Ulysses

Introduction

Ulysses, a joint ESA/NASA mission, was launched aboard the Space Shuttle on 6 October 1990 from Kennedy Space Center in Florida, heading for an unprecedented journey of discovery. It was the first mission to study the unknown environment of space above and below the poles of the Sun. With Ulysses, scientists obtained the first-ever four-dimensional map of the heliosphere – the bubble generated by the solar wind that defines the sphere of influence of the Sun.

Originally designed for a lifetime of five years, the mission has surpassed all expectations. The reams of data returned by Ulysses have forever changed the way scientists view the Sun and its effect on the space surrounding it.

After more than 17 years of observations, almost four times its expected lifetime, and having surmounted several operational challenges, Ulysses is now approaching its natural end. Its power supply is unable to keep the spacecraft warm enough, leaving it to succumb to the cold conditions in space.

History and status

The mission has a long and interesting history. The idea of sending a spacecraft to explore regions of space far from the Solar System's ecliptic plane was first proposed in 1959, but the technology was then not ready.

ESA and NASA first studied the possibility of a joint out-of-ecliptic mission in 1974. This mission, in which two spacecraft were to be sent over the poles of the Sun, was approved in 1977. By 1981, the International Solar Polar Mission, or ISPM as it was then called, had turned into a single-craft mission, comprising a European-built probe, with half the instruments from Europe and the rest from the US.

Originally approved for launch in 1983, a number of delays meant it was eventually launched by Space Shuttle *Discovery* in 1990.

During the course of its mission, Ulysses has been joined in space by other missions (SOHO, Wind, ACE, Hinode, STEREO). Together, they form a network that is studying the Sun and its environment as never before.

After just over 17.5 years, the mission is approaching its end. The declining output from the Radioisotope Thermoelectric Generator (RTG), which provides power for the craft and its payload, is unable to provide enough heat. This means that the fuel for the thrusters will freeze. In mid-January 2008, the situation worsened when the main radio transmitter failed – its warmth kept the fuel from freezing.

To overcome these difficulties, ground controllers have been using a smaller transmitter to ensure that as much science as possible is returned from Ulysses in the last few weeks of its life.

The mission is expected to end by 1 July. Once it is clear that the fuel needed to keep the main antenna pointing towards Earth has started to freeze, ground controllers will put Ulysses into a stable configuration. It will continue to orbit the Sun indefinitely.

Launch and journey

Ulysses was launched on 6 October 1990 at 12:47:15 CET, from Kennedy Space Center, Florida, USA, aboard Space Shuttle *Discovery*. It was first placed in a low-Earth orbit and then two propulsion modules injected it into an interplanetary orbit. Sixteen months later, on 8 February 1992, having travelled nearly a thousand million km, Ulysses reached Jupiter where a gravity-assist manoeuvre swung the craft into its unique solar orbit that takes it over the Sun's poles.

Orbit

The orbit was chosen to allow Ulysses to chart the heliosphere at all solar latitudes.

The orbit is an ellipse with the Sun at one focus (heliocentric), and is inclined 80° with respect to the Sun's equator (polar). The orbital period is 6.2 years. Maximum distance from the Sun (aphelion) is reached at about 810 million km (or 5.4 AU; one AU or Astronomical Unit equals the average distance between Earth and the Sun, or about 150 million km) and minimum distance (perihelion) is at about 200 million km (or 1.3 AU).

The gravity-assist at Jupiter meant that Ulysses performed a polar pass first over the Sun's south pole and then over its north pole roughly a year later. The polar passes are periods during which the spacecraft is above 70° heliospheric latitude in either hemisphere. The mission was designed to maximise the total duration of each polar pass.

Over more than 17 years of operation, Ulysses has orbited the Sun three times and performed six polar passes:

- South pole: June–November 1994, September 2000 – January 2001, November 2006 – April 2007
- North pole: June–September 1995, August–December 2001, November 2007 – March 2008

Distance travelled

During its mission, Ulysses has travelled 8.6 thousand million km (or 57.65 AU) at an average speed of 56 000 km/hr. This corresponds to the distance a spacecraft must travel to reach more than half-way to the edge of the heliosphere, well beyond the orbit of Pluto (39.5 AU).

