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Supercomputer simulations reveal the nature of turbulence in black hole accretion disks

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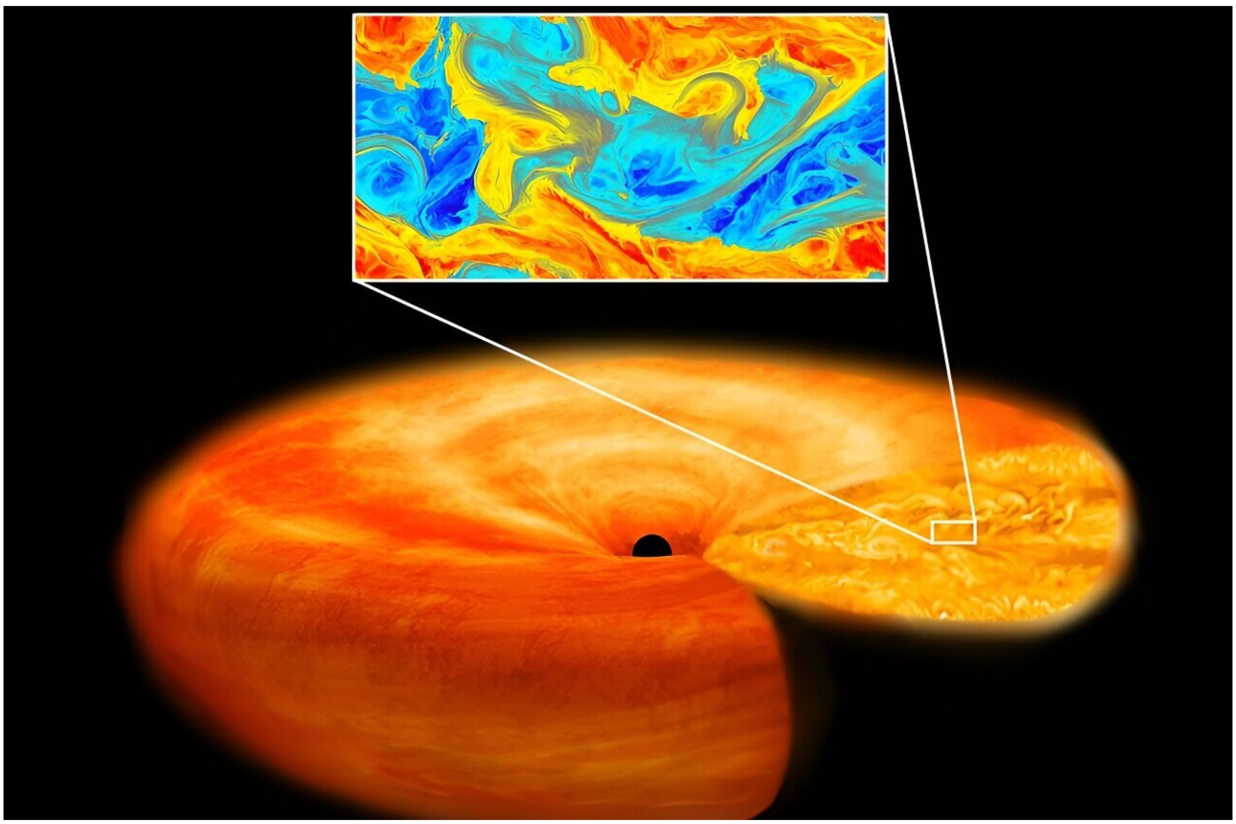


Artistic image of accretion disk turbulence. The inset is the magnetic field fluctuations computed by the simulation of this study. Credit: Yohei Kawazura

Researchers at Tohoku University and Utsunomiya University have made a breakthrough in understanding the complex nature of turbulence in structures called accretion disks surrounding black holes, using state-of-the-art supercomputers to conduct the highest-resolution simulations to date.

An accretion disk, as the name implies, is a disk-shaped gas that spirals inward toward a central black hole.

