MAGNETIC FIELDS IN THE LOWER CORONA ASSOCIATED WITH THE EXPANDING LIMB BURST ON MARCH 30TH 1969 INFERRED FROM THE MICROWAVE HIGH-RESOLUTION OBSERVATIONS

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Abstract. An expansion of the source of a great solar microwave burst was observed a little beyond the west limb on March 30, 1969. This expansion is interpreted in terms of diffusion of energetic electrons in a turbulent magnetic field in the flare region. The height of the source is estimated to have been 10^4 km.

A remarkable expansion of the radio source was observed by the quick-scan radio interferometer at 3.75 GHz (Tanaka *et al.*, 1969) during the solar radio burst on March 30, 1969. This burst occurred 10° behind the west limb of the Sun. A simple calculation of the geometry revealed that the height of the source of the burst was 10^4 km and that of the parent *S*-component was not higher than 10^4 km at 3.75 and 9.4 GHz. The extension of the expanded source was as high as $\sim 0.3\ R_{\odot}$, which indicates a stretching-out of the magnetic field of, say, tens or a hundred of Oersteds so far, according to a theory of radiation of solar microwave bursts (Takakura and Scalise, 1970).

The expansion started at 0250 UT just after the time of maximum flux and continued about 10 min as shown in Figure 1. The upper curve shows the intensity-time profile

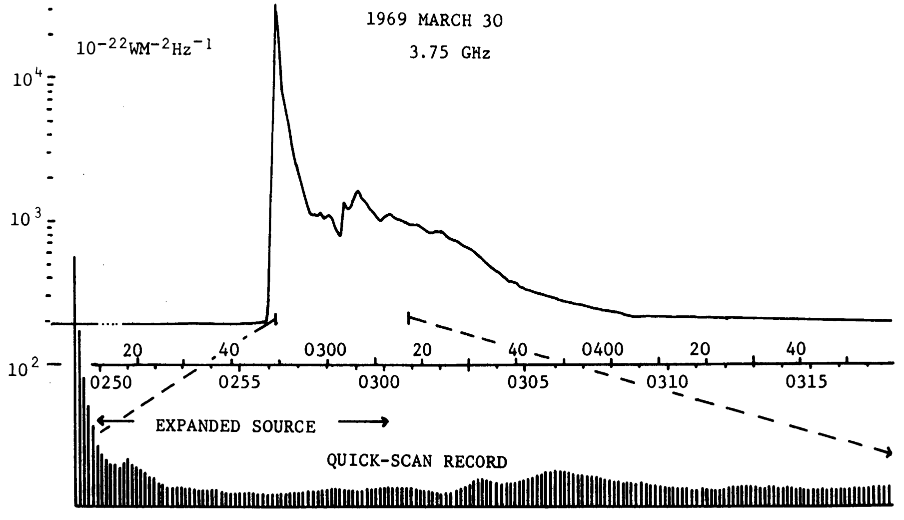

Fig. 1. The curve in the upper part shows the intensity-time profile of the burst at 3.75 GHz with the upper time scale. The row of bars in the lower part shows a schematic drawing of the quick-scan record at 3.75 GHz, representing a temporal change of the brightness of the source in an arbitrary unit in every 10 s with the lower time scale.

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of the burst with the upper time scale. The quick-scan record of every 10 s of the burst is illustrated schematically in the lower picture with the lower time scale.

As for the interpretation of the phenomenon, physical expansion of the active region itself may be rejected, since it is generally believed that the flare energy is fed by the magnetic energy of the active region, it is not possible to blow up the active region as a whole by the flare energy.

Figure 2 shows the quick-scan record of the Sun. East is to the right and west is to the left. The way of expansion suggests diffusion of high energy electrons, probably tens of keV and more, through the magnetized solar plasma.

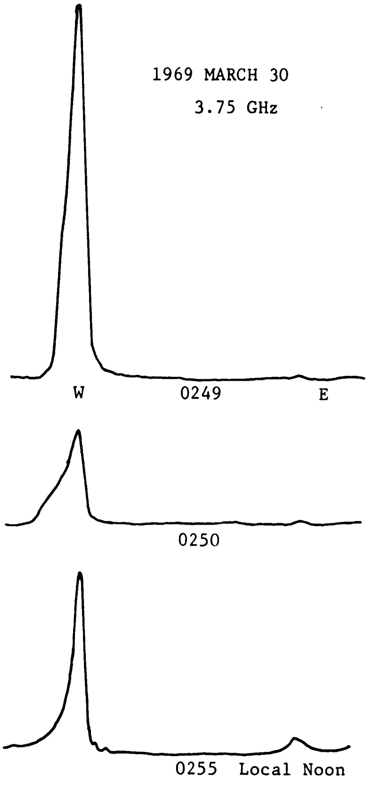

Fig. 2. Quick-scan records at 3.75 GHz showing strip scan of the solar disk at 0249, 0250, and 0255 UT. The expansion started at 0249 UT and was remarkable at 0250 UT. The interference pattern, seen at the right-hand side of the source at 0255 UT, means the obscuration of the source by the solar disk.

