and that there are definitely quark and antiquark pairs that carry spin."

The goal of the Hermes experiment is to move beyond this point, but the researchers must go about their search in a roundabout way. Unlike the spins of billiard balls, the spin of a subatomic particle has no effect on the particle's trajectory after a collision. There is, however, a way in which spin affects what happens in a subatomic collision: Pairs of colliding particles with parallel and antiparallel spins have different probabilities of interacting.

The Hermes experiment exploits this difference to reveal the contributions of various particles to the total spin of a nucleon. HERA is uniquely qualified for this task because of its ability to create a polarized beam of electrons (or of their antimatter siblings, positrons)—a beam in which all the spins are aligned in the same direction. "To get the polarized electrons or positrons, you have to tune the ring in a very precise way, and HERA really has optimized this," says Milner.

The first part of the Hermes experiment is a stationary target of nucleons, provided by hydrogen or helium gas injected into a small tube in the path of the electron beam. The nuclei of the gas atoms are also polarized by magnets so that they are either parallel or antiparallel to the electron beam. Researchers then try to measure the asymmetry between parallel and antiparallel collisions with a huge, 5-meter-diameter detector that is the heart of Hermes.

The detector's major new feature is the microstrip gas counter—a gas-filled detector in which tiny electrodes pick up the signal of ions created as particles tear through. "It is the first large microstrip gas counter ever built, and it is the most precise now available," says Jo van den Brand of the University of Amsterdam and the Dutch Institute for Nuclear Particle Physics (NIKHEF), spokesperson for the Hermes project. "Our strength is not only high tracking precision, but complete detection of all the created particles," says van den Brand.

Van den Brand expects collisions to begin in May and that the first results will become available later this summer. Even if all goes brilliantly with Hermes, however, that project by itself may not reach the bottom of the proton-spin mystery. The reason is that, in its present configuration, Hermes cannot reveal whether gluons carry spin. To probe gluon spin, researchers need beams of polarized protons, says Milner, and DESY researchers are already on the case. "Polarized protons are not demonstrated yet, but there is a group of people at DESY facility at Zeuthen working on it."

**–Alexander Hellemans**

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ASTRONOMY

# A Close Look at an Active Galaxy's Engine

Astronomers have long been eager for a peek at a quasar's engine. Quasars and active galaxies, their dimmer cousins, shine so prodigiously that researchers have had little choice but to accept a seemingly outlandish picture of what powers them: a supermassive black hole, as massive as millions of suns, sucking gas and other matter from a surrounding accretion disk.

When it comes to the gritty details of how this bizarre power source would work, however, astronomers have been in the dark. At distances of millions of light-years or more, the cores of active galaxies and quasars are simply too small to resolve. Now, thanks to an indirect strategy known as reverberation mapping, an international team of more than 100 astronomers has glimpsed the engine room—if not the power plant itself—of an active galactic nucleus (AGN).

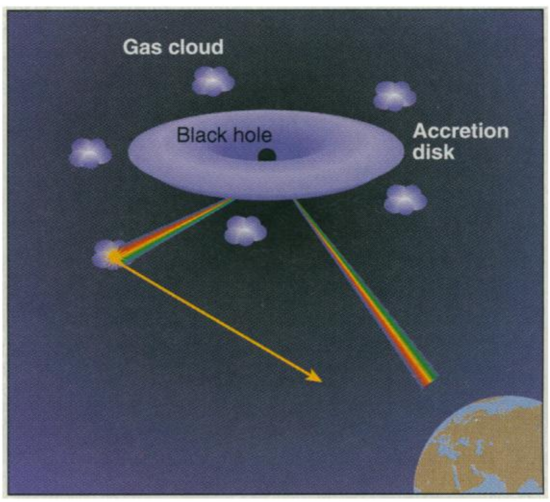
By tracking how fluctuations in light from the center of the AGN in the galaxy NGC 5548 "echo" off clouds of gas whirling around the nucleus at a distance of a few light-days, the team has mapped the clouds and how they are moving. The results, which John Bahcall of the Institute for Advanced Study in Princeton, New Jersey, calls "unique and fundamental," support the idea that the gravity of a black hole is the AGN's ultimate driving force, and they should help astronomers understand how infalling matter fuels the engine. But the study—the product of an intensive campaign of observations from ground-based telescopes and satellites, among them the Hubble Space Telescope—also delivers a mixed message about the future of reverberation mapping, bearing out its promise but at the same time demonstrating how labor-intensive it can be.

