Extended Missions in Planetary Science: Impacts to Science and the Workforce

Planetary Science and Astrobiology Decadal Survey 2023–2032 White Paper on the State of the Profession

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Executive Summary

Extended planetary missions demonstrate tremendous science value. The return in science productivity more than justifies the small expense of extending functioning missions relative to developing and launching a new mission. We recommend that the Decadal Survey explicitly highlight the value of extended missions to the planetary community and to the general advancement of space exploration, both in terms of scientific achievements and as an important career pipeline. We also request an evaluation and response to the recommendations in the 2016 National Academies Report “Extending Science”¹. Additionally, we recommend actions that would provide more robust and stable funding, and improve participation in and inclusivity of missions.

Introduction

Extended missions have a significant impact. They enormously increase the science return of their prime missions, enable continued exploration, and provide opportunities for the development of the planetary science workforce, including career development for early career scientists and engineers. For example, during its extended mission phase, Cassini returned evidence of liquid water on Enceladus, evidence for a giant methane lake on Titan, and unprecedented views of Saturn's rings. The Opportunity rover's 14-year extended mission showed evidence of previously flowing water on Mars as well as exploring a whole new region (Endeavor Crater) that was previously unreachable during its short 90-day prime mission. The Lunar Reconnaissance Orbiter (LRO) was able to build the largest volume of planetary data in existence during its extended mission, while enabling discoveries of current processes that act on the Moon on yearly timescales. There are many more examples of groundbreaking science performed in extended missions.

Despite NASA's best intentions, the potential science return of these extended missions has not been fully achieved. Steady reductions in funding, including through inflation, reduce their viability, cripple scientific analysis and dissemination, and can even threaten mission success if hardware cannot be maintained. The continued pressure to define “new science” in each extended mission phase, while a valuable effort, diminishes the importance of science investigations that require long-baseline observations. Systematic funding cuts during extended missions negatively impact the science return by hindering the team's ability to cope with the complications that come from aging spacecraft and instruments. Even if every effort is made to make operations as efficient as possible, new situations occur that require novel analyses and mitigation strategies.

Four years ago, the National Academies published their report on “Extending Science: NASA's Space Science Mission Extensions and the Senior Review Process”¹. Since then some recommendations have been implemented, but many have not. This white paper recalls that report and recommends several specific actions be taken to ensure the efficacy of extended planetary science missions, thus increasing the benefits they provide to science and exploration and to our community of scientists and explorers.

Scientific Benefits of Extended Missions

“These lengthy missions and their incredible scientific productivity are not simply due to happenstance or the unexpected longevity of some spacecraft: extended missions are a mainstay of NASA's scientific endeavor, a major part of the agency's science portfolio, and the result not only of impressive engineering but also of careful management and effective planning.”¹

“[Extended mission] discoveries have been critically important to shaping future exploration to achieve the highest priorities of NASA PSD.”¹

These two quotes provide powerful summaries of the benefits of extended missions. The science that has been accomplished by extended missions is indisputable and extensive – far more

Fig. 1: Cumulative number of papers produced by teams of two example missions over time, indicating the enormous scientific productivity of extended missions after Prime Mission end (black vertical line).

than could be covered in this white paper. The 2016 report does a thorough job of providing specific examples and describing the many positive aspects of extended missions to science and recommends that “NASA’s Science Mission Directorate (SMD) policy documents should formally articulate the intent to maximize science return by operating spacecraft beyond their prime mission, provided that the spacecraft are capable of producing valuable science data and funding can be identified within the SMD budget.”¹

Extended science missions are valuable assets in NASA’s portfolio because they provide excellent science at low incremental cost. Continuity, long-baseline data sets, and statistically significant observations of infrequent events require continued measurement over years or decades and are best provided through missions in extended phase. Extended missions may accomplish surprising new results via new destinations, observation types, or data analysis methods. NASA’s extended missions are an important part of both achieving science objectives of the decadal surveys and determining priorities or approaches for future exploration. NASA’s extended science missions constitute approximately 75% of the missions in flight by count, but cost a relatively small percentage of the overall SMD budget, on average 12% over the period 2010 to 2016. Eliminating all of the current extended missions would: only increase the funds available for new development by approximately 25%, not enough to start a new large mission; while making it difficult or impossible to achieve many decadal survey science objectives, and adversely and significantly impact SMD’s overall science return. Continuing active missions is an extremely cost-effective approach for addressing new science opportunities and training the workforce.

