Bursty Langmuir Waves: STEREO observations, simulations and interpretation

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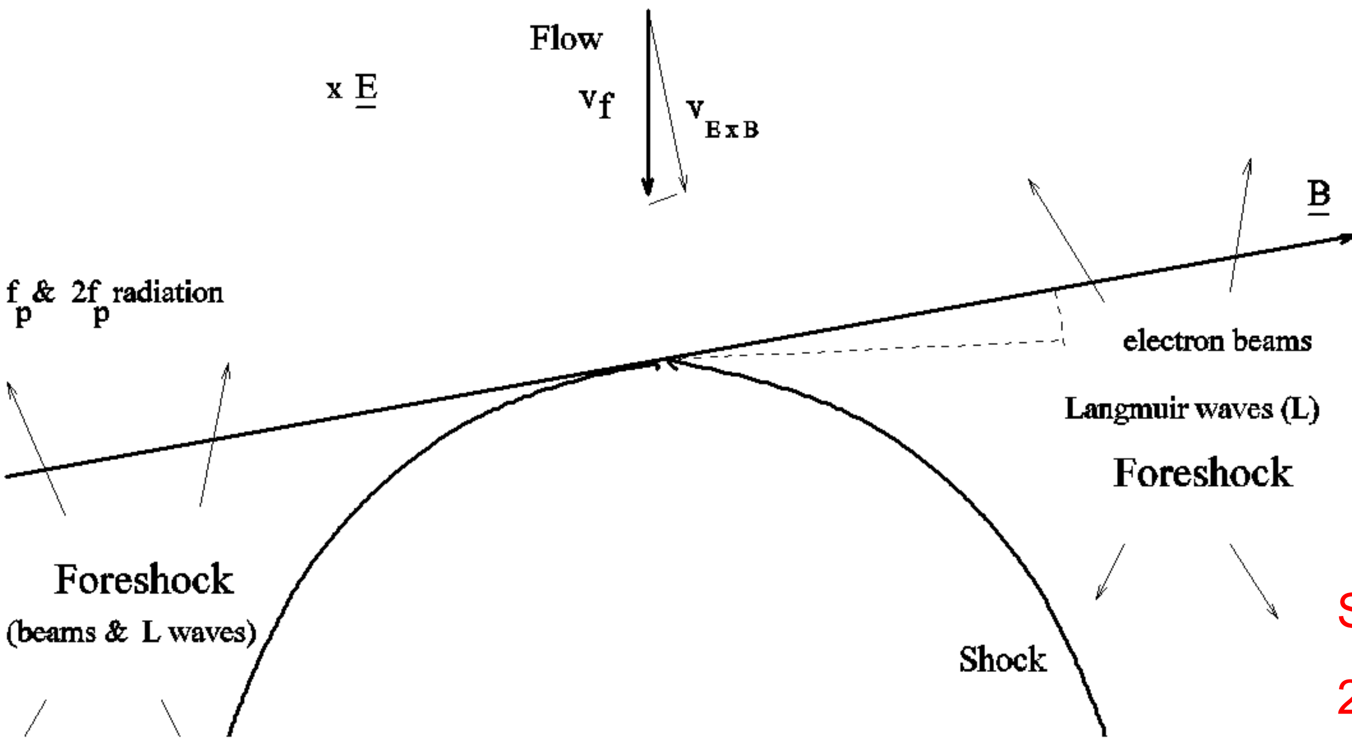


STEREO SWG

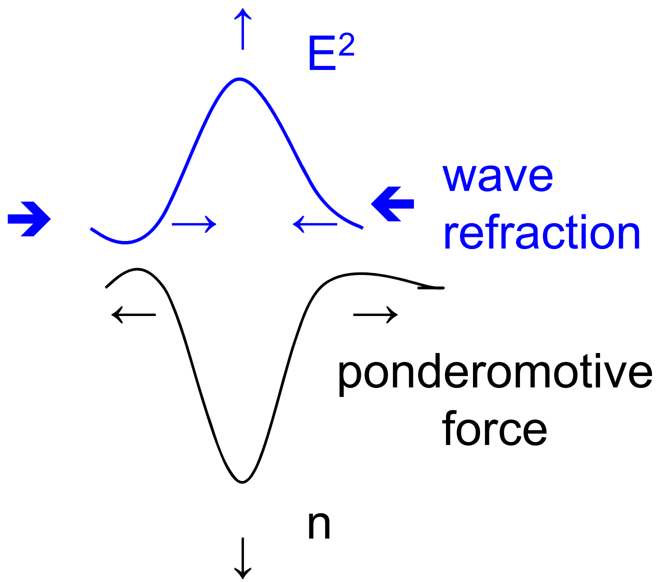
22/4/08

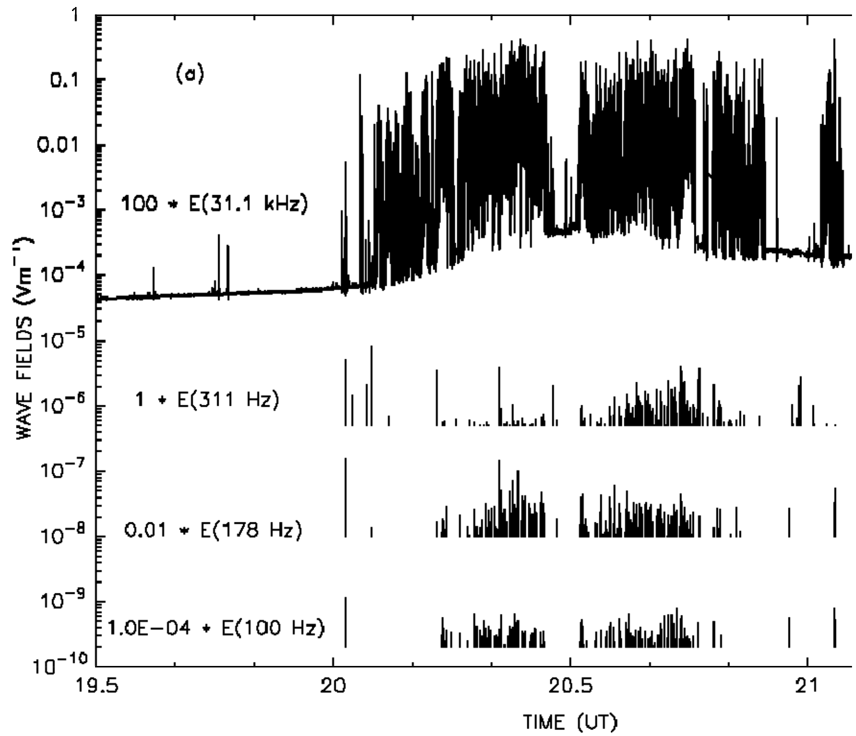
Outline

1. Introduction to bursty Langmuir waves
2. Stochastic Growth Theory (SGT) , Kinetic Localization (KL), Intense Localized Structures (ILSs) …
3. Context of STEREO observations: 5 December 2006.
4. STEREO Langmuir waves: classes, spectra,& field stats
5. Vlasov simulations of KL: first spectra and field statistics
6. Discussion and Conclusions

1. Why are Langmuir waves bursty?

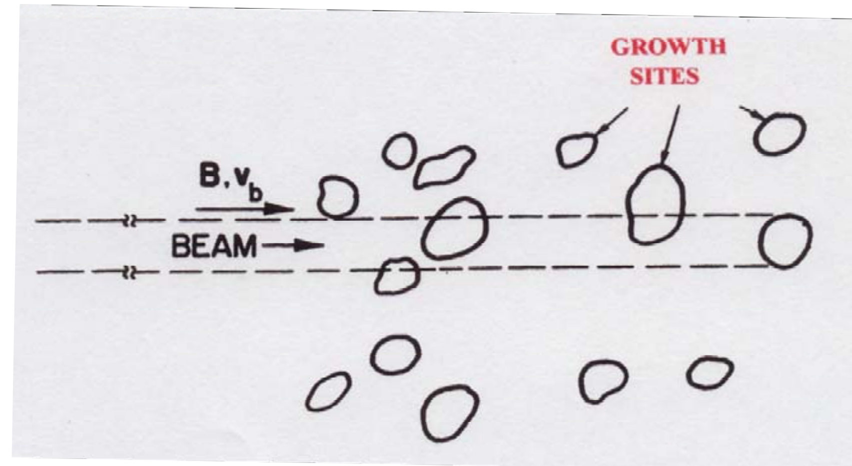
Wave Collapse





- Wave collapse or modulational instabilities? No: [C. & R., 1995]
- Stochastic growth theory (SGT)? [R., 1992; R., C., et al. 1993]
- Kinetic localization? [Muschietti et al., 1995]
- Intense Localized Structures (ILSs) [Thejappa et al., 1998;Nulsen et al., 2007]
- Trapping in eigenstates? [Ergun et al., sub., 2008]

