# esa bulletin

number 46 may 1986

## european space agency

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European Space Organisations: the European Space Research Organisation (ESRO) and the European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO). The Member States are Belgium, Denmark, France, Germany, Ireland, Italy, Netherlands, Spain, Sweden, Switzerland and the United Kingdom. Austria and Norway are Associate Members of the Agency. Canada is a Cooperating State.

In the words of the Convention: The purpose of the Agency shall be to provide for and to promote, for exclusively peaceful purposes, co-operation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems,

(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.

The Directorate of the Agency consists of the Director General; the Inspector General; the Director of Scientific Programmes; the Director of the Earth Observation and Microgravity Programme; the Director of the Telecommunications Programme; the Director of Space Transportation Systems; the Director of the Columbus Programme; the Director of ESTEC; the Director of Operations and the Director of Administration.

The ESA HEADQUARTERS are in Paris.

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

ESRIN, Frascati, Italy.

Chairman of the Council: Dr. H.H. Atkinson.

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, la Belgique, le Danemark, l'Espagne, la France, l'Irlande, l'Italie, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. L'Autriche et la Norvège sont membres associés de l'Agence. Le Canada bénéficie d'un statut d'Etat coopérant.*

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*(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;*

*(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications;*

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*ESRIN, Frascati, Italie.*

*Président du Conseil: Dr. H.H. Atkinson.*

*Directeur général: Prof. R. Lüst.*

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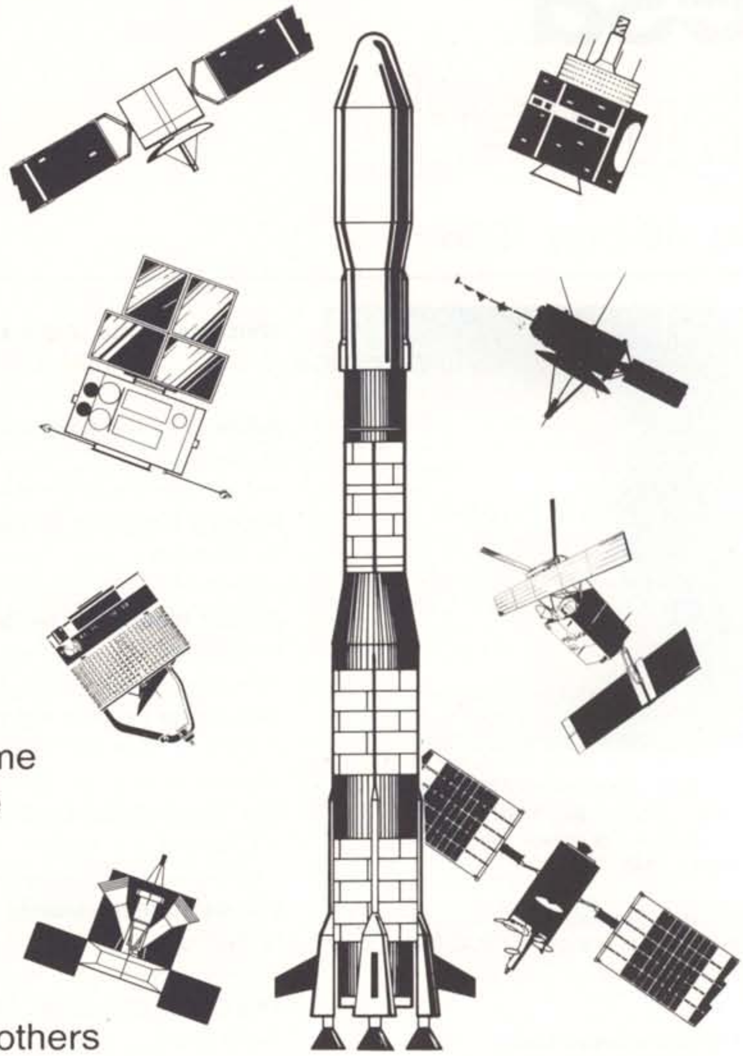

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# Welcome to the Giotto Encounter*

*R. Lüst, Director General, European Space Agency, Paris*

Ladies and Gentlemen,

In welcoming you here tonight, I offer you a paradox. You are here to witness an event that mankind has viewed with varying degrees of fear, superstition and wonder since the beginning of recorded history, and most likely well before that. I should really say thought they viewed, for the paradox lies in the fact that this well-known visitor has kept its real face and true identity hidden until tonight, when we meet in the hope that Halley's Comet will give up some of its secrets to the camera and instruments onboard Giotto.

Comets have fascinated mankind for countless centuries. Unlike the meteors that blaze fiercely for a short time and are then burnt out, comets have made their majestic passages across the heavens at a pace that has left time to contemplate their origin and their nature. As the British author Dean Swift said:

> 'Old men and comets have been reverenced for the same reason; their long beards and pretences to foretell events.'

The name 'comet' comes from the Greek word for 'hairy', and the comas and tails of many of the most visible comets have the superficial appearance of a beard.

The relatively slow passages of the comets across the night skies have enabled astrologers and others intent on duping the gullible, to associate the comets with disastrous events. As Shakespeare tells us:

> 'When beggars die there are no comets seen; the heavens themselves blaze forth the death of princes.'

Certainly there is evidence from the Bayeux tapestry that the comet may have had a decisive effect on the outcome of the Battle of Hastings in 1066. It seems that Harold was convinced that the comet foretold his defeat, and one can only wonder at the consequences for European history had the battle gone the other way.

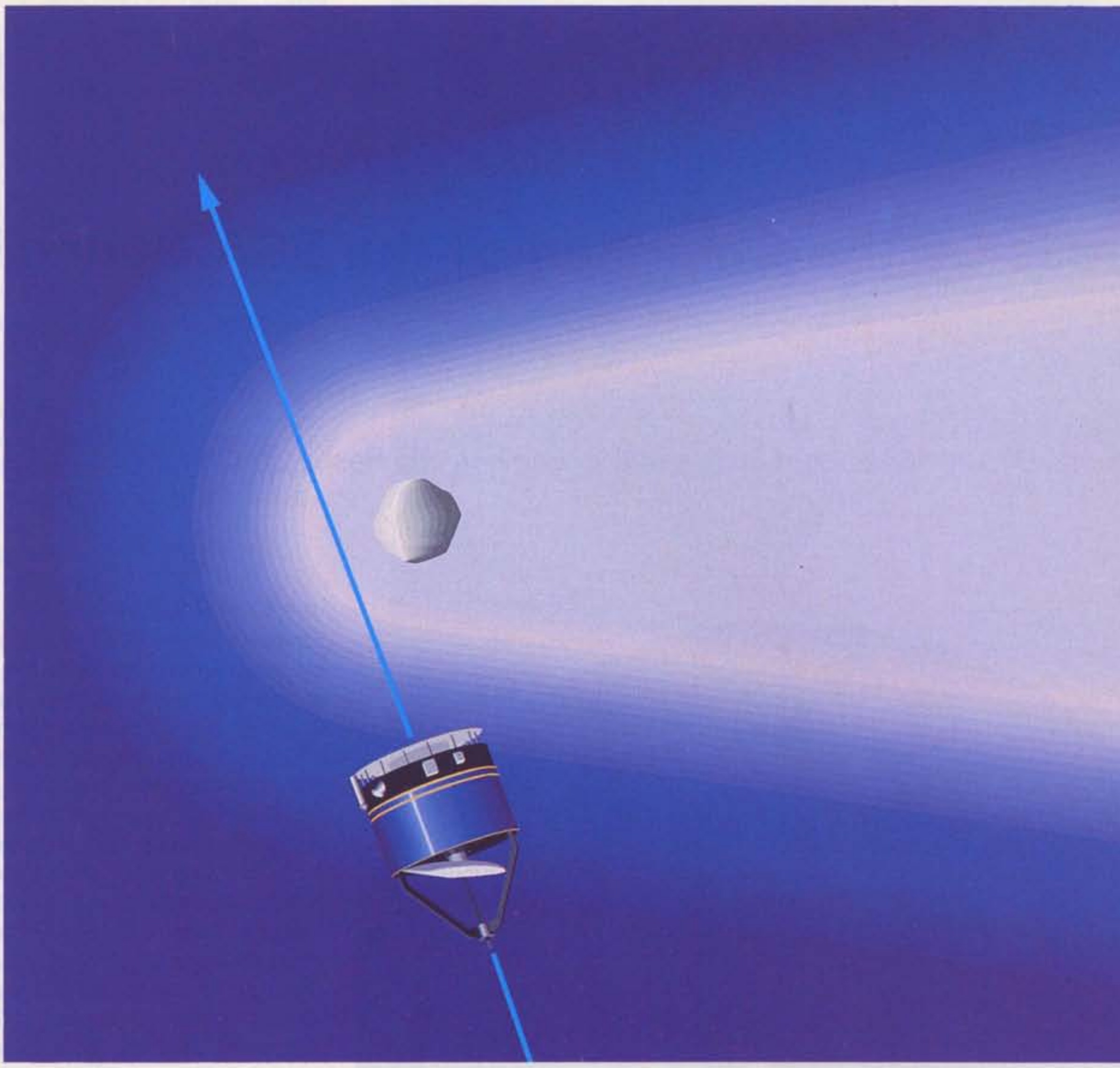
Today, however, we meet not in the shadow of aggression between nations, but in the full glow of an international collaboration that tonight reaches a climax after years of hard, selfless cooperation. The scientists and engineers from Europe, the USSR, the USA, and Japan have decided that they must not repeat the faults of the 1910 apparition, when self-interest cost many lost opportunities. This time they are working together to make the best use of the latest space technology available to them, and to give the waiting world a real chance to learn as much as possible about our infrequent visitor. The planning, and the operation of the international fleet of satellites, the ground-control and the data-retrieval and analysis teams all bear witness to the meticulous detail that has gone into the preparation of this collaborative effort.

It therefore is a great pleasure for ESA that our sister organisations, with whom we are collaborating in this exciting venture, are with us tonight. I would like to welcome Professor Hirotake Matsuo from Japan's Institute of Space and Astronautical Science. I am particularly pleased that my friend and colleague, Academician Roald Sagdeev from the Academy of Science and IKI, the Space Research Institute in Moscow, is here tonight. It will not be easy for us to compete with the excellent performance and presentation of the results of the Vega-1 and Vega-2 encounters. I was able to witness that presentation myself in Moscow last Sunday. Last, but not least, we are very pleased and honoured that NASA's Acting Administrator, Dr. William Graham, is here from Washington. I am grateful for the good cooperation that we have enjoyed over many projects in the past.

It has fallen to Europe to design, build, launch, and operate the vanguard of the spacecraft fleet, Giotto. The other members of the fleet have played their parts to the full, not only in collecting data, but also in pinpointing the precise path of Halley's Comet, and the latest position of the comet nucleus, so that Giotto's trajectory could be adjusted to pass as close as possible to its targeted 540 kilometres on the sunward side of the nucleus.

Robert Burton tells us, quoting from the Latin, that: 'A dwarf standing on the

* Speech of welcome to distinguished guests invited by the Agency to witness the Giotto encounter from ESA's European Space Operations Centre (ESOC) in Darmstadt, W. Germany, on the night of 13/14 March 1986



shoulders of a giant can look further than the giant himself'. We scientists today are standing on shoulders of giants: the Greek philosophers, Tycho Brahe, Halley himself, Newton, and all of those other scientists who, with their limited instruments, gave us the solid platform of scientific tradition from which we have been able to launch tonight's encounter with a comet.

There are three scientists who have given us theoretical insights into cometary physics during the last 40 years. Two of them I welcome here very cordially, Professor Jan Oort and Professor Fred Whipple, while the third, Professor Ludwig Biermann, my teacher, had hoped so much to be here on his 79th birthday. Sadly, a few hours after he had faced the cameras for the Giotto film that is to be presented later, he lost conciousness, and died two days later. I am so pleased that Mrs Biermann could be with us this evening.

Finally, I want to thank all the taxpayers in Europe who made it possible for us to carry out the Giotto mission. On their behalf, I greet all the Parliamentarians here and I welcome for all the Member States, the Council Members with their Chairmen, but in particular also some of their 'masters': the present Chairman of the Ministerial Council, Minister van Aardenne, who was so active in making the last Ministerial Conference in Rome such a success; Minister Granelli, who played such an essential role in preparing the Rome Conference; from the United Kingdom, Minister Pattie, who is not only responsible for industrial matters, but demonstrated in Rome so much understanding of the Science Programme.

It is also an honour for me to welcome Minister Collins from Ireland. His presence here serves as a reminder that Europe is composed of many countries, and that those that are sometimes called the 'small countries' play a far from minor role in the Agency through contributions that are financially, scientifically and politically essential to the success of our programmes.

Our European Space Operations Centre (ESOC) would not be what it is today without the continuous support it receives from the city of Darmstadt and its Mayor, Oberbürgermeister Metzger, so it is fitting that he should also be here tonight.

Finally, I should like to welcome Her Royal Highness, Princess Margaret von Hessen und bei Rhein.

Welcome once again to all of you. I hope that we will have an interesting, exciting and enjoyable evening together.

# Address by the Chairman of the ESA Council

*H. Atkinson, Director Science, UK Science & Engineering Research Council*


*Figure 1*

Ladies and Gentlemen,
You now know much about the science of Halley's Comet and about the engineering of Giotto, and so I am going to tell you a little about Halley himself (Fig. 1). It was he who turned the comet from superstition into science.

Halley was a remarkable man, working in a remarkable time — the 17th century — in which Europe was buzzing with new ideas. He began his astronomical observations as a schoolboy. As an undergraduate at Oxford University, he went to St. Helena for a year (1676) to map the Southern Skies. Because of this absence, Oxford would not grant him a degree, until the King, Charles II, ordered the University to award to him an MA for his astronomical work.

Halley saw his first comet in 1680 in France, on his way to Italy. Two years later, in 1682, he observed 'Halley's' comet and became interested in its possible motion. However, at that time there was no satisfactory theory of gravity, and so, to enable him to pursue his calculations on the orbits of astronomical bodies, he went to Cambridge to see Isaac Newton. Newton shuffled through a pile of old papers, and found some work on elliptical motion that he had done many years before, but had never published. This proved to be the key to the theoretical understanding of orbits. Halley urged Newton to publish his work, and indeed Halley finally edited and paid for the production. Thus was born Newton's Principia Mathematica, one of the most important scientific works of all time. Newton often called it 'Halley's book'.


*Figure 2 — Searching for Halley's Comet, at Greenwich Observatory (sketch by W. Heath Robinson, 17 November 1909; courtesy of Royal Greenwich Observatory)*

Halley wrote in his preface to the Principia, an 'Ode to Newton' which contains these words:

'Now we know
The sharply veering ways of comets, once
A source of dread, no longer do we quail
Beneath the appearance of bearded stars.'

and goes on:

'Matters that vexed the minds of ancient seers,
And for our learned doctors often led
To loud and vain contention, now are seen
In reason's light, the clouds of ignorance
Dispelled at last by science. Those on whom
Delusion cast its gloomy pall of doubt,
Upborne now on the wings that genius lends,
May penetrate the mansions of the gods
And scale the heights of heaven.'

In 1724, Halley gave a copy of a book that he had written on orbits to French astronomers; and they also predicted that the comet would return in 1759.

The first observation of the return of the Comet, confirming Halley's work, was in fact made on 25 December 1758 by a German, a Saxon farmer called Georg Palitzsch, and not by English or French astronomers, much to their annoyance.

Thus comets became 'science', but even at the last sighting, in 1910, the technology was still rather primitive (Fig. 2). The big leap forward today comes from technology, our new, space technology. But science and technology go hand-in-hand, and from this space technology is coming a revolution in our understanding of the Universe.

As it was in Halley's time, this cometary endeavour is a great international affair. But now new countries and continents are involved — the USSR, Japan, and the USA — and the signals from Giotto are being received first by the radio-telescope at Parkes in Australia.

We must thank and congratulate all of our international partners in this great enterprise. I believe that it is really rather appropriate that it is a European satellite — a satellite of 11 countries, soon to be 13 — which is going closer to the Comet than any of the others.

Our best wishes must go to the real VIPs: all the scientists and engineers who have worked for years on this mission, in the Agency, in industry, including British Aerospace and Arianespace, in the scientific institutes and in the universities. And I should also like to thank particularly Dr. Bonnet, ESA's present Director of Science, and his predecessor, Dr. Trendelenburg; and the present and past Director Generals: Prof. Lüst, Mr. Quistgaard and Mr. Gibson.

But thank you, also, Ministers for having the political will — and for providing the money! — to support our space science programme. Thank you again, Director General, and thank you particularly Mr. Heftman, as our host here at ESOC.

Ladies and Gentlemen, I cannot end without referring to the remarkable technical precision of the Giotto mission, both in time and in space. Even if it were to end now, before the planned closest encounter, the mission would still have been a tremendous success. Congratulations, therefore, to all concerned.

# Halley's Comet as an Outstanding Target

*R. Reinhard, Giotto Project Scientist,*
*ESA Space Science Department, ESTEC,*
*Noordwijk, The Netherlands*

**Among more than 1000 known comets, Halley was the most outstanding target for a cometary mission as it is the only comet that has a well-known orbit and a high gas and dust production rate, comparable to that of 'new' comets. A mission to Halley also required comparatively little launch energy and the comet could moreover be observed from the Earth during the flybys.**

**Between 6 and 14 March 1986, five spacecraft from three space agencies flew through the coma of Halley's Comet. The encounters all took place in March 1986, because a minimum of launch energy was required for these post-perihelion encounters. At that time, four weeks after its perihelion passage, Halley was also at its most active, exhibiting all of the well-known cometary phenomena.**

**Introduction**
It is estimated that of the order of $10^{12}$ comets exist in a vast cloud around the Sun at a distance of ~50 000 AU. Each year approximately 100 comets are newly deflected into the Jovian capture region (4—6 AU from the Sun) as a result of chance gravitational perturbations occurring in the distant reaches of the solar system due to random star passes. Occasionally, the orbit of such a comet is perturbed to become a short-periodic orbit by the gravitational pull of one of the major planets.

To date, some 1000 different comets have been recorded, and approximately 5 to 10 new comets are discovered each year. Based on their orbital periods, comets can be categorised as 'short-periodic' (with periods between 3 and 25 years), 'intermediate periodic' (25—200 years), 'long-periodic' (200—$10^6$ years) or 'new' comets. Halley, with its 76-year period, belongs to the category of intermediate-periodic comets.

Unlike the planets, which all move in roughly co-planar orbits, the long-periodic and new comets have orbits that are distributed spherically around the Sun. Their distribution in space is reminiscent of the distribution of globular clusters about the centre of their parent galaxy. There are cosmogenic hypotheses that suggest that these spherical symmetries reflect the symmetry of the parent cloud of material that later collapsed and flattened to form the main system. This has suggested to some researchers that comets may be very old, possibly predating the planets themselves. Consequently, the material they contain may be representative of the earliest condensations in the interstellar cloud that was ultimately responsible for the formation of the Sun and the planets. The likelihood that the nuclei of new comets are pristine samples of condensates from the protosolar system (possibly mixed with interstellar dust) implies that measurements of their composition and physical constitution should yield fundamental information about the chemical and physical conditions that existed at about the time that the planets were formed.

Cometary nuclei are generally thought to consist of a mixture of ices — mainly water, but also many other volatile molecules composed of hydrogen, carbon, nitrogen and oxygen — and rocky material. The dimensions and masses of most cometary nuclei are inferred to be in the range 1—10 km and $10^{15}$—$10^{18}$ g, respectively. As a result, the gravitational attraction or, equivalently, their escape velocity, is of the order of 1—5 m/s$^{-1}$, which is minute in comparison with that of the planets. The absence of external heating and heating by self-gravitation, due to the small masses of the comets, should lead to a composition qualitatively different from that of all other bodies in the solar system.

Our knowledge of comets prior to the Halley encounters stemmed largely from the fact that their nuclei, which are themselves too small to be observed from the Earth, become active as the comet approaches the Sun. Heated by insolation, the nucleus releases large amounts of gas and dust during the comet's passage through perihelion. This unpredictable and often violent process produces an 'atmosphere' of enormous extent. Neutral molecules, some highly reactive, are formed by sublimation and possibly other processes occurring very close to the nucleus ($<10^3$ km) and they expand to distances of $10^5$—$10^7$ km. Ionised molecules, also produced by very rapid, but poorly understood processes, have on occasion been observed even in the inner parts of this atmosphere. In addition, ions are accelerated out of the central region to form a plasma tail. Such tails show visual evidence of complex hydromagnetic phenomena (filaments, rays, kinks and helices).

The gas streaming away from the nucleus carries with it large quantities of fine dust, which is responsible for much of the visual brightness of a comet. At distances greater than $10^4$ km from the nucleus of a very active comet, the 'pressure' of the solar radiation exceeds the aerodynamic drag force on the dust, which is then swept out of the comet's atmosphere to form a large curved dust tail.

Surrounding the visible coma and extending out to distances of $10^7$ km is an envelope of hydrogen formed by the photo-dissociation of water.

**The reasons for a cometary mission**
Although we have a large set of observations of comets over many centuries at our disposal, our real knowledge of comets is still very limited. Most of this knowledge consists of the determination of cometary orbits, phenomenological descriptions of the coma and the tails, and analyses of cometary spectra. Observations of comets from Earth (ground-based or from near-Earth space) can only provide line-of-sight integrations, limited to molecules with strong emission lines in suitable wavelength ranges.

Cometary research cannot advance significantly beyond its present state unless certain fundamental questions are answered which could only be addressed by in-situ measurements. The following questions could already be addressed with a simple flyby mission:
— Is there a nucleus in the centre of a comet?
— What is the size, shape, albedo, composition, surface temperature, rotation rate and rotational axis of the nucleus?
— Are there active regions on the nucleus?
— What are the parent molecules?
— Which chemical processes occur in the cometary coma?
— What are the gas and the dust production rates?
— What is the dust size distribution?
— How small are the smallest dust particles?
— What is the dust-particle albedo?
— What is the composition of the dust particles?
— What are the ionisation mechanisms?
— Is there a well-defined bow shock, what is its physical character, and where is it located?
— Are there energetic particles present?
— What is the peak magnetic field strength?
— Is there a contact surface, and where is it located?
— What are the velocity distributions of neutral and ionic species and electrons?
— How far away from the comet can we observe signs of cometary activity?
— What are the abundances of the different molecules and ions making up the cometary atmosphere?
— Where are the dust envelopes?
— Are the dust particles electrically charged?

**The reasons for selecting Halley**
The most active and therefore brightest comets are the 'new' ones, comets that have never previously approached the Sun. Ideally, then, one would like to encounter a new comet, but this is at present impossible. To be able to plan a mission to a comet, its orbit must be well known, which means that the comet must have returned several times. This rules out new comets and leaves only the short-periodic and a few intermediate-periodic comets as potential candidates.

Cometary brightness, which is a measure of the gas and dust production rate, is plotted in Figure 1 as a function of the comet's periodicity. Almost all short-periodic comets are comparatively faint, with absolute magnitudes of the order of 11. Of particular interest are a group of eight comets with absolute magnitudes of less than 7 and periods of less than 200 years. The characteristics of these eight comets are shown in some detail in Table 1.

Four of the eight comets have either subsequently not reappeared or may not reappear, and two (Comets Pons-Brooks and Olbers) will not reappear before 2025, which only leaves Schwassmann-Wachmann-1 and Halley. Schwassmann-Wachmann-1 is actually much less bright than Halley because its perihelion distance is 5.5 AU. Nevertheless, because of its occasional flaring up at large distances from the Sun, Schwassmann-Wachmann-1 is a very exciting target for a cometary mission.

All in all, Halley with its 30 recorded apparitions proved, therefore, to be the most outstanding target. Halley is the only one of more than 1000 recorded comets that has a well-known orbit *and* a high gas and dust production rate, comparable to that of new comets.

Some more technically oriented criteria for the selection of a cometary target (after Boissard et al.) are:

— a reliable orbit should be available, in order to predict the ephemerides of the comet with sufficient accuracy
— the recovery of the comet should occur well before the encounter (at least 100 d), since the calculated

ephemerides should preferably be adjusted with new observations
- the comet should be visible from the Earth at encounter so that spacecraft observations can be complemented with ground-based observations
- the encounter should occur when the comet is not too far from the Sun (heliocentric distance less than about 1.5 AU) and already shows some activity
- the departure hyperbolic velocity should not exceed about 10 km/s, but should preferably be well below this figure (a low departure hyperbolic velocity allows a large payload mass for a given spacecraft)
- the relative encounter velocity between comet and spacecraft should be as low as possible, in order to have a sufficiently long observing time in the proximity of the comet.

Taking into account these criteria and considering the periodic comets that have been observed at more than one apparition and had predicted perihelion passages between 1984 and 2000, Boissard et al. arrived at 10 candidate comets with 19 favourable perihelion passages (Table 2).

As is evident from Table 2, Comet Halley met all of the criteria in a favourable way, apart from its orbital inclination (Halley has a retrograde orbit), which resulted in a very high flyby velocity. As Table 2 shows, the departure hyperbolic excess velocity required to fly by Halley was one of the lowest.

Last, but by no means least, Halley's Comet is the most famous of all the comets. Although its fame was not the main factor in its selection, the prime reasons for its choice, namely its brightness and its well-known orbit, are the very reasons for its fame. It is so bright and reappears so regularly that it could be observed at each of its last 30 apparitions, over a period of more than 2000 years. It is therefore no coincidence that it was this comet that led Edmond Halley to his most important discovery of the periodicity of some comets. Historical observations from Halley's last 30 apparitions are briefly summarised in Table 3.

**The choice of March 1986**

The Russian Vega-1 and -2 spacecraft were launched on 15 and 21 December 1984, respectively; Japan's Sakigake (formerly MS-T5) was launched on 8 January 1985; Giotto was launched on 2 July 1985; and the second Japanese spacecraft Suisei (formerly Planet-A) was launched on 19 August 1985. Although these launch dates were spread over a period of eight months, all of the spacecrafts' encounters with Halley occurred within a week of each other in March 1986: 6 March for Vega-1, 8 March for Suisei, 9 March for Vega-2, 11 March for Sakigake, and 14 March for Giotto.

