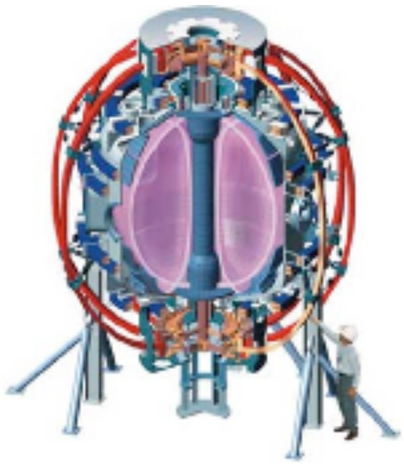
Investigation of fast ion mode spatial structure in NSTX



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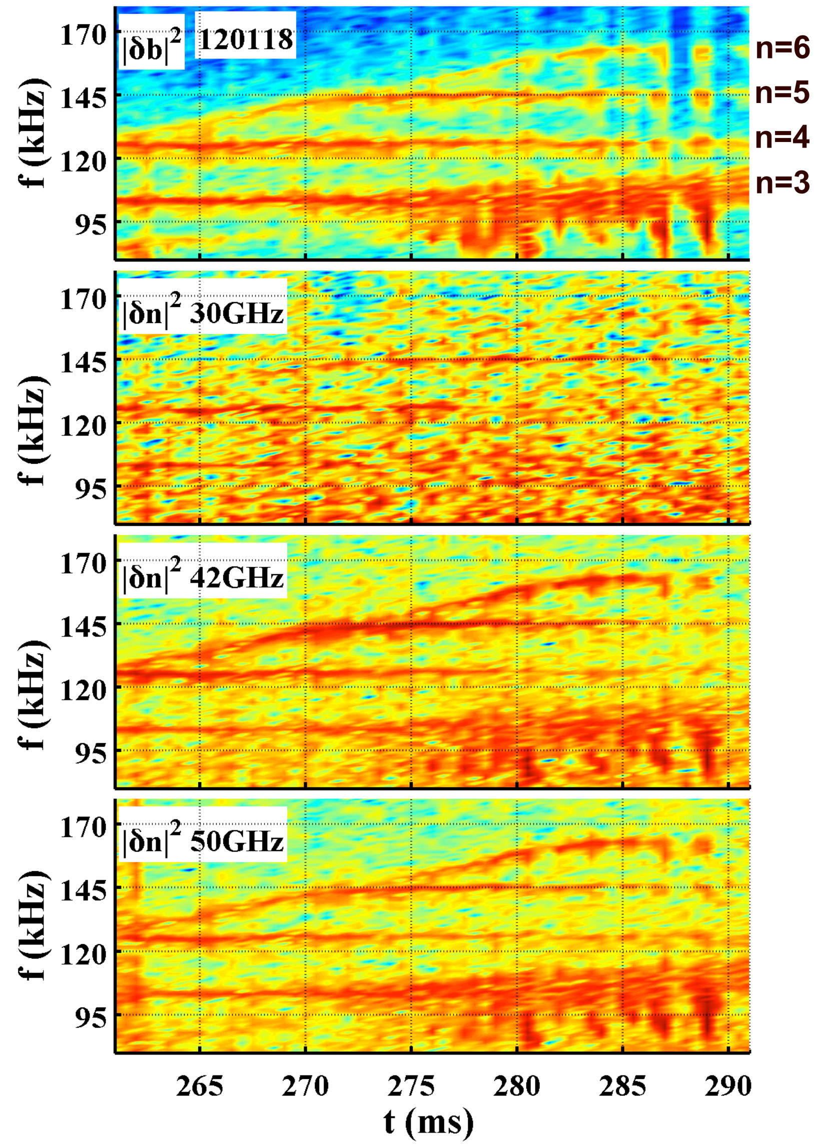
Internal density fluctuation diagnostics allow coherent modes to be probed in NSTX

