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ETG SCALE TURBULENCE AND TRANSPORT IN THE DIII-D TOKAMAK

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ETG Scale Turbulence and Transport in the DIII-D Tokamak* EX-C

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In DIII-D, high wavenumber [$k_\perp \sim$ 35-40 cm^{-1}, $k_\perp\rho_i$ = 4-10 or electron temperature gradient (ETG) scale] plasma density turbulence has been found to vary independently of low wavenumber turbulence (Fig. 1) and to correlate with changes in electron thermal energy flux. These results are important as they indicate that the high k fluctuations ($k_\perp \sim$ 35-40 cm^{-1}) are not remnants of the low k fluctuations and are consistent with high k turbulence driving at least part of the electron heat transport in the outer half of the plasma. Recent theoretical work points to high k turbulence as a potential source of anomalous electron heat transport making such measurements and comparisons highly relevant to fusion energy research. Calculation of density fluctuation levels from BES ($0 \le k_\theta \le 3$ cm^{-1}) indicate low k fluctuation levels of $\tilde{n}/n_0 \cong$ 8x10^{-3} compared to high k (35-40 cm^{-1}) levels of $\tilde{n}/n_0 \cong$ 3x10^{-6}. The total high k fluctuation level is potentially much larger than this since the equivalent k integration range should be in terms of $k_\perp\rho_e$ for the high k (compared to $k_\perp\rho_i$ for low k) rather than in absolute cm^{-1}. Integration over this range would then increase the high k fluctuation level by a factor of $(\rho_i/\rho_e)^2$. Spatially, the high k fluctuations were found to be strongly peaked towards the edge of Ohmic discharges. Finally, changes in the measured turbulence levels are consistent with relative changes in linear gyrokinetic growth rates only if damping due to electric field shear is taken into account. From these measurements an improved understanding of high k turbulence, its relation to low k turbulence and

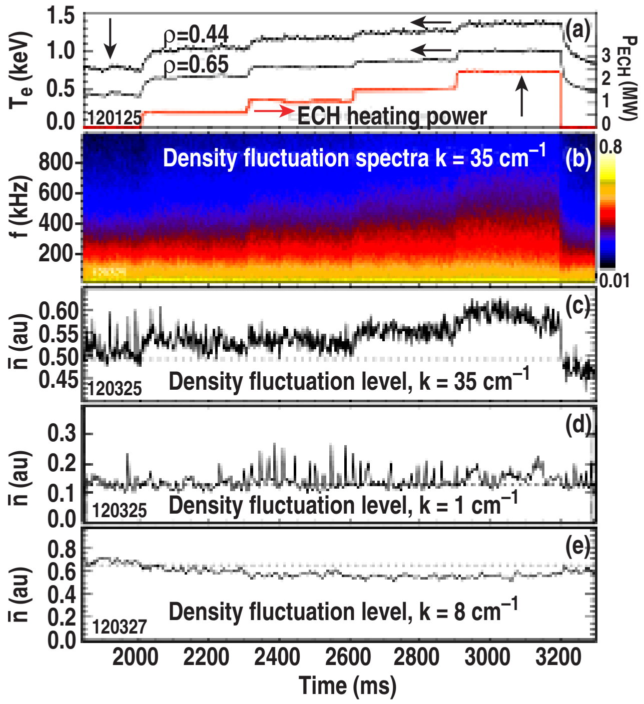

Fig. 1. (a) ECH heating power and response of electron temperature at various radii, (b) high k frequency spectra vs time, RMS density fluctuation levels for (c) high k, (d) low k and (e) intermediate k. Arrows in (a) indicate times of analysis for transport shown in Fig. 2.

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transport, and its spatial distribution and level has emerged. These and similar comparisons of transport properties and broad wavenumber turbulence measurements to theoretical predictions are essential in developing confidence in predictive capabilities of simulations.

Lower single-null plasmas with B_T = 1.9 T, I_p = 700 kA, chord average density 1-5x10^{19} m^{-3} were used for the results reported. Electron cyclotron resonance heating (ECRH) was initiated at 2000 ms with the injected power increased in a stepwise manner every 300 ms [Fig. 1(a)]. The power from theECRH was deposited in a radially localized volume centered at ρ = 0.6±0.1. The electron temperature increased due to the ECRH [Fig. 1(a)] while the plasma density decreased somewhat (~10%). The radial electric field did vary, decreasing in the outer half radius which resulted in an increased ExB velocity shearing rate.

Turbulence measurements covering a broad wavenumber range (0-40 cm^{-1}) were acquired utilizing FIR scattering (0-2 cm^{-1} and 8-12 cm^{-1}), millimeter wave backscatter (35-40 cm^{-1}), reflectometry (0-5 cm^{-1}), and phase contrast imaging (2-12 cm^{-1}). The high k (35-40 cm^{-1}) fluctuation power spectra increased in width [Fig. 1(b)] and its RMS levels increased ~15%-20% with ECRH [Fig. 1(c)]. In contrast, the lower k (<12 cm^{-1}) turbulence did not change [Fig. 1(d)] or even decreased slightly [Fig. 1(e)] with ECRH. The absence of correlation between the high and low k signals was important as it indicates that the high k fluctuations are not remnants of low k. Ohmic plasmas were shifted vertically by ~12 cm to extract spatial information on the distribution of the high k signal showing that the high k fluctuations peak significantly towards the edge. Gyrokinetic growth rates for these plasmas (from the GKS code [1]) generally show an increase in the outer half radius for the wavenumbers studied. While consistent with the increase in high k fluctuation levels this is consistent with little change in low k fluctuation levels only if the increased ExB velocity shear damping is taken into account.

Estimates of the change in the turbulent electron heat flux are consistent with the observed changes in the thermal transport from the ONETWO transport code [2]. The electron thermal flux $q_{\rm elec}$ from ONETWO increased significantly for ρ > 0.6 while the ion thermal flux $q_{\rm ion}$ did not vary strongly (Fig. 2). For comparison the change in the turbulent electron conductive heat flux $\tilde{q}_{\rm elec}$ can be estimated using the observed increase in T_e (~90% at ρ=0.65), the observed increase in $\tilde{n}$ at high k (~20%), and $\tilde{q}_{\rm elec} = n\langle \tilde{T}_e \tilde{E}_r \rangle / B \sim (\Delta T_e) \tilde{n}^2 / n$. This estimate gives a change in $\tilde{q}_{\rm elec}$ of ~500% suggesting the turbulent heat flux could contribute significantly to the observed change in $q_{\rm elec}$. Current work is concentrating on comparison of these results to nonlinear simulations.

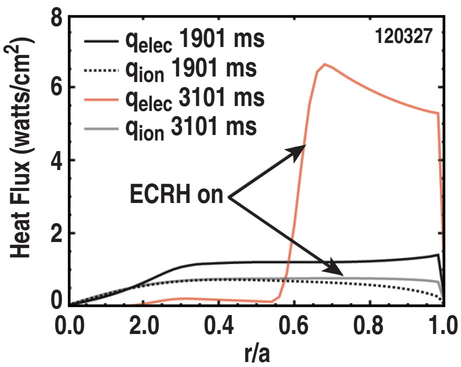

Fig. 2. Ion and electron energy fluxes for two times indicated by arrows in Fig. 1(a).

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