NASA'S SCIENCE PROGRAMS: FISCAL YEAR 2009 BUDGET REQUEST AND ISSUES

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

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March 13, 2008

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NASA'S SCIENCE PROGRAMS: FISCAL YEAR 2009 BUDGET REQUEST AND ISSUES

THURSDAY, MARCH 13, 2008

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 2:10 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Mark Udall [Chairman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, DC 20515

Hearing on

NASA's Science Programs:
Fiscal Year 2009 Budget Request and Issues

March 13, 2008
2:00 p.m. – 4:00 p.m.
2318 Rayburn House Office Building

<u>**WITNESS LIST**</u>

Dr. S. Alan Stern
Associate Administrator
NASA Science Mission Directorate

Dr. Lennard A. Fisk
Chair
Space Studies Board
National Research Council

Dr. Berrien Moore III
Executive Director
Climate Central
and
Chair
Committee on Earth Studies
National Research Council

Dr. Steven W. Squyres
Professor of Astronomy
Cornell University

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Professor
Center for Astrophysics and Space Astronomy
University of Colorado

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HEARING CHARTER

SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NASA's Science Programs: Fiscal Year 2009 Budget Request and Issues

THURSDAY, MARCH 13, 2008
2:00 P.M.–4:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Thursday, March 13, 2008 at 2:00 p.m., the House Committee on Science and Technology, Subcommittee on Space and Aeronautics will hold a hearing to examine the National Aeronautics and Space Administration's (NASA) Fiscal Year 2009 budget request and plans for science programs including Earth science, heliophysics, planetary science (including astrobiology), and astrophysics, as well as issues related to the programs.

Witnesses:

Witnesses scheduled to testify at the hearing include the following:

Dr. S. Alan Stern, Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration (NASA)

Dr. Lennard A. Fisk, Thomas M. Donahue Distinguished Professor of Space Science, University of Michigan; Chair, National Research Council Space Studies Board

Dr. Berrien Moore, III, Executive Director, Climate Central, Inc.; Chair, Committee on Earth Studies, National Studies Board, National Research Council, The National Academies

Dr. Steven W. Squyres, Professor of Astronomy, Cornell University; Principal Investigator, Mars Exploration Rover Project

Dr. Jack O. Burns, Professor, Center for Astrophysics and Space Astronomy; Vice President Emeritus for Academic Affairs and Research, University of Colorado at Boulder

BACKGROUND

Overview

Over the last year, NASA's Science Mission Directorate launched the Dawn mission that will explore two large asteroids; the Phoenix Mars lander mission; the Solar Terrestrial Relations Observatory (STEREO) mission to study coronal mass ejections from the Sun; the Time History of Events and Macroscale Interactions During Substorms (THEMIS) mission, and the Aeronomy of Ice in the Mesosphere (AIM) mission.

In 2008, the Science Mission Directorate plans to launch the Interstellar Boundary Explorer (IBEX), the Solar Dynamics Observatory (SDO), the Gamma Ray Large Area Space Telescope (GLAST), the Ocean Surface Topography Mission (OSTM), the Orbiting Carbon Observatory (OCO), conduct a fourth Hubble servicing mission, and complete contributions to international and interagency partner missions that are planned for launch in 2008.

This hearing will examine NASA's science programs within NASA's Science Mission Directorate (SMD) and their status within the context of the Fiscal Year 2009 budget request. The science programs include the following theme areas:

- Earth science, which seeks to understand how and what is causing changes in the global Earth system, the effect of natural and human influences on the

Earth system and the implications for society, and how the Earth system will change over time;

- Planetary science, which seeks to understand the origin and evolution of the solar system and the prospects for life beyond Earth;
- Astrophysics, which seeks to understand the origin, structure, evolution and future of the Universe and to search for Earth-like planets; and
- Heliophysics, which seeks to understand the Sun and its effects on Earth and the rest of the solar system.

Stakeholders in NASA's science programs include academic institutions; industry; NASA field centers, predominantly the Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL); and other government laboratories. There are a number of advisory panels that provide guidance on NASA's science programs and activities, including the National Academies, the Astronomy and Astrophysics Advisory Committee (AAAC), and the NASA Advisory Council (NAC) and its Science Subcommittees.

Fiscal Year 2009 Budget Request

The President's FY09 budget requests $4.4 billion in direct program dollars to fund NASA's science programs—Earth science, heliophysics, planetary science, and astrophysics. The budget represents a $264.7 million decrease below the FY08 appropriation. Most of this decrease is attributed to a transfer of the budget and management for the Deep Space Network and Near Earth Networks from the Science Mission Directorate to the Space Operations Mission Directorate. (Appendix A presents the President's FY09 budget request for NASA's science programs.) NASA's science programs represent 25 percent of the President's total FY09 budget request for NASA.

It should be noted that the FY09 budget has been restructured pursuant to the *Consolidated Appropriation Act,* 2008, and is now presented in seven accounts. Science, which was previously part of the Science, Aeronautics and Exploration account, is broken out as a separate line. In addition, the budget estimates presented in the FY09 request are in direct program dollars rather than in the full cost dollars used in previous Presidential budget requests.

Assumed Budget Growth for NASA Science FY 2009–FY 2020

The President's budget request for NASA and for the Science Mission Directorate is assumed to grow at one percent through FY11 and then at 2.4 percent thereafter, according to a Science Mission Directorate website [*http://science.hq.nasa.gov/research*].

Key Changes in FY 2009 Budget Request for Science Mission Directorate

- *Increases for research and analysis (R&A) grants.* Research and analysis grants fund theory, modeling, the analysis of mission data, technology development and research on concepts for future science missions. These grants are a principal source of funding and training for graduate students who will serve as the next generation of space scientists.
- *Increases intended to revitalize small science projects flown on sub-orbital rockets, aircraft, and balloons.* These small science activities provide frequent opportunities for science return and help train students and young researchers in space flights, systems integration, and project management.
- *Near-term increases for small scientist-led Explorer missions.* The FY09 budget includes plans to select several new Small Explorer missions. This step helps fill what was expected to be a gap in science mission launches over the next few years. In addition, these opportunities help maintain the vitality of the science community and offer valuable training for scientists and engineers.
- *Initiates two of the 15 Earth Science missions recommended for NASA in the National Academies decadal survey.*
- *Proposes new science missions and projects,* including an "Outer Planets" flagship mission to either Jupiter's moon Europa, the Jupiter system, or Saturn's moon Titan; a Joint Dark Energy Mission (JDEM), which would examine fundamental questions about the Big Bang, black holes, and dark energy in the universe; a Solar Probe mission that would provide close-up measurements of the Sun and the solar wind; a potential small lunar orbiter that would study the lunar atmosphere and dust and two mini-landers that would be the initial

nodes in an international geophysical network on the Moon; and a Mars Sample Return mission.

- *Makes extensive cuts to Mars Exploration and focuses future plans on a Mars Sample Return endeavor.*
- *Reduces funding for technology development programs and delays and reduces various programs across the Science Mission Directorate.*
- *No new funding is provided to the Science account relative to the five-year runout that accompanied the FY08 budget request; thus, new funding initiatives in specific program areas are funded by transitioning money from other program areas.*

Potential Issues

The following are some of the potential issues that might be raised at the hearing:

- What are the goals of the Science Mission Directorate over the next five years? What are the challenges in meeting those goals?
- What threat do the eight science missions exceeding Congressionally-set cost and schedule thresholds pose for NASA's FY09 science budget and plans?
- Can the ambitious program proposed in the FY09 be executed on a budget assumed to grow at the rate of inflation? What is the contingency strategy?
- Will NASA's approach to technology development provide adequate risk reduction for current projects and currently planned major new initiatives?
- Are NASA's science programs balanced?
- What is the status of NASA's planning to support launches of medium-class science missions? To what degree is the availability of launch vehicles affecting strategic plans for the Science Mission Directorate?

Earth Science

- How sustainable is a budget wedge for Earth Science missions that is built on cuts to other NASA science programs?
- What is the status of climate sensors removed from the NPOESS platform and how do those plans affect NASA's NPOESS Preparatory Project (NPP)?
- What lessons have been learned from the challenges related to the NPP and NPOESS programs and the re-manifesting of climate sensors that were removed from the NPOESS platform? How does NASA plan to apply those lessons to the new Earth Science missions being planned?
- What is NASA's role in the Global Earth Observation System of Systems (GEOSS) and what are the benefits of GEOSS to the U.S.? What should it be? What has been accomplished since the strategic plan for GEOSS was issued three years ago?

Planetary Science

- Is the planetary science program proposed in the FY09 budget executable?
- What are the implications of the extensive budgetary cuts and proposed changes in the Mars Exploration Program?
- Does NASA's FY09 budget request and plan for the planetary science program provide the capability to support a Mars Sample Return mission?

Astrophysics

- What are the implications of the lack of a budget wedge to support future "Decadal" priorities for astronomy and astrophysics?
- What are the implications of reductions in the Physics of the Cosmos line?
- What is NASA's rationale for proposing a Joint Dark Energy Mission budget that is considerably lower than the cost estimate in a National Academies report, which used an independent cost estimating process?
- Are NASA's plans for an exoplanet mission to explore planets near stars like the Sun consistent with the findings of the Astronomy and Astrophysics Advisory Committee's (a Congressionally-chartered committee) Exoplanet Task Force?

Heliophysics

- Is NASA's plan and proposed budget for initiating a Solar Probe mission realistic?
- How effective is the process of transferring NASA-funded research into operational space weather services?
- What is needed to ensure the optimal use of NASA-funded research to improve space weather prediction?

Cross-Cutting Issues for Science Programs

What threat do the eight science missions exceeding Congressionally-set cost and schedule thresholds pose for NASA's FY09 science budget and plans? At the posture hearing on NASA's FY09 budget request held by the Full Committee, Administrator Griffin testified that *"NASA's current development cost estimate of $325 million for the Glory Earth science mission has exceeded the 30 percent threshold and cost growth. Thus, it will require explicit authorization in the next 18 months to continue."* NASA's FY09 budget documents report that a total of eight projects have exceeded Congressional schedule or cost thresholds—Herschel, Kepler, NPOESS Preparatory Project, Glory, Orbiting Carbon Observatory (OCO), Aquarius, GLAST, and the Stratospheric Observatory for Infrared Astronomy (SOFIA). (See Appendix B) Five of the missions on the list were added this year; three are carryovers from last year. What explicit steps is NASA taking to resolve the issues with these missions and to prevent a similar situation arising with future missions, especially the new science missions to be initiated with the proposed FY09 budget?

Will NASA's approach to technology development provide adequate risk reduction for current projects and currently planned major new initiatives? The FY09 budget reduces programmatic content for Earth science technology by $14.5 million through FY12; reduces programmatic content for planetary science technology by $65.7 million through FY12; and virtually eliminates the New Millennium flight technology validation program with reductions of $210 million through FY12. NASA officials informed Committee staff that NASA plans to fund the technology required for individual missions through the mission project budgets. This approach differs from statements and advice provided through reports of the National Academies, which recommended that NASA support both cross-cutting technology as well as mission-specific technology development. Is NASA taking the right approach to ensuring that technologies for new missions are mature and that their risks are understood? How does NASA plan to constrain technical risk on future missions while also reducing funding for technology development?

Earth Science

The President's FY09 budget request provides $1.3675 billion for NASA's Earth Science program. The FY09 budget represents a 6.8 percent increase over the FY08 appropriation and provides a budget wedge of $910 million dollars over the five-year runout to initiate the first two Earth science missions recommended in the National Academies Earth Science decadal survey.

The Earth Science program funds:

- Science activities, including research on the processes related to the Earth's atmosphere, hydrosphere, biosphere, cryosphere, and land surface and their affects on the climate, weather, and natural hazards; airborne science; and supercomputing capabilities; among other focused research activities;
- The Earth System Science Pathfinder (ESSP) Program, which solicits proposals for scientists to propose small to medium-sized missions. (Three missions are operating and two missions are planned for launch within the next one to two years. The FY09 request does not include plans for future ESSP missions.)
- Technology, including the development of new instruments and measurement techniques, information technologies, and technologies for the Earth science program;
- Grants to support the applied use of NASA Earth science research to societal benefit areas including agricultural efficiency, air quality, aviation, carbon management, coastal management, disaster management, ecological forecasting, energy management, homeland security, invasive species, public health, and water management; and
- The Near-Earth Objects Observation program, which detects, tracks, and characterizes NEOs, as directed by Congress. (This program and the associ-

ated funding was moved from the Exploration Systems Mission Directorate to the Science Mission Directorate in 2007.)

Key Issues for Earth Science

How sustainable is a budget wedge for Earth Science missions that is built on cuts to other NASA science programs? The FY09 budget request includes $910 million in funds in FY09–FY13 for NASA to implement the President's FY09 budget requests new starts for the Soil Moisture Active Passive (SMAP) mission to measure soil moisture and the ICESat–II mission to measure changes in the height of ice sheets. NASA also plans to start three additional decadal missions within the five-year plan presented in the President's FY09 budget request.

Approximately $570 million of the wedge created for the decadal survey missions is funded through the transfer of funding from other science divisions, resulting in reductions in the Mars Exploration Program, a delay to the Solar Probe mission, and other programmatic cuts, according to NASA officials. Funds within the Earth Science division that were intended for a competitive selection of an Earth Science Pathfinder mission have been redirected to implement the decadal survey missions. The National Academies decadal survey report called for an increase of $500 million per year for NASA's Earth Science program (bringing the program back to the level at which it was funded in the year 2000) to enable the implementation of the decadal recommendations. While the FY09 budget request enables a positive start on the initial two missions identified, what are the implications of the gap between the FY09 plan and the resource requirements laid out by the Earth Science decadal survey? Is there sufficient funding in the five-year budget plan to permit any work on other decadal missions beyond the first two?

What is the status of climate sensors that were removed from the NPOESS platform and how do current plans for climate sensors affect NASA's NPOESS Preparatory Project (NPP)? In attempt to mitigate potential gaps in critical climate measurements that were to be part of the NPOESS program, the Office of Science and Technology Policy (OSTP), along with NOAA and NASA, agreed to sustain high priority climate measurements:

- Total solar irradiance (to be provided by the Total Solar Irradiance Sensor (TSIS))
- Earth radiation budget data (to be provided by the Clouds and Earth Radiant Energy System (CERES) sensor), and
- Ozone vertical profile data (provided by the OMPS–Limb sensor).

The President's budget requests $74 million per year through FY13 in the NOAA budget for this purpose. CERES was added to NASA's NPP mission. OMPS–Limb was restored to the NPP platform, and TSIS has not yet been assigned to a satellite. NASA's NPP mission, which is intended to provide risk reduction for sensors to fly on the NPOESS system, has been delayed 26 months due to poor contractor performance on the Visible/Infrared Imaging Radiometer Suite (VIIRS) sensor.

What is NASA's strategy for transferring Earth Science research and instruments into operational services? How are lessons learned from the interagency decision-making process to fly high priority climate sensors being used to improve the movement of NASA-funded capabilities into ongoing operational services? Section 306 of the *NASA Authorization Act of 2005* directs NASA and NOAA to establish a Joint Working Group to *"ensure maximum coordination in the design, operation, and transition of missions where appropriate."* NASA and NOAA are coordinating NPOESS climate re-manifestation, NASA's Quick Scatterometer mission, NOAA's GOES–R weather satellite program, and the series of NASA, NOAA, and French space agency missions to measure global sea level, among other activities. Does NASA have a plan and identified process for moving NASA research into operational services? What are the advantages and disadvantages of reviving the Operational Satellite Improvement Program (OSIP), which was the approach to NASA and NOAA coordination that existed during the 1970s? What are the challenges in planning and executing the transition of NASA research into operational services? What, if any, resources are required?

Over the last year, NASA has been working closely with NOAA and the Office of Science and Technology Policy on restoring high priority climate measurements that were originally planned for NPOESS. What can be learned from this process for improving the effectiveness of transitioning research into operations? The Earth Science decadal survey recommended that *"Socioeconomic factors should be considered in the planning and implementation of Earth observation missions and in devel-*

oping an Earth knowledge and information system." Do NASA's plans for new Earth science missions include the applied uses of the data for societal benefit?

Does NASA have an implementation plan to address potential gaps in the Landsat data record? The Landsat Data Continuity Mission (LDCM) will continue the observation of the longest civil Earth observation data record, which began with the Landsat program in 1972. LDCM is expected to launch in 2011. The lifetime of the currently operating Landsat 7 is uncertain. LDCM will not include a thermal imaging capability (which has been part of the ongoing Landsat data record). This capability is of value, in particular, for the management of water resources. NASA has said that the cost of a thermal imaging capability exceeds the budget that is available for LDCM. The explanatory language in the FY08 appropriation directed NASA to *"provide a plan on all continuity of data for the Landsat Data Continuity Mission (LDCM) to the Appropriations Committees no later than 120 days after enactment of this Act."* A study team to consider options for addressing a potential data gap between Landsat 7 and LDCM was created well before the FY08 appropriations direction. Is there an implementation plan in place? Will the plan include measures to acquire thermal infrared data to ensure continuity of this data?

What is NASA's role in the Global Earth Observation System of Systems (GEOSS) and what are the benefits of GEOSS to the U.S.? What has been accomplished since the strategic plan for GEOSS was issued three years ago? In 2005, 55 nations *"endorsed a 10-year plan to develop and implement the Global Earth Observation System of Systems (GEOSS) for the purpose of achieving comprehensive, coordinated, and sustained observations of the Earth system."* What benefits has GEOSS yielded for NASA's own applications projects, for U.S. researchers, and for users of Earth observation data? Are there any concrete examples of successes? What should NASA's role in GEOSS be?

Planetary Science

The President's FY09 budget request provides $1.3342 billion to fund NASA's Planetary Science theme. The FY09 budget represents an increase of $86.7 million, about seven percent relative to the FY08 appropriation for planetary science. Within the planetary budget, the programmatic content of the Mars Exploration Program is cut by $918 million through FY12; the programmatic content of the Discovery program of competitive, scientist-led missions is cut by $57.9 million through FY12; and the programmatic content of the planetary science technology program is reduced by $65.7 million through FY12.

Planetary Science funds:

- Planetary Science research, which includes research and analysis, the lunar science research;
- The Discovery program of competitively-selected scientist-led missions (medium-class);
- The New Frontiers mission of competitively-selected scientist-led missions to designated planets, moons, or bodies;
- Mars Exploration Program consisting of competitively-selected, scientist-led Mars Scout missions, and landers, rovers, and orbiters developed by NASA;
- A newly-created Outer Planets program to focus on developing the next planetary flagship mission to the solar system's outer planets; and
- A technology program to continue work on in-space propulsion and radioisotope power systems.

Key Issues for Planetary Sciences

Is the Planetary Science Program Proposed in the FY09 Budget Executable? The planetary sciences program, as detailed in the FY09 budget, would include several new initiatives:

Outer planets mission: NASA-estimated level of $2 billion for U.S. portion, and

New Frontiers mission: NASA-estimated level of $840 million

In addition, the program intends to fund additional Mars missions and maintain the Discovery and New Frontiers lines of competitive, scientist-led missions. The major planetary mission currently in development, a large rover that will identify possible Martian habitats for life (Mars Science Laboratory), has incurred a $165 million overrun, according to Science magazine, and has encountered technical challenges that could threaten the mission's 2009 launch opportunity.

- Are NASA's budgetary assumptions to support the proposed Mars Exploration Program realistic?
- Is the frequency of small and medium-class scientist-led missions appropriately balanced with the larger projects included in the plans?
- What additional steps is NASA taking to ensure robust budget estimates for the proposed program and what trade-offs will be considered?

Do NASA's FY09 budget request and Planetary Science program provide the capability to support the proposed Mars architecture, including a future Mars Sample Return Mission? The Mars Exploration Program Analysis Group (MEPAG), a NASA-chartered group to support planning for the scientific exploration of Mars, endorsed NASA's Mars architecture, albeit with significant caveats. The group concluded that *"The proposed budget does not support the SMD [Science Mission Directorate] architecture"* and that *"NASA funding through FY20 is two to three billion dollars less than required for this architecture."* A Mars Architecture Tiger Team, which was assembled to assess the architecture, also endorsed the plan, but found that *"the SMD planning budget, which includes the President's five-year decreasing budget, does not support this architecture, even with the planned rapid increase in funding beginning in FY17."* The proposed Mars Exploration Budget for FY10–FY12 is roughly half of the levels funded over the last five years. The Tiger Team identified alternative options include a program focusing only on sample return; a program that excludes sample return, a program that delays sample return, or the current program (which would require additional resources).

- What should the future Mars program be? What are the advantages and disadvantages of the various options? How will this decision be made?
- What technical challenges must be overcome to support a Mars Sample Return mission and does the Planetary Science program, as proposed in the FY09 budget, provide the vehicles to address those challenges?

What is the status of Astrobiology?

NASA's astrobiology program is an interdisciplinary program to study the origin and evolution of life on Earth and beyond Earth. The program funds competitively selected astrobiology research teams through the NASA Astrobiology Institute. Recent NASA budget requests significantly cut astrobiology (by as much as half). In January 2008, NASA issued a solicitation to support additional teams: according to the January cooperative agreement notice, *"NASA anticipates making $10–12M per year available for this selection, leading to at least seven and possibly several more awards (approximately one-third or which will be focused on preparing strategic mission objectives) each of five years duration."* What, if any, future role could astrobiology play in a future Outer Planets mission, an exoplanet mission, and the future Mars Program, including a potential sample return mission? Is astrobiology research and the development of astrobiology instrumentation on track to contribute to these planned activities?

Lunar Science

The FY08 budget request included funding for lunar science research within the planetary science research line to help support scientific research in view of future exploration of the Moon. The FY09 budget continues the lunar science research program and requests $669 million for FY09–FY13, which includes an increase of $250 million from the FY08 budget request through FY12, to develop a small lunar orbiter for launch by 2011 and two mini lander missions by 2014.

Astrophysics

The President's NASA FY09 budget request includes $1.1625 billion to fund NASA's Astrophysics program. The FY09 request represents a $175 million or 13 percent decrease relative to the FY08 appropriation for astrophysics.

Astrophysics funds:

- Astrophysics research, including research and analysis grants and scientific activities on balloons and sub-orbital rockets;
- Cosmic Origins Program, including the James Webb Space Telescope, the Stratospheric Observatory for Infrared Astronomy (SOFIA), and the Hubble Space Telescope and Hubble Space Telescope Servicing Mission–4;
- Physics of the Cosmos program to explore the nature of dark energy, black holes and other phenomena;

- Exoplanet Exploration to study and identify planets near stars like the Sun; and
- Scientist-led, competitively selected Explorer missions.

Key Issues for Astrophysics

What are the implications of the lack of a budget wedge to support future "Decadal" priorities for astronomy and astrophysics? The FY09 budget requests $315.6 million through FY13 to advance recommendations of the next decadal survey in astronomy and astrophysics, according to internal NASA budget documents. However, the request represents cuts of $75.8 million from the FY08 request for such missions, according to NASA internal budget documents. NASA officials told Committee staff that most of the budget request for future decadal survey missions would be held as reserves for the James Webb Space Telescope Mission, which requires increases in its reserves in order to manage the mission at a 70 percent confidence level. There is no room for future astrophysics observatories in the current FY09 budget's five-year budget plan. What does this mean for the health of the astrophysics program and community?

What are the implications to reductions in the Physics of the Cosmos line? What is NASA's rationale for proposing a Joint Dark Energy Mission budget that is considerably lower than the cost estimated in a National Academies report, which used an independent cost estimating process? The FY09 budget proposes $388.5 million for FY09–FY13 to develop a JDEM mission and to continue technology development for other future missions in the Physics of the Cosmos program (previously called the Beyond Einstein program). The JDEM new start responds to a National Academies study, which recommends that *"NASA and DOE should proceed immediately with a competition to select a Joint Dark Energy Mission for a 2009 new start."* NASA plans to issue an Announcement of Opportunity for the mission in FY08, which is planned to be conducted in partnership with DOE. NASA estimates the mission cost at the level of $600 million, not including a potential contribution from the DOE, and anticipates a JDEM launch in 2015. The National Academies study, *Beyond Einstein: An Architecture for Implementation,* included an analysis that estimated JDEM mission life cycle costs (as managed at a 70 percent confidence level) to be $1 billion–$1.3 billion. The National Academies study also found that *"LISA [Laser Interferometer Space Antenna] is an extraordinarily original and technically bold mission concept that will open up an entirely new way of observing the universe"* and recommended that NASA provide additional technology development funds for LISA. However, the FY09 budget request cuts about $129 million from the amount requested for these missions FY09–FY12 for future missions in the Physics of the Cosmos program, according to NASA internal budget documents.

- How will programmatic cuts affect the overall Physics of the Cosmos program and the technology investments required to continue such innovative missions as LISA?

Are NASA's plans for an exoplanet mission to explore planets near stars like the Sun consistent with the findings of the Astronomy and Astrophysics Advisory Committee's (a Congressionally-chartered committee) Exoplanet Task Force? The FY08 budget request reduced the Space Interferometry Mission (SIM) mission, which would conduct a census of planetary systems and to identify the location and masses of targets for potential further study, to the level of a technology development program. The consolidated appropriation for FY08 added $60 million and included explanatory language directing NASA to start developing SIM. The FY09 request does not present SIM as a mission development program and instead notes that *"A new medium-class Exoplanet mission, managed by the Jet Propulsion Laboratory, will begin formulation in 2010, for which a re-scoped version of Space Interferometry Mission (SIM) is being evaluated as a potential candidate."* The Astronomy and Astrophysics Advisory Committee, chartered by Congress, convened an ExoPlanet Task Force, which developed *"a 15-year strategy for the detection and characterization of extrasolar planets ("exoplanets") and planetary systems."*

- What are the advantages and disadvantages of NASA's decision not to pursue full development of SIM?
- Will the exosolar planet mission planned in the FY09 budget be revisited as part of the decadal survey, and if so, what does that mean for advancing NASA's newly created Exoplanet Exploration program?

What are the objectives of the Hubble Space Telescope Servicing Mission–4? A fourth and final Shuttle servicing mission (STS–125) is scheduled for August 2008 to install new science instruments that will improve the Hubble's observational capabilities and to replace batteries and gyroscopes that will allow the Hubble to continue operating through 2013.

Heliophysics

The President's FY09 budget request for NASA includes $577.3 million in direct program dollars for the Heliophysics theme, which seeks to understand the Sun and its effect on the Earth and the rest of the solar system; the conditions in the space environment and their effects on astronauts; and to develop and demonstrate technologies to predict space weather. The FY09 request represents a decrease of $267.6 million in direct dollars from the FY08 appropriation, due in large part to the programmatic and budgetary transfer of Deep Space Network and ground network systems (approximately $250 million) to the Space Operations Mission Directorate.

The program funds:

- Heliophysics research, including research and analysis; space missions; sounding rockets and other scientific platforms; science data and computing technology;
- the Living with a Star program that investigates solar variability and its effects on Earth (space weather) and the rest of the solar system;
- the Solar Terrestrial Probes program, which studies the interrelationships among the Sun, the Earth, and planetary systems; and
- the small and medium-class competitively-selected missions (Explorer missions) that endeavor to provide frequent flight opportunities to investigate focused research.

Key Issues for Heliophysics

How are data collected by NASA research satellites used for operational space weather services? What is needed to ensure the optimal use of NASA-funded research to improve space weather prediction? The Heliophysics Living with a Star Program includes the study of space weather and seeks improve our ability to predict variability in our Sun and solar storms. Space weather events can interfere with both on-orbit spacecraft and terrestrial assets such as electric power grids and can pose hazards to astronauts, especially during space walks. As society becomes increasingly reliant on global positioning signals for ground-based applications, communications satellites, and Earth observations systems, the potential implication of spacecraft losses or altered signals due to space weather intensifies. NASA funds space research missions to help understand the nature and behavior of space weather. NASA also funds research to develop models of space weather. NOAA is responsible for the operational Space Weather Prediction Center, which provides forecasts on and alerts of space weather events. The Air Force also has a space weather capability. This year, NASA will launch the first mission of its Living with a Star Program, the Solar Dynamics Observatory (SDO).

- What contribution will the research data from the SDO mission make to improving the prediction of space weather?
- Data from NASA's Advanced Composition Explorer (ACE) research mission have been integrated into operational space weather services. What is NASA's role in helping plan for the continuity of data that is currently provided by ACE?

Are NASA's plan and proposed budget for initiating a Solar Probe mission realistic? The Solar Probe mission, which is part of the Living With a Star Program, was the highest priority large mission ranked in the 2002 National Academies decadal survey for solar and space physics. The objectives for the mission are to travel close to the Sun to measure the *"heating and acceleration of the solar wind."* The FY08 omnibus appropriation provided $17 million *"for the solar probe mission for continued technical risk reduction activities and related studies. NASA is expected to request a new start. . .in fiscal year 2009."* NASA's current plans are to fund a new start for what is referred to as "Solar Probe Plus," a scaled down version of Solar Probe. However, the FY09 budget request does not include dedicated funding for a Solar Probe mission. The status of Solar Probe is at the stage of concept development for a potential medium-class mission at a NASA estimated level of $750 million. The FY09 request does not propose any funding for Solar Probe in FY09, and the proposed FY10 allocation is only $3.4 million, although the scheduled launch date is 2015.

APPENDIX A

FY 09 NASA Budget Request

(Budget authority, $ in millions)	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
SCIENCE	**4,706.20**	**4,441.50**	**4,482.00**	**4,534.90**	**4,643.40**	**4,761.60**
EARTH SCIENCE	**1,280.30**	**1,367.50**	**1,350.70**	**1,250.90**	**1,264.40**	**1,290.30**
Earth Science Research	375.8	380.6	388.2	390.6	400.7	409.3
Earth Systematic Missions	530.1	677.9	661.5	583.2	563.6	569.6
Earth System Science Pathfinder	113.8	88.6	58.8	37.4	50	54.9
Earth Science Multi-Mission Operations	167.8	140.5	159.1	157.9	166.5	170.9
Earth Science Technology	47.3	46.1	49.2	50.6	51.6	52.8
Applied Sciences	45.4	33.8	33.8	31.3	32.1	32.8
PLANETARY SCIENCE	**1,247.50**	**1,334.20**	**1,410.10**	**1,537.50**	**1,570.00**	**1,608.70**
Planetary Science Research	242.1	270.8	315.8	355.6	373.2	382.6
Discovery	153	247	258.3	256	326.1	140.5
New Frontiers	132.2	263.9	250.3	232.3	227.7	236.9
Mars Exploration	553.5	386.5	299.6	344.5	341.1	413.8
Outer Planets	81.9	101.1	216.7	279.4	230.6	362
Technology	84.8	64.9	69.3	69.6	71.3	73
ASTROPHYSICS	**1,337.50**	**1,162.50**	**1,122.40**	**1,057.10**	**1,067.70**	**1,116.00**
Astrophysics Research	102.2	152.3	170.4	181	203	198.9
Cosmic Origins	807.3	674.4	571.1	515.4	485.6	458.5
Physics of the Cosmos	159	157	219.8	249	271.1	326
Exoplanet Exploration	162.6	48.1	67.7	68.4	96.4	126.2
Astrophysics Explorer	106.4	130.6	93.3	43.3	11.7	6.4
HELIOPHYSICS	**840.9**	**577.3**	**598.9**	**689.4**	**741.2**	**746.6**
Heliophysics Research	181.2	184.8	180.3	175.3	179.8	187.5
Living With A Star	217.1	223.8	212	216.6	232.8	237.5
Solar Terrestrial Probes	105.9	123.1	137.5	171.4	172.6	161.5
Heliphysics Explorer Program	61	41.3	66.8	125.1	156	160.1
New Millenium	25.8	4.3	2.2	1.1		
Near Earth Networks	39.5					
Deep Space Mission Systems	210.5					
Year to Year Increase		**-5.62%**	**0.91%**	**1.18%**	**2.39%**	**2.55%**

* FY 2008 Appropriation rescinded $192.475 M in prior-year unboligated balances, effectively reducing FY 2008 authority. Not included in totals.

** FY 2008 budgets are the enacted levels per the FY 2008 Appropriation as shown in the Agency's FY 2009 Budget Estimates.

Source: NASA

Appendix B
Missions Exceeding Congressional Cost and Schedule Thresholds

Mission	% Cost Growth (from Base Year)	Delay in Months (from Base Year)
NPOESS Preparatory Project	19	26
Glory	31	3
Aquarius	6	10
Orbiting Carbon Observatory	18	3
Kepler	25	8
GLAST	5	8
SOFIA	3	9
Herschel	13	14

Source: NASA Fiscal Year 2009 Budget, Management and Performance Section

Chairman UDALL. This hearing will come to order. Good afternoon. I want to welcome all of our witnesses to today's hearing. Today's hearing continues the Committee's review of NASA's fiscal year 2009 budget request, and this time we are going to focus on NASA's space and Earth science program.

NASA's science program has long been one of the agency's "crown jewels," and it has delivered outstanding results since the dawn of the Space Age 50 years ago, results that have rewritten the scientific textbooks and captivated the imagination of the public both here and around the world.

I want to see that record of accomplishment and inspiration continue. However, I am concerned that NASA's science program is facing an uncertain future under the funding plan offered by the Administration.

I know that Dr. Stern is going to put the best face on the outlook for NASA science in his remarks today, and he will point to a number of areas, such as funding for research and analysis and sub-orbital research where NASA has taken steps to improve what was a bad situation. And he undoubtedly will point to NASA's plans to initiate a number of exciting new science missions, including JDEM, an Outer Planets mission, a Solar Probe, two of the Earth Science missions recommended by the National Academies' Decadal Survey, and a Mars Sample Return mission.

I want to commend Dr. Stern for his efforts to address some of the stresses facing the science community from past NASA budgetary challenges and for the energy and commitment he has brought to his job. Yet, as we will hear from a number of our witnesses today, it is not at all clear that it is going to be possible to sustain those new initiatives in an effective manner under the Administration's assumed funding plan.

For example, the National Academies estimated that some $7 billion would be required over the next 12 years to carry out the 15 NASA Earth Science missions recommended in the Decadal Survey. However, the Administration's budget plan for the next five years would allocate less than $1 billion to that effort.

In the area of Mars exploration, the budget plan would cut the annual funding for the Mars program in half over the next five years, while still planning for the launch of an ambitious Mars Sample Return mission by 2018. And even though the cost of a Mars Sample Return mission has been estimated to be in the $5 billion or higher cost range, NASA is planning to spend only $68 million on technology risk reduction activities for the mission over the next five years, an amount that seems quite low for a mission of such complexity and difficulty.

Congress will better need to understand NASA's plans and assumptions as well as the impact on the current integrated Mars exploration program before we can feel comfortable in moving forward.

Another area of concern is the outlook for NASA's astrophysics theme. Not only is NASA estimating a cost for its new JDEM initiative that is lower than the cost estimate contained in the recent National Academies' Beyond Einstein Report, but in addition, essentially all of NASA's five-year funding wedge for future astrophysics missions is already assumed to be needed to compensate for low levels of reserves in the James Webb Space Telescope project.

I could go on, but the basic situation is clear. NASA's challenging new science initiatives are to be built on a budget that increases by only one percent through fiscal year 2011, and that assumes only inflationary increases at best in the years beyond that.

There will be little new money. Instead, there will be a continuing need to transfer of funds across the science accounts to support each new initiative, an approach some might call "robbing Peter to pay Paul."

I am very concerned that such an approach will not prove sustainable or credible. And assurances that improved cost controls will allow all the projects to be effectively carried out will need to be validated, given that eight NASA science projects have already exceeded statutory cost and schedule growth thresholds.

We have got a great deal to discuss today. I again want to thank all of our witnesses for participating in today's hearing, and I very much look forward to your testimony.

[The prepared statement of Chairman Udall follows:]

PREPARED STATEMENT OF CHAIRMAN MARK UDALL

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Well, we have a great deal to discuss today. I again want to thank all of our witnesses for participating in today's hearing, and I look forward to your testimony.

Chairman UDALL. The Chair would now like to recognize the gentleman from Florida, Mr. Feeney, the Ranking Member, for an opening statement.

Mr. FEENEY. Thank you, Mr. Chairman, and thank you for your opening statement. I appreciate all of our witnesses for taking time from their busy schedules to be with us today, and we greatly value your input and perspectives as we approach a new budgetary year.

Today's hearings examine NASA's fiscal year 2009 science budget, the changes proposed by this budget relative to fiscal year 2008 and their rationale. I commend Dr. Stern. We are glad to see you here today and his management team for putting together an exciting, responsive fiscal year 2009 budget request. Bearing in mind the NASA science budget profile is essentially flat, the fiscal year 2009 request nevertheless makes a good effort at remedying a number of deficiencies that have been highlighted in recent years.

