Langmuir wave generation in the interplanetary medium

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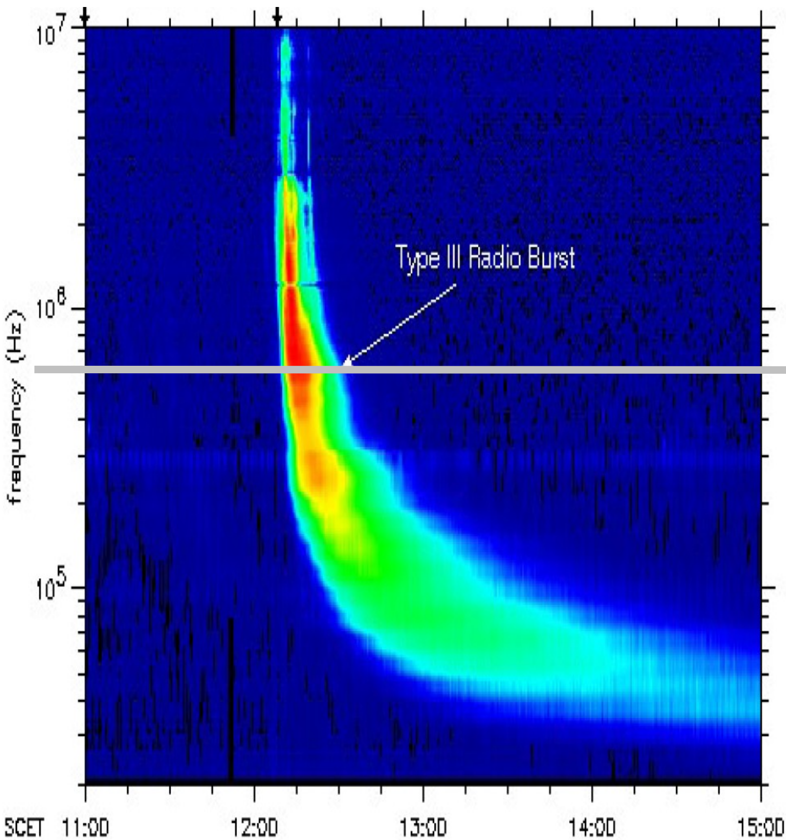
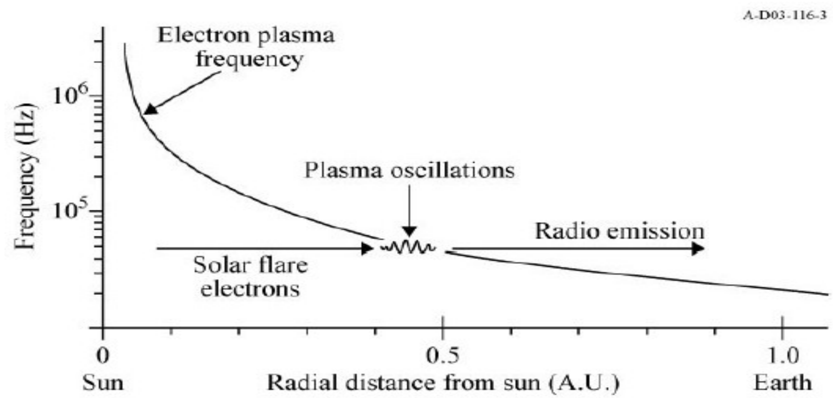
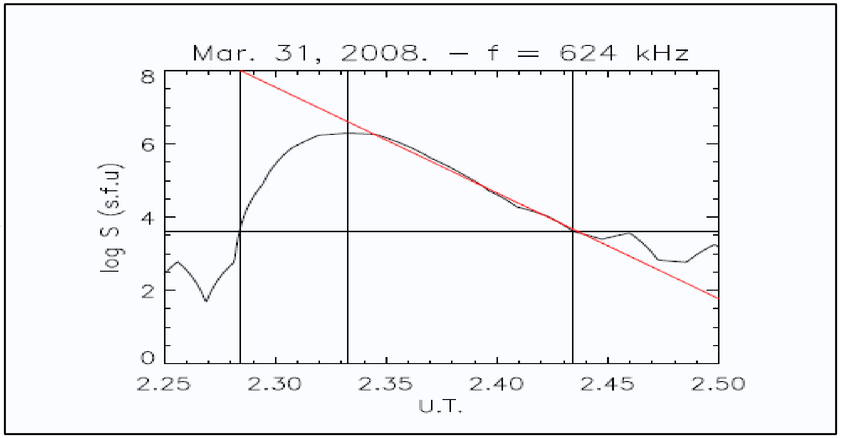
Probing the interplanetary medium using radio







>2000 radio events database available in Meudon

General questions

1) Langmuir wave generation

Wave-particle processes ?

2) Electromagnetic waves generation

Wave-wave processes ?