That's one reason the technique has been slow to bear fruit in the more than 20 years since Bahcall and two other astronomers outlined the trick behind it. He and his colleagues knew that the ultraviolet light pouring from the center of quasars and AGNs ionizes nearby gas clouds, causing them to glow like neon lights at specific wavelengths. They proposed that by measuring the delays between fluctuations in the central source and the response from the clouds—a brightening of their emission lines—astronomers could map the clouds' distribution, motion, and density. Compared to ordinary observations, says Johns Hopkins University astronomer Holland Ford, the strategy "really allows us to get one or two orders of magnitude closer to what's in the middle."

A proof of principle finally came in the late 1980s, when astronomers combined observations from ground-based telescopes and the International Ultraviolet Explorer (IUE) satellite to map gas clouds near the center of NGC 5548. But because the collaboration took data only every 4 days, says Ohio State University astronomer Bradley Peterson, the effort could only hint at the presence of clouds very close to the core, at distances of a few light-days. "We couldn't measure their light echo because they were too close," says Peterson, who heads the current mapping foray, the International AGN Watch.

This time around, Peterson and his colleagues turned their instruments—the Hubble Telescope, IUE, and ground-based telescopes—on NGC 5548 almost daily. Indeed, the surveillance was so intensive (including 39 straight days by the Hubble) that it will take years to analyze the trove of data, but already the researchers have confirmed that gas clouds lie just a few light-days from the core. What's more, the group reports in the April *Astrophysical Journal Supplement Series*, they have taken a first step toward answering a long-standing question about how the clouds and other nearby matter ultimately feed the black hole.

As Johns Hopkins University astronomer Julian Krolik puts the question: "Where is this stuff going?" He adds, "There have literally been dozens of papers discussing the character of the motion. Every bet was covered." Some researchers have argued that the clouds are streaming inward; others pictured them darting randomly; still others insisted that the pressure of radiation from the accretion disk should force the clouds outward until the central engine runs out of fuel and




**A matter of timing.** A flicker from an active galaxy's central radiation source and the answering flicker from a nearby gas cloud follow different routes to Earth, creating a time lag that is a clue to the cloud's position.

dims, allowing matter to fall inward again.

Yet another group envisioned a kind of astrophysical hurricane, with the clouds circling the core, and it is that picture that the latest results support. By measuring Doppler shifts of some of the clouds' emission lines to get their velocities, then comparing the velocities with the positions indicated by the time delays, the team was able to distinguish their overall movement. According to preliminary analyses, the clouds appear to be orbiting the central engine like planets around the sun. "I think this alone tells us that gravity is the most important force acting on the gas," says Peterson—and he's made a rough calculation indicating that the gravity at work is that of a black hole weighing in at about 20 million solar masses.

What's next for reverberation mapping? That question worries even the researchers who are most enthusiastic about the method. Astronomers would like to see whether NGC 5548 is a typical case by extending the technique to other AGNs and to distant quasars—and mapping them in greater detail as well. But doing so would demand observations still more intensive than the past long campaign, perhaps even a dedicated space instrument that could monitor an AGN or quasar continuously. "What depresses me," says Peterson, "is how hard it will be to do much better in the future."

**–John Travis**

PHYSICS

# Tuning Up an Electromagnetic Accordion

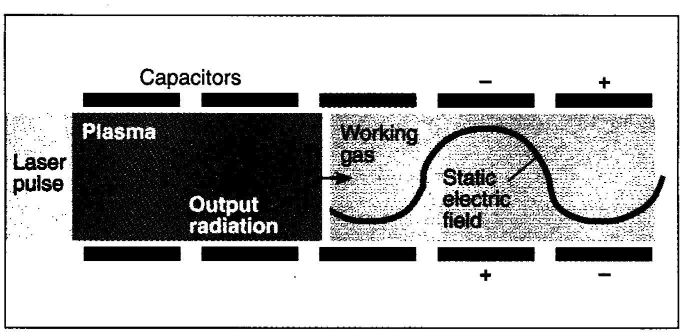
As those who love the polka can attest, it's not easy to master the accordion. But imagine how much tougher it would be if the leather bellows were swapped for an undulating electric field, the pressure from a musician's arms for a jolt from a short-pulse laser, and the sound for a burst of radiation. That's just the transformation that University of California, Los Angeles (UCLA), physicist Warren Mori and his colleagues have carried out. Yet he and his colleagues expect sweet music. As the laser pulse races through the electric field, says Thomas Katsouleas of the University of Southern California (USC), it should "accordion up" the field structure to produce a pulse of infrared light or microwaves that can be tuned as precisely as any musical note.

