Senior Review Subcommittee Report on Proposals for Mission Extensions for 2019

24 May 2019

1 Executive Summary

The NASA Planetary Mission Senior Review (PMSR) for 2019 was carried out in a series of face-to-face meetings from 6 to 10 May 2019. To comply with the provisions of the Federal Advisory Committee Act (FACA), the applicable six missions were evaluated by members of individual Subject Matter Expert (SME) panels assembled by Arctic Slope Research Services (ASRS), contracted by NASA for this purpose. Prior to these meetings individual SME panelists reviewed the mission project Senior Review / Extended Mission proposals. The subsequent face-to-face meetings allowed for members of each mission to respond to questions posed by the corresponding SME panel. Each SME panel produced a *NASA Planetary Science Division (Consolidated) Senior Review Findings 2019* report and provided two votes on each mission: one for Scientific Merit and one for Technical Merit. At the individual initiative of two of the panels, two votes were taken for two of the missions for both in-guide and over-guide variants, as documented in the extended mission proposals. These reports and votes were provided to the Senior Review Subcommittee (SRS) made up of seven Special Government Employees (SGEs) selected by personnel of the NASA Planetary Science Division (PSD) for this purpose. The SRS observed each SME panel and its deliberations and asked questions of the SMEs, but these queries were limited to procedural and programmatic questions. Each SME panel and each Senior Review proposal team were otherwise explicitly isolated from each other.

The SRS observed *all* proceedings and discussions of all panels and parties. This activity was undertaken in accord with all applicable documented requirements to ensure that the final evaluations and recommendations were consistent and without prejudice across all six missions reviewed. The SRS produced a descriptive summary for each mission, including findings of fact and recommendations to the Planetary Science Advisory Committee (PAC) for disposition of each Senior Review proposal. A high-level, bulletized summary of each SME *(Consolidated) Senior Review Findings* report was produced, the Scientific Merit and Technical Merit scores and their averages were reviewed and discussed. This publicly releasable report documents these materials and constitutes the formal and final report of the SRS to the PAC. Subject to all of these considerations, the numerical and adjectival rankings are shown in Table 1. Section 6 provides details on the SME scorings; section 7 provides details on the translation of these scorings to the SRS rankings.

Table 1. SRS Summary of Mission Rankings for 2019 (Ordered by Mission Ranking)

Mission	Recommended Budget	Mean of Scientific + Technical Merit	Adjectival Rating
Lunar Reconnaissance Orbiter (LRO)	Inguide	4.90	Excellent (Science = E)
Mars Reconnaissance Orbiter (MRO)	Inguide	4.88	Excellent (Science = E)
Mars Science Laboratory (MSL)	Inguide	4.75	Excellent (Science = E)
Mars Science Laboratory (MSL)	Overguide	4.75	Excellent (Science = E)
Mars Odyssey (MODY)	Overguide	4.75	Excellent
Mars Atmosphere and Volatile EvolutioN (MAVEN)	Inguide	4.50	Very Good / Excellent
Mars Express (MEX)	Descope	3.30	Good / Very Good
Mars Odyssey (MODY)	Inguide	2.75	Good
Mars Express (MEX)	Inguide	2.40	Fair / Good

2 Introduction

2.1 Background and Senior Review Subcommittee

The Senior Review Subcommittee (SRS) and individual review panels met in Pittsburgh, Pennsylvania, from 6 to 10 May 2019. Each review panel of subject matter experts (SME), selected by Arctic Slope Research Services (ASRS), were briefed by the lead NASA Designated Federal Officer (DFO)[1] and the ASRS lead for one hour on the Charge to the Panel. Each mission project team was then provided with 90 minutes to present a salient summary of their mission and response to panel questions. The mission project team, limited to five participants, was then excused and the review panel deliberated for 30 minutes on the presentation and responses. The project team was called back for followup for 30 minutes and then excused a second time.

The actual presentation order was determined by the availability of personnel (project, panel, SRS, and HQ). The schedule is shown in Figure 1.

	Monday 5/6/2019	Tuesday 5/7/2019	Wednesday 5/8/2019	Thursday 5/9/2019	Friday 5/10/2019
8:00 AM	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
8:30 AM	Charge to Panel 1	Panel 2 deliberation/write-up	Charge to Panel 4	Panel 5 deliberation/write-up	SRS deliberation/write-up
9:00 AM					
9:30 AM	Project 1 presentation		Project 4 presentation		
10:00 AM	**MRO**	SRS deliberation	**LRO**	SRS deliberation	
10:30 AM		Charge to Panel 3		Charge to Panel 6	
11:00 AM	Panel 1 deliberation		Panel 4 deliberation		
11:30 AM	Project 1 callback	Lunch	Project 4 callback	Lunch	
12:00 PM	Lunch		Lunch		Lunch
12:30 PM		Project 3 presentation		Project 6 presentation	SRS deliberation/write-up
1:00 PM	Panel 1 deliberation/write-up	**MAVEN**	Panel 4 deliberation/write-up	**Mars Odyssey**	
1:30 PM					
2:00 PM		Panel 3 deliberation		Panel 6 deliberation	
2:30 PM	SRS deliberation	Project 3 callback	SRS deliberation	Project 6 callback	
3:00 PM	Charge to Panel 2	Panel 3 deliberation/write-up	Charge to Panel 5	Panel 6 deliberation/write-up	End of Day 5
3:30 PM					
4:00 PM	Project 2 presentation		Project 5 presentation		
4:30 PM	**MSL**	SRS deliberation	**Mars Express**	SRS deliberation	
5:00 PM		End of Day 2		End of Day 4	
5:30 PM	Panel 2 deliberation		Panel 5 deliberation		
6:00 PM	Project 2 callback		Project 5 callback		
6:30 PM	End of Day 1		End of Day 3		

Fig. 1. The planned schedule. The order of presentations and discussions followed the plan, with care to make certain that the Project presentations all had equal amounts of time. Some of the SME and SRS discussions ran longer and discussions ended by or after ~5:30 PM on all days.

The SME Panel then deliberated (with only SRS members, DFO and Civil Servant backups to the DFO also in attendance), leading to a vote on the Scientific and Technical Merit for 90 minutes and subsequently were excused for the Panel chair to write up the *(Consolidated) Senior Review Findings* which were forwarded to the SRS as input to this report. The entire SRS membership, the NASA DFO, the ASRS lead, and the Lead Scientist, Mars Exploration Program were invited to,

[1] Two DFOs, a lead and a backup, who are both Civil Servants, were present for most of the meeting to ensure that at least one of them was always present as per FACA; this was always the case.

and generally present for, all of these sessions; detailed notes for all sessions were taken by the NASA-support Secretary. The SRS then wrote this report, as guided by the *Senior Review Subcommittee of the Planetary Advisory Committee Guidelines for Conducting the 2019 Senior Review*. The SRS consisted of seven individuals, including the Chair and Deputy Chair. The Deputy Chair and the other five members (one of whom is also a member of the PAC), were each responsible for leading and coordinating the discussion within the SRS for one of the SME panels. The Chair, as assisted by the Deputy Chair and the other SRS members, is responsible for this report.

2.2 Applicable Documents

The transition of the Planetary Science Advisory Committee (PAC) to a formal Federal Advisory Committee Act (FACA) body—and associated concerns regarding potential conflicts of interest expressed by NASA Legal Counsel and the NASA Ethics Office—led to substantive changes in previous protocols as described in governing documents dating from October 2018. In response, the SRS and NASA Program Executive drafted and adopted the *Senior Review Subcommittee of the Planetary Advisory Committee Guidelines for Conducting the 2019 Senior Review* prior to the first SRS deliberation to ensure the SRS members were all acting under the same assumptions. That document incorporates the required modifications to the *Memorandum for the Record (MoR): Plan for the 2019 Planetary Mission Senior Review* and the *Planetary Senior Review Terms of Reference (ToR)*. This unofficial document was used for internal guidance and documentation on the last day (10 May 2019) of the review, all of which consisted exclusively of SRS and NASA personnel and the ASRS lead.

