IMPURITY RADIATION SEEDING OF NEOCLASSICAL TEARING MODE GROWTH

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Neoclassical tearing modes (NTMs) is well known to be detrimental to fusion plasmas, limiting the achievable plasma beta (β_N), degrading confinement, and potentially triggering disruptions. While sustained research efforts have advanced our understanding, the critical question of the seed island required for nonlinear NTM growth remains insufficiently understood and demands further study. Recent NIMROD simulations reveal that localized impurity radiation cooling can trigger and drive resistive tearing mode instability [1][2], suggesting a potential seeding process. Furthermore, the radiation-driven tearing mode transition into nonlinear NTM growth regime when neoclassical effects are incorporated [3]. This study establishes impurity as a dual-phase mechanism–first seeding resistive island through radiation cooling, then sustaining growth via neoclassical effects–providing insights into NTM dynamics.

Key findings demonstrate that strong impurity radiation cooling localized on rational surface triggers resistive tearing instability. Subsequent nonlinear growth is consistent with the Rutherford model (except during the peaking phase, where stabilizing curvature effect is enhanced), with the tearing stability parameter Δ' emerging as the primary driver (Fig. 1a). This Δ' basically arises from current profile modifications outside the resistive layer, driven by the diamagnetic currents induced by pressure gradient perturbations from localized radiative cooling. When implementing a heuristic neoclassical closure, the extended Ohm's law incorporates a neoclassical electron viscous stress tensor that effectively model bootstrap current perturbations, i.e. $\vec{E} = -\vec{V} \times \vec{B} + \eta\vec{J} - 1/en_e \nabla \cdot \overrightarrow{\Pi_e}$. Simulations identify a threshold neoclassical electron viscosity μ_e governing nonlinear NTM evolution: seed island grows nonlinearly when μ_e exceeds this threshold, while sub-threshold conditions supress growth (Fig. 1b). The growth rate of island is proportional to the value of μ_e beyond threshold. Theoretical analysis confirms that a neoclassical driving term derived from modified Rutherford equations is able to account for the nonlinear neoclassical island growth in simulation.

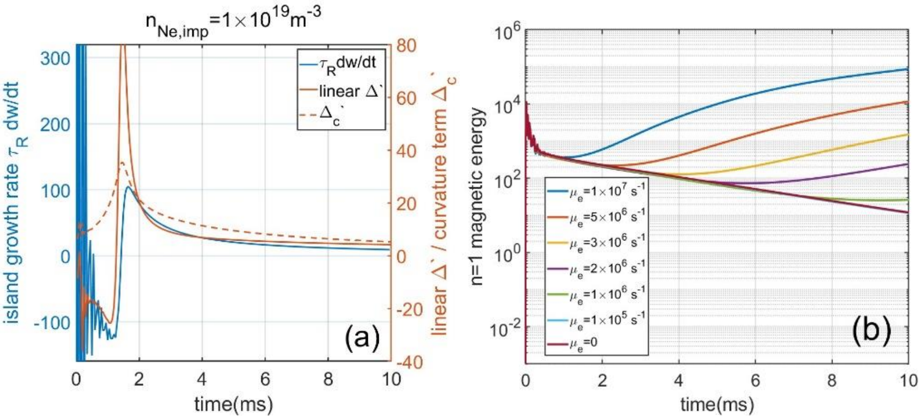

Fig. 1 *(a) The island growth rate of the 2/1 mode (blue), the linear tearing stability parameter Δ' (orange solid line) and the curvature term Δ_c' (orange dashed line) as functions of time ($\mu_e = 0$). (b) The magnetic energy of the n=1 component of perturbation with various values of coefficient μ_e as functions of time.*

ACKNOWLEDGEMENTS

This work was supported by the National Magnetic Confinement Fusion Program of China (Grant No. 2019YFE03050004), the National Natural Science Foundation of China (Grant No. 51821005), and U.S. Department of Energy (Grant No. DE-FG0286ER53218). This research used resources of the National Energy Research Scientific Computing Center, a DOE Office of Science User Facility supported by the

Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231 using NERSC award FES-ERCAP0027638.

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