High energy neutrino emission from a radiatively inefficient accretion flow based on a GRMHD simulation

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Introduction

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

• Sources of IceCube neutrinos: uncertain
  ✓ Active Galactic Nuclei (AGN)
  ✓ Galaxy Clusters
  ✓ Starburst Galaxies
  ✓ Low Luminosity Gamma-ray Bursts

For more quantitative studies, the theoretical works based on the 1-zone approximation, will be important to be explored.

ex) AGNs
  ✓ Global structure and states of the accretion flow (incl. magnetization)
  ✓ Turbulence in kinetic scale
  ✓ Black hole spin

# For a pioneering work of neutrino emission model with 1-zone approximation, see Kimura et al. (2015), etc.

In this work, we have developed v-RAIKOU code, which calculates the CR proton (CRp) acceleration and neutrino emission using 3D General Relativistic MHD (GRMHD) data. We have studied the effects of the global structure of accretion flows on the resultant neutrino SEDs.

Method

(1) Trajectories of CRp using 3D GRMHD data

• The trajectories along the stream lines (in this work where the gyro radius is less than the mesh size.

• GRMHD data (Kawashima et al. 2023) in semi-MHD state (intermediate magnetization accretion flow). GR(R)MHD code UWABAMI (Takahashi et al. 2016)

(2) Time evolution of CRp SEDs

Fokker-Planck eq.

$\frac{dN(e',t)}{dt} = \frac{\partial}{\partial e'} \left[ D(e') \frac{dN(e',t)}{de'} \right] - \frac{\partial}{\partial e'} \left[ 2D(e') N(e',t) \right] + N_{inj}(e',t)$

Solved with a method with Green function (Becker et al. 2006).

• Energy diffusion: turbulent acceleration
  w/ hard sphere approx., i.e., $D(e') = Ke'^2$
  (e': CRp energy in the fluid-rest frame)

• Injection: CRp of $e' = 2m_p c^2$ w/ higher injection rate at highly magnetized region (motivated by magnetic reconnection)

• Effects of Compression/Rarefaction are also included.

(3) High-energy neutrino SED

• $pp$ collision between CRp and MHD (thermal) proton.
• Neutrinos w/ approx. formula of pion SED (Kelner et al. 2006)
• The effects of Gravitational redshift are included.

Result

• Time averaged neutrino SED
  ✓ SEDs flatter than those of 1-zone models
  ✓ Neutrinos originated from CRp finally captured by black hole (inflow) contribute as much as those from outflowed CRp.
  ✓ These moderately flat SED may explain the origin of diffuse SEDs.

• Trajectories, SEDs and acceleration timescale of CRp:
  The CRp with various trajectories and acceleration forms the flatter neutrino SEDs.

Summary and Prospects

• We have computed neutrino SEDs of global accretion flow based on GRMHD model, with developing a new code calculating CRp accelerations and neutrino emission using GRMHD simulation data (v-RAIKOU code).

• It is found that neutrino SEDs flatter than those of 1-zone model appears due to the superposition of emission from various CRp attributed to the global structure of the accretion flow.

• The moderately flat SED may explain the origin of diffuse neutrino observed by IceCube.

• We will add the effects of the $p\gamma$ processes, combining the v-RAIKOU with general relativistic multiwavelength radiative transfer code RAIKOU (Kawashima et al. 2023)