一般相対論的輻射磁気流体シミュレーションによる超臨界ブラックホール降着円盤の質量降着率・スピン依存性の調査

Masaki Inoue[1] Email: masaki@ccs.tsukuba.ac.jp
with Ken Ohsuga[1], Hiroyuki Takahashi[2], Yuta Asahina[1][2]
[1]Tsukuba Univ. [2]Komazawa Univ.

Introduction

What is the energy source of highly luminous compact objects, such as ULXs? ⇒ **Super critical accretion disks**

Is the extraction of black hole (BH) rotational energy via magnetic fields (BZ mechanism) effective in super critical accretion disks? ⇨ Investigate **spin**, **accretion rate**, and **BH mass** dependence.

Method and Model

We perform two-dimensional axisymmetric GRRMHD simulations using the numerical code "UWABAMI + INAZUMA".

Basic Equations

Magnetofluid

The mass conservation eq.

$$(\rho u^{\mu})_{;\mu} = 0$$

The energy momentum conservation eq.

$$({T_{\mu}}^{\nu} + {M_{\mu}}^{\nu})_{;\nu} = G_{\mu}$$

Induction eq.

$$\partial_t[\sqrt{-g}(b^i u^t - b^t u^i)] = -\partial_j[\sqrt{-g}(b^i u^j - b^j u^i)]$$