This scenario was a consequence of the orientation of Halley's orbit with respect

*Figure 1 — Absolute magnitudes of comets with periods up to 1000 years. Of all the comets that have returned at least twice to the inner solar system, Halley is the brightest (data after Vsekhsvyatskii, 1964)*

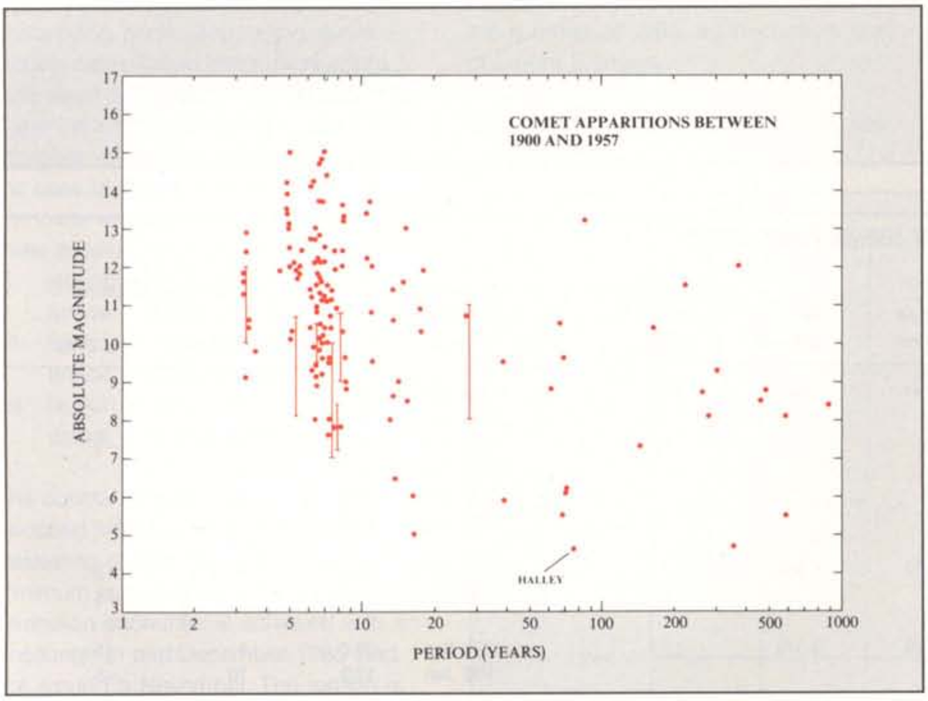



*Table 1 — Comparison of the eight brightest short- and intermediate-periodic comets*

| Designation | absolute magnitude* | orbital period (y) | Perihelion distance to the Sun (AU) | Apparitions Last | No. of | Next |
|---|---|---|---|---|---|---|
| 1901 I | 5.9 | 39.08 | 0.245 | 1901 | – | Did not reappear |
| Halley | 4.6 | 76.03 | 0.587 | 1910 | 30 | 2061 |
| 1916 III | 6.0 | 16.34 | 0.471 | 1916 | – | Did not reappear |
| 1921 II | 6.4 | 13.85 | 1.008 | 1921 | – | Did not reappear |
| Schwassmann-Wachmann-1 | 2-5 | 16.3 | 5.5 | 1974 | 4 | 1990 |
| Pons-Brooks | 6.1 | 70.88 | 0.774 | 1954 | 3 | 2025 |
| 1954 X | 6.2 | 71.95 | 0.971 | 1954 | – | ? |
| Olbers | 5.5 | 69.47 | 1.179 | 1956 | 3 | 2025 |

*Absolute magnitude is the brightness a comet would have if it were at I AU

*Figure 2 — The geometry of Comet Halley's orbit relative to the ecliptic plane*

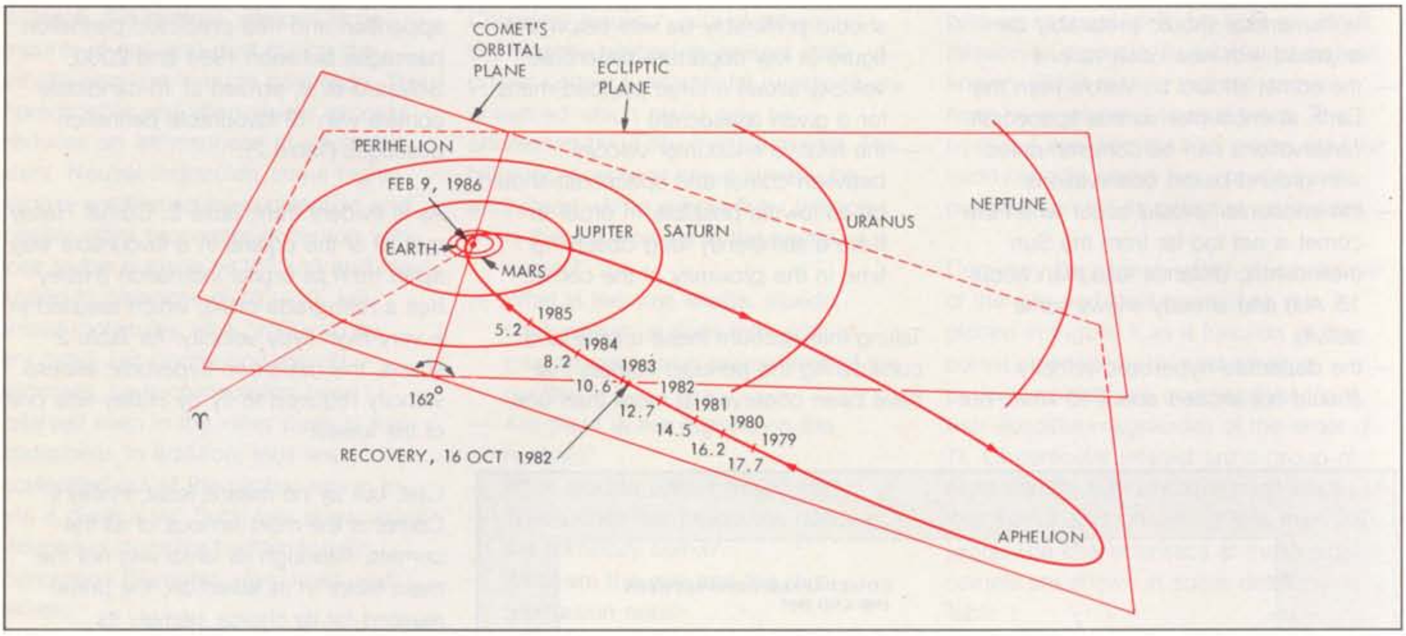



*Table 2 — Orbital characteristics of candidate comets (1984–2000)*

| Comet | Date of last perihelion passage | Orbital period | Perihelion distance | Inclination of orbit w.r.t. ecliptic | Favourable perihelion passage | | Departure conditions $v_h$ (km/s) | $\delta_A$ (deg) |
|---|---|---|---|---|---|---|---|---|
| Encke | 1977.63 | 3.31 | 0.341 | 11.9 | 1984 Mar | 27.0 | u | |
| | | | | | 1987 Jul | 17.0 | u | |
| | | | | | 1990 Nov | 3.6 | 10 | −5* |
| | | | | | 1994 Feb | 21.3 | u | |
| | | | | | 1997 Jun | 11.0 | u | |
| | | | | | 2000 Sep | 28.7 | 10 | 0 |
| Tempel-2 | 1978.14 | 5.27 | 1.369 | 12.5 | 1988 Sep | 16.7** | 4 | −5 |
| | | | | | 1999 Sep | 6.6 | 3 | −5 |
| Honda-Mrkos-Pajdusakova | 1974.99 | 5.28 | 0.579 | 13.1 | 1990 Sep | 20.0 | 4 | −5 |
| | | | | | 1996 Jan | 17.3 | 10 | −5 |
| Tuttle-Giacobini-Kresak | 1978.98 | 5.58 | 1.124 | 9.9 | 1990 Feb | 6.6** | 8 | −5 |
| D'Arrest | 1976.62 | 6.23 | 1.164 | 16.7 | 1995 Jul | 7.0 | 6.5 | −5 |
| Giacobini-Zinner | 1979.12 | 6.52 | 0.996 | 31.7 | 1985 Sep | 4.0 | 3 | −5 |
| | | | | | 1998 Nov | 9.7 | 4 | −5 |
| Borelly | 1974.36 | 6.76 | 1.316 | 30.2 | 1987 Dec | 18.2 | 5 | −5 |
| | | | | | 1994 Oct | 28.1 | 9 | −5 |
| Arend-Rigaux | 1978.09 | 6.83 | 1.442 | 17.9 | 1984 Dec | 1.4 | 6 | −5* |
| Crommelin | 1956.82 | 27.89 | 0.743 | 28.9 | 1984 Sep | 1.0 | 5 | −5 |
| Halley | 1910.30 | 76.09 | 0.587 | 162.2 | 1986 Feb | 9.3 | 3 | −5 |

* Flight time >500 d
** Close approach to Jupiter before perihelion passage

$v_h$ = departure hyperbolic velocity
$\delta_A$ = launch asymptote declination
u = launch opportunity with unfavourable departure conditions

to the ecliptic plane, in which the Earth orbits the Sun (Fig. 2). Halley crossed the ecliptic twice, the first time from south to north (ascending node) on 9 November 1985, and the second time from north to south (descending node) on 10 March 1986.

In principle, minimum hyperbolic departure velocities $V_h$ are needed for comet encounters near the ecliptic plane. This allowed two possibilities for an encounter with Halley: a pre-perihelion encounter near the ascending node, or a post-perihelion encounter near the descending node. Depending on the launch dates, these encounters could have been achieved in various ways, with some trajectories involving one or more complete revolutions around the Sun. In the case of Giotto, with less than one complete revolution around the Sun, three possibilities could be identified:

(i) launch early in 1985; arrival ~20 December 1985
(ii) launch in June/July 1985; arrival ~10 December 1985
(iii) launch in July 1985; arrival ~15 March 1986.

The optimal arrival dates could be deduced from Figure 3 (bottom). It is interesting to note there that the minimum launch energy for a pre-perihelion encounter is achieved with an encounter in mid-December 1985 and not around 9 November. The reason is, of course, that the in-ecliptic $V_h$ required for an encounter around 9 November, when Halley was 1.8 AU from the Sun, would have been much larger than the combined out-of-ecliptic and in-ecliptic components of $V_h$ for an encounter around 20 December, when Halley was only 1.2 AU from the Sun.
There were a number of other criteria to be considered when making the decision regarding a pre- or post-perihelion encounter. The post-perihelion encounter took place closer to the Sun (0.8 — 0.9 AU) than the pre-perihelion encounter would have done (1.2 — 1.5 AU). This had two advantages, one scientific and one technical. In March 1986, four weeks after its perihelion passage, Halley was at its most active, displaying all the well-known cometary phenomena. On the technical side, Giotto's solar-arrays would be able to deliver twice as much power during a post-perihelion encounter.

Also, it seemed that for a post-perihelion encounter more time would be available for spacecraft and experiment development if the encounter were to take place later. A pre-perihelion encounter in December 1985 was, however, also possible with a launch in the summer of 1985, as the bottom part of Figure 3 shows.

The distance to Earth at encounter was also a criterion in that a shorter distance would allow data to be transmitted at a higher rate from the spacecraft. The geocentric distance for a pre-perihelion encounter varied from 0.62 to 1 AU; depending on the encounter date, that for post-perihelion encounters in March 1986 varied from 0.96 AU (Giotto) to 1.15 AU (Vega-1).

The post-perihelion encounter had essentially three disadvantages. Due to the shorter heliocentric distance, more dust was being produced in March 1986 than in November or December 1985. This high dust density in the coma made it more difficult to obtain clear images of the nucleus. Secondly, due to the higher dust density, the chances of spacecraft

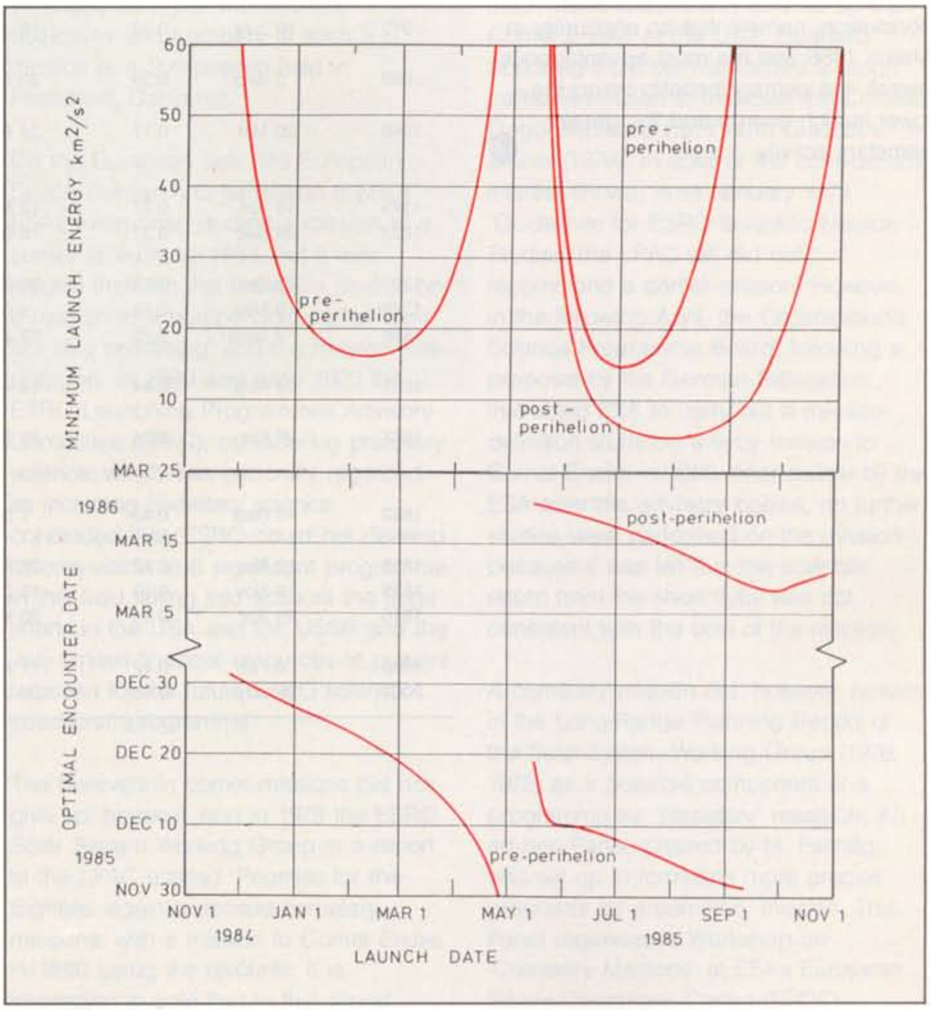


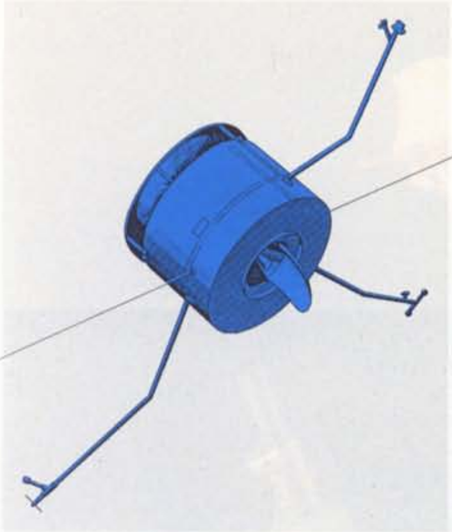

*Figure 3 — Launch opportunities for Halley encounters with less than one full orbit around the Sun. The upper plot gives the minimum launch energy required for launch dates between November 1984 and November 1985; the lower plot gives the corresponding optimal dates at the comet (after Cornelisse)*

survival were reduced for a flyby in March 1986. The survival probability was further reduced because of the higher flyby velocity in March 1986 compared to that in November or December 1985. During a pre-perihelion encounter, both the spacecraft's velocity and the comet's orbital velocity would have been lower, resulting in a significantly reduced relative flyby velocity of ~50 km/s, compared to ~70 km/s for the post-perihelion encounter that was finally chosen. The lower flyby velocity would also have had the additional advantage of allowing more time for measurements inside the cometary coma and close to the nucleus.

Having weighed the advantages and disadvantages, however, all of the space agencies involved arrived at the same conclusion, namely that an encounter in March 1986 was the most advantageous overall, the primary benefits being the lower launch energy and the greater cometary activity.

*Table 3 — Historical observations of Comet Halley's last thirty apparitions*

| Perihelion passage | | Closest approach to Earth | | |
|---|---|---|---|---|
| Year | Date | Distance | Date | Comments |
| 240 BC | 25 May | 0.45 AU | 4 June | First apparition recorded in history (Chinese records) |
| 164 | 12 Nov | 0.11 | 29 Sept | Recorded on Babylonian stone |
| 87 | 6 Aug | 0.44 | 27 July | Recorded in China, on a Babylonian stone, and in Rome |
| 12 | 10 Oct | 0.16 | 10 Sep | Recorded in China and Rome |
| AD 66 | 26 Jan | 0.25 | 20 Mar | Recorded in China |
| 141 | 22 Mar | 0.17 | 22 Apr | Recorded in China |
| 218 | 17 May | 0.42 | 30 May | Recorded in China and Rome |
| 295 | 20 Apr | 0.32 | 12 May | Recorded in China |
| 374 | 16 Feb | 0.09 | 2 Apr | Recorded in China |
| 451 | 28 June | 0.49 | 30 June | Recorded in China |
| 530 | 27 Sept | 0.28 | 3 Sept | Recorded in China and Byzantium |
| 607 | 15 Mar | 0.09 | 19 Apr | Recorded in China, observed that the tail always points away from the Sun |
| 684 | 2 Oct | 0.26 | 7 Sept | Recorded in China and Japan |
| 760 | 20 May | 0.41 | 3 June | Recorded in China and Byzantium |
| 837 | 28 Feb | 0.03 | 11 Apr | Closest approach ever, recorded in China, Japan and by several European sources |
| 912 | 18 July | 0.49 | 16 July | Recorded in Japan, Byzantium and St. Gallen |
| 989 | 5 Sept | 0.39 | 20 Aug | Recorded in China, Japan, Spain and St. Gallen |
| 1066 | 20 Mar | 0.11 | 24 Apr | Halley's Comet shown on the Bayeux Tapestry, several Far Eastern and European sources |
| 1145 | 18 Apr | 0.27 | 12 May | Halley's Comet shown in the Eadwne Psalter |
| 1222 | 28 Sep | 0.31 | 6 Sept | Recorded in Europe, Korea, Japan and China |
| 1301 | 25 Oct | 0.18 | 23 Sept | Giotto di Bondone saw Halley's Comet |
| 1378 | 10 Nov | 0.12 | 3 Oct | Recorded in China and Japan |
| 1456 | 9 June | 0.45 | 19 June | Comet positions determined by Toscanelli, error ±1° |
| 1531 | 26 Aug | 0.44 | 14 Aug | 20 comet 'papers' appeared, comet positions determined by Apian |
| 1607 | 27 Oct | 0.24 | 29 Sept | Comet positions determined by Kepler, although he assumed a straight line for the orbit |
| 1682 | 15 Sept | 0.42 | 1 Sept | 59 'papers'; Halley discovers the periodicity of his comet |
| 1759 | 13 Mar | 0.12 | 26 Apr | First predicted apparition |
| 1835 | 16 Nov | 0.19 | 13 Oct | First accurate perihelion passage prediction |
| 1910 | 20 Apr | 0.15 | 20 May | Numerous observations and papers, Bobrovnikoff's summary |
| 1986 | 9 Feb | 0.42 | 11 Apr | First space missions to Halley's Comet |
| 2061 | 28 July | 0.48 | 29 July | First landing on Halley's Comet ? ? ? |



# A Brief History of the Giotto Mission

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**Prior to the Halley encounter on 14 March 1986, scientists on both sides of the Atlantic had been aware for more than 20 years of the importance of a space mission to a comet. The Giotto mission, which has finally provided much of the data that they had hoped for for so long, demonstrated ESA's determination to proceed with at least part of an abandoned earlier NASA/ESA collaborative mission study involving a Halley flyby and a Comet Tempel 2 rendezvous.**

*Figure 1 — The Halley flyby probe studied by ESA in 1979 as part of the joint ESA/NASA Halley flyby/Tempel-2 rendezvous mission*

As early as 1960, interest in a space mission to a comet was expressed by several astrophysicists. At a Symposium on the exploration of space held in Washington, DC in April 1959, F.L. Whipple pointed to the possibility of sending a space probe to the neighbourhood of a comet. Two years later, in August 1961, P. Swings gave an extended survey of the scientific objectives and feasibility of such a mission at a Symposium held in Pasadena, California.

On the European side, the European Space Research Organisation (ESRO), ESA's forerunner, studied a mission to a comet as early as 1964, but it was judged that 'the first feasibility studies on a mission to a non-periodic comet were not very promising' and the mission was dropped. In 1969 and early 1970 the ESRO Launching Programmes Advisory Committee (LPAC), considering planetary science, which was generally regarded as including cometary science, concluded that 'ESRO could not develop its own viable and significant programme in this field taking into account the large efforts in the USA and the USSR and the very limited financial resources at present foreseen for the future ESRO scientific spacecraft programme'.

The believers in comet missions did not give up, however, and in 1973 the ESRO Solar System Working Group in a report to the LPAC entitled 'Priorities for the Eighties' again proposed cometary missions, with a mission to Comet Encke in 1980 being the favourite. It is interesting to note that in that report G. Colombo wrote 'I am convinced that the Encke mission will be of large scientific output. I am also convinced that the Comet Halley mission may be a more complete cometary mission because Halley is a younger periodic comet'.

Around this time (1972—73), studies had been carried out in Germany to see if a third Helios spacecraft could be sent to Comet Encke. In the USA, Goddard Spaceflight Center had issued a report called 'A Mission to Intercept the Comets Grigg-Skjellerup (1977) and Giacobini-Zinner (1979)'. In spite of the considerable interest shown, in its January 1974 'Guidelines for ESRO Scientific Mission Studies' the LPAC still did not recommend a comet mission. However, in the following April, the Organisation's Science Programme Board, following a proposal by the German Delegation, instructed ESA to carry out a mission-definition study on a flyby mission to Comet Encke in 1980. After review by the ESA scientific advisory bodies, no further studies were performed on the mission because it was felt that the scientific return from the short flyby was not consistent with the cost of the mission.

A cometary mission did, however, remain in the Long-Range Planning Report of the Solar-System Working Group (1976, 1978) as a possible component of a programme for 'planetary' research. An ad hoc Panel, chaired by H. Fechtig, was set up to formulate more precise proposals for a cometary mission. This Panel organised a Workshop on 'Cometary Missions' at ESA's European Space Operations Centre (ESOC), Darmstadt on 17—19 April 1978. The purpose of the Workshop was to involve a cross-section of the interested scientific community in Europe in providing suggestions for the orientation of future study and planning work. Subsequently, the Panel asked the Solar System Working Group to recommend a mission-definition study covering the following items:

(i) ESA participation in a NASA rendezvous mission
(ii) an independent ESA ballistic mission, of the multi-comet type, including Halley, Enke and Tempel 2, and possibly also C-type asteroids.

The Panel suggested that if NASA decided to go ahead with the rendezvous mission, the ESA ballistic mission should be considered as a complementary rather than as a competing mission. The various payloads would be open to both European and US experimenters. If NASA should postpone the rendezvous mission, ESA should go ahead with an independent ballistic mission.

After further review and discussion by the scientific advisory bodies, ESA accepted the invitation extended by NASA to consider participation in its cometary mission then under study. This mission involved a rendezvous with Tempel 2 during its 1988 apparition, and a fast flyby of Halley at 1.53 AU pre-perihelion at the end of 1985. ESA's share of the project was envisaged as the provision of a purely passive probe to be released from the main NASA spacecraft some 15 d before Halley encounter and to be targeted at the nucleus. NASA's share of the project was to be the provision of the main spacecraft and the solar electric propulsion system (SEPS), which was considered to be a necessary element of a cometary rendezvous mission. With the announcement in January 1980 that the necessary funding for the SEPS had not been included in the US Presidential Budget, it had to be acknowledged that the basis for a cooperative mission no longer existed.

*Figure 2 — The configuration of the Giotto spacecraft in 1980 as developed from the Geos spacecraft. A high-gain antenna was added at the top of the spacecraft and a dual-sheet dust protection shield at the bottom*

As an immediate replacement, ESA presented the HAPPEN (Halley Post-Perihelion Encounter) mission, which had been proposed earlier by G. Colombo, to its scientific advisory bodies. The concept was that a Geos-3 spacecraft, a derivative of ESA's Geos-1 and -2 spacecraft, instrumented for Earth-magnetotail research, should be retargeted at the end of its magnetotail mission to intercept the tail of Comet Halley. This mission, however, was not recommended for further study.

In response to a telex of 29 January 1980 signed by 19 members of the European scientific community, ESA also examined another option, consisting of two spacecraft based on the Geos concept, launched simultaneously by Ariane. One spacecraft, Geos-3, was to perform an Earth-magnetotail mission; the other, Giotto, was to be instrumented for cometary research and to intercept Halley as close to the nucleus as possible.

At its meeting in early March 1980, the ESA Science Programme Committee (SPC) decided:

(i) that the Geos-3 part of the combined mission should not be studied further
(ii) to pursue the study of a mission to Comet Halley, including all

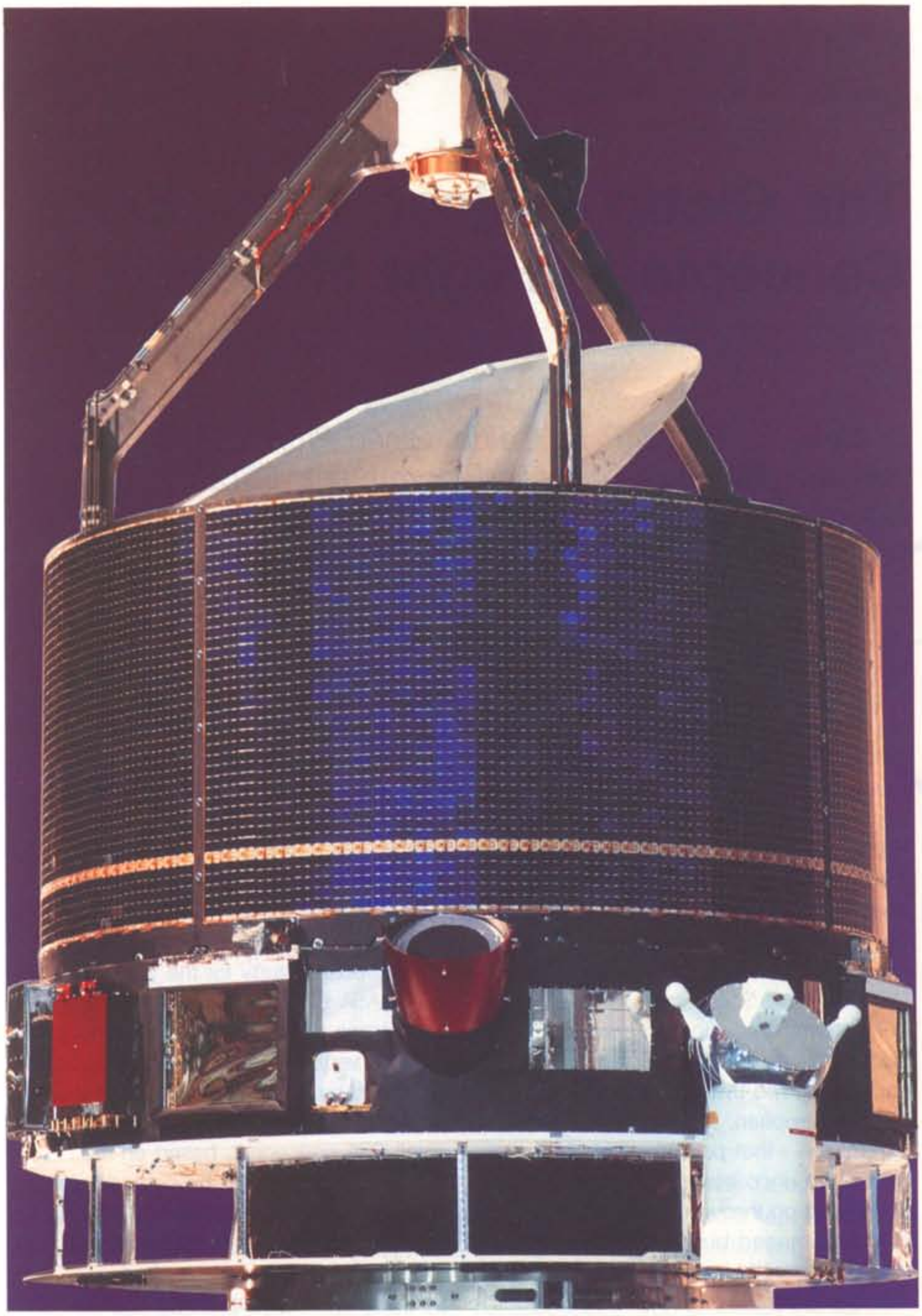


*Figure 3 — The Giotto spacecraft as finally flown. The diameter of the solar-cell array was increased from 1624 to 1814 mm and the antenna mast replaced by a tripod.*

possibilities for cooperation with NASA, and

(iii) that the total cost to ESA of the Comet Halley mission should not exceed 80 MAU.

In view of the limited time remaining before the next apparition of Halley's Comet, ESA decided not to consider totally new mission or spacecraft concepts. NASA was invited to consider providing a Delta launcher and use of its Deep-Space Network (DSN) in return for an appropriate share of Giotto's scientific payload.

Consequently, the Giotto study proceeded with three constraints:

— low project cost
— spacecraft based on the Geos design
— a shared Ariane launch with an applications satellite, or launch by a Delta rocket.

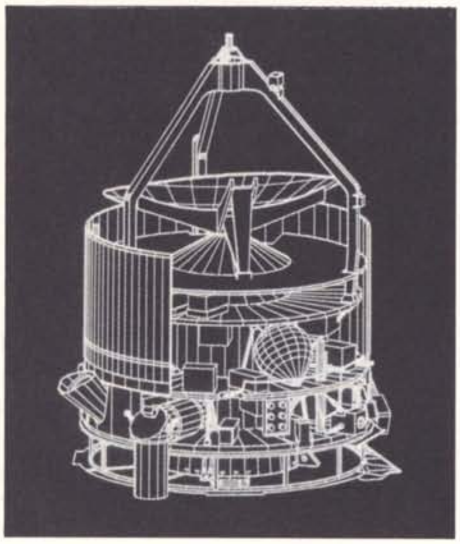
The study was completed in May 1980 and presented to the scientific community and the ESA scientific advisory bodies. The Giotto mission was strongly recommended and the SPC decided at its meeting on 8 and 9 July 1980 that it should be included in the ESA programme as the next scientific project.

