NASA ADVISORY COUNCIL

SCIENCE COMMITTEE

July 24-25, 2017

National Institute of Aerospace
NASA Langley Research Center

Hampton, VA

MEETING REPORT

Bradley Peterson, Chair

Elaine Denning, Executive Secretary

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July 24, 2017

Opening Remarks

Ms. Elaine Denning, Executive Secretary of the Science Committee (SC), called the meeting to order, described the nature of FACA regulations, and made administrative announcements. Committee members introduced themselves around the table. Ms. Denning noted that travel disruptions were preventing Dr. Bradley Peterson, Chair of the SC, from being present at that time and that he would connect via telecon, when possible, until his arrival.

Big Data Task Force

Dr. Charles Holmes presented the fifth report of the Big Data Task Force (BDTF). The Task Force held a teleconference in June, during which members worked primarily on a set of recommendations. The BDTF heard a briefing from Mr. Craig Tupper on the newly released Fiscal Year 2018 (FY18) budget, which included particulars for data center funding and NASA's high-performance computing project. There was also an informal discussion with science program officers.

The proposed FY18 budget is mostly steady and will support continued computing capacity upgrades at Ames Research Center, and provide some modest increases in the outyears for NASA supercomputing facilities. An informal session with NASA Headquarters data and computing program managers revealed that they too are pleased with the overall budget. The Planetary Data System (PDS) released a roadmap in June after a year's effort, laying out a strategy for the archive over the next ten years. BDTF feels it is a very good document that will enable NASA to handle future computing challenges. BDTF continues to focus on four research topics, and will complete their reports on these topics in November.

Dr. Holmes briefly summarized four BDTF recommendations, noting that Ms. Denning had distributed four papers relevant to these recommendations to the SC. He went on to detail each recommendation:

Regarding the first recommendation on exascale computing, Dr. Holmes noted that the Department of Energy (DOE) is leading the Exascale Computing Project (ECP), the Federal government's effort in building the next-generation supercomputer, aiming to effect a 50-fold improvement in large scale-computing power. NASA is coordinating efforts with DOE through Dr. Tsengdar Lee, Program Manager for NASA's High-End Computing Program. The ECP is looking at a top-down, holistic approach to delivering an advanced architecture and capable exascale computing system. ECP has laid out roughly 20 application areas for which it will address national challenges in high-performance computing. There are several areas that overlap with interest areas in the NASA Science Mission Directorate (SMD). BDTF feels that NASA would derive great benefit from working with ECP, through supplying its own expertise to relevant applications areas, and bringing code to the project to make sure it runs properly. BDTF feels strongly that NASA should participate in this great leap forward, from the outset of the effort.

Dr. Holmes presented a recommendation on a so-called Science Data Superhighway, noting that the NAC IT Infrastructure Committee had brought forward similar recommendations several times previously during 2011 to 2013. DOE is building a national level 100-gigabit-per-second science network, with some support from NSF. BDTF has been distressed by NASA's non-action, in fact ignorance, about this project. NSF has provided support to 100 universities to permit intra-campus upgrades thereby providing high-speed connectivity across campuses to DOE's science network. In addition the NSF is funding a project called the Pacific Research Platform (for its origin in California universities) that has provided data terminals, working at 100 gigabits per second, to plug into this high-speed network to transmit science data. Dr. Raymond Walker, a member of the BDTF, has tested the network successfully between his research group at UCLA and the Pleaides supercomputer facility at Ames. BDTF recommends that NASA/SMD take the lead to help connect many NASA-sponsored research groups to this nationwide pipeline for science data and sponsor a program of $3-5M per year, to be divided between ROSES and the Agency's Communications Services Organization. Initially such a program officer could be recruited as an Intergovernmental Personnel Act (IPA) employee. The position could be temporary (2-3 years), after which SMD should evaluate the position's efficacy. Major reasons for this recommendation include the fact that NASA-supported research groups are being left out of this new way of doing business. NASA has in fact leveraged such efforts previously, having led the way in bringing Internet connectivity to NASA.

BDTF recommends that NASA tap into NSF's Big Data Regional Hubs and Spokes project, which covers 50 states with nearly as many grants. The project is creating an infrastructure for applying data science expertise to big data problems across the nation, and is exploring ways to succeed in data-driven discovery. The project brings mathematical, statistical, and science domains together to address sticky problems, such as pulling signals out of noisy data. BDTF further recommends that SMD encourage its research community to make contact with NSF principal investigators (PIs) to learn how to apply these new data techniques. BDTF also recommends that SMD and NSF consider a joint solicitation to bring NASA science domain experts together with NSF PIs in the Hubs and Spokes project, to start building on the NSF effort. The funding could be on a scale of $1-2M, a one-time solicitation. BDTF feels it's a win-win for both communities.

Lastly, BDTF recommends that NASA/SMD stand up a Data Science Applications Program. This program would promote applying modern data science methods to many of its sponsored science data processing and analysis activities. Locally, this is starting to happen, JPL has created a Data Science Office to help promote the application of data science techniques to solve space science problems. Dr. Holmes notes that the Space Science Telescope Institute and Ames are actively promoting data science applications in areas such as advances in computer-aided science discovery in astronomy, discoveries in volcanics formation, new relationships and agents to help predict major solar events, and emerging artificial intelligence tools. BDTF feels that NASA/SMD should establish a permanent Data Program Scientist to run a roughly $10M/year applied research program. This program officer would also convene workshops and summer schools for NASA-sponsored research PIs and associates to learn these new techniques. This program officer also would be integrated into SMD's mission development process, getting involved in Announcement of Opportunity (AOs) as appropriate, participate in major project development reviews, and also, monitor developments in science operations where data science methodologies can be applied. This position should be independent of NASA's standing data archives, but would work closely with the NASA Headquarters program officers to coordinate approaches. Initially this position would be staffed as an IPA recruited from an organization actively engaged in data science applications to space science data. BDTF strongly feels a top-down focus from NASA Headquarters is necessary to get missions in line to take advantage of new and evolving data science approaches.

Dr. Mihir Desai praised BDTF's thorough report, and asked how the community at large can be made aware of this new program element. Dr. Holmes suggested several ways: broadcasting through NSPIRES, advertising through workshops, or holding Agency nights at major conferences like the American Geophysical Union (AGU). Dr. J. Marshall Shepherd asked why the Agency was not already involved in DOE's and NSF's efforts. Dr. Holmes, citing his many years at NASA Headquarters as a program officer, said his opinion was that SMD tends to worry about large projects and solving technical problems that impact the budget, and that it would take reminders from the advisory committees to keep SMD's mind on the infrastructure. Dr. Alan Boss noted that the budget is also a contributor to the problem, as it is a zero-sum game. Dr. Susan Avery commented that it is not just infrastructure, but also a cultural issue. That's why NSF established the Hubs. These working groups can get testy, so the process will need some patience. Dr. Kathryn Flanagan noted, from an astrophysics perspective, that data volumes tend to be smaller, so the division is not as connected to the big data issue. For NASA, the ability to access and use the archives requires creative use of data. Dr. Walter Secada asked if BDTF had encountered any NASA-unique issues. Dr. Holmes, alluding to his experience with Josh Peek's Astrophysics workshop, said he had talked with authors who reported getting rejected repeatedly by ROSES because their research topics fall between the cracks of ROSES elements.

Dr. Tamara Jernigan asked if there was strong advocacy in the community for joining the DOE Exascale project. Dr. Holmes noted that BDTF has three modelers in its membership, representing Earth science, heliophysics, and astrophysics, and they are in good agreement. However, BDTF does not have a means of canvassing the community at large. Dr. Mark Robinson asked how the existing archives might be modified or connected to the DOE and NSF projects. Dr. Holmes felt that NASA needs to be aware of what is happening in the research groups, and will need better connectivity between the existing archives, in order to understand what the national requirements are for increasing connectivity between data centers. The data programs themselves are doing well; it's just the broader research community is lacking the ability to connect into the larger Federal effort in high-speed connectivity. Cybersecurity, the major part of which lies in data transmission, is a separate topic that is beyond BDTF. That is the responsibility of the archive program officer in conjunction with the Chief Information Officer (CIO), to satisfy Federal security requirements. SMD is already involved with the security issue when transmitting modeling data. Dr. Holmes also noted that the upcoming Fall 2017 Meeting of the AGU will host several presentations by BDTF members.

Cassini Grand Finale

Dr. James Green of the Planetary Science Division (PSD) presented the latest results from the Cassini mission, which has entered its final phase. After 13 years at Saturn, Cassini has made numerous fly-bys of Enceladus, Titan, and has acquired a good seasonal overview of the planet. Cassini is now down in the proximal orbit as the spacecraft makes its way toward termination in September. Observations of Titan, a Saturnian moon larger than Mercury, have shown that it is the only other object in the Solar System, besides Earth, that has liquid on its surface, largely in the form of methane "lakes," with evaporation, transport and "rain." It is now believed that Enceladus harbors a global ocean beneath its ice crust.

Cassini will terminate at Saturn in order to protect these pristine icy worlds. Titan allows gravity assists to change orbital planes, and this has allowed Cassini to get unique views of some of the smaller satellites.

The end of Cassini's life is taking place over 42 short period orbits, which began in November 2016. These were followed by 20 F-ring orbits, and then 22 Grand Finale orbits occurring well below the rings. Dr. Green displayed some long-exposure images that reveal newly discovered rings: the Pallene ring, and the Janus/Epimethius ring. Mission operators had to look for "clear zones" between the rings of more diffuse icy material, to successfully make the jump down well below the rings. Cassini has since captured high-resolution images of newly observed moons such as Helene and Pan as it descends through the ring system. The tiny ring moon Daphnis is 5 miles across, and has major gravitational effects on Saturn's rings. A 26-mile wide "Keeler gap" in the A ring is kept open by Daphnis. Pan is another, slightly larger satellite in the A ring that keeps the "Encke gap" open. Another moon, Atlas, 26 miles across, also accretes ring material as it orbits Saturn. The surface of Epimethius is cratered. Cassini has viewed "propeller" events which are caused by interactions between the moons and ring material, and are thought to drive accretion activity through differential rotation. Recent orbits have shown spectacular hexagonal cloud structures on Saturn that are Earth-diameter scale in size, and hurricanes at the polar cap.

Cassini's Grand Finale orbits were initiated on 10 July. Dr. Green displayed video imagery obtained as the spacecraft skimmed the cloud tops, which included audio of dust impacts as the ring planes are crossed. These images have helped to determine whether the environment is relatively benign for passage. Cassini is still taking measurements of the mass and gravity of the planet to help determine gravity and mass of rings; some models can be used to predict the age of the main rings.

Science to be achieved during the final orbits will include accumulating data on the planet's internal structure, radar measurements of rings, data on atmospheric composition, and the highest resolution images yet taken of the planet's polar structures. As Cassini plunges into the Saturn, it will keep its orientation toward Earth to keep communications going as long as possible.

In response to a question from Dr. Robinson, Dr. Green said the composition of the smallest bodies seem to be of ice and rock. Dr. Boss remarked on the great value of gravity moment measurements. Dr. Shepherd asked how much could be learned about the atmosphere during this phase. Dr. Green replied that although Saturn seems featureless, the spacecraft is getting information indicating that below the obscuring smog, there are many cyclones; more data are incoming. Cassini continues to deliver new science that was never envisioned in the original mission.

