NSF Centers Rise Above the Storm

Launched 3 years ago amid a blast of criticism, the Science and Technology Centers program is now firmly established and is about to undergo a major expansion

ON 31 OCTOBER 1989, BEFORE AN AUDIENCE at the Center for Particle Astrophysics at the University of California, Berkeley, astrophysicist Charles Alcock outlined a novel way to search for the so-called missing mass of the universe. Center scientists were impressed—so impressed that they persuaded Alcock, who works at neighboring Lawrence Livermore National Laboratory, to collaborate with them. They next struck a deal with the Australian government to use a refurbished telescope near Canberra to implement Alcock's search. One year after he gave his talk, almost to the day, Alcock was on a plane to Canberra to begin his research.

What makes the project remarkable is that it got off the ground so fast. Credit for that, says Alcock, should go to the National Science Foundation's new Science and Technology Centers (STC) program, which is bankrolling the Berkeley center. The program, which offers grants as large as $5 million per year for up to 11 years for multidisciplinary projects, has been a lightning rod for criticism ever since NSF first proposed it. Detractors call the centers a clumsy and expensive way of funding science, adding administrative burdens and depriving individual scientists of grants. Supporters have hailed them as a fresh approach to funding science, a way to break down departmental barriers and open new pathways to better science education. To see how the STC experiment is working, *Science* visited three centers that span a wide range of activities: from the very basic science of particle astrophysics to some of the applied aspects of molecular biology to a cutting edge technology in semiconductor electronics.

NSF had several goals in mind in establishing the STC program. In addition to supporting multidisciplinary science and improving science education, the centers were also intended to encourage technology transfer from universities to industry, give center directors more discretion over their budgets, and support risky projects requiring more resources than an individual scientist's grant could cover. In Alcock's case, for example, to find clues about the missing mass of the universe, he expects to operate the Australian telescope on every clear night for 4½ years. If his search bears fruit, it will help explain what 90% of the universe is made of.

Eleven STCs are up and running today. NSF had expected to announce the next crop of 14 last October, at the start of the current fiscal year, but according to acting NSF director Frederick Bernthal, a last-minute $40-million cut in his agency's budget has forced a delay. Each of the 14 finalists is now looking for ways to cut costs and find outside revenue before NSF makes a final commitment. The first two to succeed were the Center for Advanced Liquid Crystal Optical Materials at Kent State University in Ohio, which won a grant potentially worth $18 million over the next 5 years, and the Center for Ultrafast Optical Science at the University of Michigan in Ann Arbor, which received a $14.3-million award.

Ken Heinen

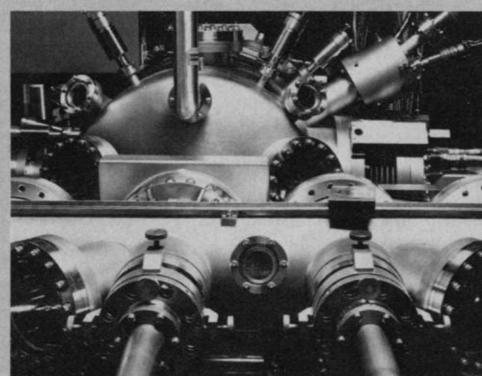
Board meeting. *The directors of the first 11 science and technology centers meet to discuss the program. First row (left to right):* **James L. Merz**, *Center for Quantized Electronic Structures, University of California, Santa Barbara;* **Surendra P. Shah**, *Center for Advanced Cement-Based Materials, Northwestern University;* **Leroy E. Hood**, *Center for Molecular Biotechnology, California Institute of Technology;* **David G. Whitten**, *Center for Photoinduced Charge Transfer, University of Rochester;* **Daniel Gorenstein**, *co-director, Center for Discrete Mathematics and Theoretical Computer Science, Rutgers University;* **James M. Tiedje**, *Center for Microbial Ecology, Michigan State University. Second row:* **James E. McGrath**, *Center for High-Performance Polymeric Adhesives and Composites, Virginia Polytechnic Institute and State University;* **Miles V. Klein**, *Center for Superconductivity, University of Illinois, Urbana-Champaign;* **Bernard Sadoulet**, *Center for Particle Astrophysics, University of California, Berkeley;* **Robert Tarjan**, *co-director, Center for Discrete Mathematics and Theoretical Computer Science, Princeton University;* **Ken Kennedy**, *Center for Research on Parallel Computation, Rice University;* **Douglas Lilly**, *Center for Analysis and Prediction of Storms, University of Oklahoma.*

