Large-Scale Sinks in Saturation Scalings of ITG Turbulence

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The zonal-flow-mediated saturation of ITG turbulence is now understood from careful analysis of nonlinear gyrokinetic simulations to be accomplished primarily by energy transfer to large-scale damped modes [Makwana et al., Phys. Rev. Lett. **112**, 095002 (2014)]. Zonal flows themselves absorb and dissipate very little of the energy, but rather facilitate large energy transfer from the instability to the damped modes. The rate is sensitive to the zonal flow level; the strength of coupling between instability, zonal flow, and damped modes; and the three-wave frequency mismatch between those constituents. In contrast, zonal flow shearing is a secondary effect. Saturation studies have not accounted for the large-scale sinks of damped modes or the key physics of the energy transfer, including the frequency mismatch.

To enable transparent analysis, we seek here to address those issues from the standpoint of a reduced fluid model previously shown to be quite realistic in its description of saturation. We perform a statistical closure of the basic equations to track the role of the frequency mismatch. We demonstrate that the dominant nonlinear energy transfer channel involves the coupling of the unstable mode, the zonal flow and the damped mode, enabled by a minimum value of the frequency mismatch. While damping of the zonal flow balances energy transfer into the zonal flow in the zonal flow evolution equation, the zonal flow excitation level drops out of the balance, forcing the turbulence level instead to scale with the zonal-flow damping rate. This well known scaling from gyrokinetics arises from energy transfer to the damped mode and is not the result of shearing being rendered less effective. The zonal flow level is set in the turbulence evolution equations by its role in controlling transfer to the damped mode and depends on the driving gradient and the collisionality.