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Space Studies Board

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May 29, 2003

Dr. Edward J. Weiler
Associate Administrator for Space Science
Office of Space Science
National Aeronautics and Space Administration
300 E Street, SW
Washington, DC 20546

Dear Dr. Weiler:

In response to your request of January 7, 2003, I am pleased to transmit a review by the National Research Council's Space Studies Board of the draft "2003 Space Science Enterprise Strategy."

The Board concluded that the document provides a thorough, informative summary of scientific objectives, goals, and the associated missions sponsored by the Office of Space Science (OSS). The integration of technology development into the four OSS strategic themes was particularly well done, and the Board was pleased to see plans for reinvigoration of the radioisotope thermoelectric generator (RTG) program. The Board is encouraged by the prospects for new scientific capabilities afforded by advanced nuclear power and propulsion activities and looks forward to seeing plans (including comparative capabilities enabled, schedules, and cost estimates) for their possible implementation.

Notwithstanding those strengths of the draft document, there are several key areas in which the Board recommends improvement and clarification. Highlights of those recommendations follow:

- To represent a true strategy, the document should provide explicit information about resources, criteria for decision making, priorities, mission plans, time lines, and contingency plans.
- The OSS should resolve the substantial variance between the missions and programs included in the document's Sun-Earth Connections section and those recommended as high priorities in the National Research Council (NRC) report *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*.
- Because the science capabilities of the Jupiter Icy Moons Orbiter mission have not been presented in significant detail in the OSS draft document, the Board cannot determine whether the mission accurately reflects the Jupiter-system objectives discussed in the NRC report *New Frontiers in the Solar System: An Integrated Exploration Strategy*.

- Although the draft document does a good job of addressing the roles of research and analysis (R&A) as a part of the overall space science program, attention to theoretical studies as high-priority elements of R&A falls short of what has been recommended in the NRC reports *The Sun to the Earth—and Beyond, New Frontiers in the Solar System, Astronomy and Astrophysics in the New Millennium,* and *Connecting Quarks with the Cosmos.*
- The OSS should present a comprehensive plan that addresses future needs and solutions for providing and sustaining human resources, especially women and minorities, required to accomplish its program. The four NRC surveys mentioned above outline specific training issues and make recommendations that the OSS should employ in a strategy for developing and maintaining a competent, sustainable workforce. In addition to a plan that engages the academic community, the plan should describe a mechanism for follow-up evaluations that would focus on accomplishments and outcomes rather than programs and processes.

The Board appreciates the opportunity to comment on the draft document. Should you have any questions, please do not hesitate to contact me or the Board's director, Joseph Alexander, at 202-334-3477.

Sincerely,

John H. McElroy, Chair
Space Studies Board

Enclosure

Assessment of NASA's Draft 2003 Space Science Enterprise Strategy

In a letter dated January 7, 2003 (Attachment 1), the NASA Associate Administrator for Space Science requested that the Space Studies Board (the Board) of the National Research Council (Attachment 2) review the draft "2003 Space Science Enterprise Strategy,"[1] which NASA provided on February 7, 2003. In carrying out the requested review, the Board focused on the main areas listed in the letter of request:

1. Responsiveness to the NRC's guidance on key science issues and to opportunities provided in recent science strategy reports,
2. Attention to interdisciplinary aspects and overall scientific balance,
3. Identification and exposition of important opportunities for education and public outreach,
4. Integration of technology development with the science program, and
5. General readability and clarity of presentation.

INPUT USED IN PREPARING THE ASSESSMENT

Detailed recommendations from the National Research Council (NRC) decadal surveys and other recent reports provided important input to the Office of Space Science (OSS) planning process. The chairs of the Solar System Exploration Survey Committee, the Solar and Space Physics Survey Committee, the Committee on Astronomy and Astrophysics, and the Committee on the Physics of the Universe attended the OSS strategic planning workshop held in San Diego, California, November 7-8, 2002, and briefed the participants on the results of the decadal strategy reports.[2] The Board director also presented the highlights of *Life in the Universe: An Assessment of U.S. and International Programs in Astrobiology*.[3] This review of the OSS strategy document incorporates inputs received from relevant standing committees of the Board—the Committee on Solar and Space Physics (CSSP), the Committee on Planetary and Lunar Exploration (COMPLEX), the Committee on the Origins and Evolution of Life (COEL), and the Committee on Astronomy and Astrophysics (CAA). The Board also had an opportunity to discuss the strategy document with NASA staff at the Space Studies Board meeting on March 24, 2003, when Ms. Lisa May of the OSS provided a briefing on the draft document. The Board then reviewed and discussed the document, along with the discipline committees' responses, and assembled this consensus assessment.

The Board has organized its assessment into six categories in keeping with the charge: (1) general observations, (2) responsiveness to the NRC's guidance on key science issues and opportunities, (3) interdisciplinary aspects and scientific balance, (4) integration of technology development with the science program, (5) opportunities for education and outreach, and (6) readability and clarity of presentation. The Board has highlighted in this short report what it believes to be the salient points relevant to these areas, which are discussed below.[4]

GENERAL OBSERVATIONS

The Board believes that the draft "2003 Space Science Enterprise Strategy" document provides an informative survey of OSS scientific objectives, goals, and associated missions. It identifies NASA's science objectives for each space science theme area and notes key missions and programs that the OSS has identified to address objectives. The document also discusses some resource requirements and external relationships to other federal agencies and international partners. The Board commends the OSS for incorporating into the 2003 draft document suggestions that the Board made for improving the 2000 plan:[5] The document provides a clear presentation of how astrobiology fits into the overall plan and does a good job of connecting the technology and future missions in the OSS theme areas.

