Measurements of 3D Structure in Solar Wind Langmuir Waves

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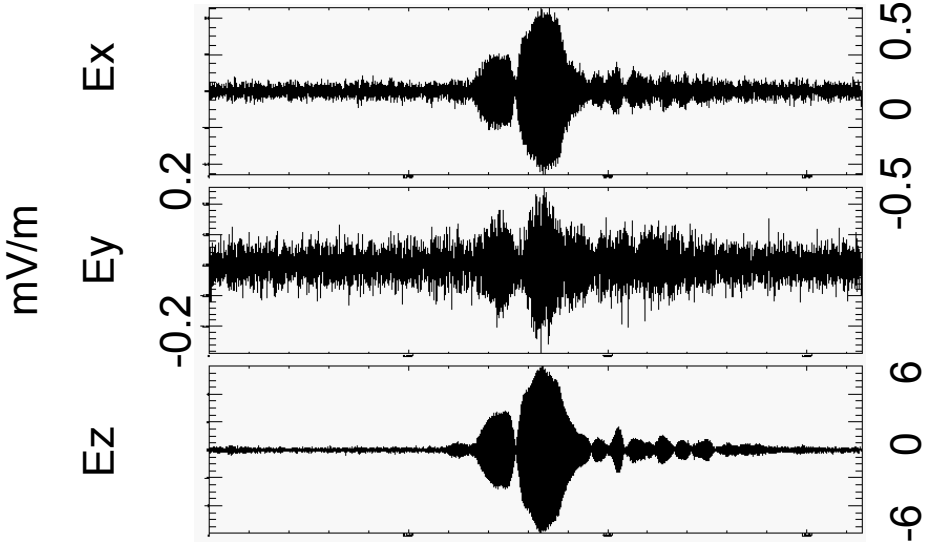
Classification of 3D Structure

- 3D Hodograms (500 plasma periods)
  - Rotated into magnetic field frame
  - DC subtracted