The STC program is one of the legacies of Erich Bloch's 6-year term as director. In the mid-1980s Bloch huddled with several assistant directors—notably David Kingsbury from the biology directorate and Richard Nicholson from physics (currently executive officer of the American Association for the Advancement of Science)—and hatched the STC program. It was one of the new initiatives that encouraged the Reagan Administration to embrace one of Bloch's central goals—a doubling of NSF's budget over 5 years. (The Bush Administration still officially supports the doubling goal, but the target date has slipped from 1992 to 1994.) At the time, any project aimed at restoring American competitiveness in high-technology industry was virtually guaranteed political support, and STCs—with their emphasis on multidisciplinary, cutting-edge research—were no exception. NSF had already won points for the Engineering Research Centers program, a similar effort started in 1984 but limited to the engineering disciplines.

As it had done earlier with the engineering centers, NSF asked the National Academy of Sciences for suggestions on how to

A QUEST for Novel Electronics

Santa Barbara, California—Few universities can afford the million-dollar price tag on a molecular beam epitaxy machine. The Center for Quantized Electronic Structures (QUEST) at the University of California, Santa Barbara, has two—as well as a million-dollar focused ion beam device. These state-of-the-art instruments for making semiconductor devices come courtesy of a $2.3-million annual grant from the National Science Foundation, one of the first awards made under NSF's Science and Technology Centers (STC) program. "We put together a team of compound semiconductor specialists here to work on semiconductor technology," says QUEST director James L. Merz, and now they've got "real delta function in that area." Or, to translate from engineer-speak, they're cooking.



Million-dollar machine. *QUEST has two of these molecular beam epitaxy machines.*

QUEST researchers are using their new machines to explore a strange new world of electronic structures that operate on a scale where quantum effects predominate. Their ultimate goal: to determine whether such devices might someday be used to make faster, more efficient electronic components.

NSF picked QUEST nearly 3 years ago as a charter member of the select group of STCs and, if it lives up to expectations, the center is promised funding almost to the end of the century. It fit NSF's concept of the STC program on at least two counts: The scale of QUEST's operations is too big to be funded under the traditional NSF investigator-initiated grants, and the work demands an interdisciplinary mix of theorists and experimentalists.

Santa Barbara had some advantages because, even before QUEST was anointed by NSF, the university had assembled a core group of engineers used to dealing with theorists. "We drew rather strongly from Bell Labs," says Merz. For years Merz, himself a Bell Labs alumnus, wooed some of Bell Labs' best and brightest from New Jersey to the sun-drenched campus here on the California coast. They include materials scientist Pierre M. Petroff and Arthur C. Gossard, an engineer who spent 27 years at Bell Labs and who was a part of the team that discovered the fractional quantum Hall effect, a condition where an electron can appear to have less than a unit charge.

Although the people were in place, it took an external force to bring them together. "For years we engineers talked about getting together with the Institute of Theoretical Physics [at the Santa Barbara campus]," says Merz, "but it was the center that really made it happen." Merz becomes quite animated as he describes one particular interaction, a seminar in which a graduate student from QUEST got into a discussion with theoretical physicist Walter Kohn about whether it was possible to build a quantum device that would put out a single charge at a time. As a direct result of that discussion, Merz says, the center now has a patent pending on just such a device.

The molecular beam epitaxy machines are at the core of QUEST's work. They can lay down alternating layers of gallium, arsenic, and aluminum a single atom thick on a semiconductor wafer made of gallium arsenide. By carefully controlling the temperature and rate of atom deposition, Petroff and his colleagues have been able to create a lattice of quantum wires that run perpendicular to the plane of the surface of the semiconductor wafer.

