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Research Note

Interferometer observations of RS CVn binaries

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Abstract.

We present radio flux measurements at 5 GHz for a sample of RS CVn-type chromospherically active binary systems made from 1988 to 1992 using the NRAL broad-band interferometer (BBI). The derived radio luminosities are consistent with previous observations but show that radio flaring is a common feature which will affect the results of rotation-activity studies. The mean brightness temperature for our sample, assuming a radio source size equal to twice the radius of the active stellar component, is consistent with a gyrosynchrotron emission process from mildly relativistic electrons.

Key words: stars: activity - stars: late type - stars: binaries: close - stars: flare - stars: variables - stars: radio continuum

1. Introduction

Despite considerable observing effort over recent years we are still far from understanding the detailed behaviour of active stars in the radio domain. Complex coronal phenomena on the Sun can nowadays be observed in detail; however, we still cannot elucidate even the basic structures on other stars. Some information can be gained by radio observations since it is believed that radio emission occurs via gyrosynchrotron radiation from mildly relativistic electrons in magnetic fields. However the details of magnetic loop structures, flare mechanics and formation are unknown.

Drake *et al.* (1989) (hereafter D89) used the VLA to observe 6 cm fluxes of ≥ 0.2 mJy from RS CVn stars and related binaries. They were able to place constraints on the emission parameters, ie. temperature and electron density. Other surveys of active star radio emission have been carried out by Spangler *et al.* (1977) who used the NRAO 91-m dish at 6-cm to detect sources with $S_6 \geq 5$ mJy, and by Owen & Gibson (1978) who found similar emission over a range of wavelengths.

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VLBI observations have had some success in investigating the coronal structures of RS CVn binaries in the radio, particularly those of Mutel *et al.* (1985) on UX Ari which showed the radio emitting magnetosphere enveloping both stars. Other observations have shown the existence of structures on the scale of a few milli-arcseconds on other stars (Trigilio *et al.* 1993) but the detail of Mutel *et al.* has never been repeated. There is however no doubt that many active stars have radio emitting magnetospheres.

Optical observations of eclipsing active binaries (Hall & Ramsey 1992) have found evidence of complex coronal structures. Mullan *et al.* (1989) found evidence for extended, cool, high-velocity coronal condensations on V471 Tau while Houdebine *et al.* (1990) discussed a coronal mass ejection (CME) on the active single star AD Leo. Although the relationship between chromospheric and coronal activity is likely to be complicated it is believed that many active stars have magnetospheres which can be detected through their radio emission.

Observations have been made of a sample of RS CVn binaries with the BBI system at NRAL Jodrell Bank, usually during other observational programmes. This paper presents a brief summary of the entire set of unpublished observations and compares these with other estimates of radio emission from close binaries.

2. Observations and data reduction

Observations have been made intermittently from 1988 to 1992 using the NRAL broad-band interferometer (BBI) system (Padin *et al.* 1987). This instrument consists of a single baseline formed by the 76-m Lovell telescope (formally known as the MKIA) and a 25×38-m elliptical telescope of which only the central 25×25-m circle is illuminated. The BBI operates at a frequency of 5 GHz (6-cm) with a baseline length of 425-m and has a maximum resolution of $\sim$ 30 arcseconds. The large surface area of the two telescopes and the wide bandwidth of 384 MHz combine to give a good sensitivity of 2 mJy min$^{-\frac{1}{2}}$. The instrument is phase-stable, and if the target position is known to within $\sim$5 arcsec then the observed and predicted phases can be usefully compared.

Table 1. Summary of the observations and the stellar parameters of the RS CVn binaries in the BBI survey. The table lists for each system the HD number, the spectral types of the hot/cool components, the distance D in parsecs, the assumed radius of the active component in solar units, the orbital period P_{orb} in days, the BBI 6-cm radio flux S_6 and radio luminosity L_6, the brightness temperature T_b and values of the 6-cm continuum flux (L_D) reported by Drake *et al.* (1989) (D89).

