In the wake of its disastrous Mars missions, the U.S. space agency is expanding its commitment to disciplined planetary missions each led by a lone scientist

NASA's New Road to Faster, Cheaper, Better Exploration

Former NASA Administrator Daniel Goldin had a vision: nimble space missions that would conserve time and money. They would be smaller than the bus-sized Galileo that traveled to Jupiter. They would reach their goals faster than the 10 years needed to launch the Magellan spacecraft to Venus, for far less money than the $3 billion extravaganza of the Cassini-Huygens mission now approaching Saturn. And they would be just plain better—certainly better than failures like the 1993 explosion of Mars Observer as it prepared to go into orbit.

But when Goldin made his "faster, cheaper, better" vision a reality through his top-down, take-no-prisoners style of management, the results were sometimes disastrous. The dual loss of Mars Climate Orbiter and Mars Polar Lander in 1999 prompted a critical re-evaluation that found the faster, cheaper, better concept to be sound in theory but weak in implementation (*Science*, 7 April 2000, p. 32). Far from turning its back on faster, cheaper, better, however, NASA is about to expand the concept to encompass a large chunk of solar system exploration and is turning to the individual enterprising scientist to make it work. For most future planetary expeditions, a team led by a principal investigator (PI) will sell its mission to NASA and deliver on its promises of faster, cheaper, and better or perish in the effort.

NASA started small when it began buying space missions from PI-led teams in the early 1990s. First came the mostly Earth-orbiting satellites in the Explorer program. These are cost-capped at anywhere from $15 million to $150 million per mission. Building on Explorer successes, NASA expanded the approach to the Discovery program of $299-million-and-less planetary missions (*Science*, 27 May 1994, p. 1244). Now, NASA is planning new efforts that will include Discovery-size missions to Mars, called Scout missions, and double-Discovery-size missions elsewhere in the solar system under the New Frontiers program. Both new types are in the new budget expected from Congress. That's a big boost for PI-led missions. "I think [New Frontiers] is one of the most exciting things in solar system exploration," says Colleen Hartman, director of NASA's Solar System Exploration Division. New Frontiers, along with Discovery, "is the future of solar system exploration."

Good deal. The faster and cheaper NEAR spacecraft recovered from near disaster to orbit the asteroid Eros and then touch down on the surface.

PI-led missions will loom large in planetary science in part because NASA likes the innovative science that competing teams led by a single investigator come up with and the way such missions consistently come in on time and on or below budget. Planetary scientists like such missions, naturally enough, because they can be in charge and keep the focus on the science despite cost and engineering pressures. And in the end, they're popular because NASA-imposed discipline and PI-induced focus make them work. "This is a great time to be in planetary exploration," says planetary geophysicist Maria Zuber of the Massachusetts Institute of Technology. "A lot of things are going to happen." They will, that is, if PI-class missions survive their current growing pains and the vagaries of space exploration.

Mission best buys

The increasingly popular Discovery-style mission is a package deal. As Wesley Huntress, who was then NASA associate administrator for space science and is now at the Carnegie Institution of Washington's Geophysical Laboratory, put it in 1994 as he launched the Discovery program: "We're asking for PIs to come in with a whole mission. 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." To date, NASA has bought nine Discovery missions, from Mars Pathfinder's renowned Sojourner rover to a yet-to-be-launched mission to search for Earth-sized planets around other stars.

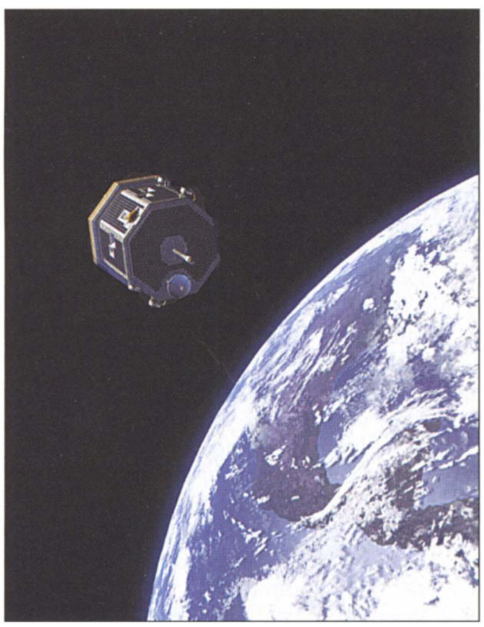
The rules for the PI-led deal have evolved a bit since Pathfinder's start in 1993, but the essentials are an open competition, a fixed price, and a fixed time to launch. Before Discovery, under the so-called strategic planning approach, a committee of planetary scientists decided, for example, that a spacecraft eventually named Cassini-Huygens would go to Saturn carrying 18 instruments—basically at least one for every planetary science specialty, from the de rigueur cameras to cloud-piercing radar. Congress had to authorize each specific mission and its budget. Most scientists didn't enter the process until they competed to provide and operate the instruments. Overall management of the mission resided with a NASA center, usually the Jet Propulsion Laboratory (JPL) in Pasadena, California.

