Numerical Treatment of Anisotropic Radiation Field Coupling with the Relativistic Resistive Magnetofluids

TAKAHASHI, Hiroyuki, OHSUGA, Ken
(NAOJ)

Radiation and/or magnetic fields, relativity, and resistivity play crucial roles in a number of high-energy astrophysical phenomena, such as black-hole accretion-disks, jets, disk winds, pulsar winds, magnetar flares, core collapse supernovae, and gamma-ray bursts. For example, the magnetic field connecting to the accretion disks around the black hole induces the magnetohydrodynamic (MHD) turbulence by the instability, i.e., the magnetorotational instability. The magnetic field is tangled by the turbulent motion and amplified, leading to the angular momentum transport outward. The gas loosing the angular momentum falls to the black hole and this process liberates the gravitational energy. The twisted magnetic fields locally dissipate due to the electric resistivity and the gas is heated up. Some part of the gas internal energy is converted into the radiation energy through the emission process. So we can observe the black hole binary system as very luminous phenomena. Moreover, when a large amount of the gas is supplied to this system, the radiation energy dominates the magnetic and gas internal energies. Thus the radiation field affects the dynamics of the accretion disks. Not only the gas, but also the magnetic field, electric resistivity, and the radiation field are all important ingredients to understand the high energy phenomena.

Takahashi [1] proposed a numerical scheme to take into account the gas and radiation field in the framework of the special relativity. We advanced their work by taking into account the magnetic field coincides with the electric resistivity. Also in the previous work, an isotropic radiation field in the comoving frame is assumed. This assumption is valid only when the optical depth is much larger than unity, while the assumption is violated in the optically thin regime. In this work, we relax this condition by taking into account the anisotropy of the radiation field [2].

We treat radiation field in the moment formalism, which is obtained by integrating transfer equation in photon's momentum space. Then we solve 0th and 1st order moment equations, which describe radiation energy (E_r), and momentum (F_r^i) conservation, respectively. In the previous work, we determine the radiation stress P_r^{ij} by assuming isotropic radiation field. In this paper, we give an explicit form by assuming M-1 closure, which admit anisotropy.

For the magnetic field and resistivity, we solved a full set of Maxwell equations by assuming a simple Ohm's law. The numerical schemes for solving these equations are now developing, while they are now applied to some high energy phenomena (e.g., [3]).

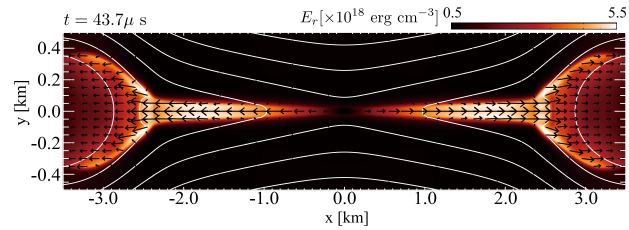

Figure 1: Color shows E_r at t = 47.3 μs, while white curves and arrows denote for magnetic field lines and radiation flux, respectively.

Figure 1 shows results obtained by applying our numerical code to the relativistic Petschek type magnetic reconnection. The initial condition is naively motivated by the black hole accretion disks. The topology of magnetic fields changes at the origin and the gas is evacuated in $\pm X$-direction. Due to the large optical depth to the electron scattering, the radiation field is confined in the outflow region with a small opening angle. We compared results with and without radiation field and found that the outflow speed is slower with radiation than without it due to the radiation drag effect. Also the reconnection rate reduces due to this effect. Thus we can conclude that the radiation field would play an important role not only for a global structure of the accretion disks but also in the small scale where the magnetic energy dissipates and is converted to the thermal/kinetic energy.

References

[1] Takahashi, H. R., et al.: 2013, *ApJ*, **764**, 122.
[2] Takahashi, H. R., Ohsuga, K.: 2013, *ApJ*, **772**, 127.
[3] Takahashi, H. R., et al.: 2011, *ApJ*, **739**, L53.