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LAMONT-DOHERTY EARTH OBSERVATORY

30 November 2020

Dr. Lori S. Glaze, Director
Planetary Science Division
Science Mission Directorate
NASA Headquarters
300 E Street, SW
Washington, DC 20546

Dear Lori:

I am pleased to submit the report of the 2020 Planetary Missions Senior Review (PMSR). Conducted during the week of 16 November 2020, the 2020 PMSR reviewed proposals for extensions of two Planetary Science Division missions, Juno and InSight. The proposals were evaluated by two largely distinct panels of Subject Matter Experts, each led by a distinct chair.

Attached please find the summary report of the 2020 PMSR, the individual evaluations of the two panels, and a list of all panelists.

I would be happy to answer any questions you might have about the process or findings of the 2020 PMSR. I look forward to discussing the review findings further with you on 10 December.

With best wishes,

A handwritten signature in blue ink, appearing to read "Sean C. Solomon".

Sean C. Solomon
PMSR Chair

Report of the 2020 NASA Planetary Missions Senior Review

Introduction

The 2020 NASA Planetary Mission Senior Review (PMSR) was conducted in a series of virtual meetings from 16 to 20 November 2020. Two proposed mission extensions were reviewed: one for the Juno mission, originally selected under the NASA Planetary Science Division's New Frontiers Program, and one for the InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) mission, originally selected under the division's Discovery Program. The proposed mission extensions would be the first for each project.

Review Process

Distinct panels of Subject Matter Experts (SMEs) evaluated each proposal. The PMSR chair and one member were common to the two panels, each of which was led by a distinct chair. All chairs and panelists were selected by Arctic Slope Technical Services, some with input from the PMSR and panel chairs, to represent a broad range of scientific, technical, and management expertise. The panelists were vetted for financial and personal conflicts of interest with the mission teams and implementing organizations.

The Juno and InSight projects submitted proposals for mission extensions by 30 September, following guidelines specified by NASA Headquarters in a Call for Proposals issued on 28 February. In accordance with that call, each project submitted three options for extended mission operation: a High scenario to "acquire high-quality science data in an extended mission consistent with the spacecraft and mission team's capabilities and operations during the nominal mission," a Medium scenario to "acquire data at a level between that of High and Low," and a Low scenario to "acquire data consistent with the lowest combination of science and budget for a minimally viable science mission." The Low and Medium scenarios were required by the Call for Proposals, whereas the High scenario was optional.

After individual reviews of the proposals by the assigned SMEs, and an initial virtual meeting of both panels on 22 October, each panel prepared a set of written questions to the corresponding project. Final versions of those questions were submitted to the Juno and InSight projects on 30 October. By 16 November each SME also submitted an individual written review of the

proposal(s) assigned to them via NSPIRES (NASA Solicitation and Proposal Integrated Review and Evaluation System).

During the week of 16 November, the lead-off meeting for each of the two panels was conducted with representatives from the project on the following schedule. For the first 90 minutes, the project made a presentation that included an overview lasting no more than 15 minutes of the proposed extended mission options, a brief update on prime mission progress since proposal submission, and a detailed response to each of the written questions submitted by the panel. For both the Juno and InSight missions, the Principal Investigator delivered the entire presentation, although four other project team members participated in the meeting for each mission and were eligible to speak, and for the Juno mission a number of other team members listened to the meeting as observers. Following each presentation, the panel met in Executive Session for 30 minutes to discuss the project presentation and develop follow-on questions. The final 30 minutes of each lead-off meeting was a question-and-answer session with the Principal Investigator and other project representatives.

Follow-on meetings by each panel later in the week of 16 November were devoted to evaluations of each extended mission scenario, conducted on the basis of the five primary criteria and five secondary criteria specified in the Call for Proposals. A written report of each project's extended mission proposal was prepared by the corresponding panel (and is attached to this report), and each panel voted on scores for science merit and the overall proposal for each extended mission option (six scores in all for each mission). The panel deliberations were conducted independently, so neither panel's assessment was influenced by that of the other group.

The Planetary Science Division was represented at each of the panel meetings by Program Officer Henry Throop and NASA Official Bill Knopf, and for portions of each of the panel's deliberations by the mission Program Scientist and/or Program Executive.

Juno Extended Mission

The Juno spacecraft, in orbit about Jupiter since July 2016, has yielded many discoveries about Jupiter's atmospheric dynamics and chemistry, internal structure, planetary magnetic field, and magnetosphere. The instruments and spacecraft subsystems are healthy, and power margins

and consumables are all adequate for continued orbital operations for several years beyond the end of the prime mission in July 2021.

The proposed Juno extended mission (EM) would take advantage of the natural northward progression of the periapsis of the spacecraft's orbit and the consequent lowering of spacecraft altitudes over Jupiter's high northern latitudes. The EM would run until the end of the mission, with an expected duration of approximately four years. Under the High and Medium scenarios, propulsive maneuvers would be utilized not only to target Jupiter-crossing longitude and perijove altitude, as during the prime mission, but also to target close flybys of Ganymede, Europa, and Io. The flyby maneuvers would act to shorten the spacecraft orbital period, yielding more close passes of Jupiter within a given time interval, and increase the rate of northward movement of spacecraft perijove. Under the Low scenario for EM operation, the satellite gravity assists and close satellite flybys would not be attempted.

The proposed EM was designed to achieve 26 scientific objectives, some of which build on discoveries made during the prime mission and others of which expand the range of mission investigations to embrace three of the four Galilean satellites (Io, Europa, and Ganymede) and Jupiter's ring system. As the spacecraft periapsis progresses northward during the EM, the Juno team would investigate the giant polygonal vortex structures surrounding the poles and extend the measurement of water abundance to Jupiter's polar region, which may differ in composition from the rest of the planet. Further investigation of the Great Blue Spot discovered in the magnetic field observations would allow studies of shearing of magnetic features by deep atmospheric winds. The low-altitude passes in polar regions would allow study of the acceleration of Jovian aurorae with the particles and fields instruments. Nighttime perijove passes would permit study of the roles of thunderstorms and shallow lightning in the dynamics of Jupiter's deep atmosphere.

