Mars Observer's Costly Solitude

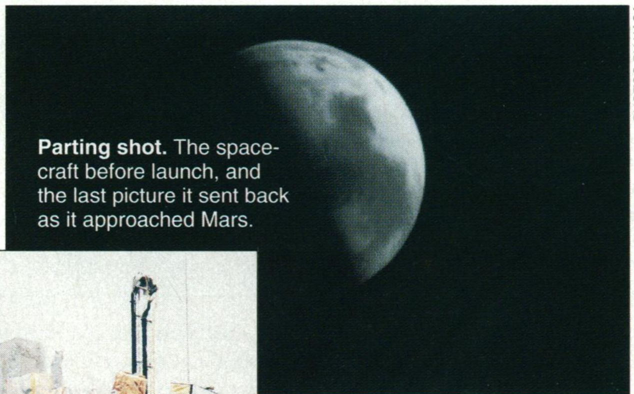
The apparent loss of the first U.S. mission to Mars in 17 years is devastating for researchers who have spent years working on the project, and it will leave a big gap in knowledge about the red planet

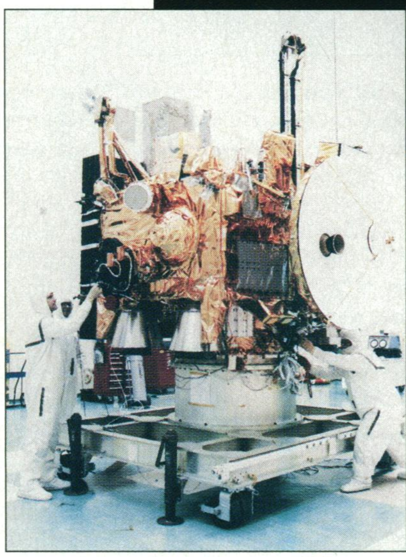
As Mars Observer closed in on the red planet last month, Alden Albee, the mission's project scientist, thought about calling *Science* to discuss the possibility of publishing a report of the spacecraft's observations when it had circled the planet for 60 days. Something made him hesitate. "I was just being cautious and decided to wait until it was in orbit," the dean of graduate studies at Caltech recalls. To Albee's horror, his restraint proved more than justified.

On Saturday evening, 21 August, ground controllers at the Jet Propulsion Laboratory (JPL), which manages the mission, lost contact with the spacecraft, and, despite their frantic efforts, it has not been heard from since (see box, facing page). By last weekend, JPL had nearly run out of ideas to shock Observer into communicating with Earth, and controllers contemplating a "listen-only" vigil in the slim hope that the spacecraft would wake up and call home.

The abrupt end of the first U.S. Mars mission in 17 years, coupled with a string of other recent problems in the space program, could not have come at a worse time politically for the National Aeronautics and Space Administration (NASA). The space agency's budget for fiscal year 1994 will be decided on Capitol Hill in the next few weeks, and NASA needed a major scientific and public relations triumph to help persuade Congress to back a big increase in funds (see box p. 1267 and ScienceScope, p. 1263). The impact on the hundreds of planetary scientists whose lives and scientific careers have been intimately intertwined with the spacecraft's progress is more immediate. "It's difficult to work on something for 10 years, and expect to work on it for another 5 years, and have it disappear," says Philip Christensen of Arizona State University, one of Observer's principal investigators. "[In] the next 3 to 6 months, most if not all the people working with me will be looking for jobs," says University of Arizona's William Boynton, team leader for Observer's gamma ray spectrometer.

Scientifically, the loss is no less disastrous. Researchers were hoping Observer would help answer mysteries about Mars' geologic history and its turbulent atmospheric circulation. And Observer's detailed mapping of Mars' surface was supposed to pave the way for future NASA and international forays to the planet—perhaps even a manned mission someday. "This is the kind of data that would allow us to really understand Mars," says Albee.





Parting shot. The spacecraft before launch, and the last picture it sent back as it approached Mars.

PHOTOS BY NASA

Indeed, he and his colleagues in the planetary science community believe the mission was scientifically so important that they are urging NASA to find some way to repeat it.

