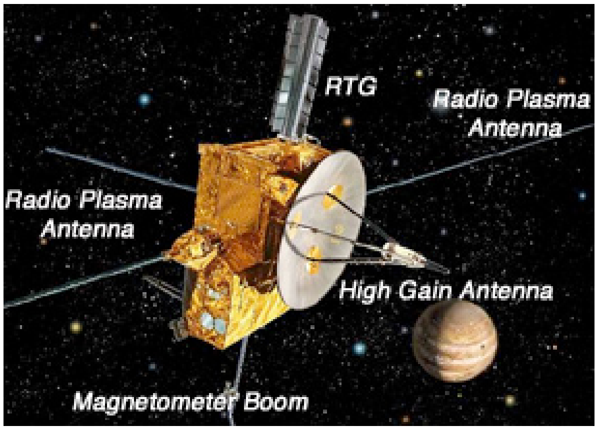

Figure 9.1 The Ulysses spacecraft.

TECHNICAL AND BUDGET

9. *Mission Description*

Ulysses is a project of international cooperation between NASA and ESA. ESA provided the spacecraft. NASA provided the Radioisotope Thermoelectric Generator (RTG), the launch vehicle, the Inertial Upper stage (IUS), and the Payload Assist Module (PAM-S), and is providing data reception via the Deep Space Network. The NASA portion of the mission is managed at the Jet Propulsion Laboratory (JPL). The spacecraft control center is located at JPL where an ESA Spacecraft Team, and a JPL Ground Operations Team jointly conduct mission operations. NASA and the European space science communities each provided about half of the ten scientific instruments and support the investigators who reduce, analyze, and archive the data and report science results. Each science team is a combined NASA/ESA effort, consisting of both U.S. and European team members. Co-investigators are about evenly divided between the United States and ESA member nations.

The Ulysses spacecraft (Fig. 9.1) is highly reliable, radiation resistant, spin stabilized (~5 rpm) and had a mass at launch of approximately 370 kg (814 pounds), including about 33.5 kg of hydrazine for attitude and spin-rate adjustments. The spacecraft's main elements are the box-like main body structure on which is mounted the 1.65 meter, Earth-pointing high-gain antenna that provides the communications link, and the RTG that supplies the electrical power. A 5.6-meter radial boom keeps three groups of experiments sensors (two solid state X- and gamma ray detectors, a tri-axial search coil magnetometer, a vector-helium magnetometer and a flux-gate magnetometer) well away from the spacecraft to avoid electromagnetic interference and to minimize the RTG radiation environment. A pair of monopole wire boom antennas with a combined length of 72 meters, extends outward perpendicular to the spin axis and a single 7.5 - meter monopole axial boom antenna protrudes along the spin axis opposite the high gain antenna to form a long, three-axis radio wave/plasma wave antenna. Experiment electronics and spacecraft subsystems are enclosed in the main body. Maximum continuing data coverage throughout the mission is a prime scientific requirement. To provide for continuous scientific data coverage, two redundant tape recorders are included. When not in contact with a ground station, data are stored on-board and replayed, interleaved with real-time data during periods of ground contact. The radio link between the spacecraft and Earth operates in X-band (downlink) and S-band (uplink and downlink). The downlink provides for telemetry data from 64 to 8192 bits/second. The prime data rates are 1024 bits/second for real-time and 512 bits/sec for stored data. Commands and ranging signals are sent to the spacecraft via the S-band link. The ten Ulysses operational instruments are listed in Table 1.1.

The spacecraft, launched in October 1990, used a gravity assist at Jupiter to attain an elliptical orbit inclined 80^{o} to the solar equator with perihelion near the orbit of Earth and aphelion near the orbit of Jupiter (Fig. 1.1). The primary mission ended in November 1995 after completion of the first ever solar polar passes. In July 2004, it will have completed two solar orbits, including south and north polar passes in 1994 and 1995 during minimum solar conditions and in 2000 and 2001 during the maximum portion of the solar sunspot cycle (Fig. 1.2). The spacecraft is currently descending from the northern hemisphere and will reach aphelion in the summer of 2004.

The spacecraft is performing well. There have been only two anomalies of any significance since launch and procedures and/or plans are in place to work around any reoccurrences.