In this request, Dr. Stern has demonstrated that he is listening to the research community by, among other things, adding resources to the research and analysis program, increasing the number and frequency of small missions and sub-orbital flights, and initiating missions proposed in the Earth Sciences Decadal Survey.

This budget request also proposes to add a flagship mission to the outer planets, initiate an exciting mission to explore the questions of dark energy, and rigorously control mission costs to ensure that the taxpayers receive maximum benefit.

I fully support all of these measures, particularly one to ensure that the continuity of missions and prevention of data gaps is preserved. Also flagship missions should not be allowed to crowd out smaller, but still scientifically important missions. A robust science portfolio should contain a variety of mission types and objectives.

Having said that, I want to re-emphasize concerns that I raised last month at our hearing on NASA's fiscal year 2009 budget. America is the world's premier space-faring nation. Space preeminence results from the inter-relationship among military, civil, and commercial space endeavors. Each augments the others. Leadership must be maintained in each activity. Strength in only one does not create space preeminence. This approach also applies to the separate NASA directorates. Each augments one another. Each must pursue and achieve excellence to ensure NASA remains the world's preeminent civil space agency. But as time passes that terrible February day when we lost *Columbia,* we run the risk of reverting to pre-*Columbia* behavior. As the Columbia Accident Investigation Board observed, NASA has usually failed to receive budgetary support consistent with its ambitions. The result is an organization straining to do too much with too little. Both the legislative and executive branches, as well as various NASA constituencies, are susceptible of lapsing into this behavior. We are often eager to assign new missions to NASA. This compliment stems from NASA's ability to perform the most difficult and extraordinary of assignments. But all of us, and I emphasize the use of the plural, shun from providing that which is necessary to continually achieve this excellence. The result of our actions is that NASA's resources are shrinking in real terms while the agency is charged with maintaining America's preeminence as a space-faring nation. The Columbia Accident Investigation Board observed "continued U.S. leadership in space is an important national objective. That leadership depends on a willingness to pay the costs of achieving it." I don't mean to divert this hearing's focus, but I want to emphasize that all of NASA's programs are interdependent. When extraordinary or unforeseen problems are encountered in one, it is not uncommon to see the effects ripple throughout NASA's other programs.

Turning back to NASA science, I remain awed by the breadth of missions that have been flown or are now flying, the discoveries they have enabled, and the cadre of exceptionally talented, motivated scientists and engineers who are the heart and soul of this enterprise. Their collective efforts have generated worldwide renown for NASA as an agency having no equal.

Having invested billions of dollars over the past 50 years to develop and nurture this extraordinary capability, it is imperative that we sustain it. As we begin the next 50 years of science and exploration, I want to ensure that NASA's science programs are not burdened by mistakes of the past. We must ensure more stability in policies, resources, and agency management. We must use accurate cost estimates. We must implement management controls to lessen the likelihood of skyrocketing growth in mission costs.

Later this spring, this subcommittee will begin drafting legislation reauthorizing NASA. I know our witnesses will provide us today with well-reasoned guidance and suggestions on how to provide policies and resources needed to sustain and build on NASA's record of achievements.

With that, again, I want to thank you, Mr. Chairman, and our witnesses, and I would yield back the balance of my time.

[The prepared statement of Mr. Feeney follows:]

PREPARED STATEMENT OF REPRESENTATIVE TOM FEENEY

Thank you, Mr. Chairman, for calling this afternoon's hearing, and my thanks to our witnesses for taking time from their busy schedules to appear before us. We greatly value your perspectives and judgment.

Today's hearing examines NASA's Fiscal Year 2009 science budget, the changes proposed by this budget relative to Fiscal Year 2008 and their rationale.

I commend Dr. Stern and his management team for putting together an exciting and responsive FY09 request. Bearing in mind that the NASA science budget profile is essentially flat, the FY09 request nevertheless makes a good effort at remedying a number of deficiencies that have been highlighted in recent years.

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Having said that, I want to reemphasize concerns that I raised last month at our hearing on NASA's Fiscal Year 2009 budget.

America is the world's premier space-faring nation. Space preeminence results from the interrelationship among military, civil, and commercial space endeavors. Each augments the other. Leadership must be maintained in each activity. Strength in only one does not create space preeminence.

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> *NASA has usually failed to receive budgetary support consistent with its ambitions. The result. . .is an organization straining to do too much with too little.*

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Later this spring this subcommittee will begin drafting legislation reauthorizing NASA. I know our witnesses will provide well-reasoned guidance and suggestions on how to provide policies and resources needed to sustain and build NASA's record of achievements.

Chairman UDALL. Thank you, Mr. Feeney. If there are Members who wish to submit additional opening statements, your statements will be added to the record. Without objection, so ordered.

[The prepared statement of Chairman Lampson follows:]

PREPARED STATEMENT OF CHAIRMAN NICK LAMPSON

I am deeply concerned about the state of NASA's budget and the Administration's request for FY09 both in general and in the case of the Science Mission Directorate. The President's budget request would not even fully cover the cost of inflation next year. While NASA has increased funding for science and new research projects, it has done so by shifting money from other accounts. Robbing aeronautics and Earth science to pay for science and exploration is not the path to a strong NASA—or to a strong American economy. I am pleased that NASA is taking steps to address recommendations made in the Decadal Surveys, but NASA cannot be successful in its missions if it is bleeding one account to boost another. I am disappointed that this is taking place and that we have been told that NASA will make do with resources available. I fear if we continue down this path of anemic funding and once again be caught behind the curve as we were in 1957.

The fact that NASA has so many priorities and missions that have not been fully funded, but has requested funding resulting in a $264.7 million decrease below the FY08 appropriation is troublesome. Especially concerning is the decreases in funding for Mars Exploration and technology development, in addition to delays and reductions in a number of programs across the Science Mission Directorate. These programs are vital to fulfilling the Vision and for expanding the benefits NASA technology provides for our society.

As the representative of Johnson Space Center, the home of the Astronaut Corp, I have long been a proponent of returning man to the Moon and sending humans to Mars. But I believe it is not just about the destination, but what we will discover about our universe and ourselves along the way. We all know the mission will spur technology and business and improve our quality of life. But we cannot do any of that if we are underfunding science. We will not have the answers we need to go further.

There is also an unquantifiable return on our investment—and that is the excitement in children's eyes when they watch a launch or tell you that they want to be an astronaut. We CAN afford to do this—we CANNOT afford NOT to.

Chairman UDALL. And in addition, I would like to include a statement for the record from the Planetary Society into today's hearing.

[The information follows:]

STATEMENT OF THE PLANETARY SOCIETY

The Planetary Society appreciates the attention and care paid to space exploration and the NASA budget by the House Science and Technology Committee. The influence of this committee has enabled the many great achievements of the United States in space. We are pleased to submit this statement relevant to your consideration of *NASA's Science Programs: Fiscal Year 2009 Budget Request and Issues.*

The Planetary Society is the largest space interest group in the world, representing more than 100,000 members and on-line activists from all walks of life. Space exploration, both human and robotic, creates enormous public interest and inspires both the generation that is privileged to work on it and the next generation that hopes we will create for them a positive vision of the future. Our advocacy for space exploration is based on that public interest.

Positive Developments

The 2009 NASA budget submission reflects many positive developments, notably in Earth and Space Science. We commend the Agency and praise Drs. Griffin and Stern for the jobs they are doing, balancing so many interests with so many constraints. After years of neglect for Earth Science by the Administration, we were pleased to see that they are proposing two new Earth-observing satellites, clearly responding to the U.S. National Research Council recommendations. A funding increase in NOAA for instrument development accompanied the NASA new starts for Earth observation missions. We hope both the NASA and NOAA increases will be supported by Congress. Earth observations are crucial to understanding the issues of global climate change. With Mars and Venus, we see examples of planets gone bad and can apply those lessons to better understanding our own world. One of the greatest benefits of space exploration has been the creation of assets that will help us deal with the great problems of monitoring and protecting the Earth.

NASA also proposes new funding to start an Outer Planets "Flagship" Mission, either to Europa in the Jupiter system or to Titan in the Saturn system. Their selection will be announced later this year. A Europa orbiter, recommended in the National Research Council (NRC) Decadal study, was advocated by The Planetary Society and endorsed by the Congress for the past two years. Previously NASA had rejected additional funds to start the mission. This year, however, they have said they will commit to the new start. The outer planets new start is overdue, and we ask Congress to support it.

Concerns Continue for Science

Over the past two years, The Planetary Society has conducted a "Save Our Science" campaign against cuts made by the Administration in the science budget to compensate for expected funding for the *Vision for Space Exploration* that has not materialized. Some saw our pro-science position as anti-exploration—but we emphatically reject any such interpretation: We are very much pro-exploration and see science and exploration as inseparable. We appreciate Congress' support of space science funding, and recognize that NASA's science program proposed in the FY09 budget takes account of that support. Some positive changes have been made, but only by transferring the pain from one program to another.

Unfortunately, the devastating cuts to science made two years ago are still felt in the new budget. This year the pain is transferred to Mars. The positive changes in NASA's new budget came at the expense of a $200 million cut (35 percent) in Mars exploration. This tactic of moving the cuts around from year to year to please one community while hurting another was more or less admitted in recent Congressional testimony when the Associate Administrator for Space Science said that they transferred money from the only program which got an "A" in the NRC Decadal Study evaluation (Mars) to bolster programs that got a "D" or "F."

Moon, Mars and Beyond is now Only the Moon

All of this moving money around within the Science budget does not alter the Administration's approach of scaling back the *Vision for Space Exploration* by reducing the Constellation program to just developing a new rocket and building a lunar base.

The *Vision for Space Exploration* was offered as a broad program of robotic and human exploration. It asserts the goal of landing astronauts on Mars, but in its first year of budget submission, the NASA Exploration Office was stripped of all Mars funding. The Mars Sample Return, then being initiated as a scientific robotic precursor to human space flight, had its funding canceled. Since then, culminating in this year's huge 35 percent cut, the program has been scaled back every year—despite the enormous public excitement about what is being found at Mars, lessons that teach us about past, present and future habitability.

That cut-back is described in the attached figure showing the Administration's proposed Mars budget since the *Vision for Space Exploration* was announced, as well as its five-year projection.

Mars Matters!

Mars exploration drives public interest in space. As Mars is the only planet we know, besides Earth, with accessible oxygen and water, it is a focus for understanding life and habitability of other worlds. For a decade now, the Mars program has been guided by the instruction to "follow the water." That strategy has proved very successful, but it is not time to turn off exploration—it is time to move to the next exciting stage.

Scientific questions about Mars now can focus on understanding conditions crucial to understanding life on other worlds and, even more importantly, conditions crucial to understanding life on planet Earth. Mars' thin CO_2 atmosphere, gigantic dust storms, and starkly revealed history of climate change provide a laboratory for studying atmospheric processes that are now changing Earth's climate.

As noted at the beginning of this statement, we are not a scientific special interest complaining that our area is being cut in favor of other scientific areas. Indeed, the Mars program problem does not affect only science program in NASA—it is a NASA-wide problem. The goal of human exploration is Mars; public interest in the search for extraterrestrial life centers on Mars; the question of humankind's future on other worlds will begin to be answered on Mars. Mars is firmly tied to understanding the processes of habitability and global climate change.

This is why the Mars program was fully restructured in 2000 into a strategic set of interrelated missions leading to robotic and then human sample return. That approach, binding exploration and science together, is now weakened. After the elimination of Mars from the Exploration program, Mars is now being diminished in the Science program. The planned 2011 Telecommunications and Science orbiter was first slipped to 2013. This year it is being moved to 2016 (with some uncertainty that it will even be included in the next five-year plan). The program of launching at every Mars opportunity, begun with Pathfinder in 1997, has been abandoned, and it appears likely that there will be no lander for more than a decade following the scheduled 2009 Mars Science Laboratory.

In principle, we support the new direction for Mars Sample Return proposed by NASA. But it is being offered with almost no technology development funds in the next five years. The Mars Exploration Program Analysis Group (MEPAG) recently reviewed this and concluded, "Without the assumption that the funding for Mars exploration will dramatically increase from the proposed level of $300–400M per year (FY11–13) to levels of $600–900M per year in the future, then MSR *cannot happen*" (emphasis added).

What we see is a microcosm of what has happened to the *Vision for Space Exploration*—offer a grand plan with promises for future years, then scale it back to remove its essence. For the Agency to be in the position of eliminating the goal of human exploration to fund its year-by-year needs is not just ironic, it is doomed to curtail public support for the program. We believe the reason that the *Vision for Space Exploration* and its first step with Constellation have failed to excite the public is because of diminishing the Mars goal and focusing on re-creating Apollo.

The Vision is Strong; Its Support is Weak

The Planetary Society is a *public*-interest group; we fully recognize the larger issues constraining NASA and its budget. We do not fault, and indeed we reiterate our praise of, the leaders of the Agency—specifically Drs. Griffin and Stern—doing great public service and the best they can in an over-constrained situation. Dr. Griffin's strong leadership to retire the Shuttle and move the human exploration goal forward deserves great praise. The lack of Administration support for its own Vision, and its reduction to a lunar base program, is not the fault of NASA. Political leadership and redirection is the only solution because budget pressures are going to get worse, and political priorities are certain to change next January.

For this reason, The Planetary Society joined with Stanford University's Department of Aeronautics and Astronautics to hold a two-day workshop of experts to "Examine the Vision." The Workshop conclusions were:

- It is time to go beyond LEO with people as explorers. The purpose of sustained human exploration is to go to Mars and beyond. The significance of the Moon and other intermediate destinations is to serve as stepping stones on the path to that goal.
- Bringing together scientists, astronauts, engineers, policy analysts, and industry executives in a single conversation created an environment where insights across traditional boundaries occurred.
- Human space exploration is undertaken to serve national and international interests. It provides important opportunities to advance science, but science is not the primary motivation.
- Sustained human exploration requires enhanced international collaboration and offers the United States an opportunity for global leadership.
- NASA has not received the budget increases to support the mandated human exploration program as well as other vital parts of the NASA portfolio, including space science, aeronautics, technology requirements, and especially Earth observations, given the urgency of global climate change.

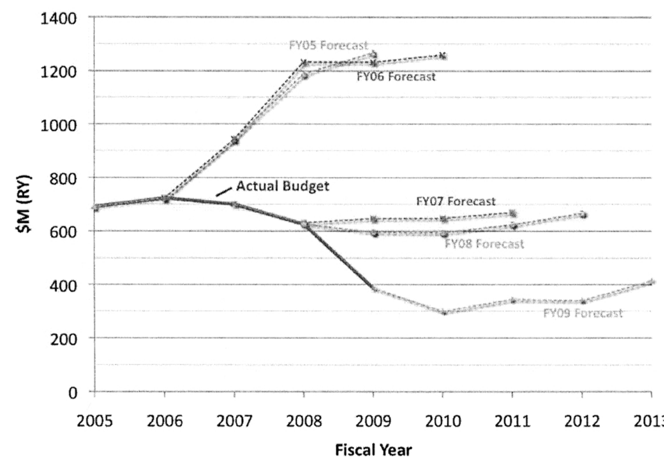
Some in the space community were looking for something more radical to come out of the workshop—a new destination or even elimination of the Vision. But the problem is not the Vision—it is with the blinders put around it. The Workshop's first conclusion emphasizes that Mars is the driver, and in our view, the lack of public enthusiasm is directly related to not tying both the Vision's human AND robotic elements to the Mars goal.

The third and fourth conclusions emphasize that the Vision has not yet found its political niche. Perhaps the next Administration will find it and will understand that the cost and risk of human space flight are only justified when they serve national and international geopolitical interests. We believe that the need to bring nations together in space and on Earth is interest enough. International cooperation, especially at the Moon where so many other nations are following American footsteps (and Russian robotic tracks), could lower costs and heighten interest. It could move us to Mars faster.

Which brings us to the fifth conclusion: The Vision has been underfunded, and that has caused dislocations that will only get greater. Budget should follow public support. Support requires that Mars be set as the goal for astronauts, and that the cost and risk be shared internationally. The proposed Mars Sample Return is also underfunded and also may fail to be realized. MEPAG and the NRC have rated Mars Sample Return a top priority, but it needs broader NASA support, and like the Vision, it needs international cooperation. We ask you to restore science and exploration funding for Mars to this end.

Congress should assert the public interest in Mars science and exploration. That way America will really have a *Vision for Space Exploration,* one that will serve our country and excite the world with adventure, discovery and inspiration.

5 Year History of Administration Mars Program Budget Proposals
Since the Vision for Space Exploration



Source: http://www.nasa.gov/budget

Chairman UDALL. Moving on, at this time I would like to introduce our panel of witnesses, and I might like to add we were conferring briefly during Mr. Feeney's statement. It looks like there will be two votes on the Floor of the House in the next 10 minutes or so, and what I would like to do is continue the hearing as long as we possibly can. Then we will recess temporarily to travel to the Floor and cast those votes.

Let me introduce this remarkable, impressive panel of witnesses we have today. First up we have Dr. Alan Stern, NASA's Associate Administrator for the Science Mission Directorate. Next to him, Dr. Lennard Fisk who is the Thomas M. Donahue Distinguished Professor of Space Science at the University of Michigan as well as the Chair of the National Research Council's Space Studies Board. Dr. Berrien Moore is at the center of the table who is the new Executive Director of Climate Central as well as the Chair of the National Research Council's Committee on Earth Studies. Next to him, Dr. Steven Squyres is the Goldwin Smith Professor of Astronomy at Cornell University as well as the principal investigator for the highly successful Mars Exploration Rover Project. And finally, it is a pleasure to introduce a constituent of mine from my home district of Boulder, Dr. Jack Burns who is a Professor of Astrophysics and Space Astronomy as well as the Vice-President Emeritus for Academic Affairs and Research at the University of Colorado at Boulder. Welcome. As our witnesses should know, spoken testimony is limited to five minutes each, after which the Members of the Subcommittee will have five minutes each to ask questions.

I am going to return to Dr. Stern, and I should so the record is clear also acknowledge that Dr. Stern is a constituent of mine as well as a long-time resident of Colorado and has taken on a very important assignment at NASA. We are very proud of the work that you have done, Dr. Stern. The floor is yours.

STATEMENT OF DR. S. ALAN STERN, ASSOCIATE ADMINISTRATOR, SCIENCE MISSION DIRECTORATE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

Dr. STERN. Thank you, Mr. Chairman. Chairman Udall, Ranking Member Feeney, Members of the Committee, thank you for inviting me here to discuss NASA's fiscal year 2009 budget request for the Science Mission Directorate. It has been my pleasure to serve for almost a year now here at NASA, and I want to acknowledge the strong support of both Administrator Griffin and the exemplary leadership team that we have at SMD.

These are exciting times in the space and Earth sciences. We are currently building or flying 85 separate flight missions, and we fund over 3,000 research grants to scientific investigators. In the past year alone, NASA satellites have observed new details of subtle interaction between the oceans, the atmosphere, and polar ice that portend global change. Messenger just gave humanity its first look at the unseen side of Mercury. Cassini continues to reveal new insights about Saturn, its rings, and moons. The Stereo Mission is providing revolutionary 3–D images of the sun, and our space telescopes Hubble, Chandra, and Spitzer are giving us tantalizing clues to the nature of dark matter, dark energy, and the revealing characteristics of planetary systems around other stars. These are just a few examples of exciting developments going on in our field. However, as we look ahead, as you know we are confronted with a series of challenges. When I arrived last April, I said that we would address the concern that SMD's portfolio had become too heavily weighted towards large missions at the expense of small and medium-scale opportunities. One of the most harmful consequences of this imbalance was in the steep reduction in the number of opportunities for flight research, particularly in the 2010 to 2012 timeframe. In addition I said that I would readdress the decline in funding for research analysis and the reduced science return on large investments that we are making in the science missions that we are flying. Well, I in the fiscal year 2009 budget request, we made budget priorities of these very important needs. We also adopted two additional budget priorities, accelerating progress on the Earth Science Decadal Survey and building a lunar science community. With Administrator Griffin's backing, the President's budget request accomplishes all of these objectives. More specifically the new budget request offers seven new funded starts, significantly increases R&A, steeply accelerates the sub-orbital program, initiates a lunar program, and makes a head-turning start on the Earth Science Decadal Survey.

As described in NASA's budget justification, the proposed program is fully supported with this request. To ensure that, we will continue to closely manage to cost and schedule through the development cycle. We will identify descoping options and appropriate trigger points. We will consider rescoping missions when cost boundaries are violated. We are also placing a new emphasis on the value of experienced principal investigators on ensuring adequate mission reserve funds and on stronger international collaboration ties.

Regarding our plans for mission new starts, it is important to note that we launched four missions last year, and we plan on launching six missions this year. As you know, when a mission is launched, its budget profile steeply declines from the development phase to the operations phase. Those 10 missions that we have launched represents 10 wedges that have opened up, and those are the wedges that are supporting in large measure the new starts financially that we are making in space and Earth sciences.

Now, I do want to point out that the nature of program management with any fixed budget means that resources are limited and choices have to be made. That is not a bad thing. In fact, it forces the clarity of purpose and prioritization that both NASA and the scientific community have embraced. But I do want to specifically highlight the fact that none of our four science areas with the budgets that we are proposing can achieve a balance program while sustaining two simultaneous flagship class missions. Therefore, it is inevitable that the astrophysics budget cannot bear a second flagship while developing JWST and that the planetary program cannot bear both the outer planets flagship and the Mars Sample Return. So we must do them in sequence and series rather than in parallel.

I believe we have been successful to date in this kind of regard, and I want to offer two examples of that success. The first is that in astrophysics we have scoped appropriate cosmology and exoplanet missions that are medium scale but can coexist with the development of JWST so that we can make progress before the development of JWST is complete in both dark energy and later in exoplanets.

The second example is in rectifying the D grade that the National Research Council gave us in terms of outer planet exploration. We intend to fix that, and we are doing that because the Mars program has enjoyed a recent high, a 25-year high in its budget that is almost unprecedented. That high is due to the fact that we have been developing a Mars flagship called MSL, the Mars Science Lab. As that development finishes, the Mars program will be returning to its historic average over the last 25 years to make room for the outer planets flagship. Then, following the development of the outer planets flagship, we will have an opportunity to ramp the Mars budget back up to do Mars Sample Return. And we take turns as we have in the past with Cassini, then Mars science lab, next outer planets flagship, and then Mars Sample Return.

In closing, I hope that the other witnesses here today share the view that the Earth and Space Science Program of the United States is the most ambitious and successful such program in the world. In fact, our efforts are the envy of the world. There is something every American can be proud of.

Thank you for the opportunity to share our plans and perspectives with you and for your support of our efforts to chart a bright future for the space and Earth sciences.

[The prepared statement of Dr. Stern follows:]

PREPARED STATEMENT OF S. ALAN STERN

Chairman Udall and Members of the Subcommittee, thank you for the opportunity to appear today as Associate Administrator for NASA's Science Mission Directorate (SMD). It's been my privilege to serve as Associate Administrator for almost a year now, and I want to acknowledge the support of SMD's exemplary management team over what has been an extremely busy and productive year.

Overview

These are exciting times for the Nation in the Space and Earth sciences. NASA satellites have observed interactions among oceans, atmosphere and ice to show how changes in the polar regions may reflect and portend global changes in climate. Elsewhere in the solar system, our MESSENGER (Mercury Surface, Space Environment, Geochemistry and Ranging) spacecraft just gave humanity its first look at the unmapped hemisphere of Mercury. Cassini continues to reveal new features of the moons and rings of Saturn, and of Saturn itself and its magnetosphere. The Great Observatories space telescopes (Hubble, Chandra and Spitzer) are giving us tantalizing clues of the nature and distribution of dark energy in the universe and revealing the characteristics of planets that circle other stars. The intrepid Voyager spacecraft are returning data from the termination shock where the shell formed by solar wind encounters interstellar space. The Aeronomy of Ice in the Mesosphere (AIM) spacecraft, launched in 2007 is providing revolutionary data on changes in noctilucent clouds that appear to be related to global change. These are but a few examples of exciting developments in NASA's space and Earth sciences program.

In 2007 NASA launched four new orbital and planetary science missions (Time History of Events and Macroscale Interactions during Substorms (THEMIS), AIM, Phoenix, and Dawn), two major airborne Earth science campaigns, plus some rapid-response airborne remote sensing aid to the California wildfire emergencies, and the first test flights of the Stratospheric Observatory for Infrared Astronomy (SOFIA) 747 airborne infrared observatory—all without any significant mishap or malfunction.

Further, no fewer than six new NASA orbital science missions reached their final stages of development and are expected to fly in 2008. These are: the Ocean Surface Topography Mission (OSTM), the Gamma-ray Large Area Space Telescope (GLAST), the Hubble Space Telescope Servicing Mission 4 (HST–SM4), the Orbiting Carbon Observatory (OCO), the Interstellar Boundary Explorer (IBEX), and the Solar Dynamics Observatory (SDO). We also continue the development of a Landsat follow-on mission and four other NASA Earth science missions, as well as a bevy of space science missions. And, we look forward in 2008 to the next MESSENGER flyby of Mercury (in October), the Phoenix Mars landing (in May), and the NASA Exploration Systems Mission Directorate's launch of the Lunar Reconnaissance Orbiter (LRO) and Lunar Crater Observation and Sensing Satellite (LCROSS) lunar missions.

These accomplishments and others in our program of over 90 flight missions and over 3,000 research grant activities describe a current program that is healthy, vigorous, and a model for the world. However, as we look ahead we are confronted with a series of challenges. NASA has heard repeatedly from the scientific community that its portfolio of missions has become too heavily weighted toward large missions at the expense of small and medium size opportunities. One of the most harmful consequences of this imbalance was a steep reduction in the number of opportunities for flight research, particularly in the 2010 to 2012 time period. Beyond the difficulties that this imbalance imposed on the current program, a lack of smaller "entry level" opportunities creates significant challenges as we seek to develop a skilled and capable cadre of investigators for the future. In addition, a decline in available resources for Research and Analysis (R&A) had the potential to exacerbate these problems and reduce the science return from the investments we make.

As we worked to develop the FY 2009 budget request we sought to address these issues by increasing the flight rate, rebalancing planned missions in favor of medium and small missions, increasing sub-orbital missions, and reversing the downward trend in funding for R&A. In addition, we adopted two additional budget priorities: accelerating progress on the new Earth Science Decadal Survey report; and building a lunar science community. The President's FY 2009 budget request for

NASA succeeds in implementing these goals while remaining within the planned Science Mission Directorate budget runout. This has been accomplished by launching numerous missions last year and thereby opening cost wedges for new missions; more closely managing costs; re-phasing the development of several missions; avoiding some cost overruns; and pursuing economies in the operations budgets for a number of missions. Looking to the future, it will be critical to continue to attack what is arguably the root cause of the imbalances we redress in the FY 2009 budget request: cost growth for missions in development. For at the end of the day, no strategy for maintaining a balanced program can succeed for long in the absence of disciplined program management.

Among the many steps NASA has taken, perhaps the most dramatic and direct is to initiate seven new missions with our FY 2009 budget request. These missions represent substantial progress in rebalancing the program and respond directly to the National Research Council's (NRC) decadal surveys (and related priority-setting activities) in each of our four disciplines within SMD: Earth science, astrophysics, planetary science, and heliophysics. These seven new missions are:

Ice Cloud and land Elevation Satellite (ICESat–II) will use lasers to measure the heights of ice sheets around the world to support climate change diagnosis and analyze forest canopies to inform our understanding of the carbon cycle. ICESat–II is planned for launch in 2015 and will be managed by NASA's Goddard Space Flight Center (GSFC) in Maryland.

Soil Moisture Active-Passive (SMAP) will observe soil moisture and freeze-thaw cycles to expand our understanding of weather and the water cycle. SMAP is planned for launch in 2012 and will be managed by the Jet Propulsion Laboratory (JPL) in California.

Joint Dark Energy Mission (JDEM) will measure cosmological parameters to explore the unseen dark energy that makes up most of the expanding universe. JDEM is planned for launch in 2014–2015 and will be managed by NASA's GSFC. JDEM is a joint mission with the Department of Energy.

Outer Planets Flagship will travel to one of three extremely interesting moons of the outer planets (Europa, Titan, or Ganymede) that may have the potential to support life. The Outer Planets Flagship is planned for launch in 2016–2017 and will be managed by the JPL.

Lunar Atmosphere and Dust Environment Explorer (LADEE) will explore and characterize the Moon's tenuous atmosphere. LADEE is planned for launch in 2010–2011, and will be managed by NASA's Ames Research Center with its program office at NASA's Marshall Space Flight Center (MSFC) in Alabama.

Lunar Network Landers will establish two nodes of a planned international seismic network for monitoring the Moon's internal processes. The landers are planned for launch in 2013–2014, and will be managed by NASA's MSFC.

Solar Probe Plus will fly through the Sun's atmosphere or "corona" to understand how the Sun's corona is heated and how the solar wind is accelerated. Solar Probe Plus is planned for launch in 2015 and will be managed by NASA's GSFC.

As is described in NASA's budget justification, these missions are fully supported within the request. These new missions are made possible within the out year projections in the FY 2009 budget request largely by the completion and launch of missions currently in development. NASA plans to launch more than 15 science missions over the next two years, creating the new mission opportunities the Agency and the community have regarded as critical to make further progress on the decadal survey priorities in each of the four science areas. Additionally, we are conducting studies of a host of other important new missions that we hope will reach new project status in coming years, including a new astrophysics mission to search for Exoplanets, a Mars Sample Return mission, two more Earth science decadal survey missions, and a future mission to study dangerous solar radiation.

Goals and Management Approach

When I testified before this subcommittee last year I described the following guiding principles for NASA's Science Mission Directorate (SMD):

- make strong progress advancing all four decadal surveys;
- accomplish more science from the SMD budget; and,
- help ensure that the *Vision for Space Exploration* is successful by increasing the scientific yield it will produce.

Further, I identified three areas for increased emphasis within NASA's budget for Science: strengthen investment in Research and Analysis (R&A); strengthen investments in mission data analysis to ensure that we get the best science value for the dollars we invest in missions; and, reinvigorate our program of sub-orbital research to train a new generation of researchers, advance technology development, and help bridge the 2010 to 2012 gap in orbital and planetary mission launches.

I will now discuss how each of these objectives is being addressed in SMD.

Advancing the Decadal Surveys in the FY 2009 Budget Request

NASA contracts with the NRC of the National Academies to identify and develop scientific consensus planning documents for each of the four science disciplines (Earth Science, Heliophysics, Planetary Science, and Astrophysics). These documents have become known as the "decadal surveys" because they assess proposed activities and recommend investment priorities over a 10-year timeframe for each discipline. In effect, "advancing the decadal surveys," means pursuing the highest value science objectives for each discipline as established by a consensus of leading scientists in the discipline.

The FY 2009 budget request includes $1.37 billion for Earth Science. This budget request represents a substantial step forward in responding to the recommendations of the first NRC Decadal Survey for Earth Science, released in 2007. The five-year budget runout requests $910 million for priorities enumerated in the survey and represents a major initiative in NASA to concentrate more heavily on Earth science at this critical time. This funding will support five Decadal Survey mission priorities, including the immediate start of two Decadal Survey new mission priorities—the Soil Moisture Active/Passive (SMAP) mission scheduled to launch as early as 2012, and the Ice, Clouds, land Elevation Satellite II (ICESat–II) scheduled to launch in 2015—as well as formulation of two additional Decadal Survey missions and a Venture class mission also recommended in the Decadal Survey.

The request also includes funding for over 1,700 research and analysis grants, the airborne program of Earth observations, the Applied Sciences program, and, seven missions in development which are important Earth science Decadal Survey precursor missions. The Landsat Data Continuity Mission (LDCM) and Ocean Surface Topography Mission (OSTM) will continue the decades-long time series of land cover change and ocean surface height data, respectively. The Glory mission targets the impact of aerosols on climate and extends the long time series of total solar irradiance measurements. The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) paves the way for the future national weather system and continues essential measurements from the NASA Earth Observing System (EOS). Aquarius and the Orbital Carbon Observatory (OCO) will make the first-ever global measurements of ocean surface salinity and atmospheric carbon dioxide, respectively. The request specifically increases funding for OCO and the Aquarius missions to maintain development schedules. The Global Precipitation Measurement (GPM) mission will make rainfall measurements on a global scale. The request retains the GPM core mission launch readiness date with a minor four-month slip in the launch of the constellation spacecraft.

As requested in the Subcommittee's invitation to testify, I have included a more detailed NASA Earth Science Architecture as Appendix I.

NASA is working closely with NOAA to restore climate sensors that had been removed from the tri-agency NPOESS effort under the Nunn-McCurdy recertification process in 2006. The FY 2009 budget request of $74 million for NOAA supports the addition of a Clouds and the Earth's Radiant Energy System (CERES) instrument onto NASA's NPP satellite, set to launch in 2010; instrument development and ongoing analyses to identify a suitable satellite platform for hosting the Total Solar Irradiance Sensor (TSIS); and development of climate data records. NASA is conducting development work on these sensors for NOAA on a reimbursable basis. In addition, NASA and NOAA are working together to initiate preparations for these sensors in FY08. These actions will be implemented through close coordination between NASA and NOAA, and they come in addition to the inclusion of the Ozone Mapping and Profiler Suite (OMPS)-Limb sensor on the NPP satellite that was announced last year.

NASA's role in the NPOESS program, in accordance with Presidential Decision Directive/NSTC–2, is to facilitate the development and insertion of new cost-effective technologies that will enhance the ability of the converged system to meet its operational requirements. NASA's primary stake in the NPOESS program is a scientific one: we look to NPOESS to provide long-term continuity of measurement of key climate parameters, many of which were initiated or enhanced by NASA's Earth Observing System. Toward this end, NASA has also entered into a partnership with the NPOESS Integrated Program Office (IPO) for the NPP satellite. NASA is committed to doing its part as a technology provider to make the NPOESS program, as restructured in the Nunn-McCurdy certification, succeed in collaboration with NOAA and the Department of Defense (DOD).

The Government Accountability Office and the Department of Commerce Office of Inspector General have reported on the NPOESS program and produced a series of recommendations which NASA will review and carry forward as lessons learned for the future. In broad terms, the issue of transitioning from research to operational climate monitoring will clearly require the continued close attention of both NASA and NOAA. NASA and NOAA are meeting on a regular basis to address these issues. In addition, experience with NPOESS and NPP illustrates the potential risks associated with attempting to address multiple mission requirements using a single spacecraft platform. As is noted below, it is absolutely critical to assure that mission concepts under consideration match a realistic projected budget profile and to appropriately "size" a mission from the earliest design phase. Notably, the Earth science Decadal Survey explicitly ruled out "large facility class (cost greater than $1 billion) missions" as inappropriate for Earth science research missions. Second, we must also effectively track and manage cost and schedule throughout the development cycle, identify and trigger de-scoping options at appropriate times to maintain cost ceilings, and consider canceling missions when those ceilings are violated. NASA is developing increasingly disciplined approaches to mission review that extend across the program and project levels.

The FY 2009 budget request for Astrophysics is $1.16 billion, which includes funding to initiate a Joint Dark Energy Mission (JDEM) in FY 2009 and to begin preparatory work to define a medium-scale exoplanet exploration mission to be initiated in FY 2010 and launched in the 2015 timeframe, for which a SIM–Lite concept and other exoplanet mission candidates will be considered. The request supports a restart of the Nuclear Spectroscopic Telescope Array (NuSTAR) Small Explorer with a launch date of no-earlier-than 2011. It also provides funding for the Kepler exoplanet search mission, which is planned for launch in February 2009 to detect planets in the "habitable zone" around other stars. The request further supports development of the Wide-field Infrared Survey Explorer (WISE), which will conduct an all-sky survey, and the James Webb Space Telescope, which will explore the mysterious epoch when the first luminous objects in the universe came into being after the Big Bang. With its first test flights completed, the Stratospheric Observatory for Infrared Astronomy (SOFIA) 747 airborne infrared observatory will begin early science observations in 2009. The Astrophysics suite of operating missions includes three Great Observatories (Hubble Space Telescope, Chandra X–Ray Observatory and the Spitzer Space Telescope), which have helped astronomers unravel the mysteries of the cosmos. The request will also support the Gamma-ray Large Area Space Telescope (GLAST), which is now planned for launch in May, 2008, to begin a five-year mission mapping the gamma-ray sky and investigating gamma-ray bursts. The request also increases funding for sounding rocket payloads, balloon payloads, detector technology and theory by augmenting Research and Analysis (R&A) funding by 35 percent over FY 2009 to FY 2012.

