Senior Review 2013 of the Mission Operations and Data Analysis Program for the Heliophysics Extended Missions

June 13, 2013

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Science Mission Directorate

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Overview

1.1 Introduction

NASA's Science Mission Directorate (SMD) periodically conducts comparative reviews of Mission Operations and Data Analysis (MO&DA) programs to maximize the scientific return from these programs within finite resources. The acronym MO&DA encompasses operating missions, data analysis from current and past missions, and supporting science data processing and archive centers. NASA uses the findings from these comparative reviews to define an implementation strategy and give programmatic direction and budgetary guidelines to the missions and projects concerned for the next 5 fiscal years (matching the Federal government's budget planning cycle).

Additionally, from the NASA Authorization Act of 2005 (Public Law 109-155), Section 304(a): "The Administrator shall carry out biennial reviews within each of the Science divisions to assess the cost and benefits of extending the date of the termination of data collection for those missions that have exceeded their planned mission lifetime."

The 2013 Heliophysics MO&DA review, referred to as the Senior Review, was conducted in March through June of 2013. The Senior Review considered the comparative scientific merit of the various flight programs comprising the Heliophysics System Observatory (HSO) along with the data analysis and archiving programs. The review compared expected scientific returns and contributions to the system observatory relative to program costs under the pressure of reduced resources for the MO&DA program. A set of findings consistent with the 2010 SMD Science Plan and 2012 Decadal Strategy for Solar and Space Physics was developed by the Senior Review panel to help prioritize the resources of the MO&DA program for FY14 and FY15 along with forward-looking findings for FY16-18. This report presents the findings of the 2013 Senior Review.

1.2 Missions Considered

The Senior Review of the Heliophysics MO&DA program considered the fourteen missions listed in Table 1-1. Of these missions, only the Interstellar Boundary Explorer (IBEX) is undergoing its first Senior Review.

At the time of the 2010 Senior Review, the THEMIS mission had bifurcated into the Time History of Events and Macroscale Interactions during Substorms (THEMIS) and the Acceleration, Reconection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun (ARTEMIS) (relocating two of the THEMIS spacecraft to lunar orbit). All five spacecraft of the original THEMIS mission are considered as a single mission for the 2013 Senior Review, even though two remain in lunar orbit. The THEMIS extended mission proposal utilizes the two spacecraft in lunar orbit to achieve the science goals of the THEMIS extended mission and no longer distinguishes an ARTEMIS project.

Table 1-1. Missions considered by the 2013 Senior Review of the Heliophysics MO&DA program.

Mission	Program	Launch Date	Age (years)	Mission Stage
ACE	MIDEX	27 Aug 1997	15.8	Extended
AIM	SMEX	25 Apr 2007	6.1	Extended
CINDI	MoO	16 Apr 2008	5.1	Extended
Cluster	ESA/NASA	16 Jul 2000	12.9	Extended
Hinode	JAXA/NASA	23 Sep 2006	6.7	Extended
IBEX	SMEX	19 Oct 2008	4.6	1^{st} Review
RHESSI	SMEX	5 Feb 2002	11.3	Extended
SOHO	ESA/NASA	5 Dec 1995	17.5	Extended
STEREO	STP	25 Oct 2006	6.6	Extended
THEMIS	MIDEX	17 Feb 2007	6.3	Extended
TIMED	STP	7 Dec 2001	11.5	Extended
TWINS	MoO	13 Mar 2008	5.2	Extended
Voyager	Voyager	20 Aug 1977	35.7	Extended
Wind	ISTP	1 Nov 1994	18.6	Extended

1.3 Instructions to Senior Review Panel

1.3.1 Review Guidelines

The Senior Review panel was instructed by NASA Headquarters (HQ) to conduct the review in the following manner:

1. In the context of the research objectives and focus areas described in the SMD Science Plan, rank the scientific merits on the expected returns from the projects reviewed during the period FY14 through FY18. The scientific merits include relevance to the research objectives and focus areas, scientific impact, and promise of future scientific impact, as well as contributing to the system science of heliophysics. It is understood that predicting the science productivity of a mission over such a long period is speculative, but missions are asked to assume the status quo operationally; hence, the need for *Prioritized Science Goals* (PSGs) in the proposal should future mission operations diminish scientific return relative to the status quo.
2. Assess the cost efficiency, data availability and usability, and the vitality of the mission's science team as secondary evaluation criteria.
3. From the assessments above, provide findings on an implementation strategy for the MO&DA

portfolio for FY14 through FY18, based on the Extension Paradigm (described in the 2012 call for extended mission proposals), which could be one of the following:

- Continuation of projects as currently baselined;
- Continuation of projects with either enhancements or reductions to the current baseline;
- Project termination.

4. Provide an overall assessment of the strength and ability of the MO&DA portfolio to meet the expectations of the HSO from FY14 through FY18, as represented in the 2010 SMD Science Plan and in the context of the recent Heliophysics decadal survey.

The panel was not asked to evaluate or assess the current utility of real-time data for operational or commercial users. However, the relevance of ongoing or new science investigations that may transition from research to operation in the future is within the purview of the Senior Review.

1.3.2 Evaluation Criteria

The Mission Extension Paradigm gives priority to maintaining understanding of the instrument performance, monitoring progress toward accomplishing the objectives of science observations, and involving the science community in formulating the mission observing program to make the best scientific use of NASA's missions.

Extended mission proposals were required to discuss the mission's potential for advancing the state of the art of the science during the FY14 to FY18 timeframe in each of the following areas, which constitute criteria for continuation of an extended mission:

- Relevance to the stated Heliophysics research objectives and focus areas, both as individual missions with unique capabilities, and contributions to system science as a part of the ensemble which constitutes the HSO **[Prime]**;
- Spacecraft and instrument health and safety **[Prime]**;
- Productivity and vitality of the science team (e.g., published research, training younger scientists, etc.), as well as maintaining the continuity of the expertise in the calibration, validation, and archiving of individual instrument data sets **[Secondary]**;
- Promise of future impact and productivity (due to uniqueness of orbit and location, solar cycle phase, etc.) **[Prime]**;
- Impact of scientific results as evidenced by citations, press releases, etc. **[Prime]**; and
- Broad accessibility and usability of the data, with a self-assessment of the utility of the data produced both as a unique mission, and contribution to system science as a member of the HSO **[Prime]**.

Items marked as **Secondary** are secondary evaluation criteria after scientific merit (of **Prime** importance).

1.3.3 Methodology of the Senior Review Panel

Elements of the Senior Review began in November 2012 when the HQ Program Office issued a call for Extended Mission Proposals from the 14 missions under review at this time. Two documents, the

SMD Science Plan and the 2012 National Academy of Science's Heliophysics decadal report, "Solar and Space Physics: A Science for a Technological Society," were cited as important resources in guiding the science strategy of extended missions. Both documents incorporate the HSO as an integral element of the strategic implementation of the Heliophysics science discipline. The Senior Review panel was instructed to use both documents in evaluating extended mission proposals.

The proposals contained a science and science implementation section, technical and budget sections, a mission archive plan, and an intended E/PO Plan. The Senior Review panel was instructed at the Panel meeting not to include E/PO considerations or related review material in its mission review.

Each extended mission proposal was also required to include a budget on a standard spreadsheet, with a "five-way breakdown" of the budget and a budget "guideline" provided by the MO&DA Program Office for each project. Labor, major equipment, and other expenses for the in-guideline budget were to be explained in sufficient detail to determine the incremental cost of each proposed task. Projects were also directed to separate the costs of obtaining, validating, calibrating, and archiving data from costs of completing scientific investigations with the data obtained.

Projects were advised that if the current budget guideline is insufficient, the project should identify the impact of the current budget on the mission, with emphasis on the science content. If the current budget guideline for the project for any of the years is zero, and it is proposed to carry on the investigations during that year, then the project was advised by the extended mission proposal guidelines to propose a minimum scenario to keep the mission viable. By identifying such a minimum acceptable funding level, the project is indicating that any lower funding level is untenable, and that the project should be terminated rather than be funded at a sub-minimal level. Three extended mission proposals contained over-guide budgets. These budget guidelines from the MO&DA Office for extended mission proposals informed the Senior Review's evaluations of those projects.

NASA HQ invited 13 members of the scientific community with expertise in solar, heliospheric, and geospace science to serve as the Senior Review panel. The extended mission proposals were available for review by panel members on March 12, and a lead reviewer for each proposal was as assigned at that time. The Senior Review panel met in person on April 23–26 in Washington, D.C., with all members present. During the Panel meeting, each mission made an oral presentation followed by an opportunity for the panel members to ask questions of clarification. Aaron Roberts presented an assessment of the Legacy Archive Plan for each mission to the Panel. The E/PO activities were evaluated separately by qualified reviewers; however, the summary E/PO report originally scheduled to be presented to the panel by C. Runyon was canceled because the MO&DA Program Office was directed to eliminate E/PO funds for each project, making the E/PO plan irrelevant at that time. The Panel assessed the scientific merit of each mission and considered the comparative costs. Teleconferences were held on May 22 and June 5 to finalize the panel findings and to review and refine this report.

2 Senior Review Panel Findings

2.1 Overview of Findings

For the 2010 Senior Review, mission teams were instructed to present budgets for only "minimal science" (i.e., no detailed analysis, data fitting, modeling, or interpretation). Second, the 2010 Senior Review panel was informed of the need to cut the prospective MO&DA "minimal science" budget from \$59.5M to \$54.7M in FY11 and from \$57.9M to \$51.8M in FY12. The need for these reductions led the Panel to undertake a line-by-line review of each mission's proposed budget, looking for instances where funding could be cut. This process necessarily involved the Panel's best judgments—generally on an instrument-by-instrument basis—as to the level of funding necessary for "minimal science."

For the 2013 Senior Review, the FY14 MO&DA budget for extended missions was set at $49.5M in February 2013 (sum total in-guide budget). However, by April 2013 the final budget for Heliophysics MO&DA was still uncertain at the time of the Panel meeting due to the federal budget sequestration that had been set in motion in March. The 2013 Senior Review did not follow the line-by-line budget review process of the 2010 Senior Review, in part because it became apparent in the mission presentations that projects used different methods for accumulating costs in "Science Operations Functions" and "Science Data Analysis/Guest Observer Funding," which made uniform budget comparisons well-nigh impossible (cf. Sec. 2.5.2, Senior Review Process finding on "five-way" Budget Breakdown for Science).

All but three extended missions—the Coupled Ion-Neutral Dynamics Investigations (CINDI), Cluster, and the Solar and Heliospheric Observatory (SOHO)—exactly met the guideline budget provided by the MO&DA Program Office. Two missions—Hinode and the Solar Terrestrial Relations Observatory (STEREO)—that did meet the budget guidelines have significantly higher costs than any of the other missions. It is the opinion of the Panel that neither the submitted material nor the presentations provided sufficient budget justification for the Panel to reach a definitive determination of cost-to-scientific-value ratio for these missions.

The Panel commends NASA, in partnership with the Heliophysics community, for steadily eliminating missions that are obsolete, superseded by newer missions, or are not sufficiently functional to merit continuation. In line with these principles, the Panel finds that two older missions in this Senior Review (Cluster and SOHO) have a cost-to-scientific-value ratio that does not warrant continuation, at least not at the budgeted costs presented in the extended mission proposals.

The Senior Review panel would like to emphasize that it does not automatically consider mature missions—those well into their extended phase, with large datasets already in hand—as easy targets for cuts. Discoveries are not confined to the "prime phase" of missions: long-timescale phenomena can be illuminated only through long-baseline observations and changing orbits can open new regions for exploration. Voyager is especially noteworthy in this regard. Thus, the Senior Review panel found that the missions currently comprising the HSO are largely complementary, because each mission possesses unique instrumentation and/or orbit. Such a constellation of missions, decades in the making, is essential for measuring and understanding the immense range of scales and physical processes inherent to the heliosphere.

2.2 Implications for Heliophysics System Science

The next few years will be particularly illuminating for the Heliophysics Division's objective of "understanding the connected Sun-Earth System," as well as the Sun's impact on more distant regions of the Heliosphere, where robotic and human explorers may go in the future. With the HSO we can observe the Sun and its impacts on the heliosphere, geospace, and planetary magnetospheres as the unusual maximum of Solar Cycle 24 unfolds.

We will see how the heliosphere responds, from the upper boundary of Earth's atmosphere to the edge of interstellar space. This period is an unprecedented opportunity for fundamental discoveries that will point the way for space science in the 21st century. Taking advantage of this opportunity necessarily requires sampling this vast region of space at multiple locations and with an array of sensitive, robust instruments measuring a broad spectrum of physical quantities. The HSO, the product of careful planning, many years of effort, and billions of dollars in investment, is poised to make these breakthroughs.

Pursuing the full complement of opportunities for new system science nevertheless poses some risk for new mission-specific science. In a zero-sum funding environment for the Heliophysics Division, the benefits of an expanding HSO are realized at the peril of new mission opportunities. The Senior Review panel remained cognizant of this issue in its deliberations, while recognizing that much of the innovative science emerging from the Heliophysics Guest Investigator (GI), Supporting Research and Technology (SR&T), Theory, and Living with a Star (LWS)/Targeted Research and Technology (TR&T) programs is made possible by HSO datasets. The 2013 Senior Review panel believes that it is essential for NASA, in consultation with the Heliophysics community, to regularly examine the larger question of the budgetary balance between MO&DA (including extended missions), new missions, and system-science data analysis.

2.3 Broader Relevance within the Science Mission Directorate

The 2013 Senior Review revealed abundant evidence that Heliophysics extended missions are providing scientific value well beyond the realm of heliophysics. Measurements from the current constellation of extended missions support not only Heliophysics science objectives and the overarching goals of the SMD but also specific goals of the other three divisions within SMD.

Heliophysics extended missions focusing on the physics and chemistry of the upper atmosphere—Aeronomy of Ice in the Mesosphere (AIM) and the Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED)—are resolving the solar-terrestrial impacts on Earth's climate, which are larger than hitherto thought. The measurements provide a means of determining the impacts of energetic solar particles on the chemistry of the mesosphere and lower thermosphere, which affect stratospheric ozone and the circulation of the lower atmosphere. These results offer new insights into the sources of change in the Earth system, a primary science theme of NASA's Earth Science Division.

As the Voyager and IBEX extended missions explore the structure of the outer heliosphere and its boundary with the interstellar medium, their measurements are also characterizing properties of the local interstellar wind and its interaction with the heliosphere. IBEX measurements provided the first direct observations of interstellar hydrogen (H), oxygen (O), and neon (Ne), determined the motion of the Sun relative to the interstellar medium and yielded the unexpected discovery of a ribbon of Energetic Neutral Atom (ENA) emissions from an as yet unknown source. Voyager 1 is the most distant man-made object from Earth. It is expected to operate at least through 2020 and will provide humankind's first *in situ* measurements of the interstellar medium. The IBEX and Voyager extended missions are clearly on the leading edge of the SMD's "great journey of discovery."

The gamma ray bursts recorded by the Reuven Ramaty High Energy Solar Spectroscope Imager (RHESSI) and the Wind satellite provide comparison data for Astrophysics missions, with the Konus observations on Wind significantly enhancing the events collected by Swift, Fermi, and the Inter-Planetary Network (IPN). STEREO's detection of nanoparticles is of fundamental importance for astrophysical research, and its measurements are providing new understanding of the growth and destruction of dust in the inner heliosphere and its internal evolution, as well as optical properties. The Advanced Composition Explorer (ACE) observations have identified hot massive stars and their superbubbles as a class of astrophysical objects in which cosmic rays originate. NASA's Fermi large-area telescope now presents compelling evidence of freshly accelerated cosmic rays within the Cygnus-X superbubble, supporting ACE results. These discoveries by Heliophysics extended missions are helping us understand how the universe works, an overarching goal of the Astrophysics Division.

Measurements of the escape of atmospheric particles into interplanetary space facilitate understanding of the processes that control the rates of atmospheric loss and the importance of a planetary magnetic field in protecting the planet's atmosphere from the solar wind. Cluster satellite measurements have quantified mass-resolved ion escape rates from Earth. Comparative interactions of the solar wind with all the terrestrial planets, and with particular emphasis on atmospheric losses, is relevant to NASA's Planetary Science Division's goal to determine the characteristics of the solar system that lead to habitable environments. The Cluster measurements provide a quantitative benchmark for the Division's upcoming Mars Atmosphere and Volatile Evolution (MAVEN) mission, which will study ion and neutral losses from Mars and test whether these rates change during disturbances in solar activity and the solar wind.

Many of the Heliophysics extended missions have provided fundamental knowledge of the ubiquitous magnetic reconnection process that occurs in magnetized plasmas. Reconnection is invoked in theoretical models of astrophysical phenomena such as star-accretion disk interaction, pulsar wind acceleration, the heating of stellar coronas and the acceleration of stellar winds, and the acceleration of ultra-high-energy cosmic rays in active galactic nuclei (AGN) jets. Heliophysics missions provide the only means of directly measuring rates and properties of magnetic reconnection in stellar atmospheres (STEREO, Hinode, and ACE), in stellar ejecta and winds (ACE and Wind), and in planetary magnetospheres (Cluster, IBEX, and THEMIS).

2.4 Mission Grades

The comparative evaluation of the fourteen extended mission proposals has been summarized in two broad categories: 1) their overall scientific merit, and 2) their contribution to the HSO goals as described in the Recommended Roadmap for Science and Technology 2009–2030 (pages 46-49). Each proposal was graded by each individual panel member, reflecting upon the charge of Section 1.3, on a score from 1 to 10, using the following scale:

- 10–8 Future contributions promise to be compelling;
- 7–4 Future contributions are rated excellent, but less compelling;
- 3–0 Future contributions appear to be relatively modest.

The merged results of the scoring by the panel members are given graphically in Figure 2-1 for the first category, overall scientific merit, and in Figure 2-2 for the second category, Value to the HSO. To assess the degree of agreement among panelists, the standard deviation (STD) of the rank also is shown. Figure 2-2 makes clear that the panel found that all of the missions reviewed could be expected to make excellent contributions to the Heliophysics/SMD enterprise.

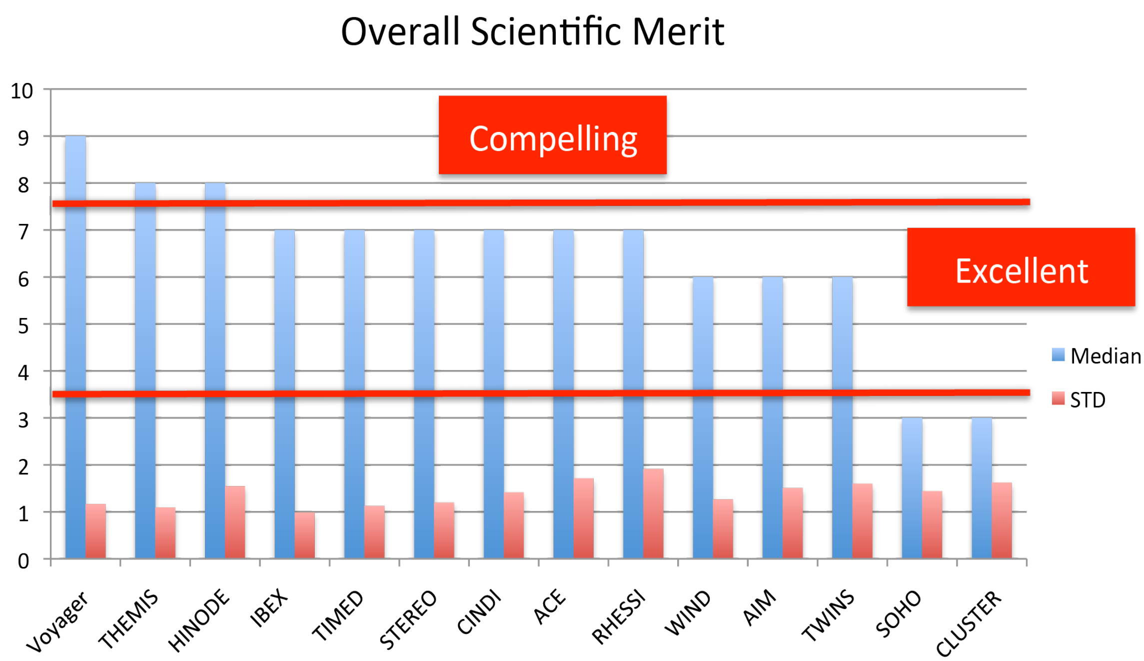


Figure 2-1. Senior Review panel rank of the overall scientific merit of the proposed extended missions

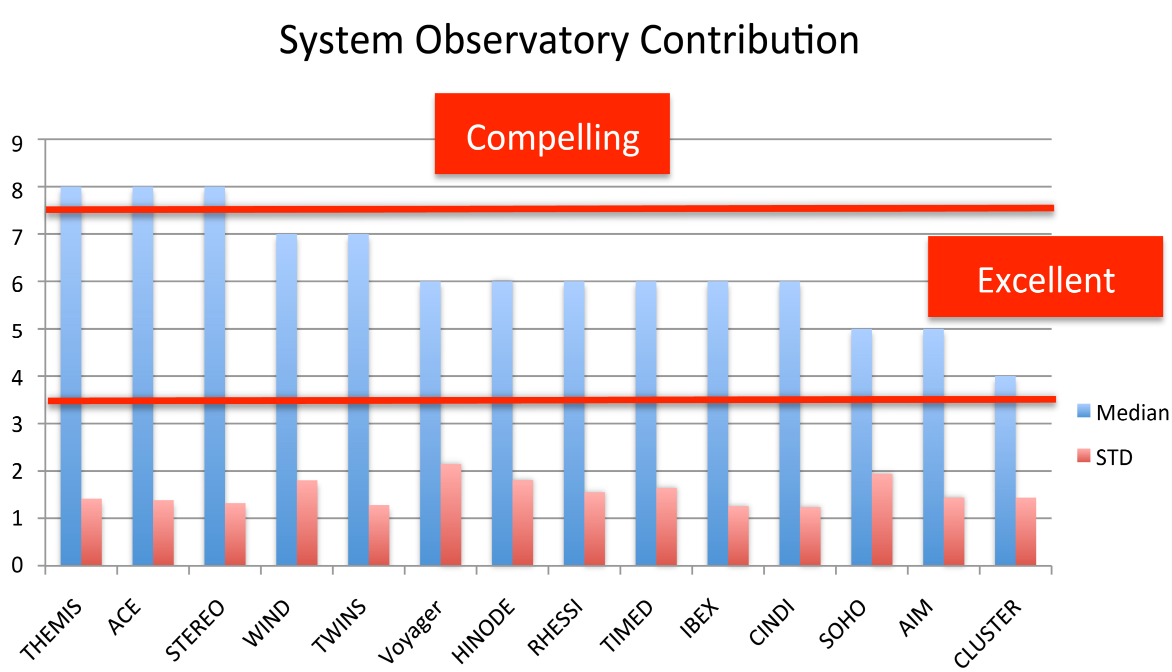


Figure 2-2. Senior Review panel rank of each mission's Value to the Heliophysics System Observatory

2.5 Major Findings

2.5.1 Mission-Specific Findings

The Senior Review panel developed the following specific findings concerning eight of the 14 extended missions evaluated by the Panel.

ACE and Wind

ACE and Wind are two well-instrumented satellites orbiting the L1 Lagrange point about 1.5 million km from Earth along the Sun-Earth line. Considering the limited resources available for supporting multiple, excellent heliospheric research missions, the Senior Review carefully evaluated the need for two missions at this one location. The Panel finds that both ACE and Wind continue to demonstrate their value through recent scientific accomplishments and have completed work enabling vital community science through the preparation and dissemination of their respective data streams. Furthermore, each mission has identified excellent future science opportunities. It is clear to the Panel that these missions conduct complementary research and are vital assets of the HSO. Wind hosts instrumentation making important measurements of kinetic process in the solar wind, and ACE is making crucial measurements of galactic cosmic rays over a broad range of elements, isotopes, ionic species, and energies. Furthermore, both missions can contribute to multipoint solar wind observations.

Cluster

The Senior Review panel finds that the Cluster extended mission proposal has notably worthy goals, but the failure of key instruments calls into question the ability of the mission to achieve its highest-priority goals. The fact that the ion Retarding Potential Analyzer (RPA)/Composition and Distribution Function (CODIF) instrument is operating on only one of four spacecraft means that four-point measurements of ion distributions, which have been a hallmark of Cluster science, cannot be realized in the proposed studies of ion-scale physics. The panel finds that the proposed level of funding in the extended mission is high given this reduced functionality. The objective to investigate the spatiotemporal properties of waves at mid-latitudes in the inner magnetosphere (with C3 and C4 at small separations), and their relation to observations of radiation belt particles and waves in conjunction with the Van Allen Probes, is achievable with the Wide Band Data (WBD) and (Research with Adaptive Particle Imaging Detectors (RAPID) Imaging Energetic particle Spectrometer (IES) instruments which are working on all spacecraft. Assuming the European Space Agency (ESA) continues to support Cluster operations beyond the current agreement with NASA extending through 2014, in the current reduced funding environment for MO&DA the panel recommends continued funding only for the U.S. Principal Investigator (PI)-led WBD instrument in the extended mission.

Hinode and STEREO

The Senior Review panel notes that the costs of the Hinode and STEREO extended missions are higher than all other missions. The panel found the submitted material and presentations to provide insufficient justification for the respective budget costs. This lack of information is a defect which increases the difficulty of making a fair and appropriate determination of scientific value of the proposals in light of cost, as well as a summary determination of the position of ranking within the review process. However, the presentation for STEREO included the information that about 40% of the budget was for scientific research and analysis, which is high when compared to other missions. In addition, the Hinode budget appears especially high to the Panel considering that international partners share most of the spacecraft operations and also share the responsibility, costs, and access to the instruments. The Panel recommends that the MO&DA office review the Hinode and STEREO proposed extended mission budgets and explore efficiencies.

SOHO

The Senior Review panel recognizes that the Large Angle and Spectrometric Coronagraph (LASCO) observations are operationally useful for the National Space Weather program, but it finds that the SOHO extended mission proposal does not provide sufficient justification for the high cost of operating the spacecraft relative to the proposed science return. Many of the proposed science goals can be accomplished using existing SOHO data and do not necessitate the new observations from the SOHO spacecraft. Some data (e.g., solar wind measurements) can be provided by instruments on other spacecraft. The proposed cross calibrations between the Solar Wind Anisotropies (SWAN) and the Probing of Hermean By Ultraviolet Spectroscopy (PHEBUS), and the Charge, Element, and Isotope Analysis System (CELIAS)/Solar EUV Monitor (SEM) and the Solar Dynamics Observatory (SDO)/Extreme Ultraviolet Variability Experiment (EVE) can be completed within the remaining (already funded) 1-year period.

The panel notes that this 2013 Senior Review recommendation is in agreement with the previous (2010) Senior Review, which recommended "…that SOHO be eliminated from the Heliophysics System Observatory starting in either 2013 or 2014."

Voyager

1. Voyager data availability

The Voyager spacecraft continue to make groundbreaking discoveries in the outer heliosphere at its interface with interstellar space. The unique nature of the Voyager measurements, from a region that is unlikely to be explored again for many decades, means that it is critical that the data be provided to the scientific community in a timely and useable manner. These data represent a unique scientific legacy for all humanity.

The Panel welcomed efforts by most teams to distribute data; however, while acknowledging challenges in calibrating these data, the Panel is concerned with the slow and patchy distribution of measurements by the magnetometer, and with data recorded several years ago still not available. The Panel is also concerned with plans to distribute only averaged data products; the non-reproducible nature of Voyager data means that all measurements must be made available for future analysis, which might even use methods not yet imagined.

The Panel urges NASA to work with the Voyager project and the Magnetometer (MAG) team so that:

- Science quality, calibrated MAG data of at least 48s average cadence be made freely available within 6 months of their receipt on the ground;
- Data that are published in scientific papers by the Voyager project be made freely available in calibrated form simultaneously with the publication of those papers; and
- A plan be developed to allow the routine public archiving of all returned data, in a Level-0 form, along with adequate documentation and, potentially, with software, to allow for calibration and analysis of the data after the end of the mission.

Given the critical and unique nature of these measurements, this effort should be a high priority. The Panel was surprised to find that similar findings from previous senior reviews have not yet been addressed.

2. The Deep Space Network (DSN)

The DSN provides 6–8 hours of downlink time per spacecraft per day for the Voyager Interstellar Mission (VIM). Because VIM does not store data onboard, this means large data gaps exist. The Voyagers have discovered boundaries of the heliosphere—e.g., the termination shock and "Heliocliff"—that are remarkably thin. The heliopause, perhaps the next boundary to be sampled, may also be thin. A lack of data during this, or any other, boundary crossing would be extremely unfortunate and would give an incomplete picture. The Senior Review panel finds it imperative that the downlink time allotted for VIM from the DSN not be reduced.

The Senior Review panel is concerned that key personnel on the VIM science team have retired and have not been replaced. The Senior Review panel finds it critical for the continued success of the VIM that there be an efficient continuity of mission operations and production of usable data for the scientific community.

THEMIS

1. The THEMIS extended mission concept to achieve cross-scale science goals is an innovative and exciting idea that the Senior Review enthusiastically supports. The proposed alignment of the three THEMIS inner probes with the Magnetospheric Multiscale (MMS) constellation to form a nested tetrahedron would enhance MMS science and provide magnetohydrodynamic (MHD)-scale context for MMS microscale measurements. This Prioritized Science Goal 1 of the new extended mission would enable true HSO studies using the Van Allen Probes, MMS, THEMIS (including the former Artemis pair in lunar orbit) and Wind/ACE. Reconfiguration of THEMIS spacecraft requires practically immediate planning to be successful, and the Panel encourages the THEMIS team to work with NASA and upcoming future missions to find a means of implementing it.
2. The Senior Review applauds the THEMIS team's exemplary science data plan, development of a community-wide data analysis suite that allows multiple missions and instrument teams to easily develop "plug in" components, providing community-wide training workshops to use the software, and for providing high quality data repositories with the necessary documentation and analysis tools for broad community use.

