Particle Physicists Take to Orbit

Faced with dimming prospects on Earth, particle physicists are turning to projects in space. An antimatter detector and a new gamma ray telescope may be the first of a flock

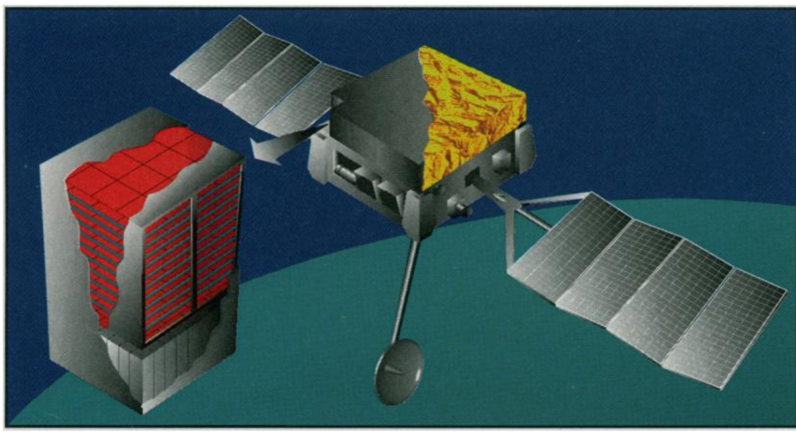
For decades, particle physicists have followed a highly predictable trend, with ever larger groups of physicists chasing ever-more-elusive particles with ever-more-powerful accelerators. But a handful of inveterate particle physicists have recently decided to take their discipline in a new direction. They are taking up second careers in astrophysics.

The trend started on Earth, with a new generation of physicist-built experiments looking for signals from the cosmos, including dark matter particles, ultrahigh-energy cosmic rays, and neutrinos from the sun and distant supernovas. And now it is moving into space, as experimental physicists apply their expertise, their state-of-the-art detector technology, and their culture of large collaborative efforts to doing astrophysics from orbiting platforms. Physicists from the Stanford Linear Accelerator Laboratory (SLAC) are working on plans for a $100 million gamma ray telescope called GLAST, for Gamma Large Array Space Telescope, which the physicists hope will fly either on a satellite or on the space shuttle by 2005. And at the European Center for Particle Physics (CERN), a European-Chinese-American collaboration led by Nobel laureate Samuel Ting has received approval to fly a $20 million detector on the International Space Station, which will search for signs of primordial antimatter in the universe.

The disciplines of astrophysics, cosmology, and particle physics have been converging for 20 years, says SLAC Director Burton Richter, who shared the 1976 Nobel Prize with Ting. One reason has been nature itself. "When you talk about the big bang," Richter says, "about how the universe evolves, which is cosmology, you've got to talk about the Higgs boson, phase transitions, about quarks and leptons, those sorts of thing. And that's all particle physics." Another driving force is the scarcity of large new accelerator projects, which makes the cosmos itself a tempting source of exotic particles and photons.

The particle physicists, for their part, say they have much to offer their new colleagues in astronomy and astrophysics. Technology developed for the latest particle physics experiments could extend the abilities of satellite detectors, if it could be made to work reliably in space. And particle physicists say that their experience at marshaling large international collaborations enables them to build satellite experiments more economically than can be done by the traditional NASA method of entrusting the instrument-building to a single contractor.

So far those promises are untested, and they imply new roles for NASA and the Department of Energy (DOE), which traditionally funds high-energy physics. But it's not the first time particle physicists have contributed ideas to space science. EGRET, a gamma ray telescope now flying on the Compton Gamma Ray Observatory satellite, was first proposed in the 1960s by Stanford University physicist and Nobel laureate Robert Hofstadter, who invented the technique of detecting particles by watching for scintillation—flashes of light—in crystals of sodium iodide. Stanford physicist Peter Michelson, who works on EGRET, explains that Hofstadter "always had this dream of flying a very large [scintillation detector] in space, looking out in the cosmos to see what nature did with the things they were studying in accelerators." It took 25 years to get EGRET into orbit, however, and Hofstadter died shortly before its launch in 1991.



