

# FINAL REPORT

## **Senior Review of the Sun-Earth Connection Mission Operations and Data Analysis Program**

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# 1 Introduction

The Office of Space Sciences (OSS) subjects its programs to scientific scrutiny by selected members of the discipline communities at approximately two-year intervals. This comparative review ensures maximum scientific return from these programs within finite resources. The Space Science Enterprise Strategic Plan available through OSS website (<http://spacescience.nasa.gov/admin/pubs/index.htm>) represents the results of extensive discussion by the space science community, crystallized into enterprise goals, science objectives, and research focus areas. This document formed the basic context for this review. Inputs to this process can be found in the report of the 2002 Sun-Earth Connection (SEC) Roadmap Committee: Sun-Earth Connection (SEC) Roadmap 2003-2008 ([http://sec.gsfc.nasa.gov/sec\\_roadmap.htm](http://sec.gsfc.nasa.gov/sec_roadmap.htm)).

The last review of missions supporting the SEC portion of the OSS program was held in June 2001. It faced a substantial budgetary shortfall and made several recommendations to OSS to mitigate the impact of this shortfall on the OSS program. Most, but not all, of these recommendations were implemented by OSS. Since the last review, IMP-8 was terminated as a science mission and the Yohkoh spacecraft ceased transmitting science data in Dec 2001. In addition NASA established a sustaining-level budget for its participation in Geotail.

While the current review, which considered proposals spanning the period from FY04-FY07, with emphasis on FY04 and FY05, did not face as serious a budget shortfall, the projected budget is nevertheless still oversubscribed. The in-guide budget given to the projects, as guidance, was a “bare-bones” budget. Although staying within the guidance given OSS by NASA/HQ, it did not maximize the science return of most of the missions that the Panel reviewed. The optimum budgets that were proposed by the missions substantially oversubscribed the available funding guidelines. Additionally, the Panel addressed the issue of increasing the OSS guest investigator program, which in turn placed pressure on MO&DA. Thus, the Panel faced several hard choices in making its recommendations. Most of the missions reviewed already had entered an extended mission phase; only two are still in their primary science phase.

## 1.1 Space Missions

This Senior Review considered 14 science proposals. The missions included distant *in situ* heliospheric spacecraft, Voyager and Ulysses; L1 *in situ* missions, ACE, SOHO, Wind; solar remote sensing spacecraft, SOHO, TRACE, RHESSI; magnetospheric missions, Cluster, FAST, IMAGE, Polar, SAMPEX, and a terrestrial atmospheric satellite, TIMED. RHESSI and TIMED are still in their prime mission phase but would enter their extended mission phase during the period covered by this review. The Panel also reviewed a proposal for the Exodus mission. This proposal would take the Genesis spacecraft to a heliospheric orbit to measure the solar wind in conjunction with other L1 spacecraft once it has completed its prime mission. The Panel received both a written proposal and presentation from each of the mission teams. Each mission was evaluated on the quality of its proposed science and contribution to the SEC roadmap. These evaluations are presented in Section 2. Section 3 contains a summary of recommendations and conclusions from the review.

## **1.2 Senior Review Panel Responsibilities**

NASA chartered the Senior Review Panel (SRP) to rank the scientific merit of each mission – on a “science per dollar” basis – in terms of the expected returns from the science goals proposed during 2004 and 2005, and to make preliminary assessments for 2006 and 2007. The review was conducted in the context of the science goals, objectives, and research focus areas described in the Space Science Enterprise Strategic Plan. The Panel also assessed the cost efficiency, technology development and dissemination, as well as data collection, archiving and distribution. Education and Public outreach served as secondary evaluation criteria. Based on the review, the Panel has recommended an implementation strategy for SEC MO&DA.

The SRP convened on 10-13 June and was comprised of 11 scientists with solar, heliospheric, and geospace expertise. A separate Panel was convened to evaluate the proposed E/PO programs and these evaluations were submitted to OSS. The SRP received a copy of this report and also made its own assessment of the E/PO programs. The reviewed projects all submitted proposals to OSS describing their planned science program under an extended mission, their relevance to the SEC roadmap science objectives and focused research areas, and past science accomplishments.

All of the reviewed proposals contained budgets for mission operations and data analysis (MO&DA) at both “bare-bones” and “optimum” 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 FY04-07 were approximately \$77M, \$78M, \$74M, and \$66M, respectively. When taken together, the in-guide (“bare-bones”) budgets of the proposals exceed the total available for the four-year period (FY04-07) of this review by approximately \$29M; the optimum proposed programs exceed it by about \$72M. The annual mismatch between the budget and proposed “bare-bones” grew from \$3M in FY04 to \$11M in FY07.

## **1.3 Methodology**

The Panel considered the scientific merits of individual programs and their contribution to the SEC enterprise. The 2001 review had assessed each project in the context of two large systems, the Sun-Earth and the Sun-Heliosphere systems. For this review, the Panel assessed each proposal in terms of its contribution to the SEC roadmap. The Panel analyzed the roles of each element, examining how the proposed observations would contribute to system understanding.

The Panel recognized that many of the missions in the extended operations phase have achieved their original science goals and now provide important correlative data needed to achieve the science goals set down by other missions in their prime phase. This is largely a service or support role, and the appropriate funding levels should cover basic mission operations, data acquisition and processing – but not substantial further mission-specific science analysis unless strongly justified as new science. That activity should now be carried out through the Guest Investigator Program. This is the principle that guided many of the Panel’s funding recommendations.

The Panel based its decision on two criteria:

- The scientific value of the research proposed using the data to be taken during the upcoming years. In particular, the Panel recognized proposals that suggested new compelling science that could only be done with new observations and not just ‘more-of-the-same’. As a secondary consideration, the Panel took into account the scientific output from the last 2-3 years, as a proxy for (ongoing) scientific productivity.
- About equal weight was given by the Panel to the intrinsic contribution of the proposed research to the SEC goals and the wider science community. In particular, the Panel recognized missions whose data are invaluable for other missions.

