§24. Spatiotemporal Chaos, Stochasticity and Transport in Toroidal Magnetic Configurations

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In order to get a more complete insight into the transport processes and zonal flow dynamics related to toroidal magnetic confinement systems we analyze nonlinear gyrokinetic Vlasov simulation (GKV) results for the tokamak and the standard and the inward shifted configurations of the helical system from the aspect of nonlinear dynamic systems theory. The basic formulae for describing the drift wave turbulence in magnetically - confined plasmas are given by the gyrokinetic equations, where time-evolution of the one-body distribution function is described as a nonlinear partial differential equation defined on the five-dimensional phase space. The nonlinear gyrokinetic ITG turbulence model of perturbed gyrocenter distribution function δf in the low-β (electro- static) limit, is numerically solved by the GKV code where toroidal flux tube coordinates *(x,y,z)* are employed. Toroidal and helical effects of the confinement field are introduced through variation of the magnetic field strength along the field line. A detailed account of the GKV code simulation model may be found in refs. 1-2. Magnetic configuration models relevant to the LHD experiments with the inward-shifted and standard (plasma configurations has been investigated in detail by the GKV code[1-2]. Furthermore, the spatiotemporal analysis has revealed that, while fluctuations of electrostatic potential of zonal flows are found in both helical configurations[3], the level of chaos in the inward shifted case was considerably lower, consistent with the observed transport reduction and improved confinement.

Spectral decomposition of the operator corresponding to the spatiotemporal dynamics which consists in expanding spatiotemporal function $\phi(x,t)$, into orthogonal eigen- functions in space and in time is performed, with a one to one correspondence between both sets of modes. In Figs 1 spatiotemporal (ST) profiles of the electrostatic potential of the zonal flow for the tokamak configuration is illustrated. We found the low dimensionality, approximately close to 3 for all three cases with evident and quantified spatio-temporal chaos [4]; each time series recorded at various spatial positions exhibits hyper chaos. A considerable reduction of spatiotemporal chaos is evident in the inward-shifted helical configuration in compared to standard one accompanied by generation of more energetic zonal flows. We found how insight into the interplay of parameters involved in two configurations may also open up new possibilities for efficient control of spatiotemporal chaos.

We also investigate the spatiotemporal chaos features with respect to increasing spatial extent and show that main quantifiers of the dynamics are extensive, i.e. they increase linearly with the system size. Further analysis is performed with the use of the independent component analysis (ICA) which can extract the statistically independent spatial and temporal events in the dynamics. Such an approach allows us to show the temporal evolution of zonal flows and GAMs independently from the residual flow, offering new insight into the formation and dynamics of coherent structures in the helical system and tokamak. The Lyapunov spectrum (LS) for $\phi(x,t)$ is estimated using pure spatial reconstruction with increasing spatial embedding dimension. The spectrum is then used to obtain the number of effective degrees of freedom given by the so called Lyapunov dimension $\boldsymbol{D}_L = j + 1/|\lambda_{j+1}| \sum_{i=1}^{j} \lambda_i$, where j is the largest integer for which $\sum_{i=1}^{j} > 0$. $\boldsymbol{D}_L$ is then shown to be directly connected to the transport properties of the configurations and in particular we show its relationship with the ion heat conductivity.

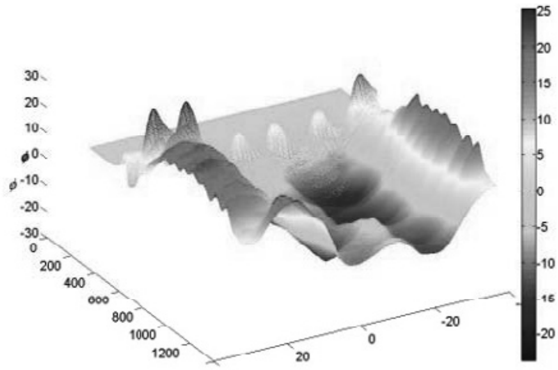

Fig. 1 ST profile of the electrostatic potential ϕ of the zonal flow in a tokamak configuration from GKV simulations.

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