Strong, Nonaxisymmetric Flows Driven in a Dipole Confined Plasma

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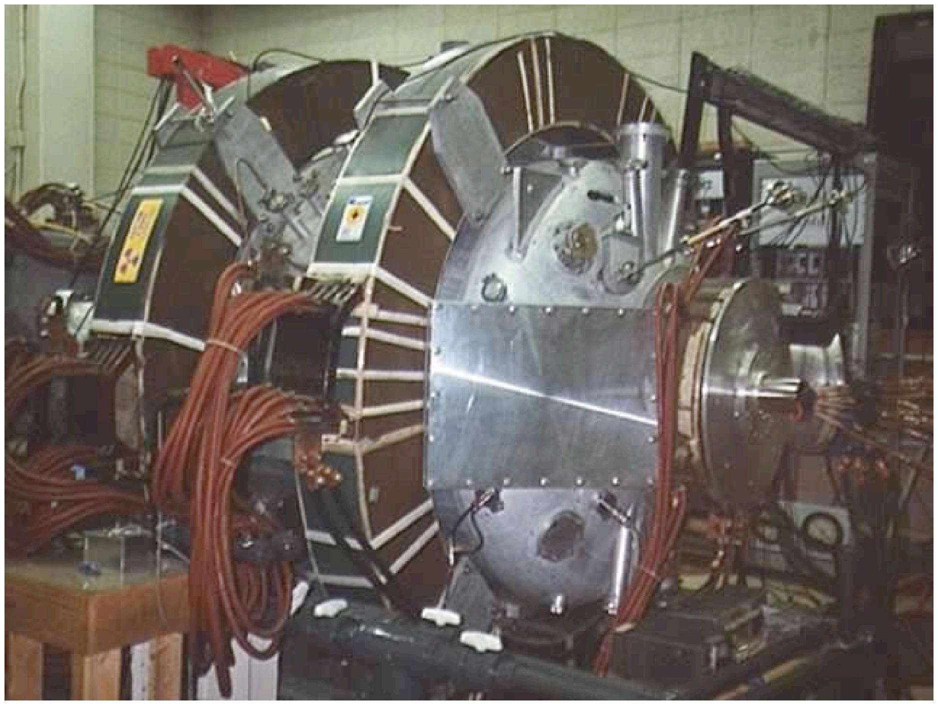
Abstract

- Previous studies using the Collisonless Terella Experiment (CTX) have shown plasma dynamics to be dominated by interchange mixing. Since the geometry of the dipole magnetic field has no shear, interchange turbulence and interchange transport become two-dimensional. The usually complicated study of plasma turbulence and transport becomes less so in dipole geometry, provided plasma dynamics is appropriately described with field-line averaged quantities. In this presentation, strong, nonaxisymmetric plasma flows are induced by application of electrostatic bias in two ways. The first approach employs a negatively biased (~-1000 V) large diameter probe inserted at various radii in order to charge a central flux-tube and drive nonaxisymmetric cross-field currents. The second approach employs a nonaxisymmetric bias applied to a series of meshes located at the inner, equatorial edge of the plasma. Very strong plasma flows can be induced, and these allow systematic study of nonlinear effects such as electrostatic structure coupling. Additionally, we observe a dramatic decrease in low-frequency turbulent fluctuations when the strength of the nonaxisymmetric bias exceeds a threshold.

The Collisionless Terella eXperiment



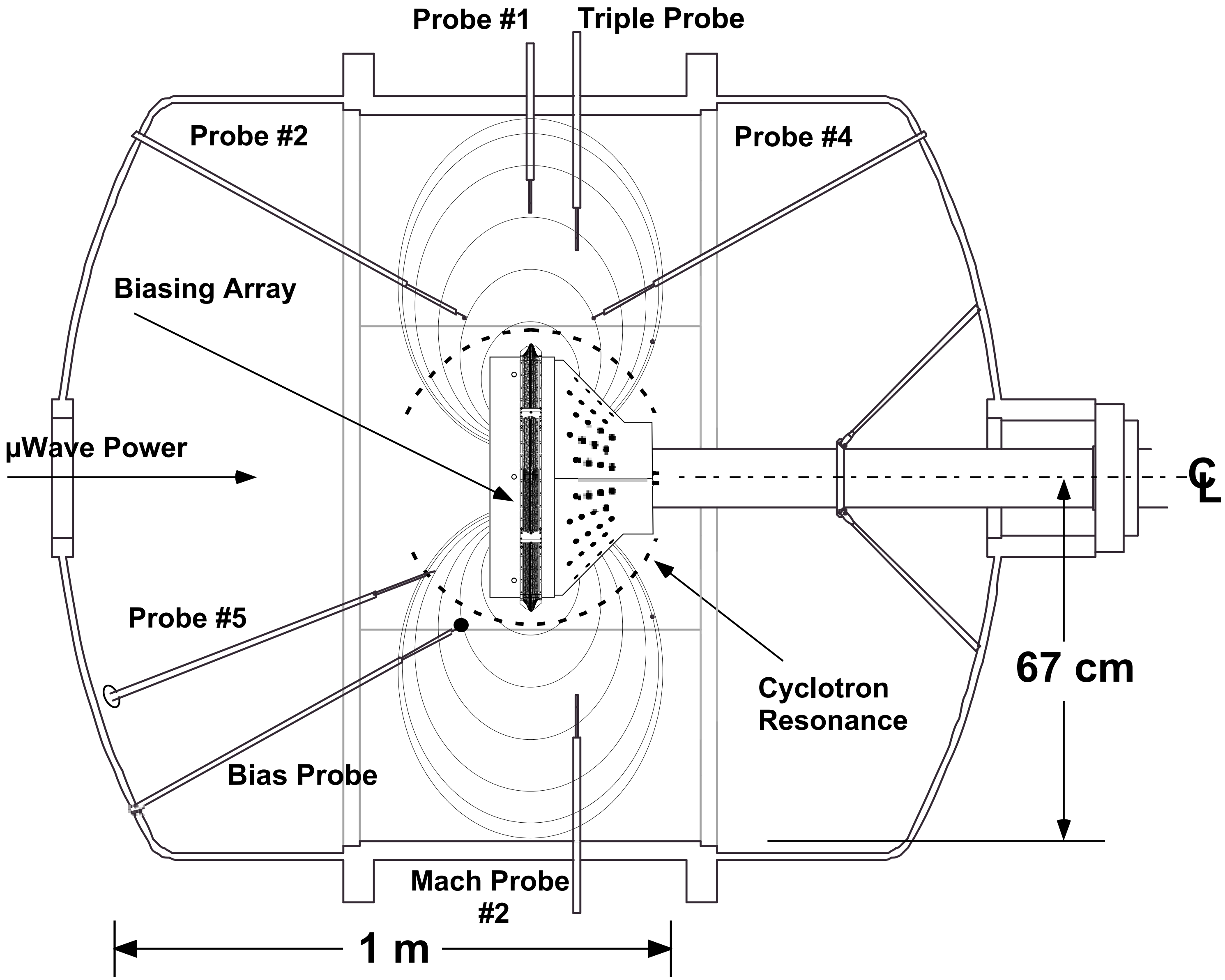
Basic parameters:

Magnetic field at equator, B_T	2 kG
Terrella radius, R_T	20 cm
Energetic electron energy, E_h	1-20 keV
Radius of peak intensity, L_h	1.5
Energetic electron density, n_h	$0.5 - 1 \times 10^{10}$ cm^{-3}
Total plasma density, n	$1 - 2 \times 10^{10}$ cm^{-3}

Dynamical parameters:

Cyclotron frequency, $\omega_c/2\pi$	2 GHz
Bounce frequency, $\omega_b/2\pi$	150 MHz
Drift frequency, $\omega_d/2\pi$	0.4 MHz
Normalized energy, $(\rho/L)^2$	5×10^{-5}

Diagnostics



- 3 Langmuir Probes
- Triple Probe
- Isat Probe
- Bias Probe
- Mach Probe
- Gridded Energy Analyzer
- Polar Imager (Array of 70 Gridded Energy Analyzers)