During the EM, under the High and Medium scenarios, the Juno spacecraft would make close flybys of Io, Europa, and Ganymede and would fly through the Io and Europa plasma tori. Under the High scenario, maps of Ganymede's surface composition would allow studies of the role of radiolytic processes in surface weathering, identify changes since Voyager and Galileo, and permit a search for new impact craters that can sharpen estimates of the modern impact flux. Juno's Microwave Radiometer would sound Europa's ice shell at wavelengths complementing anticipated measurements by the radar instrument on NASA's Europa Clipper mission,

contribute to the identification of regions of thick and thin ice, and search for signs of shallow subsurface liquid. Juno's visible and low-light cameras would search Europa's near environment for active plumes and changes in surface color and reflectance that may indicate eruption sites that have been active since the Galileo mission. The fields and particles instruments would look for evidence of recent activity. Io flybys will permit gravity field measurements that could provide evidence of a magma ocean.

The Juno EM would bring the spacecraft through Jupiter's gossamer ring and halo; permit a characterization of the structure, properties, and evolution of the dust population in the vicinity of the ring system; and enable study of changes in ring particle distribution as a result of interactions with low- and high-energy charged particles.

As a result of streamlining and efficiencies in operation, the budget for the High scenario is approximately 12% less on an annual basis than the orbital phase of the prime mission, even though the project will be taking on a complex set of new objectives and observations for the EM. Compared with the High scenario, the budget for the Medium scenario is ~15% lower and funds less engineering and science team support. A number of observations planned for the High scenario (and eight of the 26 science objectives) that involve extensive engineering or operations analyses, special spacecraft pointing, or extensive command sequence development would not be included under the Medium scenario. Under the Low scenario, with a budget ~17% less than the Medium scenario, no satellite flybys would be conducted, and maneuvers for control of perijove longitude to fill gaps in magnetic field mapping would be eliminated. The final perijove would not be as far north as under the High and Medium options, and fewer orbits would have been completed at the end of the mission. Only 10 of the 26 science objectives, all focused on Jupiter itself, would be supported under the Low scenario.

The panel gave overall scores to the Juno EM of Excellent/Very Good for both the High and Medium scenarios (see table below), with somewhat higher individual SME scores for science merit for the High scenario but slightly higher individual overall scores for the Medium scenario. The science benefit of the High option over the Medium scenario was judged to be relatively small, in that both scenarios will yield important Jupiter system observations. The Low scenario, in contrast, was rated only as Very Good/Good, both for science merit and overall, because the mission design and science program were judged to

be substantially less compelling than the Medium or High options, with no observations of satellites or rings and less low-altitude coverage of Jupiter’s north polar region.

The Juno team has archived data from most of the spacecraft instruments on time, according to the schedule agreed upon by the Planetary Data System (PDS) and the Juno mission team, and all data deliveries are now up to date. Several additional data deliveries, however, would be beneficial. Whereas the Juno team plans to archive data from the Stellar Reference Unit (SRU) to be acquired during the EM, there is no plan to archive SRU data from the prime mission. **The panel recommends that NASA work with the Juno team to support the archiving of SRU data from the prime mission. Consideration should also be given to delivering data to PDS from Juno’s Radiation Monitoring investigation,** which would be of particular value to mission planning for Europa Clipper and ESA’s JUICE (JUperiter ICy moons Explorer) mission. Moreover, **NASA should support the production and release of user guides that go beyond PDS documentation for all Juno instruments.** Such user guides, similar to those produced by the Cassini mission, would enable and enhance studies of Juno data by the scientific community outside the Juno team.

Juno	Science Merit	Overall
High Scenario	E/VG	E/VG
Medium Scenario	E/VG	E/VG
Low Scenario	VG/G	VG/G

“Science Merit” is an assessment of the scientific merit of the proposed investigation only, regardless of all other factors. “Overall” is an assessment based on all evaluation criteria, including scientific merit, budget, technical capability, management, data archiving, and other criteria as listed in the Call for Proposals.

InSight Extended Mission

With its November 2018 landing, InSight delivered the first seismometer system to the surface of an extraterrestrial planetary body since the landing of the Viking 2 spacecraft in 1976 and the shut-down of the Apollo seismic network in 1977. Moreover, the broadband seismometer package on InSight is of much higher quality than those previous experiments – comparable to the best terrestrial seismometers – and its successful deployment is a superb technical

achievement. During InSight's prime mission, the seismic experiment – in operation since early 2019 – has demonstrated that Mars is tectonically active and has begun to yield information on the seismic velocity structure of the Martian crust and mantle. InSight's supporting payload instruments – including the magnetometer, radio science system, and atmospheric science package – have provided novel information in their own right on Martian paleomagnetism, interior structure, atmospheric dynamics, and atmosphere-surface interactions.

The proposed InSight EM would continue operation of the spacecraft and its payload instruments for a second Martian year, from the nominal end of the prime mission in November 2020 through 27 November 2022. The InSight team has proposed (a) eight new science objectives for the Low, Medium, and High EM scenarios, (b) three prime-mission science objectives that would be completed during the EM under all three budget options, and (c) two additional science objectives for the High scenario alone.

These new and continuing scientific objectives address three broad sets of science questions. The first set would extend the record of InSight's unique geophysical measurements, by acquiring a longer series of seismometer observations, extending the duration of precision radio tracking measurements to probe Martian internal structure, and measuring the subsurface thermal gradient, pending the successful completion of recovery of the HP³ (Heat flow and Physical Properties Package) mole by the end of the prime mission. The EM would approximately double the temporal baseline (from one Martian year to two) over which seismic and other data would be collected, markedly increasing the overall impact of the mission data. EM seismic data would further constrain marsquake properties and seismicity rates and would substantially advance our understanding of Martian crustal structure. EM data would improve the chances that mantle seismic velocities can be reliably resolved by increasing the number of recorded marsquakes, thus providing greater signal-to-noise enhancements from stacking and other methods. The longer recording period would also improve the likelihood that a larger event that has generated surface waves and/or core phases would be detected.

