

Bispectrum and Bicoherence In Dipole Confined Plasmas

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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

IkW ECRH @2.45GHz ECRH Resonance at L=27cm

Low Density Plasma

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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.

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Correlations

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

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

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

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

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Low Density C_{1,2}(t,T)



~8 μ s Lag and 30kHz fluctuations give α =86° for probes separated by $\Delta \phi$ =90°.





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High Density C_{1,2}(t,T)



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







Longer Time High Density



As the discharge evolves, T_{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 b²>3/M *

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

$$S(t) \to_{FFT} \to \hat{S}(\omega)$$
$$< A >= \frac{1}{M} \sum_{i=1}^{M} A_i$$

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

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

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$$S_L(t) = \sum_{i=1}^{2} \sin(2\pi f_i t)$$
$$S_{NL}(t:\epsilon) = S_L(t) + \epsilon S_L(t)^2$$

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







Example Biphase and Amplitude





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 nonstationary fluctuations. **Dominant frequencies** evolve, making the bicoherence a 'smearedout' statistical measure.

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Bicoherence



•Bicoherence Max at (f₁,f₂)=(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).

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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.