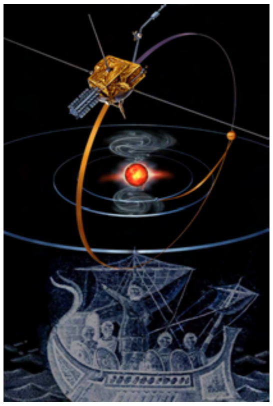
Ulysses Mission Proposal to the 2005 Sun-Solar System Connections Senior Review of Operating Missions



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APPENDED MATERIAL

"The Ulysses Mission is exploring the heliosphere in three-dimensions, transforming our view of the integrated Sun-heliosphere system and overcoming the limitations of measurements restricted to the vicinity of the ecliptic plane."

EXECUTIVE SUMMARY: ULYSSES' THIRD ORBIT

Ulysses, the only mission to explore the heliosphere in three-dimensions, is transforming our view of the integrated Sun-heliosphere system and overcoming the limitations of measurements restricted to the vicinity of the ecliptic plane. In its first orbit over the Sun, Ulysses charted the well-ordered solar minimum heliosphere arising from the quasi-steady, nearly symmetric corona. A remarkably different second orbit revealed the complex solar maximum heliosphere undergoing re-organization as the Sun ejected energy stored in coronal magnetic fields. Ulysses' observations of these ejections are defining how the space radiation environment is affected by the three-dimensional magnetic field and addressing the challenges we face to develop a predictive understanding for human space exploration. This global viewpoint knits together other heliospheric measurements, casting Ulysses as the keystone in The Great Observatory.

A fundamental Ulysses discovery is that energetic particles are far more mobile in latitude than expected. This result is linked to similar results for cosmic rays, pickup ions, and dust. There are at least occasional direct magnetic field connections across latitude. A similar result has been found during Jupiter encounters, where Jovian electron and dust jets reach Ulysses far from the ecliptic plane.

Unexpected magnetic field topology is a Ulysses theme. For example, long-lasting deviations from the classical interplanetary spiral are due to movement of field line footpoints across the Sun and are one component of new theories for the origin of the solar wind deriving from Ulysses' discoveries. Another result of non-classical field geometry is the detection of comet tail ions even when the comet lies far from the Ulysses heliocentric radial direction. These detections are due to what are now known to be commonly occurring transient magnetic field deviations.

Comet tail ions are an example of pickup ions – neutral atoms that are ionized and incorporated into the solar wind. Other sources are interstellar neutral atoms and dust. Some have sources as yet unknown. Pickup ions connect widely separate locations in and around the heliosphere. With them and in other ways, Ulysses measures properties of the local interstellar medium and the primordial universe. Pickup ions are a component of the composition and ionization state of thermal plasma. Thermal plasma abundances are also contributing to the new body of solar wind theory already mentioned – in the form of the discovery of enhanced abundance of low first ionization potential elements in fast solar wind.

Origin of the solar wind and properties of the local interstellar medium illustrate how Ulysses' measurements point both inward, towards the Sun, and outwards, towards the universe. Ulysses is describing fundamental characteristics of the solar dynamo while it is providing a description of the global solar wind at the time Voyagers 1 is in the heliosheath and Voyager 2 is about to enter the heliosheath. No other existing or approved mission is capable of doing this.

The coming years offer important opportunities to make advances using Ulysses' unique orbit. Some observations are related to the 22-year Hale magnetic cycle of the Sun – drifts of cosmic rays and dust and answering open questions about north-south asymmetry in the solar dynamo. Other observations take advantage of Ulysses' fast latitude scan in 2007-2008 in combination with SOHO, ACE, and STEREO in the ecliptic– none of which had been launched at the last solar minimum. Both the fast and slow latitude scans will provide the description of the global solar wind that is necessary to model the heliospheric interface for Voyagers 1 and 2 and, after 2008, IBEX.

Ulysses' high latitude perspective will be particularly valuable for STEREO, where Ulysses can provide in situ sampling of plasma seen leaving the Sun by STEREO and SOHO. The radio telescopes on Ulysses and STEREO will allow three-point triangulation of type II and III radio bursts caused by interplanetary shock waves and flares, a valuable tool for predicting solar-terrestrial relations.

These opportunities constitute persuasive arguments for maintaining the global coverage by Ulysses as long as possible - namely: (i) The opportune orbital configuration in 2007-2008 and beyond. (ii) The presence of new in-ecliptic missions. (ii) Voyager encounters with the termination shock and the launch of IBEX. (iv) Requirements for more knowledge about energetic particle transport to support space exploration. (v) Exploring the second half of the Hale cycle. (vi) Developing the empirical basis for models of the Sun-solar wind interface.

Finally, Ulysses meets the technical requirements of its central role in The Great Observatory. The Ulysses Data System is an accessible, distributed system under continual improvement. Ulysses is part of the International Living With a Star Program and the International Heliophysical Year program. It supports many Sun-Solar System Connections Roadmap Research Focus Areas and Investigations. All Ulysses' instruments continue to function well. A core set of instruments has been in operation since aphelion and all the instruments will begin operating in 2007. The Radioisotope Thermoelectric Generator will provide sufficient power for these operations. An online publications database documents the productivity of the Ulysses Team.

Guideline funding provides for little data validation, verification, and archiving. But, new missions increase demands for Ulysses data products. Therefore, two budgets are submitted here. The first is the minimal budget with essentially level funding that would keep Ulysses operating but not meet growing external demands. The second is an optimal budget that includes a small supplement to develop new data products, to carry out additional data validation and verification, to initiate collaborations with new missions, and to expand the E/PO effort.

1. *INTRODUCTION AND OVERVIEW*

1.1 Background

Ulysses, a joint NASA-ESA mission, is the only mission exploring the heliosphere in three dimensions. Launched in October 1990, Ulysses passed Jupiter in early 1992 to enter a solar polar orbit of inclination 80.2°, perihelion 1.34 AU, aphelion 5.4 AU, and period 6.2 years (Fig. 1.1). The ten instruments, listed in Table 1.1, all operational, measure *in situ* fields and particles, UV, X-rays, and gamma rays. Two orbits, pairs of polar passages, and fast latitude scans have been completed (O-I, -II, FLS I, II) and the third orbit (O-III) has begun.

Ulysses' first two orbits created the paradigm for 3D heliosphere; the bimodal solar wind at sunspot minimum and the chaotic and complex wind at solar maximum (Fig. 1.2). Observations of magnetic fields, energetic particles, and mass ejections addressed, and are addressing the challenges we face to develop a predictive understanding for human space exploration. The 3D view knits together other heliospheric measurements, casting Ulysses as the keystone in The Great Observatory (TGO).

Ulysses has investigated galactic cosmic rays, dust and particles, and gamma ray bursts from the interstellar medium and universe. It has determined basic properties of the solar magnetic field; its mode of reversal, and how magnetic flux is carried from the Sun and into the interplanetary medium. Many investigations have been possible only in collaboration with other missions: e.g. ACE on composition, SOHO and WIND on CMEs, Voyagers on the outer boundary of the heliosphere, and the third "interplanetary network" (IPN) on gamma ray bursts. Ulysses does not simply analyze *in situ* fields and particles. It is exploring the heliosphere as an integrated system and conducting investigations of the Sun, the local interstellar medium, and the universe.

Plans are described here for continuing the exploration, furthering collaboration with other missions, and supporting the upcoming STEREO and IBEX missions. We argue that it is imperative to continue the Ulysses Mission *at least* to the tentative April 2008 termination. The scientific objectives are to: (1) Complete measurements of energetic particles and dust farther into the 22-year Hale magnetic cycle. (2) Measure open flux and determine if the north-south asymmetry in O-I persists into a second sunspot cycle. (3) Support Voyager 1, 2 and IBEX as they explore the heliosheath. (4) Support SOHO and STEREO in the ecliptic plane during the extraordinarily long 2007 and 2008 quadratures, in studies of CMEs. (5) Conduct joint observations with ACE, SOHO, WIND, RHESSI, and IMP-8 during the summer 2007 radial alignment. (6) Analyze pickup ions near solar minimum, with ACE. These objectives are well aligned with Sun-Solar System Connections (S3C) Objectives, Research Focus Areas (RFAs), and Investigations (Table 2.1). They complement the S3C Great Observatory, International Heliophysical Year (IHY) plans, and the domestic and International Living With a Star programs (LWS, ILWS)

Ulysses is in extended phase and funding has been reduced to the minimum necessary for data reduction and archiving, with little for research. Nevertheless, team publications continue at an excellent rate (§2.2, §10). Support also comes from the S3C Guest Investigator Program (GIP) and other S3C, astrophysics, and planetary programs, with at least 24 grants mentioning Ulysses in their abstracts over the past three years – only 2-3 of which being led by Ulysses coinvestigators. Ulysses research today is often carried out by scientists from outside the Ulysses Team and from beyond the NASA and U.S. scientific communities. In Europe, for example, many nationally funded individuals and participants in ESA's Guest Investigator program are doing Ulysses research. A measure of the impact of Ulysses is the 30 abstracts that explicitly refer to the mission in the recent Solar Wind 11 / SOHO 16 international conference. Only ~1/3 of these papers had first authors who were Ulysses investigators, with the rest coming from institutions all over the world. A query to the Astrophysical Data Sys-

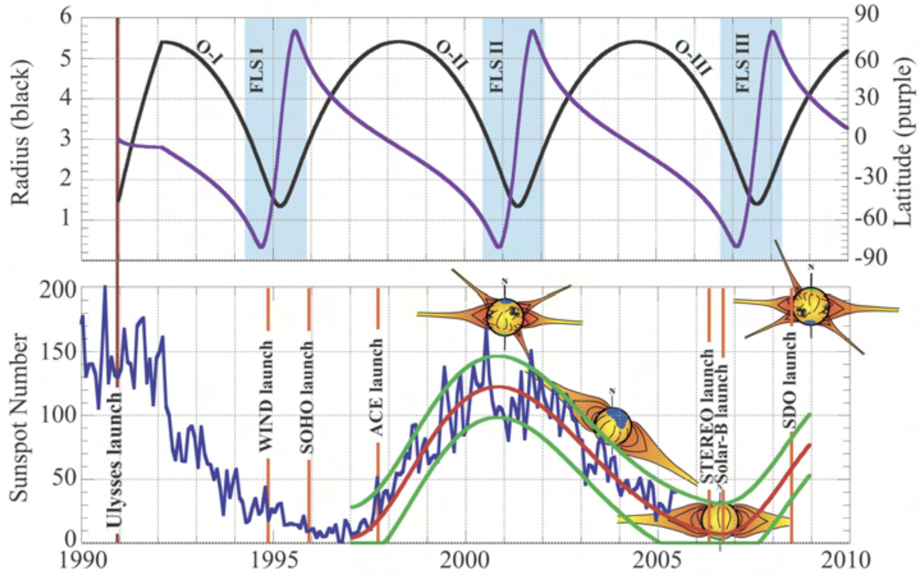

Figure 1.1. Top: The heliocentric radius (AU) and heliographic latitude (degrees) of Ulysses' three orbits (O-I, -II, -III) in 1990-2008. Blue shaded areas: The "fast latitude scans" (FLS I, II, III) and pairs of polar passes. Bottom: The observed and predicted sunspot number through 2008 (Hathaway & Wilson, priv. comm.). Schematics show the typical corona at the indicated times in the solar sunspot cycle.

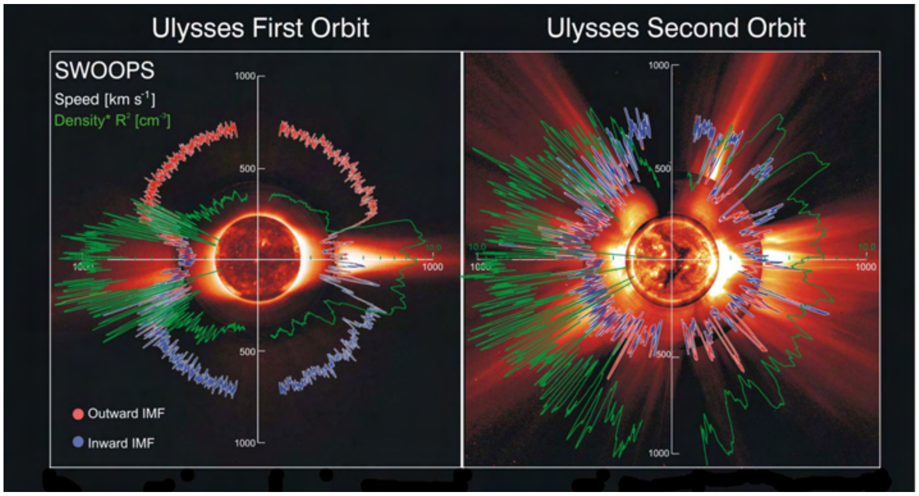

Figure 1.2. Dial plots of solar wind speed and density, with co-temporal coronal images, during O-I and O-II, with start dates as indicated in Fig. 1.1. Time runs counter-clockwise from 9 o'clock, along with heliographic latitude. The gaps at the north and south poles reflect the maximum Ulysses latitude of 80.2^{o}. The speed scale is [0,1000] km/s and the density scale is [0,10] cm^{-3}.

tem (ADS) shows that 449 abstracts refer to Ulysses from 2002 through the first 3 months of 2005.

In addition to catching people's imagination, a reason for the broad appreciation of Ulysses is that the data is easily accessible. The NSSDC and Ulysses Data System (UDS) sites, given in Table 1.1, are current to within a few months. New software tools. just released through UDS, operate with the freely available IDL kernel, making the data even more useful and accessible.

1.2 Achievements, 2003 - 2005

This interval covers the declining phase of the solar cycle, during which there were many large solar eruptions. Ulysses showed that energetic particles, dust, and cosmic rays move more easily in latitude than expected. One reason for this is magnetic field lines connecting across latitude. Unexpected magnetic field topology has become a Ulysses theme. Magnetic 'deviations' carry comet tail ions in longitude and latitude and 'sub-Parker' spiral magnetic fields indicate both how the magnetic field is connecting to the Sun and to sources of energetic particles on the termination shock. Studies of connections between widely separate locations also use pickup ions - from comets, dust, the local interstellar cloud, and other yet unknown sources. These ions, guided by the magnetic field, are used to define properties of the local interstellar medium, comets, and the primordial universe. Other investigations of solar wind ionization state and composition are building an empirical basis for new theories of the origin of the solar wind and the physics of reconnecting current sheets in the corona following mass ejections.

The magnetic field has drawn together broad aspects of heliospheric physics. An important achievement determined a property of the solar dynamo. It was shown that the solar dipole field reverses by rotating through the equator rather than reduction in amplitude through zero. A north-south asymmetry was discovered and its persistence into O-III will be carefully examined. A technique has been developed that gives the total amount of open flux from the Sun far more accurately than any ground-based method. The level of accuracy will permit looking for cycle-to-cycle changes in the open flux during the coming sunspot minimum.

These achievements and many others are reported in open literature and are described in §3 and §4. Bibliographies at the Ulysses web sites (Table 1.1) list publications to ~2005.5.

1.3 Objectives, O-III

Ulysses high inclination orbit offers exceptional observing opportunities during O-III (where this is meant to specifically refer to that portion covering FY07-FY10), especially during FLS III. Not only will Ulysses spend considerable time at mid- and high latitudes, it will do so in an opportune orbital configuration with respect to SOHO, STEREO, and SMEI. During the equatorial crossing in 2007 there will also be a remarkable latitude scan through radial alignment with Earth and all the near-Earth spacecraft.

Six broad objectives listed in §1.1 are detailed in §3 and §4. §5 contains a discussion of how these objectives sustain TGO. Although we acknowledge that spacecraft termination is planned for April 2008, the objectives cover the full FY07-FY10 period described in the Request for Proposals should support become available to continue the mission. Specifically, the orbital configura-

O-III Objectives from §1.1:

(1) Complete measurements of energetic particles and dust farther into the 22-year Hale magnetic cycle.

(2) Measure open flux and determine if the north-south asymmetry in O-I persists into a second sunspot cycle.

(3) Support Voyager 1, 2 and IBEX as they explore the heliosheath.

(4) Support SOHO and STEREO in the ecliptic plane during the extraordinarily long 2007 and 2008 quadratures, in studies of CMEs.

(5) Conduct joint observations with ACE, SOHO, WIND, RHESSI, and IMP-8 during the summer 2007 radial alignment.

(6) Analyze pickup ions near solar minimum, with ACE.

Table 1.1: The Ulysses Experiments and the Mission-Associated Web Sites

COSPIN PI: B. McKibben	Energetic particle spectra (ions 0.3-600 MeV, electrons 4-2000 MeV) and composition [Simpson and Connell, 2001], http://ulysses.sr.unh.edu/WWW/Simpson/Ulysses.html COSPIN/LET: http://helio.estec.esa.nl/ssd/let.html COSPIN/HET: http://ulysses.sr.unh.edu/WWW/Simpson/UlyDocs/HET.html COSPIN/KET: http://www.mi.iasf.cnr.it/Ulysses/ COSPIN/AT: http://www.sp.ph.ic.ac.uk/Ulysses/Research/AT/ats1.html
DUST PI: H. Krüger	Dust particles 10^{-16} to 10^{-6} g; mass, speed, flight direction, and electric charge [E. Grün et al., 1992], http://www.mpi-hd.mpg.de/dustgroup/projects/ulysses.html
EPAC PI: N. Krupp	Energetic ion composition, flux, and anisotropy [Keppler et al., 1992] - 80 keV/n to 15 MeV/n, http://www.mps.mpg.de/en/projekte/ulysses/epac/
GAS PI: M. Witte	Neutral He atom and UV detectors [Witte et al., 1992], http://www.mps.mpg.de/en/projekte/ulysses/gas/
GRB PI: K. Hurley	Solar and cosmic gamma ray burst detector (x-rays and □amma-rays, 15 to 150 kev) [Hurley et al., 1992], http://www.ssl.berkeley.edu/ipn3/
HI-SCALE PI: L. Lanzerotti	Low-energy particles (ions 50 to 5000 keV, electrons 30-300 keV) [Lanzerotti et al., 1992], http://sd-www.jhuapl.edu/Ulysses/hiscale.html and http://hiscale.ftecs.com/index.html
SWICS PIs: G. Gloeckler & J. Geiss	Solar wind ionization state and composition (thermal/suprathermal), pickup ion distributions and composition [Gloeckler et al., 1992], http://solar-heliospheric.engin.umich.edu/ulysses/
SWOOPS PI:D. McComas	Solar Wind thermal ion and electron distributions [Bame et al., 1992], http://swoops.lanl.gov/
URAP PI: R. MacDowall	Radio and Plasma Waves (plasma waves-0 to 35 kHz, radio-1 to 940 kHz, magnetic 10 to 500 Hz) [Stone et al., 1992], http://urap.gsfc.nasa.gov/
VHM/FGM PI: A. Balogh	Vector magnetometer, 0.01 to 44000 nT, 2 vectors/second [Balogh et al., 1992], http://www.sp.ph.ic.ac.uk/Ulysses/
SCE PI: M. Bird	Solar coronal sounding experiment, [Bird & Edenhofer, 1990] http://www.astro.uni-bonn.de/~mbird/ULS_public_html/
IDS PI: M. Roth	Interdisciplinary study of directional discontinuities [de Keyser et al., 2000], [http://www.oma.be/BIRA-IASB/Scientific/Topics/SpacePhysics/Ulysses.html
Ulysses Home Pages	NASA: http://ulysses.jpl.nasa.gov/ ESA/ESTEC: http://helio.esa.int/ulysses/, mirrored at http://ulysses-ops.jpl.esa.int/ulysses/ Mission Operations: http://ulysses-ops.jpl.nasa.gov/
Ulysses data archives	ESA/Ulysses Data System: http://helio.esa.int/ulysses/data_archive.html, mirrored at http://ulysses-ops.jpl.esa.int/ulysses/data_archive.html NSSDC: http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1990-090B Jupiter Data, at the Planetary Data System, http://www.igpp.ucla.edu/ssc/pdsppi/Ulysses.htm

tion with respect to SOHO and STEREO continues through May 2008 and important Hale cycle observations and support for Voyagers 1 and 2, and IBEX can continue into 2010.

