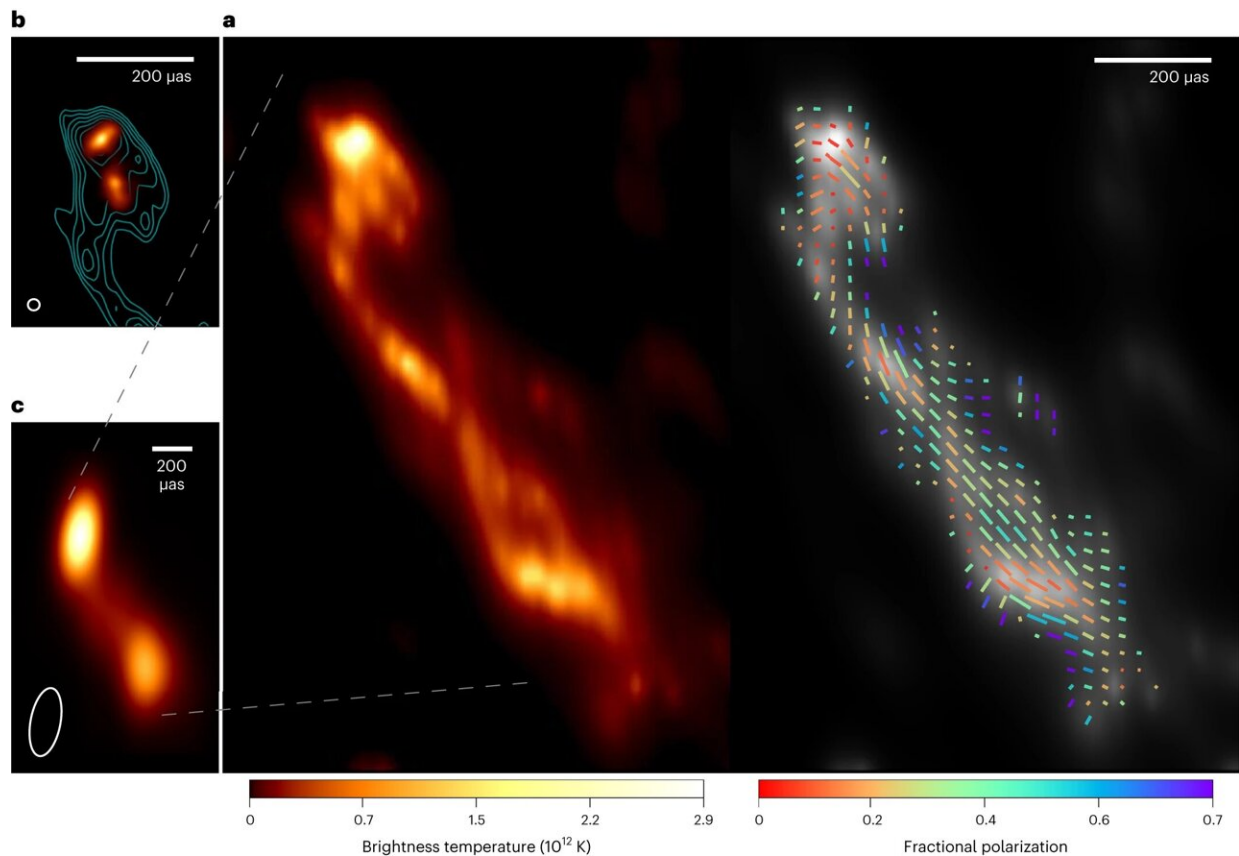


Astronomers capture formation of a powerful cosmic jet

October 26 2023, by Norbert Junkes



The filamentary structure of the jet in 3C 279 revealed by RadioAstron. **a**, Total intensity (left) and linearly polarized (right) RadioAstron image at 1.3 cm obtained on 10 March 2014. While both images in **a** show brightness temperature (color scale), the image on the right also shows the recovered electric vector position angles overlaid as ticks. Their length and color are proportional to the level of linearly polarized intensity and fractional polarization, respectively. **b**, The 1:1 scale 1.3 mm EHT image obtained in April

2017. Contours correspond to our RadioAstron image, and are shown to compare the different scales probed. These start at 90% of the peak brightness and decrease by successive factors of 3/2 until they reach 5%. Both images were aligned with respect to the pixel with maximum brightness. **c**, The 7 mm VLBA-BU-BLAZAR program image obtained on 25 February 2014. White ellipses at the bottom-left corners of **b** and **c** indicate the $20 \times 20 \mu\text{as}^2$ and $150 \times 360 \mu\text{as}^2$ convolving beams, respectively. The color bars refer only to information displayed in **a**. Credit: <https://www.nature.com/articles/s41550-023-02105-7>

Using a network of radio telescopes on Earth and in space, astronomers have captured the most detailed view ever of a jet of plasma from a supermassive black hole. The jet travels at nearly the speed of light and shows complex, twisted patterns near its source. These patterns challenge the standard theory that has been used for 40 years to explain how these jets form and change over time.

