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MAGNETIC TUBE SCALE AND ELECTRON ACCELERATION FROM THE FINE STRUCTURE OF MICROWAVE BURSTS

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ABSTRACT A typical microwave burst with fine structures (type Hand) observed by the Dwingloo multi-channel spectrometer is proposed as evidence of a magnetic tube with a small scale and acceleration of electron beams with a short time scale at the source. It is predicted from the observations and theory that the average velocity of non-thermal electrons is about $0.1c$ and the density of the beam is about 10^4 cm^{-3}. There is a micro-magnetic tube with a scale length of six hundred kilometers at the microwave source. There is also a quasi-periodic ($\sim$ 20 ms) evolution of the beam energy, which may be accelerated by tearing modes. The spectrum of the burst can be explained by the non-uniformity of the magnetic field. The evolution of the spectrum during a single pulse may result from the electron cyclotron maser instability. Hence, information from the fine structure of the spectrum of solar radio bursts is very important for understanding the mechanism of solar flares.

MAGNETIC TUBE SCALE AND NON-THERMAL ELECTRON ENERGY

Figure 1 shows a typical microwave fine structure observed by Dwingloo Observatory (Allaart et al. 1990). The main characteristic of this event is that there are at least two pairs of positive and negative frequency drifts. The relative bandwidth of this event is about 6% (0.3/5 GHz). The time scale of a single pulse is about 20 ms. These properties are comparable with the theoretical predictions of electron cyclotron maser instabilities (Huang 1987), which means that the radiation frequencies correspond to the electron cyclotron frequencies or its high harmonics at the sources.

A natural explanation for this phenomenon is that a non-thermal distribution (loss-cone or hollow beam) is formed and confined in a micro-magnetic tube, then it bounces between two reflecting points of the magnetic mirror to excite electron cyclotron maser instabilities.

There are three equations to calculate the scale of the magnetic field (L), the density (n_s) and the average velocity (V) of non-thermal electrons (Benz 1986; Huang 1992):

$$L = \lambda \Delta\omega/\omega, \tag{1}$$

$$L = V\Delta t, \tag{2}$$

$$\frac{\Delta S}{S} = \frac{\alpha E}{S}\left(1 - \frac{\omega_{iT}}{\omega_{i0}}\right) - 1. \tag{3}$$

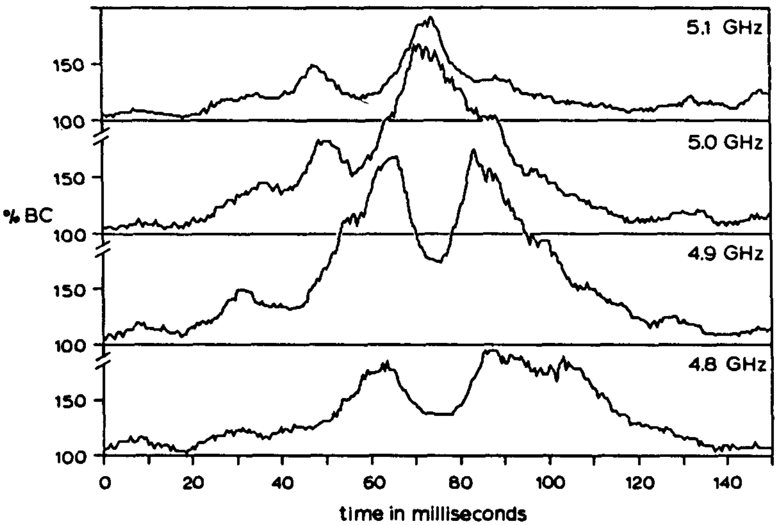

Fig. 1. Flux density of a type Hand burst versus time (ms) at several frequencies (Allaart et al. 1990). The main peak shows frequency drifts. Date = 1981 September 7. Time = 10:38:05 UT. Resolution=1 ms.

