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Radiation Magnetohydrodynamic Simulations of Accretion Flows and Outflows

Hiroyuki R. Takahashi[1], Ken Ohsuga[2]

[1] Center for Computational Astrophysics, National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan,

[2] Division of Theoretical Astronomy, National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan

Black hole and neutron star accretion disks are known to be one of the most energetic systems in high-energy astrophysical phenomena. Especially, the super critical accretion disk 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. The mechanism of outflow acceleration and the origin of hard X-rays are, however, poorly understood.

We performed 2.5-dimensional Special Relativistic Radiation Magnetohydrodynamic (SR-RMHD) simulations to study a jet formation from super critical accretion disks. We found that the jet is accelerated up to mildly relativistic speed by the radiation force. The force balance between the radiation force and its radiation drag force determines the terminal velocity. The resulting jet velocity is consistent with the observed speed in SS433.

Next, we performed 3-dimensional General Relativistic Radiation Magnetohydrodynamic (GR-RMHD) simulations to study the origin of hard X-rays. We found that the strong magnetic field near the black hole leads to the enhancement of the magnetic stress (viscosity). The disk near the black hole is not in LTE and the gas is overheated up to 10^{10} K. It is expected that the Compton upscatterd photons in the overheated region contribute to observed hard X-rays spectra.

In these studies, we assumed the central star to be a black hole. Recently, Bachetti '14 found that one of the ultra luminous X-ray sources (ULXs) is originated from the neutron star. After this finding, three ULXs are confirmed that they have a neutron star. Thus, observational facts show that the supercritical accretion is possible even onto the neutron star. Following to this fact, we performed the GR-RMHD simulations of the supercritical accretion onto the neutron star. We found that for the weakly magnetized neutron star, the powerful outflow is ejected from this system. Different to the black hole, we assume that the neutron star never swallows the accreting energy and mass. They are accumulated near the neutron star and it results in the formation of strong outflows. The kinetic energy dominates the other energy for the outflow from neutron star, while the radiation energy dominates the other energy for the black hole. The total energy flux is more powerful for neutron star than the black hole.

The power of the outflow is almost independent of the rotation for the neutron star. For the black hole, on the other hand, the rotation energy is extracted from the black hole through the magnetic field (so called Blandford Znajek mechanism). The outflow from the rotating black hole is dominated by the Poynting flux, and its power is stronger than the other sources. Thus we concluded that the rapidly rotating black hole is the most powerful source. Following to this, the neutron star is also powerful and has a massive outflow. The non-rotating black hole is the less powerful source in these systems.

In this simulation, we assumed that the magnetic field of the neutron star is negligible. But when the neutron star is strongly magnetized, the interaction of the magnetic field and the accretion disk is important. Thus we performed numerical simulations of the magnetized neutron star and the accretion disks.

We found that when the magnetic field strength is stronger than 10^{10}G with 100 x Eddington mass accretion rate, the magnetosphere is formed. Then the disk accretion is prohibited due to the strong Lorentz force. The disk gas effectively loses its angular momentum by interacting the dipole magnetic field of the neutron star. It leads to the formation of pole accretion. The accreting gas hits the neutron star and it liberates the gravitational energy. Most of the gas is reflected by the neutron star and it forms the jet. We found that jet is radiatively accelerated and its velocity reaches 0.3 light speed.

We review these mechanisms of jet and outflow launching from the black hole and neutron star in this talk.