A study of eruptive activity of symbiotic stars

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Several symbiotic systems are investigated, most of them during eruption and a small part – in quiescence. The objects of the later group, however, have spectral indication of loss of mass too.

The symbiotic binary EG And is an eclipsing system containing a normal M giant and a compact object with a stellar wind observed in the C IV resonance lines (Oliversen et al. 1985). Their profiles consist of three components – a central narrow emission component, most probably of nebular origin, a broad emission component and a P Cyg absorption. The broad component appears probably in the area of the stellar wind since it undergoes orbital variations together with the P Cyg absorption because of occultation of this area by the cool giant. The profile of the line H_α varies with the orbital phase due to change of the optical depth of the circumbinary nebula (selfabsorption). The line has maximal intensity at phases after the superior conjunction of the giant (minimal selfabsorption) and minimal intensity - at phases after its inferior conjunction. At these phases the profile is doublepeaked, with a deep absorption feature between the two peaks (Oliversen et al. 1985).

An interpretation of this behaviour in the light of the model of colliding winds is suggested. Following the winds parameters, the wind of the giant predominates over the hot wind and their region of interaction (shock region) locates behind the compact object. Because of the orbital motion the cone shaped shock region distorts in a direction opposite to the orbital motion. Besides the shock region the compact object ionizes some part of the wind of the giant too. This model provides a minimal optical depth of the nebula at phases after the superior conjunction of the giant and a maximal depth - at the opposite phases. The model H_α flux has been calculated which is in a good agreement with the observed flux (Tomov 1995).

The symbiotic binary AG Peg has undergone the most prolonged outburst among the outbursts of symbiotics, lasting about 150 years. Its optical line spectrum was investigated at the final stage of the outburst at the end of XX century. Till 1995 the emission lines H_β, H_γ and He II 4686 had two-component profiles containing a broad component indicating stellar wind from the outbursted compact object with a velocity of 1000 $\mathrm{km\,s^{-1}}$. The mass-loss rate of the outbursted object has been obtained from the energy flux of the broad component at two time periods – in 1986 and 1995. It turned out that the rate was decreased by a factor of 1.8. The energy flux in 24 optical lines was obtained at these times too (Tomov et al. 1998). It was decreased at average about 2, which is roughly equal to the decrease of the U flux and Lyman photon luminosity of the outbursted object (Tomov & Tomova 1998).

The U light of the system AG Peg has two kinds of variations: gradually decrease mainly due to decrease of the Lyman luminosity and orbital modulation due to occultation of the circumbinary nebula. An interpretation of this behaviour in the framework of the model of colliding winds is suggested. It is concluded that the emission of the occulted part of the nebula originates in a thin shell around the giant, facing the compact object and including the shock region of the winds and the wind of the giant. It is prognosticated that when the mass-loss rate of the compact object decreases to a definite limited value, only the wind of the giant will exist and the accretion in this system will be restored. Then the bright thin shell will disappear (Tomov & Tomova 2001).

The system AG Dra is a yellow symbiotic and undergoes active phases of Z And type. We determined the distance to the system and the radius of its cool component. Using these parameters we calculated the luminosity and the mass of the components as well as the accretion rate of the compact object (Tomov et al. 2000).

The line spectrum of AG Dra was investigated during its 1994–1998 active phase. The mass-loss rate of its compact object was obtained during three consecutive outbursts with use of the energy flux in the broad emission component of the lines H_γ and He II 4686. Based on these estimates we supposed that the compact object does not undergo thermonuclear outburst and more probably it is in a state of steady burning of hydrogen at its surface and the optical outbursts are caused by a change of the accretion rate (Tomova & Tomov 1999, Tomov & Tomova 2002).

The emission measure of the circumbinary nebula was obtained in quiescent state of the system and at the times of light maximum during the active phase. It turned out that during outburst it increases much more than the Lyman luminosity of the compact object. Its great increase can not be explained with shock ionization. That is why we supposed that the compact object in quiescence has a luminosity high enough to ionize the whole nebula and an appreciable quantity of its photons leave the nebula. In such a case the increase of the emission measure during outburst can be due to increase of the mass-loss rate of the cool giant. Based on this idea we suggested a scenario to interpret the growth of the optical light of AG Dra during its 1994–1998 active phase (Tomov & Tomova 2002).

