ULYSSES LAUNCH ISSUE

european space agency

esa bulletin

agence spatiale européenne

number 63

august 1990

european space agency

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(b) by elaborating and implementing activities and programmes in the space field;
(c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
(d) by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

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agence spatiale européenne

L'Agence Spatiale Européenne est issue des deux Organisations spatiales européennes qui l'ont précédée — l'Organisation européenne de recherches spatiales (CERS) et l'Organisation européenne pour la mise au point et la construction de lanceurs d'engins spatiaux (CECLES) — dont elle a repris les droits et obligations. Les Etats membres en sont: l'Allemagne, l'Autriche, la Belgique, le Danemark, l'Espagne, la France, l'Irlande, l'Italie, la Norvège, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. La Finlande est membre associé de l'Agence. Le Canada beneficie d'un statut d'Etat coopérant.

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(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;
(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellite d'applications.
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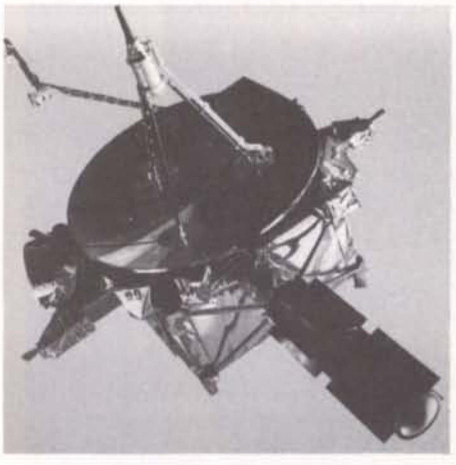

Cover: The Ulysses flight-model spacecraft

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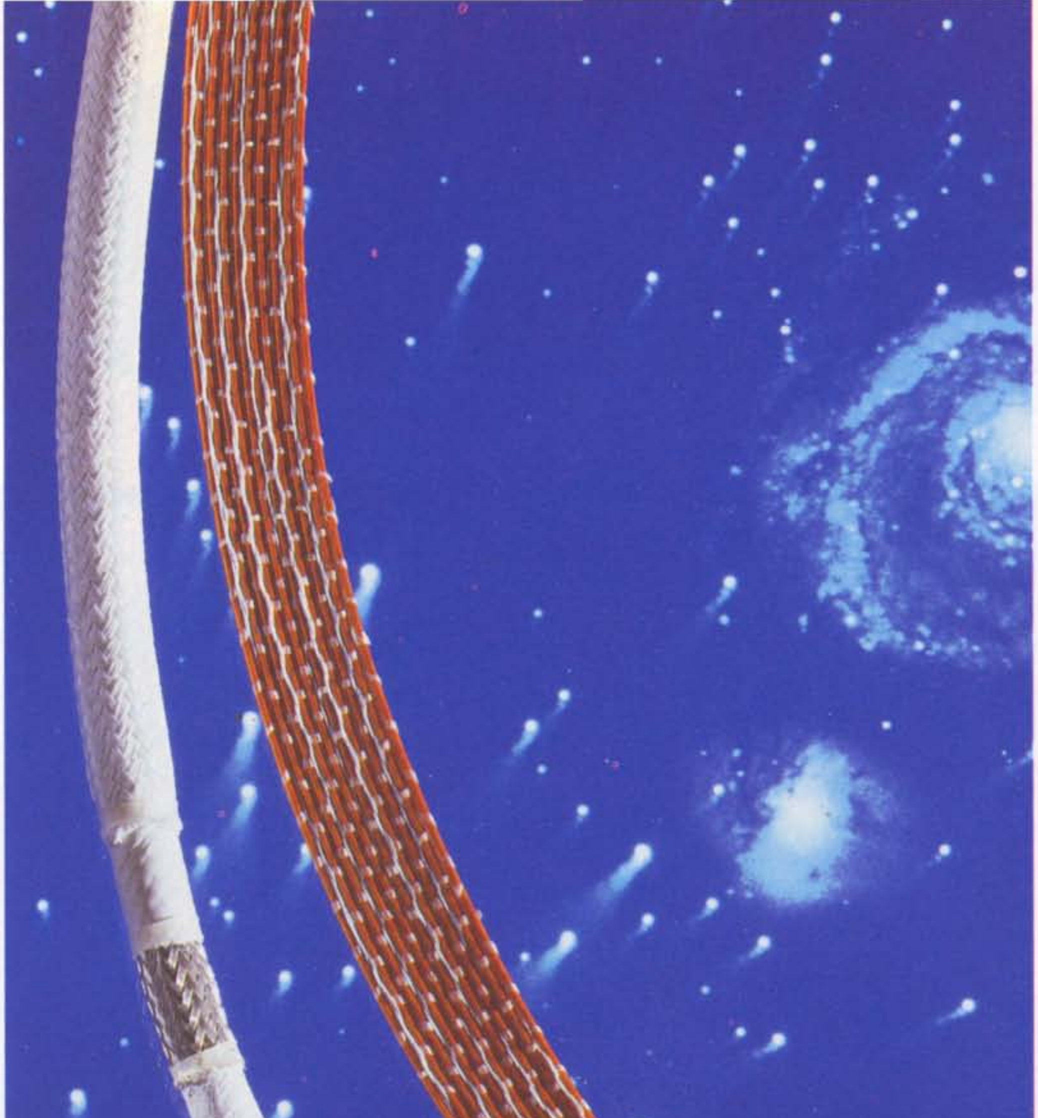

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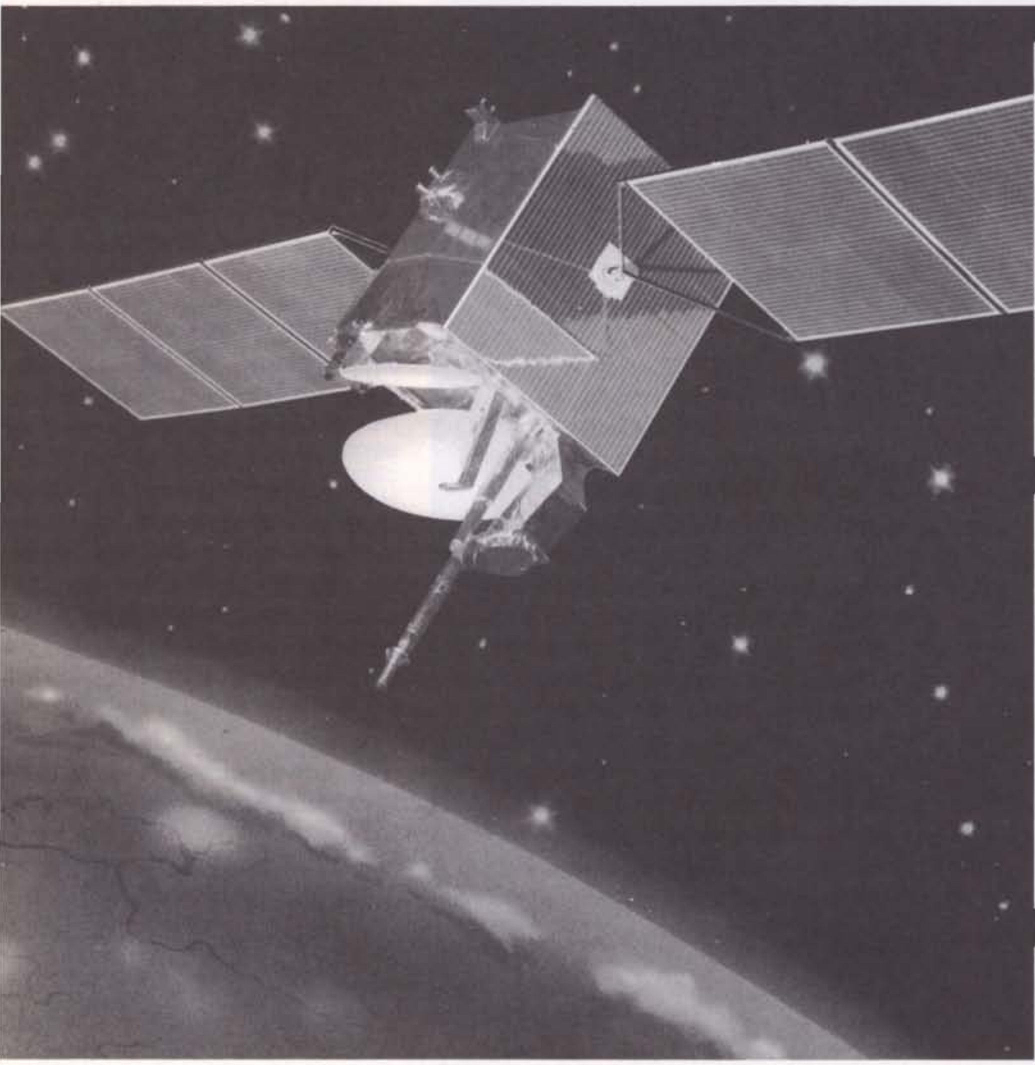
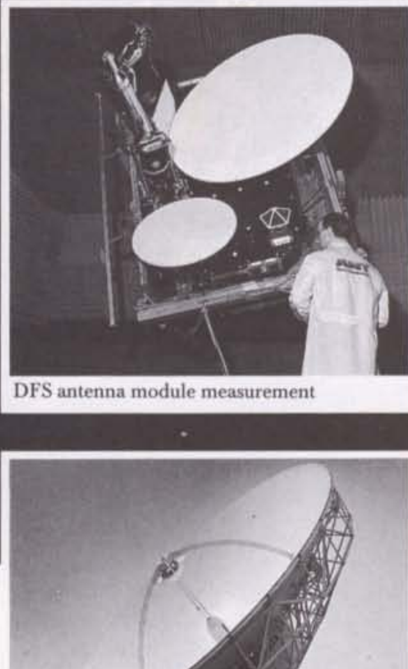
Satellite Technology from ANT:

DFS Kopernikus – The German Telecommunications Satellite



Satellite integration hall at ANT



DFS antenna module measurement

ANT 8927 E Schr.

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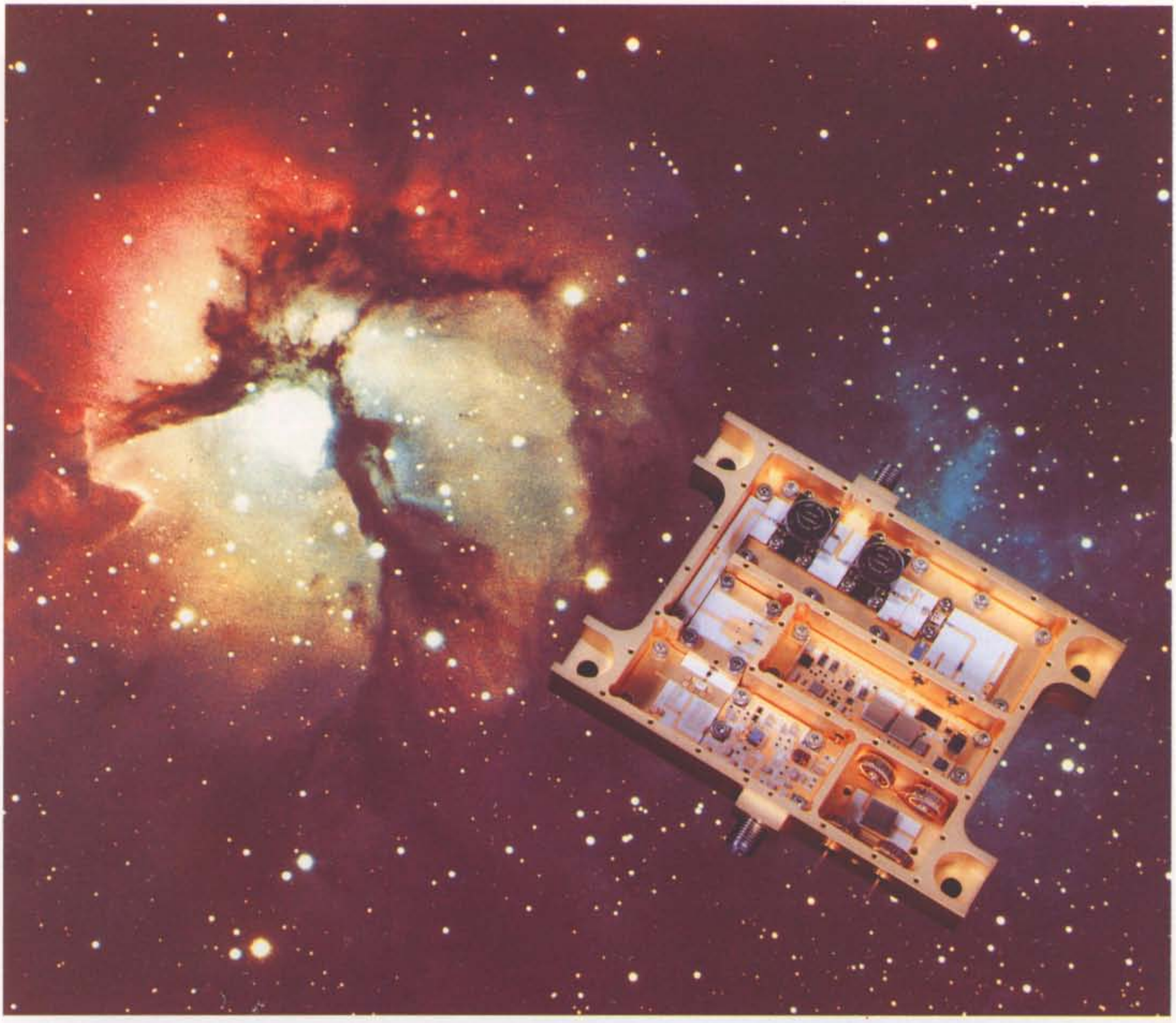
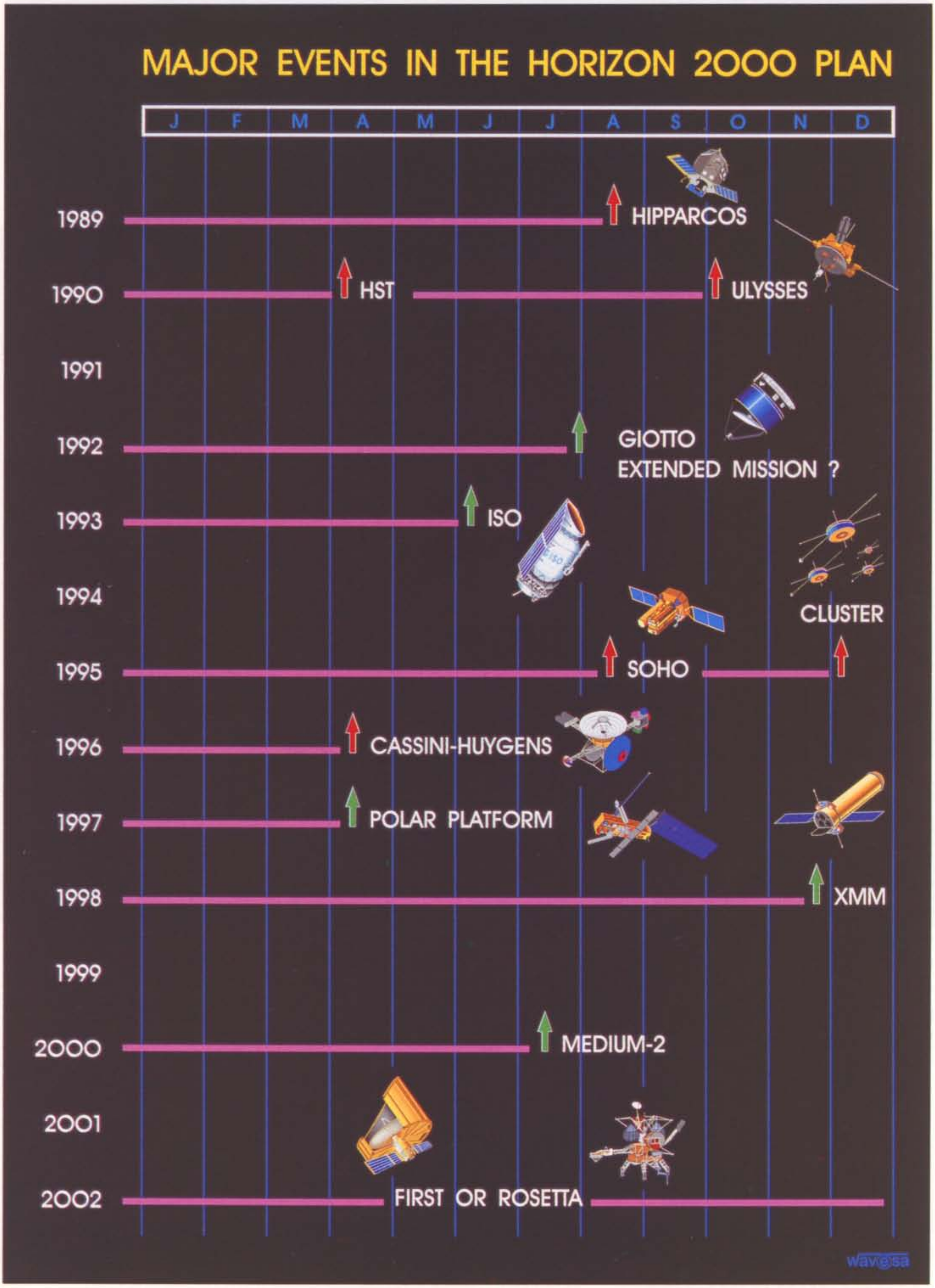



MAJOR EVENTS IN THE HORIZON 2000 PLAN
J F M A M J J A S O N D
1989
HIPPARCOS
1990
HST
ULYSSES
1991
1992
GIOTTO
EXTENDED MISSION ?
1993
ISO
1994
CLUSTER
1995
SOHO
1996
CASSINI-HUYGENS
1997
POLAR PLATFORM
1998
XMM
1999
2000
MEDIUM-2
2001
2002
FIRST OR ROSETTA

Ulysses in the Context of the ESA Scientific Programme

R.M. Bonnet
Director of Scientific Programmes, ESA, Paris

Introduction

Ulysses has been part of ESA's Scientific Programme since 1977, at which time it was called the 'Out-of-Ecliptic' mission. It was later renamed the 'International Solar-Polar Mission' (ISPM), and was finally given the definitive name 'Ulysses' in 1984. The project was started at exactly the same time as the ESA contribution to the Hubble Space Telescope, which was successfully put into orbit on 24 April 1990 by the Space Shuttle 'Discovery', the same vehicle that will also launch Ulysses.

Like the Hubble Space Telescope, Ulysses is a joint ESA/NASA project. It too has had its launch delayed as a consequence of the 'Challenger' accident on 28 January 1986. In fact the ISPM spacecraft was originally scheduled to be launched by the Shuttle in February 1983, but problems on the NASA side dictated that Ulysses should eventually have been launched by 'Challenger' in May 1986 and the spacecraft was indeed ready for that date.

Because of the long interruption in the Space Shuttle launch programme, the Ulysses spacecraft has had to be stored for almost three years whilst waiting for its opportunity to explore a part of our solar system that has until now remained beyond the reach of spacecraft.

Despite the delays, the importance of the scientific objectives of the mission remain intact and Ulysses still plays a full role in the Space Science: Horizon 2000 Programme, where it occupies a unique position, a characteristic that it shares with all the other missions of that Programme (Fig. 1).

The scientific uniqueness of Ulysses and its relation to the other Horizon 2000 missions

Because the ESA scientific budget, although the largest space-science funding pool in Europe, is still not sufficient to provide a continuous series of missions in all disciplines, the Horizon 2000 Programme can only be a minimum programme in space science. It is indeed balanced between disciplines, but can only offer at best one mission per generation of scientists in the main scientific domains of space science. This is why it is of the utmost importance that these missions should be of the highest quality and provide the scientific community with a set of unique opportunities for substantially advancing our scientific knowledge and consolidating our expertise.

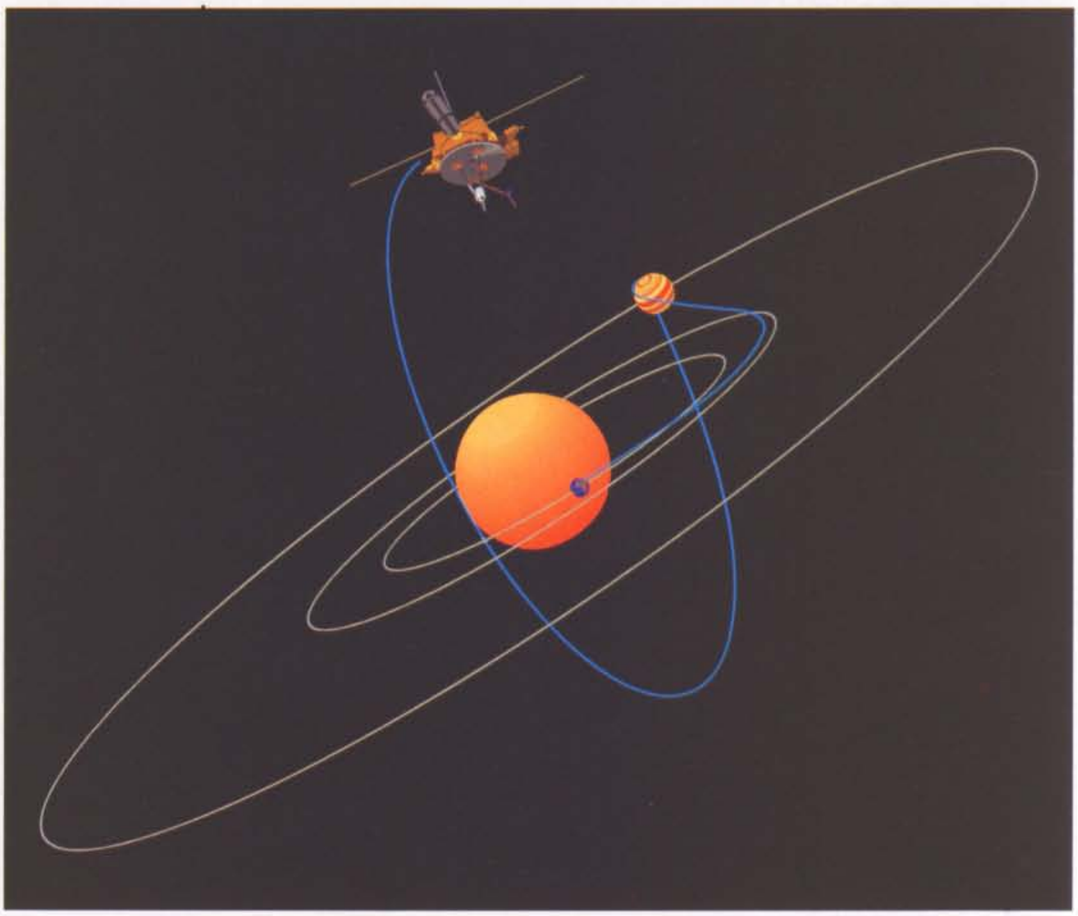
It is not difficult to find illustrations in this context, as the Agency's earlier scientific missions such as Cos-B, Geos, ISEE, Exosat, and more recently Giotto and Hipparcos, are all at the origin of major advances in our knowledge of the Universe and of the Solar System. Ulysses is clearly a mission of this stature. In making its novel pioneering journey out of the ecliptic plane, and by exploring completely virgin territory in the third dimension of our Solar System, it is highly likely that Ulysses will make major discoveries and unravel many scientific mysteries to a degree that no one can predict in advance.

The main scientific objectives of the mission lie in the area of heliospheric physics, with particular emphasis on the study of the solar wind, the interplanetary magnetic field, and the complex wave and particle interaction phenomena that exist in the interplanetary medium, delimited by a sphere of a radius equal to the distance between the Sun and Jupiter. Ulysses will in fact be the first spacecraft ever to explore the inner heliosphere over the full range of heliographic latitudes. It will be the second ESA spacecraft – the first was Giotto – to venture deep into the Solar System.

The scientific domain to be studied by Ulysses is one in which the scientific community in Europe has a considerable and proven expertise. European scientists have already made substantial contributions in this area and have gained considerable experience with such ESA missions as Geos, ISEE, and the German Helios spacecraft.

In the 1994–1995 time frame, European scientists will indeed be in a very privileged position, since at the time of Ulysses' high-heliographic-latitude passes over the solar poles, the Agency's Soho spacecraft will be beginning its operations at its assigned heliospheric in-ecliptic position at the Lagrangian point (L1). Many will also be heavily involved in the NASA GGS Programme which will also be in full swing at that time.

The relevance of the objectives of Ulysses to the totality of the Horizon 2000 Programme also stems from the fact that, with this mission, we will be able to probe the surroundings and the environment of a star under very unusual circumstances. Although there are many stars that point their axis of rotation towards us, and whose poles we can in principle see, the star that Ulysses will study, our Sun, will be observed in greater detail from directly above its poles. Ulysses will therefore provide us with a new and unique means of studying an astrophysical object in-situ. This will offer an unprecedented test of our theories, which we can later apply to other stars, stars that we will obviously never be in a position to observe so closely, even with observatories as powerful as HST, ISO, First and XMM.



But Ulysses is not just a purely heliospheric mission. Because of its unique orbit, it will also carry experiments of a completely different nature, such as gamma-ray detectors to detect the still-mysterious bursts recently interpreted by R. Sagdeev as due to the interaction of small comet nuclei arriving in the vicinity of a neutron star. In conjunction with observations conducted from other spacecraft, it will be in a unique position to identify what celestial objects are responsible for these phenomena. Another – and one of the most exciting – prospect of the mission will be its attempt to detect gravitational waves of astrophysical origin by precise Doppler tracking of the spacecraft telemetry signals. The significance of the fact that such a possibility is now entering the realms of experimental testing should not be underestimated.

Some programmatic aspects

Despite its being so rich in scientific promise, the Ulysses Programme is being carried out at the very reasonable and relatively modest cost to ESA's scientific budget of 167.5 MAU (Million Accounting Units) at 1989 economic conditions, which represents 120% of its original estimated cost at the start of the spacecraft's main development phase (known as 'Phase-B') in 1981. Most of the 20% overrun is due to the long delay in the spacecraft's launch, which has indeed been a major problem in the somewhat turbulent overall history of the mission.

In addition to the obvious cost implications, the scientists have had to wait for an additional four years for their instruments to be put into space. In the meantime some have already retired, but with the launch approaching any feeling of discouragement that the others might have suffered is fading, and everyone involved is becoming more and more excited at the imminent prospect of obtaining new results and participating in an event unique in the history of space science, and of mankind. On the positive side, the delay has, of course, provided time for further checks on and improvements in both the experiments and the spacecraft itself.

When it began in 1977, the Out-of-Ecliptic mission represented the first major joint undertaking by ESA and NASA. On the political side, therefore, it is important to point out that even today Ulysses is the first ESA scientific mission to involve such a high percentage of non-European Principal Investigators, with five of the nine investigations under US responsibility.

Everyone in Europe remembers the very painful moments in 1980 and 1981 when the Americans decided to drop their spacecraft, leaving ESA alone in developing the space hardware that would carry this set of European and US investigations. This decision caused an unprecedented rift between the two space Agencies. However, as is often the case in space matters, a major technical or programmatic setback can deliver a message that later proves its usefulness in the final implementation of that same programme or of other programmes.

Rather than looking negatively at the past history, ESA has taken the positive line of learning a lesson from this crisis. Having learnt the limits of applicability of a 'Memorandum of Understanding', the Agency now strives to protect itself in such situations, using other means such as the 'Inter-governmental Agreement' signed between the ESA Member States participating in the Columbus Programme and the US Government. There is always an element of risk in an international endeavour and this risk has to be well understood by all parties involved. There is also an enormous benefit to be expected from such endeavours: the richness of engaging in common pioneering research and programmes that would otherwise be more difficult or even virtually impossible to carry out.

Today, Ulysses stands as a propitious example of international cooperation in several respects. In October, the NASA Space Shuttle 'Discovery' and the IUS/PAM-S will carry Ulysses into space, and this ESA spacecraft will itself carry a set of nine experiments built by both European and US experimenters. When the first results are produced by the mission, it will be considered a tremendous fillip that top European and American scientists have ultimately successfully joined forces to derive the greatest benefit from these results and embarked together on this exciting scientific exploration of the unknown.

Ulysses – A Brief History

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To say that the Ulysses mission has had a long and chequered history would be something of an understatement. The idea of an out-of-ecliptic space mission was first put forward in a round-table discussion of American scientists in 1959, just two years after the launch of the first Sputnik. Despite the scientific attraction of such an exploratory mission to high solar latitudes, the technical competence to accomplish it was not available until the early 1970s, as a result of the precise targetting experience gained during the Apollo Programme and the missions to the outer planets.

Following independent studies by ESRO (later ESA) and NASA, both agencies jointly conceived a dual-spacecraft mission in 1974. This mission, known at that time as the 'Out-of-Ecliptic' (OOE) mission, was to have one spacecraft constructed by ESA and one by NASA, each carrying a complement of experiments drawn from Europe and the United States (Fig. 1). Both spacecraft were to be targetted towards Jupiter and – following a planetary gravity assist – one would have gone initially over the south solar pole and then crossed the ecliptic plane to overfly the north solar pole, while the other would have travelled first to the north and then to the south pole. In this way, scientists would have been able to make simultaneous measurements in both solar hemispheres and would have obtained stereoscopic views of phenomena on the Sun and in its atmosphere.

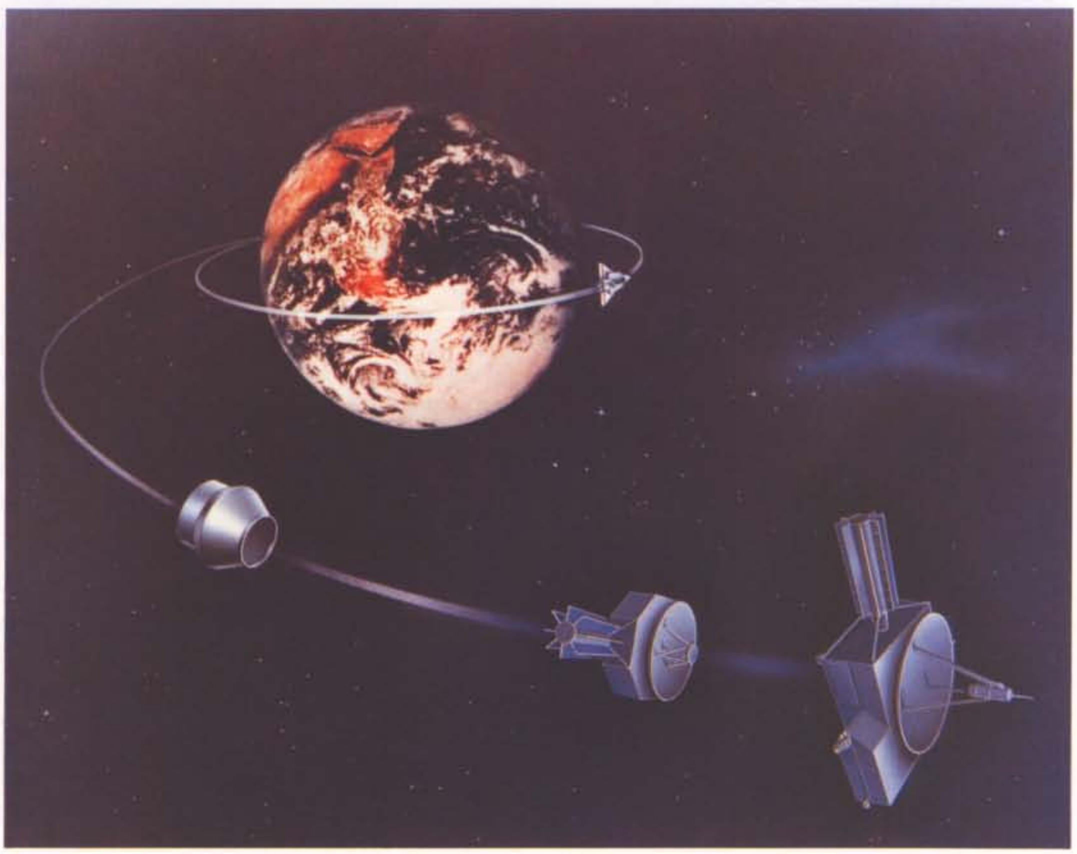

Figure 1. Artist's impression of a very early concept for the Out-of-Ecliptic mission, showing an ESA spacecraft (right), a NASA spacecraft (centre) and an Inertial Upper Stage (left)

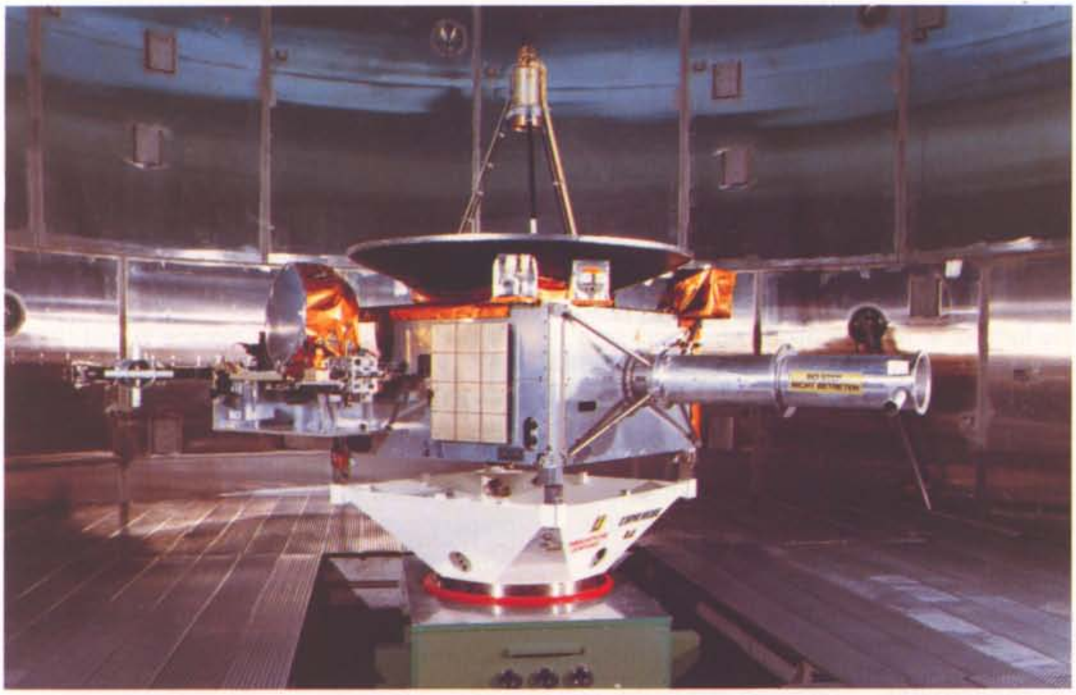

Figure 2. The final single Ulysses spacecraft under test at ESTEC, Noordwijk in 1982

In November 1977, the OOE project was formally approved by ESA's Science Programme Committee (SPC), and in February 1978, following a joint ESA/NASA Announcement of Opportunity, the scientific investigations for both spacecraft were selected, with a planned launch in February 1983. Work subsequently started on the European spacecraft with Dornier System (D) leading a consortium of some 20 industrial companies. In 1979, at the suggestion of NASA, the title of the project was changed to the 'International Solar-Polar Mission' (ISPM) which, it was felt, was more descriptive of the scientific goals of the mission.

In 1980, the project received its first setback when, as a result of difficulties with the development of the Space Shuttle, NASA announced a delay of two years in the ISPM launch. At this time, work on the ESA spacecraft was already well advanced and so the decision was taken to continue with its development and integration and then, following completion in 1983, to store the spacecraft until the new launch date.

The following year, NASA made a decision which had even greater impact on ISPM and its scientific goals. It cancelled the NASA spacecraft and delayed the launch of the ESA spacecraft by another year, until May 1986. An obvious consequence of this change from a dual- to a single-spacecraft mission was the loss of half of the scientific payload, including a number of European experiments. In addition, the NASA spacecraft was to have carried an instrument to image the Sun and its atmosphere, the corona, with a bird's eye view from above the Sun's poles. The loss of the second spacecraft also ruled out the opportunity to perform simultaneous stereoscopic observations in both solar hemispheres from two vantage points in the heliosphere, and removed the redundancy provided by having a core of key instruments on both spacecraft. Nevertheless, enough of the original unique scientific objectives remained in a programme which was far enough advanced for the ESA Science Programme Committee to reconfirm the continuation of the European spacecraft's development.

The major choice that ESA then faced was one of how best to proceed:

(a) to halt development and restart nearer the projected launch date;
(b) to continue development, but at a reduced rate so as to be prepared for the new launch date; or
(c) to continue development according to the previously agreed schedule and, following flight acceptance testing, to place the spacecraft into storage until required (this became known as the 'build-and-store' philosophy).

Each of the alternatives had its advantages and disadvantages and a study was therefore performed jointly by ESA's Project Team and the selected Prime Contractor, Dornier System. This concluded that, in view of the advanced status of development and the risk that with an interrupted or stretched programme experienced personnel would be lost from the project, the correct option was to build and store.

This finding was adopted and, although some concessions were made where development lagged, all acceptance testing was completed in the third quarter of 1983. Most of the scientific instruments were then returned to the respective Principal Investigators, while the spacecraft and associated ground equipment were put into storage until they needed to be prepared for launch. This launch preparation was to take the form of a 'recertification', which included certain functional and environmental tests to prove the continued flight-worthiness of the spacecraft.

In 1984, during the storage phase, the name of the project was changed once more, this time at ESA's suggestion. The new name 'Ulysses' was taken from the legendary Greek hero who, years after his adventurous return from the Trojan war, set out again to explore 'the uninhabited World beyond the Sun', as described in Dante's Inferno. This is a very appropriate description for a mission that will undertake a voyage to a part of the solar system where no spacecraft has ever gone before.

Table 1. Ulysses launch/launcher history

Date	No. of spacecraft	No. of launchers	Launch date	Interplanetary injection vehicle
April 1977	2	1	Feb. 1983	Four-stage IUS (AO)
April 1980	2	1	Feb. 1983	Three-stage IUS spinning
June 1980	2	2	April 1985	Three-stage IUS spinning
July 1980	2	2	April 1985	Three-stage IUS three-axis stabilised
Jan. 1981	2	1	April 1985	Centaur/Star 48 (or similar)
Sept. 1981	1	1	May 1986	Centaur
Dec. 1981	1	1	May 1986	Two-stage IUS/Injection module
Sept. 1982	1	1	May 1986	Centaur
July 1986	1	1	Oct. 1990	Two-stage IUS/PAM-S

Following the post-storage reintegration and recertification of the spacecraft and its payload during 1985, Ulysses was transported to Kennedy Space Center, Florida, in early 1986 to undergo final testing and preparation for launch on the Space Shuttle 'Challenger' in May. However, this activity was abruptly terminated when, on 28 January, 'Challenger' exploded soon after lift-off. Ulysses was therefore brought back to Europe and placed into storage for the second time. Again, most experiments were returned to the Principal Investigators.

The 1986 launch window for injection of the spacecraft towards Jupiter was to be shared between Ulysses and NASA's Galileo spacecraft, which will go into orbit around Jupiter. Post-Challenger, with the much more cautious Shuttle launch philosophy adopted, NASA argued that it would not be prudent to attempt two such difficult launches in one year. In 1987, it was finally decided that Galileo should be launched in 1989 and Ulysses in 1990.

Ulysses was taken from storage in mid-1989 and those elements that had been removed in 1986 were reintegrated. By February 1990, after a stringent series of tests, the spacecraft was declared fit for launch. In mid-May, it was returned to Florida to undergo final preparations for its launch on Space Shuttle 'Discovery' in October.

The mission's complex history has been further dominated by the variety of launch vehicles proposed over the years. The basic concept – a Shuttle launch with an Upper Stage to inject the spacecraft onto an interplanetary trajectory towards Jupiter – has remained unchanged, but the details, and in particular the type of Upper Stage, have frequently been modified. Table 1 shows the changing configuration of launch vehicles, number of spacecraft and launch dates. It is noteworthy that, despite the many changes to the launch interfaces with the spacecraft, no structural design change of any significance has been necessary.

In spite of this 'odyssey' of setbacks and delays in Ulysses' long pre-launch history, the scientific importance of this exploratory mission has not diminished. There is currently no other mission planned that will explore the high-latitude regions of the inner heliosphere. On the other hand, the scientific questions arising from the Ulysses mission's results will undoubtedly pave the way for future missions following in its footsteps.

Ulysses – An ESA/NASA Cooperative Programme

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Introduction

There can be many reasons why two or more countries might wish to cooperate on a specific scientific project. International cooperation between scientists with the sharing of concepts and results has persisted for centuries and it seems logical to expand this into cooperation between international agencies such as NASA and ESA. Secondly, ideas have a tendency to gel into specific projects along very similar time lines in various countries (as, for instance, in the invention of the telephone) and it can seem logical to maximise the scientific return by pooling the skills and technologies across a broad base and thus using each partner's experience to the utmost. Finally, and not least in importance, in these days of increasingly expensive science it makes economic sense to share the cost of projects, with a loose understanding that, just as ESA Member States share industrial contracts in proportion to their contributions, so the science output is shared according to the respective anticipated expenditures.

Ulysses qualifies as a candidate for a cooperative programme on all of these counts. The 120 or so scientists, from 40 different institutes, who are responsible for the nine experiments on-board Ulysses, have a long history of collaboration with each other and can therefore complement one another both in instrument building and in data analysis. During the 1960s and early 1970s ESA and NASA were conducting independent studies on techniques for studying the Sun from outside the ecliptic plane, and so it became very natural in 1974 for the two Agencies, as part of their general strategy of cooperation, to combine forces for a single project. It was also clear that Ulysses was going to be a very expensive project and the chances of its adoption and survival would be massively increased if it was done jointly. The two sides therefore resolved to form a cooperative programme, originally known as the 'Out-Of-Ecliptic' mission, later as the 'International Solar-Polar Mission', and finally as 'Ulysses'.

International cooperation

Cooperation between NASA and ESA is not covered by a contract. The document used instead is a 'Memorandum of Understanding' (MOU), which is signed at the highest level by the two Agencies and which sets out the framework of the agreement and the basic responsibilities that each side will undertake. However, these are not contractually binding. Instead, each side agrees to use its 'best endeavours' to carry out its side of the bargain, subject only to the restrictions inherent in the funding arrangements under which they operate. The formal MOU for Ulysses was signed by ESA's Director General and the NASA Administrator on 29 March 1979, although from a practical point of view the project had already been running for some time prior to that date.

The outline of each side's contribution to the project was delineated in the MOU, and the major points are listed in Table 1.

Table 1. Major ESA and NASA contributions to Ulysses

ESA	NASA
Spacecraft	Launch
Spacecraft operations	Radio-isotope Thermo-electric Generator (RTG)
50% of experiments	Use of Deep-Space Network (DSN) and JPL Control Center
	50% of experiments

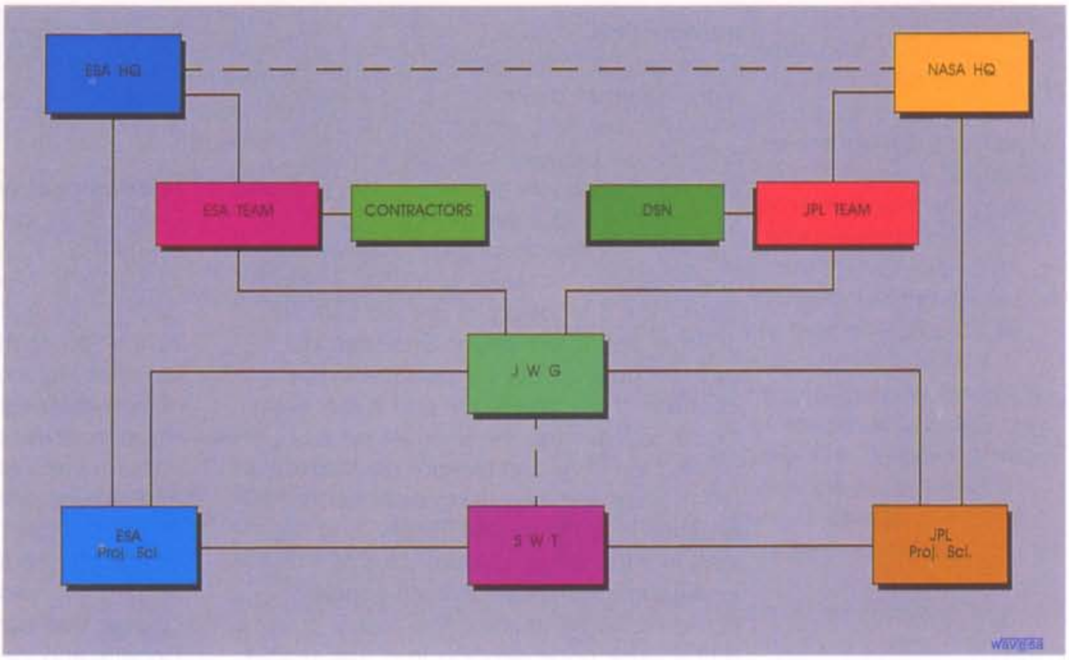
As the accompanying article on the history of Ulysses describes, NASA later cancelled its spacecraft, but it was decided not to modify the MOU but rather to let it stand 'mutatis mutandis'. In addition to laying out the responsibilities of ESA and NASA, the MOU also required each Agency to nominate a Project Manager and a Project Scientist, with these four being charged with the day-to-day running of the Project and with interpreting, where necessary, the details expressed in a general way in the MOU itself. The two Project Managers and the two Project Scientists together form the Joint Working Group (JWG), which has overall control of the Project, and the two Project Scientists additionally co-chair the Science Working Team (SWT), which consists of the Principal Investigators of the various experiments. One important distinction between the JWG and the SWT is that the former is a decision-making body with authority for expenditure, whereas the SWT is advisory in nature. Obviously, since the two Project Scientists sit on both committees, this advice is invariably well-founded and well-received.

In order to carry out the project, NASA designated the Jet Propulsion Laboratory (JPL) as its lead centre and nominated its Project Manager and the Project Scientist from staff there. ESA designated ESTEC staff members for these positions. JPL and ESTEC were charged with carrying out the respective responsibilities listed in the MOU.

One other important precept essential in a cooperative project such as Ulysses is the maintenance of independence of the two Agencies. Both ESA and NASA are responsible for carrying out their obligations according to their own procedures and without exchange of funds between them. Consequently, although the JWG is in overall control of the project, it does not interface with or instruct the various contractors. This is done by each Agency independently.

Figure 1 shows the relationships between the JWG, SWT, Project Managers and Project Scientists, and the European and US industrial contractors.

Figure 1. The roles of the Joint Working Group (JWG) and Science Working Team (SWT)



ESTEC–JPL cooperation

One major technical problem with which JPL and ESTEC were confronted very early in the Project was the huge disparity in the time-scales being used by ESA and NASA in order to meet the agreed launch date of February 1983. ESTEC wished to start design and build of the spacecraft in 1978, whereas JPL were not starting their spacecraft (which also formed the structural link to the Upper Stage and the Shuttle) until 1979. Additionally, the Shuttle was still several years from its first flight and the Upper Stage, which at that time was to be a three-axis-stabilised, three-stage Inertial Upper Stage, was in the very early stages of development. Hence ESA could not know what loads might be introduced into its spacecraft and therefore lacked one of the basic requirements for design. In order to overcome this difficulty, the experts on both sides agreed on a structural interface, from both a mechanical and a loadings viewpoint, which it was agreed would be respected on both sides of the interface. Consequently, when the NASA spacecraft was cancelled, JPL became responsible for provision of four adaptors that would accept the agreed interface on the ESA spacecraft side and respect the Upper Stage interfaces on the other. This pragmatic approach to problem solving worked extremely well and was adopted on numerous occasions when similar difficulties occurred. At no stage during the thirteen-year history of Ulysses has work had to be stopped because of timing difficulties between the participants.

Another area of close cooperation between ESTEC and JPL has been the overall mission design, for which ESA and NASA are jointly responsible. This has ranged from conceptual ideas such as using the gravitational field of Jupiter to act as a slingshot for the spacecraft out of the ecliptic plane, to the exact date of official termination of the project (when the spacecraft descends below 70° solar latitude), with its consequences for the trajectory to be followed and the operational costs to both Agencies.

Cooperation with Ulysses investigators

One of the basic differences of approach between ESA and NASA is in the manner of funding scientific investigations on projects such as Ulysses. Within ESA each investigator is responsible for his own financing, usually via the national authorities, whereas NASA funds the US scientific groups via JPL. The result of this has been that any change within a European experiment could be negotiated directly with the scientific group concerned, whereas a change to a US experiment on the spacecraft involved the scientific group, JPL and ESA. Despite this extra complication, difficulties were always resolved rapidly and amicably so that no delay to the schedule occurred.

Practical difficulties of managing an international project

Although there are obviously many advantages in ESA–NASA cooperative projects, there are also a multitude of day-to-day difficulties which the Project Managers, in particular, have to overcome. Among these might be listed:

- Equality of ESA and NASA in Ulysses.
- Philosophical differences of approach between NASA and ESA.
- Differing documentation requirements.
- Time-zone differences.
- Attendance at meetings with limited travel funds.
- Communication techniques.

In the following paragraphs, the manner in which these problems were dealt with, and overcome, within the Ulysses Programme is briefly presented.

One of the basic features of a truly cooperative project is that the partners must regard themselves as equal partners with an equal say in the progress of the project as a whole. There can be no question of a senior/junior relationship. In a way, this parallels ESA itself where each Member State, irrespective of the percentage share of the costs that it is responsible for, has an equal voice and vote in the running of ESA. In the case of Ulysses, where a strict 'no exchange of funds' rule was imposed by the MOU, such a simple solution could not be used. Instead, the Project Managers, in interpreting the MOU, decided on those areas of the cooperation where equal agreement was necessary and those where the funding agency should have the final word. Among the former are clearly included the overall mission and science objectives, and among the latter the spacecraft design (an ESA responsibility) and the RTG power source (where JPL were responsible). Less clear areas such as the launch itself, which NASA funded but which had immense spacecraft impacts, were settled on an ad hoc basis. For example, the overall choice of launcher was decided entirely by NASA, but the minutia of its interfaces were dealt with on a virtually equal basis by JPL and ESA.

