Pushing to the limits of plasma stability at the boundary of high confinement tokamak discharges

The high confinement mode of operation in tokamaks is considered to be one of the most promising regimes of operation of the future thermonuclear reactor. The mode is characterized by spontaneous formation of a particle and energy transport barrier near the edge of the plasma. The term pedestal is used to describe the resulting narrow region of strong pressure gradient just inside the separatrix (the surface that separates the hot confined plasma from the cold plasma near the walls of the device). The physics of the pedestal is important for both the present tokamak experiments and future burning plasma devices. As theoretically predicted and experimentally observed, confinement in the bulk plasma depends strongly on the pressure at the top of the pedestal (pedestal height). On the other hand, high pedestal gradients, and their associated edge currents, can provoke plasma instabilities that limit the pedestal height and, therefore, the overall performance of the tokamak. Understanding the physics which controls these edge instabilities is thus an important and active area of experimental and theoretical research.

A number of recently developed high-resolution diagnostics that measure plasma profiles and fluctuations in the pedestal region is used to study the edge physics and stability on Alcator C-Mod tokamak. Numerical computer simulations of plasma behavior are employed to evaluate stability constraints in the pedestal and to verify models of various types of edge instabilities. For typical plasma conditions in Alcator C-Mod, the dominant type of edge instability is a quasicoherent (QC) mode localized in the pedestal region that drives continuous particle transport across the separatrix. If the edge pressure exceeds a critical value, the mode is replaced by intermittent broadband fluctuations corresponding to high frequency edge localized modes (ELMs) – repetitive bursts of particles and energy transport across the plasma boundary (see Fig. 1). The threshold for this transition from the QC mode to ELMs depends on several plasma parameters, including pedestal temperature, pressure gradient, and plasma shape. Modeling of the edge stability shows that the ELMs can be interpreted as a specific class of ideal magnetized-fluid (MagnetoHydroDynamic) instabilities that are driven by a combination of pedestal pressure gradient and current. These modes are localized just inside the separatrix (Fig.2) and, when destabilized, can locally destroy the magnetic boundary of the plasma and transiently drive significant particle and energy transport across it. The modeling shows that, in the region of plasma parameters where the quasicoherent fluctuations exist, the ideal MHD modes are stable and, therefore, to understand the QC mode, nonideal terms, such as plasma resistivity and viscosity have to be included in the theory. Further experimental studies of the instabilities, together with theoretical and modeling efforts, should produce a self-consistent model of edge instabilities that will allow us to predict and optimize the pedestal characteristics and instabilities in a magnetic fusion reactor.

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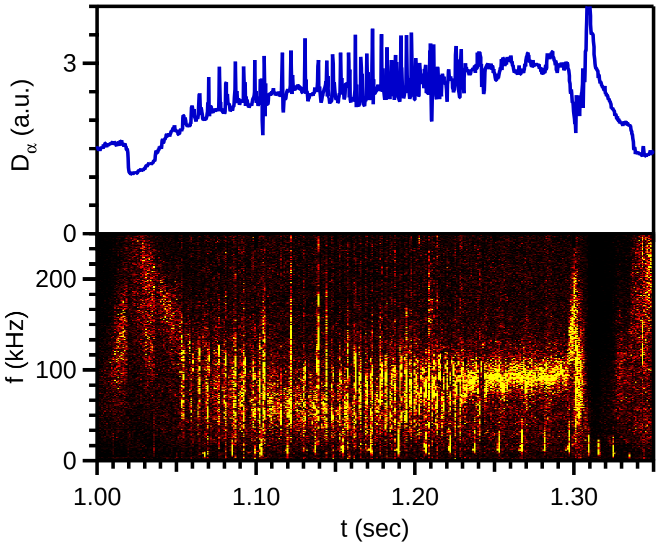
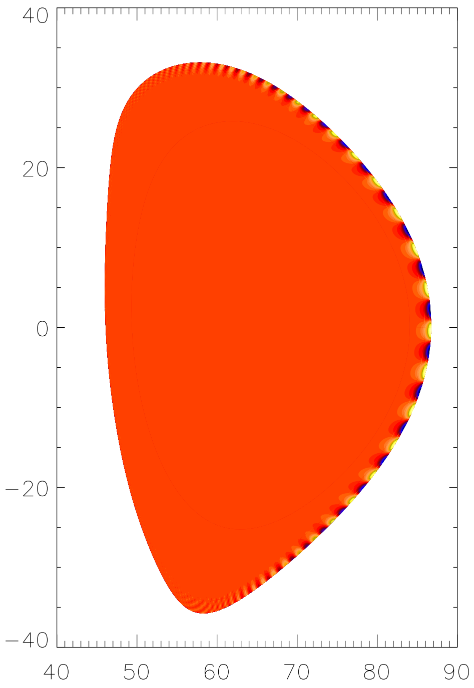


Fig.1 Time histories of deuterium radiation (blue trace) and the spectrum of edge density fluctuations during a high confinement discharge showing a transition from ELMs to the QC mode at 1.25 sec). The QC mode has a frequency of about 80 kHz in this case.



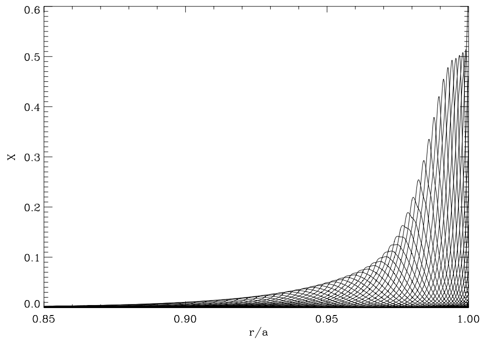


Fig.2 Calculated spatial distribution (left) and mode spectrum (above) of the ideal MHD modes corresponding to C-Mod discharge conditions when ELMs are present.