NASA's IXPE fires up astronomers with new blazar findings

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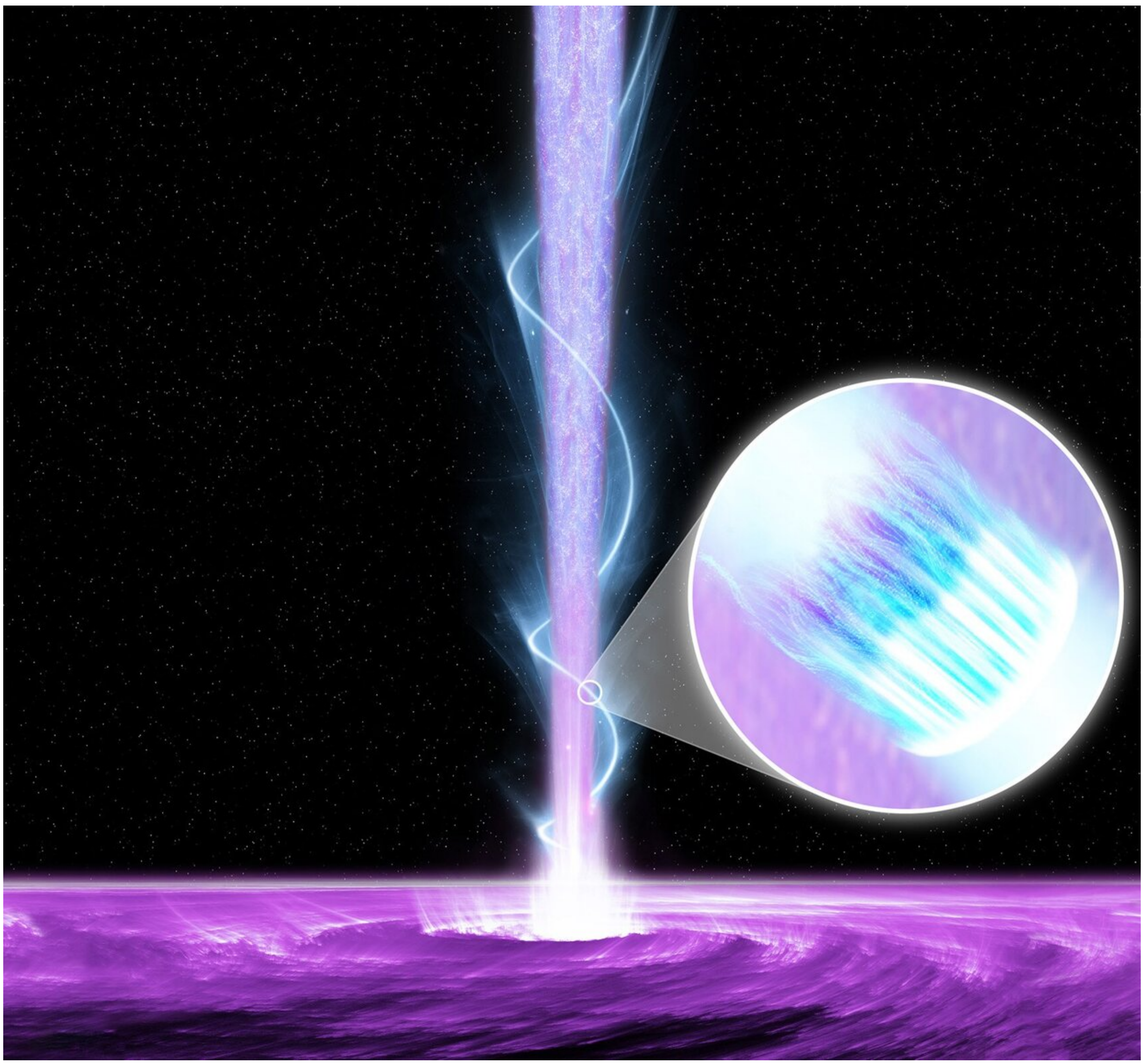

This NASA illustration shows the structure of a black hole jet as inferred by recent observations of the blazar Markarian 421 by the Imaging X-ray Polarimetry Explorer (IXPE). The jet is powered by an accretion disk, shown at the bottom of the image, which orbits and falls into the black hole over time. Helical magnetic fields are threaded through the jet. IXPE observations have shown that the X-rays must be generated in a shock originating within material spiraling around the helical magnetic fields. The inset shows the shock front itself. X-rays are generated in the white region nearest the shock front, whereas optical and radio emission must originate from more turbulent regions further away from the shock. Credit: NASA/Pablo Garcia

The universe is full of powerful supermassive black holes that create powerful jets of high-energy particles, creating sources of extreme brightness in the vastness of space. When one of those jets points directly at Earth, scientists call the black hole system a blazar.

