THE ASTROPHYSICAL JOURNAL, 297:644–648, 1985 October 15

MICROWAVE EMISSION FROM LATE-TYPE DWARF STARS UV CETI AND YZ CANIS MINORIS

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Received 1984 December 13; accepted 1985 April 16

ABSTRACT

We present simultaneous VLA[2] observations at 6 and 20 cm of two late-type dwarf stars UV Cet and YZ CMi. Multiwavelength observations put sufficient constraints on existing interpretations of quiescent radio emission from these stars. We find that the microwave emission is due to gyrosynchrotron radiation of nonthermal electrons having a power-law energy distribution. This emission originates from a source whose size is 2–3 R_* for UV Cet and 4–6 R_* for YZ CMi and L726−8A. From the lifetime of 1 hr of the nonthermal particles against radiation and collisional losses, we estimate a magnetic field of a few thousand gauss on the photosphere of the stars. The observations indicate that the ambient density in the coronae of YZ CMi and L726−8A is an order of magnitude higher than that of UV Cet. The rather long duration of the nonthermal particles against collisional losses could imply a flaring rate on the stars YZ CMi and L726−8A higher than that on UV Cet.

Subject headings: radiation mechanisms — stars: individual — stars: late-type — stars: radio radiation

I. INTRODUCTION

Microwave observations have been successfully exploited to study the solar corona for many years. Although several attempts have been made over the past few years to detect radio emission from dwarf stars (Altenhoff *et al.* 1976; Johnson and Cash 1980; Bowers and Kundu 1981) using high-resolution and high-sensitivity instruments like the VLA, only recently has it become possible to detect quasi-steady radio emission from such stars. To date, there have been several microwave detections of dwarf stars, some of which are clearly resolved as close binary systems (Gibson 1980; Hjellming and Gibson 1980; Gary and Linsky 1981; Fisher 1982; Linsky and Gary 1983). However, no single late-type star similar to the Sun has been detected as a radio source. Most of the successful observations were carried out at a single wavelength of 6 cm. Although single-wavelength observations are adequate for understanding the temporal behavior of flaring events on these stars and estimating their fluxes, they do not appear to be sufficient to understand properly the physical nature of radio emission from the stellar coronae.

Gary and Linsky (1981) and Linsky and Gary (1983) first reported the detection of microwave radiation from the coronae of nearby late-type dwarf stars which are not members of close binary systems and do not have large winds. They showed that their 6 cm observations of UV Cet as a steady 1.55 mJy source could be explained by either gyrosynchrotron radiation or optically thick gyroresonance emission from thermal electrons, or even plasma radiation. Fisher (1982) carried out simultaneous observations at 6 and 20 cm using the VLA, but his analysis was concerned with the variable nature of the stars. In this paper, we present dual wavelength observations of two late-type dwarf stars UV Cet and YZ CMi carried out with the VLA. Our observations show that the so-called steady component of radio emission from these stars is of nonthermal origin. We suggest the possibility that there are quasi-periodic, low-level, flaring activities or long-lasting noise storms on these stars similar to those on the Sun, which keep the stellar coronae filled with the nonthermal particles with power-law energy distribution. The observed emission is due to the gyrosynchrotron radiation of these particles in the stellar magnetic fields of a few hundred gauss.

II. OBSERVATIONS

Observations of two late-type dwarf stars, UV Cet and YZ CMi were carried out at 20 and 6 cm using the VLA in the A-configuration. The observations were made on 1983 August 12 and 13; the spatial resolutions were 1″.6 × 1″ and 0″.65 × 0″.45 at 20 and 6 cm for UV Cet, and 1″.2 × 1″.2 and 0″.5 × 0″.5 at 20 and 6 cm for YZ CMi, respectively. With a resolution of ~1″, UV Cet and its binary companion are clearly resolved. Due to bad weather conditions at the time of observation, the data were relatively noisy and the maps had a 5 σ noise level of ~0.4 mJy. During our 12 hr observation, there were no impulsive flaring events on these stars. However, there were large variations in flux and polarization in two of them over a period of 2 days (Fig. 1). The flux of UV Cet remains constant at a value of 1.05 ± 0.15 mJy at 20 cm and 1.27 ± 0.15 mJy at 6 cm, respectively. The degree of circular polarization was less than ~30% on both days. On the other hand, the binary companion of UV Cet, L726−8A showed large variation in total intensity over the 2 day period. The fluxes of 3.01 ± 0.15 and 0.6 ± 0.15 mJy at 20 and 6 cm on the first day decreased to 2.17 ± 0.15 and 0.3 ± 0.15 mJy, respectively, on the second day. Although the flux of the source changed by a factor of ~1.5 over the 2 days, the degree of circular polarization at 20 cm remained fairly constant at a value of ~65 ± 10%.

