Energetic Ion Transport in Tokamak Plasmas Dominated by Microturbulence, Alfvénic Activity, or Applied Magnetic Perturbations

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Experiments conducted at DIII-D [1] using both on-axis and off-axis neutral beam injection (NBI) find that energetic ion transport due to Alfvén eigenmodes (AEs) and applied 3D magnetic perturbations is of greater concern for ITER than that due to microturbulence, as shown in Fig. 1. Energetic ion transport due to microturbulence is investigated [2] by varying relevant parameters such as the value of E_b/T_e, with E_b the energetic ion energy and T_e the electron temperature. This transport effect is modeled using numerical and analytic methods to calculate the energetic ion diffusivity due to microturbulence. In all cases, any transport enhancement due to microturbulence is too small to measure. In plasmas that are unstable to AEs such as the toroidal (TAE) and the reversed-shear (RSAE), different NBI combinations are used to alter the classically expected gradient of energetic ion β ($\nabla\beta_{EI}$) [3]. Off-axis NBI greatly reduces the amplitude of core-localized RSAEs and TAEs, while global TAEs are weakly affected. Self-similarity of the resulting radial profiles of energetic ion density, as measured spectroscopically (FIDA), is modeled by a critical-gradient treatment [4] in which the profile gradient is limited to a marginal stability value based on TAE damping/growth rates. In plasmas featuring applied magnetic perturbations, energetic ion losses are observed at the rotation frequency of the applied $n = 2$ magnetic perturbation [5]. The measured energies, pitch angles, and rapid decay of the losses after beam turn-off indicate that these ions result from changes in the NBI prompt-loss. Beam deposition and full orbit modeling using M3D-C1 calculations of the perturbed kinetic profiles and fields show modulation of prompt-loss as observed. Together, these studies suggest that energetic ion transport in ITER will be dominated by MHD over microturbulence, and that NBI prompt-losses may be enhanced by the application of magnetic perturbations, causing increased heat load to the first wall.

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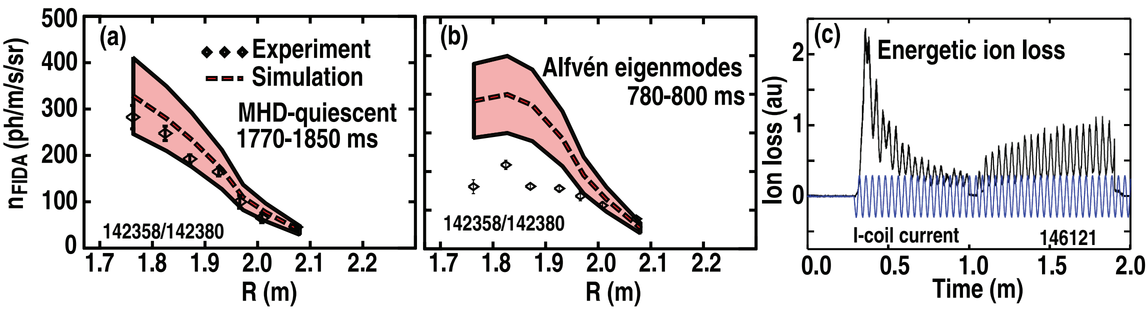

Figure 1: Measured energetic ion density profiles compared with classical transport simulations demonstrate agreement during (a) MHD-quiescent periods dominated by microturbulence, and enhanced transport during (b) periods of strong AE activity. (c) Energetic ion losses are enhanced by applied magnetic perturbations and oscillate in-phase with the coil current.