PANEL ON PUBLIC AFFAIRS

Issue

On January 14, President Bush announced a new vision for NASA, starting with a human return to the Moon by 2020 to be followed by human exploration of Mars and other destinations. The impact of the president's proposal on scientific programs within NASA and other agencies could be substantial and must be assessed carefully.

Recommendations

Extraordinary scientific and technological difficulties confront President's Bush's vision for a Moon-Mars initiative. The budget for the proposed program remains very imprecise and is expected to grow substantially. The constraints that inevitably will be imposed on other federal scientific programs are already evident, especially within NASA. Before the United States commits to President Bush's proposal, an external review of the plans should be carried out by the National Academy of Sciences.

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November 2004

THE MOON-MARS PROGRAM

The cost of overcoming technological challenges could far exceed budgetary projections. Many approved science programs could be jeopardized.

Executive Summary

Very important science opportunities could be lost or delayed seriously as a consequence of shifting NASA priorities toward Moon-Mars. The scientific planning process based on National Academy consensus studies implemented by NASA roadmaps has led to many of NASA's greatest scientific—and popular—successes. We urge the Federal Government to base priorities for NASA missions on the National Academy recommendations.

APS Executive Board Statement

Reestablishing a human presence on the Moon and sending astronauts to Mars represents a major national challenge. However such a program could only achieve its full significance as part of a balanced program of scientific exploration of the universe and studies of the interaction between humankind and its environment. In recent years, NASA has captured the public's imagination through its spectacular scientific successes with the Hubble Space Telescope, the Mars Rovers, and Explorer missions that have revolutionized our understanding of the universe.

The technical hurdles facing the Moon-Mars initiative are formidable, and the program's overall costs are still unknown. Further, the rapid pace currently envisioned for this program may require a wide redistribution of the science and technology budgets that could significantly alter the broad scientific priorities carefully defined for NASA and the other federal agencies. Launching such a massive program without broad consultation and a clear idea of its scope and budget may hurt rather than enhance, as intended, the scientific standing of the U.S. and the training of its scientists and engineers.

Before the United States commits to President Bush's proposal, an exhaustive external review of the plans should be carried out by the National Academy of Sciences and their likely budgetary impact estimated by the Government Accountability Office (GAO). *(Adopted June 2004.)*

Setting Science Priorities

Our quest to understand the universe we live in requires both substantial resources and long-range planning. To assist and foster the policy and budgetary processes, astronomers, astrophysicists, and earth and solar system scientists, under the auspices of the National Academy of Sciences (NAS) and the National Research Council (NRC), an arm of the NAS, have set scientific priorities for five decades, with a remarkable degree of success. Most of the major federally funded astronomy initiatives during this period, ranging from the Very Large Array of radio telescopes in New Mexico to the Hubble Space Telescope, find their origins in the recommendations contained in one or more of the NAS Decadal Surveys. In each case, the committee that set the priorities comprised outstanding scientists, who represented the full range of research within astronomy.

- In each case, the committee solicited advice from the entire astronomical community, resulting in strong community support for the findings.

- In each case, the priorities reflected the strengths of the scientific cases, rather than perceived political factors.

- And in each case, the committee achieved consensus.

Impact of Moon-Mars on Science Priorities: In Brief

The exploration of the universe is one of the noblest endeavors of humanity. It tugs simultaneously at our emotions and our intellectual curiosity. It is the reason that NASA's spectacular unmanned scientific successes—the images from the Hubble and Chandra Space Telescopes, the Mars Rovers, and the Explorer missions such as Wilkinson Microwave Anisotropy Probe (WMAP)—have captured the public's imagination at the same time that they have revolutionized our understanding of the universe.

We believe that human exploration also has a role to play in NASA, but it must be within a balanced program in which allocated resources span the full spectrum of space science and take advantage of emerging scientific opportunities and synergies. We further believe that our understanding of the moons and planets of our solar system takes its full significance only within the more global context of a systematic study of nature: from the early universe to the formation of planets around other stars; from the fundamental laws of physics to the emergence of life; from the relations between the sun and the planets to the complex interactions in ecological systems and the impact of humanity on its environment. Returning Americans to the Moon and landing on Mars would have a powerful symbolic significance, but it would constitute only a small step in the advancement of knowledge, since much will already be known from exploration with the robotic precursor probes that are necessary to guarantee the safety of any human mission.

