NSTX

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High resolution MHD mode structure measurements via multichannel reflectometry in NSTX*

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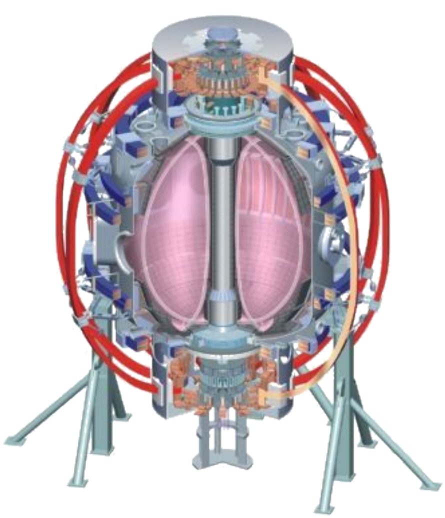

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Summary

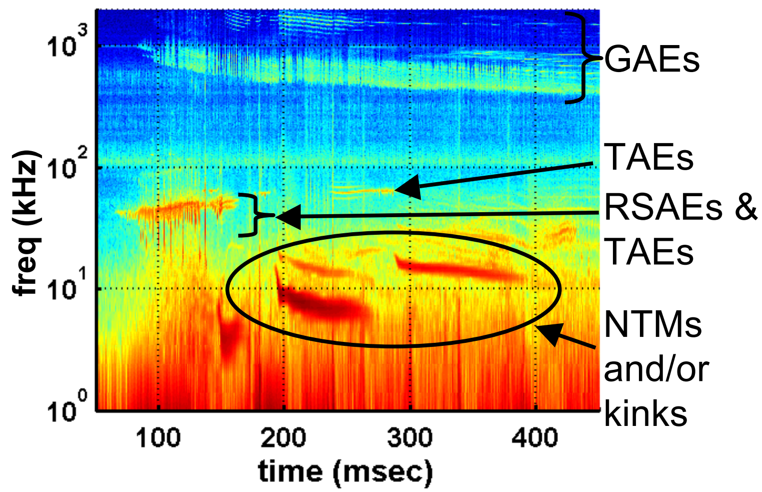
- Magnetohydrodynamic (MHD) modes—kinks, tearing modes, Alfvén eigenmodes (AE)—play critical role in many aspects of plasma performance
- MHD mode structure routinely measured in NSTX via array of fixed frequency reflectometer to facilitate comparison with theory
- *Reflectometer array upgraded* to increase spatial resolution and range of accessible plasma densities
  - 16 channels (increased from 6 channels)
  - cutoff $n_0 \sim 1 - 7 \times 10^{19}$ m^{-3} (30 – 75 GHz) $\Rightarrow$ improved access to H-mode plasmas [increased from $n_0 \sim 1 - 5 \times 10^{19}$ m^{-3} (30 – 65 GHz)]
- Initial results from new array include structure measurements of global & toroidicity-induced AEs (GAE & TAE), as well as neoclassical tearing modes (NTM)
- GAE structure measured in *previously inaccessible* high density H-mode plasmas
  - advances study of GAE-induced electron thermal transport (K. Tritz, Invited Talk PI2.00002; E. D. Fredrickson, NO4.00002)
- TAE structure measured with *significantly improved* spatial resolution
  - facilitates strong validation of M3D-K code
- NTM structure measured with high spatial resolution
  - first application of reflectometer array to NTMs in NSTX (see J.Zhang, BP9.00080)

