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Transport Control Through Modified Electric Field

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Improvement of plasma confinement in tokamaks depends on plasma edge behavior. Experiments indicate that this behavior depends on the anomalous particle transport caused by the observed electrostatic turbulence [1]. Thus, it is important to estimate the importance of chaotic particle orbits on this transport [2]. To do that, in this work we have studied the transport of particles in a magnetically confined plasma, due to electrostatic drift waves. The adopted model describes the trajectory of the guiding center of a particle in a uniform magnetic field perpendicular to a radial electric field perturbed by drift waves [2]. We have used the Hamiltonian description for the guiding center trajectories. The drift produced by the radial electric field is represented by the integrable part of the Hamiltonian, while the other part contains periodic perturbations representing the fluctuations of the electric field associated to the drift waves.

In this way we obtain chaotic orbits that determine the particles radial transport. We have used the experimental data of electrostatic turbulence measured in TCABR tokamak [3] to verify the validity of the model and the importance of the drift waves in the particles radial transport. We have also compared the values of the experimental diffusion coefficient with those provided by using the model, obtaining results with the same order of magnitude [4].

The drift velocity of the guiding centers are given by [2]:

$$\vec{v} = \frac{\vec{E} \times \vec{B}}{B^2}, \quad \vec{E} = -\nabla \phi \tag{1}$$

By analogy with the Hamilton's equation, we stand the Hamiltonian as

$$H(x, y, t) = \frac{1}{B_0} \phi(x, y, t)$$

With dimensionless variables in a frame moving with the plasma phase velocity of the first wave, we obtain the Hamiltonian for the two waves system

$$\begin{aligned} H(x,y,t) \;=\; & \phi_0(x) - u_1 x + A_1 \sin(k_{x1}x)\cos(k_{y1}y) + \\ & + A_2 \sin(k_{x2}x)\cos(k_{y2}(y-ut)) \end{aligned} \qquad (2)$$

where $u = \omega_2/k_{y2} - \omega_1/k_{y1}$ is the phase velocity difference between the second and the first waves, and $u_1 = \frac{\omega_1}{k_{y1}}$. r and θ correspond to radial and poloidal coordinates.

When the system has only one wave ($A_2 = 0$), the Hamiltonian is integrable. In this case it is relevant the dimensionless trapping profile U [2]:

$$U(x) = \frac{1}{A_1 k_{x1}}\left[\frac{d\phi_0(x)}{dx} - u_1\right] \sim v_E - u_1 \qquad (3)$$

The electric potencial function choosen to describe a non monotonic electric field profile of the tokamak TCABR is:

$$\phi_0(x) = Ax^3 + Bx^2 + Cx \qquad (4)$$

Superposition of two waves lend us to chaotic scenery. It is important to notice the grid of islands and the influence of the second wave for arising the chaos [4].

Figure 1 shows the configuration of the islands with one wave. It is important to notice the presence of the barriers at $x = 0.85$ (in green) where the trapping profile is maximum for $U_{max} = 1.3$. These barriers describe a zonal flow. Figure 2 shows how the transport depends on the grid of the first wave islands and the second wave amplitude. Moreover, we can see that the particles above (in red) and bellow (in blue) of the zonal flow (in green) do not leave its regions to the other.

To check the model, from wave spectrum obtained at the edge in TCABR Tokamak [3], we choose for the first wave frequency 20kHz and for the poloidal wave number $k_{y1} = 0.3cm^{-1}$.

We also colect several shots available in the TCABR experiments with the same caracteristics to determine the parameters A, B, C of the equation 4. We did this for a single ohmic discharge and for another one with the polarized electrode.

With the parameters of the fluctuating electric potencial and the first wave, we plot the phase space for a ohmic discharge and for a discharge with the electrode with its respective trapping parameter function.

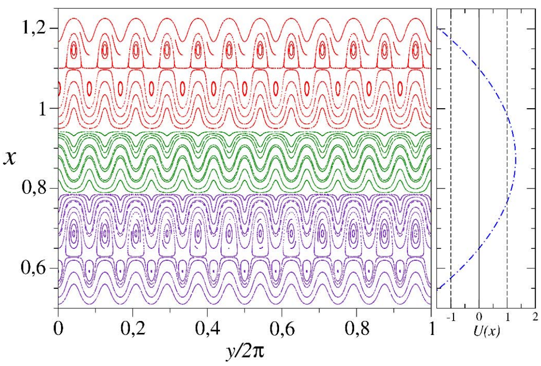

FIG. 1: First wave islands and the zonal flow for $U_{max} = 1.3$, $A_2/A_1 = 0$ in $x \times y$ plane.

