SP-1296

Extract of Ulysses section

ESA's Report to the 36th COSPAR Meeting

Beijing, China
July 2006

European Space Agency
Agence spatiale européenne

2.2 Ulysses

Introduction

Ulysses is an exploratory mission being carried out jointly by ESA and NASA. Its primary objective is to characterise the uncharted high-latitude regions of the heliosphere within 5 AU of the Sun, under a wide range of solar activity conditions. Ulysses has, for the first time, permitted *in situ* measurements to be made away from the plane of the ecliptic and over the poles of the Sun. Its unique trajectory (Fig. 2.2.1) has taken the spacecraft into the unexplored third dimension of the heliosphere.

The European contribution to the Ulysses programme consists of the provision and operation of the spacecraft and about half of the experiments. NASA provided the launch aboard Space Shuttle Discovery (together with the upper stage) and the spacecraft power generator, and is responsible for the remaining experiments. NASA also supports the mission using its Deep Space Network (DSN).

The broad range of phenomena being studied by Ulysses includes the solar wind, the heliospheric magnetic field, solar radio bursts and plasma waves, solar and interplanetary energetic particles, galactic cosmic rays, interstellar neutral gas, cosmic dust and gamma-ray bursts. A summary of the nine sets of instruments is presented in Table 2.2.1.

While the main focus of the mission is clearly the heliosphere and its variations in time and space, the investigations cover a wider range of scientific interest. Examples include studies related to Jupiter's magnetosphere (both *in situ* and via remote sensing), and radio-science investigations into the structure of the corona and a search for gravitational waves using the spacecraft and ground telecommunication systems. A major theme for Ulysses is the nature of the Local Interstellar Medium and its interface with the heliosphere; the mission continues to provide important contributions to our knowledge in this area, and to topics of a broad astrophysical nature.

In addition to the science teams selected at the start of the project, the group of

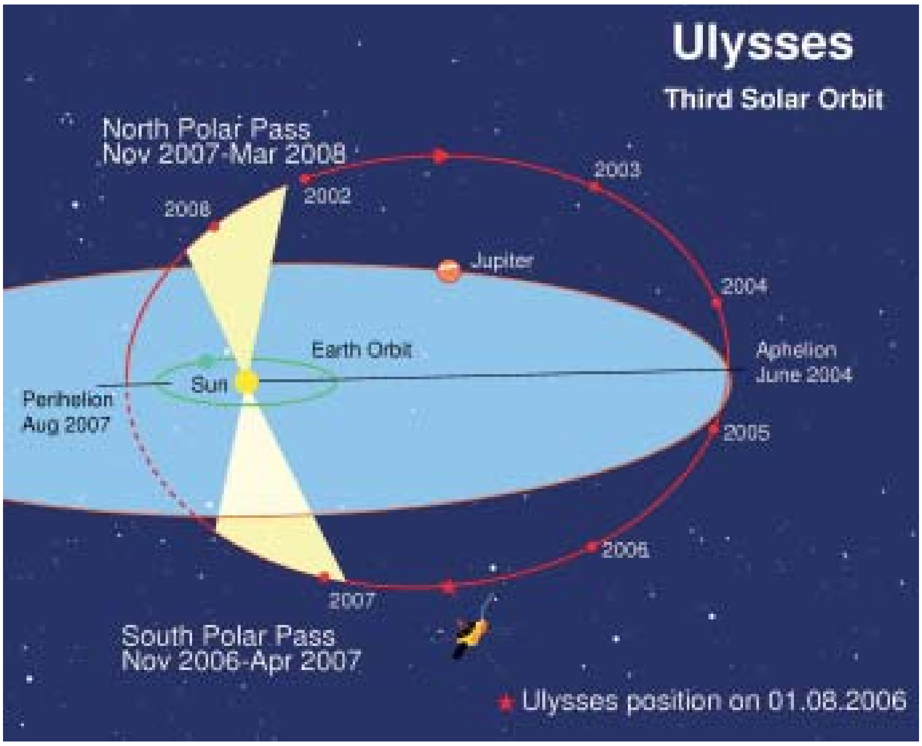


Figure 2.2.1. The Ulysses orbit viewed from 15 deg above the ecliptic plane. Dots mark the start of each year.

