An Unsung Legacy of the First Lunar Landing

A small laser reflector left behind on the moon's surface by the Apollo 11 astronauts has provided 20 years of precise data that have spawned some interesting findings

IN THE AVERAGE SCIENCE TEXTBOOK, the distance between the centers of Earth and its moon is said to be 384,400 kilometers. That may be accurate enough for most school books but it's not even in the ballpark for many researchers, who are now measuring the distance to within 3 centimeters. And, since the Earth-moon system is in constant, albeit incremental, flux, geophysicists are always recalculating the gap.

The stunning accuracy of these measurements is made possible by a laser retroreflector left in the Sea of Tranquility during the 20 July 1969 Apollo 11 landing. Laser ranging, in fact, is the sole active scientific survivor of that historic moon walk two decades ago this year. But this little instrument has not featured much in the anniversary hoopla, and that is a pity, for it has spawned a broad array of interesting findings over the past 20 years.

The extraordinary precision of the ranging data—which the National Aeronautics and Space Administration (NASA) compares to measuring the distance between New York and Los Angeles to 1/50 of an inch—has confirmed several predictions flowing from Einstein's General Theory of Relativity, for instance. It has also greatly expanded knowledge of the moon's orbit, allowing analyses of solar eclipses as far back as 1400 B.C. "The moon recedes [from Earth] at a rate of about 1.5 inches a year. And we've seen that pretty strongly for a number of years," says James G. Williams, who crunches lunar ranging data at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.*

Several geodetic satellites are also regularly laser-ranged, most notably NASA's LAGEOS-1, launched into a 3600-mile orbit in 1976. Collated ranging data garnered from both the moon and artificial satellites have detected a small but steady change in Earth's shape, confirming that its land masses are still slowly decompressing after having been crushed by the great glaciers of the last Ice Age. Lunar ranging has also shown minute variations in the moon's rotation. These result from Earth-driven torques on the moon's solid body and possibly from the turbulent effects of a fluid lunar core. Similarly, Earth's atmosphere and fluid core alter the length of the Earth day. Lunar ranging has clocked these minute variations at about 1/1000 of an arc-second over the course of a year.

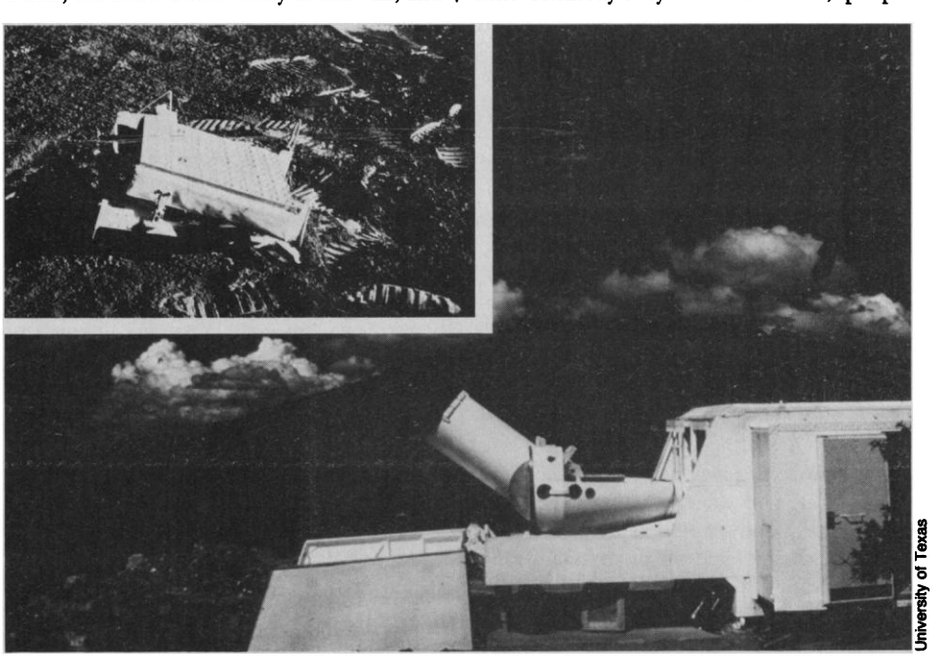
All this is done in the most unassuming of ways. The Apollo 11 retroreflector is, at heart, a low-tech device: an 18-inch-square aluminum panel mounted with 100 fused silica "corner cubes" which reflect photons of light back to their point of origin. The device emplaced 20 years ago was joined in 1971 by two others, deposited in a triangular arrangement, during the Apollo 14 and Apollo 15 moon visits. In 1971 and 1973, the Soviets also put reflectors on the moon with their Lunakhod robot, though only the second one still works.

When atmospheric conditions are good, scientists at the McDonald Observatory in Texas, the Lure Observatory in Hawaii, and the Calern Observatory in southern France regularly pulse the reflectors with 250-millijoule neodymium-YAG (yttrium-aluminum-garnet) lasers. Though the beam has spread to a mile across by the time it reaches the moon, actually hitting a retroreflector has been likened to targeting a moving dime with a rifle 2 miles away.

The telescope-pointing task is greatly complicated by the fact that all but one of the retroreflectors were left on largely featureless tracts of the moon, which means that scientists have no big targets to aim at. The laser astronomers thus prefer to shoot for the much larger Apollo 15 device, which boasts 300 corner cubes and is located near easily observable lunar landmarks. NASA is being urged to invest in automatic tracking optics for the two U.S. lunar ranging stations to help simplify targeting.

No less challenging is the job of capturing the returning beam, which is about 5 miles across when it gets back to Earth. Using sensitive metering devices, scientists detect the reflected signal photoelectron by photoelectron. On a typical night, as many as 30,000 light pulses might be zapped at the moon, with perhaps only 30 returns successfully captured. If the moon were twice as far away from Earth, in fact, the experiment would never work.