Since at the time of the SPC decision there was no commitment from NASA to provide the Delta launcher or the DSN in return for an appropriate share of the scientific payload, the SPC approval had to be based on an Ariane launch. Any later offer by NASA to provide the Delta vehicle or its DSN would require a new decision by the SPC to change the launcher.

When the NASA offer finally came in late October 1980, the SPC, considering all elements of the offer, preferred to maintain the Giotto mission in its originally approved form, namely launch by Ariane, but was pleased to see a substantial number of US investigators involved as Co-Investigators in the candidate European experiment proposals.

Since Giotto never formally acquired the status of a cooperative ESA/NASA project, ESA could not, for reasons imposed by its Council, invite US experimenters to join the mission as Principal Investigators. (There are in fact 37 US scientists involved as Co-investigators in ten of Giotto's eleven experiments).

A 'Call for Experiment Proposals' was sent out in July 1980, immediately after project approval, to interested European Investigators, with a deadline for proposal submission of 15 October 1980. The proposals were assessed technically for compatibility with the spacecraft and reviewed scientifically by the Solar-System Working Group and the Space Science Advisory Committee which acted as the Selection Committee. The final decision was made by the SPC in mid-January 1981. The payload was further complemented at the first Science Working Team (SWT) meeting in mid-February 1981 by adding the magnetometer and the energetic particles experiment. A radio-science experiment was formally accepted in May 1984.



# The Giotto Project: From Early Concepts to Flight Model

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**With Giotto's task so fully and so successfully accomplished, now is perhaps the appropriate moment to review the history of the project, from the initial concepts for the mission until the 'Night of the Comet'. An attempt will be made to provide a summary of the major decisions that had to be taken and the milestones that had to be met, the technology that was used, the inherent mission risks, and the difficulties that were encountered along the way.**

**Introduction**

The 'Night of the Comet', as the international press dubbed the night of 13/14 March, is over and scientists around the world are busy interpreting the data that the five spacecraft of the Halley armada gathered for them during their respective flybys. Ground-based observers have been conducting observations since Halley was first recovered during its present apparition in October 1982. The combined result is a truly international effort on a scale seldom before seen in a scientific endeavour. The five principal spacecraft — one European, two Soviet and two Japanese — that performed so well during the encounters are now continuing on through interplanetary space, damaged but not destroyed by the hypervelocity impacts of the cometary dust particles.

Following its successful encounter with Comet Halley on 14 March, Giotto, ESA's member of the Halley armada, has been redirected by firing the spacecraft's on-board hydrazine thrusters to make a flyby of the Earth in 1990. Many of its experiments and many of the on-board systems and subsystems, however, are now either inoperable or working outside their original design limits.

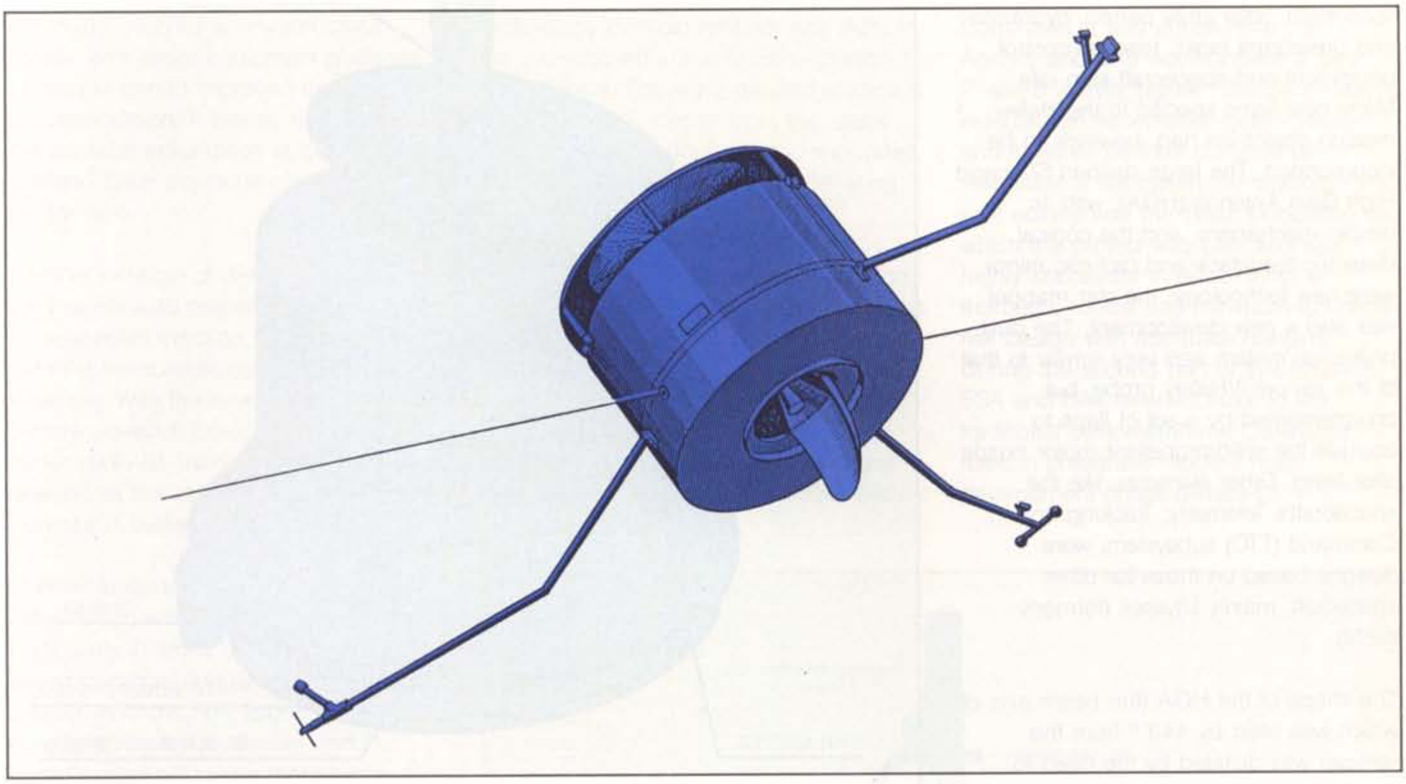
**From first concept to mission reality**

ESA first became involved with cometary science in 1974 when, as part of its future scientific-mission study programme, a mission to Comet Encke was considered. However, approval for this mission was not forthcoming and the Agency's involvement with comets was to remain dormant until 1978. On 19 August of that year, a Workshop involving participants from the scientific community recommended that a study be performed with a view to either a joint ESA/NASA cometary mission or a multiple cometary flyby mission.

The proposed study for the joint ESA/NASA mission was subsequently undertaken, the US spacecraft concept being a very large bus (3350 kg) propelled by a new-technology Solar Electric Propulsion System (SEPS). A small ESA spacecraft, based on the ISEE-B design, was to be carried by the US spacecraft and dropped to skim through Halley's Comet in December 1985, before the comet reached perihelion. The US spacecraft would have continued to an eventual rendezvous with Comet Tempel-2 and performed comet-environment studies over a period of several months. The ESA probe (Fig.1) was to be spun up and released fifteen days before the encounter with Halley's Comet and would have transmitted back scientific data in real time to the mother spacecraft during the 57 km/s flyby. It would have flown within a few hundred kilometres of the nucleus.

Although radically different from the spacecraft that eventually became Giotto, this initial probe already had some basic characteristics that were precursors for the design evolution of the Giotto mission. Firstly, the flyby was to be targeted very close to the nucleus, which

Figure 1 — The Tempel-2/Halley flyby probe proposed by ESA joint ESA/NASA mission. Its main characteristics were:
— Spacecraft mass: 143 kg
— Payload mass: 48 kg
No solar array, only batteries for the 4 h encounter; no AOCMS; spin rate of 12 rpm generated at separation from the main spacecraft by a spin table



implied full acceptance of the dust hazard; a dual-skin bumper shield design had therefore been proposed to protect the spacecraft. An intershield spacing of 250 mm was defined, which was close to the 230 mm finally implemented on Giotto.

In addition, both the 1978 ESA probe design proposal and Giotto were to be spin-stabilised. This provided a less costly and more robust attitude-control design than the three-axis alternative in the highly turbulent cometary dust environment expected close to the nucleus. The high-rate data link with the main spacecraft was to be provided via a despun high-gain antenna and the anticipated probe experiments were, with few exceptions, already very similar to those subsequently flown on Giotto.

The Tempel-2/Halley cooperative mission studies were discontinued when, in January 1980, the US Government declined funding of the SEPS module.

However, the hopes of the European cometary community were kept alive by the exploitation of an earlier suggestion by the late Prof. Giuseppe Colombo and his colleagues, who proposed the so-called 'HAPPEN' (Halley Post-Perihelion Encounter) mission. This proposal advocated a later post-perihelion flyby of Halley's Comet around 13 March 1986.

Unfortunately this resulted in an even higher spacecraft/comet relative velocity (68 km/s), but required a minimum of launch energy. The later flyby date, for what would have been an extended geotail mission carrying a plasma payload only, had the advantage of arriving at the comet during a more active phase of its orbit around the Sun. It was already clear at this stage, however, that there would be severe financial constraints on such a mission.

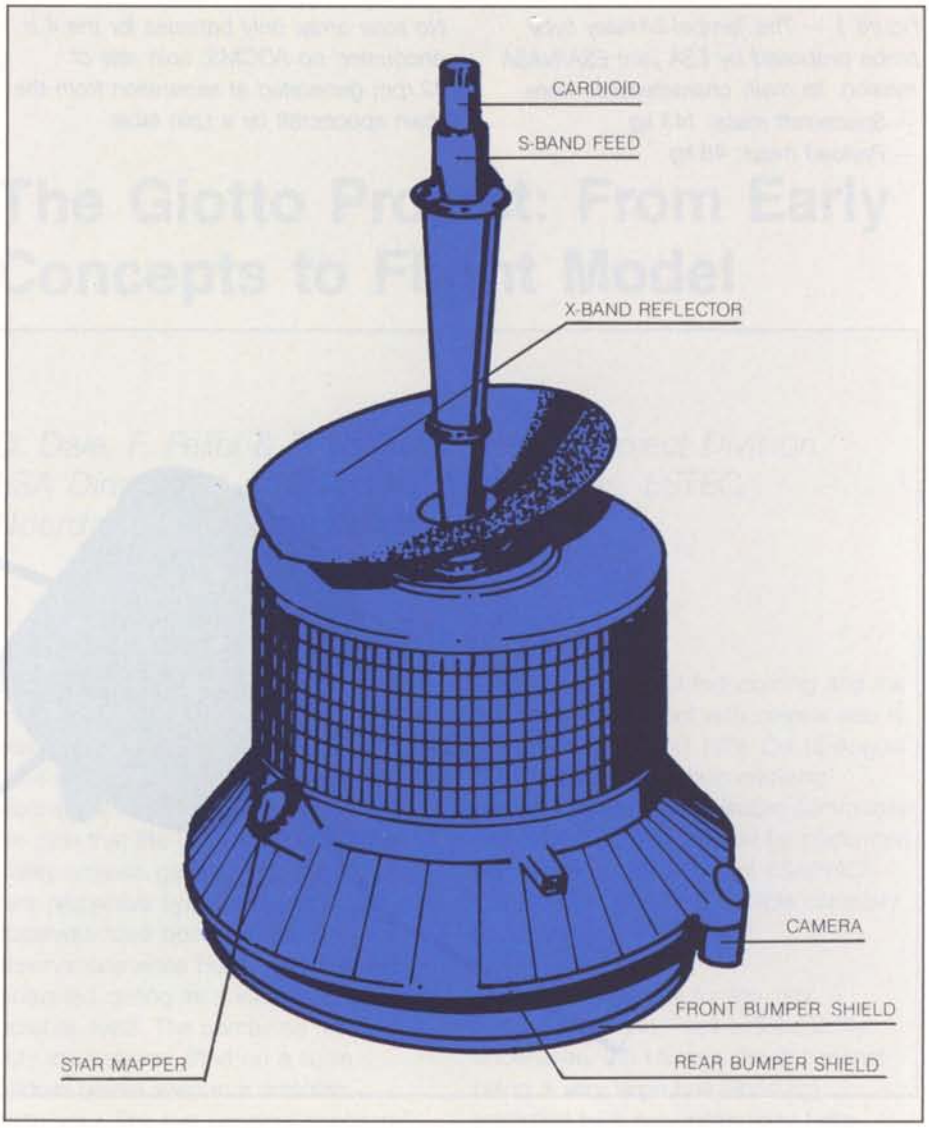
Another major constraint that surfaced immediately was the launch window.

Early analysis already showed the launch window for the encounter to be unique and only a few weeks long, during the month of July 1985.

For these reasons of cost and technical/schedule risk, it was decided to base the Giotto design on an existing spacecraft. The only spin-stabilised spacecraft able to provide approximately the right resources, and available within the ESA programme, was the Geos design. A very compressed Phase-A study was therefore performed by ESA, together with British Aerospace PLC (Geos-1 and -2 Prime Contractor), and the results presented to the ESA Science Programme Committee (SPC) for approval in July 1980.

The autonomous Giotto spacecraft (Fig. 2) maintained commonality with the Geos design in terms of primary structure, apogee boost motor (now to be installed in a reversed position), power

*Figure 2 — The original Giotto Phase-A proposal, based strictly on Geos*




subsystem, solar-array panels, hydrazine and pressurant tanks, reaction-control equipment and spacecraft spin rate. Many new items specific to the Halley mission objectives had, however, to be incorporated. The large despun S/X-band High Gain Antenna (HGA), with its despin mechanism, and the conical dielectric feedstack and dichroic mirror, were new technology; the star mapper was also a new development. The dust-protection system was very similar to that of the Tempel-2/Halley probe, but complemented by a set of flaps to occlude the solid-propellant motor nozzle after firing. Other elements, like the spacecraft's Telemetry, Tracking and Command (TTC) subsystem, were designs based on those for other spacecraft, mainly Ulysses (formerly ISPM).

The shape of the HGA (the beam axis of which was tilted by 44.3 ° from the vertical) was dictated by the need to maintain contact with the Earth while still keeping the comet—spacecraft relative-velocity vector aligned with the spin axis and hence the direction of the impacting cometary dust. Exposure of unprotected parts of the spacecraft to the hyper-velocity dust threat was consequently minimised.

Only one battery was to be accommodated in order to supplement the power furnished by Giotto's solar array in the event of dust damage to the latter during the encounter phase.

The Giotto mission as approved in July 1980 was based on use of a shared Ariane-2 launcher and flight operations from the ESOC network. The model payload consisted of a set of ten scientific instruments that had then to be competitively selected. For the high-rate data transmission at encounter (40 kbit/s), the 64 m antenna of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) radio telescope at Parkes, in Australia, would be used as the main receiver, thereby complementing the ESA ground network for the critical phase of the mission. The mission itself was designed for and totally focussed on the four crucial hours leading up to the closest approach to the nucleus.

Because of the severe time constraints on the mission, direct negotiation for spacecraft procurement with the Geos Prime Contractor was approved by the relevant ESA Committees, and so the project was quickly underway. In the period between July 1980 and March 1981, at which time BAe submitted its formal offer, the main activities were concentrated towards the experiment payload. The Announcement of Opportunity (AO) for the scientific experiments was issued by ESA shortly after the July 1980 mission approval, and in the second half of 1980 the experiment-selection process was conducted via the ESA Solar System Working Group (SSWG) and Science Advisory Committee (SAC). Their recommendations were forwarded to the SPC for final approval in January 1981.

Within this time frame the ESA project team took the opportunity to re-examine the basic system-design parameters, paying special attention to design margins and the impact of a recently completed refined mission analysis. Some of the preliminary conclusions of the earlier study were reviewed and improvements to the system design and margins were adopted with a view to further minimising schedule and technical risks. This inevitably moved the Giotto design further away from the Geos baseline.

A prime example of this design evolution process was the solar array. Its area was increased by enlarging its diameter, and hence that of the spacecraft, thereby gaining precious electrical power. This in turn resulted in simplification of the thermal subsystem, which became an overall system benefit. This modification led to the need for a new structural model, with larger equipment platforms, leading in turn to improved equipment accommodation. It meant, however, that the previous assumption of qualifying an updated Geos structural model was no longer valid.

Another example of design evolution was the internal solid-propellant motor used for spacecraft injection from Earth orbit onto the heliocentric comet-intercept trajectory. With the new, larger structure, a more powerful, European Mage 1S motor could be used, thereby gaining operational flexibility via the resulting increase in available velocity increment.

In other areas too, the margins of the initial design were uncomfortably small, particularly in terms of mass, equipment accommodation and hydrazine fuel budget. With the now larger structure, constraints could be relaxed and it became possible to incorporate four Geos hydrazine fuel tanks instead of the two previously proposed, thereby significantly improving the attitude and orbit control fuel margin. A fully redundant reaction-control system with a total of eight thrusters was incorporated to improve the reliability of the spacecraft, and four Geos silver-cadmium batteries were incorporated, again to provide greater flexibility during the mission, and a bigger energy margin in the event of dust-induced solar-array degradation.

The criticality of the despin motor (then the subject of a competitive study by European industry), which was to be coupled to the conical antenna 'stack' and used for despinning the HGA reflector to maintain Earth-pointing, was becoming a design concern. Engineering constraints imposed by the use of available dry-lubricated bearings and space-qualified electric motors imposed too narrow a 'throat' for the X-band feed horn, which needed to pass through the axis of the mechanism to illuminate the HGA. Analysis indicated that the root of the dielectric cone supporting the new-technology dichroic reflector was likely to be overstressed in the launch-vibration environment. Following detailed studies, it was decided to depart from the 'stack' concept and to adopt a tripod-supported feed system (Fig. 3), thereby alleviating these design risks.

The British Aerospace spacecraft-design proposal submitted on 9 March 1981 was largely based on strict adherence to the Geos design and as such was at variance with the minimum-risk system-design features considered necessary. Following an interim period of dialogue with Industry and ESA's Industrial Policy Committee, it was agreed that the Agency and BAe would initiate a joint Phase-B activity (system design phase) to establish an acceptable system design, and together perform competitive selections of subsystem contractors. This joint activity was the basic foundation on which the project was built and was highly successful in establishing a thorough, robust and minimum-technical-risk design with adequate margins. During the second part of this Phase-B, ESA and BAe reverted more to the traditional customer/Prime Contractor roles in preparation for the main development phase (Phase-C).

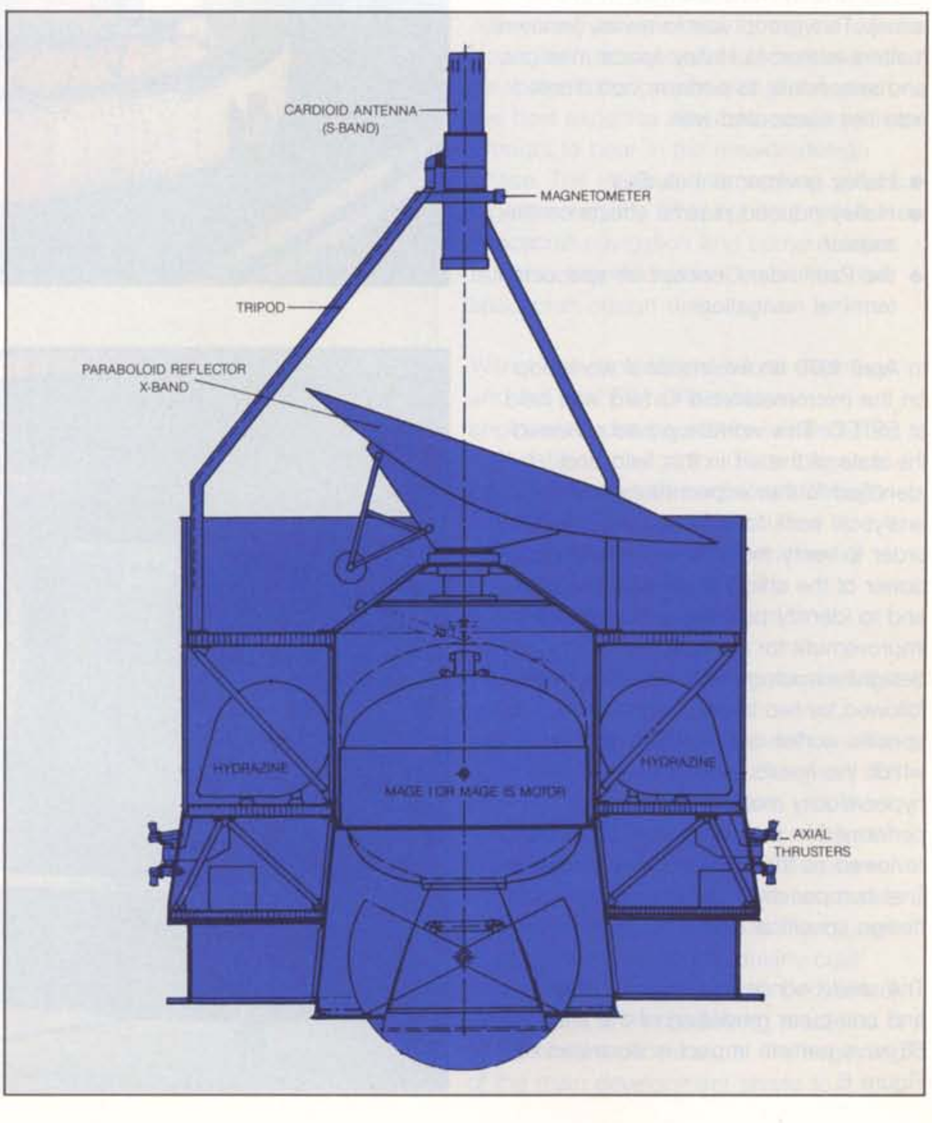



*Figure 3 — The revised Giotto configuration at the beginning of Phase-B.*

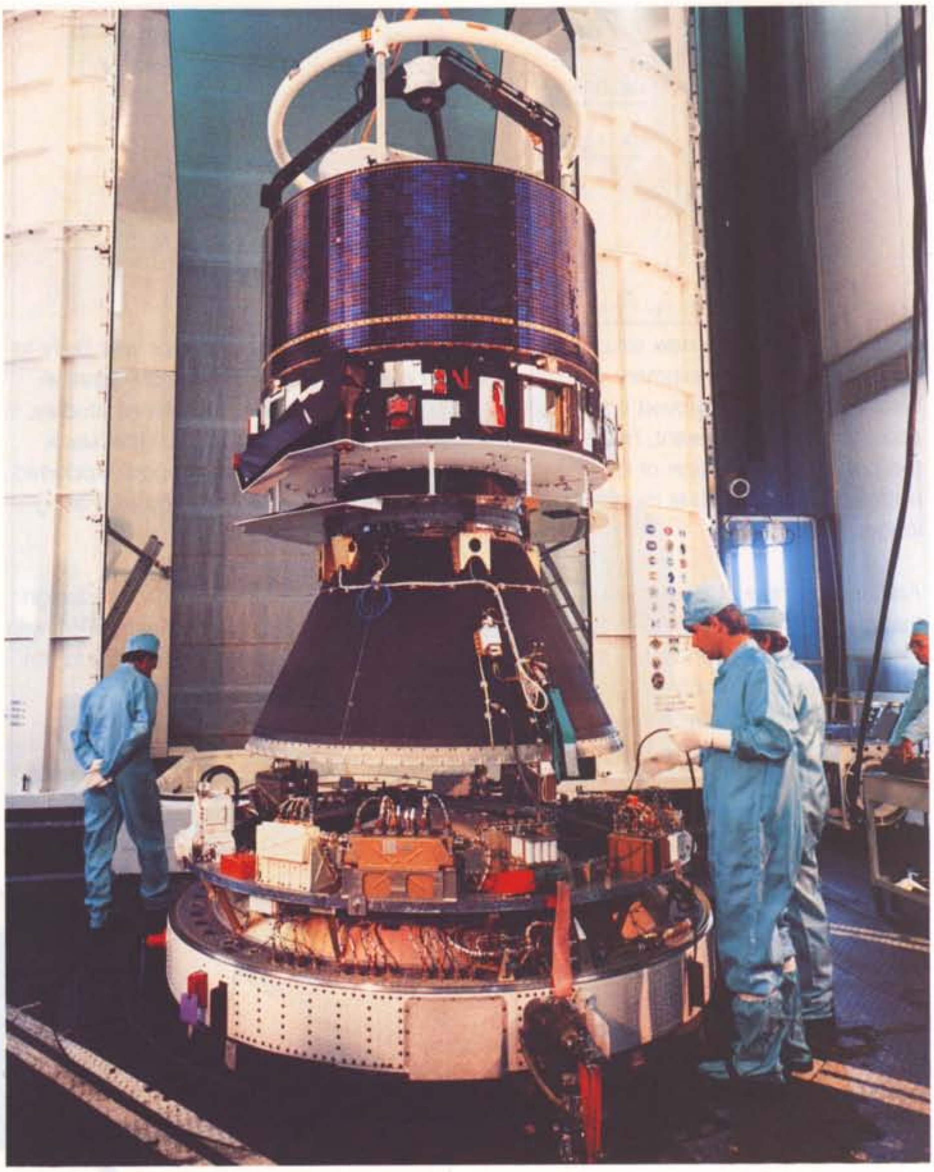


*Figure 4 — The Giotto spacecraft as finally flown*

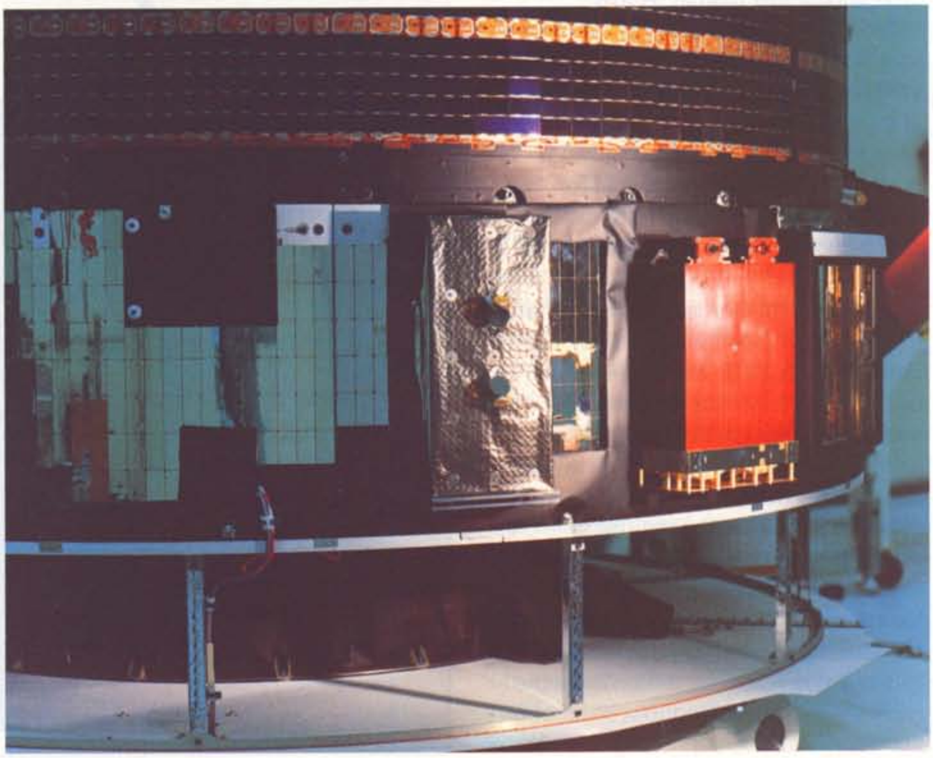


*Figure 5 — A close-up view of the dust shield. The thin white-painted bumper shield is separated from the thick rear shield by 12 struts. Also note the local double shield under the axial-thruster can*

**The international effort**

During the 1980/1981 period, the scientific community turned its attention to the forthcoming Halley event. The International Halley Watch (IHW) was established to stimulate, encourage, coordinate, standardise, archive and disseminate all the Comet Halley observations that would be made worldwide by several hundreds of astronomers (see elsewhere in this issue).

Furthermore, in the early phase of planning the Halley missions it was agreed that the Agencies directly involved in the exploration of the comet would form the Inter-Agency Consultative Group (IACG)(see elsewhere in this issue). This group was to review jointly all matters related to Halley space missions and specifically to perform coordinated activities associated with:

- Halley environment studies
- Halley-induced plasma effects on the mission
- the Pathfinder Concept for spacecraft terminal navigation.

