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GRPIC Simulations of Jet Formation

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We developed a 3D GRPIC code using the algorithm and implementation of the Kerr–Schild metric for the simulation of charged particles in a region surrounding a spinning black hole (BH). We test the overall model by using a 'toy'black hole and accretion disk system in a uniform magnetic field to produce bipolar jets. We aim to refine this code by implementing advanced simulation techniques including, initial, boundary conditions and other essential methods.

We have investigated the temporal evolution of an axisymmetric magnetosphere around a rapidly rotating stellar-mass BH by applying a two-dimensional particle-in-cell simulation scheme. Adopting homogeneous pair production and assuming that the mass accretion rate is much less than the Eddington limit, we found that the BH's rotational energy is preferentially extracted from the middle latitudes and that this outward energy flux exhibits an enhancement that lasts approximately 160 dynamical timescales. It is demonstrated that the magnetohydrodynamic approximations cannot be justified in such a magnetically dominated magnetosphere because Ohm's law loses its validity and the charge-separated electron–positron plasmas are highly nonneutral. An implication is given regarding the collimation of relativistic jets.

In the second report with our 2D axisymmetric GRPIC simulation, assuming a stellar-mass BH
solving full equations, we found that the created pairs fail to screen the electric field along the magnetic field, provided that the mass accretion rate is much smaller compared to the Eddington limit. Magnetic islands are created by reconnection near the equator and migrate toward the event horizon, expelling magnetic flux tubes from the BH vicinity during a large fraction of time. When the magnetic islands stick to the horizon due to redshift and virtually vanish, a strong magnetic field penetrates the horizon, enabling efficient extraction of energy from the BH. During this flaring phase, a BH gap appears around the inner light surface with a strong meridional return current toward the equator within the ergosphere. If the mass accretion rate is 0.025 percent of the Eddington limit, the BH's spin-down luminosity becomes 16-19 times greater than its analytical estimate during the flares, although its long-term average is only 6 percent of it. We demonstrate that the extracted energy flux concentrates along the magnetic field lines threading the horizon in the middle latitudes. It is implied that this meridional concentration of the Poynting flux may result in the formation of limb-brightened jets from low-accreting BH systems.

In future using a general relativistic Particle-in-Cell simulation, we have planned to demonstrate that the rotational energy of a rapidly rotating BH is preferentially extracted along the magnetic field lines threading the event horizon in the middle latitudes. We will show that the jets exhibit limb-brightened structures in a wide range of viewing angles.

Author: NISHIKAWA, Kenichi (Alabama A&M University)

Co-authors: HIROTANI, Kouichi (Taiwan Institute of Astronomy and Astrophysics, Academia Sinica); WATSON, Michael; MIZUNO, Yosuke (Tsung-Dao Lee Institute, Shanghai Jiao Tong University)

Presenter: NISHIKAWA, Kenichi (Alabama A&M University)