Microturbulence Characteristics in Saturated Ohmic Discharges and ITG Mode Expectations

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Comparison of Microturbulence Characteristics in Ohmic and ITB Discharges with Predictions of ITG Models[1]

C.L. RETTIG, T.L. RHODES, W.A. PEEBLES, E.J. DOYLE, UCLA, K.H. BURRELL, C.M. GREENFIELD, G.M. STAEBLER, General Atomics, J.E. KINSEY, Lehigh Univ., G.R. MCKEE, Univ. Wisconsin-Madison, C. ROST, MIT — Fluctuation characteristics measured in DIII–D discharges are compared with features predicted from gyro-fluid and kinetic codes using measured experimental profiles and geometry. In Ohmic discharges, the dominant instability is predicted to be the dissipative trapped electron mode or the ion temperature gradient mode, depending on specific conditions. Measurements of turbulence, spatial and temporal coherence, and propagation characteristics have been obtained through a density scan in neo-Alcator and saturated confinement regimes and allow comparison of measured turbulence characteristics with code predictions when the dominant mode changes. Additionally, dynamic evolution of turbulence is compared with predictions of empirical dynamical and gyro-fluid stability codes.

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☐ Prefer Oral Session
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Fluctuation characteristics measured in DIII-D discharges are compared with features predicted from gyro-kinetic codes using measured experimental profiles and geometry. In Ohmic discharges, the dominant instability is predicted to be either the dissipative trapped electron mode or the ion temperature gradient mode, depending on specific conditions. Measurements of turbulence spectra, wavenumber dependence, radial correlation length and dispersion have been obtained through a density scan in the neo-Alcator and saturated confinement regimes. This allows comparison of measured turbulence characteristics with code predictions when the dominant modes changes, aimed to identification of mode physics. In this density range, the confinement changes from neo-Alcator scaling to saturated OHmic confinement.

Summary

- Density fluctuations observed in DIII-D possess specific characteristics and scaling dependence consistent with predictions associated with the Ion Temperature Gradient (ITG) instability.
    - frequency and spatial scale are consistent with expectations

- The mode is observed in high density saturated Ohmic confinement discharges whose magnitude increases rapidly above the saturation density.

- Direct implications include: (1) Ohmic saturation is due to turning on of ITG mode due to density profile flattening and heating of ions (2) the ITG mode is real and capable of anomalous transport.

- Indirect implications: (1) the ITG mode may be the dominant mode in real experiments, (2) ITG physics based modeling could be valuable predictive tools

Motivation

- Theoretical modeling represent a possible route to achieving a physics-based predictive capability.
  - attractive tool for present and future R&D
  - interpolate and extrapolate
- Present hypotheses:
  - anomalous transport is dominated by turbulent transport,
  - dominant mode is often the ion temperature gradient instability

- However, underlying physics of the turbulence is unverified experimentally, e.g. instability could be driven by a different source of free energy.

- If a different mode is present and dominant, the scaling characteristics could be significantly different, rendering the code useless for extrapolation or enhancing physical understanding.

Background

- The η_I or Ion Temperature Gradient (ITG) mode has been proposed as the dominant instability in high density plasmas, responsible for anomalous transport.[1]

- Linear and nonlinear codes based on gyrokinetic or PIC treatments typically predict that the ITG mode is dominant.

- Although experimental studies have observed strong turbulent fluctuations in plasma density, few of the turbulence features can be associated uniquely with the ITG mode.[2]

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1. Coppi, *et al*, IAEA 1984.
2. Brower, D.L., *et al*, PRL **59**, 48 (1987).

Approach

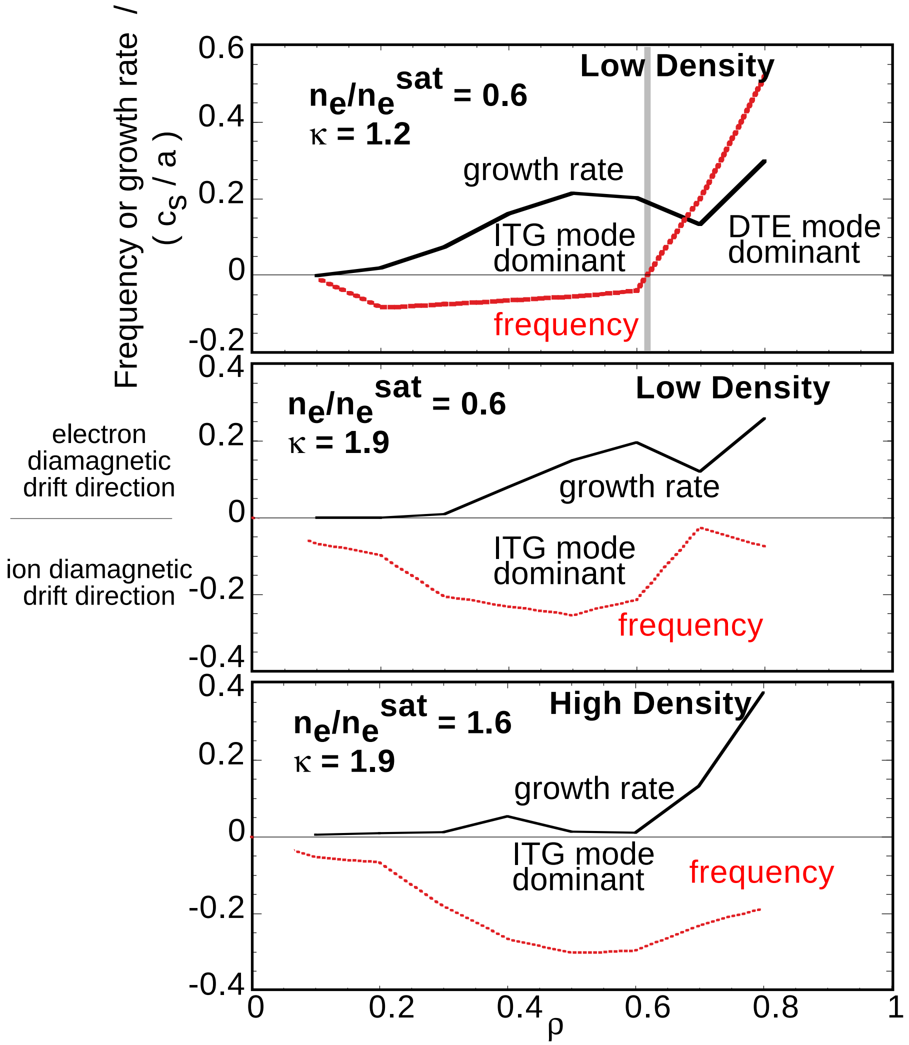
- In low density neo-Alcator discharges, dominated by electron conduction, energy confinement scales with density.
- At higher density, ion conduction becomes more important, and the energy confinement saturates, becoming independent of density.
- Compare predicted mode scaling with onset of neo-Alcator saturation to provide coincidental evidence for importance of microturbulence.

- Characterize turbulence features in the simplest possible plasma discharges in order to provide identification of the mode.
- Monitor turbulence characteristics with FIR scattering, reflectometer (poloidal dispersion system and correlation system), PCI, BES, and edge probe during the following discharges:

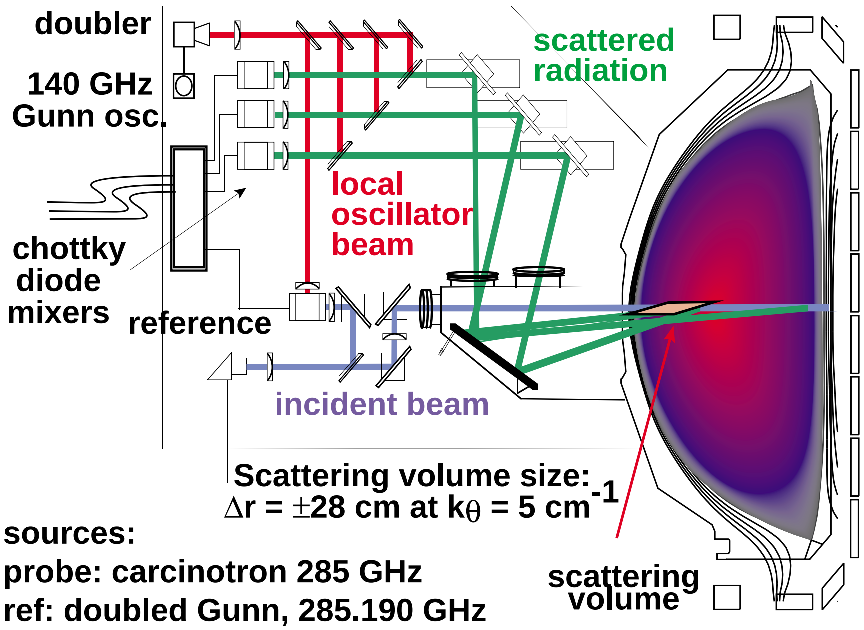
1. at low density within the neo-Alcator confinement scaling regime in which confinement scales with density;
2. in the saturated regime in which confinement time is independent of density and the ITG mode is predicted to be unstable and dominant

