Magnetic Fluctuation-Induced Charge Transport and Zonal Flow Generation in MST

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Magnetic reconnection is characterized by discrete sawtooth-like bursts in many high temperature toroidal plasmas such as tokamaks and the Reversed Field Pinch (RFP). These magnetic reconnection events, which are associated with magnetic field and current density fluctuations, enhance radial transport and degrade energy confinement. Herein, we report the first measurement of magnetic fluctuation-induced particle transport in the core of a high-temperature RFP plasma. This transport is driven by resistive tearing modes, occurring near the resonant surface, and originates from nonlinear mode-mode interactions. Charge transport results from an imbalance between the magnetic fluctuation-induced ion and electron radial flux due to particles streaming along stochastic field lines. It bursts during the sawtooth crash, reaching a maximum of 1% of the total radial particle flux. Transport related charge separation has two important consequences. First, it generates a potential well along with locally strong electric field and electric field shear at the resonant surface. Second, this electric field results in a spontaneous $E \times B$ driven zonal flow. Magnetic and current density fluctuation measurements are achieved using a high-speed laser-based Faraday rotation diagnostic.

Unlike electrostatic transport, magnetic fluctuation-induced particle transport is not intrinsically ambipolar and can be written as the difference between the ion and electron flux according to the relation $\Gamma_q = \Gamma_i - \Gamma_e = \frac{< \delta j_{//} \delta b_r >}{eB}$. The fluctuation amplitudes and their correlation are directly measured for the dominant, core resonant, m/n=1/6 (~15-20 kHz) mode giving a charge flux, Γ_q, which reaches $1.5\text{x}10^{19}$ /m^{2}s at a sawtooth crash, or about 1% of the measured radial particle flux in MST. Although charge flux is small compared to total particle flux and is largely offset by the ion polarization drift, small charge separation can significantly alter the local electric field profile and flows. At a sawtooth crash, the maximum radial electric field can reach ~5 kV/m over spatial scale of ~5 cm. We use the perpendicular momentum balance equation to determine the radial electric field and the associated $E \times B$ flow. The electric field induces a toroidally and poloidally symmetric (m=0, n=0) zonal flow structure which changes sign across the tearing mode resonant surface.