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A New Ion beam Instability and Radio Emission Driven by Shocks

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Abundant observational evidence and theoretical analyses demonstrate that shocks can accelerate beams of electrons and ions into their upstream regions and that these particles drive multiple types of plasma waves, including Langmuir and ion acoustic waves. In addition, the electrons and Langmuir waves often lead to the production of radio emission near the electron plasma frequency f_p and near $2f_p$.

This presentation is in two parts..The first is a new theoretical description of an instability for the growth of ion acoustic by a cold, relatively, slow ion beam. Although investigated here in connection with phenomena observed by NASA's Parker Solar Probe near the Sun, this instability should also be relevant in foreshock regions upstream of shocks. The second is the 3D shape of the source regions for f_p and $2f_p$ radiation upstream of Earth's bow shock, produce from Langmuir waves driven by shock-accelerated electron beams in the foreshock. These predictions are also relevant to type II solar radio bursts and the 2-3 kHz radiation observed by the Voyager spacecraft in the outer solar system.

1. Ion beam-driven Ion Acoustic Instability

Recent observations by R. Ergun and collaborators (unpublished) show the generation of trains of ion acoustic wave packets with rising tones and a relatively broadband character typical. A numerical dispersion solver with a slow proton beam showed growth but the origin was unclear. Here I show analytically using kinetic theory that a cold proton beam instability exists and can explain several aspects of the numerical calculations and observations. Starting from the electrostatic dispersion equation

$$1 + K_L^e + K_L^i + K_L^b = 0 \ ,$$

where K_L^j is the contribution for species j = e (thermal electrons), i (thermal ions) and b (ion beam), the instability is described by an equation reminiscent of a cold electron beam instability, $\alpha\,(\alpha + \alpha_0)^2 = ½$. Here α is the scaled difference from the (complex) wave frequency ω and the ion acoustic wave frequency, while and α_0 is the scaled frequency offset $(\omega - \mathbf{k}.\mathbf{v}_b)$, respectively, where $\mathbf{k}$ and $\mathbf{v}_b$ are the wavevector and the ion beam velocity, respectively. In detail, the instability is a reactive (or fluid-type) instability associated with a beam mode and the instability is favoured when the proton beam speed is close to the ion acoustic speed and the beam is relatively dense and cold. In principle, this theory allows the ion beam speed and relative number density to be determined by data-theory comparisons, thereby constraining the origin of the proton beam.

2. Radio emission from Earth's Foreshock

The standard theory for this radio emission involves shock-drift (aka mirror-reflection) of electrons at the shock, development of electron beam distributions by time-of-flight effects, driving of Langmuir waves by the beam instability, and generation of f_p and $2f_p$ radio emission by nonlinear processes involving the Langmuir waves [1]. Each of these processes can be modelled analytically. Recently P. Oppel and I revised the theory [2] and extended it to include f_p radiation produced by linear mode conversion (LMC) of Langmuir waves at density irregularities [3] and to predict the shape of the radio source. Figure 1 shows the predicted shape of the nonlinear f_p radio source for nominal solar wind parameters as viewed from the 1st Lagrange point. The radio source is strongly elongated perpendicular to the interplanetary **B** field. The total flux is ~$7\text{x}10^{-19}$ Wm^{-2} Hz^{-1}, not inconsistent with data, a factor ~3 larger and ~60 smaller than the LMC f_p and nonlinear 2fp fluxes. These and other results will be discussed in the context of other radio emissions produced near shocks.

References
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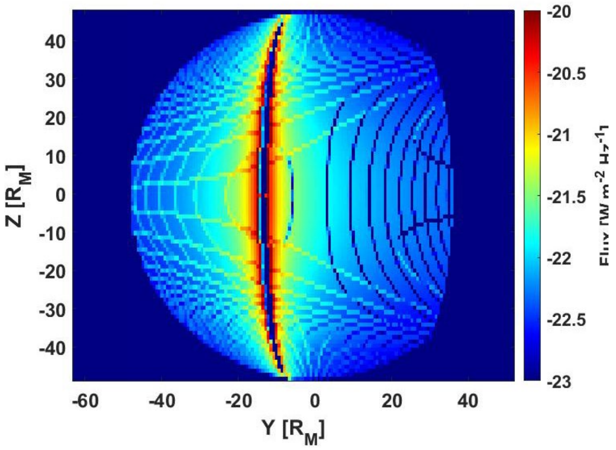

Figure 1. Nonlinear f_p radio source viewed from the L1 point, with Earth located at (0,0,0) and **B** in the X-Y plane. Units are $\text{Wm}^{-2}\text{Hz}^{-1}\text{R}_\text{m}^{-2}$, where R_m is an Earth radius.