GA–A27274

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APRIL 2012

GENERAL ATOMICS

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This is a preprint of the synopsis for a paper to be presented at the Twenty-fourth IAEA Fusion Energy Conf., October 8-13, 2012 in San Diego, California.

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

GENERAL ATOMICS PROJECT 30200
APRIL 2012

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Relating the L-H Power Threshold Scaling to Edge Turbulence Dynamics

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Measurements of long-wavelength ($k_\perp\rho_I$<1) turbulent eddy dynamics, characteristics, flows, and flow shear in the near edge region of DIII-D plasmas indicate that the dynamics of Low-Frequency Zonal Flow (LFZF) are important in the L-H transition threshold and may provide an explanation for observed macroscopic L-H power threshold scaling relations. These turbulence dynamics, measured with a 2D array of beam emission spectroscopy (BES) channels in the edge region (r/a~0.85–1.0+) of DIII-D plasmas, have revealed several important observations: fluctuation amplitudes scale with ρ* approaching the L-H transition, suggesting stronger drive of zonal flows for more favorable condition at low toroidal field; turbulence poloidal flow spectrum evolves from Geodesic Acoustic Mode (GAM) dominant at lower power to LFZF dominant near the L-H transition, and the effective shearing rate correspondingly increases; inferred Reynolds stress from BES velocimetry increases near the L-H transition; at lower density, a clear increase of the LFZF is observed prior to the L-H transition, which is not evident at higher density. These observations provide key insights into the underlying physics of the L-H transition power threshold scaling dependencies on toroidal field and density (P_{LH}=0.042 $n_{20}^{0.73}B_T^{0.74}S^{0.98}$ (MW) [1]). Understanding these mechanisms is critical to operating and optimizing performance in ITER.

Long wavelength density fluctuations are measured using 8×8 2D array of BES channels at 0.85<r/a<1 during an ion gyro-radius scan, varying toroidal field and current while keeping the other non-dimensional parameters, such as collisionality ν*, q_{95} and T_e/T_i, nearly constant at the pedestal top in the L-mode phase just before the L-H transition. The plasma

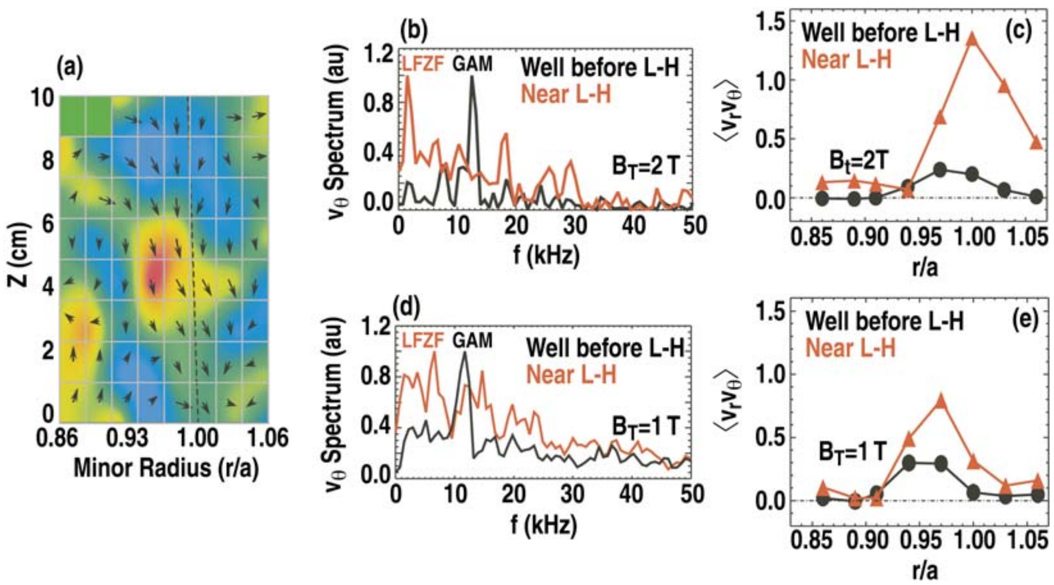

Fig.1 (a) A snap shot of the density fluctuation imaging from 2D BES measurement overlaid by the turbulent velocities (black arrows) from velocimetry technique; turbulence poloidal flow spectrum at (b) B_T=2 T and (d) B_T=1 T, and inferred Reynolds stress profile at (c) B_T=2 T and (e) B_T=1 T, with black for the time well before L-H transition and red for the time near transition.

