Senior Review of the Sun-Solar System Connection Mission Operations and Data Analysis Program

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Submitted to:

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1. Overview

1.1 Introduction

The NASA Science Mission Directorate conducts scientific peer reviews of its operating mission programs by selected members of the discipline communities at approximately two-year intervals. The goal of these Senior Reviews is to maximize scientific return from these programs within available resources. The last Senior Review of the Sun-Solar System Connection (SSSC) missions was in the year 2003. Since that review NASA has developed its new Vision for Space Exploration which includes both human and robotic exploration of the Solar System. A description of the exploration initiative is available at http://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf. NASA's future research and exploration within its Sun-Solar System Connection program aims to "explore the Sun-Earth system to understand the Sun and its effects on Earth, the solar system, and the space environmental conditions that will be experienced by explorers, and to demonstrate technologies that can improve future operational systems."

The Sun-Solar System Connection Program has been reevaluated to address the needs of the NASA Vision for Space Exploration. There have been extensive discussions in the SSSC scientific community that provide scientific objectives and research focus areas for the next decade. These discussions have resulted in the development of a new roadmap "Sun-Solar System Connection Science and Technology Roadmap 2005-2035" (http://sec.gsfc.nasa.gov/SSSC_2005Roadmap.pdf). The Roadmap defines three broad science and exploration objectives:

- ***Open the Frontier to Space Environment Prediction:*** Understand the fundamental physical processes of the space environment – from the Sun to Earth, to other planets, and beyond to the interstellar medium.
- ***Understand the Nature of Our Home in Space:*** Understand how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields.
- ***Safeguard the Journey of Exploration:*** Maximize the safety and productivity of human and robotic explorers by developing the capability to predict the extreme and dynamic conditions in space.

The SSSC 2005 Roadmap provides a set of priority research focus areas and investigations for each of these broad objectives. The three broad science and exploration objectives and associated priority focus areas provide the basis for the panel's assessments of each operating SSSC mission's relevance to SSSC goals and objectives.

The current review considered proposals spanning the period from FY07-FY10, with emphasis on FY07and FY08. The in-guide budget given to the projects as guidance by NASA Headquarters was a "bare-bones" budget with a total of $250M for FY07-FY10. The requested/minimal budgets proposed by the missions require approximately $6M more than the guideline for the period FY07-FY10. The requested/optimal budgets proposed by the missions substantially oversubscribe the available funding guidelines, by approximately $40M.

1.2 Space Missions

This Senior Review considered 13 science missions: the geospace missions Cluster, FAST, Geotail, IMAGE, Polar, and TIMED; the solar remote sensing missions, SOHO, TRACE, RHESSI; the L1 *in situ* missions, ACE, SOHO, and Wind; and the more distant heliospheric *in situ* missions, Voyager and Ulysses. All are in their extended mission phases. The Panel received both a written proposal and an oral presentation from each of the mission teams. Each mission was evaluated on the quality of its proposed science and its contribution to the SSSC Roadmap.

The IMAGE spacecraft malfunctioned on December 18 and stopped transmitting. The failure occurred a month after the meeting of the Panel. At the time of the final editing of this report, IMAGE was still silent. The Panel believes that its report should reflect the assessments made at its November meeting. We note that all of the missions reviewed here are operating years, sometimes many years, past their design lifetimes. That is an important reason for maintaining an SSSC Great Observatory with diverse capabilities for carrying out science. The loss of IMAGE will eliminate one aspect of the multifaceted capabilities of the Great Observatory, global imaging of the magnetosphere. The launch of the first TWINS satellite will restore some of the global neutral atom magnetospheric imaging, a capability to be enhanced by the stereo imaging introduced when the second TWINS spacecraft becomes operational. What has been permanently lost are the auroral imaging capabilities of IMAGE, its EUV imaging of the plasmasphere and storm dynamics, and its *in-situ* measurements of electron densities for plasmaspheric studies.

1.3 Senior Review Panel Responsibilities

The instructions given to the Senior Review panel by NASA Headquarters are summarized below. These instructions were conveyed in the call for proposals for the SSSC operating missions: (1) Rank the scientific merits -- on a "science per dollar" basis -- of the expected returns from the projects reviewed during FY-07 and FY-08 in context of the science goals, objectives and research focus areas described in the *SSSC Science and Technology Roadmap 2005-2035*. The scientific merits include relevance to the SSSC goals, scientific impact and promise of future scientific impact. (2) Assess the cost efficiency, data availability and usability, vitality of the mission's science team and education/outreach as secondary evaluation criteria, after science merit. (3) Drawing on (1) and (2) provide comments on an implementation strategy for the SSSC mission operations and data analysis (MO&DA) program for 2007 and 2008 which could include a mix of (a) continuation of projects "as currently base-lined"; (b) continuation of projects with either enhancements or reductions to the current baseline; or (c) project terminations. Also make preliminary assessments equivalent to (1), (2), and (3) for the period 2009 and 2010. Provide on overall assessment of the strength and ability of the SSSC MO&DA program to meet the expectations of the SSSC Great Observatory as represented in the SSSC Roadmap during 2007 to 2010. The Panel was not asked to evaluate or assess the utility of SSSC mission data to operational or commercial users.

1.4 Methodology

The Senior Review Panel convened on 14-17 November, 2005 and was comprised of 11 scientists with solar, heliospheric, and geospace expertise. A separate panel was convened to evaluate the proposed education/public outreach (E/PO) programs and these evaluations were submitted in a report to NASA Headquarters. The Senior Review Panel received a copy of this report and also made its own assessment of the E/PO programs. Independent mail-in assessments of mission data availability, accessibility, usability, and documentation were made by peer reviewers selected by NASA Headquarters. The Senior Review Panel received copies of these assessments. The Panel also received from the NASA Discipline Scientist for High Energy Astrophysics a report concerning the importance of the Ulysses, Wind, and RHESSI missions to high energy astrophysics.

The projects submitted proposals to NASA Headquarters by October 6, 2005 describing their planned science program; their relevance to the goals of the SSSC program; the impact of their scientific results as evidenced by citations, press releases, etc.; spacecraft and instrument health; productivity and vitality of the science team; promise of future impact and productivity; and broad accessibility and usability of the data. These proposals were provided to the Panel. Each project also made a brief presentation to the Panel and responded to questions from the Panel during its November meeting.

All of the reviewed proposals contained budgets for mission operations and data analysis at both "guideline/minimal" and "requested/optimal" scenario levels. The proposals for missions with multiple instruments also broke the budget down by instrument. The total funds requested to provide "bare bones" support of the MO&DA programs in FY07-10 were approximately $75M, $68M, $59M, and $55M, respectively. When taken together, the "guideline/minimal" budgets of the proposals exceed the total available for the four-year period (FY07-10) of this review by approximately $6.3M; the "requested/optimal" programs exceed it by about $40M.

The Panel assessed the scientific merit of each mission, as reflected in relevancy to the SSSC goals, scientific impact, and promise of future scientific impact. The Panel also assessed the cost efficiency, data availability and usability, vitality of the mission's science team and education/outreach taking into consideration the assessments of the E/PO panel and mail-in reviews on data availability and usability. Section 1.5 contains a summary of the results including grades for each mission, an overall assessment of their joint roles within the SSSC Great Observatory, and a summary of the Panel's findings. Section 2 contains evaluations for each of the missions.

1.5 Summary of Results

1.5.1 Mission Grades

The proposals were graded according to two criteria, (1) their overall scientific merit and (2) their contribution to SSSC goals as outlined in the SSSC 2005 Roadmap. Each mission was graded on a scale of 0 to 10 by each member of the panel according to the following criteria for scoring where 10 is the highest score and 0 the lowest:

- 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 results are presented below in two tables. The accompanying figures present the results in graphical form. The standard deviations provide a measure of the diversity/agreement in the assessments of the members of the Panel. Because achievement of SSSC goals in many cases requires measurements made by multiple spacecraft in different locations, the grade for relevance to SSSC goals tends to give more weight to how an individual mission contributes to the SSSC Great Observatory than is the case for the grade for science merit. For example, Voyager is making fundamentally new and unique scientific measurements as an individual mission, while the primary values of the FAST, Geotail, Polar, TRACE, and Wind missions at this point in their lifetimes is complementing other higher ranked geospace and/or solar-heliospheric missions. The latter (higher ranked) missions tended to be viewed by the panel as contributing significantly both as individual missions and as components of the SSSC Great Observatory and thus received higher grades for both science merit and contributing to the SSSC goals.

The missions fall into three groups when rated on science merit (e.g. Figure 1) with Voyager, RHESSI, and Cluster having grades of 8.7 to 8.1, a middle group with grades ranging from 6.5 to 5.9 (ACE, IMAGE, SOHO, TIMED, and Ulysses), and a third group with grades that range from 5.1 to 4.1 (TRACE, Wind, FAST, Geotail, and Polar). When rated on their contributions to SSSC goals (e.g. Figure 2) the grades for the missions exhibit an approximately linear decline in grades from 8 to 5.9 (from, in order, RHESSI, ACE, Cluster, SOHO, IMAGE, TRACE, Voyager, TIMED, Wind, FAST, to Ulysses) and then dropping approximately a point to 5.0 and 4.8 for Polar and Geotail respectively. The ordering of the missions does not differ significantly between the two methods of grading with the exception of Voyager which rates first in the science merit, but is in the middle of the set of missions when rated as contributing to overall SSSC goals.

Summary Finding: The Panel rates <u>all</u> of the reviewed missions as being capable of making excellent contributions to science (grades 4 and above) and SSSC overall goals with most, 10 of the 13 missions, receiving grades of 6 or more for their promise in contributing to the SSSC goals.

