CHAPTER 10

The Discovery Program: Competition, Innovation, and Risk in Planetary Exploration

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When Congress approved NASA's Discovery program in 1993, the action a milestone in the agency's search for lower-cost, innovative, robotic space science missions. The competitive selection of spacecraft proposals led by principal investigators (PIs) inverted the relationship between NASA centers and mission scientists. In the old model, a flight mission or series was assigned to an agency center, which would pick the instruments to hang on the spacecraft. Science often took a back seat to engineering. In the Discovery model, the winning PI would be completely responsible for delivering the science and the successful mission under a cost cap defined in the program. Rather than each mission being funded individually, which was often politically difficult, there would be a dedicated line in NASA's budget. Innovative and risky management approaches, including management by non-NASA organizations and streamlined systems engineering procedures, were

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favored. Discovery became the marquee project of Administrator Daniel Goldin's "faster, better, cheaper" approach.[1]

However, after the failures of two Mars spacecraft in 1999, Goldin and NASA became significantly more risk averse. That affected Discovery, whose own crisis began later, in mid-2002, with the failure of CONTOUR (Comet Nucleus Tour), followed by budget and schedule calamities affecting several spacecraft in development. The competitive selection process had favored the most science that could be crammed under the cost cap, leading to more technically complex spacecraft than originally expected. Mission selections slowed drastically due to the resulting cost overruns, exacerbated by raids on Discovery's budget to prop up other NASA projects, and by longer-lasting operations costs for the ambitious missions, once launched. In order to reduce the risk of failure, the agency raised budget reserve and review requirements for new proposals, further increasing cost and making flights less frequent. With "better, faster, cheaper" methods discarded and cost caps raised, Discovery could no longer be called a low-cost program. Yet the central innovation of PI-led competitions has delivered many spectacular successes in solar system exploration on a relatively lean budget, and has inspired the reform or creation of other programs on the competitive model (like Explorer, New Frontiers, and Mars Scout). It demonstrates that competition can work to reduce cost and increase innovation at NASA, but also that cost savings will suffer if the agency becomes too risk averse.

Program Origins, 1989–1993

Discovery grew out of a perceived crisis in NASA's planetary exploration program. In the 1980s, overruns and delays in the only new projects—Galileo (a Jupiter orbiter and atmospheric probe), Magellan (a Venus radar mapper), and Mars Observer (an orbital mission)—were made even worse by the *Challenger* shuttle disaster of January 1986. No NASA planetary mission was launched between 1978 and 1989. What new data there was came from spacecraft launched in the 1970s, notably Voyager and its flybys of the outer planets. Large and expensive "flagship" missions like Galileo and Magellan cost hundreds of millions or billions of dollars, resulting in few opportunities to fly experiments. An attempt to start a low-cost mission line for the inner solar system based on a commercial Earth-orbiting design, Planetary Observer, got into deep trouble as Mars Observer faltered. It proved far from simple to modify the original design; scientists also tried to pile in as much instrumentation as they could, given that it was the only Mars mission for years. After the shuttle disaster, Lennard Fisk, Associate Administrator of the Office of Space Science and Applications (OSSA), decided to postpone Mars Observer two years to the next launch opportunity in 1992, and change it to an expendable booster. Nevertheless, he had to accept the consequence: another big cost increase.[2]

By 1989, disgruntlement in the planetary science community led Geoffrey Briggs, then head of OSSA's Solar System Exploration Division, to initiate discussions of a new low-cost program, one that might give mission leadership to university scientists. However, he ran into the entrenched interest of NASA's only planetary spacecraft center, the Caltech-operated Jet Propulsion Laboratory (JPL) in Pasadena, CA, and community skepticism because of the souring of Planetary Observer. That program seemed likely to end with only one mission (as was indeed the case—and it failed). At a strategic planning workshop for OSSA in summer 1989, Stamatios M. "Tom" Krimigis of Johns Hopkins University's Applied Physics Laboratory (APL) made a key intervention. He argued that a much better model would be the Explorer Program of small Earth-orbiting spacecraft, which served the space physics community out of which he came, as well as space astronomy. He used as an example the Advanced Composition Explorer (ACE) that APL was then designing. The argument sufficiently impressed Briggs that he began an initial study of what he called the Discovery program, which would emulate the Explorer model of a permanent budget line, rather than a separate appropriation for each "new start." He appointed an entrepreneurial mission designer and scientist, Robert Farquhar, then working at the Goddard Space Flight Center, to head it on a part-time basis and created a science working group to examine potential missions. A rendezvous with a near-Earth asteroid was already in discussion as a possible objective, given growing scientific interest in the small bodies of the solar system and the relatively low energy requirement for such a mission.[3]