The second set of science questions are new to the EM and would build on discoveries made during the prime mission. These include further assessments of the character and origin of the observed time variability of high-frequency marsquakes, the poorly characterized structure of the upper few tens of meters of the Martian crust and its implications for surface history, the dynamics of the Martian atmosphere on timescales from seconds to years, the conditions

required to raise dust and move sand along the Martian surface, the current rate of meteoroid impacts on Mars, the character of the time-varying magnetic field at the Martian surface and its implications for the ionosphere and interactions between the planetary and interplanetary fields, and the origin of the puzzling magnetic “pulsations.”

The third set of science questions, new to the EM and to be addressed only under the High option, would focus on enhancements to the capabilities of the lander’s Instrument Deployment Arm (IDA) to enable two “augmented science” objectives focused on (a) measurements of the magnetization of rocks and soil, and (b) detailed visual and mechanical investigations of the regolith to a depth of a few tens of centimeters (including enhanced study of aeolian modification and threshold friction wind speed, and burial of the seismometer’s tether with the aim of decreasing “glitches” in the data).

The InSight team has met all expectations for data deliveries to the PDS to date. Moreover, during the prime mission the team agreed to an accelerated data release to allow investigators to propose to both the Mars Data Analysis and Participating Scientist Programs, and they archived the EDL (Entry, Descent, and Landing) accelerometer data, which had not been in the original plan. The InSight team has also been archiving data in two additional repositories that are utilized by the terrestrial seismological community, thereby improving the likelihood that the mission data will be downloaded and analyzed by broad segments of that community.

Nearly all spacecraft and payload systems needed to fully execute the proposed EM investigations, with the notable exception of spacecraft power, are in excellent health and are projected to have adequate margins to ensure successful operation for a second Martian year. In contrast, according to the most recent analyses presented at the panel meeting, **the power margins for the InSight spacecraft are likely to reach critically low levels during the proposed EM, potentially presenting a risk to the operation of the full science payload.** There is a substantial risk, for example, that decreasing power production because of dust deposition on the solar panels, combined with the increasing need for electrical heating at the onset of the upcoming Martian winter, could place the spacecraft in a negative power-margin state as early as sol 950 (late July 2021). **Power-saving steps outlined in the proposal and described during the presentation to the panel are intended to ensure that the mission will survive beyond sol 950, but there is little safety margin, particularly if another dust accumulation event occurs before then.**

As a result of some streamlining of operations and an assumed end to mole recovery operations, InSight's annual budget under the Medium scenario is 20% less than the final year of the prime mission, with no proposed change in science deliverables. The High scenario, with a budget ~11% greater than the Medium scenario, includes expanded staffing to complete software development, testing, and operations for the "augmented science" activities by the IDA that would not be conducted under the Medium option. The budget for the Low EM option, ~12% less than under the Medium scenario, is met by reductions to the project's science and operations team, restricting or eliminating strategic risk management and science operations and data analysis (except by non-U.S. members of the science team) and limiting science and sequence planning.

The panel gave scores of Excellent for both science merit and the overall mission for InSight's High scenario, and scores of Excellent/Very Good in both categories for the Medium scenario (see table below). Under the High scenario, the objective of burying the tether to the seismometer package is viewed as higher in priority than other augmented science activities, because of the probability that tether burial would remove a major source of glitches seen in seismic records to date and therefore strengthen the potential to collect high-quality seismic data and meet the project's seismological science objectives before the end of the EM. Moreover, the panel recommends that NASA consider conducting the software development and testing needed for tether burial sufficiently early that this objective might be completed before the end of the seismically quiet season on Mars anticipated in the spring of 2021. Under either EM scenario, NASA should ensure that the InSight team has the staffing in place to monitor and manage as necessary spacecraft power availability and usage through the end of the EM.

The Low scenario for the InSight EM, in contrast, was given a science merit score of Very Good and an overall score of only Good, because the markedly lower staffing levels for the engineering and science teams would reduce the project's capacity to respond to scientific discoveries or to spacecraft or payload performance emergencies, such as those related to lower-than-anticipated spacecraft power margins. The increase in risk under the Low option was judged to be out of proportion to the modest reduction in budget level from the Medium and High scenarios.

InSight	Science Merit	Overall
High Scenario	E	E
Medium Scenario	E/VG	E/VG
Low Scenario	VG	G

Conclusions

The Juno and InSight projects, now nearing the end of their prime missions, have both been success stories for NASA, yielding a wealth of new observations and changing our view of key characteristics of gas-giant and rocky planets, respectively. Both spacecraft are currently healthy, and both mission teams have identified compelling new science objectives that could be achieved during extended missions. The cost for completing extended missions for both spacecraft would be modest in comparison to those for new missions to these bodies.

30 November 2020

Original version

10 February 2021

Revised to fix error in description of proposed Juno Medium scenario, page 3.

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Panel Evaluation

Proposal	20-PMSR20-0004
Title	Juno Extended Mission
Principal Investigator	Bolton, Scott / Southwest Research Institute

Summary of Proposal

The proposed extension would permit continued operation of Juno at Jupiter for approximately four years or until the end of the mission. The Juno Extended Mission (EM) would continue studies initiated during the prime mission (PM) and initiate new studies made possible by the northward progression of periapsis and passage of the spacecraft near Io, Europa and Ganymede.

As the orbit of Juno progresses northward, the Juno team would investigate the giant polygonal vortex structures surrounding the poles and extend the measurement of water abundance at Jupiter to the high-latitude polar region which is thought to be unlike the rest of Jupiter. Further investigation of the Great Blue Spot discovered in the magnetic field observations would allow studies of shearing of magnetic features by deep atmospheric winds. The high-latitude passes at lower altitudes in polar regions would allow the particles and fields instruments to study the acceleration of Jovian aurorae.