3 Levelling of Missions

The SRS observed consistent and equal treatment during mission project presentations and SME panel deliberations. The SMEs covered the science topics with uniform thoroughness and fairness. This consistency was aided by the presence of some SME panelists on multiple panels and by some SMEs chairing multiple panels. Conflicts of interest were avoided throughout.

Some members of the SRS identified a potential lack of appropriate science expertise (in organic geochemistry) for MSL. However, after in-depth discussion among the SRS membership, it was concluded that this did not substantively affect the overall evaluation of the SRS for MSL.

Another concern identified by ASRS personnel and the SME panels, which affected several projects, was the lack of appropriate expertise to address in-depth the Technical Merit of several missions. The issue occurred due to the difficulty encountered by the ASRS lead in identifying appropriate, non-conflicted candidates for Panel membership. The problem was mitigated somewhat by the expertise of two of the members of the SRS and the presence of the current Lead Scientist for the Mars Exploration Program at NASA Headquarters.

4 SRS Summaries, Findings, and Recommendations by Mission

Each of the SME panel chairs completed a *NASA Planetary Science Division (Consolidated) Senior Review Findings 2019* document. Near-final drafts of each SME Finding Document were forwarded to all members of the SRS. The SRS discussion lead for each mission used the relevant mission report and related SRS discussions to draft the SRS report, which was then discussed, modified, and agreed to by the entire SRS. The results of this agreement formed the basis for this report.

Based upon a review of the materials, the SRS extracted a short summary, based heavily on a combination of the SME panel's proposal summary and its rationale for the Science Merit and Technical Merit evaluations. The SRS worked to provide consistency of language, ranking, and analysis among the different SME Panel reports. The goal was to distill down the relevant findings and recommendations to emphasize highlights for public dissemination and delivery to the PAC.

In addition, the SRS extracted the numerical and adjectival scores for Science and Technical Merit along with a précís of the strengths and weaknesses identified by the SME panels for each mission.

The SRS produced a separate summary considered to be its more important product. The goal was to produce summaries that are concise and actionable and to capture discussions of both the SME panels and the SRS. To this end, the majority of the final meeting day (Friday 10 May) was used to reach consensus language for each of the SRS "paragraph assessments." These reports are provided in the following sub-sections of this section (Section 4). Details of the adjectival and numerical evaluations, summarized at the top level in Table 1, are given in Section 5 and were used to rank the missions explicitly, as provided for in the ToR. The top level strengths and weakness of the proposed extended missions, as clarified in the oral presentations of the mission project teams during the week are provided in Section 6.

The "paragraphs" follow in alphabetical order.

4.1 Lunar Reconnaissance Orbiter (LRO)

LRO was launched in 2009 as a dedicated science and human exploration mission, and continues to benefit both communities with fundamentally new information and discoveries about the Moon. This is an extremely well written, thoughtful and compelling proposal with three science themes: 1) volatiles at local and global scales, 2) lunar volcanism, tectonism and crustal composition, and 3) evolution of the regolith and the modifying effects of impacts. Its compelling science is clearly traced to Decadal Survey objectives. The productivity of the team is a model for other extended missions, as is the usability and accessibility of the data taken and its massive use by the non-team science community. Its utilization of budget is equally impressive with the largest percentage of cost dedicated to science (reported as 65% compared to operations) of any proposed EM in PMSR-19. They regularly demonstrate an innovative budget management by handling unplanned issues without UFE, and compensating by effective manipulation of in-guide funds as needed. LRO also proposed supporting landing site assessments for the Commercial Lunar Payload Services (CLPS) contracts.

Finding. The SRS found that the new NASA polices regarding lunar exploration emerged after the LRO proposal was submitted; therefore, the Project was unable to discern implications of this new budget policy on LRO requirements. LRO already collects a significant volume of landing site data for mission; however, the new policies of returning humans to the Moon by 2024 could escalate data and data product demands that could rapidly impact their budgets as commercial and NASA missions accelerate to fulfill the new policies and objectives. Therefore, the SRS found that LRO's requested inguide funding is appropriate at this time; however, consideration should be given to the fact that product and budget demands may increase, given new NASA exploration policies, e.g. flowing from CLPS.

4.2 Mars Atmosphere and Volatile EvolutioN (MAVEN)

MAVEN's unprecedented measurements at Mars have resulted in valuable discoveries and rigorously transformed our understanding about the Martian upper atmosphere system. The team has proposed new measurements to be obtained where the new opportunities result from changes in the orbit and in the phase of the solar cycle where observations will be made. Because the planet is entering a new Mars year, this carries on the protocols from previous mission phases with measurements that can be adapted in response to previous observations. The fourth extended mission spans 1.5 additional Mars years and will run from Oct 2019 - Sep 2022. During this time the team will make new observations of Mars upper atmosphere, ionosphere, solar-wind interactions, and loss of gas to space. The measurements will be relevant to projections of volatile loss in the past.

Finding: Maven requests no over-guide funding. MAVEN is carrying no reserve, and, in the past, they have been able to solve their issues within their allocated funding. The SRS agrees with the numerous strengths identified by the Maven Mission SME Panel and their recommendation for guideline funding.

Recommendation: The SRS recommends that this scientifically productive mission receive the identified guideline funding.

4.3 Mars Express (MEX)

The proposal supports NASA's efforts associated with the European Mars Express (MEx) mission. Science objectives for the next extended mission are:

1) Understand atmospheric loss using data from the Analyzer of Space Plasma and Energetic Atoms (ASPERA) and Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) to characterize the Mars ionosphere and its interaction with the solar wind;
2) Coordinate MARSIS with the Mars Reconnaissance Orbiter (MRO) Shallow Radar (SHARAD) to determine the 3-D distribution of water on Mars;
3) Monitor the atmosphere through radio science occultations, emphasizing the convective boundary layer and gravity waves, which may affect the Entry, Descent and Landing (EDL) of future surface missions;
4) Use High Resolution Stereo Camera (HRSC) imagery to observe diverse surface features;

5) Perform multi-instrument observations during Phobos flybys to help enable robotic/human exploration and proximity operations; and
6) Coordinate the Visible and Infrared Mineralogical Spectrometer (OMEGA) measurements with MRO Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) to characterize surface compositions on Mars.

Finding. The proposed mission extension is primarily a continuation of existing observations. The SRS agreed with the SME panel that insufficient justification was provided for the science proposed. The **notable exceptions were the proposed MARSIS ionospheric and subsurface soundings and HRSC observations of the anti-Mars hemisphere of Phobos.** This situation led to two separate votes by the SME panel: one for the science proposed as written and a second for the proposed science restricted to what the SME panel considered the highest priority. This second vote supported the narrower science objectives of (1) upper atmosphere and ionosphere, (2) subsurface sounding, and (3) anti-Mars Phobos/Deimos observations. The second vote did not support the proposal's remaining science objectives of (1) study of lower atmosphere and the convective boundary layer, (2) surface feature observations, and (3) surface composition analysis.

Recommendation. The SRS agrees with this finding of the SME panel.

Finding. The SME panel noted among the key potential contributions that the synergy with MAVEN could allow improved understanding of Mars-solar wind interaction and responses of the magnetosphere and ionosphere to different drivers. Additional potential value includes further high-resolution observations of apparent liquid water sequestered at the poles in combination with MRO SHARAD radar probing. The proposal did not make a strong overall case that groundbreaking science would result from this mission extension. Productivity (as quantified through publication numbers) was low. The team did not demonstrate that the data in the PDS are widely used by the scientific community.

Recommendation. The SRS agrees with this finding of the SME panel.

Finding. The overguide includes three requests: (1) restore ASPERA science funding, (2) produce new HRSC maps, and (3) produce new HRSC metadata. The SME panel did not support any of these overguide requests.

Recommendation. The SRS agrees with this finding of the SME panel.