2.5.2 Findings on Program Process

Senior Review Process

A rigorous Senior Review process requires good preparation before the Panel meets in person and efficient organization and time management during the meeting. The Panel must read and understand the various reports (14 in this round), listen to presentations from each of the missions, prepare summaries for each of the mission proposals, develop, discuss, write, and vote on major findings, rank the missions, and generate the final report. It is clear that the greatest value for NASA and the science community comes from the discussions among the panel members that lead to findings. The discussion and consensus on findings for the 2013 Senior Review took most of the meeting time not allocated to presentations.

In the spirit of promoting best practices in the Senior Review process, leading to a Senior Review report of the highest quality, the 2013 Senior Review panel offers the following suggestions to future panels and the MO&DA Program Office.

1. A comparative summary of the budgets for the different missions should be prepared by NASA or their designee and distributed to the Senior Review panel before the Panel meeting. This information will facilitate the science-per-dollar analysis of the Panel and could be done in a form similar to the graphs presented in the 2013 Senior Report report (Sec. 4). The comparative summary charts should allow panelists to distinguish between Total Mission Costs, Science Operations Functions, and Science Data Analysis/Guest Observer Funding to understand where the mission falls in the progression toward the “minimum science” mission.
2. The Program Executive for Heliophysics Mission Operations, in consultation with discipline scientists and the Senior Review Chair, should make writing assignments to the Panel for the individual reviews at the time the proposals are distributed to panel members. A lead reviewer and writer should be assigned for each proposal and one secondary supporting reviewer. The leads of the individual review should prepare short paragraph summaries of the mission, the science questions to be addressed, and the mission and instrument Health and Status before the Panel convenes.
3. The Chair should work with the Panel to ensure that written summary evaluations on the individual proposals are completed and distributed to all panelists before the date of the Panel meeting. This writing should be focused on strengths and weaknesses of the proposals, followed by concise text describing the strengths or weaknesses noted at this point of the review.
4. During the Panel meetings the written strengths and weaknesses of a mission along with the comparative budget should be reviewed quickly just before the mission presentations. Questions for the science team could be informally developed. Allocate 15 minutes for this short internal discussion within the Panel before the presentation by the mission PI or science team.
5. Limit extended mission proposals to 30 pages. Encourage mission teams to include hyperlinks to relevant supplementary material in the proposal. Panelists found the easy access to such information helpful in finding additional details of the mission and science. Require the mission presenters to make their presentations available in either soft or hard copy to each panelist at the time of the presentation. The presentation provides useful reference material for developing the assessment of the proposal.

Progression from Prime to Minimum Science

The greater scientific community does not generally understand the nominal progression of a mission in the MO&DA program. The extended mission paradigm is to gradually move missions in funding levels from the prime mission to a "minimum science" mission over time. The minimum science mission consists of sufficient funding to calibrate, process, validate, and archive data such that they have the greatest possible value to the larger scientific community. It is expected that the mission will make these science operations processes as automated and efficient as possible. Even more important are the efforts of the program to appropriately reduce the mission operations costs in the extended phase. The Senior Review panel recommends that programs at the “minimum science mission” be allocated resources to implement a set of PSGs above the resources required to meet the archiving objectives. The extended mission projects in the MO&DA program are to be evaluated on the progress made on previous PSGs, as well as the scientific merits of the current PSGs in the proposal.

"Five-way" Budget Breakdown for Science

The "five-way" breakdown of the extended mission budget is essential to the Senior Review panel in understanding how resources are generally distributed within a mission. Missions in extended phase were asked to separate the costs of obtaining, validating, calibrating, and archiving data from costs of completing scientific investigations with the data obtained. The Panel reviewed the budget lines 3 and 4 for "Science Operations Functions" and "Science Data Analysis/Guest Observer Funding," and from this information tried to determine where the mission falls in the progression toward the "minimum science" mission. This distinction is important in setting the expectations for both past performance and potential scope and impact of the PSGs of the extended mission. The Panel found that the mission projects used a variety of methods in reporting these items for the 2013 review. Although the various costs accumulated in each category of the five-way budget breakdown will naturally vary from mission to mission, the project budget should nevertheless be structured to allow a consistent means of evaluating relative scientific value among missions and a determination of where the missions are in the progression toward a minimum science mission. To this end, the Panel encourages NASA to work with the extended mission projects in future senior reviews to ensure that the five-way budget breakdown is reported more uniformly across projects.

Guest Investigator Program

Separating the science data analysis tasks from the science operations tasks and placing funds for science data analysis in a program for open competition potentially places the ultimate scientific analysis of the data at risk. The "minimum mission" concept reallocates a significant part of the science analysis funds for the missions into a common pool, the GI program. The advantage is that these funds can be openly competed within the GI Program as administered by NASA. The disadvantage is that these funds are readily identified for easy removal from the MO&DA program, as was done with the GI program in FY10. The GI concept as part of MO&DA was developed as a suggestion to NASA through the senior review process a number of years ago.

This Senior Review panel was not asked to review the balance in science funded directly through extended missions relative to that of the GI program or to prioritize funding for the GI program relative to the extended missions. Indeed, given the issues raised above regarding the "Five-way" Budget Breakdown for Science, it would not have been possible with this review. Nevertheless, the Senior Review panel considers the GI program a high priority of the MO&DA Program and strongly supports the recommendation of the 2012 Decadal Survey that:

> "a directed guest investigator program ... should be established in order to maximize [mission] scientific return. Further, just as an instrument de-scoping would require an evaluation of impact on mission science goals, so, too, should the consequences of a reduction in mission-specific GI programs and Phase-E funding merit an equally stringent evaluation."

Future Senior Review panels would benefit from an up-front assessment from the MO&DA program office of the current and projected funding for science data analysis in the GI program relative to that in the proposed extended missions.

3 Extended Mission Assessments

3.1 ACE

3.1.1 Overview of the Science Plan

Since January of 1998, ACE has been in orbit around the L1 Lagrangian point, ~1.5 million km sunward of Earth. At this location it has made measurements of the elemental, isotopic, and ionic charge-state composition of energetic nuclei from solar wind to galactic cosmic ray energies. These observations have been used to enhance our understanding of the sources, composition and processes related to the solar wind, solar energetic particles (SEPs), and galactic and anomalous cosmic rays. In addition, continuous measurements of the background and disturbed solar wind, provided by solar wind plasma, energetic particles and magnetic field instruments on ACE, are crucial for space science, as well as for space weather.

The proposal highlights recent scientific accomplishments and five areas for exciting future work. These are: (1) solar particle acceleration and transport; (2) solar wind structure and processes; (3) global heliosphere and interstellar medium; (4) space environment and weather; and (5) the HSO. Of particular interest are accurate measurements of the properties the solar wind, suprathermal and energetic particles, and galactic cosmic rays during this unusual solar cycle.

3.1.2 Science Strengths

The ACE mission has had numerous scientific accomplishments during 2010–2012 and proposes an exciting list of high-priority science goals that can be addressed in the next several years. To carry out this work ACE makes impressive and unique measurements over an extensive range of solar wind to galactic cosmic ray energies. Among these it makes the most sensitive measurements of SEPs below ~1 MeV/nucleon and above ~ 10 MeV/nucleon range. Also, since ACE is closer to the Earth-Sun line than Wind, its solar wind magnetic field measurements more closely represent what actually impacts Earth's magnetosphere.

There are many examples of important science that can be carried out with ACE data during the next few years. New observations by ACE will be crucial for understanding changes in the solar corona as the recent and unusual solar cycle conditions (weak solar minimum and solar maximum) evolve. Research with these data will provide new insight into important questions, such as the maximum possible cosmic ray intensity at 1 AU at times like a Maunder minimum. In another example, the ACE background solar wind and cosmic ray measurements will be important for putting in context and understanding measurements made by the Voyager spacecraft as they depart the heliosphere. In addition, ACE will measure solar wind, SEPs and other solar wind features, especially as we might be entering once-in-a-century solar activity levels. ACE is well-suited to examine the production of SEPs by suprathermal seed population, and the wide separation of ACE and STEREO A and B can provide new understanding of processes producing longitudinally extended SEP events and their rapid distribution in the heliosphere.

3.1.3 Relevancy Strengths to Heliophysics Research Objectives

ACE contributes to the three broad Research Objectives for Heliophysics and all 12 Research Focus Areas within these research objectives. The Research Objectives are: Open the Frontier to Space Environment Prediction, Understand the Nature of our Home in Space, and Safeguard the Journey of Exploration. For each focus area, numerous publications are listed in the proposal authored by either ACE team members or by non-ACE authors using ACE data. The topics deal with both fundamental research problems such as magnetic reconnection, particle acceleration and magnetic dynamos, to predicting the propagation and evolution of solar disturbance and the onset of solar activity.

3.1.4 Value to the Heliophysics System Observatory

ACE observations support nearly every (if not all) Heliophysics missions, and the satellite is a major asset of the Heliophysics System Observatory. The solar wind observations are crucial for understanding the structure and dynamics of processes in Earth's magnetosphere as well as solar wind interactions with other solar system objects and with the heliospheric boundary and interstellar medium. ACE uses its extensive suite of instruments to support the broader scope of numerous other missions. For example, ACE observations will be vital for maximizing science from missions such as the recently launched Van Allen Probes to understand Earth's radiation belts, and planned new missions such as MMS. ACE supports other NASA missions such as the Mars rover, MAVEN, cometary studies, and planetary atmospheres research. The data from ACE are also used as input to, or validation of, numerous heliophysics models and are critical for refining these models. Examples include the Enlil model used for solar wind and CME predictions at Earth and other planets, and the Earth-Moon-Mars Radiation Environment Module (EMMREM) model. Furthermore, ACE provides data that support NASA's Space Radiation and Analysis Group, the National Oceanic and Atmosphere Administration's (NOAA) space weather operations, and other national assets. One indicator of the value of ACE data to the HSO is that in the last 3 years more than 750 papers by non-ACE authors used ACE data.

It is worth noting that while there is some overlap of solar wind measurements made by ACE and Wind (also at L1), it is clear that each mission conducts complementary research and that ACE has a broad mission that makes important observations such as galactic cosmic rays over a broad range of elements, isotopes, ionic species, and energies that are not available from Wind.

3.1.5 Spacecraft / Instrument Health and Status

In the last 2 years, there has been some degradation in the Solar Wind Electron Proton Alpha Monitor (SWEPAM) and the Solar Wind Ion Composition Spectrometer (SWICS); however, for the most part, this problem has been overcome. In SWEPAM, the gain of electron multipliers degrades as charge is extracted over time (affecting solar wind density, but not velocity). By repointing the spacecraft more frequently, the SWEPAM performance is improved. In SWICS, degradation of the Time-of-Flight system introduces some extra background. By changing the priority for recording heavy solar wind ions and filtering of data, SWICS remains capable of measuring abundances of ~ 40 different ion species with nearly same time resolution as before. After producing 3 years of excellent ionic charge state data, the Solar Energetic Particle Charge Analyzer (SEPICA) was turned off in April 2011, as recommended in the previous Senior Review. Finally, at nominal consumption rates, fuel reserves on ACE are adequate through 2024 and power is adequate through 2025. In summary, ACE remains healthy and capable of providing excellent and unique science data.

3.1.6 Data Operations (accessibility, quality control, archiving)

The ACE program is doing an excellent job with regard to data distribution and archiving. ACE data are easily available and accessible in a large variety of levels and resolutions through NASA's Coordinated Data Analysis Web (CDAWeb), Virtual Observatories, and the ACE Science Center. ACE is among the most used data sets in NASA's CDAWeb. Also, real-time data are available through NOAA's Space Weather Prediction Center. There have been multiple improvements in data processing and availability since the last Senior Review, including reprocessed data, a real-time shock analysis service, and a level-3 plot browser. However, it was noted that the science community would benefit from the ACE team making available high-time resolution (12-minute) SWICS data. The data usage is remarkable:

as of 2012, there are 2759 publications, 158 ACE news items, and 113,000 unique users of real-time data. Illustrating good planning, when the time comes for ACE to be terminated, the ACE team has established a plan for completing unfinished tasks and for a final version of the data to be served from a Resident or Permanent archive.

3.1.7 Proposal Weaknesses

There are no serious weaknesses to supporting the continuation of ACE observations. However, it is also apparent that the Cosmic Ray Isotope Spectrometer (CRIS) and Solar Isotope Spectrometer (SIS) instrument budgets, as also mentioned in the previous Senior Review, are at a relatively high level compared to the other instrument teams. Even though these data streams are complex, more justification for these budgets, or new processes, should be considered for the future.

3.1.8 Overall Assessment and Findings

In spite of being one of the "older" missions, ACE continues to make significant contributions to new and emerging scientific problems on topics related to the solar wind and Interplanetary Coronal Mass Ejections (ICME), solar and interplanetary energetic particles, cosmic rays and heliosphere/interstellar interactions, and space weather and the science behind space weather. During the next few years, new observations by ACE will be crucial for understanding changes in the solar corona as the recent unusual solar cycle conditions (weak solar minimum and solar maximum) evolve. ACE will contribute to new understanding of the role of seed particles for SEP events, and with multi-spacecraft imaging and *in situ* data, there will be studies of how SEP properties are controlled by evolving magnetic connections to flares and CMEs. These are but a few of the highest priority goals for ACE investigations.

The ACE budget is within guidelines and fully reasonable for supporting mission services, operations and science data analysis necessary to provide these unique and highly used data to a broad scientific community. Furthermore, ACE: plays an essential role in supporting the HSO; has done a remarkable job at making high-quality data available to the scientific community; and is important for realizing scientific goals of new missions such as the Van Allen Probes.

Overall Grade. The ACE extended mission proposal received a 7/10 median panel score for the Overall Scientific Merit, placing it solidly in the group of excellent proposals. For its contribution to the HSO, ACE received an 8/10 median panel score, placing it in the highest group of compelling missions. The Panel recommends the continued operation of the ACE mission.

3.2 AIM

3.2.1 Overview of the Science Plan

AIM was launched in 2007 as the first satellite mission dedicated to studying Polar Mesospheric Clouds (PMCs). These are water-ice clouds that occur in the summertime at high latitudes, in a thin layer between about 82 and 85 km. Because the clouds were first recorded in 1885, and there is considerable evidence that they are getting brighter and spreading to lower latitudes, PMCs are a subject of great interest as sensitive indicators of climate change.

The main achievement during the first 6 years of the mission has been to gain a significantly better understanding of the global dynamics of the middle atmosphere that control the variability of the clouds on short timescales. As a NASA HSO mission, it was also planned to study the impacts of solar and heliophysical variability on PMCs. However, because of the unusual 23/24 Solar Cycle minimum, these impacts have been difficult to assess. Nevertheless, the role of the 27-day solar rotation has been confirmed. Furthermore, as the maximum of Solar Cycle 24 approaches, there are some indications emerging that the 11-year cycle affects PMCs in the opposite way to the conventional view (which is that the cloud brightness minimizes due to warmer temperatures and Lyman-α photolysis of water). One explanation for this may be that AIM is able to detect smaller ice particles than the previous satellite measurements, which have shown the expected trend (although with an unexplained ~1-year time lag).

The Solar Occultation for Ice Experiment (SOFIE) uses the technique of satellite solar occultation to measure vertical profiles of limb path atmospheric transmission within 16 spectral bands between 0.29 and 5.32 μm. SOFIE measurements are used to retrieve profiles of PMC extinction at 11 wavelengths (0.330 to 5.01 μm), temperature, meteoric smoke extinction, and five gaseous species (O_3, H_2O, CO_2, CH_4, and NO). All 16 channels are functioning nominally. It is worth noting that the spectrometer has an exceptional signal-to-noise ratio (S/N) of 1 part in 106, which has enabled meteoric smoke to be measured by optical extinction for the first time. SOFIE temperatures have now been validated from 15 to 88 km altitude, and measurements of H_2O, NO, and O_3 all agree satisfactorily with other established techniques.

The Cloud Imaging and Particle Size (CIPS) experiment is a wide-angle imager that provides images of PMCs with a spatial resolution of 1×2 km in the nadir and about 5 km at the edges of the forward and aft cameras. The ability to image PMCs at a large range of scattering angles enables the ice particle size to be determined. The retrieved parameters include PMC presence, albedo, particle size, and ice water column content (IWC), with 25 km^2 resolution covering the summer polar region (latitudes from ~55–84°). CIPS data contain the first spaceborne daytime images of small-scale Gravity Waves (GW), which largely account for energy and momentum deposition in the mesosphere and lower thermosphere (MLT). Horizontal wavelengths greater than about 5 km can be determined. CIPS imagery has also now been used outside the summer polar region to detect GW signatures in ozone at ~55 km, although at present only wavelengths >100 km can be detected. CIPS observations of GWs around Antarctica show a strong zonal alignment in the propagation direction of small waves, in contrast to larger scale waves (λ >100 km), which have a preference for trans-polar motion.

Overview of the Science Plan (as addressed in conjunction with observations from other Heliophysics missions): The main overlap comes with the TIMED mission, particularly the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument. One synergistic application is to combine SABER data and results from SOFIE T, O_3, CO_2, and H_2O measurements to perform continued cross-validation studies of these parameters. SABER also measures radiative cooling from CO_2, which will be necessary to untangle the relative contributions of increased CO_2 and atmospheric circulation changes to the observed cooling in the MLT.

Overview of the Methodology: The AIM team has been very successful in developing new data products (e.g., meteoric smoke and GWs), thereby adding considerable value to the original mission. It is planned to continue producing these new products, along with PMC parameters, into the declining phase of Solar Cycle 24.

3.2.2 Science Strengths

Even though significant progress has been made to address the original AIM objectives, several surprises have emerged and these can best be addressed by accumulating further data over the declining phase of Solar Cycle 24. These results—particularly the cooling in the MLT and increase in PMCs toward solar maximum—show that fundamental uncertainties remain.

There are six Prioritized Science Goals (PSGs) for the extended mission:

1. How are PMC variations indicative of the dynamics of the whole atmosphere? This will continue the work from the first 6 years, looking at inter-hemispheric connections in the stratosphere and mesosphere. This has already proved to be a highly successful area of research for the team. The role of gravity waves in the mesosphere/thermosphere will be a focus.
2. How does changing solar irradiance affect PMCs and the environment in which they form? This will attempt to resolve why the expected decrease in PMC ice mass on approach to solar maximum has not occurred during Solar Cycle 24.
3. What is the response of PMCs and their environment to changing atmospheric composition resulting from terrestrial forcing? AIM measures most of the mesospheric parameters (PMCs, *T*, H_2O, CO_2, and CH_4) required to test theories concerning the influence of greenhouse gases on the MLT and PMCs. The effect of increasing greenhouse gases (GHG) on the global circulation may be to induce cooling in the mesosphere, in addition to radiative cooling by CO_2. This is an important topic for study, because there are indications (from various long-term data series) that the mesosphere is cooling much faster than can be explained by enhanced radiative cooling alone. The solar cycle will be at the same point in 2017 as in 2012, but GHG concentrations will be higher. This may permit the dominant solar cycle term to be characterized before determining the temperature change that can be attributed to CO_2 or circulation: an important reason for extending the mission out to 2018.
4. What are the drivers behind changing atmospheric circulation as indicated by meteoric smoke observations? SOFIE has provided the first optical extinction measurements of meteoric smoke. This appears to offer a new tool for characterizing variability in middle atmosphere circulation. An extended mission to solar minimum may provide sufficient observations to reach closure by separating solar and CO_2 effects on circulation changes. Another intriguing possibility is using observed seasonal changes in the mesospheric circulation to forecast circulation changes in the thermosphere.
5. What is the effect of rapidly transported launch vehicle exhaust on PMC variability during the "unique" post-shuttle era? Untangling the effects of solar variability and space traffic on multi-decadal PMC datasets is important for determining possible changes in mesospheric climate since the 1960s. The Space Shuttle Program was the major contributor to lower thermospheric water in the past 25 years, but the program has now ended.
6. How do changes in energetic particle precipitation (EPP) affect the summer polar upper mesosphere, and what are the implications for PMCs? AIM can measure NO in the MLT and O_3 in the stratosphere/mesosphere, both species being affected by EPP. This provides a link between space weather and atmospheric change.

3.2.3 Relevancy Strengths to Heliophysics Research Objectives

Strengths

The only significant overlap with other HSO missions is with TIMED. The proposal addresses the question of relevancy to the Roadmap in some detail for each of the PSGs.

PSG1: The role of gravity waves in atmospheric circulation has been a subject of various Heliophysics roadmaps, as well as the National Research Council's 2012 Decadal Survey Report (DSR) ("Solar and Space Physics: A Science for a Technological Society," released by the National Academy of Sciences) Goal No. 3, to "determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs."

PSG2: Relevant to NASA Heliophysics Roadmap Research Focus Area (RFA) H3 "Understanding the role of the Sun and its variability in driving change in the Earth's atmosphere."

PSG 3: Relevant to NRC 2012 DSR Goal #2 "to provide a comprehensive understanding of the variability in space weather driven by lower atmosphere weather on Earth."

PSG 4: Consistent with the NRC 2012 DSR Goal No. 3.

PSG 5: Relates to the NRC 2012 DSR question: How do End-Plate Potential (EPP)-initiated chemical changes translate to thermal and dynamical changes throughout the atmosphere?

Weaknesses

None noted.

3.2.4 Value to the Heliophysics System Observatory

AIM focuses on solar-terrestrial science in the Earth's stratosphere, mesosphere, and lower thermosphere, and thus operates at one of the boundaries of the HSO. Its value lies in providing important new information about solar impacts on the dynamics and chemistry of these regions, and the role of solar variability in the Earth's climate.

3.2.5 Spacecraft / Instrument Health and Status

SOFIE and CIPS are operating normally with no issues to consider. The Cosmic Dust Experiment (CDE) instrument stopped producing useful data about 9 months into the mission, and was turned off during the summer of 2012. Although the proposal states that "Little to no science was lost because of the SOFIE ability to measure meteoric smoke," this is not actually the case—nanometer-sized meteoric smoke and micron-sized interplanetary dust particles are not the same thing. During the Northern Hemisphere (NH) 2018 PMC season, AIM will reach the point, due to orbit precession, where the spacecraft is in full sunlight throughout the orbit. SOFIE will not be operable during this period, but CIPS can continue to be used for gravity wave studies.

3.2.6 Data Operations (accessibility, quality control, archiving)

Data are publicly available within approximately 1 week of the on-orbit measurement/collection time. The panel noted that the transition to a final archive is relegated to a very short time at the end of the mission, but recent contacts with NASA's Space Physics Data Facility (SPDF) are encouraging that this will be addressed. It is not clear the archived level-0 data will be of any use, given the plan to not archive a complete set of software. This plan should be part of the discussion with the SPDF. There should also be continuing interaction with the SPDF to solve the problems associated with the lack of standards for

"NetCDF" files.

3.2.7 Proposal Weaknesses

No significant weaknesses were identified. Nevertheless, there are some points that the AIM team may wish to consider:

- The solar cycle will be at the same point in 2017 as in 2012, and GHG concentrations will be higher—but only by ~10%. Will that be enough to untangle solar from GHG impacts?
- Meteoric smoke is *not* a passive tracer—it is formed from the recondensation of metallic vapors produced from meteoric ablation (and so a function of the meteoric input function as well as local concentrations of O, H, and O_3, etc., and T). The particles are also probably subject to coagulation and processing by acids like H_2SO_4, which may change their extinction cross sections significantly

3.2.8 Overall Assessment and Findings

The Panel noted the very successful accomplishments in the first 6 years of the mission. The Panel was also impressed with the broadening of the original goals of AIM following the successful measurement of several originally unplanned parameters—meteoric smoke, gravity waves, and various gas-phase constituents.

Although the total number of published papers to date is not exceptional, there is evidence that data are now starting to be used more widely by non-AIM Science Team members both in the U.S. and internationally. This trend should continue, perhaps by advertising the data products more widely to the middle-atmosphere modeling community and also to researchers who do spectroscopic retrievals.

The proposal makes a well-argued science case for extension to the next solar minimum.

The six PSGs are of variable importance and likelihood of success, though all worth pursuing. The Panel agrees with the order of priority in the proposal.

Overall Grade. The AIM extended mission proposal received a 6/10 median Panel score for the Overall Scientific Merit, placing it solidly in the group of Excellent proposals. Its median Panel score of 5/10 for contributions to the HSO places it near the lower end of the ranking in the Excellent category but with significant value for HSO science. The Panel recommends the continued operation of the AIM mission.

3.3 CINDI

3.3.1 Overview of the Science Plan

The CINDI science team proposes a focused study addressing the following fundamental question: (1) How do the equatorial thermosphere and ionosphere respond to geomagnetic energy inputs at high latitudes? (2) How is the energy budget in the equatorial ionosphere and thermosphere connected to the ionospheric dynamics and composition of the region? (3) How is the pre-sunset state of the ionosphere related to the post-sunset appearance of plasma irregularities in the equatorial region? These questions immediately address a number of research focus areas that appear in the current Heliophysics Roadmap for Science and Technology, "Heliophysics: The Solar and Space Physics of a New Era," (May 2009) and which are carried forward in the Science Missions Directorate Strategic Plan, "2010

Science Plan for NASA's Science Mission Directorate," (July 2010), and the most recent Decadal Survey for Solar and Space Physics, "Solar and space Physics: A Science for a Technological Society," (2012) by the National Research Council.

CINDI is a NASA mission of opportunity that provides measurements of the ion density, temperature, composition, and velocity as well as the neural atmosphere pressure and wind. The CINDI Instruments consist of two thermal ion sensors that constitute the Ion Velocity Meter (IVM) and two neutral particle sensors that make up the Neutral Wind Meter (NWM). The IVM sensors, which include an ion drift meter (IDM) and retarding potential analyzer (RPA), have performed as expected since their initial turn on. The extended CINDI mission will use its measurements of ionospheric and thermospheric density and motion over a range of critical altitudes in its near equatorial orbit (13 degrees inclination) to address the proposed science questions.

3.3.2 Science Strengths

The CINDI extended mission plan is well conceived and addresses compelling science topics. Additional data and operations are clearly required to accomplish the proposed science objectives. CINDI has established the properties of the quiet time ionosphere and thermosphere over its prime mission phase during the solar minimum such that the context of the proposed extended mission science is clear. The team has produced the first continuous observations of the O^+/H^+ transition height, a proxy for the effective thickness of the ionosphere, across low latitudes and at all local times. The CINDI team has also described the characteristics of large-scale plasma density structures in the topside ionosphere at solar minimum that usually peak in occurrence after midnight. During this extreme solar minimum CINDI has established that the nighttime thermospheric temperature is less than 600K and that the dominant species near 400 km is neutral helium. This was a surprising scientific result.

CINDI will be the only mission providing coincident information on the dynamic state of the ionosphere and thermosphere during the rising solar cycle. This makes it an important data set for achieving system science of the effect of the Sun and magnetosphere on the Earth. It will likely be coupled with measurements of the Extreme Ultraviolet (EUV) radiation from the SDO EVE instrument observations and the state of the interplanetary environment from ACE, and contextual imaging of the neutral atmosphere and ionosphere from TIMED.

The CINDI mission costs are very low relative to the large science return. The CINDI instrument suite is part of the Communications/Navigation Outage Forecasting System (C/NOFS) spacecraft, which is operated by the U.S. Air Force (USAF), thus reducing the cost to NASA for mission operations. The costs of the science team for producing archived data is relatively low, especially considering that the mission is just ending its primary mission phase.

3.3.3 Relevancy Strengths to Heliophysics Research Objectives

The CINDI mission strongly and clearly addresses priority investigations in the Heliophysics Science and Technology Roadmap. One of the key Roadmap science objectives, RFA F3, is to understand the ion-neutral interactions that couple planetary ionospheres to their upper atmospheres and solar and stellar winds to the ambient neutrals. CINDI is one of the few missions that can directly address this topic. It also addresses RFA H2 to understand the changes in the Earth's magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects, and RFA H3 to understand the role of the Sun and its variability in driving change in the Earth's atmosphere. The proposed investigations are carried forward in the most recent decadal survey, which outlines challenges for atmosphere ionosphere-magnetosphere (AIM) coupling that include "understand the plasma neutral coupling processes that give rise to local, regional and global scale structures and dynamics in the AIM system." The focused activities of the extended mission are also responsive to the decadal survey, which recommends "Distinct Programs for Space Physics Research and Space Weather Forecasting and Specification."

3.3.4 Value to the Heliophysics System Observatory

CINDI is the only component of the HSO that will gather *in situ* measurements of both the ionospheric and thermospheric motions during the declining phase of the current modest solar maximum. The region CINDI observes responds to solar radiation, producing ionization and wind systems that generate electric fields internally. The proposed extended program will benefit greatly from HSO assets that provide a detailed description of the external drivers. For example, the Solar EUV Experiment (SEE) instrument on TIMED provides measurements of the spectral content in the solar EUV radiation and data from SDO adds information about the spectral emissions in solar flares. These data have spawned a number of investigations for which the CINDI observations of plasma density, temperature, and composition play a critical role. The emerging measurements of neutral winds from TIMED and CINDI provide an opportunity to move forward with ion-neutral coupling studies. The availability of data from the Van Allen Probes that specify the energy content of the ring current, will add a new perspective to interpreting measurements of equatorial dynamics. During the declining phase of a modest solar maximum we might expect the re-emergence of recurrent activity from solar wind streams. This presents a new opportunity to combine measurements in the inner magnetosphere from Van Allen Probes with measurements of the equatorial motions from CINDI to uncover the role of ring current shielding during such periods. CINDI represents an important component of the HSO, enabling the connected ionosphere, thermosphere, and magnetosphere system to be included in a coherent study of the geospace environment.

