Microscopic Theory Inputs for Transport Simulations

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The experimental extraction of the nuclear equation of state and isospin asymmetry energy at sub- and supra-saturation densities from heavy-ion collisions relies on transport simulations that take as input nuclear mean fields and in-medium scattering cross sections. New microscopic methods such as chiral effective field theory (EFT) can offer improved constraints on these inputs with more reliable uncertainty estimates, but to date most of the effort has focused on the determination of the bulk nuclear and neutron matter equations of state, which themselves are not directly used in transport simulations but are instead derived from the input mean field potential. Below we summarize the research directions within the microscopic effective interaction community that would have the largest impact on bridging state of the art nuclear theory developments with modern heavy-ion collision transport simulations.

In general it may be too difficult for microscopic models to fit the C.M. energy and differential angular dependence of nucleon-nucleon scattering cross sections across the range of local densities, isospin asymmetries, and temperatures encountered in transport simulations. One proposal is to calculate instead the shear viscosity from chiral EFT in order to constrain in-medium nucleon-nucleon cross sections used in transport simulations.

Transport calculations demand reliable in-medium properties of Delta resonances and pions. For example, the in-medium mass distribution of Delta resonances and the in-medium pion s-wave and p-wave interactions at a given local density, isospin asymmetry, and temperature would be helpful. This provides a further incentive to develop a more reliable chiral EFT description of dynamical Delta degrees of freedom, which are currently integrated out in the low-energy theory of interacting nucleons and pions.

Energy density functionals for transport calculations depend on the local (out of equilibrium) phase-space distribution, while in the limit of infinite nuclear matter the finite-temperature self-energy can be calculated from the energy density functional by taking the phase-space distribution as the Fermi-Dirac distribution. Microscopic calculations of the finite-temperature self-energy would therefore provide a valuable point of comparison.

Short-range correlations and high-momentum components of the distribution function computed from microscopic many-body theory may be important for transport observables, but this would require improved off-shell simulations in order to include these effects consistently in the transport model calculation.

One may constrain nonrelativistic and relativistic energy density functionals on the market to better reproduce the low-energy mean-field potential from chiral EFT. For non-relativistic transport, a Yukawa-type momentum-dependent mean-field potential (see, e.g., Phys. Rev. C 91, 014611 (2016)) may be suitable. Generally, the parameters for the effective interactions are fitted at saturation density and zero temperature. It will be interesting to see whether the extension to higher densities and finite temperatures agrees with predictions from chiral EFT.

The nuclear equations of state including the presence of light clusters at low densities is particularly important for understanding the composition and properties of the supernova neutrinosphere and should be more vigorously pursued within the microscopic interaction community.