Recommendation. Given the present findings and analogous comments from the 2016 Senior Review, the SRS encourages serious consideration about the appropriateness of continued NASA science support for this mission. If support is continued, it should be directed at the descoped version of the science themes listed above. Further, the SRS believes this mission is categorized incorrectly as a NASA science mission and encourages rethinking of both the mission's management structure and review process, which could reduce overhead significantly.

4.4 Mars Odyssey (MODY)

An eighth 3-year extended mission (EM8, FY20-22) to the NASA Mars Odyssey (MODY) mission is proposed, during which the Thermal Emission Imaging System (THEMIS) Visible and Infrared (VIS and IR) instrument, Neutron Spectrometer (NS), and High Energy Neutron Detector (HEND) will continue to collect data. During EM8, the orbit will move to view Mars at morning

daylight local time, enabling new opportunities to study dynamic, temperature-dependent surface, atmospheric, and polar processes. Through both routine (60%) and targeted (40%) observations, the extended mission will address 1) dawn/dusk observations to improve global thermal inertia (TI) mapping and characterization of bedrock layers and surface cover and roughness; 2) landing site characterization; 3) atmospheric limb observation to characterize dust, temperature, and water ice profiles; 4) new THEMIS observations of Phobos for mapping composition and surface properties; and 5) continued NS and HEND observations for changes in the radiation environment of Mars, surface CO_2 frosts and subsurface water. In addition to these science objectives, MODY provides key contributions in the areas of communications relay for surface assets, landing site reconnaissance and characterization, and atmospheric and radiation monitoring.

Two key areas of continued MODY operations warrant explicit attention. Recent hardware failures in power components of the aged ground-based System Test Lab (STL) threaten the robustness of MODY operations; additional overguide funds are requested to modernize key aspects of this facility. Also, while MODY can meet the major EM8 scientific objectives within the in-guide budget, recent increases in the operations contract cost mean that substantial cuts to science must occur without over-guide funding.

The SME panel found that addressing negative impacts to the science team is a priority over the STL issues and unanimously supported the awarding of overguide funds requested for science. However, the long-term need for STL upgrades remains to reduce operations risks.

Finding. The SRS recognizes the demonstrated high science productivity of the MODY team and the value of the proposed science objectives and is concerned that increases in cost of contracted operations has severely impacted MODY science research, team productivity, and opportunities for adding new scientists.

Recommendation. The SRS is in full support of funding the requested overguide for science operations.

Finding. The SRS finds that residual risk to operations exists until STL upgrades can be implemented.

Recommendation. The SRS recommends that the Mars Program conduct a cost/risk analysis to determine if a STL upgrade is warranted during EM8.

4.5 Mars Reconnaissance Orbiter (MRO)

In its proposed 5th Extended Mission (EM5), the Mars Reconnaissance Orbiter (MRO) teams will pursue answers to some of the most fundamental questions of Mars science. Science observations over the 3-year span of EM5 will extend the very highest resolution data coverage for HiRISE (High Resolution Imaging Science Experiment] to other sites, testing hypotheses about the evolution of climate on early Mars and leveraging the longer temporal baseline to capture ongoing surface change today. Systematic atmospheric observations will add to the characterization of the modern climate and its interannual variability. Simultaneous observations with ongoing and newly arriving landed craft will guide in situ observations and ground-truth orbital remote sensing.

MRO's proposed EM5 science goals are: (1) Early Mars: Environmental Transitions and Habitability, (2) Amazonian Ices, Volcanism, and Climate, (3) Modern Mars: Surface Changes and Implications, and (4) Modern Mars: Atmospheric Processes.

The EM5 proposal outlines in detail the outstanding scientific questions raised by both the results of the MRO mission up to this time, as well as from other missions orbiting Mars, or those operating on its surface. The proposal describes specific hypothesis tests that will be conducted during EM5 to differentiate between competing hypotheses for the questions posed. Both the Scientific and Engineering teams have demonstrated outstanding competence in the execution of the mission to date and the proposal gives every indication that this high level of performance will be maintained during EM5. The SME panel evaluated the science merit portion of this proposal for MRO's EM5 with no major weaknesses.

The proposal covers 16 investigations of which seven are new to MRO. The in-guide budget supports the current dual mode for both a science mission and programmatic relay asset while there remain concerns of an aging spacecraft.

Flexibility of the team was shown by the work-around provided to recover use of the CRISM despite degradation and provide a new data product. Evaluations called out major strength in the areas of data use as evidenced by multiple publications for non-team community scientists. Characterizing the landing sites, such as Jezero and Gale: HiRISE stereo and CRISM add substantial scientific value to MSL and InSight by providing regional context. In some cases, the additional data from orbit may result in significant discoveries by these surface missions. Observations to understand the Noachian aquifer by tracing the mineralogy are exciting and hold a high chance of success.

Finding. The proposal included an Overguide request for three elements: (1) upgrading the SHARAD pipeline to produce 3-D volumetric data, (2) recalibrating HIRISE due to higher operating temperatures, and (3) FY21 and 22 budget increases due to inflation.

Recommendation. The SRS recommends funding items (1) and (2), in agreement with the SME panel.

Finding. The SRS finds that, considering that this is the fifth mission extension, the proposed UFE is inappropriately high and could be applied to funding a portion of the Overguide.

4.6 Mars Science Laboratory (MSL)

MSL has explored the lower strata on Aeolis Mons, detailing its sedimentologic and environmental history, with implications for habitability. For the next extended mission (EM3), Curiosity will drive higher up Aeolis Mons to investigate the unit exhibiting orbital signatures of phyllosilicates and the long-awaited transition into the sulfate-bearing unit. Specific science goals for EM3 are to understand the nature of the thick clay-bearing unit and the transition from clay- to sulfate-bearing strata, to make inferences about later fluvial activity in the crater by studying the Greenheugh pediment and Gediz Valles, to explore the origin of seasonal methane production, to understand what controls atmospheric oxygen, to show how current levels of atmospheric dust and water vapor vary with increasing elevation, and to extend measurements of high-energy radiation past the 2019 solar minimum. The rover and its instruments are in good health and operating nominally, although power continues to degrade and a number of mechanical issues have arisen as a result of age.

Guideline mission funding provides for 500 command cycles and supports a traverse well into the sulfate unit. This level of funding should achieve a 6.5-km traverse distance and analysis of 7-8 samples. The proposed Overguide mission would fund 570 command cycles, the maximum possible given power limitations. It allows exploration of Gediz Valles channel or analysis of additional samples.

Finding. The SRS finds both the project and the SME panel did not adequately acknowledge that EM 3 might be the last opportunity to complete significant scientific investigations, given the progressive reduction in RTG power output and battery storage capacity, and problems with the drill, the wheels, and memory.

Finding. New protocols for the analysis of SAM samples may expand the range of detectable organic molecules, advancing the decadal objective of determining whether there has been life on Mars. Recent efforts have revealed better organic preservation than reported earlier in the mission. Mars 2020 does not have a mass spectrometer. These three items increase the importance of sample analysis.

Recommendation. The SRS recommends funding an Overguide to add command cycles as per the Overguide option. The search for organics by SAM has the potential for producing groundbreaking science results; therefore, SAM should be provided with additional resources from the proposed Overguide science budget.

Recommendation. The SRS recommends that the MSL team should concentrate more on sampling/analysis and less on extending drive distance.

Finding. The SRS finds that, considering this is the third mission extension, the proposed UFE is inappropriately high and could be applied to funding a portion of the Overguide.

5 Ranking of Missions

The SME Panels were instructed not to compare missions but to vote on them on their inherent weaknesses and strengths. All panels were guided by the NASA Planetary Science Division (Consolidated) Senior Review Findings 2019 form. Criterion 1: Science Merit was based upon seven factors and Criterion 2: Technical Merit was based upon five factors. Following final deliberation, each panel voted simultaneously in separate votes for each criterion. The numerical votes were based upon the key 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Fair, and 1 = Poor. Average scores were then computed for each criterion as well as an average score given by the average of the two criteria.

