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MEETING REPORT

*MWadhwa*

November 26, 2018

Meenakshi Wadhwa, Interim Chair

*Elaine Denning*  
Elaine Denning, Executive Secretary

*Nov 26, 2018*

## *Table of Contents*

Opening Remarks	3
SMD Overview	3
Goals of Meeting/Introduction of Members	4
Division Advisory Committee R&A Charge Responses	4
Science Committee R&A Charge Finalization	7
Earth-Observing System Innovations	8
Ames Research Center Director's Welcome	10
Discussion of Public/Private Partnerships	11
Big Data Products Finalization	11
Public Comments	12
Discussion, Findings and Recommendations	12
Building Companies Using Open Data – Weather Underground	13
Outbrief for SMD AA	14
Joint Session HEOC/SC	15
Opening Remarks	15
SMD Cislunar Activities Overview	16
HEOMD Cislunar Gateway Overview	17
Gateway and Landed Science	20
Transformative Lunar Science	22
Public Comment	24
Discussion of Findings and Recommendations	24

*Appendix A- Meeting Attendees*

*Appendix B- NAC Science Committee Membership*

*Appendix C- Presentation Materials*

*Appendix D- Agenda*

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August 27, 2018

Opening Remarks

Ms. Elaine Denning, Executive Secretary for the NASA Advisory Council (NAC) Science Committee (SC) opened the meeting with administrative remarks. She introduced the SC Interim Chair, Dr. Meenakshi Wadhwa, who formally opened the meeting.

SMD Overview

Science Mission Directorate (SMD) Associate Administrator (AA) Dr. Thomas Zurbuchen gave a brief overview of the directorate, beginning by enumerating some changes in personnel that had much to do with recent events affecting the James Webb Space Telescope (JWST) mission. SMD is trying to ensure strength and continuity in management and has appointed Mr. Gregory Robinson as the new JWST Program Manager. Other new faces in the front office include Dr. Michael New, Deputy Associate Administrator (DAA) for Research, Ms. Sandra Connelly, DAA for Programs, and Mr. Steve Clarke, the new DAA for Exploration. Mr. Clarke will be reaching across SMD to identify activities and missions that could benefit from the agency's Exploration Campaign. With the appointment of Dr. James Green as the new NASA Chief Scientist, the Planetary Science Division (PSD) Director position has been formally announced as open.

On Mars, the Mars Exploration Rover (MER) Opportunity remains in an ongoing saga of survival; a planet-encircling dust storm that began in June 2018 has just abated, and it is not known if the rover's solar panels have survived the storm. Opportunity, and its sister spacecraft Spirit, were originally planned for a 90-sol lifetime. Opportunity has exceeded its designated life span by 55-fold, and remains a mission that is a resounding success. The Lunar Reconnaissance Orbiter (LRO) continues its science mission, and will be available to support other nations and commercial companies at the Moon as exploration activities go forward. The latest Astrophysics Division (APD) mission, the Transiting Exoplanet Sky Survey (TESS) is doing well, and has reached a stable orbit, where it will search for life in distant star systems. The Interior Exploration using Seismic Investigations, Geodesy and Heat Transport, (InSIGHT) mission is due to land on Mars in November of this year; given the history of attempted landings on Mars, there is approximately a 40% chance of a successful landing, thus the mission is a nail-biter for everyone. Two CubeSats, Mars Cube One (MarCO-A and B) will relay data back to Earth during this mission, allowing NASA to keep an eye on InSIGHT as it lands. MarCO involves the work of young scientists and marks the first use of interplanetary CubeSats. The Earth Science Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) has released its first-light data, and the International Space Station (ISS) payload, ECOSystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), went from launch to operation on station within a matter of days. The Parker Solar Probe mission to the Sun was launched successfully, witnessed by its namesake, Dr. Eugene Parker. There are over 35 missions in operation and flight, addressing science on a regular basis, including the asteroid sample return mission, OSIRIS-Rex (Origins Spectral Interpretation Resource Identification Security - Regolith Explorer), and ICESat-2 (Ice, Cloud and land Elevation Satellite-2), a complex lidar mission that is critical for monitoring ice cover at the terrestrial poles and elsewhere. The Heliophysics Division (HPD) mission, Ionospheric Connection Explorer (ICON), is due to launch from a Pegasus rocket in the very near future. ICON is designed to measure and observe the uppermost boundary of the atmosphere. Dr. Zurbuchen noted there had been large numbers of interns at NASA Headquarters this past summer, providing good opportunities for young researchers.

Communications difficulties prompted Dr. Zurbuchen to defer further discussion to later in the day.

### Goals of Meeting/Introduction of Members

Ms. Denning read remarks concerning the guidelines and rules established by the Federal Advisory Committee Act (FACA), which govern all FACA committees. Dr. Wadhwa led introductions around the table, and reviewed the goals of the meeting, in particular to finalize the Research and Analysis (R&A) charge response, and response to the findings and recommendations in the final report of the Ad Hoc Big Data Task Force (BDTF). Dr. Wadhwa also welcomed new members Dr. Vinton Cerf, Dr. Michelle Larson and Mr. Mark Weiser.

### Division Advisory Committee R&A Charge Responses

Dr. Anne Verbiscer, Chair of the Planetary Science Advisory Committee (PAC), gave a summary of the committee's response to a charge to evaluate the present state of high-risk, high-impact R&A in SMD. The sense of the PAC is that there are indeed proper processes in place to support high-risk, high-impact research proposals, but that the processes could be better implemented, and more consistently. The PAC recommends that the process needs to be implemented more evenly across panels and should be codified, and that Research Opportunities in Earth and Space Science (ROSES) calls should be adjusted to encourage such work. The PAC further recommends that NASA track these proposals by adding a means of reviewing forms for both reviewers and externals, along with providing space for panel suggestions and program officer suggestions. In response to a subset of the R&A charge questions, the PAC had several remarks, and a suggestion that the Astrophysics Advisory Committee (APAC) add representation from the solar system community, to reflect the use of astrophysics assets in solar system research and missions.

A PAC teleconference in July featured a status report from Acting PSD Director, Dr. Lori Glaze, an R&A presentation from Dr. Jonathan Rall, and two reports from the Mars and Lunar programs. The PAC produced findings on the next planetary science decadal survey. The PAC raised concerns that NASA's interpretation of FACA rules may impeding process of getting the requisite mission studies done in advance of the next decadal survey; these science definition teams (SDTs) need to be formed very soon. The PAC feels that enlisting the analysis groups might be a way to avoid the delays inherent in creating FACA-bound entities. The PAC encouraged the idea that the New Frontiers program be open to all targets and destinations and not limited to those on a list produced by the decadal survey. The PAC produced a finding that encouraged transparency of implementation with regard to NASA's Internal Science Funding Model, including provision of performance metrics that are open and available to all.

The PAC issued a finding on the Planetary Defense Coordination Office (PDCO), stating that given an increase in Fiscal Year 2019 (FY19) funding, the PAC would like to see an enumeration of PDCO program objectives, a summary program plan, and a roadmap at the next PAC meeting. For flight missions entering the Senior Review process, the PAC recommended sufficient funding and an adequate timetable to carry out the review. The PAC also issued a finding applauding the formulation of a Mercury Analysis Group.

The SC discussed the PAC finding on having more planetary science representation on astrophysics decadal survey panels. Dr. Cerf asked whether the B612 Foundation had been involved with the PDCO. Dr. Verbiscer said that the foundation had been involved at one point, but failed to deliver requirements to NASA, and thus the involvement ended. Mr. Weiser commented that a separate pot of money for program officers who oversee high-risk, high-impact research proposals creates a form of bias. Dr. Kathryn Flanagan explained that in most R&A peer review panels, a bias already exists against high-risk research, which is why the conversation on the R&A charge originated. Dr. Verbiscer pointed out that a separate pot is seen as a type of protection. Mr. Weiser felt that one could argue that the Parker Solar Probe was once seen as high-risk; should NASA try to shift the culture or create a separate class? Dr. Verbiscer said that the community recognizes the issue and is trying to do something about it. Dr. Flanagan added that

panels are often aware of limited resources, which preserves some cognizance of the issue. Dr. Michelle Larson asked whether high-risk proposals were evaluated under different criteria on a typical review committee. Dr. Flanagan, noted, in regard to planetary input into the astrophysics decadal survey, that there are many existing mechanisms to do this, but there should be care before implementing particular recommendations as these may have unintended consequences; not all of astrophysics needs planetary input. She encouraged continuing cooperation and cross-pollination between the two disciplines.

Dr. J. Marshall Shepherd, Chair of the Earth Science Advisory Committee (ESAC) gave an overview of the ESAC's response to the R&A charge, noting that much of the analysis in the presentation had been performed by Dr. Michael New. The ESAC considered the working definitions of high-risk, high-impact research to be adequate, after reviewing an analysis of the Earth Science Division's 2017 R&A panels. The analysis included 474 proposals across 11 programs, not the entire ESD portfolio, but representative. The majority of proposals were considered to have some intellectual risk; and a number of proposals were considered as high intellectual risk and impact. Most proposals were not thought to address SMD divisions other than ESD. About one-quarter of the proposals were thought to be multidisciplinary, and 33% to be interdisciplinary. In terms of impact and risk, ESAC felt most proposals had some intellectual risk while offering high or medium impact, with a number considered as both high-risk and high-impact. ESAC recommended that ESD maintain this positive track record, while encouraging Program Managers (PMs) to continue to provide explicit guidance, and to provide explicit wording in research calls and in charges to review panels. ESD should set objectives for diversity in panels, and should separately analyze and track proposals for young researchers in high-risk, high-impact programs. In its March 2018 meeting, ESAC dealt with the decadal survey and issued recommendations to ESD on preparing a coordinated plan to elicit broad community input, underscoring the importance of the ESD airborne program and international collaborations.

Dr. Susan Avery commended on Dr. Shepherd's report and asked if the R&A analysis unearthed any conclusions about how many proposals were actually pushing the envelope of process, such as in understanding the Earth system (e.g., innovative salinity probes), vs. those that deal with continuing Earth monitoring for models and the International Panel on Climate Change (IPCC). Dr. Shepherd felt that the analysis had focused more on process-type studies, and that the answer is affirmative for an atmosphere that encourages cutting-edge research. The other conclusion that emerged from the analysis is that some of these missions are very high-risk (putting a weather radar in space is high-risk, in itself). He did want to emphasize that the analysis was just a one-year sampling of the ESD program. Dr. Shepherd said that while the sense of the ESAC is that there are a sufficient number of high-impact, high-risk proposals in ESD, and that it is the perception in the community as well, there was some ESAC perception, however, that we need to understand how to get new investigators into the program, and that ESD also has a highly interdisciplinary science program specified in ROSES. Dr. Walter Secada asked whether this analysis indicated that interdisciplinary research constituted a hallmark of high-risk, high-reward research. Dr. Shepherd responded that the analysis showed that some of these high-risk, high-impact proposals were not in fact interdisciplinary, and that risk is not coming from interdisciplinary character, *per se*.