The orbit of Juno in the EM would take the spacecraft through the Io and Europa plasma tori and in close proximity to Io, Europa and Ganymede. Maps of Ganymede's surface composition would allow studies to understand the importance of radiolytic processes in surface weathering, identify changes since Voyager and Galileo, and search for new craters. Juno's Microwave Radiometer (MWR) is particularly sensitive to the upper 10 km of Europa's ice shell. Studies at wavelengths complementing expected results from Europa Clipper's radar would identify regions of thick and thin ice and search for regions where shallow subsurface liquid may exist. Juno's visible and low-light cameras would search Europa for active plumes and changes in color/albedo that may reveal eruption regions since Galileo. The fields and particles experiments would look for evidence of recent activity. Finally, the Juno EM would include a flyby of Io and search for evidence of a magma ocean.

The proposal presented three budget scenarios and outlined the science studies that can be supported for each. Relative to the High budget, the Medium budget involves less engineering support and removes the studies involving remote sensing of the satellites and remote sensing of the rings. For instance, the studies of satellite surface weathering and mapping high-latitude volcanoes on Io would be lost as would the study of the vertical structure of aurorae. The Low budget changes the orbital tour. Orbits would be longer, more fuel would be required to maintain perijove altitude, and Juno would not reach as far north. All satellite science would also be removed under the Low budget.

The instruments and spacecraft system on Juno are working well. The proposal presents a plan to archive all EM data with the PDS.

Primary Evaluation Criteria

Any individual finding may be Major or Minor. Please mark as 'Minor' if appropriate; findings not so marked are assumed to be Major.

1. Scientific impact of the mission's proposed investigations

For each finding in this section, please make clear whether the finding applies to the High (H), Medium (M), and/or Low (L) scenarios. If not marked, the finding applies to all three scenarios.

Strengths

[H/M/L] The proposed study of ammonia concentration, polar vortices, and moment of inertia (MOI) refinement would be a valuable scientific contribution. During the mission thus far, the team discovered that the water and ammonia abundances are non-uniform, providing an unexpected result. The poleward progression of perijove would allow for additional detailed measurements at high latitudes. The abundances of ammonia and water in these regions are important for understanding internal structure and formation of the planet. The low-altitude polar flybys also allow close study of the vortex structures near the poles. Additionally, refining Jupiter's MOI would be a significant advancement towards answering open interior-structure and formation questions.

[H/M] The microwave radiometry study at high Jupiter latitudes would provide important scientific information regarding processes at depth. The MWR would diagnose the vertical structure of the polar cyclones, which may be significantly deeper than mid-latitude vortices. MWR observations would also be critical in understanding latitudinal structure in the atmosphere at Jupiter, a topic with broad scientific impact.

[H/M] High-resolution magnetic field data at the Great Blue Spot would provide considerable scientific return. The demonstration of shearing of the Great Blue Spot would probably be the most direct evidence of deep zonal flows that are magnetohydrodynamically active.

[H/M/L] Fields and particles data from closer to Jupiter in the polar region would increase the chances of observing the auroral acceleration region, an important goal of the PM. The observations from the PM suggest that poleward of the main aurorae major acceleration occurs below the altitude of the Juno orbit. The periapsis closer to Jupiter would allow this potentially important region of acceleration to be investigated.

[H/M] The Juno EM would provide important observations of Io, Europa and Ganymede. The MWR investigation proposed for the icy satellites would provide new information on their ice shells, such as the ice structure and thermal gradient. Exploring the Io and Europa tori may fill in gaps left from Galileo. The proposed data acquisition in close proximity to Io in the EM could have considerable impact since there are no approved missions to explore that body.

Minor: [H/M] The reformulation of Stellar Reference Unit (SRU) data for scientific purposes would provide additional scientific return, including new observations of lightning occurrence on the night side.

Minor: [H] Another proposed SRU investigation would show Jovian rings from a unique geometry (polar view), complementing previous equatorial observations.

Minor: [H/M/L] In the proposed EM, the Juno team would archive data from two scientifically valuable support sensors - the SRU and the Radiation Monitoring Investigation (RPI) - which would be a useful resource for the planetary science community.

Minor: [H] The side view of the auroral emissions, enabled by the proposed low orbits and targeting, would provide new constraints on the structure of aurorae.

Minor: [H] Searches for Europa plumes using optical and in situ observations could confirm their existence and help determine their characteristics.

Weaknesses

Minor: [H/M] The proposal states, "This detailed characterization provides Europa Clipper and JUICE a much-needed update on the radiation environment they will encounter"; however, the design and build phases of the JUICE and Europa Clipper missions would be virtually finished by the start of the proposed EM. The proposal provided insufficient detail regarding how the EM observations would meaningfully support and inform the subsequent phases of these missions.

Minor: [H/M/L] The proposal did not adequately acknowledge that the uneven north-south sampling would hinder interpretation of the complexities of the gravity anomalies in terms of Jupiter's internal structure and dynamics of zonal winds.

2. Demonstrated scientific productivity of the mission team during prime mission

Strengths

Data from the Juno PM have had a considerable impact on our understanding of giant planets.

The team has produced more than 300 team-led papers in peer reviewed journals, demonstrating that they have been very active during the PM. The mission team has found that Jupiter has a diffuse core, a ground-breaking scientific result. Observations of odd-degree gravity perturbations strongly suggest that the surface jet flows are deep-reaching structural features. Furthermore, Juno found that the magnetic field has unexpected structure, which provides a challenge to dynamo theorists. Finally, the finding of heterogeneity in water and ammonia abundances indicates that atmospheric dynamics are more complex than previously thought.

Weaknesses

Minor: The Juno science team has not successfully distinguished between opacity and physical/kinetic temperature with respect to MWR measurements of the Jovian atmosphere, which was an important PM goal.

3. Responsiveness of the mission to PSD and NASA goals as described in the 2003 and 2011 Decadal Surveys.

For each finding in this section, please make clear whether the finding applies to the High (H), Medium (M), and/or Low (L) scenario. If not marked, the finding applies to all three scenarios.

