THE RADIO PROPERTIES OF SYMBIOTIC STARS

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ABSTRACT. Radio thermal bremsstrahlung emission has now been detected at centimeter wavelengths from about thirty symbiotic stars. These data combined with optical and IR data show that the radio emission in most systems may be understood in terms of the ionization of part of the wind of a red giant by a hot companion. The radio properties of symbiotic stars are reviewed and the agreement with and the limitations of this picture are examined.

1. INTRODUCTION

Insofar as present studies show, all radio emitting symbiotic stars (except possibly the 1985 outburst from RS Oph) emit by free-free or thermal bremsstrahlung radiation. Therefore the size of the circumstellar environment probed in the radio is 10^{15} cm or greater, limited by the maximum brightness temperature of thermal emission from a plasma at $T=10^4$K. Thus radio observations provide information about the mass outflows on spatial scales one to two orders of magnitude larger than the binary separation for most symbiotics, typically a few AU. It is important to emphasize that the radio data are therefore complementary to the optical data on the circumstellar gas, which generally sample much smaller volumes.

Until recently, radio emission was known from only a handful of symbiotic stars. The earlier work on this subject has been reviewed extensively (Hjellming, 1981, Kwok, 1982). More recently, the VLA has made possible more sensitive surveys of these objects, and as a result radio emission has now been detected from about 30 systems to a level of about 0.5 mJy (Seaquist, et al. 1984; Seaquist and Taylor, in preparation).

2. RADIO CHARACTERISTICS

Virtually all stars in the list of Allen (1984) and reachable by the VLA have now been searched for radio emission. Table 1 contains a list

J. Mikolajewska et al. (eds.), The Symbiotic Phenomenon, 69–75.

of all known radio emitting symbiotic stars and their approximate 4.9 GHz flux densities.

Table 1 Symbiotic stars detected in the radio and approximate 4.9 GHz flux density

Name	Flux (mJy)	Ref	Name	Flux (mJy)	Ref	Name	Flux (mJy)	Ref
RX Pup	34v	2	RT Ser	0.5v	1	AS 296	0.4	1
RW Hya	0.2	1	SS 96	2.2	1	He2-390	0.5	1
He2-106	20	3	H1-36	46	3	BF Cyg	2.0	1
AG Dra	0.4	1	W16-312	1.0***	1	CH Cyg	0.4-18v	5
He2-171	1.9	1	RS Oph	<0.3-63v	1,4	HM Sge	15v	3
He2-176	15*	3	V2416 Sgr	1.5	1	V1016 Cyg	45v	3
AS 210	2.0	1	SS 122	1.4	1	RR Tel	28	3
V455 Sco	0.8	1	AS 270	0.3	1	V1329 Cyg	0.9v	1
Hen 1383	2.0v**	1	H2-38	2.9	1	AG Peg	7.5v	1
Th3-7	0.4	1	AS 289	0.6v	1	Z And	0.9v	1
Hen 1410	0.6	1	HD 319167	0.5***	1	R Aqr	12	6

Notes to table

v Flux variations detected
* Flux at 8.9 GHz
** Not in Allen (1984)
*** ID or detection uncertain

(1) Seaquist et al. (1984) and/or Seaquist and Taylor, in prep.
(2) Seaquist and Taylor (1987)
(3) Purton et al. (1982)
(4) Davis (1986)
(5) Taylor, Kenyon, and Seaquist, in preparation
(6) Hollis et al. (1985)

2.1. Angular Structure

Most of the sources in Table 1 are unresolved by the VLA, so that the angular sizes are smaller than about 1 arcsec. However some of the more intense sources show structure at arcsec or subarcsec resolution. V1016 Syg and HM Sge both exhibit shell-like structures whose diameter is about 0.3-0.5 arcsec, each containing two peaks of emission separated by about 0.1 arcsec (Newell, 1981; Newell and Hjellming, 1981; Hjellming and Bignell, 1982; Kwok et al., 1984). RX Pup has been recently found to have an angular size dependent on frequency, characteristic of a stellar wind approximating a $1/r^2$ density profile (Seaquist and Taylor, 1987). In addition, the very extended (2 arcmin) optically emitting structure surrounding R Aqr has now been detected as a source of free-free emission in the radio (Hollis et al., 1987). This material is the remnant of an outburst which occurred in this system 600 years ago.

Recently, 'jet-like' radio emission on arcsec and/or subarcsec scales suggesting collimated ejecta has been discovered in four symbiotic stars - CH Cyg (Taylor et al. 1986; Taylor, this volume), RS Oph

(Porcas et al, 1986), R Aqr (Kafatos, et al., 1983), and AG Peg (Hjellming, 1985). Such features may be related to the blobs contained within the shells of V1016 Cyg and HM Sge. These discoveries strongly suggest that accretion disks play a role in collimating episodic outflows in some symbiotic stars.