WAVE-FORMS OBSERVATIONS + SIMULATIONS

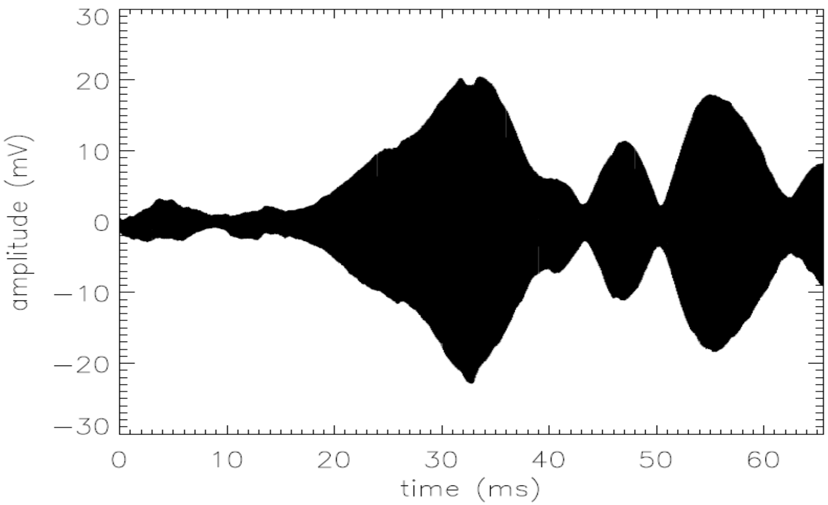
3) Radio waves propagation

Radiation diagrams ?

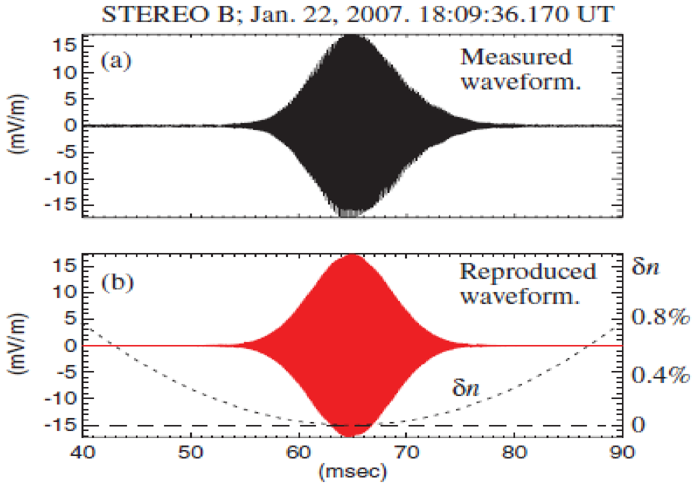
RADIO OBSERVATIONS + SIMULATIONS

Remote sensing of the coronal / solar wind / energetic paricles

Electric waveforms on S/WAVES TDS



Coherent wave-packets localized on **10-60 ms**, i.e **2-15 km** i.e **200-1500** electron Debye length at 1 AU

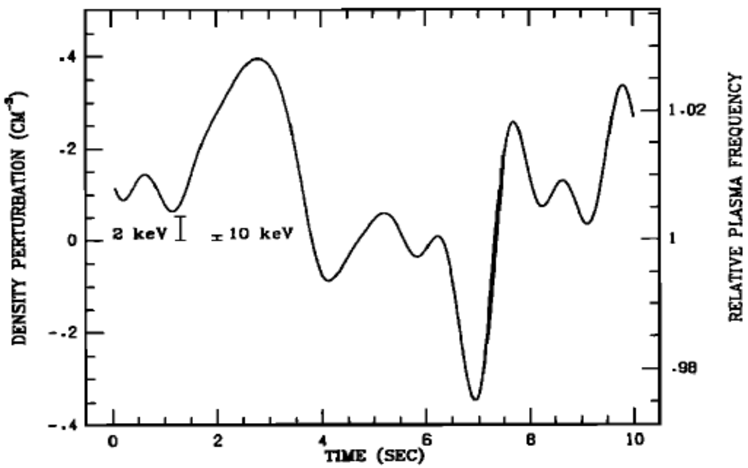


How are such wave forms generated ?

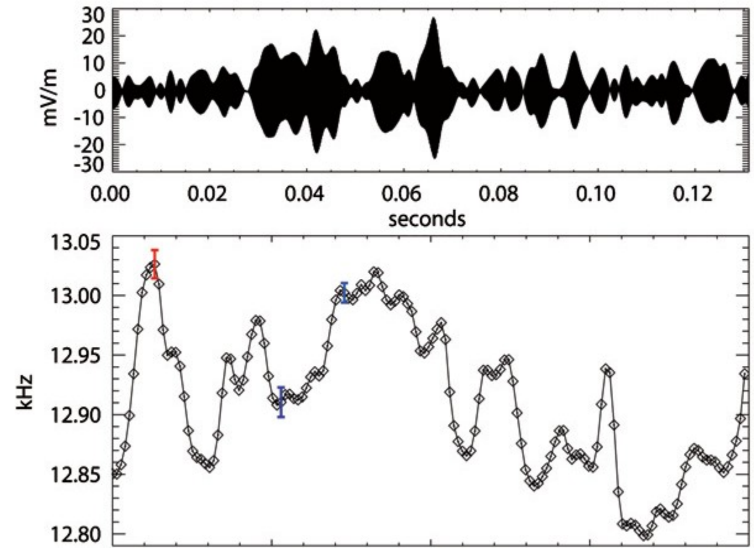
Have to model the beam-plasma interaction in the presence of small scale density inhomogeneities affecting the waves propagation

Auxiliary question : Trapped eigen-mode excitation ?

