Scaling Down Planetary Science†

As multi-billion-dollar planetary missions face extinction, space scientists are turning to a new breed of planetary probes—smaller, faster, cheaper, and (researchers hope) just as good

LAUREL, MARYLAND—It was just one stroke of the return key, something you probably do countless times a day, but this one had fundamental implications for doing science in space. In the corner of a lobby at the Applied Physics Laboratory (APL) here, Lawrence Zanetti of APL had set up his $2600 lap-top computer and turned it into an on-the-spot spacecraft command center. Connected to a ground station in Sweden via a telephone line and $200 worth of PC Anywhere software, Zanetti hit the return key to adjust the sensitivity of his magnetic field instrument aboard the Freja auroral satellite orbiting at that moment over Scandinavia. There were no teams of engineers huddled over banks of monitors, no laborious authorization process for tinkering with a very expensive instrument. But that was the point—it was low-cost science in space.

Zanetti's no-frills satellite control system may be a glimpse of the future of planetary science, an example of the kinds of strategies that will be needed to keep the field alive in the years ahead. As Daniel Goldin, administrator of the National Aeronautics and Space Administration (NASA), put it at a conference* here last month, the survival of the field depends on finding cheaper ways to explore the solar system. In the Cold War days of East-West competition, said Goldin, "we all became accustomed to a way of doing business where we didn't have to pay attention to cost. Getting the mission done was more important than cost. That…is gone and forgotten, finished." Such words of warning, together with Goldin's trademark exhortation "smaller, faster, cheaper, better," have spurred planetary scientists, engineers, and NASA managers to get serious about downsizing the gargantuan, multi-billion-dollar missions to the planets that have come to dominate the field.

*International Conference on Low-Cost Planetary Missions, Johns Hopkins University Applied Physics Laboratory, 12–15 April 1994.

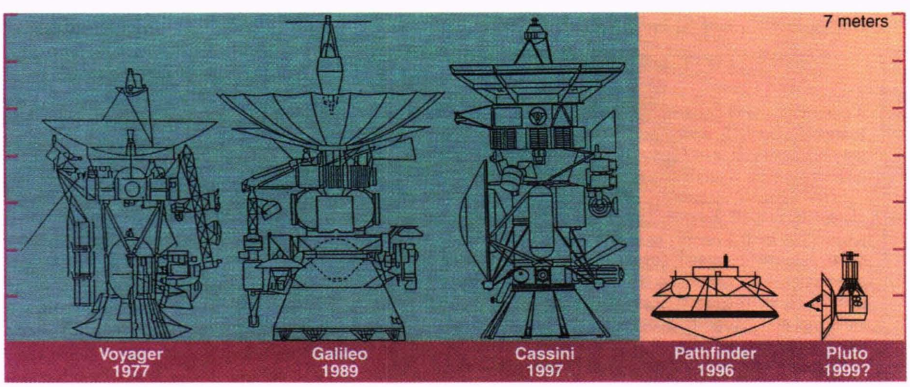
APL

First of a flock. The NEAR spacecraft.

The result is a new strategy for planetary exploration called the Discovery program. With an injection of free enterprise, a new management style, a live-or-die cost cap, and restriction to a modest-size rocket, Discovery would launch a new mission every 12 to 18 months to explore everything from asteroids to planets and the sun itself—all for just $100 million to $130 million a year compared to the $654 million now spent on planetary missions of all sizes. In spite of the daunting schedule and cost constraints, which would make these the cheapest planetary probes ever, researchers have inundated NASA with ideas for Discovery missions. Two—the Near Earth Asteroid Rendezvous (NEAR) mission and a Mars mission called Pathfinder—have already been funded; for their successors, researchers have proposed everything from a mission to orbit Mercury to one that will visit four comets (see box).

A key inspiration for these efforts is the Department of Defense (DOD)'s low-budget Clementine mission, which left the moon early this month for an asteroid flyby next August. Although the asteroid mission was abandoned last week after a computer software failure depleted the probe's thruster fuel, its lightweight, high-tech sensors, tight-knit team management, and bare-bones spacecraft operation have raised hopes that modest cost and ambitious science can go together. Indeed, Clementine-style low-cost missions could become the norm in planetary science if—and it's a big if—the Discovery program can overcome budget threats, inertia in NASA's managerial culture, and the challenge of building instruments that are not only smaller but also cheaper. Said Wesley Huntress, NASA's associate administrator for space science, "You don't do it overnight, but make no mistake—we're in the middle of a revolution. That revolution must happen or we won't [survive]."

