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Relativistic fluid dynamics from the Boltzmann equation: going beyond the 14-moment approximation

We present a general derivation of relativistic fluid dynamics from the Boltzmann equation using the method of moments. In the 14-moment approximation [1,2], traditionally employed in the fluid-dynamical modeling of heavy-ion collisions, fluid dynamics is obtained by explicitly truncating the moment expansion of the single-particle distribution function. In contrast, in our approach all terms of the moment expansion are included and the exact equations of motion for these moments are derived. These exact equations still contain the degrees of freedom and microscopic time scales of the Boltzmann equation.

We prove that in order to derive causal fluid-dynamical equations it is necessary to resolve at least the slowest microscopic time scales of the Boltzmann equation, in agreement with [3]. The truncation of the equations of motion in terms of only 14 dynamical variables is then implemented by a systematic power-counting scheme in Knudsen and Reynolds numbers, instead of the explicit truncation of the moment series, as in Israel-Stewart theory. The resulting fluid-dynamical equations and coefficients are different from the ones
obtained via the 14-moment approximation and are in much better agreement with kinetic theory. This means that the fluid-dynamical description of heavy-ion collisions based on the 14-moment approximation is incomplete.

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Primary author: DENICOL, Gabriel (Institut fur Theoretische Physik, Goethe University, 60438 Frankfurt am Main, GermanyFrankfurt University)

Co-authors: Prof. RISCHKE, Dirk (Institut fur Theoretische Physik, Goethe University, and Frankfurt Institute for Advanced Studies (FIAS), 60438 Frankfurt am Main, Germany); Dr MOLNAR, Etele (MTA-KFKI, Research Institute of Particle and Nuclear Physics, H-1525 Budapest, P.O.Box 49, Hungary); Dr NIEMI, Harri (Frankfurt Institute for Advanced Studies (FIAS))

Presenter: DENICOL, Gabriel (Institut fur Theoretische Physik, Goethe University, 60438 Frankfurt am Main, GermanyFrankfurt University)

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