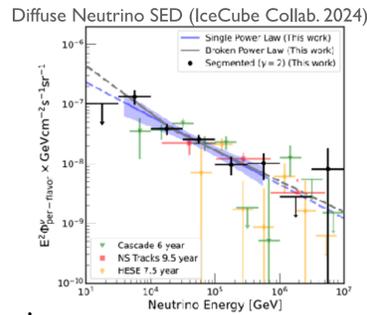


Magnetically Arrested Disks: Studies on High-Energy Neutrino Spectra and Dynamics Based on GRMHD Simulations

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Introduction

- High energy neutrino:
 - ✓ Emitted via pp and $p\gamma$ collision processes of accelerated protons
 - ✓ Trajectories are not affected by B-field attributed to the neutral charge
 - They can be a "smoking gun" of cosmic-ray (CR) acceleration

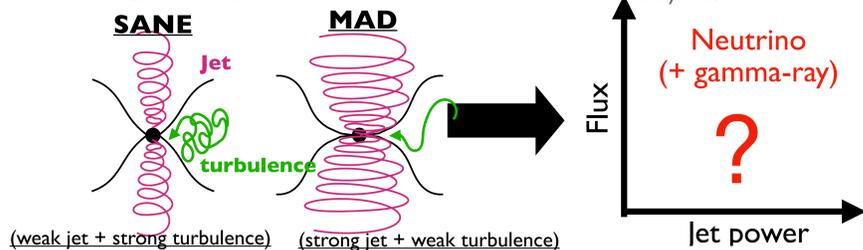


- Active Galactic Nuclei (AGN) may be one of the main contributor to diffuse neutrino observed by IceCube

• Question: Which of AGNs w/ or w/ strong jets are more significant neutrino sources?

- ✓ Jet power may be determined by a classification of accretion flows:

- Standard and Normal Evolution (SANE)
 - Magnetically Arrested Disk (MAD)
- e.g., Igmenshchev + 2003, Narayan + 2003, Tchekhovskoy 2011



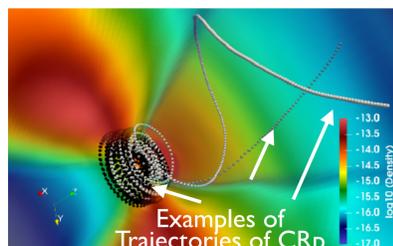
- ✓ The effects of global structure of accretion flows on neutrino SED will be important (Kawashima & Asano in prep.), but it is not explored in MADs.

We carry out General Relativistic MagnetoHydro Dynamics of MAD and compute the Neutrino SED. (The preliminary results are reported in this poster.)

Method

1 GRMHD simulation

- UWABAMI code (Takahashi+2016)
- Black Hole (BH)-spin $a = 0.9375$ (fiducial) and $a = -0.9375, \pm 0.5, 0$
- Kerr-Schild coordinate
- Simulation domain: $1.18r_g \leq r \leq 3333r_g$ $0 \leq \theta \leq \pi$ $0 \leq \varphi \leq 2\pi$
- Number of meshes $(N_r, N_\theta, N_\varphi) = (384, 192, 192)$
- Initial torus w/ dynamically equilibrium (Fishbone & Moncrief 1976)
- and poloidal magnetic field w/ plasma $\beta = 100$
- Simulations are performed with Fugaku