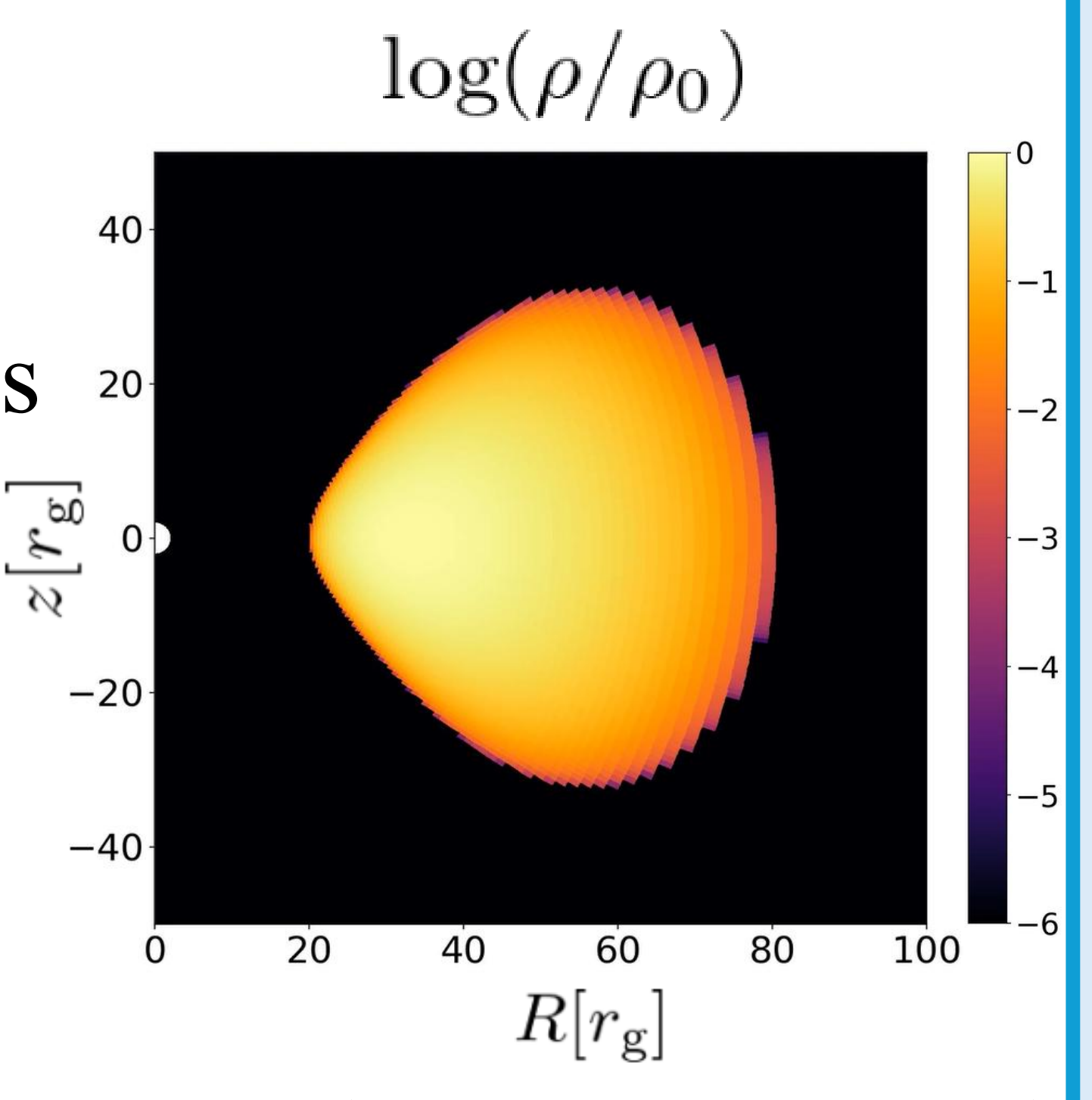
Radiation

The energy momentum conservation eq.

(M1 closure) $$({R_{\mu}}^{\nu})_{;\nu} = G_{\mu}$$

Initial Conditions

- Set equilibrium torus（Right panel）(Fishbone & Moncrief 1976)
- Weak poloidal magnetic fields in torus



