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Formation of a Staircase Pedestal in High Confinement DIII-D Plasmas with RMP Suppressed Edge-Localized-Modes

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We report the first observation of staircase pedestal formation due to the breakdown of ExB velocity shear suppression of turbulence in a high β_p pedestal in the DIII-D tokamak in plasmas where the large amplitude ELM activity has been suppressed using resonant magnetic perturbations [1]. Alternate periods of standard (single step) and staircase (double-step) pedestal formation occur cyclically with a period of ≈ 40-60 ms (Fig. 1d - 1e). Periodically enhanced density fluctuations at the pedestal-top are observed with the formation of the single step pedestal (Fig. 1a). In the wide staircase pedestal phase the pedestal top pressure increases and a strong flattening of the electron density and temperature develops in mid-pedestal (ρ ≈ 0.95), producing the staircase pedestal structure. Localized bursting fluctuations are seen in this flat region with distinct temporal and frequency signatures from the residual small ELMs (called grassy ELMs) (Fig. 1b). Gyrokinetic analysis using the newly developed CGYRO [1] code and experimental fluctuation measurements using the BES diagnostic reveal that the cyclic pedestal staircase formation results from a forward and backward transport bifurcation, due to the non-monotonic flux-gradient relation for transport in mid-pedestal (Fig. 2). In this model, broadening of the pedestal and the Er well results in reduction of ExB shear. This causes the enhancement of transport by trapped-electron-modes in mid-pedestal leading to the local flattening and globally broadening of density and temperature profiles. During the narrowing phase, driven by the large flux generated at the pedestal top (ρ ≈ 0.85), the staircase pedestal transitions back to the canonical one-step pedestal structure seen universally in H-mode plasmas. By enhancing the confinement and drastically reducing the peak of heat flux to diverter, formation of the staircase pedestal opens a path for optimizing the steady-state operation in ITER and future reactors.

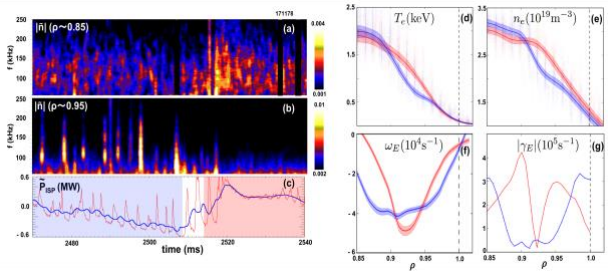

FIG. 1: Power spectrum of density fluctuation measured by BES at (a) pedestal top (b) mid-pedestal. (c) heat flux P_{ISP} at the inner strike point. Figures (d)-(g) are respectively, electron temperature electron density E×B toroidal rotation frequency, and E×B shearing rate.

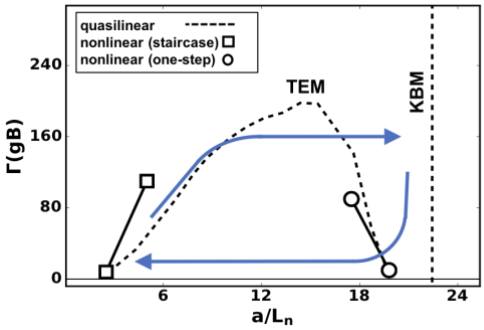

FIG. 2: Local particle flux versus a/Ln, squares and circle are the nonlinear fluxes, and dashed lines are from quasilinear calculation.

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