Senior Review 2010 of the Mission Operations and Data Analysis Program For the Heliophysics Operating Missions

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Submitted to:

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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 within SMD Divisions 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 to the missions and projects concerned for the next two to four fiscal years. The 2010 Heliophysics MO&DA review, referred to as the Senior Review, was conducted in April and May of 2010. The Senior Review considered the comparative scientific merit of the various flight programs comprising the Heliophysics System Observatory along with the data analysis and archiving programs and educational and public outreach. 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 2009 Heliophysics Roadmap was developed by the scientific review panel, to help prioritize the resources of the MO&DA program for FY11 and FY12 along with forward looking findings for FY13 and FY14. This report presents the findings of the 2010 Senior Review.

1.2 Missions Considered

The Senior Review of the Heliophysics MO&DA program considered the following fourteen missions (in alphabetical order): ACE, AIM, ARTEMIS, CINDI, CLUSTER, HINODE, RHESSI, SOHO, STEREO, THEMIS, TIMED, TWINS, Voyager and Wind. Three of the missions, CINDI, HINODE, and TWINS are just finishing their prime missions and are undergoing their first Senior Review as shown in Table 1.

Table 1 Missions considered by the 2010 Senior Review of the Heliophysics MO&DA program.

Mission	Launch	Age (years)	Stage
ACE	8/27/1997	12.7	Extended
AIM	4/25/2007	3.0	Extended
ARTEMIS	(2 of 5 THEMIS Spacecraft)		Proposed
CINDI	4/16/2008	2.0	1st Review
CLUSTER	7/16/2000	9.8	Extended
HINODE	9/23/2006	3.6	1st Review
RHESSI	2/5/2002	8.2	Extended
SOHO	12/5/1995	14.4	Extended
STEREO	10/25/2006	3.5	Extended
THEMIS	2/17/2007	3.2	Extended
TIMED	12/7/2001	8.4	Extended
TWINS	3/1/2008	2.2	1st Review
Voyager	8/20/1977	32.7	Extended
Wind	11/1/1994	15.5	Extended

At the last Senior Review panel, the THEMIS science team had proposed a bifurcation of the primary mission into THEMIS and ARTEMIS (relocating two of the THEMIS spacecraft to lunar orbit) during an extended mission phase. This concept has progressed in the last year with two of the THEMIS spacecraft currently in transition to lunar orbit. The Panel has made separate evaluations of THEMIS and ARTEMIS, including the results of an independent review of ARTEMIS conducted by a combined Heliophysics and Planetary panel.

1.3 Instructions to Senior Review Panel

The Senior Review panel was instructed by NASA Headquarters to conduct the review in the following manner with the following criteria:

1) In the context of the Heliophysics research objectives and focus areas described in the Science Mission Directorate Science Plan, rank the scientific merits - on a **"science per dollar"** basis - of the expected returns from the projects during FY11 and FY12. The scientific merits include relevance to the Heliophysics research objectives and focus areas, scientific impact, and promise of future scientific impact.
2) Assess the cost efficiency, data availability and usability and the vitality of the mission's science team as secondary evaluation criteria, after science merit.
3) Drawing on (1) and (2), provide comments on an implementation strategy for the MO&DA program for 2011 and 2012 which could include a mix of:
    a. Continuation of projects "as currently baselined";
    b. Continuation of projects with either enhancements or reductions to the current baseline;
    c. Mission extensions beyond the prime mission phase, subject to the "Mission Extension Paradigm"; or
    d. Project termination.
4) Make preliminary assessments equivalent to (1) for the period 2013 and 2014.
5) Make preliminary assessments equivalent to (2) for the period 2013 and 2014.
6) Make preliminary assessments equivalent to (3) for the period 2013 and 2014.
7) Provide an overall assessment of the strength and ability of the MO&DA program to meet the expectations of the Heliophysics System Observatory during 2011 to 2014, as represented in the SMD Science Plan and in The Heliophysics Science and Technology Roadmap 2009-2030.

The Panel was further charged to identify specific potential reductions in order to make-up the $5M/year shortfalls in MO&DA in FY11 and FY12. Due to reduced projected funding levels compared to previous budgets and the impact of new missions moving from their prime mission phase to extended missions, the MO&DA budget will be under-funded by at least $5M per year starting in FY2011. NASA Headquarters expects that this projected funding shortfall will severely affect the capabilities of the Heliophysics System Observatory and its ability to address all of the scientific goals of the NASA Heliophysics program.

1.4 Methodology of the Senior Review Panel

Elements of the Senior Review began in January 2010 when NASA Headquarters directed each of the fourteen missions under review to prepare an Extended Mission Proposal. Two documents, the SMD Science Plan and the 2009 Roadmap, were cited as critical in importance for guiding the concepts for each extended mission. Both present the array of Heliophysics missions as an integral element, the Heliophysics System Observatory. The 2009 Roadmap provides a series of open science questions that could be addressed by the continuation of specific assets of the System Observatory. The individual programs were directed to discuss their mission's potential for elucidating such answers during FY11 and FY 12 and further through FY14. The proposals were to address each mission's:

- Relevance to the stated Heliophysics research objectives and focus areas;
- Impact of scientific results as evidenced by citations, press releases, etc.;
- Spacecraft and instrument health;
- Productivity and vitality of the science team (e.g., publishable research, training younger scientists, etc.);
- Promise of future impact and productivity (due to uniqueness of orbit and location, solar cycle phase, etc.);
- Broad accessibility and usability of the data.

The proposals contained a science section, a technical/budget section, a mandatory legacy science data archiving and migration plan to a final archive, a mandatory description of the intended E/PO project (where applicable), and a budget supplied on a standard spreadsheet. Unlike previous years, NASA Headquarters did not accept so-called "Optimal" budget proposals. Rather each program submitted a proposal that was "In-Guideline" or within the budget guidance as directed. The only over-guideline budgets to be permitted would be to establish budgetary guidelines where none currently existed.

NASA Headquarters selected ten 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 distributed to the panel members by March 26th. The Senior Review panel meeting was held April 20th- 23rd in Washington DC with all members present. During the panel meeting, each mission made an oral presentation followed by an opportunity for the panel members to ask clarification questions. The Education/Public Outreach (E/PO) activities and Mission Archive Plan (MAP) were considered separately by qualified reviewers, and a summary review was presented to the panel. The panel assessed the scientific merit of each mission and considered the comparative costs. Two teleconferences were used to finalize the panel findings and develop this report.

2 Senior Review Panel Findings

2.1 Overview of Findings

In the previous two Senior Review panels, the mission teams were asked to submit both 'optimal' and 'in-guide' budgets. The former reviews were designed to maximize the scientific impact of the mission while recognizing the tight fiscal constraints that NASA faces. Although the MO&DA budgets have never been sufficient to support all missions at the optimal level, it was the happy task of the Senior Review panel to identify the missions that made the most compelling scientific cases for a higher budget.

In the current Senior Review panel, circumstances are very different. First, mission teams were instructed to present budgets for only "minimal science" (i.e., no detailed analysis, data fitting, modeling, or interpretation). Second, the 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".

Overall, the Senior Review panel finds that the mission teams have been responsive to the need for aggressive reductions in costs. As specified in its major findings in section 2.4, the Panel did identify a few instruments whose funding levels could be reduced or zeroed out, and noted two cases (STEREO and TIMED) where administrative and operational costs seemed excessive compared to the other missions. Only one proposal (Cluster) presented a budget that was deemed significantly incommensurate with "minimal science" funding.

The Panel commends NASA, in partnership with the Heliophysics community, for steadily eliminating missions that are obsolete, superseded by newer missions (e.g., TRACE by SDO), or are not sufficiently functional to merit continuation. However, the Senior Review panel 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. Thus the Senior Review panel found that the missions currently comprising the Heliophysics System Observatory (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 HSO we will have the opportunity to watch as the Sun awakens from the deepest ground state ever observed in the Space Age.

We will see how the Heliosphere responds, from the upper boundary of Earth's atmosphere to the edge of interstellar space. This 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 potentially poised to make these breakthroughs.

Unfortunately, in the opinion of the Panel, the Heliophysics MO&DA budget projection jeopardizes the scientific return from the HSO program. The budget for FYs 12 and 13 provides for the collection, verification and archiving of the data without a clear plan for the analysis of the data. This problem is exemplified by the cancelation of the GI program in FY10 which is the primary mechanism for funding the science of the HSO. Only those few new missions just entering the MO&DA program have a level of funding to make scientific progress. Obviously the Panel cannot recommend further cuts in the MO&DA budget beyond those listed in section 2.4.1. *Instead the Panel finds that the "minimum science" budget with its directives is an unacceptable plan for accomplishing the scientific promise of the Heliophysics System Observatory because it is not paired with a clear plan for cross-mission, system-science data analysis.*

Currently a relatively small portion (~$55M) of the entire HD budget (~$600M) supports extended missions, yet these missions comprise the majority of the HSO. These concerns are further aggravated by the instability in support for Heliophysics GI, SR&T, Theory, and LWS/TR&T programs, which utilize the HSO datasets. The panel therefore believes that it is urgent and essential for NASA, in consultation with the Heliophysics community, to examine the larger question of the budgetary balance between MO&DA (including extended missions), new missions and system-science data analysis.

2.3 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 Heliophysics System Observatory 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 0 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 1 for the first category, overall scientific merit, and in Figure 2 for the second category, contributions to the Heliophysics System Observatory. To assess the degree of agreement among panelists, the standard deviation (STD) of the rank also is shown in the Figures. Figure 2 makes clear that the panel found that all of the missions reviewed could be expected to make excellent contributions to the HD/SMD enterprise.

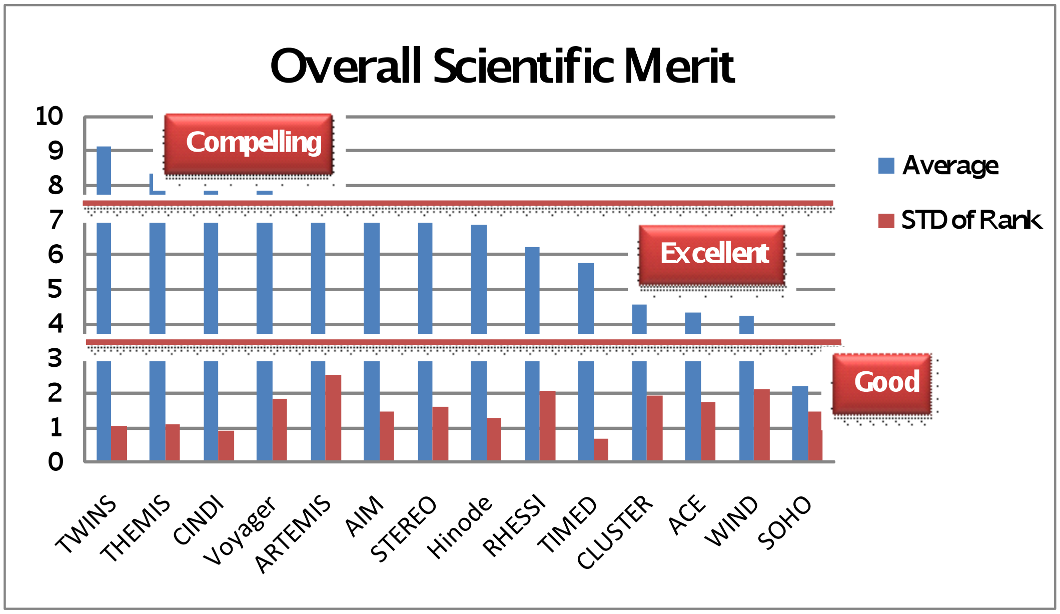


Figure 1 Senior Review panel rank of the overall scientific merit of the proposed extended missions

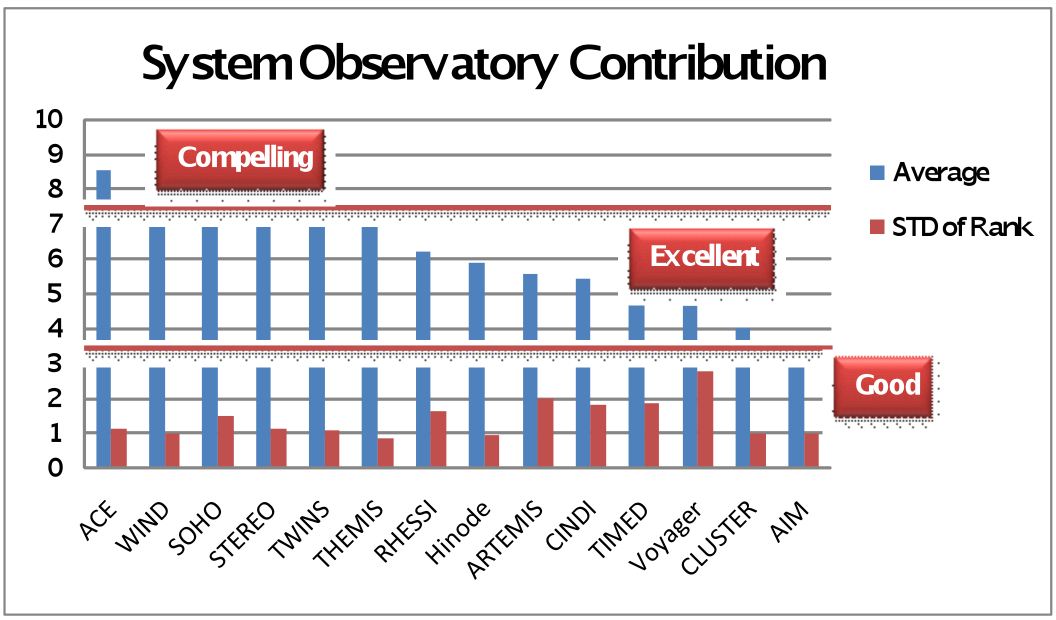


Figure 2 Senior Review panel rank of the contribution to the Heliophysics System Observatory goals

2.4 Major Findings

The Senior Review panel spent considerable effort prioritizing the MO&DA program in light of projected FY10-15 funding shortfalls. The magnitude of the shortfall is at least $5M per year starting in FY11. It is clear that this funding shortfall will severely diminish the scientific output of the Heliophysics System Observatory and its ability to address the scientific goals of the NASA Heliophysics program.

2.4.1 Budget Reduction Findings

The Senior Review panel developed the following twelve findings based on the criteria presented to address the current and future budgetary shortfall of the program:

1. The Senior Review panel finds that the level of funding proposed by the United States Cluster science team is high relative to the other missions under review by this Panel considering the probable scientific return and the primary role of European investigators in most of the instrument and operations activities. As pointed out in the Cluster proposal, the unique contributions of Cluster come from multipoint measurements, yet not all instruments are functioning on all four spacecraft. For example, only one of the four CODIF instruments is said to be operational, although significant funding has been requested for this investigation. The panel finds that the proposed level of support for the Co-I science teams is not consistent with a minimum science extended mission. It would be appropriate to have future Cluster data analysis funded through the GI or SR&T programs.

2. The SOHO mission is being recommended for continuation because of the high value of the LASCO coronagraph to the HSO. However, the panel finds that the scientific contributions of the UVCS and MTOF instruments aboard SOHO have minimal scientific value within the proposed extended mission. The MTOF instrument provides data that are close to being redundant with other on-orbit solar wind monitors. Termination of these investigations on SOHO would have minimal impact on the HSO scientific capabilities. It may be that the cost of collecting these data is negligible given that SOHO is operated to obtain the LASCO data. The UVCS and MTOF data could be archived for possible SR&T and GI uses without the expense of supporting further science activity directly.

3. The Senior Review Panel recommends that NASA Headquarters consider moving the science management of SOHO to either the STEREO or SDO programs as a cost-saving measure. The LASCO coronagraph on the SOHO spacecraft contributes significantly to the near-term scientific studies and extended mission of these programs. Hence, scientific management of the coronagraph should be tightly aligned with these missions for the next two years.

4. Given the MO&DA budget shortfalls, the Senior Review panel recommends that SOHO be eliminated from the Heliophysics System Observatory starting in either 2013 or 2014, although the Panel recognizes the scientific value of the still-operating European instruments on SOHO the primary reason for continued operation of SOHO is the LASCO coronagraph's observations from along the Sun-Earth line. It is expected that both STEREO and SDO will have obtained sufficient observations in the next two years that the scientific reasons for maintaining SOHO/LASCO will be much less compelling. The high cost of operating the SOHO spacecraft is therefore difficult to justify beyond FY12. This recommendation should be reconsidered at the next Senior Review panel in the context of upcoming Heliophysics missions and possible continued scientific contributions from SOHO.

5. The Senior Review panel finds that expected scientific return of the Hinode extended mission, given its costs, are modest relative to other missions in the Heliophysics System Observatory. In particular, the extended mission proposal did not clearly demonstrate that the XRT instrument operation and science team costs were justified. The extended mission proposal did not adequately present compelling scientific questions or the methodology to be applied in the context of the heliospheric system. The relatively high level of scientific support for the Hinode program requires compelling scientific objectives along with justification as to why additional observational data are needed to fulfill those objectives. The Senior Review panel suggests that NASA Headquarters move Hinode towards a minimum science mission with the expectation that major new analysis efforts of Hinode data will be funded through the GI or SR&T programs.

6. The Senior Review panel finds that the science data analysis budget for the CIPS instrument on AIM is relatively large given the stated scientific objectives. The panel suggests that NASA Headquarters could discuss this issue with the AIM science team to

determine whether they are operating a minimum science mission with this instrument and, if necessary, adjust the funding accordingly.

7. The Senior Review panel suggests that NASA Headquarters could reorganize the TIMED mission to eliminate the redundancy of the APL program office with the Goddard program office. The TIMED mission has moved completely to a minimum science mode, which could be reflected in a simplified management structure to reduce management costs.

8. The Senior Review panel finds that both the AIM and the TIMED extended missions have significant components focused on detecting the impact of global climate change on the Earth's upper atmosphere. Both programs have clear methodologies to address these important scientific issues that are closely aligned with overarching scientific objectives of the Earth Science Division. The Senior Review panel suggests that NASA HQ could explore sharing the costs of the AIM and TIMED programs appropriately between Earth Science and Heliophysics.

9. The Senior Review panel finds that both the STEREO and the TIMED missions have exceptionally high operating costs in comparison with other missions and their relative science merit. These high costs decrease the relative priority of these missions when considered on a science per dollar basis. The high cost of mission operations for TIMED and STEREO at this late stage in their mission timelines is surprising to the Panel because these spacecraft were constructed with total life cycle costs in consideration. The Senior Review panel suggests that NASA HQ could review the mission operations for these programs to insure that they are consistent with the extended mission risk paradigm; a specific example being the backup ground station maintained for the TIMED program with USN.

10. The Senior Review panel expects that the continued drift of STEREO in its orbits around the Sun will result in less science data being returned from this mission. It is therefore expected that the SECCHI instrument suite data analysis needs will decrease in FY13 and FY14. NASA HQ could review the science operations-/-data analysis funding for the STEREO program in FY13 to see if is consistent with the needs.

11. The Senior Review panel finds that the extended mission funding for the SEPICA instrument on the ACE mission cannot be justified scientifically under the minimum mission guidelines because the SEPICA instrument failed and has not returned data since 2005.

12. The Senior Review panel finds that an upstream solar-wind monitor is essential for maximizing the science output of STEREO, RBSP and MMS and it is therefore prudent to keep both ACE and Wind spacecraft operational through FY11 and FY12. Thereafter, NASA HQ could consider either eliminating one of the L1 missions in 2013 or 2014, or consider a significant down scope of the operating instruments to reduce costs and to be consistent with a solar-wind monitor mission. ACE and Wind are scientifically redundant as solar wind monitors. The wave measurements and ability to operate through strong solar particle events makes Wind valuable to the Heliophysics System Observatory. The real time data products of ACE are well established and valued within the scientific community.

2.4.2 Other Findings

The Senior Review process identified three issues in which there were insufficient resources within the limitations of the "In-Guideline" budget directive from NASA HQ to accomplish the scientific or Heliophysics System objectives.

