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ドリフト波乱流における密度変調が駆動する径方向流れ
Radial flows driven by density modulation in drift wave turbulence

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Turbulence and transport is an important issue for the magnetic fusion community. While the primary role of turbulence in fusion plasmas is to induce anomalous transport, it also drives nonlinear, secondary flows. Well known example of these flows is a zonal flow[1], which plays the key role in regulating fluctuation, improving confinement, and locking in L-H transition. Another important flow is a streamer[2]. Unlike zonal flows, streamers are radially elongated, and deteriorate transport. Interestingly, both zonal flows and streamers can be viewed as an extreme limit of nonlinearly driven ExB convective cells, reported from early nonlinear turbulence simulations.

An important issue in nonlinear flow physics is to clarify when and how one flow is actually realized in the system. Put differently, the selection rule for nonlinear flows need to be formulated. For this direction, it is important to understand the generation mechanism of zonal flows and streamers. One approach is to exploit disparity of the scales, which allows us to formulated the problem by using adiabatic invariants. In this approach, the evolution of flows is analyzed by imposing a test shear in the bath of drift wave turbulence. The dynamics of drift waves can be formulated via the conservation of drift wave action, or the number density of drift wave quanta. Due to shearing, drift waves are modulated and their wave number increases. In order to conserve the action, which is effectively equal to the enstrophy of drift waves, drift wave energy must decrease. In turn, flows gain energy and excited. The growth rate of zonal flows and streamers is obtained in this way and their selection is discussed based on the difference of the nonlinear growth rate.

In this approach, shearing feedback is a key physical process for the excitation of flows. This mechanism is effective both for zonal flows and for streamers. However, since streamers have a finite poloidal number, they also modulate density field. This density modulation is weak for zonal flows, and we expect that this difference leaves a footprint on the difference in the growth mechanism as well.

The purpose of this work is then to discuss the impact of density modulation on the nonlinear growth of streamer flows[3]. The density modulation leads to the modulation of drift wave frequency, which in turn modulates the wave number of streamers. We show that both shearing and density modulation set necessary phase to induce finite Reynolds stress on flows. The growth rate of streamer flows is obtained, with the density modulation feedback included. Indeed, the feedback from the density modulation becomes more effective compared to shearing feedback, for typical parameters. Relevant feature of the growth through density modulation feedback is: i.) the growth rate is proportional to the first power of fluctuation amplitude, ii.) the growth accompanies nonlinear oscillation. The result indicates the streamers propagate in the ion diamagnetic direction, in the electron drift wave turbulence. iii.) the real frequency is proportional to the three halves of the poloidal mode number. This property may be useful to identify streamers in the fluctuation spectrum. Implication on confinement physics is also discussed in detail.

References

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