Dr. Paul Scowen delivered the Astrophysics Advisory Committee (APAC) report, noting that the Cosmic Origins Analysis Group (COPAG) conducted an online survey on the subject of high-risk, high-reward research, which garnered 59 respondents. The survey showed no evidence of dissatisfaction in the community, and obtained some valuable testimonials and insight. The demographics of the survey community included both reviewers and proposers. The majority of proposals were science observations; others were technology-based, a combination of science observation and theory, or theory only. There was an even distribution between agreement and disagreement. There seem to be definite hurdles, such as panels being too conservative and risk-averse, with a preference for incremental but safe proposals. In such an atmosphere, high-risk, high-reward proposals simply can't compete. Oversubscription to some programs (such as the Hubble Space Telescope) was a case in point. Many ideas need more explanation,

and review panels do not see the real issue. Panel members may not be as *au fait* as they need to be. There was little consensus on an appropriate solution; some solutions included a separate funding pot for proposals, and explicit calls for such proposals (5-10% of the R&A pot). A change in the review and proposal process might be effected by throwing the net a little wider.

Some high risk proposals fail because, according to one survey comment, “they do not get written in the first place,” because no one thinks they will succeed. There appeared to be a consensus in the astrophysics community that reviewers tend to be picked from narrowly defined fields. APAC felt it didn’t have enough information to usefully assess this aspect of the R&A charge; APD Director Dr. Paul Hertz has since asked all peer review panels to identify high-risk, high-reward proposals, and build statistics on how it should be done. Dr. Cerf introduced “seven questions” used to assess a proposal, in no jargon: how is it done, what is new, who cares, what are the risks, what is the cost, how long will it take, and what are the metrics for success; he considered this a helpful catechism. He noted also that the National Science Foundation (NSF) has tried to address risk-averse proposals through a post-analysis of unselected proposals; he said he would report back on that analysis when complete. Dr. Wadhwa asked whether the APAC’s favoring of some sort of percentage set aside was based on a gut feeling or a more concrete, data-based rationale. Dr. Scowen said that the 5-10% number popped up consistently in several responses, emanating from the general feeling of review panel members. Mr. Weiser encouraged the SC to consider the makeup of panels: whoever makes the decision is important, and not every panel is ready for high-risk, high-reward proposals. Dr. Secada noted that unless there is a real consensus on what “high risk/high impact” means, survey responses are not useful. Dr. Cerf commented that the bouncing balloon Entry, Descent and Landing (EDL) concept used for the Mars Pathfinder vehicle was a wild idea, and a successful one. Innovative research does not get accomplished in an overly analytic mode. Science is risk; if it’s not, it’s engineering. Science is about not knowing the answer. Divisions and disciplines are a management artifact.

Dr. Michael Liemohn, Chair of the Heliophysics Advisory Committee (HPAC), delivered a briefing on the latest deliberations. HPAC finalized its R&A charge response, heard some reports on the decadal survey’s DRIVE (Diversify, Realize, Integrate, Venture, Educate) initiative and a consequent R&A funding increase. HPD has a middle-sized Explorer (MIDEX) proposal call coming out soon. HPAC also heard about high-end computing (HEC) activities at Ames Research Center and how some heliophysics accounts are being underutilized, and issued some recommendations on how to handle that. The heliophysics community is preparing for the next decadal survey. To assess the R&A charge, HPAC formed a subgroup which interviewed as many subjects as possible. It defined high-risk, high-reward projects as those which significantly impact current thinking, counter present scientific thinking, or those ideas with scant precedent, or with a methodology is not clearly established (i.e. ideas that rewrite the textbooks). There was universal agreement that such research is vitally important. Recommendations were to set aside a pot of funding at 5%, to be adjusted over time as results come in. Dr. Liemohn noted that even if the high risk project were to be a technical failure, there are still lessons learned to be gleaned from the project, which should be made public to the community to build on. HPAC recommends that proposers self-identify as high-impact/high-risk; either as a separate ROSES element or in an NSPIRES cover page question. Reviewers should understand the nature of the proposal, and should be trained to recognize cognitive bias. Panelists themselves should have lessons learned conversations. The HPD budget for high-impact/high-risk should be regularly evaluated, and a portion of this funding should be offered to early-career scientists.

For interdivisional research, the set-aside could be as low as 1% at the onset. The feeling is that HPD research of this nature can be improved. HPAC was split on whether such proposals should be placed in a separate ROSES-E (cross-SMD division) call, or in the regular ROSES A-D (each division) calls. Overall, on the matter of interdisciplinary/interdivisional research, HPAC feels that important work is being neglected, but that the right balance should not be mandated in advance. It would be very difficult

to convene such panels that are in need of outside experts. HPAC feels that ROSES program announcements should be careful to explicitly state what a high-risk, high-impact concept constitutes. Regarding suggestions for establishing an interdisciplinary center, this suggestion fits the sense of the DRIVE initiative, and should be assessed as time goes on. Dr. Wadhwa asked if the 5% figure arose from some concrete metrics. Dr. Liemohn replied that it was just a feeling shared by members of the HPAC.

#### Science Committee R&A Charge Response Finalization

The SC discussed the committee's own draft response to the R&A charge, an analysis and finding that would be sent to the NAC and if approved, directed to the SMD AA.

Mr. Weiser addressed the struggle for defining high-risk/high-impact, noting that the challenge is that it is subjective. Risk is more of a mindset and is difficult to measure. It is either embedded in one's career as a direction, or not. Coming from an industry where 70% failure is a norm, Mr. Weiser felt it useful to try to find out how program officers might be incentivized to have a mindset for risk. Dr. Flanagan said it was not clear that it was necessary to fix panels or create set-asides, but thought a systemic fix might entail identifying things that the community thinks are worth doing. The high-risk/high-impact proposals already exist in the pool of scientific ideas, thus it might be helpful to have a discipline committee identify them. Dr. Avery suggested concentrating on NASA "game-changers," such as how space measurements are transforming atmospheric science. Dr. Wadhwa suggested the initial detection of exoplanets as an example of high-risk/high-impact research. Dr. Cerf commented that NASA's Deep Space Network (DSN) was a major step forward.

Dr. Liemohn reminded the SC that there is a big difference between risk in the R&A program and in the directed Flagship missions. Dr. Avery pointed to high-risk sensors on satellites (e.g. detection of gravity waves). Dr. Wadhwa noted that the SC had reached consensus on not prescribing a certain percentage of high-risk/high-impact R&A funds. Dr. Secada commented that R&A should be characterized by a tolerance for failure, but a tolerance that tightens as things become worse; the SC should be explicit about what level of failure to tolerate. Dr. Cerf noted that the NSF concept of risk management focuses on how to deal with risk, with the mitigation strategy embedded in the proposal. He commented that the notion of discipline is an artifact, while science is a continuum; NASA should be more explicit about how to manage the risk.

The final language of the finding was as follows:

The NAC SC finds that SMD should "stay the course" with the overall Research and Analysis (R&A) strategic objectives, incorporating attention to high-impact/high-risk research, as history has shown that such investment can be game-changing. Just because incremental progress is being made, it does not mean that tremendous impact is not occurring. In general, key to the selection of high-impact/high-risk proposals is for SMD to

- 1) clearly train review panels regarding high-impact/high-risk research, and encourage proposers and review panels to address and evaluate mitigation of risk in high-impact/high-risk proposals,
- 2) have attendant expertise on the review panels,
- 3) closely coordinate with each program manager on this approach, and
- 4) have the high-impact/high-risk solicitation remain within each SMD discipline rather than in a separate proposal call that mixes disciplines, as it could not be reviewed effectively. In each solicitation, SMD could note that high-impact/high-risk proposals are welcome. This approach results in high-impact/high-risk research embedded in each review panel for their examination, which is beneficial.

Finally, the NAC SC finds that NASA SMD effectively responds to the scientific community when an interdisciplinary research need is identified, and sets up appropriate structures to promote such collaboration. Most interdisciplinary work is being done through collaborative research mechanisms (e.g. Nexus for Exoplanet System Science (NExSS), NASA Astrobiology Institute (NAI)), and may not exist outside of these. To increase emphasis, 1) SMD could encourage the scientific community to increase communication with the NAC SC in pinpointing interdisciplinary/interdivisional opportunities, and, 2) the next SMD ROSES call could welcome proposals wherein astrophysics data will be used by planetary science investigators, and conversely, planetary science data will be used by astrophysics investigators.

*For more information, reference “NAC SC Response to SMD Research and Analysis Charge” that contains SC feedback on specific questions: <https://science.nasa.gov/science-committee/meetings>*

#### Earth Observing System Innovations

Ms. Sandra Cauffman, Deputy Director for the Earth Science Division (ESD), presented new activities within the four ESD elements: Flight, R&A, Technology, and Applied Sciences. Operationally, Flight will be a very robust program over the next 3-5 years, with many missions looking at Earth in many different parameters, from homogeneous systems of small satellites to the heterogeneous A-train, to hosted payloads and CubeSats. ESD’s private sector small satellite constellation pilot is now in effect. A three-CubeSat mission, Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) just held its confirmation review; in addition, the In-Space Validation of Earth Science Technologies (InVEST) program in the Earth Science Technology Office (ESTO) launched three CubeSats earlier this year. The Venture Class Launch Services (VCLS) program is working toward producing low-cost launches (\$15M/launch).

ESD has initiated a pilot program with the goal of augmenting science via buying data from commercial constellations on orbit; NASA will analyze a year’s worth of data, perform calibration-validation, and plug the data into models. After a year, if the data proves useful, the idea would be to continue the practice. ESD attempted to start this pilot in 2016, to limited response. In 2017, ESD was able to identify four qualifying companies through a Request for Information (RFI), and has been issuing sole-source contracts with blanket purchase agreements. Funding is available to go forward, and it is expected ESD will award the contracts quickly. Participants evaluating the data will be 30-40 NASA researchers, whose grants will be augmented with the purchased data. To participate in this pilot, NASA considers the quality of geophysical information, data availability and rights, and whether the company can supply future plans for constellation(s). Ultimately, NASA wants to be able to offer the data government-wide.

ESD continues its successful Venture-class programs: opportunities include suborbital, self-contained missions, and instruments. In the Earth Venture-Instruments (EVI) program, the Principal Investigator (PI) produces the instrument, while NASA finds the host through other federal agencies, ISS, or commercial geostationary satellites. CubeSats are selected under EVI, for example. Earth Venture-Missions (EVM) is for self-contained missions in which the PI proposes, and is responsible for finding a host. Hosting approaches vary. Within this program, ESD is developing the TROPICS, Earth Surface Mineral Dust Source (EMIT), Orbiting Carbon Observatory-3 (OCO-3), and Geostationary Carbon Cycle Observatory (GEOCARB) missions. ESD also is organizing public/private partnerships with Google and Microsoft, and two nongovernmental organizations (NGOs) Mercy Corps and Conservation International, on a roughly *quid pro quo* basis. ESD seeks to harness and leverage these partnerships to help better understand the Earth as an integrated system and to enable societal benefits.

Working with Conservation International (CI), NASA brings ecosystem mapping, while CI brings economic valuation and *in situ* measurements for validation, to assess environmental health and the value of natural capital on local and global scales. NASA is working on the Gaborone Declaration for

Sustainability in Africa, and a Freshwater Health Index. NASA is able to reach decision-makers with its data, through the office of CI, and has signed a Space Act Agreement with CI to continue this work. Google and NASA are working together to leverage Earth observations with interactive storytelling. NASA provides the global data set, enabling stories such as NASA's "Earth at Night" (one of Google Earth's most viewed) and "ABCs from Space." Google greatly increases the reach of NASA data, and Google benefits from NASA's advanced data sets. NASA is working with Mercy Corps to help monitor human resilience in the face of environmental shocks and stresses. Through Mercy Corps, NASA is helping the country of Niger better understand and facilitate groundwater management. Partnerships matter greatly; NASA has been able to bring data to decision-makers in this conflict-prone region.