Details of the scoring methodology used along with the NASA criteria for the adjectival scores are given in Section 11 Appendix: NASA Ranking Definitions. The next section (Section 6) provides a précis of each SME report. This distillation, made by the SRS includes the SME votes on both scientific and technical merit along with summarized major strengths and weaknesses from the SME reports. This material was discussed by the SRS for consistency across all of the missions reviewed and was used as input to Section 4 above. The SRS did not “revote” on any mission.

6 Observations, Strengths, and Weaknesses of the Missions

6.1 Lunar Reconnaissance Orbiter (LRO)

2019 Senior Review Subcommittee Report.

PI:	Noah Petro	**Proposal No.:**	19-PMSR19-0006
Institution:	NASA Goddard Space Flight Center		
Title:	Lunar Reconnaissance Orbiter, Extended Mission #4		

Science 4.80

Excellent	Very Good	Good	Fair	Poor
4	1	0	0	0

Science Strengths

- The proposal does an excellent job of providing a traceability matrix that links proposed science questions and objectives to the objectives in the Planetary Decadal Survey.
- The proposed science in all three subject matter themes are of high scientific significance.
- Thirteen lines of inquiry are proposed, of which 10 represent new science investigations.
- The focus on surface changes of a dynamic Moon will likely result in ground-breaking science, with the determination of the volatile distribution and transport (and how it is affected by the solar cycle) leading to the biggest insights with regards to the origin and evolution of volatiles, including whether hydrogen derives from the solar wind or interior sources.
- Productivity is evidenced by the impressive publication activity by both team and non-team members.
- LRO has a mature pipeline of well-defined products to the PDS, with consistent on-time deliveries every three months (quarterly), or less, with a data latency of no more than 6 months.
- Within the past year a new Project Scientist and Deputy Project Scientist took over, plus a new Associate Project Scientist for Commercial Support was added. A new CRaTER PI and D-PI also came aboard. Six new Co-Is to multiple instruments will be added during EM4. The mission has a strong track record of providing opportunities to new investigators, having added 32 new Co-Is in EM3.

- The spacecraft is the longest operating lunar orbiter and is showing signs of age, but it is expected to operate reliably through the extension and beyond with new operational considerations.

Science Weaknesses
None

Technical 5.00

Excellent	Very Good	Good	Fair	Poor
5	0	0	0	0

Technical Strengths

- Throughout the first, second, and third extensions, the mission dealt with funding reductions by increased operational efficiencies, staffing reductions, the elimination of laser ranging from Greenbelt for LRO precision orbit determination and time transfer, and reduction of USN support with more reliance on DSN.

- LRO devotes a large a fraction of its budget to science (≥65%), which is excellent, and which may stand out among most missions.

- The range and amount of science proposed in the guideline is substantial and significant.

- The CRaTER instrument will explore its gamma-ray detection capability to map element abundances on the Moon and in the upper cm of H in limb observations.

- Mini-RF will add a non-targeted operation mode to its bistatic observation campaign.

- Current capabilities of spacecraft systems and instruments are adequate. Identified risks are judged low as low.

- There is no serious degradation that has not been recognized and which has not resulted in the implementation of operational workarounds.

- New algorithms and effective operational workarounds were developed to preserve slew and science capabilities in stellar mode, following the degradation of the Miniature Inertial Measurement Unit (MIMU).

- The team recognizes that with an aging spacecraft, engineering costs are increasing, and they offset those costs with cost savings from LEND.

- Initiative and aggressive oversight reflects well on the management structure and the capabilities of their team to deal with unexpected events.

Technical Weaknesses
None

Comments to Selection Official:

LRO has successfully operated without unencumbered UFE for many years, overcoming financial demands for anomalies, studies, increased requirements, etc., and proposes doing so again in EM#4. This is a model that should be considered for all extended operating missions, possibly with HQ holding a "UFE Pool" for unexpected issues on any extended mission thus unencumbering significant funds from FY20-22 to fund requested overguides that can enhance science and increase mission robustness for missions as needed. –

Comment in general to all:

UFE is currently applied to: MRO and MSL and not to the other 4.

6.2 Mars Atmosphere and Volatile EvolutioN (MAVEN)

2019 Senior Review Subcommittee Report

PI:	Bruce Jakosky	**Proposal No.:**	19-PMSR19-0005
Institution:			
Title:	MAVEN (Mars Atmosphere and Volatile Evolution) mission		

Science 4.57

Excellent	Very Good	Good	Fair	Poor
4	3	0	0	0

Science Strengths

- The proposed extended mission is well aligned with the objectives of the planetary science division at NASA and with the decadal survey 2013-2022
- Strong potential exists for new and ground-breaking science as MAVEN continues to explore interannual variations and the upcoming minimum of the solar cycle.
- The MAVEN science team has been very productive both with results specific to this mission and also in concert with other observations and emerging results in the Mars program.
- All deliveries to the PDS are up-to-date and have occurred on a regular schedule every three months, as expected.
- The MAVEN team has been actively training and promoting younger scientists into leadership roles, and they continue to bring new people into the formal team and the MAVEN team has demonstrated significant inclusion of members of the larger science community
- Based on publications and NSPIRES selections for MDAP, data use is strong and widespread among a larger community of researchers interested in atmospheric evolution, escape, space weather and solar wind/plasma interactions at Mars
- Most instruments and spacecraft systems appear sufficiently healthy to enable a continuation of the mission and achievement of EM-4 objectives. The team appears aware of the few issues that exist, and they are being effectively managed.
- MAVEN's extended mission continues solid measurements to gain a longer time record, and there was SRS agreement that this is scientifically highly compelling and important to continue.

Science Weaknesses

None

Technical 4.43

Excellent	Very Good	Good	Fair	Poor
3	4	0	0	0

Technical Strengths

- The in-guide EM-4 mission conveys a cost-effective effort as shown by the ratio of operations to science funding.
- The new observation types are drawn from the MAVEN team's experience with the data and the abilities of their instruments.
- Overall spacecraft health is good. The lifetimes of relevant spacecraft and instrument parts are listed and most appear to be well within lifetime for the proposed extended mission timeframe.
- There appear to be no major concerns that the spacecraft can perform the observations as proposed
- The EM-4 proposal did a good job of demonstrating that the MAVEN spacecraft is in excellent condition, and is likely to obtain great science for the foreseeable future.

Technical Weaknesses

None

6.3 Mars Express (MEX)

2019 Senior Review Subcommittee Report

PI:	Thomas Thompson	**Proposal No.:**	19-PMSR19-0001
Institution:	Jet Propulsion Laboratory		
Title:	Mars Express (MEX/ASPERA-3)		

Science 1.50

Excellent	Very Good	Good	Fair	Poor
0	0	0	4	1

Limited Science (Descope) 3.60

Excellent	Very Good	Good	Fair	Poor
0	3	2	0	0

Science Strengths

- Combining MAVEN and MARSIS observations, after MAVEN raises its periapsis in late 2020, will allow for a determination of the three-dimensional structure of the Mars-solar wind interaction and will allow the determination of the response of the Martian magnetosphere and ionosphere to different classes of driving impulses.

- Further high-resolution Flash-Memory observations of the areas where liquid water is suggested at the base of the south polar layered deposits and their surroundings, utilizing all MARSIS bands, will fill important gaps in coverage of this remarkable discovery.

- There has been on-the-job training where four potential candidates for fulfilling Principal Investigators and/or Project Scientists of major science instruments were identified.

Science Weaknesses

- The science objectives proposed are a continuation of existing measurements. There are inadequate explanations of how this continuation of research would significantly expand our understanding of the Martian atmosphere or surface over the current level.

- US investigators' funding for HRSC was previously cut by half, and the focus in the proposal will be on radiometric and geometric calibrations, updated point spread models,

and imaging water-related features and volcanoes. The potential science enabled by these new tasks do not seem to be compelling or unique.

- The proposal did not explicitly state how much each of the 16 US Co-I's would receive. At proposed funding levels the depth of research possible is at best shallow.

