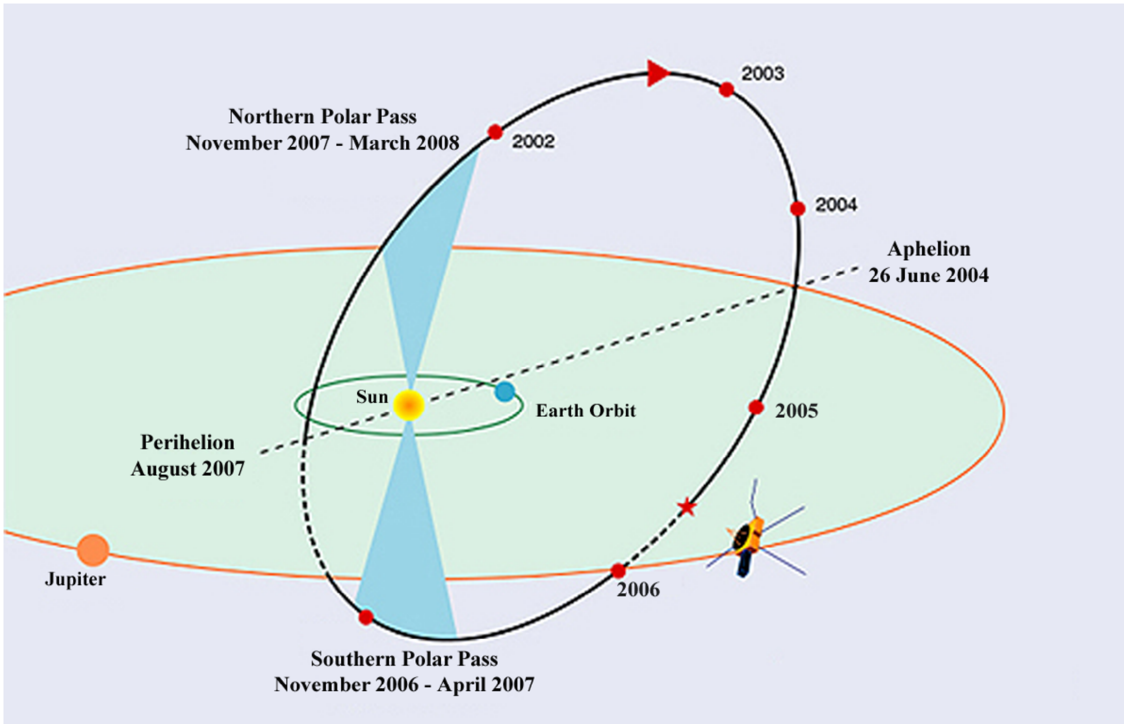

Figure 1.1. Ulysses' orbit, 2002-2008.

1. *Introduction and Overview*

1.1 Background

The joint NASA-European Space Agency (ESA) Ulysses mission was conceived to study the three dimensional (3D) heliosphere. It was launched in October 1990 and achieved a solar orbit (Fig. 1.1) with an inclination of 80.2^o, a perihelion of 1.34AU, an aphelion of 5.4AU, and a period of 6.2 years. Ten experiments, listed in Table 1.1, measure *in situ* fields and particles, UV, X-rays, and gamma rays. These experiments and the unique polar orbit have allowed Ulysses to make fundamental contributions and discoveries related to the 3D heliosphere, the Sun, Jupiter, the local interstellar medium (LISM), and the origins of gamma ray bursts. Ulysses science is truly broad based and its success has made it the touchstone for global heliospheric studies. Furthermore, Ulysses observations directly support the NASA Living With a Star (LWS) and Sun-Earth Connections (SEC) programs.

The broad utility and relevance of Ulysses to NASA and the international research community is reflected in ~30 Guest Investigator (GI), Supporting Research and Technology (SR&T), and LWS grants depending explicitly on current Ulysses data. This, in turn, has caused changes in data handling and access. The Ulysses mission was planned in the late 1970s, with data handling and public data access typical of NASA requirements of that era. Community needs have caused this to evolve into a modern, open access, distributed Ulysses data system.

Ulysses' first two solar orbits were called the Solar Minimum and the Solar Maximum Orbits, reflecting the approximate times that they occurred in the declining phase of the 22nd and the onset and maximum phase of the 23rd solar cycles. The heliolatitude and helioradius during those orbits and the upcoming orbit, in comparison to the solar sunspot cycle, are shown in the middle and bottom panels of Fig. 1.2. The upcoming orbit is referred to as the "Ulysses Full Cycle" orbit (*UFC*) for its occurrence in the 2nd half of the Hale Cycle, while the first and second orbits are referred to here as U-I and U-II.

