Ideas on the NASA Senior Review and Mission Extension Process

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Synopsis

Extended mission budgets fund a significant part of our community, particularly young scientists who in a relatively short time are exposed to a broad range of experiences and opportunities available in space science and other STEM fields. In particular, mission-funded science offers a relatively stable funding stream that enables meaningful mentoring efforts and interactions, including apprenticeships ranging from project management, to mission operations, to data processing and analysis, to hardware and software development, to STEM-related education and outreach. It moreover provides professional contacts that fuel diversity in mission leadership and in the science and technical workforce at-large. Last but not least, it sustains the scientific productivity of NASA's missions, which constitute major national investments meriting their full exploitation. Budgets cuts, however, are exercising pressure on the science and operations of the extended mission fleet despite being only a small portion of the overall Division budget.

The history of Heliophysics has demonstrated that maintaining the operation of missions beyond their prime phase invariably leads to a much deeper knowledge of the original mission science goals, together with new applications often not foreseen during their original design. Their operation as part of the Heliophysics System Observatory (HSO)---a coordinated, 1eliophysics, multipoint observing system of the heliosphere, is a prime example. Some of the first activities undertaken by the Parker Solar Probe and Solar Orbiter missions required recreating the larger context of their new observations by using the diversity of HSO mission capabilities. The marginal cost of maintaining this valuable, working science resource, in the form of both continuing high quality data access and expertise, is small compared to the cost of the original missions or of new missions to achieve similar objectives, making the operation of extended missions, the best "science per dollar" investment in Heliophysics.

We argue that reducing both extended mission operations and science budgets will have a ripple effect across the community, including reducing employment and training opportunities for young scientists, to lowering the quality/impact of the Heliophysics Systems Observatory. Instead, we suggest that the proposal process for mission extension should be re-examined. We offer several ideas for reducing costs of extended missions toward maintaining science output and streamlining the management process

Background

Heliophysics missions tend to last much longer than their designed lifetime and, more importantly, without loss of science value for the community. The necessity of designing to the rigors of launch and "infant mortality" enables the longevity for most missions. Wind, for example, is celebrating its 28th anniversary this November. It continues to be highly productive scientifically (>300 publications annually; ongoing development and release of new datasets). In fact, 13 missions subject to the Senior Review process in 2020 received high marks on their science contributions (details in the 2020 Senior Review of the Heliophysics Operating Missions).

