FEEDING BLACK HOLES: TILT WITH A TWIST

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EXECUTIVE SUMMARY

Accretion disks are typically tilted relative to the black hole rotational equator. Lack of symmetries makes numerical studies of such disks particularly challenging, especially on the curved spacetime of a rapidly spinning black hole. The GPU partition of Blue Waters enabled the research team for the first time to simulate such disks in full general relativity. The team found that, contrary to standard expectations, tilted disks tear up into individually precessing subdisks. If torn disks are prevalent around black holes, this calls for a reconsideration of the black hole accretion theory.

RESEARCH CHALLENGE

Tilted accretion is common in astrophysical systems. In fact, researchers expect that nearly all black hole accretion disks are tilted at some level relative to the black hole rotational equator. This is because the gas that approaches the black hole from large distances has no idea which way the black hole is spinning. However, studies of such tilted accretion are extremely challenging, especially in the crucial regime of luminous, radiatively efficient accretion that powers bright quasars. Such accretion disks are razor-thin and difficult to resolve numerically, requiring high resolutions and adaptive grids to follow the body of the disk as it moves through the computational grid.

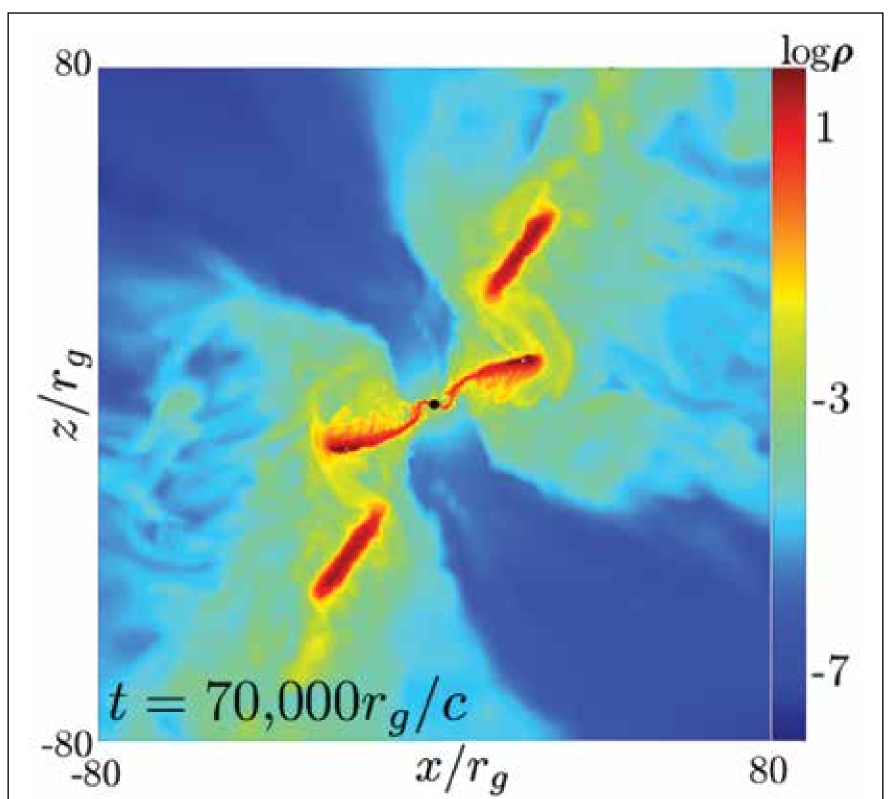

Figure 1: The inner part of a disk of half-thickness h/r = 0.03 tilted by 60° tears off from the outer misaligned part of the disk and precesses independently. This is the first demonstration of the disk tearing in a GRMHD (general relativistic magnetohydrodynamic) numerical simulation.

Figure 2: A tilted accretion disk around a spinning black hole tears up into several individual, independently precessing subdisks (blue). The jets (orange), produced by magnetized rotation of the central black hole, escape along the path of least resistance.

METHODS & CODES

Using the research team's new code, H-AMR [2] (pronounced "hammer"), which includes adaptive mesh refinement, local adaptive timestepping, and runs efficiently on GPUs, the research team was able to overcome the above challenges. H-AMR performs 10 times faster on a GPU than on a similar vintage 16-core CPU. H-AMR is parallelized via MPI with domain decomposition and scales well to thousands of GPUs, achieving weak scaling efficiency of 85% on 4,096 GPUs on the Blue Waters supercomputer. The performance of the code allowed the team to study tilted discs at higher resolutions and over longer durations than was previously possible.

RESULTS & IMPACT

The simulations carried out on Blue Waters' GPU partition revealed that the frame dragging of a spinning black hole can tear up tilted accretion disks into several individually precessing subdisks [1]. This can lead to complex, variable disk emission as the orientation of subdisks changes in time, and high-energy emission, as a result of jets running into subdisks.

WHY BLUE WATERS

Access to Blue Waters has been instrumental in obtaining these groundbreaking results, which require not only enormous amounts of computing power but also fast interconnect speeds to make use of hundreds of XK nodes. As in the past, Mark Van Moer helped enormously with 3D visualization.

PUBLICATIONS & DATA SETS

M. Liska *et al.*, "Disc tearing and bardeen–petterson alignment in grmhd simulations of highly tilted thin accretion discs, submitted to *Mon. Notices Royal Astron. Soc.*, 2019, arXiv:1904.08428.

M. Liska, C. Hesp, A. Tchekhovskoy, A. Ingram, M. van der Klis, and S. Markoff, "Formation of precessing jets by tilted black hole discs in 3D general relativistic MHD simulations," *Mon. Notices Royal Astron. Soc.*, vol. 474, no. 1, pp. L81–L85, Feb. 2018.