Bispectrum and Bicoherence In Dipole Confined Plasmas

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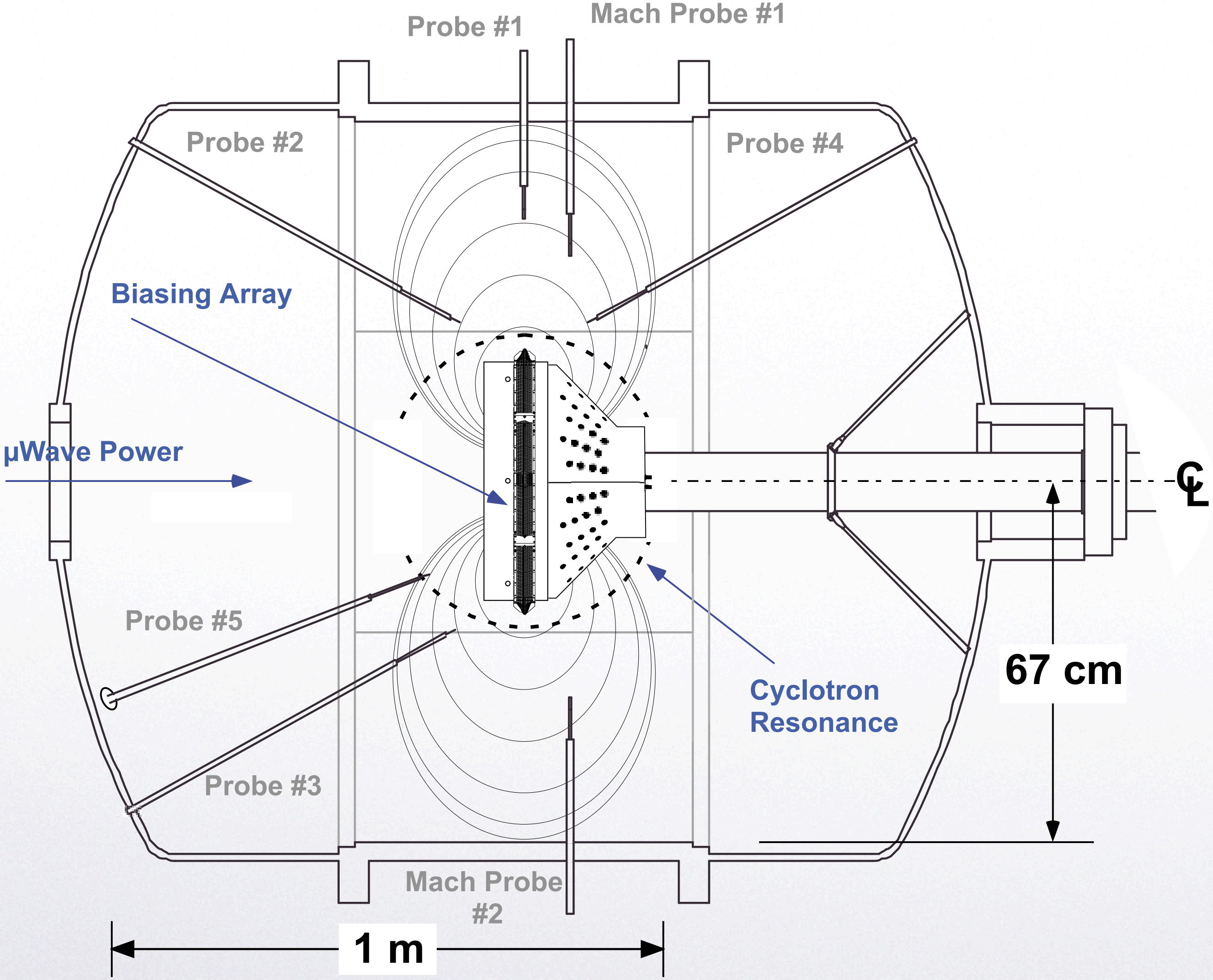
9.14.06

Outine

- Producing high density plasmas.
- General plasma characteristics.
- Fluctuation properties.
- Bispectrum.

