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Accelerating jets from black holes

An international team of researchers used multi-wavelength observations of active galactic nuclei to study how black holes launch relativistic jets. The sixteen sources were observed with the Event Horizon Telescope during its first campaign in 2017. The extreme resolution achieved by the Event Horizon Telescope enabled studies of jets closer than ever to the central supermassive black holes of these galaxies. The team investigated the acceleration and magnetization of the jets by comparing results obtained at various frequencies and angular scales. The work was led by scientists from the MPIfR in Bonn, Germany, and the IAA-CSIC in Granada, Spain.

To assess the accuracy in understanding the evolution of jets in the centers of active galaxies with supermassive black holes, an international research team led by Jan Röder (MPIfR and IAA-CSIC) compared observations made with the Event Horizon Telescope with previous studies using the Very Long Baseline Array and the Global Millimeter VLBI Array, which probe much larger spatial scales. From this comparison, they could infer how jets evolve from their origins near the black hole to many light-years into interstellar space. The intensity of radiation emitted from a given region in the sky, measured as brightness temperature, generally increases as the emitting jet plasma moves farther from the black hole.

“Our findings challenge long-standing assumptions about how jets behave,” says Jan Röder. “By analyzing a sample of sixteen active galactic nuclei, we were able to reduce the influence of individual peculiarities and obtain a broader picture of jet behavior.”
In the most common model, jets are assumed to be conical, containing plasma moving with constant velocity, while the magnetic field strength and density of the jet plasma decay with growing distance from the central engine. Based on these assumptions, predictions can be made about the observable properties of jets.

“This basic model cannot be a perfect description for all jets– most likely, only for a small fraction. The dynamics and sub-structure of jets are intricate, and observational results can suffer greatly from astrophysical degeneracies,” continues Jan Röder. “For example, we know that many jets appear to accelerate. Either the plasma itself accelerates, or it can be an effect of geometry: if the jet bends, it may point at us more directly, giving the impression of faster movement.”

“Using a sample of sixteen Active Galactic Nuclei, we were able to get a broader picture on the behavior of jets, compared to just looking at individual sources. This way, the results are less prone to influence from their respective unique properties,” says project co-leader Maciek Wielgus from IAA-CSIC. “We noticed that the brightness of jets typically increases with growing distance from the black hole, strongly suggesting acceleration.”

Eduardo Ros, also from MPIfR and European Scheduler of the Global Millimeter VLBI Array, highlights the importance of the intermediate-scale observations: “The Global Millimeter VLBI Array operating at 3.5 mm wavelength provides the key information between the highest resolutions achieved by the EHT and the more general picture of jets provided by the Very Long Baseline Array. This was evident in the case of M87, as presented by RuSen Lu and collaborators in April

2023."

Active galactic nuclei, the bright hearts of some galaxies, are powered by supermassive black holes. Powerful plasma jets emerge from some of these objects, reaching out many thousands of light years into intergalactic space. To understand the complicated physics behind this phenomenon, observations with extreme angular resolution are required, allowing astronomers to peer into the realm close to the origin of the jet.

The Event Horizon Telescope (EHT) is an array of radio telescopes scattered across the globe, working together to form a virtual telescope the size of the Earth which provides the resolution required to study black holes and their jets. The EHT is operated by an international collaboration of hundreds of scientists, and delivered the first-ever images of supermassive black holes, at the centers of the Milky Way (Sagittarius A*) and M87. Alongside these main targets, the EHT observed a number of Active Galactic Nuclei during its 2017 campaign.

In order to assess how accurate – or inaccurate – the understanding of the evolution of jets is, the researchers compared the EHT results with previous observations of the same sources. These had been carried out with the Very Long Baseline Array and the Global Millimeter VLBI Array, probing much larger spatial scales than the EHT. From this comparison, it was possible to infer the evolution of jets from close to their origins, up to many light years into interstellar space. The radiative power per solid angle received from a given source, measured by the brightness temperature, gradually increases as the emitting jet plasma gets farther and farther away from the black hole.

While there are alternative explanations of these new observations, like a deviation from the conical geometry, the basic theoretical model clearly cannot fully reproduce the properties of jets close to their origin. "More studies are needed to fully understand the acceleration mechanism, the flow of energy, the role of magnetic fields in jets of Active Galactic Nuclei, and their geometries. The expanding EHT array will play an important role in the future discoveries on these fascinating objects.," says Jan Röder.

J. Anton Zensus, director at the MPIfR and founding chair of the EHT collaboration, concludes: "These results are based on the ongoing work of the EHT and are confirmed by the Global Millimeter VLBI Array studies. They demonstrate the importance of global partnerships, cutting-edge technologies and persistent research for scientific progress. With new telescopes and the next generation of networks, we will continue to deepen our understanding of these fascinating cosmic phenomena."

The data of OJ 287 are based on a 2017 EHT proposal with Stefanie Komossa and Thomas Krichbaum as CO-PIs from the MPIfR.