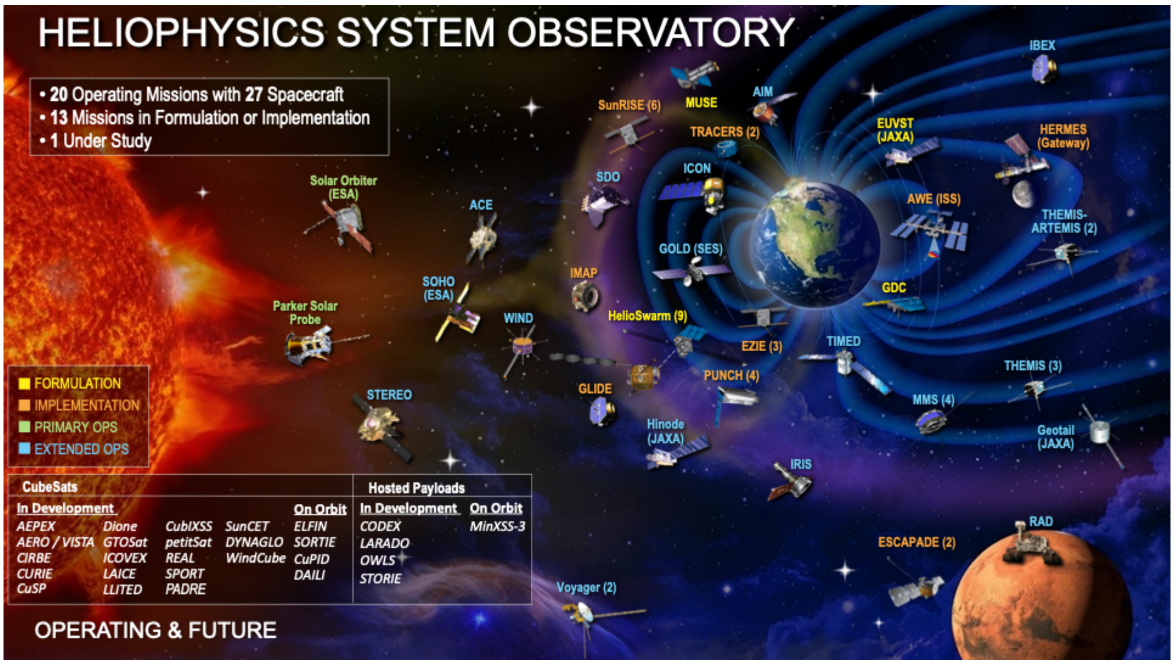

Figure 1 The current status of the Heliophysics System Observatory (credit: NASA Fleet Chart)

As more missions enter the Senior Review process, the pressures on the long-term operating budget naturally increase. Per the NASA presentation at the Decadal kickoff meeting on August 22, 2022 (slide 18) the cost of the missions in operation (Figure 1) is ~\$90M/yr (>12% of HPD FY22 budget). The cost is projected to increase to at least ~\$150M/yr by 2034, without including current missions. Whether the 2034 estimate represents a budgetary concern is difficult to assess at this point, given the uncertainty of long-term projections for HPD budgets. It does seem to be a sufficient concern for the Division, however, to issue the following charge to the committee:
"*NASA expects the Decadal Survey to fully discuss scientific and budgetary concerns for Heliophysics extended missions in its consideration of balance within the spaceflight mission programs. This includes but is not limited to 1) balancing extended operations with new starts for healthy, sustainable programs, 2) discussing points for programmatic consideration with regards to extended mission termination decisions, and 3) including clear expectations for extended missions in the budget recommendations*"

The aim of this WP is to restate the value of extended missions to the HPD research enterprise and to offer constructive suggestions to address the three points in the charge.

The Senior Review Process Now

Recent Senior Review (SR) calls offer a choice to the mission teams to propose an extension as either an ***infrastructure*** mission (funding only for operations and data curation; no funding for science investigations) or as a ***science*** mission (funding for both science operations and investigations). Without funding for science investigations, the team members in infrastructure missions have to invest time in writing proposals to seek funding from R&A programs. In addition, the science operations and data generation and curation are often conducted along with science investigations. It is the science investigation that pushes the development of new datasets and validation of the data products.

Concern: The science value of infrastructure missions may diminish rapidly if the teams do not have sufficient funding to maintain the quality of the data.

In the science mission case, the mission teams must propose focused science objectives, instead of goals, in a fashion similar to the regular R&A programs, such as HGI or HSR. This change was implemented with the 2020 SR to provide a straightforward way to review the performance of a mission. The progress on these science objectives becomes an evaluation criterion for the mission during the SR. This is a welcomed improvement in the SR process as it both focuses the teams' science plans and makes the review more concrete. On the other hand, it levies an implicit requirement on the SR cadence (nominally, 3-years).

Concern: *If a 3-yr (or more) cadence cannot be assured, it may have the adverse effect of teams shying away from the more novel or complex science in order to ensure a publication rate that constitutes a competitive Senior Review proposal.*

In the last nine years, for example, the STEREO mission Senior Reviews occurred in 2013, 2015, 2017, 2020, 2022 (under way), resulting in 5 SRs instead of 3. Beside the pressures on the team and the NASA review panels, the shortened SR cadence becomes particularly acute with the introduction of the focused science objectives in 2020. Ironically, recent significant increases in NASA-mandated reporting such as creation of Calibration and Measurement Algorithms Documents (CMADs) and more substantial Project Data Management Plans (PDMPs), including historical calibration information and software development documentation, on top of the individual contract and grant reporting by the instrument teams to the project management, detracts from the time and effort required to complete the research and publish the results. The realities of the new job market, including adjustments to post-pandemic workstyles and mobility, as well as revisions in hiring practices (e.g., involving Diversity, Equity, and Inclusion (DEI) concerns) in many institutions, have added further challenges. The community looks to the DS and NASA to enable the extended mission enterprise by reviewing the existing programs and requirements to ensure efficiency and maximum impact in utilizing any investments made.

The NASA/HPD charge on Extended Missions to the Decadal Survey Committee offers a great opportunity to rethink the process for mission extension, including revisiting the recommendations of the 2016 NAS report while taking into consideration the emerging space mission landscape (i.e., strong emphasis on smaller spacecraft, rideshares, lower cost for access to space, new data environments). We focus on a few concrete suggestions below.