2.2. Variability

Nearly all of the objects in Table 1 have been observed at least twice over a period of one to five years, and even longer in some cases. The table shows whether or not the radio flux is variable by more than about 30 percent over a time scale of several years. Most of the sources are either quiescent or very slow variables. This signifies the presence of either a stable outflow or an outburst producing radio emitting ejecta at low velocities (<500 km/s). Several are extremely variable in the radio, however, undergoing outbursts usually associated with activity in the optical. Notable examples are V1016 Cyg (Kwok, 1982; Newell and Hjellming 1981), HM Sge (Purton et al., 1983), CH Cyg (Taylor, Seaquist, and Mattei, 1986), RS Oph (Davis, 1986; Hjellming et al., 1986), and RX Pup (Seaquist and Taylor, 1987). The increased radio emission from RX Pup signals a new enhanced mass loss phase for this object. The relationship between radio and optical variations in some of these outbursts suggest nova-like activity or accretion fed outflows, but there is an enormous diversity in this relationship. For example, unlike most cases, the visual brightness of CH Cyg actually declined at the onset of the large radio outburst which began in 1984.

2.3 Radio Spectra

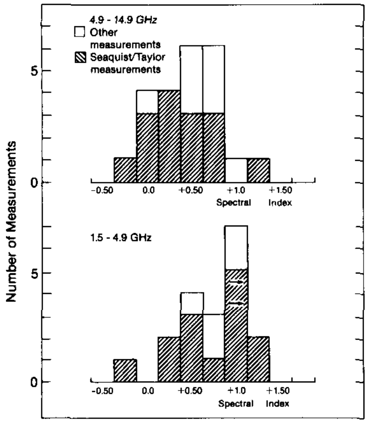

Figure 1. The distributions of spectral indices in two frequency ranges for radio detected symbiotics.

Figure 1 shows the distribution of spectral indices at cm wavelengths from observations at 1.5, 4.9, and 14.9 GHz. Essentially all sources exhibit a positive spectral index characteristic of optically thick emission from an inhomogeneous ionized region (Seaquist, et al., 1984; Seaquist and Taylor, in preparation). The horizontal arrows in the figure indicate that two of the values plotted are lower bounds. The median spectral index at the lower frequencies in near +1.0, significantly steeper than that expected (+0.6) for a steady spherically symmetric outflow at constant speed. The median index at the higher frequencies is lower (flatter spectrum), about +0.5. These results suggest a more complex geometry, and the flattening of the spectra at higher frequency indicates a transition from optically thick to optically thin emission in the cm range.

3. COMPARISON WITH IR DATA

Figure 2 shows plots of the 4.9 GHz flux vs IR magnitude for the K (2.2μm) and L (3.5μm) bands from data obtained from Allen (1982), and similar plots for 12μm and 25μm using data from the IRAS point source catalogue. D-type (dust) and S-type (stellar) IR emitters are distinguished by open and filled symbols. The principal conclusion is that a significant correlation with IR emission exists, and that it appears to strengthen with increasing IR wavelength, suggesting that the radio emission correlates best with the amount of dust in the envelope of the star. The D-type IR emitters exhibit the largest flux at both radio and IR wavelengths, and are consequently the most luminous stars at both bands. Since the D-types are generally Mira variables possessing the highest mass loss rates, and since the radio emission is optically thick, this result basically says that the surface area of the radio emitting photosphere is largest in the systems with highest mass loss rates.

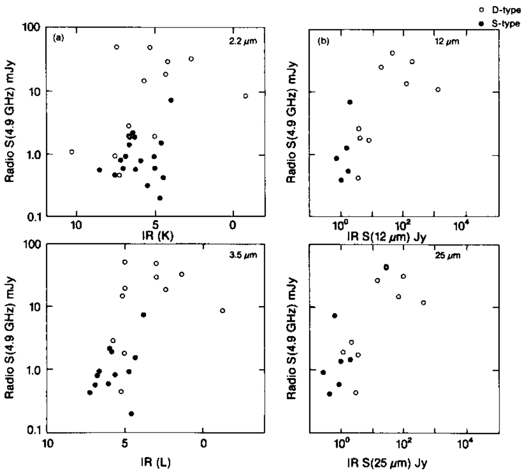

Figure 2. Plots of 4.9 GHz flux vs IR flux for various IR bands.

