Flare-related radio emission: a kinetic point of view

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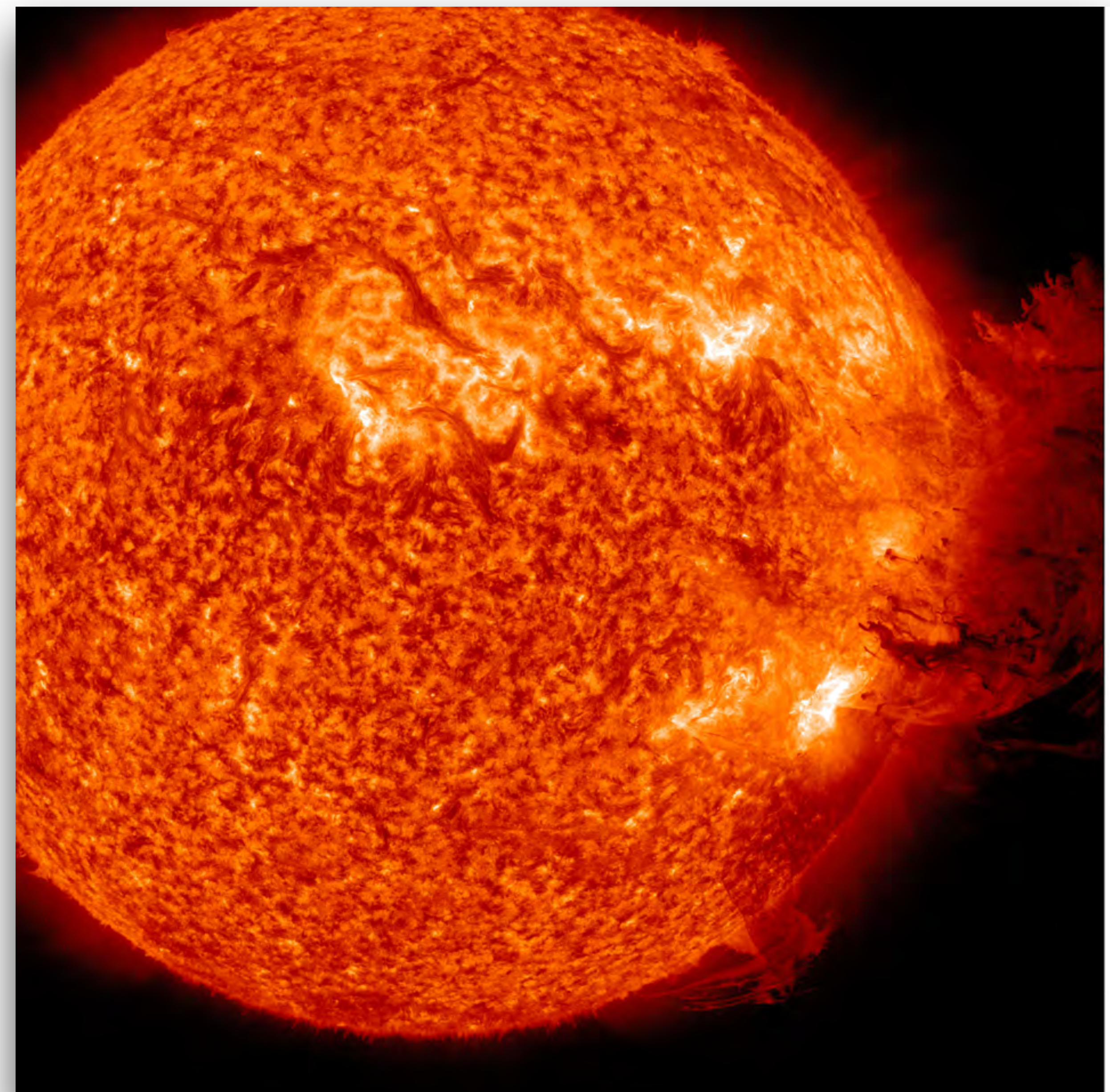
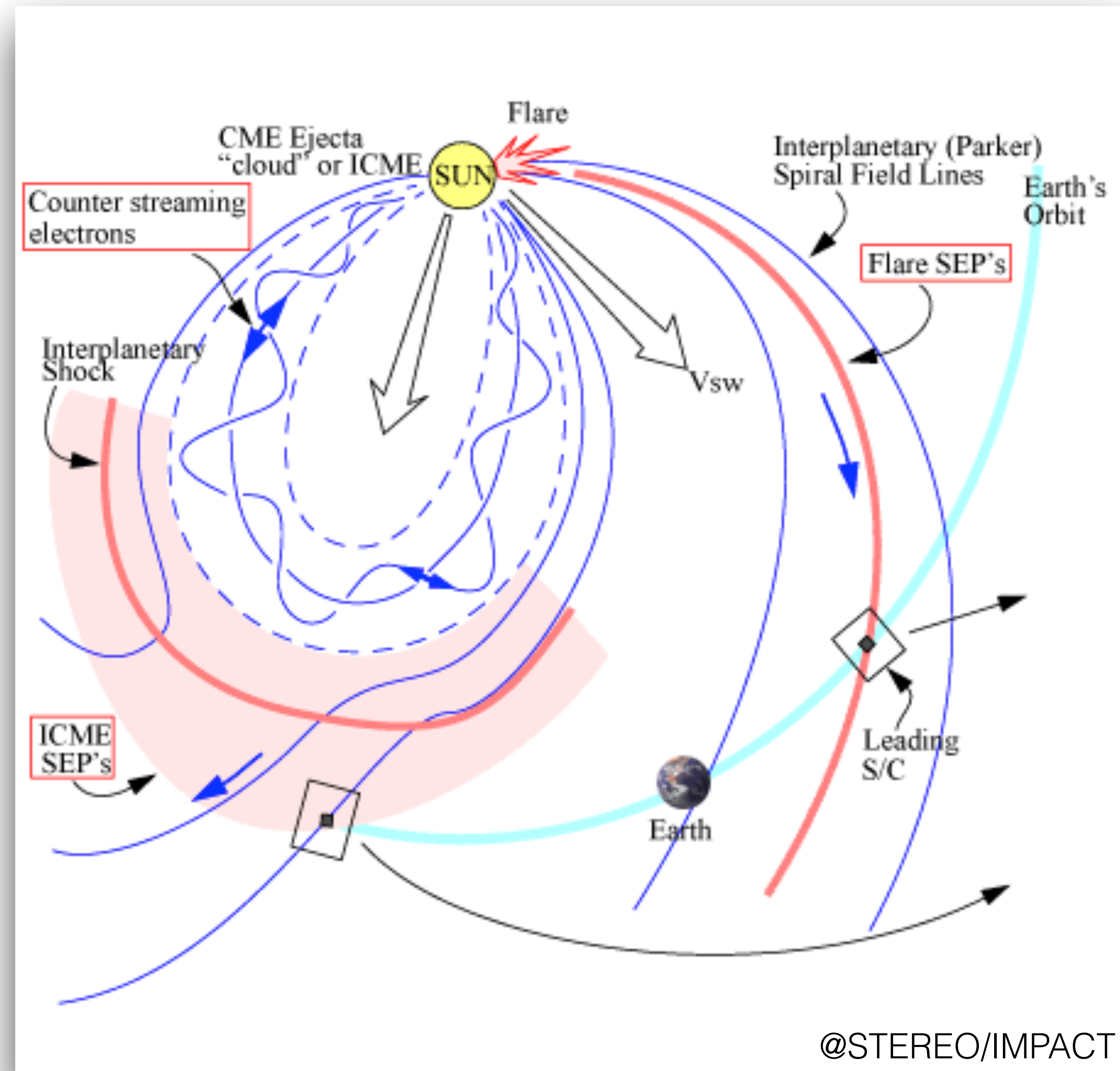
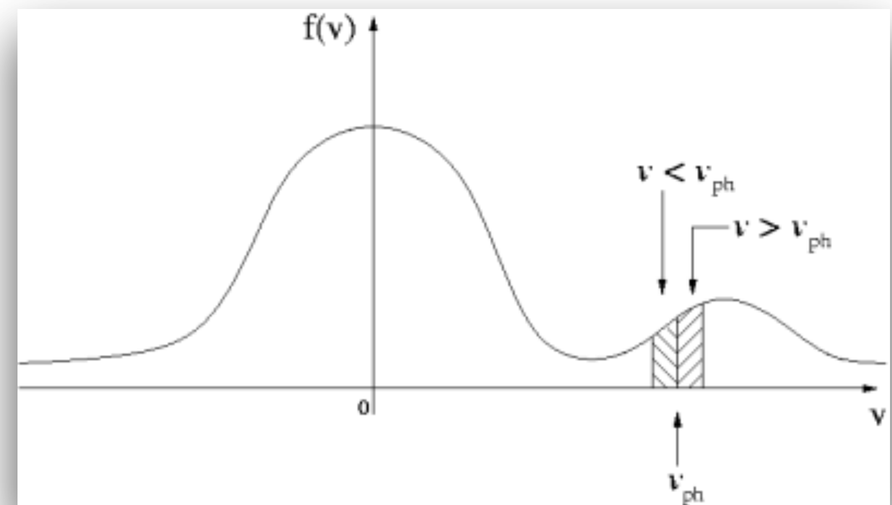
Eruptive Sun





Fundamental of beam plasma interaction



Suprathermal electrons: free energy for plasma instability (bump-on-tail)

Growth of Langmuir waves
(local plasma frequency - plasma density)

Non Linear Saturation and generation of EM emissions
(resonant and parametric (threshold) processes)