- Much of the science proposed is iterative. For instance, uniqueness and importance of OMEGA/CRISM observations was not demonstrated.

- The limited funds available for science translates to limited opportunities for developing leadership skills and roles of existing team members.

- Data use by the scientific community appears limited and declining over time.

Technical 3.00

Excellent	Very Good	Good	Fair	Poor
0	1	3	1	0

Technical Strengths

- All Stellar (gyroless) attitude control installed in April 2018 increases gyro lifetime for the mission.

Technical Weaknesses

- The cost is not supported by the limited science value of the proposed measurements and operational activities.

- Although over-guide funding would restore ASPERA participation, allow production of HRSC maps of volcanoes, and production of HRSC metadata for Phobos and Deimos images, none of these tasks is demonstrated to be scientifically compelling (with the exception of imaging at high-resolution the anti-Mars hemisphere of Phobos).

Comments to Selection Official:

Problems with delays in data delivery by European missions to the European Planetary Data Archive (PDA) appear to be a bottleneck for US instrument data delivery. Significant delay within PDA can delay delivery to PDS. Perhaps simultaneous delivery to PDA and PDS should be negotiated.

The panel finds that there is scientific value in MARSIS ionospheric and subsurface sounding and HRSC observations of the anti-Mars hemisphere of Phobos and recommends this should be the focus of any funded science activities in the extended mission. If NASA desires to continue other operational activities (e.g., ASPERA) for programmatic reasons (e.g., international relations),

NASA should be clear about its objectives and exclude all such activities from any future science review. It is a waste of resources and time for the mission team, the reviewers and the agency.

Note that a statement made during the presentation about team members being barred from proposing to MDAP or PDART is not correct. The case needs to be made that the proposed work is not separately funded by mission funds.

6.4 Mars Odyssey (MODY)

2019 Senior Review Subcommittee Report

PI:	Jeffrey Plaut	**Proposal No.:**	19-PMSR19-0004
Institution:	Jet Propulsion Laboratory		
Title:	2001 Mars Odyssey Eighth Extended Mission		

Science

Guideline Funding: 2.75

Excellent	Very Good	Good	Fair	Poor
0	0	3	1	0

Overguide Funding: 4.75

Excellent	Very Good	Good	Fair	Poor
3	1	0	0	0

Science Strengths

- The proposal strongly related science goals to Decadal Survey and MEPAG goals.
- The proposal identified new science investigations utilizing three new observation modes. Examples of studies that will be conducted using these capabilities that may result in ground-breaking discoveries include:
  - 1) Targeted observations using the new dawn/dusk orbit.
  - 2) Off axis (ROTO) observations.
  - 3) Limb profile targeting.
- The THEMIS (long-wavelength IR and visible wavelength imager), HEND (High Energy Neutron Detector and NS (Neutron Spectrometer) instruments collect unique datasets that complement observations made by past and present missions, both from orbit and from the surface.
- Odyssey investigators have a strong record of scientific discoveries and an extensive publication record (212 articles). The new observation modes should encourage continued research productivity.
- Although science analysis support is not provided by the mission for HEND and NS, the continued acquisition of the data with delivery to the PDS has resulted in new scientific accomplishments based on those measurements - demonstrating that continuing to acquire these datasets is highly worthwhile.
- The Odyssey mission has a strong record of promptly delivering raw and processed datasets to the PDS.

- Leadership training is not discussed in detail in the proposal, but the recent addition of five new Co-Is creates new opportunities for developing leadership skills on the mission.
- Odyssey datasets are widely used in science investigations throughout the Mars planetary community. The proposal identifies 494 published papers by non-Odyssey scientists utilizing Odyssey datasets.
- The instruments are in excellent operating condition and are capable of supplying datasets proposed to be acquired. The proposal states that no performance degradation has occurred to any of the currently operating instruments over the lifetime of the mission.

Science Weaknesses

- No major weaknesses noted.
- Opportunities would be greatly diminished under guideline funding because of the reduction in funded Co-I's. This would be somewhat meliorated with overguide funding although the long-term trend in reduction of science funding during mission renewals reduces the opportunities for developing leadership skills.

Technical

Guideline Funding: 2.75

Excellent	Very Good	Good	Fair	Poor
0	0	3	1	0

Overguide Funding: 4.75

Excellent	Very Good	Good	Fair	Poor
3	1	0	0	0

Technical Strengths

- The scientific productivity of the Mars Odyssey mission has been very high relative to mission costs. As noted under weaknesses, reduction of science funding to the guideline level would reduce cost effectiveness.
- The new dawn/dusk orbit plus proposed ROTO and limb measurements offer high scientific value. The ROTO and limb scanning operational modes utilize the ability of the orbiter to slew the observational platform, which was not extensively utilized during previous mission operation.
- The proposal indicated that spacecraft and instrumentation are in good health. No degradation was identified in instrument/spacecraft performance.
- The effects of possible failure modes are discussed in the proposal and the likelihood of major failures during the extended mission is slight.

Technical Weaknesses

- The increased costs associated with mission operations have greatly reduced science funding under the guideline funding level from a current 24% of project budget to 17%. Science constitutes a small proportion of the overall mission budget so that the high science productivity for the mission is a major strength, but only if science funding is increased to the overguide level to maintain the number of supported Co-Is at about the current level of 16.
- Gyro failure and antenna rotation failures, if they occurred, could reduce the operational lifetime of the mission to as short as one year. The likelihood of these events was judged to be very small.

Comments to Selection Official:

The System Test Lab (STL) is the ground-based test bed system that the Mars Odyssey team uses for development and verification of observational plans and command uploads. The system remains mostly the same since launch in 2001 and some computer maintenance contracts are no longer renewable. The proposal included funds to upgrade the STL through overguide funding. The team has been able to obtain several old but potentially operational replacement units. In addition, the team has maintained a software-based system (SoftSym) as a backup option. According to the team presentation, the combination of the replacement inventory and the SoftSym reduces the urgency for the overguide request item, and places the science funding overguide as the higher priority. If a replacement for STL does not become operational, the capability of testing flight software system patches is not possible, which would impact relay testing for Mars 2020 support if required. Thus, there is decreased urgency for an immediate replacement, but at higher long-term risk to the mission.

The THEMIS team has implemented and supported development of a website providing access to all Mars orbital data from all past and present NASA missions (http://themis.asu.edu/maps). This provides an exceptionally useful interface to image data that is widely used by the planetary community. If Odyssey funding were reduced to guideline levels this service would be in jeopardy. We recommend that this multi-Mars data service be supported at the Mars program level and not tied to individual mission funding.

6.5 Mars Reconnaissance Orbiter (MRO)

2019 Senior Review Subcommittee Report

PI:	Richard Zurek	**Proposal No.:**	19-PMSR19-0003
Institution:	Jet Propulsion Lab		
Title:	Mars Orbiter 5th Extended Mission Proposal: Keys to Understanding Mars		

Science 4.75

(One panelist abstained, stating that they were not qualified to vote on **Scientific Merit)**

Excellent	Very Good	Good	Fair	Poor
3	1	0	0	0

Science Strengths

- Review panel members felt that several of the Investigations summarized within Science Goals have high potential for ground breaking results that could change the current state of knowledge about Mars

- All stated goals for EM4 were met with several ground-breaking results. The operations and science teams have excelled at keeping the orbiter highly productive, and can be expected to continue as such through EM5 with a high degree of confidence.

- The opportunity to compare atmospheric phenomena (via MARCI, MCS) over 13 cycles spanning one complete solar cycle is important

- Characterizing the landing sites, such as Jezero and Gale. HiRISE stereo and CRISM add substantial scientific value to MSL and InSight by providing regional context.

- MEPAG goals for 20 years have outlined the potential scientific significance of interannual variability at Mars as reservoirs of volatiles exchange over timescales that allow trends to be tracked (e.g., dynamics of volatile sources and sinks).