Individual proposal evaluations addressed: science strengths, spacecraft and instrument health and status, relevancy to the SEC roadmap, data availability and accessibility, as well as education and public outreach.

Mission	Science Grade	Relevance Grade	Average of Science and Relevance
RHESSI	9.1 ± 0.8	8.5 ± 1.4	8.8 ± 0.9
Cluster	8.5 ± 1.3	8.5 ± 1.7	8.5 ± 1.0
SOHO	7.3 ± 2.1	8.4 ± 1.7	7.8 ± 1.4
IMAGE	7.2 ± 1.1	8.1 ± 1.6	7.6 ± 1.0
ACE	7.2 ± 1.6	8.0 ± 1.4	7.6 ± 1.0
TIMED	7.1 ± 1.7	7.6 ± 1.1	7.4 ± 1.2
Polar	6.8 ± 1.5	6.8 ± 2.1	6.8 ± 1.1
Voyager	6.7 ± 2.1	6.7 ± 2.2	6.7 ± 1.8
Ulysses	6.3 ± 2.0	6.5 ± 2.4	6.4 ± 1.7
TRACE	5.9 ± 1.5	6.5 ± 2.0	6.2 ± 1.5
FAST	5.9 ± 1.4	6.5 ± 1.5	6.2 ± 1.2
Wind	4.7 ± 2.5	5.9 ± 1.9	5.3 ± 1.8
Exodus	3.8 ± 2.2	4.6 ± 2.7	4.2 ± 2.1
SAMPEX	3.7 ± 3.0	4.4 ± 2.5	4.0 ± 2.4

The table above summarizes the grades given to the 14 missions based on the science impacts and relevance to the SEC mission. Scores above 8 represent programs regarded as “clearly superior” with compelling science and relevance. Grades between 5 and 8 were assigned to programs viewed as “very good”. Those missions that scored below 5.0 in the composite score are not recommended for new funding. The table gives average values and standard deviations of grades assigned by the eleven voting Panelists.

## **1.4 Summary of Major Issues**

Many of the proposals did not do an adequate job of connecting the need for additional observations back to the science topics and questions that were set down to motivate that need. While the motivating science in the proposals was generally very responsive to the SEC roadmap, there was a general lack of explanation of why additional observations were needed or how those observations would be used to close on the science goals that were proposed. Proposers should be reminded that such a clear explanation is important, as it is a primary criterion on which the Panel must judge the value of their proposed mission extension.

The cost for some experiments on some missions seemed disproportionately high (compared to similar experiments on the same or other missions) and it was not clearly explained why. In several cases there was not a clear correlation with scientific output. Areas of concern were noted in the individual assessments in Section 2.

The previous senior review recommended enhancement of the GI programs associated with the missions. The 2001 Panel also urged the SEC management to incorporate the GI program as an integral part of MO&DA funding to serve as a bulwark against countervailing fiscal pressures. This Panel is in agreement with these recommendations and has developed recommendations for several of the missions that would decrease support to the PI teams and increase the funding to the GI program proportionally (for which the PI teams could compete along with the community). However, before funds are removed for this purpose, SEC management must insure they are not lost or used elsewhere (e.g. for new missions).

The Panel received a report on use of Ulysses, Wind and RHESSI data for the study of gamma-ray bursts from non-solar system sources. These missions play an important role in the establishment of an effective gamma ray network to locate sources and in the case of RHESSI for measuring the polarization state of the incoming gamma rays to help unravel how they originate. While our recommendations are not closely linked to this synergism, OSS should try to obtain support for these programs from the Astronomy and Physics Division.

## 2 Evaluation of Missions

### 2.1 *Advanced Composition Explorer*

ACE was launched in August 1997 and placed in a halo orbit around L1 in January 1998. The spacecraft overall health is excellent and operations have been nominal. The only anomalies have been inconsequential, single-bit errors. Power output and maneuvering fuel are expected to last at least another 20 years.

The basic objective of ACE is to carry out high-precision observations of the elemental, isotopic and ionic charge-state composition of nuclei from solar wind to galactic cosmic ray energies. The science goals are to measure and compare the composition of several kinds of matter, including the solar corona, the solar wind and other interplanetary populations, the local interstellar medium, and distant galactic matter. The large detectors on ACE provide unprecedented charge and isotopic resolution with high statistical precision. The objectives for 2004-2007 address key new science objectives during approach to solar minimum and the reversed magnetic field ( $A < 0$ ) of the next sunspot minimum. ACE measurements of the composition, energy spectrum and time variation of anomalous cosmic rays will provide new insights into the acceleration and transport of particles during the  $A < 0$  magnetic phase. It will also measure the composition of solar energetic particles to determine the acceleration and transport processes, the origin, composition and nature of the seed population. ACE will provide a baseline at 1 AU for global heliospheric studies for the  $A < 0$  phase. ACE will also observe and compare the anomalous and galactic cosmic rays in the approach to the next solar minimum.

#### **Assessment and recommendations:**

ACE addresses directly all of the science objectives of the SEC roadmap. The flow of matter and energy: solar wind, solar energetic particles, their origin, acceleration and distribution in space and time. It addresses fundamental processes such as energetic particle acceleration and transport, turbulence, and CMEs.

ACE plays an exceedingly important scientific role as the primary upstream provider of definitive solar-wind observations needed for the interpretation of magnetospheric, ionospheric and atmospheric data from both spacecraft and ground-based instruments. This is an extremely important aspect of ACE - it is essential to keep it going for this reason. The mission science data are readily available on line, and the software is easy to use. ACE also satisfies important space weather operational goals.

ACE is a mission that enjoys continued vitality and health. Its science is very important and contributes to many of the goals in the SEC roadmap. The Panel strongly recommends that it be funded for the full four years of this review. However, the budget of ACE remains quite high. Efforts should be made to lower the budget to a value somewhat lower than the 'in guidelines' scenario.

