Calculation of Type III Radio Emission from a Particle Transport Model

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Abstract

Type III radio bursts are produced when beams of electrons (2 to 50 keV) originating at the Sun generate radio emission at the local plasma frequency as they move out through the heliosphere. As the beams encounter successively lower and lower plasma density the emission frequency becomes lower. If the electrons actually reach the observer, the frequency can be as low as the local plasma frequency. Recent work concludes that there is an intimate connection between the propagation of electrons and protons, and among electrons of vastly different energies. As a result we have begun an effort to incorporate calculations of radio emission into our comprehensive propagation model. I report on the first results of this calculation.

1. Introduction

The relationship between radio emission and low energy electrons has been known for some time, but Cane & Erickson [1] make it clear that solar proton events are also associated with the Type III radio bursts. They find a correlation among the arrival times of 38-53 keV electrons, protons above 10 MeV, and the times at which the associated type III burst reaches the local plasma frequency of the observer. This correlation is maintained for spacecraft near Earth (WIND, ACE, and IMP-8) and at Ulysses even though the arrival times of the particles and radio waves may differ by several hours when observed simultaneously on two spacecraft distant from each other. Our recent work [2] also concludes that there is an intimate connection between the propagation of electrons and protons, and among electrons of vastly different energies. Even more dramatic is the observation of "bidirectional streaming" of both low energy electrons and particles of neutron monitor energy associated with magnetic clouds [3].

2. Type III Radio Emission

In order to illustrate how radio emission can be diagnostic of particle propagation, I have adapted the excellent discussion of Reiner and Stone [4,5]. In the left panel of Figure 1 an observer at 1 AU (which I will simply refer to as "at

pp. 3491–3494

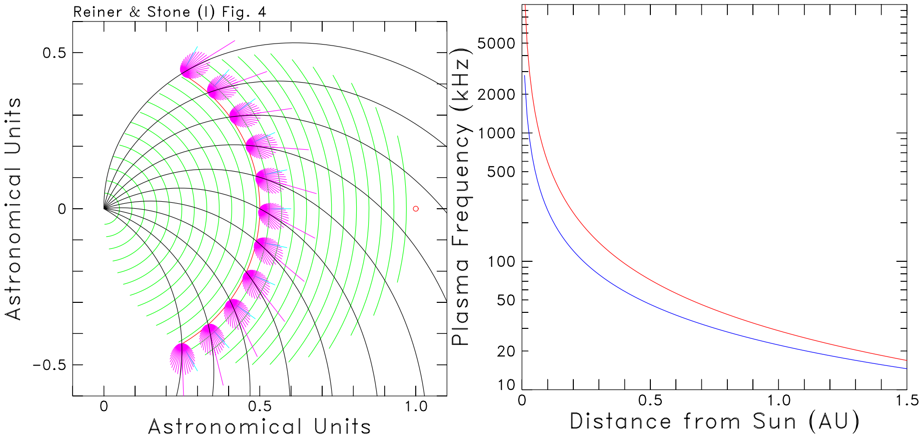

Fig. 1. Left: Basic elements of the calculation of Type III radio emission. Right: Two alternative models of the plasma frequency as a function of distance from the Sun. After Reiner and Stone [4].

Earth") is indicated by the small red circle. Typical lines of the Parker field are also shown. A small bunch of electrons is propagating along each field line, emitting radiation as it travels.

Several factors affect the ability to detect this radiation at Earth. The most basic of these is the behavior of the plasma frequency in the heliosphere, which is a monotonically decreasing function of distance from the Sun, as illustrated in the right panel of Figure 1. (For the present, I am assuming that the Type III radio waves are emitted exactly at the plasma frequency where they are generated. This is not universally accepted, but it serves to focus the current discussion.) Radio waves can only propagate if their frequency is above the local plasma frequency. One immediate consequence of this is that no signals originating at a distance from the sun greater than 1 AU can be observed at Earth. An extension of this argument quickly shows that the radio waves cannot be observed from many locations inside 1 AU either. To be observed, the requirement is that the plasma frequency at all locations on the line of sight from the observer to the source must be lower than the plasma frequency at the source. The green arcs define this region of observability. All of the electron packets shown are within this "horizon" in the figure, but clearly the two on the outside are just about to drop out of visibility. Note that a wide range of longitudes is visible when the electrons are near the Sun, but only the electrons on the field line connecting to the Earth are visible for their entire journey. This, in fact, is the key to understanding the basic phenomenology of the Type III bursts.