Similarly, for formal reviews of both the spacecraft and the ground segment, the Board consisted of senior personnel from both NASA/JPL and ESA, with some preponderance being given to the 'home team'. Both Project Managers sat, as of right, as ex-officio members of all Boards.

At a lower level, some care had to be given to the location and grouping of working meetings in order to avoid, in the days of stringent travel budgets, one partner being faced with an overwhelming proportion of the intercontinental travel bills. Obviously, where Space Shuttle and launch interfaces were concerned, and the number of participants could frequently exceed one hundred, the majority of the meetings had to be held in the USA. Even then, they were usually arranged in groups, even at the cost of inconvenience to American colleagues, so that the Europeans involved could make one two-week trip across the Atlantic rather than a number of two-day trips. JPL/ESA meetings, with smaller numbers involved, and meetings of the Science Working Team, where participation of European and Americans was roughly equal, tended to be held alternately in the USA and Europe.

Communication, with a nine-hour time differential between JPL and ESTEC/ESOC, tended always to be a difficulty. Since 8 a.m. in California equates with 5 p.m. in Europe, there was virtually no common working day time for telephone conversations. A teleconference with several people involved tended to mean that JPL personnel had to rise early in the morning and ESA personnel got home late for dinner. For more limited conversations, it usually meant that the JPL Project Manager was woken at home early in the morning, or the ESA Project Manager received calls at home at any time up to midnight.

It is also interesting to note the way in which written communication has progressed over the fourteen years of project life. Originally, most communication was by letter, but this proved to be too slow, often taking more than a week in each direction. Telexes were then used, but at the risk of inaccuracies being introduced by the various operators necessary for transmission by this technique. Later, telemail was used, followed by centralised telefax (called 'rapid fax' in the USA). Nowadays, with the advent of mini fax machines that can be installed in individual offices, both JPL and ESTEC projects have such machines, leading to extremely rapid turnaround of communications. Postal exchanges are now restricted to very formal letters, plus drawings and documents that are too large or too voluminous for fax transmission. A fairly regular courier service has proved to be the most efficient means of sending such items.

Launch cooperation

Any launch via the Shuttle is very complex compared to a launch with an expendable rocket. For Ulysses this is further complicated by the utilisation as the Upper Stage of an Inertial Upper Stage and a PAM-S, from different suppliers, to provide interplanetary injection. Consequently, on the United States' side there are several NASA Centers involved (JPL, JSC, KSC & MSFC) in addition to the US Air Force (who have responsibility for provision of the Upper Stage) and the Department of Energy (responsible for the RTG). Obviously, each of these has contractors, such as General Electric (RTG), Boeing (IUS), McDonnell Douglas (PAM-S), Rockwell International (STS) and Aerospace (consultant to USAF).

In order to pull together this massive team, an organisation was established, analogous on the launch side to the JWG, which is responsible for the complete five-year mission. This is known as the Mission Integration Panel (MIP) – where 'Mission' is confined to the launch and interplanetary injection mission – and is jointly chaired by MSFC, JPL and ESA. Figure 3 shows the principal MIP participants and their responsibilities. A number of sub-panels covering specific technical areas such as

Figure 2. The MIP Management Team. Back row, from left to right:
R. Ivanoff (NASA/JPL)
M. Pruitt (USAF)
J. Darden (NASA/MSFC)
J.J. Conwell (NASA/JSC)
G. Hampel (Dornier)
P.J. Caseley (ESA/ESTEC)

Front row, left to right:
D.E. Page (ESA/JPL)
E. Smith (NASA/JPL)
W. Meeks (NASA/JPL)
E. Kohl (USAF)
J. Johnson (Boeing)
K.-P. Wenzel (ESA/SSD)
D. Eaton (ESA/ESTEC)
L. Kruse (NASA/KSC)

mission design, thermal, structures, etc., were also created, reporting to the MIP in their specialities. These latter sub-panels were mirrored in the Shuttle system by a series of Working Groups, whose task it was to ensure that the STS was correctly configured and that operations on the ground and during the post-launch in-orbit phase were correctly geared to the mission.

Obviously, with such a complex organisation, meetings could grow to alarming sizes and numbers in excess of 100 attending a Working Group were by no means uncommon. For the formal reviews of spacecraft and mission operations, which took place at regular intervals throughout the project's lifetime, a joint ESA/NASA/JPL Board was established consisting of senior managers who made recommendations to the Project Teams on the future conduct of Ulysses. Attendance at these reviews could exceed 150 people.

'Public Relations'/'Public Affairs'
The two titles of this paragraph are the names that ESA and NASA, respectively, give to the same function, namely the task of making sure that the existence and achievements of Ulysses are made known to the public – specialised technical, scientific and general. With a cooperative project such as Ulysses, it is clearly essential that neither side appears to be claiming recognition at the expense of the other.

In order to ensure a coordinated approach, ESA and NASA have produced a Public Affairs Plan, signed off at Director and Associate Administrator level, respectively, which lays out the joint activities to be undertaken and the relative responsibilities of ESA and NASA in carrying them out. This includes participation and speakers at Press Conferences, major publications, etc. As annexes to this overall Plan, each side describes its activities in more detail to ensure full coordination and cooperation between ESA and NASA. This approach leaves both Agencies free to act within its own rules and procedures, whilst ensuring full knowledge and recognition of the partner.

Conclusion
It is hoped that the preceding paragraphs have given some feeling for the managerial difficulties in coordinating an international programme of the complexity of Ulysses. Coming from two Agencies with very dissimilar working methods and philosophical approaches, it is inevitable that from time to time problems have arisen and that tempers have got frayed. However, the mutual respect that has always existed for the technical expertise of JPL, NASA and ESA has been sufficient to rise above these temporary setbacks, and to establish a trustful cooperation that will lead to the successful launch of the spacecraft in October and an extremely valuable five-year scientific mission for Ulysses.

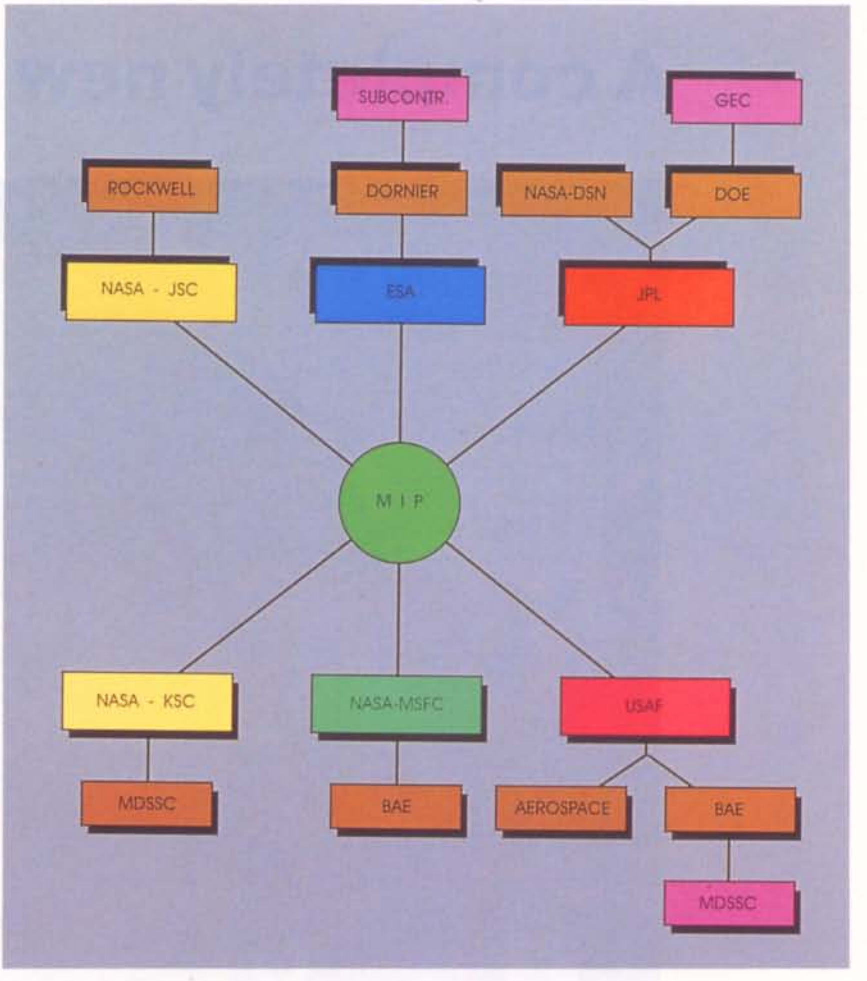


Figure 3. Participants in the Mission Integration Panel (MIP)

A completely new picture of the su

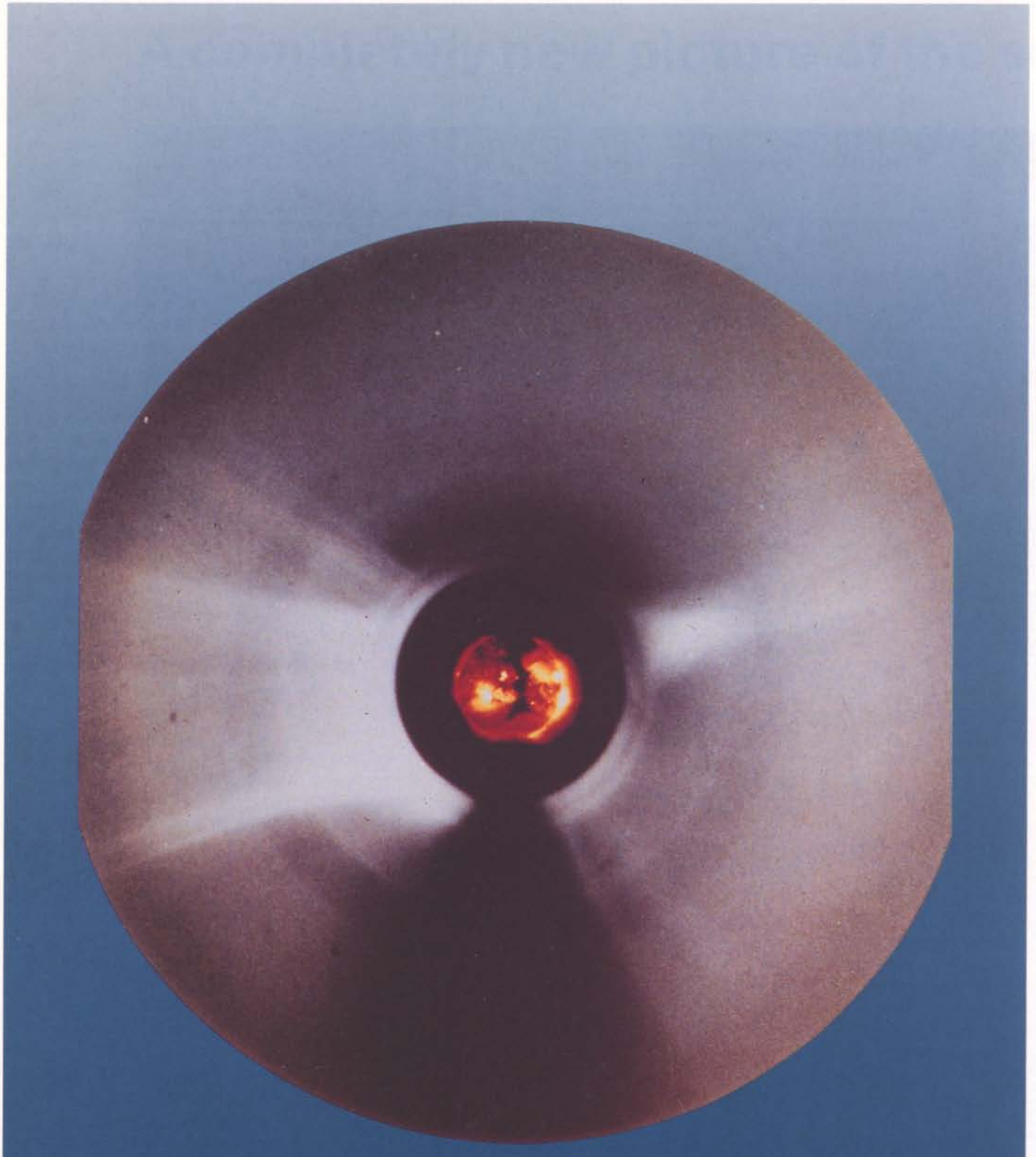


Figure 1. Photograph of the Sun's outer atmosphere, or 'corona', on which is superimposed, to the same scale, an X-ray image of the Sun. A striking feature is the corona's lack of symmetry. Bright, streamer-like structures are randomly distributed over most of the disc, while in the regions around the solar poles the corona often appears to be absent. These regions are known to coincide with so-called 'coronal holes', one of which can be seen as a dark void in the X-ray image of the Sun. The corona, which consists of very hot, ionised gas, expands more or less radially away from the Sun in a continuous stream that has been called the 'solar wind'. Normally, this wind flows at a speed of around 400 km/s. Occasionally, streams moving at up to 1000 km/s are observed that are thought to originate in coronal holes.

The Scientific Mission of Ulysses

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Ulysses will be the first mission to explore the inner heliosphere over the full range of solar latitudes, including the regions over the poles of the Sun. The heliosphere is the vast region of space extending outwards from the Sun's atmosphere, the solar corona, and embracing all planets. It is dominated by the magnetised stream of ionised gas, or plasma, that flows radially away in all directions from our star. This flow, which is called the 'solar wind', is the only large-scale astrophysical plasma that is available for in-situ study, just as the Sun is the only star close enough for its surface structure to be resolved by imaging from Earth.

Why go to high latitudes?

Why do scientists wish to explore the Sun's environment at all latitudes? Much has been learnt about the equatorial regions of the Sun's extended plasmasphere from missions near Earth (such as the HEOS and ISEE programmes) and in deep space (such as the Pioneer and Voyager missions). But in the same way that the properties of the Earth's magnetosphere vary dramatically with geomagnetic latitude, so we expect those of the heliosphere to change as we move away from the plane of the ecliptic. This viewpoint is substantiated by, for example, the striking asymmetry of the solar corona at solar minimum, as seen in eclipse photographs. Moreover, latitudinal variations in solar-wind speed, magnetic-field polarity and charged-particle fluxes have been observed when Pioneer-11 and Voyager-1 travelled from the ecliptic to latitudes of 15° and 30°, respectively, in the outer heliosphere following planetary encounters.

Vast amounts of radiation and large numbers of particles are spewed into space from the Sun's boiling surface. Although we can see sunspots, solar flares, and other features of the Sun's surface at many solar latitudes, we can directly sample only those parts of its atmosphere that lie close to the ecliptic plane.

Most visible solar features occur relatively low in the Sun's atmosphere, where the density of the gas is quite high. Scientists can identify atoms and ions and measure magnetic field strengths in these regions by observing the light produced and separating it into its constituent wavelengths (this will be one of the aims of ESA's Soho mission). Further from the Sun, however, the outer corona becomes very tenuous, and therefore remote-sensing techniques no longer work. Consequently, to learn about the high-latitude regions of the solar environment we have to get above those regions and make direct measurements. We need to replace our parochial view with a more accurate assessment of the total solar environment. This is the goal of the Ulysses mission.

The solar wind

The solar wind originates in the Sun's corona, which is extremely hot, with temperatures of over 1 million degrees Kelvin. Solar physicists don't fully understand why (again Soho is designed to study this problem). At these temperatures, atoms are stripped of their electrons; the gas becomes a plasma. Ions and electrons, normally bound to the Sun by gravity, overcome this gravitational attraction at the high coronal temperatures and burst away at supersonic speeds of several hundreds of kilometres per second. Although the solar wind blows continuously, its density and velocity are always changing. Much of this variation seems to be associated with coronal holes, which are regions where few X-rays are emitted. These regions appear as dark 'holes' in X-ray photographs of the Sun. Scientists believe that the high-speed streams – energetic gusts of the solar wind with velocities up to 1000 km/s – originate in coronal holes.

During the quiet part of the eleven-year cycle of solar activity, coronal holes occupy large regions, centred on the Sun's poles. At more active times (as in the early 1990s) they tend to shrink, although small holes may appear for short periods at other solar latitudes.

great distances. Near the equator, solar rotation winds the field into a tight spiral pattern. At the Sun's poles, where there is no rotation effect, the magnetic fields are probably radial (at least at the distance of Ulysses from the Sun). If the field lines are radial, they ought not to be twisted into the complex shapes found near the ecliptic plane, and should therefore be easier to comprehend.

The same applies to the solar-wind flow. Near the ecliptic plane, the solar wind is

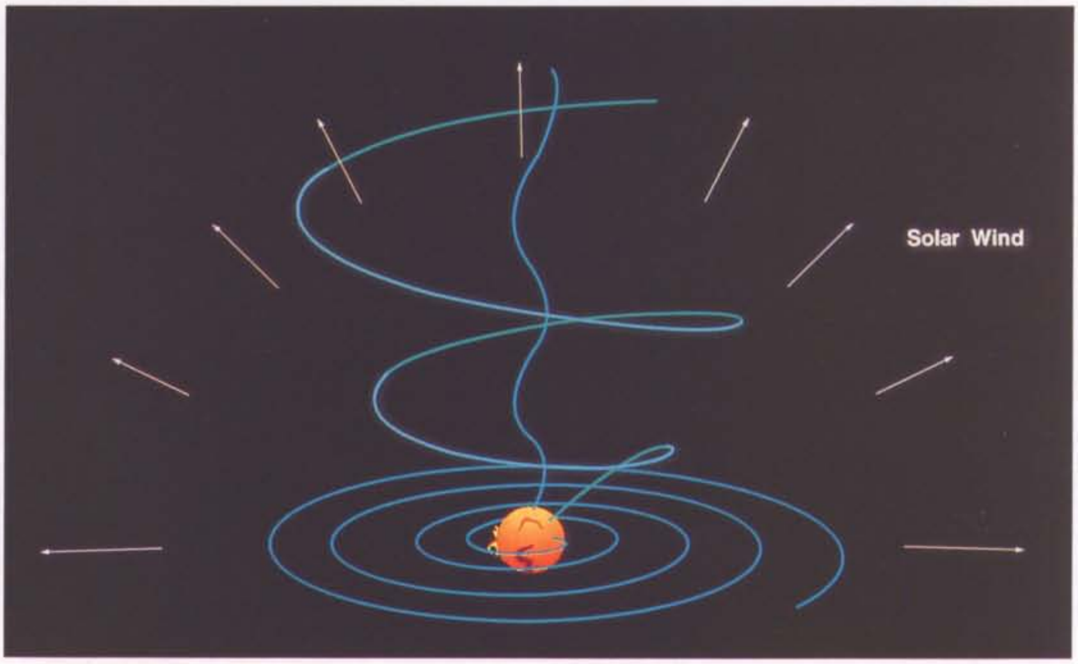


Figure 2. Structure of the magnetic fields in the heliosphere. The field lines are carried out from the Sun's corona by the radially outflowing solar wind. Near the Sun's equator, they are wound into tangled spiral patterns in interplanetary space by the rotating Sun. At the solar poles, where there is no rotation effect, the magnetic fields are expected to be radial and less tangled.

emitted in both high- and low-speed streams. As the Sun rotates, the high-speed streams overtake the slow ones, and complex stream–stream interactions dominate the solar-wind flow. Over the Sun's poles, the flow is expected to be parallel to the radial field, less complex and therefore easier to understand.

Because the solar wind flows radially from coronal holes, we will not really know what is going on in the solar wind until we put measuring instruments above the coronal holes. This is just one of the many reasons for sending Ulysses to explore the uncharted solar latitudes away from the equator.

Measuring the composition of the solar-wind plasma, the numbers of protons, alpha particles and heavy ions such as oxygen, silicon and iron, will provide unique information on conditions in that region of the solar corona in which the solar wind is accelerated. The relative amounts of these solar-wind materials are expected to differ under different local conditions in the corona where the materials are formed. The different degree of ionisation, i.e. the number of electrons removed from the ions, is a measure of the temperature of the ion source region.

The solar wind also carries magnetic-field patterns at the surface of the Sun out to

Not only does the Sun emit the solar wind, it also sporadically releases highly energetic particles. These particles enable us to sample the chemical and isotopic composition of the solar atmosphere and provide information on how particles are transported and stored in the strong magnetic fields of the corona. Observations in the ecliptic plane are difficult to interpret since the particles propagate through different regions in the corona, with the result that the composition and energy spectra we observe are the products of a complicated mixture of processes. At different heliographic latitudes, the mixture of processes involved is expected to be different, and perhaps simpler. Ulysses will enable us to make observations of solar energetic particles directly over so-called 'active regions' (prime sources of these particles), which are predominantly found at moderate solar latitudes, or directly over the magnetically open regions in coronal holes.

The background solar magnetic field is dipolar. The solar wind stretches this dipolar field so that, at large distances from the Sun, magnetic field lines going outward from the Sun's northern hemisphere are separated by a current sheet from those returning to the Sun in the southern hemisphere. This current sheet lies approximately at the latitude of the Sun's equator, and is not flat but warped. As the Sun rotates – once every 27 days as seen from Earth – the northern heliosphere, characterised by magnetic fields of one polarity, sweeps over the Earth; about two weeks later the field from south of the current sheet, which carries the opposite magnetic polarity, also passes the Earth. There tends to be little warping of the current sheet near sunspot minimum, but during periods of high solar activity it can be severely warped, reaching solar latitudes in excess of 70° at some longitudes. Every 11 years, following solar maximum, the polarity of the solar dipole magnetic field reverses.

Scientists have extrapolated 'knowledge' of these three-dimensional phenomena from direct measurements made in the ecliptic plane and observations of the solar surface made from Earth. In order to confirm these ideas, we need to travel out of the ecliptic plane and into the third dimension of the heliosphere. This is precisely what Ulysses has been designed to do.

The Sun is also a mighty broadcaster of radio signals, which travel through the solar system at the speed of light. Energetic electrons that move outward as a result of solar eruptions produce radio waves along their path following the heliospheric magnetic field lines. Ulysses will help determine the direction of such radio sources. It will also measure electric and magnetic plasma waves in the solar wind – waves associated

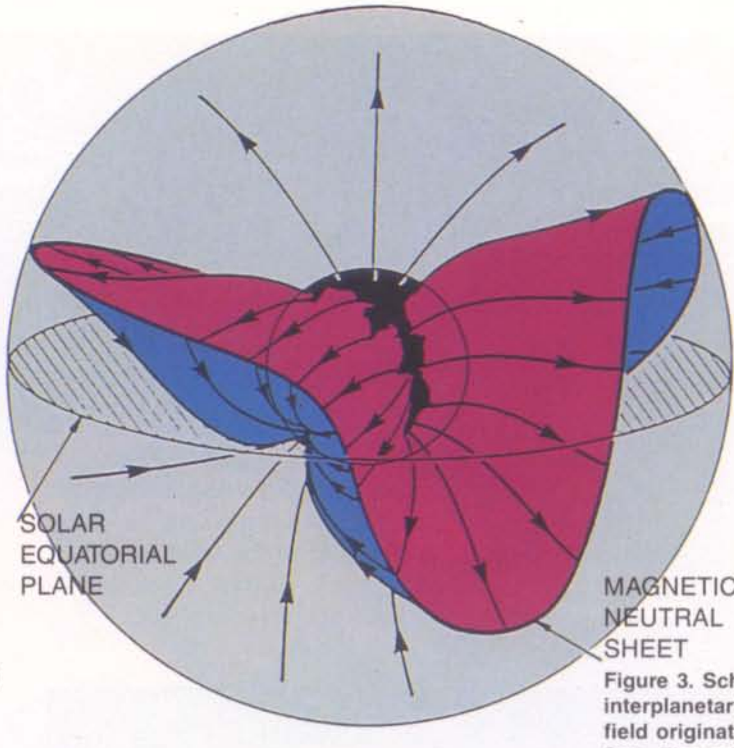


Figure 3. Schematic of the interplanetary magnetic field originating on the Sun. The solar wind carries the Sun's dipolar field outwards so that, at large distances, field lines from the northern hemisphere (directed away from the Sun) are separated from those of opposite polarity in the southern hemisphere by a magnetic current sheet. In this example, the sheet lies approximately at the latitude of the Sun's equator.

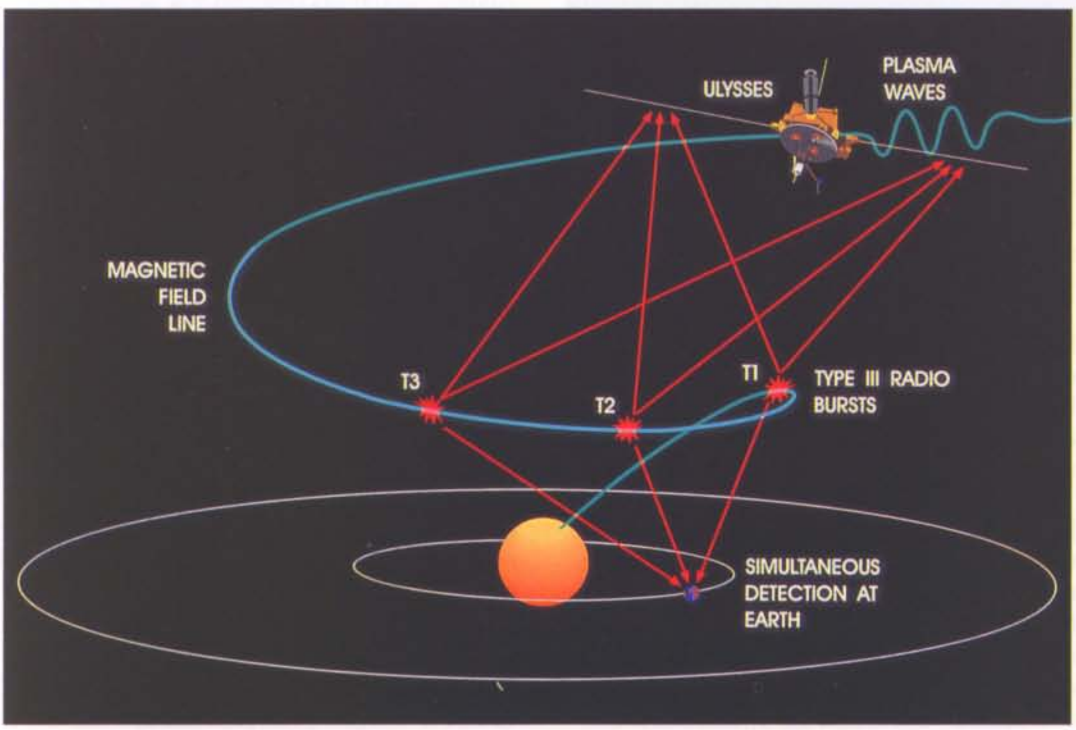


Figure 4. Detection of different types of natural electromagnetic waves by Ulysses. The spacecraft's wire-boom antennas will be used to detect radio emission produced by solar electrons spiralling around the heliospheric magnetic field lines as they travel outwards from the Sun. Together with simultaneous measurements from receivers on and near the Earth, the radio signals can be used to trace out the shape of the field lines. The Ulysses antennas also detect plasma waves generated close to the spacecraft in the solar wind. Communication between the spacecraft and the ground stations for telemetry and telecommanding is provided via Ulysses' parabolic high-gain antenna, which points continuously towards Earth.

with local variations in the properties of clouds of plasma that move through the interplanetary medium.

Another constituent of the heliosphere is cosmic dust, extremely tiny particles that move in the solar system. Depending on their sizes, the individual particles can be drawn inward toward the Sun by gravity or forced outward by the pressure of solar radiation. The dust probably originates in different ways. Some particles have undoubtedly been left behind by comets streaking through the inner solar system; others may have come from collisions between great boulders in the asteroid belt; yet others probably enter the solar system from interstellar space. Ulysses will study the origin and physics of this heliospheric dust by measuring its size distribution in space and the speed and flight direction of the dust particles as a function of latitude and heliocentric distance.

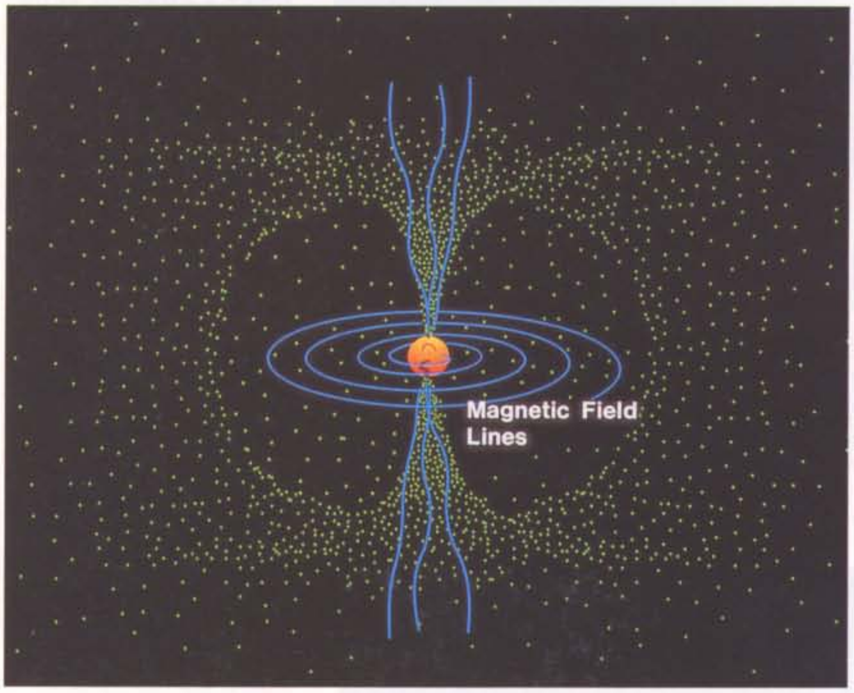


Figure 5. Artist's impression of galactic cosmic-ray particles flowing into the heliosphere. Cosmic rays – nuclei of heavy elements – originate in violent events far away in the Galaxy. Because they are electrically charged, they are forced to follow the heliospheric magnetic field lines. Near the ecliptic, these field lines are wound into a spiral, preventing cosmic rays from reaching the Earth easily. Over the poles, the field is expected to be more radial and therefore the cosmic rays should have easier access.

Not only will Ulysses study the Sun and its environment in three dimensions, its unique trajectory will also enable it to study some aspects of the Universe that are difficult to study from the ecliptic plane.

Radiation from beyond the solar system

One key area of study will be cosmic radiation – charged particles of high energy that move through space at nearly the speed of light. Cosmic-ray material is formed inside distant suns of our Galaxy. At times of violent outbursts or even explosions, such as a supernova, cosmic rays escape into interstellar space and are thought to be accelerated to these high speeds by the explosion's shock wave. Our understanding of the nature of cosmic rays is limited because the properties of the particles are severely modified as they pass through the heliosphere. The 11-year solar cycle clearly modulates the number of cosmic rays detected near Earth; when solar activity is at maximum, the cosmic-ray intensity is at a minimum. We do not understand the physical processes that cause this variation. Some recent observations suggest that the warping of the current sheet affects the ability of cosmic radiation to penetrate into the heliosphere. With the data that Ulysses will return from high solar latitudes beyond the current sheet, we hope to be able to improve our understanding of how the magnetic fields modulate the arriving cosmic rays.

Ulysses may even be able to go one step further and observe unmodulated 'virgin' interstellar cosmic rays. As the spacecraft flies over the solar poles, we may see cosmic rays that have entered the heliosphere unopposed along the radial field lines. This would give us the first direct measurement of the distribution of high-energy nuclear particles born of catastrophes in distant stars.

Another area of study will be interstellar gas that has entered our heliosphere from the surrounding 'local interstellar medium'. Charged gas is blocked from entering the heliosphere by its internal magnetic fields. Neutral particles, however, can enter freely. Neutral helium approaches the Sun from the direction of motion of our solar system, and Ulysses will attempt to sample this neutral interstellar gas directly at those times when it is moving in this direction.

There are also some scientific investigations that will take advantage of the large distance that will lie between Ulysses and the Earth. One of these is the study of cosmic gamma-ray bursts. These sporadic events do not come from the Sun, but from somewhere in the Galaxy. There is growing evidence that many gamma-ray bursts are generated by neutron stars, which are small, highly condensed objects near the ends of their lives. Accurate localisation of a gamma-ray burst can be achieved by precise measurement of the burst arrival time at several widely separated spacecraft. Ulysses will provide, in conjunction with near-Earth spacecraft, a long intra-spacecraft baseline from which to determine the location of the source of these mysterious bursts.

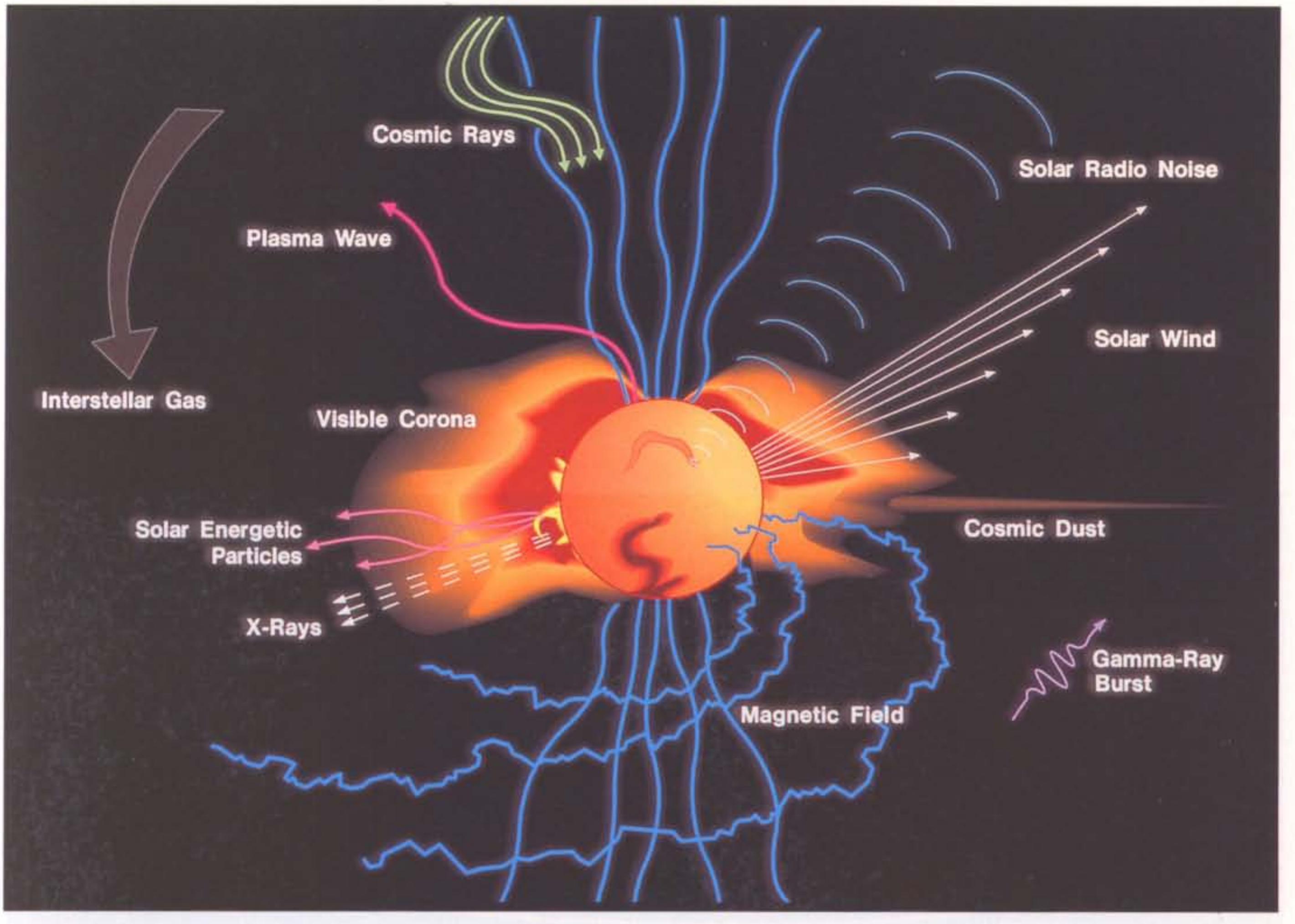


Figure 6. Schematic of various topics in the fields of solar, interplanetary and galactic science that will be investigated by Ulysses in the course of its mission.

Another more 'exotic' goal of the Ulysses mission is the search for gravitational waves. Einstein's general theory of relativity predicts that gravitational waves – ripples in the curvature of space-time that propagate through space at the speed of light – should be created during such catastrophic events as supernova explosions or the collapse of a galactic nucleus into a super-massive black hole.

To date, no gravitational waves have ever been detected directly, but the Ulysses spacecraft may be able to do so. A passing gravitational wave would cause a barely detectable change in the Earth-to-spacecraft distance. Such a change could be measured using information from the radio signals travelling to and from the spacecraft. If a gravitational wave passes the solar system during Ulysses' flight, and if the required accuracy is achieved, one should be able to detect it. The discovery of such a wave would indeed be a big step forward in checking the validity of general relativity theory.

Summary of the scientific aims
As will have become apparent from the preceding paragraphs, there are many reasons why scientists wish to explore the heliosphere at all latitudes. The major aims of Ulysses' scientific investigations can be summarised as follows:

- to assess the global three-dimensional properties of the interplanetary magnetic field and the solar wind
- to study the origin of the solar wind by measuring the composition of the solar-wind plasma at different heliographic latitudes
- to study the acceleration of energetic particles in solar flares by observing the X-ray and particle emission from active solar regions
- to increase our knowledge of waves, shocks and other discontinuities in the solar wind by sampling plasma conditions that are expected to be different from those available near the ecliptic
- to improve our understanding of interplanetary dust by measuring its properties as a function of heliographic latitude
- to improve our understanding of galactic cosmic rays by sampling these particles over the solar poles, where low-energy

cosmic rays may have easier access to the inner solar system than near the ecliptic plane
- to advance our knowledge of the neutral component of interstellar gas that enters the heliosphere by measuring its properties as a function of heliographic latitude
- to search for gamma-ray-burst sources and, in conjunction with observations from other spacecraft, to identify them with known celestial objects
- to search for low-frequency gravitational waves by using the spacecraft's radio communication link.

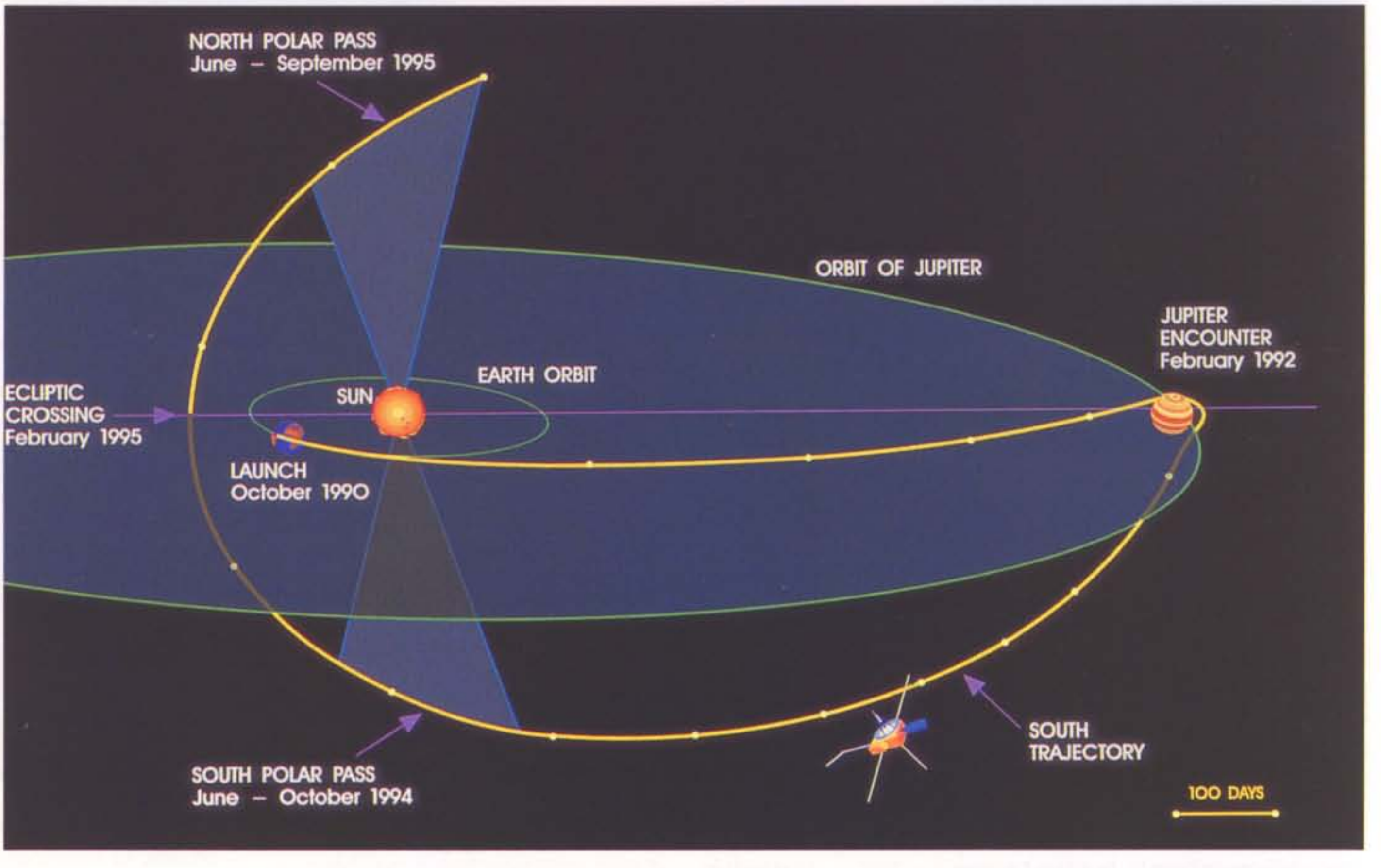


Figure 7. Ulysses' trajectory viewed from 15° above the ecliptic plane. The blue segments show regions in which the heliographic latitude of the spacecraft exceeds 70°. The dots plotted along Ulysses' trajectory are at 100 d intervals.

The scientific payload that will address these goals is described in detail in a companion article in this Bulletin.

Getting the right trajectory

How does Ulysses acquire its unique trajectory that will take it to the regions over the solar poles? Jupiter will be Ulysses' first target because there are currently no launch vehicles capable of generating the thrust necessary to get a spacecraft directly out of the ecliptic plane. Ulysses will therefore get part of the enormous thrust it needs to achieve its solar-polar orbit from the launch vehicle and the rest from the gravitational pull of the giant planet. Launch vehicles generally travel in the same direction as the Earth spins (west to east) and in the plane of its orbit, both of which provide the spacecraft with an additional send-off boost. Unfortunately, a spacecraft trying to get into a plane perpendicular to the ecliptic cannot use any of this natural boost.

An object orbiting the Sun at the same distance from it as Earth, i.e. 1 Astronomical Unit (AU), moves at a speed of 30 km/s. In the Earth's case, this velocity is entirely in the ecliptic plane. For a spacecraft to get into a polar orbit, the velocity has to be perpendicular to the ecliptic plane. To launch an out-of-ecliptic mission directly from Earth, the existing in-plane component must be compensated by an equal and opposite velocity, and a perpendicular velocity component must be supplied. This means the spacecraft would need to be accelerated to a speed of 42 km/s to achieve a 1 AU polar orbit.

First sending the spacecraft to Jupiter solves several problems. The velocity of Jupiter in its orbit around the Sun (14 km/s) can be used to cancel an equal and opposite component of the spacecraft's in-plane velocity. Furthermore, the velocity needed perpendicular to the ecliptic at Jupiter's distance from the Sun is only about 16 km/s. Consequently, the launch-vehicle capability required is much smaller – by a factor of 2.5 – compared with the Earth-launch scenario.

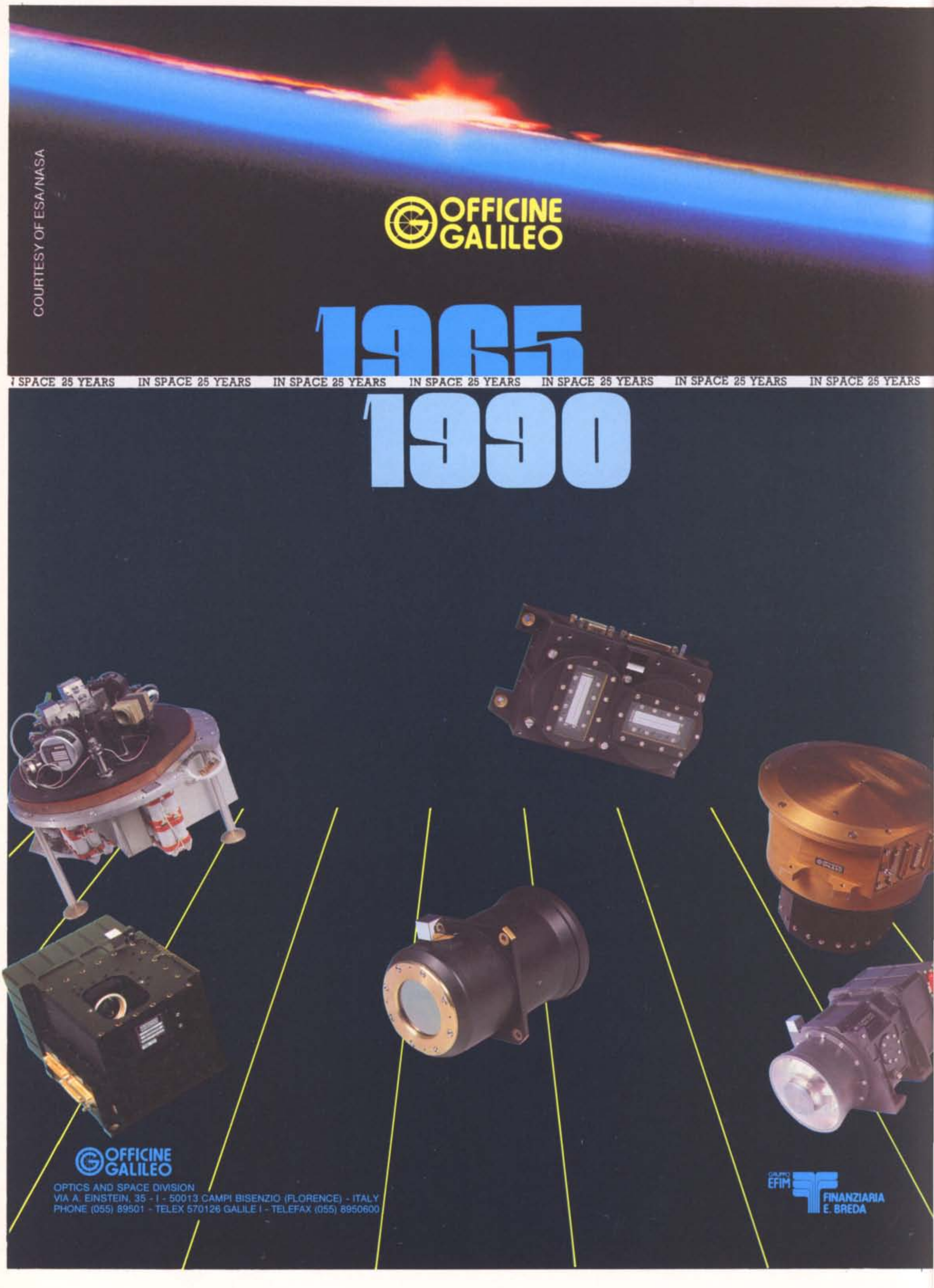
Jupiter's role is similar to that of a hand rail when descending a flight of stairs quickly. Imagine that you are running along a corridor and want to go down a flight of stairs at right angles to that corridor; you would grab hold of the rail to swing yourself into position. The force applied by the grabbing causes an abrupt change in your direction; Jupiter's gravity will do the same for Ulysses. To make the analogy even stronger, one can visualise replacing the rail by a human hand able to pull on the grabbing hand of the passing traveller. Of course, the angle of approach must be correct, the approach speed must be high, but not too high, and the hand must hold on long enough, but not too long, or disaster will occur. Ulysses' approach to Jupiter must be planned with comparable high precision.

Ulysses will be targetted so that it approaches Jupiter from the north. When it arrives in February 1992, the planet's gravity will pull the spacecraft with a force (always directed towards the planet's centre) that will cause it to swing south and out of the ecliptic plane. From this point on, Ulysses will come under the control of the Sun's gravity and orbit like a planet, except that it will move in a plane perpendicular to the ecliptic.

In mid-1994 Ulysses will be about 2 AU above the Sun's south pole, and about a year later it will pass over its north pole at approximately the same distance. Once past Jupiter, there will be no way of changing Ulysses' out-of-ecliptic orbit. Accurate targetting of the trajectory prior to the Jupiter encounter is therefore vital in order to achieve the orbit that will fulfil the scientists' wishes. They would like Ulysses to spend the maximum possible time over each polar region, in order, for example, to collect a large sample of the cosmic-ray particles entering the heliosphere along the polar field lines. They would also like the spacecraft to reach as high a latitude as possible, in order to get above the polar coronal holes. In total, Ulysses is expected to spend more than 200 days, corresponding to about eight solar rotations, at heliographic latitudes in excess of 70° and to reach a peak latitude of about 80°.

Conclusion

Ulysses will allow us, if only figuratively, to escape the confines of the two-dimensional ecliptic plane for the first time and thence to investigate the mysteries of the high-latitude regions over the Sun's poles. Not only do scientists expect to learn a great deal about the solar atmosphere and its continual battle with arriving cosmic radiation, but this first three-dimensional study of a star and its environs should provide valuable clues for the understanding of the behaviours of distant stars and of astronomy on a cosmic scale.



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The Ulysses Scientific Payload*

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Introduction
The primary objective of the Ulysses mission is to explore the interplanetary medium away from the plane of the ecliptic and over the poles of the Sun. The investigations to be performed using the scientific payload on board Ulysses encompass studies 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 interplanetary energetic particles and galactic cosmic rays and the interstellar/interplanetary neutral gas and dust, all as a function of solar latitude.

The Ulysses spacecraft carries nine hardware experiments, each provided by an international team of scientists headed by a Principal Investigator.

