Connecting Langmuir and low frequency waves

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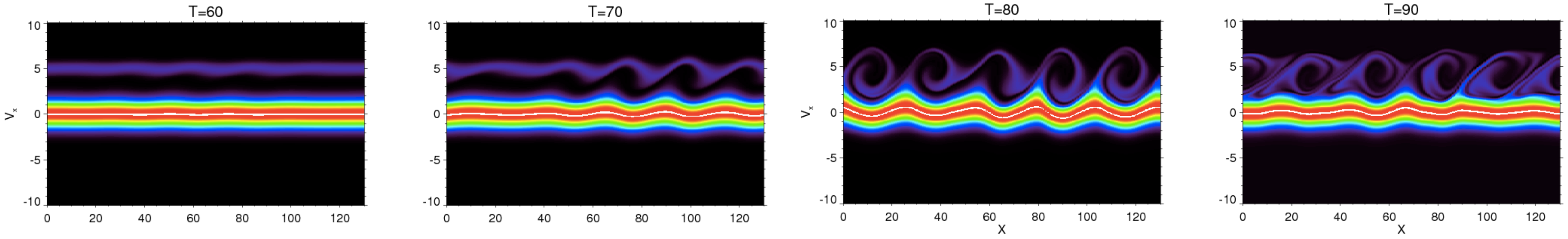


CIAS - Turbulence - May 2015

How to transfer energy between high and low frequencies

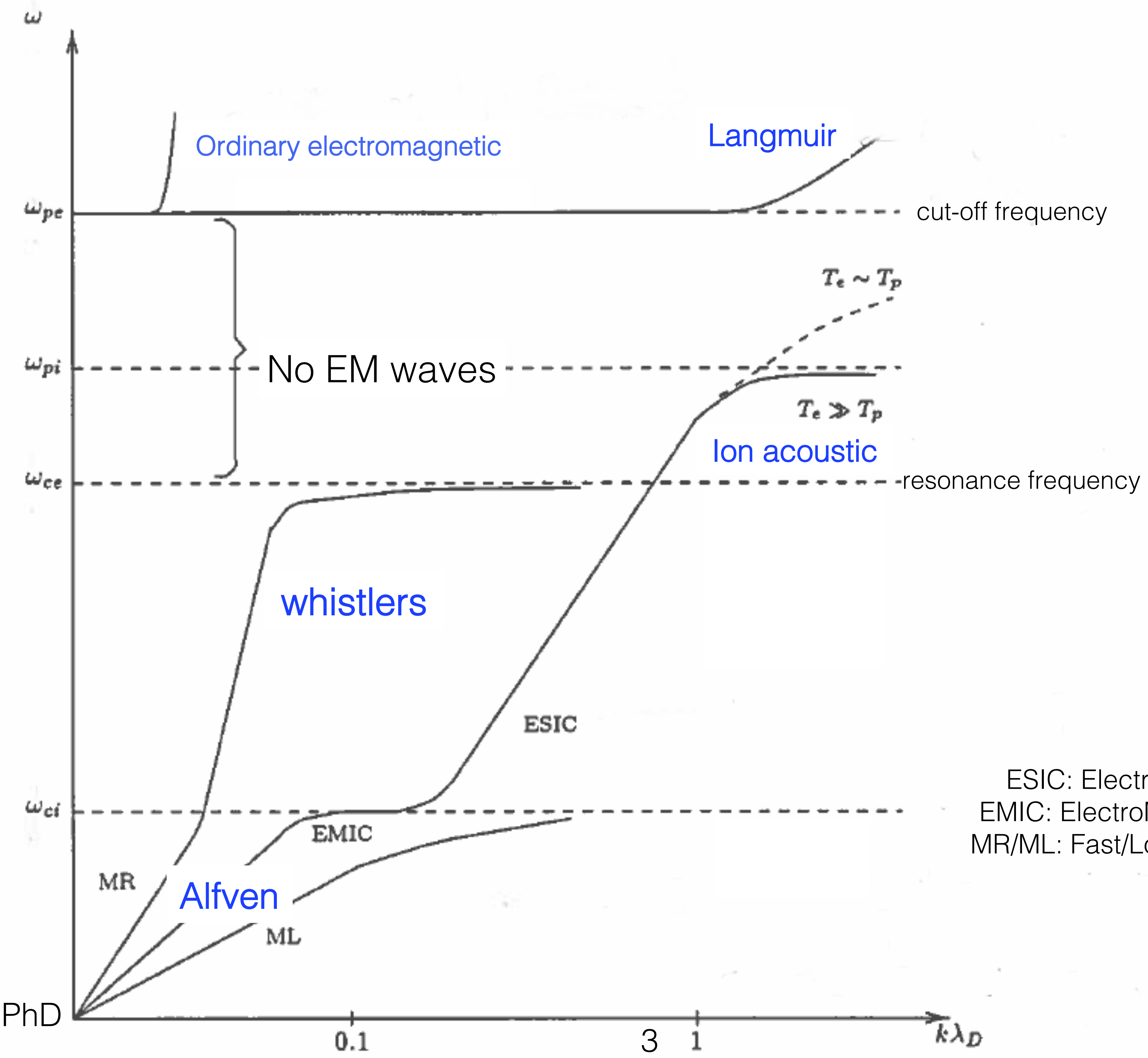
Weak turbulence

Strong Turbulence

Quasilinear evolution
Wave-Wave interaction

Large amplitude waves / Electrons trapping

Wave coupling



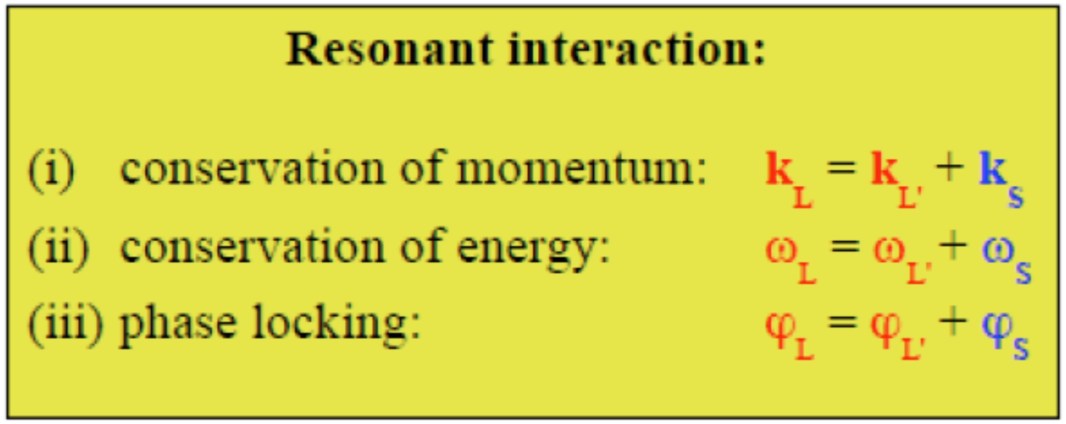
ESIC: ElectroStatic Ion Cyclotron
EMIC: ElectroMagnetic Ion Cyclotron
MR/ML: Fast/Low magnetosonic mode

@Salem PhD

Langmuir and ion acoustic waves

$$L \rightarrow L' + IAW$$

$$L + L' \rightarrow T_{2f}$$



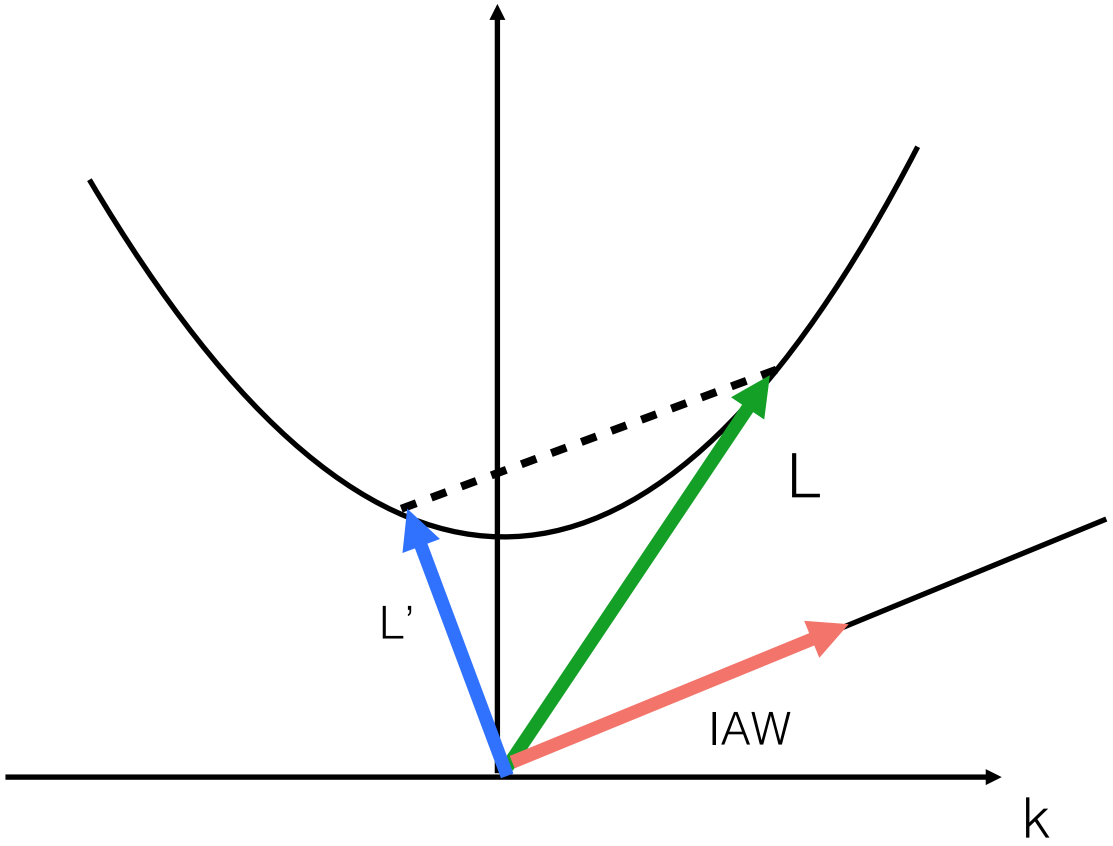
Resonant interaction:

(i) conservation of momentum: $\mathbf{k}_L = \mathbf{k}_{L'} + \mathbf{k}_S$

(ii) conservation of energy: $\omega_L = \omega_{L'} + \omega_S$

(iii) phase locking: $\varphi_L = \varphi_{L'} + \varphi_S$

ALL relations that must be checked simultaneously to verify the process



Henri, Briand, Mangeney, Bale, Califano, Goetz, Kaiser, JGR, 2009

Henri, Califano, Briand, Mangeney, JGR, 2010

Briand, Henri, Hoang, JGR, 2014

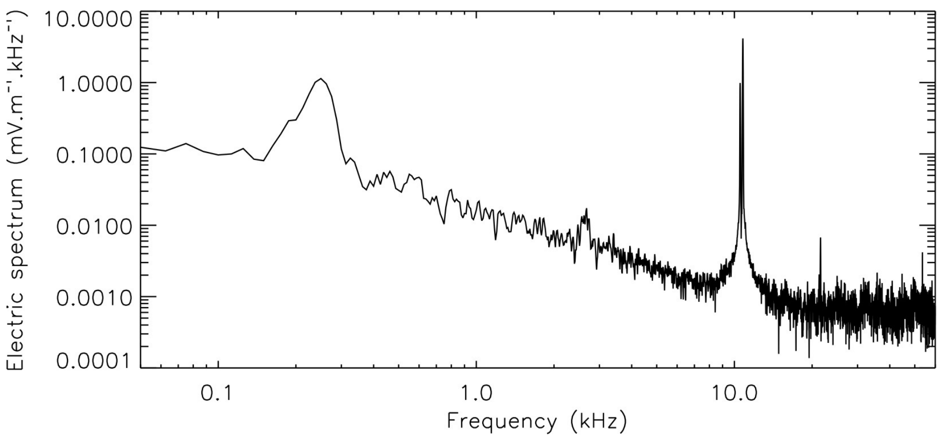
Before STEREO

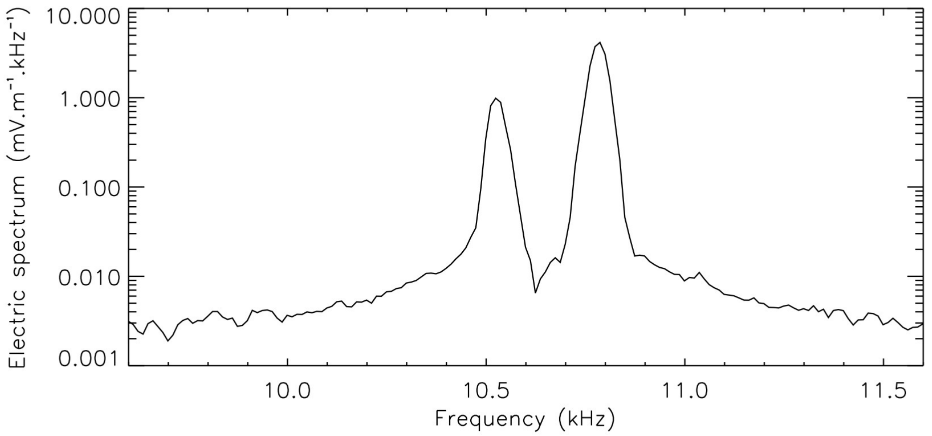
- **spectrum**: simultaneous observations of high (~fp) and low (~1kHz) frequency waves

phase information lost

- **waveform**: only access to the high frequency (too short time waveforms) - only two axes

phase information

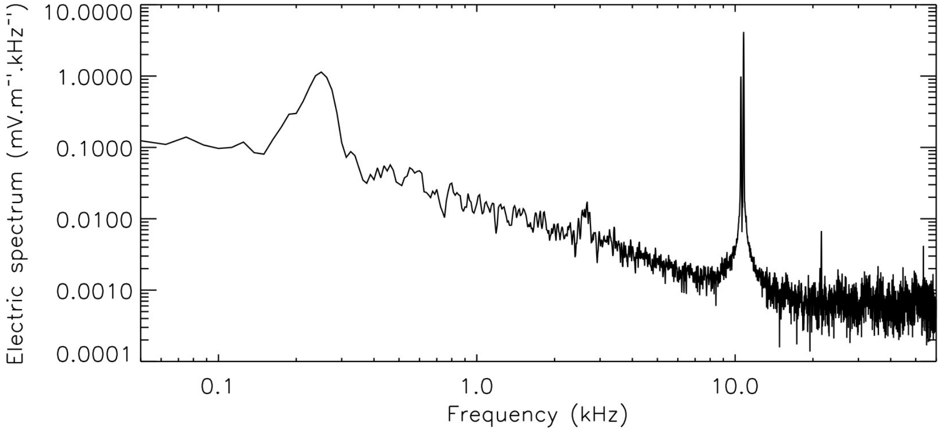




From STEREO waveforms we can access

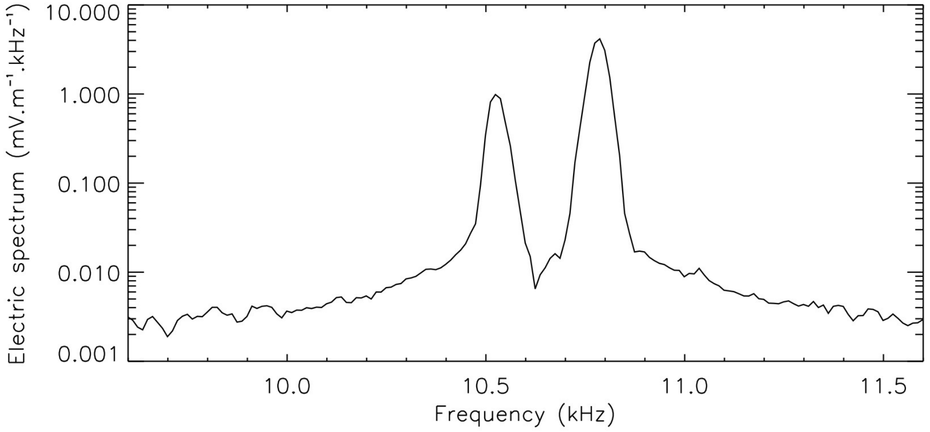
- **simultaneously** to the high & low frequency signals
- 3 antennas (**3D**)

Check of the fundamental laws



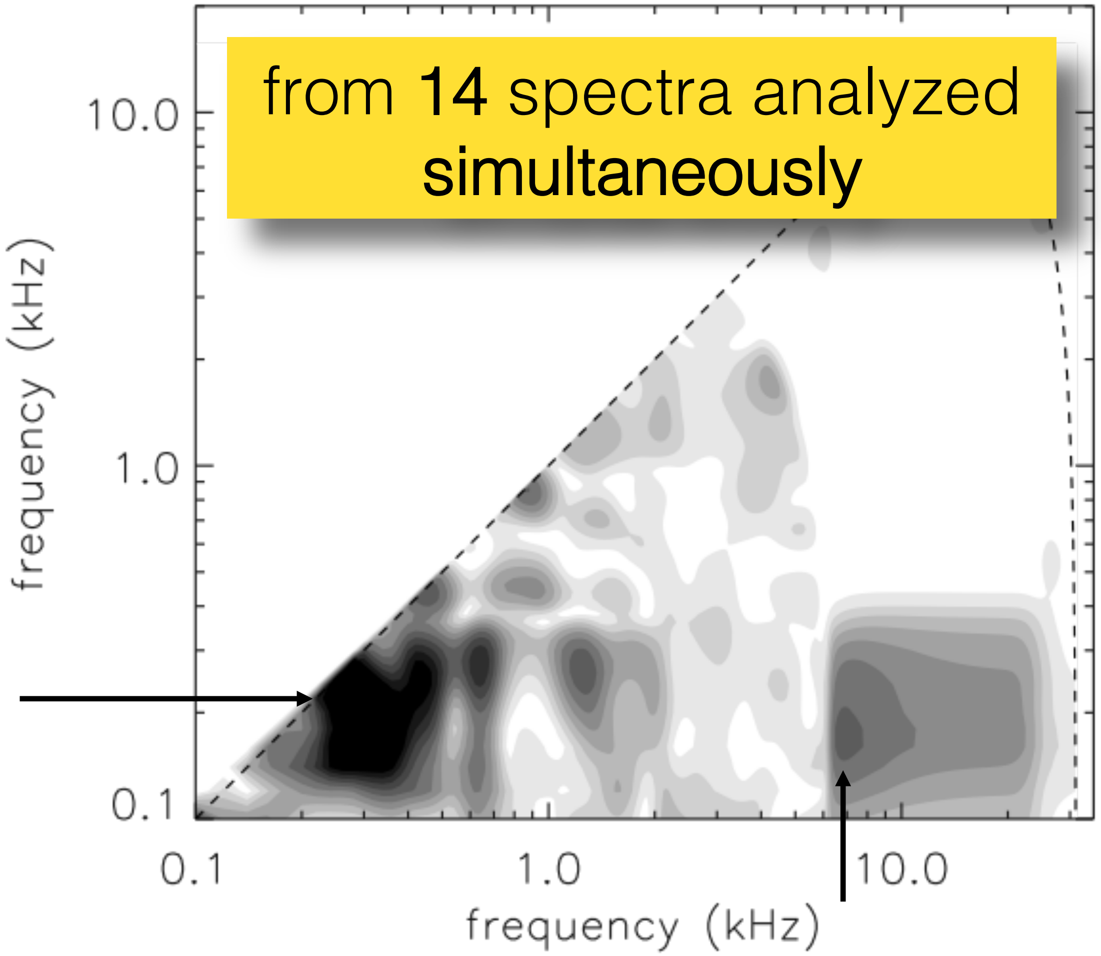
$$f_L - f_{L'} = f_{IAW}$$

taking into account Doppler-shift (which combines the conservation of energy and momentum)

