J. Astrophys. Astr. (2000) **21**, 447–450

Ulysses Observations of Nonlinear Wave-wave Interactions in the Source Regions of Type III Solar Radio Bursts

G. Thejappa[1]* & R. J. MacDowall[2]
[1]*Department of Astronomy, University of Maryland, College Park, MD 20742.*
[2]*NASA, Goddard Space Flight Center, Greenbelt, MD 20771.*
**e-mail: golla@urap.gsfc.nasa.gov*

Abstract. The Ulysses Unified Radio and Plasma Wave Experiment (URAP) has observed Langmuir, ion-acoustic and associated solar type III radio emissions in the interplanetary medium. Bursts of 50–300 Hz (in the spacecraft frame) electric field signals, corresponding to long-wavelength ion-acoustic waves are often observed coincident in time with the most intense Langmuir wave spikes, providing evidence for the electrostatic decay instability. Langmuir waves often occur as envelope solitons, suggesting that strong turbulence processes, such as modulational instability and soliton formation, often coexist with weak turbulence processes, such as electrostatic decay, in a few type III burst source regions.

Key words. Type HI bursts—electrostatic decay—modulational instability.

1. Introduction

Solar and interplanetary type III radio bursts, which occur at the fundamental and the second harmonic of the electron plasma frequency, (f_{pe}), are due to Langmuir waves excited by the outward propagating electron beams in the solar atmosphere. Several non-linear processes are believed to be involved in the excitation of Langmuir waves, the stabilization of electron beams so that they can travel several Astronomical Units (AU) in the solar atmosphere and conversion of Langmuir waves into electromagnetic radiation at f_{pe} and $2f_{pe}$. The Unified Radio and Plasma Wave Experiment (URAP) on the Ulysses spacecraft with its broad frequency coverage from ~ 0 Hz to ~ 1 MHz and its high time resolution ~ 1 ms is well suited for studies of these nonlinear processes. Several local type III interplanetary radio bursts, when the spacecraft was located inside the source regions have been identified in the URAP data (Reiner *et al.* 1992; Thejappa *et al.* 1993; Thejappa & MacDowall 1998).

2. Observations

In Fig. 1, we present the dynamic spectrum of one of the local type III radio bursts and its associated *in situ* waves. The fast drifting emission feature extending from 48.5 kHz down to local electron plasma frequency, f_{pe} ~ 10.2 kHz is the type III burst. The intense emission at the plasma line at ~ f_{pe} corresponds to Langmuir waves, as