The FY 2009 budget request for Planetary Science is $1.33 billion to support an array of five currently operating spacecraft and rovers traveling to or now studying Mars, and four more missions en route to or operating at Mercury, the Asteroid Belt, Saturn, and Pluto, as well as a series of instrument missions of opportunity. The budget request initiates an outer planets flagship mission planned for launch in 2016 or 2017. The request also continues a robust Mars Exploration Program with targeted launches in 2009, 2013, 2016, as well as expanded U.S. participation in the European ExoMars mission planned for 2013 launch, and an increase in Mars R&A funds. The Phoenix lander arrives at Mars in May, 2008; the Mars Science Laboratory continues in development for launch in 2009; a Mars Scout Aeronomy mission is planned for launch in 2013, and a yet to be defined Mars science mission is planned for 2016. The request also includes $68 million for Mars Sample Return mission advanced development. With the New Horizons spacecraft continuing on its way to Pluto, the request realigns the New Frontiers Program's Juno Mission to Jupiter to be consistent with a 2011 launch date and funds initiation of the third New Frontiers mission, as called for by the planetary decadal survey. An open competitive solicitation for this mission is planned for release near the end of this calendar year, and planetary science R&A funding is augmented by 31 percent over FY 2009 to FY 2012. The NRC recently completed a midterm review of progress against the Planetary Science Decadal Survey, now five years old. NASA will be responding to the NRC's assessment in a separate report in the coming weeks, but it is worth noting that our budget request addresses many of the issues brought forth in that report, including the delayed development of the Outer Planets Flagship, New Frontiers 3, and the need for increased R&A funds.

Guided by the NRC's recent report: *The Scientific Context for Exploration of the Moon,* the FY 2009 budget request for Planetary Science includes a Lunar Science Robotic Mission Initiative funded at $60 million per year in FY 2009 to FY 2011, and at $70 million per year thereafter. NASA plans to launch a small lunar science orbiter by 2011 and two mini-landers by 2014. The mini-landers will function as nodes in a geophysical network, as called for in the NRC study.

The FY 2009 budget request for Heliophysics of $577.3 million funds a new Solar Probe mission which has long been sought by the U.S. scientific community and is recommended highly by the most recent Heliophysics Decadal Survey. The request also supports 16 currently operational missions, which will be joined in 2008 by both the Interstellar Boundary Explorer (IBEX) mission focused on the detection of the very edge of our solar system, and the Coupled ion-Neural Dynamics Investigation (CINDI) "Mission of Opportunity" that will provide new insight on the Earth's ionospheric structure. In early FY 2009, the Solar Dynamics Observatory (SDO) to study the Sun's magnetic field is planned for launch, and the Geospace Radiation Belt Storm Probes (RBSP) mission will begin development. RBSP will improve our understanding of how the Earth's radiation belts are formed and how solar output modifies the Earth's radiation belts. RBSP will be augmented by the Balloon Array for RBSP Relativistic Electron Losses (BARREL), which was selected in late 2007 as a Geospace Mission of Opportunity. The FY 2009 budget request also increases budgets within Heliophysics for Sounding Rockets, Research Range, and R&A to achieve a more robust level of small payload opportunities. Funding for R&A is augmented by 22 percent over the FY 2009 to FY 2012 timeframe.

The Heliophysics request fully supports the Explorer program, including the three new Small Explorer (SMEX) missions we are presently in the process of selecting for flight. It further includes funding for NASA's New Millennium Program, a cross-cutting technology flight validation program with the overall goal of reducing risk and cost for science missions. However, this program has not been a cost effective mechanism for achieving this goal, and New Millennium's technology contributions to science missions have been limited, despite substantial investments. The Program has not contributed to reducing cost and risk for science Missions at a level commensurate with the resources dedicated to the program. In many cases, New Millennium has flown technologies that were not later useful for the science missions we build in response to NRC decadal surveys. Further, the resources required for launching and supporting New Millennium missions consume substantial resources which might otherwise be dedicated to technology development. In light of these facts, NASA has determined that it can achieve substantial improvement in technology development performance and application effectiveness by phasing out the New Millennium Program and integrating most technology development funds into the budgets for specific missions. We have already demonstrated this approach with the development of the James Webb Space Telescope and are now implementing this approach more widely so that we can get more science from the budget we have.

Getting More Science Accomplished from the Available Budget

The first step in controlling mission costs is to assure that mission concepts under consideration match available funding targets. Rather than selecting mission content up to the available funds or in anticipation of potential efficiency gains, we are now selecting mission content that leaves sufficient "head room" in the budget profile to deal with the future challenges that inevitably arise in developing missions that have never been done before. In Astrophysics, this means treating JDEM as a "Keplerclass" or mid size mission, while fully retaining its ability to meet the basic science requirements described in the Dark Energy Task Force Report established by the Astronomy and Astrophysics Advisory Committee and High Energy Physics Advisory Panel. Similarly, as we begin preparatory work on a medium-scale exoplanet exploration mission, we will size the science content and capabilities to fit within the available budget profile. In Heliophysics, a redesign of the Solar Probe mission to be executable within the available budget has resulted in Solar Probe Plus. The redesigned mission will use a series of Venus flybys rather than a single Jupiter flyby to provide the necessary gravity-assist to enable the probe to approach the Sun, lowering costs and producing quicker science return than had been possible previously. The new mission design substantially reduces projected costs by eliminating the need for radioisotope power systems and sparing the spacecraft from the extreme cold associated with a trip to Jupiter.

The second step in controlling mission costs is to track and manage cost and schedule effectively throughout the development cycle, identify and trigger descoping options at appropriate times to maintain cost ceilings, and consider canceling missions when those ceilings are violated. In conjunction with this, we are developing increasingly disciplined approaches to mission review that extend across the program and project levels.

For example, Kepler successfully passed its Critical Design Review (CDR), which marks the completion of the project's design phase and transition into the build up of flight hardware, in October 2006. However, certain problems continued, putting the overall mission at risk. Facing further potential cost growth of up to $54M, a Kepler project management meeting was held in Boulder, Colorado, on July 6, 2007, to examine the program's cost overruns and the program's plan for bringing the spacecraft to launch within the established budget. The plan included restructuring the project's management and changing or eliminating some tests or reducing their duration. No tests that affect the safety or ultimate performance of the system have been dropped, and all changes to the testing program were reviewed by multiple internal and external parties. The resulting plan has a healthy 24 percent reserves to launch. In addition, the lead industrial partner, Ball Aerospace & Technologies Corporation, gave up some of its earned fee on the project and the development schedule reserves were also refined. In order to keep the mission within its established cost cap, the total on-orbit observation time will be reduced by six months, but no significant science will be lost and the mission will be able to gather 90 percent of its planned data. The savings realized by avoiding a Kepler cost increase removed a threat to the Explorer Program budget and helped us re-initiate the NuSTAR mission, thereby getting more from the SMD budget.

In May 2007, the SDO mission had incurred schedule slips against the August 2008 Launch Readiness Date (LRD) that exceeded reserves. Schedule flexibility had been exhausted by instrument and spacecraft difficulties and was not recoverable. The Project's first cut at a replan identified a proposed LRD of 3/1/09 at an additional cost of $46.3 million. That estimate was subsequently improved to a 1/15/09 LRD and cost increase of $39.3 million by immediately accepting hardware deliveries with acceptable performance, deleting internal schedule reserves on instrument deliveries, and using week-end and second shifts to meet near-term deliverables. Through further iterations with the project team, NASA identified a combination of low-impact schedule de-scopes and mission scope reductions that did not impact mission science objectives. The net result of these replanning efforts was a 60 percent cost reduction in the cost increase, from $46.3 million and a seven month launch delay to $18.1 million and a four month launch delay. At present, the project is maintaining schedule and working toward the approved Life Cycle Cost (LCC) of $805 million.

NASA's approach to both the SDO and Kepler issues conform to the general principle that resources to solve project problems should come first from the mission lines or programs that include that project. Problems in programs and missions should be addressed within the Division (science area) in which they occur whenever possible. Further, we will not sacrifice the future to sustain significant budget overruns by missions in development. It is critical to the future of the program that we take these steps now to control costs and to establish a more disciplined program management regime.

Helping to Ensure Exploration Goals are Achieved

The FY 2009 budget request for SMD makes significant strides toward establishing a strong lunar research community. The request includes a Lunar Science Robotic Mission initiative funded at $60 million per year in FY 2009 through FY 2011, and $70 million per year beyond FY 2011. This effort builds on and will be highly complementary to NASA's existing lunar science research activities by providing a flight program that delivers exciting scientific results. The first mission, a small science orbiter called Lunar Atmosphere and Dust Environment Explorer (LADEE), will characterize the tenuous lunar atmosphere as recommended by the NRC. LADEE will launch by 2011, and an initial pair of surface geophysical mini-landers will follow by 2014. NASA is optimistic about the prospect of developing an International Lunar Network of geophysical landers and has already received positive feedback from a number of potential partners. The request also strengthens lunar science by providing support for the development of the newly selected Gravity Recovery and Interior Laboratory (GRAIL) Discovery mission, which will use high-quality gravity field mapping of the Moon to determine the Moon's interior structure. We also established the NASA Lunar Science Institute (NLSI) at the Ames Research Center to jump start U.S. lunar science across the Nation. NLSI will augment other, already established lunar science investigations funded by NASA by funding the formation of interdisciplinary research teams. Management of the NLSI will be modeled after the highly-successful focused research initiative of the NASA Astrobiology Institute (NAI), also managed at NASA Ames.

Strengthening Research and Analysis and Mission Data Analysis

We have taken a number of steps in this area to ensure that we get the best science value for the dollars we invest in missions. These include establishing a Research and Analysis Management Operations Working Group to identify R&A process improvements. We are also working to improve our practices for conduct of panel reviews of proposals to improve transparency and provide additional guidance to R&A program managers. We are also working to restore funding cuts from prior years. The FY 2009 budget request augments R&A in three of our four science areas (the augmentation in Earth Science came in the area of new missions as recommended by the new NRC decadal survey):

- Astrophysics R&A augmented 35 percent in FY 2009–FY 2012;
- Heliophysics R&A augmented 22 percent in FY 2009–FY 2012; and,
- Planetary Science R&A augmented 31 percent in FY 2009–FY 2012.

R&A increases in the Earth science area will be evaluated in the coming year, as will the need for additional space science increases. To better evaluate the need for funds in specific scientific disciplines, we are developing "demand metrics" that help us guide funds to areas with the strongest scientific interest, and therefore with the strongest proposal pressure.

Reinvigorating Sub-orbital Research

In recent years, cost growth in large missions constrained opportunities for new small, Principal Investigator-led missions, creating an imbalance and limiting launch opportunities, particularly in the 2010 to 2012 time period. We have made substantial progress in addressing this issue by reinvigorating sub-orbital research to train a new generation of researchers, advance technology development, and help to bridge the 2010 to 2012 gap in orbital and planetary mission launches. This includes initiating seven new missions with the FY 2009 budget request, restarting the NuSTAR mission, selecting two new Scout (ExoMars 2013) and two new Discovery Missions of Opportunity (as two new assignments for the Deep Impact and Stardust spacecraft), and creating an annual Mission of Opportunity solicitation. The FY 2009 budget request increases budgets for Sounding Rockets, Balloon Payloads, Research Range, and Research and Analysis to achieve a doubled level of small payload sub-orbital research mission opportunities.

Conclusion

It is worth stepping back to appreciate the breadth, depth and productivity of the NASA science program I am charged to lead. Not including the seven missions we are proposing to initiate in the FY 2009 request, we have 55 flight missions in operation, 30 missions in development, and over 3,000 ongoing research grants. The 14 on-orbit NASA Earth science research missions are producing definitive data sets that let us specify state of the planet and how the environment is changing. Heliophysics' 16 operating missions are revealing the behavior of our local star in detail. Missions to other planets continue to provide us with descriptions of the amazing diversity that we now know characterizes the solar system and tantalizing hints of environments hospitable to life. Our Astrophysics great observatories Hubble, Chandra, and Sptizer are probing the most profound questions of how the universe arose and evolved and our place in it. This program of research is far and away the worlds leading program. Historically, we are living through a truly spectacular age discovery in space, and the United States is leading these discoveries. We cannot only see more and farther and deeper than any other generation in history, we are learning more at an incredible rate. The Subcommittee and the American taxpayers you represent should be proud of the historic human achievement that our program represents. I certainly am, and I am committed to both inspiring the next generation of explorers with new discoveries and passing on a healthy and vigorous program of scientific exploration to the next generation of scientists.

Appendix 1:

Earth Science Architecture

Current Missions

To address the challenges of recording simultaneous observations of all Earth components and interactions to generate new knowledge about the global integrated Earth system, NASA and its partners developed and launched the Earth Observing System and ancillary satellites. Fourteen satellites comprise today's NASA Earth Observing System.

The scientific benefit of simultaneous Earth observation—the Earth System Science construct—is bearing fruit. For example, NASA's Aqua, Aura, Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), and CloudSat satellites and France's Centre National d'Etudes Spatiales (CNES) Polarization and Anisotropy of Reflectances for Atmospheric Sciences (PARASOL) satellite, collectively known as the A–Train, are in specific orbits to record unprecedented atmospheric chemistry and composition observations over the same region within 15 minutes. The A–Train, a subset of EOS, is the largest Earth science space super-observatory flown to date.

Missions in Development

Seven missions are in formulation and implementation for launch during FY 2008–2014. The new observations will extend some of the measurements made by EOS and will observe new features of the global integrated Earth system. The enormous complexity of the Earth system presents a challenge for NASA within the Group on Earth Observations (GEO): to enable sustained simultaneous observations of all key variables needed to understand Earth's changing environment.

NASA and its National Polar-orbiting Operational Environmental Satellite System (NPOESS) partners (NOAA and Air Force) are developing the NPOESS Preparatory Project (NPP) mission. NASA and the NPOESS program planned NPP as a risk reduction mission as well as the transition mission for a set of mature climate measurements from the EOS era to the NPOESS operational environment. When the NPOESS development encountered cost and schedule problems, the Nunn-McCurdy recertification process resulted in the de-manifesting of several climate sensors from the NPOESS system. These sensors included ozone profiling (OMPS–Limb), Earth radiation budget (CERES), solar irradiance (TSIS), ocean altimetry (ALT), and aerosol polarimetry measurements (APS). NASA and NOAA have been working in cooperation OSTP to develop a plan for flight of these sensors. Agreement has been reached to re-manifest OMPS–Limb on NPP via joint funding from NASA and NOAA, to re-manifest CERES on NPP, and to prepare TSIS for future re-manifesting.

Table 4.1a: Earth Science Missions in Development
(Launch Dates in Parentheses)

Ocean Surface Topography Mission (2008) Strategic mission; Systematic measurement	Required for continuity of precision, global ocean altimetry data; planned as part of a transition to operational agencies. Joint mission with NOAA, CNES and EUMETSAT.
Orbiting Carbon Observatory (2008) Competed mission; Earth System Science Pathfinder	Small PI-led mission nearing completion of development. First global measurement of CO_2 from space; small Earth science mission.
Glory (2009) Strategic mission; Initializes a systematic measurement	Addresses high priority objective of the U.S. Climate Change Science Program. Measures global aerosols, related cloud properties, and solar radiation. Mandated by the Presidential Climate Change Research Initiative of 2001.
NPOESS Preparatory Project (2010) Strategic mission; Systematic measurement	Required for continuity of several key climate measurements beyond the Earth Observing System and into the NPOESS era. Joint mission with the NPOESS Integrated Program Office.
Aquarius (2010) Competed mission; Earth System Science Pathfinder	In advanced stage of development. First global measurement of sea surface salinity from space; PI-led small Earth science mission. NASA instrument on an Argentine mission.
Landsat Data Continuity Mission (2011) 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. Joint mission with USGS.
Global Precipitation Measurement (2013) Strategic mission - Initializes a systematic measurement	Recommended by decadal survey report (NRC, 2007); extend spatial coverage to global and temporal coverage to every 3 hours via a core satellite and a constellation of smaller satellites.

Future Missions

The decadal survey priorities are now NASA's principal determinant of the priority of Earth science satellite missions beyond 2010.

The decadal survey recommended fourteen missions for NASA to launch during 2010–2020 and one mission for NASA to jointly implement with the National Oceanic and Atmospheric Administration (NOAA) for launch in 2010–2013. NASA missions were grouped into three periods—near-term, mid-term, and late-term. In contrast to decadal surveys in other areas of NASA science, the Earth science Decadal Survey recommended an integrated slate of missions rather than a list of missions prioritized scientifically from the top down with an expectation they be pursued to the limit of funds available. In the NRC's view, doing some missions but not others would break the observing strategy they proposed, requiring a reassessment. Further, the survey recognized the importance of the synergies between the flying research and operational missions—synergies that would be lost if the timeline for the decadal survey missions is greatly extended. Thus, NASA is pursing all four of the missions identified in the NRC's first time block and planning technology investments and other preparatory analyses for the others. The NRC explicitly ruled out "large facility class (greater than $1.0 billion) missions" as inappropriate for Earth Science.

Matching the matured mission concepts with the budget projections in the President's FY 2009 budget request, NASA will pursue the first two decadal survey missions and the first Venture class mission with projected launch dates as shown:

Soil Moisture Active-Passive (SMAP) – 2012	Soils moisture and freeze-thaw for weather and hydrological cycle processes.
Ice, Cloud and land Elevation Satellite (ICESat-II) – 2015	Ice sheet height changes for climate change diagnosis and assessment of land carbon standing stock.
Venture class mission – 2014 Small mission	Innovative science mission to address science goals complementary to those identified in the NRC decadal survey for NASA. The new Venture class was recommended by the decadal survey.

The next two decadal survey missions to be implemented will likely be the Climate Absolute Radiance and Refractivity Observatory (CLARREO) and the Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI) mission, with the order of these two yet to be determined. It is planned to start both by 2012, and to launch one by 2017 and the other by 2019.

BIOGRAPHY FOR S. ALAN STERN

Dr. S. Alan Stern is the Associate Administrator for NASA's Science Mission Directorate.

He directs a wide variety of research and scientific exploration programs for Earth studies, space weather, the solar system and the universe beyond. In addition, he manages a broad spectrum of grant-based research programs and spacecraft projects to study Earth and the universe.

Stern is a planetary scientist and an author who has published more than 175 technical papers and 40 popular articles. His research has focused on studies of our solar system's Kuiper belt and Oort cloud, comets, satellites of the outer planets, Pluto and the search for evidence of solar systems around other stars. He has worked on spacecraft rendezvous theory, terrestrial polar mesospheric clouds, galactic astrophysics and studies of tenuous satellite atmospheres, including the atmosphere of the Moon.

Stern has had a long association with NASA, serving on the NASA Advisory Council and as the principal investigator on a number of planetary and lunar missions, including the New Horizons Pluto-Kuiper Belt mission. He was the principal investigator of the Southwest Ultraviolet Imaging System, which flew on two Space Shuttle missions, STS–85 in 1997 and STS–93 in 1999.

He has been a guest observer on numerous NASA satellite observatories, including the International Ultraviolet Explorer, the Hubble Space Telescope, the International Infrared Observer and the Extreme Ultraviolet Observer.

Stern joined NASA in April 2007 from the Southwest Research Institute's Space Science and Engineering Division, Boulder, Colo., where he had served as Executive Director of the Space Science and Engineering Division.

He holds Bachelor's degrees in physics and astronomy and Master's degrees in aerospace engineering and planetary atmospheres from the University of Texas, Austin. In 1989, Stern earned a doctorate in astrophysics and planetary science from the University of Colorado at Boulder.

He is an instrument-rated commercial pilot and flight instructor, with both powered and sailplane ratings. Stern and his wife have three children.

Chairman UDALL. Thank you very much, Dr. Stern.

Dr. Fisk.

STATEMENT OF DR. LENNARD A. FISK, THOMAS M. DONAHUE DISTINGUISHED PROFESSOR OF SPACE SCIENCE, UNIVERSITY OF MICHIGAN; CHAIR, NATIONAL RESEARCH COUNCIL SPACE STUDIES BOARD

Dr. FISK. Thank you, Mr. Chairman. You asked a series of questions of me in your invitation of me, so let me just simply address the questions that you asked.

You asked whether the Space Science Program is moving in the right direction. There are, as has been noted, many positive features in the proposed fiscal year 2009 budget for the Science Mission Directorate. There are seven new starts, there is an increase in the research and analysis budget. The space science community is buoyed by the opportunities to pursue new science missions and it is relieved that the unwise decisions of the past that were the guard to R&A have been reversed. All of these positive features have been achieved, however, within a fixed budget of only one percent annual growth, and this is a problem. Some of the new starts come at the expense of other programs that are displaced or deferred. The growth in Earth science is clearly heartening given the importance of the program, but it came at the expense of other divisions.

So in many ways SMD is a graphic illustration of the dilemmas that face all of NASA, too few resources to accomplish the many tasks that the Nation has faced before the agency. Whether it is exploration, the use of the Space Station, aeronautics, or science, the funding is not adequate to do all the things that SMD should be doing. SMD is doing extremely well with what it has, trying to maintain the vitality of the space and Earth science program, but there is so much more that we could be doing.

You asked in particular about heliophysics. There is good news here also. There is a new start for the Solar Probe mission which together with the European Space Agency's Solar Orbiter mission for which NASA has agreed to provide part of the payload presents a historic opportunity to develop a comprehensive and predictive understanding of the basic processes that control the solar atmosphere and its influence in particular on Earth.

You asked me about the status and health of the science and engineering workforce. The civil service workforce at the NASA has a disturbing age distribution. It is strongly peaked at age 45 to 49, with only a small fraction that are under 30 and almost an equally small fraction that are over 60. It needs to be rejuvenated, but that of course is a difficult task with the constraints that exist on NASA.

With regard to the space and engineering workforce outside of NASA, there are students available to participate in the space program. Here the issue is the quality of the students. Why should the best and the brightest choose careers in space given that we have not made space a national priority?

There is a need for hands-on training of these students which has the corollary benefit by that providing such training to undergraduates invariably recruits them into careers in space.

You asked about the status of the NASA space weather program. Here there is a need to be sure that there is an adequate monitor of space weather events at the L–1 point which is in front of the

Earth, but that may well be a NOAA responsibility. We also need to recognize that a true capability to predict space weather will only come when we have developed adequate understanding of the governing physical processes, and that in turn requires a comprehensive heliophysics research program at NASA.

Finally, I would like to comment on the issues that need to be addressed in the reauthorization of NASA which I understand you are considering. We are four years into the *Vision for Space Exploration* announced by President Bush in 2004. So far the money that was promised to execute the Vision has not been provided, and it is hard to say that the Vision has generated much excitement, particularly among the young who are expected to benefit most from the future the Vision promises.

I encourage you to ask whether there was a flaw in the Vision which we did not realize at the time. Vision is about the future, extending our civilization into space, but there is little of immediate concern to the taxpayers. And so I encourage you, as I would encourage the next Administration, to provide NASA with a role that is not only about the future but it is also important in the present. It could be a geopolitical role that improves our national image. It could be a role that improves our competitive position. It could be a reemphasis on those programs in NASA that are of demonstrable interest to the taxpayer, like Earth science or like aeronautics.

Thank you very much.

[The prepared statement of Dr. Fisk follows:]

PREPARED STATEMENT OF LENNARD A. FISK

Mr. Chairman, Members of the Subcommittee, thank you for inviting me here to testify today. My name is Lennard Fisk, and I am the Thomas M. Donahue Distinguished University Professor of Space Science at the University of Michigan. I also served from 1987 to 1993 as the NASA Associate Administrator for Space Science and Applications. I am currently the Chair of the National Research Council's Space Studies Board, although the views I offer today are my own.

In your invitation letter asking me to testify before you today you asked a series of questions that I would to address now in sequence.

The State of the Space Science Program

You asked me to comment on whether the space science program is moving in the right direction. I would like to expand this question to read: Is space science moving in the right direction and are the resources adequate to achieve success?

The budget for the Science Mission Directorate (SMD), and its projected runout, has many, very positive features. There are new starts for seven different missions. Each of the major disciplines—planetary, astrophysics, heliophysics and Earth science—has at least one major new start. Earth science in particular is able to begin making progress in pursuit of the science objectives of its recent NRC decadal survey. There are also increases in the Research & Analysis program, which is vital to the health and the future of space science. The space science community is buoyed by the opportunity to pursue important new science missions and relieved that the unwise decisions of the past have been reversed.

All of these positive features of the SMD program have been accomplished within a fixed budget envelope, which is currently, and for the next few years, growing at only one percent per year. This is a problem. Some of the new starts in the budget come at the expense of other programs that are displaced or deferred. The growth in Earth science is heartening given the importance that society places on deploying NASA's technical prowess to understand global climate change. The growth in Earth science, however, came by taking funds from other science disciplines, all to remain within the fixed budget envelope. Moreover, there is no flexibility in the SMD budget, no robustness. A single major setback in the cost of some mission under development would seriously stress the carefully woven plan of maintaining the vitality of all the different science disciplines.

It needs to be recognized also that NASA's response to the NRC Earth science decadal survey is inadequate if we are serious about understanding global climate change. That decadal survey report pointed out that the Earth science budget has decreased by about $500 million per year since 2000. Restoration of at least this amount of annual funding is required in order that the Nation can have a satellite system that adequately provides the sound scientific underpinning for planning for the inevitable climate change that lies before us. However, in the runout of the SMD budget to FY 2012 only a total of about $600 million, not $500 million per year, is provided. To be sure, the increased funds for Earth science are all that are available in an overall flat budget. The new funds come from the other science disciplines, and to take more would devastate those constrained, but otherwise healthy programs.

In many ways SMD is a graphic illustration of the dilemmas that face all of NASA—too few resources to accomplish the many tasks that the Nation has placed on the agency. Whether it is human space exploration, the use of the Space Station, aeronautics, or science, the funding is not adequate. SMD is doing well with what it has, trying to maintain the vitality of the space and Earth science communities, and to move the program forward with new mission opportunities. However, there is so much more that needs to be done, whether it is a solid start on the Earth science decadal survey recommendations, a vigorous Mars program, a full Living-with-a-Star program, or a vigorous program to understand the astrophysical challenges of dark energy and dark matter. And the budget needs to be robust so that it is actually executable. The funding constraints on all of NASA and on SMD in particular need to be lifted, and the required resources need to be provided so that the Nation can have the space program that the Nation needs and deserves.

The State of Heliophysics

You asked me to comment in particular on whether the Heliophysics program is moving in the right direction. Heliophysics is the study of the Sun, the heliosphere (i.e., the region of space created by the solar wind, the outward expansion of the solar atmosphere), the plasma environment of the planets, and the coupling and interactions among these various environments. Research in Heliophysics is essential for understanding the coupling between the Sun and Earth, and for predicting the space environment through which our space assets and eventually our astronauts will fly.

There is good news in this program. As in other disciplines in space science, there is an increase in the Research & Analysis program budget and a new start for the Solar Probe mission. This good news is tempered, as in other disciplines, by the reality that the increase in budget for these elements of the program came at the expense of other planned initiatives, which cannot now be pursued. The budget envelope for Heliophysics is fixed, and in fact has been used, in part, to provide Earth Science with needed funds to make a start on its decadal survey missions. In the case of Solar Probe, then, the required funds have come from the Living-with-a-Star program, which is now unable to pursue, in the near term, either the Sentinel program or missions to the ionosphere.

The new start for Solar Probe should be viewed, then, as a realignment of the scientific priorities. NASA has judged that it is more important to make direct measurements in the region of the solar atmosphere closest to the Sun, than are other priorities such as the study of the ionosphere. This logic is understandable. The inner region of the solar atmosphere is the source of the solar wind and solar energetic particles. It is a region where current instrumentation cannot observe the governing magnetic field and where direct in-situ observations are required to resolve the many mysteries that inhibit our ability to predict the space environment created by the Sun. The Solar Probe mission was endorsed by the 2003 NRC decadal survey for this field. It was considered to be an important, large mission for which funds beyond the planned budget envelope needed to be provided. This has not proven to be feasible, and the required funds have been taken from other planned missions. The science priority, however, of Solar Probe is not in question.

The planned Solar Probe mission is very clever, and solves a number of the concerns associated with previous concepts for Solar Probe. Solar Probe needs to make multiple passes through the solar atmosphere, which is a dynamic, ever changing environment. Only by multiple passes can we avoid confusion that arises from the fact that this is such a dynamic place. The required multiple passes are achievable because the planned Solar Probe mission does not penetrate as close to the Sun as some previous versions of Solar Probes were planned to do. However, the current Solar Probe concept is judged by the scientists who have studied the mission in detail to have a penetration distance that is adequately close to be able to resolve the fundamental processes resulting in the heating of the solar atmosphere and acceleration of energetic particles.

The other important feature of the planned Solar Probe mission is that it is to be undertaken in concert with the European Space Agency Solar Orbiter mission, for which NASA has agreed to provide part of the payload. Solar Orbiter is to be placed in an orbit around 30 solar radii from the Sun, and to achieve an orbit that is inclined to the solar equator. From this vantage point, a capable set of remote sensing instrumentation will make detailed observations of the solar surface and atmosphere, and a capable set of in-situ instruments will observe the solar outputs of plasma and energetic particles in detail.

It should be possible to have Solar Orbiter in place while Solar Probe is doing its penetrations deep into the solar atmosphere, and the combination will be an historic opportunity to once and for all develop a comprehensive, predictive understanding of the basic processes that control the solar atmosphere and its influence on the heliosphere, and on the Earth and other planets. There is, however, an obligation with this combined program that must be met. The instrumentation on both Solar Probe and Solar Orbiter must be comprehensive and complete. The investment in these missions will be large, and the scientific payloads need to be capable of realizing the scientific breakthroughs that this historic opportunity will allow.

The Status and Health of the Science and Engineering Workforce

You asked for my perspectives on the status and health of the science and engineering workforce as it relates to NASA's space and Earth science plans. I would respond to this question from several different perspectives.

Let me comment first on the NASA workforce. The age distribution of the civil service workforce at the NASA centers is disturbing. It is strongly peaked at age 45–49, with only a small fraction of the workforce under 30, and almost an equal number over 60. There needs, in my judgment, to be a rejuvenation of the NASA workforce. Experience is important, but more current training, particularly in the engineering disciplines, and the enthusiasm, energy, and willingness to explore new concepts that inherently come with youth, are important as well. It will not be easy to rejuvenate the NASA workforce. Fixed budgets, the current age distribution, and the requirement mainly imposed by Congress for 10 healthy NASA centers places severe restrictions on NASA's ability to hire new scientists and engineers.

There is an unfortunate corollary to NASA's inability to rejuvenate its workforce. We want our best young scientists and engineers to aspire to participate in the Nation's space program, yet it is widely known that the prospects for jobs at NASA, and thus a major leadership role in the exploration of space, are meager at best.

Next I would comment on the science and engineering workforce outside of NASA. The number of students available to participate in the space program is probably adequate for the simple reason that space requires only a small fraction of the Nation's science and engineering workforce. The issue here is the quality of the students, their particular training, and their attitude when they enter the workforce.

There are many capable science and engineering students in this country. The question is why should the best and the brightest aspire to participate in the space program when there are so many other exciting technical challenges that lie before them. The students see a space program that is not a national priority sufficient to receive the funding and support that is necessary for its success. Under these circumstances, only those students who have always aspired to pursue a career in space are likely to enter the field, as opposed to those who have the talents and the capabilities to pursue many different technical disciplines. Thus workforce and priorities for space are linked. If space becomes a national priority, the Nation's highly capable technical workforce will respond.

There is also a question of training. It is essential that engineers in particular receive hands-on training with real space projects or space-related hardware. The vast majority of the senior technical workforce currently executing the space and Earth science program had hands-on opportunities earlier in their careers, and they all would say that it was essential for their current success. We should expect no difference for the next generation. It is incumbent upon NASA to provide the universities with the opportunities to offer their students hands-on experience if we are to continue our technical success.

The previous two items are strongly coupled. The experience in most universities is that when students have hands-on research experiences in space engineering as undergraduates they invariably decide to pursue careers in space. If NASA provides universities with the opportunities to offer hands-on experience, not only does the required training occur, but the best and the brightest are recruited into space.

Finally, there is the issue of attitude, particularly among young scientists entering the fields of space and Earth science. Space science is 50 years old this year;

Explorer 1, the first space science mission, was launched in 1958. In a science discipline at this age, which is dominated now by scientists who have practiced their disciplines for decades, inevitably there are well established points of view that have been developed, which are resistant to new ideas. It is important that the new scientists entering the field challenge these established points of view, for that is how progress is made in science. And it is incumbent upon NASA, through its Research & Analysis program, to encourage new approaches and new thoughts, so that progress is made and the true answers to the many mysteries of the universe are revealed. Consequently, I strongly support the proposed increase in funding for the Research and Analysis program.

The State of NASA's Space Weather Program

You asked what is the status of NASA's program to collect data and conduct research on space weather. There are two aspects of this issue that I would like to address: first, the monitoring of space weather that affects Earth, and second, our ability to learn how to predict space weather.

It is important to have a spacecraft at the Sun-Earth L1 point in front of Earth that can provide real-time warning of space weather events that will impact Earth, and also provide information on solar wind conditions for basic research on the response of the Earth's magnetosphere, ionosphere, and atmosphere to space weather events. At present this information is provided by the Advanced Composition Explorer (ACE), which was launched in 1997. It is unwise to rely entirely on ACE and its instrumentation, some of which is showing signs of age. It is possible to put up a relatively inexpensive spacecraft to perform the basic monitoring function. I would add that such a spacecraft may be more appropriately a NOAA rather than a NASA responsibility, since NOAA is to provide operational space weather predictions.

The second issue is our ability to develop a true predictive capability for space weather. It is not sufficient simply to monitor the immediate arrival of a space weather event, or to base predictions on general correlations between events on the Sun and the arrival of space weather disturbances at Earth. Rather, we need to have an adequate understanding of the basic physical processes that govern the acceleration of the solar wind, the release of Coronal Mass Ejections, and the acceleration of energetic particles. With this understanding, we will eventually be able to make detailed observations of the Sun, put that information into comprehensive numerical models, and make real-time predictions of the space weather that will impact the space environment of the entire solar system, and of the Earth in particular.

The pursuit of a detailed understanding of the basic physical processes that govern the solar atmosphere and its extension into space, the response of the space environment of Earth, and the development of comprehensive numerical models is the main purpose of the Heliophysics Division in SMD. It is important that these efforts be encouraged so that a true predictive capability is developed as soon as possible. Missions such as Radiation Belt Storm Probes, which are currently under development, are important for understanding the response of the Earth's magnetosphere to space weather events. Missions such as the upcoming Solar Dynamics Observatory and the proposed Solar Probe and Solar Orbiter, which I discussed earlier, are essential for developing an understanding of the basic mechanisms that heat the solar atmosphere and accelerate energetic particles.

It is also important to make maximum use of the space assets currently in place to study the Sun and the plasma environments that the Sun creates throughout the solar system. There is a flotilla of spacecraft in place known as the Heliophysics Great Observatory. These missions, from the recently launched STEREO missions that observe the Sun and its outputs in 3–dimensions to the venerable Voyager missions probing the distant heliosphere, all are essential to our understanding of the physics that governs the plasma processes in our solar system. It is important to use these missions in a coordinated way, to derive the maximum possible information from them, and in doing so to create the scientific foundation for the predictive models of space weather that we require.

Issues to Address in the Reauthorization of NASA

You asked for input on the important issues that should be addressed with respect to NASA's space science program as Congress considers its reauthorization of NASA. I would like to take the liberty of answering this question in the broader context of NASA as a whole since I do not believe that the NASA space science program can be considered separately from NASA's overall activities and goals.

We are now four years into implementing the *Vision for Space Exploration* that was announced by President Bush in January 2004, and it is worth a critical analysis of where we are. So far, with the exception of the initial FY 2005 budget, the

Administration has not requested the funds it said were required to execute the Vision. There were underestimates of the costs required to continue to fly the Shuttle and complete the International Space Station. Consequently, NASA has been forced to cannibalize much of the rest of its program to even begin to make progress on the Vision. And it is hard to say that the Vision of returning to the Moon has generated much excitement, or even understanding among the public, particularly among the young who are expected to benefit most from the future that the Vision promises.

