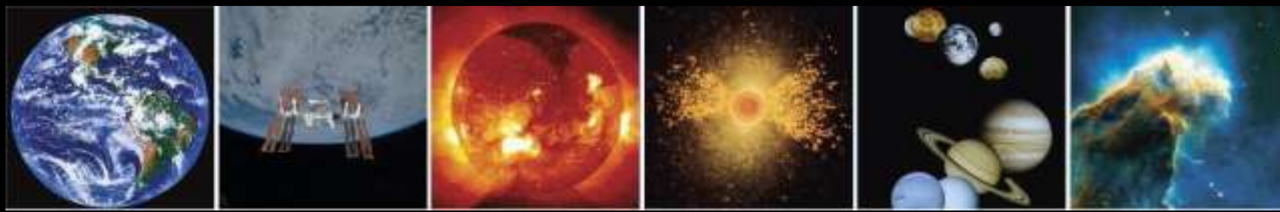
SPACE STUDIES BOARD NEWS



JANUARY—March 2011

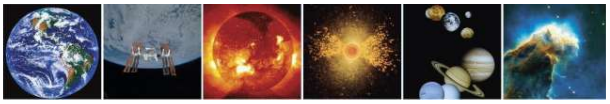
INSIDE THIS ISSUE

"NASA is sailing on a stormy financial ocean with no sign the storms will let up soon. "

—Charles Kennel, Chair, SSB

January—March 2011

SPACE STUDIES BOARD NEWS



FROM THE CHAIR

American science seems to choose Washington in April for major meetings. The National Research Council's Aeronautics and Space Engineering Board (ASEB) met for the 142nd time on April 5 and 6, and the Space Studies Board (SSB) met for its 162nd time on April 6-7. On April 6, the two boards met together for only the third time. Judging from the full attendance and by the turnout of NASA leaders (including the NASA Administrator Charlie Bolden), having a 1-day joint meeting to understand NASA's budget is a good idea. We should have had joint meetings years ago. I will leave it to historians to explain why we didn't.

You could not tell the difference between the two boards' worried reactions to the presentations on the projections of the 2011 and future federal budgets for the agencies that support the space sciences. This is not surprising, because problems at those agencies, including and particularly NASA, transcend our disciplines. We are both worried about programs that we have long been following, and perhaps even about the viability of NASA as we know it.

The only certain thing about NASA's future is that its future is more uncertain than it has ever been, notwithstanding the tremendous promise of the space sciences that is so clearly described by the SSB's set of decadal surveys. In the short term, no one can guess how the budget situation will evolve; in the long term, both the Administration and Congress agree that the deficit must be reduced, although they disagree on how to do it. The specific impact on NASA remains to be seen.

The president has proposed to Congress a "steady as you go" 2012 NASA budget, the level "notionally" held constant at 18.7 billion for the next 5 years. Would that it could be so! The new watchword is, as far as budgets are concerned, "Flat is the new up."

"There are unsettling omens. In 2012, NASA will lack its own capability to launch astronauts to low Earth orbit for the first time since the 1960s."

NASA is sailing on a stormy financial ocean with no sign the storms will let up soon. Certainly, there has been nothing calm about the atmosphere surrounding the 2011 budget, which was passed 6 months after the start of the fiscal year. The continuing resolution forced NASA to make expensive programmatic adjustments before its passage and, worse, delayed scientific progress.

There are unsettling omens. In 2012, NASA will lack its own capability to launch astronauts to low Earth orbit for the first time since the 1960s. Something new is also happening to the sciences covered by the SSB's decadal surveys. For the first time, the surveys are making recommendations within specific budget scenarios as well as taking cost and technical readiness into account. The recent planetary and astronomy and astrophysics surveys have recommended far fewer flagship missions than previous surveys have. What is unprecedented is not that, however; we cannot be certain that NASA will be able to do even our few high priority large-scale missions.

There is, for example, a chance the one and only large-scale mission recommended by *New Worlds, New*

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Horizons, for the Wide Field Infrared Telescope (WFIRST), may not be doable within the decade, and possibly not at all. NASA has made heroic efforts to complete the first priority recommendation of the last astronomy and astrophysics survey, the James Webb Space Telescope, despite enormous overruns in cost and schedule. Completing the last survey's flagship mission is directly threatening its smaller successor. Indeed, it is becoming clear that cost inflation in most if not all large projects is higher than we thought and getting higher. Launch vehicles have recently jumped in price. The current inflation in project costs compounds the other difficulties presented by a NASA budget that is at best level and likely declining.

All in all, NASA seemed to be facing a qualitatively new situation. Then, all at once, there was a ray of optimism amidst these gloomy reflections. We reminded ourselves of the many fascinating programs we are already working on. Many of these are lasting much longer than we thought they would and are supporting research objectives that were not thought of in the original proposals and surveys. Indeed, we said, the basic premise of *New Worlds, New Horizons* is that never before have so many been able to learn so much so effectively, that astronomy and astrophysics are on the brink of a new era of achievement. Notwithstanding the challenges with implementing WFIRST, NASA has adopted many of the report's other recommendations most notably an increased explorer program and augmentations of support for the smaller scale efforts, such as the programs in theory, suborbital science, and laboratory astrophysics. The SSB's recently released decadal survey of planetary science, *Visions and Voyages for Planetary Science in the Decade 2013-2022*, describes an exciting path forward in our studies of our solar system. Even in an area that has been severely cut back, our first ever decadal survey of life and physical sciences in space, *Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era*, proposes constructive ways to reconstitute a high quality science program in light of the recent commitment to continue the International Space Station.

We began to see a path to the future. NASA's capabilities and those in the U.S. science and engineering communities remain unrivalled. The United States still leads in both space science and exploration. If we scientists and engineers continue to execute the programs we have as well as we have, others around the world will still be drawn to collaborating with us because of our technical excellence and not our financial power. We can lead the world by example.

—Charles Kennel, Chair, SSB

Our decadal surveys can be found online:

New Worlds, New Horizons in Astronomy and Astrophysics (joint with the BPA)
http://www.nap.edu/catalog.php?record_id=12951
Visions and Voyages for Planetary Science in the Decade 2013-2022
http://www.nap.edu/catalog.php?record_id=13117
Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era
http://www.nap.edu/catalog.php?record_id=13048

SSB MEMBERSHIP

For more information on the membership of the SSB please visit our website at <www.nationalacademies.org/ssb>.

DIRECTOR'S CORNER

For the third year in a row the ASEB and SSB held 1 day of their respective Spring meetings in a joint session (April 6, 2011), and once again this event provided a unique forum for a dialogue among the experts on the two boards, the leadership at NASA, and staff from Capitol Hill and the Executive Office of the President. The keynote element of the day's agenda was when NASA Administrator Major General Charles F. Bolden (U.S. Marine Corps, retired) was gracious enough to spend more than 90 minutes attending the meeting.

The Administrator opened the session by giving a short overview of the FY 2012 budget request. He stressed that, while these are difficult fiscal times, NASA should still be able to fly out the space shuttle safely, operate the ISS, and develop a new transportation infrastructure—all in the context of the new NASA vision, as embodied in the recently released Strategic Plan.

In response to questions, the Administrator stressed that NASA is adopting a capabilities strategy regarding exploration—that is, developing what is needed (enabling technologies and systems) for where it wants to go. For a first "target" the President had spoken of an asteroid rendezvous by 2025, getting humans to Mars by the mid-2030s, and developing the capability to land there. The Administrator told the ASEB and SSB that NASA will have an architecture this summer that will lay out a plan using existing assets to the greatest possible extent. He added that this architecture must be affordable, sustainable over multiple congresses and administrations, and realistic.

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NASA Administrator Bolden talks to the ASEB and SSB on April 6, 2011.

Turning to the science program, the Administrator reported that Earth Science program was recovering from the recent loss of the Glory mission, as well as the earlier OCO mission. He also noted that NASA is looking into the use of the ISS as a platform for Earth science.

On the future of the James Webb Space Telescope (JWST) the Administrator noted that NASA is looking at a variety of options, from flat funding to additional funding. Significant management changes have been made both at NASA and by the contractors, and he reported that a realistic launch date for JWST would be 2018. But currently, NASA is trying to identify incremental budget increases to achieve JWST program stability and a clearly defined launch date.

On the Planetary Sciences program, the Administrator noted that at a recent bilateral with ESA on Mars exploration, both sides have recognized that they have budget limitations and have agreed that they will have to de-scope their planned missions to keep them affordable and sustainable while still working together on a joint Mars program.

Speaking about the Astrophysics program, the Administrator noted that the Astro2010 decadal survey listed WFIRST as a critical flagship mission, but that in the current fiscal and programmatic context he forecasted that the mission would probably not fly until the 2020s. Meanwhile ESA is considering a dark energy mission, Euclid, and if that mission emerges from ESA's m-class competition, ESA has indicated that it will then be prepared to discuss NASA involvement in that mission further.

The Administrator was asked what the design reference missions for heavy lift and the multiple-purpose crew vehicle will look like. He replied that the current focus is on a space shuttle-derived configuration for the launcher and an Orion-based configuration for the vehicle. But he added that the resulting configuration may not look anything like the vehicles that will actually fly. He also noted that, while it is true that a deep space vehicle can go to the ISS in principle, it is a very inefficient approach, since it is cheaper in the longer term to design a vehicle for a specific task.

