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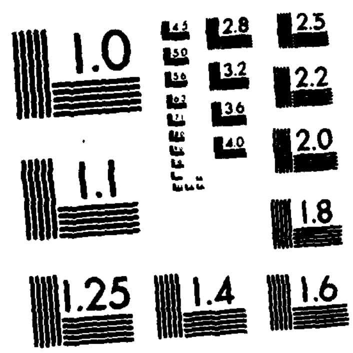


MICROCOPY RESOLUTION TEST CHART

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# SOLAR BURST PRECURSORS AND ENERGY BUILD UP AT MICROWAVE WAVELENGTHS*

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# SOLAR BURST PRECURSORS AND ENERGY BUILD UP AT MICROWAVE WAVELENGTHS

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## ABSTRACT

We summarize high-resolution microwave observations (VLA) of heating and magnetic triggering in coronal loops. Magnetic changes that precede solar eruptions on time scales of tens of minutes involve primarily emerging coronal loops and the interaction of two or more loops. Thermal cyclotron lines have been detected in coronal loops, suggesting the presence of hot current sheets that enhance emission from relatively thin layers of enhanced temperature and constant magnetic field. These current sheets may play a role in the excitation of solar bursts. A filament-associated source with a high brightness temperature and steep radiation spectrum occurs above a region of apparently weak photospheric field. This source might be attributed to currents that enhance coronal magnetic fields. Compact $(\phi = 5'')$ transient sources with lifetimes of 30 to 60 minutes have also been detected in regions of apparently weak photospheric field. We conclude by comparing VLA observations of coronal loops with simultaneous SMM-XRP observations.

## MAGNETIC CHANGES AND PREBURST HEATING

The VLA has recently been used to detect changes in the configuration of coronal magnetic fields and temperature enhancements within coronal loops that are important in the excitation of solar bursts. It has long been known that solar eruptions are intimately connected with the magnetic fields in active regions, for the ultimate source of energy for these bursts must be magnetic energy. It has only recently been realized, however, that evolving magnetic fields in the solar corona may play a dominant role in triggering solar eruptions /1/.



Fig. 1. The ten second V.L.A. synthesis maps of the impulsive phase of two solar bursts at 20 cm wavelength superposed on Hα photographs of the optical flares taken at the same time at the Big Bear Solar Observatory. The 20 cm bursts originate near the tops of coronal loops that are about 40,000 kilometers above the flaring region seen at optical wavelengths. The western solar limb is visible in both photographs.

Preflare changes in active regions are detected as increases in the intensity and polarization of the microwave emission at centimeter wavelengths. These increases precede solar eruptions on time scales of 10 minutes to an hour. The high angular resolution provided by the Very Large Array (VLA) has shown that these increases are related to preburst heating in coronal loops and to changes in the coronal magnetic field topology /2/. The VLA snapshot maps have also made possible tests of flare models that could not be carried out at optical wavelengths. For instance, the region of microwave energy release occurs at the apex of coronal loops, while the optical flares occur at the loop footpoints (See Fig. 1).

The VLA results indicate that preburst changes can be ordered into three major categories: (I) changes within a single coronal loop, (II) the emergence of coronal loops, and (III) interaction between coronal loops. As illustrated in Figure 2, coronal loops or arcades of loops often begin to heat up and change structure about 15 minutes before the eruption of impulsive bursts. Examples of the other types of magnetic interaction detected by the University of Maryland and Tufts groups are given in the review by Kundu and Lang /2/.