## **2.2 Cluster**

Cluster is a joint NASA/ESA mission consisting of a fleet of 4 spacecraft that were commissioned in February 2001. It has been exploring various regions of the inner and outer magnetosphere using a variety of spacecraft separations. The support from NASA on this mission is for the US participation, which involves 76, US scientists. In February 2002, ESA approved a 35-month extension. In a multiple spacecraft mission, the potential for spacecraft problems obviously increases. Overall, all the spacecraft are in reasonably good health. While several instruments have some problems, these are not expected to compromise the proposed mission extension.

Cluster is a groundbreaking mission as it is the first in a series of constellation-type missions. While still in prime phase/exploratory mode, with all the difficulties in inter-spacecraft calibration and optimal spacecraft separation still being resolved, some very exciting science is starting to appear. One measure of this is the increase in the publication rate in 2003 as compared to 2002. With the lessons learned during the prime phase, it is expected that the extended mission should result in major advances in our understanding of geospace including the microphysics of reconnection, thin current sheets, plasmopause irregularities, chorus generation, fine structure of the bow shock, and microscale processes in the magnetosheath.

The interest in the use of Cluster data is high, with 23% of the funded FY 2003 geospace proposals planned to use data from this mission. There has been a lack of data availability due to calibration/validation issues, but there are plans to put high-resolution data onto public archives by late 2004 or 2005. The Panel strongly endorses this plan.

### **Assessment and Recommendations:**

There is tremendous potential in this mission for answering many of the questions described in the SEC roadmap. Cluster lays the foundation for the move from the ambiguity of single-point to the richness and complexity of multipoint measurements.

The Panel noted that the wide band data (WBD) plasma wave instrument is the most expensive instrument in the budget, and there is the additional expense due to the requirements that it use the DSN. While there has been some significant science return, the high cost of Cluster-WBD is a concern. This is reinforced in the relatively low number of papers that have been published using data from this instrument compared to papers published using other instruments on this mission.

The Panel recommends that this program be funded at the minimum-level for FY04-06. As indicated in the proposal, theory and modeling should play an important role in helping to understand the complex dataset, and some resources should be devoted to it. Some funds should set aside for a Cluster special-emphasis GI program. Specifically, the Panel recommends that in-guide PI funding be decreased by 500K/year (beginning in FY05), and the GI-Cluster program be increased by \$1M per year in FY05-07. It is also recommended that some funds be moved from some instrument teams and used for developing Cluster data analysis tools as well as theory and modeling; this would greatly enhance the utility of this dataset.



## **2.3 Exodus**

Exodus is a proposed new mission that is really a relocation of the plasma module of Genesis. This module is to be relocated to a distant retrograde orbit, a heliocentric orbit, which allows the spacecraft to spend significant time 0.035 AU upstream and downstream of Earth. This would permit the study of solar-wind structures in various directions over distance scales that are totally different from those now available. Instrument health is not an issue. However, the spacecraft does not include a magnetometer. At the request of NASA the Panel focused its evaluation on the science merits of the Exodus proposal. The Panel did not consider the technical feasibility of the transition from the Genesis trajectory near Earth to the Exodus trajectory.

Through collaboration with other spacecraft at L1 and Earth, Exodus will address variations in the solar wind in various directions at scales up to .02 to .07 AU, not previously measured or scheduled. This will permit novel and important studies of the spatial structure of CME's in the radial and transverse directions, discontinuities, shapes and the spectrum of interplanetary turbulence. This kind of data, even if incomplete, is of vital importance to the study of turbulence and structures such as shocks and CMEs in the solar wind. Exodus would help establish space environment prediction of the solar wind at nearly 4 times the L1 separation, help understand solar-wind variability, and determine wind solar origins by separating spatial and temporal structure.

Exodus would address directly all of the science objectives of the SEC roadmap. These include flow of matter and energy through measurements of solar wind structure and variations; the study of fundamental processes by measuring the scale of variation and structure of coronal mass ejections; and societal impacts by relating the structure of coronal mass ejections to their impact at Earth.

### **Assessment and recommendations:**

This proposal addresses a number of important science issues through its unique ability and through comparisons with other spacecraft, to study the spatial structures of the solar wind on scales of .02 to .07 AU. However, its abilities are significantly compromised because the magnetic field is not measured. Instead, its direction (with a 180 ambiguity in its sense and a further uncertainty due to the finite angular resolution of the detector) is inferred from the electron distributions. The magnitude of the magnetic vector is not determined. This would make the inferred magnetic field difficult to interpret. We find that the science return does not justify the relatively high cost. Stereo and possibly Venus Express may be able to address some of the same science issues in the same time frame. Thus given the current budget constraints, the Panel recommends that Exodus not be funded.

## **2.4 Fast Auroral Snapshot (FAST) Small Explorer Mission**

FAST's mission objectives were to investigate the acceleration processes in the region between the ionosphere and the magnetosphere. The spacecraft was launched in 1996 in a high inclination orbit that allows it to cross both auroral zones. The complement and quality of instruments on FAST are unprecedented, and have provided an unrivaled view of the complex physical processes that dominate this region. In the proposed extended mission, conjunctive studies with other SEC missions such as IMAGE, Polar, Cluster and TIMED are being proposed. The FAST spacecraft has been operational for 6.5 years; all instruments, with the exception of the electric field instrument, are fully functional. A recent spacecraft anomaly with the MUE watchdog timer, that has been resetting every 96 hours, first appeared in March 2003. The cause of the problem has been identified as high temperatures and a workaround has been found. Data loss during these episodes is less than 15%, and it is expected that the recurrence of the anomaly will be infrequent. There is no indication that this problem is a precursor to more serious problems.

The FAST spacecraft contains an impressive complement of high-resolution instruments in an ideal orbit that has enabled new insights in the transition region between the ionosphere and the magnetosphere. The proposal describes a new and novel technique that infers the electric potential drop along a field line for determining large-scale auroral structure that promises to be a valuable tool. After an extremely successful prime mission in studying the microphysics of this region, FAST is now more an observatory type mission. Future conjunction studies with IMAGE, Polar, Cluster and TIMED should yield new and interesting science on the large-scale structure of the magnetosphere and its coupling to the ionosphere.