NASA and Microsoft are working together on developing a "dashboard" for enhanced urban decision-making; a sample application is urban heat mapping to assist vulnerable populations in Chicago. Science Activation Partnerships focus on teachers and students, and are funded through cooperative agreements (CANs); there are over 200 partnerships within the SMD Science Activation Collective (SciAct) of 25 CANs. Six are ESD-related, and they leverage social media, mobile apps, and citizen science. Examples of such projects are coverage of the 2017 solar eclipse, mosquito control, and the AEROKATS and ROVER Education Network (AREN), which leverages NASA aeronautics technology and mission know-how to enable students to do near-surface and in-situ remote sensing of local environments and water bodies. These Earth-focused SciAct projects engage kids with data in an immersive environment.

Mr. Kevin Murphy presented a briefing on the Earthdata Cloud, a NASA effort in modernizing Earth Observing System (EOS) data (EOSDIS) for Cloud operations. Earthdata Cloud uses modern techniques while allowing free and open access to Earth Science data worldwide. NASA is preparing for high-data-rate missions, and is looking to increase the opportunity for researchers to manage petabytes (PB) of data. EOSDIS has 3 million users per year, and its current architecture will be harder to manage as the annual data ingest rate increases from 4 to 50 PB per year by late 2021. Earthdata Cloud will address compliance, security and cost tracking; core archive functionality and processing; end-user training and application migration (transitioning users and apps); and the pursuit of Cloud partnerships to leverage expertise.

ESD is working with Amazon Web Services (AWS), as mandated by the Office of Chief Information Officer (OCIO), and Ames Research Center for initial testing and demonstration of load capabilities. As an agency, NASA can get better deals by volume. NASA does anticipate other major Cloud vendors to be approved within a year or two. Currently, ESD is prioritizing work to accommodate the data-intensive Surface Water and Ocean Topography (SWOT) and the NASA-ISRO Synthetic Aperture Radar (NISAR) missions. For compliance security and cost tracking, ESD has developed a NASA Compliant General Application Platform (NGAP), and is externally validating the approach. For core archive and ingest applications, NASA has developed a Cloud-native system addressing data center capabilities, and a Getting Ready for NISAR (GRFN) project that is demonstrating key components in commercial Cloud, including end-user training and application migration. To support the EOSDIS search engine, two core systems have been migrated into AWS, at an estimated savings of \$1.2M over 5 years. In addition, ESD has begun a webinar series on "How to Cloud."

NASA continues to pursue Cloud partnerships with AWS and Google, using journal articles on best practices, and helping AWS better manage NASA products through Google Earth 2.0, and the Google Search Engine. Internally, the effort has enjoyed unprecedented collaboration with OCIO. ESD is the largest Cloud user thus far in the agency, and has worked with the OCIO's Big Data Working Group. Dr. Cerf asked Mr. Murphy if he was familiar with the Data Transfer Project (DTP), and the Open Archival Information System (OAIS). Mr. Murphy said NASA had initiated DTP discussions in 2015, and with respect to OAIS, yes, NASA is quite aware and takes the requirements very seriously.

Dr. Avery asked Ms. Cauffman: what is the overall goal of the partnerships? How scalable and sustainable are the partnerships? Do they require a larger strategic plan and effort in ESD? Ms. Cauffman replied that part of the ESD program focuses on societal benefit, and the public at large does not understand how much NASA does for Earth science. Partnering with other institutions helps to publicize what NASA is doing, and augments the utility of Earth science data for the good of society. To this end, ESD has moved from pilot mode to sustainable mode with organizations such as Conservation International, is working toward a more operational way of dealing with all of these institutions, and is developing metrics. It is a work in progress. Mr. Jamie Favors of ESD commented that these NGOs were selected as leaders 5-7 years ago through a NASA strategic planning process. Mr. Weiser asked for more details about ESD's data buy pilot. Ms. Cauffman explained that the intent is to buy data already captured, by constellations that contain a minimum of three satellites, at a minimal cost, and some fractions of full-time employees (FTE) civil servant time. The FY18 budget had put aside \$10M to buy data, and there is a proposed \$20M for FY19. Dr. Secada asked if there were any plans to talk about data analysis and presentation in ways that make the data more widely useable. Ms. Cauffman said that yes, absolutely this is in process; the Google partnership is a major example. In Niger, the data are being used to understand the aquifer system. Within the data buy, NASA is augmenting grants for data analysis. Mr. Murphy noted that from a data system perspective, NASA wants to open up the growing archive of products to multiple users by standardizing products, and better integrating with other programs. Data management takes a lot of effort, and NASA wants to allow people to process data with standardized Application Programming Interfaces (APIs), and has invested in this process through some of the Earth Science Technology Office programs. NASA has worked with Google to better understand the Earth engine, and with Microsoft to simplify access to Landsat data. Dr. Cerf suggested NASA investigate Schema.org, a repository of important schema for structured data. Mr. Murphy said he was familiar with Schema, and other relevant organizations.

#### Ames Research Center Director's Welcome

Dr. Eugene Tu, Director of the Ames Research Center (ARC), presented a formal overview of ARC to welcome the Science Committee. Dr. Tu described his career beginning at ARC in 1984, working in aerospace engineering. There are six communication themes at NASA: Flight, Humans in Space, Moon to Mars, Space Technology, Earth, and Solar System and Beyond. Ames provides cross-cutting support across the Agency and supports all of these themes. ARC's unique placement in the midst of Silicon Valley means that it competes for the talent in the private sector, and it also means that ARC gets the employees who are the most passionate about the NASA mission. ARC is able to take advantage of the entrepreneurship and innovation inherent in Silicon Valley. ARC was established as the second NASA center, and is celebrating its 80<sup>th</sup> anniversary in 2019. The Center's first phase was as an instrumental player in aerodynamics and aerothermodynamics (wind tunnels, analysts, theoreticians); followed by a second phase in space and science missions (Viking, Pioneer, Galileo); and a third in information science and high-performance computing. ARC has 2600 employees, 1200 of which are civil servants. ARC is housed at the site of Moffett Field Naval Air Station that closed in the 1990s. NASA took over stewardship of all of the Moffett Field property and turned a major portion into a research park (NASA Research Park – NRP). The research park is largely full and NASA can choose partners who align to the Center and Agency missions. There are another 1600 tenants in the park from academia, government and the private sector. The total annual budget for ARC is about \$900M, with another \$150M in reimbursable funding. ARC boasts the largest wind tunnel in the world; almost all Mars parachutes have been tested in it. The Center has other smaller tunnels for various speeds, including a plasma wind tunnel for simulating entry into planetary atmospheres. Its arc jet complex is one of the largest in the world and the only major arc jet facility within NASA; many thermal protection system (TPS) materials have been developed at Ames. The Center also houses human-in-the-loop simulators for testing for autonomous systems. The Ames HEC facility is used heavily by SMD. The main computer, Pleiades, has been followed on by the addition of Electra, which will double the supercomputing ability at NASA. Thanks to its location in the dry California climate, Ames is getting high efficiencies by using ambient air to cool its new, modular

HEC systems. There are eight core competencies at the Center, many of which are cross-cutting for NASA: air traffic management (ATM), entry systems, advanced computing and IT systems, intelligent/adaptive systems, astrobiology and life science, space and Earth sciences, aerosciences, and cost-effective space missions. ARC is hosting K2, the Kepler follow-on mission, and the science program for the Stratospheric Observatory for Infrared Astronomy (SOFIA). ARC also is embracing partnerships with the Carnegie Mellon University, Singularity University, and the U.S. Geological Survey (USGS), whose West Coast Science Center, with 500 scientists, will be moving to the research park over the next three years. ARC also hosts private sector industry incubators, and all four of the Agency's virtual institutes.

Dr. Cerf commented on his experience with the Acoustic Research Center and the Defense Innovation Unit X project, and related its eventual relevance to ARC's interest in quantum computing. He added that Google has done work in training cooling systems using machine learning and artificial intelligence (AI) techniques, resulting in 40% savings in cooling costs.

At the close of the ARC briefing, Dr. Wadhwa and the rest of the SC gratefully recognized, for the record, the 100<sup>th</sup> birthday of one of NASA's "Hidden Figures," mathematician Katherine Johnson.

#### Discussion of Public/Private Partnerships

The committee discussed the range of public/private partnerships suitable for SMD. Dr. Cerf noted that the Department of Energy (DOE) is investing in and installing sensors in Chicago, for a "smart city" concept, a project that offers potential for NASA and DOE cooperation. He wanted to reinforce the idea that these types of partnerships are very valuable to the Federal government, as huge amounts of data and huge amounts of risk go hand-in-hand. Dr. Patterson greatly supported and encouraged the Earth Science data buy pilot program and the use of SmallSat constellations, which can take advantage of multiple observations multiple times per day. Dr. Avery questioned the partnerships wherein data was being applied in a new context: is NASA providing a service? How does this fit into NASA's mission? Is NASA doing this because no one else is stepping up to do this? Dr. Cerf noted that machine learning can be a powerful but a brittle tool, and imagined that NASA could test some of its ideas in another setting. Ms. Cauffman said that part of the work Earth Science is tasked to do is in Applied Sciences, providing one of the motivations to make the best use of data for multiple uses and applications. Also, in new missions, ESD has started to ask PIs up front about the applications that are related to their projects. Mr. Weiser commented that one of the first useful steps in matching up data sets could be to combine structured vs. unstructured data and analyzing them with AI. Autonomous cars are driving down the cost of lidar; CubeSats will do something similar. There are problems being tackled for the sake of society that can be turned around to facilitate science. Data scientists that are tackling AI in the private sector are working on data sets that have much in common with NASA needs. There also are more sophisticated citizen science projects that can be enabled by advances in commercial IT. Dr. Larson suggested NASA think about how it can foster creativity and ingenuity. Student interns that work in SMD, for example, can broaden their experience through programs that allow them to work in private companies. This approach also can break down some of the siloes of specialization.

#### Big Data Products Finalization

The committee finalized its draft analysis and finding in response to the report of the BDTF.

Dr. Cerf said he was troubled by the SC's conclusion that archive management should not be managed at the same level as its flight mission; this conclusion feels derelict, as if it says it is more important to collect the data than to preserve it. Dr. Flanagan agreed with Dr. Cerf's comments but felt that NASA archives are already very important to NASA and are already managed minutely. The distinction here is that the BDTF recommendation would separate out budget and management for big data, which has the potential of diminishing the resources available for the mission, misaligning the management, and

entraining unintended negative consequences. Dr. Cerf said he was more concerned that mission planning did not seem to be incorporating thinking about the archive element. Dr. Mihir Desai noted that the recommendation was simply an implementation commentary. Dr. Larson raised an issue about the language and asked who was thinking about the long-term strategy of archives.

Ms. Denning circulated the draft for final technical edits and comments. Dr. Wadhwa called for closing actions at each meeting, to avoid confusion, particularly for incoming members unfamiliar with the original discussion.

The final language of the finding was as follows:

The NAC SC finds the enthusiasm of the Ad Hoc Task Force on Big Data (BDTF) impressive. The BDTF completed a large amount of work and provided a very thorough report. Many of the BDTF's findings and recommendations reflected the thinking of the NAC SC, with divergences often having to do with *how* ideas are implemented by SMD.

