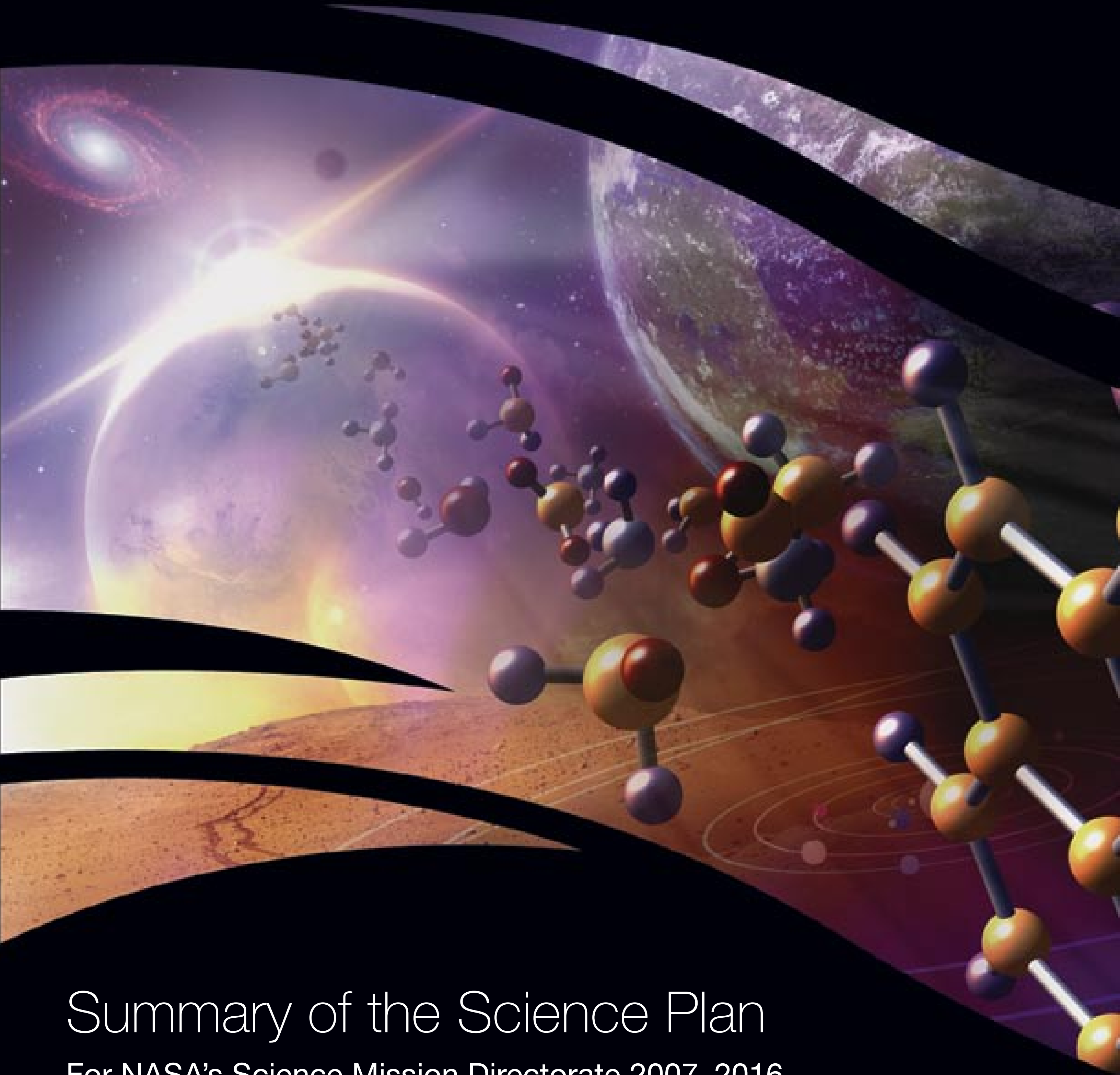
National Aeronautics and Space Administration



Summary of the Science Plan

For NASA's Science Mission Directorate 2007–2016

This Summary of the Science Plan for NASA's Science Mission Directorate emphasizes the identification and prioritization of space missions as that is the focus of the Congressional request for the Plan. The full-length version of the Science Plan articulates the research program in detail, as well as describing the research solicitation, advanced technology, data management, and related activities required to achieve NASA's space and Earth science goals.

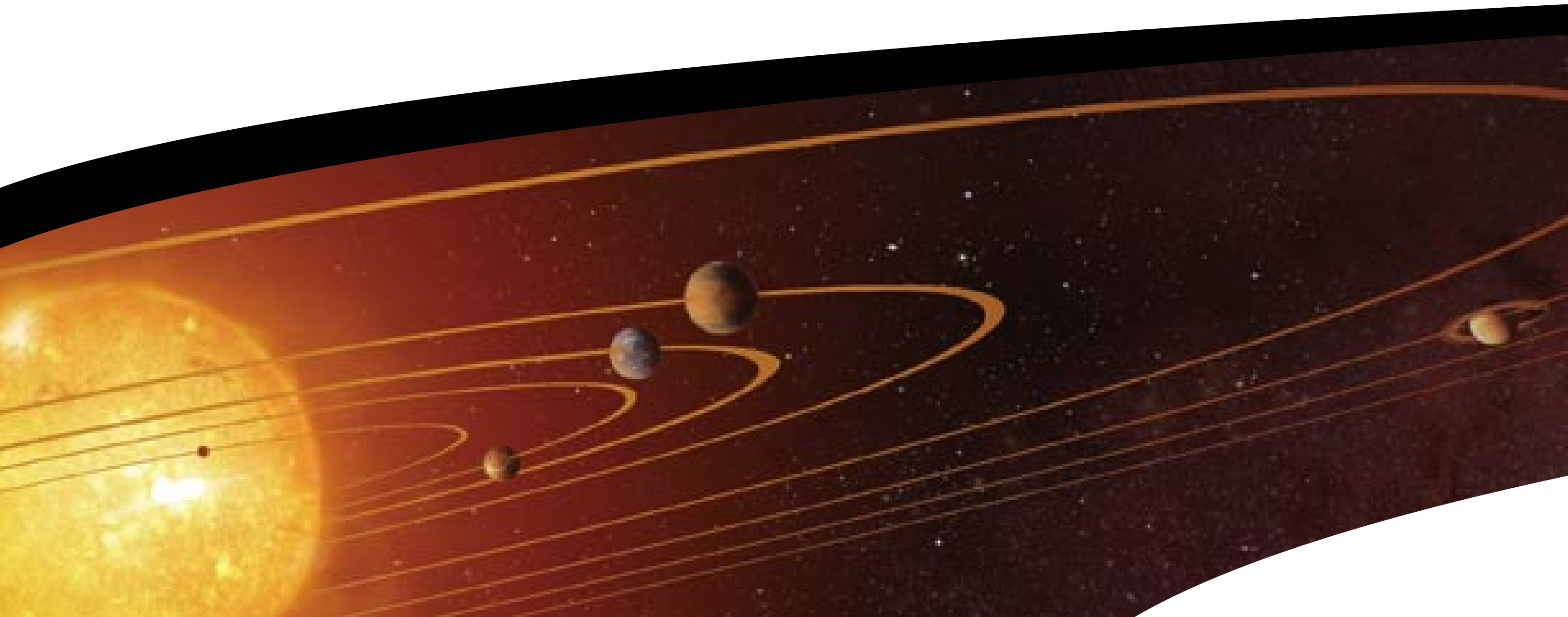
Contents

Preamble:
NASA's Vision for Science

NASA's Science Mission Directorate conducts scientific exploration that is enabled by access to space. We project humankind's vantage point into space with observatories in Earth orbit and deep space, spacecraft visiting the Moon and other planetary bodies, and robotic landers, rovers, and sample return missions. From space, in space, and about space, NASA's science vision encompasses questions as practical as hurricane formation, as enticing as the prospect of lunar resources, and as profound as the origin of the Universe.

From space we can view the Earth as a planet, seeing the interconnectedness of the oceans, atmosphere, continents, ice sheets, and life itself. At NASA we study planet Earth as a dynamic system of diverse components interacting in complex ways—a challenge on a par with any in science. We observe and track global-scale changes, and we study regional changes in their global context. We observe the role that human civilization increasingly plays as a force of change. We trace effect to cause, connect variability and forcing with response, and vastly improve national capabilities to predict climate, weather, and natural hazards. NASA research is an essential part of national and international efforts to employ Earth observations and scientific understanding in service to society.

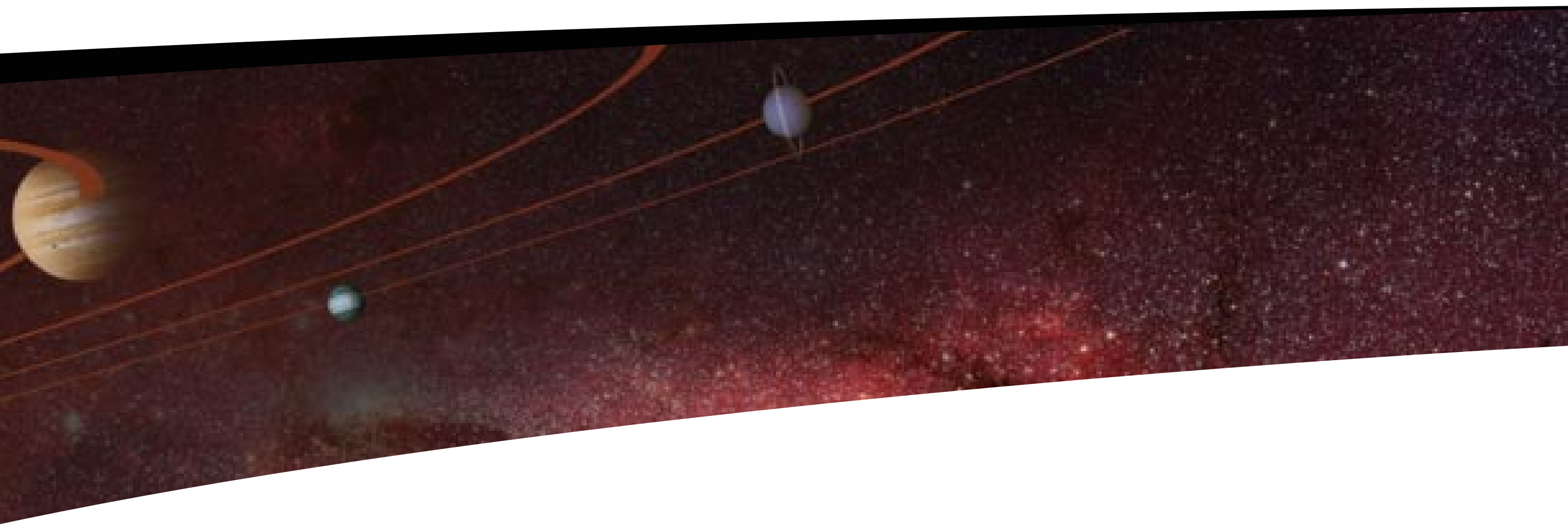
We extend humankind's virtual presence throughout the solar system via robotic visitors to other planets and their moons, to asteroids and comets, and to icy bodies in the outer reaches known as the Kuiper Belt. We are completing our first survey of the solar system with one mission that will fly by Pluto and another that will visit two protoplanets, Ceres and Vesta. We are in the midst of a large-scale investigation of Mars, with one or more robotic missions launching every 26 months when the positions of Mars and Earth are optimal. We are directing our attention to certain moons of the giant planets where we see intriguing signs of surface dynamism and of water within, knowing that on Earth, where there is water and energy there is also life. We are progressing from observers to rovers to sample return missions, each step bringing us closer to our principal goals: to understand our origins, to learn whether life does or did exist elsewhere in the solar system, and to prepare for human expeditions to the Moon, Mars and beyond.



Our solar system is governed by the Sun, a main-sequence star midway through its stellar life. The Sun's influence is wielded through gravity, radiation, the solar wind, and magnetic fields as they interact with the masses, fields and atmospheres of planetary bodies. Through the eyes of multiple spacecraft, we see the solar system as a "heliosphere," a single, interconnected system moving through interstellar space. On Earth, this interaction with a star is experienced through space weather's modifications to the ozone layer, through climate change, and through effects on radio and radar transmissions, electrical power grids, and spacecraft electronics. We seek to understand how and why the Sun varies, how planetary systems respond, and how human activities are affected. As we reach beyond the confines of Earth, this science will enable the space weather predictions necessary to safeguard the outward journeys of human and robotic explorers.

