TEXAS A&M ENGINEERING

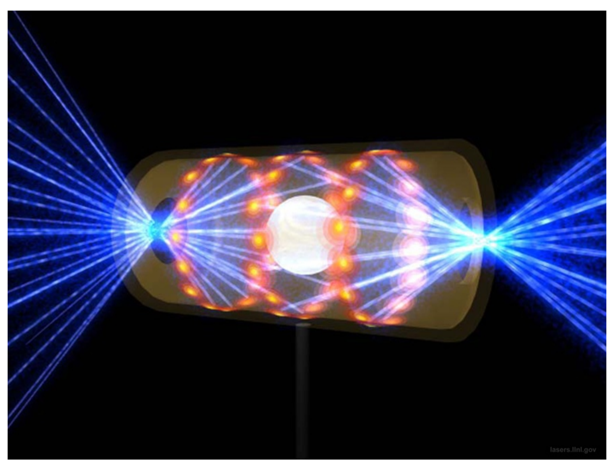
Semi-Analytic Radiative Shocks via Multigroup S_N Transport

A. Miguel Holgado, Jim M. Ferguson, Ryan G. McClarren
Department of Nuclear Engineering, Texas A&M University, College Station, TX, USA 77843

CERT Center for Exascale Radiation Transport

Motivation

- Obtaining radiative shock solutions supplements current efforts in
  - Astrophysical observations
  - Designing high-energy-density physics experiments
- The improvement of physical models aids in our understanding and potentially yields **new physics**.
  - Equilibrium Diffusion → continuity of radiative shocks.
  - Nonequilibrium Diffusion → existence of the Zel'dovich spike.
  - Radiation Transport → anti-diffusion.
- Code verification
  - Ensure that RHD codes do not suffer from significant **numerical error**
  - Verify simulations of NIF, Z, OMEGA, etc.



Physics Regime: Radiation Hydrodynamics (RHD)

We consider a regime of RHD governed by

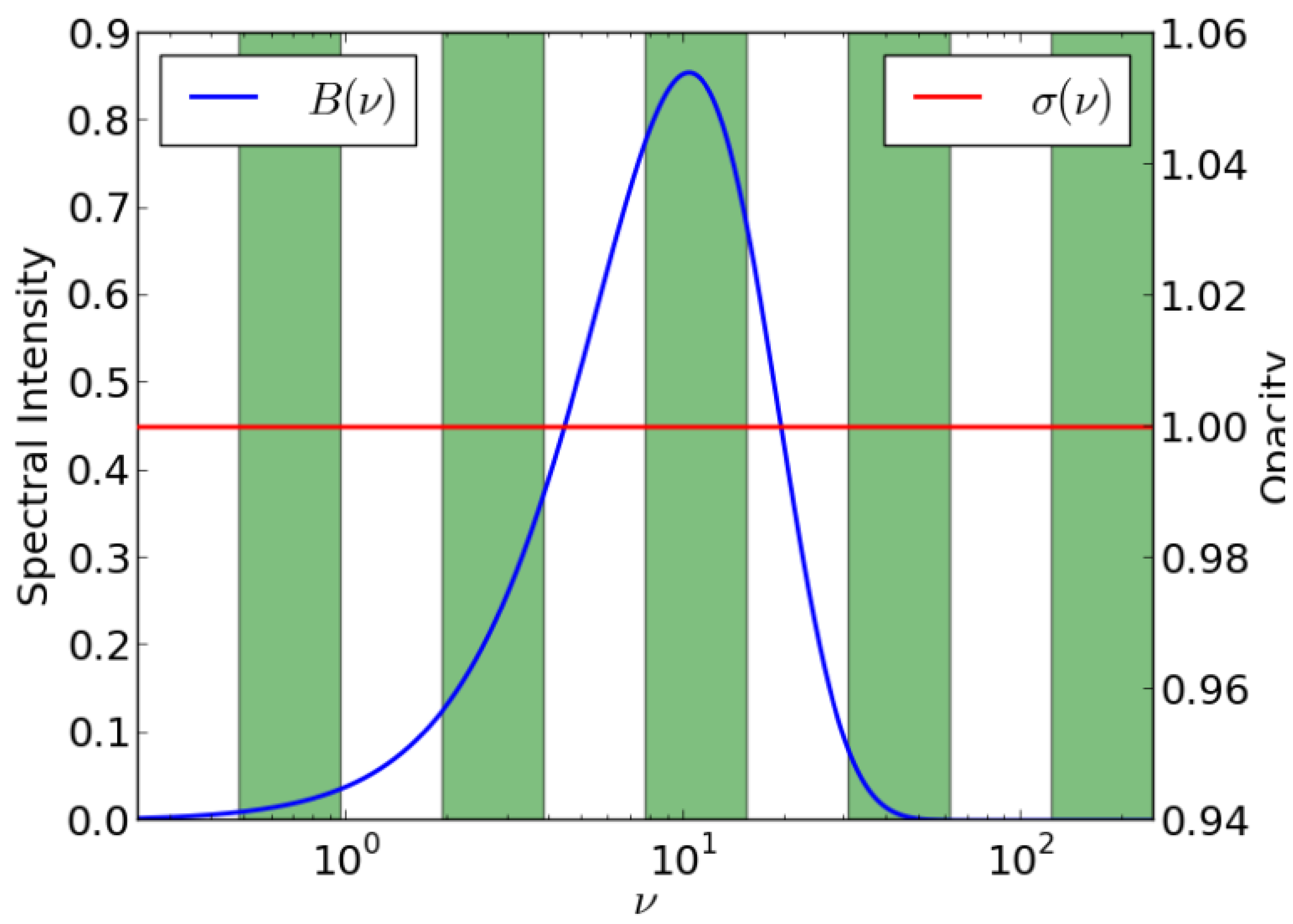
- High-energy density:
  - Material temperatures ~ 1 keV $= 11.6 \times 10^6$ K (ionizing)
  - Radiation **pressure** affects hydrodynamics
- **Inviscid** hydrodynamics (Euler equations; non-relativistic)
- Thermal **radiation** (x-ray) **transport**, which is affected by material dependence on photon frequency, ν.