Electromagnetic Decay

$$L \rightarrow T_{fp} + LF$$

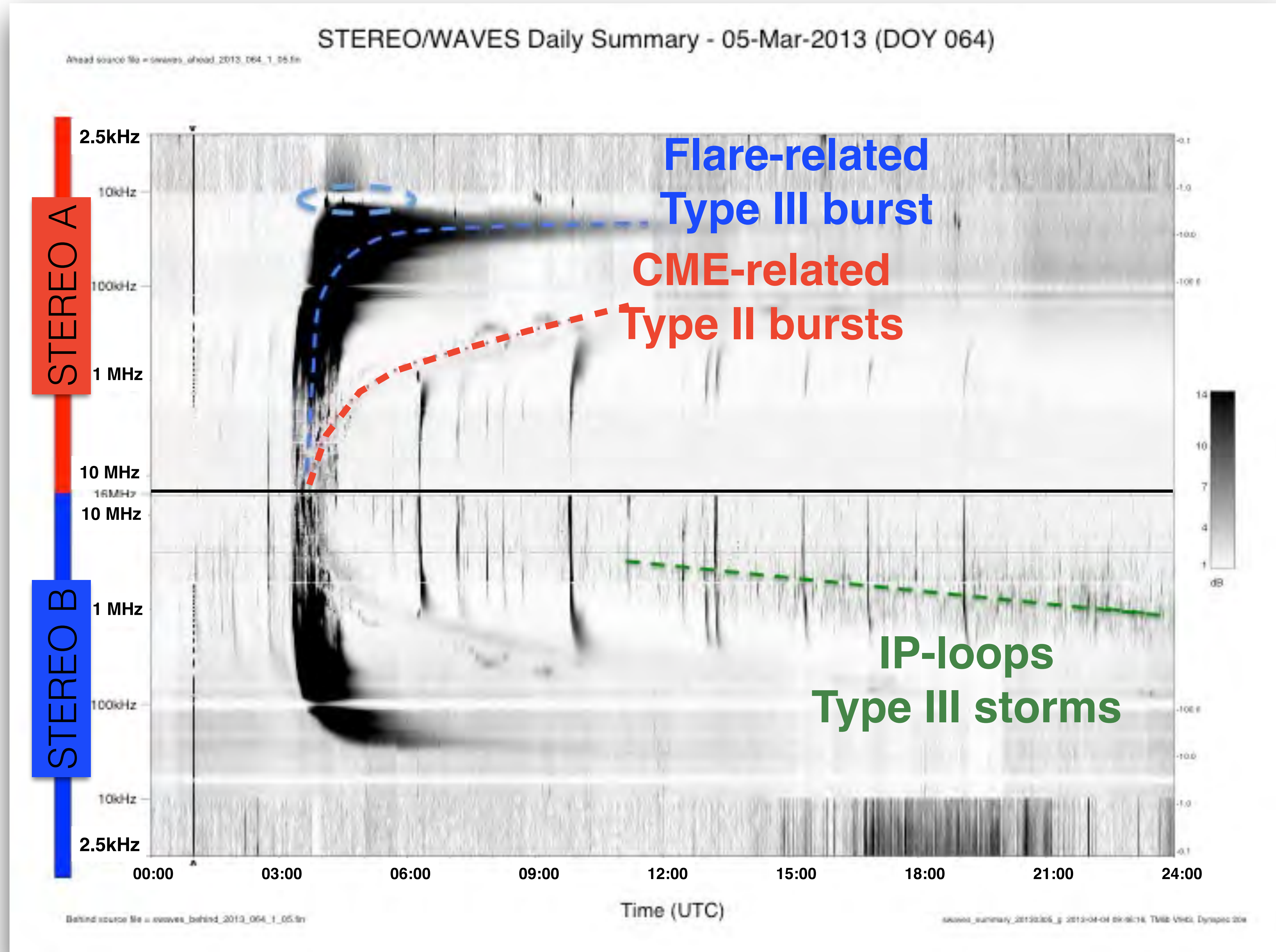
Electrostatic Decay & coupling

$$L \rightarrow L' + LF$$

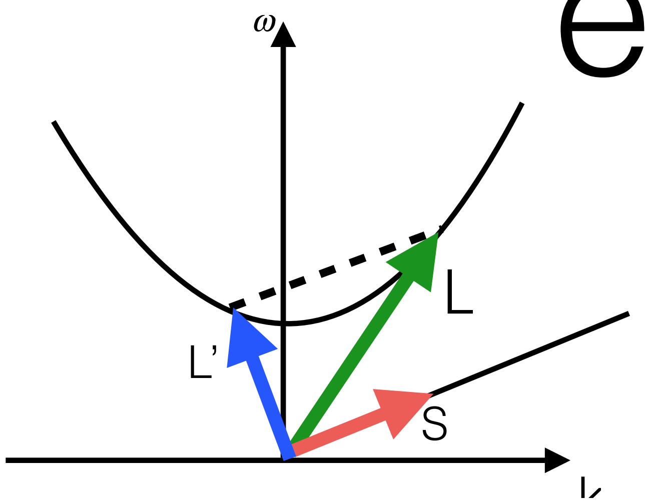
$$L' + L \rightarrow T_{2fp}$$

Lowest threshold

Solar radio emissions



Fundamental of Langmuir electrostatic decay



$$L \rightarrow L' + LF$$

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

LF = Ion Acoustic Waves

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: $\varphi_L = \varphi_{L'} + \varphi_S$

Threshold:

$$\gamma_{LED} > \sqrt{\gamma_{L'}\gamma_S}$$

$$\frac{\epsilon_0 E^2}{nk_B T} > 8\frac{\gamma_{L'}}{\omega_{L'}}\frac{\gamma_S}{\omega_S}$$

in situ observation

Kinetic simulations

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

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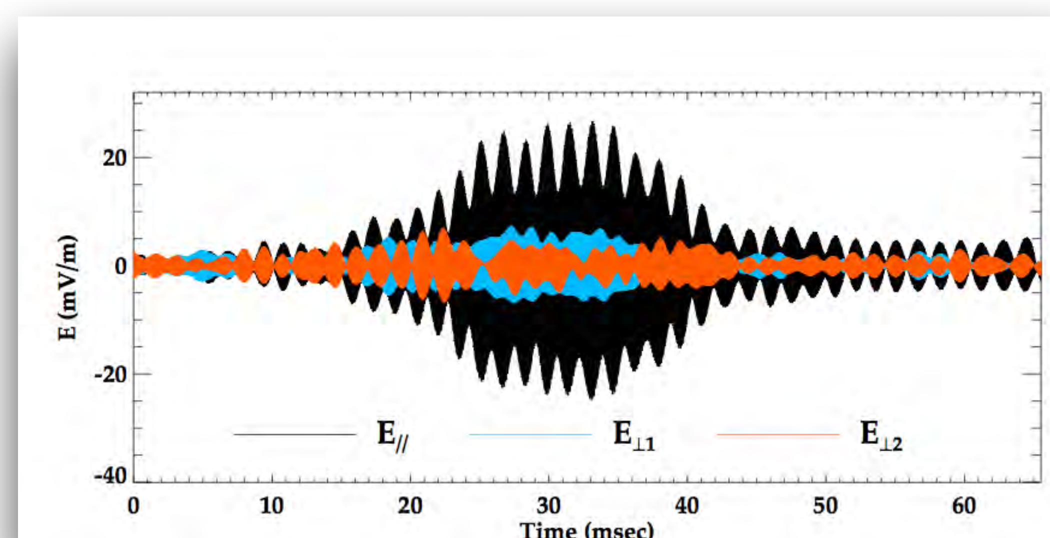
From STEREO waveforms we can access

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



A case study

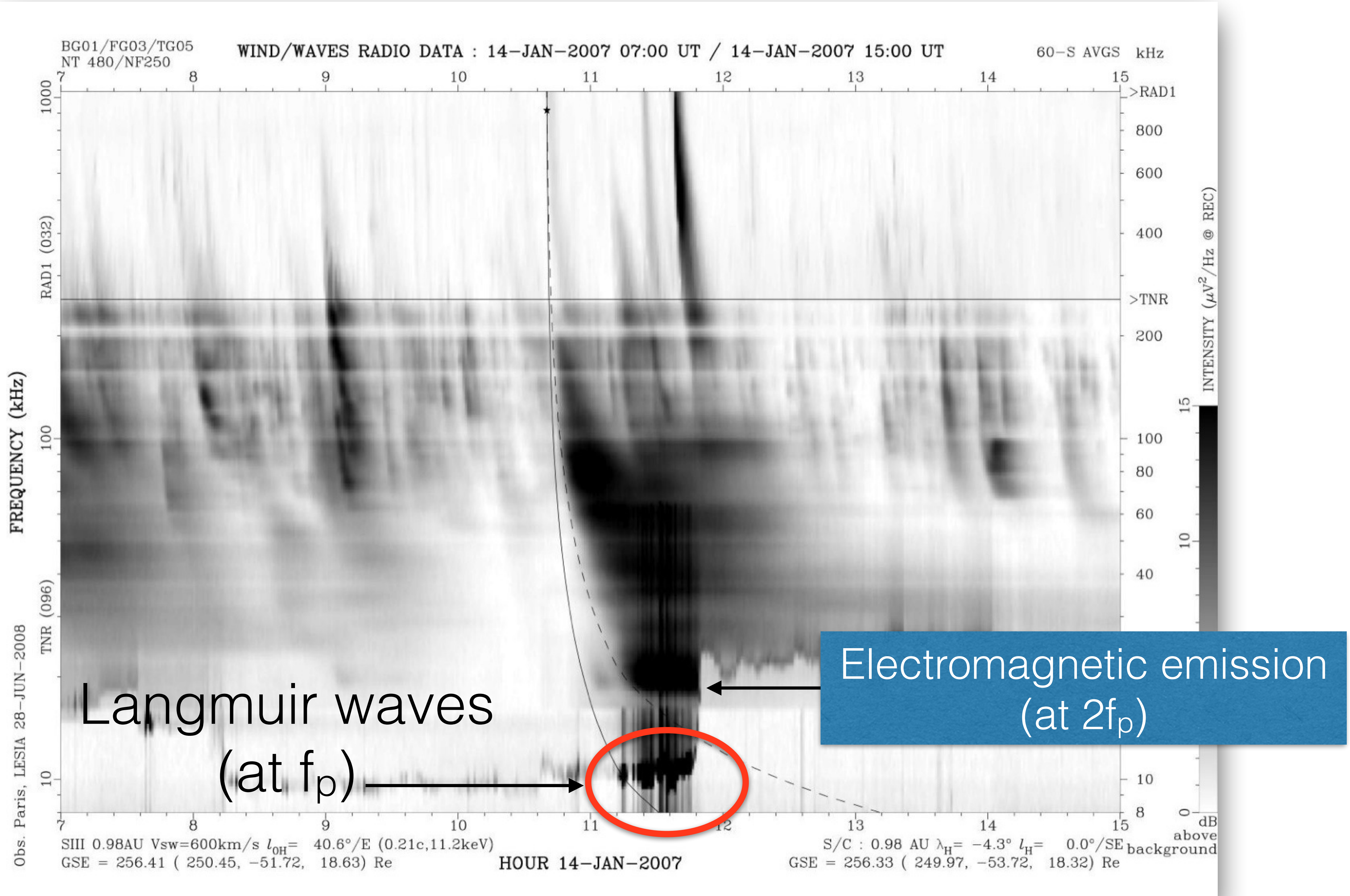
Langmuir decay & wave coupling process

confirmed from

observations & simulations

Henri P., Briand C., Mangeney A., JGR, A03103, 2009
Henri P., Califano F., Briand C., Mangeney A., JGR, A06106, 2010

STEREO Jan. 2007



Check of the fundamental laws:
1 - Energy & Momentum conservation

Theory:

$$\omega_L = \omega_{L'} + \omega_{IAW}$$

$$\vec{k}_L = \vec{k}_{L'} + \vec{k}_{AW}$$

Observed:

$$f_L^{Doppler} = f_L + \frac{\vec{k}_L}{2\pi} \cdot \vec{V}_{sw}$$

The frequency condition for resonance

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

checks simultaneously the two conservation laws (energy & momentum)

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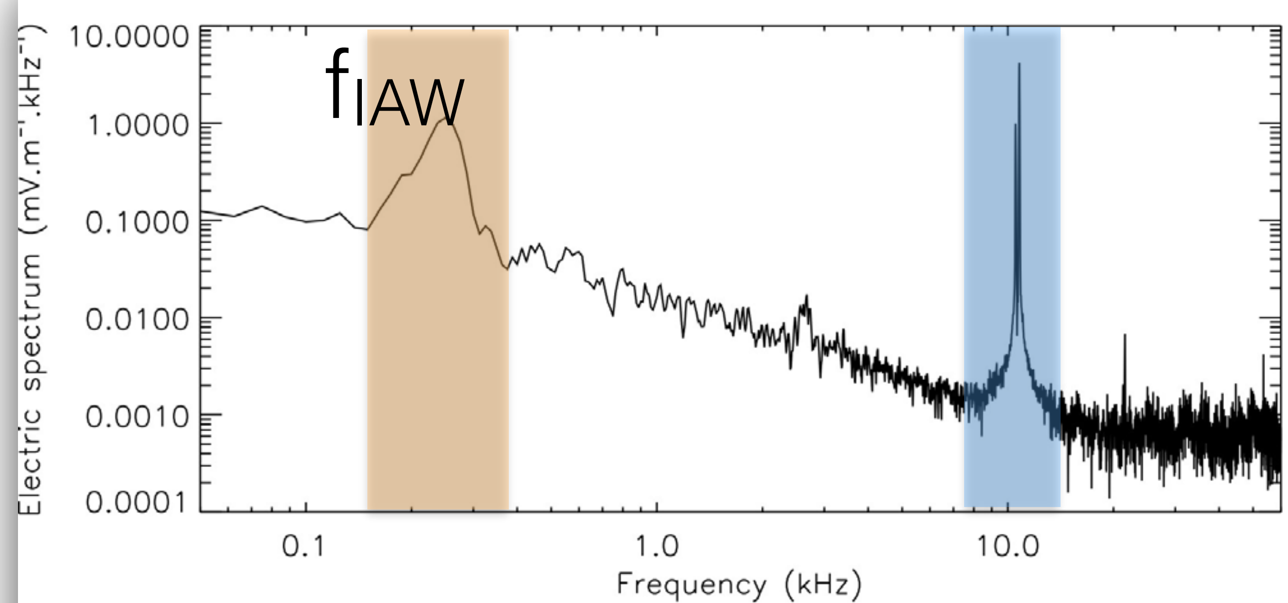