Additional Information

The EHT collaboration involves more than 400 researchers from Africa, Asia, Europe, North and South America, with close to 300 participating in this paper. The international collaboration set out to capture the most detailed images of black holes using a virtual Earth-sized telescope, and in the process also produced unprecedented results on Active Galactic Nuclei. Supported by considerable international efforts, the EHT links existing telescopes using novel techniques, creating a fundamentally new instrument, reaching extreme angular resolution.

The EHT consortium consists of 13 stakeholder institutes: the Academia Sinica Institute of Astronomy and Astrophysics, the University of Arizona, the Center for Astrophysics | Harvard & Smithsonian, the University of Chicago, the East Asian Observatory, the Goethe University Frankfurt am Main, the Institut de Radioastronomie Millimétrique, the Large Millimeter Telescope, the Max Planck Institute for Radio Astronomy, the MIT Haystack

Observatory, the National Astronomical Observatory of Japan, the Perimeter Institute for Theoretical Physics, and the Radboud University.

The AGN analyzed in this study were observed with subsets of the eight telescope stations present in the EHT 2017 array: the Atacama Large Millimeter/submillimeter Array (ALMA), the Atacama Pathfinder Experiment (APEX), the Institut de Radioastronomie Millimetrique (IRAM) 30-meter Telescope, the James Clerk Maxwell Telescope (JCMT), the Large Millimeter Telescope Alfonso Serrano (LMT), the Submillimeter Array (SMA), the UArizona Submillimeter Telescope (SMT), and the South Pole Telescope (SPT).

The data were processed at the correlator facilities at the MPI for Radio Astronomy in Bonn, Germany, and MIT/Haystack Observatory in Massachusetts, USA. Since 2017, the EHT has added the Greenland Telescope (GLT), the IRAM Northern Extended Millimeter Array (NOEMA) and the UArizona 12-meter Telescope on Kitt Peak to its network.

Authors of the publication affiliated with MPIfR include the first author, Jan Röder, and Maciek Wielgus, Andrei P. Lobanov, Thomas P. Krichbaum, Dhanya G. Nair, Eduardo Ros, Michael Janssen, Anne-Kathrin Baczko, Ru-Sen Lu, Georgios F. Paraschos, Efthalia Traianou, Daewon Kim and Yuri Y. Kovalev. The following scientists with MPIfR affiliation are also co-authors of the publication: Walter Alef, Rebecca Azulay, Uwe Bach, Silke Britzen, Gregory Desvignes, Sergio A. Dzib, Ralph Eatough, Christian M. Fromm, Dong-Jin Kim, Jae-Young Kim, Joana A. Kramer, Michael Kramer, Mikhail Lisakov, Jun Liu, Kuo Liu, Nicholas R. MacDonald, Nicola Marchili, Karl M. Menten, Cornelia Müller, Gisela Ortiz-Leon, Helge Rottmann, Alan L. Roy, Lijing Shao, Pablo Torne, Jan Wagner, Robert Wharton, Gunther Witzel, J. Anton Zensus, and Guang-Yao Zhao.