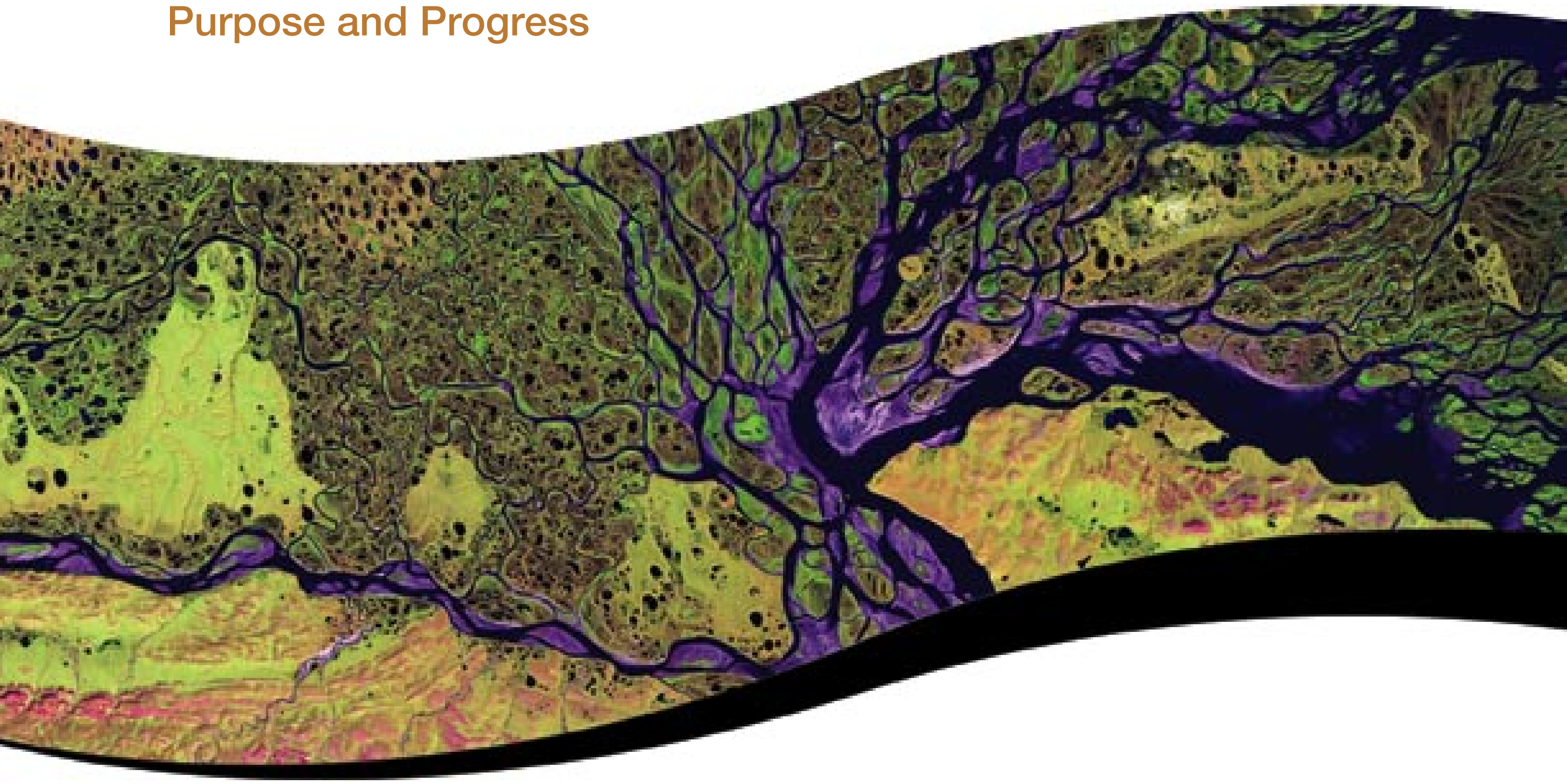
The greatest minds of the last century perceived wondrous things about the universe itself—the Big Bang and black holes, dark matter and dark energy, and the nature of space and time. Their theories challenge NASA to use its presence in space to put them to the test. NASA's Great Observatories are taking us to the limits of the theories proposed by Einstein, Hubble, Spitzer and Chandrasekhar. We are now poised to move beyond. Having measured the age of the universe, we now seek to explore its ultimate extremes—its stupendous birth, the edges of space and time near black holes, and the darkest space between galaxies. Having exploited nearly the full spectrum of light, we will explore using gravitational waves in space-time. We seek to understand the relationship between the smallest of subatomic particles and the vast expanse of the cosmos. Having discovered more than a hundred giant planets around other stars, we now seek to find Earth-like planets in other solar systems.

This is NASA's science vision: the scientific exploration of our planet, other planets and planetary bodies, our star system in its entirety, and the universe beyond. In so doing, we lay the intellectual foundation for the robotic and human expeditions of the future. What follows is NASA's plan for turning this vision into scientific discovery.



Chapter 1

Purpose and Progress



Science in the NASA Strategic Plan

The 2006 NASA Strategic Plan articulates succinctly the three-part Mission of the Agency:

To pioneer the future in space exploration, scientific discovery, and aeronautics research.

NASA has pursued these three areas throughout its history. Fresh impetus is provided by the President's Vision for Space Exploration announced in January 2004, which includes robotic exploration of planetary bodies in the solar system, advanced telescope searches for Earth-like planets around other stars, and studying the origin, structure, evolution, and destiny of the universe, in addition to extending human presence to the Moon, Mars, and beyond. Other Presidential initiatives guide NASA's study of Earth from space and build on NASA's rich heritage of aeronautics and space science research.

Goal 3 in the 2006 NASA Strategic Plan is to "*develop a balanced overall program of science, exploration, and aeronautics consistent with the redirection of the human spaceflight program to focus on exploration.*" In the arena of science, NASA's focus is in disciplines where access to space enables new scientific endeavors or enhances existing ones. Responsibility for defining, planning and overseeing NASA's space and Earth science programs is assigned by the NASA Administrator to the Science Mission Directorate (SMD). The SMD organizes its work into four broad scientific pursuits, each managed by a Division within the Directorate, implementing the four science subgoals in the NASA Strategic Plan:

- **Earth Science:** Study planet Earth from space to advance scientific understanding and meet societal needs
- **Planetary Science:** Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space
- **Heliophysics:** Understand the Sun and its effects on Earth and the solar system
- **Astrophysics:** Discover the origin, structure, evolution, and destiny of the universe, and search for Earth-like planets.

Appendix 1 lists the long-term outcomes associated with each of these areas. Collectively these goal and outcome statements comprise an overview of the science portfolio managed by SMD. Research on bioastronautics and other microgravity sciences is managed by the Exploration Systems Mission Directorate and is not addressed in this Plan.

Fundamental research on profound science questions using space-based observatories and related assets is the hallmark of all four areas of NASA's SMD. Astrophysics pursues answers to questions about the universe that are as old as humanity. Heliophysics and Planetary Science both include elements important to the success of NASA's human exploration endeavors, and the former has practical utility on Earth. Earth Science is inherently beneficial to society in practical ways and requires that means be created to transfer its results for use in decision support and policy making. Research in all four science areas is essential to the fulfillment of national priorities embodied in Presidential initiatives and Congressional legislation, and scientific priorities identified by the Nation's scientific communities.

The scientific scope of NASA's space and Earth science program is unchanged since the publication of the 2003 NASA Strategic Plan, but much has changed in the intervening years. The external environment has changed in three significant ways. First, NASA has received new direction and advice. These are summarized in the balance of this chapter. Second, projected resource levels have changed, as described in Chapter 2. These have been exacerbated by internal challenges in managing the costs of key projects. Third, a fundamental tenet of strategy in Earth Science—the migration of mature measurements to operational systems—requires reassessment due to changes in the baseline for the National Polar-orbiting Operational Environmental Satellite System (NPOESS). But the scientific challenges before us are largely the same, providing a stable framework for planning.

NASA Science in the Vision for Space Exploration

Announced by the President in 2004 and authorized by the Congress in 2005, the fundamental goal of the Vision for Space Exploration is "to advance U.S. scientific, security, and economic interests through a robust space exploration program." For the past three decades, space exploration beyond low Earth orbit has been conducted exclusively by scientific robotic missions. Now NASA is preparing for human expeditions to the Moon, Mars, and beyond, leading to a new era of joint human and robotic exploration.

Science both enables and is enabled by human exploration. For this reason the President's Commission on Implementation of U.S. Space Exploration sketched out a broad scientific program of research to advance understanding of the origin, evolution, and fate of the Earth, the solar system, and the universe beyond. While organized along spatial rather than temporal lines, the scope of the SMD program mirrors that outlined by the President's Commission.

NASA has assigned responsibilities and authorities to its Mission Directorates for achieving these objectives. For some, such as robotic exploration of Mars and advanced telescope searches for Earth-like planets, SMD has sole responsibility. For the Moon, which is the next target for human exploration of space, SMD plays a program scientist role, providing scientific expertise needed to enable successful human exploration and exploiting the opportunities afforded by human explorers and exploration systems to conduct research. A detailed description of SMD's role in fulfilling the return to the Moon portion of the Vision for Space Exploration and the key activities of the next few years in this area are given in Chapter 8.

NASA Science in National Strategies for Planet Earth

In June 2001, the President announced the Climate Change Research Initiative to augment the long-standing U.S. Global Change Research Program and form the U.S. Climate Change Science Program. NASA is a leader in this interagency effort, along with the National Oceanic and Atmospheric Administration (NOAA) and others, and provides global environmental observations and scientific research, modeling, assessment, and applications research. NASA also provides input on monitoring for the companion Climate Change Technology Program led by the Department of Energy (DOE). NASA, NOAA, the U.S. Geological Survey (USGS), the National Science Foundation (NSF), and the Office of Science and Technology Policy (OSTP) provide leadership for the interagency effort to develop the U.S. Integrated Earth Observation System, America's contribution to the Global Earth Observation System of Systems. Finally, NASA has a key role in the U.S. Oceans Action Plan (the President's response to the Congressionally chartered U.S. Oceans Commission Report) and the emerging Ocean Research Priorities Plan in partnership with NOAA, NSF, and the U.S. Navy (USN).

NASA Science in the National Strategy for Physics and Astronomy

In 2004, the President's Science Advisor adopted the National Science and Technology Council's report, *The Physics of the Universe: A Strategic Plan for Federal Research at the Intersection of Physics and Astronomy*. This document, inspired by the NRC's report *Connecting Quarks with the Cosmos*, identifies investments and actions NASA, NSF, and DOE should take to advance scientific knowledge in cosmology, astronomy, and fundamental physics in light of recent discoveries in these fields. These discoveries suggest "the basic properties of the universe as a whole may be intimately related to the science of the very smallest known things." As the Nation's provider of civil space-based observatories, NASA has a prominent role in implementing this plan.

