FINAL REPORT

Senior Review of
Sun-Earth-Heliosphere Connection
Mission Operations and Data Analysis Programs

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Senior Scientist for Space Science Research

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Introduction:

The Sun, which drives the physical processes occurring in our solar system, has distinct periods of activity. During the last several years, activity has been at a minimum. From now on, the activity will steadily increase peaking after the beginning of the millennium. The order and regularity of the Sun and the heliosphere at minimum, and the measured response of the Earth, will transition to the more chaotic circumstances of maximum conditions, with more dynamic and in many ways more important terrestrial responses.

NASA and its international collaborators, both through good planning and fortuitous circumstances, has had a **superb array of spacecraft strategically located** throughout the heliosphere and the near space environment of Earth, to study the Sun in minimum conditions, and the response of the Earth and the heliosphere:

- SOHO and YOHKOH to observe the solar interior and the solar atmosphere;
- ULYSSES to observe the three dimensional heliosphere;
- GGS, SAMPEX, FAST and IMP-8 to trace the flow of mass, energy and momentum throughout the near space environment of Earth; and
- VOYAGER to explore the distant heliosphere.

The **total investment** in this great, distributed observatory **exceeds $3 billion**, comparable to the Great Observatories of astrophysics. And as with the astrophysical counterparts, discoveries and new physical insight abound, and, most important, new quantitative insight has resulted on how the Sun and the Earth and the heliosphere are interconnected.

The growing public awareness of the significance of the information about the Sun and its influence that has been returned from this array of spacecraft is a direct measure of their importance. We are a technological civilization with infrastructure that is becoming increasingly sensitive to the environment of space and the changes therein. We are a civilization that is becoming increasingly aware of our dependency on the Sun and its variations, and curious as to the physical processes which drive its behavior and evolution. This sensitivity and curiosity is heightened when large solar events emit particles and radiation that impact and disturb Earth. Such events,

which occur infrequently near solar minimum, should be dominant near solar maximum.

An **opportunity** exists, **not to be repeated for generations**, to use this same array of spacecraft to study the Sun and the terrestrial and heliospheric responses, during the onset and peak of solar maximum conditions. Indeed, it can be argued that the **massive investment in these spacecraft will have been worthwhile only if** they are used to provide the **same level of information** on the important processes of **solar maximum, that they are currently providing on solar minimum**. For as the name implies, it is maximum solar activity that will have maximum impact on the Earth and the heliosphere, and whose behavior and consequences should be understood if the true connection among the Sun, Earth, and the heliosphere is to be determined.

The standard "mission extension paradigm" will not succeed.

It is not, however, a simple task to understand solar maximum — **simple extensions** of current missions, operated **at minimal budgets, will not succeed**.

- There is order and regularity and in many ways simplicity at minimum, but dynamic and multiply interacting processes at maximum.
- Indeed, it is fortuitous that the current array of spacecraft has been able to develop their procedures and **hone their analytic tools in minimum conditions**, in preparation for the **more chaotic circumstances** that will have to be analyzed **during maximum**. Based on this experience, great efficiencies will result.
- However, it is essential to recognize that the **problems of solar maximum are simply harder** — more complex phenomena occur, their range is more dynamic, there will be more confusion, and order and understanding will emerge only from systematic and coordinated observations and interpretations.

A new program - A Solar Maximum Campaign is required.

The assault on solar maximum needs to be treated as a new program — A **Solar Maximum Campaign**.

- A vibrant program is required, in which healthy space assets are adequately funded, and efforts are well-coordinated to return the maximum possible information.
- **There is only one foreseeable opportunity** to understand solar maximum. Solar maximum occurs only every eleven years; this array of spacecraft is unlikely to be repeated for generations, if ever.

- The Solar Maximum Campaign — the approach, the funding, the support throughout NASA and its international collaborators — must succeed. The foundation of knowledge that it will establish in the next few years will be the underpinning on which we will base our understanding of how the Sun and its connection to the Earth and the heliosphere impacts our technological civilization, and whatever adventures in space we choose to pursue.

This report constitutes a "Zero-Based Review" of what is required for a successful Solar Maximum Campaign.