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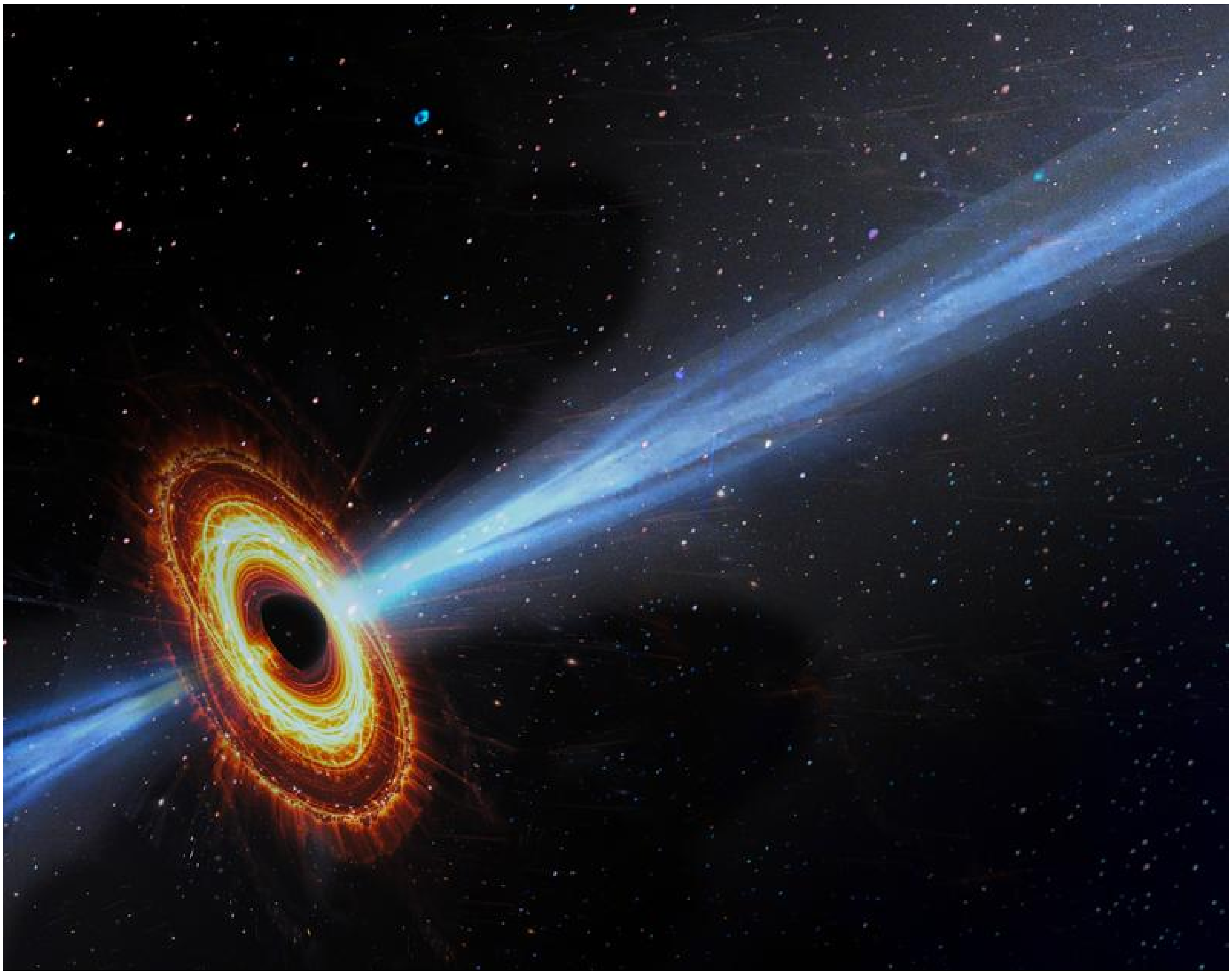
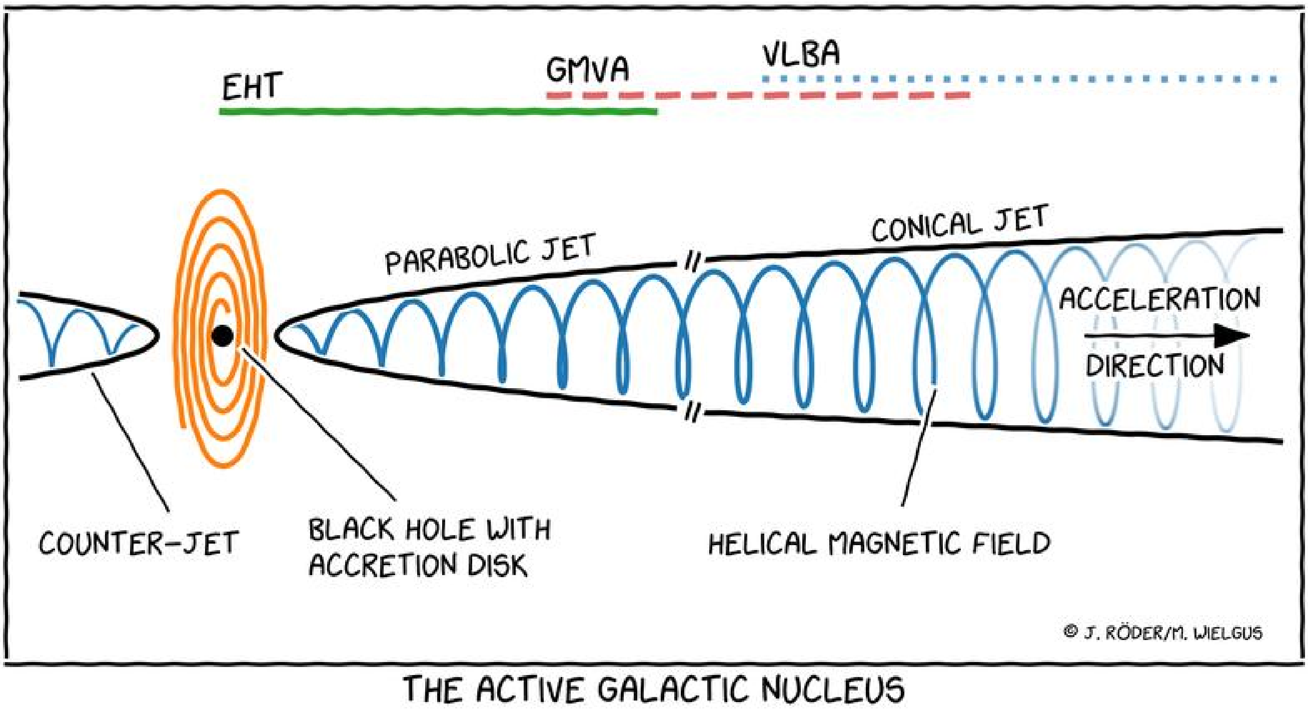


Artist’s impression of an active galactic nucleus.
Juan Carlos Algaba



Schematic view of an active galactic nucleus (AGN). From the black hole and its accretion disk, the relativistic jet is launched in a parabolic geometry, later transitioning to a conical appearance.
Jan Röder/Maciek Wielgus