BINARITY AS A FACTOR IN STELLAR RADIO EMISSION

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1. INTRODUCTION

A simple examination of Table I which lists the 26 positively detected "active" radio stars[1] reveals that 21 are interacting binaries. Thus, on face value, membership in a close binary system would appear to be an important factor in producing conditions which favor stellar radio emission. However, this conclusion ignores the considerable biases which have characterized most of the surveys (c.f., references in Wendker 1978) made to date wherein selection criteria such as binarity itself, evidence for mass exchange, strong magnetic fields, optical activity, and similarity to previously detected systems have been cited. In very few cases (c.f., Gibson 1977) have complete samples (i.e., a uniform survey of all stars in a particular class to a given luminosity limit) been observed. Therefore, it is difficult to examine the role of binarity in stellar radio emission and draw conclusions which have statistical support. However, the body of radio star data does include observations of about 700 objects and thoughtful analyses of a carefully selected subset should reveal trends which, if they do not lead to firm conclusions, should at least point out the direction for future study.

2. SAMPLE SELECTION

The primary reference source for this study was the Catalog of Radio Stars (Wendker 1978) which includes 607 entries from 222 different references published before 1978. Stars classified as normal single stars (class 2), binaries and other multiple systems (class 3), and white dwarfs, magnetic stars, and peculiar stars (class 6) were included in the sample. Cataclysmic variables (a subset of class 4 --

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[1]An "active" radio star is herein defined to be one which has two normal stellar components (i.e., components of luminosity classes I-VII) and exhibits microwave emission which is variable on timescales of minutes to a few days.

M. J. Plavec, D. M. Popper and R. K. Ulrich (eds.), Close Binary Stars: Observations and Interpretation, 31–38.

Table I

ACTIVE RADIO STARS

Name	Spectral Types	Period (Days)	Dist. (pc)	S_{max} (mJy)	L_{max} (10^{15} ergs $s^{-1}Hz^{-1}$)
λ And	G8III-IV + ?	20.5	23	20	13
UX Ari	G5V + KOIV	6.4	55	200	720
54 Cam	GOV + G2V	11.1	38	12	21
RS CVn	F4IV + KOIV	4.8	145	7	180
σ CrB	F8V + GOV	1.1	23	57	36
RZ Eri	F5V + G5IV	39.3	105	4	53
σ Gem	K1III + ?	19.6	59	19	79
AR Lac	G2IV-V + KOIV	2.0	47	500	1300
HK Lac	F IV + KOIII	24.4	150	25	670
RT Lac	G9IV + K1IV	5.1	205	35	1800
SZ Psc	G8V + K1IV-V	4.0	100	100	1200
UV Psc	G2IV-V + KeIV-V	0.9	125	14	260
HR 1099	G5V + KOIV	2.8	33	1200	1600
HR 5110	F2IV-V + ?	2.6	52	425	1400
HD 216489	gK1 + ?	24.6	200	33	1600
HD 224085	KOIV-V +?	6.7	29	92	93
CC Cas	09IV + 09IV	3.4	1000	10	12000
β Lyr	B8IIp + ?	12.9	260	20	1600
β Per	B8V + G5III	2.9	25	1020	760
α Sco AB	M1Iab + B4Ve	?	180	10	390
R Aql	gM5e-8e		150	240	6500
π Aur	M3II		170	31	1100
α Ori	M2Iab		200	110	5300
α Sco A	M1Ib		180	2	89
YZ CMi	dM4.5e		20	120	48
UV Cet	dM5.5e		5	300	8

novae, dwarf novae, and eruptive variables) and those flare stars (class 1) for which cm-wave or interferometric observations had been made were also included. X-ray stars and emission-line stars were excluded.

In addition, recently reported surveys of the RS CVn binaries (Owen and Gibson 1978), related late-type binaries (Gibson and Owen 1979), and single G- and K-subgiants (Gibson 1977) were also included as were observations of individual stars (Davis et al. 1978; Feldman 1978, 1979; Feldman et al. 1979; Gibson 1978; Gibscn and Newell 1979). In total, 469 stars of the aforementioned classes have been observed at least once.

To form a meaningful subset of this sample, two general considerations were applied. Firstly, the sample had to be large enough to assure at least minimal statistical reliability. Since the sample is not complete -- as described above -- "large enough" was a subjective choice which depended on the types of analyses to be done. In our case, we wished to compare the radio emitting properties of the various subclasses of stars, e.g.: are double-lined spectroscopic binaries stronger radio emitters than single-lined systems? or, are giants stronger than dwarfs? Therefore, we adopted the criterion that there be about 10 systems each within luminosity classes III - V for each entry in Tables II and III.