Accessing Regimes of Different Dominant Modes

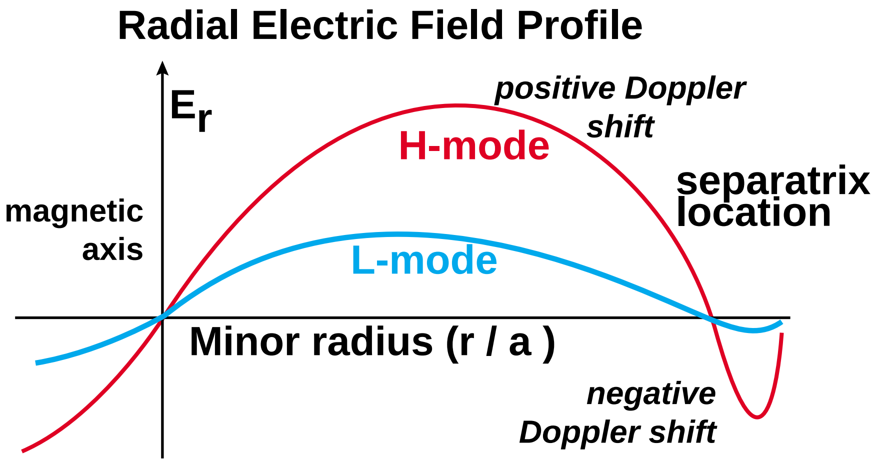
- **By scanning the plasma across regimes whose dominant modes are predicted to be different, mode identification becomes possible.**
- **The dominant mode identifiers may be observed, e.g. low frequency associated with ITG mode at high density.**



Coherent Thomson Scattering



sources:
probe: carcinotron 285 GHz
ref: doubled Gunn, 285.190 GHz



- **A spatially varying radial electric field affects the scattered spectrum via an ExB Doppler shift:**

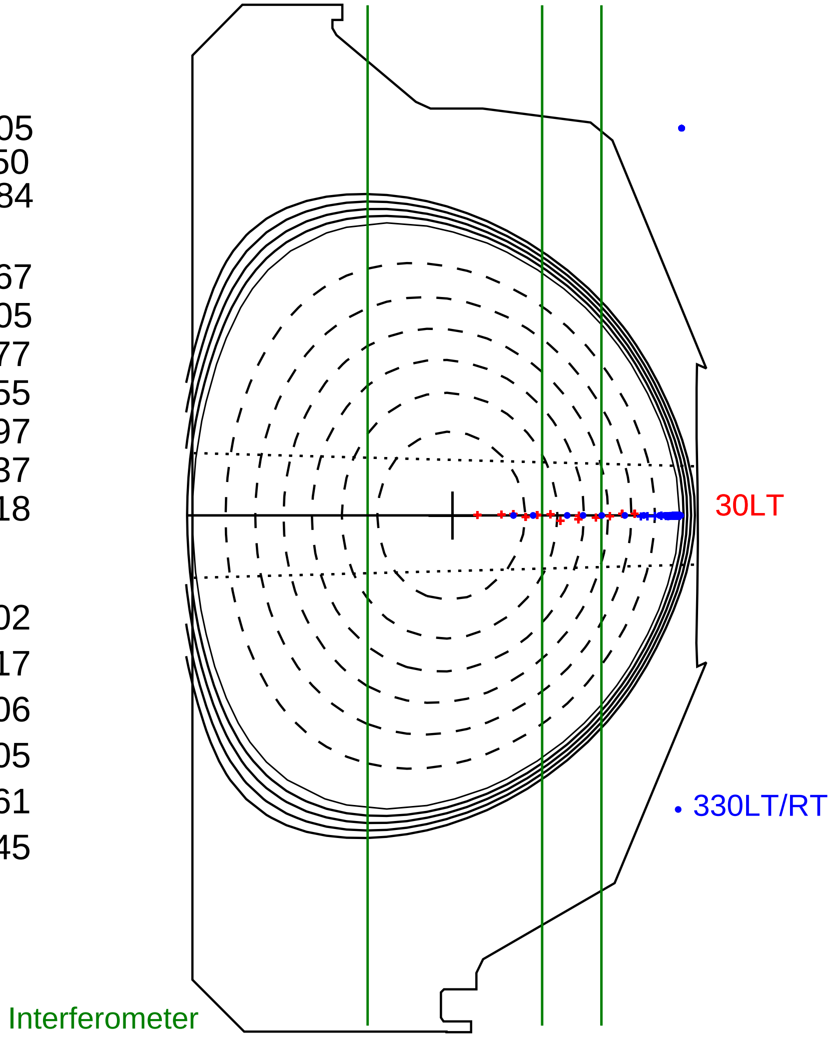
$$f_D = k_\theta\left(\frac{\underline{E}_r \times \underline{B}}{B^2}\right)$$

- **Therefore, a sheared radial electric field results in different Doppler shifts at different location within the scattering volume for improved resolution.**

Discharge Shape and Parameters

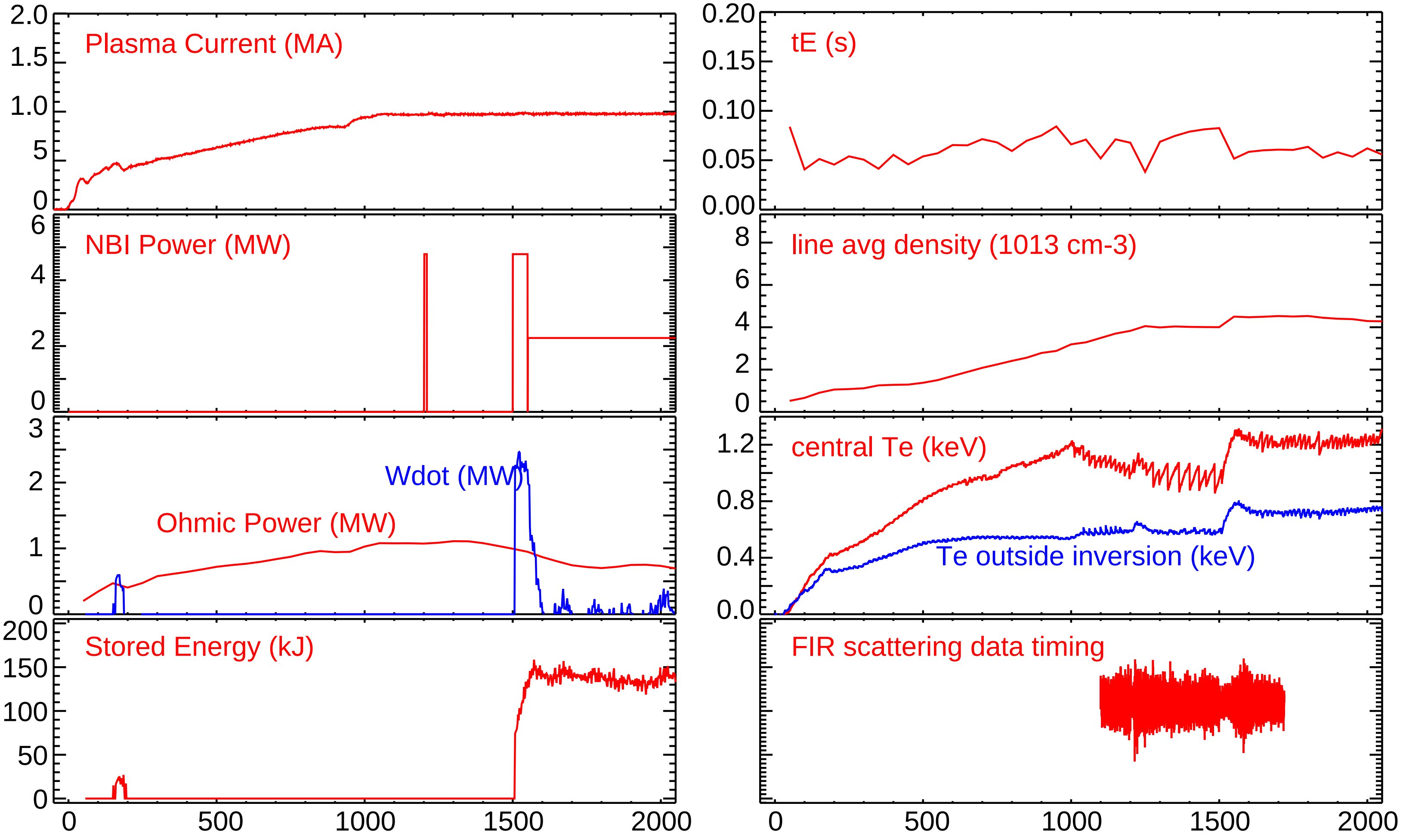
- **Low elongation was chosen to reduce anomalous rotation thence reducing the electric field and ExB Doppler shift.**

shot	99805
time	1150
chi**2	14.384
Ipmeas(MA)	-0.967
BT(0)(T)	-1.905
q95	3.577
qm	1.055
W (MJ)	0.097
Wdia(MJ)	0.137
nev1(e19)	3.518
elong	1.202
Rmidin(m)	1.017
Rmidout(m)	2.306
Rm(m)	1.705
Rout(m)	1.661
a(m)	0.645



