

Suppression of turbulent particle flux by biased rotation in a laboratory plasma

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Biased rotation was first demonstrated to improve confinement through triggering an H-mode transition in the CCT tokamak at UCLA [1]. The observation of improved confinement during biased rotation is generally attributed to the suppression of edge turbulence and associated transport by shear flows [2]. Recently, theoretical work [3] and measurements of transport flux during biased rotation in toroidal devices [4, 5] have shown that transport flux is not only reduced, but can also be reversed in shear layers. We report detailed observations of particle flux suppression and reversal during biased rotation in a cylindrical, uniformly magnetized laboratory plasma.

The experiments were performed in the upgraded Large Plasma Device (LAPD), which is part of the Basic Plasma Science Facility (BaPSF) [6] at UCLA. LAPD is an 18 m long, 0.5 m diameter cylindrical magnetized plasma column. Typical plasma parameters are $n_e \sim 1 \times 10^{12} \text{ cm}^{-3}$, $T_e \sim 7 \text{ eV}$, $T_i \sim 1 \text{ eV}$, and $B < 2\text{kG}$. Measurements of density, temperature, floating potential and transport flux are made using Langmuir probes. Flows are measured using a Gundestrup (Mach) probe with six faces.

The edge plasma in LAPD is rotated through biasing the vacuum vessel wall positively with respect to the source cathode. Figure 1 (a) shows a schematic of the LAPD, along with the rotation bias circuit, which includes a capacitor bank and an IGBT switch. The rotation bias is pulsed, with the switch open for 4 ms during the steady portion of the LAPD discharge. Typical bias voltages are on the order of 100V, and result in around 100A of cross-field current. The measured current is consistent with a Pederson (neutral) conductivity in the far edge of LAPD using a neutral density of 10^{12} cm^{-3} . The edge of the plasma source cathode in LAPD maps to a radius of $\sim 26 \text{ cm}$ in the main column. Without bias, cross-field turbulent particle

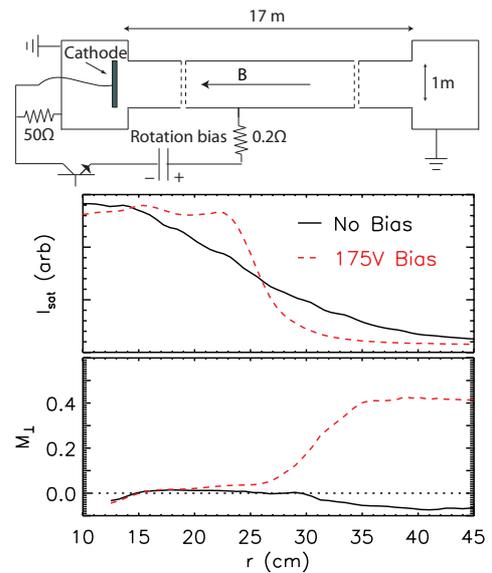


Figure 1: **(a)** Schematic of experiment. **(b)** I_{sat} profiles with and without biased rotation. **(c)** M_{\perp} profile with and without biasing.

transport causes the density profile to extend well past the cathode edge, with a fairly gentle gradient ($L_n \sim 10$ cm), as shown in figure 1 (b) (showing measured ion saturation current).

As the bias voltage is applied and increased beyond a threshold value, the measured density profile steepens dramatically ($L_n \sim 2$ cm). The second profile shown in figure 1 (b) is for an applied bias of 175V. The Mach-probe measured cross-field flow profile with and without bias is shown in figure 1 (c). The observed flow is consistent with the $E \times B$ velocity computed using the measured floating potential profile. The density profile steepening is observed to occur near the radius of maximum radial shear in the perpendicular flow. A simple estimate of the flow shear necessary to suppress turbulence can be computed by equating the shearing rate, defined as $\gamma_{E \times B} = \frac{\partial v_\theta}{\partial r}$, to the linear growth rate of the drift waves. In the case shown in figure 1, the shearing rate has a peak value of $\gamma_{E \times B} \sim 50$ kHz, which is comparable to the diamagnetic drift frequency, $\omega_* \sim 20$ kHz.