The Moon-Mars initiative presents policy makers with a major challenge: how best to implement the vision of the Administration and modify the NASA priorities without destroying the agency's balanced scientific program that was carefully crafted with strong scientific community involvement. When external factors impose a significant reorientation, it is imperative that NASA not make decisions with undue haste, without serious evaluation of their impacts, and without broad consultation. A number of mechanisms exist to engage the research community in the process, such as NASA advisory committees and the National Academy of Sciences Committee on Astronomy and Astrophysics, but thus far they have received insufficient attention.

Although the Moon-Mars initiative began the needed process of addressing the goals and access vehicles for human spaceflight and the future of the International Space Station, we are concerned that the scope of the proposed initiative has not been sufficiently well-defined, that its long-term cost has not been adequately addressed, and that no budgetary mechanisms have been established to limit the potential deleterious impact of the program on other aspects of NASA's missions. The recent analysis by the Congressional Budget Office suggests that the new initiative may only be possible at the expense of canceling proposed robotic exploration that has a much better scientific justification. We are also concerned that the impact of an ill-defined Moon-Mars program, whose long-term cost is known only to be very large, could affect programs in other science agencies (such as the National Science Foundation and the Department of Energy) through the pressure of the overall budget allocation process or by putting in question inter-agency collaborative projects.

For these reasons we recommend that before the United States commit to President Bush's proposal, an exhaustive external review of the plans be carried out by the National Academy of Sciences and their likely budgetary impact estimated by the Government Accountability Office (GAO).

Impact of Moon-Mars on NASA Science Priorities: In Detail

The funding agencies, primarily NASA (through its "roadmap" process) and NSF, have used the results of the NAS Decadal Surveys to great benefit in developing their research and funding plans. (The proritized recommendations of the current Decadal Surveys are summarized in Appendices I-III below.) In formulating their plans, the agencies have also relied on other science-driven NRC reports, such as *Connecting Quarks with the Cosmos* (2003)[1] and *Plasma Physics of the Local Cosmos* (2004),[2] which highlight important scientific problems. Constellation-X, a proposed initiative to study the formation and evolution of black holes through space-based X-ray observations, and LISA, a proposed initiative to detect the gravitational radiation from merging supermassive black holes, were ranked as high priority missions in the Decadal Survey *Astronomy and Astrophysics in the New Millennium* (2002)[3] and were both strongly

[1] On the National Academy Press web site at http://www.nap.edu/books/0309074061/html/
[2] Available at http://www.nap.edu/catalog/10993.html/
[3] Available at http://www.nap.edu/books/0309070317/html/

favored in *Connecting Quarks with the Cosmos*. NASA embraced both projects as the two "Einstein Great Observatories" in its Structure and Evolution of the Universe theme.

As a consequence of NASA's readjusted priorities in the wake of the Moon-Mars initiative, LISA has been delayed at least a year, and Con-X, which was the second highest priority major space mission of the current Decadal Survey (see Appendix I), has been delayed until at least 2016. We believe that it will be very difficult to hold the Con-X team together for ten more years, and as a result the project ultimately may have to be aborted. Other scientific missions have been delayed indefinitely, among them the Einstein Probes, which are moderate sized missions aimed at determining the nature of dark energy, observing regions near black holes, and studying the imprint of cosmic inflation on the cosmic background radiation. Their importance was emphasized in *Connecting Quarks with the Cosmos* and in the recent Office of Science and Technology Policy (OSTP) report, *Physics of the Universe* (2004).[4]

The Explorer program is another activity that is being affected by Moon-Mars. It is arguably the most successful program at NASA in benefit/cost, having produced outstanding science with small (SMEX) and medium (MIDEX) size principal-investigator-led missions—among them, WMAP, GALEX, RHESSI, IMAGE, TRACE, FAST, SWAS, and SAMPEX—covering all areas of astrophysics and solar and space physics. These missions involve academic institutions more actively than any other NASA flight program does.

Explorer spacecraft have provided extensive training for the next generation of space scientists and engineers. Explorer missions, chosen through intense competition to insure cost effectiveness, have also led to innovative instrument design and have produced new and important scientific results of great importance to the advancement of space science. Until now the Explorer budget has been kept at a constant level of funding and has not been raided for other large programs. In the aftermath of Moon-Mars, however, while the funding for Explorer missions already selected and in development is still being maintained, budgets for all new missions are being drastically reduced, by 58% in FY05, 32 % in FY06, 50% in FY07 and 14 % in FY08. These proposed cuts, at best, will postpone the selection and start of new missions by at least a year. At worst, they will cripple the Explorer program.