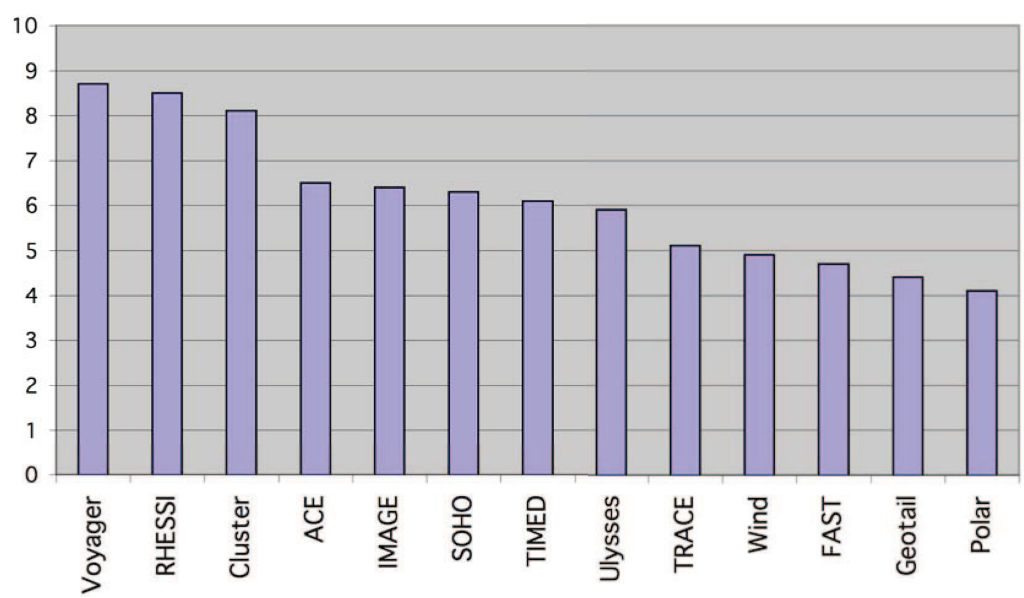
Grades: Science Merit

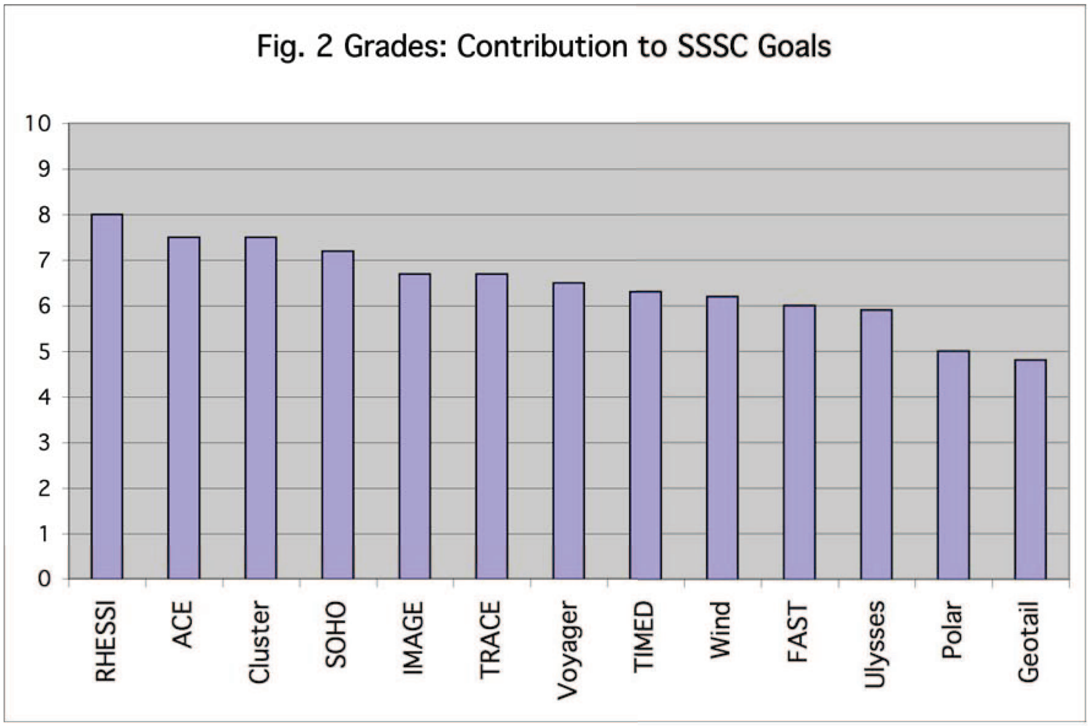
	Avg Grade	Std Dev
Voyager	8.7	1.5
RHESSI	8.5	1.3
Cluster	8.1	1.1
ACE	6.5	2.0
IMAGE	6.4	2.4
SOHO	6.3	2.1
TIMED	6.1	1.6
Ulysses	5.9	2.2
TRACE	5.1	1.8
Wind	4.9	1.6
FAST	4.7	1.6
Geotail	4.4	1.6
Polar	4.1	1.8

Grades: Contribution to SSSC Goals

	Avg Grade	Std Dev
RHESSI	8.0	1.6
ACE	7.5	1.6
Cluster	7.5	2.1
SOHO	7.2	1.8
IMAGE	6.7	1.3
TRACE	6.7	1.1
Voyager	6.5	2.8
TIMED	6.3	1.6
Wind	6.2	1.3
FAST	6.0	1.6
Ulysses	5.9	1.8
Polar	5.0	0.9
Geotail	4.8	1.4

Fig. 1 Grades: Science Merit





1.5.2 The SSSC Great Observatory

"The currently operating spacecraft missions supporting Sun – Solar System Connections research collectively constitute a Great Observatory that can address the fundamental challenge for SSSC science. The **SSSC Great Observatory** provides the simultaneous measurements in multiple locations needed to resolve temporal and spatial changes and to understand the interactions of complex systems of regimes. As we progress in the exploration of space, this essential capability must evolve to support ever more comprehensive understanding and predictive capabilities. In the years ahead, portions of this spacecraft fleet will be configured into "smart" constellations -- sets of strategically-located satellites whose data are available through virtual observatories. Researchers will work together to provide the timely, on-demand data and analysis to enable the practical benefits for scientific research, national policymaking, economic growth, hazard mitigation, and the exploration of other planets in this solar system and beyond." *SSSC 2005 Roadmap.*

The Panel finds that the current version of the SSSC Great Observatory has impressive capabilities for studying the solar structure and phenomena (SOHO, TRACE, RHESSI), the resulting solar energetic particles and solar wind at 1 AU (Wind, ACE, SOHO) and in other regions of the heliosphere (Cluster, Geotail, Ulysses, Voyager), the terrestrial magnetospheric which responds to solar drivers (Cluster, Geotail, FAST, IMAGE, Polar, geosynchronous measurements), and the upper terrestrial atmosphere (IMAGE, TIMED, and ground-based optical and magnetometer networks). The value of each mission is enhanced significantly by the synergism among the missions forming the SSSC Great Observatory. More details on contributions of each mission to the Great Observatory are given in Section 2.

In the FY07-FY10 period the SSSC Great Observatory will be augmented by new missions planned for launch in 2006 (CINDI, TWINS, STEREO, Solar-B, AIM, and THEMIS) and in 2008 (SDO and IBEX). These additions to the Great Observatory will enable study of a wide variety of phenomena with unrivalled accuracy and resolution and provide the SSSC scientific community with unprecedented opportunities for achieving scientific progress and understanding. The primary limitation will be that imposed by funding constraints for support of the missions and analysis of the data.

1.5.3 Guest Investigator Program

The Panel strongly reaffirms the value of the Guest Investigator Program (GIP) and encourages NASA to provide a means for stably funding it. In order to capture the new physical understanding made possible by the recent Voyager observations, a GIP component targeted on Voyager theory and modeling at $300-400 K/year in FY07-FY09 would be beneficial. Efforts previously supported by the TIMED IDS and Cluster-theory programs could be competed under the GIP, but with selection based solely on relative scientific merit, without any specification of a dollar amount allocated to these efforts. The Panel confirms the enthusiasm behind the suggestion from various Mission teams for a targeted GIP on Solar Eruptive Events (SEE). However, targeted research on similar topics is already underway in the Living With a Star program, and the Panel feels that the vitality of the research community would be better served by an open competition for the best science, rather than a focus on this specific area. The Panel therefore declines to endorse the SEE/GIP suggestion.

The cancellation of the FY05 GIP solicitation has had a deleterious effect on the SSSC research community, particularly for younger and soft-money researchers. Because of the cancellation, there will be a larger number of proposals than usual in the next GIP competition, but the projected budget allows for no increase to accommodate this additional proposal pressure. The disruptions will therefore propagate into the future and may have the eventual impact of driving talented researchers from our field. At minimum, it might be possible to ameliorate the impact of a GIP reduction, perhaps by rescissions on mission budgets or instrument-by-instrument review of capabilities, overlap, and ongoing scientific impact.

1.5.4 Summary of Findings

As discussed above, the Panel finds that all of the reviewed missions as being capable of making excellent contributions to science and SSSC overall goals, and that the value of each mission is strongly enhanced by the synergism within the SSSC Great Observatory. The Panel also strongly reaffirms the value of the Guest Investigator Program. Other findings of the Panel are as follows:

A. The Panel gave the highest rating on scientific merit to the Voyager mission and finds that allocating funds at or near the requested optimal level is warranted to this mission that is entering unexplored regions of space at the distant boundaries of the solar system near and beyond the heliospheric termination shock.

B. The Panel finds that due to their excellent scientific merits and relevance to the SSSC goals, the ACE, Cluster, IMAGE, RHESSI, and TIMED missions promise to make strong scientific contributions throughout the period covered by this review, FY07-FY10. The funding levels given to these projects in the fiscally constrained NASA Headquarters "guidelines" budget appear to be consistent with the above finding. Higher levels of funding would enable greater scientific output if additional funds should become available.

C. The Panel endorses the Project's proposal to terminate operations of Ulysses after a suitable period of time beyond the next solar minimum when the northern polar magnetic field is inward rather than outward. The Panel concurs that continuing operations beyond that time in 2008 is not warranted given the low power levels that will be available from the spacecraft.

D. The fiscally constrained NASA Headquarters "guideline" budget has no funding for Polar after FY06 as it approaches the end of its fuel reserves, and no funding for FAST and Geotail after FY08. The Panel rated the FAST, Geotail, and Polar missions as excellent in terms of both science and relation to the Great Observatory, albeit at generally lower priority than the other missions; FAST also being rated higher than Ulysses, Polar and Geotail in terms of Relevance to SSSC goals, and higher than Geotail and Polar in terms of science. The Panel finds that the FAST, Geotail and Polar missions could continue to provide valuable measurements beyond the above dates, particularly as elements within the SSSC Great Observatory. With the low cost of the continued operation of FAST and Geotail, and their potentially very significant scientific importance in support of the forthcoming THEMIS mission, the panel finds value in the continued operation of FAST and Geotail beyond 2008. However, in this fiscally constrained program, the Panel encourages the FAST and Geotail teams to exploit future synergies within the Great Observatory such as will be available with THEMIS to justify to the next Senior Review Panel the case for their operation beyond 2008.

E. The Panel did not rate the proposed Polar mission extension until March 2007 highly in terms of "value per dollar", particularly because of the high cost involved. However, the panel was aware of the importance of the unique Polar 2-10 MeV and 3D electric field measurement capabilities for understanding the processes that accelerate particles at high and low latitudes within the outer radiation belts. The panel believes that Polar could be ramped down to a minimum mission tuned to meet the radiation belt objectives in order to exploit the unique opportunity for new radiation belt science at low cost. If extra funds were made available, then this minimal mission would be an appropriate application of funds.

F. The Panel finds that continued operation of Wind at L1 throughout the FY07-FY10 period is important. Wind has unique instrumental capabilities that provide complementary science observations for future work with RHESSI, STEREO, and ACE. In addition, Wind is a backup for ACE for solar wind measurements at L1 and the combination of SOHO and Wind is a back-up for STEREO.

G. SOHO is the most expensive of the missions assessed by the Panel. Given the nature of the spacecraft, a large observatory class mission that was designed for considerable "hands on" attention, this is not unexpected. The panel commends the project on its efforts to lower the cost and for the proposed "Bogart" version of the mission which cuts the cost in FY10 to a value 60% below the amount in the guideline budget in FY10. However, Panel finds that it is desirable to more rapidly lower the operational cost between FY07 and FY09 given the tight fiscal constraints on the overall program reviewed by the Panel. The Panel concurs on the desirability of continuing operation of MDI until the more advanced instrument on SDO is in operation, and that cross-calibrating with MDI is vital given the fundamental importance of studying changes in the solar interior, where solar activity and the solar cycle ultimately originate.

H. Given the high (upper half) ranking of TRACE for relevance to SSSC goals and the strong complementary nature of TRACE observations for RHESSI (the highest ranked mission for relevance to goals and second highest mission for scientific merit), the Panel endorses the proposal to keep TRACE operational through a several month overlap inter-calibration period with SDO whose capabilities supercede those of TRACE.

I. Projected FY09-10 Funding: Due to the reduced funding levels projected for FY09 and FY10 compared to earlier years and the impact of new missions transferring from their prime mission funding to the extended mission budget, the latter will be severely under-funded, by the order of $15M per year in FY09 and FY10. This is in spite of the fact that the budget assumes that 5 of the 13 currently operating missions will have terminated operations in this time period. This projected funding shortfall will severely impact the capabilities of the SSSC Great Observatory and its ability to properly address the goals of the NASA SSSC program. This under-funding of the Great Observatory occurs at a particularly inopportune time, at the next maximum of the solar cycle with its expected frequent occurrence and diversity of solar-terrestrial events that impact studies of many SSSC goals.