We should ask ourselves whether there was a flaw in the *Vision for Space Exploration,* which we did not recognize at the time. The Vision is all about the future—extending our civilization into space, with the long-term benefits that we expect to accrue for our country. There is, however, little in the Vision that is of immediate concern. So when near-term needs intervene, such as providing funds for the war in Iraq or for Hurricane Katrina, it is NASA that comes up short in funding.

I would encourage you, then, as you consider the reauthorization of NASA, as I would encourage the next Administration, to provide NASA with a role that is not only about the future, but is important in the present. There are several ideas worth discussing:

NASA could use, and serve, a more important geopolitical role. The obvious one is to lead the world in the exploration of space, in a cooperative and facilitating way. NASA then becomes an instrument of our foreign policy through its ability to improve the image and impact of the United States around the world. If that is important to the next Administration then perhaps the resources necessary for NASA to play its proper role in leading the world will be provided.

NASA could use, and serve, a more important role in improving the competitive position of the United States, through the encouragement of technology development, entrepreneurialism, and technical education. This would be a new emphasis for NASA that would encompass more than just human space flight, which is an engineering challenge but which does not often emphasize new technologies. It is the science disciplines of NASA, with their needs for new sensors and electronics and robotic capability that are a better stimulus for technology.

And finally there are the programs in NASA that are of demonstrable immediate importance to the taxpayers—Earth science to provide the scientific basis for understanding global climate change, and aeronautics. In the current implementation of the Vision these programs have been allowed to decline and atrophy, and they deserve strong re-emphasis.

BIOGRAPHY FOR LENNARD A. FISK

Lennard A. Fisk is the Thomas M. Donahue Distinguished University Professor of Space Science at the University of Michigan, where from 1993–2003 he was Chair of the Department of Atmospheric, Oceanic, and Space Sciences. Prior to joining the University in July 1993, Dr. Fisk was the Associate Administrator for Space Science and Applications of the National Aeronautics and Space Administration. In this position he was responsible for the planning and direction of all NASA programs concerned with space science and applications and for the institutional management of the Goddard Space Flight Center in Greenbelt, Maryland and the Jet Propulsion Laboratory in Pasadena, California.

Prior to becoming Associate Administrator in April 1987, Dr. Fisk served as Vice President for Research and Financial Affairs and Professor of Physics at the University of New Hampshire. In his administrative position, he was responsible for overseeing the University's research activities and was the chief financial officer of the University. Dr. Fisk joined the faculty of the Department of Physics at the University of New Hampshire in 1977, and founded the Solar-Terrestrial Theory Group in 1980. He was an astrophysicist at the NASA Goddard Space Flight Center from 1971 to 1977, and a National Academy of Sciences Postdoctoral Research Fellow at Goddard from 1969 to 1971.

Dr. Fisk is the author of more than 190 publications on energetic particle and plasma phenomena in space. He is a Member of the National Academy of Sciences (NAS) and the International Academy of Astronautics (IAA); he is a Foreign Member of Academia Europaea and a Fellow of the American Geophysical Union. He currently serves as Chair of the NAS Space Studies Board; he is a co-founder of the Michigan Aerospace Corporation and a Director of the Orbital Sciences Corporation. He is the recipient of the NASA Distinguished Service Medal in 1992, the AIAA Space Science Award in 1994, and the IAA Basic Science Award in 1997 and 2007.

He is a graduate of Cornell University. In 1969, he received his doctorate degree in Applied Physics from the University of California, San Diego.

Chairman UDALL. Thank you very much, Dr. Fisk.
Dr. Moore.

STATEMENT OF DR. BERRIEN MOORE III, EXECUTIVE DIRECTOR, CLIMATE CENTRAL, INC.; CHAIR, COMMITTEE ON EARTH STUDIES, SPACE STUDIES BOARD, NATIONAL RESEARCH COUNCIL, THE NATIONAL ACADEMIES

Dr. MOORE. Mr. Chairman, Ranking Minority Member, and Members of the Committee, thank you for inviting me to testify today.

Mr. Chairman, as you and your colleagues know well, the world faces significant and profound environmental challenges. Shortages of clean and accessible fresh water, degradation of terrestrial and aquatic ecosystems, increases in soil erosion, changes in the chemistry of the atmosphere, declines in fisheries, and above all, rapid pace of substantial changes in climate. Information from NASA and NOAA's environmental satellites is critical to addressing these problems, but as a result of significant cuts over several past budget cycles, the growth in the cost of accessing space and the development of instruments and inflation generally, we find ourselves with a growing mismatch between needs and resources. The fiscal year 2009 budget begins to readdress some of this imbalance, but much more will need to be done for many budget cycles to come.

Let me now turn to some of the questions that you asked. Is NASA headed in the right direction and what changes would I recommend?

The President's fiscal year 2009 budget for NASA includes a major new initiative in Earth science and applications including a plan to provide $910 million over five years that addresses to varying degrees the Decadal Survey's nearest-term recommendations. In addition, the budget provides for the restoration for the ozone limb sensor to the NPOESS Preparatory program to integrate the Earth's radiation instrument series back onto NPP and to support identification of a possible flight for the total solar irradiance sensor. All of this is very welcome news, but I have several concerns. The initiatives funding for Earth science comes, as Dr. Fisk noted, at the expense of other NASA science programs. Approximately two-thirds of the additional $910 million for Earth science are obtained by drawing resources away from the other science areas in the Science Mission Directorate. As I will note in my next point, Earth science requires an ongoing commitment of funding and at a higher level than is provided in the fiscal year 2009 budget runup and a simple redistribution of resources will not be a long-term solution. As has been noted by Members of this committee, NASA is being asked to accomplish too much with too little. What is needed is an increase in the overall top line budget for NASA which, in turn, will allow an increase in NASA science budget.

Let me illustrate the point. This I provide in my testimony, and it is simply an update of what was in the Decadal Survey where we looked at the past 10 years in constant fiscal year 2006 dollars. We have now updated this graphic, looking in the past to now include the future, and that is to look at the proposed budget fiscal year 2008 as well as the fiscal year 2009 and the five-year runout. In fiscal year 2006 constant dollars, the runout slope turns negative after two years. This simply says that we really are not yet on a path to addressing the recommendations of the Decadal Survey.

I am encouraged, of course, and I must be encouraged about the renewed emphasis on Earth science. However, without additional resources, there is a limit to what management's best intentions can accomplish. The NASA Earth Science Program is doing what it can with the resources it has been given. It has not been given enough to accomplish what is expected of it, and more importantly, all that the Nation needs.

What further challenges do I foresee for NASA in the Earth science and what would I recommend to address those challenges? If you look at the proposed response to the Decadal Survey, you see that three missions other than the venture class, three missions are being recommended. From the first set of four missions that we recommended, one to fly in 2012 dealing with solar moisture, one to fly in 2015 dealing with sea ice, and one to fly in 2017. So by 2017, we will have flown off three of the 17 recommended missions. The overall program recommended by the Decadal Survey simply is not being adequately implemented.

I would like to suggest two challenging important actions. First, for both the Science Mission Directorate and the Earth Science Division, there should be a Congressional plus-up above the President's request. Congress did this last year, and the result was particularly positive since it served not only to achieve the direct benefits one might expect but it also encouraged industry to begin to invest anew in the technologies relevant to the missions recommended by the Decadal Survey.

For the Earth sciences, the target should be at a greater implementation of the missions recommended as well as particular technology investments in the missions in the 2013 and 2016 timeframe.

Finally, dealing with the reauthorization, we need to view NASA and particularly Earth observations in the overall federal structure. A key to making more efficient use of scarce budget resources is to develop a comprehensive approach to Earth observation from space. The Decadal Survey Committee expressed great concern that the Nation's civilian space institutions, NASA, NOAA, and the USGS are not adequately prepared to meet society's rapidly evolving Earth information needs. These institutions have responsibilities that are in many cases mismatched with their authorities and resources. Institutional mandates are inconsistent with agency charters. Budgets are not well-matched to emerging needs, and shared responsibilities are supported inconsistently by the mechanisms of cooperation.

It is important I believe that OSTP execute promptly the recommended study for a substantial overall comprehensive plan for Earth observation. I am encouraged that they are doing this. I simply worry that the time is running out in this Administration.

Thank you very much.

[The prepared statement of Dr. Moore follows:]

PREPARED STATEMENT OF BERRIEN MOORE III

Mr. Chairman, Ranking Minority Member, and Members of the Committee: thank you for inviting me here to testify today. My name is Berrien Moore III. For the past 20 years, I was Director of the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire. Recently, I have assumed the position of Executive Director for a new nonprofit organization, Climate Central, to be located in Princeton, NJ and Palo Alto, CA. I appear, today, largely in my capacity as the recent Co-Chair of the National Research Council (NRC)'s Committee on Earth Science and Applications from Space, which authored the first "decadal survey" for the Earth Sciences and as the current Chair of the National Research Council (NRC)'s Committee on Earth Studies of the Space Studies Board. This said, the views expressed in today's testimony are my own, but I believe they reflect community concerns.

Mr. Chairman, the world faces significant and profound environmental challenges: shortages of clean and accessible freshwater, degradation of terrestrial and aquatic ecosystems, increases in soil erosion, changes in the chemistry of the atmosphere, declines in fisheries, and above all the rapid pace of substantial changes in climate. These changes are not isolated; they interact with each other and with natural variability in complex ways that cascade through the environment across local, regional, and global scales. Information from NASA and NOAA environmental satellites is critical in addressing these problems, but as a result of significant cuts over several past budget cycles, growth in the cost of accessing space and in development of instruments, and inflation, we find ourselves with a growing mismatch between needs and resources. The fiscal year 2009 budget for NASA begins to redress some of this imbalance, but much more will be needed for many budget cycles to come.

I will now turn to the specific questions included in the letter of 28 February 2008 that I received from the Committee:

1. Do you believe NASA's space science program, and especially the Earth science program, is moving in the right direction? What, if any, changes would improve the program, and why? Please elaborate on your perspectives.

Last June, this subcommittee held a hearing, *"NASA's Earth Science and Applications Programs: Fiscal Year 2008 Budget Request and Issues."* In opening statements, the Chair of the Subcommittee (Udall) and its now Ranking Minority Member (Feeney) stated that:

> "I called today's hearing for the purpose of examining how well NASA's plans and programs compare to the priorities of the decadal survey, and the extent to which NASA intends to support those priorities in the FY08 budget and beyond. As numerous witnesses before this Committee have testified, the situation facing NASA's Earth Science program is not good. . .to quote the Decadal Survey, the Nation's system of environmental satellites is 'at risk of collapse.'"—Rep. Mark Udall (D–CO)

> "NASA's Earth Sciences program has produced stunning scientific results, often demonstrating, for the first time, measurements and capabilities that have never before been accomplished. I want that record of achievement to continue, and it's also my desire that we build upon the program's success to enable the goals established in the Decadal Survey."—Rep. Tom Feeney (R–FL)

The Subcommittee hearing focused on NASA Earth science programs in general and the recommendations of the recently completed National Research Council decadal survey, *"Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond"* in particular. The decadal survey outlined near-term actions meant to stem the tide of capability deterioration and continue critical data records, as well as forward-looking recommendations to establish a balanced Earth observation program designed to directly address the most urgent societal challenges facing our nation and the world.

Testifying on behalf of the Decadal Survey Steering Committee, in which I served as Co-Chair, Dr. Richard Anthes, President of the University Corporation for Atmospheric Research, outlined the key elements of the recommended program:

- Restoration of certain measurement capabilities to the NPP, NPOESS, and GOES–R spacecraft in order to ensure continuity of critical data sets.
- Completion of the existing planned program that was used as a baseline assumption for this survey. This includes (but is not limited to) launch of GPM in or before 2012 and securing a replacement to Landsat 7 data before 2012.

- A prioritized set of 17 missions to be carried out by NOAA and NASA over the next decade. This set of missions provides a sound foundation for Earth science and its associated societal benefits well beyond 2020.
- A technology development program at NASA with funding comparable to and in addition to its basic technology program to make sure the necessary technologies are ready when needed to support mission starts over the coming decade.
- A new "Venture" class of low-cost research and application missions that can establish entirely new research avenues or demonstrate key application-oriented measurements, helping with the development of innovative ideas and technologies. Priority would be given to cost-effective, innovative missions rather than ones with excessive scientific and technological requirements.
- A robust NASA Research and Analysis program, which is necessary to maximize scientific return on NASA investments in Earth science. Because the R&A programs are carried out largely through the Nation's research universities, such programs are also of great importance in supporting and training the next generation of Earth science researchers.
- Sub-orbital and land-based measurements and socio-demographic studies in order to supplement and complement satellite data.
- A comprehensive information system to meet the challenge of production, distribution, and stewardship of observational data and climate records. To ensure the recommended observations will benefit society, the mission program must be accompanied by efforts to translate raw observational data into useful information through modeling, data assimilation, and research and analysis.

In order to lay the foundation for implementing the full set of recommendations during the next decade, we further recommended these very near-term actions:

First, NASA should commit to and begin to implement its recommended Decadal Missions. Although, the NASA budget for Earth Sciences is not now adequate to implement the survey recommendations (see next question), a useful start can be made with modest resources. The survey's initial seven missions (2010–2013) should begin in 2008; the first four (CLARREO, SMAP, ICESat–II, and DESDynI) should begin intensive Phase A activities and the next three (for the time period 2013–2016—HyspIRI, ASCENDS, and SWOT) should begin pre-Phase A studies. *Increment needed beyond President's Request in FY08: $90 million.*

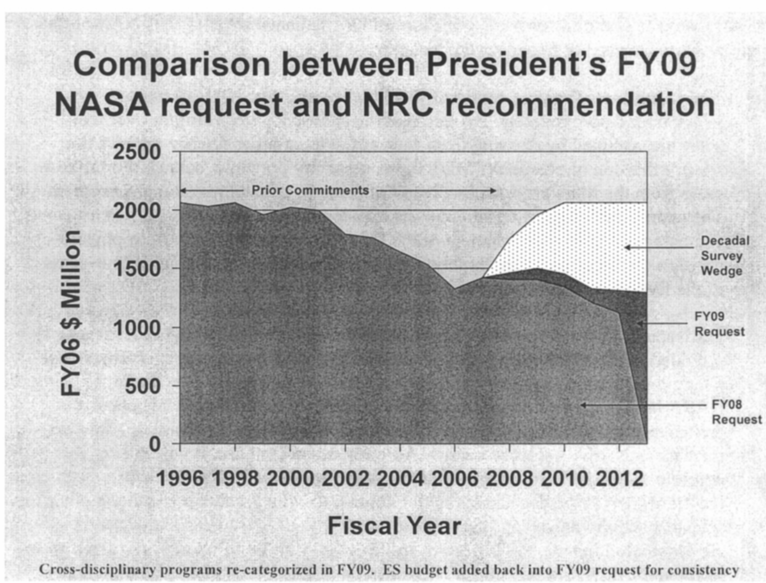
Second, NASA should increase its suborbital capabilities. NASA's airborne programs have suffered substantial diminution and should be restored. In addition, NASA should lead in exploiting unmanned aerial vehicles (UAV/technology). Both conventional and UAV aircraft are needed for instrument development, and hence risk reduction and technology advancement, and for their direct contribution to Earth observations. *Increment needed beyond President's Request in FY08: $10 million.*

Third, NASA should increase support of its Research and Analysis (R&A) program and in Earth System modeling. Improved information about potential future changes in climate, weather, and other environmental conditions is essential for the benefit and protection of society. This improvement will come from: a) better observations (the recommended missions and enhanced suborbital capabilities); b) more capable models of the Earth System; and c) a vigorous research program to use the observations in models and interpret the results. The R&A program has suffered significant cuts in recent years and these should be reversed. R&A investments are among the most cost-effective as they directly exploit on-going missions, advance knowledge to better define what is needed in the future, and sustain and develop the requisite scientific and engineering workforce. *Increment needed beyond President's Request in FY08: $20 million.*

The President's fiscal year 2009 budget for NASA includes a major new initiative in Earth science and applications, including a plan to provide $910 million over five years (FY 2009–2013) that addresses to varying degrees the items above and begins implementation of the decadal survey's nearest-term recommendations. In addition, the budget provides funding to restore the OMPS–L sensor to the NPOESS Preparatory Project (NPP) spacecraft, which is now scheduled for launch in 2010, integrate a spare CERES instrument on NPP, and support instrument development and analyses to identify a suitable satellite platform for hosting the total solar irradiance sensor (TSIS). All of this is very welcome news, but I have several concerns:

- **The Initiative's funding comes at the expense of other NASA science programs:** Approximately two-thirds of the additional $910 million over five years are obtained by drawing from each of the three other science areas in the science mission directorate (SMD). In the planetary portfolio, some $200 million came from the Mars program as a result of delay in a Scout mission procurement. The contribution from the Heliophysics division included changes such as a stretching out in the development of the Solar Probe mission. The Astrophysics division contributions were largely obtained by reducing funding in the out-years of the five-year plan, (2011–2013).

  Earth science requires an ongoing commitment of funding at a higher level than is provided in the FY09 budget run-out and redistribution of resources simply is not a long-term solution to the problem. As noted by Members of this committee, NASA has been asked to accomplish too much with too little; what is needed is an increase in the overall top-line budget for NASA, which in turn will allow an increase in NASA's science budget. Absent such an increase, it will not be possible to restore Earth science funding to the needed FY 2000 levels (as recommended in the decadal survey) without inflicting great damage to the other science portfolio areas.
- **As illustrated below, the Initiative still falls very short of what is required to implement the Decadal Survey.** Below is an updated version of a graphic that we prepared for the Decadal Survey; it now includes budget profiles from the FY08 and FY09 Presidential budgets (FY08 and FY09). As before, we present the data in FY06 dollars to remove the effects of inflation. It is evident that after an initial rise, funding for Earth science at NASA actually begins to decrease again.
- **The climate record from NPOESS is still very much in danger.** As this committee knows too well, cost and schedule problems triggered a Nunn-McCurdy review of the NPOESS program. Many of the specific capabilities related to better understand, predict, and eventually mitigate the effects of global climate change were lost in the restructured program. The changes to NPP and the decision to find a platform for a new TSIS are welcome news, but, as detailed in a forthcoming NRC report, far from what is needed. Finally, NOAA must have adequate resources to support the development and stewardship of Climate Data Records. This was addressed in both the Interim and Final reports of the decadal survey, and I call it again to the attention of the Committee.



In summary, I am encouraged by the renewed emphasis on Earth science at NASA; however, without additional resources, there is a limit to what management's best intentions can accomplish. The NASA Earth science program is doing what it can with the resources it has been given; it simply has not been given enough to accomplish all that is expected of it, and, more importantly, all that the Nation needs. I address explicitly what further needs to be done in my answer to Question Two below.

2. What, if any, challenges do you foresee for the future of the NASA Earth science program as presented in the FY 2009 budget request? What are your suggestions for addressing those challenges?

As I noted in my response to question #1, the FY09 NASA Earth science program request is very good news, but I am concerned about whether the initiative can be sustained and whether it is advisable to fund Earth science at the expense of other NASA science programs. The planned addition of $910 million over five years to the Earth science budget also still leaves a very large shortfall in what is needed to execute the recommendations of the decadal survey (see again the figure above).

The 17 missions recommended by the decadal survey are organized into sets in order to take most advantage of concurrent observations to advance our understanding of Earth as a system—four missions are recommended for launch in the 2010–2013 timeframe. In contrast, the FY09 budget plans for one to launch in 2012 and a second in 2015. A third is slated for 2017. This makes the concurrent observations between missions very difficult. The overall program recommended by the decadal survey is simply not being adequately implemented.

I would like to suggest two challenging and important actions: First, both the Science Mission Directorate and the Earth Sciences Division need a budget plus above the President's request. Congress did this last year, and the result was particularly positive since it served to not only achieve the direct benefits one might expect, but it also encouraged industry to begin to invest anew in technologies relevant to the missions recommended by the decadal survey. For the Earth sciences, the target for this Congressional increase should be a) more rapid implementation of the first four missions and b) a greater technology investment in the missions in the 2013–2016 timeframe—particularly the first two or three missions in the 2013–2016 timeframe. Second, Congress should address the inadequacies in the out-year budget; this could be particularly important as the executive branch of government goes through a transition.

3. As NASA begins to plan missions recommended in the National Academies Earth science Decadal Survey, what actions do the Decadal Survey and other community input recommend to further the applied use of the data for societal benefits and the transition of research data into operational service? What, if any impediments exist that could constrain progress in this area, and how can they be overcome?

In the decadal survey report, the steering committee expressed a particular concern with the lack of clear agency responsibility for sustained research programs and the transitioning of proof-of-concept measurements into sustained measurement systems. To address societal and research needs, both the quality and the continuity of the measurement record must be assured through the transition of short-term, exploratory capabilities, into sustained observing systems. The elimination of the requirements for climate research-related measurements on NPOESS is only the most recent example of the Nation's failure to sustain critical measurements. Therefore, our committee recommended that, *"The Office of Science and Technology Policy (OSTP), in collaboration with the relevant agencies, and in consultation with the scientific community, develop and implement a plan for achieving and sustaining global Earth observations."* In addition, we recommended that the plan recognize the complexity of differing agency roles, responsibilities, and capabilities as well as the lessons from implementation of the Landsat, EOS, and NPOESS programs.

I am pleased to note that this recommendation is being taken very seriously by the OSTP. It is my understanding that they are developing an overall strategy for Earth observations policy, which will include interagency issues of the kind raised in the decadal survey as well as issues related to the U.S. contribution to a global observing system and GEO.

The issue of an overall national strategy and plan for Earth observation is of central importance, and I return to it below in my answer to the Committee's final question.

Another area that requires attention is the NASA applied sciences program. Last year, the NRC completed a review of this program; at the end of my testimony, I attach a copy the recommendations from that report. These recommendations are entirely consistent with those in the decadal survey; we also noted that the key to meeting societal needs for Earth observation data is to have the potential "users" of these data represented in a substantive way from the earliest stages of mission development, determining priorities, designing products, and evaluating benefits. As noted in my response to question #1, renewed support for the NASA Research and Analysis program is also critical to the success of the applied sciences program.

4. The Committee on Science and Technology plans to reauthorize NASA this year and in so doing will communicate policy direction to NASA as well as to the next Presidential Administration. What, in your view, are the most important issues with respect to NASA's Earth science programs that Congress should consider in its reauthorization of NASA?

NASA should consider how to best leverage its Earth science program resources to accomplish both the intended science and societal outcomes as described in the decadal survey. An integrated programmatic approach is required to align efforts towards these common goals. This means coordination of, for example, NASA's technology development investments to ensure needed technologies are ready to support recommended missions. It also will require additional support to applications end-users' involvement in mission formulation, and targeted R&A investments to begin work on laying the scientific foundation needed to maximize the value of mission observations. In other words, we need to eliminate the traditional "stove pipe" approach, which often decouples funding priorities between program elements; sustained programmatic attention is required to implement the needed missions in a reasonable timeframe. Yet, as we stressed in the decadal survey, the program must also provide opportunities for entirely new measurements and approaches and so programmatic flexibility must be retained to both accommodate and enable new discoveries.

A key to making more efficient use of scare budget resources is to develop a comprehensive approach to Earth observations from space. As stated above in my response to question 3, the decadal survey committee expressed great concern that the Nation's civil space institutions (including NASA, NOAA, and USGS) are not adequately prepared to meet society's rapidly evolving Earth information needs. These institutions have responsibilities that are in many cases mismatched with their authorities and resources: institutional mandates are inconsistent with agency charters, budgets are not well matched to emerging needs, and shared responsibilities are supported inconsistently by mechanisms for cooperation. Further, these are issues whose solutions will require action at high levels of the Federal Government. It was for these reasons that we recommended development and implementation of a comprehensive plan for achieving and sustaining global Earth observations.

Returning to my opening comments, we know that the planet's environment is changing on all spatial scales including global, and change is rapid, perhaps more rapid than at any time in human history. Further, we know that many of these changes are occurring as a result of human activities. These human-induced changes are over and above the stresses imposed by the natural variability of a dynamic planet and are intersecting with the effects of past and existing patterns of conflict, poverty, disease, and malnutrition.

As I noted, the changes cascade through the Earth's environment in ways that are difficult to understand and often impossible to predict. Therefore, at the least, these human-driven changes in the global environment will require that societies develop a multitude of creative responses, including strategies for mitigation and adaptation. Earth observations are a critical part of developing these responses.

The linked challenges of confronting and coping with global environmental changes, and addressing and securing a sustainable future, are daunting and immediate, but they are not insurmountable. These challenges can be met, but only with a new and even more vigorous approach to observe and understanding our changing planet and with a concomitant commitment by all to alter our actions.

Box S.1
Recommendations

RECOMMENDATION 1: ASP should be assigned the responsibility within NASA to review and help establish the requirements and guidelines offered in Chapter 5 of the Decadal Study (NRC, 2007a) for effective extension of data and research to applications that meet societal needs. As part of this action, the committee recommends incorporating an ASP representative on NASA mission design and selection teams to aid ASP in increasing the use and impact of NASA products in the user community.

RECOMMENDATION 2: ASP, in collaboration with other parts of NASA, should help to develop a formal plan and structure for effective transitions from research to operations with direct input from the entire range of users and with support from Congress.

RECOMMENDATION 3: ASP should link NASA data and research to users and beneficiaries through communication in both directions, not simply in one direction that disseminates NASA products without user feedback. Communication between ASP and external users should be enhanced, as should ASP's communications with other groups in NASA that conduct research on Earth-based observations.

RECOMMENDATION 4: ASP should develop processes for sustained interactions with a broader base of users and beneficiaries of NASA observations. ASP should assess user benefits of applications of NASA observations, with public comment and user reviews, in order to evaluate levels of importance to society and to inform the development of outcome metrics. ASP should prioritize intended societal benefits from NASA products and focus efforts on high-priority benefits.

RECOMMENDATION 5: To enhance the program's success in facilitating effective partnerships between NASA and users of NASA products to generate societal benefits, ASP should

1. directly engage with a broader community of users—not just federal agencies;
2. add rigor with respect to performance metrics;
3. evaluate the number and focus of its applications areas;
4. improve the transparency and documentation of the process by which a partner agency engages the broader community, including clarification of the partner agency responsibilities in realizing the shared goal of benefits to society; and
5. clarify and broaden its policies regarding productive relationships and collaborations with the private sector, including but not limited to remote sensing data products.

Biography for Berrien Moore III

Berrien Moore III joined the University of New Hampshire (UNH) faculty in 1969, soon after receiving his Ph.D. in mathematics from the University of Virginia. A Professor of Systems Research, he received the University's 1993 Excellence in Research Award and was named University Distinguished Professor in 1997. Professor Moore's research focuses on the carbon cycle, global biogeochemical cycles, and global change as well as policy issues in the area of the global environment. In 2007 he was awarded the Dryden Lectureship in Research by the American Institute of Aeronautics and Astronautics (AIAA) and was among the network of scientists who contributed their expertise to the assessment reports of the Intergovernmental Panel on Climate Change (IPCC), resulting in that organization's designation as the 2007 co-recipient of the Nobel Peace Prize. Dr. Moore was the coordinating lead author for the final chapter, "Advancing our Understanding" of the IPCC's Third Assessment Report.

The Director of the Institute for the Study of Earth, Oceans, and Space (EOS) from 1987 to 2008, he has simultaneously served on and chaired numerous government affiliated scientific committees (NASA/NOAA, The National Academies), including the NRC Committee on Global Change Research from 1995–1998 which produced the landmark report, *"Global Environmental Change: Research Pathways for the Next Decade."* In 1987 he was appointed chairman of NASA's senior science advisory panel and in 1992 upon completion of his chairmanship, was presented with NASA's highest civilian award, the NASA Distinguished Public Service Medal for outstanding service to the agency. Most recently he co-chaired with UCAR President Rick Anthes, the National Research Council's decadal survey, *"Earth Observations from Space: A Community Assessment and Strategy for the Future."*

His scientific committee service has spanned decades and continents, including his four-year tenure (1998–2002) as the Chair of the Science Committee of the International Geosphere-Biosphere Programme and his previously mentioned service as a lead author within the *Intergovernmental Panel on Climate Change's (IPCC) Third Annual Report (TAR)* which was released in Spring 2001. In July 2001 he chaired the Global Change Open Science Conference in Amsterdam and is one of the four architects of the Amsterdam Declaration on Global Change.

Professor Moore's current professional affiliations include the following: Member, Advisory Council, Jet Propulsion Laboratory; Member, Scientific Advisory Board, Max Planck–Institute for Meteorology, Munich, Germany; Chair, National Academies' Space Studies Board Committee on Earth Studies; Chair, Steering Committee, Global Terrestrial Observing System (United Nations Affiliate); Member, Board of Directors, University of New Hampshire Foundation; Member, Board of Trustees, Mount Washington Observatory, North Conway, NH; Member, Science Advisory Team-The National Polar-Orbiting Operational Environmental Satellite System (NPOESS/NOAA).

In February 2008 Professor Moore stepped down as Director of the Institute for the Study of Earth, Oceans, and Space to lead Climate Central, an emerging, non-profit, nonpartisan think-tank dedicated to producing and providing the public, business and civic leaders and policy-makers with objective and cutting edge information about climate change and potential solutions. The group is based in Princeton, NJ and Palo Alto, CA.

Chairman UDALL. Thank you, Dr. Moore. As you all have heard, there is a vote on. I think if we move with some dispatch, Dr. Squyres and Dr. Burns, we can get your testimony in, and then the Committee will stand in temporary recess and then we will return to direct questions of the panel.

So, Dr. Squyres.

STATEMENT OF DR. STEVEN W. SQUYRES, GOLDWIN SMITH PROFESSOR OF ASTRONOMY, CORNELL UNIVERSITY; PRINCIPAL INVESTIGATOR, MARS EXPLORATION ROVER PROJECT

Dr. SQUYRES. Thank you. Well, Mr. Chairman, Ranking Minority Member, and Members of the Subcommittee, thank you very much for the opportunity to appear today.

In my opening remarks, I would just simply like to make two points. The first point is that this budget contains a lot of good news for solar system exploration. The budget includes a healthy increase in funding for research and analysis. R&A is important. It is where the Nation reaps the benefits of the missions that NASA flies. It is where data get turned into scientific knowledge, so this is a very welcome development and I applaud it.

It is also good news that there is funding for three new robotic missions to the Moon to be launched by 2014. This renewed emphasis on lunar science is consistent with NASA's focus on the Moon as the primary target of the *Vision for Space Exploration.*

And perhaps the best news of all is that the budget also calls for the development of an Outer Planets Flagship mission for launch in 2016 or 2017. This mission would be sent to the Jupiter system, to Saturn's moon, Titan, or to Jupiter's moon, Europa; and any one of these missions would have enormous scientific potential. So there is a great deal here to be pleased about, and I commend Dr. Stern and the agency for what they have accomplished.

But there is some bad news, too, and my second point is that I am concerned about the dramatic cuts in the budget to NASA's very successful program on Mars exploration. In presentations to the science community, NASA has described a very exciting future program of Mars exploration. In 2013, an orbiter would be launched to study the upper atmosphere of Mars. In 2016 another major science mission would be launched, and then in 2018 or 2020, the long-awaited Mars Sample Return mission would be sent on its way. The reason that I am concerned is that the budget doesn't appear to contain enough funds to carry out this program. Now, I say this based not just on my own intuition but on a study that I participated in recently that was chartered by NASA and that was done in response to requests from the Office of Management and Budget.

In order to fly the Mars Sample Return mission by 2018 and 2020, our study concluded that a few hundred million dollars would have to be spent on technology development over the next five years, but as you noted in your opening remarks, Mr. Chairman, the actual number in the budget is only $68 million. So we concluded that either sample return would have to be slipped well beyond 2020 or that the missions in 2013 and 2016 would have to be eliminated.

We are also concerned about the total cost of the Mars Sample Return mission. NASA's stated cost goal for MSR is $3.5 billion. That is less than twice the probable cost of the Mars Science Laboratory for a mission that is much more than twice as complex. And so we concluded that it is likely that the full cost of Mars Sample Return will exceed $3.5 billion by an amount that is comparable to an entire flagship mission, and that shortfall would have to be covered by a foreign partner. So there are problems. There are serious problems in the Mars program.

Now let me state very clearly and emphatically that the right answer in my opinion is not to move money from other parts of the space science budget into the Mars program. Everything that I talked about, the increases to R&A, the lunar program, the Outer Planets Flagship, and everything you have heard from the other witnesses is a welcome development in this budget. I applaud all of that. Instead, my strongest advice to this committee would be that you strive to add to NASA's space science budget the funds that are needed to restore the Mars exploration program to the levels that were specified in the fiscal year 2008 *Congressional Appropriations Act.* This would enable NASA to continue the program that has been a great scientific success and has captured the imagination of the American public. Again, I really want to stress that most of the news in this budget is good for solar system exploration, and if you can fix the one serious problem, the cuts to the Mars program, you can make this a space science budget the Nation can really be proud of. Thank you.

[The prepared statement of Dr. Squyres follows:]

PREPARED STATEMENT OF STEVEN W. SQUYRES

Abstract

The President's FY09 budget request for NASA Space Science contains both good news and cause for concern in the area of solar system exploration. The budget contains a healthy increase in funding for Research and Analysis. It contains significant new activity in lunar science, including the GRAIL Discovery mission and three new robotic missions to the Moon to be launched by 2014. This renewed emphasis on lunar science is consistent with NASA's focus on the Moon as the near-term target of the *Vision for Space Exploration.* The budget also calls for the development of an Outer Planets Flagship mission for launch in 2016 or 2017. This mission would be sent to the Jupiter system, to Saturn's moon Titan, or to Jupiter's moon Europa. Any one of these missions would have enormous scientific potential. So all of these are very welcome developments for which NASA should be strongly commended. The area of greatest concern within the Solar System Exploration budget is the Mars Exploration Program. NASA has described an exciting future program of Mars exploration, but a recent Mars program architecture study suggests that the budget request does not contain adequate funds to carry out this program. The budget request includes the money necessary to fly exciting science missions in 2013 and 2016. It also contains $68 million in technology development funding for Mars Sample Return. But $68 million is far short of the investment that would be needed to support launch of Mars Sample Return by the target dates of 2018 and 2020. Also, NASA's stated cost goal for MSR is just $3.5 billion, whereas the full cost of MSR will probably exceed this by an amount comparable to an entire flagship mission. The Mars program architecture study concluded that the budget request will support Mars science missions in 2013 and 2016 only if MSR is slipped well beyond 2020. Alternatively, it concluded that MSR could be carried out by 2020 only if both the 2013 and 2016 missions were eliminated. My strongest advice to this committee would be that you correct this problem by working to add to NASA's Space Science budget the funds necessary to restore the Mars Exploration Program to the levels specified in the FY08 *Congressional Appropriations Act.*

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear today. My name is Steven W. Squyres, and my title is Goldwin Smith Professor of Astronomy at Cornell University. I am the scientific Principal Investigator for NASA's Mars Exploration Rover project, and I have participated for the past thirty years in a number of other NASA solar system exploration missions.

I welcome the opportunity to talk to you today about NASA's Space Science budget for Fiscal Year 2009. My main impression of the President's FY09 budget request for Space Science is that it is a valiant attempt to do a lot with a little. The budget contains some very good news, calling for the initiation of several missions that have been high-priority goals of the space science community for many years. These include a Solar Probe mission and a joint NASA–DOE Dark Energy mission, both slated to launch in the middle of the next decade. Both of these missions are consistent with the recommendations of the relevant Decadal Surveys of the National Research Council. I will leave it to others appearing before this subcommittee today to discuss the scientific importance of these missions in greater detail than I can, but I applaud their inclusion in the budget.

There is also good news for study of the Earth, where the President's budget request opens up a funding wedge that will accelerate the recommended flight missions of the Earth Science Decadal Survey. Again, others can comment better than I on the merits of these missions. But speaking as a planetary scientist who has to live on this planet, I welcome the idea of NASA increasing the share of its resources that is devoted to study of the Earth's environment.

In solar system exploration, my own area of expertise, there is both good news and some cause for concern.

The first piece of good news is that the budget includes a healthy increase in funding for Research and Analysis. The R&A program is where the Nation reaps the benefits of the space missions that NASA flies; it turns data into scientific knowledge. The R&A program is where many new concepts for planetary missions are born, and where students learn how to do science. Increased R&A funding will mean increased award rates for research grants, larger grant sizes, and a more productive planetary science community. So this is a very welcome development.