3.3.5 Spacecraft / Instrument Health and Status

The state of the C/NOFS satellite and mission programmatic is good. The Air Force Research Laboratory (AFRL) has indicated that it intends to continue the operation of the satellite "until reentry of the vehicle." The sole concern of any consequence is that at times the angle between the Sun and C/NOFS's precessing orbit is such that battery-charging conditions might preclude full operation of the all of the instruments and the Tracking and Data Relay Satellite System (TDRSS) data system. This is not expected to affect the CINDI instruments, which do not draw significant power.

3.3.6 Data Operations (accessibility, quality control, archiving)

The CINDI team is doing a good job of making data available in a timely fashion and in useful formats. The plan needs to be strengthened in the areas of describing the move of the data, documentation, and supporting information to a final archive. There should also be stronger interaction with the Virtual Observatories (VxO) to assure that the Space Physics Archive Search and Extract (SPASE) metadata are prepared for the data products.

The CINDI Mission Archive Plan (MAP) consists of two primary components: the UT and AFRL production sites. The NSSDC is designated as a deep archive. Data are being delivered on a timely basis through the project website, subject to availability issues beyond the team's control (lack of solar activity). The team has chosen to make the data available in Hierarchical Data Format (HDF) (currently actually in ASCII), with metadata in a custom ASCII form that "conforms to the simplest of SPASE models." The HDF format will certainly be readily accessible to the user community and is therefore a good choice. The data are simple enough that conversion to other formats (e.g., Common Data Format, or CDF) should be straightforward.

3.3.7 Proposal Weaknesses

The CINDI mission can provide information only on the low-latitude ionosphere. Many of the NASA system science objectives for the Sun-to-Earth response to solar variability require a set of observations from higher latitudes of the thermosphere and ionosphere that cannot be provided by CINDI in its equatorial orbit. This is considered a minor weakness because it reflects a weakness in the HSO that there is not a mission providing more complete coverage of the ionosphere.

3.3.8 Overall Assessment and Findings

CINDI has a clear extended mission plan addressing compelling science topics. During the recent solar minimum CINDI has established the properties of the quiet-time ionosphere and thermosphere such that the context of the proposed extended mission science is clear. CINDI will be the only mission providing coincident information on the dynamic state of the ionosphere and thermosphere during the rising solar cycle and is therefore valuable to the HSO. The CINDI mission strongly addresses priority investigations in the Heliophysics Science and Technology Roadmap. The CINDI mission costs are very low relative to the expected large science return. The health and safety of the C/NOFS satellite is good with the USAF intending to continue operations of the spacecraft. The CINDI team is doing a good job of making data available in a timely fashion and in useful formats.

Overall Grade. The CINDI extended mission proposal received solid Excellent rankings for both extended mission science (median panel score 7/10) and contribution to the HSO (median panel score 6/10). The lower ranking of HSO value stems from the low impact that CINDI data has on other elements of the HSO. The Panel recommends the continued operation of the CINDI extended mission.

3.4 CLUSTER

Cluster is a joint ESA/NASA mission that was launched in July and August 2000. Cluster and SOHO were the first cornerstone missions of ESA's Horizon's 2000 Program. ESA has provided the bulk of funding for the Cluster mission to date with NASA providing contributions of roughly $210M. Its four spacecraft have revolutionized multipoint measurements in geospace. Its instrument suite provides *in-situ* measurements of dc and wave electric and magnetic fields and plasma-particle distributions from thermal to 100s of keV and ion mass composition up to 20 keV.

3.4.1 Overview of the Science Plan

In order of priority, the extended mission will conduct the following science investigations using Cluster data. The first two investigations are also primary Cluster goals for the ESA-approved mission extension through 2014.

1. Investigate and quantify the response of geospace to solar activity over more than one solar cycle (*also ESA approved*).
2. Study small-scale structures at the bow shock (*also ESA approved*).

3. Investigate the waves and fields properties of magnetic reconnection, particularly at ion scales in the magnetotail.
4. Determine the plasma wave properties of turbulence in the magnetosheath, particularly at small scales and near regions of magnetic reconnection.
5. Investigate the spatiotemporal properties of waves in the inner magnetosphere (with Cluster at small separations) as related to observations of radiation belt particles in conjunction with the Van Allen Probes.
6. Use the electric field data from the Electron Drift Instrument (EDI) to further develop the University of New Hampshire-Inner Magnetospheric Electric Field (UNH-IMEF) global electric field model of the inner magnetosphere.

Novel orbital changes in the extended mission will bring C3 and C4 to within 10 km or less from each other for ion plasma-scale studies, with C1 and C2 providing larger scale context since they will be separated from each other and from C3 and C4 most of the time by distances of ~1000s km.

Collaborations with the current THEMIS and Van Allen missions are envisioned, along with MMS and ESA Swarm missions post-launch. Orbit simulations show that the Cluster orbits will be in near conjunction with MMS and Van Allen Probes, which could provide unique, out-of-ecliptic-plane measurements complementary to those from these other missions.

3.4.2 Science Strengths

- Datasets from the same instruments and same regions will be used for comparisons over two solar cycles, e.g., of magnetic reconnection and flow of energy and momentum into the magnetosphere. This investigation seems most relevant to global and system behavior. The proposed measurements will mainly provide diagnostics of local plasma behavior, which depend on solar cycle effects through local changes in the plasma and field environment and may not be as relevant as large-scale measurements in understanding solar-terrestrial coupling phenomena across multiple solar cycles.
- The closely spaced configuration of C3 and C4 will provide novel data in key regions of geospace and in thin layers of fundamental interest—shocks, boundary layers, reconnection diffusion region at ion plasma scales. However, ion plasma instruments are not operating on all S/C, notably not on both C3 and C4, which presumably would be used to study ion plasma scale phenomena.
- Mid-latitude conjunctions with Van Allen Probes will provide valuable data on distributions of wave modes responsible for radiation belt particle losses and acceleration. The wave instrument (WBD) and energetic electric detector (RAPID-IES) are operating on all Cluster S/C, so data relevant to the electron belts should be of high quality.
- Significant scientific impact during the previous extension bodes well for the proposed extension, but with uncertainty and risk regarding the value of future data given the failure or reduced performance of many instruments.
- The scientific team is intact and remains productive, but is not supported for science in the guideline budget.
- The GI program (current grants and just submitted proposal) leverages scientific productivity from extended mission at least through 2014.

3.4.3 Relevancy Strengths to HP Research Objectives

The research objectives of the extended mission are well aligned with SMD strategic goals, and they address two overarching science goals of the Heliophysics Division. Many goals of the 2012 Decadal Strategy for Solar and Space Physics will also be addressed—three top-level goals (DS Goals 1, 2, and 4) of the Decadal Survey and four priorities of the Decadal Survey Panel on Solar Wind—Magnetosphere Interactions (SWMI-1, 2, 3 and 4).

Strategic Goal 1 - Open the frontier to space environment prediction: Understand the fundamental physical processes of our space environment.

> The extended mission will provide new insights into magnetic reconnection (*SWMI-1*), plasma processes that accelerate and transport particles (*SWMI-2*) and collisionless shock waves; it will characterize fundamental physical processes that govern how energy and matter are transported in geospace (*DS Goal 4*)

Strategic Goal 2 - Understand the nature of our home in space and how we are affected by solar variability interacting with planetary magnetic fields and atmospheres.

> The extended mission will extend measurements of changes in Earth's magnetosphere over a complete solar cycle; characterize dynamics and coupling of Earth's magnetosphere, ionosphere, … and their response to solar … inputs (*DS Goals 1, 2; SWMI-3, 4*)

3.4.4 Value to the Heliophysics System Observatory

The greatest value of the Cluster extended mission, given its reduced instrument functionality, accrues from its contributions to the HSO in outer regions of geospace, in the interplanetary medium where its measurements complement those from other HSO missions and from its out-of-ecliptic-plane orbits which complement the equatorial plane measurements of the Van Allen Probes, THEMIS, and MMS. The proposal makes a compelling case for:

- Investigation of solar-terrestrial coupling from measurements in key regions under varied driving conditions;
- Complementary mid-latitude conjunction measurements to equatorial measurements from Van Allen Probes;
- Ion plasma scale and regional (1000s km) measurements complementary to those MMS will make in the electron diffusion region;
- Complementary high-altitude measurements of currents to be resolved by ESA Swarm (three S/C) measurements in the ionosphere;
- Alignments with THEMIS to provide additional multi-point, multi-scale measurements.

3.4.5 Spacecraft / Instrument Health and Status

The S/C and instrument health as described in the proposal are summarized in Table 3-1. The proposal indicated that of the nine science teams on each of the Cluster spacecraft, seven instruments have U.S. contributions.

The rate of solar array power degradation, which was significantly impacted by the recent passage through the proton belts, will slow as perigee increases. ESA solar array experts predict that Cluster will have adequate power for science operations through at least December 2016.

Table 3-1. Cluster spacecraft instruments, PIs and institutions and current instrument performance.

Instrument			PI, Institution	C1	C2	C3	C4
FGM		Fluxgate	C Carr, Imperial College / *Margaret Kivelson, UCLA*				
WHISPER		Sounder	Jean Gabriel Trotignon, CNRS Orleans				
STAFF		Search coil	Patrick Canu, CNRS Palaiseau				
PEACE		Low-energy	A Fazakerley, MSSL / ***M Goldstein, GSFC;*** *D Winningham, SwRI*				
WBD		Wide band wave	***Jolene Pickett, U Iowa***				
EFW		Electric field and	Mats André, IRF / ***Forest Mozer UCB***				
CIS	HIA	Hot ion analyzer	Iannis Dandouras, CNRS Toulouse				
	RPA	Retarding potential	***George Parks, UCB***				
	CODIF	TOF ion	***Eberhard Moebius, UNH;*** *Lynn Kistler, UNH*				
RAPID	IES	Imaging electron	***Ted Fritz, BU***				
	IPS	Imaging proton	Patrick Daly, MPI für Aeronomie				
EDI		Electron drift	***Roy B. Torbert, UNH***				
S/C Power		Adequate through "at least"12/16; C1 has the least power capacity					
S/C Fuel		Adequate for operations through 2016					
LEGEND		***US PI, US Lead CoI,*** *US CoI*	Nominal Instrument	Minor Reduced	Reduced Performance	Instrument Not	

The projected fuel consumption for Cluster science activities is adequate for the planned orbital re-configuration that will bring C3 and C4 to within 10-km separations. By using small start/stop thruster firings coupled with long period phasing drift times to attain the required spacecraft configurations, sufficient fuel is available to support a second guest investigator Announcement of Opportunity (AO) through 2016.

3.4.6 Data Operations (accessibility, quality control, archiving)

Accessibility (Cluster Active Archive, or CAA, is an ESA contribution to the International Living With a Star, or ILWS, Program)

- Mature user interface; seemingly well supported; useful as evidenced by GI projects and number of users: 1565 total, 20 new/month; downloads: 1 TByte/month
- *New*: Have implemented direct data streaming without requiring remote file creation, transfer; visualization tools to display electron and ion distribution functions; data mining tool
- Useful links to auxiliary datasets including ground-based data and simulations

Quality control

- Two cross-calibration meetings per year are held to ensure data quality.

Archive ("data are available 1-2 years after collection")

- All data from the Cluster Active Archive have been transferred to Cluster Final Archive (CFA) at the European Space Astronomy Centre (ESAC).
- 2013: Public access will be through CFA rather than CAA. Some data are available in NASA CDAWeb.

Data operations are mature and appear to be well managed and accessible. User statistics provide good evidence that the scientific community values and uses the data.

3.4.7 Proposal Weaknesses

- Proposal does not address why single-point ion measurements (available only on C4) will be adequate for studying multi-point ion plasma-scale physics of reconnection, energy dissipation in shocks and in the magnetopause boundary layer.
- Many instruments are not functional or have limited duty cycle. The impact on extended mission science, especially with only one Retarding Potential Analyzer/Composition Distribution Function (RPA/CODIF) instrument functioning, diminishes intrinsic scientific value.
- The proposal does not make a compelling case for full mission extension beyond 2014.
- Managing operations caused by S/C systems degradation increases labor and cost for the WBD instrument and possibly for other instruments also.

3.4.8 Overall Assessment and Findings

Cluster has been a productive mission with relatively modest NASA funding ($210M) over its 13-year lifetime. The science team is intact and continues to produce good science with no support in the extended mission for science Research and Analysis (R&A). The data appear to be widely used by the community.

Extended mission science is optimized for projected orbits in the bow shock, magnetosheath, mid-latitude magnetopause, and inner magnetosphere and for revisiting regions sampled in Solar Cycle 23.

The Cluster orbits provide unique multipoint contributions to the HSO at high and mid latitudes, complementing equatorial plane measurements by THEMIS, Van Allen Probes, and MMS.

The proposal to drift orbits of S/C pairs to within 5–10 km separation is novel in the mission, but the reduced performance or failure of many instruments reduces the utility of the measurement suite and the resulting science impact in studying ion plasma scale phenomena. MMS measurements will supersede these measurements, although only in equatorial regions.

The Senior Review panel finds that the Cluster extended mission proposal has notably worthy goals, but the status of the instrumentation is not adequate to achieve the highest-priority goals. The fact that the ion RPA/CODIF instrument is working on only one of four S/C means that four-point measurements of ion phenomena, which have been a hallmark of Cluster science, cannot be realized in the proposed studies of ion plasma-scale physics. The Panel finds that the proposed level of funding in the extended mission is high given this reduced functionality. The objective to investigate the spatiotemporal properties of waves at mid-latitudes in the inner magnetosphere (with Cluster at small separations), and their relation to observations of radiation belt particles and waves in conjunction with the Van Allen Probes, is achievable with the WBD and RAPID IES instruments which are working on all spacecraft. Assuming ESA continues to support Cluster operations beyond the current agreement with NASA extending through 2014, in the current reduced funding environment for MO&DA the panel recommends continued funding only for the U.S. PI-led, WBD instrument in the extended mission.

Overall Grade. The Cluster extended mission proposal received the following median scores from the Senior Review panel: 3/10 for Overall Scientific Merit and 4/10 for Value to the HSO.

3.5 HINODE

3.5.1 Overview of the Science Plan

For its second mission extension, the Hinode proposal categorizes its set of prioritized goals into several broad areas of particular importance in solar physics. The first is understanding the structure and stability of the magnetic atmosphere. This includes observations of the emergence of flux, the study of polar crown filaments, and exploring the origin of the solar wind. Second, the mission will study the storage and release of mass and energy of the corona, by looking at correlations between chromospheric and coronal heating, characterizing properties of flare sites, isolating locations of CME initiation, and investigating the role of field line braiding in heating. The third set of goals characterizes energy and mass transfer from the photosphere to the corona, with particular focus on studying dynamic plasma jets (Type II spicules) and Alfvén wave propagation. Coordination with the Interface Region Imaging Spectrograph (IRIS) explorer mission will be used to reveal connections, if any, between chromospheric spicules and hotter counterparts. The physics of the spicules and how they are heated will also be explored. As part of a fourth set of goals, the mission extension will also quantify variations in magnetic field and irradiance with the solar cycle. This is made possible through the development of synoptic programs, which began during the prime mission at solar minimum and are planned to continue into the declining phase of the current solar cycle. High-resolution observations of the poles will continue. Combining Solar Optical Telescope/Spectro-Polarimeter (SOT/SP) data with Helioseismic and Magnetic Imager (HMI) data and improved modeling may enable the evaluation of the cycle dependence of active region magnetic energy and helicity. Many of the key science goals were completed during a historically low solar minimum. Much of the science in the first mission extension focused on solar active regions, flares, and CMEs. During Extended Science Mission 2, Hinode will observe the declining phase of the activity cycle, possibly including the largest flares of the cycle.

3.5.2 Science Strengths

Hinode provides a set of three complex imaging instruments that supply unique or, in some cases, the highest quality solar observations compared to other elements of the HSO. The science impact from this complex mission has been major. Recent science results from the previous extension include characterizing and understanding the importance of small-scale magnetic fields in the quiet Sun, tracing fields from the photosphere to the corona, understanding the role of twisted field in solar flares, and understanding the topology of active regions and CME precursors. The Hinode mission has also provided important tools like the nonlinear force free field (NLFFF) extrapolations that have been refined using Hinode observations. Hinode science data have been used in 699 known refereed journal articles and in at least 61 graduate student dissertations. The priority science goals for the next extension are realistic and important.

3.5.3 Relevancy Strengths to the Heliophysics Research Objectives

The research is highly relevant to Heliophysics objectives as described in the most recent Heliophysics Roadmap. Examples of the kinds of results obtained to date (and the relevant Roadmap focus areas) include: observations of emergence of twisted magnetic flux ropes (relevant to Roadmap area F4—creation and variability of dynamos), development of high-resolution 3D models of the photosphere from Stokes inversions (H1—causes and evolution of solar activity), highly sheared field and strong currents above a flare, and evidence for fast reconnection and inflow at a hot loop top (F1—magnetic reconnection), and fountain-like jets and spicules as an important mediator of energy flux (F2—plasma processes that accelerate and transport particles). The continued study of the high-resolution magnetic field in the photosphere provides a lower boundary to most of our understanding of magnetic fields throughout the solar atmosphere and continuing into the heliosphere.

3.5.4 Value to the Heliophysics Great Observatory

Hinode is a strategic and non-overlapping part of the Heliophysics Great Observatory. The high science impact results in many ways from the high spatial and temporal resolution of the instruments that are not duplicated by any other space- or ground-based observatory. Hinode provides several important kinds of observations through its three main instruments. First, high spatial (0.2") and temporal (1.6s) observations of magnetic fields are obtained through the SOT. As part of the SOT, the SP is 10 times more sensitive than previous instruments. Second, EUV spectra of the transition region and corona, made with the Extreme ultraviolet Imaging Spectrometer (EIS), represent the deepest solar spectra in the relevant wavelengths. Third, full-disk X-ray observations of the highest temperature emission in the corona and in flares are provided through the X-Ray Telescope (XRT). The XRT can observe coronal emission from high temperature plasma, for which the Atmospheric Imaging Assembly (AIA) on SDO is insensitive. Thus, Hinode provides the highest spatial, temporal, and temperature resolution observations available from space.

The extended mission proposal places considerable emphasis on coordination of observations with the IRIS small explorer mission with a planned launched in mid-2013. Hinode will provide magnetograms, high-temperature transition region and coronal observations to complement IRIS high-resolution chromospheric and low-temperature transition region spectra in order to carry out the study of mass and energy flow throughout the atmosphere into the corona. In addition to IRIS, the instruments on Hinode complement observations made with STEREO and SDO. Coordinated observations play a major role in the prioritized science goals for the second extended mission. Examples of these include combined SOT SP magnetic field maps, XRT and AIA images and EIS and IRIS raster maps of emerging flux. The correlation between chromospheric and coronal heating through waves and turbulence will be explored through combinations of SOT H-alpha images and magnetograms, IRIS Mg h/k maps, EIS spectral scans, and XRT images of active regions. Similar synergy is being employed to study the transfer of hot plasma from the chromosphere to the corona, and the study of Alfvén wave propagation. Hinode is in a unique position to offer high-resolution magnetic field measurements, the spectroscopic measurements of plasma motions in the lower boundary of the heliosphere, and high-resolution soft X-ray imaging complementary to the AIA broadband images and RHESSI spectra.

3.5.5 Spacecraft / Instrument Health and Status

A number of instrument issues are noted. EIS has a growing number of warm pixels, now almost one quarter of the total. In 2012, smudges appeared in NFI images (possibly bubbles in a static oil cavity) that do not change when the filter is tuned and change slowly with time. As reported in the previous review, two of six NFI blocking filters are damaged. The only non-redundant one, H-alpha, has minor damage and still somewhat usable. The Optical Tube Assembly (OTA) primary mirror for SOT has contamination accumulation that does not yet affect data quality. A filter wheel in the XRT cannot be switched during eclipse season (4 months/year). In 2012, a pinhole affecting the XRT appeared. Procedures for calibrating out the visible light contamination are underway. None of these issues is expected to provide a major impact on the proposed extended mission goals.

3.5.6 Data Operations (accessibility, quality control, archiving)

Data accessibility appears to be excellent. The Virtual Solar Observatory (VSO) acts as the primary data access point with the data archived at the Solar Data Analysis Center (SDAC) at NASA's Goddard Space Flight Center (GSFC). Uncalibrated (quick-look) data are available within hours of observations at a variety of websites including the Solar Monitor.org. Observing requests from community users are coordinated with team observations and synoptic observations. To date, 288 external requests have been executed or are currently planned. Changes of the calibration and other effects of instrument degradation are incorporated into SolarSoft software (available from the Lockheed-Martin Solar and Astrophysics Laboratory website) and documentation.

3.5.7 Proposal Weaknesses

The Hinode mission has the second-largest budget (just below STEREO) of all Heliophysics missions considered. Given that the overall operation of the spacecraft and some of the instrument costs are provided by international partners, the NASA funding that covers the science operations and data analysis for the three U.S. instrument teams appears to be unusually high. The proposal mentions that in the last 3 years the project has lowered some costs in mission and data processing operations. The NASA role in Chief Planner (CP) duties is substantially reduced and operations planning for instruments is being reduced by 15–20% annually. Unfortunately, the proposal provides little, if any, description of the tasks, and cost justifications, of the instrument teams that benefit from the bulk of the NASA funding. It is likewise unclear how the 15–20% annual savings in instrument planning claimed is reallocated. The extraordinary expense of the mission extension stands out when considering that the U.S. team members share, with a variety of partners such as Japan and the U.K., only a portion of the responsibility for, and access to, the instruments. Furthermore, the instruments have now been running successfully since 2006 and many operations may be reasonably expected to become routine. The high cost of the mission does not compare favorably with other missions that also offer high-quality scientific return for considerably less money.

3.5.8 Overall Assessment and Finding

The panel recommends a second extension of the Hinode mission and recognizes the extraordinary and unique capabilities of the three instruments on board for furthering our understanding of the Sun as the lower boundary for the entire heliosphere. However, the project is expensive and the costs are not sufficiently justified. Thus, the mission stands out in stark contrast to other missions that may also offer considerable science but for much less money. Facing budget shortfalls, the panel recommends that

NASA consider reducing the budget for this mission.

Overall Grade. The Hinode extended mission proposal received an 8/10 median panel ranking for Overall Scientific Merit, placing its science merit in the “Compelling” category. Its Value to the HSO is ranked Excellent with a 6/10 median value from the panel.

3.6 IBEX

3.6.1 Overview of the Science Plan

The Interstellar Boundary Explorer (IBEX) has two instruments that measure energetic neutral atoms (ENAs). The primary focus of the mission is to measure ENAs from the outer heliosphere and use this data to deduce information about the global structure of the heliosphere, the spectrum of energetic particles in the outer heliosphere, and properties of local interstellar medium (LISM). In the extended mission (EM) the IBEX team also proposes to focus on the global structure of the Earth’s magnetosphere and its dynamic interaction with the solar wind and ENA emission from the other solar system objects.

In the prime mission phase IBEX has made a number of important discoveries related to the structure of the outer heliosphere. A surprise was the discovery that ENAs of around 1keV peak along a band, called the “IBEX ribbon” that seems to be defined by $\mathbf{B}_{\mathbf{LISM}} \cdot \mathbf{R} = 0$, where $\mathbf{B}_{\mathbf{LISM}}$ is the draped magnetic field of the LISM just outside of the heliopause and **R** is the radial direction. The ribbon exhibits structure that varies with time. The source of the ribbon remains uncertain and is a major focus of the EM. Peaking of the highest-energy ENAs in the polar regions where the solar wind speed is the highest suggest that the source of ENAs is linked to the solar wind speed. Consistent with this idea, the spectra of ENAs are harder near the poles than the equator. Because of the time delay in the propagation of the solar wind, the present measurements correspond to solar minimum so a major goal of the EM is to study the variation of ENAs and the structure of the global heliosphere with the phase of the solar cycle. Further measurements of neutral H and He from the LISM will establish the direction of the flow of the LISM.

Because the orbital radius extends out to around 50 R_E IBEX has been able to image ENA emission from Earth’s global magnetosphere, including the magnetopause, the cusps, and the tail regions. Time resolution is sufficient to image the dynamics of the magnetosphere during its interaction with CMEs during solar maximum although spatial resolution is limited.

IBEX has been able to measure ENAs backscattered from the lunar surface during its interaction with the solar wind. During the extended mission IBEX will also seek to measure scattering from comets and cometary tails.

3.6.2 Science Strengths

The interaction of the solar wind with the interstellar medium, the primary goal of IBEX, is a priority of NASA’s SMD and the 2012 Solar and Space Physics Decadal Survey.

Because of the presence of the Voyager spacecraft in the outer heliosphere, the EM IBEX measurements will provide critical measurements on the global structure of the heliopshere that can be compared with *in situ* Voyager measurements. The recent observations of a tilted heliotail will provide additional information on the orientation of the LISM magnetic field. The EM will cover the period of solar maximum and combined with the earlier data at solar minimum will complete the exploration of the structure of the outer heliosphere over the complete solar cycle. Particularly important is to explore the impact of changing solar wind velocity and dynamic pressure on the distribution of ENAs in the outer heliophere. This additional information should enable the IBEX team to pin down the source of the ribbon and to understand the distribution and spectral shape of the globally distributed ENA flux and its implications for understanding particle heating and acceleration in the outer heliosphere.

It is now well accepted that the ENA emission from the ribbon is related to the local interstellar magnetic field giving an important constraint on models of the global heliosphere—despite the fact that we do not actually know, at present, what causes the ribbon.

The new orbit devised by the IBEX team that involves the interaction with the Moon will facilitate more accurate measurements of the direction of flow of the LISM through the measurements of neutral H and He from the LISM. The variation of the flux of neutral H over the solar cycle will provide important data for understanding the role of interstellar pickup particles in the dynamics of the solar wind.

Global imaging of the interaction of the Earth's magnetosphere with the dynamic solar wind, with resolution times on the order of minutes or less, will produce key data for benchmarking global magnetospheric models and for assisting in the interpretation of local measurements by satellites in the local geospace environment. Understanding the impact of solar disturbances on the geospace environment is a top priority of NASA's SMD and the Decadal survey.

3.6.3 Relevancy of Strengths to Heliophysics Research Objectives

IBEX has significant synergy with other heliospheric missions. In the outer heliosphere the Voyager spacecraft are in the inner heliosheath and approaching the heliopause. The comparison with IBEX is a unique opportunity because local measurements in the outer heliosphere will not be available for decades at best after the Voyager mission comes to a close. The heliopause encounters by Voyager will enable IBEX to benchmark estimates of the thickness of the inner heliosheath based on integrated fluxes of ENAs. Enhanced activity in the heliosheath associated with the propagation of solar disruptions into the outer heliosphere during solar maximum might be identifiable with both Voyager and IBEX. Comparisons of the IBEX ribbon with Cassini's Imaging-neutral Camera (INCA) measurements of a similar band are ongoing and will continue.

Global imaging of the Earth's magnetosphere with IBEX will produce a unique global view of how CMEs impact the Earth space environment while existing satellites within the magnetosphere—Cluster, THEMIS, the Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS), Artemis, Van Allen Probes—and the upcoming MMS mission produce local measurements.

3.6.4 Value to the Heliophysics System Observatory

The interaction of the solar wind with the interstellar medium, the primary goal of IBEX, is a priority of NASA's SMD and the 2012 Solar and Space Physics Decadal Survey. The IBEX EM will provide data that will facilitate planning for the IMAP mission, which was identified as a priority of the 2012 Decadal Survey. The interaction of solar wind with the Earth's magnetosphere, which controls space weather in geospace, is also a priority of SMD and the 2012 Decadal Survey.

3.6.5 Spacecraft / Instrument Health and Status

The IBEX has two instruments that measure ENAs with energies in the range of 10eV–2keV (IBEX-LO) and in the range of 380eV–6keV (IBEX-HI). ENAs are not deflected by magnetic fields and therefore are able to offer global views of heliospheric structure and dynamics. The measurements, because they are line-of-sight integrals, complicate the interpretation and typically require a parallel modeling effort for interpreting the results.

Both the IBEX-HI and IBEX-LOW instruments are operating normally.

3.6.6 Data Operations (accessibility, quality control, archiving)

Data from the IBEX mission are served from the SPDF, and are readily available. Many forms of higher-level products are available, along with the original data. Data are all described in SPASE and listed in the HDP. Overall, the IBEX archive is in good shape.

Interpretation and utilization of ENA image data is heavily dependent on analysis process so completion of the stand-alone data package for the non-expert scientists, described in the plan, is essential for the long-term utility of the data. The mission should be encouraged ensure that resources are dedicated to this aspect of the project.

3.6.7 Proposal Weaknesses

A task proposed in the EM is to study the impact of merged interaction regions and global merged interaction regions on the ENA maps, which are output over 6-month time intervals. The proposal did not adequately address why the IBEX team expects a 6-month time cadence to be adequate to address these issues. Did the evolving knot in the northern portion of the ribbon evolve from any known solar disturbance?