SMD FY2018 Budget Briefing

Mr. Craig Tupper presented an overview of the Presidential Budget Request (PBR) Fiscal Year 2018 (FY18) budget for SMD. Key science themes of SMD continue to be: discovering secrets of the universe; searching for life elsewhere; and safeguarding and improving life on Earth. SMD comprises 104 missions in their prime and extended phases, as well as additional missions in development. The FY18 program highlights include support for the formulation phase of the Europa Clipper mission, as directed by law. The Clipper is scheduled to launch in 2022. There is no budget wedge for a 2025 Europa lander, but its requirements have been determined. The budget also supports formulation for the Wide Field Infrared

Survey Telescope (WFIRST), and the completion of an independent cost and technical study. The James Webb Space Telescope (JWST) is moving toward launch in October 2018. All operating missions are supported except for the NASA support for the Deep Space Climate Observatory (DSCOVR). There is funding available for research activities for the National Space Weather Action Plan, as well as support for STEM activities. The PBR contains a proposed reduction of $170M in Earth Science, and a $300M increase in Planetary Science, mostly in Outer Planets and Ocean Worlds. In Astrophysics, the combined total through FY22 is flat. Heliophysics has a small amount of budget growth, which will still support its Decadal Survey-recommended, multi-agency DRIVE (Diversify, Realize, Integrate, Venture, Educate) initiative. Since the budget has been released, the House markup contains about $146M higher than the PBR. Major features of that increase include a roughly $50M decrease to Earth Science, and an increase of $200M to Planetary Science. Within Earth Science, the $50M reduction does not target specific projects. Within Planetary Science, the $190M is spread across the entire program and calls out a 2022 Mars orbiter, as well as $20M for a Mars "helicopter." Astrophysics has about $20M of earmarks, including $5M for Stratospheric Observatory for Infrared Astronomy (SOFIA), and funding for a WFIRST star shade. If this markup stands, Astrophysics would end up having a small shortfall. JWST was funded without comment. Mr. Tupper felt it likely that NASA would see a replay of the Senate markup being somewhat more favorable for Earth Science, with perhaps funding for some projects that were targeted for termination. He expected that SMD will end up with some additional relief for Earth Science from the Senate. In general, NASA is looking good in terms of total funding. For FY19, the budget is flat, notionally. The White House has published a memo directing agencies to consider a flat budget, but to also discuss ramifications of a 5% inflationary increase.

Mr. Tupper alluded to Dr. Holmes' previous remarks on NASA attention to SMD infrastructure, and pointed out that since NASA implemented management reforms that require missions to tailor their budget estimates to 70% confidence levels, on average SMD has been underrunning by about 3%. As to the growing use of cubesats and small satellites (smallsats), an SMD-wide initiative is in place, scattered throughout SMD for future smallsat work. NASA recently selected Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS), an Earth Science mission using cubesats, illustrating how NASA continues to seek innovative partnerships with commercial entities as well as with cross-domain sciences.

Mr. Tupper reviewed what's changed and what has remained the same in the PBR, in terms of division funding. In PSD, in addition to support for Europa, the budget supports the Mars seismometer mission InSight, and new selections, Lucy and Psyche, both of which are asteroid exploration missions. In Astrophysics, WFIRST funding was increased to support an earlier launch, and to support the new Explorer missions, Imaging X-ray Polarimetry Explorer (IXPE) and Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory (GUSTO), and funding for hardware for a replacement of Astro-H/Hitomi. Funding for the Hubble Space Telescope (HST) has been reduced through 2020. In Heliophysics, there is increased funding for cubesats and smallsats, and support for a Solar Probe Plus (SPP) vehicle award, and the Living With a Star research program. The PBR reduction of roughly $200M in Earth Science includes the proposed termination of the Orbiting Carbon Observatory-3 (OCO-3), Plankton, Aerosol, Cloud, ocean Ecosystem (PACE), and Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder (CLARREO-PF) missions, the Radiation Budget Instrument (RBI), and NASA's part in DSCOVR, but supports new selections in the Venture class: Multi-Angle Imager for Aerosols (MAIA), TROPICS, and Geostationary Carbon Cycle Observatory (GeoCARB). The Total and Spectral Solar Irradiance Sensor (TSIS-2) is delayed under the proposed FY18 budget. In a major public outreach event, NASA is gearing up major activities in preparation for nationwide visibility of a total solar eclipse on 21 August.

Dr. Shepherd asked about the rationale behind the proposed termination of Earth Science missions. Mr. Tupper felt the decision had been driven by the budget, under the ethos of trying to get the most science per dollar. He noted that over the last four to five years the trend has been that the Senate is more supportive of Earth science, and the House more supportive of Planetary Science. Dr. Avery deemed the budget reduction as devastating for Earth Science, and really wanted to hear how NASA Headquarters made their budget case to Congress. She added that the reason Earth science research at NASA is so good is that it has kept its Earth science systems perspective; losing that interconnectivity at NASA will be devastating to the program. Mr. Tupper agreed that while the budget is certainly significantly down in Earth Science, the community is somewhat relieved at the relatively light treatment, considering the present strident nature of anti-Earth-science political rhetoric. The Earth Science missions that were targeted for termination, PACE in particular, tended to be early in development and not strongly supported by the Decadal Survey. NASA is planning to complete development of the OCO-3 instrument in 2018 and put it onto the shelf should the political will ever develop to support its launch to ISS. RBI and CLARREO Pathfinder were also early in formulation and had scheduling and budget issues. Earth Science is preparing to receive its next Decadal Survey in late 2017, and NASA will continue to do its best to incorporate future recommendations from the National Academies.

Dr. Secada voiced the general Committee concern over the Office of Education elimination. Mr. Tupper felt it likely that all the education programs (such as minority university/Space Grant programs) mandated by law will continue indefinitely. The budget language is however very clear on not supporting any transfer of content from Office of Education to SMD. Dr. Desai asked about the fate of the Space Weather Action Plan under the budget, given that the Decadal Survey recommends a cross-agency collaboration in this area. Mr. Tupper noted that the Space Weather activity originated under the previous Administration, and enjoys bipartisan support. As this is a heliophysics question, he left it to SMD AA Thomas Zurbuchen to address. Dr. Robinson commented on the DSCOVR budget disposition, commenting that any science instrument needs a team that uses the data as it comes down, to better understand the instrument. If analysis is cut out of the loop, the experiment loses value. He questioned the logic for cutting funding. Mr. Tupper answered that nothing will change in DSCOVR operations— the data will continue to come down and be captured (and thus could potentially be used in the future). Under the current FY18 PBR, however, NASA will not receive funding to process DSCOVR data.

Astrophysics Advisory Committee Report

Dr. Alan Boss, filling in for Astrophysics Advisory Committee (APAC) Chair, B. Scott Gaudi, gave a status of the committee, opening with science highlights. News of TRAPPIST-1, a new exoplanet system discovered by transit photometry, caused a Twitter and Facebook storm of unprecedented intensity. The seven-planet TRAPPIST-1 system is now a top target for more intensive observation by JWST, as it contains three planets in the "habitable zone." The system is only 40 light years away from Earth. From

HST observations on quasars, examining red or blue shifts of absorption lines from within the expanding Fermi bubbles, astronomers have determined the age of an outburst from the black hole at the center of the Milky Way. Probes of these Fermi bubbles indicate an outburst occurred at the center of our galaxy about 6 million years ago. HST has also provided imagery of recurring plumes at Europa. HST has tracked the progress of a collapsing star from 2007 through 2015, showing it give way to black hole formation without a supernova outburst. Accumulating Kepler data has shown that small planets come predominantly in two types: gaseous mini-Neptunes and rocky terrestrial Earths and super-Earths.

The Astrophysics Subcommittee transitioned into the APAC in April, and has enjoyed stable membership in the interim. At the April meeting, the committee received an update from Astrophysics Division (APD) Director Dr. Paul Hertz, a number of program analysis group (PAG) reports, reports on WFIRST, JWST, Transiting Exoplanet Survey Satellite (TESS), SOFIA, the balloon and suborbital program, cost and technical estimates, ground-based support activities for space missions, and a briefing on a Cooperative Agreement Notice (CAN) on the Universe of Learning, a new STEM Activation project.

The APAC closed out three analysis groups and created one new one, and made a request of APD to hear more information on how the funding model of civil servants would be evaluated, and to obtain more information about SOFIA and the suborbital program. APAC also wants to understand more about how a proposal to set limits on the number of Center scientists will be implemented. The APAC made two major recommendations: one for establishing an SMD-wide workshop on cubesats, and one to consider inviting early career scientists to sit on the PAG Executive Committees. The committee also issued a finding on high-risk, high-impact research endeavors, and agreed to have a subset of the APAC consider information provided in this area, to determine which opinions receive consensus and which do not.

APAC also requested more information on the Human Exploration and Operations Mission Directorate (HEOMD) timeline regarding plans to play a role in assembling and servicing future space telescopes. APAC also raised concerns about changes in the focus of the TESS cameras, and how it will affect the photometric stability of the telescope, possibly leading to a reduction in planet-finding science. Other areas APAC wishes to explore further are: success rates as a function of PI gender in core Research and Analysis (R&A) research programs; strategic technology gaps for future space telescopes and resources for addressing same; and general information on cubesats. APAC held its annual Government Results and Modernization Act (GPRAMA) exercise and judged APD as Green on all its science goals. The Committee heard a JWST update, a report on new civil servant model for NASA, and updates on Science Definition Teams (SDTs) for four major Decadal Survey mission concept studies. Common themes and important topics include R&A funding and selection rates; portfolio balance and the role of flagship missions; NASA support for ground-based research and facilities; and diversity and equal representation issues in general. Dr. Flanagan suggested APAC may want to see how named fellowship productivity compares with suborbital mission productivity. Dr. Boss noted that suborbital is a dicey program, and subject to failures; the real measure of its success is in training the next generation of scientists.

Assessing the big-picture budget for APD, the division is currently planning for a 2020 Decadal Survey, having come off a favorable mid-decade assessment. The 2016 Senior Review produced results that kept all operating missions running. WFIRST is undergoing an independent technical/management/cost review, which is due to report out at the end of the summer. Partnerships between NASA and the European Space Agency (ESA) continue to provide additional science opportunities, in the form of missions such as Euclid, Athena, and the Laser Interferometer Space Antenna (LISA). The Neutron star Interior Composition Explorer (NICER) was launched to the International Space Station (ISS) in June, and TESS is scheduled for launch in Spring 2018; ESA's Euclid in 2020, and NASA's IXPE in 2020.

JWST is in great shape, with all of its mechanical work having been done. It is now a matter of mating the components together, and it remains on track for the October 2018 launch. The scheduled launch of ESA's BepiColombo represents a possible launch conflict that could slip JWST to Spring 2019. Dr. Peterson stated for the record that he could not overstate how bad such a launch schedule slip would be for JWST. Dr. Boss added to this observation that there is also concern that the funded schedule reserve could be in jeopardy due to the slip.