However, the Board does not find the draft document to be a true strategy. As the Board noted in its prior review of the draft 2000 strategic plan, more explicit information about resources, criteria for decision making, priorities, mission plans, time lines, and contingencies could have transformed this document from a "handbook for what we intend to do and why" into a strategy.[6] While some elements of a strategy are included, they are dispersed throughout the draft document and do not convey an integrated strategic approach to the OSS program. The Board is also concerned that the document, in some areas, overlooks critical strategic guidance prepared by the scientific community in NRC science strategy reports that were requested by NASA.

RESPONSIVENESS TO THE NRC'S GUIDANCE ON KEY SCIENCE ISSUES AND OPPORTUNITIES

In assessing the draft document, the Board paid particular attention to the extent to which the document reflects the guidance and priorities provided by the NRC to the OSS on space science issues. The Board is pleased that the OSS document captures some of the core elements of the solar system exploration (SSE) survey, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, and the astronomy and astrophysics (AA) survey report, *Astronomy and Astrophysics in the New Millennium*. At the same time, the Board found that the document neglects the priorities recommended in the solar and space physics (SSP) survey, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*. In addition, the Board believes that the OSS draft document could be clarified and strengthened by making explicit the process used to create the OSS program and the priorities for the program it presents.

The Board is concerned that the draft OSS document does not integrate the results of some NRC surveys into certain theme programs, the most obvious being the Sun-Earth Connection (SEC) section of the document. The goals presented in the SEC section do not refer to the SSP survey, nor does the document provide a connection between the missions included in the SEC theme and those identified as high priorities in the SSP survey. For example, the SEC theme section describes two future Solar Terrestrial Probe (STP) missions, one that will "focus on reconnection and micro-scale processes in the solar atmosphere using both high-resolution spectroscopy and imaging"[7] (referred to in that section as the Reconnection and Microscale [RAM] probe) and one that will "measure the polar regions of the Sun and the heliosphere from high solar latitude"[8] (referred to as Telemachus). Although the NASA SEC roadmap team recommended both, the SSP survey placed RAM on the deferred list and did not endorse Telemachus at any level of priority. If the OSS pursues these two missions, they would displace the STP missions—the Multispacecraft Heliospheric Mission (MSM), Solar Wind Sentinels (SWS), and the Stereo Magnetospheric Imager (SMI) [9]—that received high priorities in the SSP survey. As a result, the only remaining high-priority STPs from the SSP survey to be included in the OSS program would be the currently approved missions, Geospace Electrodynamic Connections (GEC) and Magnetospheric Constellation (Magcon). The OSS should address the mismatch between the missions included in the SEC section of the draft document and those identified as high priorities in the NRC's SSP survey report.

The Board also noted that the draft document made no mention of the important opportunity to transition the research and instrumentation devoted to the scientific study of solar and space physics into applications and operations for space weather.[10] The nation's investment in solar and space physics research can provide important dividends for society, and the OSS should include in the document its plans for transitioning SEC research and instruments into applications and operations.[11]

In another example, while the SSP survey independently identified a dedicated Jupiter Polar Mission (JPM) as its third priority,[12] the Board did not find in the draft document any mention of JPM and noticed in the SEC section (at pages 36-37) only passing mention of the SSE survey's Jupiter Polar Orbiter with Probes (JPOP) mission. It also found little mention of the relationship between these two missions (JPOP and JPM) and possible plans to combine them. The document should acknowledge that the SSP community has identified a JPM mission as a high priority and that opportunities exist to work with NASA's SSE program.

In the Structure and Evolution of the Universe (SEU) theme, the Board applauds the OSS for initiating the Einstein Probes, which relate to priorities identified in the NRC report *Connecting Quarks with the Cosmos*. However, the SEU section could be strengthened by presenting a more explicit connection to the *Connecting Quarks with the Cosmos* report, which provides a new scientific treatment of the foundation of the SEU theme.

Regarding new initiatives, the Board commends the OSS for initiating the New Frontiers Mission Line, an effort that corresponds directly with some of the priorities recommended in the NRC report *New Frontiers in the Solar System: An Integrated Exploration Strategy*. However, the OSS draft document could be strengthened with the addition of clear statements on the scientific rationale and objectives for the mission lines. The Board also applauds the OSS on reinvigorating the radioisotope thermoelectric generator (RTG) program under Project Prometheus and the prospects for new scientific capabilities afforded by the Prometheus advanced power and propulsion activities—activities identified in the SSE survey as key to enabling the future exploration of the outer planets, including the long-term operation of landers.[13] However, the Board is concerned with the appearance of a major new mission—Jupiter Icy Moons Orbiter

(JIMO)—and the perception of this mission as a priority of the NRC's SSE survey. According to the presentation by the chair of NASA's Space Science Advisory Committee to the NASA Advisory Council on March 20, 2003, "This mission [JIMO] responds to the National Academy of Sciences' recommendation that a Europa orbiter mission be the number one priority for a flagship mission in Solar System exploration."[14] Yet the science objectives of JIMO, as presented in the draft document, do not map clearly to the SSE survey's Jupiter-system objectives. Furthermore, the Board has not yet seen a scientific review of the OSS's proposed implementation of JIMO and thus has no basis on which to assess whether JIMO can achieve the science objectives recommended for the Europa Geophysical Explorer (EGE) mission.

The Board understands that JIMO is the OSS's response to an emerging budgetary and policy window of opportunity. Nevertheless it is concerned that, under the OSS draft document, the near- to mid-term exploration of Europa will become hostage to the successful implementation of an uncertain and expensive advanced technology development program. Given the uncertainties in mission design and cost, as well as the many other outer solar system missions that might utilize nuclear reactor technology to address important scientific priorities, NASA's best near-term strategy may be to consider JIMO as one of several reference missions for establishing the requirements and guiding the development of advanced power and propulsion technologies until such time as JIMO's responsiveness to the scientific priorities for the exploration of Europa and the other Galilean satellites can be assessed.