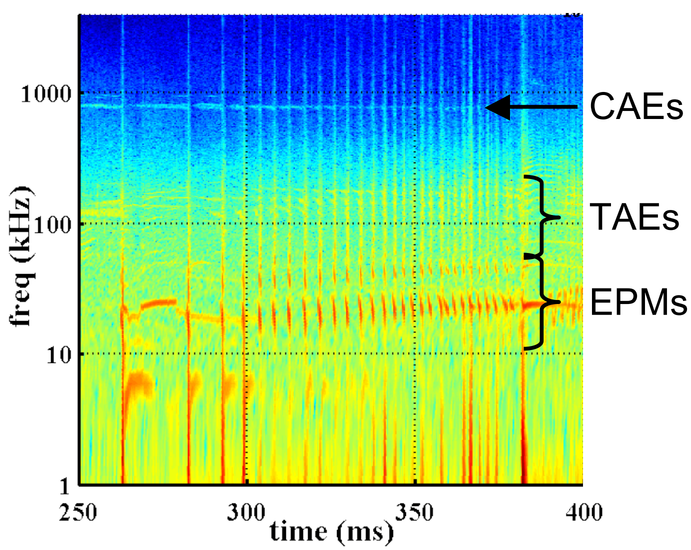
Motivation: Improved measurement of MHD mode structure promotes better understanding of plasma performance

- Magnetohydrodynamic (MHD) modes—kinks, tearing modes, Alfvén eigenmodes (AE)—play critical role in many aspects of plasma performance
  - kinks & tearing modes: change profiles and can cause bulk transport
  - AEs can cause fast-ion transport and loss:
    - change equilibrium sources (momentum, energy …)
    - damage plasma facing components
- MHD mode δn structure routinely measured in NSTX via fixed-frequency reflectometer radial array— upgrade improves spatial resolution & range of accessible plasma conditions
  - Upgrade (2010): 16 channels, $n_0 \sim 1 - 7 \times 10^{19}\ m^{-3}$ (30 – 75 GHz)
    [Previous array (2009): 6 channels, $n_0 \sim 1 - 5 \times 10^{19}\ m^{-3}$ (30 – 65 GHz)]

NSTX plasmas feature rich spectrum of MHD modes

Fluctuation spectra of
beam-heated NSTX plasmas

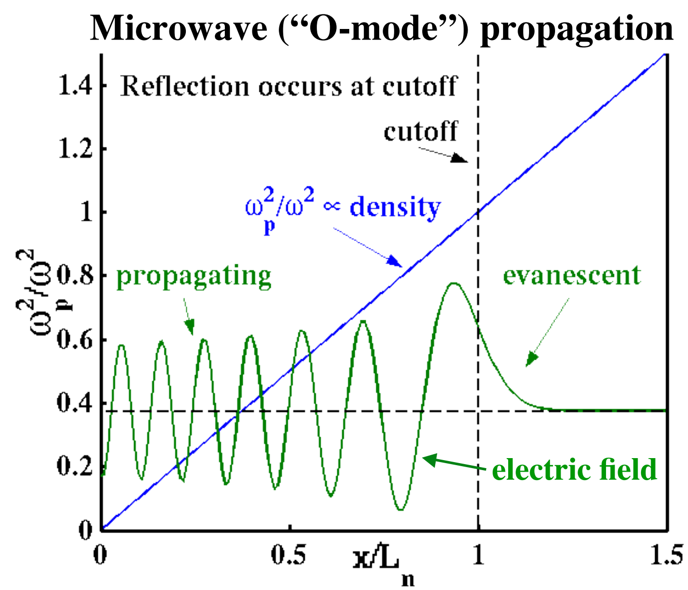




- Neoclassical tearing modes (NTM) and internal kinks – $f \lesssim$ 25 kHz
- Energetic particle modes (EPM) – $f \lesssim$ 75 kHz
- Reversed shear and toroidicity-induced Alfvén eigenmodes (RSAE & TAE) – 50 kHz $\lesssim f \lesssim$ 250 kHz
- Global and compressional Alfvén eigenmodes (GAE & CAE) – 400 kHz $\lesssim f \lesssim$ 3 MHz