In April 1979 an international workshop on the micrometeoroid hazard was held at ESTEC. This workshop had reviewed the state of the art in this field and identified further experimental and analytical work for ESA to perform in order to verify the dust-impact stopping power of the shield proposed for Giotto, and to identify potential areas of improvement for the shield design/technology. This workshop was followed by two smaller, even more specific workshops in 1980—1981 at which the results of tests and hypervelocity modelling analyses performed in the context of Giotto were reviewed so that ESA could formulate the final bumper-shield protection-system design specification.

The shield concept is shown in Figure 5, and computer modelling of the effect of a 68 km/s particle impact is illustrated in Figure 6.

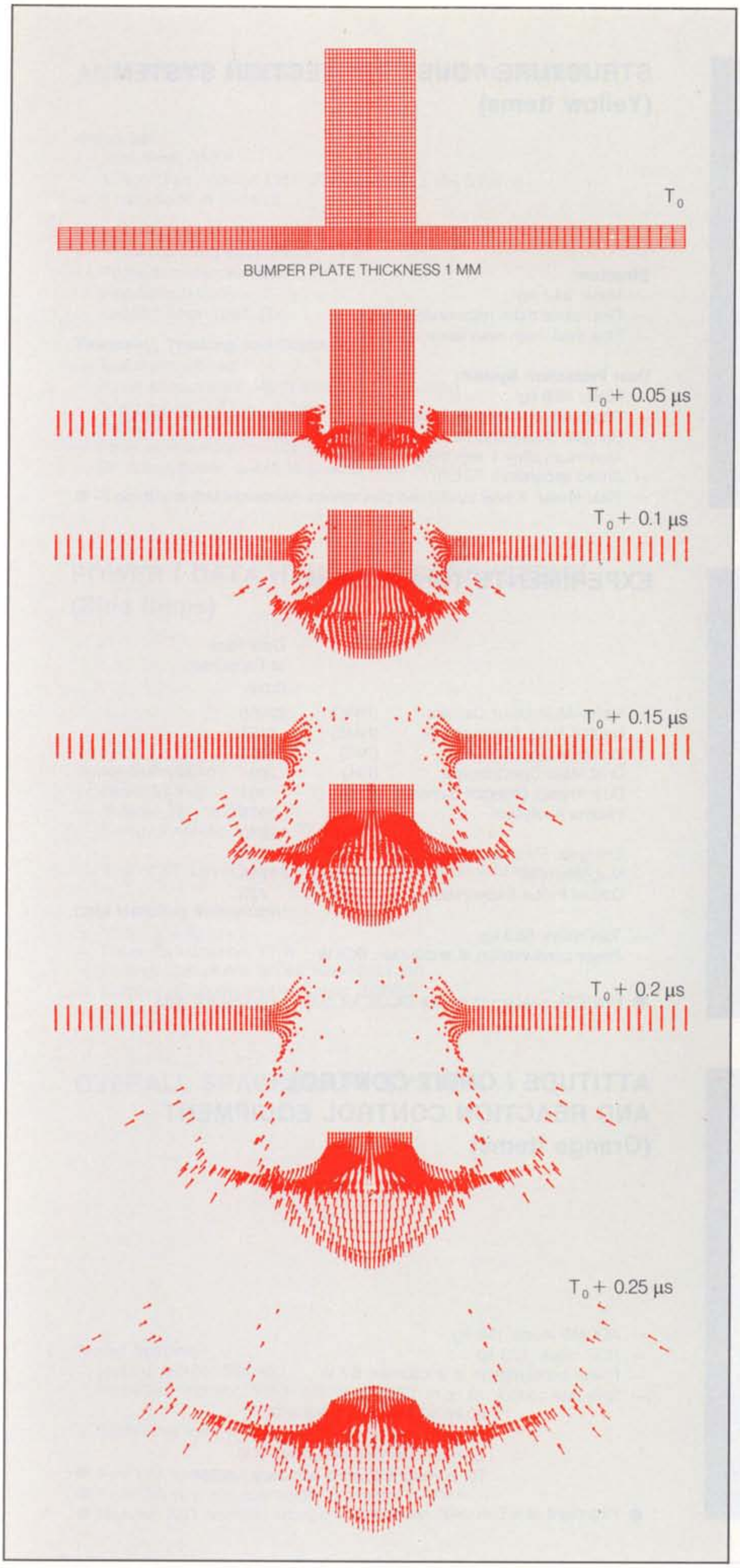



*Figure 6 — A computer-generated sequence of the hypervelocity impact of a 100 mg meteoroid on a 1 mm-thick bumper shield*

The problem of dust-impact-generated plasma also received early attention through a series of workshops, which started in 1979 and which continued throughout the life of the Giotto project. The impact phenomenon causes differential electrical charging of various external areas of the spacecraft. Consequently, the spacecraft's thermal-control coatings had to be electrically conductive, particularly in the dust-shield area. This constraint demanded qualification of a new type of coating, namely conductive white paint.

**Giotto takes shape**

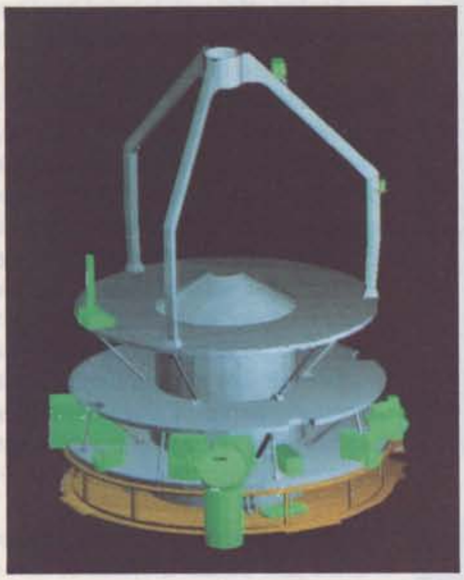
As Giotto was to penetrate the largely unknown cometary coma at very high speed and provide data for only a few hours, with no second chance, it was clear that if the project was to succeed the best expertise available needed to be brought to bear in the mission-design phase. The IACG and its working groups, together with the IHW, not only aided the spacecraft-navigation and comet studies, but also provided critical environmental spacecraft design data.

With these international efforts underway and the joint ESA/BAe systems-engineering design activity initiated, the final detailed design for Giotto began to be established with confidence, though not without its share of difficulties. A major problem area was the inherent conflicting requirements of the spacecraft's power and thermal subsystems. The latter was initally conceived as being totally passive, with switchable heaters. It was, however, required to be able to cope with a wide combination of solar aspect angles ( 35° to 140°), solar constants (from less than 1, to 2 solar constants) and a multitude of HGA solar phase angles. The power subsystem was soon found to be unable to provide sufficient power to the heater circuits during some particularly cold phases of the mission, partly because of unexpected array-shadowing problems. It was therefore necessary at the beginning of the main development phase to

## STRUCTURE / DUST PROTECTION SYSTEM (Yellow Items)

**Structure:**
- Mass: 94.7 kg
- First lateral main resonance: 30 Hz
- First axial main resonance: 53 Hz

**Dust Protection System:**
- Mass: 49.6 kg
- Designed to absorb 68 km/s impacts of dust particles up to 100 mg
- Bumper Shield and Nozzle Closure Mechanism: Aluminium alloy 1 mm thick
- Shield separation: 23 cm
- Rear shield: Kevlar reinforced plastic/foam sandwich 13.5 mm thick



## EXPERIMENTS (Green Items)

| | | Data Rate at Encounter (bps) |
|---|---|---|
| — Halley Multicolour Camera | (HMC) | 20058 |
| Neutral Mass Spectrometer | (NMS) | 4156 |
| Ion Mass Spectrometer | (IMS) | 3253 |
| Dust Mass Spectrometer | (PIA) | 2891 |
| Dust Impact Detector System | (DID) | 361 |
| Plasma Analysers | (JPA) | 3975 |
| | (RPA) | 2530 |
| Energetic Particles Expt. | (EPA) | 181 |
| Magnetometer | (MAG) | 1265 |
| Optical Probe Experiment | (OPE) | 723 |

- Total mass: 58.9 kg
- Power consumption at encounter: 50.6 W

● First ESA spacecraft to use OCOE for quick look science data

## ATTITUDE / ORBIT CONTROL AND REACTION CONTROL EQUIPMENT (Orange Items)

- AOCMS mass: 13.8 kg
- RCE mass: 12.3 kg
- Power consumption at encounter: 6.7 W
- Spin rate control: 10 r.p.m. GTO
  90 r.p.m. Mage 1S firing
  15 r.p.m. cruise
  Spin-axis pointing accuracy: ≤1°
  RF boresight pointing accuracy: ≤0.8°

● First flight of a European starmapper

## ANTENNAS / DESPIN / TTC (White Items)

**Antennas:**
- Total mass: 14.6 kg
- 1 High Gain Antenna (38.6 dBi X-band/27.2 dBi S-band)
- 1 cardioid/fill in (S-band)

**Despin Mechanism:**
- Mass (including electronics): 11.7 kg
- Redundant stepper motor
- Bias error: 0.1° (3σ)
- Random error: 0.05° (3σ)

**Telemetry, Tracking and Command (TTC)**
- Total mass: 26.1 kg
- Power consumption: 48 W S-band/96 W X-band
- Telecommand bit rate: 16 bit/s
- Decoder outputs: 64
- Receiver threshold ≤ −146 dBm
- RF output power: ≥ 4.45 W S-band/20 W X-band

● New despin mechanism

## POWER / DATA-HANDLING SUBSYSTEMS (Blue Items)

**Power Subsystem:**
- Mass: 52.5 kg
- Voltage: 28 V ±2%
- Energy available: 14 cells 16 Ah Si-Cd batteries
- Total of 33 current limited supplies to experiments and spacecraft

**Data Handling Subsystem:**
- Mass: 15.0 kg
- Power consumption: 12 W
- Coding: Convolution and/or Reed-Solomon
- Number of input/output channels: 352/372
- Bit rates: 360/46080 bit/s

## OVERALL SPACECRAFT SYSTEM

**Overall System:**
- Mass at launch: 958 kg
- Propellant masses: Solid: 374 kg
  Hydrazine + Helium: 69 kg
- Solar array max. power: 285 W

● First ESA spacecraft to fly out of earth's orbit
● First ESA scientific spacecraft launched by Ariane
● Heaviest ESA scientific spacecraft yet flown

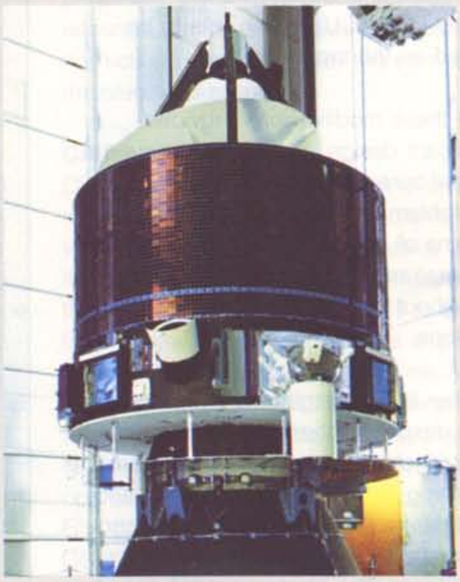


*Figure 7 — Giotto's mass-budget history*

introduce additional means of thermal control and to maximise the solar array's power output.

The effect of solar-array shadowing at high solar aspect angles, caused principally by the star-mapper baffle, was minimised by introducing an extra set of diodes that shunted the five lowermost cells of the array. Some additional heating power was also created by introducing four extra diode boards, able to shift the array electrical power working level and dissipate up to 15% of the total output power within the spacecraft. In addition, a new type of thermal-control 'shutter' was also designed, manufactured and tested (in six months) by the thermal-subsystem contractor, to provide some active thermal control, and thereby reduce the heating power requirement by 30 W. Three of these shutter mechanisms were also installed on the spacecraft. Finally, an additional, switchable internal power dumper was introduced for local heating of the X-band travelling wave tubes and the spacecraft top platform, to cater for unacceptable temperature decreases during certain mission phases. All of these active functions were to be controlled from the ground via a new electronics unit, designated the Thermal Control Unit (TCU), which was to be located on the top platform.

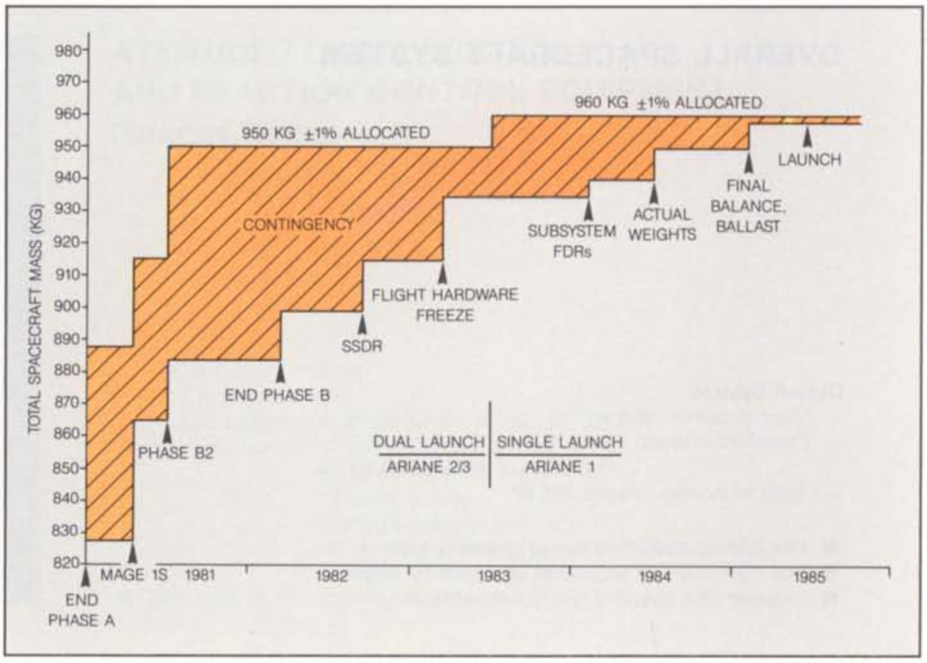
All of these modifications provided significant design improvements, but the thermal-control subsystem continued to be problematic in that the design margins of ±10°C from unit acceptance temperatures were difficult to sustain throughout the requested mission envelope.

Another item emerging as critical was the HGA despin mechanism. Its importance and criticality had been stressed from the beginning of Giotto's development, and redundant motors, sensors, and control electronics had been incorporated accordingly. The single-point failures of dry-lubricated bearings were proved viable in life tests performed at the European Space Tribology Laboratory (ESTL) in Risley (UK), and the launch bearing-offload device was partially redesigned after deficiencies were identified during the structural-model system tests. During integrated system testing in Bristol on the spacecraft electrical model (the last development model before construction of the flight spacecraft),however, the despin mechanism caused further concern due to apparently uncontrolled stoppages. An aggressive ESA/contractor recovery programme was initiated after a design review, and this led to a partial redesign of the electronic control logic together with improvement of the contractor's quality-control procedures. These measures seemed to obviate the major faults that had led to the mechanism stopping under test.

The formal qualification of the mechanism at ESTL took place in January 1985 on the flight-spare unit, but it revealed that, under particularly stringent test conditions, there were new resonance problems between mechanical and electrical components. These phenomena, coupled with lower than expected mechanism internal damping, led under certain conditions to a pointing jitter, which was stable but higher than specified. An accurate analysis of the qualification margins finally provided the necessary confidence that the mechanism would perform adequately in orbit and no slip in spacecraft schedule resulted. No in-orbit malfunction was subsequently observed.

Many other aspects of Giotto's development were more straightforward. The structural model, including the Mage 1S solid motor's nozzle-closure mechanism and the HGA, was tested within schedule and without failures, and the flight-model structural design was verified.

Stringent mass-budget control during the initial phase of the project, together with a sound initial mass contingency allocation, permitted local mass increases (harness, thermal, Mage motor-type change, despin) without the introduction of any technical or schedule problems (Fig.7).



A computer simulator for the spacecraft dynamics and onboard software used by the attitude and orbit control and measurement subsystem (AOCMS) and the data-handling subsystem was designed and established at ESTEC. Later, this simulator was complemented with a software model of the despin motor's control logic and dynamics.

This proved an exceptionally efficient facility and it was possible to validate the onboard software, verify command sequences and complement subsystem and system tests involving flight hardware. Software development was never allowed to be a schedule-critical item. The Overall Checkout Equipment (OCOE) included some innovations that improved efficiency, including: the use of a Local Area Network to link the checkout station to the experiment Electrical Ground-Support Equipment (EGSE); the direct utilisation of experimenter-supplied EGSE equipment at system level and even during flight operations (rehearsal and encounter quick-look), thereby avoiding costly duplications.

Aside from the innovations that contributed to spacecraft development, Giotto's launcher also went through a series of changes during the life of the project. The Ariane-2 upper-passenger launch originally proposed during Phase-A was later formally converted to an Ariane-3 lower-passenger launch inside the Sylda (Système de lancement double Ariane). The launcher authority, Arianespace, was responsible for the overall launch vehicle and provision of the upper-passenger companion spacecraft. However, the inflexible Giotto launch window was not attractive to potential flight companions. During the investigation of some possible candidates, an autonomous launch using the Ariane-1 vehicle previously allocated to Exosat became a possibility. This launch autonomy could have allowed direct injection of Giotto into heliocentric orbit, without any need for a Geostationary Transfer Orbit (GTO) as a parking orbit from where the on-board Mage 1S solid motor would have been fired at the third perigee of the GTO to inject the spacecraft into the final heliocentric comet-transfer orbit. The testing of the Giotto flight model was, however, well advanced at that stage and the risk associated with such a radical configuration change as removing the heavy Mage motor was considered unacceptable. A dedicated Ariane-1 launch for Giotto, with injection into a standard GTO, was therefore finally adopted as the mission plan.

**The launch campaign**

Giotto was shipped to the Agency's Kourou (French Guiana) launch site on 29 April 1985, for a planned two-month launch campaign, including a one-week margin. The launch window, dictated by the available launch energy and spacecraft design, opened at 11.13 h GMT on 2 July and closed on 24 July.

On arrival at Kourou, the spacecraft was immediately installed in the clean room and final checks were initiated. Due to development problems the Halley Multicolour Camera (HMC) was not yet onboard, and it was finally installed on the spacecraft on 17 May. Some additional last-minute problems experienced with the camera's baffle rotation mechanism and suspect mechanical components were also investigated and resolved in Kourou.

A second experiment experienced serious problems during one of the pre-launch system functional tests. By using simulators and spares available in Europe and keeping in close telephone contact, the experiment teams in Kourou and Europe were able to trace the problem to an open circuit. The experiment hardware was corrected accordingly in the Kourou clean room and the instrument re-installed on the spacecraft.

The campaign schedule was not adversely affected by these last-minute corrective efforts as they consumed only a portion of the one-week margin originally allotted.

The spacecraft itself presented no problems at all during the launch campaign. The previous V13 Ariane launch had left the ELA-1 launch pad relatively undamaged and installation of the Giotto V14 vehicle was completed on schedule. The only significant problem that the launcher team experienced was the malfunction of a third-stage valve during an automatic fuel-filling-sequence rehearsal. A manual back-up filling procedure was established, but during final operations all went well and this contingency was not needed.

Launch was accomplished on the first day of the window at 11:23:16 h GMT and the injection into Geostationary Transfer Orbit (GTO) was very close to nominal. One novel feature of Ariane's ascent on this occasion was the 'barbecue' mode — a slow roll-axis spin of 0.16 rpm — during the vehicle's third-stage flight, requested by the Giotto team to avoid high solar-array temperatures.

Giotto's subsequent injection into heliocentric orbit by the Mage 1S solid-propellant motor ($\Delta V$=1400 m/s) was so accurate that no subsequent dispersion-correction manoeuvre with the on-board thrusters was required.

**Cruise and encounter**

During the spacecraft's eight and a half month cruise phase, some problems were experienced with the reliability of the ground stations, and particularly with the ground communication lines to and from Australia. Following special efforts by ESOC, these problems were resolved by early January 1986. For the encounter and other mission-critical phases, the NASA Deep-Space Network (DSN) was operated on 'hot standby' to support the ESA-operated ground stations, and the CSIRO 64 m prime data-collection station at Parkes in Australia . In the event, the ground network operations during the encounter were perfect and reversion to the back-up system was not necessary.

During the mission the spacecraft system performed as designed, with some minor exceptions. The star mapper, which for ease of operation was being used in a high-sensitivity 'Earth mode', showed some random, spurious events probably due to electromagnetic interference. These interferences caused false inertia reference pulses for HGA pointing, and consequently small antenna depointings (some 0.1—0.2 ° for a few minutes). Although of some concern, these fluctuations were never critical for operations. The problem was resolved by using the star mapper at a lower nominal threshold level and using inertia refence pulses generated by the Sun sensor. This mode was in fact the baseline design mode for HGA pointing for the mission's cruise and encounter phases.

Giotto also suffered three unprogrammed redundancy switchovers during the mission. The last of the three, which occurred a few days before encounter, did not finally affect performance but remains the only unexplained switchover. The first two were subsequently established as being non-spacecraft-related. No subsequent problems associated with redundancies were experienced during the encounter.

The baseline Giotto mission was sized only for the four hours of encounter operations, together with three rehearsals each of five daily passes. There were no approved payload operations requirements beyond these. However, following launch, the cruise telemetry data indicated an almost completely nominal situation, particularly as regards the spacecraft's power-generation and thermal subsystems. This meant that the built-in engineering margins could be exploited for additional cruise-science operations, which therefore turned out to be significantly more extensive than originally planned.

The Halley Multicolour Camera (HMC) was in fact switched on in August 1985 for test purposes, and frequent, sometimes daily, operations were performed with the other experiments, either in the high-data-rate format of 40 kbit/s (F1) or at the lower rate of 4.6 kbit/s (F3).

The Magnetometer Experiment (MAG) and the Energetic-Particle Experiment (EPA) were allowed to remain on throughout the mission, and in September some solar-wind measurements were performed to support the ICE spacecraft's encounter with Comet Giacobini-Zinner.

Two formal rehearsals for the Halley encounter took place in October 1985 and February 1986. The planned January 1986 rehearsal was cancelled because, in the event, the experimenters preferred not to exercise their experiments at temperatures that at that point in the mission were close to their upper limits. The January rehearsal was therefore tentatively rescheduled for 10 March, but by the beginning of the month some experiments had already been activated for encounter, and the revised, expanded encounter-operations switch-on was in progress. These early instrument switch-ons were made possible by the careful management of on-board resources during the cruise phase, coupled with a spacecraft performance that was by then well established and nominal.

A small engineering support team made up of ESTEC, Fokker and British Aerospace personnel, worked closely with the ESOC operations team, focussing their attention on thermal/power management throughout the mission. No item of spacecraft equipment exceeded its in-orbit design operating limits during the mission, and all the experiments were maintained within their requested preferred limits during the critical encounter period.

The Giotto spacecraft targeting accuracy provided by the international Pathfinder arrangement, performed in collaboration with the USSR's Intercosmos and NASA, exceeded all expectations (see page 75 of this issue). The final closest approach targeting point for Giotto was thereby agreed by all Giotto Principal Investigators at 540 km, with an expected targeting error of only 40 km.

Just 15 s prior to reaching its predicted closest approach, Giotto ran into dust particles and suffered an attitude disturbance of the order of 1°, as well as damage to both the spacecraft and many of the experiments. This disturbance caused the spacecraft's telemetry signal to be depointed from the Earth and receivers at the Parkes and DSN ground stations lost lock, although a weak fluctuating signal was still measurable. For about 32 min the signal was intermittent, by which time the on-board nutation dampers had re-stabilised the spacecraft and the signal received at the ground became normal again.

Subsequent evaluation has led to the conclusion that although Giotto's mission was spectacularly successful, both the spacecraft and experiments were significantly damaged during the encounter. The spacecraft's post-encounter status is summarised in the adjacent table.

Because Giotto used so little of its original 68 kg consignment of hydrazine fuel during its journey to Halley, it was possible on 19, 20 and 21 March to perform three orbit-correction manoeuvres to redirect the spacecraft to pass close to the Earth in 1990 with a differential velocity of about 6 km/s (see page 66 of this issue). By suitable targeting of the spacecraft, the Earth can then be used to 'sling-shot' the spacecraft to another target, such as another comet or an asteroid.

As the star mapper has been inoperative since the encounter, attitude reference for these manoeuvres was provided by ground-station monitoring of the amplitude modulation of the received signal induced by the spacecraft wobble, in conjunction with spacecraft Sun-sensor data. The wobble is the result of the loss of some 600 g of spacecraft material during the encounter!

Although these manoeuvres have been successfully performed, a final decision on the eventual future of Giotto has not yet been taken, as the policy and funding requirements have still to be explored in the light of the current state of the spacecraft's subsystems and instrumentation. Consequently, the spacecraft was put into a hibernation mode (safe mode, but essentially powered down) on 2 April ready to be re-activated when the appropriate long-term decisions have been taken.

**POST-ENCOUNTER STATUS OF THE GIOTTO SPACECRAFT**

The spacecraft is wobbling by 0.2°. The imbalance is caused by the loss of some 600 g of material from the periphery of the spacecraft. Post-encounter orbit-deceleration measurements have shown that the total dust mass impacting on the spacecraft front surface during the encounter was about 2 g.

The star mapper has been partially disabled by stray light (probably due to baffle perforation) and can now only be operated on the dark side of the spacecraft.

The temperatures of several elements have risen by some 10—20 °C, probably because the spacecraft's multilayer insulation blankets have been ruptured in the neighbourhood of the dust shields.

The second travelling-wave-tube amplifier (TWTA-2) has been activated by onboard redundancy switching, so that TWTA-1 is now off. The attitude and orbit control equipment (AOCE) input buffer is corrupted, as is the data-handling unit's protected memory. All quality-check programs have ceased to function. Electromagnetic interference generated by dust impacts is considered the likely cause.

## FURTHER READING


**Special Publications (SP)**

**ESA SP-153**, 'The Comet Halley Micrmeteoroid Hazard', Proc. International Workshop sponsored by the European Space Agency, held at ESTEC, Noordwijk, The Netherlands, 18—19 April 1979 (October 1979)

**ESA SP-155**, 'The Comet Halley Probe Plasma Environment', Proc. series of Workshops held in 1979/80 at Max-Planck-Institute für Kernphysik, Heidelberg, W. Germany and ESTEC, Noordwijk, The Netherlands (May 1981)

**ESA SP-169**, 'Scientific and Experimental Aspects of the Giotto Mission', Proc. International Meeting held in Noordwijkerhout, The Netherlands, 27—28 April 1981 (June 1981)

**ESA SP-174**, 'The Comet Halley Dust and Gas Environment', Proc. Joint NASA/ESA Working Group Meeting, Heidelberg, W. Germany, 26—27 August 1981 (November 1981)

**ESA SP-187**, 'The Giotto Spacecraft Gas and Plasma Enviroment', Proc. Workshops held at ESTEC, Noordwijk, The Netherlands in 1980/81 (February 1982)

**ESA SP-224** 'The Giotto Spacecraft Impact-Induced Plasma Environment', Proc. Giotto PEWG Meeting, Bern, Switzerland, 10—12 April 1984 (September 1984)

**ESA SP-1066**, 'Space Missions to Halley's Comet', March 1986, by R. Reinhard & B. Battrick (March 1986)

**ESA SP-1077**, 'The Giotto Mission - Its Scientific Investigations', by R. Reinhard & B. Battrick (March 1986)

**ESA Bulletins**

No. 24 'Giotto - A Mission to Halley's Comet', by R. Reinhard & D. Dale

No. 29 'Space Missions to Halley's Comet and Related Activities'. The Inter-Agency meeting at Padova, 13—15 September 1981, by G. Colombo, E.A. Trendelenburg & R. Reinhard

No. 32 'The Giotto Dust Protection System', by R. Lainé & F. Felici

No. 36 'Independent Verification of Giotto On-board Software', by R. Brough et al.

No. 38 'Navigation to a Target Hidden in Dust: Comet Halley's Nucleus', by J. Fertig, F. Hechler & G. Schwehm

No. 38 'Terminal Navigation for Giotto - The Benefits of International Cooperation', by R.E. Münch

No. 39 'Exploration of Halley's Comet from the Ground: The International Halley Watch (IHW) and its Observing Nets', by The IHW Staff

No. 40 'The Giotto Payload Parts Procurement and Engineering Programme', by L. Adams et al.