1.2 Achievements

The 2001 Senior Review proposal stated that U-I and U-II addressed all original Ulysses science objectives - summarized in Table 1.2. These results may be represented by the "dial plots" of solar wind speed in Fig. 1.3, illustrating that Ulysses explored the gross 3D properties of the solar wind near minimum and maximum phases of the sunspot cycle. Nevertheless, new results continue to be reported. Bibliographies at http://ulysses.jpl.nasa.gov/ and http://helio.esa.int/ulysses/, under Science:Publications, list publications by the Ulysses Team in 2000-2003. The number of publications is plotted and discussed in Section (§) 11.3. The NASA Astrophysics Data System lists 346 abstracts mentioning Ulysses over the same interval. Ph.D.

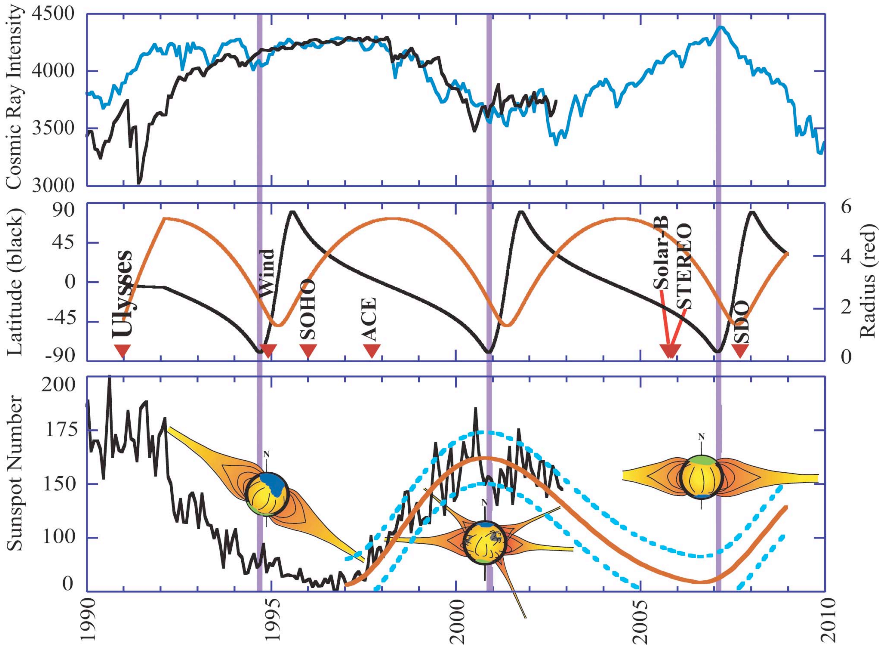

Figure 1.2. Top: Climax, Colorado cosmic ray intensity (black), and intensity shifted to the right by 22 years (blue). Middle: Ulysses orbital latitude (black) and radius (red) and launch dates for SOHO, Wind, ACE, Solar-B, STEREO, and SDO. Bottom: Solar sunspot number and predicted sunspot number through 2008 (Hathaway et al., 1994, & priv. comm.). Schematics are of the typical corona at indicated times in the solar cycle. Vertical lavender bars mark the beginning of each Ulysses fast latitude scan.

theses derived from Ulysses are listed at both of the mission web sites.

Progress in 2000-2003 has been made in mapping solar wind magnetic fields and composition to solar sources and on origins of "inner source" pickup ions (§3), isolating and identifying the importance of latitudinal transport and the interplanetary magnetic field polarity in energetic particle and dust dynamics (§4), 3D structure of the solar maximum heliosphere (§5), and properties of the LISM and gamma ray bursts (§6). Meanwhile, collaboration with other missions has grown (§7).

Nevertheless, the sum of all Ulysses` results to date represents only two temporo-spatial cuts through the heliosphere that in no way constitute a four-dimensional (4D) picture in space and time. It is argued here that there will be significant results from measurements in a different phase of the solar cycle during the Ulysses Full Cycle orbit, with a mission continuation through 2007.

