Reflectometry Measurements of Density Profiles and Fluctuations in NSTX

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Presentation Outline

- Goals and current status of the UCLA reflectometry system on NSTX.
  - Time- and spatially resolve measurements of density profile and fluctuations.
- Hardware description and improvements during summer 2001.
  - Quadrature mixer for 12-18 GHz channel – phase measurements.
  - Improvements in the S/N for HTO tuning voltage – crucial for fluctuation measurements.
  - Steps toward automatic density profile reconstruction – improvements in the analysis software, edge profile modeling.
- Results of density profile measurements.
  - Comparison with Thomson scattering.
  - Example of fast profile evolution: L- to H-mode transition.
- Fluctuation measurements – phase measurements in the SOL.
  - Turbulence suppression during L- to H-mode transition.
  - Compressional Alfven Eigenmodes.
- Summary and Future Work
  - Profile system is nearing completion – automatic analysis software is main hurdle.
  - Additional channels for dedicated fluctuation measurements.

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Goals for Reflectometry on NSTX

- FMCW (Frequency Modulated Continuous Wave) reflectometry on NSTX.
  - Immediate goal of time- and spatially-resolved electron density profiles for equilibrium and transport analysis.
  - Time-tested diagnostic – capability of routine measurements with between-shot analysis.
  - Easily configured for fixed- or stepped-frequency homodyne fluctuation measurements. Not phase, but we can get an idea of what signals might look like today.
  - Parts can be upgraded incrementally for increased capability. I/Q mixers – phase measurements for estimates of fluctuation levels.
- Lessons learned will contribute to our ultimate goal of simultaneous profile and fluctuation measurements. Turbulence and transport.
  - Multiple fixed frequency channels. Simultaneous measurements with good spatial resolution.
  - Homodyne systems with quadrature detection for phase measurements – absolute density fluctuation levels.
  - Horns are already installed for additional channels.
  - Necessary hardware and vendors have been identified. Single channel system could be available for testing during the next run period.

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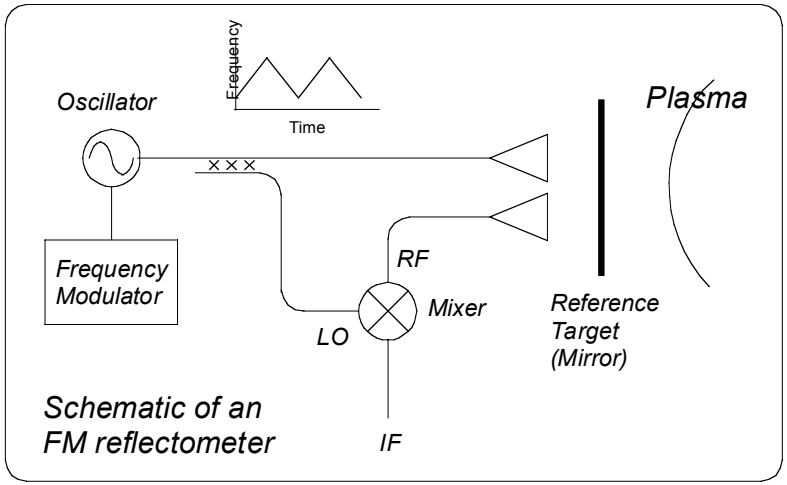
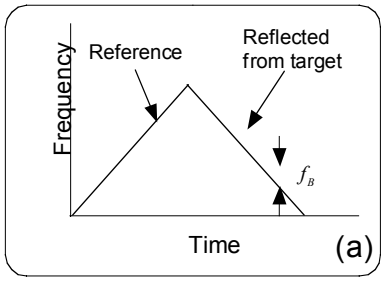
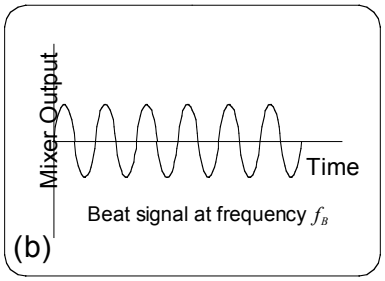
FM Continuous Wave Reflectometry