<u>SMD Input to SCaN</u>

Dr. Jeff Hayes presented a request to the SC, from the NASA Space Communications and Navigation (SCaN) program, to provide science input to the 20-year plan that SCaN must develop per the 2017 NASA Transition Authorization Act. SCaN includes the Deep Space Network, which along with other space communications subgroups were consolidated into Human Spaceflight (now HEOMD) in 2006. There are three mechanisms for SMD/SCaN coordination: the SCaN Board of Directors (BOD), the SCaN Users' Plans and Requirements Working Group (SUPRWG) which is a technical focus group with three co-chairs, and the SMD point of contact to SCaN, Dr. Hayes himself, reporting to the SMD Deputy AA.

SCaN's 20-year plan must be developed over a year's time with stakeholder consultation, including other Federal agencies and the military. SMD is requesting that the SC serve as the vehicle to provide inputs to the SCaN plan. Using the current Decadal Surveys as a starting point, SCaN is trying to determine what it will need over the next two decades that will enable the exciting science NASA wants to do. SCaN is seeking a broad, high-level idea of what sort of communications will be needed for exploring distant planets and other bodies; not a detailed implementation plan.

Some questions to address:

- Are there some technologies available now that could be infused that would increase scientific productivity?
- How should we think about cubesats and smallsats?
- How much of the current infrastructure needs to be maintained to support current missions?
- What is NASA missing that it should be doing?

Dr. Hayes noted that SCaN plans to start decommissioning some infrastructure, such as a series of 70-meter dishes, beginning in 2025. To his knowledge, Dr. Hayes thought the decommissioning would be phased: Madrid first, followed by Canberra, then Goldstone. He asked that the requested information be provided in the form of a 5-6-page white paper that represents the broad science community's needs, while also taking budgetary realities and contingencies into account, and perhaps reflecting attendance at relevant workshops.

Dr. Peterson accepted the challenge, and asked that SC plan to report back by the time of its Fall meeting. Dr. Hayes added that one particular concern is the increasing role of cubesat and smallsats, and how they interact with more traditional missions. Dr. Flanagan felt that cubesats would become increasingly significant for training next-generation talent. Dr. Desai noted that Heliophysics was planning on having a cubesat go beyond the Moon, and as it would be costly to use DSN for this mission, it would be important to have this discussion going forward.

Research and Analysis Charge Discussion

Dr. Michael New reported on the SMD R&A charge, a task that is currently underway with the NAC science advisory committees. The purpose of the charge is to assess whether the SMD R&A program has effective processes in place to carry out its research program. Sub-questions being considered are:

- What is the working definition of a high-impact project? (to be tailored by each science subdiscipline)
- Are there aspects of the solicitation/review process that could be changed to more effectively do this?
- How should any necessary changes be designed?
- How should SMD determine the balance between high-impact and moderate impact research?
- For interdisciplinary and interdivisional research, how should SMD determine the right balance between interdisciplinary and division-specific research?

Dr. New said that SMD is seeking tactical, user-focused advice. SMD has provided the committees copies of solicitations, proposal evaluation criteria, working definitions, and a Space Studies Board (SSB) report to help winnow down responses. The initial working definition of high-impact, high-risk, multidisciplinary, interdisciplinary, interdivisional research have also been provided. The advisory committees are being asked to determine if these definitions are good enough, and how they can they be improved.

The current schedule is for the science advisory committees to spend two meetings on this, and the intent is to have the chair of each committee present at the November SC meeting. Dr. Shepherd asked if the SMD liaisons were already aware of this request. Dr. New said the Executive Secretaries of the committees have been made aware, and that his briefing was also presented at the last SMD monthly meeting. Dr. Peterson supported having an initial discussion at this meeting, but felt it would take until the Spring meeting to finish. Dr. New agreed that a Spring wrap-up would allow time for the individual committees to coordinate with the SC.

Dr. Peterson noted that the Space Telescope Science Institute (STScI) routinely asks about high-risk research. Dr. Flanagan referred to her long experience on peer review panels, and observed that large projects typically need set-asides in order to be enabled; she thought high-risk projects would need similar treatment. She added that in general she felt that high-risk projects would not work well in a traditional review panel. Dr. Boss remarked that STMD practices might be applicable to the evaluation of high-risk research. Asked by Dr. Secada whether it was necessary to converge recommendations across committees, Dr. New thought it would be possible to have different modalities for different disciplines, or that SMD could hold a jamboree meeting in which all four divisions come together to discuss the results. Dr. Secada asked if there were any successful cases in the past to point to. Dr. New referred to successes in the last two rounds of the Astrobiology Institute selections. The ROSES Origins of the Solar System call is another positive example. Dr. New felt that anecdotally, the evidence suggests that peer review panels are fundamentally conservative and not well suited to evaluating high-impact science. In terms of his own practice, and that of his colleagues, he tended to reserve a little extra money for high-risk, high-impact selections.

SC briefly addressed the sub-questions and agreed that definitions of high-risk/high-impact would differ with each subdiscipline. Dr. Michael Liemohn approved of the current definition of high-impact (paradigm-shaking questions), and thought the high-risk definition needed to include language about a "certain possibility/high probability of failure." Dr. Jernigan noted that Lawrence Livermore National Laboratory (LLNL) has a high-risk program in which the manager actually gets concerned about high success rates. Dr. Boss reported that the APAC felt the definitions should not be minutely examined, as it was more important to move on to the next step. Dr. Avery asked whether NASA should determine what percentage, from a financial perspective, of a portfolio should be high-impact. Dr. Robinson felt such judgments should rest with a good program manager, who uses community feedback as a gut check. Dr. Secada raised Cassini as an example: was it a high-impact mission? Or was it opportunistic? What can NASA put in place to allow these opportunities to flourish? Dr. Avery said she would argue that NASA's observations from space on salinity, compared with *in situ* measurements, has proven much more effective in yielding information on larger-scale climate changes. This outcome was not expected at the outset of the space mission. Dr. Jernigan felt that the value of the research was really just some intrinsic function of scientific merit.

Dr. Robinson asked if there were any mechanisms in place now to get divisions to collaborate on joint projects. Dr. New cited Exoplanets and Habitable Worlds as two mechanisms. He added that any R&A change takes several cycles to work out the kinks and develop a culture. Dr. Shepherd noted that in Earth Science, there's an interdisciplinary call in the Earth Science ROSES Interdisciplinary Research program (IDS), and that SMD should look at this experience as well. Different disciplines have different terminologies that present challenges; it would be useful to look to others who deal with multidisciplinary work.

Public Comment

Dr. John Rummel commented that he was curious about how the Planetary Protection Office's recent move to the Office of Mission and Safety Assurance (OSMA) is being handled, and that he was not sure that the members of the Planetary Protection Subcommittee (PPS) had been informed that their subcommittee no longer exists. He asked if there would be a concerted effort to re-form this subcommittee in the future for when NASA needs this advice. Ms. Denning assured Dr. Rummel that information would soon be forthcoming.

Planetary Science Advisory Committee - Science Highlight

Dr. Anne Verbiscer, new Chair of the Planetary Science Advisory Committee (PAC), presented a science highlight on the subject of a stellar occultation of the New Horizons extended mission target, 2014 MU_{69}.

This small body, a Cold Classical Kuiper Belt Object, was originally thought to be 20-60 km in diameter. It is very dark, redder than Pluto, and may possibly be part of a binary system (30% of such objects are binary). As of 2017, it had only been seen by HST, for the first time in 2014. There were three stellar occultations of this object this year on June 3, July 10, and July 17, which were of interest to planetary scientists as the occultation can help to optimize the January 1, 2019 fly-by of the New Horizons spacecraft by determining dust hazards as well as size, albedo, and binarity.

The occultation is a one- to two-second event that requires careful planning. To capture the event, Southwest Research Institute (SWRI) bought 22 16-inch portable Dobsonian Telescopes, and the University of Virginia supplied three additional portable telescopes, including a 24-inch Dobsonian "Hubble," and prepared them for the first of the occultations in June. For the June 3 event, the telescopes were deployed to Mendoza, Argentina, and Clanwilliam, Western Cape, South Africa. A number of fixed telescopes in South Africa and South America, and many local observers and volunteers also took part in the effort. SWRI assembled a "picket fence" of telescopes positioned with equal spacing from the predicted center line for viewing the occultation. Just before June 3, observers in South Africa were forced to make a last-minute, unplanned drive of 600 km east, in order to ride away from predicted cloud cover on the coast. In Patagonia on July 17, some telescopes needed impromptu wind mitigation support. Fortunately, the event was successfully captured on July 17. It is the most complex occultation ever observed, and data analysis on size, albedo, orbit, binarity and dust hazard is in progress. The data will also allow some shape modeling. The current estimate on size is 30 km.

<u>NASA Observation of Total Solar Eclipse</u>

Dr. Alex Young presented NASA outreach activities planned for the 21 August total solar eclipse. The path of totality across the U.S. is a narrow swath, 70 miles in width. The eclipsed sun's corona will be about the brightness of the full Moon. At totality, one can see the coronal structure, and magnetic fields of the sun lit up by the atmosphere. NASA is focused on safety, science, education and public engagement, and is supporting the general eclipse community, using NASA's brand to promote safety and awareness. The eclipse presents an opportunity to talk about celestial mechanics, the Sun-Earth system, and unique opportunities for citizen science. It is the first total eclipse visible in the contiguous states in 38 years, the first coast-to-coast since 1918, and the first just in the U.S. land area since 1778.

Many NASA science missions and programs have relevance to the eclipse: ground observations, lunar observations, tracking planetary eclipses, and exoplanet studies. NASA assets Terra, Aqua, Suomi-NPP, high-altitude balloons, ISS, aircraft, the Solar Dynamic Observatory, and the Lunar Reconnaissance Orbiter (LRO) will all be trained on the Sun during the eclipse. The eclipse will reveal an area of the Sun that is normally blacked out by a coronagraph, allowing for unique observations that can only be done during a total eclipse. A program called Citizen-CATE (Citizen-Continental America Telescopic Eclipse) will take serial observations that will add up to an hour and a half of data on the corona. Citizen-CATE participants in have been in training for several years now. A broader citizen science initiative, supported by the Earth Science GLOBE program, will study clouds and temperature changes associated with the umbra and penumbra. Anyone can participate with the aid of an app called GLOBE Observer. Space Grant-supported science will include having balloon observations of both the ground and the corona. ISS will be looking down at the shadows, and astronauts will be taking photos. The DSCOVR Earth

Polychromatic Imaging Camera (EPIC) camera will also take imagery. NASA will be using the Moon to understand the size and location of the shadow. The eclipse gallery can be viewed at the Science Visualization Studio (SVS) NASA website, https://svs.gsfc.nasa.gov. Solar panels will also be affected by the eclipse, with an expected impact of several thousand kilowatts. Effects will be much more noticeable than a cloudy day, and more uniform. There are also 11 different Sun and Earth experiments supported through an AO, including studies of radio transfer and the impact on ionosphere.

In the Committee members' ensuing discussion on the solar corona, Dr. Boss asked if there was a chance of a coronal mass ejection (CME). Dr. Young answered that yes, but that the chances are less because the sun is in a period of low solar activity.