Finally, when asked about what advice he had for the upcoming NRC study on long-range goals for the human spaceflight program, he noted that if the program does not know where we are going, we cannot decide what capabilities are needed, and we will "look like we are playing in a sandbox." He stressed that international engagement will be absolutely critical to the future of human space exploration, and for the program to be successful public engagement will also be critical, as will demonstrated affordability. He finished the session by urging the NRC to be honest in the study: "If the baby is ugly, tell us."

I left the session with the Administrator struck by the continuing complexity of the policy and budgetary contexts in which the ASEB and SSB conduct their work. Although we are cognizant of these important issues and their impact, our study committees are challenged to respond to the tasks they have been asked to address without too much speculation on possible outcomes. It is a sign of the strength of the NRC process that we manage time and again to stay focused on providing advice that is clearly based on the engineering and science foundations of our work.

—Michael Moloney, Director, SSB and ASEB

For more information on the SSB and ASEB Board Meetings (including the joint day) go to sites.nationalacademies.org/SSB/SSB_054577 (for the SSB) or sites.nationalacademies.org/DEPS/ASEB/DEPS_058923 (for the ASEB)

SSB STANDING COMMITTEE CHAIRS

COMMITTEE ON ASTRONOMY AND ASTROPHYSICS (CAA)*

COMMITTEE ON EARTH STUDIES (CES)

Chair: Berrien Moore III
Vice Chair: Ruth S. DeFries

COMMITTEE ON THE ORIGINS AND EVOLUTION OF LIFE (COEL)**

Co-Chairs:
Robert T. Pappalardo
J. Gregory Ferry

COMMITTEE ON PLANETARY AND LUNAR EXPLORATION (COMPLEX)***

COMMITTEE ON SOLAR AND SPACE PHYSICS (CSSP)***

*Joint with the Board on Physics and Astronomy; on hiatus during the Astro2010 decadal survey.
**Joint with the Board on Life Sciences.
***COMPLEX and CSSP are on hiatus during the planetary science decadal survey and the solar and space physics decadal survey, respectively.

SSB ACTIVITIES

THE BOARD AND ITS STANDING COMMITTEES

The **Space Studies Board (SSB)** did not met during this quarter; however, the spring meeting of the board was held at the beginning of the second quarter, April 6-7 at the National Academies' Keck Center. The first day of the meeting was a joint session of the ASEB and the SSB (mentioned earlier in this newsletter in both the *Chair's Column* and the *Director's Column*), at which the boards were updated by and had discussions with a number of NASA representatives, including Administrator Bolden and Waleed Abdalati (NASA Chief Scientist), congressional staff, and Executive Office of the President staff. The boards were also briefed by Wendy Kohrt, co-chair of the steering committee for *Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era*, which was publically released that day. The second day of the meeting included briefings on the programs and budgets for the NSF Geosciences, NOAA/NESDIS, and NASA/SMD; an update from the European Space Sciences Committee; briefings from the chairs of the planetary and astronomy and astrophysics decadal survey chairs (Steve Squyres and Roger Blandford); and an evaluation of the decadal survey cost and technical evaluation process by Steve Battel (a member of the astronomy and astrophysics and the solar and space physics decadal survey committees). The agenda and many of the presentations from the meeting can be found at http://sites.nationalacademies.org/SSB/SSB_054577.

The **Committee on Astronomy and Astrophysics (CAA)** is on hiatus during the course of the astronomy and astrophysics decadal survey.

The **Committee on Earth Studies (CES)** did not meet during this quarter; however, members of the committee were involved in developing a statement of task for a congressionally mandated study that will assess Earth science programs at NASA at the mid-point of the decadal survey cycle (the first NRC decadal survey in Earth science, *Earth Science and Applications from Space*, was published in January 2007).

The **Committee on the Origins and Evolution of Life (COEL)** held its first meeting of 2011 at the National Academies' Keck Center in Washington, D.C., on March 2-5. In addition to updates concerning NASA's Planetary Science Division, Astrobiology Program, and the NASA Astrobiology Institute, the committee heard presentations on a variety of topics, including scientific activities in Antarctica, the latest theoretical studies on martian methane models, the rise of oxygen in Earth's atmosphere, and the use of nucleic acids as biomarkers. In addition, the committee heard a series of different scientific and philosophical perspectives on the recent identification of arsenic-tolerant microbes in Mono Lake and their connection, if any, to the concepts of weird life and shadow biospheres. The committee also discussed NASA's response to the Mono Lake result and its own future in light of the nascent plans to merge COEL and COMPLEX. The next and final meeting of the committee in its current form will take place at the National Academies' J. Erik Jonsson Center in Woods Hole, MA, on June 7-8.

The **Committee on Planetary and Lunar Exploration (COMPLEX)** is on hiatus until the completion of the planetary science decadal survey.

The **Committee on Solar and Space Physics (CSSP)** is on hiatus until the completion of the solar and space physics (heliophysics) decadal survey.

STUDY COMMITTEES

An edited and final version of the prepublication report issued late last year from the ad hoc **Committee on the Assessment of Impediments to Interagency Cooperation on Space and Earth Science Missions** was in preparation as the quarter ended. The committee had briefed the findings of the report to NASA and congressional staff during the last quarter; in this quarter, the report was briefed to senior officials and staff of the White House Office of Science and Technology Policy.

The ad hoc **Committee on the Assessment of NASA's Earth Science Program** was approved by the NRC at the end of this quarter. A meeting was planned for April 27-29.

The steering committee and panels for the **Decadal Survey on Biological and Physical Sciences in Space** completed revisions to the report in response to comments from some 40 external peer reviewers in late January, and the report received sign-off the following month. The committee and panels subsequently began work on report revisions in response to the editorial review, which had begun in the previous year, and this work is continuing. The prepublication version of the report, *Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era*, was delivered to NASA on March 28. A number of briefings with NASA and congressional staff were held in early April and the report was publicly released on April 5.

Many activities occurred this quarter in connection with the second **NRC Decadal Strategy for Solar and Space Physics (Heliophysics)**. In January the second meetings of the three discipline-oriented study panels that are supporting the steering committee (Atmosphere-Ionosphere-Magnetosphere Interactions (AIM), Solar Wind-Magnetosphere Interactions (SWM), and Solar and Heliospheric Physics (SHP)). A second meeting of the steering committee was held in January; and several Working Groups also held meetings in January (Explorers, Suborbital, and Other Platforms; Innovations: Technology, Instruments, Data Systems; and Research to Operations/Operations to Research (R2O/O2R)). In addition, the R2O/O2R working group was present at a survey-sponsored town-hall meeting on February 7-8, where invited speakers, working group members, and the public were encouraged to express their view of topics pertaining to space weather research-to-operations and the inverse. A solicitation to the community for mission concepts and related activities that might be undertaken in the coming decade drew 288 responses. Panels reviewed these concepts and white papers at their first and second meetings and made recommendations to the steering committee regarding a small number of concepts that might go forward in an independent cost and technical evaluation. As the quarter ended, the Aerospace Corporation was completing the first phase of this analysis, assisted by representatives of the panels and

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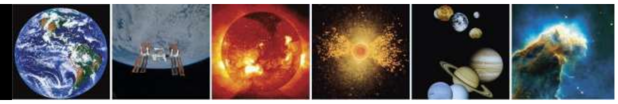

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the steering committee. Planning was also underway for the third and final meetings of the panels in late May and early June; the third and fourth meetings of the steering committee in April and June; and meetings in May of the Working Groups on Workforce and Education and Theory, Modeling and Data Exploitation Society. More information about the survey is available at http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_056864.

The ad hoc **Committee on Planetary Protection Standards for Icy Bodies in the Solar System** is developing recommendations for planetary protection standards for future spacecraft missions, including orbiters, landers, and subsurface probes, to the icy bodies in the outer solar system. The committee's first and second meetings were held at the National Academies' Keck Center in Washington, DC, and the Arnold and Mabel Beckman Center in Irvine, CA, on January 31-February 2 and March 16-18, respectively. Both meetings were devoted to gathering the necessary biological and planetological background to undertake the study. A detailed outline of the committee's report was drafted during the meeting in California. The third and final planned meeting will take place at the Arnold and Mabel Beckman Center on June 14-16. The committee's report is scheduled for delivery to NASA in early 2012.

The **Planetary Science Decadal Survey** charge was to determine the current state of knowledge and identify the most important scientific questions expected to face the community during the interval 2013-2022. Revision of the draft report in response to comments from 18 reviewers was completed in early February. The report was approved for release by the NRC on February 23 and sent to NASA and NSF on February 25. Briefings about the report's conclusions and recommendations were given to NASA, NSF, OMB, OSTP, and various congressional committees during the period of March 1-5. The report *Vision and Voyages for Planetary Science in the Decade 2013-2022* was released to the public during a presentation by the survey's chair, Steven W. Squyres, at the Lunar and Planetary Science Conference on March 7. Following the release of the report, members of the steering group made presentations about the report at the meetings of VEXAG, LEAG, OPAG, the European Geophysical Union, the NAC's Planetary Science Subcommittee, and the NAC's Science Committee. Other dissemination activities included a series of regional town hall meetings organized by the Division for Planetary Science of the American Astronomical Society. The locations of the town halls included College Park, MD, Boulder, CO, Tucson, AZ, Orlando, FL, New York, NY, Pasadena, CA, and St. Louis, MO.