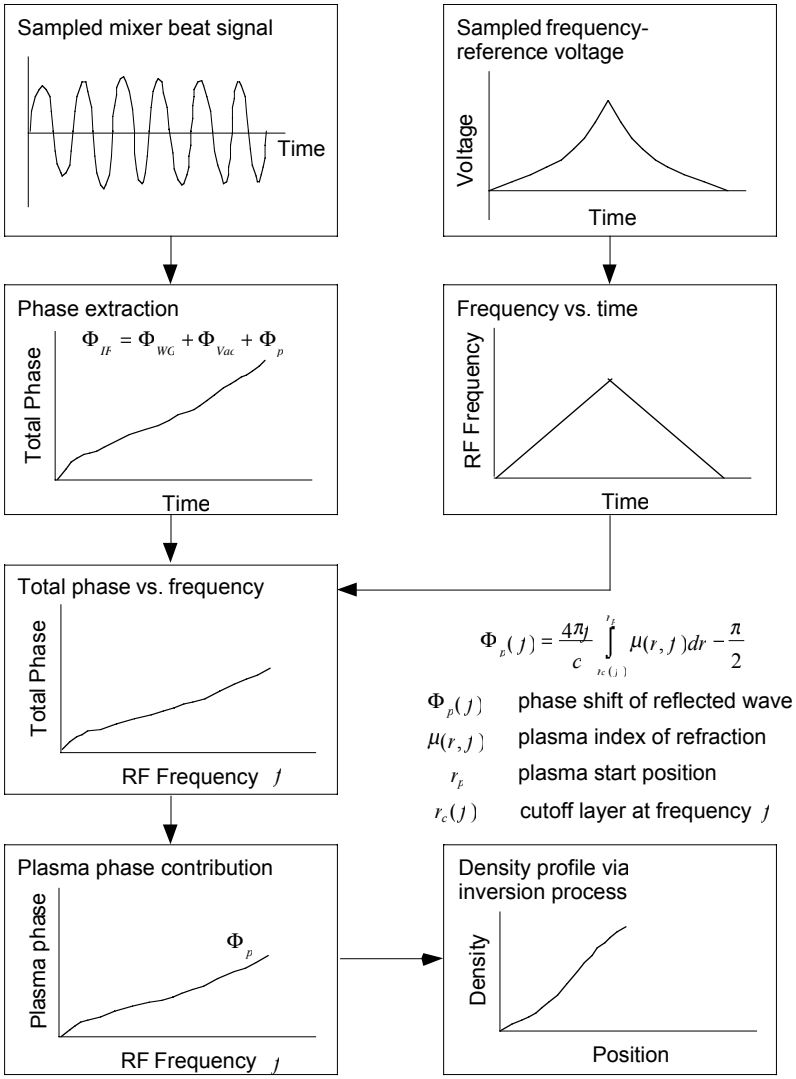




(a) Reflected wave is delayed in time with respect to the reference wave.

(b) With a mirror target, a beat with a constant frequency proportional to the mirror distance is created.

(c) The number of accumulated fringes during a sweep is linearly proportional to the mirror distance.



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

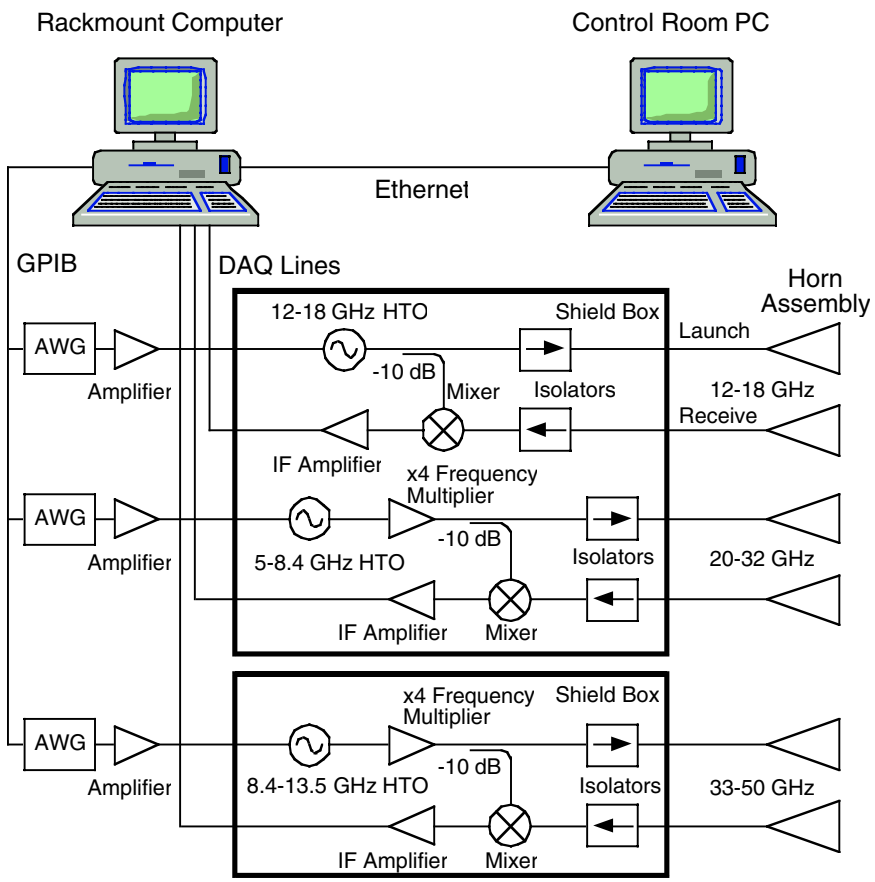
$\Phi_p(f)$ phase shift of reflected wave

