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GENERAL ATOMICS

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Theory Research Highlight

Using the EPED Model to Understand and Control the Pedestal and ELMs

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High fusion performance ("H-mode") in tokamaks is achieved via the spontaneous formation of an insulating transport barrier in the outer few percent of the confined plasma. This region acts much like the wall of a thermos bottle, separating the very hot plasma core (far hotter than the core of the sun) from a cooler layer of unconfined plasma and the material surfaces. This insulating layer is relatively thin, and is referred to as the "pedestal" because it provides an abrupt step up in the temperature and density profiles. The physics of this pedestal region is highly important for two primary reasons: (1) predicted fusion performance scales roughly with the square of the pedestal pressure (or "pedestal height"), and hence a high pedestal is required for copious fusion energy production in ITER or a fusion power plant, and (2) the large free energy in the pedestal region can drive instabilities called Edge Localized Modes (ELMs), which eject bursts of heat and particles onto material surfaces, and can cause significant material erosion in reactor-scale devices.

The instabilities responsible for ELMs are known as peeling-ballooning (PB) modes, as they balloon outward and peel off part of the insulating layer of plasma. These PB modes have been extensively studied with the efficient ELITE code, developed as a collaboration between General Atomics and the University of York (UK). As shown in Fig 1(a), PB modes have a filamentary structure that extends across the entire pedestal region. The condition for PB mode onset, calculated by ELITE, provides a constraint on the height of the pedestal as a function of its width. An additional smaller-scale instability, the kinetic ballooning mode (KBM), constrains the pressure gradient within the insulating layer by driving heat and particle transport across it. Combining PB calculations from ELITE with an efficient method to integrate the KBM constraint across the pedestal yields the EPED model, which predicts both the height and the width of pedestal. The EPED model has been extensively tested in many experiments, including a recent major effort (part of the 2011 Joint Research Target) on the US tokamaks DIII-D and Alcator C-Mod, in which good agreement was found between observations and EPED predictions of both the pedestal height and width. An extensive comparison of the model to observations on 5 tokamaks, including the dedicated studies on DIII-D and C-Mod, is shown in Fig 1(b), where good agreement is found across 270 cases, with a ratio of predicted to observed pedestal height of 0.98 ± 0.20. The EPED model is being used to predict and optimize the pedestal on the international ITER device, currently under construction, and an example prediction for a base ITER case is shown in Fig 1(b). Combining EPED pedestal predictions with turbulent transport and stability calculations in the core allows global optimization studies for ITER and planned fusion reactor designs.

In addition to operating with a high pedestal, it is also important to avoid or mitigate large ELMs. One promising regime of operation without ELMs, known as Quiescent H-Mode, yields a steady pedestal with a height (open circles in Fig 1b) and width in agreement with EPED predictions, but with a steady edge oscillation rather than bursty ELMs. The EPED model predicts that ITER will operate in a density range appropriate for QH mode, and the requirements for obtaining the strong rotation shear required for QH mode are currently being explored. Another promising method for controlling ELMs is via the use of imposed 3D resonant magnetic perturbations (RMP). The EPED model has recently been applied toward developing a working model to understand RMP ELM suppression. During the formation of the pedestal, or after an ELM, the pressure in the pedestal region rises rapidly, until the KBM limit is reached. The KBM clamps the pressure gradient, but the pedestal can continue to broaden, expanding inward until the total free energy in the pedestal becomes so high that a PB mode is triggered, usually resulting in an ELM (see Fig 1c). However, if this inward expansion of the pedestal can be halted before the width reaches a critical value, the ELM can be avoided. In a highly conducting plasma, magnetic perturbations such as the RMP are normally strongly screened by the plasma. However, near the top of the pedestal it is possible to attain low values of the perpendicular electron rotation, allowing penetration of the RMP and formation of magnetic islands or stochastic regions. If a region of strong magnetic transport is placed in the proper location near the top of the pedestal, it can prevent further pedestal broadening and suppress the ELM (stop sign in Fig 1c). This EPED-based working model is consistent with a number of observations on the DIII-D tokamak, including ranges of the the safety factor (q) required for ELM suppression, and narrowing of the pedestal during ELM suppression. A detailed understanding of field penetration and magnetic transport is under development to further quantify the model, and detailed experimental tests are underway.

See also: P.B. Snyder et al., Phys. Plasmas **19** 056115 (2012).

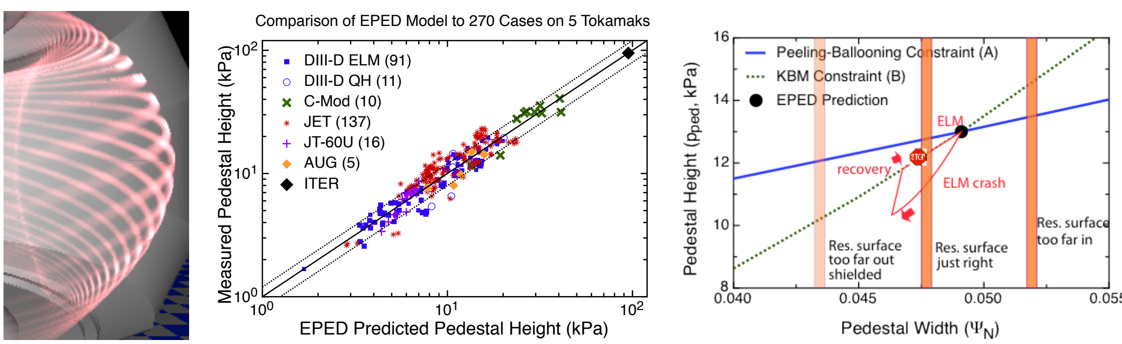

Figure 1: (a) Typical structure of a peeling-ballooning mode in the DIII-D tokamak, calculated by ELITE. (b) Comparison of pedestal height predicted by the EPED model with observations on 5 tokamaks, with a prediction for ITER also shown. (c) Illustration of a working model for RMP ELM suppression based on the EPED model. A typical ELM cycle trajectory is shown in red, with the ELM occurring at the black circle. If the RMP field is able to penetrate at a properly located resonant surface, it can prevent the broadening of the pedestal and suppress the ELM (stop sign).