Work was initiated in February on a project to review NASA's **risk model for radiation-induced cancer in astronauts**. An early draft of the NASA risk model was reviewed by NRC staff and used to develop a set of specific expertise areas and technical skillsets needed for the study. Detailed requests for nominees meeting these requirements were subsequently sent to appropriate NRC boards and committees, a large number of past participants in radiation studies carried out across the NRC, experts suggested by NASA, and liaisons to the relevant membership divisions of the NAS, NAE, and IOM. An exceptionally strong list of more than 100 committee candidates resulted from the solicitation and their individual qualifications are currently under review.

The importance of conveying an understanding and appreciation for the "grand questions" of space science and exploration that motivate the majority of NASA's programs—How is the universe evolving? Are we alone? Will the Earth remain a hospitable home for humanity in the future? What could the future hold for humans in space?—was the topic of a workshop, **Sharing the Adventure with the Public: The Value and Excitement of "Grand Questions" of Space Science and Exploration,** held on November 8-10 at the National Academies' Arnold and Mabel Beckman Center in Irvine, CA. The workshop was organized by an ad hoc planning committee and held under the auspices of the SSB, involved prominent space scientists and communications professionals and attracted an audience of more than 160. A report on the discussions that took place is planned for release in May. Workshop details can be found on the SSB Web site at http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_057195 , along with videos of each session.

The organizing committee for **The Effects of Solar Variability on Earth's Climate: A Workshop** was in the NRC's nomination process during this quarter and is expected to be approved in early April. A workshop planning meeting is scheduled for April 25. The dates and location for the workshop itself will be determined at the planning meeting.

OTHER ACTIVITIES

The **Committee on Space Research (COSPAR)** held its annual business meetings in Paris on March2 1-24. A major topic of discussion during the meetings of both the COSPAR Scientific Advisory Committee and the Bureau was the proposal raised during the Bremen Assembly of initiating a series of COSPAR Symposia to be held in non-assembly years. The basic motivation for these new events is that the biannual scientific assemblies have grown so big that only developed countries have facilities sufficiently large to host one. The off-year symposia would be formatted and scaled so that developing nations could readily host one. While many arguments were made both for and against the proposed new events, the Bureau decided that the concept had sufficient merit that one would be held as a test case in 2013 at a location to be determined.

COSPAR's next scientific assembly will be held in Mysore, India, on July 14-22, 2012. The 2014 assembly will be held in Moscow, Russia.

The **SSB outreach staff** exhibited at the AAAS meeting on February 17-21, in Washington, DC; the Lunar and Planetary Science Conference on March 7-11, in Houston, TX (which included the release of the planetary science decadal survey), and the National Science Teachers Association in San Francisco, CA, on March 10-13.

Report from the Archaemat II Field Workshop

David H. Smith, SSB Senior Staff Officer

In August 2010, David H. Smith attended the Archaemat II Field Workshop which was co-organized by Frances Westall, the liaison between the SSB's Committee on Origins and Evolution of Life (COEL) and the European Science Foundation's European Space Science Committee (ESSC). (All photographs courtesy of David H. Smith.)

Workshop co-organizers, Axel Hoffman (left) and Frances Westall (right).

Dr. Hoffman explains the geological context of the Barberton region from a vantage point above the Komati River near the township of Tjakastad.

The search for life on Mars and the study of the earliest life on Earth are closely related. Those not already convinced of the intimate connection between these two activities were rapidly disabused during the Archaemat II Field Workshop. For a week in August 2010, a diverse group of students, postdocs, established researchers, and one lapsed astrophysicist from Europe and the United States examined various key geological sites in the Pongola and Barberton regions of South Africa's western Transvall.

The first connection between life on Mars and early life on Earth follows from consideration of conditions in the early solar system. Environmental conditions on both Mars and Earth during their earliest geological eras—i.e., the pre-Noachian and Noachian (~4.5-3.7 billion years ago) and the early Archean (~4.0-3.3 billion years ago), respectively—were very similar. Both planets had dense carbon dioxide atmospheres, water, carbon, and other bioessential elements, and energy sources to drive metabolic processes.

The second connection concerns the preservation of evidence of both the environmental conditions and living organisms—if present—in the martian and terrestrial geological records. Ancient rocks are exposed at numerous locations on Mars. Unfortunately, rocks of the appropriate age are scarce on Earth. Most have been lost via a host of geological processes such as erosion or subduction. Archaean rocks do still exist in remnants of the Gondwanaland supercontinent in the southern hemisphere and in subpolar regions of the northern hemisphere. Unfortunately, recent environmental conditions have not favored the preservation of pristine materials. However, two locations have provided convincing evidence of the earliest life on Earth: Western Australia and the Transvaal. Although candidate microfossils some 3.5 billion years have been found in Australia, the most convincing microfossils are those of a somewhat younger date from South Africa. Hence, the workshop's South African venue.

Stromalolites, silicified dome-shaped algal mats are found throughout the fossil record and specimens that are still growing can be found today in, for example, Western Australia. These particular examples, found adjacent to the White Umfolozi River, are some 3 billion years old. The photograph shows an area about 25 cm across.

The third connection concerns people and their research projects. There is a significant overlap between the individuals who study ancient terrestrial life and those interested in the search for life on Mars. For example, workshop co-organizer Frances Westall (CNRS Centre de Biophysique Moléculaire) is a leading figure in both communities. She is the principal investigator of the Archaemat project, a combination of laboratory and field studies addressing

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questions relating to fossilized microbial mats and the evolution of photosynthesis on the early Earth. She is also a co-investigator for both the infrared imaging spectrometer and close-up imager on ESA's ExoMars rover. In fact, most of the workshop's participant had direct or indirect involvement with Archaemat and/or the ExoMars.

Also found adjacent to the White Umfolozi River, but upstream of the stromatolites (i.e., in younger rocks), are distinctive banded iron formations. These alternating strata of iron-rich and silica rich layers arose in the Archean era when changes in ocean chemistry caused soluble ferrous ions to be oxidized to form insoluble ferric ions. These formations are associated with the so-called Great Oxidation Event and the rise of oxygen in Earth's primordial atmosphere. The photograph shows an area several meters across.

The fourth connection concerns the techniques now used to search for ancient terrestrial life and those to be use to study martian materials in situ or following a sample return mission. So, while many participants collected rock samples for detailed study in their home institutions, Fernando Rull Pérez (Centro de Astrobiología) did not have to wait for shipments to reach Spain. He used a portable version of the Raman spectrometer he is building for ExoMars to study his samples within a few hours of being collected.

As its name implies, Archaemat II was a combination of a field trip and a workshop. A morning spent on a geological traver could be followed by another traverse in the afternoon or formal presentations in an improvised lecture room. After assembling in Johannesburg, the first day was taken up by driving across the Transvall to the valley of the White Umfolozi River near Vryheid in northern KwaZulu-Natal. This was our base for the next two nights. The focus of attention being banded iron formations and 3.0 billion year old stromatolites.

Giant stromatolites exposed in a road cutting in the vicinity of Barberton. These particular examples are about 2.5 billion years old and are several meters across.

Day three and another long drive relocated our base to the resort town of Badplaas, famous for its hot springs. An afternoon of presentations was followed by a day in the field traversing along the Komati River in the Songimvelo Nature Reserve. The presence of an armed guide during the traverse was, we were reassured, for our own protection. We were in hippopotamus territory.

After two nights in Badplaas, a relatively short drive took us to historical gold-mining town of Barberton, our base for the next three nights. En route we stopped to examine the 3.3 billion year old Josefsdal Chert. It was within this formation that Westall and colleagues had identified an exceptional well preserved fossilized microbial mat. Day six are taken up will visits to several locations, including outcrops of the 3.4 billion year old Buck Reef Chert within which fossil-like microstructures have been reported.

The afternoon and early evening of day seven was occupied by presentations, including one about the activities of COEL. Day eight, began with an examination of giant 2.5 billion year old stromatolites and then the participants dispersed. Some returned directly to Johannesburg and others took advantage of the proximity to Kruger National Park to commence additional biological studies.

—*David H. Smith*

A sample of the 3.3 billion year old Josefsdal Chert. This fine grained silica-rich rock contains well-preserved examples of a microbial mat. The microbial filaments are less than a micron across and are encrusted by evaporitic minerals. The geologic evidence suggest that the mat grew adjacent to a hot string, the mineral-rich outflow from which engulfed the mat and thus preserving it.

NEW RELEASES FROM THE SSB

Summaries are reproduced here without references, notes, figures, tables, boxes, or attachments. Copies of reports are available from the SSB office at 202-334-3477 or online at www.nap.edu/.