### **Assessment and recommendations:**

FAST is the only spacecraft that occupies an orbit that is in the scientifically important auroral acceleration region and it provides high-quality and high-resolution measurements of the plasma processes in this region. The spacecraft has very low operating costs and a high science return. For example, interest in the use of FAST data is high: 14% of the funded FY03 geospace GI proposals planned to use data from this mission. FAST uses a unified data analysis program and is readily available to the entire scientific community. Such effort by the team should be commended. Even with a modest budget, the program has an overall good array of activities especially in relation to teacher training.

The expected advances from this proposed extended mission would most likely be incremental, especially in relation to its proposed solar cycle studies. After a very successful prime mission, the spacecraft is being utilized in a valuable, low-cost support role with other SEC missions. It continues to have a significant role in the investigation of an important region, and the mission should be continued. However, given the higher priority that was given to the other missions and a limited budget, the Panel recommends that FAST be funded at in-guide level for FY04-06. The Panel recommends the termination of mission operations at the end of FY06 and funding made available only for science in FY07.

## **2.5 Imager for Magnetopause-to-Aurora Global Exploration**

The IMAGE spacecraft and all instruments are operating nominally. IMAGE is the first satellite dedicated to imaging the Earth's magnetosphere. It has produced exciting ultraviolet and energetic neutral atom images of the magnetosphere and aurorae. The IMAGE team has been very scientifically productive. For instance their observations have led to a new look at magnetospheric convection including new insight into the structure of the plasmasphere and the discovery of co-rotation lag. IMAGE global proton auroral observations have been used to infer the reconnection configuration.

The IMAGE team has proposed a number of science studies during the extended mission. Several of these provide compelling reasons for an extended mission. The IMAGE Medium Energy Neutral Imager has an identical medium energy neutral imager to TWINS. When the first of the TWINS satellites is launched sometime next year IMAGE and TWINS 1 will provide a stereoscopic view of the magnetosphere. A year or so later we will have three ENA imagers. Until the launch of TWINS, IMAGE is the only ENA imager. It is important to have IMAGE data during the declining phase of the solar cycle since it will image global effects of recurring magnetic storms. It will provide an opportunity to make equatorial airglow observations for coordinated studies with TIMED. As IMAGE moves into the southern hemisphere it will be able to investigate north-south asymmetries in the aurorae. Finally real time IMAGE data are provided to NOAA. It provides auroral imaging and will become the only full time imager when Polar runs out of gas near the end of FY05. In addition to doing auroral studies, IMAGE auroral images are useful for providing context for other studies (e.g. storm and substorm studies) using other spacecraft. IMAGE provides the only global proton precipitation observations.

### **Assessment and recommendations**

Interest in IMAGE data for magnetospheric research is very high. In 2003 27% of the geospace guest investigator proposals were for IMAGE data. IMAGE has a program to enhance undergraduate and graduate education by creating research opportunities. This should be very useful for attracting students to space physics. Since launch IMAGE has carried out a successful open data policy.

The Panel recommends maintaining the "in-guide" extended mission program for IMAGE. The data during the declining phase of the solar cycle should provide important new results on the changes in the magnetosphere during recurring storms. IMAGE data are important in support of studies based on other SEC spacecraft. The in-guide funding plan seems about right. The budget falls in FY06 and FY07 but operations and data processing should have achieved the efficiencies of a mature mission. The requested increase for 06 and 07 is mostly for increased science support. The Panel feels that while increased funding for science support for research with IMAGE data is justified it should be part of the guest investigator program. This would be based on competitive selection and thereby will encourage the broadest scientific use of the data.

## **2.6 Polar**

Despite being an old mission, Polar still produced very important and exciting science during the past two years, mainly because of its apogee had precessed to equatorial low latitudes. The most exciting science was coming from a few instruments, namely HYDRA, EFI, and MFE. In the overall SEC program, especially data from the imagers was and is important.

Most of the Polar data are easily accessible to the broader scientific community. However, some PIs should be encouraged to do their production more timely.

The project was convincing in showing that new science from continued measurements could be expected in three fields, listed in order of scientific significance as seen by the Panel:

- Microphysics of magnetopause reconnection (due to extended burst mode)
- Influence of high-speed wind streams on the radiation belts (due to solar minimum)
- Interhemispheric asymmetries of aurora (due to the precession of apogee to the southern hemisphere)

The spacecraft is healthy and has fuel reserves that will last at least until the end of 2005. With the exception of the wave experiment (PWI) and the X-ray imager (PIXIE), the instruments are working properly for reaching the science goals.

### **Assessment and Recommendations**

The mission should be funded somewhat below the in-guide level for the next two years with the saving moved to the GI program. This should be a long enough interval to obtain the data needed for the new science; furthermore fuel may run out at the end of 2005. Polar should cease operations at the end of FY05 and only science funding made available in FY06. It is recommended that instrument funding be redistributed to the most active groups/experiments (HYDRA, EFI, MFE) with the most compelling science plan. Dead (PWI) or near-dead (PIXIE) instruments should not be funded any further at any significant level.

## **2.7 Reuven Ramaty High Energy Solar Spectroscopic Imager**

RHESSI was launched in February 2002 and has operated successfully since launch. It is still in its prime mission phase. There was some degradation in one of the detectors one week after launch, but it can still be used for imaging and spectroscopy at lower energies. All other detectors are operating as expected. Radiation degradation is within the predicted limits and no annealing will be required for the proposed extended mission. Although the launch was delayed beyond solar maximum, RHESSI has observed over 8000 solar activity events.

