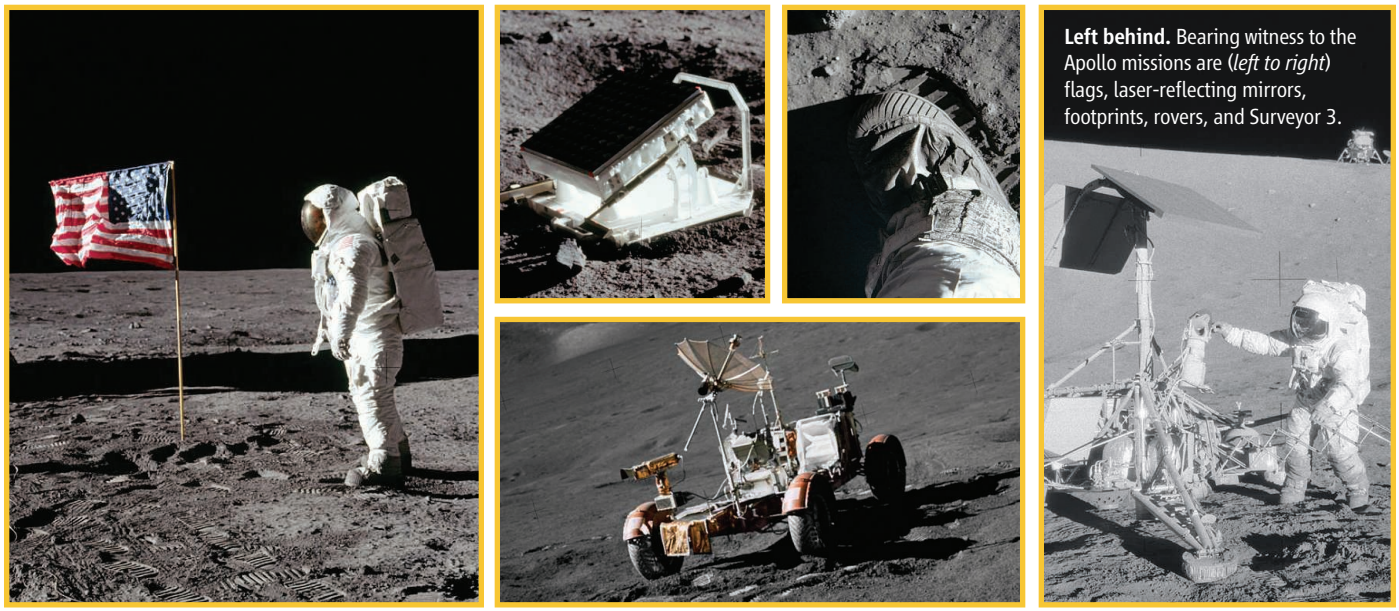

Left behind. Bearing witness to the Apollo missions are (*left to right*) flags, laser-reflecting mirrors, footprints, rovers, and Surveyor 3.

CREDITS: NASA (5)

SPACE

NASA to Launch Guidelines To Protect Lunar Artifacts

NASA is unlikely to be the operator of the next spacecraft to land on the moon, but the U.S. space agency is considering sending along some red tape.

As dozens of private teams race to return to the moon as soon as next year, spurred on by $30 million in prize money from Google and the X Prize Foundation, NASA is wrestling with how to safeguard the historic and scientific value of more than three dozen sites containing remnants of America's golden era of space exploration, including the spot where Neil Armstrong and Edwin "Buzz" Aldrin Jr. left the first footprints on the lunar surface. Later this month, the agency plans to issue what it calls "recommendations" for spacecraft, or future astronauts, visiting U.S. government property on the moon.

A 20 July version of the guidelines obtained by *Science* proposes, for example, approaching Apollo landing sites and artifacts at a tangent, to avoid crashing into them, and suggests no-fly and buffer zones to avoid spraying rocket exhaust or dust onto historic equipment. The document also includes a research wish list, written by NASA scientists and engineers, for any private team, or country, sending a craft to the moon. The list ranges from the mundane, such as taking close-up photographs of decades-old laser range-finding mirrors still used by Earth-based astronomers, to more far-out ideas, such as studying discarded food or abandoned astronaut feces.

