Computational Physics and Methods

LD IMC Radiative Transfer

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Implicit Monte Carlo (IMC) is a popular method for solving the thermal radiative transfer equations. For problems that have sufficiently small time steps and optically thick spatial cells, the standard IMC method can suffer from "teleportation error". This error is a result of standard IMC not capturing the equilibrium diffusion limit. Many "source tilting" (or source reconstruction) methods do not fully remove the teleportation error, but merely mitigate it. We have developed a modified IMC technique, called LD IMC, that retains the correct equilibrium diffusion limit.

Background and Motivation

For Marshak waves or similar problems, there are known analytic and semi-analytic solutions of the equilibrium diffusion equation:

$$C_v \frac{\partial T}{\partial t} + \frac{1}{c}\frac{\partial \phi}{\partial t} - \nabla \cdot \left(\frac{1}{3\sigma} \nabla \phi \right) = 0 \ , \qquad (0.1)$$

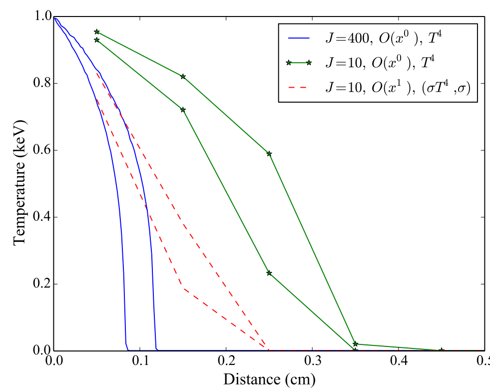
where C_v is the heat capacity and constant volume (per volume), t is time, c is the speed of light, ∇ is the spatial gradient operator, σ is the absorption opacity, T is the material temperature, a is the radiation constant, and $\phi = acT^4$ is the equilibrium radiation energy density.

In the optically thick limit, the IMC method seeks to solve Eq. (0.1), indirectly, by solving the thermal radiative transfer equations directly. The thermal radiative transfer equations can be shown to reduce to Eq. (0.1) in the limit of large σ. Standard IMC implementations with linear discontinuous reconstructed sources do not necessarily produce valid numerical solutions to Eq. (0.1) in the limit of large σ.

Following SIMC research, we have introduced discontinuous linear finite elements to solve the material energy equation (which happens to have no spatial derivatives for static material). The continuous nature of the MC particle transport is unchanged.

Impact

- LD IMC removes the lower bound on time step sizes that plague standard IMC simulations.
- The discontinuous finite elements are entirely cell-local; hence domain decomposed transport is not more complicated.
- The method has been shown to be compatible with diffusion acceleration as well as cell-centered hydrodynamic methods.
- The run times of LD IMC are within a factor of 2 of standard IMC in both 2D and 3D Cartesian geometries.



LD (red dashed) and standard (green) IMC plotted with a resolved solution (blue). LD IMC has mitigated teleportation error.

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References

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