1.4 Budget

The Ulysses budget guideline is essentially the same as in recent years. It provides for continuing operations with little analysis, validation, archiving, and monitoring of the data. Because of demand for Ulysses data and collaborations we also propose a budget that would provide optimal data validation and verification and science support for collaboration with the upcoming STEREO, IBEX and Solar-B missions and TGO in general, and for expanded studies of the 4D heliosphere and the heliosphere as an integrated system (see also §11).

2. MEETING THE CONTINUATION CRITERIA & SUSTAINING THE GREAT OBSERVATORY

Six criteria, listed in the 2006 S3C Roadmap (p. 69, 26 July version), must be met by missions proposing for continuation. It is further required that a mission "participate in TGO."

2.1 Criterion: Relevance to the goals of S3C (S3C 2006 Roadmap Investigations)

Table 2.1 is an itemized guide to how Ulysses' research objectives support the goals of S3C. For each Investigation, we refer to the location (§) where associated O-III objectives are described.

The Roadmap is primarily a strategic plan for future missions. In this plan there is no other mission that will reach high heliographic latitude within the next 10 years, with the single exception of the Solar Probe, which will only do so within a few solar radii and for a (very) brief time. An effective use of resources is to keep Ulysses in operation as long as possible.

Appendix C of the Roadmap reconciles the Roadmap with the NRC Decadal Survey, showing that they "...end up in remarkably similar places." Therefore, we make no attempt here to further show how this proposal is consistent with the NRC Decadal Survey.

2.2 Criterion: Impact of scientific results as evidenced by citations, press releases, etc.

The broad impact of Ulysses is seen in the increasing number of ADS abstracts referring to Ulysses (339 in the last period, 449 in the present). The number of team pub-

Table 2.1: 2006 S3C Science & Technology Roadmap Objectives

NASA	**S3C**	**Research Focus Areas** (those for which Ulysses is relevant)	**Investigations** (those for which Ulysses is relevant)
NASA Strategic Objective 15: Explore the Sun–Earth system to understand the Sun and its effects on Earth, the solar system, and the space environmental conditions that will be experienced by human explorers, and demonstrate technologies that can improve future operational systems.	**Objective F**: Open the Frontier to Space Weather Prediction	F1 Understand magnetic reconnection to reveal the causes of solar flares, coronal mass ejections, and geospace storms.	F1.1. What are the fundamental physical processes of reconnection on the small-scales where particles decouple from the magnetic field? §3.4
			F1.2 ... and at what scale sizes does magnetic reconnection occur on the Sun? §3.2
		F2 Understand the plasma processes that accelerate and transport particles.	F2.1 How are charged particles accelerated to high energies?§3.5
			F2.2 How are energized particles transported? §3.5
			F2.3 How is the solar wind accelerated and how does it evolve? §3.3, 3.7
		F3 Understand the role of plasma and neutral interactions in nonlinear coupling of regions throughout the solar system	F3.4 How do the heliosphere and the interstellar medium interact? §4.1-4.5, 5.5, 3.5, 3.7, 3.8
		F4 Determine how solar ... magnetic dynamos are created and why they vary.	F4.1 ... How do solar and stellar dynamos evolve on both short and long-term time scales? §3.7, 3.3
			F4.2 How are open flux regions produced on the Sun, and how do variations in open flux topology and magnitude affect heliospheric structure? §3.7
	Objective H: Understand the Nature of Our Home in Space	H1 Understand the causes and subsequent evolution of solar activity that affects Earth's space climate and environment.	H1.2 How do solar wind disturbances propagate and evolve from the Sun to Earth? §3.2, 3.5, 3.6
			H1.3 Predict solar disturbances that impact Earth. §3.2, 5.1, 5.2, 5.3, 5.4
		H4 Understand the nature of our home in space.	*H4.4 How do local interstellar conditions influence the solar system's space environment and what are the implications for the formation, evolution, and future of life in the solar system? §4.1 - 4.4, 5.5 *Tentative Investigation suggested by 'red team' review, August 2005.
	Objective J: Safeguarding Our Outward Journey	J1 Characterize the variability, extremes, and boundary conditions of the space environments that will be encountered by human and robotic explorers.	J1.2 How does the radiation environment vary as a function of time and position, and how should it be sampled to provide situational awareness for future human explorers? §3.5, 5.2, 5.3
			J1.3 What is the relative contribution to the space radiation environment from SEPs and GCRs and how does this balance vary in time? §3.5, 5.2, 5.4
		J2 Develop the capability to predict the origin and onset of solar activity and disturbances associated with potentially hazardous space weather events.	J2.2 What heliospheric observations, and empirical models are needed to enhance the predictive capability required by future human and robotic explorers? §5.1, 5.2, 5.3, 5.4
		J3 Develop the capability to predict the propagation and evolution of solar disturbances to enable safe travel for human and robotic explorers.	J3.1 How are SEPs created and how do they evolve from their coronal source regions into interplanetary space? §3.5, 3.2, 5.4
			J3.2 How do solar magnetic fields and solar wind plasma connect to the inner heliosphere and what is the nature of the near-Sun solar wind through which solar disturbances propagate? §3.3, 3.6-3.8, 5.1-5.4
			J3.3 How are energetic particles modulated by large-scale structures in the heliosphere (magnetic fields throughout the solar system) and what determines the variations in the observed particle fluxes? §3.5, 3.2, 5.1-5.4
NASA Strategic Objective 5: Explore the universe to understand its origin, structure, evolution, and destiny			1. Interstellar dust §4.3
			2. Properties and composition of the local interstellar cloud §4.1-4.5
			3. Cosmic gamma ray bursts and magnetars §4.6

lications is stable, with an occasional annual spike (Fig. 10.3.1) during the same time period. The impact is also seen in the ~30 abstracts referring Ulysses at the Solar Wind 11 / SOHO 16 conference. There is an increasing number of publications referring to Ulysses within the planetary physics community, due to interest in Jovian aurora and x-ray emission. There is also an increase in Ulysses astrophysics publications due to the Voyager 1 encounter with the heliospheric termination shock in December 2004. UDS usage has been increasing over the past three years while NSSDC usage has been ~constant. We continue to promote Ulysses discoveries ourselves with press releases and attendance at meetings organized for other mission (STEREO, Solar-B, Voyagers, ACE, SOHO, RHESSI). Mission meeting plans will be discussed in §5.

Press releases and general interest articles (partial list):

Science.NASA.gov had Ulysses news items on:

- dust streams from Jupiter
- Ulysses engineering/operations tricks to survive the cold aphelion under reduced power
- energetic particles at unexpected latitudes and longitudes
- comet tail encounter
- how the Sun's magnetic field reverses

Space Weather, an online AGU journal, published an article on Ulysses this fall

ESA news releases,

- flow of interstellar helium in the solar system (September 2004)
- Ulysses mission extended (February 2004)
- Ulysses catches another comet tail (February 2004)
- Ulysses encounter with Jupiter (January 2004)
- Ulysses galactic dust measurements (August 2003)

Coordinated analysis of the physical parameters of the local interstellar cloud: This was a major activity, sponsored by the International Space Science Institute (ISSI) in Switzerland. Associated missions include Ulysses, SOHO, ACE, EUVE, and NOZOMI. It resulted in these press items:

(i) Item on science.nasa.gov
(ii) ESA Science & Technology *news item*

ISSI published a book of general scientific interest - *The Solar System and Beyond: Ten Years of ISSI* (J. Geiss & B. Hultqvist, eds, 2005). Ulysses' contributions to solar and heliospheric physics, physics and chemistry of interstellar gas and dust, physics of the heliospheric interaction region, and pickup ions and anomalous cosmic rays (ACRs) play a prominent role in this book.

With its excellent scientific output, Ulysses has had no difficulty in maintaining interest in the mission and generating a continuous series of news items.

2.3 Criterion: Spacecraft and instrument health

There are no technical obstacles to a mission extension through 2008. All instruments and systems are healthy and the RTG supplies sufficient power to keep the core instruments operating for many years and all instruments operating during FLS III and the 3rd northern polar pass (see also §8).

2.4 Criterion: Productivity and vitality of the science team (e.g., publishable research, training of younger scientists, education, and public outreach)

§10 contains a description of Team productivity, where it is shown that the number of Team publications is stable (Fig. 10.3.1). Of the ten instruments, half have 'young' PIs (SWOOPS, DUST, GAS, URAP, EPAC). PhDs continue to be generated from the data stream, e.g.: (i) SWICS is associated with the graduate program at the University of Michigan. (ii) COSPIN is associated with the graduate program at the University of New Hampshire. (iii) VHM/FGM is associated with Imperial College, London. (iv) GRB is associated with astrophysics at the University of California at Berkeley. Awarded PhDs are listed on mission and instrument web sites.

§13, the E/PO proposal, contains a description of Ulysses E/PO programs. Team members have always carried out individual and project-wide E/PO activities, using resources from their science and operations budgets. The E/PO proposal in §13 describes the existing activities and a simple plan for Ulysses to continue these activities, participate in other NASA heliospheric science E/PO activities, and to develop support for these activities based on Ulysses continuing exploration of the heliosphere and an expected stream of new results and discoveries.

> "In [the Roadmap] there is no other mission that will reach high heliographic latitudes within the next 10 years .... An effective use of resources is to keep Ulysses in operation as long as possible."

2.5 Criterion: Promise of future impact and productivity (due to uniqueness of orbit and location, solar cycle phase, etc.)

Ulysses will be in quadrature with SOHO for five continuous months in 2006-2007 and again in 2007-2008, as described in §5. This follows the launch of STEREO. It is a unique and important opportunity that is due to Ulysses being at high latitude at the same time as what would otherwise be ~two-week quadratures. The second quadrature is during the rising portion of the sunspot cycle (Fig. 1.1). Ulysses will be able to collect *in situ* data on CMEs observed remotely, at the Sun, by SOHO and STEREO A/B during the entire intervals. This constitutes a significant promise of future impact and productivity '...due to uniqueness of orbit and location, solar cycle phase, etc.'.

Ulysses will make accurate measurements of north-south (N-S) asymmetry and total open magnetic flux from the Sun, possible only around sunspot minimum.

Ulysses will characterize the high latitude heliosphere at the time Voyager 1 is moving deep into the heliosheath in the northern hemisphere and Voyager 2 is passing the termination shock in the southern hemisphere. This is because of the ~1 year lag between the time solar wind plasma passes Ulysses and the time it reaches the termination shock (TS).

The six overarching objectives listed in §1.1 constitute the final reason to expect substantial results and impact from Ulysses in O-III.

To support our expectations for productivity in O-III, we will conduct the following activities:

1) Describe Ulysses' 2007-2008 orbital configurations at the STEREO/Solar-B planning workshop this year.
2) Propose joint workshops with Voyager 1/2, ACE/REHSSI/WIND, and with SOHO/STEREO on the relevant collaborative studies in each case.
3) Publicize UDS and use workshops and conferences to demonstrate access to Ulysses' online data.
4) Publish the next Ulysses book, now in preparation. It will cover one full solar cycle in 3D.

2.6 Criterion: Broad accessibility and usability of data

Ulysses online data are located at the sites shown in Table 1.1. This table lists NSSDC and UDS sites (and mirror sites), the individual instruments sites, and the two interdisciplinary investigation sites. As described in §10, data is deposited at the NSSDC and UDS sites soon after it is collected and is also available at the instrument sites. Help with the data can be requested through many of the instrument sites. As noted in §1.1, this year a new set of plotting routines was released at the UDS site, along with a data DVD, making much of the plotting completely portable. This represents an ongoing improvement in the already excellent Ulysses Data System.

Ulysses plans to participate in the Virtual Observatory program when it is implemented. UDS would fit easily into this framework.

> "This global viewpoint knits together other heliospheric measurements, casting Ulysses as the keystone of The Great Observatory.."

2.7 Sustaining The Great Observatory

The term "The Sun and the Heliosphere as an Integrated System" was coined to encompass the breadth and reach of Ulysses science that allows it to knit together heliospheric observations and be the keystone in TGO. Ongoing collaborations exist with many members of TGO, including SOHO, ACE, WIND, IMP-8, and Voyagers 1/2 (plus SMEI, Chandra, and the IPN). Opportune orbital configurations of Ulysses relative to SOHO, STEREO, Solar-B, and many near-Earth spacecraft in FLS III and during the summer 2007 radial alignment, mean Ulysses will continue its vital and unique role in TGO. §5 lays out the details of these points.

2.8 Other considerations

Ulysses is, or will be, an active participant in LWS, ILWS, and IHY.

CME studies with SOHO, those planned for STEREO, research on energetic particle transport, and planned investigations are well aligned with LWS goals and targeted research. At least one current LWS grant specifically identifies Ulysses data as a part of the study. Others describe "multi-spacecraft" data analysis that obviously includes Ulysses. Ulysses' studies of coronal mass ejections (CMEs), solar source(s) of the solar wind, and of the solar and interplanetary origins of energetic particles are all embodied in LWS goals and objectives.

Ulysses is already an ILWS mission, along with Cluster, MMS, SDO, SOHO, Solar-B, and STEREO. ILWS objectives are to stimulate and facilitate: (1) Study of the Sun-Earth connected system and the effects that influence life and society. (2) Collaboration among potential partners in solar-terrestrial space missions. (3) Synergistic coordination of international research in solar-terrestrial studies. (4) Effective and user driven access to all data, results, and value-added products. Ulysses' research, data systems, collaborations, and ongoing programs fully support these objectives.

Ulysses is justified in claiming it is uniquely qualified to support IHY due to its location in the heliosphere and its record of producing 'heliophysical' results. It is a registered participating mission.

Ulysses effectively expands on the concept of TGO by collaborating with astrophysics missions in the triangulation of gamma ray bursts with GRB and in the study of Jovian x-rays. Ulysses is the only out-of-ecliptic member of the 'third interplanetary network' of gamma ray burst detectors. High latitude detections are particularly useful for triangulation.

Ulysses must also receive the approval of ESA's Science Programme Committee, which was accomplished at their 106th meeting in February 2004. The committee extended ESA participation in mission operation until March 31, 2008, with added time for post-operation archiving. Ulysses is under the Solar and Solar-Terrestrial Missions Division of ESA whose other missions include SOHO, Cluster, Double Star, and Solar Orbiter.

SCIENCE SECTIONS

The following three sections address accomplishments and objectives in heliospheric physics (§3), astrophysics (§4) , and Ulysses as a component of TGO (§5), respectively. §3 begins with the Jupiter distant encounter (JDE) and continues with several strictly heliospheric topics. This order is chosen because results from the JDE on magnetic "deviations" from the classical (Parker) prediction for the spiral heliospheric magnetic field set the stage for results throughout §3 and §5 for other semi-permanent and transient deviations.

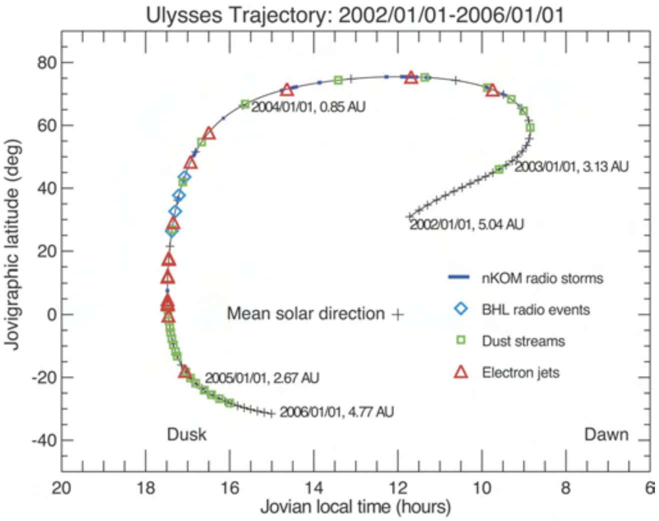

Fig. 3.1 Ulysses trajectory on 2002/1/1 - 2006/1/1 in Jovigraphic latitude and Jovian local time; + = the start of each month. Four types of data events are marked on the trajectory. This illustrates how Jovian emissions penetrate a more than 2 AU sphere around the planet.

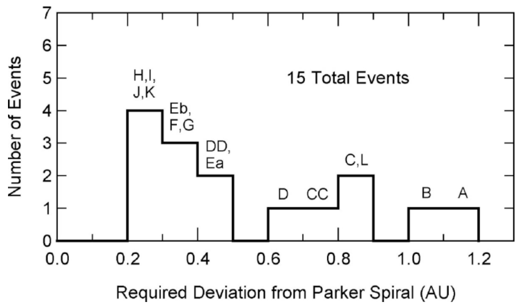

Fig. 3.2. The required magnetic field deviations from the Parker spiral for a successful magnetic connection to produce an electron jet at Ulysses for each of the events marked in Fig. 3.1.

3. *THEME 1: THE 4D HELIOSPHERE: THE HELIOSPHERE IN TIME AND SPACE*

3.1 Jupiter Distant Encounter in 2004

The Jupiter Distant Encounter (JDE) was a major objective in the 2003 Ulysses Senior Review Proposal (USR2003), with Ulysses passing (at 0.8AU) Jupiter in 2003-2004. Fig. 3.1 is Ulysses Jovicentric latitude in Jovian local time, showing that it was at high northern latitudes for many months. This perspective enabled routine detection of radio emissions, dust, and particles and several new discoveries.

Jovian Radio Emission: In the 1992 flyby, several instruments detected quasi-periodic 40 minute particle and wave bursts. URAP continued to detect these as Ulysses left the planet. Emissions were intensified when a corotating interaction region (CIR) impacted the magnetosphere. Chandra detected recurring ~45-minute X-ray bursts from the polar caps (Gladstone, 2002). Elsner et al. (2005), using Chandra, Hubble Space Telescope, and URAP, showed that the source is magnetospheric and that precipitating particles are accelerated by field-aligned electric fields.

In the JDE, URAP again detected Jovian Bursty High Latitude (BHL) emission, discovered at high latitudes during the first encounter (Reiner et al., 1995). The observations showed BHL occurs only for brief intervals every 11-13 days (Fig. 3.1, blue bars); each lasting a few hours and associated with the arrival of sector boundaries at Jupiter (Reiner et al., 2005). The cause of the short duration BHL events is still being investigated; however, reconnection or another form of energization of magnetosheath or magnetosphere electrons is suspected.

Two recurrent CIRs caused enhancements in Jovian emissions during most of the JDE. The fall 2003 'Halloween' events caused a merged interaction region (MIR) at Jupiter that also resulted in enhanced broadband kilometric (bKOM) emission, followed by a long, narrow-band kilometric (nKOM) event (Fig. 3.1, blue lines). This is, effectively, remote monitoring of space weather at Jupiter.

