NSTX

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Investigation of microtearing instability in NSTX with X-ray diagnostics

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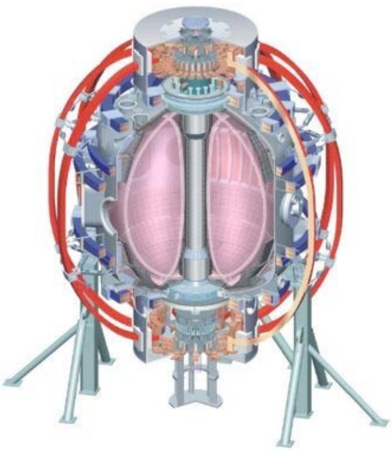


Outline

- Introduction
- Soft X-ray camera
- SVD(singular-value-decomposition) analysis of X-ray data
- X-ray spectrometer
- Summary

Introduction

- In some beam-heated H-mode NSTX plasmas, microtearing instabilities can produce overlapping islands and the resulting stochastic magnetic field can explain χ_e obtained from TRANSP analysis

  Ref: Wong et al., PRL (2007), Phys. Plasma (2008)

- It becomes desirable to search for direct and indirect experimental evidence of microtearing modes in these plasmas

X-ray emissivity

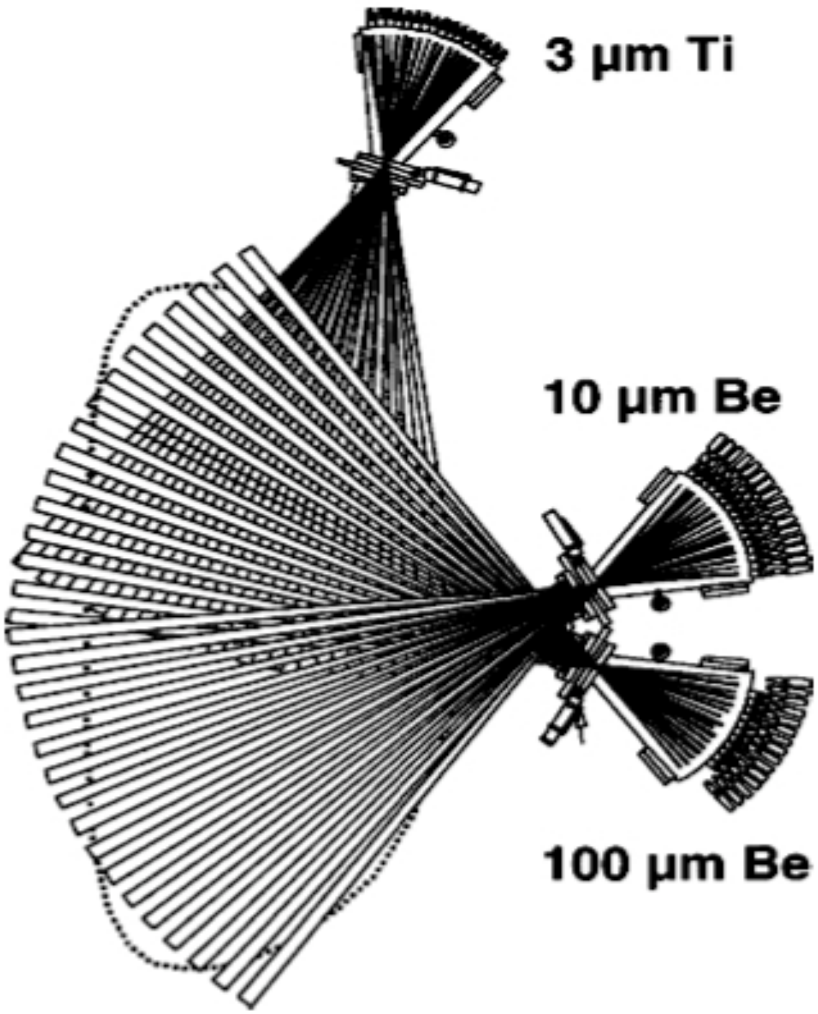
- For Maxwellian electrons in NSTX plasmas, X-ray emission is dominated by collisional excitation of impurity ions[1]; dielectronic recombination[2] is small; bremsstrahlung[3] (f→f) and radiative recombination[4] (f→b) are very small
- Emissivity for both (1), (2) & (3) scale like $\varepsilon \sim n_e\, n_z\, (Z\, e)^2 \sqrt{T_e}$
- ε is approximately constant on a flux surface for NSTX plasmas
    - see Stutman et al., RSI 74,1982 (2003)
- T_e fluctuations - δT_e give rise to $\delta\varepsilon$ which may be measurable in NSTX