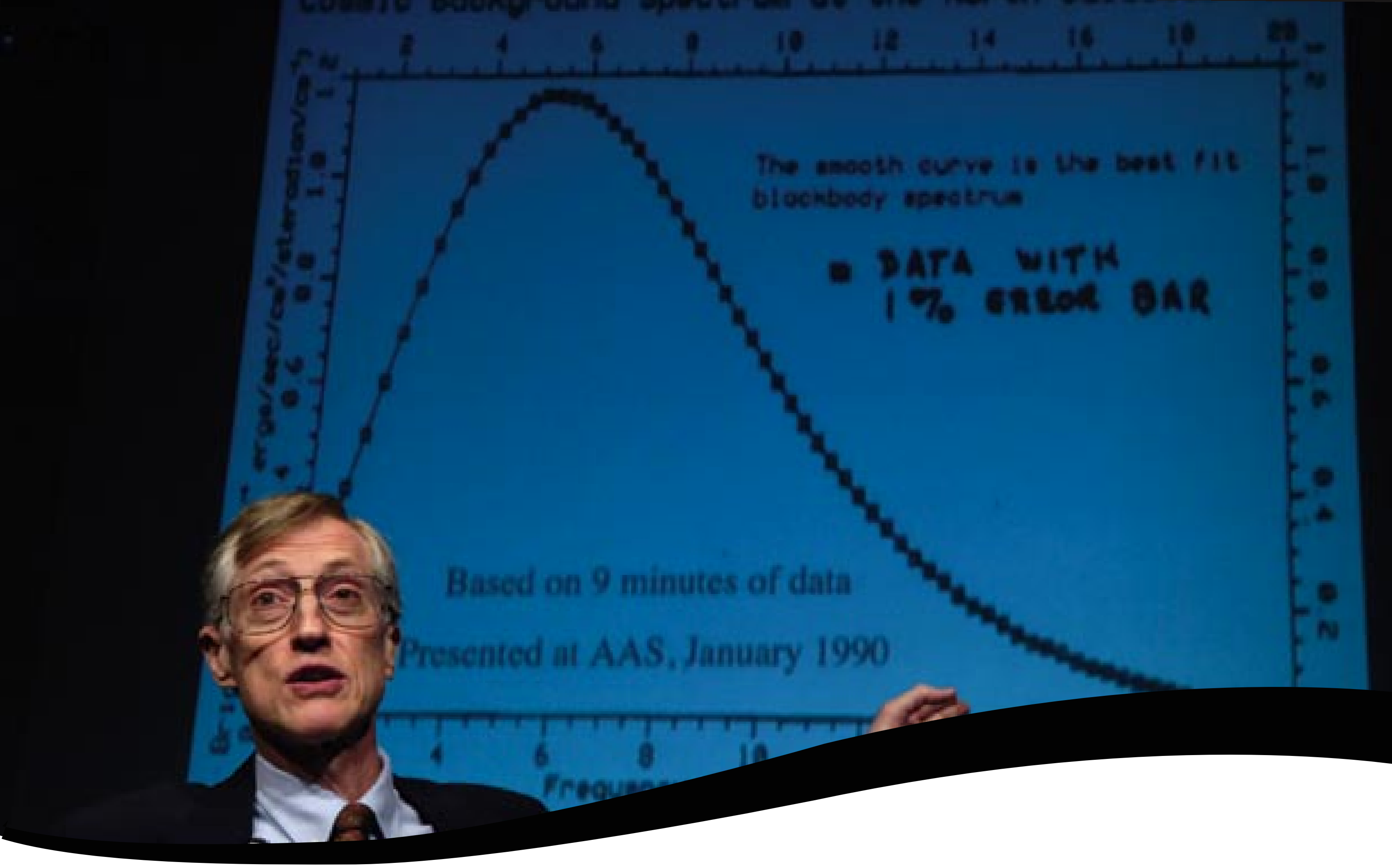
Implementing Science Community Priorities

In planning its science programs, NASA works to implement the priorities defined by the National Research Council (NRC) in its decadal surveys and other reports. These reports represent the broad consensus of the Nation's scientific communities in their respective areas. NASA also engages the broad science community in development of community roadmaps for each of SMD's four science areas that define pathways for implementing NRC-defined priorities. The most recent roadmaps were published in 2006 (see Appendix 3), and were initiated by science committees and subcommittees of the NASA Advisory Council (NAC) as it existed in 2004. These roadmaps provided the starting points for development of the science chapters of this Plan. In addition, NASA receives science advice from the Astronomy and Astrophysics Advisory Committee chartered by the Congress to convey community input in these areas to NSF, NASA, and DOE.

Implementing a Balanced Science Program

The NASA Authorization Act for 2005 calls for a balanced set of programs to carry out the Nation's space exploration, science, and aeronautics research goals. The Act further calls for NASA to submit a plan to guide the science programs of NASA through 2016. This document is intended to answer that call. It also responds to the NASA Strategic Plan and the science "roadmaps" developed by the science community in each of the four science areas. As evidenced by the NRC's report, *An Assessment of Balance in NASA's Science Program* (NRC, 2006), a proper balance across all the relevant dimensions is difficult to achieve. That is true in part because it is difficult to define. At the Agency level, one defining consideration is consistency "with the redirection of the human spaceflight program to focus on exploration." Over the next several years, the Agency is working in parallel to complete the International Space Station, fly the associated Space Shuttle missions and retire that transportation system, and begin development of the new transportation system needed to implement the Vision for Space Exploration. During this same period, SMD is planning to service the Hubble Space Telescope, develop the James Webb Space Telescope, continue robotic exploration of Mars and beyond, and attempt to implement a new NRC decadal survey for Earth science in the context of a substantial downscaling of the climate monitoring capabilities of the converged civilian/military environmental satellite system. For all these reasons and more, a balanced program in the near term may look different from a balanced program over the longer term. The common thread is fulfillment of national objectives within the available resources.

The next chapter provides a summary of science questions and prioritized missions for all four areas. The commonalities and distinctions of the four areas shape SMD's modes of operation and partnerships. Common elements of strategy are described in Chapter 3. The unique objectives, research, and missions of each of the four science areas follow in Chapters 4 through 7. Each of these chapters has its own character as befits the nature of science in each area and as maintains accord with the science community roadmaps from which they were derived. The practicalities of the interaction of science and exploration are described in Chapter 8. Chapter 9 provides a brief, concluding glimpse of the great expanse of scientific achievement to be made possible by NASA and its partners.



NASA Scientist Wins 2006 Nobel Prize in Physics

NASA Scientist, Dr. John C. Mather shows some of the earliest data from the NASA Cosmic Background Explorer (COBE) Satellite during a press conference held at NASA Headquarters in Washington, DC. Dr. Mather was a co-recipient of the 2006 Nobel Prize for Physics.
Photo Credit: NASA/Bill Ingalls

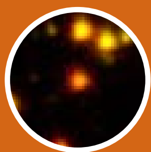
"The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2006 jointly to **John C. Mather** NASA Goddard Space Flight Center, Greenbelt, MD, USA, and **George F. Smoot** University of California, Berkeley, CA, USA '*for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation*.'"

"This year the Physics Prize is awarded for work that looks back into the infancy of the Universe and attempts to gain some understanding of the origin of galaxies and stars. It is based on measurements made with the help of the COBE satellite launched by NASA in 1989...The success of COBE was the outcome of prodigious team work involving more than 1,000 researchers, engineers and other participants. **John Mather** coordinated the entire process and also had primary responsibility for the experiment that revealed the blackbody form of the microwave background radiation measured by COBE. **George Smoot** had main responsibility for measuring the small variations in the temperature of the radiation."

From the Nobel Foundation website:
http://nobelprize.org/nobel_prizes/physics/laureates/2006/press.html

Recent SMD Highlights

The Spitzer telescope detected first light from an extrasolar world, picking up the infrared glow from two Jupiter-sized planets.



The Spitzer telescope provided the first observational evidence of dark matter, seen in the distribution of mass in the aftermath of the collision of two galaxies.

Using the Hubble Space Telescope, researchers discovered that dark energy was present in the early universe, which appears to agree with Einstein's prediction that a repulsive form of gravity emanates from empty space.

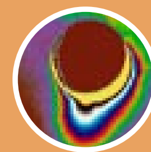
NASA solved a 35-year-old mystery regarding gamma-ray bursts, through coordination of observations from several ground-based telescopes and NASA's Swift and other satellites. The flashes are brighter than a billion suns, yet last only a few milliseconds—too fast for earlier instruments to catch.

Voyager 1 reached the edge of the solar system, entering the heliosheath—the vast, turbulent expanse where the Sun's influence ends and the solar wind crashes into the thin gas between stars. It is the human artifact furthest from the Earth.

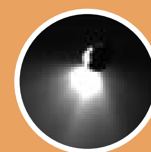
The Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) and Cluster satellites showed that a sustained bright-glowing spot in the auroral region was a signature of magnetic reconnection in the Earth's magnetosphere. The stability of the spot is the first observational evidence that magnetic reconnection could be a steady process.

The Solar and Heliospheric Observatory (SOHO) spacecraft has revealed a process by which the direction of the Sun's magnetic field may reverse every 11 years. The cumulative effect of more than a thousand huge eruptions, called Coronal Mass Ejections, flips the magnetic field of the entire Heliosphere.

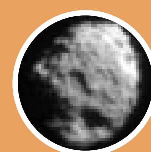
At Saturn, Cassini found geyser-like water vapor spurts on Enceladus and the European Space Agency's (ESA's) Huygens probe found that Titan's surface has been shaped by flowing liquid and blowing winds, much like the Earth's.



The Deep Impact spacecraft rendezvoused with comet Tempel 1, and its impactor collided with the target's nucleus, giving researchers the best-ever data and images of a comet.



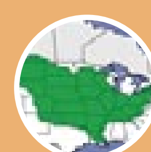
The Stardust mission successfully returned to Earth samples from comet Wild 2. The year before, the Genesis mission sampled the solar wind, collecting charged particles implanted in high-purity materials. These represent the first return of samples from space since the Apollo program.



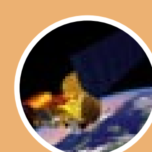
The Mars Exploration Rovers Spirit and Opportunity found evidence that water once flowed across the Martian surface. Both have completed a full Martian year of exploration and discovery. Opportunity has reached Victoria Crater.

ICESat has confirmed accelerated movement of glaciers in the Antarctic Peninsula, following the breakup of the floating ice shelf into which the glaciers flowed. ICESat also confirmed that part of the West Antarctic ice sheet has been increasingly getting thinner.

The twin Gravity Recovery And Climate Experiment (GRACE) satellites demonstrated the ability to measure variability in the water quantity continental underground reservoirs, where most of Earth's liquid fr water is stored.

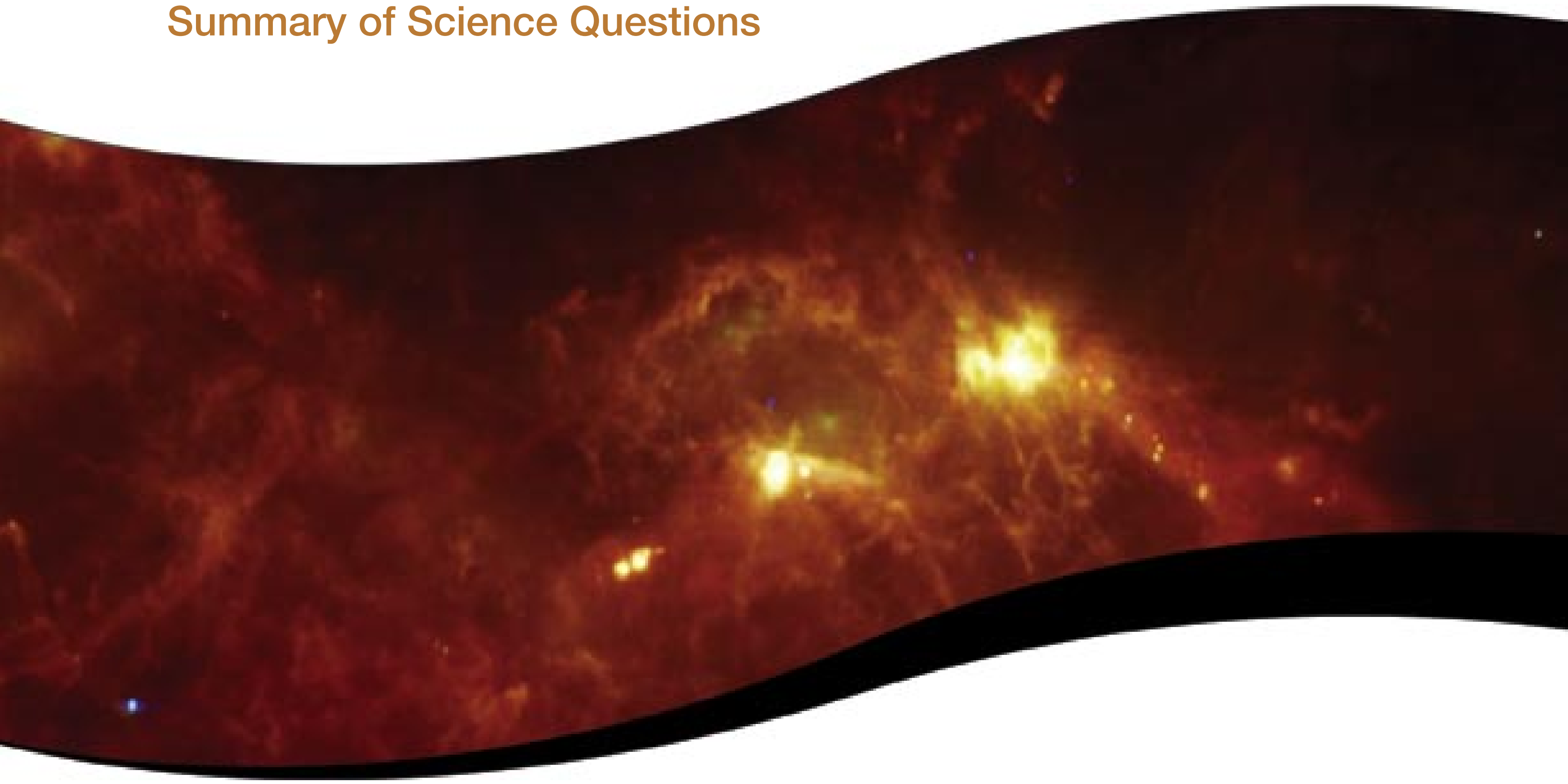


Researchers at NASA and the U.S. Environmental Protection Agency (EPA) developed a data fusion of observations from the Terra and Aqua satellites with the EPA *in situ* monitoring network to improve the air-quality forecasts issued throughout the United States.