The Senior Review panel is deeply concerned with the long term sustainability of the production and validation of scientific data from the Voyager program. The Panel suggests that NASA establish a fellowship program for young scientists to be a prestigious and competitive award that would explicitly aid in the early career development of scientists working with Voyager data. These fellowships should be focused specifically on basic analysis and validation efforts with Voyager data. NASA HQ should insure that the Voyager mission is funded to allow the project to continue to operate at the current risky, but manageable level.

The ARTEMIS program addresses topics that are of interest to both the Heliophysics and Planetary divisions of SMD. The Senior Review panel evaluated the Heliophysics portion of the proposed effort and determined that it has excellent scientific merit with low costs. The Senior Review panel strongly supports the Heliophysics portion of ARTEMIS as a portion of the extended science mission for THEMIS. The panel further finds that this Heliophysics science portion can be accomplished within the THEMIS budget with additional funding of approximately $1M. In the absence of Planetary Science Division support for the ARTEMIS mission, the panel suggests that the mission as proposed should be merged completely with the extended phase mission of THEMIS and the title of ARTEMIS discontinued.

The Senior Review panel of the TWINS extended mission determined that this mission addressed compelling and unsolved science questions on the evolution of the earth's magnetosphere during geomagnetic disturbed conditions. The methodology for addressing the posed questions was equally compelling, and the panel expected that significant progress could be made in the coming years. Several of the most important science questions from the prime phase of TWINS were not addressed at that time due to the extended solar minimum and a general lack of geomagnetic disturbances which are expected to be resolved during the extended mission phase. The Senior Review panel finds that the "In-Guideline" budget directive from NASA HQ is low given the studies to be conducted and their value to Heliophysics systems science. Therefore, the panel recommends that the TWINS program should be considered for additional extended mission funding to accomplish the ambitious proposed work plan.

3 Evaluations of Missions

3.1 ACE

3.1.1 EXTENDED MISSION SUMMARY

1) ***Overview of the Science Plan (as addressed by the mission's own instruments):*** ACE measures the composition of the solar-wind, solar energetic particles (SEPs), anomalous cosmic rays (ACRs), and Galactic cosmic rays (GCRs) with sensitivity, precision, and energy ranges that are not found on any other HSO mission The proposal outlines how these capabilities will be used in the extended mission to address heliophysics science goals, such as understanding solar particle acceleration and transport; establishing the structure and evolution of the solar wind; probing the global heliosphere and interstellar medium; and characterizing the space environment and weather. ACE also functions as a real-time upstream solar-wind monitor for both NASA and non-NASA users.

2) ***Overview of the Science Plan (as addressed in conjunction with observations from other Heliophysics missions):*** As a mature mission, with an extensive database already in-hand, it is not expected that in the next few years ACE *alone* will make breakthrough discoveries or spur substantial refinements of our present understandings. (An exception to this statement is new Galactic cosmic-ray isotope measurements, as discussed below). Therefore the focus in this proposal is primarily and appropriately on what can be accomplished via the synergy with new missions (STEREO, Hinode, and SDO) and with RHESSI in the rise phase of Cycle 24. This synergy is a new feature of the Heliospheric System Observatory (HSO). The simultaneous availability of data from all of these missions is expected to yield deeper understandings and to resolve significant long-standing questions about flares, CMEs, and SEP events.

3) ***Overview of the Methodology:*** ACE carries an extensive suite of complementary instruments measuring composition and spectra over a wide range of species and energies. These measurements are supplemented with precise observations of the in-situ magnetic field. These high quality data with nearly uninterrupted coverage provide a baseline for understanding the

more detailed and broader scope of measurements from newer missions (STEREO, Hinode, SDO) in the rise phase of Cycle 24

3.1.2 EXTENDED MISSION SCIENCE EVALUATION

3.1.2.1 Scientific and Technical Strengths

Given the dearth of solar activity in the last two years and the large and ever-growing longitudinal separation of the two STEREO spacecraft, it is likely that key issues relating to the large-scale structure of CMEs and SEP events cannot be addressed by STEREO alone. Instead, in many cases, these issues must be addressed by comparing observations from one of the STEREO spacecraft with observations from L1. ACE provides many of the measurements needed for these comparative studies. ACE instruments are functioning well, and their calibrations are well-understood. As a result, the ACE data needed for these multi-platform studies will be readily available at reasonable cost.

Solar energetic particles (SEPs) remain a high priority in the new Heliospheric Roadmap. In terms of capabilities, it should be noted that ACE still provides the most sensitive measurements ever made for solar energetic heavy ions below ~1 MeV/nucleon and above ~10 MeV/nucleon. (Intermediate energies, which have proven particularly powerful in SEP transport studies, are measured more precisely and more thoroughly on Wind.) The lower ACE SEP energies have been instrumental in clarifying the roles of various seed populations in SEP production; the higher-energy ACE SEP measurements have clarified key issues on spectral and compositional variability, whose resolution goes to the basic physical processes behind the SEP radiation hazard.

A specific new result expected in the next few years from the CRIS instrument is definitive measurements of the GCR isotopic composition of elements with atomic number above 28. These measurements deal with an important scientific problem that has been extant for decades – the origin of the source material for Galactic cosmic rays. By examining the isotopic composition of GCRs beyond the iron peak, the CRIS team expects to discover crucial information for addressing this problem. The CRIS instrument is unique in terms of its resolution and geometric factor. However, the relative abundance of the trans-iron GCR is extremely low and a statistically-adequate data sample has necessarily required many years of data collection. The very high GCR intensity over the last few years, caused by the extended solar minimum, has increased the statistics on these ultra-rare ions to a level at which compelling results now can be extracted. This complex analysis can be performed only by the science team that designed, built, and calibrated the instrument. If this analysis is not carried out now, there is very little chance of it ever being done.

3.1.2.2 Scientific and Technical Weaknesses

None major. However, we note that the proposal bulleted 75 separate tasks, 45 of which are bulleted as "high priority". As discussed below, it is unclear as to whether the proposed activities and the associated costs are commensurate with the specific instructions of SR-2010 Call for Proposals, which explicitly requests "minimal science data analysis".

Several of the proposed tasks promise to take advantage of new data from Messenger in the inner heliosphere. However, according to a recent publication (Feldman et al., JGR 115, A01102, 2010), the time-of-flight system in Messenger's Energetic Particle Spectrometer (EPS) has failed, making it impossible to distinguish ions and electrons. Accordingly, the extent to which tasks that relied on Messenger (such as the radial distribution of suprathermals) can be accomplished was unclear to the Panel. (ACE science-team members are co-authors on the Feldman et al. paper.)

3.1.3 EXTENDED MISSION RELEVANCE TO THE "Heliophysics System Observatory" and "Road Map"

3.1.3.1 Strengths

The ACE data support studies from nearly the whole spectrum of HSO missions. As amply documented in the proposal, the science objectives to which ACE will contribute are fully consonant with the Heliospheric Roadmap.

Unless a new upstream solar-wind monitor becomes available, continued access to ACE (or Wind) solar-wind data will be needed to maximize the science return from MMS and RBSP, which are expected to launch in 2012-2014. For science purposes, these solar-wind data need not be available in real time,

Although the Panel has been explicitly instructed not to consider the "utility of real time data to operational or commercial users" in our evaluation, we note that ACE provides real-time solar-wind data that are used extensively beyond the scientific community.

3.1.3.2 Weaknesses

None

3.1.4 EXTENDED MISSION COST REVIEW:

3.1.4.1 Strengths

Over the years, the ACE team has done a good job in reducing mission operation costs, thereby allowing them to devote as much of their funding as possible to data analysis and science. For the most part, the budget for the extended mission appears to be very lean, with minimal operating costs and science-team funding generally at levels appropriate for continued operations and data delivery.

3.1.4.2 Weaknesses

Except for new missions, which are just about to have their first exposure to high levels of solar activity, nearly all of the budgets the Panel has seen in the Senior Review have low levels of support, generally corresponding to less than one Full-Time-Employee (FTE) per instrument (*not* instrument package). The SIS and CRIS budgets exceed these levels. In the case of CRIS, the budget was justified as being necessary to complete a labor-intensive analysis of very rare isotopes of Galactic cosmic rays. There was no comparable justification for SIS. If NASA continues supporting mature missions only at "minimal science levels", more justification of CRIS and SIS costs in the ACE budget will be necessary.

Since 2001, the SEPICA instrument has not returned new ionic charge-state data, which were the instrument's primary contribution to the ACE database. SEPICA elemental flux measurements, whose energy ranges overlap those of ULEIS and EPAM but come from smaller geometry factors, terminated in February 2005 due to a hardware failure in SEPICA. The Panel found no justification for continued funding of the SEPICA instrument team at the $90K/year requested for FY11-FY14 in the ACE budget. This is especially true since members of the SEPICA instrument team have moved on to newer missions. The Panel therefore recommends that funding for SEPICA be zeroed-out as expeditiously as possible.

3.1.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS

Spacecraft and instrument health and status are essentially unchanged since the last SR. Power output from the solar panels is predicted to be adequate until ~2025. At nominal consumption rates, fuel reserves are adequate through 2024.

3.1.6 DATA OPERATIONS

Data management and accessibility are exemplary. The ACE team also has a record of continual improvement and expansion of their data products, including the release of extensive Level-3 data products. Overall, review of the ACE Mission Archive Plan (MAP) found that the ACE data are in good shape, and the MAP will assure future utility of the data. The MAP appears to be on track and achievable within the specified timescales. Only minor problems were identified in the MAP review, and the Panel urges the ACE team to address these issues as expeditiously as possible. The Panel refers the ACE team to the MAP Assessment report for further guidance.

3.1.7 E/PO EVALUATION

3.1.7.1 Strengths

The EP/O assessment report generally gave the ACE team good marks for their EPO efforts, particularly noting "a balanced portfolio with a good level of involvement across the spectrum of E/PO areas" and "delivering good value for the level of funding". The assessment also noted the ACE E/PO leader's successful efforts to bring ACE information to bear on SMD-wide EP/O collaborative efforts and the “continued commitment and involvement of mission scientists” in E/PO activities. The proposed future E/PO activities align well with the SMD standards and policy. The Panel refers the ACE team to the E/PO assessment report for further details.

3.1.7.2 Weaknesses

The EP/O assessment raised some specific questions on the status and future development and scope of ACE E/PO efforts. The Panel urges the ACE team to consider these questions.

3.1.8 OVERALL ASSESSMENT AND FINDING

ACE remains a cornerstone source of contextual data for the rest of the HSO. Its contributions in the next two years will be essential for realizing some of the science objectives of the STEREO mission. ACE data, which reveal the interplanetary consequences of solar flare/CME activity observed by SDO, Hinode, and RHESSI, will also enhance the science return from these missions. One area that ACE essentially has to itself is composition of Galactic cosmic rays, and the next 2-4 years are expected to bring sufficiently precise isotopic measurements in elements just above iron to definitively answer the question of GCR origin. Overall, the high quality of ACE data, the impact of those data on heliophysics science, and the productivity and vitality of the ACE team merit high marks.

The Panel recommends continued operation of ACE in its current mode throughout FY11 and FY12. Although the Panel believes that ACE will likely continue to contribute significantly to Heliophysics science objectives in FY13-FY14, its continued operation in those years should be re-examined by the next Senior Review.

3.1.9 OVERALL RATING

ACE deserves high marks in its “science per dollar” contributions to science from the HSO (Score: 8.6/10, ranking: first out of 14 missions). A lower ranking is appropriate in the “ACE alone” science, simply because a substantial database has already been acquired (Score: 4.3/10, ranking: 12th out of 14 missions).

3.2 AIM

3.2.1 EXTENDED MISSION SUMMARY

1) **Overview of the Science Plan (as addressed by the mission's own instruments):** The Aeronomy of Ice in the Mesosphere (AIM) mission is the first satellite dedicated to study the phenomenon of Polar Mesospheric Clouds (PMCs). These clouds are a sensitive marker of vertical coupling and horizontal coupling. Vertical coupling inputs are solar activity and meteoric smoke from above and atmospheric coupling from below. These clouds occur at high latitudes (>50°) in both hemispheres at altitudes near 83 km and were first observed in 1885. Their brightness and frequency have apparently increased over time and appeared at lower latitudes, possibly as a result of global climate change.

   The mission thus far has demonstrated these clouds undergo dramatic variability on all observable spatial and temporal scales. This challenges the current theory that ice particles require a substantial fraction of a day to form. Some of the variability has been found to depend on small temperature changes (~3K) caused by atmospheric waves propagating from lower altitudes and from the opposite hemisphere, demonstrating coupling of this region to virtually the entire atmosphere.

   AIM has also begun to characterize the variability of the meteoric smoke, the proposed nucleation site, and has identified a population of sub-visual ice particles in the upper mesosphere, which may be the precursors of the larger cloud particles eventually seen at lower altitudes. Water vapor has been shown to modulate longer timescale seasonal changes.

   In the extended mission, AIM will take advantage of the onset of solar cycle 24 to search for the solar irradiance and energetic particle forcing of the temporal variations seen in PMCs. The team will investigate the processes and mechanisms responsible for the hemispheric differences, seasonal teleconnection, and inter-annual variability in PMCs.

2) **Overview of the Science Plan (as addressed in conjunction with observations from other Heliophysics missions):** The main overlap comes with the TIMED mission. TIMED will enable cross validation, but also expand the latitude coverage of SOFIE, allowing study of the T, H_2O, PMC relationship over a broader range of conditions. TIMED will also assist in examining the effects gravity waves have on PMCs.

3) **Overview of the Methodology:** There are two main modes of squeezing more out of the AIM mission. One is the acquisition of more data under conditions of changing solar forcing, which is clearly expected and already happening with the ramp up of solar cycle 24. The other will be significant use of models, such as NOGAPS and WACCM/CARMA, to compare to the data and to conduct simulations.

3.2.2 EXTENDED MISSION SCIENCE EVALUATION

3.2.2.1 Scientific and Technical Strengths

Significant success in prime mission phase gives confidence that the extended mission will also achieve success. Much has been learned about the variability of PMCs and the causes of some of that variability. Gravity waves drive small temperature changes which result in significant short term variability in PMCs.

The objectives are well focused with well defined methodologies. The team has given clear and detailed descriptions of how they intend to meet their objectives.

3.2.2.2 Scientific and Technical Weaknesses

None.

3.2.3 EXTENDED MISSION RELEVANCY TO THE "Heliophysics System Observatory" and "Road Map"

3.2.3.1 Strengths
AIM is directly addressing several areas of the roadmap, including Opening the Frontier and Our Home in Space. It is providing one way of making connections from above with solar forcing to below from gravity waves. The PMC variability has been shown to depend on forcing from above and from below. Solar radiation and meteoric smoke from above and gravity waves from below. It is showing how gravity waves are responsible for variability in the state variables (*e.g.* T) describing the ITM region. The long term growth in frequency and extent of PMC's may be connected to long-term variations in solar input, but may also be a direct result of climate change.

3.2.3.2 Weaknesses
None noted.

3.2.4 EXTENDED MISSION COST REVIEW:
The AIM mission has benefited from making some prudent choices which have helped to keep costs in line. The mission operations, out of necessity, have been automated, and the chosen mission operations center keeps costs low. The costs for doing the extended mission science are somewhat high, given the charge of conducting a minimum science mission.

3.2.4.1 Strengths
Overall mission operations are cost effective.

3.2.4.2 Weaknesses
The extended mission science costs are high in comparison to other extended missions, all of whom are expected to be working at the minimum science level.

3.2.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS
The spacecraft can be considered 'fully functional,' as the mitigation solutions to all problems have been able to retain all original capabilities. SOFIE and CIPS are fully functional. Autonomous operation mitigates a problem with uplink stability and SOFIE has been able to fill the gap created when the meteoric dust experiment, CDE, failed.

3.2.6 DATA OPERATIONS
The data availability and documentation is good. There is no plan for final archiving that will be useful to the community, rather than a deep archive. The mission should work with the appropriate VxO to develop SPASE descriptions needed for registration, VxO access, and reference.

3.2.7 E/PO EVALUTION

3.2.7.1 Strengths
The AIM E/PO activities have represented good investments and have resulted in good teaching resources that have made it directly into the hands of teachers. The Panel refers the AIM team to the E/PO assessment report for further details.

3.2.7.2 Weaknesses
The international videoconference events are ill-described and need more context and definition. The E/PO effort would benefit from conducting a needs assessment and documenting the impact that has occurred thus far.

3.2.8 OVERALL ASSESSMENT AND FINDING
The AIM mission has achieved significant success in a short time and has shown how a niche topic (PMCs) can shed light on the role both solar and atmospheric forcing can play in defining the behavior of a layer of the atmosphere. There has been nothing but successes for this mission, in spite of having to deal with numerous instrument and spacecraft problems and it has achieved all of its primary objectives. All of this in spite of the unusual ground state of the recent solar minimum. The extended mission will

benefit significantly from the changes to the forcing that will come with the ramp up in solar activity, promising to shed more light on the relative importance of the various factors shown to play a role in the formation of PMCs.

3.2.9 OVERALL RATING

AIM ranked 6th in terms of Science per Dollar, scoring 7.1 out of 10, earning an Excellent ranking. In terms of System Observatory Contributions, AIM ranked 14th, scoring 3.6 out of 10, earning an Excellent ranking.

3.3 ARTEMIS

ARTEMIS (Acceleration Reconnection and Turbulence and Electrodynamics of the Moon's Interaction with the Sun) is a mission concept that takes the two outer probes of the THEMIS mission (P1 and P2) and places them in orbit around the Moon in order to address a mixture of heliophysics and planetary science topics. In the current Heliophysics Senior Review, only the Heliophysics portion of the mission is reviewed.

3.3.1 EXTENDED MISSION SUMMARY

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

   In terms of Heliophysics science, ARTEMIS will investigate: 1) Particle acceleration, magnetic reconnection and turbulence in the Earth's magnetotail; 2) Particle acceleration, reconnection and turbulence in the solar wind; and 3) Electrodynamics of the Moon's interaction with the solar wind. The tail studies will focus on revealing the 3D structure and dynamics of the distant tail. The solar-wind and wake studies will focus on examination of the seed populations for Solar Energetic Particle (SEP) particles, low-shear reconnection in the solar wind, and a further examination of solar wind turbulence in the inertial range. The lunar wake studies will examine the structure and evolution of the wake and associated particle acceleration and dynamics.

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

   ARTEMIS will contribute substantially to the greater Heliophysics Observatory in a number of ways. While the Moon is in the distant tail (60 Re downtail), the ARTEMIS probes will serve as a multi-point monitor of tail dynamics (reconnection, plasmoid/fluxrope release, etc.) that can be simultaneously observed in the inner magnetosphere with other HSO assets including THEMIS, Cluster, and Geotail and other spacecraft. While in the solar wind (which will be most of the time), the 2 ARTEMIS probes can act as an upstream solar wind monitor for other HSO assets in order to accomplish Heliophysics System Science. In addition, while in the solar wind, together with ACE, WIND and other assets, ARTEMIS will provide additional measurement points that can be used to study the three-dimensional structure (and turbulence characteristics) of the solar wind in the near-Earth environment.

3) **Overview of the Methodology:**

   Each of the THEMIS probes that will be used to create ARTEMIS, carry magnetometers, electric field instruments, electrostatic analyzers for low-energy particle measurements and solid state detector–based instruments for measuring higher-energy particles. The two probes have already returned data from initial fly-bys of the Moon verifying that the lunar wake studies to be conducted are viable.

3.3.2 EXTENDED MISSION SCIENCE EVALUATION

3.3.2.1 Scientific and Technical Strengths

Re-tasking the THEMIS P1 and P2 probes as proposed for ARTEMIS provides an excellent opportunity to explore distant tail dynamics in conjunction with a well-instrumented inner magnetosphere constellation of assets (especially the remaining THEMIS probes).

An important aspect the solar wind structure, dynamics and turbulence studies is that the two probes will be able to study the structures on variable scale-lengths (from 0.1 to 10Re). This is a particularly novel and clever approach for study the solar wind structure and turbulence and will almost certainly yield very interesting results un-obtainable via other HSO assets.

