Comparison of Broad Spectrum Turbulence Measurements (0-40 cm^{-1}), Gyrokinetic Code Predictions, and Transport Properties from the DIII-D Tokamak*

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New measurements of high-k (40 cm^{-1}) density fluctuations have recently been performed on DIII-D which address questions of anomalous electron transport. Low-k (0-1 cm^{-1}) and intermediate-k (15 cm^{-1}) fluctuation data have also been obtained which together provide a new, more complete picture of turbulence over a broad wavenumber range relevant to ITG, TEM and ETG instabilities. GKS [1] simulations of these discharges compare favorably to these measurements, with the simulation indicating a range of unstable modes: ITG, TEM and ETG. Full nonlinear simulations utilizing the GS2 [2] code will also be compared to these measurements.

The understanding of anomalous electron transport represents a significant experimental and theoretical challenge. Progress in this area will result in improved confidence in predictions for next-step fusion devices and, potentially, improved control of transport. Detailed comparison of transport properties and turbulence measurements for a broad k range to theoretical predictions is essential in developing this predictive capability. Utilizing new DIII-D diagnostic capabilities, coordinated measurements of low (0-1 cm^{-1}), intermediate (15 cm^{-1}), and high-k (40 cm^{-1}) density fluctuations relevant to the ITG, TEM, and ETG wavenumber ranges have been made. High-k (40 cm^{-1}) ETG relevant data from the new backscattering system show broadband fluctuation activity out to ~1 MHz [Fig. 1(a)]. Intermediate-k data (~15 cm^{-1}), from an upgraded FIR scattering system, is less broadband than the 40 cm^{-1} data, with k range consistent with TEM or higher-k ITG [Fig. 1(b)]. Low-k (0-1 cm^{-1}) FIR [Fig. 1(c)] and reflectometry (0-5 cm^{-1}) data are in an ITG wavenumber range

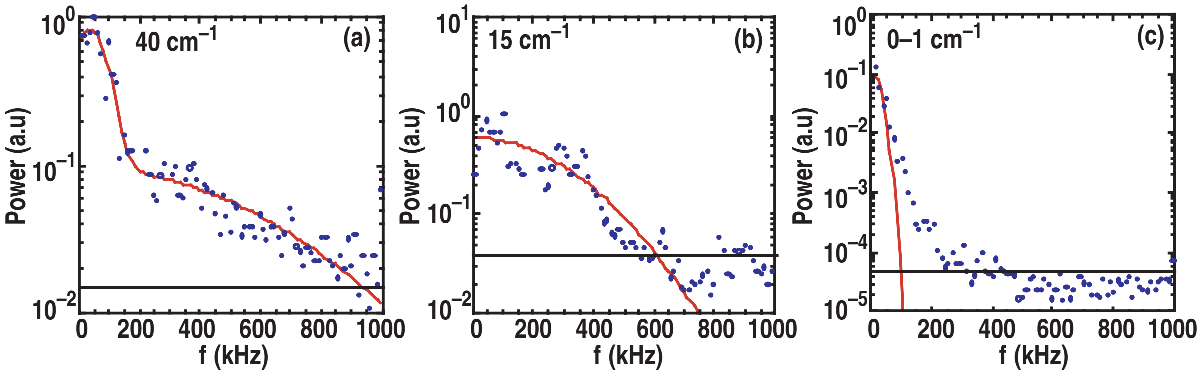

Fig. 1. Frequency spectra from: (a) backscattering diagnostic, radial-k dominant, $k_r = 40$ cm^{-1}. (b) intermediate-k FIR scattering, $k_\theta = 15$ cm^{-1}, and (c) low-k FIR scattering, $k_\theta = 0\text{-}1$ cm^{-1}. Red lines are Gaussian fits to the data while the noise floor is indicated by horizontal lines.