The Moon-Mars initiative has also caused funding cuts for the Sun-Earth Connections (SEC) Mission Operations & Data Analysis that could result in the early termination of seven of the present fleet of fourteen operating SEC spacecraft by FY2006. They include the two Voyager spacecraft that are just reaching the boundary of the heliosphere and the Wind and Ulysses spacecraft that provide our best observations for studying space weather for missions to Mars and the Moon.

Solar-Terrestrial Probe (STP) missions would also be affected. Although funding for the two missions already under development would be maintained, funding for future STP

[4] Available from OSTP at http://www.ostp.gov/html/physicsoftheuniverse2.pdf

missions would be severely cut, by 78% in FY05, 82% in FY06, 75% in FY07, 46% in FY08 and 49% in FY09.

The NRC recently released *Solar and Space Physics and Its Role in Space Exploration* (2004),[5] a report which reconsidered solar and space physics priorities in light of NASA's new space exploration vision. It found that, although the recommendations in the relevant decadal study, *The Sun to the Earth—and Beyond* (2003),[6] were formulated in 2002, before the 2004 NASA exploration vision, these recommedations remain valid. Accurate predictive tools for space weather are essential for NASA's exploration goals, but without programs such as the STP mission line, the development of such tools would be placed at serious risk.

NASA's Sub-Orbital program that supports rocket and balloon-borne experiments, the prime training ground for experimental astrophysicists and space physicists, would suffer reductions as well. The program has already been reduced substantially, but the Moon-Mars initiative would force further reductions, 5% in FY05, 17% in FY06, 23% in FY 07 and 26% in FY08 and FY09.

Finally, there is considerable speculation that the budgetary impact of Moon-Mars colored NASA's decision to cancel the Hubble Space Telescope service mission. Although NASA cited astronaut risk considerations as the prime motivator for the cancellation, the timing of the announcement, coming just two days after President Bush's Moon-Mars speech, suggests that financial considerations, prompted by Moon-Mars reallocations, might also have played a substantial role.

To address concerns over the Hubble decision, Congress asked for an independent assessment. As a result, NASA Administrator Sean O'Keefe asked Admiral Harold W. Gehman Jr., the chair of the Columbia Accident Investigation Board, to review the safety of an astronaut service mission. In response, Gehman said that only a "deep and rich study…can answer the question of whether an extension of the life of the wonderful Hubble telescope is worth the risks involved." NASA subsequently made a formal request that the National Academy of Sciences (NAS) carry out a study of the risks and benefits of using the Shuttle for the servicing mission. A NRC panel reported its preliminary findings to NASA Director O'Keefe on July 13, 2004.[7] They urge NASA to commit to a servicing mission, note that a proposed robotic mission would be quite complex and require significant development, and state that NASA should not preclude a Shuttle servicing mission at this time. The NRC panel will release its final report in fall 2004.

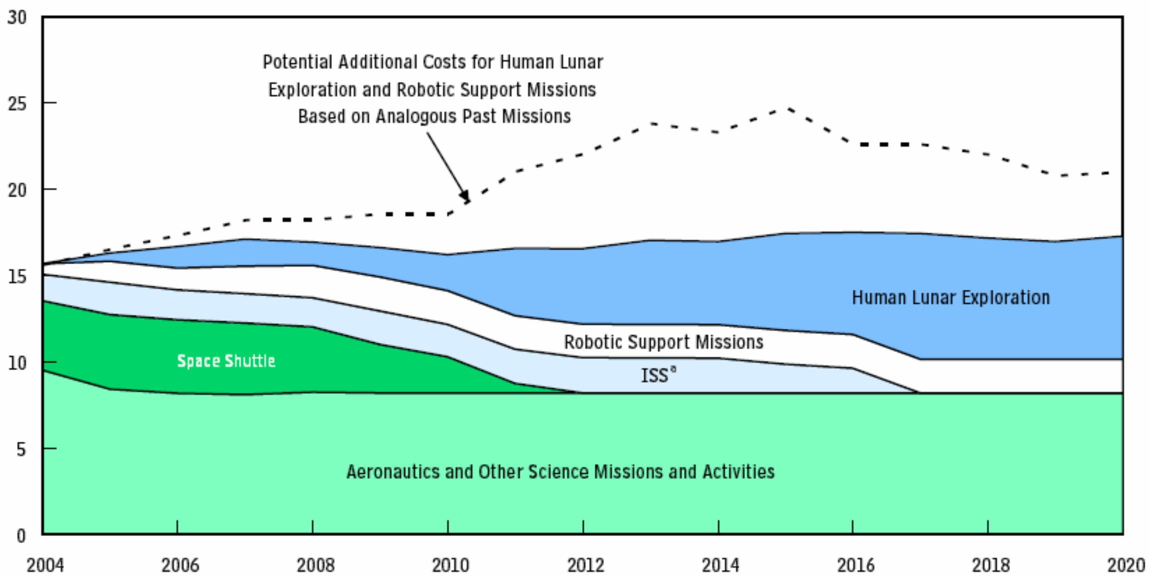
[5] On the National Academy Press web site at http://books.nap.edu/catalog/11103.html/
[6] http://www.nap.edu/books/0309085098/html/
[7] On the National Academy website: http://books.nap.edu/html/Hubble_Space_Telescope/letter_report.pdf

