Violent gamma-ray outbursts near supermassive black holes

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An artist’s view of the nuclear region of an active galaxy: a disk of accreting material (brown/yellow) spirals in onto the central supermassive black hole (black). A powerful, collimated radio jet (blue) is launched perpendicular to the disk. Inside the jet gamma-ray photons are also produced. The new findings demonstrate that the gamma-ray emission originates from the innermost region of the radio jet (white). For the active galaxy 3C 454.3 the authors estimate a distance of only a few light years from the supermassive black hole. The galaxy is in the direction of Pegasus and its signal reaches Earth after a light travel time of approx. 7 billion years. Credit: © NASA JPL/CalTech

(Phys.org) —Where in powerful jets of distant active galaxies—the mightiest and most energetic objects known—are the violent outbursts of high energy gamma-ray emission produced? Very close to the central supermassive black hole and accretion disk powering these systems, or at larger distances from the "central engine," i.e. further downstream in the jet? New insights into this long-standing question became possible recently, thanks to intensive, multi-frequency radio observations of powerful active galaxies.

An international team of astronomers led by Lars Fuhrmann from the Max Planck Institute for Radio Astronomy in Bonn, Germany, used some of the best single-dish radio telescopes for several years, in combination with NASA's Fermi Gamma-ray Space Telescope, to study the place where the high energy outbursts occur. For the first time a connection between dramatic outbursts of high energy gamma-ray emission and their counterparts at many radio frequencies has been established for a large sample of galaxies. Measuring delays in time between these events finally produced better constraints on the exact location in the vicinity of supermassive black holes where the gamma-ray outbursts take place.

The results were published in the current issue of *Monthly Notices of the Royal Astronomical Society*.

Special types of distant active galaxies and their innermost central regions show extreme physical processes. In the vicinity of a spinning supermassive black hole (billions of times heavier than our Sun) an enormous amount of energy is released, often in the most energetic form of light: high energy gamma-ray photons at mega- or even gigaelectronvolt (MeV/GeV) energies. This energy output is produced by feeding the black hole from surrounding stars, gas and dust. Matter is spiraling in onto the black hole and strong magnetic fields channel some of the infalling gas into two powerful, well collimated "jets" of plasma accelerating away from the center with velocities approaching the speed of light. Many of the connected physical processes are not understood in detail so far, for example the production of high-energy gamma-ray photons and their place of origin inside the jet, or the origin of strong outbursts of emission across the whole electromagnetic spectrum. New instruments and observing programs covering a large fraction of the whole energy spectrum nearly simultaneously allow new insights into the extreme physics of these objects to be obtained.

Telescopes utilized for the data acquisition in the radio and y-ray regime. Clockwise from upper left: Effelsberg 100m, APEX 12m, Fermi g-ray observatory and IRAM 30m. Credit: © MPIfR/N. Junkes (100m), APEX-Team (12m), NASA E/PO, Sonoma State University, Aurore Simonnet (Fermi), MPIfR (30m).

Using a combination of three of the world's most advanced single-dish radio observatories, namely the Effelsberg 100-m, IRAM 30-m and APEX 12-m telescopes covering quasi-simultaneously 11 radio frequency bands (the so-called Fermi-GST AGN Multi-frequency Monitoring Alliance, F-GAMMA program), the team of scientists was able to monitor the frequently occurring radio outbursts of about 60 powerful active galaxies over many years. "Since the era of the EGRET instrument on the Compton Gamma Ray Observatory in the 1990s, it has been discussed whether outbursts of radio emission are physically connected to similar events occurring at gamma rays" says Anton Zensus, Director at the Max Planck Institute for Radio Astronomy (MPIfR) and Fermi Affiliated Scientist. "Now with the combination of F-GAMMA radio and Fermi gamma-ray long-term data, and thanks to special analysis techniques, we finally know it!"

In addition to radio data within the F-GAMMA program, the research team used gamma-ray observations of NASA's Fermi Gamma-ray Space Telescope (launched in 2008), and a new statistical method to add up many radio and gamma-ray events. "It was illuminating to see the statistical noise going down and the average correlation popping up" explains Stefan Larsson, from Stockholm University. "This finally demonstrates that a significant connection exists, even when using different radio frequencies" he continues. The study furthermore shows that the radio outbursts arrived at the telescopes later in time than their gamma-ray counterparts, with mean delays between 10 and 80 days. "For the first time we see that the radio delays become smoothly smaller towards higher radio frequencies," adds Emmanouil Angelakis from MPIfR. "Towards higher frequencies we are looking deeper into the jet. The gamma-ray photons are thus coming from the innermost radio emitting jet regions."

Using the measured time delays the team was finally able to estimate distances of a few ten light-years or less between the radio and gamma-ray outburst regions. "Based on our delay measurements we could estimate for one of the brightest gamma-ray emitting active galaxies in the sky, 3C 454.3, how far away from the supermassive black hole most of the gamma-ray photons must have been produced. We are talking about only a few light-year distances—very close to the footpoint of the jet and the black hole itself!" proudly reports Lars Fuhrmann from MPIfR, the lead author of the paper. "This has serious implications for the physical processes producing the gamma-ray photons!" he adds. In the meantime the team is continuing to use the "Joint Eye" on the universe to collect more data and more events for detailed follow-up studies.

More information: "Detection of significant cm to sub-mm band radio and gamma-ray correlated variability in Fermi bright blazars," L. Fuhrmann, S. Larsson, J. Chiang, E. Angelakis, J. A. Zensus, I. Nestoras, T. P. Krichbaum, H. Ungerechts, A. Sievers, V. Pavlidou, A. C. S. Readhead, W. Max-Moerbeck, and T. J. Pearson, 2014, *MNRAS*, 441, 1899-1909; mnras.oxfordjournals.org/conte … /441/3/1899.abstract, Preprint: arxiv.org/abs/1403.4170.

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