CTX Dipole



B_{max}~2kG, B_{wall}~50G

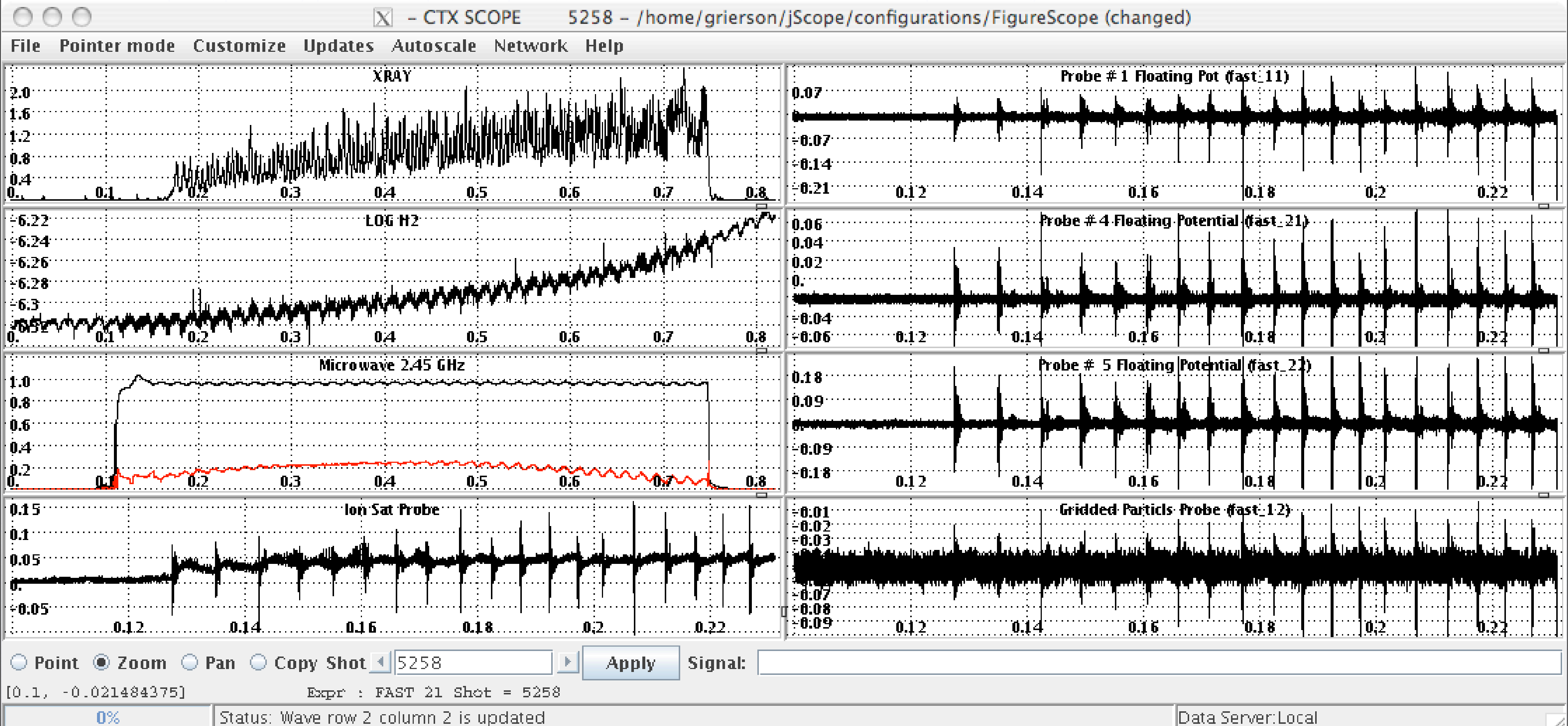
$L_{Terella}$ =20cm

$L_{Chamber}$ =70cm

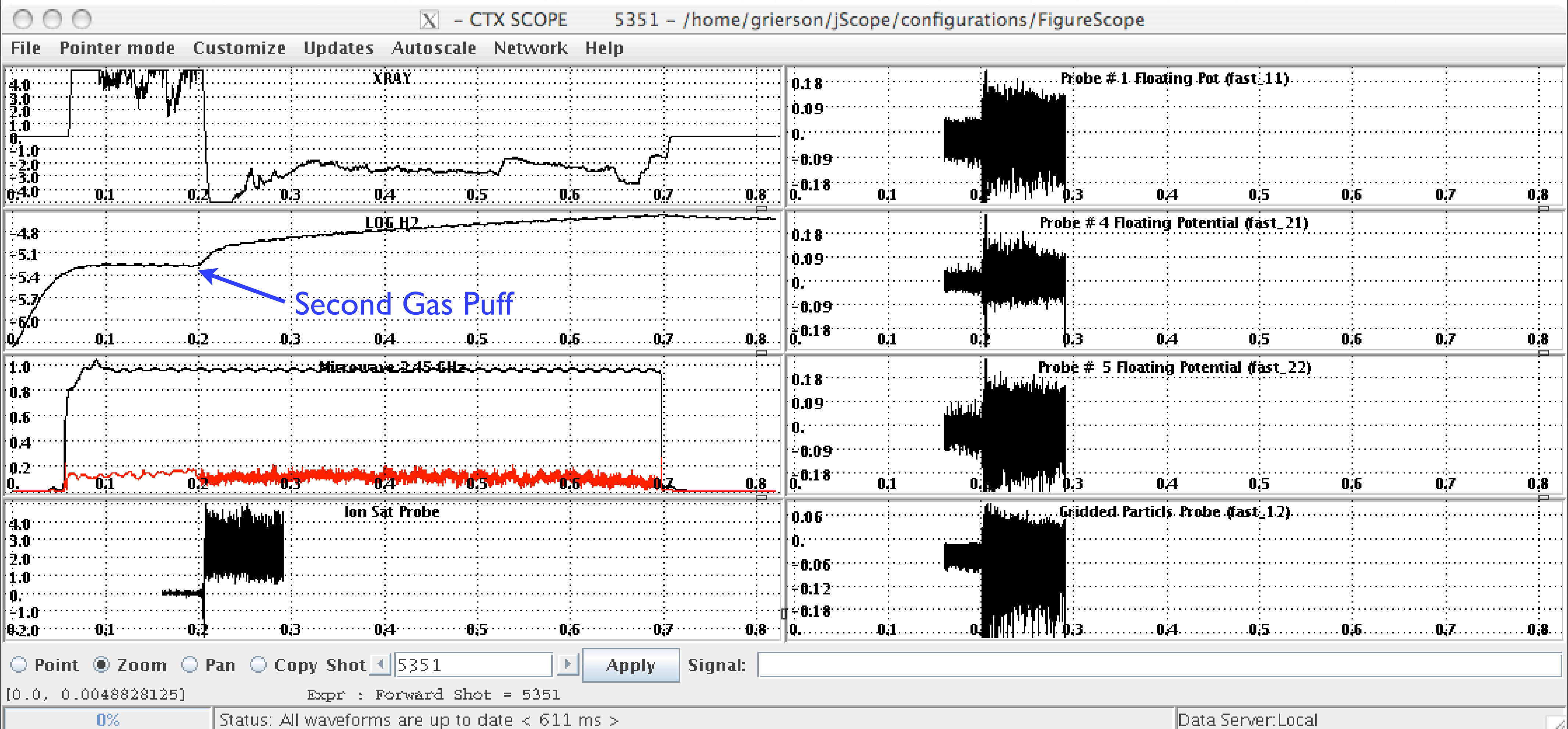
1kW ECRH @2.45GHz

ECRH Resonance at L=27cm

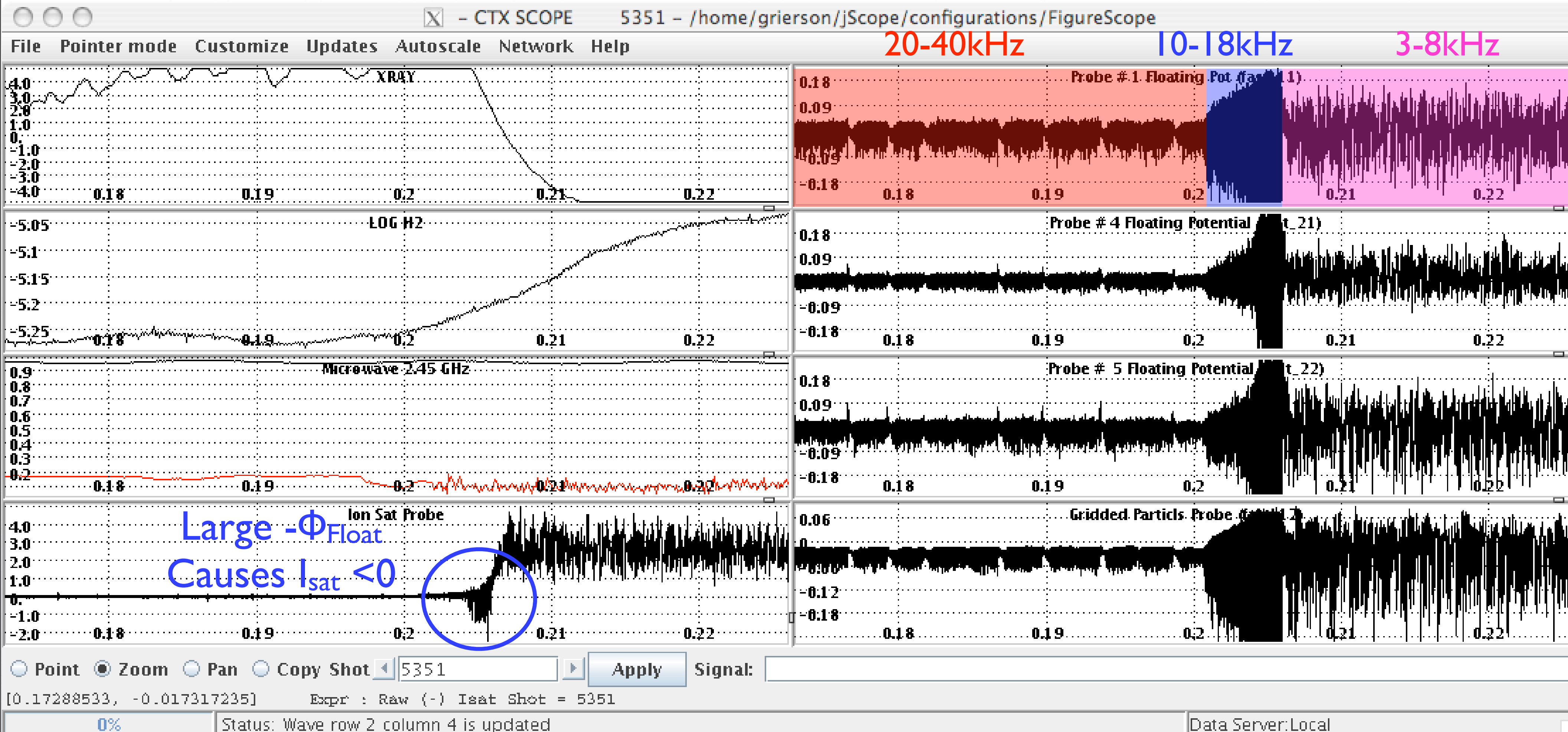
Low Density Plasma



High Density Plasma

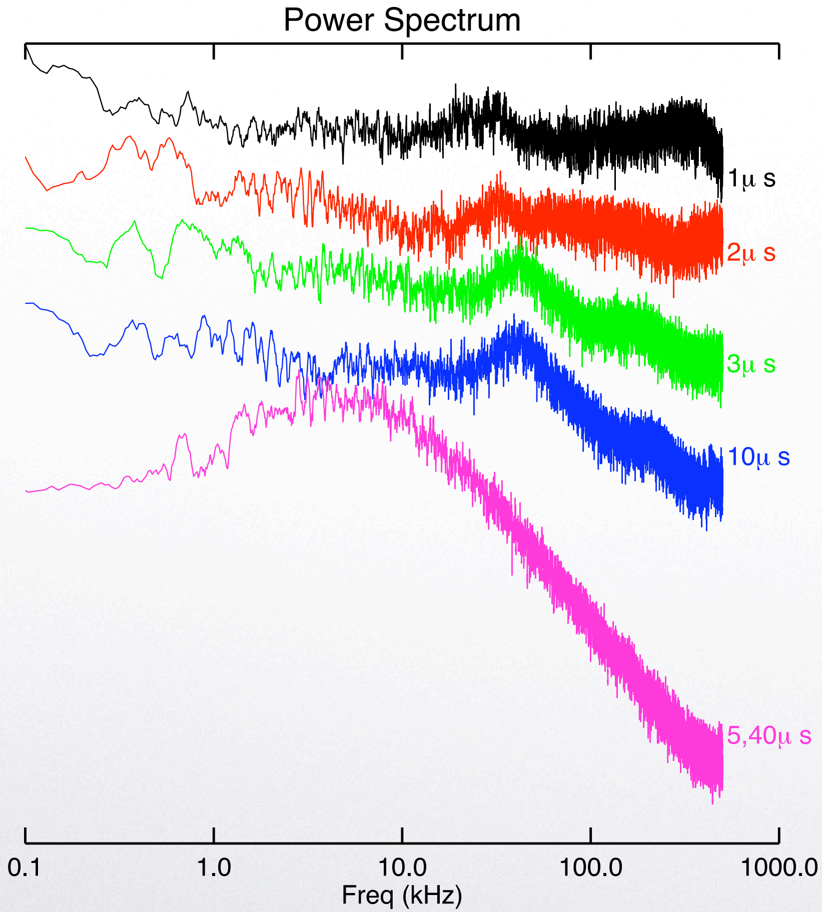


Transition



CTX SCOPE 5351 – /home/grierson/jScope/configurations/FigureScope
File Pointer mode Customize Updates Autoscale Network Help
20-40kHz