- Inertia tensor analysis
  - Treat Hodogram vector points as a solid body

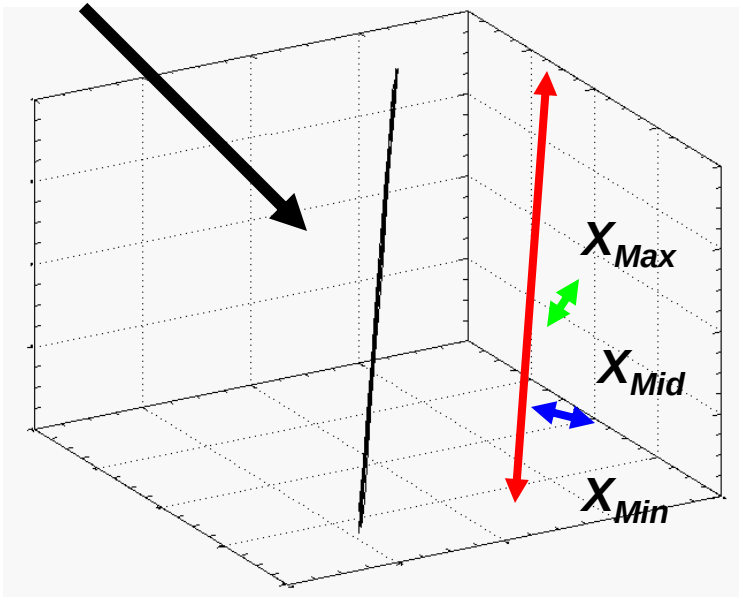


X_{Max} = Maximum variance direction

X_{Min} = Minimum variance direction

X_{Mid} = Mutually orthogonal direction

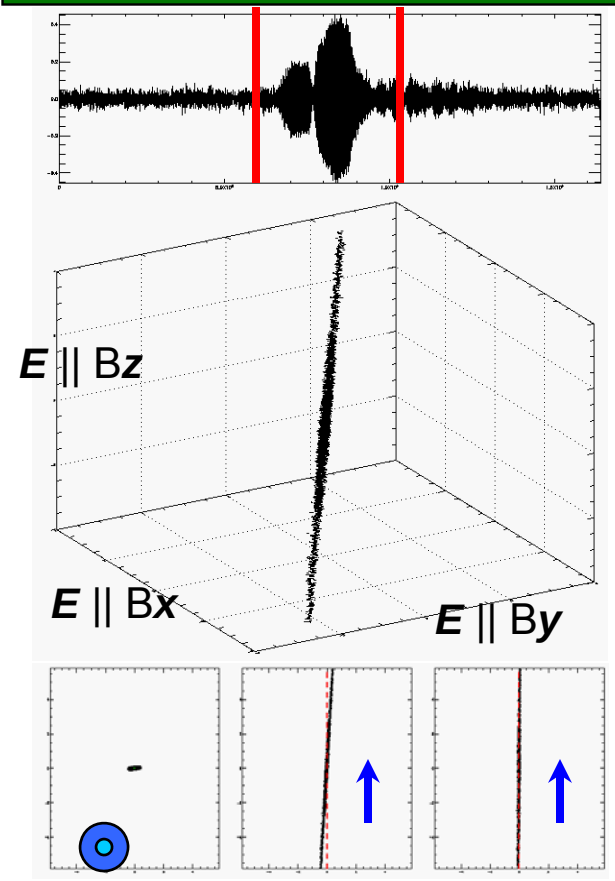
3D Hodogram

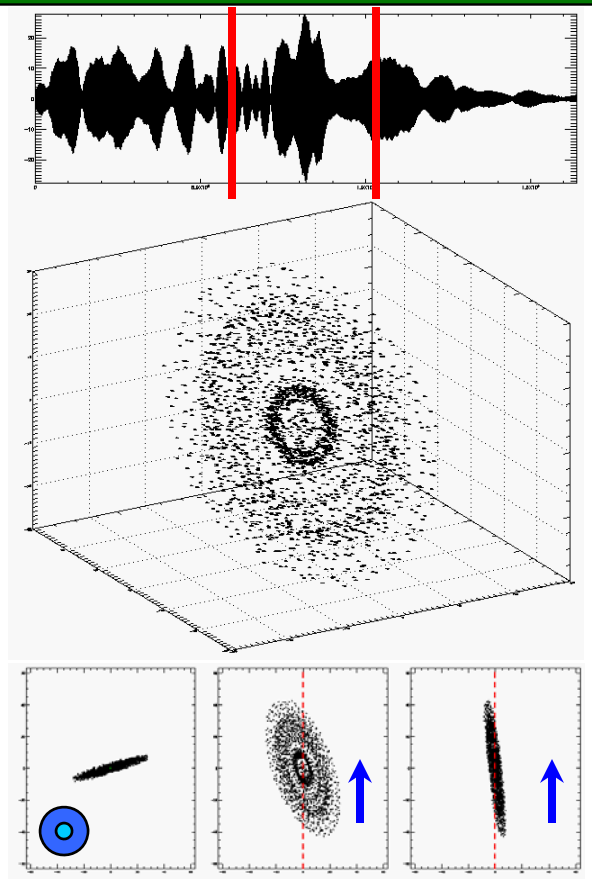


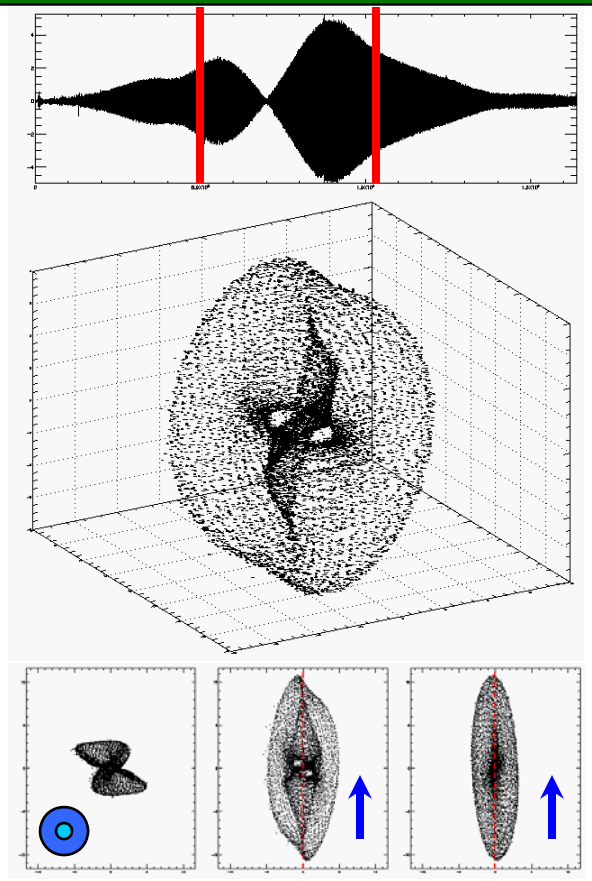
Classified by $I_{min} / I_{mid} = D$

0.08 > D	1D
0.08 < D < 0.22	2D
0.22 < D	3D

Classes of 3D structure







1D Hodogram

- Linearly polarized
- X_{Max} close to B
- (77% of all events)