The studies of the lunar wake should also yield very interesting results and should substantially enhance our understanding of the interaction of airless bodies with the solar wind.

3.3.2.2 Scientific and Technical Weaknesses
Minor. In terms of using ARTERMIS as a solar wind monitor for the HSO, it is not clear that the converted THEMIS probes will return data that is better than other currently operating solar wind assets. For example, the particle detectors may not be optimized for solar-wind measurements. ACE, WIND and other assets have detectors onboard that were optimized for solar wind measurements.

Minor (maybe even just a programmatic concern). If ARTEMIS achieves status as a new and separate mission from THEMIS, then its tail studies find much more importance in terms of how they can be used in conjunction with "other" HSO assets (most notably THEMIS). On the other hand, if P1 and P2 remain part of THEMIS, then THEMIS is a much more coherent and self-reliant mission in terms of following the chain of dynamics from the inner and mid tail regions to the distant tail.

3.3.3 EXTENDED MISSION RELEVANCY TO THE "Heliophysics System Observatory" and "Road Map"

3.3.3.1 Strengths
ARTEMIS as a solar wind monitor will contribute to Heliophysics System Science by providing knowledge about critical solar wind parameters upstream of the Earth.

ARTEMIS measurements will greatly enhance Heliophysics System Science associated with studies of tail dynamics as it will provides the much needed opportunity to see the whole chain of dynamics from solar wind input to the magnetosphere to substorm (and other types of) dynamics in the inner and mid-tail region all the way down to the plasmoid and flux rope dynamics in the distant tail. This configuration is unprecedented and will almost certainly yield large steps forward in our understanding of the Solar Wind/Magnetosphere system.

3.3.3.2 Weaknesses
Minor. As a solar wind monitor, ARTEMIS may be somewhat redundant and probably not as capable as other assets like ACE and WIND – which were specifically designed for that mission.

3.3.3.3 Relevance to Roadmap
A matrix contained in the proposal shows how ARTEMIS science goals relate to the various Heliophysics science objectives (F, H, and J) as outlined in the current Heliophysics Roadmap. The matrix shows that ARTEMIS will contribute fairly heavily to the majority of the research focus areas. ARTEMIS will directly contribute to three of the four focus areas of the "Frontiers" science objective: F1 "Magnetic Reconnection"; F2 "Particle acceleration and transport" ; F3 "ion-neutral interactions". ARETMIS will also directly contribute to three of the four focus areas of the "Home in Space" science objective: H1 "Causes and evolution of solar activity"; H2 "Earth's magnetosphere, ionosphere, and upper atmosphere"; and H4 "Apply our knowledge to understand other regions". In addition, ARTEMIS will make contributions to the "Journey" science and technology objective in two of the four focus areas: J1 "variability, extremes and boundary conditions"; and J4 "Effects on and within planetary environments".

3.3.4 EXTENDED MISSION COST REVIEW:
As proposed, the mission concept takes the P1 and P2 probes from the THEMIS mission into orbit around the Moon and the reconfigured pair of spacecraft would form a new mission called ARTEMIS. As such, the proposed mission costs are not really "extended" THEMIS mission costs, but rather constitute funding to create and operate an entirely new mission.

3.3.4.1 Strengths
The proposed budget for ARTEMIS appears to be very reasonable with funding levels generally appropriate for returning useful data in a minimal science mode. The low-cost for this mission is largely leveraged from prior and on-going THEMIS investments and very substantially increases the perceived science per dollar ranking for ARTEMIS.

3.3.4.2 Weaknesses
Since ARTEMIS is designed to be a new mission, resources would need to be allocated to it for a new nominal prime mission phase. Presumably after this prime phase, ARTEMIS would then enter into its own

extended mission phases. Since the low cost of this mission is largely levered from current THEMIS support, it is not clear that this leveraged support would/could continue if ARTEMIS and THEMIS were to proceed forward as entirely separate missions.

In addition, a significant portion of the budget would need to support science and operations that do not directly target Heliophysics investigations.

3.3.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS

The P1 and P2 THEMIS probes are in excellent health with all instruments functioning nominally. Thermal systems and power functions continue to maintain significant margins (with power functions currently exceeding mission design requirements).

Some minor glitches have been identified with some of the instrumentation and have been successfully mitigated (e.g. sun pulse seen in two sectors per spin of the SST, and some noise seen in SCM and FGM).

The proposal also shows some data obtained from preliminary lunar fly-bys which demonstrate the viability of the proposed data collection activities.

3.3.6 DATA OPERATIONS

All data operations continue to function nominally and leverage very significantly from the THEMIS system - which is already in place and working well. For Heliophsyics investigations, nominal THEMIS modes will be used for the instruments on each probe. However, flight operations for the planetary investigations require significant modifications to nominal operating modes including new flight software.

3.3.7 E/PO EVALUTION

Pre-existing E/PO Activities included:

- Heliophysics Educator Ambassador program contributor
- Podcast(s); featured on IYA website
- Teacher workshop at ASP

ARTEMIS proposes to continue to contribute to the Heliophysics Educator Ambassador program.

3.3.7.1 Strengths

Only a few prior activities were described, mainly non-specific HEA program involvement, which is the main plan for the future of ARTEMIS E/PO. It appears that ARTEMIS' role in HEA is limited, but it is good that they are staying involved and the costs are minimal. The budget section outlines support for an undergraduate to help with updates to websites, graphics development, and podcasts. Clearly the HEA program is the way to go for future efforts, and one does want continued eyes on their web presence.

The proposed E/PO activities provide excellent value for the funding. It appears appropriate for their budget to include stipends for HEA teachers to support their continued involvement.

3.3.7.2 Weaknesses

There could be some staffing concerns in terms of over-commitment by the lead.

3.3.8 OVERALL ASSESSMENT AND FINDING

The ARTEMIS mission makes excellent use of the two THEMIS outer probes to explore important science objectives in both heliophysics and planetary physics. The activities are well thought out and very cleverly designed to achieve the desired goals. The team leverages very significantly off of prior and ongoing THEMIS investments in data processing, analysis and operational capabilities - and, as a result, the budget is extremely cost-effective. This combined with a high expected scientific yield, propels the ARTEMIS proposal to a very high ranking on a science per dollar basis.

While a significant portion of the proposed activities relate to science objectives outside the scope of Heliophysics, the Senior Review evaluated only the Heliophysics portion of the proposed effort. In the context of Heliophysics, the panel determined that it has excellent scientific merit with low costs and that the Senior Review strongly supports the Heliophysics portion of ARTEMIS objectives.

However, from a purely Heliophysics perspective it was not clear to the Senior Review what is to be gained by re-tasking the THEMIS P1 and P2 probes as an entirely new mission. Since the low costs of the mission largely derives from extensive leverage off of prior and ongoing THEMIS support, it is not clear that that support would/could continue if the two missions proceed as separate missions.

The panel further finds that the Heliophysics science portion could probably be accomplished within the THEMIS budget with additional funding of approximately $1M. In the absence of Planetary Science Division support for the ARTEMIS mission, the panel suggests that the Heliophysics portion of the mission as proposed should be merged completely with the extended phase mission of THEMIS and the title of ARTEMIS discontinued.

3.3.9 OVERALL RATING

The ARTEMIS mission ranked 5th in term of expected science per dollar for the extended mission science scoring 7.6 out of 10. In term of expected Heliophysics System Observatory contributions per dollar ARTEMIS ranked 9th, scoring 5.6 out of 10.

3.4 CINDI

3.4.1 EXTENDED MISSION SUMMARY

1) **Overview of the Science Plan (as addressed by the mission's own instruments):** CINDI science team will address fundamental science questions concerning the variability and super-rotation of the upper atmosphere and neutral plasma coupling processes. The CINDI instruments are carried to orbit as part of the air Force C/NOFS satellite payload and the data from these instruments are included in the operational profile of the Air Force mission to provide a more accurate specification and prediction of radio scintillation produced by ionospheric plasma structures. The extended CINDI mission will answer four specific science questions on the dynamic state of the ionosphere and thermosphere during the rising solar cycle. Some of objectives remain from the prime mission phase due to launch during solar minimum.

2) **Overview of the Science Plan (as addressed in conjunction with observations from other Heliophysics missions):** CINDI is the only component of the Heliophysics System Observatory that will gather in situ measurements of both the ionospheric and thermospheric motions during the rising solar cycle, when a full description of the solar radiative output is available from SDO and the state of the interplanetary medium is specified by measurements from ACE and Wind. Thus, the extended CINDI mission is a unique opportunity to discover the evolution of the relative contributions of neutral dynamics and externally applied potentials (as provided by the HSO) to the electrodynamics of the ionosphere and the effects of these dynamics on the formation and evolution of plasma structures in the equatorial region.

3) **Overview of the Methodology:** 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.

3.4.2 EXTENDED MISSION SCIENCE EVALUATION

3.4.2.1 Scientific and Technical Strengths

CINDI has a clear extended mission plan addressing compelling science topics. The CINDI extended measurements will address four fundamental science questions concerning: (1) how the daily variability in the upper atmosphere neutral wind system is related to variability in the ionospheric electrodynamics; (2) how and why the ionosphere and thermosphere super-rotate; (3) how the electrodynamics of the ionosphere evolves with increasing solar EUV flux and associated increases in magnetic activity; and (4) whether variations in the F-region neutral wind can be used to improve the specification of plasma irregularity occurrence and intensity.

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 unusually peak in occurrence after midnight. During this extreme solar minimum CINDI has established that the nighttime thermospheric temperature is less than 600K at 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 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.

3.4.2.2 Scientific and Technical Weaknesses
It is not clear that the current solar cycle will develop fast enough over the next two years to such that ionospheric and thermospheric parameters will return to measurable ranges for all of the instruments of the CINDI suite. The solar cycle is fundamental unpredictable and during the deep solar minimum conations the CINDI instruments for measuring the thermosphere and ionospheric are not fully functional. This is considered a minor concern because it is unlikely that the sun will remain in minimum conditions through all of FY11 and FY 12.

3.4.3 EXTENDED MISSION RELEVANCE TO THE "Heliophysics System Observatory" and "Road Map"

3.4.3.1 Strengths
The CINDI mission strongly and clearly addresses priority investigations in the Heliophysics Science and Technology Roadmap. One of the key road map 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 which can directly address this topic. It also addresses RFA H2 which is 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 which is to understand the role of the Sun and its variability in driving change in the Earth's atmosphere.

3.4.3.2 Weaknesses
The CINDI mission can only provide information 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 than can 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.

3.4.4 EXTENDED MISSION COST REVIEW

3.4.4.1 Strengths
The CINDI mission costs are very low relative to the large science return. The CINDI instrument suite is part of the C/NOFS spacecraft which is operated by the Air Force 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 coming off of the primary mission phase.

3.4.4.2 Weaknesses
None noted

3.4.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS
The state of the C/NOFS satellite and mission programmatic is good. The Air Force Research Laboratory has indicated that it intends to continue the operation of the satellite "for as long as possible" 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 TDRSS data system. This is not expected to affect the CINDI instruments, which do not draw significant power.

3.4.6 DATA OPERATIONS
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 VxOs to assure that SPASE metadata are prepared for the data products.

The Coupled Ion Neutral Dynamics Investigation (CINDI) Mission Archive Plan (MAP) consists of two primary components the UT and AFRL production sites and 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 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., CDF) should be straightforward.

3.4.6.1 Concerns

HDF is a reasonable choice for CINDI for archival format, although a specific version is never sited. Unless there are further constraints the team should identify HDF version 5.x as the model of choice. It was not made clear how the specific parameters will be handled in HDF other than the columns in the supporting ASCII.

The ASCII metadata are said to "conform" to the simplest of SPASE model. The team should work with a VxO (presumably VMO or VITMO) to produce SPASE descriptions of the data for registration, access, and reference to the data; the VxOs are funded to do much of the work, and this will be straightforward for this case. Simple versions of SPASE descriptions based on information from the mission sites are already available at VSPO.

The CINDI website needs to include data format descriptions, and specifically details about data quality flags etc. that seem to be in the datasets.

There needs to be a specific plan with a timeline to ensure the data and supporting documentation will have a long-term home in a supported archive. It would be helpful for the CINDI team to initiate conversations with the Space Physics Data Facility, which is the designated archive for nonsolar HP data (not NSSDC) to assist with this process. The Panel refers the CINDI team to the MAP Assessment report for further guidance.

3.4.7 E/PO EVALUTION

3.4.7.1 Strengths

The EP/O assessment report generally gave CINDI good marks for their EPO efforts, particularly noting "good teaching resources have been developed and deployed directly with teachers". The proposed future E/PO activities align well with the SMD standards and policy. The Panel refers the ACE team to the E/PO assessment report for further details.

3.4.7.2 Weaknesses

The proposed future plan did not outline a budget description/justification, so it is unclear of how the funds will actually be spent. But if the team can carry out the proposed activities for $50~30K per year, it's an excellent value for the money.

3.4.8 OVERALL ASSESSMENT AND FINDING

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 Heliophysics System Observatory. The CINDI mission strongly addresses priority investigations in the Heliophysics Science and Technology Roadmap while 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 Air Force 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.

3.4.9 OVERALL RATING

The CINDI extended mission proposal was ranked compelling in extended mission science (3rd out of 14) scoring 8.1/10 and excellent in contributing data to the Heliophysics Systems Observatory (10 out of 14) scoring 5.4/10. The lower ranking stems from the low impact that CINDI data has on other elements of the HSO.

3.5 CLUSTER

Cluster is a joint ESA and NASA program, part of ESA's Horizons 2000 Program. The original costs were shared with ESA providing the bulk of the Cluster funding. ESA has approved a mission extension through at least 2012.

3.5.1 EXTENDED MISSION SUMMARY

1) **Overview of the Science Plan (as addressed by the mission's own instruments):** Many of the new science objectives proposed can be addressed primarily with data originating from the mission instruments alone from the new regions of space that the evolving orbit is taking the spacecraft. Some of the most scientifically significant objectives include:

    1. auroral acceleration regions:
        i. understand the triggering and evolution of auroral acceleration mechanisms;
        ii. determine the impact of ion composition on triggering mechanisms and characteristics of current disruption in the tail;
        iii. test for the first time the electrostatic potential model for auroral particle acceleration over a wide range of altitudes.
    2. plasmasheet/plasmapause:
        i. understand the fundamental physical processes governing plasmapause formation and structure;
        ii. quantify the significance of the plasmaspheric wind as a source of magnetospheric ions outside the plasmasphere;
        iii. determine the cold plasma characteristics and wave activity related to the energization of radiation belt high-energy particles ("killer electrons");
    3. magnetosphere/ring current:
        i. obtain understanding where conditions exist that lead to the generation of EMIC waves that are an important loss mechanism for MeV radiation belt electrons;
        ii. understand the formation and loss of complex energy and ion composition structures in the ring current;
        iii. determine the cause of dipolarization fronts.
    4. southern high latitude cusp
        i. determine the relative importance of the cusp compared to the auroral zone and polar cap in providing ions to the plasmasheet and ring current;
        ii. explore the large diamagnetic cavities filled with energetic ions and electrons that have been observed within the high altitude cusp to determine their acceleration or transportation mechanisms and the ultimate fate of the particles.

2) **Overview of the Science Plan (as addressed in conjunction with observations from other Heliophysics missions):** While science questions proposed by Cluster will primarily be answered by data from Cluster instrumentation, since the mission emphasizes micro- and meso-scale physics, collaborative studies do create excellent opportunities to participate with critical measurements to resolve important global scale science issues. They include especially the global magnetospheric electric field configuration in the inner magnetosphere as a function of magnetic activity. In spite of its fundamental role in transporting and energizing the various plasmas in the magnetosphere, the time and solar wind dependent global electric field topology is very poorly known. Simultaneous electric field and plasma parameters from the four spread Cluster and three well-spaced THEMIS spacecraft, and eventually the two RBSP spacecraft, will provide for the unprecedented and critically needed ability to develop empirical models of the geoelectric field and to thoroughly test physics-based models. This objective is a necessary next step of radiation belt/ring current physics.

Other collaborations proposed are:
with STEREO in the study of the physics of magnetic holes in the free solar wind;
with IBEX to study the charge exchange process at the Earth's bow shock;

with the U. S. Navy HAARP (high frequency ionospheric heater) that generates VLF waves (whose strength will be measured by Cluster) that upon propagating upwards into the magnetosphere often trigger VLF emissions.

3) **Overview of the Methodology:** Basic to the methodology for the science plan is the evolution of the Cluster orbit that will bring the spacecraft through the auroral acceleration region over a large range of altitudes, including low altitudes, the lowering of its inclination for much better and closer-in observations of the radiation belts, plasma sheet, plasmapause and plasmasphere and depolarization regions, and the southern apogee excursions through the dayside cusp. The specific methodology for data acquisition is based on two unique characteristics of the Cluster mission: four spacecraft each with a complete set of particles and fields instruments, and the ability to modify the spacecraft configuration/spacings to match the data needs of the science problem. The resolutions of a number of science problems proposed also depend on the abilities of the instruments to measure the ion composition of the plasmas encountered, to measure particle distributions with very high time resolution and a wide energy range, and to observe in detail plasma wave characteristics.

3.5.2 EXTENDED MISSION SCIENCE EVALUATION

3.5.2.1 Scientific and Technical Strengths

The scientific and technical strength of the Cluster mission arises from the unique orbit with a cluster of four spacecraft that is adjustable in configuration to the data needs of its science objectives. The major strength of the Cluster mission is the four spacecraft configuration. Measurements from the four Cluster spacecraft provide the ability to differentiate between temporal and spatial variations and gradients that a one spacecraft mission cannot resolve, allowing for the first time definitive studies of micro- and meso-scale phenomena without the need of unverifiable assumptions, and whose validity in past studies will now be investigated. On increasingly larger separations, the smallest spacings pertain to the auroral field line crossings, especially near- and pre-midnight where complex geometries of the aurora make one spacecraft observations very difficult to interpret without underlying assumptions that will now be tested, to the plasmapause and its fine structure, the high resolution measurements for fast transitions of depolarization fronts, unprecedented spatial details of the far cusp, and spread measurements of the plasmasphere and ring current.

The science opportunities of Cluster with other Heliophysics System Observatory missions will be unprecedented. The four-spacecraft Cluster working in the auroral acceleration region, the plasmasheet / plasmapause, ring current region and the high altitude southern cusp complement the three probe THEMIS observations in important tail regions and more distant plasmasheet regions at low magnetic latitudes, and soon to be joined by the two RBSP spacecraft in the heart of the ring current/radiation belt regions. The distribution of many plasma, energetic particle and both electric and magnetic field measurements over large spatial regions will enable the development of realistic time-dependent empirical global models of the geoelectric field, plasma, and energetic particles and to test physics-based models. These science opportunities will be augmented by TWINS neutral imaging of the radiation belts, deep tail monitoring by ARTEMIS of output of plasma (plasmoids), and accurate monitoring of the solar wind properties by ACE and Wind as input to the system.

The acquisition of the data sets to be acquired by Cluster by itself and in its participation in collaborative studies will gain added value as these missions observe their objective phenomena during the rise of the solar cycle.

3.5.2.2 Scientific and Technical Weaknesses

It is difficult to understand how the impressive list of science objectives could possibly be accomplished on a "minimum science analysis mode" budget. This was not discussed. (See Extended Mission Cost Review.)

The ability to modify the spacings between the spacecraft to suit the data needs for its science objectives may be limited by fuel availability. There is some uncertainty in the amount of fuel available.

Not all instruments are operating on the four spacecraft. This especially pertains to the ion instrumentation, but they claim that a single ion measurement from the cluster will suffice for many of the objectives.

3.5.3 EXTENDED MISSION RELEVANCY TO THE "Heliophysics System Observatory" and "Road Map"

3.5.3.1 Strengths

The Cluster mission has revolutionized space plasma in-situ observations by successfully providing simultaneous 4-point measurements that enable the separation of space and time. As the Heliophysics program attempts to link fully the physics from micro- to meso- to macroscales in the forthcoming Heliophysics System Observatory (HSO), and in particular prepare for the launch of the MMS mission in 2014, Cluster's science accomplishments from its unique 4-point sampling assures the critical micro- to mesoscale physics basis that is essential for the integrative HSO vision that encompasses all scale lengths.

