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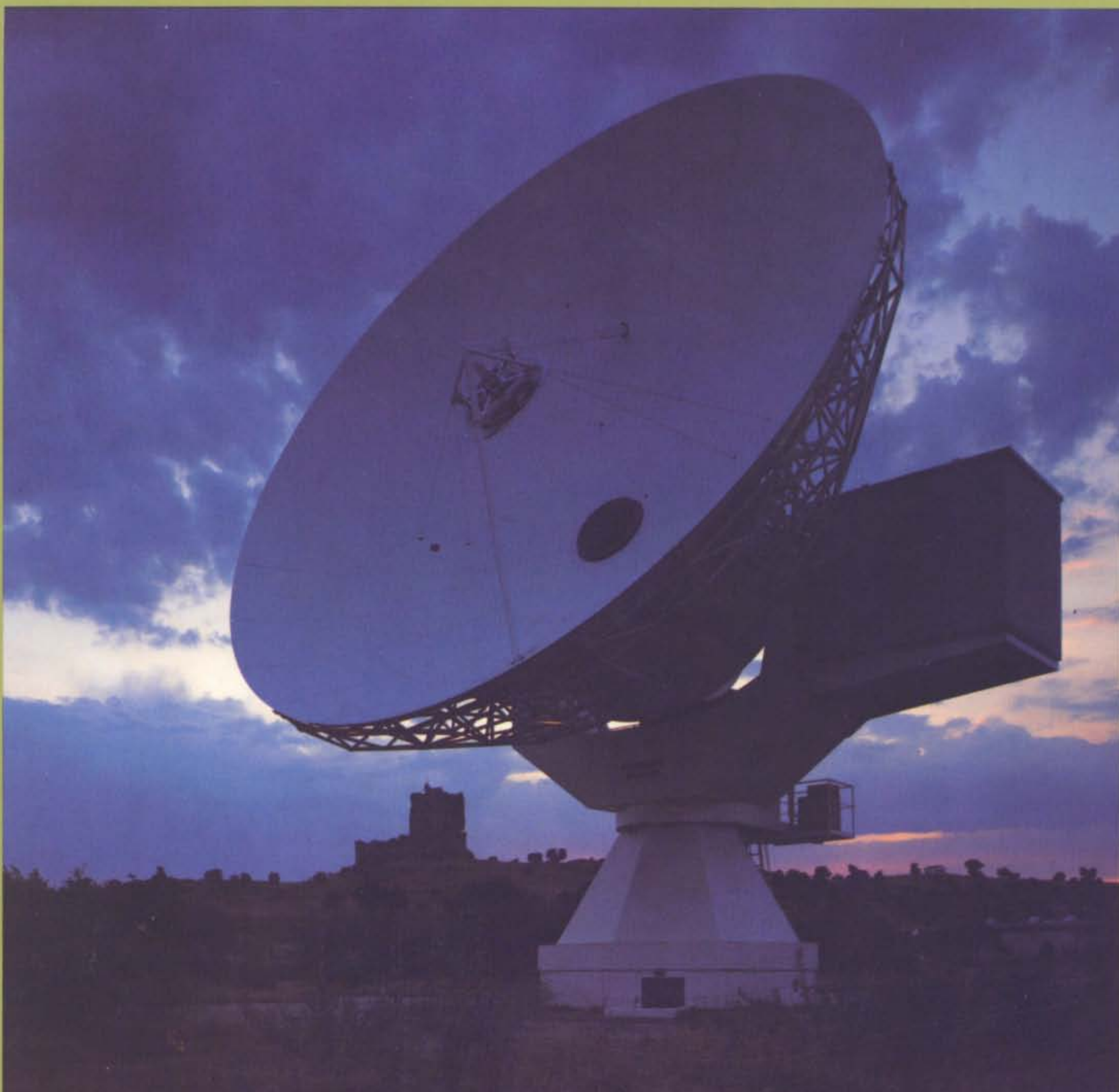

european space agency

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(a) by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
(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.

The Agency is directed by a Council composed of representatives of Member States. The Director General is the chief executive of the Agency and its legal representative.

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The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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THE EUROPEAN SPACE OPERATIONS CENTRE (ESOC), Darmstadt, Germany

ESRIN, Frascati, Italy.

Chairman of the Council: Mr H. Grage.

Director General: Prof. R. Lüst.

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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(d) en élaborant et en mettant en oeuvre la politique industrielle appropriée à son programme et en recommandant aux Etats membres une politique industrielle cohérente.

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no. 55 august 1988

contents/sommaire

Front and back covers: Reception antenna and some of the observatory facilities at ESA's Villafranca Ground Station near Madrid (see page 49).

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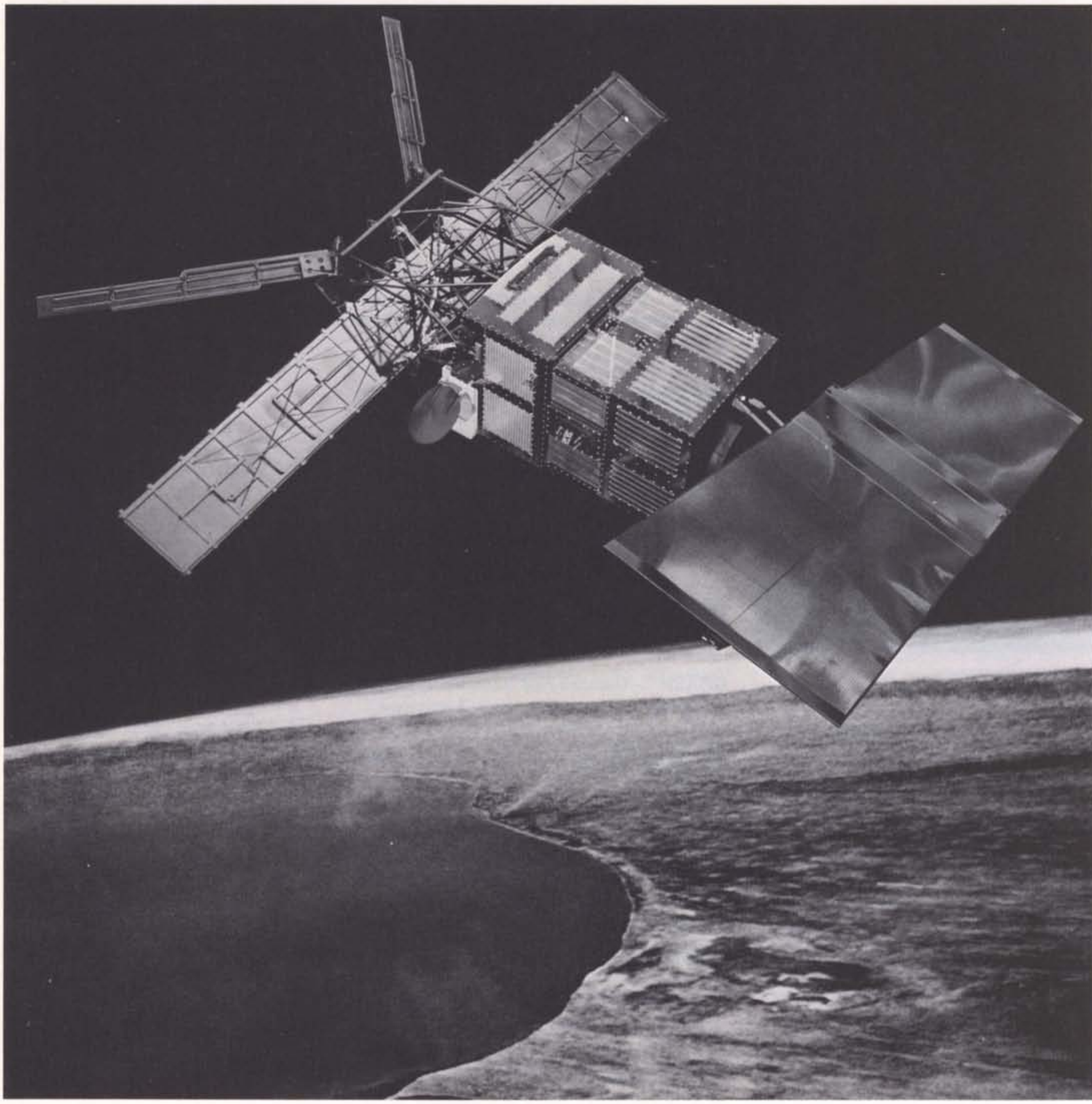

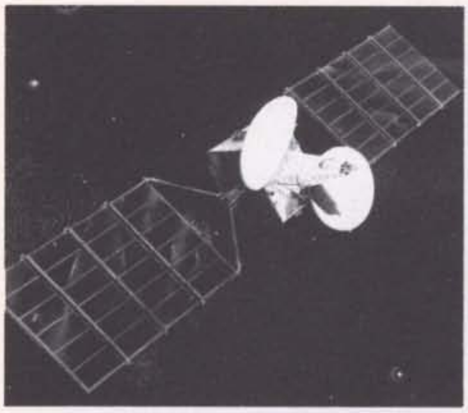
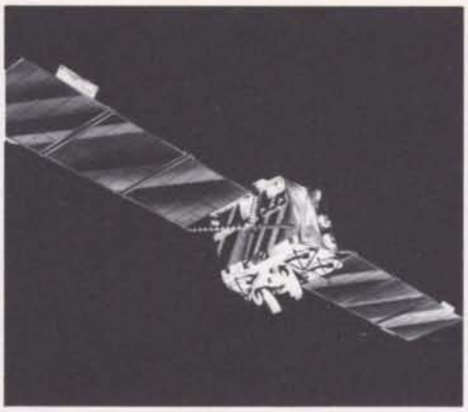
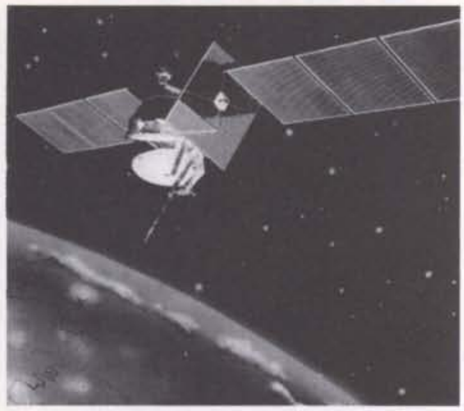
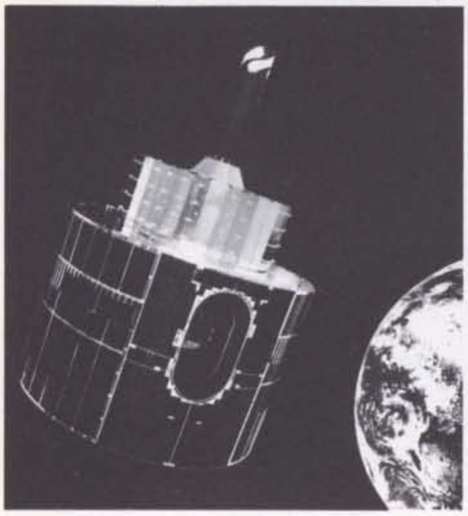
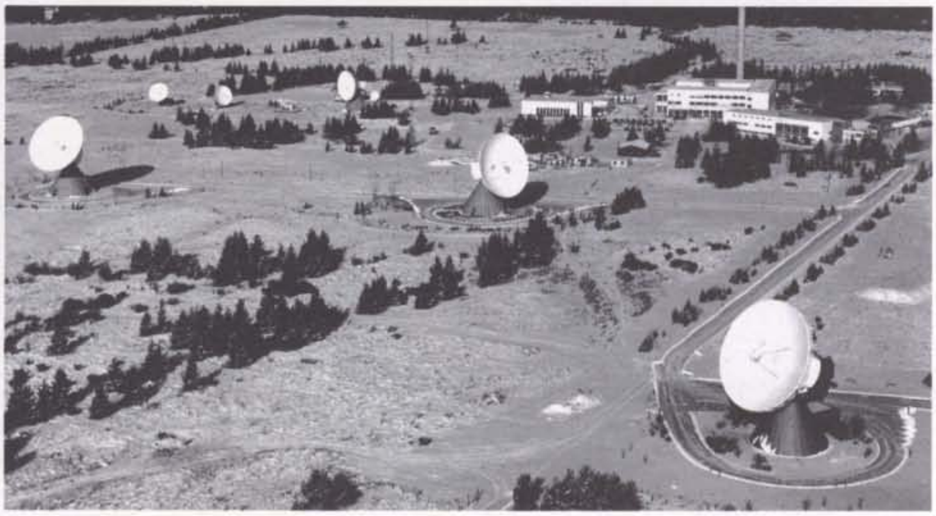

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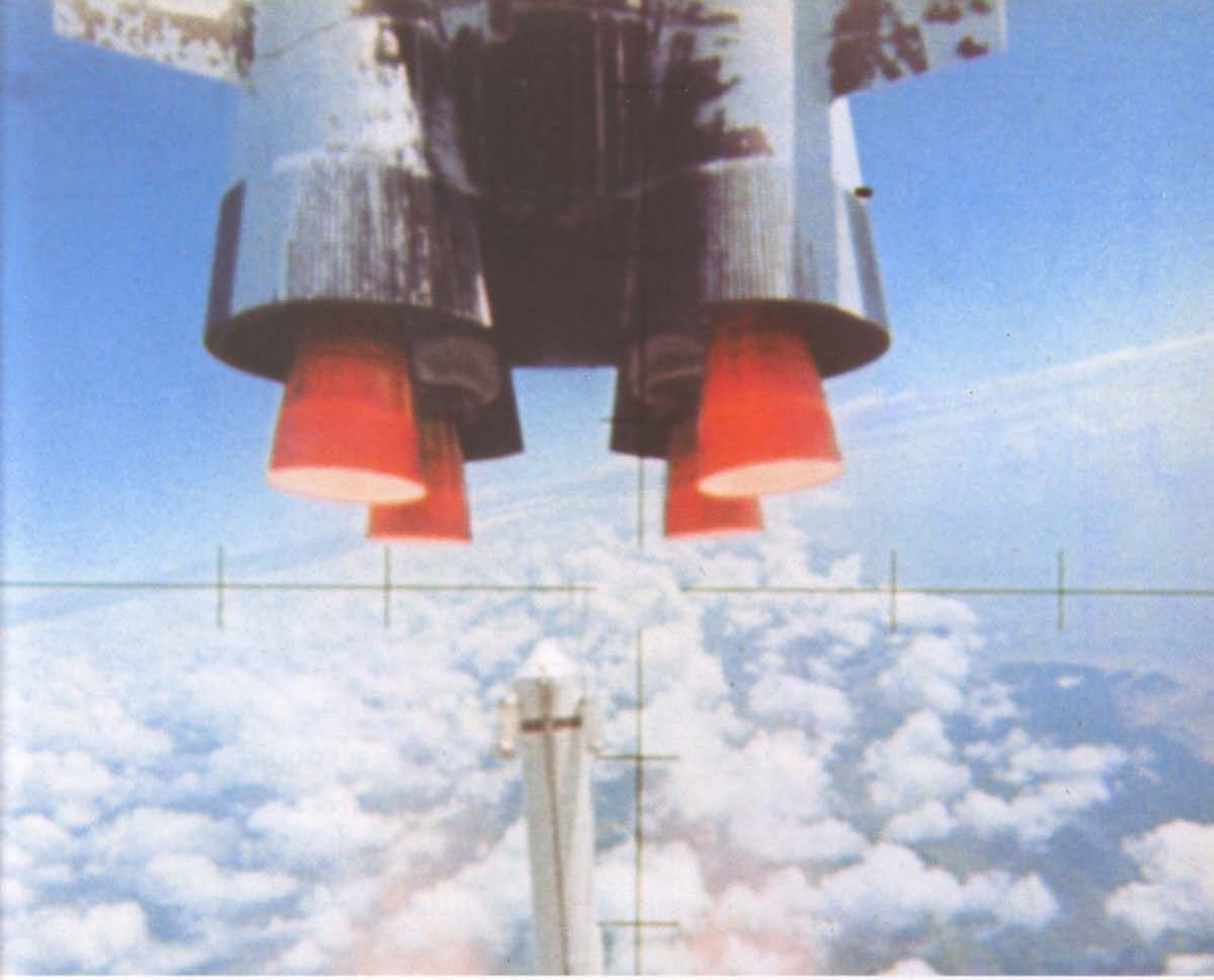

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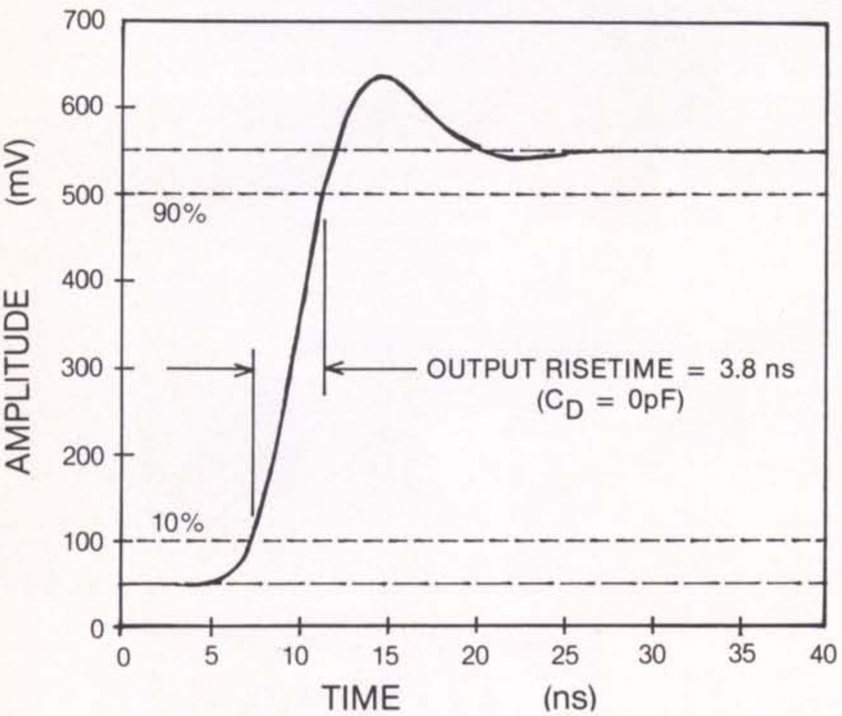

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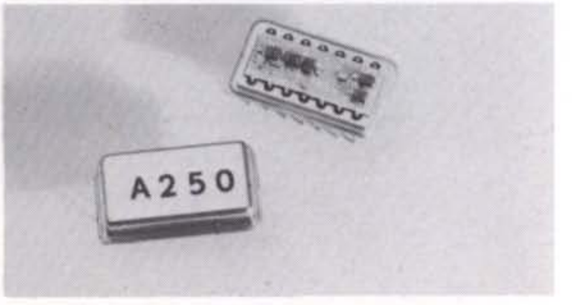

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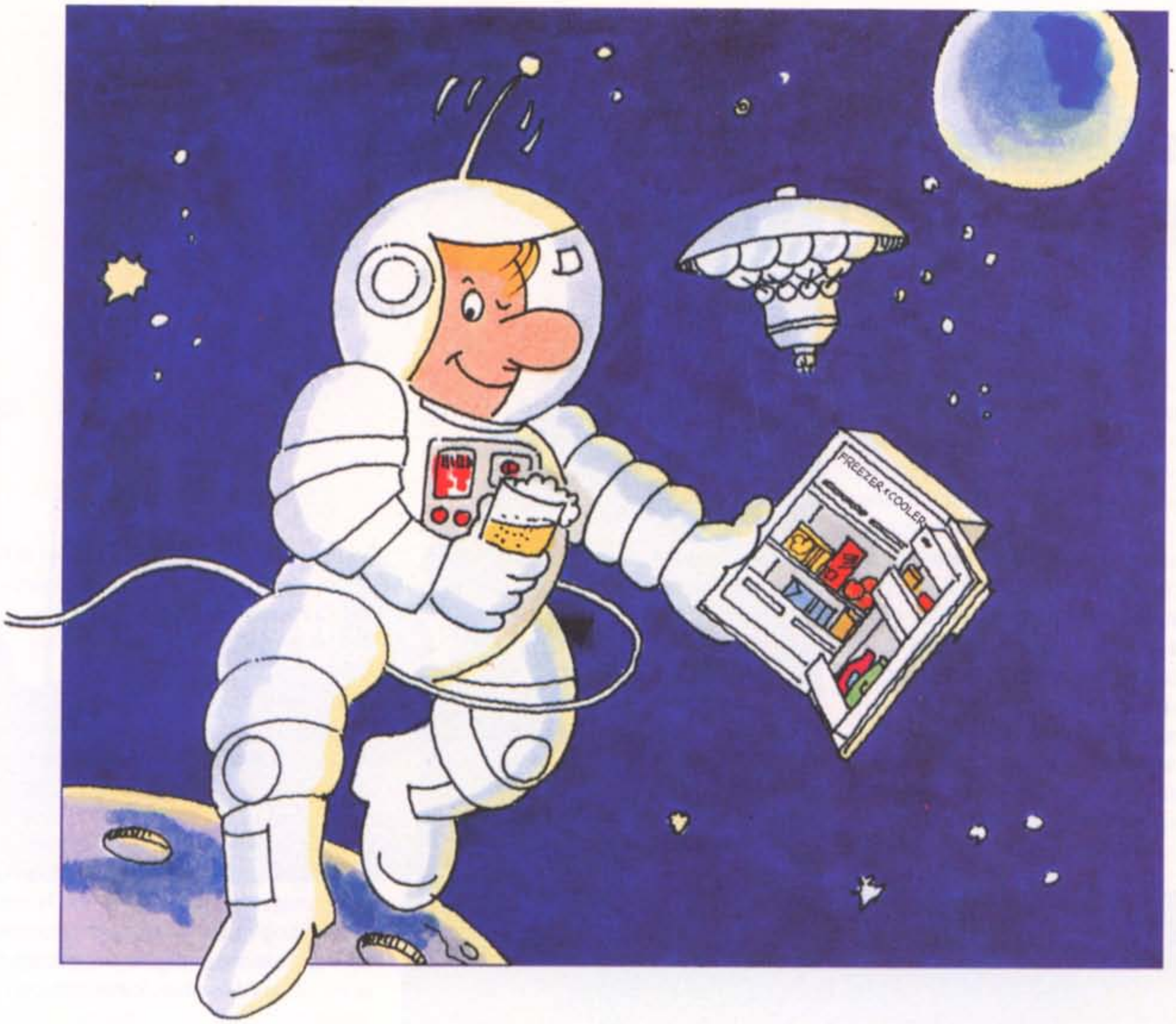


Competitive Selection of the Agency's Next Scientific Project

V. Manno, Directorate of Scientific Programmes, ESA, Paris

The forthcoming competitive selection of a new scientific project for the Agency takes place within the framework of the accepted long-term plan for space science called 'Space Science: Horizon 2000', presented at the Ministerial Conference in Rome in 1985. This plan consists in essence of four pre-defined 'Cornerstones', which give the plan coherence, and of a number of smaller missions, selected in competition, which give it the necessary flexibility. These two elements are inseparable and are both essential to a sound and balanced Scientific Programme.

Without the flexibility element, the stability given by the Cornerstones would become rigidity, while the flexibility element alone would not in itself, constitute a long-term plan. About 60% of the Horzion 2000 budget is devoted to the Cornerstones, and 40% to the flexible element.

Since 1985, the Science Directorate, in close consultation with ESA's Science Advisory Committee, and with the full support of the Science Programme Committee (SPC), has moved towards a phased implementation of this plan. Two successive implementation plans have been presented to the SPC, the latest responding to the new situation created by the Challenger explosion, and by the entry of new Member States into the Agency.

The first Cornerstone of Horizon 2000, the Solar-Terrestrial Science Programme, was started in 1986. The scientific payload has recently been selected and approved by the SPC and the Invitation to Tender is being prepared for issue to industry in Autumn 1988.

Meanwhile scientific studies and technological development efforts are being carried out in preparation for the second Cornerstone, presently called the XMM mission, which is due for launch in 1998. An Announcement of Opportunity for the payload instruments for XMM was issued in June 1988.

For the two remaining Cornerstones, the Comet-Nucleus Sample Return (CNSR) mission and the First submillimetre telescope, two scientific teams are currently working to identify alternative missions consistent with the financial envelope allocated to them. In addition,

some preliminary technological studies and development efforts are in progress. A priority choice between the two Cornerstones will be made in 1991/1992, when these preliminary activities are completed.

The flexible component of Horizon 2000, representing 40% of the financial envelope, embraces a number of smaller missions, some of which are related to utilisation of the Space-Station/Columbus elements. These missions are selected in competition at the end of a study phase in which various missions are studied in parallel and in competition. The ensemble of these activities is called a 'planning cycle', a maieutic process whereby, through successive eliminations, one project is eventually selected and approved for development.

The fundamental and essential characteristic of this process is that it is entirely controlled by the scientific community itself, with the Agency providing the necessary technical support. The missions to be studied are put forward by the community in response to a request for proposal from the Agency. Scientific screening by ESA's Astronomy and Solar-System Working Groups and the SSAC selects some 8 to 10 of these proposals, which are then submitted to an 'assessment study'. A team of consultant scientists, including the proposers, is thereby set up to prepare an in-depth scientific definition of the mission, its performance, and its system requirements. An internal technical study is conducted simultaneously to provide an assessment of the feasibility, readiness, technological problem areas and costs of the proposal. The results of these assessment studies are then presented to the scientific community.

Subsequent evaluation by the Working Groups and the SSAC narrows down the list of competitors to about four, which are then subjected to an in-depth technical system study, this time by industry. There is continuous interaction with the scientific team as the study progresses. This industrial feasibility study is the basis for a complete mission-design evaluation and costing by ESA.

The results of all the studies of the competing missions are again presented to the scientific community. The Working Groups and the SSAC make their recommendations to the ESA Executive, which in turn formulates its proposal to the SPC. At this point, it is the legislative body that takes over and selects one of the competing missions for development (or more if funds permit). The entire cycle lasts a minimum of two years, and is described in more detail in the next article.

This may look at first sight like a complex and lengthy process, but it does have considerable advantages. In particular, it permits a full involvement of the scientific community at all stages and the successive competitive stages ensure that a good scientific project will be selected primarily on scientific grounds, with industrial and political considerations only coming into play at a secondary level.

This selection procedure has already become well-known in scientific circles in Europe. We believe it has, by and large, the support of the scientists, who accept competition provided it really is fairly administered throughout. It is certainly our resolve that this must continue to be so.

It is crucial to the entire Horizon 2000 Programme that we retain the possibility for the scientific community to inject new ideas, to keep the programme of research within ESA both lively and well adapted to the relentless evolution that is taking place in the domain of space science.

The 1988 Scientific-Programme Selection

G.P. Whitcomb, ESA Scientific Programmes Department, ESTEC, Noordwijk, The Netherlands

M. Corradini & S. Volonté, Long-Term Science Planning Office, ESA Directorate of Scientific Programmes, Paris

The planning cycle and its objectives

The planning cycle for space-science mission selection consists of four main stages of activity, extending over a period of typically two to three years (Fig. 1).

The steps involved in the cycle are:

- a 'Request for Mission Proposals', by which the science community is asked to submit proposals for future missions
- an 'In-House Assessment' of these missions, lasting approximately six months, at the end of which the most promising missions are selected for further study in industry
- a 'Phase-A Study', which normally includes an industrial study of the mission implementation, lasting from nine to twelve months and leading up to selection of the mission that will finally be implemented
- the 'Final Selection', during which all the candidates are reviewed from both a scientific and programme-cost point of view, taking into account the foregoing study results.

This planning cycle has an important benefit in that it provides a means by which ESA, the scientific institutes, and industry can familiarise themselves with the problems associated with a given mission and prepare effectively for the management of the high-resource-expenditure phases during the project's implementation.

Background to the 1988 selection

The present selection cycle has had an unusually long and convoluted history, having been shaped by events (the birth of a Long-Term Plan for space science, and the Space-Shuttle accident) that were not foreseeable at the time of the initial Call for Mission Proposals in 1982. At that time, the intention was to select missions that could be flown in the early 1990s.

Of the many proposals received, two missions, Quasat and Cassini, were selected in 1983 for study at the assessment level. Quasat is a proposed Earth-orbiting element of an international, very-long-baseline interferometer, while Cassini is a proposed mission to Saturn in which ESA would provide a probe to penetrate the atmosphere of the planet's Titan moon. As both of these missions were originally foreseen to be cooperative ventures with NASA, an agreement was reached by which the agencies carried out joint assessment studies during 1984/85.

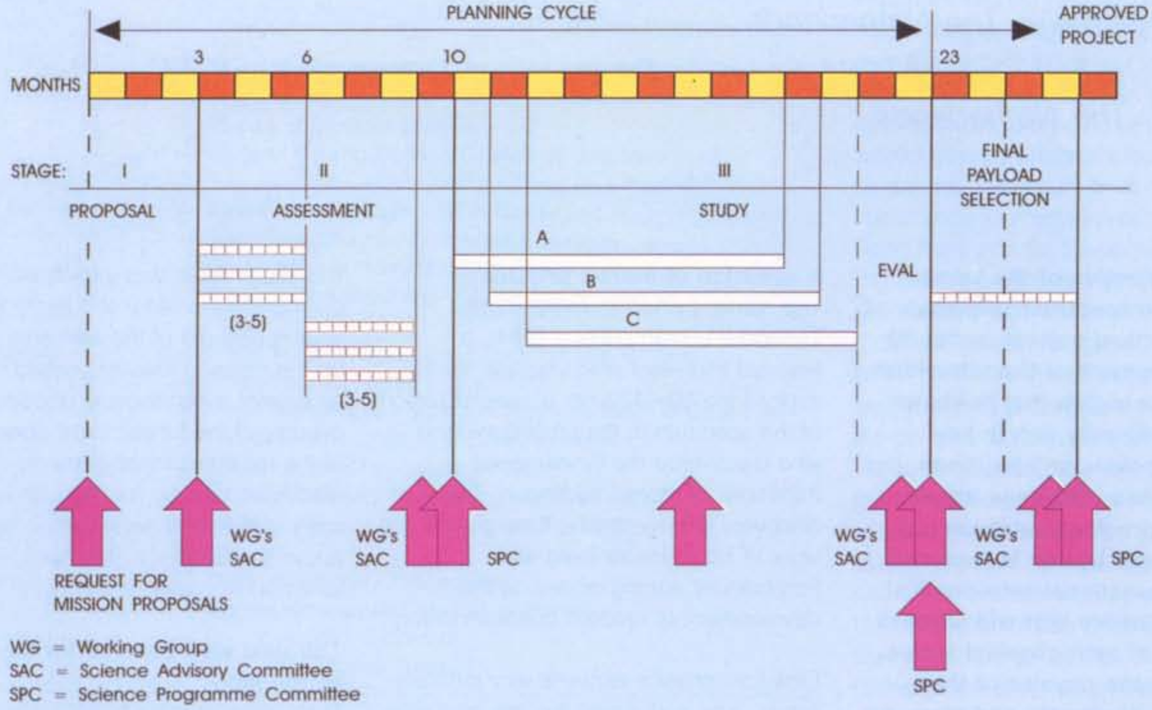
Also in 1983, ESA and NASA were discussing the possibilities of a joint venture in the field of ultraviolet astronomy, following the successful cooperation on the IUE mission. During 1984/85, parallel assessment studies of this mission were made independently by ESA and by NASA, leading to the definition of a commonly agreed mission concept called Lyman/Fuse.

Due to the cooperative nature of the missions and the need for agreements at different levels in both ESA and NASA, the assessment phases were extended beyond the usual six months. It was not until January 1986 that Lyman and Quasat were selected for further joint study at the industrial Phase-A level, while Cassini, in view of some continuing uncertainty in the NASA plans, was 'put on ice' until such time as the NASA position could be clarified. Clarification came in early 1987 and Cassini was subsequently approved for an industrial Phase-A study at the ESA Science Programme Committee meeting of March 1987.

At the same time, three other assessment studies were in progress: Caesar, a Comet Dust Sample-Return Mission; GRASP, a Gamma-Ray Spectroscopy and Positioning Mission to be flown on the Eureca carrier, and Vesta, a joint CNES-USSR mission, which ESA was requested to consider joining, to study the asteroids and at least one comet. These missions were selected after a second Call for Mission Proposals, which was issued in 1985. This Call was initiated in the context of the Long-Term Plan that had been prepared by the Agency in 1984 and endorsed by ESA's Council in 1985. This Plan introduced the concept of a fixed budget allocation from ESA for missions, so that only missions that could be seen to meet their budget criteria, either in their own right or via international collaboration, would be selected for study at Phase-A level. In May 1987 two of these, Vesta and GRASP, were approved for Phase-A study.

Following the Challenger accident in January 1986, NASA was unable to continue with the cooperation on Lyman and Quasat as originally proposed, and so ESA redirected the study work at that

Figure 1 — Structure of the planning cycle



time towards mission concepts that could be implemented without the NASA-provided launch on the Space Shuttle. Cooperation with other agencies was also sought. One consequence was a delay in the planned start of the industrial studies until mid-1987.

The GRASP mission was also affected as the chances of launching the Eureca carrier with the Shuttle were much reduced. The GRASP study was thus redirected towards an Ariane-launched option using a 'carrier-type' spacecraft such as the proposed 'Robus' from Dornier System.

Current status and future milestones
The competing candidates in the current selection are classed, in the framework of the Long-Term Plan, as medium-cost missions, which by definition have a maximum budget allocation of 220 MAU (Million Accounting Units) at 1984 economic conditions. With the possible exception of GRASP, which may be flown on a 'common carrier' spacecraft, all of the missions exceed this funding and so they have, of necessity, been studied from the start as possible cooperative ventures with other Agencies.

At the time of writing, discussions with potential partners covering the modes of cooperation and cost sharing of the respective missions are in progress. It is hoped that cooperation will be possible with the USA and Canada for the Lyman and Quasat missions, with the USA for the Cassini mission, and with France and the USSR for the Vesta project.

The current status of the studies is that the Lyman and Quasat industrial studies, which started in mid-1987, have been completed, while those of the GRASP, Cassini and Vesta missions, which started later, are due for completion by September/October 1988, in time for the November selection.

Following selection, the successful candidate will be implemented as the next ESA scientific project, with an industrial development phase beginning in 1990, leading to a launch in 1995/6.

Depending on which of the missions is selected, the period 1989/90 will be devoted to the preparatory work associated with international agreements, the selection of flight experiments, and the industrial development phase.

The following articles in this Bulletin describe each of the five candidate missions in greater detail.

Lyman — A New Window on the Universe

P. Jakobsen, Astrophysics Division, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands

A. Hawkyard & P. Jensen, ESA Scientific Programmes Department, ESTEC, Noordwijk, The Netherlands

The prime objective of the Lyman mission is the spectroscopic study of faint astronomical objects in the 90 to 120 nm segment of the ultraviolet spectrum — a region that is known to be extraordinarily rich in key atomic and molecular transitions, but nonetheless has only been briefly explored by previous astronomical space missions. Lyman is foreseen as a true international astronomical observatory facility that will address a wide span of astrophysical topics, ranging from the physics of the atmospheres of planets and stars, to reconstructing the history of element creation in our Galaxy and the Universe as a whole.

A question of atomic physics

The name 'Lyman' commemorates Theodore Lyman (1874—1954), a Harvard Professor who was the first to explore the 90—120 nm ultraviolet region of the spectrum in the laboratory, and who discovered the fundamental transitions of atomic hydrogen. This discovery led eventually, through the work of Bohr, Heisenberg and Schrödinger among others, to the development of modern quantum theory.

Quantum physics explains why different atoms, ions and molecules are only able to absorb and emit light at characteristic frequencies. In the hands of the astronomer, this feature of atomic physics becomes an extremely powerful diagnostic tool. Through spectroscopy, the light emitted by distant astronomical sources is separated into its wavelength components in order to identify the unique patterns of the elements making up the object. However, nature has somewhat mischievously placed the vast majority of the fundamental spectral lines of the most important elements in the ultraviolet, thereby forcing astronomers to carry outt their observations in space above the Earth's atmosphere, which absorbs ultraviolet radiation.

The next step forward for ultraviolet astronomy

The Lyman mission builds upon the heritage of a series of highly successful ultraviolet astronomy missions that have flown over the last two decades. These include NASA's OAO series, ESA's TD-1 satellite and, last but not least, the NASA/ESA/UK International Ultraviolet

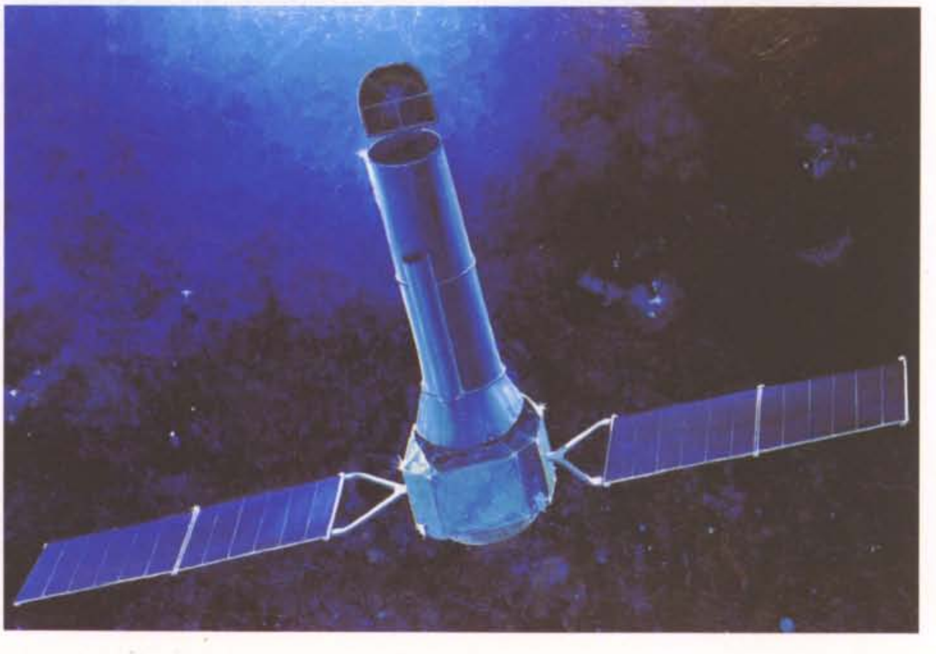


Figure 1 — Artist's impression of the Lyman observatory in orbit. Note the long telescope baffle and steerable solar arrays, which permit the observatory to view most of the sky at any given time

Figure 2 — The Lyman series of atomic hydrogen. Like all atoms, hydrogen is only capable of absorbing and emitting light at specific wavelengths. The close-up on the right shows the corresponding lines of deuterium, which are shifted in wavelength by one part in 4000

Table 1 — Lyman science objectives

Cosmology:	— Deuterium Abundance in Local Galaxies — Deuterium Abundance in Galactic Halos — HeII Gunn-Petersen Test in Z=2 Quasars
Galaxies:	— Origin, Excitation and Nature of Hot Galactic Halos — Origin of High-Excitation Plasma in Active Nuclei — Studies of Starburst Galaxies — Study of Cooling Flows in Clusters of Galaxies
Interstellar Medium:	— Atomic and Molecular Gas in Galaxy and Magellanic Clouds — Gas Phase Structure of Interstellar Medium — Composition of Interstellar Dust Grains — Physical Conditions and Composition of Supernova Remnants
Stellar Research:	— Stellar Winds of Population-I Stars in Local Galaxies — Studies of Hot, Highly Evolved Stars — Chromospheres, Coronae and Magnetic Fields of Cool Stars — Gas Streams in Interacting Binary Systems — Physics of Pre-Main-Sequence Stars — Study of Planetary Nebulae in Local Galaxies — Physics of Novae and Supernovae
Solar System:	— Study of Planetary Atmospheres — Magnetospheres and Aurorae of Planets — Photochemistry of Comets — Study of Io Plasma Torus

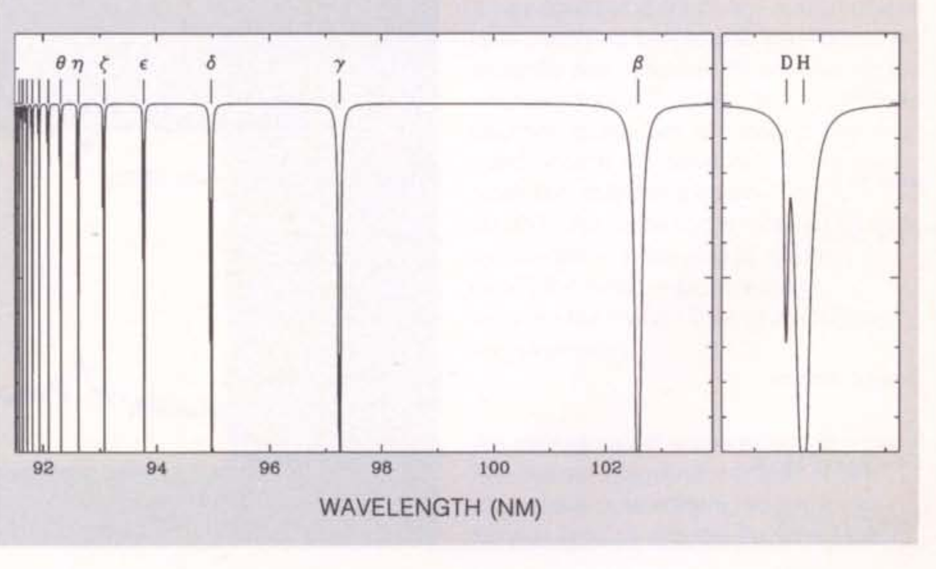
Explorer (IUE), which recently celebrated ten years of orbital operations. These ultraviolet astronomical observatories have led to major discoveries in nearly all areas of modern astrophysics.

Impressive as the list of scientific achievements of these missions has been, it is nonetheless a remarkable fact that neither IUE nor the forthcoming Hubble Space Telescope is able to readily observe the fundamental spectral lines of the two elements that make up more then 99.99% of all matter in the Universe — namely hydrogen and helium. The reason for this is purely technical — IUE and the HST are limited to functioning at wavelengths longer than about 120 nm because the optical coatings used to protect their telescopes do not reflect light at shorter wavelengths. The prime goal of the Lyman mission is to break through this observational barrier and open up a new window to the Universe. This has been made possible by recent technological advances in space optics.

The main emphasis of the Lyman mission is spectroscopy in the prime 90—120 nm spectral region, but additional instrumentation enabling supplementary observations at shorter (10—90 nm) and longer (120—200 nm) ultraviolet wavelengths is also foreseen.

Searching between the stars

The Lyman prime spectral region is arguably one of the astrophysically most important segments of the entire electromagnetic spectrum. It contains not only the so-called 'Lyman series' of atomic hydrogen lines, but also the corresponding transitions of its astrophysically important isotope deuterium. Deuterium is of cardinal importance to astronomers since the Big Bang theory of the Universe holds that this trace element, along with hydrogen and helium, was created during the first three minutes following the Universe's birth. The initial universal deuterium abundance is a very sensitive probe of the physical conditions during the Big Bang. Its accurate determination could therefore shed light on the question of whether the Universe has an open or a closed structure. On the other hand, the deuterium content of the present-day Universe should also have been affected by the nuclear processes that have been taking place deep within the interiors of stars and which have led to the production and dissemination of all the other heavy chemical elements since the Big Bang. The task of reconstructing the cosmic history of the deuterium isotope and all the chemical elements is one of the prime goals of the Lyman mission.



The Lyman prime spectral region also contains the transitions of numerous other key diagnostic atoms, ions and molecules. These range from the lines of the most abundant molecule of all, H_2, — which exists in very cold, dense conditions such as in the atmospheres of planets and in the dense interiors of interstellar clouds undergoing star formation — to the lines of the five times ionised oxygen atom, O_{VI} — which only exists in extremely hot plasma such as that present in the chromospheres and stellar winds of stars and in the ejecta of supernova explosions.

Another key task of the Lyman mission is to determine the nature and map the structure of the tenuous gas present in the vast volumes of interstellar and intergalactic space. This can be done by searching for telltale intervening interstellar absorption features in the Lyman spectra of various 'background' objects at different distances from the Earth.

Table 2 — Lyman mission summary

Objective:	UV Spectroscopy 90—120 nm (Prime) 10—90 nm (EUV) 120—200 nm (FUV)
Payload:	Grazing-Incidence Telescope Dual-Echelle Prime Spectrograph Far-Ultraviolet Spectrograph Extreme-Ultraviolet Spectrograph
Launch Mass:	1500 kg
Payload Mass:	640 kg
Onboard Propellant:	350 kg (hydrazine)
Size/Envelope:	Diameter: 3.6 m Height: 7.0 m
Spacecraft Type:	Three-Axis Stabilised
Pointing Accuracy:	1.5 arcsec (3 σ)
Power Consumption:	580 W
Telemetry:	S-band, 40 kbit/s
Payload Thermal Control:	$\pm$0.5°C
Launcher:	Ariane-4, Dual Launch Upper Passenger (Fairing 01)
Initial Orbit:	Geostationary Transfer Orbit (GTO)
Final Orbit:	Apogee: 120 000 km Perigee: 1000 km Inclination: 7° Period: 48 h
Ground Stations:	Maspalomas (Spain) Perth (Australia)
Operational Mode:	Real-Time Observatory
Design Lifetime:	5 yr

Based on results obtained from a number of previous space missions, the modern picture of a violent, evolving and highly dynamic interstellar medium involving a range of extreme physical conditions has emerged. In this theory, supernova explosions play a pivotal role by heating and enriching the interstellar medium with heavy elements, and probably also complete the cycle by triggering the formation of new generations of stars from the enriched interstellar gas. Observations carried out with Lyman will contribute enormously to our understanding of this cosmic cycle by enabling a detailed mapping of both the coldest and hottest phases of the interstellar medium throughout the disk and halo of the Galaxy. By using distant quasars as background sources, it will even be possible to probe the interstellar medium of other galaxies.

Because of the general nature and large range of the spectroscopic tools Lyman will make available, the mission will contribute to the study of virtually all classes of astronomical objects.

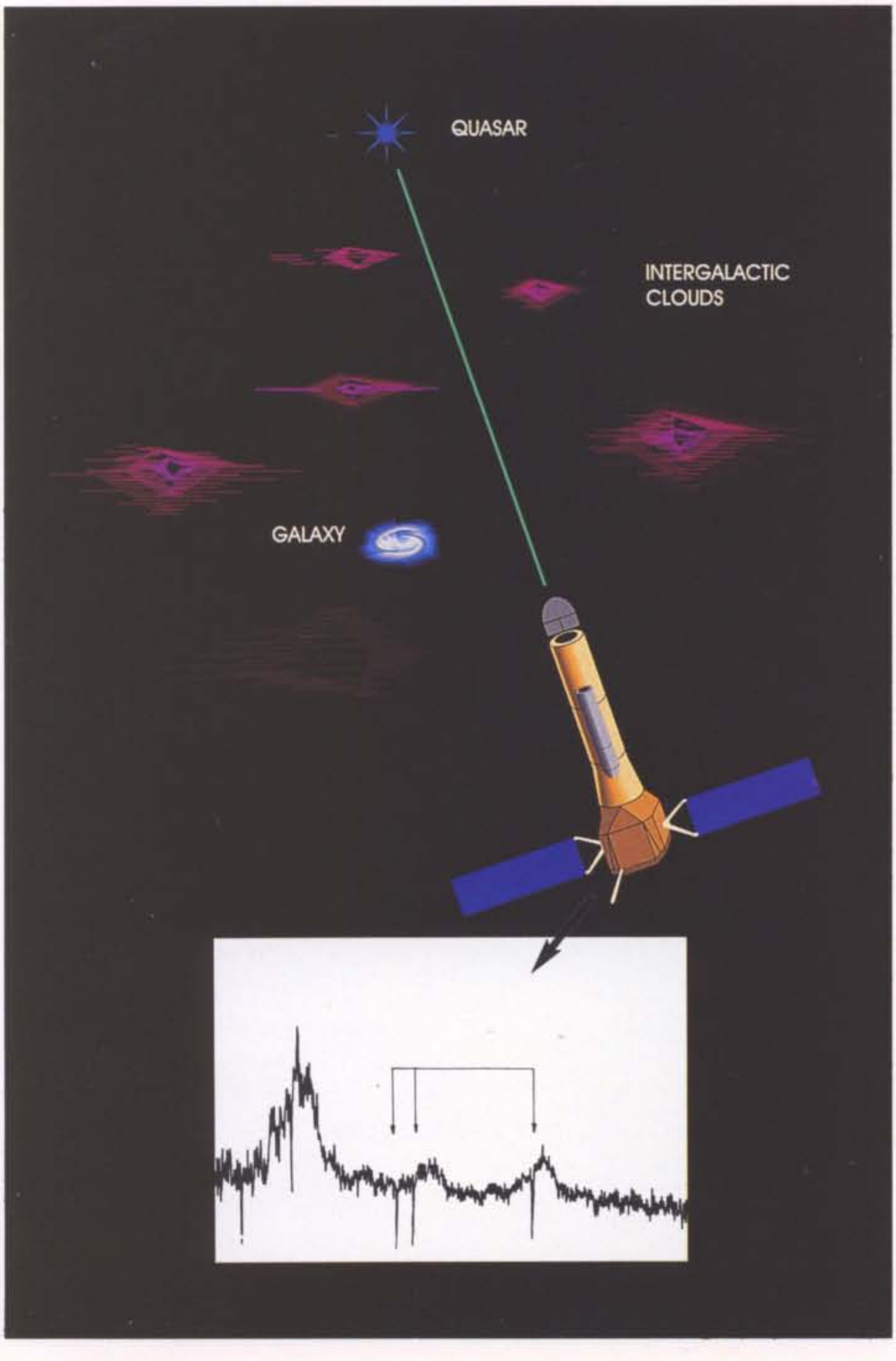
Hybrid optical technology

Nature has provided a very limited number of materials from which the optical elements of the Lyman instrumentation can be built. For example, no glasses or crystalline materials are known to transmit radiation throughout the prime spectral range — so the use of lenses and optical windows is excluded. In order to achieve its objectives, the Lyman payload borrows elements from both modern X-ray and classical optics. The model payload developed in the course of the ESA Phase-A study consists of a collecting

Figure 3 — By searching for telltale absorption signatures in the Lyman spectra of distant stars and quasars, astronomers will be able to study the otherwise invisible tenuous plasma present in vast voids of interstellar and intergalactic space

telescope feeding three spectrographs located in its focal plane.

The Lyman telescope, however, is not a conventional reflector, since it would have to be unreasonably large in order to achieve sufficient collecting area due to the poor reflectivity of presently known normal-incidence optical coatings. For this reason an 80 cm aperture 'grazing incidence' Wolter-Schwarzschild type-II telescope has been adopted. This type of telescope achieves its high throughput by focussing the light by means of very shallow reflections (≃10°) off its gold-coated surfaces. Similar telescopes have been (or are being) built for a number of X-ray astronomy missions (i.e. Einstein, Rosat, XMM and AXAF) and considerable effort has gone into optimising the Lyman telescope design in terms of performance, feasibility and cost.



A 'Dual Echelle' design for the prime spectrograph has been selected for the model payload because it offers a number of cost-saving relaxations in the key areas of telescope image quality, spacecraft pointing and thermal control compared to alternative designs. The Dual Echelle spectrograph covers the prime spectral region by means of two overlapping 'channels' spanning, respectively, 90—120 nm and 100—140 nm. The first channel employs a scaled-down version of the primary telescope as a grazing-incidence collimator and uses two crossed silicon-carbide-coated diffraction gratings to disperse the light. The second channel is more conventional and utilises high-reflectivity, lithium-flouride-coated aluminium, normal-incidence surfaces throughout. Both channels use open photon-counting microchannel plate detectors that record the full spectrum in a single exposure by detecting the location of each incoming photon and storing the accumulated spectral image in an electronic memory.

A key figure of merit of any spectrograph is its 'resolving power', i.e. its ability to separate and measure the wavelength of incoming light accurately. The two channels of the Lyman model prime spectrograph are designed to achieve a resolution of better than one part in 30 000. This resolution is dictated in part by the desire to be able to resolve clearly the small isotopic splitting between the Lyman lines of hydrogen and deuterium.

An astronomical observatory in space
The Lyman spacecraft consists of two structurally independent modules: the Service Module and the Payload Module.

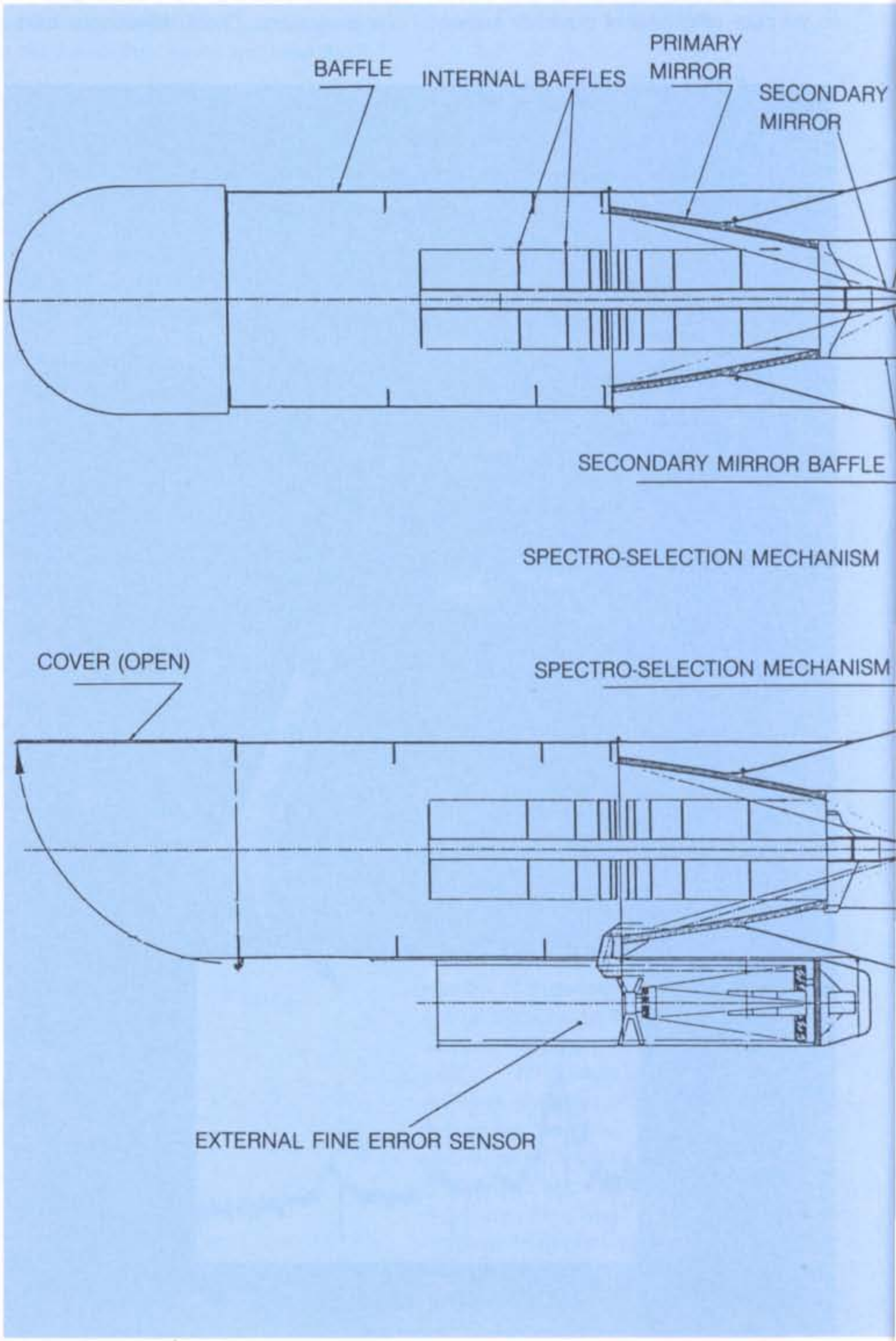
Figure 4 — Schematic of the Lyman model payload showing the grazing-incidence telescope and its baffle, the fine error sensor, and the three ultraviolet spectrographs

The Service Module provides all the support functions to the spacecraft, i.e. electrical, mechanical, thermal, attitude and orbit control, and communication with the Control Centre. In designing the Lyman spacecraft, an attempt has been made to adopt a minimum-cost solution consistent with the need to ensure adequate design margins and low risk. Extensive use has been made in the Service Module of subsystems and units developed for previous and current ESA programmes.