Physical Model

- All quantities are nondimensionalized.
- Eulerian hydrodynamics coupled to full $\mathcal{O}(u/c)$ frequency-dependent radiation transport:
  - Eulerian hydrodynamics produces shockwave solutions.
  - An ideal-gas γ-law is used for the equation-of-state.
  - Radiation is due to thermal emission of the material and the Planck function is used to describe such emission.
  - A **multigroup** model characterizes the effects of frequency dependence on shock structure.
  - A variable Eddington factor (VEF) is used to close the radiation variables.
  - Material opacities, σ, are assumed to be frequency-independent.

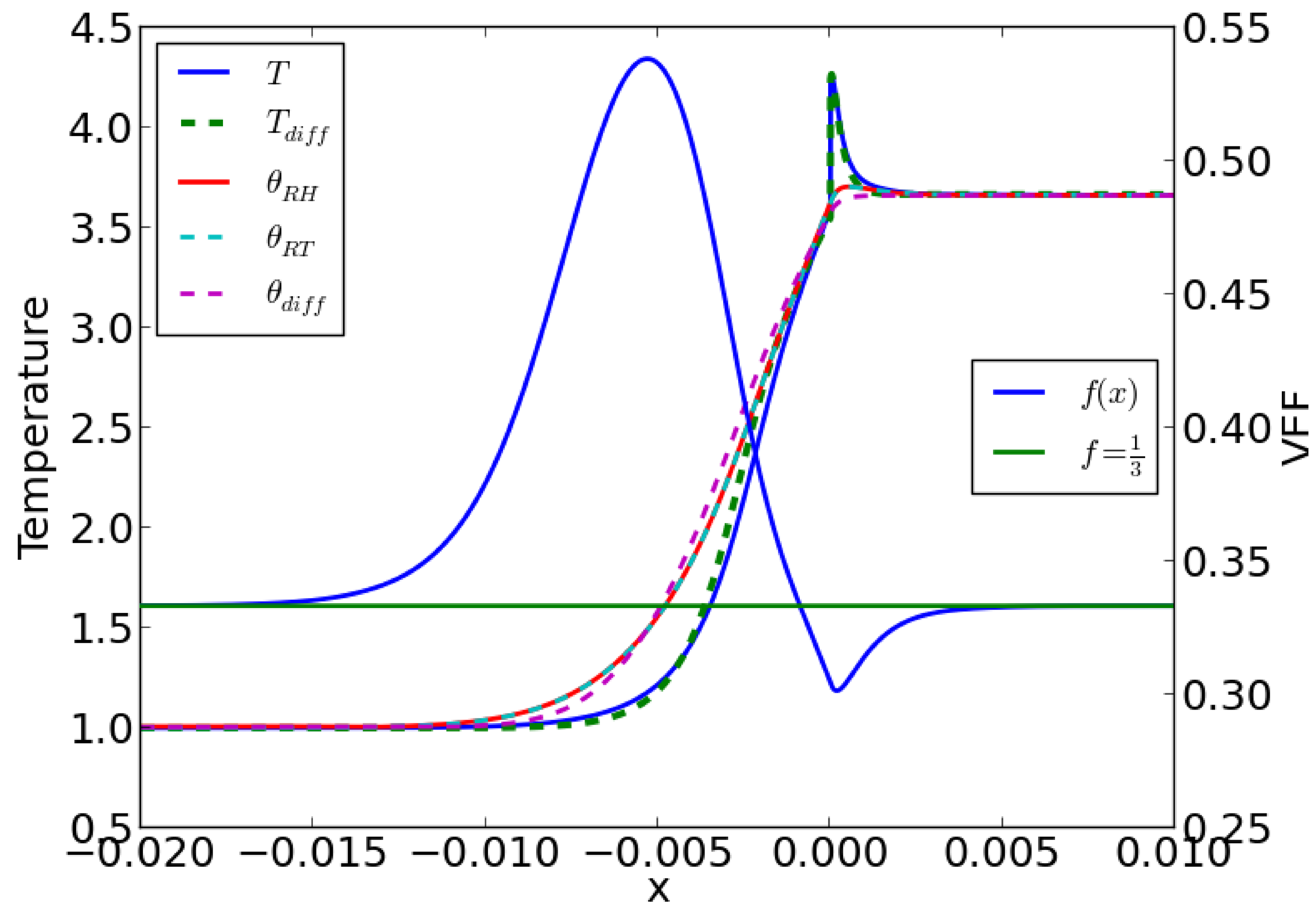
Multigroup

The Planck function, $B(\nu)$, describes how black-bodies emit radiation as a function of ν.



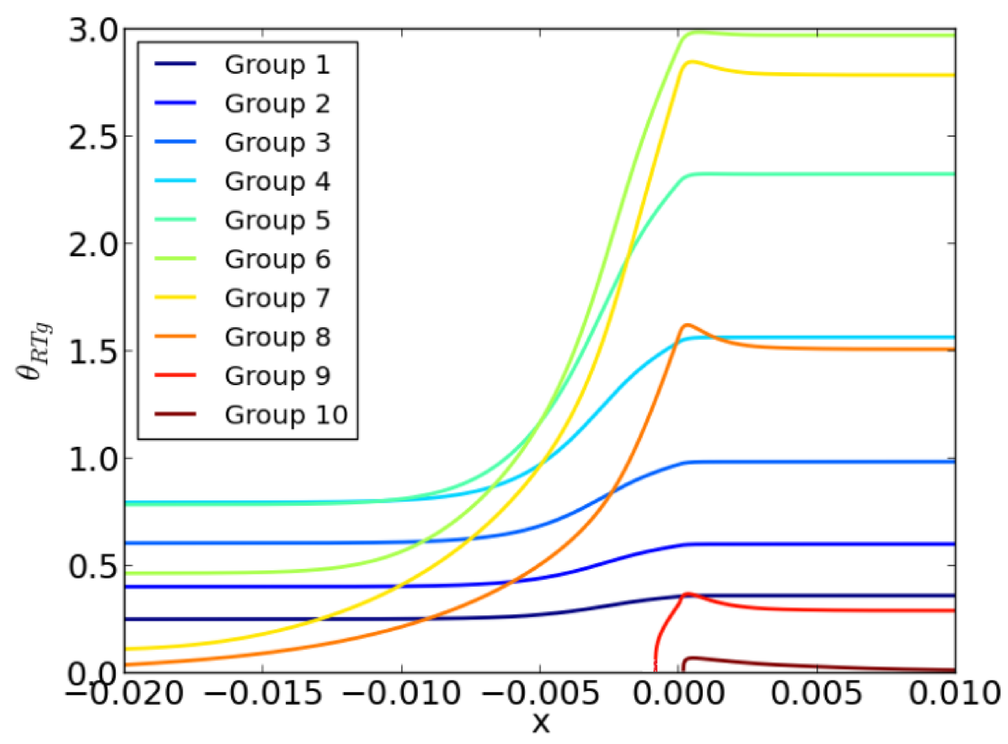
The Planck function and the material opacity, $\sigma(\nu)$, are plotted above. Multigroup is applied to the frequency domain and the plot indicates that the groups in which the Planck function is larger will more strongly contribute to the radiation temperature.

