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Turbulence driven by phase-mixed torsional Alfvén waves in nonuniform coronal loops

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High resolution observations have shown the ubiquity of Alfvénic waves in the solar atmosphere. Recently, torsional Alfvén waves in coronal flux tubes have been first detected. Here, we perform numerical simulations of torsional Alfvén waves and study their nonlinear evolution. We consider a cylindrical, radially inhomogeneous, and straight coronal magnetic flux tube that is line-tied at two rigid walls representing the solar photosphere. Standing torsional Alfvén waves are excited by perturbing the azimuthal component of the velocity. The nonlinear evolution of these waves is obtained with the PLUTO code, which solves the ideal MHD equations using a finite-volume formulation with adaptive mesh refinement. Initially, torsional Alfvén waves undergo the process of phase mixing owing to the transverse variation of density, generating small scales across the magnetic field direction. After only few periods of torsional waves, azimuthal shear flows trigger the Kelvin Helmholtz instability (KHi), and the flux tube is subsequently driven to a turbulent state. Turbulence is anisotropic and develops transversely only to the background magnetic field. After the onset of turbulence, the effective Reynolds number decreases in the flux tube much faster than in the initial linear stage governed by phase mixing alone. We conclude that the nonlinear evolution of torsional Alfvén waves, and the associated KHi, is a viable mechanism for the onset of turbulence in coronal loops. Turbulence can significantly speed up the generation of small scales previously initiated by phase mixing.

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