The scientists

With a total cost approaching $1 billion, Observer may seem like the epitome of "Big Science," but the mission actually combined many smaller observational projects, and its apparent demise has touched the careers of hundreds of individual researchers. Albee, who says Observer's deathly silence has left him "numb," is one of more than 100 investigators who have been planning the mission for the past decade. Beyond that core group, says Albee, are perhaps 500 scientists who would have worked with the data. And behind those front ranks is an army of postdocs, graduate students, and future investigators whose careers might have been shaped by the wealth of information from Observer. "I run a team of 25, with seven graduate students and five undergrads. We've been trying to teach the next generation," says Christensen.

What makes the tragedy of Mars Observer even more cruel is how close the mission came to succeeding. The team behind the spacecraft's radio science experiments had gathered at JPL on Monday and Tuesday, as the spacecraft was scheduled to go into orbit, to make final preparations for the onslaught of data they had expected, but Observer's silence turned the gathering into a wake. "It's difficult to concentrate. It's depressing to even talk at the moment. These kinds of missions demand a long-term effort from a lot of people," Stanford University's David Hinson told *Science* after the meeting.

Though it was small comfort at the time, Hinson said he may be one of the more fortunate members of the Observer team, because he has other projects to fall back on. NASA geologist James Garwin, who worked on the spacecraft's laser altimeter experiment, says: "Basically, it's my entire scientific professional career."

Then there's the plight of Michael Malin, principal investigator for the spacecraft's camera system. Originally, NASA had no plans to include any cameras on Observer, believing the Viking missions in the mid-1970s had provided more than enough pictures. But Malin fought fiercely to change the agency's mind. He developed Observer's innovative camera system and even started his own company to handle the operation of the instrument and the analysis of the images. Now his company may be out of business. The experience has been emotionally wrenching: "A TV reporter will go up to someone who's just lost children in a fire and say, 'How do you feel?' Well, that's how I feel. Like TV reporters are shoving mikes in my face. I don't get sad. I get angry."

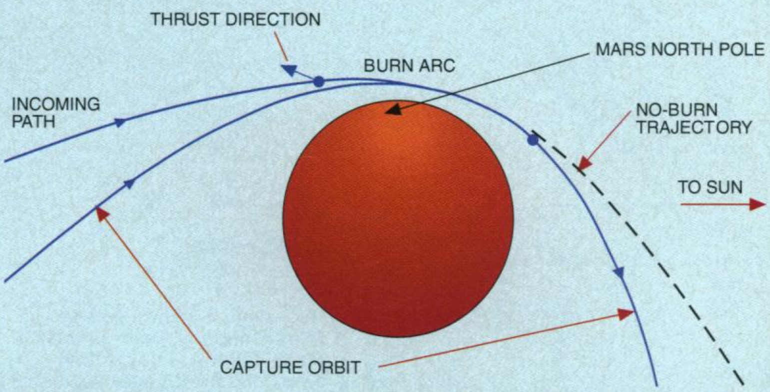
The science

Beyond the personal anguish, the apparent loss of Mars Observer is devastating to the planetary science community. It would have provided more data about Mars than all previous missions combined. After moving into a low-altitude, near-polar orbit, the spacecraft was scheduled to spend a full Martian year (687 days) probing and mapping the

The Sounds of Silence: Chronology of Despair

Ten days after they lost contact with Mars Observer, bleary-eyed ground controllers at the Jet Propulsion Laboratory (JPL) were left wondering early this week whether they would ever know what happened to their errant spacecraft. As *Science* went to press, they had run out of strategies for trying to find out, but they were still clinging to a faint hope that the spacecraft might yet rise from the presumed dead.

The nightmare sequence of events began on Saturday evening (9:00 P.M. EDT), 21 August, as the spacecraft readied itself to enter the planet's orbit after a relatively trouble-free, 11-month, 450-million-mile journey through space. Observer would face its most critical maneuver 3 days later when the spacecraft had to fire two of its four large thrusters to decrease velocity and allow Mars' gravity to pull it into a planetary orbit.



Orbital mechanics. Observer was programmed to fire its rockets to go into orbit around Mars, but there's no way to know if it did so.

