Mm/submm observations of symbiotic binary stars

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Abstract. We present and discuss mm/submm observations of quiescent S-type symbiotic systems, and compare them with popular models proposed to account for their radio emission. We find that the M giant mass-loss rates derived from our observations are systematically higher than those reported for single M giants.

1. Introduction

To date \(\sim 25\%\) of all symbiotic stars have been detected in the cm-wave radio band. In practically all cases, the radio emission is consistent with \(\Pi\) radiation from ionised gas (Seaquist, \& Taylor 1990). Seaquist, Taylor, \& Button (1984) proposed a simple binary model (the STB model) in which the radio emission originates from the red giant wind, partly ionized by the hot companion. The predicted radio spectrum turns over from optically thick to optically thin emission at a frequency, \(\nu_t\), which is related to the binary parameters. The observations of \(\nu_t\) in quiescent S-type systems with known orbital parameters thus provides a critical test of the STB model. Unfortunately, the spectral turnovers have been thusfar determined only in either D-type systems (with unknown orbital periods) or S-type systems recovering from nova outbursts, e.g. AG Peg (e.g. Ivison, Hughes, \& Bode 1995).

In the following, we present and discuss results of mm/submm observations of a sample of S-type symbiotic stars collected at 1.3 mm with the IRAM 30-m MRT (February 1997), and at 2, 1.3, 0.85 and 0.45 mm with the SCUBA submm camera on the JCMT (1997–98).

2. Testing the STB model

We have selected 20 S-type systems, all quiescent at the time of our observations. Most of these systems have been studied intensively in the optical and UV; binary periods are known for 14 of them, and for 7 systems we also have spectroscopic orbits. For more details we refer to Mikolajewska, \& Ivison (2001, hereafter MI01), and Mikolajewska, Ivison, \& Omont (2002, hereafter MIO).

Comparison of 1.3-mm flux densities with published H\(\beta\) fluxes (MIO) indicates that the radio emission from quiescent S-type systems is optically thick at least up to 1.3 mm, in agreement with the STB model which predicts a spectral
Figure 1. Continuum spectra of quiescent S-type systems. Circles refer to our new data, squares to old data. The spectra are split into optically thick/thin ff emission (dashed, dotted and dot-dashed curves, respectively; see text) and the giant photosphere (solid curve).

turnover at submm wavelengths for such systems (Seaquist, Krogulec & Taylor 1993, hereafter SKT93). Our mm/submm continuum spectra (Fig. 1) are also consistent with optically thick thermal emission for all systems except CI Cyg. To constrain $\nu_t$ and estimate the binary separation for these systems, the optically thin ff emission in the mm range (dotted curves in Fig. 1) was estimated using the H$\textsc{i}$ ff+bf emission measure derived from optical and UV data. The resulting binary separations are in good agreement with the values derived from known spectroscopic orbits (see Fig. 4 of MIO). The mm-wave emission also shows some correlation with the mid-IR flux, and the radio luminosity increases with the $K - [12]$ colour, which indicates that both the ionised gas and warm dust are involved in the mass flow, and suggests that the cool giant may be the source of this material. We note, however, that the consistency between the mm/submm-wave data and the STB binary model revealed by the work of MIO is not based on direct measurements of the spectral turnover, only on an optically thin emission measure inferred from optical/UV spectroscopy which, in addition, was not collected simultaneously with the radio observations.
Recently, MI01 have determined for the first time the 0.85 mm–6 cm spectral energy distribution (SED) of a prototypical S-type symbiotic system, CI Cyg, during quiescence (Fig. 1). Unfortunately, comparison of the binary separation and the Lyman continuum photon luminosity derived from this SED with the known orbital and stellar parameters of CI Cyg rules out both the STB model as well as models based on the interaction of winds from the binary companions. In particular, the \( f_f \) turnover frequency determined from the SED in a model-independent manner (Fig. 1) over-estimates the binary separation by a factor of \( \sim 36 \), while the optically thin \( f_f \) emission measure under-estimates \( L_{\text{ph}} \) by a factor of \( \sim 20 \) relative to the value inferred from optical/UV spectroscopy (Fig. 1). One possible cause of this low, optically thin radio emission is that CI Cyg is 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 a stellar wind. In such a case the bulk of the Balmer H\( _1 \) emission is most likely formed in dense material in the orbital plane (stream and/or accretion disc) whereas the radio emission and high-excitation forbidden lines arise from lower density regions in polar directions.

If the giant does fill its Roche lobe, the M giant’s wind in S-type systems is likely to be focused towards the secondary and/or towards the orbital plane. In particular, gravitational interaction of the cool giant’s wind with the secondary can produce an equatorial-to-polar density contrast as large as 100–1000, giving rise to a bipolar geometry of the symbiotic nebulae (Gawryszczak, Mikołajewska, & Różyczka 2002a). Such a geometry results in significantly different shapes of the H\( _{\beta} \) region, and the emerging SEDs, compared with their STB counterparts (Gawryszczak, Mikołajewska, & Różyczka 2002b). Moreover, in high-inclination systems with relatively low \( L_{\text{ph}} \) and high \( \dot{M}/v \) (\( X \sim 1 \) in the STB model) two radio lobes are expected. We note here that the recently resolved radio emission from AG Dra cannot be accounted for by the STB model (Mikołajewska 2002, and references therein) although MIO did not reveal any inconsistency between its SED (in particular, \( \nu_t \), Fig. 1) and the STB model.

### 3. Mass-loss rates

The M giant mass-loss rates derived from 1.3-mm flux densities, applying the WB relation (Wright, & Barlow 1975), are systematically higher than those reported for single M giants (MIO; Fig. 2). Similar results were obtained by SKT93 based on cm-wave observations and Kenyon, Fernandez-Castro, & Stencel (1988) from analysis of IRAS data. MIO also found a correlation between the giant mass-loss rate and the hot component’s luminosity, \( L_h \), which may suggest that illumination of the outer atmosphere of the giant is an important effect. The WB relation under-estimates \( \dot{M} \) if the wind is only partially ionized, which seems to be the case for most if not all quiescent symbiotic systems. SKT93 estimated the magnitude of this under-estimate based on the STB model as a factor of 2, 1.5 and 1.15 for \( X = 0.5, 1, \) and 5, respectively. In fact, the mass-loss rates can be under-estimated by a factor of 10 or more if the ionized region is highly asymmetric (Gawryszczak et al. 2002b). Since this effect increases with decreasing \( L_{\text{ph}} \propto L_h \), it can also account for the correlation between the mass
loss estimates based on spherically symmetric models (such as WB and STB) and \( L_h \).

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