*Work supported by U.S. Department of Energy under DE-FG03-01ER54615, DE-AC02-76CH03073, SC-6832401, DE-FG02-93ER54197, DE-FC02-04ER54698, DE-FG02-89ER53297, and DE-AC05-76CH00033.

with spectra more narrow still. These data were acquired in an Ohmic, diverted plasma, I_p = 1 MA, $n_{e,avg} = 2.6\times10^{19}$ m^{-3}, B_T = 2.1 T. Shown in Fig. 1 are Gaussian fits to the data as well as noise floors. The high-k data are well fit by two Gaussians, one relatively narrow with a width of ~50 kHz, and the other broad with a width ~490 kHz. The Gaussian widths of the 15 and 0-1 cm^{-1} data are 260 kHz and 24 kHz respectively. Not shown are spectra from reflectometer systems showing frequency widths of 20-70 kHz. The observed trend is for increasing frequency width with increasing wavenumber. The relatively narrow, low frequency (f < 200 kHz) peak in the high-k data [Fig. 1(a)] is different in spectral shape and time behavior from the broader part of the high-k spectrum. This interesting observation may be due to a spatial variation of the turbulence intensity and is under investigation, experimentally and theoretically. Experiments planned for this year's DIII-D run period will further address high-k (as well as lower k) turbulence, the effect on transport, effect of magnetic shear, L_n, L_{Te}, etc. on the turbulence, with comparison of spectra, correlation lengths, fluctuation levels, fluxes, etc. to linear and nonlinear simulations (GKS, GS2, GYRO [3]).

Calculations using the GKS linear stability code indicate that the discharges discussed above are unstable to a wide range of instabilities: ETG, ITG and TEM. Figure 2 shows the predicted real frequency of the unstable modes over the radial range ρ = 0.1-0.9 for different k values. Note that negative real frequencies indicate propagation in the ion diamagnetic direction, consistent with ITG features, while positive frequencies are consistent with electron type modes, e.g. TEM and/or ETG. Figure 2 indicates that the spectral width predicted at 40 cm^{-1} is larger than that at 15 cm^{-1} which is in turn larger than the 1 cm^{-1} prediction. The predicted frequencies are somewhat smaller than those seen experimentally but are nevertheless in qualitative agreement with the measured spectra [Fig. 1(a-c)]. The GKS calculations of the frequency are only an approximate indication of how the fully developed turbulence would behave, but they do provide a guide as to how the instabilities might appear. In addition, while the GKS code calculates poloidal wavenumber characteristics, the high-k data (40 cm^{-1}) are principally radial k. If the fluctuations are isotropic in k_r-k_θ then the simulation and experiment are directly comparable. However, if there is a significant anisotropy, for example due to streamer activity, then nonlinear simulations are needed to estimate the expected frequency range of the backscattered signal. Nonlinear simulations (GS2) are underway which will both address this issue as well as extend the experiment-simulation comparisons. These simulations will extract the data using simulated experimental diagnostics (e.g. spatial and k resolutions) in order to match the real world experiment as closely as possible.

In summary, a broad wavenumber diagnostic set is being utilized at DIII-D to address anomalous electron (and ion) transport. Measurements show significant fluctuation activity over a wavenumber range (0-40 cm^{-1}) relevant to ITG, TEM and ETG and which have qualitative agreement with gyrokinetic code calculations. Full nonlinear simulations are underway.

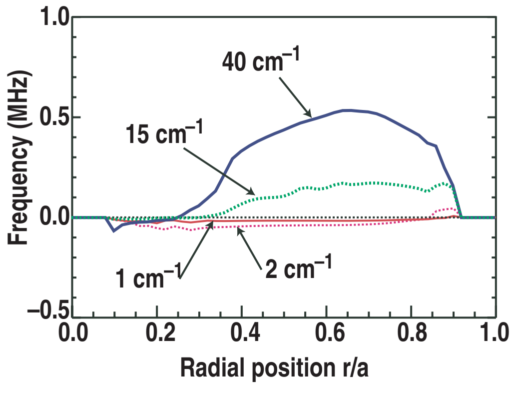

Fig. 2. GKS predictions of real frequency for 1, 2, 15 and 40 cm^{-1} for the plasma conditions of Fig 1.

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