It is in this spirit that the Senior Review has approached its task. We have reviewed each mission — SOHO, GGS, ULYSSES, SAMPEX, FAST, YOHKOH, and IMP-8 — and **determined the level of support that is necessary** from the United States to conduct a Solar Maximum Campaign that will be successful.

We present two levels of recommended support:

1. we present a **level** at which we can **reasonably guarantee** that the **Campaign will be successful** — that adequate coordination will occur among the various missions to reveal the complicated phenomena of solar maximum.
2. And second we present a **minimum level of funding below which the program will not succeed**.

The VOYAGER mission has a task which, in many ways, is distinct from the missions seeking to understand solar maximum — it is undertaking the important task of finding and observing the termination shock of the solar wind, and defining the interaction of the heliosphere with the local interstellar medium. The Senior Review has also determined the minimum funding level necessary for VOYAGER to achieve its goal.

The Senior Review Process:

- Each of the missions — SOHO, YOHKOH, ULYSSES, GGS, SAMPEX, FAST, and IMP-8 prepared a detailed **written proposal** describing their scientific accomplishments to date and their plans for studying solar maximum; in the case of VOYAGER, the plans for exploring the outer heliosphere.
- The Senior Review **Panel reviewed each of these plans** and conducted **oral interviews** with the Project Scientist and Project Manager, and with selected participating scientists.
- The **overall recommendations** of the Panel are listed below; **recommendations for each mission** are provided in the next section.

- In all cases the recommendations of the Panel are **unanimous**.

Overall Recommendations:

1. The full set of missions is required.

Each of the missions — SOHO, YOHKOH, ULYSSES, GGS, SAMPEX, FAST, and IMP-8 — **occupies a unique position in and has has unique capability** to contribute to the overall program to understand the Sun and its influence on the Earth and the heliosphere, during solar maximum conditions. There is **no redundancy or duplication** within this mission set or with the missions planned by NASA and its international partners, and the loss of any of these missions, by technical failure or funding inadequacy, would compromise an important aspect of the Solar Maximum Campaign.

The VOYAGER mission is currently pursuing the location of the termination shock of the solar wind, and defining the interaction of the heliosphere with the local interstellar medium. This quest has been underway for 20 years, and not to pursue it to completion would be unconscionable.

2. PI Teams must participate in data processing AND analysis.

The Senior Review Panel believes strongly that valid scientific data from the instruments on these missions can be obtained only if there is **active participation in the data analysis by the Principal Investigators and their immediate teams**, who are knowledgeable about the instruments. To do otherwise will result in data, and conclusions based on these data, of questionable integrity.

3. Definition of the minimum funding level.

Accordingly, in all cases, the **Review Panel defines the minimum level of funding** required for each mission to be that which will both provide for the acquisition of needed data, and will support the **active participation of the core elements of the Principal Investigator teams** in the analysis of these data. The Panel determined that the funding level for active participation of the Principal Investigator teams is roughly twice the funding level needed for data processing alone, and has set the minimum funding level for Data Analysis costs for each mission accordingly.

>> It should be recognized that in many cases the **minimum** level of funding **will not support all current Co-Investigators** and an active effort to determine the optimum investigator teams should be undertaken.

The minimum level of support required for each mission is listed in Table 1. Shown here are only costs attributable to the Office of Space

Science. The costs total to $211 million for FY98-01, including the costs required to complete current prime mission phases in FY98, and have an annual cost in FY99–01 of approximately $48 million. Although these costs are not trivial, neither are they large. On an annual basis they are only 1.5% of the $3 billion investment in these missions, which is exceedingly small in comparison with any other major NASA program.

4. Guaranteed-Success Level: The need for an Interdisciplinary Investigation Program.

The Senior Review Panel is convinced that the **range and difficulty of the problems** associated with solar maximum **exceed the capacity of the scientists directly involved in the minimum-level program**.

- To solve the **simpler problems** associated with **solar minimum**, some **350 scientists** have been engaged.
- In contrast, the minimum-level **solar maximum program** defined above will directly involve **only 200 scientists**.
- Accordingly the **Review Panel strongly recommends** to NASA that it establish an **Interdisciplinary Investigation Program**, which through competitive selection, will engage the broader scientific community to solve the important problems associated with solar maximum conditions. Broad expertise beyond that in the minimum level investigation teams is needed to interpret data from multiple spacecraft and other sources, and to carry out the essential interpretative theory and modelling. A more detailed description of this Interdisciplinary Investigation Program is provided in the next section.