- The proposal documents close to 1500 publications, ~30% from the MRO team, demonstrating active participation by a broad community and multiple ground breaking results

- The record of rapid availability and ease of access is well documented in the proposal, and regular and timely release of data to the PDS is also well demonstrated.

- The proposal outlines an aggressive program to provide opportunities at all levels for new investigators.

- Probably no other currently operating planetary spacecraft has produced more data that is utilized and analyzed by the widest swath of the community than that from MRO

- Except for the loss of the SWIR channels on CRISM, the instruments of the spacecraft, as well as the spacecraft itself, remain robust and fully capable of carrying out not only the investigations listed in the proposal, but any other task that might be assigned over the EM5 mission operations.

Science Weaknesses

NONE

Technical 5.0

(All members voted on **Technical merit**.)

Excellent	Very Good	Good	Fair	Poor
5	0	0	0	0

Technical Strengths

- The Cost effectiveness of the mission investigation, operations and functions were fully justified and well explained in the proposal.
- SHARAD will develop new observing modes for 3D imaging, improved SNR [signal-to-noise ratio], and improved vertical and spatial resolution. These new modes are very promising
- The 'all stellar' navigation technique is a great contribution to solving the persistent problem of IMU lifetime.
- The biggest loss appears to be the longer IR wavelength CRISM capabilities.
- Mitigation for minor spacecraft health weakness, such as the with the battery, C&DH [Command and Data Handling] resets, and the IMU, etc. are well described, and pose insignificant risk to EM5. No significant spacecraft health and known risks weaknesses were noted.
- Mitigation for minor spacecraft health weakness, such as the with the battery, C&DH [Command and Data Handling] resets, and the IMU, etc. are well described, and pose insignificant risk to EM5.

- The loss of the longer wavelength IR channels (e.g., SWIR) on CRISM represent the only significant degradation of any instrument on MRO.
- The spacecraft and its instruments have demonstrated themselves to be robust. No significant weakness in robustness is noted.

Technical Weakness

NONE

Comments to Selection Official:

Supporting MRO in its EM5 mission for both scientific and programmatic value to NASA's Mars Exploration program is overwhelmingly compelling. Having a recon asset of this quality beyond its design life is a gift, and continuing its operation to support surface missions of Mars 2020 rover and ESA's *Franklin* rover is essential to NASA and part of the emergent set of goals for M2M initiative.

A question was asked on the original evaluation form regarding plans for bringing on new investigators from outside the team at this time. MRO has had a single Participating Scientist opportunity that was announced and enacted in 2006 at the time of launch. Other long duration flagship-class missions, such as *Cassini*, have provided a path for new scientists to be added, usually as an addendum to the relevant Data Analysis program. The panel encourages NASA to develop a special guest investigator program, perhaps through MDAP, similar to that which *Cassini* had during the last 10 years of that mission where it was supported through CDAPS.

No ground-breaking Science Merit weakness noted. However, "ground-breaking" is a fairly subjective term. That said, one panel member felt that the case for ground-breaking science, in a 5th extended mission, was not made pointedly enough.

One panel member expressed concern that some of the overguide budget was to address the accumulated effects of inflation on the flat budget of EM4. The panelist found this portion of the overguide uncompelling because: 1) the in-guide proposal is robust (except for the recommended addition of SHARAD 3-D analysis and HiRISE Radiometric Calibration overguide request), 2) the inflation rate assumed is unrealistically high, and 3) the mission carries Unassigned Funding Expense (UFE).

6.6 Mars Science Laboratory (MSL)

2019 Senior Review Subcommittee Report

PI:	Ashwin Vasavada	**Proposal No.:**	19-PMSR19-0002
Institution:	Jet Propulsion Laboratory		
Title:	Curiosity at Aeolis Mons: Investigating the Persistence of Water and Habitability		

Science 5.00

Excellent	Very Good	Good	Fair	Poor
6	0	0	0	0

Science Strengths

- Each of the EM3 objectives are tightly aligned with Decadal Survey objectives. as described in Table 3-2 of the proposal.

- There is potential for ground-breaking science. The ability of SAM to identify new varieties of organic molecules, and to measure their abundances and isotopic compositions is revolutionizing our understanding of organic matter on Mars. Noteworthy for EM3 is the plan to use derivatization experiments that will increase the volatility of some compounds and allow their characterization. Further, MSL's ability to determine variations in mineralogy with stratigraphy, and to utilize the synergy provided by the MSL instrument package to evaluate geologic and environmental context in a new terrain, are unequaled by any mission.

- Excellent scientific productivity in the past provides confidence in continued productivity during EM3. Significant discoveries were made during EM2. Organic molecules were detected and analyzed, and sulfur isotope variations were found to correlate with changes in sulfate and sulfide production. Measurements suggesting a possible seasonal dependence on atmospheric methane were made. Highly evolved igneous materials were discovered. A declining solar cycle correlated with a 50% increase in GCRs. Observations during a global dust storm provided local assessment to complement broader observations from orbiters.

Science Weaknesses

None

Technical 4.50

Excellent	Very Good	Good	Fair	Poor
3	3	0	0	0

Technical Strengths

- The proposed use of a derivatization reagent to increase the volatility of some refractory organic compounds may enable new classes of compounds (such as fatty acids) to be detected, and a new method for removing perchlorates should help in SAM's organic analyses.

- The loss of drill feed and inability to store data on the B-side computer were serious issues encountered in EM2, but the engineers have found work-arounds. Degradation of RTG power output and battery storage capacity continue to be in line with predictions. Other issues, such as electrical shorts in the drill percussion mechanism and wheel wear, are worrisome but are expected to be manageable during EM3. The team has demonstrated great creativity and resourcefulness in adjusting to past mechanical failures, which bodes well for solving future problems.

- Permanent loss of the drill is always a potential risk to EM3 science objectives, as this seems to be the weakest system. However, the team understands that they might mitigate some of the risk by scooping fines and using sieves for sampling

Technical Weaknesses

None

7 Findings on Implementation Strategy

Table 1 reproduces the summary table from this report given in the Executive Summary of Section 1. Table 2 summarizes the SME scores of the SME reports of Section 6 and shows how the SRS used these data to provide the SRS summary. The SRS notes that the adjectival bins provide the finest credible resolution in ranking, considering the subjectivity introduced at each stage of the process, a feature never avoidable in such evaluations.

Table 1. SRS Summary of Mission Rankings for 2019 (Ordered by Mission Ranking)

Mission	Recommended Budget	Mean of Scientific + Technical Merit	Adjectival Rating
Lunar Reconnaissance Orbiter (LRO)	Inguide	4.90	Excellent (Science = E)
Mars Reconnaissance Orbiter (MRO)	Inguide	4.88	Excellent (Science = E)
Mars Science Laboratory (MSL)	Inguide	4.75	Excellent (Science = E)
Mars Science Laboratory (MSL)	Overguide	4.75	Excellent (Science = E)
Mars Odyssey (MODY)	Overguide	4.75	Excellent
Mars Atmosphere and Volatile EvolutioN (MAVEN)	Inguide	4.50	Very Good / Excellent
Mars Express (MEX)	Descope	3.30	Good / Very Good
Mars Odyssey (MODY)	Inguide	2.75	Good
Mars Express (MEX)	Inguide	2.40	Fair / Good

Table 2. Summary of SME Evaluations

Mission	Science Merit					Sci Score	Technical Merit					Tech Score	Mean S + T	Cost		Note
	E	VG	G	F	P		E	VG	G	F	P			IG	OG	
LRO	4	1	0	0	0	4.80	5	0	0	0	0	5.00	4.90	5		-
MRO	3	1	0	0	0	4.75	5	0	0	0	0	5.00	4.88	5		1
MSL	6	0	0	0	0	5.00	3	3	0	0	0	4.50	4.75	4	2	2
MODY	3	1	0	0	0	4.75	3	1	0	0	0	4.75	4.75		4	3
MAVEN	4	3	0	0	0	4.57	3	4	0	0	0	4.43	4.50	C/NV	NP	
MEX	0	3	2	0	0	3.60	0	1	3	1	0	3.00	3.30	D		4
MODY	0	0	3	1	0	2.75	0	0	3	1	0	2.75	2.75	4		
MEX	0	0	0	4	1	1.80	0	1	3	1	0	3.00	2.40			5