Discharge Timing and Sequence

- **Neutral beam blips were applied at two different times during the discharge to allow measurement of ion temperature and impurity rotation via charge exchange recombination (CER) spectroscopy.**



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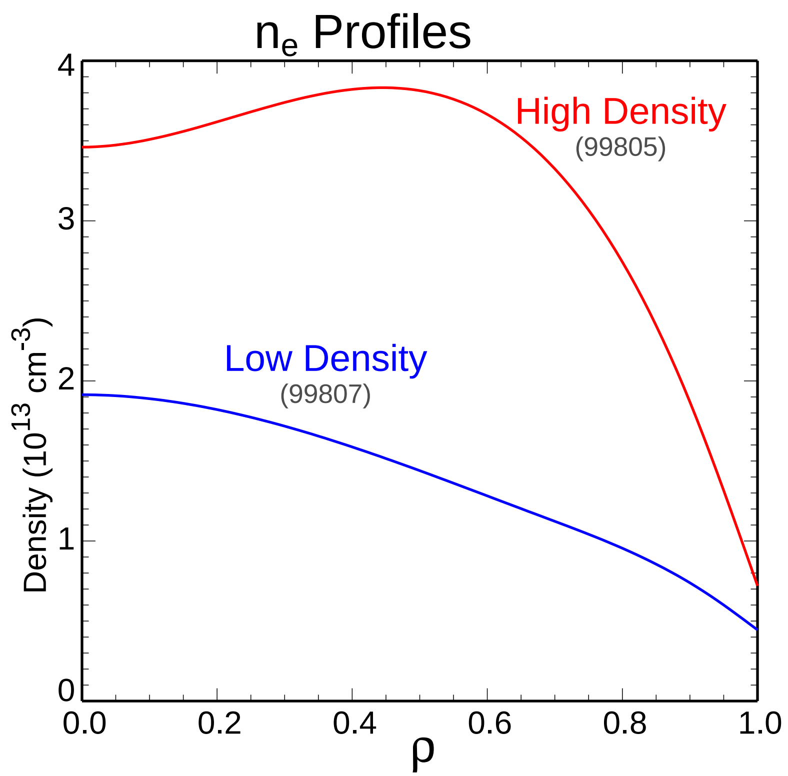
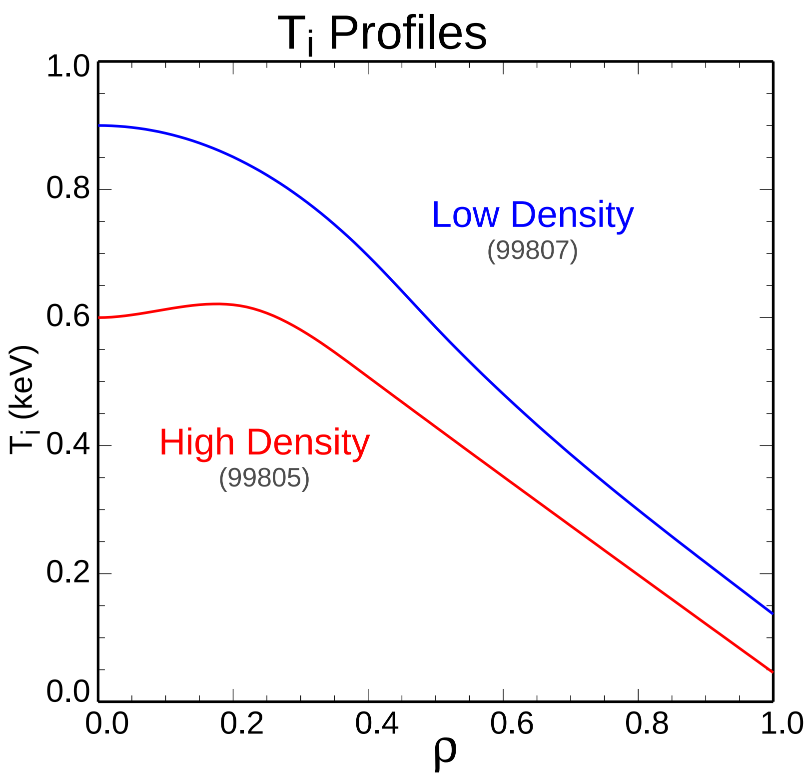
Density and Temperature Profiles

- **Density scan resulted in differing temperature profiles.**
- **In general, higher density discharges are more peaked.**

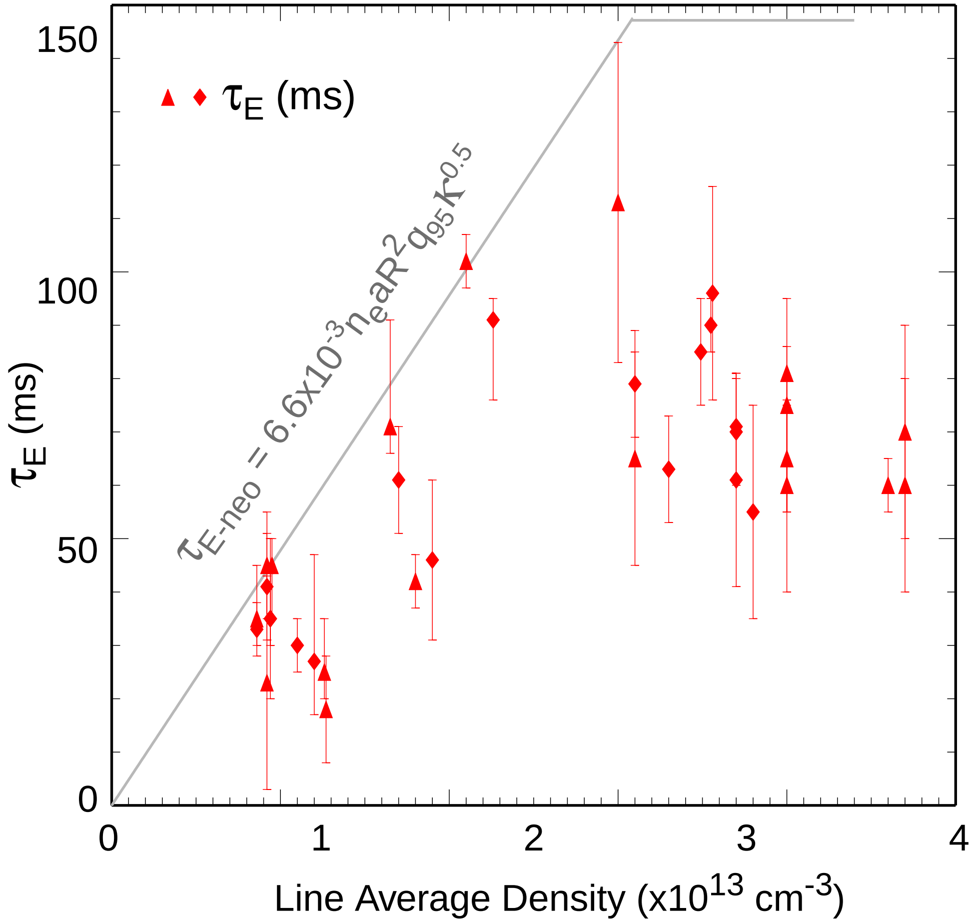




Density Scan through neo-Alcator Regime

- **In DIII-D Ohmically heated discharges, the density was scanned through the neo-Alcator scaling regime and into saturated confinement.**