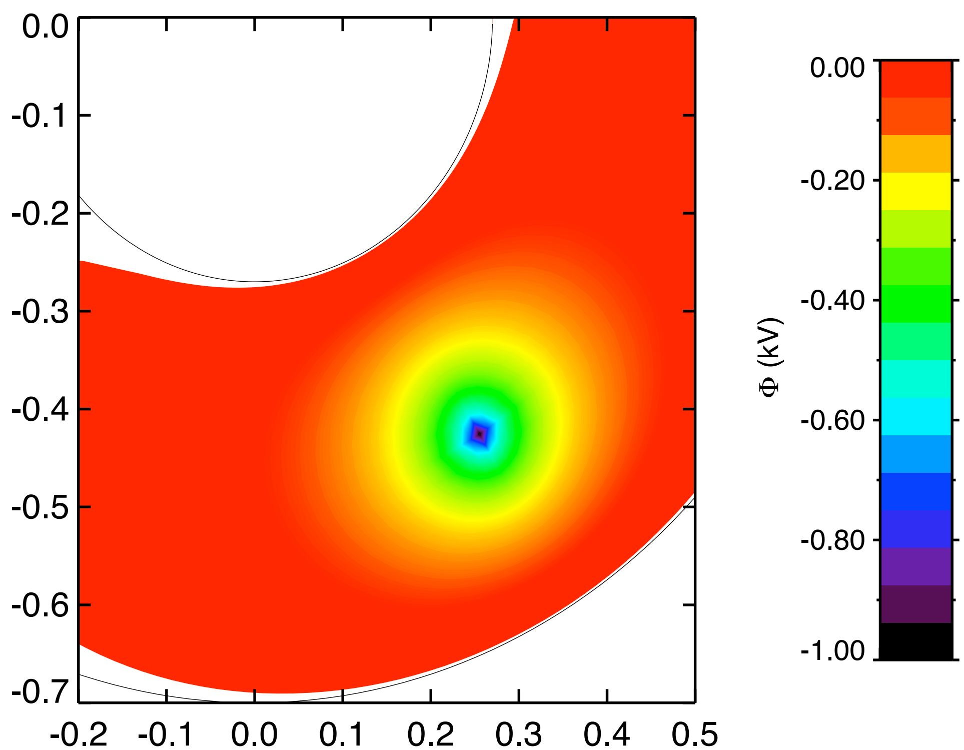
Driving Flows

- Previously biased six equatorial meshes located on innermost flux surface
- Negative bias excited centrifugal mode (Levitt et al., PRL 94, 175002(2005))
- Use biasing to create ExB flows in targeted patterns with bias probe and nonaxisymmetric biasing of the equatorial meshes

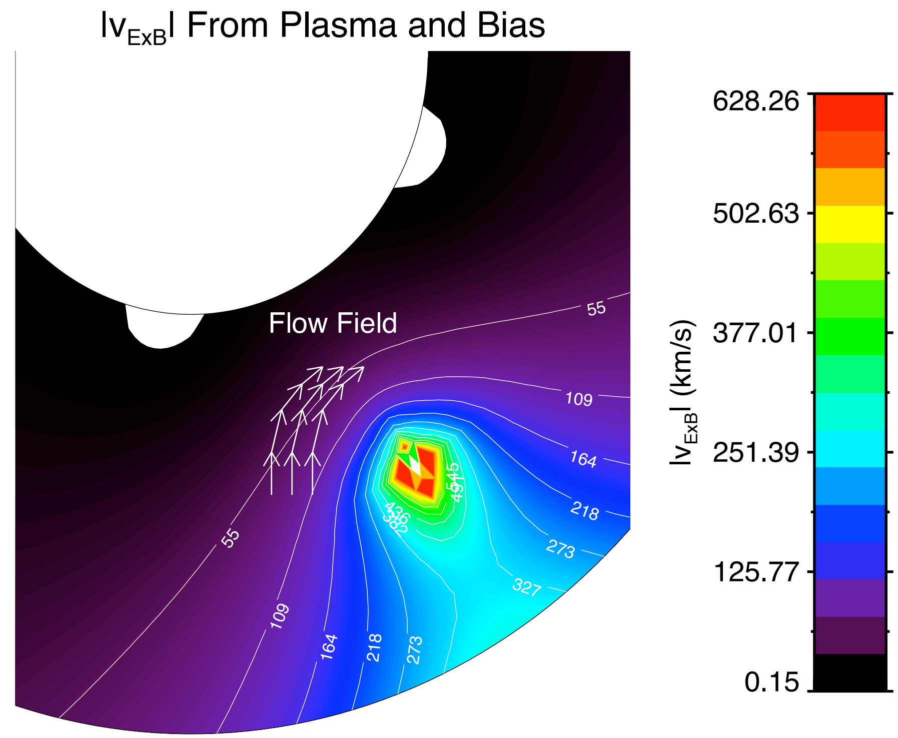
Bias Probe

- 1" Stainless sphere connected to HV Supply(0 to +/-5kV, 40mA)
- Voltage at probe tip monitored (doubling as floating probe during shots without bias)

Predicted Potential and ExB Velocity Field



Potential



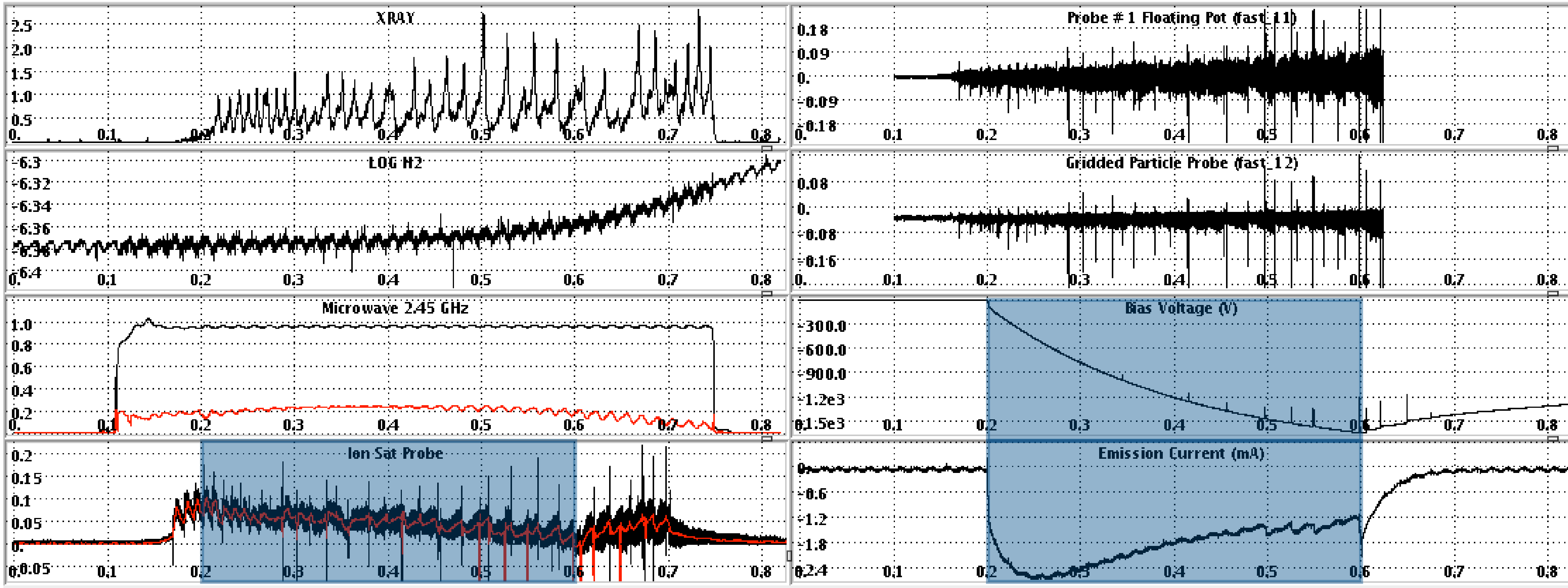
ExB Contours

- Φ_b = -1000 V

Operating Regimes

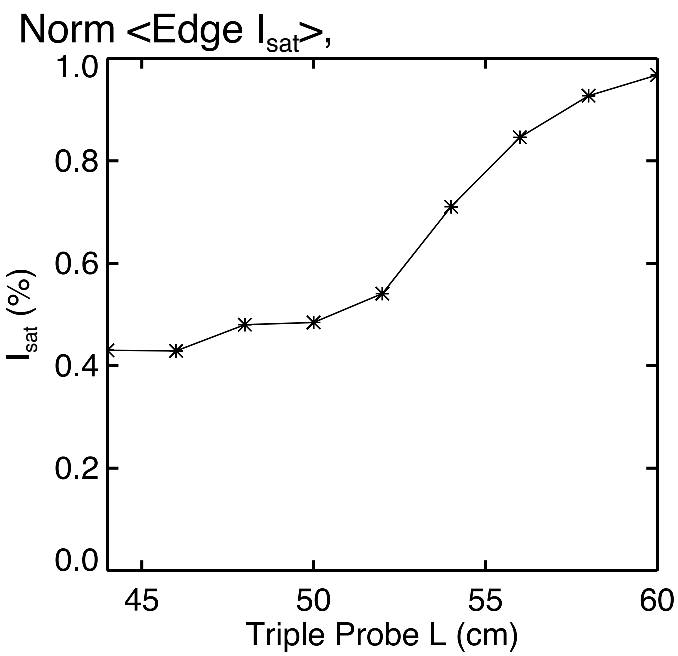
- Low Density Regime:
  - Initial 1μs gas puff, 2 μs secondary puff at .25s.
  - Bias Probe configured as floating probe
- Static Bias Regime:
  - Initial 1 μs gas puff
  - Bias Probe set to constant -1.5kV
- Triggered Bias Regime:
  - Initial 1 μs gas puff
  - Bias Probe gated (.2,.6), reaches -1.6kV

