Langmuir “snakes” and electrostatic decay in the solar wind

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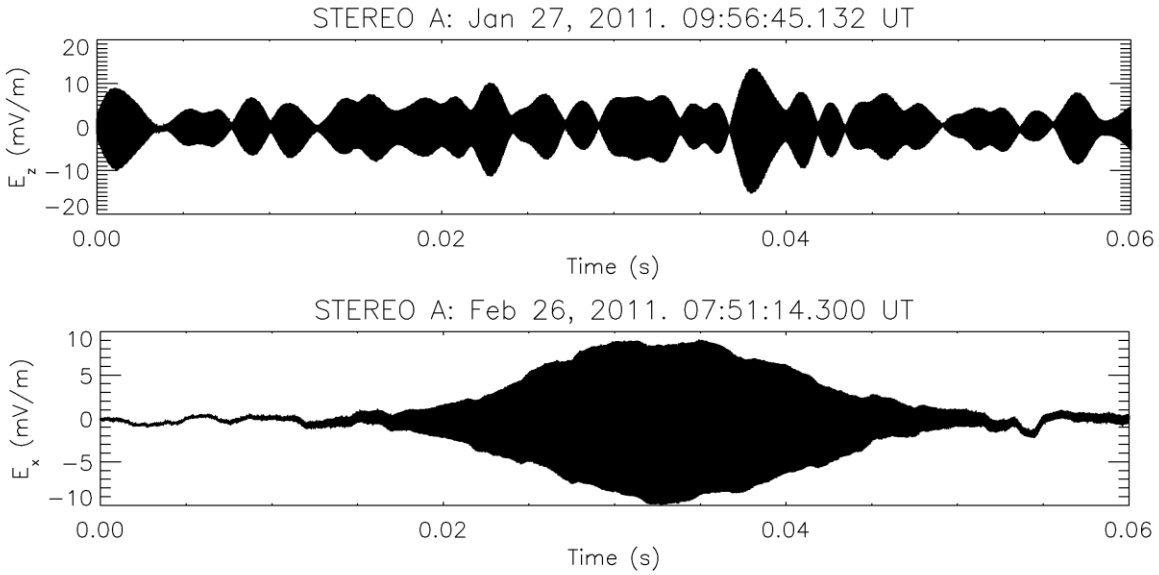
Outline

- Solar type III radio bursts
- Electrostatic Zakharov equations
- Numerical Results
- Analytic form
- Comparison with STEREO data
- Summary

1. Solar type III radio bursts

- Langmuir waves driven by electron beams occur in the solar wind and are associated with type III solar radio bursts.
- Intense Langmuir events are often explained in terms of nonlinear wave interactions, such as ES decay L → L' + S.
- Some events have localized fields consistent with Langmuir waves trapped in density wells, such as Fig. (2).

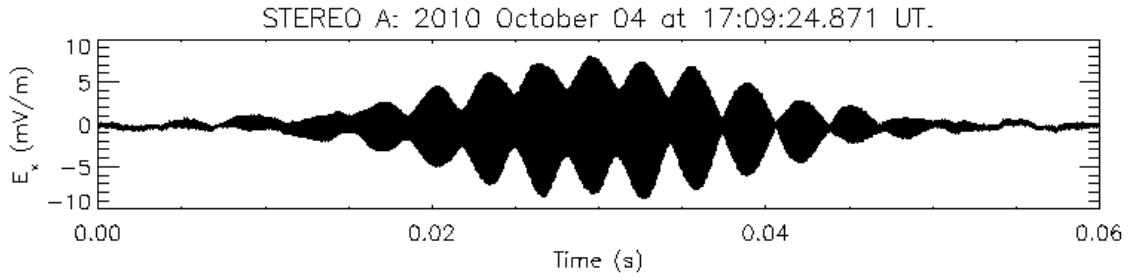


(1)

(2)

1. Solar type III radio bursts

- Sometimes Langmuir events are observed which appear localized and exhibit Langmuir beating, such as Fig. (1).
- Here we show that these waveforms are consistent with electrostatic decay.



