NAGW-91

ACTIVITY AND MAGNETIC FIELDS ON STARS FROM RADIO OBSERVATIONS

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During the past few years, owing partly to the completion of the VLA, interest in radio observations of stars has had a resurgence. New instruments have provided an increase in sensitivity by an order of magnitude, accompanied by a considerably reduced risk of mistaking radio interference for stellar radiation. Gibson (1983) gives a summary of observations of the class of stars most extensively studied to date, i.e., flare stars of spectral type dMe. Here I will describe some of the newest results on several classes of stars and comment on their interpretation in terms of stellar activity and stellar magnetic fields. I will confine my attention to outbursts of radio radiation, omitting from consideration the quiescent or steady emission that comes from some stars such as RS CVn and AM Herculis type binaries, late type stars with coronae such as χ^1 Orionis; this aspect is discussed by Brown and Crane (1978), Gary and Linsky (1981), Topka and Marsh (1982) Chanmugam and Dulk (1982) and Gibson (1983).

Figure 1, from Gary, Linsky and Dulk (1982), shows an example of an outburst of radiation that has most of the characteristics of the five examples I will show on viewgraphs. The top frame, in which each data point represents a five minute integration, shows an approximately steady component of emission from UV Ceti which could be due to a hot, magnetically confined corona or to sustained, low level flaring activity. A drastic, short-lived increase in radiation is seen in the top panel in only one or two data points and in only one polarization. The burst is expanded in the lower panel, in which 10 s integrations were used, i.e., the shortest then available at the VLA. There are factor-of-two variations in flux from one 10 s interval to another, and the radiation is >80% circularly polarized. Careful measurements of source position revealed that the outburst arose not from UV Ceti itself but from its distant binary companion, also a dMe star.

(NASA-CR-175966) ACTIVITY AND MAGNETIC FIELDS ON STARS FROM RADIO OBSERVATIONS (Colorado Univ.) 4 p HC A02/MF A01 CSCL 03B

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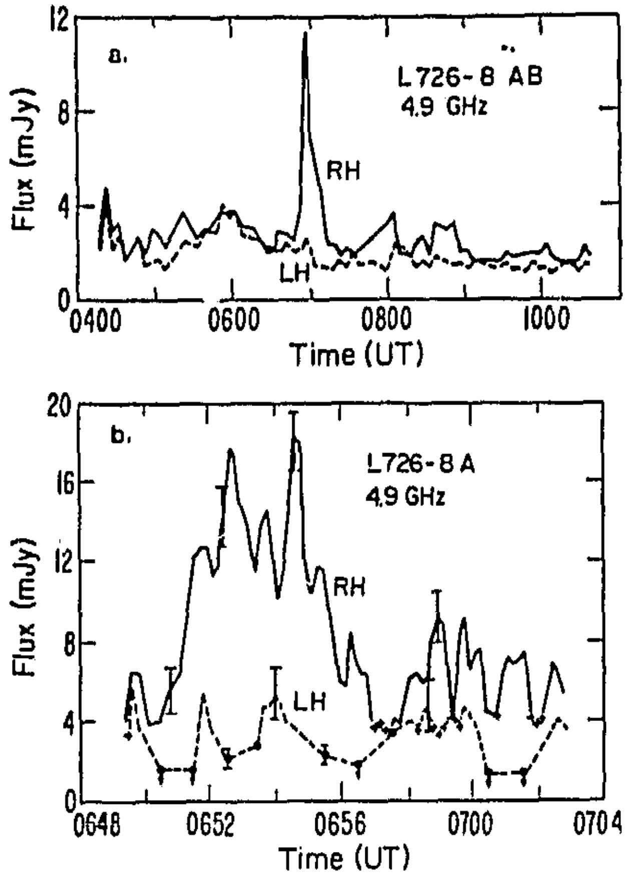

Fig. 1. Radio emission at 4.9 GHz from UV Ceti and its companion L726-8A. Top: Fluxes in RH and LH circular polarization taken from VLA maps with 5 min integration times. Bottom: Flare emission on an expanded time scale, taken from maps with 10 s integration times. (From Gary, Linsky and Dulk 1982).