Crude estimates

- Take parameters from #116313, r/a=0.5, t=0.9s
- Island full width: $\Delta r = 4\ (b_{mn}\ R\ r\ q\ /\ m\ s\ )1/2 \sim 0.85$ cm
- Put $\xi_r \leq \Delta r / 2 \sim 0.4$ cm, $L_n \sim 50$ cm, $L_T \sim 35$ cm,
- get $\delta\varepsilon/\varepsilon \sim \xi_r / L_n + 0.5\ \xi_r / L_T \sim 1.4\%$
- $\delta\varepsilon/\varepsilon \sim 1\%$ is not too difficult to detect if we have a diagnostic that can do local measurements
- However, all we have is an X-ray camera for line-of-sight measurements - difficult !

X-ray camera

Ref: Stutman et al., RSI 74,1982 (2003)



SVD analysis

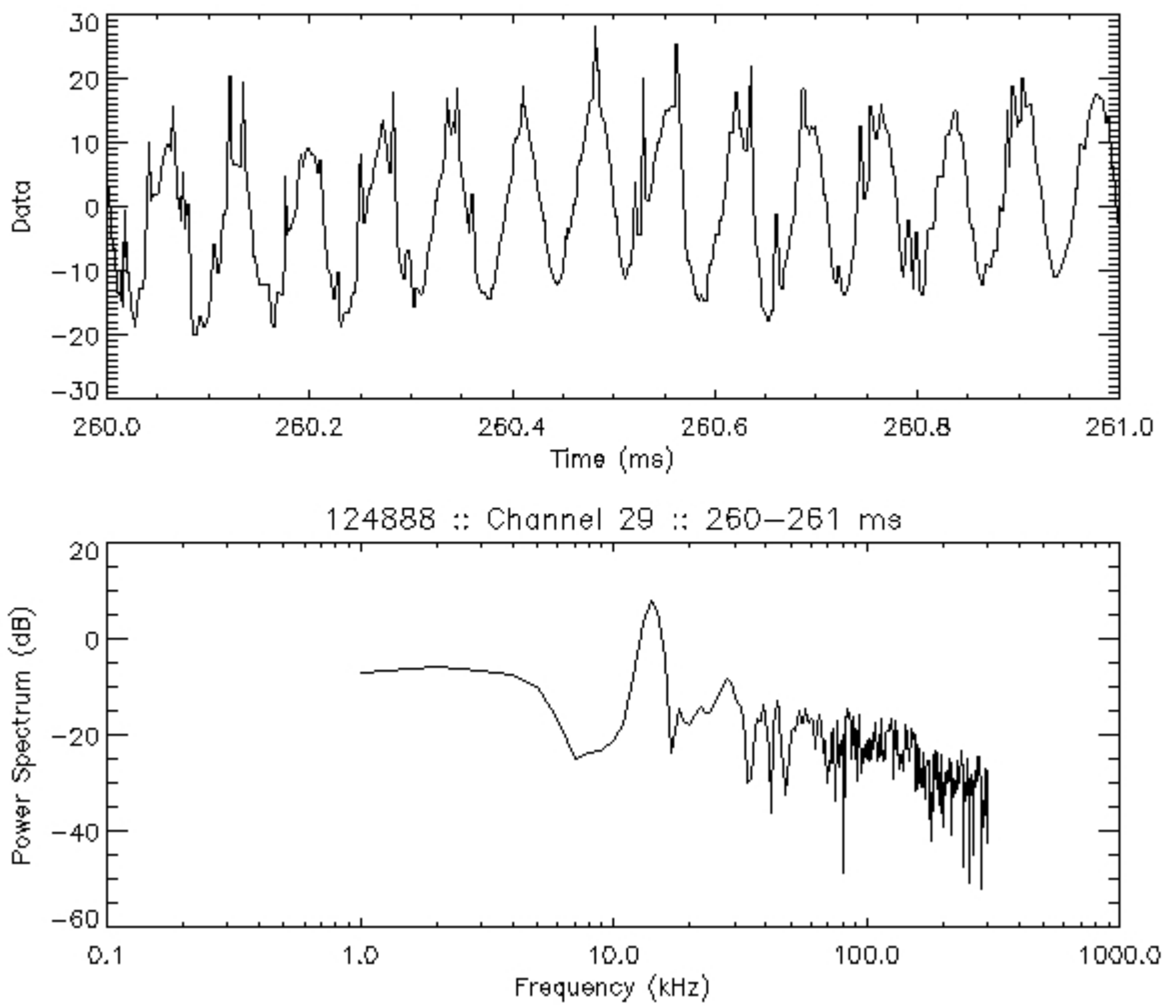
- Ref: T. Dudok de Wit et al., PoP 1, 3228(1994)
- Expand the discrete signal (n x m matrix) $y(x_j, t_i)$ into a set of modes that are orthogonal in time and space

$$y(x_j, t_i) = \sum_{k=1 \rightarrow K} A_k \phi_k(x_j) \psi_k(t_i), \quad K = \min(n,m)$$