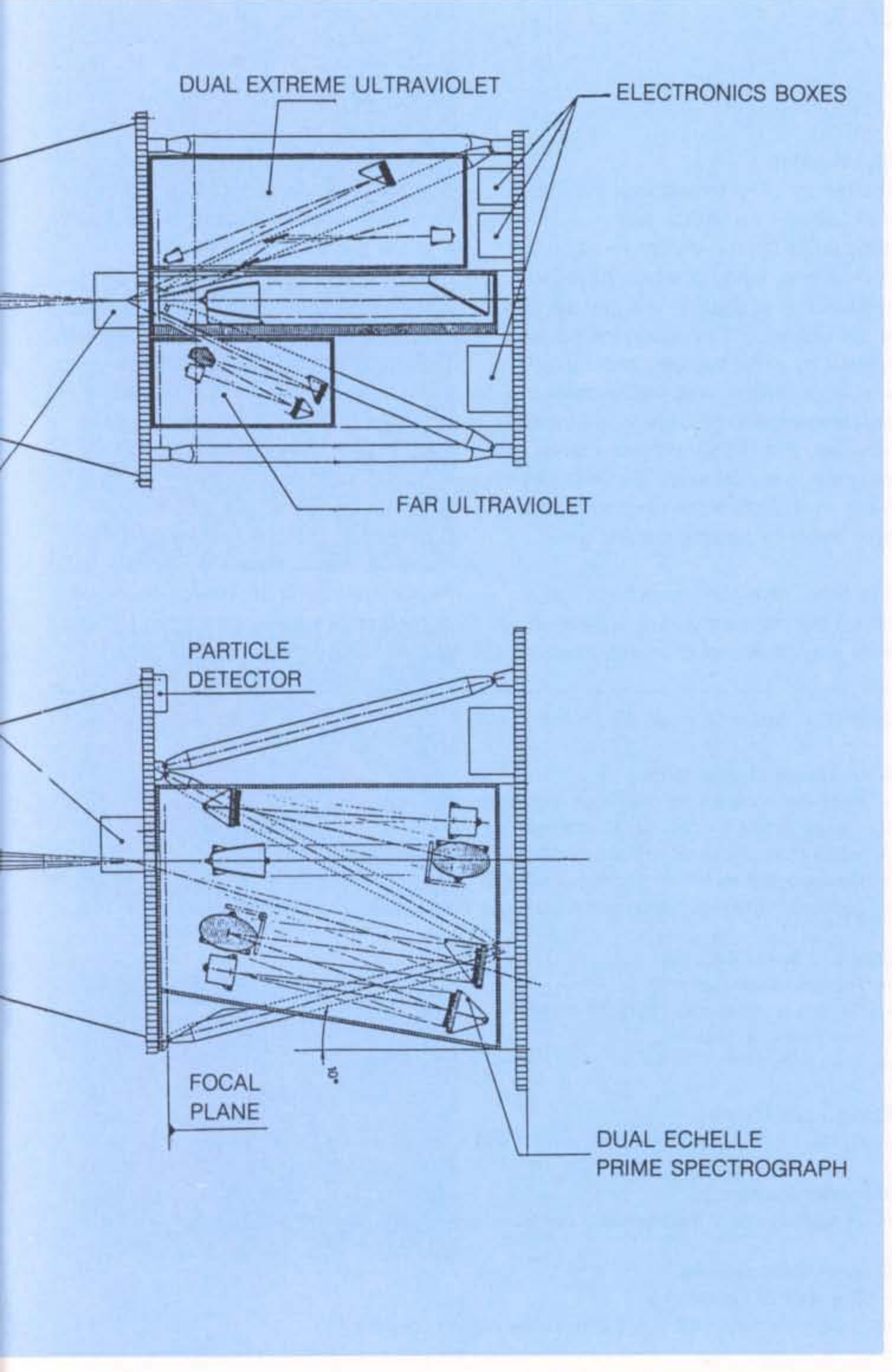
The main components of the Payload Module are the telescope optics, which provide an F/10 converging beam, and the spectrograph selector mechanism, which deflects the beam to any one of the three spectrographs.

Light focussed by the telescope enters the spectrographs through a narrow (3 arcsec wide) slit located in the telescope focus. In order to make the Lyman spectrographs as sensitive as possible, it is essential that nearly all of the light collected by the telescope pass through the slit. To ensure this, high precision is needed in the manufacture and thermal control of the telescope system, and in the attitude control of the spacecraft. A major part of the Phase-A study has been devoted to these issues, and the overall level of confidence in the proposed design remains high. The Lyman telescope system has been derived from those of previous programmes, especially Rosat. The payload thermal-control system is based on that of ESA's Faint-Object Camera for Space Telescope, which has thermal requirements similar to those of Lyman.

For a realistic telescope image quality, the goal of less than 10% slit loss requires that the target source be kept positioned on the slit to within approximately 1 arcsec. To achieve this pointing performance, it is necessary to use a sensitive fine-error sensor. The latter is basically a high-precision star tracker whose coalignment to the main telescope is continuously monitored by means of a fiducial light system. This makes it possible for the sensor to track both the position of the image of the target source and that of the slit. By informing the attitude-control system of any offsets between the two, the target image can be held on the slit with the required accuracy throughout an observation.



The operational scenario foreseen for the Lyman mission builds upon the experience gained from both the IUE and Exosat astronomy missions. The main lesson learned from the IUE mission is that giving astronomers real-time control over the spacecraft and the freedom to make last-minute changes leads to maximisation of the mission's scientific output. Exosat has demonstrated that the most efficient orbit for an astronomical space observatory is one that spends as much time as possible in the low particle background environment outside the Earth's Van Allan belts.



With a view to reducing launch costs to a minimum, the mass and volume of the Lyman spacecraft were closely monitored during the study in order to permit a shared launch by an Ariane-4. It is assumed that the potential partner will be a communications satellite and that Lyman will therefore be injected into an initial geostationary transfer orbit. Transfer to the final operational orbit will take place through of a series of apogee and perigee raising manoeuvres using onboard hydrazine thrusters.

As a compromise between observing efficiency and costs associated with launch and ground-station coverage, a 48 h, 1000 km × 120 000 km final orbit has been chosen for Lyman. This orbit should permit uninterrupted observations of up to 40 h duration. However, because of the low inclination of the standard Ariane geostationary transfer orbit (7°), two ground stations — one in Spain and one in Australia — are required for coverage.

The ground segment foreseen for Lyman is similar to that of other ESA astronomy missions, i.e. with a Mission Operations Centre having overall responsibility for all spacecraft-related tasks, and a Science Operations Centre having responsibility for the scientific exploitation of the mission. Like IUE and Exosat, Lyman will be operated predominantly in a 'guest-observer mode', with astronomers competing for spacecraft observing time via a peer-review process.

Based on experience with IUE, it is anticipated that the Lyman observatory will be used by many hundreds of ESA Member-State astronomers in pursuit of a comparable number of individual research projects.

Quasat — A 50 000 km-diameter Quasar Probe

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Quasat is an Earth-orbiting radio antenna to be used in conjunction with ground-based Very-Long-Baseline Interferometry (VLBI) networks in Europe, the USA, the USSR and Australia to produce radio images at frequencies of 22, 5, 1.6 and 0.3 GHz.

By combining simultaneous space and ground observations with baselines of up to 50 000 km, Quasat can provide radio images that are forty to two hundred times sharper than those from Earth-based VLBI networks, and one hundred thousand times sharper than those from the Hubble Space Telescope.

The reason for going into space is to create interferometer baselines longer than the Earth's diameter and thereby achieve improved angular resolution. However, equally important is the fact that images of better quality can be obtained because the spacecraft's orbital motion produces good coverage of the interferometer aperture plane.

The scientific research conducted with Quasat will address such problems as the physics of the central region of quasars and active galaxies, the distance scale and rate of expansion of the Universe, and star formation.

Introduction

The history of radio astronomy has been punctuated by a steady series of discoveries of new astrophysical phenomena, many of which have been instrumental in shaping our current view of the Universe. The enormous power emitted by radio sources, both galactic and extragalactic, was not foreseen in pre-radio-astronomy days. It is now clear, however, that high-energy processes are common in astrophysics and that they occur in radio sources ranging in size from stellar to galactic dimensions.

The need for higher resolutions has driven the radio-astronomy technique from single-antenna to interferometric observations with progressively longer baselines. The first successful VLBI experiment was conducted in 1967 with a single baseline. Since then, the technique has undergone a revolution and VLBI aperture synthesis (explained in greater detail below) is now common. Current global VLBI networks include up to 18 elements and have effective apertures of about 8000 km, allowing them to provide submilliarcsecond angular resolution.

As the body of discoveries from VLBI has grown, it has become clear that in nearly every compact source observed at centimetre wavelengths there remains spatial structure that is unresolved. In

Table 1 — Scientific goals for Quasat

Active Galactic Nuclei (AGNs)
- Nature of compact radio sources and the central engine
- Physics of jets and the role of relativistic motion
- Radio continuum and optical broad-line emission
- Cosmological evolution of compact sources
- Synchrotron radiation and inverse Compton X-ray emission.

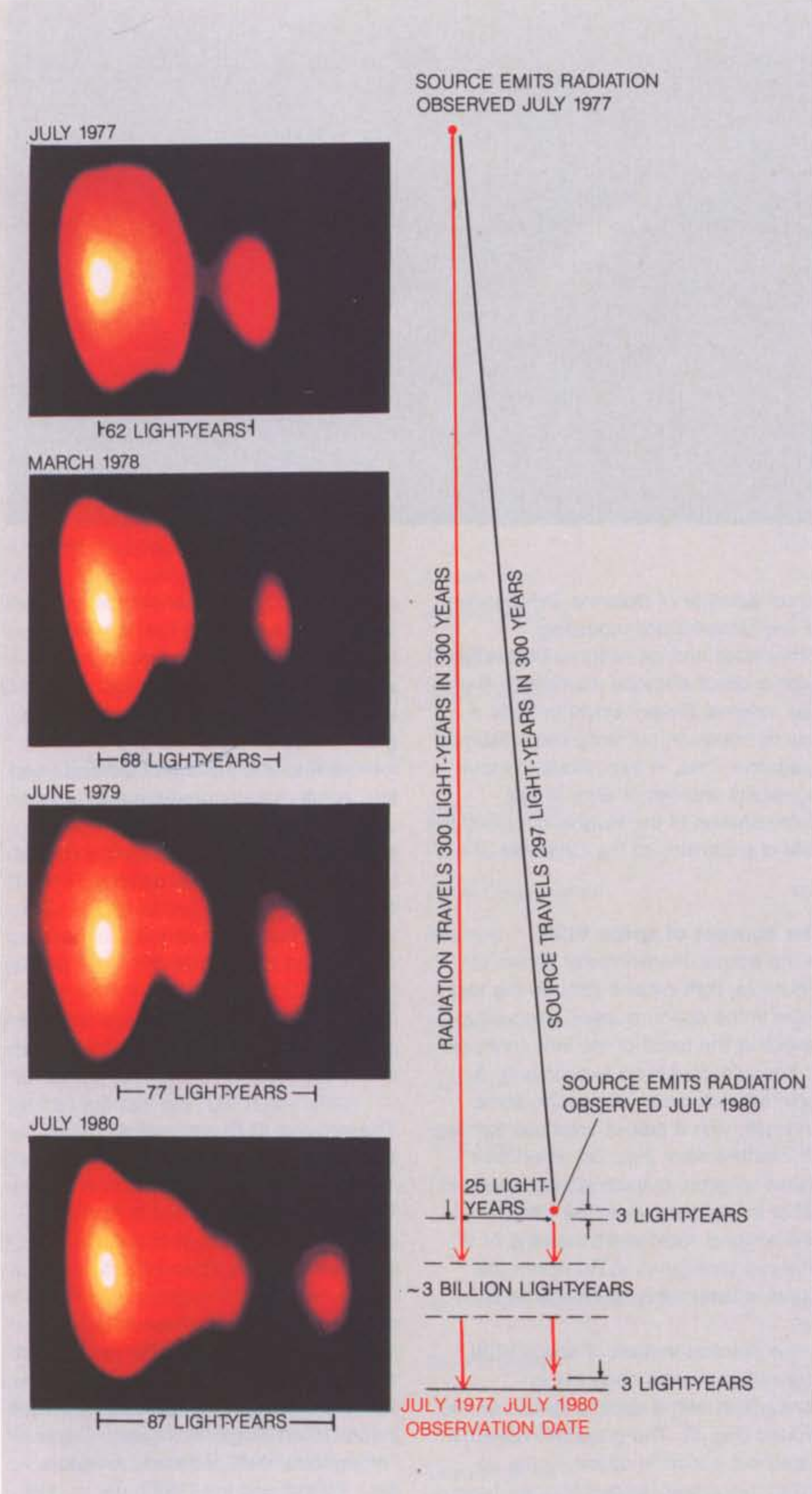
Stars and Stellar Evolution
- Aspects of star formation
- Physics of stellar and interstellar masers
- Nearby flaring stars
- X-ray stars

Extragalactic Masers
- OH and H_2O masers found in the arms and nuclei of nearby spiral galaxies

Interstellar Medium
- The patchiness of the interstellar electron distribution

Distance Measurements
- The scale of the Universe
- Independent estimate of the value of the Hubble constant

Figure 1 — Series of radio images of the quasar 3C273 with a resolution of 0.001 arcsec. In three years, the ejected blob appears to have travelled 25 light years, an apparent 'superluminal' speed of 9.6 times the speed of light. This 'forbidden' velocity is actually an illusion created by the fact that the blob is moving almost directly towards us at more than 99% of the speed of light. (Courtesy of A. Readhead, Caltech and Scientific American)



order to explore the smaller structural details, and thereby observe on scales that may be of great importance for our understanding of a wide range of astrophysical problems, higher resolution images of the highest possible quality are essential. They can only be achieved by placing a radio telescope in space.

The Quasat mission was originally proposed to ESA in 1982 by the radio-astronomy science community. Somewhat later, a similar proposal was submitted to NASA. As originally envisaged, the Quasat mission was baselined as a cooperative project involving both ESA and NASA, and possibly other national space agencies also.

Parallel assessment studies for a joint project were conducted by ESA and NASA during the period 1983—1985, and in 1987 the Quasat mission was the subject of a Phase-A study by an industrial consortium led by Aeritalia (I).

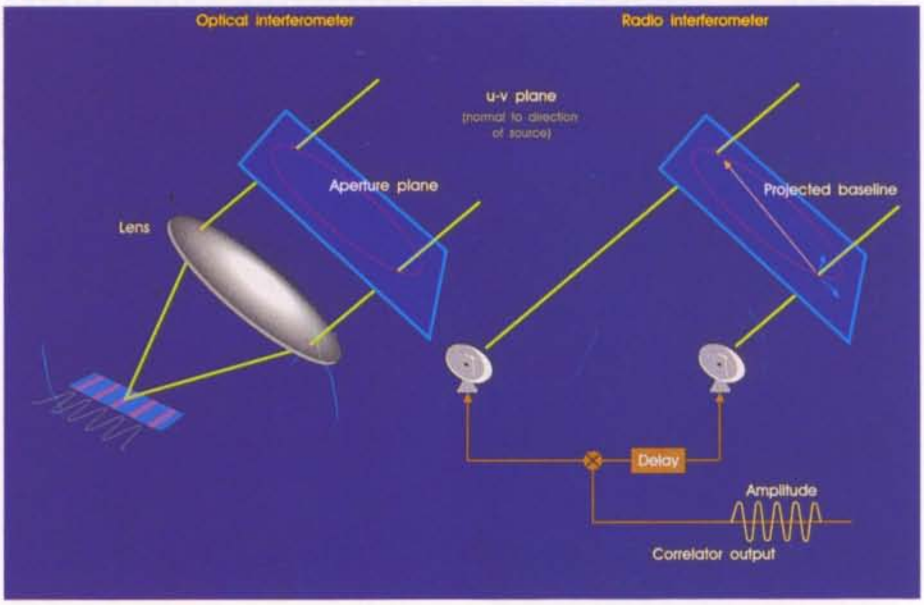
Scientific goals

The immediate observational targets with Quasat are the compact, high-brightness-temperature objects found in the nuclei of galaxies and quasars, in the molecular masers distributed throughout our own Galaxy and detectable in many nearby galaxies, and on the surfaces of numerous active stars in our Galaxy. The major goals for Quasat are summarised in Table 1.

It will be possible to study these objects at 22, 5, 1.6 and 0.3 GHz in both hands of circular polarisation. The highest angular resolution on the stronger compact quasars and radio galaxies will be achieved at 22 GHz (H_2O maser line sources can also be observed at this frequency). Observations at 5 GHz provide for twice to three times the sensitivity available at 22 GHz, thereby widening the range of objects that can be studied to include the less-luminous galaxies. Observations at 1.6 GHz have a similar sensitivity to those at 5 GHz. Some sources drop in continuum-

Figure 2a — An optical interferometer is an instrument that adds light from two separate points originating from a common source. The waves from the two points interact to produce a pattern of interference 'fringes'

Figure 2b — A radio interferometer is an exact analogue of an optical interferometer. By measuring amplitude and phase for a large number of projected baselines, one can 'synthesise' an aperture much larger than that of the individual telescopes



luminosity with increasing frequency and can only be detected at the lower frequencies. The OH maser line sources will be observed at 1.6 GHz, while the interstellar medium will be probed by observations at 0.3 GHz.

One outstanding astrophysical problem is that of explaining the central energy source in quasars and active galaxies. This 'engine' must be capable of generating an energy equivalent to the total conversion of the mass of tens of millions of Suns within a region less than a few light days across. Mass equivalent to that of a small Galaxy can be ejected and stay collimated within a few degrees for periods of more than 500 million years. It is possible that the centre is actually a spinning supermassive black hole with a total mass of about a billion Suns. The immediate environment of the central engine in the nuclei is, for the foreseeable future, hidden from direct imaging to all other wavelength regimes except the radio. Quasat will be a vital step in clarifying our concepts of the workings of the central engine and of the subsequent passage of energy to the enormous reservoirs seen at radio wavelengths as extended radio lobes. Quasat will study jets, their origin, fundamental properties and interaction with thermal material. This study will highlight important aspects such as apparent greater than the speed of light motion (Fig. 1). Quasat observations at 22 GHz will resolve components as small as 30 μarcsec, corresponding to linear dimensions of less than 1 light day at the distance of the radio galaxy Centaurus-A. This is comparable to the scales expected for accretion disks surrounding the possible central black hole.

Another objective of the Quasat mission is calibration of the scale of the Universe by direct (trigonometric) measurement of the distances to external galaxies. Recent studies in our own Galaxy have established VLBI proper-motion studies of H_2O masers as a reliable distance-measurement technique. They provide a direct estimate of distance, independent of any uncertainties regarding luminosities and extinctions. Obtaining such a direct distance estimate to even one external Galaxy would provide a crucial check on currently used distance indicators. This, in turn, would remove significant sources of error in the determination of the Hubble constant (the rate of expansion of the Universe).

The concept of space VLBI

In the optical interferometer shown in Figure 2a, light passes through the two holes in the aperture mask, producing fringes at the focus of the lens (principle of Young's double-slit experiment). A radio interferometer follows the same principle, with a pair of antennas forming an interferometer (Fig. 2b) when their phase-coherent outputs are combined either in real time (as in the case of conventional radio-interferometry) or in post-real time (as in VLBI, where the signal is temporarily stored on tape).

In the simplest version of space VLBI, one station in orbit observes in conjunction with a second station on the ground (Fig. 3). The projected baseline traces out a loop in space, in the so-called 'u-v plane'. In practice, we have a network of ground antennas and the Earth's rotation causes the baselines between the ground antennas to produce tracks in the u-v plane. Individual loops originating from ground—space baselines do not repeat themselves, and the combined Earth and spacecraft motions produce extensive, dense-coverage sampling in the u-v plane. The analogy in the optical case is to cut holes in the aperture mask corresponding to the u-v coverage. The fringe amplitude and phase information will be used to compute the corresponding image. With the dense coverage in the u-v plane, interferometer sidelobes will be low and good imaging will be possible.

The ground VLBI networks

The ground-based arrays are the other major element of the Quasat mission. The European VLBI Network (EVN), augmented by associated stations, and the US VLBI Array (the VLBA) will constitute the main support to the orbiting element, but other networks in the Southern Hemisphere, in the USSR, and in Asia are also likely to participate. The EVN will have ten telescopes located in the United Kingdom, France, The Netherlands, West Germany, Sweden, Italy, Poland and the USSR.

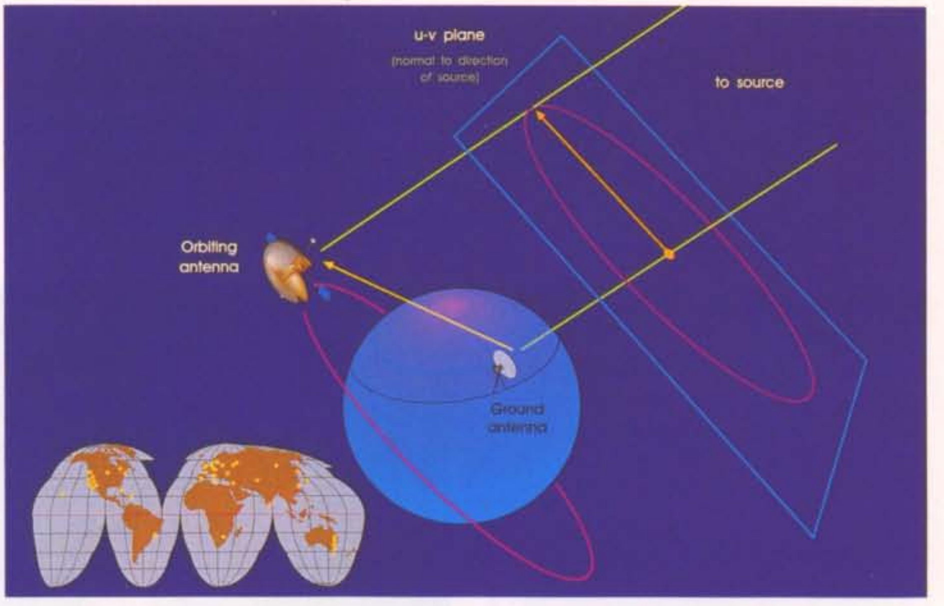


Figure 3 — Simple illustration of space VLBI, showing the global set of antennas

The global network of VLBI antennas is shown in Figure 3, which reflects the strong international character of this research.

Europe already possesses one wide-band correlation facility, and plans are being laid for a second facility to cope with European processing needs for the 1990s, including providing for the correlation of Quasat data.

The mission concept

The Quasat mission concept involves a three-axis-stabilised spacecraft carrying a 15 m-diameter, deployable radio-astronomy antenna. The spacecraft will be launched by an Ariane-4 in a dual-launch configuration and injected into the standard Geostationary Transfer Orbit (GTO). After a few revolutions in GTO, the perigee of Quasat's orbit will be raised from 200 to 5000 km and its inclination will be increased from 7° to 30° using the spacecraft's on-board propulsion system.

After Quasat's insertion into this first operational orbit, its radio-astronomy antenna, booms and solar arrays will be deployed. In this orbit, with an apogee of about 37 000 km, the space-borne antenna will provide interferometer baselines ranging up to about 50 000 km.

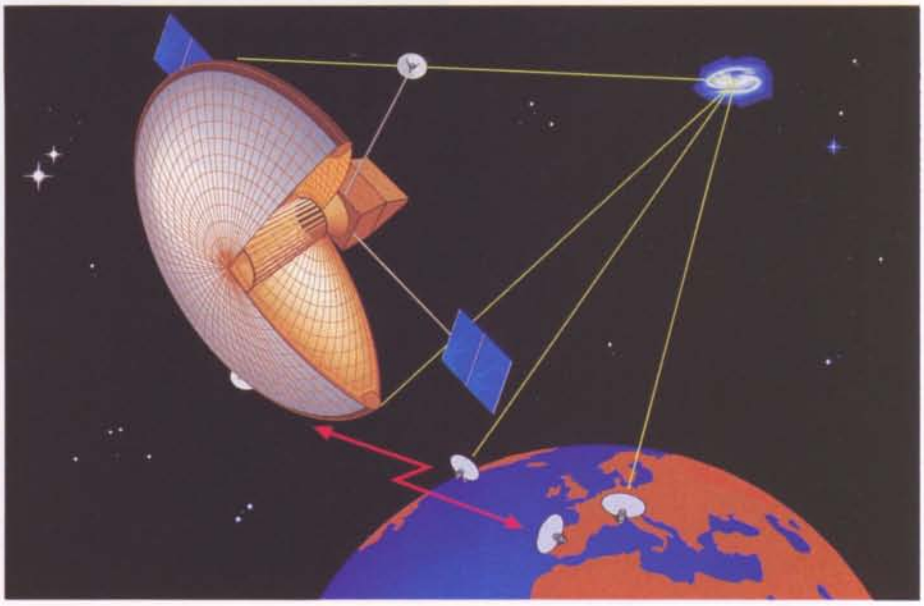
After digitisation and formatting of the received signals, the data will be transmitted to telemetry stations, where it will be recorded on VLBI tapes which will be correlated, together with tapes from the ground VLBI arrays, at a central facility.

Although this first operational orbit yields very large baselines and hence provides a very high resolution, it still leaves appreciable holes in the u-v plane. Therefore, to fulfil the various scientific requirements, the spacecraft's apogee will be lowered later to 22 000 km, thereby reducing the maximum possible baseline, but increasing the imaging quality of the orbit.

Table 2 — Quasat mission summary

Objective	Very-Long-Baseline Interferometry (VLBI) K-band (22 GHz) dual polaristion C-band (5 GHz) bandwidth: 64 MHz L-band (1.6 GHz) UHF (327 MHz) bandwidth: 4 MHz
Payload	15 m aperture, inflatable, space-rigidised. Feeds for four frequencies. Radio-astronomy receivers
Launch Mass	1445 kg (incl. 85 kg adaptor)
Payload Mass	160 kg (incl. 124 kg reflector)
Propellant Mass	615 kg (hydrazine)
Size/Envelope	Width: 2.1 m (launch configuration) Height: 4.8 m (launch configuration) Deployed reflector diameter: 16 m Reflector focal length: 5.85 m
Spacecraft Type	Three-axis stabilised
Pointing Accuracy	30 arcsec
Power Consumption	600 W
Telemetry	Science data: Ku-band, 144 Mbit/s Command and housekeeping: Ku-band, 2 kbit/s LEOP and emergencies: S-band, 2 kbit/s
Payload Thermal Control	K-band and C-band pre-amplifiers cooled to 80 K by Stirling-cycle coolers
Launcher	Ariane-4, dual-launch Lower passenger (Spelda 20)
Initial Orbit	Geostationary Transfer Orbit (GTO)
First Operational Orbit	Perigee: 5000 km Apogee: 36 000 km Inclination: 30° Period: 12.1 h
Second Operational Orbit	Apogee: 22 000 km Period: 7.8 h
Ground Stations	ESA Ku-band stations (to be developed) Alternative: Deep-Space Network (DSN)
Operational Mode	Pre-planned
Design Lifetime	2 yr (Consumables: 5 yr)

Figure 4 — Quasat in its operational state. The antenna consists of a radio-frequency (RF) transparent radome and central tube with an aluminised reflector. The surrounding torus is a structural member



Special VLBI-related requirements
A key factor in interferometry is coherence, i.e. the phase relations of the radio waves arriving at the telescopes participating in the synthesis must be preserved. The VLBI telescopes therefore use a very stable clock reference based on a hydrogen-maser oscillator. For Quasat, these hydrogen masers will be located at the telemetry stations and the derived reference signals will be relayed to the spacecraft (phase transfer). The stability required for this phase transfer is very high: 3.3×10^{-15} over 300 s.

The orbital tracking is also important. Position, velocity and acceleration need be determined with accuracies of 300 m, 10 mm/s and 2×10^{-7} m/s^2, respectively, to enable the standard correlator to acquire the fringes.

To reduce the noise temperatures of the pre-amplifiers for the two highest frequencies, active amplifier cooling is required, with temperatures of 80 K as the target. In addition, part of the feed corresponding to the highest frequency should be kept cool to reduce radio-frequency (RF) losses.

Spacecraft configuration
The operational spacecraft configuration is shown in Figure 4, while Figure 5 shows the spacecraft in launch configuration. The following primary features can be distinguished:

- a 15 m-aperture, centre-fed radio-astronomy antenna
- a spacecraft bus housing the payload package and subsystems
- four deployable booms, two of which carry the solar-array wings, while the others carry the Ku-band communications antennas.

The radio-astronomy antenna
The Contraves inflatable space-rigidised antenna used for Quasat is a new development. It consists basically of four parts:

- the paraboloid-shaped reflector membrane
- the radome membrane, with the same size and shape as the reflector membrane
- the stabilisation torus
- the central cylinder.

The antenna elements consist of a thin fibre-reinforced composite lamina (Kevlarfibres impregnated with a special matrix developed by Ciba-Geigy, CH), plus a Kapton foil. For the radio-frequency (RF) reflector, this Kapton foil is aluminised.

The structure is assembled and launched with the material in its flexible pre-pregged state, so that it can be folded for stowage in the container. Once in orbit, the antenna is deployed by inflation with nitrogen, and then cured by maintaining it at a temperature of about 110°C for 6 h by pointing the radome-side of the antenna towards the Sun. After curing is complete, the nitrogen is evacuated.

The spacecraft bus
The main features of the spacecraft bus are shown in Figure 5. The lower platform carries the feeds and the reflector pressurisation equipment. The reflector stowage container is mounted on the underside of this platform, and protrudes within the special-purpose adaptor during launch.

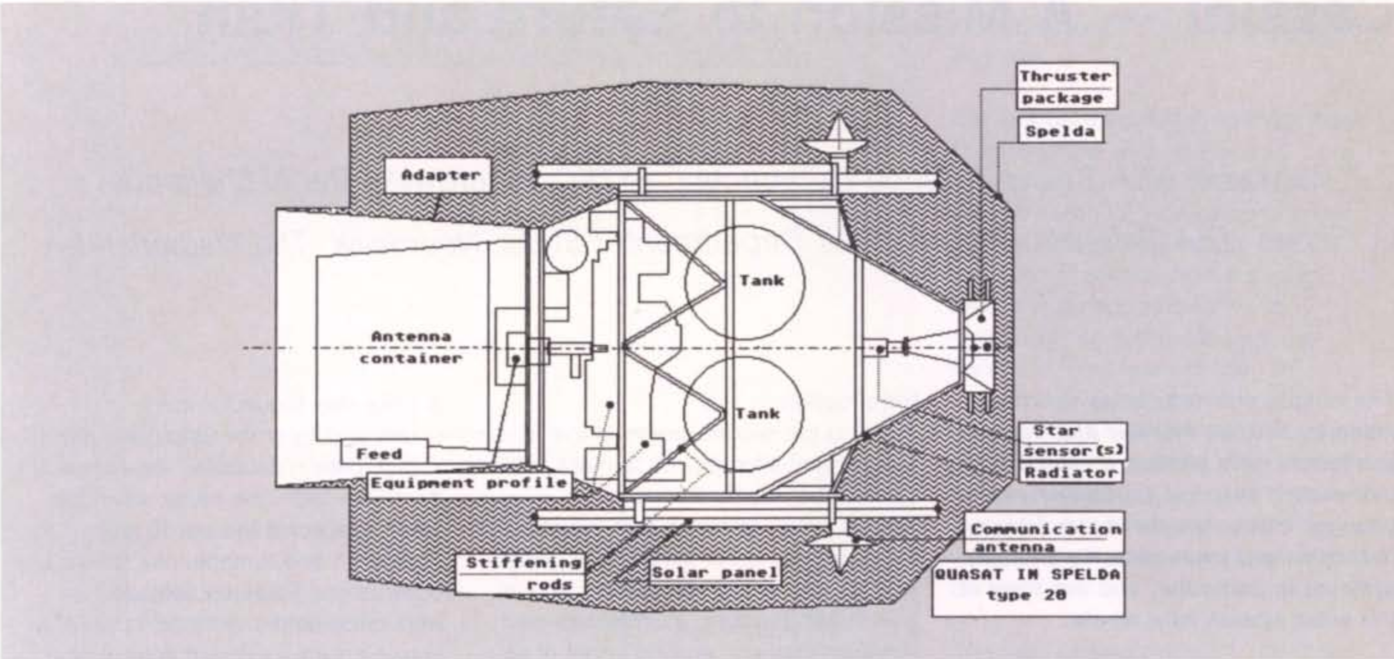
The main equipment platform is located directly above the feed. Variable-conductance heat pipes run from this platform to the radiator for equipment thermal control.

To meet the temperature requirements of the K- and C-band pre-amplifiers and of part of the feed, four Stirling coolers are used. These are mounted on a vertical panel close to the feed. Heat from the coolers is rejected via heat pipes running to the radiator.

The upper platform carries four hydrazine tanks, and the orbit-insertion and attitude and orbit control (AOCS) thrusters are mounted on the top platform.

An intermediate structure carries three offset star sensors which, together with a gyro package, provide the attitude information needed during the operational phase. During initial acquisition or in emergency modes, Sun sensors are used. Momentum wheels are used to execute the slew manoeuvres and to compensate for the relatively high disturbance torques during pointing (caused mainly by solar pressure).

Figure 5 — Quasat in launch configuration



The booms
Long (approx. 7 m) booms are required for the solar arrays and the Ku-band communications antennas in order to 'view' past the radio-astronomy antenna. These booms, manufactured in Carbon-Fibre Reinforced Plastic (CFRP), are folded in three segments for stowage. Once the latching system is released, the booms are deployed by drives at each hinge. Controlled deployment is ensured by pulleys at the hinges connected by cables. The solar-array wings are connected to the booms via BAPTA* drive units.

The 0.5 m diameter Ku-band antennas are connected to the booms via a two degree-of-freedom antenna-pointing mechanism, providing hemispherical coverage. The RF links along the booms are achieved via silver-plated CFRP waveguides mounted inside the booms. The waveguide sections are connected after boom deployment by means of open choke flanges.

Ground segment and RF links
The ground segment consists basically of the following essential elements:

* Bearing and Power-Transfer Assembly.

— Launch and Early-Orbit Phase (LEOP) Network
— Routine-Operations-Phase Network
— Mission Control Centre
— Science Operations Centre and Correlation Facility
— Ground VLBI Networks.

During LEOP, during the Orbit Transfer Phases, or in the event of an emergency, use of a standard S-band system (2 kbit/s) to support satellite tracking, telemetry and control (TT&C) is foreseen.

For the digital transmission of the scientific data to the ground, the Ku-band (14.8—1.0 GHz) has been selected, because this allows the observation bandwidth of 64 MHz to be transmitted digitally at a rate of 144 Mbit/s without the use of polarisation multiplexing.

To meet the coherency requirements on the phase transfer, a two-way Ku-band link, with relatively close frequencies for the up and down links (13.9 and 14.1 GHz), is required. This assures near link reciprocity such that the phase shift (ionosphere, Doppler, etc.) measured on the ground is twice the phase shift onboard the satellite. To ease the load on the phase-lock loop, the uplink frequency will be updated continuously to compensate for the predicted Doppler effect. The final closure of the loop takes place during correlation of the data, compensating for the measured phase shifts.

The Doppler of the phase transfer signal will also be used to provide the high-accuracy orbit determination needed.

Cassini — A Mission to Saturn and Titan

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The unique scientific observations made by NASA's Pioneer and Voyager spacecraft have yielded a wealth of information that has fundamentally changed our concepts of the Jovian, Saturnian and more recently Uranian systems in particular, and our view of the solar system as a whole.

A thorough exploration of the Jovian planetary system is the major objective of the Galileo mission, which consists of a Jupiter orbiter and an atmospheric probe, currently planned for launch in 1989.

The Cassini mission to the Saturnian system is the next logical step in the detailed systematic exploration of the outer solar system. Saturn's planet-sized moon Titan, with its intriguing atmospheric composition, is an especially interesting target.

The Cassini mission will consist of a Saturn Orbiter and Titan Atmospheric Probe, and is hence ideally suited to a joint venture. NASA will provide the Orbiter, launcher and Deep-Space Network for operations. ESA will provide the Titan Probe system and participate in the operations.

This article reviews the scientific objectives of the mission and the mission concept, with emphasis on the planned ESA contribution.

Introduction

Saturn is the second largest planet in our solar system after Jupiter. Its mass is 95 times that of the Earth and it is 120 660 km in diameter at its equator. At 0.7, its density is the lowest of all planets. With its suite of ice-rich satellites and its beautiful ring system, it constitutes the most complex and exciting target of all for planetary exploration.

Saturn lies about 1.5 million kilometres from the Sun, i.e. at 10 AU. The first observations of the planet can be traced back to 650 BC in ancient Mesopotamian records.

Major advances in the understanding of the Saturnian system were made in the 17th Century with the advent of the first optical telescopes. In particular, the Italian/French astronomer Giovani Domenico Cassini discovered four of its moons (Tethys, Dione, Rhea and Iapetus), as well as the large division in its ring system. This division, between the planet's B-ring and the outer A-ring, was named the 'Cassini Division' in his honour.

Titan is the largest moon of Saturn, rivalling the Jovian satellites Ganymede and Callisto and the planet Mercury in size. Since the discovery by the Spanish astronomer José Comas Sola, in 1903, that Titan has an atmosphere, this planet-sized moon has fascinated scientists. Later, when in 1943 the Dutch astronomer Gerard Kuiper discovered that Titan's atmosphere contained methane, the moon became more intriguing than ever.

A great step forward in our understanding of the Saturnian system, and of Titan in particular, was achieved in the 1979—1981 time frame, when the NASA spacecraft Pioneer-10 and Voyagers-1 and 2 made their spectacular observations. Fourteen new satellites were discovered in addition to the nine known previously known from ground observations; high-quality images of the Saturnian rings and the planet's atmosphere were sent back to Earth; and spectroscopic data revealed the presence of hydrocarbons, nitriles and oxygen-bearing compounds in Titan's atmosphere.

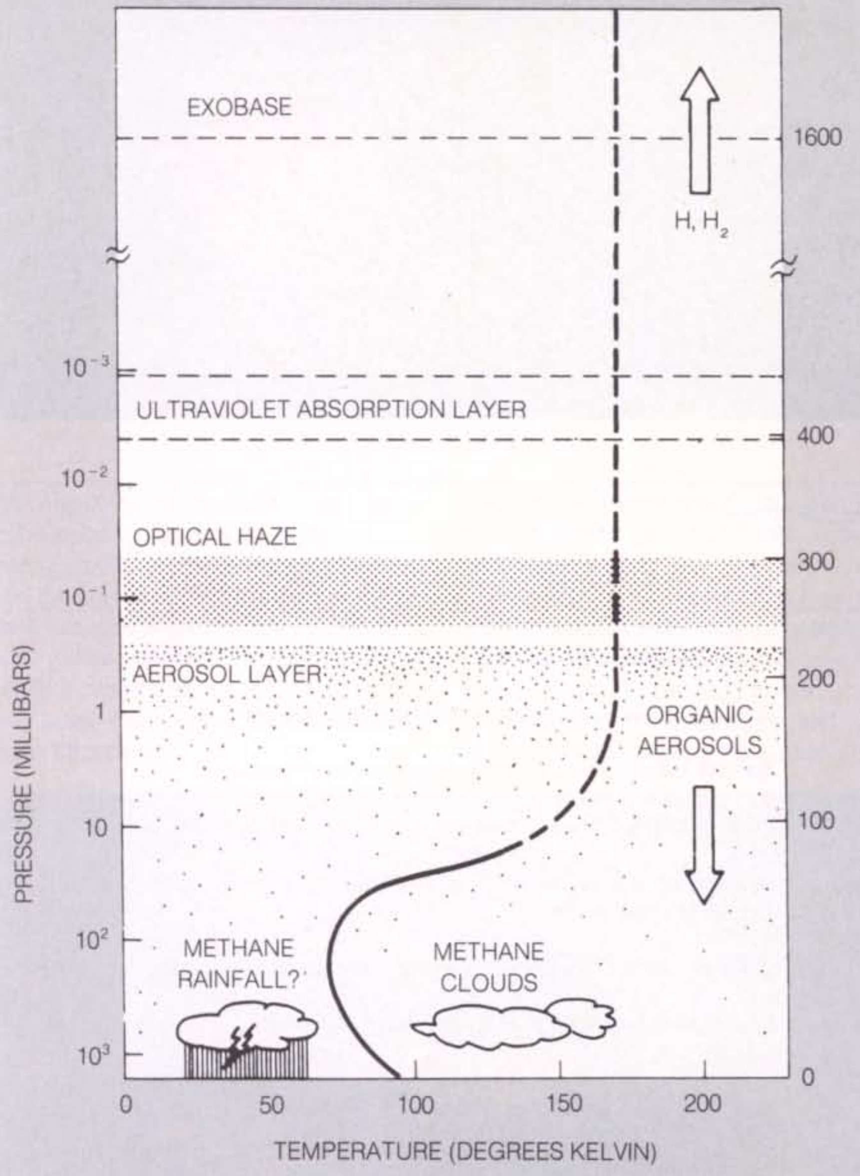
Titan and Saturn: The primary targets

Titan

Titan is surrounded by an opaque, physically and optically thick layer of haze. Although the Voyager cameras could not see through this layer, high-resolution spectroscopic and radio occultation observations provided data that have made it possible to estimate the composition of the chemically reduced atmosphere. It is composed predominantly of nitrogen, with a few percent of methane and possibly argon. The atmosphere is very cold, the tropopause temperature being about 70 K and the surface temperature about 94 K.

In addition to CH_4, a variety of hydrocarbons (C_2H_2, C_2H_4, C_2H_6, C_3H_4, C_3H_8, C_4H_2), nitriles (HCN, HC_3N and C_2N_2) and CO and CO_2 were detected. The three nitriles are of particular interest, because HCN is a precursor of purines, which are one of the building blocks of

Figure 1 — Atmospheric profile for the Titan moon of Saturn, and some of the moon's prime characteristics



Characteristics of Titan (after Lindal et al.)

Surface radius	2575. 0 ± 0.5 km
Mean density	1.881 ± 0.002 g/cm^3
Rotation period (Davies et al., 1980)	15 d 22 h 41 min 26.9 s
Distance Earth – Saturn	1.278 (min) – 1.577 (max) × 10^9 km
At the surface:	
Atmosphere pressure	1496 ± 20 mbar
Atmospheric temperature	94.0 ± 0.7 K
Acceleration of gravity	1.354 ± 0.001 m/s^2

the nucleic acids contained in living cells on Earth.

It is now believed that a complex organic chemistry is at work in Titan's atmosphere. The continuous polymerisation of hydrocarbons in the moon's atmosphere leads to the formation of aerosol particles, which may fall to the surface in the form of methane/ethane rain. Although the surface of Titan was not seen by Voyager's cameras, analysis of the available data suggests that the moon's surface may be covered, at least partially, by an ocean of CH_4/C_2H_6. In effect, Titan may have a 'hydrological system' in which CH_4 plays the role that water plays on Earth.

The main characteristics of Titan are summarised in Figure 1.

Saturn

Saturn, once thought to be very similar to Jupiter, now emerges as having a substantially different evolution and internal structure. Its atmosphere is composed mainly of hydrogen (94%), helium (6%) and traces of water, CH_4, and PH_4. The planet also has a strong internal magnetic field, which to a first approximation is that of a dipole of moment 0.21 Gauss-R_s^3 (where Saturn's radius R_s = 60 330 km). The internal field is axially symmetric and thus unique among all the planetary magnetic fields observed so far.

The huge magnetosphere of Saturn extends 20 to 22 planetary radii in the solar direction. Since Titan is orbiting Saturn at 20.4 R_s, this means that it may at times be in the solar wind. Study of Titan's interaction with either the magnetospheric or the solar-wind plasma is therefore of great interest. Its interaction with its surrounding plasma is presently thought to be Venus-like or cometary-like.

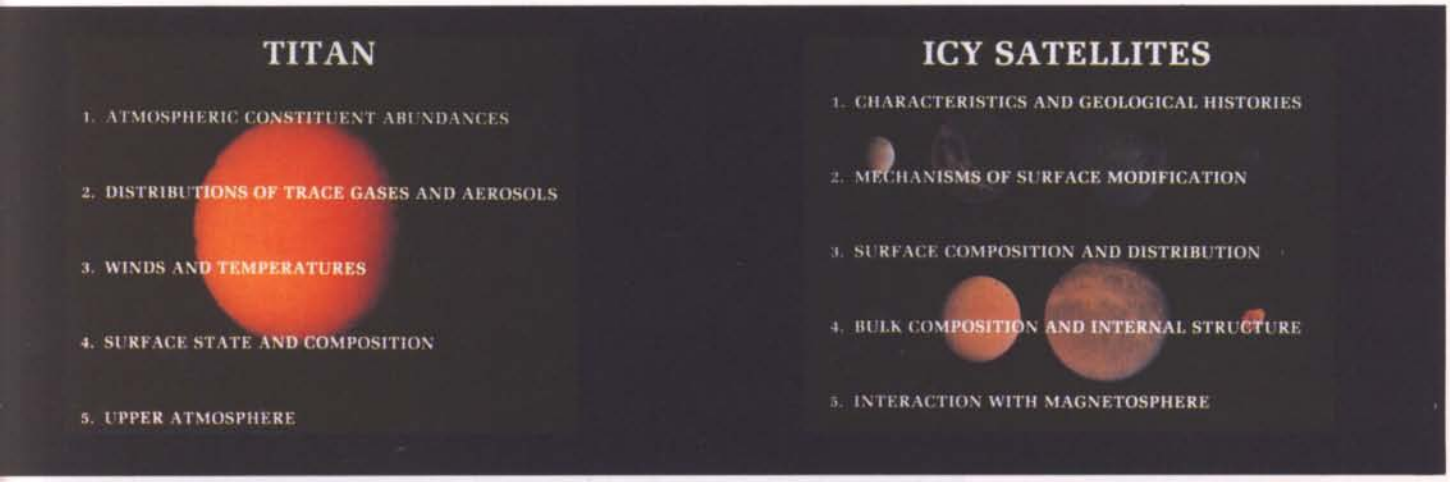
The rings of Saturn are composed of countless orbiting particles ranging in size from centimetres to tens of metres.

Figure 2 — The scientific objectives of the Cassini mission

Table 1 — Cassini Orbiter model payload (total mass 181.2 kg)

Instrument/Investigation	Main scientific objectives
Solid-State Imaging subsystem (SSI)	Imaging atmospheres, satellites and rings
Ultra-Violet Spectrometer Imager (UVSI)	Saturn and Titan composition, ionosphere remote sensing
Near-Infrared Spectrometer (NIRS)	Spectral imaging of icy satellites, rings and cloud structure
Composite Infrared Spectrometer (CIRS)	Deep sounding of Saturn and Titan. Atmosphere vertical distribution
Microwave Spectrometer and Radiometer (MSAR)	Atmospheric abundance of CO, HCN, HC_3N, and surface properties of Titan. NH_3 abundance on Saturn
High-Speed Photometer (HSP)	Stellar-occultation measurements for atmosphere and ring science
Titan Radar Mapper (TRM)	Imaging/mapping/altimetry of Titan surface. Subsurface sounding of Titan and icy satellites
Radio Science (RAD)	Titan and Saturn atmospheric structure profiles. Ring physical properties
Dust Analyser (DA)	Physical properties of dust particles
Plasma and Radio Wave Spectrometer (PRWS)	Spectral frequency characteristics of magnetospheric and ionospheric wave emissions
Plasma Spectrometer (PLS)	Composition, charge-state and energy distribution of magnetospheric plasma; 3-D measurements
Magnetospheric Imaging Instrument (MIMI)	Composition, charge-state and energy distribution of energetic ions and electrons. Detection of fast neutral species. Remote imaging of magnetosphere
Magnetometer (MAG)	Magnetic-field measurements
Ion Neutral Mass Spectrometer (INMS)	Titan aeronomy and chemical composition of Saturn's magnetosphere
Ion Analyser and Langmuir Probe (IA/LP)	Cold-plasma measurements

Figure 3 — The baseline Cassini interplanetary trajectory for a launch in 1996



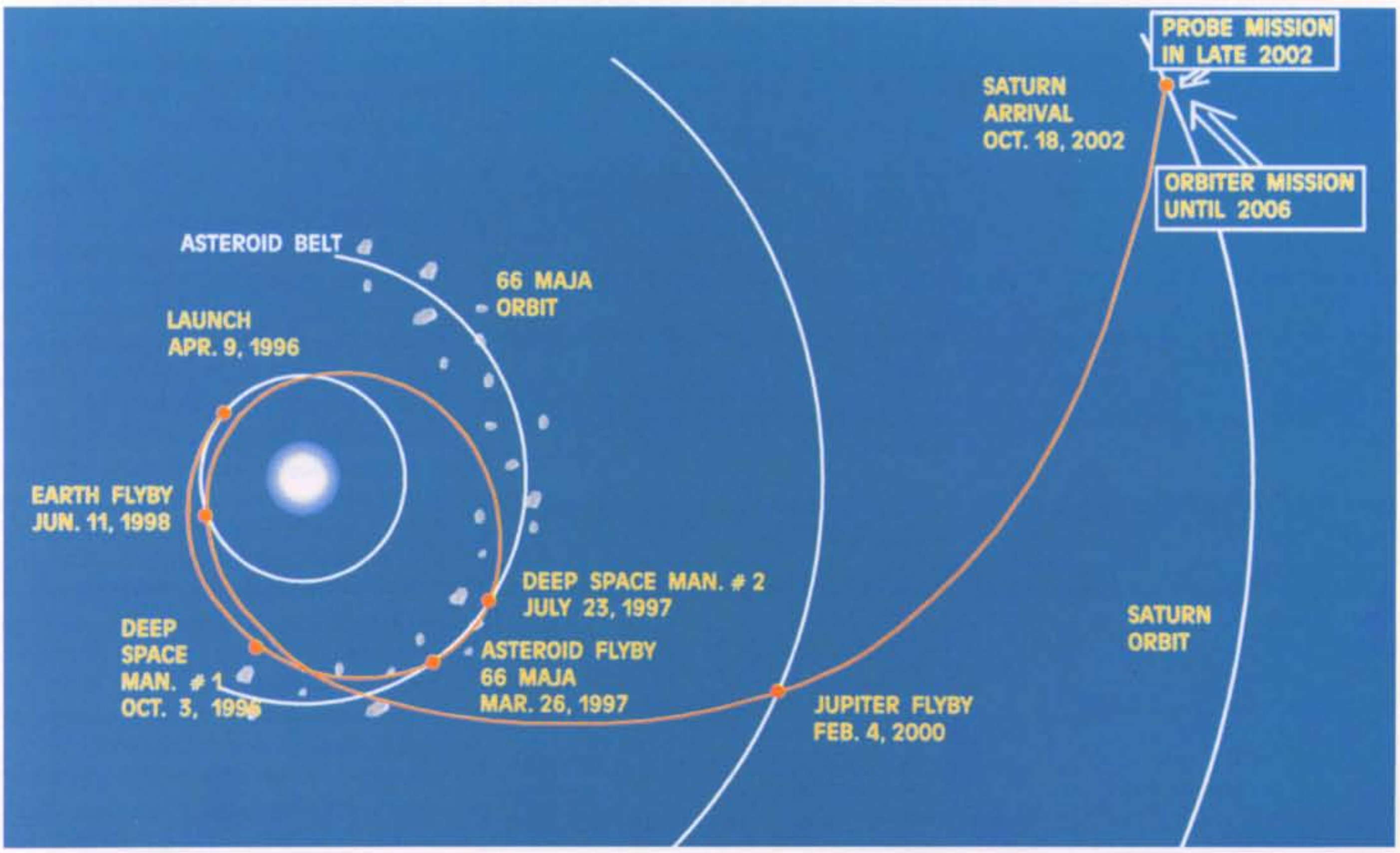
The ring particles are mostly made up of icy material, but they also contain impurities of currently unknown nature. The icy satellites of Saturn form a collection of objects of great interest to solar-system scientists. The sizes of these satellites range from small icy fragments only a few kilometers in diameter to the giant Titan moon.

The Saturnian system is so complex that it is sometimes likened to a mini solar system. Hence not only is the exploration of each part of the Saturnian system of great interest, but also the understanding of the system's overall dynamics and its evolution, which is relevant to our understanding of the formation and evolution of the whole solar system.

Scientific objectives

The Cassini mission will address a wide range of scientific objectives embracing all disciplines of the planetary sciences (Fig. 2).

The interplanetary journey (Fig. 3) will offer the opportunity for an enhanced Voyager-class mission around Jupiter,



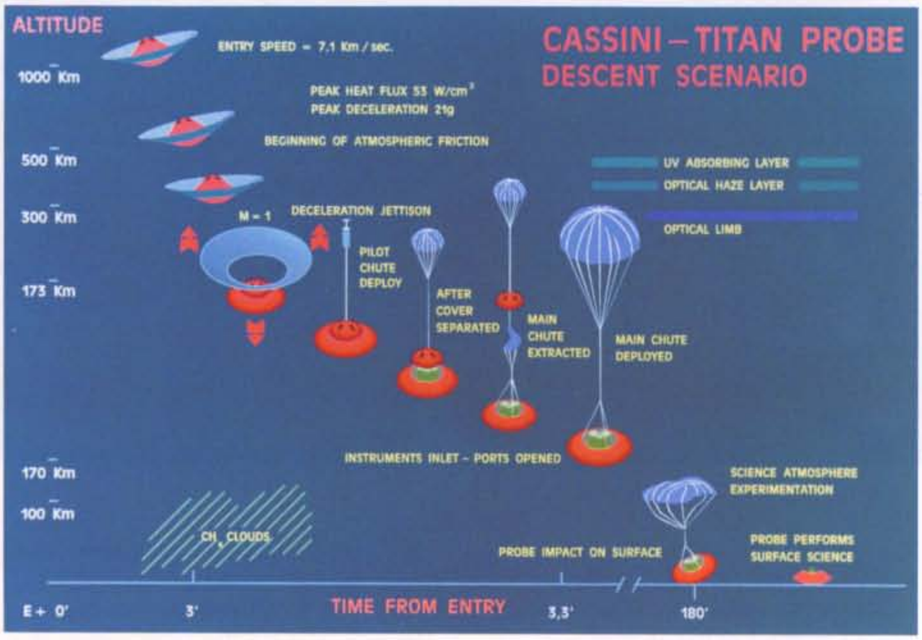
and also for at least one flyby of an asteroid, the last class of solar-system object that has not yet been visited. As the spacecraft journeys from Earth to Saturn it will also act as an interplanetary platform for conducting unique observations at distances of between 1 and 10 AU.