The Senior Review Panel recommends that the Interdisciplinary Investigation Program ramp up to level funding at $15 million per year in FY99–01. Such **funding has significant leverage** — in the Panel's judgment, this funding, which is only 0.5% of the initial investment in these missions will **effectively double the scientific output** of the Solar Maximum Campaign.

The **total required funding** is thus approximately **$63 million per year** for FY99-01, for a total funding of $260 million for FY98–01. It is at this level, and only this level, that the Review Panel is prepared to guarantee that **an effective program to solve the most complicated**, but also the **most significant problems** in Sun-Earth-Heliosphere connections — how such connections occur during maximum solar activity — will in fact succeed.

5. Recommended Strategy in case of funding shortfall.

Finally, the Senior Review Panel recommends, in the event that all of the resources required in FY98-01 for a successful Solar Maximum Campaign are not available, that NASA pursue a strategy of **proceeding with the required program at the recommended funding level for as long as resources permit**. An extraordinary opportunity will be lost if the full program is not pursued through the expected solar maximum in 2001. However, it would be a greater tragedy not to use fully the available assets while they can be supported.

	Actual	Recommended Solar Maximum Campaign			
	FY97	FY98	FY99	FY00	FY01
	73.3M	69.3M	62.2M	63.7M	65.2M
Interdisc.Invest.Prg.		4.0M	15.0M	15.0M	15.0M
SOHO	18.5M	16.4M	12.0M	12.5M	13.0M
YOHKOH	2.9M	2.9M	3.0M	3.1M	3.2M
GGS	31.7M	27.1M	16.5M	17.0M	17.6M
ULYSSES	6.2M	6.4M	6.2M	6.2M	6.3M
FAST	4.5M	4.2M	2.6M	2.7M	2.7M
IMP-8	0.5M	0.8M	0.7M	0.7M	0.7M
SAMPEX	1.8M	1.3M	1.3M	1.4M	1.4M
VOYAGER	7.2M	6.2M	4.9M	5.1M	5.3M

Table 1.

Costs by mission and program to conduct the Solar Maximum Campaign. **Costs** include Mission Operations and Data Analysis which are **attributable to the Office of Space Science**. Costs for the DSN and other operational costs (provided by the Space Operations Management Office, SOMO) are not included above. It should be noted that most of the cost is for Data Analysis. As is described in the individual mission descriptions, the fraction of the costs for Mission Operations drops from 23% in FY97 to 18% in FY01.

INTERDISCIPLINARY INVESTIGATION PROGRAM

The number of scientists involved in the proposed minimum program to understand the Sun at solar maximum, and its influence in the Earth and the heliosphere, is not adequate. The opportunities are too great; the problems are too complex and numerous; the need to coordinate among multiple spacecraft observations, too demanding. The most straightforward method to acquire needed expertise is through a new competitive selection, in which scientists propose to attack specific problems not adequately addressed by the supported Principal Investigator teams, or, in particular, who propose to pursue problems

which require multiple and coordinated spacecraft observations. Accordingly, an Interdisciplinary Investigation Program is recommended in which such a selection occurs, and which provides multiple-year funding for these new investigators to pursue their tasks in cooperation with the Principal Investigator teams.

It should be recognized that the new investigations of the Interdisciplinary Investigation Program will place a demand on the Principal Investigator teams who will need to provide data and consultation, if the interdisciplinary investigators are to succeed. Equivalently, these demands represent legitimate and new costs to the Principal Investigator teams. Accordingly, it is recommended, as part of the proposal process for selecting participants in the Interdisciplinary Investigation Program, that these costs be identified, and where appropriate, provided as supplements to the Principal Investigator teams. Such reimbursement provides a meaningful incentive to full and active participation of the Principal Investigator teams in the Interdisciplinary Investigation Program, without compromising their active participation in the data processing and analysis.