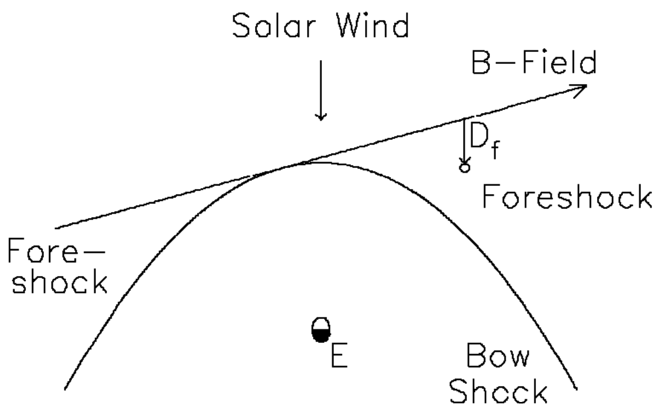
Stochastic Growth Theory (SGT)

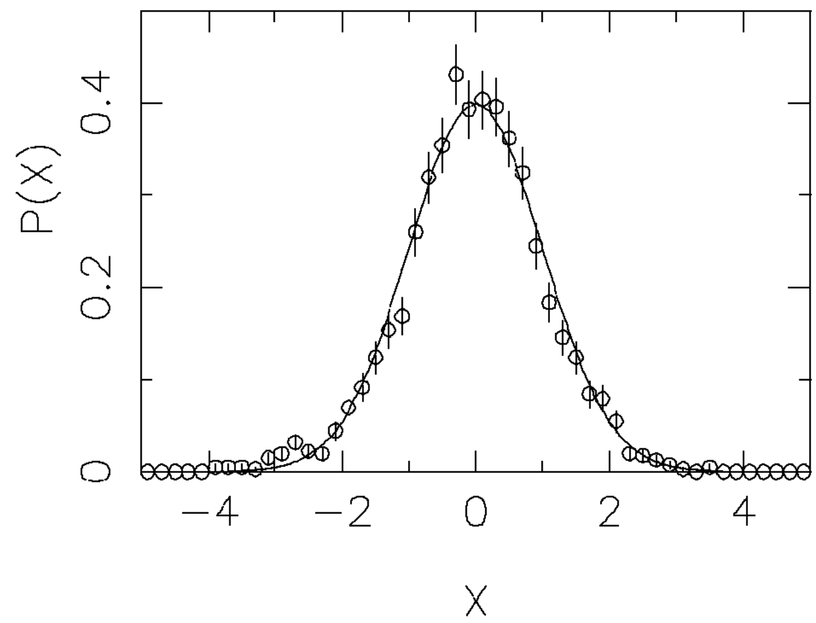


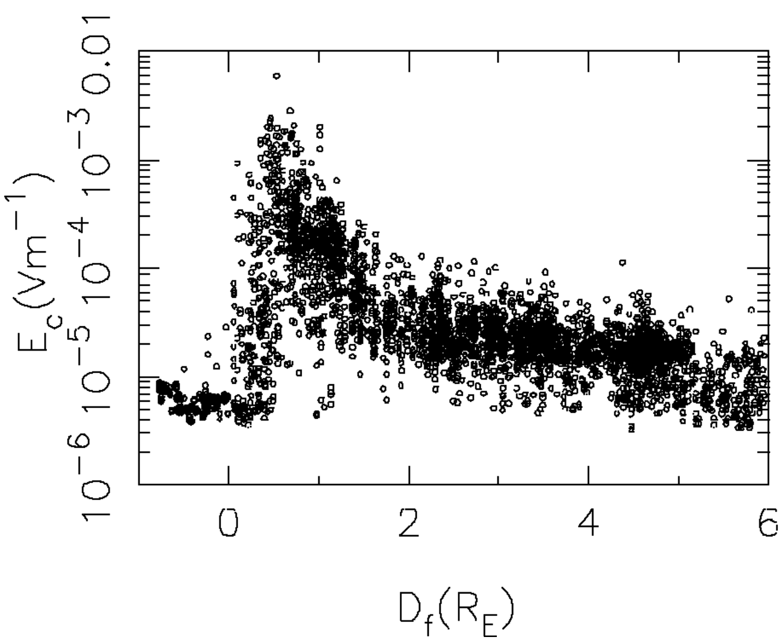
- Waves grow amid ambient fluctuations that perturb wave-particle coupling.
- Growth rate fluctuates ➔ gain G = ∫dt γ random walks.
- If N_{fl} » 1 then Central Limit Theorem implies lognormal statistics:

$$P(G) \propto P(\log E) \propto \exp[-(G-G_0)^2 / 2\sigma^2]$$

SGT in Earth’s Foreshock



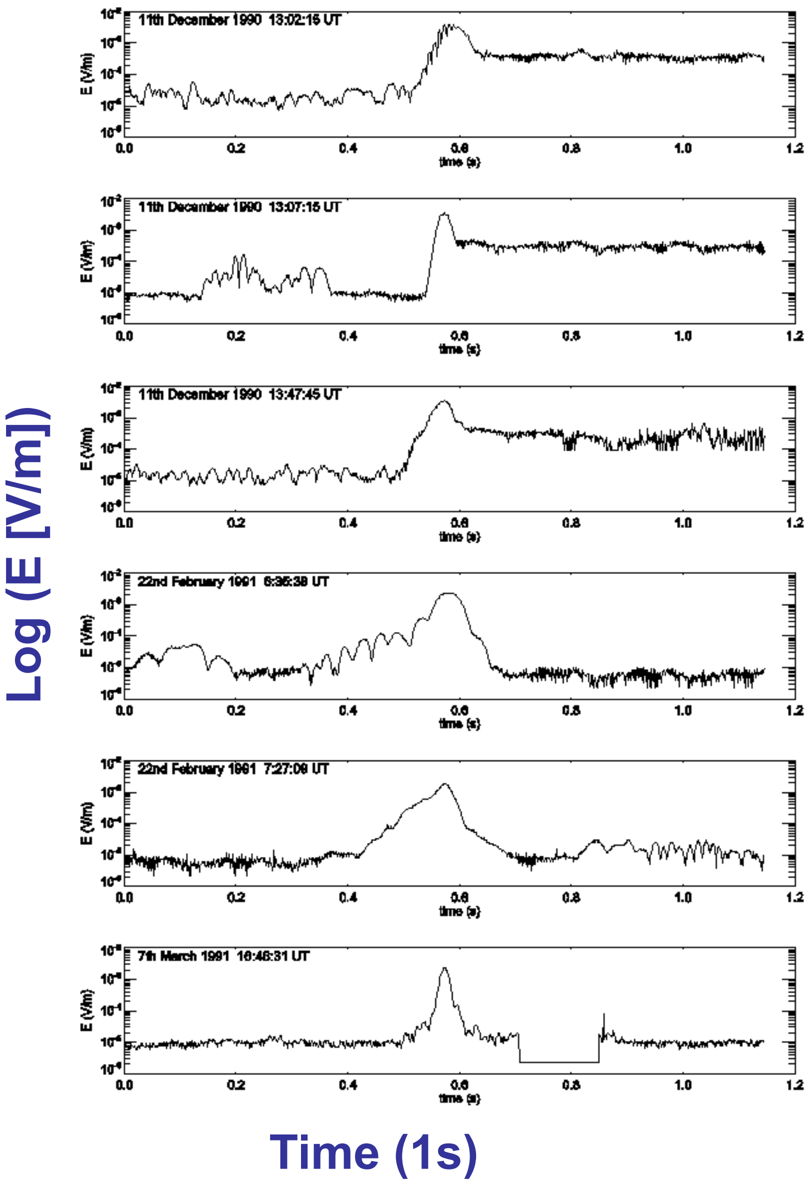




[C. & R, 1997, 1999]

Consistent with SGT prediction of Gaussian in X = A log E.

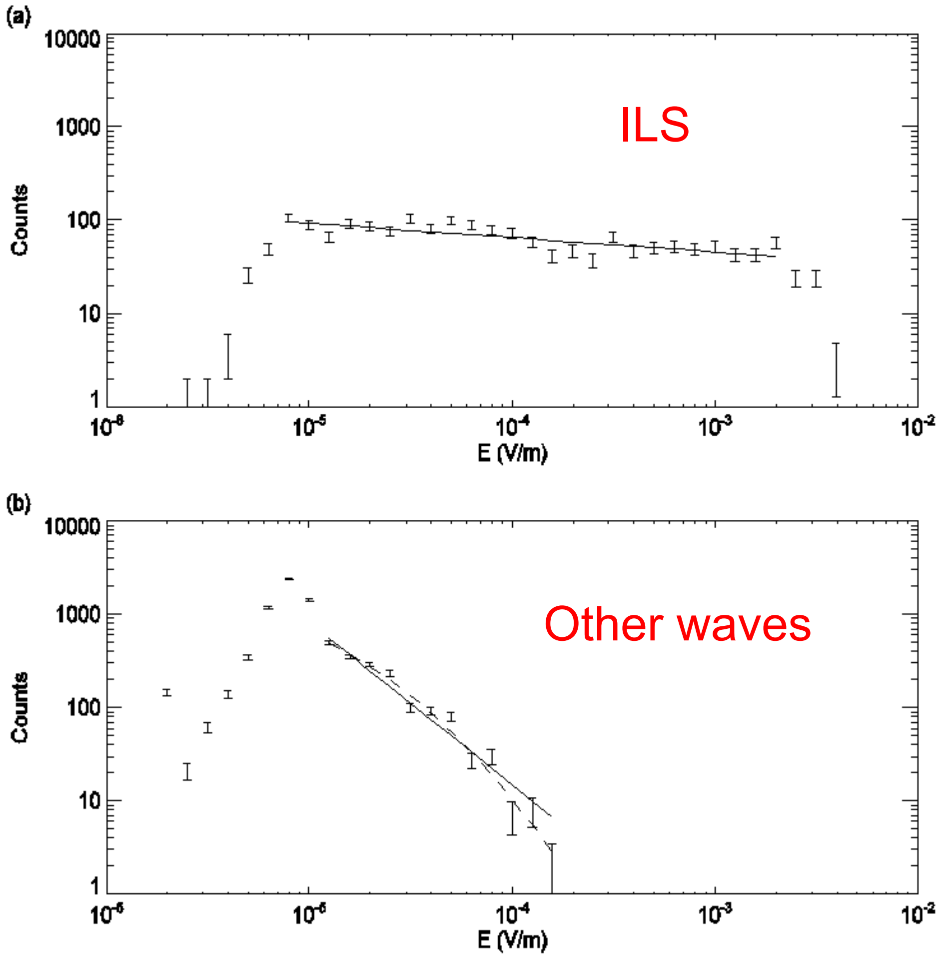
Intense Localized Structures [ILSs] in Type III Sources



- Envelope at 1.12 ms
- Attenuator ➔ high, noisy background after some peaks.
- Peak fields 1-5 mV/m.
- Durations ↔ distances 500-5000 λ_D
- Strong selection bias: only largest event in ~30 mins telemetered.