Chapter 2

Summary of Science Questions



NASA's Science Mission Directorate works continually with the science community to identify the highest science priorities and the best strategies and missions to address those priorities. These priorities are drawn from the decadal surveys and other reports of the NRC. Each of SMD's four science divisions sponsors a triennial strategic roadmapping effort, generally using committees comprised largely of members of the external science community and led by a senior leader in that community, to lay out NRC decadal survey priorities into a decadal (and longer) roadmap of missions and research programs. These committees operate under the auspices of the NASA Advisory Council (NAC) and its subordinate bodies. The products of these efforts are the building blocks of NASA strategy documents, including this Science Plan. The NRC and the NAC then review the strategy documents to assure NASA has adequately reflected community priorities given budgetary, programmatic, and related constraints.

Working with the broader scientific community and in response to national initiatives and NRC decadal surveys, NASA has defined a set of space and Earth science questions that can be best addressed using the Agency's unique capabilities. These are listed in Table 2.1. The science questions in this table originated in the community roadmaps in each science area, which in turn are sourced in NRC decadal surveys. The research objectives in this table are a form of the long-term outcomes set forth in the 2006 NASA Strategic Plan.

Answering these science questions requires comprehensive research programs be conducted by NASA and its many partners. Components of these programs include scientific research and analysis, space missions, suborbital missions, field campaigns, data management, computational modeling, and advanced technology development. Because of their centrality to NASA's role in science and to the request from the Congress for this Science Plan, space missions and mission priorities are addressed in the balance of this chapter.

Table 2.1

Science Questions and Research Objective		
Science Area	Science Questions	Research Objectives [multiyear Outcomes, 2006 NASA Strategic Plan—Appendix 1]
Earth Science: Study planet Earth from space to advance scientific understanding and meet societal needs.	• How is the global Earth system changing? • What are the primary causes of change in the Earth system? • How does the Earth system respond to natural and human-induced changes? • What are the consequences for human civilization? • How will the Earth system change in the future?	1. Understand and improve predictive capability for changes in the ozone layer, climate forcing, and air quality associated with changes in atmospheric composition 2. Enable improved predictive capability for weather and extreme weather events 3. Quantify global land cover change and terrestrial and marine productivity and improve carbon cycle and ecosystem models 4. Quantify the key reservoirs and fluxes in the global water cycle and improve models of water cycle change and fresh water availability 5. Understand the role of oceans, atmosphere, and ice in the climate system and improve predictive capability for its future evolution 6. Characterize and understand Earth surface changes and variability of Earth's gravitational and magnetic fields 7. Expand and accelerate the realization of societal benefits from Earth system science
Planetary Science: Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space.	• How did the Sun's family of planets and minor bodies originate? • How did the solar system evolve to its current diverse state? • What are the characteristics of the solar system that led to the origin of life? • How did life begin and evolve on Earth and has it evolved elsewhere in the solar system? • What are the hazards and resources in the solar system environment that will affect the extension of human presence in space?	1. Learn how the Sun's family of planets and minor bodies originated and evolved 2. Understand the processes that determine the history and future of habitability in the solar system, including the origin and evolution of Earth's biosphere and the characteristics and extent of prebiotic chemistry on Mars and other worlds 3. Identify and investigate past or present habitable environments on Mars and other worlds, and determine if there is or ever has been life elsewhere in the solar system 4. Explore the space environment to discover potential hazards to humans and to search for resources that would enable human presence
Heliophysics: Understand the Sun and its effects on Earth and the solar system.	• How and why does the Sun vary? • How do the Earth and planetary systems respond? • What are the impacts on humanity?	1. Understand the fundamental physical processes of the space environment from the Sun to Earth, to other planets, and beyond to the interstellar medium 2. Understand how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields 3. Develop the capability to predict the extreme and dynamic conditions in space in order to maximize the safety and productivity of human and robotic explorers
Astrophysics: Discover the origin, structure, evolution, and destiny of the universe, and search for Earth-like planets.	• What are the origin, evolution, and fate of the universe? • How do planets, stars, galaxies, and cosmic structure come into being? • When and how did the elements of life and the universe arise? • Is there life elsewhere?	1. Understand the origin and destiny of the universe, phenomena near black holes, and the nature of gravity 2. Understand how the first stars and galaxies formed, and how they changed over time into the objects recognized in the present universe 3. Understand how individual stars form and how those processes ultimately affect the formation of planetary systems 4. Create a census of extrasolar planets and measuring their properties

Chapter 3

Science Planning and Implementation

3.1 SMD Principles

- **Investment choices first consider scientific merit.** SMD will use open competition and scientific peer review as the primary means for establishing merit for selection of research and flight programs.

- **Active participation by the research community outside NASA is critical to success.** SMD will engage the external science community in establishing science priorities, preparation and review of plans to implement those priorities, analysis of requirements trade studies, conduct of research, and evaluation of program performance.

- **The pace of scientific discovery is fueled by prompt, broad, and easy access to research data.** SMD will ensure vigorous and timely interpretation of mission data by requiring that data acquired be made publicly available as soon as possible after scientific validation.

- **Partnerships are essential to achieving NASA's science objectives.** Other nations and agencies are engaged in space and Earth science. NASA and SMD will partner with other national and international organizations to leverage NASA's investment and achieve national goals.

- **Partnerships are essential to realizing relevant societal benefits from NASA's research.** Beyond increasing scientific understanding, many NASA programs produce results with practical societal benefits. NASA and SMD will forge partnerships with other U.S. Federal agencies to facilitate their use of NASA research data and science results in their operational products and services.

- **The NASA mandate includes broad public communication.** SMD will convey the results and excitement of our programs through formal education and public engagement. SMD will seek opportunities to promote student interest in science, technology, engineering, and mathematics disciplines and careers.

- **Sustained progress in advancing U.S. space and Earth science interests requires investments across a broad range of activities.**
  - The range of activities include basic research to understand the scientific challenges, technology development to enable new capabilities, space mission development to acquire the vital new data, and supporting science and infrastructure systems to ensure delivery of high value scientific results to the science community and the general public.
- **The nation looks to NASA for innovation in space.** SMD will accelerate the pace of scientific discovery through advanced technologies that will enable and enhance new space missions; shorten the mission development cycle; and speed the use of observation, model, and research results in the planning of future and the operation of current missions and systems.

3.1 Role of Scientific Research and Analysis

R&A programs develop the pioneering theories, techniques, and technologies that result in missions. These programs enable exploration of innovative concepts in sufficient depth to determine whether they are ready for incorporation in space missions. The results of R&A also inform and guide the scientific trades and other choices that are made during the development of missions. Sponsored researchers guide the operation of robotic missions, selecting targets for observation or sampling. R&A programs then capitalize on the new information obtained by the missions to advance understanding across the breadth of NASA science. It is R&A that turns the data returned from NASA missions into knowledge; it is this knowledge that addresses NASA's strategic objectives. NASA cannot accomplish its mission and the objectives of the Vision for Space Exploration without scientific R&A.

NASA-sponsored scientific R&A comprises an ever-evolving suite of individual PI-proposed investigations that cover the complete range of science disciplines and techniques essential to achieve NASA's science and exploration objectives. The diversity of the program is one of its critical components. NASA's R&A activities cover all aspects of basic and applied supporting research and technology in space and Earth sciences, including, but not limited to:

- theory, modeling, and analysis of mission science data;
- aircraft, stratospheric balloon, and suborbital rocket investigations;
- experiment techniques suitable for future space missions;
- concepts for future space missions;
- advanced technologies relevant to future space missions;
- techniques for and the laboratory analysis of extraterrestrial samples returned by spacecraft;
- determination of atomic and composition parameters needed to analyze space data as well as returned samples from the Earth or space;
- Earth surface-based observations and field campaigns that support science missions;
- interdisciplinary research to use findings from missions to answer science questions;
- integrated Earth system models;
- systems engineering approaches for applying science research data to societal needs (especially in Earth science and heliophysics); and,
- applied information systems research applicable to NASA objectives and data.

Once a NASA science mission launches and begins returning data, data analysis programs sponsor the analysis of scientific data returned by the mission with the goal of maximizing the scientific return from NASA's investment in spacecraft and other data-collection sources. The data analysis program is fundamental to achieving NASA's science objectives because it funds data analysis during and after a spacecraft's lifespan. NASA also funds data archiving and distribution services and partners with other Federal agencies to sustain these over the long term. Complementary investigations expand data analysis opportunites. For instance, laboratory measurements, suborbital observing campaigns, and ground-based field campaigns during and after missions greatly enhance the quality of the information that can be recovered from spacecraft data. Finally, they enable further exploration of unexpected results.

Open data policies and R&A funding enable research on space mission and related data by a broad range of researchers who publish their results in the open scientific literature. For those scientific investigations, such as weather and climate research and solar flare observation, that have practical societal benefits, scientific assessments and applications benchmarking assure their results are conveyed to agencies that can use them to improve the essential services they provide to the Nation. Results of NASA-sponsored research in areas such as the space environment, planetary atmospheres, and lunar surface composition become the scientific basis for decisions on human exploration systems and activities. As is the nature of science, answers to today's questions lead to new questions and goals for the future.

Achieving NASA's objectives requires a strong scientific and technical community to envision, develop, and deploy space missions and to apply results from these missions for the benefit of society. Such a community currently exists within the United States at universities, government facilities, and industrial laboratories. This robust U.S. research community is essential to the successful formulation, implementation, and exploitation of NASA missions.

Determining the optimal mix of investment among R&A programs, large and small missions, data management, and related activities is a challenge. Using advice from the NRC and the NAC, NASA makes that determination to best achieve its goals and objectives within the overall resource levels provided by the President and the Congress. As noted earlier, projected outyear funds are less than anticipated a year ago, and, as a result, R&A funds for data analysis and future instrument concepts are less than projected a year ago. As we move forward, NASA will work to assure an effective mix of investments across all the activities required to achieve its science goals.