Overall, NAC SC agrees with the BDTF that SMD data archive programs and projects are performing well and are properly taking steps to modernize. However, the volume, variety and velocity of NASA science data is taxing established methods and technologies. The SC finds that SMD should

- 1) make investments in hardware, software, training and education to accelerate modeling workflows,
- 2) participate in the Department of Energy's (DOE) exascale computing program,
- 3) implement server-side analytics (SSA) capabilities (with caution),
- 4) forge a joint program with the National Science Foundation's (NSF) Big Data Innovation Regional Hubs and Spokes program, and,
- 5) incorporate data science and computing advisory positions in the SMD advisory committees.

In all efforts, the SC underscores that it is important that data science and computing experts work closely and collegially with domain scientists to implement effective solutions that are based on an understanding of the domain.

As to the future, the SC commends that an SMD Strategic Data Working Group has been set up that will bring forward these ideas, without interfering with how each division manages data.

*For more info, reference "NAC SC Big Data Product" that contains SC feedback on each of the SC's Ad Hoc Task Force on Big Data findings/recommendations:  
<https://science.nasa.gov/science-committee/meetings>*

#### Public Comments

No comments noted.

#### Discussion, Findings and Recommendations

Dr. Wadhwa invited comments on findings and recommendations, and any statements for the record. Dr. Cerf commented, as a newbie, on the discussion of high-impact, high-risk proposals in R&A program. He felt the Committee did not do well in recognizing the importance of risk mitigation, vs. learning to live with risk. Dr. Larson said that high-risk, high-impact examples should evoke awe. Dr. Cerf remarked that the National Science Board had parsed out the various types of risk: financial risk, technical risk, institutional risk, and subsequently put plans in place for NSF PMs to recognize different types of risk

and techniques for risk analysis and risk mitigation. A training program for both NASA PMs and proposers would be most useful.

Dr. Zurbuchen commented that he was encouraging people to read Daniel Kahneman's *Thinking Fast and Slow* to enlarge the conversation about how SMD thinks about risk. Dr. Wadhwa mentioned the SC's brief discussion about public/private partnerships and asked for specific inputs. Dr. Zurbuchen said he had spoken to an audience of young commercial space companies that morning, and was interested in learning what models NASA may be missing that can help the Agency mine the science that is present in enormous data sets. In Earth Science, NASA is already buying services. Can NASA be a customer to get more science per dollar and become part of the growing data ecosystem? Dr. Cerf offered the example of a Google user who applied machine learning techniques to find a new planet; this person had public access to NASA data, and applied a technology that had been developed for commercial purposes. There can be two different partnerships, one that is specific to a memorandum of understanding, and an implicit one when sharing technology. The latter can create partnerships that are serendipitous; NASA can encounter informal opportunities in this way. Dr. Larson cited Zooniverse is an example, which has 1.6 million users; NASA can send a crowd off to analyze existing data. Dr. Cerf noted that Microsoft had recently acquired Github, which may be another opportunity. Dr. Avery asked Dr. Zurbuchen how NASA dealt with international entities who do not share data, noting that some Earth science data has implications for defense. Dr. Zurbuchen said that SMD engages with a variety of stakeholders who can assess threats, but NASA sticks to its aegis as a civilian agency that deals with public data, and tries to make agreements when possible. ESD data are being used by Yemen to predict outbreaks of disease, for example, which is a great example of soft diplomacy, and is one of the most powerful things NASA can do with its data.

Ms. Denning returned to the draft finding on the R&A charge and made some minor changes arising from the discussion.

#### Building Companies Using Open Data—Weather Underground

Mr. Alan Steremberg, co-founder of Weather Underground (W-U), gave a briefing to the SC, first relating how W-U was initiated as an NSF project in 1989, then known as U-M Weather. The project used data from airport codes to monitor weather. In 1997, U-M Weather became W-U and built a large zip code database, incorporating data from NOAA, NASA, FEMA, census, weather stations and weather cams. By 2012, W-U had 20 million visitors per month, and was subsequently sold to the Weather Channel.

Mr. Steremberg was a Presidential Innovation Fellow at NOAA in 2014-15, working at the CIO's office, and trying to convince Cloud providers to give NOAA "free stuff." He recognized that it was a three-sided market: NOAA, with a lot of data behind federal firewall; Cloud providers; and end users (companies, researchers). The question became how to balance providing users with what they need, and how to develop the next start-up. He started looking at radar, and decided to have the entire three-terabyte NEXRAD weather radar archive copied to the Cloud, to make maps using historical satellite data from NASA. Moving the large volume of data helped to increased usage by 2.3 times, reduced NOAA's storage, and led to new uses on such subjects as bird migration and mayfly studies, illustrating how small investments create big outcomes. Similarly funding and supporting open data will help fulfill NASA's mission. The data must also be in the right Cloud, with high-speed, low-latency, and perhaps with availability as raw data. There are now new companies being built using NOAA data, including Sasquatch, Climate Fieldview, and Element 84.

Mr. Weiser asked if the goal of Mr. Steremberg's fellowship had been pre-defined. He replied that the CIO had a vision, and that he and Maia (Hansen) had the experience to understand what they wanted. The concept started out as a very open request for proposals (RFP) to the Cloud providers, however. There were 27 other fellows, and not all the projects worked, but they were pretty audacious. There was a little

bit of luck involved; the idea was to bring in mid-career people who had had private sector experience. Asked if he had had access to the Small Business Innovative Research (SBIR) program, Mr. Steremberg said that he had, and that W-U started as a research grant targeting K-12 schools in Michigan, training teachers how to use the Internet. When the venture went private, it was through the University of Michigan's Intellectual Property office, and bootstrapped thereafter. Dr. Larson recounted that in February 2017, there was a giant fireball over the Midwest, after which NOAA weather radar data were used to locate meteorite fragments, a project that spiraled into a lot of other science work:

(<https://openexplorer.nationalgeographic.com/expedition/rovmeteoritehunt>)

Dr. Zurbuchen asked Mr. Steremberg how NASA might enhance scientific serendipity, and how the Agency could better set up its knowledge base to be a fertile ground for creative approaches to science. Mr. Steremberg encouraged thinking about open data in holistic ways. Data from NASA should be more discoverable, in general; the data have to be everywhere. At NOAA, he had wanted to have direct high-speed connections to each of the Cloud providers. The trusted Internet connections issue has besmirched this desire. Security concerns have shut down a lot of data centers, and these data now must flow through a tie-cap which is expensive and impeding. Dr. Cerf noted that Netflix has the same problem, and wondered if part of the solution could be caching part of the data outside NASA, depositing data in publicly accessible sources. He thought there could be government innovation in caching, but we don't want someone from the outside to change climate data. There are some technical solutions, such as building cross-connectivity into contracts and setting up some low-latency targets. NOAA's tape archives, e.g., could be streamed straight into a requestor's account. Mr. Steremberg agreed, adding that open data must be discoverable, documented, clearly licensed and patent-free, and accessible. Open source code also is important. Dr. Avery said the right personnel on the partnership side also is important, as is building a set of expert teams that can maximize use of the data and data products. Mr. Steremberg agreed, noting that almost all his software people were meteorologists. As a fellow, he also was able to mentor people; it is always good to put in training programs and update employees on the latest and greatest capabilities.

#### Outbrief for SMD AA

Dr. Zurbuchen continued his interrupted morning briefing and displayed a video "Science As Inspiration" (available at <https://science.nasa.gov/nasa-science-interns-share-inspiration>) that showcased NASA Science interns. NASA has had a fabulous few months with successful launches; the Parker Solar Probe is currently underrunning its budget, which is remarkable for a large mission. The newest Earth Science mission, ICESat-2, is getting ready for launch. It has a remarkable lidar system, and NASA and ESA are depending on small companies for its instrumentation. He noted that the first icebreaker in centuries has breached Arctic ice, and that the ICESat-2 mission will help understand the long-term trends in ice cover, important for world trade.

JWST was the most painful part of the Summer. It is one of the most aspirational and complex missions ever done by NASA, by money spent and by the number of entirely new technologies. It has been an agonizing path to get to the understanding of the real costs. When the mission entered the integration and testing (I&T) phase, a number of small mistakes revealed themselves, adding up to hundreds of millions of dollars. It was partly a cultural issue (people not speaking up), but complexity amplified the mistakes. Dr. Secada asked if JWST technologies were usable in other areas. Dr. Zurbuchen said that this was generally true, but that this \$600M cost increase was very unexpected. Dr. Cerf, noting that many defense projects overrun their budgets, asked whether prototyping could have helped prevent JWST's problems. Dr. Zurbuchen said that many technologies had been developed through prototyping and testing, such as the sunshield. SMD is integrating JWST's lessons learned to improve other mission development activities. Dr. Avery asked if there had been differences between in-house builds and contracts. Dr. Zurbuchen said that the instruments are far more complex than the bus; they came in on schedule and

cost. The bus did not. This is anecdotal evidence. A contractor may not have the same understanding of the mission as the in-house team.

Dr. Wadhwa asked which vulnerabilities had been highlighted by JWST's independent review. Dr. Zurbuchen said that two major issues were that the mission team needs to be made aware of the need to prevent the accumulation of small errors, pointing to weaknesses in processes and training, and that the team must find be able to find potential issues early on. Dr. Wadhwa felt that excessive optimism and unrealistic cost estimates also were to blame; cost realism must be decided independent of advocates. Dr. Cerf commented that NSF has created a large facilities office and filled it with experienced people, and assumed NASA had done the same. He observed that NASA missions are capable of greatly exceeding their lifetimes, and wondered if extended mission operations costs interfered with other missions and innovation. Dr. Zurbuchen explained that NASA uses principles to guide its mission lifetimes, leaving science priorities to the National Academies. NASA uses peer review (the Senior Review) to make decisions about funding for extended missions based on mission performance, and it cuts off missions that are no longer scientifically compelling. New program opportunities are numerous; every launch has a new technology demonstration on it. NASA is investing up to \$55M in deep space small satellite missions, for example. The new decadal survey for astrophysics is being developed and it will take up the energy of the community. This decadal survey must pull the community forward at a difficult time, and should take lessons from the heliophysics community to ensure success. HPD is going through its midterm assessment and is doing very well. The Earth science community is also preparing for its next decadal. Dr. Cerf commented that the U.S. has faltered in its commitment to internationals, and asked for a sense for how things look now. Dr. Zurbuchen noted that NASA has had to weather difficulties in the Mars program and astrophysics, but that most stakeholders stick to their commitments. However, there are trades that come up, and NASA cannot eviscerate R&A for missions. New targets for the planetary decadal survey are coming up: Neptune and Uranus. Citing recent and successful education and outreach at the Michigan Science Center Dr. Zurbuchen asked if the Committee expected to have also a finding on education or science activation.