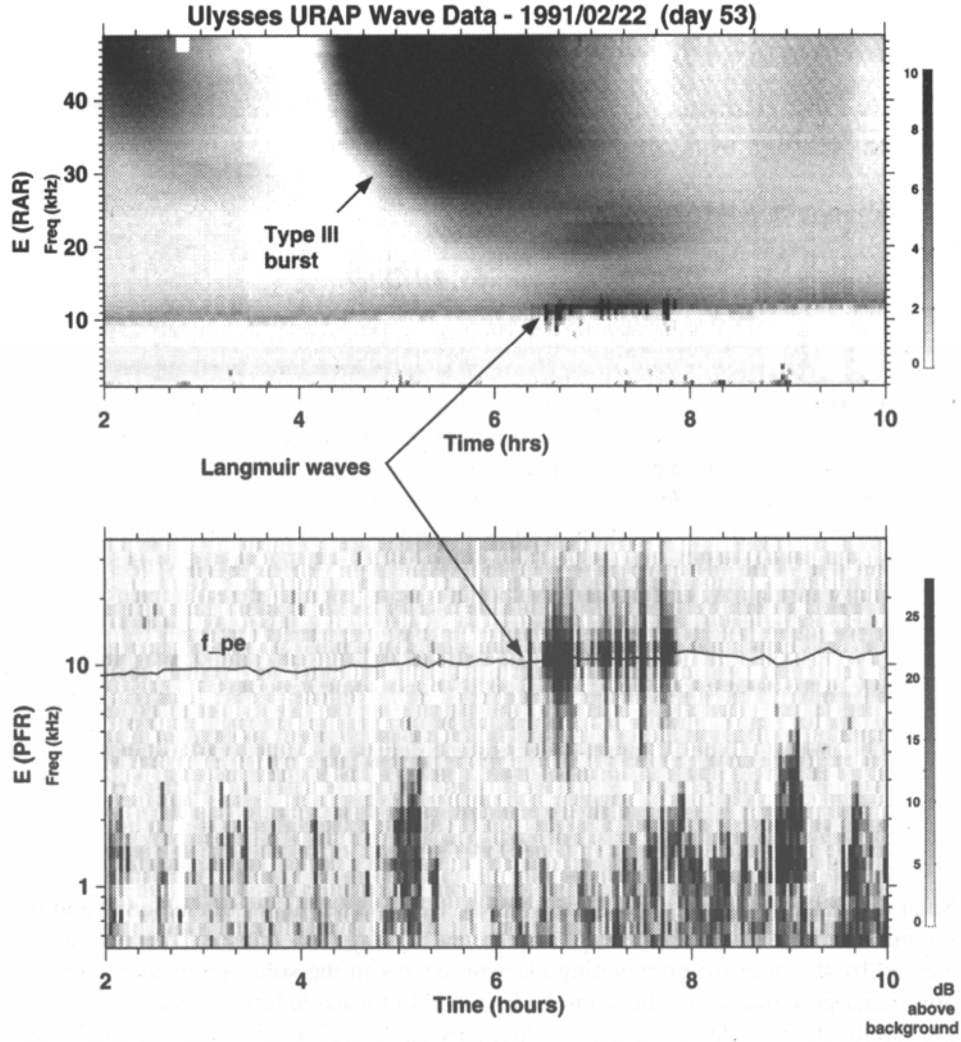

Figure 1. Dynamic spectrum of the local type III radio burst of February 22nd, 1991 and its associated *in situ* waves. The fast drifting emission feature from 48.5 kHz down to local electron plasma frequency, f_{Pe} ~ 10.2 kHz is the local type IΠ burst.

seen in the top as well as bottom panels. The random noise below ~ 5 kHz is due to high frequency ion-acoustic-like waves. The *in situ* wave data associated with these events have been extensively used for the purpose of verifying the emission mechanisms at f_{pe} (Thejappa *et al.* 1993), and at $2f_{pe}$ (Thejappa *et al.* 1996), where the observed brightness temperatures were shown to agree very well with the values predicted by the strong turbulence emission mechanisms. The fast envelope sampler (FES) of URAP, which is capable of resolving the field structures with time scales as small as one millisecond has provided several high time resolution snapshots of the Langmuir wave electric field envelopes associated with the local type III bursts. Fig. 2(a) presents one such event, corresponding to the Langmuir waves of the type III

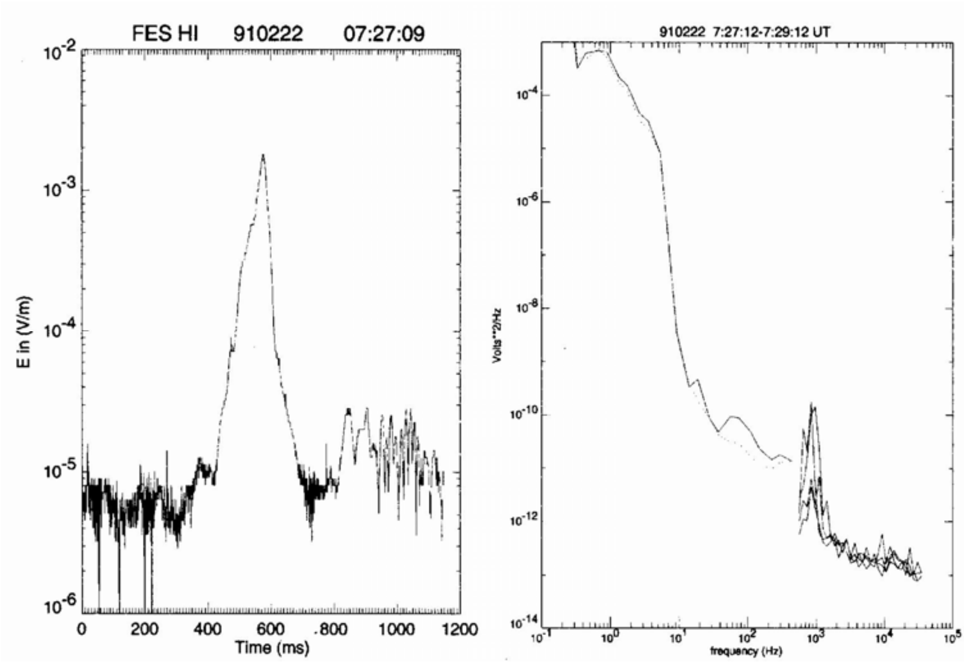

Figure 2. (a): Langrauir envelope soliton, (**b**): the spectral plots of wave electric fields during the Langmuir envelope soliton.