Reflectometers measure local density fluctuation in plasma

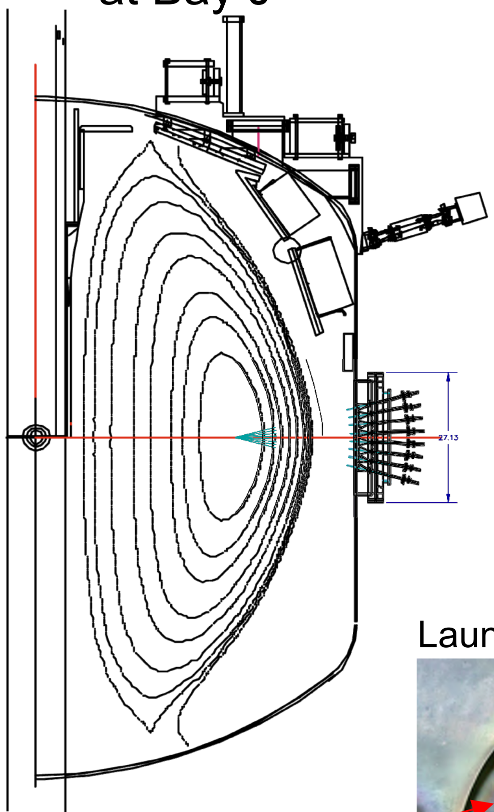
- Microwaves propagate to "cutoff" layer, where density high enough for reflection ($\omega_p = \omega$)
  - Dispersion relation of "ordinary mode" microwaves: $\omega^2 = \omega_p^2 + c^2k^2$, ω_p^2 proportional to density ($\omega_p^2 = e^2n_0/\varepsilon_0 m_e$)
  - $k \rightarrow 0$ as $\omega \rightarrow \omega_p$, microwaves reflect at $k = 0$



- Reflectometer measures path length changes of microwaves reflected from plasma
  - phase between reflected and launched waves changes ($\delta\phi$)
- Wave propagation controlled by density
  - for large scale modes $\delta n/n_0 \sim \delta\phi/(2k_{vac}L_n)$, $L_n = n_0/|\nabla n_0|$

Reflectometers provide radial array of measurements

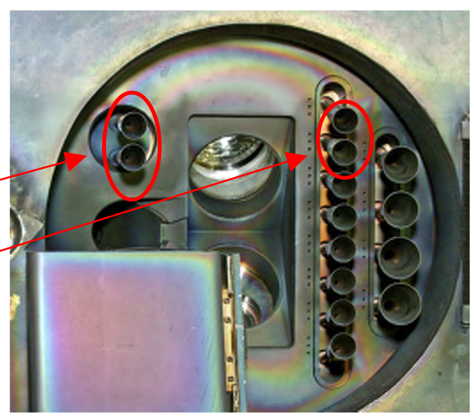
NSTX cross-section
at Bay J



- Two arrays of reflectometers: “Q-band” & “V-band”
  - –Q-band: 30, 32.5, 35, 37.5, 42.5, 45, 47.5 & 50 GHz
  - –V-band: 55, 57.5, 60, 62.5, 67.5, 70, 72.5 & 75 GHz
- Single launch and receive horn for each array.
  - –Arrays separated ~ 10° toroidally
- Horns oriented perpendicular to flux surfaces ⇒ frequency array = radial array
- Reflectometer cutoffs span large radial range in high density plasmas (n_0 ~ 7 x 10^{19} m^{-3})