Also among the good news is that there is significant new activity in the long-neglected area of lunar science. NASA recently selected the GRAIL Discovery mission, which will use twin spacecraft to orbit the Moon and map its gravity field in unprecedented detail, addressing long-standing questions about the Moon's internal structure and evolution. In addition, the budget provides funds for three new robotic missions to the Moon to be launched by 2014. These include an orbiting spacecraft called the Lunar Atmosphere and Dust Environment Explorer (LADEE), and two small landers that will touch down near the north and south lunar poles.

This renewed emphasis on lunar science is consistent with NASA's focus on the Moon as the near-term target of the *Vision for Space Exploration.* Many opinions have been expressed regarding NASA's planned return to the Moon. My personal view is that the Moon is the logical place to go next with humans, because it is the best place to demonstrate the new technologies and vehicles that will be needed to carry astronauts to more exciting and distant destinations like Mars and asteroids. And while I hope that NASA will not get bogged down in extended program of human exploration of the Moon while more appealing targets beckon, one can only welcome new low-cost missions that address science that is directly related to the Agency's central focus.

The budget also calls for the development of an Outer Planets Flagship mission for launch in 2016 or 2017. This mission would be sent to the Jupiter system, to Saturn's moon Titan, or to Jupiter's moon Europa. Any one of these missions would have enormous scientific potential.

The Jupiter system is like a complete solar system in miniature. Jupiter itself is the best example of a giant planet in our solar system, and may be representative of a class of planets that are common throughout the Universe. Its four large moons formed together and yet show enormous diversity, making them a natural laboratory for studying the processes that shape planetary bodies. At Saturn, the Cassini/Huygens mission has revealed Titan to be a complex and fascinating world, with a dense hydrocarbon-rich atmosphere and lakes of liquid methane and ethane on its surface. The chemistry that takes place in Titan's atmosphere may be closely related to some of the chemical reactions that preceded the development of life on Earth. And at Europa, observations from the Voyager and Galileo spacecraft have provided evidence that a deep ocean of liquid water may exist beneath the satellite's icy crust. Europa's ocean, if shown conclusively to exist, may be the best place in the solar system to search for extraterrestrial life.

The Outer Planets Flagship mission is directly responsive to the most recent NRC Decadal Survey for Solar System Exploration. This survey placed high priority on a Europa Geophysical Explorer mission that would scrutinize several of Jupiter's moons before embarking on detailed exploration of Europa.

My excitement over inclusion of an Outer Planets Flagship mission in the President's budget is tempered somewhat by cost concerns. All of the candidate missions being studied are very technically challenging, and all of them will require a substantial up-front investment in key technologies. Given the projected launch dates, there is enough time to prepare for these missions, and I am heartened to see the technology investment beginning now. But NASA's total projected budget for the Outer Planets Flagship mission is unlikely to be adequate for a mission of the complexity demanded by the science goals. To their credit, NASA is clearly aware of this, and the Agency has emphasized the need for a capable foreign partner to make a major contribution to the mission. Foreign partnerships for large outer planets missions can be forged—the Cassini/Huygens partnership between NASA and the European Space Agency has been a spectacularly successful example. But international cooperation can be difficult to bring about and manage, and careful planning with a committed partner will be required for this critically important mission to be a success.

I believe that the area of greatest concern within the Solar System Exploration budget is the Mars Exploration Program.

In presentations to the science community, NASA has described an exciting future program of Mars exploration. This program would continue the ongoing operations of several highly successful spacecraft at Mars, including the Mars Odyssey orbiter, the Mars Exploration Rovers Spirit and Opportunity, and the Mars Reconnaissance Orbiter. It would operate the Phoenix lander that will touch down near the north pole of Mars in May of this year. It would launch the highly capable Mars Science Laboratory mission in 2009 to explore for long distances over the Martian surface and study the planet's former suitability for life.

This program also would continue an exciting program of Mars exploration into the second decade of this century. In 2013, an orbiter mission would be launched to study the dynamics and evolution of the upper atmosphere of Mars. In 2016 another major science mission would be launched, either into orbit or back to the Martian surface. And then, in 2018 and 2020, the orbital and surface elements of the long-awaited Mars Sample Return mission would be launched.

This program of future Mars exploration would build on the momentum of some of NASA's greatest successes of the past decade. It would be balanced in its scientific content. And by including a sample return mission it would directly address what has been one of the highest priorities in Mars exploration for many years. It is my impression that this program has the strong support of the Mars science community.

Where I see cause for concern is that the President's FY'09 budget request does not appear to contain adequate funds to carry out this program. I base this statement not just on my own intuition, but on a Mars program architecture study in which I participated recently that was chartered by NASA to respond to a request from the Office of Management and Budget. The study was carried out by nineteen senior engineers, scientists, and cost analysts. The conclusions of the study were reported recently to NASA's Planetary Science Subcommittee, and I will relate them briefly here.

The budget for Mars Exploration in FY08 was about $625 million, and last year's annual budget plan going forward from FY09 to FY12 was roughly constant at that level. In contrast, the current President's budget request cuts Mars exploration to less than $390 million in FY09, and averages only about $350 million a year for the five years going forward. In the Science Mission Directorate's planning estimates, Mars program funding does not start to ramp up again until FY17, and does not return to current levels until FY19.

The FY09 budget request includes all of the money necessary to fly exciting science missions in 2013 and 2016. It also contains $68 million in technology development funding for Mars Sample Return. But there are two problems with this scenario if MSR is going to be launched in 2018 and 2020.

One problem is that $68 million in the period from FY09 to FY13 is far short of the investment that would be needed to support launch of MSR by 2018 and 2020. Mars Sample Return will be the most complex robotic planetary mission ever undertaken, by a substantial margin. In order to launch the first element of the mission in 2018, our study concluded that a technology investment of hundreds of millions of dollars—not just $68 million—would have to be made by four or five years before the 2018 launch.

The other problem is the total cost of Mars Sample Return. NASA's stated cost goal for MSR is $3.5 billion. That number is less than twice the probable cost of the Mars Science Laboratory, for a mission that appears to be much more than twice as complex. We concluded that the full cost of MSR will exceed $3.5 billion by an amount comparable to an entire flagship mission. That shortfall would have to be covered on the appropriate schedule by a highly capable and committed foreign partner, with all of the management challenges that international partnerships entail.

Putting this together, our study concluded that the President's FY09 budget request will support NASA's planned Mars missions in 2013 and 2016 only if MSR is slipped well beyond 2020. Alternatively, we concluded that MSR could be carried out by 2020 only if both the 2013 and 2016 missions were eliminated. And at a cost target of $3.5 billion, we concluded that a flagship-class contribution from a foreign partner would be required to enable sample return.

The impact on the Mars program of elimination of the 2013 and 2016 missions would be severe. There would be a lack of continued progress toward key goals of the NRC Decadal Survey, and a loss of scientific balance. Of perhaps still greater concern is the loss of technical and scientific know-how that could occur as a result of the very long hiatus between landed missions.

In addition, the Mars Exploration Program would cease to be a truly interconnected program of exploration. In a recent report entitled *"Grading NASA's Solar System Exploration Program: A Midterm Review,"* the NRC gave the Mars program the only grade of "A" in the review, and said this about it:

> *A key element of the success of this program is that it is not a series of isolated missions, but rather a highly integrated set of strategically designed missions, each building on the discoveries and technology of the previous missions and fitting into long-term goals to understand the planet, whether or not it ever had or does now have life, and how Mars fits into the origin and evolution of terrestrial planets.*

With the implementation of the President's FY09 budget request and a Mars Sample Return mission "anchored" in 2020, this key characteristic of the Mars program would be lost.

As I noted at the beginning of my testimony, the President's budget request for NASA Space Science is a valiant attempt to do a lot with a little. I admire the Agency for this attempt, and I am heartened to see that the budget contains major new initiatives across nearly the full breadth of space science. But I foresee problems, particularly in the weakening of the Agency's Mars program.

Let me state clearly that the right answer in my opinion is not to move money from other parts of the Space Science budget into the Mars program. Instead, my strongest advice to this committee would be that you work to add to NASA's Space Science budget the funds necessary to restore the Mars Exploration Program to the levels specified in the FY08 *Congressional Appropriations Act.* This would enable NASA to continue what has been one of its most scientifically successful programs. It would also allow continuation of a program that has captured the public's imagination, and that is directly relevant to the central focus of the Agency: NASA's *Vision for Space Exploration.*

If funding cannot be restored to the Mars program, then some very tough choices would have to be made. The way to make such choices, of course, would be via the same kind of community-based process that produced the Decadal Survey. My own opinion is that a post-MSL Mars program that consisted solely of a sample return by 2020 would not be the best use of limited resources. If faced with a decade-long hiatus in the exploration of Mars, I personally feel that the best thing to do about sample return—which has been and remains one of the highest-priority goals of Mars exploration—would be to postpone it a few years in favor of missions in 2013 and 2016 that would continue to make major advances in our knowledge of the planet.

Again, I thank you for the opportunity to appear before the Subcommittee today.

BIOGRAPHY FOR STEVEN W. SQUYRES

Steven W. Squyres is Goldwin Smith Professor of Astronomy at Cornell University, and is the Principal Investigator for the science payload on the Mars Exploration Rover Project. He received his Ph.D. from Cornell in 1981 and spent five years as a post-doctoral associate and research scientist at NASA's Ames Research Center before returning to Cornell as a faculty member. His main areas of scientific interest have been Mars and the moons of the outer planets. Research for which he is best known includes study of the history and distribution of water on Mars and of the possible existence and habitability of a liquid water ocean on Europa.

Dr. Squyres has participated in many of NASA's planetary exploration missions, including the Voyager mission to Jupiter and Saturn, the Magellan mission to Venus, and the Near Earth Asteroid Rendezvous mission. Along with his current work on MER, he is also a co-investigator on the 2003 Mars Express, 2005 Mars Reconnaissance Orbiter and 2009 Mars Science Laboratory missions, a member of the Gamma-Ray Spectrometer Flight Investigation Team for the Mars Odyssey mission, and a member of the imaging team for the Cassini mission to Saturn.

Dr. Squyres has served as Chair of the NASA Space Science Advisory Committee and as a member of the NASA Advisory Council. His awards include the American Astronomical Society's Harold C. Urey Prize, the Space Science Award of the American Institute of Aeronautics and Astronautics, the American Astronautical Society's Carl Sagan Award, the National Space Society's Wernher von Braun Award, and the Benjamin Franklin Medal of the Franklin Institute. He is a fellow of the American Academy of Arts and Sciences.

Chairman UDALL. Thank you, Dr. Squyres.

Dr. Burns.

STATEMENT OF DR. JACK O. BURNS, PROFESSOR OF ASTROPHYSICS AND SPACE ASTRONOMY; VICE PRESIDENT EMERITUS FOR ACADEMIC AFFAIRS AND RESEARCH, UNIVERSITY OF COLORADO AT BOULDER

Dr. BURNS. Chairman Udall, Ranking Minority Member Feeney, and Members of the Subcommittee, thank you for your invitation to discuss NASA's astrophysics program here today.

This is an invigorating time for astrophysics. In the next two years, NASA will launch several much-anticipated missions including the gamma ray observatory GLAST and the planet-finding telescope, Kepler. Next August, the astronauts aboard the Space Shuttle will extend and enhance the scientific life of the Hubble Space Telescope. The astronomy community very much appreciates the continuing efforts of this Congress to fund these important programs.

Mr. Chairman, in response to your first question about the direction of the astrophysics program at NASA, let me say that Dr. Stern and his staff have addressed many of the concerns regarding the previous astrophysics budget that was in place before they joined the agency last April. Included in the positive changes, a few of which we have already heard about, is the fact that the previous cuts in research and analysis, R&A budget, have been largely reversed. The astrophysics R&A budget is proposed to increase by 8.5 percent in 2009 and 48 percent in the next five years. The R&A program permits researchers and their students to mine NASA's investments in the astrophysics missions.

Second, NASA has begun as you said, Mr. Chairman, a new start, the Joint Dark Energy Mission, JDEM, in partnership with the DOE.

Thirdly, NASA has opened competition for three new Explorer missions, and it is reinvesting in sounding rockets and balloon experiments, thus helping to restore the much-needed balance within the portfolio of science launches, particularly with the smaller missions. In all of these areas, NASA astrophysics is moving in the right direction. However, like my colleagues on this panel, I too am concerned about the overall drop, particularly for astrophysics. Using NASA's new start inflation index, the astrophysics budget is forecast to fall by $423 million or 31 percent for 2013 in real buying power over that for 2008. This decrease is proposed to occur right during an era of significant new astrophysics discoveries that will commence particularly with the James Webb Space Telescope at the end of this five-year period.

The fundamental issue is that NASA is underfunded for its overall mission which in turn creates budgetary stress throughout the agency as noted once again by my colleagues on the panel. In my view, this is the key challenge that must be addressed by the Congress and the next Administration. The astrophysics community will soon begin its Decadal Survey. Our task will be to set priorities over an ever-broadening scientific landscape. The proposed new missions must be realistically life cycle costed and cost capped based upon the best available models and experience. I believe that all missions, even those ranked by previous Decadal Surveys, must be evaluated and reranked along with the new ideas that emerge.

As we begin the next Decadal Survey, we are facing a daunting challenge once again due to NASA's astrophysics budget. How do we start, Mr. Chairman, new missions as will surely be recommended by the Decadal Survey with a budget that is forecast to decline by 31 percent in real buying power over the next five years?

Regarding the large missions with budgets over $500 million, NASA is following the AAAC, the Decadal Survey, and other Academy committee recommendations. A few issues, though, are worthy of note. There is continuing concern about the potential cost growth and the James Webb Space Telescope, although I emphasize, I have no heard any additional imminent problems in completing and delivering the telescope to its orbit in 2013, but we must remain vigilant.

For JDEM, NASA must now select a single concept for the mission and cap the total budget at $600 to $800 million so as not to impose further stress on the astrophysics budget.

And thirdly, one of the possibly most exciting potential missions for the next decade will be the search for extrasolar planets. There are a number of promising concepts under development, but all must be vetted by the Decadal Survey. The community-based priority setting must be allowed to proceed, Mr. Chairman, without intervention if we are to select the best concept and maintain the budgetary balance within the astrophysics program.

Finally, Mr. Chairman, you asked about my views on reauthorization of NASA. From its founding days, NASA's mission has been exploration, human and robotic, scientific and technological, near-Earth and larger cosmos. I recommend that the Congress reauthorize NASA to execute this mission on behalf of and for the benefit of our nation of explorers. Furthermore, NASA should be reauthorized with a budget that reflects this bold mission and its value to the Nation. NASA must continue to explore in the broadest sense. Scientific exploration is equally fulfilling and synergistic with human exploration. NASA must continue to explore in a balanced fashion recognizing that all facets of explorations define the benefit of the agency to the Nation. Thank you, Mr. Chairman.

[Prepared statement of Dr. Burns follows:]

PREPARED STATEMENT OF JACK O. BURNS

Introduction

Mr. Chairman, Ranking Minority Member, and Members of the Subcommittee, I want to thank you for inviting me to appear before you today to discuss NASA's Astrophysics program. My name is Jack Burns and I am a Professor of Astrophysical and Planetary Sciences at the University of Colorado, Boulder and Vice President Emeritus for Academic Affairs and Research for the University of Colorado System. I also have the privilege to serve as Chairman of the American Astronomical Society's Committee on Astronomy and Public Policy and as a member of the NASA Advisory Council.

Let me begin by thanking this committee and the Congress for its leadership in crafting and passing H.R. 2272, *America Creating Opportunities to Meaningfully Promote Excellence in Technology and Science Act* (COMPETES), signed into law by the President on August 9, 2007. As aptly stated by Chairman Gordon, the *America COMPETES Act* "will help secure the United States' ability to compete in the global marketplace." It is an admirable response to the critical issues defined in the 2005 National Academies' report entitled *"Rising Above the Gathering Storm"* led by former Lockheed-Martin CEO Norm Augustine. I urge the Congress to fully finance the programs authorized in the COMPETES Act to provide a much needed enhancement of the Nation's innovation economy.

Speaking of innovation, NASA continues its long history of contributing to the country's high technology economy via spinoffs from it science programs. For example, Hubble Space Telescope (HST) images form one of the key databases behind *GoogleSky* bringing state-of-the-art imagery of the Universe into a tool now available to anyone, anywhere in the world with a computer (*http://www.google.com/educators/spacetools.html*).

In a similar vein, Microsoft recently announced its *WorldWide Telescope* software (*http://worldwidetelescope.org/*). The WorldWide Telescope is being developed using images from the HST and the ground-based Sloan Digital Sky Survey. A third example is a company called *Teraview, Inc.* that was founded to utilize Terahertz (i.e., very high frequency) technologies and sensors developed at JPL. These spin-off technologies from the space science program are being used for 3–D imaging and spectroscopy for biomedical and materials research (*http://www.teraview.com/*).

These examples demonstrate NASA's broad applications in astronomy, education and public outreach that are also fueling the private sector's technology innovations. NASA's leadership in these areas brings high visibility to U.S. science and technology achievements and attracts young people to these fields.

This is an exciting time for space science and astrophysics. In the next two years, NASA will launch several much anticipated missions including the gamma-ray large area space telescope, GLAST, the wide-field infrared survey explorer, WISE, and the planet-finding photometry telescope, Kepler. NASA will also be a major participant in international missions with the European Space Agency (ESA) such as *Herschel* that will seek thermal radiation from newly forming stars, planets, and ancient galaxies, and *Planck* that will probe the earliest epochs after the Big Bang. And, very importantly, the next Hubble Servicing Mission (SM4) will extend and enhance the life of the Hubble Space Telescope with the installation of new instruments including the Cosmic Origins Spectrograph.

While we enjoy a generous flow of data from past and current space telescopes, we are looking forward to new telescopes and new scientific challenges in the next decade. The astronomical community, under the leadership of the National Academy of Sciences (NAS), is preparing for the commencement of the Astronomy and Astrophysics Decadal Survey that is carried out once every ten years. This is an opportunity to look forward toward the future of space astrophysics in the context of a broad, national astronomy and astrophysics program. The next Decadal Survey will provide guidance for federal investment in the next generation of ground and space-based telescopes.

This priority-setting exercise has been the key ingredient in the success of U.S. astronomy and astrophysics for the past five decades. It is very important for the health of NASA's astrophysics program that we conduct an orderly evaluation of concepts across the full spectrum of astrophysics missions and wavelengths. To emphasize this point, the American Astronomical Society issued this statement in January 2008:

> *"The American Astronomical Society and each of its five divisions strongly endorse community-based priority setting as a fundamental component in the effective federal funding of research. Broad community input is required in making difficult decisions that will be respected by policy-makers and stake-holders. The decadal surveys are the premier examples of how to set priorities with community input. Other National Academy studies, standing advisory committees, senior reviews, and townhall meetings are important components. Mid-decade adjustments should also be open to appropriate community input. Pleadings outside this process for specific Congressional language to benefit projects or alter priorities are counterproductive and harm science as a whole. The American Astronomical Society opposes all attempts to circumvent the established and successful community-based priority-setting processes currently in place."*

The astronomy community appreciates the continuing efforts of Congress to fund the programs that reflect these community priorities.

Responses to the Questions from the Chairman

1. Do you believe the space science program, and especially the Astrophysics program, is moving in the right direction? If not, what changes do you think would improve the program and why? Please elaborate on your perspectives.

Associate Administrator Alan Stern and Astrophysics Division Director Jon Morse are to be congratulated for their prompt, constructive responses to the community's deep concerns regarding the previous Astrophysics program budget that was in place before they joined the Agency last April. As noted by several individuals at hearings of this Subcommittee last year, there was discontent with the proposed future of astrophysics at NASA. Some important changes have been made by the new leadership that are highly laudable, although some key long-term challenges remain.

Let me describe a few of the positive budgetary developments proposed for fiscal year 2009. First, the previous cuts in the Research and Analysis (R&A) budget have been largely reversed. This budget is proposed to increase by 8.5 percent in FY 2009 and is forecast to increase further through FY 2013 for a total of 48 percent growth over five years between 2007 and 2013. The R&A program permits researchers and their students to mine NASA's investments in astrophysics missions from the last decade. It provides investigators at universities and laboratories opportunities to conduct research on archived data, theoretical investigations of astrophysical phenomena related to NASA telescopic observations, laboratory studies, and the development of new instrumentation for future missions. In particular, it provides funding to attract young people and to train them in science and engineering, a key component of the *America COMPETES Act.*

Second, the Science Mission Directorate (SMD) has made a swift and positive response to the NAS' Beyond Einstein Program Assessment Committee (BEPAC) recommendation to begin funding for a Joint Dark Energy Mission (JDEM) in partnership with the Department of Energy (DOE) Office of Science. JDEM is proposed to have a budget of $8.5 million in FY 2009 increasing to $125 million in FY 2013.

The challenges here are concluding an equitable partnership agreement with DOE and putting a strong cost cap in place at the level of $600–800 million for the total JDEM mission (including all life cycle costs).

Third, NASA SMD has opened competition for three new small Explorer missions. This will help fill the previously identified "valley of death" in NASA's science mission launch schedule. It will also bring new university, laboratory, and industry teams, including graduate students and post-doctoral fellows, into partnerships for space science missions. In addition, SMD has restarted the previously canceled Explorer-class mission called the Nuclear Spectroscopic Telescope Array, NuSTAR, to explore the high energy X-ray sky up to energies of 80 keV. Similarly, NASA is reinvesting in sounding rockets and balloon experiments to prototype detectors and spectrographs for potential future satellite missions. SMD has begun to restore the balance within its portfolio of science launches with a healthier number of small missions.

The above investments and new starts are much appreciated by the astrophysics community. Drs. Stern and Morse have been very responsive to the recommendations of the previous NAS Astronomy and Astrophysics Decadal Survey as well as suggestions from other NAS committees. In all these areas, NASA Astrophysics is moving in the right direction.

However, I am very concerned about the overall drop in funding for Astrophysics from $1.363 billion in FY 2008 to a proposed $1.162 billion in FY 2009 (a decline of 14.7 percent). The budget is projected to remain flat thereafter. Using NASA's new-start inflation index, this forecast is a reduction of $423 million (31 percent) for FY 2013 in real buying power over that for FY 2008. This decrease is proposed to occur during an era of significant new astrophysics discoveries with observatories such as the James Webb Space Telescope and with the expected exciting recommendations from the Decadal Survey.

NASA's overall budgetary increases for several years have been below inflation and SMD's budget reflects this decline. Thus, Dr. Stern is attempting to rebalance the science portfolio, create new missions, support research and analysis of a rich archive from previous missions, and invest in future technology development—all with a flat or declining budget in inflation-adjusted dollars. This is a truly Herculean task!

The fundamental issue is that NASA is underfunded for its overall mission which, in turn, creates budgetary stress for all of the Directorates including Science. In my view, this is the key problem that must be addressed by the Congress and the next Administration.

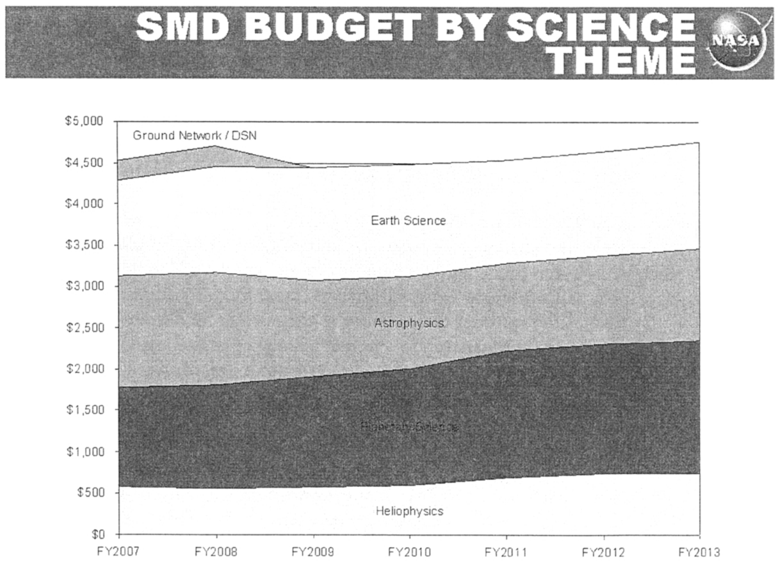
2. What, if any major challenges do you foresee for the future of the NASA astrophysics program, as proposed in the FY 2009 budget request? What are your suggestions for addressing those challenges?

As noted above, the Astrophysics community will soon begin its Decadal Survey under the leadership of the NAS. A great deal of effort from our community, involving hundreds of astronomers, as well as significant resources from federal agencies will be expended in this priority-setting endeavor. But, this is well worth the effort. Our challenge in this Decadal Survey will be to set priorities over an ever-broadening scientific landscape and to embrace new ventures beyond those that we have pursued in the past. We will build consensus on a select set of priorities for new telescopes and new missions that will advance the astrophysical frontiers ranging from exoplanets to cosmology. These new missions must be realistically costed (for construction, operations, and de-commissioning) and cost-capped based upon the best available models and experience.

I believe that all missions, even those ranked by previous Decadal Surveys but without a funded new start, must be evaluated and ranked along with new ideas. The resulting roadmap of telescopes and technologies will help guide the Congress and federal agencies toward the most prudent and productive investments in the next decade. In the past, the Congress has praised the Astrophysics community as being the first to undertake this difficult task of prioritization which has led to spectacular successes for missions such as the Hubble Space Telescope, the Chandra X-ray observatory, and the Spitzer Space Telescope.

As we begin the next Decadal Survey, we are facing a daunting challenge due to NASA's Astrophysics budget. How do we start new missions as recommended by the Decadal Survey with a budget that is forecast to decline by 31 percent in real buying power over the next five years? Even within SMD, Astrophysics is shrinking relative to the other divisions. This is shown in the figure below provided by SMD.

From FY 2007 to FY 2013, Astrophysics' budget "wedge" diminishes while Earth Science, Planetary Science and Heliophysics all grow. Earth Science is increasing in response to the exciting agenda put forward by its Decadal Survey. The declining wedge for Astrophysics has been developed before the astrophysics community has had an opportunity to make its case among the other science themes with the results from the Astronomy and Astrophysics Decadal Survey. I think we may have the cart before the horse here. I urge flexibility in budget planning for the out-years in SMD to insure that we, too, in Astrophysics have an opportunity to make our case for new investments after our Decadal Survey is completed.



The Astrophysics community must continue to assist NASA during this time of tight budgets. We must do a better job of full-costing for new missions and then we must hold these missions to those costs within realistic contingencies. This must be a partnership between astrophysicists, aerospace contractors, and NASA with an *a priori* agreement on terms by all parties.

Our community, working together with NASA, must continue to shutter space-based observatories as they age and decline in scientific effectiveness. This is often difficult and challenging. But, such decisions will become even more important in the future as we face limited budgets and a cadre of exciting new telescopes waiting in the wings.

I commend NASA Astrophysics for convening a Senior Review this Spring composed of members of the scientific community to examine most of NASA's current astrophysics missions. I urge NASA to perform a Senior Review on all its missions, including the Hubble Space Telescope after the SM4 servicing mission, over the next several years.

NASA Astrophysics faces the following challenges:

- How will NASA continue to support future technology development in key areas relevant to its next missions? NASA needs a technology-development fund agency-wide and, specifically, for the space sciences. Our community also needs further relief from the restrictions imposed by the International Traffic in Arms Regulations (ITAR) that are impeding international collaborations in space science technologies and astrophysics missions.
- How will NASA address the most exciting astrophysical questions that will inevitably emerge from the Decadal Survey in areas such as exoplanets, black holes, and dark energy? Budget stability, unlike that of the past few years, along with budgetary flexibility and new funding will be required.
- How do we train the next generation of space scientists given that the timescales for development and launch of new space missions are often measured in decades, much beyond that of the tenure of students in undergraduate and graduate programs? It is becoming extraordinarily difficult to train in-

strumentalists in this field. We need to consider creative new programs that fund students to work on missions while in graduate school through a faculty position, and/or a closer integration of rocket/balloon programs with space missions.

3. The FY 2009 budget proposes initiating missions that will have budgets over $500 million. Is NASA's approach to these proposed new missions in terms of potential scope, preliminary NASA cost estimates, alignment with science priorities, estimated launch timeframes, approach to technology development, and opportunities for international or interagency partnerships consistent with the Astronomy and Astrophysics Advisory Committee (AAAC) and decadal survey recommendations? What, if any, risks or issues need to be considered with respect to these proposed initiatives?

Within the tightening budgetary framework, NASA is following the AAAC, Decadal Survey, and other NAS committee recommendations. Let me describe some of the challenges facing NASA's largest astrophysics missions over the next few years.

In the near-term, there remains much concern about potential JWST cost growth. Most of the astronomical community was shocked by the large increase in the cost of this mission several years ago. It was caused by unrealistic estimates of the development, construction, and life cycle costs in the early design phases of this mission. I believe we have learned an important lesson from this under-costing and we must do a better job of cost estimation for new missions in the future. Although the history of JWST continues to produce nervousness among astronomers, I have not heard of any additional, imminent problems in completing and delivering the telescope to its orbit in 2013.

JWST is a remarkably powerful mission with potential science returns comparable to or exceeding those of the Hubble Space Telescope over the past two decades. The upcoming technical reviews for JWST will be important in truly understanding how well the project is doing. Such "flagship" missions have an essential role in Astrophysics since they involve the broadest cross-section of the community in observations ranging from planetary bodies in our solar system to the first galaxies that formed in the Universe. Smaller projects of the Explorer and Discovery class are faster and more nimble (i.e., able to respond quickly to new discoveries), but flagship missions such as JWST push the scientific discovery boundaries as only large aperture telescopes can do.

JDEM has been vetted by both the NAS *Quarks to Cosmos* Committee and, more recently, by the NAS BEPAC. The BEPAC concluded that "a JDEM mission will set the standard in the precision of its determination of the distribution of dark energy in the distant universe. By clarifying the properties of 70 percent of the mass-energy in the Universe, JDEM's potential for fundamental advancement of both astronomy and physics is substantial." This Committee found that the JDEM mission candidates have mature technologies, most having flown in space or developed in other programs. The BEPAC recommended as its top priority that "NASA and DOE should proceed immediately with a competition to select a Joint Dark Energy Mission for a 2009 new start." The charge and execution of this academy review was handled superbly, and NASA has acted swiftly and impressively on the BEPAC recommendation. NASA must now run a competition to evaluate and then select a single JDEM concept for its new start. In this process, the technology, the full life cycle costs, and the risks must be carefully weighed. As I noted earlier, it is critical to cap the total budget from NASA and DOE to the $600–800 million level for JDEM so as to not impose further stress on the Astrophysics budget.

Other large, potential missions are awaiting evaluation by the next Astronomy and Astrophysics Decadal Survey. One very exciting potential mission for the next decade will be the search for extrasolar, including Earth-like, planets around other stars in our Galaxy. NASA will begin this effort with the 2009 launch of Kepler, a mission designed to indirectly detect exoplanets from the change in the light as these planets transit behind and in front of their parent stars. Recently, the Exoplanet Task Force convened by the AAAC has recommended a large-scale astrometric mission. They carefully avoided specifying a particular concept because they believe a re-evaluation of the approach for an astrometric mission for planet searches is needed.

Furthermore, NASA has recently awarded several new "mission concept study" grants to examine additional ideas for exoplanet discovery with very different technologies. For example, the New Worlds Observer would use a four-meter class telescope and a flower-petal-design star shade to dramatically reduce the light from the parent star and to directly image terrestrial as well as gas-giant planets in extrasolar systems. All these exciting concepts must all be carefully vetted and reviewed by the Decadal Survey. *This community-based priority setting must be allowed to proceed without intervention if we are to select which concept is best suited, both scientifically and technologically, to fulfill the goal of detecting exoplanets.* The entire balance of the astrophysics program is threatened if we attempt to start a new large project before JWST is completed and before the Decadal Survey has finished its analysis.

Other potential flagship missions evaluated by BEPAC include the Laser Interferometer Space Antenna, LISA, that would search for gravitational waves from the merger of black holes, and Constellation-X that will view compact and extended sources of X-ray emission with ground-breaking spectral resolution. These projects are continuing to develop with support from the FY 2009 Astrophysics budget which I heartily endorse. Once again, this is consistent with the recommendations of BEPAC. Both projects have counterparts being developed by ESA. I strongly recommend that NASA enhance its efforts to seek collaborations on both projects from the international community to reduce costs and risks for these flagship missions. International partnerships will likely increase their appeal to the Decadal Survey.

4. The Committee on Science and Technology plans to reauthorize NASA this year and in so doing will communicate policy direction to NASA as well as to the next Presidential Administration. What, in your view, are the important issues with respect to NASA's space science programs that Congress should consider in its reauthorization of NASA?

From its founding days, NASA's mission has been exploration—human and robotic, scientific and technological, near-Earth and the larger cosmos. I recommend that this Committee and the Congress reauthorize NASA to execute this mission on behalf of and for the benefit of our nation of explorers. The value of NASA to America is seen best via its pioneering outlook in exploring scientific frontiers, its human reach into and beyond Earth orbit, its inspiration to the next generation to study the STEM fields, and its development of new technologies to grow America's innovation economy.

Most importantly, NASA should be reauthorized with a budget that reflects this bold mission and its value to the Nation. Much of NASA's current problems in transitioning from the Shuttle to the CEV, in its aeronautics programs, and in its science research missions are caused by underfunding. The budget is simply too small for the mission. *In my view, NASA should be reauthorized at a budgetary level sufficient to fulfill its mission or the mission should be de-scoped to reflect a lower level of commitment.* The current limbo cannot continue as it demoralizes a dedicated NASA workforce and promises unachievable goals to the taxpayers. I hope that the Congress and the next Administration will choose the high road of investment and hold both NASA and its partners in the university and industry communities to high levels of efficiency, accountability, and effectiveness. I believe that the astronomical community is ready to generate a high return on investment for our fellow taxpayers.

The reauthorization should encourage NASA to move forward with the priorities developed in the community-wide Astronomy and Astrophysics Decadal Survey. It should also authorize enough funding to execute the most important priorities in the Decadal Survey. NASA must be able to accomplish its science mission, as well as those of the other directorates, in an adequate fashion.

There has always been a level of synergy between the science and the human exploration programs within NASA. NASA's first satellite launch 50 years ago, Explorer I, demonstrated new rocket technology that would take Mercury astronauts into space and also discovered the Van Allen radiation belts surrounding the Earth. More recently, astronauts aboard the Space Shuttle have ventured four times, and will return for a fifth time this August, to service the Hubble Space Telescope and to install powerful new instruments.

The *Vision for Space Exploration* promises some hopeful new synergy between human exploration of the Moon and science. The NAC Astrophysics Subcommittee and the NAS Report on *The Scientific Context for the Exploration of the Moon* recommended that the unique radio-quiet environment of the lunar far-side is ideally suited for an array of low frequency radio telescopes that would uniquely detect the first structures to form out of the early Universe's "Dark Ages." In addition, the Ares V heavy-launch vehicle designed to deliver payloads and astronauts to the Moon has exciting capability to place very large telescopes, with apertures of 10–30 meters (compared to JWST's 6.5-meter aperture mirror), into the L2 Earth-Sun Lagrange point for extraordinarily deep viewing of the cosmos. NASA's reauthorization should promote further synergy between scientific and human exploration.

NASA must continue to explore in the broadest sense. Human explorations of the Moon and, in the future, near-Earth asteroids and Mars are exciting, fulfilling goals that will continue to define the U.S. as a great nation. Scientific exploration is equally fulfilling, contributes to the Nation's high technology economy, adds to our intellectual development as a species, and inspires both young and old. NASA must continue to explore, in a balanced fashion, recognizing that all facets of exploration define the benefits of NASA to the Nation. Human and scientific explorations produce excitement in equal measures and strong support for NASA.

In conclusion, astrophysics research continues to yield an unbroken string of revolutionary discoveries about the Universe with now over 250 planets known to orbit around stars in our Galaxy, with giant black holes of a million to a billion times the mass of the Sun modulating star formation in galaxies, and dark energy dominating the energy density of the Universe possibly requiring another revolution in our conception of gravity and the nature of matter. Space astrophysics is a proven lure for students, a testbed for new technologies, and a training ground for the Nation's next generation of innovators. As such, investments in astrophysics pay major dividends in elevating the Nation's scientific and technological literacy.

Thank you again for this opportunity to share these thoughts with you today.

Chairman UDALL. Thank you, Dr. Burns. The Committee will stand in temporary recess for approximately 20 to 25 minutes. We will return and ask the panel questions.

[Recess.]