10-18kHz
3-8kHz
XRAY
LOG H2
Microwave 2.45 GHz
Ion Sat Probe
Large -Φ_Float
Causes I_sat <0
Probe # 4 Floating Potential
Probe # 5 Floating Potential
Point Zoom Pan Copy Shot 5351 Apply Signal:
[0.17288533, -0.017317235] Expr : Raw (-) Isat Shot = 5351
0%
Status: Wave row 2 column 4 is updated
Data Server:Local

Spectral Characteristics

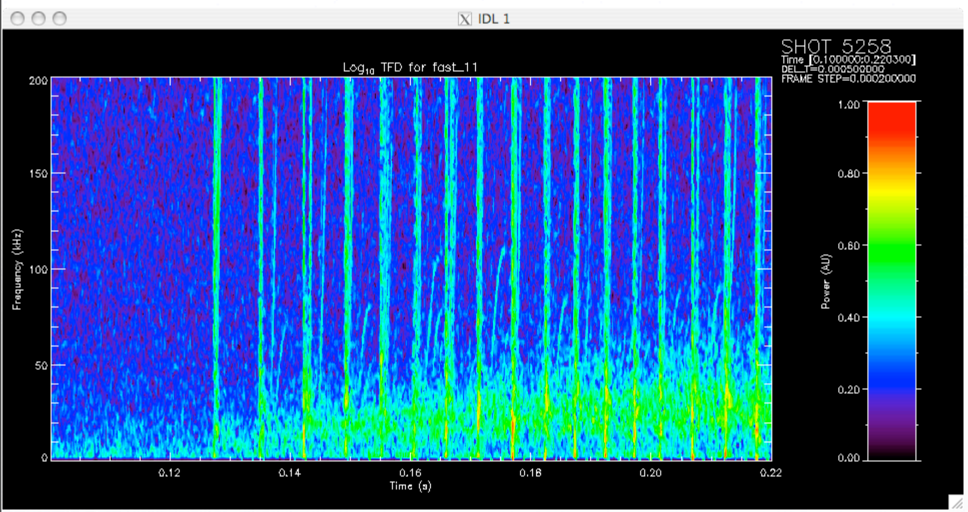


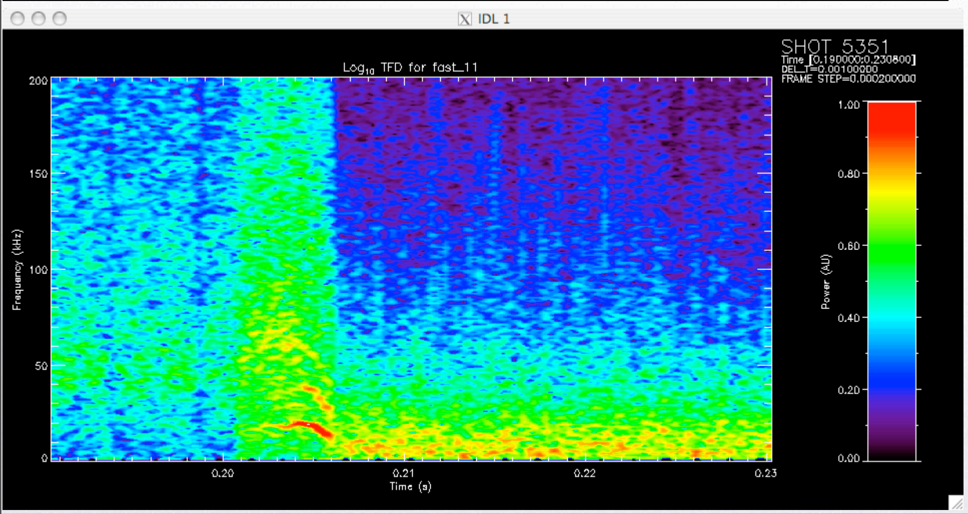
Floating Potential FFTs include HEI for low density.

