The Ulysses mission: An introduction (*)

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Summary. — On 30 September 1995, Ulysses completed its initial, highly successful, survey of the polar regions of the heliosphere in both southern and northern hemispheres, thereby fulfilling its prime mission. The results obtained to date are leading to a revision of many earlier ideas concerning the solar wind and the heliosphere. Now embarking on the second phase of the mission, Ulysses will continue along its out-of-ecliptic flight path for another complete orbit of the Sun. In contrast to the high-latitude phase of the prime mission, which occurred near solar minimum, the next polar passes (in 2000 and 2001) will take place when the Sun is at its most active.

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1. – Introduction

The goal of the joint ESA-NASA Ulysses mission is to characterize for the first time the fields and particles in the inner heliosphere as a function of solar latitude, with particular emphasis on the regions above the solar poles [1, 2]. The Ulysses scientific investigations encompass studies of the heliospheric magnetic field, heliospheric radio and plasma waves, the solar-wind plasma including its minor heavy-ion constituents, solar and interplanetary energetic particles, galactic cosmic rays and the anomalous cosmic-ray component. Other investigations are directed towards studies of cosmic dust and interstellar neutral gas, as well as solar X-rays and cosmic gamma-ray bursts. Radio science experiments to probe the solar corona and to conduct a search for gravitational waves have also been carried out. An overview of the scientific investigations is given in table I.

(*) Paper presented at the Special Session on the Ulysses mission of the XXIV International Cosmic-Ray Conference, Rome, August 28-September 8, 1995.

TABLE I. – *The Ulysses scientific investigations.*

Investigation	Acronym	Principal investigator
Magnetic field	VHM/FGM	A. Balogh Imperial College, London (UK)
Solar-wind plasma	SWOOPS	D. J. McComas Los Alamos Nat. Lab. (USA)
Solar-wind ion composition	SWICS	J. Geiss University of Bern (CH) G. Gloeckler University of Maryland (USA)
Radio and plasma waves	URAP	R. J. MacDowall NASA/GSFC (USA)
Energetic particles, interstellar neutral gas	EPAC/GAS	E. Keppler MPAe, Lindau (D)
Low-energy ions and electrons	HI-SCALE	L. J. Lanzerotti AT&T Bell Labs (USA)
Cosmic rays and solar particles	COSPIN	R. B. McKibben University of Chicago (USA)
Solar X-rays and cosmic gamma-ray bursts	GRB	K. Hurley UC Berkeley (USA)
Cosmic dust	DUST	E. Grün MPK Heidelberg (D)
Radio science (coronal sounding)	SCE	M. K. Bird University of Bonn (D)
Interdisciplinary studies		
Directional discontinuities		M. Schulz Lockheed Palo Alto Res. Lab. (USA)
Mass loss and ion composition		G. Noci University of Florence (I)
Solar-wind outflow		A. Barnes NASA/Ames Res. Center (USA)
Comets		J. C. Brandt University of Colorado (USA)
Cosmic-ray and energetic-particle transport		J. R. Jokipii University of Arizona (USA)
Shocks and waves		C. P. Sonnet University of Arizona (USA)

The Ulysses spacecraft is spin-stabilised at 5 r.p.m. and has a body-mounted parabolic high-gain antenna that is kept pointed at Earth. Power is provided by a radio-isotope thermoelectric generator (RTG) that delivered 283 W at launch. In the normal operating mode, the scientific data acquired by the Ulysses instruments are stored by a tape recorder on board the spacecraft for 16 hours and downlinked to the

NASA Deep Space Network once a day together with the real time data during an 8-hour tracking pass. The coverage to date has been excellent, being ~ 96% on average since launch. This data set represents the most complete set of continuous interplanetary measurements ever recorded. Further details regarding the spacecraft and its scientific investigations can be found in [1].

2. – The Ulysses orbit and polar passes

Carried into low Earth orbit by the space shuttle Discovery on 6 October 1990, Ulysses was injected at high speed towards Jupiter, where it underwent a gravity-assist manoeuvre in February 1992. As a result of this manoeuvre, the spacecraft is now travelling in a Sun-centered elliptical orbit inclined at 80.2° to the solar equator, as shown in fig. 1. Aphelion and perihelion distances are 5.40 and 1.34 astronomical units (AU), respectively, and the orbital period is 6.2 years (see table II).

The Ulysses polar passes are defined to be those periods during which the spacecraft is above 70° heliographic latitude in either hemisphere. The first polar pass took place in the southern hemisphere, a consequence of Jupiter's position with respect to the solar equator at the time of the fly-by. Starting on 26 June 1994, Ulysses spent 132 days at southern heliographic latitudes greater than 70°, reaching a maximum latitude of 80.22° on 13 September.