The proposal provides abundant evidence that the science objectives proposed clearly track through the Specific Research Focus Areas to all three Heliophysics Research Objectives. The capabilities of the four-Cluster mission by itself pertain to the microphysics of particle acceleration, transport and loss while in collaborations will lead to an understanding and characterization of space weather effects. In fact, 25 open issues/priority objectives in the Heliophysics Roadmap for 2009-2030 can be addressed by an extension of Cluster as a member of the HSO.

3.5.3.2 Weaknesses

None noted

3.5.4 EXTENDED MISSION COST REVIEW

3.5.4.1 Strengths

The extended Cluster mission will provide high-quality, unique data sets pertinent to the resolution of a number of very significant science questions directly related to the Heliophysics Roadmap for an overall expenditure rather modest considering the substantial investment of ESA and NASA in the program. This additional expenditure will be leveraged by the new collaborations coming into existence by the changes in orbit by THEMIS closer to the Earth, the immediate addition of ARTEMIS in the deep tail, the expected launch of RBSP into the ring current, and the rise in the solar cycle that will enable quality ENA imaging of the storm-time ring current by TWINS.

3.5.4.2 Weaknesses

The proposal has failed to justify the budgets for the US Co-I science teams.

Costs to support the US Co-I teams (but not necessarily the two PI teams) are well beyond their justification, which is lacking for the most part, and seemingly violate the "minimum science" paradigm of primarily making verified data that is well documented available to the community. This task is primarily the responsibility of the European PI team members except for the wide band and electron drift data. The general shopping list of supporting activities for PIs and Co-Is that is given has not been applied explicitly to each instrument, so the individual instrument budgets have little basis. The panel is concerned that a significant amount of scientific activity continues even in the stripped down budget. While it is understood that cross calibrations are important between the same instruments on different spacecraft, many of which have been performed by the US science teams, this type of activity should have become routine for a ten-year old mission.

3.5.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS

The spacecraft have several issues that will affect the operations during the coming years. The uncertainty in fuel remaining could restrict the amount of attitude and phasing maneuvers. The batteries continue to degrade, and it is quite possible that before the end of 2012 the spacecraft will have no functional batteries. The flight team expects to be able to continue to operate all the spacecraft and acquire the science data with perhaps some reduced coverage. This problem is somewhat compounded by the effect of radiation degradation of the solar arrays. Orbit coverage of 100% is expected in 2010, but this will decrease to 75% in 2011 and 2012, and less during eclipse seasons.

The health of the common instrument complement on the four spacecraft is overall rather good for a 10-year old mission. Fortunately, some measurements are not required from all four spacecraft, so some instrument losses have minor consequences. For those instruments for which US investigators are partially or fully responsible, the status is given in the table below (green, fully operational; yellow, some issues but providing useful data; and red, not operational). The ion instrumentation losses are especially noticeable with only one working set, but for many of the science objectives the proposal claims that only one set of measurements is required.

Instument	Type of Instrument	Responsibility	C1	C2	C3	C4
WDB	Wide band data instrument	PI: Pickett/UIowa				
EDI	Electron drift instrument (E fields)	PI: Torbert/UNH				
EFW	Electric field and wave instrument	Sweden/Co-I Mozer/UCBerkeley				
FGM	Flux gate magnetometer	Imperial College/CO-I Kivelson/UCLA				
PEACE	Low energy electron distributions	UK/Co-I Goldstein/GSFC				
RAPID/IES	Imaging electron spectrometer	Germany/Co-I Fritz/BU				
CIS/CODIF	TOF ion composition	France/Co-I Mobius/UNH				
CIS/CODIF-RPA	Retarding potential analyzer	France/Co-I Parks/UCBerkeley				

3.5.6 DATA OPERATIONS

The Cluster Active Archive (CAA) in ESA is the repository of processed and validated high- and low-resolution data, raw data, processing software, calibration data and documentation from all Cluster instruments with one exception: wide band data (WBD). The CAA now contains all mission data through the end of 2007.

The original Cluster data archiving plan did not include the WBD. However, the current UIowa PI WBD archiving plan, which is now budgeted, intends that the CAA provide long-term archiving and distribution for WBD, which currently is disseminated by the WBD PI. In the meantime, the data have started their conversion to CDF format for permanent storage and access from Goddard via CDAWeb.

The Cluster data archiving plan is consistent with the NASA Heliophysics Science Data Management Policy. With CAA actively participating in SPASE development, an underlying technology of the Heliophysics Visual Observatory, in time Cluster data will also be accessible through this system.

3.5.6.1 Overview

The Cluster mission is doing an excellent job of providing data to the community in useful forms, along with supporting software. Since 2006 ESA has maintained the Cluster Active Archive (CAA) that openly supplies detailed mission data. The data from the WBD experiment (the only U.S. experiment on Cluster) is currently being delivered to the CAA, and these data will be available very soon at the SPDF in CDF and other formats through CDAWeb.

3.5.6.2 Concerns

At present the Cluster Active Archive does not support SPASE and the Heliophysics Data Environment (HPDE). However, some of the data reside in the SPDF at GSFC. The Virtual Observatory system currently provides access to the latter data, and thus WBD should be accessible soon, but SPASE descriptions will have to be generated. This is a minor concern, and should be dealt with routinely.

It is not the responsibility of the US Cluster team, but as a general note it will be important to assure that the CAA data become easily available through VOs. While not a part of the proposal, it is known that the Cluster team is working on producing SPASE descriptions. Work with European partners should continue to make the CAA data more easily accessible through VOs.

3.5.6.3 Overall assessment
The Cluster data are being well archived in Europe, and plans are moving forward to have the US provided data (from WBD) incorporated both in CAA and in CDAWeb. This should provide a complete long-term archive for the mission. It will be important to have the CAA more seamlessly integrated into the HP data environment, but the US Cluster team cannot be expected to do the things needed to address this.

3.5.7 E/PO EVALUATION

3.5.7.1 Strengths
Pre-existing E/PO Activities:

- Sun-Earth Day participation
- Teacher/museum list-serv and communication
- Contribution to Space Weather CD
- Supporting 4 teachers in the Heliophysics Educator Ambassador Program
- Other Public Outreach: Space Day at UT Brownsville, Sally Ride Festival, Solar Week
- Project SMART (HS students doing research)
- Planetarium show content
- Podcast series
- Data sonifications at programs for the blind

A very broad program was described, with elements that appear disparate and not integrated. The proposal vaguely outlined which elements were proposed to continue, so it is unclear if they plan to continue everything, and if so only made comments about continuation infrequently. Their contribution to the HEA and involvement in Sun-Earth Day are important collaborative activities, and Project SMART seems meritorious.
There was no breakdown of the budget, and again it was not clear exactly what was being proposed for the future. Presuming all activities are proposed to continue, it's decent value for the money. Everything appears to conform to the SMD standards and policy, and their E/PO Lead is a known entity.

3.5.7.2 Weaknesses
A serious issue is the non-integrated feel of the program. The panel recommends that a programmatic restructure be imposed, which puts their assets to work in a more leveraged and more SMD community-minded manner.

3.5.8 OVERALL ASSESSMENT AND FINDING
Cluster is expected to remain a very significant contributor to solving important issues in solar wind/magnetosphere coupling and magnetosphere/ionosphere coupling. Its unique four point measurements of many of the plasma and field parameters in these regions and the evolution of the spacecraft orbits into new regions of space have enabled the opportunity of proposing new science objectives. While most of its science will come primarily from its ability to differentiate between temporal and spatial variations and gradients that a single spacecraft mission cannot resolve, allowing for the first time definitive studies of micro- and meso-scale phenomena without the need of unverifiable assumptions, it will also be a key contributor with RBSP and THEMIS to the development of physics-based geoelectric field models of the magnetosphere during magnetic storm activity.

The Panel recommends continued support for the US PI and Co-I science team but at a reduced level consistent with the directions of minimal science restricted to the validation and dissemination of new data.

3.5.9 OVERALL RATING
The CLUSTER mission ranked 11th in term of expected science per dollar for the extended mission science scoring 4.6 out of 10. In term of expected Heliophysics System Observatory contributions per dollar CLUSTER ranked 13th, scoring 4.0 out of 10.

3.5.10 PROGRAMMATIC FACTORS

The panel understands that the U.S. Cluster team was given two weeks to prepare the proposal because of uncertainty whether the mission should be included in this round of evaluations. During much of this time the U.S. PI was on travel. However, no consideration was given to this issue in the evaluation of the proposal.

The proposal budget failed to meet even the apparently vague budget guidelines provided by NASA after the decision to include Cluster in the current round of evaluations. These guidelines requested support by the US PI and Co-I instrument teams for the ESA extended mission through the end of CY12, followed by a phase down, with an amount apparently around $2M per year during the flight phase. Instead, their budgets show around $3.4 for the FYs 11 and 12, with a phase down to only around $2.25M after the flight program ended. The proposal states that these budgets are consistent with the minimum science paradigm.

While the Review Panel looked favorably on the science objectives for the extended mission and judged that the spacecraft and instrumentation were sufficiently healthy to acquire the needed data, it had considerable problems with the budgets for the U.S. PI and Co-I participation.

Regarding the U.S. Co-I budgets, there are several problems. While there is no way to penetrate the specific activities included in these budgets from the contents of the proposal, the panel identified several areas of concern. PEACE at GSFC is an obvious target with a remarkably large budget for a ten-year old mission. The two CODIF budgets together (UNH and Berkeley) total $600K, which again is very high considering that only one of the four sets of instruments is operating (as far as can be understood from the proposal). The rest of the budgets run from $317K down to $119K, not totally out of line. One could assume that they all could be scrubbed down to eliminate any pure science activities, but that is a task passed back to HQ since it would require additional documentation.

Considering the very high cost the Panel also questions the value of the new task of archiving all the wide band data. Does NASA absolutely require this activity? If it does, then all the Panel can do is to challenge its cost, which cannot be penetrated without a detailed budget. The Panel raises this as another issue for NASA HQ to look into.

3.1 HINODE

3.1.1 EXTENDED MISSION SUMMARY

In it's extended mission Hinode promises to study the roots of heliospheric mass and energy supply in the rising phase of solar cycle 24. Into the new solar cycle the mission will be able to achieve the science for which it was designed, that of the the active Sun. Hinode will perform a detailed study of solar magnetism "cradle-to-the-grave" from eruption to eventual reconnection, or expulsion, using a combination of high spatio-temporal (diffraction limited) optical imaging, EUV spectroscopy, and soft x-ray imaging.

Overview of the Science Plan (as addressed by the mission's own instruments): Based on the science results derived in the prime science mission, Hinode will continue to investigate: 1) the structure and stability of the magnetized solar atmosphere, 2) the storage (and release) of mass and energy from the corona, 3) the relentless cycle of mass and energy between the photosphere, chromosphere and corona, 4) the variation in scales of solar magnetism, from granulation to active regions, to understand subtle changes in the solar dynamo and any impact that may have on solar irradiance changes in the rising phase of solar cycle 24. The proposed science investigation is relevant to many of the open science questions posed by the community in the 2009 Heliophysics Roadmap and Decadal Survey Challenges. Hinode provides unprecedented complementary science to the recently commissioned flagship mission, the Solar Dynamics Observatory (SDO). Further, the outlined Hinode investigations offer clear connection to those of the RHESSI, STEREO, SOHO, and ACE missions also included in this senior review.

Overview of the Science Plan (as addressed in conjunction with observations from other Heliophysics missions): Investigating the emergence, evolution, and decay of sunspots which play a pivotal role in the formation and rapid destruction of coronal magnetic structures involves the combination of precision vector magnetography, coronal spectroscopy, and soft x-ray imaging. Monitoring the evolution of coronal connectivity with images and spectra will permit the assessment of global connectivity in the outer atmosphere, facilitating investigating the non-potentiality of the coronal magnetic field, and hemispheric coupling of solar dynamo models.

Observations of evolution in detailed SOT vector magnetography permit the identification of interacting magnetic flux systems likely to be the source of shearing and current build up in the corona, possible precursors to flare and CME release, visible in EIS and XRT observations.

Observations of the dynamic plasma jets (''spicules") in the magnetic chromosphere, in combination with co-spatial/temporal high-velocity intensity enhancements line profile asymmetries in the corona, permit the study of mass and energy transport through the outer solar atmosphere, and inner heliosphere of coronal holes.

Synoptic observation programs were developed during the prime mission to monitor the transport of magnetic flux to the solar poles, trans-equatorial coronal loop structures, and the helicity budget of the magnetic field to constrain existing models of solar cycle modulation and the dynamo process likely at its core.

3.1.2 EXTENDED MISSION SCIENCE EVALUATION

3.1.2.1 Scientific and Technical Strengths

Hinode provides the community with observations of solar magnetism, plasma motions, and emission throughout the outer atmosphere at a spatio-temporal resolution like no other in the history of solar terrestrial physics. The instrumentation of the spacecraft revolutionize solar physics with a combination of Stokes polarimetry, narrow- and broadband spectral imaging of the photosphere and chromosphere in conjunction with high resolution EUV spectroscopy and soft X-Ray imaging.

By monitoring the detailed evolution of prominences and filaments Hinode will provide unprecedented information on a potential trigger of coronal mass ejections. The routine observation of cool suspensions in the chromosphere and their underlying magnetic structural evolution may provide physical insight into the onset of CMEs.

Combined limb observations at a broad range of temperatures provide tests of current [standard] flare models. By observing at a range of temperatures with XRT and EIS Hinode will probe magnetic reconnection and its role in flare genesis. In combination with SOT observations of recombining or evaporating material from the chromosphere the timing and co-spatiality of the observations will provide strong observational constraints of the "Standard Flare Model", where reconnection takes place high in the corona and electron precipitate downward to hard x-ray emission sites.

Through its observations of spicule-related activity in the magnetic chromosphere Hinode will:

Connect the mass and energy transport to the corona that originates in the chromosphere. This advance challenges exiting theories of coronal heating. In combination with the high cadence, high signal-to-noise, multi-thermal observations from SDO these observations will offer the opportunity to better our understanding of the composition and energy supply to the corona.

Investigate the mass and Alfvénic energy supply to the fast solar wind originating in coronal holes. The quasi-periodicity of the mass release (as the spicule) and Alfvénic wave (on the spicule) can act as an observational constraint to the models of the nascent solar wind evolving in the community.

Hinode observations motivate/challenge advanced numerical models of the magnetic solar atmosphere. Much of our ability to understand the solar atmosphere relies upon our ability to model it. Since we only observe discrete "layers" of the Sun's atmosphere models must be developed to "join the dots" and Hinode observations are pushing the required, detail and complexity of those models. For example, we hope that advances in modeling strategies of the radiative plasma environment will feed back into observations by demonstrating likely observational signatures of magnetic flux-emergence through the photosphere, sunspot morphology and decay, or coupled energy release into the upper atmosphere.

Hinode offers a detailed observational foil to the flagship Solar Dynamics Observatory mission. The high resolution observations of photospheric vector magnetism, high cadence chromospheric imaging, coronal spectroscopy and soft x-ray imaging uniquely compliment, and enhance, the scientific value of the instruments of SDO.

3.1.2.2 Scientific and Technical Weaknesses
None.

3.1.3 EXTENDED MISSION RELEVANCE TO THE "Heliophysics System Observatory" and "Road Map"

3.1.3.1 Strengths
The science of the extended Hinode mission is relevant to the many open scientific questions presented in the Heliophysics 2009 Roadmap, as well as the challenges posed in the most recent Decadal Survey. The Hinode mission offers physical insight across the board in Roadmap 2009 RFAs F, H, J.

Hinode forms a comprehensive lower boundary for many of the solar-based observatories in GHO. For example, Study of detailed magnetism and the storage of magnetic energy and mass in the corona is an essential component in the study of destructive phenomena that affect human and robotic exploration/life of the heliosphere. By observing, and quantifying, detailed magneto-convective energy release processes on the Sun Hinode provides necessary detail for the other observatories of the GHO, directly RHESSI, STEREO, SOHO, and SDO.

Hinode is the GHO's microscope to analyze the magnetism that drives the variability in the heliosphere on all spatial and temporal scales. The higher S/N, spatial and spectral resolution, vector magnetography of SOT is necessary for support/validation for SDO/HMI. EIS is the only instrument in the GHO that provides spectroscopic measurements of plasma motions and energetics at the lower boundary of the heliosphere that are critical to the understanding of the particulate and radiative emission that pervades the heliosphere. XRT provides high resolution soft X-ray imaging that is complementary to that (only available in hot spectral blends appearing in the flare kernels of the SDO/AIA broadband images) and the spectroscopy of RHESSI.

The high resolution observations of chromospheric dynamics and associated coronal signatures can provide essential boundary conditions for the input of mass and energy into the corona and solar wind - essential measurements for the effort to model solar EUV emission, solar wind structure and on CME propagation throughout the heliosphere. Studies of mass transfer in the outer solar atmosphere will facilitate a better observational understanding of the processes contributing to solar UV radiation formation, and the lower boundary of solar wind acceleration. The advance in high resolution computer simulation across the community require high spatio/temporal resolution inputs. The mission team have illustrated their relationship with such models and the panel commends this interaction.

3.1.3.2 Weaknesses

The Hinode program should encourage cross-spacecraft scientific investigations in its extended mission. It was not clear to the panel how the Hinode project would facilitate cross-spacecraft scientific projects, i.e., those with each of the instruments providing complementary, non-contextual, observations. The panel feels that such observing plans, once developed, can be encouraged by giving them additional weight in the mission operations/scientific review process.

3.1.4 EXTENDED MISSION COST REVIEW

The Hinode mission has cut much of its operating cost and team science funding in line with a mission recently completing its prime mission and moving into extended phase. The panel understands that the instruments require additional monitoring, engineering, and calibration activities on a targeted observing platform.

3.1.4.1 Strengths

None.

3.1.4.2 Weaknesses

The panel was somewhat concerned that there might not be enough science investigation funding to accommodate the “remaining” prime mission science at the onset of cycle 24. This is a systemic/programatic issue.

The panel is concerned that the costs of operating XRT are phased-down relative to the other two components of the payload. On an instrument by instrument appraisal, the XRT component of the budget seems high, compared to the three components of the SOT/FPP and EIS. There is not enough justification provided in the budget for the panel to assess if this ~$1M excess (per instrument) for XRT is merited.

3.1.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS

Minor problems have occurred for each of the instruments on the spacecraft. None of them are serious enough to jeopardize the scientific goals of the mission.

Hinode s/c - The X-band antenna anomaly is mitigated with additional downlink support for S-band telemetry. Affects the duty cycle of the science observations, but has facilitated a streamlining of mission operations, and data bandwidth utilization.

Hinode/SOT-FPP - Issue with bubbles in the Lyot filter stage lubricant of SOT/NFI have been reduced/removed. Significant degradation in the Fe I 6302Å and some in the H[α] 6563Å filters of NFI. The latter is still functional, largest impact on Fe I, but there is redundancy in place for equivalent measurements that do not impact the science requirements of the mission.

Hinode/XRT - Temperatures in the forward end of the XRT have been higher than expected, so the operational heaters are left off to keep within the limits established prelaunch. Filter wheel 1 has a small electrical issue that does not impact instrument science. There is hydrocarbon contamination on the XRT detector that has two impacts: 1) a time-dependent accumulation of a uniform layer over time. This accumulation is mitigated with a regular schedule of CCD bakeouts and monitoring, 2) a residue of small spots have remained on the CCD since the initial bakeout and are apparent when using the thinner filters. These spots are removed in routine processing, permitting quantitative analysis.

Hinode/EIS - Warm pixel number growth is currently very slow, and their impact on EIS science has been minimal. When the detector coverage reaches roughly 30%, now estimated to be in 2013, EIS will consider performing a bakeout to reduce the number.

