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Planetary Science Subcommittee

Meeting Report

July 2-3, 2008

Goddard Space Flight Center

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MEETING REPORT

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Sean Solomon, Chair

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Michael New, Executive Secretary

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Monday, June 23, 2008

Introduction and Welcome

Planetary Sciences Subcommittee (PSS) Chair Sean Solomon opened the meeting and noted some transitions on the subcommittee, welcoming newly attending "pending" members Kip Hodges, Jeffrey Johnson, and Lisa Pratt and thanking departing members. Michael New noted and distributed a CD containing strategic planning documents for the use of committee members.

Planetary Science Division Update

James Green, Director of the Planetary Science Division, opened the review with a recognition of the recent successful Phoenix landing in the northern polar region of Mars. He noted some administrative changes, including two new vacancies occasioned by the departure of John Rummel (Astrobiology Senior Scientist) and Denis Bogan (Cassini Program Scientist). New personnel are Tom Morgan (Lunar Program Scientist), returning from a detail to Goddard Space Flight Center; Gordon Johnston, Program Executive (PE) for the Lunar Reconnaissance Orbiter/Lunar Crater Observation and Sensing Satellite (LRO)/LCROSS; Joan Salute, PE for the Lunar Atmosphere and Dust Environment Explorer (LADEE); Len Dudzinski, PE for radioisotope power systems (RPSs); and new Program Scientist, Max Bernstein. While the Science Mission Directorate (SMD) staff has been continually decreasing, PSD has been fortunate.

Two National Academy of Sciences (NAS) studies are upcoming that will review Research and Analysis (R&A) and the Near Earth Object (NEO) programs. The latter study will cover both detection and mitigation and was jointly requested by NASA and the National Science Foundation (NSF). Dr. Green anticipated positive new opportunities with the return of Ed Weiler as SMD Associate Administrator (AA). Recent activities include the selection of LADEE, and proposals for Lunar Science Institute nodes (due in August). A final release of Stand-Alone Missions of Opportunity Notice (SALMON) is expected in August, with selections to be announced in March 2009. A New Frontiers Announcement of Opportunity (AO) is due for final release in December 2008, for which previous PI certification rules have been dropped. AO requirements have been simplified so that it is easier to respond. The Discovery program is under review.

In the New Frontiers program, NASA has reviewed the National Research Council's (NRC's) New Opportunities for Solar System Exploration (NOSSE) recommendations, which were to emphasize science objectives, consider an expanded list of candidate missions, and limit selections to the list unless compelling science was identified. The list includes a Venus *in situ* explorer and comet sample return, among many others. (The NOSSE report is located at www.nap.edu). NASA accepted the first two recommendations, established a cost cap of $650M as well as no requirement for a radioisotope power system (RPS), and stipulated an Evolved Expendable Launch Vehicle (EELV) as a presumptive launch vehicle. Within the Fiscal Year 2009 (FY09) Passback direction, the Office of Management and Budget (OMB) expects NASA to execute new initiatives and absorb their costs within the agency's top line (including a mandated acceleration of Earth Science missions and a series of lunar robotic missions). Lunar research was established in FY08 with new funding for PSD. In the five-year budget projection, the

language for Mars Sample Return (MSR) emphasizes "considering" but not "committing," but the debate is far from over. OMB was pleased with the Outer Planets Flagship mission (OPF) concept, while urging SMD to manage costs rigorously. The original cost cap for OPF was $2.1B, and SMD is starting to look at the science trade space and a potential European Space Agency (ESA) contribution. Regarding the non-Mars planetary timeline, Dr. Green noted that NASA must work with ESA more closely and make its schedule more commensurate with theirs. OPF is moving farther out in the decade, and the Mars mission timeline is also subject to the same pressures.

For OPF, two studies were undertaken in partnership with ESA: a Europa Jupiter System and a Titan Saturn System mission. The studies took into account Decadal Survey (DS) requirements and then examined the funding atmosphere, a revision of ground rules between former and current SMD AA. The earliest ESA launch is 2018; the interim report, issued jointly by the two Science Definition Teams (SDTs), indicates that the missions, if limited to a total cost of $2.1B, would shortchange science from the DS and therefore were not acceptable. OPF therefore is not a done deal and has a long way to go. In the meantime, SMD must also build a more credible Mars program. There is therefore a mid-course correction for OPF, wherein the division is concentrating on costing the "sweet spot" of science per dollar and aligning its schedule with ESA's. The new schedule for delivery of a final study is to be determined (TBD). After delivery, the PSD will evaluate and downselect, considering launches between 2018 and 2022. A credible OPF cannot be done before 2020 without major sacrifices. In response to committee concerns regarding OPF trades versus the Mars program, Dr. Green replied that NASA is moving down two independent paths and trying not to collide, while conceding that the dual effort will require a lot of jockeying of resources and more information. To get OPF started, NASA was going to cut the Cassini mission short; however, now that OPF has been moved out two more years, Cassini can remain in operation. There is no expected impact of James Webb Space Telescope (JWST) costs.

Lunar missions include LCROSS and an LRO launch later this year, and the launch of the Indian Space Research Organization's Chandrayaan-1 (carrying two US-supplied instruments) in September. LADEE has been assigned to the Ames and Goddard centers, and is now launching separately from GRAIL, to be launched in 2011. LADEE will study the composition of the lunar atmosphere, characterize dust, and carry a neutral mass spectrometer, an ultraviolet (UV)/visible spectrometer, and an *in situ* dust detector. The International Lunar Network (ILN) is slated to place its first two nodes in 2013 and 2014, eventually growing to 6-8 stations. NASA is studying options for a lunar communications relay to accommodate night-side nodes. Each station will have a set of core instruments. The LASER 07 program had 160 proposals; SMD has funded this program to the tune of $10.1M over 4 years, and ESMD $3.9M. LASER is a good mixture of basic and applied science and some jointly funded proposals. A Lunar Science Conference will be held at Ames in July.

Dr. Green reviewed the division response to previous PSS recommendations: the first, on developing RPSs. PSD is now working on producing two Stirling engines for a near-term flight opportunity. NASA has also started the requisite dialogue with the Department of Energy (DOE) and is putting out a request for information (RFI) for small RPS development to follow once requirements are determined. If there are not commercially available small RPSs, NASA will have to develop the RPS itself, and this may include isotopes other than those of plutonium. To meet concerns about long-term power, NASA may allow ESA-sponsored ILN nodes to have the "easier" places to obtain power while the U.S. nodes use RPSs in darker locations. The Discovery and Scout Mission Capability Extension (DSCME) program has received 40

proposals, with 9 selections covering the Moon, Venus, comets, outer planets, Mars, and asteroid science. The program is funding mission concepts that explore the science return possible from Discovery-size missions equipped with RPSs. In response to recommendation #2, which addressed Mars Science Lander (MSL) cost growth problems, the division is still working toward a 2009 launch but is not out of the woods. The projected overrun was $190M over 2 fiscal years. For FY08, SMD found $115M, mostly from uncosted carryover and elimination of program reserve in Mars, Planetary, and "other" SMD. In 2009, MSL still needs $75M. SMD will decide and finalize plans to address this by early October 2008. Dr. Green provided a detailed list of MSL cost items, showing increases from $1.2B to $1.546B. Some precipitating factors of these increases were delays at JPL and at suppliers. Response to recommendation # 3, enabling MSR by 2020, was addressed by the following presentation.