This scientific payload, which has a combined weight of 55 kg, includes many 'third-generation' instruments that have been designed to provide the best possible performance in their respective fields. A schematic of the payload layout is shown in Figure 1 and a summary of the investigations is presented in Table 1. Besides the onboard experiments, the spacecraft and ground communication systems will be used to conduct radio-science investigations at certain times during the mission. In addition, interdisciplinary studies will be undertaken using data from more than one Ulysses experiment to address specific questions in out-of-ecliptic science.

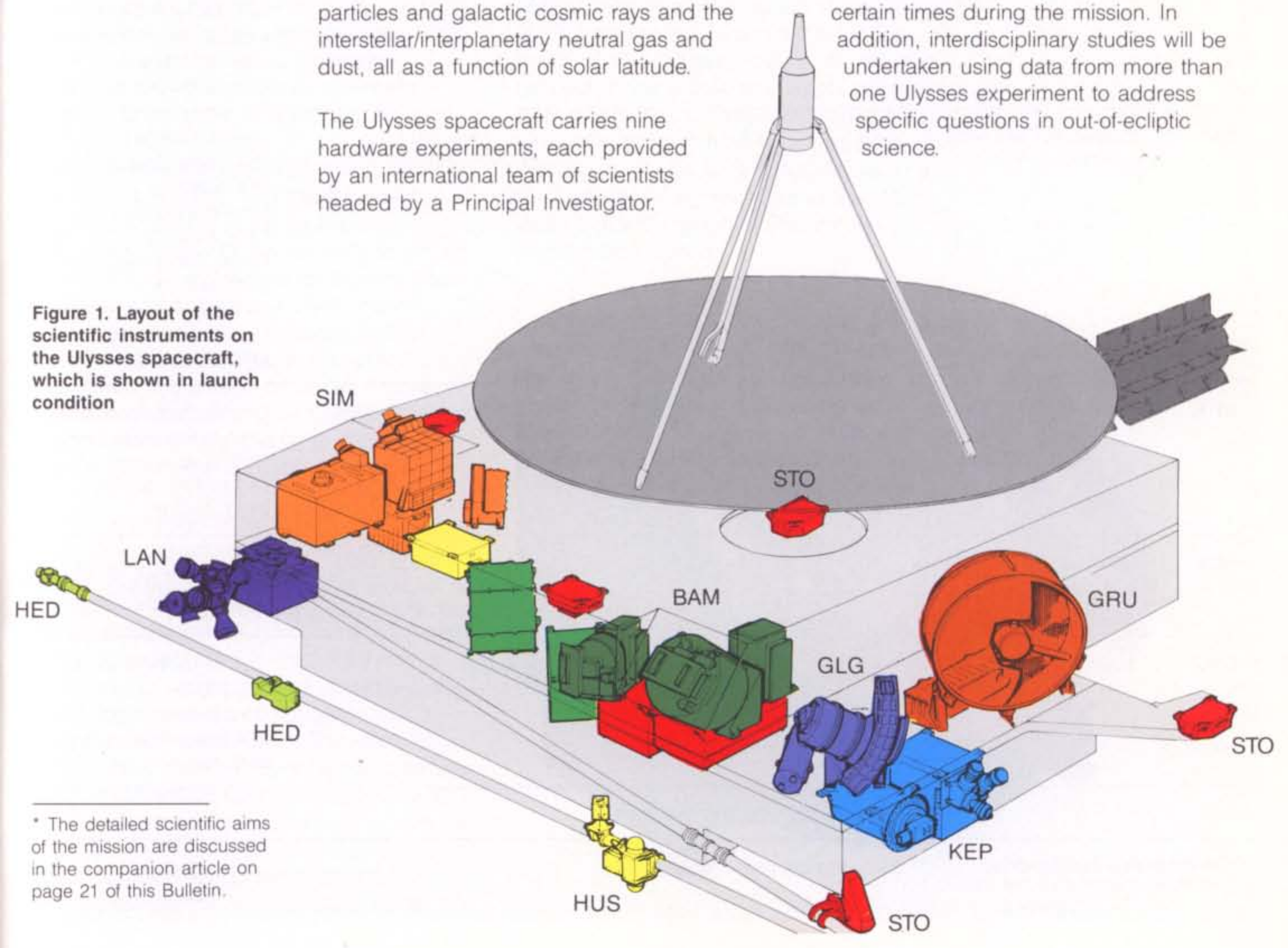


Figure 1. Layout of the scientific instruments on the Ulysses spacecraft, which is shown in launch condition

* The detailed scientific aims of the mission are discussed in the companion article on page 21 of this Bulletin.

Table 1. The Ulysses scientific payload

Expt. code	Measurement	Mass (kg)	Power (W)	Data rate (bit/s)*	Principal Investigator	Collaborating Institutes
BAM	Solar-wind plasma	6.7	5.5	160	S.J. Bame, Los Alamos National Lab. (USA)	Ames Res. Center (USA) JPL (USA) HAO, Boulder (USA) UCLA (USA) MSFC (USA) MPAe, Lindau (D)
HED	Magnetic field	4.8	5.1	80	A. Balogh, Imperial College, London (UK)	JPL (USA)
GLG	Solar-wind ion composition	5.5	4.0	88	G. Gloeckler, Univ. of Maryland (USA) J. Geiss, Univ. of Bern (CH)	Univ. of New Hampshire GSFC (USA) TU Braunschweig (D) MPAe, Lindau (D) NASA HQ (USA)
KEP	Energetic particles and interstellar neutral gas	4.3	4.0	16	E. Keppler, MPAe, Lindau (D)	Imperial College (UK) Inst. Space Phys., Kiruna (S) Aerospace Corp., LA (USA) Univ. of Bonn (D) MPE, Garching (D)
LAN	Low-energy charged particles	5.8	4.0	160	L.J. Lanzerotti, Bell Laboratories (USA)	UCB (USA) Univ. of Kansas (USA) APL, Laurel (USA) Obs. de Paris, Meudon (F) Univ. of Thrace (Gr) Univ. of Birmingham (UK)
SIM	Cosmic rays and solar particles	14.8	14.8	160	J.A. Simpson, Univ. of Chicago (USA)	Imperial College (UK) ESA Space Science Dept. NRC (Can) Univ. of Kiel (D) CEN, Saclay (F) Danish Space Res. Inst. NCR, Milan (I) MPK, Heidelberg (D) Univ. of Maryland (USA) MPAe, Lindau (D)
STO	Radio and plasma waves	7.4**	10.0	232	R.G. Stone, GSFC (USA)	Obs. de Paris, Meudon (F) Univ. of Minnesota (USA) NLR, Washington (USA) CNET/CRPE, Issy (F) INSU, Paris (F)
HUS	Solar X-rays and cosmic γ-ray bursts	2.0	2.6	40	K.C. Hurley, UCB (USA) and CESR, Toulouse (F) M. Sommer, MPE Garching (D)	Obs. de Paris, Meudon (F) SRON, Utrecht (NL) GSFC (USA)
GRU	Cosmic dust	3.8	2.2	8	E. Grün, MPK, Heidelberg (D)	Univ. of Canterbury (UK) JSC (USA) Univ. of Bochum (D) ESA Space Science Dept. MPE, Garching (D)
Total		55.1	52.2	944		

* In spacecraft tracking mode   ** Excluding antennas

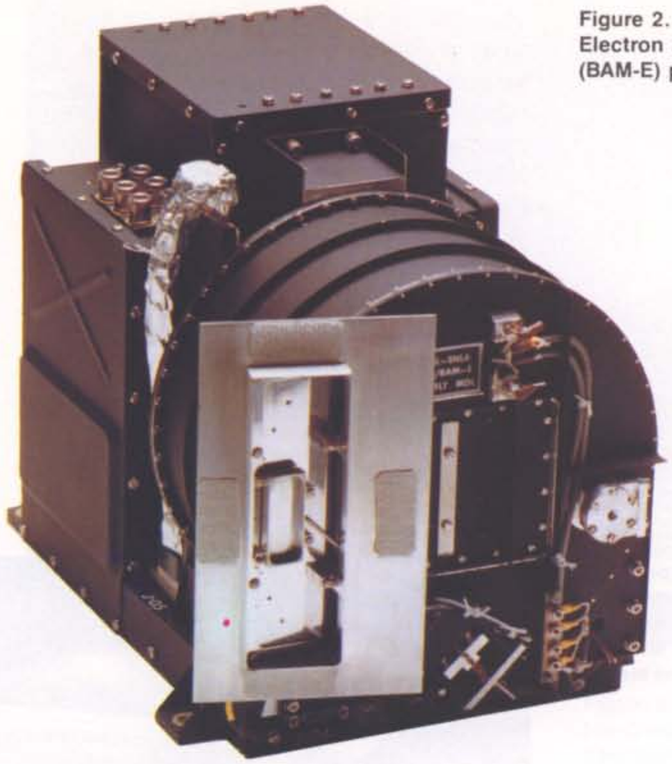


Figure 2. The Solar-Wind Electron Experiment (BAM-E) package

The scientific experiments

The Solar-Wind Plasma Experiment (BAM)

An accurate picture of the solar-wind flow at middle-to-high solar latitudes is one of the key building blocks needed to construct a representative model of the heliosphere. The Solar-Wind Plasma Experiment will measure the bulk flow parameters (density, flow speed and direction) of the solar wind in three dimensions at all heliocentric distances and heliographic latitudes reached by the spacecraft. Since the solar-wind plasma consists of two different components (electrons and positive ions, i.e. protons, alpha particles and heavier species), two separate instruments are needed to make simultaneous and independent measurements. Each instrument makes use of a curved-plate electrostatic analyser equipped with a number of Channel Electron Multipliers (CEMs). The CEMs are arranged so that particle velocity distributions can be resolved for all orientations of the spacecraft spin axis. Electrons with energies between 1 and 900 eV will be detected, while the corresponding measurement range for ions is 257 eV/Q to 35 keV/Q.

The experiment hardware consists of two independent packages which are mounted inside the spacecraft body for thermal protection, with their entrance apertures exposed to the external space environment.

The solar-wind electron experiment (BAM-E) is shown in Figure 2, and the solar-wind ion experiment (BAM-I) in Figure 3. Both instruments consist of a drum-shaped sensor and associated rectangular electronics box. The sensor contains the analyser plates, CEMs and amplifier-discriminator circuits, whereas the electronics box contains the logic cards, low-voltage converter, analyser-plate voltage supplies, CEM high-voltage supply, and interface circuits to the spacecraft power and data subsystems.

The ion instrument incorporates a stepper-motor-driven aperture wheel with seven apertures. As the heliocentric distance changes during the mission, appropriate entrance apertures will be commanded into place. To protect the ion instrument from contamination during ground operations, the wheel has a blanking-off capability which seals the entrance aperture. The electron instrument is protected by a hinged aperture cover which will be opened in space by a small pyrotechnic device.

The Magnetic-Field Experiment (HED)

The objective of the magnetic-field experiment is to establish, on the basis of in-situ observations, the helio-latitude dependence of the interplanetary magnetic field. The structure and characteristics of the magnetic field out of the ecliptic are largely unknown. Knowledge of its topology and dynamic properties in the third, unexplored heliographic dimension is of direct interest to the study of solar magnetism, as well as to the study of a wide range of phenomena in interplanetary space.

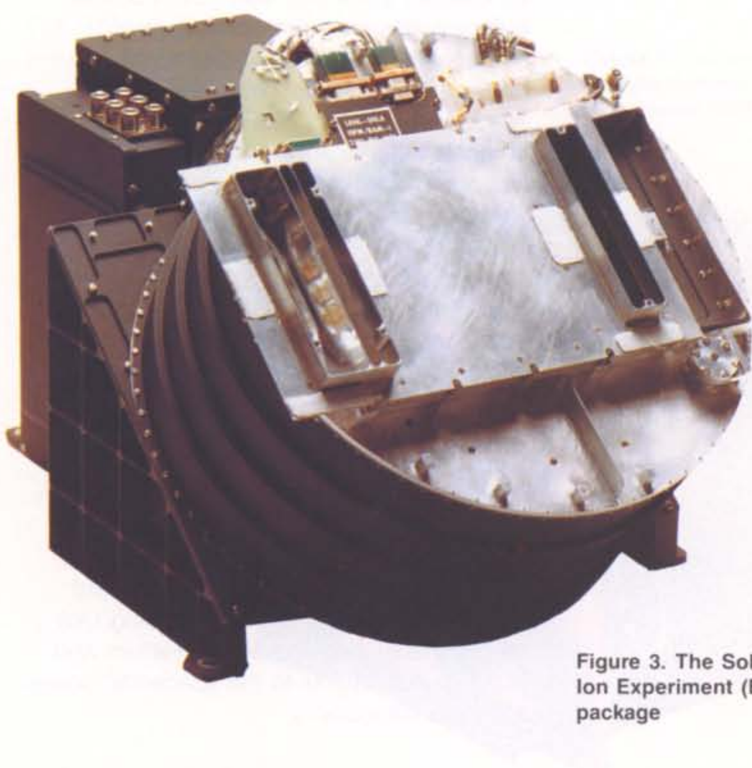


Figure 3. The Solar-Wind Ion Experiment (BAM-I) package

Magnetic fields will be measured by two types of magnetometers – the Fluxgate Magnetometer (HED-3) and the Vector Helium Magnetometer (HED-4) – mounted externally to the spacecraft body on a boom which is deployed in space. This location is necessary to eliminate, as far as possible, the magnetic effects of the spacecraft on the very sensitive instruments, which have a resolution of 4 pT in their most sensitive range. The experiment hardware is shown in Figure 4.

The Vector Helium Magnetometer measures magnetic fields by their effect on the efficiency with which metastable helium can be optically pumped. Changes in optical pumping efficiency are dependent on magnetic-field intensity and its angle with respect to the optical axis of the sensor. Associated with the Vector Helium Magnetometer is an electronics box HED-2 (not shown), located within the spacecraft thermal enclosure, which drives the sensor coils and processes the signals from the sensors, generates in-flight calibration currents, controls the instrument operating modes and prepares the science and engineering data inputs to the Data-Processing Unit.

The Fluxgate Magnetometer is based on three ring-core fluxgate sensors arranged in an orthogonal triad. Associated with this sensor is another electronics box HED-1 (not shown) which contains the on-board analogue and digital Data-Processing Unit and interfaces both the Vector Helium and Fluxgate instruments to the spacecraft power and data subsystems.

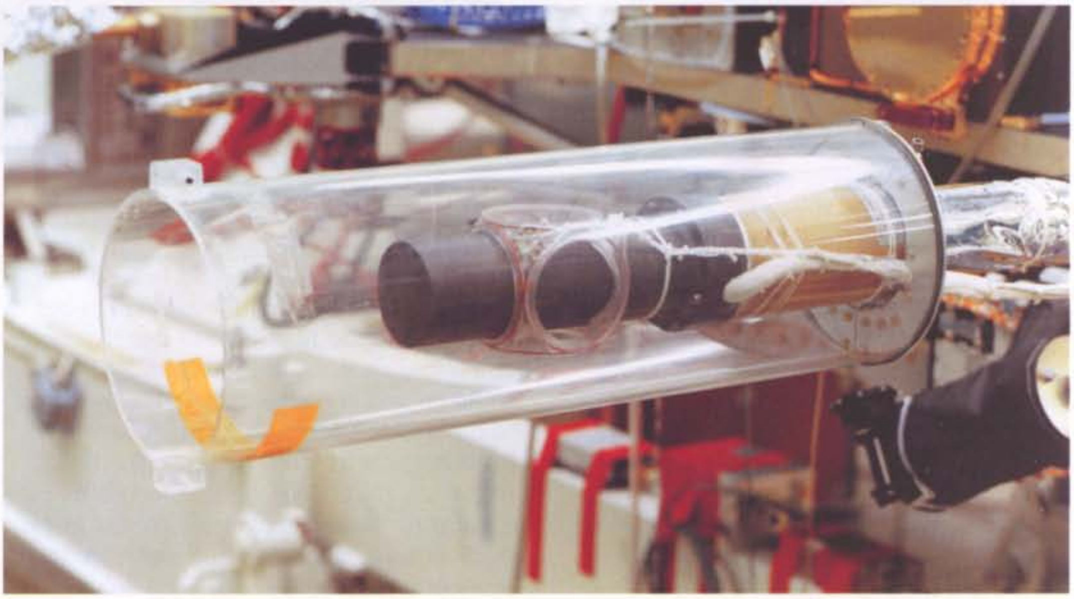


Figure 4. The Vector Helium Magnetometer (HED-4) sensor, surrounded by a protective shield used during ground testing

The Solar-Wind Ion-Composition Experiment (GLG)

The Solar-Wind Ion-Composition Spectrometer will measure the chemical and ionic-charge composition of solar-wind ions, as well as their temperatures and mean speeds. The measurements made by this instrument will have an impact on many areas of Ulysses science. Some of the questions to be addressed using data from GLG are:

(a) Where in the corona does the solar wind originate?
(b) How is the corona heated?
(c) Does the composition of the solar atmosphere vary on a global scale?

All major solar-wind ions from hydrogen (H) through iron (Fe) will be detected, at solar-wind speeds ranging from 145 km/s (protons) to 1352 km/s (Fe^{+8}). The physical parameters that are measured by the instrument, which comprises an electrostatic analyser followed by a time-of-flight telescope and solid-state detectors, are ion energy per charge, mass and total energy. By combining the speed and total energy signals, a value for the atomic mass of the ion is computed. By combining the energy per charge and total energy values, the ionisation state of the particle can also be determined.

This experiment consists of three separate but electrically connected packages. The sensor (GLG-2A) shown in Figure 5 consists of the fan-shaped collimator enclosing the electrostatic deflection system and its voltage supply, and the attached drum-shaped high-voltage bubble to which a post-acceleration voltage up to −30 kV can be applied. This bubble contains the time-of-flight telescope, proton/alpha detector, analogue electronics and sensor power supplies. The cylindrical unit (GLG-2B) also shown in Figure 5 is the −30 kV power supply.

The sensitive internal components of the sensor are protected against contamination and acoustic damage by a hinged cover, which can be opened in space by firing a pyrotechnic release device.

The basic data provided by the sensor are fed into the Data-Processing Unit (GLG-1) contained in a rectangular box (not shown) for on-board processing. GLG-1 also provides the interface to the spacecraft power and data subsystems.

The GLG-2A/2B units are mounted externally on the spacecraft and enclosed in multilayer blankets for thermal protection. GLG-1 is mounted inside the spacecraft thermal enclosure.

The Energetic-Particle and Interstellar Neutral-Gas Experiment (KEP)

The KEP instrument consists of two independent sensor systems: the Energetic-Particle Composition Experiment (EPAC) and the neutral-gas (GAS) instrument. The first experiment will measure the intensities, anisotropies, composition and energy spectra of energetic interplanetary ions in the energy range 0.4–15 MeV/n, while the second is designed to make direct observations of interstellar neutral helium atoms that have penetrated the heliosphere. The latter experiment was originally to be flown on the NASA satellite of the dual-spacecraft ISPM mission, but after the cancellation of the US spacecraft it was incorporated into Ulysses' payload by interfacing it closely with the EPAC instrument.

The energetic-particle composition measurements made by EPAC will be used to study the acceleration and transport of low-energy ions of both solar-flare and interplanetary origin, with particular emphasis on their characteristics at high solar latitudes.

The EPAC unit consists of a four-telescope detector system (KEP-2) mounted on an associated analogue electronics box (KEP-1), which also incorporates the Data-Processing Unit and interfaces to the spacecraft power and data systems. This assembly is shown in Figure 6. Each telescope contains one epitaxial detector and two surface-barrier detectors. The four telescopes are arranged such that between them they cover 80% of a full sphere per spacecraft spin. The complete telescope assembly is thermally isolated from its electronics box and projects through the spacecraft thermal enclosure.

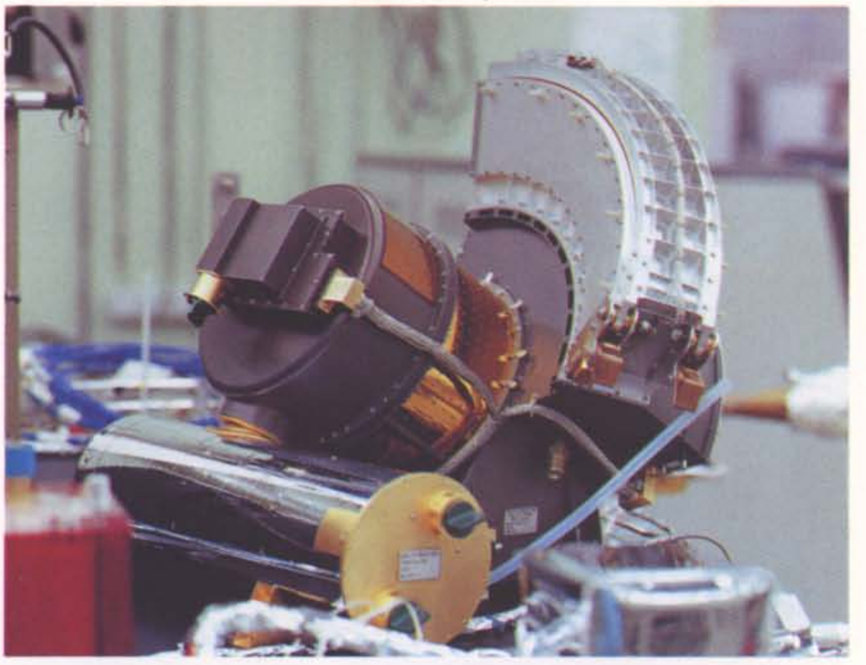


Figure 5. The Solar-Wind Ion-Composition Spectrometer (GLG-2)

The properties (density, bulk velocity relative to the solar system, and temperature) of the local interstellar gas, represented by neutral helium atoms penetrating the heliosphere, will be measured directly for the first time by the Ulysses GAS experiment. The neutral particles are detected via the secondary electrons or ions that are emitted when the helium atoms impact on a special target coated with lithium fluoride (LiF).

The GAS experiment hardware (see Fig. 7) consists of a sensor incorporating the LiF-

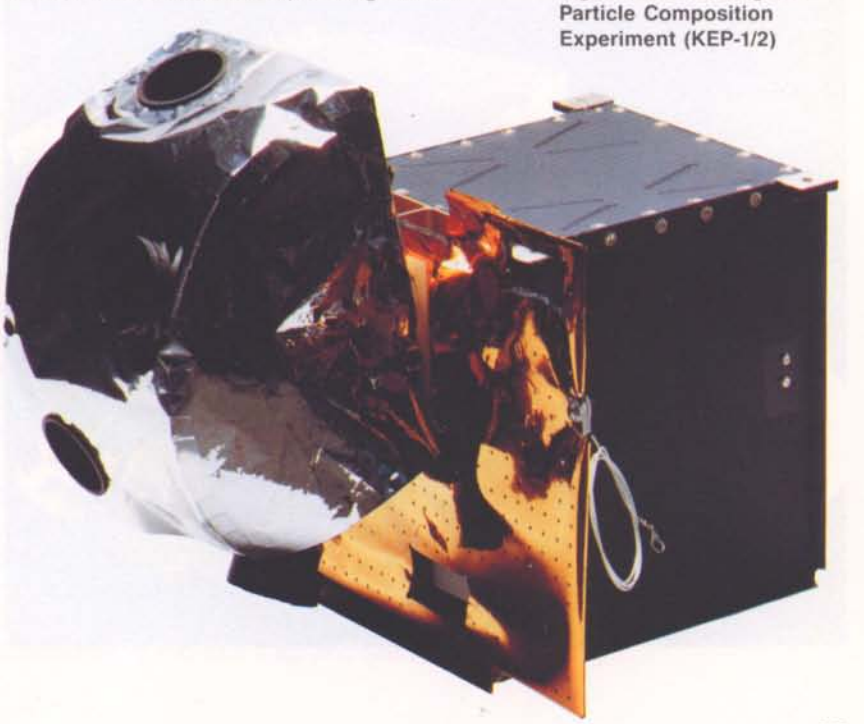


Figure 6. The Energetic-Particle Composition Experiment (KEP-1/2)

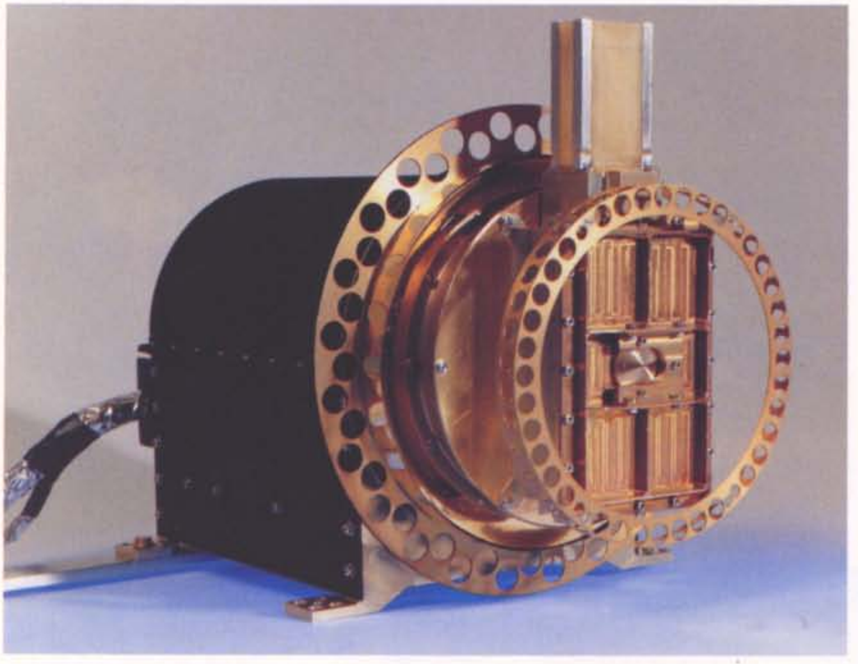
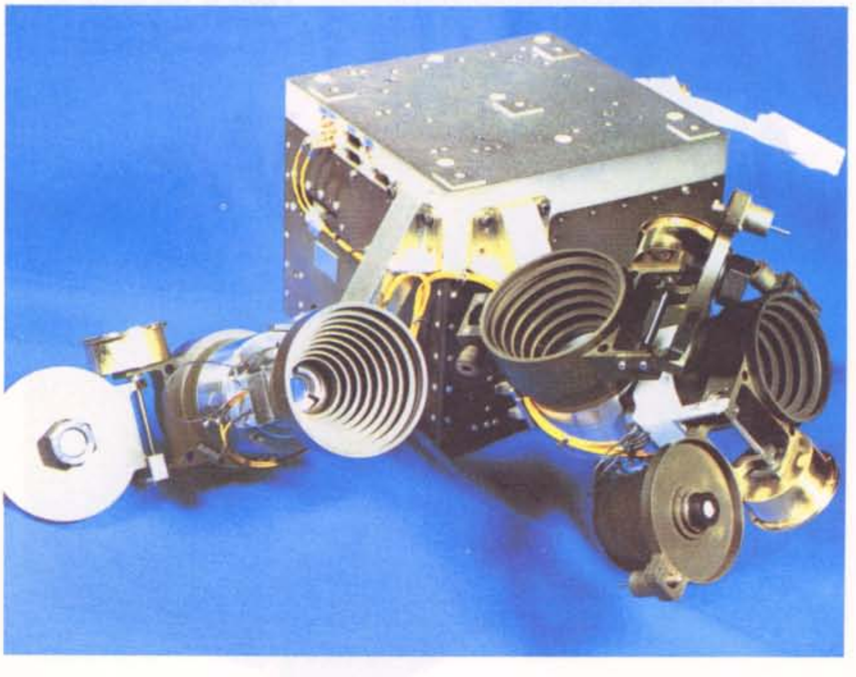


Figure 7. The Interstellar Neutral Gas Experiment (KEP-3) mounted on its rotating platform. The circular frames are thermal-blanket supports

Figure 8. The Low-Energy Charged-Particle Experiment (LAN-1/2), showing the multiple telescope apertures and cover mechanisms

coated conversion surface and Channel Electron Multipliers (CEMs) as detector elements. Also included is a tiny furnace that will be used to deposit fresh layers of LiF in the event of contamination during flight. The sensor is sealed until after launch, when it is opened to the space environment by an electrically operated cover attached to the collimator. This whole assembly is mounted on a rotating platform (KEP-3B) with a scan angle of 180°, and is mechanically attached to an associated electronics box (KEP-3A). This latter unit contains the control system for the rotating platform, power converters, housekeeping of analogue and digital data and interface circuitry to both the KEP-1 unit and the spacecraft power and data systems.



The Low-Energy Charged-Particle Experiment (LAN)

This experiment, which addresses the same general area of charged-particle physics as the KEP/EPAC instrument discussed above, will obtain measurements of interplanetary ions and electrons at the lowest energies covered by the suite of energetic-particle experiments on-board Ulysses. Ions at energies greater than 50 keV and electrons above 30 keV are detected by five separate solid-state detector telescopes oriented to give essentially complete pitch-angle coverage from the spinning Ulysses spacecraft. Two of the telescopes contain magnets that prevent low-energy electrons from reaching the detectors, permitting clean ion measurements. Thin aperture foils that stop low-energy ions but allow electrons to pass freely are included in the third and fourth telescopes. The fifth telescope, incorporating three detector elements, will perform ion-composition measurements. Experiment operation is controlled by a microprocessor-based data system.

The five detector systems are contained within two mechanical structures (LAN-2A and LAN-2B) which are mounted onto a box containing the instrument electronics (LAN-1). This assembly is shown in Figure 8. Three of the five telescope apertures are protected by hinged covers which are opened in space by pyrotechnic devices. These covers contain weak radioactive sources and they can be closed in orbit to provide calibration stimuli to the detectors.

The electronics package contains the analogue and digital circuitry, power converters, and control electronics for the cover opening/closing mechanism. It also contains the interfaces to the spacecraft power and data subsystems.

The Cosmic-Ray and Solar-Particle Experiment (SIM)

The cosmic-ray and solar-particle investigation is the third energetic-particle experiment included in the Ulysses payload. As in the case of KEP/EPAC and LAN, measurements will be made of solar and interplanetary particles in order to characterise their intensities, energy spectra, anisotropy and composition as a function of solar latitude. The SIM instrumentation, which comprises five solid-state detector telescopes and a double Cerenkov/semiconductor telescope, will cover a somewhat higher energy range than the other experiments (0.3–600 MeV/n for nuclei and 1–300 MeV for electrons, with integral measurements to higher energies). In addition, one of the telescopes will provide measurements of the isotopic composition of galactic cosmic-ray nuclei up to iron, with a view to gaining insight into the origin and interstellar and heliospheric transport of these particles.

The complete instrumentation is packaged in five units, electrically interconnected, mounted within the spacecraft thermal enclosure and viewing space through appropriate apertures. Figure 9 shows the SIM units mounted on the spacecraft platform.

The SIM-1 unit comprises the two Anisotropy Telescopes (AT), the Low-Energy Telescope (LET) and the Data-Processing Unit (DPU). Each AT consists of a stack of three surface-barrier detectors, and the two telescopes have different viewing directions. The LET is a four-element solid-state detector telescope surrounded by a cylindrical plastic scintillator anti-coincidence shield. The LET telescope aperture is protected by a hinged cover which is opened in orbit by small pyrotechnic devices. The SIM-1 unit also incorporates the LET and AT analogue and digital electronics and the user interface units. These provide an interface between each detector system and the DPU, which is the interface to the spacecraft data-handling subsystem for the complete experiment.

The SIM-2 unit contains the High-Energy Telescope (HET) and the High-Flux Telescope (HFT). The HET is comprised of a stack of Li-drifted silicon detectors surrounded by a plastic scintillator, and analogue and digital electronics which together account for most of the SIM-2 volume. Attached to the top of the SIM-2 package is the small HFT telescope, which incorporates a single silicon detector and associated front-end electronics. Both HET and HFT are protected from contamination by hinged aperture covers, which are opened in space by small pyrotechnic devices.

The SIM-3 unit consists of two separate packages: SIM-3B, which houses the Kiel Electron Telescope (KET), and SIM-3A which is the KET electronics. The KET telescope incorporates a Cerenkov detector inserted between two surface barrier semi-conductor detectors, and four photomultiplier tubes.

Power for the SIM packages is provided by a separate converter package (SIM-4), which provides each of the other SIM units with secondary voltages derived from the spacecraft's +28 V bus. This unit is not visible in Figure 9.

The Radio and Plasma-Wave Experiment (STO)

The Ulysses Radio and Plasma-Wave experiment is designed detect both distant radio emissions (via remote sensing), as well as locally-generated plasma waves. By tracking solar radio noise bursts as they travel away from the Sun, insight can be gained into the large-scale structure of the heliospheric magnetic field and solar-wind flows. In-situ plasma-wave measurements will, on the other hand, provide a diagnostic tool for studying the local properties of the solar wind along the spacecraft trajectory. Due to

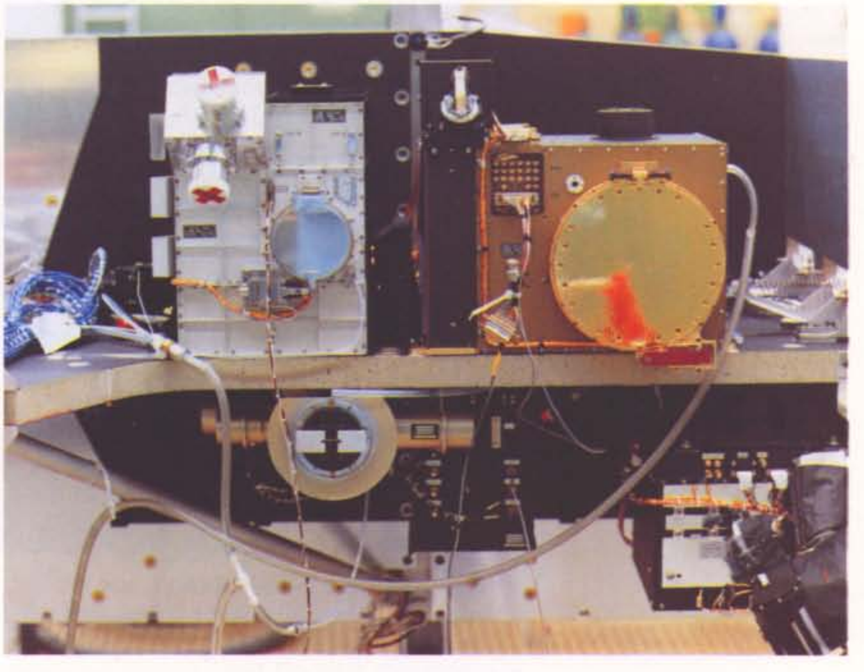


Figure 9. The Cosmic-Ray and Solar-Particle Experiment (SIM) mounted on the spacecraft platform. In this view, three of the five instrument packages are visible: SIM-1 (above left), SIM-2 (above right) and SIM-3B (below left)

the high sensitivity of the STO receivers, a special effort has been made on the Ulysses spacecraft as a whole to achieve an interference-free electromagnetic environment.

The antennas used by this experiment are provided by the spacecraft, and consist of a pair of wire booms (72 m tip-to-tip) lying in the spacecraft spin plane and forming a dipole, and an axial boom (8 m long) which forms a monopole antenna along the spacecraft spin axis. Both wire booms and monopole antenna are stowed on drums within the spacecraft during launch and are deployed in orbit under stepper-motor control.

Instrumentation supplied by the experiment group consists of three electric-field preamplifiers (STO-3A/3B/4) located at the root of each antenna and shared by the radio and plasma-wave experiments. Additionally, a two-axis magnetic-search-coil antenna (STO-6) is located on the spacecraft radial boom, which also has its own preamplifier (STO-5) located at the boom root. Main electronics packages for this experiment are located inside the spacecraft thermal enclosure, and consist of the STO-1 package containing the DC/DC converters, radio-astronomy receivers and programmer, and the STO-2 package containing the plasma frequency receiver, fast envelope sampler and Data-Processing Unit. Spacecraft +28 V power is supplied to the STO-1 unit and distributed to other locations after conversion, whereas STO-1 and STO-2 each have independent interfaces to the spacecraft data system.

The Solar-Flare X-Ray and Cosmic Gamma-Ray Burst Experiment (HUS)

This Ulysses experiment will measure the intensity and the spectral characteristics of X- and gamma-ray bursts of solar and cosmic origin. The solar X-ray data will provide information on the processes occurring at the time of solar flares, and particularly concerning the energetic electrons that are produced at the flare site. The gamma-ray data will be used, together with measurements from similar instruments on other spacecraft, to localise the sources of bursts of high-energy photons that reach the solar system from distant reaches of the Galaxy, and whose precise origin is as yet unknown. In addition, the instrument will serve a solar-flare patrol function, and will attempt to detect the recently discovered Jovian X-ray emission during the Jupiter flyby.

The experiment consists of a gamma-ray sensor (HUS-2A) and a soft X-ray sensor (HUS-2B) mounted on the spacecraft radial boom, and a Data-Processing Unit (HUS-1) mounted inside the spacecraft thermal enclosure. The gamma-ray sensor shown in Figure 10 (left) consists of two hemispherical CsI scintillation crystals coupled to photomultiplier tubes arranged such as to have a nearly unobstructed 4π field of view and measure X- and gamma-rays in the energy range 15–150 keV. The sensor housing also encloses the electronics associated with the detectors. The soft X-ray sensor (Fig. 10, right) is designed to detect solar X-rays in the energy range 5–15 keV and consists of two Si surface-barrier detectors and front-end electronics passively cooled to −50°C in order to keep the background electronic noise as low as possible.

The Data-Processing Unit (not shown) is enclosed in a rectangular box and incorporates the data-processing electronics associated with both sensor units and provides the interfaces to the spacecraft power and data systems.

The Cosmic-Dust Experiment (GRU)

This experiment will measure the properties of cosmic dust particles in the solar system. These tiny particles have masses typically in the range 10^{-19} to 10^{-10} kg, and have three probable sources: comets, asteroids and interstellar grains. Studies of the so-called 'zodiacal light', which is due to sunlight that is scattered off the interplanetary dust cloud, have provided a picture of the large-scale distribution of these particles. The GRU experiment on Ulysses will detect individual dust grains, taking advantage of the spacecraft's unique trajectory to map their distribution away from the ecliptic plane. The instrument, which is an impact plasma detector, characterises each particle by measuring its mass, speed, flight direction and electric charge. The instrument hardware consists of a large hemispherical sensor (GRU-2), shown in Figure 11, and a Data-Processing Unit (GRU-1) not shown.

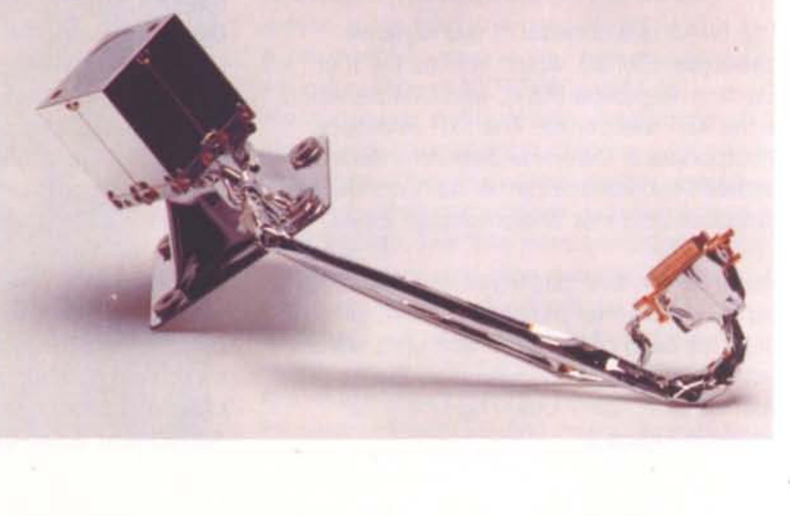


Figure 10. Sensor units for the Solar-Flare X-Ray and Cosmic Gamma-Ray Burst Experiment.
Left: the gamma-ray sensor (HUS-2A).
Right: the soft X-ray sensor (HUS-2B)

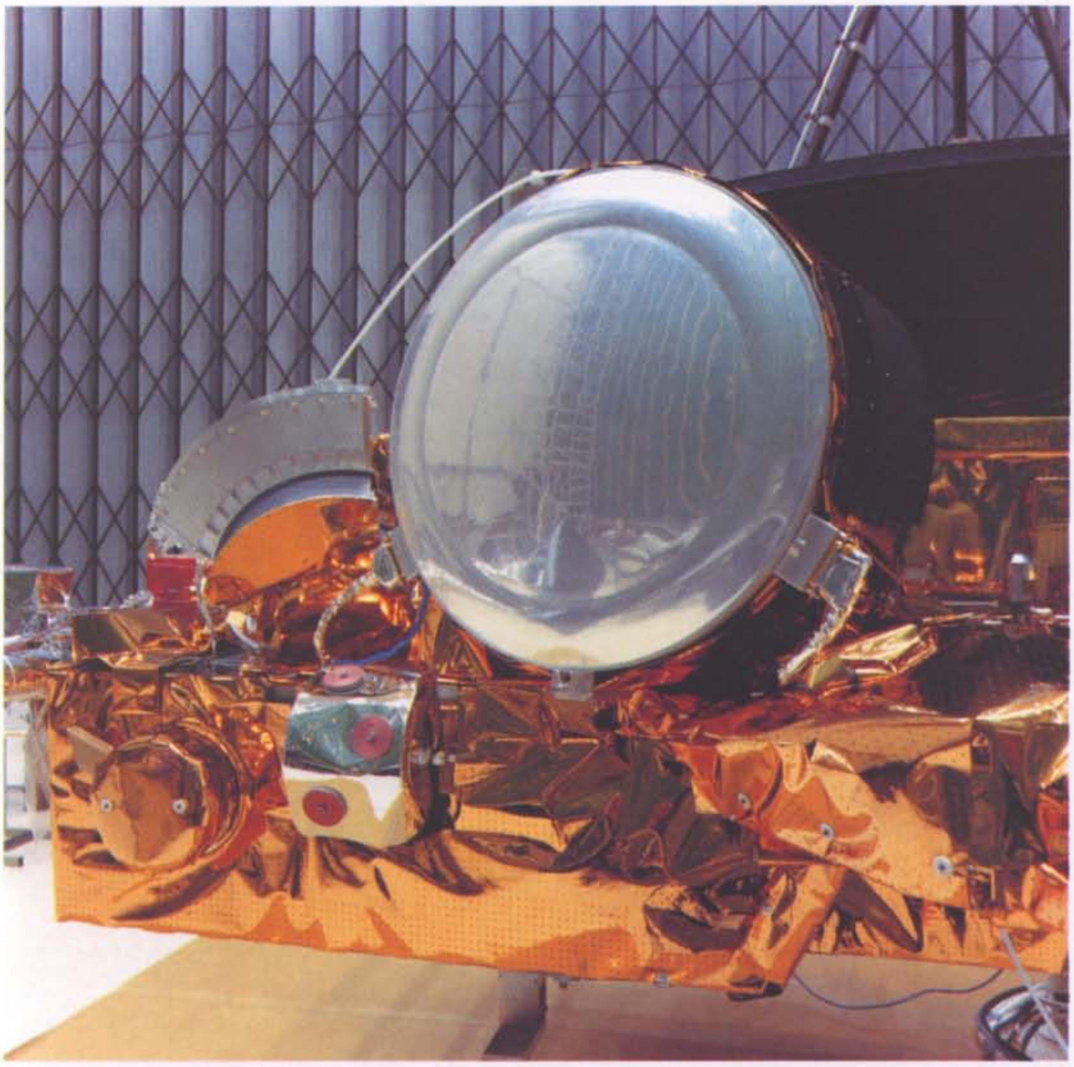


Figure 11. A view of the −X wing of the Ulysses spacecraft, dominated by the large circular cover of the Cosmic Dust Experiment (GRU). Also visible are the KEP and GLG packages enclosed in their thermal blankets

The sensor is made up of a grid system for the measurement of particle charge, an electrically grounded, gold-plated target (hemisphere) and a negatively biased ion collector. The small central module contains a channeltron and associated preamplifiers. The sensor is mounted externally on the spacecraft body and is thermally protected by multilayer blankets. For protection against ground contamination and launcher-induced acoustic noise, the sensor incorporates a large disc-shaped cover which is ejected in orbit.

The Data-Processing Unit, mounted inside the spacecraft thermal enclosure, contains the sensor signal conditioning and analysing circuits, an internal test generator for calibration purposes, and the interfaces to the spacecraft power and data subsystems.

The Radio-Science Experiments

Two radio-science experiments are being carried out with the Ulysses spacecraft by making use of the spacecraft and ground communication equipment.

The Ulysses Solar-Corona Experiment (SCE) will conduct coronal sounding using dual-frequency ranging and Doppler measurements during times of superior conjunction in order to determine the electron density and solar-wind velocity in the solar corona. There are also unique opportunities for mapping the electron content of the high-latitude heliosphere. During occultation of the spacecraft by Io, one of Jupiter's moons, there will be an opportunity to determine the electron content of the moon's plasma torus by Doppler measurement.

The Gravitational-Wave Experiment (GWE) will attempt to search for low-frequency, wide-band gravitational waves, thought to be emitted by various sources throughout the Universe. Gravitational waves could be of two types: pulses coming from catastrophic events in the nuclei of galaxies and quasars, and a continuous isotropic background that possibly originated in the early phases of the Universe. If exposed to a burst of gravitational waves, the Ulysses spacecraft will experience a minute perturbation in its orbital velocity, which in turn will produce a

Table 2. The Ulysses radio-science and interdisciplinary investigations

Expt. Code	Measurement/investigation	Principal Investigator	Collaborating Institutes
SCE	Coronal sounding (radio science)	H. Volland, Univ. of Bonn (D)	Univ. of Bochum (D)
GWE	Gravitational waves (radio science)	B. Bertotti, Univ. of Pavia (I)	JPL (USA) Univ. of Uppsala (S) CNR, Frascati (I)
IDS/L	Directional discontinuities (interdisciplinary)	J. Lemaire Inst. d'Aeronomie Spatiale de Belgique, Brussels (B)	
IDS/N	Mass loss and ion composition (interdisciplinary)	G. Noci, Istituto di Astronomia, Florence (I)	Osservatorio Astrofisica. di Arcetri, Florence (I)

Figure 12. Ulysses Principal Investigators. From left to right: J. Geiss, K. Hurley, M. Sommer, A. Balogh, L.J. Lanzerotti, S.J. Bame, E. Grün, R.G. Stone, E. Keppler & J.A. Simpson

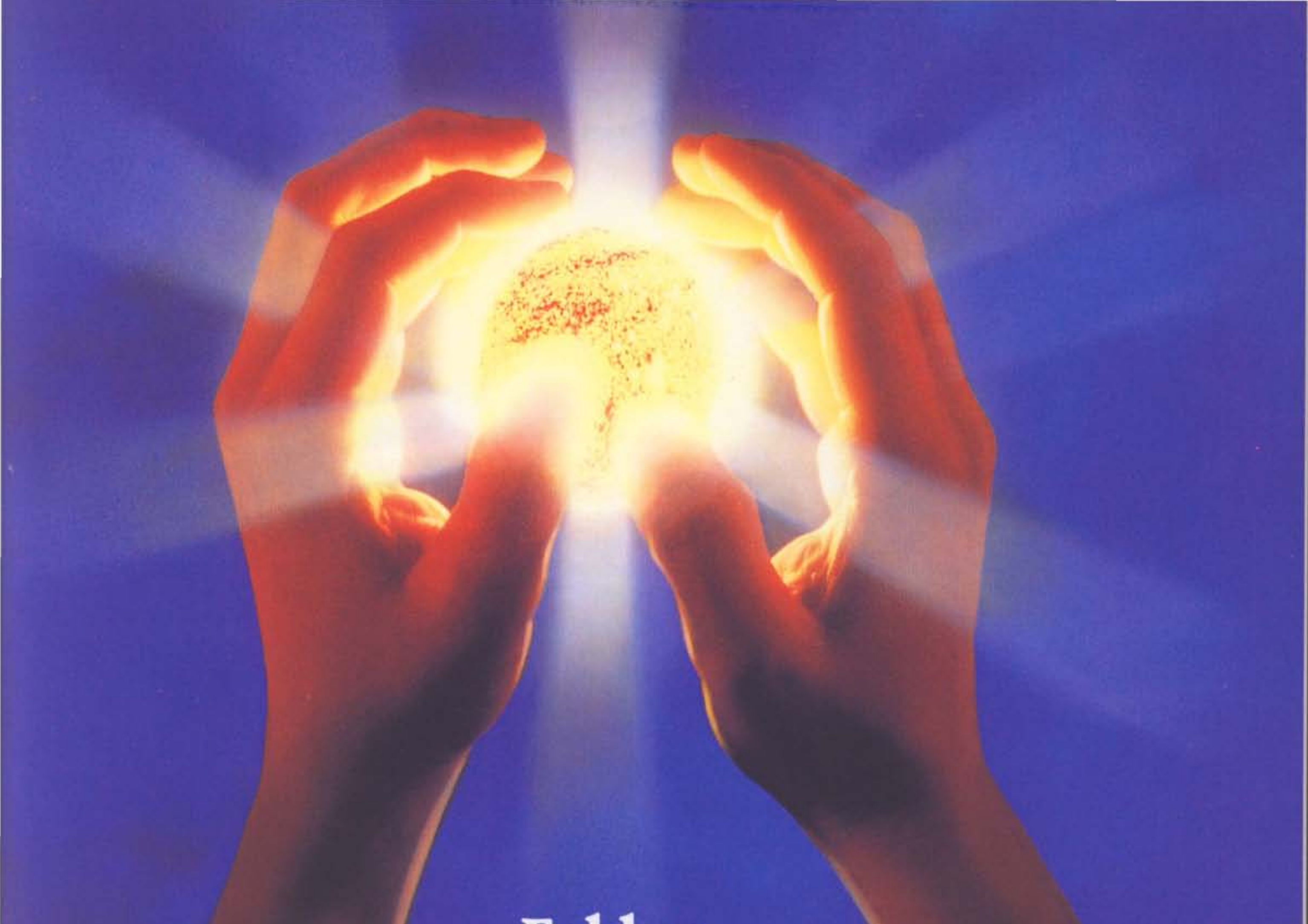
characteristic noise component in the Doppler-shifted radio signal received on the ground.

