SESSION IV

SOLAR BURSTS - METER WAVELENGTHS

SOLAR BURST OBSERVATIONS AT METRE AND DECAMETRE WAVELENGTHS

D.J. McLean
Division of Radiophysics, CSIRO, Sydney, Australia

INTRODUCTION

Our success or failure in understanding solar bursts is largely determined by the kinds of instrument with which we observe them. For example, although the basic feature of Type II bursts, a slow drift from high to low frequencies, was recognized and correctly interpreted from radiometer measurements at a few frequencies (Payne-Scott et al., 1947) other properties of Type II bursts such as fundamental-harmonic structure, split bands and herringbone structure can only be recognized on dynamic spectrograms. For this review I have chosen to group together the observations made with a particular type of instrument. I have also tended to emphasize what remains to be done rather than what has already been done. Unfortunately, with so many topics to choose from my treatment can only be cursory; and in attempting to select the interesting topics I have inevitably been biased toward the work I know best - that is, the work of the group to which I belong.

RADIO SPECTROGRAPHS

The dynamic spectrograph, introduced by Wild and McCready (1950) and Wild (1970a, 1950b), revealed that the majority of solar bursts at metre wavelengths fell easily into a simple classification scheme: the now familiar Type I, II and III bursts. But more important than that, it gave a hint about the physical processes responsible for Type II and III bursts.

Type III Bursts

Now, almost 30 years later, we are quite confident that the early ideas of the generation of Type III bursts are basically correct: a stream of sub-relativistic electrons, accelerated low in the corona, passes out through the coronal plasma and at each level stimulates electromagnetic emission at the local plasma frequency and its second harmonic. Moreover, thanks perhaps to its relative simplicity, this model has attracted a lot of attention from the theoreticians, and we

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now have a good basic understanding of how the stream of electrons generates Langmuir waves in the plasma, and how these in turn are scattered into electromagnetic waves. In interplanetary space, electron streams, Langmuir waves and the resultant electromagnetic waves have all been detected (Gurnett and Anderson, 1976, 1977). While these observations tend to confirm the theory they should not be taken to imply that the final touches have been put to the theory, but the interaction between theory and observations is strengthening both.

Type II Bursts

The earliest spectral evidence for Type II bursts suggested that the observed frequency drift corresponds to the passage of a shock wave outwards through the corona. This explanation also is still universally accepted today; however, despite a number of different theoretical approaches, we do not yet have as complete an understanding of Type II bursts as of Type III bursts. There has been little progress since the review by McLean (1974).

Type I Storms

While the dynamic spectrograph reveals the underlying physical processes for Type II and III bursts, it has not, as yet, led to such a simple understanding of a number of other types of bursts. Among these are Type I bursts, which normally occur in storms. The association of high-frequency Type I storms with low-frequency Type III storms (Malville, 1962; Stewart and Labrum, 1972; Gergely and Kundu, 1975) suggests that sub-relativistic electrons are again involved, and the short duration and narrow bandwidth of individual Type I bursts have been taken as an indication that the electrons are accelerated locally and their energy quickly reabsorbed, except that some escape from the acceleration region and generate Type III bursts. (However, we note that other, rather different, suggestions about the link between the Type I and Type III components of storms have been made by Gordon (1971), Stewart and Labrum (1972) and Aubier et al. (1978).) Drifting chains of Type I bursts, another recognizable feature of the spectra of Type I storms, have been interpreted as due to pulses of Alfvén waves, propagating through the source region and somehow triggering the energy release mechanism. Elgaroy (1977) has summarized the existing attempts at explaining solar noise storms.

Drift Pairs

The spectra of reverse-drift or forward-drift pairs are very simple, and one might hope that an interpretation would be easy to find. Roberts (1958) suggested that the second pulse was an echo of the first, but this hypothesis has been criticized - for example on the grounds that as a result of scattering near the reflection level the reflected burst should be more diffuse than the original burst (Riddle, 1974).

Regular Pulsations

Regular pulsations are another type of burst for which the simple spectrum suggests a simple underlying process, yet to date a theoretical explanation has not been established. The problem in this case is to imagine a periodic phenomenon occurring high in the solar corona with a period as long as 3 or 4 s. Rosenberg (1970) proposed radial MHD oscillations of a flux tube. Unfortunately, the discussion by McLean et al. (1971) of how these oscillations might modulate the emission is incorrect.

Zaitsev and Stepanov (1975) (see reference in Meerson et al. (1978)) suggested a model in which plasma turbulence is generated by trapped protons and the level of turbulence pulsates. Meerson et al. proposed radial MHD oscillations of an over-dense flux tube, driven by trapped energetic protons, because they found that the free oscillations proposed by Rosenberg would damp too quickly. Perhaps the basic mechanism underlying reverse drift pairs and pulsating bursts will be established in the next few years.