A major contribution to the observations was made possible by the Max Planck Institute for Radio Astronomy in Bonn, Germany, where the data from all participating telescopes were combined to create a virtual [telescope](#) with an effective diameter of about 100,000 kilometers.

Blazars are the brightest and most powerful sources of electromagnetic radiation in the cosmos. They are a subclass of active galactic nuclei comprising galaxies with a central supermassive black hole accreting matter from a surrounding disk. About 10% of active galactic nuclei, classified as quasars, produce relativistic plasma jets.

Blazars belong to a small fraction of quasars in which we can see these jets pointing almost directly at the observer. Recently, a team of researchers including scientists from the Max Planck Institute for Radio Astronomy (MPIfR) in Bonn, Germany, has imaged the innermost region of the jet in the blazar 3C 279 at an unprecedented angular

resolution and detected remarkably regular helical filaments which may require a revision of the theoretical models used until now for explaining the processes by which jets are produced in active galaxies.

"Thanks to RadioAstron, the [space mission](#) for which the orbiting radio telescope reached distances as far away as the moon, and a network of twenty-three radio telescopes distributed across the Earth, we have obtained the highest-resolution image of the interior of a blazar to date, allowing us to observe the internal structure of the jet in such detail for the first time," says Antonio Fuentes, a researcher at the Institute of Astrophysics of Andalusia (IAA-CSIC) in Granada, Spain, leading the work.

The new window on the universe opened by the RadioAstron mission has revealed new details in the plasma jet of 3C 279, a blazar with a [supermassive black hole](#) at its core. The jet has at least two twisted filaments of plasma extending more than 570 light-years from the center.

"This is the first time we have seen such filaments so close to the jet's origin, and they tell us more about how the black hole shapes the plasma. The inner jet was also observed by two other telescopes, the GMVA and the EHT, at much shorter wavelengths (3.5 mm and 1.3 mm), but they were unable to detect the filamentary shapes because they were too faint and too large for this resolution," says Eduardo Ros, a member of the research team and European scheduler of the GMVA.

"This shows how different telescopes can reveal different features of the same object," he adds.

The jets of plasma coming from blazars are not really straight and uniform. They show twists and turns that show how the plasma is affected by the forces around the black hole. The astronomers studying

these twists in 3C 279, called helical filaments, found that they were caused by instabilities developing in the jet plasma.

In the process, they also realized that the old theory they had used to explain how the jets changed over time no longer worked.

Hence, new theoretical models are needed that can explain how such helical filaments form and evolve so close to the jet origin. This is a great challenge, but also a great opportunity to learn more about these amazing cosmic phenomena.

"One particularly intriguing aspect arising from our results is that they suggest the presence of a helical [magnetic field](#) that confines the jet," says Guang-Yao Zhao, presently affiliated to the MPIfR and member of the scientists team. "Therefore, it could be the magnetic field, which rotates clockwise around the jet in 3C 279, that directs and guides the jet's plasma moving at a speed of 0.997 times the speed of light."

"Similar helical filaments were observed in extragalactic jets before, but on much larger scales where they are believed to result from different parts of the flow moving at different speeds and shearing against each other," adds Andrei Lobanov, another MPIfR scientist in the researchers team. "With this study, we are entering an entirely novel terrain in which these filaments can be actually connected to the most intricate processes in the immediate vicinity of the black hole producing the jet."

The study of the inner jet in 3C 279, now [featured](#) in the latest issue of *Nature Astronomy*, extends the ongoing strive to understand better the role of magnetic fields in the initial formation of relativistic outflows from active galactic nuclei. It stresses the numerous remaining challenges for the current theoretical modeling of these processes and demonstrates the need for further improvement of radio astronomical instruments and techniques which offer the unique opportunity for

imaging distant cosmic objects at a record angular resolution.

Using a special technique called Very Long Baseline Interferometry (VLBI), a virtual telescope with an effective diameter equal to the maximum separation between the antennas involved in an observation is created by combining and correlating data from different radio observatories.

RadioAstron project scientist Yuri Kovalev, now at the MPIfR, emphasizes the importance of healthy international collaboration to achieve such results: "Observatories from twelve countries have been synchronized with the space antenna using hydrogen clocks, forming a [virtual telescope](#) the size of the distance to the moon."

Anton Zensus, director of the MPIfR and one of the driving forces behind the RadioAstron mission over the last two decades, states, "The experiments with RADIOASTRON that led to images like these for the quasar 3C 279 are exceptional achievements possible through international scientific collaboration of observatories and scientists in many countries. The mission took decades of joint planning before the satellite's launch. Making the actual images became possible by connecting large telescopes on the ground like Effelsberg and by a careful analysis of the data in our VLBI correlation center in Bonn."

More information: Antonio Fuentes et al, Filamentary structures as the origin of blazar jet radio variability, *Nature Astronomy* (2023). [DOI: 10.1038/s41550-023-02105-7](https://doi.org/10.1038/s41550-023-02105-7)

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