- Trend towards power law
- Low density fluctuation peak shifts up as gas increased
- High density power law like $f^{-5/3}$ (which possibly corresponds to k-space as well)*

*S.-I. Itoh and K. Itoh **Spectrum fof Subcritically Excited Interchange Mode Turbulence**

TFDs





- Low density plasmas have turbulent interchange fluctuations near 20-40kHz, with little to no measurable mode structure.
- Transition fluctuations near 10-18kHz and m=1 mode structure.
- High density plasmas have fluctuations near 3-8kHz, dominated by m=1.

Correlations

- Correlations between probes can replace FFT phase measurements for non-stationary time series.
- Allows extraction of lag time.
- Lag time + <Frequency> ⇒<Phase Shift>

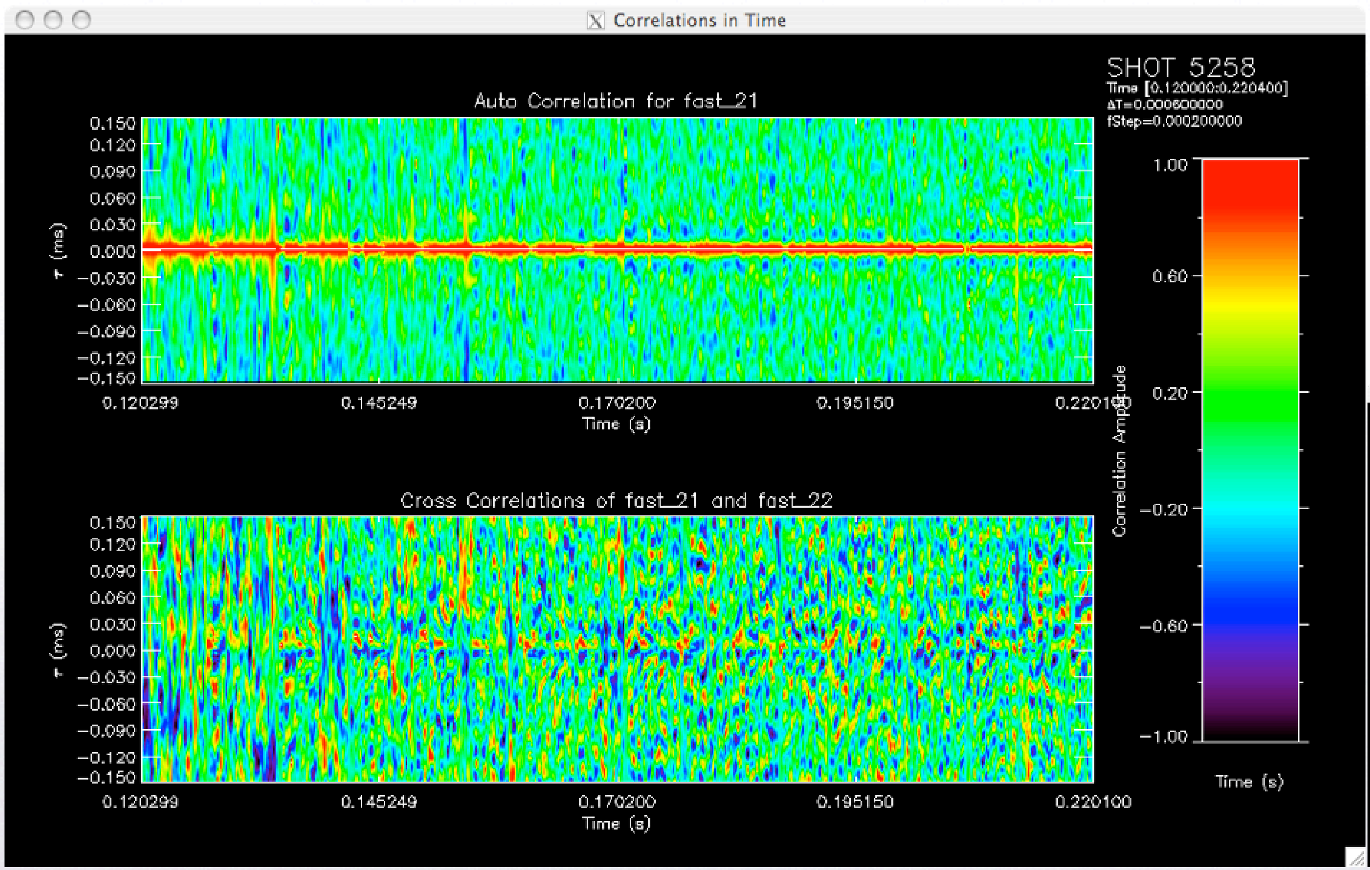
$$C_{1,2}(\tau) = \frac{\int_0^T S_1(t) S_2(t-\tau) dt}{\sqrt{\int_0^T S_1^2(t) dt \int_0^T S_2^2(t) dt}}$$

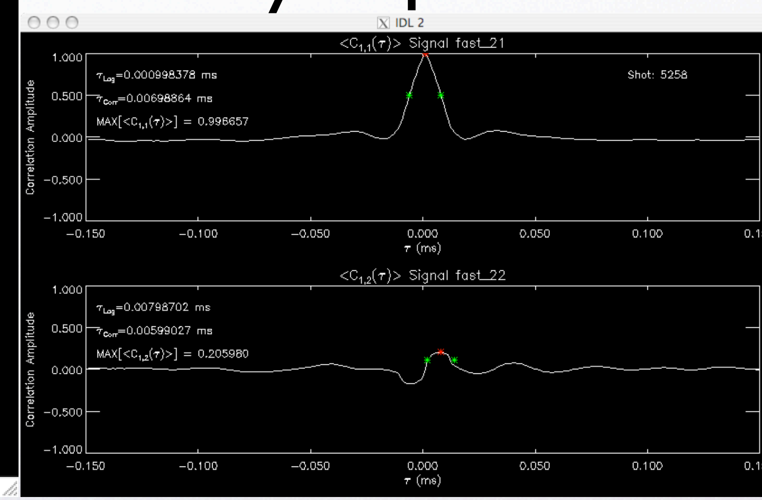
$$C_{1,2}(t,\tau) = [C_{1,2}^{(1)}(\tau), C_{1,2}^{(2)}(\tau), \ldots, C_{1,2}^{(M)}(\tau)]$$