Scope Snapshot

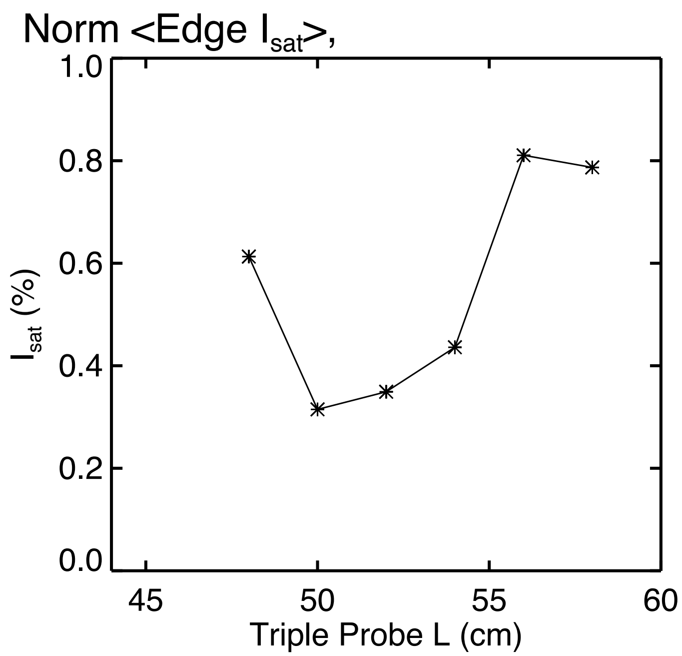


I_{sat} drops during biasing, recovering after current to probe cut

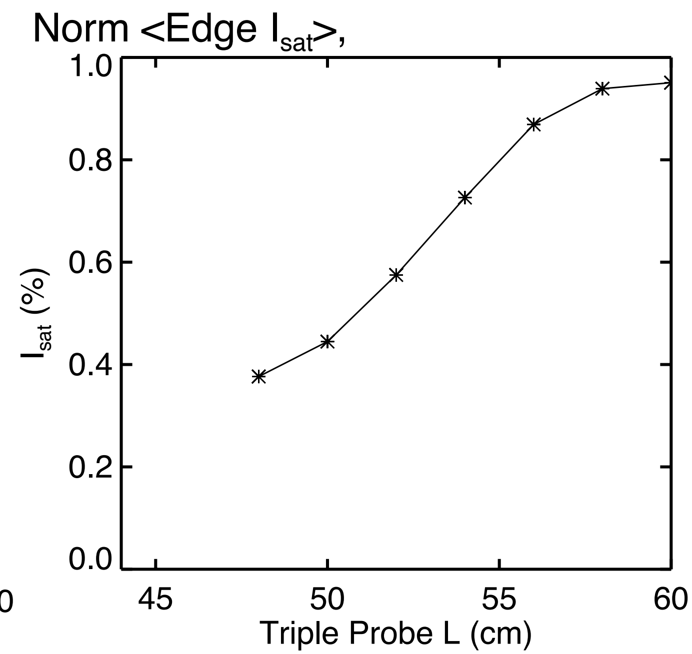
I_{sat} Profiles



Triggered



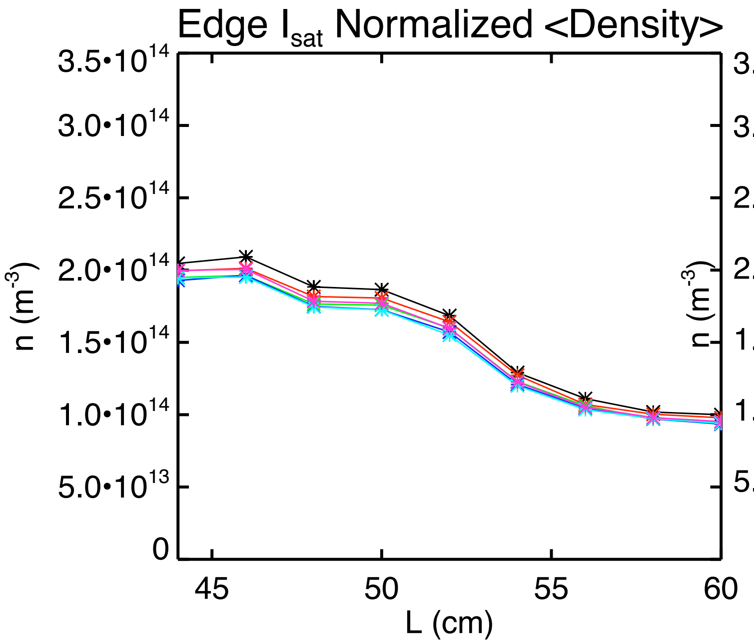
Static



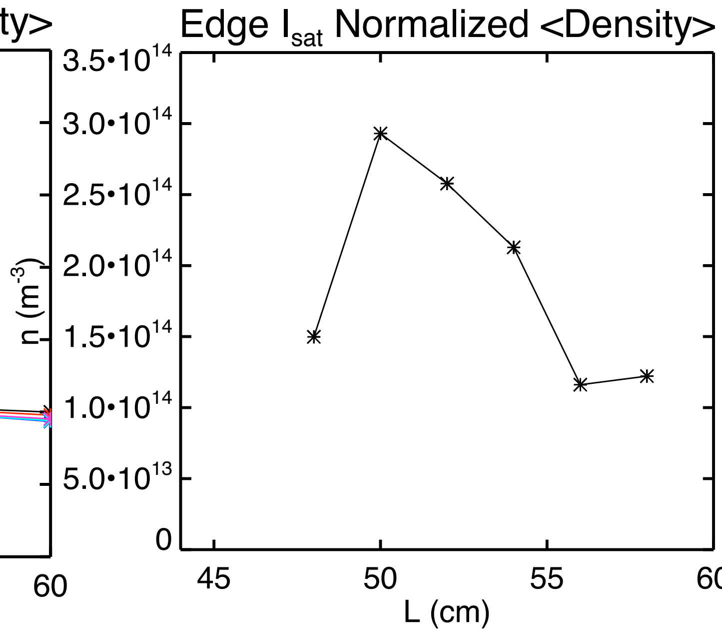
Low Density

- Average I_{sat} /$I_{sat\ @\ edge}$ shows probe perturbing the plasma
- Static Bias Case very low signal levels

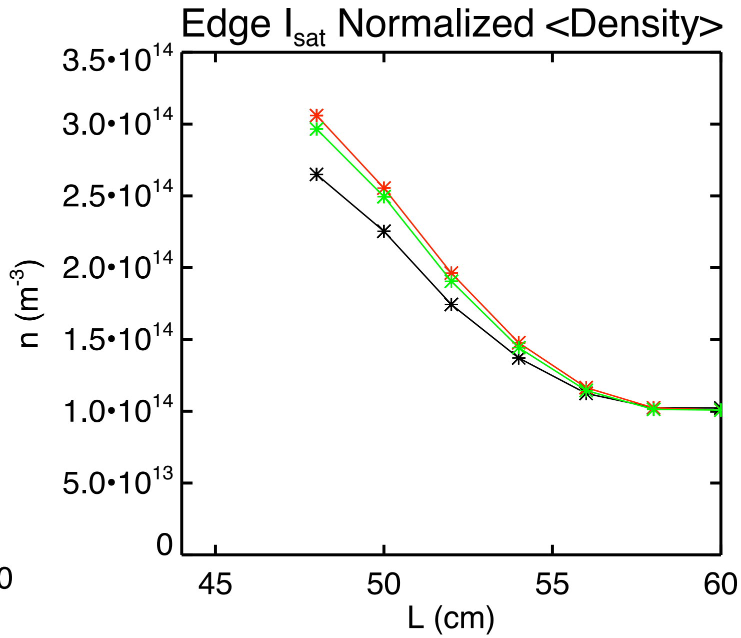
Density Profiles



Triggered



Static

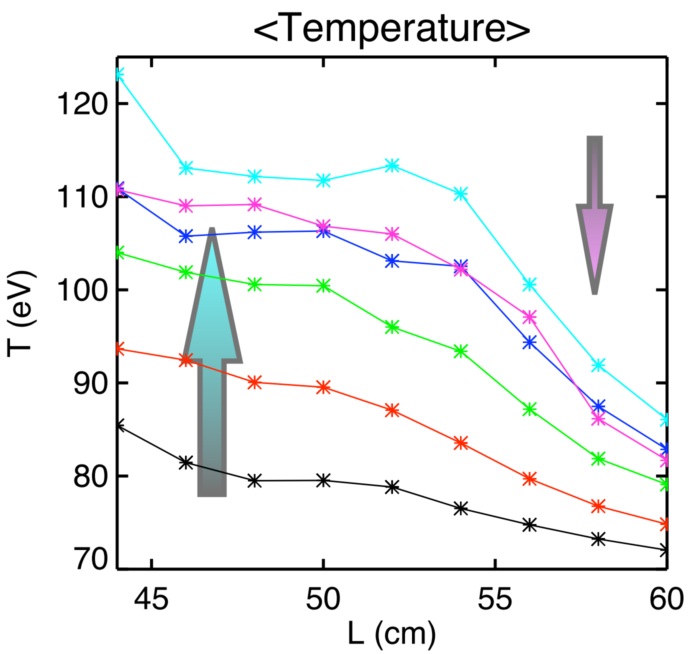


Low Density

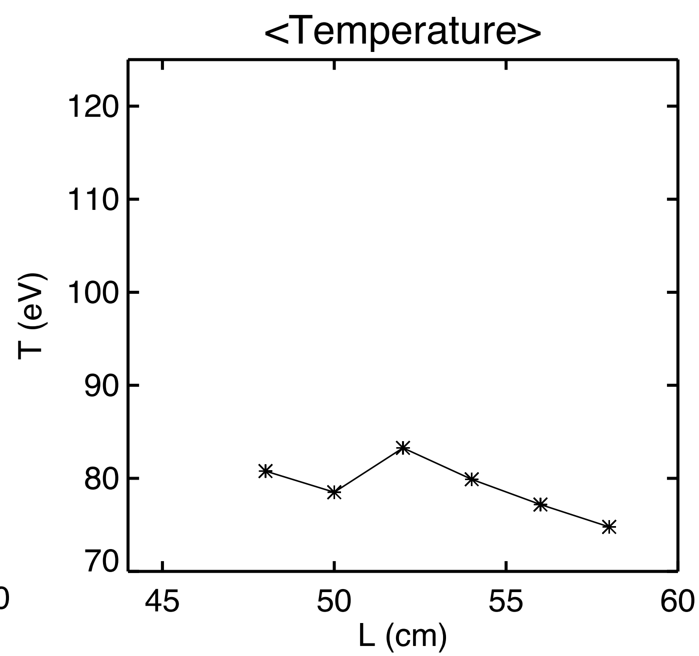
Calculated Density normalized by the I_{sat} profiles to correct for triple probe perturbing the plasma

