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Evidence of ITG/TEM Turbulence Transition Causing Edge Temperature Ring Oscillation for Sustaining Stationary I-Mode Plasmas

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I-mode, a plasma regime with high energy confinement similar to H-mode and edge particle transport comparable to L-mode, represents a potential and credible solution alternative to H-mode for standard operation scenario in the future fusion reactor [1-3]. It is characterized by a very sharp edge temperature pedestal without edge density pedestal and ELMs. More interesting, it has the following advantages: prevent metallic impurity central accumulation, facilitate fusion product ash removal, sustain quiet stationary temperature pedestal. These are crucial points for a fusion reactor. However, the intrinsic physical mechanism explaining I-mode formation is not yet elucidated.
In the EAST tokamak, I-mode was recently identified and characterized [4]. Features similar to other tokamaks have been observed: strong temperature pedestal; no particle transport barrier at the plasma edge; unfavorable plasma configuration, i.e. ion ∇B drift pointed away from the primary X-point; no heating preference (NBI, LHCD, ICRH, ECRH); presence of a weekly coherent mode (WCM) of 40−150 kHz during the whole I-mode phase. In addition, the EAST I-mode is quasi-steady state and always accompanied by a low-frequency coherent mode of 6−12 kHz, which is strongly radially localized (4–5 cm) at the plasma edge, and definitely not GAM unlike to that reported in other tokamaks. This mode could be observed by nearly all edge plasma diagnostics. It should play important role in turbulence transport process at the edge region for sustaining the I-mode.
Using ECEI/ECE and magnetic coils data, and tomography reconstruction through the 64-channel bolometer arrays across the poloidal cross-section, it has been shown that the low frequency coherent mode corresponds to a radially localized edge temperature ring oscillation (ETRO) with azimuthally symmetric structure (m=0, n=0). The location of ETRO is close to the temperature pedestal top with 10−30% relative perturbation amplitude on R/L_Te due to the drastic outward decay. Turbulence analysis with multi-channels Doppler reflectometry measurements has shown that ETRO is caused by turbulence transition between ion temperature gradient driven mode (ITG) and trapped electron mode (TEM). Then in return, the ITG-TEM transition is controlled by the local electron temperature gradient. The excitation of TEM leading to an additional outward particle flux burst, observed by divertor probes, can explain the no presence of particle transport barrier in I-mode plasmas. Experimental critical values of the electron temperature gradient corresponding to the transition from ITG dominant to TEM dominant are quantitatively compared to that calculated by turbulence gyrokinetic simulation and good agreement has been found. Another long-term conjecture on I-mode is that WCM during I-mode is believed to play the key role for driving outward flux and maintaining particle transport [5]. In our experiments, WCM synchronously grows with TEM and modulate TEM. Thus it is not excluded that WCM and TEM have the same origin. The self-organizing system including ETRO, turbulence and transport transitions can explain, or at least is consistent with all characteristics of I-mode, and should play the key role in sustaining the I-mode confinement. These results provide a novel physics basis for accessing, maintaining and controlling stationary I-mode in the future.

References

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