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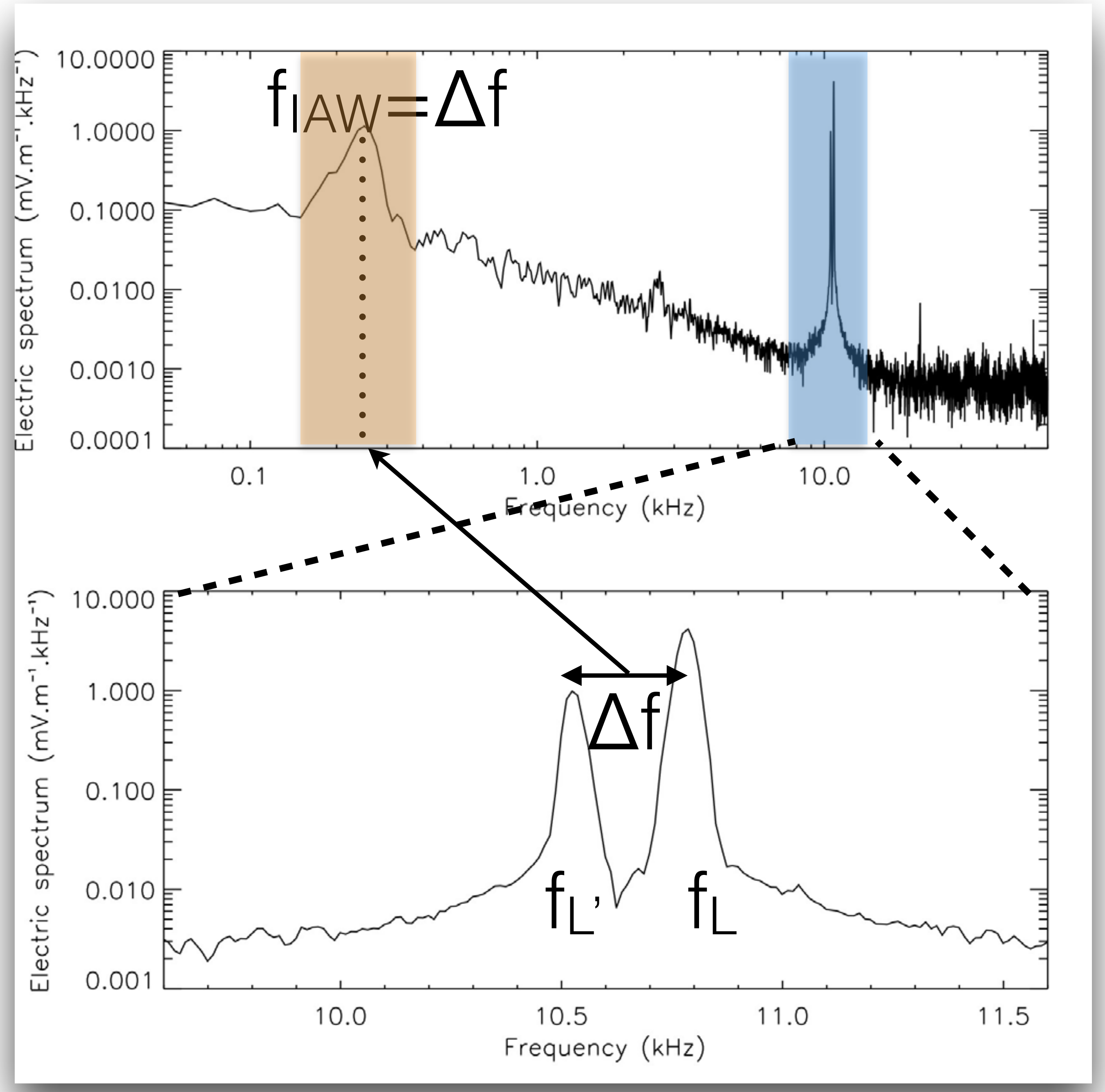

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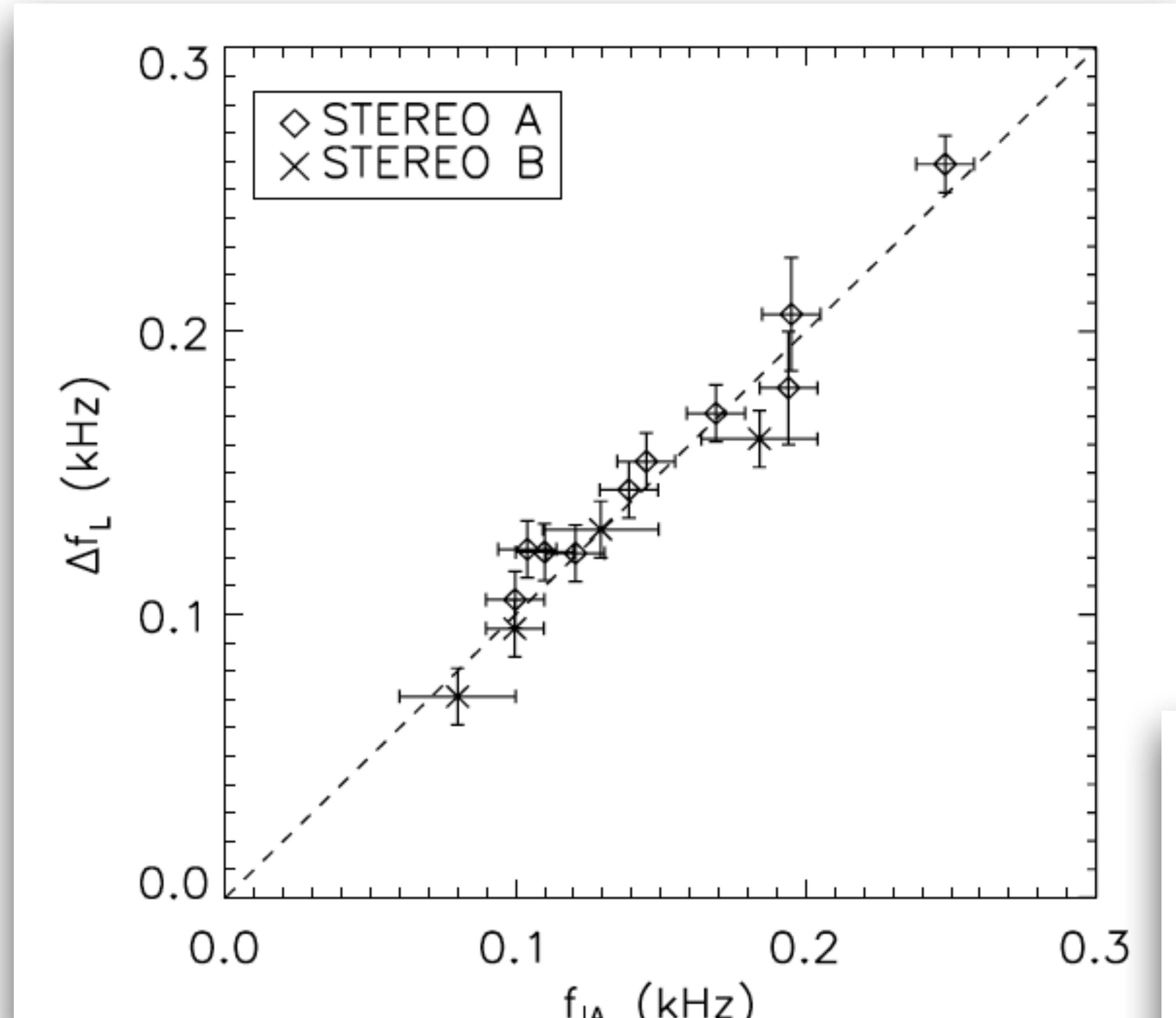
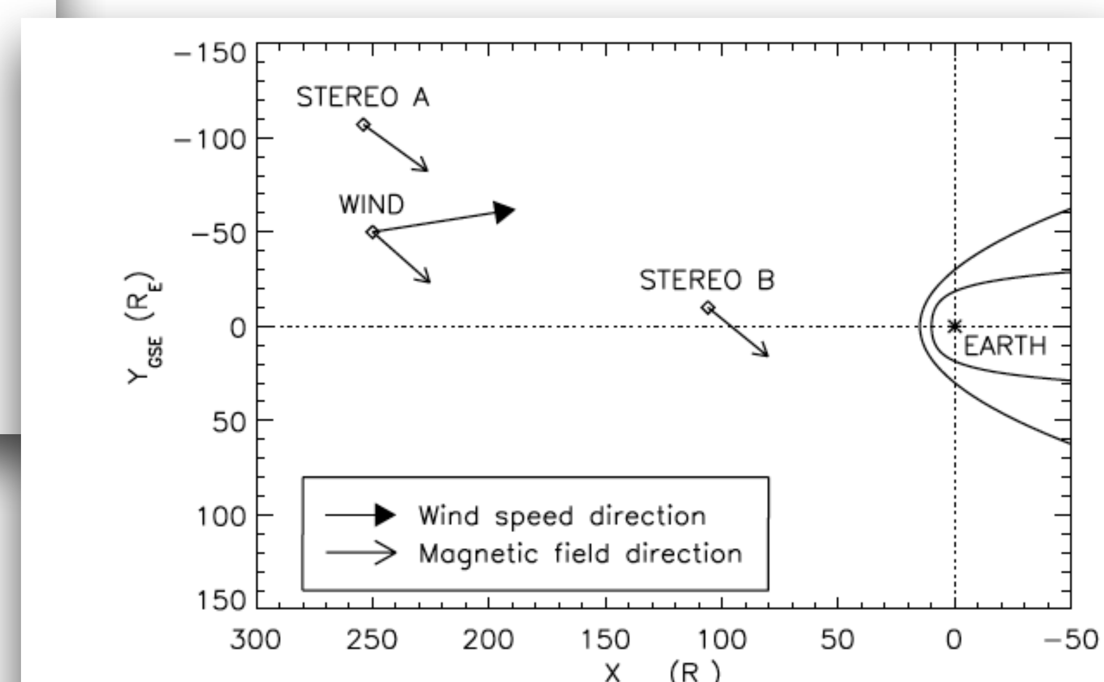


From all the Langmuir events of the Type III burst of January 2007

from STA & STB (still close)



