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High-order discontinuous Galerkin nonlocal transport and energy equations scheme for radiation hydrodynamics

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SUMMARY

The nonlocal theory of the radiative energy transport in laser-heated plasmas of arbitrary ratio of the characteristic inhomogeneity scale length to the photon mean free paths is applied to define the closure relations of a hydrodynamic system. The corresponding transport phenomena cannot be described accurately using the Chapman–Enskog approach, that is, with the usual fluid approach dealing only with local values and derivatives. Thus, we directly solve the photon transport equation allowing one to take into account the effect of long-range photon transport. The proposed approach is based on the Bhatnagar–Gross–Krook collision operator using the photon mean free path as a unique parameter. Such an approach delivers a calculation efficiency and an inherent coupling of radiation to the fluid plasma parameters in an implicit way and directly incorporates nonequilibrium physics present under the condition of intense laser energy deposition due to inverse bremsstrahlung. In combination with a higher order discontinuous Galerkin scheme of the transport equation, the solution obeys both limiting cases, that is, the local diffusion asymptotic usually present in radiation hydrodynamics models and the collisionless transport asymptotic of free-streaming photons. In other words, we can analyze the radiation transport closure for radiation hydrodynamics and how it behaves when deviating from the conditions of validity of Chapman–Enskog method, which is demonstrated in the case of exact steady transport and approximate multigroup diffusion numerical tests. As an application, we present simulation results of intense laser-target interaction, where the radiative energy transport is controlled by the mean free path of photons.

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KEY WORDS: radiation hydrodynamics; nonlocal transport; Knudsen number; multigroup diffusion; radiation coupling; high-order finite element method.

1. INTRODUCTION

Mankind has always relied on the necessity of sufficient energy resources. Inertial confinement fusion (ICF) is a major branch of nuclear fusion research and a possible answer to the still growing demand for energy. Almost all ICF devices to date use lasers to compress and heat fuel, which under the conditions known as Lawson criterion, would achieve self ignition. Understanding of the plasma creation process and plasma behavior then becomes attractive.

The problem of energy transport is one of the key problems needing to be resolved for successful implementation of ICF. Because most of the absorbed energy of the incident laser radiation deposition takes place near the critical density, the impact on the core region is performed by the hydrodynamic motion and by the energy transport, naturally nonlocal.

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