Notes:

C/NV = Consensus, but no vote

D = Limited science

IN = Inguide, i.e. guide line from NASA for cost proposal

NP = Not proposed

OG = Overguide

1 = One panelist abstained, stating that they were not qualified to vote on Scientific Merit; "Strong support for OG" but no vote

2 = 4 votes for proposal for inguide funding and 2 votes for proposal for overguide funding (6 votes were cast regarding funding level) in a separate vote (not carried out by other SME panels)

3 = OG on science; no vote on OG for STL testbed

4 = Science merit if descoped to keep MARSIS + HRSC-Phobos only, per SME panel

5 = Science merit as proposed by mission project team

With respect to the SRS evaluation of rank, based upon the work of the SME panels, that LRO, MRO, and MSL all were ranked as "Excellent" with MAVEN as "Very Good/Excellent" as proposed. Clearly, there should be no debate on scientific or technical grounds that all four of these missions should be extended in keeping within the guidelines and certainly the spirit of the recent (2016) National Academies report *Extending Science: NASA's Space Science Mission Extensions and the Senior Review Process.*

While there was no debate about the Science and Technical scores for MSL, there was discussion among the SRS with respect to the inguide and overguide. This discussion came from the SME panel vote wherein there were 4 votes for the proposal for Inguide funding and 2 votes for the proposal for overguide funding. This issue does not affect the ranking of MSL; it only affects how MSL might be implemented. The issue of exactly how Inguide versus overguide proposal options should be handled by reviewers is not a new one, and it does suggest a process improvement issue discussed in Section 9.3 below.

The situations with respect to Mars Express and Mars Odyssey extensions is not so clear. As noted, the SME panel for Mars Odyssey found issues with respect to the possible mission results under the Inguide budget, but also felt that with appropriate overguide funding, this would be an excellent mission worth continuing. The SRS concurred.

Both the SME panel and the SRS found the case of Mars Express, as expressed in the extended mission proposal, to be more problematic. The question revolved about what new, compelling science the mission could yield. It was the sense of the SRS that as proposed, the mission fell short but that with appropriate descopes in activity – and funding – continuance of the mission might make sense.

On science and technical grounds alone, the SRS agreed that the ranking, which could be derived from averaging the science and technical scores from the SME votes on those matters, is a fair, equitable, level, and reasonable metric for the ranking of the missions, with the caveat that the numbers themselves should not be given the weight of the adjectival ratings.

The SRS notes that, this said, the scientific and technical rankings of a given mission with the portfolio provide only one input, albeit a very important one, into the decision-making process. That process must balance (1) programmatic issues, such as NASA's plans for a near-term human return to the Moon, (2) the need for sufficient relay bandwidth from Mars, considering all of the assets there, and (3) international agreements and missions, such as NASA's contributions to Mars Express, against budgetary limitations. The latter typically, i.e., historically, must balance current assets against future needs, e.g. commercial developments in cis-lunar space such as CLPS and a future Mars Sample Return (MSR) mission, in a constrained financial environment.

The Senior Review for extended missions continues to play an essential role in the corresponding deliberations.

8 Minority Opinions

All initial differing opinions among the SRS membership were resolved during the SRS discussions. This report is a consensus statement amongst the SRS membership.

9 Suggested Process Improvements

9.1 Structure of This Review and Rationale

This Senior Review differs from all previous ones in two aspects:

(1) In accord with the NASA Transition Authorization Act of 2017 (P.L. 115-10) this is the first review based upon a three-year rather than two-year cadence (cf. the ToR [Glaze, 2018]).

(2) The application of FACA to the PAC necessitated a new structure due to the potential for unresolvable conflicts of interest amongst appropriate SMEs with especial focus on Mars mission extensions [Glaze and Knopf, 2019]; see Figure 2.

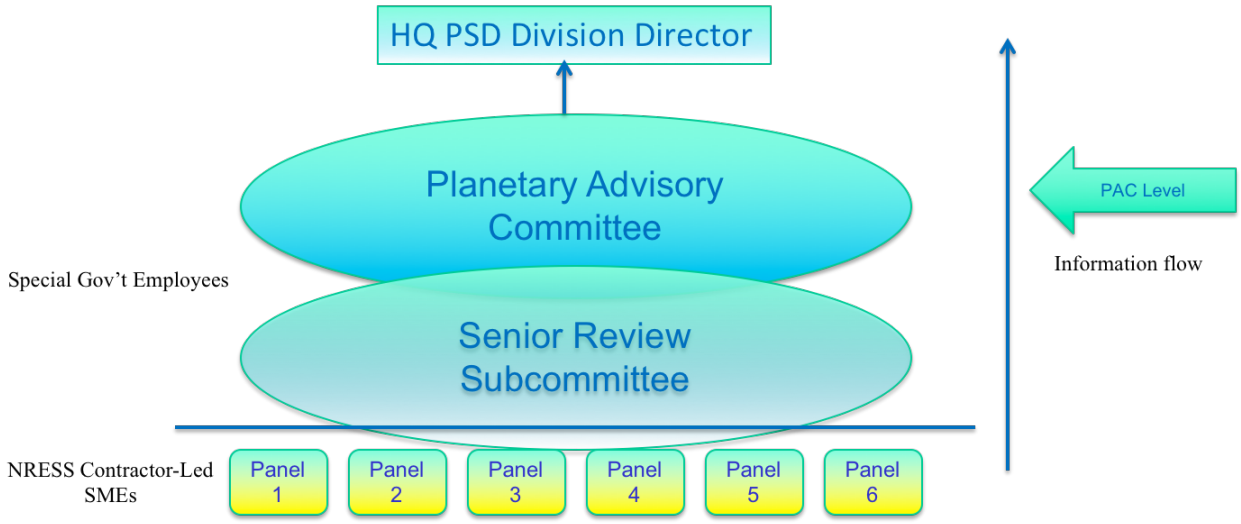

Fig. 2. Schematic of the structure of the process used for the 2019 Senior Review. This report is the product of the Senior Review Subcommittee (SRS).

9.2 What Did Work and Did Not Work: Lessons to Learn

1) Everyone would likely agree that Terms of Reference (ToR) are required for the review. However, the details and their implementation are crucial. They must:

   a) Clearly define what the Division/Directorate wants to achieve with the Senior Review,
   b) Be aligned with directions to proposers,
   c) Be signed 4-6 months prior to the Review, enabling selection of review panels and creation of memorandums for conduct of the reviews,
   d) Define exactly what will be public, from meeting proceedings to post-review documentation,
   e) Define the products and analyses/evaluations to be conducted and provided to the Planetary Advisory Committee.

2) Mission panels must contain both engineering/programmatic SMEs, as well as discipline-appropriate scientists for proper evaluation of submitted proposals. This is usually difficult to do and requires planning ahead and allowing sufficient (significant) time to populate the panels.
3) Mission panels need to have overlap of at least 1 to 2 (unconflicted) members to ensure continuity and enhance leveling during deliberations.
4) The Senior Review Subcommittee needs to have more than a single day, or significant time between panels, to discuss the review and develop a position. Without some restructuring of procedures, this makes holding the review(s) within a single week problematic. For example, the SRS does not need to hear the charge to the (SME) panel more than once and could work in parallel to some of those sessions.
5) Even though the main proposal is page limited, the total packages are overly extensive and not commensurate with the budget commitments under consideration (<2% of the PSD annual budget). In fact, this process could likely be conducted with merely a well-defined presentation package lasting 2-4 hours, which would significantly reduce burden on the proposing missions, reduce cost and complexity, and be more efficient for the review panel(s).
6) If the current proposal/presentation structure continues, the presentation content should be clearly defined otherwise they tend to become "marketing" presentations of minimal value to the PMSR decision processes.
7) Metrics such as science team and non-science team paper counts and PDS data set usages should be well defined, e.g. with a panel input via NSPIRES, so that there is a common basis for assessment.
8) This new process constitutes a significant workload and commitment, so panelists whose salaries are not covered by their home institution should be reimbursed at their current salary/rate (some honoraria were <30% of 40-hour-week pay).

