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Zonal profile corrugations and staircase formation in edge turbulence: role of the transport crossphase

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In magnetized fusion plasmas, self-generated flows known as zonal flows are an important saturation mechanism for turbulence. Recently, quasi-stationary structures called ExB staircases were observed in gyrokinetic simulations, affecting the ExB flow profile (zonal flows) but also the density and ion temperature profiles [Dif-Pradalier et al., Phys. Rev. Lett. 114, 085004 (2015)].

We present a novel analytical theory, backed by plasma fluid simulations, for the generation of density profile corrugations (staircase), independent of the action of zonal flows: Turbulent fluctuations self-organize to generate quasi-stationary radial modulations $\boldsymbol{\Delta}\theta_{\mathbf{k}}(\mathbf{r},\mathbf{t})$ of the transport crossphase $\theta_{\mathbf{k}}$ between density fluctuations $\tilde{\mathbf{n}}$ and potential fluctuations $\tilde{\phi}$. This results in turbulent particle flux modulations $\tilde{\boldsymbol{\Gamma}}(\mathbf{r},\mathbf{t})$.

The radial modulations of particle flux nonlinearly drive zonal corrugations of the density profile, i.e. zonal density $\mathbf{n}_{\mathrm{zon}}$, via a modulational instability. In turn, zonal density corrugations regulate the turbulence via nonlinear damping of the fluctuations.

The theory can help explain the generation mechanism of the 'staircase' structures. Here are the main findings: i) The present theory takes into account the convective ExB nonlinearity, and thus goes beyond the well-known 'i δ' quasi-linear approximation, ii) This nonlinear mechanism conserves energy between turbulence and zonal density. Since zonal density is a radial mode (m=0, n=0), with m,n the poloidal and toroidal mode numbers, it cannot drive transport and thus provides a benign reservoir of energy for the turbulence, and iii) In fluid simulations of the Hasegawa-Wakatani model, the radial modulation of the transport crossphase and associated staircase structure have been confirmed, partly stabilize the turbulence, and are present even with artificially suppressed zonal flows. In future studies, search for radial modulations of the transport crossphase in gyrokinetic simulations are planned for trapped-electron mode turbulence.

References

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