YZ CMi was observed for ~2 hr each day at 20 and 6 cm. The flux density of this source changed by a factor of ~5 over the 2 days (Fig. 2). On the first day, the fluxes at 20 and 6 cm were 3.15 ± 0.15 and 0.88 ± 0.15 mJy, respectively, and the

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[2] The VLA is a facility of the National Bureau Radio Astronomy Observatory, which is operated by Associated Universities, Inc., under contract with the National Science Foundation.

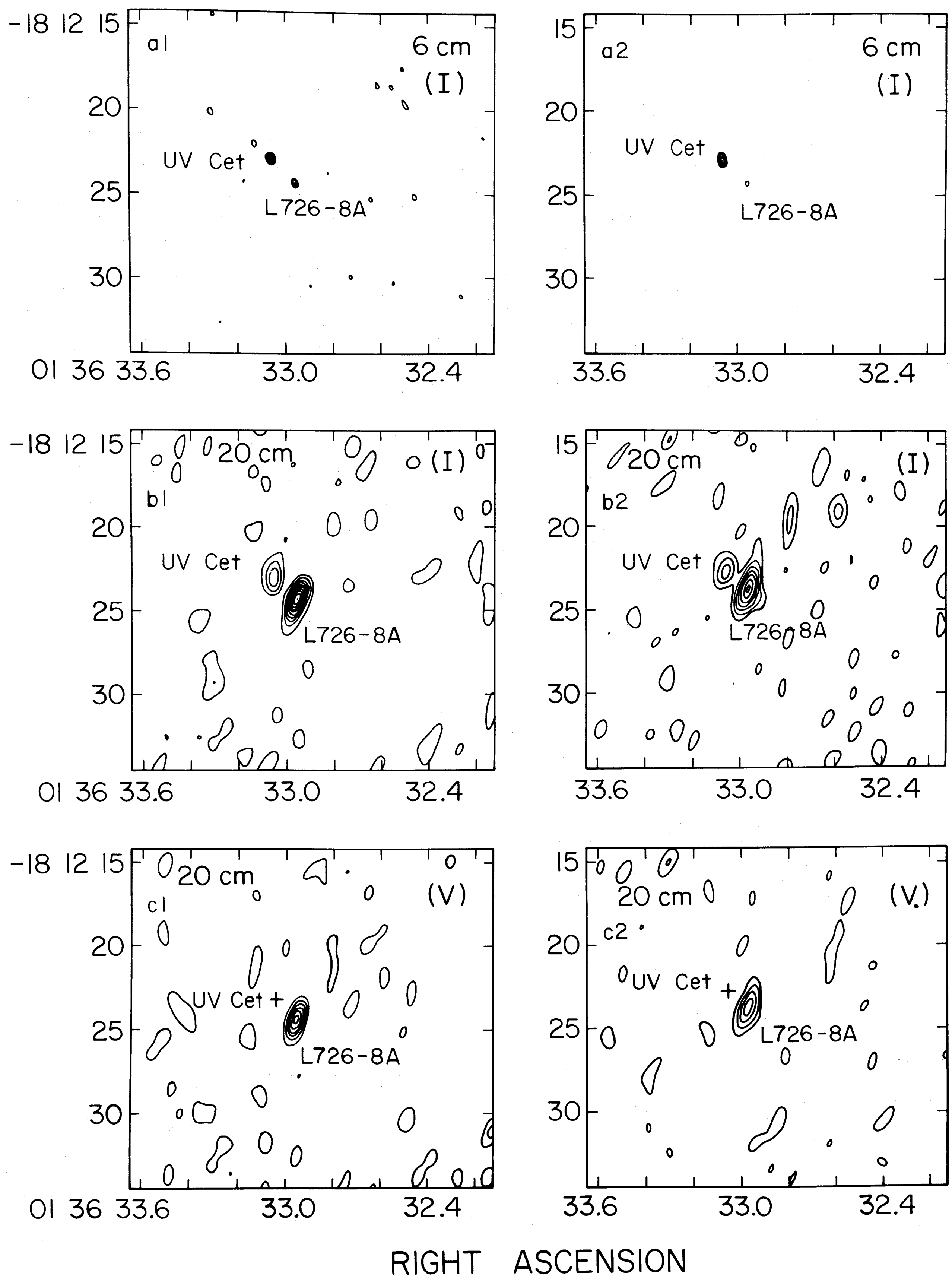

FIG. 1.—Total intensity and circular polarization maps of UV Cet and its binary companion L726−8A at 6 and 20 cm. (a1, b1, c1) are the maps on 1983 August 12, and (a2, b2, c2) are the maps on 1983 August 13. At 6 cm the circular polarization is below the noise level, and therefore the maps are not presented here. Contour interval for all maps is 0.3 mJy. In the circular polarization maps at 20 cm + indicates the position of UV Cet.