Mars Exploration Program (MEP)

Michael Meyer reviewed the Mars program activities. The Mars Reconnaissance Orbiter (MRO) is still having some technical difficulties with relay, and MSL is still a concern in schedule and cost but still on track to launch in 2009. Mars Odyssey and the Mars Exploration Rovers (MERs) continue to perform well. Phoenix has landed successfully and is in science operations. MEP is in the process of being restored to a viable architecture that meets budget realities. A Senior Review (SR) was held in March, which extended the missions of Odyssey, MER, MRO, and MEX. A status briefing on MSL has been given to Administrator Griffin, and weekly and monthly reports are given to the SMD AA. Progress has been made in the heat shield design, and a continuation review will be held with the Administrator in September 2008. A Scout-13 selection is planned for September, and extra funding has been obtained for two instruments to fly on ESA's ExoMars: UREY and MOMA (investigating organics and oxidants, and molecular signatures).

Science highlights include imaging of the internal stratigraphy of the northern polar layered deposits by the SHARAD radar on MRO. The interior of Mars is colder than expected, and the surface contains chloride-bearing salts, which could be precipitates from evaporation of ground water or volcanic outgassing. Evidence shows that acidic saline liquid water was intermittently available on ancient Mars. However, water activity measurements indicate that conditions are unlikely to support life.

Fundamental topics for FY09 include determination of baseline program contents, apart from MSR. How does MSR fit in the architecture and is it affordable? The community recognizes that NASA might have to skip opportunities to achieve sample return. The communications infrastructure in the next decade must be implemented. The FY09 budget will not support a stable executable program. MEP also wants to limit international dependencies for MSR. The Mars Architecture Tiger Team (MATT) has proposed a new architecture, which is currently being Red-Team reviewed by Scott Hubbard *et al*. MATT has identified mission blocks as being MSR-Lander and MSR-Orbiter, Network Science, Mars Science Orbiter (sensing), Mars MER+ Rover (Mars Prospector Rover; sub-MSL scale with sample caching), and Mars Scout missions. Caching design will provide for sealed and separated samples, regarded as a technical challenge. Opportunities deteriorate after 2020. If MSL and Phoenix raise the bar in organics discoveries, it would change the complement of instruments carried on the putative Rover. Despite OMB instructions to come up with an MSR-less scenario, MATT decided against doing this.

MSL will have a sample caching capability, but caching strategy is TBD. The program thinks it has enough knowledge to choose a site for MSR. A 2018 launch was ruled out as too early and too costly for

MSR. Six sites are under consideration, with more coming. Eight different aqueous minerals have been identified as astrobiologically relevant. MATT recognized that technology development for coring and encapsulation needs further effort. PSD is planning to identify money for technology development, which may show up in the 2010 budget.

Subcommittee Discussion

Dr. Solomon opened the floor to discussion. The conflict between two expensive overlapping missions, MSR and OPF, was of uppermost concern, pushing out a Venus flagship mission farther still. Dr. Green noted that NASA planned to charge the NRC to begin development of the next Decadal Survey (DS) by the end of the calendar year, which would require a good deal of the community's attention but which would afford an opportunity to inform the next DS with clearer mission concepts and expected costs, especially with regard to Venus. Some committee members felt this timing would not be soon enough. Dr. Green asked for more guidance from the community on how to guide planetary, Mars, and Moon, and how to speed up technology development in MSR. He felt that the international community was more able to make commitments on OPF than on MSR. Asked if he couldn't make a specific commitment to OPF or MSR until 2011, Dr. Green could only comment that the impending administrative change would alter the landscape, and that NASA was waiting for this input to make a commitment to a particular mission. Precursor missions may make an MSR mission a matter of national importance. In the meantime, the Agency continues to aggressively study the two approaches. The committee cautioned against creating the impression of community disunity, and of potentially alienating international collaborators.

In reply to whether ESA's September ministerial conference represented an opportunity for OPF, Dr. Green noted that ESA is due for a downselect in the Cosmic Visions proposals, which will occur well into 2009. Dr. Green did not foresee going back to major targets (i.e., Europa) 3 or 4 more times within one's scientific lifetime. With that understanding, the community must define the science questions more thoroughly for OPF and select a target accordingly.

In response to committee concerns on moving New Frontiers (NF) forward, Dr. Green felt the NF program was on a reasonable schedule, with maturing scientific concepts under study. The next important element is Discovery, defining how the next program will be put together. PSD is now the envy of SMD in many respects, and is working some programs jointly with other divisions. SMD takes seriously the charge to maintain balance in the program without gutting it. Asked why Io is on the NOSSE list, as it seems to contradict the philosophy on mission costs, Dr. Green responded that a mission could conceivably accomplish science without orbiting Io. Inventive ideas will be required to accommodate the science. In response to a question, Dr. Green assured the committee that major missions such as Mars Prospector will have independent cost analyses, especially in the light of lessons learned from MSL, but that the Venus mission had not yet been costed (too early). Asked if Discovery were going to slip, Dr. Green allowed only that some elements are under review, such as launch vehicle and the availability of Stirling technology.

Lunch talk

Dr. Peter Smith presented the latest findings from the Phoenix mission, on sol 28, two weeks into its nominal science mission.

OPF Mission Studies

Curt Neibur presented a review of OPF mission studies. Currently PSD is halfway through a 6-month-long phase II study of a Europa/Jupiter System Mission and a Titan/Saturn System Mission. The plan is to select one mission to be conducted in partnership with international partners, and to also consider a NASA-only mission, with a cost cap of $2.1B and a preferred launch year of 2016/17. The studies have undergone a Technical, Management, and Cost (TMC) review and a Science Panel review. A downselect will be made in November 2008, in conjunction with ESA. As a result of a second interim review with Dr. Weiler, three different missions are now being considered at a high level, including estimating the cost that would cover full decadal science, seeking the aforementioned sweet spot, with launch opportunities between 2016 and 2022 and further considering the interrelationships between NASA and ESA.

Within the Europa/Jupiter concept, NASA would provide a Jupiter/Europa Orbiter (JEO) (with Io flyby), and ESA would provide a Jupiter/Ganymede Orbiter (with Callisto flyby). These are two separate missions (spacecraft) that are linked but can also stand alone. JAXA is also proposing a magnetospheric Jupiter orbiter as a ride-along with either NASA or ESA. The mission supposes an Atlas V 541 as a launch vehicle, with 5 Multi-Mission Radioisotope Thermoelectric Generators (MMRTGs), allowing a 5-to-6-year mission duration, with 2-3 years of a Galilean satellite tour consisting of 3-4 Io, 8-10 Ganymede, and 4-6 Callisto flybys, and a Europa orbital period of 105 days. The final disposition is impact on Europa, which has been approved by the Planetary Protection Subcommittee. The mission will perform 5 science investigations with 6 instruments, a 68-kg payload, and 101 W of power. There is roughly a 10^{-6} chance of contaminating an ocean, in terms of planetary protection requirements. As designed, there is no dependency between efforts, but there is an enhancement of science return. To save money, interdisciplinary scientists are not included in study cost estimates.

A decade of technology investment is behind the JEO mission concept. Radiation-hardened instruments such as ASICs, and RAM for the spacecraft, are being developed for the Department of Defense (DOD) at no charge to NASA. For sweet spot determination, the team would add, in order of priority, a narrow angle camera, an augmented infrared (IR) ability, hybrid solid-state relay (SSR), a more diverse tour, a particle instrument, etc. As it stands, the "sweet spot" mission would cost $2.8B in real year dollars, $2.4B in FY07 dollars. The study also assumes that foreign partners may provide some instruments. The launch vehicle is the determining factor. JEO hits the key points of the DS and has significant technical advances over a decade's time, and a NASA-only mission is highly capable. The plus-up analysis allows optimization of science cost and risk.

