).

6. Concluding remarks

To understand the nature of SSs we need multifrequency observations from X-rays to radio wavelengths (Sect. 1). From this point of view, it seems to be rather difficult to provide a considerable contribution to the investigation of SSs on the basis of only 'simple' photometric measurements. On the other hand, within the optical, the light contributions from physically different sources in the system (the giant, hot component and nebula) rival each other and react sensitively to any instability in the system. Accordingly, the multicolour photometric measurements of SSs, usually carried out with small telescopes, plays an important role in their research. Below I point some examples.

(i) An unpredictable sudden change in the brightness is exclusively discovered by photometric monitoring. A discovery of outbursts provides an alert for observation with other facilities.

(ii) Colour indices can provide information about the nature of the composite continuum and thus to help to identify the responsible process. For example, the very negative $U-B$ index is usually connected with optical brightening that signals the energy conversion from the hot star to the nebular emission.

(iii) Disentangling the UBV photometric measurements obtained during a quiescent phase and in an active phase during total eclipses of the hot component, allow us to quantify the contribution from the nebula and giant.

(iv) During an active phase the eclipse profile signals a significant change in the ionization structure around the hot active component, and can help us to determine its radiative and geometrical parameters. However, eclipses are not present during each outburst of some symbiotic objects (here Fig.2). An additional problem connected with eclipses in SSs is their width. In some cases it is too large to be explained by a simple eclipse of the hot object by the stellar disk of the giant.

(v) The broad minima during quiescence, whose profiles reflect the geometry of the nebula, can determine the difference between the simplified ionization structure and the real situation including effects of the binary motion and accretion.

The presence of physically different sources of radiation in symbiotic systems produces a complex composite spectrum. Its resulting flux thus depends on the wavelength, activity of the star and also the projection of these regions into the line of sight, i.e. on the orbital phase of the binary. Throughout the optical the light contributions from these sources rival each other, which produces the spectrum, whose colour indices differ significantly from those of standard stars. At present, the complex variations recorded in the LCs of SSs remain far beyond our full understanding. Investigation of the interaction between the cool giant and its hot luminous compact companion in symbiotic binaries requires simultaneous, multifrequency observations. This is a challenging task, addressed mainly to large ground-based telescopes and those on the boards of satellites. In spite of this, photometric monitoring of SSs, frequently obtained with small telescopes, plays an important role in their research.

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