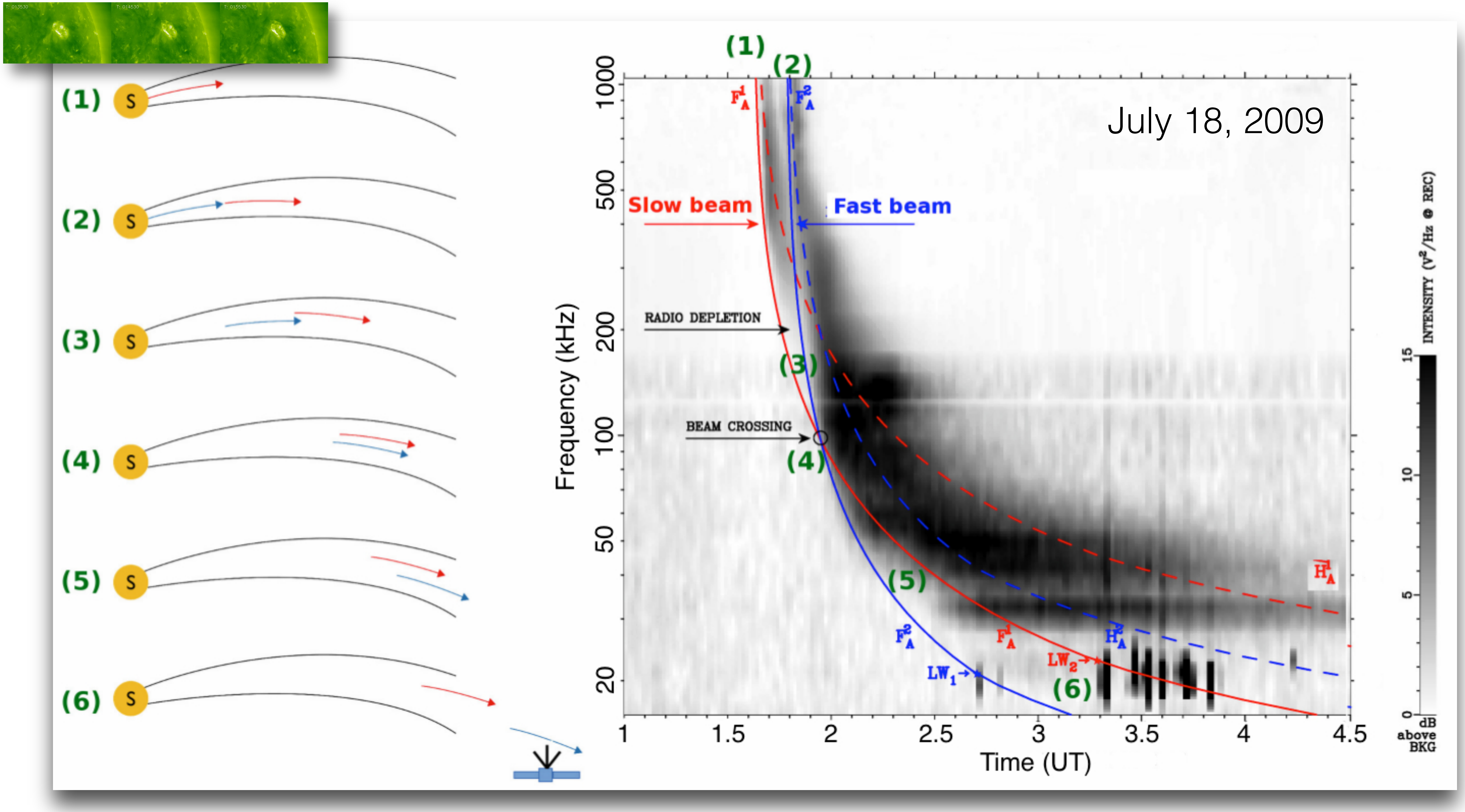


Phase locking: bicoherence

- measures the stationarity of the relative phase of the waves
- ***statistical*** *method*: to be applied to **a large set** of waveforms for statistical significance

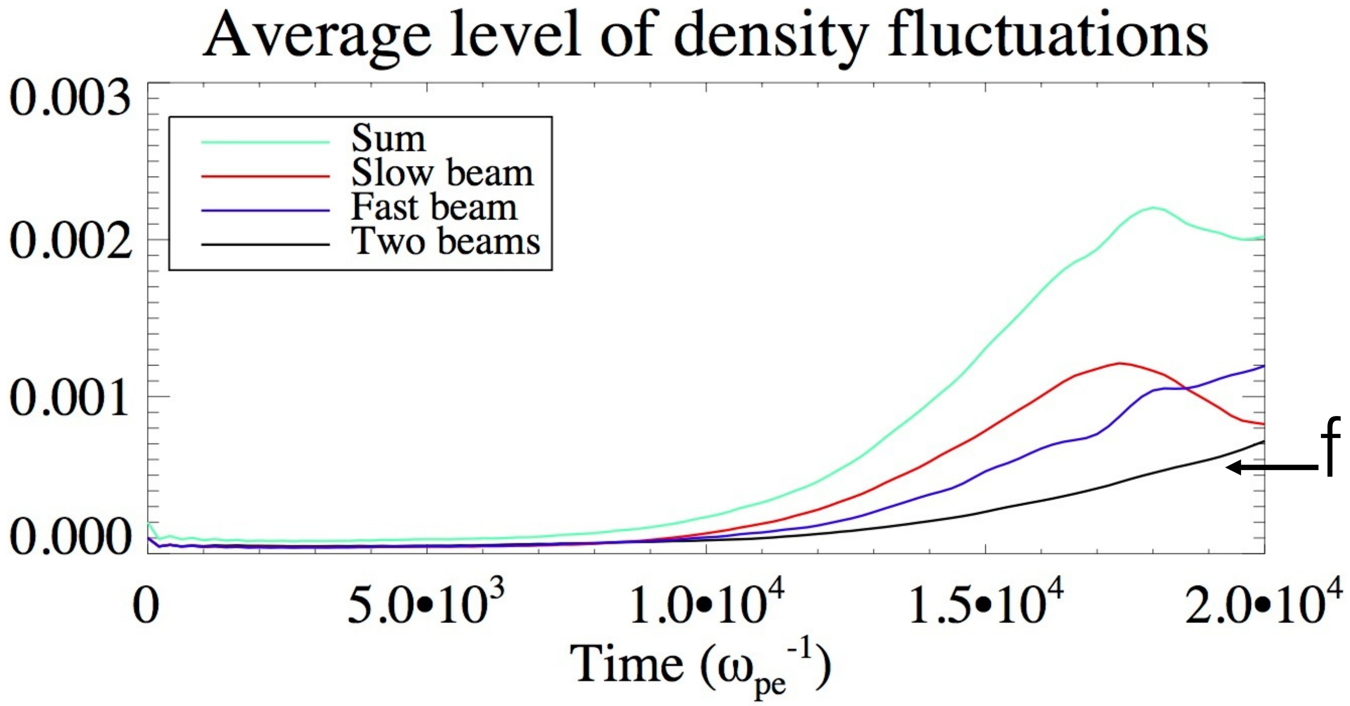


from **14** spectra analyzed **simultaneously**



1° Start of a first beam (01:38) - LW detected at 03:17; slow beam (0.09c)
2° Start of a second beam (01:47) - LW detected at 02:42; fast beam (0.16c)

When the two beams intersect (4), reduction of the intensity of the Type III emission



With two beams, the level of density fluctuations is *always* smaller than the contribution with individual beams

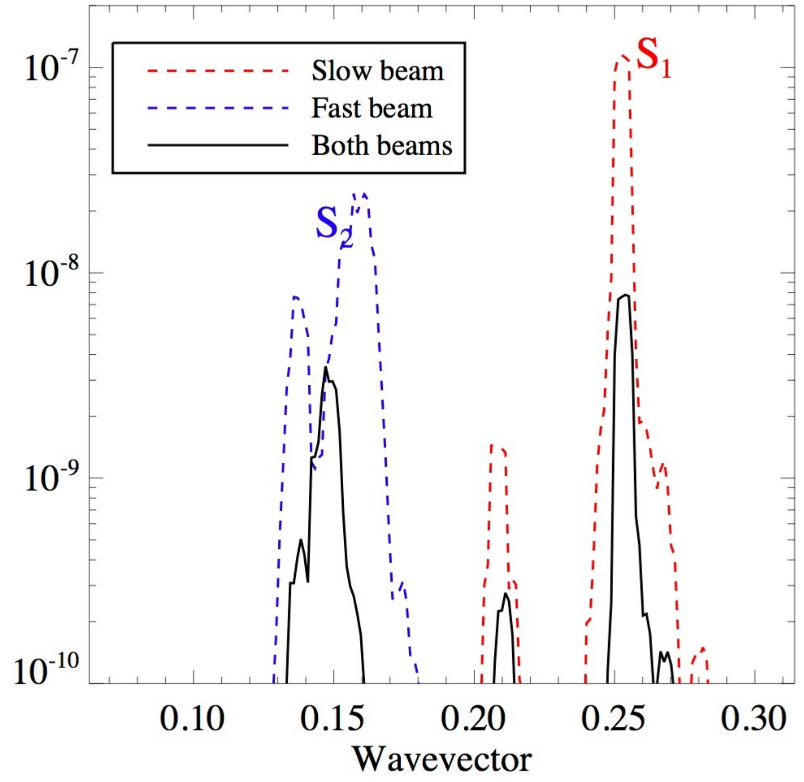
➪ Not only the fast-beam-driven LW are affected by the presence of the slow beam.
slow-beam-driven LW generation is also disturbed

1° Parametric process

even a small decrease of the LW energy to make the process inefficient

2° Coherent process

Phase beating between 3 waves. Ease if $k_{IAW} \neq k_{L,L'}$.
With 2 beams, larger spectrum of k: reduction of the phase locking



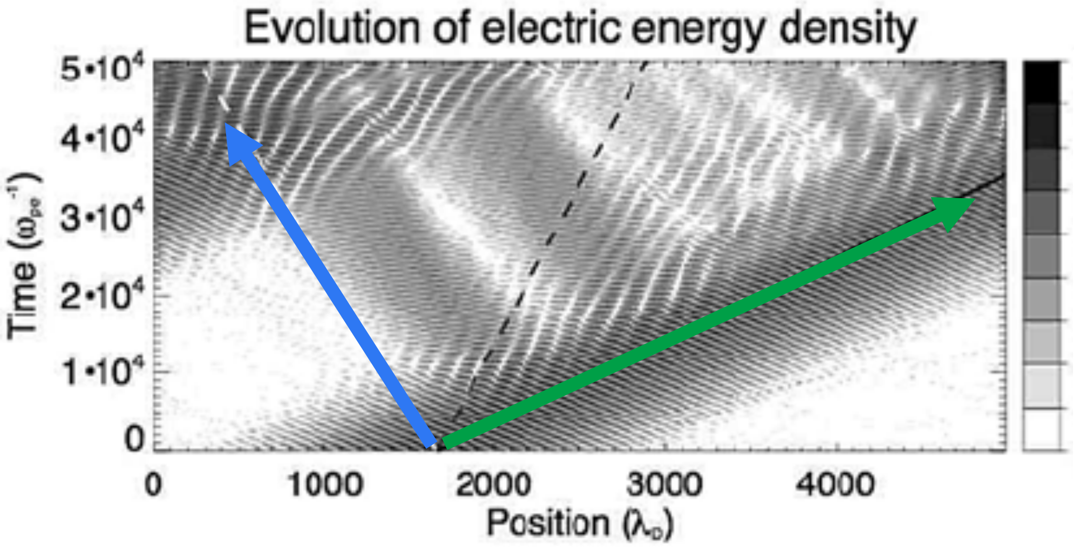
***Briand**, Henri, Hoang, JGR, 2014*

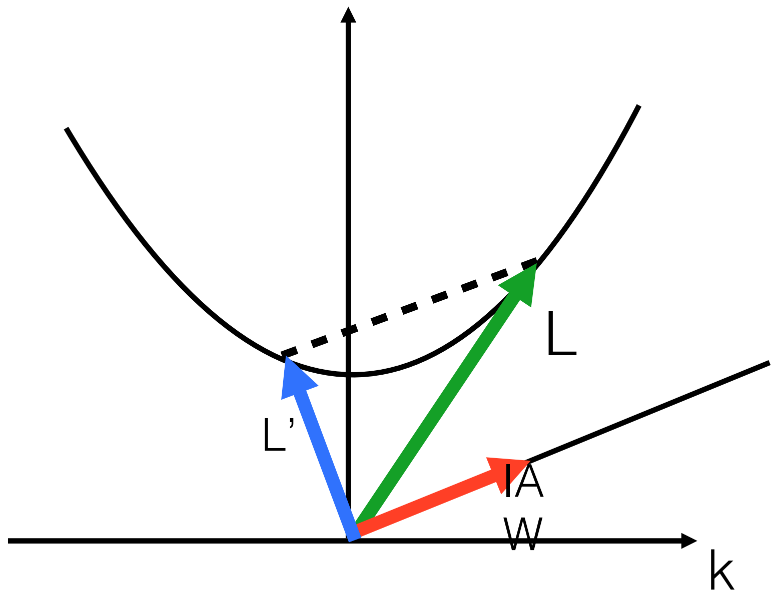
Is the threshold for decay to proceed reached?