A Titan/Saturn mission would explore Titan, an Earth-like system, and Enceladus. The core mission uses all-chemical propulsion, and would encompass a lander and a balloon. Launch would take place in 2016, with a 10 year-cruise to Saturn on a Venus/Earth/Earth trajectory, 4 Enceladus and 14 Titan flybys, with a dedicated Titan aerosampling and mapping orbit. Six instruments include a high-resolution imager, radar altimeter, mass spectrometer, thermal IR imager, submillimeter spectrometer, and radio science. The core mission assumes 18 months in Titan orbit. ESA is studying providing *in situ* elements, such as a Montgolfiere balloon released 6 months prior to NASA's arrival; its heat source would be a MMRTG (note: NASA cannot launch nuclear material on a foreign vehicle). A capable lander would land and operate on the surface of Titan for one year. The sweet spot cost for Titan is FY07 $2.3B. A solar-electric

propulsion (SEP) stage can reduce cruise time by 2 years. Jupiter will not be in line as a gravity-assist for this mission.

The sweet spot missions will be re-planned in terms of study, schedule and budget, with final reports due by the end of 2008. In the meantime, the mission planners will continue community involvement through workshops. An instrument workshop was held June 3-5, and a second workshop is scheduled for the Fall. This complex international mission is still in pre-phase A, and therefore changes are to be expected. Penetrator or surface features have also been explored – touching down on Europa will cost $1.5B to $5B.

VExAG report

Ellen Stofan presented an update on Venus Exploration Assessment Group (VExAG) activities, beginning with a status of the Venus Science and Technology Definition Team (STDT) to define a Flagship-class mission to the planet, with a launch timeframe of 2020-25. The final report is due in November 2008. The mission is to address Venus from interior to atmosphere, and to determine the effects of solar wind on the planet. Interim report conclusions were presented in May as a VExAG white paper. The mission consists of three parts: an orbiter, two balloons at 52- and 70-km altitude, and 2 short-lived landers and is in the $2-3B range. All aspects will be at technology readiness level-6 (TRL-6) by 2015, as required. A low-level balloon for surface imaging and atmospheric sampling, and long-lived elements such as a seismometer, are also being considered. At the May VExAG meeting, the community agreed that climate is key, as is system science, or the interaction between interior, surface, and atmosphere. Dr. Stofan reported much enthusiasm for the mission concept, and that the STDT strongly endorsed science goals and process. Additional input can be added via Web and at the Division for Planetary Sciences (DPS).

VExAG assessments include a need for near-term technology investment for system-level technology, high-temperature sample acquisition and handling, aerocapture, instruments, a long-traverse floater, and a Venus environmental testing facility. VExAG endorsed a Comparative Climatology research program linking the study of the Earth, Mars, and Venus (a Fall AGU session has been proposed on the subject, as well as a Chapman conference). The community also endorsed a Venus Laboratory Research initiative, to produce a significant list of laboratory measurements needed to ground-truth remote and *in situ* measurements. International coordination would be helpful in this area as well. The Venus research community would also benefit from renewed emphasis in the R&A program. Dr. Stofan presented a draft statement urging SMD to invest in aerocapture as a critical technology that can enhance future planetary missions and sought feedback, with consideration of a near-term flight validation project, as a PSS recommendation. Dr. Green suggested bringing up this subject with Dr. Weiler. The next meeting of VExAG will be in February 2009.

LEAG

Clive Neal presented recent Lunar Exploration Assessment Group (LEAG) activities, citing some progress on the Lunar Exploration Roadmap. Five activity teams are working on this roadmap, with reports due June 30. Further input will be received at the Lunar Science Conference in July, through 3 breakout sessions based on 3 roadmap themes: the pursuit of scientific activities on the Moon; use of the Moon to prepare for future missions to Mars; and extending sustained human presence to the Moon to enable eventual settlement. LEAG will have an afternoon session on July 22. The next LEAG meeting will be held jointly with the International Lunar Exploration Working Group (ILEWG) and the Space

Resources Roundtable, to be held October 28-31, 2008. Themes that will be explored are Sustainable Moon, International Moon, and Productive Moon, and there will be a special session on imminent missions to the Moon. The plenary session will address pathways to implementation of the global exploration strategy. Specific questions include reduction of costs for maintaining a sustained presence on the Moon, the status of the Space Law, use of lunar resources, etc.

Regarding a NASA Advisory Council (NAC) request for LEAG to review the Lunar Architecture Team-2 (LAT-2) output, LEAG has declined the request, but instead suggests that LEAG be involved with the Constellation Architecture Team (CxAT) lunar effort. Dr. Neal asked that PSS attempt to raise a response from NAC on this issue. The LEAG also hopes to obtain a briefing from the Commercial Development Summit on NASA's Lunar Activities, as it sees sustainability linked to commercial involvement. LEAG and the NAC have also been invited to the Lunar Capability Concepts Review at the Johnson Space Center.

MEPAG

Jack Mustard gave a brief overview of the Mars Exploration Program Assessment Group (MEPAG), beginning with science highlights, citing recent results that possibly indicate a subchondritic distribution of radioactive elements on Mars, and the evidence of low water activity over much of Mars's history. Clay minerals have been detected in Mars deltas, which has implications for sequestration of organic matter, and which may constitute a good site for sampling. The clay seems to date to the Noachian boundary (3.5B years ago), as evidence of standing water at some period. There are also meander systems that likely have clay components.

MEPAG participated in a major analysis of design reference architecture for human exploration of Mars, and a report is under preparation. CAPTEM co-organized a Sample Return conference, and CAPTEM and MEPAG are working on joint recommendations. The MEPAG Goals Document is also being revised, with final changes to be made this fall. Since the last PSS meeting, MEPAG has completed an activity on prioritization for Mars sample return, (reported on the MEPAG web site), and has had strong participation in the Mars Architecture Tiger Team (MATT) and in the International Mars Architecture for Return of Samples (iMARS) process. Next Decade Exploration is considering an as-yet unnamed mission in 2016, with a MSR-Lander in 2020. The MATT report is looking at ways to fill gaps between the two previous architectures and has produced a table of various options tied to different launch opportunities. The preferred scenario is the first element of MSR in 2020, followed by a 2022 opportunity.

The 2016 opportunity is becoming more clearly defined and may include a landed component (lander/ rover; precision landing, surface and subsurface sampling capabilities). The key technology for this opportunity is sample caching and handling. MEPAG is also involved in the Comparative Planetary Climatology program and Center for Mars Climate activities. At its next meeting on September 18, MEPAG aims to assess MATT and Red Team reviews.

OPAG

Fran Bagenal reported on the activities of the Outer Planets Assessment Group, which met in March and particularly considered the NOSSE report and questions surrounding radioisotope power systems (RPS). OPAG endorsed the idea of relaxing the $2.1 B cap on the OPF mission, and applauded the extended

Cassini mission, as well as the potential for an "extended-extended" mission (XXM), in which the exploration of Saturn from a Juno-like orbit is possible.

