# PROPERTIES OF STELLAR MAGNETIC FIELDS IN CLOSE BINARIES DEDUCED FROM NON-THERMAL RADIO OBSERVATIONS

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ABSTRACT. Analysis of VLA and VLBI observations of non-thermal radio emission from close binary stellar systems can produce reliable estimates of magnetic field strength and geometry in the source emission region. Assuming a gyrosynchrotron emission model for the non-flare emission, one can model the magnetic field as a relatively small number of stable magnetic loops of overall size $R \simeq (1\text{-}3)\text{x}10^{12}$ cm. with an average field strength of $10^1 < B < 10^2$ gauss. A correlation of mean fractional circular polarization with inclination angle along with an absence of any clear phase dependence, indicates that the loops are azimuthally symmetric with poles nearly orthogonal to the orbital plane, i.e. *axisymmetric dipolar*. The loops are probably the same as the loops derived from observations of x-ray emission of 'hot' ($T \simeq 10^7$K) coronal gas.

## 1 INTRODUCTION

Observations of non-thermal radio emission from late-type stars during the past several years has yielded an unexpectedly rich variety of interesting physics. There is now good evidence that several non-thermal emission processes are active, e.g. gyroresonant emission (Linsky and Gary 1983), gyrosynchrotron emission (Owen, et. al. 1976; Borghi and Chinderi-Drago 1985), and occasionally even coherent emission (Melrose and Dulk 1982; Lang, et. al. 1984). Recently, a series of VLBI observations of close binary systems (Lestrade et. al. 1985a and references therein) have allowed measurement of the spatial structure and brightness temperature of both quiescent and flare emission. In addition, long-term monitoring of all four Stokes parameters of several RS CVn binaries using the VLA (Mutel and Lestrade 1985; Mutel, et. al. 1985a) has revealed several correlations between mean circular polarization and other observables, such as observing frequency and orbital inclination.

These observations, when combined with simple theoretical models of the emission processes, allow reliable estimates of both the number

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density and energy spectrum of emitting particles, as well as strength and geometry of the magnetic field. In this paper, I will summarize the relevant radio data from close binaries with the aim of deducing the properties of stellar magnetic fields in regions cospatial with the radio emission.

## 2 CIRCULAR POLARIZATION OBSERVATIONS

Stellar gyrosynchrotron sources often possess a significant degree of circular polarization ($\pi \simeq 0.1$). Since the value of $\pi$ is determined in large part by the magnetic field strength and geometry, measurements of $\pi$ as a function of spectral type, binary phase, etc. provide a powerful technique for directly probing stellar magnetic fields. The relationship between $\pi$ and the ratio of observing frequency to magnetic field strength for an optically thin source is (Dulk 1985):

$$\pi \simeq 1.8\ (\nu/\nu_B)^{1.16}$$

In the above, we have assumed an mean viewing angle $\theta \simeq 45$ degrees, and an electron energy spectral index $\delta \simeq 3$. For typical value of $\pi \simeq 0.1$ at an observing frequency $\nu \simeq 1.4$ GHz, the magnetic field is $B \simeq 30$ gauss.

Detailed observations of the properties of close binaries have shown several interesting correlations. For example, there is a consistent helicity reversal between 1.4 and 4.9 GHz for several RS CVn systems (figure 1).

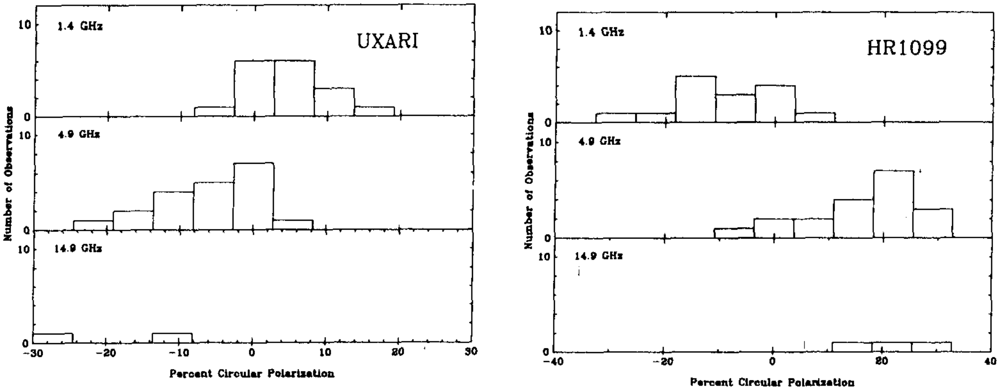

Figure 1. Histogram of fractional circular polarization at 1.4 ,4,9 and 15 GHz for the close binaries UX Arietis and HR1099 (from Mutel, et.al. 1985a). Note the reversal between 1.4 and 4.9 GHz in each system. Data are from VLA observations from epochs 1982.5 to 1985.6

The reversal is probably caused by a combination of optical depth effects (changing from x-mode to o-mode as the source becomes optically thick) and magnetic field gradients along the line of sight. The observed reversal is quite stable in time, spanning nearly 10 years in the case of HR1099 (Mutel, et. al. 1985a) . This implies that *the overall field* *geometry is stable over many hundreds of revolutions of the system.* This stability probably rules out strongly interacting magnetospheres, except perhaps in isolated cases associated with flare events.