SMD has initiated a Strategic Data Management effort to unlock data and looking at data management strategically across the divisions. The community will provide input through RFIs. The goal is to develop a five-year strategic plan for scientific data and computing. Dr. Cerf commented that the private sector has only recently come to grips with the data-intensity once experienced in science; it makes sense for NASA to leverage their experience. Dr. Zurbuchen agreed, also citing medical data management as another source to leverage. He went on to emphasize the importance of carrying out NASA's anti-harassment/anti-discrimination initiative, which will be carried out in part through a Dear Colleague letter to the entire science community. NASA is coming down hard on the issue and is going to build in accountability. The entire team is committed to a safe and positive work environment, and is learning from NSF. Dr. Avery commented that is important have the policies and documents in place, but it is also good to encourage a broader approach to the problem, and to define the terms of diversity, equity and inclusion. There are plenty of good examples at the American Meteorological Society, the American Geophysical Union (AGU), UCAR, and Exxon Mobil. Dr. Wadhwa briefly reviewed the committee's accomplishments for Dr. Zurbuchen's awareness.

August 28, 2018

Joint Session of the Science Committee and the Human Exploration and Operations Committee

Opening Remarks

Dr. Bette Siegel, Executive Secretary of the Human Exploration and Operations Committee (HEOC) opened the joint SC/HEOC meeting and turned it over to Ms. Denning, who called the meeting to order

and made administrative remarks related to FACA guidelines. Dr. Wadhwa welcomed members to the joint session, commenting that as NASA moves toward lunar exploration, it is looking to reap the full benefit of collaborative science and exploration activities. Mr. Kenneth Bowersox, Chair of the HEOC, noted that it was good to be reminded of the overlapping ties between Human Exploration and Operations Mission Directorate (HEOMD) and SMD. The common driver of both directorates is curiosity about the world that surrounds us.

#### SMD Cislunar Activities Overview

Dr. Zurbuchen presented the initial part of a briefing on NASA science in the context of exploration, saying that he was excited about working with HEOMD, as SMD and HEOMD belong together hand-in-glove, and should not be pitted against each other. This collaboration is expected to enable unanticipated discoveries. It is a fast-moving plan, but there is much trust between the two directorates. Dr. Zurbuchen reviewed the five parts of SMD, in the context of inspiration; the Earth Science Division is doing tremendous research on the Earth system with respect to its connections and modalities. The Joint Agency Satellite Division (JASD) links NASA with NOAA and weather satellites; the Heliophysics Division (HPD) studies the correlations between the Sun and the stars, the heliosphere, and the realm of plasma astrophysics, all of which affect the Earth and its infrastructure. The Planetary Science Division (PSD) strives to understand the Solar System and its worlds, and the question of whether life exists elsewhere. This latter question also drives the Astrophysics Division (APD), where an explosion of knowledge is currently under way; over 3000 exoplanets have been discovered via the missions of APD.

SMD currently has 105 operating missions and is also investing in future technologies. Research is the heart of SMD, accounting for about \$1.5B in the budget. The science fleet includes LRO and ARTEMIS (Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun) (a space weather monitor) at the Moon. The Parker Solar Probe has successfully launched and is on its way to the Sun. ICESat-2 and ICON are getting ready to launch. SMD is learning new things about the universe, and it is exciting to be part of the quest for knowledge. SMD's research can provide societal benefits, such as those offered by the Earth Science Division. The ISS continues to be a platform that improves and enables science, and has exceeded expectations. ISS carries instruments that study neutron stars, lightning, fundamental physics and ozone in the atmosphere, in collaboration with other assets at NOAA as well as at DOE.

ECOSTRESS is the latest investigation at ISS, and it went from launch to providing science data within a week's time; Dr. Zurbuchen credited the speed of implementation to HEOMD. LRO is the most powerful mission in orbit around the Moon. NASA and other countries have their sights on the Moon, not only for doing fundamental science, but for informing landing technologies for other bodies such as Mars. Mars 2020 is the next rover in the Mars program and a foundational step in support of a potential future Mars Sample Return (MSR) mission. SMD is also learning about the richness of Mars geology through its seismic mission, InSIGHT, due to land on Mars in November 2018. Dr. Zurbuchen noted that NASA has the best success record for Mars landings. Other internationals have interest in Mars and NASA using its leadership role to amplify potential partnerships, with a goal of human exploration of Mars in the 2030s or beyond. The key priorities of SMD at present are to execute a new Lunar Discovery and Exploration program in a public/private model; build on past lunar exploration and science; and plan a potential MSR mission, a decadal survey priority.

Mr. Steve Clarke, SMD DAA for Exploration, continued the presentation. The DAA for Exploration is responsible for developing and integrating a strategy to enable Moon and Mars robotic exploration, coordinating research and scientific payload development, including commercial opportunities; and identifying potential interdisciplinary research and technology opportunities. NASA is starting to integrate science and human exploration in architecture development, also involving the Space Technology Mission Directorate (STMD). Transformative lunar science, identified by the decadal survey,

includes establishing the period of giant planet migration in the Solar System (SS); absolute chronology for SS events; using the far side to view the universe; discovering the sources of lunar water and the water cycle; the nature of the lunar interior; and plasma interactions with the lunar surface. CubeSats have matured significantly for science purposes. LunaH-Map (Lunar Polar Hydrogen Mapper), being built by the Arizona State University, is slated to fly on first Space Launch System (SLS) mission, Exploration Mission 1 (EM-1). For the developing Gateway, there are ongoing discussions about putting science instruments on its exterior. NASA is seeking partnerships to develop the first element of Gateway to do cislunar research. SMD is making progress in establishing commercial lunar payload services, and will be procuring services to build small science landers, through a ten-year Indefinite Delivery Indefinite Quantity (IDIQ) Commercial Lunar Payload Services (CLPS) contract. SMD intends to award contracts by the end of this calendar year and is releasing the RFP today. The lunar-orbiting LRO has the capability to characterize future landing sites for the CLPS contractors as well as future international partners that will be flying lunar landers.

The Apollo Next Generation Sample Analysis (ANGSA) research call is under way. NASA is reviewing proposals, which probably will be awarded in early 2019. Vice President Mike Pence recently visited the sample curation facility at Johnson Space Center, viewing the site that will provide new research opportunities with modern analysis tools.

The SMD lunar integration process is progressing, with consideration of science opportunities in cis lunar space, low lunar orbit, and surface operations. From a heliophysics standpoint, there is an opportunity to obtain more information about how the solar wind interacts with the lunar surface. These studies can improve space weather models and improve the understanding of how the space environment can affect exploration crews. From an astrophysics view, there is interest in putting arrays or telescopes on the radio-silent far side of the Moon. Earth science does a lot from ISS, but the Moon provides the unique vantage point of looking at the total disc of the Earth. Humans and robots can carry out sustained science research on the Moon. The NASA Exploration Campaign timeline and strategy involves early science and tech initiatives such as CubeSats, the small commercial landers initiative, and the HEOMD lunar catalyst program to aid commercial providers. There also is a mid to large lander initiative to develop the next human-rated landers.

EM-1 is slated to launch in 2020. Small commercial landers are due to demonstrate a successful lunar landing no later than 2021, but Mr. Clarke thought it could be done in 2020; mid-sized robotic landers would follow in 2022. The Power and Propulsion Element (PPE) for the Gateway will be delivered by 2022, followed by Orion crewed exploration in the later 2020s. Exploration has a good strategy going forward, and will refine the schedule as necessary, to return to the Moon and feed forward technologies to Mars.

Dr. Cerf expressed interest in sample retrieval from the Moon, and asked about the development of pinpoint/precision landing ability for spacecraft. Mr. Clarke said that the CLPS program would be testing this ability robotically, and that the technology would also be applied to mid-sized landers (autonomous landing, hazard avoidance). HEOMD also is looking to have humans bring back lunar samples. Dr. Wadhwa asked Dr. Zurbuchen how much SMD planned to dovetail with HEOMD's initiatives. Dr. Zurbuchen said that discussion is now under way to get the key lunar exploration and research priorities in front of the next panels being stood up for both the planetary and astrophysics decadal surveys that are coming in the early 2020s, so that advanced studies could be performed in areas that the communities identify.

#### HEOMD Cislunar Gateway Overview

Mr. William Gerstenmaier, Associate Administrator (AA) for HEOMD, reported good synergy between ISS and SMD, that will leverage capabilities for Gateway and help Gateway support science in better

ways. Space Policy Directive 1 is an innovative and sustainable program that will enable NASA to create infrastructure that can be used by both NASA and the international science community. The Directive creates some urgency. Mr. Gerstenmaier reviewed strategic principles for exploration, highlighting fiscal realism along with scientific exploration. HEOMD sees science as going first to lead the way for exploration. The radiation monitor on the Mars Science Lander (MSL) is an example; it has been found that the actual radiation dose on Mars is similar to that which astronauts experience on ISS. The Mars Oxygen Experiment for In Situ Resource Utilization (MOXIE) instrument on the Mars 2020 rover will test whether oxygen can be pulled out of the Mars atmosphere for breathing, and to be used as an oxidizer for propellants. The Alpha Magnetic Spectrometer (AMS) on ISS has helped to improve the understanding of particles in space; i.e. the radiation profile and how it changes over time, which may give new clues as to how to shield crews from radiation. Once the human (Gateway) platform is in place, it can enable science just as ISS does, through technology pull and push principles. The idea is to gradually build capability: developing descent and ascent engines for lunar exploration will have applications for Mars EDL capabilities, and eventually an ascent vehicle for Mars. Architectural openness; global collaboration and leadership; and continuity of human spaceflight round out the remainder of the strategic principles. On the path to lunar surface, there are many advantages of SMD and HEOMD working together. The two directorates may want to consider integrated goals in the decadal survey process.

Mr. Jason Crusan, Director of the Advanced Exploration Systems (AES) Division of HEOMD, provided an update on Gateway formulation activities, as HEOMD works to establish this critical piece of infrastructure to enable a human return to the Moon. The objectives of AES are to enable crews in the cislunar environment and lunar surface; establish science requirements for lunar discovery and exploration; prove technologies for lunar missions that feed forward to Mars; and pursue industry and international partnerships to develop and operate the Gateway. The packaging of the Gateway infrastructure has evolved over time. PPE will be the first launch package that goes to the Gateway to enable early science. HEO will continue enhancing and upgrading the communication abilities, and will include a small pressurized volume to enable extended crew time in space. The habitation module concept has been expanded to two habitats in concert, increasing space for biological research. It is anticipated that the logistics vehicle will be obtained commercially. Initially, commercial Cygnus vehicles will be used to test fire safety. Logistics carriers can also be used as free-flying science platforms. The last element to be placed at Gateway will be an airlock, which while being designed to be largely extravehicular activity (EVA)-free, will require some maintenance. The logistics chain can be used to bring samples back from the Gateway. A robotic arm is planned as well, mainly for science payload manipulation.

Unlike ISS, the Gateway will have more capability to change its trajectory, and move to many different orbits in cis-lunar space. As an overall pressurized volume, it will comprise about 10% of ISS. Gateway will operate on 70 to 80 kW, which is about 40% of the power production of the ISS. Mr. Bowersox commented that the basic functions are the same as the original Gateway proposal, and asked about the progress of the international partnerships. Mr. Crusan reported that international partners are stepping up over time, and are working in parallel with their industry partners, evolving their participation. HEOMD will update the concepts as agreements are formalized. NASA has also published interoperability standards. Commercial entities are expected to participate in PPE. Dr. Cerf asked if the Gateway, being highly modular, could be assembled out of sequence. Mr. Crusan said the order of assembly is not as flexible as that of ISS; there is some dependency for adding tanks for the PPE. The plan is to have the first logistics flight bring up the robotic arm, thus the airlock won't be needed at the beginning of assembly. Mr. Gerstenmaier commented that NASA wants to accommodate research immediately; as Gateway is intended to be a hybrid human/robotic/science vehicle, there will be long unintended periods. For sample analysis, there have been some suggestions for including computing assets and gloveboxes. There should be some trade space for doing sample analysis on-orbit vs. on Earth.