DISCUSSION

CONGRESSIONAL THRESHOLDS

Chairman UDALL. Okay. All right. The hearing will come to order. I want to thank the panel for your forbearance. The Chair now recognizes himself for five minutes.

Dr. Stern, I would like to turn to you and I have a number of comments here that will be interspersed with some questions so bear with me as I think the focus of our hearing today. The fiscal year 2009 budget request for NASA states that eight projects have exceeded Congressional thresholds on cost of schedule growth. This is an increase of five missions over the projects listed in the 2008 budget request. The eight projects include Herschel, Kepler, the NPOESS Preparatory Project, Glory, Orbiting Carbon Observatory, Aquarius, Gamma-ray Large Area Space Telescope, and the Stratospheric Observatory for Infrared Astronomy. Given that the 2009 budget request includes several new initiatives estimated to cost $500 million or more, what specific steps is NASA taking to address the problems of the eight missions cited in the budget book and ensure that any new initiatives do not exceed Congressional thresholds? What if any margin is there in your budget request to handle any additional schedule and cost growth? I would have an additional concern that I would like to raise on this topic, and that centers on NASA's lack of responsiveness to Congress in complying with the statute that established the cost and schedule thresholds. Specifically, Public Law 109–155, the *NASA Authorization Act of 2005* is clear in stating how quickly notification of such threshold reaches is to be conveyed to the Congress. In particular the person overseeing the program experiencing such increases or delays must notify the administrator immediately and formalize such notification in writing no later than 30 days after the initial notification. In turn, not 15 days later than receiving this written notification, the administration must transmit the notification received in NASA's authorization committees.

Congressional committees receive copies of the program notifications for projects such as Glory some four months late. Considering the explicit timelines in the legislation, what caused such a lengthy delay? Furthermore, the Act requires that not later than 30 days after receiving a program's written notification, the administrator must determine if the program is likely to exceed development costs by 15 percent or more or whether the milestone is likely to be delayed by six months or more. If the determination is affirmative, not later than 15 days after the making of the determination, the administrator must transmit to NASA's authorization committees a report including a description of the increase in cost or delay in schedule an action taken or proposed be taken. We still have not received your report. Your Assistant Administrator for Legislative and Intergovernmental Affairs notified the Congressional committees that the mandated report would be submitted no later than March 2008. Even that would make it almost six months late. What is the reason for the significant delay? I am concerned that NASA is not taking these reporting requirements seriously, and I will be pursuing this issue further in the coming months.

Thank you for listening to such a long question. Now the floor is yours to answer.

Dr. STERN. Chairman Udall, let me begin with your last point, and I will apologize for the agency and offer to take that response for the record because I think it requires a detailed and careful response. I understand your frustration, and sir, I can make the commitment to you that we will work to do this better going forward. I would like to spend my time if I may speaking to your first two questions.

Chairman UDALL. Please do, Dr. Stern. Thank you for that assurance.

Dr. STERN. Yes, sir. You asked about what management tools we are putting in place and what kinds of cost reserve postures we are taking, and that is what I want to respond to. Regarding management tools, there is a whole variety of things that over the last year we have put in place. I know you may have heard about some of these. I am going to lay them out, and when you see them as a larger picture, I think you will appreciate that we are really in I think a pretty strong posture now to go forward.

We are oftentimes now lying in a bed made for us, that is, projects that were selected that had too much content for the available budget or too little reserves for them. SMD has now adopted a philosophy that doesn't try to stuff six or eight pounds in that five-pound bag. The missions that we are selecting, and I can tell you that all three that we selected last year, BARREL, NuSTAR, and GRAIL, all came in well below their cost caps and they were verified by independent cost estimates made by non-advocate parties. And we looked at those very carefully and factored those into our selection criteria. So we are trying to make sure that missions have a lot of head room. The administrator has required from a reservist posture that all missions above a threshold are required to have a statistical cost confidence level of 70 percent which often requires reserves in excess of 30 percent, which are quite large by historical standards, something that NASA had not done in the past for which Administrator Griffin should receive credit for insisting upon adequate reserves.

We ourselves in SMD have taken descope seriously. I think you have seen examples of that on the MSL mission, you have seen some descopes in some Earth science missions. They are not always hardware or instruments. Sometimes they are done in the operations phase, they are done in terms of the testing or the degree of scientific analysis. We are actually trying to put feedback loops in place. In the same vein, we have on at least one occasion told the science Principal Investigator that if he can't control his costs we are going to find another Principal Investigator for the mission, and as you are aware, we have also come forward with new missions that have cost caps which is quite unorthodox. We are turning that from a rare to a routine practice. I think that those and other tools that we are putting in place like PI minimum experience requirements are giving us the suite of dials on the control panel, if you will, to ensure that we can manage the projects that we are starting to stay in budget so that overruns become rare instead of routine.

Chairman UDALL. Thank you for that thoughtful and comprehensive answer, and the Chair now recognizes the Ranking Member, Mr. Feeney, for five minutes.

INTERNATIONAL TRAFFIC IN ARMS REGULATION

Mr. FEENEY. Thank you, Mr. Chairman. Speaking of reports, I asked Mike Griffin, other than more money which we all agree that we would like to see for NASA, what two things he would like to have and the first thing he said, well, I have got 53 reports annually due to Congress. I would like to have a few fewer reports. But he also mentioned ITAR as a very important priority legislatively this year. Some things in the program can go on with or without Congressional action this year. Does anybody have some comments on the importance of passing ITAR? Obviously they have implications for the human space flight program, but with respect to the science programs, are there implications and importances in visiting ITAR as we deal with this and you could give us advice on as we try to take this up? Dr. Burns.

Dr. BURNS. Yes, Congressman Feeney. I would be happy to address that. We have wrestled with that a good deal at the University of Colorado in building missions and particularly involving international graduate students and restrictions associated with them being involved as well as we have a number of collaborations with England, Australia, Canada, and those restrictions to very friendly countries, countries where we have a number of graduate students and collaborators have been very restrictive. Looking more broadly though, I think the issue is one in which as Dr. Stern said a little bit ago, we need to be looking at more international collaboration because sharing the costs and the risks associated with these large projects in astrophysics for example, the LISA mission, or the Constellation–X mission, we need those international collaborations. The ITAR restrictions are making it more difficult than they need to be and I think are really raising the risk factor for some of our missions.

Mr. FEENEY. Dr. Squyres, did you have something?

Dr. SQUYRES. Yeah, I would just say that ITAR is some very well-intentioned legislation that has had some unintended consequences for space science in the United States that has actually worked against the best interests of the Nation. As the Principal Investigator for the Mars Exploration Rover Project, I have had the opportunity at Cornell University to have many very talented students come and want to work on the mission. These are students and post-docs from nations like Denmark and Canada, and we have had to turn away people because of the restrictions on ITAR. And these are people who can materially advance a U.S. space mission and make it a better mission. And if there is anything that this committee or that this Congress could do to reduce the burden in a way that in no way endangers national interest, obviously that has to be foremost, but in a mission like operating rovers on Mars, I feel that we could involve international partners in a fashion that would put no national interest at risk and would benefit this nation.

Mr. FEENEY. Thank you. By the way, thanks to Chairman Gordon's permission, I expect to attend in Beijing the first Global Space Summit the third or fourth week of April. It is awfully presumptuous but not surprising given the way the Chinese have advanced in their space programs for them to be hosting the first-ever Global Space Summit. But if we are not going to deal with international partners, you know, clearly the Chinese are going to use it to every advantage as well as some others.

THE NEED FOR BALANCE

Dr. Stern, lately we have been hearing that NASA and the science community have used the word "balance" to describe managing goals obviously with the budget constraints that we have all voiced problems with, also the allocation of resources across the agency, across the Science Mission Directorate and across individual programs. Could you describe NASA's approach to the term balance and what meaning you give it as you evaluate the priorities in a resource-challenged environment?

Dr. STERN. Yes, sir, Mr. Feeney. Balance really comes in several dimensions, so it is important to recognize that it is not just the balance between the different scientific disciplines, Earth science, astrophysics, heliophysics, and planetary science, but it is also balanced within each discipline. We try to optimize for each field using its Decadal Survey as our primary guide, not optimizing for each individual program because then we can't get to balance without averaging over the fields. It is also important that we balance in terms of the mission side of the House versus the research side of the House because if all we do is fly missions and collect ones and zeros and don't spend the money to turn those into discoveries that change the textbooks, then that is another kind of imbalance.

And still there is one more that I would like to speak to, and that is the scale of missions. We got a little bit out of balance in recent years with too many large missions compared to the number of small, intermediate-scale missions, as I said earlier, that stunts progress and it slows innovation. We were certainly not in as bad a situation as space science reached in the early- and mid-1980s when it looked like we were slipping back toward that. We have made positive changes on all of these fronts with regard to the balance between programs in our new budget, for example, the Earth Science Initiative, with regard to higher R&A budgets, so we rebalance between the mission side and the analysis side. Within the individual programs, the primary example being in the planetary program where we are lagging in most of the areas, and we rebalanced using our best judgment in the Decadal Survey with regard to the Mars program. And we have made progress within the mission scales as well. When you look at our new starts, you will see in the Explorer program as well we have quite a bit more small- and medium-scale missions than large-scale missions.

ARECIBO AND NEAR-EARTH OBJECTS

Chairman UDALL. The Chair recognizes the inimitable, the one and only, the creative Member from California, Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you.

Chairman UDALL. For five minutes.

Mr. ROHRABACHER. For five minutes. All right. And that is it. I was in a discussion earlier today about Arecibo and the threat of near-Earth objects and the fact that without their radio telescope, that we will not be able to actually project the trajectory of newly observed near-Earth objects so that we will not know if some newly observed near-Earth object is actually going to hit the planet and kill millions of people. We won't know that without Arecibo, and there just seems to be this battle going on about whether or not that is worth funding its $5 million expenditure and they are already laying people off at Arecibo. Now, I am listening to all these other things and am wondering why that is more important than being able to protect the lives of millions of people should a near-Earth object which we know appear every now and then, how is what you are doing more important than that?

Dr. STERN. Sir, perhaps I will speak for the agency and others may wish to speak as well.

Mr. ROHRABACHER. All right.

Dr. STERN. Well, as you know and as you have encouraged, we have an active program to detect near-Earth objects, to plot their orbits, to determine when they are potentially hazardous.

Mr. ROHRABACHER. And with Arecibo, how will that——

Dr. STERN. Sir, with all——

Mr. ROHRABACHER. I would like to progress.

Dr. STERN. With the detection techniques that we use. They are optical. They are not radar, and in fact, most of the orbit determination work is done without radar. It is rare that, even with Arecibo, that a small, near-Earth asteroid comes close enough to be detected by radar. That has to do with the technical nature of radar.

Mr. ROHRABACHER. So my description of that, that the Arecibo telescope is a necessary component to determine trajectory of near-Earth objects is not an accurate description?

Dr. STERN. Sir, I think those facts are—you have got it right, exactly right.

Mr. ROHRABACHER. Okay.

Dr. STERN. In fact, we do that by optical techniques. When an object does come very close, we can take advantage of radar to improve the orbits, but it is extremely fortuitous, extremely rare that an object comes sufficiently close.

Mr. ROHRABACHER. I am not saying that. I am saying is Arecibo significant? Is that what is necessary for us to—realizing that near-Earth objects that come close to the Earth are rare, but also realizing that a rare object can kill millions of people, if not, even create worse problems. Is the Arecibo telescope vital to the mission to tracking that or can you track that with just optics? Are you telling me you can just track the trajectory with just optics?

Dr. STERN. Yes, sir. Arecibo is nice to have but it is not required, and it alone, for example, would not be able to track most near-Earth asteroids.

Mr. ROHRABACHER. So I have been given the wrong information. Arecibo is not necessary. Are you all in concurrence with that, Arecibo is not necessary for the tracking, to getting the right trajectory so we know if an object is going to hit the Earth or not?

Dr. MOORE. Sir, I would say that the techniques of optical and radar are complementary to one another. Each has strengths, each has weaknesses. I believe that if we had the Arecibo capability, it would strengthen our capabilities in this area. It is difficult to use words like essential or not useful at all. There is a gray zone in between. Arecibo could make a significant contribution. There are many of us in the planetary science community——

Mr. ROHRABACHER. Let me ask you this. Would it make you say a significant contribution and it makes any difference, but is it possible that you could have a near-Earth object that we find that is traced with our optics and that without the Arecibo we could make a mistake and that it could actually be something that could possibly hit the Earth, where otherwise with the Arecibo we would be able to know that it was going to hit the Earth?

Dr. MOORE. Well, speaking as a scientist, I don't think it would be responsible for me to say it is impossible, but I think it would be extremely unlikely. Keep in mind——

Mr. ROHRABACHER. By the way, it is also extremely unlikely that anything will ever hit the Earth period. We know that in our lifetime. But given something that is up there, how unlikely—you said it would only help us 10 percent or more?

Dr. MOORE. I can't assign a number for it. I would be happy to take that for the record and do an analysis, but I will tell you that we have other radar tools in our inventory.

Mr. ROHRABACHER. Okay.

Dr. MOORE. They are NASA assets. Arecibo, I remind you, is an NSF asset, and NSF chose not to fund it. It is not a NASA asset.

Mr. ROHRABACHER. Yes, what I have got——

Dr. MOORE. [inaudible] assets.

Mr. ROHRABACHER. NSF and NASA are both fighting who is going to get $5 million more in their budget, and other guy has to have—this is all, as far as I am concerned, it is all a bureaucratic budgeting and game-playing with turf just to save $5 million in their budget. But this is the first time, Mr. Chairman, that I have asked this question in which I have received the answer that Arecibo is not an essential element to tracking near-Earth objects. So I am glad you are on the record now because we will look into that, and frankly this is the first time. And I take it that everybody concurs with that except you have a little bit of a disagreement.

Dr. FISK. Can I at least decide whether I am going to concur or not here for a moment?

Mr. ROHRABACHER. Please, I ask——

Dr. FISK. I just remind you that in the last years, I believe it was in the Appropriations Act, there was a Congressionally-requested study of the National Academy on this issue that is to assess including the role of Arecibo in this problem; and the Academy is currently forming a committee as requested with NASA sponsorship to give you that kind of an answer on all aspects of this thing. I think that will provide you with all the information that you need.

Mr. ROHRABACHER. That is very good. And when is that due?

Dr. FISK. Help me out. Late 2009. That is an Academy——

Mr. ROHRABACHER. Well, by then Arecibo will be closed up, and that doesn't sound like it is going to help us at all.

Mr. Chairman, we have got some decisions to make, and I am going to be looking directly into it. And I thank you for that. You are the first person—we have been discussing this for two years, and you are the first person who stepped forward and said no, Arecibo isn't really that essential.

Chairman UDALL. I thank the gentleman from California for his passion and for his interest in this, and as he and I have discussed we are, and as the Ranking Member also has been involved, we are on track to reauthorize NASA in the next couple of months, hopefully. I guess it is the next three or four months, but this will certainly be a part of the discussions that we have as we move towards the reauthorization act. So I thank the gentleman.

THE BUDGET REQUEST AND MARS SAMPLE RETURN MISSION

The Chair will now recognize himself for an additional five minutes. We will have another round if that is acceptable. Dr. Stern, let me move back to the budget request again, particularly the reduction of the programmatic content of the Mars portion of the budget by $918 million from fiscal year 2009 to fiscal year 2012. At the same time the proposal includes a maintenance of the sequence of planned Mars missions and adding an ambitious Mars Sample Return mission for launch in 2018 which you heard about earlier. Various expert groups chartered or convened by NASA have analyzed the budget plan and have expressed their views that the fiscal year 2009 budget assumed budgets beyond fiscal year 2013 will not support the Mars program that NASA has outlined.

Let me ask you about some specific areas of concern with respect to the proposed Mars Sample Return mission. I understand that it is typically a good program management practice to spend some four to six percent of the overall mission cost on developing required new technologies for a mission before actually embarking on the project. For a Mars Sample Return mission, that is expected to cost on the order of $5 billion. Four to six percent with suggested several hundreds of millions of dollars is needed for early technology risk reduction. Can you tell me how you arrived at the low figure of only $68 million over the next five years for the Mars Sample Return technology risk reduction? Can you cite any other successful NASA science missions that spent such a low percentage on technology risk reduction without incurring cost growth and schedule delays?

Next, serious concerns have been expressed that both the funding profile and the total budget for NASA's Mars Sample Return mission are unrealistic and that an attempt to proceed with MSR's envisage will lead to the need to cancel other Mars missions and ultimately to slip the schedule and increase the cost estimate for MSR. How do you respond? And then Dr. Squyres, we will put you in the queue and would like you to respond to Dr. Stern's comments when he is finished. So we will start with Dr. Stern.

Dr. STERN. Thank you, Mr. Chairman. That is a hefty topic. I need to take a few minutes to lay out that full picture for you because the topic is deserving of it.

We have an exciting Mars program, and I want to deconstruct for just a moment the claim that our Mars program is not executable. We actually asked the Mars experts, and I hope Dr. Squyres will weigh in on this, and you say, well, we have the Mars Science Lab, the Aeronomy mission that Dr. Squyres spoke of, to-be-named mission in 2016, and then the Mars Sample Return. Which of those do you have a problem with when you say the program as a whole is not executable? And when pressed, Mars Science Lab is generally deemed by experts to be executable. I think people believe that we can to the Aeronomy mission on the roughly half-billion-dollar budget set-aside for it. It is really not possible to say that the 2016 is not doable on the $880 million budget set-aside because the mission has not yet been scoped. We have asked the science community to tell us what they want to do in that budget, and until they come back to us, there is nothing to argue about. We are looking for that guidance.

Now, with regard to your specific question about MSR, keep in mind that it was only in May of last year as we were formulating the budget that I elected that we actually take a stand, put a stake in the ground, and use Mars Sample Return as a central organizing theme for our Mars program going forward. Now, every Mars report of late, the Jakosky report to the National Academy last summer on astrobiology, the MEPAG reports and our advisory panels, et cetera, put Mars Sample Return at the top. We are not putting it at the top of our priorities. We can't execute that mission until approximately 2020 because our European partners who are interested in collaborating at about 40 percent of the total cost have commitments of their own and cannot themselves ramp their budget until the middle of the next decade.

So while we are executing MSL, the Aeronomy mission, and the 2016, we cannot be building up the MSR budget because we would be ahead of our partners and the phasing wouldn't work. Now, we put $68 million in this budget, and the purpose of the $68 million is not to do all of the technology development for MSR. To the contrary, this is our money for doing the architectural studies that we will be doing in the next couple of years to determine exactly what MSR consists of and which technologies need to be developed as well as some early lead technologies that we are making an initial commitment to.

Now, it is up to the Mars community. We have told them, if you want a smaller mission 2016 and a steeper ramp to MSR, that

$880 million is out there and it can be used for both purposes. And so we can address just the five percent sort of number for technology development, for advanced development for MSR if the community comes back with a mission that is properly scoped for 2016. If, on the other hand, the community asks to use the entire $880 million for science mission in 2016, then MSR is necessarily going to have to wait on its technology development to a later date. But that is a decision for the scientific community to make.

Chairman UDALL. Dr. Squyres, would you care to respond and provide your perspective? And I would ask the Committee's indulgence. I think this is an important enough question that I will go over my time a bit and make sure we get for the record your point of view.

Dr. SQUYRES. Yes, sir, I would be glad to. I agree wholeheartedly with Dr. Stern that a Mars program that consisted of the Aeronomy mission in 2013 for a cost of $550 million I believe it is, another Mars mission in 2016 at $880 million which is a hefty sum, followed briskly by Mars Sample Return would be an exciting program; and I think you would find that many of us in the Mars community certainly speaking for myself, I would stand solidly behind such a program. As Dr. Stern pointed out, and I agree, the money that is in the President's budget request for fiscal year 2009 fully supports that 2013 mission and that 2016 mission, and we can do great things with those two missions. The problem simply stated is that the $68 million that is available in the next five years to do studies and preparation for Mars Sample Return is not adequate in that timeframe to support, in the judgment of myself and many members of the community who look at this very hard, a sample return mission in the 2018 and 2020 timeframe.

So a consequence of the budget as it has been submitted, there are two possible outcomes. It is really very simple. One possible outcome is that we do the 2013 mission, we do the 2016 mission, we do great science, and Mars Sample Return simply moves downstream; and I don't think what I just said was too much at odds with what Dr. Stern just said.

The other possibility is if you choose to anchor in 2018 and 2020 the sample return mission, then the money that you need to spend to get ready for those missions in that timeframe, which you correctly state is in the realm of hundreds of millions of dollars, has to be taken out of the Mars program and that means you are not going to be able to do the 2013, 2016 missions.

So I think it is an either/or proposition if we are faced with the very large cuts to the Mars program that the current budget entails. If, however, the money that we are provided for Mars exploration were put back to the levels that we have enjoyed over the last several years, I believe that it would be possible to carry out in full the program that many of us in the community would like to see and that Dr. Stern I am sure would like to see as well. And that would be the 2013 mission, the 2016 mission; and in that same timeframe, do the advanced technology development necessary so that you could actually do sample return which remains a very high priority for the Mars community in 2018 and 2020. I hope that addressed your question.

Chairman UDALL. Thank you, Dr. Squyres, and I might, before I recognize Ranking Member Mr. Feeney, tell the audience and tell the rest of the Committee that when we end the hearing, and I think we will have another round depending upon people's time schedules, you are going to finish the hearing with some recent images from the Mars rovers.

Dr. SQUYRES. I would enjoy doing that.

Chairman UDALL. I know I am very much looking forward to doing that. I just wanted everybody to know here to stay because at the end of this, we will end with a bang here today. The Chair recognizes Mr. Feeney for five minutes.

THE NPOESS PROGRAM

Mr. FEENEY. Do our technical budget questions stand in between the audience and exciting video slots? Okay. Well, I will make my questions penetrating then. The NPOESS program has had significant problems over time, budgetary and meeting its goals. That led to the Nunn-McCurdy review, and ultimately that meant that a number of climate sensors were dropped from the satellite in order to limit cost growth. The program was also re-baselined at that point. Is NPOESS meeting its revised schedule and its cost milestones and what are the largest threats and challenges we have? Dr. Stern, why don't we start with you and anybody else that wants to weigh in on that.

Dr. STERN. Yes, sir, very briefly. After the restructuring, the mission has been doing much better. It is a very ambitious undertaking, and simply put, we have a long way to go. It is still early days in the development of both the payload and the spacecraft. So while I think it is doing considerably better, we have to be ever vigilant.

Mr. FEENEY. Does anybody else—Dr. Moore, please.

Dr. MOORE. I think the program has had many problems, and one of the problems has been a technology hurdle associated with the imager referred to as VIIRS. It appears that those problems are not yet behind us and that perhaps for some of the geophysical variables like ocean color, we are not going to be able to achieve the requirement. I think the question that really stands before us is that each time we believe that we have the instrument, shall we say, we are over the worst hurdles, a new hurdle appears. And so I think it is just the concern with the past performance that we have constantly stumbled, even though we thought we were near the end on this particular instrument. I agree with Alan that I think that we are beginning to see, and not to use an old phrase, the light at the end of the tunnel and hopefully it is not the train coming towards us.

WORKFORCE ISSUES

Mr. FEENEY. And when we are talking about lights at the end of tunnels and we are looking into space, those are light years away sometimes. We don't know how long those—tunnels are finite. You are on the planet.

Dr. Fisk, you raised the issue that is a concern to a lot of us on a lot of fronts at NASA and that is the workforce issue. It is something that I think all of us are focused on. It is not necessarily a specific budgetary issue, but you are the one that raised it in your talk, and I was interested given again the parameters we have with the likely budget outcome if you think that there are things we can do differently to excite future science and math scholars through our science program or for that matter through the space flight program. If you think that there are different things that NASA can be doing because it serves a twofold purpose in my view. Number one, we get kids focused on the subjects that they need to master for us to be a preeminent space society, and that is math and science, which also has a lot of import in other areas for our economy and strategic and military capabilities; but it also conceivably would help generate the sort of support that we are all looking for in the public for NASA's missions. So maybe we can get the $800 million to advance the Mars program and maybe we can shorten the gap in the human flight. So it is a dual purpose if we can find a way to do it. NASA does, by the way, of all the agencies, they get more hits from school websites, they get more interest from teachers in the science field. So Dr. Fisk, why don't you start and if anybody else has any thought about what we can do within existing parameters to get that excitement started.

Dr. FISK. I think I have always thought of this problem in sort of two different ways. There is the question of encouraging people to go into science and math in general, engineering sciences as well, and there, you know, just simply the excitement of space and making that available to the school system is obviously an extremely positive thing and it encourages people to go into the fields. But it isn't the problem. There is a separate problem which was once you have encouraged them to go into math and science in general, do they want to go into space? And that is a second problem because that problem comes up at the university level. You know, you have encouraged people to go off and get training and engineering degrees, undergraduate degrees, and so on; and then they have a whole series of options available to them which are in the best interests of the Nation, whether they are, you know, nanotechnology, various kinds of sensor technologies, any number of things. And the question is, you know, should they go and will the best and the brightest go into the space business. That problem is actually not that difficult to solve in my judgment because what happens is, you know, I think all our experiences, Jack Burns at the end, and all of us, Steve, that are in universities, have discovered that when you engage students as undergraduates in technical fields in participating in some aspects of space, research projects, hands-on experience and so forth, they inevitably want to go into the space business. And they are encouraged to do so, they see the excitement first-hand, and the converse is also true when you don't, the lures of all the other disciplines.

So the Nation can decide. If we need people in these fields, we have so many challenging activities coming up in space. We have challenging activities and our workforce is starting to get old in the space business, and as a result, you know, we need to vet these people in. They need to be the best the Nation can offer, and there is a very simple process that you can do that, engaging the universities because at this point, they have decided to go into the field, that happened earlier, and now the question is the yield factor for space. Thank you.

Dr. MOORE. To turn the problem slightly differently, I think in your discussions that we had earlier about ITAR, this is an area where not only for the university community, but for the NASA centers, a fresh vision would be very helpful. I know that it is a burdensome aspect for JPL as well as for Goddard and other NASA centers. There are certain very real reasons for ITAR, but I think that they could be scaled back and that would directly address what you have raised.

Dr. SQUYRES. I just wanted to comment that I think that a lot of what we do in the space science program has enormous potential to inspire young students to go into careers in math and science, not just in space, but in math and science overall; and I think we need to work very hard to find creative ways to engage those students in ways that are going to be captivating for them. I recently had a fascinating experience. I gave a talk to 20,000 young middle school and high school students, mostly from underprivileged school districts in Detroit. I did it at Ford Field where the Detroit Lions played. I was lined up on the 10-yard line between the hash marks with the end zone filled with middle school students and showing pictures that had come down from Mars four hours before on the jumbotron screen. They were captivated. They get turned on by this, and if we can take what we do and the passion that we all feel for what we do in space and if we can find creative ways to reach those people, it is an enormous resource out there, there really is.

Dr. BURNS. I agree very much with my colleagues on this topic, but let me add one other nuance here, an issue that we face, and that is that the timetables today are getting to be so long for these space missions, a decade or more, that it is difficult to attract students into these programs because the timetable for building these instruments is well beyond the typical tenure of a student, either undergraduate or graduate level. And so they don't have a chance to fly these missions, if you will, while they are in school. So we have a problem that is making it difficult to attract new instrumentalists who build the next generation of spacecraft sensors or imagers, and it is something that we need to face. I think Dr. Stern is helping by reimplementing—we almost drove the balloon and the rocket program out of existence, and so this is very helpful in that regard but we really need to do much more.

Chairman UDALL. I would like to thank the panel for some really important insights into this crucial area of how do we recruit young people into these important fields and then how do we retain them and give them a sense that this is very worthwhile.

The Chair recognizes again the gentleman from California for five minutes.

EDUCATION, ASTEROIDS AND EXOPLANETS

Mr. ROHRABACHER. I would just note that unless our children have a good foundation in science and mathematics, that we are not going to be able to recruit them later on. And let me just note that of all the hearings that I had, especially yesterday with Bill Gates, it is very clear that there is such a hesitation to confront the political problem of permitting science and mathematics teachers to receive more pay than the teachers of other subjects. And pay differential is the fundamental issue that is either going to make us successful in giving these fundamental skills or not because you have got dozens of people that want to teach English literature and history, and frankly for every one person that you can maybe attract to teach science and mathematics, and the science and mathematics people can make lot more money doing something else other than teaching. So we need to pay them more money. There was a movie called, and I remember they said—it was about baseball, "Build it and they will come." Well, pay more money and they will come. And unfortunately there is a major political impasse in that certain political people have relied on unions and the educational unions which would rather hold America back than give up the right to have every teacher in every subject just be paid exactly the same amount of money. That is the fundamental problem we face there.

It was also mentioned that someone is seeing the light at the end of the tunnel. I hope when they are looking through a telescope the light at the end of the tunnel isn't a near-Earth object headed in our direction. And I think some day it will be, and I understand there have been near-Earth objects—you know, they come so infrequently but there happens to have been one just a short while ago that came between the Earth and the Moon, that close. We didn't even know it was there until after it had gone by. And I think that it is worth our while to be able to look out, and by the way, that is also something that—we actually passed legislation. It gives awards to young people who, if they look into the sky and discover some near-Earth object, we give them an award, I think the Pete Conrad Award. I authored the bill that permits this and gives this award every year to a young person that discovers some object. So that is a good way of getting young people involved as well.

Let me ask, it was mentioned earlier and I believe it was you that was talking about the discovery of planet, outer planets or something that NASA is doing?

Dr. BURNS. Congressman Rohrabacher, I think exoplanets is what you were referring to——

Mr. ROHRABACHER. Yes.

Dr. BURNS.—around other star systems?

Mr. ROHRABACHER. Yes, how much are we spending discovering these extra planets?

Dr. BURNS. Well, I would have to turn to Dr. Stern because I don't know those numbers off the top of my head, but we have got a new mission which is going to be launched next year called Kepler that is going to be dedicated to looking for new stars. Right now based on ground-based observations, over 250 planets are known to now exist around other star systems.

Mr. ROHRABACHER. The question that I need to answer here is why are we willing to—this is obviously an expensive proposition. Why are we willing to launch a new program that is going to cost money to find out about planets from distant stars when we are not willing to spend even more than $3 million a year trying to find near-Earth objects that may or may not hit the Earth and kill millions of people?

Dr. STERN. I think that is for me. Let me say that in executing our exoplanets program, we are following the recommendations of the National Academy. It is a very exciting program. We have a number of spacecraft that we are turning to that task, and we are building Kepler——

Mr. ROHRABACHER. How much is that going to cost?

Dr. STERN.—and looking forward to future programs.

Mr. ROHRABACHER. How much will that cost?

Dr. STERN. Those missions are typically in the Kepler cost class, and they are $600, $800 million.

Chairman UDALL. Mr. Chairman, let us just note, $600, $800 million and we are quibbling over whether or not we are going to really have a program that can really take care of charting all of the near-Earth objects in a very quick time just to see if one of them might hit the Earth and quibbling over a $5 million telescope which may, and I am going to look into this, which may or may not play an essential role. If it doesn't play an essential role, I am going to take that back and I will call my friends at Cornell and tell them I got the wrong information. I do seem to remember, Mr. Chairman, the last time we held a hearing, all of the witnesses told us how vital this telescope was but to spend hundreds of millions of dollars to find a planet and distant stars and not be willing to——

Dr. STERN. Mr. Rohrabacher, if I may——

Mr. ROHRABACHER. Sure.

Dr. STERN.—I would like to tell you about our NEO program because it is an exciting program as well.

Mr. ROHRABACHER. It is a $3 million program, is it not?

Dr. STERN. It is commonly referred to as the $3 million program. In fact, because we were lagging in our goal that the Congress set to finish by the end of 2008 projecting 90 percent of all the kilometer class potentially hazardous objects near the Earth, I actually took some of my discretionary funds and helped that program along this year. So it is actually being funded at a little bit higher level than that. But I also want to point out, that is not the only way that we study near-Earth asteroids. We have programs in fundamental research in our planetary science division. We have flown a mission to orbit and then land on a near-Earth asteroid——

Mr. ROHRABACHER. I was there when they did.

Dr. STERN.—called NEAR. You are probably familiar with that mission.

Mr. ROHRABACHER. Right.

Dr. STERN. I think its cost level was several hundred million dollars. I think it was about $250 million. We have a mission on its way, although not to a near-Earth asteroid, to orbit two of the largest asteroids in the asteroid belt. We have a whole variety of programs that address the nature of asteroids, their composition, their structure. This all helps inform us about the near-Earth asteroid problem in one way or another, and we are doing the program that the Congress asked us to do and I expect us to meet that goal by the end of 2008.

Mr. ROHRABACHER. Very good answer. Thank you.

Chairman UDALL. I thank the gentleman from California. I want to recognize the gentleman from Florida for a comment.

Mr. FEENEY. Yes, I will be brief and I know the Chairman has some questions but I will be done for the day after this. I have a bit of an interest in the near-Earth object issue as well. I would note a couple things. Number one, some scientists believe 64 million years or so ago dinosaurs and other entities went extinct around the planet because of a near-Earth object actually colliding. We actually had a big one I think in 1908 in Siberia that would have been catastrophic. So these things do occur, and I think Congressman Rohrabacher's concerns are genuine. I would point out that I think if I remember the testimony right, something like 99 percent of the resources spent on detecting near-Earth objects are American resources. It would seem to me like other space-faring nations and scientific nations, this is one where it is not a zero-sum game. We are sort of all in it together, and I think this is one that begs for international cooperation. And then finally I would suggest, and I am sorry that Dana is not here to hear it, but you know, sometimes we give these warnings and we get to later say I told you so; but it is going to be hard to hold anybody responsible if we get hit by one of these things, the human race goes extinct. It is just going to be tough to hold any agency specifically. So one of the problems that he has is there may be more immediate concerns from folks that have to allocate resources.

With that, Mr. Chairman, we don't get to see slide shows in the Financial Services Committee, so I am going to give up my questioning time and——

Chairman UDALL. I know the Ranking Member and I will do everything possible to hold a hearing if that day does arrive.

AVIATION EMISSIONS AND EARTH SCIENCE

Dr. Stern, if I might, I am going to take a few more minutes and then we will end with some inspirational images from Mars, from the red planet. And you may want to direct this to Dr. Freilich I know who is here. What if any research are you doing in the Earth science and applications program to better understand the impact of aviation on climate and how it might be mitigated? Do you think NASA should be doing research in this area if it is not already, given the potential for regulatory actions to penalize aviation emissions down the road? And then Dr. Moore, you may want to comment once the NASA team has had a chance to comment.

Dr. STERN. Yes, sir, well, I think if you would like a full answer on it now rather than taking it for the record, I would invite Dr. Freilich to the microphone and he can give a better answer than I could, if that is acceptable.

Chairman UDALL. Please.

Dr. STERN. Mike?

Dr. FREILICH. We will take it for the record and give you a complete answer. I can say that there are several aspects of aviation and applications and science that are covered in our programs. In the science programs, our fleet of satellites measure atmospheric compositions and measure cloud and aerosol properties. Some of these clouds and aerosols are the result of aviation exhaust if you will or whatever, a result of aviation. It is fairly prevalent. Actually, when there was little aircraft flights over the United States right after the tragedy of 9/11, it gave us a remarkably clean view from our flying satellites of the situation without aircraft that could be compared to the normal situation with aircraft. And I will get you in more detail the specific studies that are going on right now. We are also in the applications program conducting a number of studies with the Federal Aviation Administration and NOAA to improve aviation and its interactions with the environment, in particular, the effects of icing on aircraft and predictions of that to better route aircraft and to improve the overall air traffic system.

Chairman UDALL. Thank you, and Dr. Moore, please comment.

Dr. MOORE. It seems clear to me that certainly in the aeronautics program, looking at aircraft efficiency and in particular the issue of carbon emissions is going to be a great opportunity. In some of these, we ought to recognize these green issues. Well, the color of money is green, and in terms of being competitive, we should think about can we improve the U.S. aircraft fleet so that on carbon emissions it has lower carbon emissions per traffic mile, per passenger mile. And that is going to be particularly important as we look to the era of cap and trade on carbon emissions or carbon tax. These will become very real economic benefits for the country if we can make the kind of engineering progress that I think that would be natural for an aeronautics program to focus upon.

Chairman UDALL. Those are excellent insights, and I agree, with the right leadership and the right incentives, in some cases the right regulatory structure, I am betting on our entrepreneurs, on our capital flows, on our technology; and it is one of the shortest but one of the most powerful sounds bites around. There is green in green, so I appreciate your pointing that out to all of us. We want to sell this technology all over the world.