Fig. 2: Relative lengths of example prime and extended missions. Percent of time spent in extended mission is shown.

Workforce and Diversity Benefits of Extended Missions

Extended missions offer an important career pipeline in the Planetary Science workforce.¹ They provide excellent opportunities for early-career scientists and engineers to participate in active mission operations and scientific research, including project leadership roles, where they can learn about systems engineering, instrumentation, and the “soft skills” of team building and project

management. All of these experiences help create a diverse, well-trained workforce for future new missions and instruments as well as general development of the Science, Technology, Engineering, and Mathematics (STEM) workforce in the United States. The length of extended missions allows for new team members to concurrently grow in their professional development and mission contributions, from undergraduate and graduate students, postdoctoral researchers, to new Co-Investigators that are added as time goes on. Operations, science planning, and organizational roles can also often be opened up to more junior team members in extended missions (e.g., science working group chairs, Strategic and Tactical planners, and Uplink and Downlink leads). Primary missions often do not allow for this turnover because more-experienced personnel are needed to ensure requirements are met. As senior leadership retires or moves on to other projects, their succession planning often involves deputies that are more junior members of the community. Participation in these roles trains the next generation to be future scientists and leaders in the field. These opportunities would disappear if there were no extended missions.

*“The predictability of data sources and operations, particularly with respect to the timeline for completing thesis research”*¹ in extended missions is arguably even better for graduate student involvement than prime missions which have a chance of failure or delay. Extended missions allow new team members to build momentum in their research and capitalize on their expertise, ideally taking a central role in achieving the mission outcomes. Through interaction with experienced mission team members, graduate students are exposed to the practical applications of mission and instrument operations which often differ from the idealized, theoretical concepts on which they are based. This hands-on experience serves to enrich and supplement their knowledge base. Longer missions provide more stability and allow greater progress scientifically and greater career progression. This type of stability greatly increases the expertise base and feeds into future missions. Extended missions may also provide another avenue by which graduate students can be retained in the field of planetary science. By offering a non-traditional alternative to the typical academic path, extended missions promote a robust and diverse future workforce by hiring and keeping these enthusiastic minds within the field. Those who work on extended missions should be lauded for training and bolstering the next generation while achieving groundbreaking science on a reduced budget.

Extended missions can present excellent opportunities to advance the career pipeline, but continued budget cuts (or just slow erosion from inflation) can make this very difficult. When a team has been reduced to the bare minimum needed for the spacecraft to function, there are few opportunities for scientists at any career stage. The small extended mission budgets and the short Phase F duration may even be too tight to allow the publication of results, and it is almost systematically the case that those mission scientists end up finishing data analyses and their publication on their own time.

Adding early career professionals increases the diversity of teams^{2,3}, which in turn improves the quality of science being done, including fostering creative problem solving and kindling innovative ideas^{2,4}. This combination of practiced experience with fresh new thoughts is extremely beneficial to the continued success of extended missions, which often require team members to adapt quickly and creatively to new issues while being bound to the confines of the original mission and limited resources.

Decadal Recommendations

We request that the Decadal Survey Committee strongly consider further evaluation of the following topics and incorporate these recommendations into the Decadal Survey. They are numbered

for reference only, and are not meant to imply a particular ranking.

Recommendation #1: The Decadal Survey should highlight the value of Extended Missions.

*“Extended missions have been mentioned in a number of decadal survey reports. However, their value has rarely been explicitly highlighted in these reports.”*¹ The last Decadal Survey (2011) based their recommendations on the assumption that all missions in flight would continue to be adequately funded including *“extended missions that afford rich new science return”*⁵ (pp. 12 and 257). The committee did agree that extended missions can *“be significant and highly productive.”* and recommended that *“early planning be done to provide adequate funding of mission extensions”*⁵ (pp. 14 and 264). This Decadal Survey should strongly reinforce support for extended missions and consider these recommendations for improving the program.

Recommendation #2: The Decadal Survey should instruct NASA to evaluate and respond to the recommendations in the 2016 National Academies Report, the Suggested Process Improvements from the 2019 Senior Review Process Report, and those from this white paper.

The National Academies Report made sixteen recommendations regarding NASA’s approach to extended missions¹. Several of these have been acted upon – for example, the change in review cadence from two to three years – which we endorse. However, many of the recommendations have not resulted in any discernible changes. Four years on, there has been no formal evaluation of how NASA is performing with respect to those recommendations, nor articulated plans made for addressing those recommendations that have not yet been followed. In fact, funding for extended missions continues to be cut with each budget cycle. While we do not have space to discuss them all, most of the outstanding recommendations are still valid, and should continue to be pursued. Furthermore, a recent report provided a set of specific Suggested Process Improvements on the Senior Review Process⁶, which should be carried out by NASA for the Senior Review Process.