Density profile expected to be far more peaked ~ L^{-6}

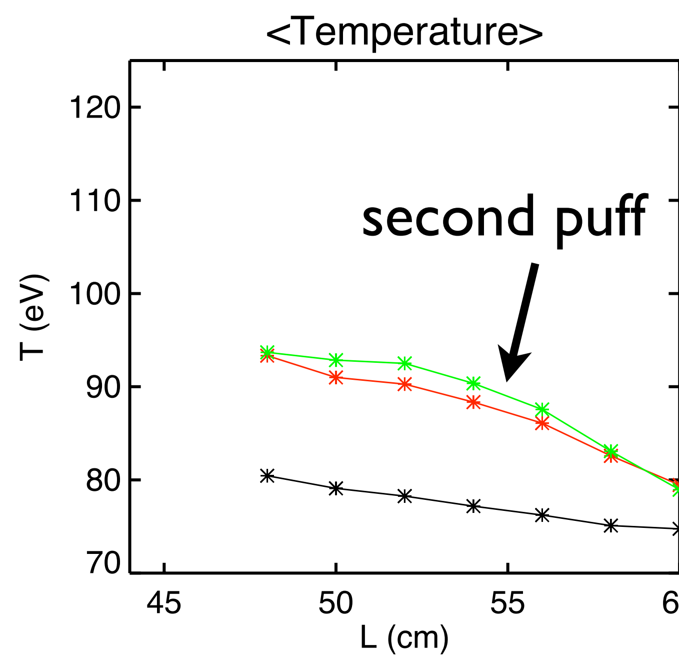
Temperature Profiles



Triggered



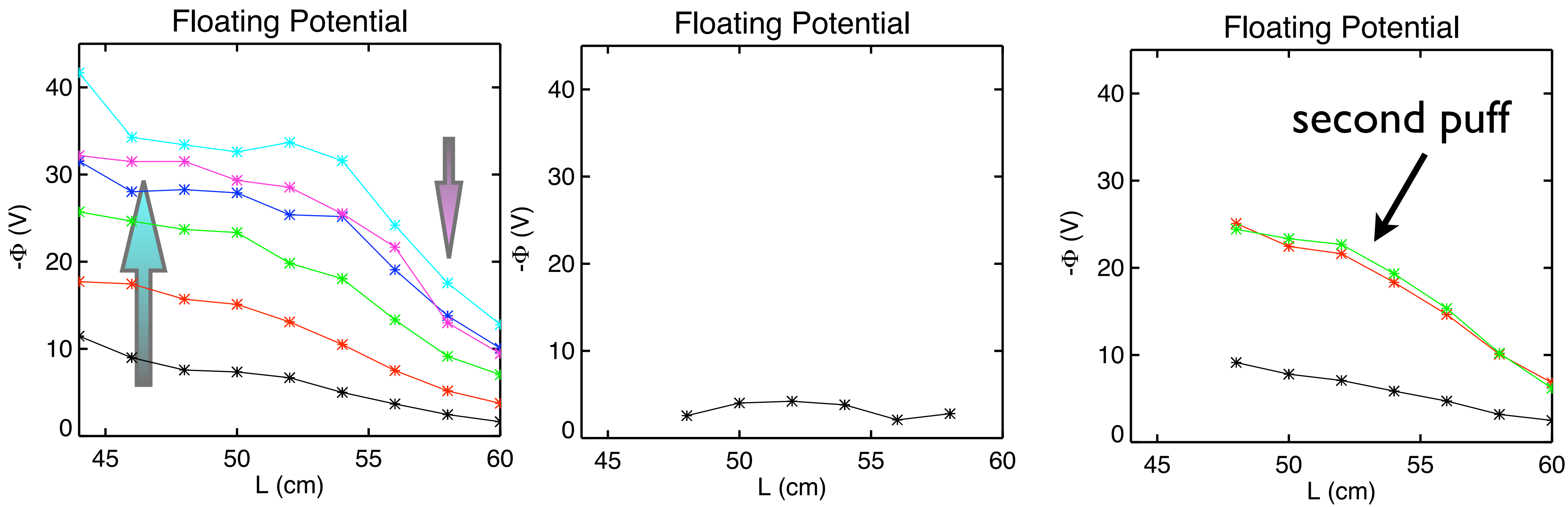
Static



Low Density(rise from secondary puff)

Multishot averages over .1s advancing during the shot (last curve decreased after bias turned off)