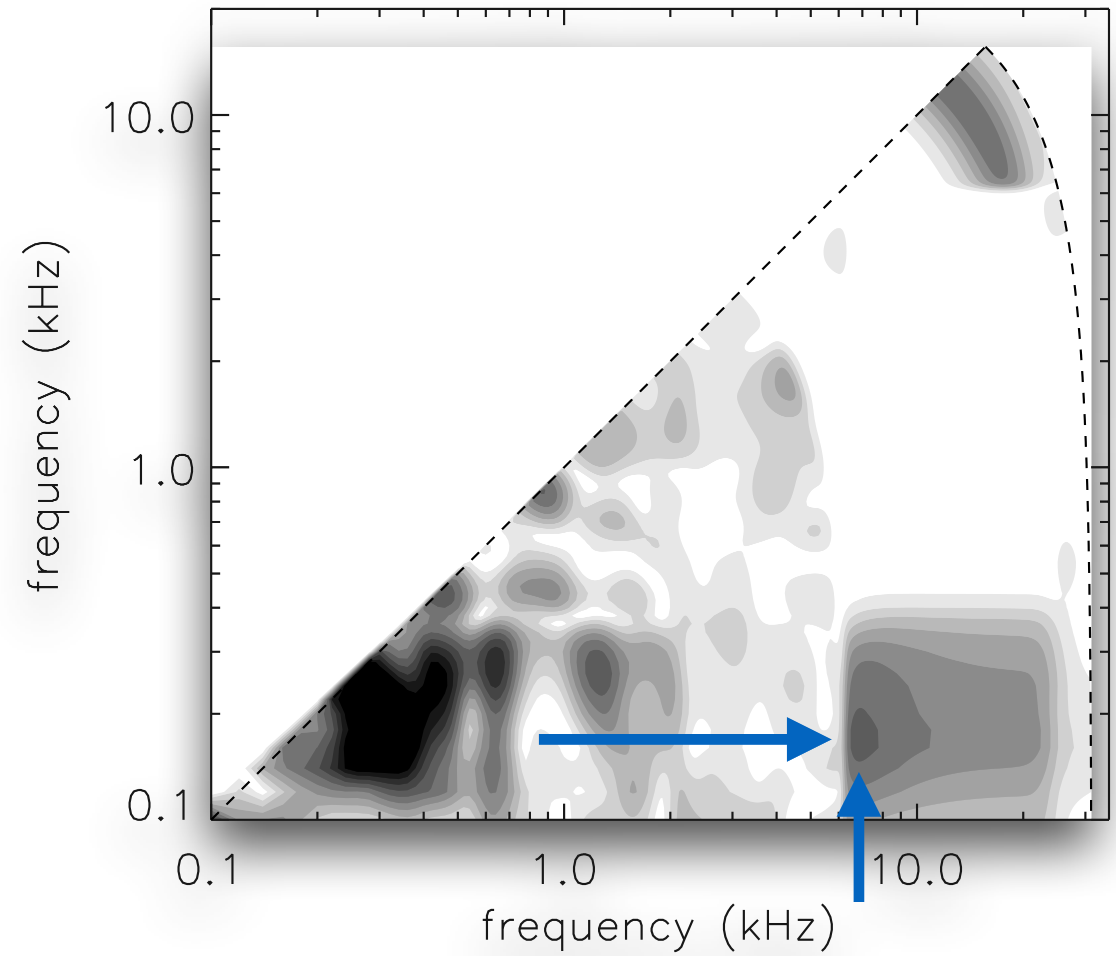
Fastest electrons: 4.10^5km/s ~0.13c

Check of the fundamental laws:
2 - Phase locking

Bicoherence analysis

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

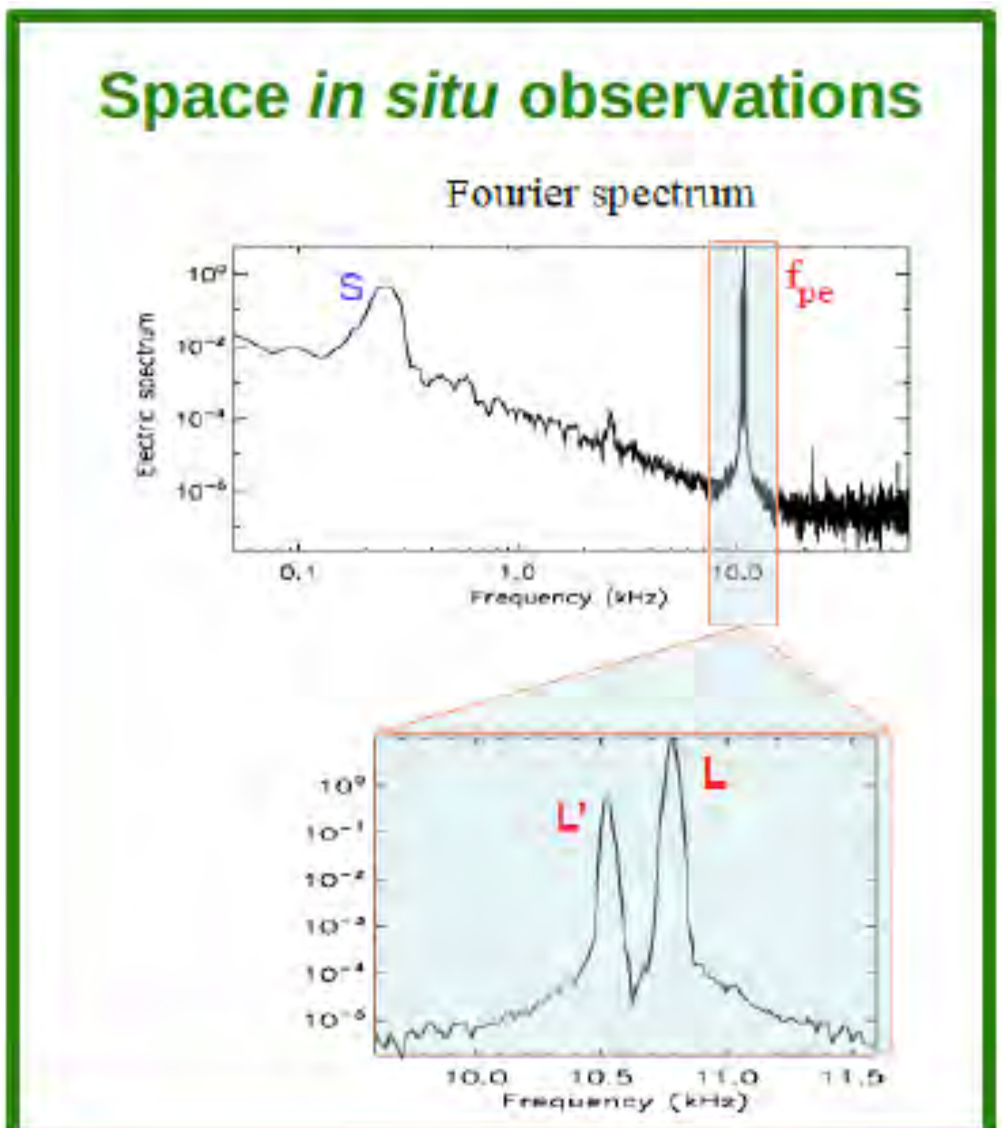
From **14** spectra of a same Type III **simultaneously** analyzed

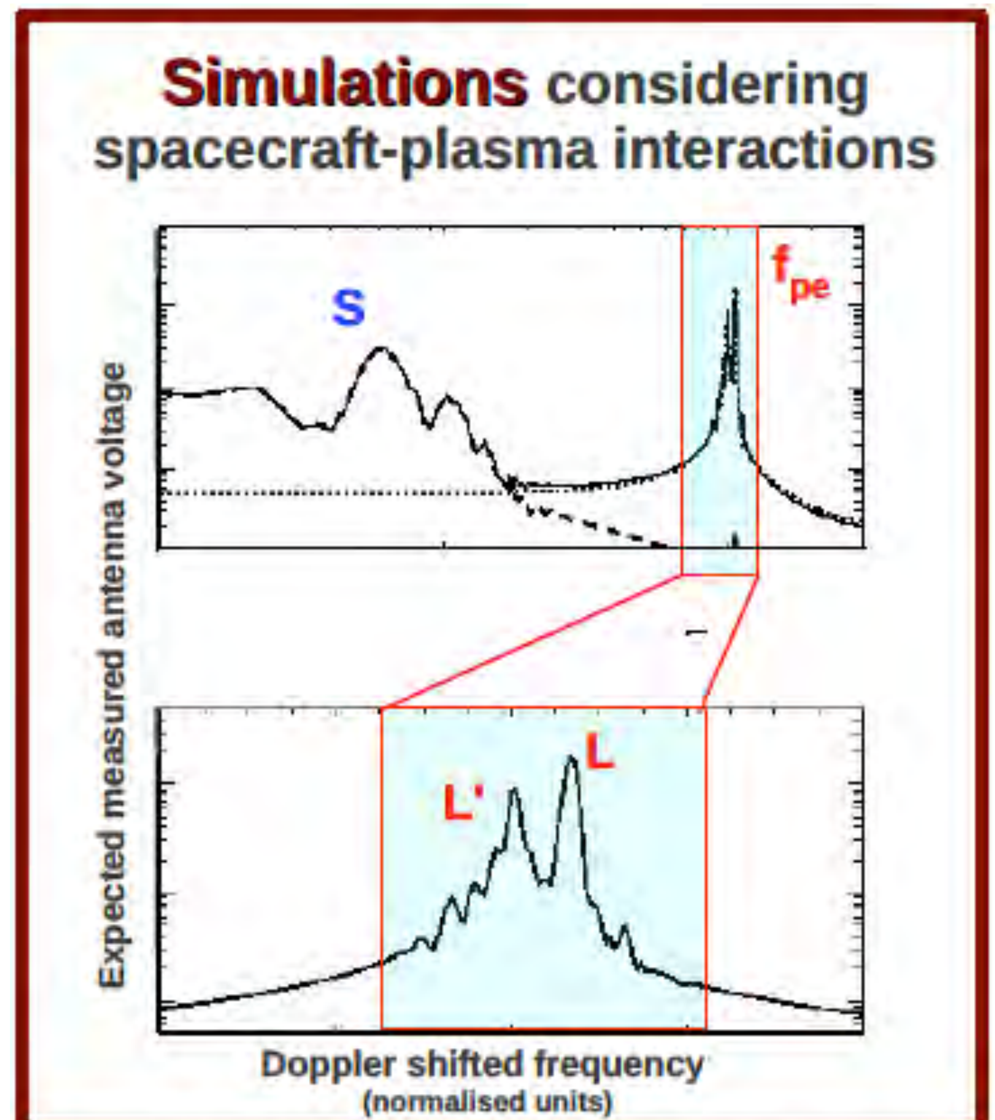


Amplitude threshold reached ?
What the simulation says …

Vlasov-Poisson

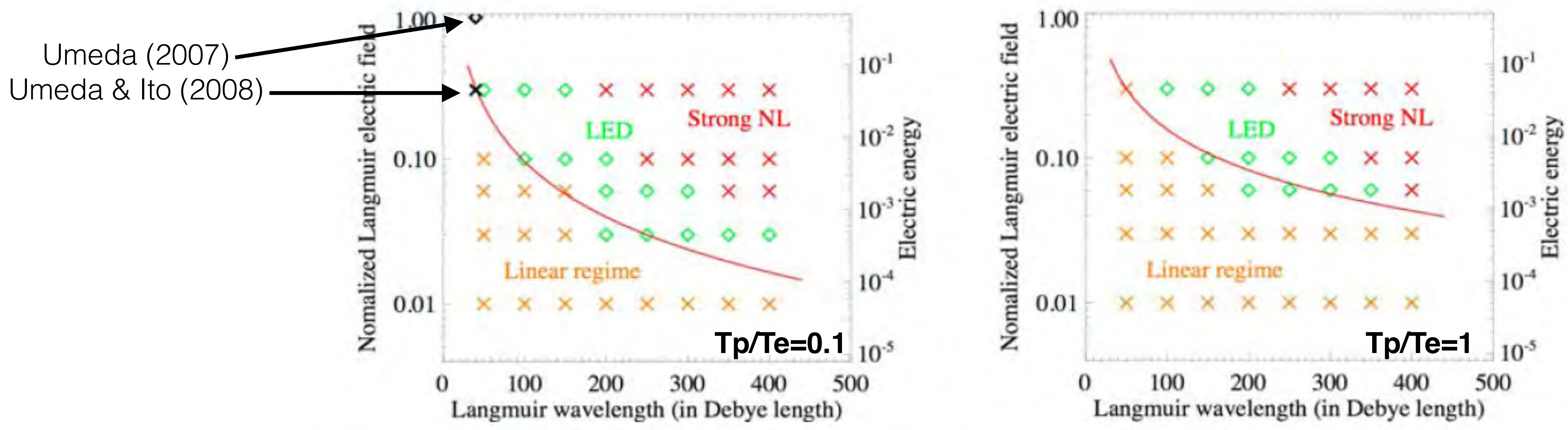
1D-1V electrostatic, Periodic conditions





