records and it will be shown up better by measurements on position and polarization. That is the reason why I did not go into more detail.

Uchida, Y.: Do you think that the acceleration of particles occurs some time after the beginning of flares? Because the intensity of type IV bursts becomes stronger and stronger on the dynamic spectrum, in the first phase.

Thompson: Yes, I would say that the emission of electrons comes mainly between the start and maximum of flare.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-II, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3A-3. Structure of the Type IV Radio Burst and Its Relation with Solar Cosmic Rays

A. BOISCHOT and M. PICK

Meudon Observatory, France

The type IV burst is actually made of at least two distinct parts. The first one is seen on centimetric, decimetric and sometimes metric wavelengths, and may be explained by a synchrotron mechanism.

The first part is followed by the second one, more intense on metric wavelengths, and which lasts generally a few hours. In some cases, the emission is received one day or more, and these long durative events have been named continuum storm. The source of the emission lies low in the corona and its diameter is relatively small. The radiation is strongly circularly polarized in the ordinary mode, like the noise storms.

A plasma Cerenkov mechanism is proposed to explain this second part. High energy electrons would diffuse in coronal streamer, exciting longitudinal plasma waves, which can transfer a part of their energy upon transverse electromagnetic waves in some regions close to the critical height.

It has been shown during the last few years that there exists a strong relation between solar radio emissions and cosmic ray increases. This is due to the fact that the radio emission, certainly non-thermal on metric wavelength, comes from high energy particles. These particles are mostly electrons, instead of the protons observed with cosmic ray detectors when the sun is active. But it is easy to believe that a mechanism of acceleration of particles in the solar atmosphere, such as Fermi's mechanism, would give acceleration of both positive and negative particles. The observation of radio solar emission is much more easy than that of cosmic rays, where we need balloons, satellites or some indirect methods such as polar cap absorption studies. The study of radio emission is then very important, not only for the knowledge of the solar physics, but also for the study of cosmic rays.

Among the different types of solar radio bursts, type IV is certainly the most important from this point of view. The synchrotron theory of its emission requires the presence of high energy electrons of a few million electron volts, the origion of which is certainly related to that of the protons observed in the neighbourhood of the earth.

But those protons are often observed two or three days after the flare; it is very improbable that the acceleration processes can last so long; it is more likely that we have to do with some storage around the sun, the particles diffusing slowly during a few days. It is then important to see if the radio emission does show up some evidence of this storage of particles. To do this, we shall first study the detailed structure of type IV emission, then propose some mechanism which may explain these features.

§ 1. Structure of type IV burst.

The type IV burst can be divided into at least two parts, which differ in many important characteristics, and, as we shall show, correspond probably to two completely different mechanism of emission[1]. This division was made by studying the development of type IV bursts on different wavelengths, between 3 cm and 2 m, the directivity and polarization of the sources of emission were also taken into consideration.

After the beginning of some flares, an intense continuum radio emission is received at the earth, with a broadband spectrum covering cm, dm, and sometimes metric wavelength. The evolution of the radiation is about the same in this whole frequency range. It lasts from ten minutes to one or two hours in some very intense cases. This emission will be named first part of type IV. In many cases, after this first part, when the cm and dm emission has already faded out, a very intense emission is received on metric wavelengths, which can persist for a few hours. This will form the second part of type IV.

a) *First part of type IV.*

It is very likely that this is the radiation first observed with the Nancay interferometer a few years ago, and which led to its definition as type IV burst.

This first part is a *continuum radiation.* The metric emission comes from *very large source*—6 to 10 minutes of arc—which can move outward with speeds of the order of 1000 km/s. The emission has low directivity: It can be detected on the earth if the flare occur either near the center of the solar disc or near the limb.

We have very few accurate measurements of the polarization of this first part, but from what we know, it seems that the flares can be divided in two categories: those having a heliographic longitude larger than 60° will give non polarized emission, and those having a smaller longitude will in general give partly circularly polarized burst. If we consider the magnetic field of the leading spot of the active region, the sense of rotation seems to correspond to the extraordinary mode of the magnetoionic theory.

b) *Second part of type IV.*

This is also an emission with *continuum spectrum*, without type I bursts, intense on metric wavelength, but which rarely extends down to the cm range. It lasts a few hours after the first part. We have very little information on the source size, position and polarization, since the study of this second part is difficult as it often overlaps with the first one.

