A 6 CENTIMETER RADIO SURVEY OF SHORT-PERIOD ACTIVE BINARY STARS

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ABSTRACT

We have observed 13 binaries with periods in the range of 0.2–2.0 days at 6 cm wavelength with the VLA. Eight out of these 13 systems were detected, of which seven are RS Canum Venaticorum systems and one is an Algol system, with observed fluxes in the range of 0.3–5.0 mJy. We briefly discuss the individual characteristics of the detected sources. As a group, relative to active binaries of longer orbital periods, the short-period active binaries have a slightly lower mean radio luminosity. There is also a clear correlation of high radio luminosity with high x-ray luminosity evident in these short-period systems, although we cannot determine a functional dependence from noncontemporary data.

I. INTRODUCTION

The RS CVn binaries (see reviews by Hall 1976, 1981; Linsky 1984) are systems with orbital periods between one and 20 days, with an F or G main sequence or subgiant primary, and a somewhat cooler G or K main sequence or subgiant secondary component. These synchronously rotating systems exhibit strong Ca II H and K emission indicative of enhanced chromospheric activity. Hall (1976) also defined a related class of binary systems—the short-period RS CVn group—as consisting of those systems with properties similar to the regular class, except that their periods are less than one day and they are not contact systems. After these classes were defined, extensive observations have shown them to be extremely luminous in x rays (e.g., Walter et al. 1980; Walter and Bowyer 1981) and in ultraviolet emission lines formed at 10^4 K (e.g., Simon and Linsky 1980), indicating that the enhanced chromospheric emission relative to similar single stars is accompanied by enhanced coronal and transition-region emission.

Radio continuum emission was detected from RS CVn systems even before the class was defined; for example, the detection of AR Lac by Hjellming and Blankenship (1973) and UX Ari by Gibson, Hjellming, and Owen (1975). This emission is a common, but not universal, property of the regular class of RS CVn’s (Spangler, Owen, and Hulse 1977; Collier et al. 1982; Feldman 1983; Mutel and Lestrade 1985). The strength and variability of the radio emission, VLBI estimates of the brightness temperature, and the presence in some cases of measurable circular polarization indicate that the emission is nonthermal, most likely gyrosynchrotron radiation from mildly relativistic electrons (cf. Owen, Jones, and Gibson 1976; Spangler 1977; Mutel et al. 1985).

The radio properties of the short-period systems (hereafter referred to as SP RS CVn’s) heretofore were poorly known. Of the eight SP RS CVn’s in the Hall, Zellik, and Nelson (1984) catalog, only one (UV Psc) has been detected previously as a radio source (Spangler et al. 1977). In their recent compilations of radio data for the regular class of RS CVn’s, Mutel and Lestrade (1985) list only one additional system—\( \alpha^2 \) CrB—in the period range 1 day < P < 2 days as a detected radio source. In a more recent paper, Turner (1985) presented 12 cm detections of both \( \alpha^2 \) CrB and DH Leo, a binary of similar period.

We have recently completed a 6 cm NRAO VLA survey of the SP RS CVn class, observing seven of the eight systems listed in the Hall et al. (1984) catalog with periods less than 1 day, together with two additional systems (HD 8358 and V772 Her) that may belong to this class. We have also observed two RS CVn systems with periods between 1 and 2 days (DH Leo and HD 166181), one Algol system of similar period (RZ Cas), and one contact W UMa system (XY Leo). We will incorporate these data into a broader study of active late-type binaries of periods from 1/4 day to 150 days (Drake, Simon, and Linsky 1986), but we feel it is useful to discuss the radio properties of the shorter-period systems separately, as our observations greatly augment the existing published data. In Sec. II we give the results of our survey—seven definite detections, one possible (3\sigma) detection, and five nondetections—and discuss the detected systems individually. In Sec. III we discuss the significance of these results and briefly compare the radio properties of the SP RS CVn and regular RS CVn classes, together with those of semidetached systems and contact systems of similar period.

II. OBSERVATIONS

The majority of the observations were made during a 21 h run with the VLA in a B/C hybrid configuration on 1985 June 14–15. SV Cam and ER Vul were observed in the A configuration on 1984 November 6 and 1985 January 17, respectively. All observations were made at 6 cm with 100 MHz bandwidth. The data were calibrated and flagged using the standard NRAO software and closure criteria, and maps were constructed using the AIPS software package. Since the typical integration time on source was about 45 min, typical detection levels at 3\sigma, where \( \sigma \) is the rms noise, were \( \sim 0.2 \) mJy.