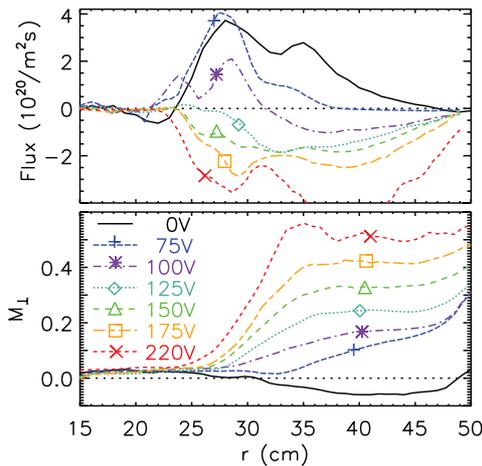


Figure 3: **(a)** Transport flux and **(b)** M_\perp profiles for various bias values.

increases again as the bias is further increased, but the radial location of the peak amplitude moves out into the far edge region (as can be seen in figure 5 (b)).

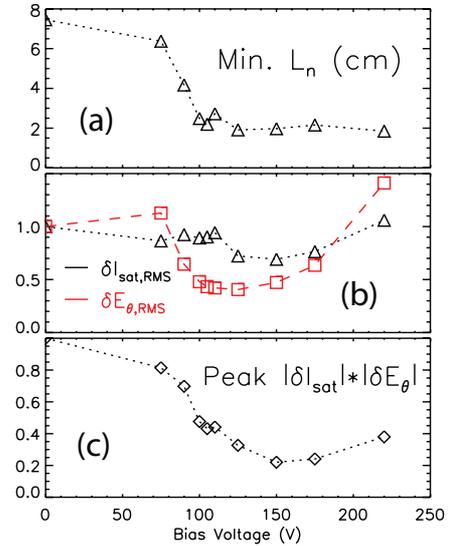


Figure 2: **(a)** Gradient scale length, **(b)** Fluctuation amplitudes, and **(c)** product of fluctuation amplitudes versus bias.

The observed profile steepening occurs for bias voltages above a threshold value. Figure 2 (a) shows the minimum density gradient scale length (L_n) versus bias voltage. For biases above ~ 100 V, the density gradient scale length decreases dramatically, but saturates near $L_n \sim 2$ cm ($\rho_s \sim 1$ cm). Figure 2 (b) shows the dependence of the peak fluctuation amplitude on the applied bias voltage. Peak ion saturation current fluctuation amplitude does not change substantially, and in fact increases first before decreasing as the bias is increased. However, the azimuthal electric field fluctuation amplitude does decrease significantly when the threshold bias is exceeded. The electric field fluctuation amplitude increases again as the bias is further increased, but the radial location of the peak amplitude moves out into the far edge region (as can be seen in figure 5 (b)).

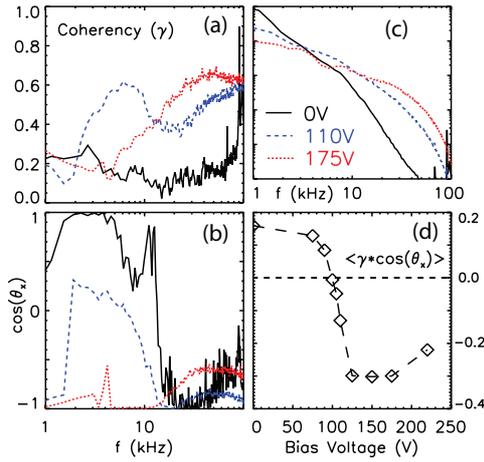


Figure 4: (a) Coherency, (b) Cross-phase, and (c) power spectrum for three biases. (d) Coherency-cross-phase product versus bias voltage.

Figure 4 shows: (a) the spatial average of the coherency and (b) cross-phase (cosine of) between I_{sat} and δE_{θ} , and (c) ion saturation current FFT power spectrum at three different bias voltages. The as the bias is increased, the FFT power spectrum shows a reduction in low frequency fluctuations as well as a Doppler shift due to the flow. The coherency actually increases as the bias is increased, also shifting to higher frequency. Changes in coherency are therefore not responsible for the observed transport flux suppression. The cross phase, however, changes dramatically as the bias is increased beyond the threshold

value, suppressing then reversing the direction of the flux as the bias is increased. The product of the frequency-averaged coherency and the cosine of the cross-phase is shown in figure 4 (d) as a function of bias voltage. This quantity is reduced and reversed at a bias which coincides with the observed profile steepening.