Response to the Extended Missions Charge to the Decadal survey Committee

In the following, we group our suggestions as responses to the three tasks outlined in the Committee charge above:

1) balancing extended operations with new starts for healthy, sustainable programs;

a. **Curtailing extended operations will not improve mission cadence**. The balance between operating and new missions was extensively reviewed by the National Academies in 2016 (available online.) According to the report, 75% of NASA science missions operated on about 12% of the total science budget (across SMD) in 2016. The same percentage (12-13% of the FY22 budget) holds for the HPD now and there is no obvious reason to expect a much higher percentage in 2034. While the NASA report concluded that currently operating missions represent an *excellent return for money* it also examined the 'buying power' of cancelling all extended missions for new missions. As Figure 2 shows, the cancellation of ALL 18 operating HPD missions will provide for only one new MIDEX every 4-5 years or two new SMEX every 3 years and a flagship mission, like PSP, every 19 years! This seems a trifling increase in mission cadence for the extreme loss of science, as the HSO will cease to exist. ***Therefore, any savings from reducing operating budgets, or even terminating missions, will be vastly inadequate for increasing mission cadence. Only an HPD budget increase can lead to more missions***. The optimum return on the nation's investment in these space assets requires a balanced program of new initiatives and the effective utilization of the existing productive spacecraft in low-cost extended operation. Use of existing assets will ultimately minimize the cost of the overall program, even though periodically it may delay or slow a new initiative.

TABLE 4.1 Approximate Buying Power Resulting from Cancelling All Extended Phase Science Missions per Division

Division	Total Budget for Fiscal Year 2016 ($millions)[a]	Approximate Savings ($milions) If All Extended Missions Are Eliminated	Equivalent Number of New Small Science Missions per Year[b]	Equivalent Number of New Large Science Missions per Year[c]
Astrophysics	768 (+JWST: 620)	214	~ 0.6 MIDEX	~ 1/10 flagship mission
Earth Science	1,921	180	~ 0.4 ESS Pathfinder[d]	~1/12 flagship mission
Heliophysics	640	78	~ 0.2 MIDEX ~ 0.4 SMEX	~1/19 flagship mission[e]
Planetary Science	1,628	216	~ 0.4 Discovery missions	~ 1/10 flagship mission

Figure 2 The 'Buying Power' of Extended Missions across SMD (source: Table 4.1 from NAS 2016 Report on Mission Extension and the Senior Review Process)

b. **Reformulate the HSO as a 'mission line'** with its own timeline and budget profile. It should be funded under an HPD budget wedge (similar to DRIVE initiative, for example). Missions in extended phase would automatically be added to the HSO 'line'. Proposed missions or missions in development would then be required to provide Extended Phase-E estimates updated at each KDP. This organization should allow HPD to compile more accurate long-term budget projections. Consolidating all extended missions under one tab should streamline the management of resources and may even help identify areas for cost savings (see detailed suggestions below).

2) *discussing points for programmatic consideration with regards to extended mission termination decisions*

a. **Demonstrate tight integration to the HSO**. Support to HSO could be used as a guide for mission termination. Some possible metrics for HSO relevance could be:

- *Science objectives tightly aligned to HSO (systems) science*. Such objectives will likely be a bit more complex to define and achieve since they will have to take into consideration mission operations from other assets and requires considerable care in coordination. It seems that a 3-yr SR cadence might be too short to demonstrate sufficient progress. A way forward might be the decoupling of the technical performance (e.g., spacecraft and payload health, data curation) from the scientific performance reviews. For example, the instrument technical aspects could be added to the usual yearly one-day spacecraft review and a 4-yr SR could be called to review the scientific progress of science missions.
- *Useful synoptic data.* A broad range of synoptic data types are the backbone data product for many HSO studies. To maximize their utility, synoptic programs should be optimized from the HSO's, rather than an instrument's, perspective. For example, the times of image acquisition or cadence or wavelength order, etc. from a given telescope may be of more use if they coincide or overlap, as the case may be, with data from other missions. The formation of an HSO-wide coordination group comprised of the respective Operation Scientists may be necessary for defining the synoptic programs. Once those are set, the group does not have to meet regularly.
- *Easy coordination for observing campaigns.* The same group could act as a central hub for coordinating campaigns (e.g., for Parker Solar Probe or Solar Orbiter perihelia).
- *Low barriers for data exploration to all users.* Ensuring uniform data standards and compliance with the various data curation efforts (e.g., Pangeo, SPASE, etc.) should be an exit success criterion for Senior Reviews and a requirement during the development phase for future missions. Important for older missions to have funds and staff for any required updates in data formats/standards.