The Interdisciplinary Investigations

These investigations, although providing no hardware of their own, will combine data from several Ulysses experiments to study specific scientific questions of relevance to the mission.

The Directional-Discontinuities Investigation (IDS/L) will look at large- and small-scale plasma irregularities or inhomogeneities in the solar wind, which is not the well-behaved, uniform medium normally considered by theoreticians. Depending on the type of variation shown by the magnetic-field and plasma parameters, a directional discontinuity can be either a tangential discontinuity, a shock, or a true rotational discontinuity. New theoretical models of these phenomena will be developed as part of the Ulysses investigation, and the magnetic-field and plasma observations obtained by Ulysses will be used to check these models and identify fundamental plasma-physical processes.

The Mass-Loss and Ion-Composition Investigation (IDS/N) will study the dependence of coronal mass loss on heliographic latitude, with a view to improving the understanding of the energy and momentum balance of the outer layers of the Sun. Secondly, a search will be made for a latitudinal dependence of the solar-wind ion composition.



The Ulysses Spacecraft

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Introduction

The Ulysses spacecraft's system design is the result of a complicated set of requirements driven by the fundamental objective of an out-of-ecliptic orbit. These design requirements can be subdivided into 'primary drivers', which are features essential to the mission, and imposed 'secondary drivers', which are features essential to meeting the mission with the technology available at the time when development started in 1978. A further problem that needed to be taken into consideration in the design was the fact that the Space Shuttle was then still several years away from its first launch, and the Upper Stage that would be needed to inject the spacecraft onto its interplanetary trajectory was only in an early design phase.

The primary system-design drivers are:
- out-of-ecliptic orbit
- experiment complement and requirements (field of view, scanning, electromagnetic compatibility).

Direct injection into the out-of-ecliptic orbit requires a launch vehicle vastly more powerful than any currently available. The electromagnetic-compatibility (EMC) requirements from the Ulysses experiments are both wide-ranging and demanding. The presence of experiment sensors for DC and AC magnetic fields, radio-frequency detectors and a number of solar-wind detectors has made EMC considerations a continuous task.

The imposed secondary drivers are:
- Jupiter flyby orbit
- spin stabilisation to meet experiment scan requirements (5 rpm selected)
- boom and antenna requirements for experiments.

There was no launch vehicle that could provide direct injection into an orbit out of the ecliptic plane. The Jupiter flyby orbit makes the mission possible with the most powerful of launchers available, but requires an aphelion of 5 AU (i.e. five times the mean distance between the Earth and the Sun) and results in a maximum spacecraft distance from Earth of 5.3 AU. The solar intensity varies from 1300 W/m^2 near Earth to 50 W/m^2 at Jupiter, which makes the use of a solar array impractical. This orbit therefore imposes the use of the Radio-isotope Thermoelectric Generator (RTG), and also gives rise to a thermal environment similar to that of continuous eclipse for a near-Earth satellite.

A further penalty from the Jupiter flyby is the radiation exposure as the satellite passes through the radiation belts trapped by the planet's magnetic fields.

The great distance of the satellite from Earth and the chosen relatively high information rate of 4 kbit/s imposes a need for an Earth-pointing antenna and use of a 20 W X-band transmitter on the spacecraft.

The constraints on the evolved physical configuration of Ulysses (Figs. 1 and 2) are listed in Table 1a, and those on the spacecraft's functional configuration in Table 1b.

Table 1a. Constraints on Ulysses' physical configuration.

1. Remote location of RTG from the experiments to reduce radiation and thermal interference.
2. High-Gain Antenna (HGA) on Earth-pointing spin axis.
3. Mass properties for spin stability.
4. Experiment location for best overall electromagnetic-compatibility (EMC) performance.
5. Rigid 5 m radial boom to place magnetometers clear of spacecraft field.
6. Boom location to avoid disturbance to spin balance.
7. Reaction-Control Equipment (RCE) location to meet manoeuvering needs without disturbing spin motion.
8. Wire booms and stiff axial boom coordinated to system axis.
9. Efficient structural layout able to accept pessimistic launch loads with considerable margin.
10. Launcher payload envelope.
11. Assembly and integration accessibility.

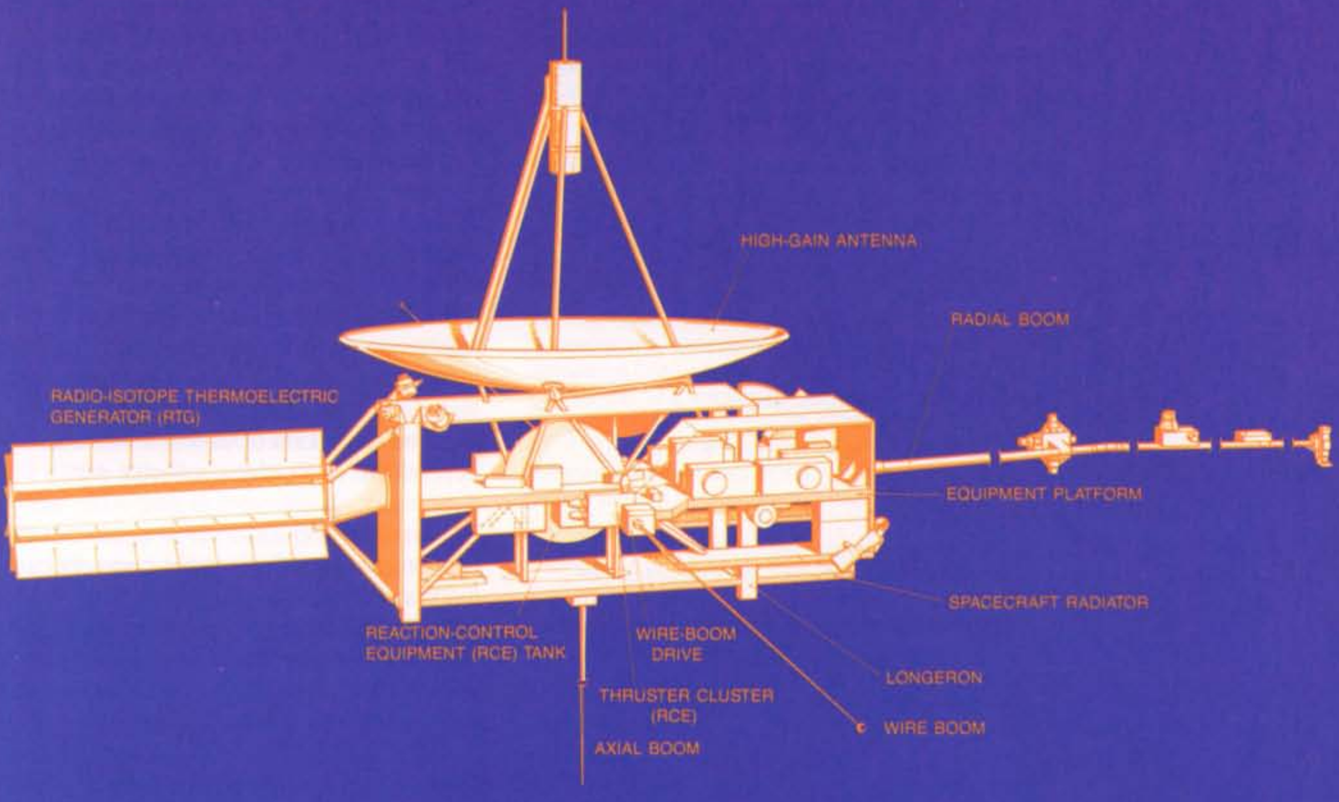
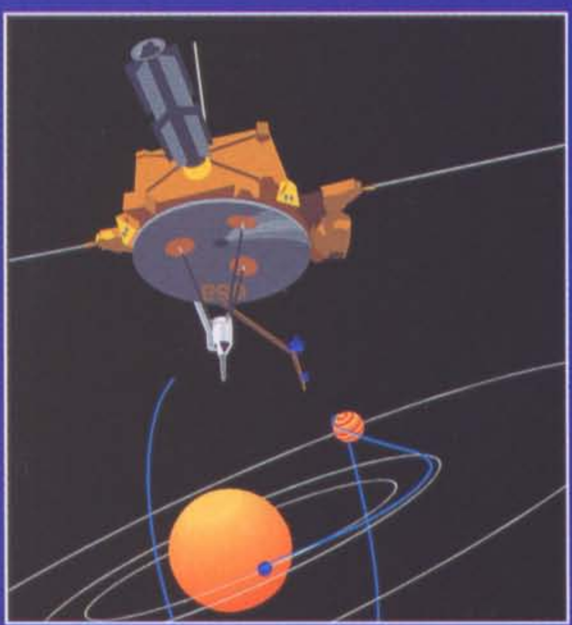


Figure 1. Flight configuration of the Ulysses spacecraft



Dimensions (booms stowed)	:	length	3.2 m
		width	3.3 m
		height	2.1 m
Weight	:	total spacecraft	370 kg
		scientific payload	55 kg
Stabilisation	:	spin-stabilised	5 rpm
Power	:	Radio-isotope thermoelectric generator (RTG)	
		begin of mission	285 W
		end of mission	255 W
Communications	:	X-band downlink	20 W
		S-band uplink/downlink	5 W
Communication antennas	:	Parabolic HGA	1.65 m
		2 LGA	
Telemetry	:	real-time	1024 bit/s
		storage	512 bit/s
Booms	:	radial dipole antenna	72.5 m
		axial monopole antenna	7.5 m
		radial magnetometer boom	5.6 m

Figure 2. Primary Ulysses spacecraft data

Table 1b. Constraints on Ulysses' functional configuration

1. Power subsystem linked to internal power dumps for regulation and spacecraft thermal control. Use of external power dumps to minimise internal dissipation when in full sunlight.
2. Separation of experiments from power and data-handling units.
3. Separation of power and signal lines within the harness to minimise electromagnetic-compatibility (EMC) problems.
4. Grounding of units via a large-section rail to minimise stray currents.
5. All converters driven to a common frequency and phase-separated to reduce EMC problems.
6. All external surfaces conductive and grounded to prevent buildup of potential differenccs confusing to experimenters' detectors.
7. Use of tape recorders to provide continuous experiment coverage with limited ground-station availability.
8. Conscan measurement of High-Gain Antenna (HGA) pointing to ease attitude-control task while tracking the Earth.
9. Use of S-band for uplink and secondary downlink (5 W) via omnidirectional antenna and HGA.
10. X-band (20 W) narrow beam (1.5°) HGA for effective primary downlink.

Systems

The experiment payload of Ulysses consists of nine investigations covering the full range of solar physics addressed by the mission. Spatial scanning is required for the majority of experiments, and mutual compromises have led to the choice of a spin-stabilised spacecraft rotating at 5 rpm. To minimise the interference resulting from radiation from the RTG, the experiments are housed in a bay as remote from it as is practicable. The EMC requirements of the experiments are met by placing the power and data-handling subsystems, which generate electrical noise, in a separate bay.

The use of the dedicated experiment bay also solves the 'field-of-view' requirement of the experiments with respect to the High-Gain Antenna's reflector which, to provide reliable communication with Earth, must be mounted concentrically with the spacecraft spin axis. From the experiment bay, the required directions of view are available beyond the edge of the reflector dish.

This basic configuration is amenable to the experiment need for a radial boom to carry magnetometers. This has been placed opposite the RTG and has also been used to locate certain sensitive experiments further from the RTG than would be possible within the main spacecraft body (Fig. 3).

The physical configuration adopted to meet these diverse mission and experiment requirements consists of a single main platform of aluminium honeycomb, which provides a mounting surface for all of the electronic units, and for the Reaction-Control Equipment (RCE) with its centrally mounted tank containing 33 kg of hydrazine. Four

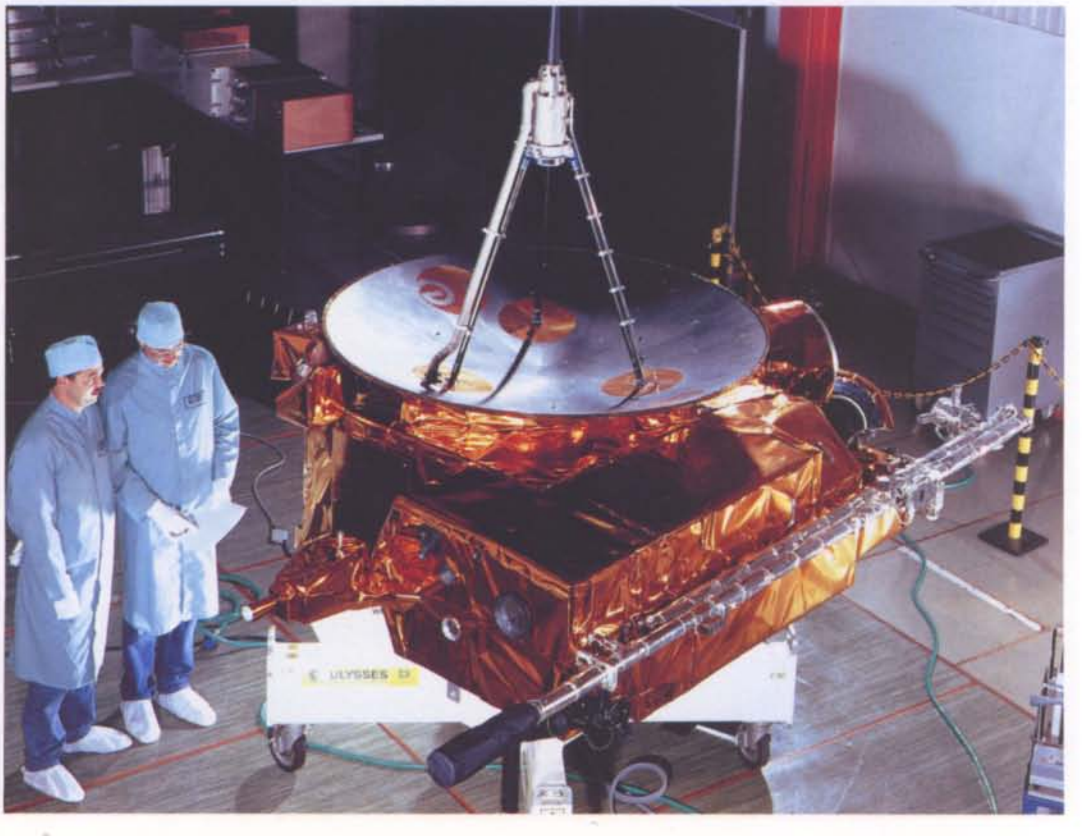


Figure 3. Ulysses flight-model spacecraft, with the radial boom folded in launch configuration

vertical longerons provide support for the top cover and for the bottom plate, which also serves as a thermal radiator.

These longerons provide the interface to the Upper Stage during launch by means of four feet below the radiator. For ground handling, they have four attachment points at their upper ends. The longerons carry aluminium honeycomb side panels, which act as shear panels to stabilise the structure, and the addition of bracing struts between the longerons and main platform produces a rigid and stable assembly.

The spacecraft's spin axis lies through the centre of the four longerons. The 1.65 m-diameter HGA dish is mounted on this axis, above the upper cover, on a braced tripod fixed to the main platform. The axis system has its origin at the spacecraft's nominal centre of gravity and is aligned with the spin axis and to the RTG centre line.

The RTG is carried on a braced flange supported from the edge of the main platform opposite the experiment bay. The radial boom is strapped to brackets fixed to the main platform at the edge of the experiment bay (Fig. 3). After orbital injection, the straps will released and the centrifugal force generated by the spacecraft's spin will carry the boom out, and latch it in its deployed position.

There is a 72 m wire boom in the plane of the central platform and at right angles to the RTG and radial boom. This consists of two separate 35 m-long, thin ribbon, metallic antennas independently deployed using centrifugal force from the brackets 2 m apart, which also carry RCE thrusters.

The final major element of the configuration is the axial boom. This is a stiff spar, approximately 2 cm in diameter, which extends 7.5 m along the spin axis, away from the HGA. It will be deployed by unwinding it from its stowage drum, 28 d into the mission, when the wire booms will also be deployed.

Visible externally on the main body is the spacecraft's thermal finish. The top and all four sides of the main structure are clad with a multi-layer (20-foil thick) thermal blanket. This has a very thin electrically conductive layer of indium tin oxide, required by some experiments, laid over the kapton external surface, which gives it a gold appearance.

During the launch and early-orbit phase, when the spacecraft will be just a short distance from Earth, communication will be by up- and downlinks in S-band through hemispherical-coverage, upper and lower antennas. Transmission is by redundant 5 W solid-state transponders which may be connected either to the rear Low-Gain Antenna (LGA-R), which is on a short stub below the radiator, or to the forward unit (LGA-F), which is on top of the HGA feed. Once the spacecraft has settled into its mission with the HGA Earth-pointing, S-band signals will be transmitted through this high-gain system, which has a 10°, 3 dB beamwidth. As distance increases, this downlink will be switched to X-band with a 2°, 3 dB beamwidth driven by a 20 W travelling-wave-tube.

A special feature of the HGA is its ability to measure the offset of the spacecraft's spin axis from the direction of the ground station by the so-called 'conscan' system. This is accomplished by means of an offset of 1.8° between the S-band antenna pattern and the spin axis, which results in a measurable variation in the uplink signal strength as the satellite rotates. Processing within the spacecraft's Attitude and Orbit Control Subsystem (AOCS) gives the offset magnitude and direction, which is either transmitted for ground analysis or employed in a closed-loop control system to minimise the offset.

The data-handling subsystem processes all commands from the ground and formats data from the experiments and subsystems for transmission either in real time or after storage in a tape recorder. Recording and playback of data is controlled by the microprocessor-equipped Remote Control and Interface Unit (RCIU). The recorders themselves are operated in start/stop mode for recording or playback of complete formats.

The decoder distributes either direct (priority-1) commands to the user, or serial commands to be processed by the Central Terminal Unit (CTU) and further distributed via the Remote Terminal Unit (RTU), which is the main interface unit for distribution and collection of signals or data.

All automatic manoeuvres (either routine or emergency), as well as major reconfig-urations, are initiated by the microprocessor-controlled Central Terminal Unit (CTU), which also contains a specially protected memory, 'the watchdog', and a continuous self-check capability for the data-handling subsystem.

The Attitude and Orbit Control Subsystem (AOCS) is comprised of the redundant sun-sensor system, the Attitude and Orbit Control Electronics (AOCE),the Attitude Measurement Electronics (AME) and the Reaction-Control Equipment (RCE).

In normal operation, attitude measurements will be made by using X-beam and meridian slit sun sensors, and the AOCS contains the necessary electronics for processing the Automatic Gain Control (AGC) signal from the Telemetry, Tracking and Control (TTC) subsystem to determine the spin-axis pointing error ('conscan' system). The sun-sensor output signals will be selected and conditioned in the AOCS electronics and routed to the data-handling (D/H) subsystem, where the spin reference pulse and the spin segment clock will then be derived.

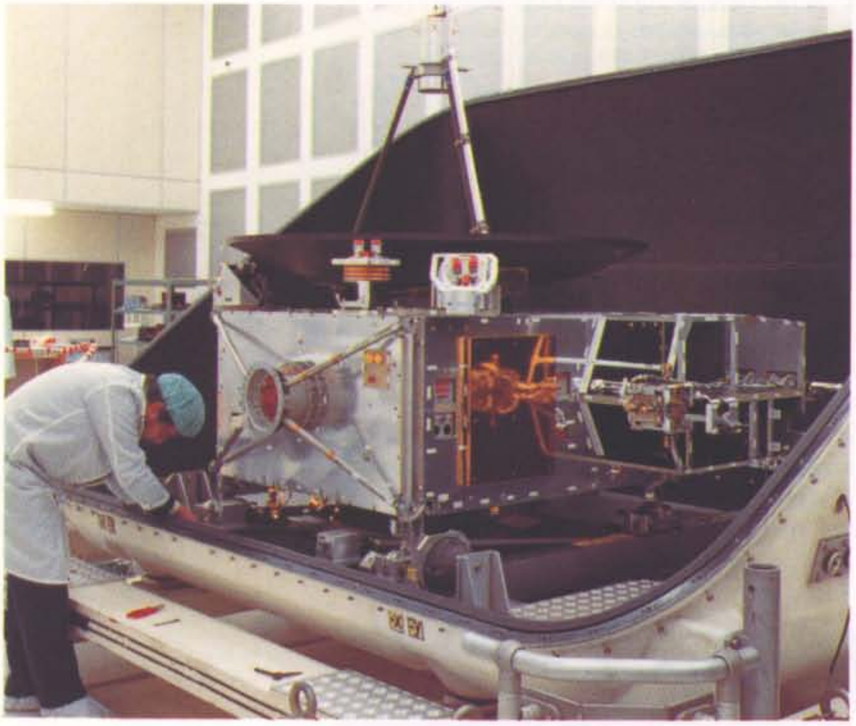


Figure 4. The Ulysses spacecraft structure photographed at ESTEC in 1983, without its thermal cladding

These signals and the sun-sensor data will then be processed within the AOCS to determine the spin rate and solar aspect angle, for closed-loop onboard control, failure detection, and recovery.

Thrusters for attitude, spin and trajectory-correction manoeuvres are activated either by telecommand or automatically within the AOCS electronics. The RCE is a hydrazine system with catalytic decomposition thrusters. It consists of a main tank with two redundant branches, each controlled by the corresponding latch valve and monitored by pressure transducers. Two clusters of four thrusters are located on the +X and −X axis, providing complete redundancy for up/down, spin and spin-axis adjustment.

The Ulysses power subsystem uses a 28 V main bus and a combination of centralised and decentralised supplies to other subsystems. The AOCS and D/H subsystems receive their secondary voltages through converters which are part of the power subsystem, whereas the remaining units and all experiments are supplied directly from the 28 V bus, protected by either current limiters (latching or fold-back types).

The main bus is controlled by using a double linear shunt regulation system operating the RTG at a constant output voltage. This is achieved by varying the resistive loads.

The wire and axial booms electronic unit is used to control deployment of all three booms. The radial boom, however, is of a self-deployable type, activated by firing pyrotechnic devices. The pyrotechnic electronic unit delivers firing pulses to release both the radial boom and the experiment-sensor covers.

Subsystems

The building blocks from which the spacecraft system is constructed are the subsystems, the special features of which are described below.

Structure

During the Ulysses design phase in 1979, the definition of flight loads imposed by the launch system (Space Shuttle plus Upper Stage) was unclear. A cautious approach was therefore taken by ensuring that generous margins were built in both for the spacecraft structure and for the explosive-nut adapter system. As a result, no redesign has been needed to cope with the conditions imposed by the wide range of launch vehicles studied during Ulysses' long search for a launcher. The options have included a Titan-IV and the Space Shuttle with Centaur and various versions of IUS upper stages. The final selection of Space Shuttle, IUS with PAM-S poses no problems for the Ulysses spacecraft.

The main spacecraft structure is a box type with two overhanging main platform balconies (Fig. 4). The main platform, the four longerons, the vertical support panel and support struts, the side panels, the webs and the radiator platform are all load-carrying elements.

The RTG support structure (RSS) can withstand the landing loads to be expected in the event of an aborted mission with a 300°C RTG (Fig. 5). Rapid mounting of the RTG to reduce radiation exposure for installation personnel is provided by four 3/8-inch bolts. Two guide pins provide location while two bolts are clamped. After thermal stabilisation, the guide pins are replaced by the other two bolts.

Mechanisms

The radial-boom and axial-boom units are specially developed for Ulysses. The wire boom is a unit designed for an earlier ESA satellite (ISEE), but modified to carry 35 m of tape in place of the original 15 m.

Radial boom

This is a horizontally folded hinge boom, in two sections with two hinges. It is mounted on the upper side of the main platform structure and stowed along the +Y face of the spacecraft, strapped at two hold-down points during launch (Fig. 6). When released from its stowed position, the boom will be deployed and locked into its final position by centrifugal force. The deployed boom extends 5.56 m in the +Y direction.

Wire boom

This boom consists of two wire antennas, stowed during ground and launch phases in two identical Wire-Boom Drive (WBD) units, with one electronic unit (WBE) to control the deployment of both. Each WBD stores a copper-beryllium ribbon 5 mm wide, 0.04 mm thick and 35 m long. They are deployed by centrifugal force acting on a tip mass and controlled by a brake with a stepper motor (Fig. 7). Synchronous motion is ensured by use of a common pulse generator.

Each WBD has a passive tubular damper which controls relative motion between the boom and the spacecraft by natural internal material damping. The tube is made of a polyurethane material and provides a damping time constant of 3.5 h under worst-case conditions.

Axial boom

The axial boom is a 7.5 m-long monopole receiving antenna extending along the −Z orbital spin axis. The deployable element is a copper-beryllium tube similar in cross-section to two hats joined at the brim. It is manufact-

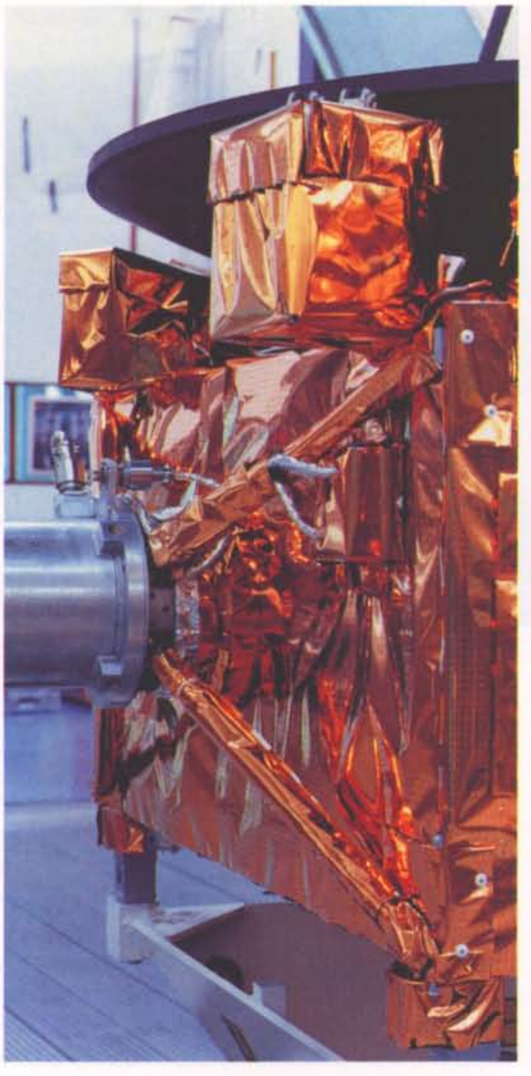


Figure 5. Mounting of the Radio-isotope Thermo-electric Generator (RTG)

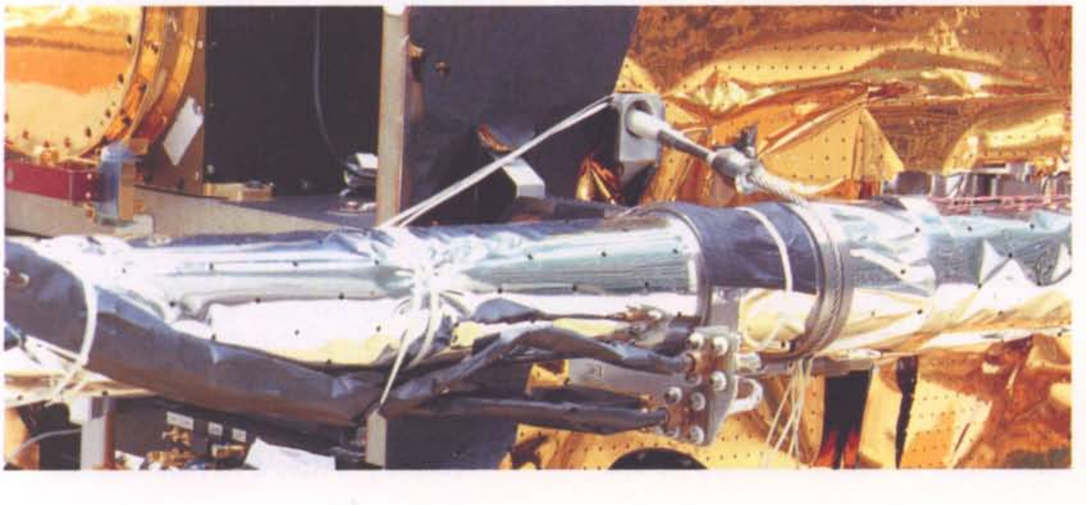


Figure 6. One of the two radial-boom hold-down points

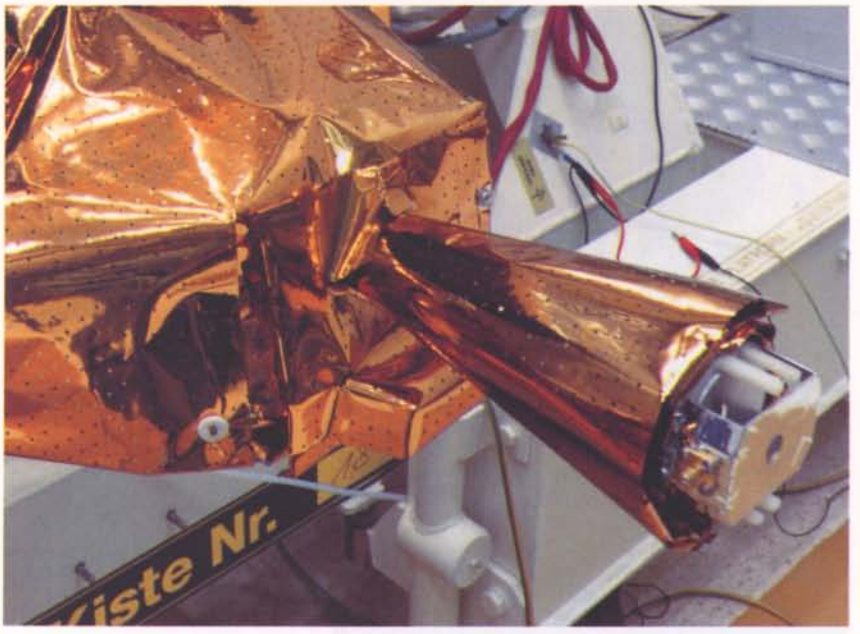


Figure 7. One of the tip masses (bottom right) used to deploy the wire-boom antennas by centrifugal force

ured from pre-formed copper-beryllium strip, spot-welded along each edge.

During launch, the tube will be stored coiled on a drum within the Axial-Boom Drive (ABD) mechanism located at the spacecraft radiator plate.

The boom element will be deployed by a traction force applied through two sets of four rollers located in the ABD tower. These rollers are driven, via a reduction gear, by a stepper motor powered by the WBE. The root stiffness of the deployed boom is provided by the grip of these rollers applied on either side of the spot-welded edge of the boom section.

Thermal control

The spacecraft is thermally controlled by passive means (radiators, thermal paints and thermal blankets) and heaters. The radiators on the spacecraft's −Z face have a constant efficiency because they are never Sun-illuminated. The effect of changing solar intensity on the rest of the spacecraft due to the varying Sun—Earth distance is minimised by use of low-absorptance blankets and compensated by the internal/external linear shunt system, which is used to adjust the amount of electrical power being dissipated within the spacecraft. This approach is possible due to the continuous supply of power from the RTG, which enables correct temperatures to be maintained out to 5 AU from the Sun.

A highly efficient thermal-blanket design (Fig. 8) employs a transparent conductive coating of indium tin oxide on the outer kapton layer, in order to minimise the solar input to the spacecraft's outer faces whilst retaining good electrical conductivity for electromagnetic-compatibility reasons.

A heater system is incorporated which is dedicated to all RCE components, to isolated experiments and to isolated spacecraft units.

Power and the RTG

The power subsystem is derived from existing designs, adapted to function with an RTG and to serve the heating requirements for thermal control.

The RTG is a Radio-isotope Thermoelectric Generator composed of two major components: the General-Purpose Heat Source (GPHS) and the thermoelectric convertor. This is the spacecraft's only power source and it will deliver approximately 285 W of DC electrical energy at the beginning of the mission, and 250 W at the end. It also dissipates approximately 4.5 kW of thermal energy. The RTG is a unit developed by the US Department of Energy (see article on page 51) in conjunction with Jet Propulsion Laboratory (JPL).

The main-bus control function is served by the PCU which maintains a regulated DC voltage level of 28 V ±2%. This main-bus power is distributed to the users in four different ways: via latching relays, via transistor switches, via convertors, and by direct connection to the main bus.

The electrical harness distributing power and signals between units and subsystems plays an essential role in the system's electromagnetic emission and susceptibility behaviour, as well as for inter-subsystem electromagnetic compatibility. Doing justice to this fact means taking special precautions that help in minimising the effects of field-to-cable coupling and cross-talk, as well as minimising electric and magnetic fields generated by voltages and currents in the interface lines (see Fig. 9 and Table 2).

Data handling

The majority of this subsystem has been developed for Ulysses, and the major units have been flown in the meantime on the Giotto spacecraft.

The special nature of the Ulysses mission demands that the data-handling subsystem have a number of unique features, the principal among them being as follows:

- Since the spacecraft will reach a distance of more than 5 AU from Earth, it is necessary to have a very low data rate

Table 2. Special features of Ulysses' electrical harness

- Three specially separated cable bundles for power, pyrotechnic and signal lines.
- Special routing for radio-frequency (RF) signals between units of the telecommunications subsystem.
- Each cable bundle wrapped in aluminium foil for shielding purposes.
- Multipoint grounding of the overall harness shields.
- Large-cross-section ground rail with single-point bonding to structure.
- Twisting of wires with their return where current greater than 1 mA flows.

(16 bit/s) for commanding in order to ensure reliable operation. There is a validation system to ensure that critical commands are checked prior to execution. Although it is possible to send commands for immediate execution, the normal mode will be to 'time-tag' them for execution within the range of 32 s to 24 d after receipt.

- There is a diversity of telemetry formats and bit rates to maximise scientific data transmission within the radio-frequency (RF) link constraints and to ensure the retrieval of data stored during non-tracking periods. The onboard storage consists of two magnetic tape recorders, each with a capacity of 44 h at 256 bit/s. This data will subsequently be transmitted to the ground interleaved with real-time data.
- There is an onboard clock monotonic throughout the mission for time-referenced commanding and time-labelling of telemetry formats. This timing is distributed for synchronisation and control to the experiments and to other subsystems. It is used together with sun-sensor information for the generation of spin-rate and spin-angle reference data.

The spacecraft's science telemetry is derived from the experiment sensors and processed within the experiment data-handling units prior to passing to the On-Board Data-Handling (OBDH) subsystem. There is also experiment and subsystem housekeeping data which is passed directly to the OBDH. Within the subsystem, this data is transformed into one of three formats. The normal format is the 'science' format, which contains mainly scientific data with limited housekeeping data. When necessary, however, 'housekeeping' or 'emergency' formats can be called up if spacecraft- or instrument-health needs to be investigated in more detail. The formatted data is then serialised into the selected bit rate and convolutionally encoded prior to being passed to the transmitter for downlinking to Earth.

During periods out of ground contact, the scientific data formats will be collected by the CTU and routed via the RCIU to the Data Storage Unit (DSU) (redundant tape recorders), to ensure their retention for subsequent transmission during the next tracking period.

Data are stored in blocks of 32 frames to maintain the scientific format structure as acquired. A temporary buffer (two 32 kbit toggle buffer) in the RCIU is filled at one of the three available data storage rates (512, 256 or 128 bit/s). When a buffer is full, the RCIU starts the tape recorder and dumps the completed data block onto it at a higher speed (16 kHz). The recorder is then stopped until the next buffer is full.

Figure 8. Ulysses' gold-coloured high-efficiency thermal blanket

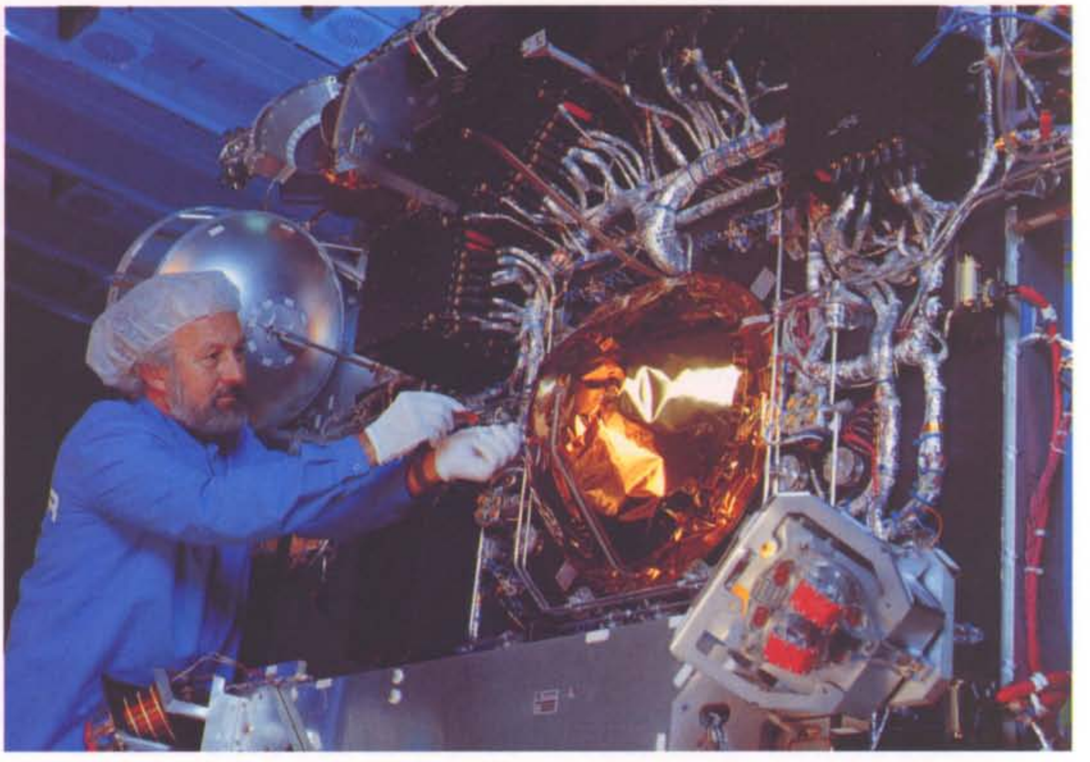


Figure 9. Part of Ulysses' electrical harness (silver-coloured) and the main electrical subsystems (black boxes) mounted beneath the main spacecraft platform

To recover stored data, the RCIU uses the same start–stop technique, and the temporary buffer is read out by the CTU at the necessary speed to accommodate the interleaving process to the commanded telemetry bit rate. The start–stop operation ensures an operational capability at different record and playback bit rates.

The capacity of each tape recorder (45 Mbit) is sufficient to fulfil the requirement of continuous storage at 512 bit/s for 16 h, or 256 bit/s during 44 h.

Telecommunication

This subsystem was specially developed for Ulysses but has also been flown successfully on Giotto in the meantime. It provides command access and data recovery out to a range of 6 AU from Earth. The transponders have S-band receivers with 5 W transmitters. Redundant 20 W X-band travelling-wave-tube amplifiers provide the primary downlink.

The receiver is of the double-conversion superheterodyne type with a second-order phase-lock loop tracking the carrier of the ground transmitter. The receiver demodulates the telecommand video signal from the RF carrier and delivers it to the decoders. When operating in the ranging mode, it also demodulates the ranging signal and delivers it to the transmitters.

The operating uplink carrier frequency is 2111.607 MHz, while the two S- and X-band downlinks are at 2293.148 MHz and 8408.209 MHz, respectively.

Immediately after launch, or in the event of a contingency, the communication link is through a low-gain hemispherical-coverage antenna. One on the HGA covers the forward zone, while the rear zone has an antenna mounted on a short stub boom.

During the routine mission, the Cassegrain High-Gain Antenna of 1.65 m diameter (see Fig. 3) will be used for S-band uplinking and downlinking and for X-band downlinking. Its gain is optimised for the downlink frequencies.

The S-band main beam is offset by 1.8° from the X-band beam, which is coincident with the direction of the spacecraft's spin axis. This permits the conical-scanning automatic tracking function (so-called 'conscan') discussed below.

Attitude and Orbit Control Subsystem (AOCS)

This subsystem has been developed for Ulysses and is novel in that 'conscan' of the RF uplink is used as a primary attitude measurement.

The task of the AOCS is to supply attitude information for all three axes and to control the position of the spacecraft's spin axis and the spin rate. The orbit trajectory must also be adjusted to remove launch errors, and any oscillatory motion of the spinning spacecraft must be damped to acceptable levels.

The AOCS supplies attitude and spin-rate information to the experiments and to appropriate subsystems for spacecraft operation. There are redundant sets of sun sensors on the two longerons on either side of the RTG. Solar aspect and spin phase can be measured over the range 1.25–135° from the spin axis centred on the HGA.

Attitude measurement of the third axis to define the spatial orientation of the spacecraft uses the RF link with the Earth. The presence of this link led to the choice of the conical-scanning technique for attitude measurement.

The 'conscan' system employs the uplink S-band signal from the ground station as a reference. As the spacecraft's S-band feed is offset by 1.8°, the 5 rpm spin motion generates a modulated signal at the receiver which is proportional to off-pointing up to at least 2°. This signal variation is present in the receiver's Automatic Gain Control (AGC) and is made available to the 'conscan' processor in the AOCS subsystem as an analogue voltage. Correlation between this signal and the spin motion, as measured by the sun sensor, gives the direction of the Earth relative to the spacecraft axis.

The spin-axis pointing is controlled by activating a hydrazine thruster with the appropriate time and direction, selected from four axial jets that lie parallel to the spin axis. Spin rate is adjusted by firing the appropriate tangential thruster (Fig. 10).

Velocity adjustments can be made by firing a balanced pair of thrusters in either continuous-axial or pulsed-tangential mode. This system, known as the Reaction Control Equipment (RCE), consists of a single diaphragm tank (visible in the centre of Fig. 9), mounted at the spacecraft's centre of gravity (position at time of launch), feeding mono-propellant hydrazine under pressure to eight catalytic decomposition thrusters (2 N) arranged on two manifolds, each isolated by latch valves.

The AOCS has the ability to operate the spacecraft in a number of automatic modes. The most significant is closed-loop 'conscan', in which periodic pointing control by the RCE is automatically commanded to reduce the observed offset until the error is inside a preset dead band (0.2°). Control of spin rate and solar aspect to within pre-set dead bands can also be set as an automatic function if so desired.

Every time a thruster is fired, some disturbance to the spacecraft's spin motion will occur. It is therefore necessary to provide nutation damping. On Ulysses, 'fluid-in-tube' nutation dampers mounted on the radiator will meet the requirement for a threshold level of less than 0.02°.

Spacecraft autonomy

The Ulysses spacecraft will be operated with intermittent ground-station coverage and consequently there will be long periods without the possibility of Control Centre intervention. Autonomous protection against failures is therefore a must. A further requirement for autonomous protection stems from the time delay in executing commands. In view of the great distance to which Ulysses' orbit will carry the spacecraft from Earth, transmission time may be up to 45 min in each direction.

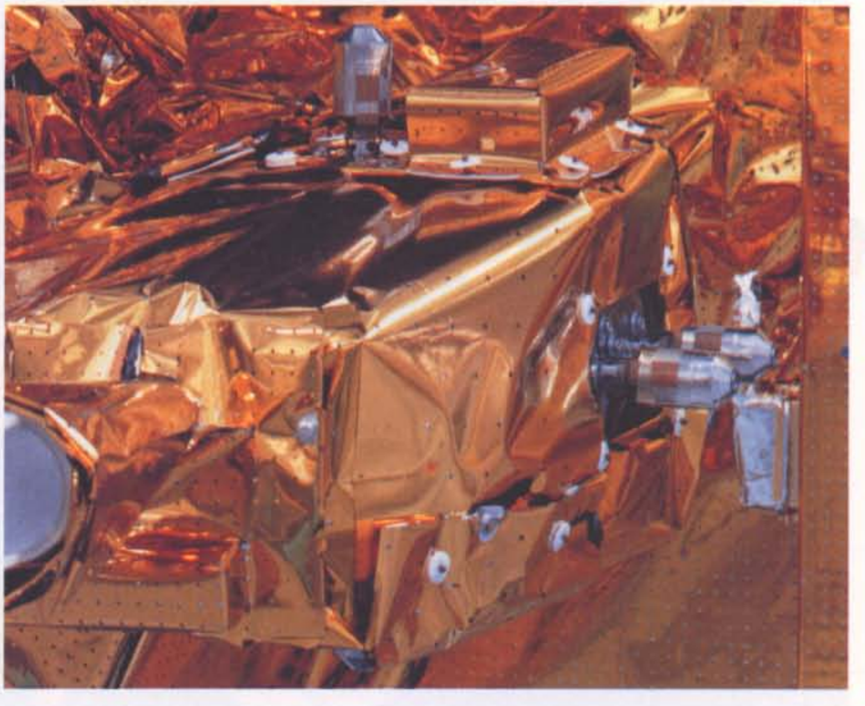
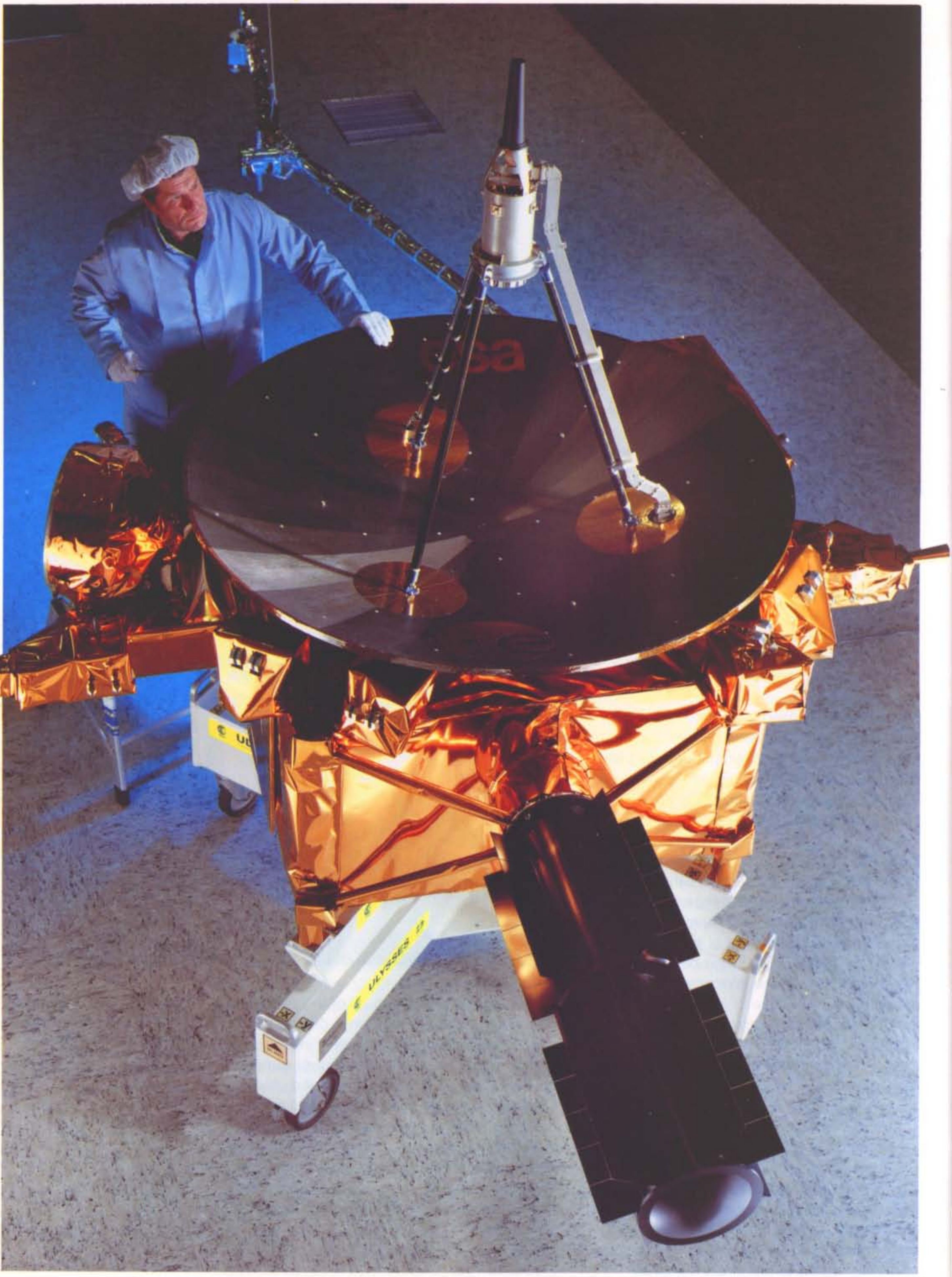


Figure 10. One of the two thruster blocks carrying thruster nozzles for attitude, spin and trajectory-correction manoeuvres

Ulysses is equipped with all of the protection one would expect to find on a complex spacecraft of this type, including in particular current limiters to protect the power supply, and onboard verification of received commands before execution. In addition to these protection schemes, the data-handling subsystem is equipped with a 'watchdog' facility designed to provide for failure-mode detection and automatic action to reconfigure the spacecraft to a safe mode in the event of a problem.


esa
ULYSSES

RTGs — The Powering of Ulysses

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Introduction
The Ulysses mission objective of exploring the polar regions of the Sun and its heliosphere has resulted in the use of an onboard electric power source unique for a European spacecraft. Current launch vehicles (rockets) do not have the power to lift the spacecraft directly out of the ecliptic plane, in which the Earth orbits the Sun, and propel it over the latter's poles. To acquire this energy, it is necessary for the spacecraft to travel first to Jupiter and use its immense gravitational field to bend the spacecraft's flight path out of the ecliptic plane and over the Sun's poles. It is during this long voyage to Jupiter and back that the spacecraft's electrical power subsystem requires a unique power source, namely a Radio-isotope Thermoelectric Generator (RTG), to be used.

The need for RTGs
The majority of the spacecraft currently orbiting the Earth or journeying to nearby inner planets such as Venus can usually obtain sufficient energy from the Sun to power all of their electrical needs. The heat from the Sun's rays is usually converted directly into electricity by devices called solar cells. However, they are not acceptable for the Ulysses spacecraft because as it travels away from the Sun on its way to Jupiter, the solar energy available decreases until, at Jupiter, it is about 25 times less than back at Earth.