<u>Earth Science Division Update</u>

Dr. Michael Freilich, Director of the Earth Science Division (ESD), presented an update. The division is organized by Research, Flight (operations and implementation of observing satellites), Applied Sciences (demonstration and testing of applications that provide societal benefits), and Technology (a fully competitive program that promotes technology maturity). Its two objectives are to understand Earth as an integrated system, and to improve life on Earth through applications. The ratio of flight to non-flight is roughly 60:40, and has been for nearly a decade.

ESD is being funded at the FY16 level at present, through the end of September. This funding level will be sufficient to pursue all current ESD plans through the end of the fiscal year. ESD is moving through FY17 as planned and will not change anything in anticipation of a future (FY18) budget. There is a proposed $156M decrease to the ESD from FY17 to FY18. This is comprised of termination of analysis activities of two Earth-Observing instruments on DSCOVR, EPIC and National Institute of Standards and Technology Advanced Radiometer (NISTAR); termination of OCO-3, PACE, CLARREO-PF, and RBI; termination of a number of proposals in carbon monitoring system science activities in R&A (reduction of $10M); and an unallocated reduction of ESD research activities for FY18. No reductions in Technology or Applied Sciences are expected. Dr. Freilich displayed a graphic on the impact of the FY18 PBR on the Flight program, showing that a moderately robust program remains in place, but with a significant reduction in missions. There are numerous cubesats in development that will be launched over the next few years. Dr. Avery asked how reduction in research activities would actually be done. Dr. Freilich said ESD would wait to see what the actual passed budget is, and then plan for a reduction that is measurable but not huge. He did not plan to broadly reduce R&A funding, and would not terminate existing grants that have made significant progress. However, he felt it was too early to discuss the allocation of cuts of unknown size.

ESD has completed its 2017 Senior Review, but the report has not yet been passed to ESD. The Senior Review assessed Aqua, Aura, CloudSat and the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), ISS-Cloud Aerosol Transport System (ISS-CATS), CloudSat, DSCOVR's Earth-observing instruments, Global Precipitation Measurement (GPM), OCO-2, QuikSCAT, Soil Moisture Active Passive (SMAP), Solar Radiation & Climate Experiment (SORCE), Total Solar Irradiance Calibration Transfer Experiment (TCTE), and Terra. The Earth Science Decadal Survey for 2017 is due in late December, and will include recommendations for NOAA, NASA and USGS.

Roadmapping studies to define a realistic mission suite for ESD, based on the science priorities defined by the Decadal Survey, will begin shortly thereafter. Dr. Freilich briefly reviewed recent and near-future flight and campaign events: ESD terminated EO-1 in March 2017, and carried out post-launch assessment reviews for Cyclone Global Navigation Satellite System (CYGNSS) and the Stratospheric Aerosol and Gas Experiment (SAGE-III). TROPICS, the first cubesat selection for Earth Science, held a Key Decision Point B (KDP-B) review in June, and Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) held its KDP-B in July. The orbit of Ocean Surface Topography Mission (OSTM)/Jason-2 was lowered to begin its Long Repeat Orbit mission phase, with new altimeter measurements.

The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2), a mission in development, suffered a failure of one of the lasers. The defective lasers were re-designed and re-built, and the mission remains on track for a September 2018 launch. ICESat-2 is a Tier-1 Decadal Survey mission. The Earth Venture Class program remains on schedule for an instrument development solicitation. The Venture Class program is also pushing the envelope on new ways of making Earth observations by hosting payloads on commercial satellites. Lastly, Dr. Freilich addressed NASA's Satellite Needs Working Group activity, which was established to identify the satellite launch needs of other Federal agencies. NASA received requests for 187 different products, with about 100 coming from DOE alone. The process kindled some focused NASA discussions on satellite needs, resulting in a report stating that about 71 of the product requests could be met nearly fully now, or in the near future, by combining measurements from on-orbit and developing missions. Dr. Freilich felt the working group had been helpful from a national standpoint. The estimated cost to generally satisfy requests for the 71 products is about $7-8M per year.

Dr. Shepherd asked to hear about ESD's top science results. Dr. Freilich reported that the SAGE-III ozone profile product development is proceeding well at one-kilometer vertical resolution. In addition, Landsat/Sentinel-2 products have completed harmonization that will provide for continuity of time series measurements. Dr. Shepherd felt it important to note that ESA and NASA had cooperated in calibration prior to the launch of these satellite assets. Dr. Freilich reported that CYGNSS is working well, acquiring frequent measurements, including L-band measurements that provide better penetration through the clouds of cyclones. The Larsen C ice shelf calving on 12 July was observed and measured by a number of Earth Science orbital assets; the iceberg is about the size of Delaware. Dr. Avery thanked Dr. Freilich for his presentation and pondered what the ice sheet calving portends for the future.

<u>Discussion with SMD AA</u>

Dr. Thomas Zurbuchen, Associate Administrator (AA) for the Science Mission Directorate (SMD), gave an update on events in SMD. Dr. Zurbuchen addressed the strategic aspects of the NASA budget, the balance of mission sizes, and integration and partnerships with other entities. SMD is working on three budgets simultaneously; the FY17 Operating Plan not fully completed. The Astrophysics community in particular is in flux at present, about $40-50M is at issue. The easiest way to fix it is in R&A or in the Explorer program. It is clear that there are many stakeholders, and it is still an open issue. SMD is pleased with the FY18 PBR, and pleased with bipartisan support in Congress thus far. The reconstitution of a National Space Council (NSC) has been announced, and Dr. Scott Pace has been named as its Executive Secretary. Dr. Zurbuchen felt that Dr. Pace was an excellent choice, as he is versed in both science and policy. He felt that the NSC could address cross-government discussions such as space weather. Dr.

Zurbuchen was eager to start work on the FY19 budget, the first one he has been able to track from the beginning.

Addressing mission balance, Dr. Zurbuchen described much of NASA's work as "civilization-scale," able to change the way we think as society changes, and citing the example of how HST observations have changed the understanding of the universe. NASA will continue to do large, flagship-level missions such as HST. However, NASA also needs to have smaller, more agile programs to pursue science, as well as to train new scientists. Smaller, PI-class missions that are often run out of universities, with diverse teams, are essential for maintaining a healthy community. Results from many Earth Science missions have been civilization-changing in every way, and therefore Dr. Zurbuchen expressed his optimism about continuing a series of smaller Earth Science missions.

SMD actively integrates with ISS, HEOMD, and the Mars and Moon exploration programs, as well as with international and commercial partners. SMD currently has a request for information (RFI) out to commercial lunar outfits to leverage any planned lunar flights. NASA would do well to take advantage of these rides.

Dr. Peterson and the Committee briefly touched on the upcoming joint session with the Human Exploration and Operations Committee (HEOC), including a talk about the Deep Space Gateway and Journey to Mars. Dr. Peterson felt the NSC could be quite relevant to the SC's charge to deliver input to SCaN. Dr. Shepherd asked Dr. Zurbuchen if he felt that the current administration understands the value of the Decadal Surveys. Dr. Zurbuchen felt that it did, having been on both sides of the Decadal Survey process; he believed the Academy process was working in general, but was sometimes hindered by ongoing technological issues, such as those encountered with new constellations of cubesats. Drawbacks to the Decadal Survey process are timescale and the cross-disciplinary aspects. The Surveys are not easily adaptable to interdisciplinary input, although Earth Science is becoming interdisciplinary simply as a matter of course.

Dr. Secada commented on the balance between science and commerce, and industry's desire to hold onto intellectual property (IP), and how IP may hinder data flow. Dr. Zurbuchen noted that NASA can easily arrange to look at subsets of data after a company derives its desired value from the data. He cited the important work that ESD's Dr. Freilich is doing, putting money on the table to see which companies step up. Dr. Jernigan observed that NASA has a rich history of negotiating these issues (e.g., Russia and ISS); the issues are not impossible or new. Dr. Desai noted that commercially hosted payloads may never be in the right orbit for science, and asked if there were a way to determine these orbits in advance. Dr. Zurbuchen pointed to good case studies such as Ionospheric Connection Explorer (ICON) and GeoCARB, in which the PI teams actively sought their commercial partners. In some cases, it is the PI who is the right interface, and sometimes it is NASA who can find the opportunity. NASA must keep up with the rapidly changing market. Dr. Jernigan added that serendipity can play a role if a PI doesn't have too many requirements; PIs need help in understanding this, and how to integrate a payload onto a launch vehicle. Dr. Desai noted that mass and power are typically not a big deal with commercial launches, but sometimes the orbits are in harsh environments. Dr. Zurbuchen observed that cubesats and smallsats are already fulfilling requirements. SMD is making it a priority to leverage smallsats and learn faster.

Dr. Avery commented that Earth observations are fundamental to Earth Science, and that science often arises from data, therefore it is critical that data be open and quality-controlled. Data must have scientific integrity, thus NASA must be careful when considering commercial data buys. She felt the 10 percent cut to Earth Science research was particularly harmful, and worried about the loss of great science because NASA is not stepping up to its leadership role and taking its case to the Hill. Dr. Zurbuchen replied that budgets are made with different stakeholders in mind, and therefore NASA will have to be the best steward it can be under the circumstances. He noted that he advocated for Earth Science every week to everyone, and supported it as he did every other discipline in SMD. Dr. Secada felt that NASA could not be expected to make the entire case. NASA is a Federal bureaucracy, subject to Federal constraints. Private citizens, academics, and elected officials must also step up to the plate. Every community has this discussion about balance. Dr. Jernigan thought it was fair to ask about the workforce pipeline and how it is affected by these targeted cuts; the nation still has to navigate the maintenance of the scientific and technical workforce. Dr. Shepherd had a broader concern that Earth Science had been thrown a temporary bone, and might have to fight harder for similar support in the future. He reported having had two graduate students drop out of geosciences given the current antipathy toward Earth Science. That is a serious issue. Dr. Zurbuchen said that from where he sat, Dr. Freilich is doing an amazing job, given the directed cuts. What is NASA not doing that it should be doing, operationally? NASA has a STEM Activation program to create connections between NASA missions and the STEM fields, through both formal and informal education. Everything NASA does is through the angle of education, including providing hands-on experience to students.

Discussion

The Committee turned to discussing the four BDTF recommendations that had been brought forward for deliberation. Dr. Holmes detailed each of the recommendations, noting that these are things NASA could start doing now. Dr. Peterson thought the subdiscipline advisory committee chairs should weigh in on the BDTF recommendations first, before the Science Committee took action. Each recommendation contains some budget implications. Drs. Shepherd, Boss, Liemohn and Verbiscer noted that they would take the recommendations back to their respective committees. Dr. Liemohn asked if the BDTF had considered archiving results from large-scale simulations, and whether NASA would serve as the repository for these large model results. Dr. Holmes mentioned that Heliophysics has been a pathfinder for archiving results from model runs at the Community Coordinated Modeling Center (CCMC). Dr. Secada felt that big data capabilities could have a big payoff for NASA science, in the way it has changed biology, for instance. Dr. Peterson promised to have comments on BDTF to Dr. Zurbuchen by Fall, or at latest in the Spring.

Dr. Peterson noted that the SCaN data request also will need to be answered in a discipline specific way at the science advisory committee level. He noted that he would like to converge that discussion at the Fall Science Committee meeting.