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

r_f plasma start position

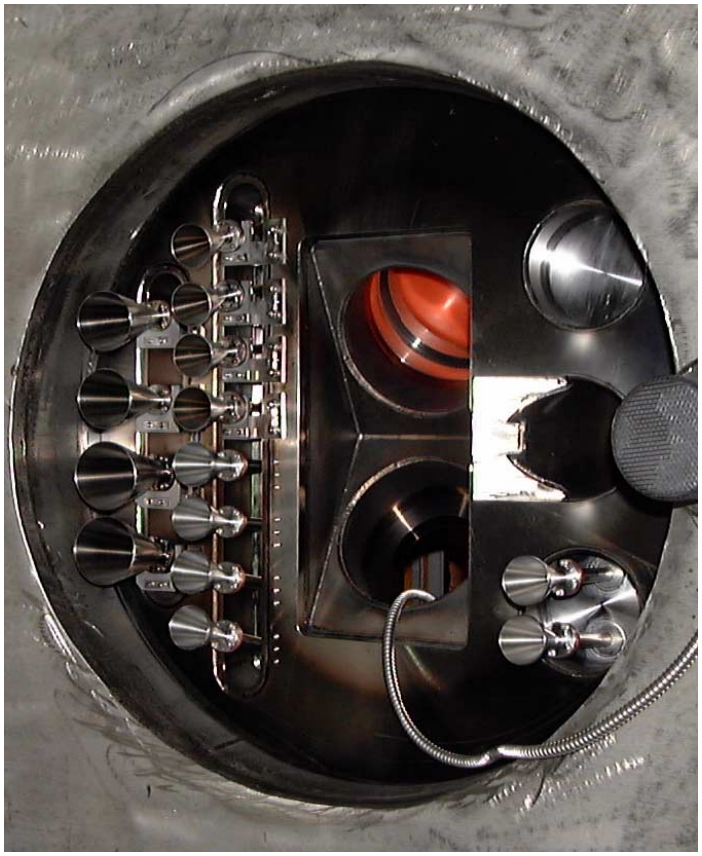
$r_c(f)$ cutoff layer at frequency f

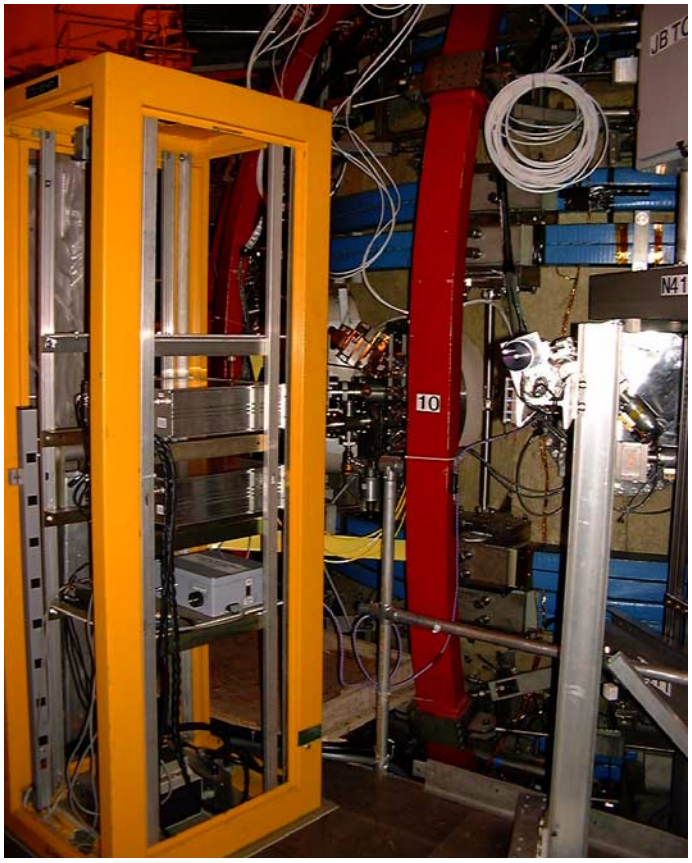
Current Status of UCLA Reflectometry System



- Profile system is essentially complete.
  - 12-50 GHz coverage over 3 bands – (1.8×10^{12} to 3.1×10^{13} cm^{-3}).
  - Sweep rates over full band in 50~100 μs. IF between 2 and 5 MHz. S/N typically greater than 20.
  - Effect of fluctuations usually eliminated by averaging several sweeps.
  - Data acquisition stores 8 MSamples per channel each shot or 409 records (profiles) at 1 ms intervals.
  - Programmable control and acquisition.
  - Operated daily during summer 2001. Data for about 50% of shots.
- Data analysis is not yet automatic.
  - Phase recovery portion is now automatic and robust (~30 min/shot).
  - Work on edge profile modeling is still ongoing. Will be online shortly!

Hardware Currently Installed on NSTX





- 7 pairs of horns located on Bay J cover. Adjacent instrument racks for mounting millimeter-wave, data acquisition and control equipment.

Improvements During Summer 2001

- Waveguide for 33-50 GHz band warped. Will be replaced before next run.
- Impact on previous measurements not clear.

- Work has concentrated on improving fluctuation measurement capabilities.
- HTO tuning voltage amplifiers rebuilt to decrease phase noise.
  - Filters for broadband noise generated by arbitrary waveform generators. Phase noise of oscillators decreased by a factor of 4.
  - Direct reading of tuning voltage monitor signal. Also eliminates time delay between mixer output and voltage sweep.
- Added I/Q mixer for phase measurement capability in edge channel.
- Code for automatic oscillator/waveform generator/digitizer calibration.
- In-vessel calibration of phase versus target distance. Confirmed relative distances between horns, center stack, and vacuum vessel.