[Thejappa et al., 1998; R.J. MacDowall, 2005; Nulsen et al., JGR, 2007]

Distinct Field Statistics for ILSs and other Langmuir waves



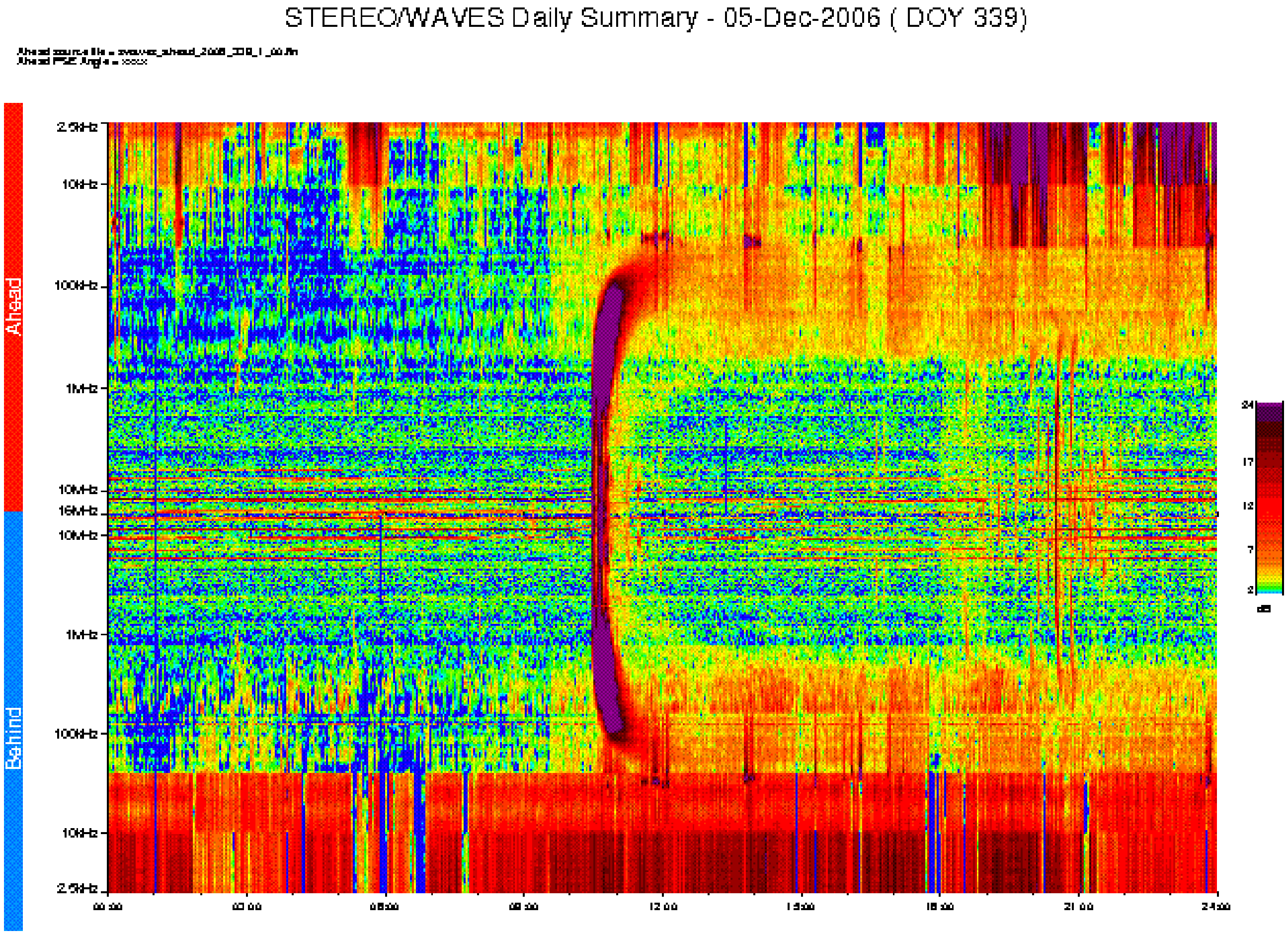
- Distinguish ILS and other wave samples.
- ILS distinct statistics - flat P(log E).
- ➔ ILSs objectively in different class of object.
- SGT? "No" for ILS but "Yes" for other waves.

[Nulsen et al., JGR, 2007]

3. STEREO Context

A

B



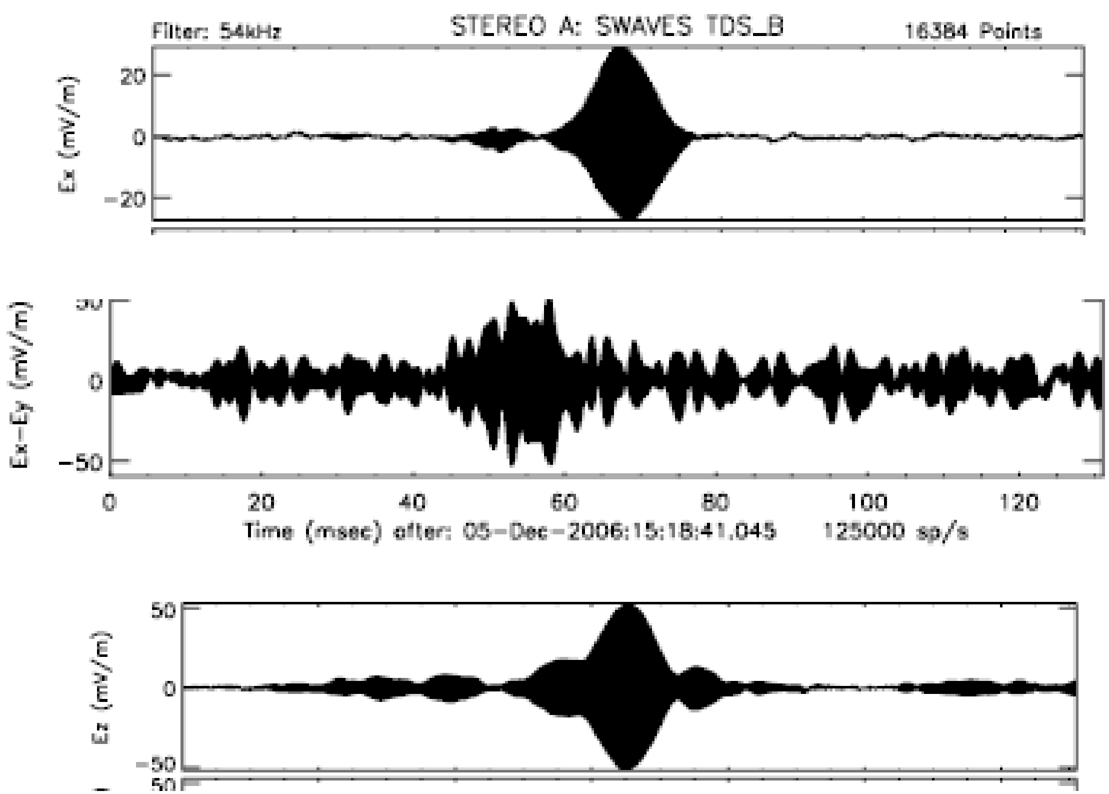
Time (UT)   15:00   18:00

15:00 – 18:00 : foreshock Langmuir waves in bursts – not type III – Both A and B.

4. STEREO TDS Langmuir observations

Bias to high E !