This Senior Review addressed only currently operating SSSC missions that have demonstrated their operational and measurement capabilities. It did not review new SSSC missions scheduled for launch in FY06-FY10 (CINDI, TWINS, AIM, THEMIS, STEREO, Solar-B, SDO, and IBEX).   The Panel did not have the information required to assess the relative merit of these new missions by the standards that the currently operating missions were assessed. Consequently, this Panel was unable to assess the relative merits of the full complement of SSSC missions that could potentially serve as elements of the SSSC Great Observatory in FY09 and FY10 when the above funding shortfalls occur. This will be a task for the next Senior Review Panel.

J. The Senior Review Panel finds that terminating the operations for five missions during the FY07 – FY10 time period is consistent with achieving optimal science per dollar return from the projected availability of funds for the operating missions. The missions and the years of termination are Polar in FY06 and FAST, Geotail, Ulysses, and TRACE in FY08. This finding is subject to the provisos noted above for Polar, FAST, and Geotail.

2. **Evaluations of Missions** (In alphabetical order)

2.1 Advanced Composition Explorer (ACE)

Science Strengths: ACE is in orbit about the L1 point and carries a comprehensive set of instruments measuring particle composition over a broad range of energies, from the solar wind to galactic cosmic rays. ACE has yielded new insights into fundamental processes of particle acceleration and transport. A few examples are an emerging understanding of suprathermal ions as seed particles for interplanetary (and perhaps coronal) shocks, new results on the coronal sites at which impulsive solar particle events are generated, and observation of reconnection exhausts in the solar wind, which represent a new and important focus for future research. Observations during the inherently simpler conditions of the approaching solar minimum, as well as future coordinated observations with STEREO and other spacecraft, will further clarify these and other issues. Isotopic measurements, which are a unique contribution from ACE, have addressed the composition of the local interstellar medium, the source of galactic cosmic rays, and the chemical evolution of the galaxy. Thus, ACE contributes not only to SSSC objectives but also to the entire NASA science enterprise.

ACE provides knowledge on the variability and dynamic range of the space radiation environment. This knowledge is an essential baseline for the design and operation of future human and robotic exploration missions. In the nearer term, ACE data will be needed for modeling and interpreting radiation measurements from the Lunar Reconnaissance Orbiter (LRO; to be launched in 2008) and the Mars Science Laboratory (MSL; to be launched in 2009).

ACE contributions are evidenced by a substantial publication record. In 2004-2005, ACE scientists have authored or co-authored 98 peer-reviewed papers and 40 conference papers. ACE's broader impact is also illustrated by 157 papers using ACE data, but with no ACE co-authors. In solar and heliospheric science, ACE scientists have been leaders in organizing conferences, workshops, and AGU special sessions. These efforts have helped to consolidate the new insights from Cycle 23 observations and to formulate directions for future studies.

Relevance to SSSC Roadmap: ACE has been highly responsive to the stated objectives of the SSSC Roadmap. ACE alone addresses more than half of the 41 priority investigations listed in the Roadmap; through coordinated studies with other missions, ACE addresses nearly three-quarters of the priority investigations.

Value to SSSC Great Observatory: ACE plays a central role in a broad range of collaborations and coordinated observations that will serve to maximize the scientific output of SSSC missions. From its vantage point at the Sun-Earth L1 point, ~ 1 million miles sunward of Earth, ACE measures changes in the solar wind, interplanetary magnetic fields, and energetic particle populations resulting from the solar eruptions, whose characteristics are detailed by TRACE, RHESSI, SOHO, Wind, and (in the future) Solar-B, STEREO, and SDO. ACE measurements quantify the interplanetary magnetic and plasma drivers behind dynamics in the geospace environment, which is the focus of Cluster, IMAGE, Polar, FAST, TIMED, and future missions, such as THEMIS. ACE also contributes to collaborative efforts, exploiting the complementary capabilities of Wind and STEREO, that probe the spatial and temporal structure of CMEs, shocks, and solar particle events at 1 AU.

Although utility to operational and commercial users is explicitly beyond the scope of this Review, we note that ACE's Real-Time Solar Wind (RTSW) data have proven valuable in forecasting geomagnetic storms and "killer" electrons in geostationary orbits.

Spacecraft/Instrument Status: The spacecraft is healthy, and the ACE team has been diligent and successful in reducing ongoing operating costs. Fuel usage for orbit-maintenance has been reduced so as to allow operations until 2022. Power output from the solar panels is expected to be adequate for normal operations until 2025.

The SEPICA instrument has failed, although the possibility of extracting some useful data is still under study; in the mean time, the SEPICA telemetry has been reallocated to SWICS and SWIMS. There has been modest degradation in the capabilities of SWEPAM, EPAM, and ULEIS. The other instruments (CRIS, SIS, SWICS, SWIMS, and MAG) continue to perform at nearly nominal design levels.

Data operations: Data services provided by the ACE Science Center (ASC) are outstanding in terms of ease of use and documentation. There are around 3000 hits per week on the ASC website. The ACE team continues to upgrade the range of data products available to the community at the ASC, and these efforts are greatly appreciated. Certain deficiencies, such as the lack of plasma distribution functions, were noted by the data-access evaluators.

E/PO: The ACE E/PO efforts are rated very good in terms of effectiveness and relevance to NASA objectives and fair in terms of cost. The proposed E/PO efforts are deemed acceptable for funding.

Proposal Weaknesses: None significant, although it was noted that the proposal provided no breakdown of the work tasks or budget justification for the individual instrument teams.

Overall Assessment and Findings: ACE provides the cornerstone for a broad range of SSSC scientific investigations, with some capabilities that are not duplicated by any other current or planned mission. Its continued operation is important for many SSSC objectives. Since ACE remains in the same L1 orbit as before, most of the science objectives focus on extending previous observations to solar-minimum conditions and coordinated studies with new missions, such as STEREO. The Panel finds that funding for the proposed continuation of the ACE mission is warranted.

2.2 Cluster

Science Strengths: Cluster is a four spacecraft constellation that over the proposed extended mission will facilitate the study of micro- and meso-scale dynamics of critical magneospheric phenomena including: the Earth's bow shock; the magnetopause and dayside reconnection; the dynamics of the tail current sheet; the auroral zone; and the plasmasphere and ring current. To facilitate these multiscale studies, three of the spacecraft are separated by 10,000 km in a triangular configuration with the fourth spacecraft perpendicular to this plane with a variable spacing down to 1000 km.

The mission will continue to explore the structure and dynamics of the bow shock and its role in producing energetic ions and electrons, which is a problem with fundamental scientific applications in space and astrophysics. The increased spacecraft separation of this extended mission will allow spacecraft to examine the macroscale structure of the shock, including the cross coupling of regions with quasi-parallel and quasi-perpendicular geometry. The changing characteristics with upstream distance will be measured providing information for assessing diffusive shock acceleration models.

Precession of the Cluster orbit will take the spacecraft near to the subsolar magnetopause, a region of critical importance in understanding magnetic reconnection and the flow of plasma from the magnetosheath into the magnetosphere. Critical questions will be addressed including the relative roles of component and anti-parallel magnetic reconnection and whether the reconnection is steady or bursty. The microscale structure of the current layers that define the electron dissipation region will be explored using a new operational mode of the EDI instrument. The role of turbulence as a mechanism for electron scattering and dissipation will be explored. Several of these issues will be investigated in conjunction with other spacecraft such as IMAGE and TWINS. Many of the reconnection issues have broad importance for wider applications in space and astrophysics, including the dynamics of the corona, the driver of space weather.

The Cluster orbit in the magnetotail will evolve so that measurements can be taken from 19 to 7 Earth radii down the tail. This changing orbit will allow Cluster to explore the critical near-Earth region where it has been suggested that turbulence can cause a disruption of the cross-tail current sheet as a precursor in substorm initiation. This information will facilitate the study of substorm onset as part of the THEMIS mission.

The Cluster orbit will also facilitate the exploration of the auroral zones in the range of 1-2 Earth radii. This is a critical region where magnetospheric currents flow into and out of the ionosphere and parallel electric fields produce intense electron beams and associated turbulence. These measurements will complement those of FAST at lower altitude. A critical goal of this study will be to quantify the flow of ionospheric oxygen into the magnetotail.

Relevance to SSSC Roadmap: The Cluster mission will address many of the goals laid out in the Roadmap. These include the physics of reconnection and specifically the mechanisms that facilitate the breaking of the frozen-in condition, the structure of shocks and their role in the production of energetic particles, and the initiation of substorms that play an important role in the injection of particles into the inner magnetosphere.

Value to SSSC Great Observatory: Because of its unique four-spacecraft configuration Cluster is a crucial element in the exploration of the physics of reconnection along with IMAGE, Polar, Geotail and THEMIS. It will also provide important information on the mesoscale structure of collisionless shocks and the associated production of energetic particles, supporting ACE, Wind and Voyager on this topic. Along with THEMIS, FAST, and Geotail, it will provide critical information on the dynamics of substorms. Combined with the full range of Great Observatory spacecraft from RHESSI, SOHO, STEREO to the magnetospheric satellites, Cluster will enable studies of the full cycle of space weather from the initiation of flares and coronal mass ejections to its impact on the magnetospheric environment and associated radiation hazards.

Spacecraft / Instrument health and status: Most of the instruments on Cluster continue to function normally. Some instruments on individual spacecraft are off-line. The central ion heads on RAPID are off-line on all spacecraft, but this does not impact omni-directional data comparison among the satellites.

Data operations: The Panel was disappointed to learn about the comparatively poor state of Cluster data availability. The data are mostly not available to the public. The web links for some data sets need work. The spacecraft should have a central clearinghouse for data from all instruments: data are generally available at separate instrument team sites, but the combined data set does not exist in a single location. Complications associated with organizing data from four spacecraft may preclude some public data availability, but there does not seem to be a coordinated effort to explain the data sets or make them available to outsiders.

E/PO: The proposal is compliant with the objectives of the NASA E/PO program.

Proposal Weaknesses: Cluster is a four spacecraft mission yet many of the studies that have come out of this mission have not fully taken advantage of the capabilities from the full constellation. The Cluster Guest Investigator theory program may help with the full utilization of all of the satellites by providing more complete information on the spatial structure of critical phenomena such as magnetic reconnection.

The Earth's bow shock is an important laboratory for the exploration of shock physics and associated particle acceleration. However, Cluster studies alone cannot provide a full picture of shock particle acceleration because the physical size of the bow shock is insufficient to produce the full range of energetic particles that are likely to be a hazard in the space environment. Cluster measurements should therefore be carefully compared with CME structure and particle acceleration from ACE and Voyager.

Overall Assessment and Findings: Cluster is a unique four satellite mission that is designed to explore the micro- and meso-scale dynamics of the Earth's magnetosphere, including the bow shock and associated energetic particles; the sub-solar magnetopause and reconnection; the magnetotail current layer and associated turbulence with respect to substorm onset; the auroral zone and oxygen outflows; and the ring current. All of these topics are identified as critical in the Roadmap and requiring physics input from other missions as part of the Great Observatory. The Panel is concerned about current impediments on the availability of Cluster data. The theory GI program is viewed as an important facilitator for taking advantage of the complex data sets produced by four satellites. The Panel supports continued funding for this key mission.

2.3 Fast Auroral SnapshoT (FAST) Small Explorer Mission

Science Strengths: FAST has proven to be a highly successful scientific mission for addressing microscale features in the dayside ionosphere that can have global consequences for space weather. FAST is a well-instrumented ionospheric satellite that was launched in 1996 into a low-altitude, highly-elliptical (350 km x 4175 km) 83^o orbit. Prior scientific contributions made by FAST include a quantification of the energy exchange between the magnetosphere and ionosphere and a confirmation that Alfven wave acceleration is a viable mechanism for powering the aurora. FAST also made observations of enhanced ion outflows resulting from ionospheric heating during substorms and from instability-driven ion acceleration within density depletion regions. The FAST satellite has contributed to at least 180 published papers and has served as the "backbone" for a recently published book on auroral plasma physics.

