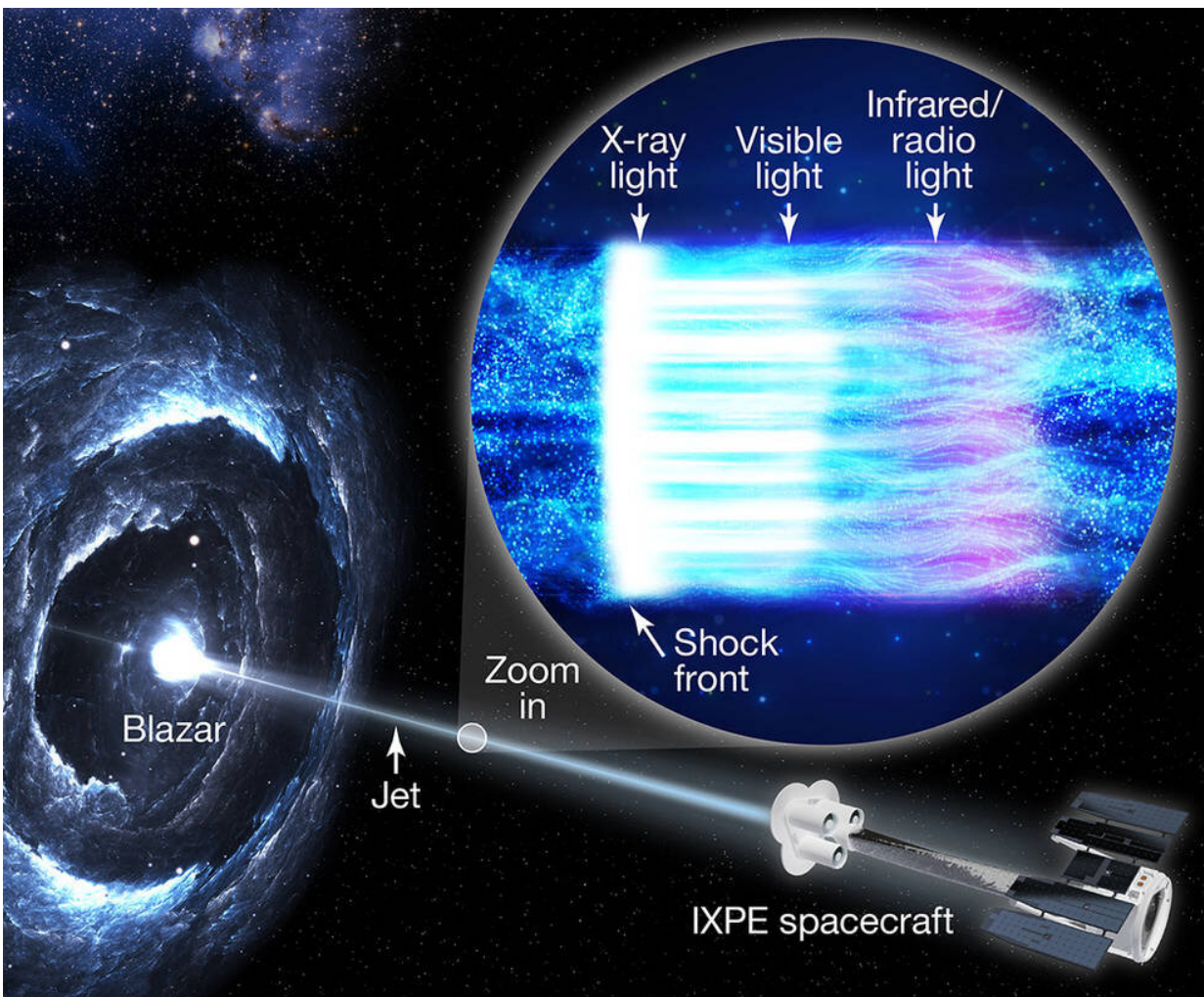


NASA's IXPE helps solve black hole jet mystery

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This illustration shows NASA's IXPE spacecraft, at right, observing blazar Markarian 501, at left. A blazar is a black hole surrounded by a disk of gas and dust with a bright jet of high-energy particles pointed toward Earth. The inset illustration shows high-energy particles in the jet (blue). When the particles hit

the shock wave, depicted as a white bar, the particles become energized and emit X-rays as they accelerate. Moving away from the shock, they emit lower-energy light: first visible, then infrared, and radio waves. Farther from the shock, the magnetic field lines are more chaotic, causing more turbulence in the particle stream. Credit: NASA/Pablo Garcia

Some of the brightest objects in the sky are called blazars. They consist of a supermassive black hole feeding off material swirling around it in a disk, which can create two powerful jets perpendicular to the disk on each side. A blazar is especially bright because one of its powerful jets of high-speed particles points straight at Earth. For decades, scientists have wondered: How do particles in these jets get accelerated to such high energies?

