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

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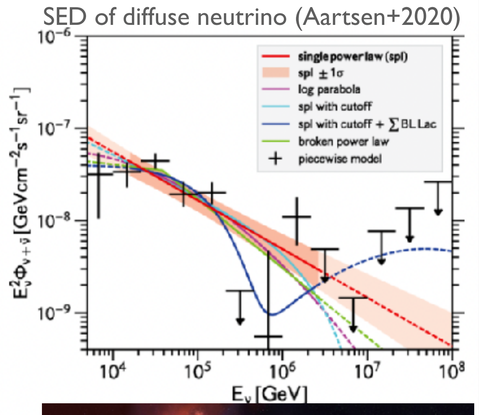
Introduction

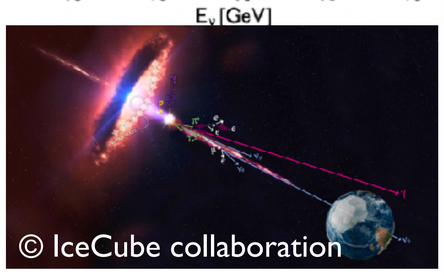
- High energy neutrino :
  - ✓Emitted via *pp and pγ* collision processes of accelerated protons
  - ✓Trajectories are not affected by B-field attributed to the neutral charge
  - → They can be a "smoking gun" of cosmic-ray (CR) acceleration

- 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 global structure of the plasma, i.e., models beyond the 1-zone approximation, will be important to be explored.

SED of diffuse neutrino (Aartsen+2020)