3.1.6 DATA OPERATIONS

Instrument data is distributed openly through the VSO and several data centers around the world facilitated by instrument teams and partners. The data-access interfaces are exemplary, data is recovered and distributed almost immediately. The instrument teams have an active quality control and monitoring policy that is adequately documented in the mission extension proposal.

The Hinode Science Center resides within the Solar Data Analysis Center (SDAC) at the GSFC. The SDAC will act as the active Resident Archive for the lifetime of the mission and beyond. Ultimately, the data will be delivered to the National Space Science Data Center (NSSDC) which will serve as the Permanent Archive.

In addition, the panel reviewed separate assessments of the mission archive plan that was prepared by independent experts convened by NASA/HQ. 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.

3.1.7 E/PO EVALUATION

The panel noted a baseline budget for E/PO that was more than many of the other missions considered, but within the Heliophysics Division guidelines. The panel reviewed a separate assessment of the mission E/PO effort that was prepared by independent experts convened by NASA/HQ. 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.

3.1.8 OVERALL ASSESSMENT AND FINDING

The panel recommends continuation of the Hinode project. Further, the panel recommends that Hinode exploit its high resolution measurements as a lower boundary for the heliosphere, continuing its efforts to enhance numerical modeling efforts that are complimentary to the scientific observations of the project.

3.1.9 OVERALL RATING

The Hinode mission ranked 8th in term of expected science per dollar for the extended mission science scoring 6.9 out of 10. In term of expected Heliophysics System Observatory contributions per dollar Hinode ranked 8th, scoring 5.9 out of 10.

3.2 RHESSI

3.2.1 EXTENDED MISSION SUMMARY

Throughout its 8 year duration, the RHESSI mission primarily has addressed one fundamental unsolved question in Heliophysics: how are particles accelerated in solar eruptions? Energetic electrons and ions are found throughout the heliosphere, particularly in regions of magnetic energy storage and release, and are observed both directly and through the radiation emitted as these particles travel along the magnetic field. RHESSI's unique capability of imaging hard X-rays and gamma rays (both continuum and line emission) provides time-dependent spatial and spectral information on the coronal particles energized during flares and CMEs, and traces their magnetic connectivity to the chromosphere. In conjunction with data from other components of the Heliospheric System Observatory (HSO), RHESSI observations yield essential clues about the initiation and evolution of solar eruptions, the origin and transport of solar energetic particles (SEPs) from the Sun into the heliosphere, and the physics of reconnection in the solar atmosphere. Observations will span nearly a full solar cycle by the end of the extended mission, allowing detection of any connections between flare particle characteristics and the phase of the cycle.

3.2.2 EXTENDED MISSION SCIENCE EVALUATION

3.2.2.1 Scientific and Technical Strengths

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 rise phase, 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 the Drake et al. (2006) reconnection model 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 and 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 only be tested 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.

3.2.2.2 Scientific and Technical Weaknesses

The proposal does not clearly present the fundamental science questions to be addressed, but rather appear to be a laundry list of assorted projects. In view of the large flare dataset already acquired by RHESSI, some 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. The discussions of the Drake et al. electron-acceleration mechanism and the Petrosian & Chen effort are promising steps in this direction.

3.2.3 EXTENDED MISSION RELEVANCE TO THE "Heliophysics System Observatory" and "Road Map"

3.2.3.1 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.

3.2.3.2 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 data base has been collected already.

3.2.4 EXTENDED MISSION COST REVIEW

3.2.4.1 Strengths

RHESSI is commended for its lean management budget and excellent "return on investment." It has been the gold standard of PI-led missions.

3.2.4.2 Weaknesses

Recent cuts to RHESSI's budget due to changes in NASA's treatment of uncosted carryover endanger the ability of this mission to attain even minimal science targets, and would result in significant attrition from the next generation of scientists being trained in this important heliophysics subfield.

3.2.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS

All systems are operating nominally, except for one of the 9 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.

3.2.6 DATA OPERATIONS

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 HP community via SolarSoft. Documentation is on-line 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.

3.2.7 E/PO EVALUATION

3.2.7.1 Strengths

The RHESSI E/PO plan proposes to continue the Heliophysics Educator Ambassador program, and broadcasting RHESSI information via podcasts and social media. While it’s unclear how extensive the prior RHESSI E/PO activities were, the proposed follow-on activities are limited in scope, leverage ongoing programs within the SMD community, and are appropriate for the extended mission. Everything appears to conform to the SMD standards and policy, and appears to be excellent value for the cost.

3.2.7.2 Weaknesses

While the panel appreciates that low funding levels limits the scope of RHESSI’s E/PO activities, there appears to be little in the way of activities proposed for the extended mission other than “more of the same”.

3.2.8 OVERALL ASSESSMENT AND FINDING

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 footpoint sources, the apparent equipartition of particle and magnetic energy in looptop 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 HP 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 HP 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, for the most part. Their E/PO efforts are cost-effective and appropriate for an extended mission with limited funding. However, the proposal lacks clear basic-science goals, and does not prioritize the list of research projects in the future plans. The panel is concerned about the impending 44% funding shortfall, and urges NASA to restore this funding to ensure that minimal science objectives can be met and that the vitality of high-energy solar physics can be sustained.

3.2.9 OVERALL RATING

The RHESSI mission ranked 9th in term of expected science per dollar for the extended mission science scoring 6.2 out of 10. In term of expected Heliophysics System Observatory contributions per dollar RHESSI ranked 7th, scoring 6.2 out of 10.

SOHO

3.2.10 EXTENDED MISSION SUMMARY

After over a decade of successful and highly productive operation, many of SOHO's instruments are degraded or have been superseded by later missions, especially SDO. However, the LASCO coronagraph on SOHO constitutes a unique resource at L1 that is not included in the SDO complement. The extended mission of SOHO, renamed Bogart, is intended to primarily support the observations of LASCO in the context of the Great Heliophysics Observatory (GHO) however several of the other instruments can, and are intended to, operate in the extended phase.

Overview of the Science Plan:

The SOHO extended mission proposes to limit scientific operation to LASCO (EIT), UVCS, and CELIAS primarily in a supporting role to other missions in the Heliophysics portfolio. Non-US PI investigations will continue to operate at (little or) no cost to NASA.

Several scientific studies are proposed by the mission team in the extended mission:

Observing the white-light corona from the Sun-Earth line with LASCO.
Identifying suprathermal seed population for SEP events
Making fixed-radius solar wind outflow maps with UVCS.
Ongoing measurements of total solar irradiance with VIRGO.
Ongoing observation of the low l-mode solar interior with GOLF.
SWAN will continue UV far side and H ionization rate observations and will provide contextual observations in support of the LAMP experiment on the Lunar Reconnaissance Orbiter (LRO).
Investigating the longitudinal distribution of energetic particle events during solar cycle 24.
Observing long-term variations in the Energetic Neutral Atom (ENA) flux.

Overview of the Methodology:

The SOHO extended mission proposes to reduce funding for US components of SOHO in order to continue operating the LASCO coronagraph, UVCS and CELIAS/MTOF. Much of this downscaling is the result of the launch of SDO; MDI will be turned off and EIT will be limited to four images a day (EIT shares telemetry and operations with LASCO, so this limited image set comes at no overhead) following the initial phase of operations and inter-calibration with SDO HMI and AIA.

There are compelling scientific reasons for preserving a coronagraph on the Sun-Earth line. For geoeffective space weather observations, the panel feels that it is useful to have both in situ (ACE, Wind) and imaging (LASCO) instruments together at L1 to fully assess the physical conditions of Earth-directed material and fields.

In addition, the STEREO spacecraft are approaching positions where stereoscopic imaging of Earth-directed CMEs is becoming increasingly difficult far from the disk (triangulation methods are effective only for the brightest, near disk structures). SOHO/LASCO, as a third coronagraph on the Sun-Earth line, provides favorable quadrature for earth-directed CME study. It also aids the STEREO mission by providing favorable limb observations of CMEs generating SEP events well connected to either STEREO-A or STEREO-B.

UVCS offers an opportunity to investigate the build-up and variation of nonthermal ion populations in the corona. These distributions have a tell-tale sign, visible as extended wings above the background of the spectral lines observed. It is thought that these suprathermal particles are the seed population for SEPs that are accelerated by CME-associated shocks.

A new set of diagnostic algorithms allows CELIAS/MTOF to offer improved diagnostics of the compositional environment (in particular the He/H ratio) at L1. Further, the real-time proton monitor offers an energy reliability not present in the GHO suite.

3.2.11 EXTENDED MISSION SCIENCE EVALUATION

3.2.11.1 Scientific and Technical Strengths

Compelling scientific arguments are made in support of LASCO continued operation. The panel agrees that the LASCO coronagraph is a unique resource on the Sun-Earth line that must be continued to facilitate science from other components of the GHO.

3.2.11.2 Scientific and Technical Weaknesses

The panel needed more scientific characterization of the UVCS spectral background to assess the merits of the UVCS portion of the extended mission. The proper characterization of the spectral background is essential to robustly estimate the portion of the line emission profile affected by an SEP seed population. While the panel can see the merit in making observations of this kind, there was little or no information provided to support UVCS's ability to make the measurement needed. Without this justification we could not assess the additional cost of this extended mission component (comparable to that of the crucial LASCO component).

Despite the robustness of CELIAS/MTOF in high particle flux conditions, it is not clear to the panel that the measurements described, such as the He/H composition, could not be adequately provided by other platforms in the GHO.

3.2.12 EXTENDED MISSION RELEVANCE TO THE "Heliophysics System Observatory" and "Road Map"

3.2.12.1 Strengths

The SOHO extended mission has an integral role in, and has clear relevance to, the Great Heliophysics Observatory and the RFAs published in the 2009 Heliophysics Roadmap. In particular, the LASCO component offers the continuation of a unique resource to study Earth-directed coronal mass ejections from L1. The measurements of LASCO offer added weight to those of the other observatory components. Failure of LASCO would present NASA with a single-point failure in the detection of geoeffective CMEs. While the UVCS and CELIAS/MTOF components of the extended mission offer relevance to the GHO, they, suffer from scientific weakness as noted above.

3.2.12.2 Weaknesses

None

3.2.13 EXTENDED MISSION COST REVIEW

SOHO operations costs in the extended mission have been trimmed in line within guidelines, especially for an aging, complex, spacecraft.

3.2.13.1 Strengths

The SOHO project management team has strived to cut operations costs to bare-bones while continuing the scientific legacy of SOHO. The panel commends their efforts.

3.2.13.2 Weaknesses

The panel is concerned that the project management team does not have enough contingency funds to restore operations in the event of another emergency like that of 1998. Such an event would see the loss of the unique LASCO operations, so further cut-backs in operations must be considered carefully from this point on.

3.2.14 SPACECRAFT / INSTRUMENT HEALTH AND STATUS

The SOHO spacecraft is healthy and capable of operating through the extended mission barring unforeseen problems.

LASCO is operating well, except for the death of the innermost coronagraph, C1, during the SOHO "vacation" of 1998. Instrument calibration and sensitivity have been reassessed recently, showing minor degradation.

UVCS reports slowness of the Lyman-alpha drive, and has suffered significant decline in spatial resolution that would limit its ability to observe large-scale coronal structure.

3.2.15 DATA OPERATIONS

SOHO has a sound Legacy Archive Plan. Further, the mission has a strong track record for making calibrated data easily available to the community and so the panel is comfortable that the integrity of the SOHO mission archive will be preserved.

3.2.16 E/PO EVALUATION

The panel reviewed a separate assessment of the mission E/PO effort that was prepared by independent experts convened by NASA/HQ. 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.

3.2.17 OVERALL ASSESSMENT AND FINDING

The panel finds that, while SOHO's scientific impact has diminished in its own right as the mission evolves from the heliophysics community's eye on the Sun to a supporting role, it is still an essential component of the Great Heliophysics Observatory. The panel recommends continuing support to the LASCO component of the SOHO mission with the removal of costs associated with the UVCS and CELIAS/MTOF operation.

3.2.18 OVERALL RATING

The SOHO mission ranked 14th in term of expected science per dollar for the extended mission science scoring 2.2 out of 10. In term of expected Heliophysics System Observatory contributions per dollar SOHO ranked 3rd, scoring 7.7 out of 10.

3.3 STEREO

3.3.1 EXTENDED MISSION SUMMARY:

1) ***Overview of the Science Plan (as addressed by the mission's own instruments):*** 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 coronal mass ejections 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 further 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 degrees. 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 3-dimensional structure of coronal mass ejections 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 mono-energetic ion beams in the solar wind.

2) ***Overview of the Science Plan (as addressed in conjunction with observations from other Heliophysics missions):*** 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-dimensional structure of coronal mass ejections 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 SEP's 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 SWAVES experiment will also have good synergy with the WIND/WAVES experiment for triangulating CMEs.

3) ***Overview of the Methodology:*** 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 in-grained 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 which can now be applied with confidence to events observed during the extended mission.

3.3.2 EXTENDED MISSION SCIENCE EVALUATION:

3.3.2.1 Scientific and Technical Strengths

The unique vantage points and complete instrumentation continue to provide significant new capabilities capable of addressing initial prime goals of addressing 3-D CME morphology and SEP events.

The ever changing perspectives leverage the advantages that various separations and angles enable.

The delayed solar minimum has allowed additional analysis techniques to be developed.

3.3.2.2 Scientific and Technical Weaknesses

The large separation limits the number of events that STEREO will be able to investigate independently. Increased reliance is needed on near-Earth assets.

3.3.3 EXTENDED MISSION RELEVANCY TO THE "Heliophysics System Observatory" and "Road Map":

3.3.3.1 Strengths

STEREO is very much a 'Great Observatory' mission, especially in the extended phase. It's relevance to other solar as well as planetary and interplanetary missions is unquestionably high. It spans from near-Earth solar and interplanetary such as SOHO, ACE, WIND, and IBEX to planetary such as 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 3 times the opportunity to have conjunctions and oppositions with well instrumented spacecraft than they do now when only near-Earth instrumentation is available.

In examining the Heliophysics Roadmap, STEREO contributes to virtually all of the appropriate Research Focus Areas, addressing 10 out of 12 RFAs in the 3 goals of Open the Frontier to Space Environmental Prediction, Understand the Nature of Our Home in Space, and Safeguard the Journey of Exploration.

3.3.3.2 Weaknesses

None.

3.3.4 EXTENDED MISSION COST REVIEW

Partly due to the nature of running two interplanetary spacecraft with large complements of in-situ and imaging instruments, but also due to decisions for how to conduct operations and science planning, the STEREO mission is very costly. There are still significant science teams in place and operating the twin spacecraft remains an expensive proposition. In terms of science per dollar, there is a lot of science, but there are also a lot of dollars. The science operations costs are high and the review team questions why that is so.

Mission operations costs are on the high end, though possibly in line with expectations of running two observatory class interplanetary missions. At least when APL is running the missions.

Science operations costs are moderate to high. We question why this needs to be so high?

Cost of the science is low, given the diverse science questions being addressed.

3.3.4.1 Strengths

None.

3.3.4.2 Weaknesses

The very high cost of maintaining the STEREO mission put it in a spotlight for further examination. Many if not all of the costs may be well justified, but high numbers will always put STEREO costs and science under a microscope. High costs are apparent for science, science operations, and mission operations. The panel is concerned about all three areas and whether there is a need for these costs to be so high.

3.3.5 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). Minimal impact since Level-1 requirements are met with energies >50eV.

PLASTIC is healthy.

SECCHI 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 has interference at 16 and 100kHz. This limits three-antenna direction finding to only strong events. Time of flight direction finding and Wind/WAVES direction finding mitigate this problem.

3.3.6 DATA OPERATIONS

STEREO data is easily accessed and available through the VSO and the STEREO Science Center and software to process and analyze the data is available in solarsoft. 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.

3.3.7 E/PO EVALUTION

3.3.7.1 Strengths

The E/PO assessment for STEREO is one of very good marks, with an extensive, multi-team effort of broad scope. The activities do a very good job of leveraging capabilities of other organizations. The budget for the E/PO efforts is reasonable for the activities occurring. The STEREO team should ensure the visualizations continue to be made, as they are a unique contribution from the mission. The panel refers the STEREO team to the E/PO assessment report for further details.

3.3.7.2 Weaknesses

No significant weaknesses have been identified, but the E/PO assessment report points out that there has been no evaluation of the effectiveness of the McAuliffe Planetarium activities. The panel urges the STEREO team to consider this and any other questions raised in the E/PO assessment report.

3.3.8 OVERALL ASSESSMENT AND FINDING

The STEREO mission is a strong participant in the Heliophysics System Observatory, providing unique data that meshes 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 high costs of science, science operations, and mission operations, work as a negative against this mission when returns are looked at on a per dollar basis. As the solar cycle ramps up, the focus on STEREO will increase, as the main objectives of the mission are activity related and progress is expected.

3.3.9 OVERALL RATING

STEREO ranked 7th in terms of Science per Dollar, scoring 7.0 out of 10, earning an Excellent ranking. STEREO ranked 4th for Contributions to the Heliophysics System Observatory, scoring 7.6 out of 10, earning a Compelling ranking.

3.4 THEMIS

3.4.1 EXTENDED MISSION SUMMARY

1) **Overview of the Science Plan (as addressed by the mission's own instruments):** The THEMIS extended mission is based upon a reconfiguration of the original five-probe constellation. In the extended mission the three inner probes are repositioned into three, almost identical orbits with an apogee of 12 RE. (The two other probes are being transferred to lunar orbit, become the ARTEMIS mission, and will not be discussed here.) THEMIS will continue studying magnetospheric physics using a constellation configuration different from that of the primary mission.

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

3) **Overview of the Methodology:** The relative positioning of the three probes will be varied over the extended mission to address a variety of science problems. For example the THEMIS science team will use a clustered configuration when apogee is near noon to study the response of the boundary to changes in the solar wind, and reconnection. At other times a string of pearls configuration of the three probes is planned for the study of magnetospheric waves important for radiation belt physics.

3.4.2 EXTENDED MISSION SCIENCE EVALUATION

3.4.2.1 Scientific and Technical Strengths

Two of the five THEMIS probes are to become the ARTEMIS mission and are discussed separately. However the THEMIS extended mission, consisting of the other three s/c, would benefit from the data returned from the ARTEMIS mission.

The new orbits and relative positioning of the five THEMIS probes opens important new science opportunities. The recent ESA decision to continue Cluster at least until the end of 2012 along with THEMIS will provide a global constellation of 7 spacecraft.

The extended mission will provide data during a different part of the solar cycle from the primary mission. During the rise to solar maximum it would be expected that THEMIS will be able to observe several large geomagnetic storms. One of the advantages of the changed THEMIS constellation configuration is that it will fill existing gaps in L vs time space. The original orbits had a few cuts, a large gap, and then a few more cuts. The new orbits will provide much more uniform coverage.

The THEMIS extended mission, if continued beyond the Spring of 2012, would be able to support the RBSP mission, especially in providing radiation-belt measurements above the apogee of the pair of RBSP satellites.

The THEMIS science team has been outstandingly productive, and has engaged many members of the external science community. The HSO community is looking forward to a continuation of the THEMIS data stream greatly augmented with the recently launched SDO.

The THEMIS vehicles have performed well and are expected to do so into the future.

3.4.2.2 Scientific and Technical Weaknesses

The particle instrumentation will have background problems in radiation belts, especially during storm times. The degree to which THEMIS can support RBSP within the same region of L space is unclear. On-orbit "calibrations" did not match the Los Alamos GEO or GPS data well at all. The calibrations that have been done so far are really only in the form of ratios of flux channels. This is not a calibration at all. Although some work was done to compare the spectra at L-shells other than those for which the correction factors were computed, the instruments have really been calibrated or validated for use in deep in the radiation belts where the fluxes are often high.

THEMIS should be able to provide phase space densities at L values well above the RBSP apogee where the electron fluxes are relatively low. However, to accomplish this, good calibration data for the energetic particle instrument aboard THEMIS still must be available.