3.3 Setting Priorities

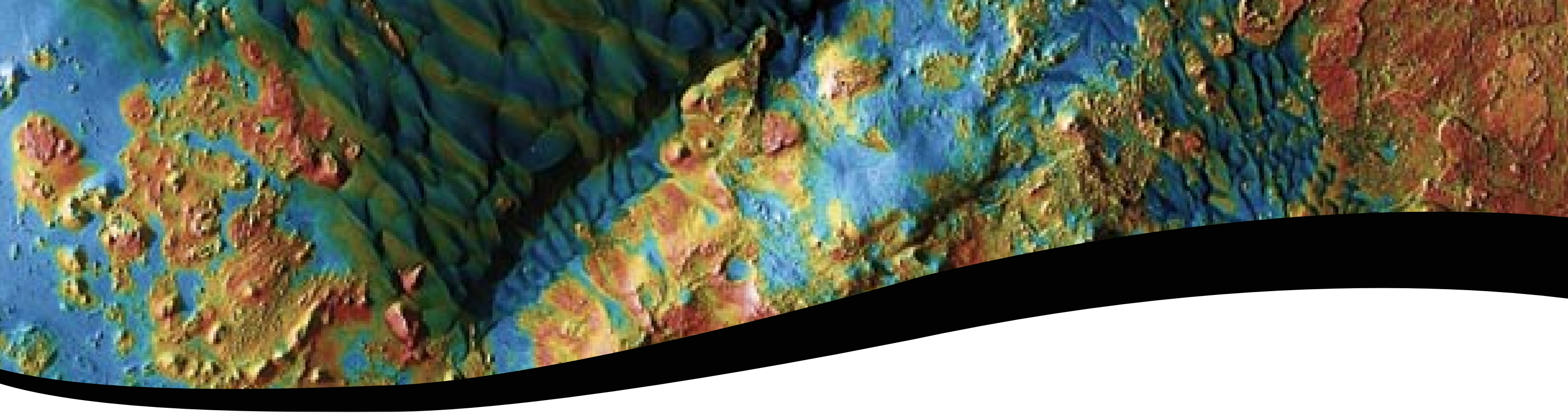
NASA's approach to setting the balance of investment among science areas is based on the following considerations:

- A commitment is made to **reasonable progress on the long-term outcomes associated with each of the four SMD-assigned science objectives in the NASA Strategic Plan** shown in Appendix 1;
- **Long-term outcomes are science based, not mission based; thus suborbital and research and analysis (R&A) programs are part of the discussion**—it is not simply a matter of weighing a mission in one area against a mission in another;
- Progress is assessed against community roadmaps laid out for each science area;
- The pace of progress can be influenced by ties to other NASA and Federal programs, e.g., human exploration timelines, in the case of the Mars Exploration Program, and the U.S. Climate Change Science Program and NPOESS in the case of Earth science;
- Some science objectives can be accomplished using a mix of small, medium and large missions; others require large missions which are more difficult to initiate.

NASA begins in each science area with **the priorities defined in decadal surveys of the NRC**, then generally sponsors science **community-led teams to develop roadmaps to plan implementation** of survey research and mission priorities. The first Earth Science decadal survey is currently in progress; thus, future missions in Earth science are not prioritized. NASA will address Earth Science future mission prioritization once the decadal survey is available.

The tables in chapters 7-4 provide lists of missions through 2016, prioritized for each major science area. The table includes all space and Earth science missions that NASA will initiate, design, develop, launch, or begin to operate from January 2007 through December 2016. The rationale is detailed in this section, and supporting information is presented in Chapters 4-7 on Earth Science, Planetary Science, Heliophysics, and Astrophysics, respectively. Currently operating missions are not included. Operating missions that have exceeded their prime mission lifetime are prioritized in periodic senior review processes led by members of the science community.

Priority has been assigned based on a combination of scientific and programmatic factors. Other things being equal, missions closer to launch are given higher priority for funding than missions further from launch. Other factors considered in the prioritization are technology readiness, mission science interdependencies, partnership opportunities, executive and legislative branch mandates, and programmatic considerations. Thus, assignment of high priority to a mission does not always mean it is developed for launch first; rather, it will be developed for launch as soon as it can be done well, implemented commensurate with the community's desire for a balanced program of small, medium, and large missions, and scheduled in accord with the phasing of available funding. The rationale for the priority order and the endorsement history of each mission are summarized in the



table, with overarching considerations for each science area in the text preceding each table.

The tables in chapters 4-7 are largely comprised of two types of missions: strategic and Principal Investigator-led (PI-led). Strategic missions are the backbone of the science roadmaps in each area and are usually large and multi-purpose in scope. Strategic missions are generally assigned to a NASA Center to implement, with science instruments and many platform components selected in open competition. Competed missions are employed to meet focused science objectives via innovative mission proposals. Competed missions are generally solicited as complete missions via open Announcements of Opportunity, and each is led by a PI. Because the decadal surveys tend to group missions by size category, one significant challenge is to integrate small, medium, and large missions into a single list for each science area, creating a balanced portfolio that includes all three types of missions as well as suborbital and R&A programs.

The largest factors driving the variance between NRC decadal survey priorities and final implementation priorities are pecuniary. Within NASA, cost increases on missions in development limit the pace at which new and smaller missions can be initiated. Externally, outyear budget horizons are lower today than at the time NRC decadal survey priorities were set. Nevertheless, NRC decadal survey priorities remain the principal determinant of the priority order of space science missions in the tables.

Overall, the mission set described in the tables are consistent with the budget projections through 2011 provided in the President's Fiscal Year 2007 request (1 percent growth through 2011) and inflationary growth (2.4 percent assumed) for 2012–2016. The NASA Authorization Act of 2005 authorized higher levels in FY2007 and FY2008, but final appropriations are not yet available. The outyear budget horizon is lower in the FY07 budget request than projected in prior years in this decade, making the task of prioritization both more important and more challenging.

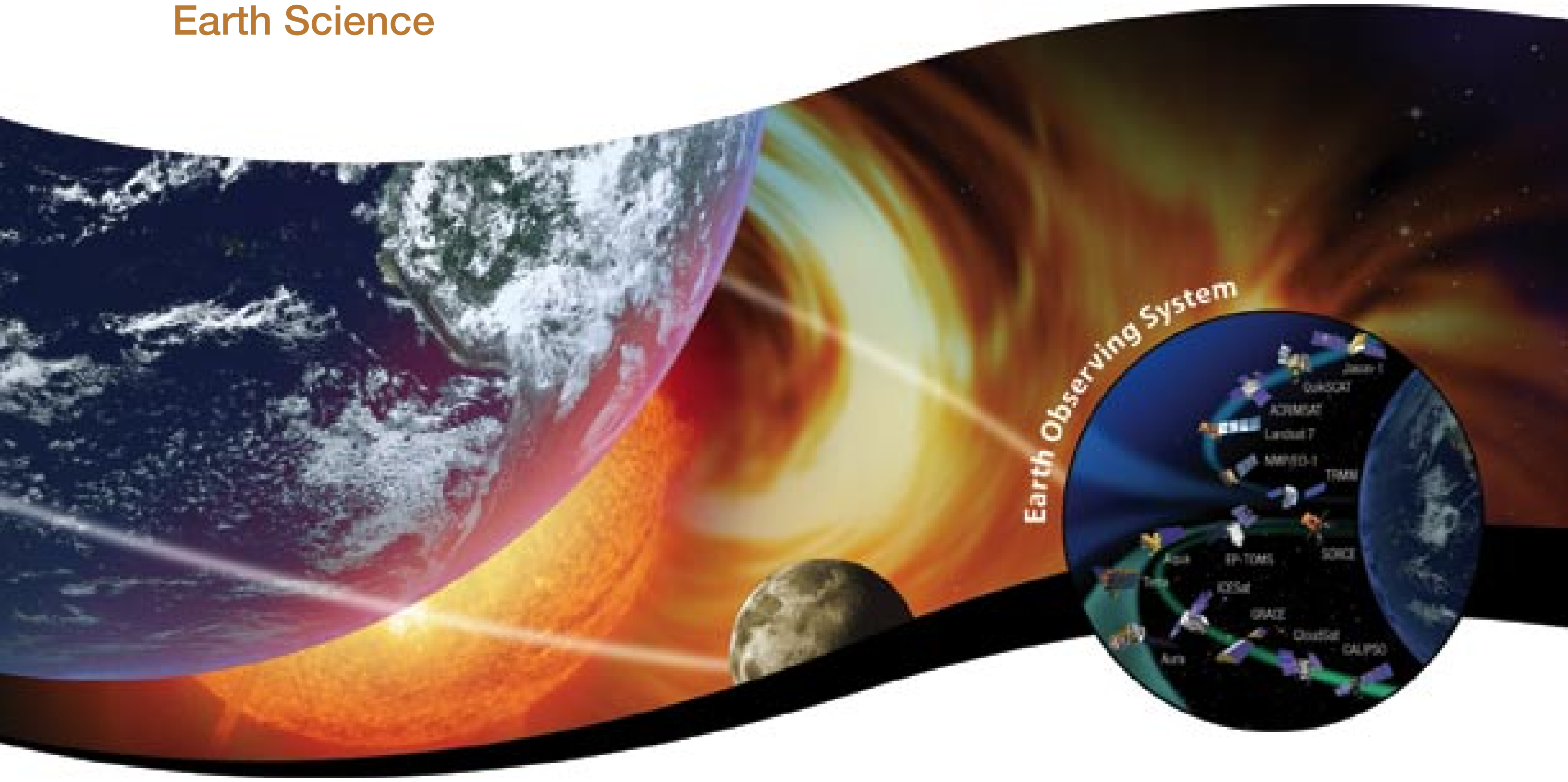
The cost classifications of some missions ("large", "moderate", etc.) are those given in the endorsing document, and do not necessarily correspond to their current costs. Projected launch dates are shown in parentheses. The tables of mission priorities will need to be reconsidered with the release of new decadal surveys and other NRC reports and science task force reports, and with the selection of competed missions and other programmatic changes. They will be updated in each subsequent edition of this Plan, nominally every three years.

The James Webb Space Telescope

Over 1000 people in more than 17 countries are developing the James Webb Space Telescope. Shown here are team members in front of the JWST full-scale model at the Goddard Space Flight Center in Greenbelt, Maryland.

Chapter 4

Earth Science



Strategic Goal:

Study Earth from space to advance scientific understanding and meet societal needs.

NASA's Earth Science Program is dedicated to advancing Earth remote sensing and pioneering the scientific use of global satellite measurements to improve human understanding of our home planet in order to inform economic and policy decisions and improve operational services of benefit to the Nation. The program is responsive to several Congressional mandates and Presidential initiatives.

The Earth is the only known harbor for highly diversified life in the universe. In contrast to Mars and Venus, Earth's atmosphere, vast quantities of surface liquid water, and internally generated magnetic field maintain an environment conducive to life and human civilization.

In Earth Science, a major challenge is to prioritize pathfinder missions that make new global measurements to address unanswered questions and reduce remaining uncertainties with systematic missions that maintain continuity of key measurements awaiting transition to operational systems managed by other agencies. The former enable researchers to probe the processes involved in global change via first-time global measurements. These often involve active remote sensing (via radars and lidars) that are more challenging to implement, and more in keeping with NASA's role as a research and technology agency. The latter build on past missions (often using newer technologies) to provide long-term continuity of measurement for those parameters that are indicators of variability and trends in global climate change and that aid in distinguishing natural from human-induced change.

Recognizing that both types of missions are crucial to the overall Earth Science effort, the priority list for missions currently in development assigns highest priority to missions that fulfill Legislative or Executive Branch mandates and interagency commitments. The major factors in systematic mission priorities are the importance of the measurement to global change research and the maturity of the operational transition plan. These are followed by missions that will make first-time global measurements. The two pathfinder missions, having been selected within the same competitive process, do not have a relative priority other than that inferred from their respective launch dates. The future representative measurements are not listed in priority order.