Strengths

The proposed EM directly addresses critical PSD and NASA goals described in the Decadal Surveys. The Juno mission (or something very similar to Juno) was explicitly suggested in the 2003-2011

Decadal Survey as a means to address several of the 'priority questions' related to the formation of the solar system, distribution of water, and other topics. The EM would further contribute to resolving these questions, many of which are also outlined in the 2013-2022 decadal survey. In addition, Jovian satellites, which are scientific targets of the proposed EM, are emphasized as important targets in the 2013-2022 survey. The EM would address additional priority questions, such as the existence of habitats beyond Earth that could sustain life. The proposal points out that 56 of the questions in the chapters on giant planets and their satellites are addressed by the Juno mission.

Weaknesses

None noted

4. Capability of spacecraft and instrument suite to achieve proposed science

This review will not evaluate operational capability of the spacecraft, but assumes that the current capabilities will persist through the end of the review period of performance, except for known limitations (e.g., fuel, instrument degradation).

For each finding in this section, please make clear whether the finding applies to the High (H), Medium (M), and/or Low (L) scenario. If not marked, the finding applies to all three scenarios.

Strengths

[H/M/L] The proposal adequately demonstrated that the amount of hydrazine is sufficient to execute the necessary maneuvers for the proposed investigation.

[H/M/L] The proposal adequately demonstrated that the Juno spacecraft and all instruments have performed well during the PM and show no abnormal signs of aging.

Weaknesses

[H/M/L] The proposal did not adequately demonstrate that radiation degradation would not meaningfully impact the performance of scientific instruments through the proposed EM, in which Juno will be exposed to larger radiation dosage than during the PM. The call for the extended mission proposal specified that "Any science degradation due to spacecraft/instrument degradation should be described in order for the panel to accurately evaluate the science merit of the proposed tasks". The Juno team presentation to the panel provided evidence that radiation would not likely have a major impact on spacecraft engineering systems. However, similar analysis of the projected health and radiation impacts on the *scientific* instruments was not provided in either the proposal or the presentation.

5. Past performance in archiving data to the Planetary Data System (PDS)

Strengths

The Juno team has archived data from most of the spacecraft instruments on time, according to the schedule agreed upon by the PDS and the Juno mission team. All data deliveries are now up to date.

Weaknesses

The Juno mission team did not deliver magnetometer and infrared auroral mapper data in a timely fashion in the PM. Portions of data from these instruments were delayed by nearly 2 years.

Secondary Evaluation Criteria

6. Extent to which the science community beyond the mission science team utilizes data and conducts research

Strengths

The proposal demonstrated that the number of non-team publications has increased steadily as the mission progressed, accounting for ~25% of the total Juno-related publications.

Minor: The Juno magnetic and gravity field models have generated significant interest in the wider community and spawned substantial research activities beyond the immediate Juno team.

Minor: The Juno team has demonstrated a strong effort to engage with the citizen science community, increasing the exposure and public interest in planetary science. Citizen scientists have processed and submitted over 8,000 images to the Juno website. It is expected that this level of engagement would continue into the EM with images of new Juno targets such as Io, Europa and Ganymede.

Weaknesses

None noted

7. Cost reasonableness

The qualitative science “value” (e.g., high vs. low) may be assessed.

For each finding in this section, please make clear whether the finding applies to the High (H), Medium (M), and/or Low (L) scenario. If not marked, it is assumed that the finding applies to all three scenarios.

Strengths

[H] The Juno operations team continues to streamline and seek efficiencies in operations, demonstrating an important focus on the “science per dollar” going forward. The operational costs are being reduced by about 12% per year even in the High budget, while the project takes on a complicated set of new objectives and observations for the EM.

[H/M] The data from the High and Medium options provide a much more compelling science program than the Low option. The Medium and High options would allow Jovian system science by adding studies of the Jovian satellites and rings, expanding the Jovian atmospheric studies, and providing more detailed measurements of deep magnetohydrodynamic shearing of magnetic field structures. The benefit of the High option over the Medium is relatively small since both contain the important new data from the moons.

Weaknesses

None noted

8. Opportunities for promoting new personnel within the mission team (e.g., transition for aspiring PIPS)

Strengths

The proposal described a plan for early-career scientists to be mentored by top management.

While the intent at the time of the proposal was to provide mentorship to only three early-career team members, the team stated during the presentation to the panel that this program would be expanded to include many additional mentors (working group leads, instrument leads) and mentees. This expansion is especially welcome to demonstrate dedication to training a new generation of scientists to be well-equipped for future PI opportunities.

Weaknesses

The proposal did not provide sufficient detail regarding the selection process for mentees, which would be useful in demonstrating that the process implemented best practices regarding equity, diversity, and inclusion, ensuring the greatest career opportunities for next-generation leadership.

9. Plan to place new mission science analysis code and algorithms into an open repository

Strengths

None noted

Weaknesses

The proposal had insufficient detail regarding the scope of the archival effort for codes and algorithms, *i.e.*, whether simple utilities are anticipated to be released, or more general tools that would significantly improve the ability of non-team scientists to use and analyze low- to high-level datasets across all instruments.

10. Plan to implement security updates and patches, including those issued by NASA's Advanced Multi-Mission Operations System (AMMOS) for all relevant components used by the flight project.

Strengths

The proposal provided a detailed plan regarding the support of the Ground Data System with AMMOS. For example, the mission team is aware that the operating system (Solaris 10) on which the ground data system is based will no longer be supported during the entire mission; during the presentation it was made sufficiently clear that the Jet Propulsion Laboratory is aware of the issue and has appropriate protocols in place for managing end-of-life for software systems.

Weaknesses

None noted

Science Merit Score

This score is for science merit alone. Cost is not considered for this criterion.

Score (High scenario): **Excellent / Very Good**

Score (Medium scenario): **Excellent / Very Good**

Score (Low scenario): **Very Good / Good**

Overall Proposal Score

This score considers all aspects of the proposal, including Scientific, Technical, Management, and Budget.