Density inhomogeneities in the solar wind

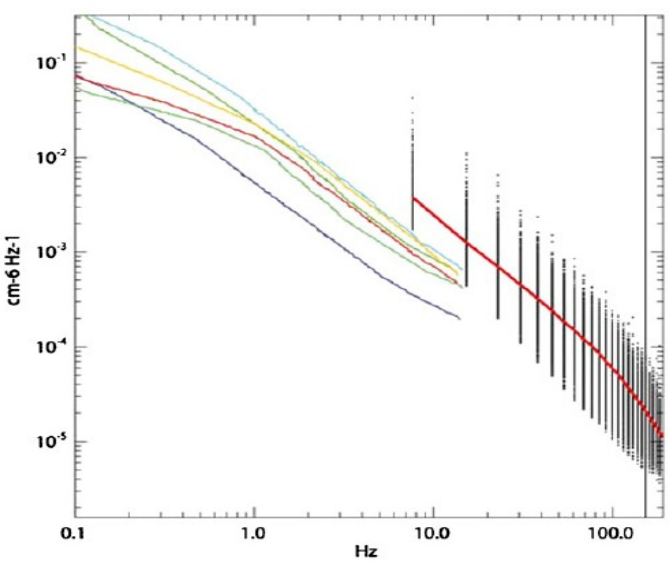


Kellogg et al, 1999



Malaspina et al, 2010

Celnikier et al, 1987 + Malaspina et al, 2010



dn/n ~ 1%   k² ld² < 1%

Turbulent density cascade, with a large enough amplitude to produce wave reflexions

Beam-Plasma interaction with density inhomogeneities

Propagation equation for Langmuir waves (HF Zakharov equation) :

$$i\frac{\partial}{\partial t}E + \frac{3}{2}\omega_p \lambda_d^2 \nabla^2 E - \omega_p \frac{\delta n}{n_0} E = 0$$

Same equation when a external charge term is included in Poisson equation :

$$\nabla \left(i\frac{\partial}{\partial t}E + \frac{3\omega_p}{2}\lambda_d^2 \frac{\partial^2}{\partial x^2}E - \omega_p \frac{\delta n}{2n_0} E \right) = -2\pi e n_b\left(x,t\right)\omega_p e^{i\omega_p t}$$

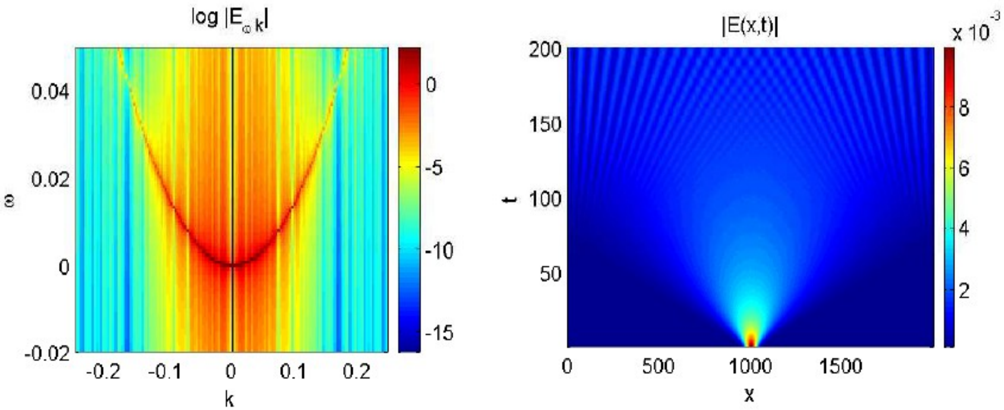
The system is closed by an evolution equation for the beam particles :

$$n_b\left(x,t\right) = \frac{\overline{n_b} L}{N}\sum_\alpha \delta\left(x - x_\alpha\left(t\right)\right), \qquad d_t x_\alpha = v_\alpha, \qquad d_t v_\alpha = -\frac{e}{m}\Re \sum E_k e^{i(k x_\alpha - \omega_p t)}$$