Continuum

The earliest spectrographs were not very sensitive and it was not till later that the existence of a variety of different types of continuum bursts was recognized. Indeed the spectrum gives us very little information about these types of bursts, since they appear as broad-band, long-duration increases of the solar radiation, generally with no spectral structure on which an interpretation can be based. In the next section we shall consider some of the different continuum bursts which can be distinguished using imaging radio telescopes.

IMAGING RADIO TELESCOPES

Moving Type IV Bursts

The most dramatic records from imaging telescopes are of moving Type IV bursts. Since Boischot (1958) defined this type of burst it has received a lot of attention. However, because Professor Dulk will be discussing Type IV later at this conference, I shall limit myself to showing how at each step better instrumentation has forced us to modify our interpretation of these bursts. From his observations at Nançay, Boischot suggested that the radiation was due to synchrotron emission by 1 MeV electrons (the height precluded plasma emission and the electron energy is consistent with the weak magnetic fields that can reasonably be assumed high in the corona). However, observations at Culgoora which can determine the degree of polarization showed that in their late stages Type IV bursts frequently have a high level of circular polarization. This is only possible for the synchrotron process if the radiating electrons are sub-relativistic (i.e. ~100 keV rather than 1 MeV) and the magnetic field is much stronger than assumed by Boischot. This in turn led to the suggestion by McLean and Dulk (1978) that the magnetic energy transported by the mass ejecta responsible for moving Type IV bursts is a major source of energy in interplanetary space. More recently, as a result of improvements in brightness calibration, Culgoora observers have been able to establish clearly that brightness temperatures of $>10^9$ K occur during the early phases of some moving Type IV bursts (Stewart et al., 1978); for such high brightness temperatures, high electron energies ($\gtrsim 1$ MeV) are required or a collective emission process such as plasma emission must be involved.

It is to be hoped that we are approaching a firm conclusion about the Type IV emission process.

Flare Continua

Another type of continuum burst, called flare continuum (Wild, 1970), is best recognized from spatially resolved data. Robinson and Smerd (1975) and Robinson (1978) distinguished two types of flare continua - those associated with Type II bursts and those associated with moving Type IV bursts. For the Type IV associated continua, typically a source appears above the Hα flare at about the flash phase and remains stationary for about 20 minutes. Subsequently the source begins to move outwards and becomes a moving Type IV burst, or else a moving source "buds off" from the stationary source, which remains visible for a few minutes longer. Despite the apparent continuity in some cases between the flare continuum and Type IV sources they must be different phenomena, since the flare continuum source appears high in the corona, very soon after the flash phase of the flare, whereas the slowly moving Type IV burst takes much longer to reach that height.

It has been suggested that flare continuum emission is from energetic electrons, generated at the flash phase of a flare, and trapped in a magnetic arch (Kai, 1975; Robinson, 1978). Kai claims that continued acceleration of electrons is necessary to explain the lifetime of these events. Robinson concludes that it is not yet possible to choose between plasma emission and gyro-synchrotron emission from the energetic electrons; it is possible that both processes are of comparable importance.

Slow-drift Continua

This is another type of event, probably closely related to Type I storms, which should receive close attention in the future. Examples are the events described by McLean (1973) and Dulk et al. (1976). In each case the low-frequency edge of the spectrum of emission drifts from high to low frequencies at a rate slower than is typical of Type II bursts - hence the name.

As for other continuum events described by Magun et al. (1975), the lower frequencies are observed higher in the corona than the higher frequencies, suggestive of a columnar source which emits different frequencies, probably related to the local plasma frequency, from different heights in the column. The event described by McLean (1973) was associated with an eruptive prominence which can be identified with the columnar structure of the radio source.

Associated with the event described by Dulk et al. (1976) was a white light transient recorded by the HAO coronameter on Skylab, and those authors identify the start of the radio source with the passage of a faint forerunner (cf. Jackson and Hildner, 1978) ahead of the main body of the white light transient.

The combination of the two sets of data (radioheliograph and coronameter) made it possible to deduce quite a lot about the physical conditions in this radio and optical transient. It is hoped that similar data obtained during the flight of the SMM spacecraft will make it possible to extend this study.

Refraction and Scattering

A general problem in interpreting spatially resolved observations of metre-wave solar bursts is that we are looking into a strongly refracting medium, and to the extent that the structure of the corona is unknown, the way in which refraction affects our observations is unknown. It seems probable that several strange observations may be explained by the refraction by large-scale structures in the corona or by scattering, i.e. refraction by many small-scale structures in the corona. When Type III bursts are observed at different frequencies, lower frequencies appear to come from higher in the corona, as predicted by the plasma hypothesis. But these heights are significantly higher than those predicted from electron density models determined from white light observations during solar eclipses (Stewart, 1976).

