Observed Properties of Mass Loss in Symbiotic Binaries

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Abstract. Both the red giants and the Mira variables in symbiotic systems have systematically higher mass-loss rates than do typical galactic giants and Miras, which suggests that only very evolved giants, and so those with highest mass-loss rates, can support symbiotic behaviour in widely separated binary systems. They often show a flattened mass-loss geometry due to an intrinsically inhomogeneous mass loss and/or tidal interactions between the binary components. The main body of a symbiotic nebula is thus formed from material lost in the giant wind, while the hot component is responsible for its ionization and excitation. In addition, the fast wind and/or jet ejection from the hot component, whenever occur, give rise to the complex, often bipolar, shape of symbiotic nebulae. Observations of resolved nebulae also suggest that the binary geometry and nebular structure are aligned but the bipolar outflow may be not orthogonal to the orbital plane in all cases.

1. Introduction

Symbiotic stars are interacting binaries composed of an evolved giant primary and a hot, luminous companion surrounded by an ionized nebula. Depending on the nature of the giant we have two distinct classes: the S-type with normal giants and orbital periods of about 1–15 yr, and the D-type with Mira primaries usually surrounded by a warm dust shell, and orbital periods generally longer than 10 yr. The hot star in most cases appears to be a white dwarf powered by thermonuclear burning of the material accreted from its companion’s wind. The presence of both the evolved giant, heavily losing mass in most cases, and the hot companion copious in ionizing photons and often possessing its own wind lends large variety to the circumstellar environment of symbiotic binaries.

This paper gives a brief summary of the observed properties of the symbiotic circumstellar envelopes. More details can be found in Mikołajewska (1999, hereafter M99), while for the most recent general review of the symbiotic stars the interested reader is referred to Mikołajewska (1997).

2. A simple case: cool giant wind ionized by the hot companion

So far ~25% of all symbiotics have been detected at radio range. In practically all cases, the radio emission at cm wavelengths is consistent with optically thick
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thermal bremsstrahlung from an ionized gas (Seaquist & Taylor 1990). According to a simple binary model, the radio emission originates from the red giant wind ionized by the hot companion (Seaquist et al. 1984). The geometry of this emission region is governed by a single parameter, $X$, which depends on the red giant mass-loss rate, the binary separation, and the Lyman continuum luminosity of the hot component. According to the model, the optically thick spectral index depends on $X$, while the turnover frequency, $\nu_t$, is related to the binary separation. The model can be thus easily tested by observing the radio spectra, determining $\nu_t$, and then comparing the model-dependent estimate of the binary separation with independently known values.

Preliminary results of such tests based on mm/sub-mm observations of $\sim 40$ symbiotics show that the model works for quiet, non-variable S-type systems, and eruptive, S-type systems during quiescence (M99; Mikolajewska & Ivison 1999, hereafter MI99). The only exception is CI Cyg, one of the few symbiotic systems in which the M giant shows strong tidal distortion, and loses mass via Roche-lobe overflow rather than via stellar wind. Most of these systems seem to have $0.2 \lesssim X < \pi/4$, which is consistent with cone shaped ionization front with opening angle increasing with $X$. Similar geometry is implied by studies of Raman scattered O\textsc{vi} $\lambda\lambda$ 6825, 7082 emission lines observed in many symbiotic stars (Schmid 1996). The radio observations suggest also that symbiotic giants have systematically higher mass-loss rates than do normal red giants. The hot component luminosity, $L_h$, is roughly correlated with the giant mass-loss rate, which has a natural explanation in the frame of proposed models for the hot component. Most symbiotics interact by wind accretion, and in general, the stronger is the cool giant wind the more material can be accreted by its white dwarf companion. As the expected accretion rate is a few per cent of $\dot{M}_{\text{wind}}$, only systems with low $L_h < 100L_{\odot}$ (e.g., EG And) can be powered solely by accretion. To power a typical $L_h \sim 1000L_{\odot}$, the symbiotic white dwarfs must burn H-rich material as they accrete it. The latter is possible only if the accretion rate exceeds some minimum value. In both cases, the resulting $L_h$ is related in someway to the giant mass-loss rate. The mass-loss rates derived for the symbiotic giants are sufficient to power the observed luminosities of their hot companions via wind-accretion.