Nutation. Shortly after deployment of the axial boom, build-up of a nutation-like disturbance was observed. This was the result of an oscillation induced by non-uniform solar heating of the axial boom coupling into the spacecraft motion, together with under-performance of the passive nutation dampers on board the spacecraft. The onboard CONSCAN system, in conjunction with continuous Deep Space Network (DSN) uplink, has been successfully employed to control subsequent episodes of nutation, which occurred in 1994 and 1995 and again in 2000 and 2001. Nutation is predicted to return in 2007, however, techniques developed during the previous two nutation seasons will allow nutation to be controlled without continuous use of DSN resources.

EPC2/TWTA2: An autonomous switchover from the prime Electronic Power Converter 2/Traveling Wave Tube Amplifier 2 to EPC1/TWTA1 occurred on 15 February 2003. A planned switchback to the primary units was unsuccessful. Though analysis is on-going, there is a possibility that there will not be a backup for the duration of the mission. The spacecraft has operated on EPC2/TWTA2 for most of its 12.5 years of orbital life. It is expected that the lifetime of EPC1/TWTA1 will be adequate to complete the proposed mission.

In addition, there have been:

Disconnect Non-Essential Loads (DNEL). The DNEL condition is a spacecraft safing mode, and is known to be associated with operation of the latching valve when coinciding with unpredictable peaks in payload current demand. Overcurrent criteria are violated, and the onboard protection logic correctly operates, placing the spacecraft in a minimum current demand mode by disconnecting the scientific payload. To date, 8 DNEL events have occurred. Recovery and return to science operations have been quick – less than 24 hours in most recent cases and operational procedures exist to minimize chances of reoccurrence.

All instruments are performing normally and are fully capable of performing the current mission and the proposed extension.

Expendables are adequate to continue operations through 2008; however, power and thermal conservation will be required, particularly during periods when the spacecraft is far from the Sun. A study recently completed by the Mission Operations Team concluded that it is technically feasible to continue science operations through 2008. The team, working with the investigators, has also developed a power-sharing plan that allows the core instruments to operate continuously.

The operations team has essentially been in place since the beginning of the mission and has successfully operated the spacecraft throughout that time. No significant changes to the team are expected.

10. *Project Management*

The Ulysses mission is jointly managed in accordance with the Memorandum of Understanding (MOU) between NASA and ESA. Letters to extend the original MOU have been exchanged by NASA and ESA. These procedures will be used for any future extensions. Under the provisions of the MOU, a joint mission operations team resides at JPL. The NASA Ground Operations Team provides for tracking and data reception, navigation and data records processing. An ESOC Spacecraft Operations Team, complemented with NASA controllers, is responsible for spacecraft operations.

A project manager, assigned to JPL's Astronomy and Physics Directorate (APD), manages the U.S.