$$< C_{1,2}(\tau) > = \frac{1}{M} \sum_{i=1}^{M} C_{1,2}^{(i)}(\tau)$$

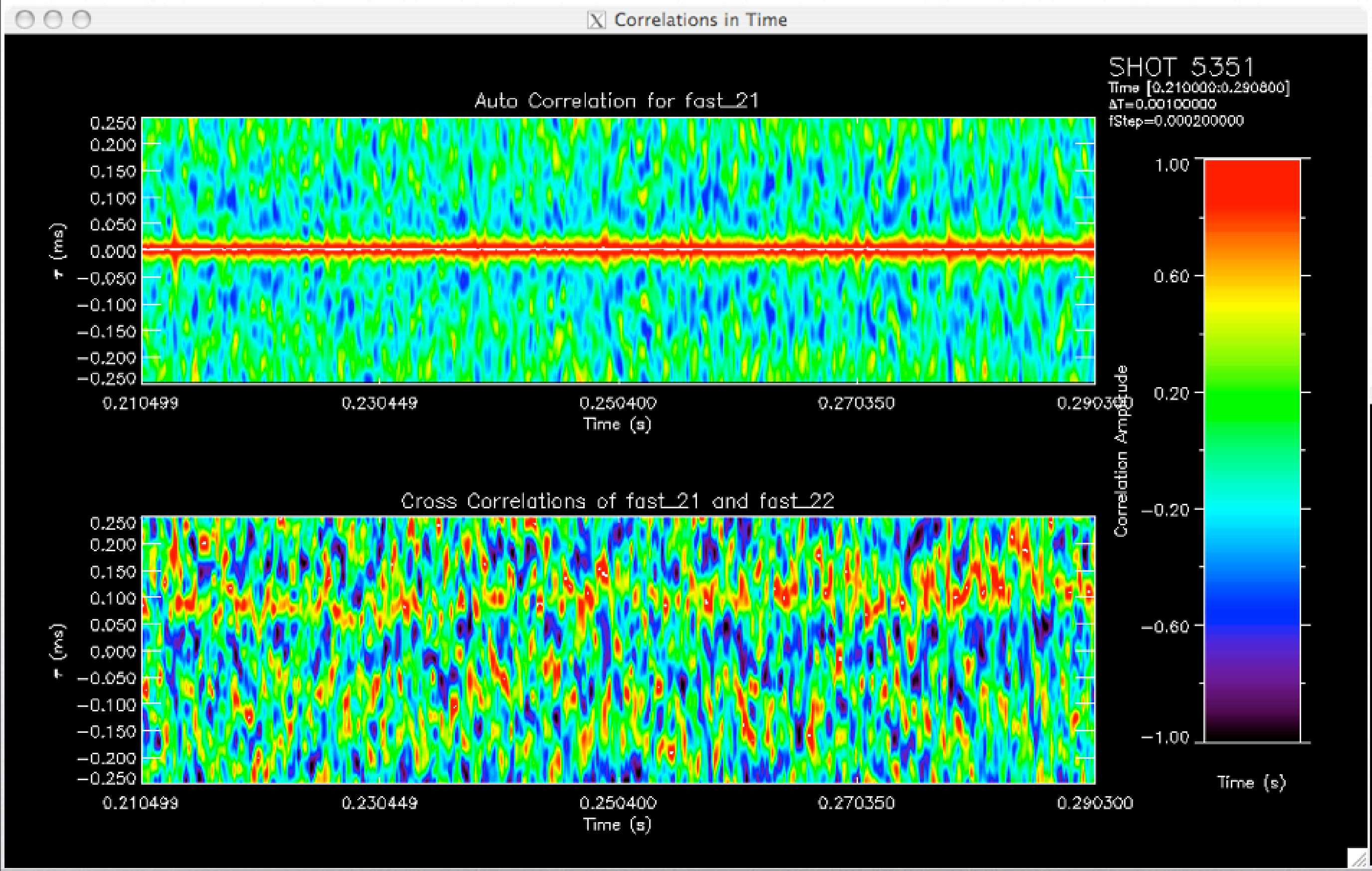
Low Density $C_{1,2}(t,\tau)$

~8μs Lag and 30kHz fluctuations give α=86° for probes separated by Δφ=90°.