The ENA backscatter from the interaction of the solar wind from the Moon is interesting, but the proposal did not present enough detail to understand why this interaction, along with the study of cometary tails, warrants the priority that was assigned to it in the EM proposal. Would the faint signals that are likely to be measured from cometary tails be likely to significantly impact our understanding of these objects? Such issues were not addressed in the proposal.

3.6.8 Overall Assessment and Finding

The IBEX mission, along with the Voyager spacecraft, is playing a key role in our evolving understanding of the structure of the outer heliosphere and its dynamics. The IBEX measurements are unique in their ability to explore the global structure of the heliosphere and its evolution over the solar cycle. The evolution of the ribbon and the spectra of the global distribution of ENAs over the solar cycle should help in unraveling the source of the ribbon and the spectrum of ENAs. A well-supported modeling effort will be key element in maximizing the scientific return on the IBEX investment.

Overall the IBEX extended mission proposal is compelling and the IBEX team has been highly productive during the PM stage of the mission. The large number of publications in top journals and the positive press that has come out of the IBEX mission support the conclusion of the Senior Review panel that the productivity of the IBEX science team has been high and will remain so in the EM phase.

Overall Grade. The IBEX extended mission proposal received a 7/10 median panel ranking for Overall Scientific Merit, placing its science merit in the upper end of the Excellent category. It received an Excellent ranking of 6/10 for Value to the HSO. The Panel recommends the continued operation of the IBEX extended mission.

3.7 RHESSI

3.7.1 Overview of the Science Plan

For the proposed extended mission, the RHESSI team proposes to use the existing hardware and mission data analysis and collection systems to investigate the high-energy consequences of the evolution of the Sun's magnetic field and its interaction with the plasmas detected near the Sun and the loci of high-energy events. No extensive modifications of the existing systems are requested, nor are changes in the operational support for mission operations. Thus the mission proposal focuses on the investigation of physical characteristics and physical properties as encountered in this phase of the magnetic activity cycle. The team clearly anticipates utilization of new results to be a valuable contribution to the discovery of new systems knowledge when combined with other results obtained from the HSO.

3.7.2 Science Strengths

The twin STEREO spacecraft are providing new perspectives of the Sun and heliosphere from orbits carrying the spacecraft from the Sun-Earth line. Having been launched as the Sun entered a deep solar minimum, STEREO has still been able to address a large range of solar and heliospheric problems. STEREO has been able to follow CMEs all the way from the Sun to 1 AU, where they could be sampled *in-situ*, showing that *in-situ* properties could be anticipated in advance, with the classic three-part structure preserved, and finding agreement with flux rope models. Heliospheric magnetic field topology is being probed with the discovery of counter-streaming electron beams associated with corotating interaction regions (CIRs). CIRs are further being probed by STEREO multipoint observations showing properties vary on short time scales. STEREO is finding continuing evidence of reconnection in the solar wind with signatures specific to reconnection at an X-line. Narrow band ion cyclotron waves have been observed in the solar wind for the first time, finding them to be ubiquitous. These waves are a potential source of solar wind heating energy farther out in the heliosphere. Another new and surprising result was the observation of impulsive solar energetic particle events with a longitude spread over more than 80° at 1 AU. STEREO is now at a separation angle of 140°. STEREO will soon be providing the first-ever complete coverage of the entire Sun. In the proposed extended mission, solar activity is expected to increase substantially over the levels seen at solar minimum. This will allow excellent prospects to study the two most critical science questions identified: characterizing the three-dimensional (3-D) structure of CMEs and the production and propagation of solar energetic particles; this will be done by combining data from the STEREO *in-situ*, imaging, and radio experiments. Some events will occur at longitudes that allow significant advances to be made from the two STEREO spacecraft alone. STEREO will also provide Solar System Space Weather benefits that Earth-based instrumentation cannot provide, will continue to investigate ion cyclotron waves and monoenergetic ion beams in the solar wind.

3.7.3 Relevancy Strengths to Heliophysics Research Objectives

RHESSI is the first and only imaging spectrograph viewing the Sun in the X-ray/gamma-ray spectral range. The mission has been highly productive throughout its lifetime, which has encompassed the maximum, declining phase, and subsequent deep minimum of the previous solar cycle. Although RHESSI is a mature mission that has observed numerous events, an extended mission would allow high-energy imaging spectroscopy of events in the rising phase of the magnetic activity cycle, which was not covered earlier in the mission. Hence, this extension is important for assessing the production and variability of seed populations for SEPs, among other scientific priorities. RHESSI is likely to produce both breakthroughs in and new challenges to our understanding of flares, their connection to CMEs, electron and ion acceleration mechanisms, and magnetic reconnection. Based on previous RHESSI results and recent theoretical developments, new research directions have been proposed for the extended mission: for example, determining why the thick-target model may not be adequate; testing recent reconnection models for electron acceleration in flares; and evaluating the predictions of stochastic particle acceleration models. Joint studies with missions such as Hinode, STEREO, SDO, ACE, and Wind will focus on important issues, including preflare conditions and triggering, the nature of sunquakes, and the connection between particles seen at the Sun and those observed as SEPs. For example, collaborative studies with ACE will measure the relative numbers of flare- and shock-accelerated particles at the Sun and at 1 AU, in individual eruptive events, allowing the relative importance of different acceleration mechanisms at the Sun and in transit to 1AU to be determined. The continuing high-quality solar oblateness measurements are novel, and will place important constraints on possible core rotation and any solar cycle dependence. During the extended mission, synergy with newer missions (e.g., SDO, Hinode, STEREO) is likely to yield new insight into rapid and highly variable particle acceleration in solar eruptions because the increased temporal and spatial resolution of the newer data will be more consistent with RHESSI's high-cadence capabilities than earlier solar missions. In addition, the coronal plasma and magnetic environment changes markedly from minimum to maximum, in a way that is not simply reversed during the decay phase of the cycle.

An extended RHESSI mission would make great strides toward answering the following key questions:

1. What is the role of suprathermal solar particles in shock-accelerated SEPs, and how are they generated? During solar minimum, the background coronal particle distribution is largely unaffected by eruptive activity, so few suprathermal particles are expected. Therefore CME-driven shocks during the early rise phase are expected to encounter fewer suprathermal particles than those occurring closer to maximum. At the peak of the cycle and well into the declining phase, the ambient suprathermal population at a given location probably depends critically on the timing, location, and magnetic connectivity of nearby prior flares. Hence the amount of seed particles available for shock acceleration may well be dictated not only by solar origin but also by the phase of the solar cycle.

2. How do flare-accelerated particles escape rapidly from the Sun? Particles accelerated at the Sun during flares can escape quickly into the heliosphere only if they can reach open field lines. How this is achieved within the impulsive timescale of typical flares is far from understood, at present. Near minimum, the demarcation between open and closed magnetic flux is relatively uncomplicated, so the escape probability of flare-accelerated particles should be highest for high-latitude events near the polar hole boundaries. Near maximum, when transient coronal holes abound, the topological intricacy of flaring regions makes the escape problem much more complex. These speculations can be tested only by analyzing RHESSI data, in conjunction with the high-cadence magnetic field and plasma data from SDO and other HSO missions, for a full solar cycle. RHESSI is Heliophysics' only probe of flare/CME particles at the Sun; without this information, instruments at L1 alone will be unable to shed much light on the origin and transport of SEPs. The RHESSI team is commended for continually improving existing routines and developing new capabilities in reduction/analysis software, in order to extract maximum return from (and confidence in) the data.

3.7.4 Value to the Heliophysics System Observatory

Strengths

RHESSI is the only active mission capable of imaging the high-energy flare emissions and deriving their time-varying spectra. It is unlikely that an equivalent mission will exist by the next solar cycle. RHESSI plays a unique role within the HSO, enabling system-wide studies of energy release and particle acceleration in flares/CMEs and their effects on the interplanetary medium, magnetosphere, and ITM. RHESSI probes the particle population at the Sun, while observations by other HSO components are required for context and full studies of the origin of solar eruptions. Pertinent portions of the Roadmap for the RHESSI mission include Research Focus Area F1, F2, H1, H3, J1, J2; also Priority Science Target STP #6.

Weaknesses

No major weaknesses. Many events have been observed in coincidence with ACE, Wind, and SOHO over the past 8 years, so a substantial multi-mission database has been collected already.

3.7.5 Spacecraft / Instrument Health and Status

All systems are operating nominally, except for one of the nine detectors. Although the serious RHESSI power anomaly in March 2010 remains unexplained, its cause is being investigated, preventative steps have been developed, and the system is nearly restored to its previous operational state. The primary issue is the need for detector annealing, which has been implemented twice and can be carried out only once or twice more. This could eventually limit the mission lifetime, but is unlikely to be necessary during the extended mission.

3.7.6 Data Operations (accessibility, quality control, archiving)

Level-0 data are made available to the community in a timely manner. The data are inherently complex and require substantial processing to yield physical properties. Analysis software, written in the IDL language, is easily accessible to the Heliophysics community via SolarSoft. Documentation is online at the RHESSI data center, which also provides rapid response to e-mail questions about the software and data. The RHESSI team has put considerable effort into developing an alternative strategy, to avoid the need to continually reduce the Level-0 observations and to eliminate dependence on SolarSoft/IDL. Their solution—saving the data as "visibilities"—is well motivated and sound. The RHESSI Mission Archiving Plan is well developed and carefully thought out. However, there seems to be no plan to archive the calibration data, which is problematic as there may be further advances which could improve the data if only the calibrations were still available. Apart from this gap, the current and future access to, and utility of, these data seem well assured. The final data products to be stored post-mission will include data at many different levels, from easily used quick-look to the far more complex raw data. The RHESSI team will review and revise the final documentation, and prepare data sets for the Resident archive at SDAC with VSO access, and for the NSSDC.

3.7.7 Proposal Weaknesses

In view of the large flare dataset already acquired by RHESSI, more detailed justification for obtaining additional flare data during the rise phase of Solar Cycle 24 would have been appropriate. A stronger connection with modeling (other than data-analysis software) would enhance the physical insight to be gained from RHESSI observations, in light of increasing computational resources/

capabilities and increasingly sophisticated numerical models of particle acceleration and eruptive flare/CME initiation.

A feature of this mission is that the S/C is located in a Low Earth Orbit (LEO) so that the duty cycle has modulation of the data stream by the day/night orbital cycle as well as rotational modulation by the Sun. This restricts the total observing time for any given active region. This is neither a weakness nor a disadvantage, simply a feature of the mission design.

3.7.8 Overall Assessment and Findings

The panel solidly recommends RHESSI for an extended mission. Now that solar activity finally appears to be on the rise, RHESSI should be able to obtain sufficient data to verify and potentially explain some of the puzzling discoveries of the last cycle: e.g., the apparent separations between electron and proton foot point sources, the apparent equipartition of particle and magnetic energy in loop top sources, the apparent correlation between the evolving shape of the high-energy flare spectrum and the production or absence of SEPs. In addition, synergy between RHESSI and several other Heliophysics missions, including SDO, STEREO, ACE and Hinode, will greatly augment our understanding of the initiation and evolution of solar eruptions and the associated energetic particles. No other Heliophysics mission exists or is planned for the foreseeable future that duplicates or supersedes RHESSI, or replaces its role within the HSO. The data archiving plans are conscientious and far-sighted.

Overall Grade. The RHESSI extended mission proposal received a 7/10 median ranking from the panel for Overall Scientific Merit, placing it in the Excellent category. Its median Panel ranking for Value to the HSO is 6/10, also solidly in the Excellent category. The Panel recommends the continued operation of the RHESSI extended mission.

3.8 SOHO

3.8.1 Overview of the Science Plan

In its proposal for seventh extended mission, SOHO team outlines three main goals covering several broad areas of heliophysics. The first goal is to provide visible light coronagraphy along the Sun-Earth line for the HSO. (This goal is relevant to NASA's Roadmap areas H1, J2 and J3.) This includes operating the LASCO coronagraph through at least FY2018 and providing data with sufficient cadence for both scientific research and space weather prediction, although the proposal provides no description of the science planned. The second goal is to continue enabling long-baseline and space weather-relevant science with European-led investigations. (This goal is relevant to Roadmap areas F2, F3, H1, H3, J2, and J3.) To address this goal, the SOHO team will continue Variability of Solar Irradiance and Gravity Oscillations (VIRGO) observations pertinent to the Total Solar Irradiance (TSI) and extend the measurements to current Solar Cycle 24. Observations from SWAN will continue to be supplied to models predicting UV irradiance and its effects on Earth's atmosphere (important for modeling of atmospheric drag for LEO satellites). Observations from Global Oscillations at Low Frequencies (GOLF) will be used to confirm the presence of quasi-biennial variations in low-degree modes and to continue search for g-modes. Extending the GOLF operations through two solar cycles will significantly improve the identification of low-degree p- and g-modes. SOHO/CELIAS/MTOF data will be used to investigate the small-scale variations in solar wind, and to establish the solar source of these microscopic fluctuations. Near real-time CELIAS/MTOF Proton Monitor data are critical for the energetic particle events. The Comprehensive Suprathermal and Energetic Participle (COSTEP)/Electron Proton Helium

Instrument (EPHIN) and Low Energy Ion and Electron Instrument (LION) instruments aboard SOHO will be used in multi-spacecraft observations of near-relativistic electrons. These additional observations will be used to investigate the importance of perpendicular transport of electrons by diffusion. Data from CELIAS MTOF and SEM will be collected to address the third goal of the proposal, i.e., the continuation of robust solar wind proton and EUV irradiance measurements (Roadmap areas H1, H3, J3). Much of the data collected to address all three goals during this extended mission will be used in supporting operational space-weather forecasts and research projects relevant to space-weather prediction.

3.8.2 Science Strengths

Strengths

SOHO data continues to serve as the basis for numerous investigations in solar and heliospheric physics. While no funding in the proposal is requested for science analysis of data, the continuing operation of SOHO will enable several European instruments on-board to provide additional data. Due to its unique location, SOHO instruments can provide data important for studies of Earth-directed CMEs, solar energetic particles, and solar wind. Long-term series may provide improvements in the potential identification of g-modes, and enable investigations of solar cycle variations in total solar irradiance (TSI) and spectral irradiance, which may lead to a better understanding of current Solar Cycle 24. The past science impact from this mission has been major. SOHO science data shaped the current knowledge of many solar processes and paved the way to several follow-up NASA missions. The science goals for the next extension are realistic and potentially important.

Weaknesses

The description of specific scientific plans is somewhat vague. It is not clear why new observations are needed to accomplish some of the stated goals. The first prioritized goal has no description of scientific research, but emphasizes instead the utility of the data for space weather applications. The second broad goal discusses potentially important science, but the proposal fails to provide sufficient justification for continued observations, above and beyond the use of existing data.

The third science goal will be curtailed to only one year (FY2014); further continuation will require additional funding. The strongest component of the proposed activity is relevant to the data-provider function of SOHO instruments for operational space weather forecasts. While the Panel recognizes the immense operational value of these data, the data-provider function is largely outside of scope of a NASA Heliophysics research mission.

3.8.3 Relevancy Strengths to the Heliophysics Research Objectives

Strengths

The research is relevant to Heliophysics objectives as described in the most recent Heliophysics Roadmap. Proposed scientific research areas address number of Roadmap focus areas including: H1, H3, J2, J3, F2, and F3.

- LASCO is an important asset for the Heliophysics Great Observatory. It provides unique (white-light and polarization brightness) images of the solar corona.
- Data from SWAN (farside coronal Ly α imaging) have been used to develop methods to predict the EUV/UV flux from the Sun.

- Data from MTOF instrument in the CELIAS investigation provide near-real time proton monitor measurements of solar wind speed, density, thermal speed, and North-South deflection angle during intense SEP events. These data are more robust than similar data from ACE.
- CELIAS SEM provides broadband EUV flux measurements that are useful for tracking throughput changes in SDO/EVE.

Weaknesses

The continuation of SOHO operations as a research mission is not strongly justified by the proposed research plans. While the space weather data-provider function is important, it is only weakly relevant to the Heliophysics research objectives.

3.8.4 Value to the Heliophysics System Observatory

SOHO instruments continue to provide imaging and *in-situ* data highly relevant to the Heliophysics System Observatory. SOHO data are often used in multi-spacecraft observations of CMEs and particle events. Calibrated past data are merged with data from instruments on other NASA missions to form extended series needed for studies of long-term processes (e.g., solar cycle).

3.8.5 Spacecraft / Instrument Health and Status

The spacecraft, and instruments needed for the extended mission, are operational and no significant problems were identified. On-board instruments that are not required for the extended mission will be (or are already) shut down. The Michelson
Doppler Imager (MDI) is in working order and could be reactivated, but it would be impractical because of anticipated high cost. The Extreme Ultraviolet Imaging Telescope (EIT) operates in low cadence mode (two daily 4-wavelength series). LASCO, SWAN, and GOLF are fully operational. The Ultraviolet Coronagraph Spectrometer (UVCS), Colronal Diagnostic Spectrometer (CDS), and Solar Ultraviolet Measurements of Emitted Radiation (SUMER) are not operational or are ending operations. SOHO operations are fully automated (risk mitigation is in place and adequate).

3.8.6 Data Operations (accessibility, quality control, archiving)

There is ready and easy public access to data from all instruments and the data are consistently calibrated. There is a good plan for archiving and preserving the data. The evaluation of the data operations is described in the Appendix: Mission Archive Plan.

3.8.7 Missing Proposal Weaknesses

The budget in FY2015 and beyond is insufficient and presents a high degree of risk for continuing operation of the mission. Furthermore, additional funding will be required in FY2014–15 to convert the SOHO spacecraft simulator to a sustainable platform and to satisfy the Information Technology (IT) security requirements. Achieving one of the three science goals requires additional funding beyond FY2014.

3.8.8 Overall Assessment and Findings

Although the budget is relatively low compared to other missions, the Senior Review panel finds that the case for additional scientific observations is insufficiently supported by the proposal to justify the cost of continuing to operate the spacecraft. Much of the proposed science can be accomplished using existing SOHO data and do not necessitate the new observations from the SOHO spacecraft. Some data (e.g., solar wind measurements) can be replaced (at least partially) by monitors on other NASA spacecraft. The Panel recognizes the importance of the LASCO coronagraph for the space weather monitoring, but recommends that the funding for continuation of LASCO operations should be provided from funds outside of the Heliophysics MO&DA program.

Overall Grade. The SOHO extended mission proposal received a median ranking of 3/10 from the panel for Overall Scientific Merit and a 5/10 median ranking for Value to the HSO.

3.9 STEREO

3.9.1 Overview of the Science Plan

The twin STEREO spacecraft are providing new perspectives of the Sun and heliosphere from orbits carrying the spacecraft from the Sun-Earth line. Having been launched as the Sun entered a deep solar minimum, STEREO has still been able to address a large range of solar and heliospheric problems. STEREO has been able to follow CMEs all the way from the to 1 AU, where they could be sampled *in-situ*, showing that *in-situ* properties could be anticipated in advance, with the classic three-part structure preserved, and finding agreement with flux rope models. Heliospheric magnetic field topology is being probed with the discovery of counter-streaming electron beams associated with corotating interaction regions (CIRs). CIRs are further being probed by STEREO multipoint observations showing properties vary on short time scales. STEREO is finding continuing evidence of reconnection in the solar wind with signatures specific to reconnection at an X-line. Narrow band ion cyclotron waves have been observed in the solar wind for the first time, finding them to be ubiquitous. These waves are a potential source of solar wind heating energy farther out in the heliosphere. Another new and surprising result was the observation of impulsive solar energetic particle events with a longitude spread over more than 80° at 1 AU. STEREO is now at a separation angle of 140°. STEREO has provided the first-ever complete coverage of the entire Sun. In the proposed extended mission, solar activity is expected to increase substantially over the levels seen at solar minimum. This will allow excellent prospects to study the two most critical science questions identified: characterizing the 3-D structure of CMEs and the production and propagation of solar energetic particles; this will be done by combining data from the STEREO *in-situ*, imaging, and radio experiments. Some events will occur at longitudes that allow significant advances to be made from the two STEREO spacecraft alone. STEREO will also provide Solar System Space Weather benefits that Earth-based instrumentation cannot provide, will continue to investigate ion cyclotron waves and monoenergetic ion beams in the solar wind.

3.9.2 Science Strengths

Given the delayed onset in solar activity for Solar Cycle 24, STEREO is more reliant than ever on near-Earth observations (e.g., ACE, Wind, and SOHO) to make the most out of investigations into the key science questions of the 3-D structure of CMEs and the production and propagation of solar energetic particles. In conjunction with near-Earth observations, STEREO will be well placed to conduct limb/line-of-sight studies of both phenomena, giving ideal limb observations of CMEs that will encounter Earth and similarly sources of SEPs will be ideally viewed from one observatory while being well connected to another observatory. Studies of the interstellar helium focusing cone will be another area for overlap with other missions. The STEREO WAVES (SWAVES) experiment will also have good synergy with the Wind/WAVES experiment for triangulating CMEs.

The unique vantage points and complete instrumentation continue to provide significant new capabilities to address Stereo's initial prime goals related to understanding 3-D CME morphology and SEP events. The ever-changing perspectives leverage the advantages that various separations and angles enable, and the delayed solar minimum has allowed the development of additional analysis techniques. In addition, the successful deployment of the Van Allen Probes expand opportunities to utilize STEREO to investigate the influence of solar modulating inputs on the Earth's environment and will expand opportunities for advances in space weather research projects and programs.

STEREO benefits significantly from being well instrumented and from the unique vantage points of the observations. This enables well-established methods of analysis to be applied to 'new' data, thus opening the door to advances. The geometry of the observations provides a natural and ingrained methodology for much of the extended mission science. The slow build-up of solar activity has also enabled various groups to make advances on their 3-D imaging techniques that can now be applied with confidence to events observed during the extended

3.9.3 Relevancy to the Heliophysics Research Objectives

STEREO is very much a 'Great Observatory' mission, especially in the extended phase. Its relevance to other solar, as well as planetary and interplanetary, missions is unquestionably high. It spans from near-Earth solar and interplanetary (i.e., SOHO, SDO, ACE, Wind, and IBEX) to planetary (i.e., Messenger, Venus Express, Mars Express, and MAVEN). As much as STEREO will benefit from SOHO, ACE and Wind, those missions will benefit from STEREO's complement of instruments and side-view perspective. The planetary missions will get three times the opportunity to have conjunctions and oppositions with well-instrumented spacecraft than they do now, when only near-Earth instrumentation is available. By utilization of new results from the Van Allen Probes, it is expected that there will be new advances in understanding of the coupling of solar-generated variability in radiation, fields, and particles that will enable advanced predictive capability for space weather researchers.

In examining the Heliophysics Roadmap, STEREO contributes to virtually all of the appropriate Research Focus Areas, addressing 10 out of 12 RFAs in the three goals of Open the Frontier to Space Environmental Prediction, Understand the Nature of Our Home in Space, and Safeguard the Journey of Exploration.

3.9.4 Value to the Heliophysics System Observatory

The magnetic variation of the Sun drives the solar system. Therefore the widest possible view of this magnetic variable star is fundamental and vital to the investigation of the system behavior. The complement of instruments, both remote sensing and *in-situ*, will provide a pair of viewpoints for observers never before available to observers constrained to the Earth-Sun line—SOHO, ACE, Wind, SDO, Hinode, and the GOES spacecraft—so that the variability of the surface of the star can be studies and understood in three dimentions.

3.9.5 Spacecraft / Instrument Health and Status

The spacecraft and instruments are generally healthy, with the few problems noted below addressed via mitigation strategies. The spacecraft is healthy, with the one exception of having to switch to a backup X-axis inertial measurement unit on STEREO-A, and the satellite can operate even with total failure. The IMPACT LET, HET, SIT, and SWPT sensors are healthy. The IMPACT STE-U instruments have never returned data. The STE-D and SWEA mitigate some of the impacts of the loss. IMPACT SWEA has lost sensitivity to lower-energy electrons (<45 eV). This has minimal impact since Level-1 requirements are met with energies >50eV. The Plasma and Suprathermal Ion Composition (PLASTIC) instrument is healthy. The Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) instrument experiences 'watch dog' resets periodically, resulting in some lost observing time. About 14 resets have occurred on each spacecraft over the life of the mission. S/WAVES-A is functioning normally. S/WAVES-B data have interference at 16 and 100 kHz. This limits three-antenna direction finding to only strong events. Time-of-flight direction finding and Wind/WAVES direction finding mitigate this problem.

3.9.6 Data Operations (accessibility, quality control, archiving)

STEREO data are easily accessed and available through the VSO and the STEREO Science Center, and software to process and analyze the data is available in the SolarSoft IDL software tree, a condensation of hundreds of person-years of software for analysis of Heliophysics missions. Documentation for the instruments and data is generally accessible on the Internet; however, documentation is still lacking for certain aspects of S/WAVES. There is a legacy archive plan for the remote sensing instruments in place, but there is no plan for the *in-situ* teams.

3.9.7 Proposal Weaknesses

Competition for the Deep Space Tracking assets is forecast to remain intense over the next 2 years. While some data have been lost due to competing mission conflict and equipment reliability, a remarkably good job of utilization of tracking assets has minimized this feature of the mission operation. This is essentially a feature of the STEREO mission operating in the complex infrastructure of NASA's DSN system. It is not specifically a weakness as much as a situation to be managed and optimized as best possible. Over the past 6 months some data have been lost because of unresolvable conflict.

3.9.8 Overall Assessment and Finding

The STEREO mission is a strong participant in the HSO, providing unique data that mesh well with virtually every solar, planetary, and interplanetary mission. The science return from the mission's own instruments has been commensurate with expectations, but future returns appear to need the rest of the HSO with every greater frequency as time goes on. The costs of science, operations, and mission operations, are relatively high. The total productivity of the mission has been very high, however. As the solar cycle ramps up, the focus on STEREO will increase, as the main objectives of the mission are activity related and considerable scientific progress is expected.

Overall Grade. STEREO received a 7/10 median grade from the Senior Review panel for Overall Scientific Merit, earning the extended mission a ranking of Excellent. It received a median grade 8/10 for Contributions to the HSO, earning a Compelling ranking.

3.10 THEMIS

3.10.1 Overview of the Science Plan

1. Overview of the Science Plan (as addressed by the mission's own instruments):

The THEMIS extended mission Primary Science Goal #1 (PSG#1) is based upon a reconfiguration of the three inner probes to become three of the vertices of a tetrahedron with MMS at the fourth vertex. The two THEMIS/Artemis probes will continue their lunar orbit to study magnetotail and "pristine" solar wind data. THEMIS will continue to focus on the same general magnetospheric science questions as the prime and first extended missions (substorms and dayside physics including foreshock physics) but will be repositioned to provide exciting "cross-scale" observations with the Van Allen Probes and MMS that will greatly extend the science output of these other Heliophysics observatories by simultaneously providing measurements of plasma processes on two spatial scales. In combination with the Van Allen Probes, THEMIS also contributes significantly to inner magnetospheric physics questions regarding storms and radiation belt physics.

The PSG#2 option does not coordinate as closely with MMS, but would raise the apogee of the three inner probes in order to take advantage periodic radial alignments of the two Artemis probes at lunar orbit in the magnetotail lobes, the three inner probes, MMS, and the Van Allen Probes at different distances down the magnetotail in order to observe tailward and earthward propagation of mass, flux, and energy due to reconnection. When this magnetospheric HSO constellation has its apogees on the dayside, they will be able to sample the "pristine" solar wind, the foreshock, the magnetosheath, and inside the magnetosphere.

2. Overview of the Science Plan (as addressed in conjunction with observations from other Heliophysics missions):

As stated above, PSG#1 focuses on using THEMIS in an exciting coordinated way with MMS and Van Allen Probes to provide *in situ* observations at key regions simultaneously to understand energy, mass, and momentum flow throughout the system. The tetrahedron configuration with MMS will allow the simultaneous study of electron (MMS) and MHD (THEMIS) scales of the reconnection region.

3. Overview of the Methodology:

The position of the three inner probes will either be moved to coordinate specifically with MMS (PSG#1) or will have their apogees raised to be in radial alignment resonance with MMS (PSG#2). The science goals require implementing tetrahedral spacecraft alignments so that studies of cross-scale dynamics of the reconnection region can be performed (PSG#1) or radial alignments to observe mass, momentum, and energy flow earthward and tailward from reconnection regions in the mid-tail region. For dayside alignments, studies of foreshock structure and its relationship to the transport of energy and momentum into the inner magnetosphere will also be possible. With the raised apogee, the THEMIS mission will also study reconnection on the flank magnetosphere. The fuel required to align the spacecraft for PSG#1 will consume the reserves that would be required for PSG#2. Thus the alignments required to pursue PSG#1 and PSG#2 are mutually exclusive, and only one can be implemented.

3.10.2 Science Strengths

Scientific and Technical Strengths

The THEMIS Extended mission will provide unique opportunities for multi-spacecraft observations in key regions of the magnetosphere to study substorms, reconnection, and ring current and radiation belt physics. With the full complement of THEMIS instruments, they provide plasma and field observations critical for understanding energy and momentum flow in the magnetotail and from the solar wind into the inner magnetosphere. The experience with Artemis provides confidence in the mission team to plan, coordinate, and implement the spacecraft maneuvers proposed to develop a “cross-scale” THEMIS/MMS configuration during both phases of the MMS mission. Current studies with Van Allen Probes also demonstrate the complementary nature of inner magnetosphere with near-Earth plasma sheet observations for understanding the role of mid-tail reconnection on substorm dynamics and radiation belt physics.