The current timeline for Gateway has an Advanced Solar Electric Propulsion (SEP) launch in 2022, with a one-year commercial period before the handoff to NASA. Enhanced habitation will include one U.S. and one international module. For enhanced science and operations, every logistics flight will enable about 90 days of crew operation. PPE has a 2022 launch date; an innovative procurement is under way for PPE through a Broad Area Announcement (BAA). A draft BAA was issued in July 2018 and the final BAA expected in September 2018. Every element has a 15-year lifetime, from time of launch, with on-orbit life extensions, and assuming xenon fuel, with an ability to refuel.

For the U.S. portion of habitation development, NASA is now holding six studies in parallel, under the NextSTEP initiative, with Lockheed Martin, Northrop-Grumman, Bigelow, Boeing, Sierra Nevada, and NanoRacks. The BAA is intentionally not a build-to-design concept; each company has its own concepts. Two vendors are looking at expandable structures. NanoRacks is looking at repurposing upper stages, which have thicker walls than standard habitats; this is a novel idea. There are many design choices to consider, and these will inform requirements. Prototypes will start coming in by early Spring of 2019. NASA has also engaged with universities for habitat designs and layouts; LED fabric screens are one such concept arising from this engagement. A number of ISS crew members are interacting with human factors testing, incorporating many lessons learned. A near-rectilinear halo orbit (NRHO) has been chosen as the nominal orbit for Gateway, which can be biased toward libration points 1 or 2 (L1 or L2), and could be optimized for the south pole of Moon. A minimum performance requirement would be two large maneuvers (from one orbit to another). Mr. Gerstenmaier said that HEOMD also wants Gateway to be able go to a halo orbit around L2 for far-side lunar activities. The limit here is that the time of the maneuver is 150-160 days. These maneuvers will also inform operations in deep space, and maneuverability throughout the Solar System. Gateway can also provide a staging orbit for lunar operations. Gateway can be thought of as a non-disposable Apollo service module; it just needs protracted time to change to low lunar orbit. Data relay services also will be available right at the beginning, and can advance over time to optical communications systems.

Gateway will have a four-person crew residing on board from 30-90 days per increment, in about 10% of the pressurized volume of ISS. It will orbit 384,000 km from Earth, and will be accessible via SLS. Its disposition in space is a six-day orbit around the Moon; the first crewed mission will be either a six- or 12-day mission. First aimed at lunar sample return, the Gateway will serve as a hub for further destinations. Dr. Tamara Jernigan asked Mr. Crusan to name his top concerns. Mr. Crusan said that the very fast development schedule is a challenge, but that he still thought it should be aggressive. Technical engineering is another challenge, as NASA gains more understanding about low energy transfers. Life support systems and pressurized volumes are well understood thanks to experience on ISS, but the systems also are a challenge to put together. NASA is looking at accommodation of both U.S. and Russian pressure suits. Suit advances include a backpack designed for work both in space and for surface operations. The mass of the portable life support system (PLSS) has been reduced by about 30% thus far. The Canadians are interested in robotics, the Japanese in habitats, and the Russians in airlock capabilities. Parameters are a little less defined for Russian participation at present. NASA has developed international docking standards to potentially accommodate international crew vehicles. International partners have also expressed heavy interest in surface operations.

Mr. N. Wayne Hale commented that stable payload orbits offer a lot of things, but that HEOMD still needs to address the tradeoff of different orbits. Mr. Crusan said that over time, as landing activities and reusable landers come in, there needs to be some place to stage them. NRHO enables landers to reach any point on the lunar surface. He noted that Gateway can be moved to other optimizing orbits, but that there is also much advantage in having a stable orbit for staring platforms. Mr. Gerstenmaier commented that low propellant usage and the ease of access to any point on the Moon are the two major advantages of the Gateway's NRHO. However, HEOMD is starting to get feedback from academia on how to use weak

stability gravity regions around the Moon, and will get trade studies done in those areas. Mr. Clarke added that while NRHO is not optimal for all science requirements, the key is to find the overlapping sweet spot for both HEOMD and SMD. Mr. Bowersox asked how many docking points would be available, Mr. Crusan said there would be at least one for logistics at any given time, and two to three ports. The idea is to have things come and go. Visiting vehicles may be bringing a descent or ascent stage. Mars-class missions will have large PPEs, so HEO is looking at how to control these stacks as the concept matures. Mr. Gerstenmaier remarked that keeping the architecture open and adaptable, while learning from ISS, will help Gateway upgrade and change over time. Dr. Wadhwa asked how NASA was engaging emerging international partners. Mr. Crusan described an ongoing bilateral process. NASA is considering a South Korean contribution to Gateway science through open discussions, and is open to adding partnerships over time. Published interoperability standards will help this process. Mr. Weiser asked how much simulation work is being done to test ideas. Mr. Crusan pointed to academic work in low energy transfers, but that some work is restricted to domestic government. Mr. Gerstenmaier said that work on orbits is similarly constrained; however, he maintained that NASA is very open to ideas; promulgating voluntary open standards is a big step forward. Standards development has been carried out very effectively with radiofrequency standards, and NASA is trying to do the same thing with avionics standards. This opens the architecture to the world.

Dr. Patterson asked if Gateway were capable of deploying CubeSats. Mr. Crusan said yes, it was. Mr. Gerstenmaier said this latter point illustrated how well ISS has evolved; while CubeSats were not envisioned for ISS, these ended up being an effective way of understanding how satellites work. There will be 13 CubeSats on EM-1. Ms. Nancy Ann Budden added that there were also DOD applications for CubeSats. Mr. Bowersox asked about progress in space debris mitigation. Mr. Crusan said that traffic management was considered under Space Directive 3, and NASA will have to consider how it is implemented in LEO. Mr. Bowersox voiced a real fear of having permanent debris around the Moon and stressed that HEOMD needs to think about it carefully.

#### Gateway and Landed Science

Mr. John Guidi presented a briefing on preparations for anticipated activity at the Gateway, which include identifying high priority technologies; developing commercial use of the Gateway independent of NASA interests; enabling collaboration with internationals; and identifying Gateway uses for science and research. All elements of the Gateway will have external payload accommodations and all pressurized volumes will have internal accommodations.

A February 2018 Deep Space Gateway workshop was held in Denver, CO, featuring 180 talks in five parallel sessions, encompassing 300 attendees. The output of this conference was a proposed 220 investigations, with 7200 data items. Key takeaways from the workshop are that NRHO offers unique advantages for some Earth science, heliophysics, astrophysics, and fundamental physics investigations, as well as some exoplanet imaging applications. With additional transportation such as “space tugs,” Gateway can enable lunar science, provide externally mounted sample collection ports, and study the space radiation environment in biological systems. Science will be constrained until the robotic arm can be installed. Overall, NASA will need to coordinate with partners in order to avoid duplication and maximize science.

Engineering takeaways are that external payloads may benefit from precise pointing and long duration stare modes. For external delivery of science elements, there is concern for contamination, especially when using a common set of analytical equipment. For automating internal payload interactions, there needs to be some thought given to how to remotely control componentry in the absence of crew. The Gateway has potential to generate much science data, however there are many potential constraints. The radiosilent far side of the Moon might be impacted by Gateway radiofrequency noise; navigation and timing issues need to be elucidated; and lunar operations will require significant infrastructure investment.

Currently it is assumed that there will be a central data recorder for payloads and onboard data computing ability to handle large amounts of data. In addition, optical science investigations will have to deal with the vibrational environment. A generic telescope facility, with sensors, may also reside inside Gateway.

Significant volume could be used for internal experiments. There is great interest in multi-use analytical equipment, and onboard storage of space radiation environment data from payloads. Such data could be used as metadata for other payloads involving space biology or crew health. Gateway infrastructure capabilities could include CubeSat or small satellite deployment platforms; communication relay/navigation equipment; and teleoperations of space or surface assets by Gateway crew or Earth payload operators for running experiments, launching CubeSats, or simple maintenance.

Sample return concepts at Gateway include dust collectors; docking of sample return spacecraft; science airlocks; glove box and in-situ analysis capabilities; cold storage units for space biological and return samples; and possibly external analytical equipment, which would decrease the need to open “dirty” lunar samples inside the Gateway. Currently, upmass for Gateway is envisioned as 1000kg; most instruments are far below this mass. Power requirements are 4kW during maximum use for science (most experiments do not need this much power). Power limits are still to be determined for un-crewed activities. Internal volume for science is a total of 12.5 cubic meters. Daily data volume is estimated at 5.15Tbits/day, thus 644GB/day is taken to be a reasonable assumption for most science needs. Dr. Cerf noted that this would depend on data rates; at 622 Mbits/second, it takes half an hour to send a terabit.

The European, Japanese, and Canadian space agencies have had their own science meetings on Gateway, and NASA is sharing data with these partners. All agencies are participating in the Gateway design and development process.

Gateway is benefiting from key ISS lessons learned: target and engage SMD and science communities early; consider having a utilization location within the program office; consider new accommodations of internal racks (incorporating modern improvements); and prioritize science among partners and users. Near-term activities include putting GPS/navigational sensors on the Gateway; consideration of utilization during un-crewed periods (automated operation); external location of experiments; logistics and dual-use logistics vehicles; external arm delivery; and standards considerations for common laboratory equipment to maximize science return. Asked about the space trash issue by Dr. Secada, Mr. Guidi said that it is recognized that debris is a problem, and that ISS teams will hold discussions on how to mitigate it. Dr. Wadhwa commented that it was important to not contaminate samples and analytical equipment, and that trades would have to be carefully considered.

Dr. Sarah Noble continued the briefing via telecon, switching gears to discussing community input to lunar science. SMD is continuing to put together workshops on the subject, including the Survive and Operate Through the Night Workshop to take place in the Fall. The Scientific Context for the Exploration of the Moon (SCLEM) report of 2007, a comprehensive assessment of potential lunar science investigations, is now out of date and in the process of being updated. The Advancing Science of the Moon Specific Action Team (ASM-SAT) set out to update eight high-priority target areas previously identified by the SCLEM, to determine where progress could be made. As an example, the ASM-SAT addressed Concept 3 (Key planetary processes are manifested in the diversity of lunar crustal rocks). Goal 3a is to determine the extent of the primary feldspathic crust and other products of planetary differentiation which can lend insight to planetary and small body formation. A potential study would be to examine rebound materials in craters to confirm some formation hypotheses. Goal 3b is to inventory the variety, age, distribution and origin of lunar rock types, particularly because it is now known (through chemical signatures) that there are lunar rocks that are not currently represented in NASA’s current lunar sample collection. Other studies within this purview would be to determine the bulk composition of the Moon, quantify the local and regional complexity of current lunar crust, and determine vertical extent and

structure of megaregolith. Some concepts not called out in the original SCEM report were also identified; these are: lunar water cycle; origin of the Moon; and lunar tectonics and seismic activity. NASA now is in a stronger position to take advantage of landed missions, and to identify ideal landing sites to further these studies.