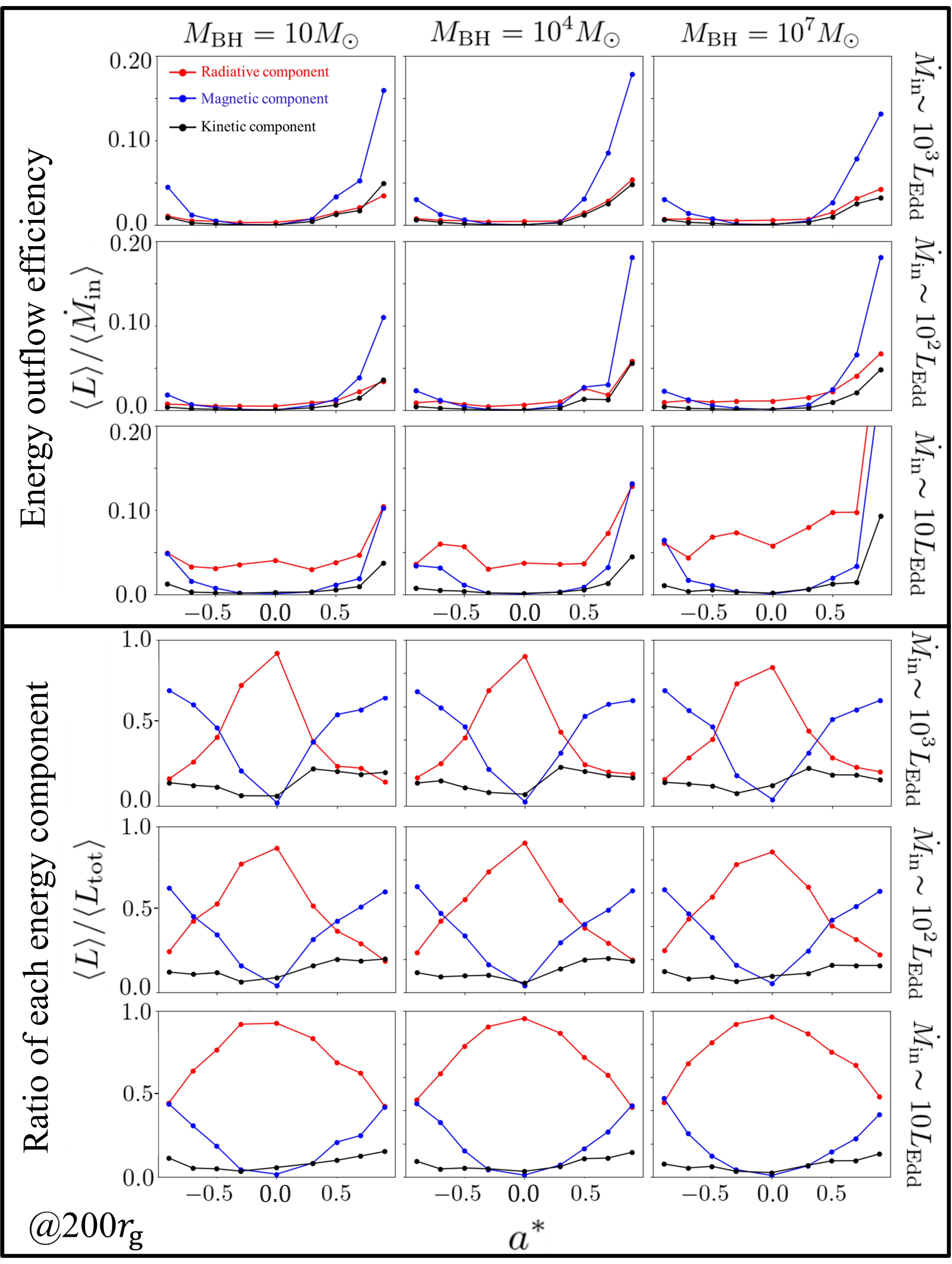
（r_g:gravitational radius）

Parameters（All 81 models）

- BH mass
  $M_{BH} = 10, 10^4, 10^7 M_{\odot}$
- Accretion rate（max. mass density）
  $\dot{M}_{in} \sim 10, 10^2, 10^3 L_{Edd}$
- Spin parameter
  $a^* = 0, \pm 0.3, \pm 0.5, \pm 0.7, \pm 0.9$

（L_{Edd}:Eddington luminosity）

Results



Spin, accretion rate, and BH mass dependence of the energy component released from the jet region

←BH spin dependence of energy outflow efficiency (top panel) and the ratio of each energy component (bottom panel)
The horizontal axis of the aligned figures shows **the BH mass**, while the vertical axis shows **the accretion rate dependence**.

Radiative component

- Energy outflow efficiency increases with increasing $|a^*|$.
- At $\dot{M}_{in} \sim 10^{2-3} L_{Edd}$, it is dominant for $-0.3 < a^* < 0.3$. On the other hand, **at $\dot{M}_{in} \sim 10 L_{Edd}$, it is dominant for $-0.7 < a^* < 0.7$.**
- **At $\dot{M}_{in} \sim 10 L_{Edd}$, energy outflow efficiency increases with increasing the BH mass.**

Magnetic component

- Energy outflow efficiency increases with increasing $|a^*|$.
- At $\dot{M}_{in} \sim 10^{2-3} L_{Edd}$, it is dominant for $|a^*| \gtrsim 0.5$. **However, at $\dot{M}_{in} \sim 10 L_{Edd}$, it does not dominate for any spin.**
- There is no clear dependence on the BH mass in both panels.