The Cassini mission

Mission overview

The Cassini mission will embark a Saturn Orbiter designed to explore thoroughly, in three dimensions, all the elements of the Saturnian system during the planned, intensive, four-year tour. The first major event after the Cassini spacecraft has been placed in orbit around Saturn will be the Titan Probe mission, described below. Once the Probe mission is complete, the Orbiter mission scenario will result in targetted flybys of a large number of icy satellites, and some 30 to 40 close flybys of Titan, at an altitude of between 800 and 1000 km. The Orbiter is instrumented with a very comprehensive scientific payload, which is summarised in Table 1.

Figure 4 — The Titan Probe descent scenario



Probe delivery

After orbit insertion around Saturn, the Orbiter-Probe composite will be placed on a collision trajectory with Titan, to allow the Probe to be targetted for a low-latitude dayside entry and descent into the moon's atmosphere. Probe separation will occur about 12 d prior to entry. Some days after Probe separation, the Orbiter will be deflected and delayed in order to overfly Titan at a minimum altitude of 1000 km about 3 h after the Probe has entered the moon's atmosphere. This tandem flight configuration will allow the Orbiter to be used as a radio-relay station to acquire Probe data for retransmission to Earth via NASA's Deep-Space Network (DSN).

Table 2 – Cassini Phase-A model payload (total mass 39.9 kg)

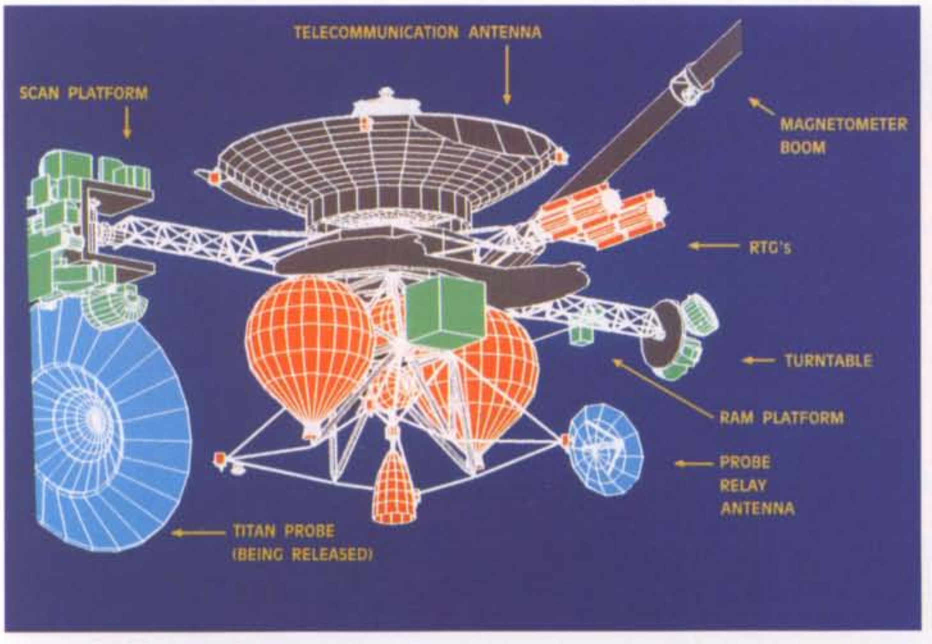
Instrument/investigation	Main scientific objectives
Atmospheric Structure Instrument (ASI)	Atmosphere temperature and pressure profile, winds and turbulence
Probe Infra-Red Laser Spectrometer (PIRLS)	Vertical profile of trace species. Nephelometry
Gas Chromatograph/Neutral Mass-Spectrometer (GC/MS)	Atmosphere composition profile. Aerosol analysis
Aerosol Collector and Pyrolyser (ACP)	Aerosol composition profile GC/MS is used as detector
Descent Imager/Spectral Radiometer (DI/SR)	Atmospheric composition and cloud structure. Surface imaging
Lightning and Radio-Emission Detector (LRD)	Titan lightning characteristics
Surface-Science Package (SSP)	Titan surface state and composition
Doppler Wind Experiment (DWE)	Probe Doppler tracking from the orbiter for zonal wind-profile measurement
Radar Altimeter Science (RAS)	Surface roughness and reflectivity. Subsurface sounding

The Probe mission

The Probe will enter Titan's atmosphere at a speed of about 7 km/s. Its 3.1 m diameter aerodynamic decelerator will brake it to subsonic velocity (approx. 270 m/s), at an altitude of at least 175 km. Parachute deployment will ensure a slow descent down to the moon's surface in approximately 2 to 3 h.

One set of instruments will be activated prior to entry into Titan's atmosphere in order to perform accelerometer measurements during the entry phase. The remainder will be activated as required during the atmospheric descent phase. Although not designed to guarantee survival after impact on Titan's surface, the Probe may 'live' for sufficient minutes to collect unique surface state

Figure 5 — The Cassini spacecraft



(i) A high-speed carbon/carbon jettisonable aerodynamic decelerator for braking from the supersonic entry speed to subsonic velocity.

(ii) A descent module in which all the scientific instruments and the subsystems are accommodated. Thermal protection is provided by a system consisting of a nose cap, lower skirt and aft cover, and suitable nonablative heat-resistant materials. A parachute system will be deployed at an altitude of about 170 km to ensure a slow atmospheric descent compatible with the scientific instruments' measurement profile.

The main characteristics of the Probe are listed in Table 3.

and composition data, including possibly a surface sample for rapid analysis prior to failure of the Probe—Orbiter radio-relay link.

The main events in the Probe's mission scenario are illustrated in Figure 4. The Probe's model payload is summarised in Table 2.

The spacecraft

The Orbiter

The Orbiter's design is based on NASA's new-generation Mariner Mark II interplanetary platform. Cassini is the second mission designed to use this platform after the Comet Rendezvous Asteroid Flyby (CRAF) mission.

The main elements of the Orbiter are shown in Figure 5. The Probe system consists of the atmospheric probe itself and its support subsystem. The latter contains all the interface elements between the Orbiter and the Probe (spin eject system, Probe radio-relay link articulated antenna, its drive electronics, telecommunications, receivers, power and data-interface units).

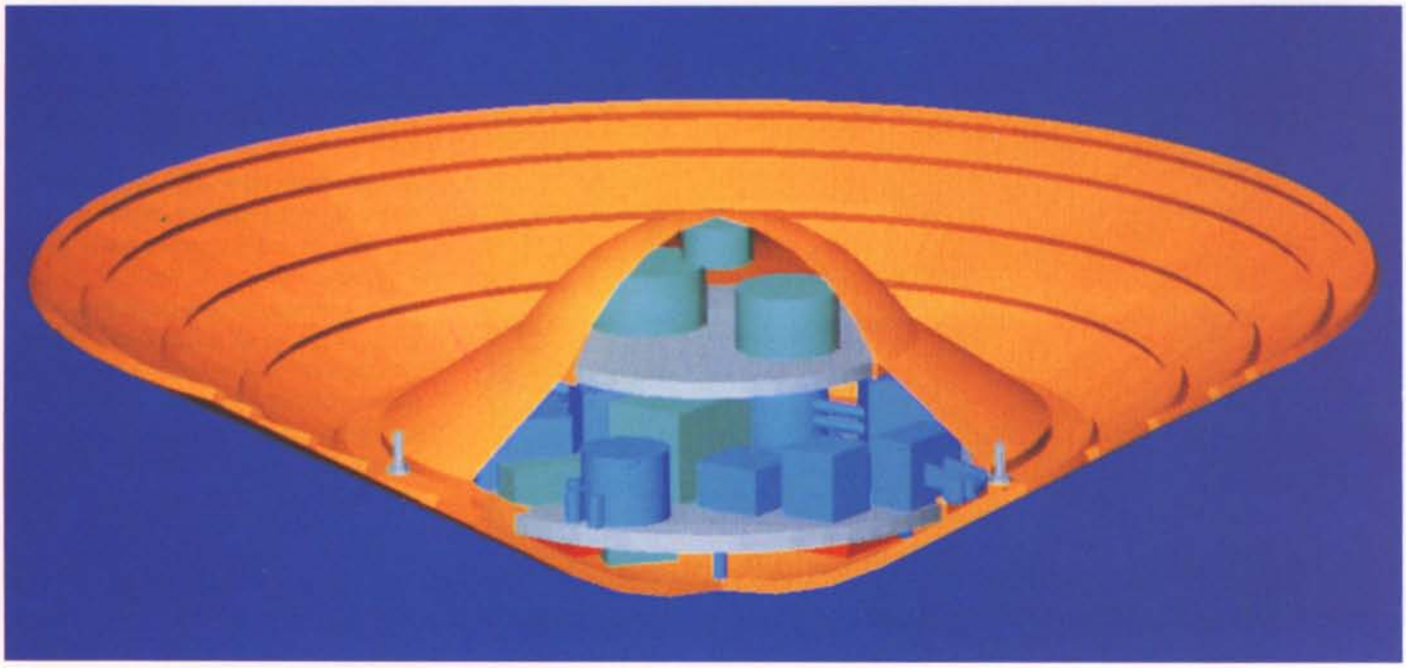
The Probe

The Probe has the following main elements (Fig 6):

Table 3 — Titan Atmospheric Probe design and performance parameters

- Model Payload: Seven scientific instruments plus Radar Altimeter Science (RAS) and Doppler Science (DS) and Impact Surface Science (ISS)
- Launch of Saturn Orbiter Titan Probe composite on Titan-4/Centaur-G' 1996/1997
- Mission: 6.8 yr interplanetary cruise. Probe post-Saturn orbit insertion, delivery, targeting and spin/separation at Titan encounter — 12 d. Entry and descent on day side. Entry latitude ±30°
- Autonomous operation during coast, entry and descent phases
- V_∞ (1000 km); Range: 6.8—5.5 km/s
- Entry velocity: Nominally 7.0 km/s
- Entry angle: Range 60°—90°; Nominally 65°
- Sonic Mach altitude: >175 km
- Chemical sampling initiation: >170 km
- Impact velocity: 4—6 m/s
- Radio relay link: S-band; 1.4 m diameter antenna; two-axis antenna pointing mechanism and probe-support subsystem on Orbiter
- Data rates: 512 bit/s to >8 kbit/s at impact
- Data transmission capability: 10—15 Mbit total
- Power: 1.4 kWh lithium sulphur-dioxide ($LiSO_2$) batteries
- Mass: 192.3 kg (allocated)

Figure 6 — The Titan Probe. The decelerator is 3.1 m in diameter



The Titan Probe system design

Given the scientific and mission requirements, there is a need for a high level of autonomy to be incorporated into the Cassini Titan Probe's design.

For simplicity, reliability, power-limitation and other operational reasons, such as long Earth—spacecraft link durations, an Orbiter—Probe telecommand link capability has not been incorporated into the Probe's design.

It is a mission requirement that the Probe should perform fully autonomously during the coast, entry and descent phases. Operations during these phases require active in-situ sensing of the Probe's environment and its dynamic behaviour, and the exploitation of real-time on-board control loops and decision-making. These capabilities are essential for the detection of atmospheric entry, based on deceleration and aero-thermodynamic heat loads, and subsequent reliable initiation of the decelerator-jettison and parachute-deployment sequences.

Adaptive control of the Probe's thermal environment, descent profile, experiment-operation profile and data management/transmission during the descent phase, are all crucial factors for mission success.

The possibility to switch data-acquisition rates along the descent profile, based on the Probe's ability to sense accurately its altitude above Titan's surface, is also an autonomous function. It depends on information that can only be sensed on-board in real time.

It is these and other similar system requirements that have led to the high degree of autonomy in the design concept. One of the major effects of this high autonomy is that it provides the operating flexibility needed to cope with the evolution in scientific and mission objectives that will occur during the approx. 12 yr of mission development and operations.

Conclusion

The Cassini mission was originally proposed to ESA by a consortium of European scientists in 1982, to be conducted as a joint endeavour by ESA and NASA. It has now reached a very mature state of design definition.

Since 1983, studies have been performed by a joint ESA/NASA Study Team. An agreement between the two agencies early in this cycle foresaw a clear division of contributions and responsibilities in the event that the mission would indeed be carried out jointly. The potential scientific return from the mission was significantly enhanced when it was decided, in 1986, to include a close Jupiter flyby in the interplanetary trajectory.

Recently,in early 1988, NASA made a very significant step forward in the planning of the Cassini mission, with its decision to merge it and the CRAF mission into a combined Mariner Mark II Programme. It is now actively preparing for submission of this programme as a Fiscal Year 1990 new start.

Based on the assessment and design feasibility studies to date, supplemented by the supporting-technology studies conducted for the most design-critical areas, Europe has the technological expertise needed to undertake development of the Cassini Titan Probe as part of this major solar-system planetary-exploration mission, which has such a high scientific-return potential.

GRASP — Gamma-Ray Astronomy with Spectroscopy and Positioning

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The GRASP mission is the first genuine high-quality spectral imager designed to operate over a wide spectral range with a high sensitivity (typically 10 mCrab or better) over the entire operational range for an observation period of 30 h.

Fundamental new astrophysical data will be revealed by this exploratory mission to investigate gamma-ray sources in what is basically an unexplored waveband for the first time with both high spectral and high spatial resolution.

GRASP is envisaged as a purely European mission to be launched in 1996 by an Ariane-4. It is a natural extension of Europe's innovative Space Astronomy Programme. After commissioning, scientific operation of the spacecraft will include the scientific community at large via a Guest Observer Programme.

The spacecraft will be three-axis stabilised and able to point to any part of the sky within a six-month period.The integration times on target will be between 1 h and 12 d. Scientific data will be returned at a rate of 40 kbit/s and passed to a central institute where it will be processed and archived ready for distribution.

Scientific objectives

Scope of gamma-ray astronomy

Astronomy has been pursued mainly on the basis of the study of thermal emission from celestial sources. Gamma-ray astronomy was conceived as an extension of cosmic-ray physics because the measurement of gamma-ray photons permits the direct study of both nuclear processes and the largest individual energy transfers associated with particle interactions.

Gamma-rays provide a direct probe, with minimal line-of-sight absorption, of the high-energy-physics phenomena that take place both in the interstellar medium and in the vicinity of compact objects. Consequently, they are more directly related than any other photons to the violent processes that determine the evolution of objects throughout the Universe.

The scope of gamma-ray astronomy with a highly sensitive spectral imager such as GRASP is vast. An exploratory mission of this type in a basically unexplored waveband — in fact **the** band that includes all the nuclear gamma-ray lines as well as discrete cyclotron absorption/emission features and particle-annihilation processes — must inevitably have fundamental consequences for our understanding of the Universe.

The major astrophysical objectives are

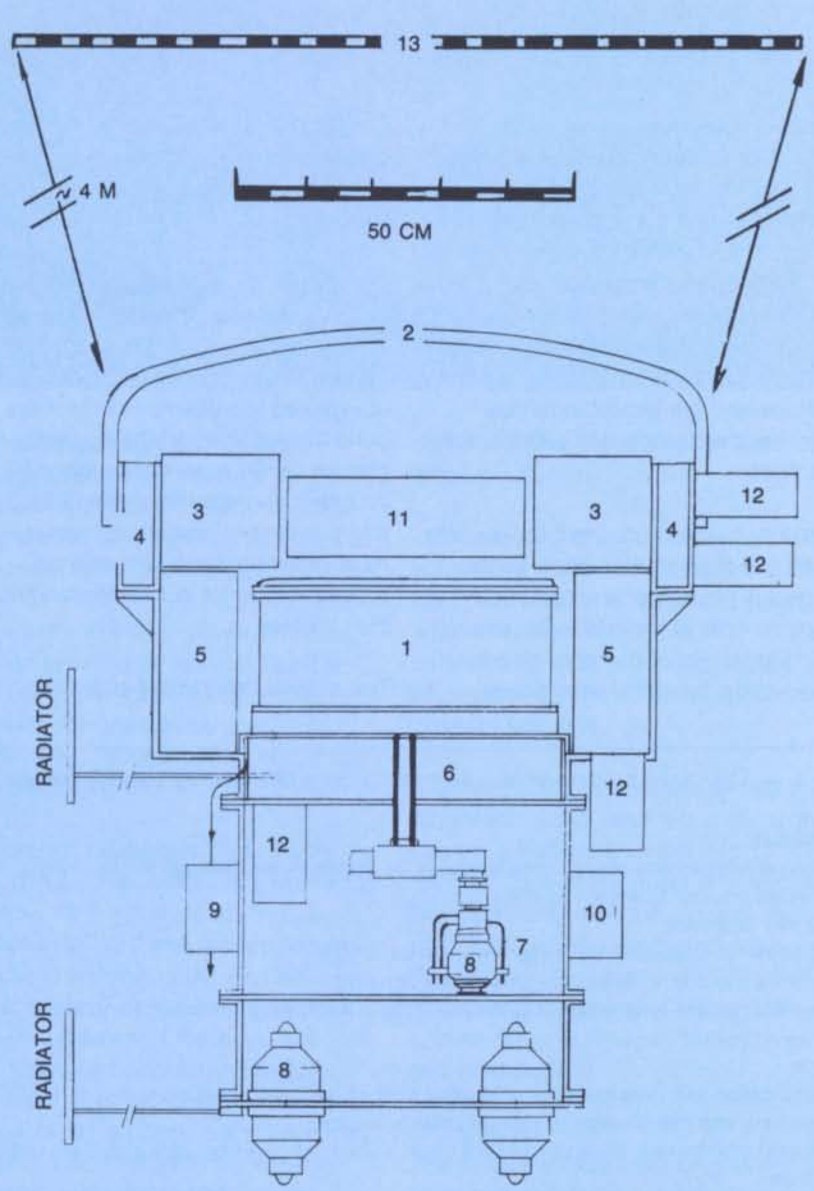
*Table 1 — The major astrophysical objectives to be addressed by the GRASP mission**

Extragalactic
- Physical environment near to central engine for nearby Active Galactic Nuclei (AGNs)
- AGN gamma-ray luminosity function
- 511 keV cosmology
- Non-thermal emission from clusters of galaxies
- Origin of the cosmic diffuse gamma-ray background
- Explosive nucleo-synthesis in supernovae in the galactic neighbourhood (<10 Mpc)

Galactic
- Identification and understanding of existing unidentified gamma-ray objects
- Discovery and identification of new gamma-ray sources
- Physical environment close to compact objects, especially neutron stars and Gamma-Ray Bursters
- Galactic mapping of recent ($<10^6$ y) nucleo-synthesis from, for example, Wolf-Rayet stars and Red Giants
- Physical environment of the Galactic Centre
- Explosive nucleo-synthesis in novae
- Search for recent (<100 y) undetected Supernova Remnants (SNRs)
- Localised and extended interstellar matter/cosmic-ray interaction regions

* The individual topics are not listed in any particular order.

Figure 1 — The GRASP payload



1 = Germanium Subsystem
2 = Veto Plastic Subsystem
3 = CsI Subsystem
4 = Veto Upper Lateral Subsystem
5 = Veto Bottom Lateral Subsystem
6 = Veto Bottom Subsystem
7 = Stirling Cycle Piping
8 = Stirling Cycle Subsystem
9 = Germanium Analogue Electronics
10 = Germanium High-Voltage Supply
11 = Collimator Subsystem
12 = Photomultiplier
13 = Coded-Aperture Mask

summarised in Table 1. Some of them are highlighted below.

Extragalactic astronomy
The study of Active Galaxies is one of the major features of the mission. The unambiguous identification of a large number of Active Galaxies will lead directly to the compilation of a gamma-ray luminosity function for these objects in the region of the spectrum where the luminosity is at a maximum. Furthermore, the detailed study of red-shifted electron-positron annihilation lines from these distant sources has fundamental cosmological implications. Precise measurements ($E/\Delta E \sim 1000$ at 1 MeV) of both the line and continuum spectra will provide a revealing probe of the physics in the vicinity of the compact objects associated with extragalactic nuclei.

Galactic astronomy
GRASP will discover new gamma-ray sources within our Galaxy, map extended objects, locate point sources precisely ($\sim 1'$), analyse their emission spectra with high resolution, and study the variability of a wide variety of spectral objects, with special emphasis on the Galactic Centre. A picture of the distribution of recent nucleo-synthesis throughout the Galaxy will be derived by mapping key emission lines (such as Al^{26}) and the positron annihilation line (511 keV). This has direct bearing on the study of stellar evolution, e.g. in the Red Giant and Wolf-Rayet phases.

Transient events
A significant number of transient events are expected to occur during the mission's lifetime. Some of these will be Gamma-Ray Bursters within the field-of-view, whilst Supernova events will be studied over longer periods by occasionally reorienting the telescope. These and Galactic Novae are exciting targets for high-resolution-spectroscopy studies, as they are potential sites of explosive nucleo-synthesis.

The GRASP payload
The GRASP telescope (Fig. 1) employs a coded-aperture mask located about 4 m from the detector assembly, which consists of two types of detectors: an array of germanium (Ge) detectors, cooled to 85 K, surrounded by a three-dimensional matrix of large caesium-iodide (CsI) detectors. The main parameters of the payload are summarised in Table 2. The subsystems are outlined briefly below.

Germanium spectrometer

At the heart of the focal-plane assembly are the germanium semiconductor detectors. Any gamma-ray interacting with the germanium will cause the release of charge, which is collected by a voltage applied across the detector and is recorded as a pulse of current. The pulse amplitude indicates the energy of the incident gamma-ray.

The germanium detector array (19 elements) provides the fine spectroscopic capability of GRASP (resolution $\Delta E \sim 1$ keV at E = 1 MeV); each of the 19 detectors consists of a stack of four hyper-pure germanium planars (each ~5 cm in diameter and 1.5 cm thick) for the detection of 15 keV to ~10 MeV photons. To reduce thermal noise, the detectors are cooled to about 85 K (see below).

Caesium-iodide imager

This is the second detector employed in GRASP. The three-dimensional caesium-iodide imager providing GRASP's fine (arcminute) positional capability consists of ~1500 caesium-iodide bars (15 mm × 15 mm × 150 mm) and operates in the range 0.5 MeV — >100 MeV with high detection efficiency (~100%) with a spectral resolution of typically $E/\Delta E = 10$.

Each caesium-iodide bar is viewed by a photodiode from above and below. Incident gamma-rays produce high-energy electrons inside the caesium-iodide bar. These electrons move inside the crystal and lose energy by ionising the crystal material, which in turn emits this energy in the form of light (scintillation). Measurement of this light emission via the photodiodes at the bar ends (ratio and sum of signals) allows both the location of the gamma-ray interaction and its energy to be determined.

Table 2 — GRASP payload and mission parameters

Payload	
Energy range	15 keV — >100 MeV
Energy resolution (at 1 MeV)	$E/\Delta E$ = 1000
Field-of-view (fully coded)	6°×6°
Point-source location	1′
Sensitivity (cf. Figs. 2 and 3)	
continuum (3 σ in 10^5 s)	10 mCrab (10^{-5} ph/cm^2/s)
line (3 σ in 10^6 s)	3×10^{-6} ph/cm^2/s
Temporal resolution	0.1 ms
Polarisation measurement range	0.5 MeV — >5 MeV
Effective gamma-ray detection area	3000 cm^2
Length (overall)	5 m
Mass (overall)	1000 kg
Diameter (overall)	130 cm
Power (overall)	332 W
Data rate	40 kbit/s
Mission	
Targetting accuracy	0.25°
Attitude stability	1′/h
Attitude reconstitution	1′
No. of pointings	$\leq 10^3$
Low Earth orbit	**Highly eccentric orbit**
Altitude: 550 km	Perigee: 4000 km, Apogee: 68 000 km
Eccentricity: 0	0.825
Inclination: 0°	65°
Period: 95 min	24 h
No. of ground stations: 1 (Kourou or Malindi)	1 (Perth)
Mission duration: ~3 y	~3 y

Coded-aperture mask

Because of their high energy, gamma-rays cannot be focussed like visible light, ultraviolet light and X-rays. It is therefore necessary to form an image using the concept of a pin-hole camera, or an extension of this principle, the shadow mask. The mask (more correctly called the 'coded-aperture mask') is made from a tungsten plate, thick enough to absorb gamma-rays, in which a complex pattern of holes is cut. Each source in the sky will cast a shadow of the mask on the detector plane. By means of computer processing, the image can be extracted from the complex shadows recorded at the focal plane.

The GRASP coded-aperture tungsten mask provides for the generation of high-quality images and enables an instrument with a large sensitive area, a wide field of view, fine angular imaging capacity and the ability to monitor source and detector background simultaneously, to be designed.

Cooling system

The cooling of the germanium detector to 85 K is achieved by a system of Stirling-cycle coolers developed by British Aerospace (UK). Each unit consists of a displacer and compressor. Several units are included in the design to cover operations and redundancy requirements.

Veto system and star camera

The detector assembly is completed by a veto system consisting of shields placed on top, at the sides and at the bottom of the detector. These shields are made out of crystals — caesium iodide, bismuth germanate, and plastic.

The veto system shields and thus reduces the gamma-ray (background) flux coming from other than the viewing direction. It identifies unwanted charged particles like cosmic protons or electrons

Figure 2 — GRASP line sensitivity

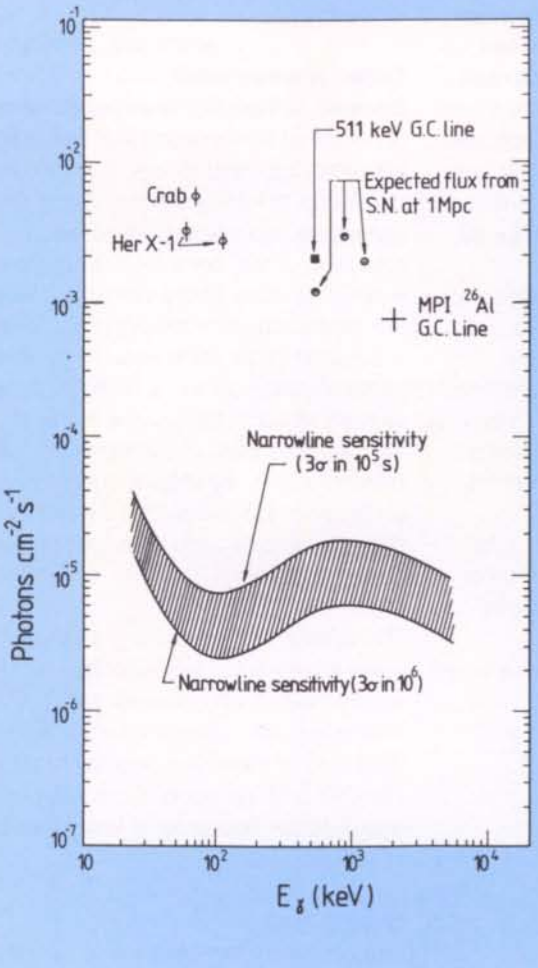
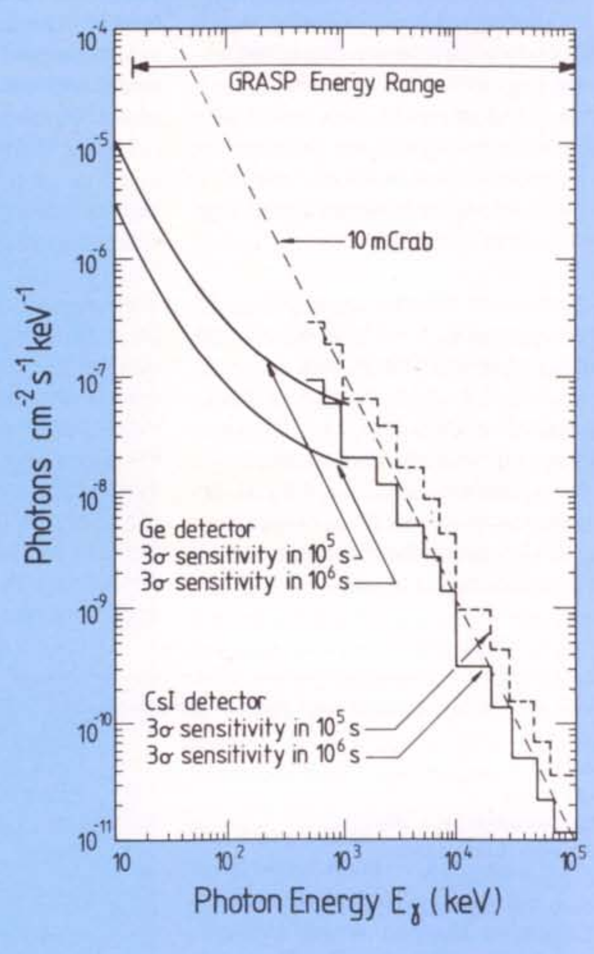


Figure 3 — GRASP continuum sensitivity



and 'vetoes' them in the data stream. In addition, the caesium-iodide imaging detector itself makes a considerable contribution to the shielding of the germanium spectrometer.

A collimator limits the field of view and enhances the directional sensitivity of the germanium detectors by further reducing the impact of isotropic background radiation.

An optical star-field camera, which monitors the sites of gamma-ray burst events in the optical waveband simultaneously with their gamma-ray detection (covering the same field of view), completes the GRASP payload.

Background rejection and sensitivity

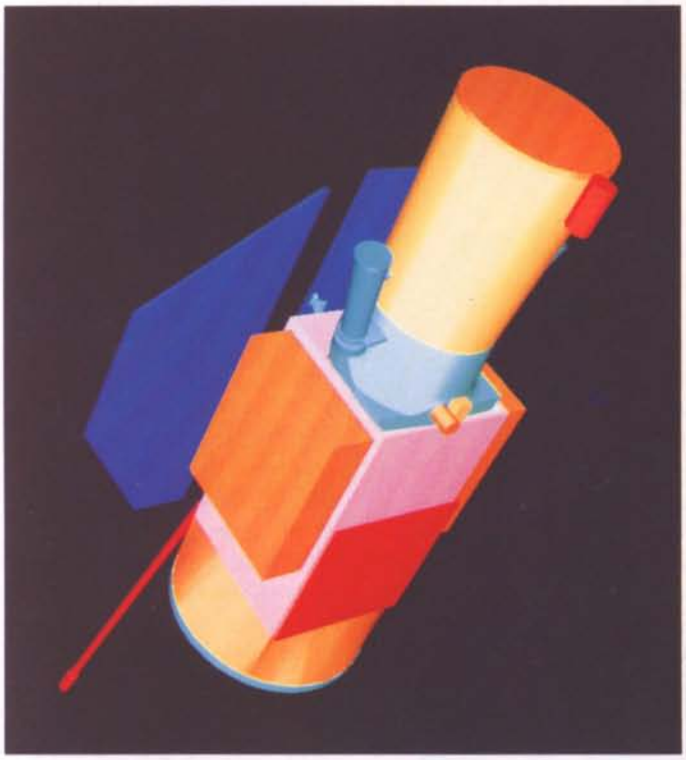
In order to ensure a good signal-to-noise ratio, efficient background rejection is achieved by selecting only those events that exhibit the multiple-site energy-deposit characteristics of gamma-ray interactions inside the germaniun/caesium-iodide detectors (like Compton scattering and electromagnetic cascades) and rejecting single-site background events due to neutron-induced beta decay.

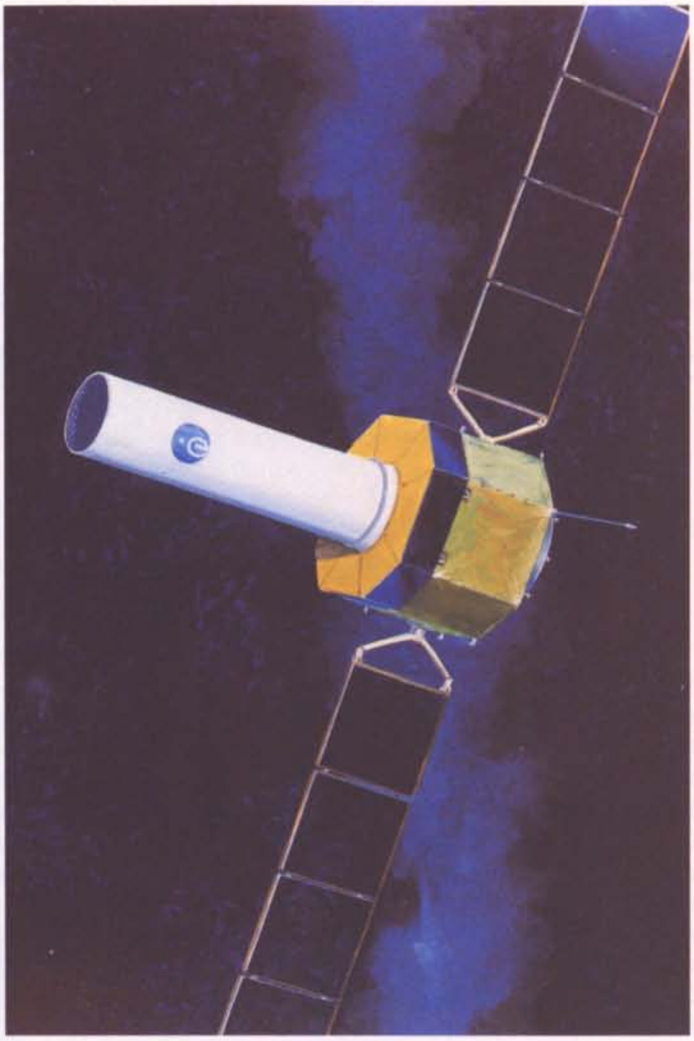
In Figure 2, the gamma-ray line sensitivity is compared to some current discrete flux measurements. Clearly, with more than two orders of magnitude improvement in sensitivity threshold, GRASP will allow great advances in the field of astrophysical nuclear gamma-ray line spectroscopy. The 3 σ continuum sensitivity, shown in Figure 3, is at the 10 mCrab level or better over the entire spectral range.

Payload studies

Numerous engineering studies are being carried out by European universities and industry to study important payload subsystems in detail. In addition, the design concept for the payload is being studied by industry (CASA, Spain; Canberra, Belgium; and Sener, Spain) to analyse the detector and mask system from the spacecraft-interface point-of-view.

Figure 4 — GRASP mission configuration (Courtesy of Dornier and Matra)





Mission requirements and design
The mission requirements for GRASP call for a three-axis-stabilised spacecraft with moderate pointing (Table 2).

In the light of ESA's Space Science: Horizon 2000 Long-Term Plan, prime mission aspects of the GRASP project (analysis, definition, trade-off and selection of spacecraft and orbit) are driven by two criteria: to optimise the scientific output of GRASP, and to achieve a realistic and, most importantly, cost-effective mission. Both the reuse of existing hardware like Robus (developed for Rosat) and the adaptability of a 'common bus' to other astronomy payloads like XMM or Lyman have been considered.

During the course of the on-going industrial Phase-A study, two contractors, Dornier (D) and Matra (F), each leading a European consortium, will evaluate the feasibility of the GRASP mission in two different orbits. The payload will be launched by an Ariane-4 in 1996 (nominal launch date) either into a circular low-Earth orbit (0° inclination, 550 km altitude) or into a highly elliptical orbit (24 h, 65° inclination). The cumulative integration periods on target are between 1 h and 12 days; the observational lifetime and efficiency will be such that a minimum of 1.6 years (24 h orbit; 1 year low Earth orbit) of useful observation on target is achieved. Both orbits give good coverage using only one ground station.

Two conceptual views of the GRASP mission are shown in Figure 4.

Scientific operations
It is planned to operate GRASP in a similar manner to the Agency's earlier Cos-B satellite. A GRASP Data Centre (GDC), located at a scientific institute, will pre-process the data (90% offline, 10% real-time) received from the Agency's Space Operations Centre (ESOC) in Darmstadt (Germany) and distribute it to the Collaboration. The features of GRASP — independent spectroscopy and imaging modes, up to 1000 pointings during mission lifetime, and coded-aperture mask with large field-of-view enabling multi-target observation — allow for the setting up of a Guest Observer Programme, which will be supported by the GRASP Data Centre.

The Vesta Missions — A Visit to the Small Bodies of the Solar System

R. Grard, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands

The heavenly bodies that orbit the Sun are classified into two main categories: the planets and their satellites, and the so-called 'small bodies', namely asteroids and comets. The Vesta missions, named after one of the largest asteroids, are proposed as a trilateral cooperative endeavour by the European, French and Soviet space agencies (ESA, CNES and Intercosmos). Two identical space systems will be launched in 1996 and will visit up to eight small bodies, including one or two comets, over a five-year period.

The Vesta missions will pursue and extend the small-bodies exploration programme that began with the flybys of Comet Halley by the Giotto and Vega spacecraft. They are also the forerunners of the ambitious Comet-Nucleus Sample-Return mission, Rosetta, planned for the turn of the century.

Asteroids and comets

Comets, which are often visible to the naked eye when they come closer than 1 AU (average distance between Earth and Sun; approx. 150 million km.) to the Sun, have been observed since time immemorial. The first known historical reference to a comet appears in a Chinese chronicle which dates back over four millenia. The release of small dust particles and the sublimation of volatile materials, mostly water, which are the major constituents of the relatively small solid nucleus, give rise to 'tails' that can be tens, and even hundreds of millions, of kilometres long, and which rarely pass unnoticed.

Asteroids, on the other hand, do not release much (if any) material, so that only Vesta, and possibly Ceres, about 500 km in diameter, can be detected without the aid of a telescope. Mankind had therefore to wait until the very first day of the nineteenth century, on 1 January 1801, for the discovery of a minor planet (the term asteroid was coined later by William Herschel, who had discovered Uranus in 1781) by a theatine abbot of Palermo, Giuseppe Piazzi. He christened this celestial object after Ceres, the protectress of Sicily and pagan goddess of fertility. This event is commemorated by the engraving shown in Figure 1. The fourth small planet was discovered on 29 March 1807 by Olbers, an astronomer from Bremen; it was named 'Vesta'.

What do asteroids and comets have in common and how do they differ?

Comets are believed to have originated from the solar nebula — a mixture of gas

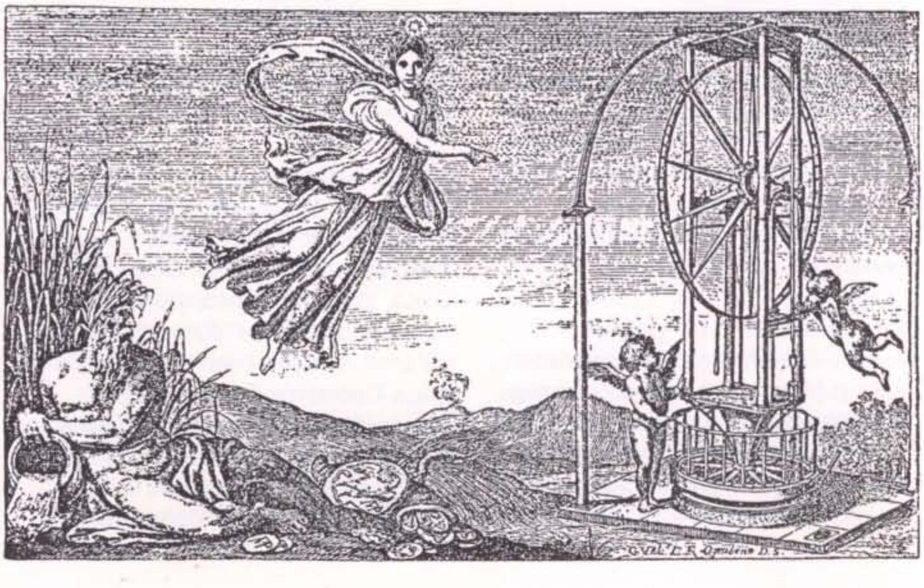


Figure 1 — Engraving commemorating the discovery of the first asteroid 'Ceres' by Giuseppe Piazzi, on 1 January 1801



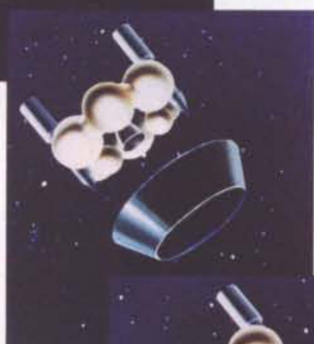




Figure 2 — The Vesta system scenario during the separation of the two modules, the Approach-Module deceleration phase and the release of the two penetrators (courtesy of CNES)

and dust — when the Sun and the planets formed five billion years ago. Cometary nuclei are even claimed to be the elementary blocks, 1 to 10 km across, from which the planets were formed.

About 2000 comets have been identified so far, but this represents only a tiny sample of a much larger population which constitutes the hypothetical Oort Cloud (named after Jan Hendrik Ooort, b. 1900, of Leiden University, The Netherlands), an immense reservoir of comets that encompasses the Sun and the planets at heliocentric distances of 1000 to 100 000 AU.

Asteroids, on the other hand, form rather well-defined belts around the Sun in the orbital plane of the major planets, at distances of 2.2 to 3.7 AU (except for the Apollo-Amor and Trojan groups, closer to the Sun and Jupiter, resp.). More than 6000 of these bodies have already been listed, with sizes ranging from 10 km to a few 100 km. Most of them populate a region of space in the vicinity of the orbit of a planet which, according to Bode's Law*, should be found between Mars and Jupiter, but it has never been located.

These introductory remarks immediately highlight a number of very interesting questions about a possible relationship between comets and asteroids. For example, are the asteroids the solid residuals of cometary nuclei that have long ago lost all of their volatile constituents? Do they represent the basic elements of a potentially larger body that has not (yet) come together? Or, on the contrary, are they the remains of a planet that was smashed by an explosion or a collision with a giant meteorite? In short, can we learn anything from these small bodies about the genesis of the major planets and their satellites?

To ensure that these fundamental questions are properly addressed by the Vesta project, the approach has been one of:

- drawing up a list of desirable measurements and observations directly related to the scientific objectives identified
- setting up an instrument payload that appears best-suited for achieving the task based on a feasible concept, and
- defining the mission strategies that will optimise instrument operation and the overall scientific return.

The space systems and their scientific payloads

Each of the two Vesta space systems consists of:

(a) a Flyby Module, with scanning platform, that will fly by several asteroids and cometary nuclei at distances of the order of 500 to 2000 km, and with relative velocities in the range 2—15 km/s, and

(b) an Approach Module that will be jettisoned in the vicinity of a selected asteroid, reduce its relative speed to less than 0.1 km/s, and then release two penetrators which will anchor themselves to a selected target (Fig. 2).

The two missions are similarly instrumented, but will be targetted at different small bodies.

The principal characteristics of the flyby and approach modules are summarised in Table 1.

Tentative lists of instruments for the combined payloads of the two

* This empirical law, first formulated by Wolf in 1778, states that the distances of the planets from the Sun in AU are given roughly by the series 0.4, 0.7, 1, 1.6, 2.8, 5.2, 10, etc.

Figure 3 — A typical Vesta mission trajectory with two Mars gravity-assists and four asteroid flybys, which had been considered previously for a launch date in 1994. The name of each asteroid is preceded by a number that indicates the order of its discovery. Similar scenarios are currently being updated to comply with the newly established development schedule leading to launches in 1996

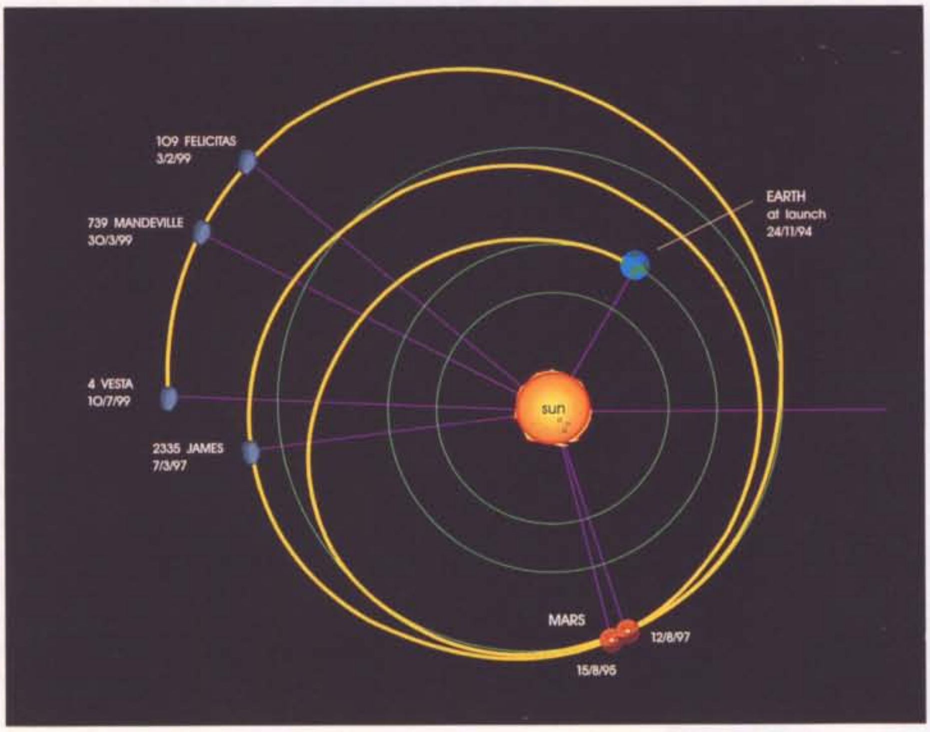


*Table 1 — Main characteristics of the Vesta Flyby and Approach Modules**

Module	Flyby Module	Approach Module
System		
Responsibility	ESA-CNES	Intercosmos
Mission duration, yr	5	3
Total mass at launch, kg	1500	500
Delta V, km/s	1.2	4
Positional accuracy, m	30	1000
Stabilisation	Three-axis	Spin
Pointing accuracy, deg	0.1	0.5
Power source	Solar array + Batteries	Batteries
Bus voltage, V	28	28
Maximum power, W	620	45
Telemetry frequency bands	S+X	L or S
Receiving station or relay	Weilheim + DSN	Flyby Module
Payload		
Responsibility	ESA-CNES-Intercosmos	ESA-CNES-Intercosmos
Number of experiments	12	4+8
Mass, kg	135	4+4
Maximum power, W	185	12+15
Maximum data rate, bit/s	4096	64+64
Operation at max. data rate, h	2/flyby	1
Data storage, Mbyte	256	0.5+0.5

* The parameter values quoted are typical figures; more accurate information will be available on completion of the Phase-A study, but the definitive figures must await the final payload- and trajectory-selection decisions. The payload of the Approach Module is distributed between the two penetrators.

modules are given in Table 2. The first category forms the core payload and consists of instruments that are absolutely necessary to the fulfilment of the basic objectives. The second category contains instruments that are presently included in the model payload, but whose presence relies on the confirmation of the resources quoted in Table 1. The third category consists of very valuable instruments that could possibly be included in the model payload during the course of the Phase-A study if additional resources can be identified, and provided their technical feasibility can be demonstrated.

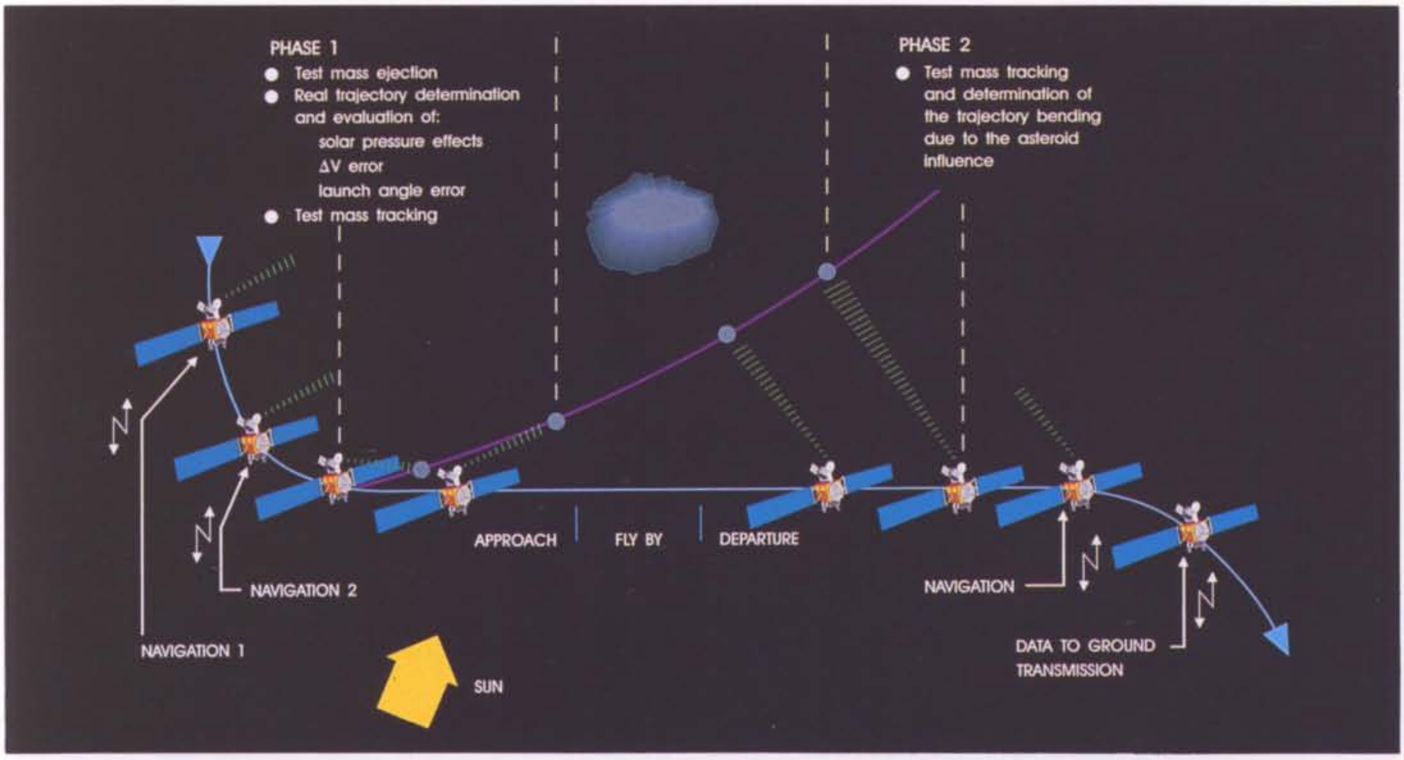
It must be emphasised that the payload presented in Table 2 is a model only, and that the decision on the composition of the final instrument complement rests with the trilateral ESA-CNES-Intercosmos Selection Committee.

Missions and measurements

The spacecraft will follow each other, a few weeks apart, on trajectories that will first bring them into the vicinity of Mars. The gravitational pull of this planet will change their orbits in such a way that they may subsequently fly within less than 2000 km of a number of small bodies. Some mission scenarios might even include more than one Mars gravity-assist, as illustrated in Figure 3.

It is planned to take advantage of this flexibility to explore as large and as representative a sample of asteroids as possible. The minor planets can be divided into several categories based on their orbital parameters and their spectral characteristics, i.e. their colours, e.g. type-C (carbonaceous), type-M (metallic), type-S (silicaceous), etc. It is also intended to complement the information obtained from the Halley flybys by visiting one or two comets with activities 10 to 100 times weaker. This will both facilitate observation of the nuclei, and reduce the risk of early mission termination by dust-particle impacts.

Figure 4 — Asteroid mass measurement with the test-mass experiment



General characteristics

The shape, dimensions and volume of the small bodies, as well as their period, axis and sense of rotation, will be determined with the visible imaging system. This instrument consists of a low- and a high-resolution camera, which can detect features with dimensions of 110 m and 8 m, respectively, from a distance of 500 km. Several techniques are envisaged for measuring the masses of the bodies, depending their size:

- careful tracking, with cameras and radar, of the trajectory of a test mass ejected from the flyby module and targetted at the small body, according to the scenario described in Figure 4;
- direct measurement of the gravitational field with the gravimeter carried by one of the penetrators;
- monitoring from Earth of the perturbation induced in the velocity of the spacecraft by the small body.