2D Hodogram

- B often in disk plane
- (7% of all events)
- E field plane stays steady

3D Hodogram

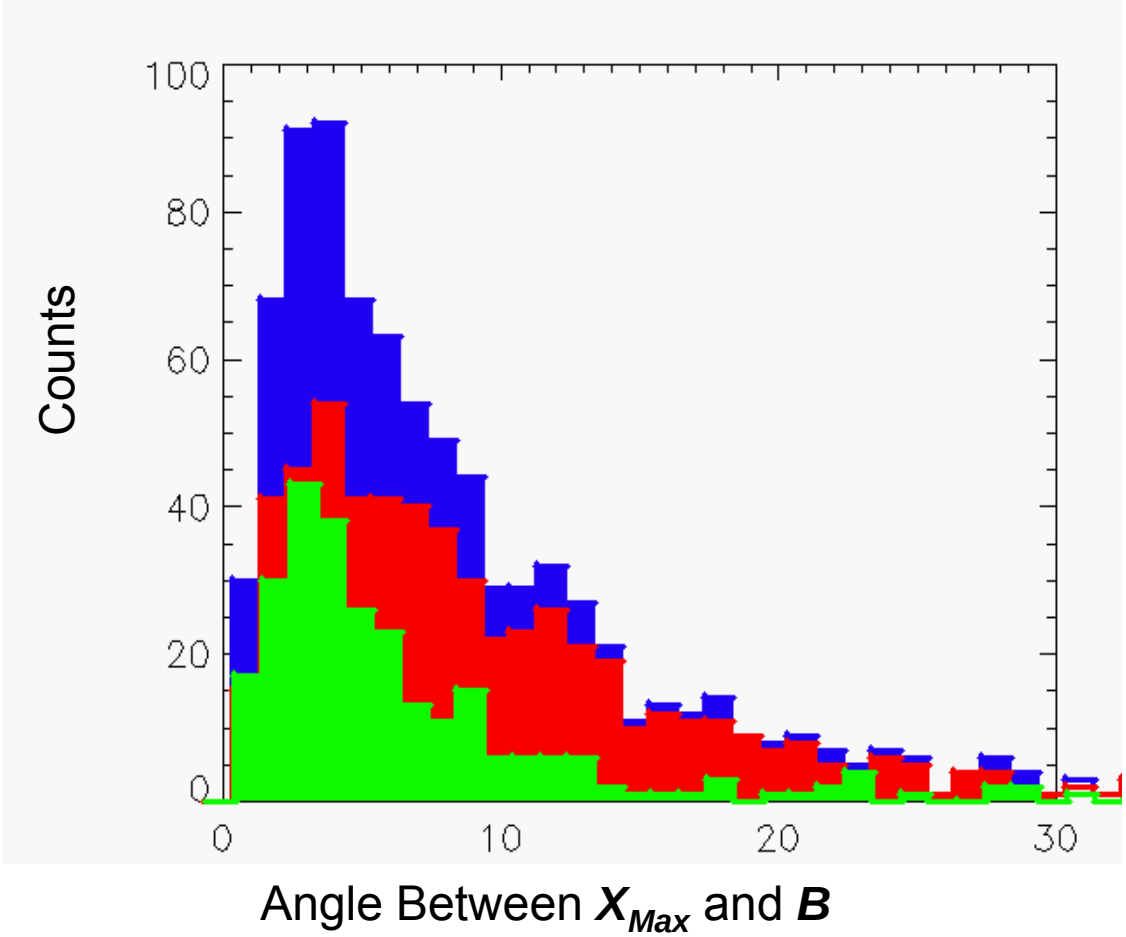
- Quasi-periodic rotation of 2D structure
- (15% of all events)

Pointing of 1D, Linear Hodograms:

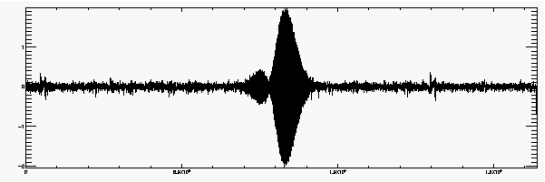
X_{Max} and B
closely aligned

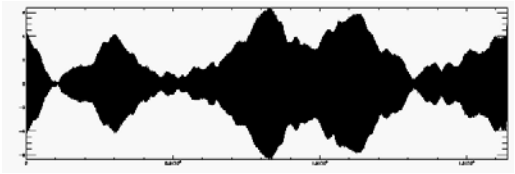
Histogram peaks ~3⁰ for distinct packets

