Anatomy of a Blazar

Astronomers are learning how the mysterious objects work, and where they get their energy / BY KATE BECKER

What is the brightest object in the night sky? Paradoxically, the most luminous things in the cosmos are invisible to the naked eye. They are "blazars," mysterious objects that glow not just with visible light—the kind our eyes can see—but with every kind of radiation, from radio waves to gamma rays.

At the BU Blazar Lab, astronomers Alan Marscher and Svetlana Jorstad and their students are trying to understand how blazars work and where they get their tremendous energy. They think that blazars are powered by supermassive black holes containing the mass of hundreds of millions of suns. But how do black holes—where gravity is so strong that nothing, not even light, can escape—power the brightest objects in the cosmos?

That is the puzzle that Marscher, a College of Arts & Sciences professor of astronomy and director of BU's Institute for Astrophysical Research (IAR), and Jorstad, an IAR senior research scientist, are trying to resolve.

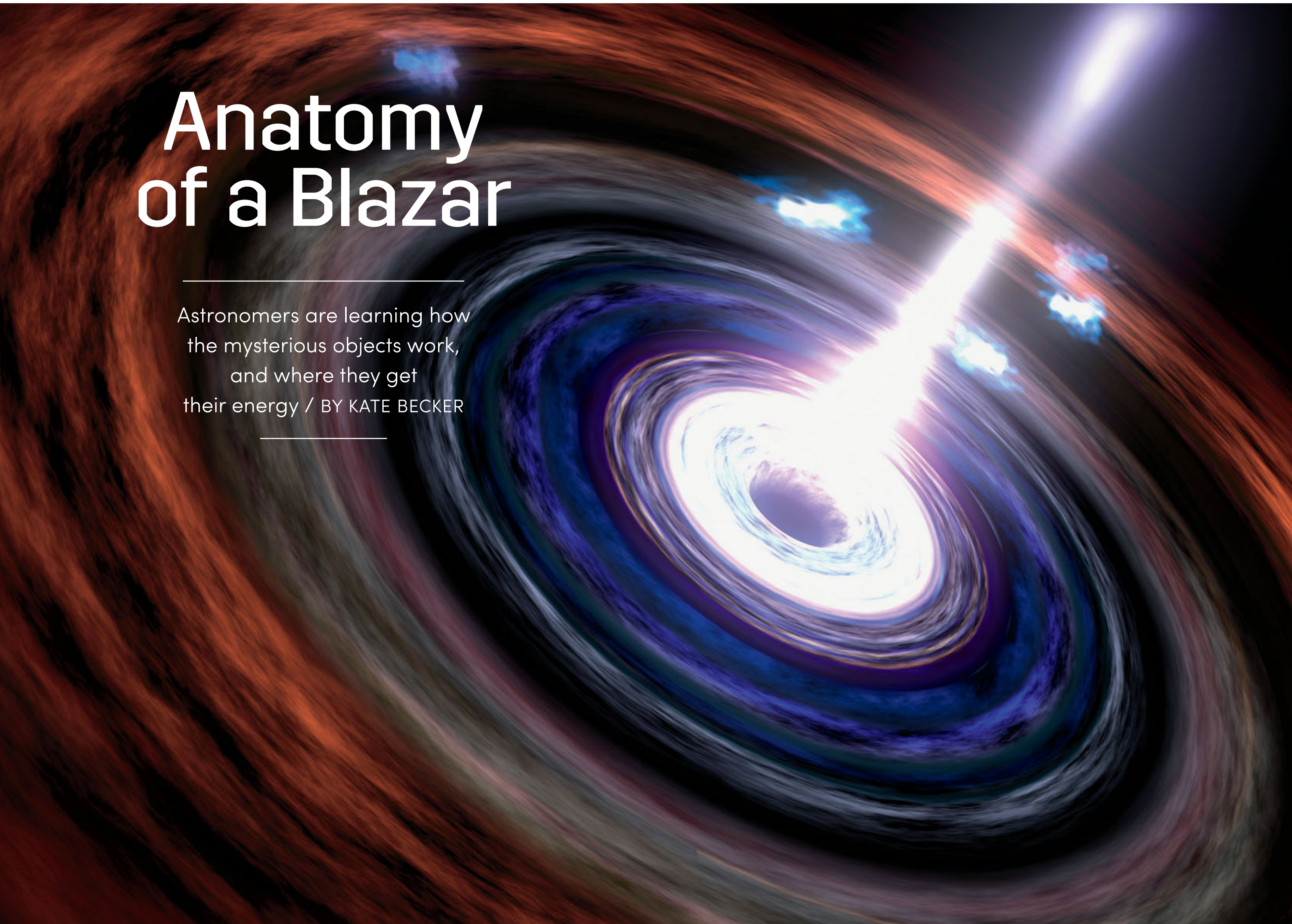
When the first blazar was discovered in 1962, astronomers were stumped: they had never seen anything like it. But time and technology, like NASA's Hubble Space Telescope, have yielded some clues.

