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First Direct Evidence of Turbulence-Driven Ion Flow Triggering the L- to H-Mode Transition

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Developing a physics-based model of the L-H transition is critical for confidently extrapolating the auxiliary heating requirements for ITER from the existing empirical L-H transition power threshold scaling. For the first time, it is shown here that the initial turbulence collapse preceding the L-H transition is caused by turbulence-generated (positive) E×B flow opposing the equilibrium (L-mode) edge plasma E×B flow related to the edge pressure gradient. Recent main ion CER measurements in Helium plasmas provide strong evidence of concomitant turbulence-driven main ion poloidal flow viθ. Near the power threshold, the transition dynamics is substantially expanded/slowed via limit cycle oscillations (LCO) between the turbulence intensity and the E×B velocity, allowing profile and flow measurements with unprecedented spatial and temporal resolution. During the LCO, viθ lags the density fluctuation level ñ, consistent with energy transfer from the turbulence spectrum via the perpendicular Reynolds stress. As the LCO evolves, the periodic reduction of edge turbulence and transport subsequently enables a periodic increase in the edge pressure gradient and equilibrium E×B flow, reducing the LCO frequency and eventually securing the transition to H-mode.
A two-predator, one prey model, similar to a previously developed model [Miki, Diamond, Phys. Plasmas 19, 092306 (2012)] but in contrast retaining opposite polarity of the turbulence-driven and pressure-gradient-driven E×B flow, captures essential aspects of the transition dynamics, including the phasing of ñ, viθ and vE×B. The interpretation advanced here explains several unresolved experimental observations, including the counter-clockwise (ñ, Er) limit cycle observed in the outer shear layer in DIII-D, and JFT-2M (consistent only with positive E×B flow drive). A positive electric field transient concomitant with initial turbulence suppression, has been demonstrated across a range in plasma density, heating power, and q95, during "fast"L-H transitions and during extended LCO transitions. The evolution of turbulence-driven and pressure-gradient driven flow is shown to depend on plasma density and q95; implications for the density/collisionality scaling of the L-H transition power threshold will be discussed.

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