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Turbulent Dynamics in Gradual-Phase Flare Loops: Insights from 3D MHD Simulations

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The gradual phase is a relatively quiet stage in the evolution of a flare, encompassing most of its duration. During this phase, the hot and dense flare loops, formed by reconnection and chromospheric evaporation in the impulsive phase, gradually cool down and decrease in density. We propose and demonstrate with 3D simulation that the seemingly calm gradual-phase flare loops are filled with low-speed turbulent motions until the flare ends. The formation of these motions is related to the characteristics of the flare loops: high density. Due to the relatively small size of the flaring regions, the density variation length scale is much smaller than the atmospheric scale height at the corresponding temperature, involving the Lorentz force in maintaining the density gradient. The force balance between the Lorentz force and thermal pressure is unstable, leading to Rayleigh-Taylor type instabilities that grow on sub-minute timescales within the loops, resulting in sustained turbulent motions until the region returns to typical coronal density. Our research uncovers an energy conversion pathway in flares: chromospheric evaporation carries significant energy into the flare loops, part of which converts into transverse wave energy through instabilities, with these waves then transporting energy back to the lower atmosphere.

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