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

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



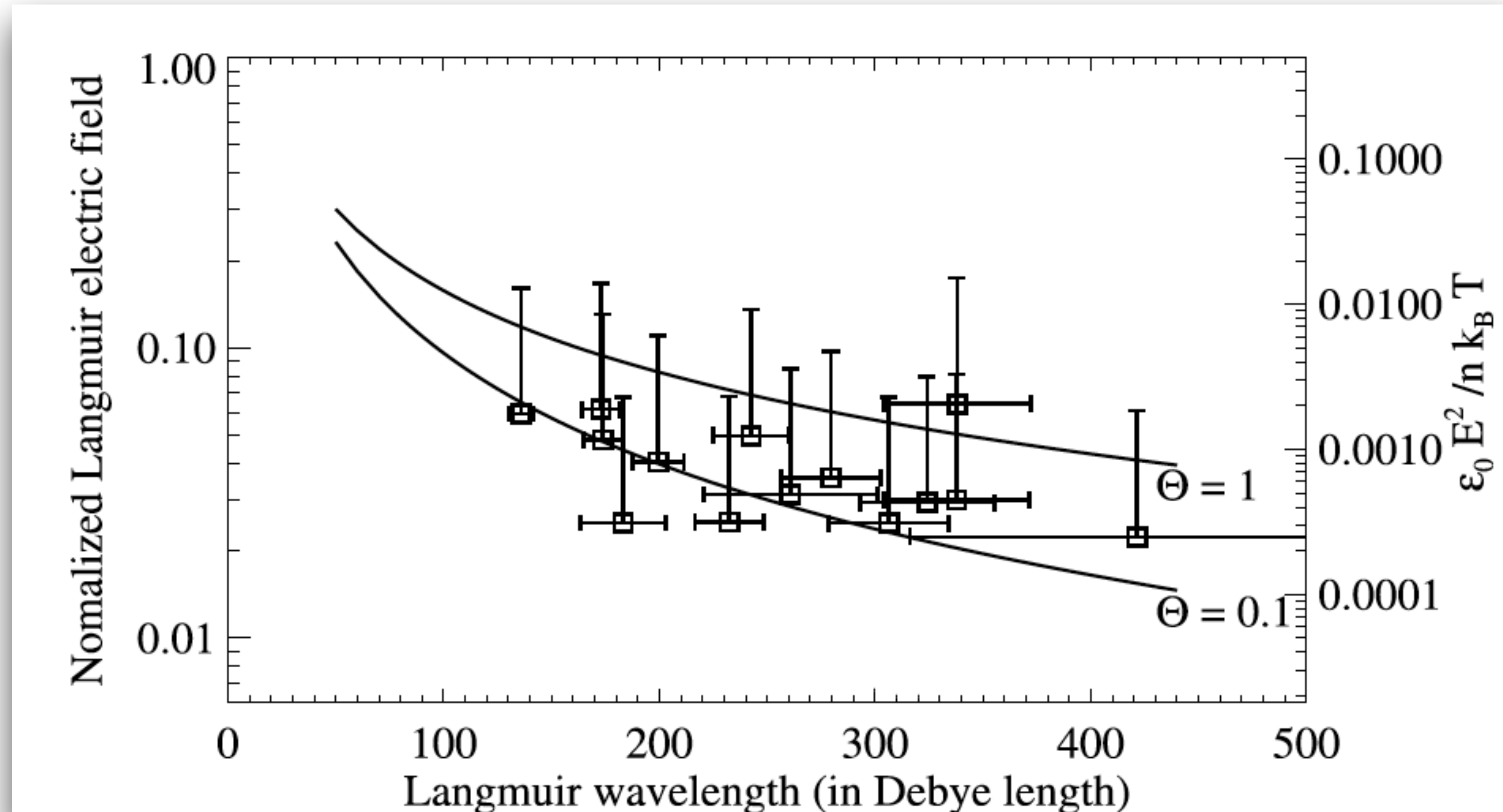
$$E_{LED}^{thres} = \left(\frac{6 k_L^{1-\beta}}{\Gamma \Delta} \right)^{1/\alpha}$$

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

	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

Henri, Califano, Briand, Mangeney, JGR, 2010

Langmuir Electrostatic Decay: Observations fit between the thresholds



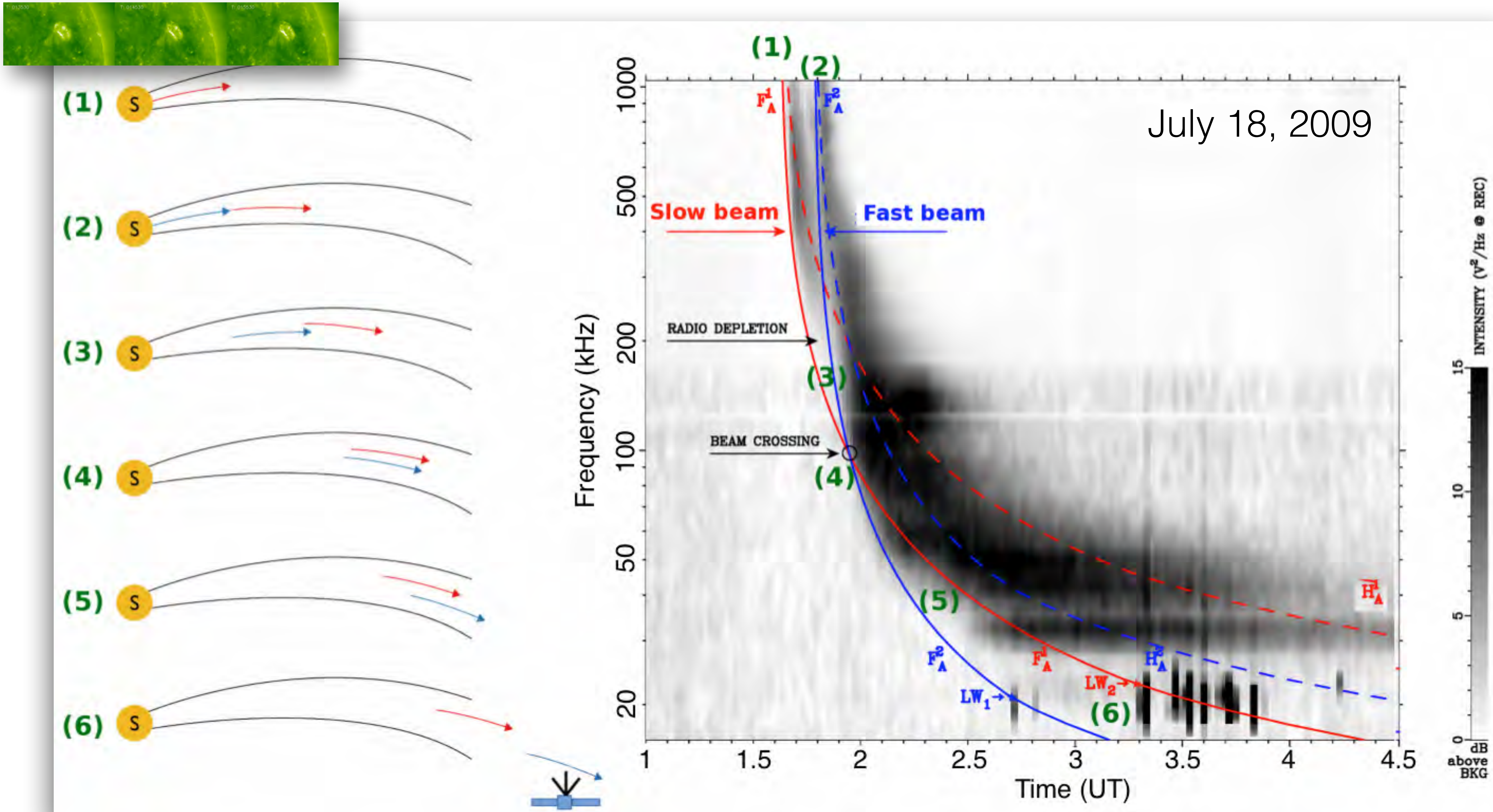
Henri, Califano, Briand, Mangeney, JGR, 2010