In preparation, Observer needed to pressurize its fuel tanks. To do this, valves are opened with a small explosive device; the device also delivers a short, small shock to the whole spacecraft. Before the explosion, which was scheduled for Saturday night, Observer followed instructions previously loaded into an onboard computer and shut down its transmitters to protect them from the shock. After pressurization had presumably occurred, JPL controllers sent commands telling Observer to begin transmitting again. They were greeted with a surprising silence.

For the first few hours, there was no sense of disaster at JPL. Observer had experienced minor communications problems several times before and so had many other planetary missions. Indeed, the Magellan mission to Venus suffered a blackout of more than a dozen hours in its early days around Venus and many had feared the spacecraft was lost. Moreover, JPL controllers were buoyed by the fact that in their last message to Observer on Friday they had, as a planned precaution, included a complete set of instructions for entering orbit. Mission controllers worked around the clock, sending commands directing the spacecraft to turn on its transmitter, to switch from its high-gain antenna to one of the three low-gain backups, and to change to a backup computer. As the hours passed with no success, concern grew.

On Monday, a day before the scheduled orbit insertion, tests on a simulator at JPL known as the Verification and Test Lab suggested an onboard clock, which orchestrates the sequence of operations aboard the spacecraft and is necessary for any computer operations, might be stuck. JPL sent commands to activate a backup timing mechanism. Silence prevailed.

Observer team members were still putting on a brave face on Tuesday. "We think the spacecraft is operating and just is not talking with us," one mission manager told *Science*. By Tuesday evening, however, it was getting harder to remain optimistic. Observer was programmed to call back after thrusting itself into orbit that afternoon, but, with live NASA television documenting the events, no signal came through. That left ground control with no idea whether Observer had been somehow destroyed, was circling Mars in silence, or had failed to fire its thrusters and sped past the planet entirely.

While JPL was struggling to regain contact with its missing craft, other scientists sprang into action. Researchers at Cornell frantically calculated whether they could bounce radar off the craft to see where it was. Their disheartening conclusion: Only if Observer had sped by Mars might they be able to detect the spacecraft a year or so from now when it had looped around the sun and was again near Earth.

NASA scientists interrupted their search for extraterrestrial intelligence to look for signals from Observer. Michael Klein, who directs NASA's Sky Survey, says his group took raw data from two NASA antennas tracking where Observer should be and, with their specialized computers, scanned more than 2 million different radio frequencies for any weak signals. The Sky Survey's own 34-meter antenna was also pressed into service to conduct a small search pattern around Mars in case the spacecraft had been somehow knocked from its expected position, perhaps by a thruster misfiring. "It may be a longshot, but it sure would be exciting if we found it," Klein told *Science*.

Perhaps the best chance of knowing whether Observer had at least gone into orbit fell prey to poor weather. Astronomers at NASA's Infrared Telescope Facility on Hawaii trained their instrument toward Mars, thinking they might be able to see the heat flare from Observer if it had fired its thrusters. As the crucial 30-minute burn approached, however, the island's normally sunny skies clouded over. The telescope couldn't even make out Mars, let alone see the faint signature of rocket motors.

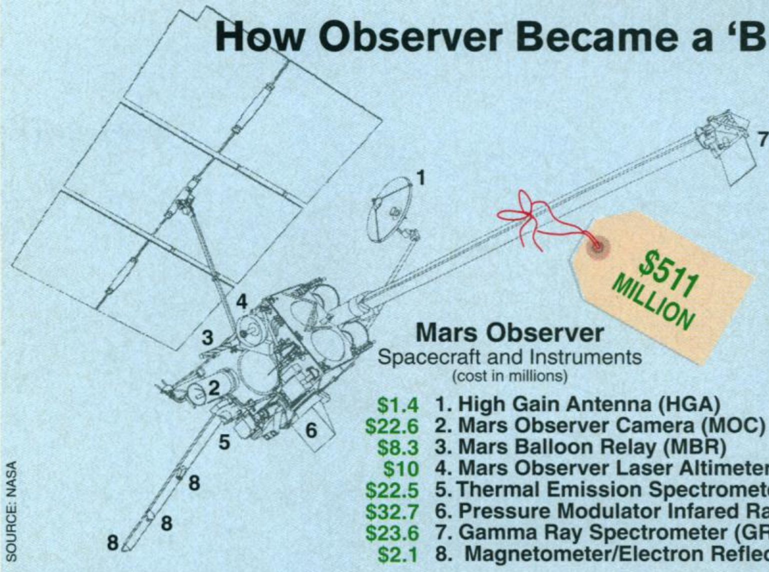
On Wednesday, controllers at JPL waited and held their breath as another critical milestone approached. At 5:56:53 P.M. EDT, it had been 5 days since JPL could confirm Observer had received their messages. The spacecraft contains a "command loss timer," which is reset every time instructions are received from Earth. But if Observer hears nothing for 5 days, the timer prompts it to look for Earth and point its low-gain antennas homeward. The milestone passed with no contact. As the weekend approached, JPL was forced to try more drastic, last-ditch efforts, even sending commands to "cold reboot" the onboard computers. Nothing worked. Their options virtually exhausted, JPL could only listen and hope the craft could overcome its problems.