RHESSI provides spectral imaging of high-energy aspects of flares and mass ejections and high-energy spectroscopy. Many “first time” observations of solar processes have been obtained. Early observations with RHESSI have revealed information on flare energetics, timing and spatial structure that will stimulate renewed efforts to model and understand flares and magnetic reconnection on the sun. RHESSI has a high potential for future “discovery” observations. It has a very good early publications rate. There are strong collaborations with other missions where RHESSI provides critical and unparalleled data on what occurred on the sun leading to phenomena observed at other locations in the heliosphere. The RHESSI group is doing an excellent job of supporting data and modeling efforts.

The extension is needed to increase the number of flares and CMEs observed to meet the mission’s primary objective of understanding particle acceleration and energy release in solar flares. Large flares and large solar energetic particle events often occur in the descending phase of the solar cycle. The extended mission will give RHESSI an opportunity to capture some of these events. This is a compelling measurement needed to clarify the relationship between SEPs, CME driven shocks and flares. Because of RHESSI’s sensitivity in the 3-15 keV range, it will be able to measure small micro-flares as the level of solar activity decreases. These measurements will address the very important unsolved problem of coronal heating. Coordinated gamma ray observations with Ulysses and Wind will aid in understanding both solar and cosmic sources.

RHESSI has had an open data policy from its inception, but most of the RHESSI data are complex to analyze and some reduction by the PI team is needed before its release to make it useful to the community. Although still a young mission, RHESSI accounted for 13% of the solar-heliospheric GI proposals in FY03 and we expect the number of requests to increase over the next few years. We commend the efforts of the team for their strong support of data dissemination to community. RHESSI data will be easily integrated into Virtual Solar Observatory effort and European grid. The RHESSI outreach program has been very effective in reaching middle and high school and producing classroom material.

### **Assessment and Recommendations**

RHESSI has a unique role and tremendous potential for understanding flares. It provides information on the (penultimate) source of many phenomena in the SEC system. An increased RHESSI specific GI program is needed to fully exploit the data. We recommend that the extended mission be funded at the in-guide level plus an enhancement of 100-200K to provide support for training in data usage and data dissemination.

## **2.8 Solar, Anomalous, and Magnetospheric Particle EXplorer**

SAMPEX is a Small Explorer mission now in its 12th year of operation. The mission has satisfied its original science objectives and now proposes continued operation to make observations germane to the Sun-Earth Connection strategic goals.

There are several minor strengths to the proposal for continued mission operations. The mission operations costs have been reduced to a very low level. The instruments on SAMPEX are operating reasonably well. Those instrument degradations that do exist are not serious and do not impede the ability of the mission to provide data in support of coordinated, multi-spacecraft studies. The science topics that were set down in the proposal to motivate a continued mission are relevant to the SEC strategic plan as set down in the Roadmap. Specifically, the topics of radiation belt dynamics, the response of the atmosphere to charged particle inputs, and the behavior of anomalous cosmic rays during the course of the solar cycle. It was noted that SAMPEX provides the only data on the charge of anomalous cosmic rays captured in the Earth's magnetosphere, and the only monitor of interstellar matter byproducts in the magnetosphere. The return to solar minimum conditions will be marked by the return of the anomalous cosmic ray radiation belt.

The proposal did not set down in any detail, even superficially, how additional observations from SAMPEX would be used, either by the SAMPEX team or in concert with observations from other spacecraft, to progress beyond what is now known, in the science topics used to justify further mission operation. Indeed, several of the science topics (e.g. radiation belt energetic electron loss processes, chemical changes to the atmosphere from energetic particle precipitation) have been studied for some decades and the proposal offered no evidence that other than incremental advances would be achieved. These are serious science weaknesses to the proposal for further operation.

The use of SAMPEX observations to assist in system anomaly assessment or in support of the International Space Station, while potentially valuable, is beyond the scope of the SEC strategic plan and does not constitute an adequate rationale for continued mission support from SEC.

### **Assessment and Recommendations**

SAMPEX has the potential to provide further observations in support of science investigations important to SEC, although this was not adequately demonstrated in the proposal. For this reason, consideration should be given to funding continued mission operations only after adequate support for higher priority missions is insured. If funding is made available, it should be used only for a minimum level of mission operations and data processing to make the data available. No funding for science analysis should be included and it is recommended that any resources for science analysis activities be obtained through a competitive Guest Investigator Program.

It is understood that SAMPEX was launched before the implementation of the open data policy. The PI has received supplemental funding to distribute the high-resolution data to the community and the Panel applauds this effort and highly encourages the continued dissemination of the data. This will greatly increase the science value of the mission whether or not the mission is continued.

## **2.9 Solar and Heliospheric Observatory**

SOHO is a broad mission addressing many basic, long-standing questions belonging to the Sun-Earth Connection theme by connecting events beneath the surface to those on the disk to those in the heliosphere. The breadth is reflected in more than 1400 publications from SOHO data since commissioning. Data are readily available by ordering on line for most of the instruments. SOHO has a particularly strong record in outreach and one would expect that this would continue through 2007. Other than the LASCO C1 coronagraph, which failed during the 1998 outage, and some limitations on SUMER pointing, the main SOHO instruments continue to perform very well and are all available for the extended mission. All three gyroscopes have failed; however, the losses have been overcome by onboard control software that allows full scientific usefulness of the remaining instruments.

The science that would result from further extending the SOHO mission is compelling on many fronts. Extension through the declining phase of activity will provide crucial data on changes in sub-atmospheric processes using MDI, solar wind and CME's using MDI, UVSC, LASCO and CELIAS, and coronal heating and solar wind acceleration through CDS, SUMER and EIT in combination with the other experiments. Synergism with RHESSI and TRACE, which were not flying during the rising phase of activity, will greatly expand the knowledge of the source and intensity of particles. Overlap with STEREO, SOLAR-B and SDO (for its first year) at solar minimum should elucidate CME behavior. SOHO is also a key element in the space weather network providing essential data from MDI (magnetograms), LASCO (CMEs), and EIT (loop structures). Understanding of space weather will come from an understanding of the sub-surface storms, from their lift off from the Sun to their presence near the Earth, as seen by ACE. The space weather work will be especially important in the present early declining phase.