Congressional Budget Office Analysis of Moon-Mars

In September 2004, the Congressional Budget Office (CBO) released a report entitled, *A Budgetary Analysis of NASA's New Vision for Space Exploration*,[8] prepared at the request of the Subcommittee on Science, Technology, and Space of the Senate Committee on Commerce, Science, and Transportation. The report re-categorized NASA's budget projections and expressed them in terms of 2005 dollars, using cost-escalation factors developed specifically for NASA's programs. It then estimated the likely cost growth, based on historical averages, noting that NASA's (and other agencies') complex technical programs have often experienced higher costs than initially estimated.

Potential Increase in Funding Needed for NASA's Human Lunar Exploration and Robotic Support Missions Based on the Costs of Analogous Past Missions

(Billions of 2005 dollars)



Source: Congressional Budget Office.

Note: This figure groups items in NASA's projected budget to more clearly delineate elements of the moon/Mars exploration vision relative to other exploration and science activities.

a. The International Space Station (ISS) category includes ISS transport.

The CBO projections are summarized in the accompanying figure. These higher costs would amount to an additional $61 billion between 2005 and 2020. If NASA funding for Exploration remained constant, the first U.S. human mission back to the Moon would occur roughly in 2027, rather than 2020. If, instead, funding of other NASA programs were reduced to cover the costs, 46 percent of total Aeronautics and Other Science funding ($61 billion out of a total $132 billion projected by NASA) would disappear.

The CBO report notes that under NASA's current plans—including the Moon-Mars initiative—the frequency of robotic missions, in which most of science is embedded,

[8] Available at http://www.cbo.gov/ftpdocs/57xx/doc5772/09-02--NASA.pdf

would decline significantly in the future, as shown in the accompanying table. However, if exploration costs were to rise beyond NASA's projected levels, as the CBO report forecasts, NASA would probably be forced to pare back those missions even further.

The number of robotic missions other than Exploration support missions to the Moon or Mars is already slated to drop from 17 between 2005 and 2009 to 10 between 2010 and 2014. The number would drop further, to six, between 2015 and 2019. A reduction in funding of more than 40 percent to accommodate higher costs in lunar exploration activities would probably force additional cuts in those numbers.

The CBO report also notes that NASA's assumption that the Shuttle fleet will stop flying in 2010 requires that astronauts be able to go to and from the International Space Station via Russian spacecraft. However, the report points out that the availability and cost of the Russian option are unknown. The CBO projects additional costs of approximately $21 billion if the Shuttle is kept operating until 2017.

NASA's Plans for Robotic Missions

	Planned or Prospective Missions (Number)			Projected Funding (Millions of 2005 dollars)		
Mission Area	2005-2009	2010-2014[a]	2015-2019[a]	2005-2009	2010-2014	2015-2019
Lunar Exploration	2	5	5	1,211	1,936	1,936
Mars Exploration	4	4	5	2,285	1,532	1,532
Solar System Exploration	3	n.d.	n.d.	2,056	2,373	2,373
Astronomical Search for Origins	2	2	n.d.	3,578	2,881	2,881
Structure and Evolution of the Universe	1	1	4	782	801	801
Sun-Earth Connection	11	7	2	3,035	3,840	3,840

Source: Congressional Budget Office based on data from the National Aeronautics and Space Administration.