At this distance, solar cells are much less effective. In addition, they would be susceptible to impacts from the asteroid belt and interplanetary dust particles, and their performance would be degraded significantly by Jupiter's intense radiation field. Moreover, solar cells only work when they are exposed to the Sun, and do not generate any electricity when in the shade. Chemical battery systems do not provide a viable option as a power source because they are heavy and short-lived without replenishment.

These and other considerations have resulted in the use of a Radio-isotope Thermoelectric Generator (RTG) for Ulysses' electrical power supply. The RTG works independently of any external energy source, and is rugged enough to survive the rather severe environmental conditions that will be encountered during the mission.

History of RTG use in the USA
RTGs are not new to the US space programme — in fact, for almost 30 years they have been enabling NASA to explore the Solar System. The United States has already launched 40 RTGs on a total of 23 spacecraft. The earliest civilian use of an RTG was on the Nimbus weather satellite. Later, five RTGs were left on the Moon during the Apollo missions to power data-gathering science stations, while two RTGs were used on each of the two Mars landers during the Viking programme. The lunar nights and atmosphere on Mars were prime reasons for using RTG power supplies. Just prior to the Viking programme, RTGs also powered a Pioneer spacecraft on its journey to Jupiter, Saturn and beyond. In addition, the Lincoln Laboratory Experimental Satellites, LES-8 and 9, and the two Voyager missions to Jupiter, Saturn, Uranus and Neptune, are still being powered by RTGs. The latest mission, that of sending the Galileo spacecraft to orbit Jupiter for over two years and releasing a probe into the Jovian atmosphere, is almost one year into its 8.5 year mission lifetime. For the 20 missions that have successfully achieved their flight plans, the RTGs have all performed successfully. The RTGs for the Pioneer and Voyager spacecraft have operated flawlessly for over a decade and continue to power those spacecraft as they travel beyond the orbits of Saturn and Uranus to the outermost reaches of space.

As new technologies were developed and power requirements increased, the power source's designation, which started out as

Systems for Nuclear Auxiliary Power (SNAPs), was changed first to Multihundred-Watt Radio-isotope Thermoelectric Generators (MHW-RTGs), and then to General-Purpose Heat-Source RTGs (GPHS-RTGs).

The electrical power outputs of RTGs have increased considerably over the 29 year period of their use in space. The first RTG launched in 1961 produced an electrical output of 2.7 W; the RTG being flown on Ulysses will produce approximately 285 W at the beginning of the mission. By the end of the Ulysses mission in September 1995, this figure will have fallen to about 250 W. This will be adequate to power the scientific instruments, data-handling subsystem, and telecommunications subsystem, as well as to control other subsystems on the spacecraft, throughout the mission. The general trend in technology development has been to improve generator performance, efficiency, and specific power (Table 1).

Power source	Initial avg. power (W)	Spacecraft	No. of missions	Mission type
SNAP-3	2.7	TRANSIT	2	Navigational
SNAP-9	26.0	TRANSIT	2	Navigational
SNAP-19	38.8	Nimbus, Pioneer, Viking	5	Navigational; Interplanetary; Mars Lander
SNAP-27	73.4	Apollo	5	Lunar
TRANSIT-RTG	35.6	TRIAD	1	Navigational
MHW-RTG	156.0	LES, Voyager	4	Communication; Interplanetary
GPHS-RTG	285.0	Galileo, Ulysses	1	Interplanetary

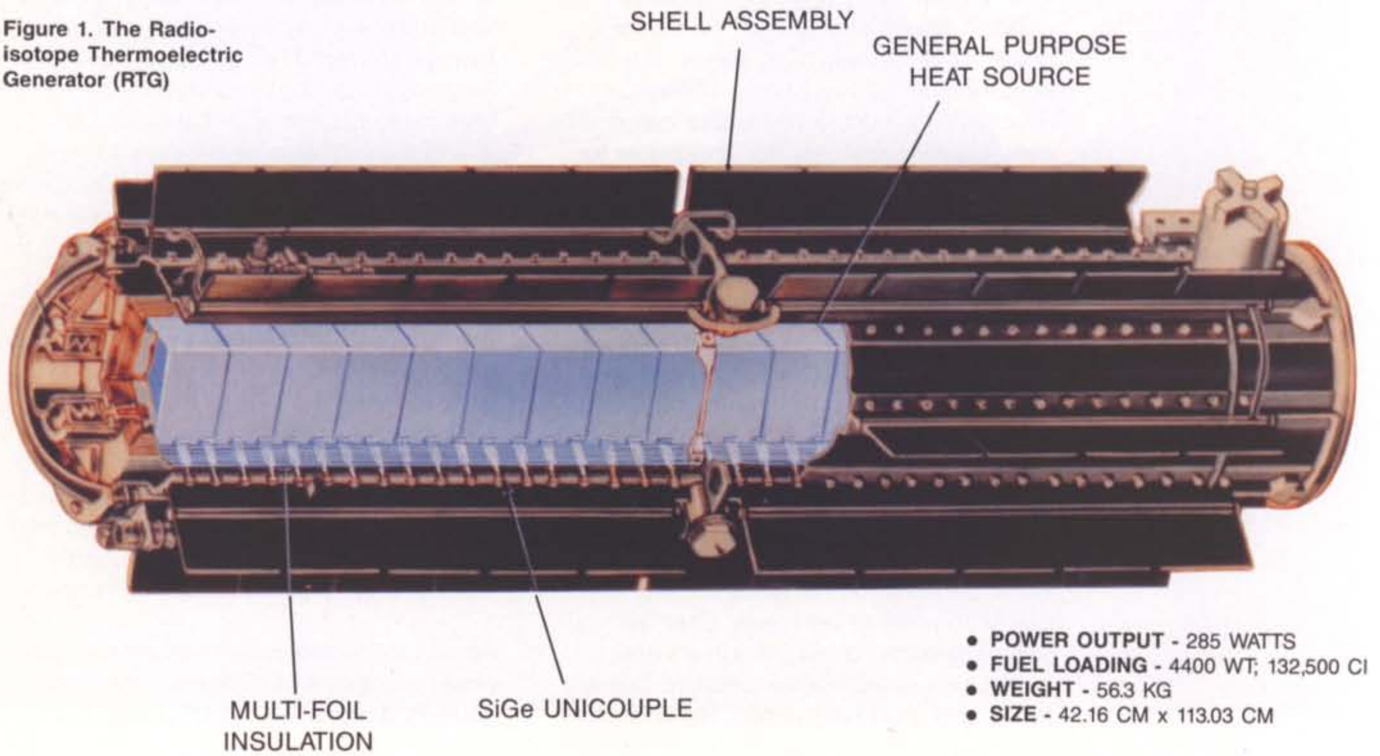
The RTG concept

The most recent development in RTG technology is the GPHS-RTG, developed under the sponsorship of the US Department of Energy (DOE). This is the generator currently being used on the Galileo mission to Jupiter, and on Ulysses. The RTG onboard Ulysses will produce enough electricity to light four standard light bulbs. The GPHS-RTG has no moving parts and is therefore not prone to mechanical failure (Fig. 1). It will deliver power for the durations of the 8.2 year Galileo and 4.7 year Ulysses missions.

The RTG system relies upon heat generated by simple radioactive decay. The radioactive material used is plutonium-238, which has a half-life of approximately 87.8 years. Its predominant method of decay is by the emission of alpha particles, which have a very large amount of kinetic energy, but lose that energy and come to a stop within a few microns of the plutonium-238 itself. The kinetic energy lost while the alpha particles are stopping is converted directly into heat. The plutonium-238 itself is in a completely oxidised and biologically inert form.

The Ulysses GPHS contains 10.75 kg of plutonium dioxide, corresponding to a total activity level of 1.325 X 10^5 Curie and 4400 W of heat per heat source. The reduction in thermal power is approximately 0.8% per year, due to alpha decay based on the half life of plutonium-238. Other radio-isotopes exist in the fuel in very small

Figure 1. The Radio-isotope Thermoelectric Generator (RTG)



- **POWER OUTPUT** - 285 WATTS
- **FUEL LOADING** - 4400 WT; 132,500 CI
- **WEIGHT** - 56.3 KG
- **SIZE** - 42.16 CM x 113.03 CM

quantities and they emit low levels of gamma rays and neutrons. A careful design, safety-testing, and safety-review process was conducted to ensure that the fuel will remain safely contained during ground handling and during all subsequent mission phases.

To maintain the simplicity and reliability afforded by a static system (no moving parts), the heat obtained from plutonium-238 decay is converted directly into electricity using thermo-electric principles. This direct energy-conversion method is not new, but was discovered 150 years ago by the German scientist Thomas Johann Seebeck. He observed that an electrical voltage is produced when two dissimilar, electrically conductive materials are joined in a closed circuit and the two junctions are kept at different temperatures. Such pairs of junctions are called 'thermoelectric couples', or 'thermocouples'. The power output is a function of the temperature of each junction and the properties of the thermoelectric materials. The thermocouples use heat from the radioactive decay of plutonium-238 to heat the hot junction of the thermocouple to approximately 1300°C, and use the cold of outer space to produce a low temperature of 300°C at the cold junction.

RTG design

The GPHS-RTG used on the Ulysses spacecraft has two major components, the General-Purpose Heat Source and the thermoelectric energy converter. Together, they form an RTG with a mass of 55.9 kg, 113 cm in length and 42.2 cm in diameter, operating at 28 V.

The General-Purpose Heat Source

The basic building block of the GPHS is a heat-source module, shown in Figure 2. A total of 18 modules are stacked and sealed inside the converter unit, forming the RTG power supply. The major design constraints placed on the GPHS are dictated by safety considerations during all mission phases, including ground handling, transportation, launch, ascent and transfer orbit and during unplanned events such as atmospheric re-entry, Earth impact and post-impact situations.

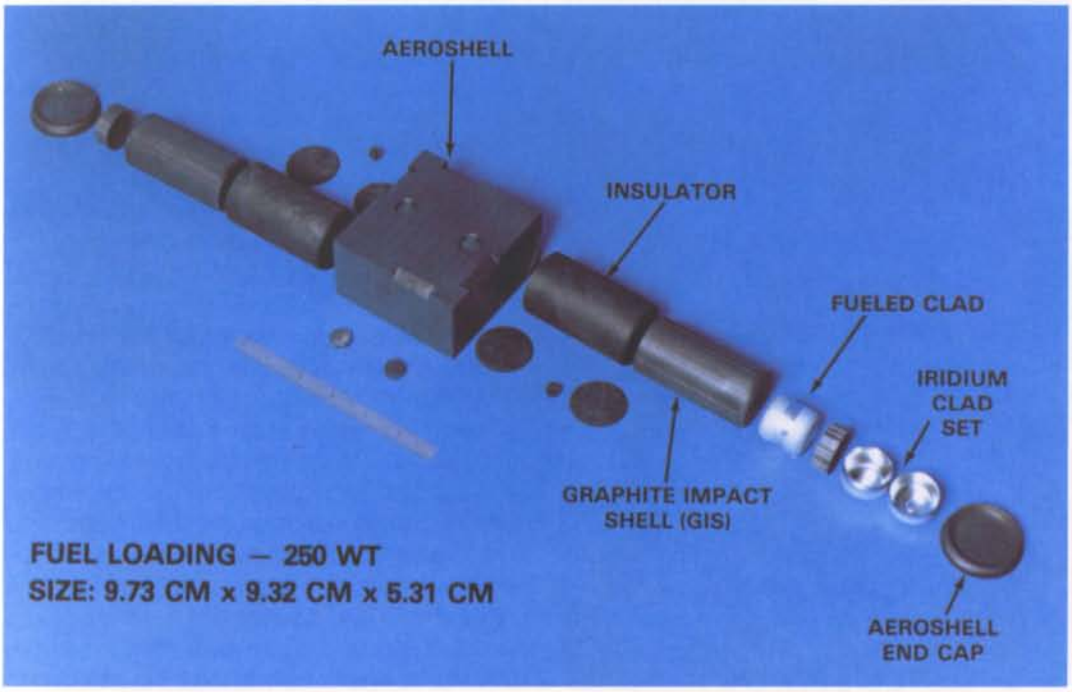


Figure 2. The General-Purpose Heat Source (GPHS)

The GPHS design relies on small, modular units so that re-entry heating and terminal velocity would be lower than they were for previous heat sources. This modular construction also minimises the likelihood of fuel releases, because an accident that might damage one module will not necessarily affect all of the modules or the four fuel capsules inside a given module. This fact was demonstrated by a series of module-impact and ground-impact tests.

The heat source for Ulysses' RTG consists of 72 ceramic pellets of plutonium-238 dioxide. The pellets themselves are about the size of a spool of thread, produce 62.5 W of heat, and are in a hard ceramic form, similar in nature to the toughest forms of ceramic kitchenware. This form makes the pellets highly insoluble in water, which again is an important safety feature in the event of an accident. It also makes the pellets more likely to fracture into large chunks, rather than dust, following impact on hard surfaces. This design feature provides further protection so that any likelihood of release and inhalation of plutonium-238 is minimised.

The plutonium-238 pellets are encased in iridium metal clads or shells ('fueled clads'). Two fueled clads are separated by a floating membrane and contained within a high-strength graphite impact shell. Pairs of the graphite impact shells are further contained within a graphite block called an 'aeroshell'.

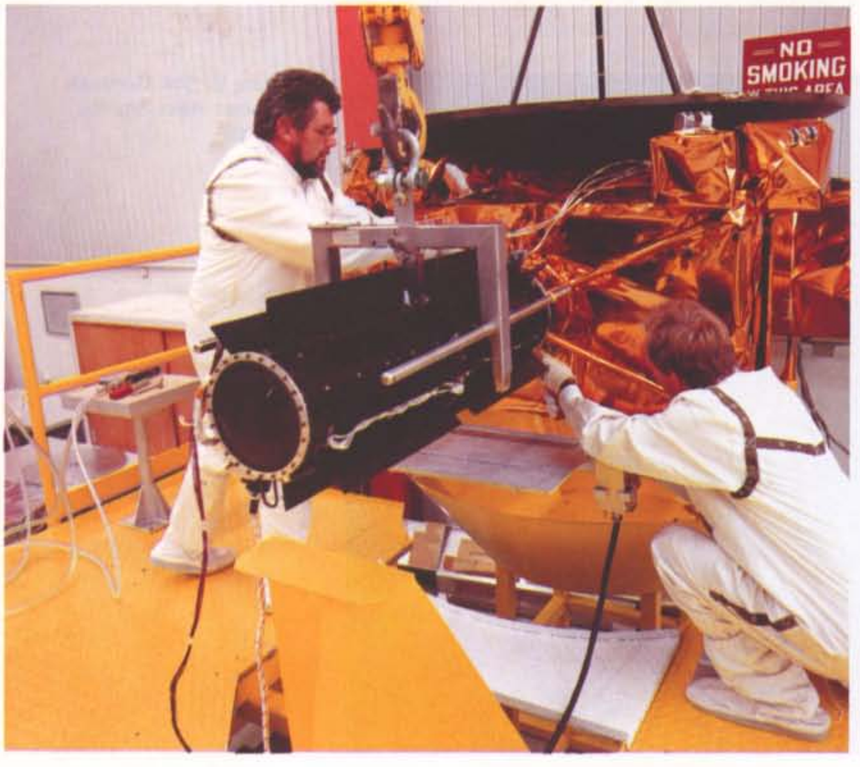


Figure 3. RTG fit-checking in progress at ESTEC, Noordwijk (NL)

The graphite material in the GPHS performs several functions. The aeroshell, in addition to acting as the primary structural member of each module, is designed to protect the two graphite impact shells (and therefore the fueled clads) from the severe aero-thermodynamic environment that may be encountered in a postulated re-entry from space. The graphite sleeve is a thermal protection that keeps the iridium clad from melting during postulated re-entry and keeps it ductile at Earth impact. The graphite impact shells and floating membranes are designed to provide ground-impact protection to the fueled clads. The graphite material used for the aeroshell and impact shell is a fine-weave, pierced-fabric composite, woven with high-strength graphite fibres in three perpendicular directions. It is one of the best materials currently available for re-entry protection.

The Thermoelectric Converter

Every electrical conductor will develop a voltage that varies as the temperature varies along its length, and is different for each conductor. For example, copper develops one voltage, while silver develops another. A complete electrical circuit that consists of one type of conductor will not generate a net voltage increase, as the temperature and voltage changes are cancelled out around the circuit. However, if two different conductors are connected in a circuit, and the joints between them are held at different temperatures, then the voltages developed in one conductor are not cancelled by the voltages generated in the other and the circuit can generate a net voltage.

This effect is the basis of the ordinary thermocouple, which is a simple temperature-measuring device consisting of two different metal legs joined together at one end. By measuring the voltage generated between the two legs of the thermocouple, the temperature of the joint, called the 'hot junction', can be accurately and reliably determined.

The ordinary thermocouple can be turned into an energy-conversion device very simply. If the device that requires the electrical power is connected to the free ends of the thermocouple, a completed circuit is formed and the electrical current is allowed to flow. Ordinary metallic thermocouples are not very efficient for energy conversion because of internal losses and a low output voltage. Since the 1950s, a number of materials, usually semiconductors, have been developed which allow these thermoelectric energy-conversion devices to convert several percent of the available heat to useful electrical power.

While relatively inefficient compared to some other processes, thermoelectric devices have no moving parts, and have operated for years with no maintenance and little degradation. Thermoelectrics therefore provide a unique and reliable source of power for special applications such as deep-space probes and certain remote power needs on Earth, the Moon, and even Mars.

The converter, in addition to the thermo-electrics described above, consists of the aluminium outer case (which is the main support structure for the thermocouples and the GPHS), a thermal-insulation system and a gas-management system used to maintain the desired internal environment for the generator. Heat generated by the radio-

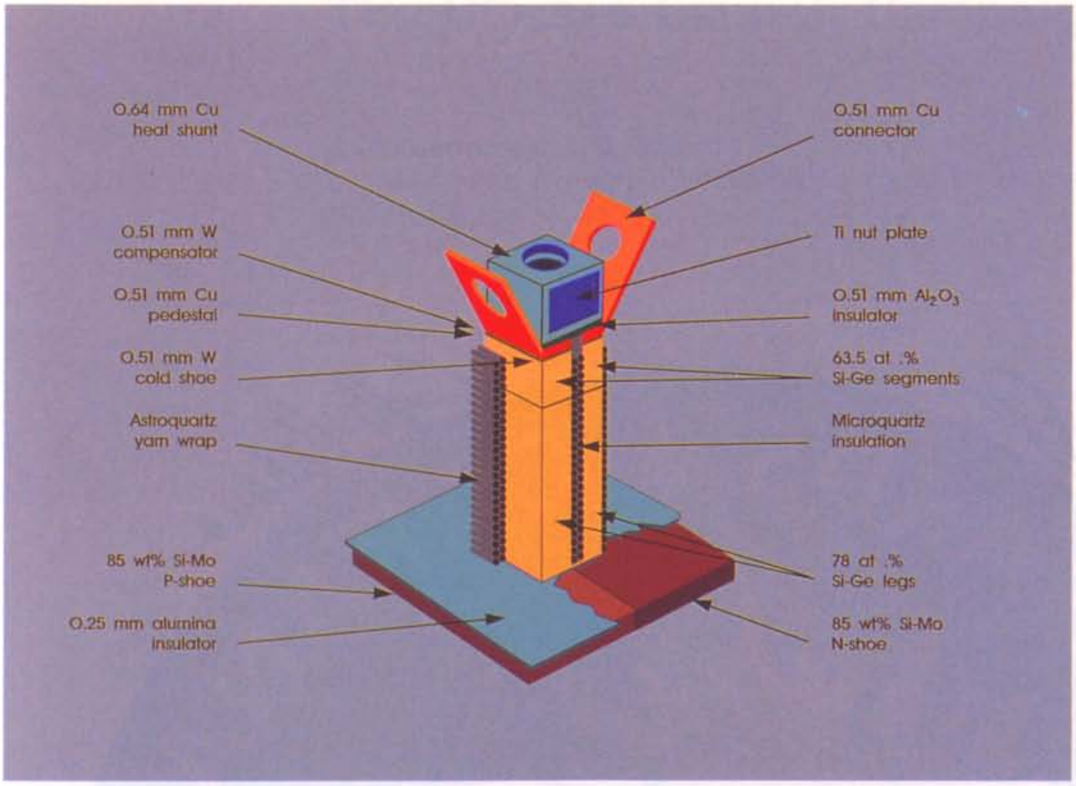


Figure 4. The Thermoelectric Unicouple

isotope fuel is converted into electrical energy by silicon-germanium thermocouples. 576 such thermocouples are arranged in 16 circumferential rows, each containing 36 thermocouples (Fig. 4). They are formed into unicouple assemblies which are individually bolted to the converter's outer case. Electrical current is conducted between the unicouples by copper electrodes that are wired in a two-string, combination series and parallel electrical wiring circuit. This arrangement permits continued operation if a thermocouple fails in either open- or short-circuit mode. The circuit loops are also arranged to minimise the net magnetic field of the generator.

Safety features

The US Department of Energy has devoted 9 years on the engineering, safety, and environmental testing of the GPHS, building on the experience gained from previous heat-source development programmes. The test-programme results have proved the present layered design described above to be the most successful of any heat source developed thus far.

During the design and production process, the RTGs were repeatedly analysed in an extensive safety and analysis programme using both physical tests and computer models. This testing process helped mission scientists, engineers and decision makers to evaluate a wide range of potential accident environments and consequences. The physical tests demonstrated that the RTGs are extremely rugged and capable of meeting the design objective of preventing/minimising any fuel release. These tests also contributed to the development of computer models that were used to simulate thousands of different accident scenarios. All of the information from the testing and modelling is included in the Final Safety Analysis Report for the Ulysses mission, considered in detail during the launch-approval process.

Conclusion

The extensive engineering and safety-testing programme for the GPHS has shown the technology to be a safe, rugged and reliable source of heat for electricity generation that assures the greatest level of health and safety for the general public. Use of similar technology on previous space missions has proved that RTGs can provide a reliable, independent and long-lived source of electricity. As space programmes continue to explore the outermost reaches of our solar system, RTGs can be expected to play a vital role in providing the energy needed for future missions. The use of a radio-isotope power system will give the Ulysses spacecraft the power that it needs to provide mankind with detailed knowledge of the Sun and the World in which we live.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The Ulysses Launch Campaign

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Introduction

The Ulysses spacecraft is to be launched using the NASA Space Shuttle STS-41/IUS/PAM-S combination from Launch Complex 39, Pad B, at the Kennedy Space Center. The 19-day launch window opens on 5 October 1990, and closes on 23 October 1990. The spacecraft was originally being prepared for launch in 1986, but launch operations were terminated and the spacecraft put into storage after the loss of the Space Shuttle 'Challenger' on 28 January that year.

Launch processing flow

The overall task of launching a spacecraft such as Ulysses on a planetary-type mission is extremely complex and involves many disciplines, industries and organisations. The Ulysses spacecraft itself, the Inertial Upper Stage (IUS) and the Payload Assist Module (PAM-S), the Shuttle, the Radio-isotope Thermoelectric Generator (RTG), the ground installations at Kennedy Space Center (KSC) in Florida to be used for the launch, and the flight Operations Control Centre at Jet Propulsion Laboratory (JPL) in Pasadena, must all be prepared according to schedules derived from one master schedule, leading to a launch on 5 October 1990.

The launch processing flow for the activities at KSC is shown in Figure 1.

Initially, the spacecraft, the Inertial Upper Stage and the Payload Assist Module must be subjected to individual ('stand-alone') testing at various locations within the KSC/USAF complex. For the spacecraft, this includes a complete checkout of all subsystems and experiments, followed by filling of the hydrazine tank that feeds the reaction-control system for trajectory correction and attitude control.

After the spacecraft and Inertial Upper Stage stand-alone activities, the IUS and the PAM-S must be mated in the Vertical Processing Facility (VPF), and the Ulysses spacecraft then mated to them. The IUS/PAM-S/Ulysses combination (known as the 'Shuttle Payload') has then to be transported to the launch pad. Its integration into the cargo bay of Space Shuttle 'Discovery' takes place there, as well as the integration of the RTG, which is performed as late as possible in the

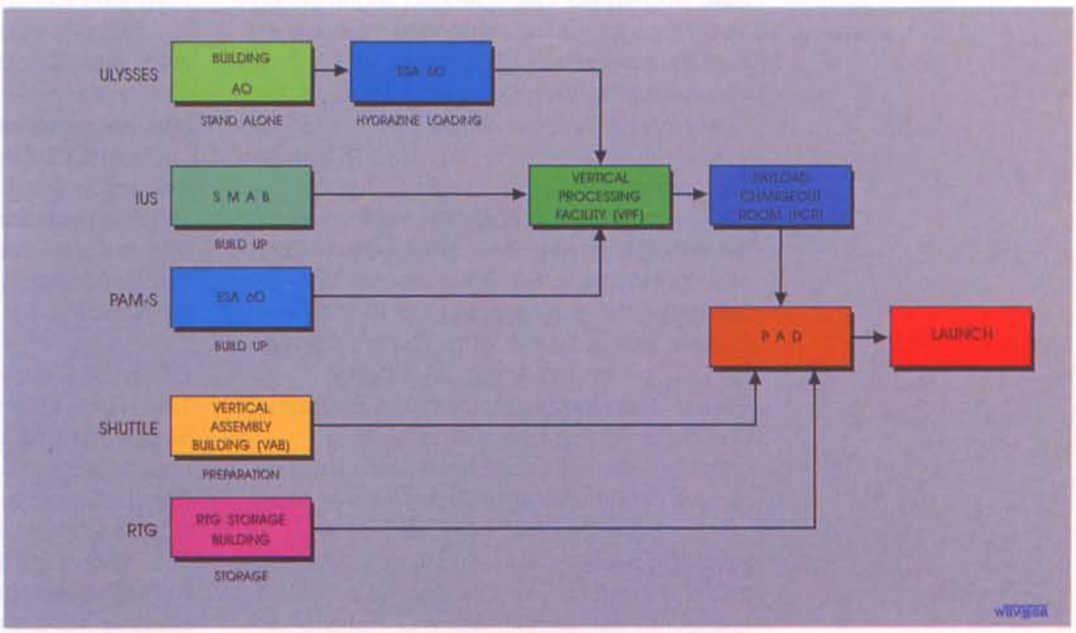

Figure 1. Launch processing flow

operations flow. After RTG integration, the cargo-bay doors will be closed for the countdown and launch. The overall complexity of this scenario leads to a preparation period of almost five months, which is very long by normal ESA standards.

Pre-launch activities
The stand-alone activities for the Ulysses spacecraft are being carried out in Building AO and the ESA-60 Facility, and to some extent in the VPF, prior to the spacecraft being mated to the IUS.

Activities in Building AO
Reintegration
At the time of its arrival in the United States on 17 May 1990, the Ulysses spacecraft was not fully integrated. The axial boom and the two wire booms, the two transponders, the Radio-Frequency Distribution Unit (RFDU), and the SIM-1 and GLG experiments were delivered separately to allow for late component replacement, after the termination of the recertification phase in Europe. The spacecraft low-gain antennas were also shipped separately. Spacecraft integration was therefore completed during the early phase of the launch campaign.

Performance verification
This verification consists of detailed Reaction Control Equipment (RCE) leak- and flow-rate measurements, an integral RCE subsystem leak test at operational pressure, and a complete spacecraft Integrated Systems Test for both subsystems and experiments. A final alignment check is made to confirm that the critical elements of the spacecraft, such as the high-gain antenna, the sun sensors, thrusters, and the axial and radial booms have maintained their intended alignments. System performance verification includes a high-gain-antenna radiation check and measurements of pyro continuity and isolation.

Compatibility tests
Two command- and data-flow tests are made to verify the mission operations software and associated interfaces. The spacecraft will be put under the control of the ESOC-staffed Ulysses Payload Operations Control Centre (UPOCC), installed at the JPL Mission Control and Computing Center in Pasadena, California. Testing consists primarily of checking telemetry-data flows and execution of commands and flight dynamics test cases.

A Deep-Space-Network (DSN) compatibility test is also performed to verify the overall spacecraft transponder communications, in addition to a DSN ground-equipment delay measurement to enable the HUS experiment to time-correlate gamma-ray burst data with ground time and thereby with similar data from other spacecraft.

One further compatibility test involves integration of the flight RTG to the spacecraft to verify both its mechanical and electrical compatibility, and to determine the radiation background for the scientific instruments, and the HUS experiment in particular.

Flight preparations
Some experiments require a degree of access for their flight preparation that is not available later in the operations flow. Such flight preparations must therefore be performed in Building AO very early in the overall flow. The majority of the thermal close-out work will also be performed in this facility.

Activities in ESA-60
Hydrazine filling and final RCE tank pressurisation are to be performed in ESA-60, which is designed for hazardous processing. A specially trained joint ESTEC/JPL team is employed, and all the precautions essential for operations involving this inflammable, toxic, corrosive fluid are implemented.

ESA activities in the VPF
Low-gain-antenna integration
The integration of these antennas and the verification of their interfaces is the last of the so-called 'stand-alone activities' for ESA.

Mating
Combined operations for ESA begin with the mating of the spacecraft to the already integrated IUS and PAM-S stages. A number of combined operations with the complete stack then take place.

Interface Verification Testing (IVT)
This testing is conducted using the Cargo Integration Test Equipment (CITE), which simulates essential Shuttle Orbiter command and telemetry datalink equipment. It is a test that is mandatory before NASA will commit the Shuttle to fly.

End-to-End Testing (ETE)
This testing is conducted using the complete Shuttle payload, including the Ulysses spacecraft, through the CITE and JSC Mission Control Center to the various Operations Control Centres, in our case the UPOCC at JPL. Spacecraft control is transferred from the ESA check-out equipment (OCOE) in Building AO to the UPOCC with the

spacecraft in launch mode. Telemetry data is stripped from the Orbiter/IUS/Ulysses composite data stream and directed to the UPOCC, from which commanding representing the in-orbit checkout within the cargo bay is carried out. The entire data link from payload to UPOCC representing the Shuttle phase of the mission is thereby validated.

Spacecraft close-out and canister loading
Prior to leaving the VPF, a final spacecraft close-out and inspection is to be made, after which the complete stack will be mounted in the KSC-provided canister for transport to the Launch Pad.

Activities at the Launch Pad
The Pad operations at KSC can be divided into two parts. When the payload first arrives, it will be lifted into the Payload Changeout Room (PCR), which is a clean facility with doors that match those of the Orbiter's cargo bay. Some three days later, the Orbiter will arrive from the Vertical Assembly Building (VAB) and its cargo doors will be opened to accept the payload. Final flight preparations for both the spacecraft and its experiments will be made in the Payload Changeout Room at the Launch Pad, before the complete payload stack is loaded into the Orbiter's cargo bay.

Once the composite is safely installed in the cargo bay, the IVT and ETE testing conducted in the VPF will be repeated with the Shuttle itself instead of CITE. As already mentioned, the last scheduled activity in the Orbiter Cargo Bay will be the integration of the RTG into the spacecraft, which will be handled by specially trained ESA and Dornier personnel (the RTG interfaces for cooling and pressure release are JPL responsibilities). Only when the RTG verification is complete will the spacecraft be configured for launch and the cargo-bay doors of Space Shuttle 'Discovery' closed.

After RTG integration, daily spacecraft health checks will be made based on a number of commands pre-stored in the Shuttle's launch processing system.

Personnel
For the launch campaign, the ESA and industrial staff will work as a combined team. The combined staff will peak at a maximum of 34 for the stand-alone activities, dropping to approximately half of this number during the combined operations (Fig. 2). During stand-alone activities, primarily one 8 h shift will be worked 5 d per week by the Ulysses Team. Overtime will be worked as and when required to ensure that the target date for spacecraft mating in the VPF is met, so as not to endanger the combined activities that follow.

During the combined activities in the VPF, NASA will operate a single 8 h shift per day, 5 d per week, and the Ulysses staff deployment will be such as to support this schedule. For the period to be spent at the Launch Pad, payload activities are scheduled on a 2x8 h shift per day, 6 d per week basis, except for STS activities, which are based on a 3x8 h shift per day, 7 d per week work schedule. The Ulysses staff will also be supporting these activities as and when required.

The staff will be deployed primarily at KSC, to support spacecraft processing. However, some of the tests require special support at the UPOCC or at JSC (in particular the Joint Integrated Simulations). A major reallocation of spacecraft staff will occur immediately after final RTG integration. They will be redeployed at UPOCC-JPL for launch and early mission operations.

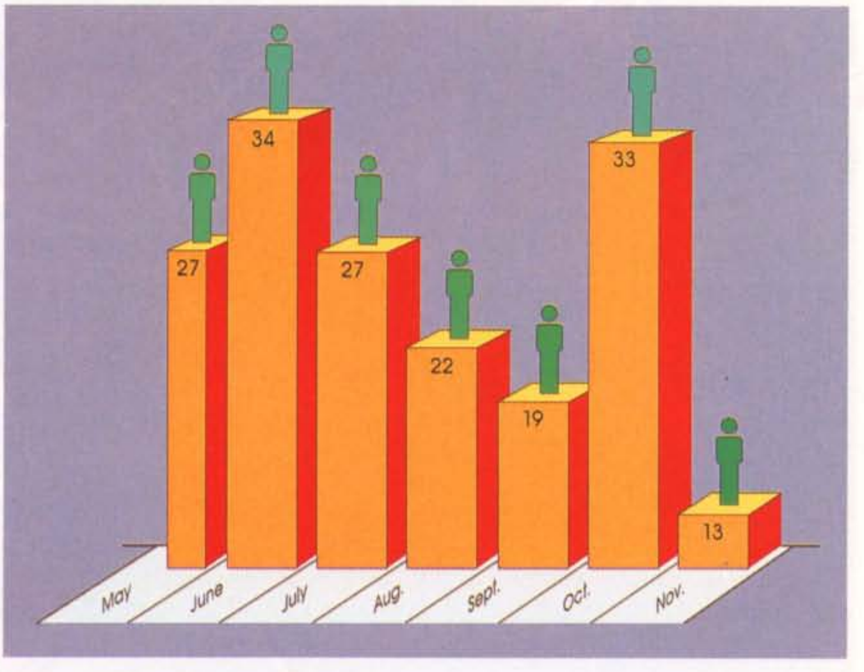

Figure 2. Overview of manpower at KSC/JPL, not including ESOC staff at the UPOCC or experiment support teams from universities

Figure 1. Configuration of the payload assembly

Post-Launch Operations and Data Production

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Post-launch operations

In-Shuttle operations

On 5 October 1990, the Space Shuttle 'Discovery' will be standing on Pad 39B at Kennedy Space Center (KSC), its payload consisting of the Ulysses spacecraft, and the so-called 'Upper Stage'* that will propel the ESA spacecraft on its journey to Jupiter and over the Sun's poles. Nine minutes before launch (i.e. at L-9 min), the Ulysses Mission Operations Manager, located at Jet Propulsion Laboratory (JPL) in Pasadena, will give a 'Go for Launch' for the spacecraft and the supporting ground segment to the Payloads Officer and Flight Director at Johnson Space Center (JSC). This information will then be relayed to the Launch Director at KSC as one of the many launch criteria that will influence the decision to launch 'Discovery'.

At L−0, provided all launch criteria are met, 'Discovery' will lift off into the Florida sky carrying with it the first spacecraft ever to undertake a journey over the Sun's poles.

At L+9 min, the Shuttle's main engine will be shut off, and 1 min later the external tank will be jettisoned.

Approximately 50 min into the flight, the Ulysses Operations Team will be called upon to provide an initial status report on the spacecraft's systems. The Upper Stage Team, located at the USAF Consolidated Space Test Center (CSTC) in Sunnyvale (Calif.), will also be required to provide such a status report. Both reports will be prepared by analysing the telemetry data being received via the Space Shuttle and the supporting ground and space networks.

Provided the Shuttle has achieved the correct orbit, and based on these two reports, the decision will then be made to open the payload-bay doors. This will occur about 1 h into the flight.

At 1 h 30 min into the flight, the Ulysses Team will be given command access to the spacecraft. The in-orbit checkout and spacecraft reconfiguration will then commence which is necessary prior to deployment of the Ulysses/Upper-Stage composite from the Shuttle. This checkout will be completed over a 3 h period, during which the Ulysses team will have discrete command 'windows' in which to carry out their task (these 'windows' must be interleaved with those for other Shuttle and Upper-Stage activities).

5 h 40 min into the flight, the Ulysses Mission Operations Manager will be required to give the 'Go for Deployment' for the Ulysses spacecraft. The Upper-Stage Team will also give a 'Go' at this time. This activity will be preceded by rotation of the Ulysses/Upper-Stage composite to its initial deployment elevation of 29°. Once the 'Go for Deployment' has been given, the tilt table will be further elevated to 58° in preparation for the deployment proper.

At 6 h 1 min into the flight, the payload will be physically separated from 'Discovery'. The Ulysses Team will then have no further contact with their spacecraft until its acquisition by the Deep-Space Network (DSN) as a free-flyer.

The timeline for the Upper-Stage burn and spacecraft separation is as follows:
L+6 h 12 min ... Release RTG cover gas.
L+7 h 8 min ... IUS-1 burn.
L+7 h 14 min ... IUS-2 burn.
L+7 h 15 min ... PAM-S ignition.
L+7 h 25 min ... PAM-S/spacecraft separation.

* The Boeing Inertial Upper Stage (IUS) and the McDonnell-Douglas PAM-S, which are known collectively as the 'Upper Stage'.

The next contact will occur when the first Deep-Space Network station acquires the spacecraft and transmits this information to JPL in Pasadena. This should occur at L+7 h 56 min via the Canberra DSN station in Australia.

Initial in-orbit operations

An on-board program will switch on one of Ulysses' S-band transmitters at the time of spacecraft separation from the PAM-S. Consequently, the Canberra station will immediately be able to establish a telemetry link, and thereafter the command link. There will then follow a technical assessment of the status of the spacecraft, which in turn will be followed by an adjustment to the spacecraft's spin rate in preparation for radial-boom deployment.

Interleaved with initial spacecraft operations will be the task of acquiring ranging and Doppler data to enable the ground navigation team to make an extremely accurate assessment of the orbit that has been achieved. This task will continue uninterrupted over a period of three days, in order to gather sufficient data to make this analysis accurately.

Operations will then have reached mission day 6, and the next step will be an Earth-acquisition manoeuvre, which is needed to point the spacecraft's high-gain antenna towards us. This operation will take place over four mission days, in 8 to 10 h periods of concentrated activity.

Mission days 10 to 13 will be used to carry out trajectory-correction manoeuvre No. 1 (TCM-1), in order to correct for any deviations from the desired trajectory introduced by the IUS/PAM-S burn. This aspect is described in detail in a companion article in this Bulletin.

From mission day 14 until mission day 60, payload switch-on will take place according to a carefully planned sequence (Table 1).

Routine operations

From this phase onwards in the mission, operations become routine in nature and continuous data gathering becomes of prime importance. During each 24 h period, one 8 h pass will be selected at an in-view DSN site. Typically, during the pass attitude corrections to keep the high-gain antenna pointed towards the Earth will be carried out, experiment reconfiguration requests will be processed, and the onboard tape recorder will be played back to ground to recover the previous 16 h of data acquired during the out-of-view period.

Payload Switch-On

Day (L+)	Event
14	Switch-on KEP. Release all covers (except LAN). Set BAM aperture to maximum. Start KEP checkout.
15	Switch-on GRU and check out. Continue KEP and GRU checkout.
16 – 17	Weekend monitoring only.
18 – 19	Switch-on SIM and check out.
20	Switch-on HED and check out.
21 – 22	Monitor and control KEP, GRU, SIM, HED.
23 – 24	Weekend monitoring only.
25 – 27	Monitor and control KEP, GRU, SIM, HED.
28 – 30	Carry out TCM 2. Switch-off SIM and HED experiments. Release excess fuel. Release LAN cover. Switch-on X-band. Switch-on STO. Deploy wire booms. Switch-off X-band. Deploy axial boom. Switch-on HED experiment and configure to required status. Continue STO checkout. Switch-on SIM and configure to required status (no checkout). Continue STO checkout.
31	Weekend monitoring only.
32 – 33	Switch-on GLG low voltages. Continue STO checkout. Continue GLG switch-on.
34	Continue GLG/STO checkout.
35 – 36	Switch-on HUS and check out.
37 – 38	Weekend monitoring only.
39 – 40	Switch-on LAN and check out.
41	Switch-off S-band, switch-on X-band. Start real-time use of tape recorder.
42 – 43	Switch-on BAM and check out.
44 – 45	Weekend monitoring only.
46 – 50	Monitor and control all experiments.
51 – 52	Weekend monitoring only.
53 – 57	Final check of all experiments. Build up routine use of tape recorder.
58 – 59	Weekend monitoring only.
60	Carry out routine-pass operations under full coverage conditions.

However, several non-nominal events will take place during the lifetime of the mission which will require deviation from this routine pattern. These critical mission event dates are as follows:

Event	Date	
First opposition	December	1990
First conjunction	August	1991
Jupiter encounter	February	1992
Second opposition	February	1992
Second conjunction	September	1992
Third opposition	March	1993
Beginning of first solar pass	May	1994
Perihelion	February	1995
Beginning of second solar pass	May	1995
End of mission	September	1995

Each of the above events gives rise to an increase in the monitoring and critical-coverage requirements that the spacecraft team must support.

Mission-operations organisation
Mission operations embrace all activities required between launch and the end of the mission. They are aimed at ensuring that the spacecraft and its payload remain functional throughout their design lifetime, and that the scientific investigations return a maximum of data.

All Ulysses operations will be under the responsibility of the Mission Operations Manager, appointed by ESA (Deputy Manager appointed by JPL). Based on the division of responsibilities between ESA and NASA, the Mission Operations Team is split into two parts, reflecting the different mission-operations tasks to be carried out by the two agencies.

To economise on the amount of skilled manpower that has to be provided by ESOC, their attendance will be limited to 8 h per day, 5 d per week. At all other times the spacecraft, when in view, will be monitored by a specially trained team of JPL technicians. This team will receive their monitoring criteria from the ESOC team, and will also be responsible for confirming that all scheduled commands to the spacecraft are transmitted correctly. In the event of them detecting an anomaly, they will immediately contact an on-call ESOC team member, who will initiate the necessary corrective action.

The data-gathering ground segment
The data-gathering ground segment can be conveniently divided into two parts:

(i) the DSN ground stations and associated multi-mission facilities at JPL, provided by NASA;
(ii) the data-processing computer, its peripherals, and associated software, provided by ESA.

In addition, JPL will provide the infrastructure for the ESA facilities and team located there.

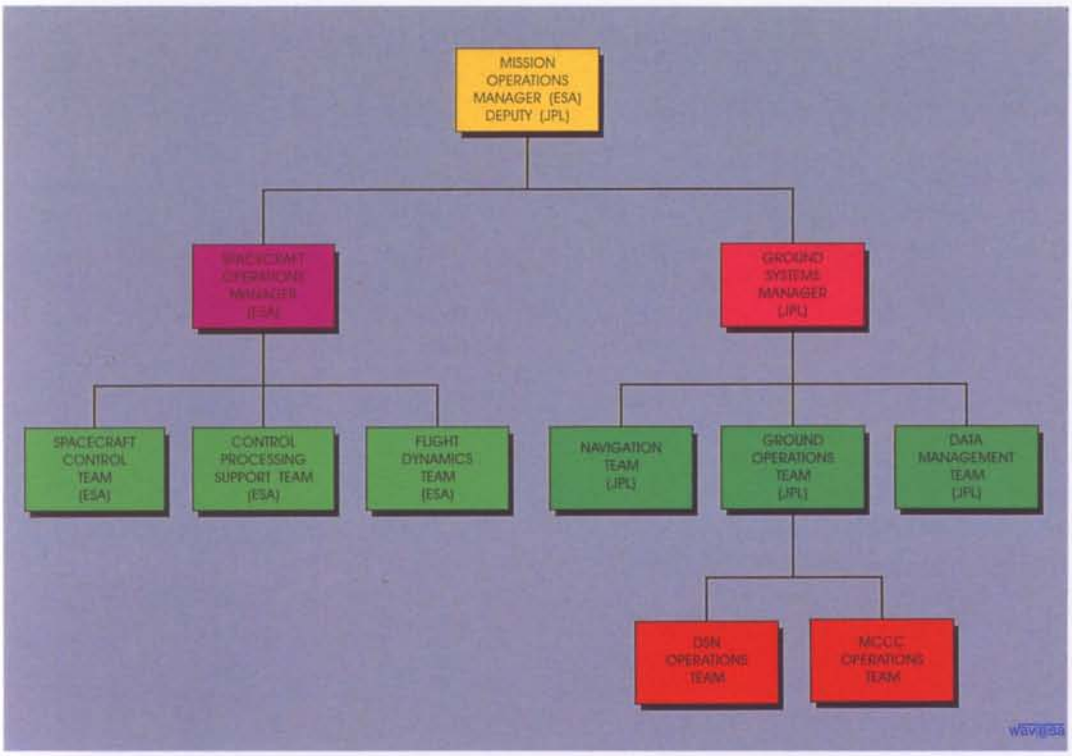


Figure 2. Organisation of the Mission Operations Team

It will process the tracking data to provide trajectory determination, and will supply the Ulysses Principal Investigators with processed scientific data generated by their experiments onboard the spacecraft, and with the radio-science data.

Telemetry data from the spacecraft will be acquired by the DSN stations at Goldstone in California, Madrid in Spain, and Canberra in Australia. These data will then be transmitted via the NASA communications network to the JPL Mission Control and Computing Center in Pasadena. Here the data will be split, with one path flowing to the ESA data-processing computer (UMCS) where it will be processed in real-time, and the other to the Data Records System, where the incoming data will the processed in non-real-time.

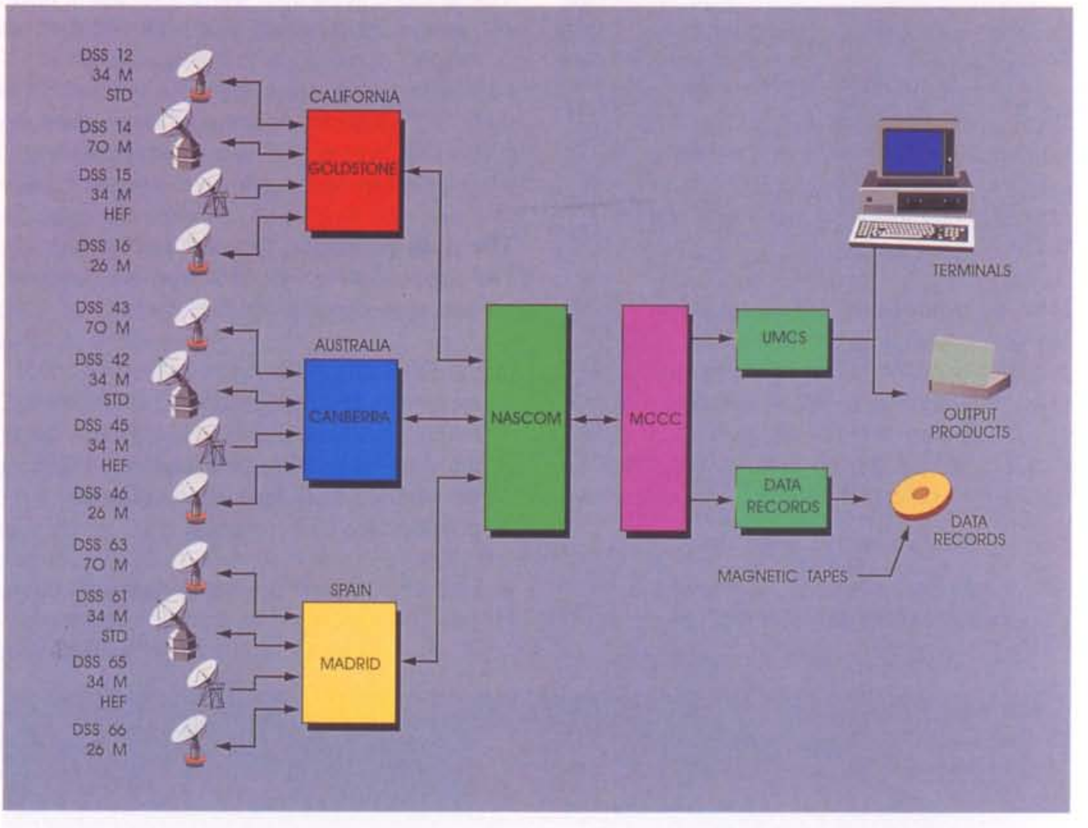


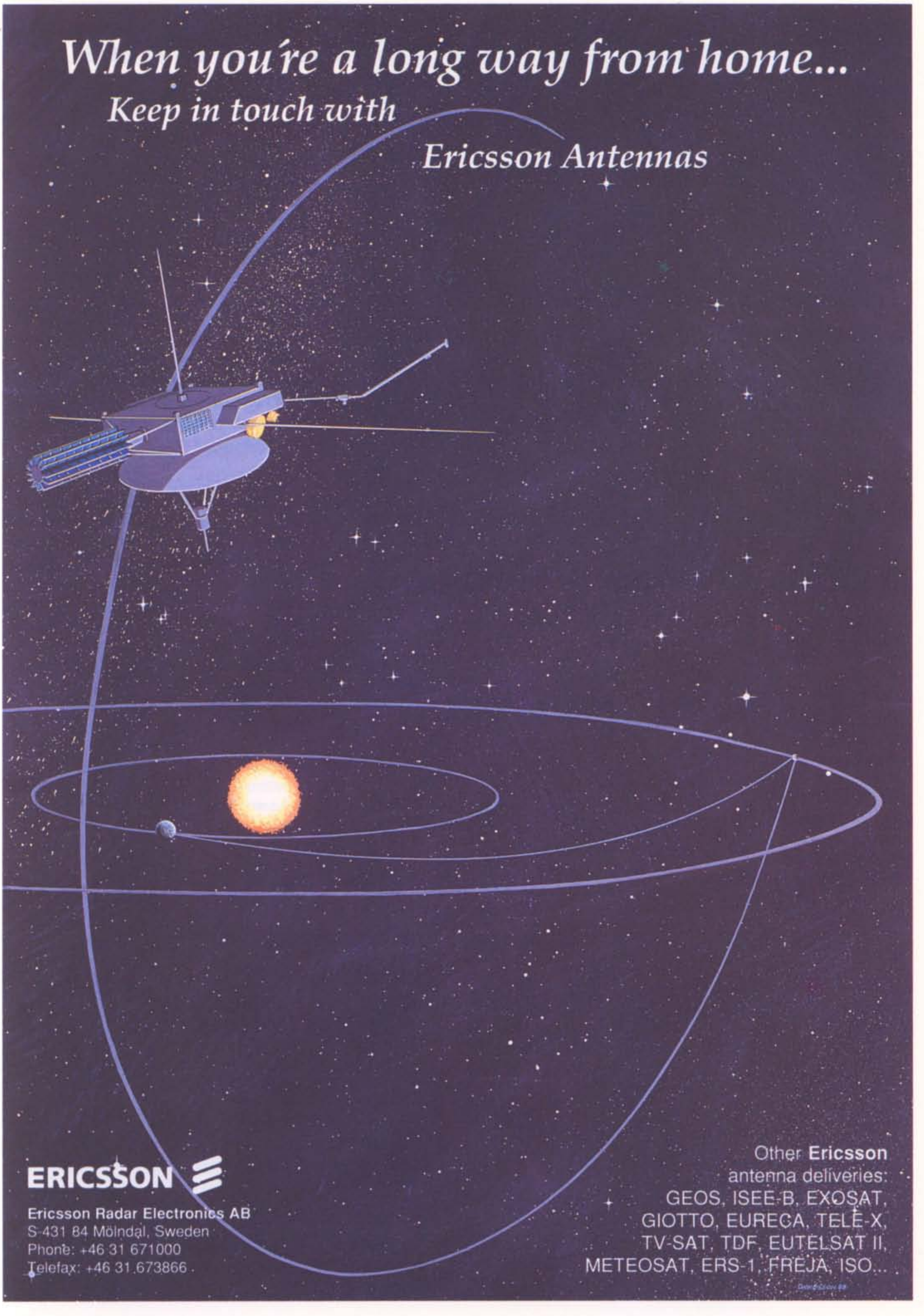
Figure 3. Overall configuration for data gathering

Ulysses data production

Data production on the ESA data-processing computer will be performed in an offline mode that does not interfere with real-time operations. Quick-look engineering data will be produced on a weekly basis for each experiment and mailed to the appropriate Principal Investigator. These data will be used by the experimenter teams to assess the performance of their instruments.