Score (High scenario): **Excellent / Very Good**

Score (Medium scenario): **Excellent / Very Good**

Score (Low scenario): **Very Good / Good**

Comments to the PI

The Juno team has maintained good communication with ground-based and space-based observers. It is important that this level of communication be maintained through the proposed extended mission, as well as expanded to include Jovian satellite scientists in the case of the High or Medium scenario.

2020 NASA Planetary Mission Senior Review

Panel Evaluation

Proposal	20-PMSR20-0002
Title	InSight Extended Mission
Principal Investigator	Banerdt, William / California Institute of Technology

Summary of Proposal

This proposal described a potential Extended Mission (EM) for the NASA Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission. The EM would begin once the Prime Mission (PM) ends in late November 2020 and would extend operation of the spacecraft for a second full Martian year of observations. The proposal describes six major EM goals designed to respond to goals defined by the Decadal Survey and MEPAG: (1) Constrain the structure and state of the Martian interior; (2) Constrain the dynamics of the Martian interior; (3) Characterize the regolith and near-surface structure at the landing site; (4) Constrain the dynamics of the Martian atmosphere and its interactions with the surface; (5) Investigate time-varying behavior of the Martian magnetic field; and (6) Constrain the impact rate on Mars.

To meet these EM goals, the InSight team proposed a set of eight new scientific objectives that they would attempt to achieve in their Low and Medium budget EM scenarios, two additional new scientific objectives that they would attempt to achieve in their High budget EM scenario, and three partially-achieved PM scientific objectives that they would also attempt to complete in the EM. These new and continuing scientific objectives are designed to address three broad sets of new science questions. The first set focuses on extending the record of InSight's unique geophysical measurements, by acquiring a longer series of seismometer observations, extending the duration of precision radio tracking measurements to probe Mars' core, and measuring the subsurface thermal gradient, pending the successful completion of mole recovery in the PM. The second set of new science questions focuses on expanding upon the current PM science objectives by assessing the character and origin of the observed time variability of seismicity, the unseen structure of the upper few tens of meters of Mars and its implications for the surface history, the dynamics of the Martian atmosphere at timescales from seconds to years, the conditions required to raise dust and move sand, the current rate of meteoroid impacts on Mars, the character of the time-varying magnetic field at the surface, and its implications for the ionosphere and its external interactions, and the origin of the puzzling magnetic "pulsations." And the final set of new science questions, exclusively in the High scenario, focuses on augmenting the PM science further through enhancements to the robotic arm capabilities, including detailed visual and mechanical investigation of the regolith to a depth of a few tens of centimeters, enhanced study of aeolian modification and threshold friction wind speed, measurements of the magnetization of rocks and soil, and burial of the seismometer's tether to potentially significantly decrease "glitches" in the data.

The InSight EM proposal also described the current state of health of the lander and its payload and subsystems, analyses of the expected energy available for full science operations under expected atmospheric opacity and dust conditions, and the power system and operations contingencies required for surviving possible dust storms. The proposal also described their plan for mission operations, designed to enhance the mission's long-term sustainability while supporting continuous data acquisition. The InSight team's productivity in terms of publications and archived data volume during the PM is tabulated, as are their plans for EM data archiving in the PDS.

Primary Evaluation Criteria

Any individual finding may be Major or Minor. Please mark as 'Minor' if appropriate; findings not so marked are assumed to be Major.

1. Scientific impact of the mission's proposed investigations

For each finding in this section, please make clear whether the finding applies to the High (H), Medium (M), and/or Low (L) scenarios. If not marked, the finding applies to all three scenarios.

Strengths

[H, M, and L] Several of the proposed Extended Mission (EM) investigations would provide important extensions of InSight's Prime Mission (PM) investigations, generating valuable new data for the scientific community. InSight has delivered the first passive seismic system to the surface of an extraterrestrial planetary body since the landing of the Viking 2 spacecraft in 1976 and the shut-down of the Apollo seismic network in 1977. Moreover, the broadband seismometer package is of much higher quality than those previous experiments--comparable to the best terrestrial seismometers--and its successful deployment is a superb technical achievement, particularly when coupled with InSight's weather station and other instruments that allow an understanding of weather-related artifacts in the seismic data. The proposed EM would approximately double the temporal baseline over which seismic and other data would be collected, markedly increasing the overall impact of the mission data. The proposed EM would further constrain marsquake properties and seismicity rates and would substantially advance our understanding of Martian crustal structure, one of the primary objectives of the PM and EM. The EM would improve the chances that mantle seismic velocities can be reliably resolved by increasing the number of recorded marsquakes, thus providing greater signal-to-noise enhancements from stacking and other methods, and increasing the chances that a larger event with surface waves and/or core phases would be detected.

[H, M, and L] Several of the proposed EM investigations would expand upon "surprise" discoveries made during the PM, providing the ability to address new science questions beyond those originally planned for the mission. For example, the EM would help to characterize and understand the apparent seasonality of high-frequency marsquakes (which has no clear explanation), the surprisingly low magnitude of the largest observed marsquakes, and unexplained pulsations in magnetic activity. Study of all of those unexpected PM results would benefit significantly from a longer recording period, perhaps especially during the expected upcoming seismically "quiet period." Atmospheric pressure fluctuations have also revealed several phenomena for the first time, from the discovery of infrasound waves to the finding of magnetic and seismic signatures from "dust devils." Extending the timescale of observations of such surprising atmospheric dynamics over multiple Mars years could provide key data to assess their origins.

[H]: The proposed EM activity for tether burial could lessen or eliminate stick-slip "glitches," significantly improving the overall scientific return of the seismology experiment by reducing the probability that important event records would be contaminated by glitches and improving the fidelity of autocorrelation and other methods applied to continuous noise records.