- Reflectometry measures local density perturbation and "plasma displacement" (if motion incompressible)
  - interpretation of reflectometry signal for coherent modes confirmed by comparison with BES data on DIII-D.
- Multiple reflectometers ⇒ radial structure of mode
  - test theory predictions
  - infer magnetic fluctuation amplitude (affects fast ion transport)
- Radial 1mm & tangential FIR interferometer data available
  - provide a survey of mode activity across entire plasma diameter
  - allows detection of modes localized on high field side
  - provide additional constraints on spatial structure
- Plans to upgrade 1mm interferometer to multi-channel radially viewing polarimeter
  - allows measure of magnetic fluctuations

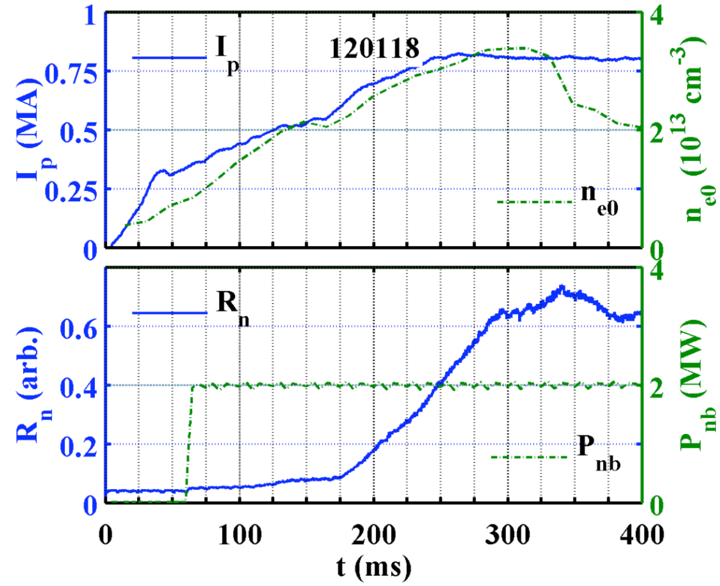
TAE spatial structure investigated — Interesting questions still to be answered

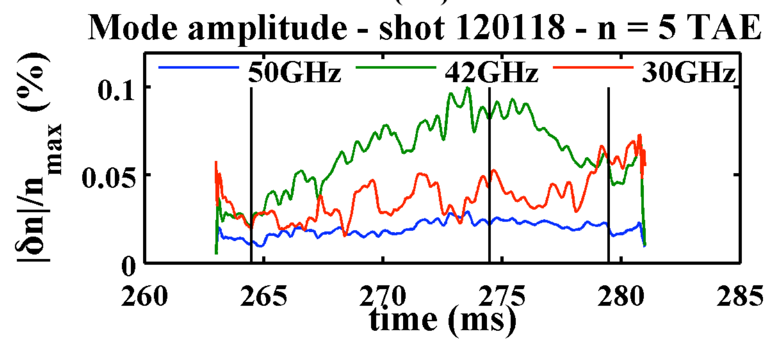
- **TAEs measurements available from:**
  - external toroidal Mirnov array (top right)
  - three fixed-frequency reflectometers (bottom right)
  - radial chord 1mm interferometer (not shown)
- **TAEs exhibit many behaviors (**bursting, persistence, slow or rapid chirping**) ⇒ what is revealed about fast ions & plasma?**
  - example: TAEs in 120118 (right) — slow frequency upsweep followed by stable frequency, successive upsweeps appear connected
- **Future work with this data set:**
  - compare with NOVA-K
  - understand effect on fast ions — compare with fast ions population measurements (NPA, SSNPA, sFLIP, neutrons …)
  - learn to exploit diagnostic capabilities of TAEs (i.e. what is revealed by TAE behavior?)