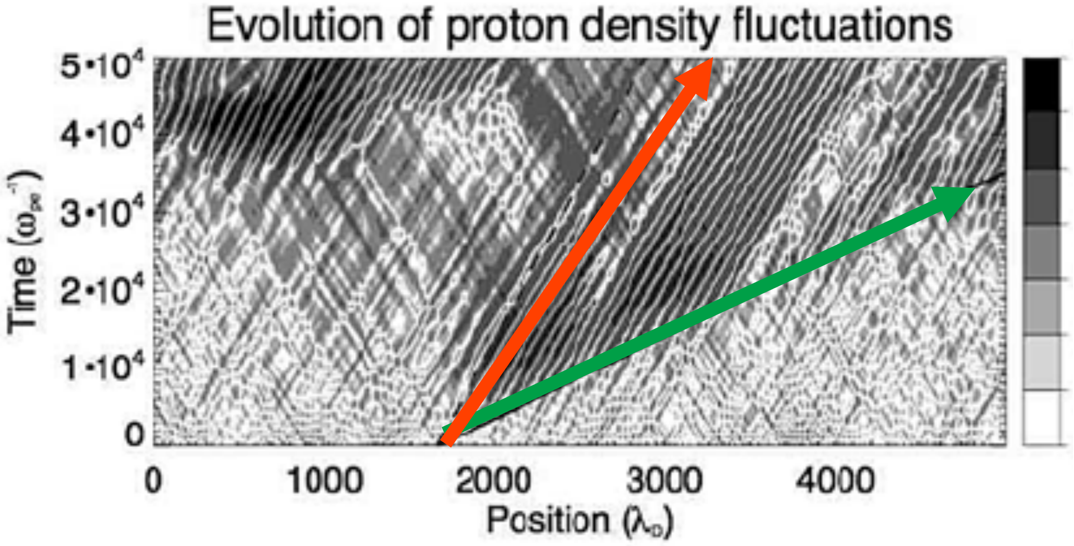
Vlasov-Poisson
1D-1V electrostatic

$$\frac{\partial f_\alpha}{\partial t} + v\frac{\partial f_\alpha}{\partial x} + q_\alpha E\frac{\partial f_\alpha}{\partial v} = 0$$

$$\frac{\partial E}{\partial x} = \int f_i - f_e \, dv$$

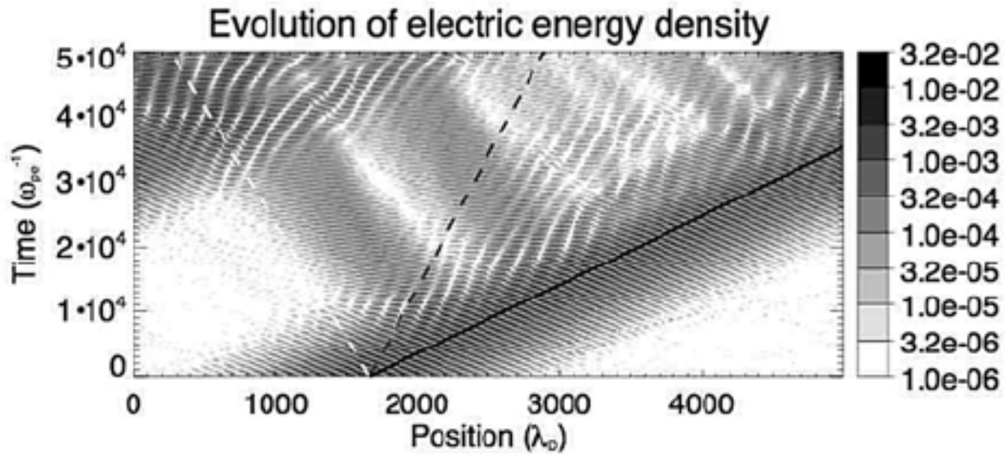

Evolution of electric energy density

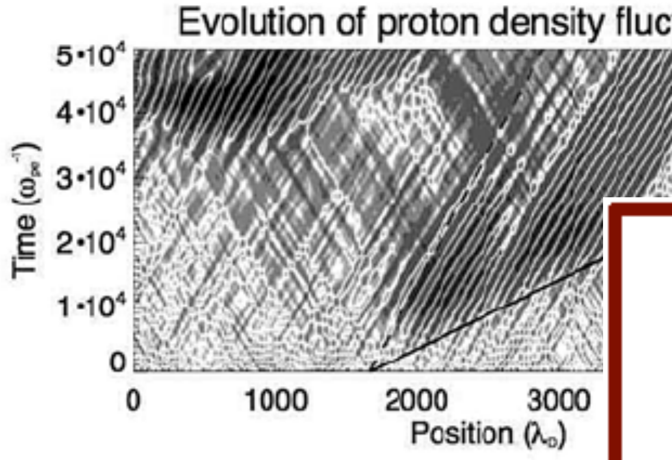



Evolution of proton density fluctuations

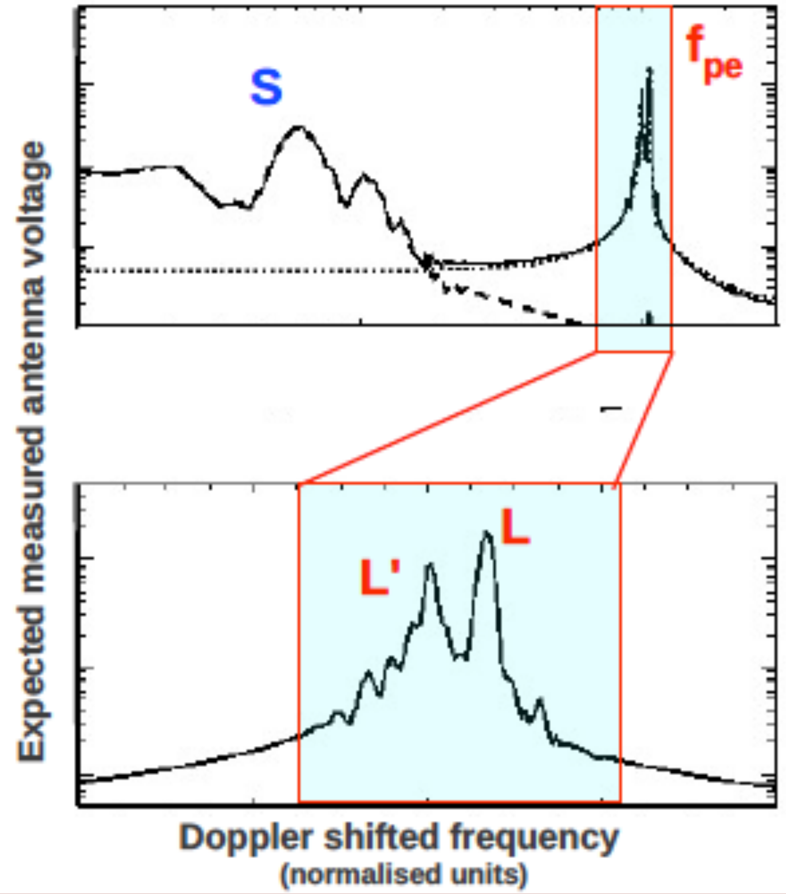
Proton density fluctuation
(tracer of the IAW waves)

Te/Ti=0.1

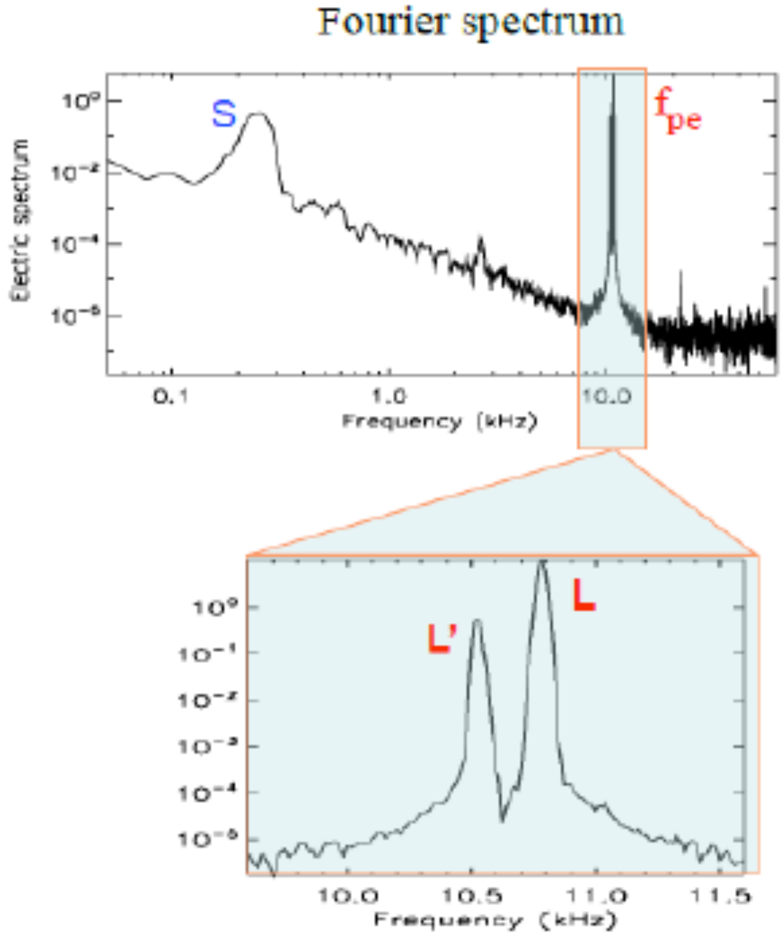




Simulations considering spacecraft-plasma interactions



Space *in situ* observations



[Henri et al., Solar WIND 12, 2010]

Langmuir Electrostatic Decay: **new threshold** for non monochromatic waves (wave-packets of width Δ)

