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Hydrodynamic theories for a system of classical weakly self-interacting ultra-relativistic scalar particles

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Relativistic hydrodynamics has been widely employed in high energy nuclear physics, with applications in heavy-ion collisions, neutron star mergers and coalescing matter in black holes [1]. Due to the acausality and instability of relativistic Navier-Stokes (NS) theory [2], one usually employs Israel-Stewart-like (IS) formulations of fluid dynamics [3] in which the constitutive relations for the dissipative currents are replaced by relaxation type equations. This comes at the expense of a more complex structure of the partial differential equations being solved, which renders the assessment of features of solutions in the non-linear regime very intricate. More recently, the Bemfica-Disconzi-Noronha-Kovtun (BDNK) theory has emerged [4], where theorems for causality, linear stability and existence of solutions can be rigorously established, but unconventional matching conditions are required. For all of the aforementioned theories, transport coefficients play a fundamental role. However, their computation is usually a very non-trivial task, even in the context of Kinetic Theory. We show that this difficulty can be circumvented for a system composed of classical ultra-relativistic scalar particles weakly interacting via a quartic potential. Then, the specific form of the cross-section [5] allows for the computation of transport coefficients without approximations beyond the power-counting scheme of the corresponding hydrodynamic theory. In this contribution, we calculate all transport coefficients of NS, BDNK and IS theories and demonstrate, in a Bjorken flow scenario, that NS and BDNK theories are pathological for large gradients and thus cannot be used to describe the early stages of heavy ion collisions. For BDNK and IS theories, attractor solutions are also analyzed.

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