Surface features

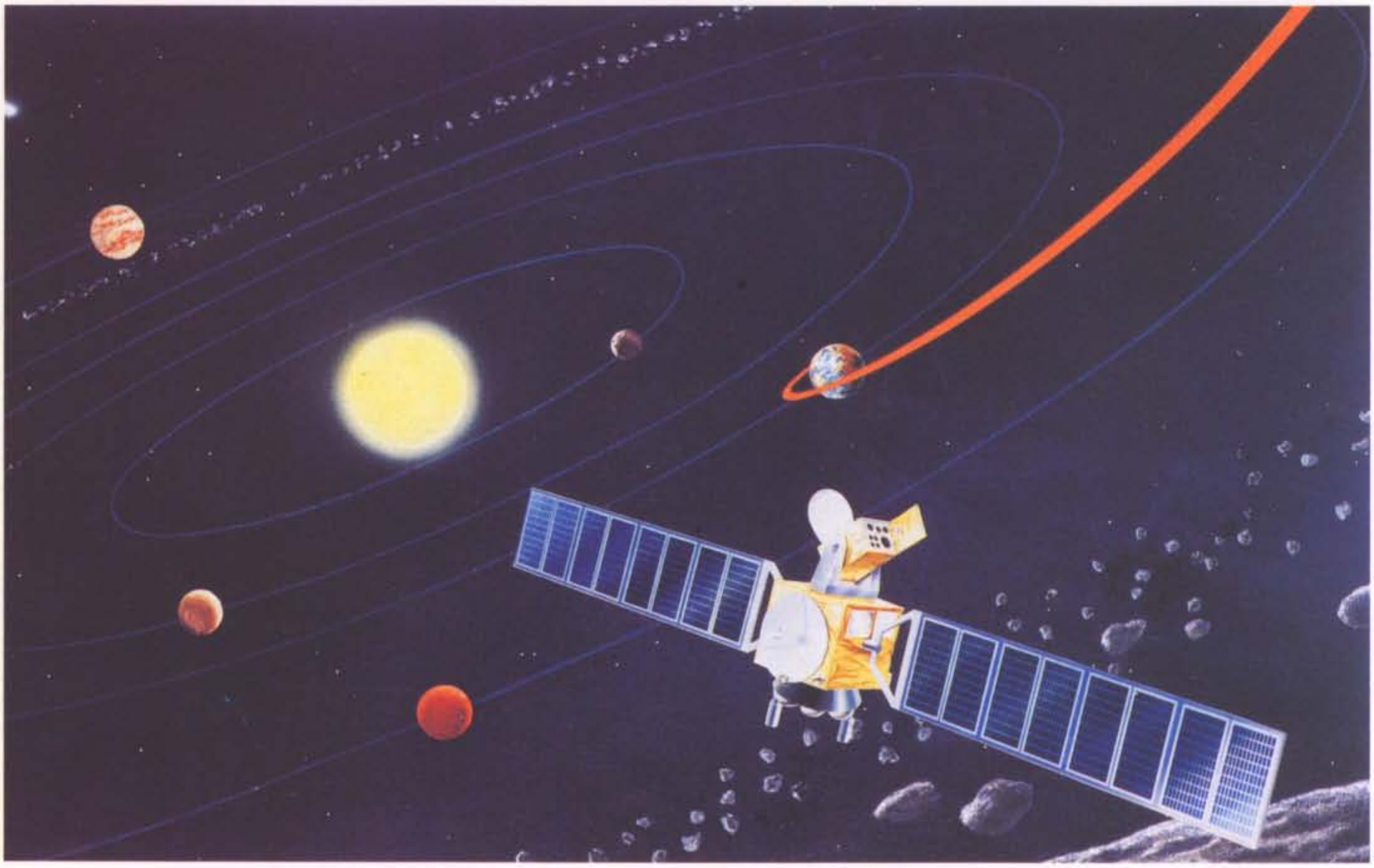
The histories of bodies without atmospheres are probably dominated by meteorite impacts. It is therefore of interest to study the properties of the

Table 2 — Candidate instruments, in order of priority, forming the scientific payloads of the Flyby and Approach Modules

Flyby Module	Approach Module
Category 1	
Imaging system*	Gamma-ray spectrometer
Infrared spectrometer*	X-ray spectrometer
Altimeter-radiometer radar*	Alpha-backscatter instrument
Low-energy ion mass analyser	Accelerometer-seismometer
Dust-environment monitor	Complex permittivity meter
Dust mass-spectrometer	Magnetic-material detector
	Magnetometer
	Gravimeter
	Thermal probe array
Category 2	
Test-mass experiment	Television camera
Magnetometer	
Plasma-wave analyser	
Electron analyser	
Energetic-ion telescope	
Cosmic-ray detector	
Category 3	
Photo-polarimeter*	Gas chromatograph
Gamma-ray burst detector	Neutron detector
X-ray spectrometer	
Neutral mass spectrometer*	
Ultraviolet spectrometer*	
Stellar seismology experiment	

* Instruments mounted on scanning platform

Figure 5 — Artist's impression of the Vesta mission



craters (depth, diameter, number density and size distribution) via complete mapping with the cameras and the radar altimeter. The small-scale structure will likewise be obtained from radar, and possibly photopolarimeter measurements, or observed in-situ with the camera carried by one of the penetrators.

Properties of the topsoil
The mineralogical composition of the surface material will be analysed from the flyby vehicle by infrared and ultraviolet imaging and dust mass-spectrometry. It can also be analysed in-situ with the chemical package (gamma- and X-ray spectrometers, alpha-backscatter instrument), and with the neutron detector. The soil cohesion will be measured with an accelerometer-seismometer on both penetrators at the times of impact. These observations will be complemented with in-situ measurements of the thermal, electrical and magnetic properties of the topsoil and, possibly, measurement of the composition of volatiles with a gas-chromatograph.

The environment
The studies of the environment of the small bodies will include:
- detection of dust particles in the range 10^{-10} – 10^{-16} g with the dust-impact monitor and, to some extent, the photo-polarimeter;
- measurement of the chemical composition of the gases released by the asteroid or the cometary nucleus with the neutral and ion mass analysers;
- analysis of the interaction of the cometary environment with the solar wind* using the magnetometer, the plasma-wave analyser, and the ion and electron detectors.

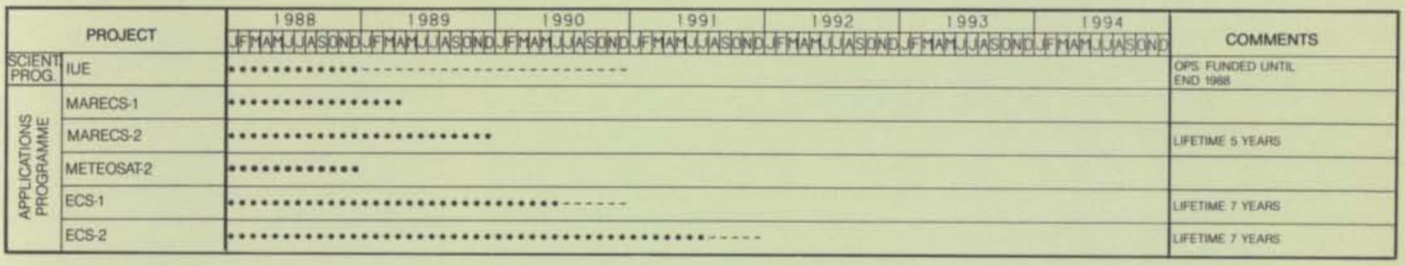
* The solar wind is a tenuous plasma that blows away from the Sun with a velocity of the order of 400 km/s at 1 AU. A plasma is a mixture of negative charges (electrons) and positively charged atoms or molecules (ions).

Cruise and Mars science
It will also be possible to carry out remote observations of the Martian surface and environment during the flybys of this planet, using essentially the same techniques as for the small bodies.

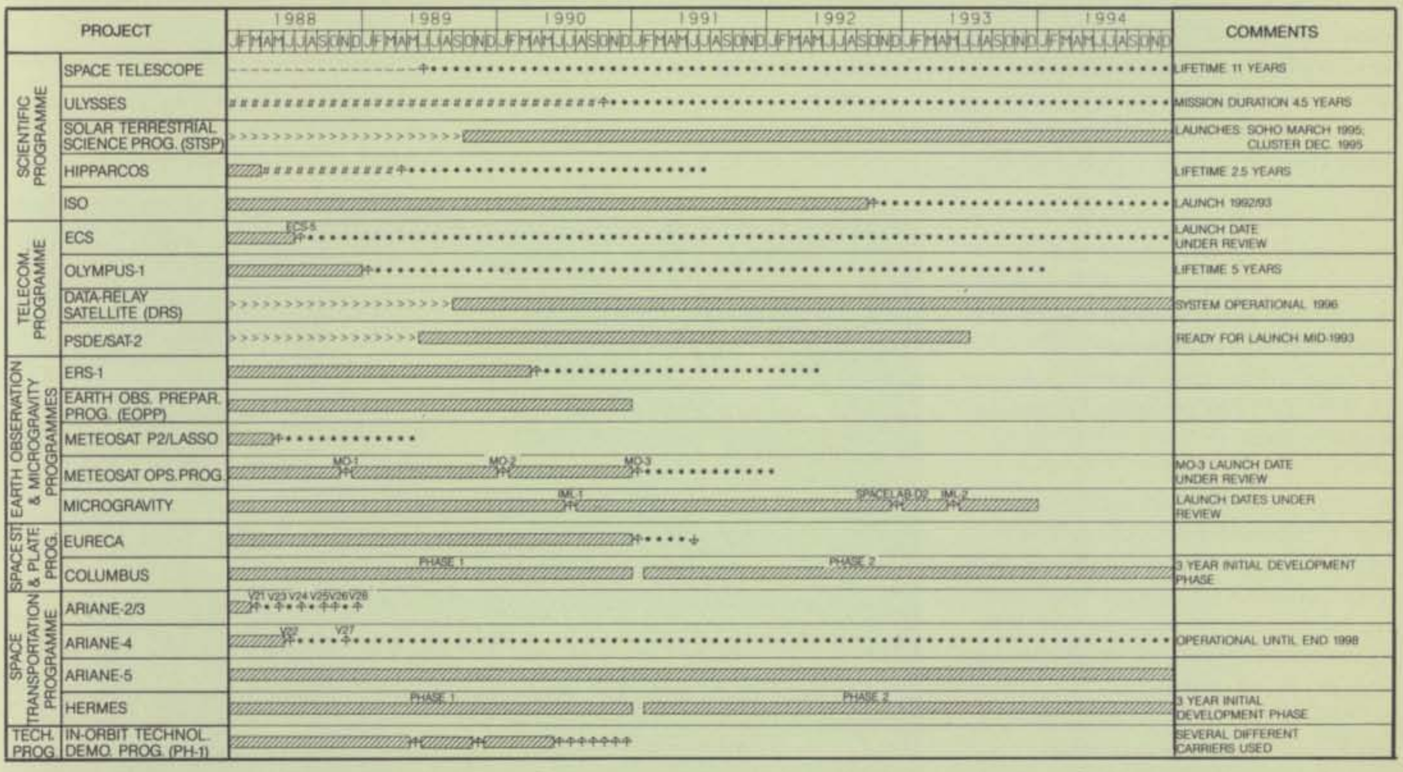
Additional objectives are being considered for the cruise phases, in the interplanetary medium, from Earth to Mars and from Mars to the small bodies at solar distances varying from 1 to 3 AU. Topics of interest are, for example, micrometeorites, the zodiacal light, the solar wind, gamma-ray bursts and stellar oscillations.

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

In Orbit / En orbite



Under Development / En cours de réalisation



= DEFINITION PHASE
~ INTEGRATION
> PREPARATORY PHASE
LAUNCH/READY FOR LAUNCH
▨ MAIN DEVELOPMENT PHASE
• OPERATIONS
\# STORAGE
\- ADDITIONAL LIFE POSSIBLE
HARDWARE DELIVERIES
RETRIEVAL

IUE

The International Ultraviolet Explorer (IUE) spacecraft celebrated its tenth year in orbit on 26 January 1988 and continues to operate well. A Call for Proposals for the 11th year of IUE observing, issued in the middle of 1987, was again three times oversubscribed. In fact, the demand for observing time in the 11th year is 8% higher than for the 10th round. Clearly, IUE is still a very important facility for the Astrophysics and Solar System community.

The spacecraft has not developed any new problems since the previous reporting period. The problem with the third electrode of battery 1 reported earlier has had only a minor impact on operations. The main effect is that power neutral conditions should be avoided. The batteries are slowly losing capacity when not used. The solar-array output has maintained its extremely low loss of efficiency at 1—2% per year.
The spacecraft slewing accuracy under two-gyro Fine Sun Sensor (FSS) attitude control remains excellent. The development of the back-up one-gyro system is proceeding according to schedule, with successful turn-on and checkout of Fine Error Sensor (FES) 1. The recovery procedures needed in the case of attitude loss with the two-gyro system have been fully tested and are already operational. FES 2 (i.e. the normal operational camera) is still losing sensitivity due partly to fatigue in the heavily used reference point. Definition of a new reference point is therefore under consideration as a high-priority item.

The archive of low-resolution data is being made available online throughout Europe, and also elsewhere. Distribution of the User-Support Software Package/Uniform Low-Dispersion Archive (USSP/ULDA) was completed at the end of March 1988.

In honour of IUE's tenth anniversary in orbit, a celebratory NASA/ESA/SERC Symposium was held at Goddard Space Flight Center on 12-15 April 1988. The Proceedings will be available from ESA Publications Division as ESA SP-281 (two volumes) in July 1988.

The lifetime of the IUE spacecraft, barring a major failure, is still predicted to extend well beyond 1990.

Space Telescope

The two flight solar-array wings which were returned to Europe at the beginning of the year are about to be modified to increase their power outputs and to protect them against the effects of atomic oxygen. The first of the new solar-array blankets is undergoing final inspection prior to fitting. The solar-array wings will be redelivered in early 1989 and, if the present launch date of 1 June 1989 for Space Telescope is maintained, will have to be refitted at Kennedy Space Center (KSC).

The Faint-Object Camera (FOC) will be removed from Space Telescope in July 1988 for minor reworking to improve scientific performance in the spectrographic and coronographic operating modes.

STSP

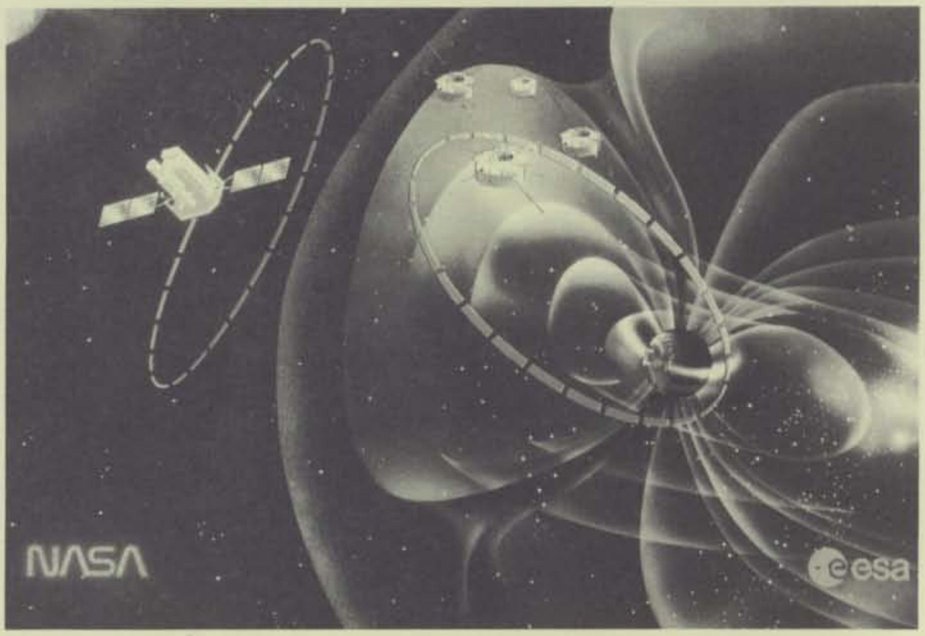
The Solar-Terrestrial Science Programme (Cluster and Soho) successfully achieved a major milestone in March 1988 with the selection of the onboard scientific instrumentation.

The investigation proposals, received from the European and American science communities in mid-1987, were subjected to a joint ESA/NASA evaluation and recommendation for selection. Formal approval for the payload complement (a total of 23 investigations; 11 for Cluster and 12 for Soho) was provided by the ESA Science Programme Committee (SPC) and the NASA Associate Administrator for Space Science and Applications.

Following this payload-complement approval, technical kick-off meetings have been held with teams representing each investigation. The technical-interface data derived and agreed at these meetings will be used as the basic source requirement for the ESA Industrial Invitation to Tender (ITT). This initial tendering action is for selection of System Prime Contractor(s) for the procurement of the Cluster and Soho spacecraft. It is scheduled for release in October 1988, following publication of an 'Advance Notification' in July 1988. Industrial proposals are requested for February 1989. Following evaluation/negotiation, Phase-B work is expected to start in October 1989.

The STSP Principal Investigators are holding their first Science Working Team (SWT) Meeting at the end of June 1988, and this will mark a major step in the interaction between the ESA/NASA project groups and the community of selected scientists.

Artist's impression of the Soho and Cluster spacecraft that will take part in the Solar-Terrestrial Science Programme (STSP)

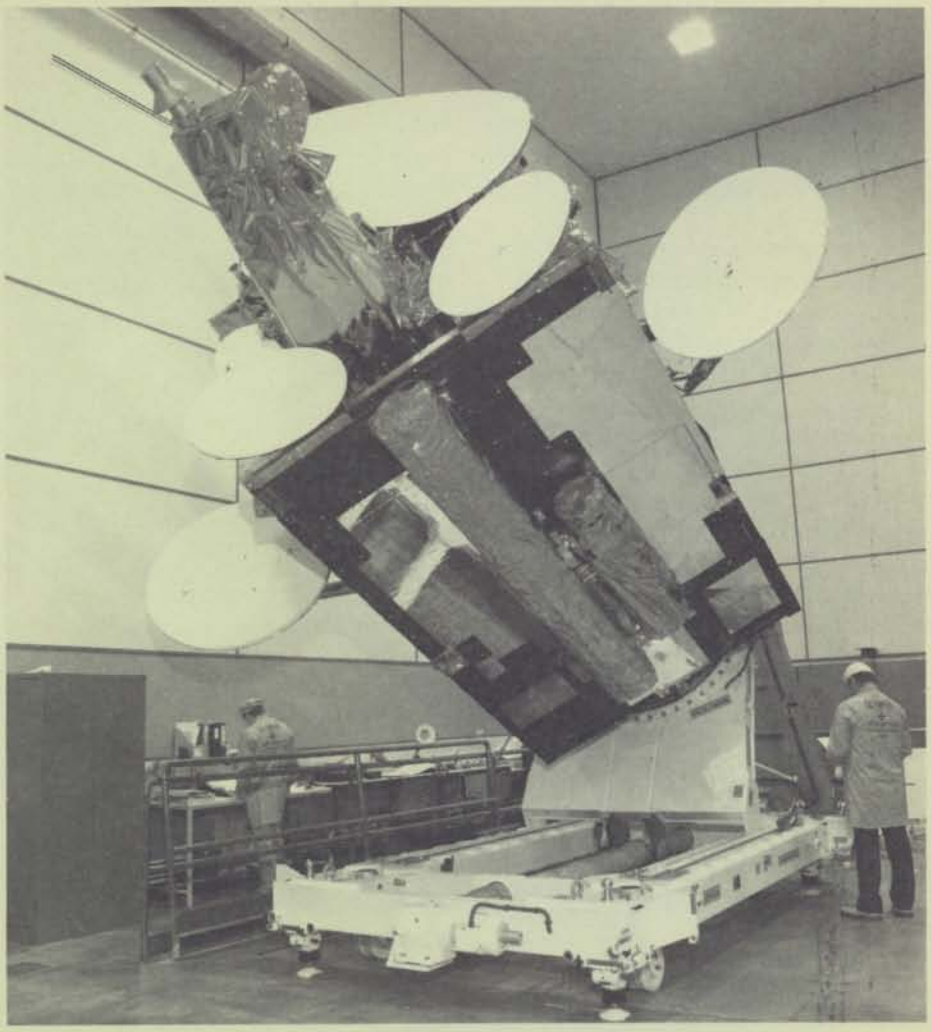


Hipparcos

Thermal-vacuum testing of the Proto-Flight Model (PFM) satellite in ESTEC's Large Space Simulator facility during March and April 1988 was the final environmental test in the satellite's acceptance-testing programme. Testing was successful, the only incident of note being the failure of one baffle cover to latch immediately after deployment. The fault has been identified and modifications are being introduced to eliminate it. Following test completion, a final Integrated System Test (IST) was performed in ambient conditions, and the satellite was then transported to Aeritalia, Turin, for post-acceptance testing activities and storage.

The satellite Flight Acceptance Review was held in mid-April as planned. The Review Board, whilst finding the acceptance testing status satisfactory, indicated three areas of concern requiring investigation and closure during the satellite storage period: the baffle cover latching (above) and unitrode diode and Deutch relay problems (reported earlier), both component types being the subject of investigation throughout the space industry.

The PFM satellite is currently in storage configuration inside its transport container at Aeritalia. Certain units requiring particular storage environments, e.g. batteries and gyros, have been removed and returned to their suppliers for storage until satellite reactivation commences at the end of this year.



Olympus thermal-model spacecraft, photographed at British Aerospace

Olympus

System level testing of the flight-model spacecraft continues on schedule in Ottawa (Canada). Electrical testing, consisting of the Integrated System Test (IST), the RF System Test and the Special Performance Test (SPT), was completed during April and May and the respective test Review Boards have been held with satisfactory results. The Test Readiness Review (TRR), conducted by the Agency to review these results and to check overall readiness for the start of spacecraft environmental testing, was held on 26 April 1988 and approval given to commence testing.

The first phase of environmental testing was a vibration test with excitation in the three principal axes, followed by an acoustic test. For both these tests, the propulsion tanks were filled with simulated propellants. Preparations are now being made for the second test phase, the major part of which is a thermal-vacuum test. The solar arrays have been removed for this activity and will be tested separately.

The test-measurement earth stations TMS-4 and TMS-5 to be used after launch are being integrated into the Redu (Belgium) in-orbit testing system. The first of the test demonstration earth stations (TDS-4) is nearing completion, while testing of the three TDS-6 stations has proceeded according to plan. The TDS-5 telecommunications uplink station is nearly ready.

PSDE

Sat-2

The Sat-2 advanced communications technology mission is proceeding as planned, with Phase-B of its development programme now in progress.

Sat-2 will provide a flight opportunity for high-technology communications payloads involving a significant development effort. The baseline payload configuration includes:

- an optical communications package
- a high-gain S-band data-relay service
- a land mobile payload combined with a navigation package
- an onboard-processing payload
- millimetre-wavelength communication
- a high-frequency propagation experiment
- spacecraft-technology experiments.

As the emphasis is on the development of the payloads, it is intended to use an existing spacecraft platform for this mission. Three Phase-B1 studies are therefore in progress to analyse the accommodation of the payloads on European platforms of half-Ariane class — Eurostar, Spacebus and Italsat — and to define detailed interfaces between payloads and platforms.

It is anticipated that on completion of the Phase-B1 studies in October, there will be a regrouping of industrial partners to match the level of funding declared by the various potential participants.

Phase-B1 studies for most payloads will also begin shortly, with the objectives of defining the payload in greater detail and assessing critical technology. The optical payload, which technologically is the most demanding, is now entering its Phase-B2, which will involve hardware procurement and breadboarding activities.

The next six months will be a formative phase for the project, during which enhanced definition of the mission options is expected, in order to make a final selection of payloads before commencing Phase-B2 spacecraft studies.

ERS

After delays in the delivery of the Engineering Model (EM) instruments, integration of the EM payload was resumed in May 1988. The forecast for completion of the EM payload tests is early 1989.

Integration of the EM payload and Flight Model (FM) platform will allow the Flight/Engineering Model (F/EM) satellite tests (functional, electromagnetic and radio-frequency compatibility) to be completed in the third quarter of 1989.

In parallel with these tests, integration of the FM payload is scheduled to reach full momentum by the end of this year, leading to finalisation of FM payload tests in the third quarter of 1989.

Following integration and testing of the FM satellite, the Flight Acceptance Review is scheduled to take place by the end of January 1990, with launch-readiness foreseen in May 1990, in accordance with the launch slot in the latest Ariane manifest. Development of the online ground segment is compatible with this schedule.

The first plenary meeting of the Principal Investigators (PIs) selected as a result of the ERS-1 Announcement of Opportunity was held at ESRIN, Frascati, on 2—5 May 1988. More than one hundred PIs attended this very successful meeting, once again demonstrating the strong interest in the mission.

Earthnet

Landsat
Landsat-5 is performing nominally, with the stations of Fucino and Kiruna acquiring data and generating products for users on request throughout the reporting period.

MOS-1
MOS-1 data are being regularly acquired at the Fucino, Kiruna, Maspalomas and Tromsø stations. The product-generation software is under development and is still expected to be completed by October 1988.

Tiros
Both the spacecraft and acquisition stations have been performing normally. ESA standard digital products generated at Maspalomas are being distributed on a regular basis. Agreement has been reached with DFVLR (Germany) regarding their contribution to the central archive of data acquired at Oberpfaffenhofen.

The Archiving Reference Station has been delivered and installed in Frascati. The equipment for Maspalomas and Tromsø has been shipped to the stations for installation.

Earthnet ERS-1 Central Facility (EECF)
The contract for Phase C/D of the ERS-1 Central User and Browse Services (CUS/BS) is presently under negotiation.

The Ground Reference System for the indexing of ERS-1 data (raw and processed) products in the CUS Catalogue has been defined, together with the cell size and numbering system. The work to define the Catalogue structure and benchmark testing of response time have begun.

ERS-1 Ground Stations
Procurement of the fast-delivery processing chains for the Gatineau (low bit rate), Maspalomas (low bit rate) and Fucino (synthetic-aperture radar) stations was started by MDA, Canada in mid-May. The first part of the work is mainly the detailed analysis of technical trade-offs related to key issues such as the hardware configurations and the transcription of raw low-bit-rate data onto optical disks for subsequent delivery to the Processing and Archiving Facilities (PAFs).

In this respect, intensive testing of optical-disk equipment and related software is being conducted at ESRIN (Italy) in cooperation with industry and the PAFs.

EOPP

The 'Aristoteles' solid-Earth mission
Since the approval of the mission's objectives and Phase-A content, extensive system-level trade-offs have been performed in the Pre-Phase-A and Phase-A studies of the Aristoteles mission by a European industrial team. The latter is led by Dornier System (D), and includes Matra, Onera, SAGEM, BGI (F) and British Aerospace (UK).

Taking into account the results of the technical trade-offs and related schedule, cost and risk, a baseline satellite concept was jointly chosen at the Phase-A Mid-Term Review in March 1988 by the Executive and the Gradiometry Working Group. The latter was established earlier this year to give scientific advice on the Aristoteles mission.

Second-generation Meteosat
In the last quarter, numerous technical coordination meetings have taken place between the Executive and Eumetsat and their consultants, to review the results of the EOPP studies on instrument and satellite aspects and prepare for the Mission Definition Workshop.

This Workshop, organised jointly by ESA and Eumetsat, was held in Bath on 2—6 May 1988. It was attended by some sixty leading members of the meteorological community. The results of the system-level studies and the instrument and technology studies were presented by the Executive, addressing visible and infrared imaging, infrared and microwave sounding and data circulation. These presentations were well received by the participants, and the Workshop has led to a refinement of the user and mission requirements for the Phase-A studies.

First polar-orbit mission
Recent activities have focussed on the definition of a mission and payload complement for the First Polar Mission Phase-A Study.

As foreseen in the EOPP Procurement Plan, the Executive proposes to place two parallel Phase-A study contracts with two industrial consortia, thereby maintaining competition for the Invitations To Tender for later phases of the Programme.

Following the proposal made during the May meeting of the Columbus Programme Board to study two alternative Polar-Platform concepts in parallel until the end of 1988, the EOPP activities in this area have had to be adjusted accordingly.

The first image received from the Meteosat-P2 spacecraft, at 13.30 GMT on 29 June 1988

Meteosat

Pre-operational programme
The highlight of recent weeks was the successful launch on 15 June of Ariane 401, carrying the Meteosat-P2 satellite as one of its three passengers.

Meteosat-P2's apogee boost motor was fired on 17 June, which took the satellite into near-synchronous orbit. Satellite control was handed over to the Meteosat Operations Control Centre (MOCC) at ESOC on 27 June, and the first image in the visible band was aquired on 29 June.

Meteosat-P2 was originally constructed as the qualification model for the pre-operational programme. Its objective is to bridge the gap until the availability of the first operational spacecraft MOP-1, presently scheduled for launch at the end of 1988. Constrained by minimum-cost considerations in view of its limited role, Meteosat-P2 has not been updated to full flight standards; it is nevertheless expected to fulfil its role more than adequately.

The P2 spacecraft also carries the LASSO experiment for international clock synchronisation. An onboard electronic package will detect and time-tag the arrival of monochromatic pulses of light fired towards the spacecraft from ground-based laser stations. The differences between the clocks that provide the time references for each of the laser stations can be deduced from the recorded times of laser firing and reception events at the various stations.

Operational programme
The manufacture and testing of the three MOP spacecraft and work on the refurbishment and improvement of the existing ground segment is progressing towards readiness in time for the launch of the first of the series, MOP-1, at the end of this year.

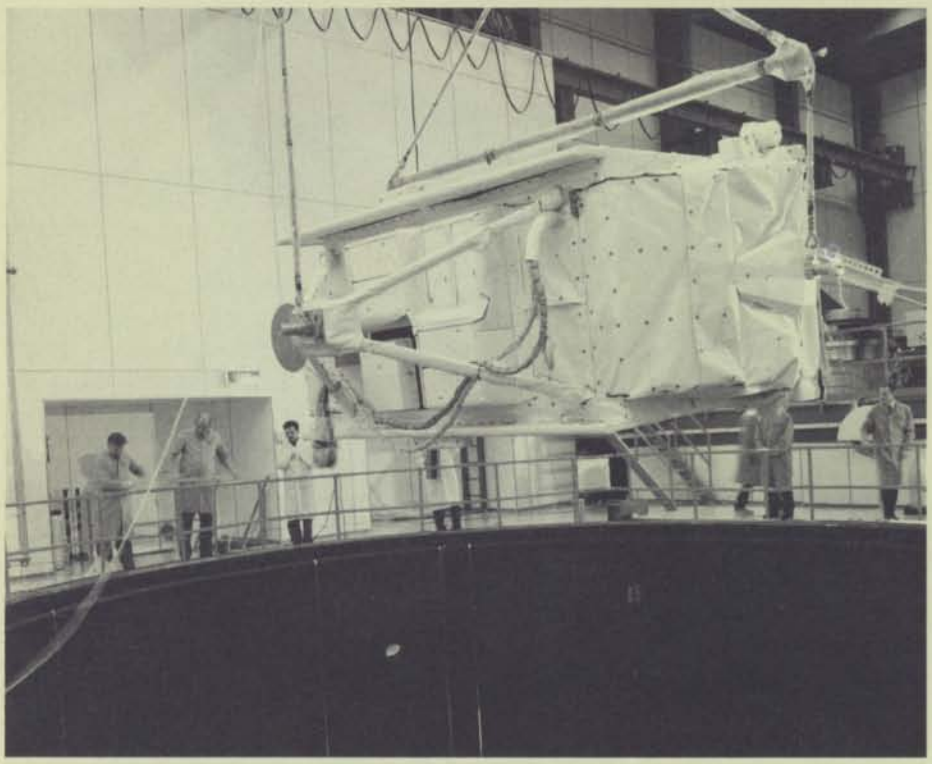
Eureca

The design-related part of the Eureca Qualification Review was completed in May. This review did not detect any inherent weaknesses in the Eureca design. The project is, however, still endeavouring to resolve some qualification problems with the battery and attitude-control subsystems. The overall thermal design is also causing concern, due to delays in thermal-model testing. Preparations for this test are now proceeding at ESTEC and test completion is planned for the first week of July.

Flight-model integration of the propulsion and attitude-control subsystems at SNIA/BPD, in Colleferro, Italy, is proceeding well and delivery to MBB/ERNO (Germany) is now planned for November 1988.

All Eureca payload instruments, except the Solution-Growth Facility, have completed engineering-model interface testing, and flight-model delivery to MBB/ERNO will commence from September 1988 onwards. Installation of the engineering-model instruments at the Microgravity Support Centre, at DFVLR in Porz Wahn, Germany, has already begun.

Eureca is still scheduled for launch in January 1991.



Eureca thermal model under test in the Large Space Simulator (LSS) at ESTEC, in June 1988

ESA has authorised the Columbus industrial consortium to perform essential Phase-C/D tasks. An industrial proposal covering Phase-C/D preparatory tasks lasting approximately one year, until mid-1989, was received in mid-May and is currently under negotiation with industry. Studies of the two Polar-Platform concepts mentioned above will be added to the scope of the contract.

In parallel with the above activities, the Columbus project has supported the ESA/CNES evaluation of new Hermes reference configurations. At the interface to the International Space Station ESA has also intensified interface requirements definition for the Attached Pressurised Module (APM) and the Man-Tended Free Flyer (MTFF). A number of bilateral meetings with NASA have been held, addressing in particular nine priority-1 issues that require resolution prior to the final placing of the Phase-C/D contract with industry. Agreement has been reached with NASA to carry out a joint utilisation study for the elements of the Main Station, which should lead to a better understanding of the outfitting of the Station as a whole and will also investigate the degree to which rack and payload exchangeability between modules will be feasible.

APM and MTFF utilisation studies managed by DFVLR have been completed. These studies have helped to clarify user requirements in terms of resources, interfaces and overall element outfitting, and their results will now be used as inputs to the forthcoming Phase-C/D activities. As an important byproduct of these study activities, a Columbus Payload Database has been created, which will henceforth be available to contractors involved in Columbus element design, operation and utilisation.

Microgravity

The Microgravity Programme has recently been given the go-ahead for extension of the Phase-2 Programme. The main objectives of this extension are: to bridge the gap in flight opportunities caused by the 'Challenger' accident by using Shuttle-independent flight opportunities; and to maintain the interest and safeguard the competence of the European microgravity science communities.

The Phase-2 extension will last until 1991 and will cover:
- Mini-missions
  - drop-tower experiments
  - parabolic aircraft flights
  - sounding rockets — Texus, Messer, Microba
- Future studies for both Columbus and non-Columbus flight opportunities
- Phase-B studies
  - large protein crystal facility
  - vapour growth facility
  - liquid structure facility
- Payloads for Spacelab-independent flight opportunities
- Mission costs.

In the meantime, work is continuing on the ongoing activities within the Phase-2 Programme. Launch of NASA's International Microgravity Laboratory (IML-1) has been brought forward from April 1991 to mid-1990, necessitating a replanning of work in Europe. The effect of the new NASA requirements on structural loads and the verification approach is being studied by industry and solutions are being sought that will minimise the cost, schedule and mass impacts.

Two sounding rockets — Texus-17 and -18 with ESA payload participations of 60% and 23%, respectively — were launched successfully in May. Both payloads functioned nominally and the results of the experiments flown are now being evaluated.

Space Station/ Columbus

Based on the results of in-house studies conducted at the beginning of the year, ESA presented a concept for a non-serviced Polar Platform to the Columbus Programme Board in May. The Agency will now continue with two parallel studies, one based on an ESA-conceived version and one based on a concept proposed by the French Delegation. Final selection is expected around the end of the year.

The United Kingdom submitted a formal application to subscribe to the Columbus Programme at a 5.5% contribution level. This was accepted at the occasion of the June Council meeting.

A full-scale mockup of the Attached Pressurised Module has been set up at ESTEC, which will be used to verify the envisaged man/machine interfaces and to test the proposed system/payload interfaces. Prototype versions of the Module Control Station and a General-Purpose Workbench will be the first elements to be installed.

In parallel, Phase-1 (1988—1990) has been prepared, the Request for Quotation for spaceplane definition has been issued, and the technology-development programme started. One important step in this preparation was the presentation to the Agency's Industrial Policy Committee (IPC) of the industrial structure foreseen for the development phase.

Hermes

The Hermes Preparatory Programme has ended with the review of the documentation submitted by industry for the spaceplane Phase-B3.

This review has shown that, despite the weight-reduction efforts undertaken, the take-off and landing weights of the spaceplane still exceed the specified limits.

To recover an acceptable margin, modified configurations are being studied. These are based on the Phase-B subsystem definition and on detailed parametric analysis of the major spaceplane dimensions and performances. Several promising concepts have already been identified, and these will now be compared taking into account the Columbus servicing-mission requirements.

Ariane

Ariane-5

Démarrage des essais sous-système du moteur HM60

Le programme préparatoire au développement du moteur HM60 avait pour principal objectif de réaliser les premiers exemplaires des matériels constitutifs du moteur afin de procéder aux premiers essais dès le début du programme de développement. Cet objectif est aujourd'hui atteint puisque les quatre principaux sous-systèmes sont intégrés sur les différents bancs et que certaines campagnes d'essais sont démarrées. On présente ci-après l'avancement de ces essais.

La chambre propulsive

La recette des circuits hydrauliques du nouveau banc de la chambre propulsive (situé au DFVLR à Lampoldhausen) a eu lieu, ce qui a permis d'affectuer courant mai, les premiers essais nécessaires à la définition de la séquence d'allumage. Le premier essai à feu est maintenant programmé en août, dès que le système informatique du banc sera complètement opérationnel. D'autre part plusieurs campagnes d'essais sur une chambre propulsive, à échelle réduite, ont validé la conception de l'injecteur, du corps de chambre regénératif et du divergent.

La turbopompe oxygène liquide

L'exemplaire no 1 de la turbopompe oxygène est à présent intégré sur le banc situé chez MBB à Ottobrun. La revue avant essais vient d'autoriser le début de la campagne d'essai en azote liquide, l'emploi de l'oxygène liquide sera décidé au vu des premiers résultats.

Les essais de roulements et de joints dynamiques, composants critiques de cette turbopompe, sont en cours et l'amélioration des caractéristiques hydrauliques de la pompe se poursuit à l'aide d'essais en similitude.

La turbopompe hydrogène liquide

La première campagne d'essais de la turbopompe hydrogène a débuté le 5 mai, à la SEP-VERNON, par un essai de mise en froid qui s'est déroulé conformément aux prévisions. Le deuxième essai, le 19 mai, a confirmé le bon comportement de la turbopompe et du banc d'essai lors de la phase de mise en froid ce qui permet de programmer les premiers essais de rotation avant la fin du mois de juin. Le système informatique de traitement des données d'essai est en place, et donne entière satisfaction aux utilisateurs.

Le générateur de gaz

Après les essais sur une chambre à échelle réduite qui ont permis de choisir la configuration de l'élément d'injection, le développement du générateur de gaz se poursuit aujourd'hui en grandeur nature.

Les premiers essais à feu, ont eu lieu. La campagne continue donc avec le même exemplaire, l'objectif étant de porter la durée de chaque essai à 100 s.

Mock-up of the Space-Station Attached Pressurised Module (APM) at ESTEC

TDP

Common Support Subsystems

Hitchhiker-G Simulator
The contract for the industrialisation of the prototype developed at ESTEC has been placed. The first operational unit will be required for the Attitude Sensor Package experiment. It will be used to simulate the Space Shuttle avionics during experiment integration and once in orbit to communicate with the experiment.

Payload Control Unit
Phase-1 of the contract has been completed with a successful Design Review. The complete design has been approved by ESA and the recurrent cost of the unit has been fixed. Phase-2 of the contract, to manufacture a prototype, has started. The industrialisation of flight units will proceed after Phase-2.

Experiments

Gallium-Arsenide (GaAs) Solar Array: Large quantities of solar cells have already been manufactured. Work has been accelerated to take advantage of early flight opportunities, possibly in 1989.

Attitude-Sensor Package: Work is progressing on this package, including the Infrared Earth Sensor, Modular Star Sensor, and Yaw Earth Sensor. The optical design of the Infrared Earth Sensor has been completed, as well as the observation-scheme definitions for all the sensors. This experiment will make use of both the Common Support Subsystems developed.

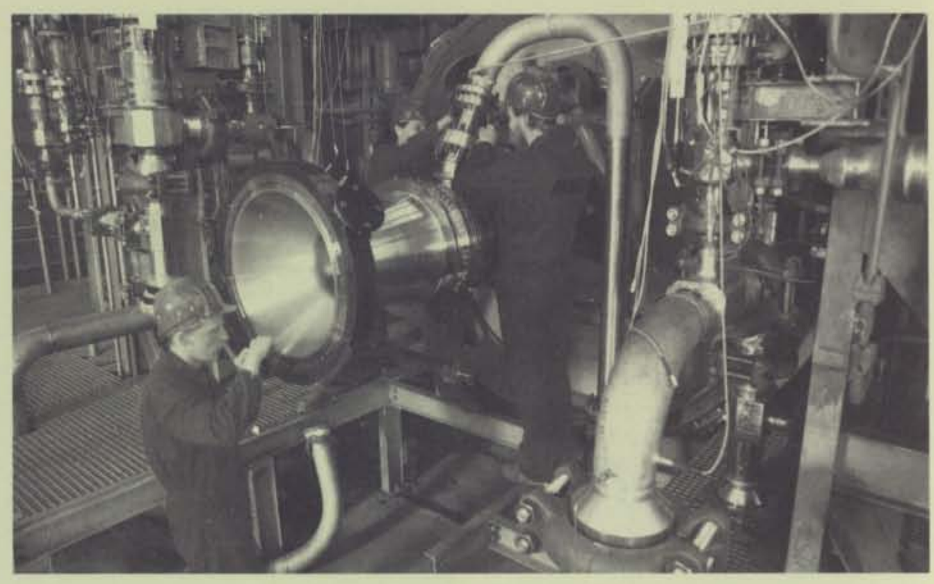
Solid-State Micro-Accelerometer: The Preliminary Design Review has been successfully completed at the beginning of July, and hardware manufacture can now start.

Collapsible-Tube Mast and Heat-Pipe Radiator: Several proposals are currently under evaluation.

Inflatable Space-Rigidised Antenna: The Invitation To Tender (ITT) is under review prior to being released.

Transputer and Single-Event Upset: The ITT has been released.

In-Space Aluminium Coating: The ITT has been released. Technical meetings have been held with the objective of simplifying the experiment and ensuring the utility of the technology to be demonstrated in-orbit.



An Ariane-5 'Vulcain' engine combustion chamber under test at DFVLR in Lampoldhausen, Germany

Liquid-Gauging Technology: The study to define the experiment has been completed and the ITT for experiment adaptation has been released. Work should start by the end of the year.

ESA/NASA cooperative experiments

International cooperation with NASA's Office of Aeronautics and Space Technology has been formalised, with an exchange of letters on a joint Phase-B for the two experiments proposed by ESA — In-Flight Contamination and Solar-Array Module Plasma Interaction. Both should be carried as passengers on the top of the Collapsible-Tube Mast on separate flights.

Discussions on further joint experiments with NASA have started.

Flight opportunities

The Final Safety Review for the Shuttle Get-Away Special experiment involving the Solid-State Microaccelerometer (G-21) is planned for the autumn. G-21 will then officially join the queue for a possible flight opportunity in the second half of 1989.

The Preliminary Safety Reviews for the Liquid-Gauging Technology (G-22) and In-Space Aluminium Coating (G-485) experiments are in preparation.

For the experiments using the Hitchhiker-G Carrier — Attitude-Sensor Package, Collapsible-Tube Mast and Heat-Pipe Radiator — manifesting is still pending. Although integration activities have started at the Johnson Space Center, NASA's pricing policy for Hitchhiker-G secondary payloads is still not finalised.

The agreement to fly the Inflatable Space-Rigidised Antenna on the USSR's MIR Space Station is still pending.

The Transputer and Single-Event Upset experiment will be carried by the University of Surrey's (UK) Uosat-C spacecraft, scheduled for launch on a Delta rocket in February 1989.

The selection of a small free-flyer satellite to carry the GaAs Solar-Array experiment is still in progress, but will be finalised this year.

In the context of looking together with the Ariane Department for further flight opportunities, an agreement has been reached with Arianespace for the launch of a 'Pathfinder Platform' carrying technology experiments next year. A general policy for dealing with Ariane secondary payloads is also under discussion with Arianespace.

In preparation for the next phase of the In-Orbit Technology Demonstration Programme, studies to define complex experiments will be awarded to industry this autumn. An Announcement of Opportunity for small experiments will be released in the summer.

The Computer Network and Data-Processing Systems at ESA's Villafranca Ground Station

D. de Pablo, ESA Computer Department, Villafranca, Spain

During the mid-seventies, a Control Centre was built at the Agency's Villafranca del Castillo ground station, near Madrid, to support the International Ultraviolet Explorer (IUE) Project. The ground segment was designed and dimensioned for an estimated project duration of three years, the satellite being launched in January 1978.

Today, after more than 10 years of successful IUE operation and data exploitation, the original concept of a devoted European Control and Data-Processing Centre has evolved into a larger infrastructure able to satisfy the needs of the Station and of a modern Observatory. The computer systems at Villafranca are integrated into the Agency's overall information system via data-network connections.

The IUE mission

The International Ultraviolet Explorer (IUE) satellite was developed to provide a general space-based facility for observing the spectra of astronomical objects in the wavelength range 1150 – 3200 Å. The project is a joint undertaking by NASA, the UK Science and Engineering Research Council and ESA. The satellite, which is in a geosynchronous orbit over the Atlantic Ocean is operated for 8 hours each day (for European observers) from the Villafranca Ground Station and for 16 hours per day from Goddard Space Flight Center (GSFC), near Washington DC.

IUE is operated in real time to offer the Guest Observer an environment similar to that found in ground-based observatories in terms of interaction with the scientific instruments (telescope, spectrographs and cameras). This interaction involves complex spacecraft operations which are accomplished by calling a series of operating procedures, each of which is designed to perform a particular function, such as rotating the spacecraft about one of its axes or reading an image from a camera.

First, one needs to move the spacecraft (i.e. the telescope) to point to the astronomical object of interest. This apparently simple manoeuvre in fact involves a series of complex procedures, because the spacecraft's motion is constrained by attitude-related factors such as the positions of the Sun, Moon

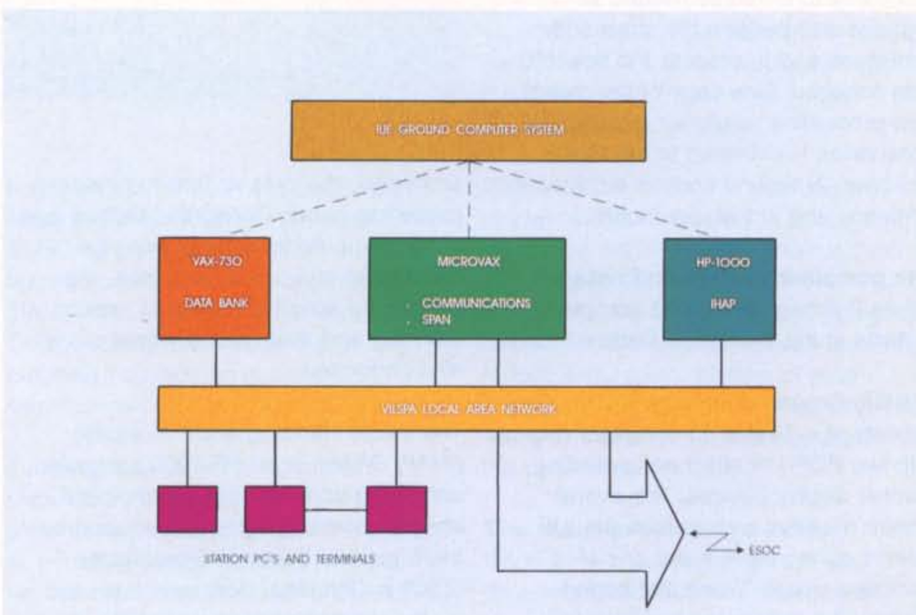


Figure 1 — The Villafranca computer systems

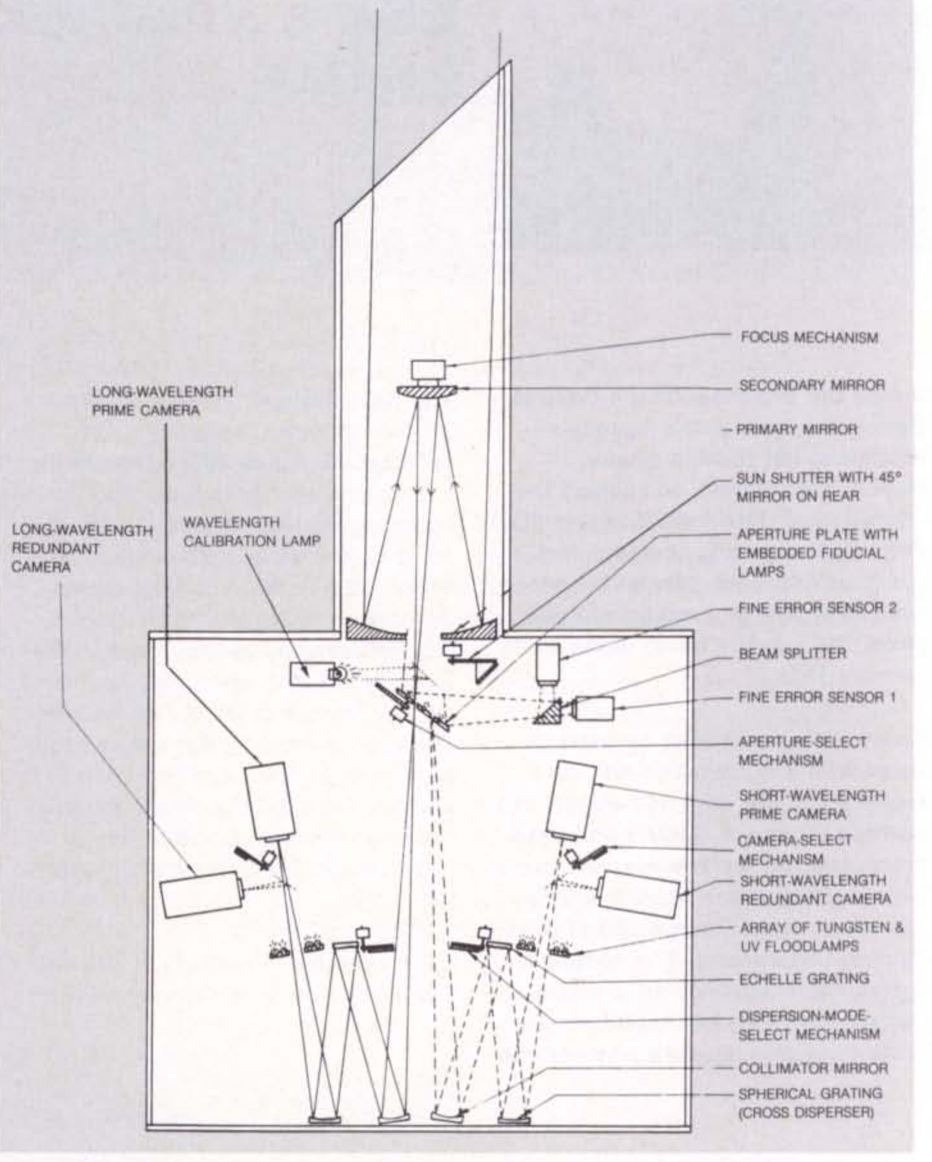


Figure 2 — The IUE scientific instrument

and Earth (pointing towards these objects could damage the cameras). The telescope's motion is also constrained by the physical limits of the onboard systems (power, temperature, state of reaction wheels, etc.), some of which are interrelated with the spacecraft's attitude. For instance, the power available to perform a certain manoeuvre depends on the angle of incidence of the Sun's radiation on the spacecraft's solar panels.

A schematic of the IUE scientific instrument is shown in Figure 1. The telescope directs the incoming ultraviolet radiation to one of the two spectrographs (long and short wavelength, respectively). A high or a low dispersion mode can be selected in both cases. Each of the spectrographs contains a prime and a redundant camera. During an exposure, an image of the spectrum of the astronomical object observed is integrated in the camera. A command function causes the image to be read and transmitted to ground, where it is reconstituted from the telemetry signal.

The IUE Control Centres — one at Villafranca, the other at GSFC in Maryland (USA) — contain the hardware and software elements needed to organise and perform the spacecraft operations and to process the scientific data acquired. One copy of the overall data-processing results for a particular observation is delivered to the Guest Observer. A second copy is archived for reference and further distribution.

The computer system and network

Figure 2 shows the various computer systems at the Villafranca Station:

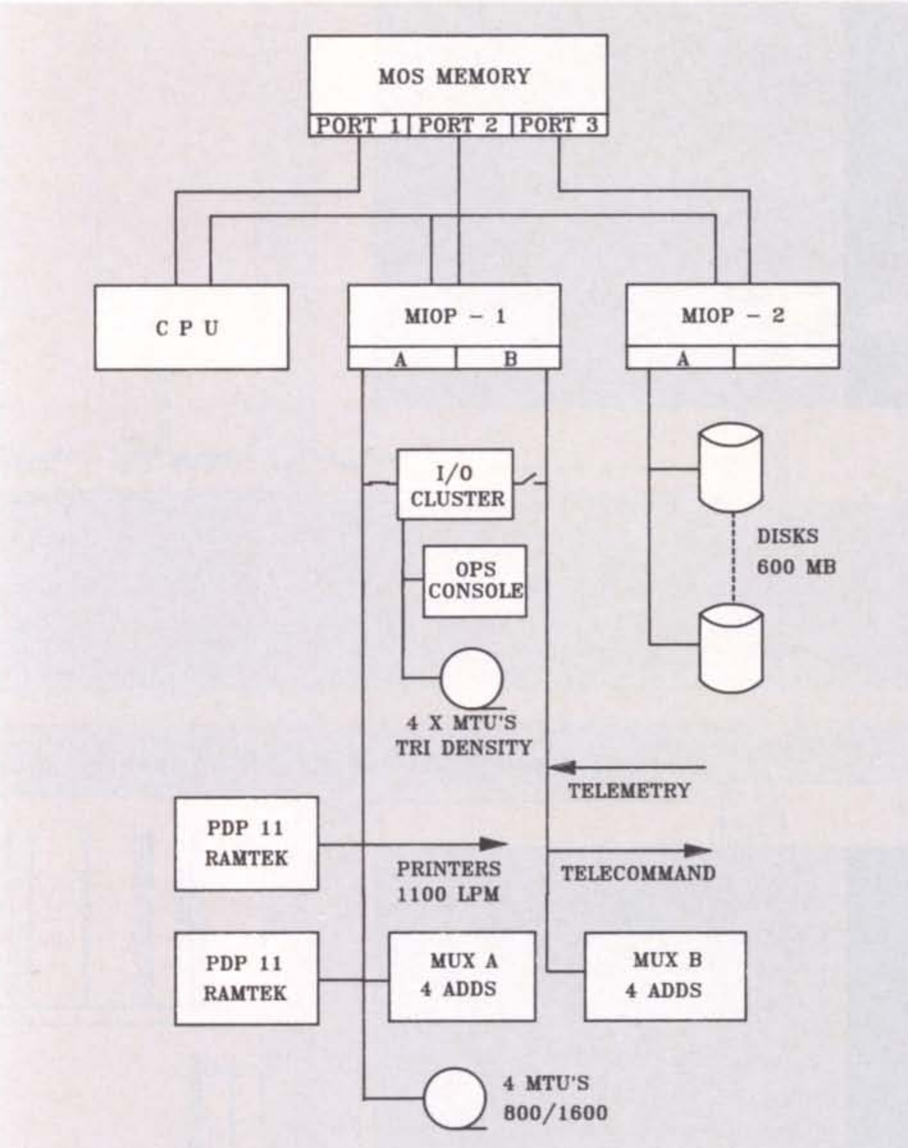
The *IUE Ground Computer System*: This consists of a Telefile 85 computer (Fig. 3) with two PDP-11s attached controlling Ramtek display devices. The overall system monitors and controls the IUE satellite during the 8 h per day of European usage. When that period finishes, the system is used for processing the data acquired during the preceding hours. During this second part of the computer day, apart from the usual tasks of a computer centre, the processing activities related to mission planning and data-bank operations are also performed.

The *Image Handling and Processing (IHAP) System* is an HP-1000 computer, containing an interactive astronomical image-processing system developed by the European Southern Observatory (ESO) in Garching, Germany. It is used by the resident astronomers at the station as a research tool.

The *Data Bank System* is based on a Vax 730 computer with a powerful data-base management system, which contains the IUE Data Bank and its application programs.

The *Communications System* is composed of a Microvax II computer used as the Station's SPAN (Space Physics Analysis Network) node, which is connected through permanent links to the European node at the Agency's European Space Operations Centre

Figure 3 — The Telefile computer system



(ESOC) in Darmstadt, Germany. This system is also the nucleus around which further SPAN nodes in Spain will be established. Linking of the Canary Islands' Instituto Astrofisico de Canarias to the network is also imminent. Currently, this Microvax also contains a subset of the Munich Image Data Analysis System (MIDAS) package, which is used as a research tool by the IUE Observatory.

The Telefile computer, which is responsible for controlling IUE, is a stand-alone configuration. All of the other computers are linked by a Local Area Network (LAN), which is connected, via ESOC, to the global ESANET, and to the Spanish packet-switching data network (IBERPAC). An attached Network Control Centre manages the incoming or outgoing connections to other ESA establishments and to external institutes.