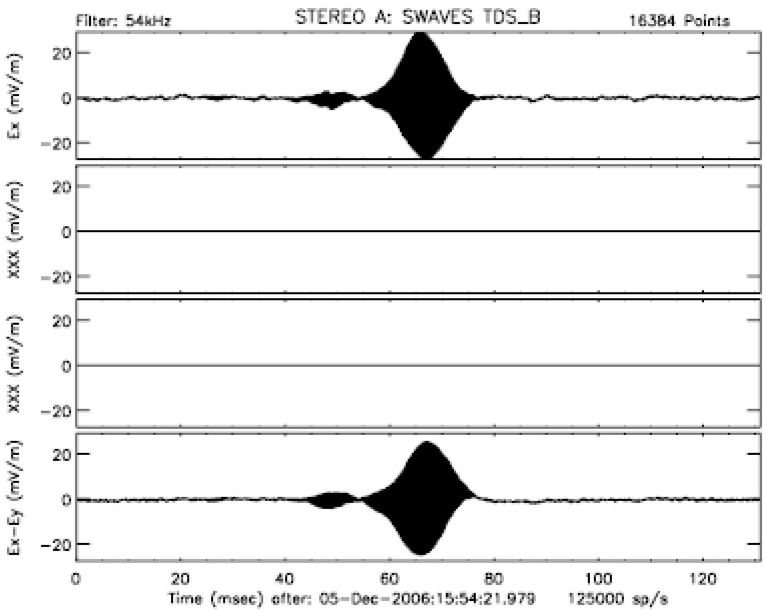
- Extensive periods of Langmuir waves 5 Dec 06
- 3 classes: isolated, chains, and mixed.

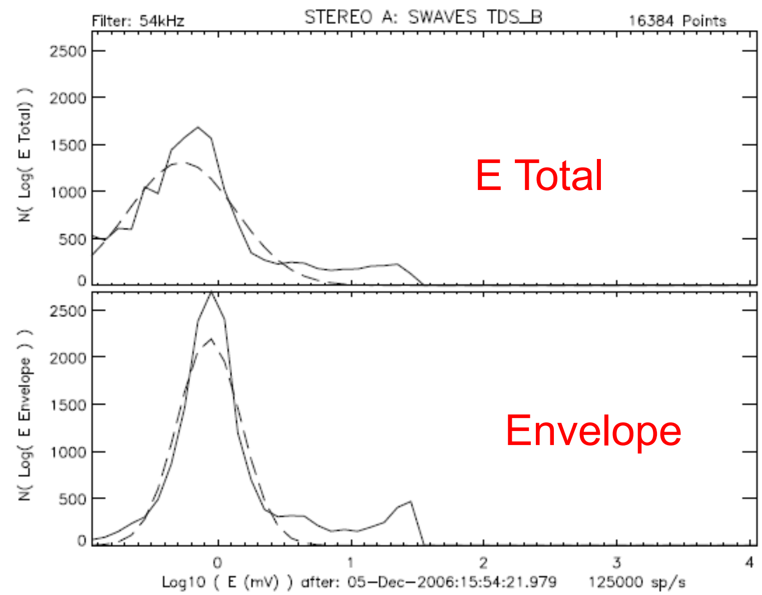


[cf. Ulysses & Wind TDS ?]

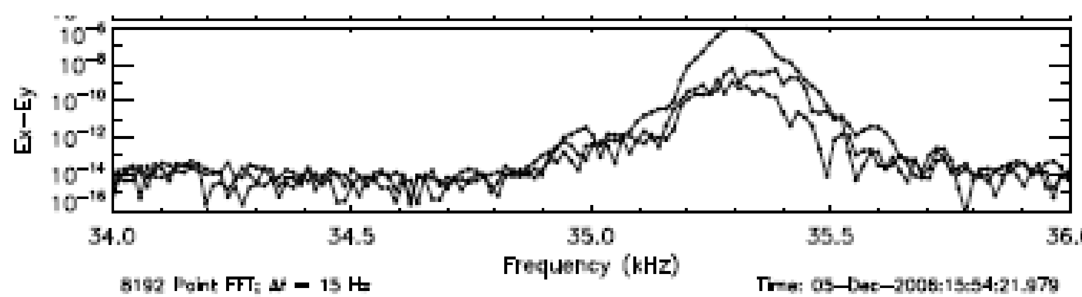
[cf. Gurnett et al. wideband…]

STEREO: Isolated wavepackets (ILS)





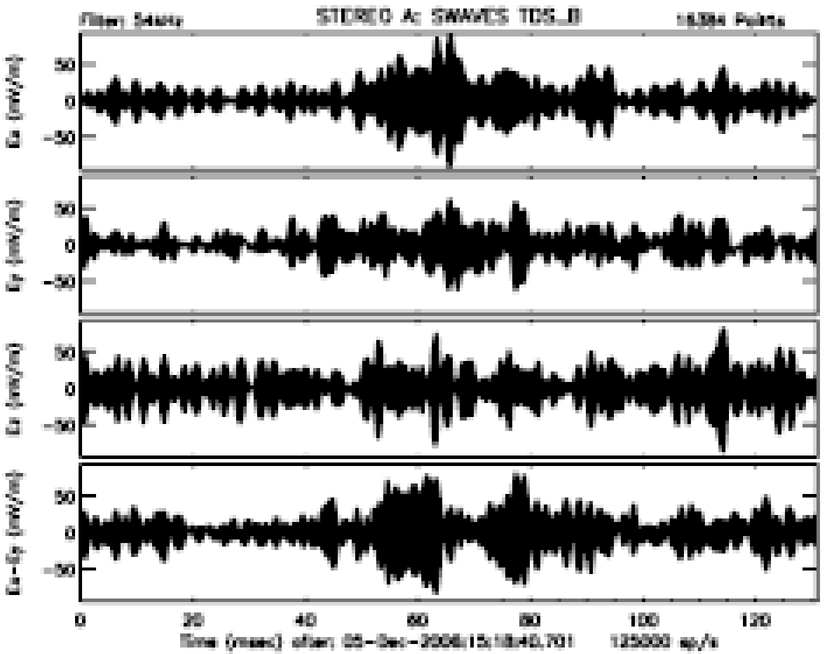
- very flat field statistics
  ➔ not SGT
- ~ Gaussian spectrum

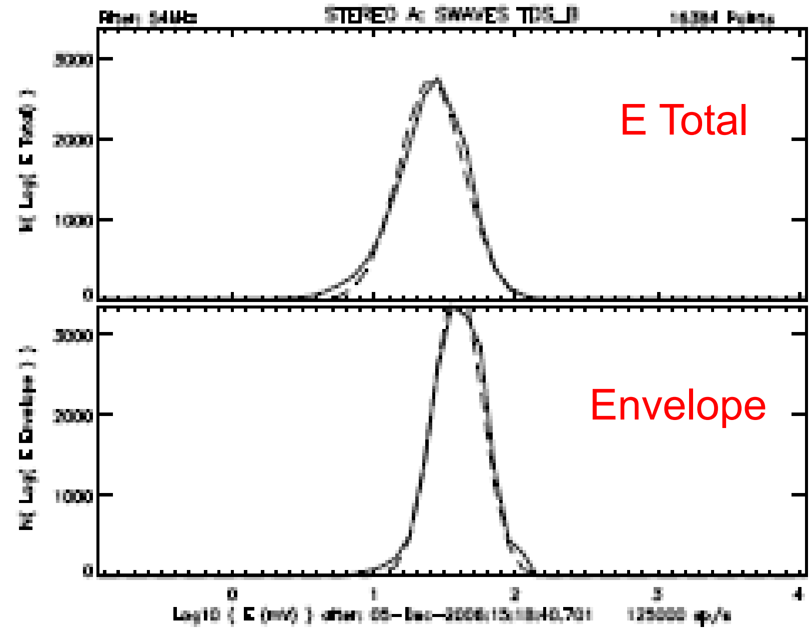


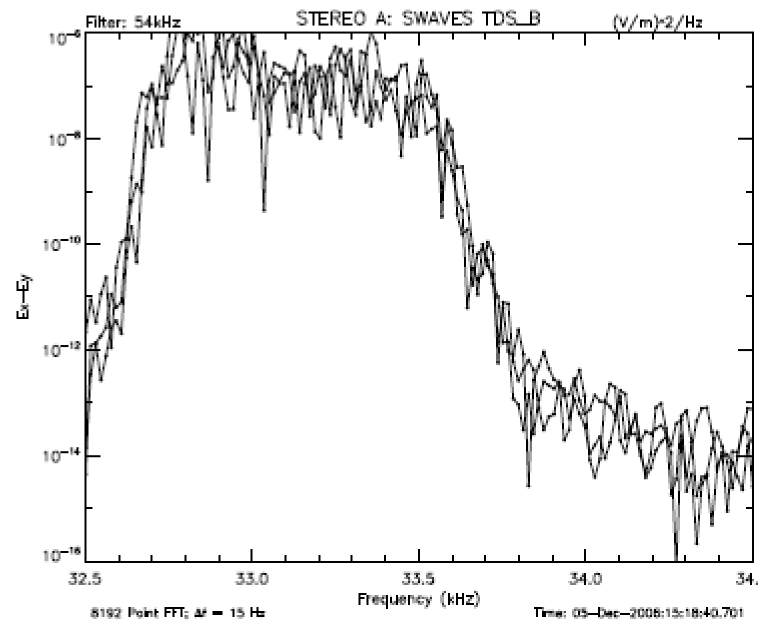
- Consistent with type III ILSs

[Cf. Ergun, Malaspina, C. et al., 2008]

Chains:

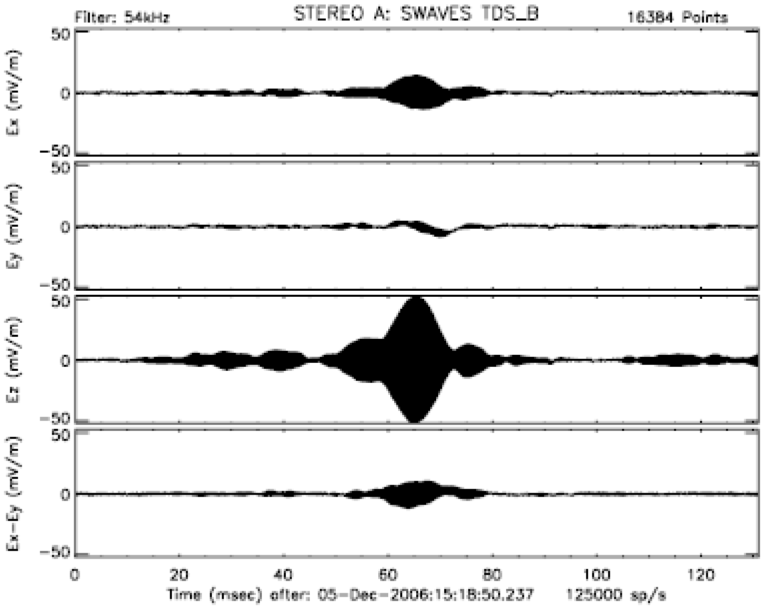


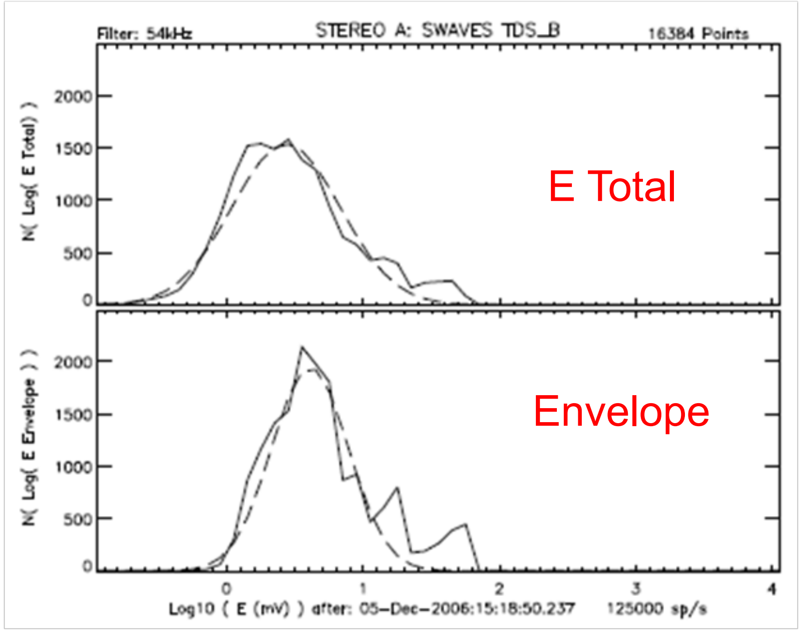


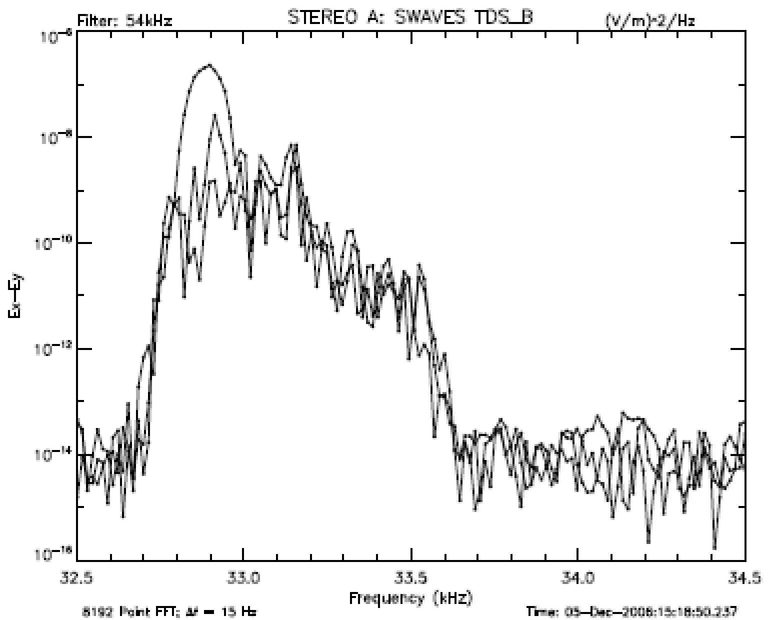


- Field statistics often close to lognormal
  ➔ consistent with SGT.
- Spectra: often flat, sometimes with Langmuir peak

Mixed events:





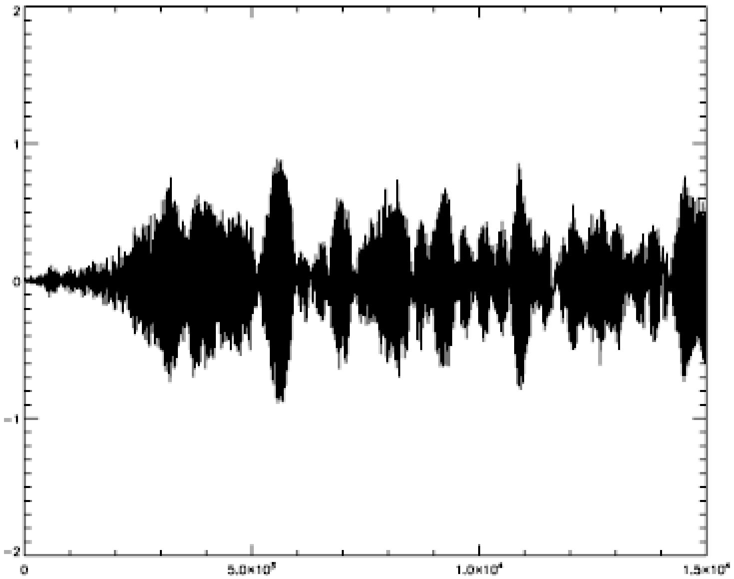


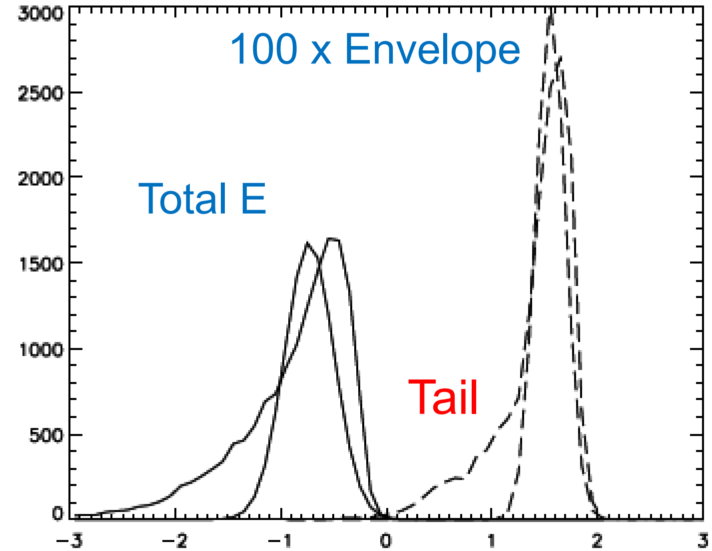
- Are they hybrids of ILSs & chains?
- Do ILSs develop into chains?

- Both ideas not inconsistent with field statistics and spectra

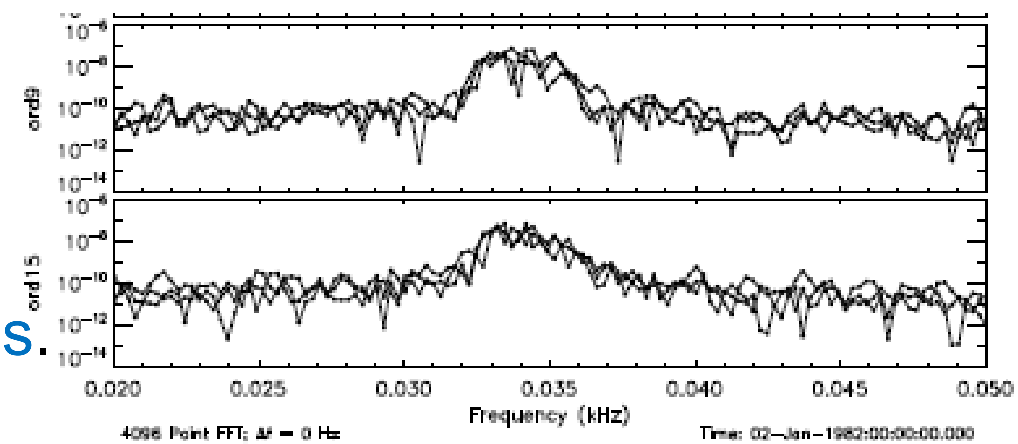
5. Vlasov Simulations of beam-Langmuir evolution ➔ "Kinetic Localization"

[sims from Muschietti et al., JGR, 1993, 1996]