In contrast to the initial climb from low to high latitudes, which took more than 2 years and covered a range of radial distances (5.4 to 2.3 AU), the subsequent south-pole-to-north-pole segment of the trajectory (the so-called «fast latitude scan») was completed in slightly less than 12 months and at nearly constant heliocentric radius. The maximum northern latitude (80.2°) was reached on 31 July 1995. It should be noted that Ulysses' out-of-ecliptic trajectory enables a survey to be made of all *magnetic* latitudes, since the inclination of the Sun's magnetic dipole axis with respect to its rotation axis is generally greater than 10°.

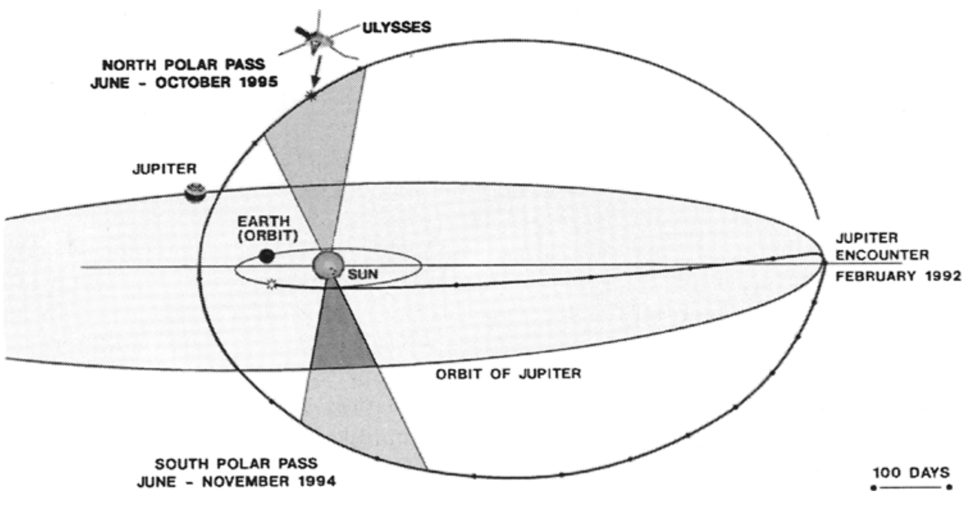

Fig. 1. – The Ulysses spacecraft trajectory, viewed from above the ecliptic plane.

TABLE II. – *Key events in the Ulysses mission.*

Event	Date	Event	Date
Launch	1990 10 06	Start of 2nd Solar Orbit	1995 10 01
Jupiter fly-by	1992 02 08	Aphelion (5.40 AU)	1998 04 15
1st polar pass		3rd polar pass	
start	1994 06 26	start	2000 09 08
max. latitude (80.2° S)	1994 09 13	max. latitude (80.2° S)	2000 11 27
end	1994 11 05	end	2001 01 16
1st perihelion (1.34 AU)	1995 03 12	2nd perihelion (1.3 AU)	2001 05 26
2nd polar pass		4th polar pass	
start	1995 06 19	start	2001 09 03
max. latitude (80.2° N)	1995 07 31	max. latitude (80.2° N)	2001 10 13
end	1995 09 29	End of mission	2001 12 12

3. – Results from the south polar pass and fast latitude scan

The phenomena being studied by the Ulysses mission are strongly influenced by the 11-year solar-activity cycle. The polar passes of the prime mission occurred during the descending phase of the current solar cycle (no. 22), close to solar minimum. At this time, the Sun is in its most simple state: large coronal holes extend from the polar regions in both hemispheres; the Sun's surface magnetic field is largely dipolar, being positive (outward) in the north and negative (inward) in the south; there is a relative paucity of energetic flare and other transient events.

Prior to the high-latitude in-situ observations made by Ulysses, it was expected that the particles and fields over the poles would reflect these conditions. In particular, it was generally expected that the solar-wind speed would increase with increasing latitude, that some imprint of the dipole-like surface field would be found in the heliospheric magnetic field, and that the cosmic-ray flux would be higher over the poles as a result of drift motions causing a net flow from the poles to the equator along near-radial magnetic-field lines.

A collection of papers summarising the findings from the south polar pass has been published in [3] and earlier high-latitude results have appeared in [4]. In this paper, which serves principally as an introduction to the accompanying papers from the Special Session on Ulysses, we present only the key findings from the south polar pass and fast latitude scan.