Vision and Voyages for Planetary Science in the Decade 2013-2022

This report by the Committee on the Planetary Science Decadal Survey is available at http://www.nap.edu/catalog.php?record_id=13117. The study was led by Steven W. Squyres, chair, and Laurence A. Soderblom, vice chair. The study was staffed by David H. Smith, study director, Dwayne A. Day, program officer, Dionna Williams, program associate, and Rodney Howard, senior program assistant (other staff listed in report).

Executive Summary

In recent years, planetary science has seen a tremendous growth in new knowledge. Deposits of water ice exist at the Moon's poles. Discoveries on the surface of Mars point to an early warm wet climate, and perhaps conditions under which life could have emerged. Liquid methane rain falls on Saturn's moon Titan, creating rivers, lakes, and geologic landscapes with uncanny resemblances to Earth's. Comets impact Jupiter, producing Earth-sized scars in the planet's atmosphere. Saturn's poles exhibit bizarre geometric cloud patterns and changes; its rings show processes that may help us understand the nature of planetary accretion. Venus may be volcanically active. Jupiter's icy moons harbor oceans below their ice shells: conceivably Europa's ocean could support life. Saturn's tiny moon Enceladus has enough geothermal energy to drive plumes of ice and vapor from its south pole. Dust from comets shows the nature of the primitive materials from which the planets and life arose. And hundreds of new planets discovered around nearby stars have begun to reveal how our solar system fits into a vast collection of others.

This report was requested by NASA and the National Science Foundation (NSF) to review the status of planetary science in the United States and to develop a comprehensive strategy that will continue these advances in the coming decade. Drawing on extensive interactions with the broad planetary science community, the report presents a decadal program of science and exploration with the potential to yield revolutionary new discoveries. The program will achieve long-standing scientific goals with a suite of new missions across the solar system. It will provide fundamental new scientific knowledge, engage a broad segment of the planetary science community, and have wide appeal for the general public whose support enables the program.

A major accomplishment of the committee's recommended program will be taking the first critical steps toward returning carefully selected samples from the surface of Mars. Mars is unique among the planets in having experienced processes comparable to those on Earth during its formation and evolution. Crucially, the martian surface preserves a record of earliest solar system history, on a planet with conditions that may have been similar to those on Earth when life emerged. It is now possible to select a site on Mars from which to collect samples that will address the question of whether the planet was ever an abode of life. The rocks from Mars that we have on Earth in the form of meteorites cannot provide an answer to this question. They are igneous rocks, whereas recent spacecraft observations have shown the occurrence on Mars of chemical sedimentary rocks of aqueous origin, and rocks that have been aqueously altered. It is these materials, none of which are found in meteorites, that provide the opportunity to study aqueous environments, potential prebiotic chemistry, and perhaps, the remains of early martian life.

If NASA's planetary budget is augmented, then the program will also carry out the first in-depth exploration of Jupiter's icy moon Europa. This moon, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, offers one of the most promising extraterrestrial habitable environments in our solar system and a plausible model for habitable environments outside it. The Jupiter system in which Europa resides hosts an astonishing diversity of phenomena, illuminating fundamental planetary processes. While Voyager and Galileo taught us much about Europa and the Jupiter system, the relatively primitive instrumentation of those missions, and the low data volumes returned, left many questions unanswered. Major discoveries surely remain to be made. The first step in understanding the potential of the outer solar system as an abode for life is a Europa mission with the goal of confirming the presence of an interior ocean, characterizing the satellite's ice shell, and understanding its geological history.

The program will also break new ground deep in the outer solar system. The gas giants Jupiter and Saturn have been extensively studied by the Galileo and Cassini missions, respectively. But Uranus and Neptune represent a wholly distinct class of planet. While Jupiter and Saturn are made mostly of hydrogen, Uranus and Neptune have much smaller hydrogen envelopes. The bulk composition of these planets is dominated instead by heavier elements; oxygen, carbon, nitrogen, and sulfur are the likely candidates. What little we know about the internal structure and composition of these "ice giant" planets comes from the brief flybys of Voyager 2. So the ice giants are one of the great remaining unknowns in the solar system: the only class of planet that has never been explored in detail. The proposed program will fill this gap in our knowledge by initiating a mission to orbit Uranus and put a probe into the planet's atmosphere. It is exploration in the truest sense, with the same potential for new discoveries as Galileo at Jupiter and Cassini at Saturn.

The program described in this report also vigorously continues NASA's two programs of competed planetary missions: New Frontiers and Discovery. It includes seven candidate New Frontiers missions from which NASA will select two for flight in the coming decade. These New Frontiers candidates cover a vast sweep of exciting planetary science questions: The surface composition of Venus, the internal structure of the Moon, the composition of the lunar mantle, the nature of Trojan asteroids, the composition of comet nuclei, the geophysics of Jupiter's volcanic moon Io, and the structure and detailed composition of Saturn's atmosphere. And continuation of the

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highly successful Discovery program, which involves regular competitive selections, will provide a steady stream of scientific discoveries from small missions that draw on the full creativity of the science community.

Space exploration has become a worldwide venture, and international collaboration has the potential to enrich the program in ways that benefit all participants. The program therefore relies more strongly than ever before on international participation, presenting many opportunities for collaboration with other nations. Most notably, the ambitious and complex Mars Sample Return campaign is critically dependent on a long-term and enabling collaboration with the European Space Agency (ESA).

In order to assemble this program, four criteria were used to select and prioritize missions. The first and most important was science return per dollar. Science return was judged with respect to the key scientific questions identified by the planetary science community; costs were estimated via a careful and conservative procedure that is described in detail in the body of this report. The second was programmatic balance—striving to achieve an appropriate balance among mission targets across the solar system and an appropriate mix of small, medium, and large missions. The other two were technological readiness and availability of trajectory opportunities within the 2013-2022 time period.

In order to help develop its recommendations, the committee commissioned technical studies of many candidate missions that were selected for study on the basis of white papers submitted by the scientific community. A subset of these was chosen on the basis of the four prioritization criteria listed above for independent assessments of technical feasibility, as well as conservative estimates of costs. From these, the committee finalized a set of recommended missions intended to achieve the highest priority science identified by the community within the budget resources projected to be available. It consists of a balanced mix of small Discovery missions, medium-sized New Frontiers missions, and large "Flagship" missions, enabling both a steady stream of new discoveries and the capability to address major challenges. The mission recommendations assume full funding of all missions that are currently in development, and continuation of missions that are currently in flight, subject to approval via the appropriate review process.

Small Missions

Missions for NASA's Discovery program lie outside the bounds of a decadal strategic plan, so this report makes no specific Discovery flight mission recommendations. The committee stresses, however, that the Discovery program has made important and fundamental contributions to planetary exploration, and can continue to do so in the coming decade. Because there is still so much compelling science that can be addressed by Discovery missions, the committee recommends continuation of the Discovery program at its current level, adjusted for inflation, with a cost cap per mission that is also adjusted for inflation from the current value (i.e., to about $500 million in fiscal year (FY) 2015). And in order for the science community to plan Discovery missions effectively, the committee recommends a regular, predictable, and preferably rapid (≤24 month) cadence for Discovery AO releases and mission selections.

An important small mission that lies outside the Discovery program is the proposed joint ESA/NASA Mars Trace Gas Orbiter that would launch in 2016. The committee supports flight of this mission as long as the currently negotiated division of responsibilities and costs with ESA is preserved.

Medium Missions

The current cost cap for NASA's competed New Frontiers missions, inflated to FY2015 dollars, is $1.05 billion, including launch vehicle costs. The committee recommends changing this cap to $1.0 billion FY2015, *excluding* launch vehicle costs. This change represents a modest increase in the effective cost cap and will allow a scientifically rich and diverse set of New Frontiers missions to be carried out, and will help protect the science content of the program against increases and volatility in launch vehicle costs.

Two New Frontiers missions have been selected by NASA to date, and a third selection is underway now. The committee recommends that NASA select two New Frontiers missions in the decade 2013-2022. These are referred to here as New Frontiers Mission 4 and New Frontiers Mission 5.

New Frontiers Mission 4 should be selected from among the following five candidates:

- Comet Surface Sample Return,
- Lunar South Pole-Aitken Basin Sample Return,
- Saturn Probe,
- Trojan Tour and Rendezvous, and
- Venus In Situ Explorer.

No relative priorities are assigned to these five candidates; instead, the selection among them should be made on the basis of competitive peer review.

If the third New Frontiers mission selected by NASA addresses the goals of one of these mission candidates, the corresponding candidate should be removed from the above list of five, reducing the number from which NASA should make the New Frontiers Mission 4 selection to four.

For the New Frontiers Mission 5 selection, the following missions should be added to the list of remaining candidates:

- Io Observer,
- Lunar Geophysical Network.

Again, no relative priorities are assigned to any of these mission candidates.

Tables ES.1 and ES.2 summarize the recommended mission candidates and decision rules for the New Frontiers program.

Large Missions

The highest priority large mission for the decade 2013-2022 is the Mars Astrobiology Explorer-Cacher (MAX-C), which will begin a three-mission NASA-ESA Mars Sample Return campaign extending into the decade beyond 2022. At an estimated cost of $3.5 billion as currently designed, however, MAX-C would take up a disproportionate share of the NASA's planetary budget. This high cost results in large part from the goal to deliver two large and capable rovers—a NASA sample-caching rover and the European Space Agency's ExoMars rover—using a single entry, descent, and landing (EDL) system that is derived from the Mars Science Laboratory (MSL) EDL system. Accommodation of two such large rovers would re-

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quire major redesign of the MSL EDL system, with substantial associated cost growth.