In addition, when the fundamental and second-harmonic components of a single Type III burst are observed at the same frequency, say 80 MHz, the two sources appear to be at about the same height, although the fundamental, emitted from the 80 MHz plasma level, should appear much lower than the harmonic, emitted from the 40 MHz plasma level. Duncan (1979) has proposed that all these effects can be explained if the corona consists of intermingled under-dense and over-dense flux tubes, and the emission of Type III bursts occurs only in the under-dense tubes. The radiation will then be ducted along under-dense tubes, until it reaches a height where it can escape. Duncan proposed that this is the observed height of the bursts - the same for both fundamental and harmonic, and indeed for almost all types of bursts, whatever the emission mechanism.

This proposal is remarkably close to that put forward by Bougeret and Steinberg (1977) to explain consistently a number of observations of Type I bursts; the observed bandwidth suggests very small sources, smaller than the observed source sizes. The early explanation of the observed sizes in terms of isotropic scattering is not consistent with the high directivity of emission revealed by the STEREO experiment (to be mentioned later). Bougeret and Steinberg claim that scattering in a fibrous medium preserves the angle between the fibres (i.e. the magnetic field) and the rays, but randomizes the components of the ray direction, perpendicular to the magnetic field. (This is another example where the addition of successive pieces of observational data has significantly modified the interpretation.)

Type II Bursts from Behind the Limb

Type II bursts due to behind-the-limb flares are a rare but interesting phenomenon for which the problems of radio propagation do not appear to limit seriously our ability to interpret spatially resolved data. Of course the conclusion that a flare occurred behind the limb can only be inferred; in each case a very active centre of activity was a few days behind the limb, and no flare or flare-producing centre was observed on the disk. To date only four such events have been reported (Smerd, 1970; McLean and Nelson, 1977; Gergely and Kundu, 1976; Nelson and McLean, 1977). In three cases, observation of a burst at the limb implied that the shock wave must have followed a curved path from the flare to the limb of the Sun, and in three cases the source was seen to move in from its early position above the limb towards the centre of the Sun, apparently continuing its curved path around the Sun rather than radially out from the flare position. At least in these special cases we can conclude that the shock wave responsible for the Type II burst was a blast wave, propagating much as in the theory developed by Uchida (1974), rather than a driven shock wave ahead of an ejected mass of gas, as suggested by McLean (1959) for example.

Coronal Magnetic Structure from Type III Bursts and Type I Storms

In a few cases the individual members of a long series of Type III bursts have been observed to come from such widely different positions that the uncertainties resulting from propagation effects could be ignored and the locus of the burst centroids interpreted as lying close to a magnetic neutral plane high in the solar corona (McLean, 1970; Kai and Sheridan, 1974). Unfortunately this phenomenon is not common enough for systematic exploitation. Similarly, when Type I storms do not lie radially above the associated sunspot group, this can be interpreted as indicating that magnetic field lines join the active region to a nearby region of opposite polarity (Lantos-Jarry, 1970; Kai and Sheridan, 1974), much as indicated by more recent, soft X-ray images of the Sun. At decametre wavelengths, storm centres are observed to be high in the corona and their positions correlate with complexes of active regions rather than with a single active region, suggesting that the fields of the different regions are not distinct at these heights (Gergely and Erickson, 1975).

Thermal Emission from the Corona

The study of the thermal radiation of the Sun at metre wavelengths is made difficult by several effects. The corona is optically thick at radio wavelengths near the centre of the disk, and so even a major increase in coronal density near the centre of the disk will not be detectable. Variations in electron density beyond the limb should be detectable, but there the effects of refraction complicate the situation; a large coronal condensation a couple of days in front of or behind the limb would look the same to a white light coronagraph, but generally the condensation behind the limb would be invisible to a metre-wave radio-telescope because there is no possible ray path from the condensation to the Earth, unless the condensation extends very high in the corona. An instrumental problem also arises: suppose that the side-lobe level of the radio-telescope is about 1% r.m.s. over the inner field of view. Then observing with modest resolution we will have perhaps 100 beam areas on the Sun, and this results in an uncertainty due to sidelobes of about $\sqrt{100} \times 1 = 10\%$. Since the effects that we can hope to see are of low contrast, this represents a severe limitation for this type of observation. It is hoped that a redesign of the signal-processing electronics of the Culgoora array currently being planned will make it possible to reduce sidelobes to a level where this type of observation can be made more frequently and more reliably (McLean, 1970; McLean et al., 1979).