INTERDISCIPLINARY ASPECTS AND SCIENTIFIC BALANCE

The draft document discusses the scientific balance across themes and within theme areas. Section 4.1, Program Elements, describes the array of components that constitute the OSS program, including flight missions, research and analysis (R&A), sounding rocket and balloon programs, advanced detector and instrument systems, ground-based programs, laboratory measurements, supporting technologies, and data management. The draft also refers to interdisciplinary scientific aspects of the OSS program in individual theme sections and in the discussion on astrobiology, which is the most visible interdisciplinary activity in the program. Overall, the document offers a balanced description of science within and among themes. In the interest of strengthening the OSS program, the Board identifies several opportunities for enhancing the scientific balance among these elements and for highlighting additional interdisciplinary activities within the OSS portfolio.

Balance Across Themes

The Board appreciates NASA's efforts to include the search for life as part of its NASA Vision and Mission, Section 2, page 6, but believes the emphasis is overstated under Goal 5, "Explore the solar system and the Universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere" and in the many repeated references to the search for life, sometimes without substance, throughout the document. This overemphasis minimizes science that is not focused on life and sometimes reduces scientific credibility. To cite two examples, first the SEC theme refers to a link between biospheres and energy from the Sun but does not elaborate on how SEC will advance the agency strategic goal, "Understand the origin and evolution of life and search for evidence of life elsewhere" as presented on page 9. To retain a credible linkage between SEC and biospheric processes, examples should be provided. The document could discuss potential ultraviolet effects on atmospheric and ocean chemistry in the form of photolysis reactions that produce oxygen radicals and oxidized forms of sulfur. These reactions could have an important influence on life even in the absence of photosynthesis. Second, studies are under way to learn which "biosignatures"—identifiable spectral features in a planet's reflected light—might reveal past or present life on a planet. However, to take advantage of this new information it will be necessary to develop space telescopes of unprecedented size and sophistication.

The Board also believes that additional attention to identifying science and technology connections across themes, and more generally across the nation's astronomical and Earth-oriented research, would strengthen the OSS draft document. For example, as pointed out in the NRC report *Life in the Universe*, there are linkages among Solar System Exploration, Mars Exploration, and Astrobiology as well as between Astronomical Search for Origins and Astrobiology,[15] but none of those connections are explicit in the draft document and others are not mentioned.

The Board did not find any mention in the document of the potential ties between the James Webb Space Telescope (JWST), which will explore the formation and evolution of planetary systems, and the Near-Earth Objects program or with other studies of the outer solar system. Another opportunity for strengthening the connection among theme discipline areas would be to describe the overlaps between studies of dark matter, neutrino masses, astrometry, and gravitational wave phenomena through the Wilkinson Microwave Anisotropy Probe (WMAP), the Solar Heliospheric Observatory (SOHO), and neutrino observatories. The OSS draft document should also provide a clearer connection between terrestrial climate, which is mentioned as a key area for the Living With a Star (LWS) program, and how this research is implemented within the broader NASA (Earth Science Enterprise) and national (e.g., Climate Change Research Initiative) contexts.[16]

The document generally achieves a consistent level of detail within the various theme sections, although the SEU theme was overly specific in its discussion of missions and mission details (box on page 46). In addition, one of the most profound astrophysical discoveries of the last decade was evidence for dark energy and the accelerated expansion of the universe, which are not yet explained in terms of fundamental physics and are noted as leading questions in the *Connecting Quarks with the Cosmos* report.[17] This discovery is so important that the Board believes it deserves mention in the list of "grand questions" in the opening paragraphs of the SEU theme. The WMAP's contribution to the exploration of dark energy could also be noted.

The role of astrobiology is presented in the document in the box "Astrobiology and the Search for Life" (following page 9). However, the Board believes that the language in the box generally underestimates the complexity and difficulty of "understanding" how life originated and evolved. At best, scientists can "explore" or "investigate" the origins and evolution of life; claiming the goal of "determining or understanding" promises much more than basic science is likely to deliver.

The Board also believes that integration of astrobiology into the document can be improved by clarifying the definition of "astrobiology" and its value as a unifying theme. The Exobiology R&A program and the NASA Astrobiology Institute support unique programs to investigate the transition from simple organic compounds to the simplest forms of living matter. A better understanding of how life emerges from prebiotic chemistry is essential for knowing what to look for as we search for other environments in which life may have originated. Earth-based projects have the power to inform us about how to interpret the organic chemistry of Titan and of cometary material in an effort to understand the starting materials available on early Earth. This research provides an example of balance across themes, but the Board cautions that knowing everything about the sources and kinds of organic material in the universe is not equivalent to achieving a full understanding about the origin of life, which may have occurred independently more than once. Another example already highlighted in the document, under "Objective: Determine the characteristics of the solar system that led to the origin of life" (page 26), is the Astrobiology program's study of life in extreme environments. Discoveries of eukaryotic and prokaryotic extremophiles "coupled with a fuller understanding of the range of possible conditions on other planetary bodies, have significantly expanded our view of the number of environments within our solar system that might be, or might have been, conducive to life."[18] The Board suggests that such discoveries warrant mention in the list of major accomplishments and offer a wonderful example of how the OSS draft document should use cross-cutting themes, supported by the OSS, to illustrate the benefits of interdisciplinary research.

Balance Within Themes

The Board has often urged NASA to foster a balance between R&A, data analysis (DA) programs, and spacecraft missions,[19] and the Board appreciates the OSS's reference to the functions of research and analysis programs, as noted in the 1998 NRC report *Supporting Research and Data Analysis in NASA's Science Programs: Engines for Innovation and Synthesis.*[20] The Board recognizes that fostering and sustaining an appropriate mix among the program elements requires continuous adjustments, and the Board notes specific opportunities to improve the balance. Section 4.1.2 (Scientific Research and Analysis) of the OSS document cites the synergy between R&A, DA, and missions, but it emphasizes the development and flight-testing of advanced detector and instrument systems for particular missions and provides scant attention to ground-based research. Acknowledging the integral importance of laboratory-based and theory-based programs or DA programs for major themes in the OSS document would help establish a better balance between mission programs and their scientific underpinnings and results.