	FY97	FY98	FY99	FY00	FY01
Interdisciplinary Investigation Program:					
S/Data Analysis	--	4.0M	15.0M	15.0M	15.0M

The total cost of a lean, but effective Interdisciplinary Investigation Program is estimated to be $15 million per year. It is recommended that the Interdisciplinary Program commence in FY98 at $4 million and obtain full funding in FY99–01. Even allowing for costs that need to be paid to Principal Investigator teams, the Interdisciplinary Program should provide approximately 125 additional scientists, which will cover the estimated shortfall in labor available to the Solar Maximum Campaign funded only at the minimum acceptable level. Funding of this additional labor force needs to be an ongoing and stable activity funded through multiple-year grants.

INDIVIDUAL MISSION CONTRIBUTIONS TO THE SOLAR MAXIMUM CAMPAIGN

SOHO

SOHO is a cooperative ESA-NASA mission and is the first space mission designed to investigate the Sun as a system from its core to the distant corona. Half-way through its initial two-year prime mission phase, and realizing only a small fraction of its full potential,

SOHO has already revolutionized our view of how the Sun works. SOHO's imaging capability strikingly conveys the importance and impact of the Sun to the public. SOHO's powerful suite of twelve instruments is very well suited to provide the foundation for Solar Maximum Campaign studies of the causes and impacts of the rising level of solar activity. During this rise, SOHO will continue to provide helioseismic information about the structure and dynamics of the convection zone and how specific activity originates and evolves near the surface. SOHO will provide measurements of the photospheric magnetic and velocity fields with unprecedented continuity. Images and spectra of the solar atmosphere and active regions at temperatures of 10^5 to 10^6 K will test and refine models of composition, evolution, and heating. Unprecedented coronagraph images will reveal the properties of coronal mass ejections and other activity in a corona that has proven to be more dynamic than anticipated even at low levels of solar activity.

During its first year of operation, SOHO has already demonstrated its ability to complement and benefit from other Sun-Earth-Heliosphere connections missions. During the Solar Maximum Campaign, SOHO, together with YOHKOH and TRACE, will give a first detailed view of the linkages of the hot (10^6–10^7 K) corona and the cooler (10^4–10^5 K) chromosphere with the photosphere below. Similarly, the observations from SOHO will reveal the origins of events and causes of variations in the heliosphere observed by the other Sun-Earth-Heliosphere connection missions. Complementary ground-based observations will provide measurements not being done in space and will enhance situations where the data transmission capability of SOHO is a limitation.

The minimum funding required for US participation in SOHO to complete its prime mission phase and to continue to provide crucial, valid data about the Sun is:

	FY97	FY98	FY99	FY00	FY01
SOHO:					
S/Dev't+Msn. Ops	3.0M	4.9M	0.2M	0.2M	0.2M
S/Data Analysis	15.5M	11.5M	11.8M	12.3M	12.8M
S/Total Rec'n	18.5M	16.4M	12.0M	12.5M	13.0M
SOMO costs	*12.1M*	*9.1M*	*12.3M*	*12.9M*	*13.5M*

This level is sufficient to maintain flight and experiment operation teams, US Principal Investigator and Co-Investigator team operations, and minimum support of Principal Investigator team science at a level below which the risk to the Solar Maximum Campaign is unacceptable. Of all the missions the Senior Review considered, SOHO is the one that would benefit most from the Interdisciplinary Investigation Program. This is because of the fundamental role the Sun plays in all heliospheric phenomena and the wide range of observations provided by SOHO.

YOHKOH

YOHKOH is a highly successful mission of ISAS with significant US participation. It is the only current space mission that provides measurements of the high energy and high temperature aspects of solar activity. The already outstanding scientific return from YOHKOH will be greatly enhanced during the Solar Maximum Campaign because of the opportunity to co-observe with new Sun-Earth-Heliosphere connection missions not previously available. Without the high-energy measurements provided by YOHKOH, Sun-Earth-Heliosphere studies would be seriously hampered during the Solar Maximum Campaign. YOHKOH provides the first opportunity to observe the rise to a solar cycle maximum with high-quality x-ray instruments. Prior measurements of flares have suggested that giant flares are not simply larger versions of small ones; this important idea will be tested. From YOHKOH observations, reconnection appears to be a key process in flares and Coronal Mass Ejections. Observations during the different magnetic topology existing during the rise to maximum activity may alter our current understanding which is now based solely on observations during the decline from maximum activity.

