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Going Relativistic with Lattice Boltzmann Methods

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The study of relativistic fluids apply to several fields of modern physics,
covering many different scales, from astrophysics, to atomic scales (e.g. in the study of effective 2D systems such as graphene) and further down to subnuclear scales (e.g. quark-gluon plasmas).

In particular, the experimental results from heavy-ion collisions at RHIC and LHC, with the first experimental observation of the quark-gluon plasma, have significantly boosted in recent years the interest in the study of relativistic fluid dynamics, both at the level of theoretical formulations as well as in the development of reliable numerical simulation methods.

For a long time, relativistic fluid dynamics has been hampered by several theoretical and computational shortcomings, as relativistic versions of the viscous Navier-Stokes equations suffer from causality problems linked to the order of the derivatives appearing in the dissipative terms. Some of these problems can be avoided by employing a lattice kinetic approach, that treats space and time on the same footing (i.e., via first-order derivatives).

This is one of the main reasons why Relativistic Lattice Boltzmann Methods (RLBMs), that discretize in coordinate and momentum space the Boltzmann equation and yet ensure that the resulting synthetic dynamics retains all its hydrodynamic properties, have been recently proposed as effective computational tools to study relativistic flows.

Several different RLBMs have been proposed in the last decade, initially limited to the study of ultra-relativistic regimes (in which the ratio $\zeta = \frac{mc^2}{k_B T}$ goes to zero; m is the mass of the particles in the fluid, T is temperature and k_B is Boltzmann constant) and more recently extended to cover a wider range of physics parameters, going from ultra-relativistic to mildly relativistic and eventually to the non-relativistic limit ($\zeta \to \infty$).

This talk presents an overview of the formal details needed to develop RLBMs and
the available options to derive effective and robust computational tools; special focus will be posed on the definition of transport coefficients, since the correct link of the kinetic level with the macroscopic one has been debated for a long time in the literature.
Finally, we present numerical results of standard benchmarks for the validation of the method in which we compare with other approaches, as well as a few examples of applications.

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