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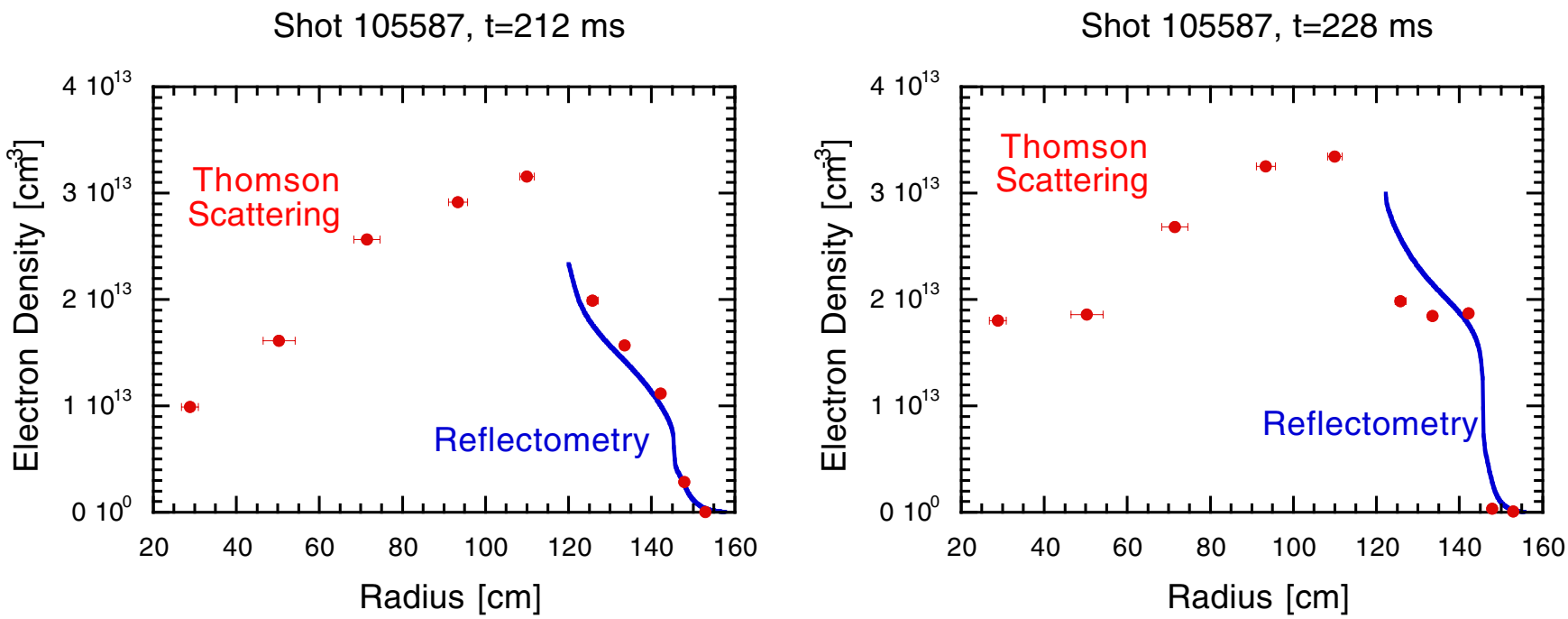