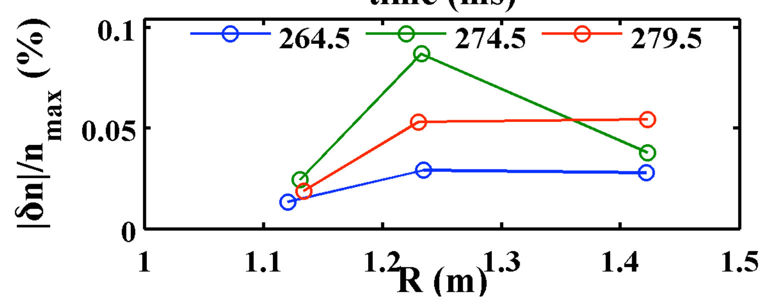


Initial results: structure of TAEs in shot 120118 evolve significantly over lifetime

- **Typical TAE investigated**
  - frequency sweeps up from f ~ 120 to 145 kHz during t ~ 263 — t ~ 271 ms
  - frequency stable after upsweep at least until t ~ 281 ms.
  - n = 5 (from external Mirnov array)
- **Density fluctuation at R ~ 121 cm (42GHz, n_c ~ 2 x 10^{12} cm^{-3}) varies significantly over ~ 20 ms; possible causes:**
  - radial mode structure evolves significantly (e.g. mode peak shifts radially)
  - mode amplitude evolves
- **Question: what causes mode evolution?**
  - variation too rapid to be caused by equilibrium change? — $\Delta f/f$ ~ 15%, $\Delta|\delta n|/|\delta n|$ ~ 300% over 10 ms
  - controlled by evolution of fast ion population? must compare with fast ion diagnostics
  - is "connection" of upsweeps (previous slide) coincidental?