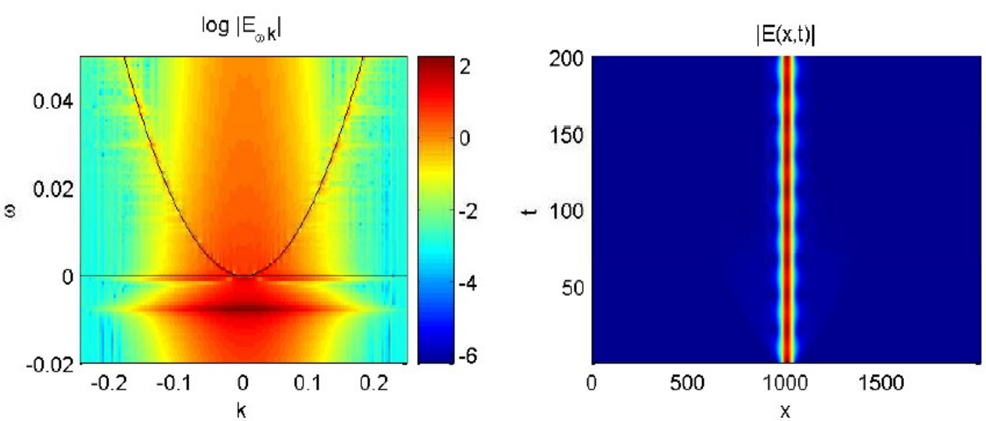
<u>Hybrid approach : waves treated like a fluid and beam electrons as discrete particles</u>

Illustration of propagation effects (no particle beam) :

Initial condition : Gaussian Langmuir wave-packet lauched at the center of the box

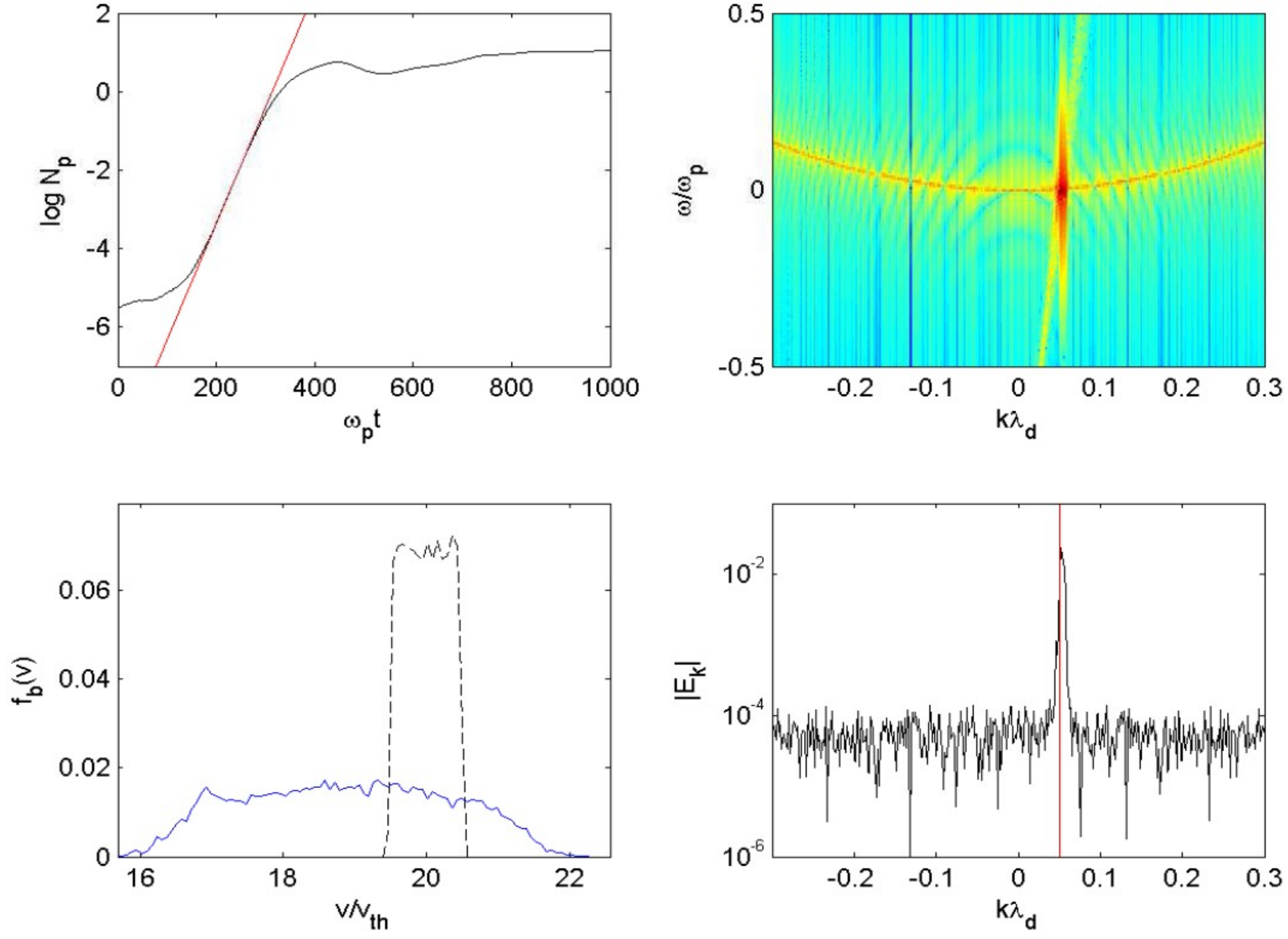


Case 1 : no density cavity. The waves propagates freely with the **Langmuir dispersion relation**, and we observe the **spatial dispersion of the wave packet**