A unique feature of FAST is its location at the confluence of magnetic field lines that map to the outer boundaries of the Earth's magnetosphere and, at times, to other satellites comprising the SSSC Great Observatory. During the initial phase of FAST the supporting measurements available from these other assets were used to facilitate the scientific "return on investment" for the FAST mission. The next phase of the FAST extended mission offers an opportunity for FAST to reciprocate and contribute to the scientific goals of the SSSC Roadmap as a supporting spacecraft in coordinated observations within the Great Observatory. To this end, the scientific objectives of the extended FAST mission are to provide the global context for scientific investigations made by other partners. These include understanding the magnetospheric consequences of substorm-induced ion outflows, determining the open/closed nature of magnetic field lines within the dayside cusp and low-latitude boundary layer, and supporting studies of the radiation belt dynamics. The extended FAST mission will also provide, among other things, a continued opportunity for understanding the solar-cycle dependence of the auroral acceleration process and mass loading of the magnetosphere by ionospheric ion outflows. Thus, the next phase of the FAST is expected to yield significant scientific contributions consistent with the goals of the SSSC Roadmap and the "vision" of the Great Observatory.

Relevance to SSSC Roadmap: The FAST team has related the primary goals of their extended mission to the priority research focused areas that seek: (1) to understand the plasma processes that accelerate and transport particles and the role of plasma and neutral interactions in non-linear coupling of geospace regions and (2) to determine the changes in the near-Earth space environment to enable specification and prediction of their effects. The FAST extended mission is intimately tied to these focused areas through coordinated observational campaigns to address, in a global sense, the relationship between substorms and ionospheric outflows, to understand the magnetic field topologies of the cusp and low-latitude boundary layer, and to assess the radiation belt dynamics within the inner magnetosphere.

Value to SSSC Great Observatory: The distinct character of the FAST extended mission is its emphasis as a unique element in the SSSC Great Observatory. As was noted earlier, FAST is at the confluence of magnetic field lines within the high latitude ionosphere that map to the outer boundaries of the magnetosphere and the magnetopause. This geometry allows FAST to provide the global context for observations made by the other magnetospheric, ionospheric, and interplanetary components (ACE, Cluster, IMAGE, Polar, THEMIS, TIMED, Geotail and Wind) within the Observatory. The global emphasis inherent in the FAST extended mission is a clear shift in the approach taken by the mission team in that the highly successful earlier work was basically a FAST-centric approach whereas the extended mission objectives consider the Observatory as a whole.

Spacecraft/Instrument Status: The FAST satellite health and status are good. The only major failure suffered by the spacecraft was the loss of the DC electric field measurements early in the mission. These measurements would be useful in providing the global context for IMF-driven convection and for examining localized convective features in ionospheric signatures of magnetic reconnection. This instrument can still acquire scientifically useful higher frequency AC electric field measurements. While the loss of DC electric field data certainly cannot be lightly dismissed, the remaining instruments are fully operational and are providing data that are highly relevant to the extended mission for FAST

Data operations: Survey data from FAST are readily available and useful for providing an initial assessment for collaborations within the SSSC Great Observatory. However, the accessibility and usability of the higher fidelity data were found to be lacking. The Panel believes that the following will improve service to users of these data: Allow users to download all of the IDL software at once rather than just routine by routine. Repair the problems with the CDF routines (currently it is not possible to get summary data and the web pages for high rate data do not work). Allow users to order larger amounts of data (e.g. 1 month) rather than one orbit at a time. Put documentation on downloadable files (e.g. PDFs) not just web pages. Add software to convert the CDF files to ASCII files. Provide sufficient documentation that users without IDL can read the ASCII files. The calibration information in IDL should be available as stand-alone documents.

E/PO: The proposal is compliant with the objectives of the NASA E/PO program

Proposal Weaknesses: The primary objective of the FAST extended mission is to support the SSSC Great Observatory. A secondary objective is to complete observations of auroral acceleration processes and auroral ion outflows throughout a full solar cycle. However, the proposal did not offer sufficient new science to provide a compelling need for a long-term NASA investment outside the context of the Great Observatory.

Overall Assessment and Findings: The extended 2007-2010 program for the FAST mission is focused on its supporting role within the SSSC Great Observatory. The Panel acknowledges the fact that having FAST at the foot of the field lines magnetically connected to other assets within the Great Observatory provides a viable rationale for the extended FAST mission, 2007-2010. An important secondary objective for FAST during the extended mission phase is to examine the solar-cycle dependence of the auroral acceleration process and mass loading of the magnetosphere by ionospheric ion outflows. During the initial period of the 2007-2010 extended mission the FAST satellite will be in a position to examine and complete these solar-cycle dependencies. In recognition of this fact the FAST budget is fully funded in the years 2007-08, but zero-funded thereafter. The FAST team is highly encouraged to foster collaborations with other assets within the Great Observatory and to demonstrate to the next Senior Review Panel in 2008 the importance of their continued supporting role in the Great Observatory.

2.4 Geotail

Science Strengths: The equatorial 9 x 30 Re Geotail orbit provides valuable coverage in key regions of the near-Earth magnetosphere and solar wind. It will be especially useful to the THEMIS mission for addressing its primary science objectives of substorm onset location and tail reconnection. Because of substantial support from the Japanese Space Agency, Geotail offers a low-cost opportunity to add another equatorial satellite to the THEMIS constellation. This is particularly important in generating an in-situ capability to determine the longitudinal extent of tail phenomena enabling bursty-bulk flows, pseudo-onsets, and full substorm break-up to be distinguished. At other times during its 5.2 day period orbit, Geotail will offer near-Earth solar wind measurements giving accurate information on local driving solar wind characteristics in support of THEMIS. Multi-point solar wind inputs are of particular importance for accurately modeling the solar wind, and hence the subsequent magnetospheric response, in support of the THEMIS mission. Geotail can also at times provide the tailward boundary conditions necessary to support Cluster and THEMIS nearer-Earth tail studies.

The Geotail satellite carries an extensive suite of fields and particles instruments that provide a full view of the plasma environment in near-Earth space. These instruments have contributed, and continue to contribute, to the evolving understanding of magnetic reconnection and associated particle acceleration in the magnetosphere. The annual drift through 24 hours MLT of the magnetopause skimming orbits will provide an important capability for studying flank instabilities and low-latitude boundary layer plasma entry physics. The Geotail particle measurements, which include the capability for species resolution, offer an important capability for studying the dynamics of heavy ions. Coordination with IMAGE and FAST offers opportunities for studying the important and poorly understood physics of ionospheric ion outflow and its role as a heavy ion plasma source.

The Geotail PWI instrument also offers in-direct solar wind density monitoring during times when SEP events prevent inferences from data from the L1 satellites due to contamination, and the EPIC measurements will continue to be used to develop radiation models such as those being developed by Marshall Space Flight Center.

Relevance to SSSC Roadmap: Geotail will contribute to an improved understanding magnetic reconnection, particle acceleration and transport, and coupling of the solar wind to the magnetosphere -- three goals of the "Open Frontier" objective in NASA's Roadmap. Through the exploration of reconnection and substorm dynamics the Geotail observations are likely to a lesser extent to contribute to the goals concerning space weather effects on the magnetosphere. However, direct reference in the proposal to the specific SSSC Roadmap goals is lacking.

Value to SSSC Great Observatory: With the addition of THEMIS, the Great Observatory will enable studies of substorm onset and reconnection with unprecedented accuracy and resolution. These studies will utilize extensive measurements from throughout the SSSC Great Observatory: solar structure (SOHO, TRACE, RHESSI), resulting solar wind drivers at 1AU (Wind, ACE), magnetospheric response (THEMIS, Polar, Cluster, geosynchronous measurements), as well as the ionospheric response (IMAGE) and the driven auroral, magnetic and current response at low altitudes (FAST, as well as ground-based THEMIS and other optical and magnetometer networks). Geotail will also provide additional measurement for the accurate characterization of the upstream solar wind, critical for geospace studies within the Great Observatory. Monitoring from closer to the Earth than ACE and Wind at L1, as well as coverage during extreme events, also contributes to studies of the extremes of solar-terrestrial coupling during severe geomagnetic storms.

Geotail also offers capability for tail flow, magnetic field, and particle monitoring of the boundary conditions for nearer Earth missions. In combination with other magnetotail satellites such as Cluster and THEMIS, Geotail will contribute to important studies including: mid-tail merging microphysics; the tail response (plasmoid, dipolarisation and particle injection) to reconnection and sawtooth events; and non-adiabatic particle access to Cluster from the tail current sheet. Geotail also in general provides information on the tail processing of the upstream solar wind conditions which are ultimately passed to the nearer Earth magnetosphere.

Spacecraft/Instrument Status: The U.S.-provided CPI and EPIC instruments are operating normally and can be expected to do so for many more years. With the exception of HEP the Japanese instrument suite is providing comprehensive data which significantly enhances the return from the US Geotail instruments and their contributions to the SSSC Great Observatory and SSSC goals.

Data operations: Summary plots easily and rapidly accessible. Digital data from both US and Japanese instruments are extensively and readily available from CDAweb and Japanese DARTS system. There is concern at the slow appearance of high resolution CPI/HPA data on the Iowa CPI web site. For example, no moments data are available since Dec. 2004.

E/PO: The proposal is compliant with the objectives of the NASA E/PO program**.**

Proposal Weaknesses: After operation since July 1992, and in its current orbit since June 1997, Geotail has made significant and valuable contributions to space physics. While there is additional science which can driven by Geotail measurements alone in further extended mission, these are likely to be incremental. However, operation in conjunction with THEMIS offers a timely and important justification for its continuation. While the proposal outlined the science objectives for the continued extended mission operations of Geotail, the objectives were not well integrated with the goals of the SSSC Roadmap.

Overall Assessment and Findings: The Geotail satellite is a well-instrumented asset providing important and cost-effective additional probe measurements particularly in support of the THEMIS constellation. While Geotail driven science advances are likely to be incremental, its value to the wider Great Observatory especially in the THEMIS era (as well as continued radiation measurements), is significant. It is important that the team maintain availability of their data to the community. The panel found excellent continuing scientific value in the extended Geotail mission and its operation until 2008, particularly in partnership with THEMIS. The panel encourages the Geotail team to present their case for continued operation within the Great Observatory in 2009, 2010 and beyond at the next Senior Review.

2.5 Imager for Magnetopause-to-Auroral Global Exploration (IMAGE)

Science Strengths: The IMAGE spacecraft has provided the scientific community with an unprecedented global view of the magnetosphere. It has led to several major advances in our understanding of the physical mechanisms responsible for the dynamical behavior and transport of plasmas during storms and substorms. ENA images have given us important insights into the physics of the inner magnetosphere, EUV images have shed ‘light’ on the complex and dynamic structure of the plasmasphere and FUV images have provided similar insight on the aurora and its relationship to magnetospheric phenomena. IMAGE measurements have lead to significant discoveries of the important processes governing inner magnetospheric electric fields and their effects on plasmaspheric and ring current dynamics. By revealing gaps in current models, IMAGE has led to significant advances in the ability to model the coupled Magnetosphere-Ionosphere-Thermosphere system. A noteworthy advance is the discovery of sub-corotation in the plasmasphere by ~10-15%, believed to be due to ionosphere-thermosphere (IT) coupling. Future work offers the opportunity for an improved understanding of these important magnetosphere-ionosphere-atmosphere coupling processes and the development of more accurate models.

The extended mission for the IMAGE team is to continue support through the ascending phase of the solar cycle. They seek to quantify and understand many of the initial discoveries of the IMAGE mission including the important physics of reconnection in a global context, the formation and structure of the ring current and its interaction with the plasmasphere, and the dynamics of the plasmasphere interaction with the ionosphere. This will allow the scientific return from IMAGE to move from hypothesis testing to detailed understanding, improved model development, and practical application.