The incoming Ulysses data will also be processed by the Data Records System (DRS), where they will be put in 'time-of-generation' order before being sorted (decommutated) by experiment. Portions of the data will be made available to the experiment teams during each tracking pass. All data will be written on magnetic tape as Experiment Data Records (EDRs), which will be the primary method of transferring data to the Ulysses experiment teams. Data that relate to the trajectory will also be included in a supplementary EDR that will also be sent to the experiment teams. These magnetic tapes will be shipped to each of the experiment teams on a weekly basis.

A so-called 'Common Data Record' (CDR) will also be produced by the DRS, in order to deliver a selected set of time-ordered, processed scientific data that will provide investigators with evidence of data trends, significant events, etc. These data will permit the identification of scientifically interesting time periods for further detailed analysis and correlative studies. They will be produced periodically and sent to each experiment team for analysis.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Orbit Design and Control for Ulysses

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Introduction

Interplanetary probes can be accelerated by presently available rockets to speeds such that they will leave the Earth's vicinity with velocities of up to 10–11 km/s. This figure is valid for smaller spacecraft like Ulysses, with an initial mass of 360 kg, when launched by very powerful rockets. For larger spacecraft, like the Gallileo probe that recently left Earth on its voyage to Jupiter, the departure velocity achievable is much lower.

The velocity of the Earth itself in its almost circular orbit around the Sun is 29.8 km/s (varying by ±0.5 km/s during the year due to the eccentricity of the Earth's orbit). Ulysses' departure velocity will in fact be 11.4 km/s, which will be the highest ever achieved by a space probe.

With such a departure velocity aligned with the orbital velocity of the Earth, a space probe would enter an elliptic heliocentric orbit with an aphelion of 22 AU*. With this departure velocity directed in the opposite direction to the Earth's velocity, it would enter an elliptic heliocentric orbit with a perihelion of 0.23 AU.

* 1 Astronomical Unit is equal to 149 million km, which is the mean distance between the Earth and the Sun.

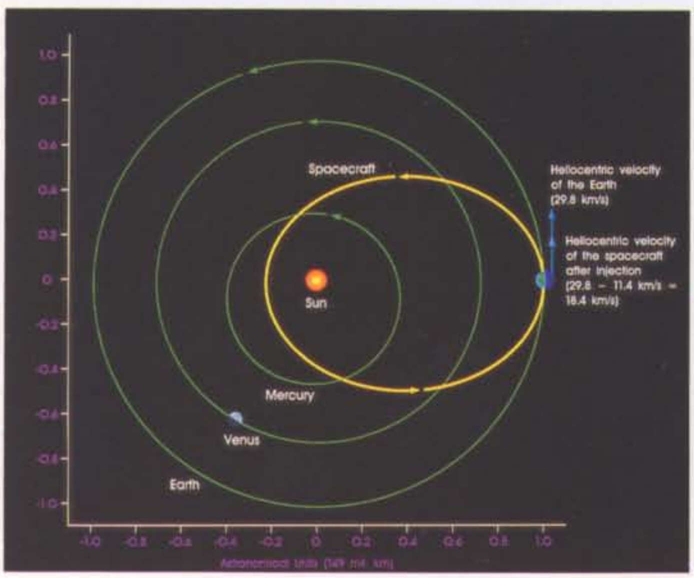
The planets of our Solar System, including Earth, circle the Sun in almost the same plane. It can be seen from Figures 1 and 2 that, with an Earth departure velocity of 11.4 km/s, heliocentric ranges from inside Mercury to outside Uranus can be reached without resorting to any 'planetary swing-by' techniques.

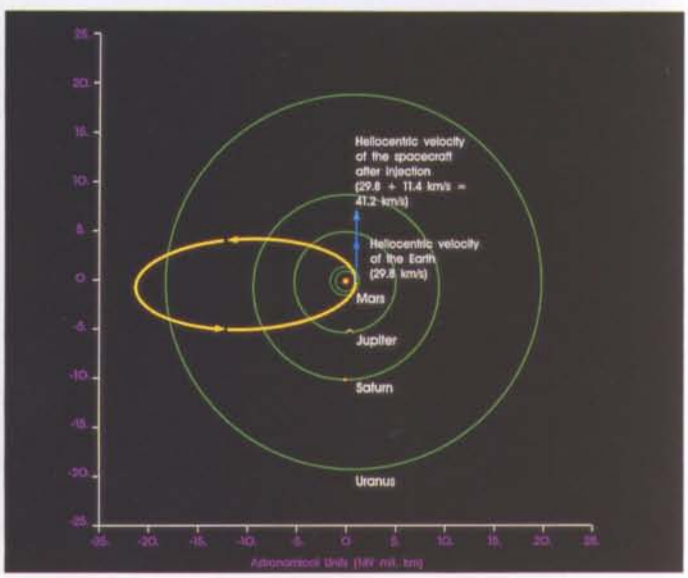
Interplanetary missions prior to Ulysses have essentially been based on the principles described above. The spacecraft have been injected into an orbital plane close to that of the Earth (the so-called 'ecliptic plane') and targeted towards a planet or other celestial body (e.g. comet) close to the ecliptic plane. For some missions, such as Voyager, this first planetary encounter has been used to deflect the spacecraft's trajectory in order to reach another planet, but this second planet has again been close to the ecliptic plane. Consequently, all spacecraft have been staying close to the ecliptic plane throughout their missions.

The Ulysses probe will be the first spacecraft to leave the ecliptic plane to observe the poles of the Sun. However, direct injection of the spacecraft from Earth into a solar-polar orbit is not possible with present launcher systems. With its Earth departure velocity of

Figure 1. (left) The inner planetary system and a possible inward spacecraft trajectory with 11.4 km/s departure velocity

Figure 2. (right) The outer planetary system and a possible outward spacecraft trajectory with 11.4 km/s departure velocity





11.4 km/s, the maximum ecliptic inclination that can be reached is 23°, the effective initial heliocentric velocity when the launcher is standing on the launch pad being 29.8 km/s in the ecliptic plane (Fig. 3).

The only means of achieving a high ecliptic inclination is to use a planet to deflect the spacecraft's trajectory and thereby change the direction of its initial heliocentric angular momentum due to the orbital velocity of the Earth (i.e. the 29.8 km/s) without using propellant.

Ulysses will use Jupiter for this purpose. It will be launched into a heliocentric orbit with the largest possible energy that the launcher system* permits, such that it follows an outbound trajectory similar to that shown in Figure 2, until it encounters Jupiter with an arrival velocity of 13.5 km/s.

The orbital velocity of Jupiter will be 12.6 km/s when Ulysses arrives (it varies between 12.5 and 13.7 km/s over a Jovian year due to the eccentricity of the planet's orbit). The simple vector diagram in Figure 4 indicates that a wide range of inclinations for Ulysses' orbit relative the orbital plane of Jupiter can be achieved, depending on the heliocentric velocity, i.e. the perihelion radius, required.

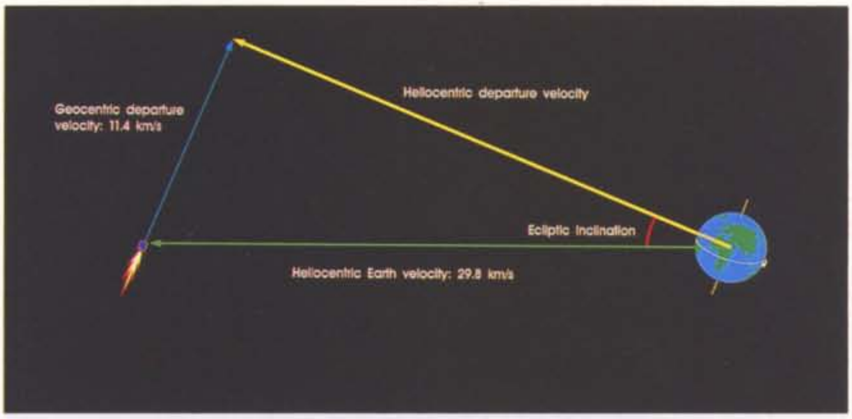
Basic swing-by analysis

The motion of Ulysses in the neighbourhood of Jupiter (several days before and after the closest approach) can be approximated with good accuracy by a hyperbola. The angle between the incoming and the outgoing asymptotes of that hyperbola depends on the asymptotic velocity and on the miss-distance, indicated in Figure 5.

For a given asymptotic velocity, i.e. arrival velocity, the deflection angle increases and the pericentre radius decreases as the miss-distance decreases. The ultimate limit on the deflection angle that can be achieved is that the pericentre radius cannot be less than one Jupiter radius. The 'miss-vector' indicated in Figure 5 with length equal to the miss-distance orthogonal to the incoming asymptote defines both the amount and the direction of the deflection.

Small changes to the Ulysses orbit will, in general, result in changes both to the

* A two-stage IUS with a PAM-S added as a third stage, fired from a 300 km-high circular Earth orbit, into which Ulysses will be placed by the Space Shuttle 'Discovery'.



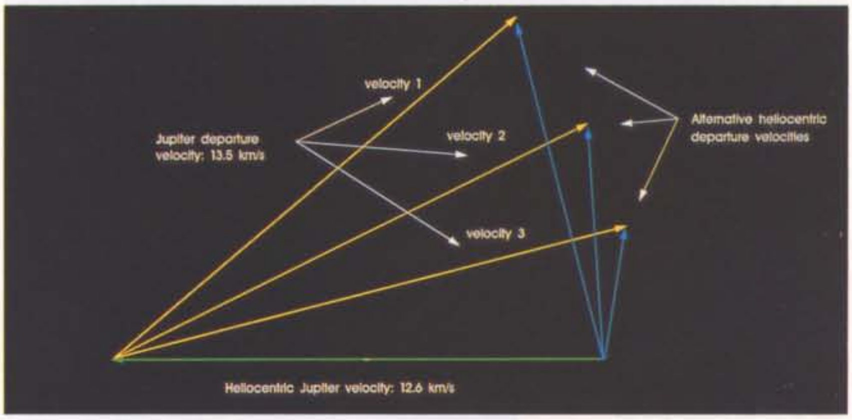


Figure 3. Direct injection into an orbit out of the ecliptic plane

Figure 4. Using Jupiter to swing into a solar-polar orbit

asymptotic arrival velocity at Jupiter (magnitude and direction) and to the miss-vector. However, to a first approximation, the change in deflection can be considered to be a function only of the change in miss-vector, neglecting the smaller effect of the change in arrival velocity.

Optimisation of the trajectory

The criteria that have been defined for the selection of the Jupiter fly-by parameters are to maximise the time spent over the polar regions of the Sun (defined as the regions above 70° heliographic latitude) and to achieve the maximum heliographic latitude. The heliographic latitude is defined relative to the rotational axis of the Sun, which deviates by 7.1° from the pole of the ecliptic plane.

Constraints to be respected in this optimisation are that the perihelion must be no lower than 1.28 AU, and the heliocentric radius at maximal heliographic latitude (south and north solar pole passages) must be no larger than 2.3 AU.

With the 13.5 km/s Jupiter arrival velocity that can be imparted to Ulysses, it turns out that a satisfactory orbit can be achieved with a pericentre radius of about 6 Jupiter radii. To avoid exposing the spacecraft to excessive radiation doses during the Jupiter passage, it was agreed to limit the optimisation to miss-

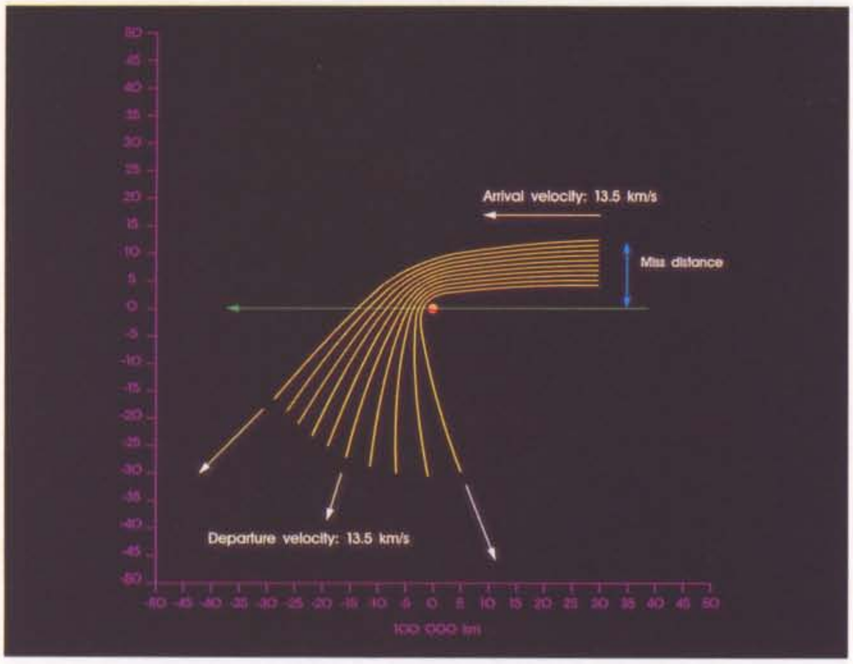


Figure 5. Possible deflections at Jupiter for a spacecraft arriving with a velocity of 13.5 km/s. The most deflected orbit has a miss-distance of 500 000 km and a pericentre radius of 2.26 Jupiter radii. The least deflected orbit has a miss-distance of 1 400 000 km and a pericentre radius of 12.2 Jupiter radii (1 Jupiter radius = 71 398 km).

vectors resulting in a pericentre distance of at least 6 Jupiter radii (i.e. more than 430 000 km).

For each arrival time (i.e. Jupiter position and velocity) and hyperbolic asymptotic arrival velocity (direction and magnitude), the optimal miss-vector (defined above) can be computed that maximises the number of days over the solar poles and the heliographic latitude reached taking these constraints into account. To a certain extent, there is a trade-off between these parameters. A higher heliographic latitude can mean a higher angular rate for the polar passage, and therefore a shorter time above 70° heliographic latitude. By increasing the arrival velocity, both of these quantities can be increased, provided that an optimal miss-vector is selected for each arrival velocity.

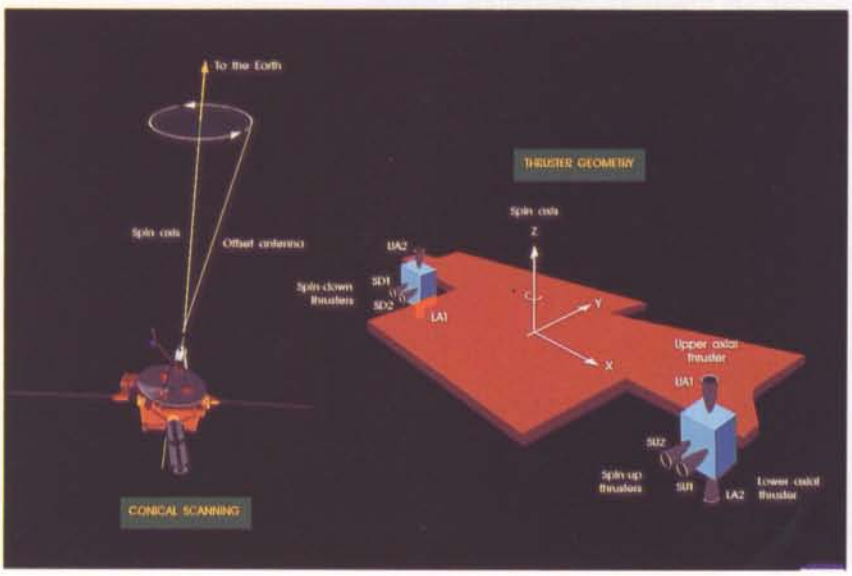


Figure 6. Ulysses' Attitude and Orbit Control System (AOCS)

The guidance system of the IUS has been programmed such that, in the case of a perfect injection (i.e. zero dispersion), the fly-by hyperbola for Jupiter will correspond to a miss-vector that is optimal for the asymptotic hyperbolic arrival velocity. The fly-by time has been chosen to be as early as possible, as this results in a maximum hyperbolic arrival velocity at Jupiter.

The Attitude and Orbit Control System (AOCS)

Ulysses is a spin-stabilised spacecraft communicating with the ground via a high-gain antenna aligned with its spin axis (Fig. 6).

The spacecraft's attitude-determination system is based on the 'conical scanning' of this high-gain antenna. The antenna's beam is slightly offset from the spacecraft spin axis and the signal strength of the uplink carrier is monitored. If the ground station transmitting that uplink signal is in the direction of the spacecraft's spin axis, the monitored signal strength will be constant; if it is offset from this direction, the spacecraft's rotation will result in a varying offset between the antenna beam and the direction to the station, and therefore in a periodic variation in the received signal strength.

From the amplitude of this signal-strength variation, the amount of offset between the spacecraft's spin axis and the direction to the Earth can be determined (based on the known characteristics of the high-gain antenna). From the phase of these variations, the direction of mispointing can be determined, the signal strength being a maximum at the moment the antenna beam's offset from the spin axis is in the same direction as the ground station. By comparing the phase of the signal-strength variation with the times of Sun-presence pulses in a meridian Sun slit on the spacecraft, it is possible to compute the pointing direction of Ulysses' spin axis relative to inertial space from the known directions to the Sun and the Earth.

This method of determining spin-axis pointing direction can only be used if the transmitting ground station is in the so-called 'main lobe' (i.e. prime coverage area) of the high-gain antenna. If this is not the case, the only accurate information about the direction of the spin axis that can be obtained is the angle between this axis and the direction to the Sun that can be determined from the Sun-sensor readings. This means that geometrically it is known on which cone around the direction to the Sun the spin axis is located (Fig. 7).

Ulysses is equipped with eight thrusters grouped together in two clusters, one on each side of the spacecraft (Fig. 6). Each cluster has a lower axial thruster giving a force in the 'upward' direction parallel to the spin axis, and an upper axial thruster giving a force in the 'downward' direction. One cluster has two spin-up thrusters, and the other has two spin-down thrusters. Orbit manoeuvres are made either by operating a spin-up and a spin-down thruster together in pulsed mode, synchronous with the spin, or by firing the lower (upper) axial thrusters of the two clusters together in continuous mode. In the first case a net force in any direction orthogonal to the spin axis can be produced; in the second, the direction of the force will be aligned with the spin axis.

The thrusters will use hydrazine drawn from a fuel tank onboard the spacecraft pressurised with gaseous helium (a so-called 'blow-down system'). The less fuel there is in the tank, the lower the gas pressure and therefore the lower the fuel feed rate to the thrusters will be, and the smaller the thruster force that will be delivered. Use of the first 13 kg of the 33.5 kg of hydrazine that will initially be in the tank will reduce the available thruster force from 2 Newton (per thruster) to 1 Newton, which is the highest allowed once the spacecraft's axial boom has been deployed (to avoid risk of damaging it).

All Ulysses orbital manoeuvres will be made in Earth-pointing mode, except possibly in certain contingency cases.

The orbit manoeuvres

Once Ulysses has been successfully injected into interplanetary orbit and this orbit has been determined using ranging and Doppler data (obtained by the NASA/JPL Deep-Space Network), the task of designing an orbit-correction strategy for the actual orbit that has been achieved will begin in earnest. The baseline is to make the orbit correction in Earth-pointing mode with a radial manoeuvre and an axial manoeuvre 10 days after the spacecraft's injection into interplanetary orbit. These two manoeuvres will provide the major trajectory correction required, but other smaller manoeuvres will be necessary as 'adjustments' for the dispersions in the two main manoeuvres.

The spacecraft's arrival time at Jupiter will be selected based both on the mission-optimisation criteria discussed above and on the fuel budget. An earlier arrival time will result in a higher arrival velocity and hence in a better mission performance as the miss-vector will be selected optimally for the arrival velocity. Arrival two days earlier at Jupiter could typically mean 10 more days above 70° heliographic latitude and a 0.5° increase in maximal heliographic latitude. There will be one arrival time that results in minimum fuel usage; the more the actual arrival time deviates from this, the more propellant will be required.

A rough rule-of-thumb is that use of 1 kg of hydrazine can provide a velocity increment (so-called 'delta-V') of 6 m/s, resulting in a 6 h earlier arrival at Jupiter. The ideal size for the trajectory correction would be something between 80 and 120 m/s, i.e. at least 80 m/s so that the axial boom can be deployed, and by preference not larger than 120 m/s in order to have comfortable fuel reserves for the rest of the mission, and also in case of contingencies, when more fuel could possibly be required than for the nominal mission plan (the initial fuel load equates to about 200 m/s of delta-V). If the actual launch accuracy is reasonably close to that predicted, it will be possible to achieve a satisfactory orbit-correction manoeuvre with the baseline strategy of an axial and a radial manoeuvre on day 10 without exceeding the 120 m/s limit.

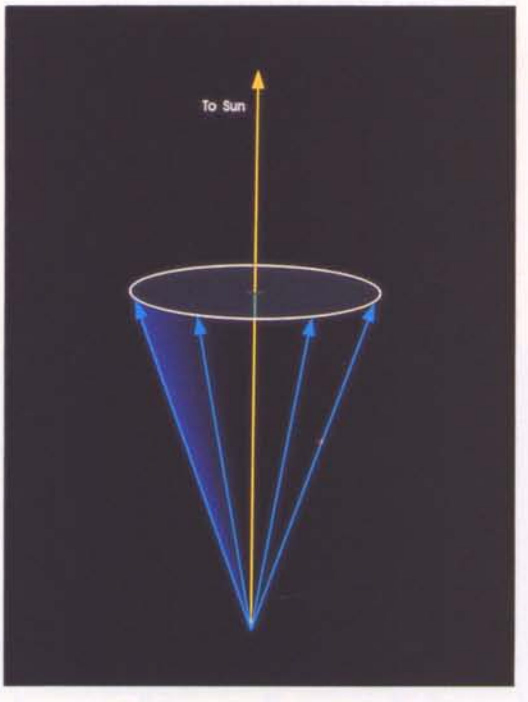


Figure 7. Possible spin-axis pointing directions knowing the solar aspect angle

As mission performance is improved by an earlier arrival date, the trade-off will ultimately be between maintaining fuel reserves for contingencies and enhancement of the scientific mission.

Industrial Cooperation on Ulysses

G. Hampel
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Industrial participation

After the initial ESA in-house studies, industrial participation in what was ultimately to become known as the Ulysses mission began when British Aerospace, a member of the STAR Consortium, undertook a feasibility study (so-called 'Phase-A' study) of the system aspects of the mission. Contractors from two other consortia, MESH and COSMOS, subsequently performed studies on specific topics related to the mission.

The Ulysses project activities began to include wider industrial participation with the tenders for Phase-B1 (design definition phase) in February 1979 by the STAR Consortium, under Dornier's leadership, and by the competing COSMOS Consortium, led by MBB.

The STAR consortium was ultimately successful in winning the contracts for Phase-B2 (final design update) and for the project's main development phase, the so-called 'Phase-C/D'. Figure 1 shows the resulting consortium as it emerged at the start of Phase-C/D, once the ESA rules governing geographical industrial return had been applied.

In the event, the joint effort by these industrial companies was to be put to the test over a much longer period than was ever envisaged at the outset. When the project started, a new type of spacecraft, the first European interplanetary probe, was to be developed and built in an extremely short time span, with little more than three years between the start of Phase-C/D and launch. A programme approach was therefore adopted that made maximum use of existing hardware, modified and supplemented with new developments wherever necessary. In this way, the experience – both technical and managerial – gained in previous projects could be effectively exploited.

Effect of launch delays

When the first launch delays due to launch vehicle schedule slippages emerged, a scheme had to be adopted that would both keep costs to a minimum and yet maintain the core team's composition (see article on page 73). The system-level qualification and acceptance-test programmes were somewhat stretched out, but continued to completion, in December 1983, without interruption. A transponder problem was resolved and some components were subsequently replaced by more radiation-resistant types, neither of which affected the spacecraft system design, before the fully acceptance-tested flight spacecraft went into storage until early 1985.

Recertification of the spacecraft in preparation for a May 1986 launch was then conducted with:
- a team that had suffered only a few personnel changes, both at ESA and in industry
- all flight- and flight-spare hardware tested and available
- a schedule that included a small buffer for contingencies.

Hence everything was thoroughly organised and the spacecraft was at Kennedy Space Center (KSC) being prepared for launch in January 1986 when the 'Challenger' accident occurred, causing a sudden halt to the programme.

It soon became clear that there would be another lengthy storage period, of as yet unknown duration, for Ulysses. By this time, virtually all of the staff of the ESA and the industrial teams were committed to other projects from mid-1986 onwards and could not be further retained for the Ulysses project. In order to protect the future of the project as far as possible, very careful archiving of all project-related documentation (including very detailed handbooks written when the first delay was announced) was instituted. Even the personal working files of all team members were collected and put into safe storage in readiness for another new start.

The storage from 1986 until 1989 was not an idle time for the remaining team members. In the process of defining a new launch scenario between ESA and NASA, the impacts of diferent launcher alternatives and launch dates had to be analysed. Following the 'Challenger' accident, NASA instituted many new procedures, mainly safety-related, which had to be absorbed and followed. Also, a number of component problems being identified in other projects had to followed up, on one occasion leading to the replacement of more than one hundred microprocessors. All of this was only possible with the close cooperation of individuals in and the managements of all the Consortium companies, who responded quickly in support of the ongoing work.

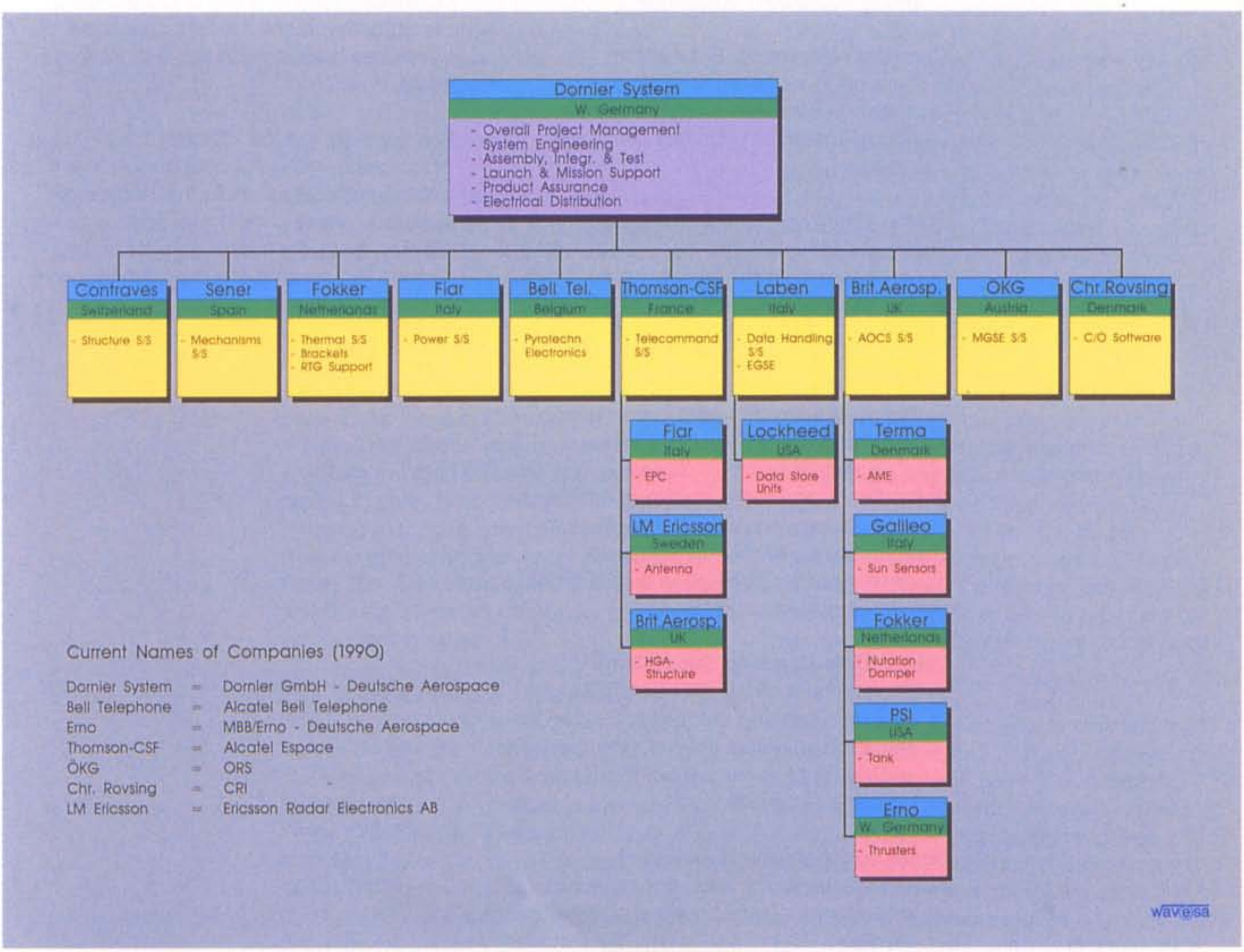
With the confirmation of the current launch schedule, the project sprang to life once again. Although only small hardware modifications were necessary to accommodate the new Shuttle safety rules, mission profile, and Upper Stage interfaces, the cooperation and participation of the 'old guard' was still a major contribution in getting to the present stage and in evaluating all of the new requirements.

When an existing design has to be modified — no matter how small the modification — there is a lot to be considered. The detailed design may be well-documented, but finding out the rationale and historical background of a particular design solution is frequently difficult. Anyone not acquainted with the details must do a significant amount of searching and reading to verify that a certain seemingly minor modification will not create problems in a quite different area.

Industrial participation since 1986

Although the formal industrial participation during Phase-C/D is as shown in Figure 1, a number of companies have had to perform additional tasks in the 1986–1989 period, often at considerable inconvenience to their ongoing projects. Principal among them, listed in alphabetical order, with the major

Figure 1. The Industrial Consortium for the Ulysses Main Development Phase (Phase-C/D)



tasks they were called upon to perform, were:

Alcatel Espace (Telecommunication Subsystem)
- Replacement of random-access memory (TCC 244 RAM) in the decoders as a precaution, prompted by an alert from another project concerning manufacturing problems with this component.
- Updating of link budgets to cover changes in the mission timeline.
- Exchanging of capacitors in flight units, due to failure of a capacitor in one transponder.
- Exchanging of coaxial radio-frequency (RF) switches for others with a better quality record.

British Aerospace (AOCS Subsystem)
- Development of new, refined trajectory-correction strategies to compensate for the difference in performance between the previously foreseen 'Centaur' Upper Stage and the IUS/PAM-S combination now used.
- Support in Attitude and Orbit Control (AOCS) and Reaction Control Equipment (RCE) subsystem operations.

Contraves (Structural Subsystem)
- Support in structural modelling and analysis of the new launch configuration.
- Recertification of structural items after storage.

Fokker (Thermal-Control Subsystem)
The spacecraft's thermal control was affected in several ways by the launch delay:
- The electrical power output of the RTG, which was fuelled for the 1986 launch, decreases with time due to the natural decay of its radioactive heat source.
- Plume heating and soak-back heating from the PAM-S before separation.

Both effects required updating of the thermal modelling, compensation of the effects by small trimmings of thermal hardware (blankets, radiator pattern), and verification during thermal-vacuum testing.

Laben (Data-Handling Subsystem)
- Replacement of the TCC 244 RAM memory units and complete retesting at unit and subsystem level of both the flight and the flight-spare units of the Data-Handling Subsystem.

Sener (Mechanisms Subsystem)
- Preparation of the axial booms, which were stored in a deployed and stress-free condition.
- Exchange of stepper motors on all boom drive mechanisms (three flight and two flight-spare models of axial booms and wire booms), functional and environmental testing of all units.

At Dornier itself, a new team was formed whose members represented a mix in terms of:
- having had previous experience with Ulysses
- having experience on space projects, but not with Ulysses
- being relatively new, but with a good basic training.

This team was supported very willingly and quickly by former Ulysses team members whenever their help was sought in resolving particularly critical questions. The same cooperative spirit was apparent throughout the Industrial Consortium, the ESA team, and the participating members of the scientific community. The combination of the eager endeavours of the new team members with the participation of the experienced members, at all levels, has made a major contribution to the timely and successful recertification of the Ulysses spacecraft, which has been carried out without major upset.

It is certainly a good indicator for the future of European industrial cooperation that it has proved possible to kindle this degree of enthusiasm and coöperative spirit in getting Ulysses ready for a third time for its long-awaited journey into the third dimension of our Solar System.

The Ulysses Storage and Recertification Activities: The Managerial Problems

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Introduction

Ulysses occupies a unique position in the history of ESA and one that it is hoped will never be repeated. Originally planned to be launched in February 1983, it was delayed by NASA management decisions to 1985 and then to 1986. Following the Space Shuttle 'Challenger' accident, it was further delayed until 1989 and then, again by management decision, priority was given to Galileo for launch in 1989 and Ulysses was further delayed until October 1990. The consequence of these repeated delays was the necessity to arrange storage and reproving of the spacecraft and also to organise the availability of the necessary skilled and experienced manpower to carry out the various activities.

One major difference between the delays prior to 1986 and those after the 'Challenger' accident was that the former were known about well in advance, whereas the Shuttle accident came, obviously, without warning close to the scheduled launch date, and at a time when most of the team, ESA and industrial, was already committed to other projects for the period immediately following the planned launch date of May 1986. It was therefore necessary during the uncertain period in early 1986 to develop in real time a planning that could satisfactorily accommodate either a shorter or longer period of delay. This contrasted with the earlier delays, which were of known duration and identified some years in advance.

The 'build-and-store' philosophy

When in 1980 NASA announced the first launch delay from 1983 to 1985 because of development problems with the Shuttle, ESA was already committed industrially for Phase-C/D (design, development and manufacture) of the ESA spacecraft. A decision therefore had to be made on the optimum way of accepting the prolongation of the project. A joint ESA–Dornier study was conducted that effectively identified three viable alternatives which merited further detailed attention:

(i) to stop the programme and restart it closer to the new launch date;
(ii) to reduce the team in size and stretch the programme to occupy a longer period;
(iii) to complete the building and integration of the spacecraft against the original schedule, and then store it until shortly before launch.

Following a more exhaustive study, it was decided that the third alternative was the correct one. To stop and restart the project, in addition to involving cancellation costs for ESA, generated the risk that key individuals within ESA, at Dornier and at subcontractors would be dispersed to other projects and not be available when Ulysses restarted. Stretching of the project duration was also undesirable, since it involved keeping a significant number of engineers working effectively part time for several years. The additional costs associated with this approach were also very high.

Consequently, the decision was made to complete the spacecraft and then to place it in storage until about one year before launch. Since the decision was made in 1980, this gave sufficient time to plan alternative work for team members (Agency and industrial) for the storage period, whilst making them available for the retest period (known as 'recertification') prior to the launch campaign.

Although the intention was to maintain the original schedule conceptually, this was not taken too rigorously and when problems arose, as they inevitably do when developing a new spacecraft, the programme was allowed to slip in time rather than working excessive overtime to rectify the situation. As a result, the flight acceptance testing of the spacecraft was concluded in October 1983, rather than October 1982 as originally predicted.

An additional problem that needed to be considered when planning for the launch slip was the fact that virtually all subsystem contractors would have delivered their flight hardware by 1982, and consequently their design engineers would have been working on other projects for some years by 1985-6. Although drawings, log books and manuals would exist, as normal, it was felt that these might not be sufficient if some major failure were to occur close to launch.

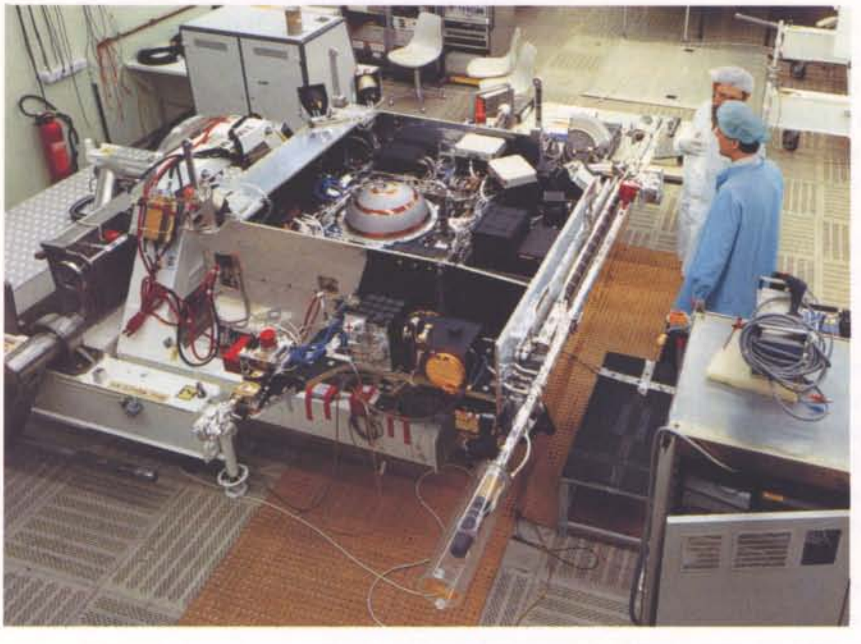

Figure 1. Ulysses flight-model spacecraft during experiment integration in March 1983

In order to overcome this problem as far as possible, it was decided that, for the major electronic subsystems (telecommunications, data handling, attitude and orbit control, power and pyro), detailed handbooks would be written by the contractors concerned, in which not only the design, but also the philosophy behind it, would be described in detail. All circuit boards would be drawn or photographed and their salient features labelled. In this way, it was hoped that skilled engineers who had not been involved in the initial design would be able to familiarise themselves rapidly in sufficient depth to be capable of effecting repairs in the event of problems.

Not all contractors were enthusiastic about preparing such handbooks, although they were to be written on contract, because they were afraid that they might be used by competitors to acquire the expertise gained over a number of years in their speciality. Consequently, care had to be taken to protect commercial security, in one case going to the extent of having some volumes locked away at all times and giving the contractor written assurances that nobody except employees of that company would ever be granted access to them. To guard against the risk of fire, all handbooks were prepared in three copies, one being kept at the contractor, one at Dornier and one at ESTEC. Although happily the handbooks had to be referred to only rarely, their value was very great, especially when the delay grew from three years to seven years.

Storage

It was felt that the best way to store the majority of subsystems was to place the complete spacecraft into its sealed transport container, fill it with dry nitrogen, and keep the container in a clean room. However, for some units this was not desirable. The majority of the Principal Investigators wished to have their experiments returned to their scientific institutes, where regular calibrations could be made to ensure that sensors were not deteriorating with age. The two tape recorders, on the advice of the manufacturer, were removed from the spacecraft and they, plus the flight spare, were operated every six months to ensure that their lubricant did not settle out. The axial boom was stored in a special container, extended to its full length and therefore under no stress.

Recertification

Having decided upon the precautions necessary prior to placing the hardware into storage, the next question to be resolved was the degree of reproving necessary after the storage period to ensure that the spacecraft was flightworthy. The problem here was to strike a balance between testing the various subsystems sufficiently and not fatiguing them by repetitive strong stressing. After consultation with the relevant ESTEC experts, it was decided that the best compromise was to carry out thermal-vacuum testing, but not vibration testing. The logic behind this was that thermal-vacuum testing tends to stress all units more or less evenly, whereas vibration testing tends to stress some areas and not others. Moreover, the many transports within Europe, plus those to the USA and back in 1986, although carefully controlled, all induced some levels of vibration.

Recertification of the flight spacecraft has now had to be made on two occasions, in 1985 and 1989-90, the main tasks being the same each time. The spacecraft has had all of the units and experiments reintegrated, followed by full functional testing of the complete spacecraft. In 1989 there was then a full magnetic testing of the spacecraft, whereas in 1985 a more moderate magnetic-cleanliness check took place. The spacecraft was then transported from Southern Germany, where the integration and magnetic testing took place, to ESTEC for thermal-vacuum tests.

During these environmental tests all subsystems underwent a full 'Integrated System Test' and the experiments a 'Short Performance Test'. During the 1989 rectification, there was also a continuous running of the spacecraft in the mode in which it will operate during the mission, with all experiments switched on. This was to prepare tapes to be used by Jet Propulsion Laboratory (JPL) for proving the software they will use to produce Experiment Data Records. Following the thermal-vacuum test, a full Integrated System Test (subsystem and experiment) was conducted, and the recertification was completed by final alignment, weighing and spin balancing of the spacecraft in its launch configuration.

The total duration of each recertification was approximately nine months and although additional time had been allowed to cover possible delays, this was not needed and on both occasions the recertification was completed exactly on the appointed day.

The ageing of components

The number and duration of the delays incurred by the Ulysses spacecraft is unique in the history of ESA, and almost so for the rest of the world (the US Galileo project experienced similar delays). A question that inevitably arose was whether deterioration of units due to ageing could occur and thereby threaten the five-year post-launch mission. As mentioned earlier, certain units such as the experiments, the axial boom and the tape recorders received special treatment, but in general it was considered that storing in a quiescent state in dry nitrogen was preferable to periodic powering and testing of the spacecraft.

For the 1984 storage period, the project team made an in-house evaluation of components that it was felt might be at risk, but when the launch was delayed until 1990 it was felt that a deeper and more independent investigation was needed. Accordingly, a study group was set up from the ESA Project Team, Dornier and ESA Product Assurance Department. They took the parts lists of all electronic components and divided them into categories according to the risk associated with each. Resistors, for example, were in general felt to be low risk, whereas microprocessors and other complex electronics assemblies were considered to be high risk. For each component falling into the higher risk categories, an evaluation was made which varied, but could include tests and destructive analysis of spare parts manufactured at the same time.

The results of this study were then analysed and compared with the results of similar investigations made at JPL for Galileo. Although the two teams had worked independently, their findings were in close agreement. The conclusion was that,

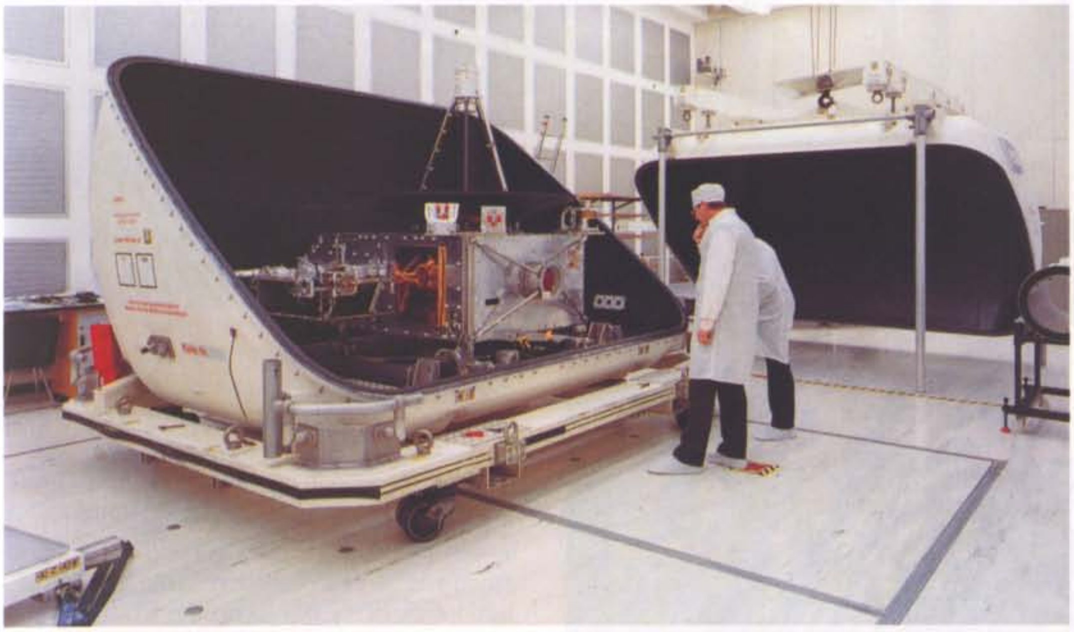

Figure 2. Ulysses being 'put into storage' at ESTEC in December 1983

despite the age of some components, there was no sign of degradation and no risk to the mission.

The spacecraft structure was also investigated for signs of degradation. All accessible inserts were pull-tested and the results compared with those obtained earlier. One of the experiment wing struts from the structural-model spacecraft, which had been used for qualification of the Ulysses structure, was also pull-tested. The results of both sets of tests showed that no degradation of the structure had occurred.

Figure 3. Ulysses spacecraft/launcher-adapter fit-check in progress at KSC in February 1986

All thermal blankets were carefully examined, both physically and electrically, and any that showed evidence of damage or had degraded electrical conductivity were replaced.

Manpower

The preceding paragraphs have described the steps taken to ensure the continued flightworthiness of the spacecraft. However, an element essential to the successful launch of a spacecraft is the continuity of trained and experienced personnel. In the current European situation where the expansion of space-related activities is far greater than the capacity to train new engineers, the problems created by delays, particularly unanticipated delays, are very considerable.

In the particular case of Ulysses, there was a significant difference between the delay from 1983 to 1985 and that from 1986 to 1990.

The first delay was relatively short in duration, the total period from the conclusion of acceptance testing in October 1983 to the start of the recertification in February 1985 being about 16 months. Additionally, it was apparent in 1980-81 that this was going to happen and advance planning could be made on how to cope with it. It was also known that the majority of the ESA team was to be employed on a subsequent scientific project, later identified as the Infrared Space Observatory (ISO), and the planning was made so that the engineers concerned would utilise the Ulysses storage period to prepare the technical documentation and start the Phase-B of ISO. During the 1986 launch campaign, personnel would be shuttled to and from Kennedy Space Center (KSC) as needed, so as to keep both projects running, and thereafter, obviously, ESOC would be responsible for Ulysses and ESTEC engineers would work full time on ISO.

For the second delay, the hiatus was much longer, lasting effectively from June 1986 until January 1989, and it came without warning when 'Challenger' exploded. Even worse from the Ulysses viewpoint, virtually the whole team was by then working on ISO and could not be reserved or recalled to Ulysses without seriously disrupting the whole ESA Scientific Programme. It was therefore decided to keep only a small nucleus (three engineers) from the ESA team to work on Ulysses and to rely on recruiting a new team when activity was due to start-up at the end of the storage period. Dornier also dispersed the vast majority of their team, retaining only one or two engineers to provide continuity for the future. This tiny joint team was kept very occupied during the storage period in adapting to the new launcher configuration and conducting the necesary studies and negotiations.

The rebuilding of the necessary team began about nine months prior to the commencement of the new recertification period. Since virtually none of the 'old' ESA team was available, it was necessary to recruit newcomers and to educate them about Ulysses. However, since they would be handling flight-quality hardware from the start, it was essential for all of them to be experienced satellite engineers. A similar approach was taken at Dornier, although much of the AIT (Assembly, Integration and

Figure 4. Ulysses being removed from its shipping container at KSC in May 1990

Test) team could be recalled from other work and thereby retain some continuity.

There were, however, three key areas where neither ESA nor Dornier was able to find sufficient engineers with Ulysses or similar experience. These were thermal analysis, attitude and orbit control, and spacecraft operations. To overcome this deficiency, recourse was made to the relevant contractors, namely Fokker and BAe, to provide coverage in these areas. Other companies, in particular Contraves for structural analysis, Laben for data handling and Alcatel for communications, were used as specialist consultants.

In educating the new team members about Ulysses, extensive use was made of classroom learning from previous members, and, so far as permitted, of the handbooks. To complete their learning, it was decided that prior to integrating the flight spacecraft, the qualification model would be integrated with flight-spare subsystems and experiments. This served the double purpose of giving hardware training to the AIT team, and also, by carrying out an Integrated System Test, of proving that the flight-spare subsystems and experiment worked correctly and harmoniously at spacecraft level.

The overall efficiency and successfulness of the approach taken has been proven by the fact that, with the flight spacecraft, the durations of the various test phases have been very similar to those experienced with the original design and integration team.

Conclusion

Despite the multiple delays and greatly expanded overall project duration, the build-and-store philosophy has been demonstrated to be an extremely reliable and cost-efficient method of carrying out the programme. There is no evidence of degradation of units or subsystems due to ageing of components, and environmental tests carried out in recertification have demonstrated the continued flightworthiness of the spacecraft. Lastly, and just as importantly, it has been possible to re-create a combined ESA/Industry team that has the same skill and dedication to the success of Ulysses as the original team.

