sunlight and generating power.

To prevent such problems in the future, the investigation panel recommended procedural changes and tests of all computer programs. A recent National Research Council report, "US–European Collaboration in Space Science," anticipated some of the conclusions of the SOHO investigation board. The research council urged clearly defined roles and responsibilities for the partners who may communicate in different languages and operate with different procedures.

Since radio contact with SOHO was reestablished on 5 August, NASA and ESA scientists have been reorienting SOHO's antenna and power panels, thawing its frozen fuel lines, which carry hydrazine to the craft's thrusters, and recharging its batteries. The thrusters are necessary to reorient the spacecraft so that SOHO's recovery can be completed. **IRWIN GOODWIN**

Drell's Retirement Evokes Memories of Dual Career as Physicist and Humanist

Sidney Drell once characterized his life as "equally divided between pursuing the dream of discovery and working to avoid the nightmare of a nuclear holocaust." During his 50 years in research and teaching, he has made impressive contributions to both: advancing the understanding of particle physics and reducing the risk of nuclear war. On 31 July, Drell officially retired from his positions as professor at Stanford University and deputy director of the Stanford Linear Accelerator Center (SLAC). The events were marked by a day-long "Sid Fest" at the laboratory.

As scientific gatherings go, this one was distinguished by its warmth and wit, as some 200 physicists, including several Nobel laureates, celebrated Drell's contributions. In short, animated and often hilarious talks, Drell's friends and disciples provided a compelling retrospective of his inventive and influential body of work and thought.

The first speaker, Condoleezza Rice, Stanford's provost and vice president for research, set the tone of the symposium. She spoke of Drell's determination to make sure that Stanford had a diverse mix in both its faculty and students. He advocated openness, informality, mentoring and, always, uncompromisingly high intellectual standards. On his dual careers in theoretical physics and public policy, Rice noted that Drell had been a founding father of SLAC, when it was housed in a warehouse and known as Project M, and of the university's Institute of International Security and Arms Control. He taught a class on arms control, an elective course that regularly attracted about 200 students. His last class lecture was on ethics, she said, "and it always ended with a standing ovation." As a former piano major in college, Rice claimed she was obliged to mention Drell's musical abilities as a violinist and as an opera buff who can quote the entire score of Mozart's "Don Giovanni."

Drell's early years in physics, as an undergraduate at Princeton and a graduate student at the University of Illinois, were recalled by Michael Peskin of SLAC. Peskin reviewed Drell's top ten scientific papers—among them, the first, written in 1949 with his thesis adviser, S. M. Dancoff, on electrostatic scattering of neutrons, and another on quantum electrodynamics at short distances, co-authored with his graduate student, J. D. Bjorken, in 1958. According to Peskin, "Sid proposed most of the major themes of high-energy physics," championing the photon, electron scattering and quantum field theory. Drell's book, *Relativistic Quantum Mechanics*, co-authored with Bjorken, is no longer "must reading" but still referred to, said Peskin.

PANOFSKY (RIGHT) ON DRELL: 'An independent expert.'

CERN's director general, Chris Llewellyn Smith, who was a postdoc at SLAC in the early 1970s, spoke of Drell's "statesmanship" in leading a Department of Energy study of priorities for high-energy physics, following the termination of the superconducting supercollider. The report of that study recommended that the US join CERN's Large Hadron Collider.

It fell to T. D. Lee of Columbia University to discuss the geneaology of US theoretical physicists, from Oppenheimer to Dancoff to Drell, and then to examine Drell's success as a mentor and inspiration to students. "Dancoff begat Drell, who begat Heinz Pagels, Tung-Mow Yan, J. D. Bjorken and Bob Jaffe." Lee later promised the audience he would cover quantum electrodynamics, quantum field theory and general relativity in the remaining 20 minutes—and he did.

After lunch, Wolfgang K. H. (Pief) Panofsky, SLAC's founding director emeritus, highlighted Drell's tireless activities in arms control, as a member of the Jason group that advises the government on strategic and technical issues and the President's Foreign Intelligence Advisory Board. "It was largely through Sid's persuasion that the government agreed that zero testing [as part of the Comprehensive Test Ban Treaty] really means zero," said Panofsky. "Sid always chooses topics that are controversial—and enjoys doing so. The government needs independent experts, and we are fortunate that Sid is both."

Another arms control expert and a prominent member of Jason, Richard Garwin of IBM, provided a rundown of the many contributions Drell has made behind the scenes for several US presidents, back to Nixon. "Sid's involvement with national security is so broad and so deep that it would take an entire day of talks such as this to begin the story. But if you were to ask Sid about it, he would say, 'If I knew, I couldn't tell you anyway.' The national security of this country owes Sid a great debt of gratitude."

The day's final speaker, Burton Richter, director of SLAC, observed that he "almost never gets to say the last word wherever Sid is concerned," and then told a few tales that were not generally known. "He's still very smart, despite his advanced age. . . . He's absolutely honest and incorruptible, but nobody has figured out what his price may be."

Drell said little more than "thanks" for the tribute. He may have considered his essay in the summer issue of SLAC's magazine, *Beam Line*, as sufficient. "What a gig this has been! And what fun to have been ringside to so much of the action," he wrote "Looking back, it has been the best of times."

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Her talk resembled Richardson's in style and content. She heaped praise on "an extraordinary organization that is staffed by exceptional people." The "dedication and professionalism" of the staff impress her. "You are dynamic and interesting people."

