NUMERICAL SIMULATION OF TYPE III BURSTS

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By the use of semi-analytical method, modeling of three kinds of type III solar radio bursts have been made. Many basic problems about the type III bursts and associated solar electrons have been solved showing some striking or unexpected results. If the fundamental radio emissions should be really observed as the normal type III bursts, the emission mechanism would not be the currently accepted one, i.e. the scattering of plasma waves by ions.

One-dimensional numerical simulations for the quasi-linear interaction of solar electrons and plasma have been made by Takakura and Shibahashi (1976), Takakura (1977), and also by Magelssen and Smith (1977), showing that the electron velocity distribution becomes a quasi-plateau in a limited velocity range.

By the use of this characteristic, an approximate method has been developed (Takakura 1977, 1979a) to compute three-dimensional plasma waves caused by one-dimensional solar electrons. Induced scattering of plasma waves has been taken into account in the evolution of the spectral energy density of plasma waves, showing that the backscattering is strong, while its effect on the electron stream is taken into account in a iterative way (1979a).

The radio emissions from such plasma waves are computed at the fundamental, second and third harmonics (1979a, b), showing that the second harmonic predominates in almost every frequency range of type III solar radio bursts.

The numerical simulations for the following three models have been made.

1) Normal type III bursts on meter waves, which show the maximum flux density in the meter-wavelength range.
2) Low frequency type III bursts, which have a broad maximum of very high flux density at about 300 to 100 kHz.

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3) Type III bursts caused by a high-density electron beam with a cross-sectional area very small compared with the observed size.

The results for the Models 1 and 2 are as follows (Takakura 1979b).

i) Induced backscattering of plasma waves by thermal ions is strong even for a solar electron cloud of rather low flux, e.g. 2×10^{11} cm^{-2} ($\gtrsim$ 5 keV) at ν_p=40 MHz, which is enough to emit the observed type III bursts as the second harmonic.

ii) The ratio β_W between the energy densities of plasma waves (ε_p) and thermal electrons ($n\kappa T$) is of the order of 10^{-6}, which is much smaller than the threshold value, $(k\lambda_D)^2$, for the soliton collapse of the plasma waves to occur by three orders in the corona and two orders near the earth orbit.

iii) The second harmonic radio emission, as attributed to the coalescence of two plasma waves travelling in quasi-opposite directions, is several orders higher than the fundamental radio emission caused by the scattering of plasma waves by thermal ions, while the third harmonic radio emission can be strong enough to be observed in a limited frequency range.

iv) The second harmonic radio waves are emitted predominantly into the forward direction ($\phi\simeq30°$) at the early phase, but the backward emission ($\phi\simeq150°$) also appears at the later phase and it predominates at low frequencies. These are attributed to the evolution of spectral energy density of plasma waves due to the induced backscattering.

v) If x-dependence of the cross-sectional area of the electron beam is $x^{1.5}$ or less as assumed in Model 2, the second harmonic radio emission can have a very high maximum flux at low frequencies, partly because the growth rate of plasma waves is inversely proportional to the plasma frequency.

vi) Near the earth, the peak of second harmonic radio emission from a given layer appears well after the passage of a whole solar electron stream through this layer. This is ascribed to the plasma waves in non-resonant regions as the result of induced backscatterings.

vii) The total number of beam electrons decreases gradually with distance due to the particle collisions with thermal electrons, the collisional decay of plasma waves before the waves are reabsorbed by the beam electrons arriving later and the scattering of plasma waves into nonresonant regions. However, the apparent velocity as derived from the frequency drift of type III burst is almost constant. The change in the velocity, if any, results from a change in growth rate of the plasma waves instead of the deceleration of individual electrons.