If the science at QUEST is moving along at an impressive clip, the educational and outreach programs are only just finding their way. Because of the esoteric nature of quantum structures, QUEST has not found an easy way to establish programs to attract pre-college and undergraduate students into scientific and engineering careers—something that all STCs are required to do. Research scientists are just learning that as hard as their research is, it may be even tougher to explain to a class of skeptical students why they are doing it. ■ J.P.

implement the program. The result was a report from a committee chaired by chemist Richard N. Zare of Stanford University. The Zare committee recommended that centers (i) be aimed at complex problems requiring resources beyond what was typically available to individual investigators, (ii) be university-based, (iii) vary in size, and (iv) be given stable budgets over a finite lifetime. NSF adopted these suggestions, as well as a requirement that the centers conduct outreach programs to attract women and minorities into careers in science. The Zare committee also recommended that the centers be supported for a maximum of 9 years, but NSF chose 11 years, with strict reviews that could lead to a cutoff after 5 or 8 years if an individual center was not working out. NSF awarded the first STC grants in 1988, and they began operating in early 1989. They focused on a vast range of scientific problems: parallel computation, storm prediction, superconductivity, and advanced cement-based materials, to name a few.

As centers moved from the drawing board to reality, their detractors became more vocal, especially as NSF's budget failed to grow at the expected rate. Robert Park, a physicist from the University of Maryland and director of the Washington office of the American Physical Society, says creating a separate office within NSF to run the centers "was a ruse to get Congress to fund the program. When Congress didn't put up the money, they went ahead and did it anyhow." Daniel Kleppner, a physicist at the Massachusetts Institute of Technology, says starting centers at a time when other parts of NSF's budget are failing to keep pace with inflation sends the wrong message to young scientists. "The message is 'go to a large center or don't bother trying [to get funded],' " says Kleppner. He and others have argued loudly that individual researchers are the lifeblood of U.S. science, and that new programs like centers should only be funded if new money is available.

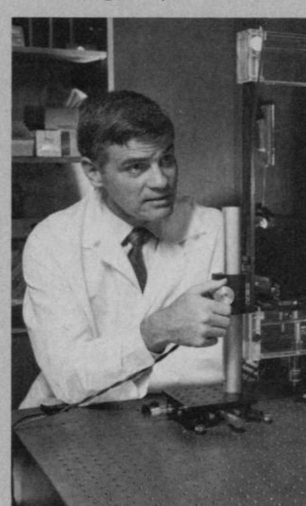
NSF officials, led by Bloch, have dismissed these criticisms. First, they point out that the total spent on STCs (including the 14 to be designated this year) amounts to only about $41 million, just 2½% of the total research budget. NSF also points out that its contribution has been heavily supplemented by support from industry, other federal agencies, and state and local governments. In addition, the program's supporters insist that NSF must keep trying new programs whatever the economic climate. Larry Smarr, a computer scientist at the University of Illinois and a member of the Zare committee, says there was a huge gap in the size of projects NSF was supporting. It was putting the bulk of its research funds into small, individual grants, each measured in tens of thousands of dollars, or was supporting a few large programs, like the National Center for Atmospheric Research or the National Radio Astronomy Observatory, whose budgets are measured in the tens of millions of dollars. In between, there was nothing. "We simply wanted to see if there were latent ideas out there for how science could organize itself on different scales," says Smarr. There were: NSF received more than 300 applications following the initial announcement, and Smarr says the quality of the 11 that received money was outstanding. He dismisses the notion that these are lower quality than research proposals submitted by individual investigators. "If you wanted to make the [individual investigators'] grants cut off at the same level of excellence that the STCs cut off at...a lot of people who are whining right now would be out in the cold," he says.

Bernard Sadoulet, director of the Berkeley Center for Particle Astrophysics, argues along with Smarr that centers are needed to supplement the "small" science grants that NSF traditionally funds. Individual awards encourage extreme specialization, he says, since the money available is usually only enough to cover a small project in a specific area. With small grants, researchers may not want to undertake risky projects, since reviewers tend to favor research proposals they are convinced will pay off. Horia Metiu, of the University of California at Santa Barbara, knows well the problems of trying to sell cross-disciplinary research projects. As a theoretical chemist, he's been collaborating with engineers and physicists at the University of California at Santa Barbara–based Center for Quantum Electronic Structures (QUEST) to predict why single layers of gallium and aluminum atoms align themselves in an ordered way on semiconductor chips, and how to use that

New Alliances, New Technology

Pasadena, California—Leroy Hood has always had a knack for forging partnerships between researchers who at first blush might seem to share little scientific common ground. In his lab here at the California Institute of Technology, electrical engineers have worked with molecular biologists, computer scientists have collaborated with protein chemists. Three years ago, Hood says he got a chance "to expand enormously these more daring interactions," when he won a grant worth $3.5 million per year to establish the Center for Molecular Biotechnology as one of the National Science Foundation's first Science and Technology Centers (STCs). Says Hood: "I think some of [the alliances] are going to pay off in really big ways."