3. Dust envelopes of symbiotic Miras

The near-IR colours of D-type symbiotic systems indicate presence of warm dust shells, with $T_d \sim 1000$ K (e.g. Whitelock 1987). In at least 50% of studied systems, extinction for the Mira component is grossly different from that for high excitation regions (emission lines, hot UV continuum), and in all of them, $E_{B-V}(\text{Mira}) > E_{B-V}(\text{hot})$ (e.g. M99). The hot component in these systems must therefore lie outside the dust cocoon of the Mira. Assuming a typical dust formation radius of $\gtrsim 5R_c$, and the Mira radius, $R_c \sim 2$–3 a.u., this immediately implies minimum binary separations $\gtrsim 10$–15 a.u., and periods $\gtrsim 20$ yr.

The IR light curves of well-studied D-type systems show, in addition to periodic pulsation of the Mira, significant long term variations of the mean light level (Whitelock 1987; M99). RX Pup, which light curve has been recently analyzed by Mikolajewska et al. (1999a), is typical of these. The changes have decreas-
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ing amplitude with increasing wavelength suggesting obscuration by dust. The Mira amplitude is practically unaffected indicating the changes are due only to increased extinction. In RX Pup, V835 Cen and He2-38, the changes in the reddening towards the Mira are not correlated with similar changes in the reddening towards the hot component and emission line formation region(s). The obscuration is also not accompanied by any related changes in temperature or luminosity of the hot component, and it apparently affects only the Mira. The physical nature of this phenomenon remains a mystery. In the specific case of R Aqr the obscuration was explained in terms of orbitally related eclipses of the Mira by pre-existing dust, and it has been suggested that the events in other symbiotic Miras are similarly caused (Whitelock 1987). There is, however, ample observational evidence that the dust obscuration phenomenon in symbiotic Miras cannot be, in general, orbitally related (M99, and references therein). In particular, the occurrence of similar changes in single Miras points to intrinsic variations in the Mira envelope.

The occurrence of dust obscuration phases may be related to intensive mass loss. In carbon Miras, the phenomenon seems to favour objects with moderate dust shells. The same seems to hold for symbiotic Miras. In particular, known periods for symbiotic Miras range from 280 to 578 day with a mean value of about 425 day (Whitelock 1987), much larger than the median value of 250-300 day estimated for single galactic Miras. They have also redder $K_{[12]}$ colours than average galactic Miras. This suggests that only long-period Miras, and so those with highest mass-loss rates, support symbiotic behaviour in widely separated binary systems. Symbiotic Miras with erratic IR variability have all colours between 3 and 5, and consequently $M_c \sim \text{a few } \times 10^{-6} \, \text{M}_\odot/\text{yr}$, significantly higher than a characteristic rate of $\sim 10^{-7} \, \text{M}_\odot/\text{yr}$ derived for O-rich single Miras with periods in the range of 200-400 day (Jura & Kleinman 1992).

In RX Pup and other symbiotic Miras, there is also no evidence for re-processing of the Mira light during the obscuration phase since weakening at shorter wavelengths ($J, H$) is not accompanied by brightening at longer wavelengths ($L$). The same is observed in R For and other C Miras, and can be hardly reconciled with a spherically symmetric dust ejection (Whitelock et al. 1997). The alternative scenarios involve ejection around equatorial disk or as puffs in random direction.