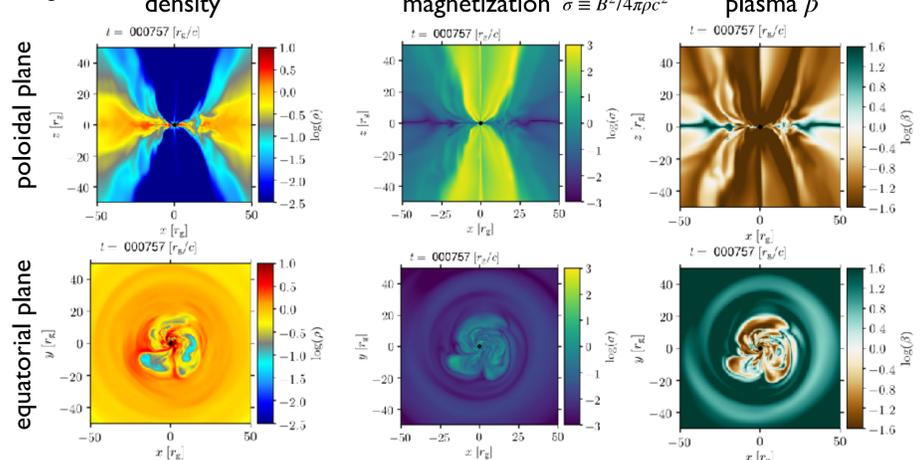
2. Neutrino SED computation

- ν -RAIKOU code (Kawashima & Asano in prep.)
- Tracer particles of Cosmic Ray Protons (CRp) along the stream lines of MAD using GRMHD data
- Turbulent acceleration + injection + compressions are incorporated by solving the Fokker-Planck equation of CRp w/ hard-sphere approximations.
- pp -collisions of accelerated CRp and thermal protons of GRMHD snapshots
- Neutrino SED computations using a formula of pion SEDs (Kelner + 2006)
- GR effects (gravitational red-shift)

Result

- GRMHD simulations
 - ✓ The results agree well with previous works (e.g., Tchekhovskoy + 2011)
 - ✓ Intermittent ($\sim 10^3 r_g/c$) eruption of magnetic flux

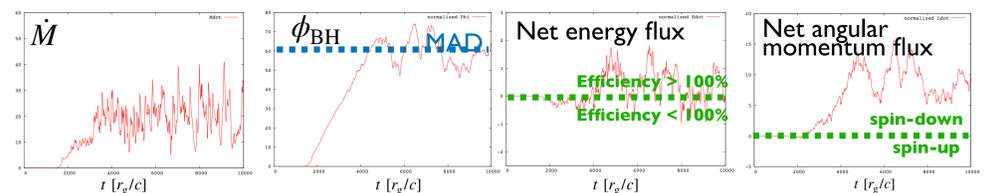
(r_g : gravitational radius, c : speed of light)



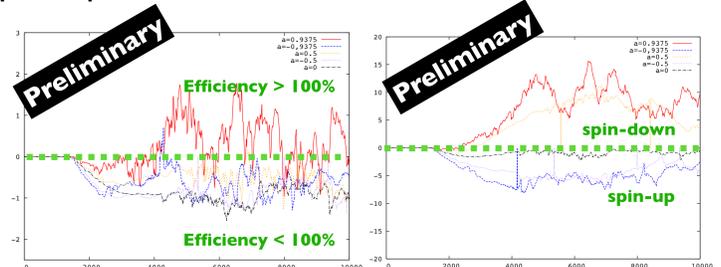
- ✓ Strong magnetic flux with $\phi_{\text{BH}} \sim 60$

$$\# \phi_{\text{BH}} = \frac{\Phi_{\text{BH}}}{\sqrt{\dot{M} r_g^2 c}}, \quad \Phi_{\text{BH}} = \frac{1}{2} \int_0^\pi d\theta \int_0^{2\pi} d\varphi \sqrt{-g} |B^r|, \quad \dot{M} = \int_0^\pi d\theta \int_0^{2\pi} d\varphi \sqrt{-g} \rho u^r \quad (r = 5r_g)$$

- ✓ Blandford-Znajek process (Blandford-Znajek 1977), i.e., the extraction of spin-energy via magnetic field seems to take place.

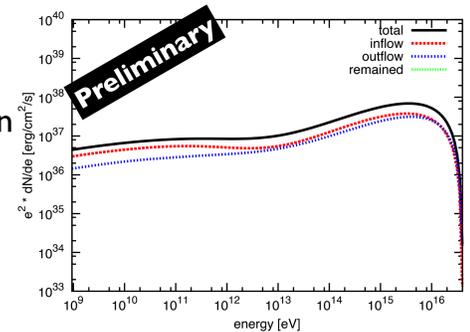


- ✓ BH-spin dependence



- Neutrino SEDs (preliminary)

- ✓ Neutrino emission via inflowing CRp dominate the SEDs
- ✓ On the other hand, semi-MAD (moderately magnetized accretion flow) shows that the neutrino SEDs are dominated by the emission via outflowing CRps
- ✓ The laminar inflow/outflow in MAD result in the above?



(To be clarified in future work)

Summary and Prospects

- We have carried out GRMHD simulations and neutrino SED computations of MAD.
- The results of GRMHD simulations agree well with the previous works.
- The neutrino SEDs are dominated by inflowing CRp-origin components in MAD, while it is dominated by outflow CRp in a moderately weak magnetic field state (semi-MAD)
- Detailed analysis will be carried out soon.