However, Discovery made little progress over the next year, and Fisk replaced Briggs with Wesley Huntress, a distinguished former JPL astrochemist, as head of solar system exploration. Huntress saw Discovery as a critical program for reforming his unit. In his view, JPL had demonstrated its skills in outstanding flagship programs like Viking and Voyager, but was complacent and entrenched in a way of doing business that favored giant, expensive spacecraft; it needed competition. Looking around, he saw APL and the Naval Research Laboratory as the institutions immediately at hand that could build small planetary spacecraft, but the latter was not interested in getting into NASA's game. Huntress gave study contracts for Near-Earth Asteroid Rendezvous (NEAR) to APL and JPL, leading to a "shoot-out" in Pasadena in May 1991. The result was embarrassing for JPL. Its first proposal said that it needed nearly $450 million for a three-spacecraft program to get a full mission to an asteroid. In contrast, APL's team said it could be done for $110 million and one spacecraft, a figure that invited skepticism as being too low. In fact, JPL's proposal was so badly received that its director asked for a second chance. After a month, a group led by Tony Spear, a known JPL maverick who had rescued Magellan from failures in Venus orbit, came back with a single spacecraft for $150 million. This was respectable, but to Huntress it was no contest, and he gave the win to APL.[4]

In fall and winter 1991–1992, Huntress's and APL's assumption that NEAR would be first was upset, however, by internal NASA politics. Michael Griffin (later NASA Administrator) had been brought into head an Exploration directorate to revive President George H. W. Bush's ill-fated Space Exploration Initiative (SEI) of 1989 for human flights to the Moon and Mars. Administrator Richard Truly gave Griffin a small lunar mission that Huntress had started in place of Lunar Observer. Afraid OSSA would lose Mars too, Richard Truly took a small lander project that had been studied at NASA Ames Research Center and gave it to Tony Spear at JPL, and combined it with a separate proposal for a microrover to be carried by the lander. That project would become Mars Pathfinder. Tom Krimigis, APL Space Department head, was unpleasantly surprised by the news in March 1992 that NEAR was now bumped to second place in Discovery, with no launch projected before 1997.[5]

Huntress and Fisk made these decisions in the context of much agency turmoil. The era of expanding NASA budgets under Presidents Reagan and Bush came to a sudden halt in 1991 due to foreign and domestic crises, the end of the Cold War, and NASA embarrassments, above all huge SEI budget estimates and the flawed Hubble Telescope mirror discovered in mid-1990. OSSA had to eliminate a couple of flagship missions and find budget reductions in others. The Bush Administration, frustrated with what it saw as NASA's costly, sluggish, and bureaucratic methods, and impressed with the Strategic Defense Initiative's faster and riskier approach, dumped Truly and brought in

Daniel Goldin as Administrator in April 1992. He was a veteran of secret military and intelligence space programs at contractor TRW and came with an agenda of forcing through "faster, better, cheaper" methods of spacecraft development. By fall 1992, Goldin had decided to get rid of Fisk and install Huntress as Associate Administrator, in significant part because Goldin had discovered the latter's Discovery program. However, Fisk's removal was put on hold by the presidential election and the inauguration of Bill Clinton. In 1993, Goldin was confirmed, Fisk quit, and Huntress was installed as head of the Office of Space Science (OSS; Applications became a separate office).[6]

Because of the 1992 cuts, Discovery's first appropriation had been pushed back another budget year, but thanks to study contracts given in the spring, APL's NEAR and JPL's Mars Pathfinder had advanced. Krimigis was determined not to accept second place without a fight. He had hired Bob Farquhar from NASA and set him to work on finding a more interesting asteroid than the minor body that was to be the targeted for a rendezvous in 1998. Farquhar, a genius with trajectory design, found that if NEAR was launched in early 1996, it could reach the important Earth-crosser 433 Eros. That would have the side benefit of beating Pathfinder to the launch pad. Yet President Clinton's first budget submission in spring 1993 had no money for NEAR, which was to begin a year later. That set up a fight. Krimigis was very experienced in Washington power games and possessed outstanding connections to Maryland's congressional delegation, above all Senator Barbara Mikulski. He orchestrated a lobbying campaign by scientists friendly to NEAR and induced Mikulski's office to question the appropriateness of Pathfinder, a technology demonstrator, to what was supposed to be a science program. Goldin, who only cared about the Mars mission, was furious about this intervention, but Huntress was very happy when Mikulski engineered a compromise in fall 1993 that funded both to the tune of $132 million. Discovery had started much better funded than Huntress had any right to expect.[7]

Discovery in the Heyday of "Faster, Better, Cheaper," 1993–2001

The program began with two predetermined missions without PIs, but Huntress' intent was always to implement the full model once Congress and the President had approved the program. That involved a competitive selection of PI proposals, with science as the primary driver for selection, followed by technical merit. Primary conditions were a mission cost cap of $150 million in 1992 dollars, not including the launch vehicle, and a mission development time of no longer than 36 months. The launcher could be no bigger than a medium-sized Delta II. The expectation was that there would be a Discovery launch every 18 or 24 months, if the President and Congress funded the program as a "level of effort" budget line of $85 million a year, with $10 million for advanced technology and instrument development and the remainder for missions. Dan Goldin was happy to use Discovery as a marquee program in his campaign to shake up NASA's bureaucracy and spacecraft development processes. Nevertheless, it would take until the FY 1996 budget (which began in late 1995) before Congress actually was impressed enough by the program's progress to legislate the standing budget line.[8]