Terminals and personal computers distributed throughout the Villafranca station allow users to work with the Vax or HP-1000 computers, and with the various systems connected to ESANET (PROFS, IRS, EARN, BITNET, etc.).

The spacecraft monitoring and control tasks

An extensive set of real-time processes are run on the Telefile and PDP-11 computers, which:

- perform the traditional satellite-control-centre functions, and
- interface with the scientific observers in a way that allows them to use the IUE telescope rather like a terrestrial telescope.

This last task implies the following sequence of activities: given the coordinates of the object to be observed, the orbital environment showing the pointing constraints (Sun, Moon and Earth) is displayed to the operator. A safe manoeuvre is then selected and commanded. Its development is monitored. When the target point is reached, the observer can use the satellite's Fine Error Sensor to obtain a quick-look image of the star field and thus confirm or refine spacecraft pointing (i.e. that of the telescope). The instruments are first commanded to begin camera exposure and then to relay the image data down to the station. The station software collects the data and stores it in a form suitable for subsequent processing.

The Telefile T-85 computer was selected in order to be compatible with the one used at NASA's Goddard Space Flight Center (a Xerox Sigma-5 computer, backed up by a Sigma-9).

The two PDP-11/Ramtek sets serve to display all the images taken during IUE operations and to analyse them without calling upon the resources of the main computer. This analysis covers histogram calculation and display, pseudo-colouring, reduction-mapping, plotting of pixel intensities across specified lines, etc. The scientific instrument is also operated from this subsystem.

The image-processing system

Once the 8 h spacecraft-control and data-acquisition shift has ended, the Computer Centre processes the payload

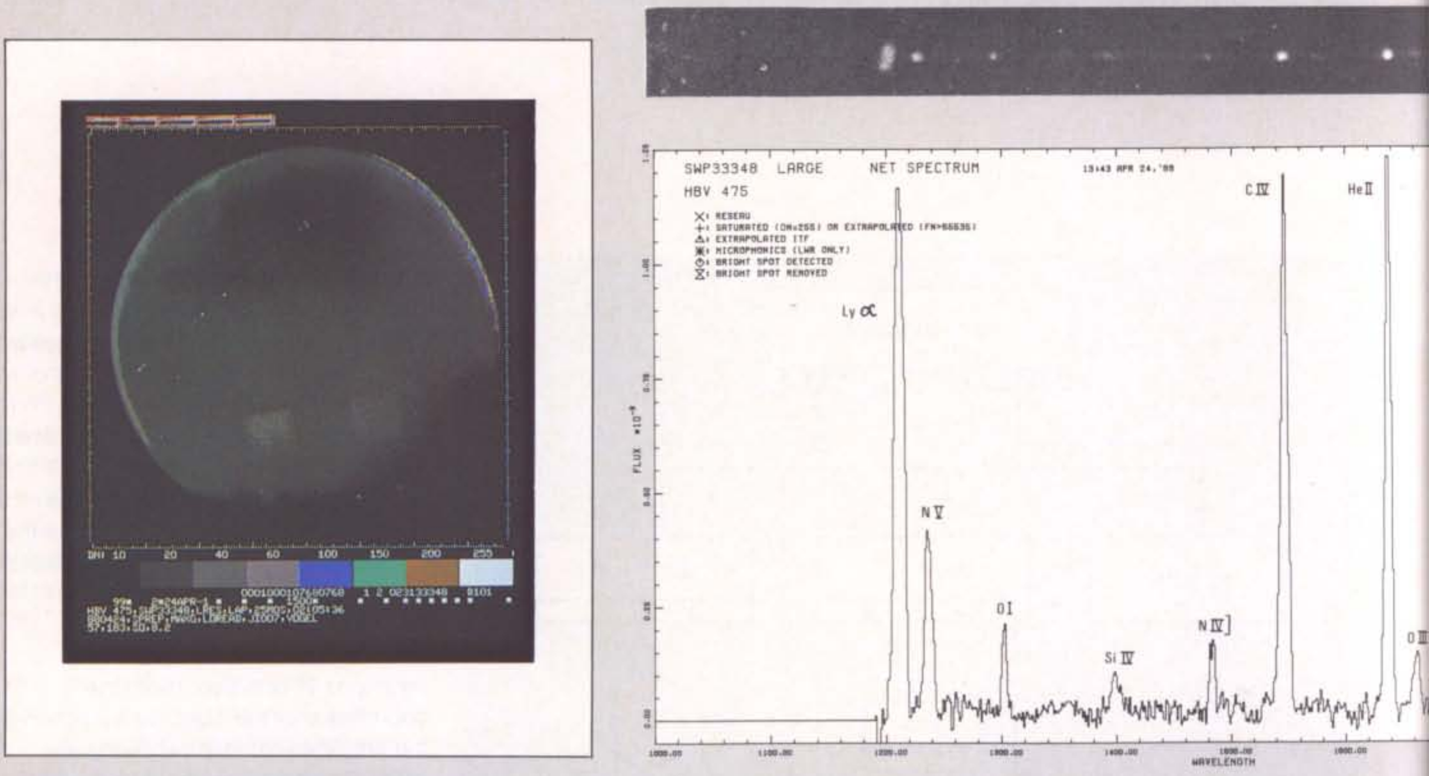


Figure 4 — Extraction of spectral data from an IUE image

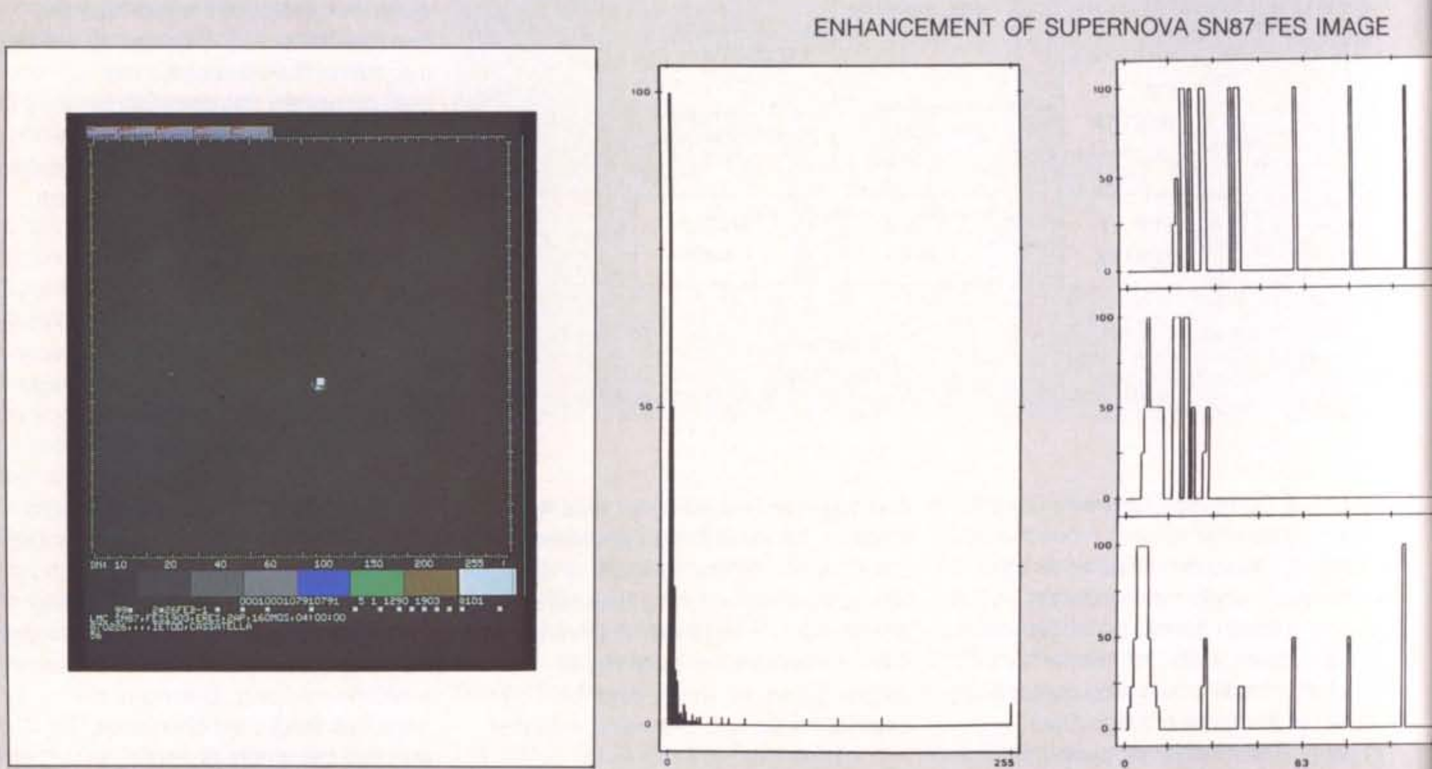
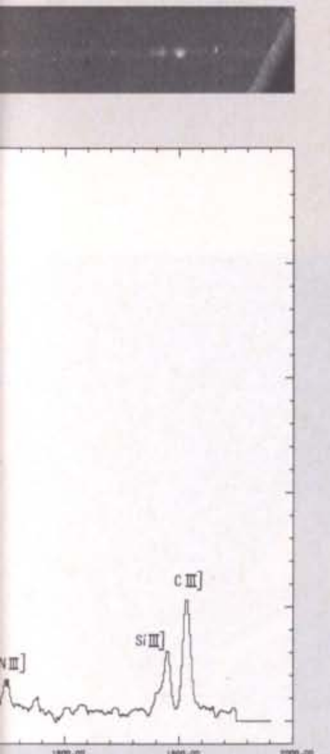
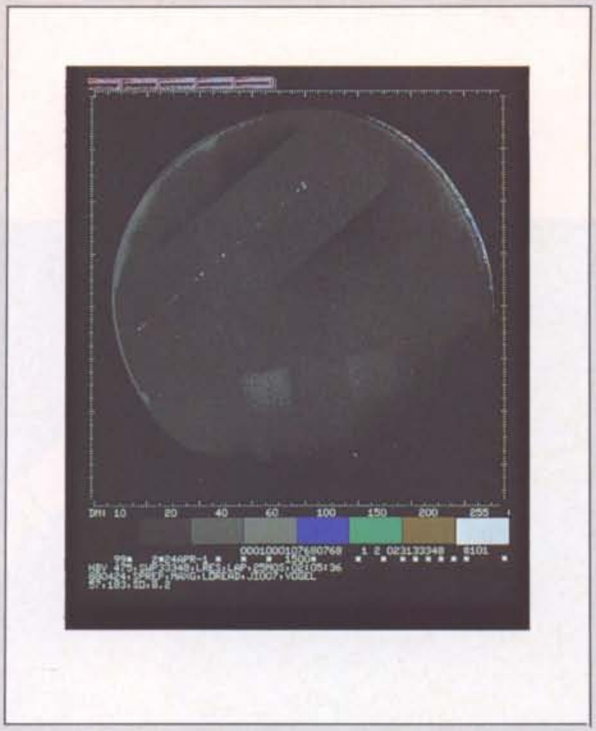
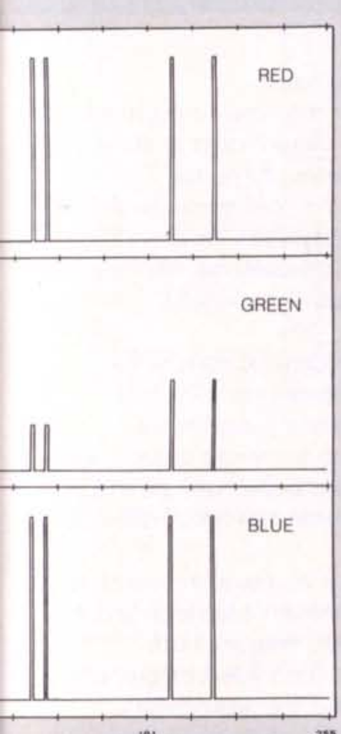
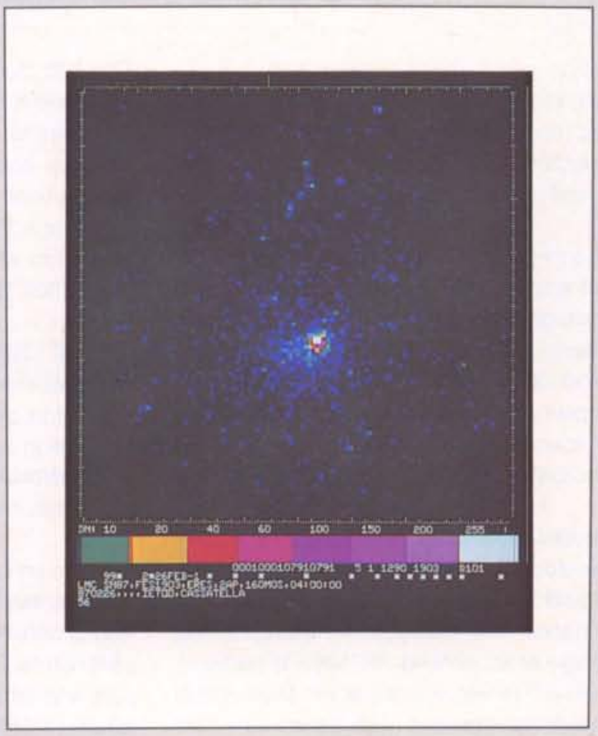


Figure 5 — Photolaboratory histogram technique to enhance an image









data that has been accumulated during this period. The raw images are retrieved from disk and each is processed to extract the spectrum of the observed object. The steps involved are:

Creation of an adequate scheme (sequence of programs with the corresponding parameters) for the processing of each raw image.

Preprocessing of the image: Elimination of microphonic noise, detection of bright spots, formatting of incomplete images, etc.

Temperature and time correction of the reseau-mark positions: The reseau marks are pre-set reference points in the image plane, used to determine the geometrical correction to be applied to each pixel. Studies have shown that the reference positions change from image to image due to the thermal sensitivity of the camera-readout electronics. A time-dependent variation in reseau positions has also been discovered.

These effects are taken into account in order to calculate the coordinates of the reference marks accurately so that the true image geometry is well determined.

Geometrical and photometric corrections: The photometric correction of the images is performed on a pixel-to-pixel basis by means of Intensity Transfer Functions (ITFs), which should establish a correspondence between the 'computer' value (0 to 255) of each pixel and a measurement of the incident flux. However, the ITF values are defined in a geometrically correct space and the true transfer function (computer value-flux) for each pixel therefore has to be re-calculated. The method used for estimating this true transfer function involves a bi-linear interpolation, on a pixel-to-pixel basis, between four values that correspond to the fluxes of the four pixels nearest to the geometrically corrected position of the pixel whose flux is being calculated.

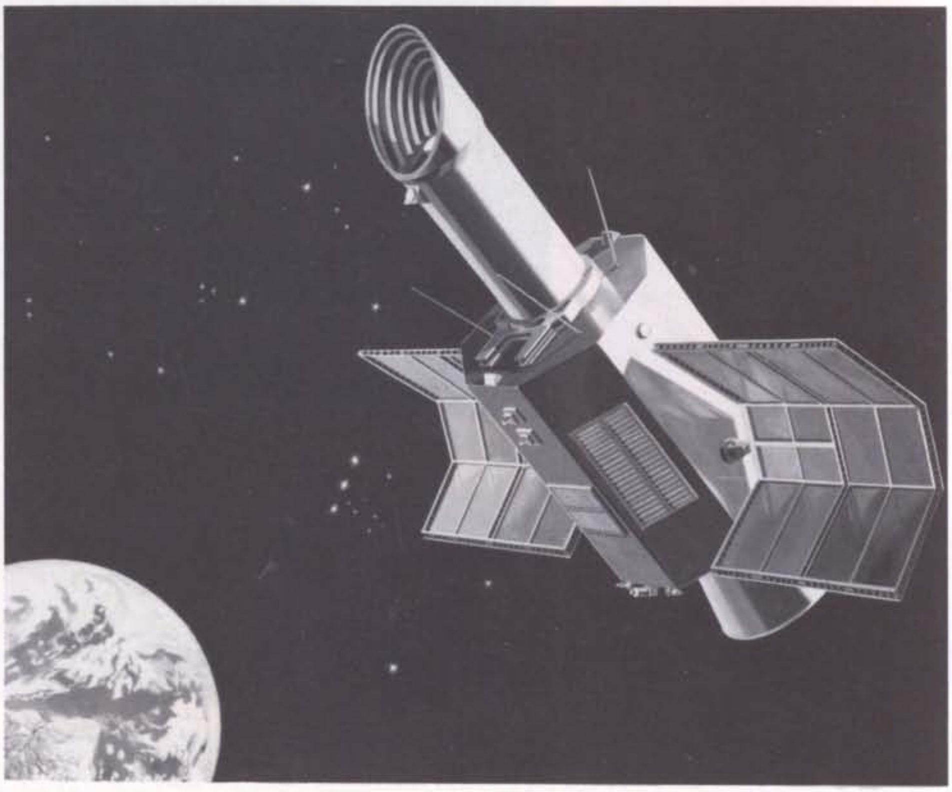


Figure 6 — Artist's impression of IUE in orbit

Extraction of spectral flux: This consists essentially of finding which pixel values correspond to which wavelength and subsequently collecting the corresponding flux (gross flux) for each wavelength sample. The difference between this value and the background value is calculated for each sample to produce a table of 'net' fluxes as a function of wavelength.

Absolute calibration: The previous task produces flux (energy) values which do not yet take into account that the sensitivity of each camera pixel is also a function of the wavelength (i.e. of its position within the image). This means that, for each image point, equal incident energies at two different wavelengths will produce different 'net' fluxes. Nor does it take into account that the flux values calculated so far are a function of exposure time. These two effects are corrected by applying an inverse sensitivity function and dividing by the exposure time.

Figure 4 shows a raw image on the left and its photometrically corrected copy on the right. The centre image (top) is a zoomed subset containing the spectrum of the astronomical object. Below it is plotted the extracted spectrum.

Output of the results: The products meaningful to the observer are: the raw image; the photometrically corrected image; and the files containing the gross, the background and the net samples of the observed spectrum and the 'absolute calibrated' value. These files are written on magnetic tape in a well-established format (IUE format) for immediate delivery to the user and for inclusion in the IUE Data Bank.

Another set of files is also produced, to be used in offline peripherals for the production of plots and photowrites, which are also delivered to the user.

Villafranca Photolaboratory: Here the computer-formatted data is converted into high- or low-resolution plots of the astronomical object spectral flux as a function of wavelength. The resolution and accuracy are sufficient to allow the scientific analysis to be conducted directly on the plot delivered to the user.

The raw image and the photometrically corrected image are transferred to photographic plates so that the observer retains a high-quality copy of the prime products of the observation. These copies are useful for visual assessment of spectrum aspects, saturation levels, unusual particulars of an image, etc.

Special techniques have also been developed to enhance graphical outputs. Figure 5, for instance, uses a histogram enhancement technique. The original IUE image of supernova SN 1987 is barely visible. Transfer functions for each of the colour components have been specifically built up for this case, based on the study of the histogram of the original image. Application of the three transfer functions produces the final pseudo-coloured image, which provides a much better view of the supernova.

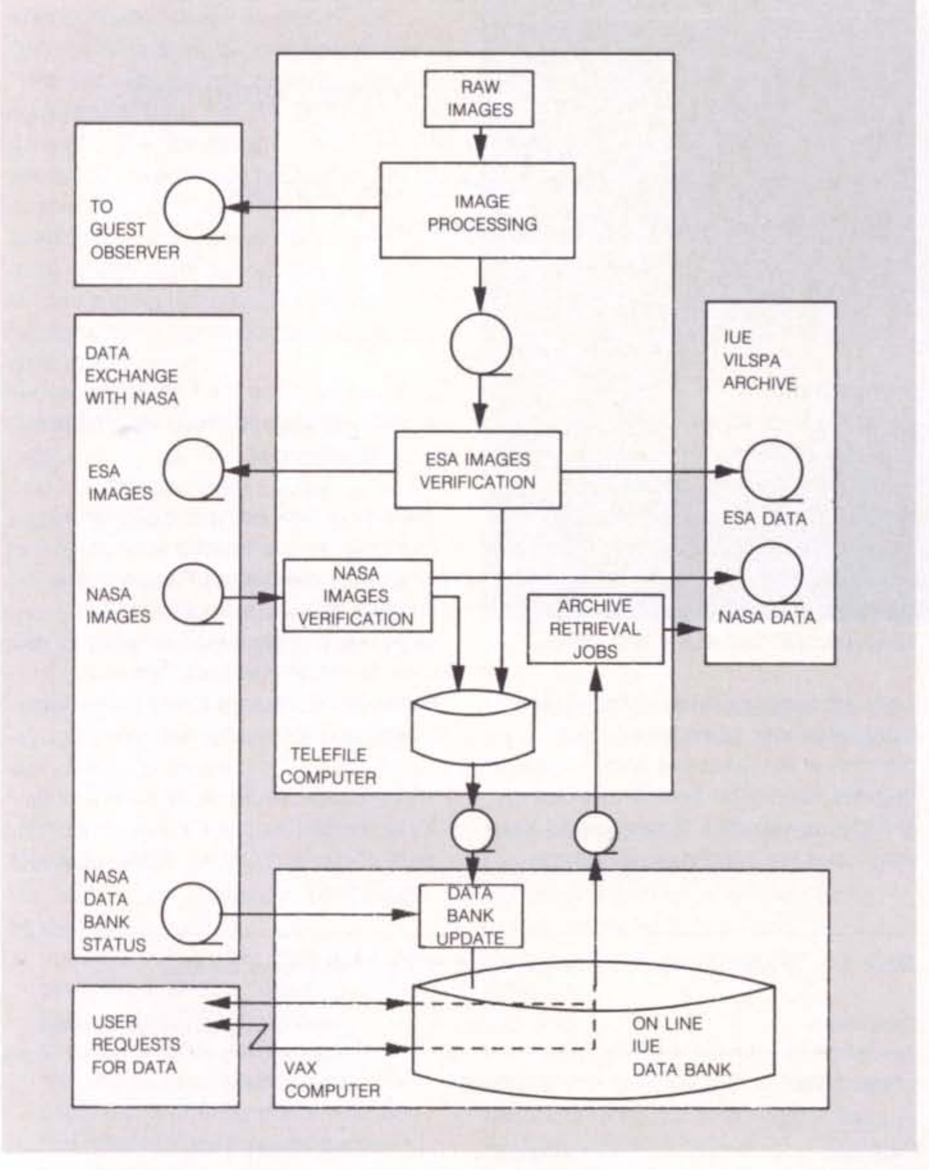
The IUE data bank

In a project of this nature it is extremely important to keep a record of all the products acquired during the observations. For this reason, an IUE Data Bank System was developed in 1982, into which additional functions have since been incorporated.

The IUE Data Bank contains all the elements (hardware, software etc.) needed to provide access to the description and the results of each of the observations performed with the IUE spacecraft, whether by NASA or by ESA.

There is on-line access to the elements that characterise an observation and the results obtained, including such parameters as observation programme, date and time of the observation, exposure mode, spectrograph used, camera, state of spectrograph apertures, start/end time of the exposure, object observed, coordinates of the object, where the observation was made, and how the processing was performed, object type, temperature of the camera,

Figure 7 — Schematic of the IUE Data Bank



fine-error-sensor readings and magnitude of the object, observer's name, dispersion, etc.

The scientific data consist of raw images, photometrically corrected images, and their extracted spectra. They are stored on magnetic tapes. This archive currently contains more than 65 000 images and their spectra.

Figure 7 shows the elements involved in the handling of the IUE Data Bank tasks. It depicts a complex procedure involving two computer systems. The Vax 730 contains a Data Bank Management System (ADABAS), with application programs to update the database, to allow on-line search functions and to create the archive-retrieval jobs to be run on the Telefile computer. In addition to its other functions of satellite control and image processing, this computer also performs certain quality-control tasks by re-reading the results of the data processing (by NASA or ESA) to produce compacted magnetic tapes to be saved in the archive.

The Network allows the IUE Data Bank to be consulted from the Station offices (Resident Astronomers' research), or from the 'outside world'. Remote users with access to either ESANET or SPAN can log into the IUE Data Bank. Scientists can also use the international packet switching networks, since the system is connected to IBERPAC. Once access has been gained to the IUE Data Bank, searches can be made and copies of the archived products can be requested on magnetic tape.

A new data archive has recently been created by combining elements from the image processing and from the IUE Data Bank: the so-called Uniform Low-Dispersion Archive (ULDA), which contains more than 24 000 spectra. It is supplied to countries with a nominated host institute that provides their national users with access to such databases. The archive is supported by an applications software package (USSP), which allows the different institutes to perform the data-base management and file-transfer functions. The IUE Control Centre at Villafranca acts as the principal centre for global user data access and for support to these national centres.

Conclusion

Since IUE's launch in 1978, more than 65000 images have been processed, archived and distributed to the observing astronomers. The computers and data processing systems in Vilspa have evolved in response to the volume of data obtained and to the need for its quick accessibility. In addition to monitoring and controlling IUE and performing its image processing tasks, the so-called Vilspa/IUE Ground Computer Systems also support the astrophysical research conducted at the IUE observatory, the office automation functions of the Villafranca Station and the IUE Data Bank activities. The facility's integration with the ESOC system and its connection to the World's networks make it an important element in the day-to-day implementation of the Agency's scientific programmes.

The High-Throughput X-Ray Astrophysics Cornerstone

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The High-Throughput X-ray Astrophysics Mission (XMM) is the second Cornerstone in ESA's Long-Term Programme 'Space Science: Horizon 2000'. This long-duration observatory facility for cosmic X-ray spectroscopy is due for launch in 1998 and has an anticipated lifetime of ten years. It will enable major advances to be made in X-ray astrophysics at the turn of the century.

Introduction

The X-ray Multi-Mirror observatory, currently known as the 'XMM' mission, is the second Cornerstone project of ESA's Horizon 2000 Programme. As such, it is an approved programme, with a launch scheduled in 1998, which will provide astrophysicists with a major X-ray spectroscopic tool in the late 1990s.

X-ray astrophysics deals in the study of highly energetic phenomena. Hot plasmas at temperatures above a million degrees radiate the bulk of their energy at X-ray wavelengths. Space-based X-ray telescopes are necessary to observe such X-rays, since the Earth's atmosphere absorbs strongly at these wavelengths (1—100 angstrom).

XMM will follow on from ESA's earlier Exosat X-ray satellite, the success of which has established Europe at the forefront of X-ray astrophysics. This extremely powerful, new observatory will provide astronomers with the tools necessary to make the next major leap forward in high-energy astrophysics.

Whilst Exosat could study such exotic X-ray sources as black holes or neutron stars in our own Galaxy, XMM will be

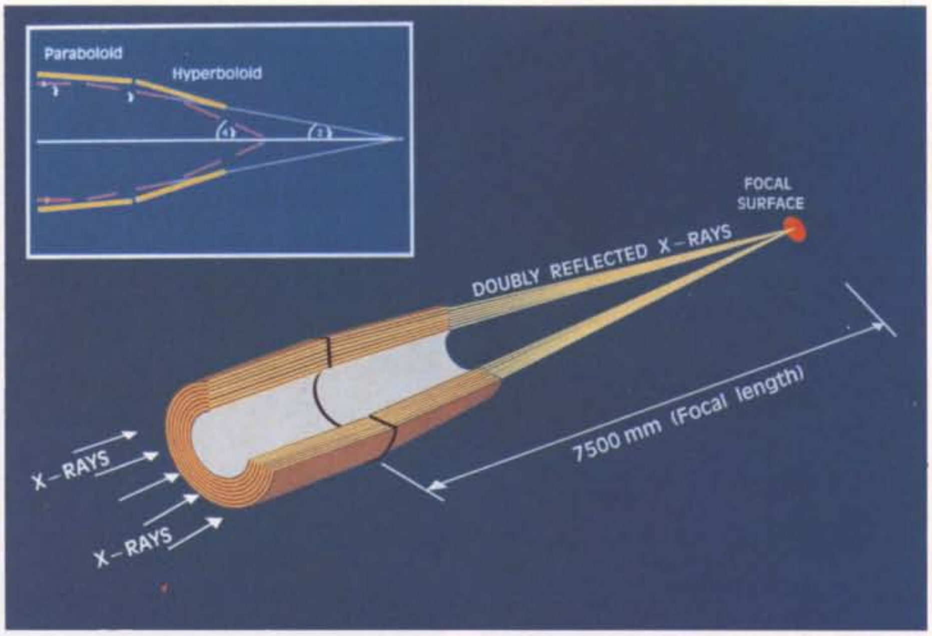
Table 1 — Principal scientific characteristics of the XMM model payload

Parameter	CCD camera	Reflection-grating spectrometer
Energy range*	0.15—10 keV	0.2—2.5 keV
Collecting area		
0.5 keV	1600 cm^2	150 cm^2
1.5 keV	2800 cm^2	440 cm^2
6.0 keV	1400 cm^2	—
Resolving power ($E/\Delta E$)**		
0.5 keV	6	400
1.5 keV	16	300
6.0 keV	50	—
Background rejection	99.5%	>99.5%

Optical monitor	
Limiting magnitude	24.5 magnitude in 10^3 s with B-filter
Waveband	1800—6000 Å
Spatial resolution	1 arcsec
Field of view	8 arcmin
Resolving power	50—100 between 3000 and 6000 Å using grisms

* 10% of peak collecting area ** ΔE = Full Width Half Maximum (FWHM)

Figure 1 — Schematic of XMM's heavily nested Wolter-I X-ray optics. The inset shows the principle of grazing-incidence reflection from a single paraboloid-hyperboloid pair. Fifty-eight such shells are nested inside one another



able to make detailed studies of such systems in other neighbouring galaxies. Here, the distance can be more clearly constrained, such that the total energy content of the star system can be accurately determined. Such stars are normally found in accreting binary systems and emit over a billion times more energy than our own Sun. Understanding the physics involved is fundamental to our understanding of how stars evolve and die.

Unlike Exosat, XMM will have the ability to look deep into the Universe and to study objects that were created when it was very young. Astronomers will literally be able to look back in time to when primeval galaxies and quasars formed, some 10 billion years ago, and study their physical characteristics. These types of observations, which are truly cosmological in nature, will allow us to refine our models of how the Universe was created and how it has evolved with time.

The payload

The XMM model payload is composed as follows:

- three mirror modules, type Wolter-I, to provide the photon collecting area and imaging (ESA-supplied)
- three CCD (Charge-Coupled Device) imaging array cameras, one at the prime focus of each mirror module
- two reflection-grating spectrometers fitted to two of the telescopes
- one optical monitor.

The principal scientific characteristics of the XMM model payload are summarised in Table 1.

The mirror modules, representing the heart of the payload, are a major technolgical challenge and are being developed by ESA. Their principal characteristics are summarised in Table 2.

The design chosen not only provides an optic with a high throughput and large bandwidth, but can also achieve the medium-resolution goal of 20—30 arcsec on-axis. The high throughput is achieved by nesting a large number of Wolter-I shells, as shown schematically in Figure 1. The X-ray telescope uses the principle of grazing-incidence (at approx. 0.5°) X-ray reflection to reflect and image the X-rays from a gold-coated paraboloid and hyperboloid surface (see inset to Fig. 1).

For the manufacture of the large number of Wolter-I shells required, electro-forming and epoxy replication techniques were studied. The technique of replicating the X-ray reflecting surface onto a very thin (±1 mm) carbon-fibre-reinforced epoxy (CFRP) carrier shell (Fig. 2) proved to have substantial advantages in terms of mass and thermal stability. It was therefore selected as the baseline technology for the XMM optics.

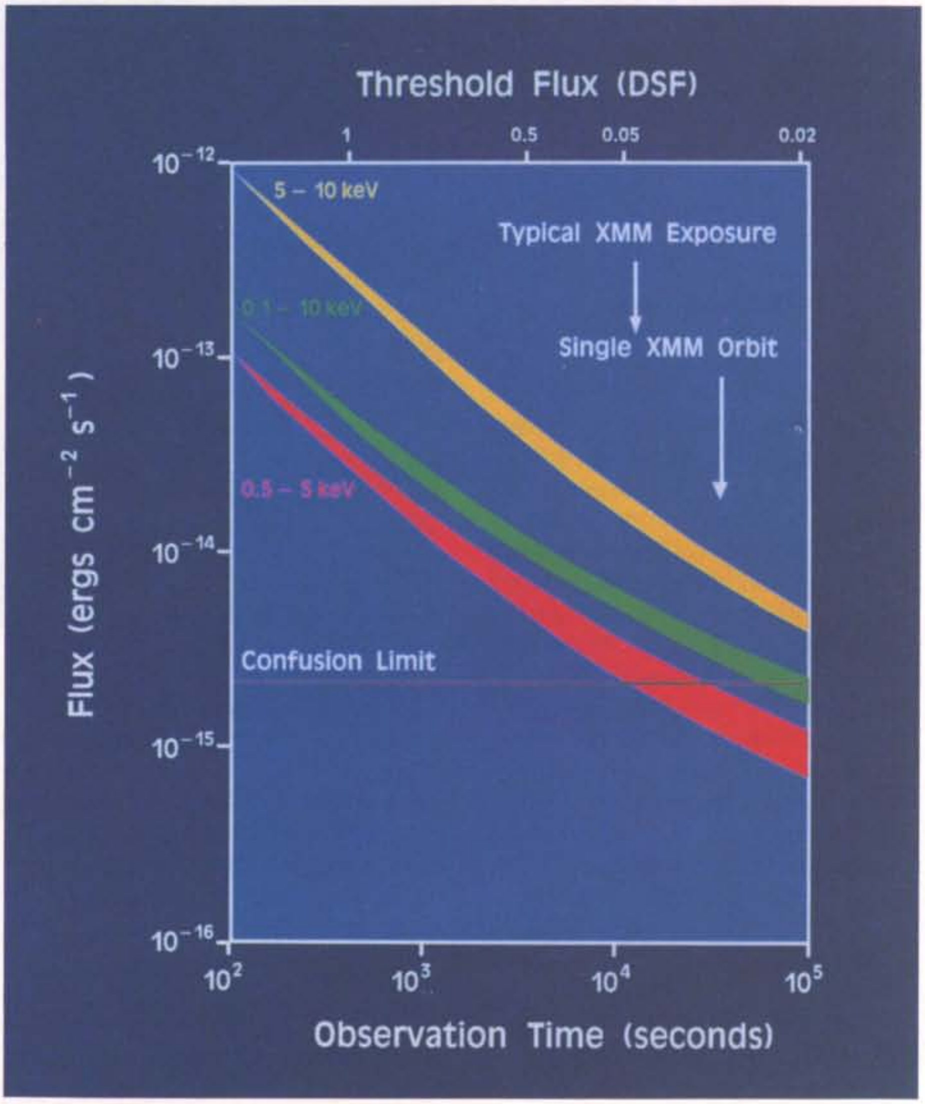
The other two main parts of the X-ray-related payload elements are a CCD array and a reflection-grating spectrometer, which fit behind each mirror module as shown in Figure 2.

The CCD array is the prime-focus camera, which will perform the mission's broadband (0.1—10 keV) imaging and spectrophotometry. It can spectroscopically resolve the helium-like and hydrogenic K lines from most of the abundant elements.

Table 2 — Principal characteristics of a single XMM mirror module

Focal length	7500 mm
Outermost mirror radius	350 mm
Innermost mirror radius	159 mm
Axial mirror length (paraboloid + hyperboloid)	600 mm
Outer-mirror wall thickness	1.40 mm
Inner-mirror wall thickness	0.64 mm
Minimum packing distance	1 mm
Reflective surface	Iridium/gold
Mirror carrier material	CFRP
Number of mirror (paraboloid + hyperboloid) pairs	58
Mirror module mass	170 kg (spec. 220 kg)

Figure 3 — The minimum detectable source strength as a function of observing time. Three different energy bands are shown, and the equivalent threshold flux in units of the Einstein Deep Space (DSF) Survey is indicated. The bands indicate when the diffuse X-ray background (extragalactic) contributes to the overall background (particle plus soft X-ray galactic background) and when it is completely resolved by the XMM telescopes. The XMM confusion limit (40 beam widths per source) is also indicated



At the exit of two of the mirror modules a stack of flat replicated reflection gratings intercepts half of the converging beam. This grating stack provides the wavelength dispersion required to meet the medium-resolution spectroscopy requirement of a resolving power of more than 250 at 0.5 keV.

The final part of the payload is an optical/ultraviolet telescope. The need to include such a telescope in the XMM observatory model payload arose in part from the intensive coordination required by Exosat's users to maximise the scientific return from a wide variety of observations. However, the optical monitor has the additional important function of providing a positional calibration for the three X-ray telescopes, as well as providing a 'post facto' refinement in the attitude system.

Figure 3 shows the minimum detectable source flux as a function of observing time. In 2×10^4 s and with one full orbit of XMM, flux limits of 2×10^{-15} and 10^{-15} erg cm^{-2} s^{-1}, respectively, can be achieved with the CCD cameras on all three modules.

The mission profile

The baseline orbit

A detailed trade-off was performed between the two main generic orbits for astronomical satellites (a detailed analysis can be found in ESA Special Publication SP-1092, the report of the XMM Instrument Working Group):

- the Highly Eccentric Orbit (HEO), in which the satellite passes through the radiation belts on every orbit and performs its observations outside them (Exosat/Cos-B type — periodicity of days)
- the Low Earth Orbit (LEO), in which the satellite is always below the radiation belts (Shuttle type — periodicity of approximately 90 min).

The HEO has the main scientific advantage of long uninterrupted observations for spectrophotometric

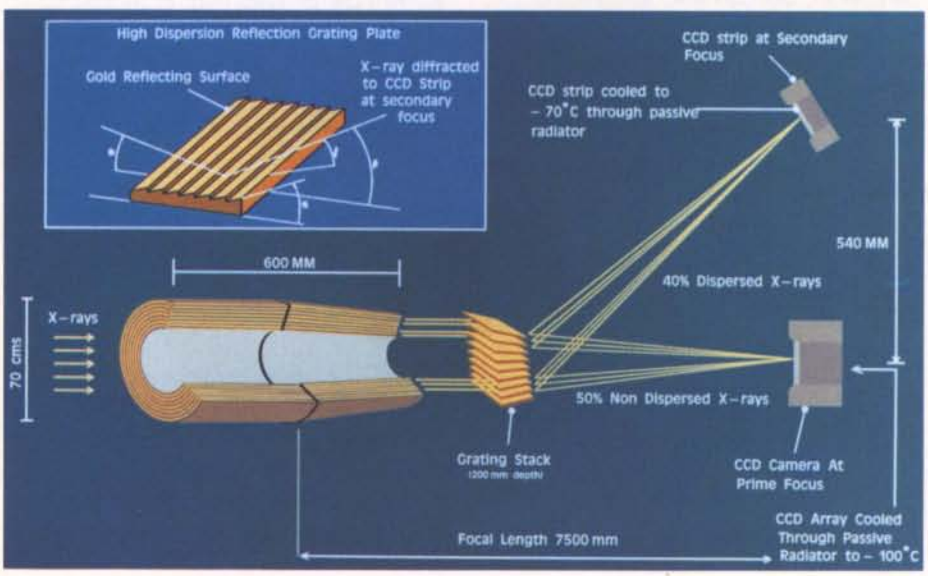


Figure 2 — Schematic of the operating principle of XMM's reflection-grating spectrometer. The inset shows the design of a single grating plate (further details can be found in ESA SP-1092)

studies and a high observation efficiency. It also allows great operational flexibility, including real-time contact. The LEO, however, has lower inherent (though variable) detector background for spectrophotometry of weak sources, and offers the possibility for in-orbit maintenance to increase lifetime or exchange instruments.

From an economic viewpoint, the slightly higher cost of a HEO launch is far outweighed by the cheaper spacecraft and lower operating costs compared with the LEO option. The HEO option — 24 h period, −60° inclination, 70 000 km apogee and 1000 km perigee — was therefore selected for XMM for a combination of scientific, operational and cost reasons.

The spacecraft will therefore be above an altitude of 40 000 km for more than 70% of the orbital period, this being considered a safe operating altitude for XMM's instrumentation. The apogee of this orbit will be in the Southern Hemisphere, because Ariane must be launched northwards from Kourou, and the Perth (W. Australia) ground station, which provides almost continuous coverage when the spacecraft is above 40 000 km, must be used.

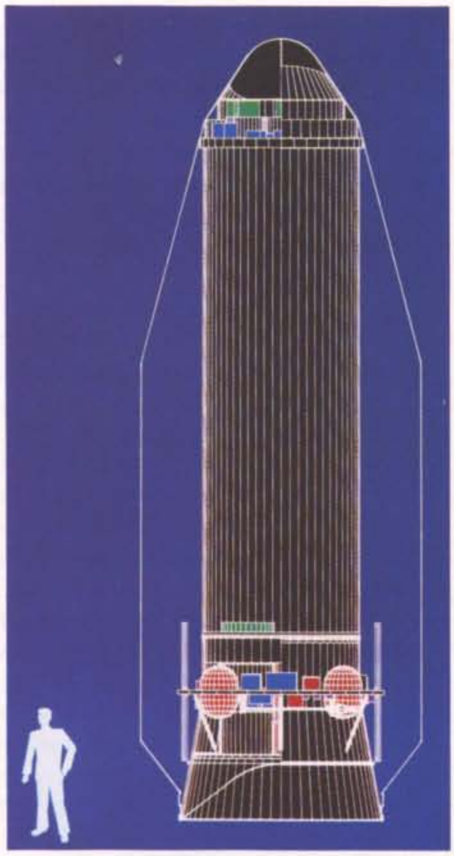
Spacecraft system design

The XMM spacecraft configuration (Fig. 4) is dominated by the telescope's 7.5 m focal length and the need to fit inside the largest standard Ariane fairing (Fig. 5).

The mirror modules are grouped at one end of a large-diameter empty tube, which connects them to the focal-plane instruments. The telescope tube is accommodated longitudinally in the Ariane shroud and, due to their weight, the mirror modules are located at the end interfacing with the launch vehicle.

The spacecraft subsystems are placed around the outside of the telescope tube on a separate 'bus' platform at the launcher-interface end. This platform carries all the equipment for the power, data-handling, attitude and orbit control and telecommunications subsystems, as well as the reaction-control tanks and thrusters. The solar arrays and telecommunications antennas are folded around the edge of the bus and are deployed once in space.

Figure 5 — XMM spacecraft launch configuration inside the Ariane-4 shroud



The focal-plane instruments are all mounted on a rigid platform. The solar aspect angle is fixed at ±20° to the perpendicular to the telescope axis and so a simple Sun shield can protect the instruments from direct sunlight. All the focal-plane instruments require passive cooling and so are connected to radiators that always point towards deep space.

The mirror modules, star trackers and optical monitor are also attached to a fixed platform at the launch-interface end of the telescope tube and all are protected from contamination on the ground and during launch by an aperture door. The mirror modules are also protected by heated thermal/optical baffles to respect their critical temperature-stability requirements.

Figure 4 — Exploded view of the XMM spacecraft

Table 3 shows the overall XMM mass budget.

Finally, the basic scientific requirements associated with spacecraft attitude control/alignment are:

- Resolution (half energy width) less than 30 arcsec.
- Lateral displacement of focus less than 10 mm.
- Loss of effective telescope area on target less than 10%.
- Knowledge of source position to less than 10 arcsec.

The specific pointing requirements for the spacecraft derived from these scientific constraints are summarised in Table 4.

Table 4 — XMM pointing requirements

Requirement	Tolerance (95% probability semi-cone)
Absolute pointing error	<1 arcmin
Absolute pointing drift	<5 arcsec/2 min <30 arcsec/10 h
Pointing reconstitution	<10 arcsec
Angular misalignment between any mirror-module pair	<1 arcmin
Image defocus error	<5 mm
Image decentre error	<2 mm
Absolute roll error	<5°
Absolute roll drift	<2.5°/h
Roll reconstitution	<30 arcmin

Table 3 — XMM mass budget

Item		Mass* (kg)	
Payload	Mirror modules	660	
	Detectors	250	
		—	
			910
Subsystems	Structure	556	
	Thermal	173	
	Mechanisms	35	
	Attitude and Orbit Control System (AOCS)	129	
	Reaction Control System (RCS)	71	
	Power	53	
	Solar array	51	
	On-Board Data Handling (OBDH)	34	
	Telemetry, Tracking and Command (TT&C)	15	
	Harness	96	
	Balance mass	25	
		—	
			1238
Total spacecraft dry mass			2148
Fuel			178
Adapter			48
			—
Total launch mass			2374
			—
Launch capacity Ariane-4 2L			2400
			—
Margin			26 kg

* Note: All masses include contingencies

Ground segment and operations
Control of the XMM observatory will be based on the use of a single Control Centre in conjunction with one ESA Ground Station in the Southern Hemisphere (baselined as Perth, in Australia). The use of this station and XMM's 24 h orbit will provide at least 70% coverage each day above the radiation belts. The nominal data rate is 40 kbit/s.

During its routine mission-operations phase, XMM will be controlled from the Main Control Room at ESOC, in Darmstadt, and a Science Operations Centre, which may also be located there.

The mission's major scientific impact
XMM has unprecedented sensitivity and spectroscopic capability. These features will allow detailed spectrophotometry of a wide variety of targets, ranging from distant quasars to nearby stars. While it is not possible here to document all the areas of astrophysics in which XMM will play a major role, two topics stand out:

(i) Stellar coronae
The discovery that stars of almost all spectral types possess X-ray coronae with luminosities of 10^{26} to 10^{34} erg/s has

been one of the major unexpected findings of recent years. This has led to stellar astrophysics emerging as an entirely new astronomical discipline.

Among the many questions that stellar coronal physics now needs to address are:

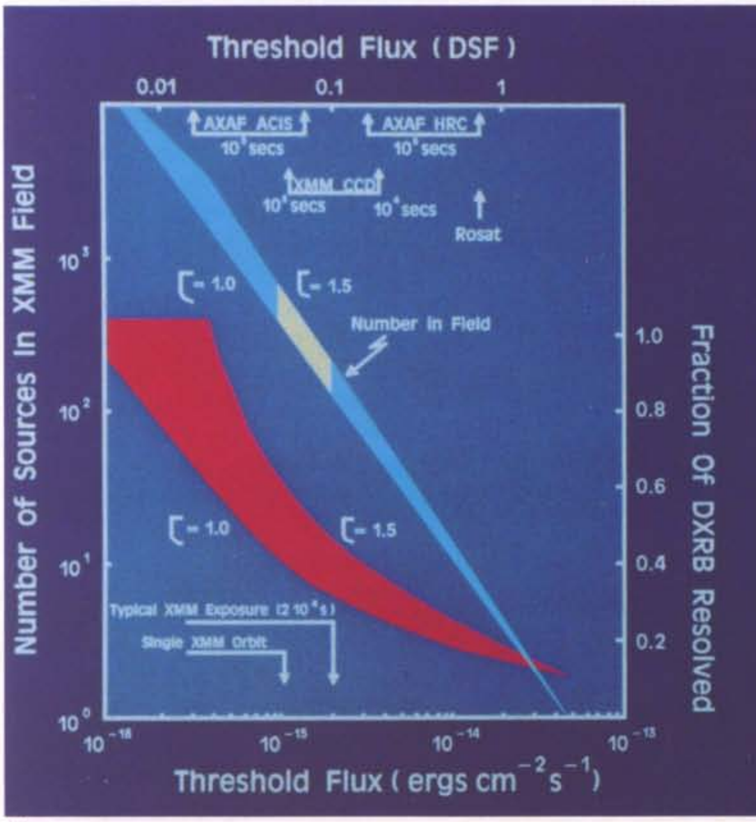
- What is the heating mechanism of stellar coronae , and how does it depend on parameters such as radiation field , mass flow, convection, rotation and age?
- What is the structure, both in temperature and density, of stellar coronae? Why and how is the plasma organised — as seems to be the case — in spatially distinct features, presumably confined by magnetic fields?
- What is the variability of stellar coronal sources on a variety of different time scales (from minutes to days and years)? How can the observed temporal variations be used to infer the mechanism of coronal heating and the structuring of stellar coronae?

The XMM mission, with its unique combination of high-throughput, large bandwidth, medium spectral resolution, and long continuous-look capability, can address all of these questions and obtain the detailed spectrophotometric data necessary to provide the answers.

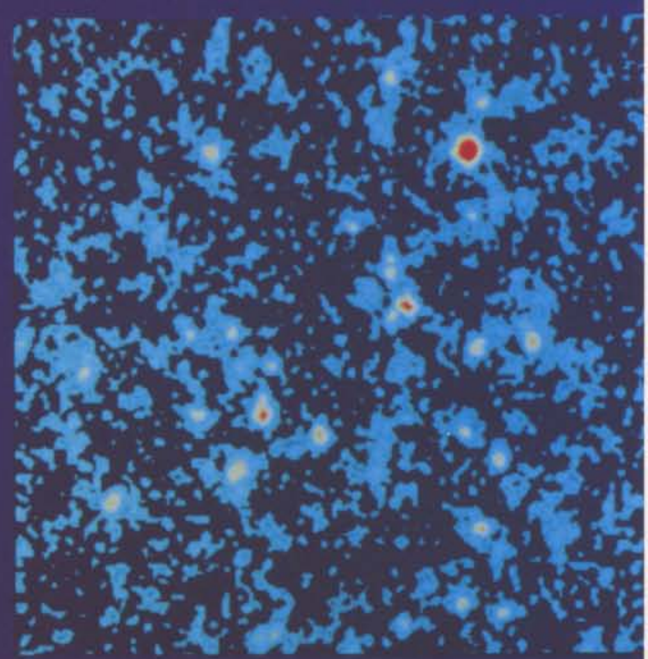
Observations of temporal variations are also crucial in order to resolve the spatial structure of eclipsing binary systems, and to study the inhomogeneous distributions of surface activity on single, rapidly rotating stars. ESA's Exosat Observatory has already demonstrated the importance of time variability as a diagnostic tool for stellar coronal emission. However, Exosat's small collecting area greatly limited the number of coronal sources that could be studied with sufficient counting statistics. XMM, with a grasp more than three orders of magnitude higher, will allow the observation of targets located at larger distances, thus increasing appreciably the number of interesting objects that it will be possible to study in this way. Unparalleled detailed spectral studies will also be performed on these stars.

As demonstrated with Exosat, an essential requirement for these temporal studies is continuous monitoring for periods of at least one stellar orbital cycle, and preferably longer. XMM's highly eccentric orbit will make this type of observation possible.

(ii) The diffuse X-ray background
The problem of the Diffuse X-Ray Background (DXRB) is the oldest observational puzzle in X-ray astronomy. The discovery of a more or less uniform glow over the whole sky dates back to the very first rocket flight with which non-solar X-ray emission was discovered. The fact that, after 25 years of spectacular



(a)



(b)

Figure 6a — The number of serendipitous sources found in the XMM field (½°) (blue) and the fraction of the Diffuse X-Ray Background (DXRB) which they constitute (red), as a function of limiting sensitivity. The flux limits for the XMM CCD camera on three telescopes for an exposure time of 10^4 to 10^5 s are also indicated, together with those of the AXAF ACIS (CCD array) and HRS (microchannel plate) experiments for a similar exposure time

Figure 6b — Simulated high-latitude 'blank' XMM field for a typical XMM exposure time of $2x10^4$ s with the full CCD payload. About 200 serendipitous sources are contained in this field

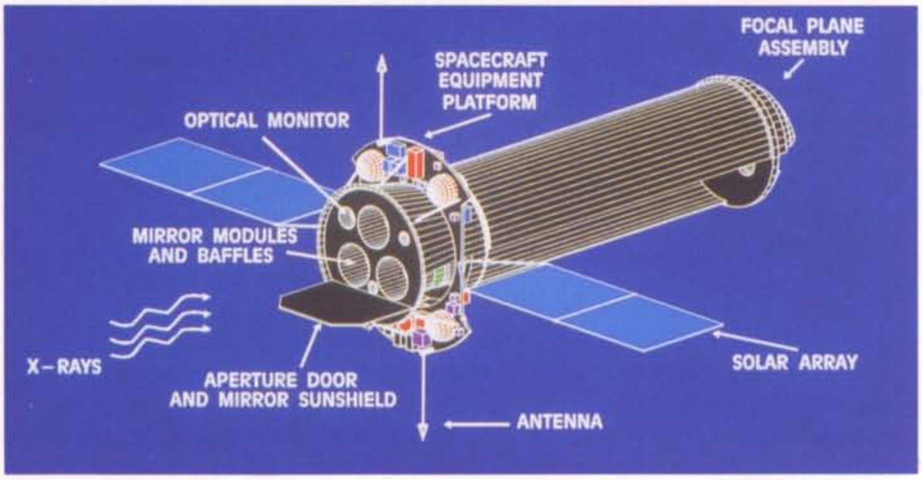


Figure 7 — XMM spacecraft's in-orbit configuration

progress in X-ray astronomy, the origin and nature of this emission is still not understood has made the puzzle even greater.

XMM will be able to clear up this mystery. With its angular resolution of 30 arcsec and vastly increased sensitivity to diffuse emission compared with the Einstein Observatory, XMM will be able to measure the DXRB directly with exposures lasting only 6 h, and obtain source counts and spectra down to a flux level ten times smaller than the deepest Einstein Observatory exposure, which took approximately a week.

Figure 6a,b illustrates XMM's capability to resolve the DXRB as lower flux thresholds are reached, the Einstein Deep-Survey flux limit serving as a useful reference point.

XMM will acquire high-quality spectra of over five thousand serendipitous sources during its lifetime, as well as obtaining broadband spectra of over a million such sources. The spectra of Active Galactic Nuclei, as well as the numerous spectra of distant quasars, clusters and galaxies obtained serendipitously during every observation, will form a 'template' of the spectra of weak objects to be subtracted from the known spectrum of the DXRB. Thus even if the DXRB is not composed of point sources at the flux level that XMM is capable of resolving, XMM will determine the spectrum of the residual component and be able to compare it to a vast library of known classes of objects. In concert with NASA's AXAF spacecraft, which will allow identification of the optical counterparts of the faint objects, XMM will completely define the possible contributions of true point-like objects — presumably quasars and active galaxies — to the Diffuse X-Ray Background.

It therefore seems highly likely that XMM will finally be able to solve one of the major cosmological mysteries 35 years after its discovery. The resolution of this problem will provide new insights into the evolution of quasars and galaxies and perhaps the measurement of a new major contributor to the mass density of the Universe.

Summary of the XMM Mission's Unique Features

- Unprecedented sensitivity: 2×10^{-15} erg cm^{-2} s^{-1} in a 6 h exposure
- High sensitivity to perform medium-resolution spectroscopy
- Imaging broadband spectrophotometry with simultaneous medium-resolution spectroscopy
- Wide bandwidth: 0.1—10 keV
- Continuous observation of a target for up to 18 h, afforded by the deep orbit
- Simultaneous optical/ultraviolet monitoring of the target
- Real-time monitoring/control of the observatory
- Long-duration facility.