Observations concerning the Enceladus plume, and its interesting chemistry, raise many questions about the process producing this plume. In addition, a Cassini XXM might examine the changing Saturn season from equinox to solstice. There is also a scientifically interesting end-of-life option for Cassini, to fly through the gap in Saturn's ring system and make measurements. This XXM, however, must be weighed against plans for the next OPF. OPAG also endorses the Discovery and Scout Mission Capability Enhancement (DSMCE) studies, which will provide opportunities to look at small focused missions in the Outer Solar System. OPAG is concerned, however, about New Frontiers technology investment and encourages that sufficient funds be included in phase A for technology development as well as the inclusion of RPSs in the New Frontiers-4 (NF4) AO to enable important science objectives and future missions. With respect to the Decadal Survey, the community must get an early start and have studies put in place to provide the DS team with information that allows them to make a decision, including data on mission costing and budget. It is less clear, however, how the DS should be updated mid-term as new data are incorporated. Dr. Bagenal expressed more concern that the survey be done properly so that it can actually be relevant for 10 years, and that Planetary not go down the road of JWST. Good technical information can avert this scenario.

OPAG believes that Uranus and Neptune probes are the logical sequence after Galileo and Cassini, and aerocapture will be an important part of that exploration. OPAG's next meeting in November will consider more information on Flagship studies, and an updated PSD Science Plan.

Small Bodies Assessment Group (SBAG)

Faith Vilas presented some meeting planning activities for a Small Bodies Assessment Group (SBAG) Town Hall meeting scheduled for July 10. An SBAG Inaugural Meeting will also be held September 23-24 at the Washington Hilton in Washington, D.C. SBAG is trying to get word out to the community and input from the community. The Group is planning a white paper for submission to the DS, covering small body science, mission concepts (remote sensing and sample return), population identification and character assessment, in situ resource utilization (ISRU), and hazard assessment. Dr. Vilas invited the community for breakout sessions at the first SBAG meeting. Dr. Weaver added that there would be a Great Planet Debate at the Applied Physics Laboratory (APL) on August 14-15. (gpd.jhuapl.edu).

CAPTEM

Chip Shearer reviewed the Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) function, which is devoted to general sampling, and plays an important role in the allocation of NASA's collected planetary materials, provides analysis and guidance for sample curation, provides sample science expertise, and sponsors workshops on the subject. Dr. Shearer reviewed some recent CAPTEM allocations such as requests for lunar samples, and Stardust and Genesis samples.

CAPTEM helped to sponsor a Ground Truth from Mars: Science Payoff from a Sample Return Mission, workshop, held jointly with MEPAG and other NASA entities, which met April 21-23 in Albuquerque, NM. Workshop materials may be viewed at www.lpi.usra.edu/captem. Workshop participants provided incredibly diverse representations of science that could be done on Mars samples. The wide range of

science presents challenges to narrowing down sample types and site selection. There seems to be an untapped reservoir of sample scientists. There was a recognition that although analytical technology continues to evolve and improve, samples may be reactive and thus will require excruciatingly correct handling. The workshop also considered a range of missions, as well as needs for advanced planning of containment protocols and facility, and called for a unified integrated committee to oversee MSR from the start and into the future. In other matters, CAPTEM is reviewing handling and allocation for "new" Apollo samples and is in the process of an engineering study for updating the air handling system in the lunar sample facility (Building 31N) at Johnson Space Center (JSC). Dr. Shearer cited the recent NRC report "The Scientific Context for Exploration of the Moon" finding and recommendation for NASA to conduct a thorough review of sample curation with an eye to future sampling. This could be done during a required CAPTEM review of JSC curation, which is considering different lunar architectures. Planning is also under way for preliminary examination of Stardust interstellar dust samples, and a Stardust Science Workshop is planned for late 2009.

iMARS

Lisa May provided an update on NASA planning for Mars sample return, including international efforts. She began by reviewing the basic components of MSR, which will include the need for telecommunications relay to support landed elements. The National Environmental Protection Act (NEPA) process must begin more than 10 years before samples arrive. Other components to be considered are mobility on the surface of Mars, a Mars Ascent Vehicle (MAV), a Sample Receiving Facility (SRF), and ground facilities for all architecture options. Programmatically, the budget must be credible and defensible. Cost estimates will determine launch date possibilities, independent estimates will be required (one has already been run at a high level), and international collaboration will probably be necessary. Caching on exoMars remains a possibility, as would a resolution to solve the caching problem by 2016. Community input has included the MEPAG Next Decade Science Assessment Group, MATT, PSS, CAPTEM, and PPS, the latter of which has endorsed NASA efforts to update the Draft Test Protocol and plans for a Sample Receiving Facility.

The International Mars Architecture for Return of Samples (iMARS) efforts include a charter by the International Mars Exploration Working Group (IMEWG) to define an affordable MSR architecture. Thus far iMARS has concluded that an Ariane vehicle would be hard-pressed to carry an MSR mission. A Phase I report on this architecture will be reported to IMEWG in July. The iMARS Phase I report conclusions include the need for sufficiently diverse, scientifically significant, carefully handled samples; the identification of 20 mission building blocks (e.g. sample container, Earth return vehicle) that could be distributed among international participants; the identification of 5 high-priority missions design options; and the recognition of the long-lead aspect of the mission (must begin effort at least 10 years before launch of flight segment). iMARS architecture and plans enable a path toward a fully international, affordable MSR mission. Public outreach and communication are vital to the effort and must be handled openly. On the question of sample sharing, Ms. May reported the consideration of a virtual Mars Sample Institute to help make those decisions. iMARS is still discussing ground facilities for receiving and curation. Compared with U.S. efforts, iMARS favors a two-element mission, while MATT favors three, but they are not incompatible. There is cross membership between MATT and iMARS.

The technology tall poles, as identified by NASA and ESA and concurred upon by iMARS, include precision landing capability; hazard avoidance; forward planetary protection; sample acquisition, handling, encapsulation, and transfer; Mars Ascent Vehicle; autonomous rendezvous and capture; high-speed Earth re-entry; and SRF technologies, including transport within and out of facility. Engineering specifics on an actual building are yet to be determined. The "stuck in the SRF" scenario is also being considered, in the event that a sample cannot be declared "safe" for open distribution. Dr. Neal suggested considering a "stuck with the SRF" scenario, in which case it might be used for curation, or for other sample return missions. Dr. Shearer suggested considering conditions of sample preservation (under Mars conditions, humidity, temperature?).

Consideration of MSR beyond 2020 has been discussed. Mass constraints and time on surface will are most heavily influenced by launch date; launches in 2028 and 2030 arrive at Mars during dust storm season. An orbiter-first and lander-second mission is contrary to MATT recommendations. A precursor rover makes some of those issues go away, but a MAV probably cannot sit on the surface for two years. Risks of launching samples into Mars orbit to wait for a later orbiter must also be assessed. However, a three-element architecture would allow ample time for sample collection.

GPRA assessment

Dr. Philippe Crane distributed materials for the grading of PSD in accordance with the Government Performance Results Act. The final version, containing text that describes each planetary subgoal and accompanying accomplishments, will be submitted to NASA management and OMB in late summer. Dr. Bagenal expressed concern about the categories and their reflection of what the division actually does, and also cited missing information, such as this year's New Horizons flyby of Jupiter, multiple Cassini flybys of Enceladus, and the MESSENGER flyby of Venus− these are exciting results that should be added to the text. Dr. Solomon added that there was also the danger that the inclusion of only 3 or 4 examples per category might give the incorrect impression that only 3 or 4 are needed for an acceptable outcome. Dr. Crane assured the committee that the language would appropriately represent outcomes, per feedback from PSS. There was brief discussion of substituting annual performance goals (APGs) that are traceable back to the Science Plan and Roadmap, but the idea was vetoed as it would likely represent a problematic message to OMB. Dr. New reminded the committee that the origin of the subgoals derived directly from the Decadal Survey in language. There was also a suggestion to expand hazards from merely NEO listings to include some geospace weather data.