As Ulysses climbed in latitude towards the south pole, the solar-wind speed did indeed increase from ~ 400 to ~ 750 km/s. Up to a latitude of $\sim 30°$ S, the tilt of the heliospheric current sheet with respect to the Sun's rotation axis gave rise to large excursions in velocity as a high-speed stream passed over the spacecraft once per ~ 26-day rotation. Poleward of $\sim 35°$, the solar-wind speed was typically 750 km/s and showed no periodic variations [5]. These observations confirm the expectation that, near solar minimum, there are two distinct solar-wind regimes: slow wind flowing from the coronal streamer belt that encircles the equator and fast wind from the polar coronal holes. Ulysses observations have also shown that the boundary between these regimes extends in height from the chromosphere, where compositional signatures have their origin, up through the corona where the solar wind is heated [6]. During its rapid pole-to-pole transit, Ulysses found the boundary between the fast and slow wind regimes to be somewhat closer to the equator, at 20° S and 20° N.

The radial component of the heliospheric magnetic field measured by Ulysses showed no variation with latitude, in contrast to what would be expected if the Sun's dipolar surface field (for which the radial component *is* greatest over the poles) was simply carried radially outward by the solar wind [7]. This result implies that magnetic stresses in the solar wind near the Sun's surface act to redistribute the magnetic flux, suggesting a greater role for large-scale divergence of the flow than was previously assumed.

In addition to the absence of a latitudinal gradient in the radial field component, the Ulysses observations have revealed the existence of large-amplitude directional fluctuations in the magnetic field over the poles. Fluctuations of this kind, which have been predicted to occur as a result of random motions of the foot-points of the field lines in the photosphere [8], affect the motion of galactic cosmic rays entering the heliosphere. Ulysses cosmic-ray measurements show a small, positive latitudinal gradient for most species [9]. Given the current global magnetic configuration of the heliosphere, the sign of the observed gradient is consistent with the predictions of propagation models that include drifts [10], although larger gradients were expected. Clearly, the enhanced latitudinal transport of cosmic rays resulting from the large directional fluctuations in the magnetic field plays an important role in producing the observed degree of spherical symmetry in the distribution of galactic cosmic rays in the inner heliosphere.

A related finding from the polar passes, also concerning cosmic-ray modulation, is the persistence of recurrent depressions in high-energy (above ~ 100 MeV/n) particle flux with ~ 26-day periodicity up to the highest latitudes surveyed [11, 12]. The lack of any increase in period towards higher latitudes (which would be expected on the basis of differential rotation if the source of the modulation was tied to the latitude of the spacecraft), suggests that the observed global modulation of these particles is driven from the equatorial regions and is possibly related to CIRs. The rapid cross-field diffusion discussed above may also play a significant role [13].

The data from the northern hemisphere obtained to date are, not unexpectedly, generally consistent with the findings from the south.

4. – The future

All experiments and spacecraft subsystems are in excellent health, and both ESA and NASA have approved the continuation of mission operations beyond the prime mission. Following the north polar pass in 1995, Ulysses will descend in latitude towards the orbit of Jupiter (aphelion in 1998, see table II). The outbound leg of the trajectory provides an opportunity to survey the latitude range between 70° and 0° at solar distances between 2.2 and 5.4 AU for a second time. In contrast to the first (1992-1994) inbound ascent in latitude, the outbound descent in latitude (1996-1998) will occur at solar minimum conditions or in the early rising phase of the next solar cycle. The spacecraft will spend a relatively long time near aphelion when both the solar latitude and radial distance are changing slowly. From June 1997 to June 1998, Ulysses will be within $\pm 10°$ of the solar equator, and from May 1997 to April 1999 at heliocentric distances greater than 5 AU. This interval will provide an opportunity to study time variations free of concern about spatial variations. The polar passes of the second solar orbit will take place in 2000 and 2001, close to solar maximum. The conditions encountered by Ulysses are expected to be quite different from those at high latitudes during the prime mission.

The period beyond 1995 will be of importance in another respect, since Ulysses —at high solar latitude—will form an important complement to ESA's SOHO and NASA's WIND missions.

5. – Ulysses data archiving/WWW access

Data from the Ulysses investigations and flight project are being archived and made accessible to the public through two channels: the National Space Science Data Center (NSSDC), and ESA's Ulysses Data System (UDS) located at Estec. For further information, contact J. F. Cooper (NSSDC, e-mail: jcooper@nssdca.gsfc.nasa.gov) or C. Tranquille (UDS, e-mail: ctranqui@estsck.estec.esa.nl). Information concerning Ulysses can be obtained via the World Wide Web as follows:

Ulysses/ESA Home Page: http://helio.estec.esa.nl/ulysses/welcome.html

Ulysses/JPL Home Page: http://ulysses.jpl.nasa.gov/

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