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Gyrokinetic Penetration of Resonant Magnetic Perturbation into Tokamak Pedestal and Core

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Suppression of pedestal crashes due to edge localized modes (ELMs) using a set of external resonant magnetic perturbation (RMP) coils is planned in ITER. This topic is of critical importance to the success of the ITER program because a single ELM crash event could damage the divertor plates.

Thus far, only special MHD and fluid codes have been used to understand the penetration of RMPs into the pedestal and core plasma. While this approach yielded some degree of success in explaining experimental implications on the perturbed magnetic field structure and the resulting plasma transport, important kinetic physics like micro-turbulence had to be neglected or simplistically modeled and the physics interpretation has been far from satisfactory.

Using a first-principles based kinetic code for RMP penetration into the plasma is strongly desired but has been difficult due to the numerical complexity and the requirement for extreme-scale computing resources. Recently, a progress in this direction was made through coupled MHD and electrostatic gyrokinetic simulations by calculating neoclassical and micro-turbulence, and neutral particle recycling together using the total-f gyrokinetic PIC code XGC [1, 2]. with fixed RMPs calculated with the MHD code M3D-C1.

In this talk, we report the first successful simulation of gyrokinetic RMP penetration into tokamak plasma in a realistic tokamak geometry, including the separatrix, using the new electromagnetic capability of XGC [3]. We study a DIII-D-like RMP ELM-suppressed H-mode plasma. Our simulation consists of a three stage "bootstrap" process designed for accelerated RMP calculation. Each subsequent stage is a continuation of the previous stage with additional physics. The first stage establishes the neoclassical equilibrium without turbulence or RMPs for a given Grad-Shafranov equilibrium. The plasma response to the RMP field is calculated in the second stage with full neoclassical physics but without turbulence using an accelerated electromagnetic algorithm similar to Ref. [4]. The third stage calculates electromagnetic micro-turbulence together with neoclassical transport and the plasma response to the RMP field.

We compare the gyrokinetic penetration calculation with XGC to MHD calculations with the M3D-C1 code. In particular, we examine whether magnetic islands and stochastic magnetic perturbations due to RMPs exist at the pedestal top and deeper into the core plasma as implied by experimental observations but not seen in MHD/fluid simulations. And we investigate how the neoclassical and electromagnetic turbulence transport fluxes change due to the RMPs. We also discuss why the electron thermal transport could be small compared to the plasma density transport in the presence of magnetic islands and stochastic magnetic field perturbation, which has been a difficult topic in MHD/fluid studies.

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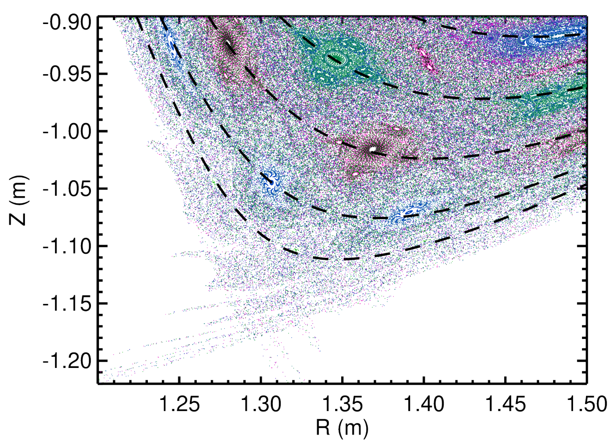

Figure 1: Poincaré puncture plot of a gyrokinetic RMP field penetration with plasma response from XGC simulation.