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FOURIER TRIAD PHASE DYNAMICS AND SINGULARITY EVOLUTION IN BURGERS TURBULENCE

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ABSTRACT

Over the past decade, numerous studies have explored the link between Fourier triad phase synchronization and shock wave collisions in physical space. Despite their success in explaining the relation between intermittent triad phase alignment with energy flux and shock interactions, none of these attempts directly addressed how Fourier phase analysis affects the merging of shocks and the emergence of stronger singularities. In this study, we try to investigate the statistical dynamics of triad phase events associated with shock collision singularities and their role in driving extreme events in physical space. Our research focuses on how intermittent triad phase behavior facilitates extreme event formation through the merging interactions of complex singularity poles. We perform numerical simulations using the forced Burgers equation with a Gaussian white-in-time forcing term. Our in-house C++ solver, optimized for parallel CPU processing, employs a Fourier-Galerkin method on a spatially periodic domain, while a third-order compact Runge-Kutta scheme handles time integration. To address the aliasing error, we applied a two-third de-aliasing technique. Fourier phase dynamics—and triad phase analysis in particular—are essential for understanding the spectral energy flux in nonlinear stochastic Burgers turbulence. Intermittent triad phase alignment leads to significant energy flux across scales, leading to shock collisions in physical space. We quantify this by analyzing mode phase evolution. Additionally, we employ complex Kuramoto order parameters as a quantitative measure to assess the coherence of triad phase synchronization over time. Our findings offer a novel perspective on nonlinear stochastic systems modeled by the forced Burgers equation. This demonstrates that Fourier triad phase dynamics governs shock collisions, leading to the merging and the formation of stronger singularities. Analyzing triad phase dynamics not only reveals singularity evolution mechanisms but also identifies locations where shocks emerge via phase synchronization. These findings enhance our understanding of the evolution of extreme events in stochastic nonlinear systems, particularly in the simulation of fluid flows, atmospheric phenomena, and astrophysical processes.