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Critical Gradient Behavior of Fast-Ion Transport from Alfvén Eigenmodes Guides Predictive Models for Burning Plasmas

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Recent experiments in the DIII-D tokamak show that many overlapping small-amplitude Alfvén eigenmodes (AEs) cause stiff fast-ion transport above a critical threshold. This result suggests that reduced models can be used to effectively predict alpha profiles, beam ion profiles, and losses to aid in the design of optimized scenarios for future burning plasma devices. Three key features of critical gradient behavior have been observed; (1) a sudden increase in incremental transport occurs above the AE linear stability threshold, (2) fast-ion losses become intermittent above threshold, and (3) stiff transport causes the fast-ion density profiles to become fixed despite increased source. Comparison with theoretical analysis using the NOVA and ORBIT codes shows that the threshold corresponds to when particle orbits become stochastic due to wave-particle resonances with AEs in the region of phase space measured by the diagnostic [1]. The measured threshold changes as beam deposition shifts AE induced stochasticity to different regions of phase space. For the first time, intermittent fast ion loss activity was observed, which peaked at the simultaneous occurrence of nearly constant frequency Toroidal Alfvén Eigenmodes (TAE) and frequency sweeping Reverse Shear Alfvén Eigenmodes. Intermittency was largely reduced when the types of AEs were altered by applying Electron Cyclotron Heating (ECH) near the minimum in the magnetic safety factor profile, resulting in a TAE dominant spectrum. The fast-ion deuterium alpha diagnostic shows that in the stiff transport regime, incremental transport is localized to mid-core radii, and the fast-ion density gradient becomes fixed at a critical value. These measurements can be used to quantitatively validate AE critical gradient transport models, giving greater confidence when applied to ITER.

[1] C.S. Collins, et al., Phys Rev. Lett. 116, 095001 (2016).

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