4. Hot component wind and geometry of resolved symbiotic nebulae

The hot components very often show evidence for some mass-loss associated with their activity, such as thermonuclearly or accretion-powered eruptions, or unstable accretion onto magnetic white dwarf. In particular, all recorded symbiotic novae eruptions were followed by a phase of intensive Wolf-Rayet-type wind from the hot component. Ejection of jets from the hot component of R Aqr and CH Cyg has been recorded in the radio and optical. There is also evidence for the existence of such winds in quiescent systems. The wind velocity is usually in the range $\gtrsim 200$–1000 km s$^{-1}$. There have been only a few attempts to estimate the mass loss rates. For the symbiotic novae, these estimates range from $M_h \sim 10^{-5} \, \text{M}_\odot/\text{yr}$ in RX Pup (Mikolajewska et al. 1999a) and $\lesssim 10^{-5} \, \text{M}_\odot/\text{yr}$ in PU Vul (Sion et al. 1993) to $3 \times 10^{-7}$–$10^{-6} \, \text{M}_\odot/\text{yr}$ in AG Peg (Vogel &
Nussbaumer 1994; Kenyon et al. 1993), and they roughly scale with their luminosity during the plateau phase. Both in AG Peg and RX Pup the intensity of the wind diminished in step with the hot component luminosity during the decline of the outburst. Similarly, the estimates of $\dot{M}_h \sim 10^{-8} M_\odot/yr$ in BF Cyg (Mikołajewska et al. 1989), $\sim 5 \times 10^{-9} M_\odot/yr$ in EG And (Vogel 1993) and $\sim 10^{-7} M_\odot/yr$ in AE Ara (Mikołajewska et al. 1999b) show some correlation with the hot component luminosity.

Whenever the wind from the hot component occurs it should collide with the cool giant wind, giving rise to high energy phenomena. In fact, among systems mentioned in this section, EG And, RX Pup, CH Cyg, PU Vul, AG Peg and R Aqr have been detected by ROSAT, and all but R Aqr show the $\beta$-type spectra that can be reproduced with the emission from a very hot, $T \gtrsim 10^6$ K, optically thin plasma possibly heated by the shocks in the collision of two stellar winds (Mürset et al. 1997). These findings are very important as the interaction of winds from the two binary components can play a major role in the final appearance of symbiotic nebulae. According to the most popular scenario, a bipolar nebula is formed under the action of a fast wind from the central object expanding in asymmetric AGB remnants. The symbiotic interacting binary system thus offer the most natural environment for production of such a bipolar nebula. The properties of dust envelopes of symbiotic Miras discussed above are consistent with the required flattened mass-loss geometry, while the presence of the fast wind from the hot component, at least occasionally, seems to be a common property of symbiotic systems.

Unfortunately, due to small relative sizes, only 17 symbiotic nebulae are thus far resolved in the optical and/or radio (e.g. Corradi et al. 1999), and only in the case of R Aqr the binary itself has been spatially resolved. Although only about 20% of all known symbiotic binaries are D-type systems with a Mira primary, most of extended, radio and/or optically resolved ionized nebulae are associated with symbiotic Miras and active S-type systems (Corradi et al. 1999). A picture gallery of these nebulae presented by Corradi & Schwarz (see Mikołajewska 1997) reveals their generally complex structure, often with bipolar lobes and jet-like components. Five of these complex nebulae, RX Pup, HM Sge, V1016 Cyg, V1329 Cyg and AG Peg, are associated with recorded symbiotic nova eruption, and two of them, CH Cyg and R Aqr, with ejection of jets.

For some systems with resolved nebulae, the orientation of the binary on the sky can be derived from polarimetric studies, allowing to distinguish between polar and equatorial outflows. The formation scenarios can be thus critically tested and revised. The scattering geometry and nebular structure are aligned in all cases although the bipolar outflow in some cases may be not perpendicular to the orbital plane (M99, and references therein).

Acknowledgments. I would like to thank the LOC for their support. This work was partly supported by Polish KBN Research Grant No. 2 P03D 021 12.

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