Relevance to SSSC Roadmap: IMAGE provides unique global context for various reconnection processes that occur in geospace. Auroral images can provide a window on dayside reconnection processes. Ring current formation can be strongly influenced by reconnection in the tail, especially during storms and substorms. IMAGE has and will continue to play a pivotal role in our understanding of the global consequences of reconnection in the tail and at the magnetopause. In addition, IMAGE provides global views of the processes important for acceleration and transport of particles in the inner magnetosphere as well as insights on the interaction between the cold plasmasphere and the ring current and its impact on radiation belt dynamics. Under storm conditions, the ionosphere is believed to a major source of magnetospheric plasma. There is potential with the LENA instrument to investigate the effects of ionospheric plasma sources.

Value to SSSC Great Observatory: IMAGE continues to provide a unique global view of cold plasma dynamics in the magnetosphere. Cold plasma is difficult to measure in-situ, and global measurements cannot be made by other techniques. Given the important role of cold plasma to processes such as reconnection, as well as wave-particle interactions in the ring current and radiation belts, this is key to the Great Observatory analysis of the processing of solar drivers in near-Earth space and energy transport to the ionosphere and atmosphere. Unique global ring current imaging is also possible with HENA and MENA. Comparative planetology studies with Jupiter images provide an important contribution to the Great Observatory. Until the successful launch of TWINS, IMAGE will be the only spacecraft that can provide global magnetospheric imaging necessary in conjunction with the other SSSC magnetospheric missions, for providing global context of the structure and dynamics of the inner magnetosphere. In addition, IMAGE will provide quantitative calibration for the IBEX mission along with the capability for stereo imaging on conjunction with the upcoming TWINS-1 mission.

Spacecraft/Instrument Status: Apart from some minor issues, most notable of which is the uncertain state of one of the power supplies, the spacecraft continues to function well. Most of the instruments continue to perform nominally. While the RPI instrument has suffered the loss of one transmitter and the loss of part of one antenna, it continues to return scientifically useful data. A problem with one of the position sensor preamplifiers on the LENA instrument was circumvented with a software workaround.

Data operations: The IMAGE team has done a first class job in making their data available to the community.

E/PO: The proposal is compliant with the objectives of the NASA E/PO program**.**

Proposal Weaknesses: The LENA instrument, while the most expensive and arguably the most technically difficult instrument, appears to be the least productive scientifically. Even though the number of LENA related papers is listed as 10 in 2005, suggesting a significant increase in scientific output from LENA, the proposal did not explain in detail what specific scientific advances related to geospace have and will be made with this instrument. A minor issue is that some of the smaller elements of the proposed investigations, such as the proposed development of an empirical model of the inner magnetospheric electric field, are incremental efforts that promise only modest advancements.

Overall Assessment and Findings: The IMAGE spacecraft has and will continue to provide the scientific community with an unprecedented global view of the magnetosphere. The spacecraft has facilitated an improved understanding across a broad of a range of important physical processes, and the proposal defines a clear route to scientific understanding and application in the rising phase of the solar cycle. The IMAGE spacecraft continues to be an important component of the SSSC constellation. It has made some significant advances and the planned scientific objectives as outlined in the proposal promise to yield closure on many open questions. Quantitative modeling should continue to be a crucial component of the IMAGE mission.

2.6 Polar

Science Strengths: Polar continues to yield numerous valuable scientific results, including insights on the dynamics of the radiation belts, the physics of reconnection, magnetosphere-ionosphere coupling, auroral phenomena, storms and substorms. The Polar team is requesting a 1 year extension for the mission to make coordinated measurements with other geospace missions and to address new fundamental science topics focusing on the radiation belts, auroral acceleration and reconnection. The orbital coverage during the proposed mission extension will be particularly valuable for the proposed work on radiation belt acceleration and loss processes in the heart of the outer radiation belt. The Polar CEPPAD instrument offers the only magnetospheric capability outside geosynchronous and low-Earth orbit for monitoring 2-10 MeV electrons, and Polar also has unique capabilities for making 3-axis electric field measurements. Of great significance is the combination of equatorial and off-equatorial coverage which will be provided by the Polar extended mission in this critical radiation belt region. The competing ULF and VLF wave acceleration theories act preferentially in the equatorial and off-equatorial regions, and wave and pitch angle distribution measurements will allow these competing processes to be distinguished. The off-equatorial coverage and measurement suite required to investigate the VLF wave acceleration is unique to Polar in this orbit. This will not be provided by any suitable instrumented missions in the near feature, including the LWS Radiation Belt Storm probes.

The Polar orbit also allows studies of wave particle interactions with the EMIC waves believed to be important for radiation belt loss. Orbital conjunctions of higher latitude orbital passes of Polar with supporting measurements from IMAGE, CLUSTER, Double Star, DMSP and the upcoming THEMIS mission will generate valuable multi-point data sets for addressing SSSC science goals. This includes a reallocation of spacecraft telemetry (science mode 2) which allows higher resolution electric and magnetic field measurements of microphysical processes in the diffusion region. Other conjunctive Polar studies, using correlative measurements with FAST and the THEMIS mission, could provide new insights in the auroral electron acceleration region at locations between those previously measured at higher and lower altitudes by Polar /Cluster and FAST, respectively, in earlier orbital phases. Finally, conjunctions with FAST will enable studies of the poorly understood ion outflow processes.

Relevance to SSSC Roadmap: The combination by Polar of equatorial and off-equatorial coverage in the inner part of the outer radiation belt enabled during the proposed extended mission phase will contribute directly and importantly to the Roadmap goal of understanding particle acceleration processes. Measurements of MeV electrons by Polar are also important for objectives related for Earth orbit staging for both human and robotic exploration. Utilizing conjunctions with Cluster and IMAGE and enabling science mode 2, the Polar team will investigate macro and micro physical processes that control reconnection on the high latitude dayside magnetopause, addressing the reconnection-related Roadmap objective. Studies of the auroral acceleration process utilizing conjunctions with high altitude satellites such as Cluster and THEMIS, low Earth orbiting satellites such as FAST, DMSP and TIMED, and ground-based observations will further contribute to this objective. Studies of auroral acceleration, magnetosphere ionosphere coupling and ion outflow will also contribute to several objectives outlined in the Roadmap.

Value to SSSC Great Observatory: During its limited useful future lifetime (October 2006 to March 2007) after the fuel on the spacecraft will have been used, Polar is capable of providing valuable measurements that complement those obtained by other magnetospheric missions (Cluster, FAST, Geotail, Image, and potentially THEMIS depending on when it is launched). The combined data can address new fundamental science topics focusing on the radiation belts, auroral acceleration and reconnection. The Polar CEPPAD instrument offers the only magnetospheric capability outside geosynchronous and low-Earth orbit for monitoring 2-10 MeV electrons and Polar has unique capabilities for making 3-axis electric field measurements. Of great significance to radiation belt studies is the combination of equatorial and off-equatorial coverage provided by Polar's orbit during the last months of its projected lifetime.

Spacecraft/Instrument Status: Nine of the eleven science instruments remain operational; the Plasma wave instrument has had power supply problems since 1997 and is operating infrequently, PIXIE failed in 2002 and the MICs sensor in CAMMICE and the SEPS sensor are not operational. All fuel on the spacecraft will have been used as of October 2006 – it will remain at an operational sun angle for the remainder of its mission until around March 2007 in order to complete the studies proposed. The team is confident that Polar will continue to operate and return data in this mode. This includes some potentially useful engineering data on the remaining inert gas.

Data operations: Despite being an "old" mission, data availability was somewhat ahead of its time so it remains easy to gain access to and analyze data from a wide range of instrument types.

E/PO: The proposal is compliant with the objectives of the NASA E/PO program**.**

Proposal Weaknesses: The major concern among the Panel members was the relatively high expense of the 1 year extension.

Overall assessment and findings: Polar is the only NASA related mission with the particle instrumentation necessary for radiation belt measurements, and its 3-D electric field measurement capability is unique. The proposed radiation belt investigations will utilize an orbital opportunity with a well-instrumented satellite that will not likely be available for quite some time. The off-equatorial measurements in particular will be critical for discriminating between proposed radiation belt acceleration processes, and will not be available from any other future mission including the LWS RBSP. This relates to the important fundamental process of particle acceleration as specified in the SSSC Roadmap and is the most timely and relevant scientific objective. If full funding for the proposed Polar extended mission cannot be found within the MO&DA budget, consideration could be given to reconfiguring the spacecraft by turning off all instruments which are not essential for the radiation belt objectives in order to exploit the unique opportunity for new radiation belt science at low cost.

2.7 Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)

Science Strengths: RHESSI is designed to measure energy releases in flares and other solar energetic events by imaging spectroscopy of hard x-rays generated by energetic electrons and gamma-ray continua and lines generated by energetic electrons and ions. This instrument acquires spatially and spectrally resolved measurements spanning energies from 3 keV (soft x-rays) to 17 MeV (gamma-rays). The x-ray and gamma-ray emission processes are quantitatively well understood and help make RHESSI a powerful tool for probing physics of solar energetic phenomena and for complementing synergistically other existing solar-terrestrial missions (e.g. SOHO, TRACE, ACE, Wind, GOES-N) and new missions (e.g. Solar-B, STEREO, GLAST, SDO) to be launched in the next few years.

RHESSI has an excellent record of making discoveries in solar-terrestrial physics (from gamma-ray imaging and spectroscopic measurements of flares to pioneering measurements of solar radius and solar oblateness at the milliarcsec level). It also observes terrestrial phenomena (*e.g.,* measurements of terrestrial gamma-ray flashes) and provides measurements of astrophysical phenomena (*e.g.,* gamma ray bursts, including measurements of the brightest cosmic gamma-ray burst ever detected showing hot [kT~175 keV] black-body spectrum from a magnetar -- a neutron star with the exceptionally strong magnetic fields). The increased sensitivity enabled by the lower background near solar minimum may yield improved data on microflares. The greater isolation (in time and space) of energetic phenomena near solar minimum may aid a better understanding of the causes and evolution of these phenomena. RHESSI has a solid publication record and the PI has been recognized by the scientific community by the award of the Hale prize.

Relevance to SSSC Roadmap: RHESSI is highly relevant to all three SSSC 2005 Roadmap goals (Open the Frontier to Space Environment, Understanding Our Home in Space, Safeguard the Journey of Exploration). It uniquely and directly targets two important questions relevant to these goals, magnetic reconnection and particle acceleration. RHESSI's data are currently playing, and will continue playing, a vital role in improving our understanding of mechanisms involved in solar energetic phenomena such as flares and coronal mass ejections. The photon emissions from flares and accelerated particles from flares and coronal mass ejections can affect the environments of the Earth, Moon, Mars and interplanetary space.

Value to SSSC Great Observatory: RHESSI provides unique, important, spatially- and spectrally-resolved measurements of high energy emissions from hot solar plasmas and solar energetic phenomena that complement synergistically measurements made by other missions making up the SSSC Great Observatory. Of particular relevance is the combination of RHESSI, SOHO and TRACE in the current complement of missions which are to be augmented by STEREO and Solar-B in the next year and SDO in three years. RHESSI is at its best when complemented by other missions that provide context for its high energy observations (*e.g.,* measurements of solar magnetic fields, solar structures and phenomena observed in other wavelengths, and solar energetic particles measured in interplanetary space).

Spacecraft/Instrument Status: The overall health of the spacecraft is good with all systems being stable. The early problem of a gradual increase in spectrometer temperature has been solved by a release of accumulated condensates into space. The detectors have not degraded to the point of requiring annealing, although several generations of annealing are possible downstream. Annealing has worked well in other spacecraft, and will be done when required by the science.