A burst with many of the same characteristics was observed at 1.4 GHz from the flare star AD Leo by Lang et al. (1983), but with a much better time resolution. In that case there were two components to the burst: (1) an erratically varying rise and fall, lasting about 30 min, with little structure less than a few seconds duration, and with a polarization degree <0.15; (2) a rapidly-varying portion, >90% polarized, lasting about 3 min, and having time structure down to the instrumental limit of 0.2 s. The first component had great similarities to solar microwave bursts and was probably due to gyrosynchrotron radiation by electrons of energy >100 keV spiraling in a field of B > 100 Gauss; we consider the interpretation of the second component later.

Bursts from the Sun with high polarization and fast time structure have been reported by Dröge (1977) and Slottje (1978) at frequencies up to 2.8 GHz. Termed "microwave spike bursts" they typically vary on time scales >10 ms, but occasionally exhibit spikes with rise times as short as the 1 ms instrumental limit. From these fast rise times source sizes <300 km are inferred.

Highly polarized bursts, with many of the same characteristics and with time scales down to instrumental limits of ~1 min have been reported for RS CVn stars (e.g. Brown and Crane, 1978).

Finally, a rather similar outburst was reported at 5 GHz from the magnetic cataclysmic variable star AM Herculis (Dulk, Bastian and Chanmugam, 1983). The outburst probably arose from close to the red dwarf secondary, whose or it lies within the magnetosphere of the primary, a white dwarf. Because AM Her is ~10 times more distant than typical flare stars and the observed flux density was comparable, the emitted radiation must have been exceptionally intense.

Turning now to the interpretation of the rapidly varying bursts of radiation, it is important to note that the inferred brightness temperatures are 10^{10} K to 10^{14} K which, with the high degree of circular polarization, imply that the radiation is coherent. Two mechanisms have been proposed to generate such radiation: (1) plasma radiation and (2) electron-cyclotron masers. While plasma radiation (e.g. Melrose, 1980) accounts for many kinds of solar bursts at low frequencies, <1 GHz, and may produce stellar bursts at similar frequencies, it encounters severe difficulties in accounting for bursts at higher frequencies. This is due to the fact that the overlying plasma is likely to reabsorb the radiation very effectively, either because of free-free absorption if the temperature T is $<10^6$ K, or gyroresonance absorption if T $>10^6$ K. Hence the electron-cyclotron maser mechanism is the most plausible so far proposed.

This maser (e.g. Melrose and Dulk, 1982) operates at the fundamental of the electron-cyclotron frequency

$$f \approx f_B \approx 2.8 \times 10^6 B$$

(where f and f_B are in Hz and B in Gauss) or perhaps its second harmonic $f \approx 2f_B$. The maser converts electron energy directly into (amplified) radio radiation which is highly polarized, and brightness temperatures to 10^{20} K or higher can be attained under reasonable conditions. Radiation at the fundamental $f = f_B$ is probably gyroresonantly reabsorbed when travelling outward through the stellar plasma, so radiation at $f \approx 2f_B$ is the more likely (note, however, that certain bursts from Jupiter, Saturn and Earth are convincingly attributed to electron-cyclotron masers operating at the fundamental).

Assuming that this mechanism is the relevant one, then the observation of bursts at frequency f implies that a field of strength $B = f/5.6 \times 10^6$ is present in the source region, e.g. 900 Gauss if f = 5 GHz. Of course, higher and lower field strengths may also exist in the source region, with masing at corresponding frequencies, but usually only one frequency is observed at a time.

In summary, radio observations are now able to elucidate certain kinds of stellar activity and reliable estimates of magnetic field strengths are being derived for the radio emitting regions.

This work was sponsored in part by NASA under grants NSG-7287 and NAGW-91 to the University of Colorado.

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