The decadal surveys recommended that significant theory, modeling, and other components of research and data analysis activities are necessary for a vital science program. For example, the AA survey recommended that 2 to 3 percent of the cost of flight projects be devoted to theory.[21] The SSE survey recommended "an increase over the decade in the funding for fundamental Research and Analysis programs at a rate above inflation to a level that is consistent with the augmented number of missions, amount of data, and diversity of objects studied."[22] Further, the SSP survey recommended several "Vitality Programs" that address theory, computation, and data analysis,[23] and the *Connecting Quarks with the Cosmos* report noted that “it is essential that an interagency initiative on the physics of the universe maintain a balanced approach that provides opportunities for investigator-initiated experiments, detector R&D, theoretical work, and computational efforts that address the committee’s scientific questions.”[24] If the recommended theory elements are not included in the document, the OSS should discuss the alternatives to or consequences of this decision. As currently structured, the minimal description of ground-based research creates an imbalance with the focus on spaceflight missions.

Another important aspect of balance within theme areas is the ability of researchers to interpret data from multiple spacecraft (box, page 14). The recognition of the importance of R&A by the science community led to arguments for the development of the National Virtual Observatory (NVO) and the parallel Virtual Solar Observatory (VSO). From the perspective of planning future observations, however, the OSS document should address observations from multiple space and ground-based observatories and how researchers can access such data. For example, the 2001 NRC report *Assessment of the Usefulness and Availability of NASA’s Earth and Space Science Mission Data* states:

> The successful implementation of methods for making complex queries of multiple databases is likely to be technically challenging and costly. The level of appropriate investment by NASA in federated data systems should be evaluated at regular intervals and should be based on 1) the importance of the scientific questions that can be addressed through the simultaneous mining of multiple databases, 2) demonstrated scientific return from past investments, and 3) the readiness of computational and communications technology to support data mining.[25]

Interagency and International Participation

The OSS document discusses the participation of interagency and international partners in the OSS program (pages 11, 51, and 64-70). The OSS and NASA collaborate with a host of U.S. federal agencies, nations, and organizations, all of which the document recognizes as providing valuable contributions to the OSS program. There are, however, functions within these partnerships that the Board did not see mentioned in the document. In interagency partnerships, for instance, the Board saw no mention of the cooperation between NASA and the National Science Foundation (NSF) on the Large Synoptic Survey Telescope (LSST), which was recommended by the SSE survey and addressed by the National Astronomy and Astrophysics Advisory Committee (NAAAC).[26] Also, in the description of NASA’s cooperation with the Department of Commerce, the Board did not see any reference to the many areas for NASA-NOAA collaboration on research in solar and space physics in support of space weather applications, as recommended in the SSP survey.[27]

Considering the importance of international cooperation in the OSS’s history, the draft document could be improved by providing additional context as to how the OSS program, especially the flight missions, relate to non-U.S. programs. One sees mention of foreign-led missions such as Solar-B and BepiColumbo; however, discussion on the gaps, overlaps, and synergies of the OSS program vis-à-vis major non-U.S. space science programs would provide a broader perspective.

The document also mentions the operational aspects of international cooperation and describes NASA's interactions with the Department of State on matters related to international agreements, interagency reviews, and the International Traffic in Arms Regulations (ITAR). The ITAR has raised serious concerns about impediments to international cooperation[28] such as problems some foreign scientists encounter in gaining access to critical discussions on international missions in which they are involved.[29] Many scientists also face significant difficulties in trying to obtain visas to the United States. The Board is aware of NASA's ongoing efforts to address the impediments to cooperation under ITAR requirements and believes that reference to such past and planned activities would address a critical aspect of the OSS's ability to facilitate international cooperation among scientists and to conduct joint missions with foreign partners. It is also important that the OSS recognize and address the problems foreign scientists face in seeking visas to the United States.

INTEGRATION OF TECHNOLOGY DEVELOPMENT WITH THE SCIENCE PROGRAM

The Board believes that the linkages between technology development and science objectives in the draft OSS document are sound and well done. The individual discussions of technology development in some theme areas, however, could be strengthened. For example, some important new technologies and hardware development capabilities are omitted,[30] and further details on descriptions of some processes associated with technology development and time lines for those developments would strengthen the document.[31] In addition, the technological needs of astrobiology are not discussed in any depth and are only highlighted on page 53. Many of the technologies referenced have no specific relevance to astrobiology, but other critical technologies are not articulated in the document. For example, the document does not mention the miniaturization of analytical instruments ("labs on a chip") for the analysis of organic compounds, including their chirality and isotopic composition, which is essential to the search for life elsewhere in the solar system. The search for life is a primary driver in the OSS document. A strategy for the development of technology for observing biosignatures and life detection should be articulated. For sample return missions, details about capabilities, required technologies associated with planetary protection, and construction time lines are not provided for curation and handling facilities.

OPPORTUNITIES FOR EDUCATION AND PUBLIC OUTREACH

Representatives of the OSS reported during the Board's meeting on March 24, 2003, that the Education and Public Outreach (EPO) sections of the OSS draft document will be rewritten. The Board agrees that the EPO sections can be improved significantly and offers suggestions for the next version. For example, the connection between the actions described on page 20 of the EPO section and the bullets on page 21 could be made clearer in order to improve the overall linkage to the EPO objectives on page 9. In addition, several aspects of the content could be improved,[32] and discussions of past achievements could be balanced with clearly articulated future goals. The OSS may also wish to consider how the text might be revised to highlight the unique capabilities of NASA to generate the excitement and enthusiasm necessary for a successful EPO program and to attract the audience it is intending to reach.