Temperature Shock Profiles for Grey-S_N Transport



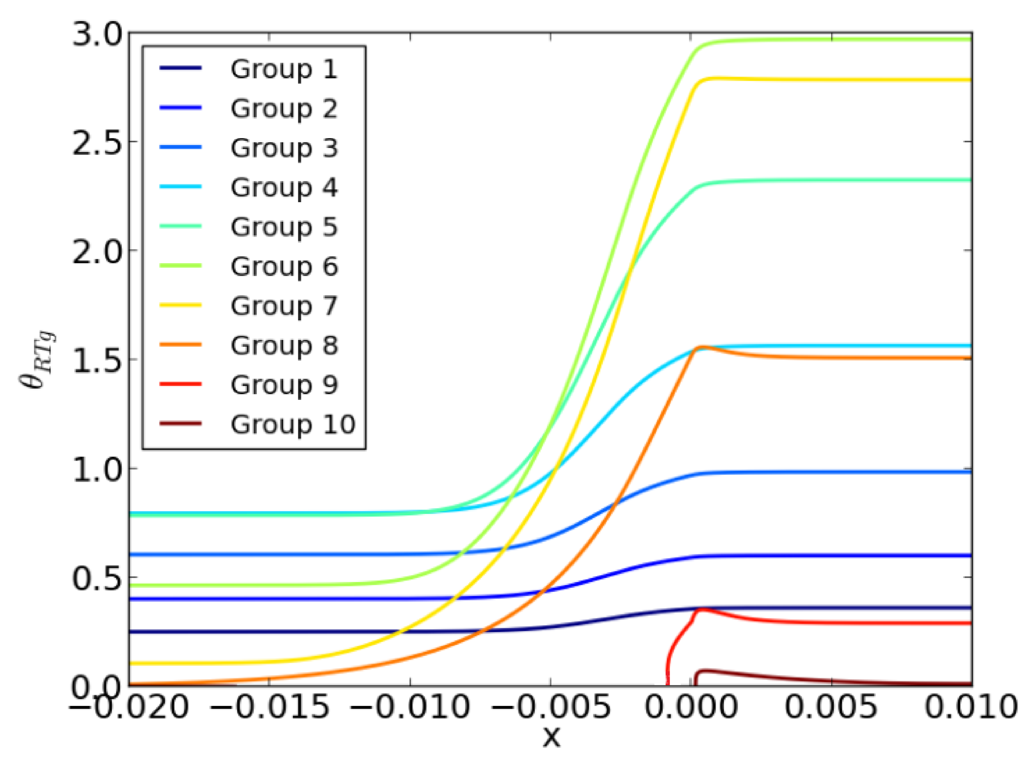
A radiative shock temperature profile for $\mathcal{M}_0 = 3$ is plotted above where $x = 0$ is the location of the shock interface. The radiation temperature exhibits anti-diffusion, which is represented by the small peak in the cooling layer. In the diffusion case, which is represented by the purple-dashed line, the radiation temperature monotonically increases over the shock domain. The VEF shows where the transmissive region and cooling layer exist.

Group Radiation Temperatures for S_4



The radiation temperature is discretized into 10 groups. The lower group radiation temperatures increase monotonically, while for groups 7 and higher, the group radiation temperatures exhibit anti-diffusive-like behavior.

Group Radiation Temperatures for S_2



We now implement S_2, which is equivalent to diffusion. This, in effect, removes the angular dependence of the radiation field. Anti-diffusive-like behavior begins to become apparent for group 8 when using S_2 (diffusion), as opposed to group 7 for S_4. The peaks are not as sharp as those for S_4. This implies that anti-diffusive-like behavior may occur due to frequency dependence and not just due to angular dependence, as previously thought.

Conclusions

- Frequency-dependent analytic opacities will be implemented in our multigroup S_N transport model in order to determine what effect frequency-dependent opacities have on radiative shock structures.
- Shock profiles for various Mach numbers and orders of S_N will also be further investigate to establish bounds for where anti-diffusive-like behavior can occur.