Eye on the gamma-ray sky. SLAC's proposed Gamma Large Array Space Telescope would gain unprecedented sensitivity from a combination of silicon-strip detectors, for tracking direction, and scintillation crystals, for measuring energy.

Michelson wanted to make sure that physicists' bright ideas for astrophysics wouldn't languish the next time around, which is one reason why he paid a visit to SLAC in March 1990, when he was thinking about a successor to EGRET. The gamma ray telescope had accomplished remarkable things, says Michelson, such as detecting active galaxies that emit much of their energy in high-energy gamma rays. Still, the technological guts of EGRET—including a spark chamber and Hofstadter's scintillation detector—consisted of outdated technology. "By the time it was launched," says one SLAC physicist, "it looked like a model T."

A sharper eye

At SLAC, a handful of physicists led by Elliott Bloom was ready with an idea for an improved version: a gamma ray telescope based on silicon microstrip detectors, a technology that had been refined for the now-defunct Superconducting Super Collider (SSC). These devices—essentially crystals of silicon etched with thousands of 10- to 20-micrometer-wide conducting strips—were designed as so-called vertex detectors, which sit close to the point where an accelerator's beams collide. Their role is to sort out the complicated track topologies of the extremely short-lived particles that spew from the collisions. Each charged particle passing through the crystal liberates electron-hole pairs, which migrate to the nearest strip, generating a signal. From the set of strips sending signals, the detector determines the trajectory of each particle with an accuracy of tens of micrometers—at least three times better than any previous detector technology.

The SLAC physicists quickly laid out a general plan for a telescope based on these detectors and by early 1992 had developed a full-scale computer simulation. As they envisioned it, GLAST would be a stack of 12 planes of silicon-strip detectors alternating with thin layers of lead. An array of cesium iodide scintillation crystals would enclose this detector "tower." Incoming gamma rays would slam into the lead and generate pairs of electrons and positrons. The electron-positron pairs would leave their tracks in the silicon detectors, indicating the trajectory of each incoming gamma ray, and then they would be absorbed in the scintillator, which would measure their energy. If it all works as expected, says Bloom, the arrangement should give GLAST a sensitivity to gamma rays some 50 to 100 times better than EGRET and an ability to see gamma rays 10 times as energetic.

"GLAST is going to be a remarkable instrument," says Bloom, "It's going to be a real telescope. It's going to image the gamma ray sky." Among other things, he says, it should see hundreds of gamma-ray-emitting active galaxies, revealing details of their spectra—possible clues to how they work—and paint a much sharper picture of the mysterious gamma ray bursts that flash from random directions in the cosmos.

The members of the GLAST collaboration hope to have their instrument built and flying within a decade, but that, of course, depends on funding. At the moment, says Bloom, "we're running at a very low budget." While 15 institutions so far are committed to GLAST, that commitment, says Bloom, consists of "people trying to do what they can." So far, NASA is contributing only $100,000 a year for detector research and development and another $80,000 for a mission concept study, which has to be completed by next fall.

Already, however, the group has settled on a cost estimate of $100 million—modest by NASA standards, say the physicists, thanks to what Richter calls the "high-energy physics style" of working. "We're looking at an international collaboration involving institutions in Japan, the U.S., and Europe, and NASA labs like Goddard," says Richter. In contrast to the NASA practice of shopping out construction to the aerospace industry, the instrument would be built by the collaborating institutions, which have considerably lower salary and overhead costs than industry. DOE and NASA would fund construction of the GLAST instrument jointly—or at least the American share, whatever that turns out to be. "Then," says Richter, "we get NASA to put it up and get the data down. The collaboration takes care of the data analysis, so NASA doesn't have to fund some big center to do it."