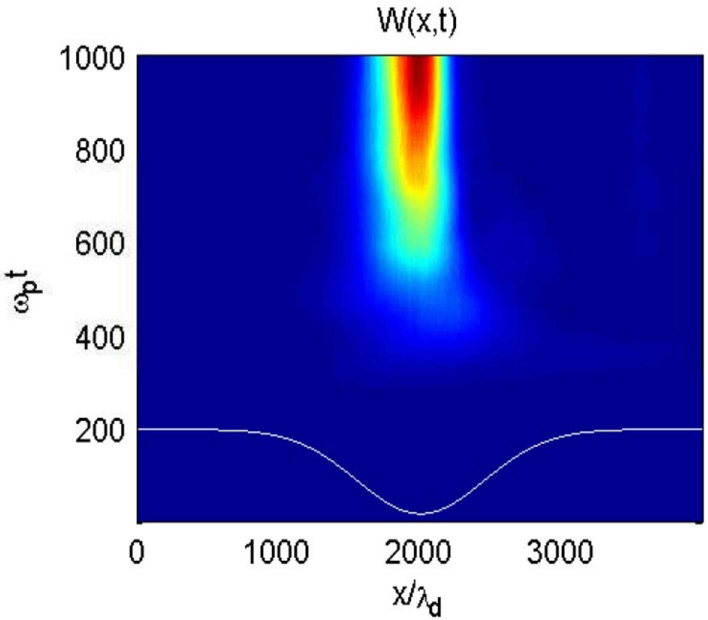


Case 2 : density cavity in the middle of the box. The waves propagates with a dispersion relation essentially different from the Langmuir one (negative eigen-frequency), and we observe **no spatial dispersion of the wave packet**. The wave packet is trapped.