Some of this music could be particularly sweet in the fields of radar, communications, and materials science, and that is one reason for the excitement over the scheme, unveiled earlier this year in *Physical Review Letters*. More recently, Mori and his colleagues John Dawson at UCLA, Katsouleas, and C. H. Lai at USC have built a working version of the electromagnetic accordion and coaxed the first "sounds" from it: short bursts of radio waves.

The group is now trying to extend its range to shorter wavelengths and pulse lengths. If they succeed, the strategy "could be much simpler" than existing techniques for creating short pulses of tunable radiation, says California Institute of Technology physicist Richard Savage. As a bonus, says Dawson, the device could provide insight into conditions near supernovae, where processes much like the electromagnetic accordion may be at work.

On Earth, the method relies on two venerable tools of physics—relativity theory and plasma physics—along with a new one, short-pulse lasers, which briefly generate light at intensities of billions of watts. When photons from such a laser slam into a low-pressure gas, they ionize it to create a plasma. By aiming the laser through a gallery of capacitors that carry alternating electrical biases, Mori and his colleagues can create a sharp ionization front—a boundary between plasma and normal gas—racing at nearly the speed of light through the sinusoidal electric field created by the capacitors.

That's where relativity theory comes in.




**Squeeze box.** A traveling ionization front, generated by a laser, compresses a stationary electric field to produce a pulse of radiation.

Imagine riding along with the ionization front; in this moving frame of reference, according to relativity theory, stationary features appear compressed in the direction of motion. As a result, the onrushing electric field appears foreshortened—accordioned up. As the foreshortened wave strikes the moving boundary of the plasma, part of it is reflected, while the rest passes into the plasma. Just as light slows in passing from air to water, the transmitted wave slows by an amount that depends on the density of the plasma.

Because of this slowing—which corresponds to a kick toward the front's direction of motion—the electromagnetic wave now looks foreshortened even to an observer at rest. In the simplest case, the laboratory observer sees a compressed electromagnetic pulse following the ionization front. "The output is an analog of what you start with, but scrunched up," says Katsouleas. At the end of the capacitor array, a glass barrier stops the ionization front, but the scrunched wave continues as a pulse of radiation.

In the preliminary experiments, the scheme generated output wavelengths as short as 1 centimeter, in the radio spectrum. But the real action would come if the team can manage to fine-tune the setup to produce coherent infrared radiation at wavelengths of from 10 to 100 microns—frequencies off-limits for ordinary lasers but much prized for studying semiconductors' electronic structure. To get to that range, Mori and colleagues need to boost the pressure of the gas filling the device (which would increase the "scrunching factor") and tinker with the capacitor array. So far, however, contamination problems have prevented the accordion from playing a song this high-pitched.

Simply by shortening the array, meanwhile, Mori and his colleagues believe they can shorten the pulses almost arbitrarily, until they contain only a few wavelengths of radiation. At microwave frequencies, such short pulses could give radar "a better feel for sharp objects," says Mori, yielding clearer images of their shape. Inscribed with a specific pattern of frequencies, such pulses could also carry coded military communications, easy to pick out of a background of jamming frequencies.

Dawson hopes for a more esoteric payoff as well: insight into the behavior of the turbulent gases surrounding supernovae. The x-rays and ultraviolet light from an exploding star can send ionization fronts plowing through the surrounding gases. Like the laboratory fronts, these should shift the frequency of an ambient electromagnetic field—in this case a field generated not by capacitors but by the cosmic microwave background, the afterglow of the big bang. Detected from Earth, the shifts should act as "frequency signatures" of magnetic fields, density, and other conditions in supernova atmospheres, says Dawson. And by trying to reproduce the frequency shifts in the laboratory, he thinks, astrophysicists could test their interpretations.

If such hopes pan out, many more physicists may decide that the relativistic accordion is just the instrument they always wanted to play.

**–James Glanz**

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