Our criterion for determining that a star is a definite radio source was that a feature of strength >4\sigma must be present within the combined error circle of the adopted optical position. The VLA positions of the detected radio sources are accurate to \( \sim \pm 0\!.2 \) (standard deviation) for the 6 cm observations in the B/C hybrid array, and \( \pm 0\!.1 \) for the A array observations. The major uncertainty in the identification is due to the probable error in the published optical positions.
positions of the systems. All the stars detected in the present survey are in the SAO catalog; thus, we have required in general that the radio source be within 1°-2° of the computed 1985 era SAO position. In discussing the individual sources below, we will explicitly mention positional information only for those sources where the radio and optical positions differ by more than 1 arcsec (HD 8358, V772 Her, and HD 166181).

The results of this survey of active binaries are presented in Table I, together with additional pertinent information on the observed systems: the Hall et al. (1984) catalog numbers or binary type for non-RS CVn systems, spectral types, orbital periods ( = rotational periods for these synchronized systems), visual magnitudes, and proper motions quoted in the SAO catalog. In Table I, together with additional pertinent information on the observed systems: the Hall et al. (1984) catalog numbers listed in the catalog of Hall et al. (1984).

We have estimated the distances of the systems using spectroscopic parallax techniques. Comparison with the Hall et al. distances show generally good agreement (≈25%). The x-ray data were obtained from a variety of sources: the four upper limits are from the HEAO-1 low-energy (0.15-2.8 keV) detector observations of Walter et al. (1980), while the radio source be within 1°-2° of the computed 1985 era SAO position. In discussing the individual sources below, we will explicitly mention positional information only for those sources where the radio and optical positions differ by more than 1 arcsec (HD 8358, V772 Her, and HD 166181).

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The inferred radio luminosity of this source ($3 \times 10^{16}$ erg s$^{-1}$ Hz$^{-1}$) makes UV Psc the most luminous 6 cm radio source we detected. This source was previously detected by Spangler et al. (1977) at levels from < 3 mJy (their detection limit) up to a 14 mJy maximum, an order of magnitude greater than the level of our detection.

d) UV Psc ($\equiv$ HD 7700)

This interesting system has been recently discussed by Stern and Skumanich (1983), who find it to be both a strong x-ray source and to have unusually strong ultraviolet emission lines. They identify this activity with the 09879 spectroscopic binary (GO V + M0 V) (the "primary") in this triple system rather than the fainter G5 V star 0.5 away on the basis of the unusually large rotation rate of $v \sin i = 75$ km s$^{-1}$ for the GO V star. We find a 1.0 mJy radio source 1° south of the 1985 SAO position of the primary (including proper motions only). Since the optical position of the spectroscopic binary relative to the secondary in the 20.1 yr visual binary (ADS 11060) is about the same in 1985 as 1950 (epoch of the SAO Catalog), we regard our measurement as a definite detection and assume, following Stern and Skumanich, that the spectroscopic binary is the radio source. This is supported by the inferred radio and x-ray luminosities of V772 Her, which are consistent with those of the other SP RS CVn's. We believe the 1° positional difference is due to errors in the SAO Catalog.

e) V772 Her ($\equiv$ HD 165990A)

This 1407 period binary was detected as a 0.77 mJy (10σ) radio source, implying a 6 cm luminosity just under $10^{15}$ erg s$^{-1}$ Hz$^{-1}$, which is the lowest of any of the detected sources. DH Leo was also detected recently by Turner (1985) as a 2.2 mJy source at 12 cm using the Arecibo interferometer.

f) DH Leo ($\equiv$ HD 86590)

This 120 period binary is an Algol system with an A2 V primary, and so is excluded from the RS CVn class by Hall's (1976) requirement that the hotter component be spectral type F or G. The prototype of the Algol class is known to be an active radio source, flaring up to flux densities of 1 Jy at centimeter wavelengths on at least one occasion (Gibson, Viner, and Peterson 1975). RZ Cas itself is a fairly strong x-ray source (McCloskey and Kondo 1984), and thus was included in the present radio survey. RZ Cas was detected as a 1.4 mJy radio source, implying a luminosity at 6 cm similar to the other detected SP RS CVn systems.