IMAGES FROM MARS

Thanks again to the panel. Dr. Squyres, do you want to end with some inspirational, exciting——

Dr. SQUYRES. Yes, sir, I would enjoy that very much. I always like showing off the latest pictures from Mars.

Chairman UDALL. If we can bring the lights down——

Dr. SQUYRES. Yeah, that would be great.

Chairman UDALL.—and make it even more exciting.

Dr. SQUYRES. Today is day 1,491 of our 90-day mission to Mars. Both Spirit and Opportunity rovers are continuing to do extraordinarily well, doing great science; and moreover, they are part of an armada of spacecraft from NASA and also European spacecraft that are at Mars right now and daily sending back new data.

I have just brought a few pictures for you.

[Slide.]

This is a recent picture from the rover Opportunity. Opportunity landed about six kilometers, about four miles, to the north of where this picture was taken, over a period of years drove to a spectacular impact crater called Victoria Crater. It is 800 meters in diameter, it is about 70 meters deep, it is a spectacular window into the subsurface of Mars. As we speak, Opportunity is down inside Victoria Crater, going down into the rocks exploring and sort of taking a trip back in time as we look at the rocks exposed there. One of the reasons that I chose this particular image is if you look off in the distance sort of on the far horizon, you will see a large cliff there. That is about 25, 30 feet high. That is a place that we have named Cape Verde, and after we finished doing the geology that we are doing at this particular location, we are going to try to get as close as we can to that and take what should be some absolutely stunning images of it.

[Slide.]

This picture came down from the Spirit rover less than 24 hours ago, so this was happening on Mars yesterday. Spirit is in a place called Home Plate investigating some rocks immediately in front of the rover you can see the rover's arm reaching out and making measurements. This particular rock outcrop is one that we have named Wendell Pruitt. Wendell Pruitt was one of the members of the Tuskegee Airmen. We have chosen the Tuskegee Airmen to name rocks in this particular area. He was one of the first great African-American fighter pilots.

[Slide.]

Here is a picture of Wendell Pruitt the rock. This was taken with our microscopic imager just a day or so ago. I will not attempt to analyze that image. I just saw it for the first time yesterday, but stuff is happening on Mars. I also wanted to show you one more image, and this comes not from the rovers but from one of that armada of orbital spacecraft. Every now and then Mars will just surprise the heck out of us, and this was a wonderful one.

[Slide.]

What you are seeing here is an avalanche caught in the act of happening. This is a picture taken from a spacecraft called the Mars Reconnaissance Orbiter. It has a spectacular high resolution camera that can look down from orbit and see objects as small as a meter or so in size, and this is near the Martian north polar region on a very steep slope, and this is an avalanche roaring down a slope on Mars and we happened to catch it as we were flying overhead, just beautifully illustrates to me what a dynamic and interesting place Mars is. So we continue to do the best science that we can, and we appreciate your support.

Mr. FEENEY. Those are terrific pictures. Mr. Chairman, you know, to a Floridian, they look a lot like parts of Colorado.

Chairman UDALL. Thanks again to the panel. Dr. Stern, thank you, Dr. Fisk, Dr. Moore, Dr. Squyres, Dr. Burns, another inspirational panel. Thank you for your commitment to this very, very important part of our future. I look forward to having you back, and thanks again for your time.

[Whereupon, at 4:04 p.m., the Subcommittee was adjourned.]

Appendix:

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by S. Alan Stern, Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration (NASA)

Questions submitted by Chairman Bart Gordon

Q1. A presentation at a recent National Research Council Space Studies Board meeting noted that "There has been a major shift to supporting mission-enabling technology development only within lines of individual missions after their new start. This increases the likelihood of having major cost overruns within the missions themselves".

a. What is your response to this argument, especially given programmatic cuts to technology development lines in the Science Mission Directorate budget?

b. What is your strategy for ensuring technology development to support the multiple new science initiatives proposed in the FY 2009 budget?

A1a, 1b. NASA does not agree with the assessment that there is increased likelihood that missions will have major cost overruns if they undertake their own technology development. The SSB presentation and mention of "cuts to technology development lines" are clearly referring to the demise of the New Millennium program. That responsibility is being transferred, not abandoned. Moreover, the data showed that the technology developed in NMP was largely not being utilized on subsequent missions. JWST is an example of a project achieving its own tech development. We also note that our projected technology development in the R&A program is increasing, not decreasing.

While funding for long-range, low technology readiness level (TRL) development has declined in recent years, NASA's technology programs have become more tightly focused on delivering critical technologies for its future missions. NASA has been able to maintain an adequate level of basic Research and Development within its present level of funding. NASA's research and technology development programs have the funds necessary to support the missions that the President has asked us to do. NASA research and technology activities primarily exist in both the Exploration Systems Mission Directorate (ESMD) and the Science Mission Directorate (SMD).

Needed technology is identified via the NASA Science Plan development and Mission Concept Development Studies. The technology itself continues to be developed via Research and Analysis (R&A), Small Business Innovative Research (SBIR), and Innovative Partnership Program (IPP).

Q2. There are concerns about the future loss of the Delta II launcher for medium-class missions and the rising cost of launch vehicles. Could you please describe in specific terms which launch vehicles will be used small and medium class missions that have not yet been assigned launch vehicles and that are planned for launch through 2014?

A2. NASA competitively procures launch services using the NASA Launch Services (NLS) contract. At the appropriate time in the mission life cycle, a Launch Services Task Order (LSTO) is initiated to solicit cost proposals from NLS suppliers for that specific mission.

The following Small Class (SC) missions on the planning manifest through 2014 have not yet been assigned launch vehicles: NuSTAR, SMEX–12, SMEX–13, and GPMC. Currently, two providers are available under NLS for Small Class services: Orbital Sciences Corporation with their Pegasus and Taurus launch vehicles; and SpaceX with their Falcon-1 launch vehicle (in process of certification). As a result of the anticipated future loss of the Delta II vehicle, there are currently no unassigned Medium Class (MC) missions on the planning manifest through 2014.

All remaining unassigned missions are sized and budgeted for Intermediate Class (IC) launches.

Q2a. What, if any, cost impacts does the current launch vehicle planning have for science missions and do the FY 2009 budgets reflect current estimated prices for launch vehicles?

A2a. The FY 2009 budget reflects estimated costs for launch services. The rising cost of launch services impacts NASA, as the increasing budget allocated to launch vehicles reduces funding available for scientific investigations.

Q2b. Will the Atlas 5 or Delta 4 be used to launch two science payloads, and if so what is required to facilitate these "piggyback" launches?

A2b. NASA regularly examines the technical and economic feasibility of co-manifesting dual payloads, and has successfully demonstrated this approach as recently as 2006 with the CloudSat/CALIPSO missions launched on a single Delta II rocket. The primary constraint affecting the dual manifest approach is orbital destination, although readiness date of the payloads is also a major consideration. It should be noted that Dual Payload Adaptor Fittings (DPAF) designed specifically for the IC launch vehicles (Atlas V and Delta IV) do not currently exist, and must be designed and qualified in order to permit future co-manifested missions.

Q3a. The Consolidated Appropriations, FY 2008 recognized the important contribution that the Arecibo Observatory makes to scientific research on space weather and global climate change, and to observations of near-Earth objects. The explanatory language accompanying the Act directs NASA "to provide additional funding for the Arecibo Observatory."

What, if any, additional funds are provided for Arecibo in NASA's FY 2008 operating plan?

A3a. NASA has committed $538,110 of FY 2008 planetary science funding to researchers that are using the Arecibo radar facility for planetary science, including NEO characterization efforts. No NASA funds were provided for Arecibo facility operations in FY 2008; Arecibo is operated by an NSF-funded FFRDC.

Q3b. Does the FY 2009 budget request include any support for Arecibo?

A3b. Over $500,000 of FY 2009 planetary science funding is planned to support researchers that are using the Arecibo radar facility. No NASA funds are planned to be allocated to Arecibo facility operations; Arecibo is operated by an NSF-funded FFRDC.

Q3c. What is the status of NASA–NSF discussions on Arecibo?

A3c. NASA and NSF officials regularly discuss the status of Arecibo, as well as many other collaborative and cooperative efforts, as a routine and regular course of business between our agencies.

Q3d. You testified that you spent some of your discretionary funds to help NASA's Near-Earth Objects program this year. How much discretionary funding was provided to the program? Was the funding for FY 2007 or FY 2008? And for what purposes is that funding being used?

A3d. An additional $1.7M was provided to the NEO observation program, for a total NEO budget of $5.1M in FY 2008. The additional funding was used to: (1) to fund one researcher using planetary radar to characterize NEOs; (2) to maintain operations and upgrade the Minor Planet Center for NEO detection and catalog efforts; (3) to begin NEO search operations using the Pan-STARRS-1 telescope starting this summer; and, (4) continue ongoing NEO search operations.

Q4. Is the U.S. supply of plutonium adequate to support the new planetary missions proposed in the FY 2009 budget request?

A4. The DOE and NASA have worked closely together to assure that the missions identified in the FY 2009 budget request have adequate Plutonium (Pu–238). With the current Pu–238 inventory in the U.S. and planned procurements from Russia, the Agency will be able to conduct all missions requiring radioisotope power systems up to and including the currently planned Outer Planets Flagship mission.

Q4a. Is NASA making any plans to acquire plutonium from Russia once the U.S. supply is depleted? If so, are you comfortable in becoming dependent on Russia for plutonium?

A4a. NASA is currently using the Department of Energy's contract with the Russians for the purchase of Pu–238. NASA is in the process of purchasing 10 kg of Pu–238 from Russia suppliers. Five kg will be purchased before the end of FY 2008 and five more in FY 2009 even though NASA will not use this supply for a number of years. By purchasing the Pu–238 as early as possible then NASA is comfortable with moving ahead with its plans for missions that will require Pu–238 heat-conversion power systems.

Q4b. Will NASA's plans for the exploration initiative require nuclear energy sources and if so, what is the plan for acquiring that plutonium?

A4b. NASA is evaluating the need for nuclear energy sources for the lunar surface. For example, NASA will likely need to place habitation modules, landers, and rovers on the lunar surface in locations where solar cells cannot produce continuous power.

While NASA is still formulating its specific lunar architectural needs, NASA believes that Radioisotope Power Systems will provide an important power source for enabling mobility for human explorers on the lunar surface. The Administration is currently developing an approach to acquire the Plutonium 238 that may be needed to meet all agency needs after 2017. NASA's exploration technology development program also has a Fission Surface Power Systems project that is examining technologies that might enable the development of a nuclear fission reactor for potential use on the lunar surface. The fission surface power system project would utilize uranium, not pu–238, as the nuclear fuel.

Questions submitted by Chairman Mark Udall

Q1. At the Full Committee hearing on NASA's FY 2009 budget request, Administrator Griffin testified that the Glory mission has exceeded 30 percent cost growth, which requires Congress to reauthorize the mission under the NASA Authorization Act of 2005.

Q1a. What went wrong with Glory and what steps is NASA taking to address the problems?

A1a. The Glory cost growth and schedule delay are primarily due to poor management and execution by the Aerosol Polarimetry Sensor (APS) instrument contractor, Raytheon Space and Airborne Systems, El Segundo, California. Approximately 20 percent of the cost growth is due to the spacecraft refurbishment work performed by Orbital Sciences, Dulles, Virginia. NASA is vigorously monitoring both contractors' performances.

Q1b. How confident are you that the mission will be ready for launch in 2009, as currently planned?

A1b. The Glory mission has been approved for a June 2009 Launch Readiness Date (LRD), a three-month slip from the previous March 2009 LRD. This new LRD will accommodate APS instrument delivery delays and includes a thorough assessment of the remaining APS development challenges. This new NASA-developed and NASA-approved plan does not rely on the APS contractor's assessments of its own performance; rather, it relies on NASA's own technical and programmatic assessment of the APS completion requirements and the contractor's capabilities, and is consistent with the contractor's performance over the past 12 months.

Q1c. Is NASA satisfied with the contractor management and performance on Glory's main instrument, the Aerosol Polarimetry Sensor (APS)? If not, what steps is NASA taking to improve contractor performance?

A1c. NASA is not satisfied with the contractor's performance, including poor planning and management execution, combined with the contractor's own burdensome institutional processes. Raytheon's decision to move its APS program to a new facility midway through development also contributed to the challenges of delivering the system within cost and schedule. NASA is vigorously monitoring the performance of the contractor, which has been inefficient, but consistent with the NASA-developed milestone plan and schedule.

Q2. NASA's NPOESS Preparatory Project (NPP) has been delayed due to contractor problems in developing the Visible Infrared Imager Radiometer suite (VIIRS) instrument.

Q2a. What are the costs to NASA of this delay?

A2a. The new NPP approved launch date is June 2, 2010. The previously scheduled launch date was September 30, 2009. The additional cost to NASA associated with this eight-month delay is an average of $2.75M per month, or a total of $22.0M. This additional amount covers costs for the technical support workforce and infrastructure required to maintain instruments, equipment and facilities that must be available at launch, for the additional eight months.

Q2b. Are you confident that the VIIRS instrument will be delivered on the schedule set to support the currently planned launch date of NPP?

A2b. VIIRS has been built and is undergoing testing to qualify for the NPP mission. In approving the present NPP launch date of June 2, 2010, the NASA DPMC and the EXCOM carefully evaluated the status of the instrument and recent test results. A number of top-level management actions, and enhanced monitoring, have been instituted to increase U.S. Government confidence in the approved VIIRS delivery and launch dates. The EXCOM meets approximately quarterly with high-level management from the VIIRS contractor. In additional, the EXCOM meets at quarterly intervals with the NPOESS Program Executive Officer (PEO), who has oversight of delivery of VIIRS on NPP. The EXCOM receives monthly status reports from the PEO. In January 2008, the EXCOM directed the PEO to meet biweekly with the leadership team of the VIIRS contractor to ensure that U.S. Government concerns are addressed. The PEO delivers a report on the outcome of those meetings to the EXCOM.

Q2c. Given the delays for NPP, is the objective for risk reduction to NPOESS still viable?

A2c. NPP remains in part a risk reduction for NPOESS because the launch of the first NPOESS satellite has been delayed to January 2013. Lessons learned from NPP hardware development and ground processing activities will inform and refine approaches for NPOESS. NPP also has a distinct NASA science objective, to extend selected key climate time series initiated by the NASA EOS research missions.

Q2d. What costs, if any, will NASA incur in adding the Clouds and Earth's Radiant Energy System instrument (CERES) to NPP?

A2d. In 2008 and 2009, NASA will refurbish the CERES Flight Model 5 instrument, make small modifications to the NPP spacecraft to allow CERES to be accommodated, and integrate CERES with the NPP spacecraft and ground data system. These minor modifications can be undertaken without significantly impacting technical risk or schedule for NPP. The NASA cost for activities related to the CERES instrument is $17.7M, primarily for data production and product generation.

Q3. During the hearing, you took the following question for the record: The FY09 budget request for NASA states that "eight projects have exceeded Congressional thresholds on cost or schedule growth." This is an increase of five missions over the projects listed in the FY08 budget request. The eight projects include Herschel, Kepler, the NPOESS Preparatory Project (NPP), Glory, Orbiting Carbon Observatory, Aquarius, Gamma Ray Large-Area Space Telescope (GLAST), and the Stratospheric Observatory for Infrared Astronomy (SOFIA).

Q3a. Given that the FY 2009 budget request includes several new initiatives estimated to cost $500M more, what specific steps is NASA taking to address the problems with the eight missions cited in the budget book and to ensure that any new initiatives do not exceed Congressional thresholds?

A3a. Three of the eight missions cited (Herschel, Aquarius, and NPP) involve challenges on the international or interagency partner's side, and while NASA is doing what it can, the Agency is dependent on partner performance. GLAST was launched on June 11, 2008. OCO is on track, with algorithm development in work to address instrument challenges. NASA is closely monitoring contractor performance on Kepler and is on track for a February 2009 launch readiness date. The contractor's performance on the main instrument for the Glory mission remains a concern, but now shows a steady rate of progress, which we have factored into our baseline cost and schedule. SOFIA now has the proper allocation of responsibilities and a phased development approach that allows early scientific research during the flight-testing phase.

For new missions, NASA is taking a number of new steps to avoid or better manage cost problems if they occur, including:

- NASA has instituted a policy requiring new missions to be budgeted at the "70 percent confidence level," based on independent cost analyses at the time of confirmation review (approval to enter development), unless waived by the Associate Administrator;
- NASA is requiring that all directed missions entering Phase A undergo an internal Basis of Estimate review and 70 percent confidence level estimate to ensure realistic cost and estimates at the start;
- NASA is providing more opportunities for scientists to obtain space flight hardware development experience, via enhanced suborbital payload development funding, and more flight opportunities in our sounding rocket, balloon, and research aircraft programs; and,
- when cost growth does threaten, NASA is ensuring that de-scopes and the reduction of award fees be considered first before turning to other sources for additional funds.

Q3b. What, if any, margin is there in your budget request to handle any additional schedule and cost growth?

A3b. As mentioned above, NASA has recently established a policy of budgeting all missions entering Phase B (preliminary design) and Phase C/D (detailed design and development) at the 70 percent confidence level, unless waived by the Associate Administrator. That is, upon establishing an independent cost estimate and mapping likelihood of completion against the range of probable costs around that estimate, NASA establishes the project budget at the cost associated with a 70 percent likelihood for success. This has proven a more successful way to estimate actual mission cost at completion than adding a percentage reserve level above a project cost estimate, which is what was done in the past.

Q3c. P.L. 109–155, the NASA Authorization Act of 2005, *is clear in stating how quickly notification of such threshold breaches is to be conveyed to the Congress. In particular, the person overseeing the program experiencing such increases or delays must notify the Administrator immediately and formalize such notification in writing no later than 30 days after the initial notification. In turn, not later than 15 days after receiving this written notification, the Administrator must transmit the notification received to NASA's authorization committees. Congressional committees received copies of the program notifications for projects such as Glory some four months late. Considering the explicit timelines in the legislation, what caused such a lengthy delay?*

Q3d. Furthermore the Act requires that not later than 30 days after receiving the program's written notification, the Administrator must determine if the program is likely to exceed development cost by 15 percent or more or whether a milestone is likely to be delayed by six months or more. If the determination is affirmative, not later than 15 days after making the determination, the Administrator must transmit to NASA's authorization committees a report including a description of the increase in cost or delay in schedule and actions taken or proposed to be taken. We still have not received your report. The Assistant Administrator for Legislative and Intergovernmental Affairs notified congressional committees that the mandated report would be submitted no later than March 2008. Even that would make it almost six months late. What is the reason for this significant delay?

A3c, 3d. First and foremost, NASA recognizes that the Agency's performance in meeting the reporting requirements outlined Section 103 of the *NASA Authorization Act of 2005* (P.L. 109–155) must improve, and the Agency is committed to responding to these requirements in a timely manner. NASA has had difficulty coordinating the process for developing the required reports with other budget cycle driven reporting requirements and requirements for similar reporting to the Office of Management and Budget (OMB). Consequently, NASA will be working with the Subcommittee staff to evaluate options for modifying Section 103 in order to provide a single reporting process with controlled frequency of updates, common data and formats to meet all requirements, and to serve both internal and external reporting needs. NASA has worked internally, and with OMB, over the past several months on the content and design of the reports to best meet the White House and Congressional requirements.

NASA accepts that the reports outlined in Section 103 are required, and we are committed to providing them. At the same time, NASA would appreciate the opportunity to work with the Committees to streamline these reporting requirements, and allow for their coordination and synchronization with the existing requirements of the budget development and implementation cycle as well as OMB reporting requirements.

Please note that NASA is committed to keeping the Congress informed of significant budget and schedule changes through multiple communications. While these communications do not substitute for the specific reporting requirements outlined in Section 103, it is a reflection of our commitment to keep the Congress informed. The specific communications are outlined below.

2/5/07 NASA submitted to Congress the FY 2008 budget justifications indicating that Hershel, Kepler and NPP had exceeded costs by 15 percent and/or schedule by six months.

3/15/07 As part of NASA's initial FY 2007 Operating Plan, the Agency informed Congress of 15 percent budget increases for Kepler, Glory and OCO.

11/13/07 NASA notified the Congress that Glory, Kepler, OCO, NPP, Aquarius and Herschel had exceeded costs by 15 percent and/or schedule by six months.

2/4/08 NASA submitted to Congress the FY 2009 budget justification. This document includes detailed budget and schedule information for each of the major programs as well as a summary table indicating specific budget and schedule changes for each program/project.

2/11/08 NASA notified the Congress that the Agency planned to submit the reports required by section 103(d)(1) and 103 (d)(2), for Glory, Hershel, Kepler, NPP, OCO, and Aquarius.

3/20/08 NASA notified the Congress that GLAST and SOFIA are reporting scheduled changes in excess of six months.

5/1/08 NASA notified the Congress that development cost for the Mars Science Laboratory had exceeded costs by more than 15 percent.

5/30/08 As part of a FY 2008 Operating Plan update, the Agency outlined plans to address cost growth for the Mars Science Laboratory and Glory missions.

7/17/08 NASA submitted to Congress the reports required by section 103(d)(1) and 103 (d)(2), for Glory, Hershel, Kepler, NPP, OCO, and Aquarius.

Q4. During the hearing, you noted that NASA would take for the record the following question: What, if any, research are you doing in the Earth science and applications program to better understand the impact of aviation on climate and how it might be mitigated? Do you think NASA should be doing research in this area if it is not already, given the potential for regulatory actions to penalize aviation emissions down the road?

A4. NASA has a long history of studying the atmospheric effects of aviation. The former Office of Aeronautics conducted targeted programs in this area to deal with the impacts of both current and projected subsonic aircraft, as well as those of projected supersonic aircraft. These programs were implemented jointly with the former Office of Mission to Planet Earth. Following the end of those programs within the Office of Aeronautics in FY 2000, NASA's Earth Science Programs (now implemented through the Earth Science Division of the Science Mission Directorate) has continued to develop the large-scale models that can be used to assess global impacts of aviation when informed by estimates of aircraft emissions, and continued process studies of cloud formation that will increase our understanding of the relation between aircraft emissions and cloud distribution and properties. Such research involves both analysis of satellite and airborne data.

NASA interacts with the Department of Transportation through the U.S. Climate Change Science Program to further coordinate these efforts. NASA's current budget supports the advancement of the science in these areas as part of an overall balanced portfolio of relevant environmental research as described in the NASA Science Plan and the U.S. Climate Change Science Program Strategic Plan. These studies are providing a broad scientific base for assessing the impacts of aviation as well as other important industrial sectors.

Q5. What are the planned flight rates for Explorer, Discovery, New Frontiers and Mars Scout mission lines that are included in the FY 2009 budget request?

A5. Nearly one *Explorer* launch per year is planned, as follows:

- April 2007: AIM
- July 2008: IBEX
- November 2009: WISE
- 2011: NuSTAR
- 2012 (planning date): Small Explorer (selection pending)
- 2013 (planning date): Small Explorer (selection pending)
- 2015 (planning date): Small Explorer (selection pending)

Approximately one *Discovery* launch every two years is planned, as follows:

- September 2007: Dawn
- February 2009: Kepler
- 2011: GRAIL
- 2014: Discovery 13 (selection TBD)

Approximately one *New Frontiers* launch every five years is planned, as follows:

- January 2006: New Horizons
- August 2011: Juno

- 2016: New Frontiers #3 (selection TBD)

Mars Scout launches planned are:

- August 2007: Phoenix
- 2013: Mars Scout 2

The flight rates above are for complete missions, and exclude Missions of Opportunity, such as instruments selected to fly on non-NASA spacecraft. Flight rates after the middle of the next decade will depend on budget levels beyond the FY 2009 budget horizon. Explorer missions are either Medium-class Explorers (MIDEX) or Small Explorers (SMEX). MIDEX missions are flight opportunities for focused science missions. SMEX missions are more highly focused and relatively inexpensive missions. The mix of MIDEX and SMEX opportunities within the Explorer program is determined based on science needs and funding availability.

Q6. The European Space Agency and the Japanese Aerospace Exploration Agency are collaborating on an Earth observation satellite called EarthCARE, which will investigate clouds and aerosol interactions. One of the Earth science decadal survey missions, the aerosol-cloud-ecosystem mission, ACE, would also look at these phenomena. In light of the constrained budgetary environment, is NASA exploring potential collaboration on EarthCARE and could such a mission satisfy the objectives of the ACE mission as recommended in the decadal survey?

A6. NASA will assess the roles that can be played by international partners, as part of the process of developing plans to move forward with Decadal Survey missions. These studies and assessments will also examine how we can best coordinate science if NASA and its international partners fly missions with related scientific goals and approaches. NASA senior management meets regularly with its counterparts from other space agencies, including ESA and JAXA, through the Committee on Earth Observation Satellites (CEOS) as well as in bilateral meetings, during which both overall cooperative approaches and specific opportunities for collaboration are discussed. The scientific and engineering teams that are currently being assembled to look at possible approaches for implementing the missions will examine the attributes of EarthCARE and ACE.

Q7. What is the approach for technology development for the two Earth science missions that are planned for implementation in the FY 2009 budget request? How do you plan to take technologies to the state of maturity required for flight, especially given programmatic cuts to Earth science technology? What fraction of the total project cost of each of the two missions do you plan to spend on technology development?

A7. The SMAP and ICESat–II missions were selected based in part on their technological readiness, in addition to their scientific priority and design maturity. For both SMAP and ICESat–II, fundamental technological risks have already been retired through earlier investments in the Earth Science Technology Program. The SMAP mission is based heavily on a previous Earth Science System Pathfinder mission—Hydros, which was developed through risk-reduction phases but was not flown. The critical radiometer technology for Hydros/SMAP benefits directly from the development of the NASA Aquarius project and is nearly mission-ready. Final development required to bring the SMAP-specific technical implementation to flight readiness will be done within the flight program. To further support the mission, an Instrument Incubator Program technology development project to mitigate the effects of radio frequency interference has also been funded starting in FY08.

For ICESat–II, the flight laser system development approach is based on the extensive lessons learned from the first ICESat mission and from other recent NASA laser activities, including the lidar currently flying successfully on the CALIPSO mission. The critical lessons from ICESat and CALIPSO and additional technology risk mitigation efforts funded through the Laser Risk Reduction Program have provided sufficient confidence to enable initiation of ICESat–II. As with SMAP, final technology development required to bring the ICESat–II-specific technical implementation to flight readiness will be done within the flight program.

For these first two Decadal Survey missions, therefore, previous technology development investments have allowed the remaining development issues to be classified more as engineering development than technology issues. In general, once the basic technology has been developed and matured within the Earth Science Technology Program through programs such as the Instrument Incubator Program and the Airborne Instrument Technology Program, further mission specific supporting development is funded and carried out within the flight project, thereby ensuring a direct link between the development and the needs of the specific flight mission.

Owing to the high level of technological readiness of the SMAP and ICESat–II missions, it is expected that less than five percent of the combined mission total development costs will be required for technology development.

Q8. Some of your Directorate's lunar research and planned mission activities are being done in conjunction with the Exploration Systems Mission Directorate (ESMD). The Lunar Reconnaissance Orbiter (LRO), for instance, will be managed by ESMD for one year and then transition to a science phase under your Directorate. ESMD is also providing funds to support the Lunar Advanced Science and Exploration Research program.

Q8a. How are science and exploration objectives handled in developing these programs?

A8a. The principal objectives of the Lunar Reconnaissance Orbiter mission were conceived from the very beginning to support the safe and effective human return to the Moon, while providing significant benefits to science. ESMD recognized the importance of utilizing the knowledge and capabilities of the space science community to make the necessary measurements. Indeed, the Objectives and Requirements Definition Team that identified and prioritized those measurements was, to a large extent, composed of senior members of the planetary science community. Recognizing the Science Mission Directorate's (SMD) experience and successful track record of engaging the space science community, ESMD requested that SMD lead the Announcement of Opportunity process for the solicitation and review of proposals to build, operate, and analyze the data obtained from the instruments that would make the necessary measurements on LRO. Selection of the instruments was jointly made by ESMD and SMD. Based on its established track record of developing robotic, remote sensing spacecraft on an aggressive schedule, the Goddard Space Flight Center was chosen to develop LRO.

While the principal focus of LRO is on achieving objectives that will enable the safe and effective human return to the Moon, it has always been recognized that the measurements made by the cadre of instruments would be of extraordinary value to the scientific community. ESMD is ensuring that the data from LRO will be made available to the scientific community by requiring that the data sets are archived in SMD's Planetary Data System. PDS is an internationally recognized repository and source of planetary (including lunar) data and provides for broad and timely dissemination of the data to the world-wide science community.

LRO's exploration objectives are expected to be achieved during one year of nominal operations. However, the spacecraft and instruments are designed and configured to operate for up to three additional years. The continued time in lunar orbit following the achievement of the exploration objectives will be devoted to science and managed by SMD. SMD has already solicited and selected Participating Scientists for LRO that will aid the LRO Principal Investigators during the exploration phase of the mission and increase the science return during the science phase. ESMD fully expects that the data returned during science phase of LRO will provide additional information of significant value to exploration, just as the exploration phase provides value to science.

Similar to their cooperation on the LRO project, ESMD and SOMD have jointly executed the Lunar Advanced Science and Exploration Research (LASER) effort in order to identify and support research that leverages the best that the science and exploration communities have to offer. For the proposals submitted to the first LASER announcement, more than 20 percent of those in the selectable range would make strong contributions to both science and exploration, collectively. Many other proposals have a main emphasis on science or exploration, but would still add to the knowledge base of the other discipline.

Q8b. What is the ESMD contribution to each of the scientific lunar activities?

A8b. ESMD is funding the exploration phase of the LRO mission at $491.0M, which does not include the Lunar Crater Observation and Sensing Satellite (LCROSS) payload co-manifested with LRO. Of the $491.0M, $26.4M represents a portion of the funds NASA recovered from Boeing in settlement of the EELV/19 Pack matter. ESMD is also providing almost $1.0M per year to support highly rated proposals in LASER, as well as $46.0M for the initial startup of SMD's International Lunar Network.

Q8c. What unique data will LRO provide the science community that other lunar robotic spacecraft cannot, such as those being launched by other nations?

A8c. LRO's cameras will provide higher resolution (meter scale imaging) than any of the other cameras to orbit the Moon on robotic missions. The laser altimeter on board LRO will provide a significantly higher density of laser shots (5 shots at a time, 28 times per second) compared to the other altimeters flying or flown (typically, one laser shot a time, one or 10 times per second). This will enable the most accurate and precise topographic maps of the Moon ever created. Additionally, unlike other lunar robotic missions, LRO:

- has an infrared radiometer optimized for measuring temperature in both the lit and permanently shadowed areas of the Moon;
- has a collimated neutron detector to search for evidence of putative water ice in permanently shadowed areas;
- will be able to geographically identify the location;
- has a radiation measurement instrument that can determine how space radiation deposits energy in a tissue-like material (tissue equivalent plastic) to aid in protecting astronauts from the harmful effects of space radiation; and,
- has an ultraviolet imaging spectrometer that can "see in the dark" by starlight and ultraviolet sky glow and identify surface water frosts that may exist in the permanently shadowed regions.

Q8d. How will NASA ensure that the transition from ESMD to SMD for LRO will be as seamless as possible?

A8d. The Science Mission Directorate (SMD) has already selected 23 Participating Scientists for supporting LRO and they are being incorporated into the ongoing activities of the LRO instrument teams and the overall Project Science Working Group, to aid the LRO PIs during the exploration phase, and to begin preparing for the LRO science phase. In addition, SMD detailed an experienced Program Executive (PE) and Program Scientist (PS) to assist in the management of LRO development and operations to ESMD. After gaining additional experience during the development and exploration operational phases of LRO, the PE and PS personnel will return to SMD to serve in that role for the science phase of LRO operations greatly facilitating a seamless transition of the mission. NASA's GSFC will continue to operate LRO throughout this transition.

Q8e. How will the results of lunar science research be infused into exploration activities?

A8e. The data resulting from the science phase of LRO will be archived in the Planetary Data System along side the data from the exploration phase. The Exploration Systems Mission Directorate plans to draw data directly from the PDS to be used for the lunar mapping, modeling, and simulation activities it is developing to meet the needs of the Constellation Program development efforts.

Questions submitted by Representative Tom Feeney

James Webb Space Telescope

Q1. The James Webb Space Telescope, scheduled for launch in 2013, is a high-risk, flagship mission. Earlier this decade it ran into serious and expensive technological challenges that forced NASA to de-scope the mission and delay its launch. How stable is the program today; is it staying within its schedule and budget profiles? Have all technological risks been retired?

A1. The James Webb Space Telescope (JWST) Project is stable, with its technology development complete, and the mission is on track to launch in June 2013. The JWST Project has remained on schedule and within its allocated budget since its 2006 replan. The top ten technology risks were retired in February 2007, when an independent review team confirmed that these technologies had achieved Technology Readiness Level 6 (engineering feasibility fully demonstrated). The international partner contributions from the European Space Agency (Near Infrared Spectrometer and Mid Infrared Instrument) have remained stable. Projections for the Canadian Space Agency delivery of the Fine Guidance Sensor have slipped seven months due to funding flow issues within the Canadian government and software development challenges; however these projected delays do not affect the expected mission launch readiness date.

The JWST Project successfully passed its Preliminary Design Review on April 4, 2008, and proceeded with the Non-Advocate Review on April 15–16, 2008. The NASA program confirmation process will continue with the Science Mission Directorate Program Management Council (PMC) Review and the Agency PMC (APMC) this summer. Once the APMC has approved the project, it will formally move into the development phase (Phase C).

SOFIA

Q2. Your budget proposal indicates that the SOFIA program will begin performing its first science mission during fiscal year 2009. Could you describe the expected capabilities of the telescope and aircraft during those early flights, and does NASA intend to take up guest observers?

A2. The objective of the early science program is to initiate science observations as soon as it has been demonstrated that the aircraft can safely conduct open door flights, and that the observatory has developed the minimum capabilities necessary for meaningful science observations. By definition, this means that many of the SOFIA observatory's full capabilities will not be available for early science observations.

During early science observations, SOFIA will be capable of obtaining scientific data with either of two instruments; a U.S. provided mid-infrared camera and a high resolution, far-infrared spectrometer provided by Germany. SOFIA will be capable of observing astronomical objects within the galaxy for exposures up to ~30 minutes each, at altitudes up to ~41,000 feet (above 99 percent of the atmosphere's obscuring water vapor), with pointing accuracy and stability better than 11 arc seconds, and with elevation ranges between 20 and 60 degrees above the horizon. Only a minimal science crew will fly on the observatory during early science. The minimal crew may or may not include the guest observer; that will depend on the guest observer proposal selected through an open, competitive process.

Q3. The FY 2009 budget proposal states that NASA will seek a foreign partner to help carry the operating costs of SOFIA. What are NASA's plans for partnering? Roughly what percentage of the annual operating costs is NASA hoping to share? Would ITAR be an issue?

A3. NASA is looking into the possibility of incorporating a new domestic or foreign partner to cost share during the operations phase, in addition to Germany's space agency DLR. NASA is considering making available up to 20 percent of the SOFIA observing time for a new partner in exchange for a proportional share of the operations costs. Most of the SOFIA program is not ITAR sensitive (the aircraft, for example, is regulated under the Department of Commerce export administration regulations). While certain elements of U.S. instruments are regulated under ITAR, a new international partner would not be operating U.S. instruments or need to have access to such ITAR information.

Explorer Program

Q4. The Explorer Program is one of NASA's most successful investigator-led programs. When does NASA plan to issue its next announcement of opportunity for a MIDEX Explorer mission, and what will be the frequency of announcements for future MIDEX Explorer missions?

A4. The next Explorer Announcement of Opportunity (AO) is for two missions and is planned for issue in FY 2011. These missions are characterized as EX–1 and EX–2 since there is no assurance that a MIDEX-sized launcher will be available in that timeframe. The frequency of future MIDEX AO's is entirely dependent on availability of future funding and mid-sized launch vehicles.

Space Interferometry Mission

Q5. Could you describe NASA's plans and schedule with respect to SIM, especially the proposed "SIM-lite" mission? Will it meet the original science objectives laid out in the Decadal Survey? How much will it cost, and when will it be ready for launch?

A5. Currently, the SIM project is charged by NASA Headquarters to re-examine its science requirements and to recast the SIM mission in light of the current scientific and technical status within a lower cost mission, what the project has been calling "SIM–Lite."