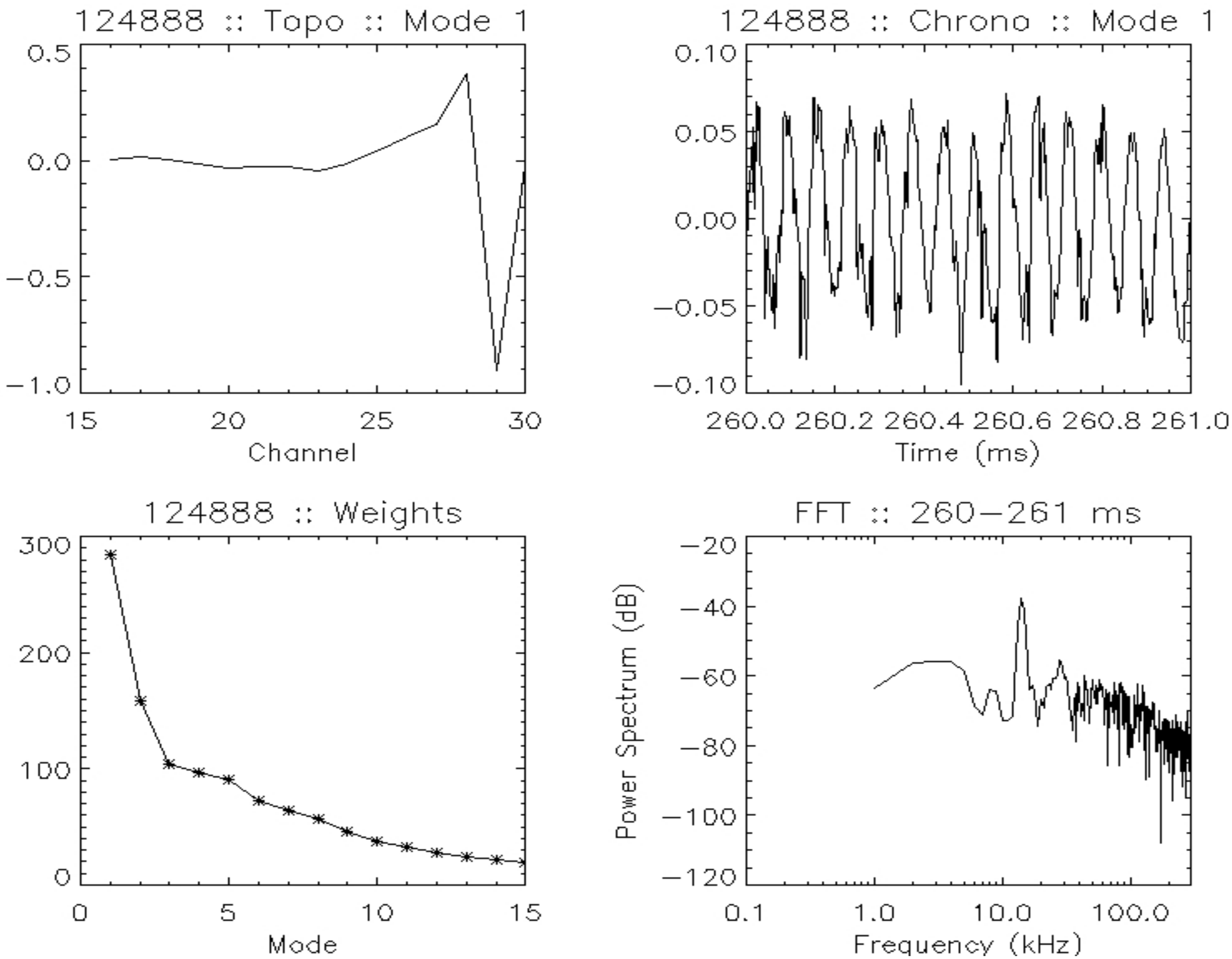
- Chrono = temporal eigenfunction = $\psi_k(t_i)$
- Topo = spatial eigenfunction = $\phi_k(x_j)$
- Weight distribution: A_k (≥ 0), k =1, 2, ….. K
- Construct the matrix $Y_{i\,j} = y(x_j, t_i)$ and use IDL subroutine to do SVD analysis