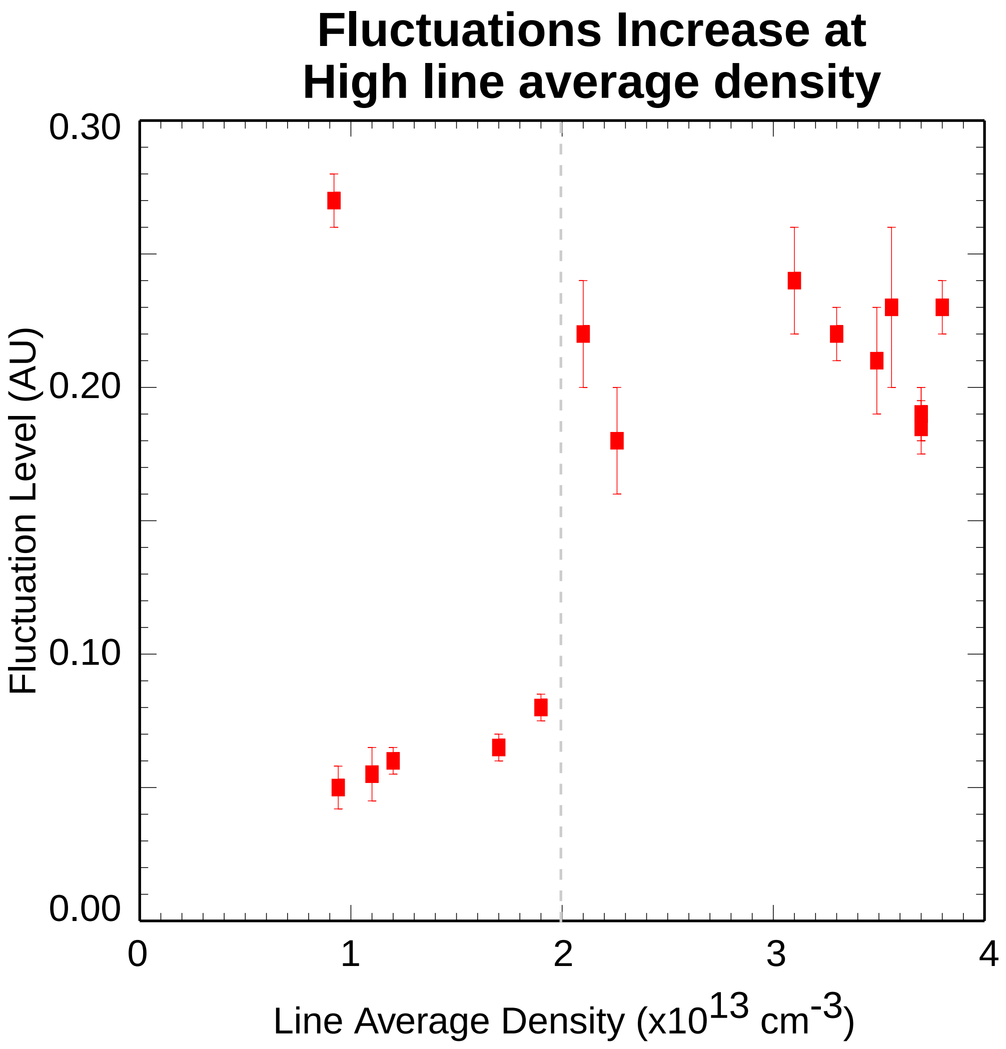
- **Experimental goal was to search for a mode which turned on when confinement saturated, then compare mode features with predictions of linear and non-linear codes.**



Energy Confinement Time versus Line Average Density

Increased Fluctuations seen at Higher Density

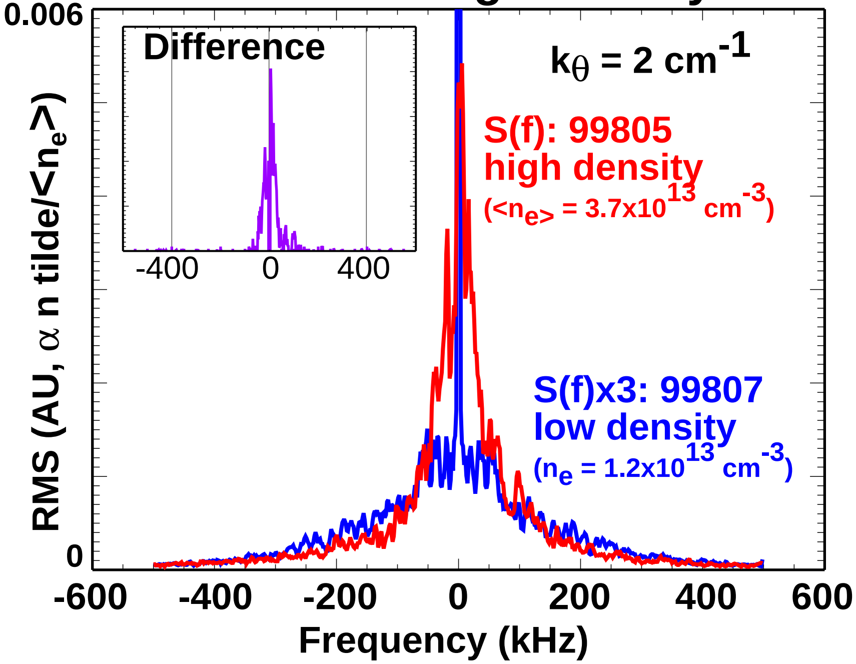
- Increased fluctuations are observed at higher density
  - above density associated with saturation
- Data averaged over 3 ms intervals, taken between sawteeth of 20 ms period.



Increased Fluctuations Concentrated in Lower Frequency Range

- The increased fluctuations observed at higher density are concentrated over low frequencies
  - wings of spectra overlay, consistent with increased fluctuations representing a new low frequency feature
- Qualitative features are similar at slightly higher wavenumber ($k_\theta = 5\ \mathrm{cm}^{-1}$).
- Data averaged over 3 ms intervals, taken between sawteeth of 20 ms period.

Scattered Fluctuation Spectra: low versus high density



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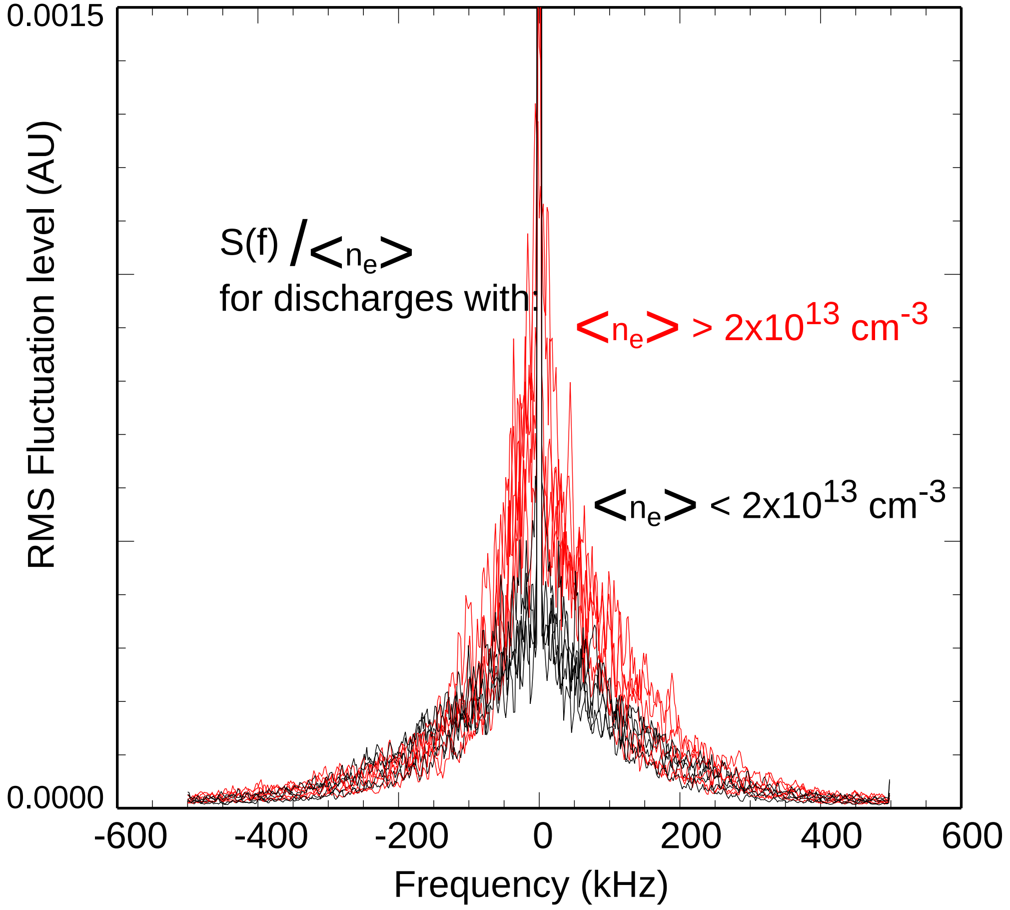
- **Data averaged over 3 ms intervals, taken between sawteeth of 20 ms period.**