No. 43 'Giotto On-Course for Halley's Comet', by D. Wilkins

No. 43 'Astrometric Observations of Comet Halley', by T.A. Morley

No. 45 'Heading for the Giotto Encounter with Comet Halley', by R.E. Münch

No. 45 'The Giotto Assembly, Integration and Verification Programme'', by H. Bachmann & J. Credland

No. 45 'Multi-purpose Electrical Ground Support Equipment for the Giotto Halley Multi-Colour Camera', by J. Turner & G. Schwarz

**ESA Journals**

Volume 4 No. 1 'The International Comet Mission', by R. Reinhard

Volume 7 No. 1 'Attitude Perturbations of the Giotto Spacecraft in the Dust Cloud of Comet Halley', by G.M. Coupé, R.M. Dean & R. Lainé

Volume 8 No. 3 'The Giotto Spacecraft System and Subsystem Design', by P. Lo Galbo

Volume 9 No. 3 'The Giotto Spacecraft's Performance during the Geostationary Transfer Orbit and Near-Earth Mission Phases', by J.L. Tracy et al.

Volume 10 No. 1 'Giotto Electrical Ground Support Equipment Design and Usage', by J. Credland & J. Noyes

# The Giotto Quick-Look Science Operations

*J. Credland & J. Noyes, Giotto Project Division, ESA Directorate of Scientific Programmes, ESTEC, Noordwijk, The Netherlands*

**The Giotto quick-look science operation was built up around the concept of re-use of pre-launch ground electrical checkout equipment supplied both by the Agency and the participating scientific institutes. This concept was driven both by the time criticality of the launch date and the relatively short life expectancy of the mission.**

**In practice the concept was extremely successful, demonstrating a cooperation between the Agency and the scientific institutes that benefited both parties.**

### Introduction

Early in the Giotto programme, the decision was taken to delegate responsibility for the analysis and display of the science telemetry data from Giotto's scientific payload to the ten experiment teams who were to supply the instruments. On previous projects the Agency itself had assumed this role within its Overall Checkout Equipment (OCOE) centralised computer system. However, this traditional approach requires software definition about one year prior to instrument delivery, to ensure that the integrated software sequences are available to support spacecraft system tests. In Giotto's case, such a software development schedule was incompatible with the extremely tight instrument design and development programme imposed by the unique, fixed launch window.

Because of Giotto's relatively short mission lifetime — a nine-month cruise phase followed by a few hours of intense scientific observation during the cometary flyby — it was in fact subsequently decided to re-utilise the existing Electrical Ground-Support Equipment (EGSE) from the ground-test phase for the scientific quick-look data analysis and display at the Agency's European Space Operations Centre (ESOC), in Darmstadt, during the cruise and encounter phases of the mission.

A block diagram of the overall structure of the Giotto electrical ground-support equipment is shown in Figure 1.

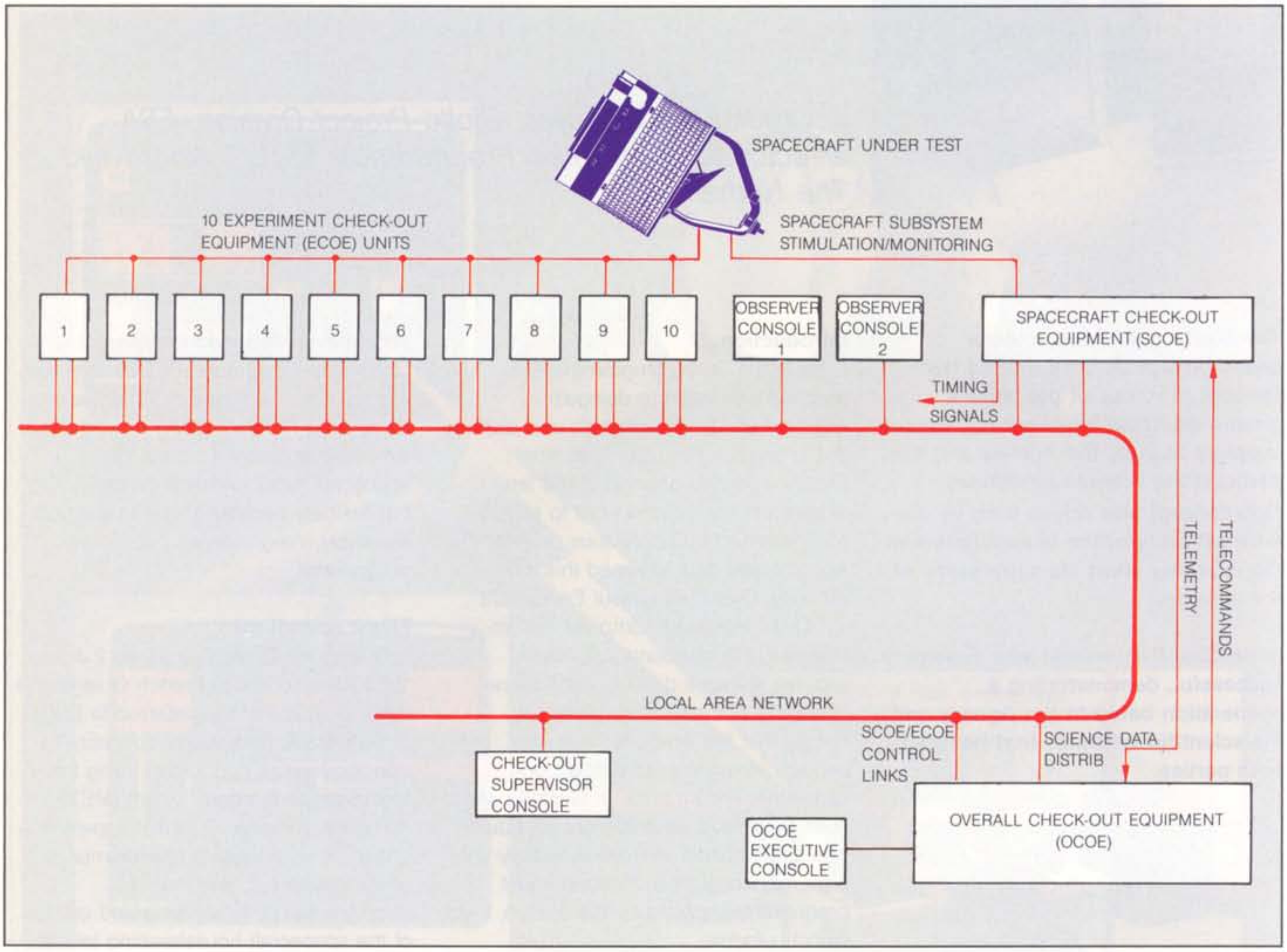
The concept of integrating the ten experimenter-provided Experiment Check-Out Equipment (ECOE) units with the Agency's centralised OCOE via a Local Area Network (LAN) proved extremely successful during the spacecraft ground-testing phase, giving the flexibility necessary during the tight assembly, integration and verification programme.

### Flight operations

Following the Giotto launch on 2 July 1985 from Kourou in French Guiana, the focus of operations transferred to ESOC in Darmstadt, from where spacecraft operations were conducted using the Multi-Satellite Support System (MSSS) computer complex. This flight-operations phase was confined to telecommanding of the spacecraft, and the decommutation, processing and display of the spacecraft housekeeping telemetry via the ESA ground station at Carnarvon in Western Australia, with the DFVLR ground station at Weilheim, Germany in support (see elsewhere in this issue).

The Giotto scientific payload was not operational during the initial phase of the mission and the telemetry downlink data rate was therefore 360 bit/s. The switch-on of the onboard instruments was commenced in late August 1985, with payload operational downlink telemetry data rates of 5.76 and 46.08 kbit/s then being used. These higher data rates after experiment switch-on required the use of larger ground stations, the prime station then being the Commonwealth Scientific & Industrial Research Organisation (CSIRO) 64 m station at Parkes, in New South Wales, with NASA's 34/64 m Deep

*Figure 1 — Giotto Electrical Ground-Support Equipment (EGSE) system used during ground checkout of the spacecraft system*




Space Network (DSN) and DFVLR's 30 m Weilheim stations as support.

**Quick-look science data**

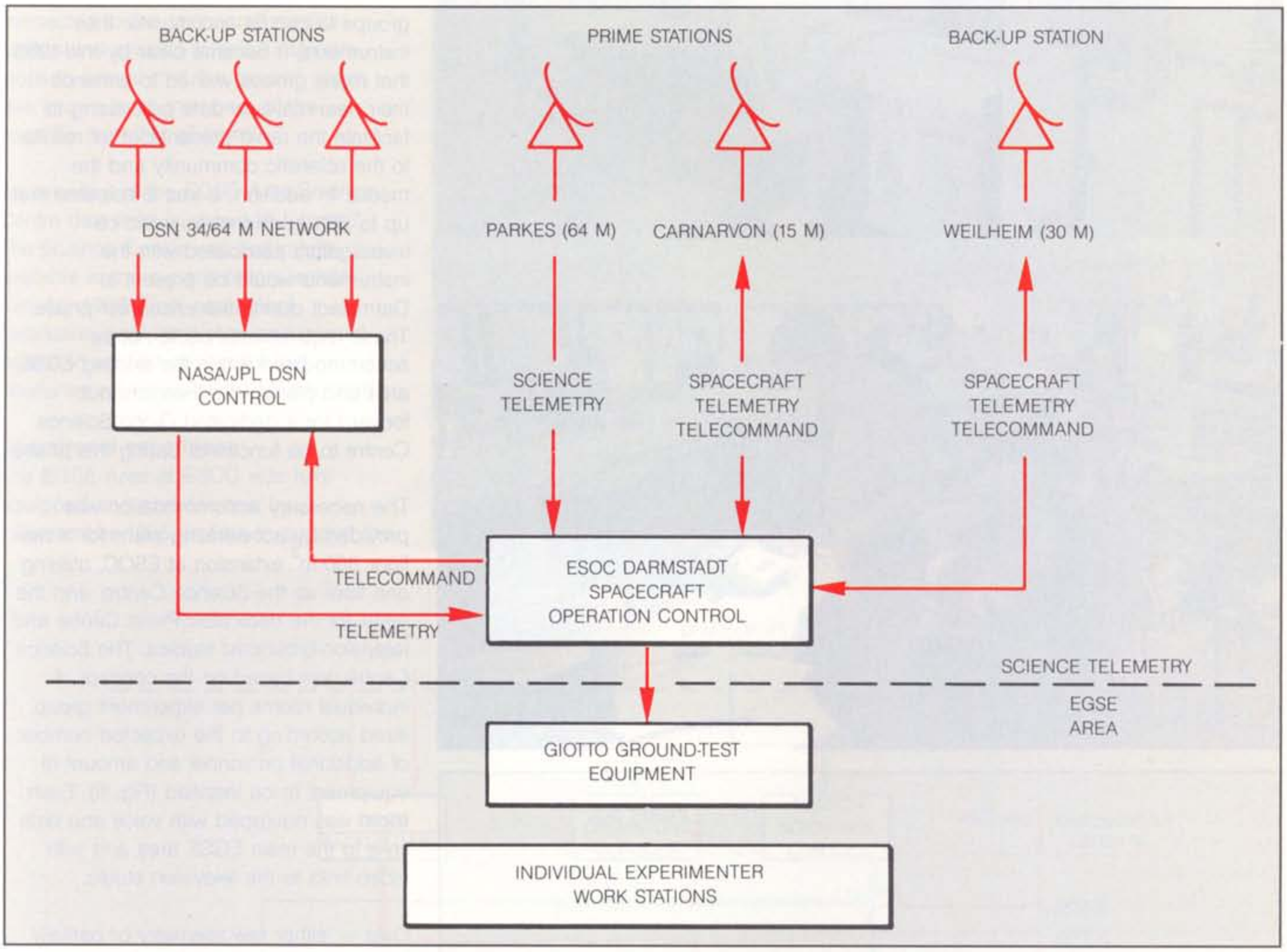
The quick-look science activity was based on telemetry data routed to ESOC from the ground stations. The spacecraft monitoring and command function was provided by the MSSS in the normal way, but the science data was routed unprocessed to the OCOE and ECOE work stations in the same manner as had been used during spacecraft ground operations. This allowed the equipment that had been used prior to launch to be re-used, with additional processing software provided by the individual experimenters. The science quick-look data flows are shown schematically in Figure 2.

Scientific data was disseminated to the experiment investigator teams in two ways. Firstly there was a need for near-real-time data to be available to the investigator teams at ESOC to allow interactive changes to be made to instrument parameters, especially during the hours directly preceding closest flyby, to enable instrument calibration parameters to be adjusted on the basis of information from other sources of Halley observations. Secondly, the final data from the cometary encounter phase was to be compiled from data tapes taken at the ground station and provided to the experimenters approximately two months after the encounter. It is this data that is now being used for detailed evaluation of the scientific return from each of the ten payload instruments.

**Giotto EGSE Area**

The quick-look science facility was installed in two large rooms at ESOC which had been specially set aside to house the EGSE facilities. All scientific payload operations were controlled from this area via the mission scientists' console, where real-time assessment of experiment operational priorities was performed and the resulting requests made to the spacecraft operations manager for the uplinking of payload commands.

*Figure 2 — Block diagram of the Giotto science quick-look data flow*




Owing to the criticality of the scientific data reception close to encounter, it was decided to implement independent data streams from the Parkes ground station and NASA's DSN station in a redundant configuration. This was achieved by routing Parkes science data via the prime MSSS computer, and DSN science data via the backup MSSS computer. Both data streams were then available in the EGSE area, allowing instantaneous selection to be made of the best data stream or rerouting of the science data in case of a hardware failure (Figs. 3—5).

In addition to serving its payload-monitoring function during the final encounter phase of the mission, the EGSE area was also used throughout the cruise phase. The dedicated switch-ons of each experiment between mid-August and mid-September 1985 were monitored by the individual experimenter groups from their ECOE work stations.

Moreover, between September 1985 and February 1986, certain experiments were operational to obtain data on the interplanetary medium, and specialised calibration operations were scheduled for many instruments. The camera, for example, imaged the Earth (see ESA Bulletin no. 44, cover & pp. 96—97), Venus and Jupiter during the cruise phase to finalise encounter operations procedures and to perform final in-flight calibration. Two other experiments were switched on from September 1985, collecting data in their onboard memories and dumping this data to the ground at regular intervals.

In addition, the Giotto payload was operational to support the ICE spacecraft's encounter with Comet Giacobini-Zinner in mid-September (see ESA Bulletin No. 44, pp. 32—39), and full payload operations rehearsals in October 1985, February and March 1986 for the Giotto encounter were controlled from the facility with all ECOE work stations manned.

**Giotto Science Centre**

Whilst the EGSE area as planned would have provided sufficient science-data processing to enable experimenter

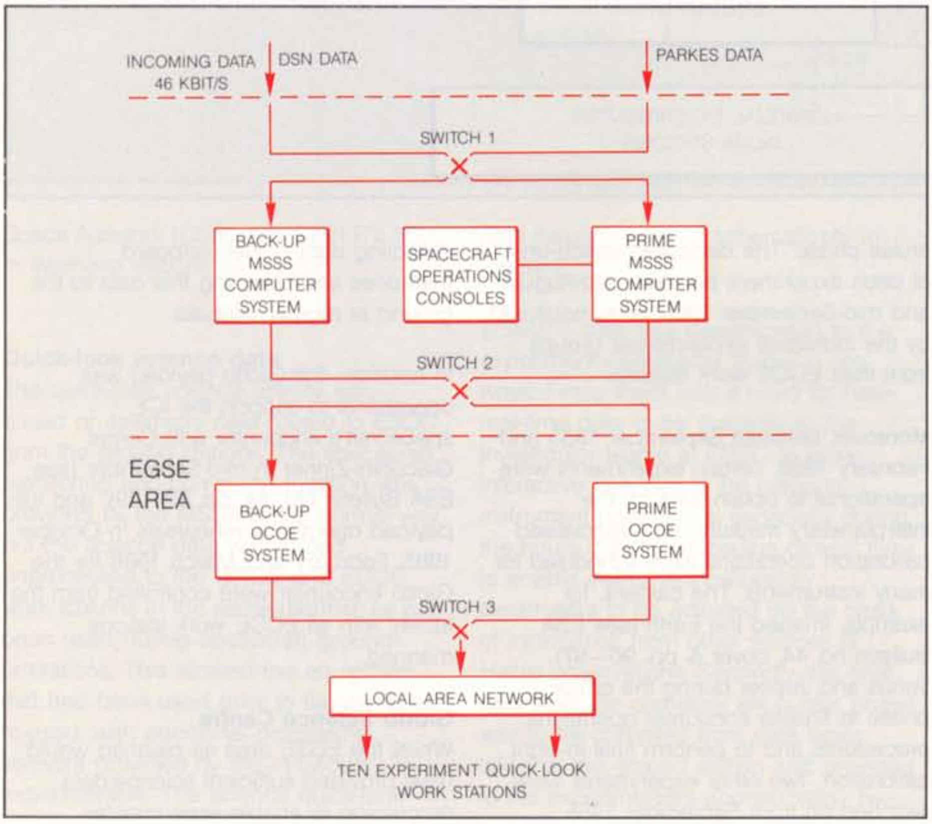



*Figure 3 — Overall Checkout Equipment installed in the EGSE area at ESOC*

*Figure 4 — Mission Scientists' console in the EGSE area*

*Figure 5 — Routing of the incoming science data streams to provide quick-look redundancy*

groups to control and monitor their instruments, it became clear by mid-1985 that many groups wished to enhance their near-real-time data processing to facilitate the rapid presentation of results to the scientific community and the media. In addition, it was anticipated that up to 200 additional scientific co-investigators associated with the instruments would be present at Darmstadt during the encounter phase. These requirements could not be accommodated within the existing EGSE area and plans were therefore put forward for a dedicated Giotto Science Centre to be functional during this phase.

The necessary accommodation was provided by accelerating plans for a two-floor 800 m$^2$ extension at ESOC, utilising one floor as the Science Centre, and the other for the dedicated Press Centre and television-broadcast studios. The Science Centre was based on the concept of individual rooms per experiment group, sized according to the expected number of additional personnel and amount of equipment to be installed (Fig. 6). Each room was equipped with voice and data links to the main EGSE area and with video links to the television studio.

Data — either raw telemetry or partially processed data — was transferred via a local area network (LAN) from the individual ECOE work stations in the EGSE area to the appropriate Science Centre room, where further scientific evaluation could take place, together with specialised processing to allow selected scientific results to be presented in near-real-time via the television network.

An important additional link was established between the Science Centre and a Vega experiment team in Moscow to allow dust data from the earlier cometary flybys of the Russian Vega-1 and -2 spacecraft to be made available to the Giotto team prior to the encounter for the Giotto targeting decision.

Each room in the Science Centre was

*Figure 6 — View of the Halley Multicolour Camera (HMC) area in the Giotto Science Centre*

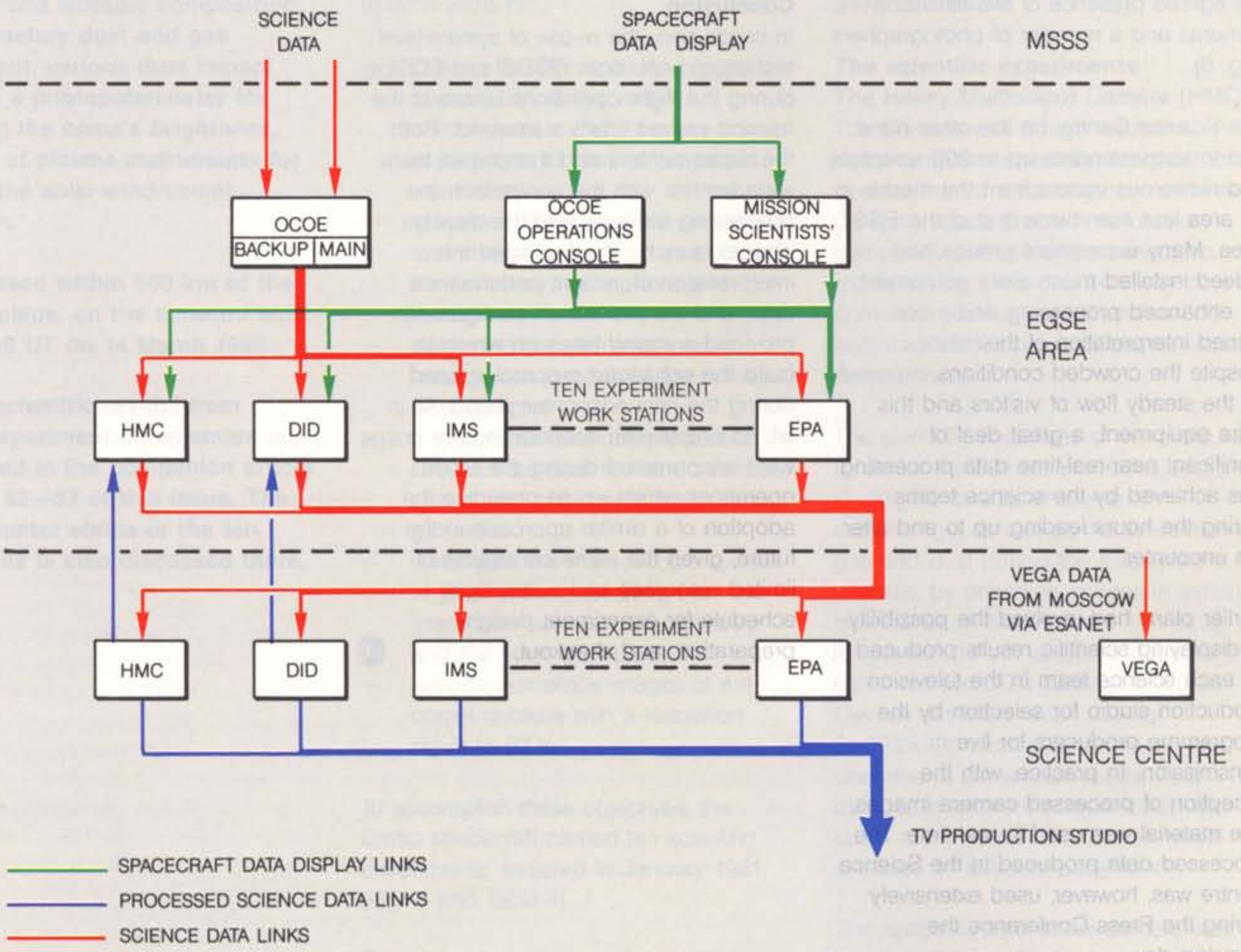
*Figure 7 — Overview of the EGSE Area/Science Centre data links*

connected to the spacecraft mission-control and mission-scientist intercom loops to ensure that the mission status was known to all members of the scientific teams at all times.

An overview of the EGSE Area/Science Centre data links is shown in Figure 7. The Science Centre was first made available to the experimenters in late January 1986. Final equipment installation was completed and correct operation verified during the last encounter rehearsal on 10 March 1986.

**Operational experience**

The EGSE Area at ESOC was fully equipped and comissioned by 1 September 1985, in time to support the



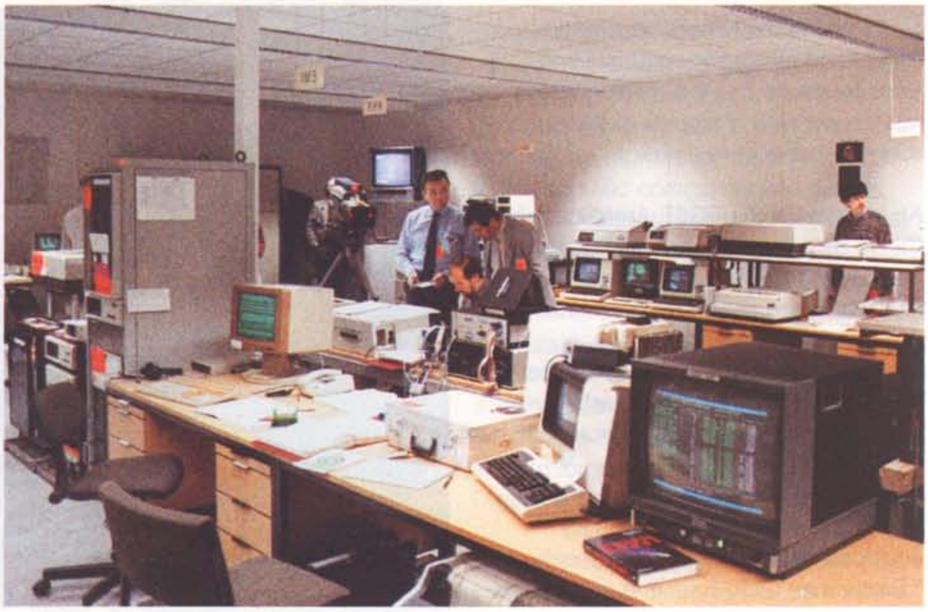
initial payload operations. From this point onwards, the area was used continually to support the near-real-time data passes (periods of visibility of the Giotto spacecraft from the European and Australian ground stations) during the cruise phase. From mid-February 1986 onwards, the science data passes involved the majority of the payload instruments, and increased occupancy of the area started to become a problem.

Accordingly, from the beginning of the week of the encounter, strict access control was introduced to maintain good working conditions. This ensured that even during the encounter phase, when attention was heavily focussed on payload operations, both the scientists and the project team were able to work with a minimum of disruption, even with the agreed presence of two television cameras and a number of photographers (Fig. 8).

The Science Centre, on the other hand, had to accommodate up to 200 scientists and numerous visitors from the media, in an area less than twice that of the EGSE Area. Many experiment groups had indeed installed much extra equipment for enhanced processing and more refined interpretation of their data. Despite the crowded conditions imposed by the steady flow of visitors and this extra equipment, a great deal of significant near-real-time data processing was achieved by the science teams during the hours leading up to and after the encounter.

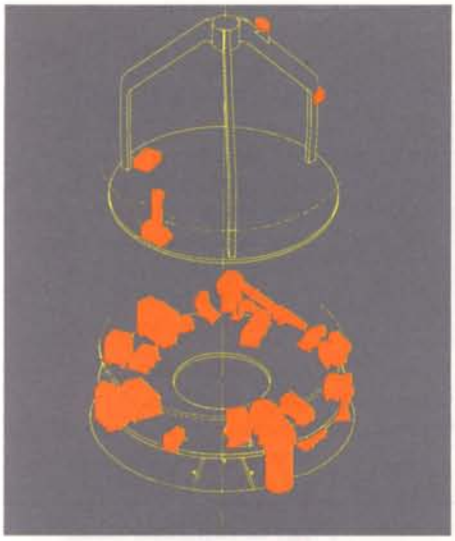
Earlier plans had involved the possibility of displaying scientific results produced by each science team in the television production studio for selection by the programme producers for live transmission. In practice, with the exception of processed camera images, little material was used in real time. The processed data produced in the Science Centre was, however, used extensively during the Press Conference the following day.

*Figure 8 — General view of the EGSE area showing the various experimenter work stations*



## Conclusion

In conclusion, the re-use of system-level test equipment, both OCOE and ECOEs, during the flight operations phase of the mission proved totally successful. Both the experimenters and the project team were familiar with the equipment, the processing software, and the displays prior to launch. This facilitated the interpretation of in-flight performance data, and the pre-launch configuration provided a sound basis on which to build the enhanced processing used during the final encounter phase. All in all, no unforeseen shortcomings or snags were encountered during the Giotto operations which would prejudice the adoption of a similar approach in the future, given the same constraints of limited resources and a very tight schedule for experiment design, preparation, and checkout.



# The Giotto Experiments

*R. Reinhard, Giotto Project Scientist, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands*

**ESA's Giotto Mission to Halley's Comet was a fast flyby at 00 UT on 14 March 1986, about four weeks after the comet's perihelion passage, when it was at its most active. The scientific payload was made up of ten experiments with a total mass of approximately 60 kg: a camera for imaging the comet nucleus, three mass spectrometers for analysing the elemental and isotopic composition of the cometary dust and gas environment, various dust impact detectors, a photopolarimeter for measuring the coma's brightness, and a set of plasma instruments for studying the solar-wind/comet interaction.**

**Giotto passed within 600 km of the comet nucleus, on the sunward side, at 00:03:00 UT on 14 March 1986.**

**The first scientific results from Giotto's experiment complement are summarised in the companion article on pages 52—57 of this issue. The post-encounter status of the ten experiments is also discussed there.**

**Introduction**
The Giotto project was approved in July 1980, allowing precisely five years between approval and launch. During the Giotto mission study phase, a Scientific Working Group formulated the scientific objectives and defined a mission concept and a model payload.