Even before program approval in fall 1993, NASA had held a workshop at San Juan Capistrano, CA, in November 1992 to prepare for future competitions. Concepts for small planetary missions were offered by 73 teams from universities, laboratories, corporations, and NASA centers. The results were encouraging—there were many imaginative ideas that might fit under the cap. OSS selected 11 of the best for further development funding, preparatory to launching the first Announcement of Opportunity (AO) competition in 1994.[9]

A follow-up management workshop was held in April at the same location. Two dozen space science insiders discussed how the PI-led model could actually be implemented. Among the key conclusions were that Discovery, which they enthusiastically endorsed, should aim for one selection and one launch a year, and not be run out of NASA Headquarters, but rather have a program office to provide "contract management and technical 'oversight.'" Regarding leadership they stated: "most PI's do not wish to be 'Project Manager' of their mission," "a few ... do not wish to team with a NASA Center," "most PI's will favor roles as mission architect and science leader," and "most universities have ***neither the will nor the means*** to accept sole responsibility for an entire mission." These conclusions addressed two key questions about the PI model: (1) were scientists, mostly university based, capable of running a $150 million mission; and (2) how were they to deal with the technical and administrative complexity of developing a spacecraft and project while adhering to federal laws and requirements? Failure was certainly a possibility, and the workshop report stated that NASA had to

"be prepared to ***cancel*** any non-performing missions, in any Phase, from A [detailed study] to C/D [full development and production]."[10] The report hit upon some of the other key questions as Discovery developed: if the traditional model for solar system exploration was thrown out (where a NASA center, almost exclusively JPL, was assigned a mission, then held a competition for the instrument selection or perhaps a spacecraft production contract), what role would the agency play in the new program? Only oversight? Would NASA centers be central or marginal? Would risk be tolerated and would projects actually be canceled? And would missions really be launched every year or two? Certainly, in the heyday of Goldin's "faster, better, cheaper," risk and speed were at the heart of NASA's rhetoric and were strongly supported by Wes Huntress in OSS.

In 1994, as scheduled, OSS released the first Discovery AO, and at the end of February 1995 Huntress chose the first new mission, Lunar Prospector, as well as three proposals for Phase A competition. Later in 1995, Stardust, which was to return samples of dust from a comet (Fig. 10.1), won over a Venus mission and one to sample solar wind particles. Two years later the latter was selected under a new name, Genesis.[11]

Lunar Prospector was an exception in Discovery history, and not only in its selection without further competition. It had originated as a private mission to prospect for Moon minerals, then the NASA Office of Exploration began funding it in 1991. Thus it had development history and prototype hardware. With Goldin's elimination of Exploration in 1994, it went searching for a home. Led by PI Alan Binder, who later exited Lockheed Martin to form his own private Lunar Science Institute, it began essentially as a Lockheed mission with minimal NASA involvement. However, the agency wanted to exercise project management, so it gave oversight to Scott Hubbard at the Ames Research Center, causing friction with Binder. The early 1998 launch on Lockheed's Athena II rocket, with a heritage of intercontinental ballistic missile solid-fuel stages, cost little (although delayed by problems) because of a special promotional price from the company. The entire project cost about $63 million, an extraordinarily low price even for a lunar mission, in significant part because there was no new technology development and a fairly basic instrument package designed to map surface elemental abundances. Its scientific result would have been unimpressive if it had not provided further evidence of possible water ice at the lunar poles, but it was cheap

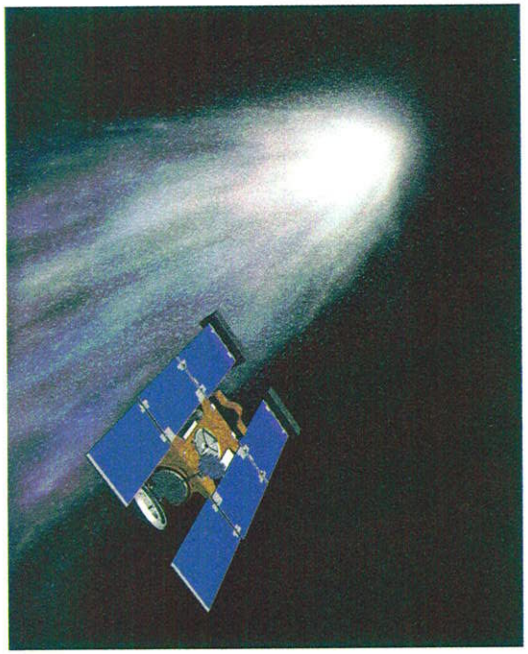

Fig. 10.1 This artist's rendering of the Stardust spacecraft shows it encountering Comet Wild 2. The spacecraft was launched on February 7, 1999, from Cape Canaveral Air Station, FL, aboard a Delta II rocket. It delivered samples from the comet to Earth in January 2006. (NASA/JPL, image number PIA03183, public domain) (Available at https://images.nasa.gov/#/details-PIA03183.html.)