The greatest benefit of YOHKOH to the Solar Maximum Campaign will come from combining its observations with new space and ground-based observational capabilities. These capabilities will place the high temperature and energy processes observed by YOHKOH into a context that reaches all the way into the solar interior and all the way to Earth and beyond. While SOHO and TRACE will be the main links to the rest of the Solar Maximum Campaign, YOHKOH observations of flares and other powerful events are important to all components of the Campaign.

YOHKOH will continue its outstanding success in capturing the public attention of the importance and excitement of solar research through its attractive scientific products and strong outreach program.

The minimum funding required to continue US participation in the YOHKOH mission during the Solar Maximum Campaign is:

	FY97	FY98	FY99	FY00	FY01
Yohkoh					
S/Dev't+Msn. Ops	1.0M	1.0M	1.0M	1.1M	1.1M
S/Data Analysis	2.0M	1.9M	2.0M	2.0M	2.1M
S/Total Rec'n	2.9M	2.9M	3.0M	3.1M	3.2M
SOMO costs	*2.0M*	*1.9M*	*2.0M*	*2.0M*	*2.1M*

This level is sufficient to preserve the close and successful scientific cooperation with Japan, maintain cost-effective mission operations, and it allows the Principal Investigator teams to both analyze and produce scientific results and to help other scientists use YOHKOH data productively. The Interdisciplinary Investigation Program will enable YOHKOH observations to be linked with lower energy phenomena at the Sun and in the heliosphere.

GGS

The GGS trio of spacecraft was designed specifically to attack the end-to-end problem of how solar outputs affect Geospace. GGS-WIND measures the constantly changing solar wind conditions that control the configuration and behavior of the magnetosphere, and detects bursts of arriving energetic particles. GGS-POLAR instruments obtain observations of the dynamic response of near-Earth space to solar and interplanetary conditions, including images of visible, ultraviolet and x-ray auroral emissions that accompany disturbed periods. GGS-GEOTAIL, a cooperative venture with Japan, probes a critical geospace region where energy is first drawn from the solar wind interaction in the Earth's magnetotail. Complementary theory and ground-based observer investigations, respectively, provide global visualizations and local perspectives of Earth's response to events on the Sun. The close coordination of the spacecraft investigations with the theory and ground-based contributions is unique in the history of Sun-Earth-Heliosphere research.

The GGS concept has already demonstrated its capabilities in its prime mission (solar minimum) years with a WWW-based information system that covered the recent "space weather" disturbances resulting from several moderate solar outbursts. Users of this system included scientists and space environment applications specialists, but also the media and the interested public. The organizing effect of this event response system, which includes a range of relevant documentation, WWW pointers, and event-specific summary data (from within and outside of the GGS "family") spanning the surface of the Sun to the surface of the Earth, serves as an example of what can be done as solar events become more intense and more frequent during 1998–2001. As such, GGS has already established itself as a backbone of what will become the broader Solar Maximum Campaign described here.

GGS has not yet had the opportunity to exploit fully coordinated multipoint observations with other spacecraft. Among those currently available or expected to be operating by the Solar Maximum are: the FAST Explorer, which would allow diagnosis of the physics leading to the auroras that GGS-POLAR images; TIMED, which will remotely sense the energy deposited in the upper atmosphere in association with conditions that GGS observes; Equator-S, a soon-to-be-launched equatorial magnetospheric spacecraft which supplies a low latitude perspective missing in the GGS trio; IMAGE, which would permit the first stereoscopic energetic neutral particle imaging of the Earth's ring current when paired with GGS-POLAR; and CLUSTER, which allows simultaneous probing of key magnetospheric boundaries while GGS is establishing the larger picture of magnetospheric conditions. Indeed measurements such as these, called out as high priorities for the discipline in recent NRC reports, will be particularly challenging at solar maximum when auroras, ring currents, and radiation belts are more intense on average, and when frequent coronal eruptions keep the magnetosphere in a particularly dynamic state.