Secondly, the working sample would need to have reasonable source-distance limits so that non-detections would be a true measure of source inactivity and, thus, a meaningul parameter in the analyses. In selecting this limit, we examined both the maximum radio luminosities of the known emitters, L_{max} (see Table 1) and the sensitivity of the radio telescopes used for the surveys. We noted that 14 of the 26 detected systems have maximum radio luminosities $\sim 10^{18}$ ergs/s^{-1}/Hz^{-1}. Assessment of the upper limits obtained in the previous surveys suggests a 20 mJy source could have reasonably been detected in most cases. These two factors were combined to set the distance limit at 200 pc. Distance estimates for the stars were obtained from the original radio surveys (e.g., Spangler et al. 1977) when possible. If not, spectroscopic parallaxes were computed from the spectral type(s), luminosity class(es), and visual magnitude using the absolute magnitudes given by Allen (1973). Applying this distance limit to the original sample resulted in the selection of 201 systems which marginally meet our first criterion.

3. DISCUSSION

The working sample is comprised of 70 double-lined spectroscopic binaries (2SB's), 78 single-lined spectroscopic binaries (1SB's), and 53 single stars. Eighty of the systems have at least one early-type (<F5) component while 131 have at least one late-type (>F5) component. Twenty-three have been detected -- CC Cas, RT Lac, and β Lyr are beyond the distance limit -- including 12 2SB's, 5 1SB's, and 6 singles. We can further break down the sample by luminosity class as shown in Tables II and III below where we tabulate the number of systems detected/number of systems observed.

Table II

SYSTEMS WITH AN EARLY-TYPE COMPONENT

		Luminosity Class				
	Total	I	II	III	IV	V
2SB's	2/26	-	-	0/4	1/3	1/23
1SB's	0/44	-	0/1	0/7	0/10	0/26
Singles	0/10	-	-	0/2	0/4	0/4

Table III

SYSTEMS WITH A LATE-TYPE COMPONENT

	Total	Luminosity Class				
		I	II	III	IV	V
2SB's	15/58	-	0/1	2/8	9/18	6/31
1SB's	5/41	-	-	3/8	2/10	0/23
Singles	6/37	2/2	1/2	1/10	0/15	2/8

Several characteristics of the working sample are immediately obvious. Most outstanding is the fact that all of the detected systems (within the distance limit) have at least one late-type component. There is now strong evidence the radio emission in many of the late-type binaries is one of a number "super solar flare" phenomena which arise near the surface of the active component (c.f., Weiler et al. 1978). The two detected systems which have both an early- and a late type component, Algol and b Per, are characterized by non-thermal radio emission which is similar in its timescales for variability, energies, and spectra to the late-type systems. Thus, there exists the unresolved question whether these systems should be classed with the late-type stars, or perhaps, with the Antares system which is discussed later.

The two other early-type detected systems are CC Cas and β Lyr (both of which are beyond the distance limit). CC Cas may be a thermal emitter. It has a somewhat longer timescale for variability compared to those of the other active radio stars and has never exhibited a non-thermal spectrum. Furtherfore, there is good agreement between its maximum radio luminosity and its excitation parameter (the luminosity of an ionization-bounded HII region). All of this suggests CC Cas may be a stellar-wind type source which undergoes variations in its mass-loss rate. β Lyr, like CC Cas, exhibits some characteristics of a stellar-wind emitter, most notably optical evidence for an expanding envelope (Sahade and Wood 1978) and a radio spectral index which is typical of an optically thick source (at cm-wavelengths) with an inverse square-law density distribution. However, the ionization mechanism for such a wind is probably not radiative since the B8IIp primary is too cool to have the required Ly-α flux to match the source's observed excitation parameter. However, collisional excitation via turbulent mass motions is a possible thermal excitation mechanism. It is also possible for β Lyr to be a non-thermal emitter whose radio spectrum appears opaque due to the large amount of absorbing gas in the vicinity of the binary. Clearly, this puzzling source must be investigated further.

Can the sample give any indication of what are the key characteristics which distinguish the active emitters from the quiscent objects? This is a very difficult question to answer because there is

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obviously interplay between a number of factors. However, there are some interesting trends in the data. For instance, the only source which clearly shows evidence for the conversion of mass kinetic energy (mass exchange) to radio emission is the wide binary Antares. In this system, particle acceleration as well as magnetic field amplification probably take place at the interface between the winds (or the wind and the magnetosphere, respectively) of the M-supergiant and the B4Ve component (Gibson 1978; Kudritzki and Reimers 1978). The question of how mass exchange plays an active role in the other active binaries is unclear. β Lyr has by far the highest rate of mass transfer of any of the systems investigated and it is a strong radio emitter which may extract its energy from the turbulent motions of mass exchange. However, in a system like Algol, which is known to undergo significant mass transfer, one has the apparent contradiction that the emission is clearly non-thermal and could be attributed to phenomena on the late-type secondary. The picture is further clouded by the fact that many of the binaries surveyed, including other Algol-type systems, early-type systems (e.g., α Vir), and cataclysmic variables show evidence for mass exchange but are not radio emitters, while the RS CVn binaries, which probably have mass exchange rates five orders of magnitude less than β Lyr, have similar radio luminosities to that system. In addition, six of the systems which do exhibit non-thermal emission are single. Thus, at present, mass exchange does not appear to play a primary role in stellar radio emission except in a few special instances. What its secondary roles might be (e.g., as a perturbation on the surface boundary conditions of a member of a close binary) remain to be investigated more fully.