NASA's Imaging X-Ray Polarimetry Explorer, or IXPE, has helped astronomers get closer to an answer. In a new study in the journal *Nature*, authored by a large international collaboration, astronomers find that the best explanation for the particle acceleration is a shock wave within the jet.

"This is a 40-year-old mystery that we've solved," said Yannis Liodakis, lead author of the study and astronomer at FINCA, the Finnish Centre for Astronomy with ESO. "We finally had all of the pieces of the puzzle, and the picture they made was clear."

Launched Dec. 9, 2021, the Earth-orbiting IXPE satellite, a collaboration between NASA and the Italian Space Agency, provides a special kind of data that has never been accessible from space before. This new data includes the measurement of X-ray light's [polarization](#), meaning IXPE detects the average direction and intensity of the electric field of light waves that make up X-rays. Information about the electric field

orientation in X-ray light, and the extent of polarization, is not accessible to telescopes on Earth because the atmosphere absorbs X-rays from space.

"The first X-ray polarization measurements of this class of sources allowed, for the first time, a direct comparison with the models developed from observing other frequencies of light, from radio to very high-energy gamma rays," said Immacolata Donnarumma, the project scientist for IXPE at the Italian Space Agency. "IXPE will continue to provide new evidence as the current data is analyzed and additional data is acquired in the future."

The new study used IXPE to point at Markarian 501, a blazar in the constellation Hercules. This active black hole system sits at the center of a large elliptical galaxy.

IXPE watched Markarian 501 for three days in early March of 2022, and then again two weeks later. During these observations, astronomers used other telescopes in space and on the ground to gather information about the blazar in a wide range of wavelengths of light including radio, optical, and X-ray. While other studies have looked at the polarization of lower-energy light from [blazars](#) in the past, this was the first time scientists could get this perspective on a blazar's X-rays, which are emitted closer to the source of particle acceleration.

"Adding X-ray polarization to our arsenal of radio, infrared, and optical polarization is a game changer," said Alan Marscher, an astronomer at Boston University who leads the group studying giant black holes with IXPE.

Scientists found that X-ray light is more polarized than optical, which is more polarized than radio. But the direction of the polarized light was the same for all the wavelengths of light observed and was also aligned

with the jet's direction.

After comparing their information with theoretical models, the team of astronomers realized that the data most closely matched a scenario in which a shock wave accelerates the jet particles. A shock wave is generated when something moves faster than the speed of sound of the surrounding material, such as when a supersonic jet flies by in our Earth's atmosphere.

The study was not designed to investigate the origins of shock waves, which are still mysterious. But scientists hypothesize that a disturbance in the flow of the jet causes a section of it to become supersonic. This could result from high-energy particle collisions within the jet, or from abrupt pressure changes at the jet boundary.

"As the shock wave crosses the region, the [magnetic field](#) gets stronger, and energy of particles gets higher," Marscher said. "The energy comes from the motion energy of the material making the shock wave."

As particles travel outward, they emit X-rays first because they are extremely energetic. Moving farther outward, through the turbulent region farther from the location of the shock, they start to lose energy, which causes them to emit less-energetic light like optical and then radio waves. This is analogous to how the flow of water becomes more turbulent after it encounters a waterfall—but here, magnetic fields create this turbulence.

Scientists will continue observing the Markarian 501 blazar to see if the polarization changes over time. IXPE will also investigate a broader collection of blazars during its two-year prime mission, exploring more longstanding mysteries about the universe. "It's part of humanity's progress toward understanding nature and all of its exoticness," Marscher said.

More information: Ioannis Lioudakis, Polarized blazar X-rays imply particle acceleration in shocks, *Nature* (2022). [DOI: 10.1038/s41586-022-05338-0](https://doi.org/10.1038/s41586-022-05338-0).
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