Radio Emission from Starspots on RSCVn Binary HR1099

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Abstract: Properties of the microwave emission from HR1099 are examined in an attempt to determine whether the emission arises as gyro-synchrotron radiation from mildly relativistic electrons trapped in magnetic fields above starspots on the active K subgiant component. It is shown that radio curves do not exhibit a systematic variation in phase with the rotation rate, as one might expect for emission from a source situated above a long-lived starspot. However, there is some evidence that the radio flaring occurs at two preferred longitude zones. Whether these zones agree with spot locations remains to be determined by light curve modelling. What we can say with confidence is that the measured spectral index of the microwave emission does not fit a simple gyro-synchrotron source model, such as that proposed to explain the observed reversal with frequency of the sense of circular polarization.

Introduction

A number of chromospherically active late-type stars are thought to be spotted (see review by Vogt 1981). Such stars include the BY Draconis types, UV-Ceti-type flare stars, and RS Canum Venaticorum (RSCVn) types. RSCVs are binary systems consisting of a late G, early K subgiant or giant which has evolved from the main sequence, and an F or early G main-sequence companion. The evolved K (or G) star shows strong chromospheric activity and light variations which migrate slowly with respect to orbital phase. (It is assumed that the two stars are close enough to be tidally locked so that the mean-latitude rotation rate is comparable to the orbital period.) Spot sizes of 10% to 40% of the stellar disc are indicated by the light amplitude variations. The change in phase is thought to be due to spots forming at different latitudes where differential shear changes the rotation rate. Large spots can last for hundreds of rotations, unlike the largest sunspots, which last only a few rotations.

For the star HR1099, also known as V711 Tauri and HD22468, light variations over the period 1976 to 1981 have been reported and interpreted to indicate the presence of two large starspots separated by longitudes ranging from 90° to 140° (Dorren and Guinan 1982; Bartolini et al. 1983). A systematic phase decrease in the light curve minimum has been attributed to the migration of the spots towards higher latitudes where the rotation rate would be slower (if the solar analogue is correct). Detailed Doppler-modelling by Vogt and Penrod (1983) for a period in late 1981 gave the spot shapes and locations shown in Figure 2(c) (to be discussed later). A more recent observation by Gondoin (1986) in late 1983 also gave a two-spot model, but with both spots at high (~60°) latitudes. We are now awaiting an interpretation of the 1986 light curves.

HR1099 was first detected at radio wavelengths in 1976 (Owen et al. 1976) and during February/March 1978 it underwent a period of sustained flaring which aroused considerable attention (Feldman et al. 1978). The derived brightness temperature of the radio flare, assuming a source size comparable to the active stellar diameter, was ~10^{10} K, consistent with gyro-synchrotron emission from mildly relativistic (~1 MeV) electrons. Since then the star has been moderately active, except for occasional intense outbursts. Several peculiar properties of the radio emission aroused our interest in this star. Firstly, it was reported by Mutel et al. (1985) that the sense of circular polarization of this RSCVn, and also of another (UX Arietis), almost always reversed between 1.4 and 5.0 GHz. Mutel et al. interpreted this result to mean that gyro-synchrotron emission arose from a source which was optically thick at 1.4 GHz but optically thin at 5.0 GHz. If this were so, then on a simple source model the radio spectrum should turn over at a frequency between 1.4 and 5.0 GHz. Secondly, a VLBI observation at 8.4 GHz of a strong radio outburst (of ~400 mJy total flux) determined the angular size of the source as ~7.5 milliarcsec, corresponding to a linear size, at the 35 pc distance of HR1099, of ~4.0 \times 10^{11} cm.
Radio Observations at Parkes and Fleurs
Monitoring of HR1099 commenced at Parkes in 1981 at a frequency of 5 GHz with five observations being made in that year, four in 1982 and two in 1984. Later in 1984 two observations were made at 22 GHz and another two at 8.4 GHz just before the installation of the ESA 8.4 GHz masers, whose primary function was to monitor the Giotto probe to Halley’s comet. These masers were operated in a noise-adding-radiometer mode by the addition of a switched noise source placed at the focus of a small sub-reflector near the centre of the Parkes dish. This sub-reflector provided the injection of noise direct into the feed horn at the focus of the dish. As with the earlier 8 GHz system, both left-hand and right-hand circular polarization components were measured. Since August 1984 32 detections of HR1099 have been achieved, with significant circular polarization present on 21 occasions.

Monitoring at Fleurs began in September 1985, with 32 synthesis observations being made at 1.4 GHz over six months. This work was made possible by the automation of the six-dish array (Bunton et al. 1985), which reduced the manpower required for observing by more than an order of magnitude. No polarization measurements were possible because only one linearly polarized component was measured, but the total flux of the source is correctly determined because the polarization is known to be circular.

The results of all these observations are shown in Figure 1. Simultaneous observations were made at 1.4 and 8.4 GHz on nine occasions.

