Reflectometry Measurements of Electron Density Profiles and Fluctuations in NSTX

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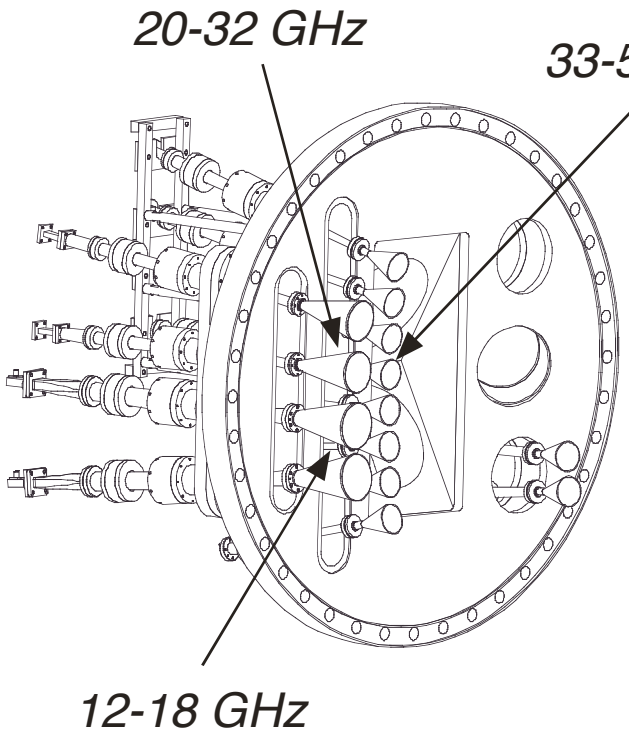
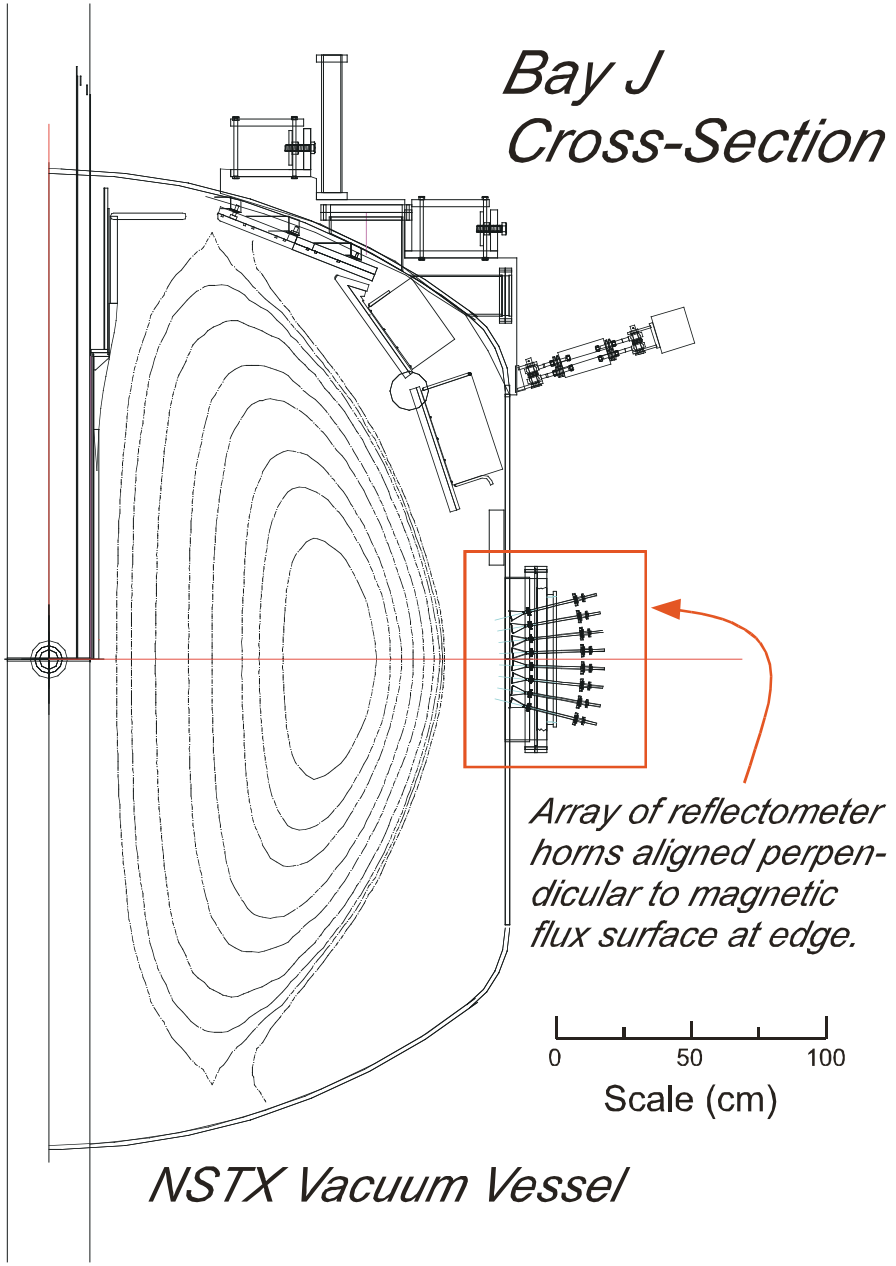
MM-Wave Reflectometery on NSTX: Goals and Contents

- Measurements of density profile and fluctuation quantities in region overlapping plasma edge and core.
  - Sensitive, local measurements with high bandwidth and excellent temporal coverage.
  - Density profiles, turbulent correlation length, fluctuation levels, magnetic field strength, Alfven modes, etc.
  - Magnetic pitch angle, RF waves, etc.
- Density profile reconstruction.
  - Between-shot analysis, edge profile modeling, FY02 data.
  - Results from ELMy H-mode discharges.
- Fluctuation measurements.
  - Turbulence at L-H transition and during H-mode, ELMs.
- Compressional Alfven eigenmodes.
  - Results from new fixed frequency quadrature systems. Simultaneous measurements of phase at three radial locations.