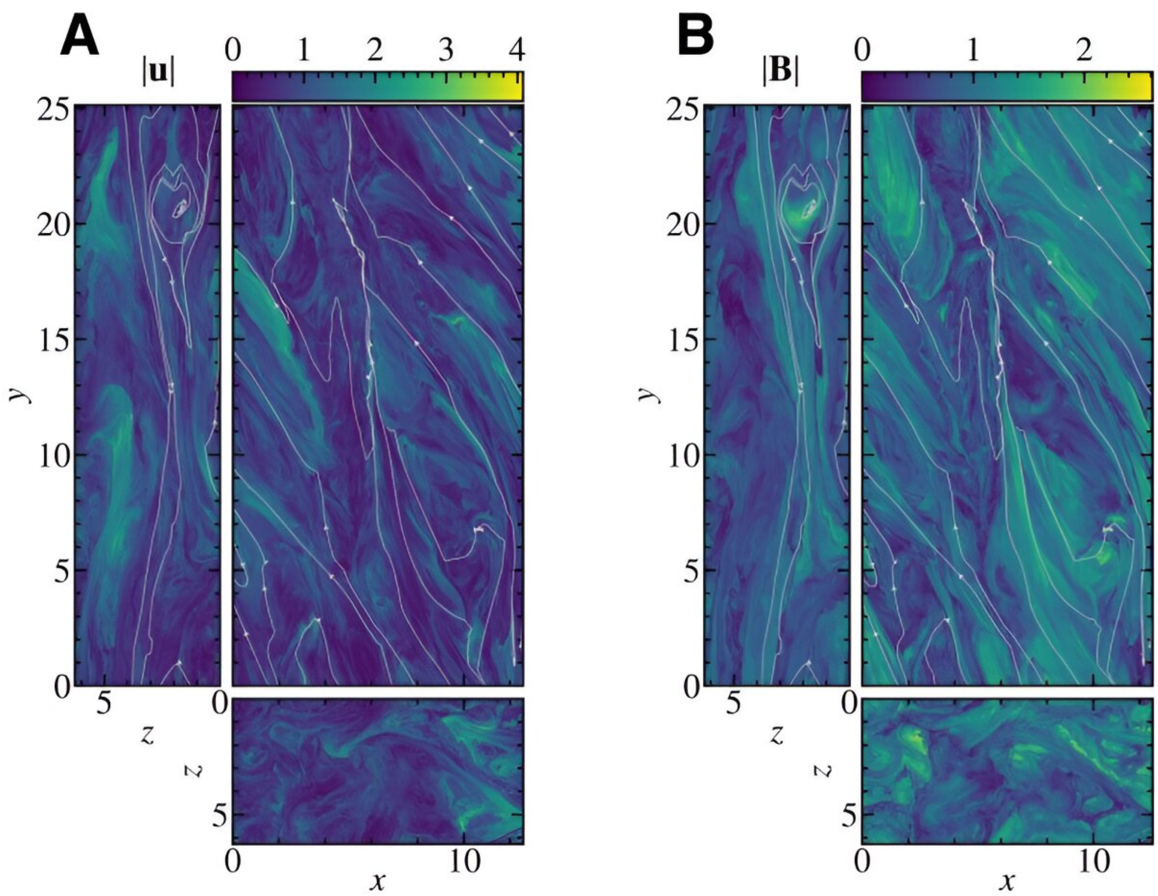
There is a great interest in studying the unique and extreme properties of black holes. However, black holes do not allow light to escape, and therefore cannot be directly perceived by telescopes.

In order to probe black holes and study them, we instead look at how they affect their surroundings. Accretion disks are one such way to indirectly observe the effects of black holes, as they emit electromagnetic radiation that can be seen by telescopes.

"Accurately simulating the behavior of accretion disks significantly advances our understanding of physical phenomena around black holes," explains Yohei Kawazura, "It provides crucial insights for interpreting observational data from the Event Horizon Telescope."

The researchers utilized supercomputers such as RIKENs Fugaku (the fastest computer in the world up until 2022) and NAOJs ATERUI II to perform unprecedentedly high-resolution simulations.

The study was published in *Science Advances* on August 28, 2024.



The spatial structures of magnetorotational turbulence in an accretion disk (modeled). (A) shows the flow and (B) shows the magnetic field intensity. White lines represent typical magnetic field lines. Credit: Yohei Kawazura; from *Science Advances* (2024). DOI: 10.1126/sciadv.adp4965

Although there have been previous numerical simulations of accretion disks, none have observed the inertial range because of the lack of computational resources. This study was the first to successfully reproduce the "inertial range" connecting large and small eddies in accretion disk turbulence.

It was also discovered that "slow magnetosonic waves" dominate this range. This finding explains why ions are selectively heated in accretion disks. The turbulent electromagnetic fields in accretion disks interact with charged particles, potentially accelerating some to extremely high energies.

In magnetohydronamics, magnetosonic waves (slow and fast) and Alfvén waves make up the basic types of waves. Slow magnetosonic waves were found to dominate the inertial range, carrying about twice the energy of Alfvén waves. The research also highlights a fundamental difference between accretion disk turbulence and solar wind turbulence, where Alfvén waves dominate.

This advancement is expected to improve the physical interpretation of observational data from radio telescopes focused on regions near black holes.

More information: Yohei Kawazura et al, Inertial range of magnetorotational turbulence, *Science Advances* (2024). DOI: 10.1126/sciadv.adp4965

Provided by Tohoku University