A Numerical Scheme for Special Relativistic Radiation Magnetohydrodynamics Based on Solving Time-dependent Radiative Transfer Equation

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Radiation transport (including the interaction between the matter and the radiation) and magnetic fields play important roles in a number of astrophysical phenomena. Although some of approximate methods (Flux-limited diffusion approximation [1], M1-closure method [2], and the Eddington approximation) are employed in order to numerically solve the radiation fields, the accurate radiation fields are not always obtained by such methods. Recently, a new algorithm were proposed for the radiation magnetohydrodynamics (RMHD), in which the time-dependent radiation transfer equation is solved and the radiation energy density, flux, and stress tensor are calculated by angular quadrature of the specific intensity [3]. However, their numerical code is accurate to $\mathcal{O}(v/c)$, and total energy as well as momentum of the radiation magnetofluids is not necessarily conserved. We develop a numerical scheme for solving the equations of fully special relativistic RMHD, in which the conservation of total mass, momentum, and energy of the radiation magnetofluids is guaranteed.

We propose a new method for RMHD, in which we solve the fully special relativistic RMHD equations [4]. By solving the time-dependent radiation transfer equation, the energy density, the flux, stress tensor for the radiation, are computed by angular integrating of the specific intensity. Ad hoc closure relation as used in FLD approximation, M-1 closure method, and the Eddington approximation is not required. The advection terms are explicitly solved, and the source terms, which describe the gas-radiation interaction, are implicitly integrated. In Figure 1, we show the results of the relativistic shock tube problem, the gas density (ρ), the gas pressure (p_g), the four velocity (u^z), the radiation energy density ($E_{\rm rad}$), the radiation flux ($F^z_{\rm rad}$), zz-component of the Eddington tensor ($\tilde{D}^{zz}_{\rm rad}$). The red lines indicate our results, and the results by the Eddington approximation and M1-closure method are plotted by blue and orange lines. The dotted lines in the panels of $E_{\rm rad}$, $F^z_{\rm rad}$, and $\tilde{D}^{zz}_{\rm rad}$ represent the reference solutions. We find that our results nicely agree with the reference solutions. Our code shows reasonable results in some numerical tests for propagating radiation and radiation hydrodynamics.

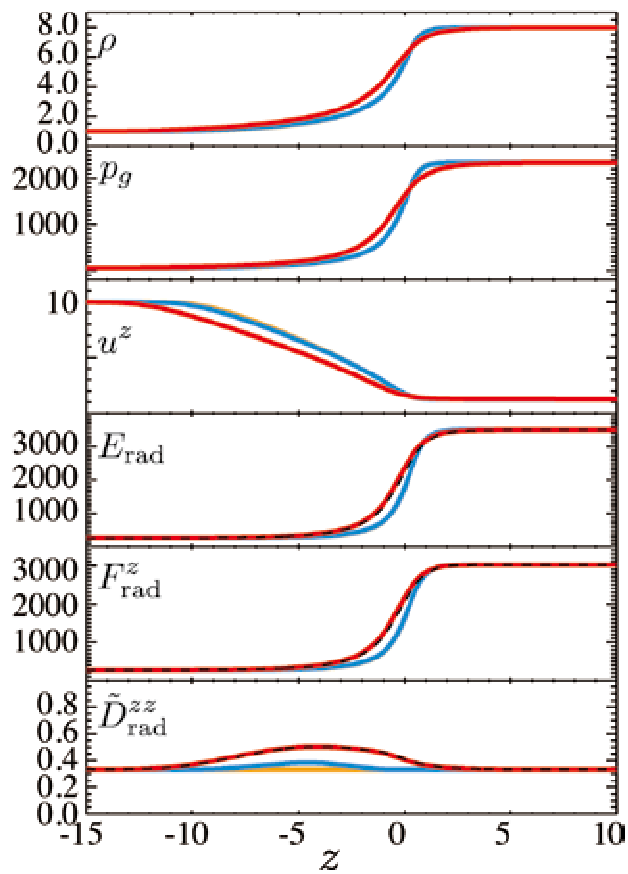

Figure 1: One-dimensional plots of the density, gas pressure, four velocity, radiation energy density, radiation flux, and zz-component of the Eddington tensor for the non-relativistic strong shock.

References

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