Test program on known MHD activities

Edge oscillation - raw NSTX data

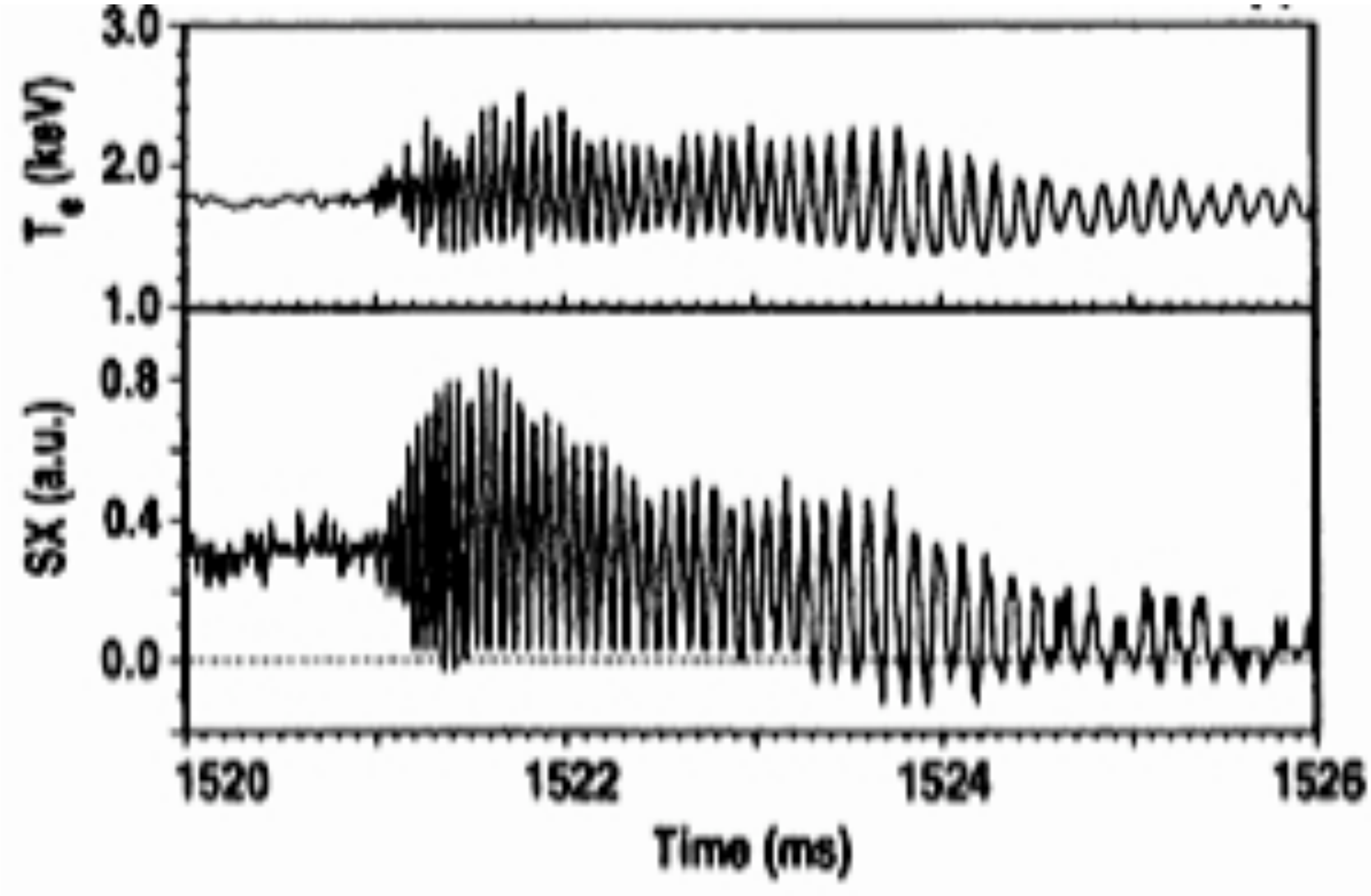


SVD result for a single mode (NSTX)