For further information, see http://helio2.estec.esa.int/ulysses/

Table 2.2.1. The Ulysses scientific payload.

Expt. Code	*Investigation*	*Scientific Acronym*	*Principal Investigator*	*Collaborating Institutes*
HED	Magnetic field	VHM/FGM	A. Balogh, Imperial College London (UK)	JPL (USA)
BAM	Solar wind plasma	SWOOPS	D.J. McComas, Southwest Research Institute (USA)	Los Alamos National Lab (USA): Ames Research Center (USA); JPL (USA); HAO Boulder (USA): Univ of Boston (USA); MSFC (USA); MPS Lindau (D)
GLG	Solar wind ion composition	SWICS	J. Geiss, ISSI (CH); G. Gloeckler, Univ of Maryland (USA)	Univ of New Hampshire (USA); GSFC (USA); TU Braunschweig (D); MPS Lindau (D); Univ of Michigan (USA)
STO	Unified radio and plasma waves	URAP	R.J. MacDowall, GSFC (USA)	Obs de Paris Meudon (F); Univ of Minnesota (USA); CETP Velizy (F)
KEP	Energetic particles and interstellar neutral gas	EPAC/GAS	N. Krupp, MPS Lindau (D)	Imperial College (UK); Swedish Inst Space Physics Kiruna & Umeå (S); Aerospace Corp (USA); Univ of Bonn (D); MPE Garching (D); Polish Acad Sciences (P)
LAN	Low-energy ions and electrons	HI-SCALE	L.J. Lanzerotti, Bell Laboratories (USA)	APL Laurel (USA); UC Berkeley (USA); Univ of Kansas (USA); Obs de Paris Meudon (F): Univ of Thrace (Gr); Univ of Birmingham (UK)
SIM	Cosmic rays and solar particles	COSPIN	R.B. McKibben, Univ of New Hampshire (USA)	Imperial College (UK); ESA Research & Scientific Support Dept (NL); NRC Ottawa (Can); Univ of Kiel (D); CEN Saclay (F); Danish Space Research Inst (DK); NCR Milan (I); MPK Heidelberg (D); Univ of Maryland (USA); MPS Lindau (D)
HUS	Solar X-ray and cosmic gamma-ray bursts	GRB	K. Hurley, UC Berkeley (USA) M. Sommer (retired), Samerberg (D)	CESR Toulouse (F); SRON Utrecht (NL); Obs de Paris Meudon (F); GSFC (USA)
GRU	Cosmic dust	DUST	H. Krüger, MPS Lindau (D)	Univ of Canterbury (UK); ESA RSSD (NL); MPE Garching (D); JSC (USA); Univ of Florida (USA); MPK Heidelberg (D)

scientists directly associated with the mission comprises nine European Guest Investigator (GI) teams, a number of NASA GIs, and the European Interdisciplinary Investigators who were selected together with the hardware teams.

Mission status

The spacecraft was launched by the Space Shuttle on 6 October 1990, using a combined IUS/PAM-S upper-stage to inject it into a direct Earth/Jupiter transfer orbit. A gravity-assist manoeuvre at Jupiter in February 1992 placed Ulysses in its final

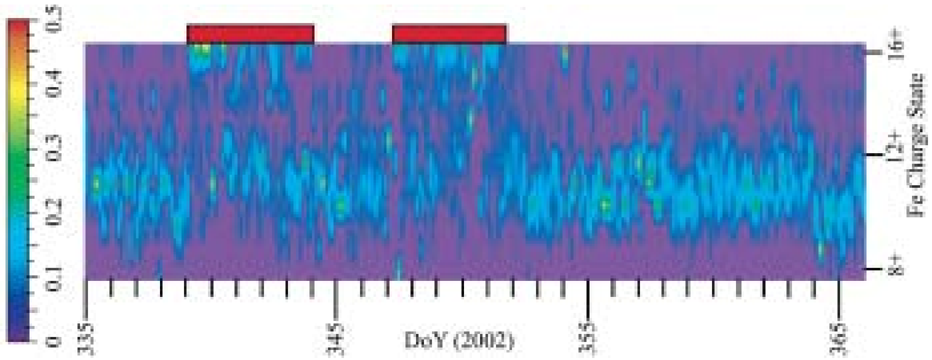
Table 2.2.2. Key dates in the Ulysses mission.