July 25, 2017
Joint Session Science Committee/Human Exploration and Operations Committee

Opening Remarks for Joint Session SC/HEOC
Dr. Bette Siegel opened the joint session, and turned it over to Ms. Elaine Denning for opening remarks and administrative remarks, who then turned the meeting over to the two Chairs. Mr. Kenneth Bowersox, Chair of the Human Exploration and Operations Committee (HEOC) gave a brief history of the impetus behind the meeting, which had hinged on a conversation with Dr. Peterson on human servicing of space telescopes. Dr. Peterson expressed gratitude to the members of the committees for agreeing to spend a day on the topic. He added that because the landscape is changing, there may be some mutually beneficial things the Human Exploration and Operations Mission Directorate (HEOMD) and SMD can do together, and hoped to exchange information and look for opportunities to cooperate. Members made introductions around the table.

HEO and Science Emerging Opportunities

HEO Future Exploration Plans
Mr. Greg Williams presented a briefing on current human exploration and operations (HEO) plans. HEOMD's goal is to expand human presence in space, with international partners and the growing presence of commercial involvement, and with a synergistic effort between robotic and human exploration. The NASA Transition Authorization Act of 2017 specifies that NASA keep an eye on long-term goals and continuity in space, including expansion beyond low-Earth orbit (LEO), human presence throughout the Solar System, and human habitation on another celestial body. Human exploration is a multi-decadal, long-term endeavor. Mr. Williams reviewed the strategic principles that guide HEOMD. First, fiscal realism is important for NASA to think about, as it needs to be able to implement ambitious programs under a fairly flat budget, unlike the Apollo years, which saw large periodic spikes in funding. Second, scientific exploration speaks to the need for human and science to move forward in tandem. The principle of technology push and pull means that NASA should be able to use technology that is developed inside and outside the Agency, and to leverage what the commercial world is doing, allowing the Agency to focus precious technology dollars on things NASA needs in the future. The principle of gradually building up capability is predicated on minimizing investment in embedded elements, and gradually build out the architecture. Economic opportunity assumes NASA technologies will spin out technologies to the economy at large. Architectural openness and resilience directs NASA to develop a multiuse, evolvable space infrastructure, minimizing unique elements and leaving open opportunities for new scientific understanding, technology development, and new partnerships. The principle of global collaboration and leadership speaks to both long-standing and emerging entities in space, such as South Korea and India. The principle of continuity of human spaceflight is based on establishing an efficient, regular cadence of missions, and avoiding gaps that interrupt the transfer of knowledge.

HEOMD is taking a multiphase approach to expanding human presence in space. Phase 0 is essentially ISS operations. Phase 1 takes place in cis-lunar space, building the Deep Space Gateway (DSG), a structure that will serve as a transportation node. Phase 2 is completing the DSG by conducting a yearlong

Mars Simulation Mission with validation crews. Phases 3-4 will involve crewed missions to the Mars environment and surface.

Phase 1 includes Orion interacting with the DSG. The DSG is envisioned as a small capability that will be crew-tended rather than crew-occupied, and serving a jumping point for the Moon and Mars. The Phase 1 plan includes the first experimental flight of Orion, Exploration Mission-1 (EM-1), through EM-5. EM-1 is the first un-crewed test flight, now scheduled for 2019, and subsequent crewed flights through 2025. Mr. Bowersox remarked that in past, the Gateway orbit was planned as a very high orbit, and asked if this were still so. Mr. Williams affirmed that DSG's high orbit will reach as much as 70,000 miles beyond surface of Moon, with orbits around Earth-Moon Lagrange points. The Gateway will also allow movement around those various points of orbits around the Earth-Moon system. Dr. Peterson noted that the astrophysics community was particularly interested in placing space telescopes at the Sun-Earth L2 point. Mr. Williams added that HEOMD is also considering launching the Europa Clipper from the Space Launch System (SLS) for a Jupiter-direct flight, and is assessing where such a flight might fit in the planning over the next year or so. EM-2 will have involvement from the Space Technology Mission Directorate (STMD). EM-3 will incorporate a habitation module. HEOMD is also discussing partnerships with the internationals in Phase 1 planning. The critical piece is power propulsion element.

Dr. Michele Gates briefed particulars on the advanced solar electric propulsion (SEP) element that was brought through development during the cancelled Asteroid Redirect Mission (ARM). Advantages of SEP are numerous: the fuel does not boil off; advanced SEP provides the ability to move around the lunar environment; and SEP provides a 5- to 15-fold decrease in propellant mass. This advanced SEP is scalable to higher power systems for Deep Space human exploration. NASA has lab-validated several Hall thrusters of 50kW, and HEOMD expects to be able to demonstrate these thrusters in the early 2020s, along with communication demonstrations. The plan is to continue to leverage work that has already been accomplished on ARM and through industry developments, and to infuse STMD-developed advanced SEP technology. Much significant work has been accomplished on advanced solar arrays, radiation tolerance, and improvements in power/mass relationships. Current work is concentrated on risk reduction and magnetic shielding. Development units for electric propulsion are in varying states of readiness, with some undergoing vacuum testing. Last week, HEOMD released an RFI intended to capture information on the current state of industry for a Power and Propulsion Element (PPE). A PPE "virtual industry" day is planned for 17 August. HEO is targeting rapid turnaround in time for an EM-2 flight.

Dr. Peterson asked if HEO was considering chemical rockets to move between points, for missions of fewer than 100 days for phases that are not crew-tended. Dr. Gates said the concept released in the PPE RFI is to fly 2000 kg of fuel, yielding 15 years of transfer among orbits. Dr. Peterson noted that moving a telescope from an Earth-Moon to a Sun-Earth Lagrange point would require gentle acceleration to protect fragile optical elements. Mr. Bowersox and the committees briefly considered the feasibility of providing enough xenon for chemical rockets, U.S. production of which amounts to three tons per year.

Phase 2, in the latter half of 2020s, will be the timeframe in which NASA develops the Deep Space Transport (DST), planned to host a crewed Mars mission by 2033. HEOMD is developing habitation concepts with six vendors, and is developing engineering models targeted for 2019 to support a crew of four. DST completion is targeted for 2026-2027; this period will include EM-6 and EM-7 flights for Transport delivery, followed by EM-8 and 9 flights for Transport Shakedown; and EM-10 and 11 flights for Mars Transit in 2027-33.

Deep Space Gateway and Transport Maturation
An HEOMD team is directing the maturation of the DSG concept, to ensure that it enables evolution to Deep Space Transport (DST) and is part of the Mars plan, as well as enabling lunar activities. The HEOMD Standards Working Group is developing the standards for this work; its leads are ISS and Advanced Exploration Systems (AES). Interoperability interface and environment standards are also in work. NASA does not yet have a formal policy on the Deep Space Gateway/Transport system, and is still getting through the first budget process. The National Space Council should have a weigh-in by the end of the summer, leading to a formal policy adoption in the Fall.

HEOMD and STMD are jointly funding instruments for the Mars 2020 rover; these are Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), Mars Environmental Dynamics Analyzer (MEDA), Mars Entry, Descent and Landing Instrumentation (MEDLI-2), and a Deep Space Atomic Clock for precise navigation. STMD is developing a resource-prospecting rover, as well as an SEP system for both the Gateway and Transport, and a Laser Communications Relay demonstration.

Mr. Williams summarized joint activities between HEOMD and STMD, including ongoing work in the Mars Exploration Program and a Mars 2020 partnership; Mars Science Laboratory (MSL/Curiosity); science instruments on ISS; Deep Space Optical Communications; and dialogue on space weather and the effects of space radiation on astronauts. SMD is funding some science for the STMD resource prospector, as well as joint work in the Frontier Development Lab, and Science in Cis-Lunar space. South Korea is planning a lunar orbiter that will host a NASA camera for imaging Moon craters. HEOMD continues to provide launch services for SMD payloads. Planetary protection, formerly under SMD, has recently come under the purview of OSMA.

Dr. Jernigan asked what the biggest challenge was for human space exploration at Mars. Mr. Williams said Entry, Descent and Landing (EDL) constituted a major challenge, as a Mars landing will require bringing 18-20 tons to the Mars atmosphere each time. The size of the Mars Ascent Vehicle (MAV) drives this necessity. NASA may need supersonic retropropulsion to accomplish human presence at Mars. Radiation protection, and *in-situ* resource utilization (ISRU) to support safety and minimize logistics are two more major issues. A human Mars program must have sustainable exploration, with routine visits to outposts, analogous to current terrestrial outposts in Antarctica. Dr. Robinson asked if the mass requirements of a habitation module had been determined yet. Mr. Williams said that Jason Crusan has more detailed information, but that initial volume requirements for a healthy, long-term crew have already been established at ISS. A habitation can't be too dependent on extravehicular activity (EVA). NASA is learning about inflatable vs. rigid habitats in a radiation environment. A habitat will require a reliable system for scrubbing carbon dioxide. The DST is currently designed as 41-megaton vehicle. An early version of a Mars habitation module is roughly the size of an ISS node. Dr. Boss asked if NASA had any formal liaison with SpaceX on interacting with the Journey to Mars. Mr. Williams said NASA is formally talking with SpaceX on how their systems are evolving, and is also having dialogue with industry on habitation system developments. Dr. Shepherd asked if HEOMD consulted with ESD on effects of things like dust devils on Mars. Mr. Williams said HEO relied on PSD for that type of information, through regular interaction.

Science Opportunities

Science Opportunities Overview

Dr. Zurbuchen presented an overview of science opportunities in human exploration, citing as one example his graduate experience while working on project for collecting solar material from the Moon. The experiment was carried out with aluminum foil that collected solar wind, yielding data on helium, neon and argon abundance, data that has only been surpassed recently by nuclear magnetic resonance measurements. He described himself as fully supportive of human exploration and science on the Moon. SMD's high-impact, integrated and multifaceted portfolio interrelate with HEOMD in many science themes: discovering the secrets of the universe (fundamental science/research); searching for life elsewhere; and safeguarding and improving life on Earth. SMD uses ISS, and through it will identify future opportunities with HEOMD on human-attended science. Dr. Zurbuchen reviewed activities in the four subdisciplines of SMD, comprised of 104 missions with 87 spacecraft, as well as numerous cubesats, balloons, and sounding rockets. Earth-based investigations include 25 major airborne missions. The science fleet is rich in variety and location. At the Moon, SMD has one spacecraft, the LRO.

SMD is preparing for the launch of JWST, a big leap in technology that is coming to fruition. Juno is detecting cyclones at Jupiter's South Pole, and involving the efforts of citizen scientists, some of whom have become co-authors on science papers. Kepler has found over 3000 confirmed extrasolar planets, from Earth- to Jupiter-sized. NASA continues to search for life elsewhere through investigation of the plumes observed at Enceladus and Europa. The GOES-16 Lightning Mapper is helping to safeguard life on Earth by improving observations of storm evolution: this technology came from the SMD R&A program, and is greatly improving forecasting. CYGNSS is measuring the surface winds of cyclones in a transformative approach for future forecasting, using a $180M constellation of smallsats versus an $800M mission. Smallsats also provide a training ground for next generation scientists.