Programme planning

An overview of the XMM programme is shown in Figure 8, and some of the main milestones are noted in Table 5. An important feature of the planning is the fact that the years to 1992 are years of technology development, particularly with regard to the mirror system, on which preparatory work has been in progress since 1986. This work is expected to continue until 1991, by which time the mirror design and the manufacturing techniques should be proven and the overall mission cost shown to be compatible with the budgetary envelope allocated.

At its meeting in Paris on 21 June 1988, ESA's Science Programme Committee approved the XMM Science Management Plan and Schedule. Consequently, the XMM project has now issued the Announcement of Opportunity

Figure 8 — Programme planning for the XMM Cornerstone mission

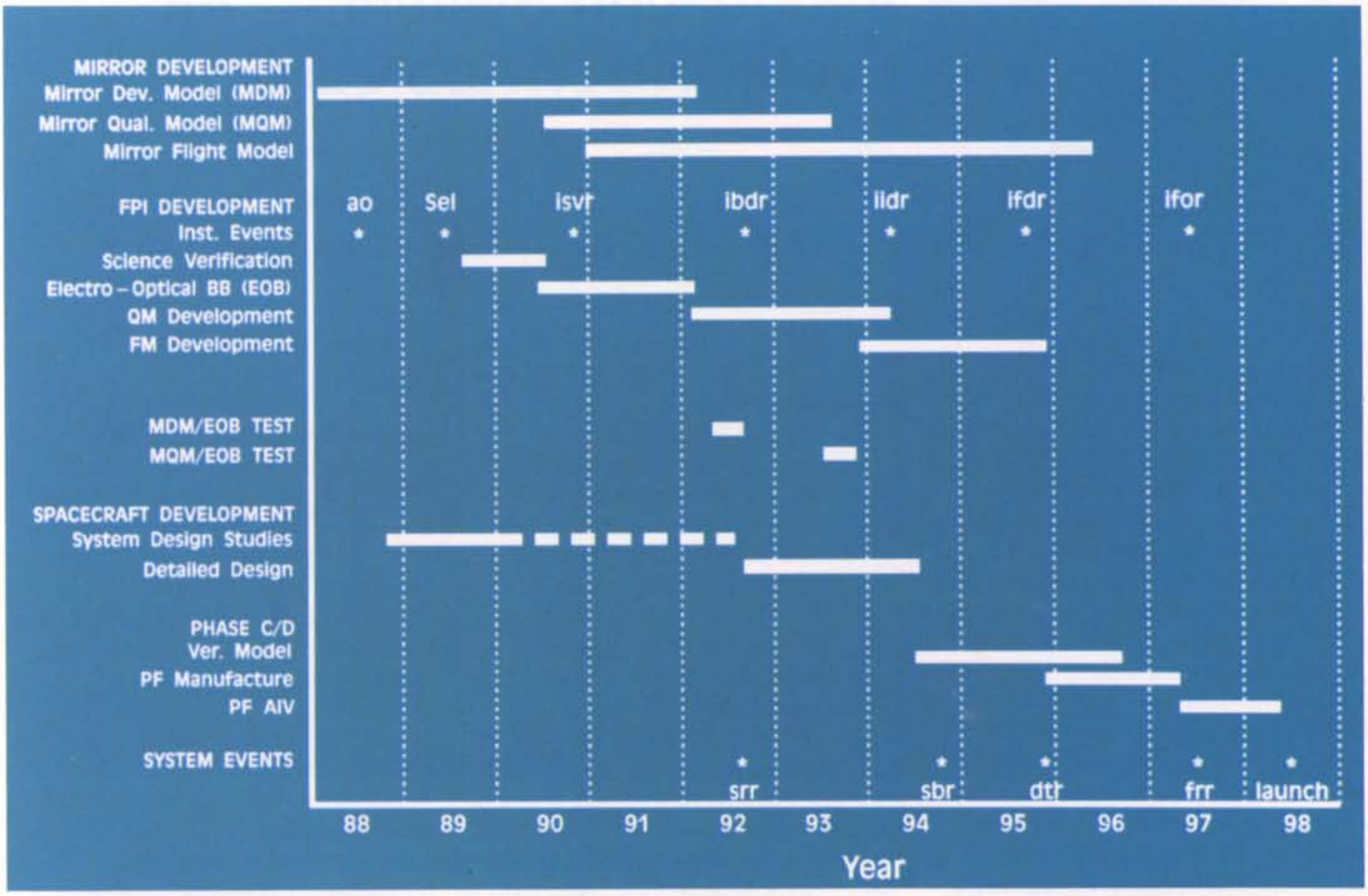


Table 5 — Milestones in the XMM Programme

Selection of investigators	June 1989
Mirror development-model delivery	Begin 1992
Instrument electro-optical model delivery	Begin 1992
Announcement of Opportunity (AO) for survey scientists	1992
Spacecraft main development phase (Phase-C/D)	1994—1997
Instrument qualification-model deliveries	1994
Instrument flight-model deliveries	1995/1996
Launch	1998

for instrument principal investigators and mission and telescope scientists.

Acknowledgements
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Further reading

The High-Throughput X-Ray Spectroscopy Mission:

— The Mission-Science Report, ESA SP-1097.

— The Report of the Instrument Working Group, ESA SP-1092.

— The Report of the Telescope Working Group, ESA SP-1084.

Towards a European Space Information System — An Evolutionary Approach

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The Agency has decided to set up an enhanced computer communications infrastructure interconnecting all its affiliated scientific institutions and major centres of excellence in the astronomical and solar-terrestrial domains and providing gateways to other networking environments. The pilot phase of the European Space Information System (ESIS) Programme was approved by the ESA Council at its December 1987 meeting. The goal of this pilot is to provide the European space-science community with general information services, and in particular with access to a selected set of space data archives (Fig. 1), such that all databases are approached in a uniform and homogeneous manner using a discipline-specific query language.

Introduction

Space scientists represent a computer-network user group that is international in nature and has a wide spectrum of service requirements. Space data needs to be catalogued and archived in readily accessible forms, easy to intepret by both specialists and multidisciplinary investigators. Whether a scientist is studying solar-terrestrial relationships or examining astrophysical phenomena across different energy regions, the same basic need of being able to readily examine data sets derived from a variety of space missions using a uniform, homogeneous access method arises. The more sophisticated the cataloguing and the better the visibility of the archived data, the wider will be its use. The scientific return from today's very large expenditures on space programmes is greatly improved when the space daata can be readily exploited long after the missions themselves have been terminated.

The Agency has also become increasingly aware in recent years of a real need among scientists to be able to communicate more efficiently with each other across Europe and with their colleagues on other continents by making use of data networks. The collaborative nature of space research makes the rapid transmission of documents, data and software an important factor in increasing efficiency. There is also a desire to ensure that maximum use is made of the opportunities afforded by space experiments through real-time control of experiment operations. Direct network connections from the spacecraft operations centre to the laboratories participating in a mission are now essential for efficient scientific working.

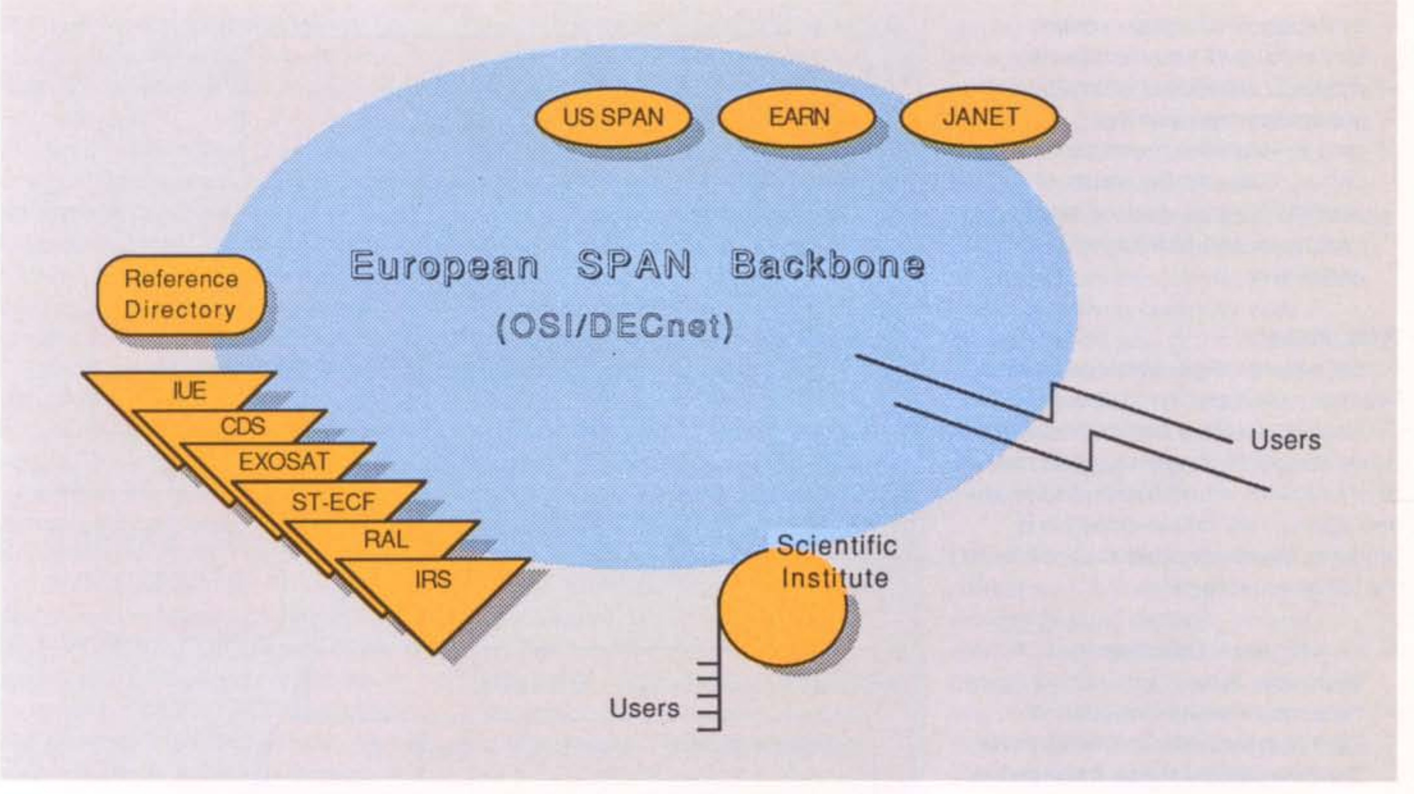
A major goal of the European Space Information System (ESIS) is to provide access to space data to all communities concerned, which include scientists directly involved in space-borne experiments, scientists involved in ground-based observations, and theoretical physicists and statisticians. The system is designed so as to explicitly facilitate the inclusion of associated institutes wishing to participate in ESIS, either by offering an additional access point or by integrating additional archives into the network, thereby building a harmonised, open and transparent environment.

ESIS is being developed along the lines of existing infrastructure elements, as well as following OSI standards. From its pilot phase onwards, ESIS will as far as possible adopt standard access methods and protocols, aiming as a final goal to make use of ISO/OSI* standards to achieve a completely open architecture.

A Workshop was held in December 1987 at ESRIN to finalise the user requirements and establish the main design concepts for ESIS. The participants at this User Workshop fully supported the objectives of the ESIS

* The Open Systems Interconnection (OSI) model has been developed within the International Standards Organisation (ISO) to provide multi-vendor interconnectivity.

Figure 1 — Schematic of the Pilot Project scenario, showing the archives participating in this phase, and the network gateways and access methods available



Programme and expressed the hope that the programme will serve to stimulate scientific data analysis and to preserve the results of our investment in space science.

User needs

In sounding out user requirements for an information system within which information can be obtained, exchanged and deposited, ESRIN approached the astronomical and solar-terrestrial communities. These contacts showed that the ESIS concept meets a clearly identifiable demand in all groups consulted, and that the expectations for ESA's role in scientific data archiving and dissemination are very high. Two particular aspects are felt to be fundamental components of a space information system: an easy to use and effective set of communication links, and liberal and powerful access to information contained in remote centres. Queries for information will therefore be formulated in ESIS in discipline-specific, not computer-specific, terms. The ESIS environment will also feature possibilities for combining measurements from different databases.

On the network side, the Space Physics Analysis Network (SPAN) serves as a good example. SPAN is a network connecting some 1000 nodes in the US and about 140 in Europe, showing that networking facilities are already being used extensively to exchange data between investigators, and to prepare, edit and transfer scientific papers when several co-authors are involved (see ESA Bulletin No. 53, pp. 45—48). On the data-management side, it was concluded that mere archiving and primitive retrieval functions do not in themselves guarantee broad dissemination of satellite-gathered data among the scientific community. The great diversity of data formats and access methods often hamper the scientific throughput for any non-Principal Investigator.

The following specific communication-link needs are identified in ESIS:

- access to remote archives, including the possibility of using services offered by host institutes
- provision of interactive means for communication among users as well as capabilities for exchanging and transferring a variety of data, including draft publications, scientific data, and software
- provision of gateways to already established networks, with connections to SPAN in the US, Janet in the UK, and EARN being of primary importance.

For data management, the following specific user requirements have been identified:

- structured access to data sets, including measurements, results databases, catalogues of objects and bibliography
- organised access to software
- transfer of data and software, organised both on-line and on a batch basis

- availability of information about spacecraft and their instruments
- access to scheduling information on observatory-type satellites
- tools to establish correlation between primary data and the results of scientific analysis, such as object catalogues and bibliographic references.

Pilot project

A pilot project will be developed over a five-year period starting in January 1988. During this project, a backbone network based largely on the emerging European SPAN network will be further deployed and software will be developed and procured to provide integrated access to the following archives:

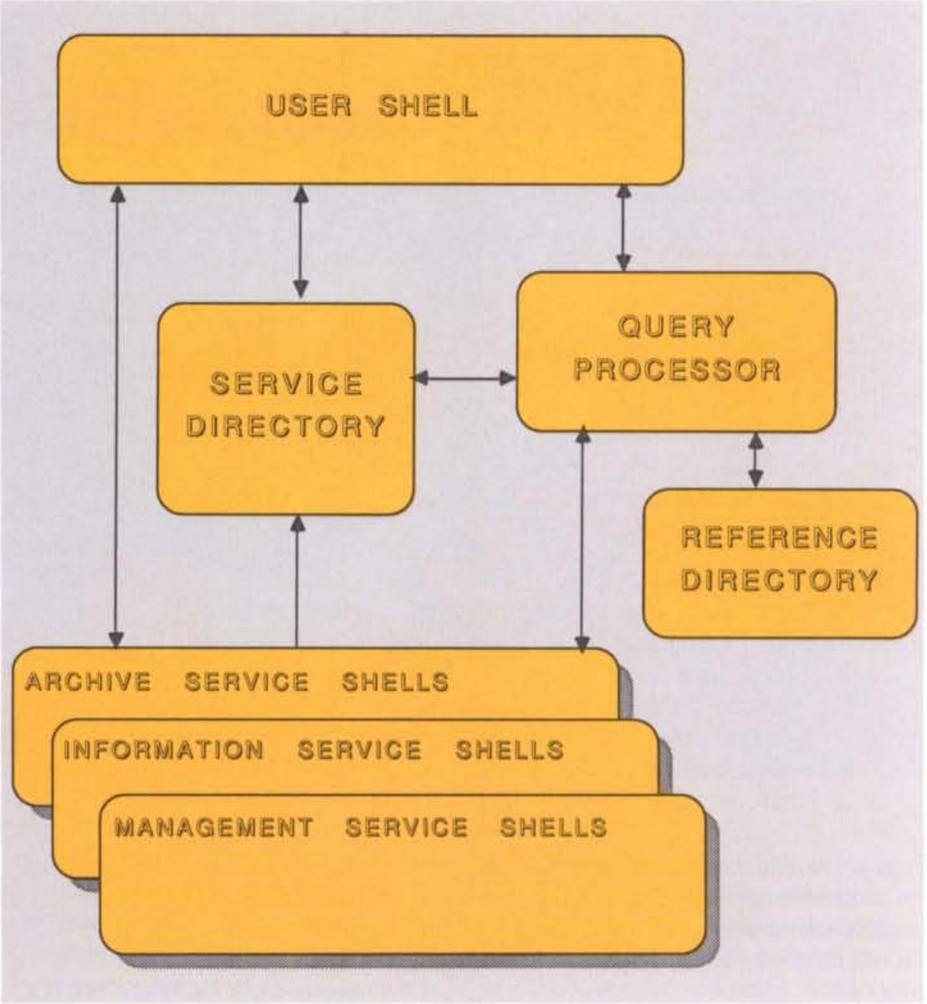
- the IUE Vilspa Database, in Villafranca, Spain
- the Exosat Results Database, at ESTEC, Noordwijk, The Netherlands
- The SIMBAD Database, managed by the Centre des Données astronomiques de Strasbourg (CDS), France
- The Space-Telescope Database, at the Space Telescope European, Garching, Germany
- the World Data Centre C1 and the Geophysical Data Facility managed by the Rutherford Appleton Laboratory, Chilton, Didcot, UK
- relevant bibliographical databases offered on-line by the ESA Information Retrieval Service (IRS), ESRIN, Frascati, Italy.

The pilot-project scenario will moreover, include a Master Reference Directory situated initially at ESRIN and gateways to the EARN and JANET networks in Europe and SPAN in the USA.

Functional architecture

An evolutionary approach will be adopted in the deployment of ESIS services. This means that, in a first phase, basic functionality will be deployed, making use of the backbone network and of existing infrastructure, as well as of available software and facilities. The pilot distributed system will subsequently be implemented on top of the basic layer. This approach ensures full compatibility between the users' current functions and the evolving ESIS environment. New services will gradually be integrated in a fully transparent manner, giving users increasing functionality periodically.

Figure 2 — Top-level functional block diagram. The User Shell obtains from the Service Directory all services available to a certain user at any given time. These services are approached through shells providing controlled access and the translation of ESIS requests into the local environment. The Query Processor and Reference Directory modules provide an integrated view of the information contained in the system



All ESIS modules are conceived to work in a highly distributed environment. Commercial products will be implemented whenever the required functionality is available and as long it is possible to remain independent of a particular vendor. A user activating an ESIS user-shell has access to all functions integrated into the system, independent of the local computing environment and method of accessing ESIS. On-line help and a tutorial service are provided. Services available in the start-up phase of the pilot will include direct access to remote archives, and network functions such as electronic mail and file transfer.

The user interface is designed to support a large number of input devices, including terminals, work stations and personal computers, and offers a highly flexible selection of dialogue modes such as menus, commands and forms. During 1988, a prototype user-shell will be installed at selected user centres, to be tested against user interface requirements, thereby encouraging users to become involved in the testing process. The final goal is to distribute the

ESIS user-shell to all clients for installation on personal work stations, local-area-network servers or site hosts.

The heart of the system is the Service Director (Fig. 2), which maintains a database of the characteristics of the registered servers, including network address, access interface and privileges, and keeps track of current availability of services. The Service Directory is structured as to provide a controlled view of the services available, respecting the security requirements of facilities and sites. In this way, all of the services available to any given client (user-authentication) at any given time (current availability) can be identified.

The Query Processor and Reference Directory modules are the part of the system where knowledge about the information contained in ESIS is stored and handled. These subsystems are the major challenge in the implementation of ESIS, since their function is the most innovative aspect of the whole system. The user interacts with these objects through discipline-specific query languages which model the user's view of the information and implement the interface between the user's vocabulary and the description of the data.

Network structure

ESIS will not set up a new network, but will make extensive use of ESA's existing infrastructure, supplying additional capacity or equipment when necessary. The system envisaged applies an evolutionary strategy based on a compatible mixture of DES-net and ISO/OSI protocols. This is compulsory in order to achieve commpatibility with current functions (European SPAN) and to implement enhanced services such as X.400 (Message Handling System) and FTAM (File Transfer and Management), which are oriented towards an open environment. ESIS will not develop network-protocol software of any kind. Instead, a layered approach is being followed in which a nonavailable function, for instance data presentation, is replaced by an 'empty box' waiting to be filled by a specific implementation. This strategy requires a homogeneous structure for the complete backbone network, consisting of an X.25-based, packet-switching infrastructure supporting both DEC-net and OSI services. The backbone will be extended to all locations where archives or user populations need to be reached. Users can access ESIS services in a variety of ways: by directly connecting their machines to the backbone network, by accessing national PTT data networks, by using OSI services on other networks such as X.400 in EARN, or eventually via the gateway functions linking ESIS to other research networks.

Conclusions

The development of the ESIS programme marks the beginning of a new area in the exploitation of space-science data with new tools making it possible to exploit data more throughly for scientific analysis. The integrated and single-point access to different databases will facilitate multi-mission, multi-spectral analysis, while discipline-specific query languages will permit scientists to access measurements made by satellites with which they are not really familiar. Finally, the network-based information services will enhance connectivity among co-investigators and facilitate international collaboration in space research.

The pilot phase will demonstrate the feasibility of the concepts that have been presented and result in a basic hard- and software infrastructure on which further information systems applications can be developed. In a first phase this infrastructure will serve the astronomical and solar-terrestrial communities, but it could also be used to build up information systems for the Microgravity and Earth Observation communities, which have very similar information requirements.

ESIS will serve as a vehicle linking service providers (archiving facilities, database producers, etc.) and their clients, itself providing the access service. In this context, ESIS is conceived — and can only succeed in meeting its goals — as an open system. The term 'open system' is understood here as an environment with heterogeneous components and evolving in nature — e.g. an environment in which new services are made available while maintaining continuity both in access method and in the overall view of the information. Research institutes that develop new (results) databases will be encouraged to make them available to the community at large by integrating them into the system.

Only if ESIS is built on the basis of full collaboration between participating working groups, archiving centres, network developers and managing centres will the final system achive the degree of functionality envisaged and — most importantly — only then will the users accept it as the highly beneficial tool it is designed to be.

Acknowledgements

The authors would like to acknowledge the enthusiasm shown by the many people involved in the discussions that have led to the ESIS design presented here. Without their contributions, the project would never have achieved its current status. In particular, G. Russo and A. Richmond (ESO/ST-ECF), F. Ochsenbein (ESO) and P. Shames and S. Lubow (STSci) have contributed many ideas to the system presented.

Telescience: Preparing for the Interactive Operation of Columbus Payloads

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Users of the Columbus elements will operate their experiments under very different conditions from previous space missions. A major objective of the international Space-Station/Columbus Programme is to provide users with 'laboratories in space' in which long-term basic and applied research can be undertaken.

'Telescience' is the concept put forward by users to describe the way in which research will be carried out in these laboratories. Experiments will be controlled by ground-based investigators and executed using a variety of techniques, including automation, telemanipulation and robotics, but also enlisting the assistance of astronauts when available.

A Telescience Preparatory Programme has been undertaken by the Agency with the objective of defining the operational limits of the concept. Scientists, system designers and operators will participate in this evaluation.

A so-called 'Telescience Test Bed', installed at ESTEC, will provide the tools for the verification of the system design specifications and the operations procedures. It will also constitute an experimental facility for the familiarisation of potential users with the interactive operation of payloads on Columbus.

Introduction

The motivation for implementing interactive payload operation on Columbus is twofold. Firstly, the laboratory modules are intended to remain in space for a period comparable to the lifetime of a terrestrial laboratory, despite the fact that their experimental facilities, as on the ground, will be periodically renewed. Scientists need to plan and execute their investigations much as they would in their own laboratories. They need to be able to oversee the execution of their investigations, review the results and, in the light of the outcome, proceed to new experiments and observations. In other words, the experiment equipment should, ideally, be transparent to the investigators, despite its remoteness.

The second consideration is more practical. The presence of astronauts onboard the Columbus Attached Pressurised Module (APM) and the other laboratory modules of the Space Station will be a considerable help in carrying out many of the planned investigations. In some cases, the assistance of astronauts will be essential, though the crew time planned for each experimental facility, averaged over the Station, is of the order of one hour or less per day. Moreover, on the Man-Tended Free-Flyer (MTFF), the experiments need to run with periodic visits by astronauts, say every six months. The effectiveness and efficiency of the crew can be greatly increased by linking them with the ground-based investigation teams.

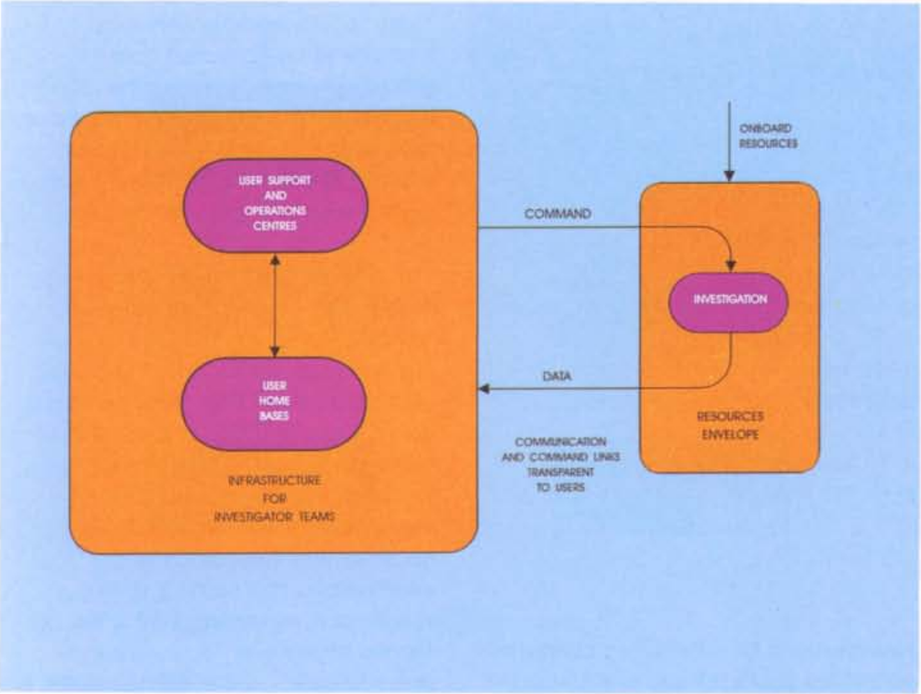
The concept of 'telescience', first proposed in the United States, has been put forward by the user community to describe the fully interactive mode of ground-based investigators operating experiments in space. It is an operating mode that will allow experiments to be performed under conditions similar to those in terrestrial laboratories. The goal is to minimise the constraints imposed on investigators by the remoteness of the experiment facilities.

The concept is not new, in that remote experimentation is routinely carried out on the ground in many hostile environments. The technique has also been used on previous unmanned space missions. In particular, most space-based astronomical telescopes (IUE, Exosat, etc.) have been operated interactively from the ground. What is new in the Space-Station/Columbus context is the scale and complexity of the payload, involving many disciplines, and with considerable emphasis on microgravity applications. The payload operations also have to accommodate the perspective of working with an infrastructure intended to operate well into the next century.

Telescience operations are implemented by providing the investigator teams on the ground with:

- a comprehensive set of measurements and observations concerning the experiment, to enable the team to oversee its execution and to evaluate its outcome;
- command facilities to enable the team to control the scientific conduct of the experiment, within allocated resources

Figure 1 — The concept of interactive 'telescience' operations



and giving due consideration to safety aspects;
- a user-friendly operational environment in the form of supportive user services and operational procedures.

It should be noted that the emphasis is on *interactive operations*. True real-time or near-real-time operations are occasionally required. The general requirement is better stated as on-line operations, with time constants characteristic of the experiments being performed.

Telescience and the user disciplines on Columbus

The core Space Station, together with the Man-Tended Free-Flyer, will be the first really large, multidisciplinary, serviceable and long-duration infrastructure to become available for basic and applied microgravity research and for the development of space-based production activities. These disciplines, although relative newcomers in space, are based on well-established scientific and industrial activities in the materials and life sciences. The research methodology applicable in these disciplines needs to be incorporated into the working practices being developed for the space-based laboratories.

The iteration involved in any experimentation whereby subsequent steps depend on the outcome of previous steps is based on the scientific judgement of the investigators. In order to ensure that this process is not unduly slowed down, investigator teams need to operate in 'telescience mode'.

For the different disciplines represented in microgravity research — life, materials and fluid sciences — telescience techniques will speed up the turnaround time for investigations by providing a complete overview of the experimental process and its outcome, including an adequate amount of onboard analysis of samples. Once the appropriate decisions have been taken on the continuation of the experimental programme, in terms of different process control parameters, or even simply the request to repeat an experiment run, commands can be sent and executed to implement the investigators' wishes.

This mode of operation can bring considerable savings in crew time: in materials-science experiments, such as crystal growth, by affording closer control over the growth process; in fluid sciences, which often requires considerable processing support as well as scientific judgement for evaluating the outputs of experiments on-line.

Studies carried out by ESA's Telescience User Team, among others, on a wide range of model experiments have provided many concrete examples of how to plan efficient payload operations based on the telescience approach.

In the case of microgravity investigations, the experiment techniques often involve complex operations and handling which are not amenable to simple automation. The most efficient way to carry out such complex experiments is to find the right balance between automation, the use of robotics and telemanipulation, the assistance of astronauts when available, onboard analysis and/or sample return, and the on-line application of scientific judgement.

The classical space sciences (space astronomy, exploration of the solar system and study of the space environment) have a long history of using remote-control techniques on unmanned missions. On-line control of such investigations (e.g. a multi-spectral auroral telescope on the Polar Platform) from the ground would follow well-established techniques which fall naturally within the telescience concept.

Telescience operations: their characteristics and requirements

There are some significant differences in between the user operations conceived for the Columbus pressurised elements and the practices developed for operating payloads on Spacelab and Shuttle flights. At the root of these differences lie the finite duration, the tightly planned mission profile, and the long period of training and preparation

Figure 2 — Pilot investigations proposed by the Telescience User Team

Figure 3 — Technical content of the Telescience Programme

Pilot Investigations Proposed by the Telescience User Team

- Human physiology (contributed by N. Foldager): The influence of microgravity on cardiovascular adaptation to dynamic leg exercise in man
- Fluid science (contributed by R. Monti/I. Martinez): Fluid dynamics experiments on Marangoni flows
- Material sciences (contributed by H. Schmidt): Optical observation of solidification of undercooled metallic drops
- Botanical sciences (contributed by D. Heathcote): Determination of the gravitropic responses of seedlings to gravitational stimuli of controlled duration and magnitude
- Medical diagnosis (contributed by N. Foldager): Investigation of telescience techniques for tele-diagnosis

for Spacelab flights, compared to the indefinite lifetime and continuous operations planned for the Space Station.

A key requirement for telescience operations is a relative freedom for users vis-a-vis the resources used by their payload. While an investigation is in progress, users may require more or fewer resources than originally requested or planned. In cases where a request for extra resources is made, it should be examined on-line and acceded to if those resources are indeed available. The operating authority responsible for the user's resources should be able to vary allocations even during the experiment's run-time.

Control of resources, and therefore the supervision of commands from the user to the payload, lie at the heart of interactive operations. If the system is to be 'operations-friendly', users should be able to command their investigations, and therefore use their resources, based on transparent operational supervision. Some resources, such as power and data rates, are relatively easy to control in a flexible manner. Others, such as inter-payload interference need more elaborate handling. Safety must remain the highest priority task of the supervisory authority.

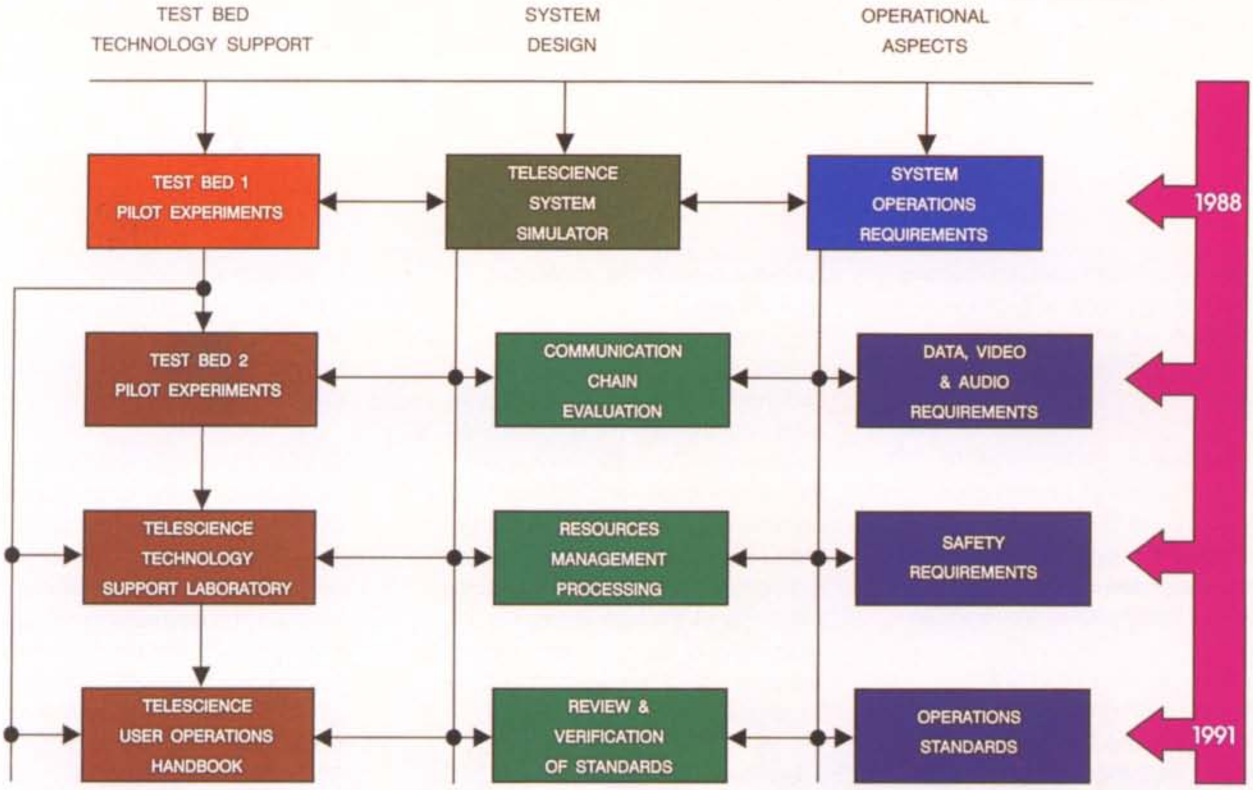
New methods for supervising commands sent to the payload need to be developed. In the complex operational modes envisaged for the Columbus payload, the effect of any single command will depend on its context and on the previous payload configuration. Given the volume and complexity of ground or onboard control software and the expected command traffic to the payload, the checking of each command is an unrealistic aim, which would create a bottleneck for telescience operations. The key feature is the a priori agreed configuration of the payload and the resources allocated for operation; a supervisory function, generalising the concept of housekeeping data monitoring and checking that resources are not exceeded, is likely to yield the most effective procedure for ensuring correct and safe functioning.

Link delays and link continuity play an important role in telescience operations. As already noted above, the telescience concept is not necessarily based on real-time operations, but knowledge of the range of link delays is important for delineating the functions for each investigation that can be controlled from the ground and those that have to be automated or controlled by the crew. It is expected that a control-loop delay of the order of 10 s would enable most functions to be controlled from the ground. Link continuity, on the other hand, has important safety implications: if ground control is interrupted due to unplanned link outages, investigations must remain in a safe configuration.

Interactive operations are enabled by providing investigators on-line with a comprehensive data set. A survey of planned microgravity experiments has shown that digital data rates will range from 0.1 to about 100 kbit/s, including housekeeping and other monitoring functions. However, for microgravity payloads, remote visual access is a necessity. For the majority of investigations, this consists of single images at rates varying from a few per second to one every hour. In some cases, normal video at 25 frames/sec is required for limited periods. There is great variety in the requirements concerning resolution, grey-scale or colour quality, and illumination. For the majority of investigations, the inclusion of a dedicated vision system is the best means of satisfying their requirements. The flexible handling of both visual and digitial data onboard and on the ground is an important user requirement.

The implementation of telemanipulation, as one of the techniques used in the control of experiments, will present the greatest challenge in developing telescience operations. It will require an integrated approach to on-line visual access to the investigation, a secure telecommand and operations environment, control of link parameters and the development of appropriate man/machine interfaces. Communications with the crew, when assisting with the investigation, requires the use of good-quality audio links. An uplink video channel will also occasionally be required for teleconferences between the crew and the specialist teams on the ground.

The user operations need to be organised in a way that fully exploits the



availability of telescience techniques. The proposed functional concept is one of a User Support and Operations Centre (USOC). Depending on the type of payload to be controlled (multipurpose facility, simple experiment, etc.), its origin (ESA, national agency, research institute, commercial company, etc.), and the discipline to which it belongs (materials, fluid, or life sciences, space science, etc.), the corresponding USOC functions may be located at a discipline-specific user centre or directly at the Principal Investigator's site, i.e. the User Home Base (UHB).

The USOC will operate the 'system' element of the payloads, such as the generation of the payload-operations time line and the resources profiles for submission to the Payload Operations Coordination Centre (POCC). The experiments themselves will be performed interactively by the Principal Investigator from his/her home base, or on site from the USOC. The POCC will coordinate all USOC requirements and define resource envelopes. It will also monitor the experiment and facility housekeeping data to make sure that experiment resources are not exceeded. Data uplinks (commands, messages, etc.) from USOCs or from UHBs will be routed and coordinated by the POCC. Although the main functional requirements for the USOCs have already been outlined, detailed definition of their interfaces, procedures and management structures remains to be carried out.

The Telescience Preparatory Programme

ESTEC has supported two activities to date on telescience operations, both performed in the period April 1986 to June 1987. In the first, a Telescience User Team was set up, consisting of scientific consultants with the task of investigating the concept of interactive operations, their benefits and requirements. About fifteen scenarios have been investigated in the area of fluid, materials and life sciences. The benefits of interactive operations were immediately obvious, ranging from a quantitative reduction in crew time required, to more qualitative benefits, such as faster turnaround between experiment sequences and accelerated evaluation of experiment results.

In the second activity, the Telescience User Team derived requirements for the Columbus-element utilisation and operations studies. The Team proposed five pilot experiments to be conducted on a Test Bed at ESTEC. These were chosen because they represent a wide range of functional and operational requirements. A study was carried out by Matra-Espace and MBB-ERNO to provide a preliminary assessment of the telescience concept's implementation.

In the 1988 — 1991 time frame, ESA is planning a Telescience Preparatory Programme, centred around three lines of coordinated activities:

(i) test beds and technological support
(ii) system studies and end-to-end simulation
(iii)operational-requirements analysis.

A Telescience Test Bed, installed at ESTEC, will provide the ability to operate ground-based pilot experiments interactively. Simple but representative experiment hardware will be interfaced to the Columbus Data Management System (DMS) and Columbus Module Control Station (MCS) test bed already available at ESTEC. The Telescience Test Bed will contain the tools needed to evaluate the operational limits of the concept and to verify the methods of operation, user interfaces, protocols and standards. It will provide the opportunity for prospective

Columbus users to familiarise themselves, in an experimental phase, with the operational features and interactive operational procedures of their experiments.

The systems studies are aimed at the definition of an accurate performance model of the ground communications infrastructure to be used for telescience operations. Integrated end-to-end standards-compability tests are foreseen.

The results of the analysis of the operational requirements will be reviewed against the Columbus System Requirements Document (SRD) and the operations concepts recommended by the ESA Central Design Authority (CDA). Detailed specifications concerning data quality and safety requirements will be derived, and operations standards will be recommended.

The Telescience Test Bed

The aim with the Telescience Test Bed is to derive from ground-based pilot experiments data applicable to:

- the need for crew member intervention
- the user facilities required on-board the Columbus elements (remote vision access, telemanipulator, payload data processing), and the applicable technologies
- the access by the user to his experiment via the ground communications system and the in-orbit infrastructure (Data-Relay Satellite System and Columbus elements)
- the performance requirements for the communications links between the User Home Base and the payload
- the control procedures to guarantee the safety of the operations, the respecting of the resource limits, and the absence of interference between simultaneous operations.

The Test Bed will therefore consist of five building blocks:

- The Payload, made up of several pilot experiments recommended by the Telescience User Team and representative from the operations point of view of the experiments to be flown on-board the Columbus modules.

- The Module Control Station (MCS), represented by the Module Control Station Test Bed existing at ESTEC. This test bed contains the facilities needed by the crew member to monitor experiment status with a view to possible intervention. Common man/computer interface techniques will be used in the Module Control Station and the Telescience User Work Station.

- The Data Management System (DMS), represented by the Data Management System Test Bed existing at ESTEC. The DMS Test Bed implements the on-board data communications function, the internetworking function with the MCS Test Bed and the transmission of audio data, according to the recommendations of the Consultative Committee for Space Data Systems (CCSDS).

- The Telescience User Work Station, offering the experimenter all the command and monitoring facilities needed to interact with his experiment. The facility to route selected data for archiving and off-line analysis will also be available. Means to communicate with the Payload Operations Control Station are foreseen.

- The Payload Operations Control Station, managing the communications and the on-board resources and controlling the real-time operations. A computer work station will be used to enter the constraints on the resources available to each user (channel capacity, experiment DC power, etc.). The user's commands to the payload and the payload housekeeping data will be monitored by the computer to check the validity of the operations against pre-defined 'rules'. Interventions from the Payload Operations Coordination Centre will be reflected at the level of the man/machine interface of the Telescience User Work Station.

- The Communications Network, carrying the experiment output data, the experiment command data, and the operations control data between the user, the payload and the operations controller. Initially, the

Figure 4 — Functional diagram of the Telescience Test Bed

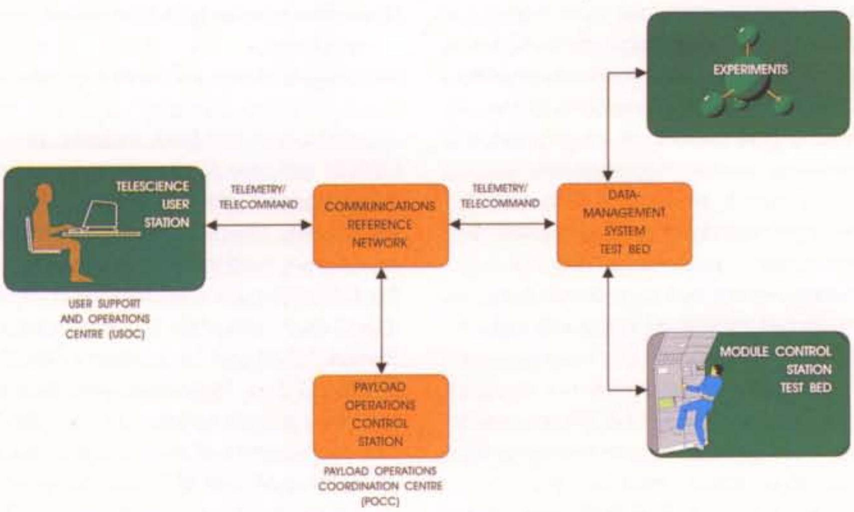
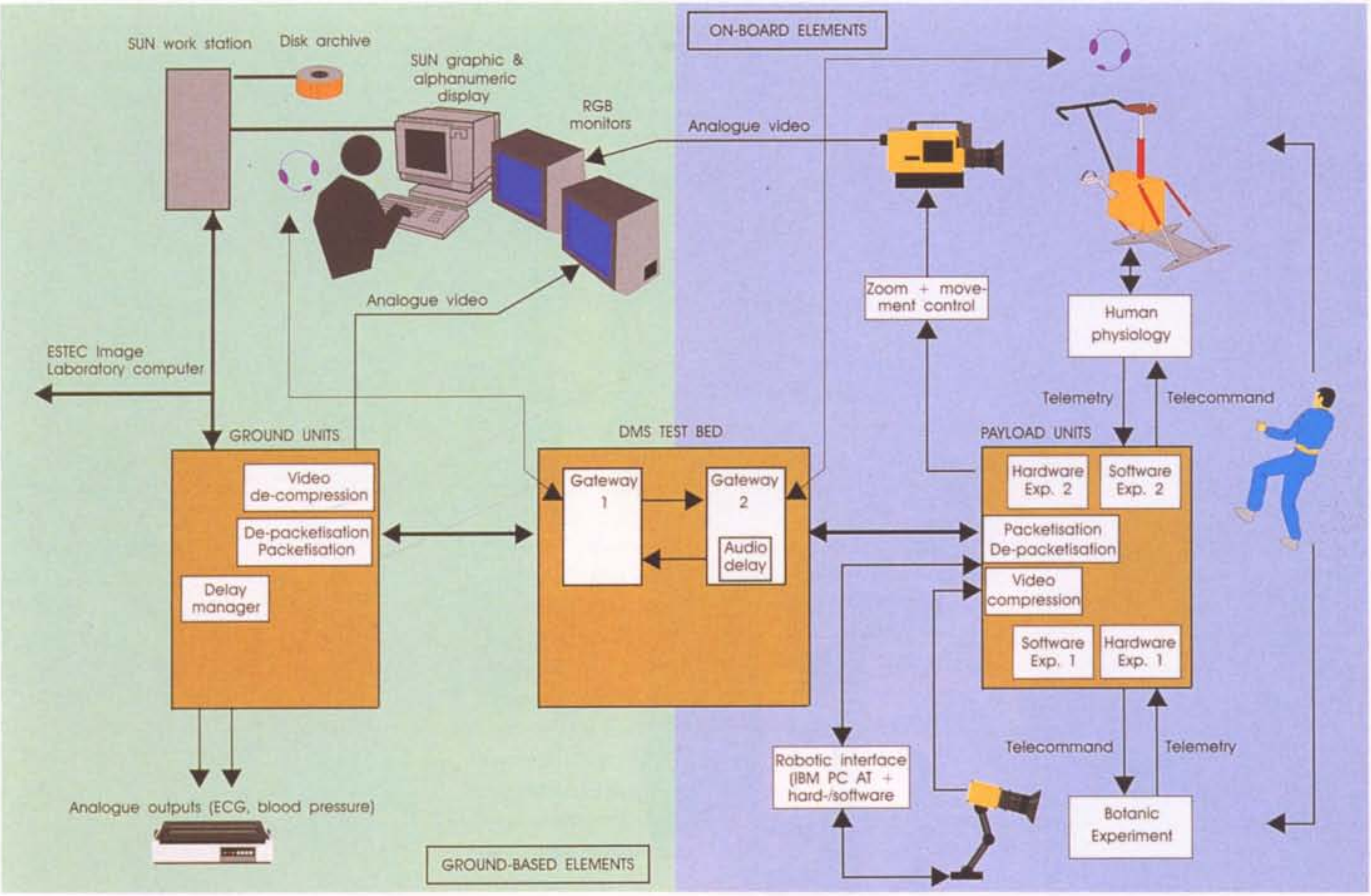


Figure 5 — The ESTEC Telescience Test Bed, Phase 1



network will be represented by a software simulation of the effects on telescience operations of network performance (delays, link errors, interruptions, access protocols, etc.).

The first phase of the Test Bed's implementation started in June 1988 and will be completed in March 1989. Two pilot experiments will be connected to the Test Bed: the Human Physiology Investigation (contributed by Dr.N. Floldager, Aerospace Medical Institute, Copenhagen) and the Botanic Investigation (contributed by Dr.D. Heathcote,University College, Cardiff, UK). In addition, a robot arm will be available, permitting an assessment of telemanipulation tasks.

During the Human Physiology Investigation, the investigator has online control of an ergometer bicycle. He can monitor the ECG and the blood pressure of the test subject whilst applying varying workloads. An audio and video link is established for the duration of the investigation.

The plant biologist, during the Botanic Investigation, can monitor the responses of seedlings to light stimuli of durations and amplitudes which he can control. Remote visual access is provided by a video camera mounted on a telemanipulated arm. The same camera is used by the investigator to take stereoscopic images in order to determine (off-line) the displacements of shoot tips.

The investigators will be asked to repeat their experiments with different link delays and under different link-quality conditions.

Conclusion

The novelty of the Columbus Programme and the unprecedented opportunities it offers for microgravity research in particular have led to a new methodology for payload operations being considered. The telescience concept is well-matched to the long-term utilisation of the Columbus elements. Its functional characteristics and the key technical and management issues its application raises are well understood, as this article has hopefully demonstrated. An evaluation programme using the test-bed concept and associated technical studies has been undertaken to derive concrete inputs for its implementation. Eventually, in-flight testing of interactive techniques on preparatory Spacelab flights will be needed. However, there is already little doubt that the routine use of these techniques will greatly increase the efficiency of Columbus payload operations, to the benefit of the return to the end user, the scientist on the ground.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Ariane-4: Europe's Launcher for the Next Decade

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The successful launch on 15 June 1988 of the first Ariane-4 marked the conclusion of its six-year development programme, aimed at providing Europe with a launcher that will meet foreseeable market demand in the 1990's. This article reviews the main elements of that programme and the primary features of the new Ariane-4 vehicle.

The decision to carry out the Ariane launcher development programme was taken at the European Space Conference in July 1973, when it was decided to merge ELDO (the European Launcher Development Organisation) and ESRO (the European Space Research Organisation) into a single European Space Agency (ESA) and to carry out the 'Ariane' launcher, Spacelab and Marots (satellite) programmes as major future European endeavours. Whereas only four European States had supported Europa-II and III, ten of them — all members of ESRO — decided to participate in the new Ariane Programme.

This Programme has proved to be one of the most important and fruitful of ESA's undertakings. Since its first successful launch on 24 December 1979, the Ariane launcher has shown itself to be fully competitive on the World market. Larger and more powerful versions have already been developed (Ariane-2 and -3) and development of the Ariane-4 launcher, which is to be the launch workhorse for the next decade, has been completed with the successful flight of Ariane-401 on 15 June 1988.

The Ariane-4 development programme

The decision to develop Ariane-4 was taken by ESA on 13 January 1982, when the need became evident for a more powerful and more flexible launch vehicle (compared to Ariane-2/3) to match the trend in the payload market. The major Programme objectives were to:

- achieve a significant increase in launch capability (payload mass and volume)
- maintain the capability of multiple launches
- create a range of mission-adaptable configurations
- improve the flexibility of launch operations.

The Ariane-4 Programme has included the development and qualification, both on the ground and in flight (by one demonstration flight, which took place successfully on 15 June 1988; see pages 96—97), of the launcher's modified or new elements. The improvement in performance has been achieved by increasing the first-stage propellant mass and by attaching newly developed, powerful solid or liquid boosters. The diameter of the payload fairing has also been increased to accommodate bigger payloads.

A new supporting structure, the SPELDA — Structure porteuse externe pour lancements doubles Ariane — allows multiple payload launches. Fairings of various heights and different sizes of SPELDA allow adaptation of the launcher to the volume of the payloads to be launched. Various launch performances can be catered for by selecting the number and type of boosters. In this way, six different versions of Ariane-4 can be arrived at.

A new launch complex, ELA 2 (Ensemble de lancement Ariane No. 2), has been built to reduce the interval between launches to one month. This allows both a higher launching rate and greater flexibility in launch scheduling.

The majority of the Ariane-4 development work was completed by 1986, manufacture of the flight hardware for the demonstration flight having started in 1985. All launcher hardware except the third stage was ready by November 1987. The demonstration flight had to be postponed after the failure of flight 18, when complementary development work on the third-stage engine repeatedly deferred its availability for the first Ariane-4 launcher.

The launch campaign finally started on 1 December 1987, before being interrupted and then resumed again on 24 March 1988, leading up to the flawless first launch on 15 June.

Figure 1 — The six versions of the Ariane-4 launch vehicle

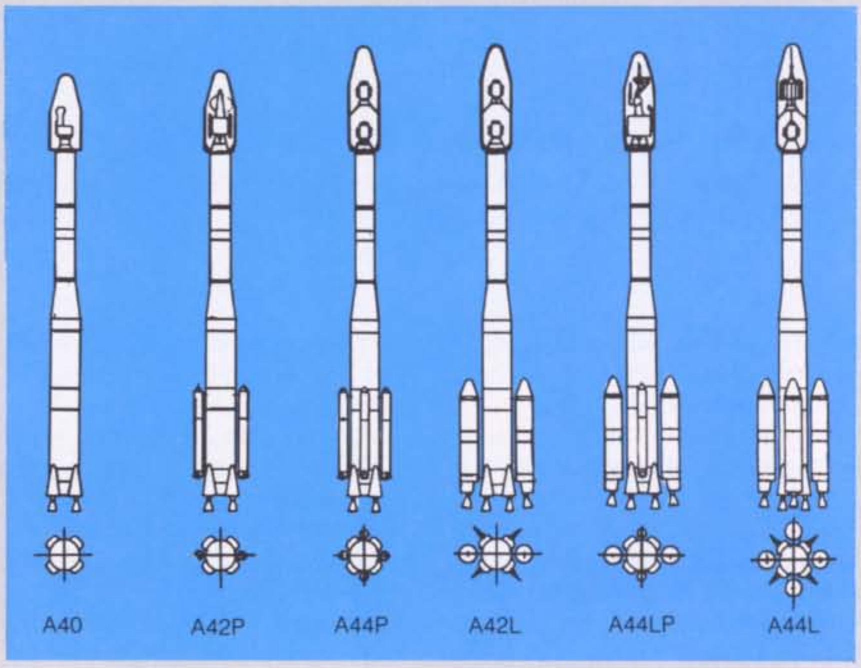


Table 1 — Participating Member State contributions to the Ariane-4 Programme

Participating ESA Member State	Financial contribution to programme cost (%)
Belgium	5.64
Denmark	0.86
France	61.99
Germany	17.53
Ireland	0.05
Italy	4.93
The Netherlands	1.30
Spain	1.86
Sweden	0.87
Switzerland	1.45
United Kingdom	3.52

The total cost of the Ariane-4 development programme, including the demonstration flight and the new ELA-2 launch facility, has been approximately 650 MAU, divided roughly as follows:
- Launcher development 340 MAU
- Demonstration flight 100 MAU
- ELA-2 210 MAU.

These costs have been shared by the 11 participating Member States, as shown in Table 1.

The Ariane-4 launch vehicle

The Ariane-4 launch vehicle can be flown in each of the six different versions shown in Figure 1, depending on the payload capability and type of final orbit required (Table 2).

The standard Ariane-4 Geostationary Transfer Orbit (GTO) has a perigee of 200 km, an apogee of approx. 35 800 km, and its plane is inclined by 7° with respect to the equator.

NEW FEATURES OF ARIANE-4 (compared with Ariane-3)

- New fairings with an external diameter of 4 m and three different heights (8.6 m, 9.6 m and 11 m)
- New payload adaptors (937B, 1194A and 1666)
- New SPELDA carrying structure for dual launches, available in two different heights (2.8 m and 3.8 m)
- New Vehicle Equipment Bay
- New onboard computer and a new emergency flight-guidance unit (gyro-laser)
- New flight-control concept, with digital flight control
- Strengthened second- and third-stage structures
- Very substantially modified first stage:
  - tanks stretched to increase propellant mass from 140 to 226 t
  - new water tank
  - new propulsion-bay layout
  - strengthened structures
- Modified solid-propellant boosters (9.5 t of grain instead of 7.3 t)
- New 39 t capacity, liquid-propellant boosters fitted with Viking engines.