Bay J Flange

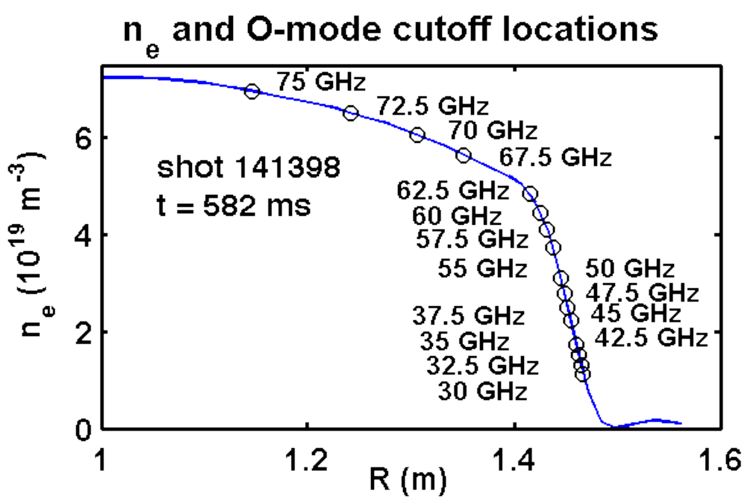
Launch and Receive Horns



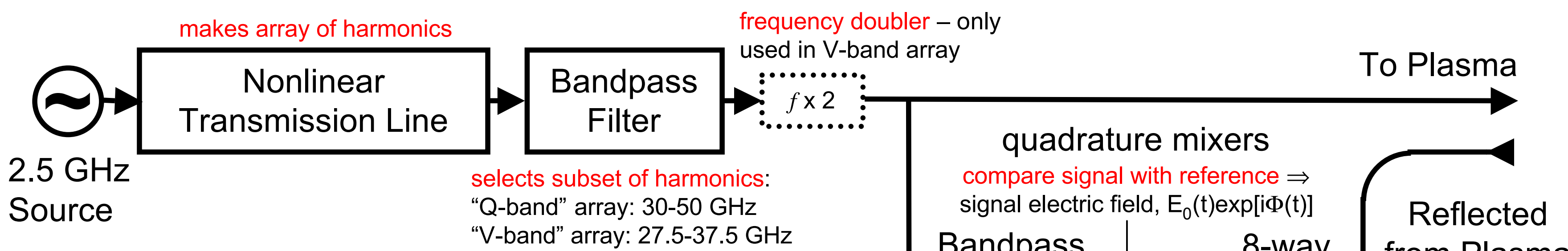
30-50 GHz

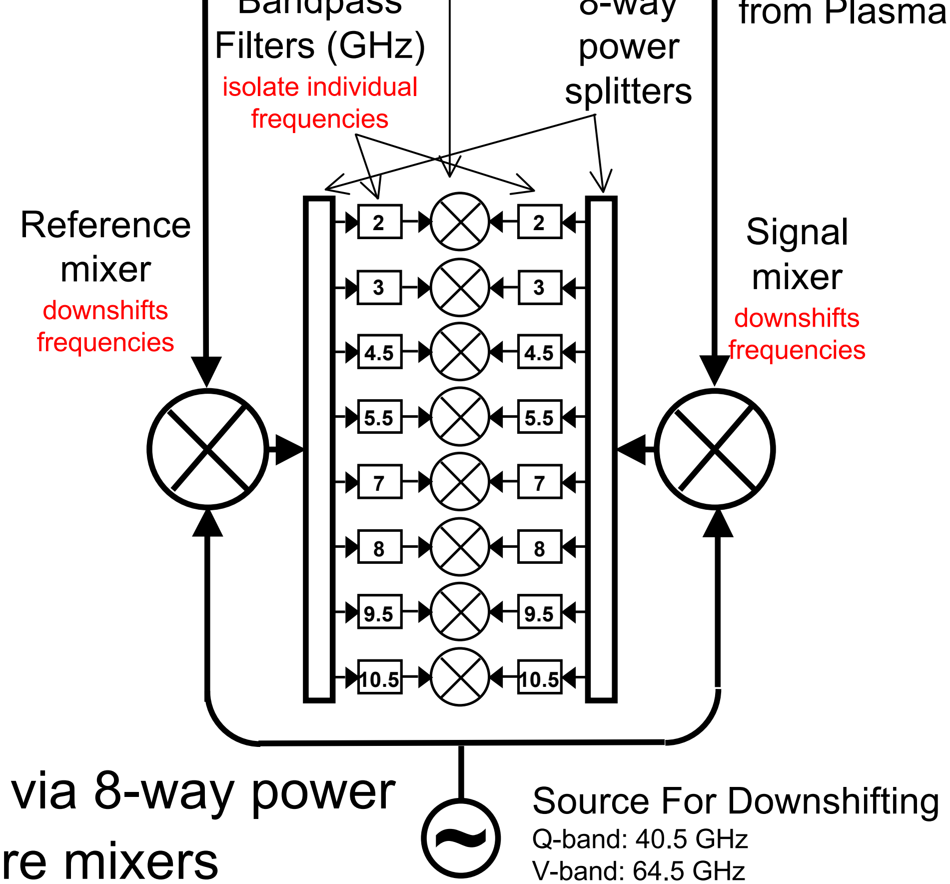
55-75 GHz

(not shown: horns modified to optimize for frequency range)



Reflectometer array design exploits nonlinear transmission line





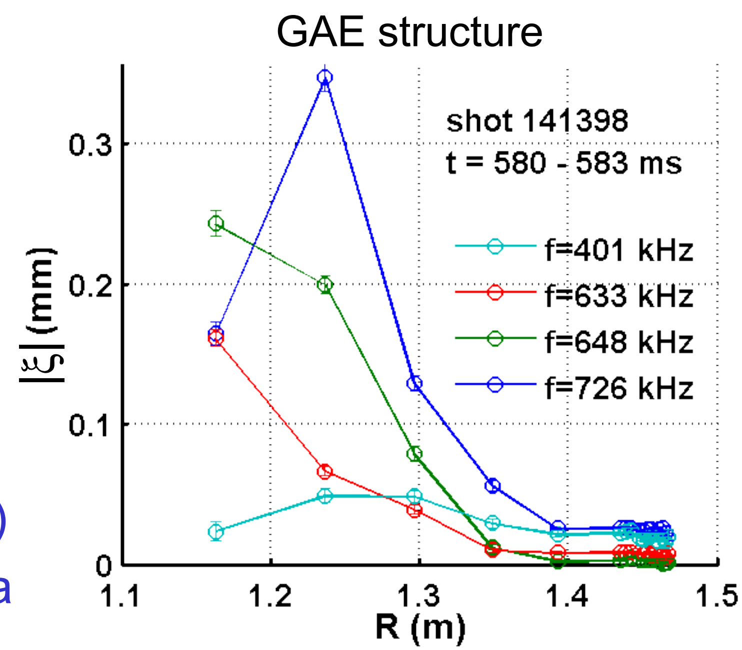
- 2.5 GHz source + nonlinear transmission line ⇒ harmonics up to 50 GHz
- Bandpass filter selects freq. range
  - Q-band: 30 – 50 GHz
  - V-band: 27.5 – 37.5GHz (frequencies doubled after filter)
- Frequencies downshifted to <= 10.5 GHz for processing
- Individual freq. isolated & processed via 8-way power splitters, bandpass filters & quadrature mixers

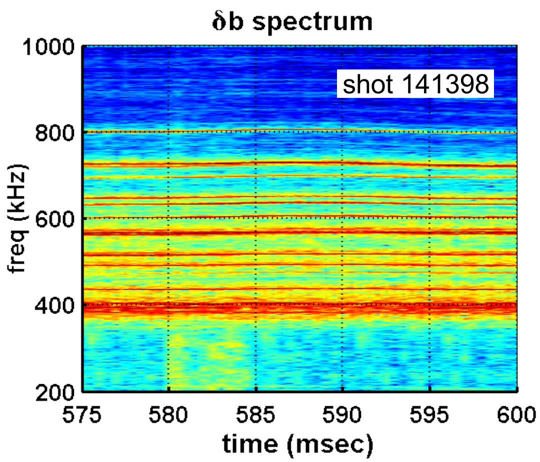
Reflectometer array measures GAE structure for investigation of GAE-induced electron thermal transport