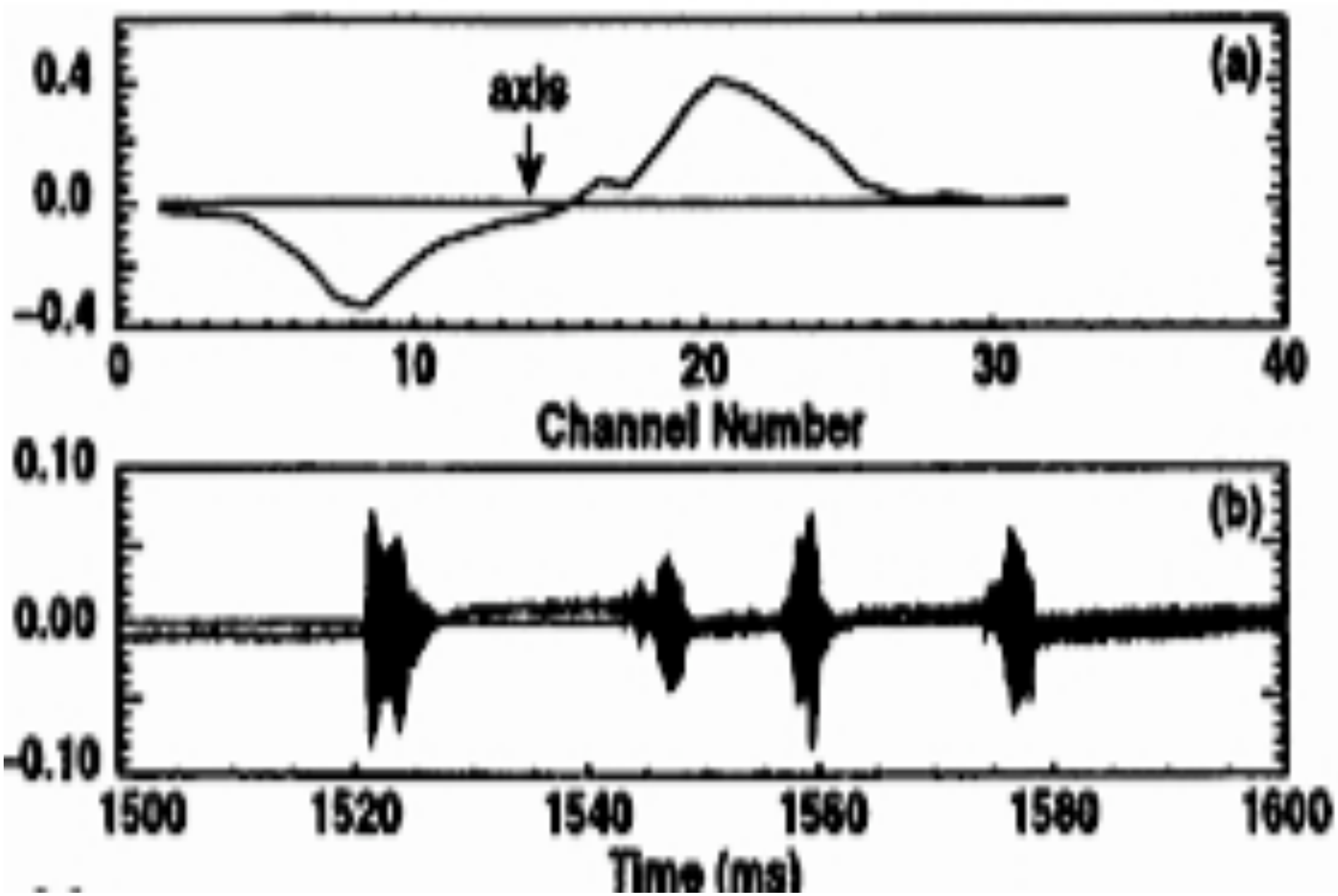
Growth of a single MHD mode (DIII-D data)