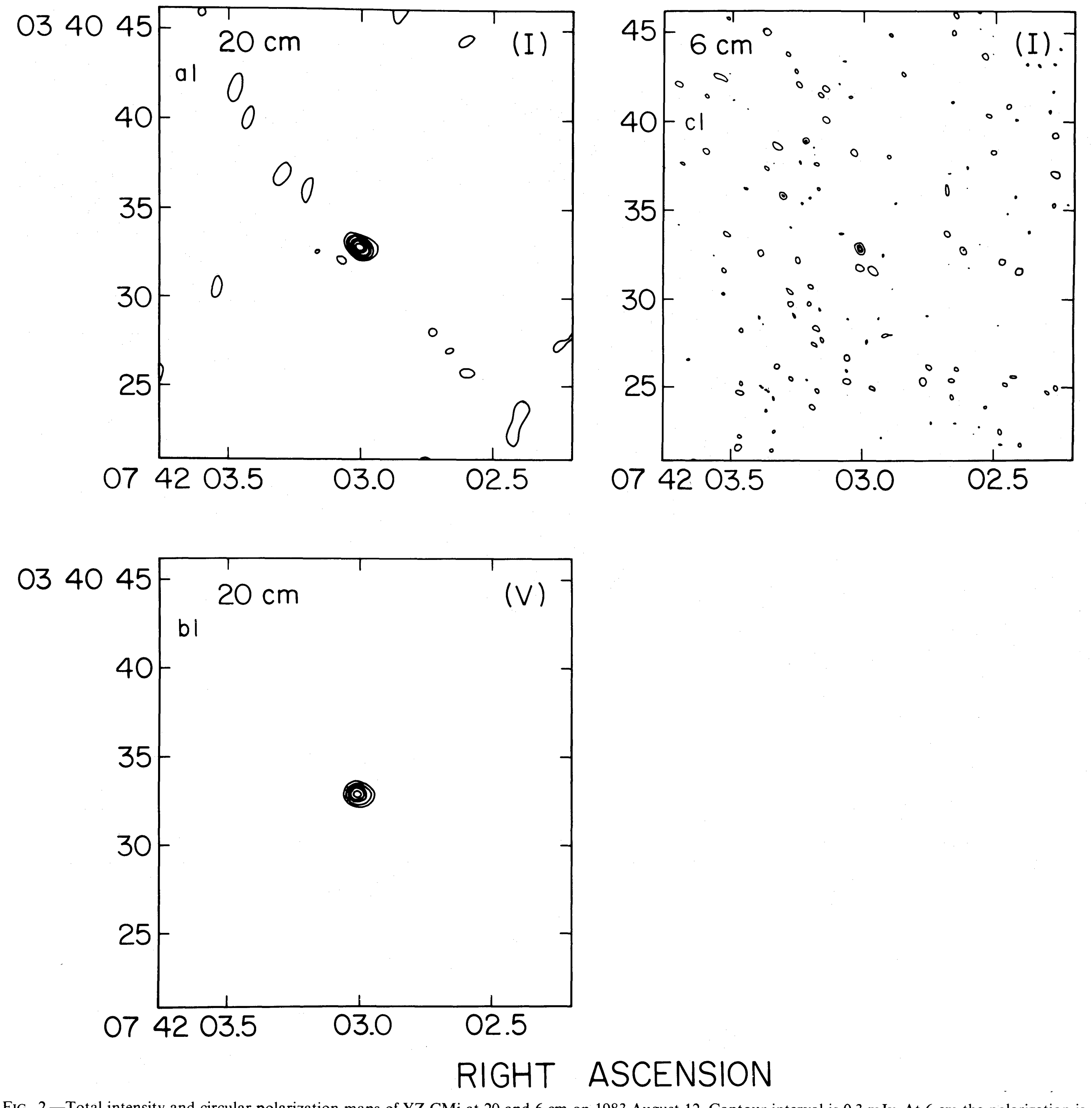

FIG. 2.—Total intensity and circular polarization maps of YZ CMi at 20 and 6 cm on 1983 August 12. Contour interval is 0.3 mJy. At 6 cm the polarization is below noise level, and therefore the map is not presented here.

degree of polarization at 20 cm was as high as 85%. On the second day, the flux at 20 cm was reduced to 0.6 ± 0.15 mJy and the degree of polarization was $\lesssim 70\%$. The corresponding 6 cm flux was below the 3 σ level.

III. DISCUSSION

a) UV Ceti (Quiescent Emission)

Assuming that the flux of 1.55 mJy of UV Cet at 6 cm is the steady component, it has been argued in the past (Gary and Linsky 1981; Linsky and Gary 1983) that the thermal bremsstrahlung cannot account for the observed high-brightness temperature. The use of gyroresonant thermal emission has shown that for coronal temperatures of $\sim 10^7$ K, the microwave source at 6 cm must be 6–7 times bigger than the stellar photosphere. The coronal temperature cannot be increased to too high values, since the soft X-ray observations of similar stars (Haisch *et al.* 1980; Swank and Johnson 1982) indicate temperatures in the range of a few times 10^6 K. To overcome this difficulty, it has been proposed that the coronae of these stars have a multitemperature distribution (Linsky and Gary

1983). The plasma observed in soft X-rays has a low temperature of a few times 10^6 K but a high electron density of $\sim 10^8$ cm^{-3}, while the high-temperature microwave component has a temperature of $\sim 10^8$ K but a low density of $\sim 10^5$ cm^{-3}. With