In the Discovery mode, Congress writes a check and NASA chooses what to spend it on. When NASA announces that the next chunk of Discovery money will soon be available, individual scientists decide where they want to go, what science they want to do, and how they are going to get there.

CREDITS: NSSDC/GSFC/NASA

Gathering a team of scientists, engineers, and managers from universities, industry, and NASA centers, the PI oversees development of a mission proposal that meets NASA's Discovery specifications: a cost cap of \$299 million for the mission—from design through launch to data analysis—and a 36-month time limit from detailed design to launch. Then the competition begins. Every time NASA announces a Discovery opportunity, which happens every couple of years, about two dozen proposals come in. NASA whittles them down to one or two winners through parallel scientific peer review and a technical, management, and cost evaluation process. The technical review judges whether the proposers can really get that much science for that little money while running as little risk as claimed.

So far, the PI approach has worked well. The Explorer program of Earth-orbiting satellites that went this route in the early 1990s has a dozen spacecraft currently studying everything from the chemical composition of interstellar gas clouds to the workings of Earth's magnetosphere. The Discovery program has launched five missions, all on schedule and within budget. Mars Pathfinder landed a rover at one-tenth the cost of a Viking lander in the 1970s. The Near Earth Asteroid Rendezvous (NEAR) spacecraft orbited Eros for a year and as a bonus even touched down on the surface. Lunar Prospector chemically, mineralogically, and geophysically mapped the moon, reporting ice near the pole. At \$63 million, it was the cheapest planetary mission ever. Stardust is collecting its namesake samples and preparing to sweep up comet dust in 2004; all samples will be returned in 2006.



Not to be. The beautifully functioning CONTOUR spacecraft was blown up leaving Earth orbit.

CREDITS: (TOP TO BOTTOM) AMES RESEARCH CENTER/NASA; CONTOUR/NASA

And Genesis is loitering at Earth's L1 point toward the sun, collecting solar wind particles for return in 2004. Only the Comet Nucleus Tour (CONTOUR) has run into a real showstopper. The spacecraft itself operated perfectly after launch, but something—presumably its rocket motor—blew it apart as it rocketed out of Earth orbit last August.

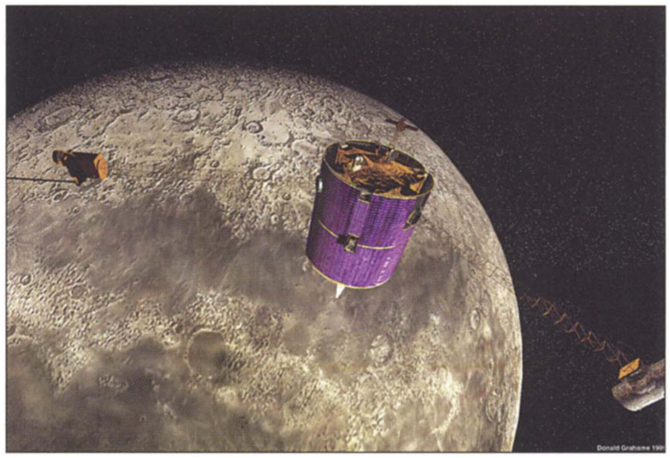
To Mars and beyond

Well before the CONTOUR failure, NASA began expanding PI-class missions beyond Explorer and Discovery. In July next year, it will pick the winning Scout mission from about 25 proposals submitted last August for a 2007 launch to Mars. The proposals range from traditional flybys, orbiters, and rovers to balloons, free-fall penetrators, gliders, and a mission to skim through the upper atmosphere to return a sample of martian dust to Earth. "The [planetary science] community really came out of their socks with innovations," says the Mars Exploration Program's lead scientist, James Garvin of NASA headquarters. "We're thrilled." The cost cap is \$325 million, on a par with the ongoing Mars Odyssey and Mars Global Explorer missions now orbiting the planet but less expensive than a single Mars Exploration Rover mission billed at \$350 million to \$400 million, two of which will be launched next year as part of NASA's strategically planned Mars program (*Science*, 10 May, p. 1006).