Location of Reflectometer Diagnostics on Bay J

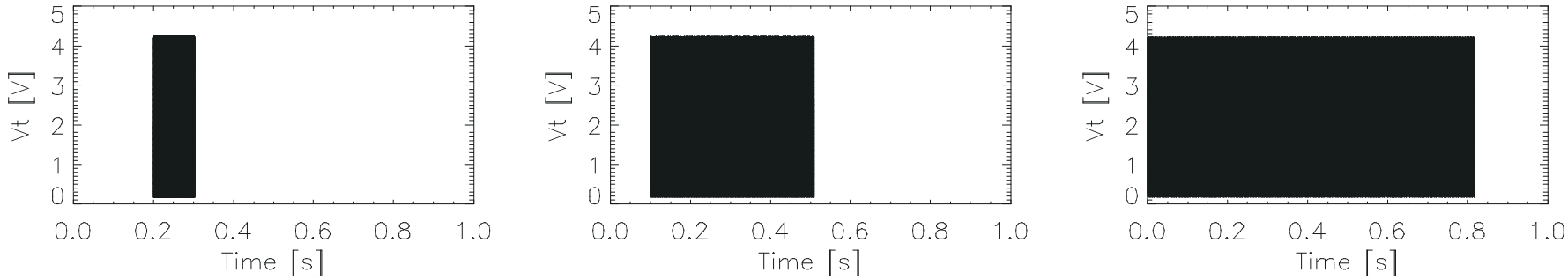




- Reflectometer uses 3 frequency bands:
  - 2 horns, 12-18 GHz.
  - 2 horns, 20-32 GHz.
  - 10 horns, 33-50 GHz.

MM-Wave Reflectometer Capabilities

- Swept-frequency operation: T=100/400/800 ms at □t=0.1/0.5/1.0 ms.



- Fixed/stepped-frequency: 3 synchronized channels, T=400/800 ms at 10/5 MHz.
  - 12-50 GHz coverage using three bands (1.8x10^{12} to 3.1x10^{13} cm^{-3}, O-mode).
  - Sweep over full band in 50 □s (reduce to 10-20 □s range).
  - To reduce turbulence effects 2 sweeps are averaged. □t=100 □s.
  - 8 MSamples each shot or 1636/2 profiles per shot (increase to 4090/2 or 8180/2).
  - LabVIEW control - easy to use GUI. Acquisition sequence is programmable.
  - Can alternate between fixed and swept frequency operation shot-by-shot (alternate between swept and fixed frequency operation during single shot).
  - Mode/polarization needs to be set manually in test cell.
  - PC data acquisition uses t=0 trigger, but not synchronized to facility clock.

Status of Diagnostic System/Profile Analysis

- Profile reflectometer has been acquiring data routinely. About 1000 shots for FY02.
- Analysis is multiple-step process involving 1) signal processing, 2) averaging and smoothing over turbulence effects, 3) edge modeling, 4) profile inversion.
- Single shot requires ~30 minutes for steps 1) and 2). This has been completed for FY02 data. Inverted profiles analyzed for May and June 2002. Will be made available on bulk storage first.
- Issue:
  - Largest uncertainties (position, gradient) due to edge modeling below lowest cutoff density (1.8×10^{12} cm^{-3}). Edge modeling using Thomson scattering edge data simplifies analysis greatly, but ... (In collaboration with EBW group, plans for 4-18 GHz system.)

Density Profile Reconstruction

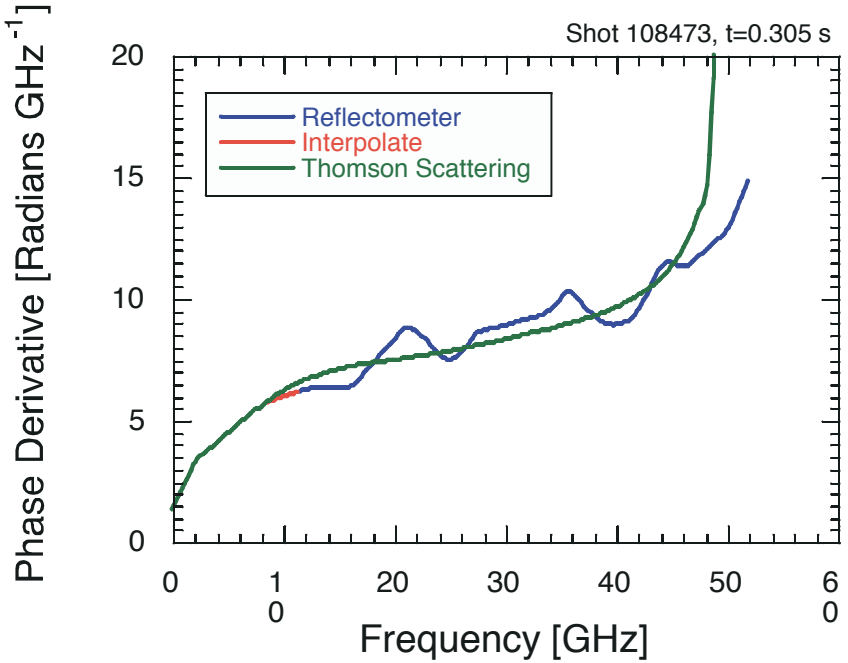
$$\phi_p(f) = \frac{4\pi f}{c} \int_{r_c(f)}^{r_p} \mu(r,f)\,dr - \frac{\pi}{2}$$