burst presented in Fig. 1. The prominent broad field structures in these FES events have the properties expected of Langmuir envelope solitons, namely the normalized peak energy densities, $W_L/n_eT_e \sim 10^{-5}$, are well above the modulational instability threshold; the spatial scales L, which range from 1 to 5 Langmuir wavelengths, show a high degree of inverse correlation with $(W_L/n_eT_e)^{1/2}$; and the observed widths of these broad peaks agree well with the predicted widths of envelope solitons (Thejappa *et al.* 1999). Sometimes, enhanced low frequency electric field signals around 50–300 Hz are observed in close association with these modulationally unstable Langmuir waves. For example, in Fig. 2(b), we plot the low frequency electric field spectra observed by the Ulysses Wave Form Analyzer (WFA) in the frequency range 0–448 Hz, as well as the high frequency electric field spectra observed by the Ulysses Plasma Frequency Receiver (PFR) (0.57–35kHz) during the 2 minute interval containing the time of the Langmuir envelope soliton of Fig. 2(a). Here, the dotted line corresponds to the instrumental background level. The prominent spectral peak at ~ 10 kHz is due to Langmuir waves, whereas, the spectral enhancement seen at ~ 100 Hz is most probably due to long wavelength ion-acoustic waves.

3. Discussion and conclusions

The simultaneous occurrence of Langmuir and ion-acoustic waves is indicative of the decay of beam excited Langmuir waves into daughter Langmuir and ion-acoustic waves. This interpretation is supported by the observations that: (1) the peak Langmuir wave intensity is well above the threshold for electrostatic decay, and (2) the observed frequency and intensity of ~ 100 Hz electric field signals agree very well with the values expected by the electrostatic decay instability. The occurrence of ion-acoustic waves in close association with the modulationally unstable Langmuir waves is good evidence that the strong and weak turbulence processes are not mutually exclusive in the source regions of the type III radio bursts; rather they coexist. One of the main roles of nonlinear processes is to remove the Langmuir waves from the spectral regions of resonance with the electron beam, i.e., to inhibit quasi-linear relaxation. The observed coexistence of weak and strong turbulence processes suggests that in some cases, the electrostatic decay instability (decay of the beam excited Langmuir wave into a daughter Langmuir wave and an ion-acoustic wave) appears to remove the Langmuir waves from the resonance with the beam. This leads to the accumulation of Langmuir waves at long wavelengths, forming the so-called weak turbulence Langmuir condensate, which eventually becomes modulationally unstable by getting absorbed by the ambient electrons through Langmuir collapse and other non-linear processes. The Langmuir waves undergoing electrostatic decay interact very weakly with the coherent field structures formed due to strong turbulence processes because of the large differences in their spatial scales. Therefore, these processes sometimes operate simultaneously. The coexistence is possible even in the presence of weak damping (γ_0), either due to collisions, or due to power-law type energetic electrons present in the solar wind plasmas, provided it is less than the Langmuir wave growth rate γ_b due to beam plasma instability by an order of magnitude.

Acknowledgements

The research of GT is supported by the NASA grants NAG57145, NCC5-372, and NAG56059.

References

Reiner, M. J., Feinberg, J., Stone, R. J. 1992, *Astrophy. J.,* **394**, 340.

Thejappa, G., Lengyel-Frey, D., Stone, R. G., Goldstein, M. L. 1993, *Astrophys. J.,* **416**, 831.

Thejappa, G., Stone, R. G., Goldstein, M. L. 1996, *Astrophys. and Space Sci,* **243**, 195.

Thejappa, G., MacDowall, 1998, *Astrophys. J.,* **498** 465.

Thejappa, G.. Goldstein, M. L., MacDowall, R. J., Papadopoulos, K., Stone, R. G. 1999, *J. Geophys. Res.,* **104**, 28279.