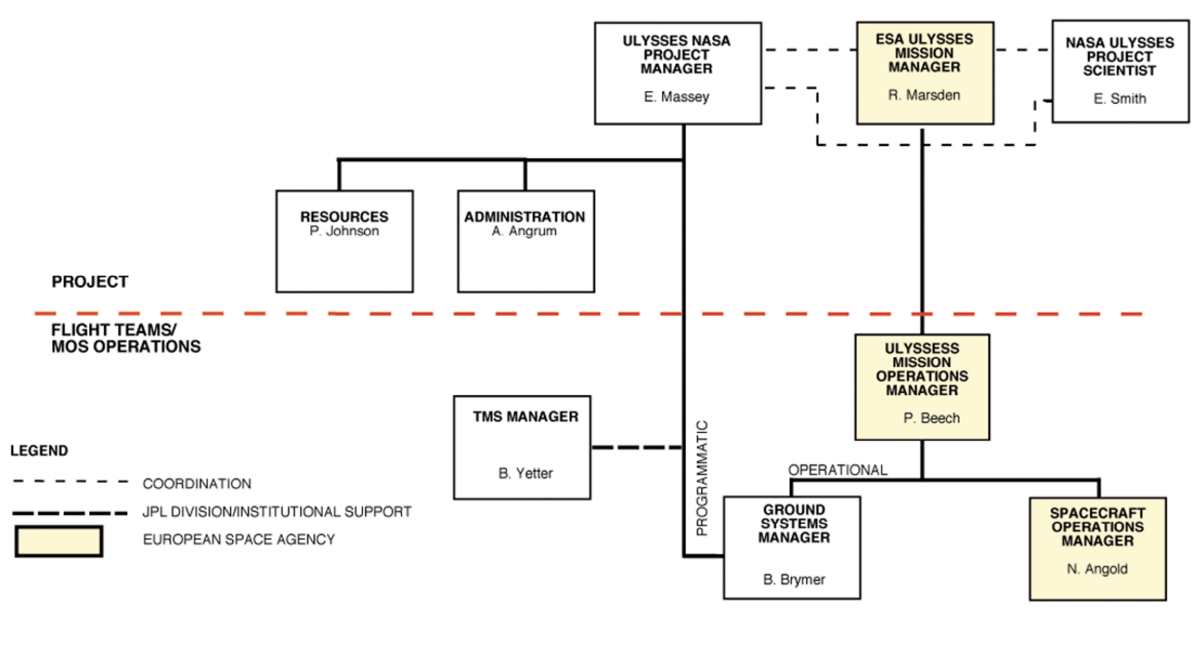

Figure 10.1:Ulysses Project Organization

portion of the project. A project scientist, who is also a co-investigator, has been assigned from the Engineering and Science Directorate by the Chief Scientist at JPL. Within ESA, a Mission Manager, combining the functions of Project Manager/Project Scientist, has been assigned from the Solar and Solar-Terrestrial Missions Division of the Research and Scientific Support Department in the Science Programme Directorate. The ESA Director of Technical and Operational Support has assigned the Mission Operations Manager who resides in JPL. The project organization is shown in Fig. 10.1.

Two mechanisms for management coordination are the Joint Working Group (JWG) and the Science Working Team (SWT) (Fig. 10.2). The JWG, co-chaired by the project managers, provides a management review and interfacing function for joint project efforts. It defines overall mission policy and approves long-term mission planning. The SWT is co-chaired by the project scientists. The SWT establishes scientific priorities and originates scientific decisions and recommendations. It also monitors mission results and advises the JWG on the conduct of the mission.

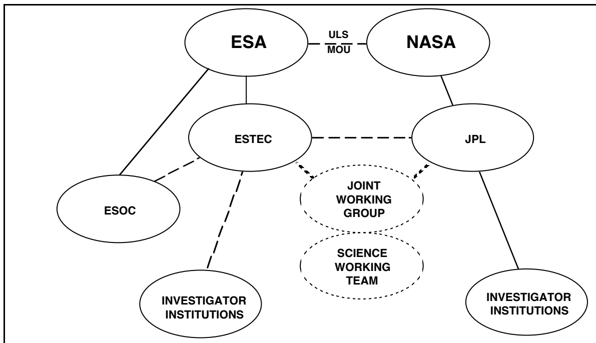

Figure 10.2: Management Organization.

11. *Mission Operations & Data Management*

11.1 Operations Concept

Mission operations are designed to minimize the number of personnel and costs. The Ulysses scientific goals require long and continuous science data acquisition. While there are no high intensity science sequences, occasional commanding of the instruments is required to initiate in-flight calibrations or to reconfigure the instruments. The need for rapid or frequent interactions between the experimenters and the mission control team is practically non-existent, so there is no formal science team as part of the operations organization. During normal operations, the spin axis must be precessed every several days to continuously point the high-gain antenna toward Earth. The Mission Operations Team is responsible for spacecraft health and for maximizing the acquisition of science data. No separate spacecraft analysis team or sequence team is used.

The spacecraft is nominally tracked by the DSN for 10 hours per day, adequate to receive all relevant science data, uplink necessary commands, monitor spacecraft maneuvers and other health and status parameters, and to read out the recorded data.

Operations will continue in this mode through September 2004. The Mission Operations Team has completed a comprehensive study and, for the proposed mission extension, divided the period from 2004 through 2008 into four distinct phases (Fig. 11.1).