The principal difference between the two parts is the directivity, besides the frequency range. The second part shows a *great directivity*, being rarely observed when the flare occurs near the limb.

In a few cases, the same kind of metric emission observed during a few days after the flare. This emission, which is called "continuum storm" is probably not different from the normal shorter second part[1], and the study of this emission enables us to determine some other characteristics of this part. It is also a metricwave continuum emission, which sometimes degenerate into normal noise storm, with type I bursts. The source of emission lies relatively *low in the corona*, between 0.2 and 0.4 $R_\odot$ at 169 Mc/s, the mean altitude of the normal noise storm being 0.7 $R_\odot$ at the same frequency. The source of emission has a *small diameter*, less than 3 minutes of arc, and a *high directivity*, like the noise storms.

The "continuum storm" is always strongly circularly polarized, and if we consider the magnetic field of the leading spot in each group as preponderant, the sense of rotation is that of the ordinary mode, as for the normal noise storm.

§ 2. Interpretation of type IV emission

Fig. 1 shows the curve of dispersion of the different modes which can propagate in the coronal plasma. The ordinate is the square of the propagation index n, or the ratio (c/v_φ) between the velocity of light and the phase velocity of the wave, and abscissa shows the ratio $(\omega_0/\omega)^2$, where ω_0 is the critical frequency of the plasma and ω the frequency of the wave.

Four modes may exist: The modes (1) and (2) correspond respectively to transverse electromagnetic waves of the ordinary and extraordinary modes, (3) and (4) the longitudinal plasma oscillations, electronic and ionic[2] respectively. The only waves which can directly get out of the solar atmosphere are the transverse waves (1) and (2). However, in certain conditions, some waves of the modes (3) and (4) may transfer a part of their energy upon the transverse modes and then emit radiations which can be observed at the earth.

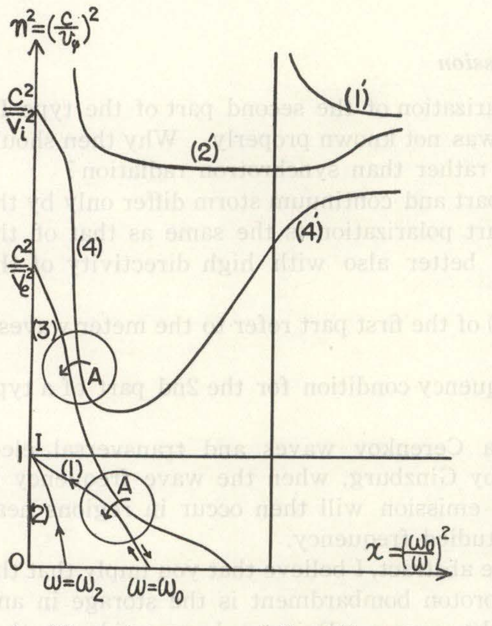

Fig. 1. Dispersion curves of the different waves which can propagate in the solar corona.

a) *First part of type IV*

The interpretation of the first part of type IV burst by synchrotron mechanism is still valid. Relativistic electrons in the coronal magnetic field will give an emission mainly on the extraordinary mode, which will propagate through a decreasing density medium, and so will follow curve (2) in Fig. 1 toward point I.

The synchrotron mechanism has nothing to do with the critical frequency of the plasma, and so can originate at altitude much greater than the critical height in the corona for each frequency. This agrees with the motion and high altitude found for the source of the first part. As a consequence of this high altitude, the refraction in the corona will have very small effect on the propagation, and the wave will always reach the earth: the directivity will be low, as is actually observed.

To compute the energy of the electrons which can explain the radio emission, we need the value of the magnetic field in the emitting region. This value is not known, but electrons of a few million electron volts are certainly sufficient.

b) *Second part of type IV.*

The second part is more difficult to be explained by synchrotron mechanism.

From the directivity of the emission, we may conclude that the mechanism of emission is probably related to the critical frequency of the plasma.

If electrons of a few million electron volts are trapped at the level of the source of emission of the continuum storm, they will very rapidly lose their energy by collisions and radiation. Furthermore, the synchrotron mechanism does not give an emission on the ordinary mode.