In the broader context of education and public outreach, the Board believes that the OSS should prepare a comprehensive, forward-looking plan that defines the level of human resources required to accomplish the OSS program; how education and training efforts, including the recruitment and training of women and minorities, will meet those demands; and the resources required to retain this skilled labor force. The OSS document properly expresses concern about human resources, namely the need to recruit, train, and retain the scientific and technical talent needed to carry out NASA's mission in the coming decades. The document discusses these resource issues specifically in the context of staffing at NASA Centers, but NASA would do well to consider this problem beyond its own staffing requirements. The success of NASA's partnerships with both industry and academia hinges on the ability to train the next generation of space scientists and engineers.

NASA should articulate a strategy for leveraging its funding for academic training in a way that encourages universities to develop interdisciplinary programs. The NASA Specialized Center for Research and Training (NSCORT) programs at the Scripps Institution of Oceanography and the Rensselaer Polytechnic Institute, as well as the Astrobiology programs at Arizona State University, the University of Washington, and the University of Colorado, are examples of successful programs to consider for other disciplines. The SSP survey also makes specific recommendations to create research opportunities in solar and space physics for undergraduate and graduate education. For example, the survey recommends that NSF and NASA establish "bridged positions" to support faculty positions in solar and space physics and that NASA support undergraduate research in solar and space physics through grant programs.[33]

Efforts to address the future needs for scientific and technical human resources require a long-term commitment beyond awards associated with individual research and analysis grants or NRC postdoctoral fellows. A follow-up evaluation mechanism would be required to appraise the effectiveness of these human resources processes and their impact on the future of the OSS program and the space science community. This evaluation mechanism should be capable of differentiating on the basis of effectiveness (outcome) rather than on intentions (programs, process).

READABILITY AND CLARITY OF PRESENTATION

The OSS draft document necessarily covers an enormous range of topics, and to do so in a way that can communicate effectively to a wide range of audiences including scientists and policymakers is a challenge. The Board believes that revisions to emphasize use of the active voice and a parallel structure in the themes will be helpful. Furthermore, short executive summaries at the beginning of each major chapter will improve the document as a communication tool for multiple audiences.

CONCLUDING REMARKS

The Board found that the strategy document in its current form is an informative guide to the interface between the OSS program and the agency's vision and goals, to the OSS's policies, and to science theme areas and their relationship to technology development. However, the document does not include explicit information about many of the elements necessary for strategic planning (e.g., time lines, resources, plans and priorities for mission programs, and contingency plans).

In assessing the document's responsiveness to previous NRC advice, in particular the survey reports,[34] the Board found the response uneven. For some themes, such as the Astronomical Search for Origins and Solar System Exploration, the linkage between proposed programs and NRC recommendations was clear, although the Board registers serious concern about the uncertain connection between the NRC's advice on a Europa Geophysical Explorer and the proposed Jupiter Icy Moons Orbiter. Other theme sections, especially SEC, do not reflect the integration of NRC advice into the proposed program. In addition, the Board found that while the document reflected the importance of research and data analysis as part of the science program, demonstrating the balance necessary for a healthy program that includes theory and laboratory-based research as well as flight programs would improve and strengthen the document.

Education and public outreach are important objectives for NASA and the OSS, and while some accomplishments are noted in the document, the Board found opportunities for a clearer and more engaging presentation of the objectives, goals, integration with theme-area science, and capabilities required for achieving success.

RECOMMENDATIONS

Responsiveness to NRC Advice

The Office of Space Science (OSS) should strengthen the "Principles and Policies" and the "Resources Requirements" sections of its strategy document to include explicit and complete information about resources, criteria for decision making, priorities, mission plans, time lines, and contingency plans.

The OSS should better reflect the recommendations of the SSP survey and the Connecting Quarks with the Cosmos *report in its document.*

The OSS should consider JIMO as one of several reference missions for establishing the requirements and guiding the development of advanced power and propulsion technologies.

Interdisciplinary and Science Balance

The OSS should strengthen the interdisciplinary aspects of its document. Appropriate modifications could include discussing the linkages between the Sun-Earth Connection and Earth science and making the scientific relationships among the OSS themes more explicit.

Education and Public Outreach

The OSS should sharpen the education and public outreach (EPO) sections in its document. The four NRC surveys outline specific training issues and make recommendations that the OSS should adopt. The OSS education sections should comprehensively address future needs and solutions for providing and sustaining the human resources required to accomplish the OSS program. Key elements of such a forward looking plan should define (1) the size and level of the skilled labor force required by industry, academia, and NASA, (2) how education and training efforts, including the recruitment, training and retention of women and minorities, will meet those demands, (3) the resources required to retain this skilled labor force, and (4) a mechanism for follow-up evaluations that would focus on accomplishments and outcomes rather than programs and processes.

Clarity and Readability

The OSS should revise the document to emphasize the use of the active voice and a parallel structure in the themes. The inclusion of short executive summaries at the beginning of each major chapter will improve the document as a communication tool for multiple audiences.

NOTES

[1] National Aeronautics and Space Administration, Space Science Enterprise, "2003 Space Science Enterprise Strategy," Draft 2, February 6, 2003, Review Draft.

[2] Space Studies Board, National Research Council, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, National Academies Press, Washington, D.C., 2003—in press; Space Studies Board, National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, National Academies Press, Washington, D.C., 2003—in press. Board on Physics and Astronomy, Space Studies Board, *Astronomy and Astrophysics in the New Millennium*, National Academy Press, Washington, D.C., 2001; Board on Physics and Astronomy, National Research Council, *Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century*, National Academies Press, Washington, D.C., 2003.

[3] Senior managers from the Office of Space Science (OSS) subsequently briefed the Committee on Planetary and Lunar Exploration and the Committee on the Origins and Evolution of Life on related aspects of the strategic planning process.