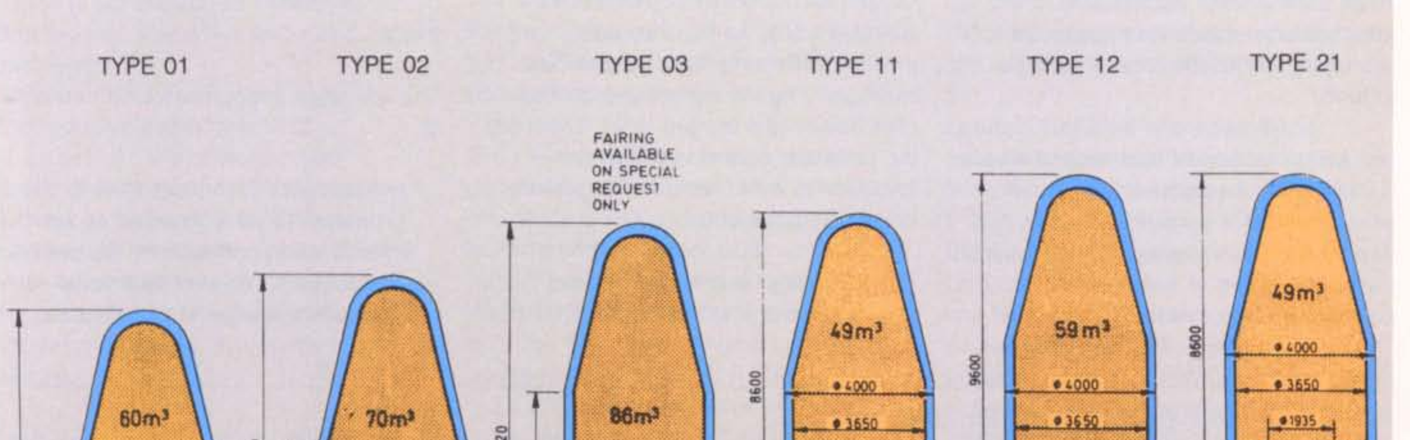


Figure 2 — Ariane-4 payload-volume configurations

Table 2 — Payload capabilities of the six Ariane-4 launch vehicles

Projected orbit	Payload capability (kg) 40	42P	44P	42L	44LP	44L
Geostationary Transfer Orbit (GTO)	1900	2600	3000	3200	3700	4200
Heliosynchronous orbit	2700	3400	4100	4500	5000	
Low Earth orbit	4600	5000				

The heliosynchronous orbit is usually used for earth-observation missions, since a satellite in this orbit always passes over the same point on the Earth at the same time of day. A typical heliosynchronous orbit would be circular with a height of 800 km and an inclination of 98.6°.

A typical circular low Earth orbit has a height of 450 km and an inclination of 28.5° (typical Space-Shuttle orbit).

For the Ariane-4 demonstration flight, a launch into GTO with a 44LP version of Ariane was selected, this being considered the most representative for other missions with other versions of the launcher.

Payload accommodation
The variety of payload-volume configurations resulting from the possible combinations of fairings and dual-launch structures is shown in Figure 2.

The new fairing has an external diameter of 4.0 m, compared with the 3.2 m of the Ariane-2/3 fairing. It is made of carbon-fibre-reinforced plastics in order to keep its mass low. At separation, which is normally initiated at an altitude of about 110 km, the clamp band that holds the fairing to the vehicle is first released. A pyrotechnic cord then cuts the fairing into two vertical halves and pushes them apart.

The Ariane-3 SYLDA dual-launch structure (Système de lancement double Ariane) is entirely enclosed by the fairing and therefore offers a smaller volume to the satellite inside it. The new Ariane-4 SPELDA dual-launch structure offers the same 4 m diameter to the satellite in the lower position that the fairing itself affords to the satellite in the upper position.

The Vehicle Equipment Bay (VEB)
The VEB, which carries most of the launcher's electrical equipment, has been entirely reconfigured to cope with the higher loads introduced by the larger and heavier payloads, SPELDA and

fairing. Its structure is fabricated in four parts from a honeycomb material with carbon-fibre facing. This new configuration has two considerable advantages compared with Ariane-2/3:

- First, it allows separation of the equipment-carrying platform from the load-carrying structure, thus allowing completely independent integration of the payloads with the SPELDA and the fairing in the clean rooms of the payload-preparation buildings, after the equipment platform has already been installed on the launcher.
- Secondly, it allows easy access to the launch-vehicle equipment for checkout or any necessary interventions after the SPELDA/fairing/payload cluster has been mounted on the launcher.

Stage separation

The stages are separated by explosive cords fitted into the rear skirts of the second and third stages. The stages are moved away from each other by retro-rockets mounted on the lower stage. Acceleration rockets fitted to the upper stage allow a small acceleration to be maintained to ensure homogeneous propellant flow to the engine during ignition.

Separation of the first and second stages is initiated by the onboard computer when the inertial guidance platform detects half-thrust decay in the first stage (due to depletion of one of the propellants). Separation of the second and third stages is initiated by the onboard computer when the increase in velocity due to the second-stage thrust has reached a pre-determined value.

Guidance and control

The Ariane-4 guidance system consists of two platforms: a classical inertial platform (like that on Ariane-2/3) used in normal circumstances, and a gyro-laser platform to which the onboard computer switches if the main platform should malfunction. A digital flight-control system, another novelty on Ariane-4, replaces the analogue control system used on Ariane-2/3. The tracking system, with two redundant radar transponders, the fully redundant destruct system, which can receive a distruct command from the ground (the only intervention possible from the ground), and the telemetry system are practically unchanged compared with Ariane-2/3.

Propulsion

The *third stage* (called H10) contains 10.7 t of cryogenic propellants, i.e. liquid oxygen and liquid hydrogen, in two aluminium-alloy tanks. They are pressurised during flight by gaseous hydrogen (the hydrogen tank) and by cold helium (the oxygen tank). Externally, the tanks are coated with thermal insulation to avoid rapid heating of the cryogenic propellants.

The third-stage engine, designated HM7B, functions with a combustion-chamber pressure of 37 bar and develops 62 kN of thrust. Its burn-time is approximately 735 s. The engine is linked to the conical thrust frame through a gimbal joint, allowing swivelling of the engine for pitch and yaw attitude control. Gaseous-hydrogen thrusters provide rotational momentum for roll control. These thrusters, together with additional hydrogen thrusters, ensure attitude control of the stage and the attached payload about all three axes after engine cut-off.

The *second stage* (known as L33) carries 34 t of 'storable' propellants (N_2O_4 + UDMH/hydrazine hydrate) in aluminium-alloy tanks. Its Viking-IV engine functions at a chamber pressure of 58.5 bar and develops 786 kN of thrust in vacuum. The burn time is 130 s. Both tank compartments are pressurised by helium gas stored in spherical bottles at a pressure of 300 bar at ambient temperature. The engine can be swivelled about two axes to allow yaw and pitch control. Roll control is provided by two tangential hot-gas jets (50 N of thrust).

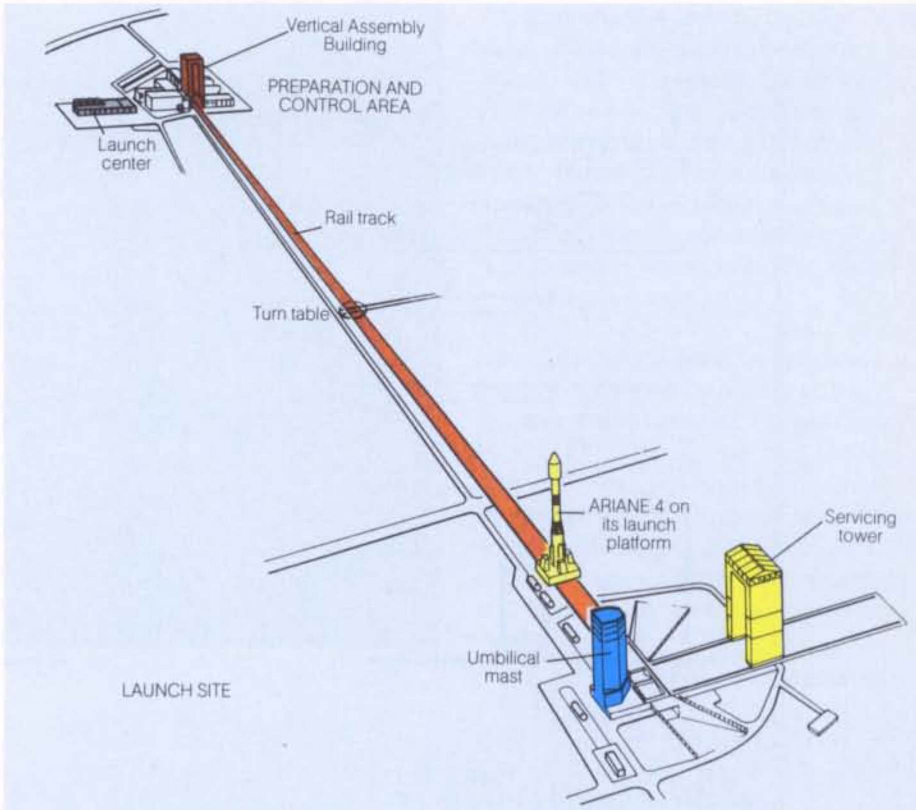
The *first stage* (designated L220) consists of:

- two identical, cylindrical, steel propellant tanks, connected by an intertank skirt of the same diameter
- a water tank, made of reinforced plastic and located in the intertank

Table 3 — Ariane-4 mass and dimension data

Element	Dry mass (kg)	Filled propellants and liquids (kg)	Height (m)	Diameter (ext) (m)
Fairing	725 to 782	—	8.6 or 9.6	4.0
SPELDA	400 to 450	—	2.8 or 3.8	4.0
Vehicle Equipment Bay (VEB)	520	—	1	2.6 to 4.0
Third stage	1200	10 700	9.9	2.6
Second stage	3600	34 000	11.5	2.6
First stage	17 500	234 000	25.0	3.8
Liquid-propellant booster	4500	39 000	19.0	2.2
Solid-propellant booster	3200	9500	12.0	1.1
Launcher (44LP, without payload)	39 300	375 700	59.8	

Figure 3 — Layout of the ELA-2 launch complex



skirt, supplying the main engines and containing a maximum of 8200 l
- a conical interstage skirt connecting the first and second stages
- a forward skirt on which the eight first-stage retro-rockets are mounted and to which the interstage skirt is connected
- a cylindrical thrust frame, the upper part of which is connected to the UH25 tank and on whose lower part the four Viking-V engines are mounted.

The water tank is completely new and has been specially developed and fully qualified under the Ariane-4 Programme. The other parts of the stage have been strengthened to cope with Ariane-4 loads. The capacity of the propellant tanks has been increased to extend the burn-time from 135 s to about 206 s.

The first-stage propulsion system consists of four Viking-V engines developing a total thrust of 2700 kN at lift-off. Each engine is an independent assembly supplied with propellant and water via its own valves.

The propellants used are UH25 (a mixture of 75% unsymmetrical dimethylhydrazine and 25% hydrazine hydrate) as fuel and N_2O_4 (nitrogen tetroxide) as the oxidiser. Up to 226 t of these propellants can be carried. During the propulsion phase, the first stage consumes about 1 t of propellant per second.

Each Viking engine has a gas generator, supplied with propellant and water for cooling the gases. The gases feed the turbine driving the propellant and water pumps and also serve to pressurise the tanks.

The throats of the Viking engines, which are made of Sephen (a carbon-based composite), have been strengthened to cope with the longer burn-time. The engine turbopump bearings have also been modified for the same reason.

The 44LP version of Ariane-4 used for the demonstration flight on 15 June had two liquid and two solid-propellant boosters fixed to the first stage.

The liquid-propellant boosters are a completely new element. They are essentially a Viking-VI engine with two identical separate steel tanks, an intertank skirt, a forward skirt and a nose cone. Water for the Viking engine is supplied from the first stage's central tank. Each booster carries between 37 and 39 t of N_2O_4 and UH25, produces 665 kN of thrust, and burns for between 135 and 143 s. After burn-out, the boosters are released by pyrotechnic cutting devices and jettisoned by small rockets.

The solid-propellant boosters are derived from the Ariane-3 solids by increasing the propellant mass from 7.3 to 9.5 t. Each booster delivers a thrust of 625 kN for 34 s and is jettisoned after burn-out by a system of four very strong springs.

The total mass of the launcher at lift-off is generally composed of 1% payload, 9% vehicle dry mass, and 90% propellants and auxiliary fluids (Table 3).

Launch facilities and operations

Ariane-4 is prepared at and launched from the second Ariane launch facility ELA-2, shown in Figure 3. This new facility allows the minimum interval between two launches to be reduced to one month (two months on ELA-1), thus providing considerably greater flexibility in launch scheduling. Whilst the concept of the ELA-1 complex calls for vehicle erection and assembly directly on the pad, at the new facility vehicle assembly and checkout take place in a remote Vehicle-Assembly Building. The vehicle is then moved, on its launch table, to the launch pad. Whilst this vehicle is undergoing final preparations on the pad, the next one can already be erected in the Assembly Building on a second mobile launch table.

The launch-operations sequence in use at ELA-2 is illustrated in Figure 5.

Figure 4 — Typical launch-campaign flowchart for Ariane-4

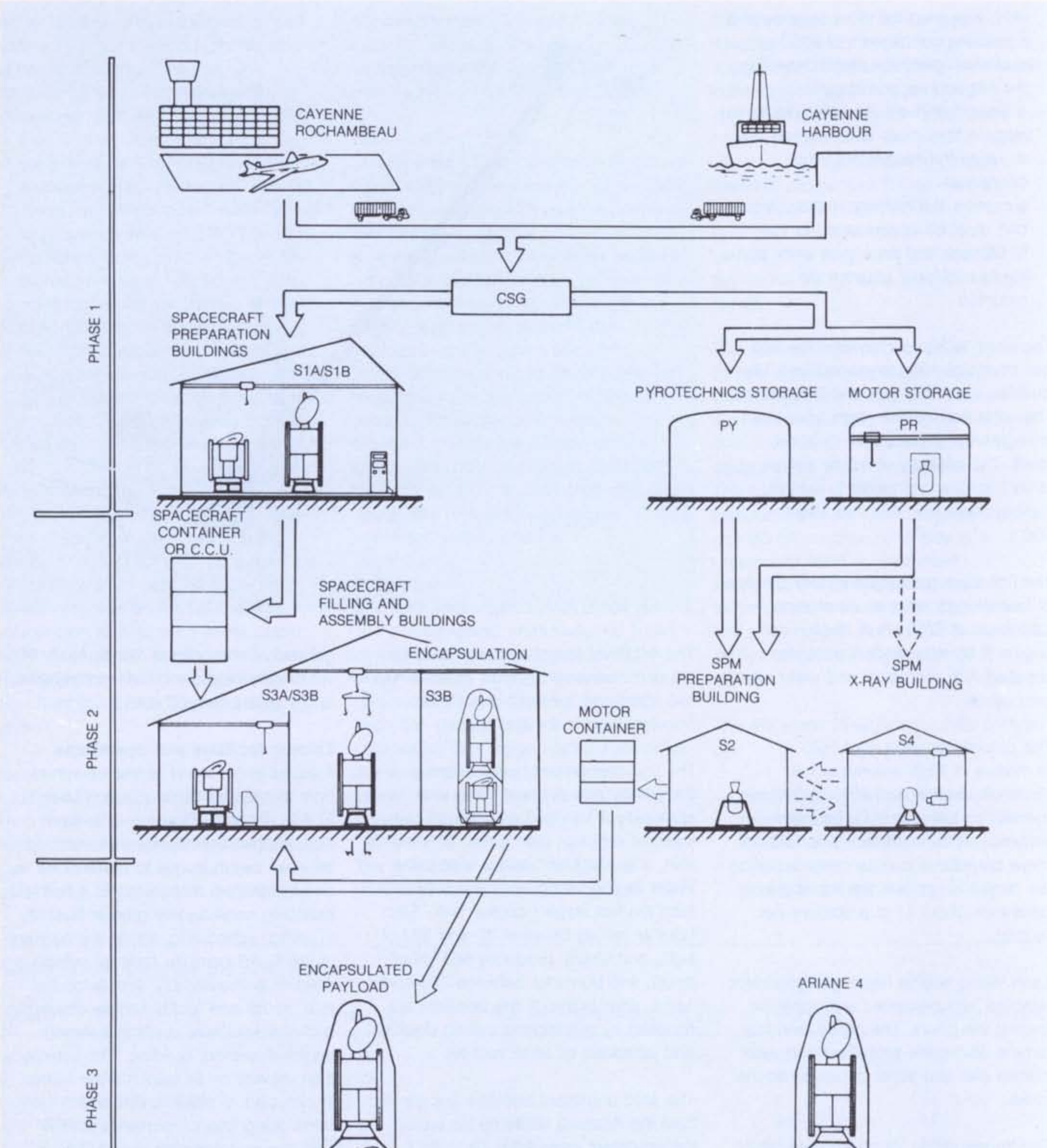
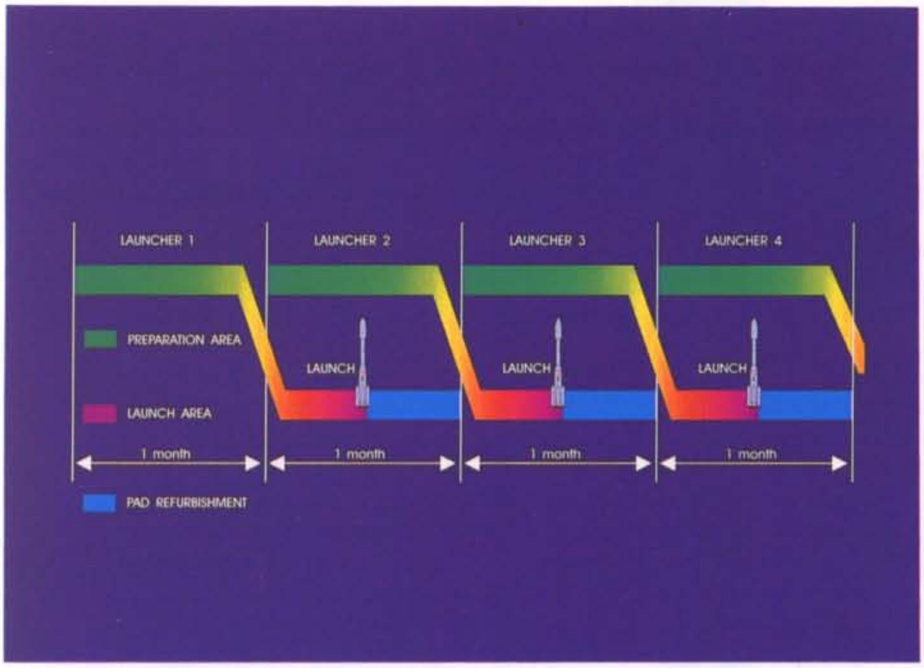


Figure 5 — ELA-2 launch operations sequence

Figure 6 — Typical Ariane-4 launch trajectory into Geostationary Transfer Orbit (GTO)



A typical Ariane-4 launch campaign starts about nine weeks prior to the launch, with the transport first on the River Seine from Les Mureaux to Le Havre and then by boat to Cayenne, French Guiana, of all the vehicle hardware, stored in special containers. Propellants (except liquid oxygen which is produced in Kourou) are also loaded on board at Le Havre.

Some ten days later the vessel arrives at the port of Cayenne, from where the launcher and propellants are transferred by road to the launch site, some 15 km west of Kourou. Erection of the launch vehicle on the mobile launch table in the assembly building and checkout take about four weeks. Transfer to the launch pad takes place about two weeks before launch (Fig. 4).

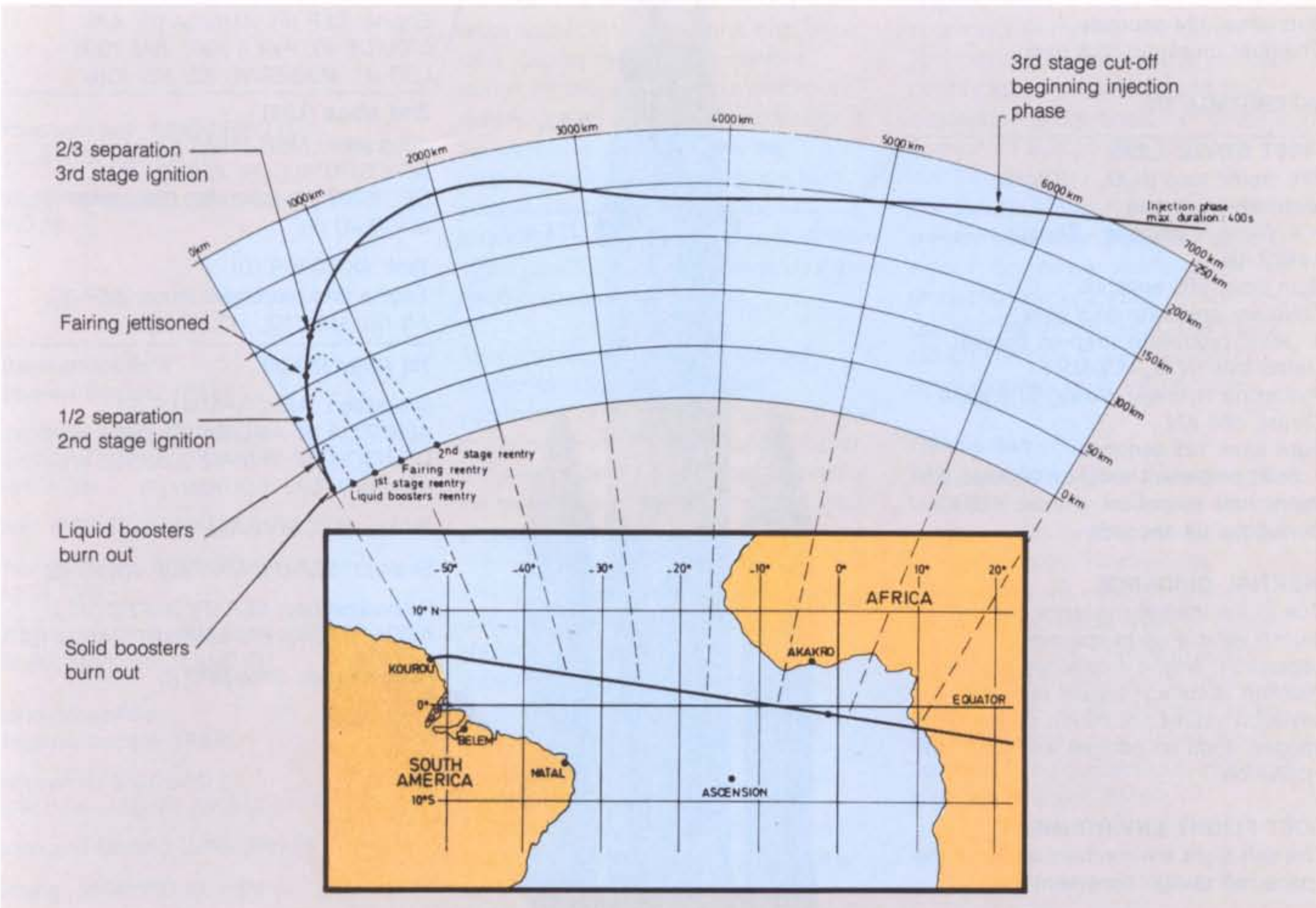
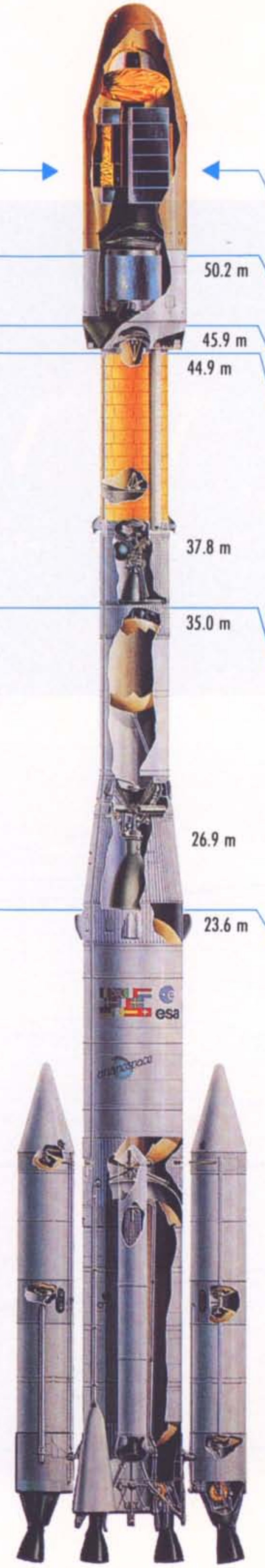


Figure 7 — European firms manufacturing elements of the Ariane-4 launcher family



DESCRIPTION

FAIRING

SPELDA

VEHICLE EQUIPMENT BAY

THIRD STAGE: H10
10.5 metric tons cryogenic propellant (LH_2+LO_2) HM7 engine - Thrust: 62 KN in vacuum
Burn time: 725 seconds
Chamber pressure: 35 bars

INTERSTAGE 2/3

SECOND STAGE: L33
34 metric tons (N_2O_4+UDMH+ Hydrazine Hydrate)
Viking IV engine - Thrust: 786 KN in vacuum
Burn time: 124 seconds
Chamber pressure: 58.5 bars

INTERSTAGE 1/2

FIRST STAGE: L220
226 metric tons (N_2O_4+UDMH+ Hydrazine Hydrate)
• 4 Viking V engines - Thrust: 4×677 KN
Burn time: 205 seconds
Chamber pressure: 58.5 bars
• Liquid propellant strap-on booster. 37 metric tons (N_2O_4+UDMH+ Hydrazine Hydrate). Viking VI engine - Thrust: 666 KN
Burn time: 135 seconds
• Solid propellant strap-on booster. 9.5 metric tons propellant. Thrust: 625 KN. Burn time: 34 seconds

INERTIAL GUIDANCE
Due to the inertial guidance of the launch vehicle up to spacecraft separation, Ariane 4 provides high orbit injection accuracy; typical standard deviation values are 50 km on the GTO apogee, 1 km on perigee and 0,02° on inclination

SOFT FLIGHT ENVIRONMENT
The soft flight environment allows a low spacecraft design constraint level

Overall direction: *ESA*

Prime contractor for development: *CNES*
Prime contractor for production: *ARIANESPAC*

Fairing

CONTRAVES (CH), *AMD/BA (F), FW (CH), PILATUS (CH)*

Spelda

BAE (GB), *AEROSPATIALE (F)*

Vehicle equipment bay
MATRA (F), *CASA (E), CROUZET (F), ETCA (B), FERRANTI (GB), FIAR (I), ROVSING (DK), SAAB (S), SAFT (F), SAT (F), SFENA (F), SFIM (F)*

3rd stage (H10)
Integration: AEROSPATIALE (F), *AERLINGUS (IR), AMD/BA (F), DEUTSCH (F), FOKKER (NL), INTERTECHNIQUE (F), SAFT (F), SELENIA (I), SNPE (F), SOURIAU (F)*
Tank: AIR LIQUIDE (F), *AVICA (GB)*
Engine: SEP (F), *AMD/BA (F), AIR LIQUIDE (F), AVICA (GB), BAE (GB), LBG (F), MBB-ERNO (D), NEI (GB)*

2nd stage (L33)
Integration: MBB-ERNO (D), *AEROSPATIALE (F), AMD/BA (F), DEUTSCH (F), ROVSING (DK), SFIM (F), SOURIAU (F)*
Tank: DORNIER (D)
Engine and propulsive items: SEP (F), *FN (B), MAN (D), VOLVO (S)*

1st stage (L220)
Integration: AEROSPATIALE (F), *AERITALIA (I), AMD/BA (F), CASA (E), DEUTSCH (F), INTERTECHNIQUE (F), ROVSING (DK), SOURIAU (F)*
Tanks: AEROSPATIALE (F)
Engines: SEP (F), *MAN (D), VOLVO (S)*
Propulsion bay: SEP (F), *ADTEC (IRL), AVICA (GB), FN (B), MAN (D), SABCA (B)*
Retro-rockets: SNIA-BPD (I)

Industrial Architect:

AEROSPATIALE (F)

Propulsion bay: SEP (F), AIR LIQUIDE (F), BAE (GB), LBG (F), NEI (GB), SABCA (B)

Ullage rockets: SNIA-BPD (I)

Propulsion bay: MBB-ERNO (D), AVICA (GB), SABCA (B)

Ullage rockets and retro-rockets: SNIA-BPD (I)

Liquid-propellant strap-on booster (PAL)

Integration: MBB-ERNO (D), AEROSPATIALE (F), FOKKER (NL), SABCA (B)

Tank: MBB-ERNO (D), AERITALIA (I)

Propulsion bay: MBB-ERNO (D), AVICA (GB)

Engine and propulsive items: SEP (F), FN (B), MAN (D), VOLVO (S)

Solid-propellant strap-on booster (PAP)

Integration: SNIA-BPD (I), AEROSPATIALE (F), MAN (D)

Grain and loading: SNIA-BPD (I)

Casing: SNIA-BPD (I), FBM (I)

In parallel the payload, which has been flown to Cayenne, is prepared in the various payload-preparation buildings which provide the necessary controlled environmental conditions. Single payloads are encapsulated by the payload fairing, dual payloads by the SPELDA and the fairing together, making a transport container superfluous and reducing the time needed for payload preparation in the launch tower. The fully integrated upper composite — consisting of the Vehicle Equipment Bay structure, the payload and the fairing in the case of a single payload; or the vehicle equipment-bay structure, the SPELDA, the payloads and the fairing in the case of a dual launch — is transported to the launch pad and installed on top of the vehicle five working days before launch.

The launch countdown, covering mainly the filling of the stages with propellants, takes about 38 h, distributed over three days. During the last 6 min before launch initiation, the ground checkout system verifies the proper functioning of the vehicle. It also separates the propellant transfer arms from the third stage 4 s before the end of the sequence, and finally commands ignition of the four first-stage engines and of the liquid-propellant boosters.

After ignition, the ground checkout system monitors the functional parameters of the ignited engines. If their status is correct, the command to open the jaws holding the launcher is given at the same time as that to ignite the solid-propellant boosters.

The typical flight time for the Ariane-4 launcher, up to third-stage engine shutdown, is 17 to 18 min. Figure 6 shows a typical flight trajectory to Geostationary Transfer Orbit, together with the major flight events.

Commercialisation

As for the Ariane-1, 2 and 3 launchers, Arianespace will be responsible for the commercialisation of the Ariane-4 launcher, which is expected to remain in operational use until 1998. This means that Arianespace will try to acquire as many satellite launch contracts as possible, will place contracts with industry for the production of the launchers, and will carry out the launches with its own teams, assisted by personnel from industry.

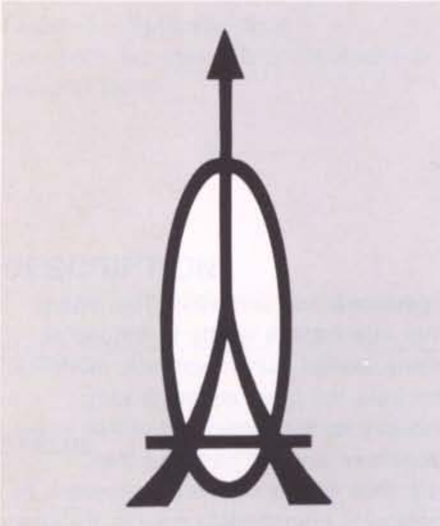
Arianespace plans to produce and launch about 70 Ariane-4s. Twenty-one of these have already been ordered and are being manufactured. Arianespace is presently negotiating a single order with industry for the delivery of the remaining 50 vehicles.

The Ariane-4 launcher is manufactured by approximately 50 European industrial companies, providing employment for up to 10 000 people. Eight firms play the role of technical main contractors, responsible for a major technical domain or a major element of the launch vehicle. The main contractors receive contracts directly from Arianespace and they subcontract a significant part of the work throughout Europe (Fig. 7).

The industrial manufacturing facilities are presently capable of producing up to eight Ariane-4s per year in a nominal production cycle, and up to ten vehicles per year by shift working. The ELA-2 launch complex is also capable of supporting ten launches per year.

Conclusion

With the return of the US expendable launch vehicle, the worldwide competition on the launch-services market will be tough during the next decade. Arianespace will need all its skills to secure a reasonable share of future satellite launches. European space industry in turn will have to produce reliable, high-quality launchers at the lowest possible cost if Ariane is to continue to be successful in this highly competitive environment.



Flight Dynamics — A Bridge for the Agency's Worldwide Cooperative Endeavours

R.E. Münch, Orbit Attitude Division, Directorate of Operations, ESOC, Darmstadt, Germany

ESA, itself a multi-national European endeavour, cooperates with a number of other space interested bodies around the World on a variety of space projects and programmes. Distant countries like Australia, Japan and China, as well as India, the Soviet Union, the United States of America and Brazil, participate in this international cooperation. These joint ventures often involve sophisticated satellite control scenarios and thereby provide challenging tasks for ESOC's Flight Dynamics Team.

Introduction

Thinking back to Giotto's encounter with Comet Halley in March 1986, and looking forward to the gravitational swingby of Jupiter, by the Ulysses spacecraft and the planned landing of a probe on one of Mars' moons, spacecraft navigation and control requirements can certainly be extremely challenging. Not only the complexity of the mathematical calculations, but also the high accuracies required for achieving the mission goals, make the flight-dynamics tasks a crucial element in the success of space projects such as these. For the injection of a geostationary satellite into its final orbit, for the initial localisation of a near-Earth spacecraft after separation from its launcher, and for the control of a cluster of satellites within a specified pattern, great demands are made on the support functions of spacecraft orbit and attitude determination and control.

Successful completion of these flight-dynamics tasks often depends on facilities, information and data that are not available in any one space agency, i.e. ground stations, astronomical observatories, computer programs, specialist experience, etc.

The necessary cooperation between agencies is usually realised on a bi-lateral or multi-lateral basis. It can be based on consultancy (exchange of expert experience) or the provision of facilities (such as computer programs and ground stations). Sometimes the co-operation involves the provision of an operational service (e.g. orbit determination), or just support to operations (comparison of processing results provided by different methods). Nevertheless, most of the cooperative projects have one feature in common: in the organisational, management and operational areas they tend to be non-hierarchical, and their success depends on the goodwill of the partners and the motivation of the technical staff involved. This is certainly true in the flight-dynamics domain, where the mathematical and technical tasks are often the most interesting and challenging elements.

The flight-dynamics discipline

The 'flight dynamics' of ESA spacecraft is the responsibility of specialists at ESOC working in the areas 'orbital mechanics' and 'spacecraft dynamics', drawing upon their knowledge of mathematical modelling, estimation, and control. In addition, they need to be familiar with the relevant engineering aspects of the spacecraft involved and the ground equipment being used.

To estimate the dynamical state of a spacecraft, it is necessary to model its orbit and attitude motions. Its 'state' at any given moment involves position, velocity, orientation and rotation rate. If the modelling were perfect, there would be no need for 'estimation'. In the real world, however, it is still necessary both to observe the spacecraft and make measurements. These in turn are not perfect, but contain errors such as statistical noise and biases.

Figure 1 — The Agency's Odenwald ground station, in Germany

Figure 2 — The Main Control Room at ESOC, in Darmstadt

Typical measurements used in the estimation processes are:

- Range: the distance between the spacecraft and a ground-station antenna
- Doppler: the relative velocity component along the spacecraft/ground antenna line
- Angles: the direction of the spacecraft as seen from the station.

These measurements are then used in the orbit-determination process. Station location and the Earth's rotation, as well as equipment behaviour, need to be modelled. The disturbances produced by the ionosphere, troposphere and atmosphere in corrupting the measurements also have to be taken into account.

The observations used for attitude estimation are typically angles measured by spacecraft sensors vis-a-vis references such as the Sun, the Earth and the stars. In general, more than just one reference and the appropriate measurements are needed in order to define the attitude state uniquely. The positions and physical characteristics of the references also have to be known, and the sensor measuring method needs to be modelled. As for the orbital measurements, disturbances stemming from sensor misalignment and the sensor triggering mechanism have te be considered.

For the actual estimation process, we have to find a relationship between the measurement and the state we want to estimate. This relation, which we call the 'observation equation', its formulation and degree of realism, have a major impact on the estimation method chosen and the numerical accuracy of the solution found. It is left to the specialists to establish the best combination of observation equation and estimation method for a particular application.

Once the estimation task has been performed, the resulting dynamical state can be compared to the one required. If the difference is not acceptable, appropriate changes are implemented. Most of these 'control actions' are critical and have a direct impact on mission success. The mathematical calculations therefore need to be very precise and must respect all environmental and operational constraints. In the case of a geostationary-orbit injection, for example, the calculations for the timing and direction of the apogee boost motor's burn require the utmost care. Even slight deviations can cause loss of the mission, or at least degrade it severely.

Mathematically speaking, the problems have to be solved by optimisation, typically by minimising a specified cost function, such as on-board fuel usage. Often, there are several inviolable constraints involved. The control devices used have different characteristics and therefore also need to be modelled in the mathematical algorithms. We have thrusters (gas jets) that are driven by cold gas, hydrazine or bi-liquid propulsion, and they can be operated in continuous or pulsed mode for both orbit and attitude changes. There are also the solid-fuel rocket motors which are used only for orbit changes and are not re-usable after burnout, and inertia wheels which can be used to make the spacecraft rotate in any desired direction by varying their speed.

What we have achieved with the control manoeuvres that we have implemented is determined by again estimating the 'state' of the spacecraft. Modelling and actuator-performance errors can then be assessed. By closing the loop between estimation and control, we learn more and more about spacecraft system behaviour and are thus able to adapt the parameters of our mathematical calculations optimally for future applications.

Consultancy and provision of facilities
These are the two most common types of cooperation. Exchanges of experience between flight-dynamics specialists take place in the course of their day-to-day work, but this exchange manifests itself most noticeably during specialised international conferences and seminars. ESA has already organised two such international symposia on 'Spacecraft Flight Dynamics', in Darmstadt, in 1981 and 1986. The truly international character of these symposia, the quality of the papers presented, and the number of highly competent participants have demonstrated the value of such endeavours on both occasions.

In addition, the contacts made at these Symposia have already led to cooperative projects: the last symposium in 1986 opened the door to cooperative endeavours with the People's Republic of China in the area of 'Precise Orbit Determination', and was also a major milestone in cooperation with the Soviet Glavcosmos/Intercosmos organisations (see next section).

Another very successful endeavour from ESA's point of view has been the provision of a facility for the control of geostationary satellites. This Portable ESA Package for Synchronous Orbit Control, called 'PEPSOC', is a set of computer programs developed by ESOC's Orbit Attitude Division that has attracted interest far beyond the boundaries of ESA's Member States. This package, which has been used to support the Agency's geostationary satellites since 1983, has been provided to various interested third parties under a special licensing agreement.

Operational services
One example of the provision of operational services by ESA to one of its Member States was the orbit-determination task that it performed for

the Swedish Viking satellite throughout its lifetime, from February until October 1986, under a special contract with the Swedish Space Corporation.

A similar but more extensive ESA role is being planned for Italy's Italsat project. Here the flight-dynamics task (injection into geostatinary orbit) is part of an overall service to be provided by ESOC. This will involve full ESOC control over the spacecraft, from the moment of its separation from Ariane until it is positioned at its operational longitude.

Further afield, in the context of an overall consultancy and support arrangement with the Brazilian National Institute for Space Research (INPE), ESOC's flight-dynamics specialists will not only provide advice in the orbit and attitude area, but will also furnish an operational service for the support of the first Brazilian spacecraft. During the first orbits after separation from the launcher, it will be ESOC's responsibility to pinpoint the spacecraft's position, and perform the orbit-determination task. Range, range rate and angular measurements from ESA's ground stations, a Brazilian station and possibly an Indian station will be used for this purpose. Only after this initial task has been successfully completed will responsibility for the satellite's operation be handed over to the newly established control centre in Brazil.

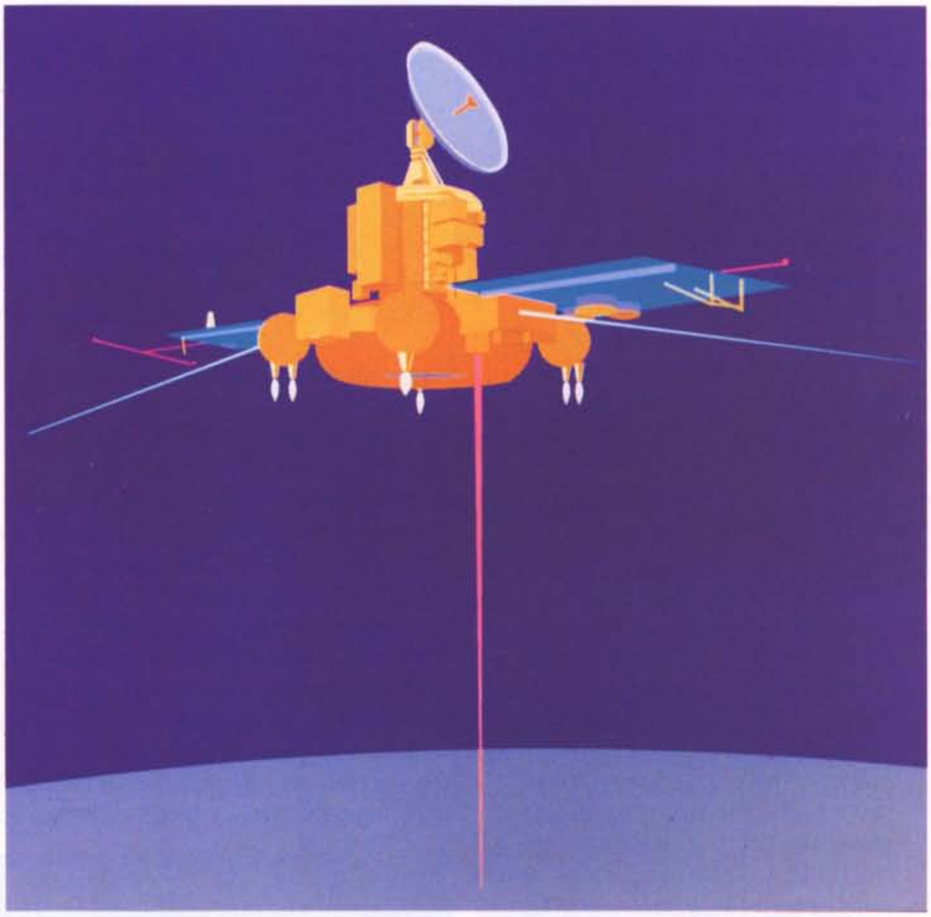


Figure 3 — Artist's impression of the Phobos spacecraft

Figure 4 — The Swedish Viking satellite

Support to operations

In July 1988, the Soviet space organisations Glavcosmos and Intercosmos will launch two spacecraft to reach planet Mars early next year. These spacecraft will be manoeuvred into Mars orbit, firstly to observe the Mars moon Phobos in order to determine its orbit more precisely, and secondly to fly synchronously with the Phobos moon around Mars, approaching to within 50 m of the moon's surface. At this height, automatic stations will be released from the spacecraft to 'land' on

Figure 5 — The nucleus of Comet Halley, photographed in March 1986 by ESA's Giotto spacecraft

Phobos and perform scientific measurements. The spacecraft will then return to a higher Mars orbit, from which they will continue to explore Phobos, Mars and the Sun.

The Soviets first expressed a wish to have support from ESOC's flight-dynamics specialists for this Phobos mission during the ESA Spacecraft Flight-Dynamics Symposium in October 1986. Their offer of collaboration was based on the success of the earlier Pathfinder cooperation for Giotto (see below). The support arrangements, finalised at a recent meeting in Moscow (May 1988), contain the following elements:

- *Observational database:* ESOC will establish, update and maintain a central computer database for the observations of the Mars moon Phobos. This will contain all observations made since the Moon's discovery in 1877, including those made by the American space probes Mariner-9 (1971/72) and Viking-1/2 (1977/1980). All future measurements will also be incorporated, including those from ground observatories at the next Mars opposition in September 1988. To these data will eventually be added the measurements taken by the two Phobos spacecraft.
- *Observation campaign:* Capitalising on the intensive contacts made with astronomers and observatories in the context of the Giotto project, the ESOC specialists have prepared a detailed observational campaign for the Phobos mission starting in September this year. Preparations include precise prediction of observing conditions for the various observatories around the World that are taking part.
- *Phobos orbit determination:* ESOC will model the moon's motion using all the data in the observational database. A final update will then be made with the Phobos measurements (camera images) shortly before closest approach.
- *Compatibility testing:* As the cooperative endeavour relies on the performance of critical tasks (e.g. the moon-orbit determination) in parallel with different mathematical algorithms, a common basis for the comparison of the results obtained by the participating groups — NASA/JPL and French CNES specialists will also participate — is a prerequisite.

Past and future joint endeavours

Giotto

An example 'par excellence' of a past cooperative endeavour in the flight-dynamics area is the 'Pathfinder Project', which greatly facilitated the successful encounter of ESA's Giotto spacecraft with Comet Halley in March 1986. ESA collaborated in this joint project with both NASA (USA) and Intercosmos (USSR). (Further details can be found in ESA Bulletins Nos. 38, 45 and 46).

The key task on that occasion was to bring the orbit-determination accuracy for the comet into line with the estimated Giotto spacecraft orbit-determination accuracy (of the order of 100 km), such that a flyby could be safely planned at a distance of approx. 500 km on the sunward side of the cometary nucleus.

This goal could not be achieved with only ground-based astrometric measurements of the comet because the estimated accuracy was such that a risk-free encounter on the sunward side would have required targetting for a minimum miss distance of some 2000 km. The necessary improvement in the comet's orbit-determination accuracy was provided by means of images of the comet taken during the flybys of the Soviet Vega-1 and Vega-2 spacecraft a few days before Giotto's planned encounter. To make sure that these measurements would be fully exploitable, the large antennas of NASA's Deep-Space Network (DSN) were used to obtain improved positioning accuracies

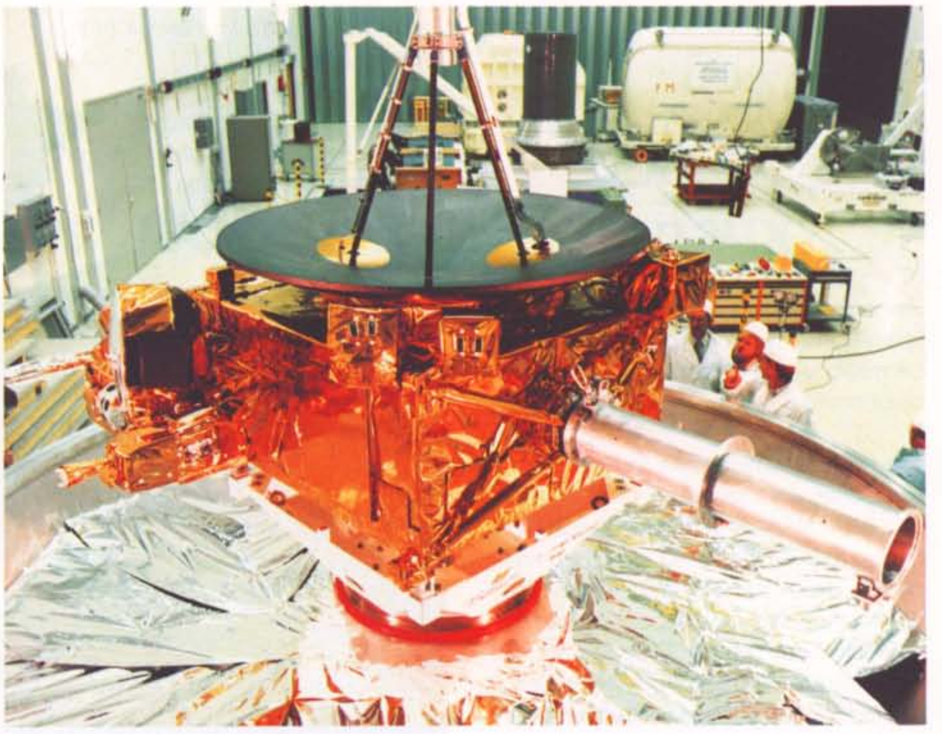


Figure 6 — The Ulysses spacecraft

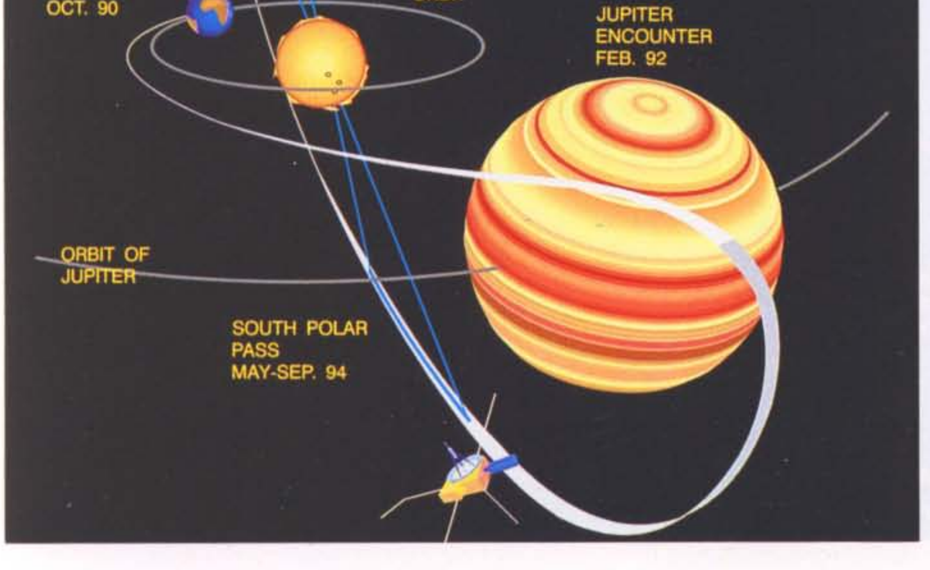


Figure 7 — The planned flight scenario for the Ulysses spacecraft

for the Vega spacecraft taking the images.

Based on the improvements obtained, Giotto could be manoeuvred 'at the last minute' to achieve its final flyby distance of 596 km.

Ulysses

ESA's Ulysses satellite is another example of a truly international full-scale joint project, in this case involving NASA and ESA. The Ulysses spacecraft, built by ESA, houses experiments both from the ESA Member States and from the USA. NASA will be responsible for the spacecraft's Shuttle launch, currently planned for October 1990, and JPL in Pasadena will be used as the control centre, with computers, software, and personnel provided by ESA. NASA's Deep Space Network (DSN) will be used for spacecraft tracking and communications.

This project again involves a unique degree of cooperation on the flight-dynamics support side. Some tasks will be performed by NASA/JPL, while others will be ESA's own responsibility. Analysis of the optimal trajectories to achieve the best scientific return from the helio-polar flight path is a JPL task, along with the determination of the spacecraft's trajectory using DSN tracking. Implementation of the trajectory corrections, i.e. the strategy for the manoeuvres and the spacecraft-specific command preparation, will be the responsibility of the ESOC specialists. All other flight-dynamics tasks are also under ESA's responsibility, e.g. the planning and implementation of the attitude manoeuvres necessary to keep the spacecraft antenna pointing towards Earth and the related attitude verification task.

During the early-orbit phase of the mission, and during subsequent critical mission phases, the ESOC specialists will be using their own computer software at JPL. They will also be present in California for special phases of the mission, one of these being the spacecraft's Jupiter swing-by.

ISEE and Cluster

These two missions are of similar nature from a flight-dynamics point of view. ISEE, the International Sun-Earth Explorer, was a joint project undertaken by ESA and NASA. NASA built two spacecraft, one around the libration point between the Earth and the Sun, the other orbiting the Earth in a highly eccentric orbit. ESA built the third spacecraft, which shared the Earth orbit with the NASA spacecraft.

The flight-dynamics link between the latter two spacecraft was the scientific requirement to fly them in a prescribed configuration, i.e. in the same orbit but with prescribed separation distances, which were to be changed periodically.

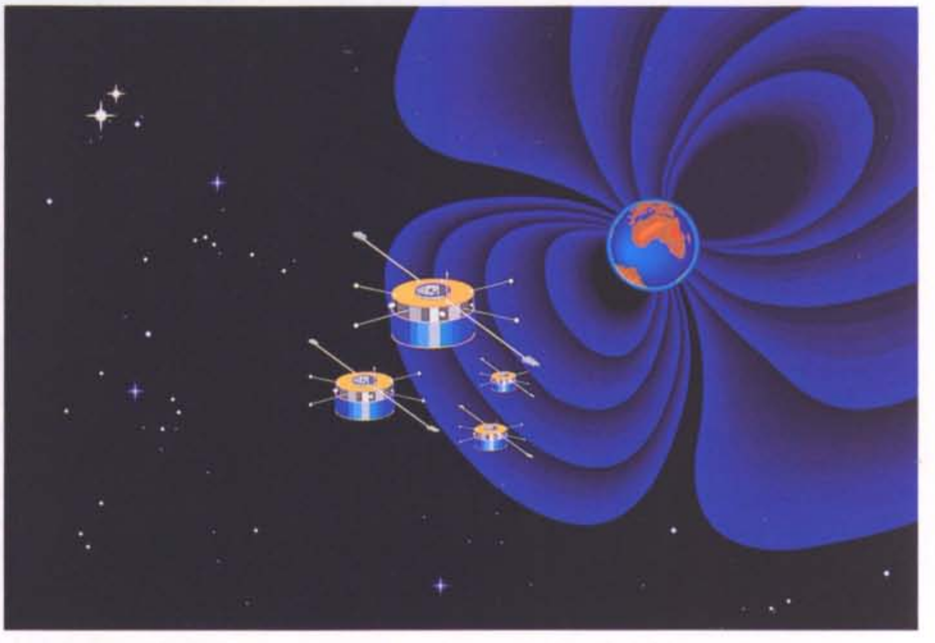
Figure 8 — Artist's impression of the Cluster spacecraft

Figure 9 — ISEE-3 spacecraft manoeuvres, from launch to halo orbit and cometary exploration

The active partner was the ESA spacecraft, which consequently had to be manoeuvred to respect the scientific requirements.

The flight-dynamics tasks for the ESA spacecraft were shared between NASA and ESA. NASA's Goddard Space Flight Center (GSFC) was used as the control centre, NASA being responsible for the estimation tasks, i.e. orbit and attitude determination. The ESOC specialists supported the mission from Darmstadt, where they were responsible for the control aspects, i.e. changes in orbit and attitude.