Discussion
An initial inspection of the raw data shown in Figure 1 reveals that, contrary to what one might expect for radio emission from a long-lived star-spot with sustained flaring, there is no sign of significant modulation effects at the rotational period of 2.84 days. Radio emission was always observed on the days in question, and this implies that a continuously active region (or regions) was always in view. This is consistent with the two-spot models proposed for the primary star in 1983 (Gondoin 1986) and in 1981 (Vogt and Penrod 1983). In both models there is at least one spot at or near the north pole of the star. The inclination of the pole makes this spot continuously visible.

To test for more subtle modulation effects the normalized flux density for each month was plotted against orbital (rotational) phase (Figure 2). All the peaks in the 1985-86 data occurred in the orbital phase range 0.3 to 0.85. Outside this range the flux is usually \( \leq 50\% \) of the peak flux for any one month. This suggests that one of the regions (assuming two active regions) is hidden for part of the star’s rotation and that the flare activity occurs randomly. If the time period for which this spot is hidden is truly from orbital phase 0.85 to 0.3, then it has an orbital phase of about 0.1 and is near the equator. This is consistent with the earlier Vogt model but not the later Gondoin model. However, there is a difference of over two years between the mean epochs of the current data and the Gondoin data, so that it is quite possible that the star returned to a state similar to that proposed by Vogt for 1981.

Also shown on Figure 2 are the circular polarization estimates for 21 events. We give the percentage polarization only when the ratio \( (R - L)/(R + L) \) is greater than twice the rms noise. In other cases the median distributions of \( R \) and \( L \) measurements are significantly different, giving the sense of circular polarization only. Note that the sense is always right-hand for observing frequencies of 5 and 8.4 GHz, in agreement with the earlier measurements of Mutel et al. (1985). Indeed a literature search reveals that radio emission from HR1099 at frequencies of 5 or 8.4 GHz has remained right-hand for the past 10 years. This suggests that the magnetic field direction in the vicinity of the radio source region has also remained unchanged for that length of time.

Our 1.4 and 8.4 GHz data give a mean spectral index \( \alpha \) of \(-0.1 \pm 0.2\), consistent with a VLA determination of \(-0.25 \pm 0.05\) based on three observing frequencies of 1.4, 5 and 15 GHz (Pallavicini et al. 1985). This result raises a serious problem for the interpretation of the radio polarization of HR1099 suggested by Mutel et al. (1985). On their interpretation the reversal of the sense of circular polarization at a frequency between 1.4 and 5 GHz is caused by a gyro-synchrotron source which is optically thick at 1.4 GHz and optically thin at 5.6 GHz. However, as shown schematically in Figure 3 for this source model, the spectral index would change sign from a value of \( 2.5 \) at frequencies below the turnover value (assumed to be 3 GHz) to a value \(< -1.0\) at higher frequencies. This assumes that the radiating electrons have a power-law energy distribution with an electron energy spectral index, \( \delta \), of \( \geq 3.0\); then the high-frequency slope, \( \alpha \), is \(< -(\delta-1)/2\), i.e. is \(< -1.0\) (see eqn. 43 and Figure 3 of Dulk (1985)). What is observed is that the spectral index remains essentially flat between 1.4 and 15 GHz (upper triangular areas of Figure 3) with no sign of a turnover in this frequency range. We note that our data is based on nightly averages of \( \sim 4 \) to \( 8 \) h, but the result also holds for a much shorter time interval of \( \sim 30 \) min based on VLA data reported by Pallavicini et al. (1985) and also Gibson et al. (1978).

It is clear that a simple gyro-synchrotron source model will not account for the radio observations of HR1099. We are now investigating more complex source models based on rather limited knowledge of possible magnetic geometries. From the work of Nelson and Stewart (1979) we know that it is possible to retain the gyro-synchrotron hypothesis and produce a much flatter low-frequency slope to Figure 3 by allowing the source to expand with coronal height (i.e. with decreasing frequency). How to explain the polarization reversal without a corresponding reversal in the magnetic field direction remains a problem.
Figure 1—Daily averages of the flux density of HR1099. 
(a)—(e) Vertical bars represent either twice the standard error of the means of individual 30-min observations at Parkes or twice the rms noise level on the Fleurs (1.4 GHz) synthesis maps; horizontal bars show the total observing time centred on transit time, given to the nearest hour by the UT value in brackets on each plot. The symbol R shows times when the radio emission was significantly polarized in the RH circular sense. Digits preceding R give the estimated percentage polarization.
A Search for 843 MHz Radio Emission from Active Stars

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Abstract: Known Southern flare stars and RSCVn-like variables are being observed with the Molonglo Observatory Synthesis Telescope in an attempt to detect quiescent (non-

Figure 2—Plots of flux density (normalized to peak value) versus orbital (or rotational) phase of HR1099 base on the ephemeris given by Fekel (1983) of zero photometric phase $T_0 = \text{HJD } 2,442,766.080 + 2.83774 E$. Filled circles refer to 5 or 8.4 GHz observations from Parkes, open circles to 1.4 GHz observations from Fleurs. The inset of (c) is taken from the starspot model of Vogt and Penrod (1983).

Figure 3—Comparison of the observed spectral index limits of HR1099 versus the expected low-frequency and high-frequency limits for a simple gyro-synchrotron source model with a power-law electron energy spectral index of $\delta = 3$. Higher values of $\delta$ give steeper negative slopes (see text).