Density Normalized Fluctuation Spectrum Changes at the Saturation Density



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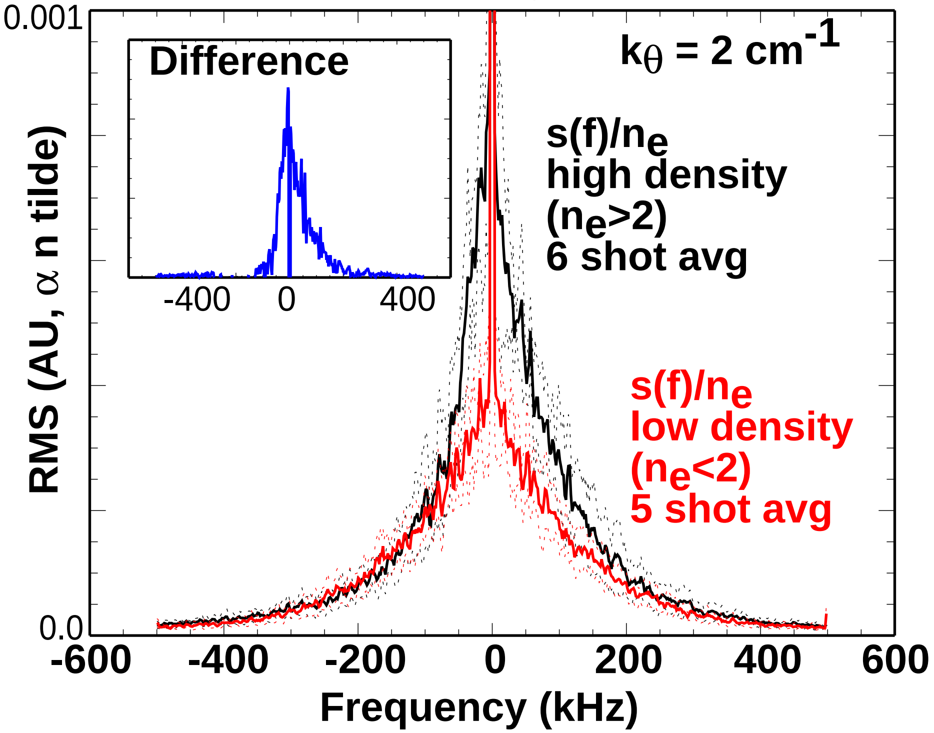
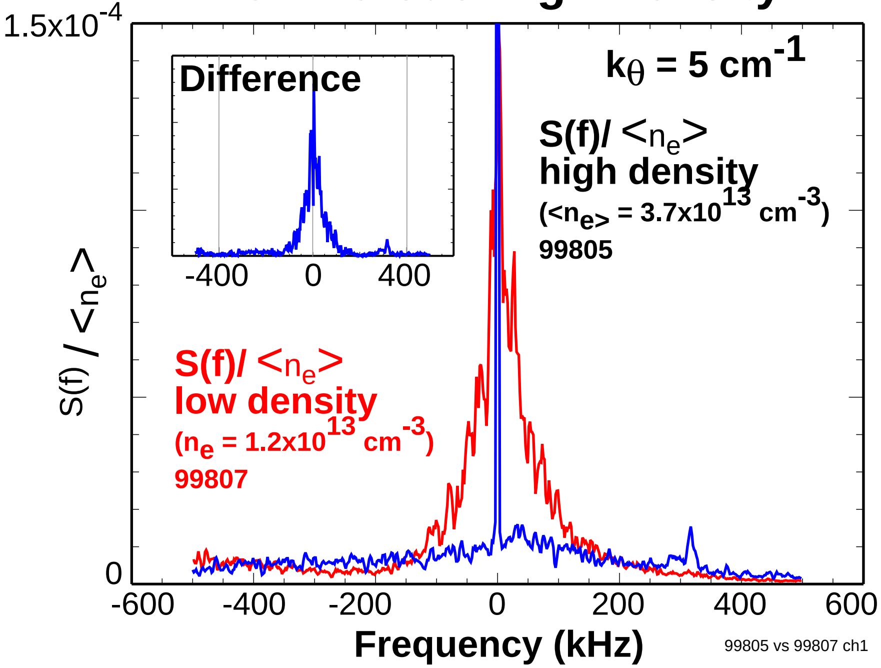
Scattered Fluctuation Spectra: low versus high density



Similar Characteristic Scaling at Shorter Wavelength

- **At shorter wavelength, turbulence level is smaller at lower density.**
- **Fluctuations at $k_\theta = 5\ \mathrm{cm}^{-1}$ turn on at higher density.**

Scattered Fluctuation Spectra: Low versus High Density



Statistical Dispersion of Fluctuations Consistent with ExB Velocity

- **Frequency width Δf to define mode mean frequency.**
- **Fluctuations measured at two different wavenumbers k_1 and k_2.**
- **Mean phase velocity:**

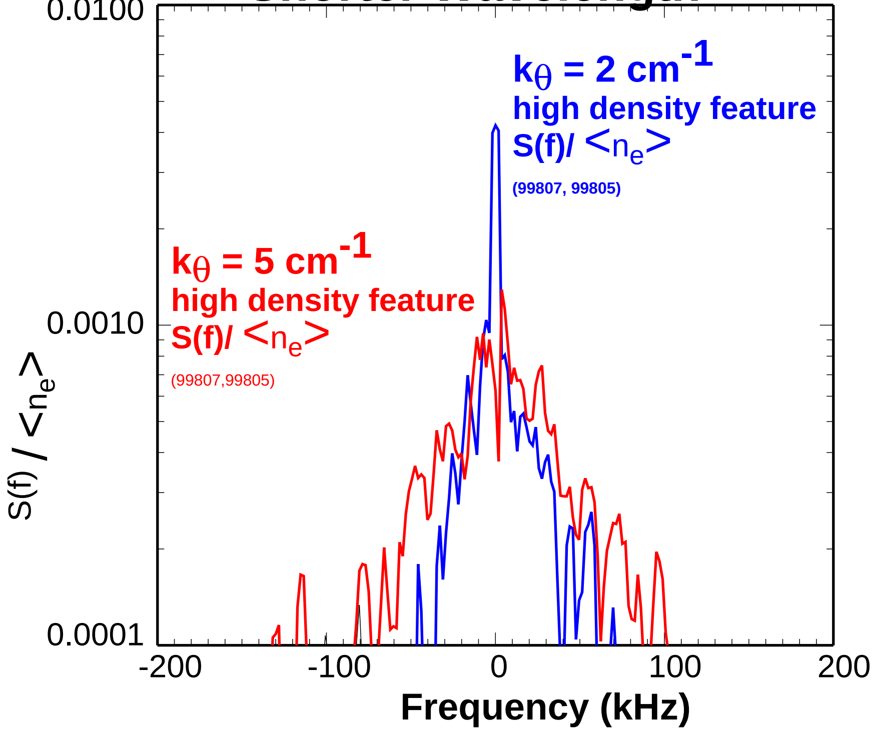
$$v_\phi = \frac{2\pi(\Delta f_1 - \Delta f_2)}{k_1 - k_2} \approx 0.8\frac{km}{s}$$

compared with the ExB velocity:

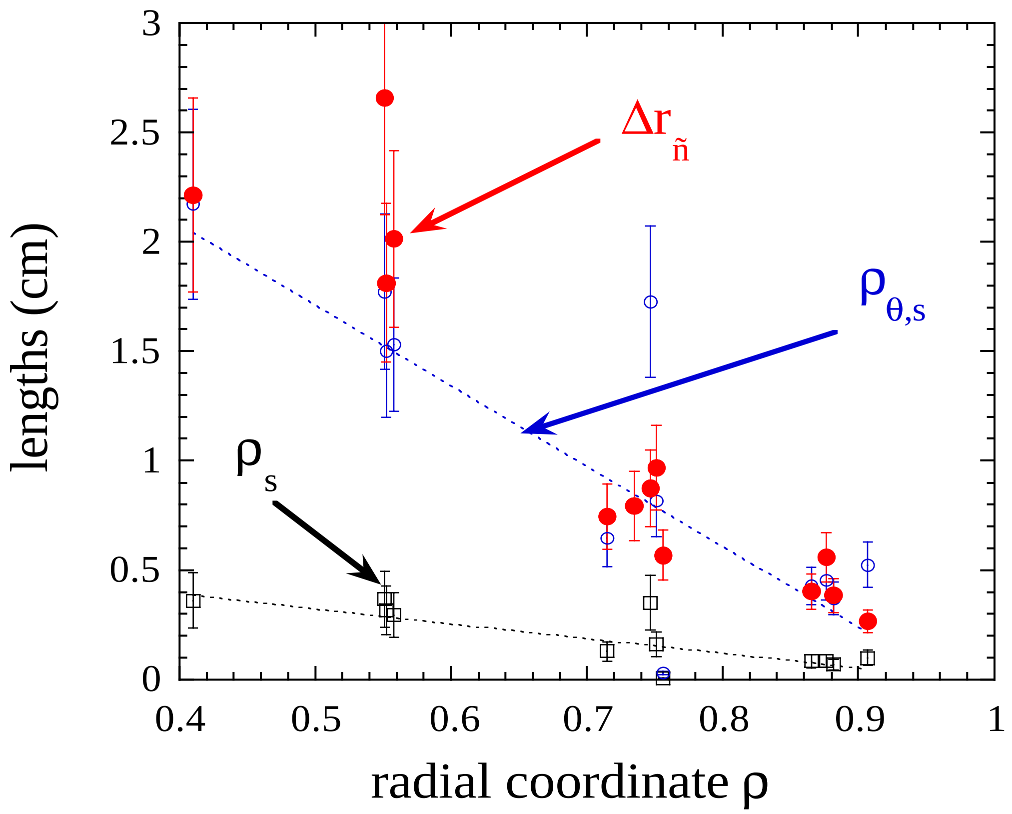
$$v_{E\times B} = \frac{E}{B} \approx 0.5 km/s$$

for $E_r \approx 1$ kV/m.