- URAP will continue to observe Jovian space weather throughout O-III, thereby monitoring solar transients near Jupiter.

***Jovian electrons*:** COSPIN and EPAC analyzed interplanetary propagation characteristics of <30 MeV Jovian electrons. The studies had two foci: electron jets and the general distribution of electrons. Confined, anisotropic jets of electrons were discovered in O-I and again observed during the JDE (Fig. 3.1, red diamonds). A total of 15 jets were seen over ~2 years. Large-scale, direct magnetic connections across the mean magnetic field (deviations) are required to explain the observations (Fig. 3.2). Deviations enhance the propagation of energetic particles across the mean field direction in ways not contemplated by - or easily integrated into - current models (McKibben et al., 2005). The observations can only be reproduced using models in which latitudinal transport is enhanced relative to the radial transport (Ferreira et al 2003a, 2004;).

Jovian dust: In 1992 DUST discovered streams of 10-nm sized electrically charged particles originating from Io (Fig. 3.3). The grains were ejected from the Jovian system by electromagnetic interaction with the magnetosphere and data indicated strong electromagnetic interaction with the heliospheric magnetic field (HMF). The streams were observed by Galileo in 1996-2002 (Krüger et al., 2005a) and served as a monitor for Io's volcanic

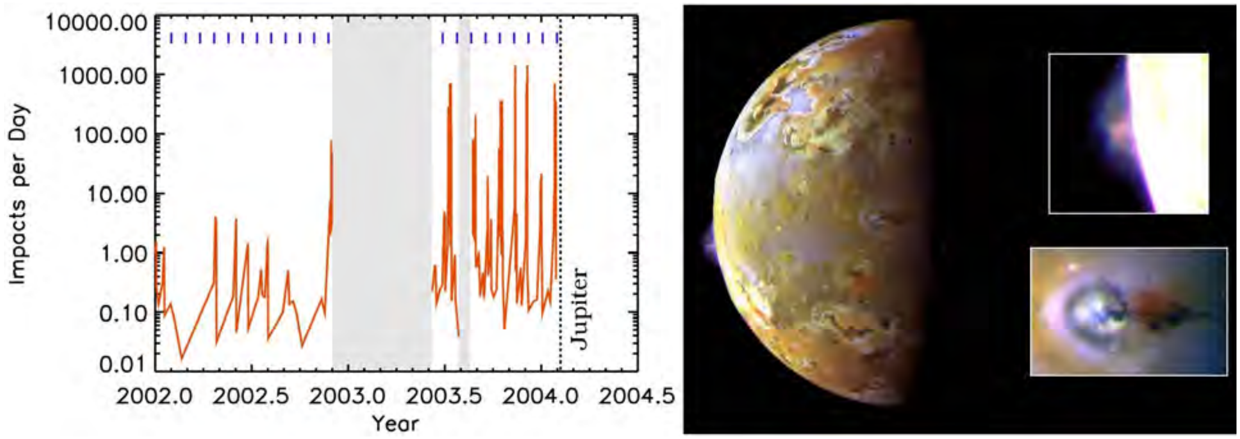

Fig. 3.3. Jovian dust streams originating at Io and whose ejection from the Jovian magnetosphere is modulated by CIRs and ICMEs. Solar rotation is indicated by the purple marks across the top of the plot.

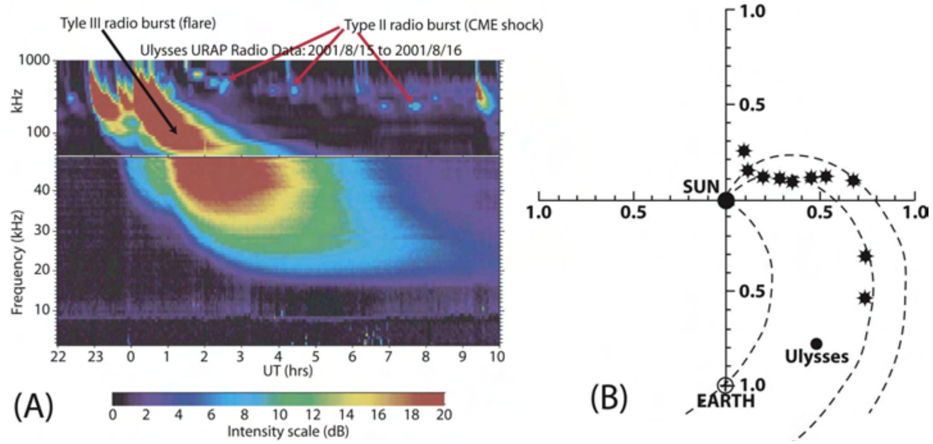

Fig. 3.4 (A) Dynamic spectrum of 12 hours of URAP data (August 15-16, 2001). The type II (CME shock) and associated type III (flare) radio bursts are indicated. (B) Triangulation of type III burst source locations in ecliptic, using radio source direction data from Ulysses and WIND.

activity (Krüger et al., 2003). In 2003-05 DUST detected 24 dust streams within ~3.4 AU of Jupiter, over the entire range in Jovigraphic latitude (Fig. 3.1, green squares) (Krüger et al., 2005b). The impact rate fluctuated with the 26-day solar periodicity and the impact direction correlates with the HMF (Krüger et al., 2005c). The occurrence and duration correlate with CIRs (Flandes and Krüger 2005), just as does the radio emission (Fig. 3.3).

- DUST will continue investigating Jovian dust streams in O-III, studying magnetic deviations, and CIR and ICME triggering of dust streams.

3.2 CMEs and ICMEs

CME/ICME shocks: USR2003 proposed URAP triangulation tracking of Type II and III radio bursts, in conjunction with WIND and STEREO. Cliver et al. (2005) used Ulysses and WIND to triangulate the type III burst of August 15-16, 2001 associated with a far-side halo CME. This confirmed the location of a coronal shock wave that caused acceleration of solar energetic particles (SEPs) over a broad range in longitude (Fig. 3.4). The electrons associated with Type III bursts have not so far been observed in SWOOPS data.

- SWOOPS data will be studied for signatures of Type III burst electrons in O-III.

Hoang et al. (2005) analyzed the type II radio burst of May 2001 to determine the fundamental and harmonic brightness temperatures of the type II emission ahead of the shock. MacDowall et al. (2005) used enhancement of Jovian radio emissions (see §3.1) to detect arrival of transients from the 2003 Halloween events at Jupiter.

- In O-III, URAP will routinely track radio bursts from flares and CME-driven shocks.

Ulysses' high inclination orbit provides an ideal perspective for triangulation, as for the August 2001 event (Cliver et al. 2005) (Fig. 3.4). In April 2006, with the launch of STEREO, WIND and Ulysses will offer the possibility of four-position triangulation on radio sources. This will be especially useful for following transients propagating near the ecliptic plane and understanding their motion through the heliosphere.

Quadratures: During SOHO-Sun-Ulysses quadrature, SOHO instruments can measure coronal properties of plasma traveling towards Ulysses - the only existing mission carrying out *in situ* measurements during quadratures. Several CME quadrature studies have been conducted (Bemporad et al. 2005; Suess et al. 2005; Poletto et al. 2004) and an International Space Science Institute (ISSI) data analysis working group is being proposed to study coronal current sheets and the resulting hot plasma. §5 contains orbital plots and a discussion of quadrature observations in 2006-2008. Quadrature objectives in observing CMEs overlap with STEREO prime objectives (§5.2) and help prepare for STEREO.

- Quadrature CME studies will continue in O-III.

***Overexpanding CMEs*:** Ulysses discovered overexpanding CMEs at high southern latitudes in FLS I. Further examples were observed in FLS II (Reisenfeld et al., 2003). Events of this nature have not yet been identified near the ecliptic plane and all but two of the events occurred before the launch of SOHO. To gain understanding, a combination of remote (SOHO, STEREO) and *in situ* (with ACE, WIND, STEREO) measurements at low and high latitudes will be used with SMEI, STEREO, and interplanetary scintillation (IPS) observations.

- The evolution and overall magnetic structure and topology of over-expanding CMEs will be examined in FLS III (see also §3.5).

Merged Interaction Regions (MIRs): Measurements from WIND, ACE, Ulysses, Cassini, and Voyager 1 and 2 determined that a MIR, but not a global MIR (GMIR) formed from the 2003 Halloween CMEs (Burlaga et al., 2005; Richardson et al., 2005). MIRs have long-lasting effects on energetic particles (see also §3.5) and cause large HMF deviations (see also, Zurbuchen & von Steiger, 2004). MIRs will continue to be seen in FLS III, both as a consequence of CIRs and of increasing activity following sunspot minimum.

- The O-III objective is to determine MIR extended effects on energetic particles fluxes.

3.3 Sources of the solar wind and the HMF

Solar wind latitudinal variation: In O-I, McComas et al. (2000) found a 1.0 km s^{-1} deg^{-1} gradient from 26° to 80° at solar minimum. McComas et al. (2003) found that at solar maximum the fastest speed wind in coronal holes does not exceed the speed observed in coronal holes at the same latitude during solar minimum (Fig. 3.5).

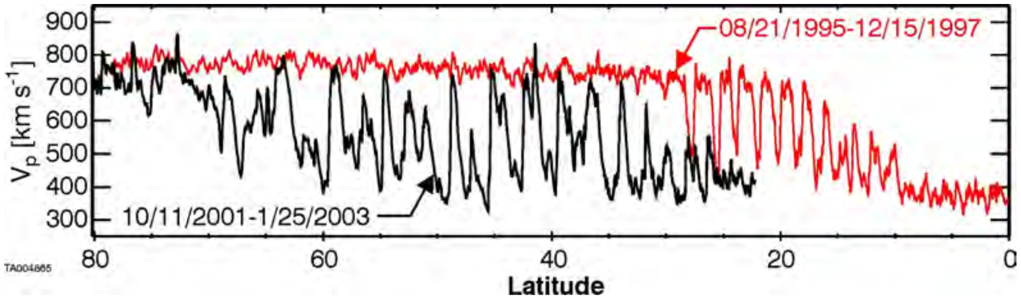

Fig. 3.5 SWOOPS solar wind speed versus latitude in O-I and O-II. Red: solar minimum, O-I. Black: solar maximum, O-II (McComas et al., 2003).

- FLS III will be used to understand the reasons for latitude variations in the solar wind speed and why speed in coronal holes varies with latitude.

Coronal hole boundary layers (CHBLs): Footpoint motions driven by the Sun's differential motion convect open magnetic field lines across coronal hole boundaries (Fisk & Schwadron, 2001). The resulting solar wind speed gradients along field lines produce 'sub-Parker' spirals" (see §5.5). The transition from fast to slow wind in CIRs can be used to analyze the fast-slow wind source differences. McComas et al. (1998) found a two-part interface structure. McComas et al. (2002) found rarefaction regions where the freezing-in temperatures and speed monotonically varied and were consistently anticorrelated. McComas (2003) suggested that CHBLs bound the flow from all coronal holes. A model has shown that the two-part structure of the interface arises naturally from a similar structure in the CH boundary at the Sun (Schwadron & McComas, 2005).

- Models of CHBLs will be tested in FLS III. Comparison with SOHO and STEREO remote observations of solar wind sources in FLS III, near sunspot minimum, is an opportunity to correlate coronal hole boundary properties to the fast-slow wind boundary.

These coordinated observations between Ulysses and SOHO or STEREO are not something that can be conducted in a passive way. Remote observations must be planned in advance to take advantage of orbital geometry (e.g. quadratures). SOHO was launched too late for observations at the last solar minimum so FLS-III presents a new opportunity for the coming minimum. This is further discussed in §5, in connection with TGO.

Mapping solar wind back to the Sun: A component of testing solar wind theory will be accurate mapping of solar wind back to the Sun. In O-I, the technique of mapping the solar wind back to the Sun using a source surface model of the corona was applied with only marginal success. In O-II, ballistic mapping and source surface models was further developed and now they are reliably used to determine the sources of the solar wind (Neugebauer et al., 2002; Riley et al., 2005). For the 2001 solar maximum, the mapped and observed polarities were in good agreement (Fig. 3.6) except at high latitudes.

- Ulysses will test improved MHD and source surface models at high latitudes near solar minimum in FLS III.

CIRs: In O-III, Ulysses will be in the CIR latitude zone (Fig. 1.1) where dynamics in the interior of the interaction regions can be studied. Ulysses discovered systematic latitudinal patterns of CIR shocks and flow deflection and opposed meridional tilts in the northern and southern solar hemispheres during the O-I (Gosling and Pizzo, 1999).

- Measurements of CIRs in and out of the ecliptic will characterize CIR tilt. Multi-point measurements will be available for the first time with ACE, Wind, and, after 2006, STEREO.

3.4 Internal processes

Reconnection: Direct evidence for local (*in situ*) reconnection in the solar wind has been found in ACE data (Gosling et al 2005). The prime evidence is an accelerated ion flow within a magnetic field reversal region, implying Petschek-type reconnection. These reconnection events are almost all found in low plasma β compression regions of ICMEs.

- SWOOPS and VHM/FGM will be searched for reconnection signatures in O-III data.

Suprathermal Tails: ~5 to ~1000 keV tails on velocity distributions of solar wind pickup ions (SWICS) occur downstream of shocks and in CIRs. Weaker suprathermal tails are seen even during quiet times far removed from shocks (Gloeckler et al. 2000). The mechanism for producing the quiet time tails is unknown. It could be statistical acceleration mechanism or heating of preexisting material by compression. To

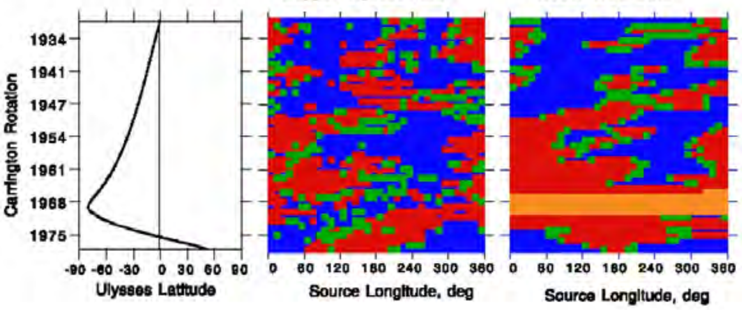

Fig. 3.6. Left: Ulysses' latitude vs. Carrington rotation (CR). Middle: Polarity of the HMF at Ulysses, mapped back onto CR and longitude on a 2.5 R_{SUN} source surface (SS). Right: Polarity expected at the Ulysses' SS footpoint using the Wilcox Solar Observatory potential-field source surface model. Red (blue) denotes outward (inward) field and orange denotes implied outward field (Neugebauer et al. 2002).

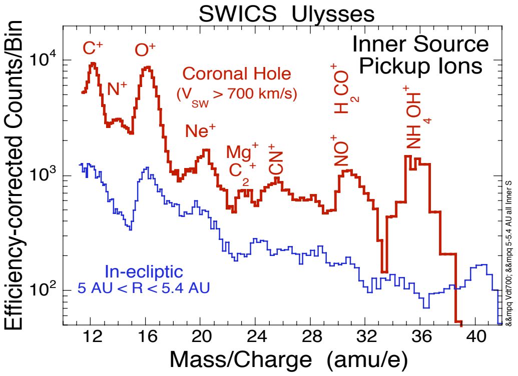

Fig. 3.7 Mass distribution of ISPIs at high latitude during solar minimum (red) and low latitudes (blue) around 5 AU. Those above mass ~24 are primarily molecular ions.

ing material by compression. To determine the mechanism, during O-III we will:

- Measure the composition of the suprathermal tails during the quietest periods at solar minimum
- Determine the solar cycle and latitude dependence of suprathermal sources and search for N-S asymmetries
- Combine Ulysses data with that of MESSENGER, ACE, STEREO and Cassini, to determine the spatial distribution and relationship to shock accelerated ions

Inner Source Pickup Ions (ISPIs): Inner source pickup ions (ISPIs), discovered with SWICS, are singly ionized ions with velocity distributions that peak at or below the solar wind speed and a composition of the most abundant elements that is similar to the solar wind. Their intensities decrease roughly with inverse heliocentric distance, implying a source near the Sun. There are latitudinal (Fig. 3.7) and solar cycle variations that are not understood. The origin of ISPIs remains an open question. One scenario (Schwadron et al., 2000) is that ISPIs originate as solar wind material that is imbedded in dust grains close (~ 10-30 Rs) to the Sun and then released as slow moving atoms and molecules that are subsequently ionized and picked up by the solar wind. During O-III we will:

- Measure near-ecliptic ISPIs at ~3-5 AU and compare these to ACE to deduce the radial decrease and better characterize the composition.
- Measure high-latitude ISPI composition during FLS III and compare this to solar maximum and the in-ecliptic composition, and to that recorded with ACE.
- Determine the latitudinal and temporal variations of inner source He^+ and Ne^+ at Ulysses, ACE and MESSENGER to characterize the spatial distribution and solar cycle variations of dust in the vicinity of the Sun through which Solar Probe will fly.
- Search for north–south asymmetries in the dust distribution using Ulysses, ACE and MESSENGER observation of inner source He^+ (see also §3.7).

Like interstellar pickup ions (§4.2 and Fig. 4.2), ISPIs connect processes occurring at widely separate locations in the heliosphere and therefore require viewing the heliosphere as an integrated system to understand them.

URAP Type III plasma waves: URAP was used in 2003-2005 to study microphysical processes of waves, including Langmuir waves (Osherovich and Fainberg, 2004), ion acoustic waves (Thejappa and MacDowall, 2004) and ion cyclotron waves (Kellogg et al., 2005).

- URAP will continue analyzing in situ waves associated with Type III solar transients. This, with similar data from WIND, addresses fundamental plasma processes in the solar wind.

Alfven waves: Magnetic fluctuations in the high latitude magnetic field were found to be strongly Alfvenic and to dominate transport of galactic cosmic rays (GCRs) near the poles (Jokipii et al. 1995). Differential streaming of protons and alpha particles in the fast wind (SWOOPS) and remote observations of the Sun (TRACE, Yokoh, SOHO) have been used to show that even large amplitude fluctuations, with local field reversals, are true folds in the magnetic field (‘switchbacks’). These can be generated by the eruption of small loops in coronal holes (Yamauchi et al. 2004a, b).

- We will compare Alfven wave properties in FLS I and III to evaluate their effects on polar entry of GCRs.

The full range of magnetic field irregularities in the Ulysses data was discussed recently by Erdós & Balogh (2005). It is shown that there is a remarkable difference between the fluctuations in fast and slow wind. These results affect models of GCR modulation (§3.5).

3.5 Particle transport and acceleration

GCRs at solar maximum: During FLS II, around solar maximum, dynamic conditions prevented accurate measurements of latitudinal gradients or modulation asymme-

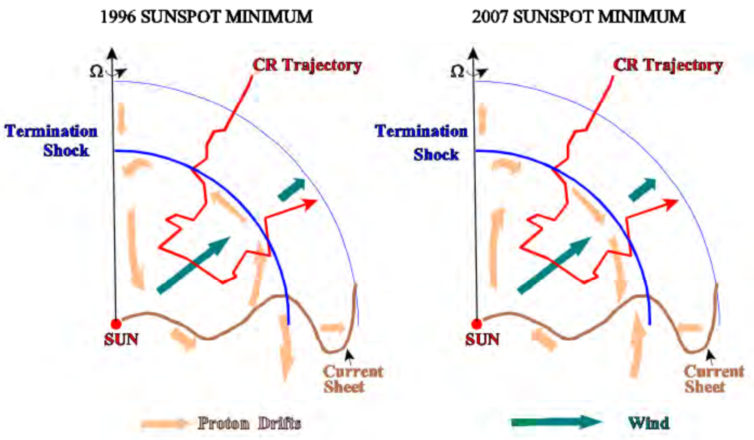

Fig. 3.8 Schematic of drift patterns for energetic nucleons for positive (left panel) and negative (right panel) signs of the solar magnetic dipole field.

