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Development of a general relativistic radiation magnetohydrodynamical code based on solving Boltzmann equation

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Elongated, narrow structures called astrophysical jets are observed in active galaxies, galactic microquasars, star-forming regions, and so on. Astrophysical jets are formed around compact objects like a black hole. Ohsuga et al. (2009) first performed multi-dimensional radiation hydrodynamic simulations of an accretion flow around the black hole. They revealed that the radiation is important for simulating the jet formation and structures of an accretion disk exactly. The general relativistic effects should be considered since the jet formation and disk accretion are phenomena nearby the black hole. Sadowski et al. (2014) and Takahashi et al. (2016) are take account of the general relativistic effects by performing general relativistic radiation magnetohydrodynamical (GR-RMHD) simulations. They show that the magnetic field collimates the jet. We need to perform GR-RMHD simulations of the accretion flow since all of the radiation, magnetic fields, general relativistic effects are important for simulating the jet formation and the accretion disk.

Previous studies adopted an approximation method to solve the radiative transfer, for example, the Flux limited diffusion (FLD) approximation or the first moment (M1) method. These methods cannot solve the radiative transfer exactly. Especially in the optically thin region, there are problems like non-physical interaction between radiations. Figure 1 shows the radiation energy density profile for propagation of two beams of photons achieved by using M1 method. Non-physical collision between two beams occurs in the center region and beams are destroyed by collision.

In order to solve the radiative transfer more exactly, we develop a GR-RMHD code based on solving Boltzmann equation. We solve a conservative form of Boltzmann equation in general relativity (Shibata et al. 2014). When we solve the radiative transfer, we need to determine the radiation pressure. For M1 method, the radiation pressure is estimated from radiation energy density and radiation energy flux by using some assumptions. On the other hand, for our method, we can determine the radiation pressure from the intensity without any assumptions since we have the intensity of each direction by solving Boltzmann equation. Figure 2 shows the result of beam crossing for our method. Two beams can transmit each other without non-physical collision which occurs for M1 method. In addition, we will also report results of other test simulations of the interaction of the radiation with optically thick cloud for absorption or scattering, propagation of the radiation around Kerr black hole, shock tube problems, and so on.

References

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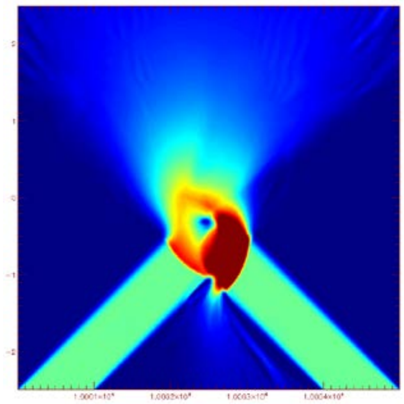

Figure 1 Radiation energy density profile for propagation of two beams of photons by using M1 method. Non-physical collision occurs at the center.

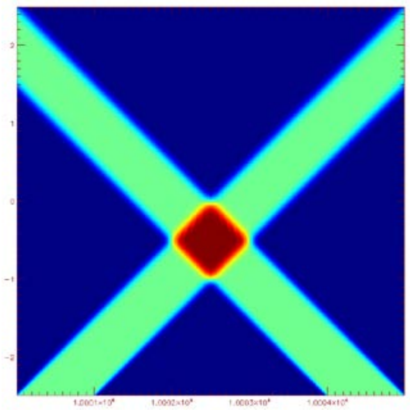

Figure 2 Radiation energy density profile for beam crossing by using our method. The radiation can transmit without non-physical collision.