NASA's recommendations won't be legally binding—according to the 1967 Outer Space Treaty, the lunar surface has no owner—but the agency is hopeful that the teams racing for the moon, which requested the guidelines and have been providing feedback to the agency, will sign on to a final version. The principal motivation is to determine "how we preserve and protect these sites," says Robert Kelso, NASA's liaison for beyond-low-Earth-orbit commercial initiatives at Johnson Space Center in Houston, Texas, and the developer of the guidelines.

Archaeologists and historians have for more than a decade mused about how to study and curate human artifacts on the moon and even those floating in space. In 2000, anthropologist Beth O'Leary of New Mexico State University in Las Cruces, who held a small NASA grant, approached the U.S. National Park Service, which administers the National Register of Historic Places, for help adapting heritage preservation guidelines to cover American-owned artifacts on the moon. At the time, she says, the agency told her it did not have the jurisdiction to work on such guidelines. "The great irony is we don't own the surface of the moon, so in a sense we don't own the footprints" left by Apollo astronauts, O'Leary says.

The need for such guidelines became more pressing when about half of the 28 teams vying for the Google Lunar X Prize indicated an interest in going after the "heritage" bonus. The first $20 million of the award is for landing a robot that can move 500 meters and send back images from the moon, but teams can earn up to an extra $4 million by making a precision landing near one of the manned landing sites, says Google Lunar X Prize Senior Director Alexandra Hall.

"What we don't want to happen is what happened in Antarctica at Scott's Hut," says Roger Launius, senior curator of space history at the National Air and Space Museum in Washington, D.C. "People took souvenirs, and nothing was done to try to preserve those until fairly late in the game."

Lunar looting is unlikely anytime soon. X Prize competitors seeking the heritage bonus will probably carry only cameras, Kelso notes, so the risks NASA assessed had more to do with avoiding crashes with artifacts or knocking abrasive lunar dust onto them. An attempted $1.7 million sale of a moon rock via eBay earlier this year suggests that demand for lunar artifacts would be high, however, if a sample-return mission were possible. One NASA engineer points out that the golf ball hit by astronaut Alan Shepherd still lies in a lunar crater.

In the 20 July guidelines, NASA proposes that the Apollo 11 and 17 sites remain

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off-limits, with ground-travel buffers of 75 meters and 225 meters from each respective lunar lander. Furthermore, NASA simulations and footage from previous lunar missions led Kelso to conclude that 2-kilometer-radius no-fly zones over each site would prevent rocket exhaust from contaminating artifacts. NASA, however, would condone limited activities among the artifacts of other sites, according to the document.

And there are lessons to be learned by poking around some of the less historic Apollo sites, suggests NASA's Mike Squire, who led the committee of engineers that contributed to Kelso's guidelines. Lunar rovers and other artifacts could serve as "witness plates" for measuring radiation, micrometeorites, and moon dust, much as Apollo 12 astronauts collected pieces of the Surveyor 3 lander for study back on Earth. High-resolution photos of one of the rovers could show how its various materials have degraded in the lunar environment, for example.

Both the engineers' appendix and a similar one crafted by NASA scientists note that observations from a new lander might help resolve the ongoing debate over whether and how lunar dust mobilizes at lunar sun up and sun down (*Science*, 24 June, p. 1493). But answering that question will require well-planned imaging. "Integrating lunar scientists into a Google X Prize team would be a real bonus for both sides," says NASA planetary scientist Barbara Cohen in Huntsville, Alabama, who helped write the scientific appendix.

And those feces? To make room for rock samples on the return trip, Apollo astronauts left behind food, "defecation collection containers," and bags of urine. The NASA guidelines suggest that an instrument on a future lunar robot could "investigate the state of biological matter" in these items, perhaps determining whether any bacteria remain viable—and how they've mutated—after decades of exposure to solar radiation.

–LUCAS LAURSEN

Lucas Laursen is a writer in Zurich, Switzerland.