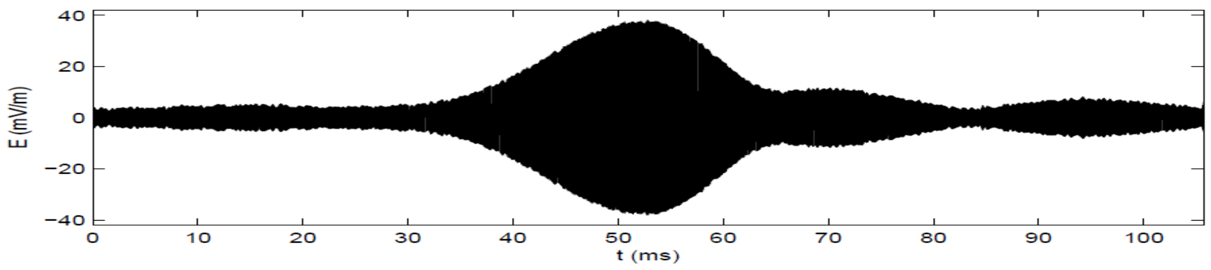
Beam-Plasma Instability

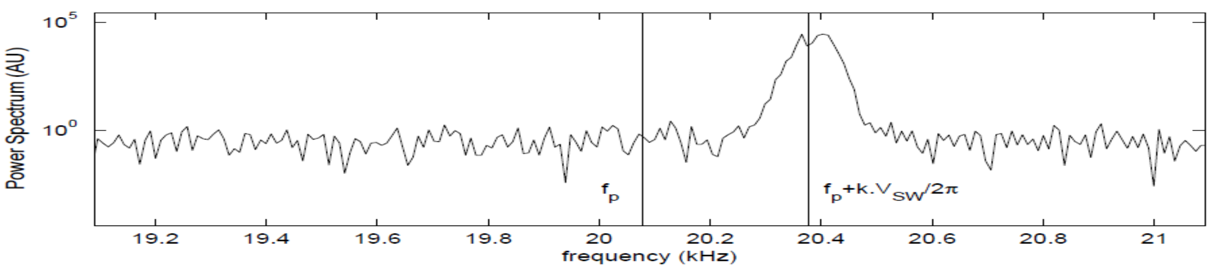


Beam-plasma instability in the presence of a density cavity

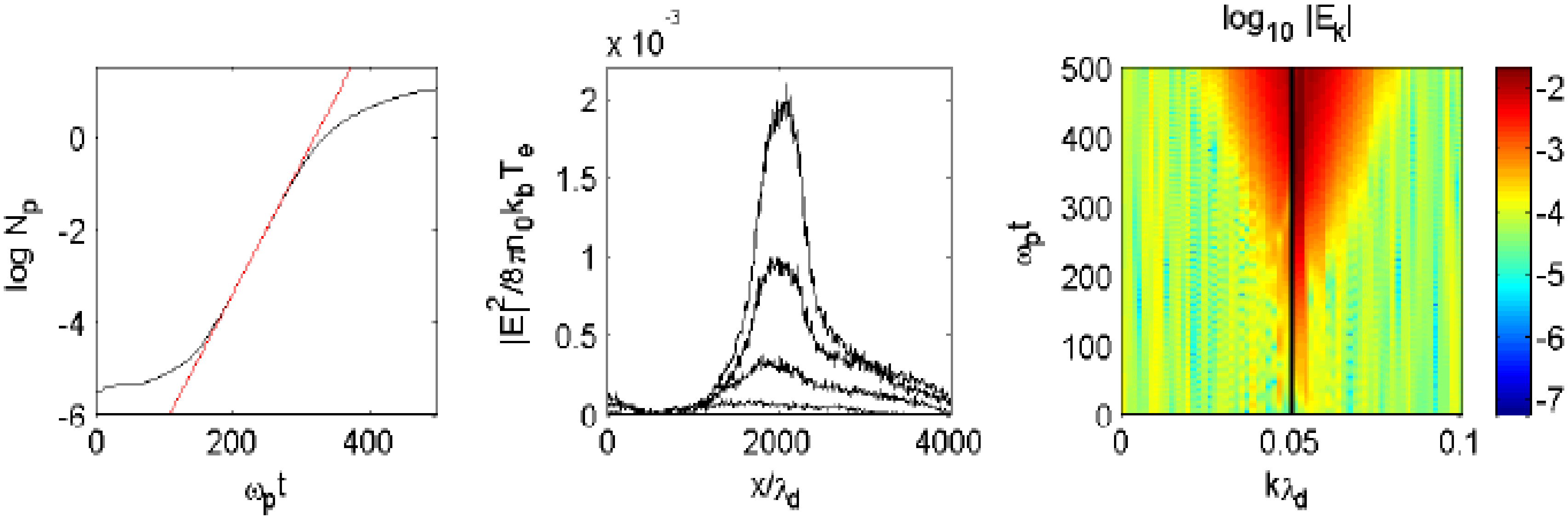


- Beam speed : c/10
- Cavity size : 1000 Debye length (10 km)
- Cavity depth : 1%





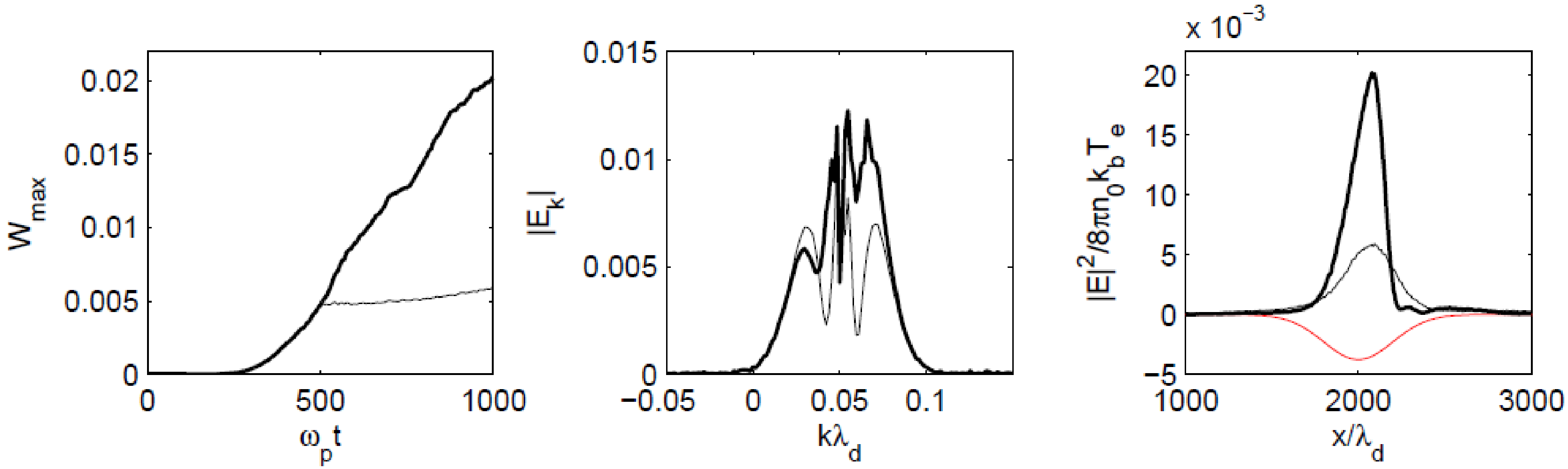
Physics of the localization : Plasmon diffusion / reflexion