11.1.1 Phase 1: Slow Latitude Scan, 1 October 2004 – 17 November 2006

In this phase continuous data at a lower bit rate would be taken. Payload power sharing would be required to maintain minimum power in the internal power dumpers. Only the core instruments would operate continuously. Open-loop slews for Earth-pointing would be performed on approximately 2-4 day intervals. DSN support would be halved from previous support to 70 hours in each 14-day period.

11.1.2 Phase 2: Third South Polar Pass, 17 November 2006 – 3 April 2007

Continuous data taking at the standard rate is required and DSN support would return to the standard 70 hours every 7 days. In February 2007, nutation would return and last for approximately a year. But, since attitude reconstruction software will be available, nutation levels could be allowed to build up between passes without undue impact to science return. Operational tools developed during the last nutation period provides assurance that nutation can be controlled without continuous uplink coverage. The DSN support requirements will not be increased during this or any other phase solely due to nutation. During the nutation period, Earth-pointing will be accomplished by closed-loop conscan. Cold case heaters must remain on, so payload power sharing will be required. Again, only the core instruments would operate continuously.

11.1.3 Phase 3: Fast Latitude Scan, 3 April 2007 – 30 November 2007

In this phase, data return and minimum tracking requirements are identical to Phase 2, 70 hours per week. Thermal predictions indicate that the cold-case heater can be switched off for almost this whole period, allowing for full payload operation during most of the phase. Nutation operations, as described for Phase 2, will continue during this period.

11.1.4 Phase 4: Third Northern Polar Pass, 30 November 2007 – 15 March 2008

Science data requirements and minimum DSN support requirements are identical to Phase 2. It will not be possible to keep the cold-case heater off during the entire period, so instrument power sharing will be required, but only near the end of this phase. Nutation continues until February 2008 when Earth-pointing will again be performed using open-loop skews.

11.2 Data Processing and Distribution

Figure 11.2 illustrates the processing of Ulysses telemetry into data records and finally into archival products. The data stream, supplemented by DSN station generated data, is formatted into data blocks and transmitted to JPL's Advanced Multi-mission Operations System (AMMOS). At JPL, all Ulysses data blocks are forwarded to the Ulysses Mission Control System (UMCS) computer. Concurrently, all Ulysses blocks are recorded at the pre-processor level for periodic transfer to the Data Records System (DRS) which generates Experiment Data Records (EDR), i.e., the records containing science data; Quicklook EDRs, and Supplementary Experiment Data Records (SEDR), i.e., records containing spacecraft trajectory and attitude data. The DRS also makes and archives EDRs containing stand-alone engineering data frames. Both EDRs and SEDRs are distributed to Principal Investigators and other identified data users.

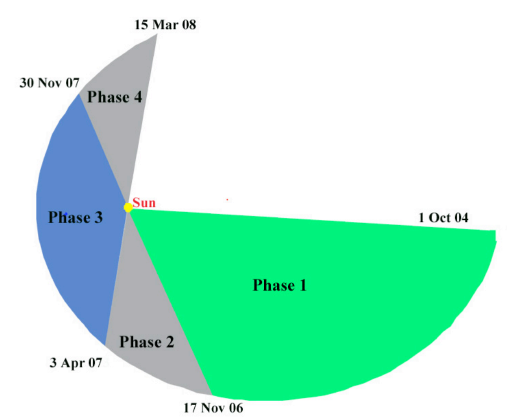

Figure 11.1: Phases of the mission extension.

The Common Data Records (CDRs) are a non-validated set of key scientific parameters for use in event selection by the Ulysses investigators for further analysis. Common Data Records are being routinely produced and delivered on CDROM within two months of EDR processing.

Production and distribution of these data records are the responsibility of the JPL Ulysses Data Management Team (DMT). Data are made available online electronically and delivered on CDROM. The CDROM is distributed to the Principal Investigators and data archives at the National Space Science Data Center and ESA's Ulysses Data System. Only the SEDRs are considered suitable for archiving; science data are provided to the archives by the investigators.

11.3 Science Data Management

The Ulysses Science Data Management Plan outlines the responsibilities of the investigators with regard to the management of scientific data resulting from the conduct of the Ulysses mission. Their responsibilities, summarized here, may be categorized as data reduction, data analysis, reporting of results and archiving.