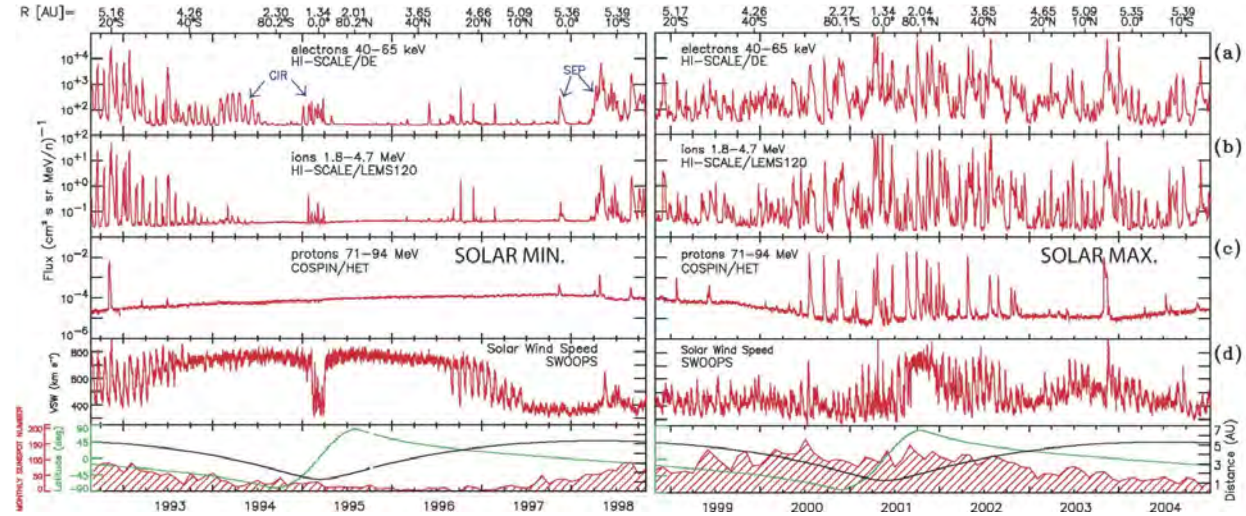

Fig. 3.9 Daily averages of the 40-65 keV electron intensities: 1.8-4.7 MeV ion intensities, 71-94 MeV proton intensities, solar wind speed, and monthly sunspot number (red hatched area) with Ulysses heliographic latitude (green line) and Ulysses heliocentric radial distance (black line).

tries. The only conclusions possible from COSPIN were that intensity latitude gradients were smaller than the intensity from fluctuations in local modulation conditions and that the modulation appeared spherically symmetric.

The lack of latitude gradient implies an unexpectedly efficient propagation of energetic charged particles across the mean magnetic field. Understanding the propagation is a major challenge for Ulysses (McKibben et al. 2003; Heber et al. 2003; Belov et al. 2003). An innovative numerical simulation has been applied to studies of particle propagation and gradients in the 3-D heliosphere and the heliosheath (Qin et al. 2004).

***GCRs and the full Hale cycle*:** In O-III, with solar minimum and A<0, drifts will be reversed (Fig. 3.8). Of interest will be co-rotating particle variations at high latitude. The behavior of cosmic ray electrons has so far defied satisfactory explanation (Clem et al., 2002). With the launch of STEREO in 2006, a network of spacecraft will be in place for spatial and temporal characterization of SEPs, CIR and CME-accelerated particles, and cosmic ray modulation in the inner heliosphere.

- The objective for O-III is to measure latitude gradients of GCRs and ACRs when A<0. Open questions are: (i) Will the decrease continue to high latitude or only to middle latitudes? (ii) Will the magnitude of the gradients be comparable to those in 1994-95? (iii) How does the latitude structure of CIRs compare to that of GCRs?

For these studies, IMP-8 is the baseline for all of the latitude gradient measurements. Even if measurements of 10-100 MeV/n protons and helium are available from STEREO, IMP-8 is needed to minimize uncertainties.

Electron charge-sign modulation: COSPIN/KET measures the cosmic ray electron spectrum from a few MeV to several hundred MeV. In late 2001, following reversal of the Sun's dipole, KET observed changes in the electron/proton ratio due to drifts (Fig. 3.8). However the magnitude was less than expected (Clem et al. 2002; Heber et al. 2003, 2003a; Ferreira et al. 2003, 2003a, 2004;).

- Following the modulated cosmic ray electron/proton ratio in FLS III will provide insights into drifts as a function of location in the inner heliosphere - a problem in current models.

SEPs, global overview of solar maximum vs. minimum: Energetic particles characterize transport conditions along particle trajectories. O-I exhibited 26-day recurrent CIR events, with the sporadic isolated SEPs, while O-II exhibited numerous transient events (Fig. 3.9). Elemental abundances show a gradual change from a CIR-dominated population (i.e., low H/He and high C/O ratios) to a SEP dominated population (i.e., high H/He and low C/O ratios). Anomalous He, O, and Ne

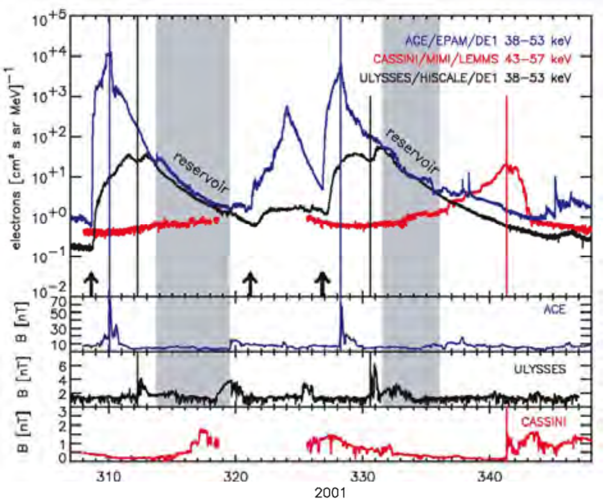

Fig. 3.10. From top to bottom. Electron intensity as measured at ACE (blue), Ulysses (black) and Cassini during Nov-Dec 2001. The arrows indicate the onset of the parent solar event. Magnetic field magnitude observed by the three spacecraft. Vertical lines indicate the passage of interplanetary shocks, and gray shaded areas the time intervals when energetic particle reservoirs were observed.

ions were measured at high latitudes at solar minimum, whereas during solar maximum their fluxes were swamped by the higher intensities of solar particles (Lario et al., 2003; McKibben et al., 2003; Maclennan et al. 2003).

- These measurements will continue into O-III to define the characteristic changes over the Hale cycle.

SEPs: Multi-spacecraft energetic particle measurements around FLS II, combined with COSPIN and HI-SCALE, led to conflicting interpretations of particle transport in the heliosphere. Common points in COSPIN and HI-SCALE data include: (i) Most large events at Earth also had large flux at Ulysses, regardless of the location on the Sun or the relative locations of Ulysses and IMP-8 (Dalla et al. 2003; Sanderson et al 2004). (ii) Onset delays as a function of spacecraft position were best organized by the latitudinal distance between the original flare and the foot of the field line through the spacecraft, independent of longitude. (iii) After a few days the intensities at Ulysses and IMP-8 approached each other and then showed parallel decay for the remainder of the event. This is the "reservoir effect" (McKibben et al., 2003; Zhang et al. 2003). (iv) Studies of particles from the 2000 Bastille Day event identified a period of apparent direct cross-field propagation. This was not found in other high latitude events. An interpretation from HI-SCALE suggested Ulysses was skimming along the flank of a CME (Zhang 2003). (v) Intensities of ~few MeV/n nuclei were enhanced at all latitudes. in FLS II. Over the solar poles, the particles consisted primarily of SEPs, whereas at low latitudes there was a significant admixture of particles accelerated at CIRs and stream interfaces (Hofer et al., 2003).

Models of particle transport assuming that (i) energetic particles are injected from localized sources on the Sun and (ii) energetic particles propagate along field lines whose footpoints move at the solar source surface with speeds and time scales characteristic of the supergranulation motion cannot reproduce these observations (Giacalone, 2002). Alternative explanations for access of SEPs to high latitudes include: (a) Wide sources, presumably CME shocks (Lario et al. 2000). (b) Efficient cross-field diffusion (McKibben et al. 2003). (c) Distribution of energetic particle through the heliosphere by magnetic field structures (deviations). Isolated events in 2007 may be easier to interpret in one of these frameworks than the frequent events observed near solar maximum. Objectives for O-III include:

- Determine if we observe the same events at high latitudes and near Earth.
- Determine the effect of CMEs on SEP populations.
- Conduct short-base-line studies of accelerated energetic particle density gradients, propagation, and interaction with solar wind and magnetic structures during the 2007 radial alignment (§5.2, §5.4).
- With the two STEREO spacecraft, there will be four observation points for exploring particle intensity gradients and propagation in FLS III (see also §5). The extent magnetic field deviations are responsible for the observed phenomena will be studied.

MIRs and the Halloween 2003 MIR: Ulysses provided the only measurements from ~5 AU of the MIR from the Halloween 2003 events. Comparison with IMP-8 and ACE showed that: (i) Time intensity profiles near Earth and at Ulysses were different. There was no reservoir effect. (ii) Stream interfaces and CME boundaries seemed to exercise dominant control over energetic particles. (iii) The MIR reaching Ulysses seemed to exclude the surrounding SEP populations from its interior. (iv) Tight coupling between SEPs and the magnetic structure after the events seems inconsistent with rapid cross-field

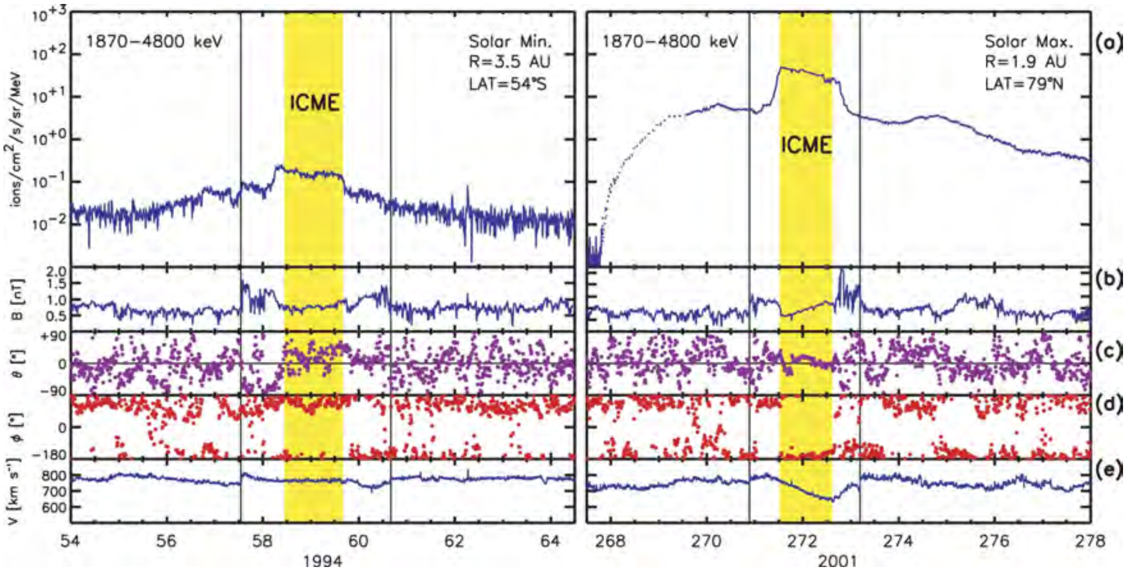

Fig. 3.11 Left: In-ecliptic ICME. Right: polar, over-expanding ICME. Top to bottom: Spin-averaged 1870-4800 keV HI-SCALE/LEMS ion intensity (blue), magnetic field magnitude (blue), magnetic field RTN polar angle (purple), magnetic field RTN azimuth angle (red), and solar wind speed (blue). Solid vertical lines indicate the passage of interplanetary shocks and yellow bar the passage of the ICME (Lario et al., 2004b).

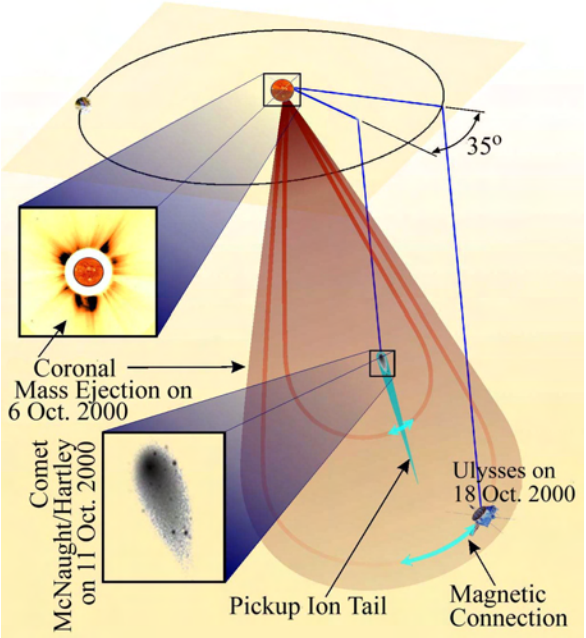

Fig. 3.12. Relative positions of the Sun, Ulysses, and comet McNaught-Hartley. The orbit of Earth is shown for reference. A CME occurred on 2000 October 6. The CME, represented by the brown, drop-shaped region, crossed the pickup ion tail of comet McNaught-Hartley, in turquoise, on 2000 October 14. The CME reached Ulysses on 2000 October 18. Turquoise arrowed arcs indicate the diffusive spread of pickup ions along a magnetic flux tube (red loops) as the loop is dragged by the solar wind, first intercepting the comet close to its nucleus and then, about 4.5 days later, Ulysses (Gloeckler et al., 2004; Schwadron 2004).

propagation (McKibben et al. 2005).

- MIRs will be followed in O-III to see if they reflect similar properties.

CIRs: In O-III the CIR structure will be compared with that in O-I, when the solar magnetic field had the opposite polarity. Observations of interest are:

- Measuring persistence to high latitude of modulation in GCRs due to near-equatorial CIRs. In O-I this provided strong evidence for enhanced latitudinal propagation, but it should be sensitive to the sign of the solar dipole (Fig. 3.8).
- Persistence to high latitude of low energy particle fluxes accelerated at the shocks bounding the CIRs should be less sensitive to the sign of the solar dipole.
- Studies of the composition of low energy particles at high latitude will be used to determine the source as SEPs vs. CIR accelerated particles, and for investigations of the seed-populations (see also §3.4).

Energetic particle reservoirs: Reservoirs are observed during isolated major SEP events (McKibben et al. 2003) and during sequences of events (Roelof et al. 1992; Maclennan et al. 2001). Fig. 3.10 shows ~40 keV electron intensities measured by Ulysses (black) during the events of November 2001 when it was above 70°N, in high-speed solar wind (Lario et al. 2003a). Similar decaying intensities were observed by ACE (blue). These equal intensities were observed only after the transient moved past Ulysses. Cassini, at 6.6 AU and close to the Sun-Earth line, did not observe the prompt components. Lario et al. (2004a) interpreted this as the result of an MIR from multiple CMEs prior to the events in November. The interpretation means that particle reservoirs form behind HMF structures that are able to reflect and confine energetic particles, and only observed when these structures are beyond the spacecraft. This leads to the following objective:

- Will the reservoir effect re-appear in FLS III? Is it associated with phase of the solar cycle or with the position of Ulysses?

Overexpanding ICMEs: During O-II, Ulysses observed over-expanding ICMEs in the northern high speed solar wind (Reisenfeld et al., 2003). Fig. 3.11 shows energetic particle, solar wind and magnetic field observations during the passage of an over-expanding ICME in O-I (left) and O-II (right) (Bothmer et al. 1995; Lario et al. 2004b). The highest intensities were observed in association with the passage of the ICME and not with the

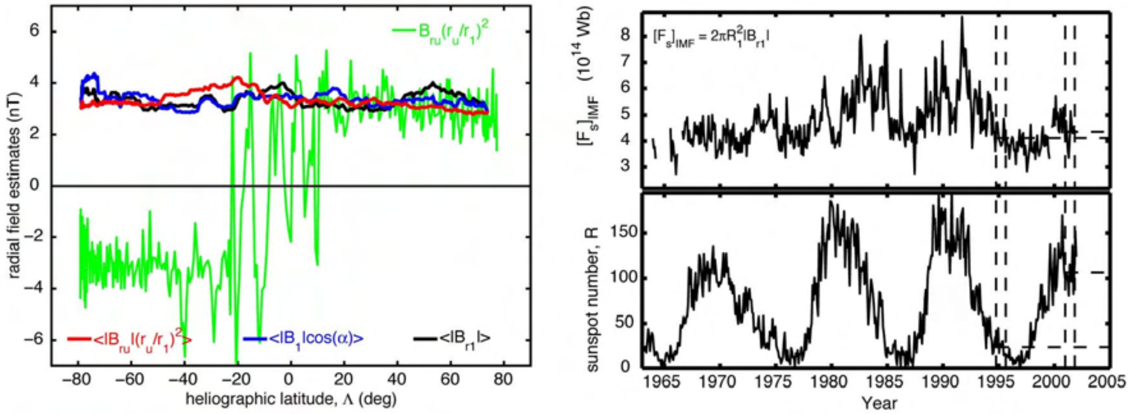

Fig. 3.13 Ulysses ~constant radial HMF strength in latitude (green) is used to evaluate several models (red, blue, black). The result allows calculating the amount of past open flux and aa far back in time (Smith & Balogh, 2003; Lockwood et al. 2004).

shocks. This contrasts with typical in-ecliptic 1 AU observations (Richardson, 1997), which is probably associated with the magnetic field topology. ICMEs propagating into high-speed solar wind streams are not able to drive strong shocks that efficiently accelerate energetic particles. Particle confinement within the ICMEs is responsible for the slower decay of the intra-ICME intensities with respect to those outside the ICMEs.

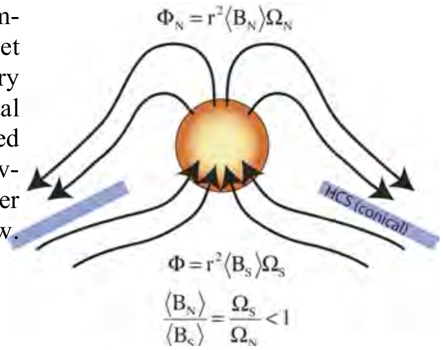

Fig. 3.14 Schematic of an asymmetric heliospheric current sheet extending into the interplanetary medium. Because equal total signed magnetic flux is confined to different solid angles, the average value of B_R is smaller above the HCS than below. (Smith et al. 2000).

- In O-III, energetic particles in overexpanding ICMEs will be used to help define the topology of high latitude ICMEs (see also §3.2).