The International Heliospheric Study

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The 'heliosphere' is the cavity around the Sun that is occupied by the Sun's atmosphere. Spacecraft that have travelled out to distances of more than 7.5 billion kilometres from the Sun have not yet encountered the heliospheric boundary, and the search for this frontier, where our solar system ends and interstellar space begins, is just one of the exciting challenges of the International Heliospheric Study.

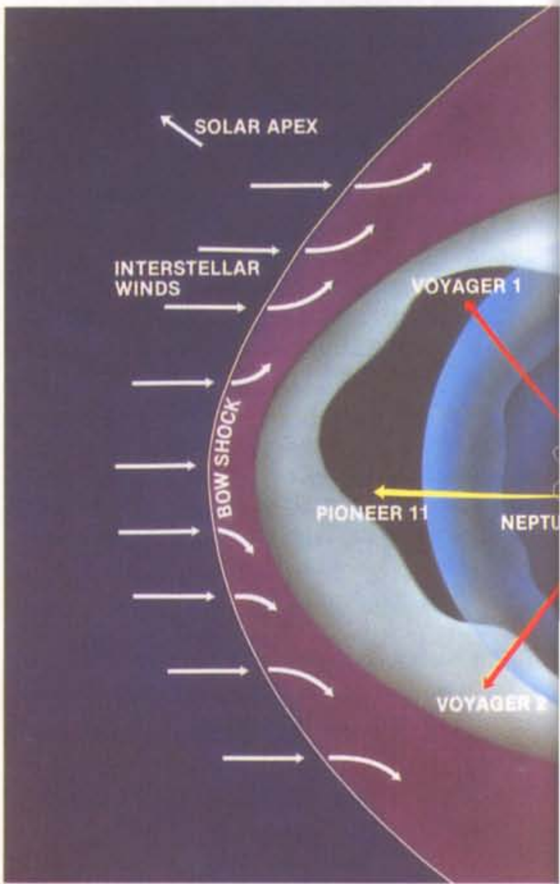
About a hundred years ago it was noticed that activity on the solar surface was frequently followed a few days later by disturbances in the Earth's magnetic field. Eminent scientists were unwilling to accept that any relationship existed between the two observations, because no law of physics could explain how the disturbances were communicated to Earth. Earlier this century, it was realised that the tails of comets looked as if they were being pushed away from the Sun in a direction that was along the line joining the Sun to the comet. There seemed to be at all times a force directed radially from the Sun.

Measurements made around 1960, at the beginning of the space age, showed that there was indeed a radially directed force. The early spacecraft detected the solar wind, ever present, and consisting of protons and electrons flowing radially from the Sun at speeds of around 450 km/s. Since the wind is radial, it is necessary to travel through solar latitude and measure in-situ if we are to sample the solar atmosphere originating in the various latitudinal regions of the Sun.

The solar wind, because it is a nearly perfect conductor of electricity, carries with it the magnetic field with which it started near the Sun. It is presumed that this wind and magnetic-field regime extends out into space to a position where the pressure it can exert is counter-balanced by the pressure of the local interstellar medium with its own gas and magnetic-field regime. The position of pressure balance may vary with time as the solar wind changes in intensity, and there may be interesting shock-wave features where the solar wind changes from being supersonic, as it is at the Earth, to subsonic as it slows down near the heliospheric boundary.

For almost 30 years it has been known that the intensity of the cosmic radiation penetrating the solar system decreases as solar activity increases and the solar wind blows harder. A simple explanation would be that the size of the heliosphere increases at these times, presenting a greater barrier to the incoming radiation. However, more detailed study shows that, if we apply what we have learned so far about the solar wind from spacecraft measurements, and if we make reasonable guesses about the position of the heliospheric boundary, we still cannot explain many features of cosmic-ray behaviour.

A deficiency of spacecraft measurements to date is that they have been made in, or



close to, the ecliptic plane, and are therefore almost certainly not representative of other regions of the heliosphere. The ecliptic plane is that plane in which the Earth orbits the Sun. Spacecraft launched in past years have taken advantage of the Earth's orbital velocity and of its west-to-east spin motion. To get into a trajectory perpendicular to the ecliptic plane required more energy than launch vehicles could supply. However, just as it would make little sense to study the Earth's atmosphere from the equator only, so too it makes little sense to try and understand the Sun's atmosphere using only unrepresentative measurements made at its equator. (The Sun's equator is offset by only 7° from the ecliptic plane).

The Ulysses mission — originally called the 'Out-of-Ecliptic' mission — was therefore proposed years ago to broaden our knowledge by exploring through the whole range of helio-latitudes. The energy now available from a NASA Shuttle launch, assisted by a pull from the gravity of the giant planet Jupiter, will make it possible to place the Ulysses spacecraft into an orbit perpendicular to the ecliptic, so that the solar atmosphere and the arriving cosmic radiation can be studied together at all helio-latitudes.

This new opportunity for solar-atmosphere and cosmic-ray exploration was of great interest not only to the ESA and NASA scientists directly involved, but also the world-wide scientific community. Consequently in 1982, at its meeting in Ottawa, COSPAR approved a co-ordination effort called the 'International Heliospheric Study', so that interested parties could inform and guide each other in a study of the heliosphere. COSPAR – the Committee on Space Research established by the International Council of Scientific Unions – is a truly world-wide scientific organisation and is not limited to countries with spaceflight capabilities of their own.

As originally foreseen, the International Heliospheric Study was to be centred around Ulysses and was to bring in related measurements from spacecraft in the ecliptic plane and from solar observatories and various ground-based facilities. When the Ulysses launch date had to be slipped due to NASA's diffulties, COSPAR decided to start the Study in any case in 1986 in order to take maximum advantage of the fortuitous constellation of the Pioneer-10 and 11 and Voyager-1 and 2 spacecraft, which had originally been launched by NASA in the late 1970s to study the planets.

With their planetary missions behind them, these spacecraft are now headed towards the heliospheric boundary (Fig. 1). It is unlikely that such a configuration of spacecraft will be available again in the heliosphere for many decades. Together with Ulysses, exploring the high latitudes for the first time, these spacecraft in the distant heliosphere present us with the marvellous opportunity, in the early 1990s, of making major advances in understanding the three-dimensional solar atmosphere and how the cosmic radiation makes its way through it to us on Earth.

The COSPAR Task Group on the International Heliospheric Study, charged with organising scientific meetings and information exchange, has as its members: W.I. Axford (Germany), R.V. Bhonsle (India), S. Grzedzielski (Poland), K.I. Gringauz (USSR), M. Oda (Japan), E.J. Smith (USA), E.C. Stone (USA), K.-P. Wenzel (ESA), and D.E. Page (ESA/JPL, Chairman).

An IHS newsletter is issued from time to time and symposia have been held in Moscow (August 1987), San Francisco (December 1987), Helsinki (July 1988) and Warsaw (September 1989). Further plans include a symposium during the 1992 COSPAR meeting in Washington DC, and the 1993 ESLAB Symposium, which will be based on the Ulysses results available at that time.

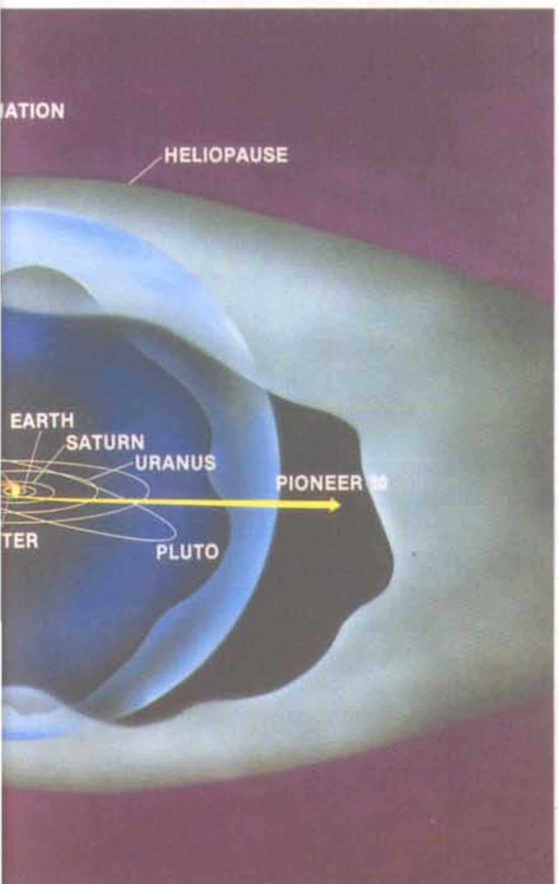


Figure 1. The Pioneer and Voyager spacecraft in the heliosphere (Courtesy of E.C. Stone)

In brief

A Successful Flight for Ariane V37

On the night of 24/25 April, 25 minutes after midnight European time (22 h 25 min UT). Ariane Flight 37 lifted off smoothly from the ELA-2 launch pad in Kourou, French Guiana at the very beginning of the launch window. The Ariane 44L launch vehicle, equipped with four liquid strap-on (PAL) boosters, used the SPELDA dual-launch system to carry its two passengers, France's TDF-2 and Germany's DFS Kopernikus 2. After a smooth flight, the two satellites were correctly released into Geostationary Transfer Orbit (GTO).

TDF-2 is a three-axis-stabilised five-channel direct broadcasting satellite built by the Eurosatellite Consortium for Télédiffusion de France, the second satellite of a two-part system. Its final location will be at 10° West.

DFS Kopernikus 2 is a three-axis-stabilised 11-channel multipurpose telecommunication satellite built by the German R-DFS Consortium for the Deutsche Bundespost Telekom. It will operate at 28.5° East.

New Chairman of the ESA Council

At the ESA Council meeting of 27 June, Delegates unanimously elected Prof. Francesco Carassa as their new chairman. Prof. Carassa succeeds Mr Henrik Grage of Denmark and will chair the Council for a period of two years from 1 July 1990.

Prof. Carassa, born in 1922, is of Italian nationality. He graduated in electrical engineering from the Politecnico di Torino in 1946. From 1947 to 1962 he worked at the Central Radio Laboratory of the Magneti Marelli Co., becoming director of the Laboratory in 1955. In 1962 he left industry to become Professor of Electrical Communication at the Politecnico di Milano, where he founded the 'Centro di Studio per le Telecomunicazioni Spaziali' of the Italian National Research Council.

In 1967 Prof. Carassa proposed an experiment which was to become the Sirio satellite, launched in August 1977. Over a period of five years Sirio acquired data on rain attenuation distributions, depolarisation, joint attenuation distributions, variation of attenuation statistics with frequency and from location to location etc.

From 1969 to 1972 Prof. Carassa was rector of the Politecnico di Milano. He is currently President of the Scientific Council of the 'Centro di Studio per le Telecomunicazioni Spaziali', President of the 'Centro Studi e Laboratori Telecomunicazioni' (CSELI), President of the 'Istituto Internazionale delle Comunicazioni', Member of the 'Consiglio Superiore delle Poste, delle Telecomunicazioni e dell'Automazione' and Chairman of ESA's Telecommunications Advisory Committee. He has been President of Italtel and is now Honorary President.

Giotto – the First-ever Controlled Earth Swing-by of an Interplanetary Space Probe

On 2 July Giotto passed within 22 731.1 km of the Earth and the mission-control team at ESOC in Darmstadt were standing by to use this closest approach to perform a gravity-assist manoeuvre to swing Giotto on towards its new target, comet Grigg-Skjellerup. (To understand a gravity-assist manoeuvre, imagine you are running along a corridor and, as you turn the corner, you grab the bannister and swing around it, increasing your momentum.)

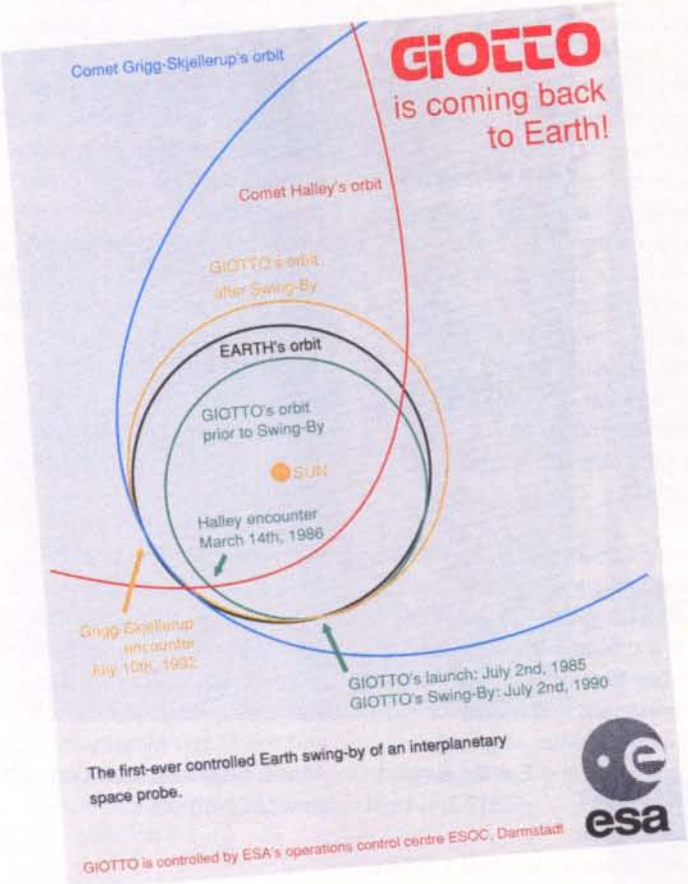
Although the gravity-assist technique is not new, this was the first time that the Earth's gravitational force has ever been exploited in this way. The technique itself has been used many times before, e.g. the Mariner 10 mission to Venus and Mercury in 1974, and by Voyager, which swung by Jupiter, accelerating on towards Saturn. Jupiter will also be used to swing the ESA/NASA Ulysses spacecraft out of the ecliptic plane and over the poles of the Sun.

Giotto is currently speeding on towards its new target, and has now (23 July) been put into hibernation mode until May 1992, when it will be reactivated ready for its new encounter on 10 July of that year.

Recommendation by the GEM Payload Review Group

After extensive checking of the spacecraft and its payload, the GEM project submitted its report on 29 May to the Giotto Extended Mission (GEM) Payload Review Group, established to assess the scientific validity of extension of the Giotto mission. In spite of the loss of the imaging capability of the Giotto camera, the Group concluded that there are strong scientific reasons for proceeding with the Giotto Extended Mission, namely:

- The dust distribution will be derived for a comet whose dust characteristics are very different from those recorded by the same instrument at comet Halley. In conjunction with a ground-based observation programme, these results should yield significant new information on the gas-to-dust ratio in a less active cometary environment.
- The dust measurements will also have important progammatic use in future European and international space programmes – both CRAF and Rosetta require engineering models of the cometary dust environment.
- The complement of magnetic-field and charged-particle instruments still operating will make a major contribution to cometary plasma science and to the study of solar wind – cometary interactions. The contrast with comet Halley will be particularly interesting because comet Grigg-Skjellerup is less active. The working instrumentation carried by the GEM spacecraft is superior to that aboard NASA's International Cometary Explorer for its encounter with comet Giacobini-Zinner, in particular in permitting the direct detection of pick-up ions.



The Group's recommendation to undertake the GEM mission as an optional programme was endorsed by ESA's Science Programme Committee (SPC) at its meeting on 12/13 June.

Go-ahead for ERS-2 and POEM-1

ERS-2

It was announced at the ESA Council Meeting of 27/28 June that subscriptions from Participating States have now reached the level required to start the ERS-2 programme. Building of the second ERS satellite can now begin in ernest, ready for a launch in 1994.

The main objective of the ERS-2 programme is to provide continuity of Earth observation for the science and applications communities worldwide, following on from ERS-1. The aim is to increase the capacity of the Participating States to exploit both management of our planet's resources and the monitoring of its environment and climate. ERS-2 will also continue to provide the data needed to increase scientific understanding of the role of oceans and ice in determining the global climate. The inclusion of the Global Ozone Monitoring Experiment (GOME) in the ERS-2 instrument complement will provide valuable insights into the ozone problem.

The ERS-2 programme comprises:

- The procurement of a second flight satellite and associated hardware, both of which will be as far as possible identical to ERS-1 and utilise the designs and skills developed under the ERS-1 programme. Apart from the inclusion of GOME, deviations from ERS-1 are only foreseen in the case of obsolete components, and for improving the geographical distribution of the work within the Participating States without increasing the cost.
- The maintenance and upgrading of the ESA ERS-1 ground segment for use by ERS-2.
- Launch of ERS-2 by Ariane-4 and the subsequent commissioning of ERS-2 in orbit.
- Exploitation of the ERS-2 system, comprising both space and ground segment, for a baseline period of two years.

POEM-1

At the same meeting, the ESA Council unanimously adopted a Resolution initiating the first European Polar Orbit Earth Observation Mission (POEM-1).

The objective of the programme is to meet the requirement of long-term data continuity for scientific and operational observations of the Earth and its environment. In this context, ESA will be working closely with the scientific communities, its international partners and with the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat), to ensure that the requirements of the operational meteorological community are taken into account.

POEM-1 will be mounted on the Columbus Polar Platform and is the first of a series of such payloads.

Queen Beatrix of The Netherlands Inaugurates ESTEC Test Centre Extension and Opens Noordwijk Space Expo

On Friday 29 June 1990, two important events took place at ESTEC:
- the inauguration of the extension to the ESTEC Test Centre
- the formal opening of the Noordwijk Space Expo, a permanent space exhibition and Visitors' Centre, located on the ESTEC site.

Her Majesty The Queen of The Netherlands inaugurated both facilities in the presence of her son, His Royal Highness Prince Johan Friso. The events were hosted, respectively, by Prof. Reimar Lüst, Director General of ESA, and Dr Rudolf P. Dessing, Chairman of the Board of the Noordwijk Space Expo Foundation.

After an address of welcome from Prof. Lüst, and an explanation of 'ESTEC and its Test Centre' for the assembled guests, from Mr Marius Le Fèvre, Director of ESTEC, Queen Beatrix followed her inauguration of the new facilities with a tour of each of the new units.

The Queen, accompanied by Prince Johan Friso, then moved on to the Noordwijk Space Expo, which has been accommodated in the southwest corner of the ESTEC site, on land made available by the Agency. There, the welcoming addresses were given by Dr Rudolf Dessing and Dr Jacobus E. Andriessen, the Dutch Minister for Economic Affairs.

As in the ESTEC Test Facility, the Queen and Prince Johan Friso showed great interest in Europe's space activities, making an extended tour of the most prominent features of the exhibition. Here, a number of senior ESA staff were on hand to provide detailed explanations of the missions and purposes of the many ESA spacecraft and launch vehicles that are on show. American space history is represented by a model of the lunar module and there is an extensive Russian exhibit, including a copy of Yuri Gagarin's space suit.

Extension to the ESTEC Test Centre

The new extension to the Test Centre will prepare ESTEC for testing the new large ESA space projects. It contains three main elements: the Large European Acoustic Facility (LEAF), the Compact Payload Test Range (CPTR), and an additional Test-Preparation Area.

The Large European Acoustic Facility (LEAF)

Acoustic noise tests form an integral part in the process of verification of space hardware. The qualification and acceptance of spacecraft and their payloads using acoustic-noise tests ensures that no damage to these structures will occur during the launch phase. The main objective of an acoustic test facility is the simulation of realistic spectral noise pressure levels, comparable to those generated by the launcher engines and by the air flow passing over the fairing during the atmospheric flight.

The Compact Payload Test Range (CPTR)

The radio-frequency link between a spacecraft and the ground or another spacecraft is a critical parameter that must be verified before launch. This is particularly important in the case of communications satellites which link different locations on the Earth's surface via the satellite itself.

It is therefore necessary to have a facility in which the effects of the large separation between the satellite and ground stations can be simulated in a relatively small space, and interference from the outside world eliminated. The Compact Payload Test Range serves this role.

A unique feature of the ESTEC CPTR is that it allows direct measurements of the satellite's Earth coverage characteristics or links between different ground stations by placing suitable transmitters and receivers at different locations in the focal plane. These can then communicate with each other via the satellite in a manner that accurately reproduces the in-orbit operational conditions and characterises the satellite's performance.

Typically, this facility will be used for verifying the performance of large communication satellites, Earth-observation radars and for accurate measurement of the radiating characteristics of very large antennas.

The Test Preparation Area

The new Test Preparation Area of 280 m^2 (cleanliness class 100 000, 15 m crane height) will further facilitate the handling and preparation of large spacecraft for testing.

Noordwijk Space Expo

The Noordwijk Space Expo has a dual purpose: it will serve both as a permanent exhibition on space activities and as a Visitors' Centre for ESTEC itself. This attractive, dynamic and educational exhibition will be open to the public six days a week. It features authentic space hardware, large-scale models, audio-visual presentations, lectures and guided tours through the 'world of space'. The emphasis is on European cooperation and achievements in the field of space research and development. At least 100 000 visitors are expected annually to the large exhibition area, covering 1700 m^2.

More than 30 European aerospace companies and space-related organisations in the ESA Member States have donated funds to the Noordwijk Space Expo Foundation. Local authorities, the Province of South-Holland and the Dutch Ministry for Economic Affairs, have also provided substantial financial support.

ESTEC staff member Ms C. Beskow presents a bouquet to Her Majesty Queen Beatrix; Mr E. Classen, Head of ESTEC's Testing Division, looks on

Left to right: Prof. R. Lüst, ESA's Director General, Prince Johan Friso, Her Majesty Queen Beatrix, Mr E. Slachmuylders, Head of ESA's Mechanical Systems Department, and Mr H. Grage, Chairman of the ESA Council

Mr M. Le Fèvre, Director of ESTEC, giving his welcoming address at the opening of the LEAF

Her Majesty Queen Beatrix presses the button to open the large door into the LEAF

Queen Beatrix signs the visitor's book at the Noordwijk Space Expo

Queen Beatrix meets the Board Members of the Noordwijk Space Expo Foundation

Dr Rudolf Dessing, Chairman of the Board of the Noordwijk Space Expo Foundation, welcoming the assembled guests

Queen Beatrix touring the exhibition

Left to right: Her Majesty Queen Beatrix, Prince Johan Friso, Prof. R. Lüst, Dr J.E. Andriessen and Mr H. Grage

ESA's Advanced Telecommunications Programmes Approved

Three major advanced telecommunications programmes, Artemis, DRS and ATSR, were approved by the ESA Council at its meeting of 27/28 June.

Artemis, the Advanced Relay and Technology Mission Satellite, will carry three experimental payloads to demonstrate new technologies and services:
- a laser beam optical communication payload to provide high data-rate links with low-Earth-orbiting satellites within the framework of future data-relay systems
- an S-band high-performance multiple access payload to prepare for the operational data relay system
- an L-band mobile payload to demonstrate satellite communication services for European land vehicles.

The design of the Artemis geostationary platform is new, making it possible to launch larger payloads while maintaining the satellite mass at the half Ariane-4 level. It will be launched in 1994.

The Data-Relay System (DRS), will comprise a space and ground infrastructure that will provide communications between various users including the Columbus Free Flyer, the Hermes spaceplane, the Polar Platform and the ground. The development phase of the DRS programme will be confirmed at the end of 1991, for a launch in 1996.

Both the Artemis and DRS programmes are under the prime contractorship of Selenia Spazio (I). The Italian Government is contributing 45% of the development costs. Austria, Belgium, France, The Netherlands, Spain, Sweden, Switzerland, the United Kingdom and Canada have also subscribed to these two programmes.

The ESA Council also approved a four-year extension of the Advanced Systems and Technology Programme (ASTP), which will concentrate on medium- and long-term research and development of advanced satellite technologies and telematics.

MOU on NASA/ESA Cassini Mission

At its meeting of 27/28 June, the ESA Council approved the international agreement between ESA and NASA on the joint NASA/ESA Cassini mission. ESA and NASA officials will now finalise the text of the Memorandum of Understanding for signature.

ESA's part in this mission is to provide the Huygens probe that will fly from the NASA-built Cassini Saturn Orbiter to explore the surface of Titan, one of Saturn's moons.

Cassini is scheduled for launch in 1996, with the probe landing on Titan in 2002. En route, Cassini will fly-by Jupiter and travel through the asteroid belt, sending back data.

Meetings between Hungarian Delegation and ESA

Following earlier contact and an exchange of letters, two formal meetings have recently taken place between a Delegation of the Republic of Hungary and an ESA Delegation. Heading the Hungarian Delegation, on both occasions, was Prof. Ferenc Marta, President of the Hungarian Intercosmos Council, and the ESA Delegation was led by Prof. Reimar Lüst, the Agency's Director General.

At the preliminary meeting on 16/17 May, at ESA Headquarters in Paris, the two Delegations expressed their desire to further the long and successful cooperation in space research that already existed between Hungary and ESA. After an exchange of information on existing activities and prospects for future cooperation in the fields of space science, earth observation, microgravity and telecommunications, the Hungarian Delegation expressed its hope that a cooperative agreement could be concluded in the near future.

At the follow-up meeting in Budapest on 19/20 July, the Hungarian and ESA Delegations finalised the text of a Cooperative Agreement and agreed to submit it for approval to the Hungarian Government and the ESA Council, respectively.

While in Hungary, the ESA Delegation was invited to visit the Central Research Institute for Physics (KFKI) and the Institute for Geodesy, Cartography and Remote-Sensing (FOMI). Prof. Lüst met with Ferenc Madl, Minister for Science and European Integration and the Delegation was also received by Frigyes Geleji, President of the State Office for Technical Development.

Cosmic-Ray Experiment Returned from Space

After six years aboard NASA's Long-Duration Exposure Facility (LDEF), the return of the Ultra-Heavy Cosmic-Ray Nuclei Experiment was greeted with great enthusiasm by the investigators of ESA's Space Science Department and the Dublin Institute for Advanced Studies, its joint developers.

The LDEF, a huge platform for the exposure of materials and detectors to the space environment, had been launched in April 1984 and, at the last possible moment before reentering the Earth's atmosphere, was retrieved by the Space Shuttle in January 1990.

Following an initial inspection at Kennedy Space Center, the Cosmic-Ray Experiment was returned to ESTEC, where it will be dismantled. The cosmic ray detectors will then be sent to Dublin for processing and analysis.

The Cosmic-Ray Experiment, the largest single experiment on the LDEF, contains 20 m^2 of special plastic that functions as nuclear track detectors. When an atomic nucleus, moving at high speed, passes through this material, it leaves an invisible trail of damage which, like the latent image on a photographic plate, can be developed and made visible by processing.

During its long stay in space, the experiment has collected a large number of these nuclear tracks, analysis of which will allow the experimenters to determine the relative abundances of the rare ultra-heavy species (nuclear charge >65) in the cosmic radiation.

There is also considerable scientific and engineering interest in the experiment's large-area thermal covers, which have been exposed to space for over five years. The importance of understanding the long-term effects of the Low-Earth Orbit (LEO) environment on spacecraft materials is of particular significance in the Space Station/Columbus context. Atomic oxygen erosion and micrometeoroid/space debris impacts are two important environmental factors and ESA Materials and Processes Division will be involved in this analysis.

K-P. Wenzel
ESA Space Science Department

Figure 1 – The Long-Duration Exposure Facility (LDEF) being retrieved from orbit by the Space Shuttle. Five 'trays' of the Cosmic-Ray Experiment are visible (Courtesy NASA)

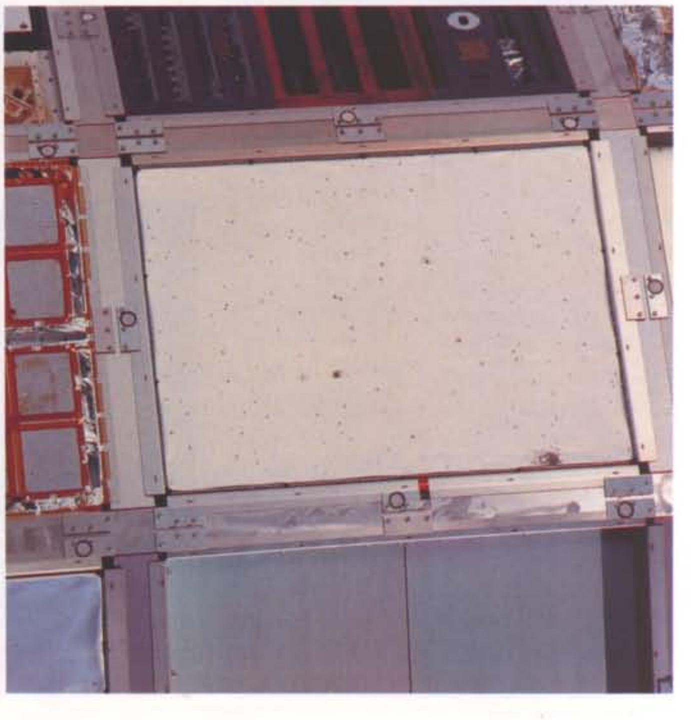


Figure 2 – One of the 16 trays containing the joint ESA SSD/Irish Cosmic-Ray Experiment is shown during the in-orbit photo survey. The silver teflon thermal blanket has become milky in appearance and is peppered with numerous micrometeoroid impacts (Courtesy NASA)

15th ESA/Japan Meeting

The 15th meeting between ESA and Japan took place at ESRIN, the Agency's establishment in Frascati, Italy, on 12 – 14 June. The Japanese Delegation was led by Mr T. Ishii, Deputy Director General of the Research and Development Bureau of Japan's Science and Technology Agency; Mr G. Van Reeth, ESA's Director of Administration, led the ESA Delegation.

After a review of activities since the previous meeting in 1989 in Japan, both Delegations expressed their strong desire for continued and increasingly active cooperation. The recent Space Agency Forum for the International Space Year (SASIFY) meeting in Kyoto, Japan, was heralded as a successful step in this direction. ESA and Japan have recently signed a Memorandum of Understanding (MOU) on the use of Meteosat MOP-1 data, and it is hoped that a further MOU on mutual data acquisition from ESA's ERS-1 and Japan's J-ERS will be finalised by the end of 1990. Other aspects of earth observation discussed included continued cooperation with regard to the Polar Platform complex and future missions such as Japan's ADEOS and TRM and ESA's ERS-2 and Aristoteles.

In the area of product assurance, ESA already provides procurement and inspection support with regard to electronic components for space

applications procured by NASDA from European suppliers. This agreement been renewed for another three years.

Exchange of data regarding general policies and requirements to ensure the safety, reliability and quality of space programmes has already proved beneficial and will be increased, particularly in view of future manned systems such as the International Space Station Freedom.

Both ESA and Japan are actively developing spaceplanes – ESA its manned Hermes spaceplane and Japan HOPE, an unmanned spaceplane to be launched by the Japanese H2 rocket. The two Delegations agreed that a mutual review of spaceplane design would be of great value.

Information was also exchanged in the Space Station and microgravity areas, with ESA inviting Japan to indicate its interest in participating in ESA-planned Space Station precursor flights (e.g. Eureca and Spacelab). Increased coordination could also be beneficial with regard to microgravity and other utilisation databases.

In the field of telecommunications, information will continue to be exchanged on in-orbit anomalies, inter-satellite links and data-relay satellites.

ESA's Science Directorate and Japan's Institute of Space and Astronautical Sciences (ISAS) presented summaries of their respective activities and discussed possible collaboration in the area of infrared astronomy, in particular in the context of ESA's ISO programme.

Delegates at the 15th ESA/Japan meeting, Frascati, Italy, 12 – 14 June 1990

More generally, it was agreed to continue the exchange of staff between ESA and NASDA and to discuss further the idea of establishing an ESA office in Tokyo. The next meeting between ESA and Japan will take place in Tokyo in 1991.

First Eurostep Conference and Launch of the Operational Service

Eurostep, the association for the use of satellites in training and education programmes, held a very successful conference at Lisse, The Netherlands, in April. The conference marked the launching of Eurostep's experimental educational broadcast channel carried on ESA's Olympus satellite, and two hundred pioneer members met to discuss the past, present and future of this unusual venture.

The creation and development of Eurostep is described in ESA Bulletins No. 56 (pp. 35-38) and No. 60 (pp. 63-67). Since 8 January 1990, Eurostep has produced six hours of test transmissions daily. Since 1 April, the Eurostep experimental service has been run in its operational format, and will expand later this year towards nine hours daily, equivalent to 3000 hours a year.

The theme of the conference was 'sharing experience', providing the opportunity to learn from colleagues in Europe and to hear about advances in other parts of the World, particularly the United States. The conference opened with videotaped messages of encouragement from the President of the European Parliament, Enrique Baron Crespo, and ESA's Director General, Prof. R. Lüst. The European Commission was represented by Richard Charters d'Azevedo, Head of the Task Force on Human Resources, Education, Training and Youth who outlined the challenges of change facing Europe, and how distance and open-learning can help.

The Proceedings of the conference will be published shortly by Eurostep.

J. Chaplin

Further information on Eurostep is available from:

Eurostep
Rapenburg 63
2311 GJ Leiden
The Netherlands

Tel: 31.71.120863

ATSR to fly on ERS-1

In London on 23 July, the Agency's Director General, Prof. Reimar Lüst, and the Chairman of the UK Science and Engineering Research Council, Prof. Sir William Mitchell, signed an Agreement to fly the Along-Track Scanning Radiometer (ATSR) as part of the ERS-1 payload.

The United Kingdom has been involved in the ERS-1 programme since its inception. The ATSR was designed and built by a British Consortium led by SERC's Rutherford Appleton Laboratory (RAL). Members of the RAL consortium include Oxford University, University College London's Mullard Space Science Laboratory and the UK Meteorological Office, with a contribution from Australia. The Microwave Sounder was built by CRPE at Issy-les-Moulineaux, France.


Photo: BNSC

Seated: Prof. Sir William Mitchell (left), Chairman of SERC, Prof. Reimar Lüst, ESA's Director General. Standing: Mr Arthur Prior (left), Director of the British National Space Centre & Dr David Llewellyn-Jones (RAL), ATSR Principal Investigator

The ATSR is designed to measure sea-surface temperature from space to an accuracy of a few tenths of a degree centigrade. The global weather and climate system is provided by thermal, water vapour and momentum fluxes across the ocean-atmosphere boundary layer. Sea-surface temperature measurements from the ATSR, together with data from the other sensors aboard ERS-1, will enable scientists better to understand the complex interactions between ocean and atmosphere. Over land, ice and clouds the ATSR can be used to take other scientific measurements.

Hubble Space Telescope

In assessing the Hubble Space Telescope's optical performance, ground controllers have been conducting a series of focussing tests during the last weeks. These tests involve moving the Telescope's secondary mirror to a number of positions on each side of the expected focus. Images were then taken with both of the cameras at each position to assess how the quality of the image changed with secondary mirror motion.

The tests have revealed that the image quality anticipated for the HST optical system cannot be fully achieved at any secondary mirror setting. Although very sharp image cores of diameter 0.1 arcsec or less are obtained at a range of focus settings, these cores only contain 10 – 20% of the light. The remaining light is not being correctly focussed by the Telescope resulting in a diffuse halo approximately ten times larger than the sharp image core that it surrounds.

Analysis of the images indicates that the focus of the HST suffers from what opticians call 'spherical aberration'. This particular type of image blur occurs when light from the inner and outer portions of a lens or mirror does not focus at precisely the same point. The only plausible explanation for this is that an error was made when the mirrors of the Telescope's optical system were manufactured some ten years ago.

A Board of Investigation has been set up by NASA, under the chairmanship of Dr Lew Allan, Director of JPL, to establish how such a problem could have occurred and gone undetected. ESA has an observer on the Board.

Recent test images obtained at the 'off-axis' position in the HST focal plane of ESA's Faint Object Camera (FOC) have enabled scientists to determine that the fault almost certainly lies with the large primary mirror. The error is of the order of 0.002 mm at the outer edges of the primary mirror. This error is somewhat akin to a sight defect that can be corrected by glasses, so it is highly likely that it can be corrected in the three 'next-generation' HST scientific instruments currently being procured by NASA for installation onboard HST during a future Shuttle refurbishment mission.

Of the current complement of scientific instruments onboard HST, all five are affected by the focussing problem, but to varying degrees. Worst affected are the two cameras, the Wide-Field Planetary Camera and ESA's Faint-Object Camera (FOC). However the HST astronomers are confident that a large number of important astronomical observations can still be carried out with HST in its present state, observations that could not be done from ground-based observatories. Although the imaging capabilities of both cameras will be less sensitive than expected, the exposures do carry unique high-resolution information that can be extracted in many cases. Equally importantly, the FOC, the two spectrometers and the photometer will still be able to carry out unique and important astronomical observations in the ultraviolet.

Programmes under Development and Operations / Programmes en cours de réalisation et d'exploitation

In Orbit / En orbite

	PROJECT	COMMENTS
SCIENT PROG.	IUE	
SCIENT PROG.	HIPPARCOS	OPERATIONAL 3 YEARS
APPLICATIONS PROGRAMME	MARECS-A	LEASED TO INMARSAT FOR 10 YEARS
APPLICATIONS PROGRAMME	MARECS-B2	LEASED TO INMARSAT FOR 10 YEARS
APPLICATIONS PROGRAMME	METEOSAT-3	LIFETIME 3 YEARS
APPLICATIONS PROGRAMME	METEOSAT-4 (MOP-1)	LIFETIME 5 YEARS
APPLICATIONS PROGRAMME	ECS-1	LIFETIME 7 YEARS
APPLICATIONS PROGRAMME	ECS-2	LIFETIME 7 YEARS
APPLICATIONS PROGRAMME	ECS-4	LIFETIME 7 YEARS
APPLICATIONS PROGRAMME	ECS-5	LIFETIME 7 YEARS
APPLICATIONS PROGRAMME	OLYMPUS-1	LAUNCHED 12 JULY 1989

Under Development / En cours de réalisation

	PROJECT	COMMENTS
SCIENTIFIC PROGRAMME	SPACE TELESCOPE	LAUNCHED APRIL 1990
SCIENTIFIC PROGRAMME	ULYSSES	LAUNCH OCTOBER 1990
SCIENTIFIC PROGRAMME	SOLAR TERRESTRIAL SCIENCE PROG. (STSP) (SOHO, CLUSTER)	LAUNCHES: SOHO MARCH 1995, CLUSTER DEC. 1995
SCIENTIFIC PROGRAMME	ISO	LIFETIME 1.5 YEARS
SCIENTIFIC PROGRAMME	HUYGENS	TITAN DESCENT DEC. 2002
COMMS. PROG.	DATA-RELAY SATELLITE (DRS)	SYSTEM OPERATIONAL 1996
COMMS. PROG.	PSDE TECH. MISSION	READY FOR LAUNCH MID-1994
EARTH OBSERV. & MICROGRAVITY PROGRAMMES	ERS-1	LAUNCH DATE UNDER REVIEW
EARTH OBSERV. & MICROGRAVITY PROGRAMMES	EARTH OBS. PREPAR. PROG. (EOPP)	
EARTH OBSERV. & MICROGRAVITY PROGRAMMES	METEOSAT OPS PROG. (MOP-2, MOP-3)	MOP-2 LAUNCH DATE UNDER REVIEW
EARTH OBSERV. & MICROGRAVITY PROGRAMMES	MICROGRAVITY (IML-1, EURECA, D2, IML-2)	
SPACE ST. & PLATF. PROG.	EURECA	READY FOR LAUNCH MAY 1991
SPACE ST. & PLATF. PROG.	COLUMBUS (PHASE-1, PHASE-2)	3 YEAR INITIAL DEVELOPMENT PHASE
SPACE TRANSPORT. PROG.	ARIANE-4 (V35/36, V37/38, V39/40)	
SPACE TRANSPORT. PROG.	ARIANE-5	FIRST FLIGHT APRIL 1995
SPACE TRANSPORT. PROG.	HERMES	3 YEAR INITIAL DEVELOPMENT PHASE
TECH. PROG.	IN-ORBIT TECHNOL. DEMO. PROG. (PH-1)	SEVERAL DIFFERENT CARRIERS USED

: DEFINITION PHASE — > PREPARATORY PHASE — ▨ MAIN DEVELOPMENT PHASE — ▪ STORAGE — ◇ HARDWARE DELIVERIES

~ INTEGRATION — ↑ LAUNCH/READY FOR LAUNCH — ■ OPERATIONS — - ADDITIONAL LIFE POSSIBLE — ↓ RETRIEVAL

Olympus

Le satellite continue à bien fonctionner; ses quatre charges utiles sont largement utilisées pour de nombreuses expériences. Le Centre de contrôle de Fucino (Italie) en assure sans difficultés la conduite opérationnelle.

Des essais au sol ont confirmé l'origine des incidents qui avaient nui au bon fonctionnement de l'un des détecteurs terrestres infrarouge au début de la mission. En conséquence, on modifiera la conception des détecteurs qui seront embarqués sur les satellites suivants. Le deuxième détecteur, qui n'a pas connu les mêmes difficultés, fonctionne normalement. On dispose de solutions de secours dans le cas où des problèmes similaires surgiraient. Après certaines difficultés qui ont été aplanies, l'un des commutateurs de guide d'onde de la charge utile 20/30 GHz fonctionne de nouveau normalement.

Pour éviter les effets des zones d'ombre et les risques de collision, on continue à coordonner l'exploitation des satellites se trouvant à poste à 19 ouest (TDF, TV-Sat et Olympus). On espère que dans un proche avenir, il sera possible de les séparer suffisamment pour éviter que les cellules de contrôle se chevauchent. Il est toutefois inévitable qu'à long terme de nombreux satellites soient placés et exploités à la même position; l'ESA a donc lancé à cet effet une étude visant à élaborer une stratégie optimale dans cette éventualité.

Le modèle thermique qui avait été utilisé durant la phase de développement d'Olympus a été remis en état et installé au nouveau Centre d'exposition spatiale de Noordwijk ouvert au public.

La charge utile de télévision directe est de plus en plus utilisée. Eurostep en a commencé début avril l'exploitation opérationnelle; on estime aujourd'hui à environ mille le nombre de points de réception. Depuis mai, le programme de la BBC est crypté en soirée; il devrait devenir le canal Enterprise en septembre. En juin, la RAI a utilisée son canal pour retransmettre la Coupe du monde de football en direct de Rome.

La charge utile des services spéciaux a été utilisée conjointement avec la station terrienne transportable TDS-4 pour une expérience de télé-enseignement à Bilbao à l'occasion d'une conférence sur le développement régional dans la CEE. L'Université technique de Graz a procédé à d'autres essais AMRT-SS alors que le CERN projette une expérience de transmission de données à haut débit destinées à des physiciens se livrant à des expériences sur les particules à haute énergie.

L'utilisation de la charge utile de télécommunications 20/30 GHz pour l'application à la visioconférence de l'expérience DICE (Expérience de communications directes inter-établissements) a bien progressé; on se prépare actuellement à la mise en oeuvre de stations terriennes. A Madrid, début juin, l'Exposition Eurotelcom a servi de cadre à une démonstration à grande échelle de l'expérience CODE (Expérience en coopération sur les données d'Olympus). La CODE qui permet à des établissements de communiquer entre eux et d'échanger des données via le satellite Olympus fait appel à de petits terminaux transportables dotés d'antennes paraboliques d'un mètre de diamètre.

La charge utile de propagation compte aujourd'hui de nombreux utilisateurs; 25 stations devraient l'utiliser d'ici la fin de l'année.

Olympus a déjà servi à de nombreuses opérations intéressantes. C'est ainsi que les charges utiles de télécommunications 20/30 GHz et 'Services spécialisés' ont été utilisées conjointement avec les stations terriennes transportables TDS-4 et TDS-6 pour assurer la couverture en direct du lancement puis de la mise en orbite du Télescope spatial Hubble; la qualité technique des images était excellente.

STSP

La prolongation de la phase B de SOHO, annoncée dernièrement, s'est traduite par un décalage entre les phases B de Cluster et de SOHO.

Toutefois, plusieurs approvisionnements communs ont fait l'objet d'un accord entre les deux projets, notamment en ce qui concerne l'approvisionnement des pièces, les sous-systèmes d'énergie, les équipements électriques de soutien au sol et les répéteurs. Les spécificiations et les conditions contractuelles de ces éléments ont été harmonisées pour réduire au maximum les travaux de développement et les coûts.

Cluster

La Revue des Impératifs système a été menée à bonne fin à l'issue de la phase B1 et la base de référence de conception du système a été établie. Avec le démarrage de la phase B2 le 1er mai, des propositions ont commencé à être envoyées dans l'industrie pour l'approvisionnement au niveau des ensembles de sous-systèmes afin de mettre définitivement au point la structure industrielle. Le choix des soumissionnaires potentiels a été arrêté en étroite coopération avec SOHO pour respecter les règles de retour géographique sur l'ensemble du STSP.

Tous les principaux contractants des sous-systèmes ont été choisis et ont reçu l'autorisation officielle de mise en route des activités de phase B2 qui seront axées sur l'élaboration des plans et spécifications au niveau de tous les ensembles. Pour respecter les impératifs du calendrier, des activités d'approvisionnement anticipé de phase C/D commenceront pour l'approvisionnement des pièces, des réservoirs de propulsion et des équipements de soutien au sol.

La demande de prix de la phase C/D sera envoyée à Dornier à la mi-juillet, la réponse étant attendue pour la mi-octobre. Si l'évaluation est satisfaisante, on se propose de lancer la phase C/D comme prévu en février 1991.

Les travaux relatifs à la charge utile scientifique avancent conformément au calendrier avec l'assemblage et les essais du matériel du modèle de développement. A la réunion de l'équipe de travail scientifique tenue en avril, aucun problème majeur n'a été décelé. Les premières discussions ont eu lieu sur le concept de l'exploitation en vol de la charge utile et la définition de la dissémination des données de bout en bout.

Un avis d'offre de participation doit être lancé en juillet concernant un système de données scientifiques de Cluster afin de permettre l'échange rapide des données scientifiques entre les participants. On pense qu'un système réparti sera proposé pour la transmission des données à de nombreux Etats

Olympus

The satellite continues to perform well, with all four payloads being extensively used for a wide range of experiments. Control of the satellite from the operations control centre at Fucino in Italy has proceeded smoothly.

The cause of the early problem experienced with one of the infrared earth sensors has been traced and confirmed by ground testing. The design of sensors to be used on future spacecraft will be changed. The second sensor does not exhibit the problem and continues to work well, but alternative strategies are available should it develop similar problems. A problem with the operation of one of the waveguide switches in the 20/30 GHz payload was overcome and the payload is back to normal working.

Coordination of the operations of the satellites located at 19°W (TDF, TV-Sat and Olympus) has continued in order to avoid shadowing or the risk of collision. It is hoped that in the near future it will be possible to separate the satellites sufficiently to avoid overlap of the control 'boxes'. However, in the long term it is inevitable that multiple satellites will have to be located and controlled at a single location, so ESA has begun a study to determine the optimum strategy for that eventuality.

The thermal model system that was used during the development phase of Olympus has been refurbished and installed in the new Space Expo building at Noordwijk where it will be on display to the general public.

Use of the Direct Broadcast payload has increased. Eurostep started its fully operational schedule at the beginning of April and is currently estimated to have about one thousand locations for reception. The BBC evening service to Europe has been encrypted since May and is expected to become the Enterprise channel from September. RAI used their channel for live transmissions of the World Cup from Rome in June.

The Specialised Services payload has been used in conjunction with the TDS-4 transportable earth station for an educational broadcast experiment from Bilbao on the occasion of a conference on regional development within the EEC. The Technical University of Graz has carried out further SS-TDMA tests while CERN are planning a high-rate data-transfer experiment, sending data to the physics community engaged in high-energy particle experiments.

Good progress has been made in using the 20/30 GHz communications payload for Direct Inter-establishment Communication Experiment (DICE) video teleconferencing and earth stations are being prepared for deployment. A full-scale demonstration of the Cooperative Olympus Data Experiment (CODE) capability was made at the Eurotelecom exhibition in Madrid in early June. CODE enables establishments to communicate and exchange data via the Olympus satellite using small portable terminals with 1 m diameter dishes.

There are now a large number of users of the Propagation payload: 25 stations are expected to be operating by the end of the year.

Many interesting operations have already been performed using Olympus. For example the 20/30 GHz communications and Specialised Services payloads were used in conjunction with the TDS-4 and TDS-6 transportable earth stations to provide live coverage of the launch and subsequent deployment of the Hubble Space Telescope: the technical quality of the pictures was reported to be excellent.

STSP

The recently announced extension to Soho Phase-B has resulted in a misphasing of the Soho and Cluster Phase-Bs. Despite this, several common procurements have been agreed between the two projects, in particular parts procurement, power subsystems, electrical ground-support equipment and transponders. Specifications and contractual conditions have been harmonised for these items to minimise the development effort and cost.

Cluster

The Systems Requirements Review was successfully held at the end of Phase-B1 and a system-design baseline established. Commencing with Phase-B2 on 1 May, procurement proposals have been issued to Industry at subsystem-unit level, to establish the final industrial team structure. Potential bidders have been established in close cooperation with Soho to achieve the overall geographical return targets for STSP.

All sub-system lead contractors have been selected and formally released for Phase-B2 activities, which will concentrate on establishment of all unit-level plans and specifications. In order to meet the schedule requirements, advanced Phase-C/D procurement activities will be started with respect to parts procurement, propulsion tanks and ground-support equipment.

The Request for Quotation for Phase-C/D will be issued to Dornier in mid-July, with a response due mid-October. Following satisfactory evaluation, it is intended to start Phase-C/D on schedule in February 1991.

The scientific payload is progressing on schedule with development-model hardware being assembled and tested. At the Science Working Team Meeting held in April, no major problems were identified. Initial discussions took place on the flight-operational concept of the payload, together with end-to-end data dissemination definition.

An Announcement of Opportunity is due for release in July, inviting proposals for a Cluster Science Data System to enable rapid interchange of scientific results between the participating scientists. It is expected that a distributed system will be proposed covering many Member States and including US participation.

Discussions are continuing between the Agency and the Soviet Academy of Sciences regarding potential collaboration between the Cluster and Regatta-A projects. A formal proposal for cooperation is expected before mid-1991.

Negotiations are proceeding with the Ariane-5/Apex Programme Authority to establish the baseline for the launch of Cluster on Apex flights 501 or 502. An AO has been issued for potential passengers, with responses due in mid-July. Following evaluation of the proposals, the launch configurations for both flights will be established.

membres, y compris des instituts américains.