The committee recommends that NASA fly MAX-C in the decade 2013-2022, but only if it can be conducted for a cost to NASA of no more than approximately $2.5 billion FY2015. If a cost of no more than about $2.5 billion FY2015 cannot be verified, the mission (and the subsequent elements of Mars Sample Return) should be deferred until a subsequent decade or cancelled.

It is likely that a significant reduction in mission scope will be needed to keep the cost of MAX-C below $2.5 billion. In order to be of benefit to NASA, the Mars exploration partnership with ESA must involve ESA participation in other missions of the Mars Sample Return campaign. The best way to maintain the partnership will be an equitable reduction in scope of both the NASA and ESA objectives for the joint MAX-C/ExoMars mission, so that both parties still benefit from it.

The second highest priority Flagship mission for the decade 2013-2022 is the Jupiter Europa Orbiter (JEO). However, its cost as currently designed is so high that both a decrease in mission scope and an increase in NASA's planetary budget are necessary to make it affordable. The projected cost of the mission as currently designed is $4.7 billion FY2015. If JEO were to be funded at this level within the currently projected NASA planetary budget it would lead to an unacceptable programmatic imbalance, eliminating too many other important missions. Therefore, while the committee recommends JEO as the second highest priority Flagship mission, close behind MAX-C, it should fly in the decade 2013-2022 only if changes to both the mission and the NASA planetary budget make it affordable without eliminating any other recommended missions. These changes are likely to involve both a reduction in mission scope and a formal budgetary new start for JEO that is accompanied by an increase in the NASA planetary budget. NASA should immediately undertake an effort to find major cost reductions for JEO, with the goal of minimizing the size of the budget increase necessary to enable the mission.

The third highest priority Flagship mission is the Uranus Orbiter and Probe mission. The committee carefully investigated missions to both ice giants, Uranus and Neptune. While both missions have high scientific merit, the conclusion was that a Uranus mission is favored for the decade 2013-2022 for practical reasons involving available trajectories, flight times, and cost. The Uranus Orbiter and Probe mission should be initiated in the decade 2013-2022 even if both MAX-C and JEO take place. But like those other two missions, it should be subjected to rigorous independent cost verification throughout its development, and descoped or canceled if costs grow significantly above the projected cost of $2.7 billion FY2015.

Table ES.3 summarizes the recommended large missions and associated decision rules.

Following the priorities and decision rules outlined above, two example programs of solar system exploration can be described for the decade 2013-2022.

The *Recommended Program* can be conducted assuming a budget increase sufficient to allow a new start for JEO. It includes the following elements (in no particular order):

- Discovery program funded at the current level adjusted for inflation;
- Mars Trace Gas Orbiter conducted jointly with ESA;
- New Frontiers Missions 4 and 5;
- MAX-C (descoped to $2.5 billion);
- Jupiter Europa Orbiter (descoped);
- Uranus Orbiter and Probe

The *Cost Constrained Program* can be conducted assuming the currently projected NASA planetary budget. It includes the following elements (in no particular order):

- Discovery program funded at the current level adjusted for inflation;
- Mars Trace Gas Orbiter conducted jointly with ESA;
- New Frontiers Mission 4 and 5;
- MAX-C (descoped to $2.5 billion);
- Uranus Orbiter and Probe

Plausible circumstances could improve the budget picture presented above. If this happened, the additions to the recommended plan should be, in priority order:

1. An increase in funding for the Discovery program,
2. Another New Frontiers mission, and
3. Either the Enceladus Orbiter mission or the Venus Climate Mission.

It is also possible that the budget picture could be less favorable than the committee has assumed. If cuts to the program are necessary, the first approach should be descoping or delaying Flagship missions. Changes to the New Frontiers or Discovery programs should be considered only if adjustments to Flagship missions cannot solve the problem. And high priority should be placed on preserving funding for research and analysis programs and for technology development.

Looking ahead to possible missions in the decade beyond 2022, it is important to make significant near-term technology investments in the Mars Sample Return Lander, Mars Sample Return Orbiter, Titan Saturn System Mission, and Neptune System Orbiter and Probe.

NASA-Funded Supporting Research and Technology Development

NASA's planetary research and analysis programs are heavily oversubscribed. Consistent with the mission recommendations and costs presented above, the committee recommends that NASA increase the research and analysis budget for planetary science by 5 percent above the total finally approved FY2011 expenditures in the first year of the coming decade, and increase the budget by 1.5 percent above the inflation level for each successive year of the decade. Also, the future of planetary science depends on a well-conceived, robust, stable technology investment program. The committee unequivocally recommends that a substantial program of planetary exploration technology development should be reconstituted and carefully protected against all incursions that would deplete its resources. This program should be consistently funded at approximately 6 to 8 percent of the total NASA Planetary Science Division budget.

NSF-Funded Research and Infrastructure

The National Science Foundation supports nearly all areas of planetary science except space missions, which it supports indirectly through laboratory research and archived data. NSF grants and

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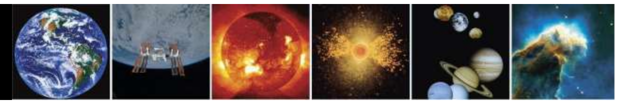

NEW RELEASES FROM THE SSB (CONTINUED)

Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era

This report by the Committee on the Planetary Science Decadal Survey is available at http://www.nap.edu/catalog.php?record_id=13048. . The study was led by co-chairs Elizabeth Cantwell and Wendy Kohrt. The study was staffed by Sandra Graham, study director, and Danielle Johnson, senior program assistant (other staff listed in report).

Summary

SCIENCE AND EXPLORATION

More than four decades have passed since a human first set foot on the Moon. Great strides have been made since in our understanding of what is required to support an enduring human presence in space, as evidenced by progressively more advanced orbiting human outposts, culminating in the current International Space Station (ISS). However, of the more than 500 humans who have so far ventured into space, most have gone only as far as near-Earth orbit, and none have traveled beyond the orbit of the Moon. Achieving humans' further progress into the solar system has proved far more difficult than imagined in the heady days of the Apollo missions, but the potential rewards remain substantial. Overcoming the challenges posed by risk and cost—and developing the technology and capabilities to make long space voyages feasible—is an achievable goal. Further, the scientific accomplishments required to meet this goal will bring a deeper understanding of the performance of people, animals, plants, microbes, materials, and engineered systems not only in the space environment but also on Earth, providing terrestrial benefits by advancing fundamental knowledge in these areas.

During its more than 50-year history, NASA's success in human space exploration has depended on the agency's ability to effectively address a wide range of biomedical, engineering, physical science, and related obstacles—an achievement made possible by NASA's strong and productive commitments to life and physical sciences research for human space exploration, and by its use of human space exploration infrastructures for scientific discovery. This partnership of NASA with the research community reflects the original mandate from Congress in 1958 to promote science and technology, an endeavor that requires an active and vibrant research program. The committee acknowledges the many achievements of NASA, which are all the more remarkable given budgetary challenges and changing directions within the agency. In the past decade, however, a consequence of those challenges has been a life and physical sciences research program that was dramatically reduced in both scale and scope, with the result that the agency is poorly positioned to take full advantage of the scientific opportunities offered by the now fully equipped and staffed ISS laboratory, or to effectively pursue the scientific research needed to support the development of advanced human exploration capabilities.

Although its review has left it deeply concerned about the current state of NASA's life and physical sciences research, the Committee for the Decadal Survey on Biological and Physical Sciences in Space is nevertheless convinced that a focused science and engineering program can achieve successes that will bring the space community, the U.S. public, and policymakers to an understanding that we are ready for the next significant phase of human space exploration. The goal of this report is to lay out steps whereby NASA can reinvigorate its partnership with the life and physical sciences research community and develop a forward-looking portfolio of research that will provide the basis for recapturing the excitement and value of human spaceflight—thereby enabling the U.S. space program to deliver on new exploration initiatives that serve the nation, excite the public, and place the United States again at the forefront of space exploration for the global good. This report examines the fundamental science and technology that underpin developments with payoffs for human exploration programs will be substantial, as the following examples illustrate:

- An effective countermeasures program to attenuate the adverse effects of the space environment on the health and performance capabilities of astronauts, a development that will make it possible to conduct prolonged human space exploration missions.
- A deeper understanding of the mechanistic role of gravity in the regulation of biological systems (e.g., mechanisms by which microgravity triggers the loss of bone or cardiovascular function)¾understanding that will provide insights for strategies to optimize biological function during spaceflight as well as on Earth (e.g., slowing the loss of bone or cardiovascular function with aging).
- Game changers, such as architecture-altering systems involving on-orbit depots for cryogenic rocket fuels, an example of a revolutionary advance possible only with the scientific understanding required to make this Apollo-era notion a reality. As an example, for some lunar missions such a depot could produce major cost savings by enabling use of an Ares I type launch system rather than a much larger Ares V type system.
- The critical ability to collect or produce large amounts of water from a source such as the Moon or Mars, which requires a scientific understanding of how to retrieve and refine water-bearing materials from extremely cold, rugged regions under partial gravity conditions. Once cost-effective production is available, water can be transported to either bases or orbit for use in the many exploration functions that require it. Major cost savings will result from using that water in a photovoltaic powered electrolysis and cryogenics plant to produce liquid oxygen and hydrogen for propulsion.
- Advances stemming from research on fire retardants, fire suppression, fire sensors, and combustion in microgravity that provide the basis for a comprehensive fire-safety system, greatly reducing the likelihood of a catastrophic event.
- Regenerative fuel cells that can provide lunar surface power for the long eclipse period (14 days) at high rates (e.g., greater than tens of kilowatts). Research on low mass tankage, thermal management, and fluid handling in low gravity is on track to achieve regenerative fuel cells with specific energy greater

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than two times that of advanced batteries.