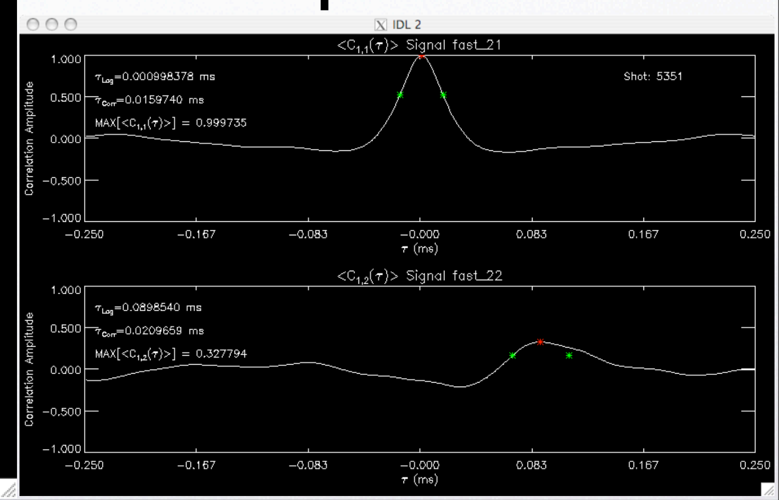




High Density $C_{1,2}(t,\tau)$

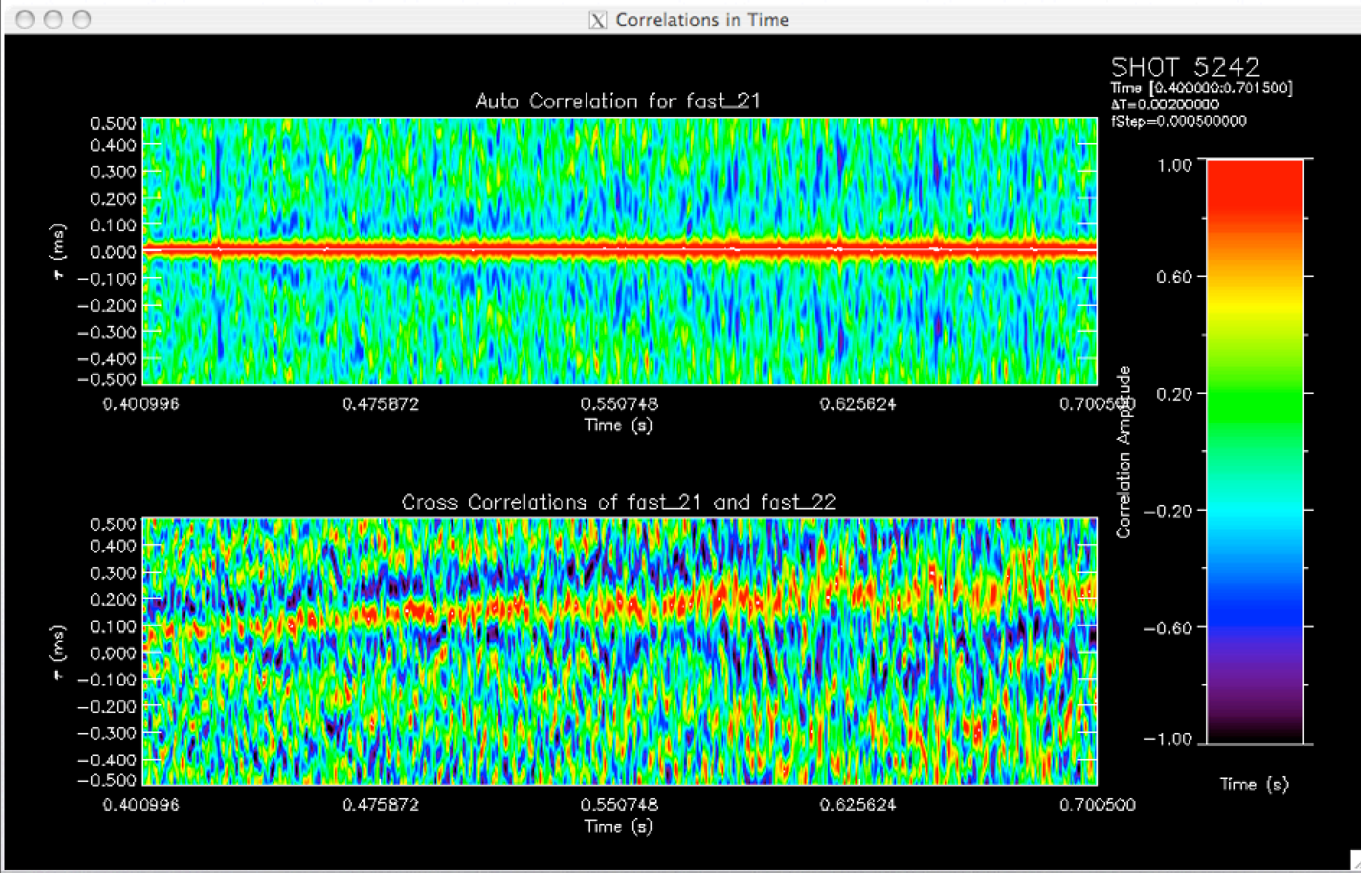


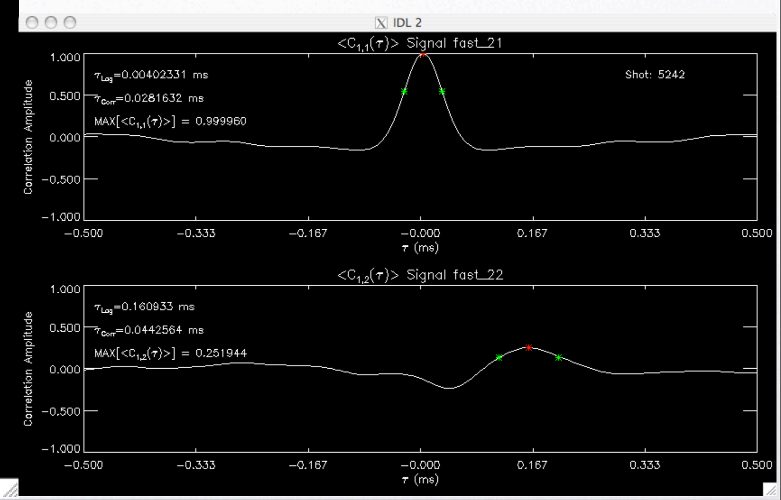
~89μs Lag and 3-4kHz fluctuations give α=90-110° for probes separated by Δφ=90°.



Longer Time High Density

As the discharge evolves, τ_{Lag} ↑ and f ↓, keeping an m=1 mode structure.





Bicoherence

- Transform a time series to the frequency domain.
- Create the Bispectrum over many records (ensemble average)
- Form power-weighted Bispectrum (bicoherence) after M samples have be taken.
- 95% confidence for $b^2 > 3/M$ *

$$S(t) \rightarrow_{FFT} \rightarrow \hat{S}(\omega)$$

$$< A >= \frac{1}{M} \sum_{i=1}^{M} A_i$$

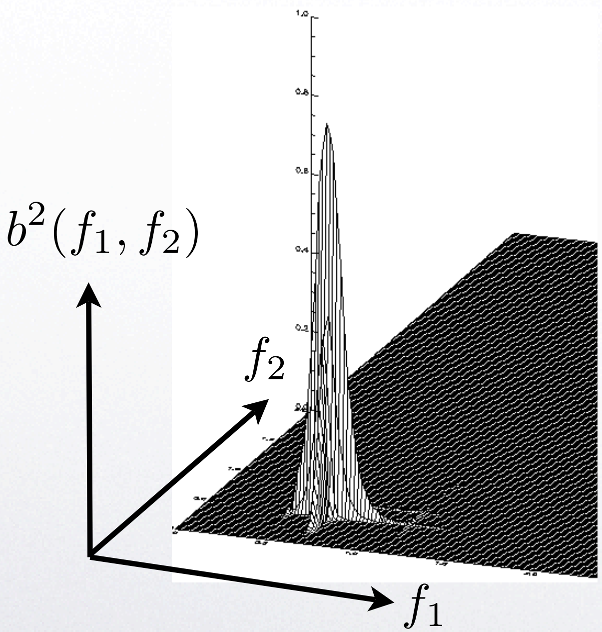
$$\hat{B}(\omega_1, \omega_2) =< \hat{S}(\omega_1)\hat{S}(\omega_2)\hat{S}^*(\omega_1 + \omega_2) >$$

$$\hat{b}^2(\omega_1, \omega_2) = \frac{|\hat{B}(\omega_1, \omega_2)|^2}{| < \hat{S}(\omega_1)\hat{S}(\omega_2) > |^2| < \hat{S}(\omega_1 + \omega_2) > |^2}$$

*V.Nosenko, J.Goree, and F.Skiff, Phys. Rev. E 73 016401 (2006)