J. F. Denisse proposed to explain the emission of the second part and continuum storm by a plasma Cerenkov processes[3]. High energy particles ejected or accelerated at the beginning of the flare would remain trapped, somewhere near the sun, in magnetic configuration probably associated with coronal streamers. Those particles, slowly diffusing into the streamers, would excite plasma waves of mode (3) or (4), which can transfer their energy to electromagnetic waves.

The excitation mechanism of such plasma waves has just been studied by M. Cohen[4] who showed that one need electrons with energy less than a value necessary for synchrotron emission. The plasma wave is excited at a given point with a frequency just greater than the critical frequency of the plasma.

V. L. Ginzburg and V. V. Zhelezniakov[5], gave a summary of the works done on the problem of coupling between longitudinal waves (3) and (4) and transverse modes (1) and (2). The coupling takes place if there are small scale inhomogeneities in the corona, or strong gradient of density or magnetic field.

The circles A in Fig. 1 show the regions where the coupling is more likely to take place, since the phase velocities of the modes are closer. This coupling generally gives the *ordinary mode* in agreement with the observations.

On the other hand, the excitation of plasma waves and the coupling with electromagnetic waves take place at an altitude where the critical frequency is close to the wave frequency so that a center of emission on meter wavelengths is relatively low in the corona. The centimetric and decimetric waves are strongly absorbed near the corresponding critical heights, and this may explain why we don't observe the second part in these high frequency ranges.

References

1) M. Pick: Thesis Paris 1961. To be published in Ann. d'Astrophys.
2) J. F. Denisse and J. L. Delcroix: Propagation des ondes dans les plasma (edited by Dunod, Paris 1961).
3) J. F. Denisse: U. R. S. I. General Assembly London (1960).
4) M. Cohen: Phys. Rev. **123** (1961) 711.
5) V. Ginzburg and V. V. Zhelezniakov: Paris Symposium on Radioastronomy (edited by R. N. Bracewell, Stanford University Press 1959).

Discussion

Wild, J. P.: You remarked that the polarization of the second part of the type IV burst (as opposed to the continuum storm) was not known properly. Why then should its origin be in Cerenkov plasma radiation rather than synchrotron radiation?

Boischot, A.: We think that the second part and continuum storm differ only by the time scale, and we suppose that the 2nd part polarization is the same as that of the continuum storm. Cerenkov radiation fits better also with high directivity of the 2nd part.

Kundu, M. R.: Does the diameter ($8'-10'$) of the first part refer to the meter waves?

Boischot: Yes.

Biermann, L.: What was the precise frequency condition for the 2nd part of a type IV burst and the continuum storm?

Boischot: The coupling between plasma Cerenkov waves and transversal electromagnetic waves takes place, as shown by Ginzburg, when the wave frequency is close to the plasma frequency. The radio emission will then occur in regions near the critical altitude in the corona for the studied frequency.

Noyes, J. C.: From the last sentence of the abstract, I believe that you imply that the reason for the long duration of polar cap proton bombardment is the storage in and subsequent slow release of protons from the corona. Do you have evidence that protons are stored in the corona rather than elswhere in interplanetary space?

Boischot: The evidence is only indirect for protons, but may be similar to apparent storage of electrons in the corona, based on long-lived synchrotron or Cerenkov radiation from these electrons.

Takakura, T.: The 2nd phase may be attributed to synchrotron radiations from a radio source above a *followig* sunspot. When a gas cloud is ejected at the flare, weaker part of sunspot magnetic field is more easily pushed out. Therefore, a magnetic bulge is more likely made above the *following* spot (say $0.3\,R_{\odot}$ in height) than above the preceding spot. High degree of polarization, rather narrow bandwidth and the directivity would be explained by the *fundamental* waves of the synchrotron radiations from relativistic electrons in helical orbits. The waves can escape due to Doppler frequency shift into the direction nearly parallel to the magnetic lines of force in the magnetic bulge.

Tanaka, H.: You have said that the polarization of the first phase of type IV burst is of extraodinary sense. But according to our observations, the polarization on decimeter-wave region corresponds to the ordinary sense.