Event	*Date*
Launch	1990 10 06
Jupiter flyby	1992 02 08
start	1994 06 26
maximum latitude (80.2°, 2.3 AU)	1994 09 13
end	1994 11 05
1st Perihelion (1.34 AU)	1995 03 12
2nd Polar Pass (north)	
start	1995 06 19
maximum latitude (80.2°, 2.0 AU)	1995 07 31
end	1995 09 29
Start of Solar Maximum Mission	1995 10 01
Aphelion (5.40 AU)	1998 04 17
3rd Polar Pass (south)	
start	2000 09 06
maximum latitude (80.2°, 2.3 AU)	2000 11 27
end	2001 01 16
2nd Perihelion (1.34 AU)	2001 05 23
4th Polar Pass (north)	
start	2001 08 31
maximum latitude (80.2°, 2.0 AU)	2001 10 13
end	2001 12 12
Jupiter approach (0.8 AU)	2004 02 04
Aphelion	2004 06 30
5th Polar Pass (south)	
start	2006 11 17
maximum latitude	2007 02 07
end	2007 04 03
3rd Perihelion	2007 08 18
6th Polar Pass (north)	
start	2007 11 30
maximum latitude	2008 01 11
end	2008 03 15
End of Mission	2008 03 15

Sun-centred out-of-ecliptic orbit, which has a perihelion distance of 1.3 AU and an aphelion of 5.4 AU. The orbital period is 6.2 years. Key mission milestones, including details of the polar passes (defined to be the parts of the trajectory when the spacecraft is above 70º heliographic latitude in either hemisphere), are presented in Table 2.2.2.

The mission celebrated its 15th launch anniversary in October 2005, and all spacecraft systems and the nine sets of scientific instruments continue to function well. Spacecraft operations, conducted by the joint ESA-NASA Mission Operations Team at JPL have proceeded in a highly efficient and productive way, with no anomalies during the reporting period. Data coverage over the mission lifetime to date is an impressive 97%. The payload power-sharing strategy introduced in May 2002 to cope with the decreasing output of the Radioisotope Thermoelectric Generator (RTG) that provides onboard power has continued, albeit with a further restriction. Starting in October 2004, a fixed 'core payload' configuration (measuring magnetic field, solar wind ions, energetic particles and cosmic rays, radio waves and dust) was introduced. This configuration was chosen on scientific grounds, and because it provided the best compromise from the thermal and power standpoints. A fixed configuration was deemed necessary in order to avoid thermal and power transients at a time when critical areas of the spacecraft were colder than at any time in the mission to date. Maintaining the hydrazine fuel above its freezing point has been a high operational priority during the reporting period. This approach minimised both the risk to the spacecraft, and the impact on the scientific output of the mission. More flexible payload operations will be possible again starting in 2007, when Ulysses is close enough to the Sun that the Cold-Case Heater that warms the equipment platform is no longer required. It is anticipated that sufficient power will be available to operate the full payload complement during the majority of the third polar passes. Currently, the spacecraft continues its climb to high southern latitudes as it moves closer to the Sun, and will reach 50º south by mid-2006.

Figure 2.2.2. Iron charge state vs. day-of-year (DOY) from Ulysses/SWICS, normalised to a total flux of unity for each data sample. The normal solar wind charge state is ~10–11. The red bars at the top draw attention to intervals of unusually large enhancements in the high iron charge state Fe^{16+}. (Courtesy S.T. Suess)



In February 2004, the SPC agreed to extend the mission until March 2008. This third extension will enable the spacecraft to complete a third set of polar passes. On the NASA side, the 2005 Sun-Solar System Connections (S3C) Senior Review Panel also recommended that Ulysses be funded through its return to the north solar pole in 2008.