Les entretiens entre l'Agence et l'Académie des sciences soviétique se poursuivent au sujet de la possibilité d'une collaboration entre les projets Cluster et Regatta. La proposition de coopération en bonne et due forme est attendue avant la mi-1991.

Les négociations se poursuivent avec les responsables du Programme Ariane-5/Apex pour choisir le modèle de référence du lancement de Cluster sur le vol Apex 501 ou 502. Un avis d'offre de participation au vol a été lancé aux passagers potentiels et les réponses sont attendues à la mi-juillet. Après évaluation des propositions, les configurations de lancement des vols 501 et 502 seront arrêtées définitivement.

ISO

Les activités relatives à ce projet ont été largement dominées par les essais des premiers ensembles de matériels. Le modèle structure/thermique du module de service a subi avec succès les essais mécaniques à l'Aérospatiale à Cannes. Il se trouve maintenant à l'ESTEC pour les essais de simulation solaire dans le Grand Simulateur spatial. Le module de charge utile a été soumis aux essais thermiques en conditions ambiantes chez MBB à Munich d'où il doit être transféré chez IABG, également à Munich, pour des essais thermique complets sous vide à froid. Le modèle de qualification du télescope a subi en juin des essais sous vide à la température de l'hélium liquide à l'Institut d'Astrophysique de Liège.

Les modèles d'identification et de qualification des quatre instruments scientifiques subissent les derniers essais avant d'être livrés dans le courant de l'été. Ces modèles seront placés dans un cryostat spécial où, à la fin de l'année, on vérifiera qu'ils restent compatible entre eux à la température de l'hélium liquide.

Parallèlement à tous les essais conduits sur les premiers lots de matériels, on a commencé la fabrication des éléments mécaniques du modèle de vol du satellite. La fabrication du matériel de vol des instruments scientifiques a également été lancée. Pour respecter la date de lancement de mai 1993, il est impératif que les activités de fabrication de longue durée commencent aux dates prévues.

Les travaux relatifs au secteur sol de l'observatoire se poursuivent normalement bien que l'on rencontre quelques difficultés en ce qui concerne le soutien à apporter aux activités d'essai parallèles. Tous les travaux relatifs au secteur sol sont axés sur l'élaboration de la conception détaillée et la réalisation des modules de logiciel à utiliser pour les essais de matériels.

Huygens

L'appel d'offres pour la phase B a été adressé à l'industriel; les propositions doivent parvenir à l'Agence pour le 27 juillet. Dans l'intervalle, les études sur l'installation de la charge utile se poursuivent.

La procédure de sélection des expériences est en cours et se terminera le 1er octobre. Les impératifs d'interfaces entre Huygens et Cassini font l'object d'amendements lors de réunions de travail conjointes ESA/NASA.

ERS

ERS-1

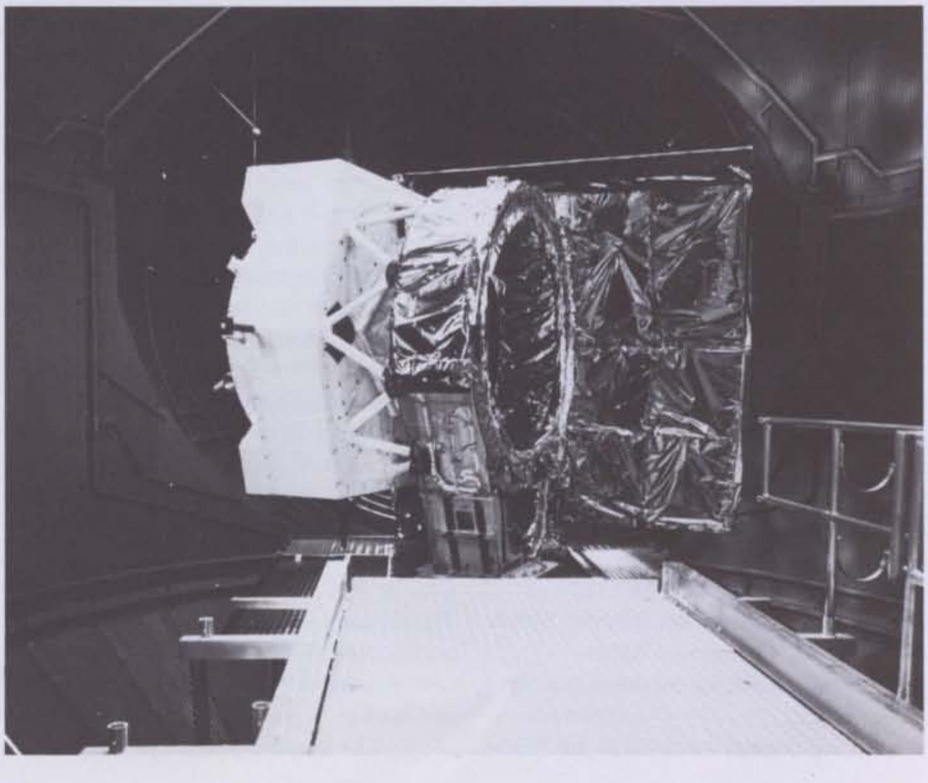
Après livraison définitive du modèle de vol du processeur du radar à synthèse d'ouverture (SAR) qui fait partie du détecteur actif à hyperfréquences (AMI), les nouveaux essais fonctionnels nécessaires au niveau du satellite et des instruments ont tous été menés à bien.

Le modèle de vol du satellite est actuellement soumis à une série d'essais d'alignement et sera ensuite préparé aux essais de recette d'environnement (essais vibro-acoustiques) chez Intespace.

La mise au point du logiciel et des procédures opérationnelles du secteur sol se poursuit à l'ESOC et dans le cadre d'Earthnet.

ERS-2

Les souscriptions au programme ERS-2 devraient atteindre à la mi-1990 les 80% de l'enveloppe financière nécessaires au démarrage du programme (voir page 81).



Structural and thermal model of the ISO Service Module prior to testing in the LSS at ESTEC

Le modèle structure/thermique du module de service d'ISO avant essais dans le Grande Simulateur spatial à l'ESTEC

ISO

Project activities are largely dominated by testing of the first sets of hardware. The structural-thermal model of the service module has been successfully mechanically tested at Aerospatiale, Cannes and is now at ESTEC for solar simulation testing in the Large Space Simulator. The payload module has completed thermal testing in ambient conditions at MBB, Munich and is now being prepared for extensive thermal testing under cold vacuum conditions at IABG, Munich. The qualification-model telescope was tested in vacuum at liquid-helium temperatures at the Institute d'Astrophysique de Liège in June.

The engineering-qualification models of the four scientific instruments are in final testing prior to delivery in the Summer. They will then be put together in a special cryostat and tested for mutual compatibility at liquid-helium temperatures toward the end of this year.

In parallel with these tests on the first sets of hardware, manufacturing of the satellite flight model mechanical hardware has begun. Manufacture of the scientific instrument flight hardware is also well underway. These activities are long-duration and must therefore start on schedule in order to maintain the May 1993 launch date.

Work on the observatory ground segment is proceeding well although there are some difficulties in supporting the parallel test activities. All efforts in the ground segment are geared to elaboration of the detailed design and development of software modules to be used in testing hardware.

Huygens

The Invitation-to-Tender for Phase-B has been issued to Industry, with proposals due in by 27 July. In the meantime, payload accommodation studies are underway.

The experiment selection process is on-going and will be finalised on 1 October. The interface requirements between Huygens and Cassini are being amended in joint ESA/NASA working meetings.

ERS

ERS-1

Following final delivery of the Flight Model Synthetic Aperture Radar (SAR) processor as part of the Active Microwave Instrument (AMI), all necessary functional re-testing at instrument and satellite level has been successfully accomplished.

The Flight-Model Satellite is now undergoing a series of alignment tests and will be made ready for vibration and acoustic acceptance testing at Intespace.

Development of the ground segment software and operational procedures is continuing, both at ESOC and Earthnet.

ERS-2

Subscriptions to the ERS-2 Declaration are expected to reach the 80% needed to start the programme by the middle of the year (for latest information see page 81).

Inclusion of the Global Ozone Monitoring Experiment (GOME) was confirmed by the Earth Observation Programme Board, following the successful completion of the GOME feasibility study.

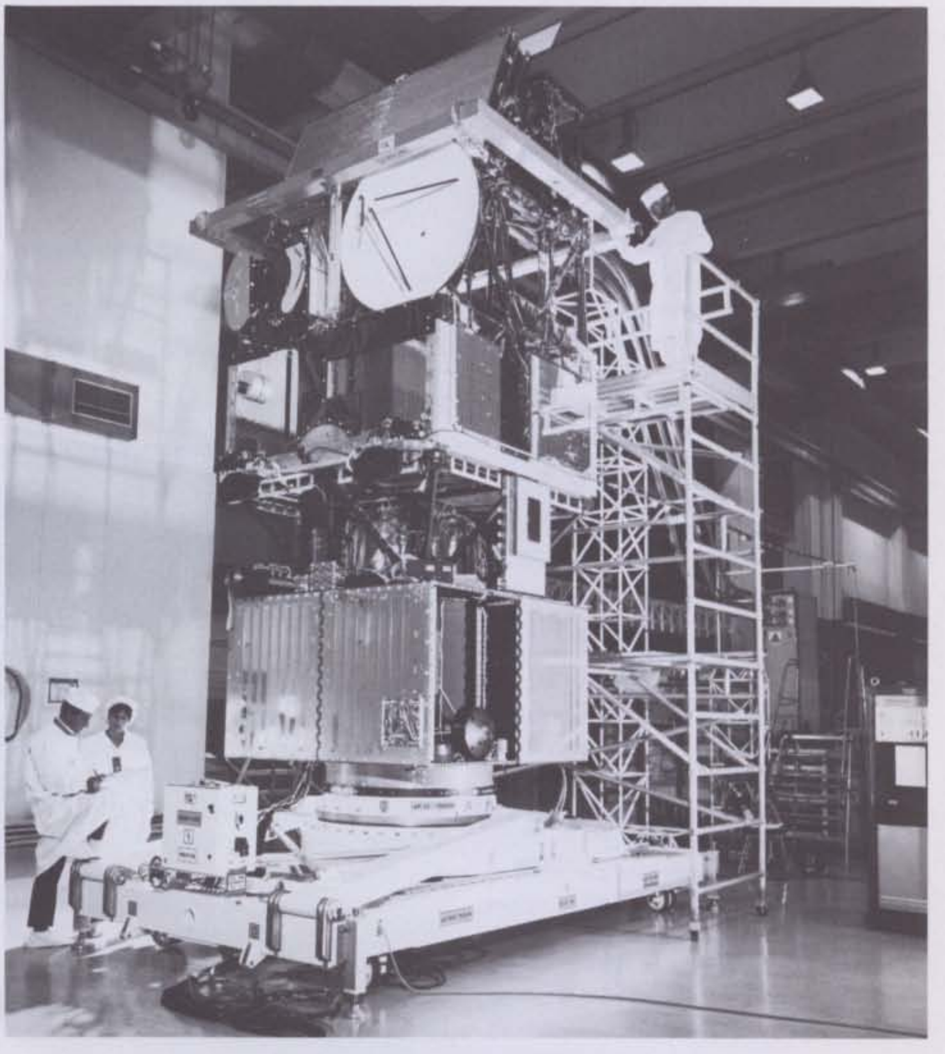
Meteosat

During the investigation of the image anomaly on Meteosat-4 (MOP-1), Meteosat-3 (P2) was used as the operational spacecraft. However, due to a partial failure in Meteosat-3, operations were switched back to Meteosat-4 on 19 April and have since been maintained by the latter with essentially noise-free images.

MOP-2 is being kept in storage awaiting the outcome of the MOP-1 anomaly investigation while MOP-3 has now been completely integrated and is undergoing performance testing.

ERS-1: essais d'ambiance acoustique et de vibration au CNES, Toulouse

ERS-1 acoustic and vibration testing at CNES, Toulouse



L'étude de faisabilité de l'expérience de surveillance de l'ozone à l'échelle du globe (GOME) ayant donné de bons résultats, le Conseil directeur du Programme d'observation de la Terre a confirmé l'inclusion de l'expérience dans la charge utile.

Météosat

Pendant l'analyse des anomalies d'image de Météosat-4 (MOP-1), Météosat-3 P2 a fait office de satellite opérationnel. Cependant, en raison d'une défaillance partielle de Météosat-3, Météosat-4 a été remis en service le 19 avril et assure depuis lors le service opérationnel pour l'essentiel sans bruit d'image.

MOP-2 reste entreposé dans l'attente du résultat de l'analyse des anomalies de MOP-1 tandis que MOP-3, maintenant complètement intégré, fait actuellement l'objet d'essais de fonctionnement.

Earthnet

Les stations Earthnet assurent de façon nominale l'acquisition, l'archivage, le traitement et la diffusion des données de Landsat, MOS-1 et Spot et distribuent aux utilisateurs un volume considérable de produits.

Les stations de Maspalomas, Tromsø, Oberpfaffenhofen et Rome du Réseau coordonné d'Earthnet ont régulièrement acquis et archivé les données des satellites NOAA-10 et 11. Les données de la station Agrhymet de Niamey sont transférées à Frascati de façon systématique pour archivage et redistribution. La CEE est favorable à une procédure similaire pour la station de Nairobi.

Un certain nombre d'activités se déroulent dans le cadre de l'accord de coopération ESA/CCE:
- *l'acquisition de données de Landsat et Spot à Maspalomas*
- *le projet OCEAN (fondé sur l'exploitation des données de l'analyseur 'couleurs de la mer' pour zones côtières)*
- *le projet de surveillance de la forêt tropicale à l'échelle du globe (TREES)*
- *le soutien aux pays asiatiques dans le cadre d'activités régionales liées à ERS-1.*

En outre, les réunions coordonnées avec la CCE se poursuivent dans des domaines d'intérêt communs parmi lesquels figurent la promotion d'ERS-1, des contributions à l'Année Internationale de l'Espace et en général l'utilisation des données de télédétection et de surveillance de l'environnement.

ERS-1

Les chaînes de traitement des produits à livraison rapide d'ERS-1 ont été installées et essayées à Frascati et dans les stations de Fucino et Maspalomas. La chaîne qui doit être installée à Gatineau a été préparée en vue de son expédition. L'intégration du service central utilisateur d'ERS-1 et du service de lecture rapide est achevée. La mise en oeuvre des installations de traitement et d'archivage (PAF) et des algorithmes et produits associés progresse de façon satisfaisante.

La première réunion du groupe de travail des exploitants potentiels de stations sol de réception des données d'ERS-1 s'est tenue à l'ESRIN en mars. Il a été confirmé lors de cette réunion qu'outre les stations de l'ESA, plusieurs stations sol, en Europe et ailleurs dans le monde, comptent être prêtes à acquérir les données du SAR dès le lancement d'ERS-1.

EOPP

Aristoteles

L'étude complémentaire sur Aristoteles s'est conclue par une présentation finale à laquelle a succédé une revue du concept de référence qui a donné de bons résultats.

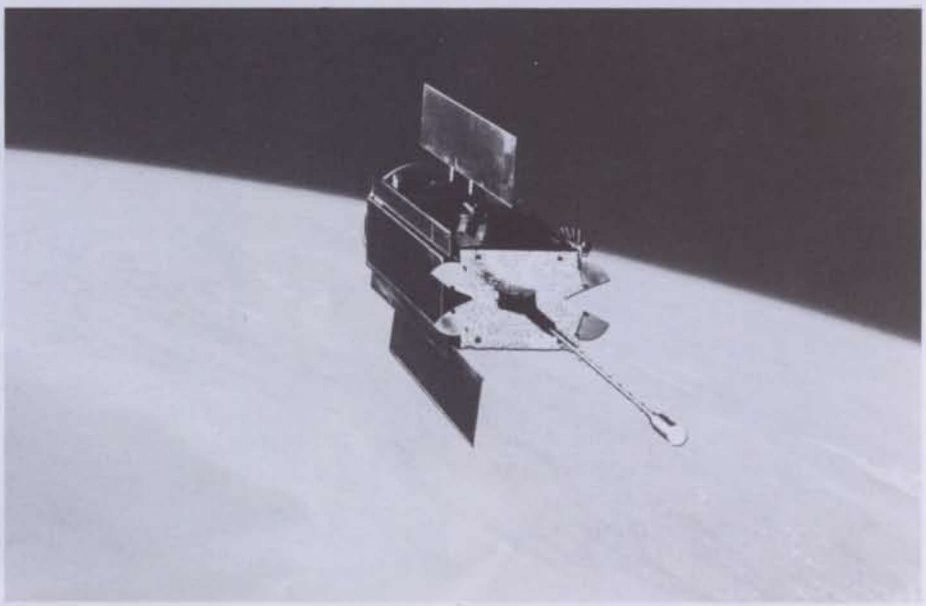
Le concept du satellite, compatible avec un lancement double Ariane, présente une configuration à 5 réservoirs. La stratégie de maintien à poste (à une altitude de 200 km) a été arrêtée sur la base de la dernière analyse de la mission et des capacités de reconstitution d'orbite en partant de l'hypothèse que l'on pourra utiliser le système de poursuite du GPS et disposer de mesures Doppler de la vitesse radiale fournies par le réseau de poursuite à usage multiple de l'ESOC. Pour l'instrument Gradio, on est parvenu à une configuration satisfaisante qui se caractérise par une plaque de base en verre zérodur (pour des raisons de stabilité dimensionnelle) et trois dispositifs d'étalonnage embarqués pour les accéléromètres. En ce qui concerne le magnétomètre, un bilan de propreté électromagnétique montre la faisabilité des concepts proposés.

Compte tenu des encouragements reçus lors de la dernière réunion du Conseil directeur du Programme d'observation de la Terre, la possibilité d'une coopération ESA/NASA sur Aristoteles est à l'examen.

En avril, la mission Aristoteles a été

Artist's impression of Aristoteles

Vue conceptuelle d'Aristoteles



Earthnet

Landsat, MOS-1 and Spot data acquisition, archiving, processing and dissemination have been performed nominally by Earthnet stations, with a considerable volume of products distributed to users.

The Earthnet Coordinated Network stations of Maspalomas, Tromsø, Oberpfaffenhofen and Rome regularly acquired and archived NOAA-10 and NOAA-11 data. Data from the Niamey-Agrhymet station have routinely been transferred to Frascati for archiving and redistribution. A similar procedure, supported by the EEC, is envisaged for the Nairobi station.

In the framework of the CEC – ESA cooperative agreement, a number of activities are ongoing:

- acquisition of Landsat/Spot data at Maspalomas;
- the OCEAN project (based on Coastal Zone Colour Scanner data exploitation);
- the global tropical forest monitoring project (TREES);
- support to Asian countries for ERS-1 related activities over the region.

In addition, coordination meetings continue with CEC in areas of common interest, including: ERS-1 promotion, International Space Year contributions, environmental monitoring and remote sensing data utilisation in general.

ERS-1

The ERS-1 Fast Delivery Processing chains have been installed and tested in Frascati and at the Fucino and Maspalomas stations. The final chain has been made ready for shipment to Gatineau for installation. Integration of the ERS-1 Central User and Browse Services has been completed. Implementation of the Processing and Archiving Facilities (PAF) and related algorithms and products is progressing well.

The first meeting of the ERS-1 Potential Ground Station Operators' Working Group was held at ESRIN in March. It was confirmed at the meeting that, in addition to the ESA stations, several ground stations in Europe and around the World expect to be ready to acquire ERS-1 SAR data by the time of launch.

EOPP

Aristoteles

The Aristoteles Additional Study was concluded with a final presentation. This was followed by a successful Baseline Design Review (BDR).

The satellite design, compatible with an Ariane dual launch, features a five-tank configuration. The orbit-maintenance (altitude 200 km) strategy has been finalised based on the latest mission-analysis results and orbit-reconstitution performance, assuming the availability of the GPS tracking system and of Doppler range rates from the ESOC Multi-Purpose Tracking System network. A satisfactory configuration has been arrived at for the Gradio instrument, featuring a zerodur glass baseplate (for dimensional stability reasons) and three on-board calibration devices for the accelerometers. On the magnetometer payload side, an electro-magnetic cleanliness budget shows the feasibility of the proposed concepts.

Following encouragement at the last Earth Observation Programme Board, the option of cooperation with NASA on Aristoteles is now being explored.

A short presentation on the Aristoteles mission was made to the European Geophysical Society in April.

Meteosat Second Generation (MSG)

The second mid-term review of the three-axis-stablised satellite system study was completed in April.

The concept of a High-Resolution Visible Imager Instrument has been refined. A parametric study of candidate concepts for a High-Spectral-Resolution Sounder has been completed, followed by a Preliminary Concept Review, and the instrument concept is now being defined in further detail.

Plans have been prepared jointly with Eumetsat for the continuation of MSG preparatory activities. Technical and programmatic information was made available to Eumetsat on both the three-axis-and spin-stabilised systems. In March the Eumetsat Scientific and Technical Group recommended the adoption of a spin-stabilised satellite configuration as the MSG baseline. The Eumetsat Council is expected to endorse this at its next meeting. The Phase-A study is currently scheduled to be initiated early in 1991 within the framework of the EOPP Extension.

Polar Orbit Mission

The Phase-A study of the first Polar Mission has been completed, and the final presentations of the overall system and instruments have been held. An extension of this study has been approved by the Earth Observation Programme Board to cover the period until the new optional programme for this mission is established.

The further evaluation of the Earth Observation and Space Science Announcement of Opportunity (AO) instrument proposals for the First Polar Orbit Mission has been completed jointly with the Science Directorate. The AO selection will be made at delegate level later this year.

Eureca

The Attitude-and-Orbit-Control Subsystem (AOCS) development and qualification test programme has been completed at MBB Ottobrunn and this subsystem is now being integrated into the carrier system.

In parallel, the Eureca system, including 13 experiment facilities, located at MBB/ERNO in Bremen, has been linked up with the European Operations Centre (ESOC) in Darmstadt to perform system-compatibility tests between the Eureca flight segment and the ESOC ground segment.

The Eureca Qualification Status Review, conducted in May at ESTEC, Noordwijk, identified various actions directed toward the formal close-out of open qualification/verification activities and requests to assess a few major items in detail for further review by the Board co-chairmen (e.g. thermal design).

Major efforts are currently concentrating on the preparation of detailed procedures for the forthcoming system tests to be conducted in the period July – October of this year. With this programme accomplished by the end of the year, the Eureca system would be ready for launch by mid-May 1991. Delay in the Shuttle launch programme could, however, cause a delay to the fourth quarter of 1991.

brièvement présentée à la Société européenne de Géophysique.

Météosat de deuxième génération (MSG)
La deuxième revue à mi-parcours de l'étude du système de satellite stabilisé trois axes a été menée à bien en avril.

Le concept d'un instrument imageur à haute résolution dans le visible a été affiné. En ce qui concerne le sondeur à haute résolution spectrale, il a été réalisé une étude comparative des concepts candidats, suivie d'une revue du concept préliminaire et l'on travaille à l'heure actuelle à une définition plus détaillée de l'instrument.

L'ESA et Eumetsat ont élaboré un plan commun pour la poursuite des activités préparatoires de MSG. Des informations techniques et programmatiques ont été mises à la disposition d'Eumetsat au sujet des systèmes trois axes et à stabilisation par rotation. En mars, le groupe scientifique et technique d'Eumetsat a recommandé l'adoption, comme base de référence des satellites MSG, d'une configuration de satellite stabilisée par rotation. Le Conseil d'Eumetsat devrait faire sienne cette recommandation lors de sa prochaine session. Actuellement, il est prévu que l'étude de phase A commence début 1991 dans le cadre de l'Extension de l'EOPP.

Mission sur orbite polaire
L'étude de phase A de la première mission sur orbite polaire est terminée et des présentations finales sur les instruments et sur le système dans son ensemble ont eu lieu. Le Conseil directeur du Programme d'observation de la Terre a approuvé une extension de cette étude afin de couvrir la période allant jusqu'à l'établissement du nouveau programme facultatif de cette mission.

Il a été achevé conjointement avec la Direction Science spatiale l'évaluation complémentaire des propositions d'instruments AO (offre de participation) pour l'observation de la Terre et les sciences spatiales en vue de la première mission sur orbite polaire. La sélection des instruments AO sera faite au niveau des délégués dans le courant de l'année.

Eureca

Le programme de développement et d'essais de qualification du sous-système de commande d'orientation et de correction d'orbite (AOCS) s'est achevé chez MBB à Ottobrunn et on intègre maintenant ce sous-système au porte-instrument lui-même.

Parallèlement le système Eureca, y compris 13 des installations pour expériences, qui se trouve chez MBB/ERNO à Brême, a été relié au Centre européen d'opérations spatiales (ESOC) à Darmstadt en vue des essais de compatibilité au niveau système entre le secteur spatial d'Eureca et le secteur sol de l'ESOC.

La revue de la situation de la qualification d'Eureca conduite en mai à l'ESTEC (Noordwijk) a permis de déterminer plusieurs mesures visant à la conclusion d'activités de qualification et de vérification en suspens. L'évaluation détaillée de certains éléments importants (ex. conception thermique) pour revue ultrérieure par les co-présidents de la commission a été demandé.

Actuellement, l'essentiel des travaux porte sur la préparation de procédures détaillées en vue des essais système qui doivent être réalisés entre juillet et octobre 1990. Le programme s'achevant à la fin de l'année, le système Eureca devrait être prêt pour la mi-mai 1991. Cependant, des retards sur le programme de lancement de la Navette pourraient contraindre à reporter le lancement au quatrième trimestre 1991.

Station Spatiale Freedom/Columbus

Laboratoires
La réunion de la Commission d'évaluation des offres (TEB) de l'Agence tenue à la mi-janvier à l'ESTEC a marqué l'achèvement de l'évaluation de la proposition de phase C/D. La TEB a entériné les principales conclusions des travaux des groupes d'évaluation dont une vive recommandation visant à apporter quelques modifications majeures à la structure industrielle, en particulier, pour ce qui concerne le Laboratoire autonome et la Plate-forme polaire.

Début février a eu lieu à l'ESTEC la première réunion d'information sur l'évaluation complète de la proposition industrielle de la phase C/D à l'attention du maître d'oeuvre et des contractants 'Eléments'. Les principales conclusions des travaux de la TEB y ont été résumées ainsi que les plans de l'Agence relatifs à une phase de revalidation de la proposition devant aboutir à la présentation en octobre 1990 d'une mise à jour détaillée de celle-ci. Fin février, se sont tenues des réunions d'information spécialisées consacrées aux propositions de Laboratoire autonome et de module pressurisé. Des réunions similaires au niveau des sous-systèmes ont eu lieu en mars; elles ont été suivies par le démarrage de la phase de revalidation de la proposition.

La première Autorisation préliminaire d'engagement de travaux (PATP-1) destinée à couvrir les tâches industrielles jusqu'à fin mars 1990 a été prolongée à partir de la fin janvier : elle a été suivie, début avril, par la tranche 1 de la PATP-2. Après consolidation et revalidation de la proposition industrielle, il est projeté de lancer en avril 1991 l'ensemble du contrat de la phase C/D du secteur spatial.

Sur la base des résultats de l'évaluation de la proposition et d'évaluations internes menées en parallèle, on a retenu pour la phase de revalidation de la proposition les principales options de configuration suivantes:

1. *Configuration du Laboratoire autonome basée sur le concept de module de ressources remplaçable accompagnée de dispositions au niveau de la conception pour que le bras télémanipulateur d'Hermès (HERA) puisse être installé en orbite.*

2. *Module Laboratoire raccordé avec le sas monté dans le cône d'extrémité, la possibilité d'installer des bâtis simples de charge utile étant retenue. Les services de charge utile qui avaient été revus à la baisse dans la proposition industrielle doivent être rétablis.*

Courant janvier, la NASA a présenté des possibilités de calendrier d'assemblage de la Station spatiale proposant une date de lancement du Laboratoire raccordé et une date la plus précoce possible pour

Space Station Freedom/ Columbus

Laboratories

The Phase-C/D Proposal Evaluation was completed with the Agency's Tender Evaluation Board (TEB) meeting, held at ESTEC in mid-January. The TEB endorsed the main findings of the Evaluation Panels, including a strong recommendation that some key changes in the industrial setup be implemented, in particular with respect to the Free Flyer Element and to the Polar Platform.

The first full Phase-C/D industrial proposal evaluation debriefing for the Prime and Element Contractors was conducted at ESTEC at the beginning of February. All major TEB findings were summarised, together with the Agency's planning for a Proposal Revalidation Phase leading to submittal of a comprehensive proposal update in October 1990. Dedicated follow-up debriefings for the Free Flyer and Pressurised Module proposals were conducted at the end of February. Proposal debriefings down to sub-system level were completed in March, followed by the initiation of the Proposal Revalidation Phase.

The planned extension of the initial Preliminary Authorisation-to-Proceed (PATP-1) to cover industrial tasks up to the end of March 1990 was implemented at the end of January and was followed at the beginning of April by PATP-2 Slice-1. Then, following consolidation and revalidation of the industrial proposal, it is planned to issue the full Space Segment C/D contract in April 1991.

Based on the results of the Proposal Evaluation and parallel in-house assessments, the following key configuration options have been selected as the basis for the Proposal Revalidation Phase:

1. Free Flyer configuration, based on the Replaceable Resource Module concept and with design provisions for on-orbit accommodation of the Hermes Robotic Arm (HERA).
2. Attached Laboratory Module with the airlock installed in the end cone, retaining the capability of accommodating single payload racks. Those payload services descoped in the industrial proposal are to be reinstated.

In the course of January NASA submitted options in the Space Station Assembly schedule addressing the Attached Laboratory launch date and the earliest servicing date at Space Station Freedom for the Free Flyer. ESA has confirmed its preference for the following dates:

1. Attached Laboratory launch: Third quarter of 1997
2. First Free Flyer servicing: February 1999.

These options will not be consolidated until the end of the Space Station Preliminary Design Review (PDR) at the end of this year or in early 1991.

Much effort has been devoted in February to reaching agreements with NASA and NASDA on the Space Station payload rack interchangeability issue. The major interface agreements/ definitions were agreed at a multi-lateral Level 2 Rack Steering Group Meeting in Tokyo at the end of March. A large number of ESA high-priority issues were closed during a joint Level II programme review in ESTEC at the end of April.

Concerning the Columbus ground segment, the System Architecture Design started towards the end of last year, as a preliminary to the detailed design of the ground segment.

Proposals for the detailed definition of the Manned Space Laboratories Control Centre (MSCC), the Free Flyer Centre (FFC) and the Attached Laboratory Centre (ALC) have been evaluated and discussed with Industry, allowing the industrial work to start at the end of March/early April.

As regards utilisation, activities related to cooperative Spacelab missions are continuing: in addition to ESA, NASA and Germany, Italy has expressed its interest in conducting cooperative flights in preparation for Space Station missions.

A number of different industrial activities to define and develop utilisation ground- and flight-hardware are underway. The Columbus Automation and Robotics Testbed contract began in April. The development contract of the initial Columbus Utilisation Information System started earlier this year with interviews with various user groups in order to review user requirements.

Polar Platform

The Polar Platform was transferred from the Directorate of Space Station and Microgravity to the Directorate of Observation of the Earth and its Environment at the beginning of April. This groups the development of the spacecraft bus and the payload and other associated aspects (POEM-1 once approved) in the same Directorate.

Following the issue of a complete self-standing set of top-level requirements, Industry has been requested to update the Polar Platform proposal.

TDP

Experiments

Gallium Arsenide (GaAs) Solar Array
The small satellite (UoSat-4) that was carrying the Phase-1 experiment (solar panels made of soldered 2×2 cm cells) has not yet been recovered; a partial reflight of the experiment is under consideration.

Phase-2, a solar panel made of 2x4 cm cells with welded interconnectors, is approaching its Critical Design Review. It will be carried aboard the Space Technology Research Vehicle (STRV-1) of RAE (UK).

Transputer and Single Event Upset
This experiment was also launched on-board UoSat-4 and no data have been received. A reflight is under discussion.

Solid State Micro-Accelerometer
The flight unit is in storage waiting to be sent to the launch site.

Attitude Sensor Package
The Critical Design Review has been completed successfully and the manufacturing phase has been initiated.

Collapsible Tube Mast (CTM)
The bridging phase has been initiated and will be concluded by the end of this year.

Metal Deposition In-Orbit
The Preliminary Design Review was successfully completed in June.

Liquid Gauging Technology
The Critical Design Review is foreseen for September.

la première desserte du Laboratoire autonome à la Station spatiale. L'ESA a confirmé qu'elle préférait les dates suivantes:

1. *Troisième trimestre 1997 : lancement du Laboratoire raccordé*
2. *Février 1999 : Première desserte du Laboratoire autonome.*

Ces options ne seront pas consolidées d'ici la fin de la Revue de conception préliminaire (PDR) de la Station spatiale à la fin de l'année ou début 1991.

Le mois de février a été consacré, pour l'essentiel, à la recherche d'accords avec la NASA et la NASDA sur l'interchangeabilité des bâtis de charges utiles de la Station spatiale. C'est à Tokyo, fin mars, que les principales interfaces ont été définies et approuvées lors d'une réunion multilatérale de niveau II du Comité directeur 'Bâtis'. Bon nombre de questions hautement prioritaires de l'ESA ont été closes fin avril à l'ESTEC à l'occasion d'une revue de programme conjointe de niveau II.

En ce qui concerne le secteur sol de Columbus, la conception de l'architecture du système a commencé à la fin de l'année dernière, étape préliminaire vers la conception détaillée du secteur sol.

La définition détaillée des Centres de contrôle des laboratoires habités (MSCC), du Laboratoire autonome (FFC), du Laboratoire raccordé (ALC) a fait l'objet de propositions qui ont été évaluées et examinées avec l'industrie; les travaux industriels ont ainsi pu commencer fin mars, début avril.

Pour ce qui concerne l'utilisation, les activités liées à des missions Spacelab menées en cooperation se poursuivent; s'ajoutant à l'ESA, à la NASA et à l'Allemagne, l'Italie a fait savoir qu'elle souhaiterait exécuter des vols en coopération pour se préparer à des missions de la Station spatiale.

Différentes activités industrielles liées à la définition et au développement de l'utilisation des matériels des secteurs sol et spatial sont en cours de réalisation. L'exécution du contrat relatif au banc d'essai 'Automatisation et robotique' de Columbus a commencé en avril. Le contrat de développement du premier Système d'information sur l'utilisation de Columbus a été lancé plus tôt dans l'année ; on a commencé par interroger divers groupes d'utilisateurs pour passer en revue leurs besoins.

Plate-forme polaire
Au début du mois d'avril, la responsabilité de la plate-forme polaire, élément qui fait partie du Programme Columbus de l'Agence, a été transférée de la Direction Station spatiale et Microgravité à la Direction Observation de la Terre et de son environnement ; cette dernière regroupe les travaux de développement du véhicule spatial lui-même, de la charge utile et d'autres aspects connexes (Mission POEM-1 lorsqu'elle aura été approuvée).

A la suite de la diffusion d'un document indépendant et complet sur les impératifs de haut niveau, l'industrie a été invitée à actualiser la proposition de plate-forme polaire.

TDP

Expériences
Générateur solaire à l'arséniure de gallium (GaAs)
Le petit satellite (UoSat-4) à bord duquel était embarquée l'expérience de la phase 1 (panneaux solaires constitués de cellules soudées de 2x2 cm) n'a pas encore été récupéré; on envisage le réemport d'une partie de l'expérience.

En ce qui concerne la phase 2 de cette expérience qui porte sur un panneau solaire équipé de piles de 2x4 cm à interconnecteurs soudés, on approche de la revue critique de la conception qui sera conduite à bord du véhicule de recherche technologique spatiale (STRV-1) du RAE (RU).

Transordinateur et perturbations sous l'effet de particules élémentaires
Cette expérience était également embarquée à bord d'UoSat-4 ; aucune donnée n'a été reçue ; son réemport est à l'examen.

Micro-accéléromètre à l'état solide
L'unité de vol est entreposée dans l'attente de son expédition sur le site de lancement.

Ensemble de détecteurs d'orientation
La revue critique de la conception a donné des résultats satisfaisants et la phase de fabrication a commencé.

Mât à tube enroulable (CTM)
La phase relais a commencé et sera terminée à la fin de l'année.

Expérience de dépôt de métaux en orbite
La revue de conception préliminaire a été menée à bien en juin.

Technologie de jaugeage des liquides
La revue critique de la conception est prévue pour septembre.

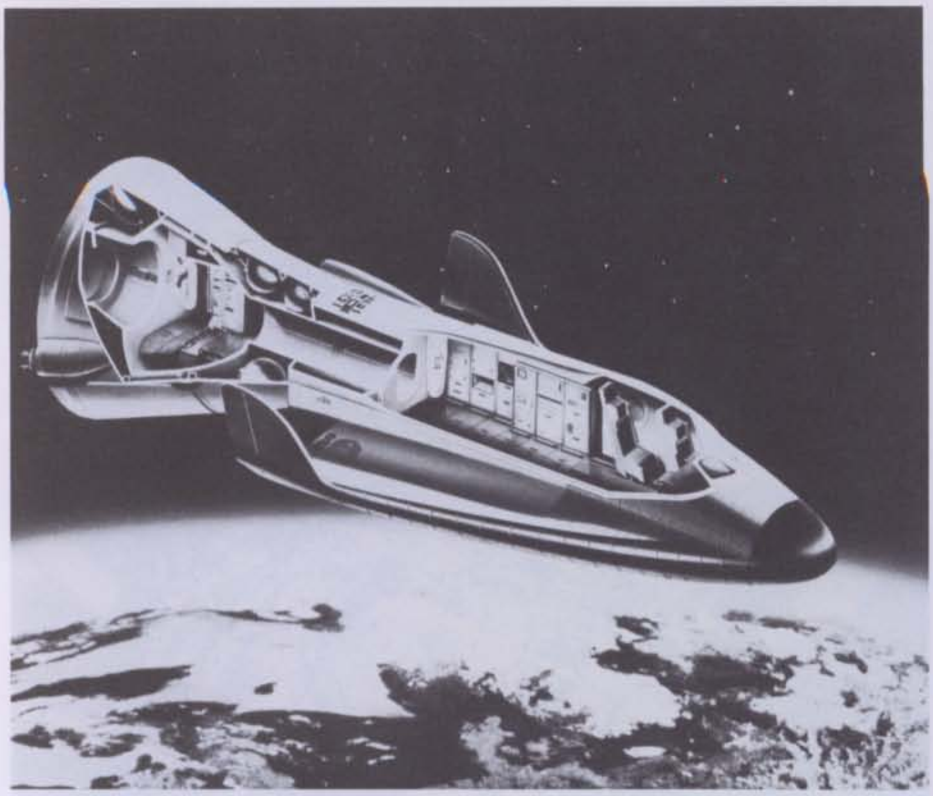
Technologie de structures gonflables rigidifiables dans l'espace
La phase A a pris fin en juillet. Il est prévu qu'une revue de sécurité préliminaire ait lieu aux Etats-Unis en août. La Phase B commencera en septembre.

Ecoulement diphasique
La revue de conception préliminaire est fixée à septembre.

Expérience ESA/NASA en coopération
Dans le cadre de l'expérience de contamination en vol (IFCE/CTM), la NASA fournit un soutien à l'ESA pour la conception du système de larguage du CTM. En ce qui concerne les décisions relatives à la phase C/D de cette expérience et de l'expérience d'interactions entre le module de générateur solaire et le plasma (SAMPIE), on continue d'attendre les résultats relatifs au CTM.

Occasions de vol
Le lancement des expériences Hitchhiker-G (ensemble de détecteurs d'orientation) a été reporté à janvier 1992 (Navette STS-50). Le lancement GAS du micro-accéléromètre état solide (G-21) à bord du STS-1 a été reporté à décembre prochain. le lancement du STRV-1 qui emportera la phase 2 de l'expérience de générateur solaire à l'arséniure de gallium est prévu pour le début de 1992.

Préparation de la phase suivante du TDP
La première réunion des participants potentiels doit avoir lieu en septembre.



Vue éclatée d'Hermès (juillet 1990)

Cut-away view of the Hermes spaceplane (July 1990)

Inflatable Space Rigidised Technology Experiment
Phase-A was completed in July. A preliminary Safety Review in the United States is scheduled for August. Phase-B will start in September.

Two-Phase Flow
The Preliminary Design Review is scheduled for September.

ESA/NASA cooperative experiments
In the framework of the In-Flight Contamination Experiment (IFCE/CTM), NASA is providing support to ESA in the design of the CTM's Jettison System. Phase-C/D decisions for this experiment and the Solar Array Module Plasma Interaction Experiment (SAMPIE) are pending the CTM status.

Flight opportunities
For the Hitchhiker-G experiment (Attitude Sensor Package) the launch has been shifted until January 1992 on-board STS-50. The Get-Away Special launch of the Solid State Micro-Accelerometer (G-21) on-board STS-40 has now been delayed until December of this year. The STRV-1 launch, carrying the Gallium Arsenide Solar Array Phase-2 experiment is foreseen for early 1992.

TDP Next Phase Preparation
The first meeting of the Potential Participants is scheduled for September.

Ariane

Ariane-5
The first Vulcain engine was integrated on the PF50 test stand at SEP Vernon on 4 April, in accordance with a planning schedule drawn up three years ago. This important milestone in the development of the engine is the result of considerable effort on the part of the programme contractors over the last year.

The first cooling-down test has taken place, and the engine behaved according to predictions. The first ignition test of the engine combustion chamber is planned for early July.

Progress in the development of the P230 solid booster is satisfactory despite the usual difficulties encountered with such a huge project in the tropical environment of Kourou. The first Scale One test of a P230 solid booster in Kourou is still scheduled for the second half of 1991.

Hermes

Important decisions at space-vehicle configuration level were presented to the Programme Board on 22 May, namely:

- choice of the ejectable seats, of Buran type (Mach 3), as the most reliable and feasible crew escape system. As a consequence, seat development will be coupled with that of IVA suits, making use of current expertise in the field
- selection of aluminium alloy instead of composite materials for the cold structure
- confirmation of winglets versus central fin
- cancellation of the Hermes Propulsion Module, with the possibility of direct injection of Hermes into its transfer orbit by Ariane-5.

Hermes Robotic Arm (HERA) and EVA activities are continuing along the lines indicated by the configuration reviews.

Concerning the ground segment, the definition phase of the Flight Control Centre has started as planned.

Programme aspects
The key decision has been the delay of transition to Phase 2 until June 1991, in order to consolidate the technical configuration and the management aspects. As a consequence, a transition budget request, in advance of the Phase-2 decision, has been submitted to the Programme Board.

Management aspects
An administrative arrangement has been signed by the Directors General of ESA and CNES aiming at a more efficient management organisation. This agreement foresees a unique ESA/CNES programme team, headed by a Programme Director and monitored by a Supervisory Board.

The relevant legal texts are expected to be finalised shortly and the transition period is being used to make organisational and staffing adjustments.

Industry has also been requested to implement for Phase-2 an organisation which optimises the industrial structure on a European scale.

Ariane

Ariane-5

Le 4 avril, conformément au calendrier établi il y a trois ans, le premier moteur Vulcain a été intégré sur le banc d'essai PF50 de la SEP à Vernon. Cette étape importante dans la mise au point du moteur est l'aboutissement d'un effort considérable déployé par les contractants depuis un an.

Le premier essai de refroidissement a eu lieu; le moteur s'est comporté conformément aux prévisions. Le premier essai d'allumage de la chambre de combustion du moteur est prévu pour début juillet.

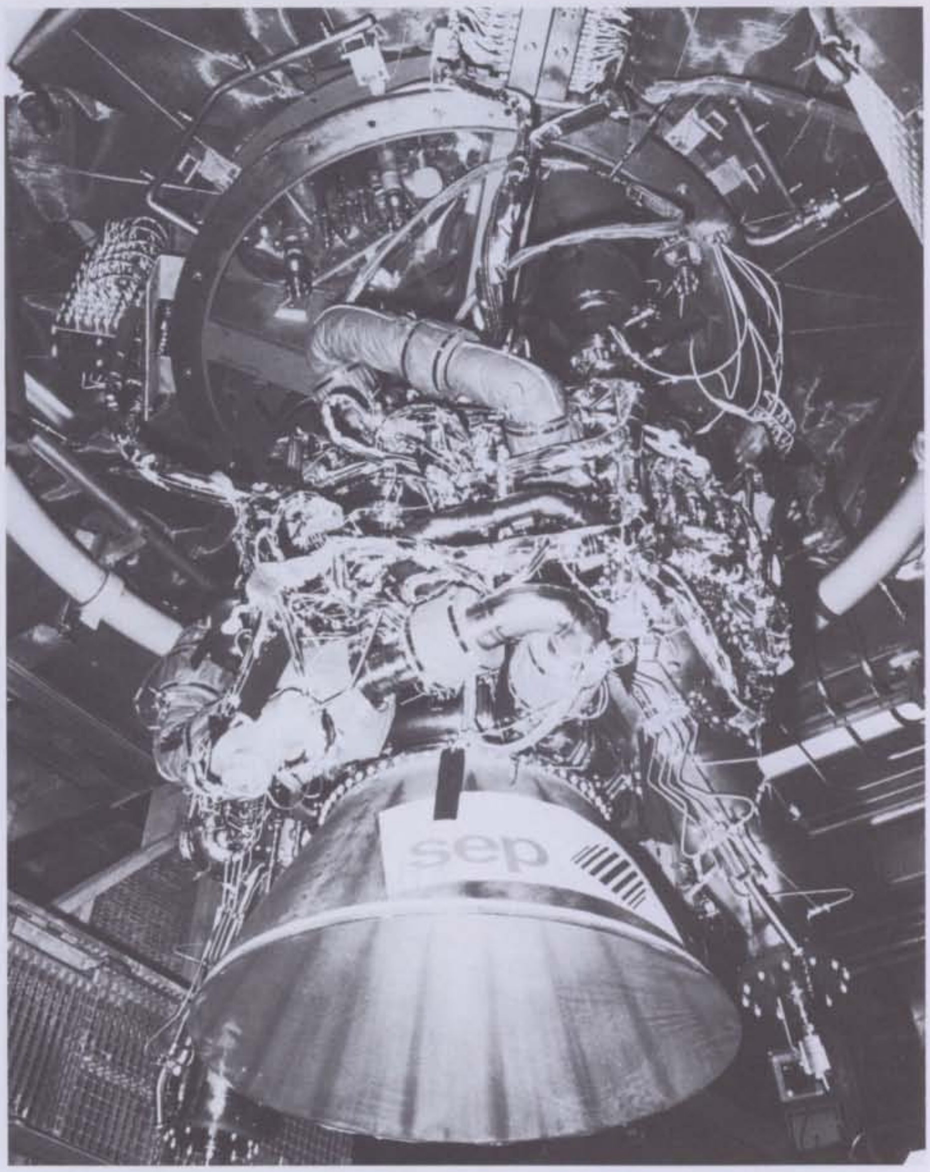
Les travaux de mise au point du propulseur à poudre P230 se poursuivent de manière satisfaisante malgré les difficultés que l'on rencontre habituellement avec un projet de cette envergure dans l'environnement tropical de Kourou. Le premier essai grandeur réelle d'un propulseur à poudre P230 à Kourou est toujours prévu pour le second semestre 1991.

Hermès

Des décisions importantes relatives à la configuration du véhicule spatial ont été présentées au Conseil directeur du Programme réuni le 22 mai. Elles portent sur les points suivants:

- *choix des sièges éjectables de type Bourane (Mach 3) qui constituent le système de sauvegarde de l'équipage le plus fiable et le plus facilement réalisable. En conséquence les travaux de développement de ces sièges pourraient être associés à ceux des combinaisons IVA en fonction de l'expérience actuelle dans ce domaine;*
- *choix de l'alliage d'aluminium au lieu de matériaux composites pour la structure froide;*
- *confirmation des dérives en bout d'aile à la place de la dérive centrale;*
- *suppression du module de propulsion Hermès et possibilité d'injection directe d'Hermès sur son orbite de transfert par Ariane-5.*

Les travaux sur le bras télémanipulateur d'Hermès (HERA) et les activités EVA se poursuivent selon les axes tracés par les revues de configuration.



Vulcain Engine No. 1 at the PF50 test facilities in Vernon

Moteur Vulcain No. 1 aux installations d'essais PF50 à Vernon

Quant au secteur sol, la phase de définition du Centre de contrôle en vol a commencé comme il était prévu.

Aspects relatifs au programme

La principale décision a été de reporter à juin 1991 le passage à la phase 2 afin de consolider la configuration technique et les aspects relatifs à la gestion. En conséquence une demande de budget de transition a été soumise au Conseil directeur du Programme avant que soit prise la décision de passer à la phase 2.

Aspects relatifs à la gestion

Les Directeurs Généraux de l'ESA et du CNES ont signé un accord administratif visant à une organisation de gestion plus efficace. A cet effet sera créée une équipe de programme ESA/CNES unique placée sous la direction d'un Responsable de programme et suivie par un Conseil de surveillance.

La version définitive des textes juridiques appropriés devrait être prête sous peu et la période de transition est mise à profit pour procéder à des ajustements sur le plan de l'organisation et des ressources en personnel.

L'industrie a également été invitée à mettre en place pour la phase 2 une organisation qui puisse optimiser la structure industrielle à l'échelle européenne.

Publications

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ESA Journal

The following papers have been published in ESA Journal Vol. 14, No. 2:

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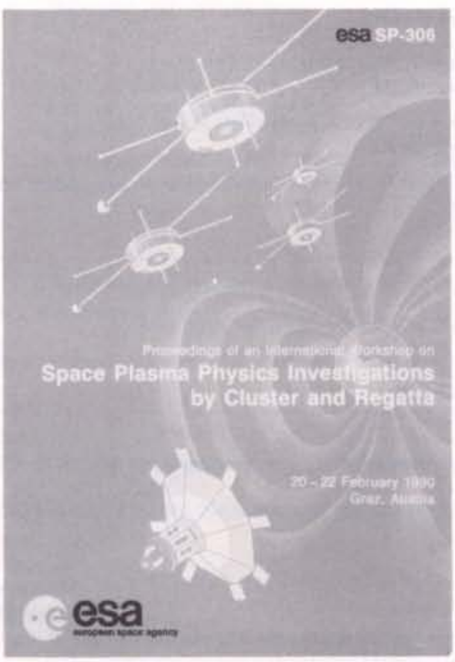

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