Data reduction involves the conversion of the digital telemetry data into measurements in physically meaningful units based on pre-flight and in-flight calibrations. It includes transformation of the measurements, as appropriate, into physically significant coordinate systems (such as solar-heliospheric coordinates), and averaging of such measurements over time (e.g., one minute, one hour averages) and the derivation of related quantities (such as angles, degree of anisotropy, variances). This process also includes analyses of the data and the instruments required to validate the data. Validation ensures that the instrument's background noise and other variables are properly accounted for in the data to be used for scientific analysis by the co-investigators and, eventually the larger scientific community. The Principal Investigators are responsible for making these validated reduced data available to their Co-Investigators and to the appropriate institutions for archiving.

The Principal Investigators are also responsible for organizing the efforts of their teams to analyze and interpret their data and to report their findings in a timely manner. The analyses are carried out at the institutions to which the Principal and Co-Investigators belong. With members of their teams, they are required to participate, as appropriate, in making those results available to the general public through press conferences, news releases and interviews. They participate in special sessions of scientific conferences at which scientific results from the project are presented. There also are special publications, generally agreed upon by the SWT, to which they and their teams contribute. They also publish their results as a series of articles in scientific journals on a schedule of their own choosing. Since 1992, the publications have continued at a high rate. During 2001-02, the Ulysses Team has

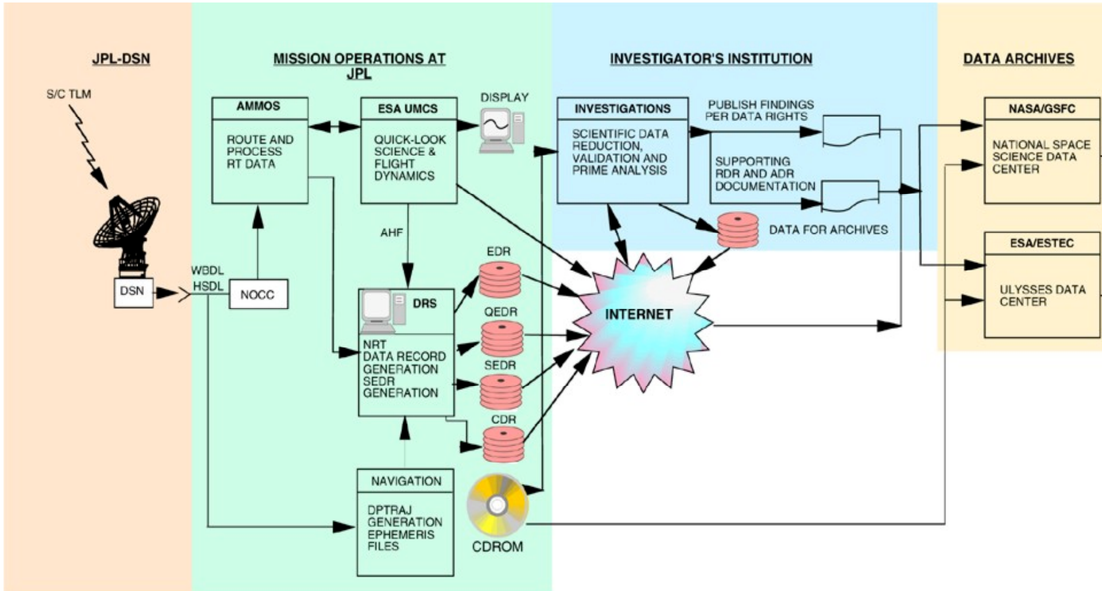

Figure 11.2: Data Processing and Distribution

published 100 refereed articles and another 43 have been refereed or submitted for refereeing in FY03 (see Fig. 11.3). In addition, they have participated in special sessions at the Spring 2001 AGU meeting, the EGS 2002 General Assembly and the 2002 COSPAR meeting, presenting a total of about 70 papers and posters.