3.6 Comets

Direct detection of cometary matter generally requires spacecraft close to the comets. Sampling and remote sensing have established the characteristic composition of cometary gas. Two unplanned crossings of cometary tails by Ulysses have shown that it is possible to sample cometary pickup ions at large radial and angular separation from the comet, using the characteristic composition for identification.

The first unexpected comet tail crossing occurred in 1996 during a near-radial alignment with comet Hyakutake that was 0.35 AU away (Gloeckler et al. 2000a; Jones et al., 2000). The second unexpected Ulysses comet tail crossing was with comet McNaught-Hartley, and perhaps comet C/2000 S5, at large angular separation from Ulysses (Gloeckler et al., 2004). The detection was possible due to a coronal mass ejection (CME) that mixed and distorted the HMF (another magnetic field ‘deviation’) to guide the pickup ions from the comets to Ulysses more than 1 AU away. The geometry is illustrated in Fig. 3.12, showing how an ICME contained a magnetic field deviation that guided cometary ions to Ulysses.

- There are no specific objectives for the remainder of O-III other than chance comet encounters.

3.7 The Sun and the solar cycle

Field evolution and reversal: Despite the complexity of the solar wind at solar maximum, the HMF remained relatively well structured in FLS II. The heliospheric current sheet (HCS) was highly inclined and the global dipole magnetic field axis appeared to reverse by rotating in latitude (Jones et al. 2003). This behavior is a fundamental aspect of the solar dynamo.

- HCS inclination will be followed through O-III.

Amount of open flux: VHM/FGM was used to discover that the radial component of the HMF, when mapped to constant radius, is constant (Fig. 3.13) (Smith et al., 2000; Smith & Balogh, 2003). This, and the physical explanation (Suess & Smith 1996), give the total open flux from the Sun, a long sought result. The errors in the Ulysses approach are at least a factor of 10 smaller than with other techniques. The result furthermore allows estimate of open flux far into the past using the geomagnetic aa index (Fig. 3.13) (Lockwood et al. 2004).

- Measure open flux through the rest of the Hale cycle and further develop the relation between the aa index and open flux in FLS III.

The open flux analysis leads to two further objectives in FLS III.

- Estimate polar cap field strength using the HMF in fast wind and a modeled expansion factor (§3.3)
- Possible systematic variations from constant radial field versus latitude will be investigated (Smith et al. 2002, 2003). Deviations from constancy imply meridional flux redistribution.

North-south asymmetry: During O-I, Ulysses discovered a global N-S asymmetry in the magnetic field (Fig. 3.14), energetic particles, and other properties. It was unobservable at solar maximum but should be detectable again in FLS III. As with the field reversal, this has fundamental bearing on the solar dynamo - namely its quadrupole moment. FLS III goals include:

- Search for asymmetry in the HMF, GCRs, and ACRs.
- N-S asymmetry was unobservable at sunspot maxi-

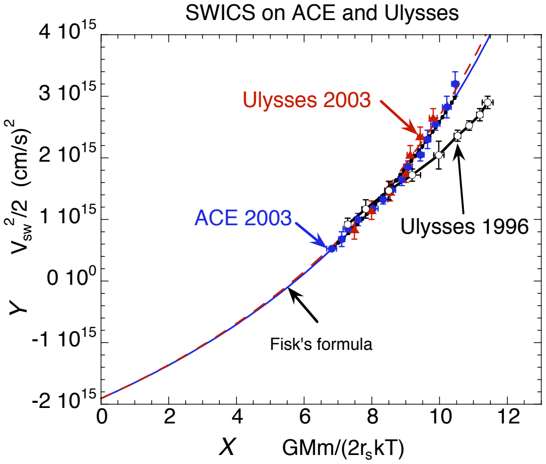

Fig. 3.15 Solar wind speed versus inverse coronal electron temperature, from Ulysses (red triangles) and ACE (blue circles) in 2003. ACE and Ulysses were both sampling near-ecliptic solar wind. Dashed and solid curves are fits to the Ulysses and ACE observations, respectively, using Fisk’s model. The 1996 Ulysses high latitude curve (open circles) has a flatter shape from which smaller loop heights are inferred (Gloeckler et al. 2003; Fisk 2003).

mum in FLS II but should be present in FLS III.

- Is the shift north or south, i.e. dependent on the sign of the dipole? FLS III?

N-S Asymmetry in coronal temperature and loop structure: SWICS O-I results implied N-S asymmetry in coronal electron temperature and loop sizes, from the anti-correlation between the freezing-in temperature and solar wind speed (Gloeckler et al. 2003). Fisk (2003) and Schwadron & McComas (2003) developed models that infer loop sizes, lifetimes of loops, and open magnetic field strength (see also §3.3). Fisk's model (2003) suggests significantly larger loop heights and stronger open field in the southern compared to the northern latitudes (Fig. 3.15).

- Simultaneous Ulysses/ and ACE/ SWICS measurements in FLS III, not available at the last minimum, will separate temporal from spatial variations and establish the nature of the temperature-loop asymmetry.

In FLS I URAP made high precision measurements of the electron density and temperature gradients over the solar poles in solar minimum conditions. A N-S asymmetry in the thermal electron temperature was detected.

- In FLS III, URAP and SWOOPS will confirm whether the N-S asymmetry seen in FLS I still exists and extend measurements of the electron temperature radial gradient.

Comparative solar cycles: Variations in O-I/II differed from previous solar cycles. Richardson et al. (2004) showed with IMP 8, WIND, Voyager 2, and Ulysses that solar wind dynamic pressure rose sharply near solar maximum, peaked slightly after maximum, and then slowly decreased. During the current solar cycle the dynamic pressure rose slowly, peaked much later in the solar cycle, and then dropped sharply.

- O-III will follow these cycle-to-cycle variations and their implications for V1 and V2 observations.

3.8 Heliospheric Dust

Beta-meteoroids**:** Beta-meteoroids are sub-micron dust particles for which solar radiation pressure is at least comparable to gravitational attraction and electromagnetic interaction with the HMF. They originate in the inner solar system, are probably mainly produced by collisions and, under solar radiation pressure, move outward (Wehry & Mann, 1999). Electromagnetic forces tend to carry them poleward (equatorward) when A>0 (A<0) (Fig. 3.8). Spacecraft orientation permits their detection only at high latitudes. Dust fluxes show a north-south asymmetry that cannot be explained by existing Hale cycle models (Wehry et al. 2004).

- During FLS III, beta-meteoroids will again be detectable, but when A<0. This will place better constraints on beta-meteoroid production due to evaporation, and address the persistence of N-S asymmetry.

Interplanetary dust: DUST had the best detection geometry to measure interplanetary dust during its in-ecliptic trajectory in 1991/92 and around its two perihelion passages (Fig. 1.1). Data indicate a long term variability of the flux. A potential explanation is a temporal variation in the interplanetary dust cloud which would be a new discovery.

- Data from FLS III will be compared with FLS I data for temporal variations in interplanetary dust.

"Big" (~10 micron) interplanetary dust: Between 3 and 18 AU, Pioneer 10/11 dust detectors measured a constant flux of particles ≥10 micron. Potential sources are long-period comets and Kuiper Belt objects. The flux measured by DUST between 3 and 5 AU was a factor of 5 lower than predicted by Pioneer (Krüger et al., 2001). The analysis is based on a low number of big particle detections.

- O-III will be used to resolve this discrepancy by improving the statistics of detection.

4. *THEME 2: THE INTERSTELLAR MEDIUM AND THE UNIVERSE*

4.1 Local interstellar medium (LISM) properties

Local interstellar cloud: A collaborative effort (Ulysses, SOHO, EUVE, ACE) to combine observations of the interstellar helium flow through the solar system has been completed. Hosted by ISSI in Bern, Switzerland, the international team compiled for the first time a consistent set of the physical parameters of helium in the local interstellar cloud (LIC). This represents an important milestone in our understanding of the Sun's interaction with the LISM. The coordinated analysis was possible

Table 3.1; *Topical List of O-III Major Objectives -The 4D Heliosphere; The Heliosphere in Time and Space*
• Understand the composition & structure of CMEs & ICMEs, their effects on SEPs, and the overexpansion of certain, high-latitude ICMEs (RFAs F1, F2, H1, J3)
• Study the 3-D structure of the solar wind, including coronal hole boundary layers, signatures of reconnection, and suprathermal and energetic particles in collaboration with ACE, SOHO, STEREO, & Wind (RFAs F1, F4)
• Extend studies of pickup ions at solar minimum to determine the contributions from various sources and to better characterize their composition, spatial and temporal variation, and relation to dust (RFA F3)
• Measure particle transport throughout the heliosphere and relate its evolution to the Hale cycle (RFA F2)
• Characterize magnetic field 'deviations' and particle 'reservoirs' and explain their effects on SEPs and cosmic rays (RFAs H1, F2, J1, J3)
• Investigate N-S asymmetries during O-III and compare to asymmetries in O-I to understand their evolution and to develop constraints for the solar dynamo (RFA F4)
• Understand the behavior of interplanetary dust at solar minimum and throughout the Hale cycle (RFA F3)

only with the comprehensive fleet of solar, heliospheric, and astronomical spacecraft. The results appeared in a special section of *Astronomy & Astrophysics* (v426(3), 11 Nov. 2004) and several news items (§2.2).

GAS neutral He measurements: Interstellar He density can be derived only with knowledge of the loss-processes neutral particles suffer. This is possible with GAS due to the high latitude orbit of Ulysses where EUV irradiance comes more from the polar, than equatorial, solar photosphere (Witte, 2004; Witte et al. 2004). A 3D model of solar EUV irradiance, based on measurements of SOHO /EIT and /SEM, has been developed for 2000-2002, taking into account the variation with solar latitude (Auchere et.al, 2005). This model and GAS He measurements were used for the ISSI study discussed above (Fig. 4.1).

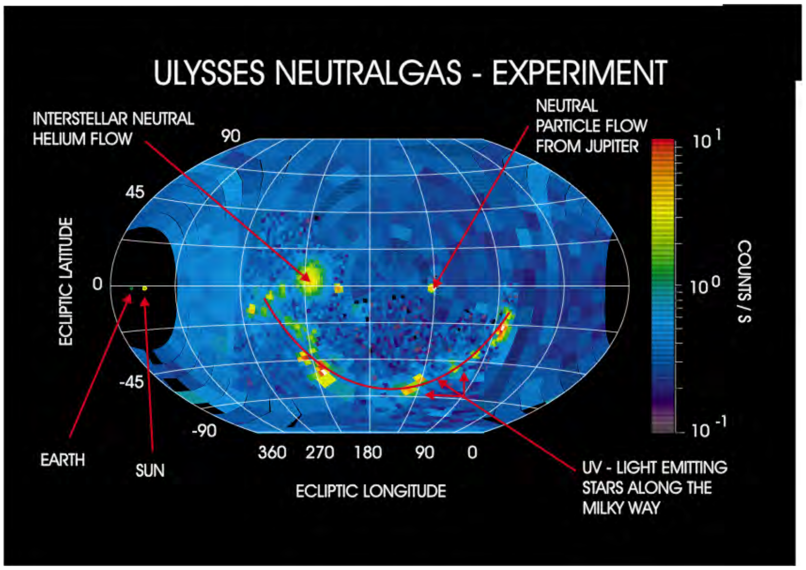

Fig. 4.1 Summary map of GAS measurements of neutral He over the whole sky. This is a graphic representation of the detailed information available in this data and how it has been valuable for determining properties of the LIC.

- Further observations with Ulysses and SOHO are planned in FLS III to address the solar cycle and latitudinal variations of EUV irradiance.
- Also in FLS III, a completely different method of determining the total ionization rate of He will again become available: GAS will be able to simultaneously observe particles arriving on direct and indirect orbits due to gravitational focusing, probing the same solar EUV field but in different regions (Witte et.al 1996; Witte, 2004). This will enable estimates of the contribution of other, less efficient ionization processes.

4.2 Local interstellar cloud pickup ions

SWICS discovered interstellar pickup H^+ in O-I (Gloeckler et al. 1993). Other interstellar pickup ions (LICPIs) from the LIC reach distances covered by Ulysses and were also detected. LICPI measurements allow us to study physical and chemical properties of the LIC (Gloeckler et al. 2001) (Fig. 4.2). Ulysses is the only mission making these measurements.

Recent accomplishments are: (1) Ulysses measurements of LICP H^+ played a key role in predicting the crossing of the termination shock (TS) by Voyager 1 in late 2004 (Gloeckler & Geiss, 2004). (2) Studies of velocity distributions upstream and downstream of shocks with SWICS and HI-SCALE, made it possible to construct H^+ differential energy spectra upstream and downstream of the TS (Gloeckler et al. 2005). (3) Participation in the ISSI project mentioned above (Moebius et al., 2004). During O-III we will:

- Complete observations of heavy LICPIs and determine more accurate values for their abundances in the LIC
- Determine acceleration efficiencies for ACRs.
- Determine the isotopic ratio of ^{22}Ne/^{20}Ne, and thereby improve our knowledge of galactic evolution.
- Combine SWICS abundances of LICPIs and the abundance of corresponding elements in the solar wind with V1 and V2 composition measurements of low energy (~0.5 to ~3 MeV/nuc) particles at the TS to establish the relative contribution of solar wind and LICPIs to the low energy particles accelerated by the TS.
- Determine spatial, latitudinal and solar cycle variations of ionization rates for H and He using Ulysses, Cassini, ACE and MESSENGER measurements of interstellar H^+ and He^+
- Examine long-term pickup H^+ and He^+ variability to detect any density inhomogeneities in the LIC
- Determine accurate values for the LIC neutral H and proton densities and set limits on the LIC magnetic field strength by combining LICPI measurements with interface models, remote sensing of the LIC and TS, and data from V1 and V2.

4.3 Interstellar dust

DUST interstellar dust measurements imply larger particle sizes than deduced from astronomical methods. The gas-to-dust mass ratio of the interstellar medium is a factor of 4-5 larger than derived from UV and optical extinction curves. Models for the dynamics of dust in the heliosphere (Landgraf 2000) explain the factor of 3 variation of the dust fluxes observed until 2000. In 2001-04 the interstellar dust flux stayed relatively constant, in agreement with improved models (Landgraf et al. 2003). The models predict a rather constant flux until 2008. This assumes that the dust phase of the LIC is homogeneously distributed over length scales of 50 AU.

- DUST observations in O-III will test the prediction of the models, leading to better constraints on the gas-to-dust mass ratio and improved understanding of dust in interstellar space. This is dependent on recent advances in understanding of interplanetary and instrumental effects on the measurements (Altobelli et al., 2004).

4.4 Neutral atoms

Solar wind ^{3}He and protosolar deuterium: Knowledge of solar light isotopes (^{3}He and ^{2}H or D) is used for models of galactic chemical evolution (Geiss & Reeves, 1972). Accurate ^{3}He/^{4}He abundance in the in-ecliptic slow solar wind will come from the Genesis mission. But, it will be difficult to derive from it the outer convection zone ^{3}He/^{4}He abundance because of the variability and fractionation. To reduce the systematic uncertainty and to gain confidence in the method used by Gloeckler and Geiss (1998) to correct for fractionation, SWICS measurements of the solar wind ^{3}He/^{4}He ratio through O-III are needed. Simultaneous observations of the ^{3}He/^{4}He ratios with ACE/SWICS (not available in O-I) will make it possible to separate temporal and spatial effects. During FLS III we will:

- Determine a more accurate solar wind ^{3}He/^{4}He abundance ratio and derive the protosolar D abundance

Interstellar Abundance of ^{3}He: The present-day ^{3}He/^{4}He ratio in the interstellar medium (ISM) is important for studies of galactic chemical evolution and, along with measurements of the ISM D/H ratio, for establishing the amount of baryonic matter in the Universe. The only way to obtain the ^{3}He/^{4}He ratio in the nearby ISM is by measuring pickup He^{+} (Gloeckler & Geiss, 1996, 1998).

- Measuring the pickup ^{3}He^{+}/^{4}He^{+} ratio at solar minimum, in O-III, from Ulysses and ACE, will reduce its uncertainty to ~8.5% - comparable to the uncertainty in the interstellar D/H ratio (Linsky & Wood, 2000).

4.5 The heliospheric interface, Voyagers, and IBEX

V1 passed the heliospheric TS at ~94 AU in December 2004, at 34° north heliographic latitude. At the same time, V2 was at ~75 AU and 26° south latitude. They are both moving at ~3.5 AU/year. It is anticipated that V2 will reach the TS in 2010. Both spacecraft can operate to beyond 2015 and V1 may reach the heliopause in 2010-2015. It takes solar wind plasma about a year to travel from the Sun to 100 AU. Therefore, solar wind determining the location and motion of the TS at V1 encounter passed Ulysses in late 2003, when Ulysses was just north of the equator (Fig. 1.1).

- As V1 & V2 explore the heliospheric interface, Ulysses, in O-III, will provide the crucial solar wind properties as they vary in latitude. This will be used to make predictions for the position and motion of the TS, as was recently done by Izmodenov et al. (2003) (Fig. 4.3) using IMP-8 data in the ecliptic. Only Ulysses can supply global solar wind properties.

In 2008, the IBEX mission will be launched. IBEX will explore the heliospheric interface by the detection of neutral atoms. This can only be done in combination with models that require global solar wind conditions to simulate the interface.

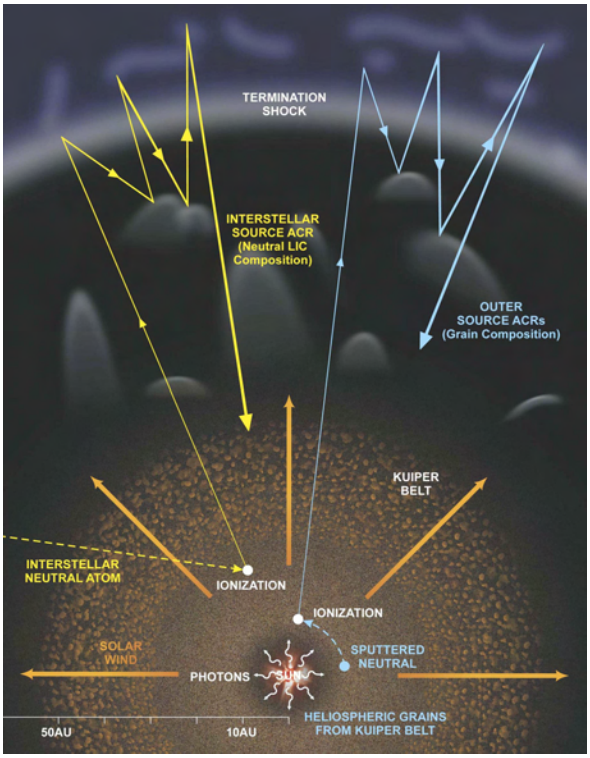

Fig. 4.2. Outer source pickup ions as the source of anomalous cosmic rays through acceleration at the termination shock (Schwadron et al., 2002).

- Ulysses measurements made between now and 2008 are perfectly timed for supporting the IBEX mission. FLS III will occur at an especially useful time for supporting IBEX, providing an effectively instantaneous cut through the inner heliosphere in latitude.

4.6 Gamma ray bursts and magnetars

Cosmic gamma-ray bursts (GRBs) are the most luminous explosions in the Universe. Their study is related to NASA's Objective #5 (Table 2.1). A typical burst liberates 10^{52} ergs so that GRBs may be detected to at least the distances of the most distant quasars. They convey information on the formation rates of stars, the metallicities of early galaxies, and the epoch at which the Universe re-ionized.