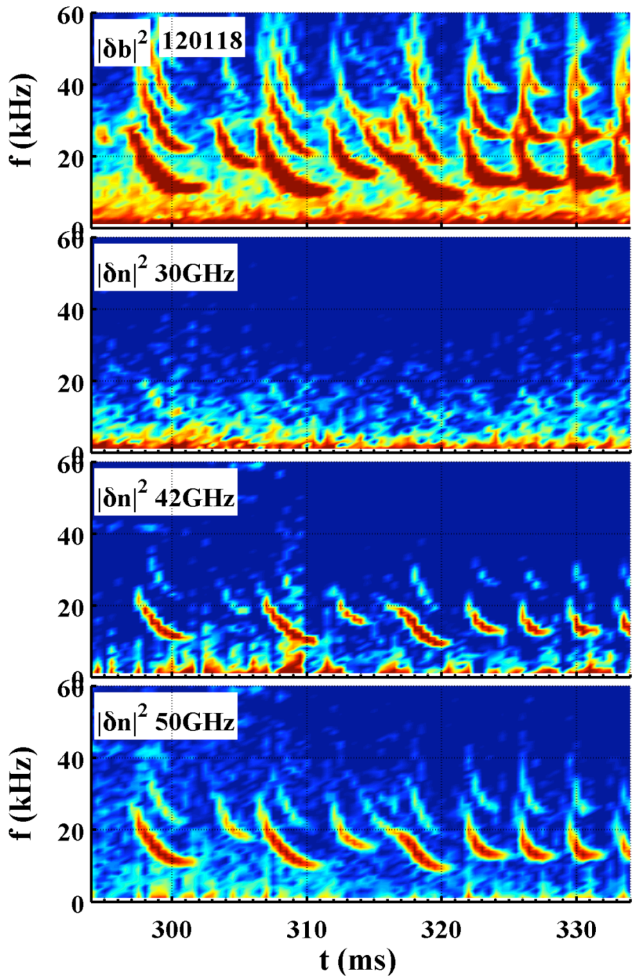


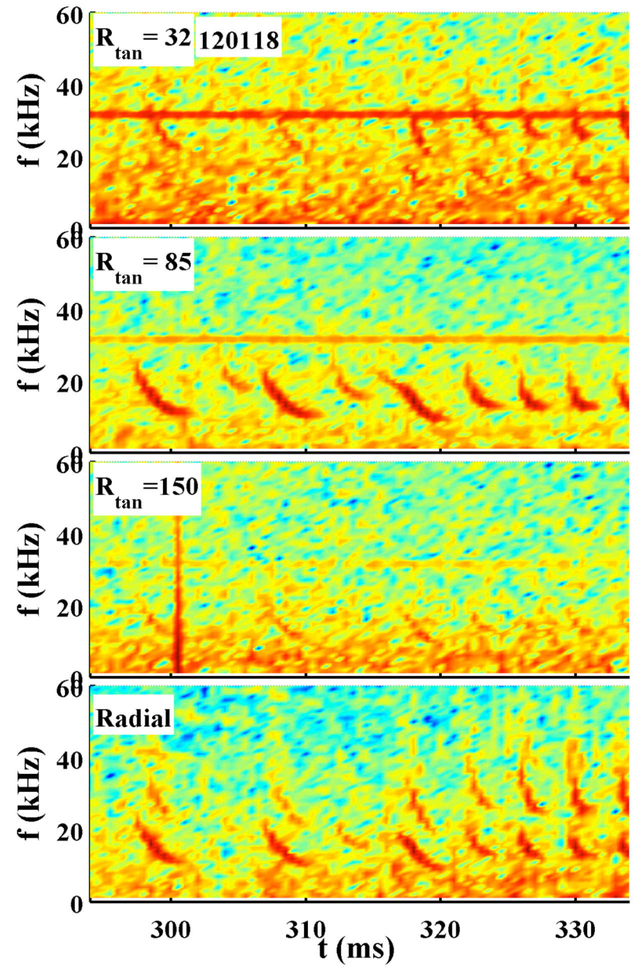




EPM spatial structure to be investigated

- **EPM measurements available from:**
  - external toroidal Mirnov array (top left)
  - three fixed-frequency reflectometers (bottom 3 left)
- radial chord 1mm interferometer (bottom right) and tangential FIR interferometers (top 3 right)
- complementary data available from USXR chord arrays (not shown)

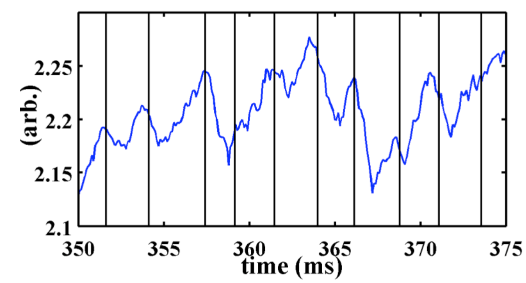




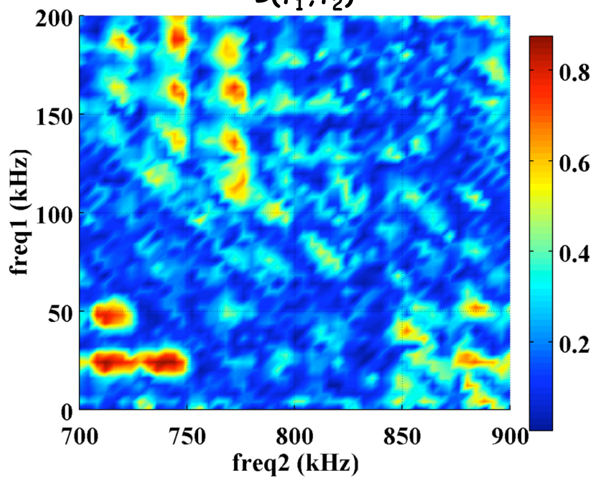
Future work: further investigation of three-wave interactions of EPMs, TAEs and CAEs/GAEs

- CAE (GAE?) spectrum broadens thru sideband generation during fast ion loss events (drops in neutron rate)
- broadening appears to result from three-wave coupling
- bicoherence measurements indicate three-wave coupling occurs
  - Bicoherence of "x" defined here as $B(f1,f2) = |\langle x(f_1)x(f_2)x^*(f_1+f_2)\rangle| / (\langle |x(f_1)x(f_2)|^2\rangle \langle |x(f_1+f_2)|^2\rangle)^{1/2}$