Nevertheless observations with the Culgoora and Nancay radioheliographs have been successful in detecting coronal structure in two simple cases. Coronal holes near the centre of the disk can be detected at 160 MHz, because the reflection level for 160 MHz radiation drops below the base of the corona into the colder chromosphere. As a result a depression of 10% or 20% brightness can be detected (Dulk and Sheridan, 1974; Lantos and Avignon, 1975; Dulk et al., 1977).

In addition, at least one, particularly dense, slow-moving white light transient beyond the limb has been detected by its thermal emission (Sheridan et al., 1978).

SWEPT-FREQUENCY POLARIMETER

At this conference, Suzuki et al. (1979) will present a paper on the conclusions about the structure and strength of the coronal magnetic field deduced from observations of fundamental harmonic Type III bursts made with the new colour polarimeter, the radioheliograph and the radiospectrograph at Culgoora. The success of this work results partly from having three such powerful instruments working together, but also from the fact that the theory of polarization in Type III bursts had already been worked out by Melrose and Sy (1972) and Melrose et al. (1978).

Other interesting data on the polarization of drift pairs will be presented by Gary et al. (1979). Perhaps this information will help in the search for a theoretical explanation of these bursts.

Other types of bursts for which the colour polarimeter holds similar promise include slow-drift continua and herringbone Type II bursts.

STEREO

Conceptually very simple, the French STEREO experiment consists of two identical radiometers, one on the Earth and the other on a space vehicle in the solar orbit. Large differences between the recorded intensities for Type I bursts show that this type of emission is highly directive (Steinberg et al., 1974). This result limits the amount of scattering which we can assume for propagation in the coronal plasma, which in turn makes it difficult to reconcile the observed source sizes for bursts with the short duration of those bursts. We have already discussed the fibrous source structure proposed by Bougeret and Steinberg (1977) in an attempt to reconcile these data.

THEORY

The theoretical study of solar radio bursts involves at least three elements: the macro structure of the source region (e.g. stream of electrons, shock wave, moving cloud of magnetized plasma), the micro structure (i.e. plasma processes and emission process within the source), and propagation effects between the source and the observer. Throughout this review I have alluded to the state of the theory of the different types of bursts, and stressed the importance of having the theoretical development keep pace with observations. The plasma physics involved in much of the theory is quite difficult and it is probable that it will take some years yet to develop a complete theory of all the different types of bursts. As an example of how long it might take, Wild (1950b) ascribed Type III bursts to the passage of electrons through the corona. Nearly 10 years later Ginzburg and Zheleznyakov (1958) laid down the basis for the theoretical explanation of the process of emission, and only now, another 20 years later, we are coming to understand the dynamics of the cloud of electrons (Grognard, 1979; Takakura and Shibahashi, 1976; Takakura, 1977, 1979a, 1979b; Magelssen and Smith, 1977). It is to be hoped that parts of our theoretical understanding of Type III bursts will be applicable to other types of bursts.

CONCLUSION

The great variety of metre-wavelength solar radio bursts makes it difficult in a short space to offer a unified review. A number of times I have shown how conclusions drawn on the basis of observations made with a single instrument have had to be modified when extra information became available from newer instruments. Although I have only stressed this for radio observations, the argument applies with equal strength to any other relevant source of data. Solar radio astronomers make extensive use of a great variety of other data - Hα images, both of the disk and of prominances beyond the limb, geomagnetic data, ionospheric data and K-coronameter data. More recently, space observations have offered EUV and soft X-ray images, data on interplanetary disturbances and white light coronagraph images. The most exciting prospect for us at Culgoora, and for others similarly placed, is the opportunity to combine our images of coronal transients with white light images of coronal transients from the HAO white light coronagraph on the SMM satellite. We fully expect that once again the combination of several different sorts of data will tell us much more than the individual observations taken separately.

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DISCUSSION

Vlahos: You mentioned something about correlation of type I storms and type III bursts. Have you seen any type I/type V correlation or type I/J correlations?

McLean: Storm type III bursts usually have very simple structure, no harmonics, no U-bursts, etc. One exception is the occasional association of drift pair storms with type I and type III storms.

Stone: There exists about a 95% correlation between 169 MHz noise storm data and 1.65 MHz hectometer storms observed in space, suggesting the possible connection of open field lines in I.P.M. to type I noise storm regions. (Unpublished data 1968-1969). Is this correlation known and understood?

McLean: Clearly the electrons responsible for type III storms are on open field lines. The conventional wisdom is that type I storms occur in closed field structures. This makes it more difficult to understand a close association between the phenomena.