As for what might have gone wrong, a leading theory has become transistor failure. JPL acknowledged last Thursday that both the master and backup clocks on the spacecraft depended on a suspect lot of transistors. In June, a clock failure had delayed the launch of a weather satellite and an investigation later found that the device's transistors, the same as used on Observer, contained a weak weld that was susceptible to breaking. While there are no data to confirm the notion, the jolt of pressurization may have prompted the failure of both clocks, dooming the craft.

NASA has named Timothy Coffey, director of research at the Naval Research Laboratory, to head an investigation into the loss of communications with Observer.

–J.T. and J.C.

How Observer Became a 'Billion-Dollar Mission'



Mars Observer provides an object lesson in how budget constraints, and scheduling delays, can drive a mission that started out with a modest price tag into the billion-dollar range. The final tally for the ill-fated spacecraft—including development, construction, launch, and operation for 11 months—now stands at $845 million.

That hefty price tag certainly was not what NASA envisioned in the early 1980s when the agency's solar system exploration committee laid out plans for revisiting Mars. The panel recommended a quick series of modest missions, part of a new Observer class of spacecraft, that would save money by carrying just a few routine instruments and using designs of current Earth-orbiting satellites instead of being designed from scratch. The first such craft might cost around $200 million, but the price of subsequent Observers would drop to $150 million, officials hoped. In many ways, the approach foreshadowed the "smaller, cheaper, faster" Discovery missions NASA administrator Daniel Goldin now supports, says David Morrison, who chaired the NASA committee.

The series, however, never got off the ground in that form. Rejecting NASA's proposal, Congress and the Office of Management and Budget approved planning for only a single mission, which eventually became Mars Observer. With only one shot at the red planet, planetary scientists started to pile instruments originally planned for multiple missions on a single platform, at the same time making them increasingly sophisticated. Late in Observer's conception, for example, NASA added a camera system that eventually cost more than $20 million. Moreover, since there would not be a string of Observer spacecraft, the cost of Mars Observer was driven up $60 million by the need to include backups for everything in case of a launch disaster.

These escalating hardware costs, according to NASA officials and outside analysts, were accompanied by even bigger cost increases caused by the agency's dependence on the space shuttle as launch vehicle. Observer, for instance, had to be built for a man-rated vehicle, a safety demand that significantly increases costs. In addition, a special booster was needed to send the spacecraft from shuttle orbit to Mars.

Then came the explosion of Challenger in 1986. Observer had not been scheduled to launch until 1990, but the shuttle disaster rocked NASA's budget plans and meant some drastic consequences for the Mars mission. Among them were a 2-year delay in launching, a decision to send the Observer up on a Titan III rocket, and a resulting design reconfiguration. Those events, says NASA, added $93 million to Mars Observer's final cost. "Until the Challenger accident came along, we were in reasonably good shape. That was a very big cost hit," says Geoffrey Briggs, NASA's director of solar system exploration from 1983 to 1990.

In the final analysis, where did the $845 million go? According to NASA headquarters, the spacecraft and instruments, including spares, and the cost of integrating them add up to $511 million. Costs attributed to the 1992 launch, including the price of the Titan III itself, total $282 million. To top it off, throw in another $30 million in operational costs over the last 11 months, approximately $15 million for expenses like tracking the spacecraft with NASA's Deep Space Network of antennas, and $7 million for NASA's contribution to the Mars Balloon Relay, and there's not much change from $1 billion.