Another factor which does play a role in stellar radio emission is the magnetic field, especially when one considers that 24 of the 26 detected systems are synchrotron or gyrosynchrotron emitters. In this respect, we need to consider the effect of binarity on the magnetic field both in the "passive" (i.e., as a factor in determining the structure of the radio emission region) and the "active" (i.e., as a factor in the possible storage and subsequent release of energy) sense. In examining the passive case, it is interesting to note that there appears to be a tendency for stronger emission from systems which have active components which fill or nearly fill their Roche lobes. Two examples are Algol and HR 1099. Both have been observed by VLBI (Clark et al. 1976; Cohen 1979) and apparently have sizes comparable with the system size. Likewise, observations of AR Lac with the VLA (Owen and Spangler 1977) did not reveal any evidence for radio eclipses which also implies the radio emission region is at least twice as large as the component stars. If we combine these data with the inferred magnetic field strengths determined by observations of circular polarization (c.f., Owen et al. 1976), B $\sim$ 30 Gauss, we find that the magnetic field energy density is large and should be a significant factor in the intrabinary gas dynamics. The weakest emission, of the detected cases, comes from dwarf systems (both single and binary) and evolved single-lined systems (e.g., λ And and σ Gem) which are well contained within their Roche lobes. It would seem physically possible for gas to escape from the "active" stars and drag with it magnetic field whose lines are anchored to that star. Thus, in the more active binaries the size of the radio source may correspond to the volume into which "spillover" from the active star occurs while in the less active binaries or single stars spillover may not occur and the radio emission volume may be characteristic of the volume of the star itself or perhaps something analogous to a magnetic loop anchored to its surface. Clearly there would be great benefit from a concerted effort to observe radio stars with VLBI techniques.

The question of how magnetic fields would play an "active" role in close binaries is confusing. On one hand, there is no evidence for radio emission from early-type stars with large global magnetic fields, e.g., the Ap-stars. On the other hand, relatively strong emission arises from late-type systems which exhibit phenomena usually associated with starspot activity. Thus, at present, it appears the presence of magnetic field is primarily of consequence in those systems which have stars with convective envelopes. The most obvious role it would have in those stars would be in the action of a convective dynamo. Binarity could have several effects on this activity. Firstly, it could significantly affect the rotational velocity of the star. Single late-type stars are magnetically braked as they evolve onto the main sequence and typically have rotation velocities $\sim$ 20 km/s. In close binaries where tidal synchronization takes place, this same late-type star may have a rotation velocity an order of magnitude higher. Perhaps this is one reason why the RS CVn binaries are at least 100 times more luminous than their single counterparts.

A second consequence of binarity -- tidal distortion -- may also have a marked effect on dynamo action. There is a general tendency for enhanced radio activity in systems with distorted components. Systems with subgiant or giant components, especially if the active component is the secondary, tend to be stronger emitters than dwarf systems which have more spherical components. Among the detected single-lined spectroscopic binaries, the weakest are those with primaries which are well contained within their Roche lobes. However, it is confusing at best to distinguish between tidal distortion and its implied consequence, Roche lobe spillover (and its effects) with regard to their relative importantance to the radio emission process.

Based on the available data, two other factors may be important to stellar radio emission but the role of binarity in enhancing these processes is very unclear. There is weak evidence that the maximum radio luminosity depends on the depth of the convective zone. Stars like Betelguese do have very deep convective zones and it is a very strong radio emitter at times. On the other hand, late-F and early-G main sequence stars, which have relatively shallow convective zones, are much weaker. The second factor is that stars which are likely to be in rapid phases of evolution appear to be more active (as measured by flare frequency rather than flare energy) than stars in long-lived states. There is good evidence that the components of the RS CVn systems are rapidly evolving as evidenced by their positions within or astride the Hertzsprung gap (Popper and Ulrich 1977). There is also evidence that the dMe-stars may be in the process of evolving onto the main sequence. Possibly these two factors act to affect the differential rotation, and thus the dynamo action in these systems.

4. SUMMARY

Certainly binarity is important to stellar radio emission. Gibson's (1977) observations that single late-type subgiants are at least a factor of 100 less luminous than binaries with similar components is perhaps the best evidence of this fact. However, our understanding of which specific aspects of binarity affect the radio emission process is still minimal. At present, there appear to be at least three fundamentally different types of radio binaries:

i) CC Cas-type -- thermal emitters possibly having a variable stellar winds,

ii) Antares-type -- non-thermal emitters with energy derived from shock-excitation at the collision of two stellar winds, and

iii) RS CVn-type -- non-thermal emitters with energy derived from dynamo action in the component star's convective zone.

In class i) the effect of tidal interaction on the production of a stellar wind has yet to be addressed. In class ii) the physics of interacting stellar winds including the associated instabilities requires considerable attention because it is important to other branches of astrophysics. In class iii) we have suggested that a number of factors may be important including, rotation, tidal distortion, etc. Whether or not all of these factors can be integrated onto a working model of the source is unclear. However, it is an important, if not an unenviable, task which must be addressed if we are to move to a higher level of understanding of these systems.

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