GA–A26666

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MAY 2010

GENERAL ATOMICS

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J.C. HILLESHEIM,[1] T.L. RHODES,[1] L. ZENG,[1] A.E. WHITE,[3]
G.R. MCKEE,[4] K.H. BURRELL, E.J. DOYLE,[1] J.C. DeBOO,
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This is a preprint of a paper to be presented at the 23rd IAEA Fusion Energy Conference, October 11–16, 2010 in Daejon, Republic of Korea and to be published in Proceedings.

[1]University of California-Los Angeles, Los Angeles, California
[2]University of California-San Diego, La Jolla, California
[3]Massachusetts Institute of Technology, Cambridge, Massachusetts
[4]University of Wisconsin-Madison, Madison, Wisconsin

Work supported in part by
the U.S. Department of Energy
under DE-FG03-08ER54984, DE-FG02-07ER54917,
DE-FG02-89ER53296, DE-FG02-08ER54999
and DE-FC02-04ER54698

GENERAL ATOMICS ATOMICS PROJECT 30200
MAY 2010

GENERAL ATOMICS

The first systematic investigation of core electron thermal transport and the role of local ITG/TEM/ETG-scale core turbulence is performed in high temperature, low collisionality DIII-D H-mode plasmas. Core ITG/TEM-scale turbulence is substantially reduced/suppressed by $\boldsymbol{E}\times\boldsymbol{B}$ shear promptly after the L-H transition, resulting in reduced electron thermal transport across the entire minor radius. Nonlinear gyrokinetic (GYRO [1]) simulations indicate that a significant portion of the remaining H-mode electron heat flux results directly from residual short-scale TEM/ETG turbulence. The studies are performed at ITER-relevant collisonality ($\nu_e^* \sim 0.05$, $r/a \le 0.6$) and are important since ITER plasmas will be electron heat-dominated due to α-particle heating. Taking advantage of the unique set of DIII-D turbulence [2,3] and profile diagnostics, experimentally determined H-mode electron transport fluxes and turbulence spectra are directly contrasted for the first time with nonlinear gyrokinetic simulation results.

Figures 1(a-c) show reduced ITG-scale $\tilde{n}$ and $\tilde{T}_e$ fluctuations and intermediate-scale core density fluctuations measured by Doppler backscattering (DBS) across the L-H transition (indicated by a vertical dashed line), and a comparison of the (normalized) maximum linear instability growth rate in the ITG/TEM range ($k_\theta \rho_s \le 3$) with the $\boldsymbol{E}\times\boldsymbol{B}$ quench rate $\alpha_E \langle \omega_{E\times B} \rangle a/c_s$ evaluated from charge exchange recombination (CER) data. Here, $\langle \omega_{E\times B} \rangle a/c_s$ is the normalized Waltz-Miller shearing rate, $\alpha_E \sim 0.3(\kappa)^{1/2}$ is the quench factor determined empirically by systematic variations of the shearing rate in GYRO simulations [4], and κ is the local plasma elongation. Linear instability growth rates are calculated using the trapped gyro-Landau fluid code (TGLF [5]). Around the time of the L-H transition [indicated by the drop in D_α line intensity, Fig. 1(e)], the shearing rate exceeds the maximum linear ITG/TEM growth rate in the core plasma (shown for r/a= 0.4). In contrast, the ETG growth rate (not shown) always exceeds the shearing rate by a factor of 3-10. The electron temperature starts increasing first near the edge (pedestal formation) but also within 5-10 ms in the core [Figs. 1(d,g)]. Time-dependent TRANSP transport analysis shows that the electron diffusivity is significantly reduced across the minor radius [Fig. 1(f)], implying globally reduced electron thermal transport.