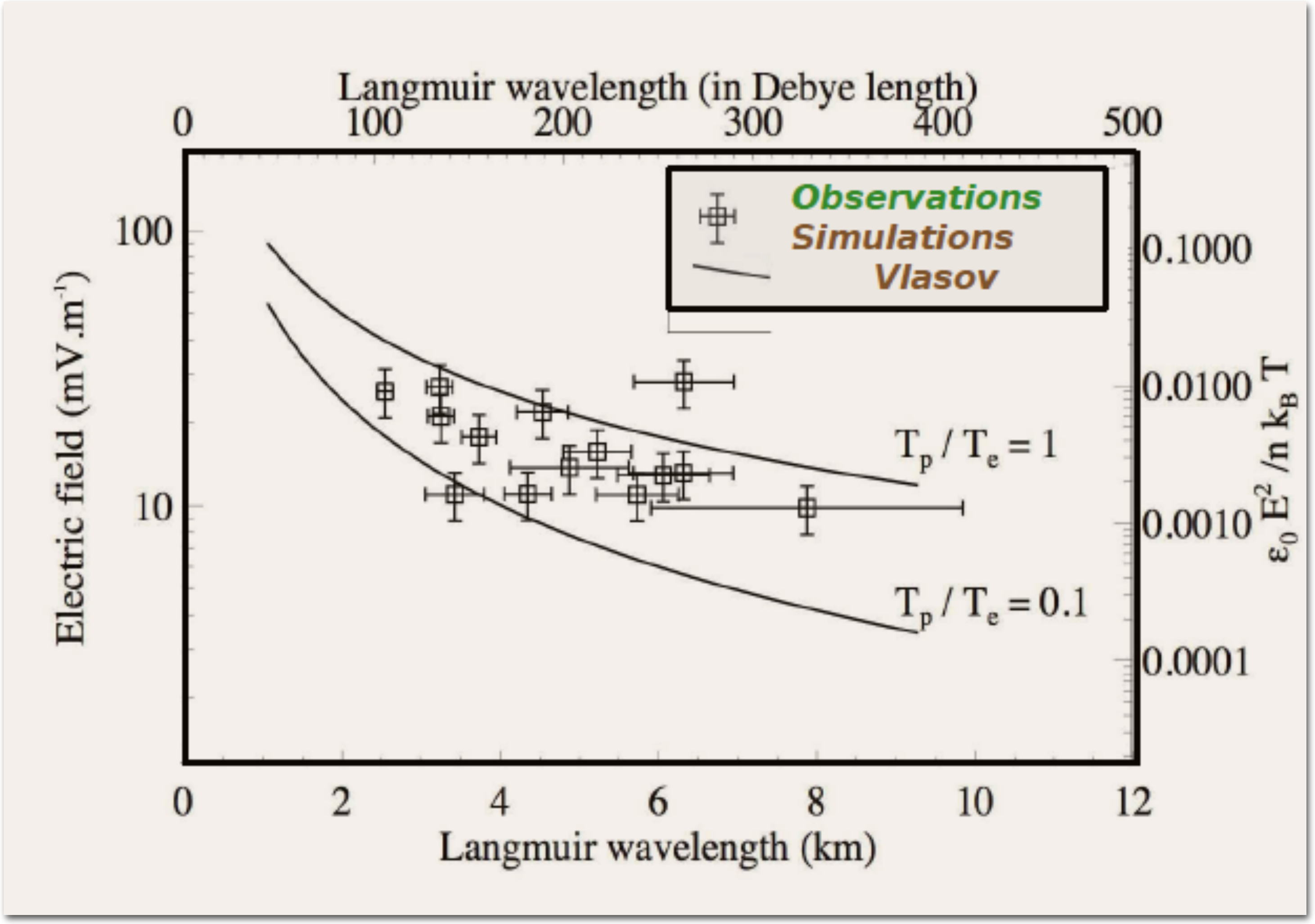
Characteristic time of wave packets collisions = instability growth rate

(function of IAW Landau damping through ion-to-electron temperature ratio)

$$E_{LED}^{thres} = \left(\frac{6 k_L^{1-\beta}}{\Gamma \Delta} \right)^{1/\alpha}$$

	Γ	α	β
$T_p/T_e = 0.1$	0.026	1.11	0.59
$T_p/T_e = 1$	0.025	1.82	0.30

Growth rate $\gamma_{LED} = \Gamma E_L^{\alpha} k_L^{\beta}$



Henri, Califano, Briand, Mangeney, JGR, 2010

Other (expected) waves for coupling

- With whistlers:
  - Radio emission: Type IV solar emission (L+W —>T) (Kuijpers 1975; Chernov et al. 1976, 1989, 1998; Katoh et al. 2014, ApJ)
  - Solar wind: Luo et al. 1999 (L<—> l + W; *l: left-hand circularly polarized radio wave*);Chian & Abalde 1999, Solar Phys.
  - CME: Langmuir, whistler (Moullard et al. 2012)
  - Observation of Langmuir/Upper hybrid, whistler in the auroral ionospheric region (Colpitts & Labelle 2008).
  - Separatrix of reconnection regions can lead to Langmuir, whistlers and low hybrid waves (Fujimoto, 2014);

Other (expected) waves for coupling

With kinetic Alfven waves: L<—> W + KAW

In solar corona
(Voitenko et al. 2003)

Planetary magnetosphere: direct coupling between Langmuir, Alfven and whistlers (Chian, 1995, Lopes & Chian 1996)

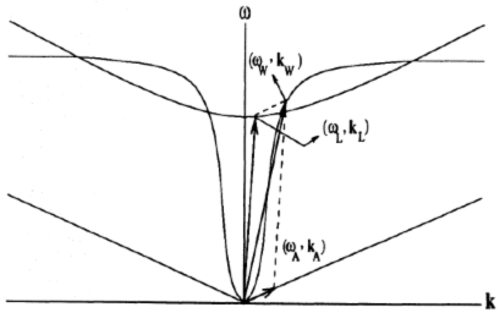
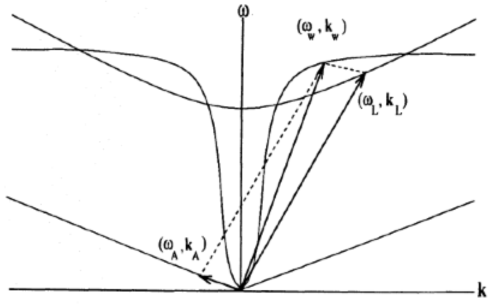


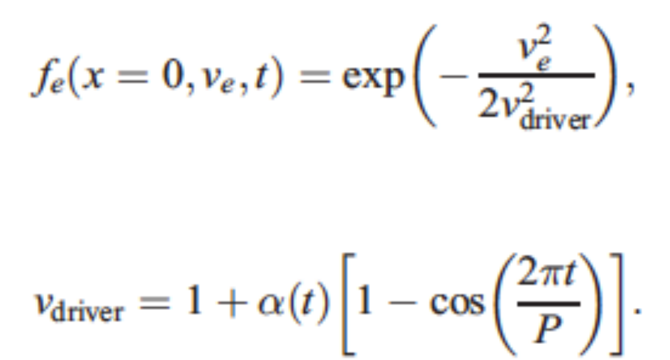
Fig. 2. Two examples of wavevector kinematics for $W \rightleftharpoons L + A$



Other coupling also possible

Langmuir Turbulence: a new mechanism of generation

Temporal variation of the temperature of the electron distribution function

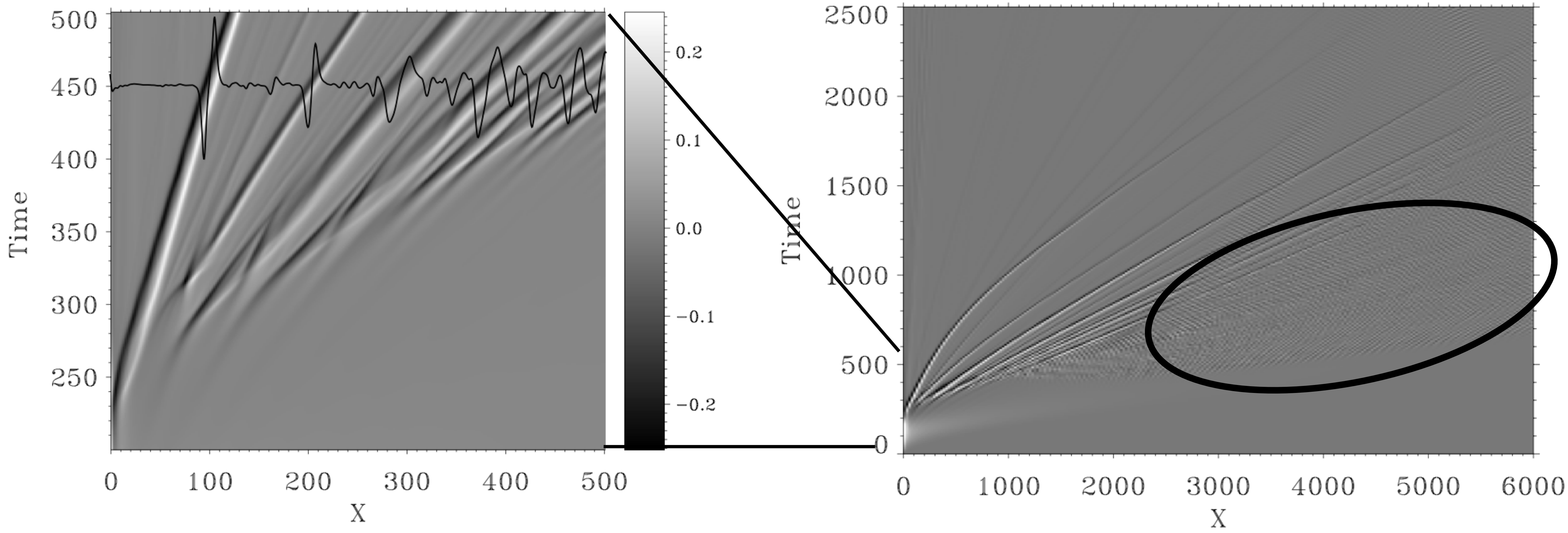


$$f_e(x=0,v_e,t) = \exp\left(-\frac{v_e^2}{2v_{\rm driver}^2}\right),$$

$$v_{\rm driver} = 1 + \alpha(t)\left[1 - \cos\left(\frac{2\pi t}{P}\right)\right].$$

