Poloidal and Toroidal Flow Damping and Long-Range Correlations across the L-H Transition

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Understanding the connection between L-H transition trigger physics and the macroscopic L-H power threshold scaling is of importance for minimizing auxiliary heating requirements in burning plasmas. In particular, understanding flow drive and damping across the relevant ion collisionality range is crucial. Direct, high resolution measurements of the poloidal and toroidal main ion flow damping during the trigger phase of the L-H transition are consistent with neoclassical poloidal flow damping in the plateau regime in DIII-D. These measurements have been made at intermediate plasma density (2-3x10^{19} m^{-3}) using main ion poloidal and toroidal CER in He plasmas, in L-H transition preceded by limit cycle oscillations (LCO) [1,2]. It is demonstrated that (i) the Reynolds stress gradient changes sign across the shear layer, consistent with the observed poloidal flow acceleration in opposite directions; (ii) the measured Reynolds stress drive is quantitatively balanced by the flow acceleration and damping terms; (iii) the laboratory frame toroidal velocity is not significantly modulated during LCO. It is demonstrated that the Pfirsch-Schlueter parallel ion flow modulation during the LCO balances the toroidal velocity modulation. This data presents compelling quantitative evidence that the L-mode-LCO transition is triggered via $\boldsymbol{E}\times\boldsymbol{B}$ shear flow amplification mediated by the perpendicular Reynolds stress gradient.

To elucidate the connection between trigger physics and power threshold scaling, turbulence-flow coupling has been investigated across the relevant density range in deuterium and hydrogen plasmas with ITER-similar shape. Significant differences in the long-range toroidal correlation of the $\boldsymbol{E}\times\boldsymbol{B}$ flow across the L-H transition have been found. The flow correlation is highest at intermediate plasma density in deuterium plasmas, near the power threshold minimum. $\boldsymbol{E}\times\boldsymbol{B}$ flow correlation is less pronounced at high density, and is also reduced in hydrogen plasmas, which exhibit an L-H power threshold roughly a factor of two higher than corresponding deuterium plasmas.

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