Scientific highlights

The unique perspective offered by Ulysses' orbit naturally lends itself to multi-spacecraft studies of transient solar wind features. Examples are the SOHO-Ulysses 'quadrature' campaigns conducted when Ulysses is positioned off the solar limb as seen from Earth. Remote-sensing observations from SOHO can then be used to track disturbances leaving the Sun in the direction of Ulysses, and the *in situ* measurements at Ulysses reveal the evolution of these structures as they travel outwards in the heliosphere. A prerequisite is the ability to identify the same parcel of plasma at both locations. The quadrature campaign in November 2002, at which time Ulysses was at 4.3 AU and 27ºN off the west limb of the Sun, was particularly successful. For the first time, it was possible to identify the same very hot plasma remotely at the Sun with SOHO and *in situ* at Ulysses. Four large coronal mass ejections (CMEs) were observed by SOHO leaving the Sun in the general direction of Ulysses over a period of several days at the end of November. By the time they reached Ulysses some 15 days later, the interplanetary counterparts of these CMEs (ICMEs) had apparently merged to form a single large solar wind structure that drove a strong interplanetary shock. The plasma of this merged structure contained unusually large enhancements in highly ionised iron ions (charge state Fe^{16+}), indicating a high-temperature source (Fig. 2.2.2). Such high-charge states are often seen in the solar wind and have been identified with ICMEs. The data from SOHO/UVCS also showed high Fe charge states, in particular in the aftermath of the 26 November 2002 CME. In this case, it was very hot plasma at $6\text{-}10 \times 10^6$K that was apparently produced high in the solar atmosphere, above 1.5 solar radii. The most likely source of such hot plasma was a reconnection event occurring in post-flare loops.

The major episode of solar activity in October/November 2003 (dubbed the 'Halloween' events) appeared to be the last in the present sunspot cycle. This proved not to be the case, however. In January and September 2005 the Sun, although rapidly approaching solar minimum, again produced displays of major activity. The latter period included one of the largest solar flares of cycle 23, an X17+ flare on 7 September, occurring as the active region responsible rotated into view of the Earth on the Sun's east limb. A very large and very fast CME was also associated with this

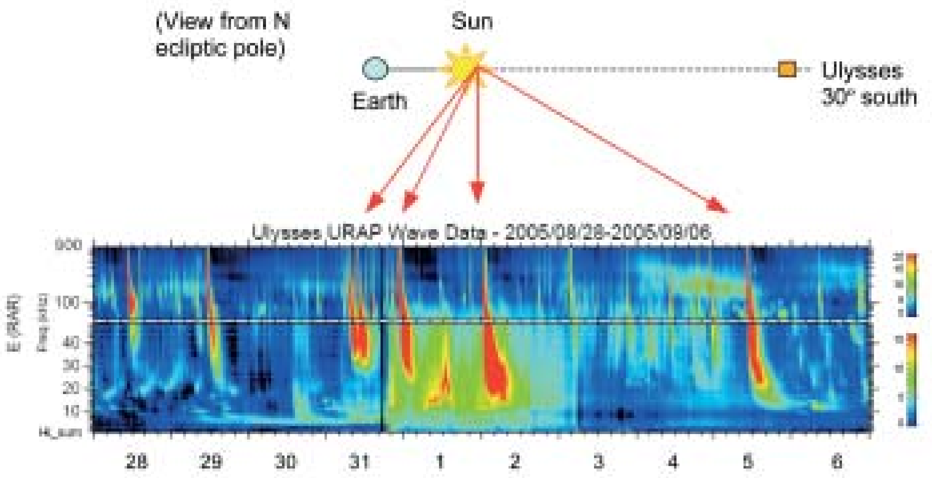


Figure 2.2.3. Radio bursts from Active Region 10808, detected aboard Ulysses by URAP in August/September 2005. (Courtesy R.J. MacDowall)

flare. At the time, Ulysses was positioned almost directly behind the Sun as seen from Earth, at 30ºS latitude and 4.8 AU from the Sun (Fig. 2.2.3). This geometry provided Ulysses with a unique view of the source of the activity for several days prior to its appearance on the visible (from Earth) solar disc. Based on observations from the Ulysses radio experiment, it is likely that region 10808 produced at least four intense flares while on the far side as viewed from Earth. The X17+ flare produced an unusually intense radio burst observed by Ulysses, and a shock was observed *in situ* at Ulysses on 14 September. Assuming the shock was driven by the disturbance associated with the X17+ flare, this implies a transit velocity of ~1210 km/s over a distance of almost 5 AU! The radio bursts associated with some of the X-class flares occurring after the X17+ flare had surprisingly low intensities. This is consistent with what was seen for the 2003 Halloween events. A possible explanation is that the entire inner heliosphere was filled with energetic electrons to a flux level sufficient to block the plasma instability that would otherwise initiate the radio emission process.