The Next Steps on the Moon Special Action Team (NEXT-SAT) also has identified investigations that address key science questions, which include a variety of impactors, CubeSats, small satellites, a fixed stationary lander, a mobile rover, and sample return missions. Some desired technology investments for these missions include precision landing and hazard avoidance, and thermal management in cryogenic environments. Surface missions could investigate lunar magnetic anomalies, increase the understanding of magnetic “swirl” patterns, and obtain in-situ measurements with a lander. A lander with mobility would be the best way to measure changes across a swirl site. Sample return also can be informative here.

ARC held a Lunar Science for Landed Missions workshop in January of this year, which was co-chaired by the Lunar Exploration Analysis Group (LEAG) and Solar System Exploration Research Virtual Institute (SSERVI). The resulting reports identified many sites, and detailed excellent science to be done at every step. The reports have been archived. Dr. Wadhwa asked Dr. Noble to highlight specific results from the last decade that helped to prioritize goals. Dr. Noble cited the discovery of novel rock types, and lunar water findings. Areas of pyroclastic deposits seen from lunar orbit can be potential targets for water discovery.

#### Transformative Lunar Science

Dr. Nicolle Zellner presented new ideas about how to study the bombardment of the Moon and what it can reveal about the impact history of Earth. The Moon’s surface is largely undisturbed, and its cratering rate can help yield information about interesting terrestrial events that correlate in time with lunar bombardment. Lunar impact samples can yield important information that can be applied to understanding biological events on Earth and Mars and may even eventually be extrapolated to exoplanets. Recent advances in lunar sample analysis are showing that lunar bombardments are tapering off over time. Early studies of samples from the Apollo missions seemed to indicate there was a terminal lunar cataclysm 3.9B years ago, and there is isotopic carbon evidence indicating that first life on Earth appeared shortly after the hypothesized lunar cataclysm. The National Research Council (NRC) has stated that determining the lunar impact flux is a science high priority. One of the ways to interpret lunar impact data is to examine samples, of lunar glasses in particular. There are two types of lunar glasses: volcanic, which contain water and other volatiles, and impact. Impact glasses are small and numerous in the Apollo sample collection, and can be examined with electron microscopy. Some glasses are unique in composition and history. For example, there is some indication that there was an influx of material on the Moon about 800 million years ago, which might point to a breakup of material in the asteroid belt that then fell onto the Moon. More data on this would help to answer the question of the nature and timing of lunar impacts and whether a 3.9B-year-old cataclysm, in particular, actually occurred.

LRO provided new data that resulted in new interpretations of the bombardment history of the Moon. Laser altimetry data, for example, identified a number of new basins on the Moon, implying that a greater number of impacts occurred before the 3.9B year mark, and some of these impacts may be as old as 4.5B years, implying prolonged bombardment for hundreds of millions of years, and not just the “terminal” cataclysm hypothesized at 3.9B. Isotope re-calibrations show that many Apollo samples may have been contaminated by the major Mare Imbrium-forming event of 3.9B years ago. Thus, lunar samples are being re-examined with newer analytical techniques that are providing more detailed interpretations of samples.

Dynamical models also are being developed, improved, and applied to understanding the lunar bombardment. For example, the family of Hungaria asteroids that sit far above the plane of the ecliptic

may have been responsible for prolonged bombardment, as they moved into this position as a result of major relocation events in the Solar System (e.g., Uranus and Neptune changing place). Additionally, there is evidence on Earth of impact samples (glasses, spherules) in terrestrial Archean sediments that support the idea of a prolonged bombardment. GRAIL data on lunar gravitational anomalies have also helped to identify new lunar basins, and to establish that the six known basins are larger than previously measured, constituting more evidence that the Moon's early impact flux needs to be revisited. Modern findings are starting to upend the 3.9B cataclysm concept; a "sawtooth" bombardment (i.e., prolonged) seems to be more supported. In relation to biological events on Earth, old biogenic carbon found in a zircon provides evidence that a biosphere may have existed on Earth 4.1B years ago, which further supports theories of biological niches surviving on Earth in spite of (less cataclysmic) impacts. Some asteroidal material has been found in lunar samples, and it is believed that the asteroid Vesta is represented by some meteorites. Obtaining more lunar samples will help us learn more about the Earth and Solar System in general. Ms. Budden noted that Johnson Space Center has had many workshops over the last 30 years, and the basic reasons for going back to the Moon remain the same, but they are more compelling with the new body of knowledge.

Dr. Jack Burns provided an astrophysics perspective on returning to the Moon. A SSERVI team, has identified a number of concepts, the first of which is low-frequency radio heliophysics, to study coronal mass ejections (CMEs) from the Sun. CMEs are accompanied by solar bursts (type II and III), for which there are limited data. Low-frequency arrays on the moon can make observations of these bursts. SunRISE is a mission concept now in a Phase A study, which will launch in 2022 if funded. The mission concept comprises six CubeSats. Ideally, an array of antennas on the lunar surface could make these low-frequency (1-10 MHz) measurements, and determining the timing and location of solar bursts would help to inform and refine space weather alerts. Radio observations also can inform planetary magnetospheric science and detect the space weather environments of extrasolar planets. Magnetic fields can help shield life; extrasolar planet magnetic fields can be detected by low-frequency radio emissions from the Moon. The long-term future for such low-frequency arrays will be on the radiosilent, far side of the Moon.

For astrophysics and heliophysics, next-generation 10-15 meter aperture telescopes could be constructed in space and sent to L2, to characterize the atmospheres of potentially habitable planets. Assembly could be done via robotics and human astronauts at the Gateway; the delta-v necessary to move a telescope to L2 is modest. Dr. Burns thought this concept would appear in the next decadal survey. The basic questions to be answered by such a telescope are: What is first light? What characterizes the first stars and galaxies? The distribution of neutral hydrogen is informative here. A large space telescope could investigate stars out to redshifts of 30-100, and help to more closely bound the origins of the universe.

Dr. Burns detailed a Dark Ages Polarimeter Pathfinder (DAPPER) concept to search for deviations from the standard model of cosmology, possibly produced by dark matter, via low-frequency radio absorption. There are many papers which speculate that dark matter cooling plays a role here. High redshift areas are the perfect places to look for exotic physics, and arrays on the lunar far side can help in the search. Mission concept work is underway for a "1% Pathfinder." A lunar mission simulation has modeled deployment of radio telescope elements on lunar surface, and the construction of a robotic rover using an arm and 3-D printed elements. The experimental array subsequently detected an FM band, demonstrating proof of principle.

The Gateway also can serve as infrastructure for lunar robotics, to provide communications relays and "orbital computing," or a Space Cloud, at the Gateway. Studies also are being conducted in a virtual reality/augmented reality (VR/AR) simulation testbed, with the aim of improving surface telerobotics on the far side of the Moon, and enabling rover teleoperation. Initial work has looked at the problem of glare, a major issue during the Apollo era. VR/AR can also be used to train astronauts.

Dr. Larson asked how the Gateway makes telescopic construction any more feasible than ISS. Dr. Burns said the Gateway was closer to L2, as one example, but that he would have to defer to other experts to answer the question. Dr. Cerf commented that remote control from Earth would suffer from considerable latency; it would be very close to the “cognitive horizon,” a lesson learned from extensive work in medical telerobotics. Any latency longer than a half-second is problematic. A delay as little as 2.5 seconds is extremely frustrating to operators. The implication is that you have to be closer to Earth to deploy telerobotics. Dr. Burns agreed, noting that the problem also feeds forward to Mars. In response to a question, Dr. Burns felt that the new astrophysics decadal survey would almost certainly show interest in cosmic dawn missions.

#### Public Comments

No public comments were noted.

#### Discussion, Findings and Recommendations

Mr. Bowersox began the session wrap-up and discussion of potential findings and recommendations. He commented favorably on the good cooperation between SMD and HEOMD, which has demonstrated that there is much interesting work to be done in cislunar space and from lunar orbit, with added synergies between cislunar and lunar orbit. It will be important to prioritize science through the decadal surveys in concert with HEOMD. Dr. Cerf offered a strong endorsement of the Gateway platform, saying it offered exciting possibilities, and a terrific opportunity to demonstrate networking capabilities for communications. General Lyles presented questions emanating from the National Space Council: Is there a balance between exploration and science discovery? Is there more that can be done to ensure the balance is maintained? Dr. Budden pointed to an observation from the HEOC which acknowledges the advancement toward Gateway; she agreed to share it for expansion into a joint finding. Dr. Jernigan asked whether an international cooperation finding might be warranted, as such cooperation was as important to ISS as it is anticipated to be for Gateway. Dr. Scowen cautioned about whether the Gateway is pristine enough for astrophysics in terms of ultraviolet spectrum throughput. Vibration also would limit the value of optical instruments mounted on the Gateway.

Mr. Hale commented on NASA’s adherence to the decadal surveys and asked how much was actually being implemented. Dr. Wadhwa noted that the new astrophysics decadal survey will be valuable for the Gateway. General Lyles asked if there were any policy barriers that preclude the balance between discovery and exploration. Dr. Wadhwa felt that community-driven science would support the balance. Mr. Gerstenmaier said there were similar decadal survey guidelines for HEOMD, and didn’t see any conflict with science. He felt their goals were very much in alignment. He recommended a joint finding on the “two-way street” between HEOMD and SMD. Dr. Scowen added that the decadal survey process is flexible and allows response to development and discovery. Dr. Cerf asked if there had ever been a decadal survey about infrastructure to support a joint human-robotics effort. Mr. Bowersox noted that there was a recent National Academies’ pathway report that was meant as a decadal survey guideline for HEOMD. Mr. Gerstenmaier commented that human spaceflight is so diverse, and there have been a vast number of recommendations that are hard to prioritize. Exploration is more driven by aspiration, which then leads to infrastructure, which in turn becomes an enabler for science. It is hard to fit human spaceflight into the decadal survey paradigm. Dr. Larson felt this was a real opportunity to give NASA support at a seminal time. Mr. Weiser cited two striking issues: collaboration, and the development of teleoperated robotic rovers. There are a number of commercial entities working on these technologies that can help reduce cost, weight and time for both parties. Dr. Verbiscer echoed Dr. Jernigan’s statement on including international partners. Dr. Jernigan suggested adding a comment on the complementary and symbiotic nature of human-robotic interaction. Dr. Scowen felt that science and exploration are not quite on an equal footing at the Gateway. Mr. Bowersox agreed, saying that critical exploration requirements would be likely to have priority over science requirements, but that the science community needs to

clearly articulate their requirements and priorities to maximize the utility of the Gateway, and the conflicting priorities could be handled through an arbitration process. .

The committees briefly broke to write joint draft findings and recommendations, then came to consensus on final language.

The session was adjourned at 3:00 pm.

