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Stochastic Cosmic-ray Acceleration in Black-hole Accretion Flows

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The Universe is filled with high-energy particles, including atomic nuclei (Cosmic-rays; CRs), gamma-rays, and high-energy neutrinos, whose origins and production mechanisms are still unknown. Black hole accretion flows are potential candidates for the origin of these high-energy cosmic particles. CRs produce high-energy neutrinos through hadronic interactions, and recent high-energy neutrino signals from a Seyfert galaxy M77 provides a hint of particle acceleration in accretion flows. In this talk, I discuss the particle acceleration and high-energy emission from accretion flows in active galactic nuclei (AGN). In low-luminosity AGN (LLAGN), where the accretion rate is low, the accretion flows cannot cool efficiently, leading to formation of hot accretion flows consisting of collisionless plasma. In AGN with a high accretion rate, such as quasars, an optically thick, geometrically thin accretion disk is formed. Hot coronae, which emit X-rays, are expected to be formed above the disk via magnetic energy dissipation. AGN coronae also consist of collisionless plasma. Since CRs are accelerated in collisionless plasma, accretion flows in both quasars and LLAGN can be potential sources of CRs.

Accretion flows are believed to be in turbulent states because of the magnetorotational instability (MRI), which likely induces magnetic reconnections. Non-thermal protons can be accelerated by the reconnection. The accelerated protons interact with a larger scale turbulence, further accelerated to higher energies. Based on this scenario, we phenomenologically model the stochastic CR acceleration in hot accretion flows in LLAGN and hot coronae in luminous AGN. We model the target photon fields and plasma quantities in quasars using the empirical relations of multi-wavelength observations [1]. On the other hand, we calculate the photon spectra from LLAGN based on theoretical modeling, and we calibrate the parameters using X-ray data [2,3]. We demonstrated that black-hole accretion flows can accelerate CRs up to PeV energies and that they can account for the data of astrophysical neutrinos detected by IceCube ([1-4]; Figure 1).

In the aforementioned works, we utilize the simple treatment for particle-wave interactions, assuming particles efficiently interact with the turbulent eddy of its gyration scale. However, feasibility of the treatment in accretion flows are unclear. To investigate the CR acceleration process in accretion flows, we are performing a set of magneto-hydrodynamic (MHD) and test-particle simulations dedicated to black-hole accretion flows. We first perform MHD simulations to obtain the realistic turbulent field generated by MRI, and then, we solve the orbits of test particles in the MRI turbulence. Our simulations revealed that the evolution of the CR energy distribution function is well described by the diffusion equation in energy space (Figure 2), and in the range of our investigation, the CR particles tend to interact with the largest scale eddy in the accretion flow [5,6].

References

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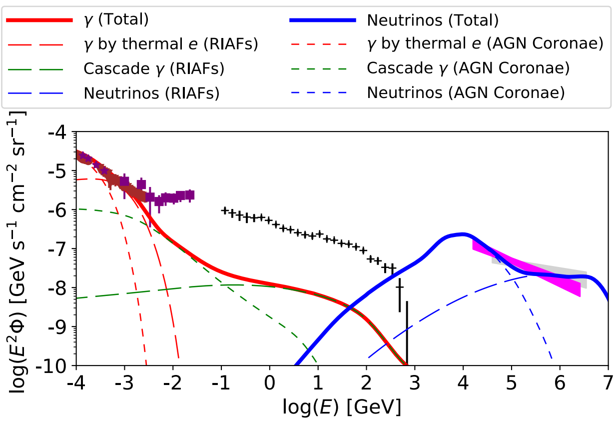

Figure 1: The cosmic gamma-ray (red lines) and neutrino (blue lines) background intensities from AGN accretion flows (taken from Ref. [4]).

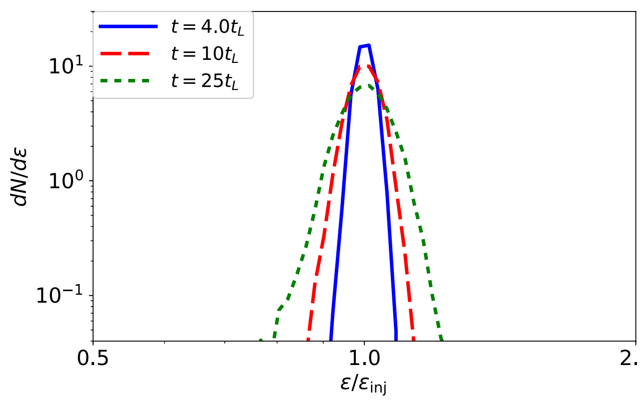

Figure 2: Time evolution of the energy distribution function of the CR particles in MRI turbulence (taken from Ref. [6]).