A second case

Parametric (threshold) process

Phase coherency importance

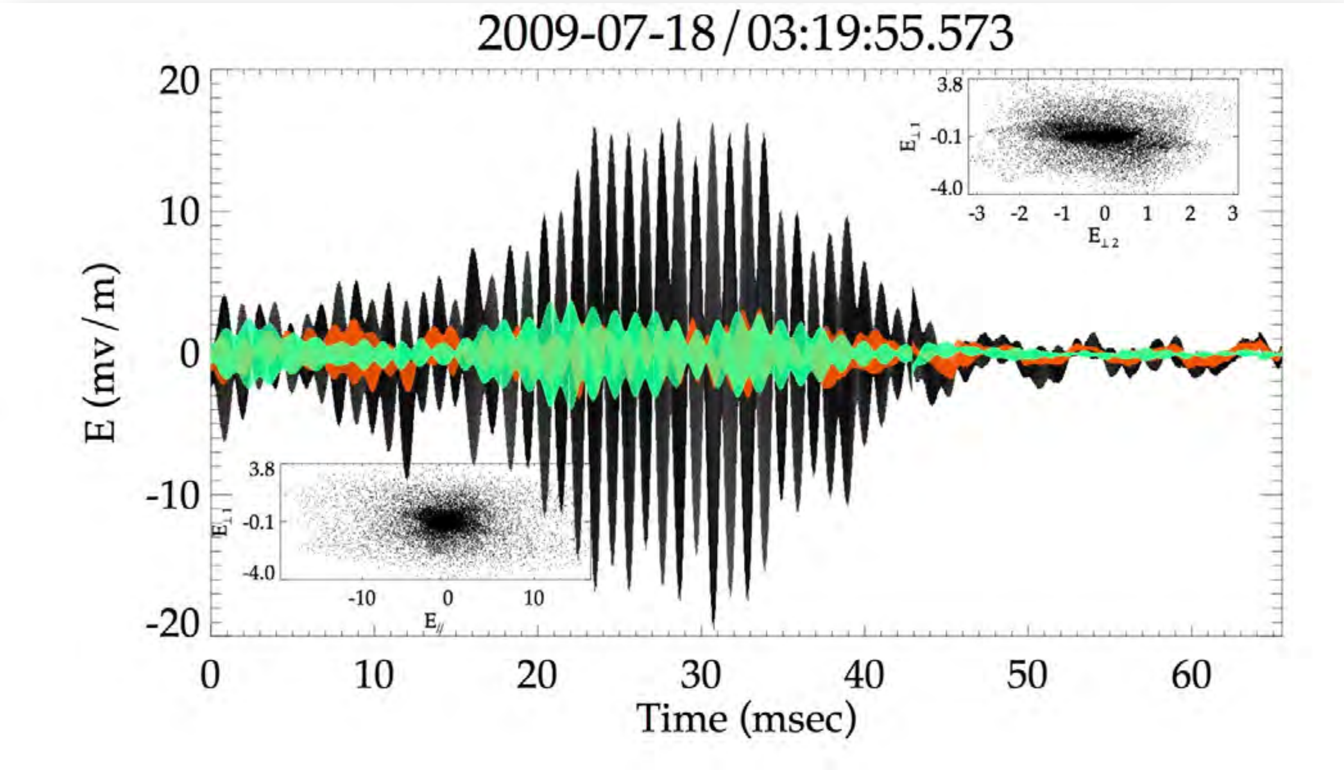
Briand C., Henri P., Hoang S., JGR 2014

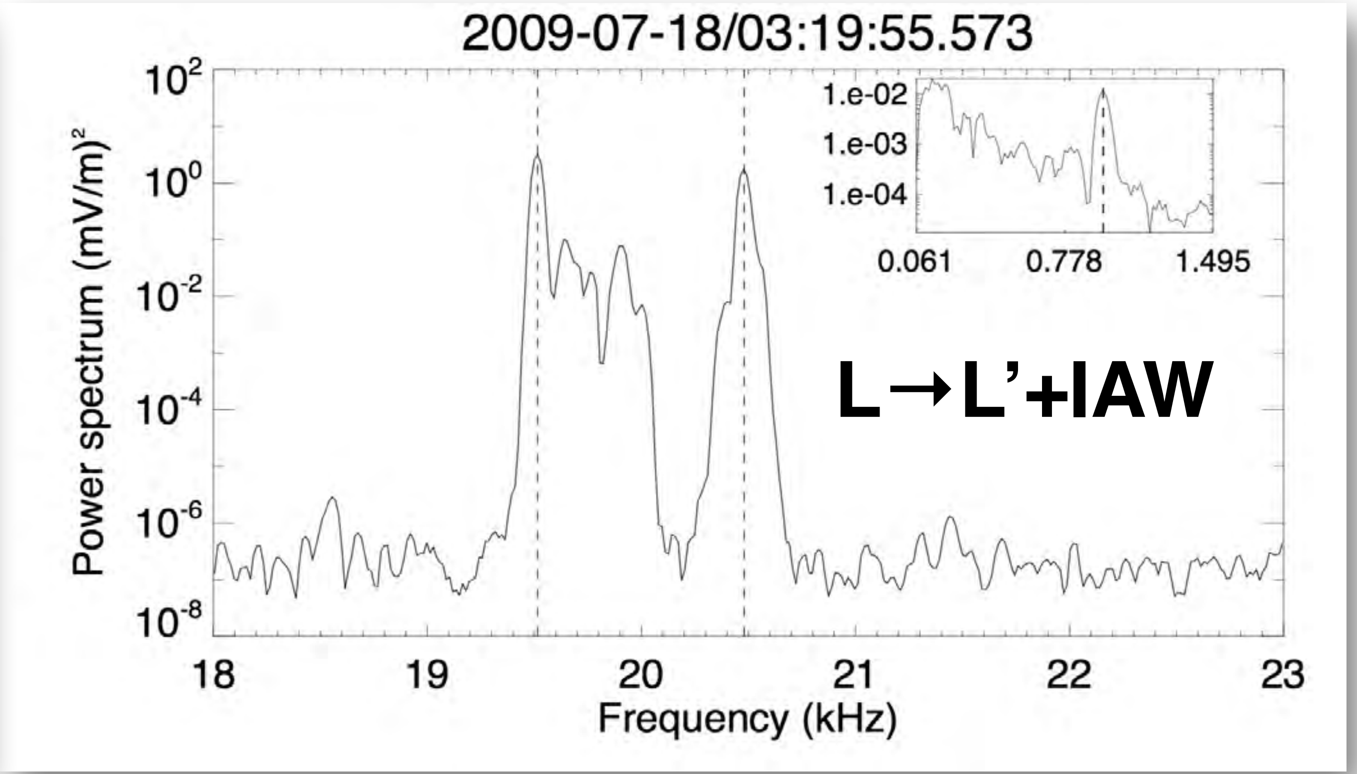


1° Start of a first beam (01:38) - LW detected at 03:17; slow beam (0.09c)

2° Start of a second beam (01:47) - LW detected at 02:42; fast beam (0.16c)

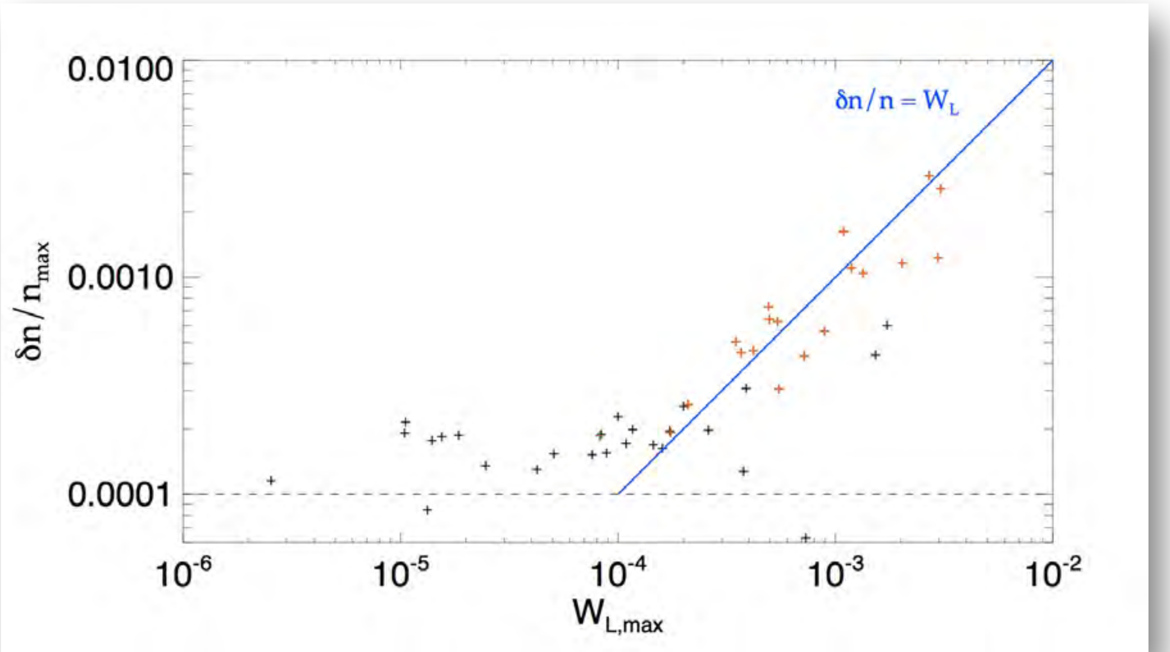
At the time the two beams intersect (4), decrease of the Type III intensity





$$V_b \approx \frac{2 f_p V_{SW} \mid cos(\theta) \mid}{f_{IA}}$$

Compatible with the EM observations



$\delta n/n \sim \epsilon_L / \epsilon_{th,e}$

Level of density fluctuation as expected when associated with Langmuir decay

In situ signatures compatible with Langmuir decay

Vlasov Simulations

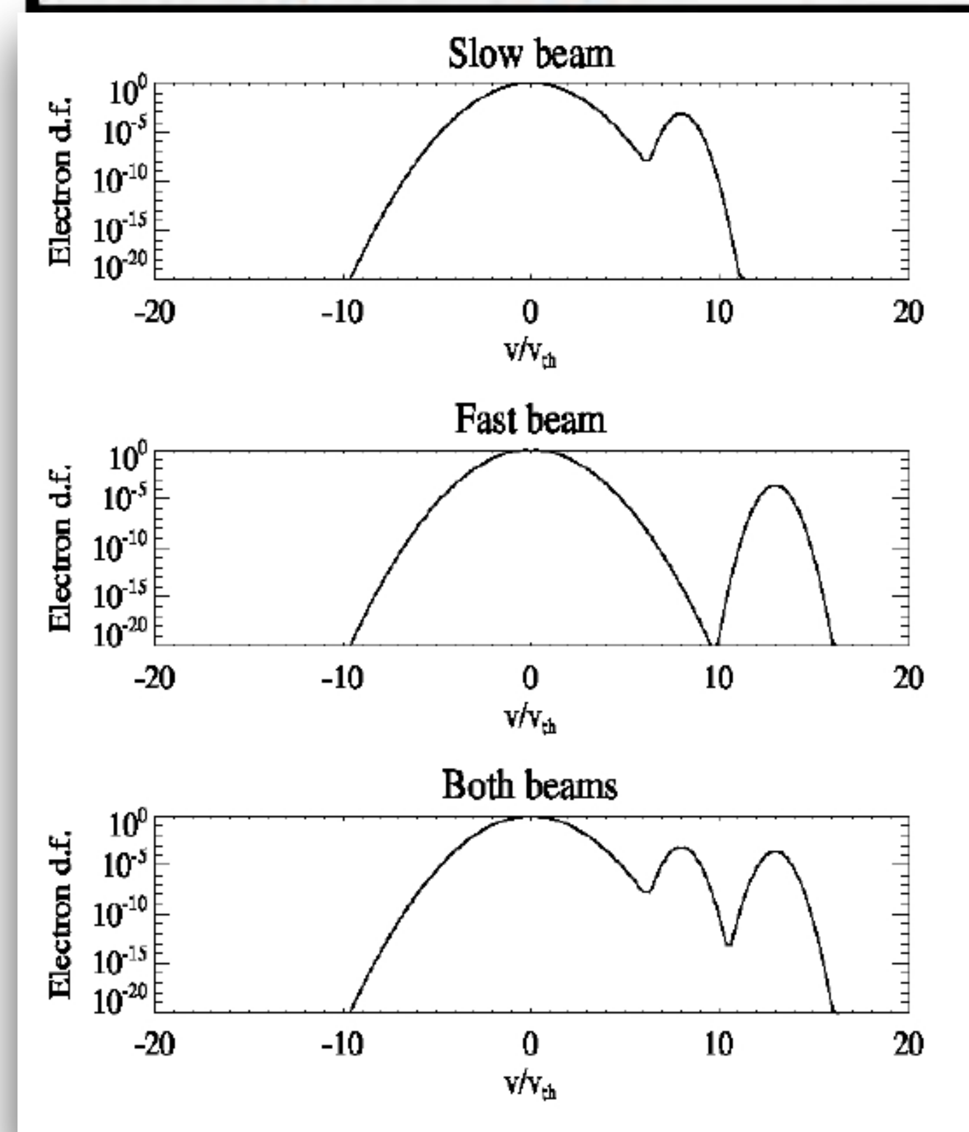
Box size: L~10,000 Debye lengths; Periodic boundary conditions;

Initial conditions: - Maxwellian distribution functions,

+ electron beams :

Beam speed	Beam thermal speed	Beam density
8 V_{th}	0.5 V_{th}	1.5 10^{-2}
13 V_{th}	0.5 V_{th}	0.5 10^{-2}