Note: n.d. = not determined (in NASA's long-term plans).

a. Prospective missions derived from NASA's long-term plans.

Spectacular Successes and Synergies

NASA exists and receives support because of a broad national sense that outer space is a frontier that we should explore. However, exploration is an extraordinarily costly challenge with returns that are infrequent, especially accomplishments on a scale that can capture the public imagination. This poses a major challenge for an agency that must justify its budget to a skeptical administration and a hard-pressed Congress on an annual basis. Space Science has arguably been the single biggest rationale for continued support for NASA. The frequent dramatic discoveries from the major ongoing missions, particularly Hubble, but also Compton Gamma Ray Observatory, Chandra X-ray Observatory and now Spitzer Space Telescope, have provided a cornerstone of public and congressional support for NASA.

These Great Observatories have proven to be a spectacular scientific and public outreach success for NASA. The Hubble Deep Field is probably one of the best-known science images of all time, and schoolchildren can now recognize the moons of Jupiter from spacecraft images. The discovery of dark energy, the discovery that gamma ray bursts are at cosmological distances and hence the biggest explosions since the Big Bang, the detection of some of the earliest galaxies (whose light began its journey toward us less than a billion years after the Big Bang), and dramatic insights into the nature of extra-solar planets, are some of the discoveries from these missions in combination with important new ground-based observatories. The public interest and support for the Hubble Space Telescope after its announced premature demise indicates the recognition of such missions as a national treasure.

Ground-breaking discoveries from the equally important shorter-lived programs, such as the cosmology satellites COBE and WMAP (which have allowed us to measure our universe with a level of precision that was a dream back when NASA was young) complement these ongoing missions. Exploration programs such as the Mars Rovers capture the public's imagination and provide substantial scientific returns. The combination of dramatic discoveries, spectacular images, and the sense of national pride that arises from scientific exploration can underpin NASA's longer term efforts.

Current Status of Solar System Exploration

The Decadal Survey and NASA's roadmap provide a clearly articulated and compelling plan for future exploration of the solar system. Apart from the Cassini mission that entered Saturn orbit on June 30, 2004, there are three main components:

(1) A carefully planned sequence of unmanned Mars missions, aimed at "finding the water" and thereby placing constraints on present or past existence of life on Mars. Sample return from Mars is among the long-term (ten to fifteen year) goals.

(2) The Discovery and New Frontiers programs, the former (exemplified by MESSENGER, a mission to Mercury launched August 3, 2004) focused on the more accessible inner solar system and asteroid belt and the latter, more ambitious and expensive (exemplified by the New Horizons mission to Pluto and the Kuiper belt, scheduled for launch in 2006) focused on the outer solar system.

(3) Project Prometheus, the newest and most expensive component, aimed at developing and implementing nuclear power in space both through the use of reactors to produce electrical power and propulsion, and through diversifying the use of radioisotope power sources.

We note that Project Prometheus had not yet been proposed at the time the last Decadal Survey was written, but Prometheus's proposed implementation respects the priorities identified in that survey, albeit at a cost and a level of risk greatly in excess of those anticipated when exploration targets were prioritized.

Although by many measures the planetary exploration program is very healthy, the planetary science community and, indeed, the broader scientific community have expressed concern that undue emphasis on Moon and Mars potentially could threaten its vitality. Although Moon-Mars could expedite the development of valuable technologies for some other exploration programs—for example, a heavy lift launch vehicle with capabilities required for the delivery of spacecraft such as JIMO (Jupiter Icy Moons Orbiter), the first of the Project Prometheus missions[9]—vigorous exploration of the outer solar system might be hurt because its high costs would inevitably come into conflict with the large budgetary demands of the new initiative.

Although our understanding of the Moon and Mars undoubtedly will be enhanced by the new initiative, the scientific value of the effort may be limited by poor correspondence between the technical goals of the program and the scientific goals of planetary exploration. It is vitally important that the scientific and technical goals of any exploration program be linked as closely as possible.

Human vs. Robotic

The recent spectacular success of the Mars Rovers reminds us that it is possible to address many important scientific questions by robotic means. The limited autonomy possible with current technology typically reduces the pace at which science is done (so that Rovers may take weeks to do what a field geologist might do in a day). But this is an acceptable compromise given the very large difficulties and costs of using people. The current Rovers cannot reach the most challenging terrains (e.g., cliff faces), but these would also present obstacles to an astronaut and may be achievable with future improvements in robotic systems. Robotic exploration serves as a valuable element of an exploration program; it enables the human explorer to sharpen or even answer questions previously identified and to formulate new ones.

