General Relativistic Radiation MHD Simulations of Supercritical Accretion onto a Magnetized Neutron Star: Modeling of Ultraluminous X-Ray Pulsars

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Gas accretion onto compact objects such as black holes (BHs) or neutron stars (NSs) is known as one of the most energetic phenomena in the universe. These systems are powered by liberating the gravitational energy through mass accretion, so that the mass accretion rate is an important key parameter determining their activities. In particular, the supercritical accretion, where the accretion rate exceeds the critical rate $\dot{M}_{\rm crit}$ ($\equiv L_{\rm Edd}/c^2$, $L_{\rm Edd}$ and c are the Eddington luminosity and light speed), is of interest since the large amount of gas falls onto central objects. Such energetic phenomena are thought to happen around the black hole since the black hole can swallow the gas and energy.

A recent finding of pulsations in ultraluminous X-ray sources (ULXs) changes the situation. The X-ray pulsation with a period of P = 1.37 s and its time derivative $\dot{P} \simeq -2 \times 10^{-10}$ s s^{-1} has been observed from M82 X-2 [1]. After this notable discovery, X-ray pulsations have been observed in other two ULXs [2,3]. These observational facts indicate that a supercritical accretion happens onto a NS (namely, ULX Pulsar), since the luminosity of these ULX Pulsars highly exceeds the Eddington luminosity for the neutron stars.

In this paper, we, for the first time, performed the General Relativistic Radiation Magnetohydrodynamic (GR-RMHD) simulations of supercritical accretion onto the strongly magnetized neutron star [4]. Figure 1 shows results of GR-RMHD simulations. NS is situated at the origin. Far from the NS, a geometrically thick, supercritical accretion disk is formed. Close to the NS, the accretion disk is truncated around $r = 3R_*$, where R_* = 10 km is the neutron star radius. Inside this radius, the magnetic energy of NS dominates. The gas accretion is prohibited by the magnetic pressure. Alternatively, the angular momentum of the disk gas is efficiently transported to the NS due to the magnetic torque. Then the gas losing angular momentum falls on to the NS along the magnetic field lines. The gravitational energy is liberated by the collision of accreting gas with the NS. Thus, the magnetic pole of NS shines brightly. The angular momentum transport to the NS results in the spin up of NS. The estimated spin up rate in our simulation is about $\dot{P} = -3 \times 10^{-11}$ s s^{-1}, which is quantitatively consistent with the observed value. Thus, our results support the scenario of supercritical accretion onto the NS.

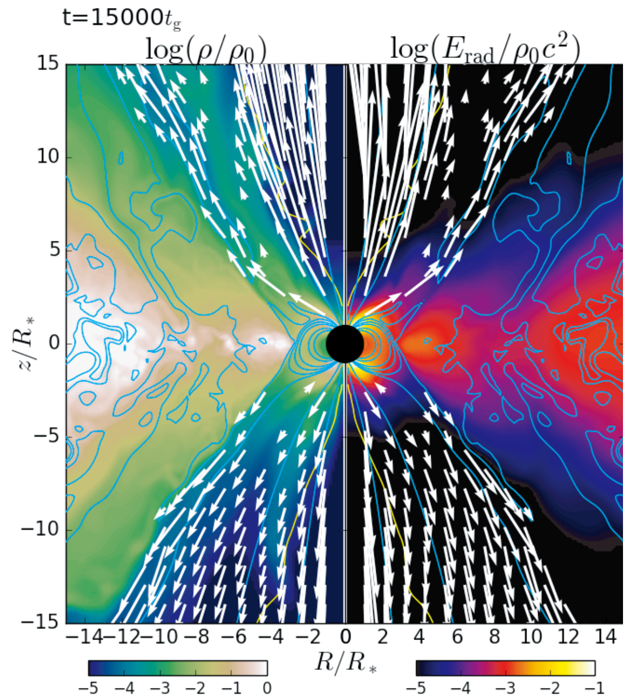

Figure 1: Supercritical accretion onto NS using GR-RMHD simulations. Color shows mass density (left) and radiation energy density (right), and arrows show fluid velocity (left) and radiation flux (right). Contours show magnetic field lines.

References

[1] Bachetti, M., et al.: 2014, *Nature*, **514**, 202.
[2] Fürst, F., et al.: 2016, *ApJL*, **831**, L14.
[3] Israel, G. L., et al.: 2017, *Science*, **355**, 817.
[4] Takahashi, H. R., Ohsuga, K.: 2017, *ApJL*, **845**, L9.