The work done in the first extended mission to better understand the energetic particle detector responses in the inner magnetosphere, the 3-D electric field measurements, and the community software development and training all give confidence that the THEMIS measurements will provide valuable data from important regions of the magnetosphere to help place the MMS and Van Allen Probes data into context. The THEMIS mission science objectives attack fundamental questions in mid-tail substorm physics and dayside foreshock physics in their own right, but with the timely and coordinated PSG#1 objectives clearly make a powerful HSO mission constellation to study magnetosphere-ionosphere dynamics.

Scientific and Technical Weaknesses

No science or technical weaknesses identified.

3.10.3 Relevancy Strengths to the Heliophysics Research Objectives

The THEMIS Extended mission concept directly addresses two science targets of the last NASA Heliophysics Roadmap: (1) Understand the origin and transport of terrestrial plasma from its source to the magnetosphere and solar wind, and (2) Understand how magnetospheric dynamics provides energy into the coupled ionosphere-magnetosphere system. The multi-spacecraft measurements of plasma, energetic particles, and fields in different regions of geospace (inner magnetosphere, magnetotail, flanks, magnetosheath, foreshock, and pristine upstream solar wind) directly address NASA Heliophysics Research Objectives.

3.10.4 Value to the Heliophysics System Observatory

Strengths

The THEMIS Extended mission proposal is a HSO proposal. It is innovative in seeking not only serendipitous science opportunities with Van Allan Probes and MMS, but actually has designed an extended mission to coordinate the new THEMIS orbits to provide a “cross-scale” mission to study the global and kinetic physics of reconnection. The extended mission addresses tail physics, flank magnetopause physics (Kelvin-Helmholtz instabilities and reconnection physics), dayside foreshock physics, and inner magnetospheric radiation belt and ring current physics. The complement of plasma and field instruments on THEMIS provide important information about plasma flows, energetic particle populations, and electric and magnetic fields in key regions of the system. In combination with other HSO assets, essentially all of the key regions of the magnetosphere are sampled simultaneously at high time resolution, enabling the resolution of a number of long-standing space physics questions.

Weaknesses

None noted.

3.10.5 Spacecraft / Instrument Health And Status

The proposal states that all spacecraft systems continue in nominal operation, except for one of the P1 electric field probes. However, the E field data from this spacecraft are still usable.

3.10.6 Data Operations (accessibility, quality control, archiving)

Data management and accessibility are exemplary. The high productivity of the THEMIS mission to date is in part a direct result of this situation. In addition, the development and adoption of a data analysis system that allows other missions and instruments to “plug in” easily has allowed true cross-mission collaboration already with the Van Allen Probes and is planned with MMS. The outreach to the community for training at workshops has been exemplary.

Strengths

The Panel endorses the findings of those experts and refers the project management and instrument teams to the appropriate Appendix of the review for more details.

Weaknesses

None

3.10.7 Proposal Weaknesses

The Panel found no Scientific or Technical Weaknesses. The concept is exciting, the spacecraft are in excellent health, and the data operations and management exemplary. The only weakness is the need for additional funds beyond the in-guide budget within a severely constrained Heliophysics budget.

3.10.8 Overall Assessment and Findings

1. The THEMIS extended mission concept to achieve cross-scale science goals is an innovative and exciting idea that the Senior Review enthusiastically supports. The proposed alignment of the three THEMIS inner probes with the MMS constellation to form a nested tetrahedron would enhance MMS science and provide MHD-scale context for MMS microscale measurements. This Prioritized Science Goal 1 of the new extended mission would enable true HSO studies using the Van Allen Probes, MMS, THEMIS (including the former Artemis pair in lunar orbit), and Wind/ACE. Reconfiguration of THEMIS spacecraft requires practically immediate planning to be successful, and the Panel encourages the THEMIS team to work with NASA and upcoming future missions to find a means of implementing it.
2. The Senior Review applauds the THEMIS team’s exemplary science data plan, development of a community-wide data analysis suite that allows multiple missions and instrument teams to easily develop “plug in” components, providing community-wide training workshops to use the software, and for providing high-quality data repositories with the necessary documentation and analysis tools for broad community use.

Overall Grade. The THEMIS extended mission proposal received an 8/10 median ranking from the Panel for both Overall Scientific Merit and Value to the HSO with both contributions considered Compelling.

3.10.9 Extended Mission Cost Review

The funding plan for PSG#1 requires a $950K increase to the “modified/corrected” guide budget, but is modest for the potential scientific return of a coordinated THEMIS/MMS cross-scale configuration. The PSG#2 plan will provide crucial data to understand mid-tail dynamics, foreshock physics, and flank reconnection studies.

3.11 TIMED

3.11.1 Overview of the Science Plan

The Thermosphere, Ion, Mesosphere, Energetics and Dynamics (TIMED) spacecraft was launched in 2001 into a 625 km circular 74.1-degree inclination orbit. TIMED uses four remote sensing instruments—Sounding of the Atmosphere using Broadband Emission Radiometry (SABER), Solar EUV Experiment (SEE), Global Ultraviolet Imager (GUVI), and the TIMED Doppler Interferometer (TIDI)—to measure the temperature, composition, dynamics, and energetics of the ionosphere, thermosphere, and mesosphere (ITM) and serves as the “terrestrial anchor” (along with AIM) of NASA’s HSO. This region is the interface to the lower atmosphere and is influenced directly by solar and magnetospheric forcing. The ITM region is relatively free of the more complex feedback mechanisms in the lower atmosphere (ocean, ice, clouds) and is an ideal region to look for the early effects of global change. The mission has amassed a significant database of these measurements from the second half of the previous solar cycle, SC-23, (which had an extremely low activity tail) and up to the peak of SC-24 (an extraordinarily low peak). The experimenters now propose to produce a set of ITM measurements for the second half of SC-24 and examine them in the context of terrestrial forcing. The length of that database would allow examination of decadal-scale changes and global change.

For the Extended Mission the experiment team has developed the following PSGs:

1. Characterize, compare, and study ITM drivers and response differences between SC-23 and SC-24;
2. Determine and understand long-term decadal-scale changes in the ITM;
3. Explore new TIMED science topics arising from HSO Collaborations:
    - Hydrogen escape
    - Polar mesospheric clouds: signatures of atmospheric coupling
    - Exploring connections to the Inner Magnetosphere

The proposal contains a comprehensive list of 26 Key Science Questions to help focus their investigation on each PSG.

3.11.2 Science Strengths

For the latter half of SC-23 and through the maximum of SC-24 the TIMED mission has provided a significant database of ITM variability and allowed numerous investigations of the composition, dynamics, and energetics of this region in response to a range of solar, geomagnetic, and lower atmosphere forcings. Observations from the mission have revealed the importance of forcing from below (gravity waves, tides, sudden stratospheric warmings, etc.) during a time of anomalously low solar activity. The science team has been able to document the effects of increased greenhouse gases and has shown, for example, that the fixed-altitude density of the thermosphere and ionosphere has lowered in response to increased radiative cooling. PSG1 will allow extension of these investigations through a complete SC-24 to provide comparisons to the observations from SC-23—with a background of increasing greenhouse gases.

PSG 2 focuses on using the continuous long-term characterization of the state variables of the ITM to study decadal-scale changes to this region and study the long-term effects of the buildup of greenhouse gases in the context of a full solar cycle and a half, thereby helping to separate the two effects. This activity will provide additional new insights into the connections between the ITM and tropospheric weather and climate. A major challenge for ITM investigations of global change has been to separate these effects from a large amplitude solar cycle. The TIMED science team has a rare opportunity to separate these effects. The TIMED team has already made discoveries in this area and the proposed extension is focused on further investigations separating the two forcings.

PSG 3 provides a comprehensive system science approach multiple spacecraft including:

- Ionosphere drivers: COSMIC, CNOFS/CINDI; SDO, Wind, ACE, THEMIS, Van Allen Probes
- Polar mesospheric clouds and minor constituents: AIM
- Terrestrial forcing: Aura, Aqua, TRMM, Jason 1&2, COSMIC
- Hydrogen escape: TWINS

The TIMED orbit allows sampling at all local times and is suited for collaboration with other ITM platforms.

The proposed extended mission directly addresses all four challenges for Atmosphere-Ionosphere-Magnetosphere Interactions (AIMI) from the 2012 National Research Council Heliophysics Decadal Strategy (HDS).

3.11.3 Relevancy Strengths to Heliophysics Research Objectives

TIMED, along with AIM, is the terrestrial anchor of the NASA's HSO, and as such provides the majority of the "to Earth" link of the "from Sun to Earth" connection. TIMED data provide for improved understanding of the fundamental processes of the space environment, which is the primary Heliophysics Research Objective. Relevance, continued progress, and advancements in space physics of the TIMED mission relative to heliophysics have recently been documented in the HDS report. Particular strengths of the TIMED mission relate to an improved understanding of couplings between the ionosphere and upper atmosphere and changes caused by solar activity, understanding the role of the Sun as an energy source to the atmosphere, and separating the effects of terrestrial forcing from solar forcing.

3.11.4 Value to the Heliophysics System Observatory

TIMED, together with AIM, provide the terrestrial end of the Sun-Earth chain and illustrate the response of the Earth to solar forcing. TIMED and AIM data provide insights into polar mesospheric cloud physics and evolution and gravity wave forcing from below to aid in studies of global change in the context of solar forcing. Solar irradiance data from the SEE instrument are used to cross-calibrate and validate measurements from other solar platforms. The long-term database of TIMED, across more than one solar cycle, helps complete the time series from other HSO platforms.

3.11.5 Spacecraft / Instrument Health and Status

The spacecraft and instruments are showing their age but appear to be capable of supporting the PSGs as planned. The SABER instrument appears to be in the best health and is the primary instrument for the extended mission. The GUVI instrument can no longer scan across the limb and is used in spectrographic mode at 30 degrees off nadir. The TIDI performance has improved from what it was during the early orbit, but the PSGs do not depend strongly on it. The SEE instrument has only a 3% duty cycle. Table I gives a summary of the TIMED instruments, their observing parameters, and their current status.

TIMED

Element	Type	Obs Parameters	PI	Status
Spacecraft			Sam Yee	Operational, aged, but likely to complete extended mission
SABER	IR Limb scanner	O_3, H_2O, CO_2, O, H mixing ratios CO_2 15. 4 and 4.3 µm, O_3 9.6 µm, NO 5.3 µm, H_2O 6.8 µm, OH 2.0 and 1.6 µm emission rates Solar and chemical heating rates, IR cooling rates	Chris Russell	Operational - excellent
SEE	Solar EUV/FUV	Solar spectral irradiance from 0.1 to 194 nm	Tom Woods	Operational – filter wheel anomaly 3% duty cycle
GUVI	FUV Nadir – limb scanner	Thermospheric Day T, O, N_2, O_2, O/N_2	Andy Christensen	Scan mechanism failed (30 deg off nadir) spectrographic mode
TIDI	630 nm Doppler interferometer	Horizontal vector winds, $O_2(1\Sigma)$ airglow emission rates	Wilbert Skinner	Operational – improved since early orbit

3.11.6 **Data Operations** (accessibility, quality control, archiving)

The TIMED spacecraft has been in orbit for a dozen years and the data processing is fairly autonomous, quality control is good, and Johns Hopkins University's Applied Physics Laboratory (JHU/APL) archives the data. SABER requires the majority of the labor and is consuming most of the budget. Neither the proposal nor the presentations were clear about the balance between data processing and research and analysis.

While data are well preserved, useful, and available, the documentation of how to read them, and what the variables mean, needs improvement. Although there has been some planning for the final archive with SPDF, the current plan seems to be to wait until the last minute and then deliver. More of a continuous archive process is needed. There are issues with the uniformity of metadata with the TIMED NetCDF, which need to be resolved in the context of a final archiving plan. The team should be encouraged to complete the GUVI reprocessing.

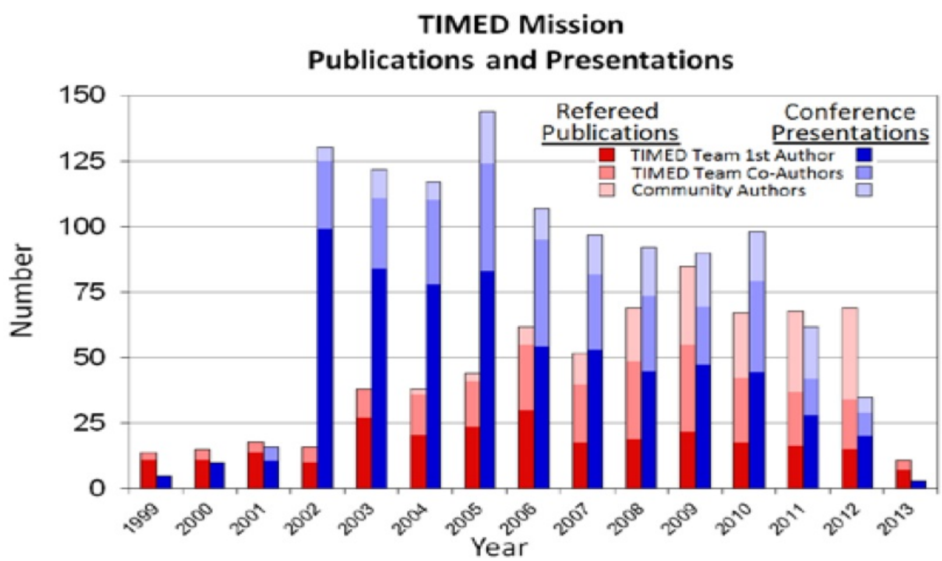
3.11.7 Proposal Weaknesses

The SABER instrument is the primary instrument of the extended mission. The role of the other instruments (TIDI, SEE, and GUVI) is limited. SEE has only a 3% duty cycle and GUVI can view at a single look angle.

3.11.8 Overall Assessment and Findings

In its 12-year lifetime the TIMED mission has produced a significant set of coordinated specifications of the state variables and variability of the ITM from an extended solar minimum of SC-23 to the peak of SC-24. TIMED is the "terrestrial anchor" of the HSO and has revealed how the ITM is driven from the Sun and magnetosphere as well as from various forms of terrestrial forcing. The decadal length of the database is providing important insights into terrestrial forcing and global change. The proposed extension reveals the versatility of TIMED and takes the mission in a totally new direction to examine in detail solar and global climate change forcing of the ITM and makes extensive use of system science with multiple spacecraft.

The publication rate, especially from investigators outside the TIMED team, is significant and stable and even growing as shown in the figure below.



Overall Grade. The TIMED extended mission proposal received a 7/10 median ranking from the Panel for Overall Scientific Merit, placing its intrinsic science contributions at the upper end of the Excellent category. Its Value to the HSO received a median panel ranking of 6/10 and solidly in the Excellent category.

3.12 TWINS

3.12.1 Overview of the Science Plan

Since the previous review the TWINS team has developed new analysis tools to extract information on the precipitating ion fluxes, assess the angular and spectral distributions of the ring current ions from the STEREO Energetic Neutral Atom (ENA) images and extraction of information on the geocoronal hydrogen distribution and temporal dynamics. These have led to significant findings—such as the local time dependence of ion pitch angle distributions, continuous imaging of ion spectra, and space-time dependences in the neutral hydrogen exosphere, to name a few—that were highlighted in the proposal. In addition, a significant number of studies combining TWINS observations with other missions in the HSO have been published.

The TWINS proposal detailed a science program that addresses broad system science topics using the ENA stereoscopic images of the inner magnetosphere. They identified three broad science targets that include the spatial, energy, and pitch angle distributions of the ring current ions, the processes by which they are energized, and the ion precipitation from the magnetospheric system. Their topics focus on understanding the ion temperature distributions within the magnetosphere, the distribution of the neutral hydrogen important to the ENA process, and the ion composition throughout the inner magnetosphere system.

3.12.2 Science Strengths

The team identified 16 prioritized science goals for the extended mission ranging from examination of the time evolution of ring current pressure, energy, and pitch angle distributions to determining ion composition and species dependent transport and loss. These investigations comprise key questions at the forefront of Heliophysics research in energetic particle dynamics and magnetosphere-ionosphere coupling. The proposed investigations provide unique and strong contributions to addressing Research Focus Areas (RFAs) in the Heliophysics Roadmap (2009), such as: F2 (Particle acceleration and transport), H2 (Earth's magnetosphere, ionosphere, and atmosphere), and H3 (Role of the Sun in driving change in the Earth's atmosphere). In particular, the TWINS contribution to the Van Allen Probes science will be particularly strong and important during the TWINS extended mission since it will be the only means of assessing the global ion distributions and composition during the Van Allen Probes' main mission period.

3.12.3 Relevancy of Strengths to Heliophysics Research Objectives

TWINS offers the only magnetospheric imagers dedicated to characterizing the global dynamics of the ring current through the extended mission period. Combining this with *in-situ* measurements from the HSO enables the transport, acceleration, and loss of the ring current, including the coupling to the underlying ionosphere, to be understood. TWINS directly supports goals from the Heliophysics Decadal Survey of determining the dynamics and coupling of the Earth's magnetosphere, ionosphere, and atmosphere, and their response to solar and terrestrial inputs (HDS-2) and, more generally, to discover and characterize the fundamental processes that occur (HDS-4).

3.12.4 Value to the Heliophysics System Observatory

The TWINS proposal described strong synergies with missions from the HSO such as the Van Allen Probes and THEMIS (*in-situ* particle measurements of the ring current particles) plus IBEX (monitoring of the plasma sheet), as well as the Ampere mission, which can monitor the structure of the field-aligned currents coupling the magnetosphere-ionosphere system that are partially driven by ring current pressure gradients. The TWINS extended mission addresses key aspects of the Research Focus Areas F2 (Particle acceleration and transport), F3 (Ion-neutral interactions; the core of ENA science), H2 (Earth's magnetosphere, ionosphere, and atmosphere from global perspective), H3 (Role of the Sun in driving change in the Earth's atmosphere, including exosphere), and their parallels in J1 and J4 of the Heliophysics Roadmap (2009). Recent TWINS analyses provide confidence that O+/H+ ratios will be derived for storm events during the solar cycle maximum and the extended mission phase of TWINS in support of all Heliophysics magnetospheric science, especially that being done by the Van Allen Probes during their prime mission, and supports the Heliophysics goal to “Understand the Sun and its Effects on Earth and the Solar System.”

3.12.5 Spacecraft / Instrument Health and Status

The two host spacecraft are operating nominally, and the ENA instruments are operating well on both TWINS satellites with no signs of premature aging. The team’s early problem with the TWINS actuator (TWA) on the ENA instruments was corrected by a software upgrade. The implemented fix has been shown to be reliable and should continue to work well beyond the 4 years of the Senior Review. The degradation of one of the LAD sensors on TWINS-B has reduced somewhat the neutral hydrogen coverage but remaining capability is adequate to support the TWINS science. It is expected that the host spacecraft will continue to be operated for many years beyond the period of this review.

3.12.6 Data Operations (accessibility, quality control, archiving)

TWINS is doing a good job of making data available. The plan for data availability and distribution is comprehensive, covering the full range of data and documentation and with significant consideration given to the provision of quality information that will help long-term use of the ENA images. The data are being served as ASCII, IDL savesets, and as CDF, which makes scientific use and long-term archiving easy. Providing pre-generated images also is commendable in that many users will preferentially use these given the complexity of the data reduction. Documentation is available in ASCII and PDF formats.

The TWINS data are being regularly delivered to SPDF, and the team website provides detailed access to the data. The data are openly available with no waiting period, and are well calibrated and documented. The team provides value-added products such as a tool that generates synthetic ENA images from model ring currents. The archive plan is comprehensive and well thought out.

The usefulness of the data is limited due to a lack of good inversion algorithms or products based on them. Such algorithms exist only within the team and with a few outside researchers, but nothing has been taken into a production mode that would provide utility to a large community. Thus all that is provided are images that are qualitative with probative value. It would be useful to have inversions that have various published assumptions, or, better, to have more than one inversion based on a variety of algorithms. The team is clearly aware of this need, but there was no specific plan stating how they would move in this direction. The mission should be encouraged to increase the priority of such efforts.

3.12.7 Proposal Weaknesses

There are no serious weaknesses in the proposal to continue TWINS observations. Minor: There are potential linkages between precipitation and energy transport to the atmosphere that are currently not fully utilized, although TWINS has verified capabilities to observe structure of ions that originate from pitch angles close to the loss cone—Low-altitude Emission (LAE) observations. These observations represent important coupling to the ionosphere-thermosphere-atmosphere regions and are important to Heliophysics science. The focused science targets are numerous and perhaps overly ambitious. The team should clearly focus on the key areas F2, F3, H2, and H3, from the Heliophysics Roadmap, where the strength of the TWINS mission lies.

3.12.8 Overall Assessment and Findings

This is an excellent proposal to address ring current and plasma sheet energetic particle dynamics, and their coupling to the ionosphere, in the inner magnetosphere during storms. The scientific focus is at the core of Heliophysics research focus areas, and the measurements make an important contribution to the HSO. The TWINS ENA imagers are operating well; the instruments are well calibrated, and have proven performance to be able to address excellent science in the impending maximum phase of the solar cycle and its early subsequent decline. The proposal has many strong major science and technical strengths, and no major weaknesses. The proposal is therefore rated excellent.

Overall Grade. The TWINS extended mission proposal was ranked Excellent in Overall Scientific Merit by the Panel with a median score of 6/10. The very low cost of its operation makes its science per dollar high for the extended mission. The median Panel ranking for Value to the HSO is 7/10, placing it near the upper end of the Excellent category. The Panel recommends the continued operation of the TWINS extended mission.

3.13 Voyager

3.13.1 Overview of the Science Plan

The Voyagers continue to surprise and excite scientists with new discoveries as they continue their exploration of the distant heliosphere on their way to the interstellar medium. Voyager 1 (V1) and Voyager 2 (V2) are both in the heliosheath—the region between the termination shock and heliopause. The Voyagers measure plasma, high-energy charged particles over a wide energy range, magnetic fields, and plasma waves. They provide essentially real-time *in-situ* data and will make the first direct *in situ* measurements of the local interstellar medium (LISM) when they cross the heliopause.

Voyager 1 recently observed a remarkable depletion (to background) of anomalous cosmic rays (ACR) while the intensity of galactic cosmic rays (GCR) and magnetic field magnitude both increased simultaneously. This occurred over a period of days or less, suggesting V1 crossed into a new region of space. Unexpected anisotropies of energetic particles, ACRs, and GCRs were also observed near this region, which has been called the “Heliocliff”. The magnetic field direction did not change upon its crossing, suggesting V1 is still within the heliosphere. But, it appears that the Voyagers’ crossing of the heliopause is imminent.

New measurements to be made by the Voyagers in the extended mission will address many basic, long-standing questions about the plasma and magnetic properties of the outer heliosphere and LISM, the nature of the termination shock (TS) and its role in the acceleration of ACRs, the role of the heliosheath in the modulation of GCRs, the spectra of low-energy interstellar GCRs, and the source and location of heliospheric radio emissions.

The proposal lists the following prioritized science goals that can be addressed directly by the spacecraft instruments:

1. Determine the characteristics of the energetic particles, solar wind plasma, and magnetic field in the heliosheath, and identify the underlying physical processes that produce these characteristics.
2. Determine the location of the heliopause, and observe the nature of this boundary at two locations.
3. Determine the energy spectra, composition, anisotropy, and gradient of low-energy cosmic rays and energetic particles in the LISM.
4. Determine the strength, direction, and variations in the local interstellar magnetic field.

5. Determine the density, speed, temperature, and variations of the ionized component of the local interstellar wind.
6. Search for the source of kilohertz radio emissions in the interstellar medium and determine their generation mechanism.

   V1 and V2 measure:

   (a) The properties and radial evolution of thermal plasma with the Plasma Science Investigation (PLS) (Voyager 2 only). The instrument measures the characteristics of the solar wind, and will also measure, for the first time, the cold and dense interstellar plasma when Voyager 2 crosses the heliopause.

   (b) The energy spectrum and angular distribution of suprathermal, energetic ions and electrons from tens of keV to tens of MeV with the Low-Energy Charged Particles (LECP) collector; this instrument also measures the intensity and angular distribution of GCRs with energies greater than 200 MeV.

   (c) The energy spectrum and anisotropy of ACRs and GCRs with the Cosmic Ray Sub-system (CRS).

   (d) The heliospheric and interstellar magnetic field intensity and direction with the Magnetometer (MAG).

   (e) The electrical field components of plasma waves from tens of Hz to 56 kHz with the Plasma Wave Subsystem (PWS).

3.13.2 Science Strengths

1. The Voyager Interstellar Mission explores the farthest reaches of the Sun's influence *in situ*. This is likely the only opportunity for such measurements for many decades to come.
2. The Voyager spacecraft will likely reach the heliopause and enter the interstellar medium during their operational lifetimes. The Voyager crossings of the termination shock provided the first concrete information on the scale size and the shape of the heliosphere. The V1 crossing of the "Heliocliff" revealed another unexpected heliospheric boundary associated with increased magnetic field, depleted ACRs, and increased GCRs, with puzzling variations in ACR and GCR anisotropies. This boundary is still to be understood. Voyager 1, in the northern hemisphere of the heliosphere, crossed the TS at 94 AU while V2, in the southern hemisphere, crossed it at 84 AU. Some models based on interpretation and analysis of energetic neutral atoms from IBEX and SoHO predict the minimum thickness of the heliosheath along the V1 trajectory to be about 20–25 AU, while large-scale computer models predict it to be between 30–50 AU. Thus, V1 (currently just over 120 AU) could be near heliopause now, and the observation of the Heliocliff may be a precursor of this crossing. The asymmetry in the TS crossing distances verifies that the southern hemisphere of the heliosphere is pushed inward, probably by the interstellar magnetic field. The observed asymmetry may allow V1 and V2 to cross the heliopause at roughly the same time and provide simultaneous observations of the LISM.
3. Voyager 1 is currently providing the first measurements of low-energy galactic cosmic rays. Due to the depletion of low-energy cosmic rays after the crossing of the Heliocliff, the low-energy part of the GCR spectrum is now revealed for the first time. Once the Voyagers cross the heliopause, they will likely measure the un-modulated GCR spectrum, which provides a particularly important

boundary condition with significant consequences for our understanding of cosmic rays in the Earth environment.

4. V1 and V2 provide *in situ* measurements at two separate locations providing information on the global nature of the heliosphere. This also provides a measure of both radial and temporal gradients in the intensity and spectra of anomalous and galactic cosmic rays.

5. The larger magnetic fields beyond the Heliocliff make it easier to provide accurate measurements of the magnetic field strength and direction. The magnetic field increased by about a factor of two across the Heliocliff and is presently just over 0.4 nT (4μG).

3.13.3 Relevancy Strengths to Heliophysics Research Objectives

The 2013 Senior Review panel finds that the Voyager mission is highly relevant to the goals and objectives of NASA's Heliophysics Research program. Voyager makes measurements that directly address two of the four overarching goals from the most recent Heliophysics decadal survey: (1) Determine the interaction of the Sun with the solar system and the interstellar medium; and (2) Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe. In addition, along with measurements from other Heliophysics space missions, Voyager also addresses a third overarching goal of the decadal survey: Determine the origins of the Sun's activity and predict the variations of the space environment: the Voyager spacecraft are playing a unique role in developing an understanding of the entry and modulation of GCRs as they propagate toward Earth's space environment.

Moreover, Voyager science addresses two of NASA Heliophysics strategic goals: (1) Open the Frontier to Space Environment Prediction: by increasing our understanding of the space environment from the Sun to Earth, to other planets, and beyond to the interstellar medium; (2) Understand the Nature of Our Home in Space: by measuring the boundaries of the heliosphere, which lead to variations in cosmic rays at Earth that are affected by solar activity.

3.13.4 Value to the Heliophysics System Observatory

Voyager benefits from measurements from other Heliophysics spacecraft closer to the Sun that monitor solar disturbances that propagate to the outer heliosphere. Merged interaction regions and interplanetary shocks can influence the location of the heliospheric boundaries and flows within the heliosheath. Because we are currently at the maximum in the sunspot cycle, solar transients from the increased solar activity are anticipated.

In addition, the Voyagers establish "ground truth" at two points within the heliosheath. The Voyagers measure ionized particle populations locally while the IBEX instruments measure neutral atoms produced by the interactions of lower-energy neutral particles with these higher-energy charged-particle populations. The resulting images produced by IBEX are integrations along lines of sight (LOS) many tens of AU in length. Voyager measurements can provide *in situ* information that relate to the distribution of the energetic protons along these LOS.

The following science goals will be addressed with its instruments and those made by other Heliophysics spacecraft mission instruments:

1. Determine the effects of the solar cycle progression on the heliosheath and on generation of transients in the LISM.

2. Provide *in situ* observations in support of HSO studies of global heliospheric processes and mappings of the heliospheric interaction with the LISM.

Strengths

1. The Voyagers are the only components of the Great Observatory that are, for now and in the foreseeable future, making *in-situ* measurements of the furthest region of the heliosphere. As such, the mission addresses directly a number of important science challenges and goals outlined in the Heliophsyics decadal survey.
2. V1 and V2 measure variations in the heliospheric plasma due to solar disturbances, which are measured by other Heliophysics spacecraft, thereby measuring the extent of the Sun's influence.
3. V1 and V2 provide important local measurements of energetic particles that interact with neutral particles to create energetic neutral atoms that are imaged by IBEX. The combination of local and integrated line-of-sight measurements provides important information about the structure of the heliosphere.

Weaknesses

None.