Star	HD	Spectral Type	D (pc)	$R_\star/R_\odot$	P_{orb} (days)	Date	Scans	S_6 (mJy)	$\log L_6$	$\log T_b$	$\log L_D$
UX Ari	21242	G5V/K0IV	50	3.48	6.44	Oct 88	3	8.79 ± 0.41	16.42	9.03	17.08
HR1099	22468	G5IV/K1IV	33	3.68	2.84	Sep 92	2	15.93 ± 0.75	16.32	8.88	16.17
12 Cam	32357	K0III/	160	12.00	80.90	Feb 91	1	$\leq$ 1.25	$\leq$ 16.58	$\leq$ 8.12	16.23
σ Gem	62044	K1III/	56	14.00	19.60	Dec 90	1	20.41 ± 0.45	16.89	8.29	15.75
54 Cam	65626	F9IV/G5IV	38	3.14	11.07	Feb 91	1	4.96 ± 0.45	15.93	8.64	15.30
DM UMa	-	K0-1IV-III	76	1.90	7.50	Feb 91	2	2.04 ± 0.49	16.15	9.29	16.32
RS CVn	114519	F4IV/G9IV	145	4.06	4.80	Dec 91	2	1.86 ± 0.42	16.67	9.15	17.13
HR5110	118216	F2IV/K2IV	46	2.60	2.61	Feb 91	2	6.95 ± 0.54	16.25	9.11	16.73
σ^2 CrB	146361	F6V/G0V	21	1.16	1.14	Aug 92	6	6.69 ± 0.85	15.55	9.12	15.85
WW Dra	150708	G2IV//K0IV	180	3.90	4.63	Dec 90	1	$\leq$ 1.03	$\leq$ 16.60	$\leq$ 9.12	16.87
V792 Her	155638	F2IV/K0III	80	9.50	27.54	Dec 90	1	$\leq$ 0.96	$\leq$ 15.87	$\leq$ 7.61	15.75
29 Dra	160538	WD/K0-2III	185	14.00	905.90	Dec 90	1	$\leq$ 1.16	$\leq$ 16.68	$\leq$ 8.08	17.50
MM Her	341475	G2/K0IV	190	2.83	7.96	Dec 90	1	1.38 ± 0.38	16.78	9.57	16.62
V815 Her	166181	G5V/[M1-2V]	36	0.89	1.81	Dec 90	2	17.97 ± 0.37	16.45	10.25	15.38
BY Dra	234677	K4V/K5-7V	16	-	5.98	Sep 92	6	2.69 ± 0.86	14.92	-	-
V478 Lyr	178450	G8V/[dK-dM]	46	0.87	2.13	Dec 90	1	2.80 ± 0.43	15.85	9.67	15.50
HR7275	179094	K1IV-III	90	7.00	28.60	Dec 90	1	2.05 ± 0.40	16.30	8.31	15.96
RT Lac	209318	G5:/G9IV	205	3.40	5.07	Dec 90	1	$\leq$ 1.14	$\leq$ 15.91	$\leq$ 8.54	16.87
AR Lac	210334	G2IV/K0IV	50	2.81	1.98	Sep 92	15	1.98 ± 0.43	15.77	8.57	16.30
λ And	222107	G8IV-III	25	7.00	20.52	Dec 90	1	30.71 ± 0.93	16.36	8.37	15.18
II Peg	224085	K2-3V-IV	26	2.30	6.72	Sep 92	54	2.76 ± 0.75	15.35	8.32	15.77

Our sample consists of 21 close binaries which have been classified as RS CVn-type systems (Hall 1976). Most observations consisted of a single scan of 30-40 minutes duration and contained complex visibility data at 20 second integrations. Some sources were observed regularly over a range of hour angles. The flux density calibration was made to within ± 5 % by observing VLA calibrators such as 3C286 and 3C48 and using the flux density scale of Baars *et al.* (1977). Phases were also calibrated in order to determine whether the signal was originating at the target position or from a confusing source within the beam of the Lovell telescope. The noise level varies mainly as a function of gravitational distortion of the Lovell telescope at low elevation angles, and due to atmospheric inhomogeneities, but was typically 0.3-1.0 mJy for a full scan. Common practice has been followed in setting a detection threshhold at the 3σ level since the interferometer indicates the position of the source to within a few arcseconds (Spencer *et al.* 1993). For multiple observations we have decided to follow D89 and form a geometric type mean flux $< S_6 >$ such that,

$$< S_6 >= 10^x \quad \text{where} \quad x = \frac{1}{n}\sum_{i=1}^{n} \log_{10} S_6^i \qquad (1)$$

Since the geometric mean does not give undue importance to large values of the variable this will tend to decrease the effect of possible flaring activity during the observations. Upper limits for the non-detections are given at the 3σ level and where more than one measurement has been combined the noise levels are similarly combined and compared to the 3σ level. For those sources with multiple scans no significant flux variations were found. Details of the observations and various stellar and systemic parameters are shown in Table 1.