$\phi_p(f)$ phase shift of reflected wave

$\mu(r,f)$ plasma index of refraction

r_p plasma start position

$r_c(f)$ cutoff layer at frequency f



For O-mode, equation for phase curve can be written:

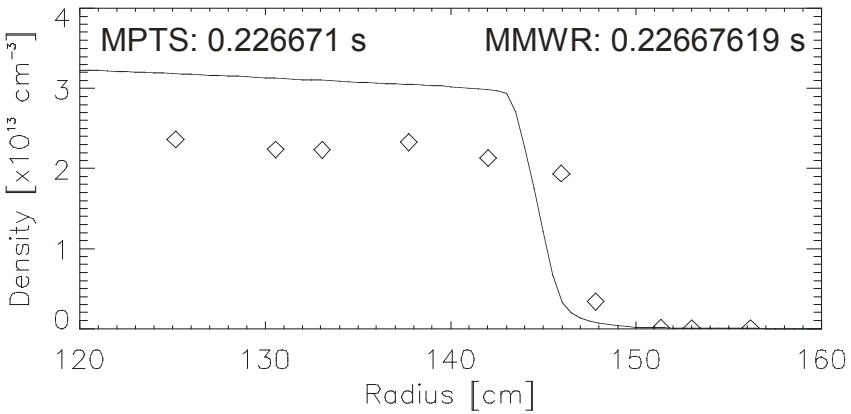
$$\vec{\phi} = \mathbf{M} \cdot \vec{r}$$

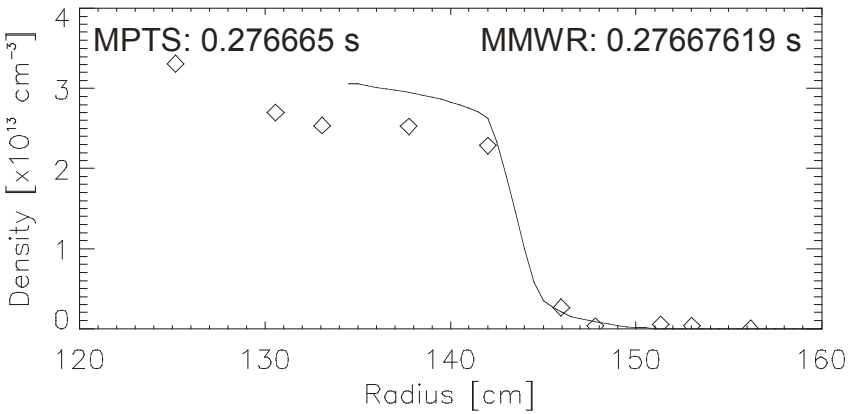
Then $\vec{r}$ is recovered via

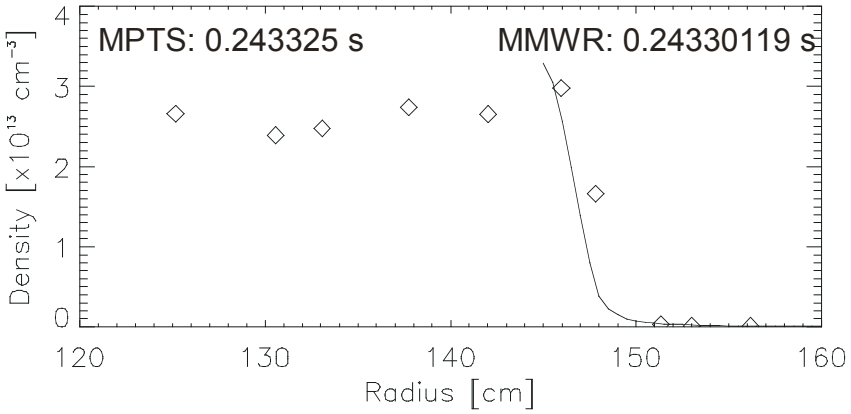
$$\vec{r} = \mathbf{M}^{-1} \cdot \vec{\phi}$$

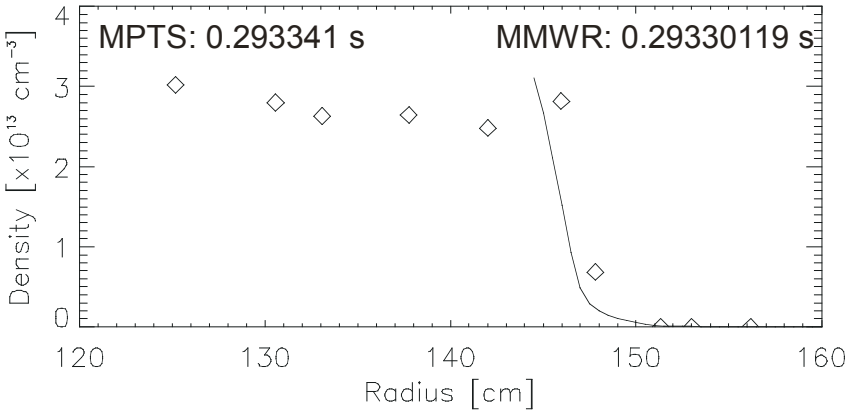
- Edge portion of phase curve required for density profile reconstruction.
- Modeled edge influences position of cutoff layer and gradient (influence largest at edge and decreases inward).
- Using edge points from Thomson scattering 20 pt data significantly decreases amount of computation.