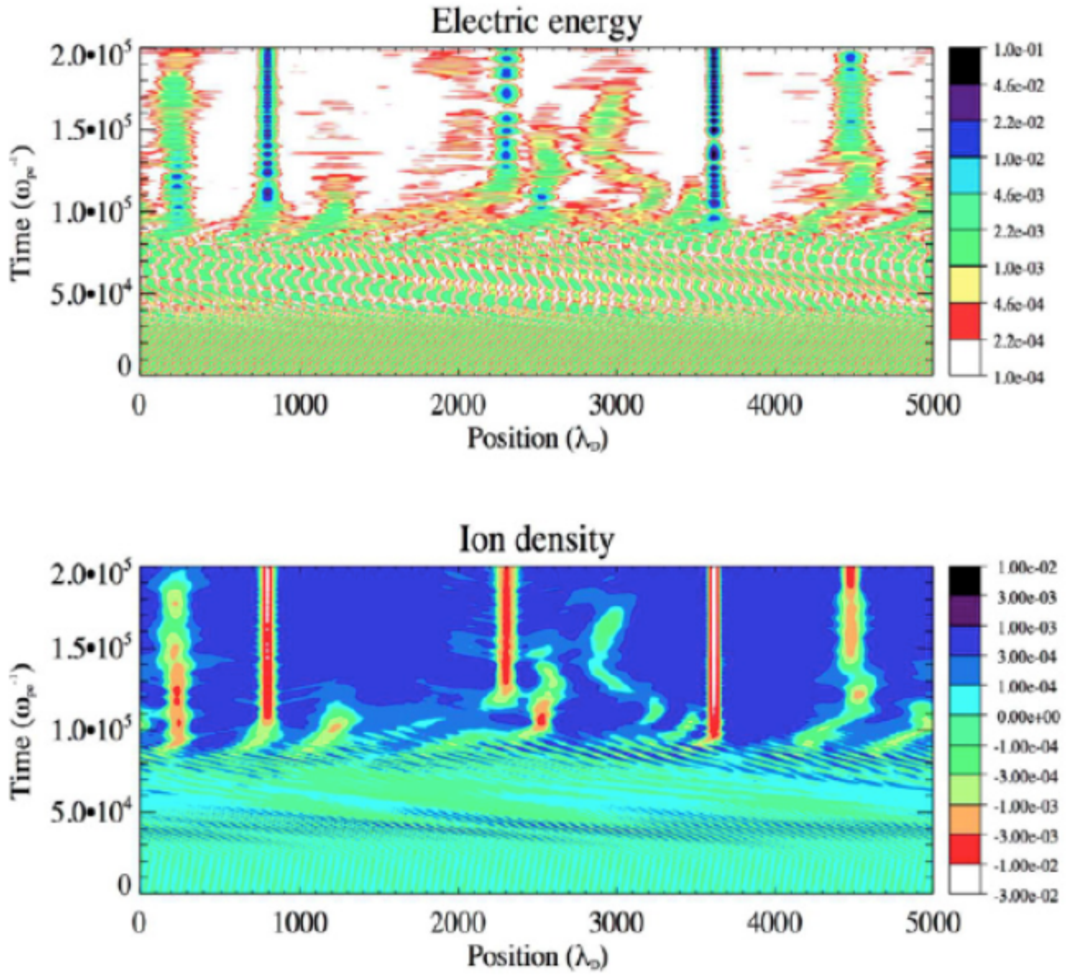
- Development of bipolar structures

- Development of a large area of Langmuir turbulence



Briand et al. 2007, JGR + Phys. Let.A

C - From weak to strong Langmuir turbulence



Henri, Califano, Briand, EPL, 2012

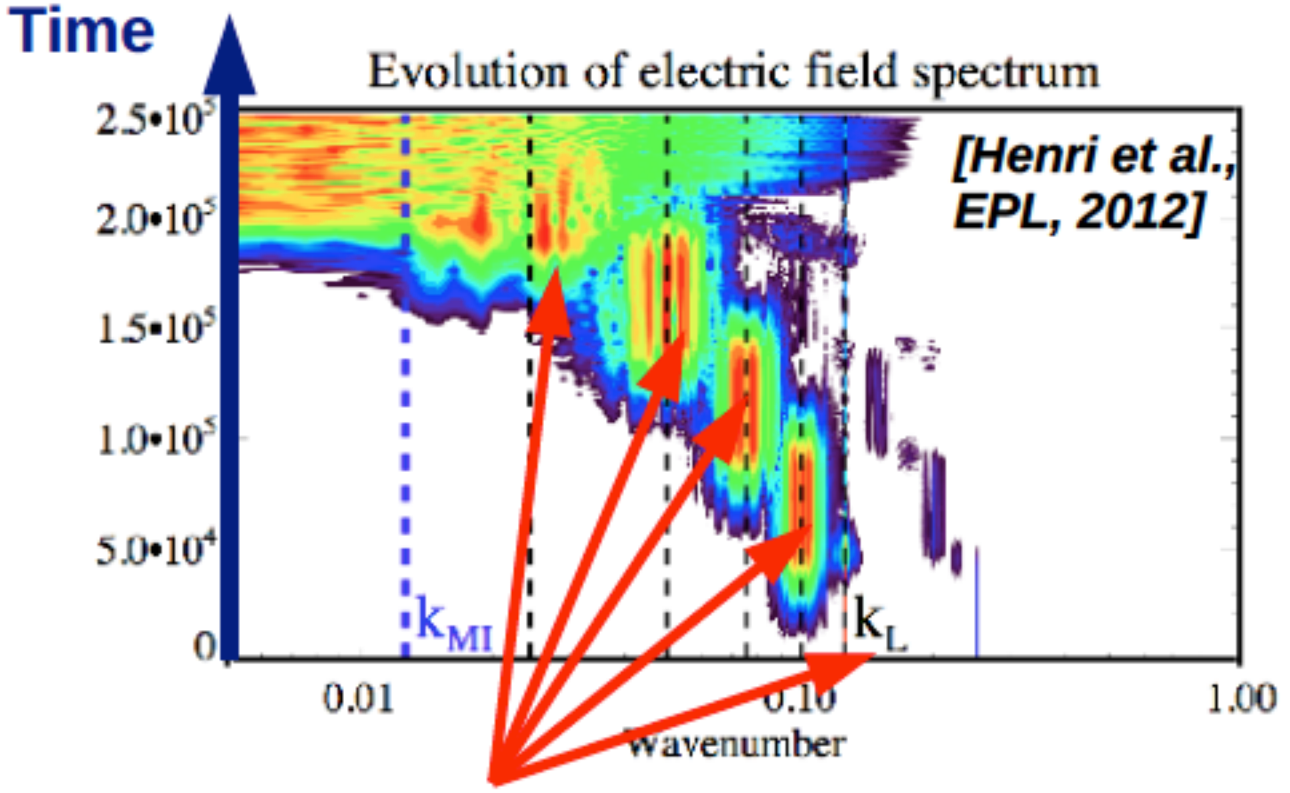
Strong turbulence

  - Collapse of soliton
  - Trapping of Langmuir waves
  - At the end of the collapse, transfer of the energy of the waves to the electrons.
- AGAINST:
  - In the solar wind, energy of the waves too small for strong turbulence to occur
- PRO
  - Terrestrial auroral magnetosphere/ionosphere (Eliasson 2015; Isham et al. 2012)
  - Pulsar (nanopulses) (Asseo 2006, Hanskins 2003)

Start from a large amplitude monochromatic Langmuir waves

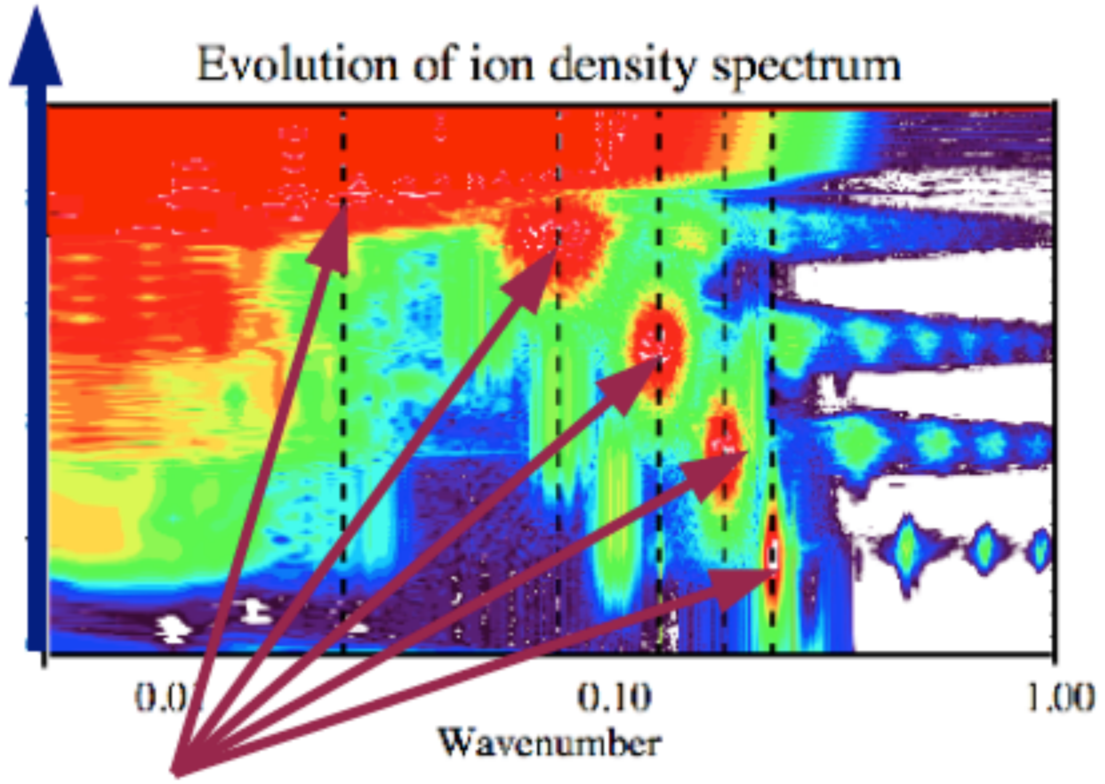
1st part of the evolution:

Electrostatic cascade: succession of Langmuir decay
quasi-linear, WEAK TURBULENCE



[Henri et al., EPL, 2012]

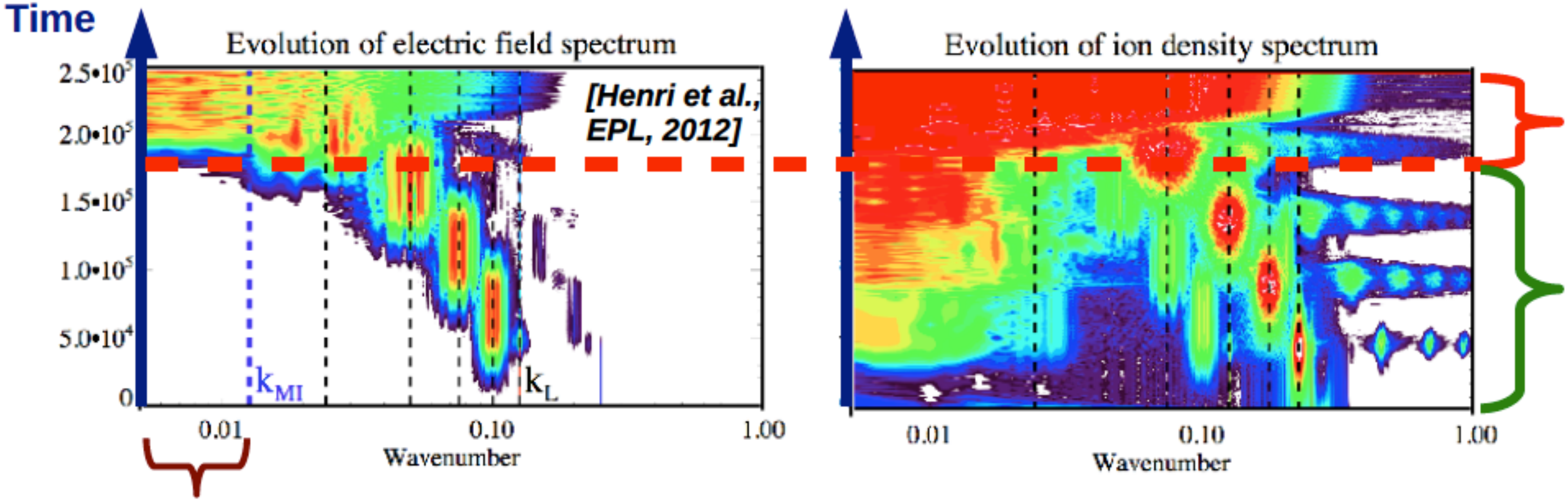
Langmuir waves



Ion Acoustic waves
PSEUDO-MODE

@ Te=Ti

2nd part of the evolution:
Formation of Langmuir solitons, standing coherent structures strongly nonlinear, STRONG turbulence regime