g) RZ Cas ($\equiv$ HD 17138)

h) HD 166181

III. DISCUSSION AND CONCLUSIONS

Of 11 RS CVn and RS CVn-like binaries with periods between 0.5 and 1.8 days, we have definitely detected seven as 6 cm radio sources with an average radio luminosity log $L_6 = 15.7$. The four nondetected SP RS CVn systems have 3σ upper limits in the range log $L_6 = 15.3$–15.5. These numbers may be compared with the average value of log $L_6 = 16.1 \pm 1.0$ found for all RS CVn systems observed at radio wavelengths by Drake et al. (1986). Thus, radio emission appears to be as prevalent in the shorter-period RS CVn binaries as in the regular and long-period RS CVn's, although perhaps at a slightly lower level on the average. In addition to the RS CVn's, we have also detected the Algol system RZ Cas but failed to detect the W UMa system XY Leo. The radio luminosity of RZ Cas is comparable to that of the SP RS CVn's, which suggests that (a) Algos will be a fruitful source of new stellar radio sources, and (b) Algos and RS CVn's share a common origin or explanation for their radio activity.

The extreme activity levels in RS CVn systems are believed to be correlated with the rapid rotation enforced on the components as tidal torquing synchronizes their rotation rates with their orbital motion. The interaction between the turbulent convection in the envelopes of these cool stars and the rapid rotation presumably results in strong dynamo-generated magnetic fields which, in turn, are responsible (by analogy to the solar case) for the enhanced levels of "activity" manifested in the chromospheric and transition-region emission lines and in the strong levels of x-ray and radio emission. The situation for Algol systems, on the other hand, is much more uncertain; it has been suggested, for example, that the radio emission of β Per is due to mass loss and/or transfer from the cool component (e.g., Florkowski 1980). There is general agreement, however, that the x-ray emission in Algos, although perhaps somewhat weaker than in RS CVn's, mostly originates in the same type of region, namely, the corona of the cool, somewhat evolved component (e.g., White et al. 1980; White and Marshall 1983). Our detection of RZ Cas as a 6 cm source with log $L_6 = 15.96$, typical of RS CVn's, together with Gibson's (1985) finding that the radio emission properties of Algol itself are indistinguishable from those seen in RS CVn's, suggest that the two classes comprise a single class of radio sources.

The low upper limit of 14.55 to the radio luminosity of the contact binary XY Leo confirms the finding by Hughes and McLean (1984) that W UMa systems are not, in general, detectable as radio sources with the VLA. (They detected only one definite and one possible source at 6 cm out of 12 W UMa systems observed down to 3σ detection levels of 0.1–0.2 mJy.) Thus W UMa's seem to be at least one order of magnitude less luminous than similar period RS CVn's at centimeter wavelengths. They are also weaker x-ray sources than RS CVn's; Crudace and Dupree (1984) find values of log $L_x \sim 29$–30 for W UMa systems, whereas RS CVn's have log $L_x$ values in the range 30–32.

Finally, we note that even in our small sample of binaries a correlation between x-ray and radio emission is apparent; this correlation is strongly confirmed in the study of the whole range of RS CVn's (Drake et al. 1986). Of eight systems detected at 6 cm, four have measured Einstein fluxes in soft x rays which average $10^{-11}$ erg cm$^{-2}$ s$^{-1}$. Of the five radio nondetections, two have measured x-ray fluxes at $2 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, significantly lower than for the radio sources. Since the x-ray emission from active, late-type
stars is generally believed to be thermal emission from coronal plasma at \( \sim 10^7 \) K, the reason for correlation with the (nonthermal) radio emission is not yet clear. However, the continuous hard x-ray variability seen in the solar corona (Lin et al. 1984) and the approximate equality of flare and "quiescent" x-ray energies in dMe stars (Doyle and Butler 1985; Skumanich 1985) suggests that stellar coronae may be heated largely by flare (nonthermal) events of all scales. Whatever the causal relationship, it is clear that radio emission is prevalent in the SP RS CVn binaries and is strongest in those systems that have the highest (observed) x-ray fluxes.

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