Exploring the solar system has never been cheap. The cost of missions planned in the 1960s and early 1970s came in at around $600 million each (in 1994 dollars) when everything from design through construction, launch, and operation was included, according to figures compiled at the Jet Propulsion Laboratory (JPL) in Pasadena. And in the 1970s costs headed up. Launched in 1977, the two Voyagers, which flew by the four outer planets, have racked up $2.2 billion in costs. The Galileo spacecraft, after expensive delays due to the Challenger accident, is finally on its way to Jupiter—and a final cost of from $2.2 to $3.1 billion. And the Cassini mission to Saturn will probably total $2.5 billion.



JPL

Thinking smaller. Planetary craft of traditional design (shown with their final boosters attached) loom over the small-is-better design for the Pathfinder Mars mission and a concept for the Pluto Fast Flyby.

A Flock of Prospects for Low-Cost Missions

There's nothing like the threat of extinction to concentrate the mind. Now that the multi-billion-dollar missions that have come to dominate planetary science are no longer affordable, investigators have inundated the National Aeronautics and Space Administration (NASA) with ideas for missions that would cost a tenth as much. Two of these Discovery missions are already in the design and development stage (see main text), and NASA has funded studies of 14 more mission concepts, which would send probes to Mars and the sun, and to comets, asteroids, and planets in between. Here is a sampling of the missions and their strategies for meeting Discovery requirements—a development cost limited to $150 million and a modest-sized launch rocket.

■ **Venus Environmental Satellite (VESAT).** To monitor Venus's atmosphere without the costly step of sending probes through the planet's obscuring clouds, Kevin Baines of the Jet Propulsion Laboratory (JPL) in Pasadena and his colleagues propose to take advantage of the latest in detector technology. By capturing the torrid atmosphere's near-infrared glow, which can leak through the clouds, VESAT would study everything from winds, clouds, and chemistry to the patterns of surface temperature, conceivably catching a passing weather front.

■ **Small Missions to Asteroids/Comets (SMACS).** In the ultimate smaller-is-better proposal, Michael Belton of the National Optical Astronomy Observatories in Tucson and his colleagues propose four separate missions for the price of one Discovery project. Each SMACS spacecraft would be so tiny—just 100 kilograms—that it could be launched by the small Pegasus XL rocket, which hitches a ride part of the way to space aboard a high-flying airplane. That would bring launch costs down to about $10 million each, one quarter of the cost of the largest launcher allowed under the Discovery program. The four targets could then be chosen to sample the extremes of asteroid evolution—primitive to metallic—and comet life history.

■ **Hermes Global Orbiter (HGO).** Although spacecraft have flown by Mercury three times, they all saw the same side of the planet. Robert Nelson of JPL and his colleagues propose to get a complete picture of the smallest inner planet by putting a spacecraft into orbit around it. Because of the need to shed so much of the spacecraft's orbital energy to drop to Mercury's orbit, a direct flight is out of the question with a Discovery-size rocket. But two close flybys of Venus and two of Mercury during a 3-year tour of the inner solar system would provide the needed gravity assists. Nelson and his colleagues would limit the added costs of operating the spacecraft during the extended cruise by combining mission operations with those of Voyagers 1 and 2, two spacecraft launched in the 1970s that are now heading toward interstellar space.

■ **Near Earth Asteroid Returned Samples (NEARS).** As its acronym implies, the NEARS mission has much in common with the first Discovery mission, NEAR (Near Earth Asteroid Rendezvous), to be launched in 1996. Eugene Shoemaker of Lowell Observatory in Flagstaff, Arizona, and Andrew Cheng of the Applied Physics Laboratory in Laurel, Maryland, would copy both the overall design of the NEAR spacecraft and its laser altimeter. They would also borrow two spare lightweight cameras from the Department of Defense's Clementine mission and an atmospheric re-entry capsule design from Pioneer Venus probes that flew more than 20 years ago. The key novelty aboard NEARS: a "six-shooter" that would fire up to six sample tubes into the surface as the spacecraft briefly touched down on the tiny asteroid Nereus, collecting up to 600 grams of sample that would return to Earth and plummet to a parachute landing in New Mexico.

–R.A.K.

Cassini is the last of its kind, a planetary science dinosaur. A budget-cutting Congress has held NASA's budget level since 1991 (*Science*, 1 April, p. 25), and it canceled the Comet Rendezvous Asteroid Flyby mission that was to be launched in tandem with Cassini. Goldin says he would have canceled Cassini as well if NASA had not promised to share costs with foreign partners.