1.3 Science Objectives, 2004-2007

A general reason for the expectation of new results in 2004-2007 is illustrated in Fig. 1.2. Energetic particle and dust dynamics depend on magnetic polarity of the Sun, following the 22 year Hale solar magnetic cycle**,** and not the 11 year sunspot cycle. Fig. 1.2 shows this with the galactic cosmic ray intensity measured by neutron monitors at Climax, Colorado. The top panel shows the ongoing data stream and data from the last Hale cycle that is shifted by 22 years, illustrating the asymmetry of the cosmic ray intensity in alternate halves of the magnetic cycle. The *UFC* fast latitude scan (*UFC*-FLS) starts at the peak of intensity in the next, and as yet unexplored, half-Hale cycle. Ulysses will not only make measurements during a different portion of the solar cycle than in U-I and U-II, it will make completely original measurements of energetic particles and dust during *UFC*.

Science objectives described in §3-§7 go into considerable detail and exhibit the breadth of Ulysses science. There are, however, a few overarching topics which thread through four themes and which we list here.

The first general topic, under Theme 1, Sources of the Solar Wind (§3), can be described as solar sources and interplanetary consequences during declining phases of the solar cycle. Ulysses will follow the heliospheric current sheet (HCS) downward in latitude as its tilt decreases with the approach to solar minimum (see cartoons in Fig. 1.2). This will better define the topology and structure of the HCS, the contrast in composition between fast and slow wind, sources of slow and fast wind, and properties of CMEs in the neighborhood of the HCS. Studies will be closely coordinated with studies of the corona from, e.g., SOHO and with *in situ* measurements in the ecliptic.

The second general topic, under Theme 2, The Sun and the Heliosphere as an Integrated System (§4), is latitudinal transport and the Hale cycle. It has long been known that energetic particles are transported in latitude more effectively than has been understood. This general problem is now known to include cosmic rays, anomalous component cosmic rays, dust, and solar, interplanetary, and Jovian energetic particles. It involves both microscopic and macroscopic properties of solar wind plasma and magnetic fields. *UFC* will provide otherwise unobtainable new data for attacking these

Table 1.1: The Ulysses Experiments	
Acronym	Experiment - Measurement
COSPIN	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.uchicago.edu/WWW/Simpson/UlyDocs/HET.html COSPIN/KET: http://naysika.mi.iasf.cnr.it/Ulysses/ COSPIN/AT: http://www.sp.ph.ic.ac.uk/Ulysses/Research/AT/ats1.html
DUST	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/galileo/ulysses/
EPAC	Energetic ion composition, flux, and anisotropy [Keppler et al., 1992] - 80 keV/n to 15 MeV/n , http://www.linmpi.mpg.de/english/projekte/ulysses/epac.html
GAS	Neutral He atom and UV detectors [Witte et al., 1992], http://www.linmpi.mpg.de/english/projekte/ulysses/gas.html
GRB	Solar and cosmic gamma ray burst detector (x-rays and gamma-rays, 15 to 150 kev) [Hurley et al., 1992], http://ssl.berkeley.edu/ipn3/index.html, and the Gamma-ray Burst Coordinates Network at Goddard Space Flight Center, http://gcn.gsfc.nasa.gov/
HI-SCALE	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://kuspa1.phsx.ukans.edu:8000/~ulysses/index.html
SWICS	Solar Wind Ion Composition (thermal/suprathermal) [Gloeckler et al., 1992], http://solar-heliospheric.engin.umich.edu/Ulysses/index.html
SWOOPS	Solar Wind thermal ion and electron distributions [Bame et al., 1992], http://swoops.lanl.gov/
URAP	Radio and Plasma Waves (plasma waves-0 to 60 kHz, radio-1 to 940 kHz, magnetic 10 to 500 Hz) [Stone et al., 1992], http://urap.gsfc.nasa.gov/
VHM/FGM	Vector magnetometer, 0.01 to 44000 nT, 2 vectors/second [Balogh et al., 1992], http://www.sp.ph.ic.ac.uk/Ulysses/

problems that have importance for solar, heliospheric, planetary, and galactic studies.

The third general topic, under Theme 3, The 4D Heliosphere: The heliosphere in space and time (§5), is north-south asymmetries and the long-term behavior of the heliosphere. It was discovered in U-I that the heliosphere is north-south asymmetric. This was unexpected. Useful observations were not possible near solar maximum, in U-II, but will again be possible in *UFC* and are a major goal.