To understand why particles in the jet move with great speeds and energies, scientists look to NASA's IXPE (Imaging X-ray Polarimetry Explorer), which launched in December 2021. IXPE measures a special property of X-ray light called polarization, which has to do with the organization of electromagnetic waves at X-ray frequencies.

An international team of astrophysicists have published new findings from IXPE about a blazar called Markarian 421. This blazar, located in the constellation Ursa Major, roughly 400 million light-years from Earth, surprised scientists with evidence that in the part of the jet where particles are being accelerated, the magnetic field has a helical structure.

"Markarian 421 is an old friend for high-energy astronomers," said Italian Space Agency astrophysicist Laura Di Gesu, lead author of the new paper. "We were sure the blazar would be a worthwhile target for IXPE, but its discoveries were beyond our best expectations, successfully demonstrating how X-ray polarimetry enriches our ability to probe the complex magnetic field geometry and particle acceleration in different regions of relativistic jets."

The new study detailing the IXPE team's findings at Markarian 421 is available in the latest edition of *Nature Astronomy*.

Jets like the one beaming out of Markarian 421 can extend millions of light-years in length. They are especially bright because as particles approach the speed of light, they give off a tremendous amount of energy and behave in weird ways that Einstein predicted. Blazar jets are extra bright because, just like an ambulance siren sounds louder as it approaches, light pointed toward us also appears brighter. That's why blazars can outshine all of the stars of the galaxies they inhabit.

Despite decades of study, scientists still don't fully grasp the physical processes that shape the dynamics and emission of blazar jets. But IXPE's groundbreaking X-ray polarimetry—which measures the average direction of the electric field of light waves—gives them an unprecedented view of these targets, their physical geometry, and where their emissions originate.

Research models for the typical outflow of the powerful jets typically depict a spiraling helix structure, similar to the way human DNA is organized. But scientists did not expect that the helix structure would contain regions of particles being accelerated by shocks.

IXPE found surprising variability in the polarization angle during three prolonged observations of Markarian 421 in May and June 2022.

"We had anticipated that the polarization direction might change but we thought large rotations would be rare, based on previous optical observations of many blazars," said Herman Marshall, research physicist at the Massachusetts Institute of Technology in Cambridge and a coauthor of the paper. "So, we planned several observations of the blazar, with the first showing a constant polarization of 15%."

Remarkably, he added, initial analysis of the polarization data from IXPE appeared to show it dropped to zero between the first and second observations.

"Then we recognized that the polarization was actually about the same but its direction literally pulled a U-turn, rotating nearly 180 degrees in two days," Marshall said. "It then surprised us again during the third observation, which started a day later, to observe the direction of polarization continuing to rotate at the same rate."

Stranger still was that concurrent optical, infrared, and radio measurements showed no change in stability or structure at all—even when the polarized X-ray emissions deviated. This means that a shockwave could be propagating along spiraling magnetic fields inside the jet.

The concept of a shockwave accelerating the jet's particles is consistent with theories about Markarian 501, a second blazar observed by IXPE that led to a published study in late 2022. But its cousin Markarian 421 shows more clearcut evidence of a helical magnetic field contributing to the shock.

Di Gesu, Marshall, and their colleagues are eager to conduct further observations of Markarian 421 and other blazars to learn more about these jet fluctuations and how frequently they occur.

"Thanks to IXPE, it's an exciting time for studies of astrophysical jets," Di Gesu said.

More information: Laura Di Gesu et al, Discovery of X-ray polarization angle rotation in the jet from blazar Mrk 421, *Nature Astronomy* (2023). DOI: 10.1038/s41550-023-02032-7

Provided by NASA