Changing frequency - determination of m/n difficult from Mirnov data



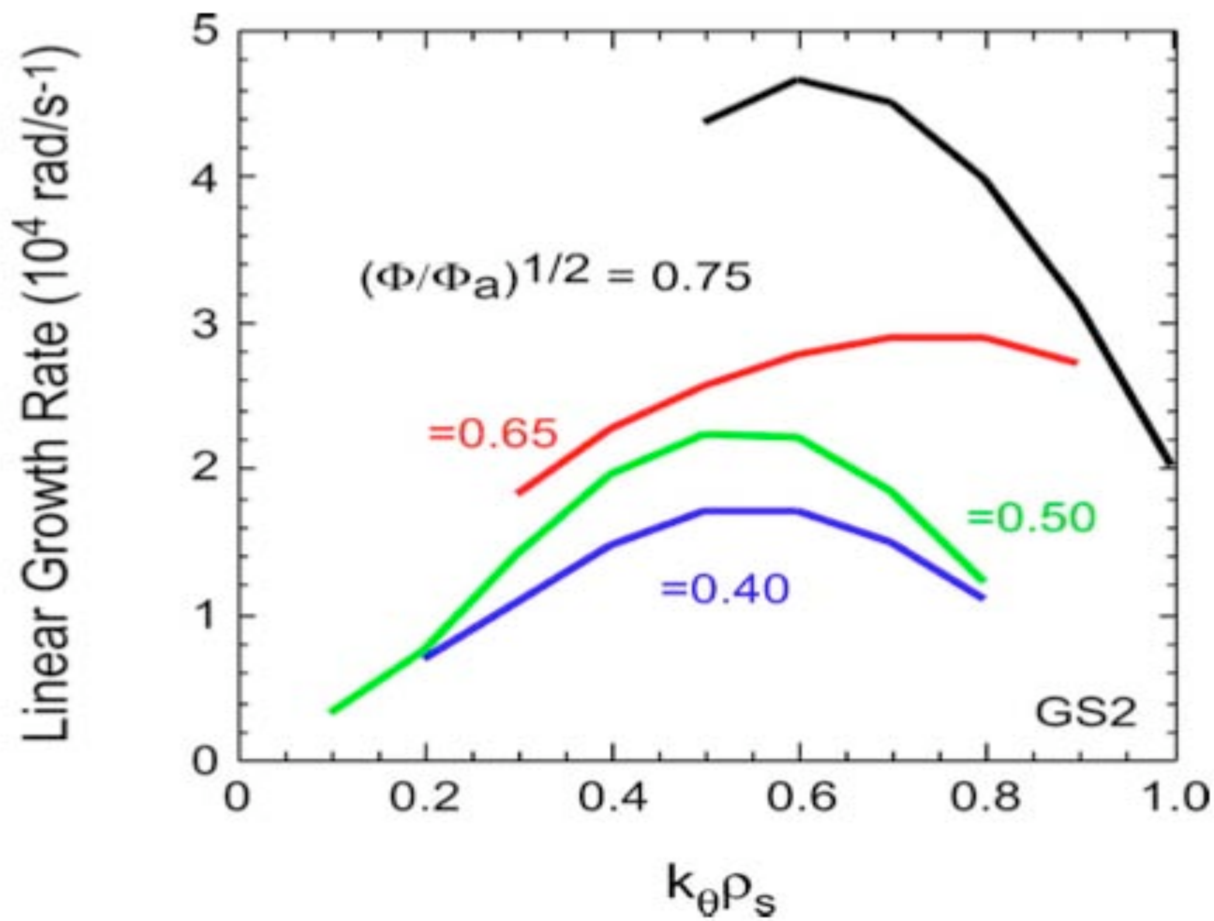
SVD result of ECE data in DIII-D

m=1 mode from topo - Wong et al.,PRL (2000)