The fourth general topic, under Theme 4, The Interstellar Medium (§6), is properties of the LISM and cosmic gamma ray bursts. The former requires *in situ* composition measurements in combination with 3D global heliosphere models. The latter utilizes Ulysses' high latitude perspective, and Ulysses being a key member of the "third interplanetary network" of cosmic gamma ray burst detectors which today includes Wind, HETE, Mars Odyssey, and Integral. This network is currently in demand for magnetar studies.

A specific additional topic is an observation of opportunity during a distant encounter with Jupiter in 2004.

1.4 Coordinated Observations, 2004-2007

Ulysses' high latitude observations offer important support for other existing and planned LWS and SEC missions, including SOHO, WIND, ACE, RHESSI, TRACE, HETE, the two Voyagers, Integral, STEREO, SDO, and Solar-B. Ulysses is also an International Living With a Star (ILWS) mission, joining Cluster, MMS, SDO, SOHO, Solar-B, and STEREO. While Ulysses was never an isolated mission, it now undertakes many joint observations and campaigns. This expands the ability of Ulysses to continue fulfilling its original science objectives and to contribute to the science objectives of other missions and programs.

By these collaborations, Ulysses has itself gained two new science objectives that are listed in Table 1.2, involving its relationship with the other missions and programs. Some of these collaborative opportunities did not exist at Ulysses' launch (SOHO, ACE, and Wind, were launched after 1995) while Solar-B, SDO, and STEREO will be launched during *UFC* (Fig. 1.2). The new missions are designed to analyze the origins and effects of solar activity and the 3D structure of interplanetary disturbances. Ulysses will work with them in the same way as it works now with SOHO in quadrature studies. The SDO Science Working Team report explicitly anticipates such activities. There will also be an important new capability with the launch of STEREO in triangulation of type II and III solar radio bursts, where the out of ecliptic Ulysses view-

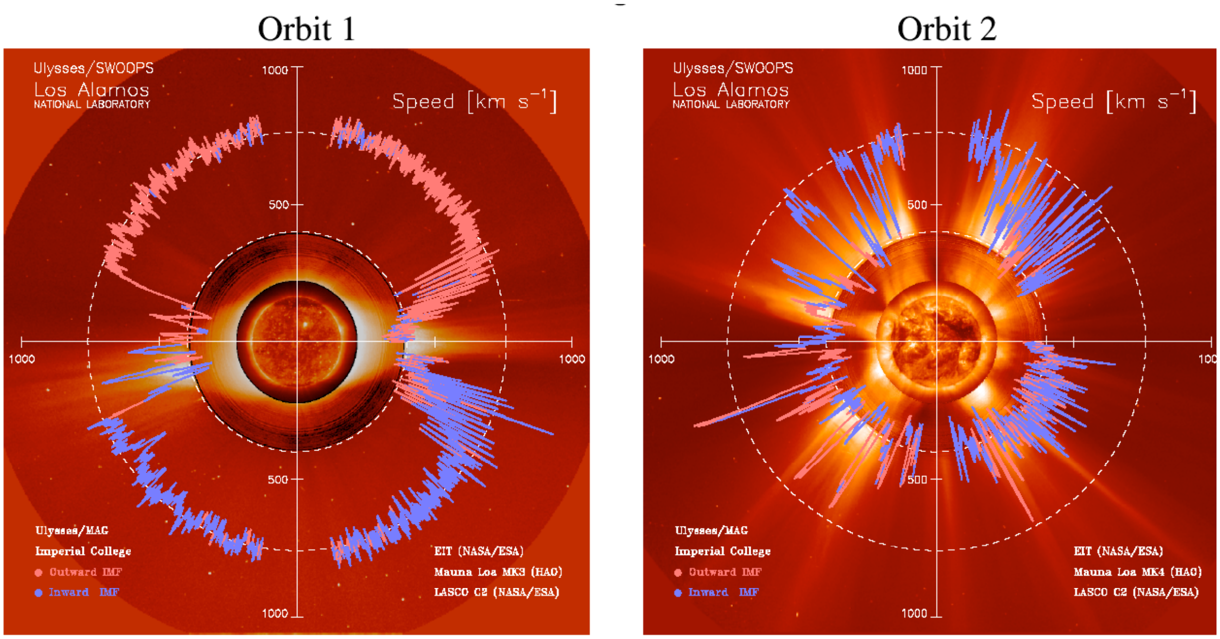

Figure 1.3. Dial plots of solar wind speed with co-temporal coronal images two years prior to solar minimum (Orbit 1) and at solar maximum (Orbit 2). Time runs clockwise from 3 o'clock, along with heliographic latitude. The solar wind speed scales are 500 km/s (1000 km/s) on the inner (outer) dashed circle. The 6.2 year orbits start in 1992 and 1998. The gaps at the north and south poles reflect the maximum Ulysses latitude of 80.2^{o}. The final U-II data point is from December 2002.

point will remove ambiguities in source locations, propagation properties, and plasma physics.

