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Turbulence and Transport Response to Resonant Magnetic Perturbations in ELM-Suppressed Plasmas EX-C

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Long wavelength density fluctuations increase rapidly and significantly in the outer regions of DIII-D plasmas with the application of radial resonant magnetic field perturbations (RMP) to suppress edge localized modes (ELMs) [1]. Correspondingly, particle transport is increased and global energy confinement decreased in these low collisionality RMP-ELM suppressed discharges. This process is evident through a reduction in core and pedestal density, which has been quantified through perturbative gas-puff-modulation studies, as well as interpretative modeling of density sources and sinks [2]. Low and intermediate wavenumber turbulence ($k_\perp \rho_i < 2$), measured with beam emission spectroscopy (BES) and Doppler backscattering, is modified and generally increases throughout the outer region of the plasma in response to RMPs. The dynamical behavior suggests that the turbulence is directly affected by the RMP, which may partially or largely explain the resulting increased transport and stabilization of the pedestal against peeling-ballooning instabilities that are

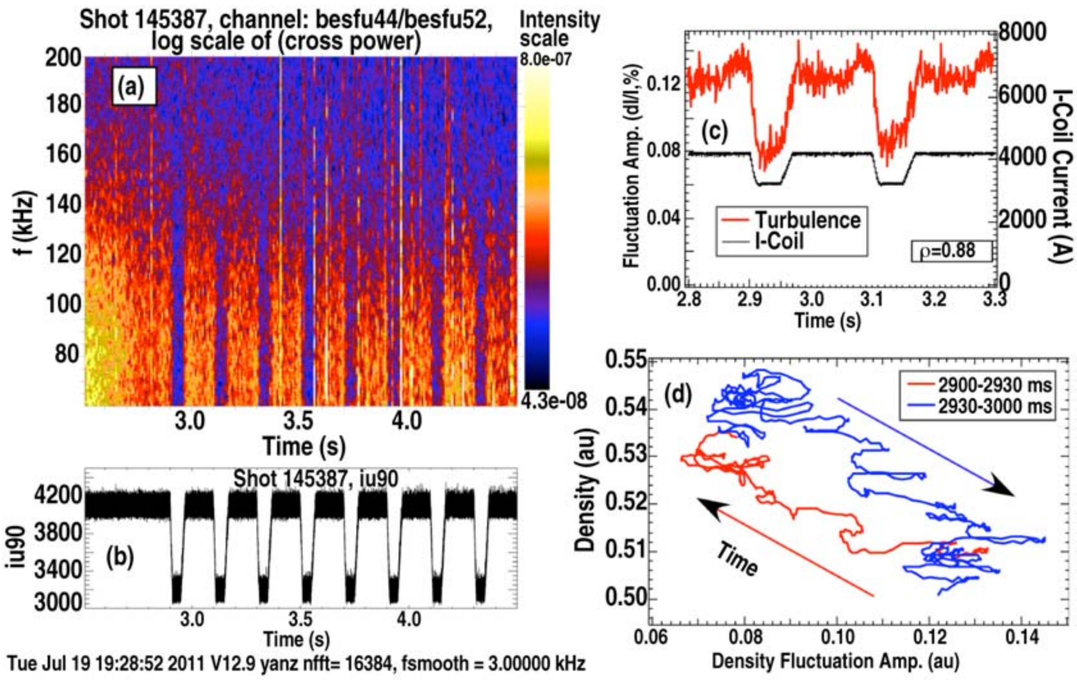

Fig. 1. (a) Spectrogram of density fluctuations from BES during a modulated RMP ELM-suppressed discharge, (b) internal coil current (suppressed zero), (c) integrated low-k fluctuation evolution at ρ=0.88, (d) relation of density fluctautions to local density.

thought to drive ELMs. Understanding this transport process is crucial to extrapolating the RMP ELM-suppression technique to ITER.

Radial magnetic field modulation experiments indicate that the turbulence modifications occur significantly faster than transport time-scales and faster than the local pressure gradients and shear evolve. Figure 1 illustrates the response of long-wavelength density fluctuations, measured with BES inside the pedestal region (ρ=0.88), to modulated radial fields [Fig. 1(b)]. Fluctuations can be seen to rise and fall with the internal coil current across a broad spectral range: 60-200 kHz. The temporal response is seen more clearly in Fig. 1(c) which integrates the fluctuations spectrally (red curve) and phase locks to multiple modulation cycles (to improve signal to noise for fast measurements). As fluctuations increase, local density decreases. The fluctuation changes are mapped to density changes [also measured locally via BES in Fig. 1(d)], during the radial field modulation cycle, indicating that turbulence changes lead local density modifications. Note that the local density change is small (~5%) during the modulation cycle, while the fluctuation magnitude oscillates by ~30%. The local poloidal turbulence velocity, measured with a 2D array of BES channels, responds more slowly to these modulations, suggesting that fast shear modification isn't primarily responsible for the rapid turbulence response. Taken together, these measurements indicate that the radial magnetic field appears to directly and rapidly cause the increased turbulence, and is not acting primarily by changing gradients or shear. The mechanism is unclear, but it has been hypothesized that RMPs may damp zonal flows and thereby cause an increase in turbulence and transport [3], consistent with these results. Figure 2 compares the spectra during the ELMing phase of a discharge (black) with that during the application of steady RMP (red) later in the discharge when ELMs are suppressed, showing that the increase is broadband across the low-k spectrum ($k_\perp < 3\ \mathrm{cm}^{-1}$).

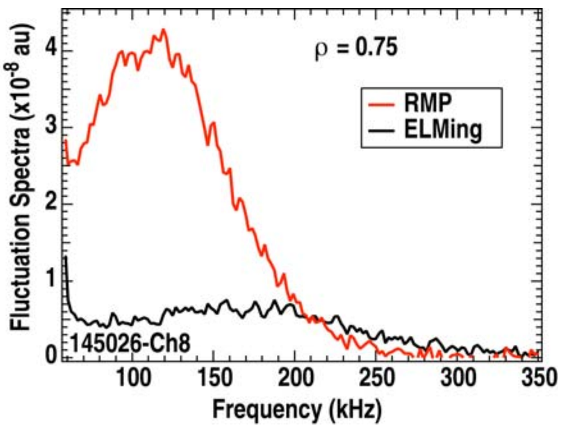

Fig. 2. Comparisons of density fluctuation spectra for low-*k* fluctuations (BES) at ρ=0.75 with and without RMP.

While the overall response of turbulence and transport to RMP is complex owing to the highly nonlinear interactions between the plasma profiles and gradients therein as well as radial magnetic field perturbations, these new measurements of fluctuations suggest that a direct turbulence mechanism mediates the interaction between RMP fields and local transport. This mechanism may play a major role in the ELM suppression process. Elucidating this connection and the possible role of zonal flow behavior will be critical to projecting this ELM suppression technique to ITER and other burning plasma experiments.

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