A major function of the SWT is the planning of inter-experiment correlative studies. The SWT has defined the contents of the Common Data Record and established guidelines for its use. The SWT also participates in decisions as to when and where the scientific results will be presented and published and in the planning and implementation of workshops intended to address specific topics. In addition to the special sessions mentioned above, the group [has in progress] special issues of *Annales Geophysicae*, *Geophysical Research Letters* and, jointly with Voyager and ACE, the *Journal of Geophysical Research* (JGR).

The Ulysses PIs are required to supply archival data directly to the NSSDC and the Ulysses Data System (UDS) at ESTEC. Each PI has recommended which of his data products would be made available in a form usable by other scientists and has negotiated an agreement with the NSSDC and UDS on products provided and their formats. The investigators are committed to submit validated data to the archives as quickly as possible. The complexity of the data, and the need to remove any anomalous portions, require substantial analyses and utilization of these data by the cognizant instrument teams. Validated data are submitted to the archives within a year after first reception (data through December 2002 have been submitted to the NSSDC). The SWT monitors the status of submittals at its biannual meetings. The web site at http://spdf.gsfc.nasa.gov/SPD.html provides a summary of data availability. Archived data can be accessed at the NSSDC Master Catalog (http://nssdc.gsfc.nasa.gov/nmc/tmp/1990-090B.html) and the ESA Ulysses Data System (http://helio.estec.esa.nl/ulysses/archive/). In addition, various teams provide access to data at their web sites (Table 1.1). Direct links to the data are at http://ulysses.jpl.nasa.gov/science/data.html

Ulysses participated in the Heliospheric Missions Guest Investigation Program that ended in FY2000. This program led to many collaborative efforts, several of which still continue. The project now participates in the SEC GI, LWS, and SR&T programs. Ulysses has always embraced the active participation of the broad science community. There are close collaborations with other missions investigating the Sun and the heliosphere, including ACE, SOHO, Voyager, and WIND. A heliospheric science workshop, held in conjunction with Voyager and ACE in the fall of 2001 is one example. The special JGR issue on the heliosphere and its interaction with the interstellar medium is one of the projects resulting from that workshop. Another is a CDROM tutorial on heliospheric science, released as part of the Voyager 25th Anniversary commemoration. A complement of European Guest Investigators participates in the Ulysses data analysis and has been a motivation for the collaborations with SOHO and ACE. ESA expects to continue supporting their GI programs in the future.

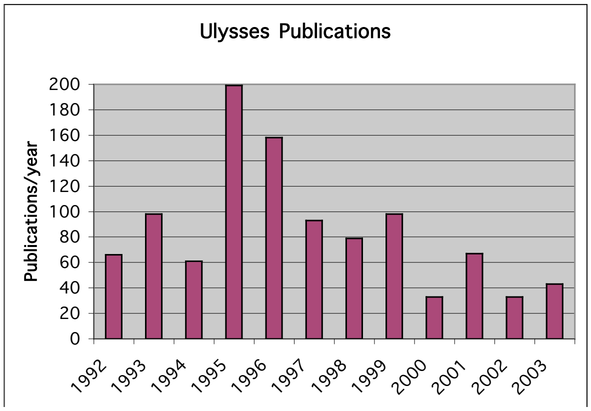

Figure 11.3. Ulysses publications by year.

11.4 Agreements

In addition to the overarching and on-going MOU between NASA and ESA, certain agreements exist within the Project. Agreements are in place within the various science teams that define responsibilities for data processing, distribution, analysis and archiving. Not all investigator institutions have the capability to independently process, reduce or validate their instrument's data. Therefore, in some of the teams, all data processing is performed at a single location and distributed to the co-investigators at various locations, both in the U.S. and Europe. In other cases, European investigators process some sensor head subsets of the instrument's data while American investigators process data from other sensor heads in the same experiment. These collaborations between the U.S. and European investigators are extremely important for efficient data processing and scientific analysis. These collaborations are vital to the project, since neither the European nor the NASA team members could perform these tasks independently.

12. Budget Discussion

Ulysses was conceived as a low-cost mission and has continually operated with a small management and operations staff. Since the beginning, the project has constantly revised its operational methods and responsibilities to live within the continually downward trend of the operational budget. In 1998, Ulysses and Voyager project management was combined into a single project office. As a result of previous budget reductions and consolidation, the mission is already at or near barebones.