–J.T. and J.C.

planet's surface, atmosphere, and interior. Observer would have delivered eagerly awaited answers about Mars' geology, geophysics, weather, and climate. Among the key questions: Has Mars ever had an Earth-like atmosphere? Where is the planet's water hidden? (*Science*, 12 February, p. 910) Are there active volcanoes on its surface? How do planet-wide dust storms develop? Does Mars have a molten core and consequently a magnetic field?

To address such issues, Observer was loaded with seven scientific experiments:

■ *Gamma Ray Spectrometer (GRS)*—By measuring the intensities of gamma rays from the Martian surface, GRS would have provided a detailed planet-wide analysis of the elements on the planet's surface.

■ *Mars Observer Camera (MOC)*—Two low-resolution cameras would have provided daily weather and surface maps and a high-resolution camera could have targeted sites of special interest.

■ *Thermal Emission Spectrometer (TES)*—Like GRS, TES would have analyzed the mineral content of the Martian surface. Other goals included observing movement of polar ice caps and the distribution of atmospheric dust.

■ *Pressure Modulator Infrared Radiometer (PMIRR)*—By detecting infrared radiation from the atmosphere itself, PMIRR would have provided measurements of atmospheric pressure, temperature, water vapor, and dust that could have led to global atmospheric models of Mars.

■ *Mars Observer Laser Altimeter (MOLA)*—MOLA was designed to develop an extremely detailed topographic map of Mars by bouncing short pulses of laser light off the surface.

■ *Radio Science (RS)*—By measuring minute Doppler shifts in Observer's radio signals back to Earth, investigators would have built up a gravity map of Mars as well as explored the planet's atmosphere.

■ *Magnetometer and Electron Reflectometer (MAG/ER)*—This experiment might have settled whether Mars has a magnetic field and, if not, whether it had one in the past.

More important, perhaps, than the individual data from each of these instruments would have been the opportunity to combine all these results over a full year, providing a cross-checked, dynamic portrait of the red planet. Observer "was not designed for just one little question. This represented the possibility of accruing an incredible dataset that would have been used for generations of scientists....We were going to end up with better global data for Mars than we have for Earth. Atmospheric profiles, cloud patterns

—all these things would have systematically been done and they would have been in a database accessible to the world community," says Albee.

Looking at the future

In addition to raining a torrent of data of immediate interest down on Earth-bound researchers, Mars Observer was expected to provide a key stepping stone toward future trips to the planet. Russian scientists were hoping to use Observer's maps to help choose sites to land instruments on the planet's surface in missions scheduled for 1994 and 1996. And they were planning to use a French-built relay system on Observer to transmit back up to 10 times as much data as their own orbiter could handle.

Observer's data would also have fed directly into NASA's Mars Environmental Survey (MESUR), a proposed mission to land as many as two dozen geophysical probes on different regions of the planet. Although photographs from the Viking mission can pinpoint relatively safe sites to land, Observer's detailed mapping would have allowed NASA to pick from among many more targets and would have indicated which ones would be of greatest scientific interest. "Without the measurements of geochemistry [from Observer], intelligently choosing the sites will be difficult," says Boynton.

Considering the importance of Mars Observer, Boynton and his colleagues in the planetary science community are already urging that the mission be repeated. The next launch windows for a return to Mars are late 1994 and 1996, which means that decisions would have to be made quickly. Rebuilding the spacecraft itself might not pose a great problem: Once NASA realized Observer would be a one-of-a-kind mission, it bought backups for the major components (see box, page 1266). There are also spare parts for most, if not all, the instruments. For example, says Christensen, "we can rebuild our [thermal emission spectrometer] in 6 months to a year, given the funding."

Funding, of course, is the biggest problem. A repeat Observer mission should cost significantly less—perhaps 20% to 30% of the original mission's cost says Boynton—but in the current funding climate, NASA will be hard pressed to muster political support for funding the space station and also get additional money to try Observer again. Nevertheless, *Science* has learned that NASA has inquired at Lockheed, which is now managing the Russian Proton launch system, about the availability and feasibility of a rocket to launch a carbon copy of Observer.