Magnetars, which are galactic, produce intense, short fluxes of gamma-radiation. They are neutron stars with the largest known magnetic fields in the Universe, $>10^{15}$ G. The study of magnetars sheds light on matter and energy under extreme conditions (Hurley, 1999).

GRB has made major contributions, detecting over 1800 GRBs and over 200 magnetar bursts. It is the flagship of the 3rd Interplanetary Network (HETE, INTEGRAL, Mars Odyssey, RHESSI, Swift, Wind, and Ulysses) which derives positions by triangulation. The network detects strong bursts at a rate of 200/year, which is about two times greater than any single mission, and in addition, monitors the entire sky for bursts from both the known and as-yet undiscovered magnetars.

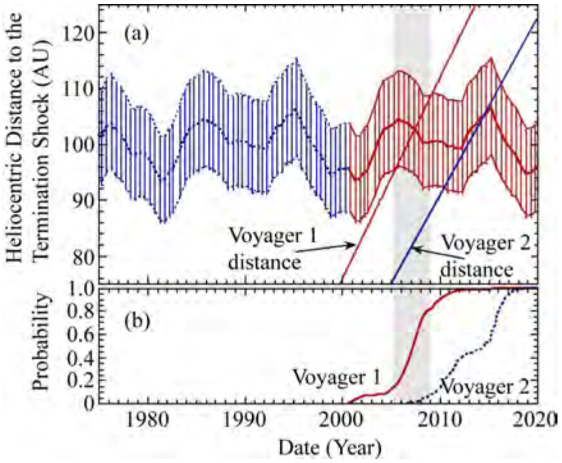

Fig. 4.3 Location of the termination shock and probability of shock encounters by V1 and V2. Shown in blue is the calculated mean and ±1-σ limits of the termination shock distance using IMP 8 solar wind speed and densities. Shown in red is the calculated mean and ±1-σ limits of the termination shock distance using a repeat of the previous 20-year sequence (Izmodenov et al. 2003).

- IPN data will be used to search for neutrino emission from GRBs, and to study the GRB-supernova connection.

GRB, off since February 2004 to conserve power, will be turned back on in the course of 2007. In the coming years, the AGILE, Astro-E, GLAST, and MESSENGER missions will be added to the IPN.

5. *THEME 3: ULYSSES AND THE GREAT OBSERVATORY*

5.1 Continuing participation in TGO

Ulysses has long been an active participant in TGO in three ways: (i) Making coordinated observations with other s/c, as in quadrature, gamma ray bursts, MIRs, and pickup ion studies. (ii) Effectively creating the concept of "the Sun and the heliosphere as an integrated system," which supports many solar and heliospheric missions by developing a global description. (iii) Supporting other s/c such as V1 & V2 without active coordination. This participation will continue into O-III.

Objectives in §3 and §4 contain a broad range of topics that sustain TGO in the three areas listed above. We list a few of these topics here (the numbers in parentheses refers to the above list):

- §3.2: ICME studies with WIND and SOHO. (i)
- §3.3: Description of the global solar wind. (ii)
- §3.4: Investigating suprathermal ion tails and ISPIs with ACE and Messenger. (i)
- §3.7: Determining the amount of open magnetic flux from the Sun, how the magnetic field reverses, and north-south asymmetry. (ii)
- §3.5: GCRs in the Hale cycle. (ii)
- §3.5: SEPs and magnetic field 'deviations' in support of LWS and ILWS. (iii)
- §3.1 (JDE) and §3.6 (comets): Continuing support of planetary and solar system origins research, at a low level. (ii) (this is a generalization of S3C TGO to encompass other NASA projects and missions)
- §4.1: Determining global heliospheric properties at the time of V1, V2, and IBEX exploration of the interface region. (iii)
- §4.2, §4.3, §4.4: Continuing improvement of LIC properties at the time of V1, V2, and IBEX exploration of the heliospheric interface. (iii)
- §3.5: Energetic particle propagation and transport. Ulysses high-latitude perspective, in combination with V1/V2 measurements, is essential for understanding energetic particles at the TS. (iii)

5.2 2007-2008 quadratures with SOHO & STEREO

- Ulysses-Sun-SOHO quadrature studies are discussed in §3. These will continue in O-III. STEREO will be launched in 2006 and the two spacecraft will also be used when they are in quadrature with Ulysses. However, the opportunity is considerably better than usual:

Normally, a quadrature occurs about twice a year as Earth /SOHO move around the Sun, since Ulysses is, to first approximation, fixed in space. The angular separation changes by ~1°/day. Events within 5-10° of the limb generally will reach Ulysses. Therefore, Ulysses is close enough to the limb for useful quadrature observations over an interval of 10 days to two weeks.

Three things are different in 2007-2008. The first is that, due to Ulysses passing near the poles and perihelion, quadratures with SOHO last 5-6 months rather than two weeks (the 'opportune' configuration mentioned in §1). The second is that STEREO A & B, launched in April 2006 and moving apart by ~22°/year, will be a few to a few-tens of degrees from SOHO in 2007-2008 and slightly away from quadrature with Ulysses when SOHO is in quadrature. Having three-point images of CMEs as

Table 4.1: *Topical List of O-III Major Objectives - The Interstellar Medium and The Universe*
• Measure LIC pickup ions at solar minimum, in combination with ACE, MESSENGER, etc. (RFA H4)
• Constrain models of the LISM and LIC more precisely by extending the time series of data provided by Ulysses and other missions (RFA H4)
• Analyze interstellar dust near perihelion and near solar minimum (RFAs F3, H4)
• Obtain more accurate values for astrophysical elemental and isotopic abundances, such as the protosolar D abundance (astrophysics topic)
• Extend Ulysses' monitoring of gamma ray bursts and magnetars as the flagship of the current gamma ray observatory network (astrophysics topic)

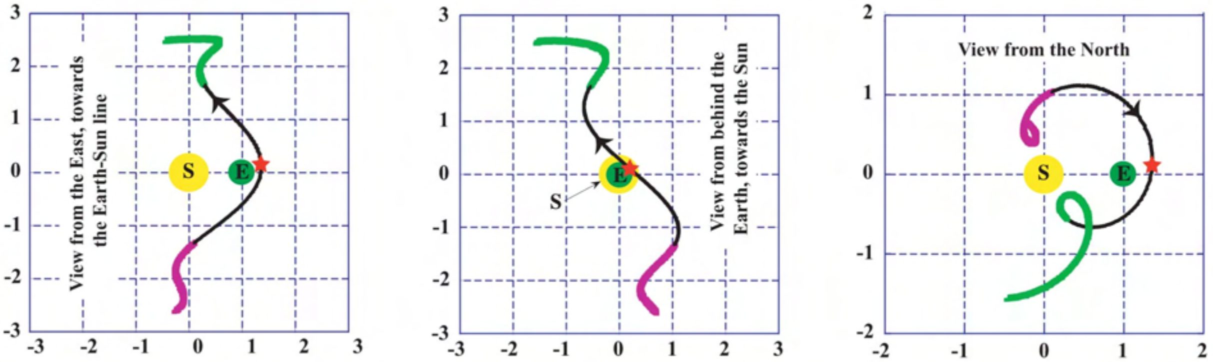

Fig. 5.1. Orbit of Ulysses in a fixed Earth-Sun coordinate system. The purple and green sections refer to the SOHO-Sun-Ulysses quadratures. The plot begins on 19 December 2006 and ends on 28 May 2008. The purple quadrature continues from 19 Dec 2006 to 19 May 2007, +/-5° from the limb of the Sun. The green quadrature continues from 2 December 2007 to 28 May 2008, +/-10° from the limb of the Sun. The red star marks the location of a radial alignment of Ulysses with ACE/WIND/SOHO/IMP-8/Earth in the summer of 2007.

they leave the limb of the Sun allows, at the minimum, an accurate determination of proximity to the limb. However, it may also be possible to even do tomographic reconstructions. The third is that solar minimum will pass in early 2006 and solar activity will be increasing. There is an opportunity for extraordinary coordinated observations (potentially also including WIND, SMEI, and other missions). We will advertise this opportunity at the STEREO planning meeting in November 2005 and have already advertised it to IHY.

Fig. 5.1 shows the Ulysses-Sun-SOHO(Earth) orbital geometry in 2007-2008. The STEREO spacecraft locations are shown in Fig. 5.2 approximately one and two years after launch. The purple sections of the orbit show the winter 2007 quadrature, from 19 December 2006 to 28 May 2007, during which the Ulysses-Sun-SOHO angle is 90 +/-5° and Ulysses is in the south. The green sections of the orbit show the winter 2008 quadrature, from 2 December 2007 to 28 May 2008, during which the Ulysses-Sun-SOHO angle is 90 +/-10° and Ulysses is in the north. The red star marks the equatorial radial alignment (§3.5).

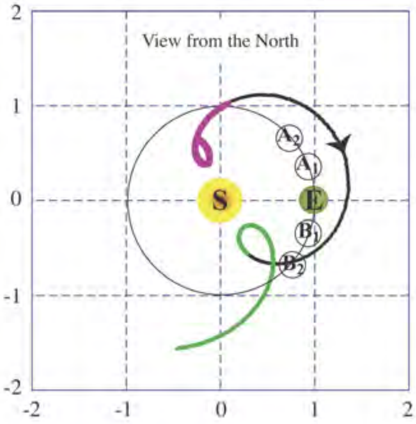

Fig. 5.2 Locations of STEREO A & B one- and two-years after launch, overlayed onto the view from the north of the SOHO-Sun-Ulysses geometry in 2007-2008 (Fig. 5.1).

5.3 Type II bursts, STEREO, WIND

- The orbital configurations in Figs. 5.1 and 5.2 are also useful to illustrate the opportunities for radio triangulation that will exist in 2007-2008.

§3.2 describes how triangulation of Type II and III radio bursts has been developed with WIND to track ICME shocks. This was undertaken in preparation for triangulation with STEREO A/B which also have radio receivers. Ulysses will already be moving to high southern latitudes when STEREO is launched (Fig. 1.1), providing a valuable out-of-ecliptic viewpoint. Ulysses' location relative to Earth (SOHO) (Fig. 5.1) shows it will continue to provide this service throughout FLS III except for the brief time it crosses the ecliptic in summer 2007. The rising level of solar activity in 2007-2008 is favorable for Ulysses support of STEREO CME studies.

5.4 SEPs:

With a STEREO launch in early 2006 (and the extension of the ACE, IMP-8, and WIND missions), there will be the opportunity for multi-point measurements of solar wind, HMF and SEPs near 1AU in the ecliptic plane during 2007 and 2008. Fig. 5.1 shows that Ulysses will be in near radial alignment with Earth /ACE /WIND /IMP-8 at that time. Once again, Ulysses can add the third dimension to TGO. Ulysses crosses the ecliptic plane in August 2007 at 1.39AU with a longitude separation only 12° west of Earth (even more favorable for magnetic connection than near-zero-alignment).

- Ulysses will further examine magnetic deviations and their importance in particle propagation in O-III.

5.5 Voyagers & IBEX - continued

During 2007-2008, Ulysses will be in FLS III, the first scan during the rise-to-maximum activity phase of the solar cycle. During this phase, the outbreak of new-cycle active regions occurs at mid-solar latitudes, but not usually simultaneously in the northern and southern hemispheres. One latitude can lag the other by as much as a year. Ulysses will cross the latitudes of both V1 and V2

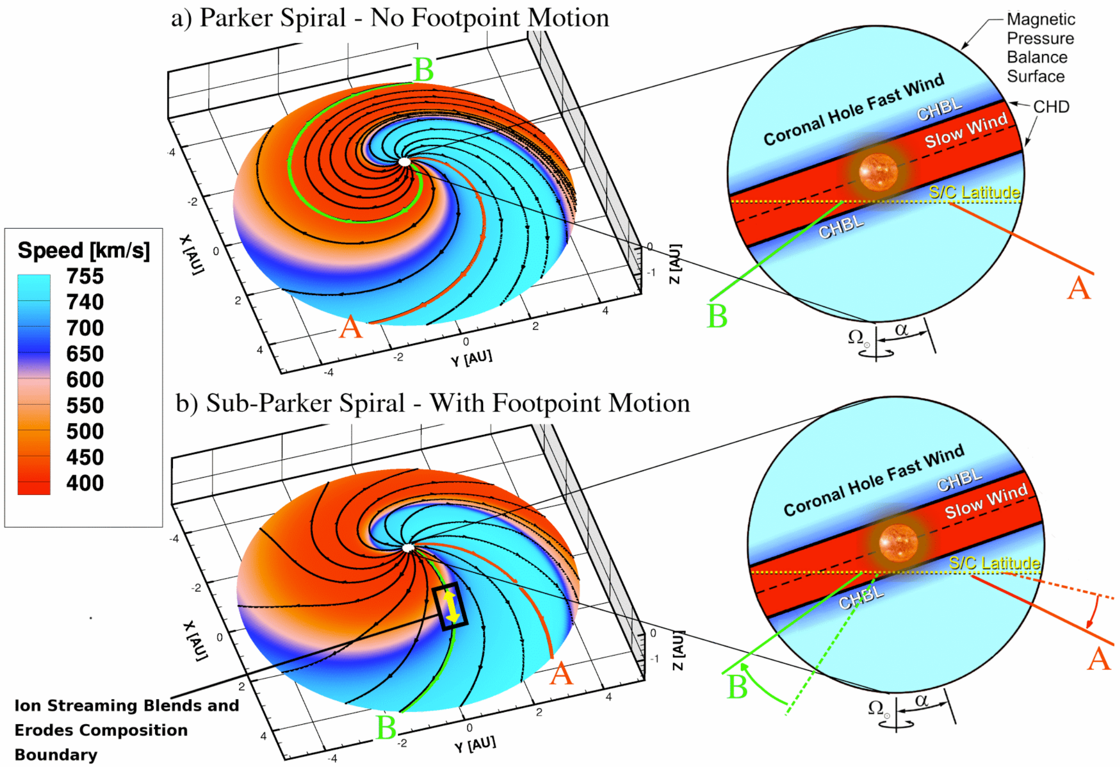

Fig. 5.3. Sub-Parker Spirals (Schwadron & McComas, 2005): Magnetic fields in a CIR without (a) and with (b) footpoint motion at the Sun. In panel (b) differential rotation of magnetic field footpoints creates a magnetic connection across stream interfaces, causing magnetic field lines (black lines) to cross stream interfaces. With footpoint motion, field lines are connected across the stream interface, and across composition boundaries. Differential streaming then causes the mixing of charge-states across composition boundaries on individual field lines.

when it is likely that both will be past the TS and within the heliosheath. V1 observations (*Science, v309*, 23 September 2005) indicate a dynamic heliosheath, implying that it is being influenced by the dynamics and evolution of solar wind coming from the inner heliosphere.

- Only Ulysses will be able to measure these critical latitude regions in the near future, especially during FLS III.

Sub-Parker spiral and V1/V2: A sub-Parker spiral in the HMF (VHM/FGM, SWOOPS) has been reported in a number of papers (Schwadron and McComas, 2005). This is explained by magnetic field lines connecting fast and slow wind due to magnetic footpoints at the Sun moving across the coronal hole boundary (Fig. 5.3). In rarefaction regions, field lines become less transverse. These features lead to favored particle acceleration locations on the TS (FALTS).

- Observation and prediction of sub-Parker spiral distributions in the outer heliosphere will be done in O-III in support of V1/V2 observations in the outer heliosphere and heliosheath.

IBEX: The IBEX (Interstellar Boundary Explorer) mission is scheduled for launch in 2008. It will complete its first all-sky energetic neutral atom (ENA) image of the heliosheath region beyond the TS over the following 6 months. The solar wind that determines the dynamics

Table 5.1; *Topical List of O-III Major Objectives -Ulysses and The Great Observatory*
• Support STEREO, SOHO, & Solar-B with *in situ* measurements, particularly during the long-duration quadratures of 2007-2008 (RFAs J2, F1, H1)
• Study the evolution of ICME shocks using radio triangulation with STEREO & WIND (RFAs J2, J3)
• Provide latitudinal measurements of solar wind and energetic particles during the 2007 radial alignment with ACE, WIND, STEREO, IMP-8, & SOHO (RFAs F2, J1)
• Characterize the solar input to the heliospheric interface during exploration by V1, V2, & IBEX (RFA F3)
• Participate in inter-mission studies of the heliosphere to the fullest extent possible and continue to characterize the 4D heliosphere for TGO (all RFAs)

of the TS will have left the Sun a year earlier, in FLS III. If Ulysses data were acquired up to the end of the year in 2008, these could be related to the dynamics of the TS up to the end of 2009.

- Ulysses data from 2007 onward will provide data for the interpretation of the IBEX ENA images of the first 50 AU of the thickness of the polar heliosheath.

5.6 Meetings & workshops

Ulysses Team members will attend mission workshops and conferences with the purpose of advertising the opportunities for Ulysses' support that are presented by the orbital configurations described in §5.2 & §5.4. Specifically, we will:

a) Make presentations at the STEREO / Solar-B planning workshop in November 2005.
b) Call for ACE and Voyager joint planning workshops.
c) Participate in IBEX planning workshops.
d) Propose an ISSI data analysis group on coronal current sheets and their interplanetary signatures.

> "Deviations [of the magnetic field] enhance the propagation of energetic particles across the mean field direction in ways not contemplated by - or easily integrated into - current models."

6. SCIENCE SUMMARY

Ulysses continues to stimulate frontier research on sources of the solar wind, the Sun and the heliosphere as an integrated system, the local interstellar medium, and the universe. Major advances and discoveries have been produced in the past few years.

The mission is all about time and space. Its long-period orbit means that plots such as shown in Fig. 1.2 are neither a snapshot in time nor a simple time series. For derived science, this means that results and discoveries often involve connections: the solar-interplanetary magnetic field connection, the interstellar neutral atoms/dust-pickup ion-anomalous cosmic ray connection, the Io volcano-Jovian dust stream connection, the global solar wind-termination shock-heliosheath connection, the sub-Parker spiral-acceleration of particles at the termination shock connection, the magnetic field deviations-energetic particle drifts and transport connection, and so on in a far from exhaustive list.

Its continuing role in TGO shows Ulysses is irreplaceable and must not be terminated prematurely. For O-III, we are proposing science objectives to reveal secrets of the Hale cycle, to support many inner heliosphere missions during FLS III and Voyagers 1/2 and IBEX as they explore the heliosheath, and to expand our knowledge of the local interstellar medium and the universe. These objectives respond to the 2006 S3C Roadmap, the VSE, the IHY, LWS/ILWS, and to the requirement to participate in the Great Observatory.

With the extension of Ulysses, we are confident that the mission will remain, in O-III, the keystone in heliospheric research that it is today.

TECHNICAL/BUDGET SECTIONS

7. *MISSION DESCRIPTION*

Ulysses is an international project between NASA and ESA. ESA provided the spacecraft. NASA provided the Radioisotope Thermoelectric Generator (RTG), the launch vehicle, the Inertial Upper stage (IUS), the Payload Assist Module (PAM-S), and is providing data reception via the Deep Space Network. NASA funds the U.S. investigators, while the space agencies and other institutions of their home countries fund European investigators.