Ulysses supports all research with the Ulysses Data System (UDS) and other online, distributed data archives. Ulysses data are available on the internet shortly after being received, at individual team web sites and at the NSSDC and ESA mission sites given in §11.

1.5 Technical Status

There are no technical obstacles to a mission extension through 2007. In 2002, the Ulysses project office undertook a comprehensive examination of the "...operational implications of a 3^{rd} solar orbit (including high latitude passes)..." This study was an investigation of the technical capability of the spacecraft and of each instrument to survive and operate during *UFC*, and of alternative plans for operation. As described in the Technical and Budget §9-§12, all instruments on Ulysses continue to be fully operational. The RTG can supply sufficient power to keep the core instruments (SWOOPS, SWICS, VHM/FGM, HI-SCALE, COSPIN) operating continuously and other instruments operating as required, into 2008. All the instruments will be operating during *UFC*-FLS.

1.6 Relevance and Science

§2 is a supplement to the present section. It meets the Announcement of Opportunity (AO) request for explicit identification of how Ulysses fits into the science context of the Space Science Enterprise (SSE) Strategic Plan and SEC Roadmap. §3-§7 are detailed science sections. Rather than listing

Table 1.2: Original Ulysses Mission science objectives
[Astron. Astrophys. Suppl. Ser., Vol. 92(2), 1992]

- *Investigate for the first time as a function of heliographic latitude the properties of the solar wind, the structure of the Sun/wind interface, the heliospheric magnetic field, solar radio bursts and plasma waves, solar X-rays, solar and galactic cosmic rays, and both interstellar and interplanetary neutral gas and dust.*

Additional objectives include

- *Study of the Jovian magnetosphere during the Jupiter flyby.*
- *Detection of cosmic gamma ray bursts and triangulation on burst locations with other detectors.*
- *Search for gravitational waves.*

New objectives evolving since launch:

- *Combine Ulysses measurements with those from ongoing and new missions to analyze coronal mass ejections and sources of the solar wind to enhance the ability of those missions to meet their own science objectives and to construct models of the 3D Sun and heliosphere*
- *Test predictive models of heliospheric disturbances to support the Living With a Star program.*

objectives, accomplishments, and plans instrument by instrument, the breadth of Ulysses science is emphasized in the context of the four themes listed above. This is followed in §7 by a summary of joint observations and observing campaigns. These sections document major scientific achievements in 2000-2003 and major objectives for Ulysses operations through 2007.

1.7 E/PO

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

1.8 Budget

The Ulysses budget request is for funding that is essentially level with recent years. It provides for continuing operations but little analysis and only minimal validation and monitoring of the data. The demand for Ulysses data for extended studies of the 4D heliosphere and for collaborative work leads us to also propose a budget that would provide optimal data validation and verification, minimal science support for cooperative studies with other missions and programs, support of collaboration with the upcoming STEREO, Solar-B, and SDO missions, and for expanded studies of the 4D heliosphere and the heliosphere as an integrated system.

2. *Relevance to the NASA Office of Space Science*

Ulysses objectives to determine how and why the heliosphere evolves on large spatial and temporal scales are central to the SSE and to the SEC objective "...to understand the changing flow of energy and matter throughout the Sun, heliosphere and planetary environments." Ulysses' objectives are also close to the LWS objective "...to define the origins and societal impacts of variability in the Sun-Earth Connection." This section connects Ulysses science to specific parts of the SSE Strategic Plan and the SEC 2002 Roadmap.

2.1 The Space Science Enterprise

Table 2.1 lists relevant SSE goals and objectives and points to related sections (§) in this proposal.

2.2 The SEC Roadmap

The SEC Division's primary goal (2002 SEC Roadmap) is to "Understand how the Sun, heliosphere, and planetary environments are connected in a single system." The Roadmap is a plan for new missions and does not explicitly address Ulysses or other ongoing missions. Ulysses can, however, fundamentally enhance or even facilitate some of the missions and contributes directly to several science objectives, research focus areas, and investigations. The passage of time has in no way removed the relevance of Ulysses to SEC but has, rather, enhanced its relevance.