Following the diffusion model, which has been often applied to the solar cosmic ray propagation through the interplanetary space (Parker, 1963), and with an assumption of spherical symmetry, the diffusion equation is

$$\frac{\partial U}{\partial t} = \frac{D}{\varrho^2} \frac{\partial}{\partial \varrho} \left(\varrho^2 \frac{\partial U}{\partial \varrho} \right) - KU ,$$

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where U, D, and K stand for the particle density, the diffusion coefficient, and the loss rate of particles respectively.

A solution of this equation is

$$U(\varrho, t) = \frac{N}{4(\pi D t)^{3/2}} \exp\left(-\frac{\varrho^2}{4Dt} - Kt\right),$$

where N denotes the particle number injected initially.

Taking the x-axis along the scanning direction of the interferometer, we integrate the density $U(\varrho, t)$ over two dimensions perpendicular to the x-axis. And we obtain the one dimensional particle density $U(x, t)$ given by the following relation:

$$U(x, t) = \frac{N}{\sqrt{(\pi D t)}} \exp\left(-\frac{x^2}{4Dt} - Kt\right). \tag{1}$$

Here we further assume that the radio source was optically thin at 3.75 GHz, which may be assured in this case. Then the particle density $U(x, t)$ is proportional to the strip brightness distribution, which is the observable quantity. Thus, from the Equation (1) we obtain the following equation for the half-power source size $W(t)$:

$$W(t) = (\ln 2 \cdot 4Dt)^{1/2},$$

namely, $W(t)$ is proportional to the square root of time t. This relation is seen in Figure 3 to hold well. From this figure we derived that

$$D = 6.5 \times 10^{17}\ \mathrm{cm}^2\ \mathrm{s}^{-1}.$$

Since the solar atmosphere is regarded as collision-free, we have to consider the collision between energetic electrons and magnetic field irregularities to explain the diffusion process.

Motion of a charged particle in a random magnetic field is discussed by Jokipii (1966). Assuming a superposition of a constant magnetic field and homogeneously

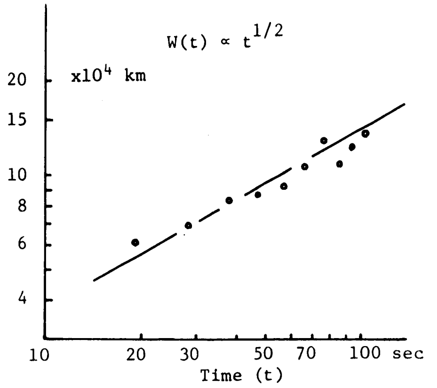

Fig. 3. The half-power width of the source is plotted against time. The solid line shows a relation that the width is proportional to the square root of time.

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turbulent fields of small quantities, he has noted that a particle undergoes a random walk in a plane perpendicular to the constant field.

Here, however, we shall follow a fundamental procedure discussed by Schatzman (1967). Let us consider a magnetic field consisting of a constant field B_0 and a fluctuating part δB, and put the characteristic correlation length of the irregular field L and the transverse velocity of a charged particle V. And if we denote the transverse displacement of the guiding center of a particle over L as δL, it may be given by the following equation (Alfvén and Fälthammar, 1963);

$$\delta L = (\delta B/B_0)\,L\,.$$

Thus the transverse motion of a charged particle is described as a random walk in a plane perpendicular to the constant field, with a step δL and a correlation time $\tau = L/V$, in a case of isotropic pitch angle distribution.

Then the transverse diffusion coefficient D is given by the following relation (Chandrasekhar, 1943):

$$D = (\delta L)^2/2\tau = LV\,(\delta B/B_0)^2/2\,.$$

The observed value of D is 6.5×10^{17} cm^2 s^{-1}, and V may be 10^{10} cm s^{-1}, that is 30 keV. Then

$$L\,(\delta B/B_0)^2 = 1.3 \times 10^8 \text{ cm}\,.$$

Since the correlation length may be much smaller than the scale of the active region:

$$\delta B/B_0 = 0.36 \quad \text{for} \quad L = 10^9 \text{ cm}\,.$$

The substance of δB may be inferred as finite amplitude MHD waves, which may play an important role in heating the flare region and in acceleration of solar cosmic rays.

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