GGS is a three-spacecraft enterprise that has barely scratched the surface of its potential for discovery in the solar minimum prime mission, whose demands for rapid-turnaround results are certain to increase with solar activity, and whose assets are viewed as both the US contribution to the ISTP (with SOHO) and, among other participating agencies, as a NASA

solar maximum contribution to the National Space Weather Program. The Senior Review Panel recommends that the minimum funding required for GGS to complete its current prime mission phase and to continue to provide crucial, valid data is:

	FY97	FY98	FY99	FY00	FY01
GGS:					
S/Dev't+Msn. Ops	5.0M	4.2M	2.8M	2.9M	3.0M
S/Data Analysis	26.7M	22.9M	13.6M	14.1M	14.5M
S/Total Rec'n	31.7M	27.1M	16.5M	17.0M	17.6M
SOMO costs	*9.2M*	*9.5M*	*9.8M*	*10.2M*	*10.6M*

This funding is the minimum required in order that the US Principal Investigator and Co-Investigator teams can perform their necessary functions of being active particpants in the analysis and interpretation of GGS data.

The Senior Review Panel further recommends that the information and observation coordination function for the Solar Maximum Campaign be expanded to include appropriate interfaces with the SDAC at GSFC and archived Sun-Earth-Heliosphere connections data useful for establishing solar cycle trends and cycle-to-cycle variations. The latter could be accomplished via either incorporation of the present Space Physics Data System organization at GSFC into the present GGS project information and data system, or by a comparable external coordination activity arising as part of the Solar Maximum Campaign.

Finally, as for SOHO, GGS will particularly benefit from the Interdisciplinary Investigation Program, which will provide new expertise to address the new and complex sun-earth connection problems of solar maximum, and which will facilitate the use of GGS data, which is of central importance, in the broader studies of the Solar Maximum Campaign.

ULYSSES

ULYSSES was launched in October 1990 on a voyage into the uncharted space above the poles of the Sun. About all that was known of these regions was the prevailing high speed solar wind (600–800 km/sec) from the polar coronal holes (from radio scintillation data) and a radial magnetic field, in contrast with the frequent low velocity solar wind streams (300–400 km/sec) and the tightly-wound spiral magnetic field at low latitudes.

ULYSSES achieved its 4-year orbit over the poles of the Sun with a gravity assist from Jupiter in February 1992, flinging the ULYSSES spacecraft into an elliptical orbit with aphelion at the orbit of Jupiter (5 AU) and perihelion at about 1 AU. ULYSSES passed over the south polar region of the Sun during June–November 1994 at a radial distance of 1.4 AU. and over the north polar region during June–September 1995 in the years of low solar activity (minimum in 1996).

The ULYSSES mission, to explore the unknown dynamical conditions in space expected on this unique voyage, was conducted as an international effort between NASA and ESA. Equipped with an array of state-of-the-art instruments, ULYSSES records the solar wind speed, density, temperature, and ion composition, pick-up ions and neutral helium from interstellar space, the energetic electrons and ions, the energy and isotopic composition of the galactic cosmic rays and the anomalous cosmic rays, the vector magnetic field, and plasma waves and radio waves. It is no coincidence, then, that along the way the ULYSSES instruments provided answers to a number of pre-existing questions, e.g., the helium-3 content of interstellar gas and the relative abundances of the iron and nickel isotopes among the cosmic rays, the latter showing that the cosmic rays come from ordinary interstellar matter rather than from the interior of a supernova. In passing over the poles of the Sun, ULYSSES found that the galactic cosmic ray intensity is only a little higher than at low latitudes in spite of the open radial magnetic field extending to the outer heliosphere. ULYSSES encountered the blasts from coronal mass ejections at all latitudes, with a new class of over-expanded ejections appearing at high latitudes. It was a particular surprise to find that the effects of corotating interplanetary structures of forward and reverse shocks, which occur in the spiral stream patterns at low latitudes, extend into the highest latitudes, which suggests that there are efficient mechanisms for connections among latitudes, not previously expected.

The exploration of ULYSSES to date has been during the quiet years of solar minimum when conditions in the heliosphere were relatively calm. The next pass around the Sun brings ULYSSES over the south polar region during September 2000–January 2001 and over the north polar region during September–December 2001 in the more turbulent years of solar maximum. We should anticipate complex processes and phenomena, with unanticipated characteristics.

ULYSSES is our one scientific opportunity to explore and understand the conditions in the heliosphere at high latitudes and its relation to low latitude activity, at all levels of solar activity. It is imperative that this exploration both be pursued vigorously, and in coordination with the Solar Maximum Campaign. Conditions at low latitudes will then be thoroughly studied at the same time so that precise associations and comparisons can be made between low and high latitudes, to the advantage of both studies. Done correctly, the successful completion of the ULYSSES mission will go down in history as one of the major feats of space exploration.