Within Roadmap missions, Solar Orbiter and Telemachus will continue the global heliospheric exploration started by Ulysses into the next Hale cycle. But, they will not be launched for several years. A cost-effective strategy for achieving the

Table 2.1: Space Science Enterprise Goals and Objectives

NASA Mission	Enterprise Goals	Enterprise Objectives
To advance and communicate scientific knowledge and understanding of Earth, the Solar System, and the universe	Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life	<u>Science Objectives</u> ▪ Understand the structure of the universe, from its earliest beginnings to its ultimate fate (§4, §6) ▪ Explore the ultimate limits of gravity and energy in the universe (§6) ▪ Learn how galaxies, stars, and planets form, interact, and evolve (§4, §5, §6) ▪ Understand the formation and evolution of the Solar system and Earth within it (§3, §4, §5, §6) ▪ Understand our changing Sun and its effects throughout the Solar System (§3, §4, §5, §7) ▪ Chart our destiny in the Solar System (§3, §5, §7)
	Share the excitement and knowledge generated by scientific discovery and improve science education	<u>E/PO Objectives</u> ▪ Share the excitement of space science discoveries with the public (§13) ▪ Enhance the quality of science, mathematics, and technology education, particularly at the pre-college level (§13) ▪ Help create our 21st century scientific and technical workforce (§13)

goal to maximize high latitude observations over the Hale cycle is to take advantage of continued Ulysses observations to minimize the gap between it and Solar Orbiter and Telemachus.

Tables 2.2a/b list SEC and other Roadmap objectives, research focus areas, and investigations, show to which of these Ulysses contributes, and point to the related proposal sections (§).

2.3 Ulysses and the Living With a Star (LWS) Program

Ulysses supports the objectives of the LWS program, which include:

- "Quantify the physics, dynamics, and behavior of the Sun-Earth system over the 11-year solar cycle."
- "Improve understanding of the effects of solar variability and disturbances on terrestrial climate change"
- "Provide data and scientific understanding required for advanced warning of energetic particle events that affect the safety of humans."

LWS solar-heliospheric missions officially begin with SDO's launch in 2007. However, LWS grants have already been awarded. A current LWS grant specifically identifies Ulysses data as a part of the study. Another grant described "multi-spacecraft" data analysis that obviously includes Ulysses. Ulysses therefore has explicit relevance to LWS and can be expected to have growing relevance in the future. Specifically, studies of coronal mass ejections (CMEs) using Ulysses measurements, studies of the solar source(s) of the solar wind, and of investigations of the solar and interplanetary origins of energetic particles are all embodied in LWS goals and objectives.

2.4 International LWS Program (ILWS):

The charter of ILWS is to "Stimulate, strengthen, and coordinate space research to understand the governing processes of the connected Sun-Earth System as an integrated entity." Besides ESA and NASA, the program includes CSA, RASA, and ISAS. ILWS missions include Ulysses plus Cluster, MMS, SDO, SOHO, Solar-B, and STEREO. The objectives are to stimulate and facilitate: (1) Study of the Sun-Earth connected sys-

Table 2.2a: SEC Science Objectives, Research Focus Areas, and Investigations

Science Objective	Research Focus Area	Investigation
1. Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments.	**1.1.** Understand the transport of energy and matter within the Sun, the solar atmosphere, and into the solar wind.	**1.1.1** Understand the transport of mass, energy, and magnetic fields within the sun and into the solar atmosphere. (§3) **1.1.2** Determine through direct and indirect measurements the origins of the solar wind, its magnetic field, and energetic particles. (§3)
	1.2. Determine the evolution of the heliosphere and its interaction with the galaxy.	**1.2.2** Determine the interaction between the sun and the galaxy. (§6)
2. Explore the fundamental physical processes of plasma systems in the solar system.	**2.1.** Discover how magnetic fields are created and develop and how charged particles are accelerated.	**2.1.2** Determine how charged particles are accelerated to enormous energies. (§4)
	2.2. Understand the coupling across multiple scale lengths and its generality in plasma systems.	**2.2.1** Understand how small scale processes couple to large scale dynamics. (§4) **2.2.2** Test the generality of processes in diverse plasma environments. (§4)
3. Define the origins and societal impacts of variability in the Sun-Earth connection.	**3.1** Develop the capability to predict solar activity and the evolution of solar disturbances as they propagate in the heliosphere and affect the Earth.	**3.1.1** Develop the capability to predict solar activity and its consequences in space. (§3,4,5,7) **3.1.2** Develop an understanding of the evolution of solar disturbances, how they propagate through the heliosphere, and affect the Earth. (§4,5,7)
	3.2 Develop the capability to specify and predict changes to the Earth's radiation environment, ionosphere, and upper atmosphere.	**3.2.1** Develop the capability to specify and predict changes to the radiation environment. (§3,4,5,7)
	3.3 Understand the role of solar variability in driving global change in the Earth's atmosphere and in controlling long-term space climate.	**3.3.2** Develop the capability to predict the long-term climate of space. (§3,4,5)

