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Intermittence and turbulence in fusion devices

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The intermittence parameter, C(1), is a quantity originating in chaos theory that allows measuring the degree of multifractality of fluctuating signals [1]. This parameter is related to the fractal dimension of the underlying dynamics and is of prime importance in the framework of our efforts to improve our understanding of turbulence. For reference, we note that in the past, the degree of intermittence has been studied using the 'flatness factor' (kurtosis), which is a quantifier of the shape of the probability distribution function of the fluctuating variable that does not take the actual time-varying properties of the variable into account; whereas C(1) does, explaining why the latter is a more powerful and precise quantifier of turbulent dissipation.

Recently, our group has shown how this parameter responds to dominant helicities linked to rational surfaces, revealing radial and poloidal structures of turbulence that have not been detected by other means. This technique also allows identifying the vortices generated by these helicities. It is known that such dominant helicities typically correspond to low order rational surfaces and that associated transport barriers may form, given the right circumstances. Furthermore, the parameter also responds to (zonal) flow.

In one set of experiments, we made use of Langmuir probe data in discharges during which the rotational transform was scanned dynamically in the TJ-II stellarator [2]. Up to five rational surfaces could be identified based on the intermittence of the floating potential, which is a first in plasma physics, to the best of our knowledge. The effect of the radial electric field on intermittence was also studied using a specific subset of experiments in which the electron density was raised on a shot by shot basis. The observations are contrasted with results from numerical calculations using a resistive magneto-hydrodynamic model to facilitate interpretation.

While the previous analysis was necessarily limited to the edge region, we obtained some tantalizing first data on intermittence in the core region using ECE data from the W7-X stellarator, that appear to confirm the response of the intermittence parameter to turbulent helicities in the plasma core [1].

In another set of experiments at TJ-II, the magnetic configuration was kept fixed while the plasma state was changed gradually from electron to ion root [3]. Analysis of the intermittence of the plasma potential measured by a Heavy Ion Beam Probe showed significant changes in the core region, while radial minima of the intermittence were found to be associated with the location of topological structures of the flow corresponding to some important low-order rational surfaces. The local pressure gradient was also estimated, and a clear correlation was found between the steepening of the pressure gradient and the deepening of the minima of the intermittence, suggesting that these minima are associated with pressure gradient driven modes. By estimating the rotation velocity of the plasma from the measured plasma potential, it was possible to make a rough reconstruction of the two-dimensional radial-poloidal map of intermittence, thus clarifying the topological structure of the intermittence.

Finally, in a set of repetitive experiments with electron to ion root transitions, the Langmuir probe position was varied on a shot to shot basis, allowing the reconstruction of a spatiotemporal map of the evolution of important turbulent quantities in the plasma edge region, such as the cross phase between transport-relevant variables, revealing the outward propagation of the changes associated with the transition [4]. Although the turbulence amplitude was found to increase, the intermittence showed that the turbulence condenses in a reduced number of dominant modes and becomes less bursty. The causal relationship between variables is studied using the Transfer Entropy, clarifying the interactions between the main variables and offering a rather complete picture of the complex evolution of the plasma across the confinement transition.

References

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