Histogram peaks ~4⁰ for non-distinct packets (enhancement ~11⁰)

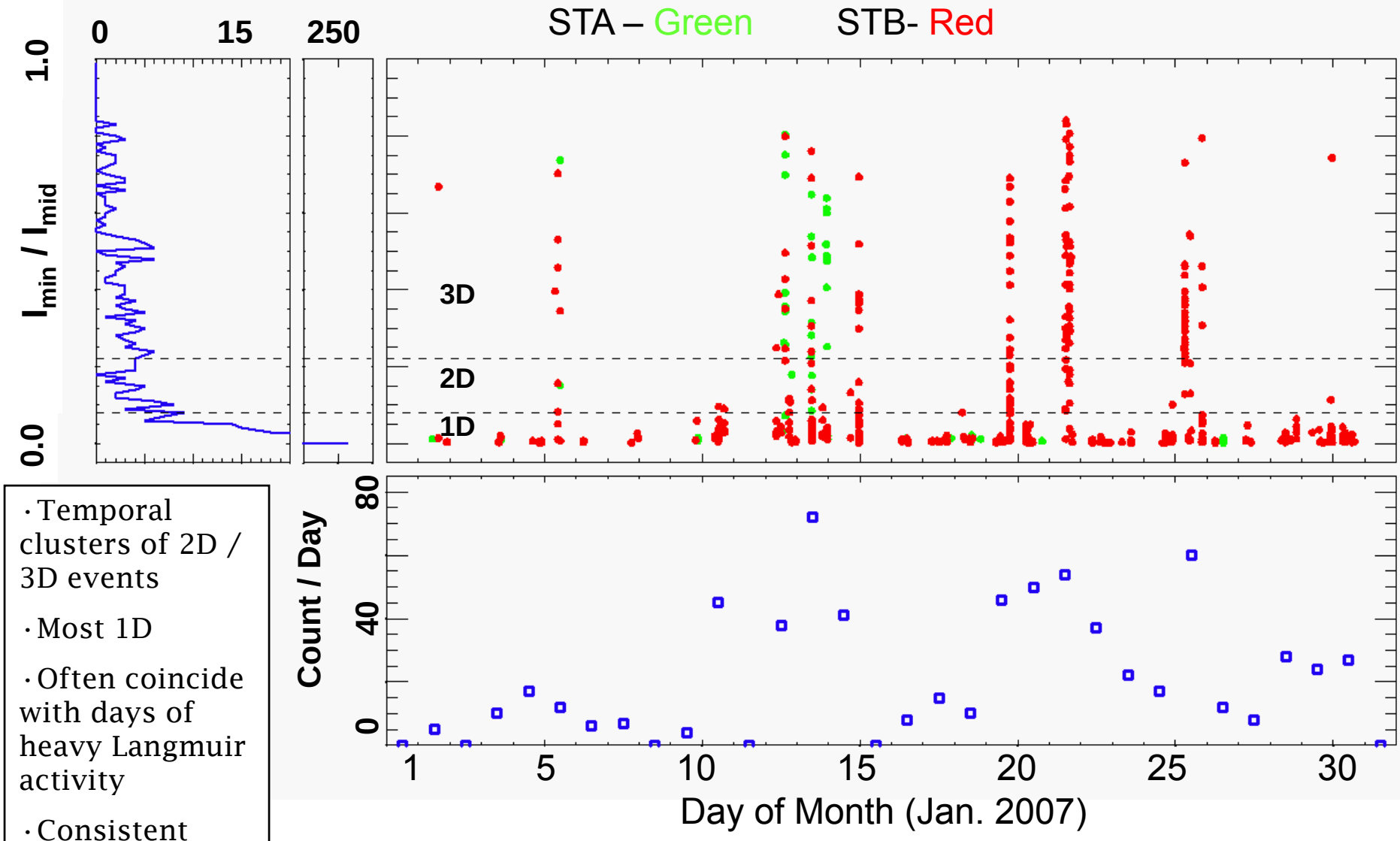


Green: Distinct Packets Red: Other Waveforms Blue: All waveforms





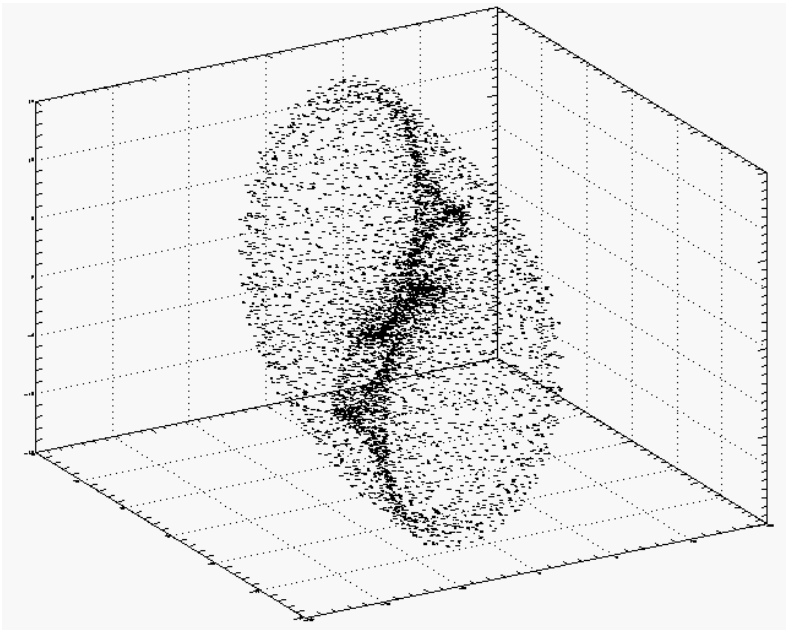
Temporal Clustering of 2D/3D events

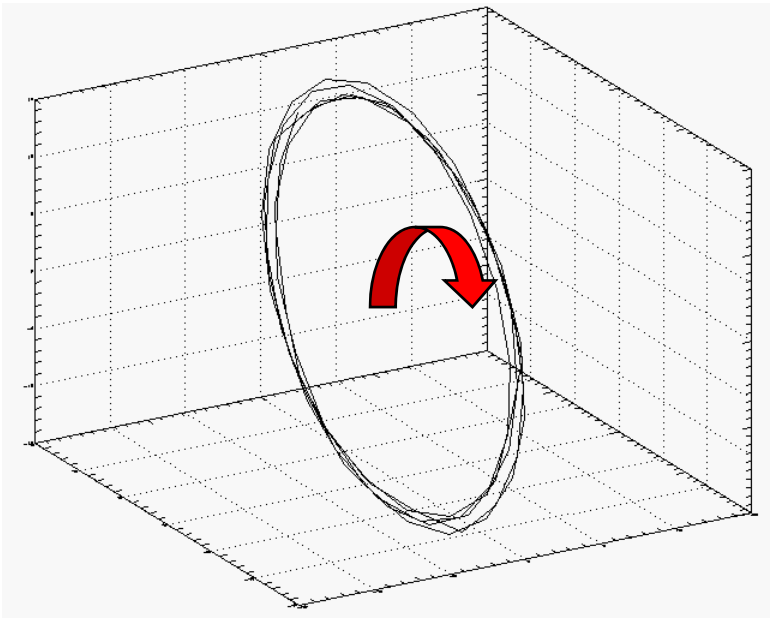


