Nonlinear Refractive Suppression of Turbulence and Transport by Strong Magnetic Shear

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Flow shear suppresses turbulence through both linear and nonlinear mechanisms.[1] In the former, shear flow has a stabilizing effect on linear instability. In the latter it speeds up turbulent decorrelation, reducing correlation lengths in the direction of the shear.[2] Magnetic shear is also associated with transport suppression, notably in internal transport barriers. The formation and location of internal transport barriers are quite sensitive to linear stabilization from reversed magnetic shear, hence magnetic shear effects are usually thought of as essentially linear. However, we show that under certain conditions magnetic shear suppresses turbulence via a nonlinear mechanism that is mathematically equivalent to the nonlinear mechanism of flow-shear suppression.

We have analyzed this effect in extended MHD using a reduced model for microscale magnetic turbulence. The fluctuations can be thought of as interacting, random kinetic Alfvén waves. Because the propagation velocity is proportional to magnetic field strength, strong magnetic shear refracts turbulent wave activity away from regions where propagation and spreading would otherwise carry it. The scale of refractive extinction is determined from the balance of the wave propagation term and the nonlinearity. It leads to a reduced turbulent scale in the shear direction with the inverse shear dependence of BDT theory.[2] However, flow shear plays no role because there is no flow. In decaying kinetic Alfvén wave turbulence this effect leads to the formation of current filaments that avoid being mixed and diffused by the turbulence, and therefore become long lived. We present analytic theory deriving the scaling relations, refracted fluctuation structure, and showing the degree of transport suppression. We also present simulation results that support the refraction hypothesis by showing that the long-lived current filaments satisfy the BDT shear suppression criterion, only with respect to magnetic shear and not flow shear. As a property of wave refraction, this effect should apply more generally to any situation in wave turbulence where there are strong gradients in quantities affecting wave propagation velocity but not instability.

[1]P.W. Terry, Rev. Mod. Phys. **72**, 109 (2000).

[2]H. Biglari, P.H. Diamond, and P.W. Terry, Phys. Fluids B **2**, 1 (1990).