3.13.5 Spacecraft / Instrument Health and Status

The currently operating instruments are in good health and all five will continue to operate until 2020; afterward some instruments will have to be turned off to ensure that enough power is available to make measurements until 2028. The complement of instruments does not include the plasma instrument on V1, which has not been operational for many years. The typical uncertainty in the magnetic field is of the order of 0.03nT, making measurements of very weak magnetic fields in the heliosheath uncertain; although V1 is presently measuring stronger magnetic fields with much smaller relative uncertainties. The instruments are fully capable of making measurements of the heliosheath plasma and ionized component of the interstellar medium, as well as high-energy charged particles, plasma waves, and magnetic fields in these regions in order to achieve the science goals of the mission. Currently, five investigator teams are supported, though data are collected for one additional instrument—Voyager 1's Ultraviolet Spectrometer (UVS).

3.13.6 Data Operations (accessibility, quality control, archiving)

The Voyager team is doing a reasonable job of making most data available to the scientific community in a timely manner; however, as pointed out in Section 2.5.1, the Senior Review panel is concerned that very important high-quality, up-to-date magnetic-field data is not readily available.

A complete report of the Voyager data operations is provided in the Appendix. The Senior Review panel concurs with this assessment

3.13.7 Proposal Weaknesses

The lack of up-to-date, high-quality magnetic-field data is a weakness of the proposal. Since the heliopause will likely be crossed during the operational lifetimes of the spacecraft, having accurate data from all instruments in a timely manner is very important. The Senior Review panel urges both NASA and the Voyager team to address the issue raised in Section 2.5.1.

3.13.8 Overall Assessment and Finding

The 2013 Senior Review panel finds the continuation of the Voyager Interstellar Probe mission to be very compelling. The Voyagers explore a region of space that will not be explored again in the foreseeable future. Moreover, the spacecraft continue to make new and exciting discoveries as they have since their launch (although the scientific emphasis changed from planetary encounters to understanding the solar wind / LISM interaction). The instrument team is very active and works closely with guest investigators—primarily modelers and theorists—to help interpret the unique observations.

Voyager has revealed surprise after surprise since their crossings of the termination shock several years ago, including observations within the past year of another unexpected boundary—the Heliocliff—which has some characteristics of what would be expected if the spacecraft had entered the interstellar medium. Yet the magnetic field direction remains consistent with the heliosheath field. It appears imminent that at least Voyager 1 will soon cross the heliopause. When it does so, the spacecraft will return the first *in situ* measurements of the local insterstellar medium—this alone provides a truly compelling reason to continue the mission.

Overall Grade. The Voyager extended mission proposal received a 9/10 median ranking from the Panel for Overall Scientific Merit, placing its intrinsic science contributions at the upper end of the Compelling category. Its Value to the HSO received a median panel ranking of 6/10 and solidly in the Excellent category. The panel recommends the continued operation of the Voyager extended mission.

3.14 Wind

Wind is a venerable spacecraft approaching its 20th year of operation. Currently in L1 halo orbit upstream of the Earth, Wind carries a comprehensive package of instruments to measure the plasma and fields around the spacecraft, including energetic particles and radio waves.

The spacecraft and instruments are in overall good health and Wind continues to be a remarkably productive mission scientifically. By acting as a near-Earth measurement point and reference for comparison with other spacecraft in terms of solar wind and energetic particle data, Wind enables multi-point ICME analyses and studies of energetic particle acceleration processes. In addition, the mission's long solar wind and field data sets have recently been re-analysed by the instrument teams, producing ground-breaking discoveries regarding fundamental plasma processes such as instabilities, wave-particle interactions, shocks, and reconnection, which are directly relevant to NASA's heliospheric research objectives.

3.14.1 Overview of the Science Plan

The Wind project's Prioritized Science Goals are:

1. Study the long-term variation of solar wind abundances and energetic particles over two solar cycles;
2. Extend the kinetic analysis of the acceleration and heating of the solar wind;
3. In conjunction with other NASA assets, study the propagation and evolution of ICMEs in the inner heliosphere; and
4. Study dust particles in interplanetary space.

3.14.2 Science Strengths

The high-quality Wind data are useful in a remarkably wide range of studies and are used by a large community, as evidenced by over 800,000 data downloads from CDAWeb in 2012. Of particular note are the high-time resolution fields measurements and high-precision and -cadence measurements of thermal and supra-thermal plasma populations. These full 3-D distributions of protons and electrons from the bulk population to those at higher energies are the best available measurements for undertaking studies of fundamental space plasma physics processes such as reconnection, shocks, turbulence, and instabilities.

Wind's ability to remotely detect shock waves using radio waves is unique in near-Earth space and is particularly useful in conjunction with data from radio receivers on the twin STEREO spacecraft.

Wind's Energetic Particle Acceleration, Composition, and Transport (EPACT) measurements of solar energetic heavy ions in the 1–10 MeV range, complementing those from ACE, are important for studies of particle transport from the Sun into the heliosphere.

Wind's ability to make an absolute measurement of the local plasma density allows precise calibration of plasma instruments, not only on Wind itself but also on ACE and, in the future, the Deep Space Climate Observatory (DSCOVR).

Unlike some detectors, Wind's plasma instruments do not saturate during high particle fluxes, meaning that it can take continuous measurement during the passage of the most extreme coronal mass ejections and interplanetary shocks.

The recent realization that Wind can detect the arrival direction of micron-sized dust particles at the spacecraft has enabled the study of the dynamics of interplanetary dust and dust streams, an area that is of growing interest.

Wind is currently experiencing a resurgence in scientific productivity as a direct result of the instrument teams (particularly MFI, 3DP and SWE), both from their own research efforts and their release of newly calibrated data products used by other researchers worldwide.

3.14.3 Relevancy of Strengths to Heliophysics Research Objectives

Wind contributes directly to a wide range of Heliophysics research objectives:

- Open the Frontier to Space Environment Prediction: Wind's detailed measurements of particles and fields help us to understand magnetic reconnection and the processes that accelerate and transport particles.
- Understand the Nature of Our Home in Space: Wind measures coronal mass ejections and other solar transients, both remotely and locally, and provides important information on the state of the solar wind upstream of the Earth.
- Safeguard the Journey of Exploration: Wind's measurements of solar energetic particles characterize the variability and extremes of the space environment that will be encountered by human and robotic explorers. Its entire instrument complement provides input into studies to help develop the capability to predict the propagation and evolution of solar disturbances.

3.14.4 Value to the Heliophysics System Observatory

Wind contributes several unique measurements to the HSO. Its sensitive radio measurements make it possible, in combination with measurements from the twin STEREO spacecraft arrayed around the Sun, to triangulate the origin of the emission, remotely probing the motion of coronal mass ejections through interplanetary space. Wind's measurements of solar energetic particles in the important 1–10 MeV energy range, combined with those from ACE nearby and STEREO farther away, make it possible to study particle acceleration and propagation in a global sense in the inner heliosphere. In the coming years, in the second half of Solar Cycle 24, we can expect several large energetic particle events and Wind will make a vital contribution to their analysis.

Located upstream of the Earth, Wind shares with ACE the duty as a monitor of the near-Earth solar wind. Studies combining Wind data with those from THEMIS and Van Allen Probes, along with MMS in the future, will continue to provide vital information on the effects of interplanetary plasma, fields, and energetic particles on conditions in near-Earth space.

3.14.5 Spacecraft / Instrument Health and Status

The currently operating instruments are in good health and all five will continue to operate until 2020; afterward, there will need to be some instruments will have to be turned off to ensure that enough power is available be able to make measurements until 2028. The complement of instruments does not include the plasma instrument on V1, which has not been operational for many years. The typical uncertainty in the magnetic field is of the order of 0.03 nT, leading to significant error bars on measurements of very weak magnetic fields in the heliosheath; although V1 is presently measuring stronger magnetic fields with much smaller relative uncertainties. The instruments are fully capable of making measurements of the heliosheath plasma and ionized component of the interstellar medium, as well as high-energy charged particles, plasma waves, and magnetic fields in these regions in order to achieve the science goals of the mission. Currently, five investigator teams are supported, though data are collected for one additional instrument (Voyager 1's UVS).

3.14.6 Data Operations (accessibility, quality control, archiving)

Overall Wind data provision is excellent, with the timely release of high quality data products via CDAWeb and the availability of pertinent documentation. Indeed, the detailed re-analysis of the existing magnetic field, SWE and 3DP data sets by the instrument teams is an exemplar of what can be done to enable new science from existing instruments. These new data releases have made Wind NASA's principal platform for the study of the kinetic processes that occur in plasmas throughout the solar system and indeed the Universe.

The Panel noted concerns that high-energy EPACT data products are not released to the public in as timely a manner as those from other instruments and urge the Wind project to address this issue.

3.14.7 Proposal Weaknesses

Minor: One Prioritized Science Goal of the proposed extended mission is to study the long-term variation of solar wind composition and solar energetic particles. The Panel noted that, with more than one solar cycle of data already collected, there was no guarantee of significant additional science output from another 2 years of such measurements. However, the combination of Wind data with those from other NASA assets during the declining phase of Solar Cycle 24 was very likely to result in new understanding of energetic particle and kinetic processes.

3.14.8 Overall Assessment and Findings

The proposed Prioritized Science Goals were judged by the Panel to represent excellent science, building on the revitalized output of this mission in recent years; Wind's only weakness was its own longevity, with a great deal of data already collected. Wind was also considered to be a central element of the HSO, particularly by virtue of its unique measurements of solar energetic particles and radio emissions in near-Earth space.

Overall Grade. The Wind extended mission proposal received a 6/10 median ranking from the Panel for Overall Scientific Merit, placing its intrinsic science contributions solidly in the Excellent category. Its Value to the HSO received a median panel ranking of 7/10 and at the upper end of the Excellent category. The Panel recommends the continued operation of the Wind extended mission.

4 Cost Comparisons

The operating missions under review completed a budget template as part of their extended mission proposal to the MO&DA Program. This template was provided by the Program Office with instructions and definitions for breaking the projects into a common “five-way” work-breakdown structure (WBS). The five categories are Development, Mission Services and Operations, Science Operations Functions, Science Data Analysis, and Education & Public Outreach. Although it is difficult to apply a general functional breakdown to the specific WBSs of every flight project, it does provide a comparative measure among missions, for the purpose of identifying funding activities and evaluating the “science per dollar” value of the programs. However, the projects were allowed to modify the provided breakdown to fit the project’s particular situation, so the comparisons are not exactly uniform and certainly not rigorous. The figure below shows the total proposed budget for each extended mission for each year of FY14–18. As noted already in Section 2, all budgets are in-guide except CINDI, Cluster, and SOHO, which are over-guide.

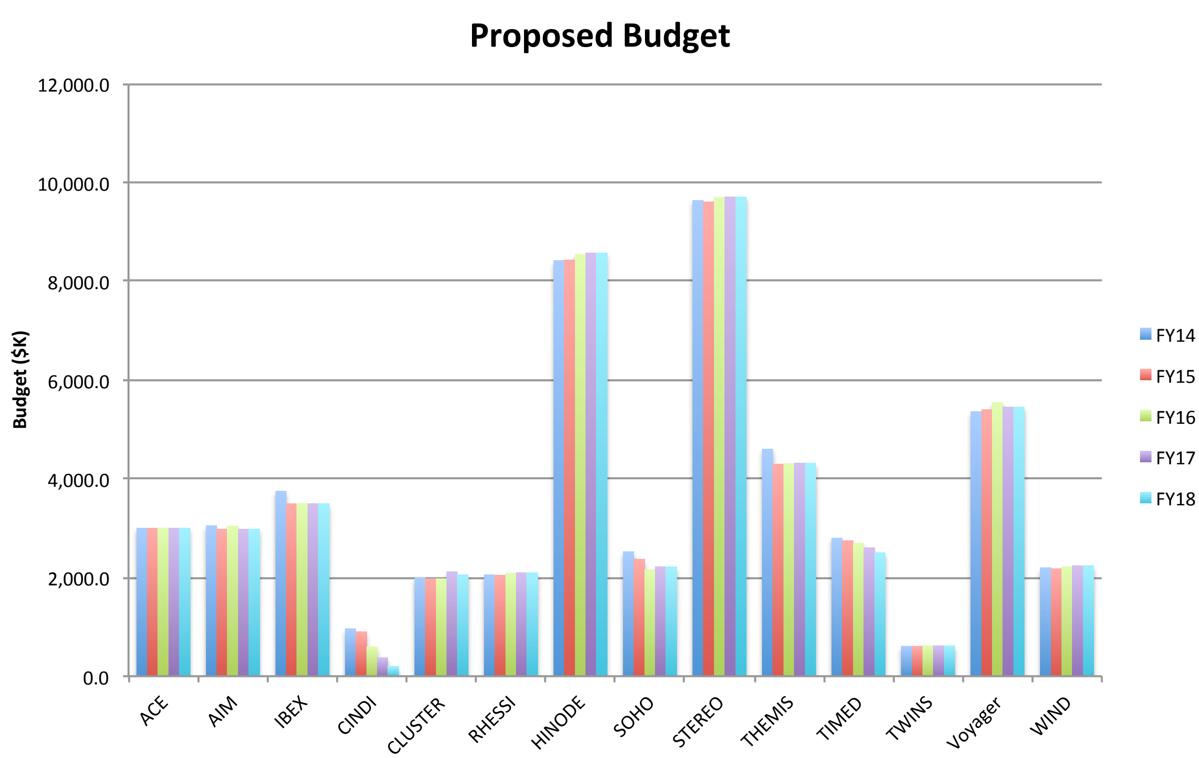
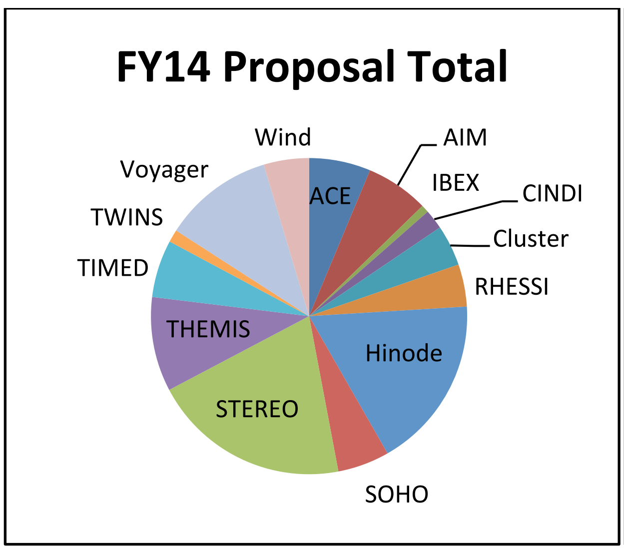
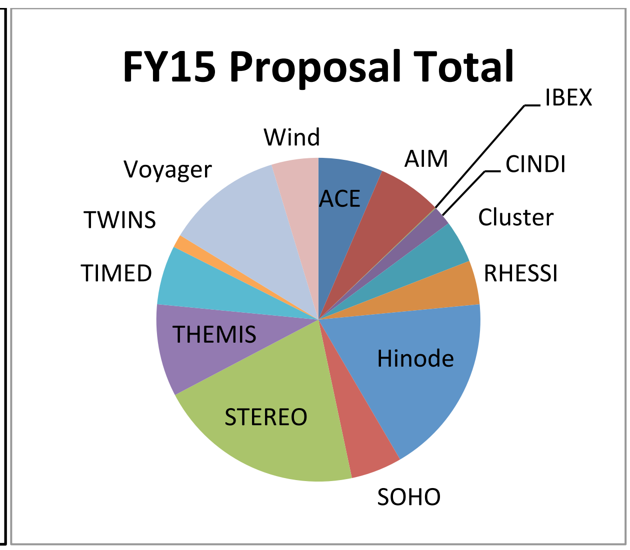


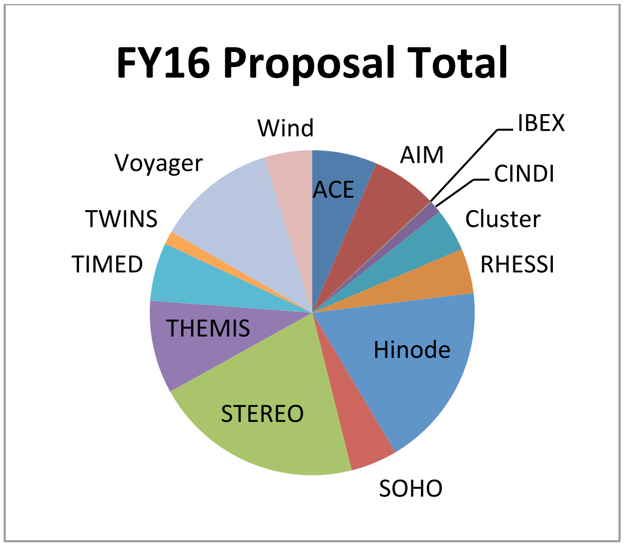
Figure 4-1. Proposed budget for each extended mission for FY14–18.

4.1 Overall Project Costs

A set of comparative pie charts was developed to aid in cost review of the various programs. The total proposed costs for the missions, the total of all five of the supplied WBSs, are presented for the next four fiscal years in the following set of figures.







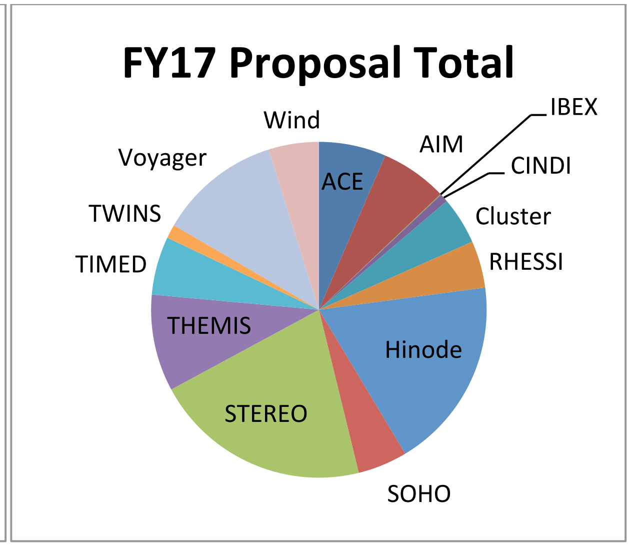


Figure 4-2. Relative portion of the total requested budget for each extended mission.

4.2 Science Operations Functions and Science Data Analysis Costs

A set of comparative pie charts for the scientific activities of each of the missions were developed to aid in cost review of the various programs. The Senior Review panel found significant discrepancies among the missions in how they split science costs in the 5-way WBS between the “Science Operations Functions” to “Science Data Analysis” categories. The following pie charts compare the totals of these two work breakdown categories for each of the missions over the next four fiscal years.

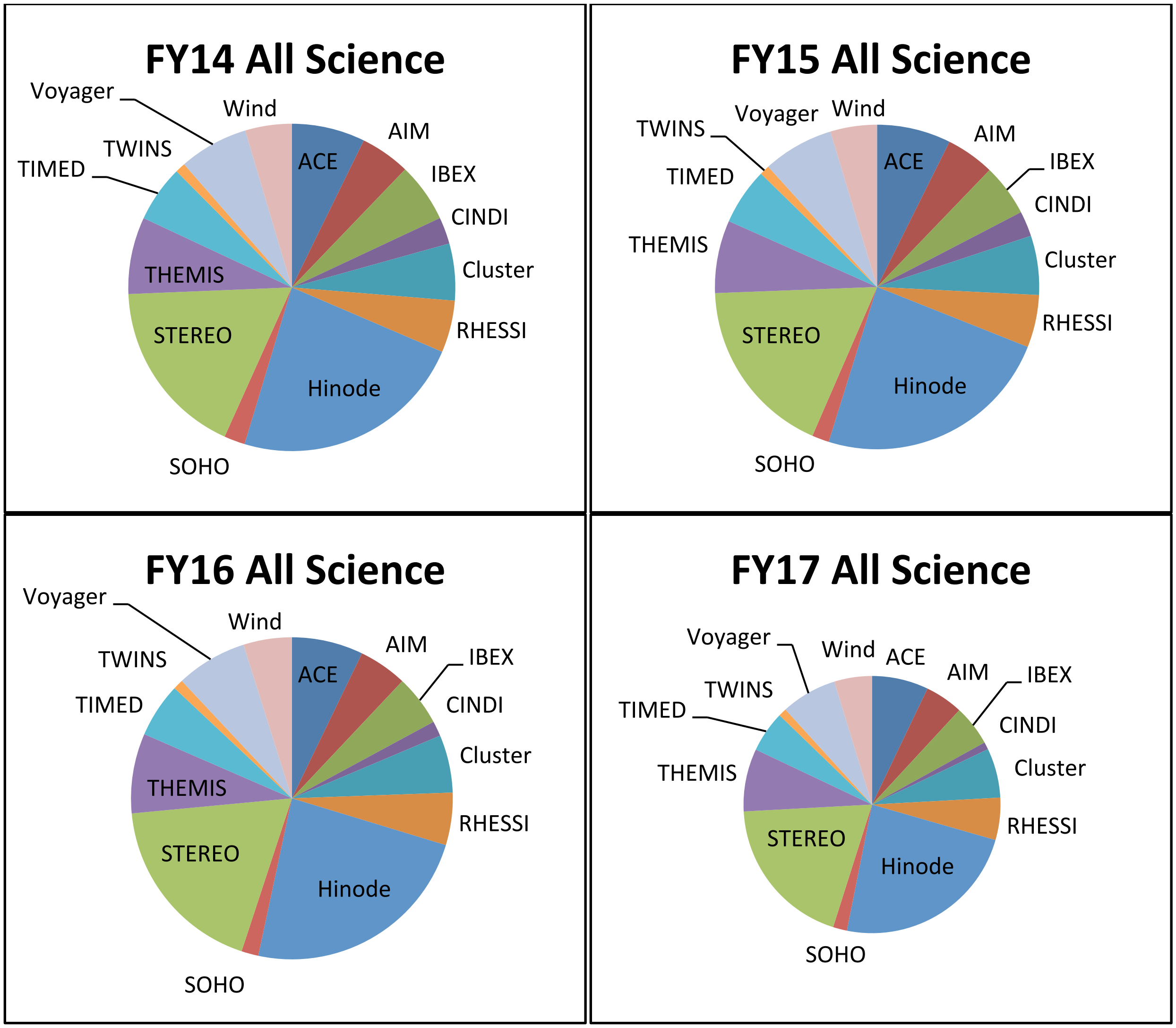


Figure 4-3. Relative portion of the budget for Science requested by each extended mission. "All Science" includes the sum of "Science Operations Functions" and "Science Data Analysis" in the 5-way budget breakdown.

4.3 Mission Operations Costs

A set of comparative pie charts for the mission operations activities of each of the missions were developed to aid in cost review of the various programs. The following pie charts compare the totals of this work breakdown category for each of the missions over the next four fiscal years.

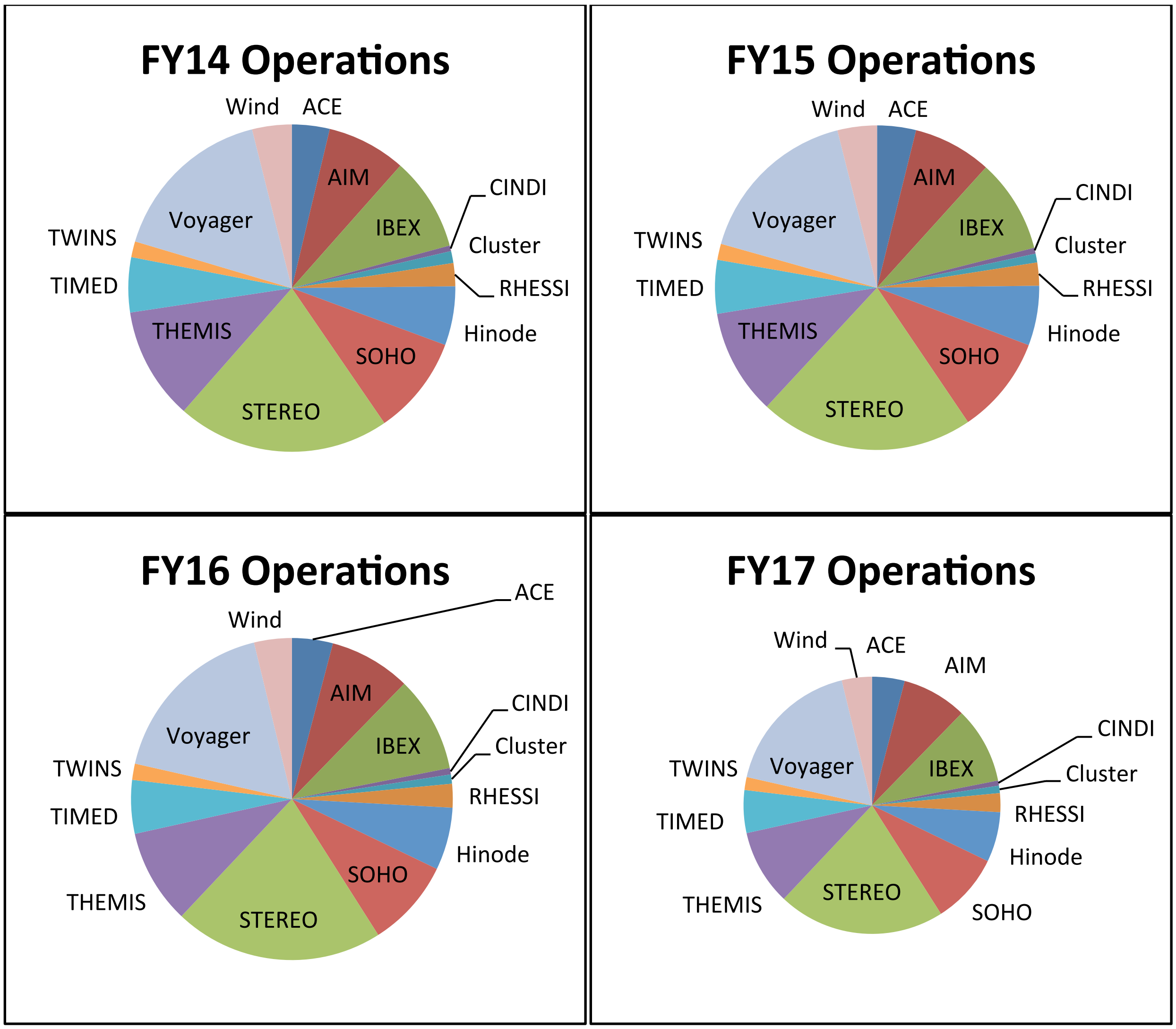


Figure 4-4. Relative portion of the budget for Mission Operation requested by each extended mission.

Appendix 1: Mission Archive Plans Assessment

General notes:

The Heliophysics Data Portal is working well and keeping track of the products. Nearly all products are registered at some level, and the registration makes basic access easy.

Solar products tend to depend on SolarSoft for basic and higher level processing, and SolarSoft requires IDL and (for non-Windows) a UNIX script install. SolarSoft has a steep learning curve. We might consider making the "prep" routines a web-based service, or having a VSO "prep this" option. We could also make stand-alone IDL prep routines that could be run with the free IDL Virtual Machine or as a Runtime application. Most of the solar missions are aiming for fully calibrated final products; this will avoid reading/calibration problems using IDL in the future. Other missions depend on IDL for much of their analysis software, and even SPDF has IDL imbedded in its CDAWeb access software, although CDF does not depend on it. There is a potential concern in this, but it is hard to see ways to avoid such choices. Even open source software is subject to change and obsolescence.

We still have yet to fully work out the Solar Final Archiving questions, although since STEREO, HINODE, and SOHO store all their data at SDAC, this is hopefully not a major issue (apart from SDO). RHESSI should not be a major problem, although we need to work out how to offer the higher-level products.

NetCDF tools are in rougher shape than CDF and FITS tools. TIMED is the most problematic in this regard. Many (most?) of their products (SEE excepted) present challenges for use by a non-expert; both IDL and some work are required. Improved documentation and better pointers to analysis programs could improve this greatly with modest effort.

ACE Archive

The ACE mission is doing a very nice job with its data distribution and archiving. Essentially all data are flowing into and from both the ASC and CDAWeb. Level 3 graphs and images are now archived and available from SPDF as well. The products are listed in HDP, and are well documented. The presence of the files at SPDF implies final archiving is easy.

A relatively minor point in an overall excellent system is that the SWICS data are capable of 12 min resolution, considerably better than the 1 hr now available, as evidenced by published papers. It would be good to have the full 12 min set (to the extend possible given counting statistics) available. Likewise, energy spectra that would extend data from higher energy particle instruments would be very useful to the extent possible. If necessary, the team could seek Data Upgrade funds for these tasks.

Wind Archive

The Wind mission has done a good job of producing, archiving, and making available the highest resolution data from most instruments. The presence of nearly all the data at SPDF, distributed via CDAWeb, assures long-term archiving and distribution. The Wind web site systematically documents the data and instruments.

One significant exception to Wind's good record is the high-energy particle data from EPACT, which has been slow in being released. The project should be encouraged to release all the data that are in acceptable shape, and to determine if Data Upgrade or other funds could produce more data.

STEREO Archive

STEREO solar products are stored at SDAC and served through the STEREO Science Center and VSO. The NRL mission team provides access as well, and also provides images and movies of all the SECCHI products. Value added products are being produced by others, and a Data Upgrade project exists to bring SECCHI STEREO B HI images to nearly the same standard as for STEREO A.

The in situ measurements from STEREO are being produced and openly served from the mission and PI sites, with much of the data being archived at SPDF and served through CDAWeb. Thus the data are being produced in standard CDF format, and should be archived for the long term. IDL-based software tools are available, and the use of standard formats implies that researchers can use their own tools.

Overall, the STEREO data are well stored, served, and documented. The data are usefully being stored in Final Archives, as well as elsewhere, which should make the transition to post-mission operations quite straightforward when finally needed.