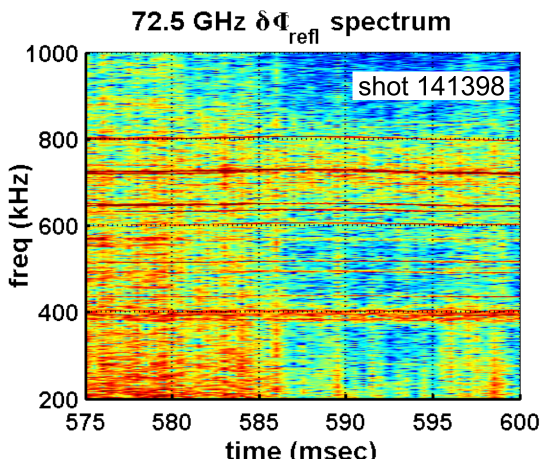
- GAE-induced electron thermal transport studied in core of beam heated plasmas

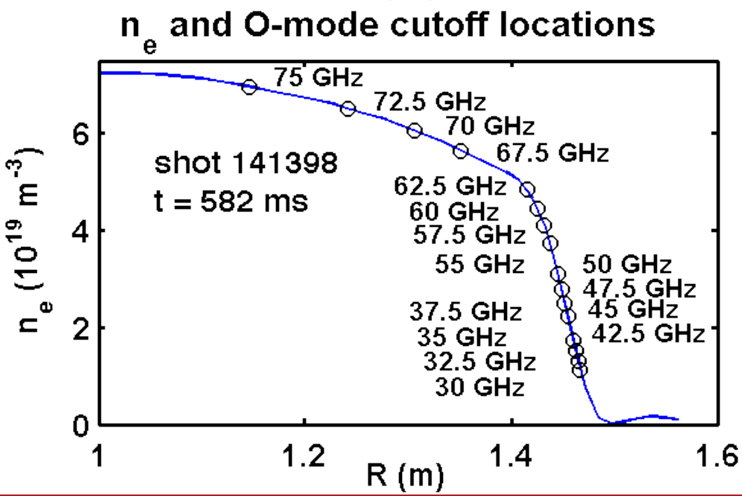
  See K. Tritz Invited Talk PI2.00002

- Upgrade allows core access in H-mode plasmas
  - GAEs localized in core
- GAE structure measured
  - will be compared with theory (HYM, NOVA-K)
  - will be used in predicting thermal transport via perturbed electron orbit calculation (ORBIT)