A year ago, Bloom, Michelson, and their colleagues submitted a proposal to DOE, and Bloom says the DOE response has been "cautiously encouraging." Meanwhile, Michelson has shepherded GLAST proposals through what Bloom calls "some very severe peer reviews" in the NASA community. Space scientists are cautious about how the technology will make the transition to space. After all, says Stanley Hunter, an astrophysicist in the high-energy astrophysics branch at NASA's Goddard Space Flight Center, GLAST will have about 80 square meters of silicon-strip detectors, containing more than a million channels of silicon strips and more than 4 million connections, all of which have to survive the rigors of launch and then work reliably for years after that.

"The problem," says Hunter, "is simply that space flight is a much different game than an accelerator project. In an accelerator project, if it breaks you can go in and fix it." But he and other astrophysicists agree with Bloom about the potential payoffs, and, says Bloom, GLAST has received highest marks on every NASA proposal the collaboration has submitted.

GLAST COLLABORATING INSTITUTIONS

NASA Ames Research Center

University of Chicago, Department of Physics

NASA Goddard Space Flight Center, Laboratory for High-Energy Astrophysics

ICTP and **INFN**, Trieste, Italy

Kanagawa University, Engineering Department

Lockheed Martin Corporation, Palo Alto Research Center

University of Maryland, Department of Astronomy

Max Planck Institut für Extraterrestrische Physik, EGRET group

U.S. Naval Research Laboratory, E.O. Hulburt Center for Space Research, X-ray and gamma ray branches

University of California, Santa Cruz, Department of Physics

SLAC, Particle astrophysics group

Sonoma State University, Department of Physics & Astronomy

Stanford University, Physics Department and EGRET group

University of Tokyo, Department of Physics

University of Washington, Physics Department

All together now. GLAST, like a typical high-energy physics project, has many collaborators.

In search of antigalaxies

The GLAST physicists are optimistic that they can knit together NASA, DOE, and an international collaboration to do science in space, says Richter, in part because Sam Ting has already shown it can be done. While Ting's project, known as AMS, for Alpha Magnetic Spectrometer, is much less expensive than GLAST, scientifically it is also much more of a gamble. Its quarry is primordial antimatter left over from the big bang.

Fundamental principles of quantum physics and cosmology suggest that the universe was born as roughly equal parts matter and antimatter. As the universe expanded and cooled, explains University of Utah physicist Michael Salamon, who is collaborating with Ting, protons and antiprotons began to annihilate each other, releasing energy. By now, just one proton remains for every 10 billion protons and antiprotons in the early universe.

The unanswered question, however, is why any protons at all were left over to form the universe of today. Did the universe begin with a slight excess of matter, or is there some asymmetry in the laws of physics that caused the annihilation process to favor matter over antimatter? Or does an equal share of antimatter still remain squirreled away somewhere, far out of view, in the form of antimatter stars and antimatter galaxies? Many theoretical astrophysicists believe that last possibility is so unlikely, says Boston University physicist Andy Cohen, that they regard trying to test it as "a stupid thing." The problem, he explains, "is that the known physical laws can't move [the antimatter] fast enough to get it far enough away so that we wouldn't see it now."

But only experiments can settle the question, says Ting. "A lot of theorists say that there should be antimatter," he says, "and some say there should be none. The important thing is the last search was done 20 years ago.... You don't know what you're going to get."

It is already clear that no nearby galaxies are made of antimatter; if they were, they would be pouring out gamma rays at a specific energy as antimatter stars and gas encountered ordinary matter and annihilated. The absence of this signal, says Alvaro de Rújula, a theorist at CERN, suggests that everything up to the size of superclusters of galaxies, "some 60 million light-years across, is made of the same stuff." The only way to detect more distant antigalaxies is to sample their "stuff" directly, says Salamon, "and the only samples that can reach us from these distances are cosmic rays." Detecting a nucleus of anticarbon in a cosmic ray, he says, would "conclusively demonstrate" the reality of antistars, if not antigalaxies.