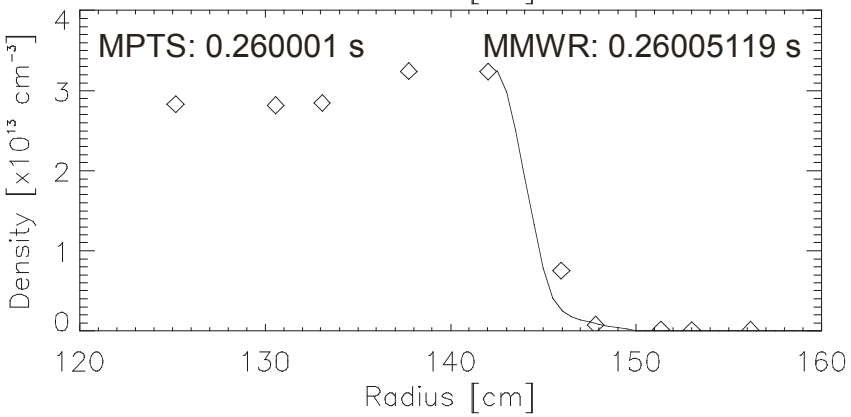
Comparison with Thomson Scattering (Shot 108487)







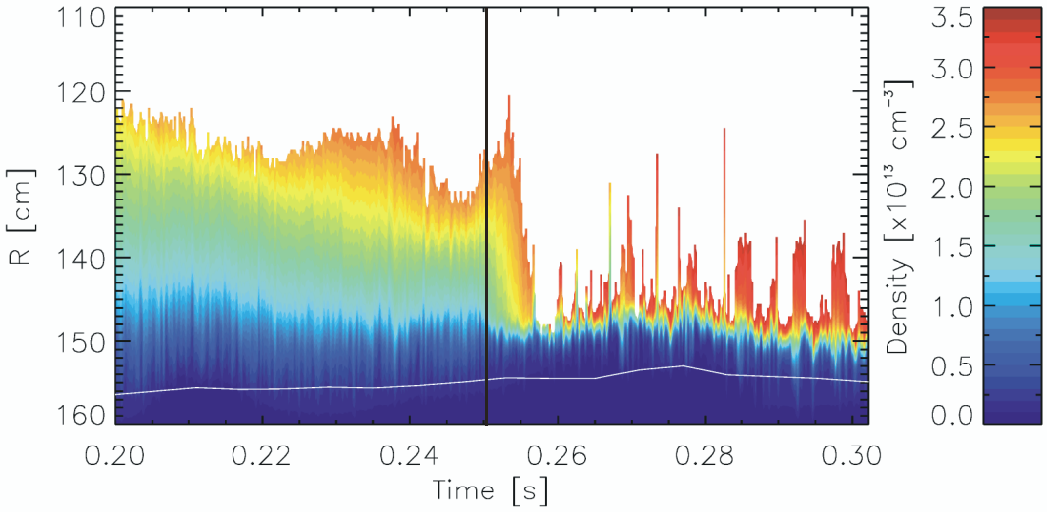




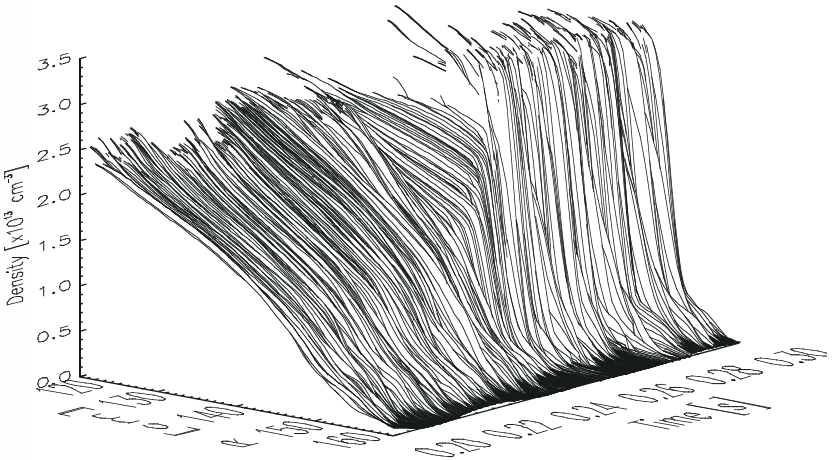
- Using spline fit to Thomson edge pro file below n_e=9x10^{11} cm^{-3}.
- Typical discrepancy of less than 2 cm between reflectometry and Thomson scattering profiles.
- Spatial resolution of <5mm.

NB-Heated Discharge: L- to H-Mode Transition (Shot 108470)

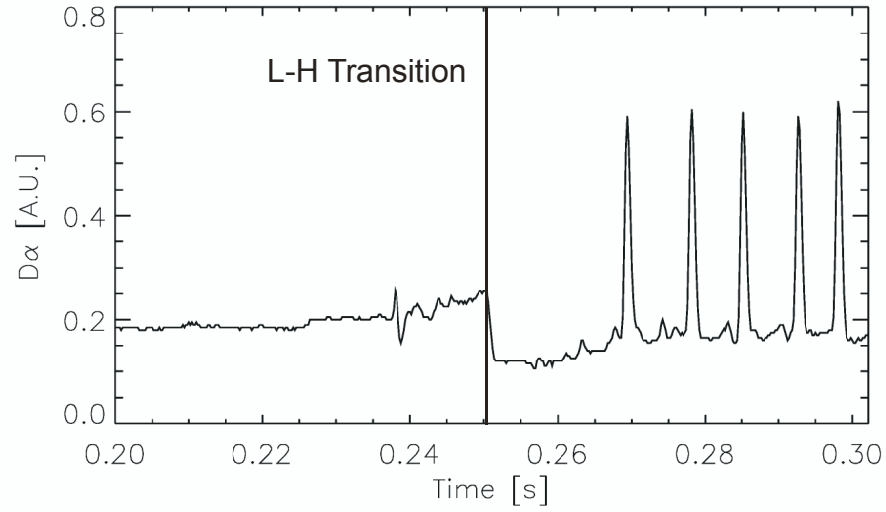
Shot 108470, Density Profile Contour Plot