LASCO images provide context for CME studies and remain valuable. However, they are not calibrated, thus they remain of limited scientific value. The UVCS data remain difficult to acquire and have not been widely used. SUMER is a valuable instrument, but is used only irregularly. Most of the SOHO research, highlighted in the proposal, is from MDI and LASCO with relatively less from EIT, SUMER, CDS, and UVCS.

### **Assessment and recommendation:**

With its broad array of effective instrumentation, SOHO is an essential contributor to the SEC science goals. The cost of operating SOHO is high, but this is understandable in light of the required extensive, and daily, hands-on operation and its broad array of diverse instrumentation. The costs further reflect the experience of the temporary loss of the spacecraft. SOHO accounted for 33% of the solar-heliospheric GI proposals in FY03. As for the science center and science data analysis functions, they seem disproportionately larger than for the other projects that the Panel is examining, especially science operations. It is important to keep the MDI (Stanford) core team intact for SDO. However, the science functions of the UVCS (SAO) and CDS/SUMER/EIT (Goddard) should be reduced with and redirected to the GI program in FY06/07. However, the funding for FY04 and FY05 should remain as proposed in the in-guide budget.

## **2.10 Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics**

The TIMED mission examines the coupling between the ionosphere/magnetosphere and the neutral atmosphere in the mesosphere and lower thermosphere (MLT). The instrumentation monitors the energetic inputs into the mesosphere and lower thermosphere and the response to these inputs. Collaborations with other satellites allow the chain of phenomena resulting in impacts on the MLT region to be characterized.

TIMED has the potential to identify the mechanisms through which solar effects influence the Earth's atmosphere and thereby allows global change to be decoupled from longer-term solar cycle effects. To carry through this goal will require an extended mission well into the period of declining solar activity to separate the effects of declining activity from seasonal, annual and inter-annual variations in the neutral atmosphere.

The spacecraft is healthy and performing nominally, apart from some degradation in one of the gyros, which is not expected to impact longer-term operation. Of the instruments, GUVI is performing nominally and is producing excellent data. There are minor problems with the XPS filter wheel on the SEE instrument and the SABER instrument has some minor problems due to anomalous off axis signals. Neither of these anomalies is expected to compromise the longer-term measurement goals of the mission. A light leak and accumulation of ice on the detector have affected the performance of the TIDI instrument. Spacecraft rolls that heat the detector have remedied the latter effect, but the light leak has affected the S/N of the instrument and resulted in a significant reduction in the quality of measurements.

Data from GUVI and SEE are readily available. SABER data will be available shortly. TIDI daily means of the meridional and zonal winds are available. It is unclear whether TIDI data at a higher resolution will become available to the community. There has been a considerable and commendable effort in E&PO on the part of the TIMED mission.

### **Assessment and Recommendations:**

TIMED is about 75% through its prime mission phase. Only a mission extending through solar minimum can address the very important science associated with decoupling solar cycle effects from global change. For these reasons, the extended mission should be funded although with the following additional recommendation.

Shortly after the end of the prime mission phase, a major review of the instrument capabilities and their ability to achieve the proposed goals should be undertaken. Particular attention should be paid to how well the TIDI capabilities have been recovered and to what extent any gaps in these capabilities can be covered by other means. Resources may have to be shifted from TIDI to these other avenues.

The Panel recommends approval for the TIMED extended mission for three additional years until the second quarter of FY07. The TIMED science budget in FY06 and FY07 should be reduced and the amount moved to the GI program. The ground-based segment of this mission is important and should not be compromised. The funding for the Interdisciplinary Scientists is considered important for the primary phase of the mission and should be maintained at in guide levels until FY06.



## **2.11 Transitions-Region And Coronal Explorer**

TRACE is the solar microscope and resolves structures that are just hinted at in the images taken with other instruments. Solar-B (2006) and SDO (2008) will eventually provide a comparable (but still lower) resolution. TRACE is a source of upper-solar atmosphere information for ground-based studies of the photosphere and chromosphere, and of structure and temporal evolution for coronal spectroscopy. Overall, TRACE health is excellent. The solution to the quadrant selector problems reported at the Senior Review will enhance science output. The 50% decrease in sensitivity noted in the last Senior Review has not affected TRACE science.

The strongest justifications for continued TRACE observations are: (1) The TRACE loop images can be used in conjunction with the new SOLIS vector magnetic data to verify the force-free field extrapolations and study the origin of loop heating; (2) The images are an indispensable source of context information for the new interferometric observations of RHESSI; (3) In light of the recent fix of the quadrant selector problems, the Panel recommends many more observations of loops on the limb in collaboration with SOHO/CDS where TRACE cycles through the three coronal passbands. These observations should go a long way to resolving the current coronal loop controversy. (4) TRACE is a partner in 3 of every 4 SOHO Joint Observing Programs.

TRACE addresses all of the SEC objectives. TRACE explores fundamental plasma processes by observing the coupling of fields and structures across multiple scale heights within the corona as well as from the TR to the corona. The observations aid modeling of solar impulsive events, and investigate the lower boundary conditions to heliospheric perturbations; the data also help understand energy dissipation in the solar outer atmosphere to aid in model development and validation of UV, EUV, and X-ray solar irradiance.

TRACE has an open data policy. Instrument-specific IDL software are available free of charge for data calibration, processing, and analysis. TRACE accounted for 17% of the solar-heliospheric GI proposals in FY03.

TRACE images, especially the posters, have captivated the imaginations of everyone – from scientists to school kids. Teachers display them in their classrooms, children hang them in their bedrooms; they appear on book covers, web sites, and interspersed in scientific presentations. There are really the only solar images that can “compete” with astrophysics (HST) for the *Wow!* factor.

The proposal emphasizes images and movies (as did the TRACE presentation to the Panel), further propagating the impression that TRACE observations focus more on morphology than on quantitative physics parameters. The Panel suggests a renewed emphasis on quantitative data analysis to counteract this impression.