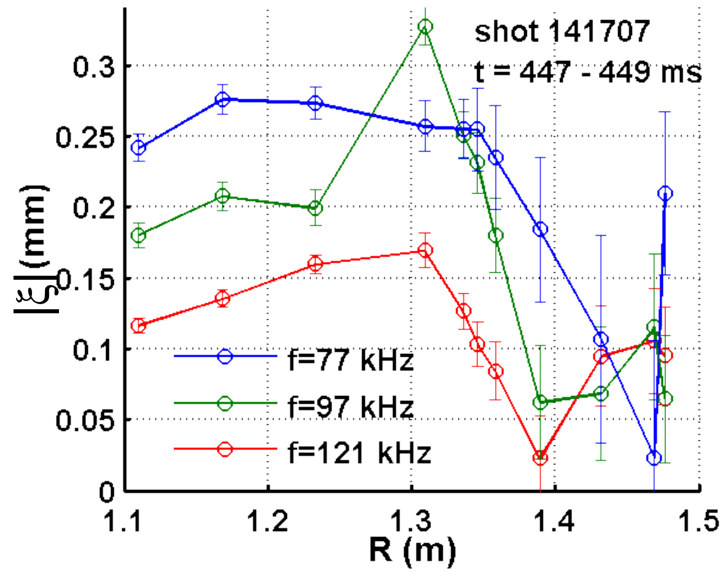


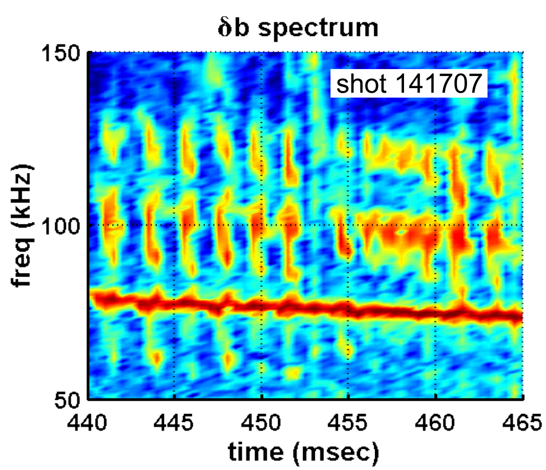


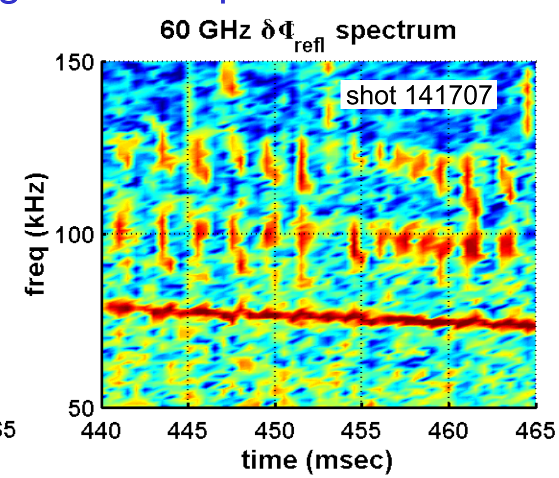
Reflectometer array provides improved measurement of TAE structure

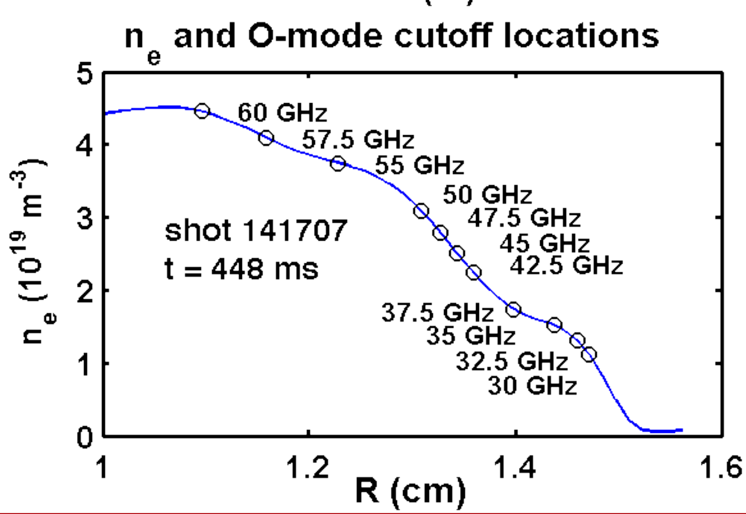
- TAE structure routinely measured in NSTX via reflectometry
  - TAEs play critical role in fast-ion transport in NSTX – extensively studied
- Upgrade significantly improves spatial resolution in moderate density plasmas ($n_0 < 5.5 \times 10^{19}$ m^{-3})
  - channels < 65 GHz *increased from 6 to 12*
- Measurement advances campaign to validate of M3D-K code
  - High resolution strengthens comparison