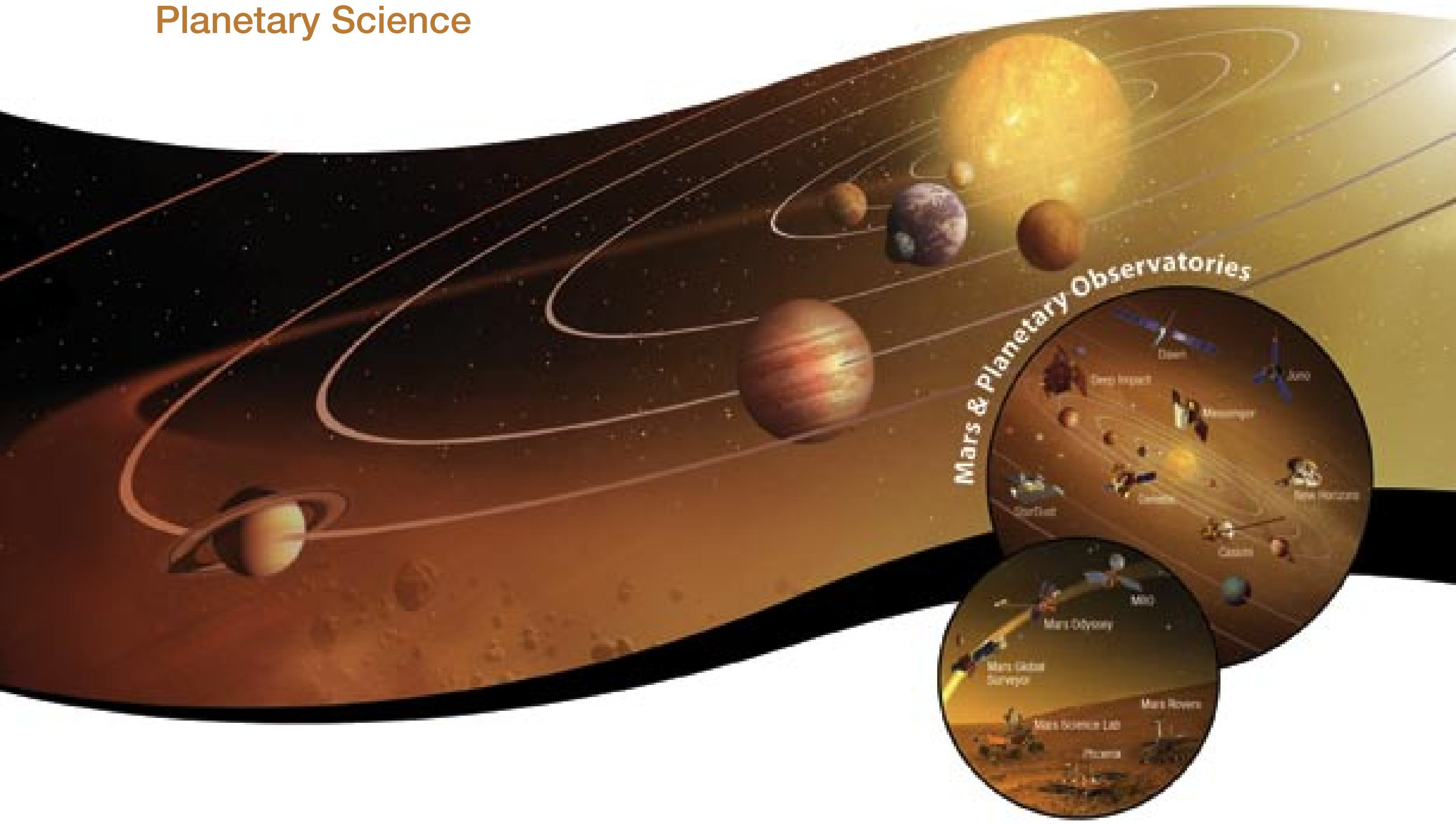
Earth Science Mission Priorities

Missions	Priority Rationale
NPOESS Preparatory Project [2009] Strategic mission - Systematic measurement	Required for continuity of several key climate measurements between the Earth Observing System and NPOESS. Implementation of the NPOESS Presidential Decision Directive of 1994. Joint mission with the NPOESS Integrated Program Office
Landsat Data Continuity Mission (LDCM) [2010] Strategic mission - Systematic measurement	Required for continuity of long-term global land cover change data; post-LDCM land imagery acquisition by an operational agency is planned. Mandated by the Land Remote Sensing Policy Act of 1992. Joint mission with USGS
Ocean Surface Topography Mission (OSTM) [2008] Strategic mission - Systematic measurement	Required for continuity of ocean altimetry; planned as part of a transition to operational agencies. Joint mission with CNES, NOAA and EUMETSAT
Glory [2008] Strategic mission - Initializes a systematic measurement	Addresses high priority objective of the U.S. Climate Change Science Program. Measure global aerosols and liquid cloud properties and solar radiation. Mandated by the President's Climate Change Research Initiative of 2001
Orbiting Carbon Observatory (OCO) [2008] Competed mission - Earth System Science Pathfinder	Nearing completion of development. First global measurement of CO_2 from space; small Earth science mission
Aquarius [2009] Competed mission - Earth System Science Pathfinder	In advanced stage of development. First global measurement of sea-surface salinity from space; small Earth science mission. Joint mission with Argentina
Global Precipitation Measurement (GPM) [2012] Strategic mission - Initializes a systematic measurement	Recommended by 2005 interim report of decadal survey committee; extend spatial coverage to global and temporal coverage to every 3 hours with constellation
Earth System Science Pathfinder (ESSP) [2014] – TBD Competed mission	Could address one of the future representative mission elements below; focus and relative priority to be determined using 2007 decadal survey; solicitation no earlier than 2008 for 2014 launch
Future Representative Mission Elements *(unprioritized)*: Changes in Earth's Ice Cover Global Ocean Carbon, Ecosystems and Coastal Processes Global Soil Moisture Global Wind Observing Sounder Multi-spectral Atmospheric Composition Sea Surface and Terrestrial Water Levels Vegetation 3-D Structure, Biomass, Disturbance Wide-swath All-weather Geodetic Imaging	Mission concept definitions and priorities to be determined after the 2007 decadal survey is available. Mission concept studies will likely result in integrating several of these elements into a single mission based on common or compatible technologies and observing techniques. The resulting mission concept set is likely to be a mix of strategic and competed missions

The forthcoming first NRC decadal survey for Earth science will identify science community priorities for future measurements, as well as begin to address issues arising from recent changes in the NPOESS program. Also influencing the priorities are the U.S. Climate Change Science Program (CCSP), the Oceans Action Plan, and the U.S. Integrated Earth Observation Strategy, which plans the U.S. contribution to the Global Earth Observation System of Systems.

Chapter 5

Planetary Science



Strategic Goal:

Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space.

Solar system exploration is a grand human enterprise that seeks to discover the nature and origin of the celestial bodies among which we live and to explore whether life exists beyond Earth. The quest to understand our origins is universal. How did we get here? Are we alone? What does the future hold? Modern science, and especially space science, provides extraordinary opportunities to pursue these questions. We are at the leading edge of a journey of exploration that will yield a profound new understanding of our home, the Earth, and of ourselves. Robotic exploration is the key precursor for the expansion of humanity into our solar system.

While NASA conducts missions to a broad range of solar system targets, Mars remains the prime target for sustained science exploration. The most recent NRC decadal survey in Planetary Science (*New Frontiers in Solar System Exploration*, NRC 2003) prioritized Mars missions independently from missions to other solar system bodies and this distinction is continued in this Plan. Thus, two prioritized lists of missions are maintained for Planetary Science. NASA seeks to maintain a balance in solar system exploration between detailed investigations of individual bodies and broader-based exploration of multiple bodies throughout the solar system.

Priorities for missions on both lists have been assigned based on development stage, strategic value and launch date. In general, missions in development are assigned higher priority than missions not yet initiated, with strategic missions given higher priority than PI-led missions within each phase of development. Missions to the outer planets tend to be strategic due to their cost. Orbital mechanics also influence launch order; delays of months in launch can translate into addition of years of transit time. All other considerations being equal, missions are prioritized according to launch date, unless a mission has significant heritage in a high-priority goal of the NRC decadal survey.

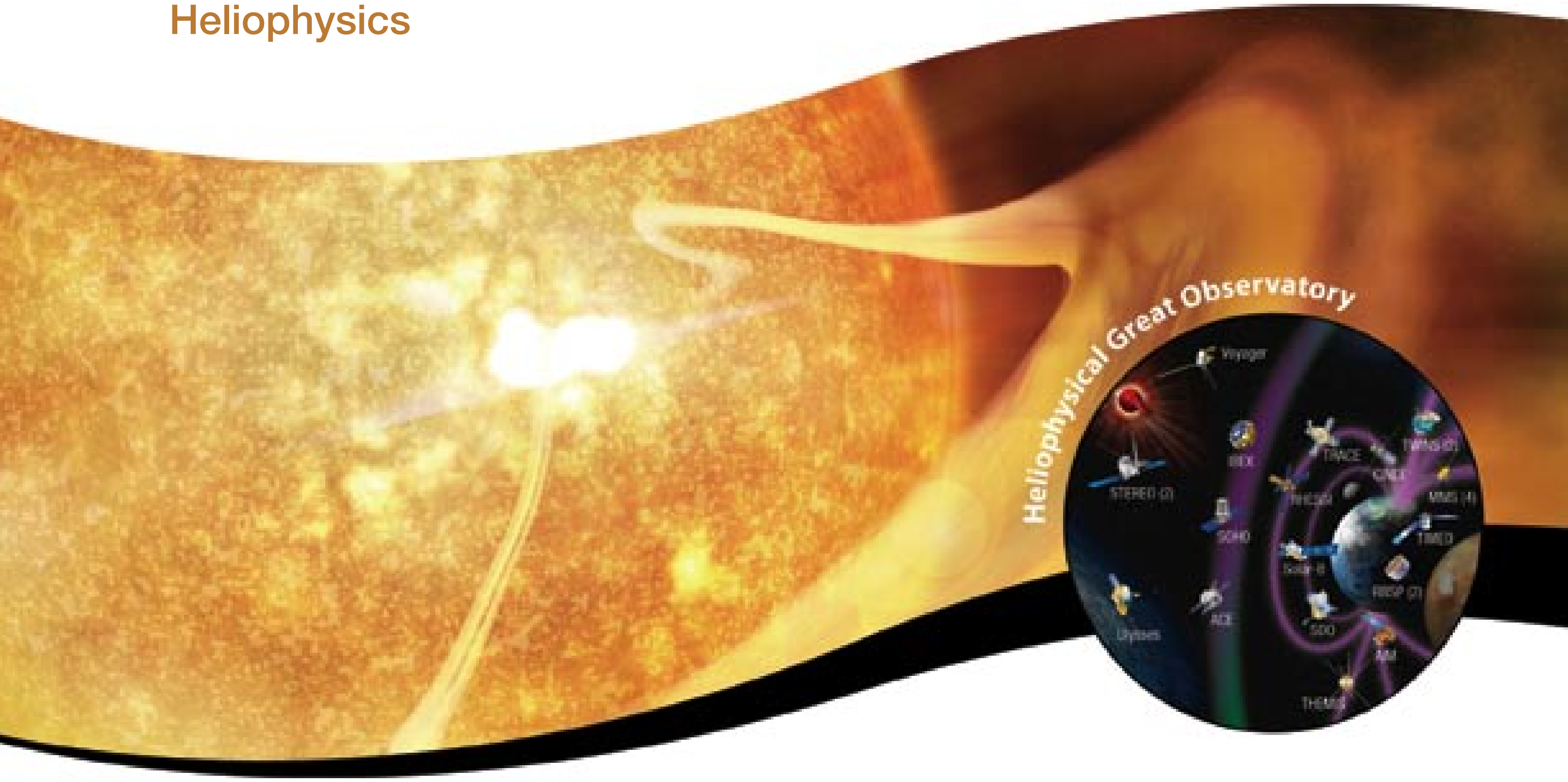
Planetary Science Mission Priorities and Rationale—Mars

Missions	Priority Rationale
Mars Science Laboratory [2009] Strategic mission	High-priority medium mission in 2003 decadal survey in advanced stages of development; roving analytical laboratory to address questions of habitability
Phoenix [2007] Competed mission – Mars Scout	Small Mars mission in final stages of development; fixed lander in northern polar plains of Mars
Mars Science Orbiter [2013] Strategic mission	Provides science responsive to 2003 decadal survey and required communications services
Astrobiology Field Lab, Mid-Size Rovers, or Network Landers [2016] Strategic mission	Provides science responsive to 2003 decadal survey; choice to be determined in part based on Mars Science Laboratory and Mars Reconnaissance Orbiter results
Mars Scout-11 [2011] Competed mission – Mars Scout	Opportunity for a small Mars mission to capitalize on new science
Other Solar System Destinations	
Juno [2011] Competed medium mission - New Frontiers	High-priority, medium-class mission in 2003 decadal survey; also high priority in 2003 Heliophysics decadal survey. Jovian gravity, composition and magnetic fields
Dawn [2007] Competed small mission - Discovery	Small planetary mission in final stages of development; investigations of the two large asteroids Ceres and Vesta
Discovery 2006 [2013] Competed small mission	Next small planetary mission; three mission concepts selected to proceed to Phase A, down-select anticipated in 2007
Europa Explorer [beyond 2016] Strategic mission	Highest-priority large mission in 2003 decadal survey; probe habitability and accessibility
Titan/Enceladus Explorer [beyond 2020] Strategic mission	Second highest-priority strategic mission in the 2006 solar system exploration roadmap; survey Titan's atmosphere and surface; Enceladus portion TBD
New Frontiers 3 [2015] Competed medium mission	Opportunity for high-priority medium class missions in 2003 decadal survey; solicitation NET 2008 following assessment of the field of candidate missions
Discovery 2008 [2015] Competed small mission	Opportunity for a small planetary mission; more than one mission may be selected; solicitation NET 2008

In the broader program of solar system exploration, the most recent NRC decadal survey in Planetary Science identified one large mission, a Europa geophysical explorer. Although funding resources have thus far been insufficient to begin implementation of an outer planets mission of this scale in the time frame of that survey (2003–2013), NASA is working toward that end. The decadal survey also identified five priority medium-class missions, and NASA designed the New Frontiers competed mission program to create opportunities to implement them. One, the New Horizons/Pluto Express, was launched in 2006; a second is the Juno mission to Jupiter now in development. In parallel, NASA is working on high-priority science that can be accomplished with small (Discovery) missions; the decadal survey recommended a launch rate of one such mission every 18 months. The Discovery 2006 and 2008 entries reflect planned solicitations and may represent more than one actual mission for each solicitation.

