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Studies of Turbulence and Transport in the Alcator C-Mod and DIII-D Tokamaks with Phase Contrast Imaging and Gyrokinetic Modeling

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Experimental results are presented where the macroscopic plasma conditions were manipulated by external actuators, such as injection of medium to low Zi impurity gases with ohmic heating (Alcator C-Mod) to dilute the main deuterium ion species, or deploy a different mix of NBI and ECH heating methods (DIII-D), thus enabling us to study the resulting changes in transport and turbulence. Subsequently we were able to carry out quantitative comparisons between gyrokinetic code predictions (GYRO and GS2) and compare them with measurements of the fluctuating density spectrum based on a calibrated Phase Contrast Imaging (PCI) technique. In Alcator C-Mod, dilution by nitrogen seeding was found to decrease the ion temperature gradient scale lengths in the outer regions of the plasma where ITG modes were dominant. GYRO simulations reproduced the observed change in the energy transport with the seeding as a reduction in ITG driven transport. The PCI measured density fluctuation amplitudes also decreased substantially with nitrogen seeding. Simulations of these plasmas with the nonlinear gyrokinetic code GYRO were performed and the density fluctuations from nonlinear GYRO simulations were found to agree with the experimental PCI measurements. On the DIII-D tokamak experiments simulating the NBI heated ITER Baseline Scenario showed that added electron cyclotron heating (ECH) affected turbulent fluctuations at different scales, as measured by Phase Contrast Imaging (PCI) diagnostic. After turning off the ECH power, the intensity of fluctuations at frequencies higher than 200 kHz increased within 20 ms, due to electron modes that were enhanced by the prompt response of the electron temperature inverse scale length in the outer third of the minor radius. Such modes were observed in nonlinear gyro-kinetic simulations to generate a significant transient heat flux and an inward particle pinch. In contrast, the behavior of fluctuations at lower frequencies was dictated by the slower time evolution of other equilibrium quantities such as density and flow shear. In particular, the intensity of fluctuations was observed to decrease with the mean flow shear exceeding the maximum linear growth rate of ITG modes.
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