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The study of L-I-H transition dynamics in magnetically confined plasma

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The transition from low confinement mode (L-mode) to high confinement mode (H-mode), the so-called L-H transition is not only a possible route to obtain higher plasma efficiency in magnetically confined plasmas. As shown in Ref. [1], with slow power ramp-up, plasma parameters such as line average electron density and D-alpha signal exhibit quasi-periodic oscillation prior to the full transition to H-mode. This phenomenon can be described using the predator-prey relationship among microscale turbulence, mesoscale turbulence-driven flow i.e. zonal flow shear, and macroscale mean $E \times B$ flow shear. As a result, the transition occurs through the intermediate phase (I-phase), which is characterized by limit-cycle oscillations (LCOs) of plasma parameters.

The understanding of fundamental dynamics during the L-H transition is significant. This process requires a certain amount of external power to initiate the transition. In this work, we utilize the primitive zero dimension 2predator-1prey model [2] to study the dynamics of the transition with the preceding limit-cycle oscillations during power ramp-up. The drift wave turbulence (prey) is self-consistently driven by profile gradient. The zonal flow (predator) is driven by drift wave turbulence through Reynolds stress and the mean flow is related to profile gradient through the radial force balance equation. The model is numerically solved by the BOUT++ fluid simulation framework [3].

Numerically, we show that increasing linear zonal flow damping rate, which may relate to the ion-ion collisional frequency due to the collision between trapped particles in the banana orbit and zonal flow, leads to the delay of transitions. In addition, the duration of limit-cycle oscillation also extends i.e. the I-phase window regimes are larger as shown in Figure 1. It implies that the injection of particles during the I-phase may delay the transition and upshift the power threshold since the injection of density increases the plasma density leading to an increase in the ion-ion collisional frequency hence the zonal flow damping rate. At the L-I transition, the turbulence-driven zonal flow is stronger than the flow-damping effect so zonal flow is increased before it performs self-regulation with the drift wave turbulence, subsequently, the LCO appears. At the I-QH transition, zonal flow peaks before the moment of transition i.e. zonal flow momentarily absorbs almost all of the turbulence energy as the zonal flow's role is to trigger the transition. So, the profile gradient is free from turbulence transport leading to a rapidly increased mean flow which will lock in the transition. After the transition to H-mode, turbulence is suddenly suppressed by mean flow, followed by the decay of zonal flow.

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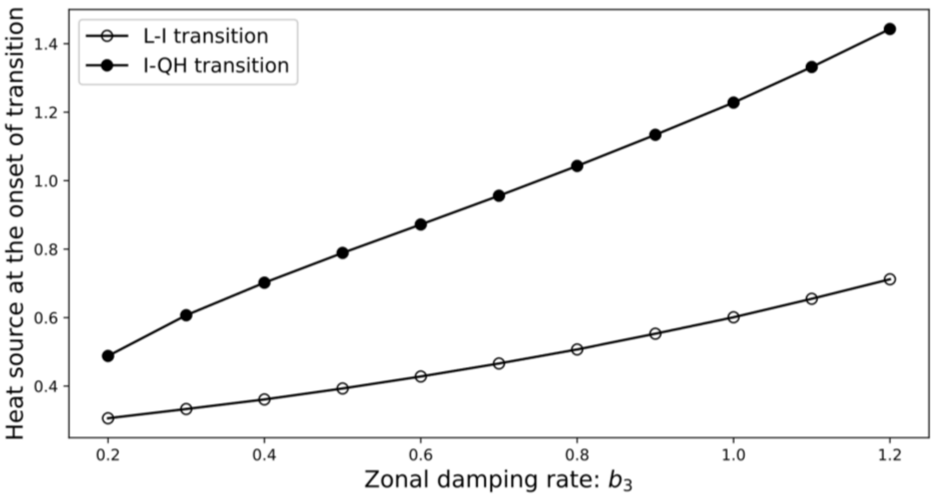

Figure 1. The effects of zonal flow damping rate on the onset of L-I transition (clear-circle line) and I-QH transition (full-circle line). The increasing distance between the two lines indicates the extension of the I-phase.