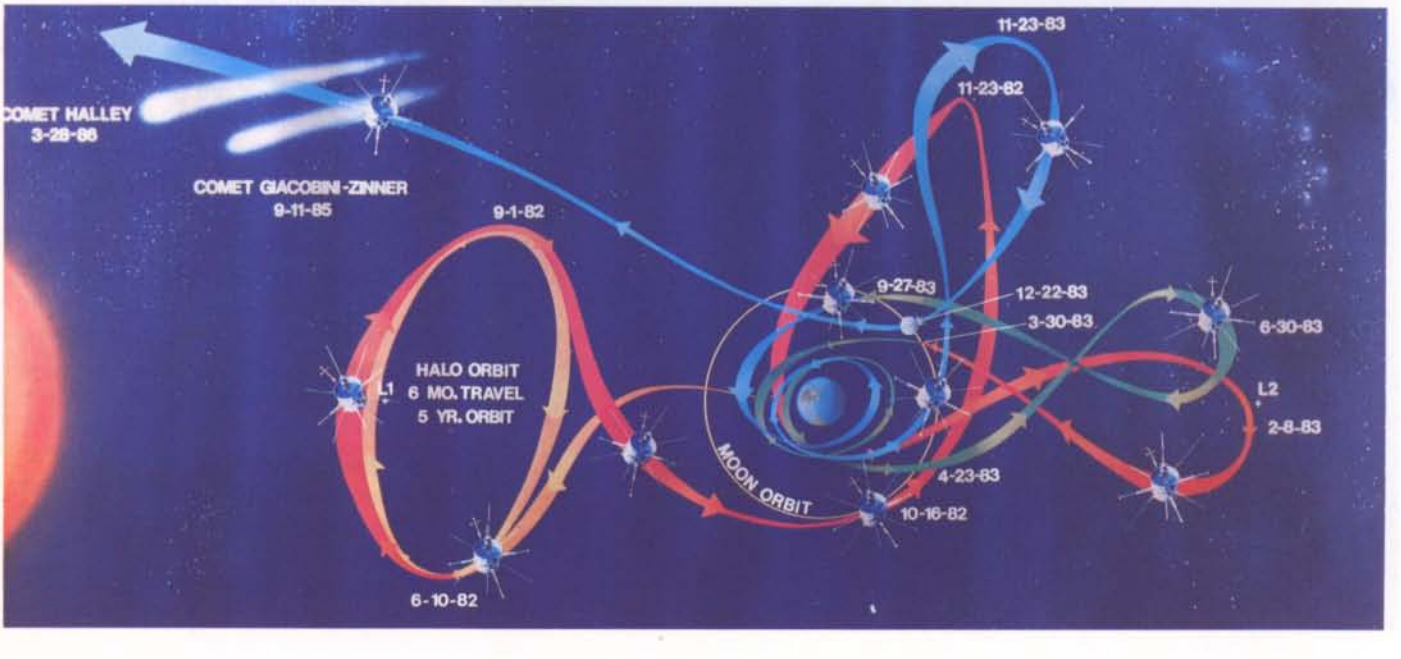
Whilst the ISEE project was operational from 1977 to 1987, the launch of the Cluster spacecraft is not planned until 1995. The cooperation for ISEE was with NASA, while that for Cluster will be with Intercosmos/Glavcosmos, with ESA providing four spacecraft and the Soviets two. The flight-dynamics task for the Cluster spacecraft is, however, similar to that for ISEE, in that all spacecraft should fly in a prescribed configuration at certain times to allow the spatial and temporal distribution of events, especially in the Earth's geomagnetic tail, to be studied.



Control of the individual spacecraft will rest with their owners, and so the common strategy and verification of the flight configuration needs to be particularly well coordinated between the Soviets and ESA. The past success of the Pathfinder Project and the success of the ongoing Phobos cooperation nevertheless provide an excellent basis for addressing this challenging task.

Conclusion

Worldwide international cooperation in space projects for peaceful purposes contributes greatly to a better understanding between nations. The flight-dynamics specialists at ESOC, although very much engrossed in their challenging technical tasks, are mindful of this aspect and are proud to be able to participate in the 'building of bridges' between nations.



Les accords internationaux conclus par l'Agence

G. Lafferranderie, Conseiller juridique, ESA, Paris

Par sa nature d'organisation internationale, par la nature des activités qu'elle conduit qui ne peuvent exister, se développer, sans des relations avec d'autres entités juridiques, l'Agence est appelée à conclure des Accords internationaux. A ce jour environ 200 'Accords' ont été conclus.

La capacité juridique de l'Agence
Sans entrer dans le débat sur le fondement de la capacité d'une Organisation internationale de conclure des Traités (débat qui a notamment pris place lors de la Conférence de Vienne sur le droit des Traités entre les Etats et les Organisations internationales ou entre les Organisations internationales elles-mêmes, qui a adopté une Convention le 20 mars 1986, reproduisant largement celle de 1969 sur le droit des Traités entre Etats), notons que la Convention de l'ESA, dans son article XIV.1, stipule que l'Agence peut coopérer avec d'autres Organisations et institutions internationales et avec les Gouvernements, Organisations et institutions d'Etats non membres; elle lui reconnaît expressément le moyen d'action particulier qu'est la possibilité de conclure des accords internationaux (ce que la Convention du CERS/ESRO ne faisait pas, sans que cela ait d'ailleurs entravé la capacité de cette organisation de conclure de tels accords).

L'Annexe I de la Convention énonce de son côté que l'Agence a la personnalité juridique et notamment la capacité de contracter. Mais l'article XIV précité de la Convention n'est pas le seul à considérer car l'Agence peut conclure des accords internationaux également avec les Gouvernements des Etats membres ou leurs institutions, pour divers motifs. Ainsi, on relèvera:
— l'article VI.1.b selon lequel l'Agence peut passer des *'arrangements* particuliers qui permettent l'exécution de certaines parties de ses programmes par des institutions nationales des Etats membres ou en coopération avec ces derniers, ou bien qui concernent la prise en charge par elle-même de la gestion de certaines installations nationales';
— l'article XV.3: 'Des *accords* concernant le siège de l'Agence et les établissements créés conformément à l'article VI sont conclus entre l'Agence et les Etats membres sur le territoire desquels sont situés ledit siège et lesdits établissements';
— l'article XXIV.2,
— l'article XXII.1 et 2 de l'Annexe I,
— l'article XXVIII de l'Annexe I: 'L'Agence peut, sur décision du Conseil, conclure avec un ou plusieurs Etats membres des *accords complémentaires* en vue de l'exécution des dispositions de la présente Annexe, ainsi que d'autres arrangements en vue d'assurer le bon fonctionnement de l'Agence et la sauvegarde de ses intérêts'.

Parfois, certaines Résolutions invitent le Directeur général à conclure des Accords; ainsi de la Résolution no 2 sur la Station spatiale adoptée le 30 janvier 1985 à Rome.

Qu'appelle-t-on Accord international? Peut-on identifier certains critères qui permettent de savoir si on est en présence d'un Accord international et quel est l'effet qui s'attache à cette qualification?

Les traits de l'Accord international
La terminologie
On constate que la Convention emploie diverses appellations: Accord, Accord

Figure 1 — Cérémonie de signature du Protocole d'Accord relatif à la participation de l'Europe au programme de Navette spatiale, à Washington le 24 septembre 1973. On reconnaît le Dr A. Hocker, Directeur général de l'ESRO (assis à gauche) et le Dr J. Fletcher, Administrateur de la NASA (à droite).

spécial, Accord complémentaire, Arrangement. Dans la pratique, d'autres appellations sont également utilisées bien qu'on s'efforce de s'en tenir dans toute la mesure du possible à celle d'*Accord*.

Ainsi, le terme de *'Mémorandum d'Accord'* (Memorandum of Understanding: MOU) est utilisé dans les relations avec la NASA et autres agences américaines ou non américaines. Dans le droit constitutionnel américain, le Mémorandum d'Accord entre dans la catégorie des *'Executive Agreements'* conclus par une agence gouvernementale sous l'ombrelle des pouvoirs du Président. Il n'a pas la force juridique interne du Traité (ratifié par le Sénat); de ce fait, il ne peut aller à l'encontre de la loi et le Congrès a tout loisir d'adopter une loi qui vient contrecarrer ses effets sur le territoire américain.

Dans certains cas, le poids du 'MOU' est renforcé s'il a fait l'objet d'une 'joint' ou 'concurrent' Resolution adoptée par le Congrès avant sa signature. Sinon, la seule obligation de l'Exécutif est de faire rapport au Congrès dans un certain délai après sa signature. Il en découle que le MOU est rédigé de manière spécifique: les parties 'feront leurs meilleurs efforts'; les engagements financiers seront pris 'sous réserve de la disponibilité des fonds' (votés chaque année par le Congrès) ou sous réserve des procédures d'allocation des fonds. Généralement, ces textes ne contiennent pas de clause d'arbitrage obligatoire. Mais le MOU reste un accord, obligatoire, au plan international.

Le terme *d''Arrangement'* est né à l'Agence de l'utilisation de l'article VIII de la Convention du CERS/ESRO; il visait un accord entre les Etats membres participant à un programme (pris collectivement) et l'Agence, entité juridique de droit international public. Il définissait les droits et obligations de chacun dans l'exécution d'un programme facultatif. Aujourd'hui, cet 'Arrangement' est remplacé par le mécanisme de l'article V.1.b et de l'Annexe III de la Convention; les dispositions des Arrangements, utilisés pour entreprendre les programmes de développement Ariane, Spacelab, Météosat, OTS/ECS, Marots/Marecs, Aérosat, se retrouvent dans la Déclaration et dans le règlement d'exécution, instruments qui ne font plus l'objet, ni de signature, ni de procédure de ratification ou d'acceptation. Mais ce terme pourrait refaire surface dans le cadre de la mise en oeuvre de l'article IX.2 de la Convention, qui reprend le libellé qui fut celui de l'article VIII de la Convention du CERS/ESRO ('projet spécial' entrepris par un ou plusieurs Etats membres auquel l'Agence apporte son aide. En fait, cet article est aujourd'hui mis en oeuvre par voie d'échange de lettres).

Le terme de *'Convention'* a aussi été utilisé (Convention entre l'Agence et Arianespace). Pour mémoire on rappellera l'appellation d''Arrangement contractuel' (!) qui avait été utilisée pour désigner un instrument juridique conclu entre le CERS/ESRO, le Gouvernement du Canada et la Société Comsat General (Société américaine de droit privé) pour la réalisation du secteur spatial Aérosat.

Le terme d'arrangement doit être réservé à des mesures d'application, de mise en oeuvre d'un Accord et être hiérarchiquement dépendant de celui-ci (voir par exemple les 'arrangements d'exécution', 'implementing arrangements' prévus dans le Mémorandum d'Accord NASA/ESA sur la Station spatiale).

Dans cette catégorie, on rangera également les textes dénommés 'Avenants' (Avenants à la Convention avec Arianespace).

De même, un *'Protocole'* est un document accessoire à un accord existant, en précisant l'application, et signé par les mêmes parties. Il peut s'agir d'un Protocole financier, Protocole sur les privilèges et immunités (cas du CERS/ESRO, CECLES/ELDO), d'un Protocole portant amendement ou extension d'un Accord. Mais rien n'empêche les Parties de compléter, préciser ou prolonger l'Accord existant par un échange de lettres.

Jusqu'à présent, on a identifié sous l'appellation générique d'Accords des instruments juridiques se présentant sous la forme d'un document rédigé en un ou deux exemplaires, en une ou plusieurs langues, faisant l'objet de signature, comportant un préambule, un dispositif et des clauses finales.

Or, sous ce vocable d'Accord, il convient aujourd'hui de faire entrer d'autres instruments juridiques comme la *'Déclaration'*. Ce terme recouvre des textes différents: tout d'abord la Déclaration d'un programme facultatif, visé à l'Annexe III de la Convention qui énonce les droits et obligations des Etats participants et de l'Agence, définit le contenu technique du programme, fixe l'enveloppe financière, le barème des contributions. Cette Déclaration est un Accord international obligatoire bien qu'elle ne soit ni signée ni objet, en principe, d'une procédure de ratification (elle fait l'objet d'une souscription, soit par écrit, soit oralement).

Il y a également la déclaration unilatérale d'acceptation d'un Accord international pré-existant: ainsi l'Agence est liée par sa déclaration d'acceptation de l'Accord sur le sauvetage des astronautes, le retour des astronautes et la restitution des objets spatiaux, de la Convention sur la responsabilité internationale pour dommages causés par des objets spatiaux, de la Convention sur l'immatriculation des objets spatiaux.

Il y a enfin la Déclaration sur la production du lanceur Ariane, ouverte à souscription en janvier 1980 entrée en vigueur en avril 1980, à laquelle l'Agence n'est pas partie mais qui oblige l'Agence à faire certains actes. Cette Déclaration n'a été ni signée ni soumise à procédure de ratification mais a fait l'objet d'une procédure de souscription, notifiée à l'Agence.

Le règlement d'exécution d'un programme facultatif, élaboré, accepté, par les Etats participants, approuvé par le Conseil, doit aussi être considéré comme un accord complémentaire de la Déclaration de programme.

On pourrait compléter cette liste, mentionner par exemple les 'Deposits' ou 'Trust Fund Agreements' parfois conclus avec la NASA dans le cadre d'un MOU.

Tout ceci pour souligner la liberté laissée à l'Agence dans l'appellation de l'instrument juridique, pour s'adapter aux impératifs de la situation ou posés par son partenaire. Quelle que soit l'appellation, qui n'est donc pas le critère pour savoir si on est en présence d'un Accord international ou pas, ce qui est important, c'est le concours de la volonté des partenaires. L'Accord est d'abord l'expression de la volonté de deux parties, qui s'expriment sur un objet déterminé et qui fixera les droits et obligations de chacun dans la réalisation de cet objet.

La forme

La présentation formelle n'est pas non plus déterminante. L'Accord peut être conclu sous diverses formes:

— sous forme traditionnelle, d'un texte signé, comprenant préambule, dispositif, clauses finales;
— sous forme simplifiée, d'échange de lettres, de notes, soit simultanées, soit successives, constatant dans les mêmes termes l'accord établi lors de négociations;
— sous forme d'échange de correspondances (lettres, télex) se caractérisant par une diversité de documents qui consacrent un accord progressif.

Enfin, il faut mentionner le cas particulier d'un Accord qui a été conclu sous la forme de deux Résolutions parallèles adoptées par les Conseils du CECLES/ELDO et du CERS/ESRO en avril 1975; cet échange de Résolutions a scellé la volonté commune, droits et obligations, des deux Organisations.

L'objet de l'Accord

La conclusion d'un Accord international par l'Agence est par définition rattachée à sa raison d'être, à sa mission. Il pourra s'agir, sans que ceci soit exhaustif:

— d'un Accord de coopération, soit de coopération générale, accord-cadre d'échange d'informations de nature générale, de documentation, de personnes (tels que les Accords conclus avec l'Académie des Sciences de l'URSS, OMCI, OMM, Chine, Japon, Indonésie, accords conclus dans les années 1970), soit de coopération ponctuelle (participation d'un Etat non membre à un programme facultatif, participation à un programme commun), soit d'association aux activités de l'Agence (Accord avec la Finlande par exemple);
— d'un Accord sur le fonctionnement de l'Agence, que ce soit les Accords d'établissement avec les Etats membres (ESTEC, ESOC, ESRIN, Redu, ELA, Villafranca), les Accords sur l'implantation et le fonctionnement de moyens de l'Agence (stations aval Ariane ou stations de contrôle de satellites, réseau Earthnet, avec la Côte d'Ivoire, Gabon, Brésil, Australie...);
— ou bien les Accords sur la situation du personnel (échange de lettres sur la mise en oeuvre des privilèges et immunités, sur la sécurité sociale...);
— d'un Accord sur la gestion des programmes (accord de délégation de tâches, par exemple entre l'Agence et le CNES pour les programmes Ariane ou Hermés, entre l'Agence, la DFVLR, MRST/PSN pour le programme préparatoire Columbus);
— d'un Accord de coordination de moyens (par exemple avec le CNES, IABG, IAL sur les moyens d'essais coordonnés);
— d'un Accord d'accès aux moyens d'un Etat membre et d'utilisation (Accord avec la France sur le CSG).

La variété des thèmes correspond à l'éventail des activités et programmes de l'Agence, à la richesse de ses relations.

Le partenaire de l'Agence

L'Accord sera conclu avec le Gouvernement d'un Etat non membre, l'institution d'un Etat non membre (NASA, NASDA, etc.), une Organisation internationale intergouvernementale (Eutelsat, Eumetsat) ou bien avec un organisme d'un Etat membre (CNES, DFVLR, etc.). Le nombre d'Accords

Figure 2 — Signature de l'Accord ESA-CNES concernant l'exécution du programme préparatoire Hermes, le 16 avril 1987. De gauche à droite: M.F. d'Allest, Directeur général du CNES, Prof. R. Lüst, Directeur général de l'ESA, M. J. Feustel-Büechl, Directeur des Systèmes de Transport spatial et M. J.-J. Capart, chef du projet Hermès à l'ESA

conclus avec les Organisations internationales est relativement faible. Les Accords sont principalement conclus avec des organismes d'Etats membres ou d'Etats non membres. En général, l'Accord sera bilatéral mais on pourra avoir un accord multilatéral.

La durée de l'Accord
On trouvera des Accords pour lesquels la durée est précisée. Dans ce cas, ils pourront faire l'objet d'une procédure de reconduction (le principe de reconduction et les termes du nouvel Accord devant être agréés avant l'expiration de la première période); parfois, la durée sera fort longue, jusqu'à plusieurs dizaines d'années. Lorsque la durée n'est pas indiquée, l'Accord contiendra une clause de dénonciation.

Les langues
Les langues de l'Accord tiennent compte bien sûr des contraintes de l'Agence et de son Partenaire. Soit l'Accord est établi en plusieurs langues, au minimum trois: anglais, français, allemand, ou bien en une seule convenue avec le Partenaire, solution qui évitera des conflits d'interprétation entre versions authentiques. Des traductions peuvent ultérieurement être établies.

La conclusion de l'Accord
Par 'conclusion' on comprend l'élaboration, la négociation de l'Accord d'une part, son adoption, la signature et l'entrée en vigueur d'autre part.

La négociation
Elle est de la responsabilité du Directeur général. Dans le passé, il a été tenté de systématiser cette procédure, mais la négociation ne se prête pas à cet exercise. Le Directeur général informe les délégations d'une demande de coopération ou bien le principe même de la coopération est inscrit dans un document de programme. Il se peut qu'avant l'ouverture de négociations le Directeur général demande des instructions. Ainsi, par exemple, lorsque la Finlande a fait part de son souhait de devenir membre associé, les négociations ne se sont pas ouvertes aussi longtemps que l'Exécutif n'a pas disposé des lignes directrices sur le statut de membre associé développées par un groupe de travail établi par le Conseil et endossées par ce dernier. On peut encore citer la négociation des Accords sur les installations d'essais coordonnées à partir de principes directeurs approuvés par le Conseil au préalable.

Dans certains cas, le texte pour la négociation duquel le Directeur général est responsable est dépendant d'un texte supérieur lui-même en cours de négociations; ainsi de la négociation du Mémorandum d'Accord sur la Station spatiale dont certains termes dépendaient de la négociation du projet d'Accord intergouvernemental (IGA). (Les Résolutions de Rome et de La Haye constituaient aussi des instructions de négociations). La communication entre ces deux négociations était facilitée par le fait que les membres de l'Exécutif responsables de la négociation du projet de MOU assistaient le groupe gouvernemental de négociations du projet d'IGA.

La rédaction du projet d'Accord, sa négociation, restent de la responsabilité de l'Exécutif. Une fois un texte élaboré, que les négociateurs considèrent achevé et en état d'être présenté, le projet d'Accord suivra tout un long processus à travers les organes délibérants de l'Agence.

L'approbation
Le projet d'Accord sera présenté au Comité consultatif des Relations internationales (IRAC) lorsqu'il s'agit d'un texte conclu avec un Etat non membre, un organisme d'un Etat non membre, une Organisation internationale. L'IRAC examinera le texte sous son angle 'politique' et le recommandera au Conseil. Le texte sera par ailleurs soumis au Comité administratif et financier qui l'examinera sous l'angle juridique. Parfois, le Conseil directeur de programme compétent aura à se prononcer. Finalement, sous réserve parfois d'un processus itératif avec le partenaire, le texte sera soumis au Conseil pour approbation. Selon la nature du partenaire, l'unanimité pourra être requise (Etat non membre, Organisation internationale) ou la majorité simple de touts les Etats membres (Accord avec un organisme d'Etat membre).

Lorsque le Conseil reçoit un texte qui fait l'objet d'une recommandation unanime des organes consultatifs, l'adoption ira le plus souvent sans débat. Il reste que cette procédure peut parfois apparaître comme longue et complexe; des tentatives ont été faites pour l'alléger. Certains ont pu se demander si par exemple un Conseil directeur de programme pourrait être compétent pour approuver le texte d'un Accord et autoriser le Directeur général à le signer. Rappelons qu'un Accord international lie l'Agence et derrière elle chaque Etat membre. Aussi, tout système allégé doit-il faire en sorte de permettre à chaque Etat membre de s'exprimer.

Une procédure simplifiée existe dans le cas où le principe de l'Accord est prévu dans la proposition d'un programme facultatif dont le Conseil a autorisé l'exécution dans le cadre de l'Agence (par exemple un accord d'utilisation ou d'exploitation d'une installation sur le territoire d'un Etat non membre ou avec une autre Organisation internationale). Cet Accord demandera l'approbation unanime, y compris de ceux des Etats membres qui ne participent pas au programme considéré. Dans la procédure simplifiée, le Directeur général informe le Conseil et l'IRAC; une délégation a un droit d'évocation à l'IRAC; en l'absence d'objection dans un certain délai, l'unanimité est considérée comme acquise. Par ailleurs, le texte fait toujours l'objet d'un examen par l'AFC et le Conseil directeur du programme concerné. Le projet final est alors envoyé aux délégations nationales. Si, dans un certain délai, aucune délégation n'a demandé son examen, le Directeur général est autorisé à le signer.

Signature — Entrée en vigueur

Avant sa signature, le texte peut faire l'objet d'une certaine 'toilette'. Les orginaux sont confectionnés et la date et les modalités de signature arrêtées. Le Directeur général ne présente pas de 'pleins pouvoirs'; sa qualité de représentant légal de l'Agence au titre de la Convention et l'autorisation du Conseil suffisent. Parfois, il faut formellement notifier ceci au Partenaire qui dans certains cas produit lui des 'pleins pouvoirs'. Après signature, le sceau de l'Agence est apposé et l'original revenant à l'Agence archivé; sur sa base, des copies certifiées conformes (par le Conseiller juridique) sont établies. L'Agence notifiera la signature et l'entrée en vigueur et publiera le texte final (Série LEG). Sauf dispositions contraires de l'Accord, l'entrée en vigueur a lieu par la signature; il arrive que l'entrée en vigueur ait lieu à la date d'échange des instruments d'acceptation ou à l'issue d'un délai suivant la notification de l'acceptation. Dans certains cas, l'Accord pourra rétroagir et porter effet à la date qu'il spécifie.

L'Accord, une fois en vigueur, est un texte de portée obligatoire pour l'Agence, quelle que soit son appellation.

Accord et contrat

L'Accord, comme le contrat, sont l'expression juridique d'un concours de volontés. D'où parfois il peut être difficile de savoir quand il faut recourir à la forme de l'Accord ou à celle du contrat. Déjà les dispositions précédentes ont fourni des indices:

— Dans le cas de l'Accord, le partenaire de l'Agence sera en principe le Gouvernement d'un Etat membre ou non membre ou d'un organisme en relevant, une Organisation internationale. Le contrat sera, lui, conclu en principe avec une personne de droit privé.
— L'objet diffère: le contrat s'appliquera en général à une prestation de services ou la fourniture de produits au bénéfice de l'Agence et dont l'Agence aura arrêté les spécifications. Dans certains cas (activités opérationnelles), c'est l'Agence qui fournit une prestation de services ou délivre un produit. Cette livraison se fera sur la base d'un coût, contre paiement, alors que la coopération dans le cadre de l'Accord se fonde sur le principe de non-échange de fonds (ou de troc); un retard, un défaut de fourniture s'accompagnera de sanctions financières sur l'autre partenaire. Un retard, un défaut dans la mise en oeuvre d'un Accord ne s'accompagne pas d'une telle sanction (voir le cas de la coopération avec la NASA dans le MOU ISPM).
L'Accord définit les responsabilités de chaque Partenaire vis-à-vis d'un objectif arrêté en commun.
— La négociation du contrat se fera à partir des 'Clauses et conditions générales des contrats de l'Agence'. De telles clauses n'existent pas pour les Accords pour la négociation desquels il faudra chaque fois définir le contenu de l'Accord, négocier chaque disposition; une standardisation est fort difficile.
— Le contrat se réfèrera à un droit national.
— Le contrat n'est pas soumis à la procédure d'examen des organismes délibérants; le Conseil n'a pas à en approuver le texte ou à autoriser le Directeur général à le signer. Le contrat n'est pas public; les délégations n'en reçoivent pas de copie car il contient des informations commerciales à caractère confidentiel.

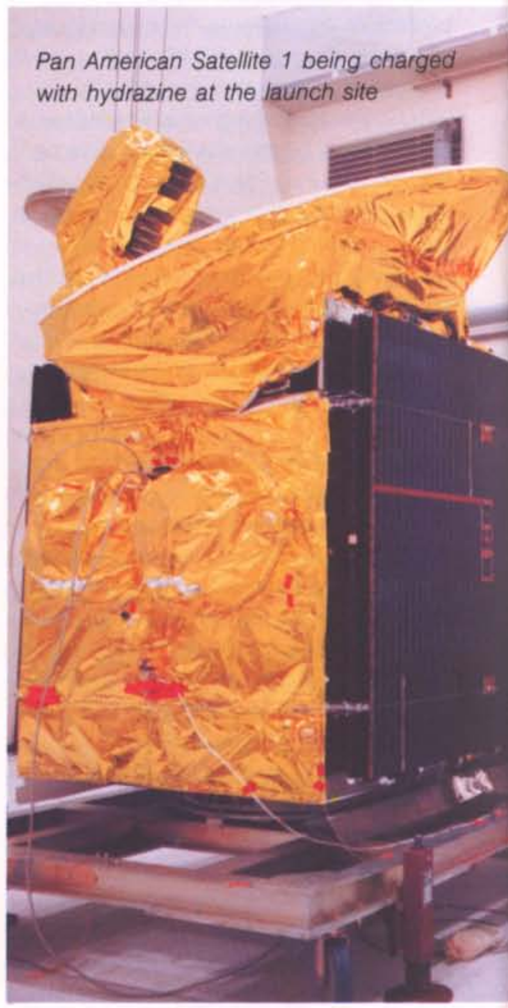
En ce qui concerne les activités opérationnelles, qui peuvent le cas échéant être au bénéfice d'organismes d'Etats non membres, le Conseil se prononce sur le principe (à la majorité simple) et sur l'extension des dispositions appropriées de l'Annexe I de la Convention. Ici encore le texte n'est pas soumis à une procédure d'examen des organes délibérants.

On a essayé de tracer les contours de l'Accord international, d'identifier un certain nombre de critères. Ceci n'est pas sans importance car l'Accord conclu par l'Agence, du fait de sa large discussion, de sa portée, est revêtu d'une certaine image publique. Par leur confection, l'Agence participe au développement du droit international.

In Brief

Final preparation of the Meteosat-P2 spacecraft at the launch site

Radio-amateur satellite Amsat-IIIC being prepared for launch



Pan American Satellite 1 being charged with hydrazine at the launch site

Three Satellites Launched by Ariane-4

ESA successfully carried out the first Ariane-4 launch on 15 June 1988 at 11 h 19 min 01 s UT (08 h 19 min 01 s local Kourou time), from the second Ariane launch pad (ELA-2) at the French Guiana Space Centre in Kourou.

The new launcher placed three satellites with a combined mass of 3513 kg into Geostationary Transfer Orbit (GTO): ESA's own Meteosat-P2, Pan American Satellite 1, and the radio-amateur satellite Amsat-IIIC.

This was the demonstration flight for Europe's new Ariane-4 launcher. The version used on this occasion, known as the '44LP', had two liquid- and two solid-propellant boosters. This configuration provided an opportunity for in-flight validation of all of the new elements on Ariane-4. The flight culminates the six-year Ariane-4 Development Programme, aimed at providing Europe with a launcher that will meet foreseeable market demand during the 1990s.

Lift-off of the first Ariane-4 vehicle, at 11 h 19 min 01 s UT on 15 June 1988 from the second Ariane launch pad in Kourou, French Guiana

First Images from Meteosat-P2

The first images from the Agency's Meteosat-P2 satellite, launched by Ariane-4 on 15 June, were received at the European Space Operations Centre (ESOC) in Darmstadt on 29 June, as the satellite drifted towards its final operating position. The three images shown here were taken in the visible, infrared and water-vapour wavebands on 1 July.

Early images from Meteosat-P2 taken in the visible, infrared and water vapour wavebands on 1 July 1988

VIS

IR

WV

The Phobos Mission

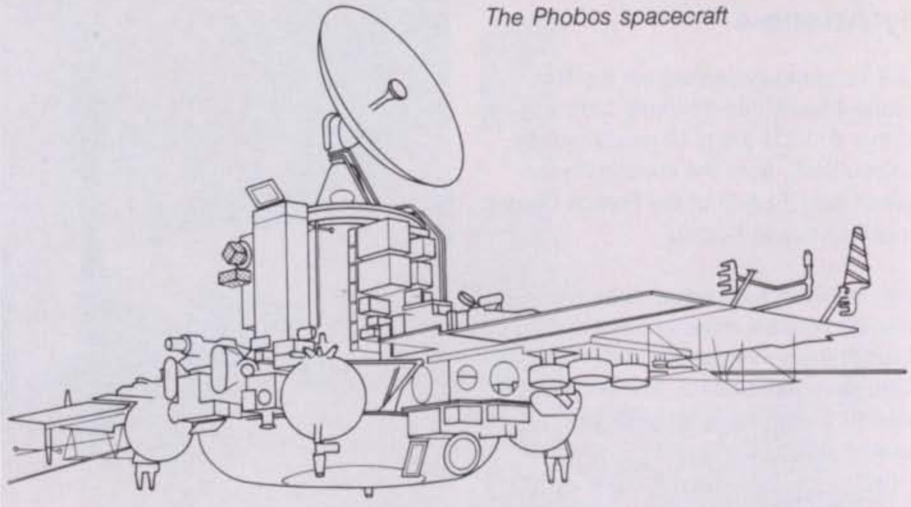
In the first half of July, more than a decade since the last space mission to Mars, two Soviet spacecraft were launched in rapid succession towards the Red Planet and its tiny moons Phobos and Deimos.

The two highly advanced space probes are carrying an impressive array of scientific instruments to perform a variety of investigations, both at Mars and during the 200-day journey from Earth.

A large international group of scientists is participating in the multi-disciplinary mission. ESA's Space Science Department, in collaboration with institutes in the USSR, France, West Germany, Hungary and the US, is providing hardware for two investigations: the Plasma and Wave instrument (APV-F), and the Low Energy Telescope charged particle detector (LET). ESA/SSD is also participating, together with institutes in Switzerland, France and the USSR, in the Helioseismology Instrument (IPHIR).

The two Phobos spacecraft will carry out studies of the Martian moon Phobos, the ionosphere and magnetosphere of the planet Mars, the Sun and the interplanetary medium. Within this ambitious programme, the LET experiment will measure the composition and energy spectrum of low energy cosmic rays and solar flare particles, taking advantage of the dual spacecraft configuration to make two-point measurements in interplanetary space. The objectives of APV-F encompass studies of the electric field wave spectrum and plasma density in the Martian magnetosphere and the solar wind. IPHIR will provide the first continuous observations from space of solar intensity oscillations.

A highlight of the mission will be the low-altitude hovering encounter with the tiny moon Phobos. The spacecraft will be brought to within 50 m of Phobos' surface and then ion and laser beams will be fired to release secondary ions from the surface material for analysis by onboard instruments. In support of these observations, APV-F will monitor the electric potential of the space probes throughout the remote sounding phase. During the hovering manoeuvre, an automated lander and an ingenious spring-loaded 'hopper' will also be deployed to make detailed measurements of the surface layers.


The Phobos spacecraft

Following their successful launches on 7 and 12 July, the two spacecraft are performing nominally. They will arrive at Mars in the last week of January 1989, when they will be placed in orbit around the planet in preparation for their encounters with its moon Phobos. According to preliminary mission planning, the first vehicle will carry out this spectacular manoeuvre on 8 April 1989.

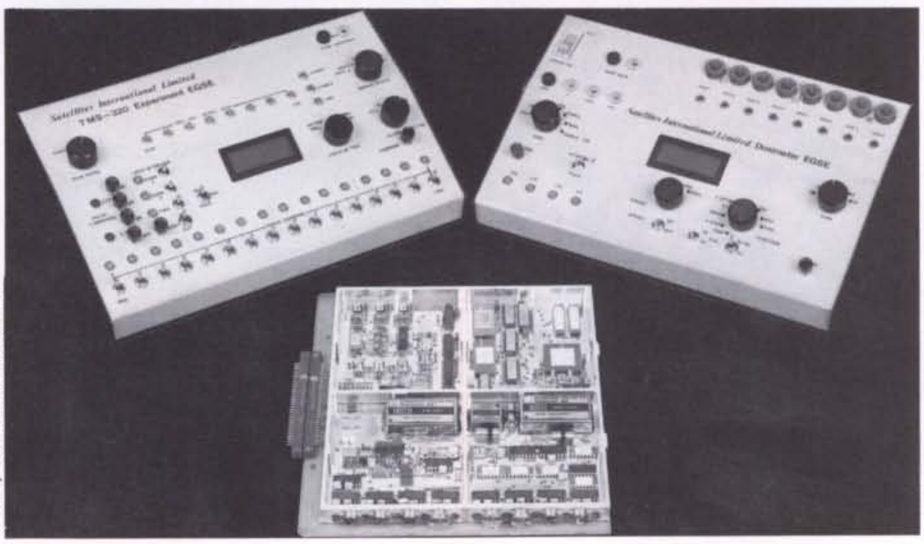
R.G. Marsden & R. Grard

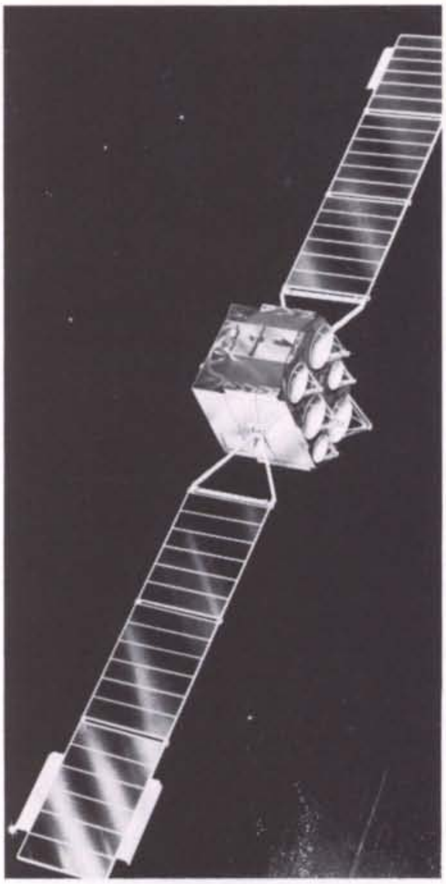
Successful Switch-on of Meteosat Radiation Effects Experiment

Meteosat-P2, successfully launched on 15 June, carries an instrument known as the 'Latch-up Experiment' which actually comprises three radiation experiments:
- Meteosat memory latch-up and single-event upset (Expt. 1)
- Signal processor and memory latch-up and single-event upset (Expt. 2)
- Dosimetry and shielding (Expt. 3).

Experiment 1: the experiment was initially conceived in January 1987 when concern was expressed regarding the possible cosmic-ray-induced latch-up of semiconductor memory devices intended for use in the Meteosat Operational Programmme. The Meteosat Project

The so-called 'ESTEC board' and associated test equipment for the Meteosat-P2 Radiation Effects Experiment. Experiments 2 and 3 and power conversion and distribution are implemented on this board


Courtesy Satellites International Ltd.



Artist's impression of an ECS satellite

ECS/Eutelsat 1-F1 Fifth Anniversary

The fifth anniversary of the launch of the first ECS satellite on 16 June marked a major achievement for both ESA and Eutelsat.

Since its Ariane launch on 16 June 1983 ECS-1, renamed Eutelsat 1-F1 when it commenced commercial operations, has established itself as the workhorse of Europe's communications satellites. The satellite is operated under a joint arrangement whereby Eutelsat utilises all of its communications capacity while ESA controls the spacecraft in geostationary orbit.

Eutelsat 1-F1 currently operates at 13° East and is dedicated to Europe's cable television and radio traffic. Its transponders have been switched on for approximately 400 000 h, more than any other satellite operating in Europe and its output power has consistently exceeded expectations.

Eutelsat 1-F1 is now expected to exceed its design life and remain operational until late 1990. Later this year it will be be moved to 16° East, where it will continue in full service. Its original 13° East orbital slot will be filled by ECS-5 (to be renamed Eutelsat 1-F5), due for launch on Ariane V24 on 21 July 1988 (see page 101 for latest news).

Office decided to test an experimental memory onboard Meteosat P2, using eight of the memory devices intended for operational use. This experimental memory is configured to detect, register and reset both latch-up and single-event upset occurrences.

Experiment 2: because of the interest in advanced, digital signal-processing technology for the Second Generation Meteosat Programme, a digital signal processor and high-density static memory components were also embarked (two different types of 256 Kbit memory devices were flown in order to evaluate different components). The experiment is configured to detect, record and reset both latch-up and single-event upset occurrences.

Table 1 — Composition of latch-up experiment unit

Experiment	Investigator — contractor	Aim	Content
Expt 1. Memory SEU* and latch-up**	Meteosat Project Crouzet	To provide in-orbit SEU and latch-up data on semiconductor memory for Operational Meteosat	8 Matra Harris 6504 memory chips with SEU and latch-up monitoring circuits
Expt. 2. Signal processing SEU and latch-up	ESTEC SAGEM Satellites International Ltd.	To provide in orbit SEU and latch-up data on TMS-320 DSP and associated memory for possible application in 2nd generation Meteosat	TMS 320-C25 chip and 2×256 k memories with SEU and latch-up monitoring circuits
Expt. 3. 8-channel dosimeter	ESTEC Satellites International Ltd. Radiation Effects and Monitors (REM)	To measure total absorbed dose behind various shields. To evaluate influence of total dose on SEU and latch-up sensitivity, to extend existing Meteosat-1 data	8 Radfet solid state dosimeters with various shields. Exposure and read-out circuitry, central power conversion and distribution for full unit.

*A single-event upset (SEU) is the change of state of a memory cell from 0 to 1 or vice versa, caused by the passage of a high-energy particle, ordinarily a heavy ion.
**In some integrated circuits parasitic bipolar transistors form a four-layer structure that can be triggered into a high-current conduction mode by the passage of a heavy ion. If not limited in some way, this current can cause burnout.

Experiment 3: the effect of cumulative total dose radiation damage on the latch-up and single-event upset sensitivity of memory devices is largely unknown. It was therefore decided to measure the total absorbed dose by means of eight solid-state dosimeters previously developed by ESTEC. The dosimeter experiment is configured also to investigate the effectiveness of different shielding materials. The dosimetry and shielding data will be of use in the design of radiation countermeasures which may be required for the Meteosat Second Generation Programme.

Following the successful launch and switch-on of the Latch-up Experiment, ESTEC is now responsible for monitoring the orbital operation of the entire experiment as well as performing all necessary ground testing, analysis and data interpretation. The results of this experiment will be valuable not only for the Meteosat Operational and Second Generation Programmes, but also for other ESA programmes intending to use the geosynchronous orbit.

For further information please contact J. Doutreleau (Expts. 1 and 2) or L. Adams (Expt. 1 and 3) at ESTEC.

Introduction of Vector Computing Facility at ESTEC

On 1 April 1988, the IBM facility in ESTEC was upgraded from a 3090 model 150 to a 3090 model 20E. This change principally involved exchanging the old single-processor 150 CPU for a dual-processor 20E CPU. Since each of the two model-20E CPUs has twice the power of a 150 CPU, this represents a four-fold increase in CPU power. Each CPU now has 32 Mb of memory and 64 Mb of expanded store available.

The 20E has been further enhanced by the addition of the 'Vector Facility' hardware and software, and on 1 July the Information Services Division inaugurated the Agency's first 'Supercomputer' facility.

As a result of the upgrade, the computing power now available compares favourably with that of other high performance computers (Table 1).

Table 1 — Approximate Floating-Point Performance per Processor

Computer	Scalar power	Vector power
IBM 3090 + VF	10 Mflops	37 Mflops — well-vectorised Fortan 75 Mflops — ESSL subroutines 117 Mflops — peak performance
Cray X-MP	12 Mflops	210 Mflops peak performance
FPS 264	5 Mflops	38 Mflops peak performance

* 1 Mflop = One Million Floating Point Operations per second.

To ensure good performance, the machine's two processors will be run as two logically separate machines. Processor 1 will be dedicated to Office Services and the general computing community, and will not have access to the Vector Facility. Processor 2 will have the Vector Facility and will be for the use of the intensive computing community.

The final hardware and software configuration is therefore as follows:

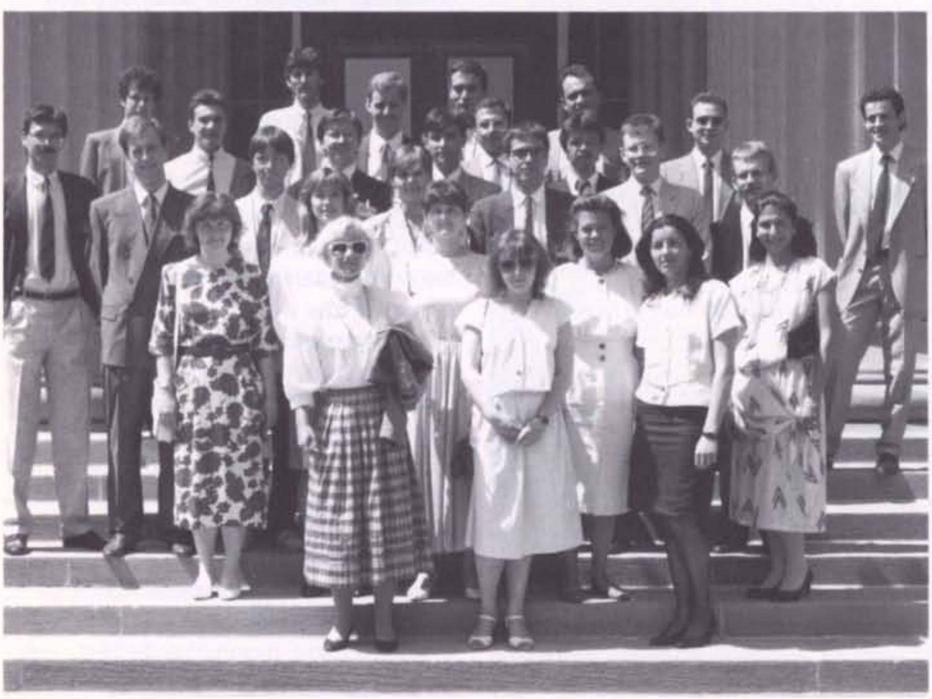
VM/XA Supervisor	
VM/HPO	Vector
Office Service + General Purpose users.	Vector users + Compute Intensive users.

Should a failure occur in either processor, its workload can be handled by the other, with some degradation in performance. If Processor 2 should fail, the Vector Facility will be temporarily unavailable.

The Vector Facility is presently supported with the VM/CMS operating system and the new Fortran 2.3 compiler. In 1989 it is planned to install AIX, which will be the basis for the future standard UNIX operating system to be offered by 'The Open Software Foundation' (IBM, Digital, Apollo, HP, Nixdorf, Siemens, and Bull). Interconnection of work stations supporting Ethernet and TCP/IP is under investigation, and is planned to be implemented on a test basis in the near future.

Further information about the Vector Facility can be obtained by contacting J.C. Lewis at ESTEC (Tel. 01719-84707; on EARN - ESTEC(JLEWIS); on SPAN - ESTCS1::JCLEWIS).

Opening of the International Space University



The first session of the International Space University (ISU) commenced on 20 June at the Massachusetts Institute of Technology. Of the 104 students, from 21 different nations, a total of 28 came from ESA Member States. Over a two-month period the students are following an intensive course of lectures in various space fields, including space policy, science, engineering, life sciences, business and management, and taking part in a project to design an International Lunar Facility.

ESA Member State students at the International Space University

ESA Support for the 'Dutch Viking' Atlantic Crossing

ESA/ESTEC is providing a satellite communications terminal for an Atlantic crossing by two Dutchmen, Henk Brink and Willem Hageman, in a motorboat named the Dutch Viking. Only 6.5 m in length, the tiny polyester capsule is the smallest boat in the World to be equipped for satellite communications.

The Dutch Viking is carrying a PRODAT terminal, a mobile communications system conceived and developed at ESTEC. The lightweight equipment is fitted with a very compact antenna measuring only 10 cm in diameter.

The little boat left St. Johns, Newfoundland on 1 July and hopes to reach The Netherlands towards the end of the month. Throughout the 2335 mile journey, it will be possible not only to monitor Dutch Viking' progrees, but also to exchange meteorological and other data in real time. The signals will be relayed by Marecs B2 via ESA's Villafranca ground station.

This is the second Atlantic crossing by the Dutch pair. In the summer of 1987 they made a record-breaking crossing in a large helium-filled balloon for which ESA provided a specially developed lightweight PRODAT terminal.

The Dutch Viking and crew

The ISU's medium-term plan includes a further four annual summer sessions, the next of which will be held in Europe. In the course of the 1989 session ESA will provide the ISU with 20 h of transmission time on the Olympus satellite for use in the dissemination of lectures.

Subsequent sites under consideration include the Soviet Union and Japan. At the end of the first five years the intention is to instigate a full-time programme with a permanent campus.

The deadline for applications for the 1989 summer session is 31 December 1988. Further details may be obtained from:

The International Space University
636 Beacon Street, Suite 201-202
Boston, MA 02215.

ECS-5 Launched by Ariane V24

Ariane V24 was successfully launched on Thursday 21 July at 23 h 12 min 03 s UT from the French Guiana space centre in Kourou. Aboard the Ariane-3 launcher, as a double payload, were ESA's operational telecommunications satellite ECS-5 and the Indian communications/ meteorological satellite INSAT 1C.

All flight sequences went according to plan and the two spacecraft were injected into geostationary transfer orbit with the following parameters: perigee 198 km (199 km predicted); apogee 36 028 km (35994 km predicted); inclination 7° (nominal).

Since separation, ECS-5 has been controlled from ESOC in Darmstadt, via the Agency's Redu ground station. On Saturday 23 July at 12 h 23 min, the spacecraft's apogee boost motor was fired and its solar arrays were successfully deployed some seven hours later. Earth aquisition was achieved on 24 July at 08 h. The satellite is now drifting eastwards and will reach its initial operational position at 16°E in mid-August.

ECS-5 is the fifth and final flight model in the ECS series. After a short period of in-orbit testing during the summer, it will be handed over to Eutelsat for commercial use, at which point it will be renamed Eutelsat 1-F5. Control of the satellite, from the dedicated ECS control centre at Redu in Belgium, will remain the responsibility of the Agency.

Publications

The documents listed have been issued since the last publications announcement in the Bulletin. Requests for copies should be made in accordance with the Table and using the Order Form inside the back cover of this issue.

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ROLFE E J (ED)

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BURKE W R (ED)

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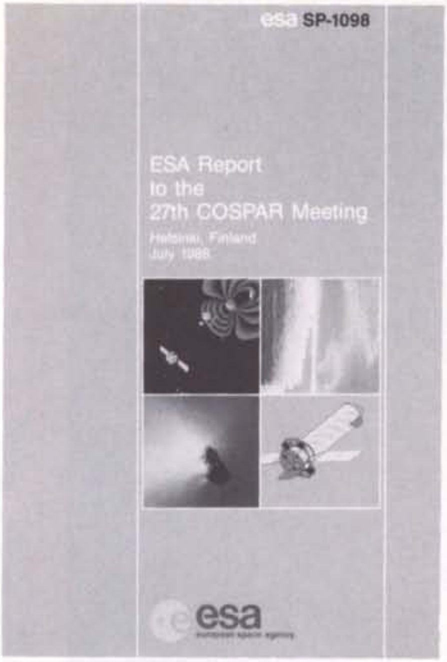

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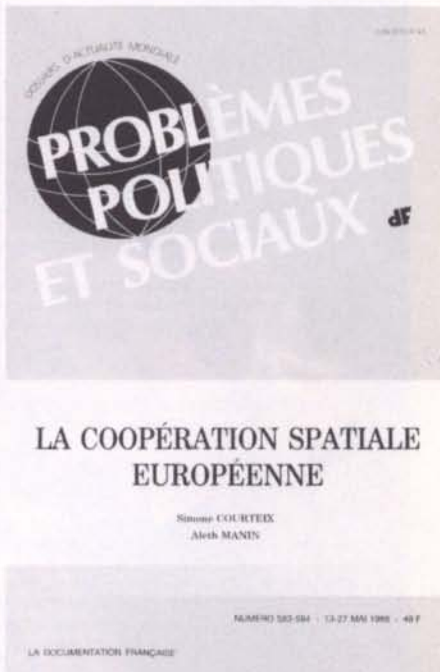

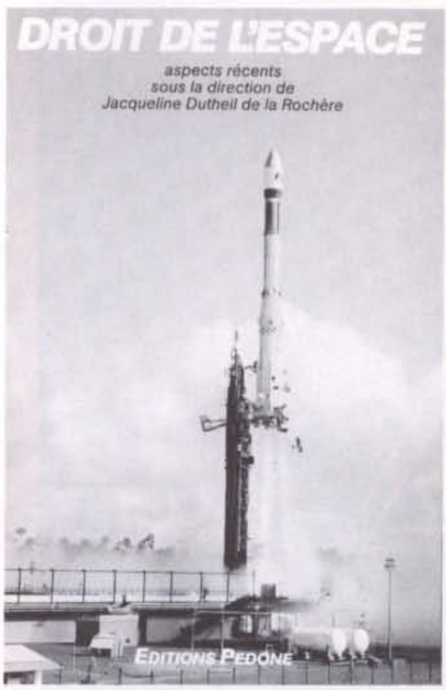

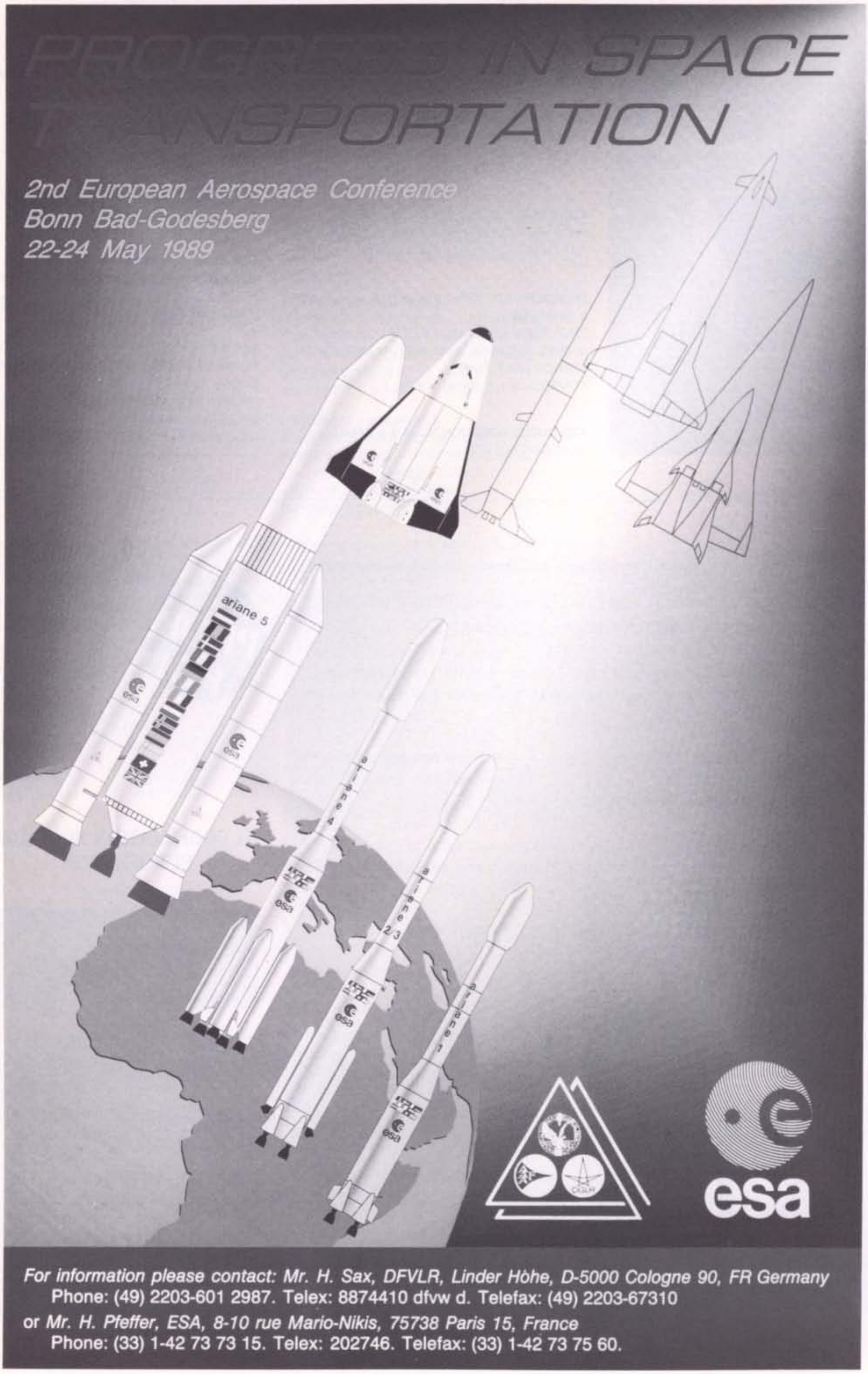
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or Mr. H. Pfeffer, ESA, 8-10 rue Mario-Nikis, 75738 Paris 15, France
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UNIVERSITEIT GRONINGEN

Richt uw sollicitatie vergezeld van een curriculum vitae, vóór 1 september a.s. aan het hoofd van de afdeling Personele Zaken van de Universiteit Groningen, Postbus 72, 9700 AB Groningen. Vermeld het betreffende vacaturenummer op uw brief en de envelop. Graag zien wij op onze vacatures ook vrouwen solliciteren, vooral voor functies waarin zij thans ondervertegenwoordigd zijn.

Algemene inlichtingen worden graag verstrekt door Karin Kaagman en Truida Olinga van de afdeling Personele Zaken, telefoon 050-635353.

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Name ....

Function ....

Organisation ....

Mailing Address ....

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Town & Postal Code ....

Country ....

Customer's Ref. .... Signature ....

Date ....

ADDITIONAL INFORMATION

1. Publications are available in printed form (as long as stocks last), in microfiche and as photocopies.
2. Publications in the ESA TT series are not available in printed form.

european space agency
agence spatiale européenne

member states	etats membres
austria	allemagne
belgium	autriche
denmark	belgique
france	danemark
germany	espagne
ireland	france
italy	irlande
netherlands	italie
norway	norvège
spain	pays bas
sweden	royaume-uni
switzerland	suède
united kingdom	suisse