SOLAR TYPE I RADIO BURSTS: AN ION-ACOUSTIC WAVE MODEL

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ABSTRACT (paper submitted to Astronomy and Astrophysics)

We propose a model for type I emission based on scattering of Langmuir waves by ion acoustic waves, which are associated with the evolution of the associated active region on the Sun.

i) The observed complete circular polarization (o-mode) of the type I bursts indicates that plasma waves, presumably Langmuir waves, are important. Radio emission by Langmuir waves occurs when these waves are scattered by suitable low-frequency waves.

ii) The absence of detected radiation at the second harmonic indicates that the intensity of the Langmuir waves is low. The ratio in observable fluxes of harmonic to fundamental is $\lesssim 10^{-2}$. The actually emitted ratio is still lower because the fundamental is absorbed. Therefore, explanations in the manner of type III bursts are not adequate.

Our model will predict an extremely low ratio of harmonic to fundamental emission in type I bursts, of the order of 10^{-5} in apparent brightness temperature. An important check on our theory, therefore, would be a more thorough search for the second harmonic.

iii) The brightness temperature of the emitted radiation is of the order of 10^{13}K: One observes $T_b < 10^{10}$K when using the observed angular dimension of 3', which is produced by coronal scattering. Temporal structure down to 0.1 second implies $T_b < 2\mathrm{x}10^{11}$K. Absorption during emergence of the radiation from the plasma level (100 to 300 MHz) implies raising T_b by another one to two orders of magnitude. We adopt a burst surface area of 6000 x 6000 km^2.

The high brightness temperature at the fundamental, combined with the low intensity of the Langmuir waves, requires an intense low-frequency wave.

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iv) We ask: What already known or anticipated process in the corona, specifically in a complex and evolving active region, could yield a small source of intense low-frequency waves? What could we then learn from the radio emission concerning this process? One of the possibilities cited for coronal heating, specifically in active regions, is the dissipation of electrical currents by ion-acoustic waves generated by a current-driven instability.

We produce a first model based on Langmuir and ion-acoustic waves. We concentrate on the scattering (merging) of oppositely traveling Langmuir and ion-acoustic waves, each with $k \lambda_D = 0.1$.

The optical depth for the radio emission is controlled by the intensity of the ion-acoustic waves. Both laboratory and theoretical estimates yield ion-acoustic wave energy densities of order 10^{-2} of the thermal energy density. Then optical depth unity is reached over a distance of merely about ten meters. Thus the volume occupied by the waves can be very small, as expected for a current-driven instability.

The brightness temperature is proportional to the intensity of the Langmuir waves. If the ion-acoustic waves heat the plasma to about 2×10^7K, the Langmuir wave energy density needs to be only 10^{-7} of the thermal energy density, or about 10^3 times the level of thermal fluctuations. We stress that it takes astoundingly little Langmuir wave intensity to create intense radio emission. (The ratio of needed Langmuir wave intensity to thermal fluctuations is proportional to $1/T_e$). No clear source of Langmuir waves (traveling opposite to the ion-acoustic waves) is identified: Runaway particles are ineffective within the small source; coronal trapped particles produce negligible waves in the hot burst source if their harmonic emission in the rest of the corona is unobservable. However, the general nonthermal nature of the source, and the need for heat conduction and dynamic phenomena, make the needed Langmuir waves plausible.

v) We have also considered the continuum radio emission. Its complete circular polarization is taken as evidence for the absence of second-harmonic emission. Therefore, the emission must again be due to scattering of plasma waves on low-frequency waves.

We explain the continuum in terms of trapped electrons (with energy of order 20 kev) generated in the burst source. At a density of order $10^{-5}n_e$, these energetic electrons suffer a very slow loss-cone instability. They can remain trapped for some minutes, but they produce enough upper-hybrid waves to make the continuum emission by combination with low-frequency waves plausible. No obvious low-frequency waves are identified. Lower-hybrid waves are a possibility.

It appears, therefore, that type I bursts, type I continuum, and the evolution of the active region can be related to each other. In fact, if type I bursts are to be explained in this manner, they may be an important aspect of coronal evolution. The ion-acoustic waves re-

represent an anomalous resistivity and, thus, a site of very localized magnetic reconnection. One expects that magnetic fluxtubes emerging from the photosphere in a developing active region complicate the coronal magnetic field. The magnetic reconnection at type I bursts may then re-simplify the magnetic field. However, very little magnetic energy is released as heat. With the parameters we use, the thermal and particle energies in type I bursts are at least one order of magnitude less than needed for the average heating in an active region.

In summary, type I bursts may be a sensitive radio diagnostic for the gradual (non-flare) evolution of active regions.

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DISCUSSION

Papadopoulos: Every time you have anomalous resistivity of an ion-acoustic instability you always end up with a very small percentage of runaway electrons. These can very easily produce a very small enhanced level of plasma waves. You can have a mechanism going on without producing $2\omega_p$ because we don't produce counterstreaming waves, and the enhanced waves scatter only the thermal ω_p waves. Then you can again have the harmonic ratio very small.

Wentzel: The problem with plasma waves from runaway electrons is that they travel parallel to the ion-acoustic waves,thus yielding no radiation. In general, nonthermal electron tails can easily produce high levels of Langmuir waves, but if the electron produced waves in most of the corona are to be so weak as to produce negligible second-harmonic continuum, then they produce even fewer Langmuir waves in the type I source than we need. We need a source of nonthermal electrons that remains relatively local. That requires more careful estimates than we are able to make so far.

D.Smith: To my knowledge in the corona the thermal level of plasma waves $W_p/nKT \approx 10^{-14}$. You said that the level of waves only need to be 10^3 times the thermal level, but you used $W_p/nKT = 10^{-7}$. What is the nature of this discrepancy?

Wentzel: We have taken the thermal level of Langmuir waves to be of order (but several times less than) $nkT_e/(n\lambda_D{}^3)$, with $n\lambda_D{}^3 = 3 \times 10^9$ at $n = 10^8$ cm^{-3} and $T_e = 2 \times 10^7$ K.

Melrose: Could you please explain how you obtain a brightness temperature $\approx 10^6$ times the thermal level in view of the fact that one has $T^t \lesssim T^\ell$.

Wentzel: If the electron temperature is of order 10^7 K, a brightness temperature of 10^{13} K is reached by invoking an energy density roughly 10^3 times the thermal level and a fraction of wave number space of order 10^{-3} ($k\lambda_D \simeq 0.1$)