The operational cost of the ULYSSES mission has been substantially reduced through critical reorganization of personnel and data handling. Any further reductions in the budget will rapidly eliminate the science, making the operational expense more difficult to justify.

The minimum funding required for the participation of the United States in the ULYSSES program is:

	FY97	FY98	FY99	FY00	FY01
ULYSSES:					

S/Dev't+Msn. Ops	1.2M	1.3M	1.3M	1.4M	1.4M
S/Data Analysis	5.0M	5.1M	4.9M	4.8M	4.9M
S/Total Rec'n	6.2M	6.4M	6.2M	6.2M	6.3M
SOMO costs	*3.6M*	*3.8M*	*3.9M*	*4.1M*	*4.2M*

In view of the central role played by ULYSSES in providing a unique data set on conditions out-of-the-ecliptic, and on the impact of these data on many other studies in Sun-Earth-Heliosphere connections, the Senior Review Panel recommends a substantial participation in the Inter-disciplinary Investigation Program to provide both more scientific analysis, and more linkage to the observations of other missions, than is permitted by the minimal budget.

Fast Auroral SnapshoT (FAST) Small Explorer Mission

FAST was launched into polar orbit in August 1996 near solar minimum as part of the Small Explorer (SMEX) program. It is still in its prime phase of operations. The mission objective is identify the physical processes responsible for accelerating auroral particles. To do this FAST simultaneously measures at very high rates (1) the fluxes and energies of electrons and ions entering and leaving the ionosphere, (2) the masses of energetic ions, (3) electric fields, and (4) magnetic fields. The particle measurements indicate how much they were accelerated and where they originated. The field sensors allow FAST to perform as a combination voltmeter and ammeter that measures how the high-latitude ionosphere and the distant magnetosphere are electrically connected. They also act as antennas that listen to radio waves emitted by the accelerating auroral particles.

Early measurements from FAST have radically improved understanding of how electrons must be accelerated to form aurora and to support the currents that flow in the auroral circuit. During the Solar Maximum Campaign, FAST will help us to understand (1) how auroral acceleration processes vary with altitude, season and phase of the solar cycle, (2) the efficiency of energy transport from the solar wind to the ionosphere, and (3) the total amounts of particle and electrical energy deposited in the upper atmosphere. The third item is critical for quantitative interpretation of measurements from the TIMED satellite.

The Senior Review Panel recommends that FAST operations and data analysis be funded at the levels:

	FY97	FY98	FY99	FY00	FY01
FAST:					
S/Dev't+Msn. Ops	1.0M	0.9M	0.5M	0.6M	0.6M
S/Data Analysis	3.5M	3.3M	2.1M	2.1M	2.1M
S/Total Rec'n	4.5M	4.2M	2.6M	2.7M	2.7M
SOMO costs	*1.6M*	*1.1M*	*0.5M*	*0.5M*	*0.5M*

The Panel also recommend that the analysis of FAST data be enhanced through vigorous participation in the Interdisciplinary Investigation Program.

IMP-8

After 24 years in orbit, IMP-8 continues to transmit measurements of magnetic fields, plasma, energetic particles and cosmic rays to ground VHF stations with about 80% coverage. Approximately 60% of the data is from the solar wind and 40% from the magnetosheath and magnetotail. It represents an important and very frugal contributor to the data sets of the ISTP/GGS and the Sun-Earth-Heliosphere connections programs as we approach solar maximum. In particular, its proximity to the magnetosphere makes it a reliable indicator of the upstream solar wind affecting the magnetosphere and, in addition, it will provide overlap with WIND and ACE and hence continuity to the observations of very large solar cosmic ray events and galactic cosmic rays.

IMP-8 has been the satellite of choice for many correlative studies. It is being used as a baseline for exploratory missions such as VOYAGER and ULYSSES. As a result, the publication rate of IMP-associated studies averaged 40 per year over 18 years and peaked at over 100 in 1995. It is likely that this increased demand will continue in view of the high level of satellite activity in the next few years until solar maximum.