Weaknesses

[L] The Low budget option substantially increases the risk of not meeting EM science mission success by reducing the team's capacity to respond to problems or discoveries, especially given the post-proposal recognition of lower-than-anticipated spacecraft power margins. The Low budget scenario reduces mission operations; science, technical, and management planning; and analysis personnel to a level below that necessary for the highest-quality data collection, analysis, and archive validation. In the team presentation, the seismological objectives were noted as being of highest priority to the InSight team; however, the Low budget scenario spreads cost savings across all areas of the project, imparting additional risk to the entire ensemble of measurements. If the Low budget scenario is selected, there is substantial risk that the dataset returned would be significantly lower in volume and/or quality than what would be returned from the Medium or High scenarios.

Minor [H/M/L]: The proposed EM heat flow objective would not be achieved if the mole does not reach at least 3 meters depth.

Minor [H/M/L]: The assertion that the InSight team would be able to distinguish between the two- and three-layer crustal models was not sufficiently supported by methodological details to establish that these models are currently resolved or would be reliably resolved with more data. Moreover, other models for crustal structure may emerge once additional data are collected during the EM. Similarly, the evidence for the reliable identification and timing of mantle P and S waves, including surface reflections, was not firm enough to ensure the EM would be able to resolve the mantle velocity structure. It should be noted that the InSight team has submitted papers on these topics; once these results are peer-reviewed and published, a better assessment of these issues will be possible.

2. Demonstrated scientific productivity of the mission team during prime mission

Strengths

The InSight team has published studies in numerous peer-reviewed journals and has provided updates on major mission results to the scientific community during several major international conferences and workshops. The team has produced more than 60 peer-reviewed papers across roughly 18 months of operations, despite setbacks with the progress of the mole and a lower-than-anticipated number of seismic events on Mars. This represents considerable scientific productivity. The InSight Participating Scientist program has substantially augmented the science team, contributing significantly to the team's productivity.

Minor: Several experiments have achieved success in objectives beyond level-1 requirements in the PM, motivating new analyses and increasing the scientific output of the InSight team. These include detailed imaging characterization of the geology of the landing site; measurement of specific surface properties such as the thermal inertia of the surface around the lander, Young's modulus of the duricrust, and compliance of the deeper near-subsurface.

Weaknesses

Minor: Given the problems with the mole deployment, the HP3 team has been unable to make substantial progress towards measuring the heat flux on Mars, a baseline objective of PM (*Determine the heat flux at landing site to within +/- 5 mWm²*). After much effort the mole is buried at a depth of only 45 cm (in contrast to the nominal depth of 3-5 m) as of the time of the review.

3. Responsiveness of the mission to PSD and NASA goals as described in the 2003 and 2011 Decadal Surveys.

For each finding in this section, please make clear whether the finding applies to the High (H), Medium (M), and/or Low (L) scenario. If not marked, the finding applies to all three scenarios.

Strengths

[H, M, and L] The proposal's Science Traceability Matrix makes clear connections between Decadal Science Goals/Questions and the research to be performed in the EM under all three budget scenarios.

[H] Burying the tether as part of the High budget scenario has the potential advantage of increasing the overall quality of seismic records that form the basis for all analyses of Martian interior structure and seismic source characterization, thus increasing the likelihood that the Decadal goals would be sufficiently met.

Weaknesses

Minor [H]: The proposal did not sufficiently demonstrate that two of the High mission's science objectives (*Determine the magnetization of surface materials; Study regolith layering at the scale of tens of centimeters*) would substantially address the associated Decadal Survey Questions identified in the Science Traceability Matrix.

4. Capability of spacecraft and instrument suite to achieve proposed science

This review will not evaluate operational capability of the spacecraft, but assumes that the current capabilities will persist through the end of the review period of performance, except for known limitations (e.g., fuel, instrument degradation).

For each finding in this section, please make clear whether the finding applies to the High (H), Medium (M), and/or Low (L) scenario. If not marked, the finding applies to all three scenarios.

Strengths

The proposal demonstrated that almost all of the required spacecraft and payload systems needed to fully execute the proposed Extended Mission investigations, with the exception of spacecraft power, are in excellent health and/or have adequate expected resource margins to ensure their success.

Weaknesses

According to the most recent analyses presented by the InSight team, the power margins of the spacecraft are likely to reach critically low levels during the EM, potentially representing a risk to the operation of the full science payload. There is a substantial risk, for example, that the decreasing solar power production due to dust deposition combined with the increasing need for electrical heating entering the upcoming Martian winter could place the spacecraft in a negative power-margin state by as early as sol 950 (July 29, 2021).

Minor [H]: The proposed EM did not include sufficient detail regarding the nature or magnitude of the development and validation of the Instrument Deployment Arm (IDA) software that would be required to accomplish the augmented EM science investigation. The proposed augmented IDA activities are not the

same as the trenching and digging activities performed by the Phoenix mission's robotic arm. Insufficient detail was given in the proposal to determine if the "heritage Phoenix software" (p. 39) would actually enable the IDA to complete the proposed work.

Minor [H/M/L]: The proposal lacked sufficient detail on the statistical likelihood of the different kinds of data glitches and drop-outs compromising the success of the seismology investigation. There are several sources of "glitches" inherent to the seismological data, some of which have inferred origins (for example, those related to the tether), but others of as-yet-unknown origin that pose ongoing issues with analyzing the data.

5. Past performance in archiving data to the Planetary Data System (PDS)

Strengths

The InSight team has an exemplary record of performance in PDS archiving. The InSight team has met all expectations for PDS deliveries, including meeting all six quarterly data releases to date (May 2019 to present). The InSight team agreed to an accelerated dataset release to allow investigators to propose to both MDAP and the Participating Scientist Program and quickly corrected a small number of errors that were found in metadata labels. The team also archived the Entry, Descent, and Landing (EDL) accelerometer data, which was not in the original plan.

Minor: In addition to deliveries to PDS, the InSight team has been archiving data in two repositories (IRIS and IPGP) that are utilized by the terrestrial seismological community, thereby improving the likelihood that the mission data will be downloaded and analyzed by broad segments of that community.