Human exploration could offer one real advantage: serendipity, the opportunity to notice and respond immediately to the unexpected. In this regard, astronauts on Mars might achieve greater scientific returns than robotic missions, but at such a high cost and

[9] The priority put forward in the relevant Decadal Survey was to carry out orbital exploration of Europa, a most likely place on which to find liquid water and therefore a potential site for life. The proposed plan ran into serious trouble because of its high cost (in the $1.5 billion range). The Europa Orbiter was dropped and replaced by JIMO, a mission created to piggyback on the Prometheus nuclear powered propulsion initiative. The costs and technical feasibility of this multi-moon mission to the Jupiter system (now said to be in the $8 billion and up range) are still highly questionable, and there is a high risk that large expenditures will be followed by endless delays, increasing costs, and ultimate cancellation. So whether there will be any scientific exploration of the highest priority target, Europa, is very uncertain, and whether JIMO is the best way to carry out the highest priority science has not really been considered by the NRC.

technical challenge that one could not expect to justify their presence on scientific grounds alone.

In addition to the cost and risk of deploying humans on Mars, a negative impact on the astrobiological goals must also be considered. Inevitably sending astronauts to Mars will contaminate the surface with terrestrial life forms and thereby compromise a prime target of the exploration program, the search for life on another solar system body. As part of the NRC study proposed here, it is important that there be a scientific assessment of the knowledge relating to present or past life that should be acquired by robotic means before an astronaut landing is undertaken. The results of this analysis would be relevant in defining the appropriate time frame for landing humans on the surface.

The Role of the National Academy of Science Decadal Studies

Under the auspices of the National Academy of Sciences (NAS), astronomers and astrophysicists have carried out long-range planning and priority-setting exercises for many decades. The success of these efforts is based on several key principles:

- The members of the committee that sets the priorities must be outstanding scientists.
- The members of the committee must represent the enormous range of science within astronomy and astrophysics such that any one sub-discipline has only a small representation.
- The members of the committee must gather input from the entire astronomical community, so that the community can support the final report.
- The committee's prioritization of projects and programs must be based on the strength of the science, not on perceived political factors.
- Members of the committee must be willing to compromise to achieve a consensus, since it is only through such a consensus that the recommendations can be effective.

The most recent Astronomy and Astrophysics Decadal Survey, *Astronomy and Astrophysics in the New Millennium*, had panels on radio and sub-millimeter wave astronomy; ground-based optical and infrared astronomy; space-based optical and infrared astronomy; high-energy astrophysics from space; solar astronomy; particle, nuclear, and gravitational wave astrophysics; and theory, computation, and data exploration. Each of these fields contains hundreds of astronomers and astrophysicists with very divergent views, making consensus-building a daunting task. Yet the survey ultimately achieved a consensus, and it has provided strong guidance for NASA programming.

The success of the NAS Astronomy and Astrophysics Decadal Surveys has spawned similar consensus-building efforts in space physics (*The Sun to Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*) and planetary physics (*New Frontiers in the Solar System—An Integrated Exploration Strategy*[10]). Other National Research Council reports, such as *Connecting Quarks with the Cosmos*, have also helped highlight the importance of Space Science programs and missions.

While the Decadal Surveys provide a strategic framework for the development of new missions and facilities—through a community-developed, rank-ordered list of science-based projects—implementing plans for carrying out the Decadal Survey recommendations requires an additional step. Within NASA the "road map" process provides the mechanism.

By law, every three years NASA is required to develop internal implementation plans as part of a "strategic" planning process. The process, which is really more tactical than strategic, usually begins with the set of previous plans and modifies them to incorporate incremental developments, based on recommendations in decadal surveys and other high-level reports such as *Quarks to the Cosmos.*

The roadmap effort has developed into an inclusive process. In recent years, the planning process in each of NASA's major space science themes (Origins, Structure and Evolution of the Universe, Sun-Earth Connection, and Solar System Exploration, including Mars) has drawn on the advice of the relevant advisory subcommittee of the Space Science Advisory Committee (SScAC). Each subcommittee, comprising scientists appropriate to the field, is charged with writing a new roadmap that includes new Survey recommendations and updates and reworks the previous roadmap to reflect the latest scientific, technical and political developments. The subcommittee works closely with NASA personnel, and presents its plans to the full committee.