Mission objectives

The goal of Ulysses was to study the heliosphere – the magnetic bubble created by the solar wind which carries the solar magnetic field well beyond the outer reaches of the Solar System – in four dimensions (space and time). The study of the solar wind, a constant stream of charged particles expelled by the Sun, has also been one of the major objectives. This 'wind' is very different from wind on Earth, but its gusts and shocks which cause aurora and magnetic storms may affect weather on Earth and can harm satellites, power supplies and communications.

The science objectives of the Ulysses mission were:

- to determine the solar wind's global properties and behaviour in three dimensions, to study its origin by measuring its composition at different solar latitudes, and to learn more about waves and shocks by sampling solar wind conditions at all latitudes
- to study how energetic particles of solar and interplanetary origin move and are accelerated by observing their properties at all latitudes
- to study the magnetic field of the Sun and of the heliosphere

- to study galactic cosmic rays – mainly protons and electrons with high energies – and to learn more about their origin
- to learn more about how the heliosphere interacts with interstellar space, and to improve our understanding of interplanetary and interstellar gas and dust
- to look for gamma-ray burst sources and, in combination with observations from other spacecraft, help identify them with known celestial objects.

Major discoveries

Thanks to its suite of instruments and its special orbit around the Sun, in addition to the long duration of its mission – a major achievement on its own – the key discoveries of Ulysses range from the best-ever understanding of the heliosphere and the role played by its magnetic field in all the phenomena occurring inside it, to important astrophysical questions such as the evolution of the Universe. Key discoveries:

- **Nature and behaviour of the heliosphere's magnetic field.** Ulysses has found that the heliospheric magnetic field, which originates from the Sun's magnetic field, is both more complicated and at the same time simpler than previously thought. It is more complicated because its field lines do not follow an ordered spiral but a more chaotic pattern and spread more in latitude than initially believed. It is simpler because the Sun's magnetic dipole – similar to a bar magnet – simply rotates by 180° to accomplish the known reversal in polarity. Besides, at distances beyond three to five times the radius of the Sun, the outward (radial) component has the same strength at all latitudes.

- **The solar wind in four dimensions.** Ulysses found that, at solar minimum, the wind from the cooler regions close to the Sun's poles fans out to fill two thirds of the heliosphere, and blows at a uniform speed of 750 km/s (fast wind), much faster than the wind that emerges from the Sun's equatorial zone at 350 km/s. Ulysses also studied the origin of the wind in the solar corona, the nature of the magnetic field it carries away from the Sun, and its interaction with the interstellar gas and plasma that surrounds the heliosphere.

- **Energetic particles climb up to the Sun's poles.** Ulysses has revealed that previous ideas on how charged energetic particles are transported in the heliosphere need thorough revision. Since the Sun's magnetic field lines, which drive the flow of charged particles, are more chaotic and can undergo big excursions in latitude, such particles can also be found over the poles even at solar minimum, far away from the solar storms that originated them. This is important, as astronauts in deep space may be exposed to radiation from sources previously considered 'safe'.

- **No easier access to the heliosphere for cosmic rays.** Ulysses found that at solar minimum, cosmic rays from within our galaxy do not have – as previously believed – any easier access to the heliosphere at the polar regions where the magnetic field was thought to be weaker and more radial. On the contrary, their distribution is almost spherically symmetric. This is the result of waves propagating along magnetic field lines in the fast solar wind that oppose this access.

- **'Titanic shock' between the heliosphere and interstellar gas.** The nature of the interstellar cloud of dust and gas that the Solar System crosses and the size of the heliosphere can now be better understood thanks to Ulysses's measurements of interstellar helium that penetrates the heliosphere itself. Ulysses also found that interstellar wind is fast enough to create a shockwave where the heliosphere's outer fringes meet interstellar gas, affecting the access of the gas itself.

- **Interstellar dust can enter the heliosphere.** For the first time, Ulysses detected tiny dust particles of interstellar origin, proving that they can enter the heliosphere.

- **Lifetime of galactic cosmic rays.** Ulysses has studied the abundance of many radioactive cosmic rays (produced when cosmic rays collide with atoms of interstellar gas and lose neutrons or protons, leaving behind radioactive species); only two kinds were measured prior to Ulysses. It showed that they spend most of their lifetimes of 10–20 million years in the galactic halo (the area above and below our galaxy's disc where the amount of matter is significantly lower) before they reach us.

- **Will the Universe collapse in the end?** Ulysses measured the abundances of helium isotopes in interstellar gas for the first time. These measurements, which are important for studies of the Big Bang, support the theory by which the amount of matter in the Universe is not enough to lead to a final cosmic collapse at the end of time.