3C1. Progress in learning how the Sun's family of planets and minor bodies originated and evolved.

PSS voted unanimously on Green. Some text on the Jupiter flyby was to be added.

3C2. Progress in understanding the processes that determine the history and future of habitability in the Solar System.

PSS voted unanimously on Green. Dr. Anbar cited 4 papers in *Science* that relate to this astrobiological goal, and the chemistry of Titan (organic species) was also suggested as an addition.

3C3. Progress in identifying and investigating past or present habitable environments on Mars and other worlds, and determining if there is or ever has been life elsewhere in the solar system.

PSS voted unanimously on Green. Evidence for an ocean on Titan was suggested as an addition, and the exoplanet statement was moved to 3C2.

3C4. Progress in exploring the space environment to discover potential hazards to humans and to search for resources that would enable human presence.

PSS voted unanimously on Green. It was recommended that Phoenix ice results be fleshed out, Arecibo results added, and references added for asteroid discoveries (Steve Ostro) and Mars dust (lidar data). Open issues were dust storm hazard to missions and space weather.

Dr. Solomon ended the day on a high note, relaying an email from Pat Dickerson, former PSS member, who conveyed greetings and warm wishes to the committee.

June 24, 2008

Discovery and New Frontiers Program Office Lifecycle Cost

Mr. Paul Gilbert briefed the committee on the results of a mission cost study, undertaken in response to previous requests for information regarding cost drivers for planetary missions, and addressing general causes for cost overruns. The Discovery and New Frontiers Program Office defines success as delivering mission science to the PI, meeting the launch date and cost cap, and meeting launch frequency. Five candidate missions were selected for analysis, which involved examining raw data, historical timelines, and a subsequent search for root causes. Most major findings were systemic to all missions. Study staff interviewed mission managers, TMC reviewers, PEs, PIs, etc. and tried to obtain a mix of data. It was difficult to obtain these data due to inconsistencies and a lack of traceability in documentation. These documentation issues often lead to an inability to infer the real cost cap.

Various issues that proved to be deleterious to cost containment were: technology challenges; longevity engineering issues; higher than anticipated ($1M/year) implementation costs of the NASA Independent Assessment Team (IAT) recommendations ; higher than expected development costs for science instruments (exceeding preliminary design estimate by $18M during phase C/D in one instance (with the problem attributed to a contractor)); and lack of a revalidated vendor quote since the concept study report (CSR) estimate. Another project had start-stop issues due to the events of September 11, 2001. In other instances, a project had three different PMs during phase C/D; a contractor never had prime responsibility; a contractor had no primary system-level planetary experience; and in one project, the PI and PM expended reserves at a high rate during phase C/D.

A “gate” study taking line items from each mission, from AO to preliminary design review (PDR), confirmation review (CR), critical design review (CDR), and other fundamental milestones of every mission yielded several observations, primarily that one cannot perform credible estimates in the early stage of a project. The inability to perform credible estimates remains a NASA-wide problem for missions. Immaturity of phase A concepts, optimistic key assumptions (heritage, personnel sharing and multi-tasking), and perhaps competitive pressures influence this inability to estimate adequately. These missions are complex, and the project must recognize this when estimating cost. Poor program documentation also played a significant role; particularly significant project decisions should be documented at major review milestones such as the DPMC, PCB, etc). Risk transition at phase

boundaries were also an issue − programs and projects were not tracking or mitigating risks identified in the phase A competitive review process, such as upper stage certification, or hidden costs for nuclear compliance processing.

Major Findings:

- Optimistic hardware/software inheritance and TRL assumptions. These cause difficulties in phase C/D. A suggested solution is to poll centers and talk more about heritage tracking and big dollar assumptions.

- Insufficient project management and technical insight into contractor performance. This causes train wrecks in testing and verification, misinterpretations, etc., causing re-work, re-testing and waivers. The mitigation approach is observing practices in the field and examining interactions in teams that build instruments and spacecraft.

- Inadequate planning for Operations/Phase E. The focus is generally on building at this phase; especially on long-duration missions, overruns build up, usually a result of underestimating the complexity of operation. Projects must capture more knowledge in documentation; NASA has asked missions to highlight staffing levels during planning.

- Inadequate mission re-plans. The impacts of funding, mission scopes and schedules are not sufficiently understood. Missions must do thorough impact assessments to anticipate perennial problems such as budget instability, staff changes, etc. and must allow enough time to adequately re-baseline costs when these changes do occur.

- A lack of integrated project schedules. This resulted in uncoordinated activities, inefficiencies in resource management, poor decisions, and increasing costs. To fix this, an experienced scheduler must work with the project. Earned Value Management (EVM) is ineffective without a valid schedule that has resources loaded into it.

- Fault Protection and Autonomy (FPA). Missions underestimate the time and effort required to complete fault protection and autonomy. This tends to be deferred to phase C/D; software, e.g., is a money sponge. PSD has chartered an FPA working group to come up with best practices in this area so that the community can do a better job in scoping fault protection.

- Ineffective management structure. Unclear roles and responsibilities. Mr. Gilbert cited one mission that could not identify who owned the whole system. (Center and contractor pointed to each other). Functions need to match what is on paper, and projects must flesh out roles and responsibilities.

- Project team inexperience. This was manifested in many ways, such as inadequate schedules, poorly defined management structures, inaccurate cost estimates, and inadequate performance oversight. The system needs to operate differently to reduce risk when bringing a new player into the planetary field. When asked, Mr. Gilbert replied that he did not see a direct correlation with PI experience or inexperience. A PI may be weak on projects, but if s/he has a strong project manager, the project works. The phenomenon is very team-dependent. NASA's view, however, is that the PI is in charge, and responsible even if s/he delegates.

- Consideration of review team findings. In many instances, issues were identified but not addressed by projects. As a result, the program offices have strengthened the Standing Review Board (SRB) process, and issues must be tracked, issued, and mitigated. Refutations of risks must be traceable and documented.

In general, projects began to see impacts in late phase C/D from findings that are embedded in the project before confirmation review. The ability to de-scope content (cost) falls sharply after confirmation, and therefore cost impacts dominate in phase D. Mitigations must occur in the pre-confirmation period in the project life.

Mr. Gilbert summarized by saying his office was not done with heritage reviews, and that modeling improvements will go on indefinitely, while continuing to monitor life cycle cost (LCC) management. The committee discussed the outcomes briefly, likening the message to having to "eat right and exercise" in lieu of seeking a magic pill. Mr. Gilbert concurred, adding that too much science was being put into missions, but that well-defined roles and crisply maintained management and schedule, from phase A onward, were key to success.

In order to disseminate findings, efforts are underway to print these results, as well as to sit with PMs and PIs and walk through items in a lessons-learned database, and to continue active field monitoring. The committee called for a PI handbook, and suggested that PI training be made mandatory, taking advantage of the wealth of experience and numerous courses available at NASA.