Recommendation #3: During the lifetime of an approved extended mission, the budget should be consistent with their new science goals and maintained as long as the funds are appropriated.

*“Experience and knowledge gained during the prime phase frequently result in lower costs for extended mission operations, but occasionally there may be counteracting effects that can create upward pressure on operational costs. After the first few years of extended operations, most missions have implemented all (or almost all) practical steps to reduce operational costs. Further budget cuts often then result in disproportionate cuts to project-funded science activities, increasing risks that science will be diminished or not performed at all.”*¹

If a proposal passes a senior review, and gets budget approval for its extended mission, ideally NASA should commit to the proposed budget for the duration of that extended mission. Reducing the budget of an extended mission across the extended mission duration can significantly disrupt mission operations. Maintaining a constant budget is not always possible, as NASA’s own budget fluctuates from year to year, but budgets for the selected extended missions should be placed in the budget plan that NASA submits to the White House and should be part of the President’s budget. Unexpected and unplanned-for budget fluctuations (to-date, as much as 20%⁷) result in mission teams having to spend even more time and effort reformulating their activity plans and can greatly impact the efficacy of extended missions, which are typically already on very tight budgets. Furthermore, when these mid-term budget restrictions arrive, they seem to have no rela-

tion to the scores and outcomes of the Senior Review, and without full explanation and transparency can appear arbitrary. Historically, these mid-stream funding revisions are generally due to new missions needing extra funds during development phases C-D, and so the budgets of extended missions are raided for funds. Yet this activity is fundamentally similar to not funding the extended mission at all in favor of new missions—the perils, pitfalls, and impacts of which are detailed in the National Academies Report¹. As extended missions already operate on tight budgets, the impacts of their funding reduction are typically much more severe than the benefits seen by the recipients of these funds.

This topic of extended mission budget stability was not addressed by the National Academies Report¹, but it recommends that “*NASA should strongly support a robust portfolio of extended-phase science missions. This support should include advance planning and sufficient funding to optimize the scientific return from continued operation of the missions*”¹, and “*NASA should continue anticipating that missions are likely to be extended and identify funding for extended missions in the longer-term budget projections,*” emphasis added.

Recommendation #4: Explicitly reserve a set amount, 15%, of the PSD budget for extended missions.

The National Academies Report¹ recommended that “*NASA should continue to provide resources required to promote a balanced portfolio, including a vibrant program of extended missions*”¹. The amount we recommend is in line with the proportion of PSD budgets in recent years for extended missions, so it does not represent an increase, merely assurance of stability for future budgets. Reserving a set fraction of the budget would help protect the budgets of extended missions from being redirected for other purposes. This would, in turn, maintain the relative proportions of new and extended missions, supporting the finding of the 2016 study that the then-current proportions of prime and extended missions represented a good programmatic balance.

Recommendation #5: NASA should ensure that both operations and science for extended missions after the first two Senior Reviews should be funded at constant levels, taking inflation into account.

We echo the National Academies Report recommendation¹: “*Given the demonstrated science return from extended missions, NASA should continue to recognize their scientific importance and, subject to assessments and recommendations from the Senior Reviews, ensure that, after the first two Senior Reviews, both operations and science for high-performing missions are funded at roughly constant levels, including adjustments for inflation.*”¹

Missions in their prime and extended missions with healthy science budgets produce scientific output. Often when faced with reduced budgets, mission teams are forced to prioritize data acquisition over science activities, which include science-informed planning, data product creation, and scientific analysis. While this might preserve the ability to return raw data, it can also erode the scientific quality of those data, reduce the impact and efficacy of the extended mission funding, and increase risk as personnel are stretched thin to deal with spacecraft and instrument anomalies. Furthermore, at least in the case of missions with short extended mission duration (e.g., Discovery-class missions), there is little money or time during Phase E to publish the extended mission results. The burden placed on teams to continuously write short-term extended mission proposals likewise detracts from their science output. Inflation needs to be accounted for because even holding the same dollar amount without adjusting for inflation results in significant real cuts over time (~30% over 10 years, in the case of some long-lived Mars missions).