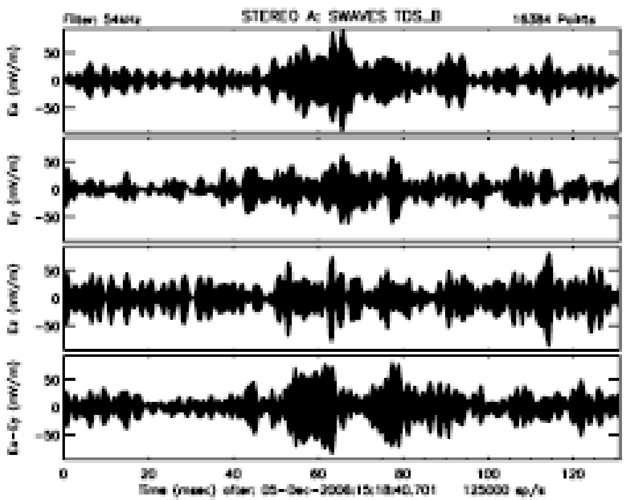


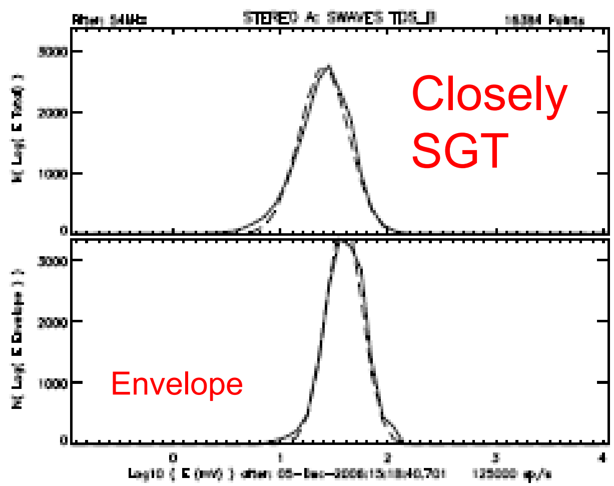
- Time series & spectra quite similar
- Field stats ~ lognormal except strong low-E tail
- Similar to STEREO chains.

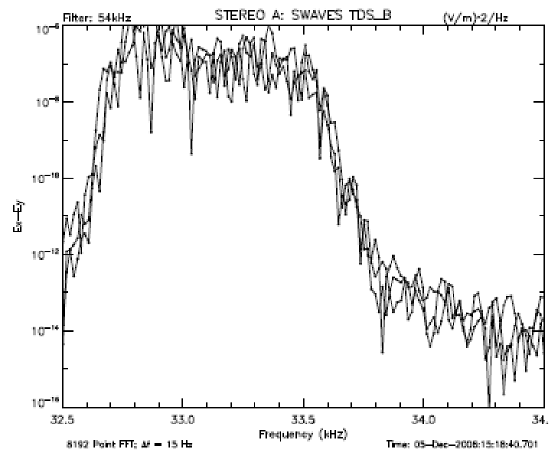


- Perhaps evolution / parameters issues?

STEREO “chains” versus simulations



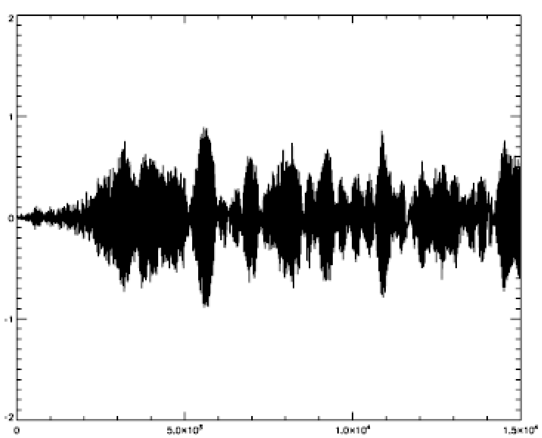


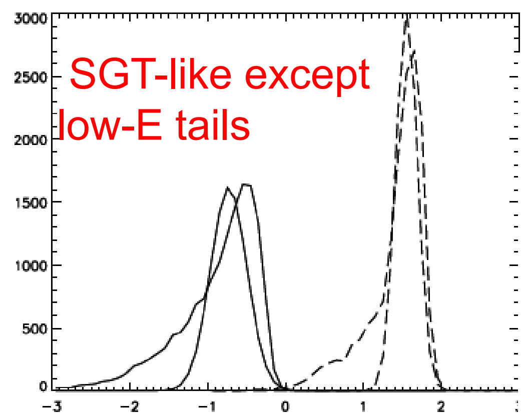


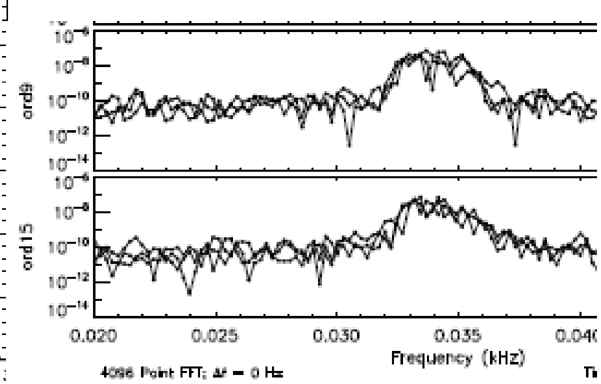
Similar time series

Field statistics?

Spectra similar







Chains? ➔ SGT but not kinetic localization for STEREO?

6. Conclusions

I. STEREO sees multiple classes of Langmuir wavepackets.
   – Objectively separated for first time. [Bias to high E still!]
   – Mixed/hybrid cases: evolution or superposition is unclear?

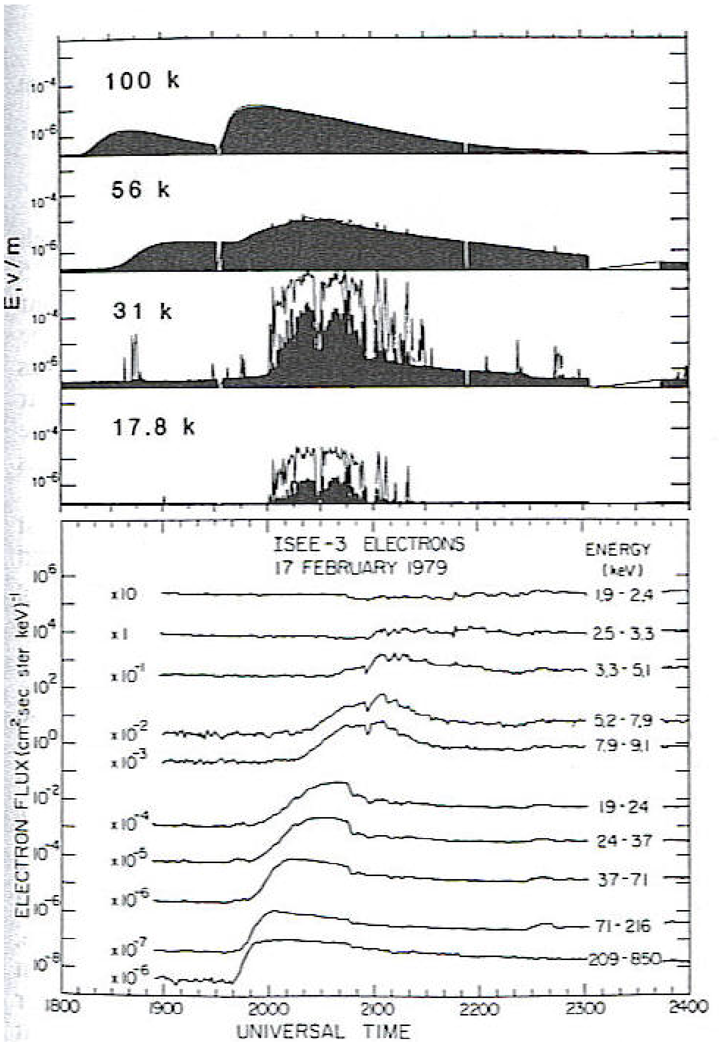
II. ILSs / Isolated wavepackets: flat field distributions and ~ Gaussian spectral components
   – ➔ not consistent with SGT.
   – Trapped eigenstates (probably not collapsing)?
   – Very similar to ILSs in type III sources.

III. Chains: often closely lognormal field statistics & enhanced but ~ flat power spectrum (sometimes a superposed peak)
   – May be consistent with SGT but not kinetic localization.

IV. First detailed analyses of kinetic localization in simulations:
   – Time series and power spectra very similar to chains.
   – Field statistics: low-E tails on otherwise quite SGT-like distribs.