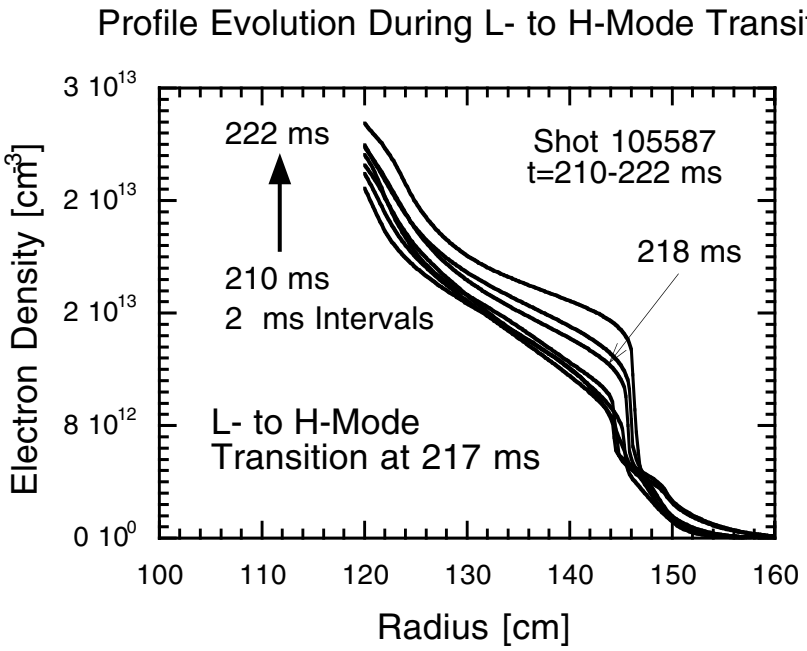
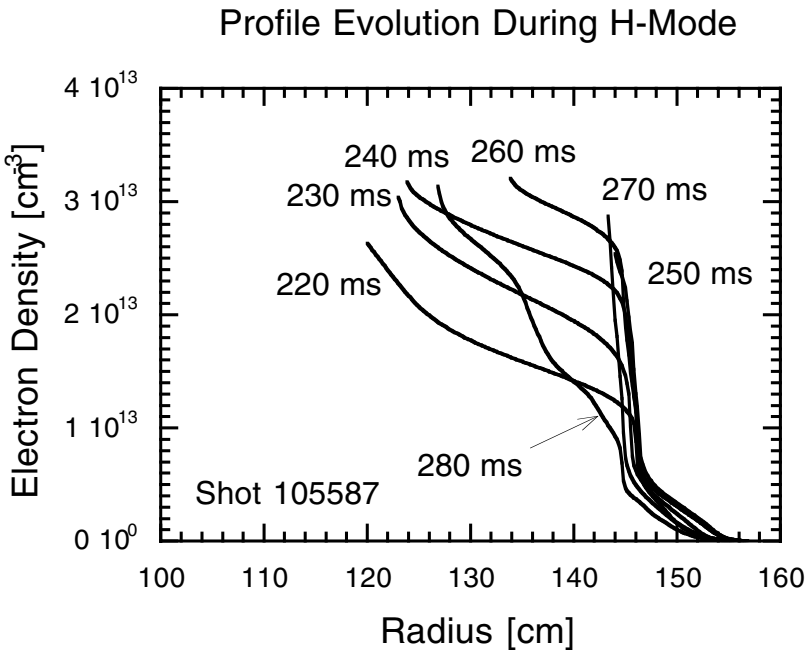
Comparison with Thomson Scattering