ex) AGNs

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

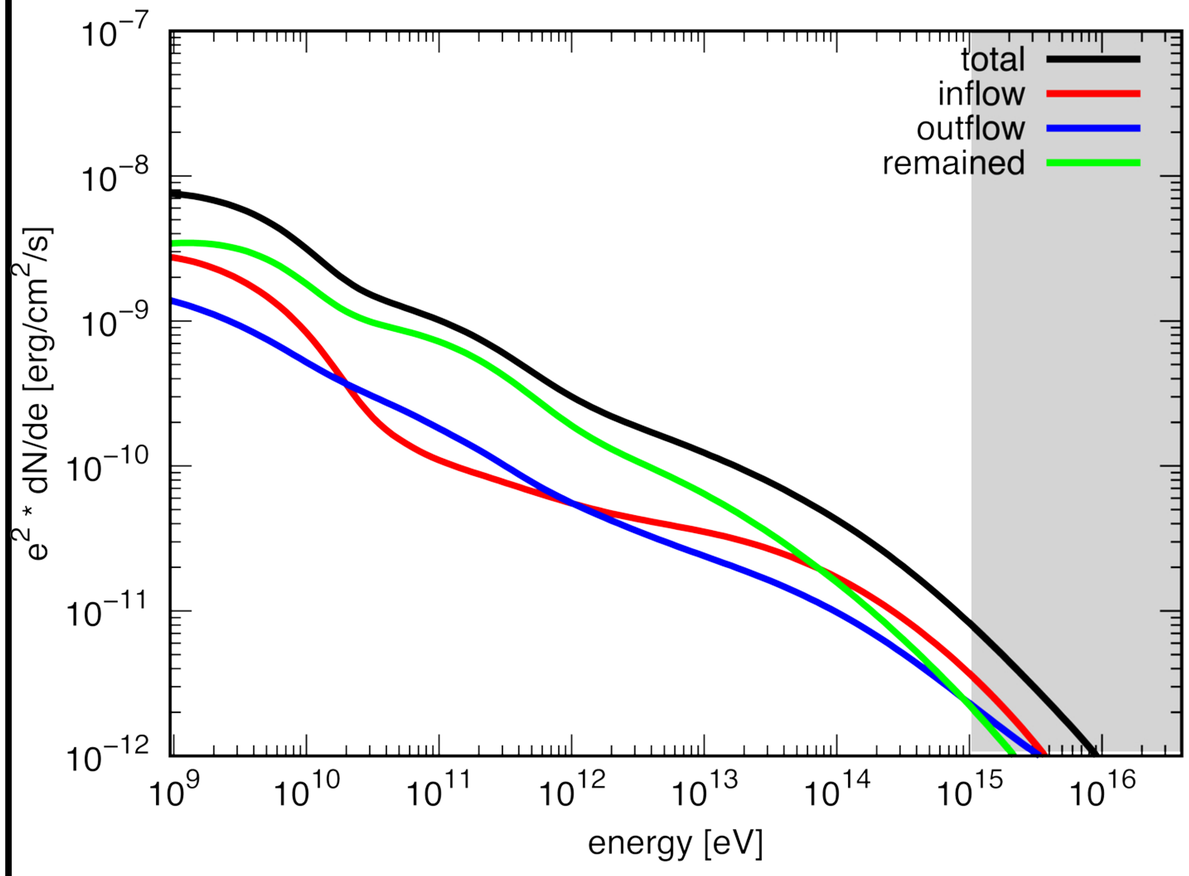
→ ✓ CR acceleration
✓ Neutrino SEDs

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

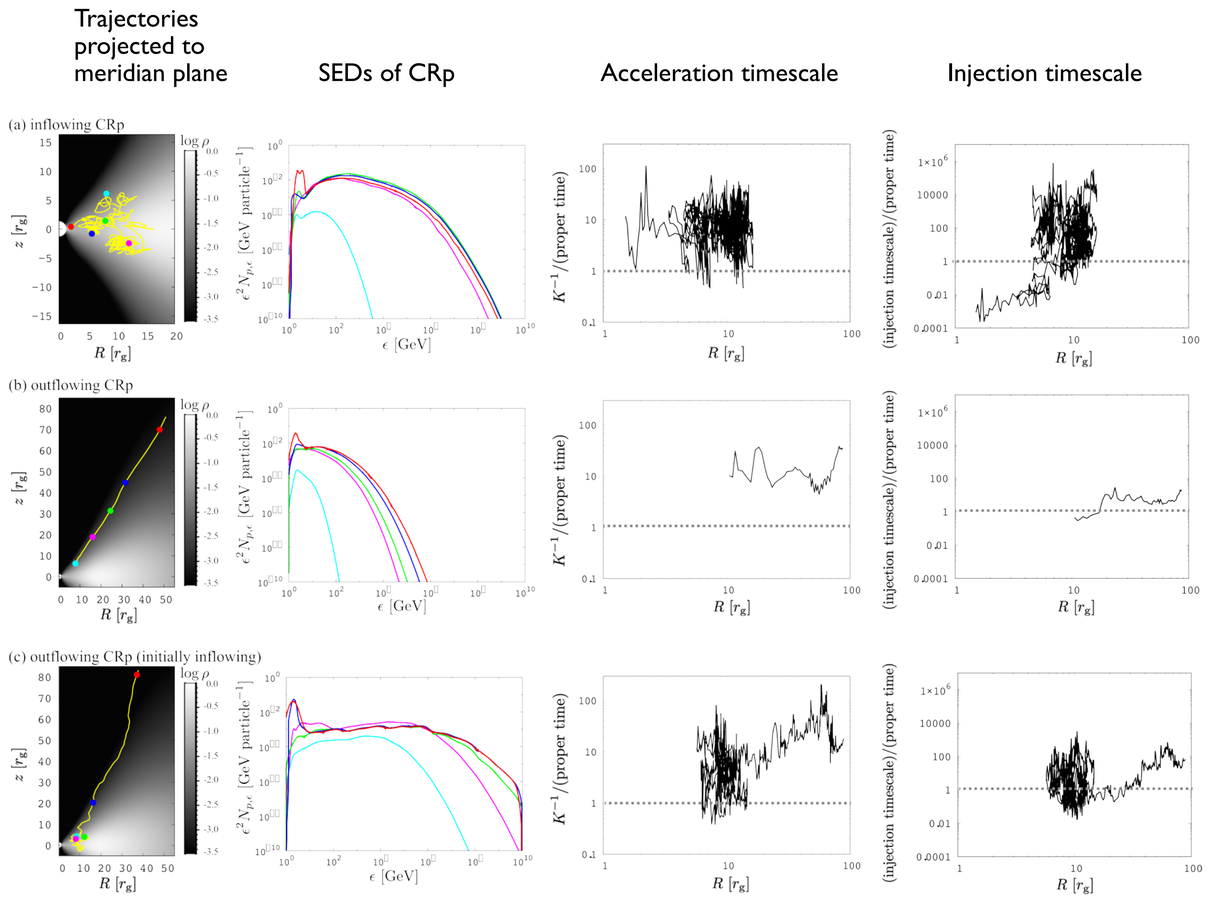
In this work, we have developed ν-RAIKOU code, which calculates the CR proton (CRp) acceleration and neutrino emission using 3D General Relativistic MHD (GRMHD) data.
We have studied the effects of the **global structure** of accretion flows on the resultant neutrino SEDs.