Desperate measures

Some of the factors that led planetary science to the brink of extinction were beyond anyone's control. Planetary scientists started with the easy missions, the flybys of the moon, Mars, and Venus. The more difficult missions—flybys of the outer planets and planet-orbiting missions—inevitably cost more. And then there was the 1986 Challenger shuttle accident, with the resulting delays and costly redesigns as craft originally slated for launch from the shuttle were shifted to conventional rockets.

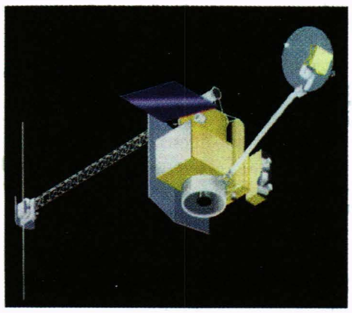
But the most frequently cited cause of planetary science's budgetary woes is the growing bulk and complexity of planetary spacecraft. A typical mission of the 1960s weighed around a quarter of a ton; Galileo came in at a hefty 3 tons. Most scientists see it as a chicken-and-egg problem. As the number of missions fell during the post-Apollo squeeze on NASA's budget, one participant explains, each remaining mission "looked like the only bus out of town, so you wanted to pile everything on it." The result was a more expensive spacecraft, a longer development process, more complex management, the need to use a larger booster rocket—and a cost spiral that stretched out the interval between missions even further.

NASA managers realized that only radical steps could get them out of this trap. As Sven Grahn of the Swedish Space Corporation and the Freja auroral project put it at the conference: "For a low-cost mission, you want total desperation—no money [to spare], or a fixed launch date. That's the way to save money." That sort of thinking, inspired in part by the dozens of low-cost satellites that have been flown to study Earth's magnetosphere, had been fermenting within NASA and the academic community for several years. An extra prod came from Congress: A report that accompanied the fiscal year 1992 appropriations bill directed NASA to prepare a plan for small planetary projects.

Speaking to the conference, Mary Kicza of NASA headquarters described the desperate measures NASA has adopted. Each Discovery mission will be limited to 36 months and $150 million (fiscal year 1992 dollars) for design and development, excluding launch and operations. If the minimum amount of science promised by the mission cannot be delivered within the $150-million cost limit, the mission should be canceled. The spacecraft must be launched on a rocket of the Delta-II class or smaller, a rocket with one quarter of the lifting capacity of the Titan 4 scheduled to launch Cassini.

To foster innovation, Kicza added, the program will have another novel element—competition. In the past, planetary missions were conceived by committees of scientists advising NASA, then parceled out to a NASA center, most often JPL. Discovery missions, on the other hand, come in as proposals from scientists, who will run the mission if they are funded. "We're asking for PIs [principal investigators] to come in with a whole mission," Huntress told the meeting, including proposed liaisons with industry, universities, and NASA centers. "If we like it—if we like your science, if we like the way you're going to manage it, if we like the cost—we'll buy it, pay you, and you do it."

Planners concede that the Discovery constraints may be too stringent for some kinds of missions, notably those to the outer planets. As Larry W. Esposito of the University of Colorado notes, "you can't send 15 [Discovery-class] missions to equal one Cassini mission" to Saturn. For example, a probe venturing that far from the sun needs a $100-million radioisotopic thermal generator instead of inexpensive solar cells, which doesn't leave much room for anything else under the Discovery cost limit. What's more, studying the interactions of a giant planet's satellites, rings, and powerful magnetic field is best done with a large package of different instruments aboard a single spacecraft. The one mission to an outer planet that NASA is now considering, a plan to send two probes to the outermost planet called the Pluto Fast Flyby, is small, fast, and cheap by past standards, but at about $500 million, its projected cost exceeds the Discovery limits.


TRW

Budget route to Mercury. Concept for Hermes, which would orbit the planet.

An age of Discovery?

Ideas for Discovery missions to the inner solar system, however, are proliferating. Says Noel Hinners, vice president and chief scientist at Martin Marietta Civil Space & Communications in Denver and a former NASA associate administrator for space science: "I'm still amazed how innovative people get when someone hands them a box and says that's it, that's all you can fill up."

To get things started quickly, NASA presented two well-studied mission concepts to Congress as anchors for the program. One was the NEAR mission, which had already worked its way up through the NASA advisory system. The other was Pathfinder, a project to land a microrover on Mars. Congress gave them new-start funding in fiscal year 1994. In search of successor missions, NASA has funded the study of 14 less evolved mission concepts, embodying a range of scientific goals and cost-cutting strategies. One will be selected by 1996 for a 1999 launch, and additional Discovery missions would be picked about every 2 years after this selection. Planetary scientists view this frequency as the key attraction of the program.

