perfect copies of normal eyes. "These eyes have everything a [normal] eye has, from the bristles to the lens to the pigment cells," says UCSD's Zuker. And Gehring says his team recently confirmed that the eyes are functional as well: Their photoreceptor cells respond to light.

These results stand in stark contrast to what usually happens when developmental biologists coax a tissue to take steps down the wrong developmental path. Typically the wayward tissue may make a protein or a partial structure characteristic of the path it is forced to take—but not a whole organ. In the case of *eyeless*, says Rubin, "you are definitely not talking about the tissue just expressing an eye [protein]. You are making a whole tissue with all its complexities."

This is not, however, the first case in which genetic engineering has been used to design flies with complete structures in the wrong place. In 1987, for example, Gehring's group turned on a gene called *Antennapedia* in the heads of flies, where it is not normally expressed, and as a result the flies grew legs where their antennae should have been. But that experiment and others like it were fundamentally different from the *eyeless* experiment, says William McGinnis, who studies fruit fly development at Yale University. *Antennapedia* is not a master gene for leg formation, he says, but instead is concerned with "assigning a spatial position" to a tissue. Turning on *Antennapedia* in the head tells the head to develop as the midbody would, and that includes the formation of legs instead of antennae. In contrast, the *eyeless* gene, McGinnis says, specifies "a functional organ rather than a spatial identity."

The ability to induce a complete organ is what appears to make *eyeless* a "master control gene." And that is particularly exciting for researchers who study eye development in fruit flies, says UCLA's Zipursky. A great deal is known about the genes that cause the production of the different cell types in the eye—genes such as *sevenless*, which triggers the formation of one of a specific type of photoreceptor cell, or the genes that code for the rhodopsin pigments that detect light. But little is known about the hierarchy of regulatory genes that turn on these and the hundreds of other genes necessary to form eyes. *Eyeless* may help change that. "What's very exciting here is that *eyeless* is really high in that hierarchy," Zipursky says. Using a variety of experimental methods, researchers should be able to find the genes that are activated by *eyeless* and thus begin to fill in the complex cascade of genes turning on genes that leads to the eventual activation of the structural genes that make eyes.

The current paper also strengthens the evolutionary connection that was made when the link between *eyeless*, *Small eye*, and *Aniridia* was discovered, says Nipam Patel, a developmental biologist at the University of Chicago who studies the evolution of genes that control development. As different as the eyes of flies and mice are, says Patel, the finding that they not only share a common control gene, but that the mouse form of the gene can function in flies, is powerful evidence that they have a common ancestry.

Patel says evidence of a common ancestry in no way contradicts the view that image-forming eyes evolved independently. It merely means they diverged from a common ancestral eye and that the development of that eye was likely governed by the ancestor of the *eyeless* gene. That early eye, says Patel, may have been a mere eyespot, a cluster of light-sensitive cells with no image-forming ability that is common in lower animals. But as nature improved on that eye in all the ways that led to various image-forming eyes, it apparently continued to use the *eyeless* gene to control the ever-more complicated process of eye development.

That suggests that *eyeless* should participate in eye formation in other species as well. And that may well be true. Gehring's group has already found counterparts of *eyeless* in a diverse range of animals including squid—which have very advanced image-forming eyes—and planarians, tiny flatworms with rudimentary eyespots, although the gene has not yet been shown to be essential for eye formation in these animals.

As researchers use *eyeless* to probe the mysteries of eye formation in fruit flies and other animals, they will undoubtedly make comparisons up and down the phylogenetic tree. And the similarities and differences they find will lead to a better understanding of just how much our eyes do have in common with those of our distant animal relatives—as well as how our eyes are formed. The one thing it won't do is give us eyes in the back of our heads, useful as that might be.

–Marcia Barinaga

PARTICLE PHYSICS

Searching for the Spin of the Proton

Since its 1992 inauguration, the Hadron-Electron Ring Accelerator (HERA) at DESY, Germany's particle physics laboratory near Hamburg, has been the front-runner in the effort to understand what goes on inside protons—the particles which, along with neutrons, make up the atomic nucleus.

Toward the end of this month, researchers at DESY will start up a new $20-million detector called Hermes—a collaboration among 10 countries (Armenia, Belgium, Canada, Germany, Italy, Japan, the Netherlands, Russia, the United Kingdom, and the United States)—aimed at answering one of the most nagging unknowns in physicists' understanding of the proton: what carries its spin. Theory predicted that a proton's spin was obtained by adding together the spins of its three main components—quarks. But a shock result in 1988 showed that the constituent quarks contribute only part of the spin. "It came as a surprise," says Hermes collaboration member Richard Milner of the Massachusetts Institute of Technology (MIT). "People believed that our understanding of the spin of the proton was in good shape."

The spin of a subatomic particle is very different from the spin of a billiard ball. For a start, the spin is not created by an external force, but arises from within, and in common with many quantities described by quantum mechanics it can only assume discrete values. Quarks, the building blocks of protons and neutrons, can only have spin states of $+1/2$ or $-1/2$, which are usually symbolized as spins with their axes pointing up or down. Protons and neutrons—the nuclear constituents known as nucleons—always have a spin of $+1/2$.

Seven years ago, the neat picture of quark spins adding up to make the nucleon's spin was shattered by the results of a group called the European Muon Collaboration working at CERN, the European particle physics center near Geneva. Subsequent experiments at CERN and at the Stanford Linear Accelerator Center in California revealed that the traditional picture was fundamentally inadequate: Only about 30% of a nucleon's spin comes from its main quarks.

So where does the rest come from? Earlier experiments at DESY offer some clues. The HERA ring is unique in that it can accelerate counter-rotating beams of electrons and protons and smash them together to probe the proton's structure. Experiments with HERA's two existing detectors, H1 and Zeus, confirmed that the three main quarks—known as "valence" quarks—play a major role, but that the interior of the proton is also awash with other particles (*Science*, 24 June 1994, p. 1843). These other nuclear constituents include gluons, which carry the "strong" force that binds the valence quarks together, along with "virtual" quarks and antiquarks that pop up out of the vacuum in pairs and instantly recombine, annihilating each other.

Those additional findings suggested that whatever provides the missing 70% of the proton's spin is to be found in this tangle of particles. But precisely where is a mystery. According to Robert Jaffe from the Center for Theoretical Physics at MIT, all that the current experiments "tell us for sure is that the valence quarks do not carry all the spin, 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

Alexander Hellemans is a science writer in Amsterdam, the Netherlands.

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).

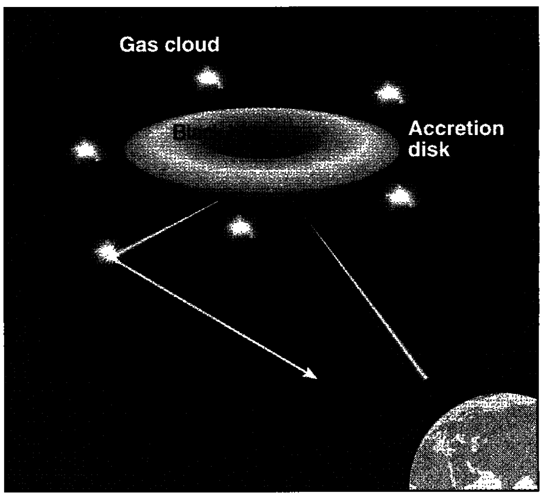
By tracking how fluctuations in light from the center of the AGN in the galaxy NGC 5548 "echo" off clouds of gas whirling around the nucleus at a distance of a few light-days, the team has mapped the clouds and how they are moving. The results, which John Bahcall of the Institute for Advanced Study in 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.