In the 1960s and 1970s, Luis Alvarez, who later won the Nobel Prize, George Smoot, and their colleagues from the University of California, Berkeley, searched for antimatter cosmic rays with a superconducting magnet suspended from a high-altitude balloon. When cosmic rays passed through the magnet's powerful field, ordinary nuclei, carrying a positive charge, curved in one direction; any nuclei made of antimatter, which would carry the opposite charge, would have curved in the opposite direction.

The researchers sampled some 40,000 cosmic rays, says Smoot, but none of them turned out to be antimatter. But physicists now think that's not nearly enough to be sure that they've even seen cosmic rays from beyond the galaxy. "If you really want to do an experiment looking for evidence of antinuclei made in antistars in distant antigalaxies," says Boston University physicist Steve Ahlen, who is working with Ting, "you would like to be able to sample much more than a million cosmic rays ... [even] one or two orders of magnitude beyond that."

This is what Ting believes he can now do, by going into space. He undertook the project in late 1993 in essence, he says, because he realized that he would shortly be out of work. Ting was, and still is, head of the L3 experiment at CERN, with some 600 physicists in his collaboration. But his proposal for an experiment at the SSC had been rejected, and he was not going to be leading one of the two experimental collaborations at CERN's planned rival to the SSC, the Large Hadron Collider (LHC). He decided to do "something totally different" and try to settle the long-standing antigalaxies question.

The task, however, would not be easy. Ting assumed at first that the need for a powerful magnetic field meant that, like his predecessors, he would have to use a superconducting magnet, cooled by a long-lasting supply of liquid helium. But it would cost hundreds of millions of dollars to build a superconducting magnet big enough to do the job and safe and reliable enough to fly in space. In March 1994, however, when Ting paid a visit to the Institute of Electrical Engineering in the Chinese Academy of Science in Beijing, the antimatter project suddenly seemed much more realistic.

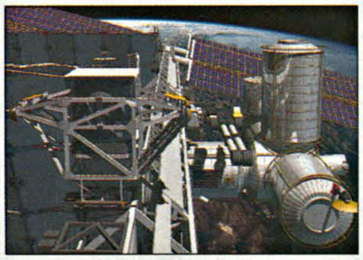
He discovered that the Chinese researchers had been building extraordinary permanent magnets made of a new material—iron alloyed with boron and neodymium, an element on which China has a virtual monopoly. The institute eventually agreed to build a permanent magnet for Ting's antimatter search for just $600,000. To track the paths of cosmic rays inside the magnet, Ting and his co-workers opted for silicon microstrip detectors based on technology developed for the L3 experiment, says physicist Roberto Battiston, whose group at the University of Perugia in Italy led the detector work.

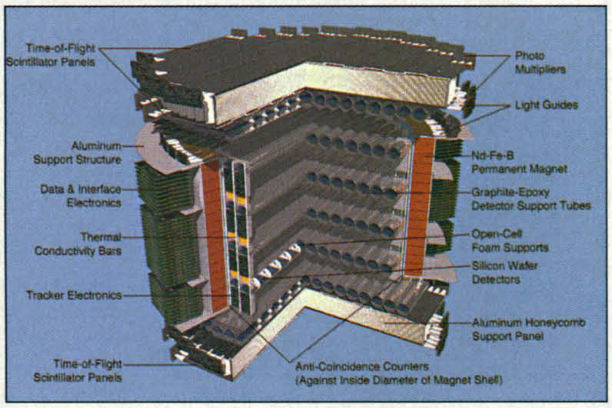
The final design for what was then called the Antimatter Magnetic Spectrometer (AMS) is a 2000-kilogram cylindrical magnet enclosing six planes of silicon-strip detectors. The device should be capable of tracking the path of a cosmic ray to within 10 micrometers, enabling it to distinguish matter from antimatter and also to search for the decay products of certain dark matter particles—exotic matter that many theorists believe pervades the universe.