The roadmap process has proven to be of enormous value, since it deeply involves the science community and the agency in the joint development of a long-range plan. It has allowed the community and the agency to speak with one voice, making it easier for the Office of Management and Budget and Congress to reach agreement on NASA's budget.

[10] http://www.nap.edu/books/NI000529/html/

Findings and Recommendations

We summarize our findings as follows:

- Space Science has provided NASA with one of the principal appeals for continued public and federal support.
- The recent spectacular successes of the Mars Rovers amply demonstrate that we can use robotic means to address many important scientific questions.
- Human exploration has a role to play in NASA, but it must be within a balanced program in which allocated resources span the full spectrum of space science and take advantage of emerging scientific opportunities and synergies.
- Astronauts on Mars might achieve greater scientific returns than robotic missions, but they would come at such a high cost that scientific grounds, alone, would probably not provide a sufficient rationale.
- **The scope of the Moon-Mars initiative has not been well-defined, its long-term cost has not been adequately addressed, and no budgetary mechanisms have been established to avoid causing major irreparable damage to the agency's scientific program.**
- Under the auspices of the National Academy of Sciences and the National Research Council, astronomers, astrophysicists, and other space scientists have successfully carried out long-range planning and priority-setting exercises for many decades, which NASA has used effectively in developing its "roadmaps," allowing the agency and the science community to speak with one voice.
- **To accommodate the Moon-Mars initiative, NASA has already begun to reprogram its existing budget, resulting in indefinite postponement or serious delay of science programs that were assigned high priority by the National Academy of Sciences decadal studies.**
- In addition to affecting NASA's internal priorities, an ill-defined Moon-Mars initiative of very large scale could harm programs in other science agencies.

Therefore, we make the following three recommendations:

- **NASA should continue to be guided by the recommendations of the National Academy of Sciences (NAS) decadal studies in formulating its science programs.**
- **Before the United States commits to the Moon-Mars proposal, a review of the initiative's science impact should be carried out by the NAS.**
- **Before the United States commits to the Moon-Mars proposal, the likely budgetary impact should estimated by the Government Accountability Office.**

Appendix I

Astronomy and Astrophysics in the New Millennium

 http://books.nap.edu/catalog/9839.html

Prioritized Ground and Space Initiatives & Estimated Federal Costs 2000 to 2010[a]
Total Decade Cost: $4,670 Million

Major Initiatives	$ Millions
Next Generation Space Telescope (NGST)[b]	1,000
Giant Segmented Mirror Telescope (GSMT)[b]	350
Constellation-X Observatory (Con-X)	800
Expanded Very Large Array (EVLA)[b]	140
Large-aperture Synoptic Survey Telescope (LSST)	170
Terrestrial Planet Finder (TPF)[c]	200
Single Aperture Far Infrared (SAFIR) Observatory[c]	100
Subtotal Major Initiatives	**2,760**

Moderate Initiatives	$ Millions
Telescope System Instrumentation Program (TSIP) 50	50
Gamma-ray Large Area Space Telescope (GLAST)[b]	300
Laser Interferometer Space Antenna (LISA)[b]	250
Advanced Solar Telescope (AST)[b]	60
Square Kilometer Array (SKA) Technology Development	22
Solar Dynamics Observatory (SDO)	300
Combined Array for Research in Millimeter-Wave Astronomy (CARMA)[b]	11
Energetic X-ray Imaging Survey Telescope (EXIST)	150
Very Energetic Radiation Imaging Telescope Array System (VERITAS)	35
Advanced Radio Interferometry Between Space and Earth (ARISE)	350
Frequency Agile Solar Radio telescope (FASR)	26
South Pole Submillimeter-wave Telescope (SPST)	50
Subtotal Moderate Initiatives	**1,604**

Small Initiatives	$ Millions
National Virtual Observatory (NVO)	60
Others	246
Subtotal Small Initiatives	**306**

[a]Cost estimates for ground-based capital projects include technology development, funds for operations, new instrumentation and 5-year facility grants; cost estimates for space-based projects exclude technology development; full costs are given for all initiatives except TPF and the SAFIR Observatory.