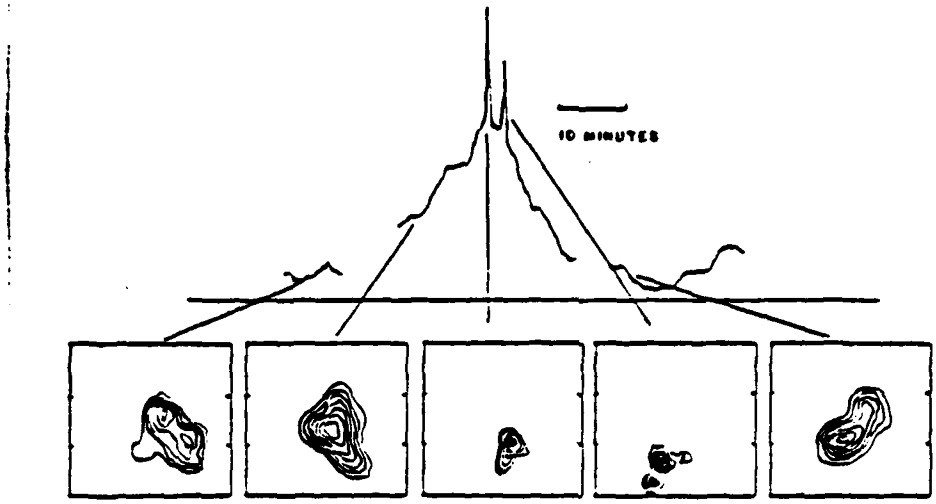


Fig. 2. The time profile of a solar burst at 20 cm wavelength suggests heating within a coronal loop prior to the emission of two impulsive microwave bursts. Radio and X-ray data have been combined to derive a peak electron temperature $T_e$ of $2.5 \times 10^7$ K and an average electron density $N_e$ of $10^{10}$ $cm^{-3}$ during the heating phase. The changing orientation illustrated in the 10 second VLA snapshot maps could be related to the shear of photospheric fields.

## THERMAL CYCLOTRON LINES AND EVIDENCE FOR CURRENTS

Theoretical work has shown that individual cyclotron lines might be detected as narrow-band enhancements in the radio-frequency spectra of solar active regions /3/. The spectra of individual cyclotron lines have subsequently been observed at wavelengths near 20 cm when the apex of a coronal loop is resolved /4/ - see Figure 3. This is because the magnetic field strength is relatively constant near the loop apex; the cyclotron lines would merge into a continuum along the loop legs where the magnetic field strength decreases uniformly with height. Neutral current sheets might also play a role, leading to intense radio emission from a thin layer near the loop apex. Both a uniform field and a steep temperature gradient in the uniform region are probably required to detect the cyclotron lines. In any event, observations of individual cyclotron lines indicate magnetic field strengths of $H = 145 \pm 5$ G at the apex of some coronal loops. Observations of individual cyclotron lines provide an unusually accurate method of specifying the coronal magnetic field strength, while also suggesting the presence of currents.

Evidence for current amplification of the coronal magnetic field may be provided by sources of high brightness temperature and steep radiation spectrum above regions of apparently-weak magnetic field /5/. An example is the filament associated source D whose spectrum is shown in Figure 4. If this emission is due to thermal gyroradiation, strong magnetic fields are required to produce gyroradiation at the first few harmonics of the gyrofrequency. Higher harmonics produce insufficient optical depth to account for the high brightness temperatures. The strong magnetic fields could be obtained if currents amplify the magnetic field in the low corona to values greater than those expected from extrapolations from the photosphere. The emission could alternatively be due to nonthermal radiation in weak magnetic fields. Nonthermal synchrotron radiation from mildly relativistic electrons is one possibility, but some as yet unspecified mechanism must be continuously accelerating the electrons.

## COMPACT VARIABLE SOURCES

We have recently discovered compact, variable highly-polarized sources in regions of apparently-weak photospheric magnetic field /6/. Our subsequent VLA observations have confirmed the existence of compact, variable 2 cm sources that are not associated with active regions, but these sources had no detectable circular polarization.

The 2 cm maps showed two compact ($\theta \approx 5''$), highly circularly polarized ($\rho_c$ = 80 to 90%) sources that vary on time scales of 30 to 60 minutes. The left circularly polarized source varied in maximum brightness temperature from $T_B = 2.0 \times 10^5$ K to $T_B < 0.5 \times 10^5$ K.