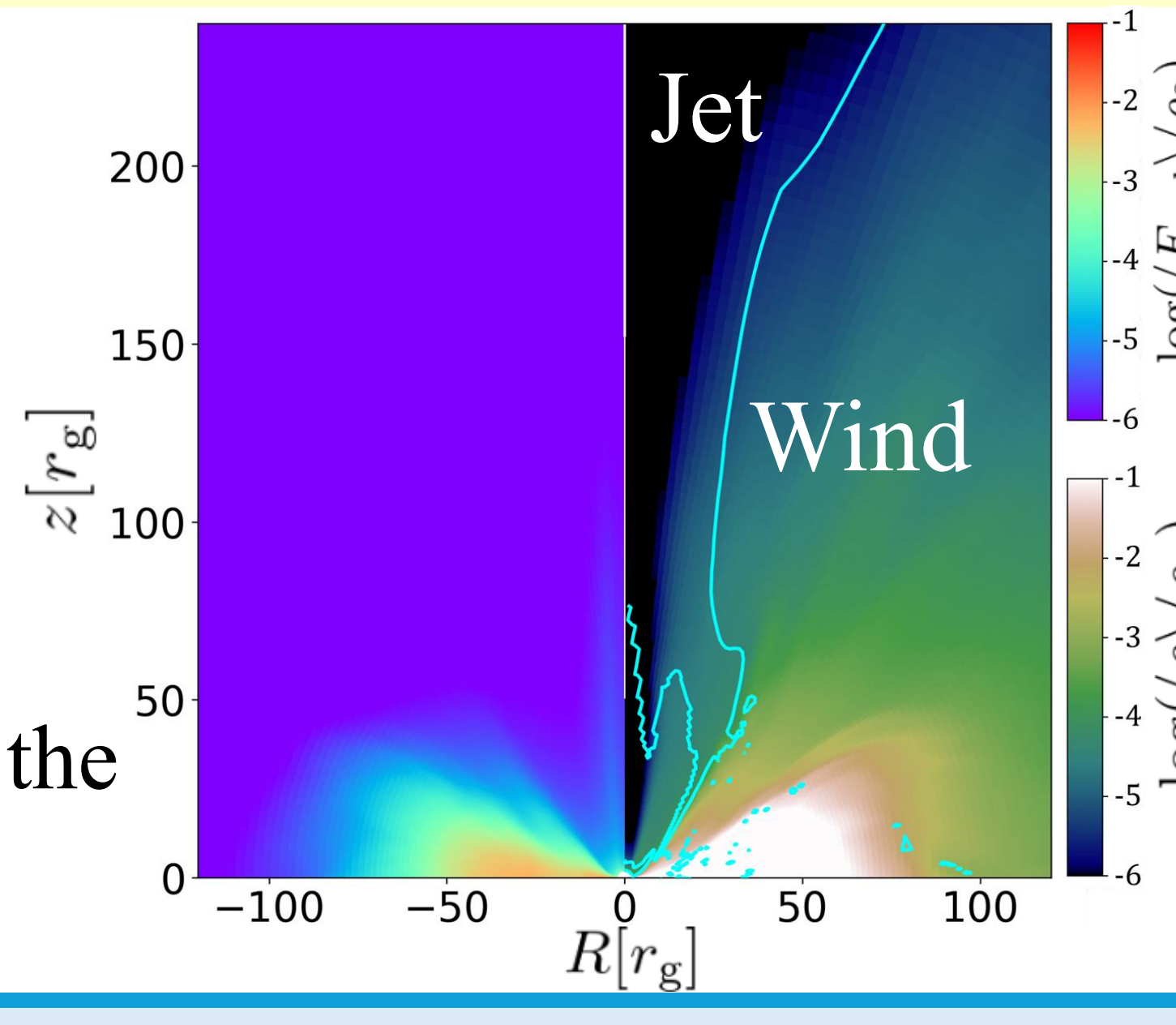
Kinetic component

- Energy outflow efficiency increases with increasing $|a^*|$.
- There is no clear dependence on the accretion rate in both panels.
- There is no clear dependence on the BH mass in both panels.

Using time-averaged data from the quasi-steady state at 3000~5000$t_g (= r_g/c)$.

The energy released from BH is mostly ejected from the jet region. →

(The boundary between jet and wind is defined by the Bernoulli parameter)



Conclusions

- We investigated the radiative, magnetic, and kinetic energy components released from the jet region in super critical accretion disks.
- The energy outflow efficiencies of all components increase with increasing $|a^*|$.
- For $|a^*| \lesssim 0.5$, the radiative component dominates, while for $|a^*| \gtrsim 0.5$, the magnetic component dominates. For $\dot{M}_{in} \sim 10 L_{Edd}$, the radiative component dominates for any spin.
- For $\dot{M}_{in} \sim 10 L_{Edd}$, the larger the black hole mass, the higher the energy outflow efficiency of the radiative component.