Faster, better, cheaper science

Once Ting and his collaborators had brought the cost of his antimatter detector down to earth, they still faced the challenge of rounding up support. In the spring of 1994, Ting discussed the concept with Roald Sagdeev, former head of the Soviet space program and now a professor at the University of Maryland. Sagdeev was impressed enough to call Dan Goldin, head of NASA, and suggest he get together with Ting, which Goldin did. Goldin says Ting's presentation was "brilliant," and he saw in it an opportunity to give NASA's beleaguered space station project a chance to do some fundamental science.

As Goldin explains it, Ting's particle physics approach to building the experiment offers "blockbuster" science at minimal expense. "This is faster, better, cheaper by all accounts," says Goldin, echoing the credo he's tried to bring to NASA. "Three years ago at NASA most experiments cost on the order of a billion dollars and took a decade to build. Here walks in a man who says, 'Hey, I don't need billions, or hundreds of millions; this thing can get done for tens of millions.' " As a huge particle physics collaboration, the institutions of L3 already had the resources, expertise, and engineering skills necessary to build the experiment without shopping it out to industry. The group would then fly the device on the Space Shuttle, to work out the bugs and calibrate it, before fitting it to the space station.





K. BOLLWEG/B. HUNGERFORD/B. SAULS

Upping the anti. In the Alpha Magnetic Spectrometer, a powerful magnet and a set of silicon-strip detectors would pick out any antimatter cosmic rays and detect dark matter particles. It could fly aboard the space station by 2001 (*top; left foreground*).

Goldin agreed that NASA would pay to fly the instrument on the shuttle and attach it to the space station—a total cost of $13 million, by his estimate. Ting would have to get the money to actually build the detector from DOE and his international collaborators. Goldin also requested that Ting change the name of the device from Antimatter Magnetic Spectrometer to Alpha Magnetic Spectrometer. The new name acknowledges the projected host platform, the International Space Station Alpha; it also, says Salamon, "avoids the implication that the only science it is doing is a search for cosmic ray antimatter," which few physicists expect the project to find.

DOE has now agreed to contribute $3 million toward construction costs, and Ting's European, Russian, and Chinese collaborators will provide the remaining $17 million. The collaboration, working in Europe, plans to have the AMS instrument built by 1997, in time for a 1998 test aboard the Space Shuttle. If the space station continues on schedule, AMS will be installed as an externally attached payload in February of 2001. "It will remain there," says Salamon, "the instrument pointing away from the direction of Earth, for the equivalent of three full operational years," sampling some 10 billion cosmic rays.

If DOE decides to fund GLAST as well as AMS, it will put new pressure on DOE's already stressed resources. For the future, says Richter, the key question will be "What do these [projects] have to do with high-energy physics? Because that after all is the DOE's mission." At a meeting in mid-December, the DOE's High-Energy Physics Advisory Panel (HEPAP) did suggest to DOE that it create some kind of mechanism to deal with nonaccelerator and space-based proposals. As a result of HEPAP's prompting, says Bloom, DOE now plans to convene a special nonaccelerator physics panel in the next few months to review the GLAST proposal.

But HEPAP physicists and others see the need for a permanent review mechanism. Between traditional accelerator programs and a possible contribution to CERN's LHC, DOE's high-energy physics budget has had to stretch a long way already. "The high-energy physics community is going to have to take a look at the kind of physics you can do in space," says Richter, "and come to some consensus on what the right balance is."

That consensus will be crucial, because GLAST and AMS are unlikely to be the last of particle physicists' excursions into space. As de Rújula points out, the number of major high-energy physics collaborations starting up in the next 10 years is now down to two, both at the LHC. "And so the number of people who can be at the heads of those experiments is now down to two," he says. "That puts out of business very many people who should be doing interesting things, and there's a lot of space in space to do interesting things."

–**Gary Taubes**