## Appendix A Meeting Attendees

### NAC Science Committee Members

Meenakshi Wadhwa, Arizona State University, *Interim Chair*  
Susan Avery, Woods Hole Oceanographic Institute  
Vinton Cerf, Google, Inc.  
Mihir Desai, Southwest Research Institute  
Kathryn Flanagan, Space Telescope Science Institute  
Jeffrey Hoffman, Massachusetts Institute of Technology (*via telecon*)  
Tamara Jernigan, Lawrence Livermore National Laboratory  
Michelle Larson, Adler Planetarium  
Michael Liemohn, University of Michigan (*via telecon*)  
Pat Patterson, Space Dynamics Laboratory  
J. Marshall Shepherd, University of Georgia, Chair, Earth Science Advisory Committee (*via telecon*)  
Walter Secada, University of Miami  
Paul Scowen, Arizona State University (*designee, Astrophysics Advisory Committee*)  
Anne Verbiscer, University of Virginia, Chair, Planetary Science Advisory Committee  
Marc Weiser, RPM Ventures  
Elaine Denning, NASA Headquarters, *Executive Secretary*

### Human Exploration and Operations Committee (HEOC) Members

Kenneth Bowersox, Aerospace Consultant, *Chair*  
Nancy Ann Budden, Office of the Secretary of Defense  
Stephen “Pat” Condon, Aerospace Consultant  
Ruth Gardner, Kennedy Space Center  
Tommy Holloway, Aerospace Consultant  
Lon Levin, SkySeven Ventures  
Mark McDaniel, Attorney  
Michael Lopez-Alegria, Commercial Spaceflight Federation  
James Voss, University of Colorado, Boulder  
Bette Siegel, NASA Headquarters, *Executive Secretary*

### NASA Attendees

Daniel Andrews, NASA ARC  
Brad Bailey, NASA ARC  
Jaya Bajpayer, NASA ARC  
Michael Bicay, NASA ARC  
Angela Boyle, NASA ARC  
Sandra Cauffman, NASA HQ  
Anthony Colaprete, NASA ARC  
Jason Crusan, NASA HEOMD  
Kristina Gibbs, NASA SSERVI  
Jamie Favors, NASA HQ, ESD  
John Guidi, NASA HEOMD/AES

N. Wayne Hale, NAC  
Bill Hill, NASA HEOMD/ESD  
John Karcz, NASA SMD and ARC  
David Korsmeyer, NASA ARC  
Laura Lent, NASA ARC  
Gen. Lester Lyles, NAC Chair  
Forrest Melton, NASA ARC  
Thomas Roellig, NASA ARC  
Sam Scimemi, NASA HEO ISS  
Kimberly Ennico Smith, NASA ARC  
Sid Sun, NASA ARC  
Jay Trimble, NASA ARC  
Ryan Vaughn, NASA  
Allison Zuniga, NASA ARC  
Thomas Zurbuchen, SMD AA, NASA HQ

Non-NASA Attendees

Jack Burns, University of Colorado  
Ravi Deepah, Science and Technology Corp.  
David Frankel, PB Frankel, LLC  
Patricia Sanders, NASA ASAP  
Alan Steremberg  
Ana Wilson, Zantech IT  
Nicolle Zellner, Albion College  
Joan Zimmermann, Zantech IT  
Robert Zimmermann, Symbiotek

Telecon/Webex Attendees

Ogan Abaan, SB Genomics  
Gale J Allen, NASA  
Louis M Barbier, NASA  
Francesco Bordi  
Lynn Bowman, NASA  
Lin Chambers, NASA  
Stephen Clark, Spaceflight Now  
Christopher Dateo, NASA  
Tremayne Days, NASA  
Monty DiBiasi  
Jessie Dotson, NASA  
Kelly Fast, NASA  
T. Jens Feeley, NASA  
Jeff Foust, Space News  
Martin Frederick, NGC  
Ellen Gertsen, NASA  
Stephanie Getty, NASA  
Lori Glaze, NASA

Helen Grant, NASA  
James Green, NASA  
Paul Hertz, NASA APD  
Gordon Johnston, NASA  
Ben Kallen, Lewis-Burke  
Jason Kalorai, STScI  
Erin Kennedy, GAO  
Irene Klotz, Aviation Week  
Janet Kozyra, NASA  
Rob Landis, NASA  
Doug Lassiter  
Tsengdar Lee, NASA HEC  
Marcia Lindstrom, NASA  
Sarah Lipsky, Ball Aerospace  
James Lochner, USRA  
Jacilyn Maher, NASA  
Nivedita Mahesh, ASU  
Hemil Modi, NASA  
Mark Mozena, ULA  
Kevin Murphy, NASA  
Rachel O'Connor, Ball Aerospace  
Joshua Peek, STScI  
Eliana Perlmutter, Lewis-Burke  
Julie Pradel, Stetson U.  
Jose Ramos, GAO  
Naseem Rangwala, NASA  
Ursula Rick, Univ. of Colorado  
Joey Roulette  
Mary Sladek, NASA  
Gerald S. Smith, NASA  
Marcia Smith  
Stephen C. Smith  
Micheline Tabache, ESA  
Paul Voosen, AAAS  
Nicholas White, USRA  
Ashlee Wilkins, AAS  
Alexandra Witze, Science  
Dan Woods, NASA HQ

## **Appendix B**

### **NAC Science Committee Membership**

Dr. Meenakshi Wadhwa (Interim Chair)  
Arizona State University

Dr. Susan K. Avery  
Woods Hole Oceanographic Institution

Dr. Vinton Cerf  
Google, Inc.

Dr. Mihir Desai  
Southwest Research Institute

Dr. Kathryn Flanagan  
Space Telescope Science Institute

Dr. Jeffrey Hoffman  
Massachusetts Institute of Technology

Dr. Tamara E. Jernigan  
Lawrence Livermore National Laboratory

Dr. Michelle Larson  
Adler Planetarium

Dr. Michael Liemohn  
University of Michigan

Dr. Feryal Ozel  
University of Arizona

Dr. Pat Patterson  
Space Dynamics Laboratory

Dr. Walter G. Secada  
University of Miami

Dr. J. Marshall Shepherd  
University of Georgia

Dr. Anne Verbiscer  
University of Virginia

Mr. Marc Weiser  
RPM Ventures

Ms. Elaine Denning (Executive Secretary)  
NASA Headquarters

## Appendix C Presentation Materials

1. NASA Science Update; *Thomas Zurbuchen*
2. Planetary Science Advisory Committee (PAC) R&A Charge Responses; *Anne Verbiscer*
3. R&A Charge to SMD Advisory Committees; *Marshall Shepherd (ESAC)*
4. Response to the High-Risk/High-Reward Charge; *Paul Scowen (APAC)*
5. HPAC: Heliophysics Advisory Committee Report to the Science Committee, *Michael Liemohn*
6. Earth Observing System Innovations; *Sandra Cauffman*
7. Earthdata Cloud – Modernizing EOS Data and Information System (EOSDIS) for Commercial Cloud Operations; *Kevin Murphy*
8. From the Sun’s Corona to the Edge of the Heliosphere: New Frontiers of Heliophysics Research; *Mihir Desai*
9. NASA Ames Research Center: An Overview; *Eugene Tu*
10. Building Companies Using Open Data – Weather Underground; *Alan Steremberg*
11. SMD Cislunar Activities Overview; *Thomas Zurbuchen, Steven Clarke*
12. Cislunar and Gateway Overview; *William Gerstenmaier, Jason Crusan*
13. Gateway Science Summary; *John Guidi*
14. Community-Driven Priorities for Lunar Landed Science; *Sarah Noble*
15. Rethinking Solar System Bombardment: New Views on the Timing and Delivery of Lunar Impactors; *Nicolle Zellner*
16. Transformative Science from the Moon: Astrophysics, Cosmology and Heliophysics; *Jack Burns*

## Appendix D

### Agenda



Dial-In (audio) & WebEx (view presentations online) information is located on page 3.

#### NASA Advisory Council Science Committee

**August 27-28, 2018**

**NASA Ames Research Center  
NASA Ames Conference Center, Building 3  
Moffett Field, CA 94035**

#### **Agenda** **(Pacific Time)**

##### **Monday, August 27– Location – Showroom**

8:00 – 8:05	Opening Remarks	Ms. Elaine Denning Dr. Meenakshi Wadhwa
8:05 – 8:30	SMD Overview	Dr. Thomas Zurbuchen
8:30 – 8:45	Goals of Meeting / Introduction of Members	Dr. Meenakshi Wadhwa All
8:45 – 10:00	Division Advisory Committees R&A Charge Responses Planetary Science Advisory Committee Earth Science Advisory Committee Astrophysics Advisory Committee Heliophysics Advisory Committee Discussion	Dr. Anne Verbiscer Dr. Marshall Shepherd Dr. Paul Scowen Dr. Michael Liemohn All
10:00 – 10:15	<b><i>Break</i></b>	
10:15 – 11:00	SC R&A Charge Response Finalization	All
11:00 – 12:00	Earth Observing System Innovations Earth Science Data Buy Hosting Platforms for Instruments Public/Private Partnerships Science Activation Partnerships Earthdata Cloud – Modernizing EOS Data and Information System (EOSDIS) for Commercial Cloud Operations	Ms. Sandra Cauffman Mr. Kevin Murphy
12:00 – 1:00	<b><i>Lunch</i></b> – Member Research Presentation “From the Sun’s Corona to the Edge of the Heliosphere: The New Frontiers of Heliophysics Research”	Dr. Mihir Desai



Dial-In (audio) & WebEx (view presentations online) information is located on page 3.

1:00 – 1:30	Ames Research Center Director Welcome	Dr. Eugene Tu
1:30 – 2:00	Discussion of Public/Private Partnerships	All
2:00 – 3:00	Big Data Products Finalization	All
3:00 – 3:10	<b><i>Break</i></b>	
3:10 – 3:15	Public Comments	
3:15 – 3:45	Discussion, Findings and Recommendations	All
3:45 – 4:30	Building Companies Using Open Data – Weather Underground	Mr. Alan Steremberg
4:30 – 5:00	Outbrief for SMD AA	Dr. Thomas Zurbuchen
5:00	<b><i>Adjourn SC Meeting</i></b>	

**Tuesday, August 28 – Location – Ballroom**

8:00 – 8:10	Opening Remarks	Ms. Elaine Denning Dr. Meenakshi Wadhwa Dr. Bette Siegel Mr. Ken Bowersox
8:10 – 9:15	SMD Cis-lunar Activities Overview	Dr. Thomas Zurbuchen Mr. Steven Clarke
9:15 – 10:15	HEOMD Cis-lunar Gateway Overview	Mr. William Gerstenmaier Mr. Jason Crusan
10:15 – 10:30	<b><i>Break</i></b>	
10:30 – 11:30	Gateway and Landed Science	Mr. John Guidi Dr. Sarah Noble
11:30 – 12:30	Transformative Lunar Science	Dr. Nicolle Zellner Dr. Jack Burns
12:30 – 1:15	<b><i>Joint Lunch</i></b>	
1:15 – 1:20	Public Comments	
1:20 – 2:45	Discussion, Findings and Recommendations	
2:45	<b><i>Adjourn Joint Meeting</i></b>	



Dial-In (audio) & WebEx (view presentations online) information is located on page 3.

#### **Dial-In and WebEx Information**

##### For August 27:

**Dial-In (audio):** Dial the USA toll free number 1-888-324-2680 or toll number 1-517-308-9418 and then enter the numeric participant passcode: 8870080. You must use a touch-tone phone to participate in this meeting.

**WebEx (view presentations online):** The web link is <https://nasa.webex.com>, the meeting number is 995 388 125, and the password is SC@Aug2018 (case sensitive).

##### For August 28:

**Dial-In (audio):** Dial the USA toll free number 1-888-324-9238 or toll number 1-517-308-9132 and then enter the numeric participant passcode: 3403297. You must use a touch-tone phone to participate in this meeting.

**WebEx (view presentations online):** The web link is <https://nasa.webex.com>, the meeting number is 996 163 984, and the password is Exploration@2018 (case sensitive).

*\* All times are Pacific Time \**