Data operations: The data service is excellent. At the time of the last Senior Review, shortly after the 2002 launch, the software had some problems, but it is now mature. The proposal notes that RHESSI data could be made even better by optimizing the spectral and spatial inversion techniques to maximize the utility and precision of the data. The primary operations facility is at SSL in Berkeley and is fully operational.

E/PO: The proposal is compliant with the objectives of the NASA E/PO program**.**

Proposal Weaknesses: The only weakness in the proposal is that the list of achievements was confined primarily to the RHESSI team.

Overall Assessment and Findings: RHESSI is a scientifically powerful mission that can provide valuable measurements through solar minimum into the next solar maximum. RHESSI is an important participant in the SSSC Great Observatory and is most scientifically productive when operating in concert with both current missions and new missions to be launched in the next few years. There are no other high-energy solar missions on the horizon. Therefore, the Panel endorses the proposed continuation of the RHESSI mission.

2.8 Solar and Heliospheric Observatory (SOHO)

Science Strengths: SOHO provides extensive measurements of (1) of the solar interior and atmosphere using a suite of instruments operating at visible, UV and XUV wavelengths, (2) solar wind and energetic particles *in situ*, and (3) optical measurements of the heliosphere. Measurements extend from near the last solar minimum through solar maximum, into the declining phase of the current solar cycle with the potential of continuing into the next solar maximum. The breadth of the scientific accomplishments of SOHO is breathtaking and is extensive and well reflected in the 200-300 annual publications in refereed journals using SOHO data.

In the further extension of the mission, local helioseismology from MDI is likely to reveal new information about solar cycle variations in solar interior dynamics and magnetism, i.e., meridional flows (with impacts on dynamo predictions) and tachocline fluctuations. Studies of the origin of activity with SOHO will be enhanced by and will enhance the capabilities of Solar-B and STEREO. Of particular interest is what happens beneath the surface before, during and after Coronal Mass Ejections (CME's) and flares.

SOHO/LASCO provides the only space-borne (far more capable than ground-based instrumentation) coronagraphic observations until the STEREO launch and thereafter it will provide a third space-based coronagraph uniquely on the Earth-Sun line. Further, SOHO will serve (in combination with Wind) as backup to STEREO (*e.g.* redundancy in case of failures on the STEREO spacecraft). SOHO/EIT and LASCO provide a complement/redundancy to GOES data in space weather studies, and will be more powerful with the advent of Solar-B with its high resolution vector magnetic field measurements.

SOHO provides critical Total Solar Irradiance (TSI) measurements extending back to 1996 and complementing the measurements from SORCE and ACRIM. Having long term and redundant measurements of TSI is vital to having a robust, photometrically reliable record of this parameter that is important to understanding global climate change and the solar cycle.

The MDI line-of-sight magnetograms (90 min cadence with 4 arc second resolution) will continue to be a baseline in space weather forecasting. The atmospheric dynamics of solar flares and CME's have been uniquely elucidated by the images from the LASCO coronagraph and coronal spectral scans from UVCS, and, coupled with full-disk images in the EUV from EIT, have provided a powerful array to profoundly probe a number of phenomena from active region loops, bright points, blinkers, but most importantly studies of the origins of flares and CME's and their propagation from the Sun.

Relevance to SSSC Roadmap: SOHO is highly relevant to all three Roadmap broad objectives. More than any other spacecraft, instruments like MDI, UVCS, and LASCO onboard SOHO provide data that enable us to understand how solar activity and space weather are generated and reach the vicinity of the Earth. Thus, SOHO has a vital role in the Roadmap objective "Open the Frontier to Space Environment Predictions" by providing a broad spectrum of data advancing our understanding of flares, CME's, particle acceleration and even the solar dynamo itself. SOHO has a vital role in the Roadmap objective "Understanding Our Home in Space" because of its fundamental role in understanding solar variability/activity and its causes. SOHO has a vital role in in the Roadmap objective "Safeguard the Journey of Exploration" by determining the fundamental origin of space weather from beneath the surface of the Sun. SOHO instruments also provide data on the origin and propagation of space weather.

Value to SSSC Great Observatory: SOHO is an integral part of the SSSC Great Observatory because of its extensive capabilities for imaging and studying the physics of both the solar atmosphere and the solar interior. It measures solar magnetic fields and their evolution, images the inner and outer corona, makes spectroscopic measurements of the chromosphere and corona, probes the solar interior, and measures the total solar irradiance. It is a vital monitor for solar activity, particularly CME's. Its power is enhanced significantly by complementary measurements made by RHESSI and TRACE, and future measurements by SOLAR-B and STEREO. SOHO, in combination with Wind and ACE, will provide a third vantage point that will strengthen the science results from the Great Observatory after launch of STEREO and will provide a backup if one of the STEREO spacecraft fails.

Spacecraft/Instrument Status: Overall the instruments on-board SOHO are in good condition and the spacecraft seems stable even though it has been operating in a gyro-less mode since 1999. All 12 instruments are still functioning, although the LASCO C1 coronagraph did not survive the 1998 event (C2 and C3 are nominal). The UVCS Lyman-alpha detector is off most of time since 1998. One of the detectors on SUMER functions with reduced resolution, and the instrument has lost its independent pointing capability, but it can scan slowly using solar rotation.

Data operations: The data archiving is mature and the data are readily accessible. Team members are willing and able to work with outside requests that push the envelope of the data. This ensures quality control where it probably matters most. Some of the key SOHO data reduction programs can be adapted to SDO.

Extending SOHO costs about twice as much as other missions in this Senior Review. Two major parts of this cost are mission operations motivated by the 1998 loss of SOHO and nearly continuous telemetry requirements for the rich SOHO data.

E/PO: The SOHO team has been extremely effective in getting its message to the public through CNN and many local newspapers. The impressive, diversified E/PO efforts from Stanford, SAO and NASA Goddard have been effective. Amateur comet-hunting fosters wide community interest and participation.

Overall Assessment and Findings: SOHO is an integral part of the SSSC Great Observatory in the study of the solar system and can provide unique, vital data in its extended mode until SDO is flying and has been calibrated against SOHO. This cross-calibration is important for optimal and prompt science from the HMI instrument on-board SDO.

Extending SOHO would have excellent scientific return, because it is capable of continuing to provide important measurements into the next solar maximum. The proposed plan on how to simplify operations and scale back on the number of instruments appears reasonable in view of the limited available funding. Putting the savings into the Guest Investigator program is good way to maximize science per dollar of MO&DA funds.

There will be no white light coronagraph on SDO, so operating SOHO's LASCO instrument alone after the calibration period between SDO and SOHO is warranted. This vastly scaled-down SOHO mission (the so-called "Bogart" option) would give Earth-Sun line coronal images to complement those upwards of 90 degrees from the twin STEREO spacecraft. Because of the relatively high cost of SOHO before starting the Bogart option in FY10, there is merit in developing a plan for a more efficient, leaner transition to the period of cross-calibration with SDO and the start of the Bogart mission. This would enable lowering the costs in FY07-FY09. A closer look at the SOHO planning function is merited. In the event of an extended delay in the launch of SDO, SOHO might look to a modified Bogart mission that also includes MDI until HMI on-board SDO is calibrated against MDI, since the inter-calibration between MDI and HMI is highly desirable so as to produce a reliable long-term baseline of nearly continuous observations.

2.9 Thermosphere-Ionosphere-Mesosphere Energetics & Dynamics (TIMED)

Science Strengths: The Ionosphere/Thermosphere/Mesosphere (ITM) system brackets the region where the geomagnetic forcing penetrates to its greatest depth in the Earth's atmosphere, radiative forcing is significant and hydrodynamic influences (over a broad range of timescales - minutes to the solar cycle) propagating from below dissipate. This region responds non-linearly to this set of drivers and exhibits strong variability. The ITM is not well understood. A significant component of the science being undertaken by TIMED is exploratory. During the first 4 years of the mission, a number of features associated with the manner that the Earth's ionosphere/atmosphere responds to the various drivers have been identified for the first time (enhancements in NO and its role in the energy budget, significant composition changes and correlated changes in the character of the ionosphere, correlations between energetic particle precipitation and NO_x enhancements in the stratosphere, the characterization of planetary waves and tides, and plasma bubbles and ion/energetic neutral aurora in the low/mid latitude regions). New phenomena are being discovered, their spatial and temporal structure investigated and the physical mechanisms for known phenomena are being identified.

The next 4 years, during solar minimum provide a special opportunity for these investigations. The simultaneous occurrence of multiple drivers during this time period will be at a minimum and the responses to an individual driver can be tracked and the effects measured. Solar minimum also provides the best opportunity to characterize what might be called the "ground state" of this region of the atmosphere - its character in the absence of significant perturbations. These observations provide a counterbalance to the observation set recorded during the first four years at solar maximum when the simultaneous occurrence of multiple drivers was the rule rather than the exception.

Given the dynamical richness of wave phenomena and non-linear coupling between motions of various time-scales in the neutral atmosphere, long time series of global observations are needed to resolve the interactions in the ITM region. TIMED observations through solar minimum will provide a valuable baseline for this study and a foundation for future missions. Linkages with other satellite missions (FAST, IMAGE, DMSP, CLUSTER for ionosphere/magnetosphere investigations; RHESSI, SOHO, SDO, ACE, for solar irradiance/solar wind ITM investigations and AURA, AIM, CHAMP and ground based observations for lower atmosphere/ITM studies) have been identified and will increase in importance during the extended mission.

Relevance to SSSC Roadmap: This mission contributes to all three major objectives in the SSSC Roadmap. "Understand the Nature of our Home in Space", is the objective to which TIMED makes the most significant contribution. Within the current mission set TIMED measurements are the only ones addressing the ionosphere/upper atmosphere changes identified in this objective. It is unique in identifying solar variability issues on the Earth and exploring the associated mechanisms. It also makes valuable contributions to the objective, "Open the Frontier to Space Environment Prediction", as it is the only mission that examines in detail the plasma/neutral interactions in a planetary atmosphere and the resulting atmospheric response, and ionosphere/thermosphere interactions and their role in the terrestrial dynamo. As the Earth atmosphere has similarities to that of Mars, the studies undertaken on the Earth's atmosphere by TIMED are also relevant to the objective, "Safeguard the Journey of Exploration" (currently these studies are not possible for the Martian atmosphere). Observations of the dynamics of the Earth's atmosphere are relevant to aerobreaking and aerocapture, ionospheric effects on communication, and chemical changes on Mars.

Value to SSSC Great Observatory: The TIMED mission is crucial to the goals of the Great Observatory. Currently it provides the only means for phenomena from the Earth's lower atmosphere to be linked to the ITM region and solar forcing. It is uniquely situated for examining the mechanisms and processes comprising the response of the ITM region to external influences. Observations from this mission show the resulting phenomena to be more complex than initially expected. Moreover the response is variable and depends on the state of the neutral atmosphere at the time of the external forcing. Because of this complexity, the mission remains exploratory in nature.

Spacecraft/Instrument Status: The spacecraft remains healthy. Problems associated with the spacecraft's Inertial Reference Units (IRU) noted in the last review are being dealt with in a manner which has little impact on spacecraft operations. The standard operating mode is star-tracker-mode in which the IRU are turned off and attitude calculations are performed with the star trackers. Apart from periods when the moon enters the field of view (roughly 1% of the time), this new mode is proving satisfactory.

The instruments status has not changed since the last review. The GUVI and SABER instruments are performing nominally. SEE is performing nominally apart from some of the XUV Photometer System (XPS) photometers. This issue, identified prior to the last Senior Review, has been looked after by including similar measurements from the SORCE XPS. The TIDI instrument is functioning well and issues related to the light leak have been dealt with through data analysis work-arounds. The observations from this instrument are now being used for scientific studies.

