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Hydrodynamic initial conditions from non-linear causality

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Relativistic hydrodynamics has been successful in describing space-time evolution of matter created in high-energy nuclear collisions. It is conventionally supposed that the created matter starts to behave as fluids all at once at a certain initial time. It is, however, not at all trivial from which stage after the collision the fluid picture can be applied to the system. According to the hydrodynamization theory [1], any solutions of hydrodynamic equations converge to an attractor. Thus, hydrodynamic description might be justified anyway even starting from the system far away from local equilibrium. Do we really describe space-time evolution of the system using hydrodynamics even when the system is far away from local equilibrium? In this study, we address this issue from a point of view of causality.
A recent study shows necessary and sufficient conditions for the solutions to be causal in non-linear relativistic hydrodynamic equations [2]. When they are applied to numerical hydrodynamic simulations, it turns out that causality tends to be violated at the early time and/or in peripheral regions [3]. This indicates that violation of causality has something to do with how far the system is away from local equilibrium. Motivated by these observations, we scrutinize a one-dimensionally expanding conformal system from a view point of causality and constrain the initial conditions whose solutions by no means violate the causality. We first define the degree of non-equilibrium and then describe its time evolution solving the Muller-Israel-Stewart type constitutive equation in one-dimensionally expanding system. We find that it is acausal in fact when the system is far away from local equilibrium. Using these solutions, we quantify a range of the inverse Reynolds number in which hydrodynamic description is justified from a view point of causality. This sheds light on the understanding of initial stages in high-energy nuclear collisions.

References:
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Category

Theory

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