Characterization of Zonal Flows and Their Dynamics in Experiment and Simulation*

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Using newly developed algorithms, the *nonlinear* transfer of internal energy $|\tilde{n}|^2$ due to convection of drift-wave turbulence by a geodesic acoustic mode (GAM, a finite-frequency zonal flow) has now be measured directly in a high-power device. By combining spatially resolved density fluctuation measurements obtained via an upgraded beam emission spectroscopy (BES) system in the edge region of the DIII-D machine with a velocity inference algorithm, the convection of turbulent fluctuations by the GAM has been directly measured. These measurements indicate that GAM convection leads to a transfer of internal energy from low to high frequencies, in agreement with expectations from theory and simulation. In addition, the GAM is found to modulate the intensity of the density fluctuations, providing further support for the idea that the GAM is a significant player in the edge turbulence dynamics. The upgrades to the BES system have also allowed us to identify and characterize the zero mean frequency (ZMF) zonal flow branch for the first time in the core of a tokamak plasma. Calculations of the measured nonlinear interactions in long run-time simulations of the gyrokinetic code GYRO are found to be in good agreement with the experimental observations, and are used to develop new insights into the roles of GAM and ZMF flows in regulating drift-wave turbulence in different regions of parameter space. Complementing these measurements of how the zonal flows affect the turbulence are measurements of the turbulent momentum balance in a linear plasma column, which explicitly demonstrate the generation of a collisionally damped zonal flow by the Reynolds stress.

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