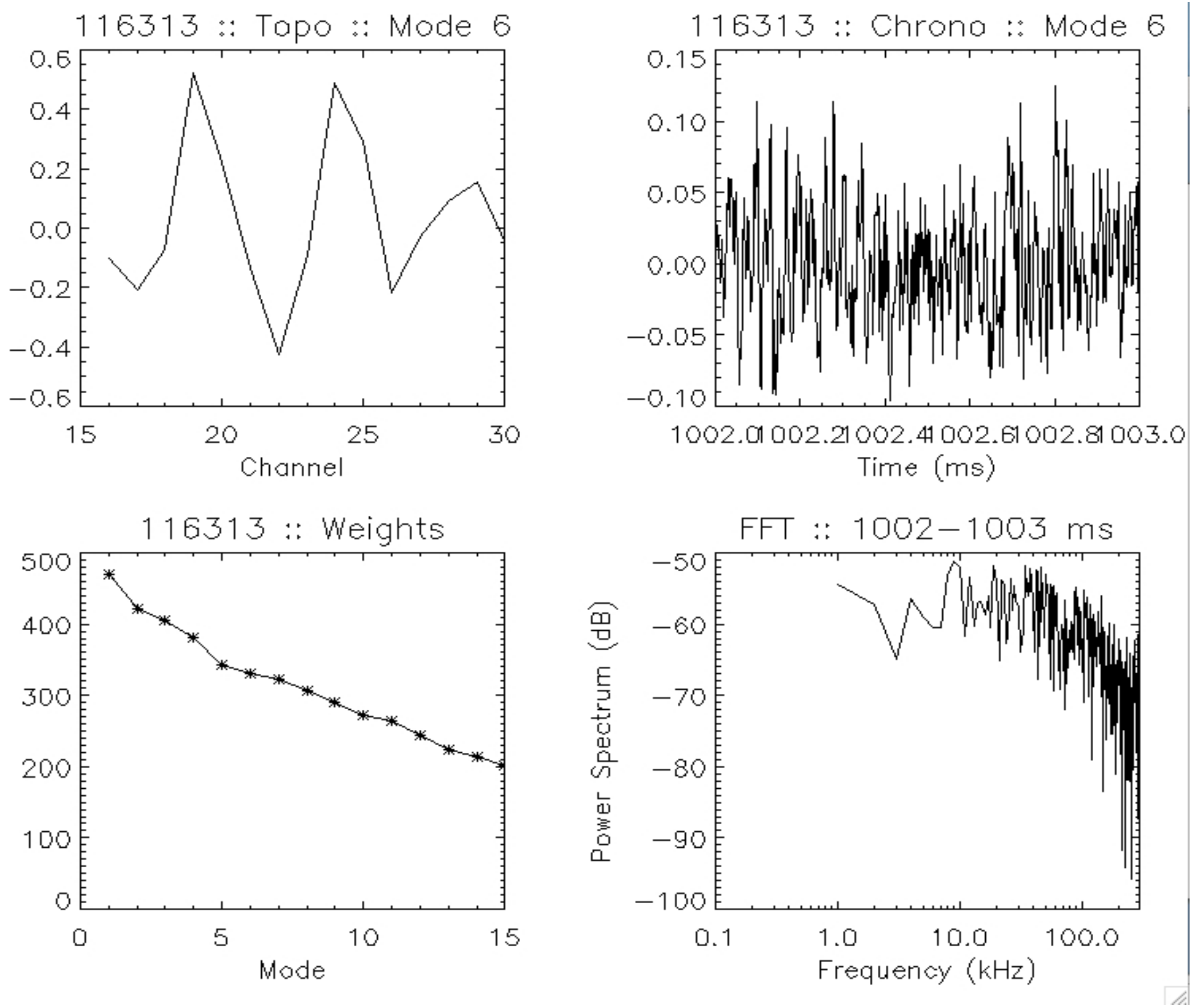


Growth rate of microtearing modes (NSTX#116313, 0.9s)

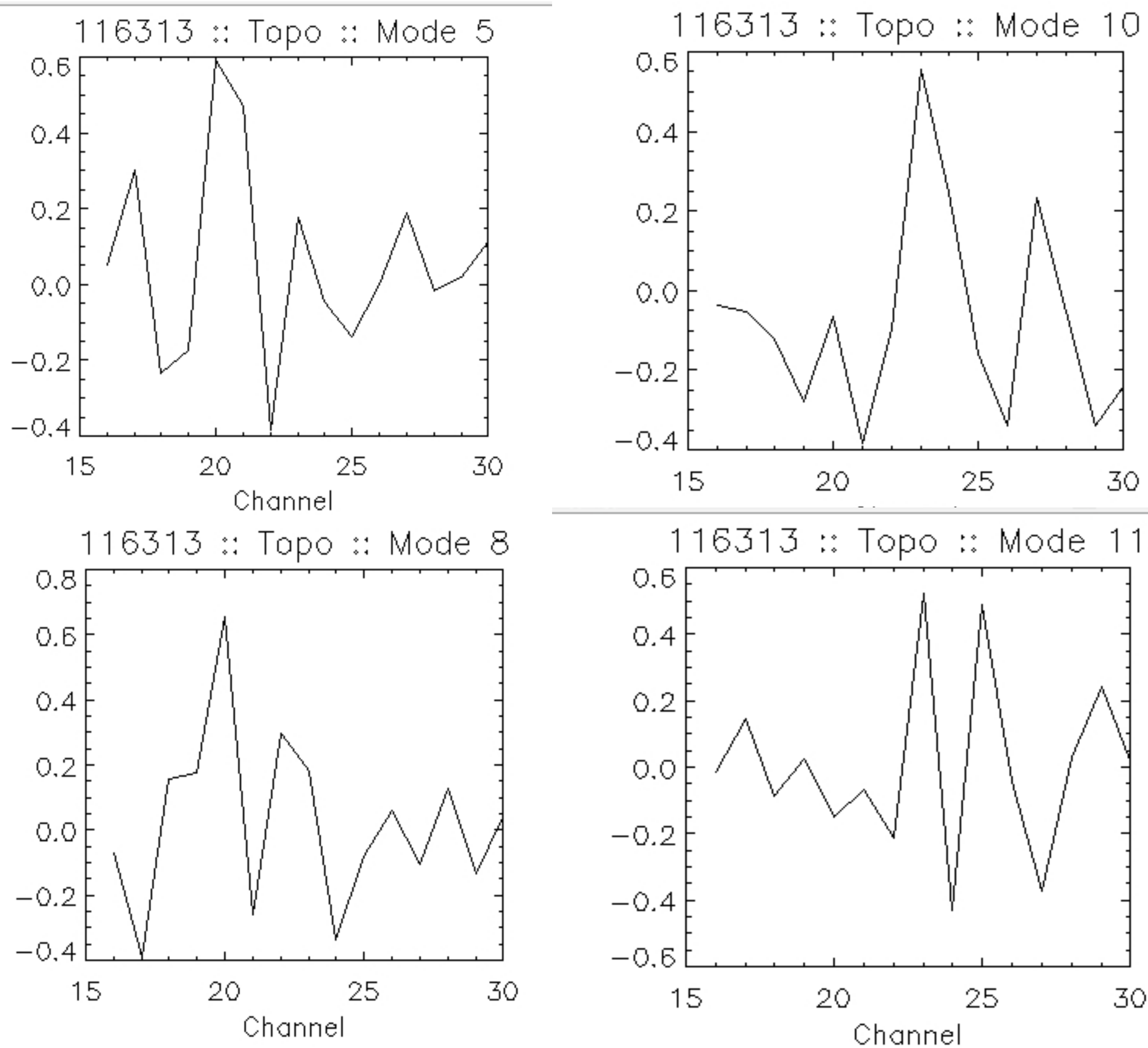
Broadband expected - many unstable modes