(1)

2. Electrostatic Zakharov equations

- The electrostatic Zakharov equations model the evolution of Langmuir and ion-acoustic waves.
- These equations are:

$$\nabla \cdot (i\partial_t + \nabla^2 + i\hat{\gamma})\mathbf{E} = \nabla \cdot (\delta n \mathbf{E}), \quad (1)$$

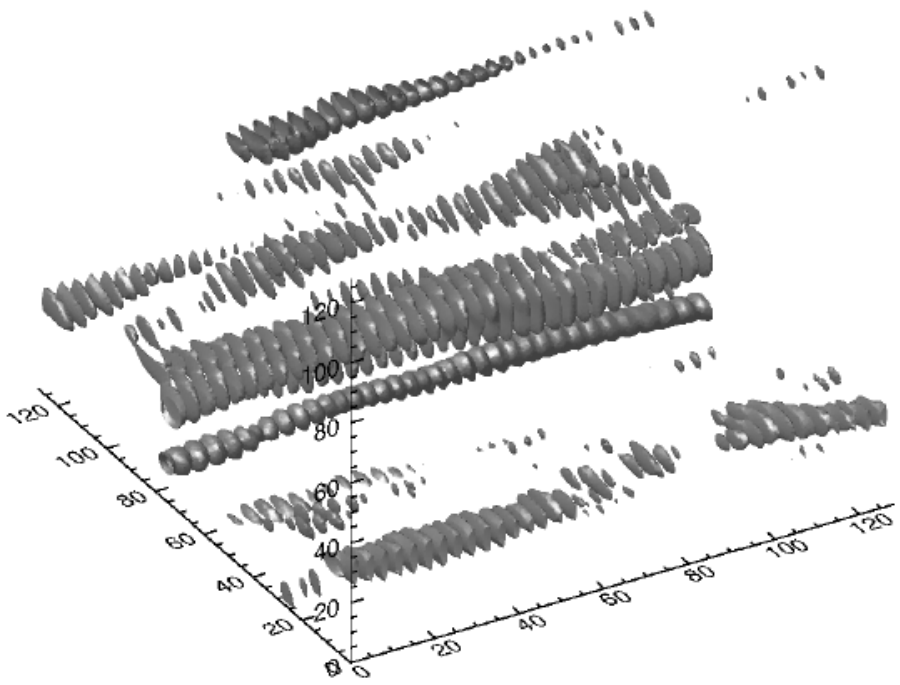
$$(\partial_t^2 + 2\hat{\nu} c_s \partial_t - c_s^2 \nabla^2)\delta n = \nabla^2 |\mathbf{E}|^2, \quad (2)$$

- They include the effects of electrostatic decay, modulational instabilities, and wave packet collapse.
- We use the linear driver $\Gamma(\mathbf{k}) = (\Gamma_b - \gamma_0)\,\delta(k_x - k_b)\exp\left(-\frac{k_y^2 + k_z^2}{w_0^2}\right)$

where $k_b\lambda_D = 0.1$. Background damping γ_0 is applied.

3. 3D Zakharov simulation results

- Find Langmuir waves undergo electrostatic decay and are truncated to a single backscatter.