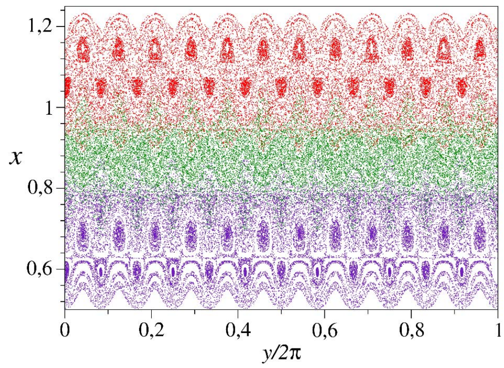

FIG. 2: Two waves, $A_2/A_1 = 0.4$, with a strong zonal flow at $x = 0.85$.

Measured in the TEXT tokamak [1], the mean of the wave phase velocities is close to the drift velocity v_E, indicating that $U \sim v_E - u_1 \sim 0$. By this result, we can estimate the potential needed to polarize the electrode.

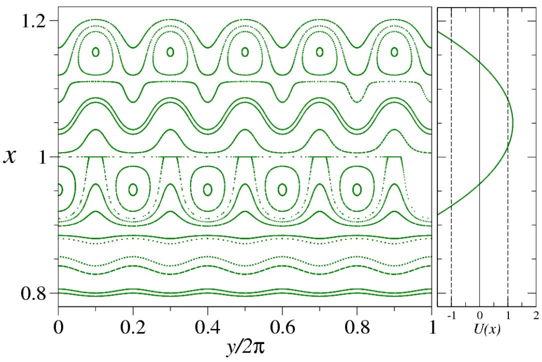

FIG. 3: Phase space with the trapping parameter for a ohmic discharge in TCABR.

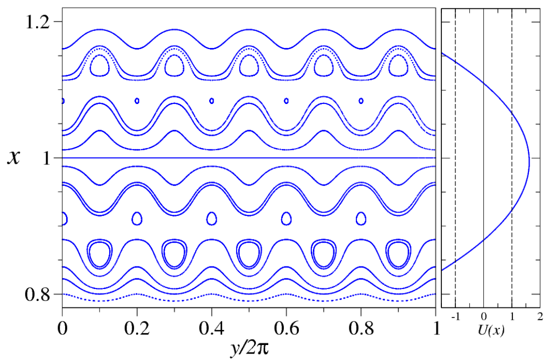

FIG. 4: Phase space with the trapping parameter for a polarized electrode in TCABR.

The typical TCABR parameters are: $B_0 = 1.1T$, $f = 20kHz$, $k_{y1} = 0.3cm^{-1}$, then we calculate the phase wave velocity $u_1 = \frac{\omega}{k_y} = \frac{2\cdot\pi\cdot 20\cdot 10^3 kHz}{30m^{-1}} \cong 4.2km/s$. In the experiment[3], the polarized electrode is inserted $\Delta x = 1.5cm$ inside the plasma with the limiter grounded. Putting all together we obtain:

$$\Delta\phi = u_1 B_0 \Delta x = \frac{2\pi\ 20\cdot 10^3}{30}\ 1.1\ 0.015 \approx 70V$$

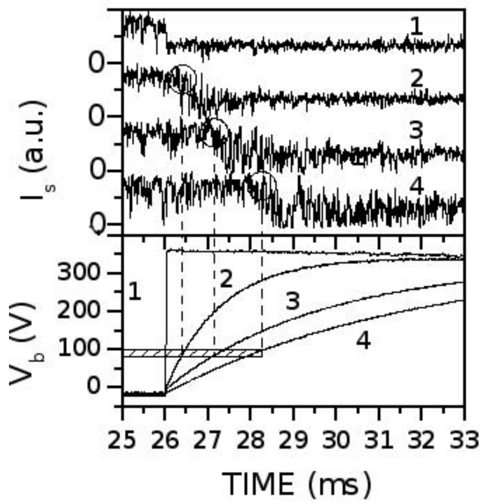

FIG. 5: From the top to below: the fluctuation of the ionic saturation current (I_S) and the electric potencial applied to the electrode (V_b).

Comparing with the experimental result[3] done independently from our estimation, as shown in the figure 5, we see that our estimation is close to the experimental result which is $80 - 100V$.

The figure 5 shows a reduction of the fluctuation of the ionic saturation current (I_S) after the electrode reaches the potencial around $100V$.

The model showed that the drift waves are important for the radial transportation of the particles. The trapping profile U estabilishes conditions to characterize the confinement type[4]. We verify the connection of the radial transport of the ion guiding centers with the drift waves amplitudes and frequency for a given radial electric field. The electric potential estimated for the electrode is close to the value measured in TCABR.

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