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How secondary flow is selected in drift wave turbulence: Role of parallel flow shear

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Turbulence and transport is an important issue to understand the evolution of various systems, including astrophysical objects as well as laboratory plasmas. From extensive studies, there are mounting evidence that secondary flows, such as zonal flows[1] and/or streamers[2], play an important role in the nonlinear dynamics and the resultant transport. While zonal flows reduce transport, radially elongated streamers enhance transport. Then it is an important issue to clarify their selection rules, i.e. when and how one flow is preferred than the other.

In order to approach this problem, a model has been proposed based on modulational analysis[3]. Both cases of a coherent wave and the spectrum of modes are considered. In these models, large scale shear flows modulate the ambient turbulence, and the small scale turbulence in turn amplifies the large scale shear flows through Reynolds stress. However, in order to address the difference in the excitation of zonal flows and streamers, it is also important to account for the difference in the modulation of the field that provides free energy (e.g. the density for drift waves). Density modulation is in principle zero for zonal flows (or weak, up to finite Larmor radius correction), while it is finite for streamers. The field modulation in turn enters the intrinsic frequency modulation, very much like the frequency modulation of plasmons by the ion acoustic waves. Since this mechanism seems more effective for streamers, this effect can be a key for solicitating streamer excitation.

Once identifying relevant excitation mechanisms, it is also important issue to clarify how one can control the excitation and can select a preferred flow by experimentally relevant parameters. In this direction, a parallel flow (a flow along the magnetic fields) is an useful degree of freedom, as reported from toroidal as well as linear devices[4]. Parallel flows enter fluctuation dynamics by suppressing those driven by density gradients etc or by acting as a free energy by itself. The latter corresponds to the parallel velocity gradient driven turbulence. Since parallel flows enter fluctuation dynamics, it is natural to ask how they impact the nonlinear dynamics of fluctuation to drive large scale (perpendicular) flows.

In this work, we discuss our recent results related to the issues discussed above. Principle results are:

1) Density modulation by streamers enhances the modulational growth rate. This effect is complementary to the large scale flow shearing. Both modulates the wave numbers and results in the induced diffusion of the drift wave spectrum. The excitation by the density field modulation can be dominant.
2) The growth of streamer may be larger than that of zonal flows for small-medium size tokamak (rho*<1/200).
3) Streamer growth may not be quenched by the magnetic shear. Streamer cell with twisted slicing structure may arise.
4) Parallel flow shear can control the excitation of zonal flows and streamers[5]. This is shown for the case of coherent waves with the modulation analysis. The parallel flow modifies the dispersion of underlying drift waves. This in turn enters the response of the large scale flow, which is set by the group velocity of underlying fluctuations.
5) When the parallel flow shear exceeds the critical value, underlying turbulence changes from drift wave turbulence to the parallel velocity gradient (PVG) turbulence. Nonlinear evolution of convective cell in PVG turbulence is formulated and energy transfer into the large scale flows are calculated[6]. Our result indicates that zonal flows are preferred for the typical parameters for PVG turbulence.

References

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