SVD result (#116313,1.002-1.003s)



SVD result - continue



Summary of NSTX SVD results

- Topo frequently exhibits wave-packet structure although the camera spatial resolution is marginal
- Chrono usually consists of irregular / intermittent bursts
- No sign of single mode growth - has temporal resolution

  - $f_{Nyquist}$= 300kHz , i.e., Landau’s Scenario NOT observed
- No single frequency signal observed - usually see broadband fully developed turbulence (Ruelle-Takens scenario ?)
- More work is needed for data interpretation

More data needed

- All the useful data we have now are from one horizontal array (15 channels: #16 - #30)
- The other two arrays have thick filters
- Need more data with all 46 channels using the same thin filter (10 μm Be)

D_e and the X-ray energy spectrum

- Kinetic eq: $\partial f/\partial t = e/m\, E \partial f/\partial v + C(f) + L D_e L f$

  $L = \partial / \partial x - (eE^A/m)/v^2$

  E - applied electric field, E^A - ambipolar electric field

- Perturbative solution: $f = f^{(0)} + f^{(1)} + f^{(2)} + \ldots.$
- 0-th order: $0 = C(f^{(0)}) \rightarrow$ local Maxwellian
- 1st order: $0 = C(f^{(1)}) - e/m\, E\, \partial f^{(1)}/\partial v \rightarrow$ Spitzer resistivity
- 2nd order: $0 = C(f^{(2)}) + L D_e L f^{(0)} - e/m\, E\, \partial f^{(1)}/\partial v$

  and $f^{(2)}$ gives information on D_e

- Ref: K. Molvig et al., PRL 41, 1240 (1978)

X-ray spectrometer

- Energy range: 5 - 25 keV (Amptek-X123)
- Energy resolution: 260 eV
- Temporal resolution: 3 - 10 ms @ 200,000 counts/s

No Liquid Nitrogen
Accomodates all Amptek detectors

Figure 1.

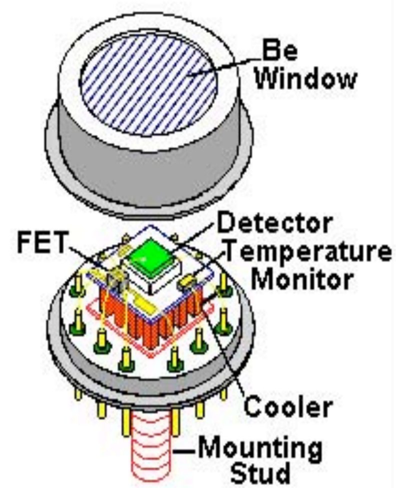


Figure 2.

Summary

- It may be possible to obtain some direct and indirect experimental evidence of microtearing modes from the X-ray emission from NSTX plasmas
- Preliminary SVD analysis shows wave-packet structures in data from X-ray camera - more data from all 46 channels are needed
- X-ray spectrometer is being installed - will get some data in 2009