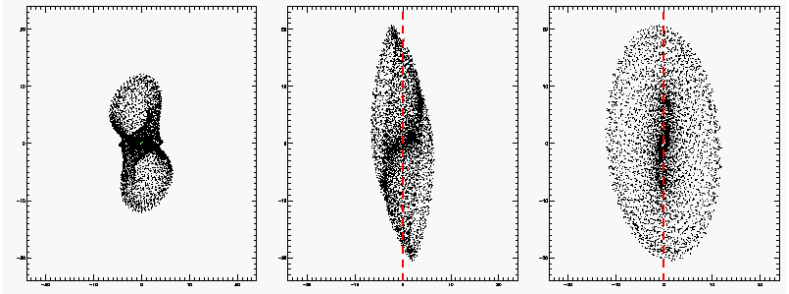
- Temporal clusters of 2D / 3D events
- Most 1D
- Often coincide with days of heavy Langmuir activity
- Consistent over many months

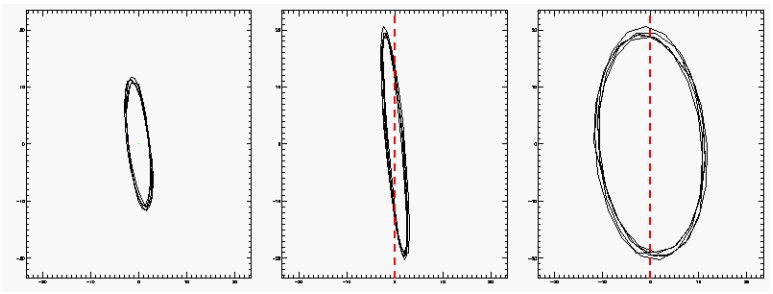
Does not appear to be shock correlated...