Neutron Rate
(with fluctuation bursts marked)

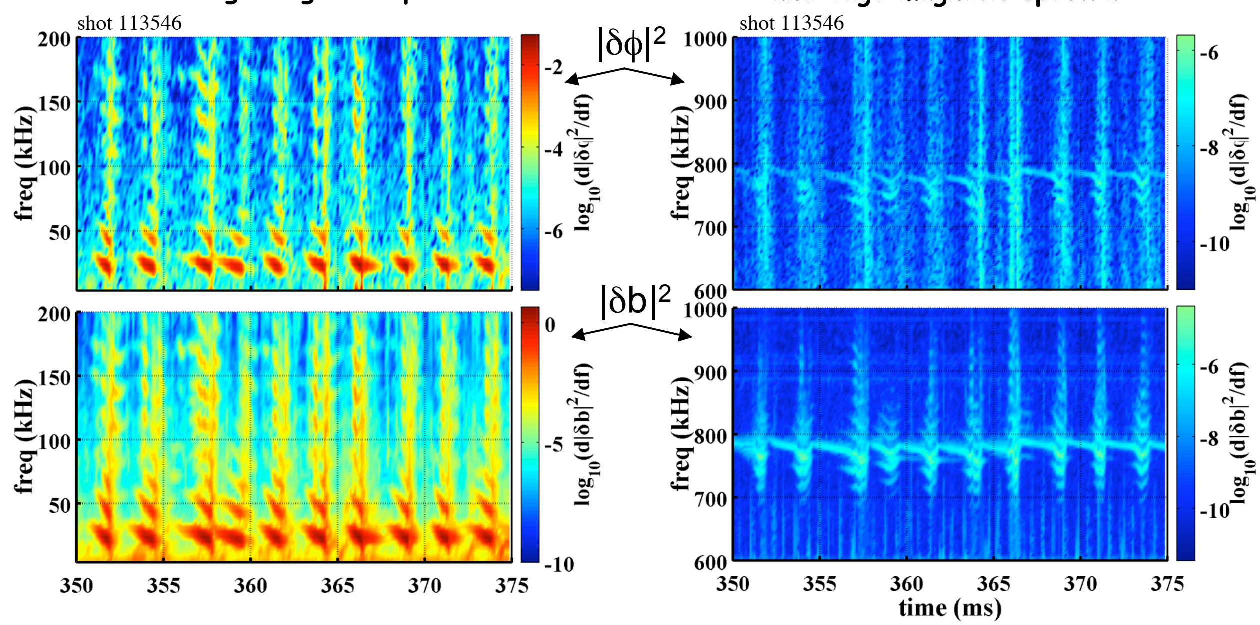


Bicoherence of δb
$B(f_1,f_2)$



TAEs and EPMs
50 GHz reflectometer phase and edge magnetic spectra

CAEs
50 GHz reflectometer phase and edge magnetic spectra



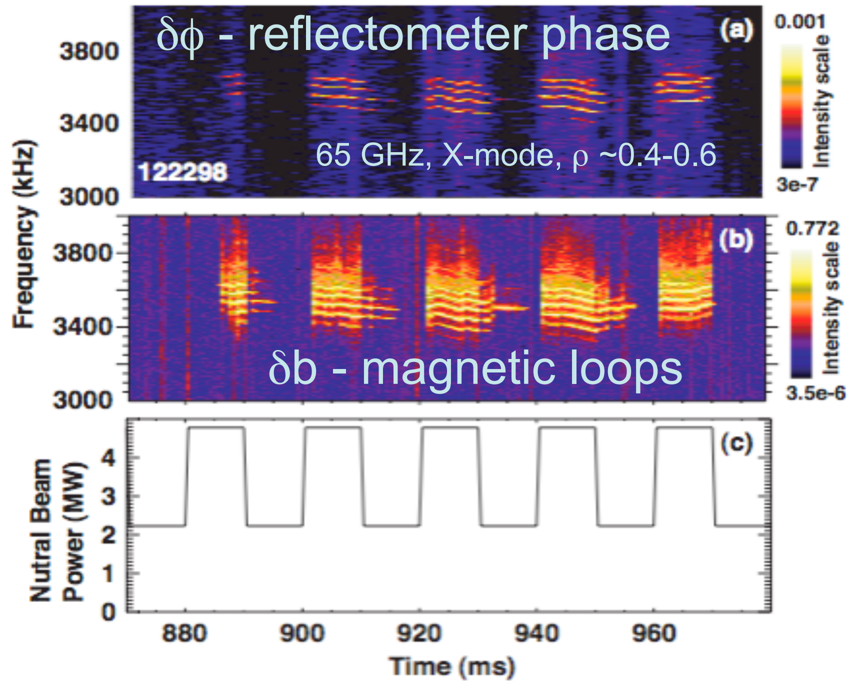
On-going work: continue cross-machine studies of fast ion driven modes