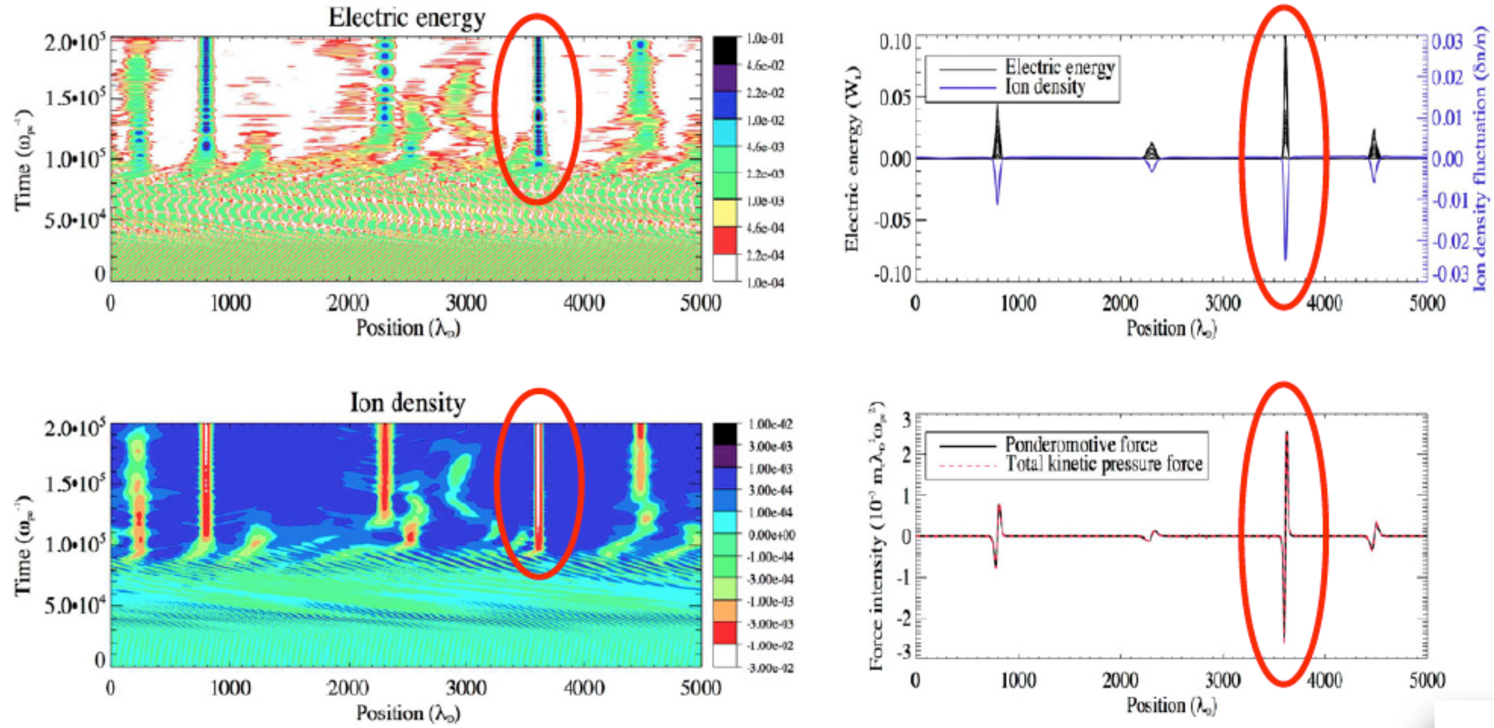
Evolution of electric field spectrum

Evolution of ion density spectrum

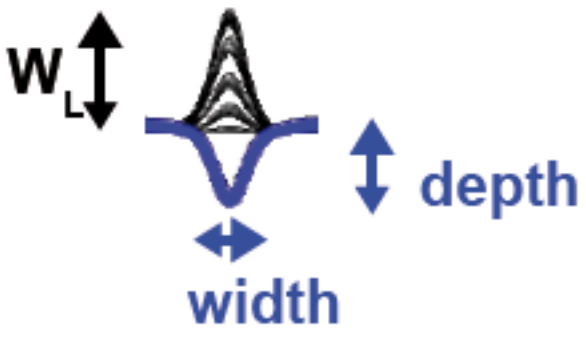
[Henri et al., EPL, 2012]

Langmuir modulational instability

strong turbulence
weak turbulence



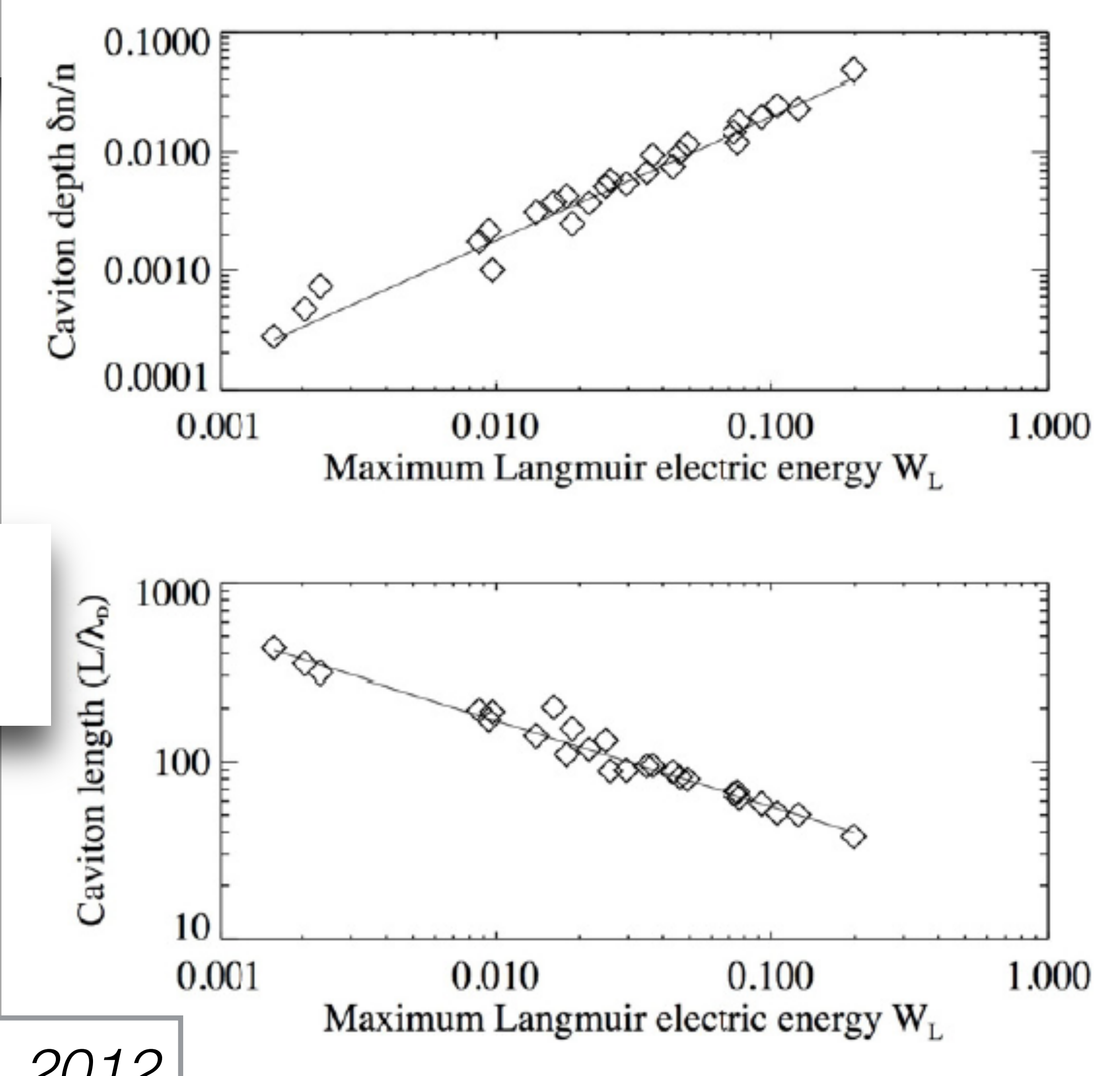
Example of (standing) Langmuir Caviton



Same scaling laws for
standing and *propagating* cavitons
(Langmuir solitons)

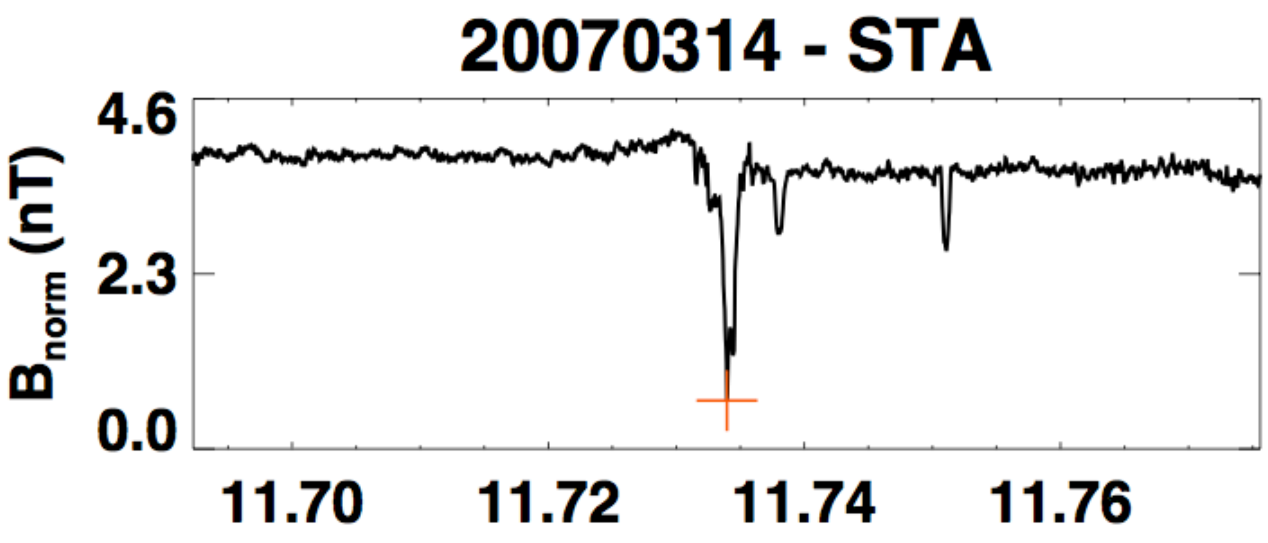
Cavitons can saturate at low energy (until $\varepsilon_0E^2/nk_BT \sim 10^{-3}$) unlike the wide-spread belief that such structures should be found at higher energy ratios ($\varepsilon_0E^2/nk_BT \sim 1$).