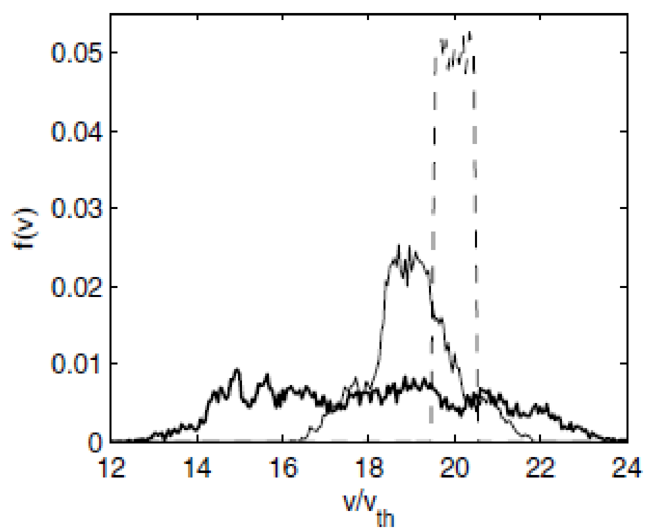


$$(\delta n E)_k = \sum_{k'+k''=k} \delta n_{k'} E_{k''} \quad \Rightarrow \quad \left(\frac{d}{dt} + i\Omega_k\right) E_k \sim -i\frac{\omega_p}{2n_0} E_{k_{res}}(t=0)\delta n_{k-k_{res}}$$

In the linear stage of the instability, the propagation effects tends to localize the electrostatic energy in the cavity

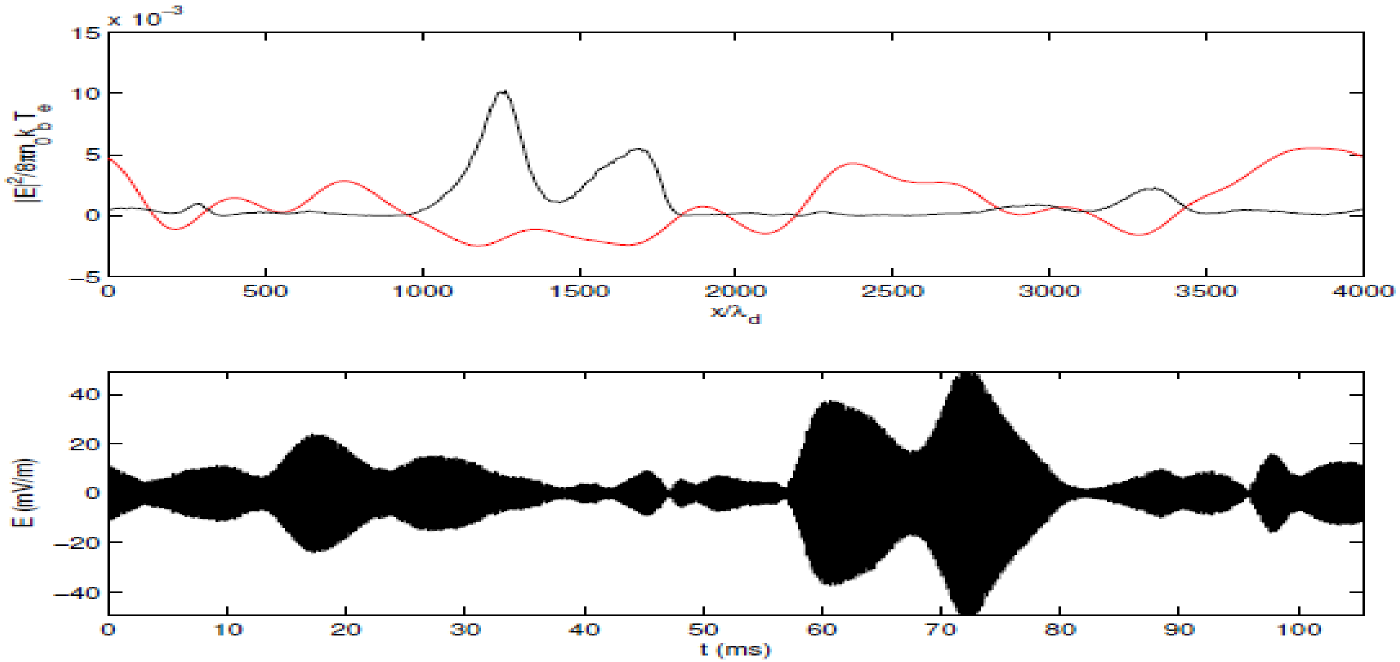
Physics of the localization : wave-particle non-linear effects