TAE structure



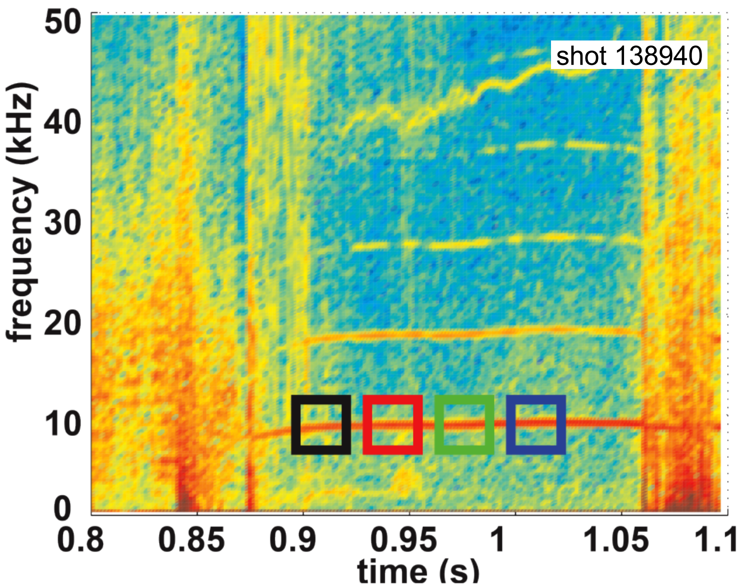






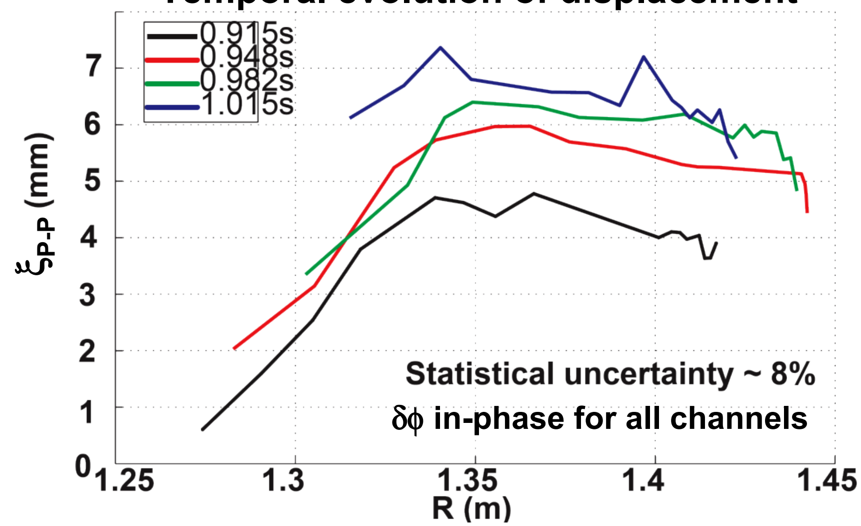
Reflectometer array measures NTM mode structure with high spatial resolution

Phase spectrum of 30 GHz reflectometer

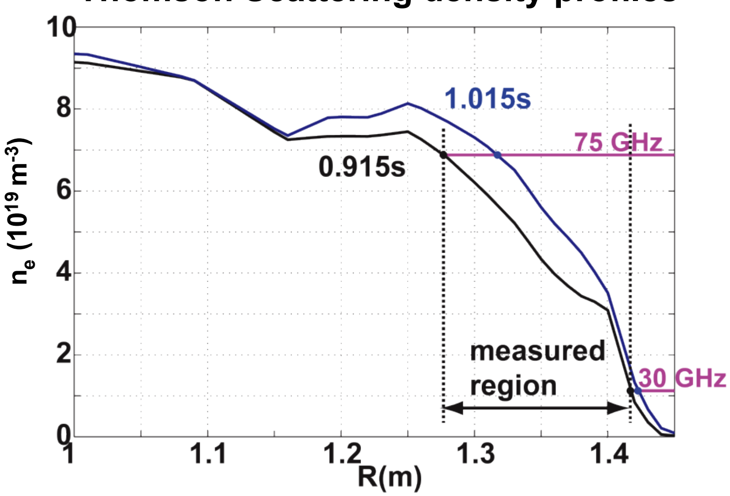


See J. Zhang poster BP9.00080

Temporal evolution of displacement



Thomson Scattering density profiles



- 2/1 NTM at R ~1.25 m
  - Flat region in density profile at R~1.25 m
  - Equilibrium reconstruction (EFIT02) indicates q=2 at R=1.22 m
- Displacement appears to approach inversion near R ~1.25 m
  - Consistent with identification as NTM

Conclusions

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