The scientific objectives for the Giotto mission were to:

- provide the elemental and isotopic composition of the volatile components in the cometary coma; in particular to identify the parent molecules
- characterise the physical processes and chemical reactions that occur in the cometary atmosphere and ionosphere
- determine the elemental and isotopic composition of the cometary dust particles
- measure the total gas production rate and the dust flux and size/mass distribution and derive the dust-to-gas ratio
- investigate the macroscopic system of plasma flows resulting from the interaction between the cometary and the solar-wind plasma
- provide numerous images of the comet nucleus with a resolution down to 50 m.

To accomplish these objectives, the Giotto spacecraft carried ten scientific experiments, selected in January 1981, (Fig. 1 and Table 1).

Giotto was launched on 2 July 1985 by an Ariane-1 rocket. The Halley Multicolour Camera was the first experiment to be switched on on 10 August 1985, followed by the Magnetometer Experiment and Energetic Particles Experiment switch-ons on 22 August. These two experiments remained on thereafter, using their memories to bridge gaps in ground-station coverage. The complete switch-on sequence is shown in Table 2.

**The scientific experiments**
**The Halley Multicolour Camera (HMC)**
The Camera was a high-resolution imaging system specially designed to operate from the rotating, spin-stabilised (15 rpm) space probe. It functioned in a completely self-contained, automatic mode during the close, fast flyby of the cometary nucleus, and searched for, acquired and tracked the comet nucleus automatically.

The scientific objectives of the HMC were to detect the cometary nucleus and to investigate its size, shape and morphology, as well as the interaction of gas and dust during the evaporation process, by providing images in various filter bands. A telescope of 1 m focal length and 16 cm aperture focussed the light onto two CCD (Charge-Coupled Device) detectors, each having 2×292×390 picture elements, which operated in a line-scan mode. Four pictures in different colours could be taken at the same time. A filter wheel provided 11 different pass bands.

The optical system of the camera was a modified Ritchey-Chrétien design with

**Table 1. Giotto's scientific payload**

| Experiment | | Mass (kg) | Power (W) | Data Rate (bit/s) Format 1/2/3* | | | Principal Investigator | Main Collaborating Institutes (hardware) |
|---|---|---|---|---|---|---|---|---|
| Camera | | 13.51 | 11.5 | 20058 | 20058 | 723 | H.U. Keller,<br>MPI für Aeronomie, Lindau<br>W. Germany | Laboratoire de Physique Stellaire & Planétaire, Verrières-le-Buisson.<br>Institut d'Astrophysique, Liège.<br>Istituto di Astronomia, Padova.<br>DFVLR, Oberpfaffenhofen.<br>Ball Aerospace, Boulder. |
| Neutral Mass Spectrometer | M-Analyser<br>E-Analyser | 12.70 | 11.3 | 4156 | 4156 | — | D. Krankowsky.<br>MPI für Kernphysik,<br>Heidelberg, W. Germany | Physikalisches Institut,<br>University of Bern.<br>Laboratoire de Géophysique Externe, CNRS, Saint-Maur.<br>The University of Texas at Dallas. |
| Ion Mass Spectrometer | High Energy Range Spectrometer,<br>High Intensity Range Spectrom. | 9.00 | 6.3 | 3253 | 3253 | 1084 | H. Balsiger,<br>Physikalisches Institut,<br>University of Bern,<br>Switzerland | MPI für Aeronomie, Lindau.<br>JPL, Pasadena.<br>Lookheed Palo Alto Research Laboratory. |
| Dust Mass Spectrometer | | 9.89 | 9.1 | 2891 | 5782 | — | J. Kissel, MPI für Kernphysik,<br>Heidelberg, W. Germany | |
| Dust impact Detector System | Meteoroid Shield Momentum Sensor,<br>Impact Plasma & Momentum Sensor,<br>Capacitor Impact Sensor | 2.26 | 1.9 | 361 | 903 | — | J.A.M. McDonnell,<br>Space Science Laboratory,<br>University of Kent,<br>Canterbury, UK | Rutherford Appleton Laboratories, UK.<br>MPI für Kernphysik, Heidelberg.<br>ONERA/CERTS/DERTS, Toulouse.<br>ESA Space Science Department.<br>Istituto di Fisica, Lecce.<br>Istituto di Fisica, Bari. |
| Plasma Analysis 1 | Fast Ion and Implanted Ion Sensors | 4.70 | 4.4 | 3975 | 1265 | 1355 | A. Johnstone,<br>Mullard Space Science Lab.,<br>Holmbury St. Mary, UK | MPI für Aeronomie, Lindau.<br>Istituto Plasma Spaziale, Frascati. |
| Plasma Analysis 2 | Electron Electrostatic Analyser,<br>Positive Ion Cluster Comp. Analyser | 3.21 | 3.4 | 2530 | 1807 | 904 | H. Rème<br>Centre d'Etude Spatiale des Rayonnements, France<br>Toulouse, | MPI für Aeronomie, Lindau.<br>Space Sciences Laboratory, Berkeley. |
| Energetic Particles Analyser | | 0.95 | 0.7 | 181 | 181 | 181 | S.M.P. McKenna-Lawlor,<br>St. Patrick's College,<br>Maynooth, Ireland | Dublin Institute for Advanced Studies, Ireland.<br>MPI für Aeronomie, Lindau. |
| Magnetometer | | 1.36 | 0.8 | 1265 | 1265 | 407 | F.M. Neubauer,<br>Institut für Geophysik und Meteorologie, Köln,<br>W. Germany | Institut für Geophysik und Meteorologie, Braunschweig.<br>Laboratory for Extraterrestrial Physics NASA/GSFC.<br>Istituto di Fisica, University of Rome. |
| Optical Probe Experiment | | 1.32 | 1.2 | 723 | 723 | — | A.C. Levasseur-Regourd,<br>Service d'Aéronomie du CNRS, Verrières-le-Buisson,<br>France | Laboratoire d'Astronomie Spatiale, Marseille.<br>Space Astronomy Laboratory,<br>University of Florida, Gainesville. |
| Radio Science Experiment | | — | — | — | — | — | P. Edenhofer<br>Institut für Hoch- und Höchstfrequenztechnik,<br>W. Germany | Radioastronomische Institut.<br>Universität Bonn.<br>DFVLR, Oberpfaffenhofen |
| TOTAL | | 58.90 | 50.6 | 39393 | | 4654 | | |

*Format 1: from CA–70 h until CA–1 h Format 2: from CA–1 h until CA+1 h Format 3: during cruise phase (CA = Closest Approach)

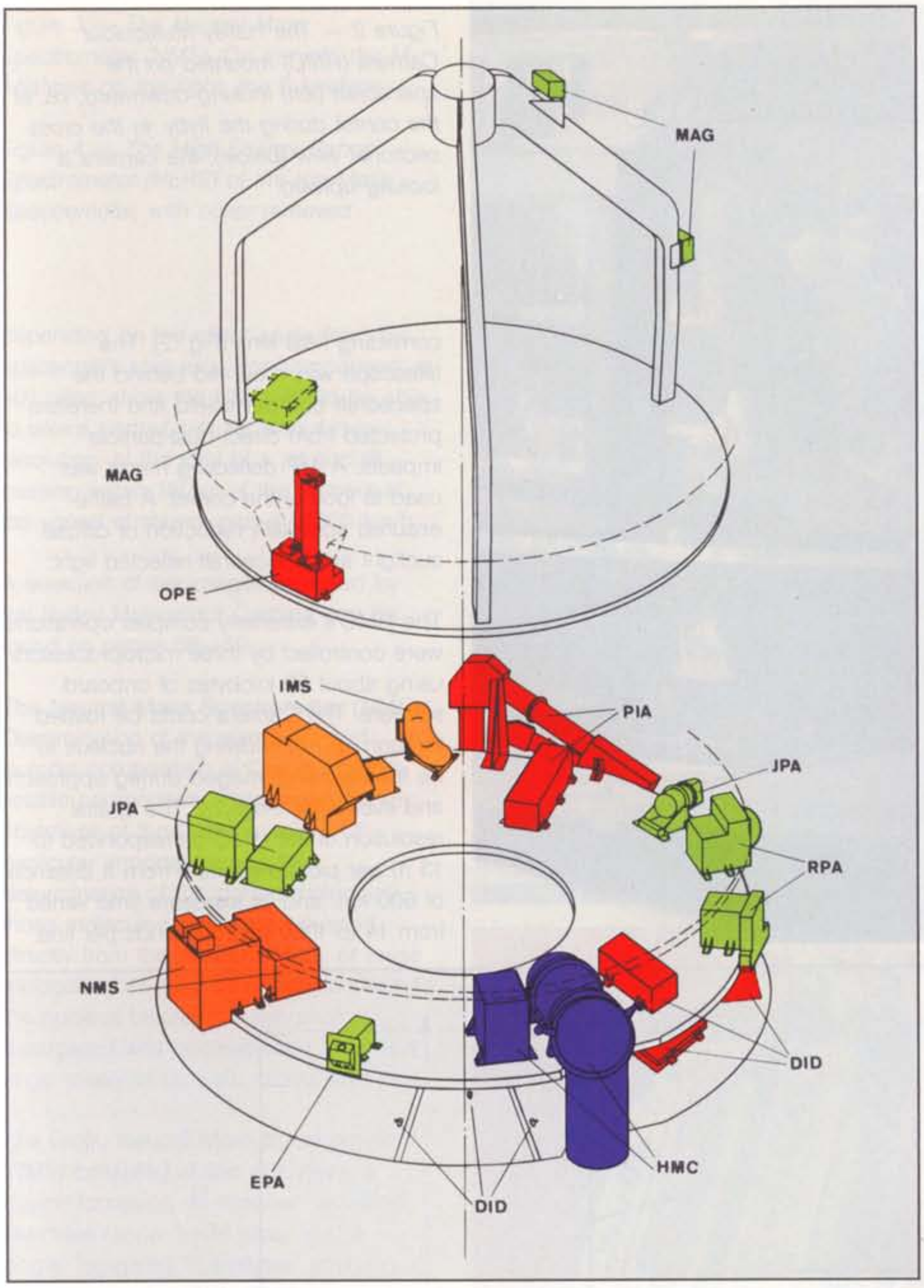



*Figure 1 — Locations on Giotto of the ten hardware experiments, which can be loosely grouped into four categories: imaging, gas mass spectroscopy, dust experiments and plasma experiments (experiment codes listed in Table 2)*

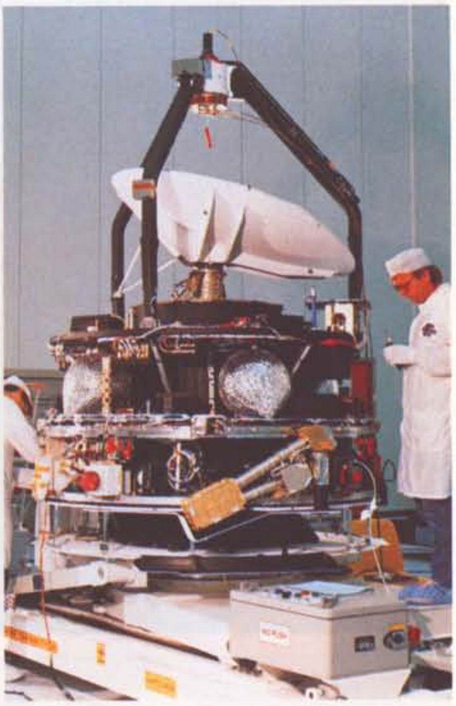


*Table 2 — Giotto Experiment switch-on sequence*

| Experiment | Format | Switch-on date |
|---|---|---|
| Halley Multicolour Camera (HMC) | F3 | 10 August |
| **Magnetometer (MAG)** | F3 | 22 August |
| **Energetic Particles Analyser (EPA)** | F3 | |
| **Halley Multicolour Camera (HMC)** | F1 | 6 September |
| Magnetometer (MAG) | F1 | 7 September |
| Energetic Particles Analyser (EPA) | F1 | |
| **Ion Mass Spectrometer (IMS)** | F1 | |
| **Johnstone Plasma Analyser (JPA)** | F1 | 8 September |
| **Rème Plasma Analyser (RPA)** | F1 | |
| Neutral Mass Spectrometer (NMS) | F3 | 12 September |
| Neutral Mass Spectrometer (NMS) | F1 | 13 September |
| Optical Probe Experiment (OPE) | F1 | |
| Neutral Mass Spectrometer (NMS) | F1 | |
| **Neutral Mass Spectrometer (NMS)** | F1 | 7 October |
| **Dust Impact Detector (DID)** | F1 | 8 October |
| **Optical Probe Experiment (OPE)** | F1 | 9 October |
| **Particulate Impact Analyser (PIA)** | F1 | 13 October |

* Bold entries = main functional performance check

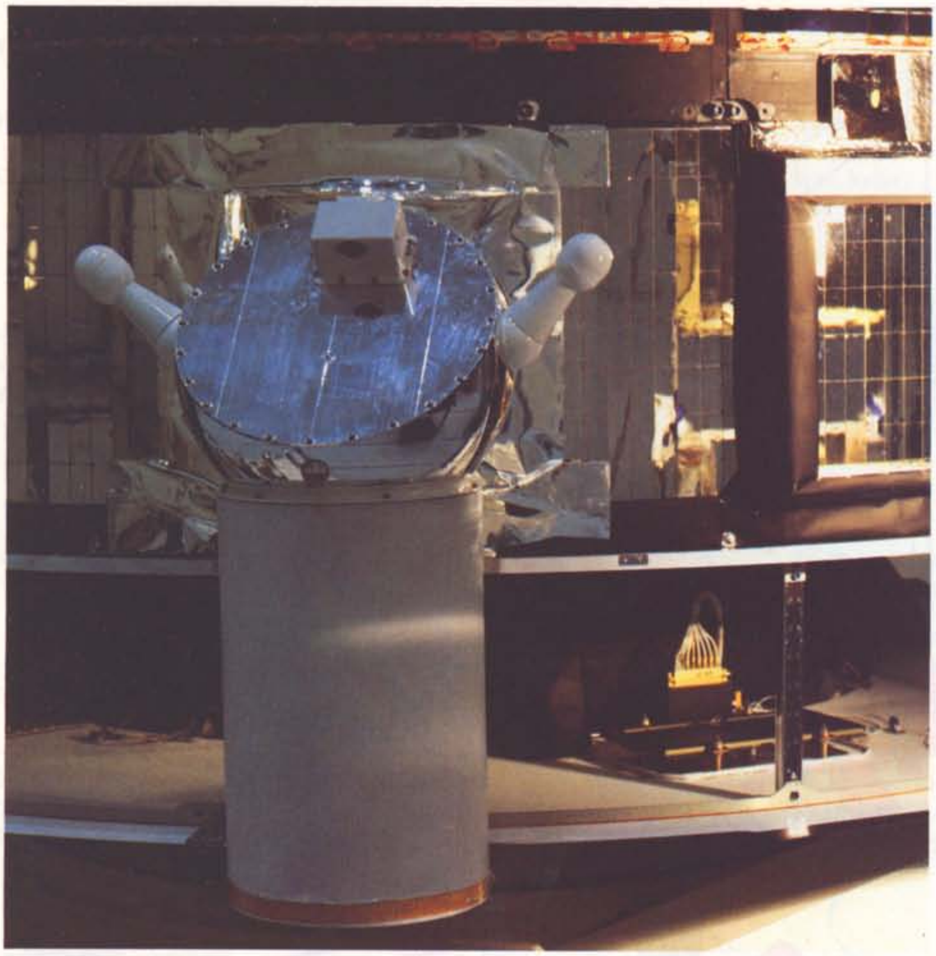


*Figure 2 — The Halley Multicolour Camera (HMC) mounted on the spacecraft (left) looking downward, i.e. at the comet during the flyby. In the cross-sectional view (below), the camera is looking upward.*

correcting field lens (Fig. 2). The telescope was mounted behind the spacecraft bumper shield and therefore protected from direct dust-particle impacts. A 45° deflecting mirror was used to look at the comet. A baffle ensured adequate reduction of diffuse sunlight and spacecraft-reflected light.

The HMC's extremely complex operations were controlled by three microprocessors using about 50 kilobytes of onboard software. The Camera could be rotated through 180°C, allowing the nucleus to be followed and imaged during approach and even after the flyby. The spatial resolution of the HMC corresponded to 13 m per picture element from a distance of 600 km, and its exposure time varied from 14 to 1000 microseconds per line,

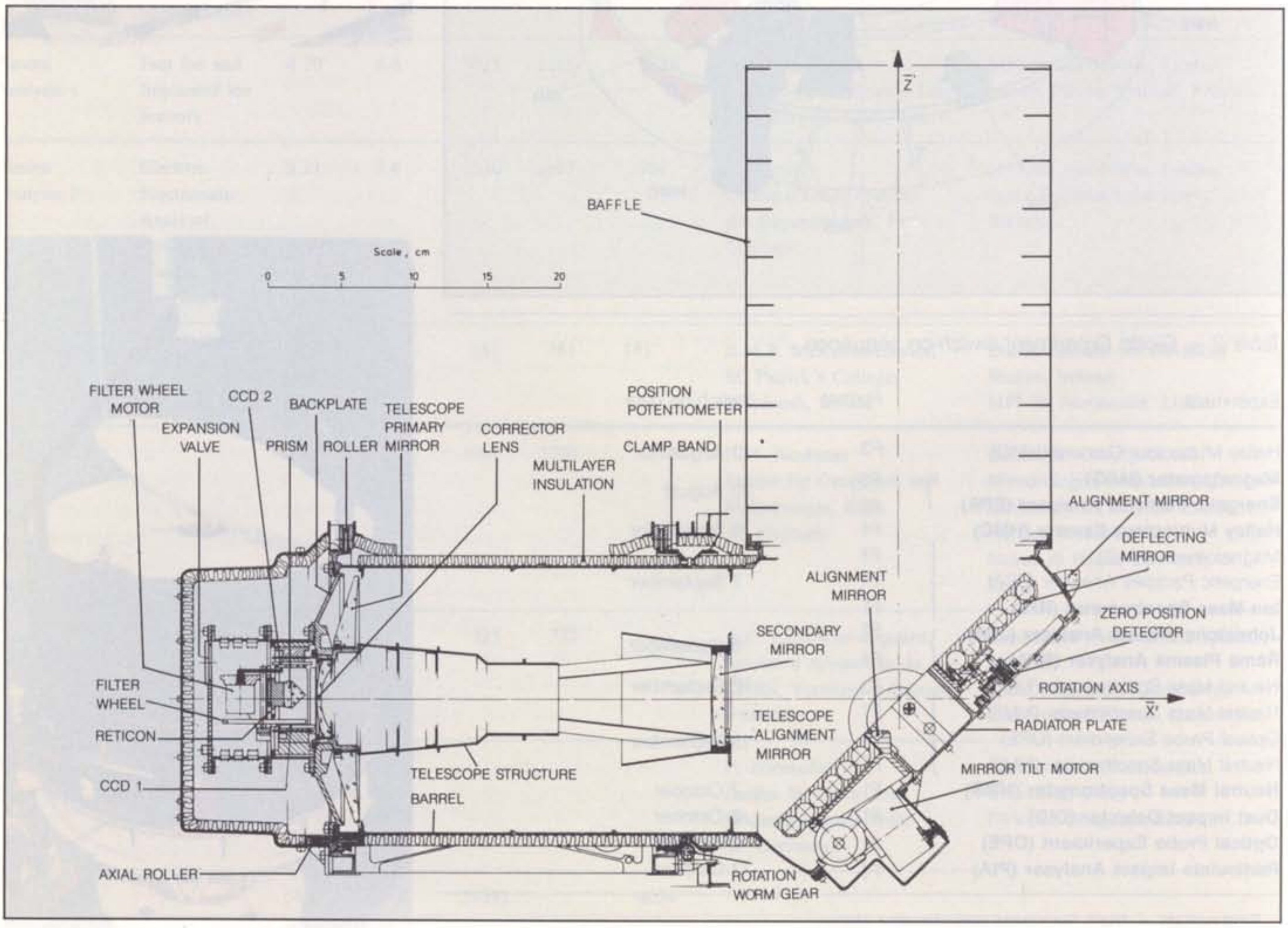
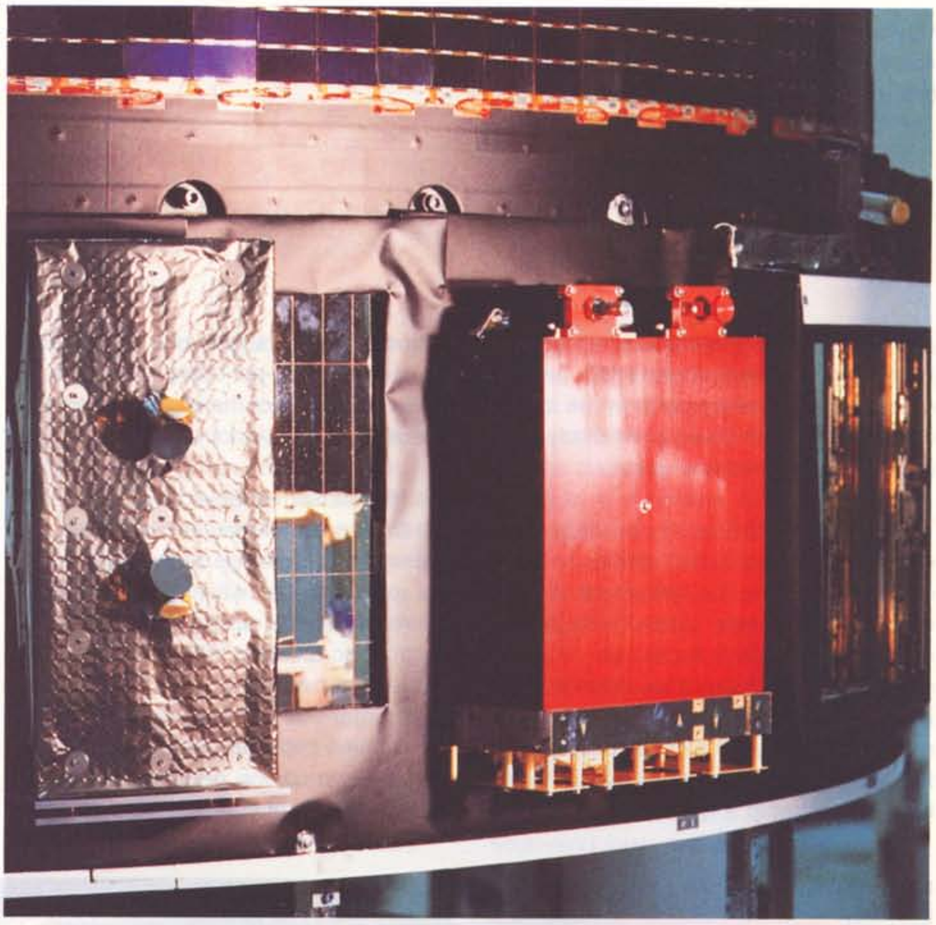
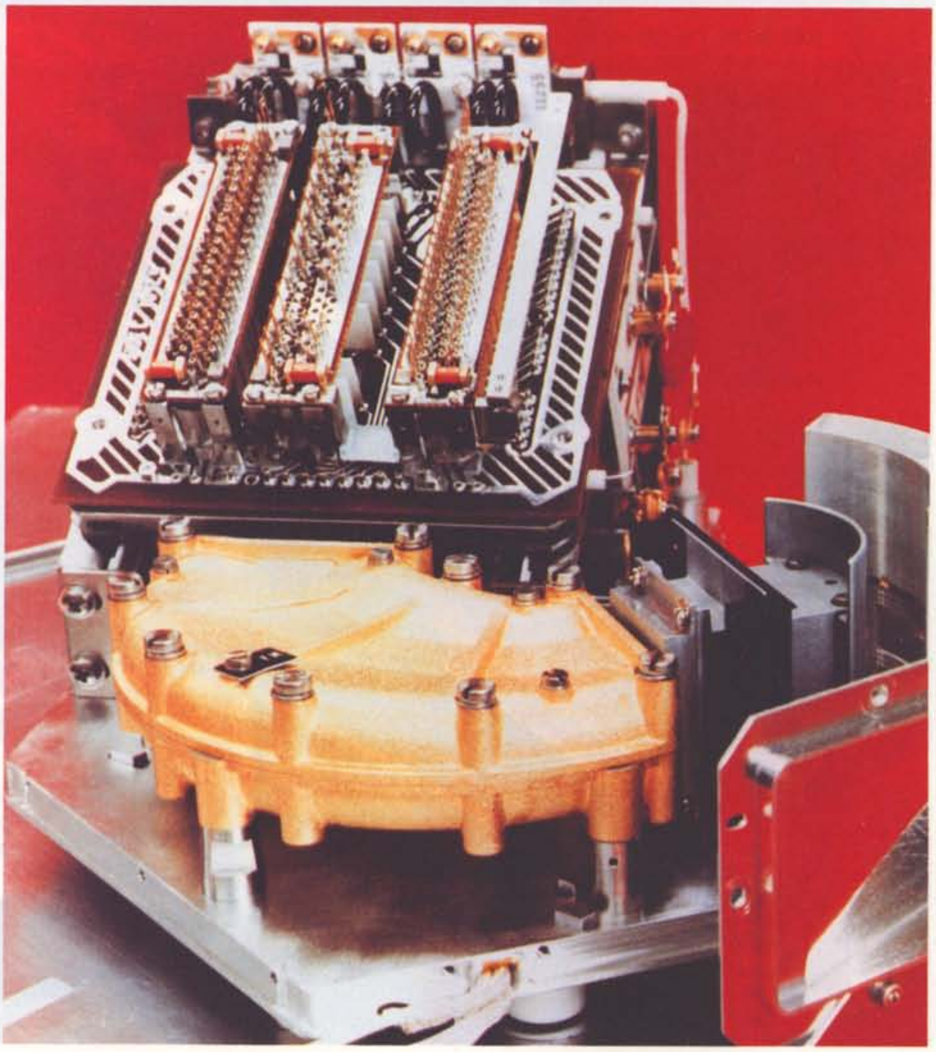


*Figure 3 — The Neutral Mass Spectrometer (NMS). On the left, the M-Analyser; on the right, the E-Analyser*

*Figure 4 — The High-Energy Range Spectrometer (HERS) of the Ion Mass Spectrometer, with cover removed*





depending on the offset angle from the spacecraft's spin axis. For comparison, at 90° offset angle the HMC would be able to take a portrait picture, with 4 mm resolution, of the pilot of a jet aircraft passing within 160 m of the camera at the speed of sound, namely 1200 km/h.

A selection of the images provided by the Halley Multicolour Camera can be found on pages 58—59.

**The Neutral Mass Spectrometer (NMS)**
Determination of the elemental and isotopic composition of Comet Halley's volatile components was one of the key objectives of the Giotto mission. Of particular importance was the determination of the parent molecules, those molecules which are released directly from the nucleus. Many of these molecules can only be observed close to the nucleus before they are photo-dissociated and photo-ionised to form a large variety of radicals, atoms and ions.

The Giotto Neutral Mass Spectrometer (NMS) consisted of two analysers, a double-focussing 'M-analyser' covering the mass range 1—36 amu, and a single- focussing 'E-analyser' covering the energy range 210—2180 eV equivalent to the mass range 9—89 amu. For analysis, the cometary neutrals had to be ionised, which was achieved by bombardment with an electron beam. If the electron beam was switched off, the NMS could be used to measure cometary ions. During the flyby both modes were employed, further away from the nucleus predominantly the ion mode, close to the nucleus predominantly the neutral mode. The NMS field of view was ±4° around the spacecraft spin axis, i.e. the instrument was looking in the ram direction of cometary particles.

