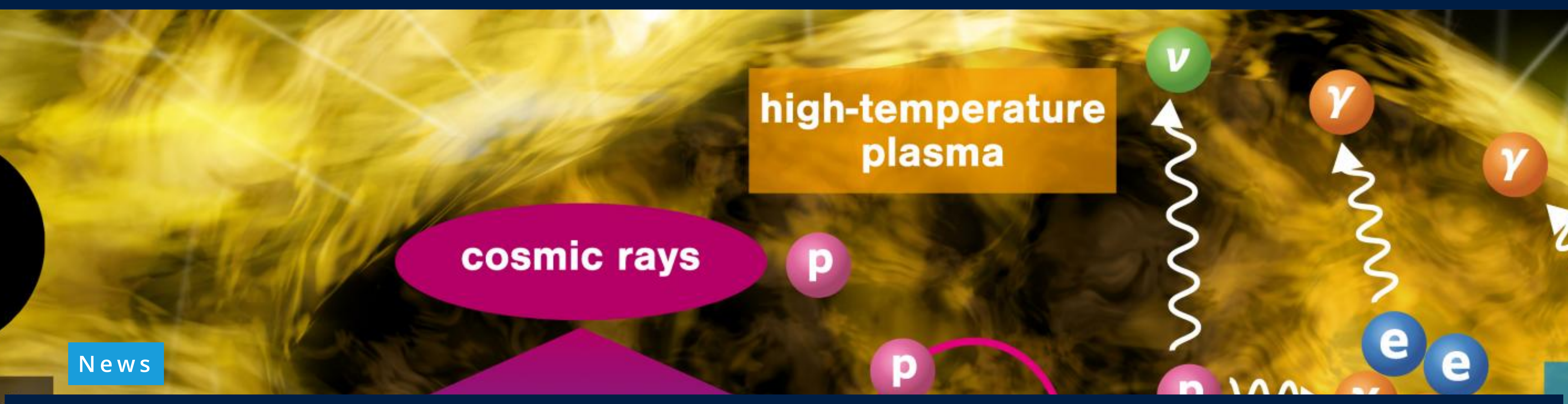

News

Gamma-rays and neutrinos from mellow supermassive black holes

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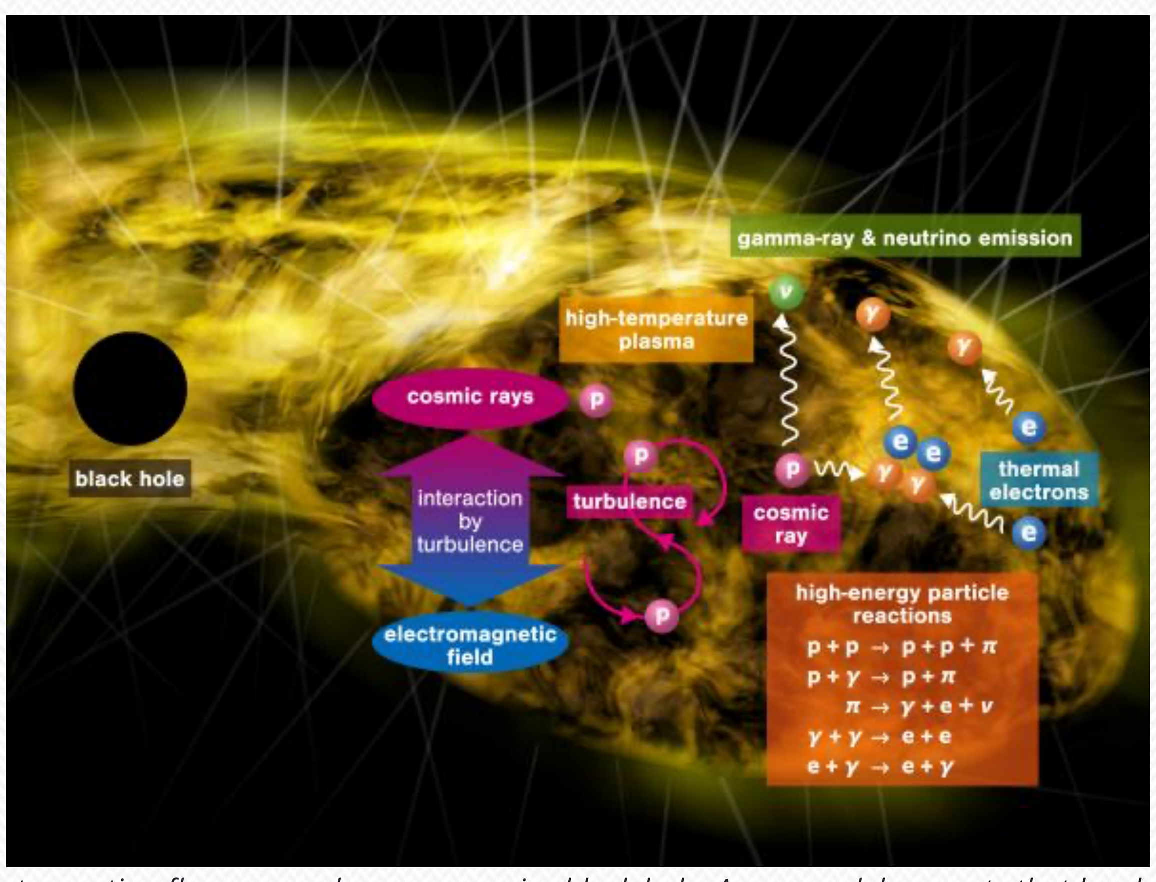
Supermassive black holes, even if they are not so active, can be major factories of high-energy cosmic particles in the universe, according to a new model proposed by an international research team including Penn State scientists. A paper describing the model that may explain the mysterious connection between observed gamma rays, with relatively low energies measured in the megaelectron volt range, and neutrinos appears September 23, 2021 in the journal *Nature Communications*.