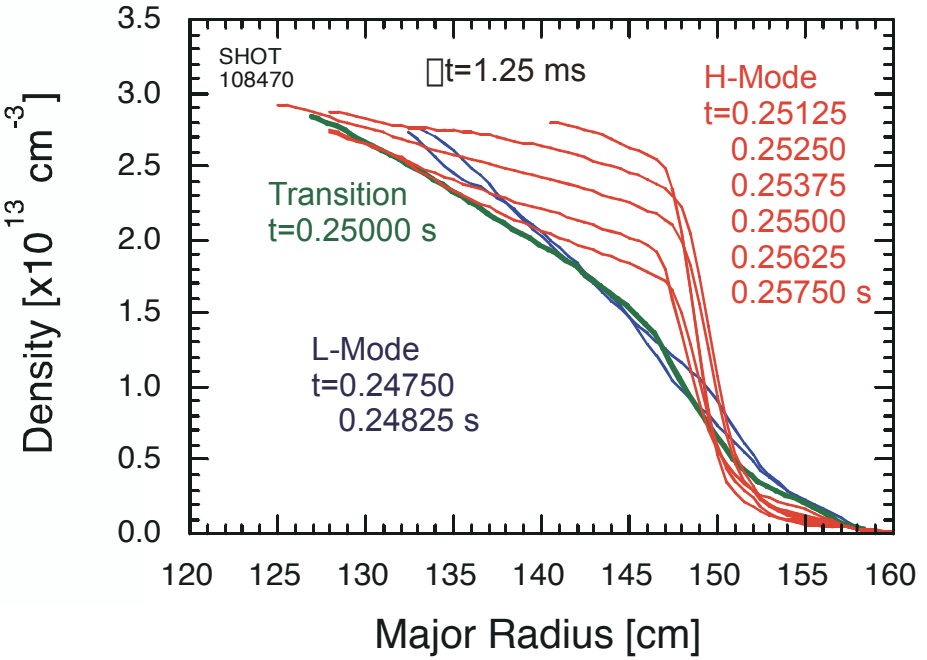


Density Profile Surface Plot (t=0.200-0.300 s)



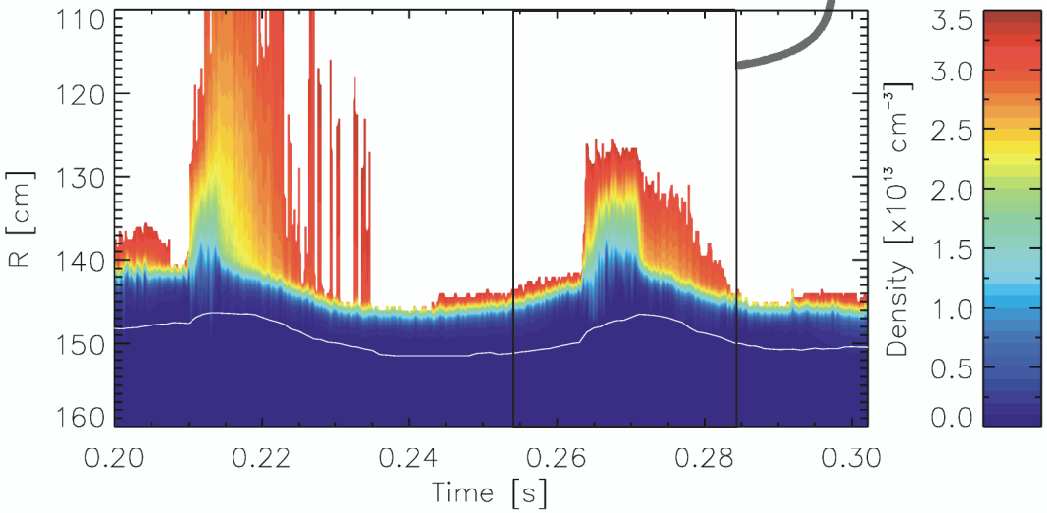
Shot 108470, Bay C Dα Intensity (Lower Divertor)



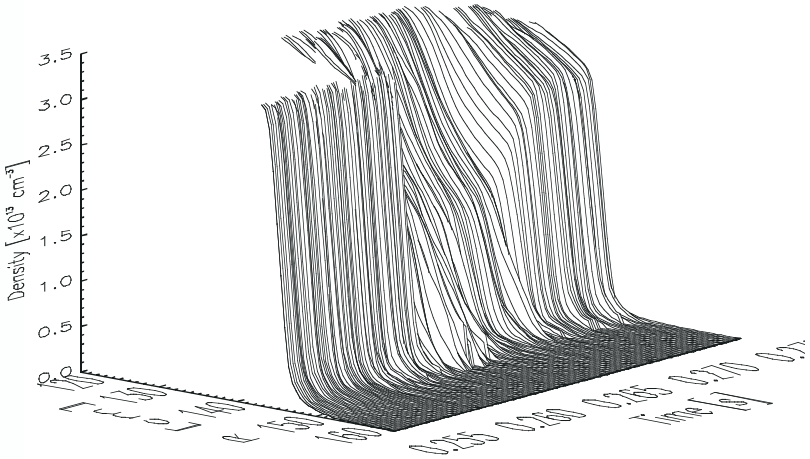


NB-Heated Discharge: H-Mode, Giant ELMs (Shot 108487)