4. COMPARISON WITH OPTICAL DATA

Seaquist et al. (1984) showed that the radio luminosities are correlated with red giant spectral types, consistent with the aforementioned observation on the correlation with IR emission from dust, since the D-type stars, or Miras, have the latest spectral classes. These authors also showed that the radio luminosity is correlated with the equivalent width of the H beta emission line. The latter correlation is expected since both indices measure in some way the amount of ionized gas in these systems.

However, the radio and H beta emission do not necessarily arise from the same volumes. For S-type stars, the observed (optically thick) radio fluxes are an order of magnitude less than the optically thin radio fluxes predicted from the H beta line (Seaquist and Taylor, in preparation). This factor is somewhat larger than expected, since figure 1 indicates that many sources are nearly optically thin at 14.9 GHz. For D-types, the observed and predicted fluxes are comparable, suggesting that the H beta emission in the D-types emerges primarily from an extended volume comparable to that producing the radio emission. In S-types a significant fraction of the H beta emission must come from smaller volumes not detectable in the radio, such as an accretion disk, a stream between the stars, or chromospheric emission.

5. MODELS FOR THE RADIO EMISSION

A picture compatible with the binary interpretation is the binary model worked out in detail by Seaquist et al. (1984) and Taylor and Seaquist (1984), hereafter the STB model. Note the erratum to these papers in Ap.J. <u>317</u>, 555, 1987. In this picture, the hot companion to the red giant ionizes a cone-shaped region of the red giant wind, whose geometry is governed by a single parameter $X = \mathrm{const} * a\ L\ (\dot{M}/v)^{-2}$, where a is the binary separation, L is the Lyman continuum luminosity of the hot companion in photons/sec, $\dot{M}$ is the red giant mass loss rate, v is the wind speed. The application of the model to the radio data yield mass loss rates ranging from 10^{-9} to 10^{-7} $M_\odot$ yr^{-1} for S-type and 10^{-7} to 10^{-5} $M_\odot$ yr^{-1} for D-type stars, if $v = 10$ km/s.

This steady-state model accounts for a large number of the radio emitting characteristics of symbiotic stars. They include for example the steep radio spectra compared with that of spherically symmetric outflows, and the optically thin turnover at cm wavelengths, indicated in figure 1, combined with the relatively quiescent fluxes of many symbiotics.

The model also explains the coexistence of neutral gas (signified by IR emission from dust) with the ionized component, which is a consequence of a source of ionization external to the red giant wind. The model furthermore explains the observation by Kenyon et al. (1986) and Allen (1983) that in D-type systems the hot companion and the emission line region lie outside the region of circumstellar dust, whereas the Mira variable is heavily obscured.

The explanation for the correlations between radio and IR emission and spectral type is not as clear. Higher mass loss rates alone may be insufficient to produce higher radio luminosity because high densities may produce smaller ionized volumes, whereas a larger radio photosphere is required. A likely possibility is that the red giants with the most extensive mass loss reside in the widest binaries, as pointed out, for example by Kenyon (1986). A larger radio photosphere and higher radio luminosity for D-type symbiotics would be the result, as observed.

The diversity in radio morphology and the eruptive nature of symbiotic novae highlight certain limitations of the steady-state binary model, and require some variants of the STB picture. For example, account needs to be taken of the interaction between eruptive mass loss or a fast wind from the hot companion and the pre-existing red giant wind. The interaction between such a wind and mass outflow from the cool star explains the properties of symbiotic novae like HM Sge and V1016 Cyg (Kwok, this volume; Girard and Willson, 1987; Willson et al., 1984; Purton et al., 1983). Other examples include AG Peg (Hjellming, 1985), RX Pup (Seaquist and Taylor, 1987; Allen and Wright, this volume) and R Aqr (Hollis et al., 1985). If episodic outflow from the hot companion dominates the radio emission, it may be possible to recognize this by the spectrum at mm and sub mm wavelengths. The spectrum in this regime may exhibit either no optically thin turnover at all, or a turnover which evolves rapidly, signifying the expansion of an inner boundary of the shell produced when the ejection terminates. In the latter case, the decrease in the optically thin mm flux would be readily detectable even for modest shell expansion velocities (100 km/s).

6. CONCLUSION

The radio emitting properties of symbiotics stars generally support the binary picture of the symbiotic phenomenon. The application of binary models to the radio data promises to yield important constraints on the binary parameters and mass loss from these systems. The diversity of behaviour of symbiotic stars however strain the validity of the simplest form of the binary model in individual cases. Further tests for investigating the geometry of the radio emitting circumbinary nebulae include the use of mm and sub mm wavelengths to probe volumes intermediate in scale between that seen at cm wavelengths and that seen in the IR and optical region.

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