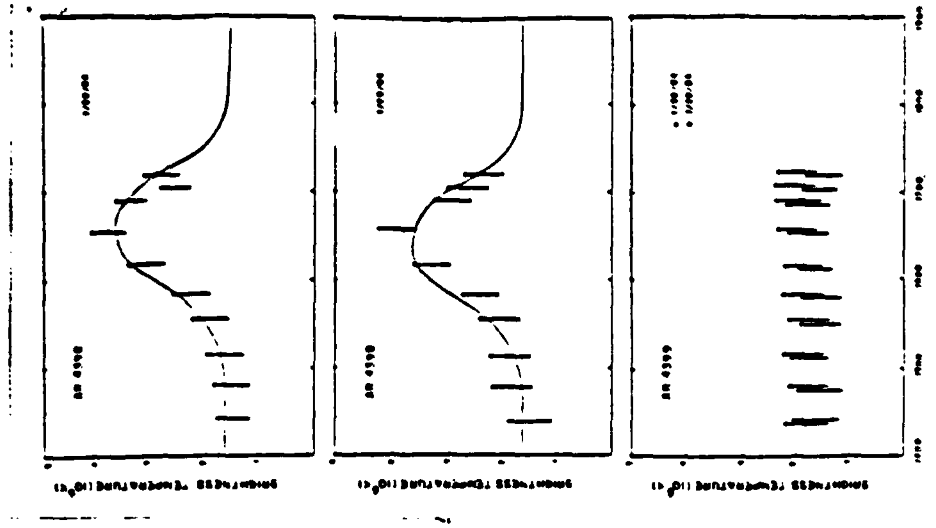

Fig. 3. VLA data at ten closely-spaced frequencies near 1440 MHz (20 cm) showing thermal cyclotron line spectra from active region AR 4398 on successive days, together with optically-thick thermal bremsstrahlung spectra from active region AR 4399 on the same days.

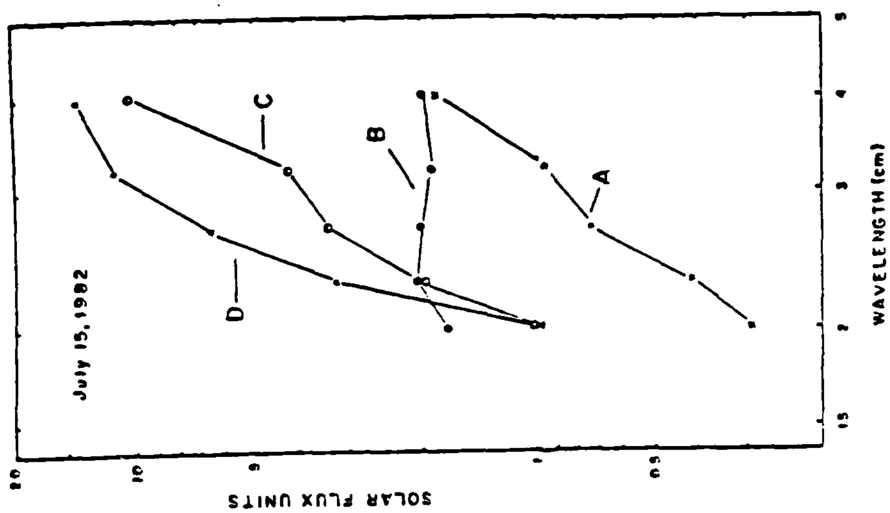


Fig. 4. The radiation spectra for the three types of sources usually detected at short centimeter wavelengths. The most common type of source is the sunspot-associated component (A and C) that is attributed to thermal gryoresonance radiation in the legs of coronal loops that are connected to the underlying sunspots. Source D is a filament-associated component located above a magnetic neutral line in regions of apparently-weak magnetic field. It may be due to thermal gyroradiation in current-amplified magnetic fields. The filament-associated source B has the flat spectrum of optically-thin thermal bremsstrahlung.

Comparisons with Mt. Wilson magnetograms indicate that the two compact, variable sources were located in regions of apparently-weak photospheric magnetic field (H < 80 G), and that they did not overlie sunspots. The high polarization of these sources is therefore somewhat enigmatic, for the polarization of thermal radiation requires strong magnetic fields of H = 2,000 G.