Here, λ is the characteristic length of the magnetic field and its value is about 10^4 km (Benz 1986). $\Delta\omega/\omega$ is the relative bandwidth (6%). Δt is the time for the non-thermal electrons to move from the top to the bottom of the magnetic tube (20 ms). $\Delta S/S$ is the modulation strength of the pulses (81% for the highest peak at 5 GHz). S is the burst flux (172 sfu for the maximum at 5 GHz). The expression for the dimensionless factor α is

$$\alpha = \frac{c\Delta\Omega}{\Delta f}. \tag{4}$$

where $c \sim 10^{10}$ cm/s, $\Delta f \sim 10^9$ Hz, and $\Delta\Omega \sim L^2/R^2$ ($R \sim 10^8$ km). ω_{iT} and ω_{i0} are the exponential growth rates of a single pulse at the initial and saturation phases, respectively. The ratio of ω_{iT}/ω_{i0} is about 0.86 for the highest peak at 5 GHz. Hence, a group of self-consistent values are calculated from equations (1)-(4):

$$L \approx 600 \text{ km},$$

$$V \approx 3 \times 10^9 \text{ cm/s},$$

$$n_s \approx 2 \times 10^4 \text{ cm}^{-3}.$$

MAGNETIC TUBE AND NON-THERMAL ELECTRON VARIATIONS

Note that the drift rates (or the time delays of the peak values between two adjacent channels) vary while the energetic particles move through different sections of the micro-magnetic tube. It is supposed that the density of the non-thermal electrons is 10^4 cm^{-3} and its variation may be neglected. Hence, the scale of each section (channel) of the micro-magnetic tube and the average velocity of the non-thermal electrons at each section (channel) can be calculated from equations (2)-(4) for two pairs of positive and negative frequency drifts (16 peaks) in Figure 1. There are some interesting results shown in Table 1:

TABLE I Parameters from the burst of Figure 1

No.	S (s.f.u.)	ΔS (s.f.u.)	Δt (ms)	ω_{iT}/ω_{i0}	V (10^9 cm/s)	L (10^6 cm)
1	105	20	2	0.292	0.82	1.63
2	115	35	5	0.821	0.76	3.80
3	110	35	4	0.635	0.71	2.82
4	105	20	1	0.458	1.23	1.23
5	120	30	1	0.595	1.39	1.39
6	130	55	5	0.412	0.60	2.98
7	130	85	5	0.860	0.89	4.43
8	120	55	4	0.833	0.90	3.60
9	130	50	3	0.838	1.05	3.16
10	215	60	4	0.614	0.82	3.27
11	150	120	5	0.865	0.95	4.73
12	125	60	2	0.806	1.24	2.49
13	135	50	2	0.843	1.31	2.62
14	200	70	7	0.851	0.80	5.46
15	175	100	3	0.778	1.08	3.25
16	135	60	20	0.818	0.40	8.09

(1) The length scale associated with the two middle sections (4.9 and 5.0 GHz) is usually larger than that of the top (4.8 GHz) and the bottom (5.1 GHz) sections, which may explain why the peak fluxes at 4.9 and 5.0 GHz are always higher than those at 4.8 and 5.1 GHz.

(2) The non-thermal electrons are accelerated twice during their move down from the top to the bottom of the micro-magnetic tube, which is consistent with the increasing peak values of the burst flux at each channel. A possible mechanism for the acceleration is the electric field induced by the periodic tearing modes (Huang 1990), which can accelerate the thermal electrons to 1 kev energy in one period (several tens of ms for typical coronal conditions).

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REFERENCES

Allaart, M.A.F., Van Nieuwkoop, J., Slottje, C., Sondaar, L.H. 1990, Solar Phys., 130, 183

Benz, A.O. 1986, Solar Phys., 104, 99
Huang, G.L. 1987, Solar Phys., 114, 363
Huang, G.L. 1990, Adv. Space Res., 10, No. 9, 173
Huang, G.L. 1992, Acta Astronomica Sinica, 33, No. 4, in press.