Another alternative under consideration involves the Clementine series of military satellites that were scheduled to test technology for the Ballistic Missile Defense Organization. NASA declines to comment publicly, but space agency officials have asked whether a small fleet of Clementines, outfitted with one or two of Observer's instruments, might be ready by November 1994.

For the moment, however, the shaky hope of another foray to Mars offers little solace to a scientific community that is reeling from the loss of Observer. "With planetary science, there's a 10- to 15-year gap between experiments. That's what really hurts. Most experimental scientists can redo an experiment in a few months," says Christensen. Still, he and his colleagues aren't about to give up. "Planetary scientists, because it's a risky business, are an incredibly optimistic group. The process of looking to the future is already starting."

–John Travis

With reporting by Jon Cohen in Pasadena.

NASA's Troubles Come in Droves

August was a very bad month for the U.S. space program. In addition to the lost link to Mars Observer, three spy satellites blew up, a weather satellite went dead, and a space shuttle launch was delayed three times. Although none of the incidents appear to be related, they will inevitably be linked in the public mind. And National Aeronautics and Space Administration (NASA) officials are nervous that they may face a backlash when Congress returns next week to decide the fate of the agency's 1994 budget. Last month's black eyes include:

- An Air Force Titan IV rocket carrying three secret spy satellites worth nearly $1 billion exploded shortly after launch on 2 August. The Titan IV is considered the main heavy-lifter for the space program for the rest of the century, and it has already suffered two test engine failures on the launch pad. With the space shuttle on its way out, and exotic alternatives still on the drawing board or in early experimental versions, NASA is worried about the fate of future heavy payloads.
- Engine problems delayed the latest shuttle launch for the third time in a month. Because the main engines were ignited just before the last launch was scrubbed, NASA engineers must replace them, adding to the delay. And the researchers behind its scientific cargo, the Orbiting Far and Extreme Ultraviolet Spectrometer (ORFEUS) telescope, must find a replacement for one key target—3C273, the brightest quasar in the sky—no longer in view because of the 2-month delay.
- A National Oceanic and Atmospheric Administration (NOAA) weather satellite known as NOAA-13 went dead on 21 August, less than 2 weeks after it had been launched. Preliminary indications point to faulty connections between the satellite's solar cells and batteries. Although most of the instruments in the failed NOAA-13 were duplicates of others already orbiting, two were unique science experiments that had tagged along for the ride—the Energetic Heavy Ion Composition Experiment (EHIC) designed to study the composition of the sun, and the Magnetospheric Atmospheric X-Ray Imaging Experiment for studying high-speed atmospheric phenomena. An earlier version of EHIC was launched more than a decade ago on a military spy satellite that failed, and the explosion of the Challenger space shuttle delayed the search for a suitable replacement vehicle. Now, as NOAA-13 orbits lifelessly, EHIC researchers are scrambling to place yet another incarnation of the ill-fated experiment on the next NOAA craft.
- Finally, a moment planned as a NASA highlight—Galileo's encounter last week with its second asteroid, Ida—was flawlessly choreographed but served as a reminder of continuing problems with Galileo. Because the Jupiter probe's main antenna failed shortly after its launch in 1991, first pictures from the encounter will take at least 2 weeks to make it to Earth, rather than the 10 minutes or so that designers intended.

Opinions vary on what all this disarray will mean for the space program, but even optimists agree it can't help. "It's certainly further ammunition for NASA opponents and critics," says Steven Aftergood of the Federation of American Scientists. He suggests that opponents of the space station will capitalize on NASA's misfortunes to argue that the agency can't be trusted with a $20 billion project. But Lori Garver, executive director of the National Space Society, says that history suggests that legislators understand the risks of space: "In the past, when you've had a series of events like this, Congress has tended not to take it out on [NASA] politically" she says. What might really cripple NASA, however, would be the failure in December of its shuttle mission to repair the Hubble Space Telescope, says Glenn Mason of the Association of American Universities space scientists working group. August's disasters "raise the ante tremendously for the Hubble repair mission," he says.

–Christopher Anderson