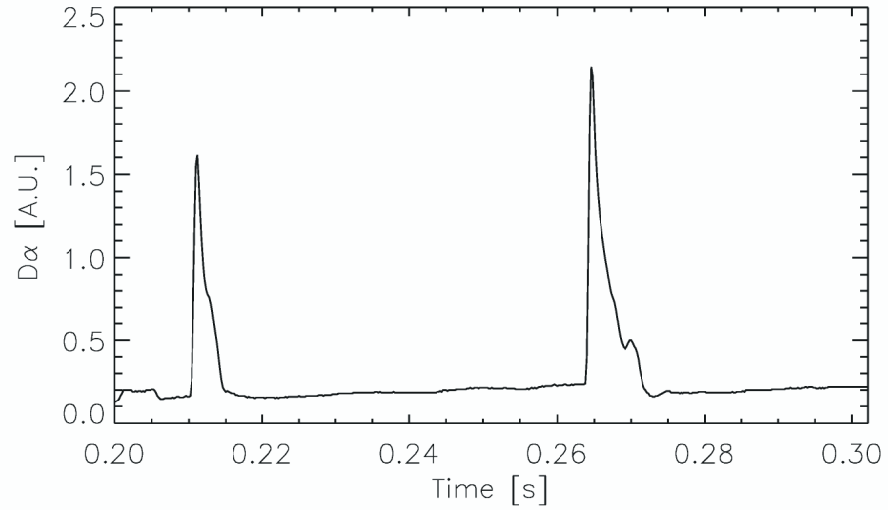
Shot 108487, Density Profile Contour Plot



Density Profile Surface Plot (t=0.255-0.275 s)