James E. Faller, a fellow at the Joint Institute for Laboratory Astrophysics (JILA) at the University of Colorado in Boulder, dreamed up the lunar laser ranging scheme in the early 1960s, when lasers were in their infancy and voyages to the moon were yet little more than a gleam in President Kennedy's eye. "Before that, people



University of Texas

Difficult shot. *Hitting the laser reflector (inset) is like targeting a moving dime with a rifle 2 miles away. On a typical night 30,000 pulses are fired and 30 returns captured.*

*Lunar ranging data is also being analyzed at the Harvard/Smithsonian Center for Astrophysics, Massachusetts Institute of Technology, and the University of Texas, as well as in France and China.

had been interested in pulsing light off of the lunar surface itself," Faller said. "But only a tenth of [the light] is reflected back, and the uncertainty in the distance is about 1 kilometer," or the average height of the lunar mountains.

"The Lunar Laser Ranging Team was really very lucky to get the [retroreflector] package on the Apollo 11 flight," recalled Peter L. Bender, also a physicist at JILA and a lunar ranging veteran. "Our experiment was developed as a contingency which was actually used because they didn't yet have the confidence to plan on a longer stay on the lunar surface. Ours was very simple to set up because it was completely passive."

When the reflectors were first installed, lunar ranging was accurate to about 1 meter. But over the past 20 years, the precision has steadily been honed down to the 3 centimeters achievable today—thanks largely to better measuring gear developed at the McDonald Observatory by Eric C. Silverberg. And now that President Bush is talking about returning to the moon with a permanent scientific colony early in the next century, laser zappers are talking excitedly about what a new generation of ranging devices might offer.

Sighting is one problem that could be easily solved. "If we do go back, it would be really lovely to put an infrared pulsed-laser diode [near each retroreflector] that would blink every second or so and that would serve as a beacon," Faller said.

As for accuracy, 3 centimeters is far from being the outer limit. By implanting active transponders on the moon that could be modulated to lock phase with and return a continuous-wave laser signal from Earth, "we could get down to 1 millimeter for the absolute range and something like 30 microns for differences in range to the different transponders," says Bender.

Such microscopic accuracies would contribute greatly not only to further unraveling the riddles of relativity, but also to plumbing the mysteries of the moon's liquid core. Even if the federal budget deficit conspires to forestall a return to the moon, however, the retroreflectors already up there show no signs of wearing out.

"We hope they will last pretty much forever," said Jean O. Dickey, director of NASA's Lunar Ranging Working Group at JPL. "They're passive devices, so there's no energy source up there. The only way that they would be disrupted is if moon dust gradually accumulated on them over a long period of time. But we don't see any sign of that." ■ DAVID C. MORRISON

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Can Psychotherapy Delay Cancer Deaths?

A new study says yes, but that does not necessarily mean that cancer patients have mental control over their disease

FOR HARD-NOSED ONCOLOGISTS who have for years shunned the notion that the mind can influence the fate of cancer patients, the news in the 14 October issue of *Lancet* will be unsettling. Stanford psychiatrist David Spiegel reports there that psychotherapy lengthened by a year and a half the lives of women with metastatic breast cancer, while reducing their anxiety and pain as well. And he's not just another Shirley MacLaine.

Having undertaken the study to disprove what he calls "the wish-away-your-cancer types," Spiegel spent several years trying to poke holes in its conclusions. Though he now stands solidly behind them, he hurries to point out that his results do not mean that psychotherapy cures cancer. Nor do they prove that patients have mental control over their disease. But, he says, they do suggest that psychotherapy can improve both the quality and quantity of life for cancer patients.

"It is the first study that I think is scientifically sound that has shown some change in survival," says Jimmie Holland, chief of psychiatry at New York's Memorial Sloan-Kettering Cancer Center. But she nevertheless has qualms. "What I am fearful of is that the 'alternative' field will go crazy with this and say, 'Aha, we told you all along, psychotherapy cures cancer, so stop your radiation therapy.' "

Spiegel never conceived of such an outcome when, 13 years ago, he began an evaluation of the short-term effects of group therapy on patients with advanced breast cancer. "The whole point of the original study was that we could make them feel better," says Spiegel. "We didn't in any way imply you were going to wish away your illness. In fact we were saying 'face your mortality.' " The result was that patients who received therapy became less anxious, fearful, and depressed and learned to reduce their pain through self-hypnosis.

Then a few years ago, Spiegel got irritated with popular psychology programs that claim to help patients conquer cancer through positive thinking. So he decided to follow up on his earlier study. "Here was a perfect setup," he recalls thinking. "I had shown this great psychological impact, and I knew there would be no difference in survival."

But when he tracked down information on the 86 participants in his study, he was stunned. While those in the control group lived an average of 19 months after joining the study, those who received a year of group therapy lived an average of 37 months. And the three women who were still alive after 10 years had all received group therapy. "I nearly fell off my chair," Spiegel says. "I just couldn't believe it."

"I echo his views; I am also surprised," says Boston University psychologist Bernard Fox, a well-known skeptic in the field of psychosocial oncology. Fox, and Sloan-Kettering's Holland, were among the colleagues Spiegel asked to scrutinize the manuscript before he submitted it for publication.

While at least one study has purported to show an effect of psychotherapy on cancer survival, and another has shown no effect, Fox says Spiegel's is more rigorous than the former two because assignment to therapy or control groups was random, and all patients received standard medical treatment, including surgery and radiation or chemotherapy. "They are very careful experimen-

Stanford University

Surprising results. *Stanford's Spiegel found a positive effect from psychotherapy.*