and fast, as Goldin wanted. Other than APL's NEAR mission, which came in at a little over $100 million up to thirty days past launch, it was the only Discovery project that was much below the cost cap.[12]

The history and patterns of Discovery mission selections can be seen in Table 10.1. It is striking that all but two were chosen in 2001 and earlier, not counting the selection currently in process. (The Science Mission Directorate or SMD, the new name of OSS since 2003, has announced will probably pick two in 2016).[13] The sustainability of a selection every other year and launches on a similar pace required occasional missions like Lunar Prospector that were very cheap, relatively quick, and short-lived. Once Discovery drifted into the selection of more exciting, scientifically valuable programs up against the cost cap, with longer development times and even longer operational lives, an AO every other year would become unsustainable.[14]

Also notable is the greater diversity in the 1990s in the lead centers managing these projects. Johns Hopkins APL had three out of the first eight, and Ames one. Since Deep Impact in 1999, every mission has

Table 10.1 Discovery Missions

Name	*Selection*	*Launch*	*Principal Investigator/ Institution*	*Lead Center*	*Subcontracting Manufacturer*	*Target*
Mars Pathfinder	1992	1996	None/JPL (M. Golumbek, PS)	JPL	JPL	Mars
NEAR	1992	1996	None/APL (A. Cheng, PS)	APL	APL	Mathilde, Eros
Lunar Prospector	1995	1998	A. Binder/Lunar Science Institute	Ames	LM Sunnyvale	Moon
Stardust	1995	1999	D. Brownlee/ University of Washington	JPL	LM Denver	Comet Wild 2
Genesis	1997	2001	D. Burnett/ Caltech	JPL	LM Denver	Solar wind/ Earth–Sun L1
CONTOUR	1997	2002	J. Veverka/ Cornell	APL	APL	2 comets (failed)
MESSENGER	1999	2004	S. Solomon/CIW	APL	APL	Mercury
Deep Impact	1999	2005	M. A'Hearn/ University of Maryland	JPL	Ball Aerospace	Comet Tempel 1
Dawn	2001	2007	C. Russell/UCLA	JPL	Orbital Sciences	Vesta, Ceres
Kepler	2001	2009	W. Borucki/Ames	JPL/ Ames	Ball Aerospace	Extrasolar planets
GRAIL	2007	2011	M. Zuber/MIT	JPL	LM Denver	Moon
InSight	2012	2018*	W. B. Banerdt/JPL	JPL	LM Denver	Mars
Lucy	2017	2021	H. Levison/SwRI	Goddard	LM Denver	Jupiter's Trojan asteroids
Psyche	2017	2023	L. Elkins-Tanton/ ASU	JPL	JPL	Psyche

Abbreviations
APL Applied Physics Laboratory, Johns Hopkins University
ASU Arizona State University
CIW Carnegie Institution of Washington
CONTOUR Comet Nucleus Tour
GRAIL Gravity Recovery and Interior Laboratory
InSight Interior exploration using Seismic Investigations, Geodesy and Heat Transport
JPL Jet Propulsion Laboratory, California Institute of Technology
LM Lockheed Martin
MESSENGER MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MIT Massachusetts Institute of Technology
NEAR Near-Earth Asteroid Rendezvous
PS Project Scientist
SwRI Southwest Research Institute
UCLA University of California, Los Angeles
* InSight delayed from 2016 to 2018 Mars launch opportunity due to instrument problem

been JPL's, with the exception of Kepler, which came out of Ames, but NASA put project management at JPL, which was considered to have more capacity to deal with complex projects. Noteworthy also is that Mars does not appear between the first and the last chosen, because in 2001 the agency launched a parallel competition program for smaller missions to the Red Planet, Mars Scout. It chose two before it became a victim of SMD budget cuts and overruns on Mars Science Laboratory.[15]

From the standpoint of 2001, however, the Discovery program was already a smashing success for Goldin's faltering "faster, better, cheaper" campaign. In addition to Lunar Prospector, the NEAR Shoemaker spacecraft flew by asteroid Mathilde in 1996 and orbited and ultimately landed on Eros in 2000–2001 (after a near-fatal, in-flight emergency delayed the asteroid rendezvous by a year), and Mars Pathfinder made a spectacular, airbag-cushioned landing in 1997. Moreover, Stardust and Genesis launched and began to collect samples, and several new, exciting missions were in the works. The program had sustained an AO every other year since 1994 and had made five launches in five and a half years since NEAR in early 1996. Discovery's record of success with competitions and PI-led projects moved NASA not only to start Mars Scout, but also to revise the selection process for the Explorer program that inspired Discovery, and to begin contemplating such a program for mid-sized, outer-planet missions, New Frontiers.[16]

Discovery's Time of Troubles, 2002–2005

The program's visible troubles began on August 15, 2002, when the CONTOUR spacecraft disappeared near the end of its scheduled burn to leave a high-Earth orbit on a trajectory to intercept Comet Encke. Subsequent telescope searches turned up three possible objects. The review board ultimately blamed the impingement of the solid rocket's expanding plume on the spacecraft for its failure, although APL believed that an explosion in the older, "recertified" motor it had purchased was actually at fault. Tom Krimigis, then approaching the end of his tenure as APL Space Department head, describes the reviews and investigations as painful and onerous.[17] It hurt the laboratory's reputation as a reliable implementer of "faster, better, cheaper" projects and accelerated a cultural change in the Discovery program.