The transport flux is calculated using the product of the ion saturation current (density) fluctuation amplitude, the azimuthal electric field fluctuation amplitude, the coherency between these two fluctuations, and the cosine of the cross phase between the signals. The maximum possible value of the transport flux is then product of the two fluctuation amplitudes, and this is shown in figure 2 (c). The product of the two amplitudes decreases by around a factor of 5 when the bias is above the threshold value.

Figure 3 shows the measured electrostatic particle transport flux as a function of radius for several values of bias voltage, along with measured perpendicular flow profiles for each bias voltage. As the bias is increased, the transport flux is first reduced, but then reversed. Re-

versal in the flux is first observed in the far edge of the plasma. At the highest bias, the measured turbulent flux is inward at all radial locations, and has similar magnitude as the outward flux with no applied bias.

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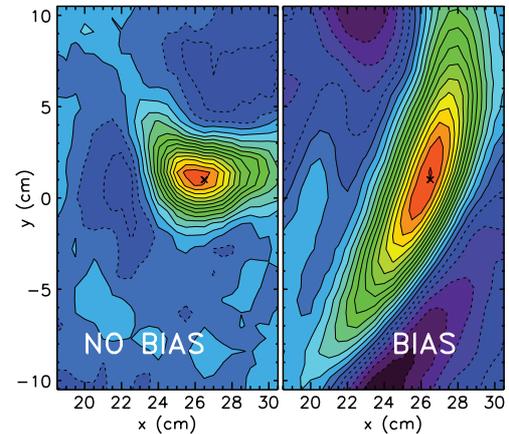


Figure 5: 2d correlation functions with and without bias.

Two-dimensional correlation functions in the turbulence were measured using two probes: a fixed reference probe, placed near the peak of the fluctuation amplitude, and a moving probe (axially separated from the fixed probe, which was placed shot-to-shot in 900 spatial positions in a 10 cm by 20 cm plane perpendicular to the field. Figure 5 shows the zero delay 2d correlation function with and without rotation bias. During biased rotation, the azimuthal correlation increases substantially, and the correlation function appears sheared. However, the radial correlation length does not decrease substantially as compared to the unbiased case.

The measured reversal of transport flux is consistent with two observations: (1) depletion of the edge plasma and (2) profile overshoot when biasing well above the threshold.

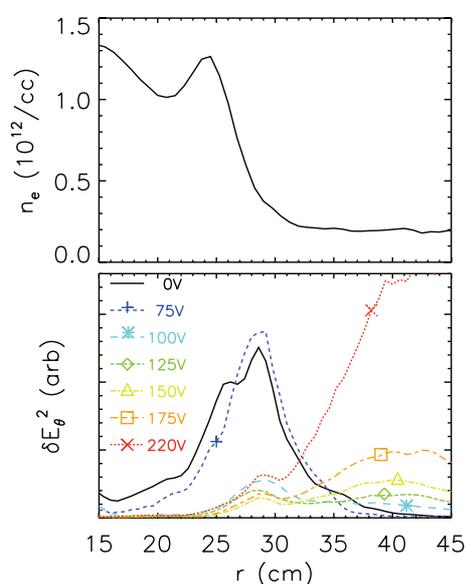


Figure 6: (a) Profile early during overbiased rotation. (b) Electric field fluctuation amplitude profile at several bias voltages.

Figure 6 (a) shows an example of overshoot in the density profile, early in time during overbiased rotation. Local reversal of transport flux has been predicted in drift wave turbulence in strong shear flows, but thermodynamic issues prevent the net flux from becoming negative if the fluctuations are driven solely by the density gradient [3]. In these experiments, evidence for a new class of fluctuations is seen as the bias is increased. Strong electric field fluctuations are observed in the far edge during rotation as shown in figure 6 (b). These fluctuations do not appear to be driven by the density gradient, and may explain the apparent turbulent pinch.

References

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