Floating Potential Profiles

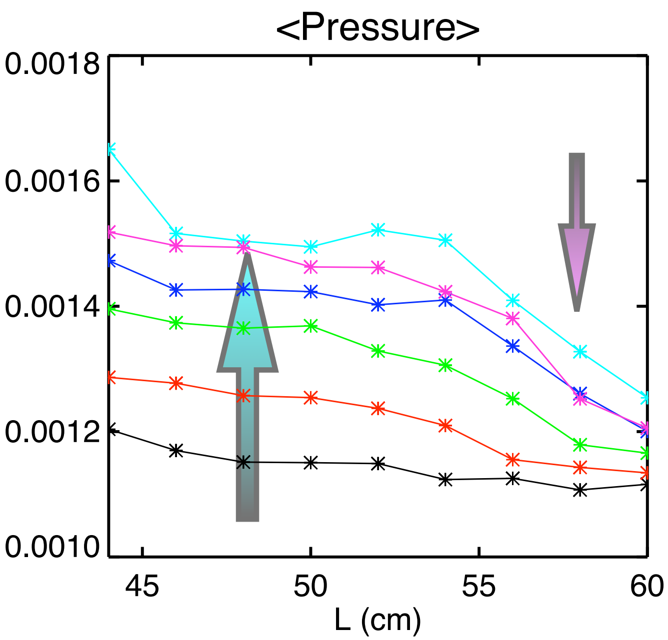


Triggered

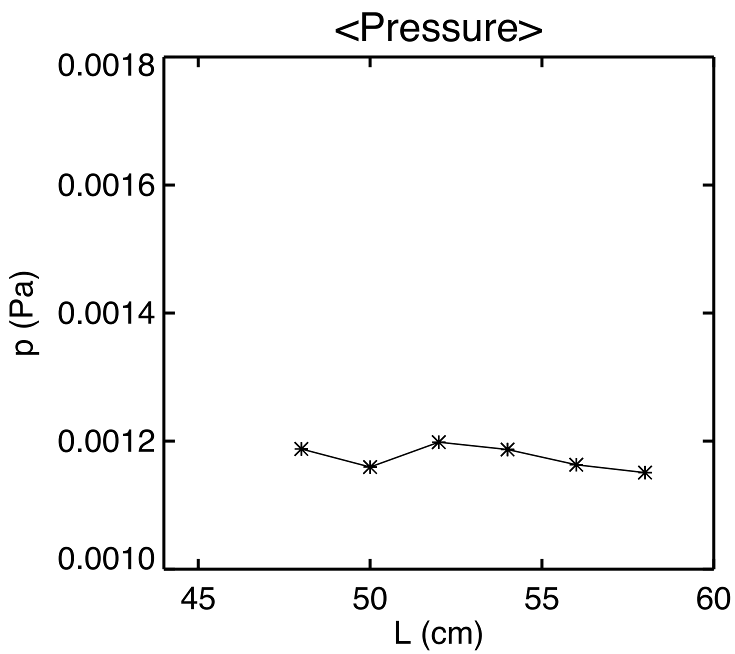
Static

Low Density

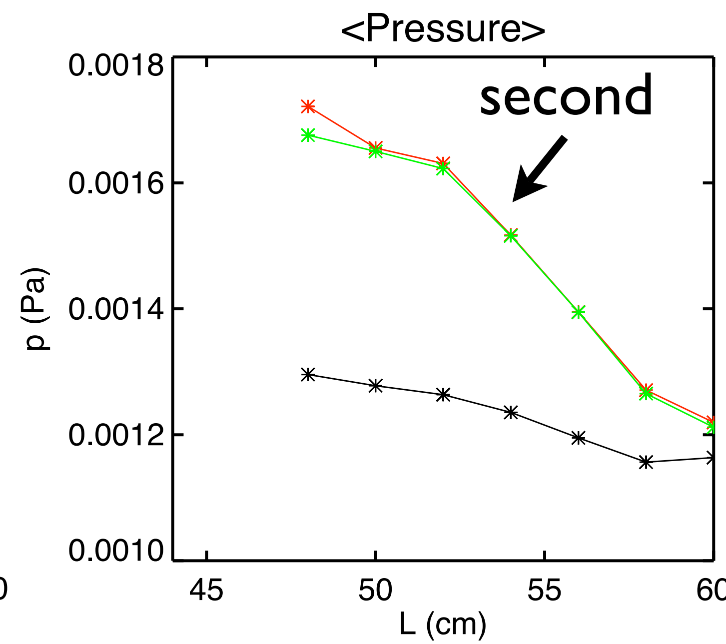
Pressure Profile



Triggered



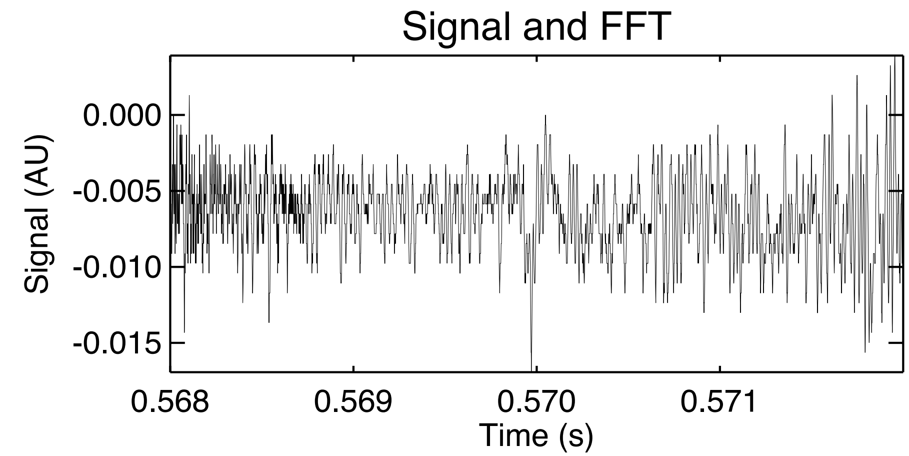
Static

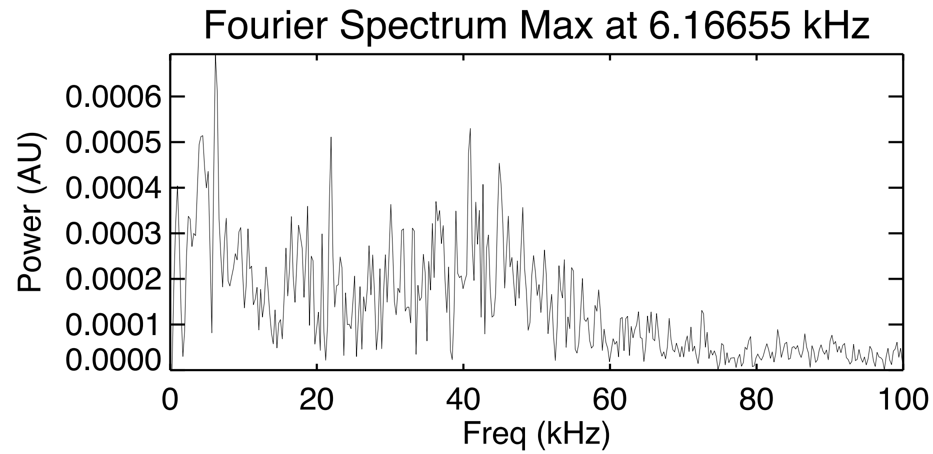


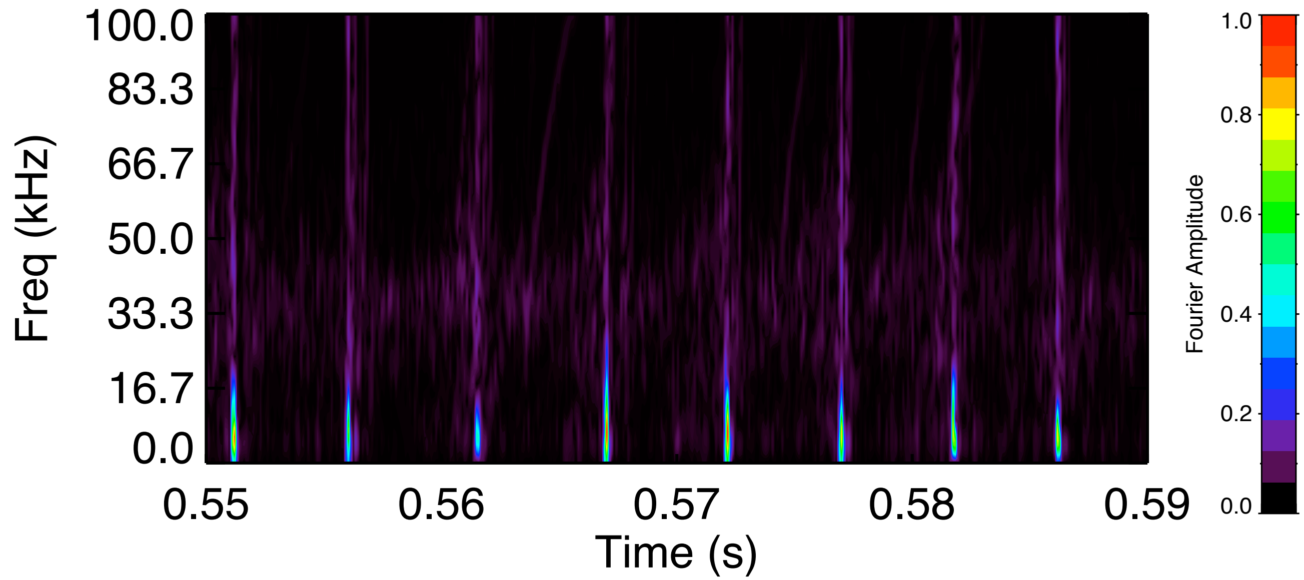
Low Density
(secondary puff)

