ASTRONOMY

Gamma Rays Open a View Down a Cosmic Gun Barrel

Among the most spectacular displays in the cosmos are the colossal jets of material that blast out of certain galaxies, crackling with radiation across the entire electromagnetic spectrum. Most of the jets point away from Earth. But a few—so-called blazars—are aimed straight at us, bombarding our atmosphere with high-energy gamma rays. Lately, astronomers have been tracking the flashes of light produced when those gamma rays smash into the atmosphere. As Trevor Weekes of the Fred Lawrence Whipple Observatory in Amado, Arizona, puts it, they are "looking down the barrel of a gun" to see how it works. They got their best view yet early this year, when one of these celestial guns fired a volley straight into their detectors.

At a meeting of the American Astronomical Society's High Energy Astrophysics Division in Estes Park, Colorado, last week, groups from Europe and the United States reported that they had nabbed a blazar called Markarian 501 in a violent outburst. Over several months starting in February, its brilliance in high-energy gamma rays sporadically flared to levels equivalent to 10 billion suns, making it the brightest object in the sky at those wavelengths. At the same time, observations from other instruments on the ground and in space showed that Markarian 501's intensity at longer wavelengths, such as x-rays and ultraviolet, danced roughly in step with the gamma rays.

To theorists, the synchrony implies that the ultimate power source for all these forms of radiation is a beam of charged particles accelerated, perhaps by a spinning black hole, to nearly the speed of light within a small, magnetized region. The details of that dance, say these researchers, offer clues to the troupe of particles and interactions responsible for it. By watching it, says Alan Marscher of Boston University, "we can understand what's going on as close to the black hole … as anyone's ever been able to observe inside a jet."

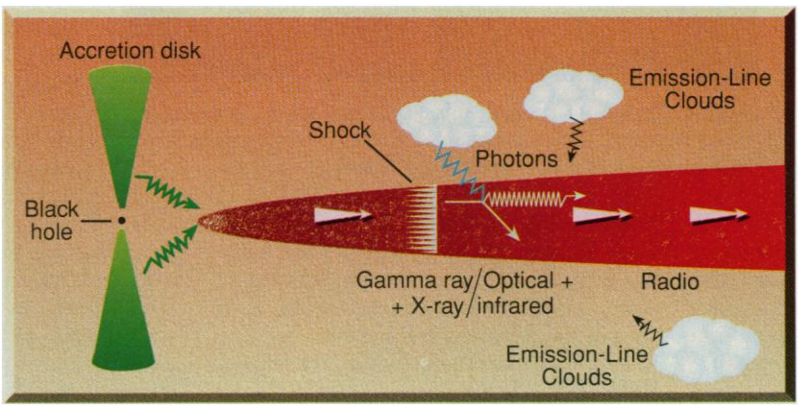
To look down a cosmic jet, astronomers in this new field look up at the night sky for faint bursts of light that are the electromagnetic version of sonic booms. Gamma rays at energies of trillions of electron volts (TeV) don't reach the ground, and satellite-based detectors are ineffective in these energy ranges. But when a high-energy gamma ray crashes into the atmosphere, its interactions with air molecules trigger a narrow tube of Čerenkov light, which can be traced back to the gamma ray's ultimate source in the heavens. Among the first to study blazars by this technique, called atmospheric Čerenkov imaging, are researchers at the Whipple Observatory, which is run by the Harvard-Smithsonian Center for Astrophysics.

Last year, the Whipple Observatory's 10-meter reflecting dish demonstrated the principle by seeing a blazar called Markarian 421 flickering on time scales as brief as 15 minutes. Since then, two new gamma ray detectors have joined the hunt: the French Čerenkov Array at Thémis (CAT) and the High Energy Gamma Ray Astronomy facility (HEGRA) at La Palma in the Canary Islands. HEGRA was built mainly with German backing and is now recovering from a recent fire (*Science*, 31 October, p. 807).

As a result, there were plenty of eyes on Markarian 501 after the Whipple group noticed it brightening in February. Instruments at other wavelengths also joined the vigil, including the orbiting Compton Gamma Ray Observatory at less energetic gamma wavelengths, the Rossi X-ray Timing Explorer, and x-ray detectors aboard the Italian BeppoSAX satellite. "Markarian 501 was a big surprise," says BeppoSAX investigator C. Megan Urry of the Space Telescope Science Institute (STScI) in Baltimore, who worked with Laura Maraschi of the Osservatorio Astronomico di Brera, Elena Pian of STScI, and others. "For many years, people dismissed it as boring; it didn't vary a whole lot."

By March and April, no one was yawning. Pian and her colleagues captured a tremendous x-ray flare in early April. In the TeV range, says Axel Lindner of HEGRA and the University of Hamburg in Germany, the blazar—although 300 million light-years distant—brightened for hours or minutes until it shone 10 times more brightly than the nearby Crab Nebula, a brilliant but steady source of gamma rays. "It had gone from the dimmest source we knew of in the gamma ray sky to the brightest," says Michael Catanese of Iowa State University in Ames, who presented the Whipple team's results in Estes Park. "We'd never seen anything like that." Changes across the spectrum occurred roughly together, and "the results of the three [TeV] experiments agree very nicely," says Lindner.

The roughly synchronous changes imply a single source for all the radiation, says Charles Dermer, a theorist at the Naval Research Laboratory in Washington, D.C. One candidate, he says, is the shock waves that would naturally form in a jet of material squirted out at nearly the speed of light along the axis of a spinning black hole. Intense electric fields in the shock waves would function as a staggeringly powerful particle accelerator.



Jet power. A jet of particles erupting from a black hole collides with photons from within the jet or sources close to it, boosting them to ultrahigh energies.

Dermer adds that the radiation's spectrum offers a clue about how the accelerated particles then ignite the brilliant displays seen from Earth. The spectrum, he says, has two humps, one at optical and x-ray wavelengths and the other in gamma rays. The low-energy hump probably comes from so-called synchrotron radiation, thrown off by fast electrons when their paths bend in magnetic fields. The high-energy hump probably results when the electrons crash into photons—either from the synchrotron process or from glowing gases outside the jet—boosting their energy.

Raymond Protheroe of the University of Adelaide in Australia points out that there could be a simpler explanation for the highest energy radiation: Fast protons in the jet might smash into ambient material, shattering into a cascade of unstable, lighter particles. These would quickly decay into the gamma rays that reach Earth.

Either process would have to be taking place at the very heart of the blazars. The rapid variability of the TeV radiation—indicating emission from a small region—and its remarkable intensity suggest that it emanates from within a tenth of a light-year of the putative black hole. Observers are seeing right into the chamber of the gun.

–James Glanz