[4] This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: John Baross, University of Washington, Joseph A. Burns, Cornell University, John Huchra, Harvard-Smithsonian Center for Astrophysics, Louis J. Lanzerotti, Lucent Technologies, Norman H. Sleep, Stanford University, and Alar Toomre, Massachusetts Institute of Technology.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Wesley T. Huntress, Jr., Carnegie Institution of Washington, Geophysical Laboratory. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

[5] See Letter from Dr. Claude R. Canizares, Space Studies Board Chair, to Dr. Edward J. Weiler, NASA Associate Administrator for Space Science, "A Review of NASA's Office of Space Science Strategic Plan 2000," May 26, 2000.

[6] A recent NRC review of the Administration's Climate Change Science Program Strategic Plan listed the following elements that should be included in any strategic plan:

- A clear and ambitious guiding vision of the desired outcome;
- A set of unambiguous and executable goals that address the vision and broadly describe what the program is designed to accomplish;
- A clear timetable for accomplishing the goals and criteria for measuring progress;
- An assessment of whether existing programs are capable of meeting these goals, thereby identifying required program changes and unmet needs that must be addressed in subsequent implementation planning;
- A set of explicit prioritization criteria to facilitate program design and resource allocation; and
- A management plan that provides mechanisms for ensuring that the goals are met and for coordinating, integrating, and balancing individual program elements and participating agencies.

See National Research Council, *Planning Climate and Global Change Research: A Review of the Draft U.S. Climate Change Science Program Strategic Plan*, National Academies Press, Washington, D.C., 2003, pp. 1-5.

[7] National Aeronautics and Space Administration, Office of Space Science, "2003 Space Science Enterprise Strategy," Draft 2, February 6, 2003, p. 37.

[8] National Aeronautics and Space Administration, Office of Space Science, "2003 Space Science Enterprise Strategy," Draft 2, February 6, 2003, p. 37.

[9] National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics, Executive Summary*, National Academies Press, Washington, D.C., 2002, p. 6.

[10] See National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, Chapter 5 "Solar and Space Environment Effects on Technology and Society," prepublication copy, National Academies Press, Washington, D.C., 2002. For more information on the transition of research to operations, see also National Research Council, *Satellite Observations of the Earth's Environment—Accelerating the Transition of Research to Operations*, prepublication copy, National Academies Press, Washington, D.C., 2003.

[11] National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics,* Chapter 5, "Solar and Space Environment Effects on Technology and Society," prepublication copy, National Academies Press, Washington, D.C., 2002.

[12] National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics, Executive Summary*, National Academies Press, Washington, D.C., 2002, p. 6.

[13] National Research Council, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, prepublication copy, National Academies Press, Washington, D.C., 2002, p. 222.

[14] Presentation on Space Science by Dr. Andrew Christensen to the NASA Advisory Council, March 20, 2003.

[15] See National Research Council, *Life in the Universe: An Assessment of U.S. and International Programs in Astrobiology*, National Academies Press, Washington, D.C., 2003, p. 36.

The report recommends that:

"NASA should foster more extensive links between the Astrobiology and the Astronomical Search for Origins programs. In the short term, these linkages require cooperation between the NAI and major astronomical institutions, such as the Space Telescope Science Institute and universities with extensive astronomical programs, in creating joint workshops and focus groups to educate researchers in both areas and to initiate more extensive and novel research endeavors."

[16] For more information on national climate change initiatives and programs, see *Our Changing Planet: The Fiscal Year 2003 U.S. Global Change Research Program and Climate Change Research Initiative*, A Report of the Climate Change Research Program and the Subcommittee on Global Change Research. A Supplement to the President's Fiscal Year 2003 Budget. Available online at <http://www.usgcrp.gov/usgcrp/Library/ocp2003.pdf>. Accessed on April 10, 2003. Also see the NRC report *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics,* prepublication copy, pp. 2-6 and 5-6, for discussion on the Coupling Complexity Research Initiative, a space physics program proposed to handle nonlinearity, multiprocess coupling, and multiscale and multiregional feedback, which are useful for integrating data on the near-Earth space domain, including the solar wind, magnetosphere, radiation belts, ionosphere, and thermosphere.

[17] See National Research Council, *Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century*, National Academies Press, Washington, D.C., 2003, p. 2.

[18] National Aeronautics and Space Administration, Office of Space Science, "2003 Space Science Enterprise Strategy," Draft 2, February 6, 2003, Review Draft, p. 26.

[19] See, for example, Space Studies Board, National Research Council, *Supporting Research and Data Analysis in NASA's Science Programs: Engines for Innovation and Synthesis*, National Academy Press, Washington, D.C., 1998.

[20] National Research Council, *Supporting Research and Data Analysis in NASA's Science Programs: Engines for Innovation and Synthesis*, National Academy Press, Washington, D.C., 1988, pp. 3-4, 63-64.

[21] Although theory is mentioned in passing in the section on R&A in the OSS strategy document, it is not given the same prominence as, for example, laboratory astrophysics or suborbital programs. The Astronomy and Astrophysics Survey Committee's decadal report recommended significant changes in NASA support for theory and modeling. The specific NRC recommendations were that (i) 2 to 3 percent of the cost of flight projects be devoted to theory (for a $2 billion program like the James Webb Space Telescope, this would mean $40 million to $60 million in theory support over a ~10-year period); (ii) a National Astrophysics Theory postdoctoral program be established (10 3-year postdoctoral positions each year, or ~$2.25 million per year); and (iii) the Astrophysics Theory Program be significantly augmented (+$3 million per year). The NRC committee believed strongly that the ensuing theoretical activities would materially improve NASA's return on investments in space. See National Research Council, *Astronomy and Astrophysics in the New Millennium*, National Academy Press, Washington, D.C., 2001, pp. 132-135.

[22] National Research Council, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, prepublication copy, National Academies Press, Washington, D.C., 2002, p. 297.