**The Ion Mass Spectrometer (IMS)**
The Ion Mass Spectrometer was made up of two sensors, a High-Energy Range Spectrometer (HERS) optimised for measurements in the outer coma, where a turbulent transition between solar wind

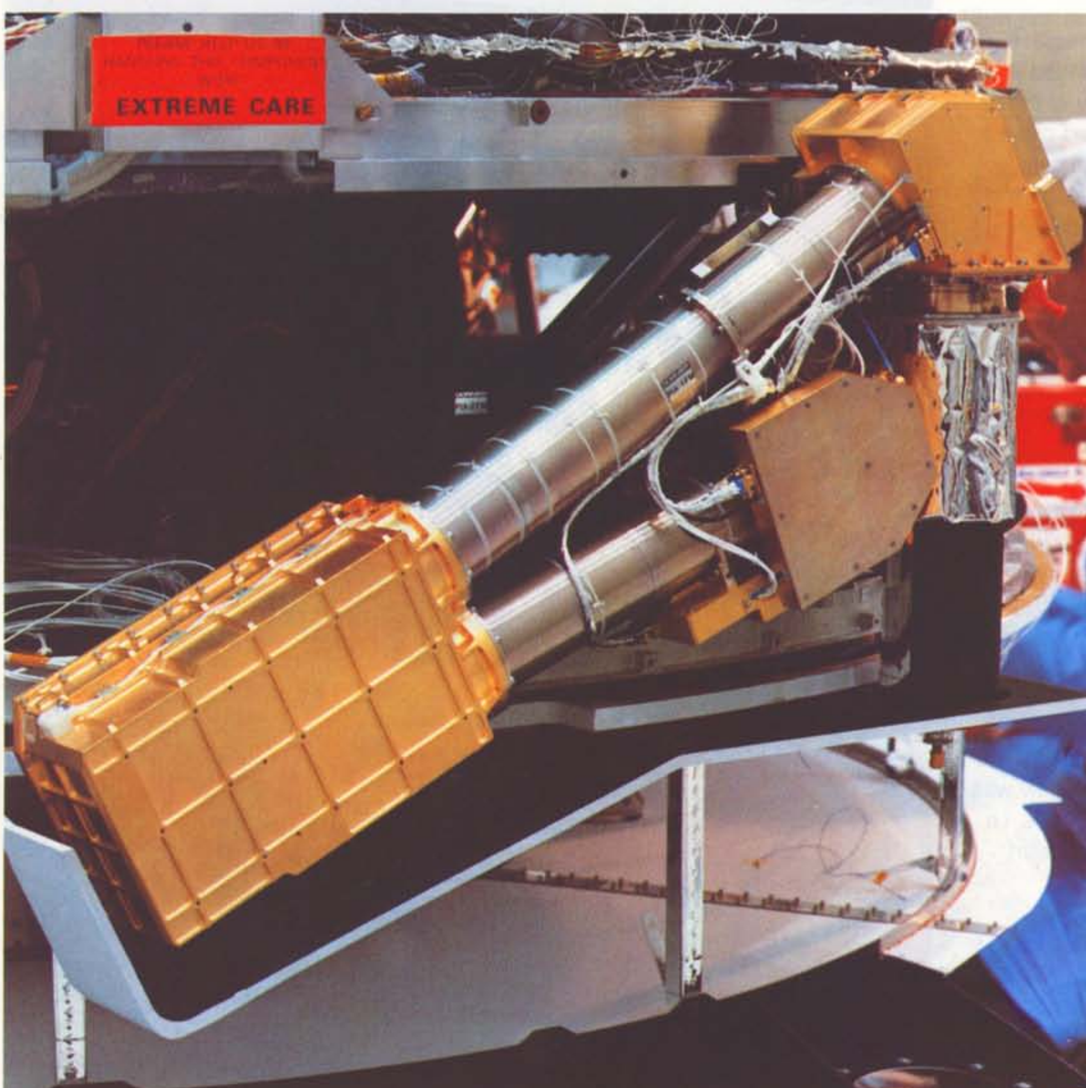



*Figure 5 — The Particulate Impact Analyser's (PIA) Sensor and electronics box (thermal paint not yet applied)*

and cometary ions was expected, and a High-Intensity Spectrometer (HIS) optimised for measurements in the inner coma, where high fluxes of relatively cold cometary ions were anticipated.

The HERS sensor (Fig. 4) consisted of an electrostatic mirror to deflect the cometary ions into the instrument, a pair of grids with variable applied voltage, a sector magnet which served as momentum-per-charge filter, and an electrostatic deflector which spread the momentum-analysed ions according to their energy per charge. The beam was then imaged onto a two-dimensional microchannel plate, with one dimension a measure of mass-per-charge, and the other a measure of the elevation angle of the ion's velocity vector.

The HIS sensor employed two quadrispherical electrostatic analysers. The energy-per-charge of the particles that were analysed was selected by the differential voltage applied to the first electrostatic analyser, while the momentum-per-charge (and thus mass-per-charge) was determined by the acceleration potential applied between a pair of plane parallel grids located behind the exit of that analyser. The ion The second quadrispherical analyser was used to focus the ion beam providing a mass per charge spectrum. The beam of ions was spread out using a specially designed device called the 'igel' located at the end of the second analyser and finally registered by line channeltrons. Channeltrons were used instead of a microchannel plate because of the expected high count rates. The Mass Analyser (MA) was complemented by an Angle Analyser (AA) to extend the angular field of view and to allow for some resolution in elevation.

**The Particulate Impact Analyser (PIA)**

This dust mass spectrometer measured the chemical and isotopic composition of the individual dust particles (Fig. 5). When a dust particle impacted on the instrument's target, a plasma was generated, from which ions were extracted and accelerated via an acceleration grid. The accelerated ions passed through a time-of-flight tube (approximately 1 m long), where they were separated in time according to their mass. The spectrum of elements that made up each dust particle was then recorded by an electron multiplier at the end of the drift path.

**The Dust Impact Detector System**

The Dust Impact Detector System consisted of three independent subsystems with seven individual sensors. Six sensors were mounted on Giotto's front shield, while the seventh detector was

*Figure 6a — The Dust Impact Detector System (DID), mounted on the front sheet of the spacecraft's bumper shield. Details of the Meteoroid Shield Momentum Sensor (MSM) and the Impact Plasma and Momentum Sensor (IPM) are shown on the right*

*Figure 6b — Schematic of Giotto's front meteoroid shield showing sensor locations*

located on the rear shield to monitor those dust particles that were able to penetrate the front dust shield. An ambient plasma monitor was also incorporated into DID to measure the impact plasma generated by both dust and gas impacts on the spacecraft. The system was controlled and its data processed by a microprocessor-based system that allowed the wide range of impact rates (varying from a few per minute, to $\sim 10^{-6}$ $s^{-1}$ at closest approach) to be handled.

Impacts of large dust particles on the front sheet of the spacecraft bumper shield (Fig. 6) were detected by three microphones mounted 120° apart at the outer edge of the front sheet of the spacecraft's bumper shield (Meteoroid Shield Momentum measurement, MSM). They registered the shock wave generated by each dust-particle impact. In this way, the whole 2 $m^2$ front-sheet area of the Giotto spacecraft acted as a 'detector'.

A Capacitor Impact Sensor (CIS) 1000 $cm^2$ in area measured the flux of dust particles $>10^{-10}$ g penetrating a thin (70 $\mu$m) mylar dielectric material. Aluminium deposits on both faces acted as a capacitor. When impacted by a sufficiently large particle, the dielectric of the capacitor was perforated and the device discharged through the impact-generated plasma. The counting rate was limited by the capacitor recharging process to $\sim 1000$ impacts/s.

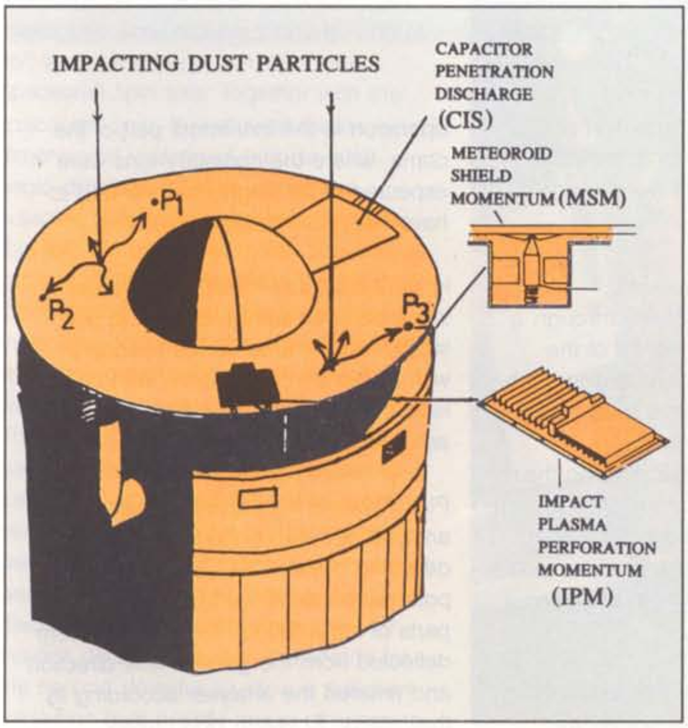
Very small dust particles were detected by an Impact Plasma Detector (IPM), which had very high count-rate capability. This sensor was also located on the front sheet of the spacecraft bumper shield.

The main objective of this system of dust-impact detectors was to record the distribution (spectrum) of the impacting particles with masses between $10^{-17}$ and $10^{-3}$ g.

**The Johnstone Plasma Analyser (JPA)**
This instrument was designed to measure the three-dimensional energy distribution of positive ions in order to study the interaction between the solar wind and ionised cometary particles. It included two complementary sensors: the Fast Ion Sensor (FIS) measured the energy per charge distribution (from 10 eV/q to 20 keV/q) in all directions, once every rotation of the spacecraft; the Implanted Ion Sensor (IIS) measured the energy per charge distribution (from 90 eV/q to 90 keV/q) over a similar angular range, with discrimination into five mass groups, but took 32 rotations to obtain a complete distribution.

The FIS sensor (Fig. 7) measured the three-dimensional velocity distributions of solar-wind ions, giving their flow speed and direction, temperature and density, and followed the development of the solar wind as it was thermalised, slowed-down and deflected. The FIS experiment could be operated in different modes, depending on the angular width and the energy spread of the ion distribution.

The task of the Implanted Ion Sensor (Fig. 7) was to search for cometary neutrals which were expected to reach



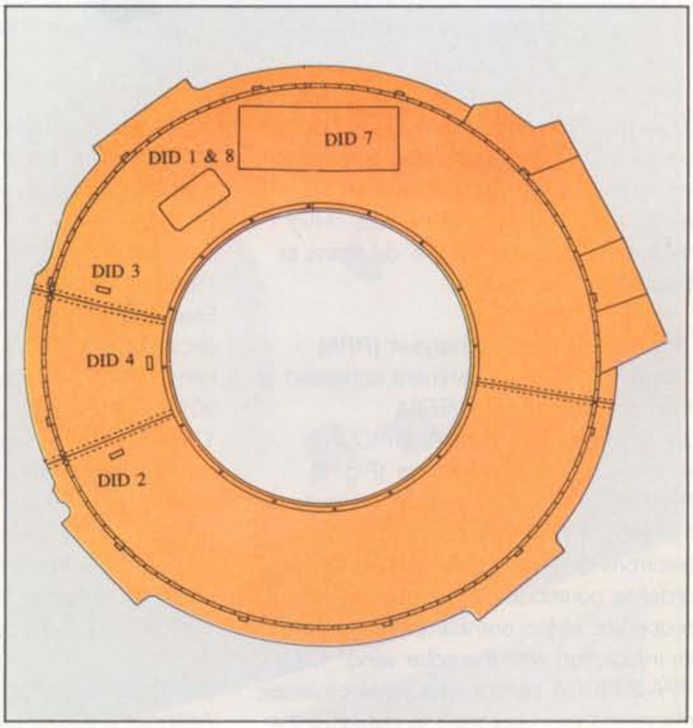
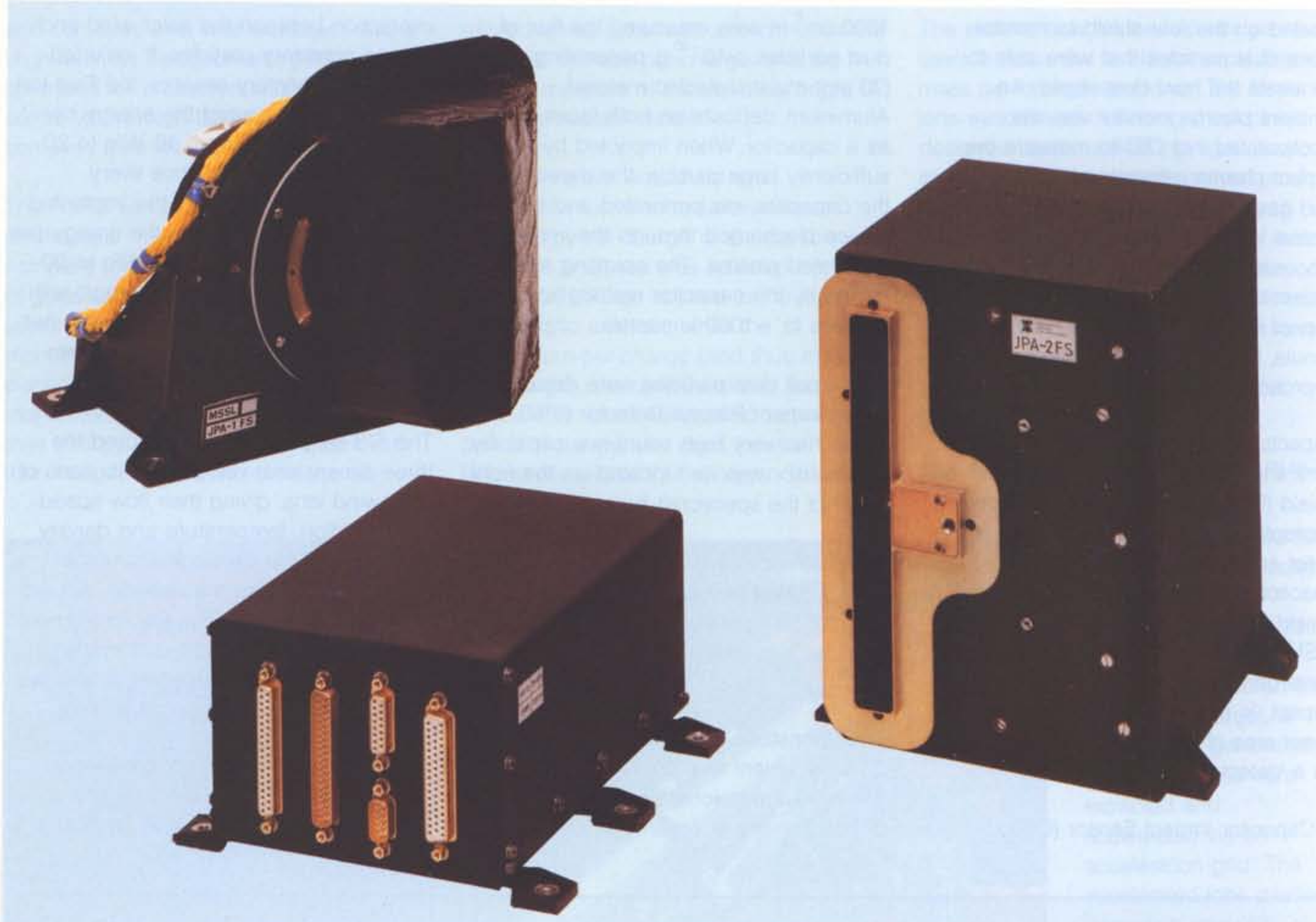



*Figure 7 — Flight units of the Johnstone Plasma Analyser (JPA) instrument. Top: Fast Ion Sensor (FIS). Below left: Data Processing Unit (DPU). Below right: Implanted Ion Sensor (IIS)*




large distances from the nucleus before being ionised and becoming 'implanted' in the solar wind. It combined an electrostatic analyser with a time-of-flight measurement, allowing the ion mass to be determined.

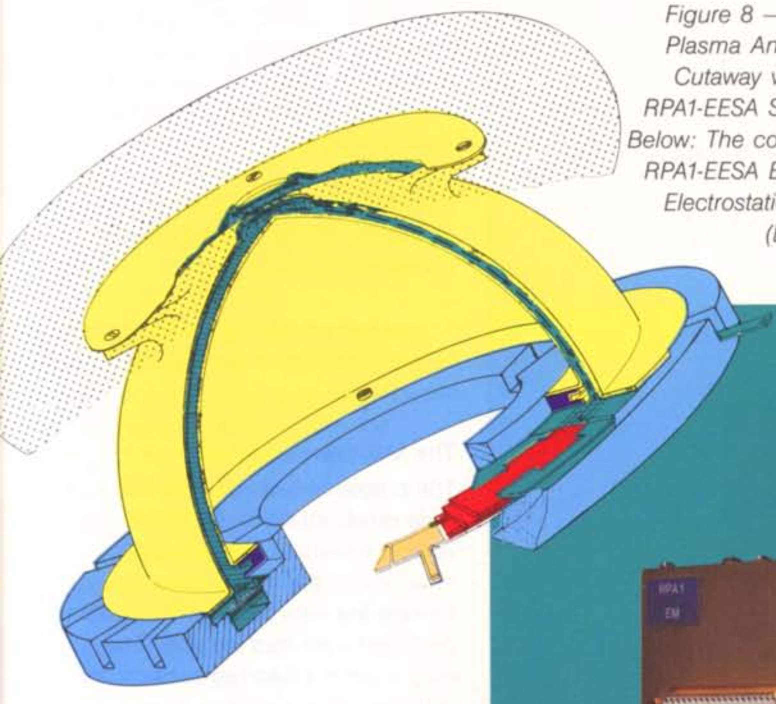
**The Rème Plasma Analyser (RPA)**
The RPA plasma experiment consisted of two sensors, the RPA1-EESA spectrometer and the RPA2-PICCA electrostatic energy analyser (Fig. 8). RPA1-EESA was designed to measure the three-dimensional distributions of electrons between 10 eV and 30 keV, in order to contribute to defining the properties of the cometary plasma and its interaction with the solar wind. The RPA-2 PICCA sensor was an electrostatic mass analyser designed to measure the composition and the distribution of cold cometary positive ions, including clathrate hydrates in the mass range 10 to 203 amu.

Particles entered the Electron Electrostatic Analyser (EESA) through a circular opening in the centre of the hemisphere and were deflected through 90° before being detected by one of the 17 sections of a ring-shaped microchannel plate, depending on their incident polar angle. Azimuthal resolution was provided by the spacecraft's spin. The potential between the analyser plates could be varied in 39 steps, providing a 10% energy resolution.

The Positive Ion Cluster Composition Analyser (PICCA) was designed for operation in the innermost part of the coma, where the cometary ions were expected to be singly charged and to have negligible thermal velocities.

In the spacecraft frame of reference, these particles were expected to flow strictly radially towards the spacecraft with a velocity of 68.4 km/s, with their kinetic energies ranging from 245 eV (10 amu) to 5 keV (203 amu).

PICCA was a hemispherical electrostatic analyser with two channeltrons as detecting devices. By varying the potential between the top and bottom parts of the aperture, the particles were deflected from the general flow direction and entered the analyser according to their mass. To obtain good mass



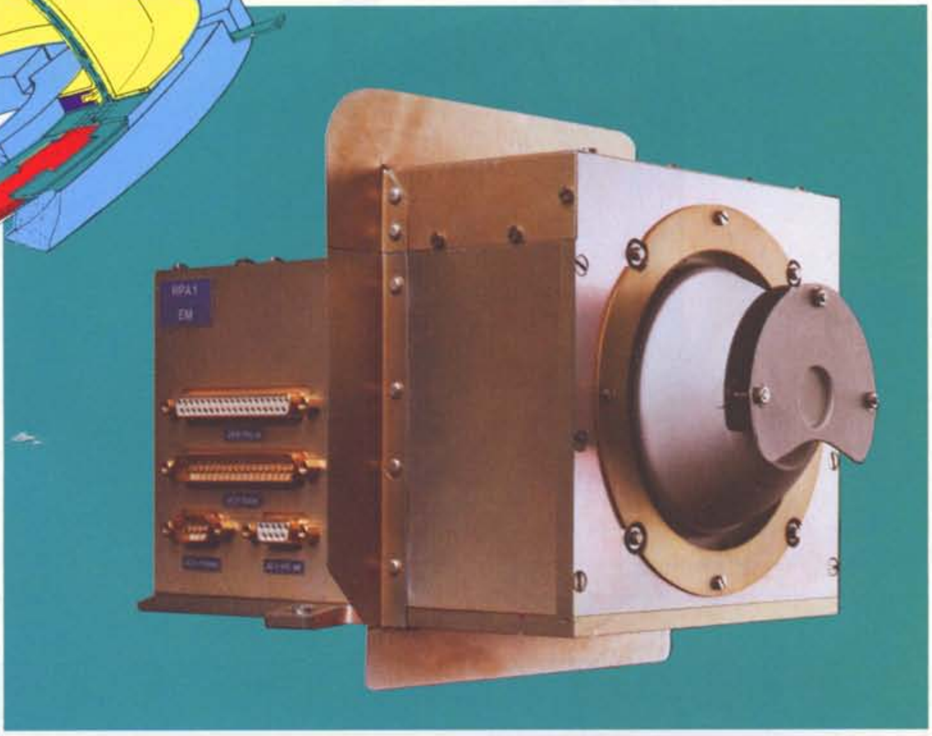


*Figure 8 — The Rème Plasma Analyser. Above: Cutaway view of the RPA1-EESA Spectrometer. Below: The complete RPA1-EESA Electron Electrostatic Analyser (EESA)*

resolution, the ions were decelerated before entering the electrostatic analyser. The hemispherical analyser itself was operated at two different fixed voltages, corresponding to two mass ranges (10—50, 50—203 amu).

**The Energetic Particles Experiment (EPA)**

The prime purpose of the Energetic Particles Experiment (Fig. 9) was to extend the range of the Giotto plasma analysers to higher energies. It consisted of three small identical telescopes, each with two solid-state detectors. Two telescopes were mounted side-by-side at 45°, and a third one at 135° to the spacecraft spin axis. Together with the spacecraft spin, this allowed three-dimensional viewing of particle pitch-angle distributions. One of the two adjacent telescopes was covered by a thin foil, the other was open. Low-energy protons could not penetrate the foil and therefore the covered telescope measured only electrons, while the open telescope measured both protons and electrons.

The energy of the incoming charged particle was determined by measuring the energy deposited in the first solid-state detector while the second detector was used in anti-coincidence i.e. to reject particles of too high an energy. Five discriminator thresholds were used for the first detector and two thresholds for the second detector to allow a sufficient resolution over a wide range of energies.

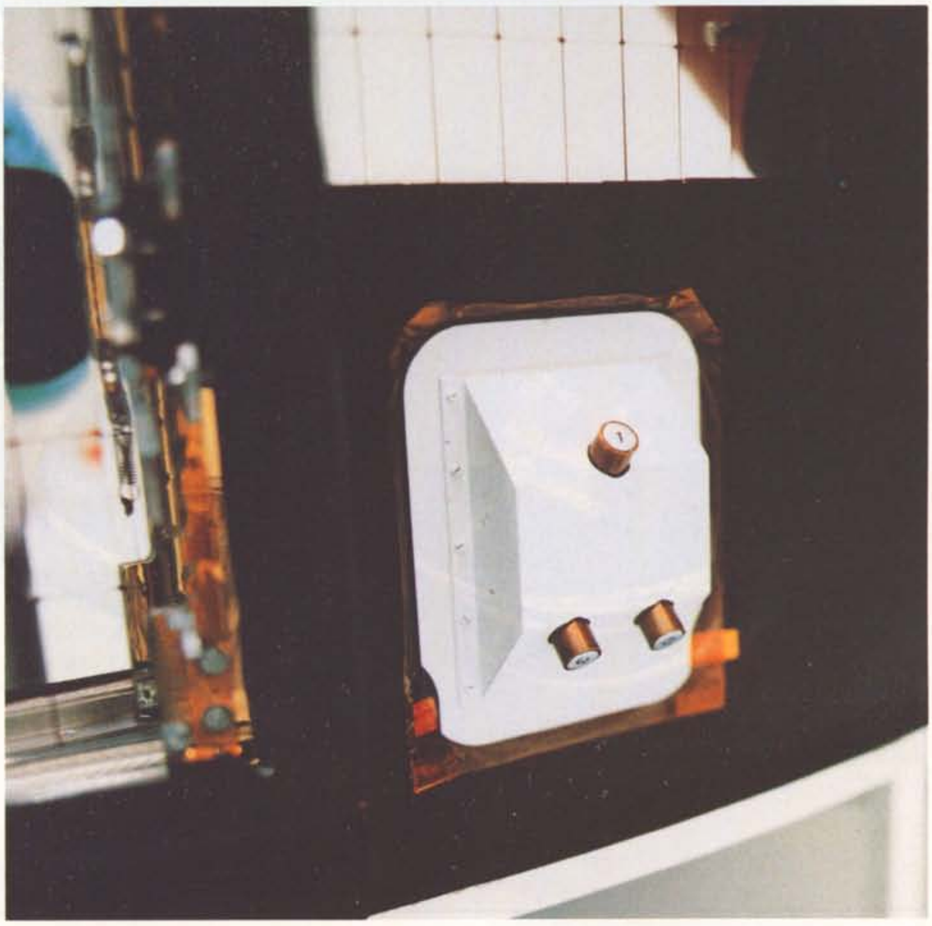


*Figure 9 — The Energetic Particles Experiment (EPA) instrument mounted on the Giotto spacecraft experiment platform. Covers 1, 2 and 3 were in place at that stage to protect the apertures of the three telescopes*

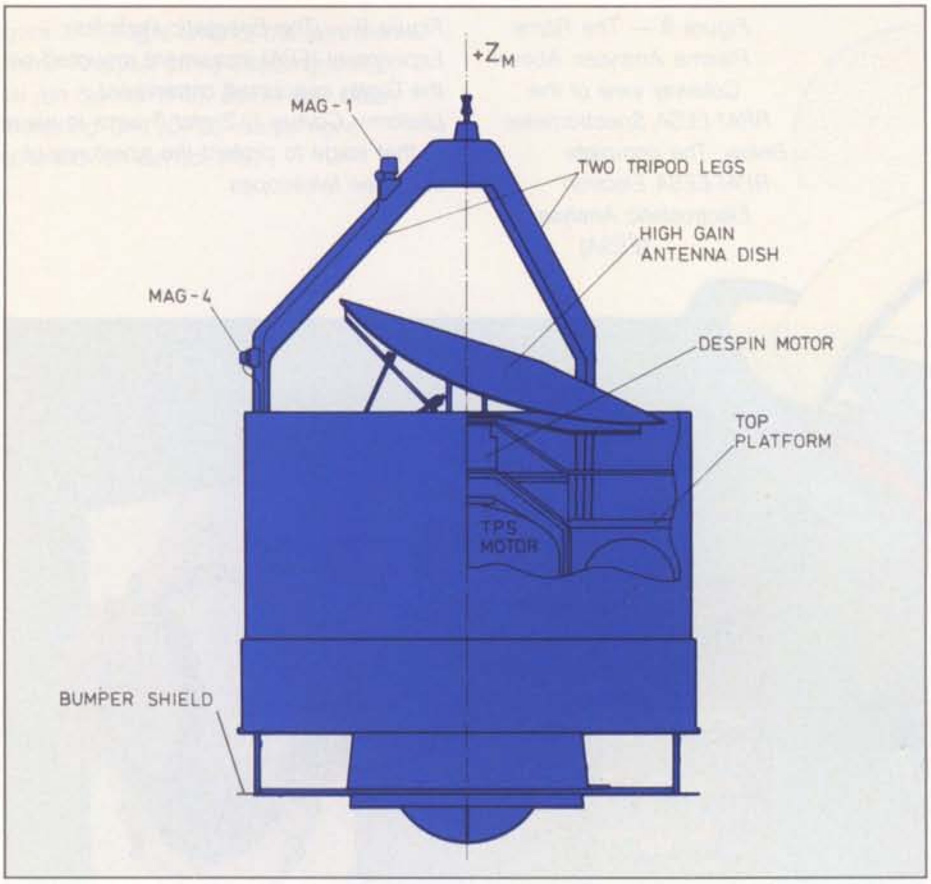


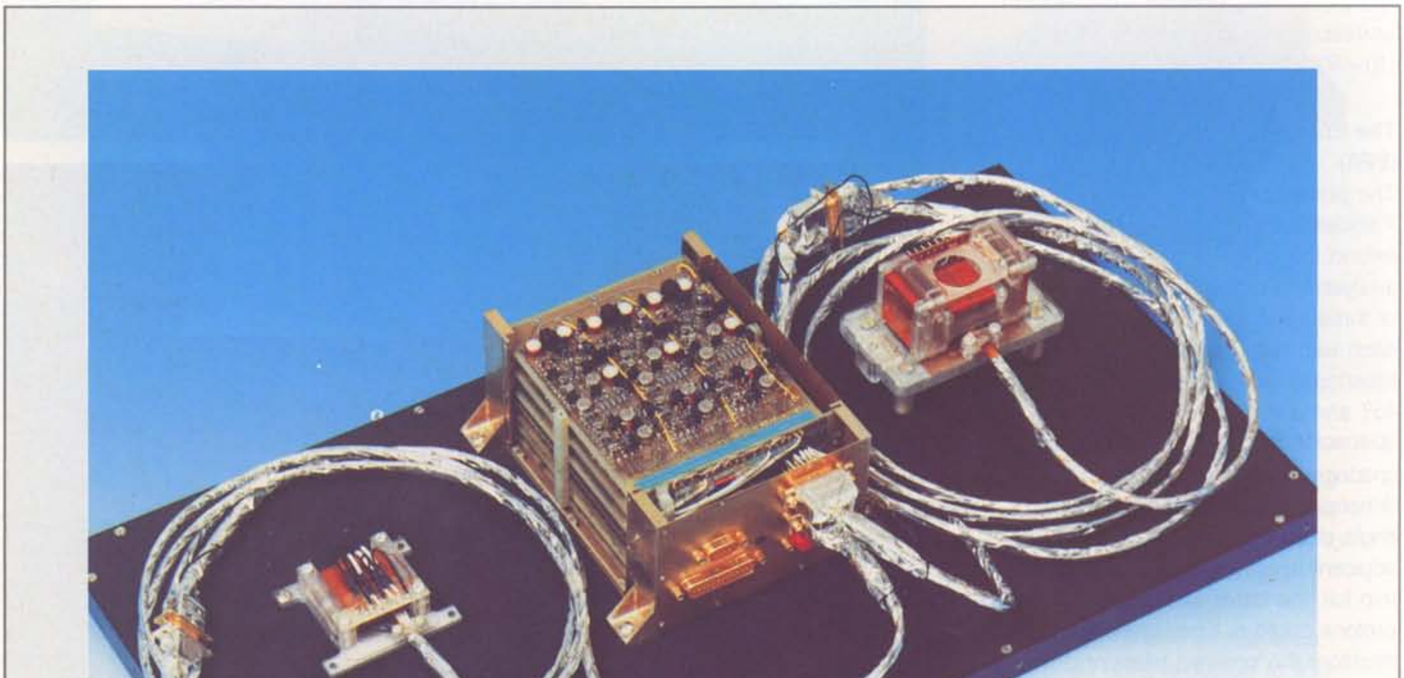

*Figure 10 — The Giotto spacecraft, showing the outboard triaxial sensor system (MAG-1) and the inboard biaxial sensor system (MAG-4) of the Magnetic Field Investigation*

*Figure 11 — Sensors and associated electronics for the Magnetic Field Investigation (MAG)*

An experiment internal memory of 64 kbit of RAM allowed up to 13 days of data storage.