Progress made but unanswered questions

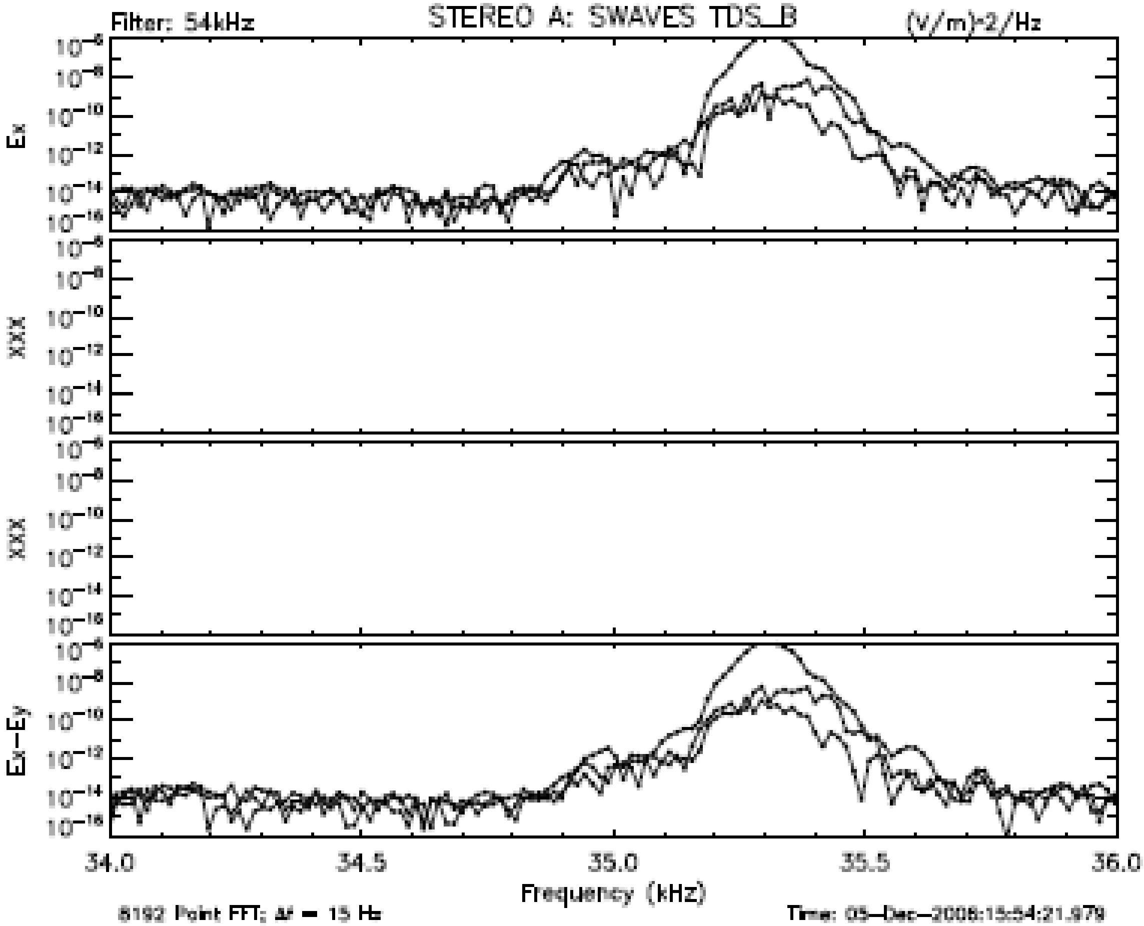
1. Why are Waves Bursty?



[Lin et al., 1981]

- Type III solar burst
  - Electron beam
  - Langmuir waves
  - Radio waves: f_p & $2f_p$
- Earth's foreshock
- Type II solar bursts
- Why do waves become bursty and electron beams persist?

STEREO TDS spectra



Incredible dynamic range:

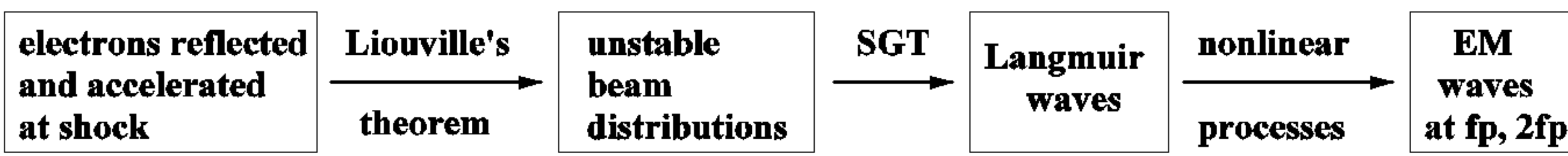
- very linear A-to-D
- 8 orders of magnitude to the background
- 6 orders in 150 Hz

2.1 Standard Foreshock Model

- Electron acceleration: mirror reflection (Fast Fermi)
  - Only one
  - Q-⊥ region of shock (3D)

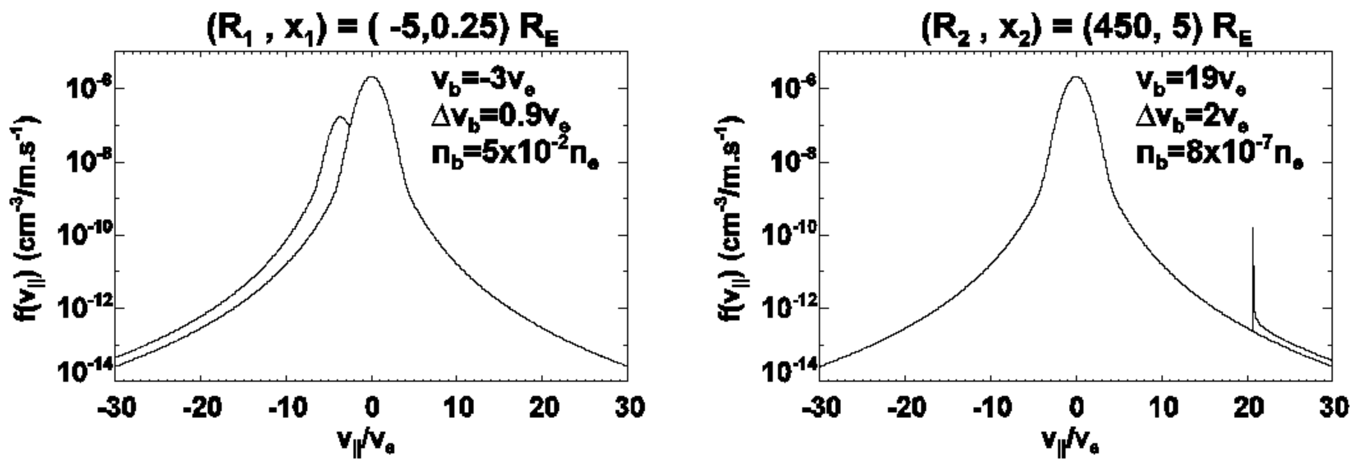
  (but C. & R. [1999], Bale et al. [2003], Burgess, Lembege, …)
- Beam formation: cutoff / time-of flight effects
- Linear wave growth: Langmuir / beam mode instability
  - upshifting/downshifting ↔ $3 > v_b / V_e > 1$ ➔ $\theta_{bn} > 80°$.
- Growth limiter: quasilinear relaxation (C., Dum, Klimas …)
- Nonlinear processes:
  - Langmir decay + radio emission processes
- Linear mode conversion?

- Semi-quantitative, analytic, macroscopic theory exists:



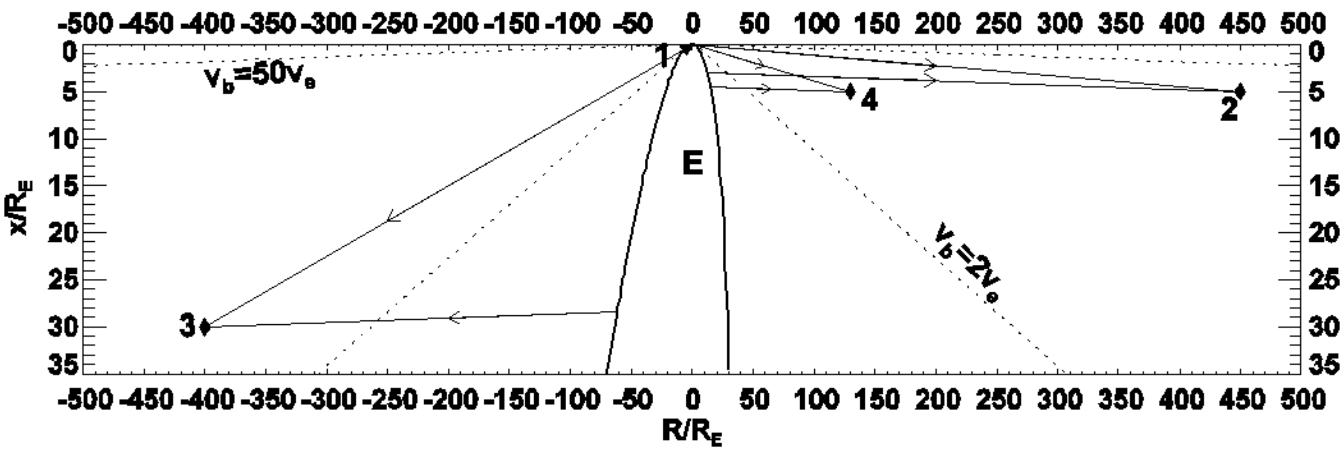
[Knock et al., 2001; Kuncic et al., 2002, 2004; Kuncic & Cairns, 2005]

2.1.1 Electron beams by time-of-flight effects



B →

v_{ExB} ↓



[Filbert & Kellogg, 1979; C., 1986; Kuncic et al., 2004]

Mirror reflection / Shock-drift acceleration

electrons reflected and accelerated at shock —**Liouville's theorem**→ **unstable beam distributions**