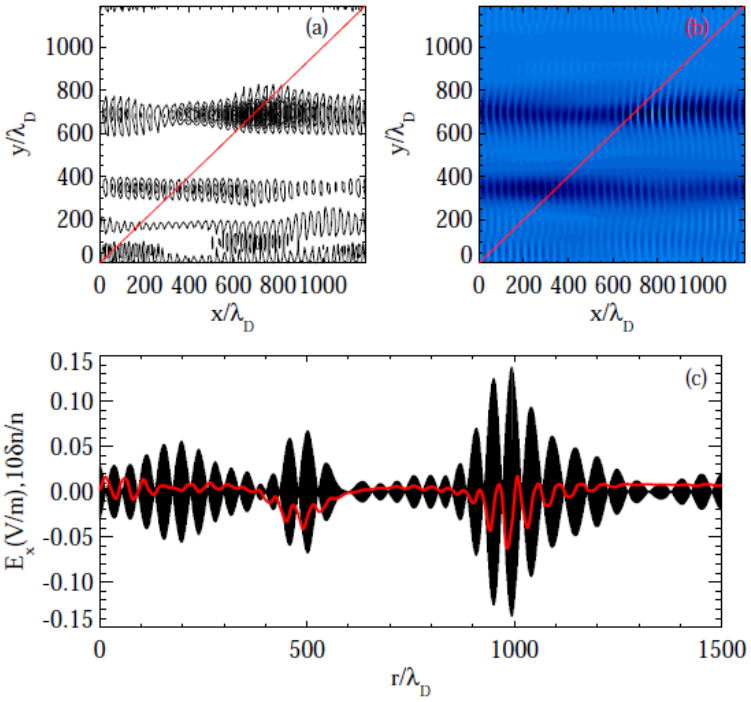


- Driven and backscatter Langmuir waves develop in “snakes” parallel to the magnetic field.

3. Satellite transits through snakes

- If a satellite passes through a snake, localized periodic beating will be observed.

- Figure shows contours of energy density and density perturbations.
- Bottom panel shows observed fields along the red line.



4. Analytic form

- When Doppler-shifted frequencies are included, the predicted electric field is:

$$E_x(\mathbf{r}) = A_0 \sin\left(2\pi f_L^d t\right) e^{-w_0^2(v_{sw}t|\sin\theta|-y_0)^2/2}$$

$$+ A_1 \sin\left(2\pi f_{L'}^d t\right) e^{-w_1^2(v_{sw}t|\sin\theta|-y_0)^2/2}$$

where

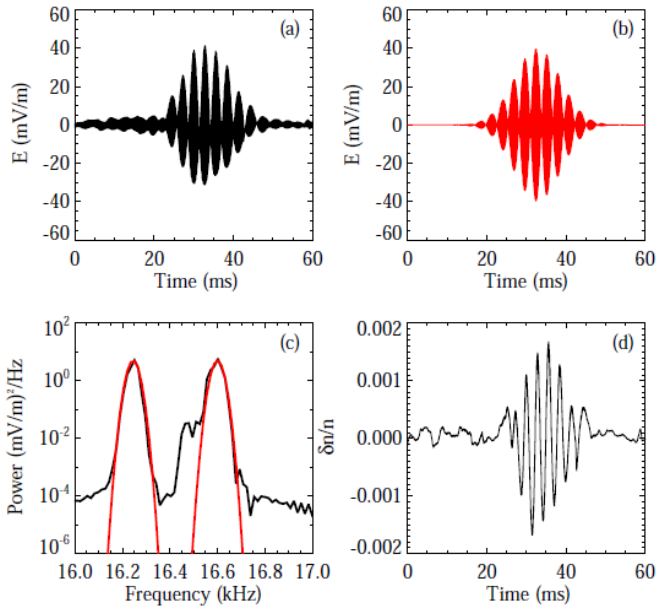
$$f_L^d = f_L + \frac{k_b v_{sw}|\cos\theta|}{2\pi} = f_p\left(1 + \frac{3v_e^2}{2v_b^2} + \frac{v_{sw}|\cos\theta|}{v_b}\right),$$

$$f_{L'}^d = f_{L'} + \frac{(-k_b + k_0)v_{sw}|\cos\theta|}{2\pi} = f_L^d - \Delta f_{LL'}^d,$$

