Exploring geometry dependence of saturation in stellarator turbulence

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Minimizing energy and particle losses due to microturbulence remains a significant challenge facing magnetic confinement fusion energy. In this work, we examine the physics of turbulence saturation in stellarator plasmas. In particular, we analyze nonlinear energy transfer dynamics associated with coupling to stable modes at the same scale as the driving instability[1]. Three-wave coupling between an unstable and stable mode can efficiently dissipate energy and lead to a substantial nonlinear reduction in transport[2]. The identity of the mediating third mode can differ depending on magnetic geometry, with either zonal or non-zonal saturation being dominant in stellarators[3, 4]. A tantalizing prospect is whether the geometric flexibility of stellarators can be exploited to increase nonlinear energy transfer and provide a means for controlling turbulence through 3D shaping.

A numerical fluid model of Ion Temperature Gradient (ITG) driven turbulence has been implemented in general 3D geometry to examine nonlinear energy transfer to stable modes. Zonal-flow-mediated energy transfer is shown to dominate in quasi-axisymmetric geometry (QAS), while non-zonal modes mediate energy transfer for quasi-helically symmetric geometry (QHS), consistent with observations from gyrokinetics. Scans over different geometric quantities will be presented exploring the dependence of the zonal vs. non-zonal energy transfer channels on geometry. Configurations predicted to have lower transport due to larger nonlinear energy transfer to stable modes will be compared against nonlinear gyrokinetic simulation. Insight into geometric dependence of the two saturation channels provides valuable input for future stellarator optimization schemes focused on reducing turbulent transport.

This work is supported by U.S. DoE grants DE-FG02-99ER54546, DE-FG02-93ER54222, and DE-FG02-89ER53291.

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