The SIM mission concept is mature in its science objectives, mission design, and costs. The same level of maturity is desired for SIM–Lite. The initial review of the science case, and the only in-depth review that was explicitly in competition with other opportunities, was performed by the 1990 National Research Council (NRC) Astronomy and Astrophysics Decadal Survey, which is now nearly 20 years old. The most recent external reviews of SIM were on technical performance and status rather than science performance requirements. Studies of reduced-cost/reduced-performance SIM design concepts imply potential reductions in the science product and so must be evaluated by NASA.

The activities the SIM project will perform in FY 2008 and FY 2009 will focus on maturing the SIM–Lite mission concept in the areas of science, mission architecture, budget and schedule. The SIM–Lite science requirements will be evaluated with respect to the significant scientific developments now available since the 1990 NRC Astrophysics Decadal Survey. The evaluation will take into account the impact of developments in observational astrometry since 1990—including ESA's Hipparcos mission, the NASA/ESA Hubble Space Telescope, ESA's planned GAIA mission, and other missions with astrometric capability—as well as possible future moderate class astrometric missions currently in the concept stage. In addition, the science performance of SIM–Lite will be evaluated against the original science objectives laid out in the 1990 NRC Astronomy and Astrophysics Decadal Survey and subsequent reports, such as the imminent Exoplanet Task Force report of the Congressionally-chartered Astronomy and Astrophysics Advisory Committee. The science performance of SIM–Lite will be developed by the project, assessed by an external group, and presented to NASA Headquarters by September 2008.

A SIM–Lite mission architecture will be derived from the science case developed above. Design trade studies will be completed that will lead to the detailed point design for SIM–Lite that the project would like to have under consideration for implementation. Trade studies normally done during Phase B are to be completed no later than March 2009 and presented to NASA Headquarters.

By no later than March 2009, the SIM project will develop an optimized budget profile and schedule for moving the SIM–Lite concept into implementation, assuming the development Phase C/D would begin by the end of FY 2010. In parallel, beginning in the fall of 2008, an external Independent Cost Estimate (ICE), initiated by the Science Mission Directorate, would be performed on the SIM–Lite point design. It is expected to be completed by the spring of 2009. It is noted that the Astrophysics budget presently cannot accommodate the development of a new flagship-class mission prior to launch of the James Webb Space Telescope. However, NASA Headquarters is requesting this information to fully understand the SIM–Lite mission and what is required. Funding is projected in the FY 2009 President's Budget Request to develop a medium-class exoplanet mission for launch in the middle of the next decade, for which SIM–Lite may be a candidate, pending the outcome of this science, technical and cost study.

Earth Science—Research to Operations

Q6. As a research agency, many of the measurement technologies and capabilities developed by NASA quickly generate a strong constituency in the science community, especially in the Earth Sciences discipline. NASA and National Oceanic and Atmospheric Administration (NOAA) are working together to facilitate the smooth transition of new capabilities to enable their quick adoption by NOAA. Are you with satisfied with the NASA–NOAA relationship? Do you believe NOAA has the necessary resources?

A6. NASA and NOAA coordinate activities at many levels.

At the executive level, the NASA and NOAA Administrators, along with the Under Secretary of the USAF, oversee the development of the Nunn-McCurdy certified NPOESS. NASA and NOAA are continuing the development of the GEOS–R series of satellites, and the two Administrators meet annually on the status of GOES–R. The NASA Earth Science Division Director and the NOAA Assistant Administrator for Satellites and Information Services are co-chairs of the NASA–NOAA Roundtable. The Roundtable oversees the NASA–NOAA Joint Working Group on Research and Operations. In January 2008, the Roundtable established a joint working team to develop processes to transition the NASA satellite nadir altimetry measurement capability to NOAA for operational service.

At the scientist level, NASA and NOAA have numerous coordinated activities. An example occurred in March-April 2008 when NASA and NOAA coordinated aircraft measurements over the Arctic under the auspices of the International Polar Year; in the vicinity of Antarctica at the same time, NASA and NOAA conducted the joint GASEX field experiment in the Southern Ocean (from the NOAA research vessel Ron Brown) to quantify air-sea gas exchange rates under high wind and wave conditions.

The successful GOES and POES programs demonstrate that NOAA, working with NASA, can adopt measurement capabilities demonstrated by NASA research satellites for operational services.

Joint Dark Energy Mission

Q7. With respect to the upcoming competition for a JDEM mission, what is the relationship between NASA and the Department of Energy? Will NASA alone make the selection? Given DOE's investment in technologies related to JDEM, what role will they play?

A7. NASA and DOE have tentatively agreed on a framework for partnering in the formulation, implementation, and operation of a Joint Dark Energy Mission (JDEM). Each agency will manage its own contributions, but NASA will be responsible for the overall success of the space mission. A Memorandum of Understanding (MoU) between the two agencies is being drafted that will formalize the principles of cooperation between the two agencies.

To facilitate the procurement process, the Announcement of Opportunity (AO) for JDEM will be issued by NASA, but the agencies are cooperatively writing the AO and will agree to its final wording. Both agencies will participate in the proposal evaluation and selection process. Specifically, NASA will not make the selection unilaterally. The details of these processes will be formalized in the upcoming DOE/NASA MoU.

The need for mission cost control dictates that each agency will provide to the mission components for which it has established expertise and management experience, and commensurate with budget availability. Thus, for example, NASA will provide the launch vehicle, spacecraft, and overall mission management for JDEM. Both agencies have long heritages of detector technology development, and both may contribute to the instrumentation of the JDEM payload. Each agency will manage its contributions according to its own established management protocols. Both will contribute to science operations and data processing.

Landsat Data Continuity Mission (LDCM)

Q8. How would you characterize the risk of future gaps in data continuity for the Landsat program, and what steps is NASA taking, or should take, to minimize the risk?

A8. Development and launch of LDCM to replace the existing Landsat-5 and -7 satellites, which are nearing the end of their operational lives, is of the highest priority due to the impact a data gap would have on scientific investigations of land use and land cover, as well as on many other user applications for the 30-m resolution multispectral measurements. Both Landsat-5 and -7 are experiencing technical problems and both satellites are predicted to run out of fuel in late 2010. The current LDCM development schedule will not result in new data until late 2011 (July 2011 launch followed by a period of on-orbit checkout and data validation). The joint USGS/NASA Landsat Science Team reported in January 2008 that provision of 30-m resolution multi-spectral data from LDCM by March 2012 (the start of the 2012 northern hemisphere growing season) was the highest priority schedule driver for LDCM.

The 39-month development for LDCM and its OLI instrument, leading to a July 2011 launch date, is aggressive. The Operational Land Imager (OLI) contractor (Ball Aerospace) has made significant internal on-risk investments in long-lead parts. Technical progress on the instrument has been good to date.

Contractors' Failure to Perform

Q9. It has come to the Committee's attention that one contractor has failed to deliver critical instruments for two key NASA science missions (NPOESS and Glory), resulting in very costly delays to the programs, and ultimately, to the agency and the taxpayers. What leverage does NASA have to deal with poorly-performing contractors? What additional authorities could Congress provide NASA to address contractor performance problems?

A9. NASA employs a number of tools to deal with poorly performing contracts. At the first sign of poor performance, we generally implement tighter oversight and review processes in order to identify and correct the origin of the performance problem. NASA can negotiate or direct management and/or organizational changes to remedy problems (i.e., the Agency can direct increased staff in specific areas, replace or augment staff, management, etc.). Such actions are normally done in parallel with lowering the contractor's award fee grades (and less award fee). NASA also elevates the performance concern to higher levels in the corporate structure and engages those contractor officials in periodic reviews and reporting. If the performance doesn't improve, the award fee will be further reduced (to zero if appropriate). If appropriate, the Agency may also provide additional resources in areas to strengthen the contractor where the organization is weak. These resources may take the form of expertise in areas such as planning, scheduling, systems engineering, design, fabrication, integration, test, provisioning of parts, and risk management. If appropriate, the contractor program and/or project manager may be replaced. Many of NASA's contracts have "provisional" award fee structures. If the contract's performance is extremely poor, NASA may recover previously awarded fee amounts.

NASA may also choose to de-scope the work to be performed by the contractor by reducing contractual requirements. This effectively removes work and potential profit from the contractor.

NASA considers past performance as a factor when evaluating contractor proposals for selection on future work. Because of this, NASA may ask and the contractor may agree to provide corporate resources to improve project performance in order to protect the company's competitive position for future work

In extreme cases, the contract may be terminated. NASA is not aware of any additional authorities that would effectively improve the Agency's ability to deal with contractors in the highly technical, risky environment of space systems development.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Lennard A. Fisk, Thomas M. Donahue Distinguished Professor of Space Science, University of Michigan; Chair, National Research Council Space Studies Board

Questions submitted by Chairman Mark Udall

Q1. What, if any, effect will the virtual elimination of the New Millennium program, have on future missions?

A1. In my judgment, the virtual elimination of the New Millennium program will not have a major impact on future missions. Although the New Millennium did result in new and important technologies, it is unclear whether this approach is the most cost-effective, e.g., it is not clear that it is necessary to fly the new technology in order to demonstrate its suitability for use in other missions, nor is it clear that the hand-off from the New Millennium program to other flight programs has been optimum.

Q2. What should be the flight rates for Explorer, Discovery, New Frontiers and Mars Scout mission lines in terms of the program balance needs described in various National Academies reports? Do you believe the proposed budgets included in the FY09 budget request would support the necessary flight rates for those programs?

A2. I call your attention in particular to the NRC Report: *An Assessment of Balance in NASA's Science Programs,* the so-called Balance Report, issued in 2006. Finding 2 of this report stated:

"The program proposed for space and Earth sciences is not robust; it is not properly balanced to support a healthy mix of small, moderate-sized, and large missions and an underlying foundation of scientific research and advanced technology projects; and it is neither sustainable not capable of making adequate progress toward the goals that were recommended in the National Research Council's decadal surveys."

In support of this finding, the Report noted:

"Explorers and other small missions have been delayed or canceled. Explorer, ESSP and Mars Scout missions are among the smallest missions in NASA's science portfolio, and because of their centrality to science research, all of the NRC decadal survey reports have considered them vital and inviolable. These small missions fill critical science gaps in areas that are not addressed by strategic missions, serve as precursors to larger missions, support the rapid implementation of attacks on very focused topics, provide implementation and the use of new approaches to incorporate into the long planning cycles needed to get a mission into the strategic planning queues, and provide particularly substantial means to engage and train science and engineering students in the full life cycle of space research projects. The steady successes and productivity of the small missions are strong arguments for their role in a balanced overall mix of mission sizes."

The *Balance Report* was issued in 2006, and in particular discussed the FY 2007 budget for NASA science, which the Report judged not to provide an adequate balance of small, moderate-sized versus larger missions. The balance for science has been permitted to grow only at about one percent per year, and thus balance was still inadequate in FY 2008. The proposed budget for SMD in FY 2009 makes an attempt to introduce more smaller missions back into the NASA portfolio. It is unclear, however, what the fate will be of these new smaller missions, particularly since some of the larger science missions appear to be making demands on the available funding.

The imbalance between smaller and larger missions thus persists, and is a weakness in the program that interferes with the progress of science, and the training of the next generation of space scientists and engineers, and it needs to be corrected.

Q3. Your testimony noted that "a true capability to predict space weather will only come when we have developed adequate understanding of the governing physical processes, and that in turn requires a comprehensive heliospheric research program." *Do you believe NASA's heliospheric program is comprehensive in a way that is enabling an understanding of the physical processes required to predict space weather? If no, what is missing from the program?*

A3. We should never underestimate the challenge of understanding the physical processes that govern space weather. These processes, which involve complex interactions between plasmas and magnetic fields, are more challenging than the processes that govern terrestrial weather. We should also never settle for anything less than a predictive capability that is based on a thorough understanding of the governing physics. In particular, we should not rely on a predictive capability that is based on correlations with similar past events. Rather, we need to understand the underlying physics, incorporate the physics into powerful numerical models, and drive the predictions of the models by comprehensive observations. It would be unwise to entrust the safety of our space assets and in particular our astronauts to anything less.

The Heliophysics program is a comprehensive program, which, within the resource limitations that plague all of the NASA, is attempting to make the required observations, understand the underlying physics, and model it. If there is any criticism that can be levied, it would be that the program could use a greater degree of organization so that the research results of the various aspects of this complex set of problems converge towards a true predictive capability. I would also encourage the Heliophysics program to be ever alert for and to encourage new ideas and new approaches. In a field where so much remains to be known, it is necessary not to rush to judgment, but rather to systematically incorporate new concepts so that the best and most reliable predictive models result.

Questions submitted by Representative Tom Feeney

Technology Development

Q1. NASA's science directorate has reconfigured its technology development activities by eliminating a generic directorate-wide program, and instead assigning technology development responsibility to individual missions. The rationale appears to be that mission-specific technology requirements is less wasteful. Do you agree with this rationale and what, if any, shortcomings might arise from this approach?

A1. This is an area in which a balance is required. There is a need to develop mission-specific technology, to ensure that challenging new missions can be undertaken successfully. There is also a need to develop new technology unrelated to specific missions, since such initiatives have frequently resulted in measurements and missions that we did not assume were possible. The pendulum on this issue has swung back and forth. There have been periods when NASA's primary emphasis was on technology unrelated to missions, whereas the reverse is true today.

In my opinion, this is yet another example of where a balance needs to be reestablished in the NASA program. This is also an example of where reductions in the Research & Analysis program have created difficulties, since R&A funding has been a traditional source for the development of new technologies unrelated to missions.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Berrien Moore III, Executive Director, Climate Central, Inc.; Chair, Committee on Earth Studies, Space Studies Board, National Research Council, The National Academies

Questions submitted by Chairman Mark Udall

Q1. What, if any, effect will the virtual elimination of the New Millennium program have on future missions?

A1. The primary impact is to retard significantly needed technology advances. It is well established that technology challenges area primary cause for cost increases. Second, the recommended Earth science missions require advanced technologies—this requirement is unavoidable; it is not an added luxury. Therefore, the virtual elimination of the New Millennium program creates, in effect, a perfect storm for cost increases and program failures.

Q2. The European Space Agency and the Japanese Aerospace Exploration Agency are collaborating on an Earth observation satellite called EarthCARE, which will investigate clouds and aerosol interactions. One of the Earth science decadal survey missions, the aerosol-cloud-ecosystem mission, ACE, would also look at these phenomena. In light of the constrained budgetary environment, should NASA explore potential collaboration on EarthCARE and could such a mission satisfy the objectives of the ACE mission as recommended in the decadal survey?

A2. In my view, this path should, at least, be aggressively explored, and if this pathway of international collaboration is not taken, then it must be clearly stated as to why it is not taken. In this regard, the "perfect" must not become the enemy of the "good"—we cannot afford that mistake. The Decadal Survey was very clear about the value on international collaboration (such as accomplishing the requirements of ACE via collaboration on EarthCARE and on the problem of the "perfect" mission.

Q3. Do you agree with NASA's approach for technology development for the two Earth science missions that are planned for implementation in the FY09 budget request? How should NASA take technologies to the state of maturity required for flight, especially given programmatic cuts to Earth science technology? What fraction of the total project cost of each of the two missions should NASA spend on technology development?

A3. My problem with NASA's approach is that a) it is too narrow-namely it should focus on the technology needs of more missions and b) it appears that on two of the missions (ICESat–II and CLARREO) that there is an unacceptable cost growth, which further retards development of other missions. In my view, much of this cost-growth is from unnecessary added costs at the Centers.

To take technologies to the state of maturity requires first a focused well-funded, industry active program on technology development and second it requires that missions begin with extended Phase A study and that if problems or cost growth appears, then the mission should be placed in the "break-down" lane so that other missions are not trapped in the queue and before huge marching armies are engaged.

What Fraction—I am not sure; in fact, I am not sure that there is a magic fraction that suits all missions.

Q4. Dr. Moore, if the Glory satellite, which will carry a solar irradiance measurement instrument, is further delayed, what are the potential implications for maintaining data continuity of this measurement?

A4. The threat is real; I am very disappointed in the very poor development of the primary instrument (APS). This failure on top of the failed development path for VIIRS is simply unacceptable.

Q5. Recently OSTP, NASA, and NOAA agreed to continue three high priority climate measurements and restore climate sensors that were removed during the restructuring of the NPOESS program. One of those sensors, TSIS, has not yet been assigned to a satellite. Dr. Moore, what is your understanding of the status and issues related to assigning TSIS to a satellite?

A5. Since I am so late in responding, for which I apologize, this issue is now resolved and TSIS will fly on the first NPOESS mission (C–1).

Q5a. When does TSIS need to fly to ensure data continuity of solar irradiance?

A5a. Ideally now, but certainly no later than 2010. If there are indications of continuing slippage of Glory, then we may need to consider flying TSIS on NPP.

Questions submitted by Representative Tom Feeney

Technology Development

Q1. NASA's science directorate has reconfigured its technology development activities by eliminating a generic directorate-wide program, and instead assigning technology development responsibility to individual missions. The rationale appears to be that mission-specific technology requirements is less wasteful. Do you agree with this rationale and what, if any, shortcomings might arise from this approach?

A1. Having mission-focused technology development is not a bad idea. What are bad ideas are: a) Having *only* mission-specific technology development pathways, and b) Having too limited a set of missions for which there is technology development money. I think that there is a need for a general and robust technology development program that is advancing technologies for the missions set forth in the Decadal Survey, and I think that the current investment on individual missions should be widened.

Earth Science—Research to Operations

Q2. As a research agency, many of the measurement technologies and capabilities developed by NASA quickly generate a strong constituency in the science community, especially in the Earth Sciences discipline. NASA and NOAA (National Oceanic and Atmospheric Administration) are working together to facilitate the smooth transition of new capabilities to enable their quick adoption by NOAA. Are you with satisfied with the NASA–NOAA relationship? Do you believe NOAA has the necessary resources?

A2. It appears to me that the NASA–NOAA relationship has improved in the last six months—this is good, but it continues to need encouragement. NOAA does not have sufficient resources, and I seriously question its location and structure. The challenges of global environment change and particularly global climate change are of such scope that I believe that we need a fresh look at not only NOAA but other federal agencies as well, including the Earth sciences program at NASA. Change is needed, but we must recognize that structural change can also be a step backward: the Homeland Security Agency is, in my view, a case in point.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Steven W. Squyres, Goldwin Smith Professor of Astronomy, Cornell University; Principal Investigator, Mars Exploration Rover Project

Questions submitted by Chairman Mark Udall

Q1. What, if any, effect will the virtual elimination of the New Millennium program have on future missions?

A1. The New Millennium program has played the important role of allowing new technologies to be tested in flight before they are put to use on science missions. This program has been important because of the historical reluctance of major science missions to use technologies that have not previously been shown to work in space. Elimination of the program would mean either that other opportunities would have to be found for flight-testing critical technologies, or that science missions that wanted to fly such technologies would have to take on greater risks.

Q2. Dr. Squyres, what technical requirements must be met to successfully execute a Mars Sample Return mission and how far along are we in addressing those requirements.

A2. There are many technical requirements for a successful Mars Sample Return mission. They include (but are not limited to) the following:

(1) A landing system capable of delivering a substantial mass to the Martian surface.

(2) A roving vehicle capable of identifying and selecting an adequate set of samples.

(3) A sample collection system capable of collecting soil, pebbles, and intact rock cores.

(4) A sample handling system capable of delivering samples to a Mars Ascent Vehicle.

(5) A Mars Ascent Vehicle capable of being stored on the Martian surface for an extended period of time and then launching a sample container into orbit around Mars.

(6) An on-orbit rendezvous system capable of locating and retrieving the sample container while it orbits Mars.

(7) A system for effectively containing the samples during their return to Earth, preserving their scientific integrity and assuring no release into the terrestrial environment after landing.

(8) A landing system capable of delivering the samples to the Earth's surface.

(9) A sample receiving facility capable of providing appropriate quarantine of the samples and where they can undergo a thorough preliminary evaluation.

(10) Laboratory facilities at NASA centers, universities, and other institutions where detailed scientific study of the samples can take place.

The landing system under development for the Mars Science Laboratory (MSL) mission may take care of item (1), and the rovers developed for the Mars Exploration Rover mission and MSL should take care of item (2). The landing system in item (8) might be derived from the ones developed for the Stardust and Genesis missions. The other items, however, require considerable work, and in my estimation will cost several hundred million dollars between now and initiation of the project.

Q3. What science objectives must a Mars Sample Return mission meet in order to make the multi-billion dollar investment worthwhile? What type of Mars Sample Return mission would not be worth the investment?

A3. In order to be worth a multi-billion dollar investment, I feel that returned samples from Mars must meet several criteria. A few of the most important are listed below.

First, they must be well selected. A "grab sample" of whatever material is closest to the lander is unlikely to provide the desired answers to key scientific questions involving ancient climate, habitability, and life. Instead, the samples should be collected by a roving vehicle over an extended period of time. This can be done as part of the Mars Sample Return mission itself, or can be done ahead of time in a sample "cache" that the MSR mission then retrieves.

Second, the context of the samples must be established and known. This means that the samples must be collected, documented, and stored en route to Earth in a fashion that makes it possible to know after the fact where each one was collected.

Third, their physical integrity must be preserved. The transit to Earth and landing on Earth must not be so violent that the samples are severely damaged in the process.

Fourth, the total sample mass must be adequate. I am reluctant to recommend a specific mass value, because the mass requirements for state-of-the-art laboratory analytical techniques are constantly evolving. But the total sample mass should be thoroughly reviewed by a group of experts before mission requirements are finalized.

Q4. What priority was ascribed to lunar science within the broader context of the National Academies decadal survey for solar system exploration? What science benefit would the proposed lunar orbiter and landers provide for both research on the Moon and elsewhere in the solar system?

A4. Lunar science figured prominently in the last solar system decadal survey. Specifically, a *South Pole-Aitken Basin Sample Return* mission was one of the highest priority missions identified. This mission would return a sample from the largest impact basin on the Moon, potentially sampling the lunar mantle.

The proposed new lunar orbiter and landers do not address science called for in the decadal survey. Instead, they are aimed at issues that may be relevant to future human exploration of the Moon.

Q5. Last year the Science Mission Directorate instituted requirements and pre-screening measures for scientists who planned to propose for competitive missions that are led by a scientist rather than a NASA official. The larger of these scientist-led mission classes, New Frontiers, "have more stringent requirements than medium or small class missions" according to information on NASA's New Frontiers website. What is your perspective on these requirements?

A5. These requirements are very stringent, and may be overly constraining. Certainly I expect that a principal investigator (PI) who meets the requirements will probably be qualified. But the negative impact of having such stringent requirements is that they would dramatically reduce the pool of prospective PIs from whom NASA could draw. A very dedicated but somewhat inexperienced PI might do an excellent job if paired with an experienced Project Manager with whom he/she could work closely. So rather than a "one size fits all" set of requirements on PIs imposed before they can propose, I would rather see NASA thoughtfully assess the qualifications of mission leadership teams as part of the proposal evaluation process. This should take place, in my opinion, via evaluation of the combined experience of the PI and the Project Manager.

It certainly would be reasonable for NASA to provide guidelines within the Announcement of Opportunity regarding the kind of experience the agency expects a project management team to have.

Q6. How important is the availability of plutonium to the future planetary science program? What are the impacts of not having access to this resource?

A6. Plutonium–238, which is used in radioisotope thermoelectric generators (RTGs), provides an enabling source of electrical power for certain classes of solar system missions. These include missions to deep space, such as high-capability missions to the Jupiter system and any missions to targets more distant than Jupiter. They also include long-lived, high-capability missions to the Martian surface, where the availability of solar power can be compromised by environmental dust. At the present, there is no substitute for RTGs as power sources for such missions. Therefore, without reliable access to ^{238}Pu certain high-priority missions would not be possible. The planned Outer Planets Flagship is an example.

Questions submitted by Representative Tom Feeney

Q1. NASA's science directorate has reconfigured its technology development activities by eliminating a generic directorate-wide program, and instead assigning technology development responsibility to individual missions. The rationale appears to be that mission-specific technology requirements is less wasteful. Do you agree with this rationale and what, if any, shortcomings might arise from this approach?

A1. My personal view is that it is wise to have a "mixed portfolio" of technology development activities. What I mean by this is that both directorate-wide and mission-specific technology development approaches have merit. Some technologies have wide applicability to a broad range of missions. Such technologies, for example, include advanced propulsion concepts and advanced avionics. Others tend to be much more mission-specific. In my opinion it is prudent to have a directorate-wide program of technology development that focuses on technologies of broad applicability, and then separate mission-specific technology development activities that focus on targeted technologies that are not covered by the directorate-wide program.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Jack O. Burns, Professor of Astrophysics and Space Astronomy; Vice President Emeritus for Academic Affairs and Research, University of Colorado at Boulder

Questions submitted by Chairman Mark Udall

Q1. What, if any, effect will the virtual elimination of the New Millennium program have on future missions?

A1. The New Millennium program was conceived in 1995 by NASA's Office of Space Science and the Office of Earth Science to "speed up Space Exploration through the development and testing of leading-edge technologies" that would fly on future space science missions. This program was created to provide a talented pool of younger instrument builders needed for future missions in astrophysics and Earth sciences. This program was a valuable proving ground for them.

The impact of the New Millennium program on astrophysics has certainly diminished as funding has declined. On the positive side, much of this development is now supported via the *Astronomy and Physics Research and Analysis (APRA)* program within the Astrophysics Division at NASA. This program provides funding for research on state-of-the-art technology development for instruments that may be proposed to fly on future missions, instrument testbeds to be flown on balloons or sounding rockets, and for laboratory research.

Thus, in astrophysics, I do not see a major loss in the elimination of the New Millennium program. Instead, robust investment in technology development and testing should occur through an expansion of the APRA program. Instrument development for future astrophysics missions is extremely important and more investment is required.

Q2. The FY09 budget request for NASA's astrophysics program proposes funding of about $315 million for future missions to be recommended in the next National Academies astronomy and astrophysics decadal survey. Most of those funds, however, are to be held for the James Webb Space Telescope, which requires additional reserves to support management of the 70 percent confidence level, according to NASA officials. What are the implications of the lack of a budget wedge to support "Decadal" priorities for astronomy and astrophysics?

A2. Simply stated, without a budget wedge for Decadal priorities, the astrophysics community will be unable to begin any new large missions in the next decade. As a result, we will abandon our leadership in much of the space astrophysical sciences. Meanwhile, ESA is stepping up its efforts with new missions proposed between 2010 and 2020 (ESA's "Cosmic Vision"). Japan, Germany, Russia, India, and China have ambitious plans for new missions in space astronomy and high energy astrophysics. With no astrophysics budget wedge for NASA, other nations will gain 10 years of steady advancement over the U.S. while we finish one large, but important observatory (JWST) and no new starts.

It is important to note that JWST will be a powerful observatory that will potentially observe the first galaxies and stars, and will support the aspirations of many astronomers. JWST successfully completed its Preliminary Design Review and Non Advocate Review (NAR) in April 2008. After studying the reports from these reviews, NASA will establish the agency cost baseline for the mission that will be reported to Congress. If the PDR/NAR recommends additional funds above those already accounted for in the 70 percent confidence level for JWST, some or all of the $315 million identified in the FY 2009 projected budget out-years will disappear, thus diminishing or eliminating the prospects of any new starts recommended by the Decadal Survey. The AAAC has recently expressed similar concerns.

Q3. The National Academies study that recommended JDEM be developed and launched used an independent cost estimator to assess the potential cost of a JDEM mission. That independent cost estimator estimated that a JDEM would cost NASA $1–1.3 billion in total life cycle costs, even when taking into account a potential contribution from DOE. NASA, on the other hand, estimates that the cost of JDEM would be about $600 million for development (for the NASA portion), and it plans to launch the mission in 2015.

a. In your view, will the JDEM that NASA is initiating be able to achieve the high priority science for this path finding area of science on the budget and timeframe that NASA has laid out?

b. What are your views on the variance in cost between NASA's estimate and the estimates of the Academies study?

A3. Costing on government projects is an inexact science, at best. The NRC BEPAC made a good effort to estimate the costs for JDEM but had limited time to do so. NASA has independently estimated its costs for JDEM at $600 million. Who is really correct here? This is difficult to know because both the NRC and NASA costed a generic JDEM without knowing which of several technology avenues will be pursued (see for example, the Dark Energy Task Force Report, *http://www.science.doe.gov/hep/DETF-FinalRptJune30,2006.pdf*). Furthermore, this is complicated because two federal agencies are involved and the costs of working across NASA and DOE in an equal partnership are unknown. The real costs can only be determined after specific JDEM proposals are submitted, evaluated, and a final telescope is chosen.

With this qualifier, I do believe that a mid-sized JDEM with a NASA cost ceiling of $600 million coupled with planned ground-based telescopes could make significant advancements on Dark Energy. I recommend that NASA solicit proposals with this cost cap and carefully consider the feasibility and accuracy of the budgets proposed by the principal investigators. If none of the proposed JDEM missions are deemed viable unless the costs exceed $1 billion, I recommend that NASA request the Decadal Survey to examine JDEM relative to the full spectrum of astrophysics priorities. The BEPAC considered only a limited set of *Beyond Einstein* missions in ranking JDEM as its top selection. Given the likely limited resources of astrophysics beyond 2010, the Decadal Survey should weigh in on a >$1 billion JDEM relative to other proposed observatories to determine if it is the top priority for a next large astrophysics mission.

Q4. How well will the FY09 budget request help advance other major projects in the Physics of the Cosmos program (formerly Beyond Einstein Program) such as the Laser Interferometer Space Antenna (LISA) and the Constellation-X observatory (Con-X)? What are your perspectives on the future of these projects?

A4. At $5.7 million for LISA and $8.3 million for Con-X in FY 2009, this funding is barely enough to keep these highly rated projects alive. The projected outyear funding in FY 2013 grows to $35 million and $45 million, respectively, for LISA and Con-X. However, this projected funding is totally inadequate to advance either mission to flight if the Decadal Survey recommends one or both as a top priority.

As noted in my testimony, I strongly recommend that NASA aggressively pursue and fund international partnership agreements on both of these missions to reduce costs and risks. Both missions offer exciting science but have technology hurtles. Both will be reviewed again by the Decadal Survey to determine their readiness for launch in the timeframe of the next decade.

Q5. Are NASA's plans for an ExoPlanet mission consistent with the findings of the Congressionally-chartered Astronomy and Astrophysics Advisory Committee (AAAC) ExoPlanet Task Force Report? Do you believe that a medium-class ExoPlanet mission, as proposed by NASA in the FY09 budget request, should be ranking by the National Academies decadal survey and therefore delayed until the completion of the survey process? If so, what if any steps should NASA take to prepare for an ExoPlanet mission in the interim?

A5. Among the recommendations of the 2008 Annual Report of the AAAC is the following regarding ExoPlanet missions: "given the pressure on the astrophysics budget and the limited opportunities post-2009, the AAAC recommends that any new medium class or larger ExoPlanet mission only proceed if it is prioritized to do so by the Decadal Survey." I concur and urge NASA to delay competition of a mid-sized ExoPlanet mission until the Decadal Survey has had an opportunity to evaluate the now wide range of exciting technologies for extrasolar planet detection—both astrometric and occulter techniques. NASA has funded multiple strategic concept studies for ExoPlanets in this current fiscal year and the results will need to be evaluated by the Decadal Survey.

NASA already has an exciting medium-size mission to search for ExoPlanets that will be launched in 2009 called Kepler. Similarly, the French along with other international partners have launched the COROT mission that will search for ExoPlanets via periodic micro-eclipses when the planets transit in front of their parent stars. We should evaluate the results of these missions in considering next steps for larger potential ExoPlanet searches.

The AAAC also stated that the "astrometric mission recommended in the ExoPTF report is *not* the Space Interferometry Mission (SIM)." Furthermore the AAAC goes on to say that the "ExoPTF explicitly recommended a detailed review of technology before embarking on its recommended narrow angle astrometry mission." I strongly agree with the AAAC in objecting to the efforts of individuals or groups who are seeking Congressional direction to force a new start for SIM in FY 2010 that would "distort the astronomy community's strategic, consensus-driven priorities."

Q6. You testified that NASA's astrophysics budget, "is forecast to fall by $423 million or 31 percent in real buying power over that for 2008. This decrease is proposed to occur right during an era of significant new astrophysics discoveries that will commence particularly with the James Webb Space Telescope at the end of this five-year period." *Are there specific projects or programs that you are particularly worried about in terms of the decreases and their affect on the health of astrophysics? If so, what are they?*

A6. The entire portfolio of astrophysics research for the next decade is endangered by an anemic, inflation-adjusted projected budget. This decline will affect all areas of the program—new missions, continued missions, Explorers, and R&A. It is difficult to imagine how NASA can begin *any* new missions, large or medium, as will be recommended by the Decadal Survey with the budget forecast for the out-years beyond 2010. Certainly, Con-X and LISA will be impossible.

In many ways, the current decade is a golden age for NASA astrophysics with three observatory class missions (HST, Chandra, Spitzer) and a robust fleet of mid-sized telescopes (Kepler, WISE, Herschel, Planck, and GLAST). On the other hand, by the middle of the next decade we will have only one space observatory (JWST), and possibly JDEM, but not much else. The current budget forecast does not have room for a significant ExoPlanet mission. As noted above, we are seriously jeopardizing America's leadership in space astrophysics while the Europeans, Japanese, and Chinese gain a decade worth of competitive advantage and experience over the U.S.

Q7. Dr. Burns, you testified on the problem of attracting "new instrumentalists who build the next generation of spacecraft sensors or imagers" *and noted that* "we almost drove the balloon and the rocket program out of existence, and so this is very helpful in that regard but we really need to do much more." *What more should be done?*

A7. Funding for technology development within NASA needs to be substantially increased. It is an investment in not only NASA's future missions but an investment in America's national innovation expertise. NASA must maintain the health of its Explorer, sounding rocket, and balloon programs, all of which are training grounds for the next generation of space scientists and technologists. We must maintain the launch capability for small, university-class payloads.

Other possibilities might include a national Astrophysics Instrumentalist postdoctoral fellowship similar to the Hubble fellowships, and a program of fellowships bridging graduate school through postdoctoral training for space scientists working on detector and telescope development. Such fellowships for graduate students and post-docs might be explicitly attached to the sounding rocket and balloon programs.

Questions submitted by Representative Tom Feeney

James Webb Space Telescope

Q1. The James Webb Space Telescope, scheduled for launch in 2013, is a high-risk, flagship mission. Earlier this decade it ran into serious and expensive technological challenges that forces NASA to de-scope the mission and delay its launch. How stable is the program today; is it staying within its schedule and budget profiles? Have all technological risks been retired?

A1. As I understand it from NASA Astrophysics, JWST recently successfully completed a major milestone in passing its Preliminary Design Review (PDR) and the Non Advocate Review (NAR). This PDR/NAR indicates that JWST has retired most, but not all, of its technical risks. From our community's experience, we have learned that risks cannot be completely retired until the mission is launched and the telescope is operating successfully. Nonetheless, the successful PDR/NAR reviews were an important step forward suggesting that the James Webb Space Telescope's major technology issues are in-hand and that the program is now stable. Currently, JWST appears to be close to its cost and schedule targets. Astrophysics Division Director Morse, with guidance from NASA Administrator Griffin, is maintaining a substantial reserve for JWST which is prudent for such a technologically challenging project.

Technology Development

Q2. NASA's science directorate has reconfigured its technology development activities by eliminating a generic directorate-wide program, and instead assigning technology development responsibility to individual missions. The rationale appears to be that mission-specific technology requirements is less wasteful. Do you agree with this rationale and what, if any, shortcomings might arise from this approach?

A2. Mission-specific technology development for a mission-oriented agency such as NASA makes sense. However, it would be unwise to devote all technology development funding to just specific missions since this would miss an opportunity for cross-mission synergies and for "blue sky" technology innovations.

NASA needs a mixture of investment strategies for technology development. SMD's concentration of resources for technology development on individual missions is sensible to enhance the probability of successful telescope operations. But, as I noted in my response to Chairman Udall's first question, the *Astronomy and Physics Research and Analysis (APRA)* program should also be increased to provide cross-mission technology development funding, to involve students and postdoctoral researchers in future instrumentation, and to provide some cross-fertilization and an outlet for development of creative new technologies. The APRA program provides an opportunity to design innovative new optics and detectors that can be tested on rockets and balloons before they would fly in space. Programs such as APRA should be willing to take risks on the development of technologies that might not be flown on future missions but could still contribute potential applications beyond astrophysics into the private sector.

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