In keeping with its charge, the committee developed recommendations for research fitting in either one or both of these two broad categories:

1. *Research that **enables** space exploration:* scientific research in the life and physical sciences that is needed to develop advanced exploration technologies and processes, particularly those that are profoundly affected by operation in a space environment.
2. *Research **enabled by** access to space:* scientific research in the life and physical sciences that takes advantage of unique aspects of the space environment to significantly advance fundamental scientific understanding.

The key research challenges, and the steps needed to craft a program of research capable of facilitating the progress of human exploration in space, are highlighted below and described in more detail in the body of the report. In the committee's view, these are steps that NASA will have to take in order to recapture a vision of space exploration that is achievable and that has inspired the country, and humanity, since the founding of NASA.

ESTABLISHING A SPACE LIFE AND PHYSICAL SCIENCES RESEARCH PROGRAM: PROGRAMMATIC ISSUES

Research in the complex environment of space requires a strong, flexible, and supportive programmatic structure. Also essential to a vibrant and ultimately successful space life and physical sciences research program is a partnership between NASA and the scientific community at large. The present program, however, has contracted to below critical mass and is perceived from outside NASA as lacking the stature within the agency and the commitment of resources to attract researchers or to accomplish real advances. For this program to effectively promote research to meet the national space exploration agenda, a number of issues will have to be addressed.

Administrative Oversight of Life and Physical Sciences Research

Currently, life and physical science endeavors have no clear institutional home at NASA. In the context of a programmatic home for an integrated research agenda, program leadership and execution are likely to be productive only if aggregated under a single management structure and housed in a NASA directorate or key organization that understands both the value of science and its potential application in future exploration missions. The committee concluded that:

- Leadership *with both true scientific gravitas and a sufficiently high level in the overall organizational structure at NASA is needed to ensure that there will be a "voice at the table" when the agency engages in difficult deliberations about prioritizing resources and engaging in new activities.*
- The *successful renewal of a life and physical sciences research program will depend on strong leadership with a unique authority over a dedicated and enduring research funding stream.*
- It *is important that the positioning of leadership within the agency allows both the conduct of the necessary research programs as well as interactions, integration, and influence within the mission-planning elements that develop new exploration options.*

Elevating the Priority of Life and Physical Sciences Research in Space Exploration

It is of paramount importance that the life and physical sciences research portfolio supported by NASA, both extramurally and intramurally, receives appropriate attention within the agency and that its organizational structure is optimally designed to meet NASA's needs. The committee concluded that:

- The *success of future space exploration depends on life and physical sciences research being central to NASA's exploration mission and being embraced throughout the agency as an essential translational step in the execution of space exploration missions.*
- *A successful life and physical sciences program will depend on research being an integral component of spaceflight operations, and on astronauts' participation in these endeavors being viewed as a component of each mission.*
- The *collection and analysis of a broad array of physiological and psychological data from astronauts before, during, and after a mission is necessary for advancing knowledge of the effects of the space environment on human health and for improving the safety of human space exploration.*

Establishing a Stable and Sufficient Funding Base

A renewed funding base for fundamental and applied life and physical sciences research is essential for attracting the scientific community needed to meet the prioritized research objectives laid out in this report. Researchers must have a reasonable level of confidence in the sustainability of research funding if they are expected to focus their laboratories, staff, and students on research issues relevant to space exploration. The committee concluded that:

- In *accord with elevating the priority of life and physical sciences research, it is important that the budget to support research be sufficient, sustained, and appropriately balanced between intramural and extramural activities. As a general conclusion regarding the allocation of funds, an extramural budget would need to support a sufficiently robust extramural research program to ensure that there will be a stable community of scientists and engineers prepared to lead future space exploration research and train the next generation of scientists and engineers.*
- *Research productivity and efficiency will be enhanced if the* historical *collaborations of NASA with other sponsoring agencies, such as the National Institutes of Health, are sustained and strengthened and expanded to other agencies.*

Improving the Process for Solicitation and Review of High-Quality Research

Familiarity with, and the predictability of, the research solicitation process are critical to enabling researchers to plan and conduct activities in their laboratories that enable them to prepare high-quality research proposals. Regularity in frequency of solicitations, ideally multiple solicitations per year, would help to ensure that the community of investigators remains focused on life and physical science research areas relevant to the agency, thereby creating a sustainable research network. The committee concluded that:

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- Regularly *issued solicitations for NASA-sponsored life and physical sciences research are necessary to attract investigators to research that enables or is enabled by space exploration. Effective solicitations would include broad research announcements to encourage a wide array of highly innovative applications, targeted research announcements to ensure that high-priority mission-oriented goals are met, and team research announcements that specifically foster multidisciplinary translational research.*
- The *legitimacy of NASA's peer-review systems for extramural and intramural research hinges on the assurance that the review process, including the actions taken by NASA as a result of review recommendations, is transparent and incorporates a clear rationale for prioritizing intra- and extramural investigations.*
- The *quality of NASA-supported research and the interactions with the scientific community would be enhanced by the assembly of a research advisory committee, composed of 10 to 15 independent life and physical scientists, to oversee and endorse the process by which intramural and extramural research projects are selected for support after peer review of their scientific merit. Such a committee would be charged with advising and making recommendations to the leadership of the life and physical sciences program on matters relating to research activities.*

Rejuvenating a Strong Pipeline of Intellectual Capital Through Training and Mentoring Programs

A critical number of investigators is required to sustain a healthy and productive scientific community. A strong pipeline of intellectual capital can be developed by modeling a training and mentoring program on other successful programs in the life and physical sciences. Building a program in life and physical sciences would benefit from ensuring that an adequate number of flight- and ground-based investigators are participating in research that will enable future space exploration. The committee concluded that:

- Educational *programs and training opportunities effectively expand the pool of graduate students, scientists, and engineers who will be prepared to improve the translational application of fundamental and applied life and physical sciences research to space exploration needs.*

Linking Science to Needed Mission Capabilities Through Multidisciplinary Translational Programs

Complex systems problems of the type that human exploration missions will increasingly encounter will need to be solved with integrated teams that are likely to include scientists from a number of disciplines, as well as engineers, mission analysts, and technology developers. The interplay between and among the life and physical sciences and engineering, along with a strong focus on cost effectiveness, will require multidisciplinary approaches. Multidisciplinary translational programs can link the science to the gaps in mission capabilities through planned and enabled data collection mechanisms. The committee concluded that:

- A *long-term strategic plan to maximize team research opportunities and initiatives would accelerate the trajectory of research discoveries and improve the efficiency of translating those discoveries to solutions for the complex problems associated with space exploration.*
- Improved *central information networks would facilitate data sharing with and analysis by the life and physical science communities and would enhance the science results derived from flight opportunities.*

ESTABLISHING A LIFE AND PHYSICAL SCIENCES RESEARCH PROGRAM: AN INTEGRATED MICROGRAVITY RESEARCH PORTFOLIO

Areas of Highest-Priority Research

NASA has a strong and successful track record in human spaceflight made possible by a backbone of science and engineering accomplishments. Decisions regarding future space exploration, however, will require the generation and use of new knowledge in the life and physical sciences for successful implementation of any options chosen. Chapters 4 through 10 in this report identify and prioritize research questions important both to conducting successful space exploration and to increasing the fundamental understanding of physics and biology that is enabled by experimentation in the space environment. These two interconnected concepts—that science is enabled by access to space and that science enables future exploration missions—testify to the powerful complementarity of science and the human spaceflight endeavor. For example, the research recommended in this report addresses unanswered questions related to the health and welfare of humans undertaking extended space missions, to technologies needed to support such missions, and to logistical issues with potential impacts on the health of space travelers, such as ensuring adequate nutrition, protection against radiation exposure, suitable thermoregulation, appropriate immune function, and attention to stress and behavioral factors. At the same time, progress in answering such questions will find broader applications as well.

It is not possible in this brief summary to describe or even adequately summarize the highest-priority research recommended by the committee. However, the recommendations selected (from a much larger body of discipline suggestions and recommendations) as having the highest overall priority for the coming decade are listed briefly as broad topics below. The committee considered these recommendations to be the minimal set called for in its charge to develop an integrated portfolio of research enabling and enabled by access to space and thus did not attempt to further prioritize among them. In addition, it recognized that further prioritization among these disparate topic areas will be possible only in the context of specific policy directions to be set by NASA and the nation. Nevertheless, the committee has provided tools and metrics that will allow NASA to carry out further prioritization (as summarized below in the section "Research Portfolio Implementation").