3) *including clear expectations for extended missions in the budget recommendation*

a. **Reduce spacecraft operation costs**. Mission teams have been quite innovative in reducing the complexity of spacecraft operations, especially for older missions where the synoptic programs and data products have matured. Much of those savings come from adopting a more synoptic[1] posture, thereby reducing spacecraft maneuvers or special programs (e.g., high cadence programs). New operational programs are not run – only programs that have been run before are permitted. However, operations costs vary considerably across HPD missions without an obvious scaling with number of instruments or spacecraft operations complexity. It seems that further cost savings may be attainable. Such savings could be accomplished by
   - *consolidating MOCs into a smaller number of centers.* A centralized MOC may be possible. These centers could be competed or directed, depending on security or operational concerns. The need for redundancy should be folded in.
   - *NASA could consider public-private partnerships* with industry, whereby a commercial entity handles the spacecraft operations and NASA only 'pays' for the telemetry. Universities or other non-governmental organizations may also offer low-cost alternatives. This may be possible only with near Earth operations. A cost-benefit analysis is likely required to see if such a model would reduce the HSO operating costs.
   - *Efficient use of ground-based infrastructure*. It is widely acknowledged that the deep space network (DSN) is oversubscribed. As a result, scheduling is complex and must be done in advance, thus complicating mission operations and coordinating campaigns. An improved DSN will reduce operational complexity and should reduce costs across NASA and mission teams. The operations costs of the SDO mission are driven by the need to maintain its dedicated ground station. Leveraging this asset by other missions (current or future ones) should reduce costs while likely increasing science return. Ground infrastructure expansion (and/or leveraging) may be supported by private sector investment with proper incentives, such as 'data-buys'.

b. **Optimize science operations costs**. Any limited benefit from severely reducing instrument team budgets is detrimentally countered by removing the people with the experience AND motivation to ensure high quality data and to improve them as the scientific landscape changes. Team performance on these aspects could be reassessed as time goes by; for example, in each Senior Review round the science teams should
   - *provide (or reaffirm) a Succession Plan* outlining their plans for transferring knowledge as older team members retire or change responsibilities. NASA has started requiring such plans and the process should be expanded and streamlined. Ideally, the plan will go beyond the replacement of the PI/instrument lead and will have a strong mentoring component providing younger scientists with SOC

[1] We use the term 'synoptic' here to refer to long-term datasets taken with the same observing parameters, i.e., cadence, wavelength, exposure, etc

experience. There should be a funding avenue, for infrastructure missions, in particular, to hire earlier career people and train them on instrument operations. This option would also allow those missions to keep their data formats current (see below).

- *Provide or renew the plan for data curation and improvements* with easily accessible data portals, new products, and software upgrades. The plan should strive to ensure that the instrument data are easily accessible and are needed (and used) by the community.
- *Consolidate Science Operations Centers (SOCs)*. Admittedly, this is not a straightforward task under the current model. Much of the SOC structure is instrument-specific and relies on the experience of the instrument team to function efficiently. Outsourcing of the SOC is a rare occurrence. Some SOC functions could be consolidated in principle, such as telemetry unpacking and L0-L2 data processing. However, observation planning, trending and calibrations, and certainly any special events, will require inputs from the individual teams. Only teams with experiments in several missions have consolidated SOCs in their institutions. We believe that SOC consolidation *across institutions* may provide higher cost savings and enhance the uptake of data products by the community. The task could possibly be made easier *if a plan for SOC standardization was inserted as a requirement during the mission design phase*. A dedicated study is likely required for more informed recommendations.

c. **Provide For Contingency Operations**. As part of the reduced complexity, there will be times such as an instrument anomaly when the Team expertise is needed to help diagnose the anomaly and/or write new operational procedures. This requires both apprentice training and retention of experienced team members as advisors where practical. 'Lessons learned' from experiences throughout the mission, and with similar instruments and systems, can also be made more accessible and routinely consulted.