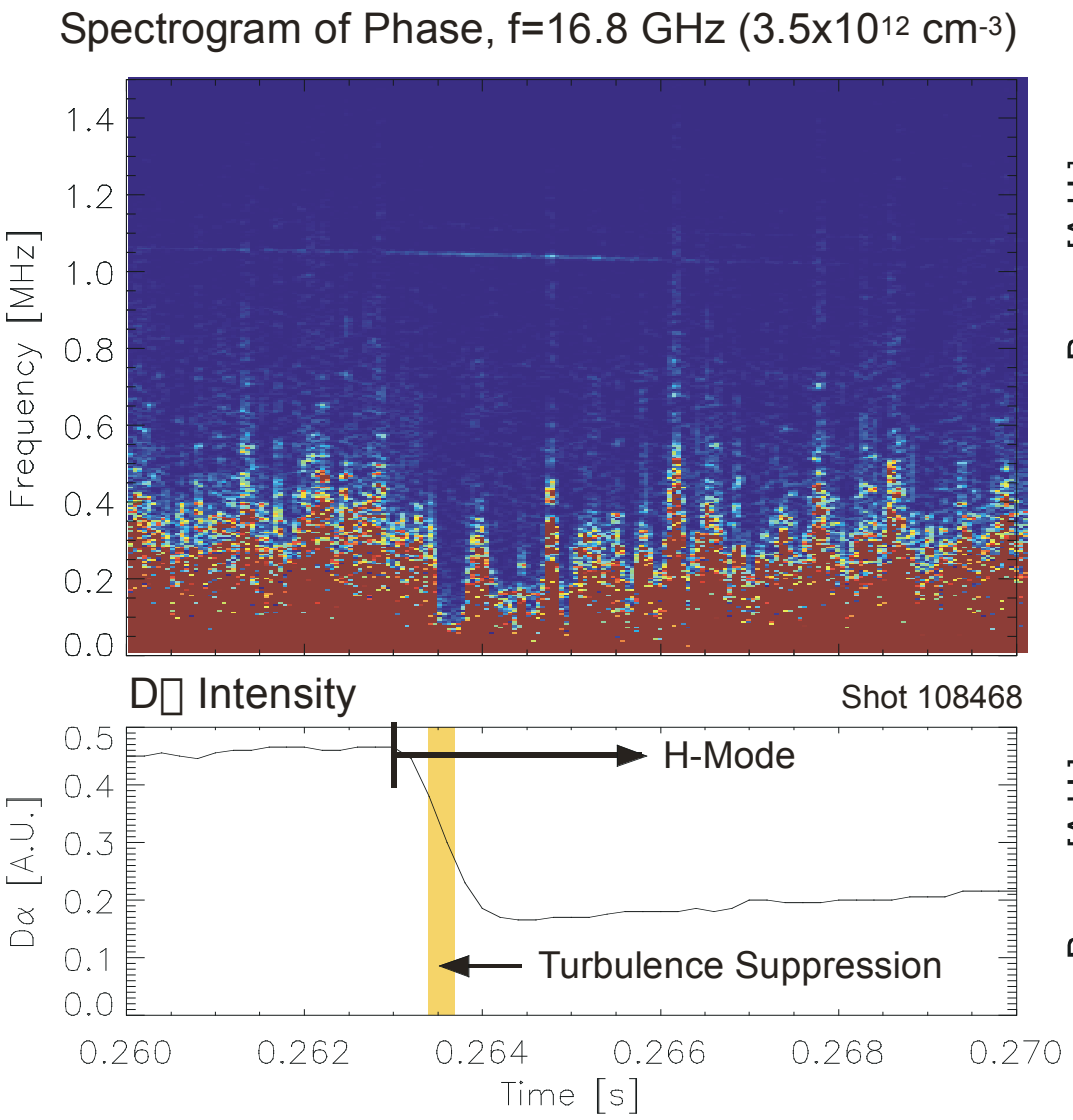


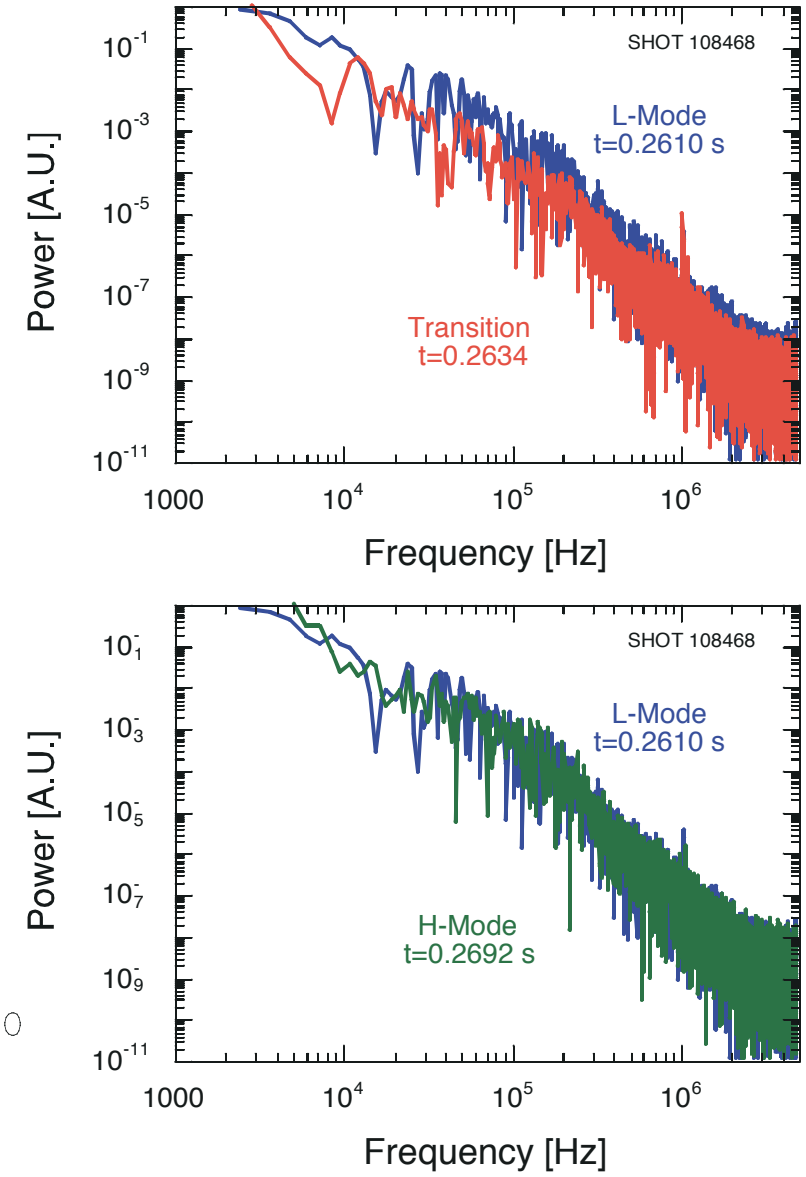
Shot 108487, Bay C Dα Intensity (Lower Divertor)



- Density contour tracks with EFIT01 LCFS very well.
- Rapid changes (fluctuations) in density profile with onset of ELMs. Δt=100 μs not fast enough to catch evolution.
- Fast ELM-like profile changes seen without corresponding Dα signature.
- Looking into decreasing sweep time to ~10 μs.

Turbulence Suppression/Fluctuations at L-H Transition

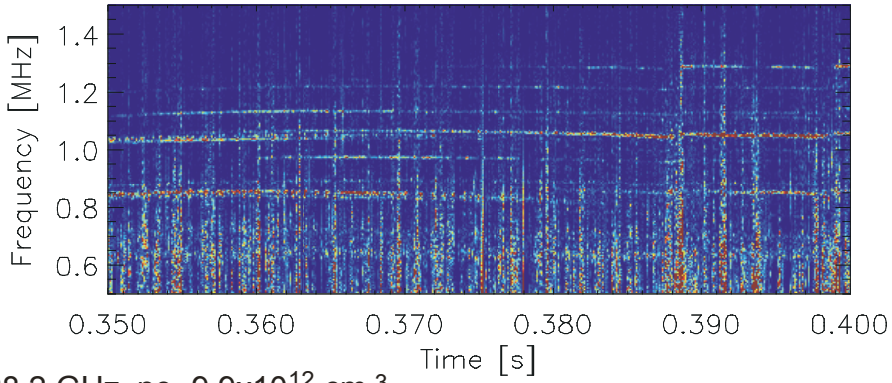




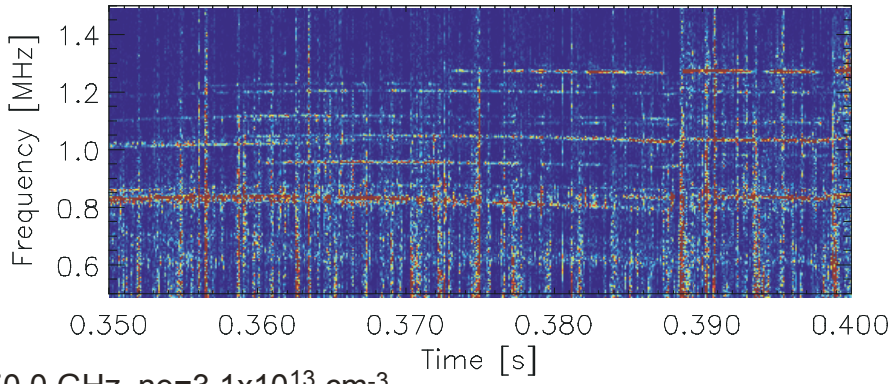
Fluctuation Measurements: Compressional Alfven Eigenmodes