Weaknesses

None noted

Secondary Evaluation Criteria

6. Extent to which the science community beyond the mission science team utilizes data and conducts research

Strengths

None noted

Weaknesses

Minor: The proposal lacked sufficient detail regarding data download statistics (Table 9-1) to ascertain data usage beyond the immediate mission team. For example, the proposal did not sufficiently describe the demographics of the requestors (e.g., U.S. vs. international, educational vs. research institutions vs. non-science usage), nor did it indicate whether web bots and search engines were excluded.

7. Cost reasonableness

The qualitative science “value” (e.g., high vs. low) may be assessed.

For each finding in this section, please make clear whether the finding applies to the High (H), Medium (M), and/or Low (L) scenario. If not marked, it is assumed that the finding applies to all three scenarios.

Strengths

Minor [M]: The Medium EM budget scenario is lower by about 20% (on a per annum basis) than the final-year budget of the Prime Mission, without a decrease in the predicted scientific outcomes.

Minor [H]: For a 10% or less increase over the Medium EM budget scenario, the High EM budget scenario mission’s goal of burying the seismic tether, especially if accomplished before the end of the upcoming quiet season (~sol 1200; April, 2022), would provide the best chance to collect the highest-quality data and therefore the highest chance of achieving the seismic objectives before the end of the EM.

Weaknesses

Minor [H]: The cost justification for the non-tether-related aspects of the High EM budget scenario (*i.e.*, to study regolith layering at tens of centimeters and to determine the magnetization of the surface material) lacked sufficient detail.

Minor [L]: The increased risk to mission science and impact to the mission science team associated with the Low extended mission scenario would be disproportionately large relative to the cost savings to the mission.

8. Opportunities for promoting new personnel within the mission team (e.g., transition for aspiring P/PS)

Strengths

Minor: The addition of a Deputy Project Scientist or Project Data Scientist in 2022 would create an opportunity for advancing an early-career scientist while benefiting the project's needs.

Minor: The proposed EM included the formation of a diversity and inclusion working group, which is important for ensuring equitable opportunities across the mission team.

Minor: The proposed EM included a plan to rotate Science Working Group leads to ensure that early-career scientists would be given leadership opportunities.

Weaknesses

Minor: The proposal did not describe an adequate succession plan for science team leadership and further stated that the proposed EM would be conducted "with no changes in management approach or key personnel planned" (p. 33). This may be a potential lost opportunity, as the career trajectories of a number of junior-level project and payload personnel could benefit substantially from advancement under leadership mentors, with likely little increase in mission risk. The proposal mentioned adding only one additional younger member of the Project Science Office within the next two years.

9. Plan to place new mission science analysis code and algorithms into an open repository

Strengths

None noted.

Weaknesses

The proposal did not include adequate plans for publishing science analysis code or algorithms in the future. Although some PM data processing algorithms have been documented within archived data product Software Interface Specification (SIS) documents, the proposal did not address whether or how new mission science analysis code and algorithms would be made available in an open repository.

10. Plan to implement security updates and patches, including those issued by NASA's Advanced Multi-Mission Operations System (AMMOS) for all relevant components used by the flight project

Strengths

Minor: Required security protocols and procedures are described and justified in the proposal. For example, the project committed to keeping all mission operations and Ground Data System (GDS) software patched and stable. AMMOS updates and patches for GDS would be provided through Multi-mission Ground Systems and Services, and all software changes would be reviewed by the project prior to implementation.

Weaknesses

Minor: The proposal did not sufficiently demonstrate that security updates and patches would be implemented for AMMOS components that are used by the flight project. The proposal did not indicate how updates and patches were evaluated or discuss which updates might have been postponed or rejected and why.

Science Merit Score

This score is for science merit alone. Cost is not considered for this criterion.

Score (High scenario): **Excellent**

Score (Medium scenario): **Excellent / Very Good**

Score (Low scenario): **Very Good**

Overall Proposal Score

This score considers all aspects of the proposal, including Scientific, Technical, Management, and Budget.

Score (High scenario): **Excellent**

Score (Medium scenario): **Excellent / Very Good**

Score (Low scenario): **Good**

Comments to the PI

The panel commends the PI and team for their transparency in providing the latest details on the performance predictions for the spacecraft in the proposed EM, for being very clear about the challenges and risks associated with the predicted power situation, and for the new analysis of nighttime camera sensitivity that precludes the science objective related to meteor searches. More generally, we appreciate the PI's and team's thorough and detailed responses to our questions.

NASA 2020 Planetary Mission Senior Review (PMSR)

PMSR Review

Chair: Sean Solomon / Columbia

Juno Panel

Chair: Ray Walker / UCLA + PDS Plasma

Jim Adams / NASA (retired)

Jonathan Aurnou / UCLA

Ulrich Christensen / Max Planck

Michele Dougherty / Imperial College

Timothy Dowling / U. Louisville

Richard Holme / U. Liverpool

Erwan Mazarico / NASA GSFC

Sean Solomon / Columbia



Mars InSight Panel

Chair: Jim Bell / ASU

Jim Adams / NASA (retired)

David Brain / LASP

Amitabha Ghosh / Tharsis, Inc.

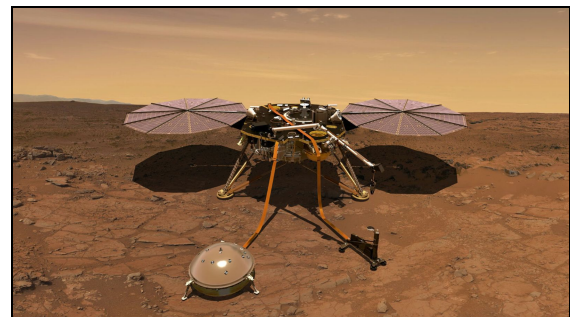
Yosio Nakamura / UT Austin

Peter Shearer / UCSD-Scripps

Sean Solomon / Columbia

Tom Stein / Washington University + PDS Geosciences

Lara Wagner / Carnegie



Panel Organization

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