High Density Feature Broader at Shorter Wavelength

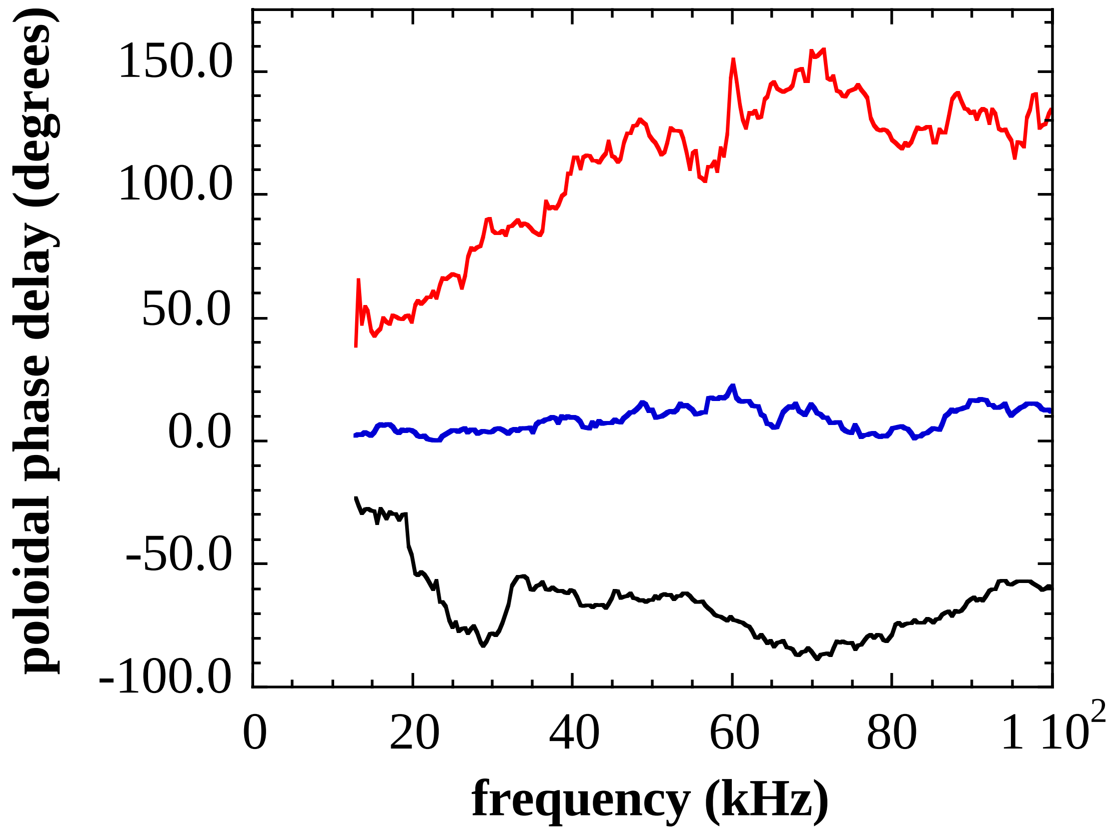


Radial correlation length approximately same as either rq,s or 5-8 rs - in general agreement with both ITG and electron drift wave predictions



- Generally $\Delta r > \rho_s$
- $\Delta r \sim 5\text{-}8\ \rho_s$ is general prediction of many theories.
- Magnitude and radial behaviour generally consistent with both ITG and electron drift waves.

Poloidal phase varies as density changes



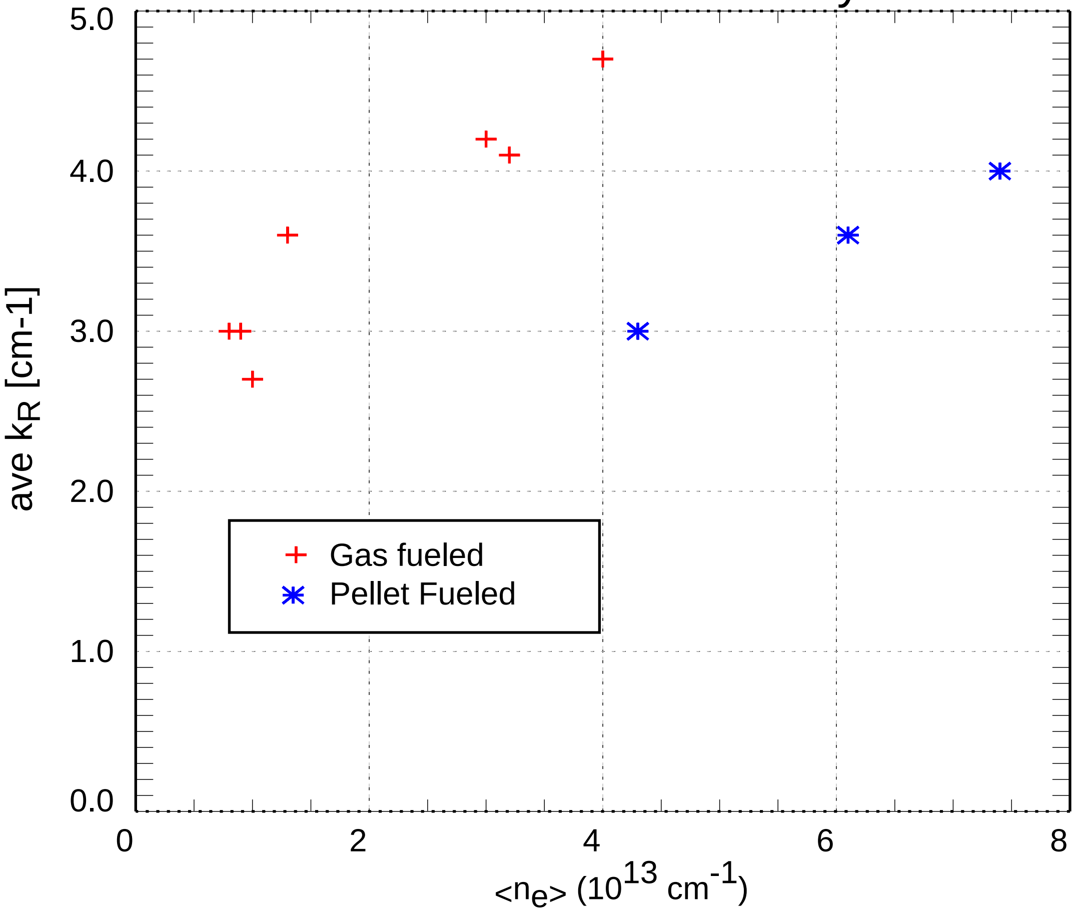
- **n_e low ~ 0.8×10^{13} cm^{-3}**
- **n_e med. ~ 1.7×10^{13} cm^{-3}**
- **n_e high ~ 3.7×10^{13} cm^{-3}**

- **Poloidal phase of fluctuations (~ k_θ) varies with n_e.**
- **Is poor phase at high ne due to counter-propagating modes?**

Edge Turbulence Wavenumber

- Data obtained via Phase Contrast Imaging (PCI) indicate that the edge mean wavenumber scales with line average (and local) density.
- Consistent with constant value of $k_\perp \rho_s$
- Pellet fueled discharges exhibit a different scaling.

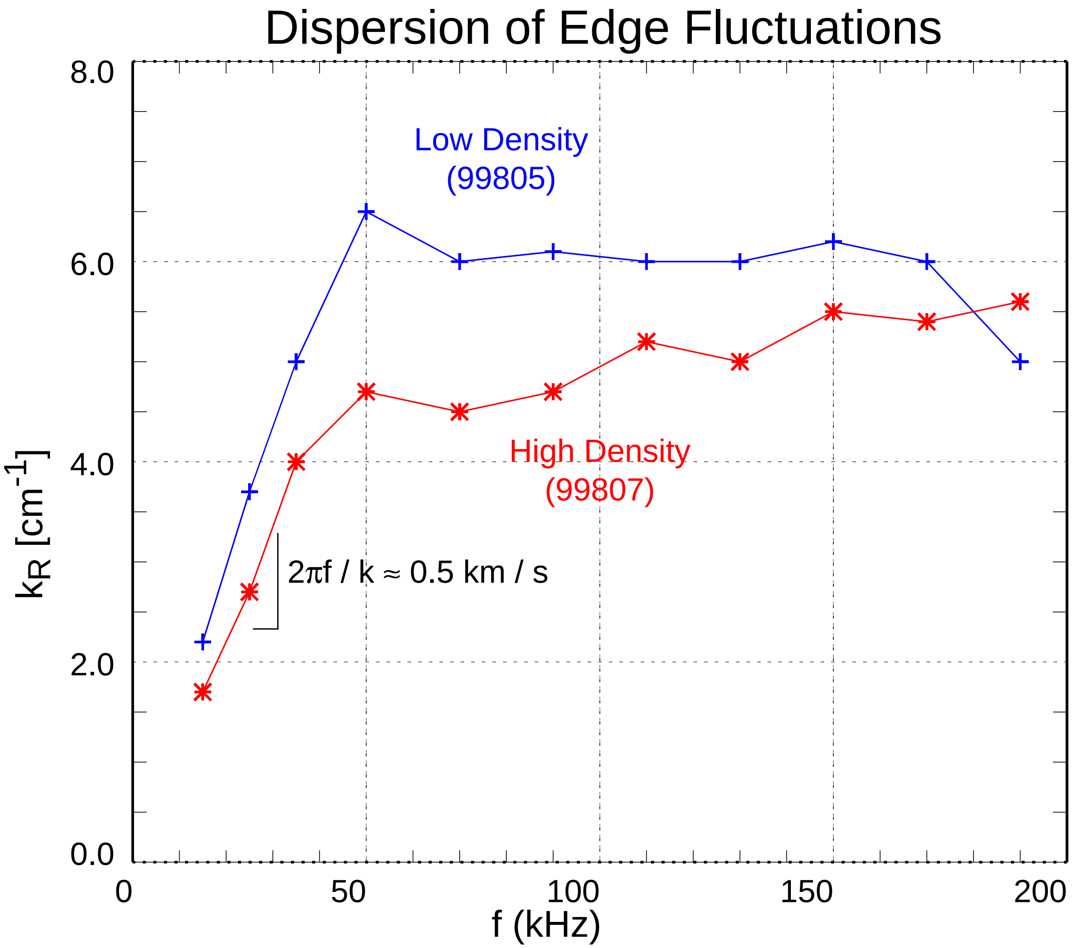
Mean Wavenumber in Edge Scales with Density