- Reflectometry profile reconstructions typically within a few cm of Thomson scattering measurements. Good agreement over a wide variety of profile shapes.
- Edge profile below 1.8x10^{12} cm^{-3} must be modeled. Largest source of uncertainty. Future measurements via edge probes or X-mode reflectometry will help.
- Problems reconstructing above off-axis density peaks.

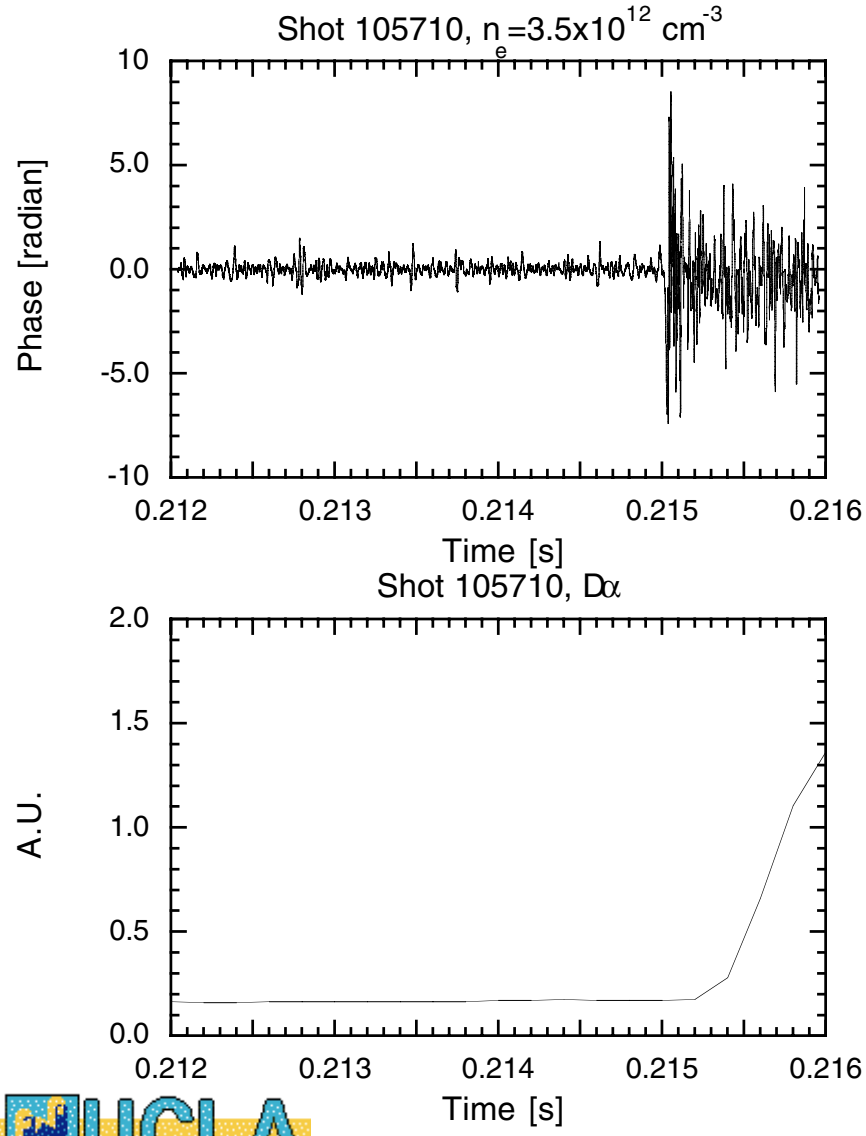
Profile Evolution During H-Mode

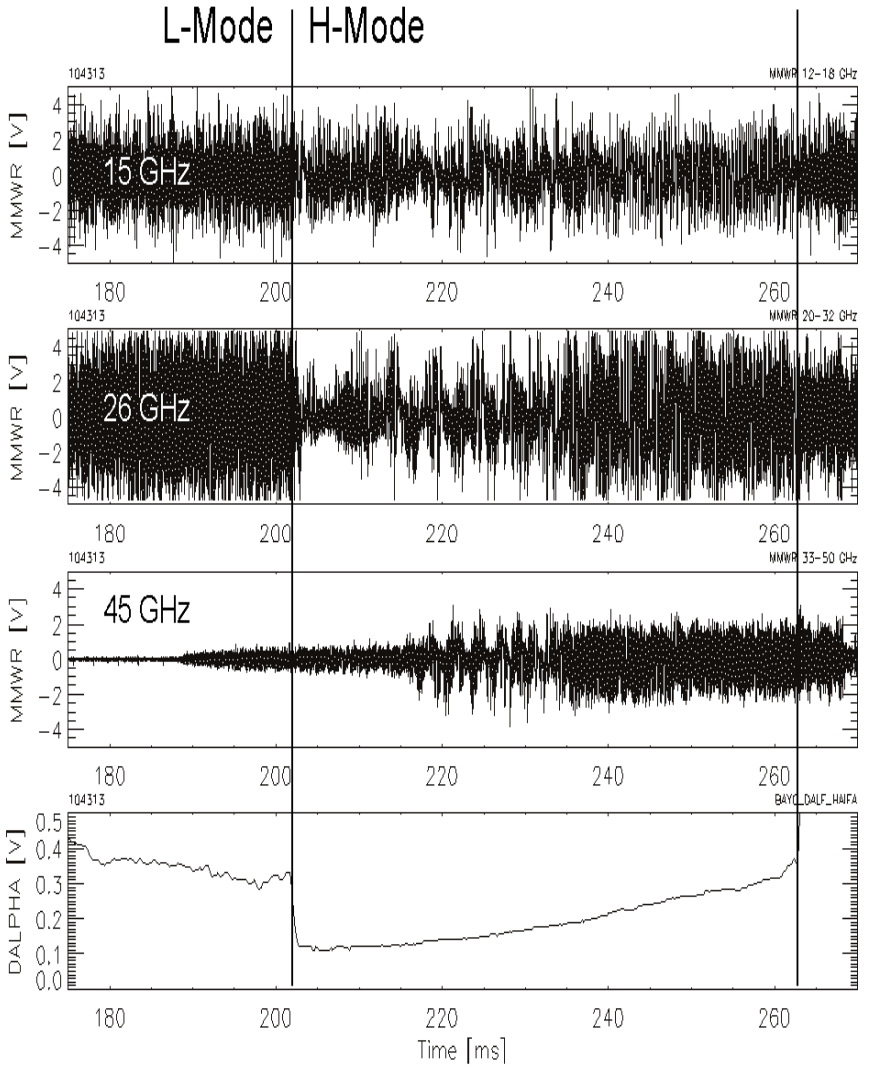




- Documents time evolution of rapid profile change at L- to H- transition, as well as gradual increase in the edge density pedestal during H-mode.
- Profile at 280 ms after reconnection event.