"Black holes are ubiquitous in the universe, and galaxies are known to host supermassive black holes at their centers," said **Kohta Murase**, associate professor of physics and of astronomy and astrophysics at Penn State and an author of the paper. "These monster black holes play various roles in the universe. They are thought to be emitters of high-energy gamma rays and neutrinos and in particular the active black holes that are commonly observed with X-rays and gamma rays."

Gamma rays—high-energy photons that are more energetic than visible light by many orders of magnitude—and neutrinos—subatomic particles so tiny that their mass is nearly zero and they rarely interact with other matter—are created by energetic cosmic-ray accelerators in the universe, which include extreme astrophysical objects such as black holes and neutron stars. The high-energy gamma rays, those with energies in the megaelectron to gigaelectron volt range, have been observed by space satellites like the Fermi gamma-ray telescope, and high-energy neutrinos have been measured by the IceCube neutrino observatory buried beneath the ice in Antarctica. However, despite the recent theoretical and observation progress, the origin of these high-energy cosmic particles is still unknown.



A schematic picture of hot accretion flows around a supermassive black hole. A new model suggests that low-luminosity active galactic nuclei may be the dominant sources of high-energy neutrinos and gamma rays observed in the universe. Credit: Shigeo S. Kimura, Tohoku University

"It is widely believed that active supermassive black holes—so-called active galactic nuclei—especially those with powerful jets, are the most promising emitters of high-energy gamma rays and neutrinos," said Murase. "Indeed, many jetted active galactic nuclei have been observed through gamma rays and high-energy neutrino events coincident with their flares have also been reported. However, recent studies have revealed that they are not sufficient to explain the observed gamma rays and neutrinos, suggesting that other sources are necessary."

The new model proposes that not only active black holes but also non-active, "mellow" objects are important as gamma-ray and neutrino factories.

Black holes are not dark. An accretion disk forms when matter falls onto a black hole and a huge amount of gravitational energy is eventually released. The gases in the disk are heated up during accretion, forming high-temperature plasma. In bright active galactic nuclei, the plasma disk cools via efficient radiation. However, when the gas accretion is inefficient, implying that the black hole is not active, the temperature can be kept as high as tens of billions of degrees Celsius and gamma rays can be generated. Such mellow black holes are dim as individual objects, as seen in Sagittarius A—the massive black hole located in the center of the Milky Way galaxy—but they are numerous in the universe. The research team found that the resulting gamma rays from radiatively-inefficient supermassive black holes may be a major contributor to the observed gamma rays especially in the megaelectron volt range.

The new model shares aspects of the physical properties in a scenario proposed in previous research by the Penn State group, which studied high-energy neutrino and gamma-ray production in the high-energy, high-temperature coronal region of active galactic nuclei. In both cases, protons can be accelerated to energies more than 100 or 1000 times higher than those achieved by the Large Hadron Collider—the largest human-made particle accelerator. The accelerated protons then can produce high-energy neutrinos through interactions with matter and radiation, such that supermassive black holes—including both active and non-active galactic nuclei—can explain a large fraction of the observed IceCube neutrinos in a wide energy range.

"Future multi-messenger observational programs are critical," said Murase. "Our proposed scenario predicts electromagnetic counterparts of the neutrino sources in gamma-rays in the megaelectron volt range. Most of the existing gamma-ray detectors, like the Fermi Gamma-ray Space Telescope, are not tuned to detect them. To test our new model, observations with future gamma-ray experiments such as AMEGO-X would be necessary as well as next-generation neutrino experiments such as IceCube-Gen2 and KM3Net."

In addition to Murase, the research team at Penn State includes former Institute for Gravitation and the Cosmos Fellow **Shigeo S. Kimura** and Eberly Chair Professor, Emeritus **Peter Mészáros**. The work was funded by the U.S. National Science Foundation, the Japanese Society for the Promotion of Science, the Penn State Institute for Gravitation and the Cosmos, and the Eberly Foundation.

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