The Guideline/Minimal proposal would continue support at a minimal level through March 2008. Mission operations, including project management and data management, would be reduced from approximately 8 full-time equivalents (FTE) to 7 FTE during Phase 1 (FY05-06) of the extension. The number of real-time controllers would be reduced. Concurrently, DSN tracking time will be halved. In Phases 2-4, during the polar passes and the fast latitude scan, an additional real-time controller would again be needed. In FY06, about 1/2 FTE would be required to update nutation analysis software to accommodate DSN hardware changes. Throughout the mission, the project will continue to explore other means to reduce costs.

The guideline/minimal budget allows for data ingestion, processing and analysis necessary to assure validity of the data and data archiving. It also includes the efforts to monitor and maintain instrument health and status, including instrument calibrations and reconfigurations. It supports the twice-yearly participation in SWT meetings and limited science analysis to support publications and participation in science meetings.

To validate the data, it is necessary to bring it to a level where rudimentary science analysis can be performed. With these limited resources, the significant effort required to support detailed scientific analysis, model comparisons, and publish and disseminate the results would continue to be seriously limited. Additionally, post-doctoral and exchange post-doctoral fellows and graduate research assistants participation in Ulysses data processing and analysis and support to guest investigators and others in the scientific community would continue to be curtailed.

The science objectives described in this proposal assume funding at the optimal budget level. The minimal budget would result in about one-half of the objectives, the most important ones as judged by the teams, being achievable. Of the 18 objectives identified in Tables 3.1, 4.1, 5.1 and 6.1 during FY 04-05, ten are judged to have the highest priority and to be consistent with the low level of funding. They are:

1) Characterize the 3D heliosphere during A<0 (including solar wind composition and properties of CMEs)
2) Galactic and Anomalous Cosmic ray gradients during A<0
3) Observation of Jovian electrons during the Distant Jupiter Encounter
4) Jovian Radio Emissions from high latitude magnetosphere (Distant Jupiter Encounter)
5) Dynamics of interstellar dust during A<0
6) Tilt and dynamics of the Heliospheric current Sheet

7) Inner source of Pick-up-ions, evolution with distance.
8) Ion Cyclotron Waves and Pick-up-ions, generation and evolution
9) Ionization rates of interstellar atoms
10) Gamma Ray Bursts, Magnetars

The remaining objectives would still constitute a strong justification for continuing the mission. The apparent disparity between the increase in achievable science and the modest increase in going from the minimal to the optimal budget is caused by the largely irreducible Science Center tasks and associated costs. Almost the entire increase in funds in the optimal budget goes into the Science Data Analysis category (and the remainder into validation and certification), which increases the direct scientific involvement and significantly increases the scientific output. Thus, going from the minimal to the optimal budget is cost effective.

Most of the increases in science data analysis would provide more funds for graduate students, post-doctorates and investigators. This will result in increased analyses of science results leading to more publications and presentations at science meetings, better support of official and unofficial guest investigators, and additional support for public outreach. Other proposed enhancements include:

1) GRB correlative analyses with Wind, Mars Odyssey, RHESSI, HETE-2 and INTEGRAL missions.
2) Production of visualizations of heliospheric phenomena by the SWICS team at the University of Michigan. These would be used in public outreach by the entire Ulysses team.
3) Improved URAP data archival products. Provide continuous radio direction finding data to archives.
4) Additional Jovian radio data analysis. Development of models to support those analyses
5) Initiate radio triangulation with STEREO.
6) With Wind, STEREO and others, develop a solar radio astronomy web site. The Project would only fund Ulysses elements.

Costs for Deep Space Network and in-kind costs for AMMOS services, though not part of the Ulysses budget submission, are provided in Table III of Appendix 1. FY04 costs are based on 10-hour per day coverage. Costs for FY05-06, during the slow latitude scan phase, are based on 70-hours coverage every two weeks. Costs during FY07-08, corresponding to phases 2-4, are based on 70 hours coverage per week. Data and mission services charged to Ulysses are listed in Item 2 of Tables I and II.

Estimated civil service costs were obtained from team members at GSFC and MSFC and are listed in Item 3 of Table III, Appendix 1.