9.3 Assessing Mission Options

For this review, as well as previous ones, extended mission proposers were given explicit information on budget guidance and mission options (Section II. of *Guideline Narrative for Planetary Mission Senior Review Science Evaluation, 11 October 2018* - DRAFT). Noting that "Each mission will be provided funding targets for FY19 and a budget guideline for FY20 through FY22" the proposers were provided with three options: (1) Within Guideline (referred to herein as "inguide"), (2) Science De-Scope, and (3) Overguide. Depending upon the proposal and its context, these categories can be handled quite differently amongst the missions. As a result, the different SMEs handled the options differently: the MSL panel held a vote on overguide versus inguide, although the science and technical votes were the same for each. MAVEN did not propose an overguide option, separate science and technical votes were taken (with different results) for the overguide and Inguide options for Mars Odyssey, and the SME panel for Mars Express invented a de-scope option and then took separate votes on the science merit alone of these two options.

While the SME panels can have no direct effect on how the proposals are written, they should be given explicit guidance to hold separate science and technical votes on all options presented in the extended mission proposals.

10 Appendix: SRS Guidelines Used in Conducting the 2019 Senior Review

Senior Review Subcommittee of the Planetary Advisory Committee
Guidelines for Conducting the 2019 Senior Review
10 May 2019

The Senior Review Subcommittee (SRS) is composed entirely of Special Government Employees (SGEs), whose charge is to report to and advise the Planetary Science Advisory Committee (PAC) on the outcome of the extended mission reviews (aka "Senior Reviews") conducted by Arctic Slope Regional Corporation (ASRC) for the years 2020-2023.

The guiding documents for this review are the Memorandum for the Record (MoR): Plan for the 2019 Planetary Mission Senior Review, (signed) Thomas Zurbuchen, PhD, 13 Sep 2018, and the Planetary Senior Review Terms of Reference (ToR), (unsigned). The intent of this guidelines document is to provide a general approach for how the SRS will conduct their review and development of their report to the PAC. These guidelines were unanimously agreed to by the members of the SRS and the NASA Program Executive in charge of this Senior Review prior to panel deliberations and generation of findings and recommendations, and they all also believe it is responsive to the guiding documents listed above.

The guidelines are:

1) The primary purpose and scope of the SRS Senior Review is to provide the Planetary Advisory Committee (a) an independent assessment of the cost and benefits of extending operating missions past their current termination dates, and (b) an overall assessment of the PSD operating mission portfolio. The SRS will be informed by the ASRC panels' mission evaluations.
2) The SRS's principle responsibility is to provide independent leveling of the ASRC proposal-evaluation panel assessments to ensure accurate and impartial interpretation of the proposals prior to documenting the SRS assessments as directed per the ToR and MoR.
3) The SRS will provide a report to the PAC for their deliberations and use in reporting to the Planetary Science Division (PSD) Director. The SRS report will:
    a. Summarize the consolidated Senior Review evaluations of each SME panel for each proposed extended mission, summarize strengths and weaknesses for the seven Science Merit criteria and the five Technical Merit criteria, and provide summarized scores for each mission.
    b. Rank missions based on science merit, PSD strategic goals, technical capability, and cost reasonableness.
    c. Provide observations, findings, and/or recommendations on:
        i. Continuation of missions at their in-guide level,
        ii. Continuation of missions above or below their in-guide level, and
        iii. Termination of mission(s).

   d. Provide findings on implementation strategy for the overall operating mission portfolio.

4) Any significant minority opinions amongst the members of the SRS in any portion of the report will be separately identified and summarized.
5) Any SRS assessments that significantly diverge from the ASRC panel's findings, observations, and/or strengths and weaknesses will be explained in the SRS report.
6) The SRS will provide the NASA Senior Review Program Executive a separate document, or appendix to the main document, identifying process improvements, lessons learned, and any other general observations from this new Senior Review process that, in its opinion, can improve future such Senior Reviews under this Senior Review's structure.

The SRS document is the subcommittee's formal report to the Planetary Advisory Committee, and it is recognized as a potentially public document and/or containing potentially public material, as determined by and at the discretion of, the PAC.

This document itself will be made publicly available.

11 Appendix: NASA Ranking Definitions

Standard NASA usage for evaluating/ranking proposals consists of five qualitative descriptions, which, in turn, are linked to integral numerical scores. In evaluating Scientific Merit and Technical Merit, the respective SME panels, at the conclusion of their discussions, provided simultaneous integral votes for both of these categories. These discussions and votes were observed on a non-interference basis by the SRS and were formally transferred to the SRS and are reported in this document.

2019 PMSR – Definition of Adjectival Grades from the *Charge to the* (each SME) *Panel* by the ASRS Lead. Added parenthetical numerical scores were used in tabulating and averaging votes:

Excellent (Score = 5)

- A comprehensive, thorough, and compelling proposal of exceptional science/technical merit as documented by numerous or significant strengths and having no major weaknesses.

Very Good (Score = 4)

- A fully competent proposal of very high science/technical merit whose strengths fully outbalance any weaknesses.

Good (Score = 3)

- A competent proposal having neither significant science/technical strengths nor weaknesses, or, whose science/technical strengths and weaknesses essentially balance.

Fair (Score = 2)

- A proposal whose science/technical weaknesses outweigh any perceived strengths.

Poor (Score = 1)

- A seriously flawed proposal having one or more major science/technical weaknesses and no offsetting strengths.

Review panels typically use intermediate scores as well: “Very Good/Excellent” for 4.5, “Good/Very Good” for 3.5, “Fair/Good” for 2.5, and “Poor/Fair” for 1.5. This practice was adopted here as well. Hence, the adopted range is

Adjectival Score	Center Score	Range - Low	Range - High
Excellent	5.0	4.75	5.00
Very Good / Excellent	4.5	4.25	4.75
Very Good	4.0	3.75	4.25
Good / Very Good	3.5	3.25	3.75
Good	3.0	2.75	3.25
Fair / Good	2.5	2.25	2.75
Fair	2.0	1.75	2.25
Poor / Fair	1.5	1.25	1.75
Poor	1.0	1.00	1.25

12 Appendix: Acronyms

ASPERA	Analyzer of Space Plasma and Energetic Atoms
ASRS	Arctic Slope Research Services
CLPS	Commercial Lunar Payload Services
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars
DFO	Designated Federal Officer
FACA	Federal Advisory Committee Act
HiRISE	High Resolution Imaging Science Experiment
HEND	(Mars Odyssey) High Energy Neutron Detector
IMU	Inertial Measurement Unit
LRO	Lunar Reconnaissance Orbiter
MARSIS	Mars Advanced Radar for Subsurface and Ionospheric Sounding
MAVEN	Mars Atmosphere and Volatile EvolutioN
MEX	Mars Express
MoR	Memorandum for the Record
MODY	Mars Odyssey
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
MSR	Mars Sample Return
NASA	National Aeronautics and Space Administration
NS	(Mars Odyssey) Neutron Spectrometer
NSPIRES	NASA Solicitation and Proposal Integrated Review and Evaluation System
PAC	Planetary Science Advisory Committee
PDS	(NASA) Planetary Data System
PMSR	Planetary Mission Senior Review
PSD	(NASA) Planetary Science Division
SGE	Special Government Employee
SHARAD	Mars Reconnaissance Orbiter (MRO) Shallow Radar (SHARAD)
SME	Subject Matter Experts
SMD	(NASA) Science Mission Directorate
SRS	Senior Review Subcommittee
STL	(Mars Odyssey) System Test Lab
THEMIS	Thermal Emission Imaging System
ToR	Terms of Reference
UFE	Unallocated Future Expense

13 References

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