SMD Mission Cost and Schedule Drivers Study

Claude Freaner, NASA HQ, presented the results of a 40-mission analysis, and a 10-mission study from 2000-07, including data on cost and schedule growth causes, primarily as input into commonly used cost models. Internal (57.5%) and external (20%) influences on cost growth were examined. Roughly 63% of internal cost growth was caused by instruments. Externally, the majority was caused by launch vehicles. Best practices for cost containment were deemed to be modest mission scoping, robust cost and schedule estimate, monthly estimates to complete (re-do it every month, monitor regularly, assess impact of engineering changes), and effective use of EVM.

Mr. Freaner used an example of concept growth on the STEREO mission to illustrate. There were substantial differences between the initial concept and final implemented configuration, in what was admittedly a directed mission. Irrespective of some impact of full-cost accounting (FCA), the STEREO mission schedule was 70 months (vs. 40 months projected) in development, and the satellite mass rose from 211 to 630 kg, while transponder power went from 20 to 60 W. Typical cost-risk analyses will not capture this type of concept evolution, as the input does not match output, in the case of STEREO. The effect of design changes on the Complexity Based Risk Assessment (CoBRA) model, which was used in this case, is expected to be fairly linear, as the complexity of system increases in the model along with the development cost and schedule. With STEREO, this matched up well.

Mr. Freaner addressed results of a 10-mission study, in which mass, power, cost, and schedule were identified at the beginning of phase B, and then assessed against various points (PDR, CDR, etc.). CloudSat, SWIFT, Dawn, MESSENGER, SIRTF, EO-1, GALEX, MRO, STEREO, and New Horizons were included in this assessment. Almost all missions experienced complexity growth according to the

CoBRA cost model, and the collective result implied an inherent optimism in complexity, cost, and schedule. He conceded that some growth may be due to an increase in knowledge. However, the average launch mass growth of these missions was 43% (against planning for 30% per NASA standards). Mass growth occurs primarily after PDR and exceeds typical guidance, and the growth is relatively constant. Most projects had 20-30% reserves. Whether competed missions were better than strategic or directed missions was "easy enough to figure out from available data." PSS felt it important to make this distinction.

Summary of findings

Average power growth of missions was 42%, with generally constant growth over time. Cost growth was 76% on average, and 113% over baseline without reserves. Cost growth occurs primarily after CDR. Average growth in schedule is 36%, occurring after CDR and exceeding typical guidance, with an 18 month average slip through launch (planetary missions generally a little less). It was generally conceded that planetary missions are driven by launch windows, and so must spend money to avoid launch slip. Most schedule growth occurs after CDR and falls apart at ATLO. Overall, the range of mass growth is large and exceeds typical industry guidance. Minimum instrument growth exceeded the 30% guidelines. Instruments constitute the "little tail that wags a big dog." The study also found that the use of expanded design reserves accounts for greater future design uncertainty.

Recommendations:

The 40-mission study found no impact of funding at phases A and B, however, Mr. Freaner felt intuitively that there is a major correlation. With competed missions, there is no one-size-fits-all solution. While trying to identify uncertainties, certainly more margin up front is better, and 30% guidelines are inadequate. The take-home message is that power and mass growth cause problems. The cost estimators can't validate the design, and while additional work by TMCs in better validating designs will help, the projects must be properly scoped. More detailed studies of a larger mission set will help to develop better guidelines, but Mr. Freaner and others maintained that models are good enough to test with accurate input parameters. More detailed information about instruments would be useful in this regard, as well as past history of performance on a per-institution basis.

Mr. Freaner commented, in response to a question, that increased reserve is not the entire answer – if the money is there, it will be spent. Sequestration of information on funding was seen as one solution, as has been done in some mission scenarios.

<u>SSO Studies of Mission Cost Drivers</u>

Cindy Bruno presented results from a Science Support Office study on mission cost drivers based on detailed analysis of data at key milestones (Project Milestone Performance History; PMPH), in order to determine implementation approaches that enhance the performance of SMD missions. Results have been transmitted to the NAC (Ms. Bruno took an action to send these results to Dr. New). The study resulted in 20 findings, 13 conclusions, and 12 recommendations.

Initially, 15 missions were selected, spanning the 4 divisions of SMD. There was some difficulty in obtaining complete data sets in comparable formats. In response to a request, the study added 9 missions (Dawn, NEAR, etc). Results were:

Cost history of 21 of 24 missions showed growth ($2B in total), and schedule slips were observed for 19 of 24 missions. Cost drivers were found to be 24% external in origin, 76% internal, and included the impact of FCA. Eight projects cited early planning issues. The four projects that used EVM had lower average cost growth (19% vs. 31%). Cost growth for science instruments (91%) was more than twice the growth for flight systems (44%). On a percentage basis, average cost growth was highest for the WBS elements covering project-level management functions; and although management functions are only about 10% of total cost, a growth in management of 116% is enough to impact cost. Payload cost is 25-40% of a mission, typically. There was a brief debate on cost of payload, with PSS contending that payload cost tended to run 25% or less.

Fifteen of 21 projects showed substantial increases after CDR. There was no correlation between planned reserve level and actual cost performance, and an increase in reserves up front did not appear to be significant. Mr. Freaner suggested at this point that giving a project no reserves may be the best approach, given that the program manager would have to come back on hands and knees for more money. The unfortunate consequence of OMB policy is that it leads to NASA CFO strictness on carryover, so that programs spend money lest OMB rescind it. A participant commented that reserve levels would not control the problem, but rather projects must firmly understand the fundamental engineering problems early on, and spend the money in this area. NASA has received this advice over and over.

Mr. Gilbert suggested leaving the reserves to the PI and leaving flexibility to the PMs, as long as there is monitoring and accountability. Mr. Freaner agreed, adding that the 40-mission study suggested that a percentage of reserves be divided amongst different levels of the project. Dr. Green noted that successful projects are a partnership between HQ, PM and PI, and that the best cost estimates occur when the competition stops.

Ms. Bruno continued the presentation, citing no correlation between percent of funds spent up to CDR and actual cost performance. A JPL historical study, however, has suggested that missions performing at the best level had spent 10-15% of their funds by CDR (in directed missions). Adequate phase B funding is good for mission success but not necessarily overall cost performance. An additional consideration is fitting within the budget cap by year. Dr. Green commented at this point that the policy needed to be more flexible, to allow projects to have adequate budget when it is needed.

Ms. Bruno reviewed recommendations stemming from this survey, which called for more emphasis on detailed technical design concepts, more rigor in process of generating early cost estimates, more conservatism in base estimates, and advocating options for extending phases A and B whenever possible. To compensate for internal and external impacts, projects must develop a credible baseline plan, keep the funding profile constraints out of the AO, avoid redirection from SMD, become educated on EVM and verify that projects are applying it. In order to curtail instrument cost growth, projects must address the weaknesses of current NASA tools for early estimation of science instrument costs and require a variety of baseline instrument estimates (using analogies, parametric models and grass roots estimates). For general cost performance improvement, it was recommended that NASA hold budget reserves at the program level. The key internal factors for cost growth were identified as over-optimism in early formulation and instrument development complexity, and the external factors were identified as launch and budget instability. Practices that improved performance of missions were the presence of ample reserves, best project managers, and best management practices.

The committee had a brief discussion on what factors might be controllable, conceding the political realities as well as the need for the community and HQ to work together to determine limits on large (i.e., Flagship) missions.

Lunar Capability Concept Review (LCCR)

Clive Neal provided a review of a Constellation transportation systems conference held in June at Johnson Space Center (JSC), and reported being impressed by progress thus far. This conference used reference missions to examine the Ares V, Ares I, Altair, and Orion vehicles. There will be a similar conference on surface operations in 2010, overseen in part by the OSEWG.