The center has just moved into brand new quarters at the recently completed Beckman Institute on the Caltech campus. The STC grant has allowed Hood to recruit several new people, buy more equipment, and increase links to industry. In an interview with *Science* at the Beckman Institute—a building so new most labs have not yet had a chance to festoon their doors with the usual assortment of cartoons and graffiti—he spoke with an almost evangelical zeal about what he hopes to achieve with the new center. Hood doesn't think small: He wants nothing less than to revolutionize the way molecular biologists work—from the way they sequence proteins to the way they search sequence databases. Chemists John R. Yates III and Patrick R. Griffin, for example, are using mass spectrometers to analyze protein samples. This is a completely new approach to protein analysis, and if it works, it will allow researchers to analyze far smaller samples in far less time. Molecular biologist and computer scientist Tim Hunkapillar is developing a new generation of special-purpose chips that will quickly analyze large DNA sequences. Molecular biologist Debbie Nickerson has a pilot system she is automating that uses fluorescent markers attached to DNA probes that can quickly detect mutations in genes. Then there's Jerry Solomon, who was working on image analysis at the neighboring Jet Propulsion Laboratory and is now collaborating with the center on the analysis of the dot patterns proteins make when they are separated on two-dimensional gels.



Matchmaker. *Leroy Hood is planning more "daring interactions."*

Hood insists that these projects—many of which started before the center grant came through—benefit from the center style of support: "It's enormously more than we did before because there's a big difference between a budget of $400,000 and a budget of a couple of million dollars," he says. "The key to the center concept is the idea of having many disciplines that are all juxtaposed that can interact effectively." Nickerson agrees that being at the center has provided her with unique opportunities: "I'm a biologist. To think that I talk with laser people and robotics people and computational people is just incredible."

The Pasadena center has also tried to break some of the traditional barriers between academia and industry. Chemist Mark L. Stolowitz, who left his academic job to go to a start-up biotech company, says before the advent of centers it was very hard to get back into university-based research. "There didn't exist appropriate appointments for someone who was at the vice-presidential level at a small company." Now Stolowitz has a research appointment at Caltech where he is developing a new set of reagents and techniques for standard chemical-based analysis of proteins. Hood is also building a corporate partners program where industry will be able to make use of center research—for a fee.

Hood's group has pushed hard to get the center involved in education. Researchers here have designed a new biology course for high school students and are applying to several foundations in the hopes of getting enough money to implement it. Hunkapillar, who heads outreach activities for the center, admits that expert researchers are not necessarily expert educators. "All the good intentions in the world aren't going to make [the outreach education programs] work," he says "but it takes good intentions."

For a while this fall it looked as if a large monkey wrench might jam the smoothly oiled research machine that Hood has erected. Hood was offered Charles Cantor's old job as director of the human genome effort at the Department of Energy's Lawrence Berkeley Laboratory, but late last month Hood decided to stay at Caltech (see page 25).The Caltech center may well be the epitome of what NSF hopes to achieve with the centers program. But if Hood had shifted gears and gone to Berkeley, one of the program's strengths—dependence on a strong director—may have turned out to be a weakness. ■ **J.P.**

information to manufacture novel semiconductor structures. Metiu says if he took such a project to the chemistry division at an agency like NSF, it would say that the project should be supported by the engineering division. But if he went to the engineering division, it would pass the buck to chemistry. QUEST gave him the money to dive right in, and according to director James L. Merz, "In a short period of time we've beaten the pants off the people who were trying to understand [this] ordering phenomenon."

If the positive side of block-grant type funding is flexibility, the negative side is the tendency to build up dead wood—researchers who are supported year after year with no peer review of the work they are doing. Metiu says he was initially a critic of the center concept for that reason. But possibly because the centers are new and subject to intense scrutiny, Metiu says the Santa Barbara center has developed a de facto system of peer review. "The pressure [for the available funds] is so high we're squeezing out the weak people," he says. And Sadoulet points out that traditional peer-review schemes don't eliminate all the dead wood: "The [science] agencies tend to keep the same people on board."