Other effects are important in the computation of the observed intensity. The radiation is beamed in the direction of propagation of the particles. The Reiner and Stone [4,5] assumption for this beaming, illustrated in Figure 1, is

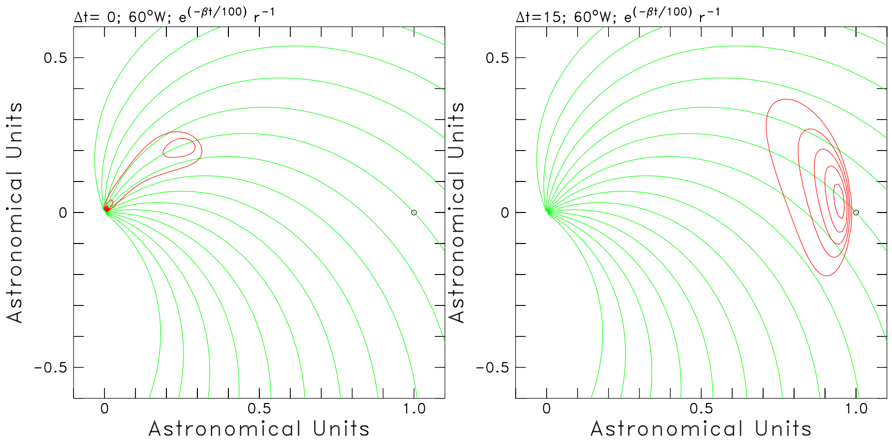

Fig. 2. Distribution of 50 keV electrons (from a flare at W60, S12) in the model of Bieber *et al.* [6]. Left: At the flash time (see text for definition). Right: Fifteen minutes after the flash time.

used in the subsequent calculations, as is their assumption for the intensity of the radiation as a function of plasma frequency. Refraction will tend to focus the radiation in the radial direction, but I follow Reiner and Stone [4,5] in ignoring this effect. Finally, Reiner and Stone [4,5] worked with specific observations, and included simulations of the receiving antennae in the work, whereas I have just assumed perfect, omnidirectional sensitivity.

To illustrate the main idea of our present work, consider a simple adaptation of the propagation model of Bieber, Evenson, and Pomerantz [6], which is best described as a modified Reid [7] Axford [8] approach. (In that paper we studied both 50 MeV protons and particles at neutron monitor energies.) The adaptation consists of running the model for a particle velocity appropriate to 50 keV electrons with the "scatter free" assumption for interplanetary propagation (one of the cases treated in the paper) and an escape time (scaled by velocity) of 100 seconds. In this calculation, the "flash time" refers to the time at which photons from the start of the event would reach the earth. I have also scaled the particle density as the inverse first power of radial distance, rather than the inverse square. This is equivalent to projecting all of the particles into the ecliptic plane, in keeping with the two dimensional nature of the Reiner and Stone [4,5] analysis.

Figure 2 illustrates the density of electrons in this model at different times. At the flash time (left panel) the electrons are still all in the inner part of the heliosphere because they are travelling at far less than the speed of light, but Type III radiation has already begun to arrive since it propagates at the speed of light. Cane and Erickson [1] interpret lateral spreading of the electrons as arising from perpendicular diffusion well out in the heliosphere, whereas in this model

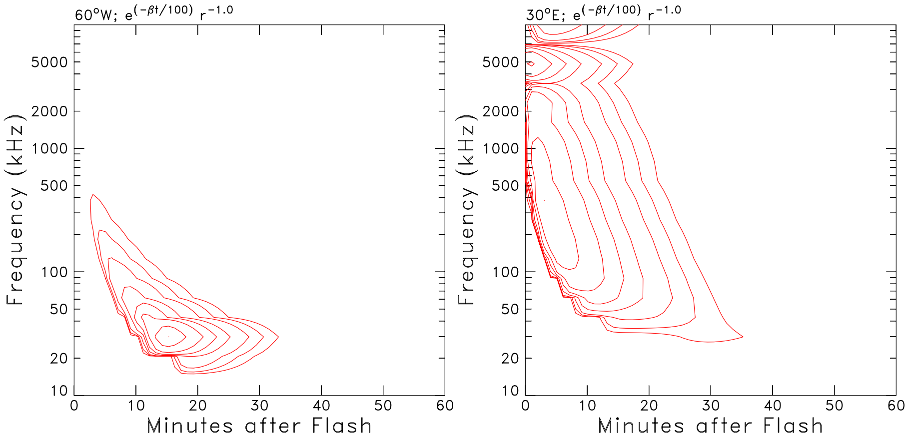

Fig. 3. Simulated Type III emission from identical flares occurring at W60 (left) and E30 (Right).

the lateral transport is occurring near the sun. Fifteen minutes after the flash (right panel) the first electrons are just about to reach the Earth. The distribution of electrons closely resembles that deduced by Reiner and Stone [4,5] from their analysis of the evolution of the radio emission. The left panel of Figure 3 shows the calculated radiation seen by a "well connected" observer at W60, whereas the right panel shows the event viewed from E30. Unfortunately, the dynamic range of this contour plot is not sufficient to show the emission at all times. But it is clear that the observations depend critically on the location of the observer, with the systematics just as reported by Cane and Erickson [1]. (I am working with Bill Erickson to be able to display the results of the calculation better.)

3. References

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