3.4.3 EXTENDED MISSION RELEVANCY TO THE "Heliophysics System Observatory" and "Road Map"

3.4.3.1 Strengths

THEMIS extended mission directly addresses Decadal Survey Challenge 3: Understanding the space environment(s) of Earth … and … dynamical response to external and internal influences.

THEMIS is an important component of the Great Observatory. THEMIS, ARTEMIS, Cluster, Wind, ACE, STEREO in-situ measurements along with the optical measurements from SDO, STEREO, and SOHO comprise a constellation of unprecedented capability. And in the near future RBSP will be added to the mix.

3.4.3.2 Weaknesses

None noted

3.4.4 EXTENDED MISSION COST REVIEW:

3.4.4.1 Strengths

The funding plan appears to be reasonable for the following few years for currently proposed THEMIS extended mission.

3.4.4.2 Weaknesses

Past difficulties, especially with execution of the ARTEMIS activities leads to some concern that costs might not be controlled.

3.4.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS

The proposal states that all spacecraft systems continue in nominal operation. Earlier, recent spacecraft fielded by the same institution have demonstrated long productive lives.

3.4.6 DATA OPERATIONS

Data management and accessibility are exemplary. The high productivity of the THEMIS mission to date is in part a direct result of this situation.

3.4.7 E/PO EVALUTION

3.4.7.1 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.

3.4.7.2 Weaknesses

3.4.8 OVERALL ASSESSMENT AND FINDING

3.4.9 OVERALL RATING

The THEMIS mission ranked 2nd in term of expected science per dollar for the extended mission science scoring 8.3 out of 10. In term of expected Heliophysics System Observatory contributions per dollar THEMIS ranked 6th, scoring 7.0 out of 10.

3.5 TIMED

3.5.1 EXTENDED MISSION SUMMARY

The TIMED (Thermosphere, Ion, Mesosphere, Energetics and Dynamics) spacecraft was launched into a 625km-altitude highly inclined (74.1 degree inclination) circular orbit. The TIMED prime mission was to characterize and study the physics, dynamics, energetics, thermal structure, and composition of the least well-understood region of the Earth's atmosphere – the mesosphere-lower thermosphere-ionosphere (MLTI) system located between altitudes of approximately 60-180km above the surface of the Earth. This region is of interest because it is the interface between the Earth's lower atmosphere below and the magnetosphere above and can be influenced by forcing from either of these regions. The MLTI system can undergo rapid changes in character due to both natural and human-induced (anthropogenic) effects. Prime Mission for TIMED was January 2002-January 2004 and it is currently in extended mission phase.

1) **Overview of the Science Plan (as addressed by the mission's own instruments):** The primary science goals to be addressed in the TIMED extended mission is the processes related to human induced variability of the mesosphere and lower thermosphere and in particular to separate the anthropogenic variability from natural variability during the expected rise in solar activity associated with the current approach to solar maximum. The release of greenhouse gases in the troposphere due to human activity is predicted to have a dramatic effect on the thermal structure and composition of the MLTI system by direct alteration of its infrared energy balance. Continued data collection and analysis as solar activity increases will allow TIMED researchers to test these predictions and possibly separate the anthropogenic sources of variability of the MLTI system. The secondary goal is to characterize and understand the solar cycle-induced variability of the MLTI region during the rising solar cycle.

2) **Overview of the Science Plan: (as addressed in conjunction with observations from other Heliophysics missions):** TIMED data will contribute to AIM studies of PMCs (Polar Mesospheric Clouds, e.g. noctilucent clouds), gravity waves, and the effect of gravity waves on PMCs. In addition, TIMED long-term measurements of solar irradiance will contribute to studies of long-term solar variability that will be continued into the future by other HSO assets, thereby allowing continuous coverage of multiple solar cycles.

3) **Overview of the Methodology:** TIMED carries 4 instruments (GUVI, SABER, SEE, and TIDI) which utilize advanced remote-sensing techniques to measure global temperature, pressure, winds, and chemical composition of the MLTI region.

   GUVI (the Global Ultraviolet Imager) is a horizon-to-horizon scanning imaging spectrograph designed to measure emissions from the upper atmosphere in 5 different wavelengths. It provides: global maps of thermospheric composition (N2, O2, O, and H); temperature in the lower thermosphere; auroral oval size; particle energy inputs into the high latitude regions; height integrated Pederson and Hall conductivities and Joule heating at high latitudes and a measure of the integrated solar EUV flux below 40nm. GUVI provides information on how the atmosphere is affected by tidal and planetary waves and provides input to test and constrain Thermosphere General Circulation Models (TGCM).

   SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) uses a sounding technique to provide information on the temperature and chemical structure of the atmosphere between about 16-177km.

   SEE (Solar EUV Experiment) consists of an EUV grating spectrograph to measure extreme UV solar spectral irradiance from 30-115nm and a set of 12 Si diodes to measure the solar soft X-ray irradiance from 0.1-35nm. The primary purpose of SEE is to provide absolute UV irradiance measurements in support of the other TIMED instrumentation.

   TIDI (TIMED Doppler Interferometer) consists of a Fabry-Perot interfermoeter with a 4 telescopes as input and a CCD as a detector. TIDI is designed to provide global horizontal vector wind fields from the Earth's limb as well as information about noctilucent clouds, gravity waves, densities of various species, airglow and auroral emission rates.

3.5.2 EXTENDED MISSION SCIENCE EVALUATION

3.5.2.1 Scientific and Technical Strengths

The recent unprecedented solar minimum provides a characterization of the "MLTI ground state". The MLTI region is forced from above by energy flowing through the magnetosphere and by below by energy flowing from lower atmospheric processes such as gravity waves. This most recent extended mission has obtained observations from the MLTI when the forcing from above is at a minimum thus allowing the extended mission to probe differences from this baseline.

TIMED observations may provide some of the most sensitive indicators of global climate change. The cooling of the upper atmosphere is larger and more detectable over long periods of time using SABER temperature data than the warming of the lower atmosphere. The long term temperature observations from TIMED may be one of the more important diagnostics of global change.

The understanding of water in the upper atmosphere is important to understanding the chemical and energy balance of the region. The proposed extended analysis SABER and corresponding development of analysis code will allow this important parameter to be determined.

3.5.2.2 Scientific and Technical Weaknesses

Some of the proposed science could be done with existing data. Taking data during the upcoming rising phase of the solar cycle may be important for the anthropogenic variability studies, but its not clear other studies are totally necessary to have full solar cycle coverage. Over it's already long mission duration a large variety of solar driving has already been seen.

It is not clear that some of the proposed science can be resolved simply by going to a full solar cycle. Even if a full solar cycle is observed, it is not clear that this will guarantee closure on science questions related to solar cycle variability, given that every solar cycle phase is different from every other one. Fully understanding solar cycle variability probably would require many solar cycles worth of data.

There is a significant focus on scientific questions that are not priority for the Heliophysics division. TIMED science is increasingly directed towards global climate change research. This may be great science but is not necessarily a high priority within Heliophysics. The anthropogenic effects on the MLTI region have a lower science priority than other natural occurring process a judged by the decadal study and roadmap.

3.5.3 EXTENDED MISSION RELEVANCE TO THE "Heliophysics System Observatory" and "Road Map"

TIMED is essentially at the lower end of the Sun-Earth chain and its observations will not contribute much to many other assets in the HSO. Nevertheless, TIMED data can be used together with data from the AIM spacecraft in order to: 1) enhance PMC (Polar Mesospheric Cloud) studies; 2) study gravity waves and their possible effects on PMCs. In addition, long-term solar irradiance measurements from TIMED can be used to validate and cross-calibrate similar observations from other platforms that will continue these measurements into the future and combining solar irradiance measurements from SOHO, SNOE, TIMED, SORCE, SDO, GOES, and SOLAR will allow for development of improved irradiance models. In addition, by combining properly cross-validated measurements from multiple HSO assets, composite time series covering multiple solar cycles can be developed.

3.5.3.1 Strengths

TIMED is creating the only long term dataset and is the only monitor for the lower thermosphere. TIMED provides a scientifically important set of observations of the region driven in part by energy flowing through the heliosphere. TIMED mission (SABER TIDI) are the only NASA assets examining the neutral component of the atmosphere and the long term data set is of high importance.

The TIDI data has greater sensitivity and is becoming more scientifically valuable as the instrument is drying out. TIDI is able to return wind observations of the thermosphere from altitudes that were not previously possible. The data from the extended mission should allow new science questions to be addressed.

GUVI data is excellent for understanding the thermosphere reactions to geomagnetic storms through the O to N2 ratio measurements. These data are important for observing the final disposition of energy flowing from the sun, through the hemisphere and into the thermosphere.

3.5.3.2 Weaknesses

While the traceability matrix provided conveys a sense that TIMED science addresses most of the Roadmap Focus Areas, the panel feels that many of the connections made are not well founded. For example, the proposal indicates that TIMED addresses focus area F1 ("Understand magnetic reconnection as revealed in solar flares, coronal mass ejections, the solar wind, and in the magnetosphere."), by addressing the proposed key science objectives of: "Secular trends in the MLTI", "Polar processes in the MLT", "Global MLTI behavior during the ascending phase of the solar cycle", and "Long-term solar irradiance variations". It is not at all clear how the proposed science objectives contributes to this focus area. As well, contributions of TIMED science to some of the "Journey" focus areas are somewhat marginal.

TIMED science certainly contributes to J1 and J4 ("J1: Characterize the variability, extremes, and boundary conditions of the space environments that will be encountered by human and robotic explorers; J4: Understand and characterize the space weather effects on and within planetary environments to minimize risk in exploration activities.") and in fact addresses one of the priority investigations ("What is responsible for the dramatic variability in many of the state variables describing the ITM region?"). TIMED science contributions to J2 ("Develop the capability to predict the origin, onset, and level of solar activity in order ,to identify potentially hazardous space weather events and safe intervals") and J3 ("Develop the capability to predict the propagation and evolution of solar disturbances to enable safe travel for human and robotic explorer") seem somewhat more nebulous. Basic understanding of the MLTI system may contribute to theoretical and computation modelling of the Sun-Earth-Inner heliosphere system, but TIMED science does not directly address the priority investigations associated with focus areas J2 and J3.

Contributions of TIMED science to the goals of the Heliophysics Roadmap Focus Areas are most concrete in the H1-3 focus areas ("Understand our home in space"). TIMED science will address a number of priority science investigations in this category including: "What is responsible for the dramatic variability in many of the state variables describing the ITM region?" ; "How do the magnetosphere, ionosphere-thermosphere systems interact with one another?"; "How do coupled middle and upper atmospheres respond to external drivers and to each other?"; and "How do long-term variations in solar energy output affect Earth's climate".

3.5.4 EXTENDED MISSION COST REVIEW

3.5.4.1 Strengths

The costs of the individual science teams generally appear low but perhaps reasonable for a mission in the "minimum science mode".

3.5.4.2 Weaknesses

The TIMED mission appears to have exceptionally high operating and management costs for a spacecraft in the minimum science mission mode. This is surprising to because TIMED was constructed with total life cycle costs in consideration. It is clear that relative to the science dollars going to the science teams, a relatively large amount of the funds go to APL and GSFC for program management. This seems expensive and/or out of balance relative to the needs of science and data archiving. Why two project offices and what advantage is had at this late stage of this mission for science?

It is not clear that the management of TIMED program is promoting science production and data archiving from the TIMED mission. TIMED maintains an expensive backup ground station with USN. It is not clear that this is required since NASA is willing to accept increased risk for missions in extended phase. 80-90% of data return is acceptable for missions in extended phase. It appears that while increased risks are acceptable for TIMED in extended phase, other line items in the budget remain flat. This raises a question in terms of priorities as it appears the mission should be more willing to accept increased S/C health/safety risks than to cut science and maintain management operations.

3.5.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS

The TIMED spacecraft is performing nominally and within specification. One of 4 reaction wheels was lost in February 2007. Fixes have been implemented and pointing is within specs most of the time. Inertial Reference Units have limited life left (unit #1 less than 60 days, unit #2 less than a few days). Timed is operating on star trackers alone since 2005 and pointing requirements are still being met.

The GUVI scan system has failed. Operations are now entirely in the "spectrograph mode". No limb imaging data is being returned but the disk imaging data is of high quality.

SABER is operating as designed and is expected to last for at least 4 more years.

The last senior review recommended SEE be turned off since it would be redundant with the EVE instrument on SDO. LASP is working on FY09 funding levels. Once overlap with SDO measurements is achieved, "SEE observations will be terminated."

The TIDI instrument is operating nominally. The operations are currently making conservative use of moving parts to maximize life.

3.5.6 DATA OPERATIONS

The TIMED mission is doing a very good job of serving data to the ITM community. The products are well documented, and the teams have produced excellent documentation and IDL tools for accessing and processing the data. The data are stored in NetCDF which is an appropriate archival format, commonly used and well supported. The strong connection with VITMO makes the data available in a more uniform way, with additional services provided to assist in finding the most appropriate data for a given study. The plan provides an extensive list of data, software, and documentation products (via the text and the website) that are to be archived, with a timeline for completion by six months after the end of the mission.

3.5.6.1 Concerns

The plan does not identify a particular plan for the long-term archive, stating simply that it "will depend on the actual configuration for the Resident Archive that NASA selects." The idea of a MAP is to indicate what the plan for an RA and long-term archive would be, and how final archiving will be handled. While some TIMED products are in CDAWeb, there is no systematic plan for the long-term preservation and serving of the extensive set of mission products. Discussions with SPDF should be initiated to determine what the final archive status will be, whether it involves actually moving products to SPDF or not. These discussions should include the issue of making useful products available that are independent of software that will be hard to maintain for the long term.

Regarding data products, the plan states that "only the highest resolution, routinely produced products will be supplied to the archive". However, many of the higher-level data products are of significant scientific interest, as are summary plots for browsing, and these should be preserved.

An issue that is broader than TIMED but includes it is whether the NetCDF metadata used for the mission is compatible with that being used for other ITM missions. This is a general HP Data Environment issue that should be worked out by all the relevant parties, including VxOs, SPDF, and the missions.

3.5.7 E/PO EVALUTION

A reasonable collection of activities was presented to continue into the future, which seem to be well coordinated. They will continue participating in the Heliophysics ambassador program, and the Summer Camps. They also will involve college students with two topics of research related to the TIMED mission. Unlike some of the other missions who scatter themselves in a hundred directions and really have no idea what sort of impact they are having, TIMED has done a lot of background work and planning. They have a narrow focus in three specific well-defined areas, and will have more of an impact than most of the other missions. In addition, they will have some informal impact with the website and podcasts – but they present this as sort of a "well, everyone should automatically be doing these things" rather than as a "this is what we are doing for E/PO outreach" like other missions: websites, podcasts, etc., are basics; just the background. It is the actual professional development and sustainable goals that will have a longer-term effect on the target audiences. 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.

3.5.8 OVERALL ASSESSMENT AND FINDING

The TIMED mission has recently produced unprecedented observations during solar minimum which provides a characterization of the "MLTI ground state". Moving forward in the extended mission the TIMED observations may provide some of the most sensitive indicators of global climate change by observations of the upper atmosphere but this scientific question is not a priority for the Heliophysics division. The proposed understanding of water in the upper atmosphere is important for the understanding the chemical and energy balance of the region and is a priority but it is not clear that the proposed science questions can be resolved simply by going to a full solar cycle with TIMED data. Never the less TIMED is seen as an important monitor of energy flowing through the heliosphere and ending in the thermosphere. The TIMED mission appears to have exceptionally high operating and management costs for a spacecraft in the minimum science mission mode and It is not clear that the management of TIMED program is promoting science production and data archiving from the TIMED mission.

3.5.9 OVERALL RATING:

TIME earned lower marks in its contributions to science in its extended mission (Score: 5.8/10, ranking: tenth out of 14 missions). A slightly lower ranking was earned in the HSO contributions (Score: 5/10, ranking: 11th out of 14 missions). Lower rankings are related to the relatively high costs of TIMED.

3.6 TWINS

3.6.1 EXTENDED MISSION SUMMARY

The TWINS mission involves the flight and operation of two energetic neutral atom (ENA) imagers as a mission of opportunity on two non-NASA US Government satellites in Molniya orbits. The TWINS team proposed a detailed program of work to address three broad science topics using the only imager currently flying and which is capable of imaging energetic particles in the magnetosphere. The TWINS team will examine three broad science targets focusing on:

The global 5-Dimensional Ring Current
Ring Current and Plasmasheet Energization
Ion precipitation

These broad science targets are all related to understanding the injection, transport, acceleration and precipitation of these energetic particles in the ring current and plasmasheet in the magnetosphere, and their coupling to the ionosphere. These three broad scientific targets are focused into a well-defined program of work addressing eleven key questions at the forefront of Heliophysics research in energetic particle dynamics and magnetosphere-ionosphere coupling in the inner magnetosphere.

The TWINS mission will also provide unique and strong contributions to addressing Research Focus Areas (RFAs) 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 the Heliophysics Road Map (2009). The TWINS team also makes linkages to additional RFAs in their proposal, however, these are considered by the panel to be of lower relevance. The TWINS team also describe strong synergies of operation with the THEMIS (in-situ particle measurements of the ring current particles) and IBEX (monitoring of the plasmasheet) missions from the Heliophysics Great Observatory, as well as the newly operational Ampere mission which can monitor the structure of the field aligned currents coupling the magnetosphere-ionosphere system and driven partially by ring current pressure gradients.

The TWINS team will utilize two-satellite ENA views from the TWINS spacecraft to reconstruct images of the ring current and near-Earth plasmasheet dynamics by imaging ENAs produced through charge exchange with energetic ions. These ENA views offer the capability to monitor two pitch angle populations in the same volume and hence constrain the pitch angle distribution morphology around the orbit. The TWINS team has demonstrated the viability of their technique during their prime mission, despite the extended period of solar minimum. Importantly, the team have also not only for populations in the equatorial plane but also an unexpected capability to view energetic particle populations close to the ionosphere arising from mirroring particles close to the loss cone and believed to offer a proxy for precipitation into the ionosphere. The TWINS team have also identified partnerships and access to state of the art models which examine the coupling of the ring current to the ionosphere arising from pressure gradients, and resulting field aligned currents, as well as the wave-particle interactions which are believed to play a key role in energization, transport and loss of energetic particles in the ring current.

3.6.2 EXTENDED MISSION SCIENCE EVALUATION

3.6.2.1 Scientific and Technical Strengths

The TWINS team has demonstrated the viability and capabilities of the ENA instruments for determining the dynamic structure of the ring current. The extended period of solar minimum has also allowed the team to complete a detailed calibration and characterization of the instruments.

The upcoming ascending phase of the solar cycle offers the TWINS team the opportunity to deliver the magnetic storm science which the instruments and mission were designed to address. The TWINS mission provides a unique capability to test and validate inner magnetosphere ring current, and dynamic energetic particle ring current-ionosphere coupling, models and to identify any missing or poorly represented physics.

The TWINS instruments are operating well, and the mission and team are well-placed to deliver excellent science returns in the upcoming rising and maximum phases of the solar cycle.

TWINS will address high priority science targets to be addressed with appropriate methodologies with reasonable cost.

The TWINS team contains appropriate modeling expertise and capabilities, including access to coupled magnetosphere-plasmasphere-ionosphere models, which will be needed to make significant progress towards their science objectives.

3.6.2.2 Scientific and Technical Weaknesses

(Minor) **The extent of the science objectives which can be addressed with TWINS is impressive, and the science targets are extensive**. However, these are much more than can realistically be addressed to closure with the funds available. The Senior Review panel encourages the team, which has already established important collaborative links to other mission teams, to seek additional funding from GI, TR&T and other funding lines as much as practicable.

(Minor). **The ENA images cannot be used to infer the O+ and H+ ratio in the ring current routinely, and may only be possible at certain times**. The overall ability of TWINS to provide energetic O+ densities in the ring current, which occur most predominantly during storms, may be limited and the TWINS team does not expect this to be available routinely. Observations during the recent April 2010 storm provide some confidence that such ratios will be able to be derived for certain storm events during the rising phase of the solar cycle during the extended mission phase of TWINS. However, since the resolution of the ENA actuator problem in July 2009, TWINS has only observed small number of storms.

