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Special self-similarity class of hydro mixing in high energy density plasmas: perspectives in supernovae and the inertial confinement fusion

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Rayleigh-Taylor (RT) and Richtmyer-Meshkov (RM) instabilities and RT/RM interfacial mixing govern a broad range of processes in high energy density plasmas, in nature and technology. Examples include the RT/RM instabilities quenching ignition in inertial confinement fusion, the blast wave induced RT/RM mixing in supernova remnants, and RT/RM dynamics influencing materials' processing in nanofabrication. [1-7]

In high energy density settings, at astrophysical and at atomic scales, RT/RM flows are driven by variable accelerations and strong shocks, have sharply and rapidly changing fields, and are anisotropic, non-uniform, and statistically unsteady. Their dynamics depart from canonical scenarios; yet, they can exhibit self-organization and order. [7-11]

We employ the group theory approach to analyze RT/RM dynamics with variable accelerations typical in high energy density plasmas. We directly link the conservation laws governing RT/RM dynamics to the symmetry-based momentum model, precisely derive the model parameters and yield rigorous analytical solutions in the scale-dependent and scale-invariant regimes. We discover the special self-similar class in RT/RM mixing with variable acceleration, and explore its symmetries, scaling laws, spectral shapes, correlations, fluctuations. We reveal that the self-similar dynamics can vary from super-ballistics to sub-diffusion depending on the acceleration and retain memory of deterministic (initial and experimental) conditions at any acceleration. [1,7-11]

The obtained results are consistent with the existing experiments and numerical simulations, and explain the long-standing puzzles observed in RT/RM experiments at high Reynolds numbers. [1,9,11]

To implement the theory frontiers, we propose and launch the experiments at high power laser facilities, including the Omega and the National Ignition Facility in the USA. Our experiments employ the already existing platforms and the accurately chosen experimental conditions for the laser beam and the target (including the accelerations increasing in time and decreasing in time, and both the coherent and random initial perturbations patterns) for acquiring the data in the extreme parameter regimes never earlier achieved. [3,4]

We reveal perspectives, unexplored before, for better understanding, and ultimately – controlling, self-similar interfacial mixing in high energy density plasmas, from supernova remnants to inertial confinement fusion. [1-11]

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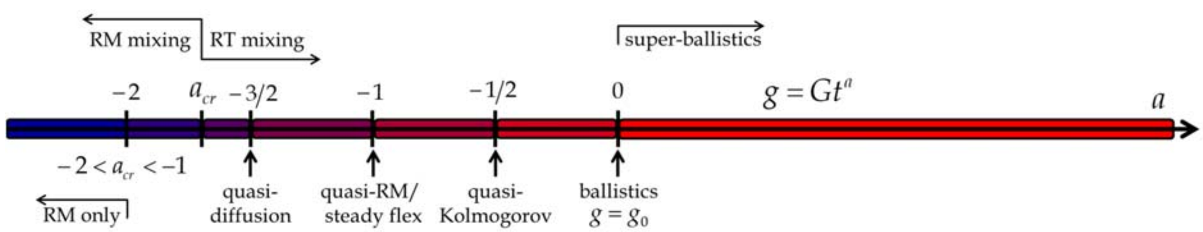

Figure 1. The dependence on the acceleration exponent in the self-similarity class in Rayleigh–Taylor/Richtmyer–Meshkov mixing with acceleration varying as a power-law in time. The special self-similar class contains point and interval subclasses, set by the acceleration's exponent. The point sub-classes are: the ballistics, quasi-Kolmogorov, quasi-Richtmyer–Meshkov, quasi-diffusion, Richtmyer–Meshkov mixing, Richtmyer-Meshkov only dynamics. [1,].