In recent years, the effort of the science team has been almost entirely consumed in responding to requests from other projects. The Senior Review Panel believes that there should be a minimal level of IMP-initiated science and hence recommends the following program:

	FY97	FY98	FY99	FY00	FY01
IMP-8:					
S/Dev't+Msn. Ops		0.2M			
S/Data Analysis	0.5M	0.6M	0.7M	0.7M	0.7M
S/Total Rec'n	0.5M	0.8M	0.7M	0.7M	0.7M
SOMO costs	*1.0M*	*1.0M*	*0.9M*	*0.9M*	*0.9M*

The IMP-8 project is seen as an integral part of Interplanetary Investigation Program and should have access to the resources of that program.

SAMPEX

From a polar orbit just above Earth's atmosphere, SAMPEX measures energetic particles that are of great scientific interest in many respects. SAMPEX measures anomalous and galactic cosmic rays, using Earth's magnetic field as a mass spectrometer. It also provides images of Earth's ring current in energetic neutral atoms.

In addition to this scientific interest, energetic particles are also an important element of space weather: they must be understood so that they their occurrence can be reliably forecast.

Since its launch near solar minimum, SAMPEX has measured dramatic variations in the outer-radiation-belt electrons — often called "killer electrons" because of their effects on communication satellites. Learning to predict when electron fluxes will reach levels that endanger spacecraft will require careful event studies that combine low-orbit SAMPEX observations with higher-altitude data from POLAR and other spacecraft; such studies must be performed for the great events near solar maximum. It has also been determined that energetic ions from the Sun could pose a danger to Space Station astronauts, and SAMPEX-type instrumentation may be capable of providing useful warnings. Furthermore, correlations of SAMPEX and UARS data have provided evidence that the energetic electrons that rain down on the atmosphere from the magnetosphere may affect the ozone that shields us from the Sun's ultraviolet radiation; this connection needs to be understood, particularly for conditions of solar maximum.

The cost of maintaining the SAMPEX scientific program through solar maximum is modest:

	FY97	FY98	FY99	FY00	FY01
SAMPEX:					
S/Dev't+Msn. Ops	0.5M	0.3M	0.3M	0.3M	0.3M
S/Data Analysis	1.3M	1.1M	1.1M	1.1M	1.2M
S/Total Rec'n	1.8M	1.3M	1.3M	1.4M	1.4M

Most SAMPEX research will center on correlations with data from other spacecraft, and the Senior Review Panel recommends that the SAMPEX mission play an active role in the Interdisciplinary Investigation Program. The Panel specifically recommends a test of the effectiveness of a SAMPEX-based early-warning system for Space Station astronauts.

VOYAGER

The major event eagerly awaited of the VOYAGER mission in the years immediately ahead is the encounter with the termination shock that marks the first step in the transition from the outer heliosphere to the interstellar medium. Identification of the termination shock and confirmation of its role in acceleration of the anomalous cosmic rays, will constitute a milestone in solar system exploration. Because the position of the termination shock cannot be predicted accurately, continuous operation of the spacecraft is absolutely essential.

In addition to the search for the termination shock, the VOYAGER mission is making unique measurements on the evolution of the solar wind and the shock waves that propagate within it, as well as on galactic cosmic ray composition and modulation.

The minimum level of funding for the VOYAGER mission to continue to pursue its pioneering exploration of the outer heliosphere is:

	FY97	FY98	FY99	FY00	FY01

VOYAGER:

S/Dev't+Msn. Ops	4.9M	3.9M	2.4M	2.5M	2.6M
S/Data Analysis	2.3M	2.4M	2.5M	2.6M	2.7M
S/Total Rec'n	7.2M	6.2M	4.9M	5.1M	5.3M
SOMO costs	*10.3M*	*18.9M*	*11.0M*	*15.9M*	*16.4M*

The Mission Operation costs recommended here are below those currently expended or planned to be expended by the VOYAGER project. The Panel believes that the above costs can be achieved by reducing the management portion of the operational budget, in particular through the consolidation of the VOYAGER and ULYSSES projects, and urges that this cost-savings activity be pursued. It is essential that the Data Analysis funds recommended be maintained.

Active participation in the Interdisciplinary Investigation Program would significantly enhance the science return, in particular regarding the linkage to other missions that are also concerned with solar wind structure, interplanetary shocks, and anomalous cosmic rays.