The embarrassing losses of Mars Climate Orbiter and Mars Polar Lander in 1999, plus several other failures in non-Discovery "faster, better, cheaper" programs, had already begun to increase OSS requirements for more intensive reviews and more elaborate oversight. NASA Independent Assessment Teams (NIAT—everything had to have an acronym) and NASA Program Requirement 7120.5, a systems-management instruction created in the mid-1990s, were required on all missions. The new reviews first become visible in available Discovery documents in March 2001. Deep Impact was formally considered for termination before the beginning of Phase C/D for technical troubles and overruns. Troubles were mastered to the extent that the program was ultimately confirmed in May. In the process, NASA added $8.7 million over the cap to account for new, more stringent review processes that had not been previously required.[18]

Immediately after the CONTOUR failure, problems in the program multiplied. MESSENGER, which was also being developed and built by APL, began to run into schedule pressure due to late delivery of components and technical challenges with its lightweight structure, propulsion system, and innovative ceramic fabric heat shield to protect the spacecraft from intense solar heating at Mercury. The March 2004 launch date begin to look problematic. Deep Impact's cost overruns led to another termination review in October 2002, although it survived that one too. There were also warning signs of future technical problems with the Kepler telescope, which had very stringent optical and charge coupled device (CCD) requirements in order to make it capable of detecting extrasolar planets down to Earth size. Those challenges would ultimately lead to large cost increases. In addition, questions arose about the Dawn mission, which would use solar-electric propulsion to visit two of the largest main-belt asteroids, Vesta and Ceres. In hindsight, it becomes apparent that Discovery's success in the 1990s had led the review and selection committees to accept very ambitious and complex proposals with a very high science return on budgets and schedules that were quite optimistic. Several program insiders have commented on MESSENGER, which was not only to fly by Mercury but also go into orbit around the planet with seven scientific instruments, a package worthy of a medium-class mission. It was much more complex and scientifically ambitious than Lunar Prospector, or even NEAR and Mars Pathfinder.[19]

Concern also grew in 2002 about the general state of the program. David Jarrett, who had been program manager since 1999 at a new Discovery office created in the NASA Management Office at JPL, noted in September that the budget was already overcommitted and that a FY 2002 shortfall had been covered by "borrowing" from other NASA programs. The prospective gap worsened from FY 2005 and beyond, and that did not even account for the unknown total expense of Kepler.[20] It is unclear when OSS, now led by Edward Weiler, decided not to issue a Discovery AO for 2002, but it must have been at least a year earlier.

When NASA finally issued one in 2004 it led to a failed process. According to Wes Huntress, who had left the agency in 1998 for the Carnegie Institution of Washington and who had served as President of the Planetary Society in the early 2000s, the AO's funding profile was "backloaded"—meaning a lot of the money would come later, rather than early in the development phase when it was needed—leading to "unachievable cost profiles and launch dates." Nothing would be selected except a "Mission of Opportunity" proposal for a US instrument on a lunar orbiter developed by India, Chandrayaan 1. The Solar System Exploration Division had created that new line in 1998, with budgets limited to $35 million. It was a response to the fact that all spacecraft missions were being proposed right up to the cap, as proposers and selection committees favored as much science as could be squeezed in for the money. An overview of Missions of Opportunity can be seen in Table 10.2.[21]

In 2003 and 2004, the technical troubles of the Discovery program only worsened. In addition to the ongoing troubles of Deep Impact and Kepler, MESSENGER's overruns and delays led a busted cost cap and to two launch window postponements in 2004, from March to May, and then to August. NASA required the last delay because the independent review teams were not confident in the autonomy system of the spacecraft, which would respond to problems and emergencies before Earth could be contacted. More testing was required. The new window had a major impact on the mission—Mercury orbit would come almost two years later, in 2011, requiring an entirely new trajectory and a considerable increase in its long-run operational cost. This change was questioned by some APL veterans, who viewed the delay as caused by NASA's excess caution. Whether it saved an ultimately very successful mission is unknowable, but the delay certainly reflected an agency more afraid of failure.[22]

Table 10.2 Discovery Missions of Opportunity

Name	*Selection*	*Launch*	*Principal Investigator/ Institution*	*Lead Center*	*Spacecraft*	*Target*
Aspera-3 (instrument)	1998	2003	D. Winningham/ SwRI	SwRI	Mars Express (ESA)	Mars
NetLander instruments	2001	Canceled	W. B. Banerdt/ JPL	JPL	NetLander (France)	Mars
M3 (instrument)	2005	2008	Carle Pieters/ Brown University	JPL	Chandrayaan 1 (India)	Moon
EPOXI	2007	2005	M. A'Hearn/ University of Maryland	JPL/ Ball	Deep Impact bus	Extrasolar plan-etsComet Hartley 2
Stardust-NEXT	2007	1999	J. Veverka/ Cornell	JPL	Stardust bus	Comet Tempel 1
Strofio (instrument)	2009	2018?	S. Livi/SwRI	SwRI	BepiColombo (ESA)	Mercury