Another correlation, shown in figure 2, is between $\pi$ and orbital inclination.

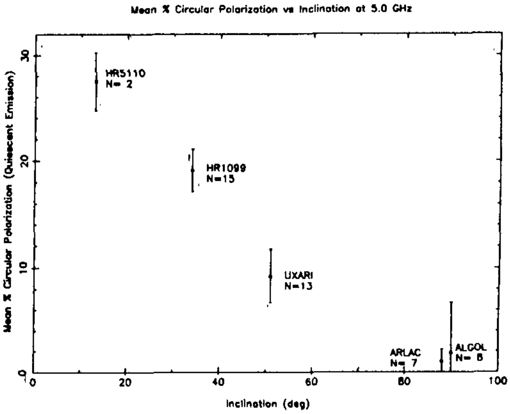

Figure 2. Fractional circular polarization versus orbital inclination angle for six close binaries (Mutel, et. al., 1985a).

Since the eclipsing systems are least polarized, while those which are most nearly pole-on are most polarized, it appears that the polar regions are producing oppositely polarized emission which cancels for observers in the equatorial plane. This suggest a dipolar geometry aligned with the rotation axis. The absence of phase dependence, either on the total intensity or on $\pi$, indicates that the field is nearly azimuthally symmetric.

## 3 VLBI OBSERVATIONS

An ongoing series of high angular resolution observations of the radio emission from several nearby close binaries has shown that the angular size of the non-flare emission is almost always about the size of the binary system. (Lestrade, et. al., 1985a). Furthermore, the observed brightness temperature at a given frequency can be used to infer the average strength of the magnetic field, which lies consistently in the range $10 < B < 100$ Gauss (Lestrade, et. al. 1985b). The flare emission, on the other hand, arises from compact self-absorbed synchrotron sources ($r \simeq 10^{10}$-$10^{11}$ cm.), probably associated with active regions (Mutel, et. al. 1985b). Dual polarization VLBI observations support this model by showing that the polarized emission arises from the large-scale, partially opaque 'halo' regions while the unpolarized component arises from a compact, optically thick 'core'.

## 4 CORONAL MAGNETIC FIELD MODELS

The radio data suggest that stable, large-scale ($r \simeq 10^{12}$cm.)

magnetic structures exist whose geometry is nearly phase independent and symmetric about the equatorial axis of the system. Occam's razor leads us to the conclusion that the dominant geometry is that of a simple dipole centered on the active star. These structures are probably the same as the 'hot' coronal loops inferred from x-ray observations (e.g. Barstow 1985), based on the agreement in overall size and the equipartition of magnetic and thermal electron gas pressures ($P \approx 10^2$ dynes/cm$^2$). The (mildly) relativistic radiating electrons form a tiny (≃1%) tail superposed on the thermal energy distibution.

A alternate geometry is that of a joint magnetosphere between the two stars, as suggested by Uchida and Sakurai (1983). This geometry appears less likely for two reasons. First, two rapidly rotating *single* stars have recently been detected (Mutel and Morris, in prep.) whose radio characteristics appear similar to the active binaries. Second, one would expect some systematic variation of polarization with orbital phase, which is not observed.

Another alternative is that of Gibson (1983), who suggests a 'leading-following' spot model for active regions near the surface of the active star, similar to that actually observed on the sun. (In fact, the model was first proposed by Kundu and Vlahos (1979) for solar microwave bursts). Since there is an asymmetry in the effective area at the feet of loops associated with active regions, a net circular polarization can occur because the strength of the B-field is larger at one foot, changing the gyro-frequency. If one assumes that there are an equal number of northern and southern hemispheric active regions, the net polarization will be a function of inclination angle, as observed (figure 2). The model appears unlikely for the non-solar case for two reasons. First, the observed VLBI source size of the non-flare emission is nearly always significantly larger than the size of the active star. Secondly, the overlying thermal plasma from the x-ray emitting gas would be optically thick at decimeter wavelengths, so that 'seeing' down to many active regions would be impossible.

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