The recommended research portfolio is divided into the five disciplines areas and two integrative translational areas represented by the study panels that the committee directed. The extensive details (such as research timeframes and categorizations as enabling, enabled-by, or both) of the research recommended as having the highest priority are presented in Chapters 4 through 10 of the report and much of this information is summarized in the research portfolio discussion in Chapter 13.

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Plant and Microbial Biology

Plants and microbes evolved at Earth's gravity (1 *g*), and spaceflight represents a completely novel environment for these organisms. Understanding how they respond to these conditions holds great potential for advancing knowledge of how life operates on Earth. In addition, plants are important candidates for components of a biologically based life support system for prolonged spaceflight missions, and microbes play complex and essential roles in both positive and negative aspects of human health, in the potential for degradation of the crew environment through fouling of equipment, and in bioprocessing of the wastes of habitation in long-duration missions. The highest-priority research, focusing on these basic and applied aspects of plant and microbial biology, includes:

- Multigenerational studies of International Space Station microbial population dynamics;
- Plant and microbial growth and physiological responses; and
- Roles of microbial and plant systems in long-term life support systems.

Behavior and Mental Health

The unusual environmental, psychological, and social conditions of spaceflight missions limit and define the range of crew activities, and trigger mental and behavioral adaptations. The adaptation processes include responses that result in variations in astronauts' mental and physical health, and strongly stress and affect crew performance, productivity, and well-being. It is important to develop new methods and to improve current methods, for minimizing psychiatric and sociopsychological costs inherent in spaceflight missions, and to better understand issues related to the selection, training, and in-flight and post-flight support of astronaut crews. The highest-priority research includes:

- Mission-relevant performance measures;
- Long-duration mission simulations;
- Role of genetic, physiological, and psychological factors in resilience to stressors; and
- Team performance factors in isolated autonomous environments.

Animal and Human Biology

Human physiology is altered in both dramatic and subtle ways in the spaceflight environment. Many of these changes profoundly limit the ability of humans to explore space, yet also shed light on fundamental biological mechanisms of medical and scientific interest on Earth. The highest-priority research, focusing on both basic mechanisms and development of countermeasures, includes:

- Studies of bone preservation and bone-loss reversibility factors and countermeasures, including pharmaceutical therapies;
- In-flight animal studies of bone loss and pharmaceutical countermeasures;
- Mechanisms regulating skeletal muscle protein balance and turnover;
- Prototype exercise countermeasures for single and multiple systems;
- Patterns of muscle retrainment following spaceflight;
- Changes in vascular/interstitial pressures during long-duration space missions;
- Effects of prolonged reduced gravity on organism performance, capacity mechanisms, and orthostatic intolerance;
- Screening strategies for subclinical coronary heart disease;
- Aerosol deposition in the lungs of humans and animals in reduced gravity;
- T cell activation and mechanisms of immune system changes during spaceflight;
- Animal studies incorporating immunization challenges in space; and
- Studies of multigenerational functional and structural changes in rodents in space.

Cross-Cutting Issues for Humans in the Space Environment

Translating knowledge from laboratory discoveries to spaceflight conditions is a two-fold task involving horizontal integration (multi- and transdisciplinary) and vertical translation (interaction among basic, preclinical, and clinical scientists to translate fundamental discoveries into improvements in the health and well-being of crew members during and after their missions). To address the sum effect of a range of physiological and behavioral changes, an integrated research approach is warranted. The highest-priority cross-cutting research issues include:

- Integrative, multisystem mechanisms of post-landing orthostatic intolerance;
- Countermeasure testing of artificial gravity;
- Decompression effects;
- Food, nutrition, and energy balance in astronauts;
- Continued studies of short- and long-term radiation effects in astronauts and animals;
- Cell studies of radiation toxicity endpoints;
- Gender differences in physiological effects of spaceflight; and
- Biophysical principles of thermal balance.

Fundamental Physical Sciences in Space

The fundamental physical sciences research at NASA had two overarching quests: (1) to discover and explore the laws governing matter, space, and time and (2) to discover and understand the organizing principles of complex systems from which structure and dynamics emerge. Space offers unique conditions in which to address important questions about the fundamental laws of nature, and it allows sensitivity in measurements beyond that of ground-based experiments in many areas. Research areas of highest priority are the following:

- Study of complex fluids and soft matter in the microgravity laboratory;
- Precision measurements of the fundamental forces and symmetries;
- Physics and applications of quantum gases (gases at very low temperatures where quantum effects dominate); and
- Behavior of matter near critical phase transition.

Applied Physical Sciences

Applied physical sciences research, especially in fluid physics, combustion, and materials science, is needed to address design challenges for many key exploration technologies. This research will enable new exploration capabilities and yield new insights into a

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broad range of physical phenomena in space and on Earth, particularly with regard to improved power generation, propulsion, life support, and safety. Applied physical sciences research topics of particular interest are as follows:

- Reduced-gravity multiphase flows, cryogenics, and heat transfer database development and modeling;
- Interfacial flows and phenomena in exploration systems;
- Dynamic granular material behavior and subsurface geotechnics;
- Strategies and methods for dust mitigation;
- Complex fluid physics in a reduced-gravity environment;
- Fire safety research to improve screening of materials in terms of flammability and fire suppression;
- Combustion processes and modeling;
- Materials synthesis and processing to control microstructures and properties;
- Advanced materials design and development for exploration; and
- Research on processes for in situ resource utilization.

Translation to Space Exploration Systems

The translation of research to space exploration systems includes identification of the technologies that enable exploration missions to the Moon, Mars, and elsewhere, as well as the research in life and physical sciences that is needed to develop these enabling technologies, processes, and capabilities. The highest-priority research areas to support objectives and operational systems in space exploration include:

- Two-phase flow and thermal management;
- Cryogenic fluid management;
- Mobility, rovers, and robotic systems;
- Dust mitigation systems;
- Radiation protection systems;
- Closed-loop life support systems;
- Thermoregulation technologies;
- Fire safety: materials standards and particle detectors;
- Fire suppression and post-fire strategies;
- Regenerative fuel cells;
- Energy conversion technologies;
- Fission surface power;
- Ascent and descent propulsion technologies;
- Space nuclear propulsion;
- Lunar water and oxygen extraction systems; and
- Planning for surface operations, including in situ resource utilization and surface habitats.

For each of the high-priority research areas identified above, the committee classified the research recommendations as enabling for future space exploration options, enabled by the environment of space that exploration missions will encounter, or both.

Research Portfolio Implementation

While the committee believes that any healthy, integrated program of life and physical sciences research will give consideration to the full set of recommended research areas discussed in this report—and will certainly incorporate the recommendations identified as having the highest priority by the committee and its panels—it fully recognizes that further prioritization and decisions on the relative timing of research support in various areas will be determined by future policy decisions. For example, and only as an illustration, a policy decision to send humans to Mars within the next few decades would elevate the priority of enabling research on dust mitigation systems, whereas a policy decision to focus primarily on advancing fundamental knowledge through the use of space would elevate the priority of critical phase transition studies. The committee therefore provided for future flexibility in the implementation of its recommended portfolio by mapping all of the high-priority research areas against the overarching metrics used to select them. These eight overarching metrics, listed below with clarifying criteria (see Table 13.3) added in parentheses, can be used as a basis for policy-related ordering of an integrated research portfolio. Examples of how this might be done are provided in the report.

- The extent to which the results of the research will reduce uncertainty about both the benefits and the risks of space exploration (Positive Impact on Exploration Efforts, Improved Access to Data or to Samples, Risk Reduction)
- The extent to which the results of the research will reduce the costs of space exploration (Potential to Enhance Mission Options or to Reduce Mission Costs)
- The extent to which the results of the research may lead to entirely new options for exploration missions (Positive Impact on Exploration Efforts, Improved Access to Data or to Samples)
- The extent to which the results of the research will provide full or partial answers to grand science challenges that the space environment provides a unique means to address (Relative Impact Within Research Field)
- The extent to which the results of the research are uniquely needed by NASA, as opposed to any other agencies (Needs Unique to NASA Exploration Programs)
- The extent to which the results of the research can be synergistic with other agencies' needs (Research Programs That Could Be Dual-Use)
- The extent to which the research must use the space environment to achieve useful knowledge (Research Value of Using Reduced-Gravity Environment)
- The extent to which the results of the research could lead to either faster or better solutions to terrestrial problems or to terrestrial economic benefit (Ability to Translate Results to Terrestrial Needs)

Facilities, Platforms, and the International Space Station

Facility and platform requirements are identified for each of the various areas of research discussed in this report. Free-flyers, suborbital spaceflights, parabolic aircraft, and drop towers are all important platforms, each offering unique advantages that might make them the optimal choice for certain experiments. Ground-based laboratory research is critically important in preparing most investigations for eventual flight, and there are some questions that can be addressed primarily through ground research. Eventually, access to lunar and planetary surfaces will make it possible to conduct critical studies in the partial gravity regime and will enable testbed studies of systems that will have to operate in those environments. These facilities enable studies of the effects of various aspects of the space environ-

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ment, including reduced gravity, increased radiation, vacuum and planetary atmospheres, and human isolation.