In addition, PI-led planetary missions will be scaled up for the non-Mars part of the solar system. Like Discovery, New Frontiers will be a new line in the federal budget, so that NASA will not have to go back to Congress for approval of each mission. That smoothes the funding process, although Congress still takes a hand in funding specific larger missions (*Science*, 18 October, p. 511). The New Frontiers cost cap will be \$650 million, with no more than 47 months to launch; the first in the series must leave Earth no later than 2008. With that sort of funding, missions could launch every 3 years or so with more ambitious goals. New Frontiers missions might include a flyby of Pluto and comet nuclei in deep-space storage beyond it or the return of a bit of the moon's mantle from an existing crust-piercing giant crater. Those are among the five "flight mission priorities" recommended last July by the National Research Council's decadal survey of solar system exploration.

How to please everyone

The imminent expansion of Discovery-style planetary science suits scientists just fine. "Discovery is great," says Joseph Veverka of Cornell University, who as PI of CONTOUR just lost his whole Discovery mission. "It's a very healthy process. It's a great idea to extend it to other NASA endeavors. It should be the entire Mars program." The planetary community's enthusiasm is fueled in part by the frequency of Discovery missions. A new one starts every 2 years or so, whereas flagship missions like Galileo are a once-in-a-decade event. Cheaper, smaller, and therefore more frequent is better, everyone agrees.



Truly cheap. The Lunar Prospector reported ice at the moon's pole in the course of the least expensive planetary mission ever.

In fact, the frequency of the missions helps keep the size and costs down. In lean times, when missions are infrequent, a committee of scientists might pile instruments on a spacecraft for fear it's the last bus out of town. Even in better times, though, a committee can end up designing a complex mission in order to please as much of the community as possible, says Michael A'Hearn of the University of Maryland, College Park, PI of the Discovery Deep Impact mission to glimpse the interior of a comet.

In Discovery, the cost cap tends to counter this natural expansiveness. "NASA says, 'Here's your budget. Do it within this cost or we cancel your mission,' " says William Borucki of NASA's Ames Research Center in Mountain View, California, PI of the new-start Kepler mission to search for extrasolar planets. "And they do cancel missions." Last January NASA pulled the plug on the Explorer mission FAME—intended to measure the precise position and brightness of 50 million stars—when it was projected to run over its $160 million budget by at least $60 million. And A'Hearn is sweating out a NASA review that is considering whether Deep Impact is pushing its budget limits too hard.

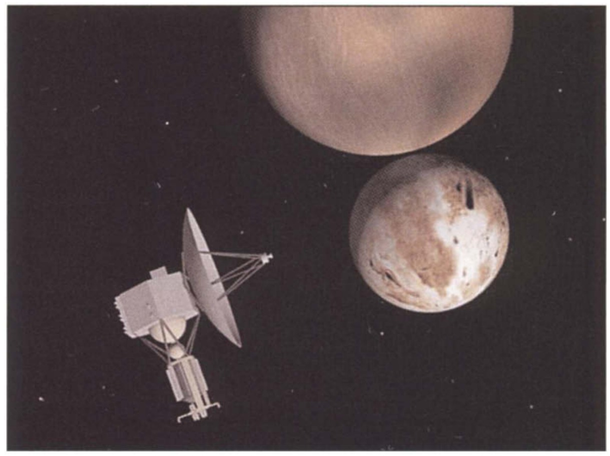
Keeping focused is key to the success of Discovery missions, most observers say, and the lone PI is crucial to maintaining that focus. In the pre-Discovery days, "NASA centers [such as JPL] were everything," Huntress said in 1998. "Scientists were along for the ride. It was thought that planetary science is too complicated for scientists." That has changed. "In terms of focus and [making] a host of tradeoff decisions, the role of the PI is absolutely central" in Discovery-style missions, says geophysicist Sean Solomon of the Carnegie Institution of Washington's Department of Terrestrial Magnetism, PI of the MESSENGER mission to Mercury. "In contrast to other solar system missions, you don't have the usual tension between engineers and the science team, because every important decision falls on the PI-scientist. Science informs each decision. It's a very good model for a mission."

A watchful eye

Not that the PI is doing all the rocket science in a third-of-a-billion-dollar mission. "The PI has a great deal of control but also has a management team that knows how to do a mission," says Borucki. "I'm the person who takes the blame if it fails," says Stardust PI Donald Brownlee of the University of Washington, Seattle. But it's his project manager, Kenneth Atkins of JPL, and engineers at Lockheed Martin Astronautics in Denver, Colorado, who "really do the nitty-gritty stuff. Difficult things do come up, but we can usually reach a consensus. When we can't, I have the ultimate responsibility."