3D and 2D quasi-periodic rotation









300 Plasma oscillation periods

Rotation Freq. << Plasma Freq.
(~ 25 – 75 Hz) << (~ 10 kHz – 35 kHz)

Langmuir wave has components || and ⊥ to ***B***
Response of plasma wave to Ion-Acoustic wave?

5 Plasma oscillation periods

Packet Scale Sizes

Using discreet packets
1D, pointing close to ***B***:

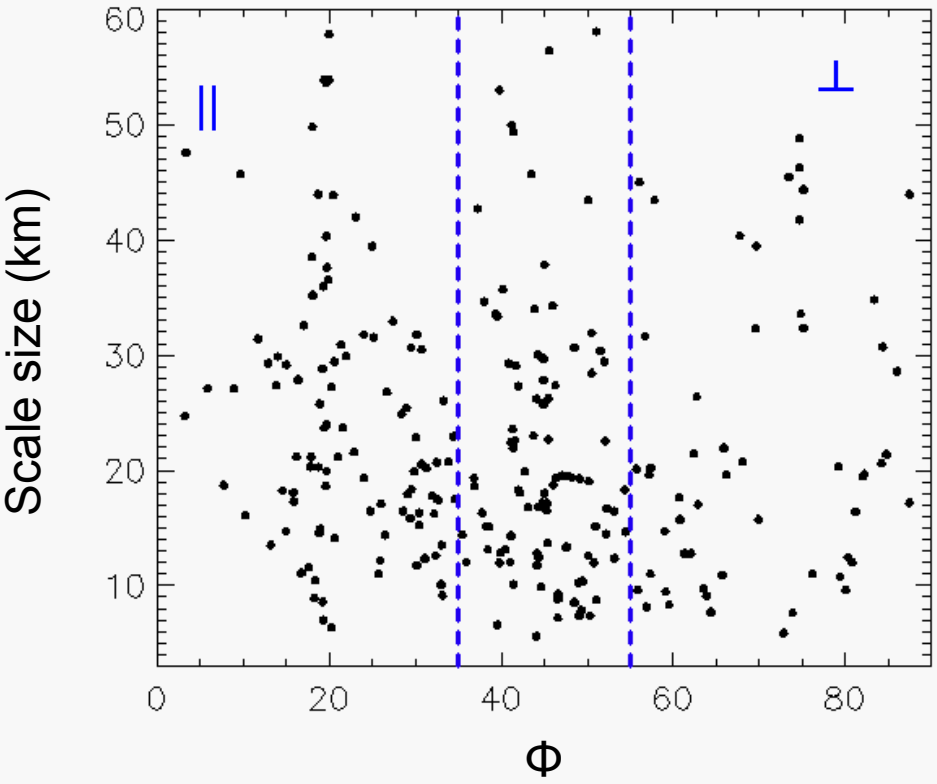
Scale size = Packet Δt * $V_{solar\ wind}$
(along flow direction)

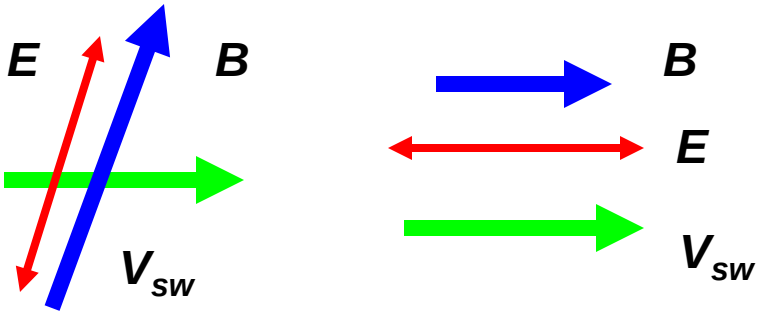
Φ = angle between ***B*** and V_{sw}

$\Phi > 55^0$ for $\perp$ scale size

$\Phi < 35^0$ for || scale size

Avg. || scale size ~ 25 km
Avg. $\perp$ scale size ~ 28 km





Similar Packet Scale Sizes in
|| and $\perp$ directions

(on average)

Possible Causes of 3D Structure

Reflection at density gradients

Kellogg, P.J., Goetz, K., Monson, S.J., Bale, S.D., Langmuir waves in a fluctuating solar wind, J. Geophys. Res. 104. 17,069, 1999.