Abbreviations
Aspera Analyzer of Space Plasma and Energetic Atoms
EPOXI Extrasolar Planet Observations and Characterization (EPOCh) and Deep Impact eXtended Investigation (DIXI)
ESA European Space Agency
M3 Moon Mineralogy Mapper
Stardust-NEXT Stardust-New Exploration of Tempel 1
SwRI Southwest Research Institute

The overruns on several projects led planetary division director Colleen Hartman to issue a new requirement in spring 2003 that a cost reserve of 25 percent be carried on all future proposals. In November, Kenneth Ledbetter, one of Weiler's deputies, stated that the Discovery program was no longer the "poster child of NASA's Space Science activity." It "was rapidly gaining a reputation for cost overruns, schedule delays, broken promises and even failures." Reviews indicated that the program management structure was not working well. Jarrett had a very small number of civil servants in his office in Pasadena, supported by a separate office of JPL employees (who worked for Caltech), but it was hard for the laboratory to get good people in those positions. "Program executives" and "program scientists" overseeing the various projects, but having no control over budgets, were still located at NASA Headquarters, dividing responsibility further.[23]

OSS decided to consolidate management in a single JPL office and "firewall" its staffers from the parts of JPL engaged in missions and proposals. Additional support and analysis was to come from the non-profit Aerospace Corporation. JPL Director Charles Elachi appointed an experienced project manager to take over the office, but the whole move proved abortive. By the end of 2004, the Discovery and New Frontiers Office (they had been combined shortly before) was transferred to the Marshall Space Flight Center in Huntsville, AL. The sources are unrevealing, but there was dislike of Aerospace's meddling and JPL's apparent conflict of interest. The new program manager at Marshall, Todd May, had to work to build credibility and confidence in his office, as Marshall had almost no experience or investment in planetary exploration—precisely the neutrality that was desirable to many.[24]

As if to punctuate Discovery's public embarrassments, after the return capsule from the Genesis solar-wind sampling mission reentered the Earth's atmosphere on September 8, 2004, its parachute failed to open. It crashed into the Utah desert, contaminating and partially shattering its sample surfaces. It appeared that NASA and Discovery had failed again. Subsequent analysis revealed that an accelerometer sensor the size of a pencil eraser had been installed upside down by the contractor and testing had been inadequate to reveal the error. It was essentially the same landing system as the one on Stardust, launched earlier, so concern grew that its return was compromised too. (Its testing had been more extensive and there were no problems during landing on January 15, 2006.) The public came away with the impression that Genesis had been ruined, but in fact many of the sample surfaces were intact and the contamination was easily detected during analysis. Indeed, Genesis met virtually all its scientific objectives and delivered important new insights into the isotopic composition of the Sun and how it differed from the Earth's. The spectacular success of Deep Impact's "impactor" capsule crashing into Comet Tempel 1 on the July 4, 2005, further lifted program spirits and reputation. The main spacecraft returned amazing pictures and data about the comet's structure and composition.[25]

Discovery 2.0, 2005–Present

Out of the crisis emerged version two of the Discovery program. The PI-led competitive selection and the goal of producing lower-cost planetary missions, mostly to inner solar system targets, remained, but all

of the "better, faster, cheaper" objectives of the original program were thrown overboard or eroded away. The development time of 36 months was increased to 45–51 months. Budget caps on several missions had been violated without any being terminated. Spacecraft and mission development was to be handled under elaborate systems management regulations, with multiple independent reviews. Highly paid personnel had to spend countless hours producing reports and viewgraphs and then sit in meetings discussing them. APL, notably, was forced to evolve away from its traditional, paperwork-light methods and operate more like JPL, with more NASA oversight and intervention, much to the distaste of APL veterans like Tom Krimigis. It raised the question as to why competing centers were even needed, if their management models were all alike. Perhaps not coincidentally, JPL became dominant as lead center for missions, as it reorganized to support multiple Discovery proposals that fit NASA's desired management model.[26]

More elaborate proposals and reviews meant that final selections of new spacecraft missions from AOs took longer—about two years instead of one—and became few and far between for budgetary reasons. As noted earlier, there were only two new Discovery missions approved in the fourteen-year period after 2001. The less expensive Missions of Opportunity have partially compensated for the shortage of full mission proposals seeking funding below the cap, yet the monetary cap on spacecraft missions has grown significantly above the rate of inflation. In the AO of 2014 it was $450 million without launch; Discovery's original $150 million cap would be about $253 million in 2014 dollars (Fig. 10.2).[27] In short, a small planetary mission is now around a half a billion dollars.

