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Non-thermal Emission from the Vicinity of Stellar-mass and Supermassive black holes

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Stellar-mass black holes and supermassive black holes are actively discussed as the sources of high-energy cosmic rays and gamma-rays. These black holes accrete matter from ambient media and release a large amount of gravitational energy, efficiently emitting multi-wavelength electromagnetic waves. Current generation gamma-ray detectors enable us to detect TeV gamma-ray signals from both stellar-mass and supermassive black holes.

Recent magnetohydrodynamic simulations and radio observations indicate that accretion flows onto supermassive black holes are strongly magnetized. In a highly magnetized accretion flows, non-thermal particles are efficiently accelerated by magnetic reconnection or MHD turbulence. We model the nonthermal emission from the vicinity of the black holes, considering that the magnetic reconnection or MHD turbulence accelerate the non-thermal protons and electrons. In this scenario, thermal electrons, non-thermal electrons, non-thermal protons, and secondary electron-positron pairs will emit multi-wavelength electromagnetic waves. Comparing the prediction to multi-wavelength data, we can discuss particle acceleration efficiency in the system.

First, we apply this model to nearby radio galaxies and confirm that our model can explain GeV gamma-ray data of nearby radio galaxies [1]. Magnetic reconnection can accelerate cosmic ray protons up to 10^{18} eV, and these protons emit GeV gamma-rays via synchrotron radiation. Non-thermal electrons accelerated together with protons emit MeV gamma-rays, which is below the sensitivity of current detectors. Thermal electrons in accretion flows emit radio signals via synchrotron radiation, which contributes to mm wavelengths data (see Fig. 1).

Next, we apply this scenario to Galactic X-ray binaries in quiescent state. The electromagnetic wave predicted from our scenario can reproduce the optical and X-ray data of nearby quiescent X-ray binaries. Considering the uncertainty of number density of quiescent X-ray binaries, our scenario can also reproduce the PeV cosmic rays observed on Earth [2].

Lastly, we apply this model to isolated black holes wandering in interstellar medium and predict the electromagnetic signature from isolated black holes. If isolated black holes are in typical interstellar medium, they likely emit optical and X-ray photons as in quiescent X-ray binaries [3]. If isolated black holes are in molecular clouds, they can accelerate cosmic rays up to PeV energies. These PeV cosmic rays interact with ambient dense gas, producing sub-PeV gamma-rays. This scenario can explain mysterious LHAASO unidentified sources that are undetected in lower-energy gamma-rays [4] (see Fig. 2).

References
[1] Kimura & Toma 2020 ApJ, 905, 178
[2] Kimura, Sudoh, Kashiyama, Kawanaka 2021 ApJ, 915 31
[3] Kimura, Kashiayma, Hotokezaka 2021 ApJL, 922, L15
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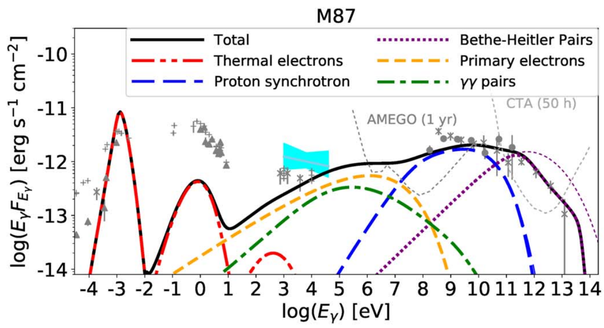

Figure 1: Multiwavelength spectrum from M87. Our model can explain mm wavelength and GeV gamma-ray data.

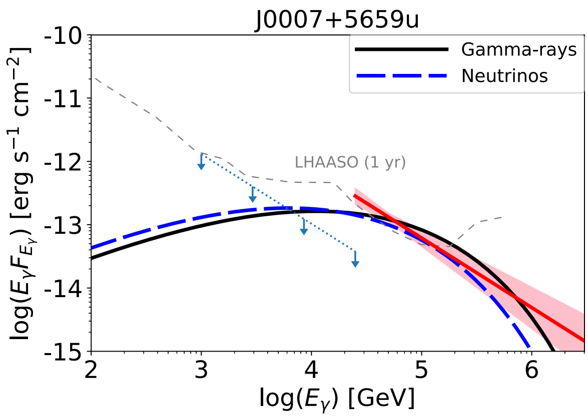

Figure 2: Gamma-ray spectrum from an isolated black hole and comparison to a gamma-ray unidentified source.