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How Structures Excite Turbulence and Flows in Edge Plasma

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A number of recent experimental results in L-mode on different fusion devices support the physical picture that blobs and voids are created in pairs from edge gradient relaxation events (GREs).[1,2] More specifically, each time the edge gradient collapses, it produces an inward-moving void and an outward-moving blob, as sketched in Figure 1. Therefore, in addition to waves and zonal flow generated locally, coherent structures are also important components of edge turbulence. These moving structures complicate turbulence models based on the local production. As outward-moving blobs can cross the LCFS and broaden the SOL, voids move inward towards the main plasma and affect the edge dynamics. Indeed, in the experiments on MAST, bursts of zonal flow power are clearly observed following the bursts of the power of density fluctuations. The latter occur at the time when density voids are detected.[3] This is strong evidence that coherent structures (voids) can drive zonal flow. Existing theories on coherent structures focus exclusively on the scalings of blob transport and blob stability (relevant to the SOL). The role of voids in edge plasma dynamics has not yet been addressed. Therefore, this work aims to propose a model elucidating how coherent structures are involved in edge turbulence dynamics.

As illustrated in Figure 2, just as a moving charge will radiate electromagnetic waves, a moving coherent structure, which can be viewed as a macro particle, will perturb the background plasma and induce a “wake”. Since the structure speed is comparable to the electron diamagnetic drift velocity, the drift wave is a reasonable candidate for the structure wake. Therefore, we start from the Hasegawa-Wakatani (HW) equation and construct our model on the basis of the classical drift wave-zonal flow paradigm. According to the distance from the structure, the space of concern could be divided into two regions: the near field region surrounding the structure and the far field region where the wake is located, as depicted in Figure 2. Since coherent structures cannot form with adiabatic electrons, we take the hydrodynamic limit in the near field region and the adiabatic limit in the far field region, respectively. The structure enters the equations for the far field via density profile modulation and can be treated as a source term in the Hasegawa-Mima (HM) equation. Resembling the idea of the dressed test particle model, the far field equation is solved in certain limits using the Green’s function of the linearized HM equation. The solution, i.e., the electrostatic potential φ, depends on multiple parameters, including the void magnitude, void extent, and the relative magnitude of the void speed to v_*. The resultant velocity field $\tilde{v}_x$ and $\tilde{v}_y$, Reynolds stress $\langle \tilde{v}_x \tilde{v}_y \rangle$ and Reynolds force $\langle \tilde{v}_x \tilde{v}_y \rangle'$ are also calculated. Notably, the Reynolds force is found to be non-trivial, indicating the generation of the zonal flow. The level of zonal flow generated by this mechanism is compared with that generated from ambient drift wave turbulence. This comparison gives an estimate of when the effect of structures on zonal flow generation becomes noticeable.

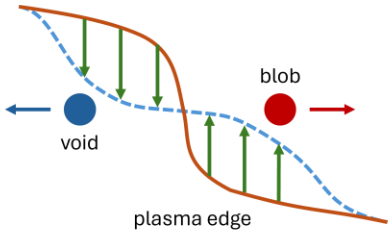

Figure 1. The illustration of the creation of a pair of blob and void via edge gradient relaxation events.

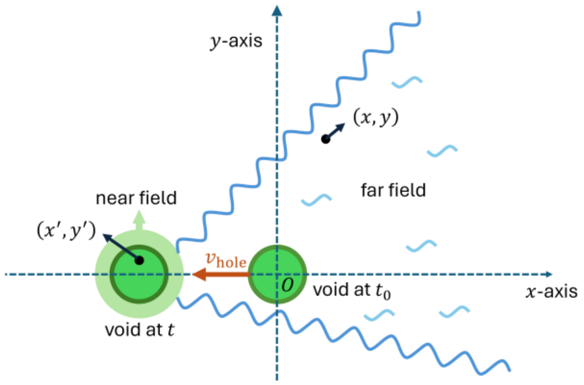

Figure 2. The wake of a density hole moving in the x direction. Note that the envelope of the wake is asymmetric about the x axis since drift wave has a preferred propagation direction.

Our model incorporates coherent structure into a predator-prey model for the first time. The turbulence excited by the moving voids can significantly enhance the turbulence level in the edge-core coupling region, as it may be comparable to or even exceed the local production. Additionally, the zonal flow driven by the structures can contribute to the regulation of edge plasma transport. The effect of the turbulence and zonal flow on the structures will be studied in future research on the self-consistent model.

References

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