Unbiased Low Density

- Shot #5531, Probe #5
- Quiet period between HEI bursts displayed in FFT

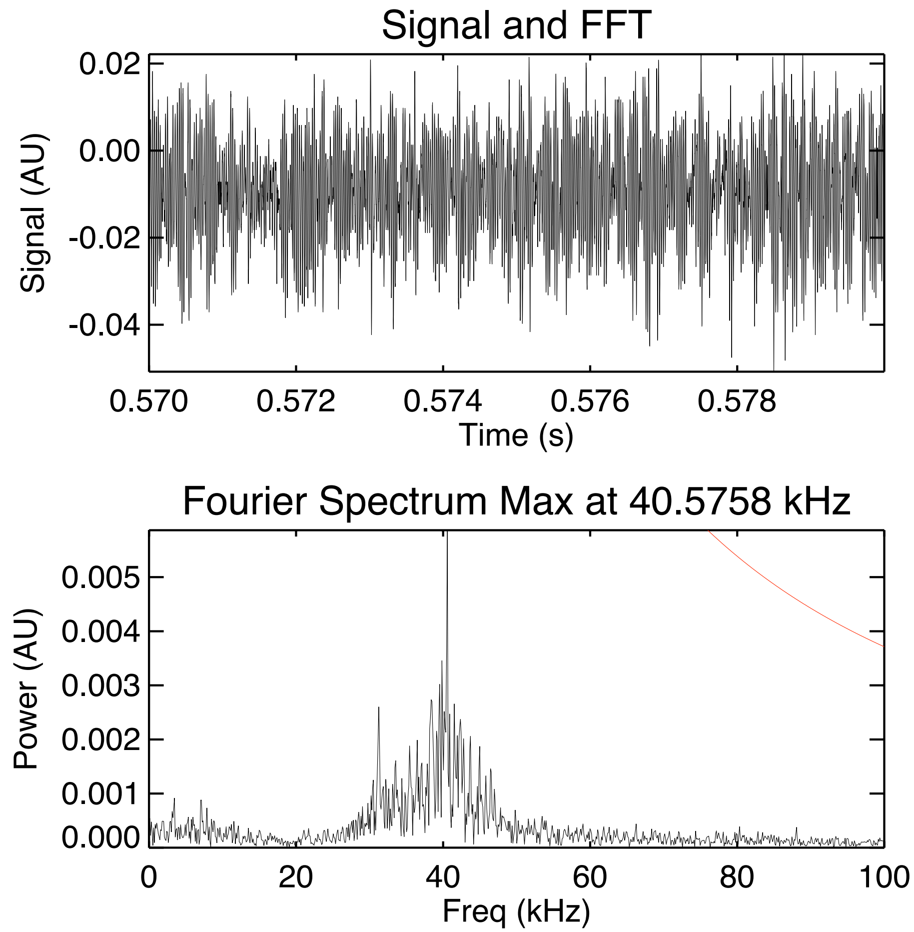


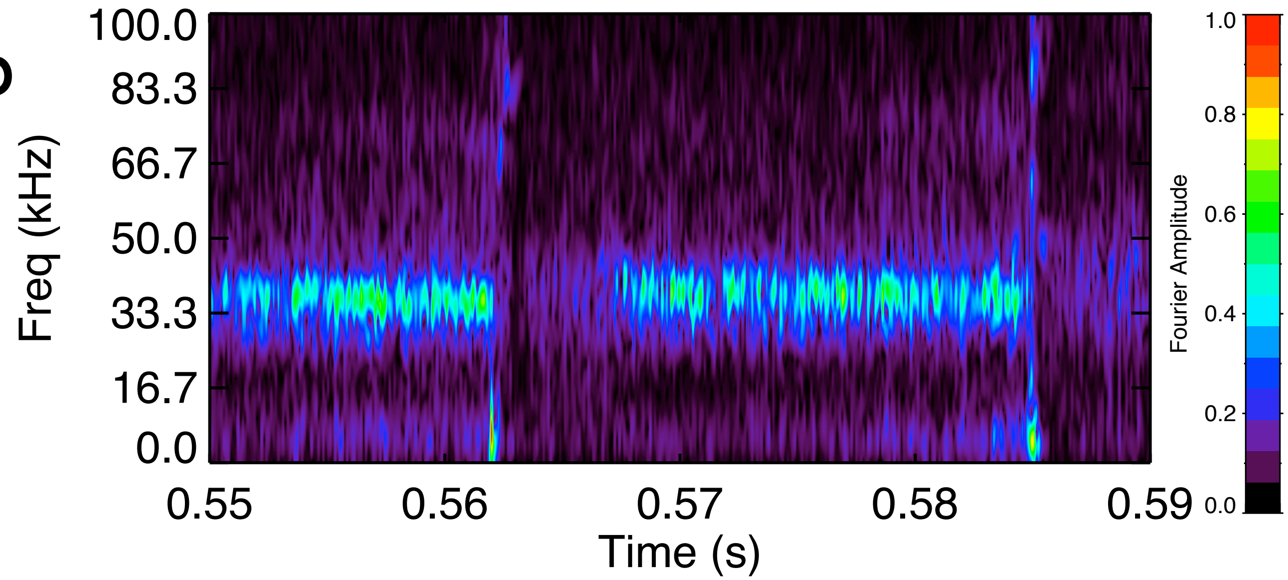




Triggered Bias Probe

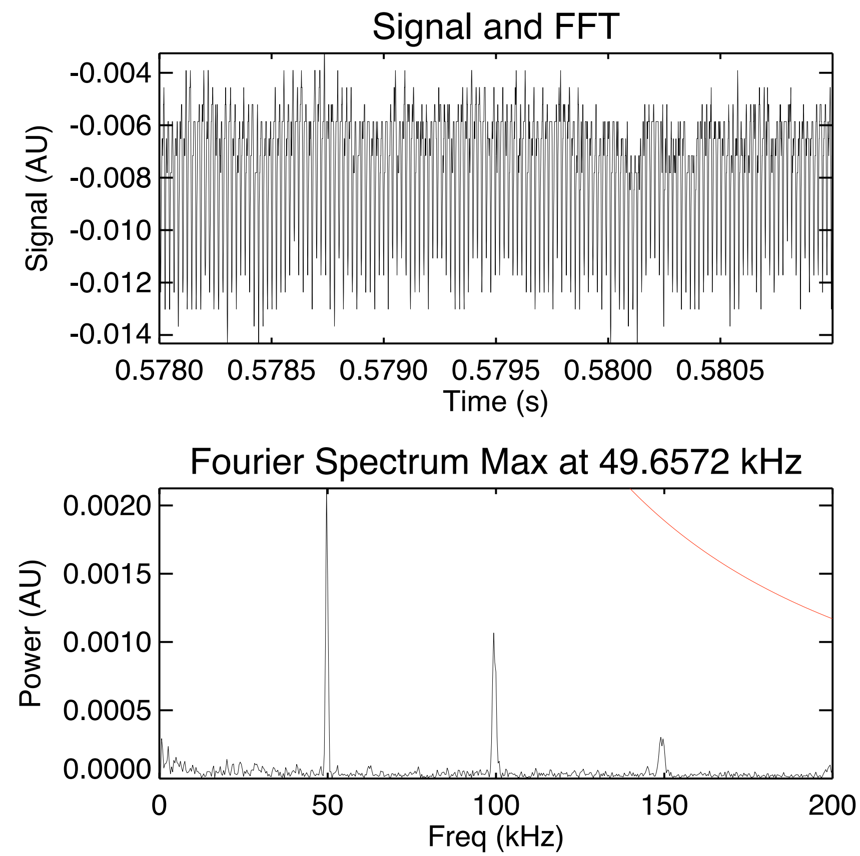
- rarely recover similar nonlinear signals, slow frequency climb
- Shot #5510, Probe 5

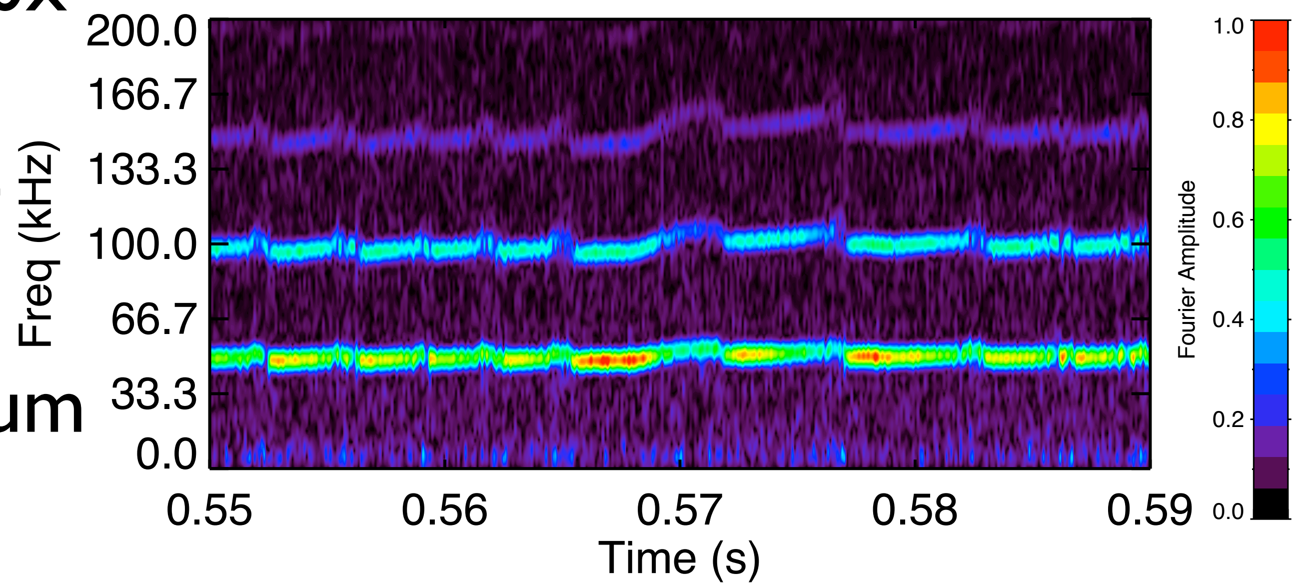




Steady State

- Shot #5540, Probe #5
- radial current, polar loss current 1000x less than probe emission current
- as voltage rises turbulent spectrum falls away





Bicoherence

- Technique to detect three-wave coupling within a signal
- Bispectrum formed through ensemble average of many records (hundreds)
- Bicoherence is the power-weighted bispectrum