an electron temperature of $\sim 10^8$ K, the 6 cm source size comes out to be ~ 2 times the star radius, and the observations fit quite well with the theoretical model. However, as we shall see later, the simultaneous 6 and 20 cm observations are not quite consistent with the multi-temperature model.

Assuming that the source is circular in shape and that the observed flux is due to optically thick emission from the isothermal plasma, one gets a relation between the source radii at the two wavelengths

$$r_{20\ \mathrm{cm}} = 3.3(S_{20\ \mathrm{cm}}/S_{6\ \mathrm{cm}})^{1/2} r_{6\ \mathrm{cm}} , \quad (1)$$

where $S_{20\ \mathrm{cm}}$ and $S_{6\ \mathrm{cm}}$ are the fluxes of the source at 20 and 6 cm, respectively.

For UV Cet, the ratio of flux densities at the two wavelengths $S_{20\ \mathrm{cm}}/S_{6\ \mathrm{cm}} \approx 0.83$, and so $r_{20\ \mathrm{cm}} \approx 3r_{6\ \mathrm{cm}}$. If we assume that the emission at both wavelengths is due to gyroresonant mechanism from the high-temperature thermal electrons, and if the sixth harmonic becomes optically thick (as argued by Gary and Linsky 1981), the ratio of magnetic fields at the two levels from where the 6 and 20 cm emission originates is ~ 3. This implies that for the isothermal corona and optically thick gyroresonant emission, the magnetic field above the stellar photosphere varies as r^{-1}. This variation of magnetic field with height does not represent a potential configuration, thus causing difficulties in explaining the multiwavelength observations on the basis of thermal gyroresonant emission.