3.6.3 EXTENDED MISSION RELEVANCE TO THE "Heliophysics System Observatory" and "Road Map"

3.6.3.1 Strengths

(Major) The TWINS mission will addresses key aspects of the Research Focus Areas F2 (Particle acceleration and transport), H2 (Earth's magnetosphere, ionosphere and atmosphere), and H3 (Role of the Sun in driving change in the Earths atmosphere) in the Heliophysics Road Map (2009). TWINS offers the only operating dedicated magnetospheric imagers to characterize the dynamics of the ring current. Using partner in-situ measurements from the Great (System) Observatory enables the transport, acceleration and loss of the ring current, including the coupling to the underlying ionosphere, to be understood. Specifically, the stereoscopic ENA imagers offer a unique capability to diagnose both the pitch angle distributions in the equatorial ring current, as well as the mirroring particles close to the ionosphere. These offer global images of the dynamic ring current, as well as related precipitation into the ionosphere, which are critical to understanding wave-particle interactions and related particle transport and loss in the inner magnetosphere.

(Major) The TWINS mission will provide a key contribution to the Heliophysics Great (System) Observatory in understanding energy transport from the magnetosphere to the ionosphere and atmosphere. Partnerships with THEMIS, IBEX and with the newly funded Ampere constellation, together with related state-of-the-art modeling, will allow significant and important progress on these priority issues. Specifically, IBEX can characterize the plasmasheet source for transport to the ring current seen by TWINS; Ampere will also characterize the field aligned currents coupling the ring current and the ionosphere and which can be driven by ring current pressure gradients whose dynamic structure is revealed by TWINS. The Great (System) Observatory goal to "Understand the Sun and its Effects in Earth and the Solar System" will be advanced significantly by the flight of the TWINS mission, especially in relation to energy transport through the plasmasheet and ring current in the inner magnetosphere. In this way TWINS imaging will contribute in a unique way to the Great (System) Observatory.

3.6.3.2 Weaknesses

(Minor) Potential linkages from the TWINS mission results from precipitation and energy transport to the atmosphere are under-developed. The TWINS mission has the capabilities to observe structure of energetic ions close to the ionosphere which originate from equatorial pitch angles close to the loss cone. These particles may represent an important coupling to the ionosphere, thermosphere and atmosphere and hence an important target for Great Observatory collaboration with TWINS. However this is not fully developed in the proposed TWINS science program.

(Minor) The TWINs proposal lacks an element of focus, and overstates its relevance, in relation to some of the focused science targets in the Heliophysics Road Map. The proposal claims relevance to areas F1, F2, F3, H2, H3, H4, J1 and J4. However, some of these claimed relevancies are insignificant. The TWINS mission is very strong in relation to the Heliophysics Road Map in the key areas F2, H2 and H3 and the team could perhaps have focused more clearly on these key areas where the strength of the TWINS mission lies.

3.6.4 EXTENDED MISSION COST REVIEW

3.6.4.1 Strengths

The TWINS mission offers high scientific return at low cost. The TWINS mission utilizes a flight of opportunity two fly the two TWINS instruments on two non-NASA US Government satellites in Molniya orbits. The operation of the two instruments, and the calibrations, processing and serving of these data sets are proposed at comparatively modest cost.

3.6.4.2 Weaknesses

None.

3.6.5 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 has a problem with the TWINS actuator (TWA) on the ENA instruments which was documented in an anomaly report. This related to problems with the monitor feedback from the control software, but this has now been corrected with a software upgrade. This was implemented on 20 July 2009. The same solution was implemented for the CAPS instrument which experienced the same problem on Cassini with an actuator from the same supplier. The fix requires a daily calibration for pointing, but this has minimal effect on the operational duty cycle taking less than 10 minutes per day. The TWINS team has confidence that this solution will continue to work well beyond the 4 years of the senior review.

3.6.6 DATA OPERATIONS

TWINS is a relatively new mission, but it 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 (via CDAWeb) 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, which are also good choices for long term access.

The TWINS ENA data are made freely and publicly available from the TWINS web site at http://twins.swri.edu using an Oracle database accessed through a web interface. This is the primary TWINS data distribution mechanism. Pre-generated TWINS images and ancillary data plots are available through this web page via a web-based selection tool. Public users browse sequentially through TWINS images and other support plots and data. The TWINS team also states that anyone can request an account to use the capabilities of the TWINS Science Data System (SDS). The TWINS platform also includes a Lyman Alpha Detector (LAD) which can be used to examine the neutral geocorona, and these data are also available from the TWINS website.

TWINS images, image data files, and attitude and ephemeris data files are provided to the NSSDC/SPDF for distribution through the CDAWeb interface. Currently this contains ENA data from selected TWINS events from the prime mission; the additional “non-event” data is being added. Through this interface, users can obtain Level 1 TWINS ENA images with 15 minute time resolution and 4 degree angular resolution in 9 energy bins spanning 0.5–75 keV, both as images and as raw data files. It is not clear from the proposal whether LAD data is available from CDAweb.

There is a minor concern that although the interaction with the Virtual Observatory system is important, details in the proposal relating to VxOs is not as specific as in other areas. The team seems to be depending on the interaction with SPDF to provide SPASE metadata; this may be a reasonable plan, but the negotiation with SPDF or a VxO needs to take place to assure SPASE metadata are created. As mentioned above, TWINS is a relatively new mission but not all of the supporting data documentation is currently available. Some won't be available until 2011, and this should be rectified by the team. In the long run the usefulness of the TWINS data will depend on the quality of the documentation. It is recommended that the TWINS mission organize a review of their data and documentation with emphasis on whether scientists can use the data based entirely on the documentation.

Overall, the TWINS mission is doing a very good job of supplying useful data to the community in a timely fashion. The interaction with the Final Archive (SPDF) is proceeding well. Some attention should be paid to creating proper SPASE descriptions through interaction with SPDF or an appropriate VxO (probably VMO), and the mission documentation should be checked, as it is completed, to assure that it provides what users will need to use the data independent of the team and software.

3.6.7 E/PO EVALUTION

3.6.7.1 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.

3.6.7.2 Weaknesses

3.6.8 OVERALL ASSESSMENT AND FINDING

This is a compelling proposal to address ring current and plasmasheet energetic particle dynamics, and 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 will make an important contribution to the Heliophysics Great (System) Observatory. The TWINS ENA imagers are operating well; the instruments are well calibrated, and have proven performance to be able to address compelling science in the upcoming rising and maximum phase of the solar cycle. The proposal has many strong major science and technical strengths, and no major weaknesses. The proposal is therefore rated excellent.

3.6.9 OVERALL RATING

The TWINS mission ranked 1st in term of expected science per dollar for the extended mission science scoring 9.1 out of 10. In term of expected Heliophysics System Observatory contributions per dollar TWINS ranked 5th, scoring 7.2 out of 10.

3.7 Voyager

3.7.1 EXTENDED MISSION SUMMARY:

1) ***Overview of the Science Plan (as addressed by the mission's own instruments):*** The Voyager spacecraft continue their epic journey of discovery, traveling through a vast unknown region of our heliosphere on their way to the interstellar medium. Voyager 1 (V1) and Voyager 2 (V2) are both in the heliosheath, making the first in situ observations of the shocked solar wind beyond the termination shock (TS), with the first crossings of the heliopause (HP) and the first in situ observations of the local interstellar medium (LISM) still to come. The science plan outlines how these encounters will address many basic, long-standing questions about the plasma and magnetic properties of the LISM, the nature of the TS and its role in the acceleration of the anomalous cosmic rays (ACRs), the role of the heliosheath in the modulation of galactic cosmic rays (GCR), the spectra of low- energy interstellar GCRs, and the source and location of the heliospheric radio emissions.

2) ***Overview of the Science Plan (as addressed in conjunction with observations from other Heliophysics missions):*** The Voyagers distance form the sun allows for the study of the evolution of the solar wind, shocks, and cosmic rays. The interpretation of Voyager data is greatly enhanced by comparison with data from spacecraft at 1 AU (Wind, ACE, IBEX, and STEREO),. These data make deconvolution of solar cycle, distance, and latitude effects possible. Further, the Voyagers establish "ground truth" at two points within the heliosheath. Dramatic as they are, the IBEX and Cassini/INCA ENA images integrate the superthermal proton intensities (weighted by the neutral H-atom densities) along lines of sight (LOS) many tens of AU in length. The Voyager spacecraft can provide guidance as to the distribution of the energetic protons along these ENA lines of sight.

3) ***Overview of the Methodology:*** As the Voyagers proceed outward toward and beyond the heliopause, they are making in-situ measurements of totally unexplored regions of the heliosphere. The prime mission science payload consisted of 10 instruments (11 investigations including radio science) on each spacecraft. Only five investigator teams are still supported, though data are collected for two additional instruments (Planetary Radio Astronomy (PRA), and Voyager 1's Ultraviolet Spectrometer (UVS)). V1 and V2 measure:
    a. The properties and radial evolution of the solar wind (ions 10 eV - 6 keV, electrons 4 eV-6 keV) with the Plasma Science Investigation (PLS);
    b. The Energy spectrum of low-energy particles (electrons 10-10,000 keV, ions 10-150,000 keV/n) with the Low-Energy Charged Particles(LECP) collector;
    c. The energy spectrum of high- and low-energy electrons (3-110 MeV) and cosmic ray nuclei (1-500 MeV/n) with the Cosmic Ray Sub-system (CRS);
    d. The high (50,000 - 200,000 nT) and low (8-50,000 nT) magnetic field intensity with the Magnetometer (MAG);
    e. The electrical field components of plasma waves in frequency range of 10 Hz to 56 kHz with the Plasma Wave Subsystem (PWS).

3.7.2 EXTENDED MISSION SCINECE EVALUATION:

3.7.2.1 Scientific and Technical Strengths

The Voyager Interstellar Mission explores, in-situ, the heliospheric boundaries and the local interstellar medium. It appears likely that this is the only opportunity for many decades to come.

Although the uncertainties in the Heliopause position are large, the Voyager spacecraft have a good chance of reaching this heliospheric boundary in 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. Voyager 1, in the northern hemisphere of the heliosphere, crossed the Termination Shock at 94 Astronomical Units (AU) while V2, in the southern hemisphere, crossed it at 84 AU. Based on these TS distances and model predictions, the heliopause and LISM are probably 30-50 AU further out.

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 HP at roughly the same time and provide simultaneous observations of the LISM.

3.7.2.2 Scientific and Technical Weaknesses
The Senior Review Panel continues to be concerned that the "graying" of the Voyager Investigator Teams leaves the mission's science objectives vulnerable to a knowledge gap that may effectively terminate the mission. A new generation of scientists (instrument builders and data analysts) should be apprenticed to the Voyager Teams, tranined to operate the Voyager instruments and to extract science-quality data. These tasks would be distinct from efforts to model and interpret Voyager observations.

3.7.3 EXTENDED MISSION RELEVANCY TO THE "Heliophysics System Observatory" and "Road Map"

3.7.3.1 -- Strengths:
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 "Challenges" by the Decadal survey. For example, Challenge 2: "Understanding the heliospheric structure, the distribution of magnetic fields and matter throughout the solar system, and the interaction of the solar atmosphere with the local interstellar medium.", and Challenge 4: "Understanding the basic physical principles manifest in processes observed in solar and space plasmas.".

3.7.3.2 Weaknesses
None.

3.7.4 EXTENDED MISSION COST REVIEW
As pointed out in the proposal, the Voyager Interstellar Mission project has continually adapted its operations concept and workforce in response to changes in funding levels. The project has undergone a continual transition from multiple specialized teams to a single operations team wherein each member performs multiple interdisciplinary functions. New, internally developed processes and efficiency enhancements have made this possible.

Similarly, there have reductions in the level of funding for science data processing, analysis and archiving. The funding reductions have resulted in a reduction in the number of graduate students and post- docs supported by the project, so the co-investigators are performing much of the data processing and validation.

3.7.4.1 Strengths
The principal investigators are analyzing their data and are reporting their findings in a timely manner. They participate, as appropriate, in making these results available to the science community and to the general public. They present their results at science conferences, through news releases and via publications in the popular press and scientific journals.

3.7.4.2 Weaknesses
There is great concern that after 2011 the funding for project staffing and science analysis activities, both already at bare-bone levels, will be insufficient to maintain spacecraft health and science returns. The proposal asks for "…A supplement of about \$0.5M per year to the guideline budget, beginning in 2012 would allow the project to continue to operate at the current risky, but manageable level…". In addition to the \$0.5M, funds are needed for undergraduate and graduate students for the data processing and analysis tasks. The Senior Review supports these requests.

3.7.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS
Spacecraft and instrument health and status are essentially unchanged since the last Senior Review. Voyager spacecraft subsystems and instruments required for the interstellar mission are operating well and are fully capable of supporting the science mission through 2020 and beyond. Although both

spacecraft are operating on some redundant hardware, with careful monitoring of spacecraft health, considerable functional flexibility still exists to operate a long duration mission.

3.7.6 DATA OPERATIONS

Science data are returned to earth in real time at 160 bps. Real time data capture uses 34 meter Deep Space Network (DSN) resources with the goal to acquire at least 16 hours per day of real time data per spacecraft. This goal is not always achieved due to the competition for DSN resources with prime mission projects and other extended mission projects.

Once a week per spacecraft, 48 seconds of high rate (115.2 kbps) PWS data are recorded onto the Digital Tape Recorder (DTR) for later playback. An additional 48 seconds are recorded each week on Voyager 1. These data are played back to Earth once every 6 months per spacecraft and require 70 meter DSN support for data capture. After transmission of the data (either real time or recorded) to JPL, it is processed and made available in electronic files to the science teams located around the country for their processing and analysis.

After release, Voyager science data are available on-line at the National Space Science Data Center (NSSDC) and at the investigators' institutions. Panel members have heard anecdotal reports of corrupted Voyager datasets at NSSDC. Steps should be taken to ensure the integrity of these unique datasets and to guarantee they are readily useable by the Heliophysics community

The Mission Archiving Plan appears to be specific and with enough detail to allow a user to locate a desired data product.

3.7.7 E/PO EVALUTION

3.7.7.1 Strengths

The Panel endorses the findings of the EPO review, which commended the Voyager EPO plan as “SMD cooperation and networking at its finest”. Costs have been judged to be reasonable, and the EPO program is in line with SMD policy and standards.

3.7.7.2 Weaknesses

None

3.7.8 OVERALL ASSESSMENT AND FINDING

The Voyager Interstellar Mission continues to challenge physical theories regarding our heliosphere. It has also provided observational surprises that lead to major advances in physical understanding. The continued ACR modulation in the heliosheath, the pre-shock slowdown and lack of heating of the thermal plasma at the TS, the low shock strength of the TS, and increases in the 6- 14 MeV galactic electron intensities in the heliosheath are a few examples of observations forcing revisions to long-standing hypotheses on particle acceleration in this region of space. The combination of the IBEX ENA mapping and the Voyager in situ observations will advance understanding of the Heliosphere-LISM interaction in a global sense. Because of these results from the mission, and the discoveries to follow, the Voyager Interstellar Mission deserved very high marks.

The Panel recommends continued operation of the Voyager spacecraft. Further, the panel endorses a supplement of about $0.5M per year to the guideline budget, beginning in 2012, so that the project can continue to operate within manageable levels of risk.. In addition, the Panel suggests that NASA establish a Voyager Postdoctoral Fellowship program to bring young scientists into the Voyager teams as apprentices trained to carry on instrument operations and data reduction tasks. The Panel envisions a prestigious, competitively-selected program, which over the course of a few years, would ensure continuity of Voyager ‘s mission of discovery.

3.7.9 OVERALL RATING

The Voyager mission ranked 4th in term of expected science per dollar for the extended mission science scoring 8.1 out of 10. In term of expected Heliophysics System Observatory contributions per dollar Voyager ranked 12th, scoring 4.7 out of 10.

3.7.10 PROGRAMMATIC FACTORS

Programmatic changes since the beginning of the VIM have significantly reduced flight team staffing levels. As opposed to the multiple teams of specialists available earlier in the mission, each member of the current flight team performs multiple interdisciplinary functions and only limited backup capability exists.

The mission impact of the reduced staffing includes reduced operational flexibility, greatly reduced anomaly response capability, and potential delays in science data delivery. In addition, many important but non-critical tasks are not being performed.

In FY12 and beyond, the project must reduce planned obligations by about 10% from the FY10 levels. This would mean cutting the operations team by about 2 full-time equivalents or reducing the science budget by about 20% - or some combination of the two. There is no easy reduction in operations, since the loss of any person means the loss of multiple functions and an increase in risk. And after 2011, science analysis activities would be limited to a few topics at a time when Voyager is continuing to reveal many surprises in the heliosheath that increasingly require more, not less, analysis.

If we wish to continue this unique mission, the funding for it has to be stabilized at a level that will give some probability for survival for at least another 10 years.

3.8 WIND

3.8.1 EXTENDED MISSION SUMMARY

1) ***Overview of the Science Plan (as addressed by the mission's own instruments):*** The Wind science plan addresses fundamental wave-particle interaction processes in the space environment, the evolution of solar transients in the heliosphere, and the geomagnetic impact of solar activity. These studies capitalize on the unique capabilities of Wind, such as 3D particle distributions over a wide range of energies and delivered at higher temporal cadences than available from any other mission. Since the last Senior Review, Wind has produced a number of important results, many of which flow from the Wind team's continued efforts to develop new data products, with analyses of these data products then funded by competitively-selected Guest Investigator projects. The Wind Science Plan for the next 2-4 years continues this proven strategy.

2) ***Overview of the Science Plan (as addressed in conjunction with observations from other Heliophysics missions):*** The Wind science plan outlines substantial support for other heliospheric missions, thereby advancing the objectives of the Heliospheric System Observatory (HSO). Wind has been doing this for many years, but the rise phase of Cycle 24 and the new capabilities of STEREO, Hinode, and SDO provide new opportunities: For example, together with SOHO/LASCO, Wind replicates the functionality of a STEREO spacecraft, thereby increasing opportunities for high-priority multi-point studies as the two STEREO spacecraft become too widely separated to carry out these studies on their own. The simultaneous availability of high-cadence solar observations from SDO, Hinode, and RHESSI and high-cadence in-situ field, plasma, and energetic particle measurements from Wind at L1 will facilitate new insights into the origins of solar energetic particles (SEPs) and the evolution of interplanetary structures. Looking to 2012 and beyond, it is clear that the science return from RBSP and MMS would be greatly reduced if there were no operational upstream solar-wind monitor. Wind, along with ACE, can ensure that an upstream monitor will be available to support these new flagship missions.

3) ***Overview of the Methodology:*** Wind carries a suite of instruments for precise, in-situ measurements of the interplanetary magnetic field, the solar wind, energetic electrons and ions, and radio and plasma waves. Wind differs from all other currently-operating interplanetary spacecraft in that it spins about an axis perpendicular to the ecliptic. This feature, along with the wide opening angles of the instruments, enables Wind uniquely to map out complete distribution functions, thereby facilitating investigations of wave-particle interactions in unprecedented detail. In addition, Wind provides essential and mutually-beneficial cross-calibration for ACE solar-wind plasma and magnetic fields, something that may become more important as both instrument suites continue to age.

3.8.2 EXTENDED MISSION SCIENCE EVALUATION

3.8.2.1 -- Scientific and Technical Strengths

Wind provides unique capabilities that are not duplicated on the other L1 spacecraft, ACE and SOHO. These unique capabilities include: (1) Wind/WAVES observations of solar radio emissions; (2) Wind/SWE and Wind/3DP full 3D-distributions of ions and electrons, continuously from thermal plasma to MeV energies, with high temporal cadence; (3) Wind/EPACT measurements of solar heavy ions at ~1-10 MeV/nucleon, including full-sky, magnetically-sectored angular distributions. Because of the low levels of solar activity in 2008-2009, it has not yet been possible to exploit Wind's capabilities by making comparisons with simultaneous observations of solar radio emissions, interplanetary shocks, CMEs, and SEPs from STEREO.