On the other hand, the program has rung up a series of scientific and technical triumphs, largely from missions picked between 1995 and 2001: Stardust returned comet dust samples, MESSENGER flew by and then orbited Mercury for years, Dawn has used its innovative solar-electric propulsion to orbit two major main-belt asteroids, and the Kepler telescope (which was transferred out of the Discovery program in its operational phase) has found hundreds and perhaps thousands of new planetary systems, some with objects near Earth sized. GRAIL, picked in 2007 from a much-revised 2006 AO, produced new insights into the structure of the Moon. Mission of Opportunity funds allowed the launch of American instruments on foreign planetary spacecraft and the creative redeployment of the Stardust and Deep Impact main-bus vehicles for other objectives. Thus the second iteration of Discovery has been just as

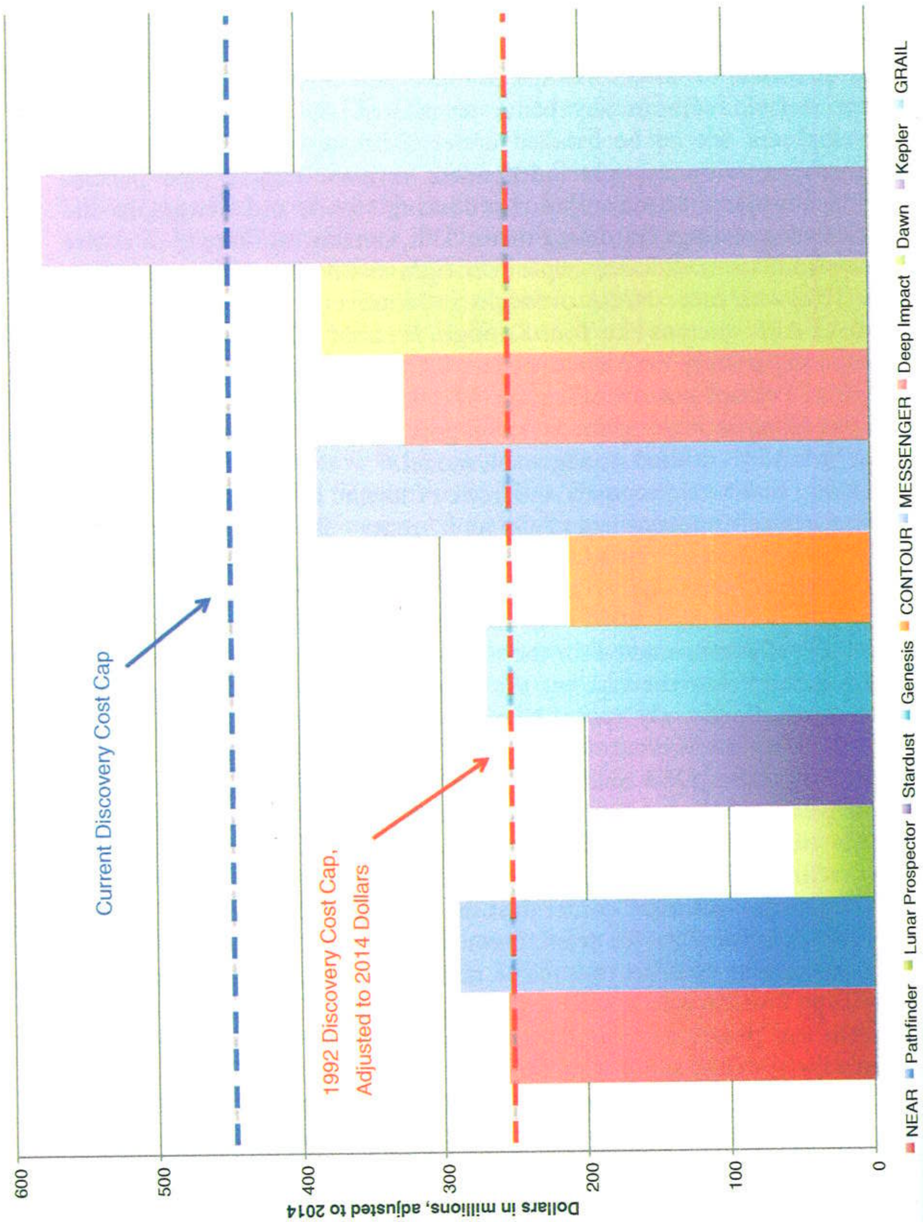

Fig. 10.2 Costs of NASA Discovery missions. (Courtesy of Jason Callahan/Planetary Society.)

successful as the first. It has produced rich scientific results with spacecraft more sophisticated and more long-lived than was expected at the beginning.[28]

Many of Discovery's budgetary problems were not self-generated. In addition to NASA leadership's pressure to avoid failures that might lead to public and political embarrassment, Administrator Mike Griffin took $3 billion out of the long-term space science budget to pay for President George W. Bush's Moon–Mars human spaceflight program, according to Wes Huntress. There were also large overruns on Mars Science Laboratory and the Webb Space Telescope. Moreover, the Delta II was phased out as obsolescent and launch vehicle prices increased for all programs. Discovery's launch costs rose to over $80 million in the early 2000s and are now of the order of $100 million.[29]