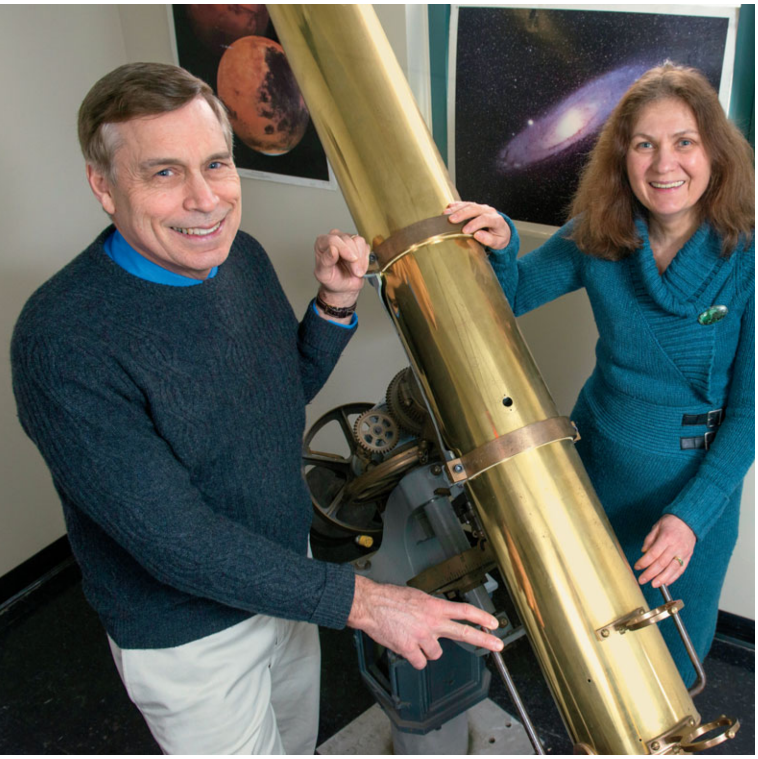
First, astronomers tracked blazars to ancient galaxies located hundreds of millions, or even billions, of light years from Earth. Each of these galaxies, like our own Milky Way, is centered on a supermassive black hole that's engulfed millions of suns' worth of matter. Somehow, researchers think, those behemoth black holes must be firing up the blazars.

But even though nearly every galaxy has a supermassive black hole, only a small fraction of galaxies—about one in ten—are "active," radiating a huge amount of energy. And fewer than one in a thousand active galaxies is a blazar. What makes them different?

It all starts with the black hole's diet. Black holes gobble up anything that gets too close. When a black hole is

▼ A jet of particles and radiation shoots out from near the supermassive black hole at the heart of an active galaxy. When the jet is pointed right at Earth, telescopes see it as a blazar. (Still image is from a computer animation.)