Model 3 (Takakura 1979c) is to demonstrate that the fundamental radio emission of type III bursts on meter waves can be comparable to the second harmonic if the flux of electron beam is high enough (30 times Model 1), but the cross-sectional area of the beam being 10^{17} cm^2 in the corona (10^{-3} times smaller than Model 1) in order to give the observed radio flux. In this case the optical thickness τ_1 for the negative absorption (amplification) of the fundamental radio emission is -23 to -25, which is nearly proportional to the electron flux. Therefore, the intensity of the fundamental waves depends strongly on the parameters

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which determine the electron flux, while the second harmonic is insensitive to the electron flux since $\tau_2 \simeq 1$. Furthermore, the third harmonic radio emission becomes comparable to the second harmonic in this model.

In the above reasons, it is very unlikely that the pairs of type III bursts of the first and the second harmonics occur frequently with comparable intensities. If the observed pairs of normal type III bursts should really be the pairs of the fundamental and the second harmonics, the fundamental radio waves would be emitted by another mechanism. One possibility is the coalescence of the plasma waves with the low frequency waves (Takakura 1979d), whistler or ion acoustic waves, preexisting on the way of the electron beam which excites the plasma waves. Whistler waves may be excited due to loss-cone instability in a closed magnetic flux tube along which electron beam travels emitting U or J type bursts, which have been used as the evident examples of harmonic pairs. However, it is not evident whether such low frequency waves can also exist along the open magnetic field in the corona. Accordingly, harmonic pairs of U and J bursts may not support the view that the observed pairs of normal type III bursts are really harmonic pairs.

We cannot, however, rule out the possibility that single type III bursts with short durations or group of such bursts are the fundamental waves emitted by the scattering of plasma waves by thermal ions, though the cross-sectional area of the electron beam must be 10^{14} cm^2 or less in the corona in order for the second harmonic waves to escape the detection.

In the above simulation, oscillating two-stream and stimulated modulational instabilities (e.g. Bardwell and Goldman 1976) and the collapse of plasma waves into soliton (e.g. Nicholson et al. 1978) are not taken into account, although induced scattering (electron-ion decay) is taken into account. The first two instabilities seems unimportant since the change in wave number is small (Smith 1977, Nicholson et al 1978). Nicholson et al. (1978) have made the simulations showing that the collapse began at the later phase, but they have set $\beta_W = 10^{-4}$ in their simulation which is about 50 times greater than that of present Model 2 at 0.45 AU. Accordingly, it may be valuable to test whether the collapse occurs or not in the condition derived in the Model 2, i.e., $\beta_W = 2\times10^{-6}$, $k\lambda_D = 0.02$, $\Delta k \simeq k/3$ and an effective duration is 800 sec.

Even if the collapse occurs at the later phase of the passage of an electron cloud, the dynamics of the electron beam would not be quite different from the quasi-linear diffusion of inhomogeneous electron beam since the energy of the plasma waves is in any case reabsorbed as the Landau damping by the electrons arriving later. If the collapse occurs, however, a modulation of electron flux may occur. This could be the cause of type IIIb bursts.

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DISCUSSION

Benz: At what frequency do you expect emission at the third harmonic?

Takakura: The third harmonics can be higher than the fundamental at $f_2 \lesssim 80$ MHz for Model 1 and $f_2 \lesssim 2$ MHz for Model 2.

Papadopoulos: Your results are very model dependent (e.g. in order for the non-local time change of the distribution to stabilize the beam, the time scale for energy change $\frac{\Delta\varepsilon}{\Delta t}$ must be much faster than the quasi-linear time $\tau = \frac{n}{n_b} W_e^{-1}$. This implies $\frac{\Delta\varepsilon}{\Delta t} >> \frac{\varepsilon}{\tau}$, where ε is the beam energy. This is unrealistically fast for type III bursts. Can you comment on that?

Takakura: If the electron flux is too small, the plateau may not appear (cf. Model 3 in paper by Takakura, Solar Phys. 52, 429, 1977). If, however, the electron flux is as large as the real solar electrons, the plateau is easily formed as shown by Takakura (cited above), Magelssen and Smith, Solar Phys. 55, 211, 1977 (and Grognard, this symposium).

Due to the quasi-plateau, the growth rate of the plasma waves becomes very small but also the required change in f(v) to keep the plateau is small. You should recognize that the dynamics of electron beams of finite length is quite different from that of homogeneous beam.

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