SMD is already working together with HEOMD on advances in deep space optical communications. SMD recently held an AO that offered opportunities to PIs to carry optical communication componentry to deep space, helping to incentivize PIs to fly HEO technologies, as well as commercial technologies. LRO is providing images of the Apollo 17 landing site, and SMD is committed to using this asset going forward. SMD has an RFI out to industry to ask them what they are planning to do at the Moon, with the intent to piggyback some science instruments or sensors onto commercial flights. SMD is working with HEOMD to develop instruments for the Mars 2020 rover, to observe atmospheric conditions, provide ISRU, and to add sensors to the heat shield that will monitor EDL conditions. These efforts show the working-level connections between SMD and HEOMD to determine which essential technologies are needed for Mars. Autonomous operations, precision landing, and resource characterization of the moons of Mars are other areas of common interest. Both directorates need to understand space weather, to shield against the bombardment of cosmic rays and predict solar storms. SMD and HEOMD are cooperating on including a deep space communication element on the future Psyche mission, which can greatly increase bandwidth.

There are numerous science instruments on ISS, and an increasing number of Earth Science instruments. ISS has turned out to be a good platform for science investigations that could not be otherwise done. ISS has always shown a deep commitment to hosting science. SAGE-III is monitoring the upper atmosphere, taking continuous measurements of ozone that are unprecedented in accuracy. SAGE-III was launched up to the ISS in a resupply trunk, illustrating how SMD has taken advantage of unique opportunities. NICER is studying x-ray pulses from neutron stars and is currently going through commissioning on ISS. SLS, being developed primarily for human exploration, also enhances science reach to the outer Solar System by greatly reducing transit time. There is much to learn about the complex chemistry of the Outer Planet systems, and SMD needs to go there and analyze the components to the next level of understanding. SLS could provide multiple looks at multiple worlds in a much shorter period of time; two to three years versus decades of investigation. Human servicing of large telescopes is yet another area of collaboration between SMD and HEOMD. HST is the most productive science mission in NASA history, having produced 15,000 published papers and numberless novel observations. The ability to service space telescopes could greatly expand their scientific utility and lifetimes.

Dr. Desai asked how integrated SMD would be with Mars human exploration going forward. Dr. Zurbuchen said the two would become increasingly integrated as both sides progress forward on the notional plan, utilizing new science discoveries and folding them into the process. Science will accompany humans as they visit Mars. Dr. Flanagan asked whether the community should consider satellite assembly of a large-aperture telescope. Dr. Zurbuchen felt that, absolutely, the community should be thinking about it, especially if the Decadal Survey and the mid-term assessments call for it. Learning how to do the assembly is on the critical path. He noted that JWST took a few "miracles." NASA needs to look toward these sorts of forward-thinking concepts. Another issue to seriously consider is how NASA can continue to advance technology development while controlling costs; there are unintended consequences associated with unknowns interacting with unknowns. Dr. Robinson noted the possibilities opening up with the DSG capability and how it might be used to mitigate the current techniques that limit sample gathering from Moon to Earth. He envisioned inexpensive small landers that could obtain small lunar samples and bring it back to the Gateway. Dr. Zurbuchen encouraged such thinking, and looked forward to the DSG workshop. Mr. Williams extended his appreciation to those who helped him identify workshop participants. Dr. Avery expressed her excitement at where HEOMD and SMD are going. She asked: Is there interaction with ESA on the human crew to Mars? What is SMD doing in the space weather on Mars subset? Is there a plan to have a daily forecast for surface operations on Mars? Dr. Liemohn noted that the Mars orbiter MAVEN is quantifying what is happening in the present-day upper atmosphere on Mars, and is finding that when there is a coronal mass ejection (CME), the loss from the upper atmosphere jumps from 10 to 100 times, resulting in more ionizing radiation at the surface. Dr. Zurbuchen added that interactions between ESA and NASA remain strong, and that ESA is sending instrumentation to Mars, and also working together with NASA in determining future landing sites on Mars.

Future Telescopes Human Servicing

Dr. Jeffrey Hoffman gave a briefing on servicing large space telescopes, and other large complex space systems. HST has been the prime example for servicing, and brought together science and human space flight. Most people remember the 1993 HST "re-focus mission;" however the other multiple, planned service missions were able to increase and upgrade the value of HST. Some of the modules were very amenable to serving, and some were not (magnetometers, e.g.). Mission planners learned it was better to design in advance for EVA service rather than to make unplanned service missions; this philosophy is applicable to both human and robotic servicing. While Dr. Hoffman greatly supported the idea of robots in space, he remarked that they are not very adaptable at present.

Servicing HST made it incredibly productive by any measure, and the bottom line is that human servicing made this possible. Each visit gave the Astrophysics community a new telescope with which to work. HST is now using 21st century detectors that are three orders of magnitude better than those on the telescope at launch. It is important to note that previous missions have run into problems with configuration control (CC); planners must therefore put great effort into CC, especially for robotic missions. Configuration control was superb for HST, and constitute one of the reasons that servicing missions were so successful. Sophisticated robotic techniques are now in development; the "Robonaut hand," for example, can use tools originally developed for astronauts. ISS has also greatly benefited from the ability to service it.

It is also useful to reflect that Chandra experienced a bombardment of particles on its critical detectors, and could not have been serviced had the detectors been damaged. There is no chance to upgrade them at present. Spitzer could have been much more productive if its cryogens could have been replaced. The Alpha Magnetic Spectrometer (AMS) experienced the same problem after it ran out of the liquid helium that cooled its superconducting magnets. Astrophysics is now looking beyond JWST to more complex space telescopes in the future, which inherently possess a concomitant, increased risk of failure. Therefore, design for servicing must be done from the start, to allow for new technology, to make servicing safe but flexible on human rating; and plans must include careful control and configuration.

Dr. Peterson asked which human rating requirements were the most onerous. Dr. Hoffman replied that human ratings required good common sense about safety, and must consider how to more easily send equipment to a human environment. It's hard to think what could requirements could have been relaxed about HST. The requirements that were put on the servicing were put in place long before HST actually needed servicing. Dr. Robinson asked if there had ever been a satellite designed for servicing. Dr. Hoffman pointed to the Defense Advanced Research Projects Agency (DARPA) Orbital Express as a demonstration project. There have been many proposed systems, many in the commercial world. He felt it was on the horizon, with the development of new power systems and the desire to scavenge antennas. There has been plenty of robotic servicing on ISS to change out modules and transport large pieces of hardware. Robotic operations do tend to be much slower than human. Ideally, HEOMD would like to get robotic servicing internal to ISS, for maintenance tasks such as cleaning filters. Mr. Williams noted that Goddard Space Flight Center (GSFC) has done several robotic re-fueling activity demonstrations for ISS.

Future Assembly and Servicing Study Team

Dr. Ronald Polidan reported on the progress of a community-based team devoted to future assembly and servicing of large, complex telescopes in space, the Future Assembly and Servicing Study Team (FASST). FASST will consider the requirements for serving large-aperture telescopes in future. These flagship observatories have great potential for returning spectacular science for their lifetimes, and it is recognized that servicing can expand these lifetimes.

FASST is a technology pull exercise, with an eye to being prepared for the release of the 2020 Astrophysics Decadal Survey. The process of identifying the necessary technology for the missions called out by the Survey should be done sooner rather than later, to provide risk reduction in time for the missions selected by the 2020 Survey. In addition, NASA is now in a disruptive period, with industry beginning to provide low-cost launch opportunities, in-space robotic technologies being advanced, rapid evolution of science instrumentation, and the development of the DSG that could make assembly and servicing a regular part of large science systems.

FASST terms of reference direct the team to develop two or three top-level system architectures, a technology development roadmap, and identification of public and private partnership opportunities through workshops and technical interchange meetings. Planned activities are to release an RFI to determine the current state of the art; work with NASA scientists and engineers; establish collaborative partnerships with HEOMD, STMD, industry, and academia; perform design studies of in-space assembly; perform a design study of astronaut and or telerobotic assembly and service from a Gateway-type facility; and establish regular technical interchange meetings (TIMs). The first TIM at GSFC will take place 1-3 November, and will address the impact of reductions in cost for medium-lift launch vehicles, advances in robotic capabilities in refueling, upgrades and assembly, and strategies for deployment in cis-lunar space. TIM products and deliverables include identification of technology gaps, an initial concept of Gateway operations, and a preliminary schedule. Key questions will center around priority engineering design activities to enhance the Gateway, an assessment of capabilities of astronaut EVA and telerobotics, a technology capability development plan, especially for near-term priorities, and determination of next steps for coordination between scientists and Gateway designers. The point of contact is Dr. Harley Thronson at GSFC.

Dr. Zurbuchen said the biggest concern is the high cost of large telescopes, because servicing and assembly becomes more attractive as cost concerns rise. NASA needs to learn how to break the exponential scaling law that governs space telescopes. Dr. Polidan noted that FASST will certainly be looking at the cost drivers that fuel this law. Dr. Peterson observed that about $2-3B of the JWST cost was due to its low operating temperature. Dr. Zurbuchen remarked that a telescope larger than JWST could easily cost $25B. Dr. Boss asked if there were any concepts being worked on to lower mass. Dr. Polidan said FASST would be looking at interferometers, new mirror designs, etc. and other options to break the cost curve.

Science Enabled by Human Exploration

Dr. Ben Bussey gave a briefing on an impending study that arose in part from an International Space Exploration Coordination Group (ISECG) science white paper that describes the international view on science that could be achieved from visiting three destinations outlined in the ISECG's Global Exploration Framework, with the DSG in place. The places where humans explore may not be ideal for science, however the presence of humans and associated infrastructure provides opportunities that can yield Decadal Survey-relevant science. Human exploration enables fewer mass, power, and volume constraints, and the DSG could relieve pressure for other orbital and surface assets.

A DSG science study is being held to determine what high-quality science can be conducted from DSG, and what strategic knowledge gaps (SKGs) can be closed. The study is jointly sponsored by SMD and HEOMD, and is co-convened by Headquarters, Johnson Space Center (JSC), GSFC, and Marshall Space Flight Center (MSFC). The Steering Committee includes an Executive Committee and a Science Analysis Group. The Steering Committee includes discipline experts from NASA Centers, academia, and ESA. Two parallel activities are in progress to provide an initial list of potential instrument resources to DSG engineers; the initial list is needed by September 2017 to potentially influence DSG design. These instruments can reside on the power propulsion bus, habitation module, or logistics module. Other resources such as data volume, crew time, and DSG orbit placement will be considered. The current default orbit is a near-rectolinear halo orbit (NRHO). Next steps will be to plan an early 2018, three-day DSG Instrument Workshop. The Steering Committee will decide how many parallel sessions the workshop should have, and what disciplines should be covered in each session. The Steering Committee will identify four to five session chairs, all to be vetted by the SMD division directors, and then downselect to three chairs. The 2018 workshop will be based on the highly successful Tempe, AZ lunar workshop held in 2007. A call for abstracts will go out in September, and abstracts will be due at the end of the calendar year. The workshop will take place in February 2018. Dr. Bussey noted that ESA is organizing a similar, European-focused workshop. The workshop will yield a clear exposition of possible science opportunities and identify international collaborative concepts. Its results can influence future Decadal Surveys, instrument AOs, and input to STMD for technology investment areas.