The report states the following on research and analysis programs:

"It is largely through the work supported by research and analysis (R&A) programs within the Office of Space Science that the data returned by flight missions is converted into new understanding, advancing the boundaries of what is known. The research supported by these programs also creates the knowledge necessary to plan the scientific scope of future missions. Covered under this line item are basic theory, modeling studies, laboratory experiments, ground-based observations, long-term data analysis, and comparative investigations. The funds distributed by these programs support investigators at academic institutions, federal laboratories, nonprofit organizations, and industrial corporations. R&A furnishes the context in which the results from missions can be correctly interpreted. Furthermore, active R&A programs are a prime breeding ground for principal investigators and team members of forthcoming flight missions.

"Healthy R&A programs are of paramount importance and a necessary precondition for effective missions. This conclusion has been stated repeatedly and forcefully before, . . . and is shared by NASA's Office of Space Science itself. The three R&A "clusters" (i.e., Origin and Evolution of Solar System Bodies, Planetary Systems Science, and Astrobiology and Planetary Instrumentation) most closely associated with solar system exploration were supported at the level of $96 million in FY 1999. This level is now expected to rise at about 3 percent per year above the underlying inflation rate for several years. This proposed rise is included in the President's FY 2003 budget. Nevertheless, serious problems remain with these programs. The proposal oversubscription is typically 3:1, which—we believe—is too high since then new proposals can rarely be funded. Also, the availability of authorized funds is often subject to delays and, in recent times, the value of the median grant has fallen to below $50,000 per annum, a level generally too small to support a researcher or a tuition-paid graduate student . . . .

"We agree with the Space Studies Board recommendation that NASA should routinely examine the size and number of grants to ensure that the grant sizes are adequate to achieve the proposed research . . . . We support the budgetary proposals that would steadily grow solar system exploration R&A programs. **The SSE Survey recommends an increase over the decade in the funding for fundamental Research and Analysis programs at a rate above inflation to a level that is consistent with the augmented number of missions, amount of data, and diversity of objects studied.**

"R&A programs are not presently—and, in our opinion, should not be—tied to specific mission goals. Thus, individual research projects do not correspond to particular missions. Nevertheless, as the breadth and depth of the space exploration missions increase, the R&A programs should expand and be redirected correspondingly. Therefore, in a broadest sense, R&A programs must be responsive to the current mission opportunities even if they are not rigidly coupled to them.

"Previous NRC studies have shown that after a serious decline in the early- to mid-1990s . . . the overall funding for R&A programs in NASA's Office of Space Science has, in recent years, climbed to approximately 20 percent of the overall flight mission budget . . . . Figures supplied by NASA's Solar System Exploration program show that the corresponding value for planetary activities is closer to 25 percent and is projected to stay at about this level for the next several years. The SSE Survey believes that this is an appropriate allocation of resources.

"Finally, **to maintain and enhance the scientific productivity of the entire solar system exploration enterprise and to ensure the creation of new intellectual capital of the highest quality in the field, the SSE Survey recommends the initiation of a program of Planetary Fellows, i.e., a postdoctoral program analogous to the Hubble and Chandra fellowships which have done so much to nurture the next generation of astronomers and astrophysicists.** The purpose of this program would be to allow the brightest young investigators the opportunity to develop independent research programs during their most creative years. These would be prestigious, multiyear fellowships, based solely on highly competitive research proposals and tenable at any U.S. institution."

[23] National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, prepublication copy, National Academies Press, Washington, D.C., 2002, pp. 2-5, 2-6.

The report states:

"Over the past decade and more, theory and modeling have played an increasingly important role both in defining satellite missions and other programs and in interpreting data through the development of new physical models. The enhanced role of theory and modeling is a consequence of the development of powerful computational tools that have facilitated the exploration of the dynamics of complex nonlinear plasma systems at both large MHD spatial scales and kinetic microscales. Before the advent of these tools it was not possible to study these dynamical processes through analytic techniques alone.

"In the coming decade, the deployment of clusters of satellites and large arrays of ground-based instruments will provide a wealth of data over a very broad range of spatial scales. Theory and computational models will play a central role, hand in hand with data analysis, in integrating these data into first-principles models of plasma behavior. Examples of the catalyzing influence of theory and computation on the interpretation of data from observational assets are many. A case in point is recent research in the area of magnetic reconnection, where new theoretical developments have spurred the successful search for signatures of kinetic reconnection in satellite data.

"Theory and modeling activities have further importance in the application of the results from solar and space physics to allied fields such as astrophysics and fusion energy sciences. The solar-heliosphere system is the space physicist's laboratory wherein a wide variety of plasma processes, parameters, and boundary conditions are encountered (cf. Chapter 4). Many of these phenomena can be sampled directly and the results applied to systems where direct measurements are either very difficult or altogether infeasible. The identification of the critical dimensionless parameters controlling plasma dynamics through analysis combined with state-of-the-art computation is central to the successful extrapolation to differing environments, where absolute parameters may be very different from those in the solar-heliosphere system.

"NASA's Sun-Earth Connection Theory program has been very successful in focusing critical-mass theory and modeling efforts on specific topics in space physics. The NSF has long encouraged and supported theoretical and modeling investigators through its grants program. Theoretical work provides the community with state-of-the-art computational models that are developed and utilized with support from all the funding agencies. This theoretical understanding is used extensively for interpreting individual measurements as well as for developing physics-based data assimilation procedures for diverse but coupled parameters.

"In view of the strongly coupled nature of the solar-heliosphere system and the complementary objectives of the solar and space physics programs of the different federal agencies, two interagency initiatives are being proposed by the committee. One of these—the Virtual Sun—will incorporate a systems-oriented approach to theory, modeling, and simulation that will ultimately provide continuous models from the solar interior to the outer heliosphere. . . . The Virtual Sun will be developed in a modular fashion by focused attacks on various physical components of the solar-heliosphere system and on cross-cutting physical problems. The solar dynamo and three-dimensional reconnection are areas ripe for near-term concentration because they complement the planned ground- and space-based measurement programs.