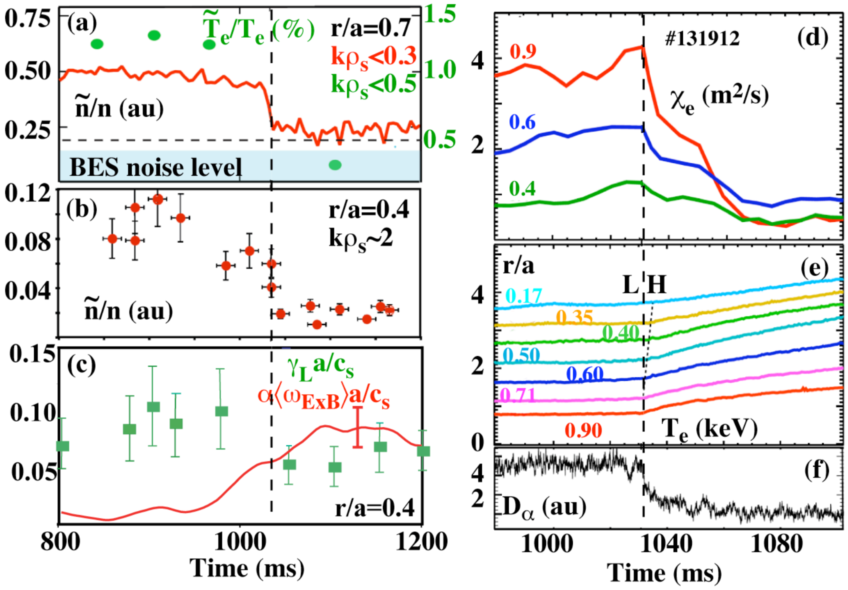

Fig. 1. (a) ITG-scale density and electron temperature fluctuations (r/a=0.7); dashed line: CECE detection limit; (b) density fluctuation level for $k\rho_s \sim 2$; (c) comparison of maximum nonrmalized linear ITG/TEM growth rate ($k\rho_s$<3,from TGLF) with the *ExB* quench rate (r/a=0.4); (d) electron thermal diffusivity from TRANSP for three normalized radii, (e) time evolution of local electron temperature; (f) D_α signal.

Figures 2(a,c) show wavenumber spectra of core density turbulence, measured by DBS. In L-mode, spectra are best described by an exponential dependence on $k_\theta \rho_s$ as observed previously in the TORE SUPRA tokamak. In H-mode, density fluctuation levels are reduced at low and intermediate wavenumber (ITG/TEM scale), and the spectra are flatter in this spectral region. At higher wavenumbers ($k_\theta \rho_s$>4) fluctuation levels continue to decay exponentially. Comparing linear instability growth rates from TGLF with Miller-Waltz quench rates [Figs. 2(b,d)] we find that the wavenumber range of reduced large/intermediate-scale turbulence is well predicted by the wavenumber range where the quench rate $\alpha_E<\omega_{E\times B}>a/c_s$ exceeds the normalized linear growth rate.

Figure 3 shows the wavenumber spectrum of density fluctuations predicted by a preliminary nonlinear GYRO simulation with 40 radial and 40 poloidal modes, spanning $1\leq k_\theta\rho_s\leq 40$. The spectrum labeled $k_r=0$ takes into account the instrumental DBS sensitivity which intrinsically detects modes with $k_r=0$ [2]. Multi-scale simulations with improved low-k resolution are underway to more adequately simulate the experimental results. However, initial flux estimates show that turbulence in the range $k_\theta\rho_s>1$ accounts for roughly 50% of the local electron thermal flux in H-mode ($r/a=0.6$).

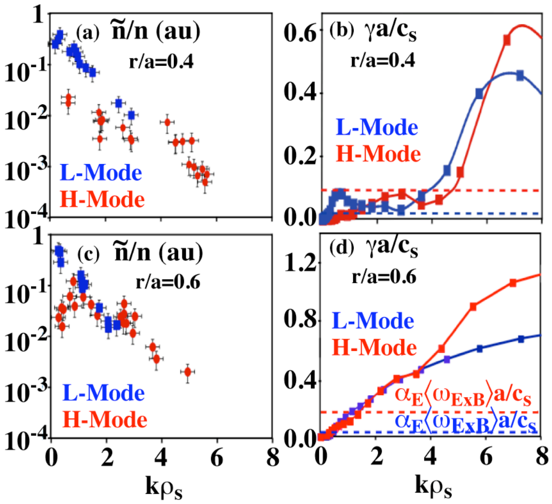

Fig. 2. Density fluctuation wavenumber spectra (L/H-mode) at $r/a=0.4$ (a) and $r/a=0.6$ (c); corresponding normalized linear growth rates and ExB quench rates (b,d).

In summary, we have observed significantly reduced large/intermediate-scale turbulence and reduced electron thermal flux in the core of low collisionality H-mode plasmas. Initial GYRO simulations indicate that TEM/ETG-scale turbulence accounts for a substantial part of the residual H-mode electron thermal flux. Measured wavenumber spectra show qualitative agreement with initial nonlinear gyrokinetic calculations which indicate a somewhat flat fluctuation spectrum in the ITG/TEM spectral range.

This work was supported in part by the US Department of Energy under DE-FG03-08ER54984, DE-FG02-07ER54917, DE-FG02-89ER53296, DE-FG02-08ER54999, and DE-FC02-04ER54698.

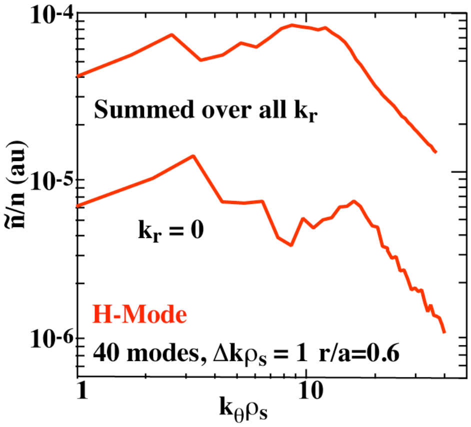

Fig. 3. Density fluctuation specta from GYRO; the spectrum labeled $k_r=0$ takes into account the DBS detection sensitivity.

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