3. Results and discussion

The radio emission mechanism involved in the coronal environments of radio stars is far from clear but is most often attributed to either gyrosynchrotron emission (Owen *et al.* 1976), synchrotron radiation (Mutel *et al.* 1985) or the electron-cyclotron maser (Melrose & Dulk 1982). It now seems that the latter two mechanisms are to be associated with compact regions of activity giving rise to a *flaring* phase with $T_b \geq 10^{10}$ K. The *quiescent* levels of activity are more often associated with gyrosynchrotron emission ($T_b \sim 10^{8-9}$ K) from mildly relativistic thermal or non-thermal populations of electrons. In an extensive study of radio continuum emission and the X-ray properties of RS CVn and related binaries D89 (and Drake *et al.* 1992) suggested that only the radio flaring component of the gyrosynchrotron emission should be attributed to non-thermal electrons and the non-flaring basal flux is a *thermal* gyrosynchrotron process. An observational test for distinguishing between a thermal or a non-thermal (power-law) population of electrons is that S_ν should decrease as ν^{-8} for thermal electrons at $\nu \geq \nu_{peak}$ rather than $S_\nu \sim \nu^{-\alpha}$ with α = 0.5-5. Without extensive observations of polarization and multi-frequency fluxes from RS CVn systems it is impossible to distinquish with any certainty the thermal or non-thermal nature of the electron population. Drake *et al.* (1992) discuss this problem in depth.

The brightness temperature of a radio source is related to the flux density S by,

$$S = \frac{2k\nu^2}{c^2} \int T_b d\Omega \qquad (2)$$

where $d\Omega$ is the differential angle and the integral is over the projected area of the source and $\nu = 5\ 10^9$ Hz is the observing frequency. Some observers (eg. Mutel *et al.* 1985; Lestrade *et al.* 1984) have been able to deduce the source sizes directly from visibility measurements whereas others have used a projected area equal to the overall size of the binary system (Owen & Gibson 1978). Direct measurements using VLBI techniques by Lestrade *et al.* (1984) showed that the radio emission originated from a region several times the size of an individual star but other VLBI observations suggest the active corona can be as large as the entire binary system (Trigilio *et al.* 1993), typically 2-30$R_\star$. Without any knowledge of the size of the emission region we have followed D89 in setting a lower limit to the source size of $2R_\star$ where $R_\star$ is the stellar radius of the active component. Our estimates of brightness temperature require knowledge of stellar angular diameters. In order to remain consistent with the results of D89 we have used their values for the distances and radii of the active components. Some radii are therefore estimates based on luminosity class and the radii used in the calculations are the rms values for both the hot and cool components. Distance estimates are based primarily on spectroscopic parallaxes. Table 1 shows luminosities and brightness temperatures calculated using standard relations. For comparison the 6-cm luminosities reported by D89 are also given.

We are able to directly compare the BBI results with the VLA data. Inspection of Table 1 shows that our luminosity measurements differ from those of D89 by a factor between 0.1 and 60. However the mean variation is a factor of 1.05 which shows that they are consistent but that both the BBI and D89 fluxes have been affected by flaring activity. Slee *et al.* (1987) questioned the existence of a true quiescent emission level which is independent of flare emission. Many authors (Morris & Mutel 1988; Slee & Stewart 1989; D89) examine the correlation of radio luminosity with stellar parameters such as rotation period, in an attempt to find evidence of dynamo-induced activity. However the uncertainty in the flare state of the RS CVns would immediately conceal any such correlation. We suggest that short-term monitoring observations of active chromosphere stars is inadequate for rotation-activity studies. For those stars where our data differ most from the D89 results further observations are required.

D89 found typical brightness temperatures in the range 10^7-10^{10} K. The mean of our sample is $10^{8.8}$ which is consistent with temperatures expected from gyrosynchrotron emission from mildly relativistic electrons. Mutel *et al.* (1985) inferred $T_b = 10^{8.9}$ from the halo component of the UX Ari system and $T_b = 10^{8.3}$ for HR1099. A mean brightness temperature for a sample of 153 active chromosphere stars (including Algol-type and AM Her binaries) observed with the Parkes 64-m dish by Slee *et al.* (1987) was $10^{8.9}$ if the difference in assumed source size is taken into account. It therefore appears that although a range of brightness temperatures of three orders of magnitude or more is observed in active close binaries the mean value is remarkably consistent. Although the mean brightness temperature is consistent with incoherent gyrosynchrotron radiation (Dulk 1985) several sources show emission close to or above the limit where this mechanism becomes unlikely ($T_b \sim 10^{10}$). In these cases it may be appropriate to invoke a coherent mechanism such as cyclotron maser emission (Chanmugam 1987). Alternatively the source sizes may be much larger than an individual component as implied by the results of Lestrade *et al.* (1984).

4. Conclusions

We have presented 6cm continuum fluxes for a small sample of RS CVn-type active chromosphere binary systems. These systems have been observed previously in a VLA survey and the present results are consistent with those measurements. However the variation in radio flux shows that flare activity may be a significant factor in rotation-activity studies. A gyrosynchrotron emission process can be successfully invoked for the radio emission although no conclusions as to the thermal or non-thermal nature of the electron population can be made without spectral information. In some cases a coherent process may be necessary to explain the high brightness temperature unless the source sizes are much larger than assumed.

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