Spacecraft

Design: the overall design was dictated by the large distances from Earth and the Sun (up to 950 million km from Earth, 810 million km from the Sun). At such distances, solar power could not provide enough electricity; instead, a Radioisotope Thermoelectric Generator was provided. A large antenna (1.65 m diameter) was necessary to communicate with Earth from large distances. The thermal design had to accommodate the widely-varying temperatures during the mission. The electronics were hardened to withstand the strong radiation near to Jupiter during the close flyby in 1992.

Mass: 366.7 kg at launch

Dimensions: 3.2 x 3.3 x 2.1 m LxWxH

What's on board?

The 10 instruments consist of an array of sophisticated sensors for gauging the invisible wind, ions and electrons, dust grains and gas, magnetic fields, radio and plasma waves, X-rays, and gamma-rays that permeate the space around the Sun.

Magnetometer (MAG): MAG has been performing measurements of the magnetic field in the heliosphere and studying how it varies at different heliospheric latitudes. Measurements of Jupiter's magnetic field were also performed.

Principal Investigator: A. Balogh, Imperial College of London (UK).

Solar Wind Plasma Experiment (SWOOPS): The SWOOPS experiment has been studying the solar wind at all solar distances and latitudes and in three dimensions.

Principal Investigator: D.J. McComas, Southwest Research Institute (USA)

Solar Wind Ion Composition Instrument (SWICS): SWICS has been determining the composition, temperature and speed of the atoms and ions that comprise the solar wind.

Principal Investigators: J. Geiss, ISSI (CH) and G. Gloekler, University of Michigan (USA).

Unified Radio and Plasma Wave Instrument (URAP): URAP has been studying radio waves from the Sun and electromagnetic waves generated in the solar wind close to the spacecraft.

Principal Investigator: R.J. MacDowall, NASA/GSFC (USA).

Energetic Particle Instrument (EPAC) and GAS: EPAC has been investigating the energy, fluxes and distribution of energetic particles in the heliosphere, while GAS studied the electrically-uncharged gas (helium) of interstellar origin.

Principal Investigator: N. Krupp, Max Plank Institute for Solar System Research, Lindau (D).

Low-Energy Ion and Electron Experiment (HI-SCALE): HI-SCALE has been investigating the energy, fluxes and distribution of energetic particles in the heliosphere.

Principal Investigator: L.J. Lanzerotti, New Jersey Inst. of Technology (USA).

Cosmic Ray and Solar Particle Instrument (COSPIN): COSPIN has been investigating the energy, fluxes and distribution of energetic particles and galactic cosmic rays in the heliosphere.

Principal Investigator: R.B. McKibben, University of New Hampshire (USA).

Solar X-ray and Cosmic Gamma-Ray Burst Instrument (GRB): GRB has been studying cosmic gamma-ray bursts and X-rays from solar flares.

Principal Investigator: K. Hurley, UC Berkeley (USA).

Dust Experiment (DUST): DUST has carried out direct measurements of interplanetary and interstellar dust grains to investigate their properties as functions of the distance from the Sun and solar latitude.

Principal Investigator: H. Krüger, Max Plank Institute for Solar System Research, Lindau (D).

Partnership

Ulysses is a joint ESA/NASA mission. ESA provided the spacecraft, built by Astrium GmbH, Friedrichshafen, Germany (formerly Dornier Systems). NASA provided the Space Shuttle launch and the Inertial Upper Stage and the Payload Assist Module to put Ulysses into its correct orbit. NASA also provided the RTG to power the craft and payload. ESA's European Space Research and Technology Centre (ESTEC) and European Space Operations Centre (ESOC) have been managing the mission with NASA's Jet Propulsion Laboratory (JPL). Ulysses is tracked by NASA's Deep Space Network. A joint ESA/NASA team at JPL has overseen spacecraft operations and data management. Teams from universities and research institutes in Europe and the United States provided the 10 science instruments.

Cost

The overall cost of Ulysses is about €1000 million at today's prices. ESA's share has been about €450 million at current prices, including the spacecraft and about €2.5 million annually for spacecraft operations. NASA's share has been about $520 million (about €338 million) at current prices, including development, launch and 17 years of mission operations and data analysis. The European instruments, hardware and operations have been funded nationally.

Leadership

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