RHESSI Archive

The data from the RHESSI mission are in very good shape, well documented, and easily available from more than one site. The project is in the process of producing calibrated products that will be immediately useful for many science studies without the need for the complex, SolarSoft/IDL-based software necessary for typical detailed analysis. They are also producing "visibilities" that will provide both a compact representation of the data and a means for doing detailed analysis that is independent of the IDL-based SolarSoft tools. The mission should be strongly encouraged to finish both the "standard" product and the visibility product and to adequately document these potentially extremely useful products for independent, long-term use. There is a good plan for archiving the data long term, with SDAC as the primary archive.

Voyager Archive

The Voyager data are mostly being produced in a timely manner and are accessible, well documented and easy to read. As it is the oldest mission in the current NASA HP fleet, it is not surprising that most of the files are ASCII tables; these are being served by PI sites and from PDS and SPDF, although no one site has everything. For ease of access in the current environment, it would be useful to have ISTP CDF versions of the datasets all collocated in the SPDF archive, but this is not incumbent on the Voyager team.

The Voyager team has not caught up to the HP changes such that it is SPDF that now has all the active mission data, serving as the Final Archive, and not NSSDC. Some of the links and information have changed. The links at HDP are correct, however, and the team does not seem to be aware that the HDP listings imply the existence of SPASE metadata, at least at the basic information and registry level, and thus they are doing better in this regard than they realized due to the production of SPASE files by others.

The longstanding issue of the provision of the high-resolution MAG data has possibly found a solution, and the HDMC is working with the technical expert on the data to provide complete files. Hopefully this process will be successful. There are still issues in the provision of the most recent data, due to the very significant difficulties in the data processing, but at the least any data that have been used in publications should be made available to the public, and a plan should be put in place to systematically deliver data as it is produced. The level zero data and well-documented algorithms used to produce calibrated data should be made available to the community as well.

LECP files seem very complete and carefully documented, but difficult for the non-expert to use. It is difficult to understand how to obtain basic calibrated files in forms that can be straightforwardly used in the midst of overwhelming detail. Some data are stored in complex Excel files that would require working with the PI team or a long time studying documentation to use. With the low levels of funding this late in the mission it may be difficult to improve this situation, but ideally CDF files that could be used by increasingly standardized software would be helpful. The APL LECP "browse plots of the latest data and flat files of angular and scan-averaged intensities of key channels from launch onward" were not obvious on the site, and many seemed to be password protected for no clear reason.

It is not clear exactly what is meant by "we propose to make the changes necessary to make the entire CRS processing system suitable for virtualization" nor how this upgrade is to be funded and maintained. It is also not clear what is missing from the routinely produced 15-min CRS files, or why it should not be possible to make a full resolution (what cadence?) archive of calibrated data.

It is stated that alpha-particle density and velocity are provided by PLS in the early part of the mission, but a search only revealed proton data.

Overall, the Voyager mission archive is in good shape. It would be useful to have a cohesive set of files in self-describing format for final archiving, but this is something to be worked out with the archives; the mission is doing an adequate job with available resources.

TWINS Archive

The TWINS data are being regularly delivered to SPDF, and the team web site provides detailed access to the data. The data are openly available with no waiting period, and are well calibrated and documented. The team provides value added products such as a tool that generates synthetic ENA images from model ring currents. The data are conveniently available in standard formats. The archive plan is comprehensive and well thought-out.

The usefulness of the data is limited due to a lack of good inversion algorithms or products based on them. Such algorithms exist only within the team and with a few outside researchers, but nothing has been taken into a production mode that would provide utility to a large community. Thus all that is provided are images that are qualitative in probative value. It would be useful to have inversions that have various published assumptions, or, better, to have more than one inversion based on a variety of algorithms. The team is clearly aware of this need, but there was no specific plan stating how they would move in this direction. The mission should be encouraged to increase the priority of such efforts, as possible.

TIMED Archive

TIMED has been a very productive spacecraft, with many useful data products including very helpful derived products. These datasets are now being produced, kept safe, and served by the data center at APL and the various instrument sites. Very nice browse tools are available. The main problem with the TIMED archive is that it does not readily provide the “independent scientific data usability” called for in the HP Data Policy. This is something of a problem now, but will become more so post mission, when it will be necessary to have long-term products that are of use to the community without substantial support from the team members. This has two aspects: the data can be difficult to use without expert assistance given the current distribution methods and documentation, and there has been relatively little interaction with the Final Archive (SPDF). An exception is that the simpler SEE data are available from both SPDF and from LISIRD, and their lack of complexity makes it easy to document what variables mean.

Images and movies of, for example, GUVI L3 Thermospheric O/N2 are easy to find, but while it is possible to find and access, for example, IDL savesets of the data and even load them into IDL, it is quite difficult to find information about what the downloaded variables mean, how the information is stored, or how to use them; e.g., there is a 3-D "data" tensor in one product with no obvious way of understanding what is what. There were no detailed examples of use cases. This does not represent a situation in which long-term archival storage will be of use. The situation is the same for NetCDF files, which are easily downloaded, but then it is difficult to see how to use the (sometimes somewhat hard to find) IDL analysis routines. In one case, the "read_tidi_data" file will apparently return a structure containing the data, although it is stated that the structure "will be different for each type of TIDI data file" with no further explanation.

The VITMO distribution of TIMED data is good in that it allows searches using various criteria to find intervals of interest, but it does not work well for the complete end-to-end problem. Mostly this just reflects that the data delivered are the same as would be from the standard web sites with little value added, leading to the same problems as above. For example, although VITMO in principle will provide previews of data, it typically does not do this; the user is better off at the standard web site. Also, the metadata delivered to the user in principle includes product documentation and reading tools, but in practice these fields are often not populated.

It is interesting how much basic processing continues more than 10 years into the mission. In particular, it is hoped that the reanalysis of the GUVI data will lead to reliable products, thus obviating the need for caveats such as those for some current GUVI data: "These data may not be certified. … GUVI data products posted on this Web site are primarily intended to assist in focusing research efforts."

In short, the TIMED data are generally in very good shape in terms of being safe and openly available, but some effort needs to be expended in making the data useful for other than expert users and for the long term. Clearer documentation of the contents of products and analysis routines, and better pointers to these, could improve the situation greatly with modest effort. There should also be an active, continuing interaction with SPDF to determine the best long-term solution for the data preservation and delivery, and to solve the problems associated with the lack of standards for NetCDF files in terms of, for example, metadata provision and the treatment of time variables.

THEMIS Archive

Data for the THEMIS observations are transferred from the MOC to the SOC via automated scripts and served from there. The data are mirrored on SPDF and other international data sites. Ground based observations are collected via regular schedule of hard-disk transfers from the remote observing sites and then archived in the SOC; these data are also served through CDAWeb. The products are registered and accessible from the HDP. The delivery of data to SPDF assures archiving for the long-term. Fairly extensive documentation is easy to find and use.

The team is to be commended for its efforts to educate the scientific community on the data and the many ways to access it including the website and via TDAS, the IDL software used by the team and freely distributed to others. The strong IDL-dependence of the analysis routines is both shared with much of the HP community, and obviated by the provision of files in standard formats. Overall the THEMIS archive is in good shape.

SOHO Archive

The SOHO mission has an extensive set of products that are well documented and easily available though mission sites and VSO. They are accessible through the HDP. There is an extensive set of final products. The MDI archive has been merged with the SDO HMI archive assuring continuity of the missions. The final products are to be delivered as calibrated products, thus obviating the need for the use of SolarSoft (IDL) for this purpose. In general, the SOHO archive is in good order. Issues of long term archiving of the data need to be addressed in more detail, but this is a general concern for solar data that cannot be solved at the mission level.

IBEX Archive

Data from the IBEX mission are served from the SPDF, and thus they are readily available. Many forms of higher-level products are available, along with the original data. Data are all described in SPASE and listed in the HDP. Overall, the IBEX archive is in good shape.

Interpretation and utilization of ENA image data is heavily dependent on analysis process so completion of the stand-alone data package for the non-expert scientists, described in the plan, is essential for the long-term utility of the data. The mission should be encouraged to be sure that resources are dedicated to this aspect of the project.

HINODE Archive

The HINODE archive consists of an extensive set of products that are well preserved and documented. While current processing uses IDL SolarSoft “prep” files, the final archive will contain fully calibrated files in addition to the level-0. All data are to reside at SDAC as well as the JAXA mission archive, which should satisfy long-term archiving needs, although in the case of EIS it was not clear if the Level-1, calibrated, files were intended to be produced and archived. Data are available via VSO, JAXA, and other interfaces at NASA and in Europe. Overall there is a rich set of access methods and tools, although the access is sometimes bewildering. This is in part due to the complexity of the data, but things like overview movies should be helpful in this regard. (These seemed to be available in principle, but were not found.) The team should be encouraged to try to assist users in this and other ways so that the data will be useful by a wider audience and for the long term.

Cluster Archive

The Cluster Mission Archive Plan is very short, but basically adequate. The Cluster Active Archive has been systematically gathering, documenting and providing access to the best mission data, including that produced in the US. It uses CEF for storage, which, although unique to Cluster and somewhat difficult to use without tools, is ASCII and thus readable without special software. The CAA delivers CDF files on request, and although these files do not completely meet the ISTP standards, they are straightforwardly readable, for example, with IDL, and there are various downloadable tools that can be used for detailed analysis of the mission data. Although it is not stated in the MAP, the ESA/ESAC archive is supposed to maintain the CAA functionality. If ESAC dropped, e.g., support for CDF, this would be a major drawback, but NASA will not have control over this. It is to be hoped that the CAA will be able to maintain public access to both CEF and CDF files until the ESAC archive is fully operational. The existence of Prime Parameters at CDAWeb is useful, although it is not always clear how reliable those data are for publication purposes; this may be difficult to change at this late date, but if possible the provision of research-quality data via SPDF would be beneficial.

CINDI Archive

The C/NOFS mission has both NASA and DoD components. Despite this, the push to have more than just the NASA-specific CINDI dataset archived and accessible from the Final Archive (SPDF) is underway and looks to likely be successful. High-resolution VEFI data are going to be provided to SPDF through a Data Upgrade grant. The MAP itself deals with the particle instruments that are in the NASA funded CINDI project, and the plan for data production seems complete and reasonable.

There is no discussion of documentation in the MAP beyond the mention of SPASE descriptions; if the data are to be useful outside the team, this will be necessary. A search for such documentation was hampered by a lack of response of the "cindispace" site at UT Dallas.

AIM Archive

The AIM mission has done a good job of producing and providing data. Data plots are readily available, as are NetCDF files of the data. The IDL routines provided for reading the data seemed straightforward. The plan for final archiving is fairly comprehensive, although probably optimistic in its timetable. While it is not mentioned in the MAP, the mission has contacted SPDF and has expressed considerable interest in beginning plans in the near future to smooth the transition to a final archive; this collaboration should be encouraged. The AIM data products are listed in the HDP with appropriate access paths.

The MAP states: “The code used to process the final higher-level data products will also be archived. Since this code is meant to serve as a future reference only, and not as software product, it will not include proprietary libraries or system setup and installation procedures necessary to reprocess the data.” This would seem to imply that the mission is not intending to make it possible to reprocess AIM data in the future; this is perhaps a realistic expectation, but it is not the standard approach.

Appendix 2: Education and Public Outreach Assessment

To: Jeff Hayes
Program Manager, Heliophysics Education Public Outreach
From: Cassandra Runyon
Chair, Senior Review > Heliophysics Education Public Outreach

Heliophysics EPO Senior Review Panel Members: Gina Brissenden, Sanlyn Buxner, Cynthia Hall, Jake Noel-Storr

Date: April 18, 2013
Re: **2013 Heliophysics EPO Senior Review**

Fourteen Education and Public Outreach (EPO) programs were reviewed as a part of the Heliophysics Senior Review between April 15-17, 2013. Table 1 summarizes the various education components mentioned in each of the mission EPO progress reports and proposals for continuation.

Overall Recommendations for Heliophysics EPO Program

The Heliophysics Educator Ambassador (HEA) Program and the Communities of Practice (CoP) are strong programs that provide support to formal and informal educators teaching heliophysics science. The programs are valuable and appear to be effective based on metrics collected by members of the Science Mission Directorate Education and Public Outreach Forum (SEPOF). However, there is a need to coordinate these two collaborative programs across all of the Heliophysics missions. Based on review of the programs and metrics provided for these programs, it is recommended that funding for HEA be provided to IBEX for overall coordination. It is also recommended that funding for CoP be provided to THEMIS for overall coordination. Perhaps these two collaborative efforts could be funded by contributions from each participating mission proportional to their EPO budgets. Heliophysics mission contributions to HEA would provide stipends for teacher participants as well as a coordinated evaluation of the HEA program. The same would hold for CoP.

Further, it is recommended that Heliophysics EPO programs determine a uniform – across-the-board – stipend for teachers participating in the HEA and CoP programs. Currently, several missions provide HEA educators approximately $600 each, while CoP participants receive approximately $2000.

It is further recommended that the Heliophysics EPO program conduct a needs assessment for consolidation of the many varied web sites currently in use, under development and/or being planned for/by the different Heliophysics missions and instruments. Doing so will facilitate public and educator access to Heliophysics data, imagery, EPO activities, mission highlights and more. In addition, the need for specific Heliophysics website(s) should be established beyond what is provided by the existing NASA web infrastructure, e.g. Wavelength and DLESE. The need must demonstrate a uniqueness and added value that cannot by its very nature be incorporated into already existing NASA EPO web/portal infrastructure.

And, finally, it is strongly recommended that all NASA funded Heliophysics EPO activities and resources intended for K-12 and informal education initiatives be vetted by NASA Education Product Review.

Individual Reviews for Heliophysics Mission EPO Programs

Table 1: Overview of SMD Heliophysics Mission EPO activities as mentioned in Progress Reports/Proposals for Senior Review

MISSION	Request ($K) FY2014	Years Active	Formal	Informal	Outreach					Collaboration				Volunteer	Evaluation	International
					Public	Web	Podcast	Facebook	Twitter	SEPOF	CoP	HEA	SWAC			
ACE	28	15	•	•	•	•	•			•			•	•	◆	
AIM	23.4	10	•			•		•		•		•			◆	
CINDI	30	5	•	•	•	•		•		•	•	•			✓	
Cluster	20	14	•		•	•	•			•		•			O	•
Hinode	81.8	2	•	•	•	•		•		•					O	•
IBEX	153.2	8	•	•	•	•		•	•	•	•	•			✓	
RHESSI	20	12	•	•	•	•				•	•	•	•		◆	
SOHO	0	19				•									O	
STEREO	119.1	5	•	•	•	•		•	•	•		•			◆	
THEMIS	102.6	6	•	•	•	•				•	•	•			◆	
TIMED	19.8	5	•	•	•	•					•	•			O	
TWINS	0	6			•	•		•	•					•	O	
Voyager	71	35	•	•	•	•						•	•		◆	
Wind	20	20			•	•				•					O	

• = EPO program addresses activity category
✓ = Sufficient EPO Evaluation
◆ = Insufficient EPO Evaluation
O = Evaluation not addressed

Mission: ACE

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

The ACE EPO program primarily consists of maintaining and expanding the Cosmicopia website and the development of a new Heliophysics website called HelioSPOTLIGHT. Project scientists plan to continue giving public presentations in classrooms, museums and community events, participate in a month long program for high school students and educators, Project SMART, at the University of New Hampshire (UNH), contribute to Solar Week (opportunity for middle school girls to see positive female role models in science), present ACE science in their university instruction, and mentor and work with high school and undergraduate students on special research projects. Additionally, ACE plans to contribute data to the NASA Space Weather Viewer.

General Comments and Recommendations

Overall, the project is a small effort that has the potential to impact how heliophysics science is organized and presented to the public. Although Cosmicopia and localized outreach efforts have been successful in the past, the proposal lacks sufficient information to warrant recommendation for continuation of the program. Should the ACE PI and EPO team wish to continue, it is suggested that they consider revising the EPO proposal to include more details.

Specifically, more details are needed to demonstrate how the ACE EPO program addresses customer needs, including how it contributes to the larger Heliophysics EPO program and supports NASA education outcomes. The ACE project team needs to define outcome goals and a simple strategy to collect data to assess how they are meeting those goals in the form of an evaluation plan, which can be done internally. Additionally, the team needs to make clearer their role in the new HelioSPOTLIGHT website being developed under the Wind EPO plan. Additionally, it is not clear what ACE EPO will do if Wind EPO is not funded.

ACE EPO has the potential to leverage with other heliophysics missions, but does not include a plan for doing so. Additionally, due to reported past performance, it is highly desirable to have a timeline with benchmarks, deliverables, and dates, as well as identified responsible personnel for completing the project. It is suggested that content and activities related to ACE be merged within the Heliophysics 'cluster' of programs and activities on the Heliophysics EPO, or Science Mission Directorate Education and Public Outreach Forum (SEPOF) website. Further, it is suggested that ACE EPO consider condensing the two web initiatives into one location, perhaps link directly to the SEPOF heliophysics website for easier public access.

Intrinsic Merit

Significant Strengths:

The Cosmicopia website has a demonstrated audience shown by high monthly visitation and is well connected on the web as a reputable source of information about stellar science. Additionally, future plans for the site are to consolidate information about solar science that is currently located on other sites.

HelioSPOTLIGHT.org will be an improvement on the existing website.

Internship programs for high school students show continuity of engaging students who are interested in math and science and further engaging them in exciting projects doing real work.

Significant Weaknesses
There is no formal evaluation plan. Instead, the team *"[relies] on the application of education research, user feedback, and years of networking and experience to improve the program..."* It is hard to assess whether the ACE EPO team and related projects are making an impact and meeting the goals of the program without some kind of formalized evaluation, even a systematic internal evaluation. The application of education research is laudable but still may not help meet stated goals.

Due to the reported previous EPOESS award not being finished, there is a question as to whether this team has a high probability for successful implementation of similar proposed work.

Relevance
Significant Strengths
Content of the ACE EPO website being developed and other outreach activities are directly related to SMD science and will incorporate the complex connectedness of heliophysics science.

Significant Weaknesses
None

Cost
Significant Strengths
The budget is reasonable to support the two individuals who will be paid to update and support the Cosmicopia/HelioSPOTLIGHT website and provide multimedia to the Space Weather Action Center and Space Weather Viewer.

Significant Weaknesses
It is unclear how development of *HelioSPOTLIGHT.org* is being supported as there is no explanation of the budget or the level of effort for this part of the project. Developing a website is not a small endeavor. It is important to understand the source of support for this part of the project because of its importance to the overall success of the ACE EPO outcomes.

Collaboration
Significant Strengths
The new EPO Co-leads are active members of the Heliophysics EPO Forum and there is evidence of past collaboration with the IBEX team. The new Cosmicopia website has the potential to gather information from other heliophysics missions in one place but no partnerships are explicitly discussed (see Weakness).

Significant Weaknesses

There are no explicit plans to collaborate with other missions in the current EPO plan other than the statement that other EPO teams will collaborate on the development of the HelioSPOTLIGHT.org web site.

Mission: AIM

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

AIM EPO programs "use the beautiful images of Polar Mesopheric Clouds (PMCs) … '*clouds on the edge of space*' to motivate interest and learning that promotes a deeper understanding of the issues surrounding changes in our atmosphere"—specifically, global climate change. The EPO team will continue to partner with the Heliophysics Educator Ambassador (HEA) program led by the IBEX mission, including SDO; AIM; IBEX; MMS; RBSP; RHESSI; TIMED; THEMIS/ ARTEMIS; and Voyager. Activities will include: 1) participating in the HEA Planning Session; 2) administering the HEA Facebook page for teachers; 3) collaborating with past teacher professional development workshop participants to create new K12 (Kindergarten through 12th Grade) activities for their website; 4) continue to provide videoconference events for teachers and students involving mission scientists; and 5) collaborate with Hampton University (an Historically Black College) to include AIM-related content in one non-science majors physics course and one teacher professional development workshop.

General Comments and Recommendations

While AIM EPO has successfully shared exciting data and imagery of noctilucent clouds and the Earth's mesosphere over the last ten years, insufficient information is provided to warrant a recommendation for continuing the EPO program. It is suggested that the AIM PI and EPO team submit a revised EPO proposal for continuation that includes more specifics on the planned program, as follows:

Specifically, the AIM EPO Team should develop a more robust evaluation plan based on, as of yet unstated, education goals, expected outcomes, and measures of success. While the modest budget may not support a full external evaluation of these efforts, some form of evaluation is needed – perhaps leveraging evaluation tools and/or efforts used by the Science Mission Directorate Education and Public Outreach Forum (SEPOF). Further, clarify how collected evaluation data will be used to modify/enhance the AIM EPO program. Along these lines, results from previous evaluations should be provided to demonstrate the success of previous AIM EPO efforts, and to demonstrate how these past evaluations have enhanced their EPO program and influenced their proposed efforts.

Before delving straight into creating the various types of content they propose, it is suggested that the needs for such products be established (see Relevance Weaknesses, below, for suggestions) as well as an explanation as to how AIM is contributing to the larger heliophysics EPO program and how it supports NASA's education outcomes and SMD heliophysics goals.

Once created, it is not clear whether the AIM EPO team is planning to submit their activities and EPO resources to NASA Education Product Review, which they should do.

The budget, budget justification, and management plan should more carefully describe how the funding and personnel would work together, so as to demonstrate a high probability of successful implementation of the proposed EPO efforts.

A dissemination plan should be created for the college course curriculum so that its reach goes beyond that of Hampton Univ.

It is not clear who will maintain the AIM EPO website(s) and link AIM data to Space Weather Action Center (SWAC) for further dissemination. This should be described.

Intrinsic Merit

Significant Strengths

There are clear links to the science theme of their mission regarding global climate change and Earth's atmosphere. The budget seems well within what is reasonable to succeed at primarily creating new content for the project website, contributing content to two professional development workshops per year and traveling to a conference. It does draw on participants from past AIM EPO efforts to help create the new content, and make this new content available to educators who already come to their website and/or have been to their past teacher professional development workshops. They state their past videoconferences were "well received" and "requested by many teachers." (see Weakness)

Significant Weaknesses

While the proposal states that previous videoconferences were "well received", the reach of the AIM EPO is not clear (e.g., how many participants). There is no discussion of the management beyond a statement that the budget is to fund time and travel for the EPO Director and Manager to coordinate the program. The proposed work would be much improved with a more robust evaluation plan. There is mention of an evaluation company that was used in the past to evaluate the Heliophysics Education Ambassadors (HEA) Working Group, and they will "participate in all evaluation requests administered by the evaluators." It is unclear whether the AIM EPO team has input/insight on the evaluation with respect to the goals, expected outcomes, and measures of success of the EPO efforts. In addition, it is not clear whether evaluation is included in the budget.

Relevance

Significant Strengths

There is significant use of NASA content related to global change and AIM science in the proposed work.

Significant Weaknesses

Customer need has not been well established. This could have potentially been established by stating how many teachers/posts are involved in their Facebook efforts, website statistics about unique users, downloads of current materials, actual requests for new content, and a survey of past workshop participants.

Cost

Significant Strengths

The budget seems well within what is reasonable to succeed at primarily creating new content for the website, contributing content to two professional development workshops per year and traveling to a conference.

Significant Weaknesses:

There does not appear to be anything budgeted for evaluation, but this may be an oversight within the very brief budget description in the proposal that is actually addressed in the budget.

Collaboration

Significant Strengths

The AIM EPO collaborations seem strong, involving the HEA program led by the THEMIS mission, including SDO; AIM; IBEX; MMS; RBSP; RHESSI; TIMED; THEMIS/ARTEMIS; and Voyager

Significant Weaknesses

None

Mission: CINDI: C/NOFS

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

The CINDI EPO program proposes to provide: materials for 6^{th} grade and up formal education harnessing the excitement of a NASA mission and of the science content involved; professional development for teachers; outreach materials for classrooms and informal settings also in collaboration with other missions in the heliophysics portfolio; and other opportunities. In particular the CINDI team will provide support for the Heliophysics-wide Heliophysics Educator Ambassador (HEA) and Communities of Practice (CoP) programs; provide teacher professional development in Texas and nationally; and provide outreach through their character "Cindi" who has a Facebook presence and comic books.

General Comments and Recommendations

The proposed work is strongly endorsed pending the submission of an evaluation plan including goals and outcomes to be assessed by the EPO team internally. Additionally, the panel recommends this program as a candidate for expanded national workshop offerings through additional support.

Intrinsic Merit

Significant Strengths

The mission EPO plan provides a well balanced portfolio of education and outreach activities and materials that will have a broad impact due to their ease of dissemination. The project will support existing successful efforts to train educators to teach about heliophysics content and leverages other opportunities, both provided by NASA and other partners, to extend the impact of the EPO activities. Alignment of existing curricular materials to the Next Generation Science Standards (NGSS) will make materials useful to science teachers and ensure a higher probability of their use in the classroom. The continuation of informal products will reach a wide audience as demonstrated by current use of similar materials.

The comic book product is excellent for encouraging girls' interests in science. The teacher support through Texas regional and national workshops, and through the HEA and CoP programs is ample to support the development of interest in STEM using this mission as a motivator. This small effort has the potential to reach a large audience through its diverse efforts and will provide content to an underserved community by providing materials in Spanish.

Significant Weaknesses

There is no evaluation plan provided. It is clear that there is assessment expertise on the EPO team, it would help to see a small section on outcomes/metrics to understand if the program is meeting its intended goals, even if data is collected by the EPO team for an effort with such modest person effort.

Relevance

Significant Strengths

The program is relevant for teachers and students and thoughtfully includes standards based content. The comic book series and Facebook page are particularly relevant to attracting girls into NASA related careers. The described activities align well with SMD heliophysics content and will help stakeholders understand the interconnectedness of heliophysics science.

Significant Weaknesses

None

Cost

Significant Strengths

The costs are very appropriate for the work described. Due to the nature of existing projects and responsibilities of the EPO leads, there is sufficient time allocated to support this effort including personnel time, sponsorships, and materials support.

Significant Weaknesses

None

Collaboration

Significant Strengths

The mission collaborates with all heliophysics-wide strategies, and also through workshops and products has a large degree of dissemination on the national scale. Support of the HEA and the CoP will leverage funds of other missions to make a larger impact at a relatively low cost. Other non-NASA partnerships also help leverage funds/audience.

Significant Weaknesses

As there is no evaluation described, it is possible that lessons learned are not adequately shared.

Mission: Cluster

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

The past Cluster EPO program primarily focused on informal and outreach activities for a variety of audiences. Included in the cadre of activities was Sun-Earth Day, Heliophysics Educator Ambassador (HEA) program, planetarium shows and podcasts. Sixty-nine graduate students have incorporated Cluster data for their M.S. and/or Ph.D. theses. While a variety of past programs are described, it would appear that going forward, they propose to only fund two participants in HEA.

General Comments and Recommendations

Although very successful in the past, insufficient information is provided with respect to needs, goals, outcomes, evaluation, and budget justification to warrant recommendation for continuation. It is suggested that content and activities related to Cluster be merged within the Heliophysics Senior Review EPO group of programs and activities on the Heliophysics EPO website.

Intrinsic Merit

Significant Strengths

The Cluster EPO program has reached a large audience over the mission's 20 year span via a variety of dissemination mechanisms. The Space Weather CD is widely disseminated.

Significant Weaknesses

The Cluster EPO progress report lacks detail regarding content alignment with NASA and National Science Education Standards (NSES). The report does not address the soon-to-be-released Next Generation Science Standards (NGSS), nor does it discuss future initiatives. There are no established needs, stated goals and outcomes, evaluation plan, nor budget justification.

Relevance

Significant Strengths

Cluster EPO shares data with underserved audiences and collaborating with the Heliophysics Educator Ambassador program.

Significant Weaknesses

The report does not make a clear link to NASA's and SMD Heliophysics priorities. The Heliophysics EPO Senior Review Panel Members are left to infer the connection. Customer need is not established.

Cost

Significant Strengths

The proposed cost is low.

Significant Weaknesses
The report/proposal lacks a budget and full justification for the requested funding continuation. It is not clear whether the requested funds are sufficient, or overly expensive, to appropriately support the EPO activities.

Collaboration
Significant Strengths
Cluster EPO works with other Heliophysics missions in support of the HEA.

Significant Weaknesses
The report/proposal does not clearly identify how the EPO program is collaborating with other missions, aside from stating that it helps to train teachers.

Mission: Hinode

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

The Hinode (previously Solar-B) Education and Public Outreach (EPO) program seeks to engage K12 (Kindergarten through 12th Grade), undergraduate and graduate students, teachers, and the public in Hinode science. The team has a large array of programs that connect to the mission science through outside funding (e.g. National Science Foundation Research Experiences for Undergraduates; [NSF REUs]) or through mission scientists volunteering at various public events on a local (to Marshall Space Flight Center [MSFC]), or national, scale. Public engagement is through web-chats associated with feature solar activities, social media, and websites. The Extreme Ultraviolet Imaging Spectrometer (EIS) EPO team provides materials for national and international events (through the obvious mission connections with Japan and Europe). There have been numerous public lectures, science festivals and fairs. K12 activities include opportunities for high school students to work in a research environment and Science4Girls events. There are also educator professional development (PD) events developed by the Chabot Space & Science Center.