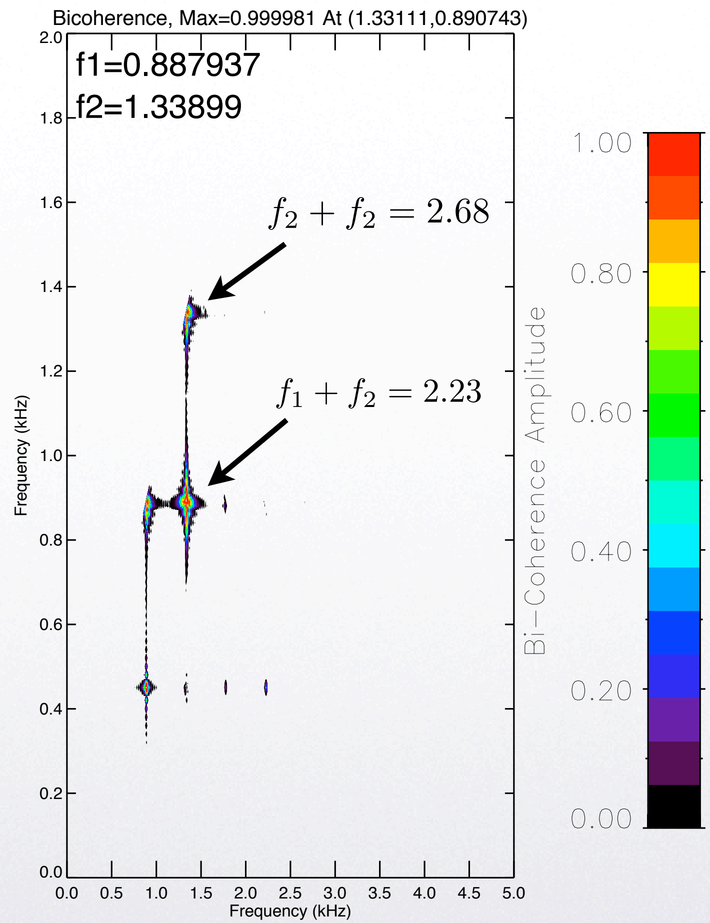
Examples

Bicoherence Surface

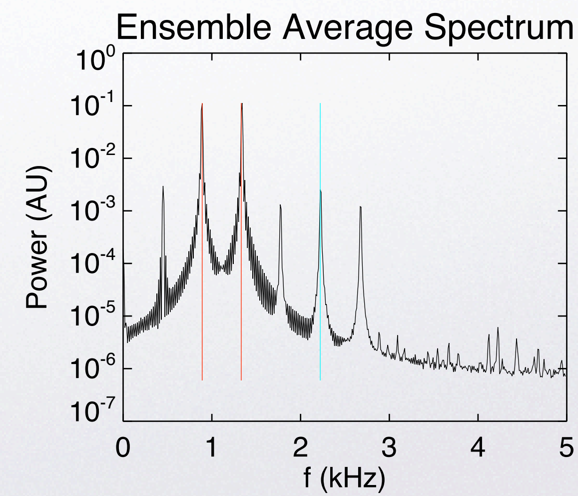


$$S_L(t) = \sum_{i=1}^{2} \sin(2\pi f_i t)$$

$$S_{NL}(t:\epsilon) = S_L(t) + \epsilon S_L(t)^2$$



Strongest 3-wave coupling at sum $f_1+f_2 \sim 2.23$, although others exist.

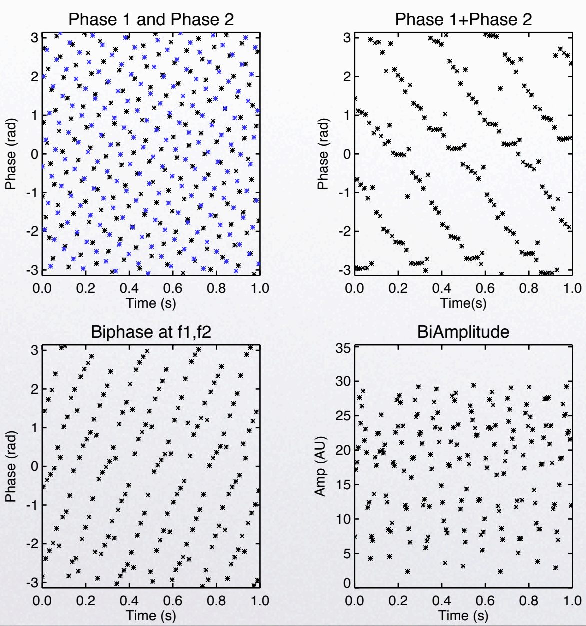


Example Biphase and Amplitude

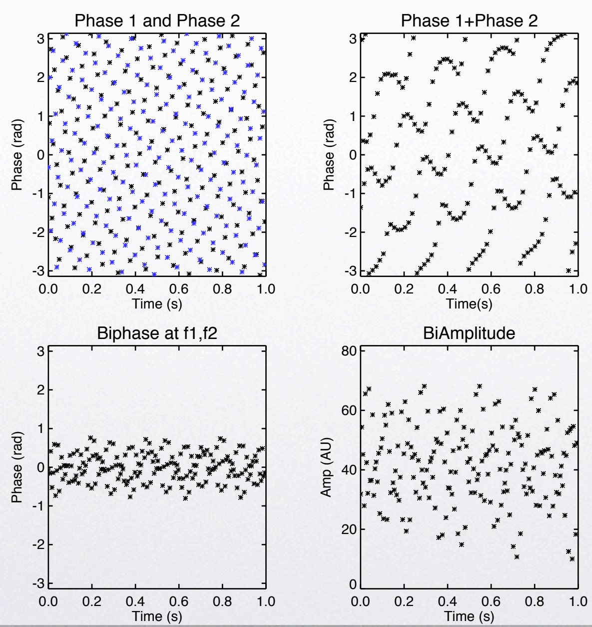
$$B(\omega_1,\omega_2) = |B(\omega_1,\omega_2)|e^{i\angle B(\omega_1,\omega_2)} = Ae^{i\varphi_B}$$

$$S_{NL}(t:\epsilon) = S_L(t) + \epsilon S_L(t)^2$$

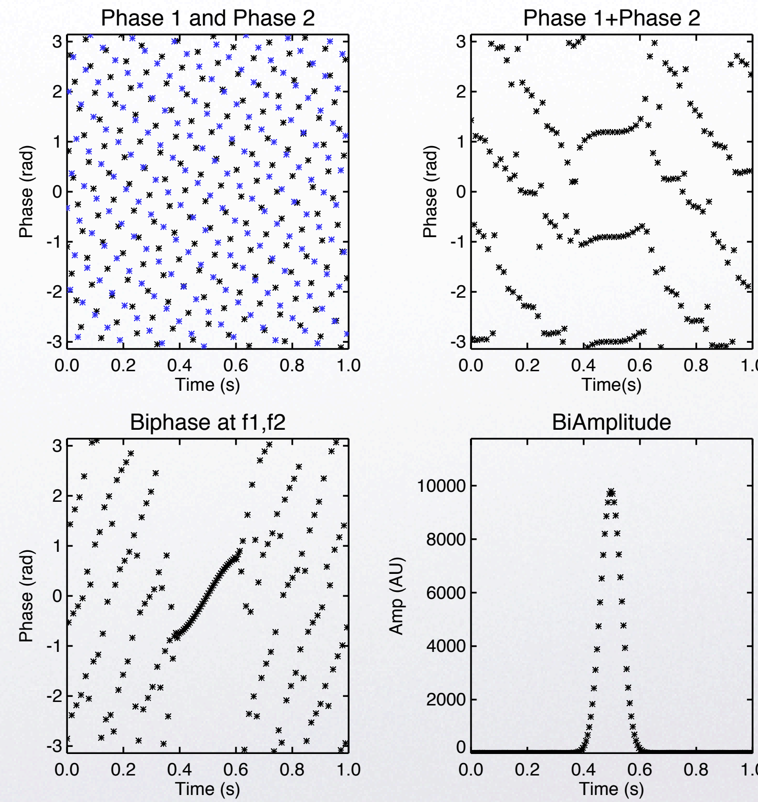
ϵ=0.0



ϵ=.1%



ϵ is a Gaussian [0,1]

