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The hydrodynamic expansion through regularized moments

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Relativistic hydrodynamics is surprisingly predictive, even in the presence of large gradients and large deviations from equilibrium. In some of its incarnations, the method of moments can be used to justify the hydrodynamic behavior of a relativistic gas. However, it can't be directly generalized. If long range interactions are introduced through a medium-dependent mass or a semi-classical gauge field, some diverging integrals would appear at the higher orders after a naive, direct, application of the method [1]. Even if it is not necessary at the lowest orders, it has been shown that it is convenient to reorganize the expansion around resummed moments. In this way one avoids systematically, at all orders, any coupling with ill-defined moments [1].
If one uses the quantum precursor of the distribution function, that is the Wigner distribution, such ill-defined moments arise at the very first step, therefore a regularization scheme is needed from the very the lowest order (hydrodynamics). Even in a physical case that is arbitrarily close to the kinetic limit, some of the moments, which are otherwise well defined in kinetic theory, are divergent due to the off-shell nature of the Wigner distribution. However, in this case too, it is possible to introduce a set of regularized moments [2]. They are well defined at all orders, and they can be used to generalize the method of moments (and the hydrodynamic expansion) in the quantum case. In the kinetic limit they reproduce the ordinary expansion from the method of moments. More importantly, they can be used to estimate whether hydrodynamics is expected to work or to fail in the cases in which the naive generalization of the method is ill-defined and gives no answers. Finally, it can be checked in the exactly solvable (0+1)-dimensional expansion, that the approximate solutions from the regularized hydrodynamic expansion maintain the fast convergence to the exact solutions (already seen in relativistic kinetic theory) even for initial conditions which are very far from the kinetic limit [2].

[1]arXiv:1808.06436
[2]arXiv:2003.09268

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