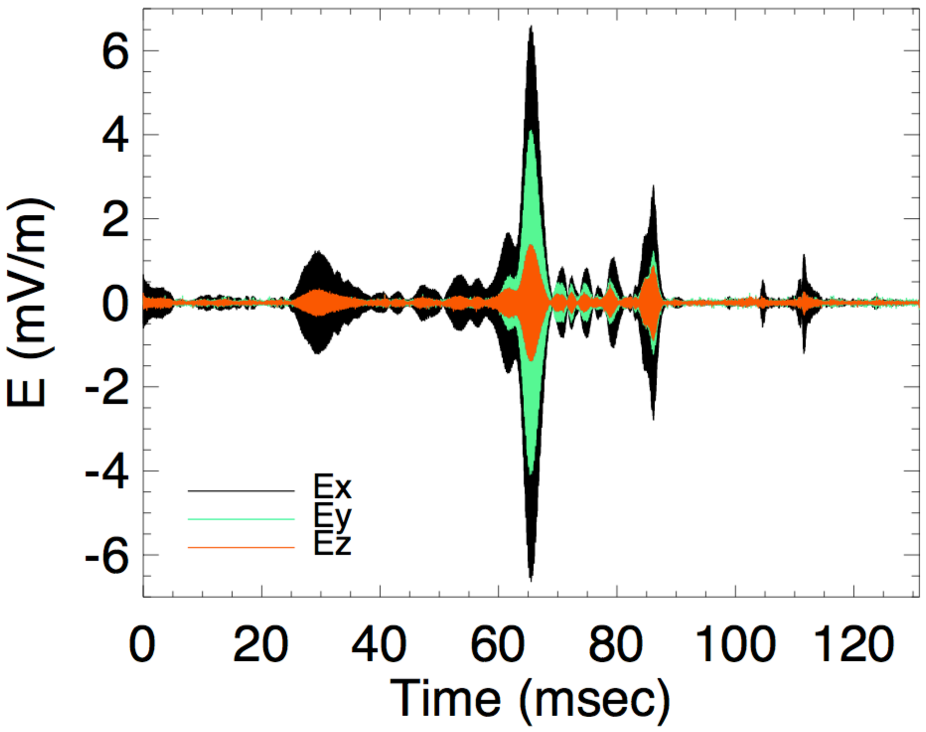
Scaling laws for (standing) Langmuir Cavitons

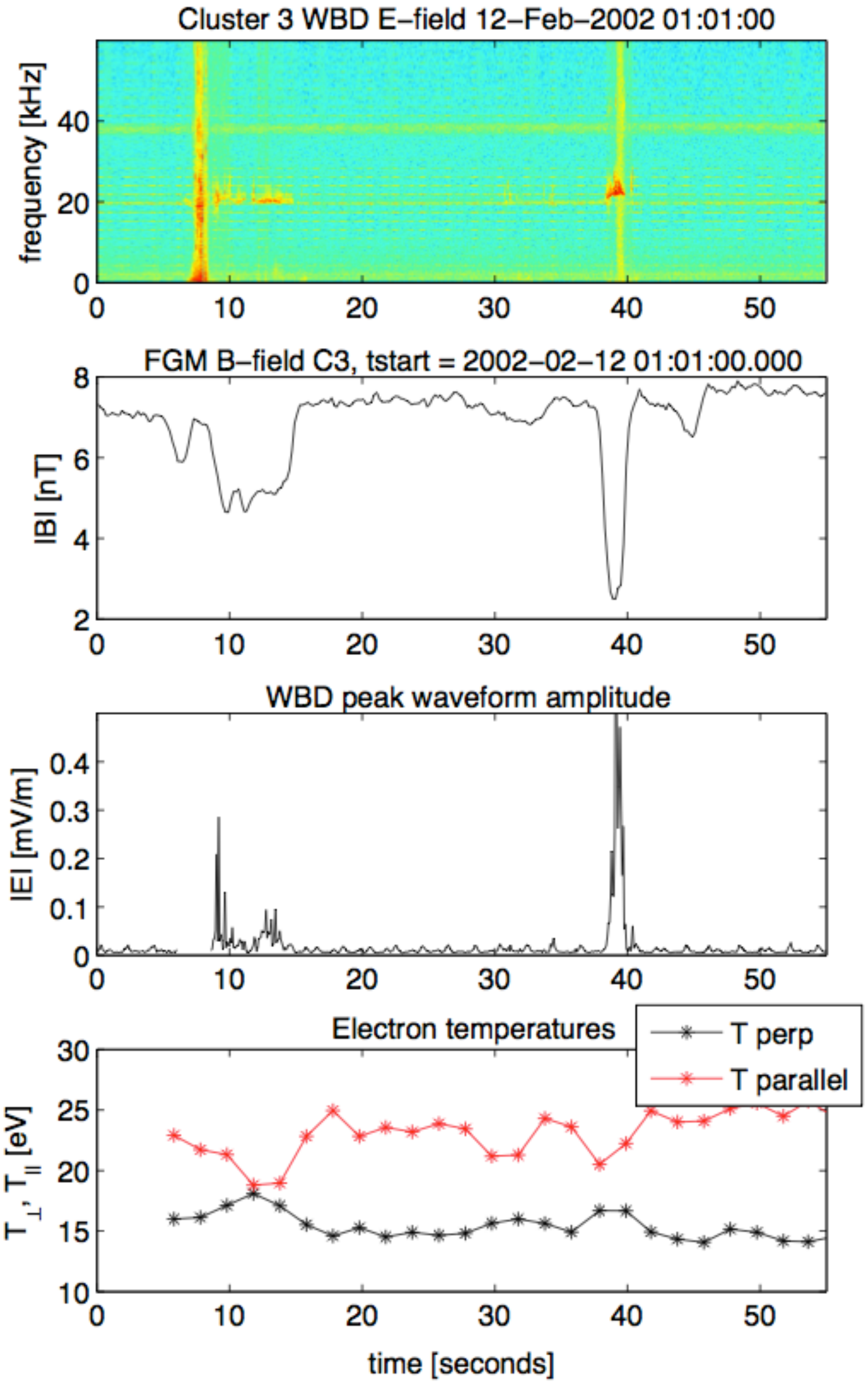


Henri, *Califano, Briand, European Physical Journal, 2012*

Wave trapping in magnetic holes







Summary
&
futur works

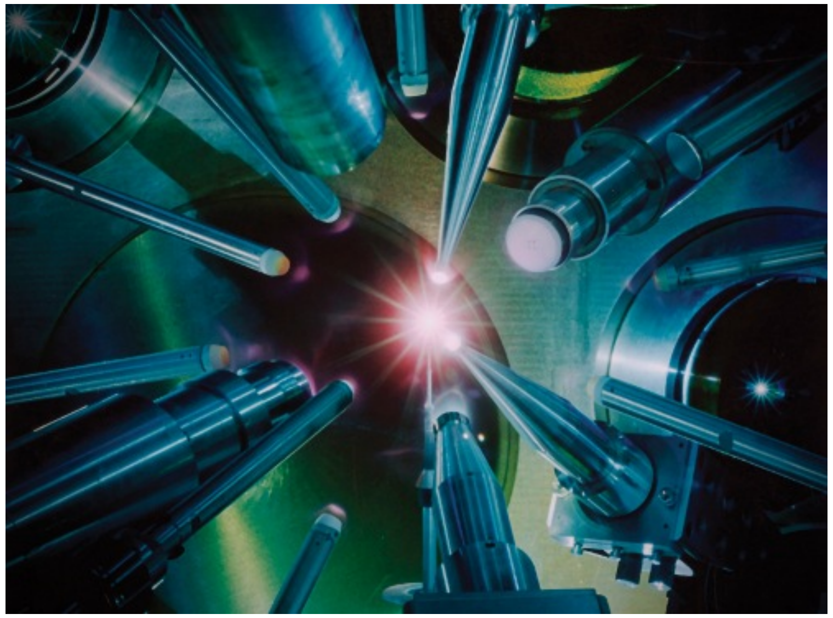
Observing requisite

- **Waveforms** are **mandatory** to check the conditions for wave coupling (k, w, phase locking and coherence)

- Futur instruments must be able to provide electric waveforms to detect from a few Hz to hundred(s) kHz to study the different coupling and transfer of energy from high to low frequencies

- Particle Distribution Function: high resolution in energy (some instabilities very sensitive to the thermal velocity of the beam), and high time resolution

A universal question



Collaboration: inertial confinement fusion community (LULI)

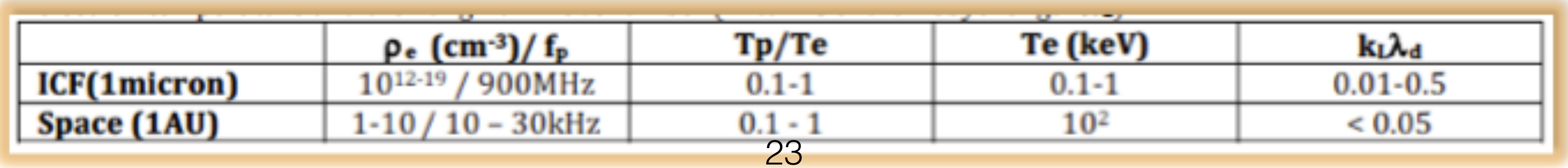
PIC simulations + data from laser experiments

Laser is dispersed through *Ion Acoustic Parametric Decay*

Production of hot electrons

Ion waves: source of anomalous resistivity

Saturation of the Raman instability



	ρ_e (cm^{-3})/ f_p	Tp/Te	Te (keV)	$k_L\lambda_d$
ICF(1micron)	10^{12-19} / 900MHz	0.1-1	0.1-1	0.01-0.5
Space (1AU)	1-10 / 10 – 30kHz	0.1 - 1	10^2	< 0.05