Table 2.2b: Additional SEC Science Objectives and Research Focus Areas relevant to Ulysses	
4. Learn how galaxies, stars, and planets form, interact, and evolve.	**4.2** Delineate the current state of the local interstellar medium and its implications for galactic evolution. (§4, §6) **4.3** Determine the interaction between the interstellar medium and the astropheres of the Sun and other stars. (§4, §6)
5. Probe the origin and evolution of life on Earth and determine if life exists elsewhere in our solar system.	**5.1** Explain the role of varying solar activity as life evolves. (§3, §5, §7) **5.3** Understand the role of energetic particles on the evolution and the persistence of life. (§4, §7)
6. Chart our destiny in the solar system	**6.1** Explain the role of varying solar activity in the future of terrestrial climate and habitability. (§5)
Astrophysics Objectives – beyond SEC, the Structure and Evolution of the Universe (SEU) 2002 Roadmap	
Objective SEU-4: Explore the cycles of matter and energy in the evolving universe.	**SEU 4.4** Identify sources of gamma ray bursts. (§6)

tem 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. The research, data systems, collaborations, and ongoing programs described below are fully supportive of these objectives.

2.5 NASA Guest Investigator (GI) and supporting Research & Technology (SR&T) Programs

In 2000-2002, 29 GI and SR&T projects explicitly utilizing Ulysses data were funded. There are, in addition, 4 more funded projects that utilize multi-spacecraft data sets that obviously include Ulysses data. These 33 PIs expect access to Ulysses data to achieve their peer reviewed science objectives. This is 12% of *all* awards, verifying that Ulysses is relevant to the GI and SR&T programs. With normal renewal rate, there will still be many investigators using Ulysses data in 2004-2008, even with no new grants. Furthermore, no more than 6 of the 33 grants were awarded to Ulysses CoIs; Ulysses data is well utilized outside the Ulysses Team.

2.6 Ulysses and the NRC 2002 Decadal Survey

No *approved* mission of any nation will provide measurements to as high solar latitudes as attained by Ulysses. This led the recent U.S. National Research Council Decadal Survey of Solar and Space Physics (*The Sun to the Earth – and Beyond*, National Academies Press, 2003) to specifically mention Ulysses in the chapter "Strengthening the Solar and Space Physics Research Enterprise". When constructing prioritized NASA objectives for the next decade, the Survey Committee wrote in the section "Cost-Effective Use of Existing Resources" that "optimal [science] return is obtained not only through the judicious funding and management of new observing systems, but also through the … funding and management of existing resources."

The Survey Committee included in its formulation strategy for the future of heliospheric research the necessity for the continuation of Ulysses, stating, "…many existing missions still return essential data at relatively low cost." ... "The two Voyager missions at distances greater than 60 AU [and] the Ulysses mission out of the ecliptic over the solar poles" were specifically noted as missions central to the Survey's decadal objectives.

2.7 *Ulysses and ESA*

Ulysses is under the purview of the Solar and Solar-Terrestrial Missions Division of ESA. Other missions in this division are SOHO, Cluster, Double Star, and Solar Orbiter. At its meeting in June 2000, ESA's Science Programme Committee approved the continuation of the mission until September 2004, when Ulysses will have completed two full orbits of the Sun. Presently, ESA is waiting for the results of the 2003 NASA Senior Review before acting on a further Ulysses extension. However, ESA has placed Ulysses into the ILWS program with other ESA missions (see §2.4).

The ESA GI program supports Ulysses data analysis, complementing the NASA GI program. The ESA GI program is discussed further in §11.