Data operations: The data operations are satisfactory in general. Scientific access to the data is good since the data and information on the formatting and calibration are available from the mission web site and associated links. The reporting of instrument validation activities for SABER and GUVI was missing although calibration and testing were mentioned. TIDE and SEE both cover validations issues well.

E/PO: The TIMED program is a good program, but with a few specific weaknesses. There is a lack of specific goals and assessment of the target audience, a detailed programmatic evaluation plan is missing, and there is insufficient detail on how the program addresses and positively impacts pipeline (of personnel) and diversity issues.

Proposal Weaknesses: Although this proposal presented valid general extended mission scientific goals, direct linkage between these goals and specific measurements were not identified. Collaborative efforts between instruments for enhanced science were not described in suitable detail. Budget items were not clearly linked to mission functions making the evaluation of the role and importance of particular line items difficult. There is significant potential for linkages and collaborations with other missions. A few such linkages are mentioned in the proposal, but their form and the scientific benefits were not clearly outlined. Their establishment and exploitation are important for the success of the

Great Observatory concept. TIMED provides the "Earth-centered" impact of solar influences which is a significant component of this concept.

Overall Assessment and Findings: This is a vital mission with significant ongoing scientific investigations. It is the only mission which investigates the processes and mechanisms through which the terrestrial atmosphere "accommodates" the external energy and momentum inputs and tracks the evolution of the atmosphere, its response and its feedbacks to the ionosphere. On its own, it has been and will provide significant scientific insights into the behavior of the ITM region of the atmosphere. It constitutes the terrestrial anchor for the SSSC Great Observatory.

The Panel believes that an important emphasis for this mission over the next few years will be developing and providing suitable data products to the user community. This will ensure that scientists proposing to the Guest Investigator Program have confidence in and access to the TIMED data. The longer term heritage of this mission will be its data archive and effort to establish this should be under way.

Funding at the baseline level with some additional funding (if available) for SABER in the first two years as identified in the optimal budget to assist in the development of their data products has merit. The Panel believes that phasing out the IDS role and increasing the emphasis on the Guest Investigator program also has merit.

2.10 Transition-Region And Coronal Explorer (TRACE)

Science Strengths: Over the next three years, new science advances based principally upon TRACE data will touch upon coronal seismology and dynamical magnetic field evolution, topological complexity and reconnection. The high time cadence ($\Delta t \sim 10$ s), excellent spatial resolution ($\Delta x \sim 800$ km), and diverse range of spectral bandpass (for $10^{3.6}$—$10^{6.2}$ K) capabilities of the instrument make it optimal for detecting Alfvén waves on coronal loops and capturing the energetics of vertically-propagating acoustic waves. By the same token, TRACE is well-suited to document the behavior of the underlying drivers of eruptive phenomena, including magnetic field emergence, reorganization and destabilization.

Structures observed in the TRACE movies serve as the best current proxy for the Sun's chromospheric and coronal magnetic fields. As such, they are effectively combined with force-free magnetic field extrapolations to estimate stored magnetic free energy and quantify the magnetic helicity. Together with sequences of morphological changes, this information will provide a useful tool for predicting and forecasting solar activity and space weather events until the STEREO, Solar-B, and SDO missions are operational.

Value to SSSC Great Observatory: The TRACE mission operations and instrument capabilities lend themselves naturally to frequent and effective coordinated campaigns and supporting contextual roles with the many other satellites of the SSSC Great Observatory. TRACE can provide unique rapid imaging of solar activity and dynamics on both large and small scales from now until launch of SDO. TRACE provides high spatial resolution coronal context for high energy measurements of solar activity by RHESSI and will complement the vector magnetic field, EUV and soft x-ray measurements to be made by Solar-B. TRACE is frequently employed in joint observing programs with SOHO. It will provide a high resolution view of the Sun along the Earth-Sun line to complement imaging by the STEREO spacecraft. TRACE, in combination with SOHO and RHESSI now, and, in addition, Solar-B and STEREO in the future, provides a solar context for Sun-Earth system investigations. An overlap of TRACE operations with the AIA instrument on-board the SDO would be very helpful in validating the existence and nature of faint and ephemeral features (i.e., loop voids) and ensuring a continuity of high resolution EUV imaging capabilities. However, concurrent operations are not required for the successful calibration and deployment of the AIA.

Data operations: The open data policy and the prompt (often within 24 h) availability of all TRACE data are underlying factors that have ensured the wide reliance and high utilization of its capabilities by the solar, heliospheric, magnetospheric and aeronomy communities. "Helpful", "cooperative" and "prompt" are the descriptive terms most often associated with TRACE data archiving, quality control, and accessibility. High-level full disk composite images are routinely available. The "SolarSoft" suite of IDL-based data handling and the display routines eliminate the unnecessary startup overhead that discourages use and hinders productivity. One consequence of this agreeable situation is the extensive scientific research that is carried out by individuals who are not directly connected with the LMSAL, SAO or MSU teams.

Spacecraft/Instrument Status: The spacecraft and on-board instrumentation remain in excellent working condition. Periodic annealings of the lumogen coating on the CCD have significantly reduced the number of 'hot pixels' and have returned the response and sensitivity of the detector back to circa 2001 levels. Steady orbital decay is responsible for the increasing duration of the spacecraft eclipse periods, and eventually, it will lead to the existence of a secondary eclipse season. However, the impact on the batteries and power supply does not become an issue for concern until late 2008, when all orbits will suffer eclipses of varying duration.

Relevance to SSSC Roadmap: The TRACE mission admirably supports many of the articulated goals of the recent SSSC Roadmap. Detailed observations of the temporal evolution of solar magnetic fields, their reconnection and the resulting eruptive processes, allows us to better understand the fundamental physical processes of the space environment from the Sun to the Earth. An essential component of these observations is the characterization of the Sun's magnetic field topology and the refinement of limits on the temporal and spatial scales of magnetic reconnection. This contextual description of the solar atmosphere is a key ingredient in any attempt to trace detected energetic particle populations back through interplanetary space to their coronal source regions. At the same time, it affords the opportunity to identify and detect precursors of solar disturbances and to monitor the early stages of the initiation and evolution of solar storms. Finally, it should be emphasized that the evolution of coronal magnetic fields continually recorded by TRACE over the year to decade time scales places new constraints theories for the operation of the solar dynamo, the nature of magnetic flux emergence, and the long-term trends in solar variability.

E/PO: The Panel notes that the E/PO section of the TRACE proposal does not do adequate justice to the unique and extensive set of ongoing activities supported and developed by this effort. TRACE images and science products have been featured in a variety of media, from exhibition materials at planetaria and regional science museums, to television programs and educational documentaries. The extensive distribution of posters and calendars (over 13,000 copies) has contributed to the public's de facto association of TRACE images and movie sequences with solar physics research. An exhibition of TRACE images has toured the country, stopping, for example, in the halls of the National Academy of Sciences in Washington. Individual TRACE images are on permanent display at the National Science Foundation, the Boston Science Museum and the Museum of the Rockies. In addition to these activities, the TRACE centers routinely host summer visits and support internships for high school and college students and make numerous visits to classrooms and student workshops.

Overall Assessment and Findings: TRACE serves as a key element of the SSSC Great Observatory through its rapid imaging of solar activity and dynamics on both large and small scales. In combination with SOHO and/or RHESSI, the TRACE mission provides a solar context for Sun-Earth system investigations. The imaging data are readily available, easy to work with, and are visually exquisite. An overlap of TRACE operations with the AIA instrument on-board the SDO would be useful for validating the existence of some faint features observed by TRACE and ensuring continuity of high resolution EUV imaging capabilities.

2.11 Ulysses

Science Strengths: Ulysses is a unique asset for studying the 3-Dimensional structure of the heliosphere – energetic particles, radio waves, neutral particles, dust and plasma and magnetic field. Its orbit has aphelion at about 5 AU and perihelion at about 1.34 AU, with an orbital period of 6.2 yr. Its orbit carries it to +/- 80 degrees latitude at about 1 AU. No other spacecraft has gone to such high heliographic latitudes. Hence Ulysses is an exploratory mission which has and will continue to help understand the physics of the upper solar atmosphere and solar wind as a function of heliographic latitude.

Observations over the next 3 years will be in a phase of the solar magnetic cycle which has not been observed before, and will essentially complete Ulysses observations of 22-year solar magnetic cycle effects. These observations are absolutely fundamental to our understanding of cosmic-ray time and space variations which depend on the sign of the magnetic field and latitude. Also, the unexpected observed latitudinal asymmetry may vary with the sign of the magnetic field. (Strictly speaking, 22 years after Ulysses launch would be in 2014, but the period during sunspot maximum does not exhibit a north-south magnetic-field asymmetry, so observations during the next sunspot maximum do not appear to be critical). In addition, 22-year solar cycle effects on cosmic rays, clarified by observed latitudinal effects on Ulysses will impact our understanding of proxy records of climate history.

The study of solar minimum during the period of time when the northern magnetic field is negative has not yet been done, yet this is the period when the structure is cleanest and most-easily interpreted. 22-year solar magnetic effects have important consequences for cosmic rays, the understanding of which will aid in understanding long-term climate effects as revealed in proxy records such as ice cores. Hence continuation through the coming solar minimum is critical. Study of the latitude variation is fundamental to the study of the physics of solar wind and energetic particle acceleration in the solar corona. Ulysses will provide a multipoint perspective of the heliosphere, in conjunction with the STEREO mission**.**

An issue of considerable current importance is the latitudinal transport of energetic particles. The magnitude of this cross-field transport has traditionally taken as being small, but some Ulysses observations suggest that this may be much larger than previously thought.

Ulysses provides essential and unique boundary conditions for many processes observed in the rest of the heliosphere, including cosmic rays, anomalous cosmic rays, basic transport processes, interstellar neutrals, etc. Knowledge of the latitudinal structure of the heliosphere and its behavior over the 22-year solar magnetic cycle are essential inputs into the structure of the heliosphere and its interaction with the interstellar medium.

In addition, Ulysses can reveal new aspects of basic plasma physics because the high-latitude solar wind is different from that in the equator. Hence, for example, particle acceleration and transport, magnetic reconnection, and CME evolution can be studied. The morphology and dynamics of interstellar dust and neutral particles can be studied. Ulysses will provide out-of-ecliptic observations to complement new in-ecliptic missions. The vitality of the science is exemplified by the large number of recent publications cited in the reference list.

Ulysses also contributes crucial measurements of gamma ray bursts from astronomical sources for high energy astrophysics research.

Relevance to SSSC Roadmap: Ulysses contributes to the three broad objectives of the Roadmap. Because of its traversal of heliographic latitudes over the range from the equator to both poles, Ulysses provides basic and unique input into the study of the fundamental physical processes in the space environment. This includes in particular the acceleration of the solar wind and the transport and acceleration of energetic particles.

Understanding the physics of the heliosphere in the third dimension is a vast improvement and is vital to understanding our home in space. Likewise, the study of the wind and energetic particles in three dimensions is vital to understanding the radiation environment in space, to help safeguard exploration. Many fundamental processes such as particle acceleration, magnetic reconnection, and turbulence can be studied at high latitudes, under conditions different from those prevailing in the heliospheric equatorial regions.

Value to SSSC Great Observatory: Ulysses makes a fundamentally important contribution to the SSSC Great Observatory. It is the only spacecraft which visits the far polar regions of the heliosphere (> +/- 30 degrees latitude), providing *in situ* data concerning variation of the solar wind (and consequently the solar corona and magnetic field) with latitude. In combination with other heliospheric missions (e.g., ACE, Wind, SOHO and Voyager now and STEREO in the future), Ulysses acquires vital data for improving our understanding of heliospheric physics.

Spacecraft/Instrument Status: The spacecraft is healthy and conservation measures have helped to extend the mission. The RTG generators will run down and not provide enough power as the spacecraft heads further from the Sun in 2008. The mission will not continue beyond this point. Combining some operations with Voyager has reduced operations costs. Data archiving and access are good, but data from a couple of the European instruments are not on line.