Dispersion of Edge Fluctuations Similar in High and Low Density Discharges

- **Dispersion measured via PCI in the edge indicates phase velocity approximately 0.5 km/s.**

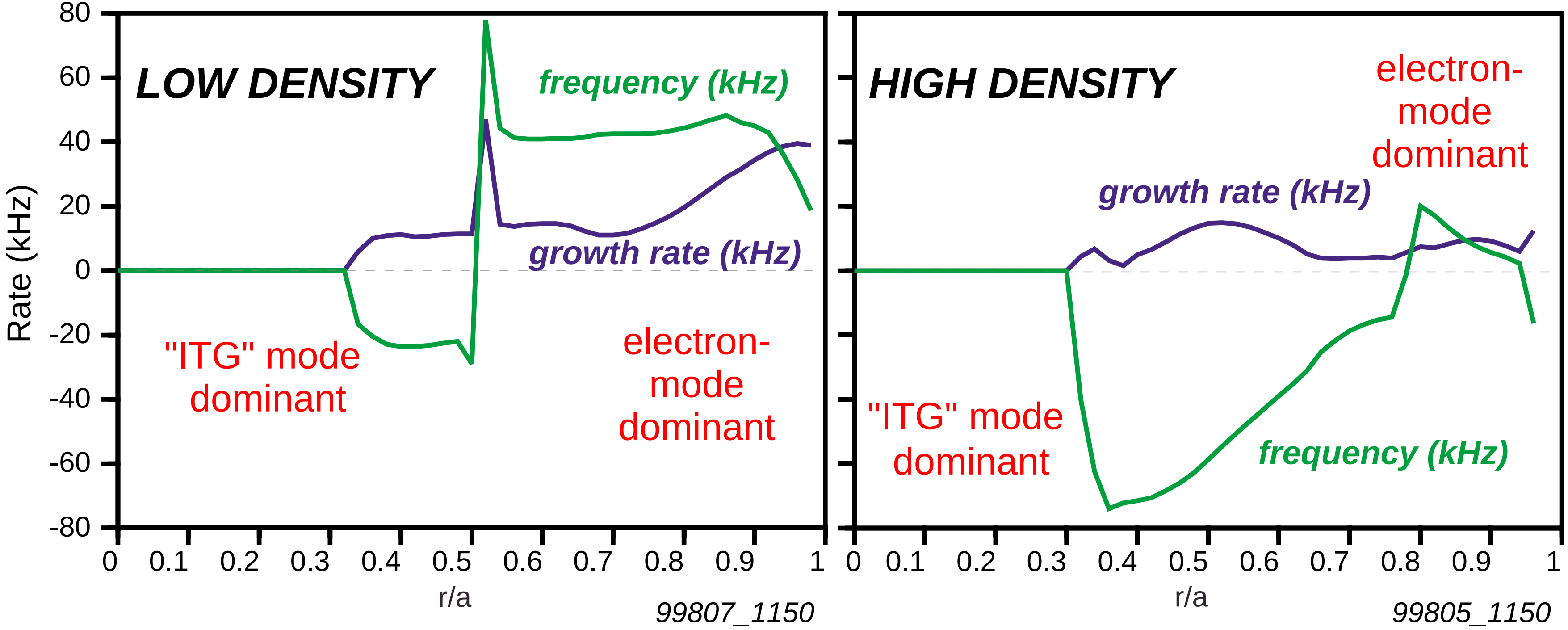
- **Velocity similar in low and high density discharges.**



Gyrokinetic Stability Analysis Predicts ITG Mode in High Density Discharges

- **Negative value of frequency corresponds to ion diamagnetic drift direction.**
- **In high density plasma, region of “ITG” mode is much greater, while that of “DTE”-like mode is less**
- **“Electron” mode linear growth rate is still significant in high density plasma.**
- **In high density plasma, both modes are likely unstable in outer region.**

Linear Growth Rate and Frequency of Most Unstable Mode at $k_\theta = 2\ \mathrm{cm}^{-1}$



Value of η_i Much Greater than Threshold Range in High Density Plasma

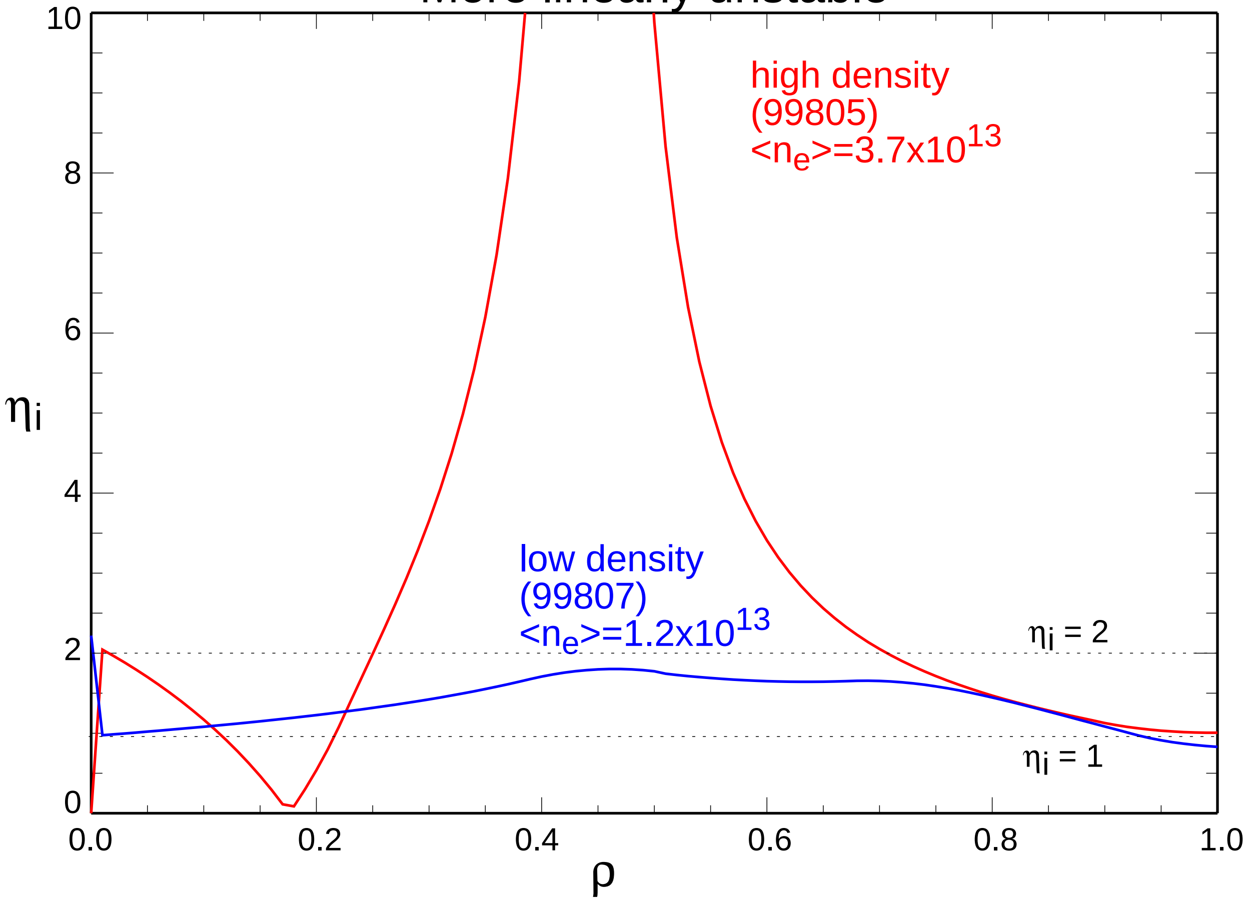
- **Linear stability predicted via parameter:**

$$\eta_i = \frac{L_{N_I}}{L_{T_I}} \rightarrow \frac{L_{n_e}}{L_{T_i}}$$

- **Critical value of 1-2 is predicted from linear theories as threshold for instability.**