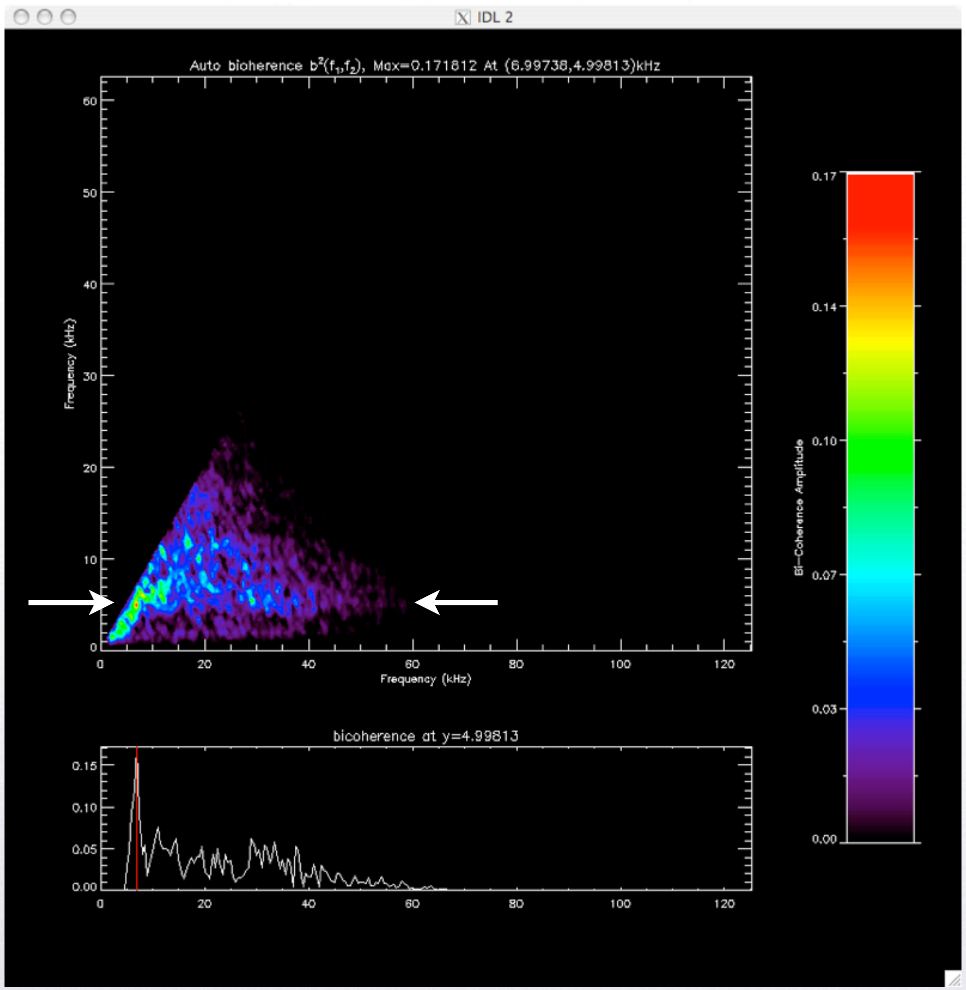


The Analysis Procedure

- For the following figures, 740 records have been taken to calculate the bicoherence.
- The records overlap by 75% to accurately measure the biphase evolution.
- The frequency pair where the Max Bispectrum occurs is tracked in time, as well as the amplitude (BiAmplitude).
- The BiAmplitude is qualitative, and measures the intensity of mode-mode coupling in time.
- The frequency pairs record where (in frequency-space) the coupling occurs in time.

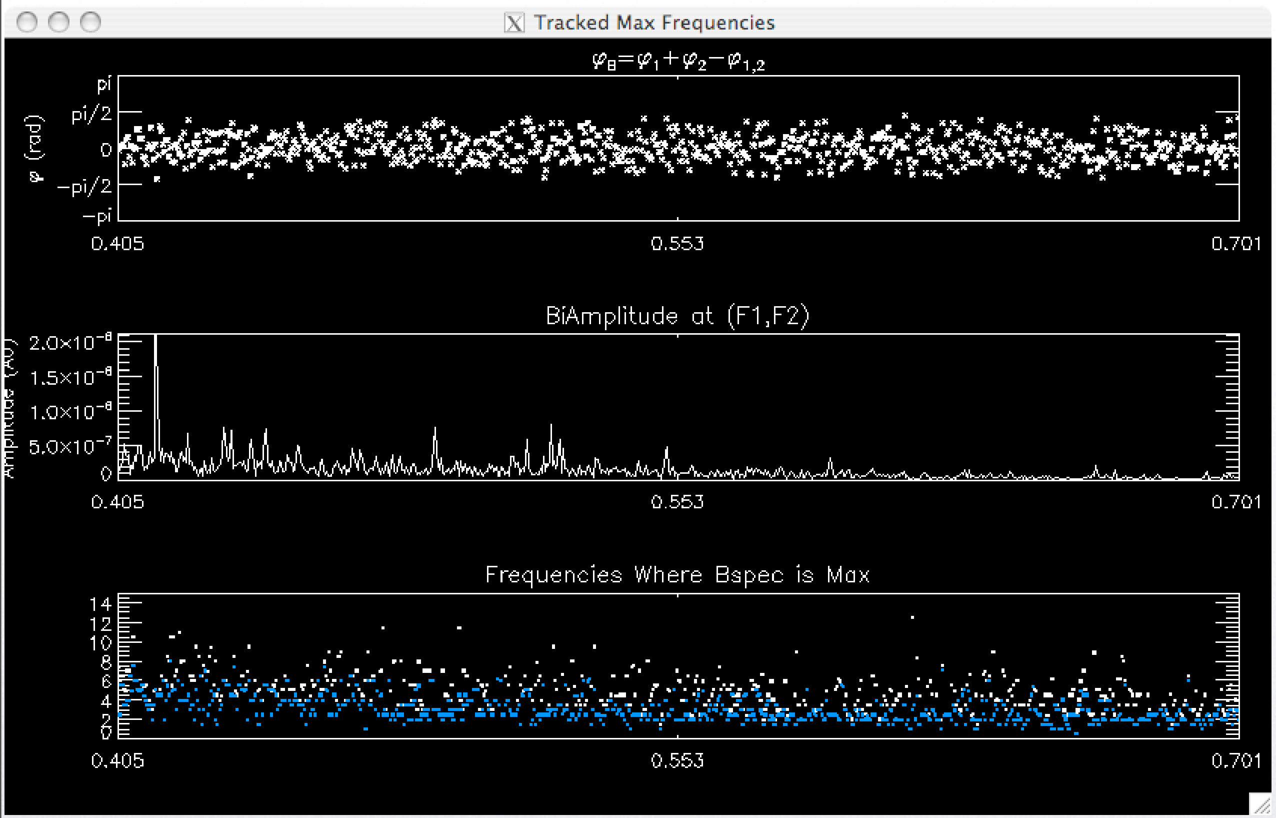
This rather lengthy explaination is necessary, because we are using a Fourier Mode technique to measure non-stationary fluctuations. Dominant frequencies evolve, making the bicoherence a ‘smeared-out’ statistical measure.

Bicoherence



- Bicoherence Max at $(f_1,f_2)=(7,5)$ kHz indicating mode-mode coupling (not harmonic).
- Coupling exists above statistical cutoff (0.004) across many frequency pairs (triangle-like region).
- 5kHz mode coupled to 7-40kHz modes (white arrows).

Biphase



- Tracked pairs maintain a biphase close to zero (phase coupled)
- BiAmplitude displays intermittency, but decreases over time.
- Frequencies at Max BiSpectrum decrease.

Summary

- High density plasmas have been formed in the CTX device by increased fueling.
- The increased fueling causes a suppression of the Hot Electron Interchange mode, but gives rise to low frequency (3-8kHz) turbulent interchange modes.
- Low frequency modes have $k_{||} \approx 0$ (not shown) and power-law frequency spectrum.
- Bicoherence for mode-mode coupling significant (Dominated by non-linear processes)
- Frequency of fluctuations decrease as neutral pressure continues to rise.