General Relativistic Radiation MHD simulations of Super-Eddington accretion flows around a magnetized neutron star; modeling of the ULX Pulsars

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Ultra-Luminous X-ray sources (ULXs) are bright, point-like X-ray sources whose luminosity exceeds the Eddington luminosity for a stellar-mass black hole. Such a high X-ray luminosity suggests that they host either intermediate-mass black holes accreting at the sub-Eddington rate, stellar-mass black holes accreting at the super-Eddington rate, and/or neutron stars accreting at the super-Eddington rate.[1] Recent observation reported coherent pulsations with a period of ~1 s from several ULXs, so-called ULX pulsars.[2] The pulsations indicate that some ULXs are powered by the super-Eddington accretion onto a magnetized neutron star since the mass of the neutron star is comparable to that of the sun.

We have performed general relativistic radiation magnetohydrodynamics simulations of the super-Eddington accretion flows onto a neutron star with a dipole magnetic field to model the ULX pulsars.[3] In our simulations, a truncated accretion disk outside the magnetosphere, accretion columns near the magnetic poles of the neutron star, and radiatively driven outflows launched from the accretion disk appear (Figure 1). Such outflows become effectively optically thick and would be responsible for the blackbody radiation at 10^7 K with a radius of 100-500 km, observed in the galactic ULX pulsars, Swift J0243.6+6124.[4] The resulting blackbody radius increases as the mass accretion rate increases.

Our simulations also show that the neutron star is spun up by the accreting gas, which would reduce the pulse period. The spin-up rate increases as the mass accretion rate and/or magnetic field strength at the neutron star surface increase. The surface magnetic field strength of the neutron star is limited to be lower than 4×10^{12} G to explain the observed blackbody radiation without contradicting the observed spin-up rate, $\sim 10^{-8}$ s s^{-1}. Our results support the hypothesis that the super-Eddington phase in the 2017-2018 giant outburst of Swift J0243.6+6124 is powered by the super-Eddington accretion onto the magnetized NS.

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References

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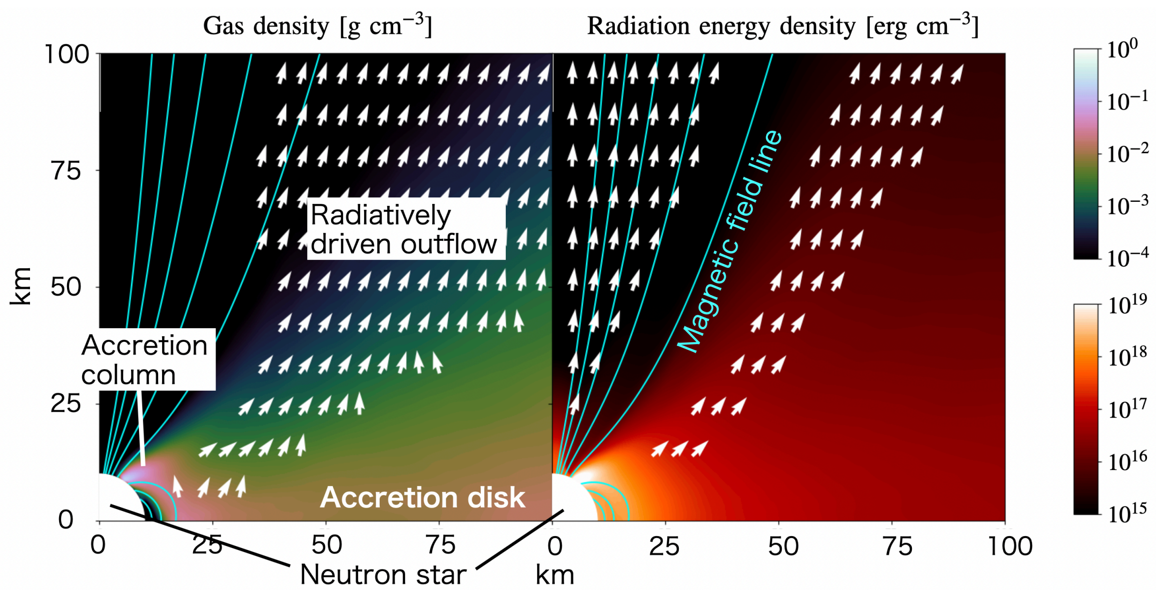

Figure 1. Quasi-steady state structure of the super-Eddington accretion flows and outflows around a neutron star with a dipole magnetic field. Left: the vectors show the gas velocity in the region where the mass outflow rate exceeds one-hundred times larger than the Eddington rate. Right: the radiative flux one-thousand times larger than the Eddington rate is denoted by white vectors.