On the other hand, if the emission is due to gyrosynchrotron radiation from nonthermal electrons having a power-law energy distribution, the effective source temperature is a function of wavelength and even for optically thick emission $T_{b6\ \mathrm{cm}} \neq T_{b20\ \mathrm{cm}}$. Assuming that the radiation at both wavelengths originates from the same source volume, we get a relation between the fluxes and the brightness temperatures at the two wavelengths as

$$S_{6\ \mathrm{cm}}/S_{20\ \mathrm{cm}} \approx 10 T_{b6\ \mathrm{cm}}/T_{b20\ \mathrm{cm}} . \quad (2)$$

For a source like UV Cet for which the ratio of flux densities at the two wavelengths is ~ 1, $T_{b20\ \mathrm{cm}}/T_{b6\ \mathrm{cm}} \approx 10$. This condition can be satisfied by any proper combination of the magnetic field, power-law index of the electron energy distribution (δ), and density of nonthermal particles (Shevgaonkar and Kundu 1984; Dulk and Marsh 1982) and, therefore, the source parameters cannot be estimated uniquely. However, the polarization data could constrain these parameters. Since the degree of polarization is small at both wavelengths, the emission must be occurring close to the optically thick regime. However, if the emission at both wavelengths is optically thick, the brightness temperature at 6 cm will be greater than that at 20 cm, which is inconsistent with the observations.

Alternatively, it is possible that the 20 cm wavelength lies on the low-frequency side of the turnover frequency, whereas the 6 cm wavelength lies on the high-frequency side, indicating that the peak frequency of the spectrum lies somewhere between 2 and 5 GHz. For a peak frequency of 2 GHz and a nonthermal electron density of $\sim 10^5$ cm^{-3}, the magnetic field in the emitting region comes out to be ~ 300 G (Dulk and Marsh 1982). From the optically thick brightness temperature of a few times 10^8 K at 20 cm, the physical volume of the microwave source should have a radius of $\sim 2.5\ R_*$, where R_* is the radius of the star. Assuming that the whole corona participates in emitting the microwave radiation, the magnetic field at 2.5 R_* is ~ 300 G; therefore, with a simple, radially outward magnetic field with r^{-2} variation, the photospheric magnetic field comes out to be 2000 G, which is a reasonable estimate for the average magnetic field on the surface of the star. For a magnetic field of ~ 300 G the lifetime of the nonthermal particles is ~ 1 hr (Bekefi 1966, p. 200). This implies that to have a long-lived nonthermal emission, there must be continuous, or at least periodic, particle acceleration at a rate of about once an hour.

Thus, the microwave flux density of a few millijanskys which we assume as steady flux may not be a steady component of emission in the strictest sense. It is conceivable that there are low-level flare activity at regular or quasi-regular intervals which keep the stellar corona filled with nonthermal particles. An additional justification for this idea is that our measured flux of 1.27 ± 0.15 mJy of UV Cet at 6 cm is at the lower limit of the error bar given for the flux by Linsky and Gary (1983). If we assume that our flux value is indeed smaller than the flux of 1.55 ± 0.27 mJy, then it cannot be the steady component of the star. Thus, the flux measured by us is probably not the quiescent or steady component; rather, we have been observing a time-integrated flux of short-lived miniflares. The production of nonthermal particles could occur in a manner analogous to that responsible for radio noise storms (Kundu 1965, p. 443). If the flaring events occur quasi-periodically at a rate of once an hour, the nonthermal particles will survive against radiation losses if the magnetic field is $\lesssim 300$ G. However, although the nonthermal electrons do not lose their energy due to radiation, they will thermalize quickly if the ambient coronal electron density N_e is high. The thermalization time due to energy exchange of the mildly relativistic nonthermal electrons is (Chiuderi-Drago and Melozzi 1984)

$$\tau_\epsilon \approx 1.2 \times 10^{-18} \frac{v^3}{N_e} \mathrm{s} , \quad (3)$$

where v is the velocity of the nonthermal electrons. For $v \approx 0.4c$ and $\tau_\epsilon \approx 1$ hr, the ambient electron density is $\lesssim 5 \times 10^8$ cm^{-3}, which is similar to the estimate given by Linsky and Gary (1983).

b) YZ CMi and L726−8A (Variable Emission)

Following arguments similar to those used for UV Cet, the microwave emission from these stars could be explained as due to gyrosynchrotron radiation from nonthermal electrons. However, apart from the fact that the emission from these stars is variable, these stars exhibit a high degree of circular polarization. Also, the ratio of flux densities at the two wavelengths for these stars lies between 5 and 10, whereas for UV Cet this ratio is ~ 1. The high degree of polarization and a negative spectral index, $\alpha (S \propto \nu^\alpha)$ (Table 1) indicate that both 6 and 20 cm wavelengths lie on the high-frequency side of the spectral turnover frequency, i.e., the spectrum peaks at a frequency $\lesssim 1$ GHz (20 cm). Taking the peak frequency as ~ 1 GHz and similar particle density as that in UV Cet, the magnetic field in the microwave source on these stars is ~ 100 G. Assuming a brightness temperature of a few times 10^8 K at 20 cm, the size of the microwave source is $\sim$4–6 times the radius of the star, which in turn gives a photospheric magnetic field of ~ 3000 G. The main difficulty in this model is that the high degree of