### **Assessment and Recommendations:**

TRACE makes important contributions to SEC Roadmap goals and should continue to be funded at in-guide levels, with possible additional funds for the data archive. The Panel encourages the TRACE team to continue to cut mission operation costs to free up money to improve the TRACE data archive in the ways described in the proposal.

## **2.12 Ulysses**

The third orbit of Ulysses around the Sun during 2004-2008 will provide closure on understanding the response of the 3-dimensional heliosphere to the 22-year solar magnetic cycle. The Ulysses polar orbit helps address the primary science objective of the SEC Roadmap, which calls for understanding “the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments.” The 2007 South-pole pass will measure particle populations during the South-pole-positive phase of the cycle. Since Ulysses was launched during the 1990 solar maximum (North-pole positive) there is no South-pole data at this polarity. The rapid 7-month orbit from South to North ecliptic pole in 2007/2008 will measure cosmic ray and solar wind gradients for this solar cycle phase. The Ulysses mission has been a successful scientific collaboration with ESA. The ten instruments are healthy, and power sources are adequate through 2008.

About 95 per cent of the heliosphere mass beyond 1 AU originates outside of the heliosphere in interstellar space. Observed interstellar byproducts in the heliosphere include neutral helium and hydrogen, pickup ions, anomalous cosmic rays, and interstellar dust. The polar Ulysses orbit allows measurements of the flow of these populations uncontaminated by ecliptic material.

Multiple-spacecraft observations have created new science opportunities. Ulysses-ACE coordinated observations of pickup ions distinguish between interplanetary versus interstellar sources of low-ionization-potential pickup ions. Ulysses observations of the same coronal plasma observed remotely by SOHO yields the first observations of the relative acceleration of solar wind in equatorial versus polar coronal holes as a function of the solar cycle. Triangulation observations of cosmic gamma-ray bursters, coordinated with RHESSI, Wind, and other spacecraft, provide source positions and additional sky-coverage during seasons not observable from Earth orbiting satellites.

In response to funding cuts resulting from previous reviews, combining the Ulysses and Voyager project management at JPL has minimized the Ulysses mission costs. The requested funding is for a ‘bare-bones’ budget that focuses primarily on support for operations and data acquisition.

Most of the Ulysses science teams have done a good job of making their data available to the community, and publishing scientific results. In 2000-2002, NASA supported 33 GI and SRT programs utilizing Ulysses data.

### **Assessment and recommendations:**

The Panel recommends funding the extended mission at the in-guide level though its return to the north solar pole in 2008, which follows the rapid latitude scan from southern to northern solar poles during 2007/2008. This extension will bring closure on understanding the effect of the 22-year Hale magnetic cycle on particle gradients, energy, composition, and fluxes in the 3D heliosphere. It will also allow completion of multiple-spacecraft observations with recently launched spacecraft that have brought new science opportunities. The Panel recommends providing only minimal support for the Jupiter encounter.

## **2.13 Voyager**

Voyager consists of two planetary spacecraft (V1 & V2) that have been reborn as a mission to the heliosphere frontiers. V1/V2 are the only spacecraft that can study particles and the shock and plasma structure of the distant heliosphere. They are the sole source of data on the expanding solar wind in the outer heliosphere, and the only opportunity to conduct in situ measurements of anomalous cosmic ray production, cosmic-ray modulation, and the heliosphere-interstellar medium interaction. These measurements have significant implications at the Earth, since the galactic and anomalous cosmic ray populations are measured in the terrestrial magnetosphere and at the Earth's surface.

Voyager exploration of the heliosphere frontiers cannot be duplicated for 10-20 years because of propulsion limitations. The positive-negative latitudes of V1/V2 measure heliosphere asymmetry. The Voyager mission operations have been consolidated and automated to minimize the costs attached to operating older technology. Instruments are in good health and V1/V2 have power to supply the core science instruments until 2020. Voyager has a good "science per dollar" ratio because of modest mission costs and extraordinary spacecraft locations and forms a successful component of JPL outreach activities.

Significant increases in energetic-particle populations starting in mid-2002 show that V1 entered a region of high particle intensity. This did not occur at V2, closer to the Sun. The LECP team has interpreted this as a possible termination shock crossing, but it was unconfirmed by the magnetometer or the radio-wave instrument (which is not on all the time). The CRS data indicate V1 moved 7.5 AU closer to the termination shock (which itself moved inwards). V1 is moving radially at about 3.5 AU/year and may enter the heliosheath region in 2-5 years, depending on the unknown strength of the interstellar magnetic field. V1 will then measure the properties of a remote region that directly impacts the Earth, since most galactic cosmic ray modulation occurs in the heliosheath.

### **Assessment and recommendations:**

Voyager should be supported at the "in-guide" level in FY04-06. Science operations should be continued until completion of a thorough review by the next Panel to insure the mission is still scientifically compelling. The Panel recommends that NASA continue to seek ways to reduce mission operations, as well as increase data analysis through the guest investigator program.

The Panel felt that more attention should be given to making the digital Voyager data available promptly to the space-physics community, especially as the Voyager spacecraft are near the termination shock.

## **2.14 Wind**

The Wind spacecraft, launched in November 1994, is healthy and has a large capacity for orbital maneuvers. It is currently on a trajectory past the L2 point, and afterwards will return to L1 to serve as a backup for ACE. Wind can remain active at L1 for at least another 10 years. The instruments on Wind are healthy. Of the two tape recorders on the spacecraft, only one remains.

In its current orbit near L2 the spacecraft will monitor distant magnetotail plasmas to determine how these react to various solar wind inputs. At L1 the spacecraft can act as a backup for ACE as an upwind solar wind monitor. These data address the following science objectives:

- The plasma, fields and particles instruments can be used as part of a “heliospheric cluster” to determine the directions and extents of various plasma and particle phenomena upstream of earth.
- The Waves experiment is a kilometric radio monitor that can be used to remotely sense interplanetary shocks and electron streams on their motion through the heliosphere from Earth. It can be used for triangulation of radio bursts in conjunction with other monitors – Ulysses, and, when launched, STEREO.
- A gamma-ray monitor on board the spacecraft is also used in conjunction with instruments on other spacecraft to determine the location of gamma ray bursts.