"The Coupling Complexity Research Initiative . . . will address multiprocess coupling, nonlinearity, and multiscale and multiregional feedback in space physics. The program advocates both the development of coupled global models and the synergistic investigation of well-chosen, distinct theoretical problems. For major advances to be made in understanding coupling complexity in space physics, sophisticated computational tools, fundamental theoretical analysis, and state-of-the-art data analysis must all be integrated under a single umbrella program. Again, this initiative is motivated by the anticipated ground- and space-based measurements that will provide spatially distributed data that must be incorporated into a single understanding of the physical processes at work in different volumes of geospace."

[24] National Research Council, *Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century*, National Academies Press, Washington, D.C., 2003, p. 172.

[25] See National Research Council, *Assessment of the Usefulness and Availability of NASA's Earth and Space Science Mission Data*, National Academy Press, Washington, D.C., 2001, pp. 7, 76.

[26] NASA town meeting presentation at the American Astronomical Society, January 8, 2003.

[27] National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, prepublication copy, National Academies Press, Washington, D.C., 2002, p. ES-12.

[28] National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, prepublication copy, National Academies Press, Washington, D.C., 2002, pp. 7-9 and 7-10.

[29] Letter from the Association of American Universities and the Council on Governmental Relations to Dr. Gerald Epstein, Assistant Director for National Security, Office of Science and Technology Policy, July 17, 2000; Letter from the Association of American Universities and the Council on Governmental Relations to the Honorable John H. Marburger, Director, Office of Science and Technology Policy, July 11, 2002; Statement by Bruce Alberts, President, National Academy of Sciences, Wm. A. Wulf, President, National Academy of Engineering, and Harvey Fineberg, President, Institute of Medicine, "Current Visa Restrictions Interfere with U.S. Science and Engineering Contributions to Important National Needs," December 13, 2002.

[30] Other technology areas that will need early attention include thermal protection system (TPS) technologies and associated structural materials used for atmospheric entry missions, aerocapture technology development, and developments needed to meet the anticipated future Deep Space Network (DSN) demand.

[31] There is some discussion on p. 52 of how mission technology needs for the anticipated mission set will be used to decide which technologies to develop, but there is no mention of metrics for prioritization or funding levels. No time lines are given in any of the technology discussions, even though this should be relatively easy to do for the Mars program. Some time lines are needed for critical technologies to show that those technologies will be ready when needed for missions.

The Mars objective ". . . determine if life exists . . ." (p. 32) fails to mention that there are numerous complex issues related to biohazards and Mars sample quarantine associated with eventual Mars sample return. These issues will take time to clarify, and adequate quarantine and analysis facilities must be developed in parallel with technologies for sample return. It will require 7 years or more to develop and construct a suitable facility, effectively a clean room inside a BSL-4 containment laboratory. See Space Studies Board, National Research Council, *The Quarantine and Certification of Martian Samples*, National Academies Press, Washington, D.C., 2002.

Mechanisms for importing technologies from outside NASA appear to be oriented primarily toward requiring potential technology providers to actively approach NASA. Significant advantages may accrue from having NASA actively identify and approach potential technology providers outside NASA and the aerospace industry.

[32] Some comments that may guide revision of the Education and Public Outreach section:

1. The proposed plan (p. 20, line 14) discusses that the goal is to meet the needs of educators, but the means by which the needs of the educators will be assessed are not specified;
2. Items in the Future Efforts List are still too vague;
3. In general, there is no specific plan on how any of the EPO activities will be accomplished.

[33] National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, prepublication copy, National Academies Press, Washington, D.C., 2002, pp. 6-3, 6-5.

[34] Space Studies Board, National Research Council, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, National Academies Press, Washington, D.C., 2003—in press; Space Studies Board, National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, National Academies Press, Washington, D.C., 2003—in press. Board on Physics and Astronomy, Space Studies Board, *Astronomy and Astrophysics in the New Millennium*, National Academy Press, Washington, D.C., 2001; Board on Physics and Astronomy, National Research Council, *Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century*, National Academies Press, Washington, D.C., 2003.

Attachment 1

National Aeronautics
and Space

Headquarters
Washington, DC 20546-0001

January 7, 2003

Reply to Attn of:

S

Dr. John McElroy

Chair, Space Studies Board
National Research Council
2101 Constitution Avenue, NW
Washington, DC 20418

Dear Dr. McElroy:

The Office of Space Science is currently working to update the Space Science Enterprise strategic plan, with the objective of issuing a new version in September 2003. Subcommittees of the Space Science Advisory Committee (SScAC) have prepared new mission roadmaps and we held a workshop to discuss an updated strawman science and mission program in November. We are now assembling a draft revised plan and will circulate it for community comment.

I would like to request that, as for the 2000 plan 3 years ago, the Space Studies Board review the new draft plan and provide us with comments in the following areas:

Responsiveness to the Board's guidance on key science issues and opportunities in recent Board reports;
Attention to interdisciplinary aspects and overall scientific balance; Identification and exposition of important opportunities for education and public outreach;
Integration of technology development with the science program; and
General readability and clarity of presentation.

Helpful suggestions in other areas would also be welcome.

According to our present schedule, a draft of the plan should be available for your review by the end of January 2003. We also expect to be able to brief the plan to the Board and relevant committees at your request. Because we plan to present a final draft to the SScAC at their meeting in June 2003, leading to production of the report beginning in July 2003, we would need to have a formal report from the Board expressing its findings and suggestions no later than mid-to late-May 2003.

We look forward to having the Board's inputs to this vital activity. Please contact Dr. Marc Allen at (202) 358-0733 if you have any questions about this request.

Sincerely,

Edward J. Weiler
Associate Administrator
Space Science

Space Studies Board

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