TABLE 1

OBSERVATIONAL PARAMETERS OF UV CETI, L726 − 8A AND YZ CMi

Source	λ (cm)	1983 August 12 I(mJy)	1983 August 12 % P	1983 August 12 α[a]	1983 August 13 I(mJy)	1983 August 13 % P	1983 August 13 α[a]
UV Cet (L276−8B)........	20	1.05 ± 0.15	...	0.20	1.05 ± 0.15	...	0.12
	6	1.33 ± 0.1	...		1.21 ± 0.1	...	
L726−8A	20	3.01 ± 0.15	64.5 ± 10 R	−1.34	2.17 ± 0.15	64.5 ± 10 R	−1.98
	6	0.6 ± 0.1	...		0.2 ± 0.1	...	
YZ CMi	20	3.15 ± 0.15	85.1 ± 10 L	−1.06	0.6 ± 0.15	...	...
	6	0.88 ± 0.15	...		<0.2	...	...

[a] $S \propto \nu^{\alpha}$.

polarization cannot be easily explained. As we go deeper than 4 to 6 R_* into the stellar atmosphere, the magnetic field increases rapidly and the nonthermal emission becomes optically thick, giving a low degree of polarization. The only solution is to find a mechanism which prevents the nonthermal emission from becoming optically thick. This can be obtained by assuming that the coronae of these stars have a mixture of dense, low-temperature thermal plasma and nonthermal particles. The thermal plasma becomes optically thick due to thermal bremsstrahlung at a higher level of the stars atmosphere than for nonthermal emission. Since the thermal plasma has a low temperature, the dominant brightness in that case is not due to the optically thick thermal bremsstrahlung, but to the optically thin nonthermal emission.

If we assume a temperature of $\sim 5 \times 10^6$ K for the thermal electrons (same as that deduced from X-ray observations by Haisch *et al.* 1980) and a thickness of the microwave source $\sim 10^{10}$ cm, we get an ambient electron density of a few times 10^9 cm^{-3} in the microwave source. The above discussion indicates that the average photospheric magnetic field on these stars is of the same order of that on UV Cet. However, the coronae of these stars have a higher ambient electron density by almost one order of magnitude compared to that of UV Cet. It should be noted that in a high-density plasma, the lifetime of the nonthermal electrons is mainly governed by the collisional losses. For a density of a few times 10^9 cm^{-3}, the thermalization time of the nonthermal particles is $\sim$10–15 minutes. This implies that long-lasting emission from these stars should require flaring rate of a few times an hour.

IV. CONCLUSIONS

Simultaneous high-resolution observations of two late-type dwarf stars UV Cet and YZ CMi at 6 and 20 cm are presented here. These multiwavelength observations put sufficient constraints on existing interpretations to conclude that the quiescent microwave emission from these stars is of nonthermal origin; namely, gyrosynchrotron radiation. This quiescent or long-period variable emission is probably an integrated effect of many short lived miniflares or it could be analogous to the noise-storm radiation observed from nonflaring active regions on the Sun. Assuming that the whole stellar surface participates in producing the microwave emission, the radius of the radio star is found to be $\sim$2–3 R_* for UV Cet and $\sim$4–6 R_* for L726 − 8A and YZ CMi.

Assuming a r^{-2} variation, the extrapolated photospheric magnetic field for all the stars lies in the range of a few thousand gauss, which is consistent with the observed fields (Robinson, Wordin, and Harvey 1980; Marcy 1980). However, the high degree of polarization of L726 − 8A and YZ CMi requires that these stars should have an ambient density of a few times 10^9 cm^{-3}, which is an order of magnitude higher than that of UV Cet. The rather long duration of the nonthermal particles against collisional losses would imply that the frequency of the nonthermal particles against collisional losses would imply that the frequency of flaring events on the stars L726 − 8A and YZ CMi is relatively higher than that on UV Cet.

This research was supported by NSF grant ATM 84-15388.

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