Wind, like ACE addresses directly all of the science objectives of the SEC roadmap. Ion and field data are generally easily available via the Web. Some of the other data are behind in being made available. The Waves experiment has only plots available. The digital data can be used to determine radio signal directions, and this is not available nor are the techniques used to provide these directions available. The proposal had inadequate detail of the group’s plans for EPO.

As a direct backup for ACE, Wind does not have as efficient a transmitter for data transmission to the ground. The campaign modes of operation, good in conjunction as support roles with other instruments, do not highlight the next years’ unique capabilities of the Wind spacecraft or a plan of what will be studied.

### **Assessment and recommendations:**

The Wind instrument analyses (and its orbit) were significantly modified following the last Senior Review. Far less money was made available to mission scientists. The data analyses are now organized around campaigns, and the spacecraft is on its way to L1 to serve as a backup for ACE following a pass of L2. One of the compelling reasons for continuing Wind is the Waves data. The Waves team should make their digital data available.

The Panel feels that the roles of Wind as part of the L1 cluster and as a backup to ACE are important and recommends funding at the in-guide level for FY04-07.

### 3 Summary of Conclusions and Recommendations

The Senior Review Panel was impressed by the overall quality of the proposed science activities. We found that all the proposals were basically responsive to the SEC roadmap and the three primary science objectives of the SEC Division. After examining the SEC roadmap and the science goals of the proposed extended missions, their relationship to one another and to upcoming missions regarding mutual science synergisms, and the predicted funding availability, the Panel developed its rankings and recommendations. The RHESSI and TIMED mission have joined the SEC fleet since the previous review and the proposed Exodus mission would also be a new addition to SEC, although it is an existing NASA Discovery mission (Genesis). When taken together, the in-guide (“bare-bones”) budgets of the proposals exceed the total available for the four-year period (FY04-07) of this review by approximately \$29M; the optimum proposed programs exceed it by about \$72M. Thus the Panel recommendations necessarily call for decreased mission costs and activities. At the same time the Panel encourages SEC to seek increased funding necessary to enhance the science return of its missions. The most significant recommendations are:

1. As was recommended by the previous Panel, the present Panel believes that the SEC Guest Investigator (GI) program should be strengthened. However, our specific recommendations to reduce funding for operations and investigator teams should only be implemented if it can be assured that the funds freed up go into the GI programs. The recommendations are based on the premise that the Panel desires to increase competition to insure the best science; it does not wish to reduce overall science funding.
2. It was noted that overall instrument health requires adequate support of the instrument teams. Thus the recommended reductions in instrument team support must be implemented with care to insure adequate interest remains to keep the experiments healthy.
3. Several missions were deemed to have high operational costs and should investigate ways to reduce operational costs to increase scientific support. ACE, Polar, SOHO, Ulysses and Voyager should look at ways to develop more effective operations and convert MO funds to DA funds.
4. Some missions appear to have substantially higher support for the mission science teams than others. While this often is required because of the complexity of the data, the Panel would like to see some of these funds moved to a GI program. The Panel acknowledges that primary phase missions typically have higher costs than missions in extended phases. Mission scientists are encouraged to propose scientific research projects under the GI program. Specific recommendations are given below.
5. Although the proposed science for Exodus and SAMPEX is interesting, it was not deemed as compelling or relevant to the SEC roadmap as the other missions. Thus, given the current budgetary constraints, no mission funds should go to Exodus or SAMPEX beginning in FY04.

6. ACE should be funded for FY05-07 but efforts should be made to lower operating costs to a value below the “in-guide” budget and use the savings for data analysis.
7. The “in-guide” PI funding for Cluster should be reduced by \$500K/year starting in FY05 and a GI program with a Cluster focus should be increased by \$1M per year in FY05-07.
8. FAST should be funded at the “in-guide” level in FY04-06 and cease operations at the end of FY06 with only science funding provided in FY07.
9. IMAGE should be funded at the “in-guide” level except the IMAGE request for extra science funding in FY06-07 should go to the GI program.
10. Polar should cease operations at the end of FY05 with continued funding for Polar science in FY06. It should be funded below the “in-guide” level in FY04 and 05 with the savings moved to the GI program.
11. The Panel recommends approval for a RHESSI extended mission. In addition, RHESSI should be enhanced above the “in-guide” level by \$200K/year and a RHESSI Guest Investigator program established.
12. SOHO should be funded at the “in-guide” level in FY04 and 05. SOHO should switch to more of an operational support mode in FY06 and 07 after Solar-B and STEREO come online. By switching to more routine operations fewer funds should be needed for mission planning. All funds saved from lower MO should go towards enhancing data products and their distribution and to the GI programs. Science funding for some of the SOHO science functions (UVCS, CDS, SUMER, and EIT) should be reduced in FY06 and go to the GI program.
13. The Panel recommends approval for a TIMED extended mission for three additional years until the second quarter of FY07. The TIMED science budget in FY06 and 07 should be reduced from the proposed amount and moved to the GI program.
14. TRACE should continue to be funded at in-guide levels, with possible additional funds for the data archive. The Panel encourages the TRACE team to continue to cut mission operation costs to free up money to improve the TRACE data archive in the ways described in the proposal.
15. Ulysses should be funded at the in-guide level though its return to the north solar pole in 2008 except that only minimal funding should be provided for the Jupiter encounter. Ulysses should look for ways to convert operational funds to data analysis.
16. Voyager should be supported at the “in-guide” level in FY04-06. Science operations should be continued until completion of a thorough review by the next Panel to insure the mission is still scientifically compelling. NASA should continue to seek ways to reduce MO and increase DA through the GI program.
17. Wind should be funded at the ‘in-guide’ level for FY04-07.