General Comments and Recommendations

The Hinode Program has a significant research program for undergraduate and graduate students. While this student research program is merited, a research program for upper level students is more "engagement in the scientific research enterprise" rather than EPO. The Hinode mission should continue these efforts through alternative programs, such as the NSF REUs, though we do not consider them fundable through the Heliophysics missions EPO programs. Other activities seem very localized or superficial in nature, and we believe can also be supported, or continue to be supported by external sources or volunteer efforts. Upon submission of a revised budget justification, a more robust evaluation plan (including goals and outcomes), demonstration of how their efforts are connected to science education standards (either current or next generation), connected to the benchmarks for scientific literacy for public audiences, and connected to NASA SMD and Heliophysics goals, it is recommended that the Solar Optical Telescope (SOT) instrument team's EPO activities alone continue to be funded. In addition, collaborations with other Heliophysics-wide programs are strongly encouraged as the budget permits.

Intrinsic Merit

Significant Strengths

The SOT Instrument team clearly has a plan of outreach and engagement in science, partnering with many other groups, and providing effective outreach on a national scale. The programs from the other instrument teams and MSFC have fostered strong researcher-learner partnerships at various levels through non-mission-funded activities. Encouraging participation by Historically Black Colleges and Universities (HBCUs) is valued.

Significant Weaknesses

Other than the SOT team's plans, many activities are either local to MSFC, or international in nature. The primary focus of the Hinode mission's EPO proposal is on upper level research:

while one should expect, and encourage, internships of this nature to be included in the broader impacts of a science research proposal, it is not EPO.

There is no information provided on any type of evaluation plan, or on any specific goals or outcomes of the EPO program.

Relevance

Significant Strengths

The SOT team partners with various groups to engage the public on a national scale. The team utilizes NASA resources and facilities. Students involved in the high school program are developing 21st century skills through computing, data analysis, web programming, and video production. Plans include the involvement of underrepresented communities.

Significant Weaknesses

There are no described connections to science education standards (either current or next generation) nor to the benchmarks for scientific literacy for public audiences.

This program is relevant to NASA, but specific NASA EPO goals and objectives are not identified. Clarification of the specific EPO program goals and objectives is needed.

The Hinode EPO program overall is primarily focused on undergraduate and graduate students engaging in the scientific research enterprise as active and contributing researchers, not as learners.

Cost

Significant Strengths

None

Significant Weaknesses

It is very unclear what the EPO budget is being spent on from reading the proposal text. It has clearly been aimed at about 1% of the mission budget, but by reading the proposal itself it is impossible to determine where and why this is being spent, as the huge majority of programs appear to be supported by outside sources or by volunteers. The proposal needs a budget justification.

Collaboration

Significant Strengths

It seems that the vast majority of the mission EPO is run in collaborations with various offices at MSFC or with external groups (through for examples several NSF REU programs). There is high leverage with programs that are at no cost to the mission. The SOT team at Lockheed Martin Space Applications Laboratory (LMSAL) collaborates with many external groups to provide programing on a national and distributable scale.

Significant Weaknesses

There appears to be very little collaboration with the heliophysics-wide initiatives such as the Community of Practice (CoP), Space Weather Action Center (SWAC), or Heliophysics Educator Ambassadors (HEA) program.

Mission: IBEX

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

The Interstellar Boundary Explorer (IBEX) mission science objective is to discover the nature of the interactions between the solar wind and the interstellar medium at the edge of our solar system. The EPO program is conducted out of the Adler Planetarium, Chicago, IL. Team efforts include planetarium shows, curriculum development, educator professional development, and afterschool programs to raise awareness to the forces inside and outside the interstellar boundary, as well as showcase the tools used to detect and measure them. The team has a well-developed, described and charted plan for public outreach that includes both their own efforts and collaborations with the rest of the heliophysics EPO community. Dissemination is conducted on a national scale – in particular through distributed media for planetaria and their associated formal and informal audiences.

General Comments and Recommendations

The IBEX EPO program provides a well-defined portfolio of activities, which cross many domains of education and public outreach. The programs are all intentional and meaningful; robust evaluation efforts ensure that valuable results are achieved. The proposed work involves many diverse groups and will achieve strong results in maintaining and growing the future pipeline of STEM professionals. We highly recommend that IBEX continue its EPO program as described.

We further recommend that the IBEX mission EPO team become the primary responsible mission for the Heliophysics Educator Ambassador (HEA) program. Other missions should contribute stipends, logistical support, and evaluation funds to IBEX in proportion to the number of educators that they are able to support. Via this mechanism, IBEX should establish consistent compensation to teachers for participation, and consistent, meaningful, and non-duplicated evaluation across the HEA program.

Intrinsic Merit

Significant Strengths

The project has an extremely well developed plan based on the needs of all stakeholders. The plan includes developing planetarium components for both visually and hearing impaired individuals that will have significant impact on the future of the planetarium community beyond the scope of this mission. The team is adept at working with diverse audiences, and is well placed as a key developer of the HEA Program. The EPO Team is strongly placed in the NASA EPO community and is able to maintain and develop dissemination and collaboration. The project has strong evaluation components both formatively and summatively, which provides results to the EPO community at large.

Significant Weaknesses

Sustainability beyond the funding cycle is not addressed except through the train the trainer professional development. A large number of the partnerships and connections rely on the role of particular individuals funded through this mission, so if they were to be lost or replaced there may be key factors of the intrinsic merit that were also lost.

Relevance

Significant Strengths

Curriculum development through Lawrence Hall of Science (LHS) and Great Explorations in Math and Science (GEMS) meet the Space Science sequence for grades 6-8. IBEX Space Explorers Afterschool Science Club utilizes these materials and works primarily with underrepresented communities. All of the programs involved have evaluation plans for both formative and summative stages. Findings from “customer needs” to “audience outcomes” are thoroughly assessed and maintain the relevance of the programs and products developed. The programs are structured in a thoughtful manner to provide a meaningful and relevant portfolio of activities.

Significant Weaknesses

While stated as “in progress” there is no direct information provided about the plans to work with people with disabilities (visual impairment, hearing impairment, dyslexia)

Cost

Significant Strengths

The budget is well structured, includes (and matches) a clearly defined timeline and includes funding for meaningful evaluation. The request is appropriate for all of the activities approved.

Significant Weaknesses

None

Collaboration

Significant Strengths

The IBEX project is the lead on many heliophysics-wide collaborations (including the HEA Program, LHS GEMS, and Community of Practice [CoP]); individuals work on the project in a cross-forum manner. Every aspect of the project is well aligned with appropriate collaborations to maximize impact and dissemination prospects.

Significant Weaknesses

None

Mission: RHESSI

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

The RHESSI EPO program includes formal, informal and public outreach activities that address NASA and SMD education outcomes. RHESSI is actively involved in the Space Weather Action Center, Sun-Earth Day activities and open houses. RHESSI supports the Heliophysics Educator Ambassadors (HEA) and Community of Practice (CoP) Programs, and plans to support increased numbers through online interactions in the future.

General Comments and Recommendations

The RHESSI program supports NASA and SMD Heliophysics outcomes, and National Science Education Standards (NSES). The program works with cross-Heliophysics programs such as the HEA and CoP. We recommend that the EPO program continue pending clarification and more details of the evaluation plan and budget justification. They also should be required to coordinate with, and provide a description as to how they are coordinating with, other Heliophysics missions that participate in Cal Day Open House, including how they are using associated funding.

Intrinsic Merit

Significant Strengths

The RHESSI EPO program has successfully reached an international audience over the mission's 12 year lifetime. The RHESSI EPO program is developed with customer needs in mind and addresses the NSES and is gearing up to modify activities in support of the Next Generation Science Standards (NGSS). The program supports Heliophysics-wide initiatives such as the CoP and the HEA as well as on a more local scale to Berkeley Space Science Laboratory (SSL) supporting the Cal Day Open House. The team is focused on the importance of using real data in science lessons at the K12 (Kindergarten through 12th Grade) level.

Significant Weaknesses

The proposal is lacking sufficiently defined measures in their evaluation plan. Some refinement is needed in the description of the goals and measures of success of the program to indicate what levels of impact and engagement will be considered successful, and what evidence will be used to demonstrate success, in the future work. In addition, a description is lacking as to how they are coordinating with other Heliophysics missions that participate in Cal Day Open House, and how they are using associated funding.

Relevance

Significant Strengths

The RHESSI EPO program supports NASA and SMD Heliophysics outcomes, including working with diverse audiences and helping to feed the STEM pipeline. The program maintains good connections with the education community and provides relevant data to several portfolio wide initiatives. Contributions at Cal Day are relevant to the public visitors at that event.

Significant Weaknesses
The report does not make a clear link to NASA's and SMD Heliophysics priorities. The Heliophysics Senior Review EPO Panel is left to infer the connection.

Cost
Significant Strengths
Proposed cost is reasonable. Cost includes support for staff participation in the Cal Day Open House, Heliophysics CoP, Space Weather Action Center (SWAC) and web dissemination.

Significant Weaknesses
None

Collaboration
Significant Strengths
RHESSI EPO collaborates with other heliophysics missions through the SWAC (10 missions with 36 instruments), HEA, CoP, educator professional development opportunities and public open houses.

Significant Weaknesses
None

Mission: SOHO

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)
The SOHO EPO program has been very successful, helping students and the public to see and experience solar activity and interactions between the Sun and Earth. The present EPO program only acts to provide Large Aperture Solar COronograph (LASCO) data to other Heliophysics EPO efforts.

General Comments and Recommendations
SOHO has provided a long history of EPO activities during all of the primary phases of its mission. We encourage the SOHO team to continue providing useful data and results to the broader Heliophysics EPO community. In particular, it should be ensured that the LASCO instrument data that provides unique and popular imagery has a safe online home in the Heliophysics EPO community. Further, we recommend that all existing materials and data are provided to cross-heliophysics EPO forums for their continued dissemination and use. Given the age and the very small budget overall for mission support, we recommend that the formal SOHO EPO program be discontinued.

Intrinsic Merit
Significant Strengths
The SOHO EPO program has successfully reached an international audience over the mission's lifetime. Following cancellation of the formal and informal EPO in FY10, SOHO focused on web-based dissemination. LASCO continues to provide unique views of the Solar Corona that can be used in education and outreach to enhance understanding of that domain of the Heliophysical system.

Significant Weaknesses
None

Relevance
Significant Strengths
SOHO EPO is relevant to NASA and SMD Heliophysics.

Significant Weaknesses
Currently, SOHO data are simply provided to other EPO efforts for them to determine relevant use.

Cost
The proposed EPO cost for SOHO is zero; the proposal states that EPO personnel costs will be covered by current Heliophysics missions (e.g. STEREO) to upload LASCO data to Heliophysics websites.

Significant Strengths
None

Significant Weaknesses
None

Collaboration
Significant Strengths
SOHO EPO relies on collaboration with other Heliophysics programs for its continuation.

Significant Weaknesses
SOHO itself, by having no EPO staff, is not well positioned to direct or guide collaborations.

Mission: STEREO

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

STEREO EPO is well established, including 360° Sun, The Sun Today, and the STERO Website all providing content for science museums, classroom activities, and various social media outlets. Projects reach students, teachers, and the general public in high numbers and document success at improving public awareness of STEREO science, the connection between Sun and Earth, STEM careers, teacher science and pedagogical content knowledge. They also have a summer undergraduate intern program. They propose to continue these efforts, and to add a Cal Day public outreach event, and curriculum development, training and distribution program to bridge science, math, and reading to increase the amount of science taught in elementary school.

General Comments and Recommendations

Overall, the proposed work builds upon, and continues, what seem to have been, successful EPO efforts on the part of STEREO.

The proposed work is endorsed pending the receipt and approval of the following: 1) submission of a full budget justification for each component/effort in the budget, specifically detailing what the requested funds will be spent on and that fully delineates all salary, travel, and materials; 2) submission of a more in-depth description of effort being put into website maintenance by Goddard Space Flight Center (GSFC) and EPO collaborations; and 3) submission of an evaluation plan that includes stated goals and outcomes for each component of the EPO effort, including data collection methods that will allow for the documentation of results as to the achievement of the stated goals and lessons learned to be shared with the EPO community.

In addition, STEREO should coordinate with other Heliophysics Senior Review Mission Cal Day participants to leverage resources and to ensure that there is no duplication of effort.

Intrinsic Merit

Significant Strengths

Throughout the proposal, metrics and outcomes are stated based on previous STEREO EPO efforts, establishing their ability to reach their target audiences and goals. The proposed efforts will have a broad impact getting up-to-date heliophysics content into museums and science centers in a dynamic way. The overall effort has the potential to have a large national impact through a variety of informal and formal education programs. They have appropriately budgeted and planned for the evaluation of the Think Scientifically book series and associated professional development. They have demonstrated an understanding of connecting their EPO efforts to the science of the mission, but more importantly, to the science of the Sun and its connection to Earth and our lives on it. They conscientiously choose to work with their target audiences in creating new materials (such as teenagers providing input in creating their *Coronal Mass Ejection (CME) Launcher* game).

Significant Weaknesses
There is no current evaluation plan, although some evaluation is budgeted for. Although this project is made up of a diverse set of plans and team members and it was stated that previously a diverse set of evaluation was used, it would be helpful to establish a central place to enforce and collect that information. It is unclear if evaluation is being conducted by all projects and how that information is being shared to the whole team.

It is not clear how all of the outreach events (such as Cal Day and the continuation of already existing events) could continue beyond NASA funding.

Relevance
Significant Strengths
The proposers have done an excellent job of using the literature to demonstrate a national need bridging math, literature, and science to get more science teaching into elementary classrooms and the need for free online professional development and other training materials. There is strong evidence that many of the components will help students, teachers, and the public understand the interconnectedness of heliophysics science and that many of the resources will help other educators teach dynamically about these topics.

Significant Weaknesses
None

Cost
Significant Strengths
Though their budget is one of the largest, their program is ambitious, reaches a large number of people, significant funding is put toward curriculum development and evaluation.

Significant Weaknesses
It is not clear for what the large ~$36k in FY16-18 for EPO Collaborations will be used — that was not part of FY14-15 budget. This should be made more explicit in the new budget justification. It is unclear specifically what funds will be spent on for several other components (EPO Collaborations, Cal Day, website maintenance) which are not properly justified and need to be included in the new budget justification.

Collaboration
Significant Strengths
There collaborations are extensive, both inside and outside of NASA, and a great strength of this program, and include formal education institutes like UC Berkeley and various Oakland middle schools, the American Museum of Natural History, NASA's Museum Alliance and Heliophysics Education Forum, etc.

Significant Weaknesses
None

Mission: THEMIS

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

The THEMIS EPO plan is to support the Heliophysics Educator Ambassador (HEA) program by providing four participant stipends in FY14, another 5 in each FY15-18, and resources to participants as well as science presentations during the workshops. The HEA program, led by IBEX, will train informal educators from across the country who, after they are trained, will facilitate workshops in their own communities for middle school teachers, utilizing a premade curriculum. Additionally, the team will support a virtual heliophysics Community of Practice (CoP) for educators coordinated by the Heliophysics EPO Forum through four stipends per year for teacher leaders and providing information to the community on applicable science. The team will continue to operate the Geomagnetic Event Observation Network by Students project, maintain the mission website, and support two public outreach events each year in California.

General Comments and Recommendations

This proposed work is endorsed with the following recommendations: 1) It is strongly suggested that THEMIS take on an oversight/management role in the CoP, and that the distribution of educator stipends and CoP program evaluation lies within their responsibility, with other Heliophysics EPO mission budget dollars to support CoP stipends and evaluation being managed by THEMIS. Via this mechanism, THEMIS should establish consistent compensation to teachers for participation, and consistent, meaningful, and non-duplicated evaluation across the CoP program; 2) The team should provide a stronger budget justification, particularly with respect to salaries; and 3) There should be an explicit assignment of the evaluation role of the non-CoP related program components to a team member, or someone to collect the evaluation data from partner programs.

Intrinsic Merit

Significant Strengths

This program will support successful existing programs to engage informal educators using a train-the-trainer model to effectively broaden the impact of training for teachers in heliophysics content. Additionally, support for the heliophysics CoP will engage educators who could potentially feel isolated and want a stronger connection to NASA science and scientists. The GEONS project serves traditionally underserved and underrepresented communities in rural areas and engages students in NASA heliophysics content. Each of the above has a demonstrated audience. The website provides mission science to the public and teachers and has features that were responsive to previous HEA participants. The yearly outreach events have been evaluated and found to be effective at engaging the public in mission science. The EPO projects build on previously NASA-funded programs and will inform participants about other NASA funded projects.

Activities for educators are aligned to the AAAS Benchmarks for Scientific Literacy, National Science Education Standards, Next Generation Science Standards, and National Mathematics Standards making them useful for teachers who are trained and supported by the program.

The proposal has a robust evaluation plan for the CoP effort by a competent evaluation firm. Evaluation findings will be a contribution to the field of supporting educators.

Significant Weaknesses
Although there is a matrix of objectives and outcomes for the overall E/PO program, there is no explicit evaluation plan for other components of the E/PO plan. Although it might be assumed that some of this might be conducted by other missions through the collaboration, it is not articulated. It is unclear who will be responsible for documenting outcomes for the rest of the program.

Relevance
Significant Strengths
The proposed activities have a strong linkage to SMD Heliophysics content and will highlight and explain the interconnectedness of heliophysics science. Additionally, each component of the plan will include up-to-date science information

Significant Weaknesses
None

Cost
Significant Strengths
The budget requested is reasonable to support the proposed efforts of the proposal including personnel for each project, the evaluation of the CoP, stipends for educators, travel, and supplies.

Significant Weaknesses
The proposal is lacking a strong budget justification, particularly with respect to salaries.

Collaboration
Significant Strengths
This program incorporates substantial partnerships with other heliophysics missions demonstrating excellent leverage of resources and existing programs. Additionally, there is a tight linkage to the SMD Heliophysics EPO Forum.

Significant Weaknesses
None

Mission: TIMED

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

TIMED proposes to continue two activities it has been involved with in the past: the Heliophysics Educator Ambassador (HEA) Partnership and teacher participation in NASA SMD Heliophysics EPO Forum Community of Practice (CoP). Specifically, they propose to fund 4 informal educators/teachers per year to "attend and fully participate in" the HEA 3-day workshop. They also propose to pay an honorarium to one informal educator/teacher per year in support of the CoP, to attend and participate with Heliophysics EPO staff to "shape and design" the CoP. They also propose to continue participating in events by providing materials and support, as well as distributing materials through website, direct mail, etc.

General Comments and Recommendations

Overall, the proposed work builds upon, and continues, what seems to have been successful EPO efforts on the part of TIMED. They have strong collaborations with other Heliophysics missions. However, the proposed TIMED EPO program is lacking a strong evaluation plan; due to the modesty of the budget, it is not necessary to have an external evaluator, but there are numerous methods for evaluating that can be accomplished internally. There also may be opportunities to conduct evaluation utilizing the Science Mission Directorate Education and Public Outreach Forum. The TIMED team must establish needs before proceeding to content creation. Educator stipends should be consistent across all HEA and CoP efforts.

It is recommended to fund TIMED with the inclusion of a more formal evaluation plan in their proposal based on education goals, expected outcomes, and measures of success, and with the stipulation that they establish needs before proceeding to content creation.

Intrinsic Merit

Significant Strengths

There is a high probability of success of this program. The HEA workshops are well established, and there is sufficient support for participants. The CoP is supported across at least one other Heliophysics mission (STEREO EPO), with all missions being invited to participate. Many teachers have already been reached by Heliophysics EPO, so it is likely there is a large community of teachers already eager to participate in this CoP.

The TIMED EPO team is actively involved with the Space Grant Consortia, a well-established network of STEM professionals and STEM educators.

Significant Weaknesses

The Deliverables for the workshops and CoP are "summative reports" in FYs 14, 15, and 18 without any detail as to the type of information these will include, but there is no explicit mention of evaluation. The little bit of past evaluation data of the HEA workshops presented in the proposal seems to come from one Likert scale question asked pre- and post-workshop. They report "the HEAs came to the workshop minimally prepared to teach the topics we were presenting (average 2.35 out of 5 across all topics) but left well prepared to teach the topics presented (average 4.12 out of 5 across all topics)". "Feeling" well prepared is not the same thing as "being" well prepared. But then, maybe some other type of evaluation resulted in these reported scores that had something to do with their actual knowledge or skills. It just isn't clear.

In addition, the educator stipends should be consistent across the entire HEA and CoP effort.

Relevance

Significant Strengths

NASA content, people, and facilities are proposed to be used. The HEA is aligned to NASA Education Outcome 2. Workshops include demonstrating the importance of TIMED research to daily lives.

Significant Weaknesses

The proposal does not specifically address a Customer Needs Focus, either by the intended audience of teachers or from the education community, at large. Though one could suppose it is probably not a stretch for the EPO team to be able to recruit five informal educators/teachers they propose to support each year.

Cost

Significant Strengths

The budget seems quite modest and sufficient to carry out the proposed work. Timelines were defined. There was cost sharing with Van Allen Probes and Solar Probe Plus.

Significant Weaknesses

While HEA is evaluated by Cornerstone, it is not clear if there are any funds set aside for evaluation of the overall proposed TIMED EPO program, but this may be an oversight of the proposal that is actually addressed in the budget.

Collaboration

Significant Strengths

There is significant collaboration among Heliophysics EPO missions in the HEA workshops, including: IBEX, CINDI, THEMIS/ARTEMIS, RHESSI, TIMED, Voyager, MMS, Van Allen Probes, Solar Probe Plus, IRIS, and SDO. And all of Heliophysics EPO will be invited to participate in the CoP. There is also a partnership with APL and Langley.

Significant Weaknesses

None

Mission: TWINS A & B

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

Funding for the TWINS EPO program was drastically cut following the last Senior Review in FY10. As a result, team members no longer support formal and informal education activities, and instead volunteer their time for various public outreach activities.

General Comments and Recommendations

The funding was discontinued in FY10 – all outreach since then has been pro bono by the science team. It is recommended that the science team continue with pro bono outreach efforts, if they are willing.

Whether or not there is additional EPO funding, the TWINS EPO team is strongly encouraged to make the TWINS data and scientific results available to the Heliophysics Forum website and to any heliophysics-related activities that address TWINS science. Further, the TWINS EPO team is encouraged to leverage developed tools to measure the success of their activities, such as simple surveys for workshops and presentations. Support for, and examples of, these are available through the Science Mission Directorate Education and Public Outreach Forum (SEPOF).

Intrinsic Merit

Significant Strengths

The TWINS science team shares STEM related activities and presentations at various public venues on a pro bono basis. TWINS introduces educators and students to technology, creativity, communication, presentation, and publications through the Space Weather Action program and Facetime presentations – building 21st century skills.

TWINS EPO provides NASA STEM content in an engaging manner to a wide group of users, including formal, informal and public.

Significant Weaknesses

It is not clear how the outreach activities and presentations support NASA and SMD outcomes. The TWINS web site does not include any links to EPO – only to the teams presentations and publications. Numbers and demographics were not provided for many of the projects making it hard to assess the different audiences reached by the program.

Relevance

Strengths

The TWINS science team is reaching out to K-12 educators, afterschool programs and public to increase interest in STEM, which meets NASA's EPO Strategic Framework and President's Co-STEM report. Science being conducted by the TWINS is relevant to NASA and SMD science.

Significant Weaknesses

The report does not make a clear link to NASA's and SMD Heliophysics education priorities.

Cost

The Heliophysics Senior Review EPO Panel acknowledges and commends the TWINS A & B science team members for volunteering their time to prepare and deliver outreach activities to the public.

Strengths

None

Significant Weaknesses

None

Collaboration

Strengths

None

Significant Weaknesses

There is no evidence of collaboration with other Heliophysics EPO programs.

Mission: Voyager 1 & 2

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

The Voyager missions have an eclectic mixture of EPO activities that are continuing through the extended life of the mission. Events range from camps, to school visits, to exhibits at JPL for public days, and include participation in heliophysics-wide EPO activities. Highlights such as the 35th anniversary of the missions (in 2011) and 40th (in 2016) are significant opportunities for EPO activities. The mission does support Heliophysics wide programs such as the Heliophysics Educator Ambassadors (HEA) and Community of Practice (CoP) though teacher stipends. The Voyager probes are NASAs longest running mission, though it should be noted that the missions were not originally in the heliophysics portfolio.

General Comments and Recommendations

We recognize that the Voyager missions are the longest serving NASA missions, and have inspired generations with their data and findings throughout the solar system.

While Voyager supports a wide range of EPO activities, there is concern with the nature of a number of the events being proposed: for example that they may serve more as Public Relations events, rather than EPO activities. As such, the EPO program is not endorsed for continued funding, unless the team can develop a more intentional education plan that includes a needs assessment and evaluation of activities in a balanced format across the Heliophysics EPO portfolio. Such a plan should purposefully contain the educational value of the proposed efforts, as well as the intentions and outcomes.

There is also concern that the program does not have the substantial level of dissemination of content or strategies from the various EPO programs described for sharing or replication particularly considering the longevity of this mission. Further, there is concern that the EPO budget request, which is one of the largest in the senior review portfolio, serves to primarily support one day a week of an EPO coordinator’s time and a great deal of hardcopy materials, both of which were not well justified in the proposal text beyond the scope of Public Relations.

Intrinsic Merit

Significant Strengths

The Voyager missions have inspired people for the most substantial time of any NASA mission. The mission EPO is locally very strong at JPL, as it has been historically. The EPO program supports a large number of initiatives that are primarily focused in Southern California and Kansas. The EPO team leverages the success of the HEA and the Solar System Ambassadors.

Significant Weaknesses

It is not clear that the Voyager mission EPO as a part of the heliophysics portfolio is really understood, and most aspects also include the planetary components. Perhaps there should be funding of some efforts from planetary. The evaluation plan is very weak. The EPO evaluation plan is through NASA OEPM, which is not an evaluation tool. It is more of a reporting tool.

In addition, they do not mention a) how any of the results have been used or b) what their own goals, objective, outcomes, and measures of success are, other than entering data into OEPM as requested.

Relevance

Significant Strengths

The Voyager missions remain a valuable part of the “space heritage” of NASA and can be used to teach a lot about the size scale of our solar system (both from a planetary and heliosphere perspective). The EPO team is working with Compton School District, which serves a large underrepresented and underserved community.

Significant Weaknesses

From the description, it is not clear if the mission EPO actually has any size/scale of the solar system/heliosphere activities that are used with the various audiences that are reached, as that is the unique aspect of these missions that would be useful to include and that relate to educational standards.

There is no significant statement about how the EPO activities will be connected to current or future educational standards.

Cost

Significant Strengths

While supporting many initiatives the cost versus mission cost is low, and contributes to the entire Heliophysics mission EPO enterprise.

Significant Weaknesses

There is mention of increased 40th anniversary public engagement, though no education or outreach plan is explained, so appears to be a Public Relations activity for NASA/JPL rather than a part of a strategic EPO plan. A substantial portion of the funding is directed to hardcopy materials that may not have value as “EPO Materials” as described. In addition, the EPO coordinator’s time is limited yet expensive. There is no budget justification, however to explain many of these costs.

Collaboration

Significant Strengths

The plan includes support for heliophysics-wide initiatives, and collaboration with many external partners.

Significant Weaknesses

Many of the events are very local to southern California, and it should be expected that in a mission of this longevity that there would be much more dissemination and collaboration with other sites, increasing the capacity beyond the scope of the “local” projects.

Mission: Wind

EPO Program Overview (2 – 4 sentences describing Mission EPO Program)

The proposed EPO plan is to create a "one-stop-shop" for already created heliophysics resources, *HelioSPOTLIGHT*, which will organize resources by science topic and audience.

General Recommendations

The recommendation is to not fund WIND EPO unless the following is done:

- Better articulate the role of *HelioSPOTLIGHT* in the community of Heliophysics missions.
- Document and articulate user needs (both in content and interface), EPO goals and outcomes, website design and development strategies, a plan to keep the content current and relevant, an explicit evaluation plan, and budget justification.
- Establish explicit partnerships with other Heliophysics missions to support populating the website and maintaining up to date content as it becomes available.

The Heliophysics ACE mission proposal also mentioned the development of the *HelioSPOTLIGHT* website as a cornerstone of their proposal, more detail or documentation of how each heliophysics mission will support or contribute to this effort is needed.

Intrinsic Merit

Significant Strengths

The proposed website will serve to consolidate, in one place, existing information and resources about heliophysics science. This will create a single place for visitors to go to get information instead of many disperse places. This will create a "single face" for NASA heliophysics information, something that teachers and the public have been asking for. The website will also be viewable on many types of devices and be able to be updated with new technologies.

Significant Weaknesses

There is no evaluation plan. Although the proposal discusses how the website will be responsive to the needs of each audience, there is no discussion about how these needs will be assessed or how the success of the website will be assessed.

There is no description of how the resources will be uploaded into this website. It is unclear if resources will be provided by other missions and if this information will be a replication of what other missions have on their own websites. It is also unclear how audiences will be pointed to this new site and if other Heliophysics missions support this website explicitly. There is no documentation of how information on the website will be kept up to date.

Relevance

Significant Strengths

The website is directly linked to SMD Heliophysics science and will serve as a way to bring heliophysics science resources together to facilitate audience understanding of the complex interconnectedness of heliophysics science.

Significant Weaknesses
None

Cost
Significant Strengths
The funding seems reasonable for the development of the site although it is unclear if the funding will be enough to integrate all of the resources.

Significant Weaknesses
There are no funds allocated for evaluation explicitly. There is some concern that this level of support may not be enough to integrate all of the resources, there is too little information about FTE to make this determination. $20K for a lead scientist (mentioned in another proposal) will cover much less time than for an assistant, more information is needed.

Collaboration
Significant Strengths
The development of this project implies collaboration in populating content.

Significant Weaknesses
There is no specific mention of collaboration with other missions, groups, other than using their resources. The ACE proposal also mentioned the development of this website as a cornerstone of their proposal, it would be helpful to understand how each heliophysics mission will support or contribute to this effort.