These efforts to do sophisticated planetary science on a shoestring are taking a cue from Clementine, which exemplifies the technology needed to build a craft that is smaller—and hence cheaper to launch—but still capable. Although Clementine's prime objective is testing Star Wars technology for intercepting missiles, five of its instruments perform key science functions—imaging, compositional mapping, and topographic surveying—while weighing between 0.5 and 1.9 kilograms each and drawing a total of less than 60 watts of power.

Clementine holds another, less encouraging lesson for Discovery planners, however: High-tech, lightweight sensors don't come cheap. Clementine achieved smaller and faster largely by assembling technology whose development had already been done and paid for by DOD. The spacecraft itself, launch costs, and mission operations probably ran only about $80 million, says deputy program director Stewart Nozette, but the development cost of the instruments was in a different league altogether. The true cost is lost in a myriad of secret DOD programs, so the best Nozette can do is estimate that it's "a big number, but it's not bigger than Cassini's cost."

Discovery missions won't have DOD's deep pockets to draw from. As a result, NEAR, scheduled for a 1996 launch to the asteroid Eros, will have to rely on a mix of tried-and-true and cutting-edge technology to map this small body. "NEAR is not a new-technology–driven spacecraft," says project scientist Andrew Cheng, "but it's not old-fashioned either." Its mineral-mapping gamma-ray detector has a novel, lightweight design that has never been flown in space, and its advanced infrared spectrograph is based on the design of an instrument on a DOD weather satellite, but its x-ray detector is similar to the one flown to the moon on Apollo, 25 years ago.

Another cost-saving strategy may entail fewer trade-offs and bring quicker and perhaps larger reductions in costs, say planetary scientists: streamlined management. "If you look at the way Clementine was run," says Cheng, "and compare it with the [traditional NASA approach], it's like night and day, no comparison." Huntress of NASA knows what Cheng is talking about: "We can no longer accept the dogma [in NASA] that so many people, all looking over one another's shoulders, are so important for assuring success. There are better ways to assure success."

One model for an alternative approach, say many observers, is found at APL, the laboratory that has been entrusted with NEAR. In designing, building, and launching 54 small Earth satellites for DOD and NASA since 1959, APL has honed an alternative to the assembly-line approach often used in planetary missions, in which a spacecraft system might be designed by one group, fabricated by another, tested by a third group, integrated with the rest of the spacecraft by a fourth, and operated by yet another. "That approach requires a tremendous amount of documentation and introduces a lot of errors in passing from one team to the next," says Stamatios Krimigis, who is head of the space department at APL. Instead, at APL a single team oversees the system from conception to flight.

Meanwhile JPL, a bastion of the traditional approach, is trying to adapt to smaller, cheaper management. JPL lost out to APL in a competition for the NEAR mission but was given a chance to show it could remake itself as it develops the Pathfinder mission to Mars. Project manager Anthony Spear says that engineers and managers have come together on the same floor where they "live together day in and day out." As a result, he says, "we got everyone cost conscious....Classically, engineers like to do the very best, but [now] they're doing what we need and not more."

And now for the real test...

The Discovery concept may be catching on in the planetary community, but what are its chances of survival in the real world? In the late 1970s, the planetary science community embraced a program concept called Observer, hoping it would give their field the continuity and reliability it lacked even then. In retrospect, Observer sounds a lot like Discovery: an ongoing series of missions of low to intermediate cost focused on a few narrow scientific objectives. The first in the series was Mars Observer, but "Mars Observer probably broke all the rules [of the Observer concept] for various reasons, including Challenger," says Hinners. As a result, the Observer concept died long before Mars Observer itself went silent last August.

The fate of Observer sobers everyone, and already there may be warning signs. To some researchers, the complexity of NASA's recent draft request for Discovery proposals revealed that managers at NASA headquarters "still only know how they've done things before. Below the top level, all the old bureaucratic procedures are still there," as one researcher put it. What's more, Discovery faces competition within NASA from other planetary science missions—Galileo, Cassini, Pluto Fast Flyby, and the Mars Surveyor program (a replacement for Mars Observer).

Then there are the hurdles in Congress, the next of which will come when it considers funding the winner of the current Discovery competition in the fiscal year 1996 budget. In spite of the uncertainties, though, planetary scientists are guardedly optimistic that they have a winner this time. Says Hinners, "I guess I'm stupidly optimistic that maybe this time it can work."

–Richard A. Kerr