Chapter 6

Heliophysics



Strategic Goal:

Understand the Sun and its effects on the Earth and the solar system.

NASA launched the Mariner 2 spacecraft to Venus in August 1962. Completely successful in its planetary mission, it also resolved a long-burning controversy: interplanetary space is completely filled with streams and clouds of material ejected by the Sun. Not everyone had accepted Eugene Parker's theory of the solar wind when it was first published in 1958. It was fiercely debated until these and other *in situ* observations confirmed the vigorous and dynamically complex outflow.

Thus, a new view of our solar system was born. At the center is a magnetically variable star that affects the planets of the solar system and sculpts the heliosphere out of the local interstellar medium. The variability of this star has significant impacts on life and technology that are felt here on Earth and throughout the solar system.

The Heliophysics flight strategy is to deploy modest-sized missions, frequently, to form a small fleet of solar, heliospheric, and geospace spacecraft that function in tandem to understand the coupled Sun-Earth system. Operating this group of spacecraft as a single observatory (the Heliophysics Great Observatory) allows measurements across distributed spatial scales to be linked with a variety of models to fill observational gaps and provide predictions of tomorrow's space weather. Continuing and evolving this distributed asset to meet the needs of the Vision for Space Exploration are among the Heliophysics Program's highest priorities.

Resources are available to implement a portion of the NRC decadal survey for priorities set in Heliophysics (*From the Earth to the Sun: A Decadal Survey for Solar and Space Physics*, NRC 2003), albeit on a longer time scale, which impacts the envisioned science synergies between missions. The missions Solar Probe, Ionosphere/Thermosphere Storm Probes, Inner Heliospheric Sentinels, Geospace Electrodynamic Connections, and Magnetospheric Constellation must necessarily be implemented outside the decadal time frame of the survey (2004–2014).

Mission prioritization has been determined by the Helio–physics roadmap process, which resulted in concept mission studies and mission priorities aligned with the available

Heliophysics Mission Priorities and Rationale

Missions	Priority Rationale
Solar Dynamics Observatory (SDO) [2008] Strategic Mission: Living with a Star	#3 priority space-based moderate initiative in the astrophysics decadal survey (2001), nearing completion of development
Interstellar Boundary Explorer (IBEX) [2008] Competed Mission: Small Explorer	Nearing completion of development; image the 3-D boundary of the heliosphere
Magnetospheric Multiscale (MMS) [2013] Strategic Mission: Solar Terrestrial Probe	#1 priority mid-scale mission in 2003 decadal survey; study microphysics of three fundamental plasma processes: magnetic reconnection, energetic particle acceleration, and turbulence
Radiation Belt Storm Probes (RBSP) [2012] Strategic Mission: Living with a Star	#2A priority mid-scale mission in 2003 decadal survey; observe how radiation environments hazardous to satellites and humans form and change
Explorer/MIDEX [2013] Competed Mission: Medium Explorer	2008 solicitation for launch in 2013 for new science and vitality of the Heliospheric Great Observatory; the 2003 decadal survey endorsed continuation of a vigorous Explorer program
Explorer/SMEX [2015] Competed Mission: Small Explorer	2010 solicitation for launch in 2015 for new science and vitality of the Heliospheric Great Observatory; the 2003 decadal survey endorsed continuation of a vigorous Explorer program
Ionosphere/Thermosphere Storm Probes (ITSP) and Inner Heliospheric Sentinels (IHS); [beyond 2015] Strategic Missions: Living with a Star	#2B and #4 priority mid-scale missions in the 2003 decadal survey; order between these two missions not yet determined. Space weather missions in differing orbits to enable prediction
Solar Orbiter [beyond 2013] Strategic Mission: Living with a Star	#4 priority small-scale mission in 2003 decadal survey; partnership with ESA to measure properties and dynamics of solar wind
Solar Probe [beyond 2016] Strategic Mission	High priority flagship-scale mission in 2003 decadal survey to probe the processes controlling heating of the solar corona; requires new funding
Geospace Electrodynamic Connections (GEC) [beyond 2016] Strategic Mission: Solar Terrestrial Probe	#5 priority mid-scale mission in 2003 decadal survey to determine the fundamental processes coupling the ionosphere and magnetosphere

funding profiles based on the factors of scientific importance and strategic value to NASA's goals. The list includes also two Explorer missions, a Medium Explorer (MIDEX) and a Small Explorer (SMEX), that will be competitively selected through future Announcements of Opportunity to best meet heliophysics science objectives.

Considerable synergy exists between Heliophysics and other science areas. For example, the Solar Dynamics Observatory is a high priority in the astrophysics decadal survey, and Planetary Science's JUNO mission is the third mid-scale mission in the Heliophysics decadal survey.

Chapter 7

Astrophysics

Strategic Goal:

Discover the origin, structure, evolution, and destiny of the universe, and search for Earth-like planets.

In the Astrophysics plan that follows, we tell our science story in a roughly chronological fashion, starting with the beginning of time and ending with the search for life on extrasolar planets. The science goals described are breathtaking: we are starting to investigate the very moment of creation of the universe, and are close to learning the full history of stars and galaxies. We are discovering how planetary systems form and how environments hospitable for life develop. And we will search for the signatures of life on other worlds, perhaps to learn that we are not alone.

The most recent NRC decadal survey *Astronomy and Astrophysics in the New Millennium* (2001) lists the James Webb Space Telescope as its top-ranked major space-based initiative. The recent NRC report *Assessment of Options for Extending the Life of the Hubble Space Telescope* (2005) strongly endorsed the fourth Hubble servicing mission. The table reflects the other top priorities of the decadal survey, as well as its endorsement of "the continuation of a vigorous Explorer program." Also of influence are the NRC report *Connecting Quarks with the Cosmos* (2003) and the National Science and Technology Council response *Physics and Astronomy in the 21st Century* (2004). The Beyond Einstein program is in part an implementation of these reports. NASA (in partnership with the DOE) has requested the NRC to form a committee to recommend which Beyond Einstein mission to implement in the first opportunity identified, and the NRC's report is expected by September 2007, in time for input to the FY2009 budget. The first Beyond Einstein mission is scheduled for a launch in approximately 2015–2016 (the exact date depends on which mission is selected to proceed first: Joint Dark Energy Mission, Constellation-X, Laser Interferometer Space Antenna, Inflation Probe, or Black Hole Finder Probe). A second Beyond Einstein mission will be one of the remaining four Beyond Einstein Program missions.

The President's Vision for Space Exploration also called for NASA to "conduct advanced telescope searches for Earth-like planets and habitable environments around other stars". The Navigator Program is NASA's implementation of this objective and is represented by the Space Interferometry Mission (SIM) and Terrestrial Planet Finder (TPF). Both

Astrophysics Mission Priorities

Missions	Priority Rationale
James Webb Space Telescope (JWST) [2013] Strategic mission	Top-ranked space-based “Major Initiative” in the 2001 decadal survey; infrared successor to Hubble to image first light from the Big Bang
Hubble Space Telescope – Servicing Mission 4 (HST-SM4) [2008] Strategic mission	Continued operation endorsed by 2001 decadal survey; Report of the HST-JWST Transition Panel (2003). Shuttle mission to replace instruments and equipment to extend HST life
Gamma-ray Large Area Space Telescope (GLAST) [2007] Strategic mission	Top-ranked space-based “Moderate Initiative” in the 2001 decadal survey; all-sky survey of high-energy gamma ray sources
Herschel Space Observatory (Herschel) [2008] **Planck Surveyor (Planck) [2008]** Instruments on international missions	ESA mission with NASA as partner; U.S. participation endorsed in the 2001 decadal survey; star formation and cosmic background radiation, respectively
Kepler [2008] Competed mission - Discovery	The 2002 solar system exploration decadal survey “endorses the fundamental importance of the Discovery line of missions.” Survey 100,000 stars to search for Earth-size planets
Wide-field Infrared Survey Explorer (WISE) [2009] Competed mission - Explorer	2003 selection in MIDEX (Explorer) competition. The 2001 decadal survey “endorses the continuation of a vigorous Explorer Program”. All-sky survey in infrared for a wide range of studies
Stratospheric Observatory for Infrared Astronomy (SOFIA) [2010 Initial Operating Capability] Strategic Mission	Endorsed as a “Moderate” program in the 1991 decadal survey; reaffirmed in the 2001 decadal survey. Observations of stellar and planet-forming environments
Explorer/MIDEX [2013] Competed mission – Medium Explorer	2008 solicitation for launch in 2013. The 2001 decadal survey “endorses the continuation of a vigorous Explorer Program”

the 1991 and 2001 decadal surveys endorsed SIM, and TPF was endorsed in 2001, to search for exo-planets and perform other groundbreaking astrophysics.

The Astrophysics list includes two new Explorer missions, a MIDEX and a SMEX; as these are to be competitively selected in future Announcements of Opportunity, their science goals are not yet defined. Because the Explorer and Discovery competitions cut across divisional boundaries, there is no guarantee that the Astrophysics Division will fly missions from any specific future solicitation. Their number and inclusion here are based on the statistics of previous awards amongst the SMD divisions in these programs.

The priorities for those missions that launch after 2015 will be likely be re-established following the release of the next astronomy and astrophysics decadal survey (expected by 2010 or 2011).

Astrophysics Mission Priorities—Continued

Future strategic missions planned for launch after 2015 (unprioritized)	*The priorities for those missions that launch after 2015 will be likely be re-established following the release of the next decadal report of the Astronomy and Astrophysics Decadal Survey (expected by 2010 or 2011).*
Space Interferometry Mission (SIM) Strategic Mission	Endorsed by the 1991 decadal survey as a new Moderate Program; re-endorsed in 2001 decadal survey. Characterize other planetary systems
Beyond Einstein-1	One of the five missions below, based on the recommendation of the NRC in a study now underway for this purpose:
Constellation-X (Con-X)	Second-ranked space-based "Major Initiative" in the 2001 decadal survey; x-ray observation to study black holes, dark matter and energy
Joint Dark Energy Mission (JDEM)	Endorsed by the NRC *Connecting Quarks with the Cosmos* report (2003); measure cosomological parameters of the expanding universe, joint mission with DOE
Laser Interferometer Space Antenna (LISA)	Second-ranked space-based "Moderate Initiative" in the 2001 decadal survey. Measure gravitational waves; joint mission with ESA
Black Hole Finder Probe (BHFP)	One potential implementation (the Energetic X-ray Imaging Survey Telescope) is the fourth-ranked space-based Moderate Initiative in the 2001 decadal survey; census of black holes
Inflation Probe (IP)	One potential implementation (Cosmic Microwave Background polarization) is endorsed by the NRC *Connecting Quarks with the Cosmos* report (2003); stringent test of inflationary cosmology and Big Bang physics
Terrestrial Planet Finder (TPF) Strategic mission	Third-ranked space-based "Major Initiative" in the 2001 decadal survey; characterize all components of other planetary systems, image Earth-like planets and search for signs of life
Beyond Einstein-2	One of the four missions not selected as the Beyond Einstein-1

Many of the missions listed in the tables in the preceding four chapters are implemented through mission lines referenced in the tables. These mission lines are defined in the following table.