Within ESA, Ulysses is under the purview of the Solar and Solar Terrestrial Missions Division that also has responsibility for the SOHO, Cluster, Double Star and Solar Orbiter missions. Based on the outstanding scientific success of Ulysses, ESA's Science Programme Committee, at its 106th meeting in February 2004, unanimously agreed to extend ESA's participation in science operations from October 2004 (the previously agreed end date) to March 31, 2008. This extension will enable data acquisition up to the end of the third northern polar pass. The additional funding also covers post-operational data archiving within the Ulysses Data System. ESA also recognized the important role played by Ulysses for existing and soon-to-be-launched solar and heliospheric spacecraft by placing it into the ILWS program with other ESA missions. The ESA guest investigator program supports Ulysses data analysis, complementing the NASA GI program.

Within NASA, Ulysses is one of 14 operating missions within the Sun-Solar Systems Connections (S3C) theme's Mission Operations and Data Analysis (MO&DA) program. The 2003 SEC MO&DA Senior Review Panel recommended that Ulysses be extended until the end of the northern polar pass in March 2008. NASA accepted the recommendation contingent on ESA approval and funding of its part of the mission (accomplished in February 2004).

The Jet Propulsion Laboratory (JPL) manages the NASA portion of the mission. 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 scien-

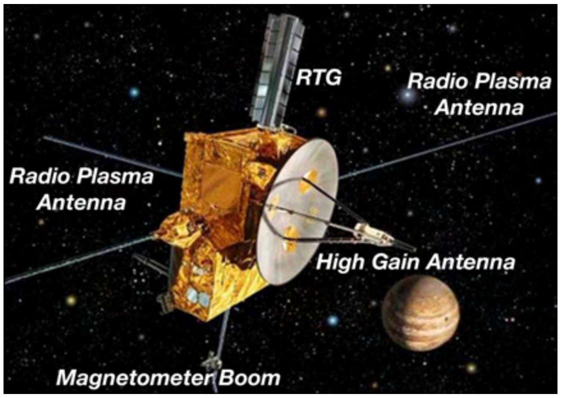

Figure 8.1 The Ulysses spacecraft.

tific instruments and support the investigators who reduce, analyze, and archive the data and report science results. Each science team consists of both U.S. and European members. The co-investigators are about evenly divided between the United States and ESA. The ten Ulysses operational instruments are listed in Table 1.1.

8. THE SPACECRAFT

The highly reliable Ulysses spacecraft (Fig. 1) is radiation resistant, spin stabilized (~5 rpm) and had a mass at launch of approximately 370 kg (814 pounds), including 33.5 kg of hydrazine for attitude and spin-rate adjustments. Its main elements are the box-like main body on which is mounted the 1.65 meter, Earth-pointing high-gain antenna that provides the communications link, and the RTG that supplies electrical power. A 5.6-meter radial boom, containing three groups of experiment sensors (two solid state X- and gamma ray detectors, a tri-axial search coil magnetometer, a vector-helium magnetometer and a flux-gate magnetometer), kept well away from the spacecraft to avoid electromagnetic interference and minimize RTG radiation. A pair of monopole wire antennas, with a combined length of 72 meters, extends perpendicular to the spin axis and a single 7.5 - meter monopole axial antenna protrudes along the spin axis opposite the high gain antenna to make triaxial radio wave/plasma wave measurements. Experiment electronics and spacecraft subsystems are enclosed in the main body. Near continuous data coverage throughout the mission is a prime scientific requirement. To provide continuous scientific data coverage, two redundant tape recorders are included. When not in contact with a ground station, data are stored on-board and then replayed, interleaved with real-time data during periods of ground contact. The radio link between the spacecraft and Earth operates at X-band (downlink) and S-band (uplink and downlink). The downlink telemetry data rate is 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 spacecraft was launched in October 1990 and 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, during minimum solar conditions. The mission was then extended to allow two more polar passes in 2000 and 2001 during solar maximum (Fig. 1.1).

The spacecraft is currently heading southwards prior to the start of the third south polar pass in November 2006. This will be followed by a fast latitude scan (FLS III) from south to north, passing through perihelion in August 2007 and a third north polar pass, ending in March 2008 (Fig. 8.2).

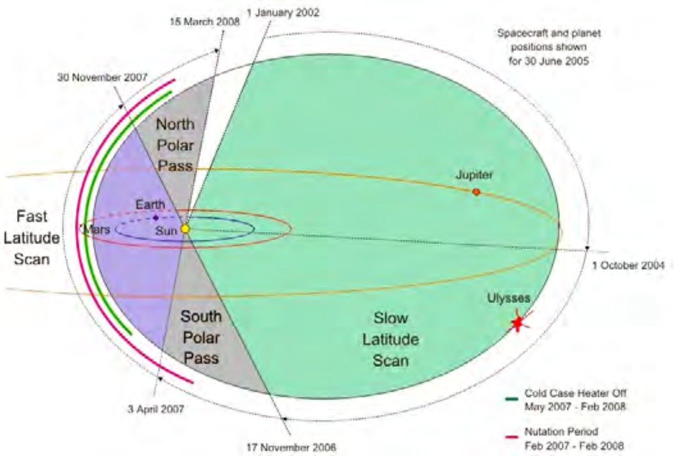

Fig. 8.2. Ulysses' Third Orbit.

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, the spacecraft began nutating. Nutation was the result of an oscillation induced by non-uniform solar heating of the axial boom coupling into the spacecraft spin, 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, was successfully employed to control nutation in 1990-91, 1994-95 and 2000-01 when the spacecraft was nearest the Sun. Nutation is predicted to return in 2007 but the techniques developed during the previous two nutation seasons will allow it to be controlled without continuous use of an uplink.

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, it is possible that there will not be a backup for the duration of the mission. The spacecraft had operated on EPC2/TWTA2 for almost 12.5 years of orbital life. EPC1/TWTA1 has operated flawlessly for about 2.5 years and it is expected that its lifetime will be adequate to complete the proposed mission.

Disconnect Non-Essential Loads (DNEL). DNEL is a spacecraft safing mode. It has occurred several times in association with operation of the latching valve coinciding with peaks in payload current demand. When overcurrent criteria are violated, onboard protection logic operates, placing the spacecraft in a minimum current 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 cases. Operational procedures now exist to minimize chances of reoccurrence.

All instruments are performing nominally and are fully capable of completing the proposed mission extension.

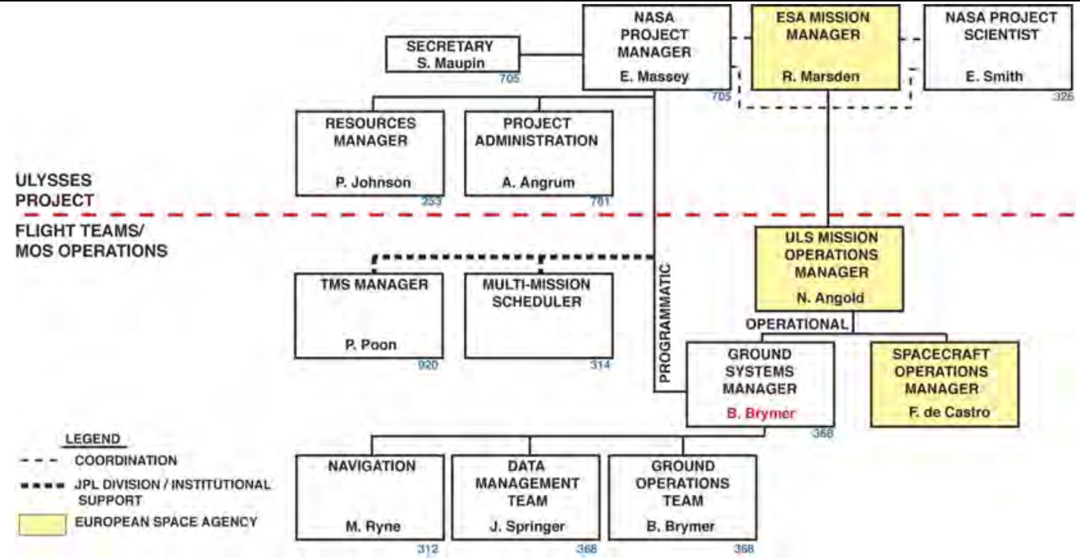

Figure 9.1: Ulysses Project Organization

Expendables are adequate to continue operations through the northern polar pass and beyond; however, power and thermal conservation is required, particularly when the spacecraft is far from the Sun. A recent study by the Mission Operations Team concluded that it is technically feasible to continue science operations through 2008. The team, working with the investigators, also developed a power-sharing plan that allows core instruments to operate continuously. Past 2008, as the spacecraft travels further from the sun, power availability will be marginal for meaningful science operations and thermal control.

The operations team has been in place since the beginning of the mission and has successfully operated the spacecraft. No significant changes to the team are expected before March 2008.

9. PROJECT MANAGEMENT

The Ulysses mission is jointly managed in accordance with a Memorandum of Understanding (MOU) between NASA and ESA. The MOU has been extended several times by NASA and ESA. The current MOU covers the period up to December 2008. Under the provisions of the MOU, a joint mission operations team resides at JPL. An ESOC Spacecraft Operations Team, complemented with NASA controllers, is responsible for spacecraft operations. The NASA Ground Operations Team provides tracking and data reception, navigation and data records processing.

A project manager, assigned to JPL's Astronomy and Physics Directorate (APD), manages the U.S. participation in Ulysses. A project scientist, who is also a co-investigator, has been assigned from the Engineering and Science Directorate by the JPL Chief Scientist. An ESA 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. 9.1.

Two mechanisms for management coordination are the Joint Working Group (JWG) and the Science Working Team (SWT) (Fig. 9.2). The JWG, co-chaired by the project managers, provides a management review and interfacing function for project efforts. The JWG 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 makes scientific decisions and recommendations. It also monitors mission results and advises the JWG on the conduct of the mission.

10. MISSION OPERATIONS & DATA MANAGEMENT

10.1 Operations Concept

Mission operations are designed to minimize the number of personnel and costs. The Ulysses scientific

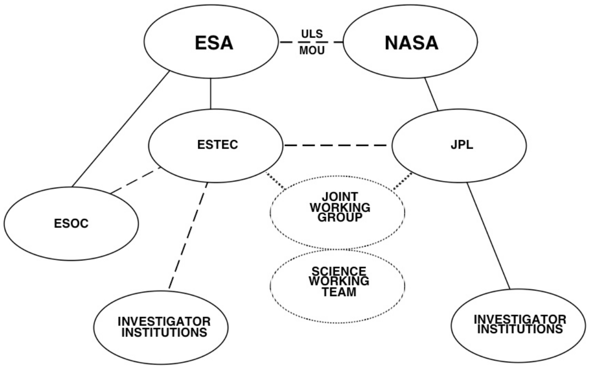

Fig. 9.2. Management Organization

goals require long, continuous scientific 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 only requirement is that 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.

Throughout the nominal mission, the spacecraft was 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. Starting in October 2004, in an effort to minimize costs, the nominal DSN support was halved from the previous level to 70 hours in each 14-day period. Continuous data are still acquired, but at a lower bit rate. The decreasing power output from the RTG, together with the need to avoid freezing the hydrazine fuel, requires that the cold case heaters remain on and has necessitated payload power sharing. Only the core instruments are operated continuously. Open-loop slews for Earth-pointing are performed on approximately 2-5 day intervals.

The above, reduced mode of operations is planned to continue until the start of the third south polar pass in November 2006. Continuous data acquisition at the standard rate is once more planned and DSN support returns to 70 hours every seven days. In February 2007, nutation returns and lasts for approximately a year. With attitude reconstruction software, nutation levels can be controlled between passes without seriously impacting science return. Operational tools developed during the last nutation period assure that nutation can be controlled without continuous uplink coverage. Thus, DSN support requirements will not be increased during this phase. During the nutation period, Earth-pointing will be accomplished by closed-loop conscan. Nutation operations will continue until February 2008, after which Earth-pointing will again be performed using open-loop slews.

Cold case heaters will remain on at the start of nutation, so payload power sharing will be required with only the core instruments operating continuously. Thermal predictions indicate that at the start of the Fast Latitude Scan (April 2007), the cold-case heater can be switched off, allowing full payload operation during most of the Fast Latitude Scan and the northern polar pass. Near the end of the pass, however, as the spacecraft moves farther away from the Sun, it will not be possible to keep the cold case heater off, and instrument power sharing will again be required.

10.2 Data Processing and Distribution

Figure 10.2.1 illustrates the processing of Ulysses telemetry into data records and 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.

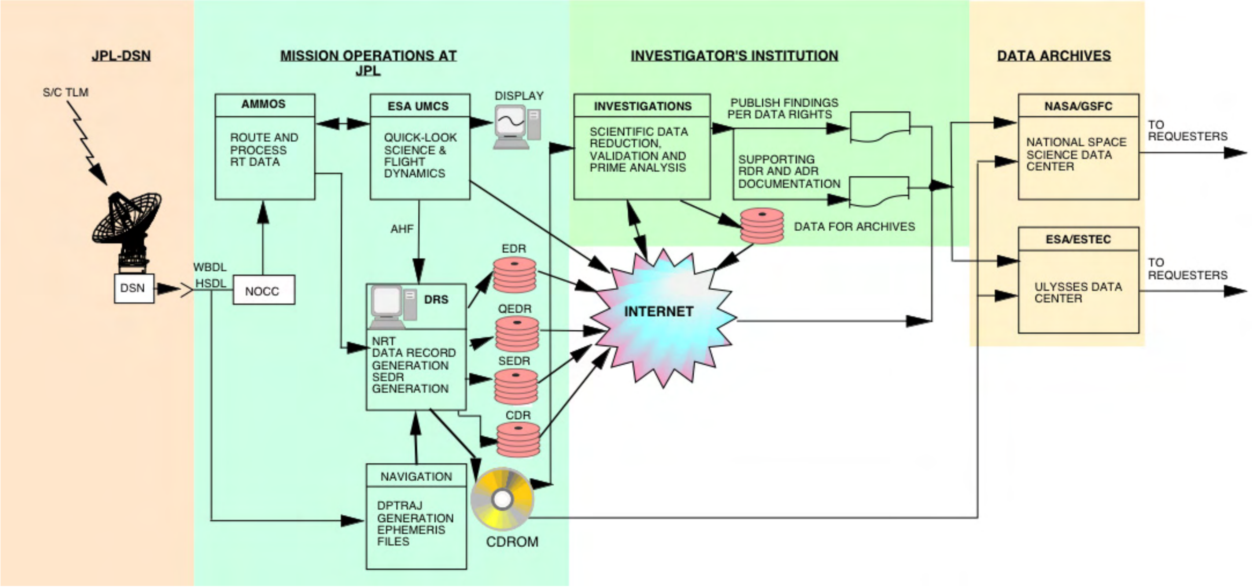

Figure 10.2.1: Data Processing and Distribution

The Common Data Records (CDRs) are a non-validated set of key scientific parameters for use by the Ulysses investigators in selecting events for correlative studies. Common Data Records are 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 on-line 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. The SEDRs are suitable for archiving. Science data are provided to the archives by the investigators.

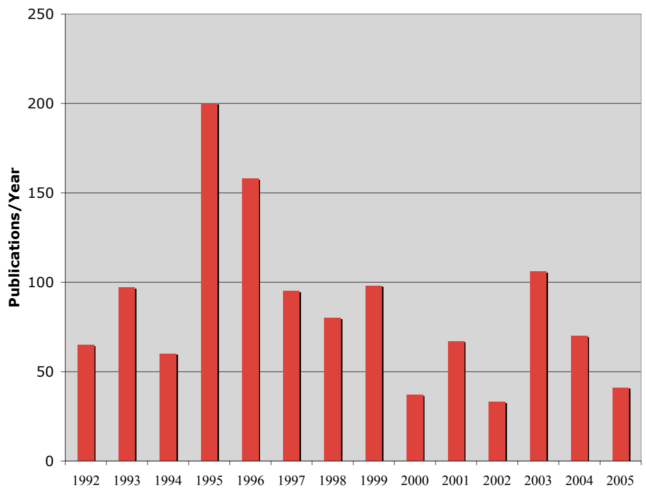

Figure 10.3.1; Ulysses Publications by year

10.3 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 mission. These responsibilities, summarized below, are 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 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 scientific conferences at which scientific results are presented. They also contribute to special publications, generally agreed upon by the SWT. They publish their results as articles in scientific journals on a schedule of their own choosing. Since 1992, the publications have continued at a high rate. During 2003-04, the Ulysses Team has published 187 refereed articles and another 41 have been refereed or submitted for refereeing in FY05 to date (see Fig. 10.3.1). In addition, since the last Senior Review, they have participated in sessions at AGU, EGU, Solar Wind 11/ SOHO 16, ICRC and COSPAR meetings, presenting a total of about 165 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. One recent special topic was the Jupiter Distant Encounter. The SWT agreed to participate in special sessions at the AGU as well as publish the results in Planetary and Space Science. At its most recent meeting, the SWT agreed to propose joint workshops: (1) with Voyagers, and SOHO on the outer heliosphere. (2) with SOHO, ACE, etc. on north-south asymmetries, and others as appropriate. It also has agreed to pursue publication of a book in late 2006 describing Ulysses results through the solar activity cycle.

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. Data through June 2005 have been submitted to the NSSDC at the time of this writing. The SWT monitors the status of submittals at its biannual meetings.

The most recent data go first to the NSSDC FTP site; logs of these updates are in the file ulysses_update.txt at ftp://nssdcftp.gsfc.nasa.gov/, in the subdirectory /spacecraft_data/ulysses/. Archived data can be accessed via the NSSDC Coho Web at http://cohoweb.gsfc.nasa.gov/cw.html. A summary of data availability is accessible at the Space Physics Data

Facility's Data and Orbit Services site at http://spdf.gsfc.nasa.gov/data_orbits.html and at the ESA Ulysses Data System site at http://helio.esa.int/ulysses/data_archive.html. 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.

Since 2003 through September 2005, there were more than 90,000 accesses to the archived data at the NSSDC and more than 2,750,000 accesses to the UDS.

Ulysses team members participate in the SEC GI, LWS, and other SR&T programs, as described in the Science Sections. 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 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.

10.4 Agreements

In addition to the overarching 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 in the U.S. and Europe. In other cases, European investigators process subsets of the instrument's data while American investigators process data from other sensors in the same experiment. These collaborations between the U.S. and European investigators are extremely important for efficient data processing and scientific analysis. They are also vital to the project, since neither the European nor the NASA team members could perform these tasks independently.

11. BUDGET DISCUSSION

The objectives described in this proposal assume funding at the requested/optimum budget level. Funding at the reduced level would principally mean less participation by US scientists. Participation by team members would be reduced and, in some cases, unfunded. The number of graduate students involved in analyzing data would be reduced. Since the operations costs are essentially irreducible, the difference between the optimum and guideline budgets would be borne by the scientists. The guideline budget, however, will allow us to support what are clearly our highest priority goals:

- Participation in the Great Observatory
- The objectives in support of the S3C Roadmap (Table 2.1)
- Support of new missions (STEREO, IBEX) as well as continuing missions (such as WIND, ACE, SOHO, Voyager)
- Observations made during the Fast Latitude Scan
- Correlative studies made possible by the two lengthy quadratures

If Ulysses is funded at the level of the lower in-guideline budget, the objectives will be reconsidered in consultation with the PIs and their teams in order to identify those objectives with the lowest scientific priority, which are less likely to be carried out

Ulysses was conceived as a low-cost mission and has continued to operate with a small management staff and mission operations team. As the budget has continued its downward stream over the years, the project has revised its operational methods and responsibilities to live within the budget. In 1998, management of Ulysses and Voyager was combined into a single project office. In 2002, an independent review confirmed that the planned mission operations levels through 2008 were at the minimum for acceptable operational risks. That plan is being followed today and is the basis for this in-guideline proposal. Mission operations, including project management and data management, consists of about 7 FTE. This includes three mission controllers who conduct the ground operations; they will be increased to four prior to the return of nutation. In FY06, about 0.5 FTE will be required to update nutation analysis software to accommodate DSN interface changes. The optimal budget includes no increases for operations.