“Extended missions often experience additional cuts to their budgets at subsequent Senior Reviews, which along with inflation, often result in disproportionate cuts to project-funded science activities. This is because mission management normally prefers to limit increased risk and, therefore, attempts to minimize cuts to the operations budgets. In turn, mission science teams then seek support from research and analysis programs. However, those programs are also under increasing funding pressure, which means that all-too-frequently science is diminished or sometimes not performed at all.”¹

Recommendation #6: NASA should consider augmenting planetary science extended missions budgets with appropriate funding from other directorates when their activities support that directorate, or when programmatic duties are required.

Extended missions not only provide a scientific bounty, they also provide critical reconnaissance and programmatic support. Many planetary science extended missions provide critical information to plan future robotic missions that directly support objectives of the Human Exploration and Operations (HEO) Directorate. Even now, the agency is preparing for human landings on the Moon and Mars, and requests from HEO to step up observations and activities are arriving as unfunded mandates on extended missions operated by the Planetary Sciences Division. All the data relayed from the surface of Mars is provided by orbiters in their extended missions. These spacecraft are therefore mission-critical to new missions, yet are asked to maintain this capability with declining funds. NASA should pay in full, from the appropriate budgets, for the programmatic duties these spacecraft perform.

Recommendation #7: NASA should include consideration of opportunities for new and diverse perspectives in an extended mission proposal as merit criterion.

New and diverse scientists can bring valuable new perspectives to ongoing missions of all durations, and this is even more acute for longer-lived missions. Many of these benefits are described in terms of a participating scientist program below, and while that recommendation is about bringing new individuals onto the team, this recommendation addresses what to do with them, and how to provide opportunities for internal growth and change. Having the team think about broader ways that they would support, encourage, and utilize new members of their team has value. This is not necessarily just about adding new scientists, which is near-impossible given budget cuts, but could be about taking advantage of natural attrition to provide leadership opportunities to different members of the team, planning for succession, bringing in interns, graduate students or post-docs, performing education and outreach activities, or a host of other activities. Extended missions are excellent opportunities for more inexperienced team members to gain critical new skills that will train them for more prominent roles in future missions. Other white papers submitted to this Decadal Survey provide more specific recommendations along these lines, for example making funding to missions dependent on demonstrated progress related to diversity, inclusion and equity⁴. Although the senior review directives include evaluation of early-career opportunities, budget cuts make that implementation very difficult to accomplish.

Recommendation #8: Given adequate time and resources, NASA should issue a participating scientist opportunity for all extended missions.

Participating Scientist programs provide new and diverse perspectives on mission priorities, scientific analysis, and science planning. Competitive calls such as these, which are open to the entire community, are preferred to avoid homophily and cronyism, and to increase participation

by underrepresented minorities. Demonstrating that point, missions with multiple Participating Scientist programs in extended missions were the only ones that substantially increased the proportion of women on their teams³. Data analysis programs alone, while immensely important for our field⁸, do not provide opportunities for scientific participation in active missions. Previous work^{2,9} lays out an excellent case for Participating Scientist programs: *“Adding PSs for extended missions can have the benefit of expanding the mission team far beyond its original constituents, and can bring in earlier-career researchers who may not have even been in the field when the mission was selected. These PSs can also bring in new and occasionally crucial ideas, especially if science results regarding a mission target have continued to be published after a mission was designed. Although PSs added during the later stages of a mission may have fewer opportunities to get involved in mission design or operations, they can still bring tremendous value to the mission science return, and can still benefit from being part of a mission team.”*²

Recommendation #9: The composition of the Senior Review panel is critical to positive, meaningful outcomes, and we ask NASA to revisit their approach following the National Academies Report recommendations.

*“NASA’s Science Mission Directorate should assemble Senior Review panels that (1) are comprised primarily of senior scientists knowledgeable about and experienced in mission operations so as to ensure that the operational context of the science being proposed and evaluated is considered in the review...; (2) are assembled early to avoid or accommodate conflicts of interest, and ensure availability of appropriate expertise; (3) Include some continuity of membership from the preceding Senior Review to reap advantage of corporate memory; and (4) Include some early-career members to introduce new and important perspectives and enable them.”*¹

The most recent suggested Senior Review process improvements⁶ also repeat these recommendations, indicating that they may still not be part of current practice. Furthermore, given the often-small pool of relevant expertise, some level of conflict of interest may need to be accepted and managed to provide the right information to the panel, just as some level of risk is acceptable when we fly missions.

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