The symbiotic prototype Z And was investigated during its last and most prolonged 2000–2013 active phase. Mechanism for increase of the optical light during each outburst of the active phase and scenario for evolution of the geometrical structure of the outbursting compact object to interpret the line spectrum have been proposed.

We found a mechanism for increase of the optical light comparing the light curve with results of two dimensional gas dynamical modeling of a system with parameters of Z And. These results show that a region of shock waves begins to form about 70 days after the onset of the expansion of the compact object, which reaches its maximal development about 20–30 days later. This region can raise the optical light of the system with several tenths of stellar magnitude.

The optical light rises at three stages separated by two plateaus. During the first stage the bolometric luminosity grows because of the accretion luminosity only. During the second stage it grows because of increase of the burning rate of hydrogen. At this stage the optical light rises because of an increase of the bolometric luminosity, an expansion of the compact object leading to strong energy redistribution and an appearance of a stellar wind creating a hot region in the nebula. The second stage ends because of decrease of the mass-loss rate leading to "contraction" of the observed photosphere and energy redistribution to shorter wavelengths. The third stage is determined by a new increase of the mass-loss rate and development of a region of shock waves in the nebula. This was established observationally with finding of a shock ionization which raises the light of the system in its maximum by 0.1–0.2 mag. The region of shock ionization appears about 50 days after the onset of the hot wind and reaches maximal development after 20–30 days later in a good agreement with the gas dynamical modeling (Bisikalo et al. 2006).

During the active phase the system Z And had spectral indication of stellar wind from the compact object which appeared and faded at each outburst. The line spectrum, however, reached its maximal development during the 2006 outburst when the lines of hydrogen and helium acquired high velocity satellite components indicating collimated ejection together with the wind components. The line H_γ had four groups of components. It, however, evolved quickly and some of them developed and other gradually faded (Tomov et al. 2012, 2014). To interpret this behaviour we proposed a scenario containing two stages of the evolution of the outbursting compact object using results of gas dynamical modeling of a system with parameters of Z And. According to this results a geometrically thin disc from accretion of a stellar wind with a radius of 50–60 $\mathcal{R}_\odot$ and a mass of $5{\times}10^{-7}$ $\mathcal{M}_\odot$ exists in the system in its quiescent state. During the first (and every following) outburst the stellar wind of the compact object "strips" the disc. At the end of the outburst some part of the ejected mass stays in the potential well of the compact object. After the cessation of the wind it begins to accrete again and because of conservation of the initial angular momentum falls into the disc. In this way an extended (geometrically thick) disc-like envelope forms, which spreads out at great distance from the orbital plane. Because of centrifugal barrier two hollow cones with a small opening angle appear around the axis of rotation. During the next outburst the stellar wind propagates only through these cones (collimated wind) and gives rise to the satellite components of the spectral lines (Tomov et al. 2010, 2014).

We calculated the mass-loss rate of the compact object using the energy flux of the broad emission component and satellite components. It decreased from $(4-5)\times10^{-7}(\mathrm{d}/1.12\ \mathrm{kpc})^{3/2}$ $\mathcal{M}_\odot \mathrm{yr}^{-1}$ at the time of the light maximum to about $1{\times}10^{-7}(\mathrm{d}/1.12\ \mathrm{kpc})^{3/2}$ $\mathcal{M}_\odot \mathrm{yr}^{-1}$ in December 2006 (Tomov et al. 2012).

The model of collimated stellar wind proposes a better possibility to interpret the line profiles of all symbiotic systems containing satellite components indicating collimated ejection and an additional P Cyg absorption at different velocity than the "traditional" model with a magnetic disc. Besides

Z And there are three other systems: Hen 3-1341, StHα 190 and BF Cyg. We considered every one of them (Tomov et al. 2014).

The model of collimated stellar wind proposes a possibility to interpret the light curve of the system BF Cyg during its last 2006–2016 outburst too. It is supposed that as a result of a decrease of the mass-loss rate of the outbursting compact object after the first maximum and accretion of some part of the ejected material an extended disc-like envelope covering the accretion disc forms in the time between the first and the second light minima. It collimates the wind giving rise to bipolar outflow which is observed as satellite components of the Balmer lines. Uneclipsed part of the envelope is responsible for the decrease of the depth of the orbital minimum. This envelope has a transient nature and its destruction determines the increase of the depth of the orbital minimum with fading of the optical light (Tomov et al. 2015).

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