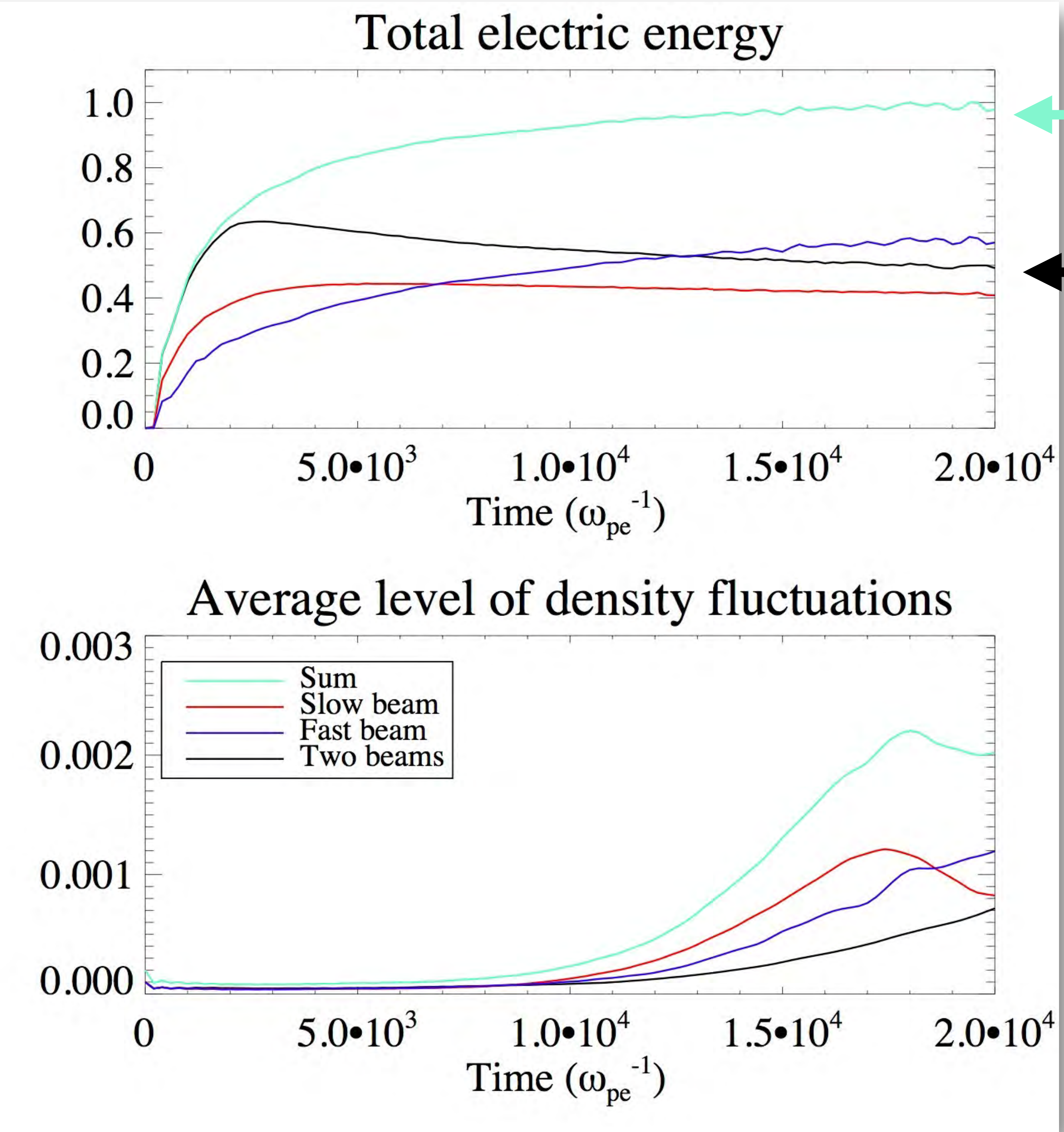
Suppose initially *homogeneous* plasma



Slow beam only

Fast beam only

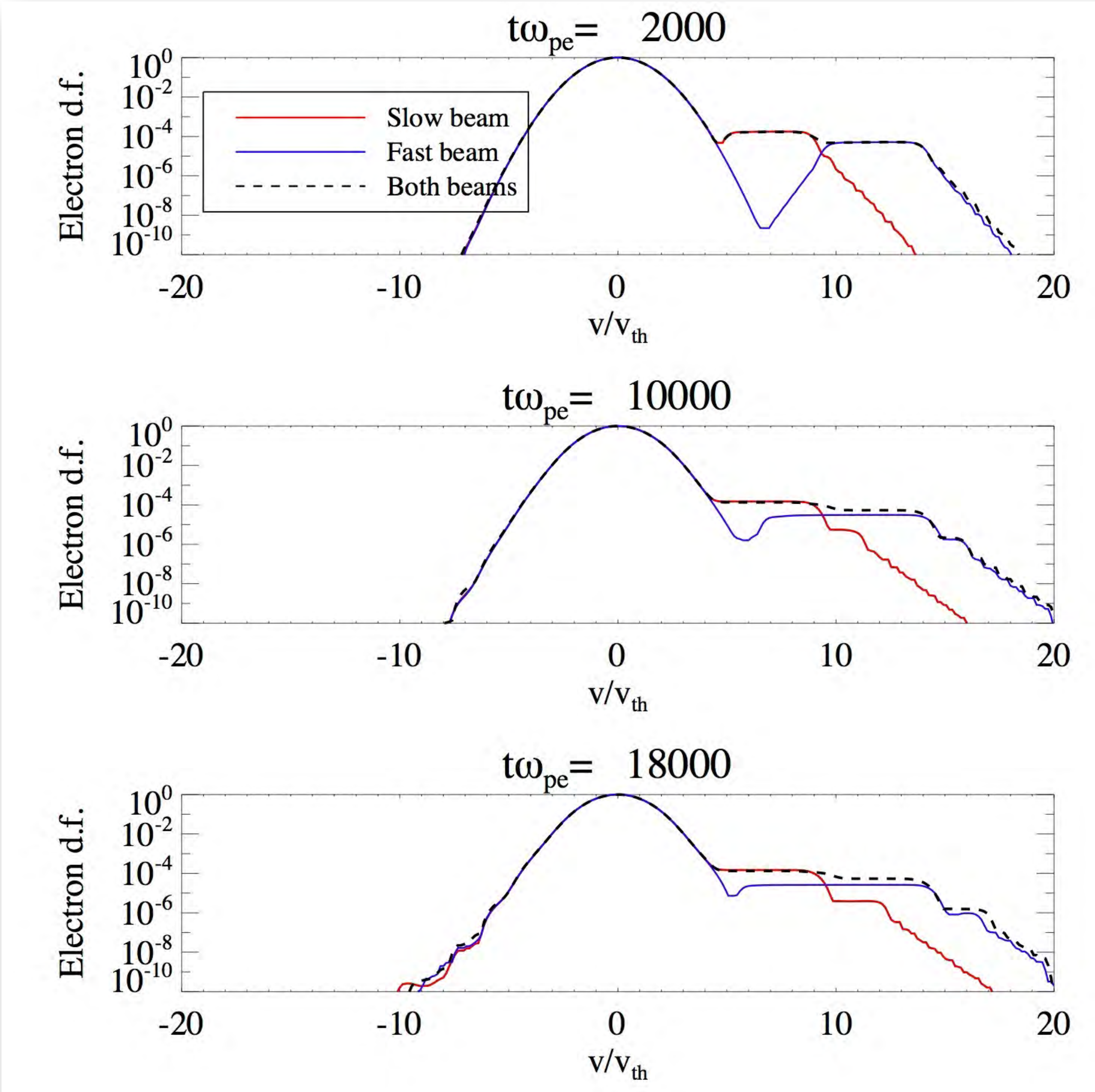
Two beams



Sum of two isolated beams

Interaction of two beams

decay-produced density fluctuations:
proxy of the efficiency of the Langmuir decay



Screening of the fast beam by the presence of the slow beam

↓

Less electric energy conversion

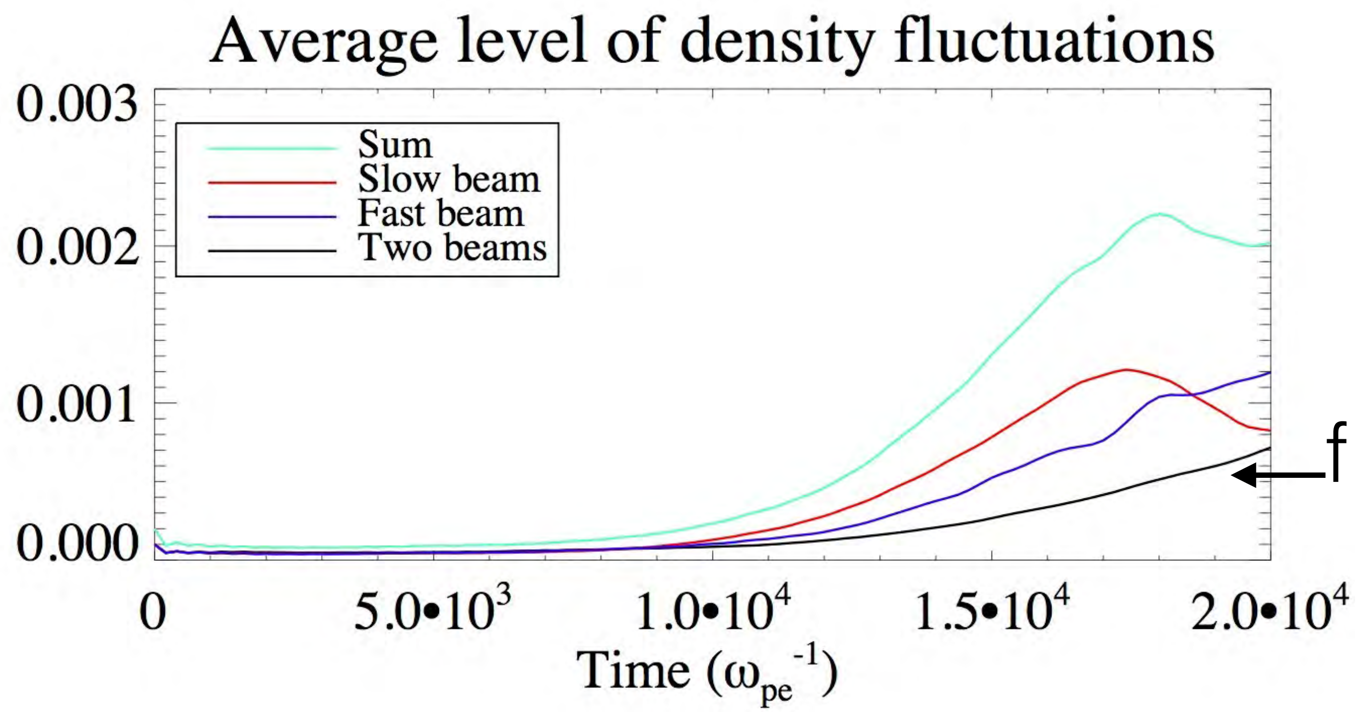
↓

Lower level of LW

↓

Lower level of EM

Beam-driven Langmuir waves generation is less efficient:
whatever the ES to EM conversion mechanism, as long a it depends on the beam-driven Langmuir waves amplitude, production of the EM drops



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.

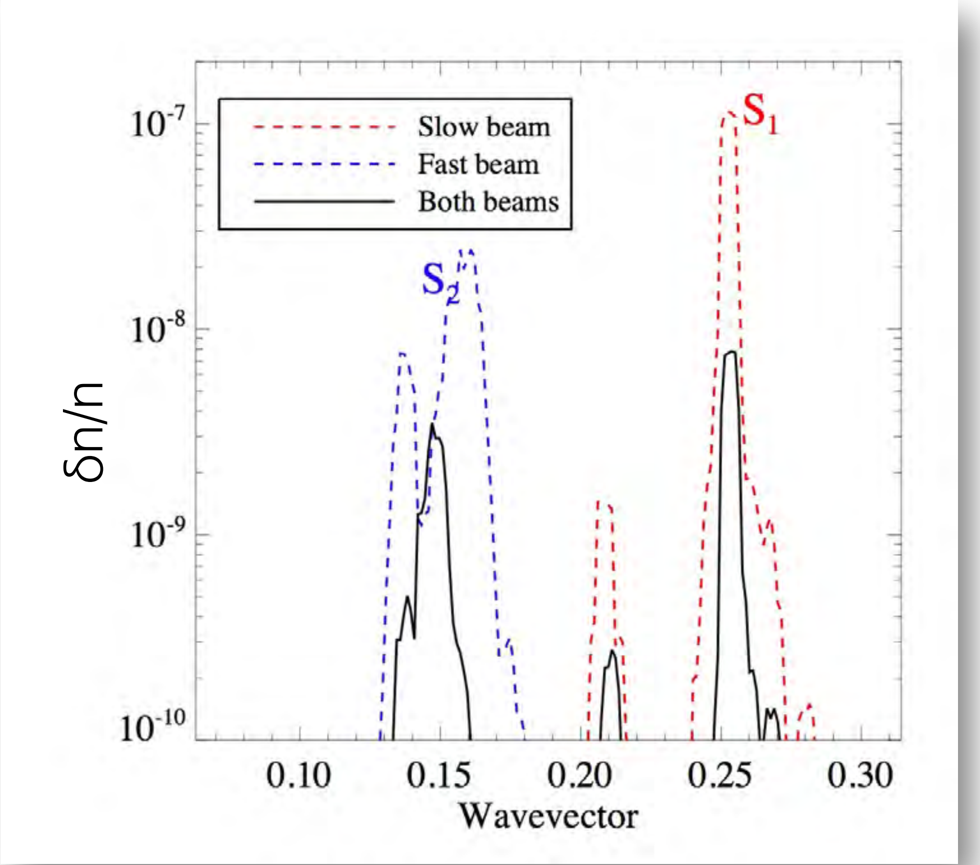
slow-beam-driven LW generation is also disturbed

1° Threshold process

even a small decrease of the mother LW energy can 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 - seen in the δn/n proxy



Conclusions

Strongest solar radio emissions depend on electrostatic waves produced by electron beams

First time the fundamental laws can be checked.