Program/Mission Lines			
Mission Lines	Mission Class*	Objectives and Features	Example Missions
Earth System Science Pathfinder (ESSP)	Competed, PI-led small missions	Address focused Earth science objectives and provide opportunities for new science investigations.	OCO, Aquarius
Earth Science Systematic Missions	Strategic missions of all sizes	Make new global measurements to address unanswered questions and reduce remaining uncertainties with systematic missions that maintain continuity of key measurements awaiting transition to operational systems managed by other agencies.	NPP, LDCM, OSTM, Glory, GPM
Discovery	Competed, PI-led medium missions	Explore solar system bodies and/or remotely examine the solar system and extrasolar planetary system environments.	Dawn, Kepler
Mars Scout	Competed, PI-led medium missions	Provide regular opportunities for innovative research in support of Mars objectives.	Phoenix
New Frontiers	Competed, PI-led large missions	Explore the solar system with frequent missions that will conduct high-quality, focused scientific investigations designed to enhance our understanding of the solar system.	Juno
Mars Exploration (core)	Strategic medium and large missions	Maximize the scientific return, technology infusion, and public engagement of the robotic exploration of the Red Planet. Each strategic mission has linkages to previous missions and orbiters and landers support each other's operations.	MSL, MSO
Explorers	Competed, PI-led small missions	Provide flight opportunities for focused scientific investigations from space with the Heliophysics and Astrophysics science areas.	WISE, IBEX
Solar Terrestrial Probes (STP)	Strategic medium missions	Execute a continuous sequence of defined strategic projects to provide in-situ and remote sensing observations, from multiple platforms, for the sustained study of the Sun-Earth System.	MMS, GEC
Living With a Star (LWS)	Strategic medium to large missions	Strategic sequences of missions to resolve the highest-priority unknowns in the connected system from the Sun to the Earth.	SDO, RBSP, ITSP, IHS, Solar Orbiter, Solar Probe
Beyond Einstein	Strategic medium and large missions	Complete Einstein's legacy and lead to understanding the underlying physics of the very phenomena that came out of his theories.	Con-X, LISA, JDEM, BHFP, IP
Navigator	Strategic large missions	Interrelated missions to explore and characterize new worlds, enable advanced telescope searches for Earth-like planets, and discover habitable environments around neighboring stars.	SIM, TPF

* Small missions have life cycle costs less than approximately $300M. Mid-size missions have life cycle costs between approximately $300M and $750M. Large missions have life cycle costs in excess of $750M. Flagship missions, in contrast to Mission Lines, are individual strategic missions and are in excess of $1 billion.

Chapter 8

Science and Human Exploration

The expansion of the human sphere beyond low Earth orbit will create opportunities for scientific discovery at every step. This Science Plan provides the framework and direction for realizing those opportunities.

There is extensive cross-fertilization between human exploration and science. The report of the President's Commission on Implementation of U.S. Space Policy found that "Science has held key position in America's space program since its inception nearly 50 years ago and remains an integral reason for exploring space. Science and exploration are synergistic: science is the attempt to explain nature, while exploration is the establishment and pushing back of a frontier. New frontiers reveal new and unprecedented natural phenomena, for which science is called upon to offer explanations. The Commission finds implementing the space exploration vision will be enabled by scientific knowledge, and will enable compelling scientific opportunities to study Earth and its environs, the solar system, other planetary systems, and the universe. Science in the space exploration vision is both *enabling* and *enabled*."

New scientific understanding is critical to enable the successful human exploration of the Moon and other destinations. One of the objectives of NASA's Heliophysics Science Program is to *Safeguard the Journey of Exploration*. NASA is undertaking the science investigations necessary to maximize the safety and productivity of human and robotic explorers by developing the capability to predict the extreme and dynamic conditions in space. The Planetary Science Program is addressing the question, *What are the potential hazards to humans in the space environment and are there resources that would enable a human presence away from the Earth?* Instruments and techniques designed to conduct robotic scientific investigations of the planets and other bodies in the solar system are now being turned toward the Moon in preparation for the scientific exploration of the Moon by humans.

This Science Plan includes precursor science investigations that are important for achieving the Vision for Space Exploration, including research and analysis, data analysis, and mission developments that have already begun. Some examples include the Moon Mineralogy Mapper experiment on Chandrayaan-1, the Mars Science Laboratory, the Solar Dynamics Observatory, and the research and data analysis programs in planetary science, heliophysics, and other disciplines. Additional precursor science investigations are also underway, but are beyond the scope of this Science Plan. The Exploration Systems Mission Directorate (ESMD) is undertaking the exploration research required to enable human exploration. One example is research required to ensure human health and safety. Further, ESMD is contributing the Radiation Assessment Detector instrument on the SMD's Mars Science Laboratory mission.

NASA is in the process of engaging the science community in developing and prioritizing the scientific studies that will form the backbone of the exploration science program. We are identifying the opportunities available to the scientific community—all branches—to do things that would not previously have been possible now that we are returning humans to the Moon, will be going to Mars, and will be creating the option to explore and utilize the near-Earth asteroids. The program of human exploration allows provides new venues for scientific discovery. We are now asking the question *what will we do at these places that we could not previously have planned to do?*

NASA is also developing the exploration architectures and systems necessary to enable both human exploration and new science opportunities. ESMD leads these activities; SMD participates in both strategy and architecture development to ensure compatibility and opportunity for science. The Mission Directorates are working closely together to undertake the high-priority science investigations that will enable the exploration program as well as the compelling science investigations that are enabled by the human and robotic exploration program.

A near-term priority is the identification of high-priority science investigations enabled by the first stop on the journey of exploration, the Moon. NASA has requested a study by the NRC Space Studies Board on lunar science priorities. NASA is also conducting and participating in community-based workshops and roadmapping activities, including a NAC sponsored workshop in early 2007. Funded opportunities for both studies and investigations will be openly competed and peer reviewed, consistent with SMD practices described in this Science Plan, beginning with a solicitation in 2006 for proposals from the science community for concepts for lunar surface science. When the time is right, a solicitation for scientific analysis of Lunar Reconnaissance Orbiter data will be issued. The potential range of science investigations is quite broad, but generally falls into four categories: science of the Moon (research with the Moon as the subject), science on the Moon (use of the Moon as a laboratory), science from the Moon (use of the Moon as a platform), and science near the Moon (research concerning the trans- and cis-lunar space environment). These activities and studies will identify compelling science investigations that are enabled by human exploration and address NASA's strategic science objectives. NASA, under the leadership of SMD, will undertake the highest-priority science investigations.

NASA has well-established, community-based processes to ensure that its science investigations are effective, relevant, and of the highest science quality. SMD will use these processes to identify science opportunities and establish priorities for exploration-enabled science activities. Recognizing that exploration-enabled science opportunities must compete with ongoing and planned science activities for resources, it is important to prioritize exploration-enabled science activities in the context of the rest of the SMD program. An important question to answer during the time period covered by this Science Plan is whether the science activities enabled by the human exploration program and identified as compelling by the science community have greater or lesser priority than activities previously planned by SMD.

The *Vision for Space Exploration* provides both the impetus and the opportunity for the science that enables exploration and for the science that is enabled by exploration. Human exploration of space beyond low Earth orbit is a core element of the Vision and, hence, of this Science Plan. NASA's Science Mission Directorate has a vital role in advancing the scientific interests of the United States as part of this national vision.

Chapter 9

Summary—At the Brink of Understanding

At the beginning of the 20th century, whole new vistas opened in scientific knowledge. Einstein's theories of relativity and Planck's quantum mechanics opened new ways of thinking about the universe. The work of Rutherford, Bohr, Thomson and others peered inside the atom. Bethe discovered that the fusion of hydrogen atoms powers the Sun. Ever-larger telescopes revealed the amazing diversity of planetary bodies in our solar system and the wonders of stars and galaxies beyond. Swedish scientist Svante Arrhenius asked the important question "Is the mean temperature of the ground in any way influenced by the presence of the heat-absorbing gases in the atmosphere?" For the past nearly 50 years, NASA has used its unique capabilities in space exploration and aeronautics to test and build upon these discoveries. NASA's ability to provide the vantage point of space and to attack scientific questions in a program management mode has led to substantial progress, with a stream of new discoveries that has become a veritable river in recent years.

Now at the beginning of the 21st century, humanity is poised for another great era of discovery. NASA and its partners are leading many of these paths of inquiry. We have measured the age of the universe, and we are close to being able to read its history and project its future. We have discovered over 180 planets around other stars, and we can conceive of means to survey our neighborhood in the galaxy and detect, if they exist, Earth-like planets. We have discovered water in what were thought to be unlikely places in our solar system, and we can devise probes to explore those places in search of life or its precursors. We have observed violent solar flares and their impacts in Earth's neighborhood and beyond to the edge of the solar system, and we can envision the potential to "instrument the solar system" to enable monitoring and prediction of events and phenomena that may affect human and robotic explorers. We have put in place the first capability to observe all the major components of the Earth system, and we can see a way forward to understanding and predicting the causes and consequences of Earth system change.

In short, we are at the brink of understanding. While we do not yet see the answers, the pathways to many of them lie open before us. We are limited by resources, not navigation. Other National endeavors lay claim on the same pool of resources, and it is incumbent upon NASA's Science Mission Directorate to exercise wise stewardship of the American taxpayers' investment. This Science Plan describes how we will use those resources to return the new scientific understanding and benefits anticipated in the Vision for Space Exploration, other Presidential initiatives, and Congressional direction. And if the past is prologue, our discoveries will lead us to yet greater vistas beyond.

References

The following documents were used in development of this Science Plan:

2006 NASA Strategic Plan
http://www.nasa.gov/about/budget/index.html

Science Community Roadmaps

- Science Program for NASA's Astronomy and Physics Program, 2006
- Heliophysics: The New Science of the Sun-Solar System Connection, 2006
- Solar System Exploration, 2006
- Mars Exploration Strategy for 2017-2016, 2006

All posted at: *http://science.hq.nasa.gov/strategy/comm.html*

National Research Council Decadal Surveys and Related Reports

- Astronomy and Astrophysics in the New Millennium, NRC 2001
- New Frontiers in the Solar System: An Integrated Exploration Strategy, NRC 2003
- The Sun to the Earth-and Beyond: A Decadal Survey for Solar and Space Physics, NRC 2002
- Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation, NRC 2005
- From Quarks to the Cosmos, NRC 2002
- An Assessment of Balance in NASA's Science Programs, NRC 2006
- Assessment of NASA's Mars Architecture 2007-2016, NRC 2006
- Review of NASA's Solid Earth Science Strategy, NRC 2004
- Preventing the Forward Contamination of Mars, NRC 2005

U.S. Government Plans

A Renewed Spirit of Discovery, 2004
http://www.whitehouse.gov/space/renewed_spirit.html

A Journey to Inspire, Innovate, and Discover: Report of the President's Commission on Implementation of United States Space Exploration Policy, June 2004
http://govinfo.library.unt.edu/moontomars/docs/M2MReportScreenFinal.pdf

The Physics of the Universe: A Strategic Plan for Federal Research at the Intersection of Physics and Astronomy, 2004
http://www.ostp.gov/html/physicsoftheuniverse2.pdf

Strategic Plan for the U.S. Climate Change Science Program, 2003
http://www.ostp.gov/nstc/html/ccspstratplan2003-all.pdf

Strategic Plan for the U.S. Integrated Earth Observation System, 2005
http://usgeo.gov/docs/EOCStrategic_Plan.pdf#search=%22US%20IEOS%22

U.S. Ocean Action Plan, 2004
http://ocean.ceq.gov/actionplan.pdf#search=%22US%20Oceans%20Action%20Plan%22

Other Reviews of the draft Science Plan

Letters forwarding recommendations of the NASA Advisory Council Science Subcommittees;
all available at: *http://science.hq.nasa.gov/strategy/NAC_sci_subcom/index.html*

Letters forwarding recommendations of the NASA Advisory Council; all available at:
http://www.hq.nasa.gov/office/oer/nac/minsmenu.html

Industry Comments (available upon request)
NASA Science Associates Group

- Consensus Views
- Consolidated Comments Submitted

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