The enigmatic presence of highly polarized sources in regions of apparently-weak photospheric magnetic field may be explained by any one of three hypothesis. First, the photospheric field may have strengths of up to 2,000 G in compact regions that are not readily detected by the photospheric magnetograms. Alternatively, the magnetic field in the transition region or the low corona may be amplified by currents to a strength above that in the underlying photosphere. If either of these hypothesis is true, then the high circular polarization of the 2 cm sources can be attributed to either thermal gyroradiation or the propagation of thermal bremsstrahlung in the presence of a magnetic field of strength H = 2,000 G. A third hypothesis is that the compact 2 cm sources are due to non-thermal gyrosynchrotron radiation of mildly relativistic electrons in relatively weak magnetic fields of strength H = 50 G.

## ONGOING COMPARISONS OF VLA AND SMM-XRP DATA

We are continuing with a comparison of 20 cm coronal loop data (VLA) with soft X-ray data obtained with the SMM satellite. In some instances, there is radiation at 20 centimeters wavelength near sunspots where no X-ray radiation is detected /7/. In other cases, the 20 centimeter radiation appears at the apex of coronal loops, but with a slightly lower brightness temperature, $T_B = 1.4$ to $1.7 \times 10^6$ K, than the electron temperature, $Te = 3.0 \times 10^6$ K, inferred from the X-ray data. This may be explained by a low temperature plasma with $T_e = 10^5$ K that lowers the effective brightness temperature of the radio bremsstrahlung while not affecting the X-ray data that only detects the $10^6$ K plasma /8/.

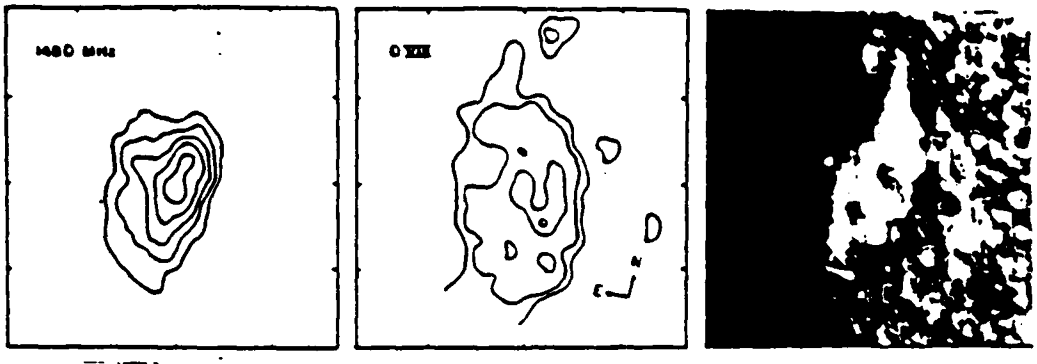

Fig. 5. A comparison of the 20 cm emission (V.L.A.-left), soft X-ray (S.M.M.-middle) and Hα (SOON-right) emission of an active region on the same day. The angular spacing between fiducial marks on the axes is 60 arc-seconds.

As illustrated in Figure 5, there are other instances in which the 20-cm radiation and the soft X-ray emission have the same angular extent. In this case, the maximum brightness temperature of the radio emission has the same value as the electron temperature, $T_e = 3 \times 10^6$ K, inferred from the X-ray data. At first sight it would seem that the 20-cm emission is the thermal bremsstrahlung of the X-ray emitting plasma (electron density $N_e = 2 \times 10^{10}$ $cm^{-3}$), but in this instance we have also detected a cyclotron line. Preliminary modeling indicates a thin layer of $T_e = 4 \times 10^6$ K with a magnetic field strength of H = 145 or 187 G (harmonic n = 4 or 3). The thermal electrons that give r se to the X-ray radiation therefore also seem to produce strong gyroresonant radiation at 20 centimeters wavelength.

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