Typically, because of the cost and scarcity of the resource, spaceflight research is part of a continuum of efforts that extend from laboratories and analog environments on the ground, through other low-gravity platforms as needed and available, and eventually into extended-duration flight. Although research on the ISS is only one component of this endeavor, the capabilities provided by the ISS are vital to answering many of the most important research questions detailed in this report. The ISS provides a unique platform for research, and past NRC studies have noted the critical importance of its capabilities to support the goal of long-term human exploration in space. These include the ability to perform experiments of extended duration, access to human subjects, the ability to continually revise experiment parameters based on previous results, the flexibility in experimental design provided by human operators, and the availability of sophisticated experimental facilities with significant power and data resources. The ISS is the only existing and available platform of its kind, and it is essential that its presence and dedication to research for the life and physical sciences be fully utilized in the decade ahead.

With the retirement of the space shuttle program in 2011, it will also be important for NASA to foster interactions with the commercial sector, particularly commercial flight providers, in a manner that addresses research needs, with attention to such issues as control of intellectual property, technology transfer, conflicts of interest, and data integrity.

Science Impact on Defining Space Exploration

Implicit in this report are integrative visions for the science advances necessary to underpin and enable revolutionary systems and bold exploration architectures for human space exploration. Impediments to revitalizing the U.S. space exploration agenda include costs, past inabilities to predict costs and schedule, and uncertainties about mission and crew risk. Research community leaders recognize their obligations to address those impediments. The starting point of much of space-related life sciences research is the reduction of risks to missions and crews. Thus, the recommended life sciences research portfolio centers on an integrated scientific pursuit to reduce the health hazards facing space explorers, while also advancing fundamental scientific discoveries. Similarly, revolutionary and architecture-changing systems will be developed not simply by addressing technological barriers, but also by unlocking the unknowns of the fundamental physical behaviors and processes on which the development and operation of advanced space technologies will depend. Thus this report is much more than a catalog of research recommendations; it specifies the scientific resources and toolboxes to define and develop with greater confidence the future of U.S. space exploration and scientific discovery.

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Vision and Voyages (continued)

support for field activities are an important source of support for planetary science in the United States, and should continue. NSF is also the largest federal funding agency for ground-based astronomy in the United States. The ground-based observational facilities supported wholly or in part by NSF are essential to planetary astronomical observations, both in support of active space missions and in studies independent of (or as follow up to) such missions. Their continued support is critical to the advancement of planetary science.

One of the future NSF-funded facilities most important to planetary science is the Large Synoptic Survey Telescope (LSST). The committee encourages the timely completion of LSST, and stresses the importance of its contributions to planetary science once telescope operations begin. Finally, the committee recommends expansion of NSF funding for the support of planetary science in existing laboratories, and the establishment of new laboratories as needs develop.

STAFF NEWS

Lloyd V. Berkner Space Policy Internship

In the upcoming quarter the SSB will be welcoming three new Lloyd V. Berkner Space Policy Interns, Rachael Alexandroff (Princeton Universty), Mahmuda Afrin Badhan (Mount Holyoke University), and Katie Daud (Bloomsburg University).

The goal of the program is to provide promising students with the opportunity to work in the area of civil space-research policy in the nation's capital, under the aegis of the SSB. Additional information on the program can be found at http://sites.nationalacademies.org/SSB/ssb_052239.

***Gabriele Betancourt-Martinez** completed her assignment with the SSB as an Autumn 2010 Lloyd V. Berkner Space Policy Intern in December. Her reflections on her experience with the SSB appear below.*

I never had to wear business casual attire for my previous jobs: closed-toed shoes and jeans were quite enough for astrophysics labs. But one late summer morning saw me clicking down 5th Street NW towards the Keck Center in my high heels and slacks, wondering what was in store for me during my first week as an autumn 2010 Berkner Space Policy intern.

Almost immediately I found myself hunched over my laptop, typing furious notes to keep up with the quick banter of the Heliophysics Decadal Survey Steering Committee Meeting. Next I was writing biographies and hunting down contact information for Heliophysics panel

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(*Staff News* continued from page 18)

nominees. Soon I was scouring the Astronomy Picture of the Day database and the NASA website for images to add to the Planetary Science Decadal Survey, and somewhere in there I was told that I had to call the travel agent to make flight reservations for the COEL meeting in Woods Hole, MA.

Confession: just a year and a half ago, I did not know what space policy was. I had a general notion of science policy as the decision-making at a governmental level that eventually trickles down to individual research projects, and I was attracted to the fact that it blends science with communication, equations with people skills. As I progressed through college and neared graduation, investigating various internships and jobs in the realm of science policy piqued my interest. I itched to get a taste of the field during my year off before grad school; the Berkner internship provided me with much more. Thanks to my experience at the SSB, I got a sense of the excitement, variety, and finally, true meaning of space policy through assignments from different topics (from forward contamination on Mars to nanotechnology funded by the state of Ohio), stages of development (from beginning to post-end), and types of projects (from small studies and large decadals to workshops and committee meetings).

Two projects particularly influenced me. The first, writing a briefing document for the Astro 2010 implementation panel about Euclid, a mission proposed to the European Space Ageny, completely flipped my view of astronomy decadal surveys upside down. Instead of being a final, unquestioned document to be faithfully followed because it results from the input of the entire astronomy community, I realized the decadal could be a living, debatable document, subject to change because of budgetary constraints. The second project, assisting Marcia Smith, the official rapporteur for the SSB workshop in Irvine, CA entitled “Sharing the Adventure with the Public: The Value and Excitement of ‘Grand Questions’ of Space Science and Exploration,” gave me lots of food for thought about scientific communication as both a story and as a science in itself. Together, these assignments helped me realize two things. First, I love having the technical background to be able to convey to non-scientists the full significance and impact of scientific ventures that might be furthered through strong policies. Second, I want to be able to go beyond simply stating the facts--I want to be an effective and compelling communicator of this science.

The verdict? I’ve definitely caught the space policy bug, and am excited to re-enter the field in the future. For now, I will continue to work on the science side as I enter a PhD program in astronomy at the University of Maryland, College Park, this fall. I will also continue to speak without pausing for nearly ten minutes when somebody asks me how I spent my autumn or “So...what does space policy actually mean?”

Thank you to everyone at the SSB for the incredible opportunities I was given during this internship: I learned an incredible amount about the individual topics that space policy envelopes, how the federal government, NRC, and larger policy community work, the amazing city of Washington, D.C., and myself as a young adult exploring and embarking on my life path.

Staff Changes and Additions

Dwayne A. Day joined the Aeronautics and Space Engineering Board as a senior program officer after nearly 6 years with the Space Studies Board. He has served as a staff officer or study director for NRC studies on the assessment of space radiation hazards to astronauts, the future of NASA’s workforce, NASA’s performance in solar system exploration, options for the next New Frontiers mission selection, near Earth objects, and the recently completed planetary decadal survey, among others..

Amanda Thibault joined the Aeronautics and Space Engineering Board as a research associate but will also be working on some Space Studies Board projects. Amanda grew up in Wichita, Kansas, and received her B.S. in atmospheric science from Creighton University in 2008. She went on to study lightning trends in tornadic and non-tornadic supercell thunderstorms at Texas Tech University and participated in both phases of the VORTEX II field project. She graduated from Texas Tech with a M.S. in atmospheric science in August 2010. She is a member of the American Meteorological Society.

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April 6-7 *Space Studies Board*—**Washington, DC**

April 12-14 *Decadal Survey on Solar and Space Physics (Heliophysics): Steering Committee*—**Washington, DC**

April 25 *Organizing Committee on the Effects of Solar Variability on Earth's Climate: A Workshop*—**Washington, DC**

April 27-29 *Committee on the Assessment of NASA's Earth Science Program*—**Washington, DC**

May 25-27 *Decadal Survey on Solar and Space Physics (Heliophysics): Panel on Solar and Heliospheric Physics*—**Boulder, CO**

June 1-3 *Decadal Survey on Solar and Space Physics (Heliophysics): Panel on Atmosphere-Ionosphere -Magnetosphere*—**Woods Hole, MA**

June 7-8 *Committee on Origins and Evolution of Life (COEL)*—**Woods Hole, MA**

June 14-16 *Committee on Planetary Protection Standards for Icy Bodies in the Solar System*—**Irvine, CA**

June 14-16 *Decadal Survey on Solar and Space Physics (Heliophysics): Steering Committee*—**Boulder, CO**

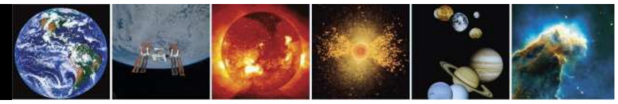
June 20-22 *Decadal Survey on Solar and Space Physics (Heliophysics): Solar Wind-Magnetosphere Interactions*—**Washington, DC**

Future ssb Meetings

November 8-10, 2011, in Irvine, CA

April 4-5, 2012, in Washington, DC
(April 4 is a joint session with the ASEB)

November 5-7, 2012, Irvine, CA



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