The Lunar Capability Concept Review (LCCR) was meant to define a point of departure (POD) for designing transportation strategies to the Moon. There are two initial reference missions at this stage of the review, a lunar sortie crew and an un-crewed cargo lander.

In terms of Ares V trade space, there was discussion of moving to the more commonly used fuel HTPB (instead of PBAN), and a recommendation of using vehicle design 51.0.48 while maintaining another design as a back-up. LCCR is also considering a loiter option in both Earth and lunar orbit. Ares V is sensitive to Loiter, Attitude, Power, and Altitude.

The Altair Lunar Lander is designed to transport 4 crew members to and from the lunar surface, with global access capability, anytime return to Earth, a descent stage (O/H fuel), and an ascent stage (hypergolic or O/CH_3 fuel). Technology development is planned for propellants. There is also a sortie variant of the lander, as well as cargo and outpost models. The design approach has produced a minimum-function vehicle which is not flyable, but which provides a basis on which to add components that reduce risk. The launch shroud that packages the lander may be either biconic or ogive in configuration. The ogive configuration is more aerodynamic but more difficult to produce with composites. The shroud is larger than the Vehicle Assembly Building (VAB) at KSC, which means more infrastructure will be needed. LCCR is also considering allowing Altair and Orion to be able to do a four-day loiter in order to access the top ten NRC sites, and also perform science while in loiter mode.

The vehicle architecture has 3 elements: descent module, ascent module, and airlock. The pilot cannot see the landing area, however. A center of gravity problem may lead to a rearrangement of tanks. The Altair design is thus far within mass limits and the Constellation architecture. In terms of sample return, the lander would be bringing back less than an Apollo mission. This crewed configuration would also not include a rover, however, considerable mass is being kept in reserve to buy down risk. There may be a recommendation to the NAC for mobility on a sortie mission. CAPTEM has argued for a minimum total return mass of 230 kg. Overall, the program should be able to increase Apollo capability in order to avoid a public relations disaster.

Action items by Constellation include stochastic modeling of sample return mass on the Altair ascent stage, study of Orion volume capacity for increasing return sample mass, and the consideration of a robotic rover. *In situ* resource utilization (ISRU) is close to being in the critical path. Dr. Neal reported being optimistic about moving in the right direction.

Discussion

There was a brief discussion of lunar capabilities. The architecture allows travel to the far side, but communications, under the auspices of the Space Operations Mission Directorate (SOMD), are still to be determined. There is an assumption of at least one or two communications satellites in the architecture, and a Moon landing by 2018. The goal is to have two landings per year to build up the architecture. Committee members felt that mobility was critical to optimize science, and that multiple cores, trenches, etc., were essential for sample return. It was generally felt that PSS could guide the direction of science activities, sample choice, etc., through at least an annual briefing from the lunar community. Dr. Neal provided some names from the Constellation program to this end. CAPTEM was also cited as a resource in this regard. The issue of intelligent sampling by trained astronauts (e.g., geologist/astronauts) was also raised, as well as different lithologies from disparate lunar sites.

The committee discussed possible questions for Dr. Weiler and tentatively scheduled its next meeting for October 2-3, 2008.

Discussion with Ed Weiler

Dr. Solomon addressed PSS concerns about the budget scenario for large flagship missions MSR and OPF, and how to accommodate the ambitions of the science community. SMD Associate Administrator Edward Weiler gave his perspective as a former Goddard center director (CD), beginning by noting that the Cassini mission, in today's dollars, is $5B without the probe. It is clear that MSR is not going to cost $3.2B, with $58M in its technology budget. JWST has retired 40% of its budget in technology, by comparison. The HQ cost estimate for MSR is $6-8B, and OPF has been costed at $3-3.5B. These numbers are not close to what is in the budget. MSR can be accomplished only at the expense of all other Mars missions. The Mars architecture put in place after 1999 is working just fine, and the community must make difficult choices. In response to a question of whether the community really had to make a quick decision between Titan and Europa, Dr. Weiler noted that he would be meeting ESA's director within a few weeks, but that the fundamental goal for PSD was to get the best program possible, assuming no international cooperation. International cooperation is for enhancing science or moving it to the left, not for making it more complex and expensive. He added that he sensed a consternation in the community, but felt that this period in fact is not the worst of times. PSD has on the order of $10-15B assets in orbit, is fixing HST, has missions *en route* to Mercury and Pluto, has assets around Saturn and Titan, and has multiple assets around Mars.

Asked about prospects for aerocapture technology development for the outer planets and Venus, Dr. Weiler replied that he thought the New Millennium Program (NMP) was a great program, and would consider it in the 2010-11 budget. In the meantime, aerocapture may be testable using the Earth atmosphere in either the sounding rocket or balloon program. While there is a major administration change looming, there is no budget for NMP without stealing from other programs. A fine use of Discovery may be in such testing, such as a technology demonstration in a mission to Venus, for example. However this sort of decision must be determined by community will and the PSD director. Dr. Weiler also expressed approval of the LRO model, which was created by SMD through an AO, then given over to the Exploration Systems Mission Directorate (ESMD); it could perhaps demonstrate technologies as well. Asked if PSD might participate in a lunar *in situ* resource utilization (ISRU)

demonstration mission, Dr. Weiler felt that the best way to participate would be through a grass roots effort, noting that the worst collaboration results when two AAs get together. Asked about what directions the community might take to strengthen international collaborations, Dr. Weiler replied that JWST has represented the biggest dollar amount of collaboration in international partnership. U.S. and European scientists had differing ideas of "noble work," but the communities got together at the grass-roots level to make it easier to get things done, and to encourage clean interfaces. He commented that international partnerships need to avoid critical-path problems, but that MSR will be tough without international collaboration. Dr. Weiler added that he would be happy to pursue international collaboration on flagship missions, such as a joint mission to Titan or Europa, the earlier in the planning process the better.

Responding to queries on his philosophy on R&A, Dr. Weiler felt it was easy to defend the data analysis part of R&A but that it was harder to get into the "NSF" portion of R&A. His philosophy was that R&A should support current and future missions, and not general, curiosity-based research. The essential budget trade-off is missions vs. R&A, but overall R&A is back where it was in 2004. It will be important to establish R&A wedges in each mission budget, thereby getting it in the OMB runout. Asked how tradeable a New Frontiers launch rate is with flagship missions, Dr. Weiler replied that if the highest priority in the community is Europa and it means sacrificing a Mars opportunity, so be it. The advice will have to come from the National Academies, not a Working Group. As this effort might precipitate a holy war in the planetary community, he therefore preferred to have the Decadal Survey to back up the decision. The only trade space is between New Frontiers and Discovery, and the lunar program. The community needs to decide. NASA wants the community, and not Congress, to make the decision. The community can go to the NAC and request an NRC study. Dr. Weiler preferred to defer to an NRC decision on Europa/Titan, possibly by midsummer 2009. The committee generally agreed that an OPF was desired by 2018, with a decision to start in 2010 being reasonable; a decision could be derived from an interim report of the next Decadal Survey.