Like water droplets from a rotating garden sprinkler, the magnetic field carried away from the rotating Sun by the radially out-flowing solar wind is on average wound into a spiral pattern (an Archimedean spiral) in the heliosphere. A recurring theme in many of the results obtained by Ulysses, however, is the unexpectedly large degree to which the instantaneous heliospheric magnetic field direction measured at the spacecraft deviates from this pattern. Theories exist to explain such systematic deviations from the spiral pattern, but these require radial distances of several AU for a deviation of order 1 AU to develop. Observations of 'jets' of energetic electrons from Jupiter's magnetosphere, acquired by Ulysses during its distant encounter with the planet in 2003/2004, show that such deviations are common within a radial interval of as little as 0.1 AU, however. Electron jets were discovered during Ulysses' first Jupiter flyby in 1992, and were identified as brief (lasting minutes to hours), highly focused bursts of MeV electrons flowing away from Jupiter along the heliospheric magnetic field. Jets were observed up to distances of 1 AU from Jupiter and were interpreted as evidence for direct magnetic connection to Jupiter's magnetosphere. In the recent cases, the position of Ulysses relative to Jupiter was such that magnetic connection along the average spiral field could not have occurred, implying large deviations. If such large deviations are indeed common, they may play a significant role in the distribution of charged particles throughout the heliosphere.

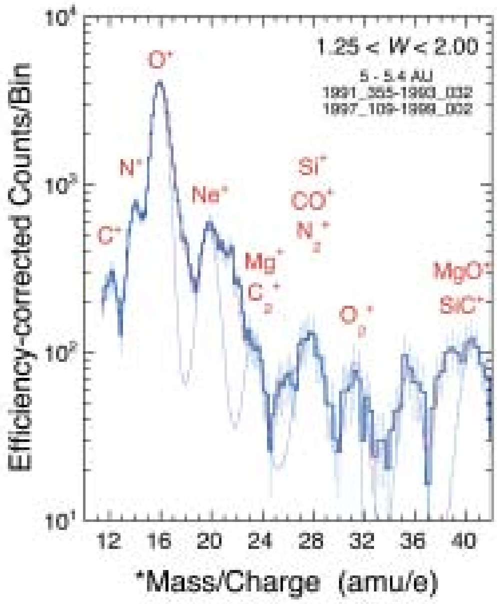


Figure 2.2.4. Spectrum of 'inner-source' pick-up ions measured by Ulysses/SWICS. (Courtesy G. Gloeckler)

It is not yet clear how or why such large-scale deviations develop, whether they are consistently present throughout the solar cycle, or how they can be incorporated into current theories of particle propagation.

Another topic of continuing interest, and one to which Ulysses is making unique contributions, is the study of 'inner-source' pick-up ions (Fig. 2.2.4). In contrast to pick-up ions of interstellar origin (created through ionisation of neutral interstellar gas that penetrates the heliosphere), the precise origin of the inner-source ions remains uncertain. Among the possible candidates are neutral solar wind atoms that are implanted in, and subsequently released from, dust grains close to the Sun. The composition of the inner source is certainly not cometary in nature, making Sun-grazing comets, for example, an unlikely progenitor. Ulysses measurements have demonstrated clearly that the population of inner-source ions extends out as far as the orbit of Jupiter, suggesting that several different sources may be contributing. In addition to the intrinsic interest in these ions, they also form a potentially important seed population for injection into shock acceleration processes that give rise to fluxes of energetic particles of non-solar origin found throughout the heliosphere.

Ulysses data archive

Data from the Ulysses investigations and flight project are being archived and made accessible to the public through two channels: the ESA Ulysses Data Archive at ESTEC, and NASA's National Space Science Data Center (NSSDC). There is no formal proprietary period for Ulysses data, which are placed in the public archives immediately following verification by the PI teams. The ESA archive provides a number of on-line facilities to browse and download selected measurements made by the scientific instruments. The user is able to view 26-day and 1-year summary plots of the main parameters measured, and (if of interest) download ASCII data files and accompanying documentation for further analysis. A new plotting tool was introduced in 2005 that allows the user flexibility in defining start and end times and provides the capability to combine parameters from different experiments on the same plot. The ESA archive is accessible via the Ulysses homepage.