was operated in a favorable geometry (ion ∇B drifts towards the X-point), and the L-H transitions were obtained with the heating power just above the threshold power. The long wavelength density fluctuation amplitude integrated over 50-150 kHz is found to scale with ρ* approaching the L-H transition. This higher normalized turbulence amplitude at lower toroidal field (higher ρ*) implies a higher drive for zonal flows, thought to play a dominant role in triggering the L-H transition.

At both ρ* values, an increase of the lower frequency component of the turbulence poloidal flow spectrum is observed as the discharge evolves towards the L-H transition as shown in Fig. 1(b,d). Applying an imaging velocimetry technique [2] to the 2D BES measurements, radial and poloidal turbulent velocity fields can be obtained, indicated by the arrows overlaid on the 2D BES fluctuation image shown on Fig. 1(a). An inferred Reynolds Stress, $\langle \tilde{v}_r(t)\tilde{v}_\theta(t)\rangle$, from these velocity fields is then calculated. The radial profiles are shown in Fig. 1(c,e) for a time well before the L-H transition (black) and near the transition (red) at two toroidal fields, respectively. The inferred Reynolds stress gradient increases in the pedestal region approaching the L-H transition in both cases. Similar observations were made by the multi-tip reciprocating Langmuir probe measurements. This increase of the Reynolds stress gradient is consistent with the observation of the increase of LFZF like flow component near the L-H transition. The lower frequency and higher amplitude of the LFZF suggests a stronger shear state near the transition [3].

During a density scan at fixed toroidal field and current, a clear increase of the LFZF like flow component was also observed in the turbulence poloidal flow spectrum measured from BES approaching the L-H transition at two lower densities ($1.7\text{-}2.3\times10^{19}$ m^{-3}). However, this is not evident at the higher densities ($3.8\text{-}4.3\times10^{19}$ m^{-3}). Moreover, no GAM was observed at these higher densities, consistent with higher collisional damping of zonal flows at higher density. Figure 2 shows the equilibrium turbulence poloidal flow from BES measurements for four different densities. It is found at two lower densities there is much higher shear than that at higher densities, with the local shearing rate exceeding the turbulence decorrelation rate. These observations suggest that the combination of the increased turbulence flow shear and zonal flow shear at lower density facilitate the L-H transition.

These results of the edge turbulence dynamics scaling with toroidal field and density across the L-H transition are qualitatively/semi-quantitatively consistent with the density and toroidal field scaling of the L-H transition power threshold. At lower toroidal field (higher ρ*), larger turbulence amplitude is generated to drive strong enough flow shear which facilitates the L-H transition at lower input power. Similarly the stronger flow shear observed at lower density favors the L-H transition at lower input power.

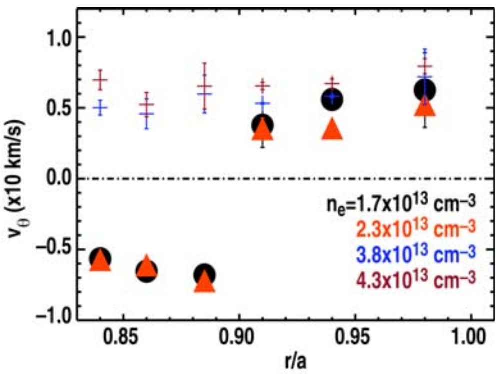

Fig. 2. Turbulence poloidal flow profiles for different densities near L-H transition.

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

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