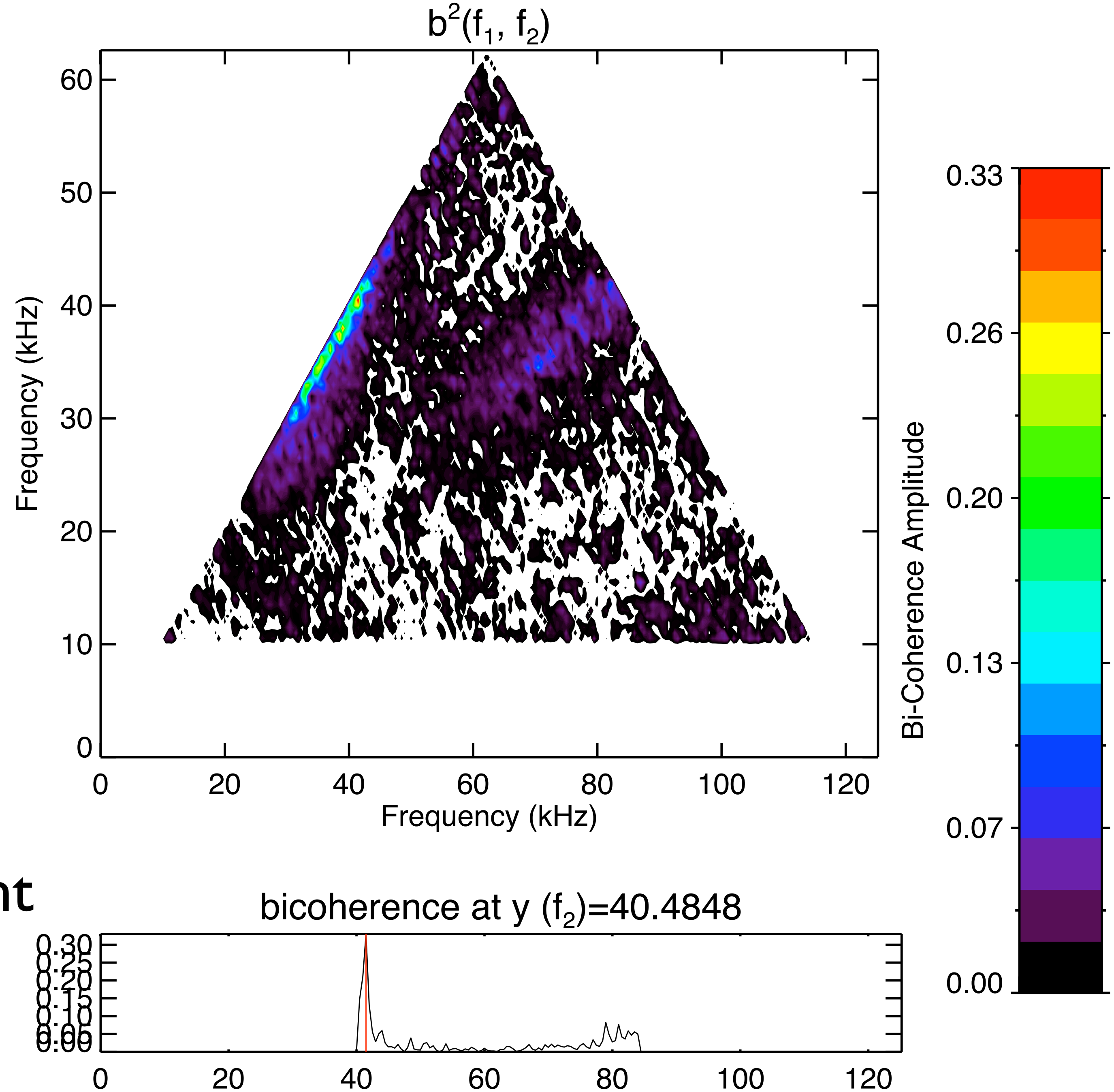
$$S(t) \rightarrow_{FFT} \rightarrow \hat{S}(\omega)$$

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

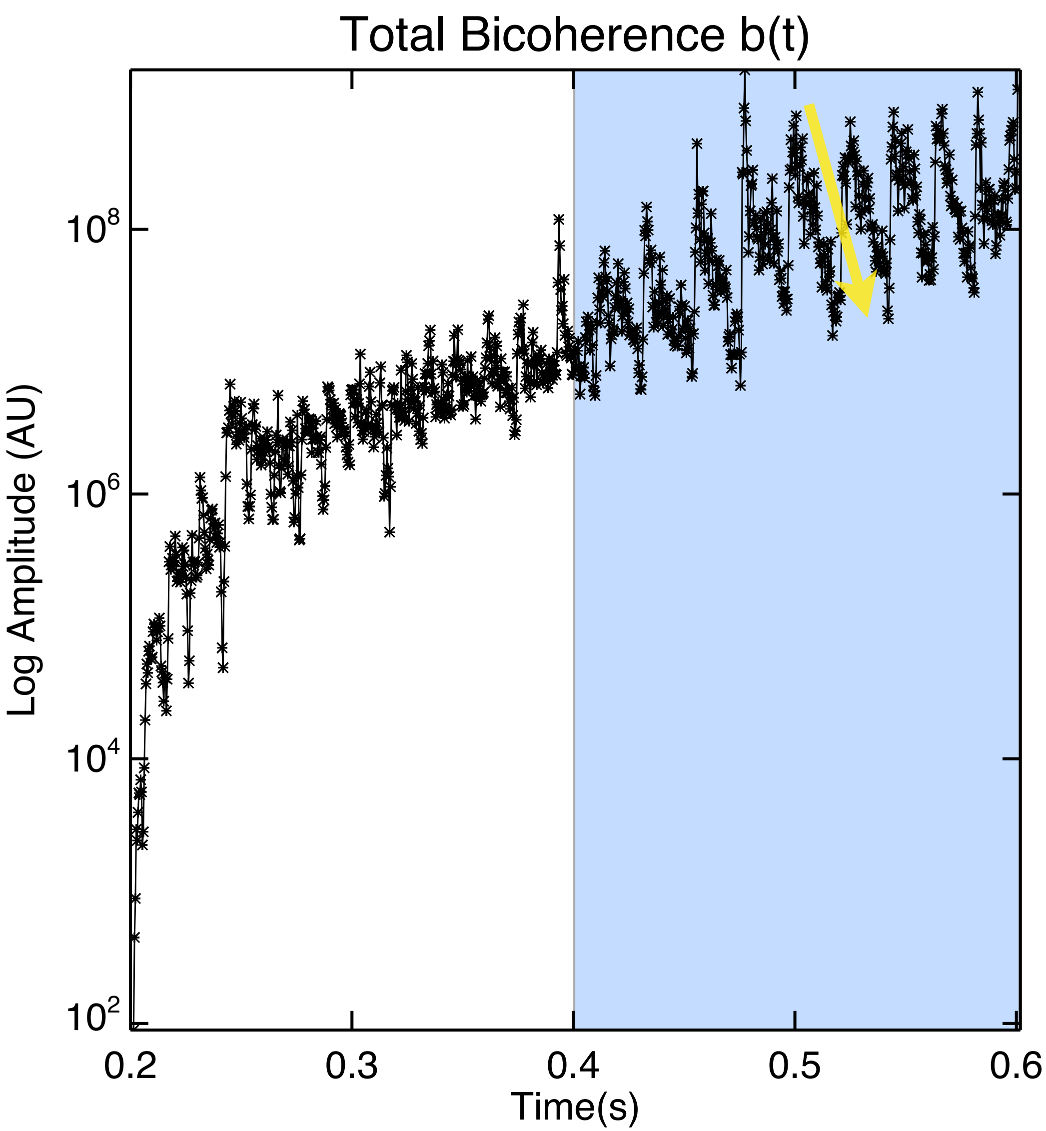
$$\hat{B}(\omega_1, \omega_2) =< \hat{S}(\omega_1)\hat{S}(\omega_2)\hat{S}^*(\omega_1 + \omega_2) >$$

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

- Triggered Bias:
- Regions on-axis indicate harmonic coupling
- Only frequency pairs above statistical cutoff plotted
- Ensemble average over long window (on-axis component smeared out as frequency evolves)