[b]Cost estimate assumes significant additional funding to be provided by international or private partner. See NAS report for details.
[c]Mission could start at the turn of the decade. The committee attributes $200 million of the $1,700 million total estimated cost of TPF to the current decade and $100 million of the $600 million total estimated cost of the SAFIR Observatory to the current decade.

Appendix II

The Sun to the Earth – and Beyond: A Decadal Research Strategy in Solar and Space Physics (August 2002)

http://www7.nationalacademies.org/ssb/SSB_SSPsurvey.pdf

Priorities: Ranked Within Program Category

Large Program
1 Solar Probe

Moderate Programs
1 Magnetosphere Multiscale
2 Geospace Network
3 Jupiter Polar Mission
4 Multi-spacecraft Heliospheric Mission
5 Geospace Electrodynamic Connections
6 Suborbital Program
7 Magnetospheric Constellation
8 Solar Wind Sentinels
9 Stereo Magnetospheric Imager

Small Programs
1 Frequency Agile Solar Radio Telescope
2 Relocatable Atmospheric Observatory
3 L1 Monitor
4 Solar Orbiter
5 Small Instrument Distributed Ground Network
6 UNEX

Vitality Programs
1 NASA SR&T
2 National Space Weather Program
3 Coupling Complexity Initiative
4 Solar and Space Physics Information System
5 Guest Investigator Program
6 Geospace Theory Program
7 Virtual Sun Initiative

Nearly all of the projects listed are either planned or have been recommended in previous NASA and NSF planning efforts. Program descriptions are contained in the report.

Appendix III

New Frontiers in the Solar System: An Integrated Exploration Strategy (July 2002)

http://www7.nationalacademies.org/ssb/SSB_SSEsurvey.pdf

Solar System Flight Mission (Non-Mars) Priorities: Ranked Within Class

Small Class (<$325 Million)
1 Cassini Extended Mission

Medium Class ($325-650 Million)
1 Kuiper Belt/Pluto
2 South Pole Aitkin Basin Sample Return
3 Jupiter Polar Orbiter with Probes
4 Venus in-situ Explorer
5 Comet Surface Sample Return

Large Class (>$650 Million)
1 Europa Geophysical Explorer

Appendix IV

American Physical Society Panel on Public Affairs (POPA) Task Force on NASA Funding for Astrophysics

Authors

Roger Blandford, Stanford	SSB (Co-Chair Comm. on Astronomy and Astrophysics)
Fiona Harrison, Cal Tech	SScAC
Garth Illingworth, UCSC	SScAC
Margaret Kivelson, UCLA	SSB
Bob Lin, UC Berkeley	Director of Space Sciences Laboratory, UC Berkeley
Michael S. Lubell, CCNY	APS Director of Public Affairs
Chris McKee, UC Berkeley	Co-chair of 2002 NAS Astronomy Decadal Study
Bernard Sadoulet, UC Berkeley	Chair-elect of APS Division of Astrophysics
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Charge to the Task Force

To prepare a brief report summarizing the science opportunities that will be lost or seriously delayed as a consequence of shifting NASA priorities toward Moon-Mars.

To draft a resolution to be considered by the American Physical Society Executive Board in mid-June.

Task Force Procedures and Timeline

After several phone calls and a brief partial meeting, the Task Force authors met in Berkeley on May 8, 2004 and agreed unanimously on a draft resolution and on the organization and basic content of its report. Subsequent drafting of the report was done by email.

The Task Force authors agreed that the report should stress the desirability of making major funding decisions based on the best science, guided by the NAS decadal studies.

The APS Executive Board unanimously approved the draft resolution June 18, 2004, at their retreat at Lake Tahoe.

Joel Primack and Michael Lubell edited the final report in early October 2004.

The APS Executive Board authorized release of the report on November 21, 2004.

Acronyms Used in Appendix IV

AAS	American Astronomical Society
AGU	American Geophysical Union
APS	American Physical Society
BNL	Brookhaven National Laboratory
CCNY	City College of the City University of New York
DAP	Division of Astrophysics
JPL	Jet Propulsion Laboratory
LLNL	Lawrence Livermore National Laboratory
NAS	National Academy of Sciences
POPA	Panel on Public Affairs (APS)
PPC	Physics Policy Committee (APS)
SSB	Space Studies Board (NAS)
SScAC	Space Science Advisory Committee (NASA)
UC	University of California
UCLA	University of California, Los Angeles
UCSC	University of California, Santa Cruz