One of the side effects of the greatly reduced selection rate is that it became nearly impossible for a proposal highly ranked in one competition to win in a later one, as Genesis and MESSENGER did in the 1990s. The proposal-writing effort has become too massive and the odds too poor because of the few selected. The current planetary division director, James Green, has been trying to return Discovery to a more frequent AO schedule. Yet given the increased expense of a mission, and the lack of interest within NASA in going back to riskier development methods, it does not seem at all likely that the rate can be accelerated that much. Indeed, given the elaborate review and the quality of the proposals, he decided to make two selections in 2017, which means skipping the next AO cycle and waiting several years for another.[30]

Discovery and Innovation at NASA

Discovery remains an important and influential program in the history of space science at NASA. It expanded the number of missions funded on a standing budget line, rather than one "new start" at a time, and it pioneered the competitive bidding of entire spacecraft missions by PIs, its most important innovation. That model led to the reform of the Explorer program that inspired it, and the creation of New Frontiers and the more short-lived Mars Scout. This organizational innovation resulted in many imaginative missions. Mars Pathfinder took on a risky Mars landing based on difficult-to-test airbags, but it was really a technology demonstration, not a science mission. Most missions grew out of competitions where, as intended, the science output was the chief driver in design and selection, although some did include noteworthy technological innovations: Stardust used a marvelous, ultralight "aerogel" to stop cometary particles; Dawn became the first spacecraft to use ion propulsion as the basic propulsion for an interplanetary mission; Deep Impact smashed a hole in Comet Tempel 1; MESSENGER was protected by a new ceramic fabric heat shield. However, funding the development of cutting-edge technology was never the program's purpose. Such lines existed elsewhere in NASA, but, like the New Millennium program, tended to come and go and not necessarily work well in the absence of a specific mission objective. The Discovery program demonstrated that open competitions could lead to innovation, although it was most often in project organization or the imaginative use of technologies on the cusp of readiness.

If mission competitions were Discovery's longest-lasting influence on NASA, clearly its original development methodology was not influential. Of course, that was only part of the larger story of a space agency briefly willing to take risks, and then shrinking back from the consequences of a series of failures in 1999—although Discovery was not very visibly affected until it ran into its own crisis in 2002. The program was a milestone in lowering the cost of planetary exploration, by sustaining a line of relatively cheap and innovative missions. Nevertheless, after the flight from risk was compounded by inflationary increases beyond NASA's control, the definition of relatively cheap got revised sharply upward, as shown by mission caps that are nearly double when accounting for inflation.

The two most influential early founders of Discovery, Tom Krimigis and Wes Huntress, are now very critical of the agency's unwillingness to take risks, but they take pride in the scientific output of Discovery, which has been stellar. They are reluctant to admit, however, that that was achieved in part by taking on ambitious missions that pushed the low-cost model to its breaking point. They and others praise the program's impact on the planetary science discipline, both in the sustained production of new data and in its power to nurture graduate students and postdocs in their career training and development. In contrast to the difficult situation of the 1980s, where long gaps in new data were punctuated by a handful of very expensive flagship missions, Discovery has succeeded, alongside NASA's Mars program and a handful of outer-planets missions, in keeping up a continuous flow of new data for almost two decades.

Is there an option to return to a riskier, less bureaucratic Discovery program? Clearly it is possible, but does not seem at all likely. As Howard McCurdy has shown in his examination of the fate of "faster, better, cheaper," both high-cost and low-cost approaches to spacecraft development can work.[31] Discovery's history alone demonstrates that point. Yet the low-cost approach, while saving much money, is more likely to produce failures, which the current agency leadership, and the US political system to which it reports, seems unwilling to contemplate. One scientist has commented that the current environment is encapsulated in a community joke: "Dare to fail ... but don't fail!"[32] After a quarter-century, Discovery still appears to be thriving, but that mantra is likely to remain its guiding principle for the foreseeable future.

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CHAPTER 11

Partnerships for Innovation: The X-33/ VentureStar

Howard E. McCurdy

At the height of the Apollo program to land Americans on the Moon in the 1960s, Robert Gilruth called in Max Faget and urged him to "get off this blunt-body, parachute stuff. It's time we thought of landing on wheels."[1]

Gilruth was director of NASA's Manned Spacecraft Center (renamed the Johnson Space Center in 1973), Faget his chief engineer. The two had worked together as members of the Pilotless Aircraft Research Division, a small group of aeronautical engineers employed at the Langley Research Center before NASA was formed. The engineers built spacecraft models and launched them from a test facility at Wallops Island, VA. They tested hundreds of models to see how vehicles of various shape would perform while flying through the atmosphere.[2] In 1958, when NASA was created, Gilruth and Faget joined 33 other engineers in what was known as the Langley Center's Space Task Group. Faget designed the blunt-shaped Mercury space capsule that landed with indignity in the ocean after reentering the atmosphere. The capsule design evolved into the Gemini, Apollo, and Orion spacecraft.

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