Langmuir Z-mode Coupling

Bale, S.D., Goetz, K., Monson, S.J., Transverse Z-Mode waves in the terrestrial electron foreshock. Geophys. Res. Lett., 25, 1, 9, 1998.

3D Eigenmodes

3rd Possibility

A Langmuir wave Eigenmode is:

High frequency response of the Zakharov equations to an energetic electron beam passing through a shallow, pre-existing parabolic density cavity in the solar wind.

1D Eigenmodes

Pre-Existing Density Cavity:

$$\Delta n = n_0 \frac{x^2}{L^2}$$

Electric Field High-Frequency Response

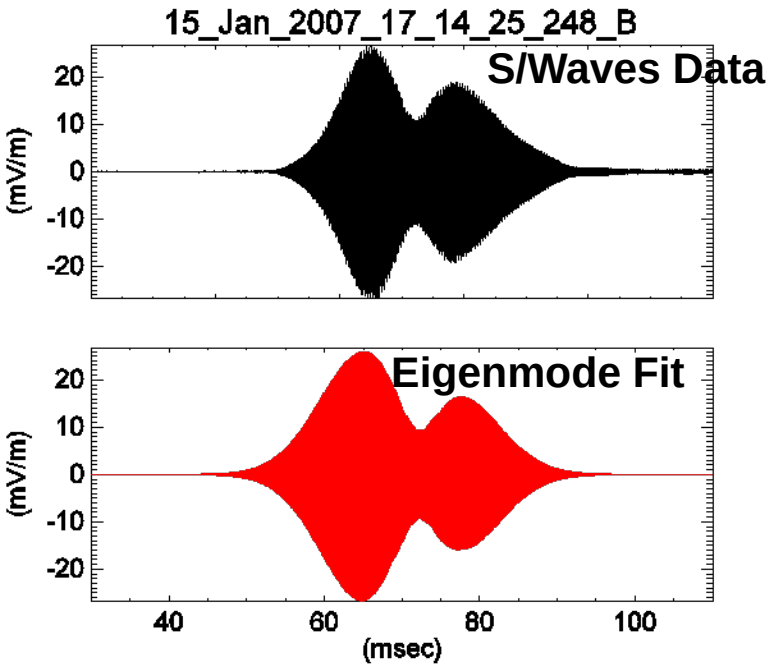
$$E(x,t) = \sum_n^{\infty} A_n E_n$$

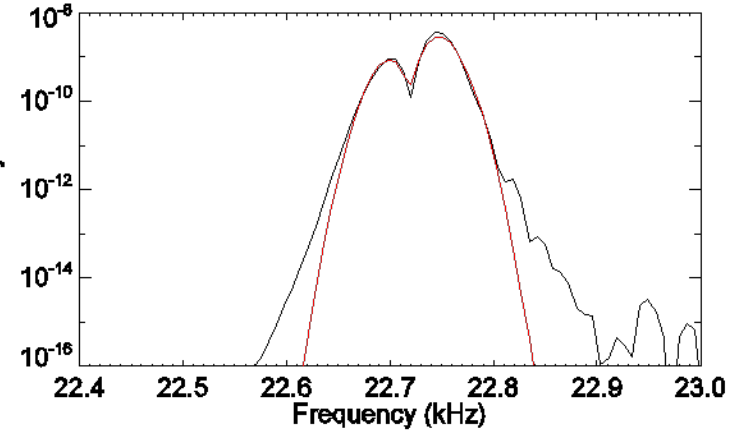
Plasma Oscillation

Envelope

$$E_n = H_n(Qx) e^{-\frac{(Qx)^2}{2}} e^{i(k+\Delta k)x - i(\omega+\Delta\omega)t+\phi}$$

$$Q^2 = \frac{\omega_{plasma}}{\sqrt{3} v_e L} \qquad v_e = \sqrt{\frac{k_b T_e}{m_e}}$$