Moreover, because of the growing longitudinal separation of the two STEREO spacecraft, once solar-activity picks up, it will be impossible to address key issues relating to the large-scale structure of interplanetary CMEs (ICMEs), radio emissions, and SEP events by using STEREO alone. Instead, these issues will necessarily be addressed by comparing observations from one of the STEREO spacecraft with data from Wind, ACE, and SOHO/LASCO.

The Wind solar-wind measurements are noteworthy for their robustness and reliability. In particular, plasma parameters are derived from three different instruments (SWE, 3DP, and WAVES) that operate based on different physical principles. As a result, the Wind solar-wind measurements are used for cross-calibration with ACE, which currently provides real-time solar-wind data to NOAA and other users. In addition, the SWE instrument can operate through high-energy particle events, which often cause datagaps in the ACE solar-wind measurements.

Solar energetic particles remain a high priority in the new Heliospheric Roadmap. Wind/EPACT still provides the most sensitive measurements ever made for solar energetic heavy ions at ~1 – 10 MeV/nucleon. (Lower and higher energies are measured by ACE.) These intermediate energies have proven particularly powerful in SEP transport studies. In terms of SEP capabilities, ACE and Wind are complementary, not duplicative. Because the STEREO particle instruments are an order of magnitude smaller than those on ACE and Wind, there will be many SEP events where STEREO ion-statistics above 1 MeV/nucleon will deliver a more robust comparison with Wind SEP data than what can be achieved through comparison to higher-energy SEP measurements from ACE.

Wind/3DP is the only instrument sufficiently sensitive to detect suprathermal electrons, starting from just above the solar-wind halo and strahl. These observations are highly complementary to those made by instruments aboard ACE; they contribute to studies of particle acceleration mechanisms, wave-particle interactions in the solar wind, and the topology of large transient structures, such as magnetic clouds and ICMEs. The close proximity of Wind and ACE has made possible studies of these processes on spatial scales of tens to hundreds of Re. A new feature of research in the next two years will be combining observations at L1 with observations of these same processes and structures simultaneously observed elsewhere by STEREO.

Of particular note in this regard is the recent use of Grad-Shafranov reconstructions in determining magnetic cloud cross-sectional geometries across multiple spacecraft (Liu et al., JGR 2006; Mostl et al., Annales Geophys., 2009), at least at spatial scales comparable to the Wind-ACE separation.. Such multipoint reconstructions have not yet been well resolved using spacecraft separated by greater distances such as Wind/ACE and STEREO, because the separations are on the same order as the structures being integrated. However, the success of the Wind-ACE reconstructions has encouraged others to attempt the larger-scale integrations (Mostl et al., JGR 2009).

Wind's scientific productivity remains high and its observations continue to lead to significant scientific discoveries for NASA/SMD research objectives.

Wind has recently demonstrated the ability to deliver real-time solar-wind measurements (in case ACE were to fail), provided that adequate telemetry coverage with ~30m antennae can be found.

Although not relevant to Heliophysics, we note that the Konus gamma-ray instrument on Wind (provided and supported by Russia) continues to supply observations of gamma-ray bursts (GRB) at energies higher than those monitored by NASA's Swift satellite and with higher sensitivity to soft gamma-ray repeaters (SGR) that other currently operating instruments. Wind/Konus is expected to continue to enhance the science return from NASA's Swift and Fermi astrophysics missions.

3.8.2.2 -- Scientific and Technical Weaknesses
None major. Table 1 of the proposal overlooks the ability of ACE/EPAM to measure electrons at ~50-400 keV.

3.8.3 EXTENDED MISSION RELEVANCE TO THE "Heliophysics System Observatory" and "Road Map"

3.8.3.1 Strengths
The Wind science plan supports studies from nearly the whole spectrum of HSO missions. As amply documented in the proposal, the Wind science plan clearly focuses on the top-level objectives of the Heliophysics Road Map (i.e., RFAs F1, F2, H1, and J1-J3).

As already noted, an upstream solar-wind monitor is essential for maximizing the science output of RBSP and MMS, whose projected launch dates of 2012 and 2015, respectively. If either one of these missions were forced to operate without an upstream solar-wind monitor, the loss to magnetospheric science could not be recouped. Both ACE and Wind are well beyond their design lifetimes, and it is impossible to choose which one is more likely to fail first. The cost of continued operation of *both* ACE *and* Wind throughout the prime missions of RBSP and MMS (roughly $60M) is only a few percent of NASA's investment in these new missions ($1580M). Although NOAA may provide a new monitor at L1 in the next few years, it is debatable as to whether achieving NASA's science objectives should depend on another agency. In any case, the Wind/ACE solar-wind capabilities need to be maintained until an equivalent satellite is operational at L1 and the new solar-wind instrument has been cross-calibrated with Wind/ACE. The Panel therefore deems it prudent to plan to continue operating both Wind and ACE for the foreseeable future, with the continued need for both spacecraft re-evaluated at future Senior Reviews.

3.8.3.2 Weaknesses
None

3.8.4 EXTENDED MISSION COST REVIEW

3.8.4.1 Strengths
The proposed Wind budget is very lean. The mission team is to be commended for its efforts to reduce operating costs. It is clear that the Wind team has taken the call for "minimal science" in the MO&DA budget very seriously. It is difficult to imagine making further cuts, unless an instrument ceases to operate.

3.8.4.2 Weaknesses
None

3.8.5 SPACECRAFT / INSTRUMENT HEALTH AND STATUS
Spacecraft and instrument health and status are excellent in spite of the age of the mission. Health and status are essentially unchanged since the last SR. During the past few years, the spacecraft experienced a few latch-ups and single-bit flight software errors, most likely due to the unprecedented high levels of Galactic cosmic rays. These anomalies served to test the spacecraft and instrument recovery procedures. In all cases, all instruments were returned to full science operations within a couple of days.

Some periods of excess charging in the spacecraft batteries were observed, but there are several modes to manage the battery situation, and there has been no lasting adverse impact.

The Wind team has taken prudent steps to extend the life of its digital tape recorder by minimizing its use and to carefully manage the spacecraft batteries.

To maintain its current orbit around the L1 point, Wind needs to carry out four station-keeping maneuvers every year. Wind has enough fuel to maintain its orbit for 60 years.

The proposal did not report on the status of solar-panel output. NASA should confirm that the present performance and rate of decline are within nominal ranges.

3.8.6 DATA OPERATIONS
In the past five years, the Wind team have made tremendous improvements in the scope and availability of their data. The Panel commends the team on these efforts and encourages them to pursue their plans for further enhancements, especially the planned production of the MFI level 4 data and expansion of the available Wind/EPACT data.

The MAP assessment found that, overall, WIND data are generally in quite good shape and that Wind is providing excellent data services to the community. However, the MAP assessment noted several specific concerns about the Wind data, and the Panel urges the Wind team to address these issues.

3.8.7 E/PO EVALUATION

3.8.7.1 Strengths

The Wind E/PO plan is a combination plan with that of the STEREO/IMPACT instrument team. The Wind/EPO plan focuses on teacher workshops and contributions to a website. The costs are minimal and SMD EP/O policies and standards are met. 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.

3.8.7.2 Weaknesses

The EP/O assessment team noted the need to examine the value of teacher workshops. It was unclear to the Panel, however, as to whether this should be a responsibility of the Wind EP/O effort or part of a larger agency-wide assessment.

3.8.8 OVERALL ASSESSMENT AND FINDING

Wind makes measurements of radio emissions, magnetic fields, solar-wind, and energetic particles at L1 that are complementary to those of other HSO missions. Particularly noteworthy are Wind's unique 3D coverage and very high temporal resolution. These unique capabilities have proven particularly valuable for studying reconnection in the solar wind, wave-particle interactions at shocks, and energetic-particle transport. Since the last Senior Review, the HSO has expanded greatly with the addition of Hinode and SDO, both or which make solar observations of unprecedented high temporal resolution. As solar activity increases in the next two years, Hinode and SDO will provide completely new opportunities to exploit the capabilities of Wind, in exploring how transient conditions in interplanetary space reflect the solar activity that caused them. Comparisons of SEP composition and spectral data from Wind and STEREO will also be a high priority.

The next two years will also provide an unprecedented opportunity to see how the magnetosphere, ionosphere, thermosphere, and mesosphere respond to increasing solar activity after a prolonged and deep solar minimum. Fully exploiting these new observations from ongoing magnetospheric and ITM missions requires an upstream solar-wind monitor. Both ACE and Wind provide solar-wind measurements at L1, although the measurements from Wind are arguably more robust.

The Wind spacecraft and instruments are healthy, and the Wind team provides excellent and ever-improving access to their data. The Panel therefore recommends continued operation of Wind in its current mode throughout FY11 and FY12.

Longer term, an upstream solar-wind monitor will also be needed to maximize the science return from SMD's $1.6B investment in RBSP and MMS, with expected launches in 2012 and 2015, respectively. Wind, together with ACE, provides a cost-effective way of assuring that L1 measurements will be available when needed. The Panel therefore deems it prudent to plan to continue operating both Wind and ACE for the foreseeable future, with re-evaluation of the continued need at each future Senior Review.

3.8.9 OVERALL RATING

Wind deserves high marks in its "science per dollar" contributions to science from the HSO (Score: 7.8/10, ranking second out of 14 missions). A low ranking is appropriate in the "Wind alone" science, simply because a substantial database has already been acquired (Score: 4.4/10, ranking: 13th out of 14 missions). The tight budgets under which Wind has operated for many years should also be recognized as factor in the low "Wind alone" science ranking.

4 Cost Comparisons

The operating missions under review completed a budget template as part of their extended mission proposal to the Mission Operations and Data Analysis Program. This template was provided by NASA Headquarter with specific instructions and definitions for breaking the projects into a common "five-way" work-breakdown structure (WBS). The five categories are Development, Mission Operations, Science Operations, Science Data Analysis, and Education & Public Outreach. Although it is difficult to apply a general functional breakdown to the specific work-breakdown structures of every flight project, it has been necessary for the purposes of this comparative review. This breakdown has served as a guide for the purpose of identifying funding activities and evaluating the "science per dollar" value of the programs. The projects were allowed to modify the provided breakdown to fit the project's particular situation. The intended activities under this WBS are:

1) Development:
   a. Development or re-engineering of post-launch flight software and ground systems.
   b. For science data centers: development or re-engineering of new capabilities, software tools, technology enhancements, improved services, etc.

2) Mission Operations: "Control Center", communications and management functions including:
   a. Space Communications Services: Antenna operations for prepass and postpass tracking operations, spacecraft commanding and telemetry tracking including radiometric data, TDRSS support, telecommunication services such as the use of dedicated circuits (tail circuits) or the use of local area networks.
   b. Mission Services (i.e. satellite control centers and navigation): Command generation and telemetry monitoring, health and performance monitoring of the spacecraft, instruments, and ground systems, spacecraft trajectory or orbit, and attitude planning and determination, resource constraints analysis (spacecraft power, data storage, telemetry rates, TDRSS, DSN, etc.), mission analysis and planning/scheduling activities.
   c. Other mission operations including: Project management and accounting functions, mission system engineering.

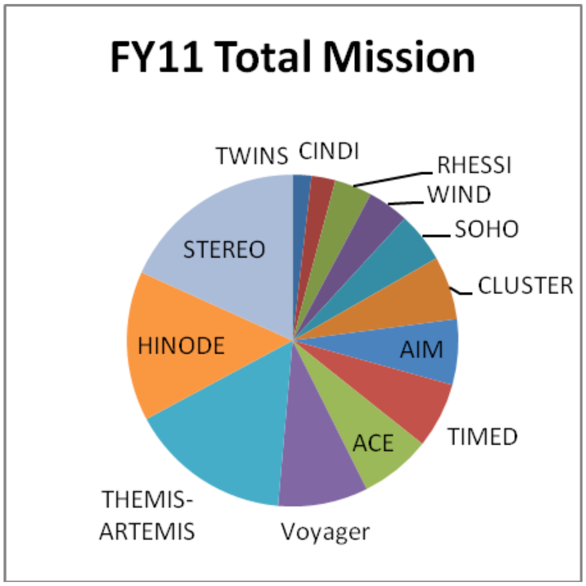
3) Science Operations Functions:
   a. Sequence generation, science planning & data processing and distribution including: science events planning, integration, and optimization; science and engineering activity integration; instrument and observation performance analysis; mission and/or science operations centers; services for guest observers/guest investigators; science data calibration/physical unit conversion; validation and certification of processed data; data products distribution to investigators for analysis; science teams products for science data processing; generation of quick-look and common pool data sets; standard data processing; science data archiving; multi-mission data centers.

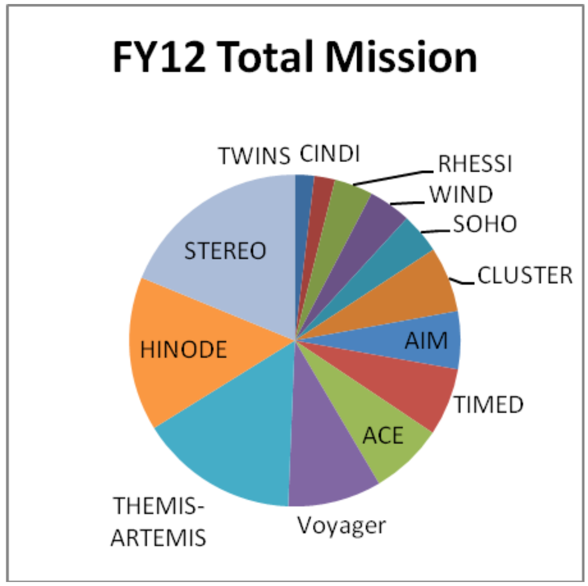
4) Science Data Analysis:
   a. "Science" functions: Customized Data Processing, analysis activities, writing and editing documentation, presentation and publication of scientific results.
   b. Guest Observer Funding

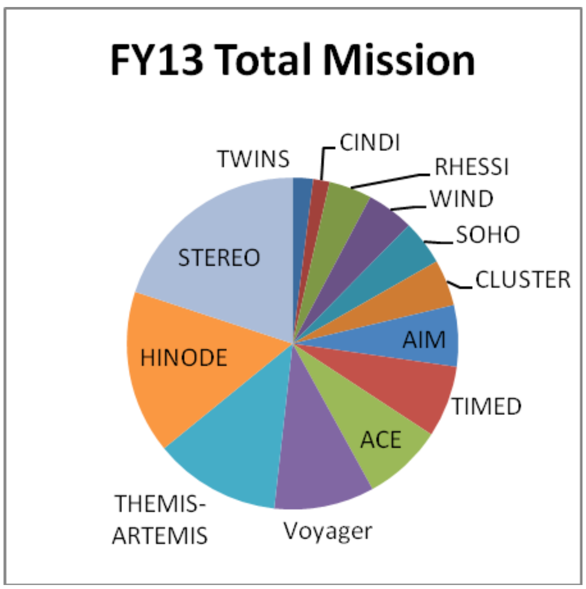
5) Education and public outreach (E/PO):

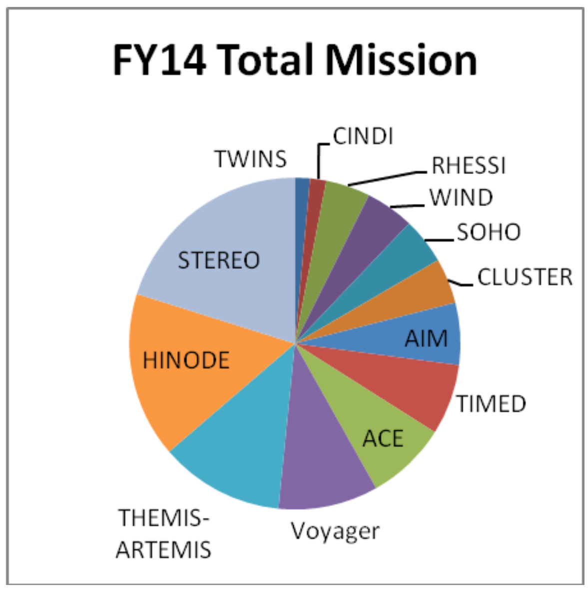
4.1 Extended Mission Cost Comparison

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



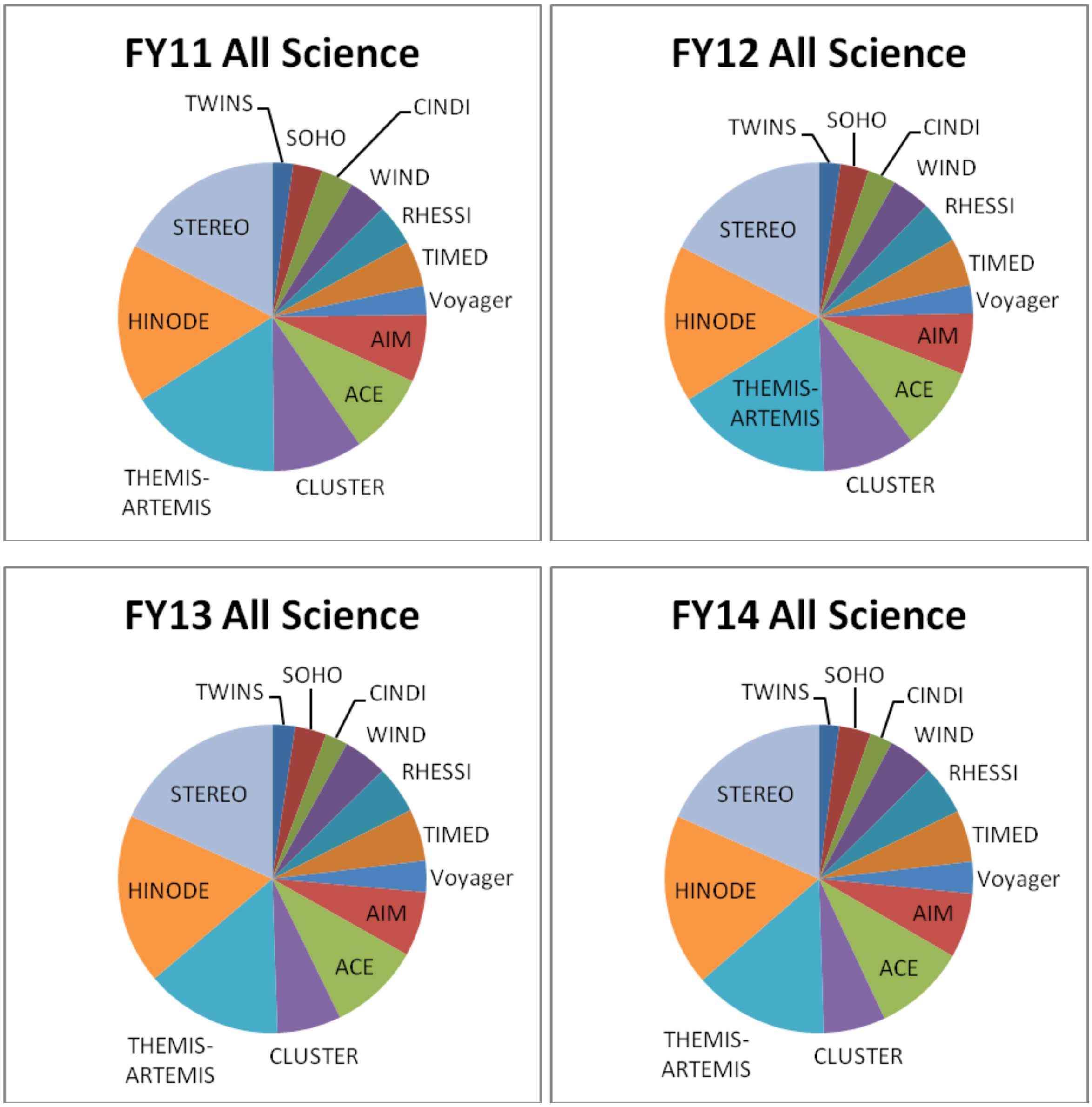






4.2 Science Operations Functions and Science Data Analysis.

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 work breakdown structure 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.



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.