E/PO: E/PO are more than adequate, and include many different approaches, examples include the JPL ambassador's program, contributions to museums, etc.

Overall Assessment and Findings: This Panel finds that the continuation of Ulysses through and somewhat beyond the next sunspot minimum will enable the first study of the structure of the solar-minimum heliosphere when the northern polar magnetic field is inward (rather than outward), and provide major closure to our understanding of the large-scale structure of the heliosphere and how it depends on the solar magnetic cycle. The Panel concluded that extension of this mission to its anticipated end in 2008 has merit.

2.12 Voyager

Science Strengths: The Voyager 1 and 2 spacecraft constitute a priceless asset which is exploring the furthest reaches of the heliosphere and the interaction of the heliosphere with the interstellar medium. The orbits of V1 and V2 are outward from the Sun, in approximately the direction of the incoming interstellar plasma, and the spacecraft are currently at distance of approximately 90 AU, many times further from Earth than any other working spacecraft. The directions in which the Voyagers are moving differ, which is useful in elucidating the spatial and temporal structure of the outer heliosphere and boundary regions. Voyager is a scientifically compelling part of the SSSC Great Observatory. It is, and will remain for the next two decades and more, the only spacecraft in the far reaches of the heliosphere, providing *in situ* data concerning the interaction of the heliosphere with the interstellar medium. This provides essential boundary conditions for many processes observed in the rest of the heliosphere, including cosmic rays, anomalous cosmic rays, interstellar neutrals, etc.

The crossing of the heliospheric termination shock by V1, and the beginning of the exploration of the subsonic region called the heliosheath is the beginning of a new era in space exploration. This has engendered great interest in the wider scientific community, the press, and the public. V2, following behind, provides a considerable increment in our knowledge, helping to remove the ambiguities associated with single-spacecraft observations.

The observations in the vicinity of the termination shock and beyond have challenged existing theoretical paradigms. The termination shock and heliosheath have been revealed to be much more dynamic than previously thought, with the shock moving in and out at speeds of the order of 100 km/sec. Some previous models, which were successful in explaining phenomena observed well inside of the termination shock, were basically static. It is possible that including the dynamical motions into the established paradigms will be adequate, but also that new physics may be required. The new physics which has been revealed in the past several years is exemplified by the large number of refereed publications cited in the reference list.

Relevance to SSSC Roadmap: The science encompasses our understanding of the large-scale structure of the heliosphere, including the dynamics of the termination shock and heliosheath. Also, the science includes the entire regime of collisionless plasma physics, including the mechanism for the acceleration and transport of energetic particles (Anomalous Cosmic Rays), turbulence (nature of magnetic and plasma fluctuations), and the nature of collisionless shocks. Hence it addresses directly the major themes of the SSSC Roadmap. The continued Voyager mission is essential to furthering our understanding of the interaction of the heliosphere with the interstellar medium. The effects of interstellar neutrals in slowing down the solar wind address the physics of plasma-neutral interactions. Voyager provides fundamental input into the study of the fundamental physical processes in the space environment.

The galactic cosmic rays, which must enter the heliosphere through the boundary regions, and the anomalous cosmic rays, which are accelerated there, are a large part of the space environment in the inner heliosphere. The anomalous and galactic cosmic rays are impeded or modulated by the heliosheath in their entry into the inner heliosphere. *In situ* observation of these processes may lead to a further understanding of how changes on the Sun could change the intensities of the cosmic rays and hence better predict the cosmic-ray environment at Earth or at spacecraft.

Value to SSSC Great Observatory: The two Voyager spacecraft are a unique asset that is exploring the furthest reaches of the heliosphere and the interaction of the heliosphere with the interstellar medium. In combination with other solar-heliospheric missions (e.g., ACE, Wind, SOHO, Ulysses now and, in addition Solar-B, STEREO, SDO, and IBEX in the future) Voyager also provides unique measurements for studying the evolution of the solar wind as it flows from the Sun to the outer limits of the heliosphere.

Spacecraft/Instrument Status: The operational status of Voyager is adequate to make the desired studies. The plasma detector on V1 is no longer working and although this has impact, the remaining instruments have been adequate to determine that the termination shock was crossed in December, 2004. On V2 the radio instrument is not working well and the magnetometer is noisier than on V1, due to more sensitivity to the spacecraft fields. Some important instruments are either not working (plasma on V1 radio waves on V2) or not optimal (magnetometer on V2), but the available data are still very important and usable.

Data operations: Data access and availability are excellent, except for the magnetometer data which has historically lagged considerably. Significant improvement of the magnetometer data accessibility has occurred over the past year or so, but it is still not up to par with the other instruments.

E/PO: E/PO are rated as very good.

Overall Assessment and Findings: The Voyager mission (V1 and V2) is observing the unique region of interaction of the heliosphere with the interstellar medium, and will not be replaced for at least 2 decades. The science return is priceless. Continuing the Voyager project as long as possible in order to study this unexplored region of space is most important.

The Panel finds that there is merit in having the 'minimal' budget for the highly ranked Voyager 1 and 2 missions augmented to $5M per year beginning in FY 07 to avoid shortfalls. In addition, the Panel believes that an additional augmentation by approximately $400K per year for a guest investigator program specifically targeted to the Voyager mission would be extremely important in enhancing the scientific return.

Optimal science return mandates that the magnetic field data should be put on line more promptly. We note that the other instrument teams put their quick look data on line a much shorter time after receiving them. The science return from the Voyagers will continue to suffer significantly if the magnetometer quick look data are not placed on line essentially as promptly as the data from the particle instruments

2.13 Wind

Science Strengths: The core science teams are still intact and productivity remains high. Over 50 refereed papers have been produced so far in 2005. Some recent science results discussed in the proposal have shown the continued value of using Wind observations together with other spacecraft. One example is tracking the acceleration, escape, and propagation of energetic particles from the corona and through space to 1 AU with SOHO and RHESSI. Other examples are the observation of magnetic reconnection events in the solar wind and the spectral comparison of solar energetic electrons at 1 AU with the photon spectra from RHESSI for the same events. A last example is the determination of high-Z ($Z > 40$) abundances above several MeV/nucleon in both impulsive and gradual solar energetic particle events.

Possible science goals for the extended mission that were not discussed in the proposal include detailed spectral studies of ACR and CIR particles with unprecedented precision during the approach to solar minimum. Comparative studies with RHESSI of SEP events, which will be generally smaller and less energetic at solar minimum, will benefit from the superior sensitivity of the Wind EPACT instrument. Simpler interplanetary conditions will allow the study of these events to yield better insights into acceleration and transport processes. SOHO and Wind will provide an important complement to the STEREO coronal mass ejection/radio observations. However, some future plans for science research given in the proposal are less compelling and appear to be continuations of previous work efforts using more observations, some in combination with additions to the Great Observatory. These include the development of programs to predict magnetic cloud development and shock approach at Earth, the study of 3D transient shock structure with *in-situ* observations of STEREO and remote radio imaging of Ulysses, the study of CIR formation with Ulysses, multi-spacecraft studies of turbulence, and more IP reconnection studies.

The Wind mission was originally the interplanetary component of a complement with Polar and Geotail. Its role as the standard 1 AU particles and fields observatory has been largely usurped by ACE, but Wind still makes valuable measurements that are essential for the future studies. The WAVES instrument is valuable for detecting shocks over a broad range of solar frequencies/distances, and only the WAVES can be used to calibrate the STEREO SWAVES experiment. The 1-14 MHz observing range is not matched by other current missions. The data quality of the thermal noise radiation (TNR) technique for solar wind density is superior to that of other space experiments and is used to calibrate SWE, which in turn provided a calibration for ACE/SWEPAM. It is important to note that the SWE does not saturate during very high rate periods. The 3DP instrument provides measurements of ions and electrons to get high sensitivity solar wind moment values and yields the best available pitch-angle distributions of 40 to 400 keV electrons. The very high MFI cadence (22 vectors/sec) is important for turbulence studies.

Among the unique capabilities of the EPACT particle instrument are: measurements of SEP ion angular distributions covering nearly the whole sky; measurements of SEP ions at intermediate energies of ~3-10 MeV/nucleon with a a geometry factor ~50 times larger than other instruments in this energy range; and the only measurements we have of SEP ions above 3 MeV/nucleon from the upper two-thirds of the periodic table. These measurements have already demonstrated their value in developing and constraining new SEP models. The complementary nature of ACE and Wind particle capabilities serves to strengthen the science return from the Great Observatory.

Wind also contributes crucial measurements of gamma ray bursts from astronomical sources for high energy astrophysics research.

Spacecraft/Instrument Status: The spacecraft remains in good health and in a stable orbit at L1 with fuel to maintain position for a decade. One instrument, the TGRS, failed early. One of the three SMS instruments and two of the four EPACT telescopes are not fully operational. These partial failures also occurred early in the mission. Otherwise all instruments are operational.

Relevance to SSSC Roadmap: Wind contributes to 7 of the 12 Focused Research areas of the SSSC Roadmap. The combined capabilities of SOHO and Wind essentially duplicate those of a STEREO satellite, thus providing a means to achieve at least part of STEREO's new science objectives in case of failure of one of the STEREO satellites. Wind also provides a complete set of solar wind observations that provide the drivers for models of magnetospheric responses. It is therefore important to maintain the L1 location of the Wind satellite.

Value to SSSC Great Observatory: The Wind measurements at L1 complement the capabilities of those on ACE. The MFI high cadence, the 3DP high ion and electron sensitivities and pitch-angle distributions, the TNR solar wind densities, the dynamic range of the SWE, the EPACT energetic particle measurements, and the broad frequency range of the WAVES instrument are important contributions to the Great Observatory science return unmatched by other missions. Wind, combined with SOHO, will provide a third vantage point that will strengthen the science results from the Great Observatory and provide a backup in case one of the STEREO spacecraft fails.

Data operations: The large number of 220 data products at the CDAW website indicates real value for the solar-heliospheric community. The CDAW website is a convenient and popular place to get up-to-date data and key parameters, and new high-time resolution data are now available. The specialized data bases [shocks, type II bursts] are useful summaries. The WAVES digital data is now available. A major concern is that the documentation is poor and/or unavailable, which greatly compromises the usefulness of the data. The data from the EPACT experiment are only partially available from the CDAWeb, and in many cases it is not clear whether the data there are appropriate for scientific study. While no calibration parameters, information, or validation samples are provided, they do not appear to be necessary with the Wind data.

The team seems to have made a real effort to keep costs low. The cost increase in FY07 appears due to engineering realignment of operations with another spacecraft following the Polar termination in March 2007; however, that funding will be required earlier if Polar is terminated in FY06.

E/PO: The determination of the effectiveness of the Wind program was hampered by a complete lack of text describing most of the facets required. The proposal did not provide any EPO budget so the amount of funding for EPO elements could not be determined. The proposal was rated unacceptable with regard to the objective of the NASA E/PO program**.**

Proposal Weaknesses: The proposal is poorly written, with word-for-word repetition and internal inconsistencies. The text and figures sometimes do not correspond, and there is a frustrating lack of references, both in the body of the proposal and in the bibliography. It appears that at least some of the proposed scientific tasks have not been adequately vetted with the instrument teams. It is also unclear whether the allocation of funds among the instrument teams reflects the tasks outlined in the proposal. These weaknesses make it difficult to confidently assess the likely future impact of Wind-specific studies. It is difficult to believe that the Wind team carefully reviewed the proposal before its submission to the Senior Review. This poor proposal puts the Wind user community at risk.

Overall Assessment and Findings: The unique capabilities of the Wind measurements are important to maintain for future work, particularly with RHESSI, STEREO and ACE. Continued operations at L1 will provide an important component for the Great Observatory. The proposal does not reflect the full capability and importance of this mission.