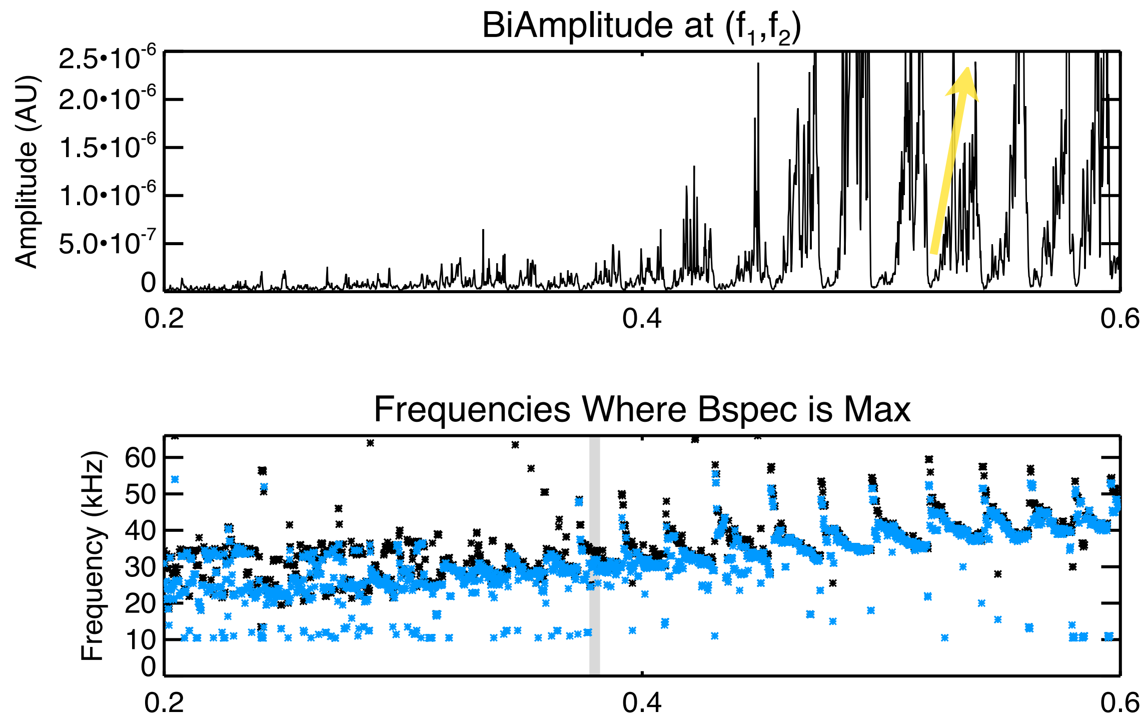
Total Bicoherence



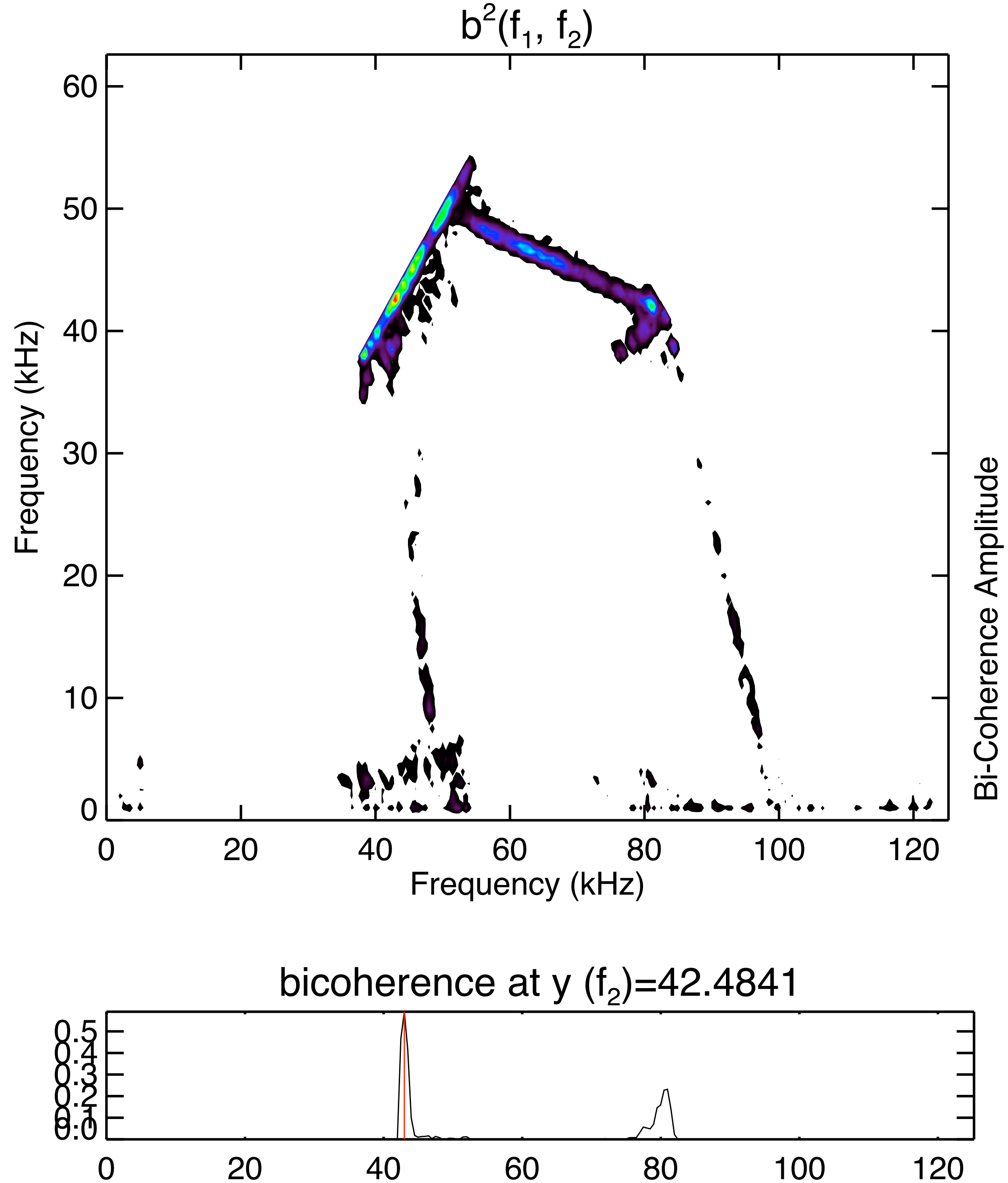
- Triggered Bias Shot
- Statistical Measure of coupling across all freq. (sum of full plane)
- During [0.4,0.6] HEIs cause jumps, followed by decay

More Bicoherence

- Top plot shows biamplitude at the max. frequency pair, increasing between HEIs
- Lower plot displays frequencies of the max. biamplitude. At ~.37s (V=1kV) behavior shifts, Coupling becomes harmonic (overlaid dots)

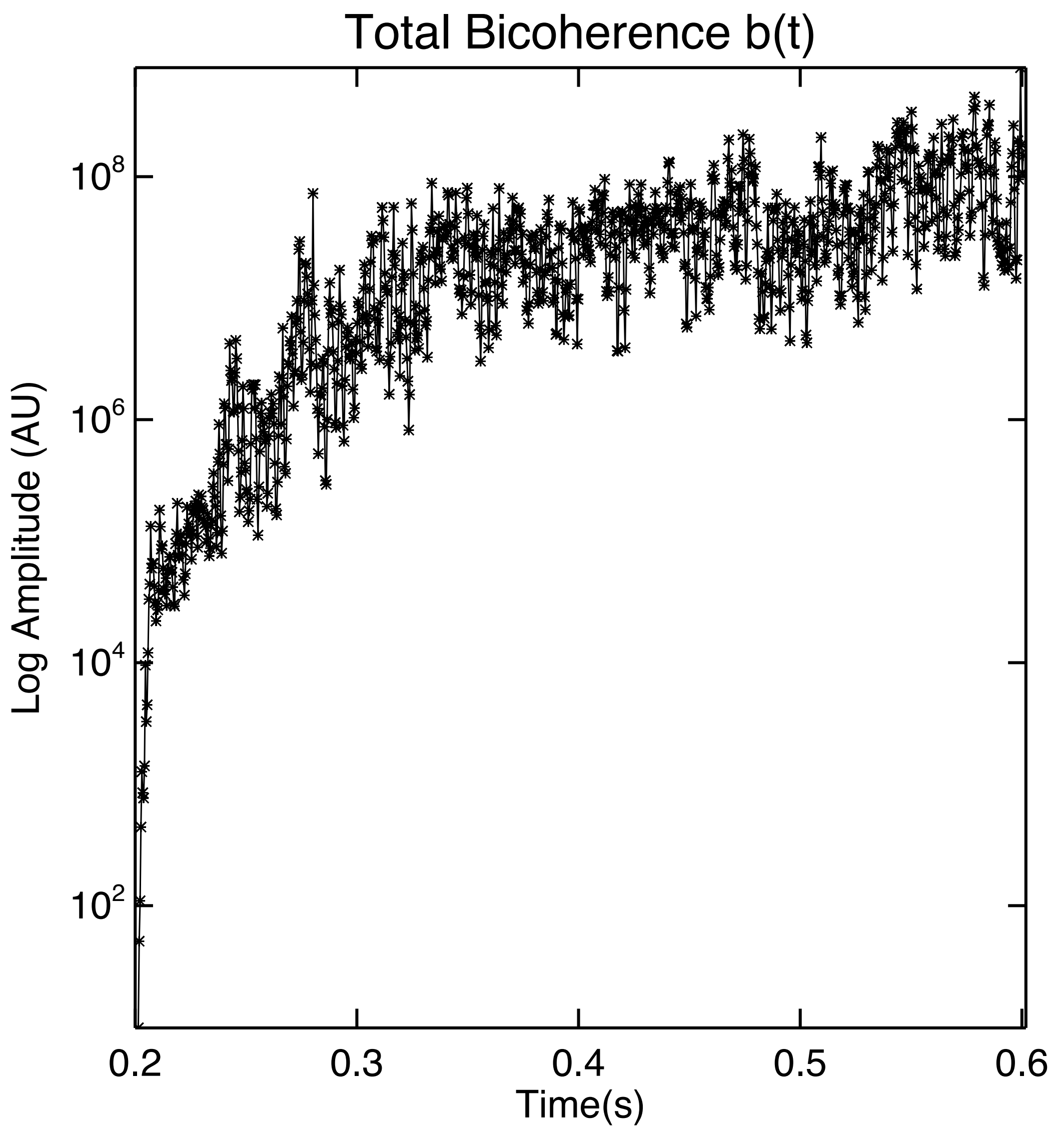


- Static Bias, Shot 5540
- Coupling very concentrated, most frequency pairs below statistical floor
- Off diagonal line indicates coupling, other than harmonic



Total Bicoherence

- During a static bias shot, rises during plasma formation then saturates
- Amplitude similar to triggered bias case, despite lower coverage of the bicoherence plane



Conclusions

- Application of high negative voltage excites existing mode in CTX while suppressing the turbulence normally present, this is seen during triggered biasing and most obviously during static biasing
- Hot Electron Interchange bursts disrupt nonlinear bias mode during triggered bias operation, as the mode recovers bicoherence rises in the mode, but drops over all frequencies
- Triggered biasing decreases (more negative) the floating potential (similar temperature and pressure profile increases)

Future Work

- Apply positive bias with bias probe through high current power supply (~500mA)
- Additional Bias Probes?
- Modulate voltage frequency and phase, will this suppress/enhance the nonlinear mode?