A few hours later, before the DC Science Writers Association, Colwell was more forthcoming about the direction she would take. She advocated cross-disciplinary research, which relies on interconnections among the fields of mathematics, physics, chemistry, biology, materials science, engineering and even the social and behavioral sciences. "Our broader grasp of these interconnections provides tremendous advantage for preventive, not remedial, solutions," she said. "As this perspective increases, our collective power to generate insight grows proportionately."

Like Richardson, she listed her priorities for the agency. Unlike Richardson, she ranked them:

▷ Science and engineering education—principally grades K through 12. "America's continuing leadership will depend more on the caliber of its human resource than on any other resource. It will not be enough to have a top layer of scientific elite, and another of mediocrity below. And the situation is only worsened by widespread public science illiteracy."

▷ Biocomplexity—reaching well beyond biodiversity. "When we speak of sustaining biodiversity, we mean primarily maintaining the plant and animal diversity of the planet, itself a very important goal. . . . We must do that, but also discover the complex chemical, biological and social interactions that comprise our planet's systems. From these subtle but very sophisticated interrelationships, we can tease out the fundamental principles of sustainability. Our survival as a human species and the ecological survival of the entire planet depend on our ability to achieve what is truly an interdisciplinary task."

▷ Information technology—the new age of exploration. "The first age of exploration spanned approximately two centuries. Our new era is in its infancy. . . . Contributions from information science and technology will create whole new disciplines and fields of knowledge, trigger new industries and find new worlds, literally and figuratively."

In speaking to her staff that afternoon, Colwell had revealed a comic sense about her new job. To celebrate her new career in Washington, she told her staff, friends had presented her with two books: *Aesop's Fables* and Lewis Carroll's *Alice in Wonderland*.

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Once Lost in Space, SOHO Is Found; NASA and ESA Struggle to Revive It

Space satellites rarely attract public notice until things go wrong. So it is with the Solar and Heliospheric Observatory (SOHO), which had been revolutionizing the study of the Sun in its two-and-one-half years in orbit when controllers at NASA's Goddard Space Flight Center lost contact with the $1 billion spacecraft early in the morning of 25 June, during routine maneuvers and calibrations. For more than a month, SOHO was spinning in space, without power to communicate or operate the 12 scientific instruments on board. But, on 23 July, by the ingenious use of the National Astronomy and Ionospheric Center's 305 m radiotelescope at Arecibo in Puerto Rico to transmit a radar signal toward SOHO and with the 70 m dish of NASA's Deep Space Network in Goldstone, California, acting as a receiver, SOHO was located and tracked. Then began a series of actions to revive the dormant satellite. On 3 September, at a press briefing held simultaneously at NASA headquarters in Washington and the European Space Agency (ESA) in Paris, Roger Bonnet, ESA's science director, announced that SOHO was no longer doomed. He was optimistic that it would be completely healthy by October, "as a result of a dramatic rescue operation."

SOHO, a joint venture of ESA and NASA, was launched in December 1995 as part of the International Solar–Terrestrial Physics Program. Positioned 1.6 million km sunward of Earth, at the Lagrangian L1 point, where the gravitational pulls of Earth and Sun are in balance, the spacecraft became fully operational in April 1996. Until it went mute, SOHO's instruments, built in the US, France, Germany and Finland, provided scientists with many dazzling discoveries: huge tornadoes in the solar atmosphere, 51 comets passing near the Sun or plunging right into it; "rivers" of charged particles on the Sun's surface, and the first detection of sunquakes deep inside.

Although the spacecraft was designed to operate for only two years, SOHO was functioning so well that project scientists had hoped to extend the mission to 2003, as the Sun goes through a period of maximum activity that is expected to peak in 2001.

"We had no idea if we would ever be in touch with SOHO again," said Joe Gurman, a Goddard project scientist. "We knew it was a race against time, because without power to receive or send communications and without direction to reorient itself, it wouldn't be long before SOHO's orbit decayed. But if we can restore the spacecraft to its original healthy condition, there is every likelihood that it will provide data to the year 2003."

The spacecraft's health will not be known until the solar panels are generating power and the instruments are thawed. The critical maneuver is the relay of signals to fire the rocket thruster motors to put SOHO back into the correct position facing the Sun. The final test will be to switch on the 12 instruments, which were designed to operate at –20°C, and discover how many survived the extreme cold of as much as –200°C in deep space.

The cause of SOHO's near demise was the subject of a NASA–ESA investigation board, which released its final report on 3 September. The board blamed the controllers who lost contact with the craft during a series of recalibrations that normally take 48 hours but were compressed into 24 hours so that scientists would not lose a day of data. The errors occurred in turning off one of three gyroscopes during routine "momentum management," when thrusters are fired to hold the spacecraft steady while a set of wheels, which maintain the spacecraft's attitude by counteracting external torques, is slowed down. As soon as this procedure was completed, the gyro told SOHO—incorrectly—that the spacecraft was spinning 20 times too fast. The system went into a safeguard mode called Emergency Sun Reacquisition, which kicks in automatically when an anomaly is detected in the craft's orientation.

From there on, the troubles cascaded. To save wear and tear, the computer shuts down another gyro while the wheels are braked. But because an essential command sequence had been omitted from on-board software during a rewrite last year, the first gyro failed to come back on, unknown to the controllers. The control team did not check the status of the craft to bring it back on line and used new software that had not been adequately tested and was in conflict with another gyro. When instrument readings didn't gibe, the controllers made a snap decision that the first gyro was faulty and turned it off. Without the gyros, the thrusters fired to stabilize the spacecraft. The false readings triggered continuous firings and SOHO began spinning faster and faster, preventing the solar panels from collecting