Dr. Weiler and the committee entertained some lunar science and exploration thoughts, airing some concerns that the Decadal Survey should consider technology readiness and costs, as well as avoid blurring between the Roadmap and the Survey. Dr. Weiler regarded technical readiness as important, and believed the divisions should be spending more on technology. However, the Decadal Survey is not good at estimating costs. NASA scientists and contractors are in sell mode. NRC thinks in terms of phase C/D costs and usually estimated costs at half of what NASA estimates. However, the next Survey will be using cost estimators. Asked if he would consider an International Lunar Network (ILN) cost increase over the current $200M, Dr. Weiler replied that an increase will take money from other missions, and that he did not want to pursue minimal missions.

Regarding mission cost controls, Dr. Weiler noted that contrary to what has been publicized in the press, SMD has not overrun by $5B. SMD has had 20 programs over 5-6 years with an overrun of $1.2 B, averaging to about 12% per mission. New Horizons overran by $100M; some agencies would kill for that low a figure. SMD's biggest accomplishment was the cancellation of 7 missions. The Mars 2001 Lander would have failed, and it ended up doubling the Mars runout budget. Realistically, NASA is unable to anticipate all possible problems in a challenging business. What one cannot excuse is being lied to time after time, or frank mismanagement of missions. MSL is going to find a way to get off the ground, but there are other options if they fail. Dr. Weiler admitted being nervous about the next two months, with its critical deliveries for MSL.

Asked if MSL would buy down risk for landing systems, Dr. Weiler answered in the affirmative, adding that Sky Crane and other advanced systems were the wave of the future. He also foresaw a Scout mission in 2013 and repeated landings over the next decade, building up a solid technological base that will justify spending $6B. MSL must succeed, but he did not plan on throwing a lot more money at it. Asked if he foresaw a substantive change on how reserves are set for missions, Dr. Weiler replied that he can decide to select anything that has a medium to high cost risk. In bigger programs, the Administrator has made the decision for the divisions. The 70% confidence level requirement means fewer missions. He described being berated recently by a reporter for the MSL 20% overrun, noting that Hubble overran by 300%. He cited Goddard's RAO as the best estimating group, which makes assumptions partly based on cost history. They were the only ones who estimated JWST correctly. Most contractors propose at 20% confidence levels.

On the subject of the relative importance of PI experience, Dr. Weiler felt that a mission requires an integrated team, and that an inexperienced PI coupled with a good program manager could be quite successful, but that of course an experienced PI was most desirable. However, a PI must be a team builder and not a dictator. He suggested holding three-day workshops with selectees for each mission. The committee briefly discussed ways in which to inspire the next generation of explorers, the US gaps in math and science education, and the need for openings for young engineers. With much of NASA's workforce ready to retire, there will be huge opportunities in 5-6 years. Dr. Weiler expressed full support for NASA's Education and Public Outreach program, and that he would be giving consideration to NASA's unique educational resources for the 2010-11 budget. He also pointed out that while the Space Act does stipulate that NASA report out science activities, the agency needed to have more female scientists and more plain-speaking communicators reporting on results, effectively and by useful analogy.

Asked if NF and Discovery programs might include student-built instruments, Dr. Weiler felt that NASA's Wallops Island had a good program for students, and that perhaps provisions could be put in new AOs in Discovery and NF. Overall, he looked forward to having science become more of a driving force in exploration, and participation in the lunar robotic program, agreeing that communication could be clearer between the lunar and planetary communities, and that discussions about access to launch vehicles must be held across the directorate, leveraging the assets of other divisions if possible. Dr. Weiler closed by saying he would not make promises he couldn't deliver, adding that his concept of "science sweet spot" means minimum increase, and he encouraged the committee to consult closely with Dr. Green.

Discussion of findings

Dr. New reviewed the issues that had been raised in discussion.

- MSR, OPF, Venus pileup. Is there a still a flagship mission queue and does it alternate outer and inner planet missions?
- New proposed Mars architecture and iMARS
- Role of NF and Discovery in achieving strategic missions
- Venus Lab/Climate
- Restarting NMP or flight demonstration technology program

- Ask NAC to respond to LEAG's demurral on the request to review LAT-2.
- OPAG recommendation that NF4 allow the use of RPS
- Task CAPTEM to address the NRC "4R" finding – evaluating JSC lunar facility for lunar sample handling and future capabilities.
- Recommendation to create a PI handbook
- Mobility systems for lunar sortie systems
- The membership of the COMPLEX group does not include experts in chemistry, magnetospheres, etc., and may lack balance.
- Planetary Protection procedures for a Sample Receiving Facility.

The committee concluded with a brief discussion of Ares vs. Atlas vehicles, and the relative risks of taking the first ride on a new vehicle, deciding to defer a fuller consideration until the next meeting. Dr. Solomon thanked the committee for its efforts and adjourned the meeting.

Appendix A
Attendees

Subcommittee Members
Sean Solomon, Chair, Carnegie Institute
Lars Borg, Lawrence Livermore National Laboratory
Faith Vilas, MMT Observatory
James Head, Brown University
John Mustard, Brown University
Hal Weaver, Applied Physics Laboratory/JHU
Caitlin Griffith, University of Arizona
Charles Shearer, University of New Mexico
Lisa Pratt, Indiana University (pending)
Kip Hodges, Arizona State University (pending)
Clive Neal, University of Notre Dame
Jeffrey Johnson, USGS (pending)
J.A. Slavin, NASA Goddard Space Flight Center
Frances Bagenal, University of Colorado
Ellen Stofan, Proxemy Research
Tom Cravens, University of Kansas (pending)
Ariel Anbar, Arizona State University
Gregory Herzog, Rutgers University (pending)
Michael New, Executive Secretary, NASA HQ

Other Attendees
James Green, NASA HQ
Richard Vondrak, NASA Goddard Space Flight Center
Bob Bartlett, NASA Goddard Space Flight Center
Michael May, NASA Goddard Space Flight Center
Paul Ostdiek, Applied Physics Laboratory
Michael Mumma, NASA Goddard Space Flight Center
Michelle Minitti, Arizona State University
Randall Correll, Ball Aerospace
Karl Hibbins, Applied Physics Laboratory
Joe McDermott, Lockheed Martin
Curt Niebur, NASA HQ
Jon Malay, Lockheed Martin
Melissa McGrath, NASA Marshall Space Flight Center
Carlton Allen, NASA Johnson Space Center
Paul Atcheson, BATC
Ruthan Lewis, NASA Goddard Space Flight Center
Jennifer Kearns, NASA HQ
Gordon Johnston, NASA HQ
John Cooper, NASA Goddard Space Flight Center
Lamont DiBiasi, DiBiasi Associates
Jaime Reyes, Lockheed Martin
Richard Kerr, Science
Dave Beaty, Mars Program Office

Gregg Vane, Jet Propulsion Laboratory
Amy Simon-Miller, NASA Goddard Space Flight Center
Jennifer Elfalan, Aerospace Corporation
Mike Kaplan, Boeing
Marian Norris, NASA HQ
Larry Zanetti, Applied Physics Laboratory/JHU
Lisa May, NASA HQ
Greg Williams, NASA HQ
Ed Grynzeck, NASA Goddard Space Flight Center
Philippe Crane, NASA HQ
Hashima Hasan, NASA HQ
Nick White, NASA Goddard Space Flight Center
T. Jens Feeley, NASA Science Mission Directorate
Kathleen Beres, consultant
Bernard Foing, European Space Agency
Michael Wargo, NASA HQ
Paul Gilbert, NASA
Claude Freaner, NASA HQ
Cynthia Bruno, NASA Langley Research Center
Joan Zimmermann, Harris Corporation

Appendix B

Agenda

Appendix C

Subcommittee Membership