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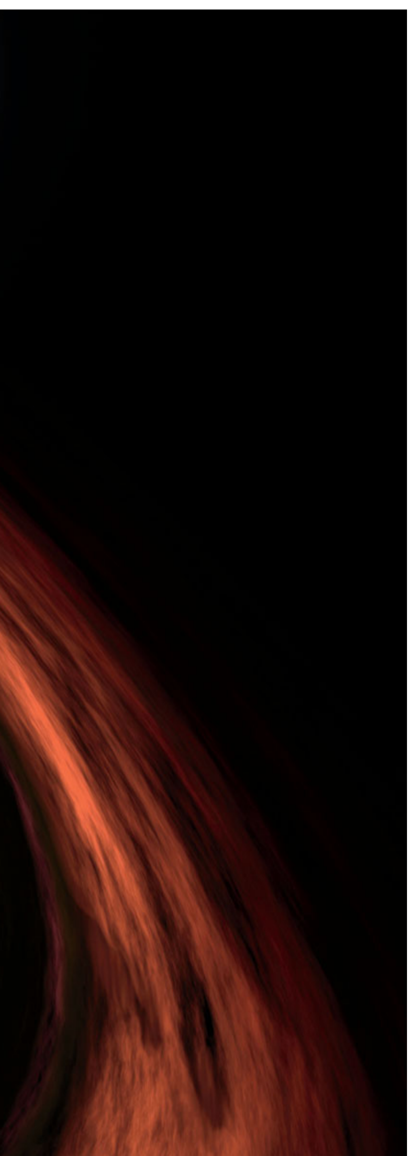

MELISSA OSTROW (TOP); COURTESY OF NASA/GODDARD SPACE FLIGHT CENTER CONCEPTUAL IMAGE LAB

"well fed," says Marscher, matter on its way down the gullet will congeal in a pancake-shaped disk centered on the black hole. Friction in the disk heats it up and makes it glow and flicker with ultraviolet and visible light. That explains one part of the mystery—why some galaxies are "active" when others aren't—but something more seems to happen to transform an ordinary active galaxy into a blazar capable of firing off high-energy gamma rays and X-rays.

Astronomers think that "something" is a jet: a fire hose of charged particles, magnetic fields, and radiation that shoots out from the top and bottom of the rotating disk. When fast-moving electrons near the black hole meet the strong magnetic field inside the jet, they give off a broad spectrum of radiation, from low-frequency radio waves all the way up to high-energy X-rays. Meanwhile, those electrons can also ram into particles of light, called photons, and give them the extra boost of energy to make gamma rays.

But what, exactly, kicks the electrons up to such high speeds? Astrophysicists are still debating, but many think that the electrons are whorled through a corkscrew-shaped magnetic field that shoots them out at blinding velocity.

If that hypothesis is right, the twisty magnetic field should leave a characteristic imprint, called polarization, on light coming out of the jet. To isolate that signature, Marscher, Jorstad, and a team of international collaborators had to wait for a blazar to discharge a flare—temporary, concentrated emission—that would give them a chance to trace out the shape of the magnetic field. In 2005, they found just what they were seeking: while peering nearly straight down the barrel of the jet of a powerful, flaring blazar called BL Lacertae, they caught the polarization within the flare rotating by one-and-a-half turns, mapping out exactly the spiral shape astronomers had predicted. They presented their results in *Nature* in 2008.

Now, thanks to a partnership between BU and the Lowell Observatory, Marscher and Jorstad have near-continuous coverage of more than three dozen blazars on the Perkins telescope, a 1.8-meter optical telescope near Flagstaff, Ariz. When a flare erupts, Jorstad quickly notifies the managers of NASA's *Swift* satellite, which can be rapidly pointed toward the flare source to capture ultraviolet and X-ray readings, and taps into publicly available data from the Fermi Gamma-ray Space Telescope. By scrutinizing differences in the shape and timing of the flare at different wavelengths, she, Marscher, and their colleagues can deduce the physics behind the flare.

Marscher and Jorstad also enlist a network of radio telescopes, called the Very Long Baseline Array (VLBA), to take pictures of the flare as it moves and changes. Because the telescopes that make up the VLBA are located on opposite sides of the Earth, the VLBA can pick out, or "resolve," fine details about 1,000 times better than the Hubble Space Telescope. In fact, even though the jets of the flare are enormous—many light years long, in some cases—they are so far from Earth that the VLBA is the only instrument in the world that can actually see bright spots moving through the jets.

Now the researchers in BU's Blazar Lab are trying to understand the source of the blazars' most energetic gamma ray flares. Astrophysicists expected that the gamma rays would all be coming from very close to the black hole at the center of the blazar. But to everyone's surprise, the BU team found that a major fraction of the gamma rays is coming from a point that is light years away. How does such an extreme burst of energy happen so far from the blazar's central engine? The BU team is testing out a variety of ideas using computer models, and they hope to put them to an actual test soon with the Discovery Channel Telescope at Lowell Observatory.