Shot 108824, Reflectometer Phase Spectrograms

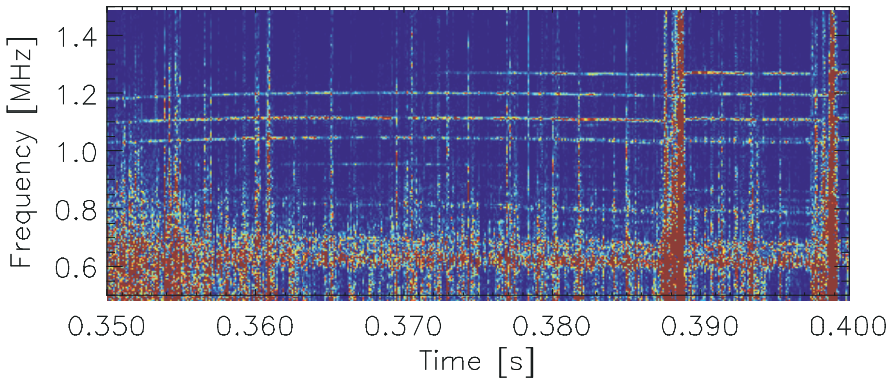
f=17.6 GHz, ne=3.8x10^{12} cm^{-3}

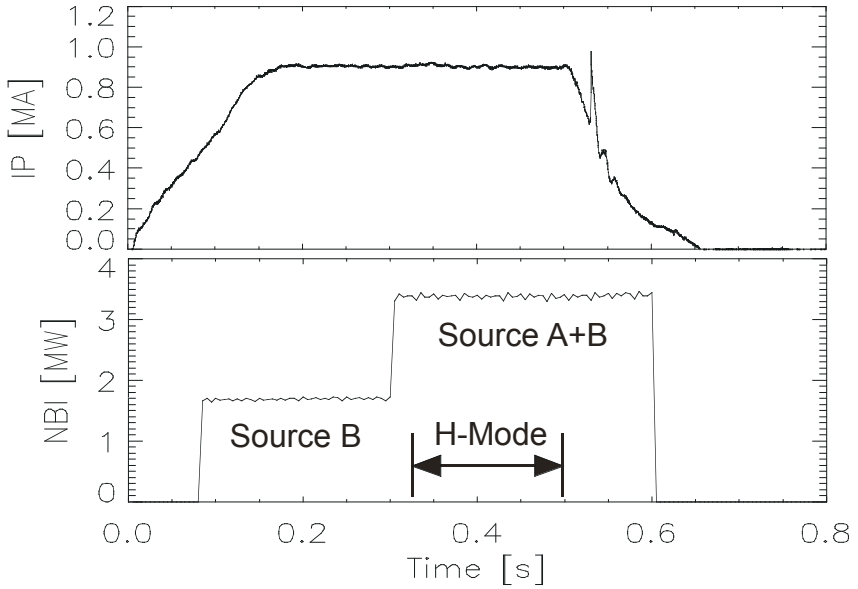


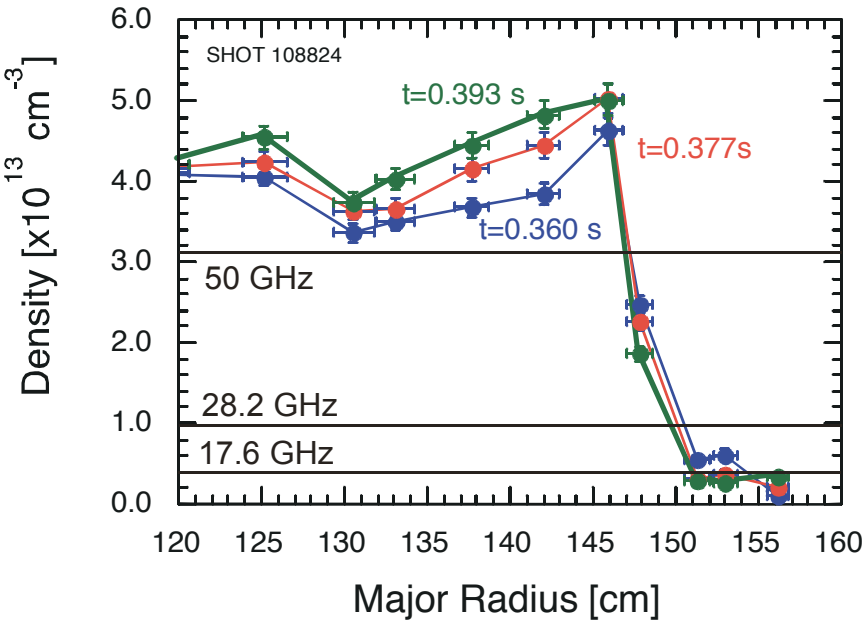
f=28.2 GHz, ne=9.9x10^{12} cm^{-3}



f=50.0 GHz, ne=3.1x10^{13} cm^{-3}







Concluding Remarks

- Synchronous measurements at three radial locations of □□ due to CAEs: Analysis goal: □n/n~□$B_{||}$/B (Fredrickson, Gorelenkov, Kramer). Spatial points sufficient?

- Profile analysis software runs automatically. Batch analysis using petrel cluster. Between-shot analysis is possible if network and multiple dedicated CPUs are available.
- Inverted profiles analyzed for May and June 2002 data for shots with 20 point Thomson data (edge modeling). Should be trivial inverting remaining shots. Uncertainty?
- Where is data? Problems with running Unix and accessing VAX storage