Dr. Jernigan remarked, that having been in human exploration for a long time, she remembered when Astrophysics was afraid that piggybacking on HEO activities would undercut their own program. Has this attitude changed? Dr. Bussey expected that there would probably be more fiscal constraint than mass constraint. DSG will never replace standard free flyers for astrophysics; therefore it's important to show the concept as just an additional opportunity afforded by HEOMD. Dr. Robinson asked if the occupation of DSG was planned to be continuous. Dr. Bussey replied that after the Gateway is in place, HEO expects to have a capacity of 100-200 kg upmass per year. Crews will be on roughly 30-40 day campaigns initially, with stays getting longer with experience. Having crew doesn't necessarily negate good science. Mr. Williams noted that the Deep Space Transport was slated to be built immediately after the Gateway.

Dr. Boss asked if a Halo orbit was considered to be unlikely. Dr. Bussey said the plan was to elucidate what science can be done in which orbits. Dr. Boss asked: if Halo is not chosen, for instance, is it possible for the Orion vehicle to take astronauts back and forth to L2? Dr. Bussey answered that it depends on what you want to do, whether good science can be carried out by a crew at L2. Dr. Peterson explained that one idea was to build the telescope at DSG and bring it to the L2 point, where it can be serviced by humans or robots in the future. Dr. Bussey thought it would be useful to have a workshop session on telescope servicing to air out these ideas.

Mr. Hale noted that DSG has an airlock, with potentially a robotic arm for sample capture. Orion will not have an airlock. That implies that the entire DSG would have to move to L2. Mr. Bowersox agreed that there would need to be another module. Dr. Boss suggested assembling the telescope at the DSG and using an ion engine to take it to L2. Dr. Desai asked Dr. Bussey to elaborate on available mounts for instruments. Dr. Bussey said there would be several external mounting points on the modules that would be standardized, but that it also must be noted that there are thermal and propulsion limits on how low a circular orbit could be for an extended period of time.

Discussion

The Committee held a brief preliminary discussion on findings and recommendations. Mr. Bowersox suggested a very simple finding that documents the good joint work that is already ongoing. Dr. Boss suggested a recommendation to NASA to be careful at this early phase to be very inclusive about the space telescope/exploration architectures to be studied, and to keep minds open to instruments such as interferometers, and other innovative ways to meet mass and cost constraints. NASA should think beyond monolithic mirrors. Dr. Peterson proposed writing a finding to praise a productive joint meeting, and a recommendation to have STMD become more involved with SMD and HEOMD. Mr. Bowersox felt a NAC finding on how well the AAs are working together would also be appropriate. The Committee discussed the eventual output of the FASST report, a white paper from the DSG Science Workshop and their availability to principal customers such as the Decadal Survey committees and NASA. Dr. Boss asked whether there was any way to proactively pursue Department of Defense (DOD) or U.S. Air Force launch opportunities for astrophysics missions. Dr. Peterson noted that the community was looking at anything other agencies could offer. Mr. Bowersox thought that the National Space Council would be helpful in identifying launch opportunities. Mr. Williams noted that NASA has a formal liaison with DOD through the Office of International and Interagency Relations (OIIR).

Space Radiation

Dr. Lisa Simonsen provided a briefing on the Mars radiation environment and its predicted effects on human exploration. Near the Earth, the closest Mars analogue is ISS, which is conferred some protection against SPEs (solar particle events) and low energy galactic cosmic rays (GCRs) by orbiting within the Earth's magnetosphere. The total (annual) dose rate at ISS is about similar to that which would be experienced on Mars. In deep space, however, there is no protection from SPE or GCR; the dose rate in deep space is about three times higher than at ISS. At Mars, a human would have some protection against radiation from the Mars atmosphere and planetary shielding; which would allow a two- to three-year mission. Phobos probably gives protection via mass shielding, but it lacks an atmosphere. At ISS/LEO, 60% of radiation exposure is from GCR, and 40% from trapped protons. Currently HEO uses dosimetry, operations, and EVA planning used to limit exposure at ISS.

Space radiation poses four major health risks: cancer, cardiovascular disease, central nervous system (CNS) effects (acute and late, cognitive and behavioral), and acute radiation syndromes. NASA is using environmental data to optimize and validate radiation mitigation strategies, updating its risk models and calculations of dose limits.

Dr. Cary Zeitlin reported on new data that has been gleaned from radiation sensors on Mars Science Laboratory (MSL)/Curiosity. MSL's Radiation Assessment Detector (RAD) is a joint HEOMD/SMD project, which has been operating successfully since August 2012. RAD records radiation doses in both silicon and plastic and is able to discriminate neutrons from gamma rays. RAD was turned on for most of the trip to Mars, and was partially shielded by spacecraft. Average shielding depth was recorded as 16 g/cm^2, close to the 20 g/cm^2 experienced by a crewed vehicle. Dose rates on a cruise to Mars are expected to be characterized by near constant GCR and a predicted five solar particle events, but it must also be noted that dose rates can spike by factors of 10 to 100. Once MSL landed, the dose rate dropped by a factor of 2.5 (against the expectation of a factor of 2 on an airless body). Gale Crater appears to be particularly well shielded. Atmospheric shielding is greater than cruise shielding. RAD data from over five years indicated that four small SPEs have been seen; the atmosphere seems to shield against these events fairly well. There is also shielding from local terrain; when the rover was parked hard up against a cliff, the dose rate dropped noticeably. A cliff face would seem to be a good place for a habitat. Terrain makes a difference.

On the Mars surface, high-energy neutrons are a potential contributor to overall radiation exposure. The presence of a radioisotopic thermal generator (RTG) is not seen as a significant contributor. The dose equivalent from neutrons is about 5% of the total dose. An MSL-RAD workshop was held in June 2016; its proceedings will be available on-line and in a special issue of the journal *Life Sciences in Space Research*.

ISS has an MSL-like RAD sensor as well as a Fast Neutron Detector (FND). ISS and Mars are surprisingly similar in terms of radiation dose, differing only by 10-15%. The neutron contribution on ISS is about 20-30% of the total dose equivalent. The ISS Alpha Magnetic Spectrometer-2 (AMS-2), a high-energy physics experiment, built originally for dark matter and antimatter observations, also measures GCR, and has provided the first-ever continuous measurement of GCR protons over an extended period of time period and within the energy range that is of importance to human space flight. AMS-2 has provided detailed insight on the space radiation environment. HEOMD will be placing silicon sensors in Orion to monitor radiation, and will also use SMD assets to help predict space weather.

Dr. Simonsen resumed the briefing, and offered context for predicted radiation exposure levels in space exploration; 50-100 millisieverts (mSv) would be a typical exposure over a 6-month period. Extrapolating to the Deep Space Gateway (DSG), one would expect 35-70mSv during a period of solar minimum. At the Deep Space Transport; 350-750 mSv. Fly by and Mars surface operations would expose crew to 1000-1300 mSv, which is currently above the dose limit. A single ISS mission is equivalent to one tenth of a Mars mission exposure. Protection and mitigation approaches include understanding the environment and timing of the solar cycle, research validating exposure limits, research in biomarkers (radiation sensitivity), and a strong program for developing in-mission biological countermeasures. In optimizing radiation protection, vehicle and habitat design to support trade studies, HEO is looking to minimize parasitic mass, and using existing mass to protect against SEP: e.g., the Mars surface habitat, atmosphere, and terrain will all be used for protection.

SPE protection measures include reconfigurable logistics, water walls around crew quarters, the use of waterbags/sleeping bags, and wearable vests and blankets. Recently there has been a shift in thinking on GCR shielding; new radiation transport codes indicate that more shielding may not reduce risk. Once maximal exposure is achieved, remaining risk can be mitigated by shortening the mission duration, use of biological countermeasures, or simply acceptance of increase. STMD is holding Thick Shield Project beam experiments, and has considered compound shielding, finding compound shielding to be more relevant to electronics than to humans. Titanium, for instance, produces secondary alpha particles upon bombardment. HEOMD is currently analyzing DSG, looking at mass to move around, and trying to come up with SPE protection without adding parasitic shield mass. HEOMD also is supporting NextSTEP Habitat development companies in early design phases, and is using environmental data to develop requirements. Simulation of the GCR primary and secondary environments is being done with a mixed field, high energy capability at the NASA Space Radiation Laboratory. Testing is being performed on cellular and animal models.

In summary, HEOMD is employing several different means to mitigate radiation risk, including monitoring, operational dosimetry, and storm shelter shielding (crew movement/confinement). The shield design for the DSG is designed to withstand a solar flare event of the magnitude of a major 1989 coronal mass ejection. For Orion, a 1972 SPE was used for reference.

Dr. Boss asked if HEO had considered winding a coil around the spacecraft to create a magnetic field. Dr. Simonsen said that NASA has conducted trade studies and has ruled out coils in terms of relative mass, as well as safety issues; however, there are plans to reconsider the concept every 10 to 15 years. To date, the most tested concepts have been based on cryogenic superconducting magnets, which have lots of stored energy, presenting its own disadvantages. Dr. Desai asked about the biggest uncertainties driving GCR simulation. Dr. Simonsen said that models, dose rate, and translatability to humans presented the largest uncertainties. At ISS, the procedure is to avoid EVAs when the Station passes through the Southern anomaly, and to route crew to the most heavily shielded areas of ISS during an event. For DSG, active dosimetry, space weather forecasting, and storm shelters will more useful.

Dr. Simonsen noted in closing that one Mars mission raises lifetime cancer risk by 10-12%. NASA has an ongoing Longitudinal Study of Astronaut Health to track these trends.

Public Comment

No public comments were noted.

Discussion

Mr. Bowersox suggested that the joint committees offer a finding on radiation risk. Mr. Hale felt the recommendation should center on cutting down the transit time to reduce the time of exposure to radiation, as there seems to be no promising radiation shield design in the foreseeable future. Mr. Bowersox likened the expected risk associated with Mars transit time to be about equivalent to the pack-a-day smoking risk (15%) associated with developing lung cancer; a significant risk. The committees decided that this product should be a recommendation rather than a finding, and it should be transmitted to the NASA Administrator. The recommendation advised NASA to expand its efforts to explore innovative shielding technologies, and improve deep space propulsion techniques (SEP being not fast enough on its own) to reduce cruise times to reduce radiation exposure. Mr. Williams noted that STMD is doing work on nuclear-thermal propulsion, but it is not advanced enough for use in the DST architecture.

The committees discussed and approved a joint HEOC/SC finding, for transmission to the NASA Administrator, that acknowledged that the ongoing HEOMD and SMD collaboration yields mutual benefits, and yields benefits to NASA overall.

The committees also discussed and approved a joint finding on the servicing and assembling of satellites on-orbit, potentially lowering life-cycle costs for large satellites. It also acknowledged science input from external groups (e.g. FASST). The finding was for transmission to the HEOMD and SMD AAs.

Lastly, the committees issued a joint finding, for the HEOMD and SMD AAs, to applaud NASA efforts in maximizing the science benefit from the DSG, as specified in the existing Decadal Survey and other key NASA science planning documents.

Dr. Peterson adjourned the meeting at 5:06 pm, commenting favorably on a productive meeting.