5. New results and issues related to SGT

1. Small deviations from lognormal for pure SGT [Krasnoselskikh et al., 2007]?

2. Different classes of wavepackets have different statistics [Nulsen et al., JGR, 2007].

3. Several mechanisms for achieving SGT?

Sigsbee et al. (2004) Results

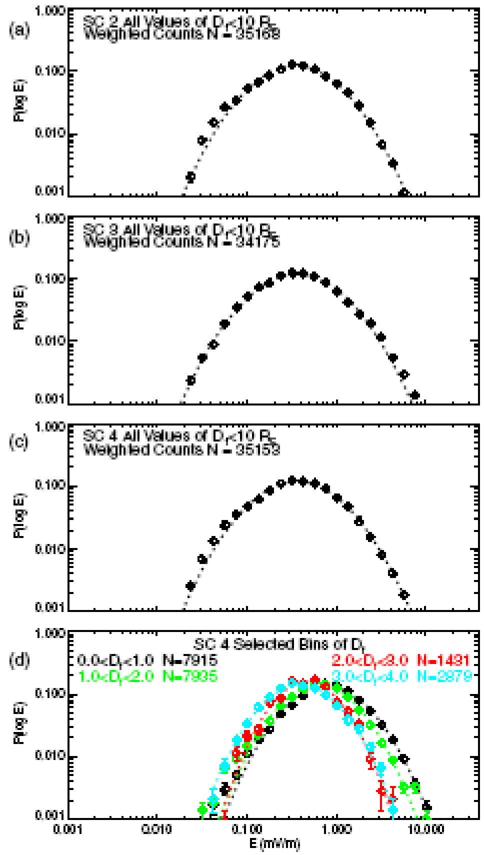
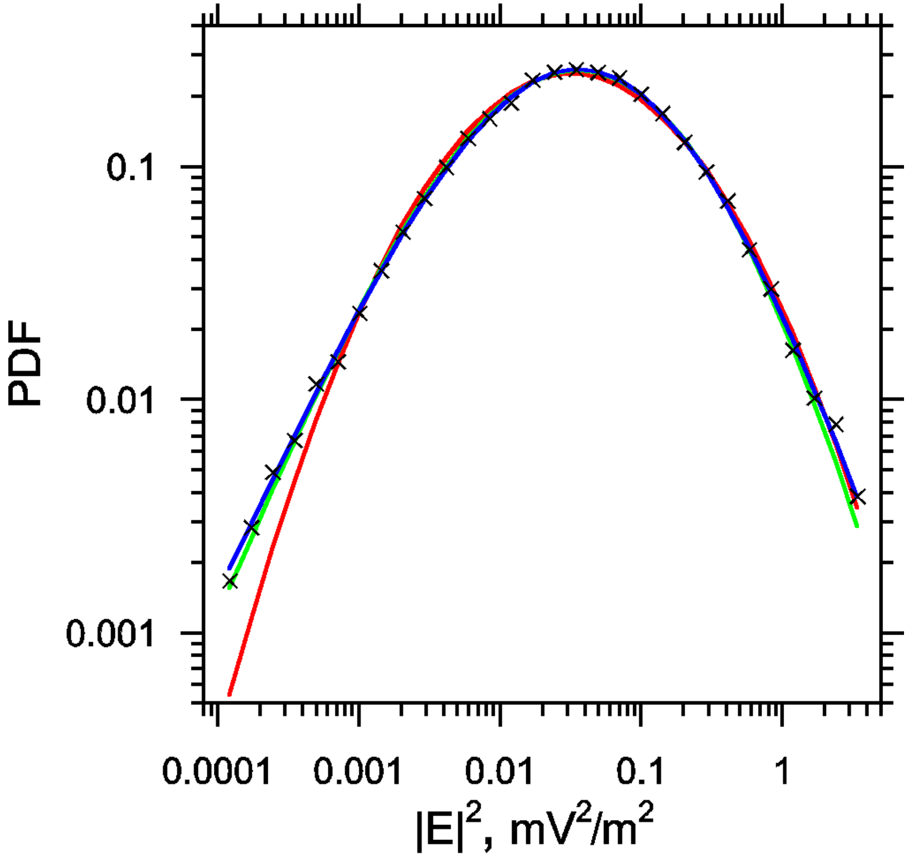


Fig. 4. Probability distributions for the electric field waveform amplitudes observed by the Cluster WBD Plasma Wave Receiver on 26 March 2002. The probability distributions for all values of D_f using weighted counts for **(a)** spacecraft 2, **(b)** spacecraft 3, and **(c)** spacecraft 4. The dashed lines show the fit to the Gaussian function predicted by stochastic growth theory. **(d)** Probability distributions from spacecraft 4 for selected 1 R_E bins in D_f.

5.1 PDF for Langmuir wave energy density for the period 9:25-10:13 UT on February 17, 2002



x – experiment

maximum likelihood fit of a log-normal distribution

fit of Pearson class IV distribution obtained by maximum likelihood method

fit of Pearson class IV distribution with parameters derived from estimates of moments

Possible Interpretations:

1) N_{fl} too small for pure SGT ← [Krasnoselskikh et al., JGR, 2007]

2) Averaging over D_f.

Pearson type IV distribution

$$P(X) = c(X^2 + A^2)^{1/2b_2} \exp\left(-\frac{B}{Ab_2}\operatorname{atan}\frac{X}{A}\right)$$

STEREO/WAVES Daily Summary - 15-Dec-2006 (DOY 349)

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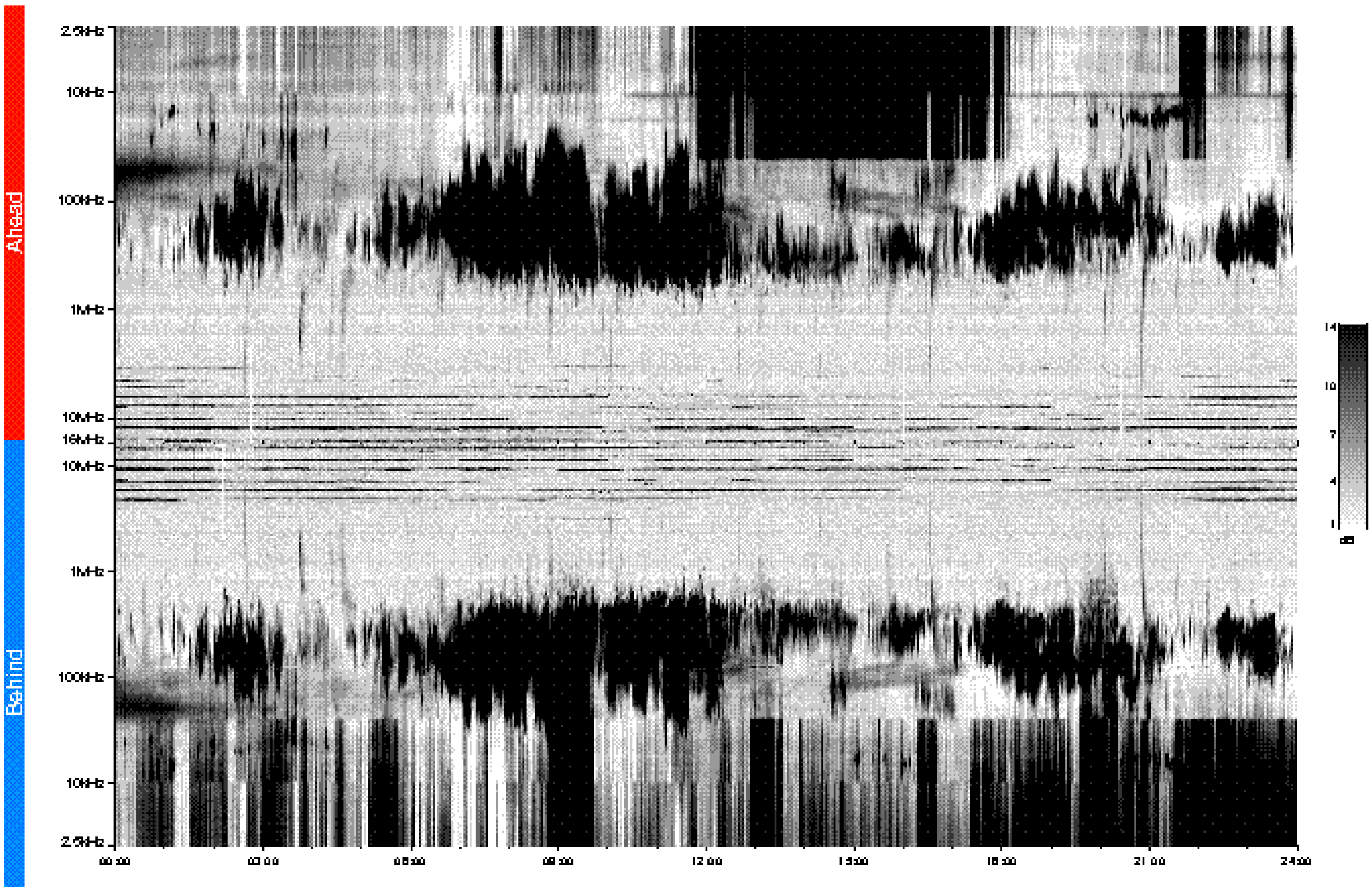

Behind PSE Angle = xxxx
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Time (UTC)

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