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.



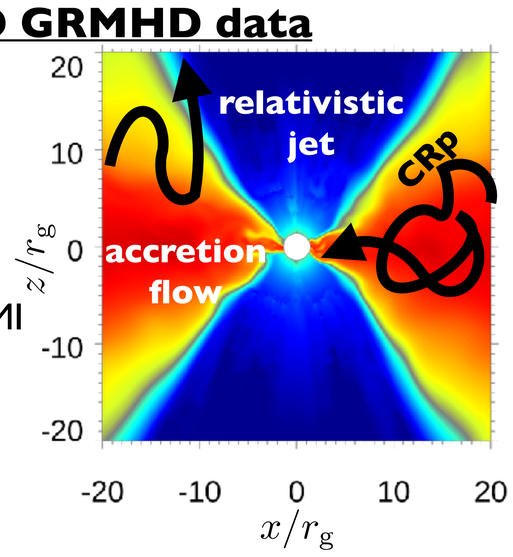
- Trajectories, SEDs and acceleration timescale of CRp:
  The CRp with various trajectories and acceleration forms the flatter neutrino SEDs.



Method

(1) Trajectories of CRp using 3D GRMHD data

- The trajectories along the stream lines
  # We are interested in the acceleration up to ~ PeV in this work where the gyro radius is less than the mesh size.
- GRMHD data (Kawashima+2023) in semi-MAD state (intermediately magnetized accretion flow). GR(R)MHD code UWABAMI (Takahashi + 2016)



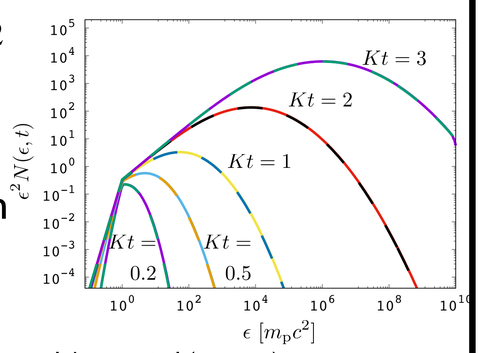
(2) Time evolution of CRp SEDs

Fokker-Planck eq.

$$\frac{\partial N(\epsilon',t')}{\partial t'} = \frac{\partial}{\partial \epsilon'}\left[D(\epsilon')\frac{\partial N(\epsilon',t')}{\partial \epsilon'}\right] - \frac{\partial}{\partial \epsilon'}\left[\frac{2D(\epsilon')}{\epsilon'}N(\epsilon',t')\right] + \dot{N}_{\rm inj}(\epsilon',t')$$

Solved with a method with Green function (Becker + 2006).

- energy diffusion: turbulent acceleration w/ hard sphere approx., i.e., $D(\epsilon') = K\epsilon'^2$ (ϵ': CRp energy in the fluid-rest frame)
- injection: CRp of $\epsilon' = 2m_{\rm p}c^2$ w/ higher injection rate at highly magnetized region (motivated by magnetic reconnection).
- Effects of Compression/Rarefaction are also included.



solid: numerical (our test)
dashed: analytic (Asano & Meszaros 2016)]

(3) High-energy neutrino SED

- *pp* collision between CRp and MHD (thermal) proton.
- Neutrinos w/ approx. formula of pion SED (Kelner + 2006)
- The effects of Gravitational redshift are included.

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 (ν-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 the diffuse neutrino observed by IceCube.
- We will add the effects of the *pγ* processes, combining the ν-RAIKOU with general relativistic multiwavelength radiative transfer code RAIKOU (Kawashima+2023)