Appendix A
Attendees

NAC Science Committee Members
Bradley Peterson, Ohio State University, ***Chair, Science Committee***
Susan Avery, Woods Hole Oceanographic Institution
Alan Boss, Carnegie Institution (for B. Scott Gaudi, Chair, Astrophysics Advisory Committee)
Mihir Desai, Southwest Research Institute
Kathryn Flanagan, Space Telescope Science Institute
Tamara Jernigan, Lawrence Livermore National Laboratory
Michael Liemohn, University of Michigan (for Jill Dahlburg, Chair, Heliophysics Advisory Committee)
Mark Robinson, Arizona State University
Walter Secada, University of Miami
J. Marshall Shepherd, University of Georgia
Anne Verbiscer, University of Virginia
Elaine Denning, NASA Headquarters, ***Executive Secretary, Science Committee***

NAC Human Exploration and Operations Committee Members
Kenneth Bowersox, ***Chair, HEOC; Chair, NAC***
Shannon Bartell, Aerospace Consultant
Pat Condon, Aerospace Consultant
Joseph Cuzzupoli, Aerospace Consultant *(via telecon)*
Ruth Gardner, NASA KSC
N. Wayne Hale, NAC
Patricia Sanders, NAC, ASAP Chair
Robert Sieck, Aerospace Consultant *(via telecon)*
Gerald Smith, NASA Stennis (retired)
Bette Siegel, ***Executive Secretary, HEOC***

NASA Attendees
Ben Bussey, NASA HQ
Steve Gaddis, NASA LaRC
Ruth Gardner, NAC
Michele Gates, NASA HQ
James Green, NASA HQ
Jeffrey Hayes, NASA HQ
Eracemia Kennedy, NAC
Donna Lawson, NASA LaRC
Diamond Mangrum, NASA student
Catherine McLeod, NASA JSC
Sherry Monk, NASA LaRC
Doreen Neil, NASA
Patricia Pahlavani, NASA LaRC
Bhaskar Roberts, NASA NIFS
Lisa Simonsen, NASA
Deb Tomek, NASA LaRC
Greg Williams, NASA HQ
Alex Young, NASA GSFC

Cary Zeitlin, NASA
Thomas Zurbuchen, SMD AA, NASA HQ

Non-NASA Attendees
David Frankel, PBF LLC
Dan Mazanek
Ronald Polidan, Polidan Science Systems & Technologies, LLC
Ana Wilson, Ingenicomm, Inc.
Joan Zimmermann, Ingenicomm, Inc.

Telecon/Webex attendees
Gale Allen, NASA HQ
Chaitan Baru, NSF
Louis Barbier, NASA HQ
DaMara Belson, NASA HQ
Linda Billings, NIA
Heather Bloomhard, American Astronomical Society
Kathleen Boggs, NASA
Lynn Bowman, NASA LaRC
Sandra Cauffman, NASA HQ
Arthur Charo, National Academy of Sciences
Joel Charriot, American Astronomical Society
Stephen Clark, Space Flight Now
Martha Cloudsley, NASA Langley Research Center
Kathryn Crowe, NASA MSFC
Steve Davison, NASA HQ
Monte Dibiasi, SW Research Institute
Annette Domber, Ball Aerospace
John Dyster, Orbital ATK
Richard Eckman
David Eisenman, NASA JPL
Dan Evans, NASA
Shannon Ewan, NASA HQ
Walt Faulconer, Faulconer Consulting Group
Jeff Foust, Space News
Michael Freilich, NASA HQ
Chris Gilbert, GE Consult
Sandra Graham, National Academies
Helen Grant, NASA HQ
Thomas Greathouse, Southwest Research Institute
John Grunsfeld, NASA GSFC
Hashima Hasan, NASA HQ
Amanda Hendrix, Planetary Science Institute
Debra Hernandez, NASA
Paul Hertz, NASA HQ
Jeff Hoffman, MIT
Marchel Holle, National Academies
Charles Holmes, BDTF
Ethan Hopper, SpaceX
Russell Howard, Naval Research Lab

Grace Hu, OMB
Dave Huntsman, NASA Glenn Research Center
Rick Irving, NASA
Angie Jackman, NASA MSFC
Jay Jackson, NASA HQ
Jennifer Kearns, NASA HQ
Emre Kelly, Florida Today
Jim Kurose, NSF
Dan Lester, Exinetics
Ruth Ann Lewis
Charles Lillie, Lillie Consulting
James Lochner, USRA
Peg Luce, NASA HQ
Michael Maloney, National Academies
Alfred McEwen, University of AZ
Kevin Metrocavage, NASA
Bogdan Mihaila, NSF
Danielle Montecalvo, National Academies
Chris Moore, NASA
Mark Mozena, United Launch Alliance
Michael New, NASA HQ
Jeffrey Newmark, NASA HQ
Renee Pullen, NASA HQ
Phil Putter, NASA HQ
Michelle Rodrigues, SRI International
Richard Rogers, Stiller Solutions
John Rummel, SETI Institute
Kurt Rutherford, SWRI
Michael Skrutskie, University of VA
Marcia Smith, Space Policy Online.com
Mary Sladek, NASA HQ
Philip Sloss, NASA Spaceflight.com
Nasia Sossey, NASA HQ
Bill Stabnow, NASA
Eileen Stansbery, NASA HQ
Craig Tupper, NASA HQ
Harley Thronson, NASA GSFC
Jim Ulvestad, NSF
Dan Vergano, Buzz Feed News
Carol Warner, NASA
Colonel Yensnon, NSF
Myria Zambachas, GSFC
James Zimmerman, NASA Retired

Appendix B
NAC Science Committee Membership
(July 2017)

Dr. Bradley Peterson (Chair)
Ohio State University

Dr. Susan K. Avery
Woods Hole Oceanographic Institution

Dr. Jill P. Dahlburg
Naval Research Laboratory

Dr. Mihir Desai
Southwest Research Institute

Dr. Douglas Duncan
University of Colorado at Boulder

Dr. Kathryn Flanagan
Space Telescope Science Institute

Dr. Bernard Scott Gaudi
The Ohio State University

Dr. Tamara E. Jernigan
Lawrence Livermore National Laboratory

Dr. Mark S. Robinson
Arizona State University

Dr. Steve W. Running
University of Montana

Dr. Walter G. Secada
University of Miami

J. Marshall Shepherd
University of Georgia

Anne Verbiscer
University of Virginia

Ms. Elaine Denning
Executive Secretary
NASA Headquarters

Appendix C
Presentations

1. Big Data Task Force Update; *Charles Holmes*
2. Cassini Grand Finale; *James Green*
3. Science Mission Directorate Fiscal Year 2018 Budget Briefing; *Craig Tupper*
4. Astrophysics Advisory Committee Report; *Alan Boss*
5. SMD Input to SCaN; *Jeffrey Hayes*
6. Research and Analysis Charge Discussion; *Michael New*
7. Planetary Science Advisory Committee Report; *Anne Verbiscer*
8. NASA Observation of Total Eclipse August 2017; *Alex Young*
9. Earth Science Division Update; *Michael Freilich*
10. Human Exploration and Operations Mission Directorate Future Exploration Plans; *Gregory Williams*
11. Deep Space Gateway and Transport Maturation; *Gregory Williams, Michele Gates*
12. Science Opportunities Overview: SMD and HEOMD; *Thomas Zurbuchen*
13. Future Telescopes Human Servicing; *Jeffrey Hoffman*
14. Future Assembly and Servicing Study Team; *Ronald Polidan*
15. Science Enabled by Human Exploration; *Ben Bussey*
16. Mars Space Radiation Environment; *Lisa Simonsen, Cary Zeitlin*

Appendix D
Agenda

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

NASA Advisory Council
Science Committee

July 24-25, 2017

National Institute of Aerospace
100 Exploration Way
Hampton, VA 23666

Agenda
(Eastern Time)

Monday, July 24

NAC SCIENCE COMMITTEE PUBLIC MEETING – ROOM 141

8:30 – 8:45	Opening Remarks / Introduction of Members	Ms. Elaine Denning Dr. Bradley Peterson
8:45 – 9:30	Big Data Task Force Report	Dr. Charles Holmes, NASA (ret.)
9:30 – 10:10	Cassini Grand Finale	Dr. James Green
10:10 – 10:30	SMD FY18 Budget Briefing	Mr. Craig Tupper
10:30 – 10:40	*Break*	
10:40 – 11:00	Astrophysics Advisory Committee Report	Dr. Alan Boss, Carnegie Institution of Science
11:00 – 11:30	SMD Inputs for SCaN Congressional Action	Dr. Jeffrey Hayes
11:30 – 12:00	Discussion	
12:00 – 1:00	*Lunch*	
1:00 – 2:10	R&A Charge Discussion	Dr. Michael New
2:10 – 2:15	Public Comments	
2:15 – 2:25	*Break*	
2:25 – 2:40	Planetary Science Advisory Committee – Science Highlight	Dr. Anne Verbiscer University of Virginia
2:40 – 3:10	NASA Observation of Total Solar Eclipse	Dr. Alex Young NASA Goddard Space Flight Center

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

3:10 – 3:50	Earth Science Division Update	Dr. Michael Freilich
3:50 – 4:30	Discussion with SMD AA	Dr. Thomas Zurbuchen
4:30 – 5:00	Discussion	
5:00 – 5:30	Outbrief for SMD AA	Dr. Thomas Zurbuchen

Tuesday, July 25

NAC HEO Committee / Science Committee Public Meeting – Room 137

9:00 – 9:15	Opening Remarks for Joint Session	Dr. Bette Siegel / Mr. Ken Bowersox / Ms. Elaine Denning / Dr. Bradley Peterson
9:15 – 12:15	*HEO and Science Emerging Opportunities*	
9:15 – 10:15	HEO Future Exploration Plans	Mr. Greg Williams
10:15 – 12:15	*Science Opportunities*	
10:15 – 11:00	Science Opportunities Overview	Dr. Thomas Zurbuchen
11:00 – 11:10	*Break*	
11:10 – 11:45	Future Telescopes Human Servicing	Dr. Jeffrey Hoffman Massachusetts Institute of Technology
11:45 – 12:15	Future Assembly and Servicing Study Team	Dr. Ronald Polidan Polidan Science Systems & Technologies, LLC
12:15 – 1:15	*Lunch*	
1:15 – 2:15	Science Enabled by Human Exploration	Dr. Ben Bussey
2:15 – 2:30	Break	
2:30 – 3:30	Space Radiation	Dr. Lisa C. Simonsen, Dr. Cary Zeitlin
3:30 – 3:35	Public Comment	
3:35 – 5:15	Discussion, Findings, and Recommendation	
5:15	*Adjourn*	

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

Dial-In and WebEx Information

For Monday, July 24, 2017

Dial-In (audio): Dial the USA toll-free conference call number 1–888–592–9603 or toll number 1–312–470–7407 and then enter the numeric participant passcode: 5588797. 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 991 826 993, and the password is SC@July2017 (case sensitive).

For Tuesday, July 25, 2017

Dial-In (audio): Dial the USA toll-free conference call 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 991 050 585, and the password is Exploration@2017 (case sensitive).

**** All times are Eastern Time ****