Multi-Dimensional Eigenmodes

- Can generate similar Hodogram structures

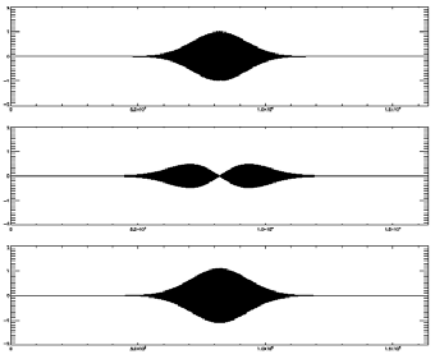
- Possible when density cavity scale sizes isotropic (hinted at by isotropic packet sizes)

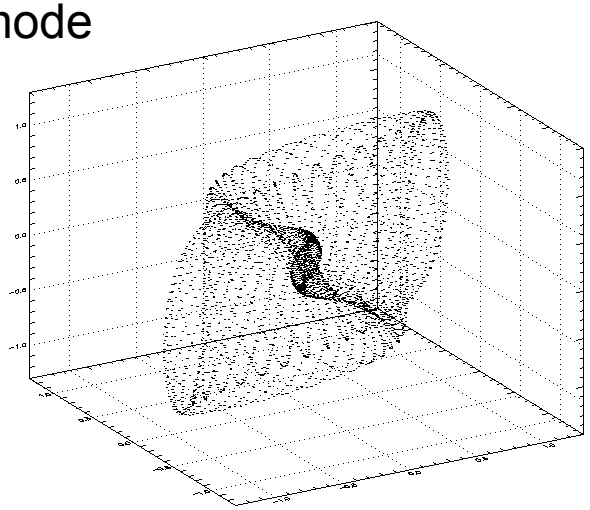
$$E_{total} = \Sigma\, E_{nx^*} E_{ny^*} E_{nz}$$

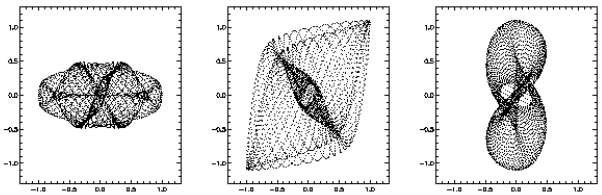
- Too many free parameters to test by direct E field fits

- Currently Lack a trigger mechanism for choosing 3D over 1D

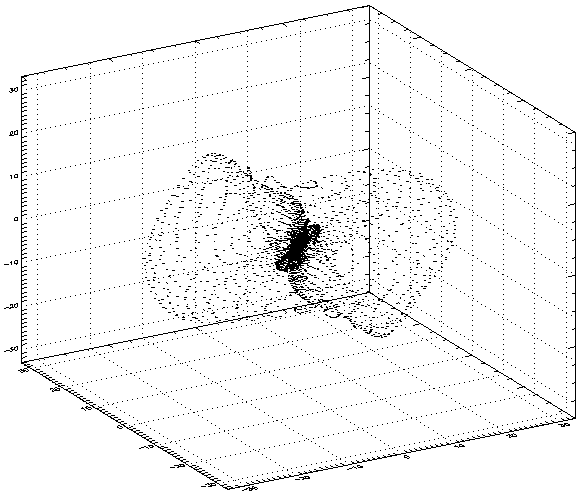
Artificial 3D Eigenmode

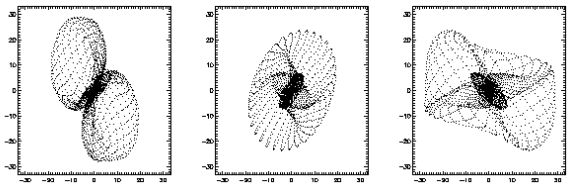






Real Data





Summary of Observations, Current, and Future work

Observations:

- Most Langmuir waves (~77%) are 1D, polarized along ***B***
- Many (~23%) have significant structure $\perp$ to ***B***
- High-D events are clustered in time
- High-D are elliptically polarized, some w/ slow rotation
- On average, packet sizes are nearly isotropic wrt ***B***

Possible (current work):

- 3D structure may be evidence of 3-wave coupling
  - possibly two Langmuir waves and one or more low freq waves
- Near-Isotropic packet sizes possibly indicate isotropic density cavities (can measure a few directly if $\delta n / n_0 > 1\%$)

Open questions (future work)

- Time clustering of 3D events related to the driving electron beam or the ambient environment?
- Possible that 3D structure can be attributed to 3D eigenmodes?
  - Perhaps eigenmode responding adiabatically to quasi-periodic changes in the density cavity size / shape (possibly by Ion-Acoustic wave?)

Fin