Turbulence Suppression During L- to H-Mode Transition

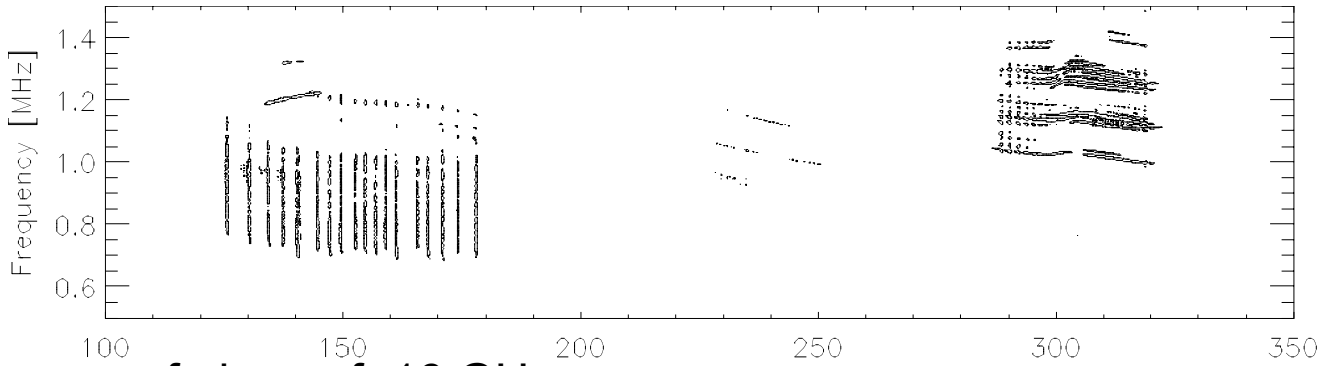




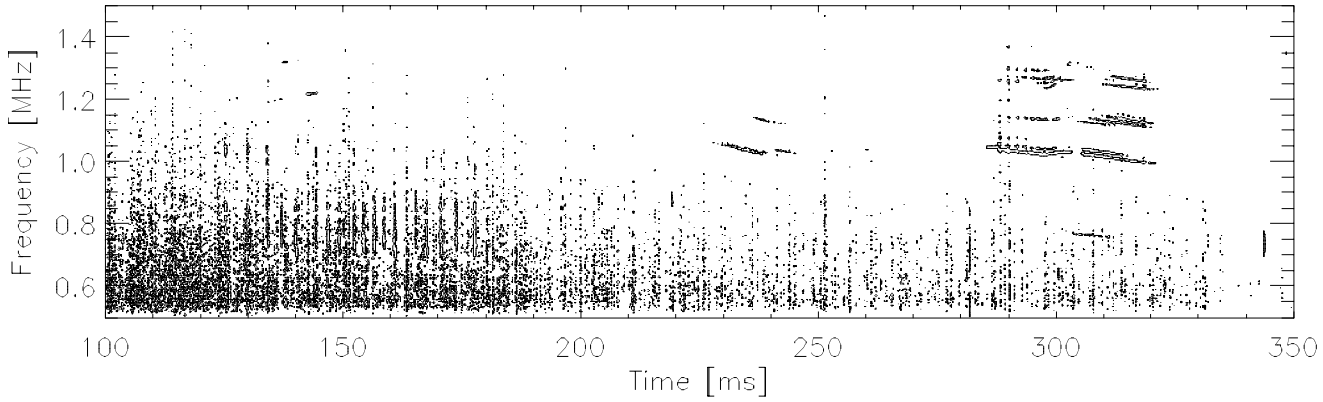
Compressional Alfven Eigenmodes

Spectrogram of raw Mirnov signal.

Shot 106233



Spectrogram of phase, f=16 GHz.



Summary and Future Work

- Profile hardware for 12-50 GHz FMCW reflectometer is essentially completed.
  - Diagnostic operates routinely, however automatic data analysis is still being developed. Issues with edge profile modeling.
  - Reconstructed profiles show good agreement with Thomson scattering.
  - Demonstrated ability to track rapid profile evolutions (1ms time interval).
- Major improvements for fluctuation measurements.
  - Phase measurements using I/Q mixer for 12-18 GHz channel.
  - HTO phase noise much lower. Rapid frequency sweep/step capability intact.
  - Above hardware used to look at CAE's and turbulence suppression during L-H transition.
- Further analysis will require absolute density fluctuation via measurement of phase.
  - Dedicated multi-channel system for simultaneous measurements spanning profile.
  - Single channel system could be available for testing during the next run period.
- Turbulence radial correlation length via homodyne correlation reflectometry. Magnetic field strength measurement via dual-mode correlation reflectometry.
  - Preliminary results outlined in previous presentation by M. Gilmore.
- Measurement of magnetic field pitch angle.
  - Toroidally separated arrays of vertically oriented reflectometers utilized to search for correlation of density fluctuations aligned along magnetic field.