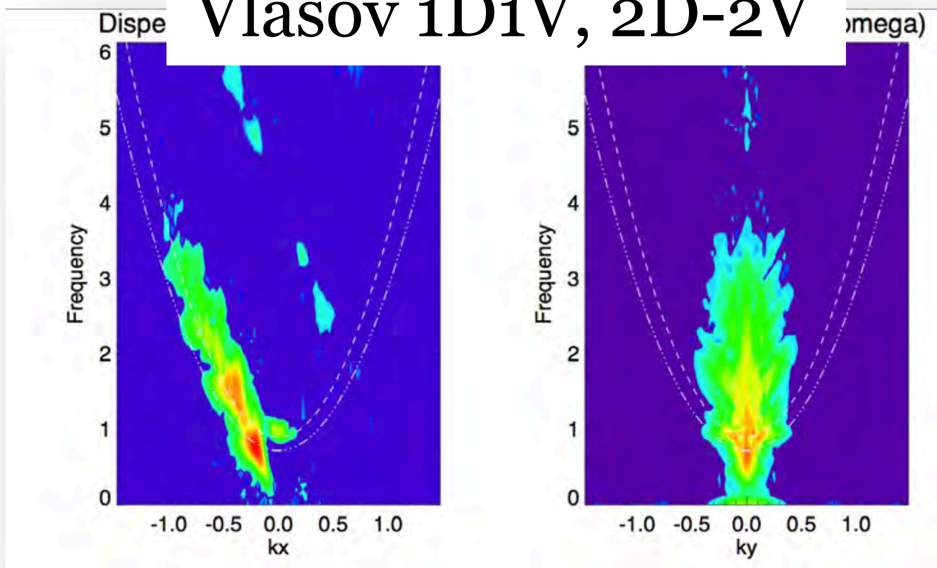
Not only Langmuir wave amplitude is of importance but also the coherence between the waves

Langmuir decay threshold compatible with observations (new theoretical threshold)

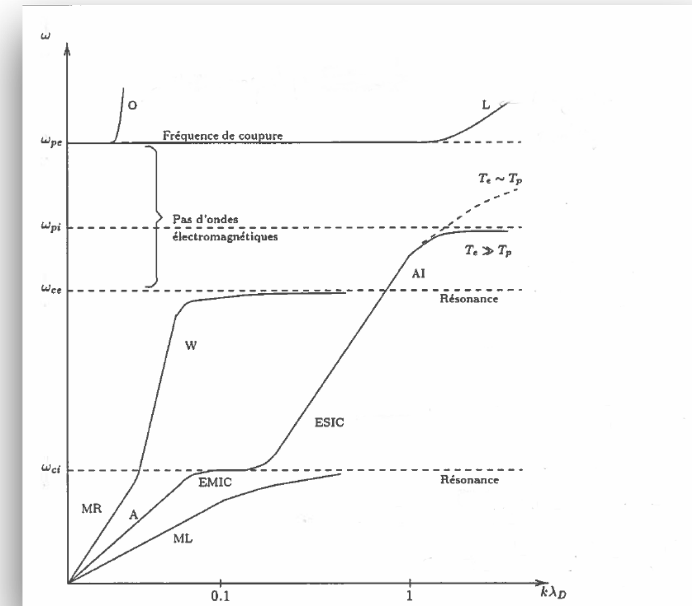
A good way to transfer energy from high to low frequencies

NEXT ...

Vlasov 1D1V, 2D-2V



Parametric decay in 2D, inhomogeneous plasma

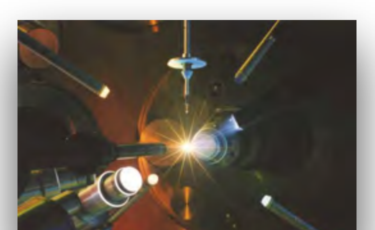


Coupling with lower frequency waves (transfer of energy - turbulent cascade)

Labs experiments (laser facilities)

Laser plasma interaction (Stimulated Raman Scattering)

$$T_{fp} \rightarrow L + LF$$

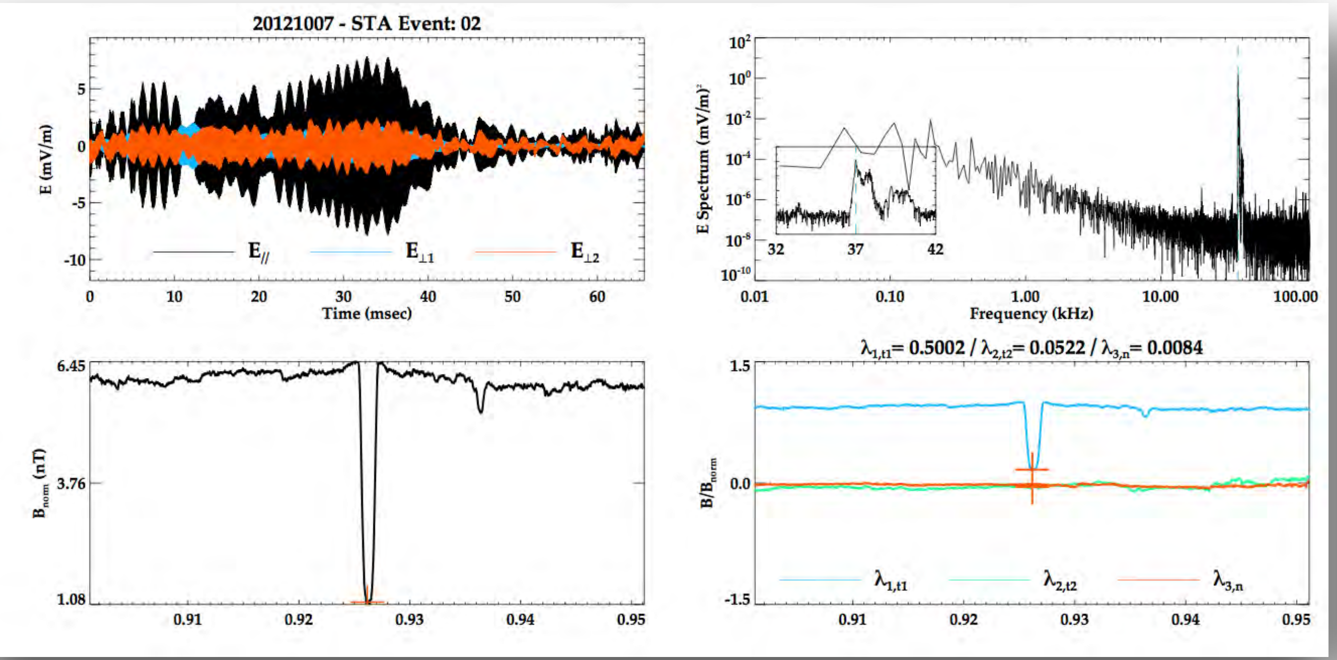


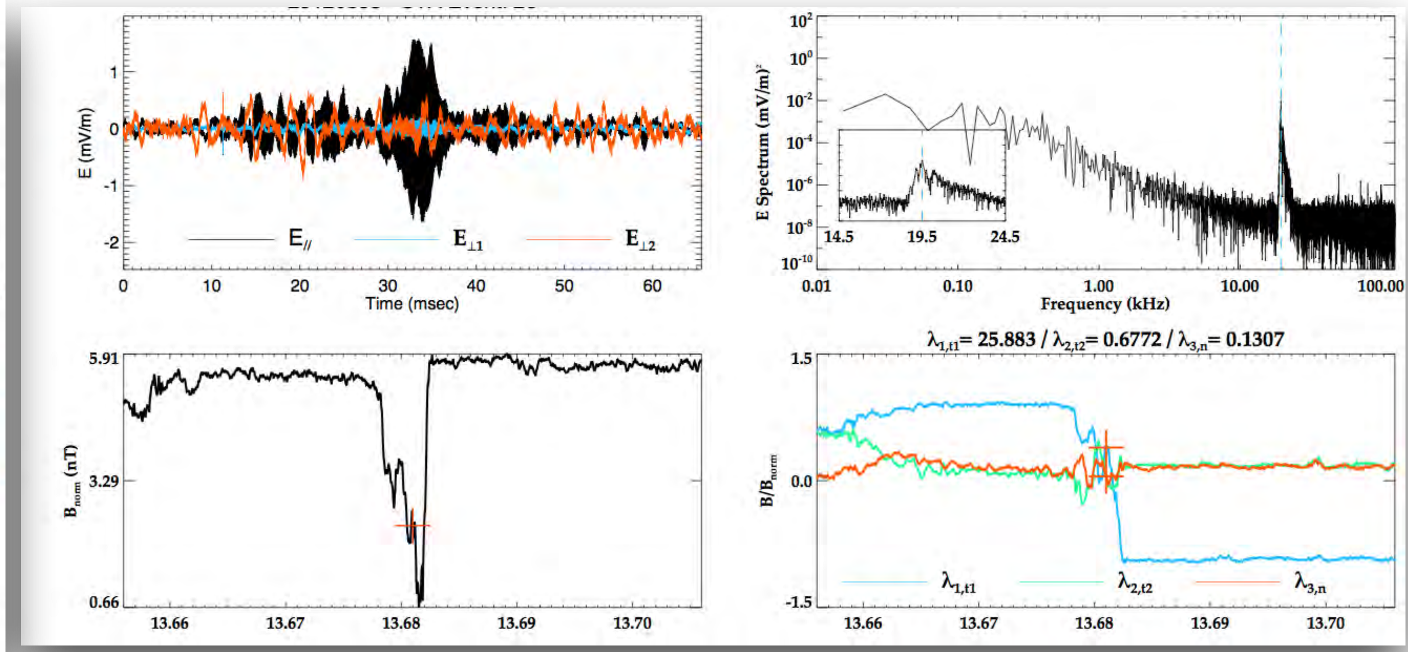
	ρ_e (cm^{-3})/ f_p	Tp/Te	Te (keV)	$k_L\lambda_d$
ICF(1micron)	$10^{12\text{-}19}$ / 900MHz	0.1-1	0.1-1	0.01-0.5
Space (1AU)	1-10 / 10 – 30kHz	0.1 - 1	10^2	< 0.05

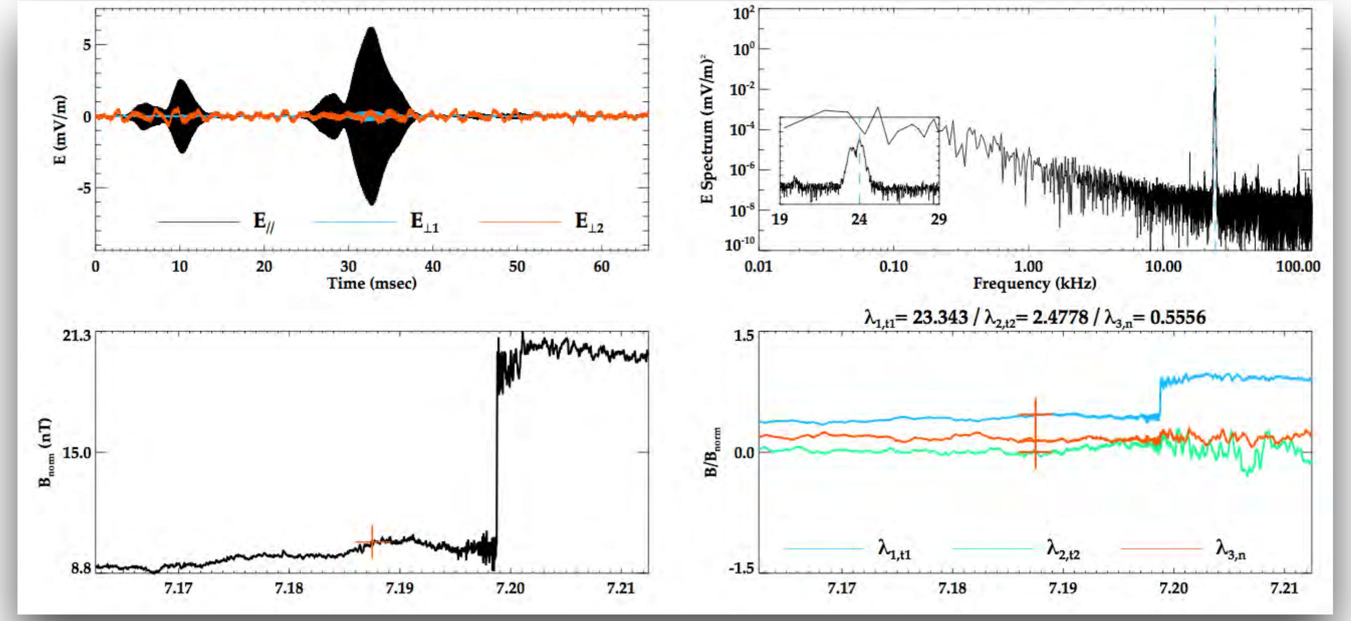
Tp/Te and $k\lambda_D$: comparable

CDPP to access a database with ALL Langmuir observations of STEREO (2007-2014)

CDPP : Centre de Données de Physique des Plasmas / Center of Plasma Physics Data







Open on Oct. 1st

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