Turbulent transport structures in gyrokinetic flux-driven simulations

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Flux driven simulations of plasma turbulence are characterized by transport structures, typically avalanche like bursts of transport in the radial direction of micro-barriers, the so-called corrugations in the poloidal direction. Quantifying these processes in terms of their importance regarding plasma confinement is difficult in both experiments and numerical simulations. In the latter, a very important and readily available output is the electric potential. Since this field directly governs the turbulent convection, it contains a wealth of information. We concentrate on the analysis of the GYSELA code data for Ion Temperature Gradient electrostatic turbulence with adiabatic electrons and global 3D geometry of a tokamak with circular cross section.

We investigate the chaotic properties of the electric drift dynamics using the 3D maps of the electric potential as well as 2D maps in a poloidal plane, at fixed toroidal angle, as it governs turbulent transport. The quantification of chaos is based on the eigenvalue analysis of the tangential map of the electric potential. This corresponds to analyzing a “local Lyapunov exponent” λ of the drift trajectories. More precisely, on can show that λ^2 is the relevant measure with $\lambda^2>0$ characterising the regions where sensitivity to initial conditions is generated, hence “chaotic regions” or “X-point regions”, while $\lambda^2<0$ in the vicinity of potential minima and maxima, hence “O-point regions”, are regions with regular trajectories.

This allows one to consider a topological analysis of the potential maps. In particular one finds that the structure motion is slower than that of the particles. Radially extended regions with $\lambda^2\approx0$ and strong electric potential shear will characterise the avalanche channels. The correlations of these regions with O-points are clearly evidenced while their connection to the X-point regions is harder to pin down. In particular, these regions are those where the electric potential results from the ongoing charge separation in the active region of the avalanche and the wake of prior avalanches. It is also the regions where zonal flows interact with the avalanches. One finds that ahead of the avalanche front, the X-point region is connected to the way particles pour-out of the front, while in the X-point region in the wake of the structure, the particles are channeled into the avalanche.

The dynamics of these topological properties then provide a means to investigate the avalanche transport. The electric potential structure of the avalanche dipole and that of the corrugation can be used to evaluate the stopping capability of the micro-barrier and the way in which the avalanche transport structure can either strengthen or weaken the micro-barrier. In particular some aspects of Hamilonian dynamics are used to analyse the breaking of the zonal potential structure, with the opening of radially oriented isopotential lines. The superimposition of a streamer like structure for the avalanche and a zonal-like structure for the corrugation then provides a means to determine some aspects of the resulting confinement properties.

The impact on kinetics stems from both the gyro-averaging effect of potential maps for the transverse direction and the opening of micro trapping in the parallel direction due to electric potential wells (a $\rho_*^{1/2}$ effect).