Of course, NASA isn't simply handing money over to an appealing mission. First, it submits the proposal to a rigorous technical review. "NASA is letting a scientist run a $300 million program, but it's saying, 'Convince us you have a good team, there are no technical showstoppers, and it's low risk,' " says Solomon. "Those elements are not always present in comparable NASA-sponsored missions." The review of proposals, which is run out of NASA's Langley Research Center in Hampton, Virginia, "is extremely intensive and comprehensive," says Borucki. "It means we will have spent a great deal of time on design" before actually building the spacecraft. In the case of Borucki's Kepler mission, a decade of repeated Discovery submissions, reviews, rejections, and redesigns finally brought success.

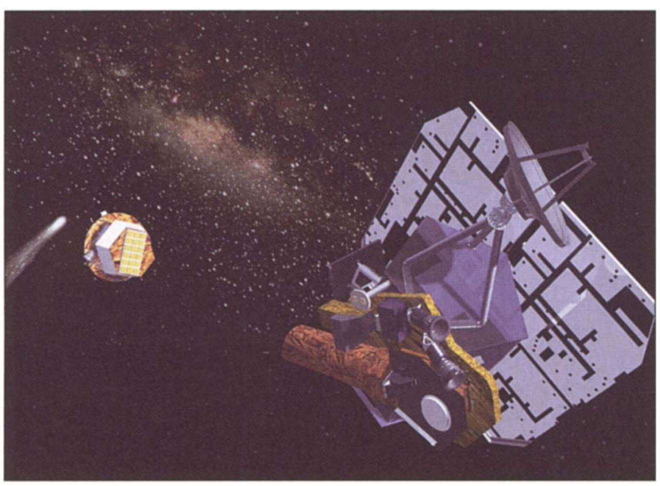
The Discovery process has also succeeded in the eyes of NASA, scientists, and engineers because it brings out the best and brightest ideas. "Competition is good," says Noel Hinners, who recently retired from Lockheed Martin Astronautics. "It does stimulate innovative ways to do new science." An alternative to strategic planning was essential to Stardust's mission to sweep up the first samples ever of interstellar material and comet dust. "We proposed this mission [to other programs] in a variety of forms and never succeeded," says Brownlee. It seemingly lacked the broad appeal of less-focused missions. "Discovery opened a real opportunity. It probably never would have flown otherwise."



Big ideas. Under the New Frontiers program, PIs could take on larger missions, such as a trip to Pluto and its huge moon Charon.

Not without flaws

Of course, Discovery missions have not been perfect. The CONTOUR loss made that point all too clearly. A formal mission loss report is due out shortly, but most scientists are assuming it was an unlucky break, a failure in a tried-and-true rocket engine that could have happened no matter how risk-averse managers were. There have been other, less catastrophic failures, however. The NEAR mission almost ended when a miscalculation of the jolt from the spacecraft's rocket shut down its firing and caused NEAR to fly by Eros instead of going into orbit. Quick-thinking controllers managed to line up a second approach a year later. But NEAR's near-infrared spectrometer broke shortly after entering orbit, and its gamma ray spectrometer proved to be less sensitive than expected and never returned useful data from orbit. And the essential batteries on Genesis are operating above design temperatures, which could shorten the mission.



Bang for the buck. The cash-strapped Deep Impact mission promises to blast a comet nucleus with a 32,000-kilometer-per-hour projectile.

The Discovery cost cap can also limit the science return. NEAR carried lower cost solar panels and a high-gain antenna that could not be steered; the whole spacecraft had to be turned toward a target, which degraded both infrared and x-ray data. The gamma ray instrument's lack of a boom to hold it away from the spacecraft's contaminating gamma rays added to the instrument's problems. And the laser altimeter on MESSENGER will not be able to trace the topography of Mercury's southern hemisphere because of the spacecraft's elliptical orbit required by the small size of its onboard rocket.

Planetary scientists have been largely tolerant of the Discovery program's limitations but have pushed the limits fairly hard. The latest Discovery missions—MESSENGER, Kepler, and Dawn—are at the ultimate cost cap and represent the limit in spacecraft and mission complexity within NASA's intent for Discovery. The supereconomy missions like Lunar Prospector are things of the past. And inflation is starting to pinch Discovery budgets, especially in the realm of launch costs.

But Scout and especially New Frontiers have come along just in time. Scientists' enthusiasm for competing to lead missions seems undiminished. "It's such a great opportunity to propose for what we consider key scientific questions," says Larry W. Esposito of the University of Colorado, Boulder. He has frequently proposed and has never won, but "I've become addicted to proposing for missions."

–RICHARD A. KERR

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