SOLAR SYSTEM DYNAMICS

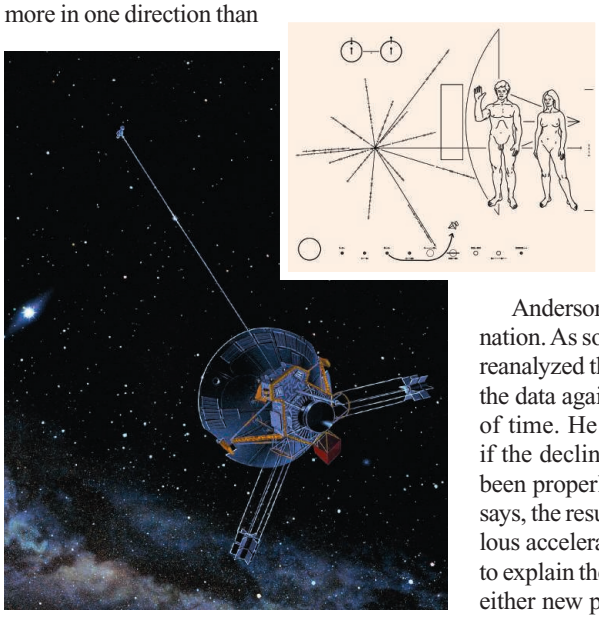
Mystery Pioneer Anomaly Is Real But Still a Mystery

The two Pioneer spacecraft have left the solar system, but something seems not to want them to leave. For years, they seemed to be slowing ever so slightly more than they should as they headed out of the solar system, as if some unknown force were gently tugging them back. Researchers have now unearthed long-forgotten Pioneer records that confirm the reality of this "Pioneer anomaly" and reveal for the first time that the anomaly has actually been shrinking.

To some, the shrinking anomaly suggests that the culprit may be the way the spacecraft were shedding their own waste heat. But according to an outsider who reanalyzed the newly retrieved records, the heat explanation falls short. Whatever is slowing the Pioneers, says celestial mechanicist John Anderson, likely lies beyond the spacecraft themselves in as-yet-unknown or even new physics.

Just detecting the Pioneer anomaly might appear miraculous. To calculate how much a Pioneer should have slowed, researchers had to take account of anything that anyone could imagine acting on it—including the gravity of the sun and planets, the pressure of sunlight, and the recoil from a spacecraft's 8-watt radio transmitter beaming a signal back to Earth. Once they calculated the slowing, they compared it with how much a Pioneer actually did slow, as gauged by analysis of the Doppler shift in the frequency of its radio transmissions.

Blasted away from Earth at more than 51,000 kilometers per hour, both Pioneer 10, launched in 1972, and Pioneer 11, launched in 1973, were decelerating almost 10^{-9} meters per second per second faster than calculated, according to a 2002 *Physical Review D* study. Anderson, who is retired from NASA's Jet Propulsion Laboratory (JPL), was that study's first author. At that rate, it would take a decade for a Pioneer to slow 1 kilometer per hour more than it should. The most likely force unaccounted for in the calculations, according to the 2002 authors, was heat radiating from the Pioneers' power sources, four radioisotope thermoelectric generators (RTGs). If emitted more in one direction than another, the heat could have acted like rocket exhaust to slow the spacecraft.



Slow to leave. The two Pioneer spacecraft—carrying plaques (*inset*) describing their origin on Earth—have mysteriously slowed.

The reality of the infinitesimal anomalous slowing has now been tested against an expanded data record by astrophysicist Slava Turyshev of JPL, a co-author of the 2002 *Physical Review D* paper, and three colleagues. With financial support from NASA and a space-advocacy group, The Planetary Society, Turyshev and his colleagues spent most of a decade digging into tracking data in outmoded formats. With twice the record length for Pioneer 10 and three times the length for Pioneer 11, they came up with the same size anomaly, they report in a *Physical Review Letters* paper published 19 August. For the first time, they also found that the anomaly was diminishing slightly with time. That would be consistent with heat emissions causing the slowing, because the RTGs cool as their radioactive fuel decays.

Anderson is not happy with the heat explanation. As soon as the paper was published, he reanalyzed the new extended records, plotting the data against distance from the sun instead of time. He finds the anomaly shrinking as if the declining pressure of sunlight had not been properly calculated. If that's correct, he says, the result "leaves me with a truly anomalous acceleration." Heat emission is too small to explain the slowing, Anderson finds, so "it's either new physics or old physics we haven't discovered yet." New physics could be a variation on Newton's laws, whereas an example of as-yet-to-be-discovered old physics would be a cloud of dark matter trapped around the sun.

Whatever is slowing the Pioneers, researchers will have to identify it without additional Pioneer data; the last Pioneer went silent in 2003, 12 billion kilometers from Earth.

–RICHARD A. KERR

CREDITS: NASA (2)