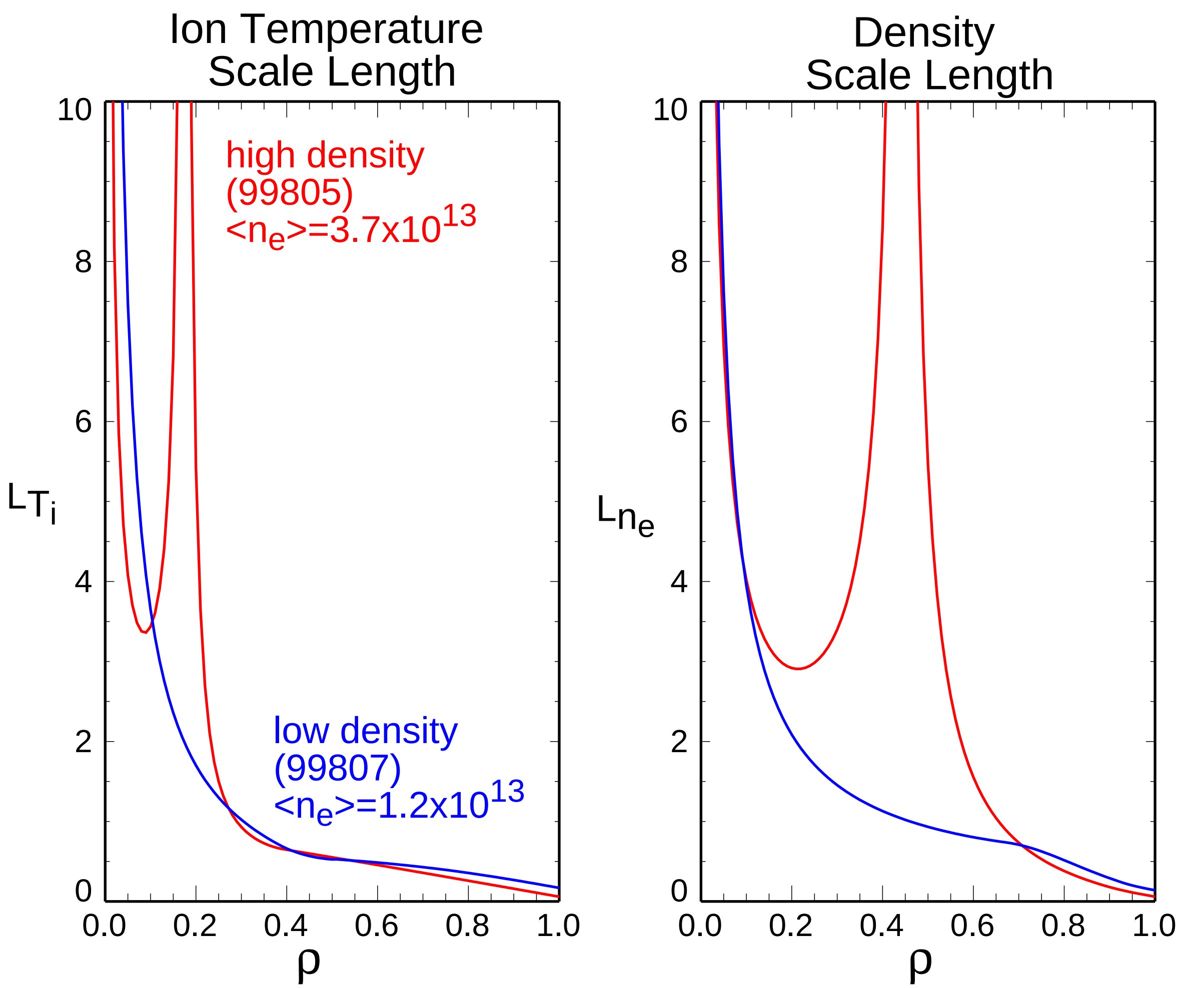
- **Mode much more unstable at higher density.**

Value of η_i is Greater at higher density:
More linearly unstable



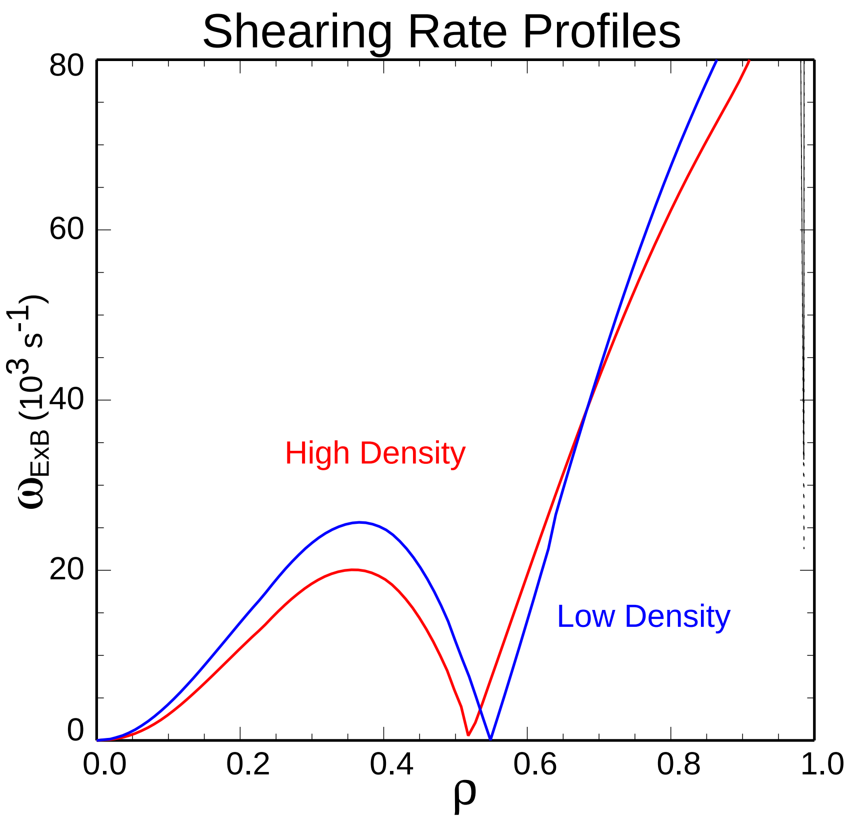
Density Profile Flattens at Higher Density

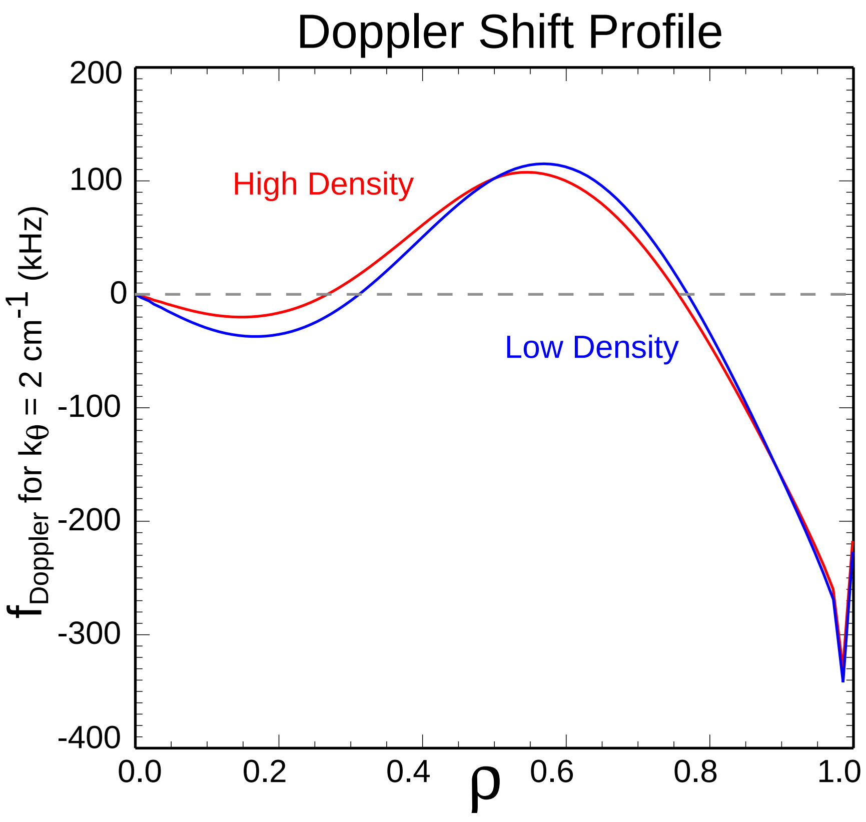
- **ITG mode becomes unstable at higher density more because the density profile flattens than from the temperature profile peaking.**



Radial Electric Field Affects Turbulence and Measured Frequency

- **ExB shearing rate, ω_{ExB}, although very small, is still comparable to growth rate in specific parts of the plasma.**
- **The radial electric field value, Er, Doppler shift the scattered radiation, still in a range comparable to that measured.**


Shearing Rate Profiles


Doppler Shift Profile

Summary

- Experiments to directly identify turbulence characteristics of the ITG mode have been performed in which the density was scanned through the neo-Alcator regime into saturated confinement:
  - confinement saturation was observed at higher density though,
  - confinement was not as long as that observed in prior DIII-D experiments.

- Above the density associated with saturation, a low frequency turbulence feature is observed (normalized to line average density), while the high frequency portion of the spectrum remains constant.

- Profiles in discharges at densities above the saturation are different such that η_I is greater and the ITG mode is unstable.

- Dispersion measuring reflectometer data is consistent with two modes at densities above the saturation density, one mode below.