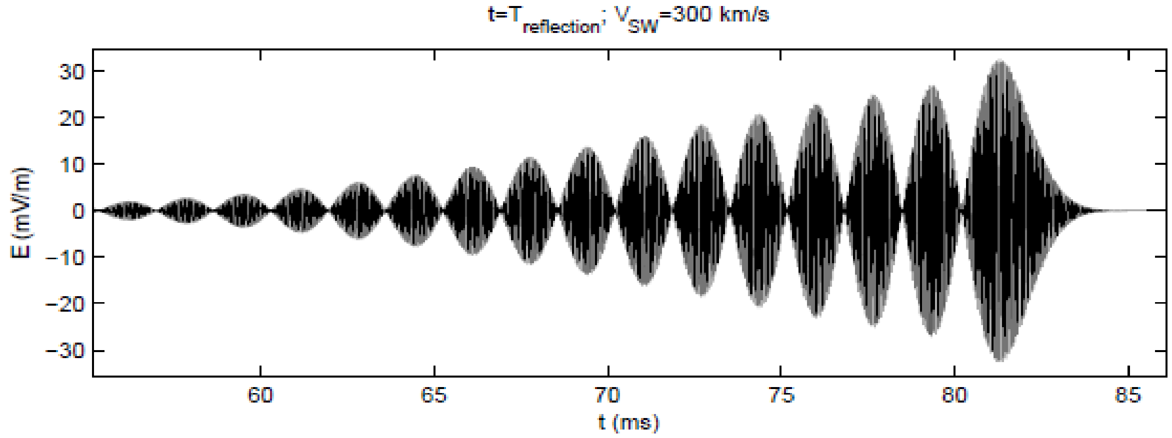
Enhancement of the localized energy due to particles diffusion by the localized wave packet.

Realistic case : turbulent density spectrum

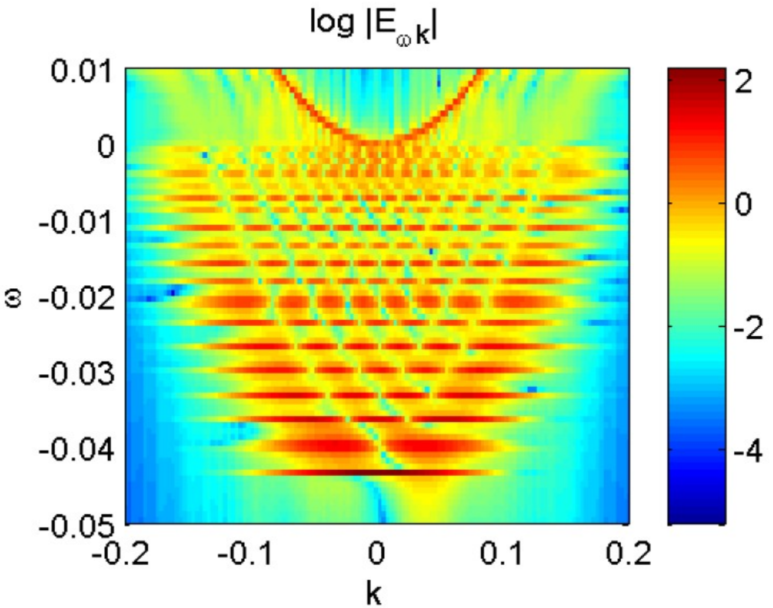


Reproduction of wave forms similar to the one observed by S/WAVES, for solar wind and beam parameters similar to the one observed at 1 AU

Other things to study with the numerical code



Langmuir waves near reflexion points



Trapped eigen-modes :

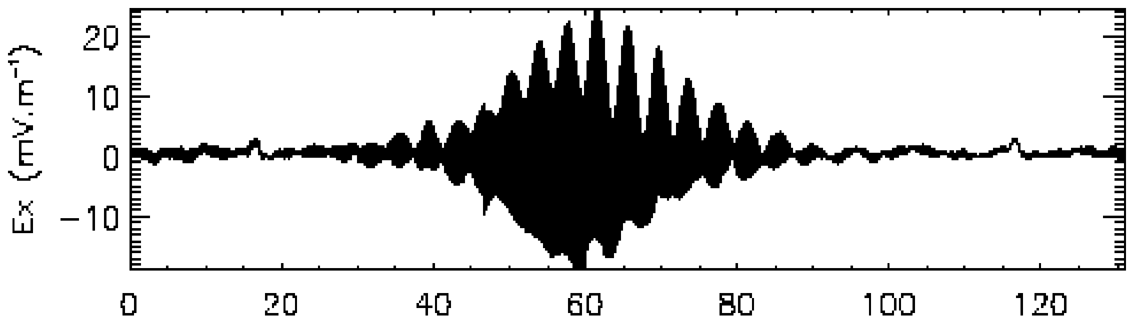
where do they come from ?

Other things to study : radio wave generation

$$\frac{\partial^2}{\partial t^2}\delta n - c_s^2\nabla^2\delta n = \frac{\nabla^2 |E|^2}{16\pi m_i}$$

Wave-wave processes : L => L' + S

Observed during types III (P. Henri et al., 2009) :



Fondamental generation : L + S => F

Harmonic generation : L + L' => H