- Cross-machine studies of fast ion driven modes is an on-going effort

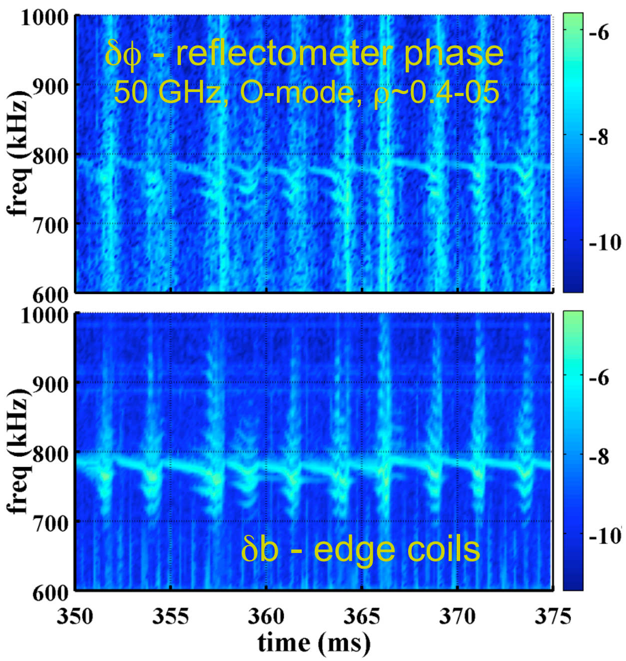
  For example:

  - TAEs: W.W. Heidbrink, et al., Plasma Phys. Control. Fusion vol. 45 (2003) pg. 983
  - CAEs: N.N. Gorelenkov, et al., 9th IAEA TCM on Energetic Particles in Magnetic Confinement Systems, November 9 - 11, 2005, Takayama, Japan

CAE measurements on DIII-D



CAE measurements on NSTX



- UCLA Team uses reflectometry to study fast ion driven modes in DIII-D and NSTX ⇒ can contribute to cross-machine studies

Summary

- Investigation of fast ion mode structure motivated by effect of modes on fast ion transport
- Array of diagnostics to investigate fast ion modes:

  <u>Density fluctuations</u>
  - three fixed-frequency reflectometers (EPMs, TAEs and CAEs/GAEs)
  - radial chord 1mm interferometer (EPMs and TAEs)
  - tangential chord FIR interferometer arrays (EPMs. TAEs and CAEs/GAEs?)

  <u>Other fluctuations</u>
  - external toroidal Mirnov array (EPMs, TAEs and CAEs/GAEs)
  - USXR chord array (EPMs)
- Initial results of TAE structure investigation available
  - structure measurements to be compared to NOVA-K in near future.
  - results show moderately rapid structure evolution ⇒ What controls evolution — equilibrium or fast ion population?
- Extensive simultaneous measurements of EPM density fluctuation exist. To be analyzed in near future.
- On-going and future work includes:
  - further investigation of three-wave interactions of EPMs, TAEs and CAEs/GAEs
  - cross-machine study of fast ion modes