Another frequently cited drawback to centers is that they tend to centralize power in the hands of their directors. Charles Yanofsky, professor of biological sciences at Stanford University, says young scientists working at a center or any large laboratory can feel pressure to "just do what the boss says. That's not my idea of a good way to treat promising new individuals." Directors like Merz, however, don't feel that centers generate a follow-the-leader mentality, but, "When push comes to shove, I have to make the decisions," he admits.

So if STCs are not just large research factories, what are they? "My model for what a center should be is a true intellectual consortium," said NSF acting director Bernthal at a luncheon with *Science's* news staff. At the centers visited by *Science*, it was clear that the science was thriving and the enthusiasm was high. What is still unclear, however, is what kind of identity centers will establish for themselves—how far they will be able to go in breaking down departmental barriers, whether they will provide new direction in the training of research scientists. Despite their enthusiasm for the program, NSF officials admit they aren't sure how these questions will be answered. "We need to try to define for ourselves what we're trying to achieve," says Bernthal.

Although they are philosophically committed to education and outreach, some of the centers seem to be groping their way in this area with no clear sense of direction. Graduate education efforts are more focused, but these are closest to what already exists: Graduate students are now supported by multiple investigators instead of a single individual. The promise for more fundamental change is tantalizing. If the centers flourish, "The intellectual landscape at academic institutions will change," says Aravind Joshi, a computer scientist at the University of Pennsylvania. Pennsylvania is one of the finalists for the next round of centers, and Joshi will be director of a center in cognitive science if NSF comes up with the money. Joshi says cognitive science is a perfect example of why centers are needed. No single department can embrace the entire field. Mathematics, philosophy, computer science—are all needed, and the center type of support makes it easier for each of the departments to participate.

Centers represent a break from the business-as-usual approach to science funding. Will they turn off a generation of young scientists, as critics like Kleppner worry? Possibly. Or will they open science up to a new and broader constituency? That is also possible. NSF has rolled the dice on an experiment in science, and it will take some time to know whether it has come up with a winner.

■ JOSEPH PALCA

In Search of "Dark Matter"

Berkeley, California—Copernicus may have displaced humans from the center of the universe with his hypothesis that the earth circles the sun, not vice versa. But if cosmologists are correct, an even bigger displacement is in store. Says Bernard Sadoulet, director of the Center for Particle Astrophysics at the University of California, Berkeley: "We are not made of the stuff that the universe is made of."

Sadoulet is referring to the theory that at least 90% of the mass of the universe is "dark matter," something different from the "stuff" we can see: stars, planets, and ourselves. With its $2-million annual budget as one of the National Science Foundation's Science and Technology Centers, Sadoulet and his colleagues have launched a multi-pronged attack on the dark matter problem—what it is, how much of it there is, what role it plays in the structure of the universe, and how to detect it.

Sadoulet's own work focuses on an entirely new class of material called WIMPs (Weakly Interacting Massive Particles). Collaborating with low-temperature physicists, he is developing a new set of detectors that will be able to find WIMPs' weak energy signature amid the earth's noisy background. Another team at the center, led by Kim Griest, Charles Alcock, and others, has speculated that the dark matter may simply be small stars in the halo of galaxies that are not massive enough to shine. They will use an Australian telescope to look for indirect evidence of these stars—which they've called MAssive Compact Halo Objects, or MACHOs—as an alternative to the WIMP hypothesis.

WIMP detector. *Berkeley scientists are hoping WIMPs or MACHOs will account for 90% of the mass of the universe.*

Others at the center are studying different parts of the energy spectrum to try to learn more about how dark matter was formed at the birth of the universe. Andrew Lange, who uses sensitive cryogenic detectors flown aboard high-altitude balloons to study the microwave background, says the center encourages collaborations in a way that individual grants would not. "The center makes a source of funding available if we can get a group of people together," he says.

The Berkeley center has also made a big push in education. In addition to the 60 or so graduate students involved in various center projects, it has summer programs for undergraduates and high school teachers, and hopes eventually to have high school students using a University of California at Santa Barbara telescope for astronomy experiments. Center staff have also received a tentative commitment from *Rolling Stone* magazine to do a profile of center graduate students to help debunk the myth that physicists are all nerds.

■ J.P.