General Relativistic Radiation Magnetohydrodynamic Simulations of Accretion Flows onto a Black Hole or a Neutron Star

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Black hole and neutron star accretion disks are known to be one of the most energetic systems in high-energy astrophysical phenomena. Their energy is supplied by gas accretion onto the central star. The mass accretion rate $\dot{M}$ is the important parameter determining not only the luminosity and jet power of the system, but the disk dynamics and structures. When the $\dot{M}$ exceeds the critical value, which is so called the Eddington accretion rate $\dot{M}_c$, the radiation pressure dominates the gas and magnetic pressures in the accretion disks. The super critical accretion $\dot{M} > \dot{M}_C$ is of interest in the sense that the large amount of gravitational energy is liberated, and the relativistic outflows and hard X-rays are observed.

We performed radiation magnetohydrodynamic (RMHD) simulation of gas accretion onto the black hole [1-2]. We found that the jet is accelerated up to mildly relativistic speed$\cong 0.4c$, where c is the light speed. The jet is irradiated by the inner disk close to the black hole and accelerated by the radiation force. The accelerated jet is decelerated by the radiation drag force, where the radiation is emitted from the outer disk. The terminal velocity is determined by the force balance between these forces and thus by the disk structure. The resulting jet velocity is consistent with the observed speed in SS433.

Next, we considered the neutron star case and performed general relativistic radiation MHD simulations using our UWABAMI code[3-4]. We consider weakly magnetized neutron star and strongly magnetized neutron star. For the weakly magnetized neutron star, the accreting gas is accumulated on the surface of the neutron star. The gas accretion from the disk continues without being blown away, even though the mass of radiation energy is accumulated in the accreting gas. The accretion disk and generated atmosphere is highly optically thick for supercritical accretion disks, the radiation flux F_{rad} is much less than the radiation energy $E_{rad}c$. The radiation force is thus not enough strong to blow the gas away from the neutron star. This situation is the same for strongly magnetized neutron star, but the atmosphere is not created, but the gas falls along the magnetic field lines. The accreting gas forms accretion columns on the neutron star. The radiation from the accretion column would be responsible for X-ray pulse observed in some of the ULXs.

Different to the black hole, there are some the launching mechanisms of the outflow for neutron star. A part of the accumulated gas is blown away and it forms the outflow. This outflow is mainly accelerated by the radiation force. The centrifugal force also plays a role for launching / accelerating the outflow emanating from the outer disks. Since the gas is accumulated on the neutron star surface, the outflow is more massive than that for black hole. This difference between black hole and neutron star outflows would explain the variety of X-ray spectra observed in ULXs.

The study of supercritical accretion important for explain the ULXs, but for most of the black hole candidate, the gas accretion rate is much less than the Eddington value. In such case, the gas density in the disk is not too high enough that the electron temperature approaches to the ion temperature though the Coulomb collision. Determination of electron temperature is important for explain the radio – X ray spectra observed in the black hole candidate and supermassive black hole. The electron temperature is, however, not determined in conventional MHD simulations. We upgraded our UWABAMI code to solve the electron temperature and study the distribution of electron temperature around the black hole. We found that the electron temperature is lower than the ion temperature in the accretion disks, while it is higher for the jet region. The turbulent motion in the accretion disks efficiently heats up the ions, but the turbulence is not strong in the jet region. Thus electrons efficiently heat up in the jet regions. We also study the effect of the black hole spins. We found that the electron temperature is higher for the larger spin parameters. This would be due to the energy subtraction form the black hole through the Blandford Znajek process. The Poynting energy is transferred in the jet regions, and it heats up electrons. We expect that this difference affects on the X-ray spectra which would be originated from the upward Compton scattering. It would explain the variety of observed X-ray spectra, and we expect the black hole spin can be drawn from the observations .

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