The guideline budget also includes funds in FY08 and FY09 for planned mission closeout and for processing, analyzing and archiving the final data sets. Project management, except for resource management would phase out in FY08 and management responsibility will transfer to the project scientist at JPL.

Attributable Deep Space Mission Systems costs are included in Table IV, Line 2a of Appendix 2. FY06 costs are based on 70-hours of coverage every two weeks. Costs during FY07-08, when nutation returns, are based on 70 hours coverage per week. Direct costs for DSMS and MGSS tailored services are included in Item 2b of Tables II and V. Estimated center Full Cost Accounting costs were obtained from Resource Analysts at GSFC and MSFC.

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13. *E/PO PROPOSAL*

Education and Public Outreach Operations Plan

The Ulysses Project has been committed to carrying out NASA's mission to inspire the next generation of explorers. The entire NASA/ESA Ulysses project management and science teams are actively involved by sharing science events, encounters and milestones to excite and inform the public of space science discoveries and by enhancing the quality of public outreach products at pre-college levels. By participating in NASA's Summer High School Apprenticeship Research Program, (SHARP), Academic Part Time and the International Space University (ISU) Intern Program, Ulysses contributes significantly to the 21st century scientific and technical workforce. The project has leveraged its limited E/PO budget by partnering with others and by participation in established programs. Participation in the following programs describes how the project meets or exceeds NASA's E/PO goals.

13.1 Engaging the Public

Ulysses has a six-year partnership with the NASA/JPL Solar System Ambassadors Program. Presently 459 Ambassadors (~40% added in 2 yrs.) in 50 states and Puerto Rico are bringing the excitement of space to the public. Ambassadors are space enthusiasts and volunteers from various walks of life who are interested in providing greater service and inspiration to their communities. In August 2004, via a teleconference seminar titled "Increasing Science with Diminishing Resources -Extending the Ulysses mission to 2008", the Ulysses Science and Operations Team trained Ambassadors on Ulysses present status and future plans. Solar System Ambassadors were interviewed about the program. They commented that their expectations are frequently met or exceeded and that they find value in online instruction and training chats. Solar System Ambassadors have reached ~ 58,600 people with Ulysses presentations in the past 10 months.

Partnering with NASA's Space Place Program (JPL), Ulysses disseminates Sun-Solar System Connection (SSSC) literature to more than 300 rural museums, libraries and planetariums and Amateur Astronomer Clubs for K-6 students. Space Place has a formative evaluation process. Teacher-advisors evaluate each product for age appropriateness, appropriate choice medium, and the ability of the proposed material to support concepts typically covered in the formal education setting. In addition, the Program Evaluation and Research Group, (PERG at Leslie University) is in the process of conducting a summative program-wide evaluation.

Annually, Ulysses participates in the JPL Open House, which welcomes 50,000+ people over a two-day period. Exhibits, models and hand-outs are available for general public dissemination while team members answer questions regarding the mission and its various science objectives.

The Ulysses COSPIN/KET instrument team participated in the "Lange Nacht der Sterne" at the Planetarium Scholerberg in Osnabrueck, Germany in September 2004. The event opens science institutions like Max-Planck, Sternwarten and Planetarien to the general public. More that 800 visitors attended the event.

ESA's Project Scientist, Dr. Richard Marsden, gave public lectures at the Volkssterrenwacht Armand Pien in Gent, Belgium on "Ulysses; exploring the heliosphere in four dimensions".

Figure 13.1. JPL Annual Open House

13.1.1 World Wide Web:

The Ulysses presence in hyperspace has extended to a total of 18 web sites. The JPL managed website averages approximately 18,000 visitors per month. All websites can be accessed via the JPL homepage at http://ulysses.jpl.nasa.gov. In addition, each home page provides links to the other mission partners, both in the USA and Europe, creating further worldwide exposure.

13.1.2 Media Relations

Science Studies Weekly, a newspaper for young science students, developed a current events article about Ulysses. The story is about the spacecraft's mission, longevity, and surprises like the encounter with the Comet Hayutake. The paper is distributed to approximately 700,000 students and 30,000 teachers.

13.2 Informal Education

LA's BEST - Better Educated Students for Tomorrow - is a nationally recognized after-school education, enrichment and recreation program serving more than 21,000 children with the greatest needs and fewest resources throughout the City of Los Angeles. LA's BEST After School Enrichment Program provides a safe haven for children, ages 5 to 12, at 130 elementary schools each day during the critical hours after school -at no cost to parents. Established in 1988, LA's BEST is a partnership including the City of Los Angeles, the Los

Angeles Unified School District and the private sector. Ulysses team members visit 3-5 LA County schools, primarily minority inter-city based schools each year in support of the program. Using a scale model, presenters provide discussion about the planets and the solar system. They also provide hands-on activities, i.e., having the students make their own star finder to take home.

Figure 13.2: LA's BEST Students Participating in Star Finder Activity

Dr. Bruce McKibben of the COSPIN investigation participated in the 2004 summer seminar for undergraduates in the Space Science Center at the University of New Hampshire. The seminar, "Cosmic Rays And What They Tell Us About The Heliosphere", used Ulysses data to discuss 3-D structure.

The SWOOPS Team members are a part of the Young Engineers and Scientists (YES) Program. The program is designed to open students' minds to the world of engineering and science in order to delineate and clarify different career fields and to offer them the opportunity to explore their interests. This is an enriching summer program for high school juniors and seniors held at the Southwest Research Institute in San Antonio, Texas. In the summer of 2004, twelve students entered the program and, over the past 4 years, 54 students have benefited from the program. More information is at http://yesserver.space.swri.edu/.

Approximately 200 students, teachers, and administrators attended a physics lecture given by the Dr David McComas of the SWOOPS investigation. The lecture, "The Three-Dimensional Structure of the Solar Wind", was presented on January 6, 2005 at O'Connor High School in the Northside Independent School District, San Antonio, Texas.

Ulysses team members lead "Sun-Earth Day" activities at JPL and Pasadena. Ulysses activities engage K-12 schools and the general public in space science activities, demonstrations, and interactions with space scientists. In collaboration with the Sun-Earth Connections Education Forum (SECEF) [no written indication of name change] and Telescopes in Education (TIE), Ulysses team members hosted 98 eighth grade students at JPL. Activities included viewing the Sun safely with an H-Alpha telescope, a web cast and teleconference, including Q and A, with SECEF members and Scientists. In classrooms, project personnel shared stories, images, and activities with 500 (80% minority) local students in grades 5-12.

Figure 13.3: Eliot Middle School Participates in Sun-Earth-Day at JPL

In collaboration with the Genesis Mission the Ulysses Team participated in the Local KidSpace Museum "SunSational Festival". The festival included local organizations, artists, health-care professionals, the American Cancer Society and Pasadena Water and Power. In keeping with the museum theme, a kinesthetic demonstration of the Sun/Heliosphere interaction and auroras was presented to kids from pre-school to grade 4 with

Figure 13.4: Sun-Earth Day at JPL with Dr. Bruce Goldstein

participation from the audience.

Ulysses team members regularly support the JPL Speakers Bureau by responding to special requests from local area grades K-14 schools, museums, and community organizations.

"Read Across America" – Each year for Read Across America Day, special guests visit classrooms to read stories to students. The Ulysses Associate Project Scientist, Dr. Steve Suess, participated in this MSFC event, giving 54 second graders a special treat at the U.S. Space and Rocket Center. Dr. Suess showed pictures of the Sun and a movie about our Solar System. Each student left with the NASA book "Our Very Own Star, the Sun".

Figure 5: Read Across America Day with ULS Dr. Suess

13.3 Formal Education

The University of Michigan Space Systems Program created a module that studies thermal properties of spacecraft. In collaboration with the Ulysses ESA Operations Team and the Ulysses SWICS Science team, a Ulysses spacecraft model and Ulysses data were incorporated into the module as a key exercise. Two full weeks of class time are devoted to this exercise. The models are used to explain the different thermal technologies used in the presence of an RTG and large heliocentric variability. Students analyze SWICS and its temperature variations and compare them with the specifications. Finally, students make a small 5-parameter model of Ulysses and compare it with real data.

A partnership with Educator/Product Developer, Paul Williams, has produced three educator workshops based on the Ulysses multidisciplinary activity "The Maunder Mystery Story". Over ninety Educators in the New Hampshire area have participated in the workshop.

Ulysses SWOOPS Team members contributed to the 2005 Los Alamos Space Science Outreach (LASSO) Program which involves 10 elementary and middle school teachers from Northern New Mexico. Team members participated in planning and presentations related to the Ulysses mission science results. When they return home, teachers will develop lesson plans that incorporate space science information learned. http://stb.lanl.gov:8080/wosaserver/web?pg=/education/k-12/lasso/index.xml.

Ulysses COSPIN investigators made a presentation to the New Hampshire Association of Science Teachers. Using Ulysses as an example, ten K-12 Science teachers learned how NASA builds robotic spacecraft.

13.4 Products

The Gamma Ray Burst Team has collaborated with the Swift E/PO group and Professor Lynn Cominsky of the Sonoma State University to develop the GRB Education Unit. These standards-based activities are designed to use gamma-ray bursts to engage students and teach them science and math concepts.

13.5 Plans for FY06-08-Engaging the Public:

Ulysses Project will continue to interact with Solar System Ambassadors through teleconference discussions regarding mission status and science events. Ambassadors will be exposed to key personnel while examining new science results from the Ulysses Mission. The mission will continue to support the Ambassador program with educational materials and handouts for community presentations. The Program is projected to increase by 100 Ambassadors per year.

Working with the SpacePlace, the Ulysses project will develop one Fun Fact per year in English and Spanish for the SpacePlace website. The website receives approximately 10,000 unique visits per day. Ulysses will produce one Kids News Article in both English and Spanish that will appear in up to 14 different newspapers and be distributed to 250 astronomy clubs.

"Community Nights" - In a partnership with the Arizona State University Mars K-12 Education Department, the Ulysses project proposes continued participation in the development of the Ulysses Solar System kit. These kits have been beta-tested by over 100 Girl Scout Troops and are presently scheduled for revision and updated for introduction to the Girls Scouts of the USA (GSUSA) Nationwide. The portable exhibits will be loaned to educational facilities, community organizations and other NASA EPO partners.

13.5.1 World Wide Web:

The Ulysses Project team will continue to maintain and update the website on a quarterly basis. Plans include new on-line activities, additional educational resources and updated science news.

13.5.2 Public Information:

In FY04, Ulysses Science Members contributed to at least 3 news articles on science.nasa.gov website. The Associate Project Scientist at Marshall Space Flight Center has plans for more as opportunities arise or are created.

13.6 Informal Education:

By providing opportunities for K-12 teacher training, enhancing curriculum and engaging students in NASA related career fields, the Ulysses project plans to support Presidential Executive Order 13021 Tribal College, Tribal Pre College Initiatives. The project will work with the JPL Tribal College Initiative and the Minority Education Initiatives in the Education and Public Outreach Office.

The Ulysses Team at JPL will continue work with the JPL Education Office to add value to the LA's Best program. The Ulysses ESA operations team has encouraged their members to participate in local school visits with presentations and hands-on activities. This partnership will increase Ulysses visibility in the local elementary, middle and high schools by about 50%. Team members will continue to engage local schools in the yearly Sun-Earth-Day activities with a commitment to collaborate more with our ESA partners and Goddard Space Center Student Observation Network (SON) on student research and activities.

Ulysses team members have agreed to support the Eliot Middle School Tutoring Program. The program meets two times a week, offering one-on-one tutoring for 35-45 students per session.

13.7 Conferences/Workshops

Ulysses will continue to support educational and science conferences requiring NASA Center presence, i.e., NSTA, CSTA, AAS, AGU, and Space Congress. The Ulysses project and partner, Paul Williams, have proposed educational workshops for the 2006 NSTA and the Fall California Science Teachers meeting.

13.8 E/PO Products

The project will develop products to support the education and public outreach programs according to the NASA Science Mission Directorate (SMD) Communications guidelines. These will include, as appropriate, brochures, educational wall sheets, content for web sites and packages for SEC related conferences and workshops. Educational materials will be distributed through the NASA Education Resource Centers and through distribution to schools involved in the various E/PO programs in which the Ulysses project is involved.

13.9 E/PO Budget

By participating with other missions at JPL and with the Sun-Earth Connection Forum, the project has been able to leverage its E/PO funds. The requested E/PO funds will be used to participate in the various partnerships/subcontracts the Voyager Project will be involved in, like Solar System Ambassadors, The Space-Place, and Educator Consultants. The Ulysses Project will purchase equipment to provide a more enhanced outreach program at the local schools and to support the Sun Earth Education Forum's annual Sun-Earth Day. The equipment will include two sun spotters and a solar telescope. Because of the freeze on NASA products, no new handouts have been developed. Instead, the Project will reprint the Ulysses educational wall sheet and bookmarks to support NASA sanctioned educational conferences. Activity supplies such as UV beads, sunspot record cards and evaluation forms will be purchased for hands-on activities. Travel funds are requested to attend the NASA supported conferences and Ulysses science working group meetings. Direct Labor costs will cover the Ulysses Web Master and the audiovisual personnel.

	FY-06	**FY-07**	**FY-08**
1. Direct Labor (salaries, wages, and fringe benefits)	8000	8000	8000
2. Other Direct Costs:			
a. Subcontracts	15000	15000	15000
b. Consultants	2000	2000	2000
c. Equipment	4200	3000	3000
d. Supplies	13800	15000	15000
e. Travel	7000	7000	7000
f. Other			
3. Facilities and Administrative Costs			
4. Other Applicable Costs			
5. SUBTOTAL--Estimated Costs	50000	50000	50000
6. Less Proposed Cost Sharing (if any)			
7. **Total E/PO Estimated Costs**	50000	50000	50000

APPENDIX 1. ACRONYMS

Acronym	**Meaning**
3D	Three-Dimensional
§	Section
$xxK	Thousands Of Dollars
A	Magnetic Polarity
AAS	American Astronomical Society
ACE	Advanced Composition Explorer
ACR	Anomalous Cosmic Ray
ADS	Astrophysical Data System
AGU	American Geophysical Union
AMMOS	Advanced Multi-Mission Operations System
AO	Announcement of Opportunity
APD	Astronomy & Physics Directorate
AU	Astronomical Unit
BEST	Better Educated Students for Tomorrow
BHL	Bursty High Latitude (radio emission)
C	Carbon
CDR	Common Data Records
CDROM	Compact Disk – Read Only Memory
CHBL	Coronal Hole Boundary Layer
CIR	Corotating Interaction Region
CME	Coronal Mass Ejection
CONSCAN	Conical Scan
COSPAR	Committee on Space Research
COSPIN	Cosmic & Solar Particles Investigation
CR	Carrington Rotation
CSA	Canadian Space Agency
CSTA	California Science Teachers Association
CTU	Central Terminal Unit
D	Deuterium
DMT	Data Management Team
DNEL	Disconnect Non-essential Loads
DRS	Data Records System
DSN	Deep Space Network
E/PO, EPO	Education & Public Outreach
EDR	Experiment Data Record
EPAC	Energetic Particles Composition
EPC	Electronic Power Converter
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTEC	European Space Research & Technology Centre
EUV	Extreme Ultraviolet
FALTS	Favored particle Acceleration Locations on the Termination Shock
FGM	Flux Gate Magnetometer
FLS	Fast Latitude Scan (FLS I, II, III)
FTE	Full-time Equivalent
GCR	Galactic Cosmic Ray
GI	Guest Investigator
GIP	Guest Investigator Program
GMIR	Global Merged Interaction Region
GRB	Gamma Ray Burst (and GRB detector)
GSFC	Goddard Space Flight Center
GSUSA	Girl Scouts of the United States of America
H	Hydrogen
HCS	Heliospheric Current Sheet
He	Helium
HI-SCALE	Heliosphere Instrument for Spectra, Composition, and Anisotropy and Low Energies
HMF	Heliospheric Magnetic Field
IBEX	Interstellar Boundary Explorer
ICME	Interplanetary CME
IHY	International Heliophysical Year
ILWS	International Living With a Star (Program)
IMP	Interplanetary Monitoring Platform
IPN	Interplanetary Network (gamma ray detectors)
IPS	Interplanetary Scintillation
ISAS	The Institute of Space and Aeronautical Science, Japan
ISM	Interstellar Medium
ISPI	Inner Source Pickup Ions
ISSI	International Space Science Institute
ISU	International Space University
IUS	Inertial Upper Stage
JDE	Jupiter Distant Encounter
JPL	Jet Propulsion Laboratory
JWG	Joint Working Group
K-12	Kindergarten through 12th Grade
K-6	Kindergarten through 6th Grade
KET	Kiel Electron Telescope
LA	Los Angeles
LASSO	Los Alamos Space Science Outreach
LIC	Local Interstellar Cloud
LICPI	LIC Pickup Ions
LISM	Local Interstellar Medium
LWS	Living With a Star
MHD	Magnetohydrodynamic
MIR	Merged Interaction Region
MO&DA	Mission Operations & Data Analysis
MOU	Memorandum of Understanding
MSFC	Marshall Space Flight Center
N	Nitrogen
NASA	National Aeronautics & Space Administration
Ne	Neon
NRC	National Research Council
NSSDC	National Space Science Data Center
NSTA	National Science Teachers Association
N-S	North-South
O	Oxygen
O-I, O-II, O-III	Ulysses' Orbits I, II, and III
PAM-S	Payload Assist Module, Special
PERG	Program Evaluation Research Group
PI	Pickup Ion / Principal Investigator (context dependent)
PSC	Protostellar Cloud
QEDR	Quicklook EDR
RFA	Research Focus Area

RTG	Radioisotope Thermoelectric Generator
S	Sulfur
SDO	Solar Dynamics Observatory
SECEF	Sun-Earth Connections Education Forum
SEDR	Supplemental EDR
SEP	Solar Energetic Particles
SHARP	Summer High School Apprenticeship Research Program
Si	Silicon
SMD	Science Mission Directorate
SMEI	Solar Mass Ejection Imager
SOHO	Solar & Heliospheric Observatory
SON	Student Observation Network
SR&T	Supporting Research & Theory
SS	Source Surface
SSMO	Space Science Mission Operations
SSSC	Sun-Solar System Connection
STEREO	The NASA STEREO Mission
SWICS	Solar Wind Ion Composition Spectrometer
SWOOPS	Solar Wind Observations Over the Poles of the Sun
SWT	Science Working Team
S3C	Sun-Solar Systems Connection
TGO	The Great Observatory
TIE	Telescopes in Education
TS	(Heliospheric) Termination Shock
TWTA	Traveling Wave Tube Amplifier
U.S.	United States
UDS	Ulysses Data System
UMCS	Ulysses Mission Control System
URAP	Unified Radio & Plasma (waves)
URL	Uniform Resource Link
USR2003	Ulysses 2003 Senior Proposal
UV	Ultra-Violet
VHM	Vector Helium Magnetometer
VSE	Vision for Space Exploration
V1, V2	Voyager 1, Voyager 2
WKB	Mathematical approximation for small wavelengths compared to spatial gradients
WSO	Wilcox Solar Observatory