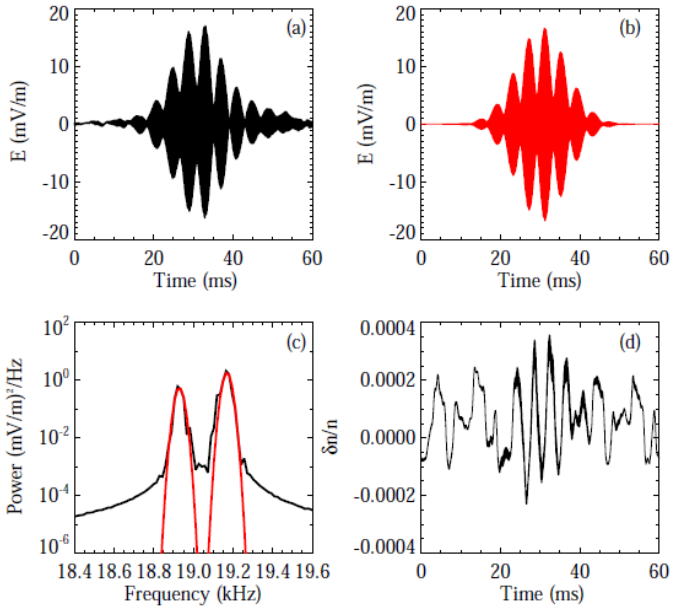
$$\Delta f_{LL'}^d = 2f_p\left(\frac{1}{v_b} - \frac{v_s}{3v_e^2}\right)(v_s + v_{sw}|\cos\theta|)$$

5. Comparison with STEREO data

- The analytic form is able to reproduce many of the observed waveforms and spectra.
- Observed and predicted Δf agree well.



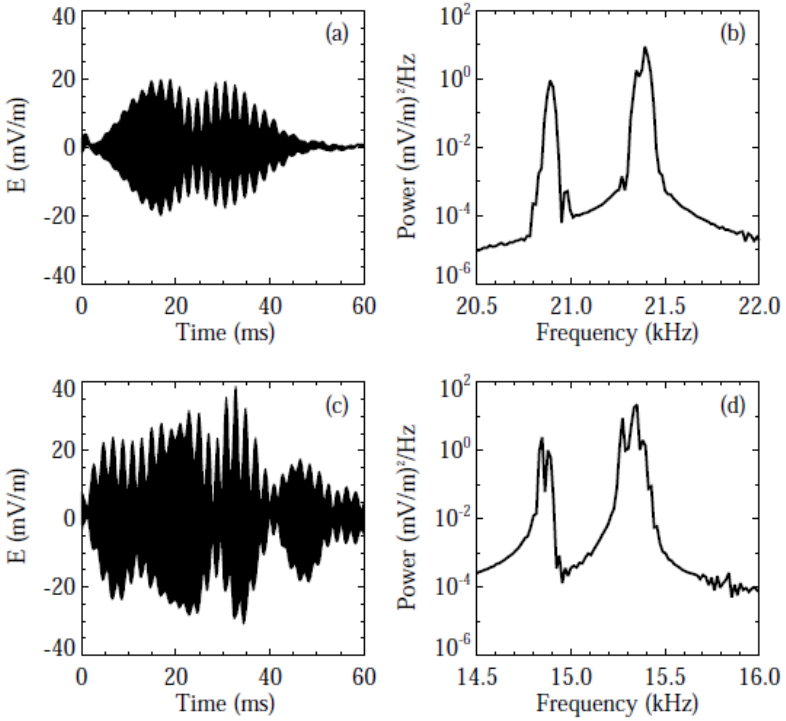
2011 Dec. 19 at 13:50:55.160 UT, STEREO A.



2011 Jan. 22 at 10:27:12.789 UT, STEREO B.

5. More STEREO data

2011 March 21 at 04:08:36.297 UT.



2010 October 04 at 17:08:06.293 UT.

- Some Langmuir events are more complicated: Different snake spatial profiles and paths more parallel to the snake can occur.
- In both examples the observed Δf are consistent with electrostatic decay.

6. Summary

- 3D Zakharov simulations show that electrostatic decay develops in snake-like channels parallel to B.
- The predicted electric field profiles are often consistent with STEREO observations (~40% of events during type III bursts have 2 spectral peaks).
- These results provide evidence for electrostatic decay and decay in snake-like channels in the solar wind.

[Graham et al., submitted to GRL, 2012]