### The Magnetometer (MAG)

The magnetic field was measured by a wide range (0.004 — 65536 nT) triaxial ring-core fluxgate magnetometer mounted on the tripod where it was furthest from the spacecraft and also protected from dust impacts. The magnetometer had two sensors: an outboard sensor located about 1.1 m above the upper face of the spacecraft body, and an inboard sensor located about 0.5 m above it (Figs. 10 & 11). The measurement of the ambient magnetic field was disturbed by the spacecraft

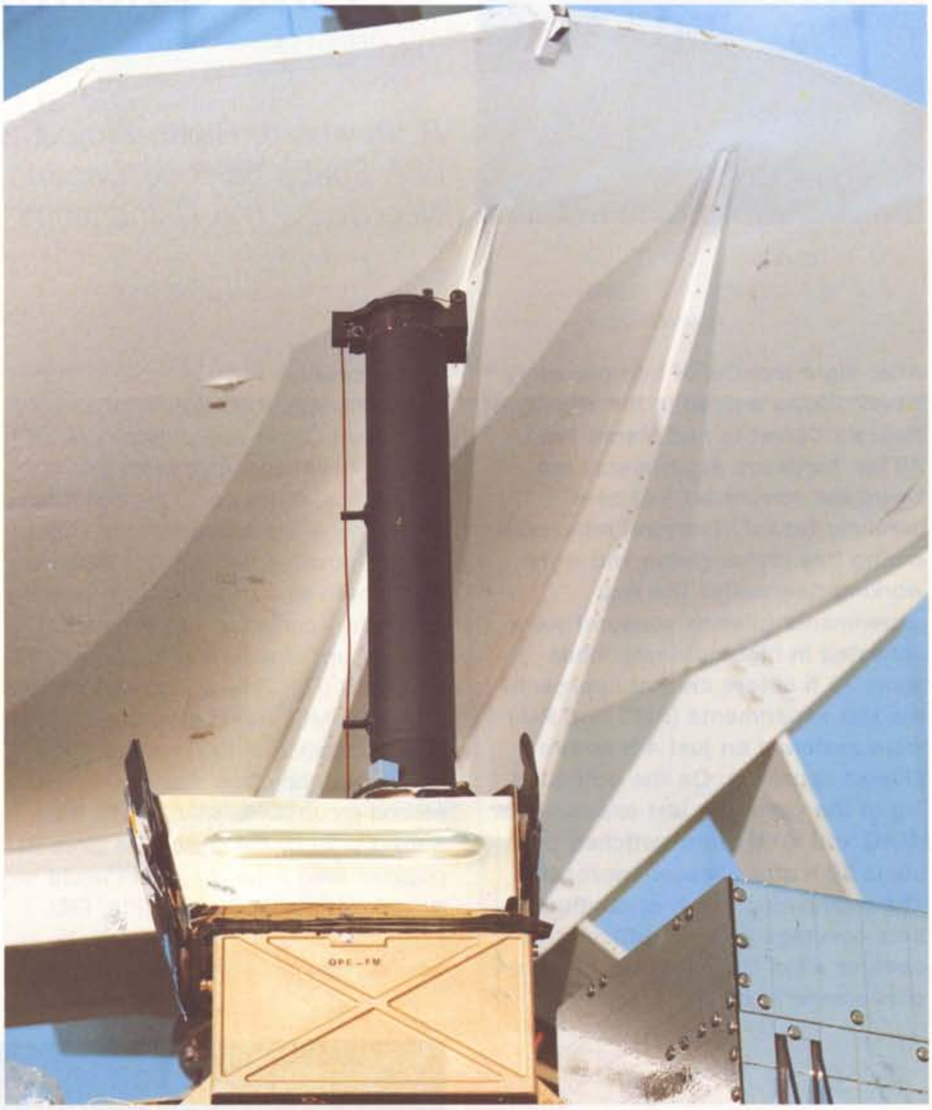


field, which generally had two sources: fields due to magnetic materials, and stray fields due to varying electric currents. From the difference in the readings of the two sensors, the spacecraft field could be estimated and its contaminating effect on the ambient field could be eliminated to some extent. It turned out that most of the contamination was due to the antenna despin motor and the camera. The outboard sensor was triaxial (three orthogonal sensors for the measurement of the three components of the ambient magnetic field vector), while the inboard sensor was biaxial (one ring core with two pick-up coils for the measurement of two magnetic field components only).

**The Optical Probe Experiment (OPE)**
Observations of cosmic dust have traditionally been classified as either 'remote' (essentially optical) or 'in-situ' (mass spectrometers or impact detectors). Optical remote sensing results in a column brightness (integration over the line of sight), interpretation of which is impossible without assumptions about both the spatial distribution of the dust grains and their scattering properties. During the Giotto flyby, a third type of observation, in-situ photo-polarimeter observation — referred to as 'optical probing' — was possible.

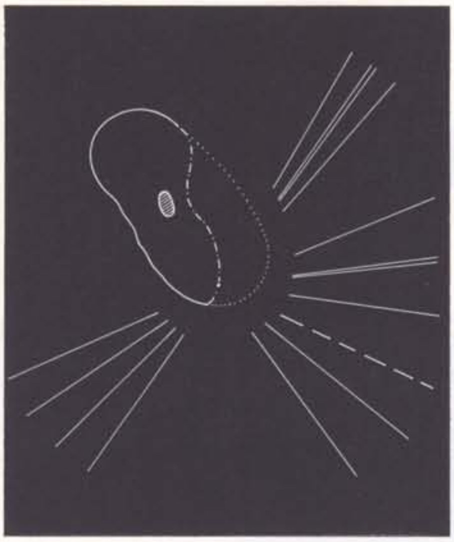
Because of the less critical engineering demands (smaller baffle, no dust-particle impacts), a rearward-looking instrument was chosen (Fig. 12). The photo-polarimeter utilised a small refracting photometer with an objective lens of 24 mm diameter (18 mm effective), eight interference filters, two spectrally matching polaroid foils, and a microchannel plate for spectral analysis. The rotation of the analysers needed to determine the polarisation was provided by the spin of the spacecraft. One complete polarisation measurement was performed during each half of a spacecraft spin.

*Figure 12 — The Optical Probe Experiment (OPE) mounted on the Giotto spacecraft*



The cometary dust was observed in four spectral bands which were free or almost free of gaseous emissions. The discrete gaseous emissions of OH, CN, $CO^+$ and $C_2$ were monitored simultaneously.

**Radio Science (GRE)**
As the Giotto spacecraft traversed the cometary coma it was slowed down by the dust and gas impacts. Although the deceleration was only 0.0003% of the relative flyby velocity, the effect was measurable by using the Doppler shift of the Giotto radio signal. A phase change was also produced by the electrons along the path of the radio signal, i.e. in the cometary ionosphere, the interplanetary medium and the Earth's ionosphere. Since the dual-frequency downlink configuration (X- and S-band) was not available during the encounter, these two effects were difficult to separate and the electron measurement was severely degraded.



# The Giotto Encounter with Halley's Comet — First Scientific Results

*R. Reinhard, Giotto Project Scientist, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands*

**After eight months of interplanetary travel, Giotto arrived in the vicinity of Halley's Comet in mid March 1986. All ten hardware experiments on board the spacecraft had been carefully tested in several rehearsals during this cruise phase and were working flawlessly. The first experiments (plasma sensors) were activated in high-data-rate mode some 70 h before closest approach; the last experiments (HMC and PIA) were switched on just 4 h before closest approach. On the outbound leg of the pass, the last experiments (MAG and EPA) were switched off some 30 h after closest approach. The intervening 100 h of continuous data coverage proved sufficient to observe all of the expected cometary phenomena in detail.**

**The encounter**

The Giotto spacecraft was targeted to fly by Halley's Comet at a closest distance of 500±40 km on the sunward side of the nucleus, 40 km being the combined uncertainty in the spacecraft and Halley-nucleus positions (Fig. 1). This distance was chosen as a compromise between the partially conflicting requirements of three groups of experiments onboard the spacecraft (Fig. 2). The Halley Multicolour Camera (HMC) investigators wanted to fly by at a distance of 1000 km from the nucleus, but no closer than 500 km. A second group (OPE, MAG, NMS, IMS) wanted to fly by the nucleus as close as possible, even if the spacecraft would not survive, while a third group (PIA, DID, EPA, JPA, RPA) also wanted to fly by as close as possible while maintaining a high survival probability (the experiment acronyms are explained in the caption to Fig. 2). The flyby distance that was actually achieved was 600 km, derived independently from camera observations (variation in offset angle with time) and from spacecraft orbit determinations from the ground (ranging). The relevant encounter parameters are summarised in Table 1.

Although Giotto was targeted relatively close to the nucleus where the dust fluxes were high, the spacecraft was expected to survive. This expectation was based on spacecraft attitude perturbation calculations, assuming a model in which dust particles are emitted homogeneously over the nucleus' surface towards the Sun. The existence of dust

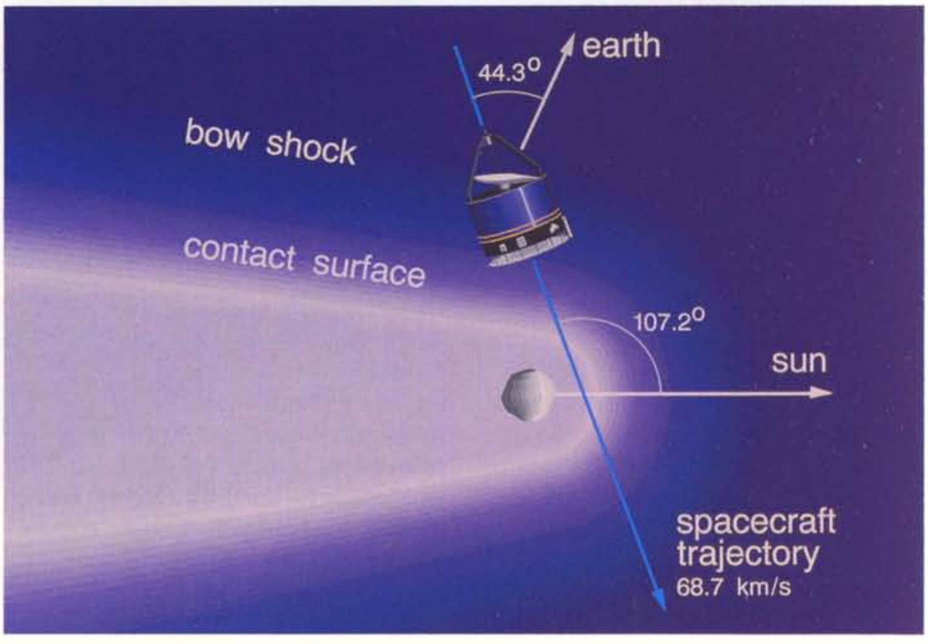



*Figure 1 — Schematic of the encounter geometry, with Giotto passing the nucleus 600 kilometres on the sunward side. The spacecraft entered the visual coma about an hour before the time of closest approach. Giotto crossed the bow shock at $1.15\times10^{6}$ km and the contact surface at 4700 km from the nucleus*

jets, in which the dust fluxes increase by a factor of 3 to 10 was also known, but not their exact location or their activity pattern. It was thought that if Giotto entered such a dust jet, its probability of survival would be small. The large particles associated with these regions have outflow velocities of a few tens of metres per second and, as the Halley nucleus rotates once every 52 h, they form tight spirals around it.

In the event, Giotto was hit by a 'large' dust particle 15 s before closest approach, and the spacecraft was tilted and began to wobble, or nutate, around this new axis. As a result, signals were received from Giotto only intermittently for the next 32 min whilst the nutation dampers onboard the spacecraft damped the wobbling motion such that the maximum deviation from nominal attitude was less than 1° and continuous data were again received at the ground station. As the dust-protection system was designed to provide protection against impacting dust particles only if the spacecraft's spin axis deviated less than 1° from its direction of travel, some experiment sensors suffered damage during this 32 min period. Other experiments (camera baffle and deflecting mirror, dust-impact detector sensors on the front sheet of the bumper shield, and most experiment apertures) which were exposed to impacting dust particles regardless of any attitude perturbation also suffered damage.

The status after the flyby of the ten hardware experiments making up Giotto's payload is summarised in Table 2.

*Figure 2 — The ten hardware experiments making up the Giotto payload. Nearly all experiments were mounted on the lowest of the three platforms, the 'experiment platform'. They can be loosely grouped into four categories:*

*Imaging (blue)*
*HMC Halley Multicolour Camera*

*Gas Mass Spectroscopy (yellow)*
*NMS Neutral Mass Spectrometer*
*IMS Ion Mass Spectrometer (consisting of HERS — High Energy Range Spectrometer, and HIS — High Intensity Spectrometer)*

*Dust Experiments (violet)*
*PIA Particulate Impact Analyser (Dust Mass Spectrometer)*
*DID Dust Impact Detection System*
*OPE Optical Probe Experiment (also measured gaseous emissions)*

*Plasma Experiments (green)*
*JPA Johnstone Plasma Analyser (consisting of FIS — Fast Ion Sensor, and IIS — Implanted Ion Sensor)*
*RPA Rème Plasma Analyser (consisting of EESA — Electron Electrostatic Analyser, and PICCA — Positive Ion Cluster Composition Analyser)*
*MAG Magnetometer*

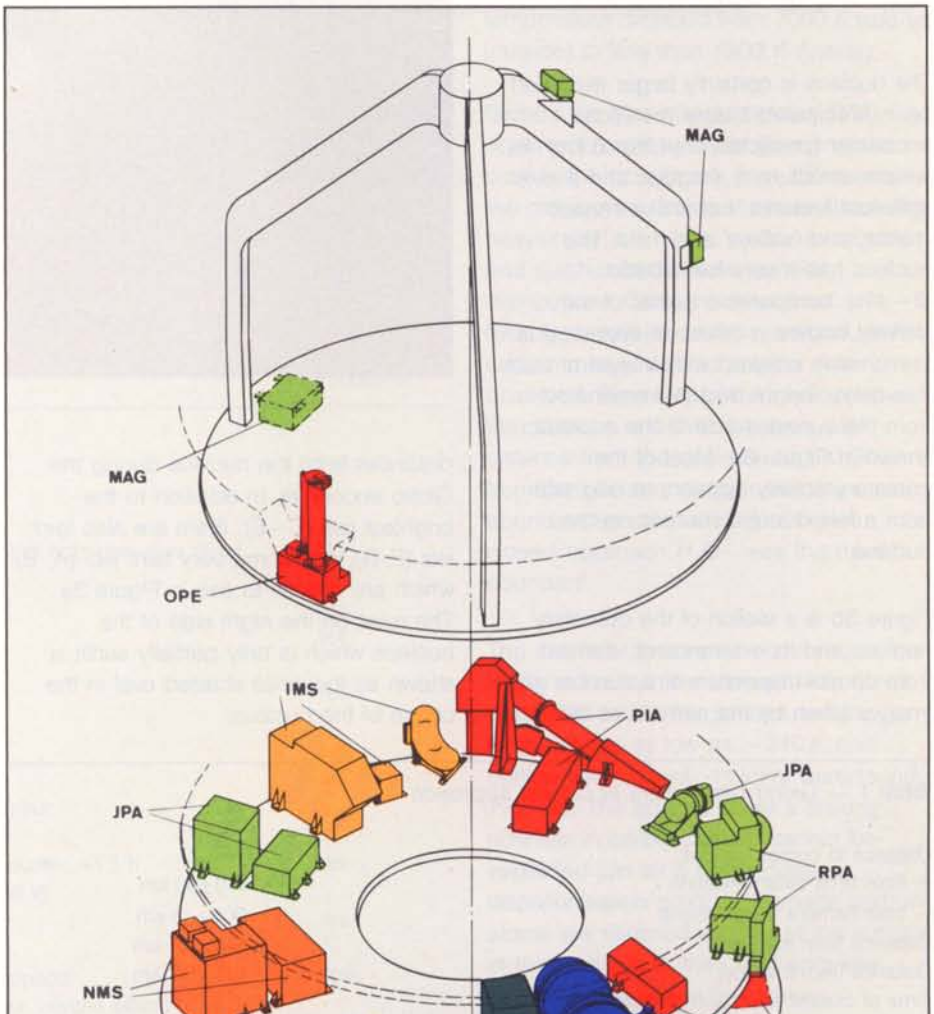


*Figure 3a — Image No. 3443, taken by the Giotto camera (HMC) at a distance of 18 270 km from the nucleus. The Sun is on the right 27° below horizontal and 15° behind the image plane. The overall frame is 30 km across (courtesy H.U. Keller, image copyright MPAe Lindau)*

**First results**

**The cometary nucleus**

The images received from the Halley Multicolour Camera (HMC) (Fig. 3a) revealed that Halley has a single nucleus with an elongated, nonspherical, potato-like shape. The nucleus is about 15 km long, and between 7 and 10 km across. The length of the minor axis is somewhat uncertain because it was directed sunward, and the sunward side of the nucleus was partially obscured from view by dust.

The nucleus is certainly larger than had been anticipated before the Giotto encounter (predicted diameter 6 km). Its surface structure is irregular and shows spherical features, not unlike impact craters, and 'valleys' and 'hills'. The nucleus has a very low albedo (2—4%), comparable to that of the darkest bodies in the solar system. It is presumably covered with a layer of dust. Two major, bright dust jets emanated from the sunward side of the nucleus, shown in Figure 3a. Most of the cometary activity appears to originate from a few discrete sources on the nucleus.

Figure 3b is a sketch of the cometary nucleus and its environment, derived from careful inspection of a number of images taken by the camera at different distances from the nucleus during the Giotto encounter. In addition to the brightest jets (C—E), there are also faint jets (F, G), and some very faint jets (A, B) which are difficult to see in Figure 3a. The relief on the night side of the nucleus which is only partially sunlit is shown as the small shaded oval in the centre of the nucleus.

*Table 1 — Giotto parameters at closest approach*

| | |
|---|---|
| Distance to comet nucleus | |
| — from orbit determinations | 610±40 km |
| — from camera observations | 605± 8 km |
| Distance from the Earth | $144\times10^6$ km |
| Distance from the Sun | $135\times10^6$ km |
| Time of closest approach (spacecraft time) | |
| — derived from orbit determination | 00:03:00.4±2 s UTC |
| — derived from camera observation | 00:03:02±1 s UTC |
| Phase angle (angle between the spacecraft velocity in the comet frame of reference and the Sun—comet line) | 107.05° |
| Angle between Sun—comet and spacecraft—comet lines | 29.3° (south) |
| Spacecraft velocity in the comet frame of reference | 68.373 km/s |
| Spacecraft spin period | |
| — before dust impact | 3.998 s |
| — after dust impact | 4.010 s |

A rotation period and rotation axis for the nucleus could not be derived from the images, as the observation time during which the nucleus was resolved was too short. A nucleus rotation period of 52±1 h derived from ground-based observations of jets, or 53±2 h derived independently from comparison of the images taken by the cameras of the Russian Vega-1 and Vega-2 spacecraft and from the periodic activity variation observed in the ultraviolet images taken by Japan's Suisei spacecraft, is still the best value available.

**The neutrals**

The Neutral Mass Spectrometer measurements confirmed the expectation that water is the dominant parent molecule in the Halley coma. At the time of the Giotto encounter, the comet's total gas production rate was $6.9 \times 10^{29}$ molecules per second (uncertainty ±50%), of which $5.5 \times 10^{29}$ molecules per second ($\sim 10^7$ g/s) were water vapour. The radial outflow velocity of the gas was 900 ±200 m/s. Upper

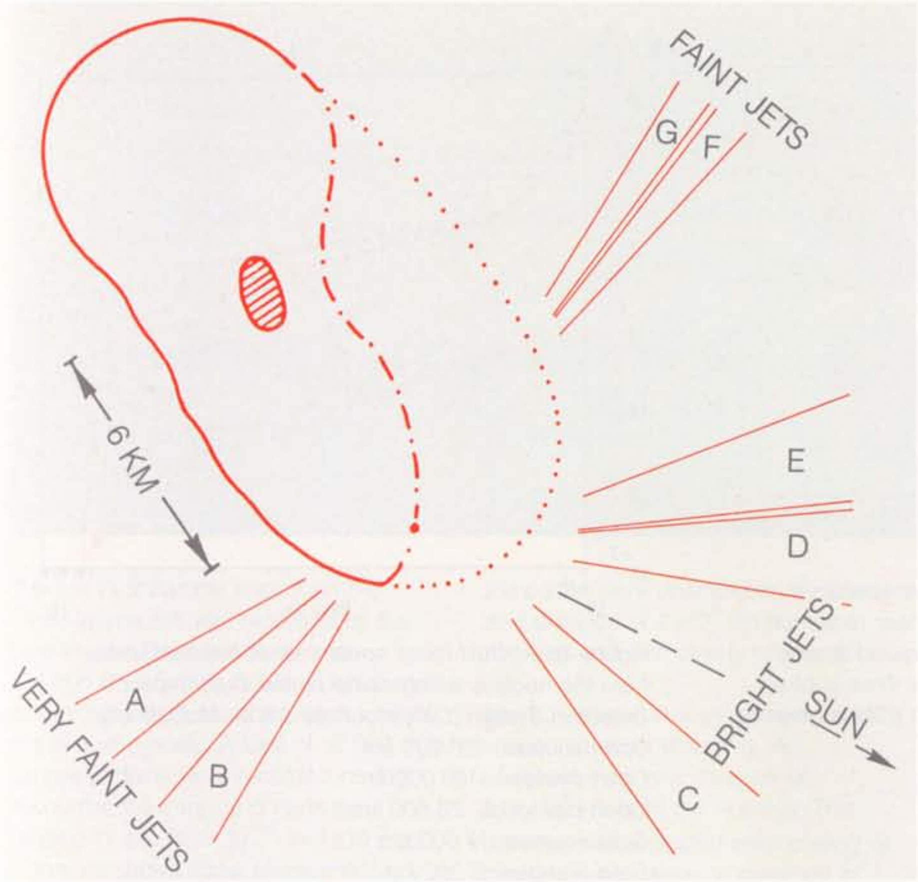



*Figure 3b — Sketch of the nucleus and dust jets emanating from it. The orientation is the same as in Figure 3a (courtesy H.U. Keller)*

*Table 2 — Health of the Giotto payload after the encounter*

| Experiment | Damage assessment | Functional |
|---|---|---|
| HMC | Mirror degradation<br>Baffle perforation<br>Needs further investigation | ? |
| NMS | Charge Coupled Devices (CCDs) of both detectors dead | No |
| IMS | HERS : HV damage<br>HIS : No damage | No<br>Yes |
| PIA | No damage | Yes |
| DID | MSM : No damage<br>CIS : Recovered<br>IPM : Shows anomalous behaviour | Yes<br>Yes<br>No |
| JPA | FIS : Stopped working at encounter +1.5 h (high voltage drop of 400 V)<br>IIS : No damage | No<br>Yes |
| RPA | EESA : Inlet damaged by dust impacts (two parts in close contact, corona effect) Reduced performance (electron density OK, distributions distorted)<br>PICCA: High voltage problem, needs further investigation | 50%<br>? |
| EPA | No damage | Yes |
| OPE | No damage | Yes |
| MAG | No damage | Yes |

limits for the carbon dioxide/water, ammonia/water and methane/water mixing ratios were derived to be 3.5%, 10% and 7%, respectively.

**The ions**

The Neutral Mass Spectrometer indicated that, close to the comet, the water group of ions were dominant. Other ions seen were carbon, oxygen, sodium, sulphur and iron. Across the contact surface, 4700 km from the nucleus, the ion temperature dropped from 7000 K (outside) to less than 1500 K (inside).

Giotto's Ion Mass Spectrometer (IMS) observed cometary hydrogen ions well outside the bow shock, in a diffuse shell-like distribution. Inside the bow shock the heavier carbon, water, carbon-monoxide and sulphur ions showed similar distributions. Closer to the comet, hydrogen, helium, carbon, oxygen, water, carbon monoxide and sulphur were observed. Figure 4a shows their relative abundances and their variation with distance from the nucleus. At 100 000 km from the nucleus, oxygen was the most abundant species, while just before closest approach $H_3O^+$ was the most abundant.

The chemical processes occurring in the Halley coma can be derived from these variations. Inside the contact surface, ion temperatures as low as ~340 K and outflow velocities of ~1 km/s were found (Fig. 4e). The spectra show a striking richness in carbon, which cannot be explained just as a photo-dissociation/ionisation product. Perhaps carbon atoms are released directly at the surface of the nucleus, or they may originate from the dust grains themselves.

**The dust**

Preliminary analysis of spectra observed by Giotto's Dust Mass Spectrometer shows the presence of hydrogen, carbon, nitrogen, oxygen, sodium, magnesium, silicon, potassium, calcium and iron. Most of the dust particles were rich in hydrogen, carbon, nitrogen and oxygen.

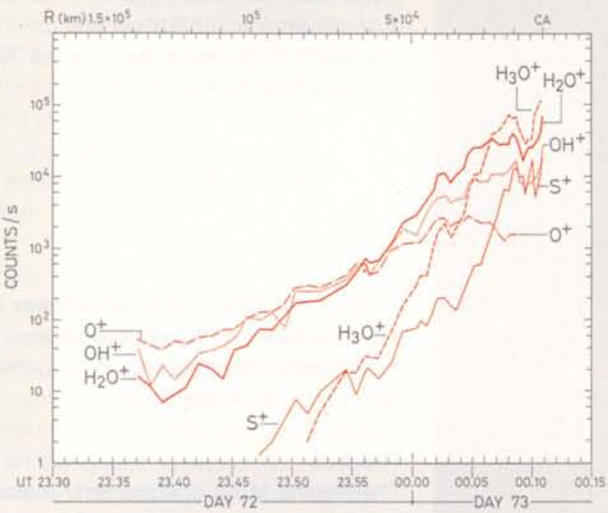



*Figure 4a — Time profiles of various ionic species in the Halley coma as observed by the HIS sensor of the Ion Mass Spectrometer (IMS). The time is Ground Station Receive Time (to obtain Spacecraft Event Time subtract 8 min). The distance to closest approach (CA) is given at the top (courtesy H. Balsiger)*

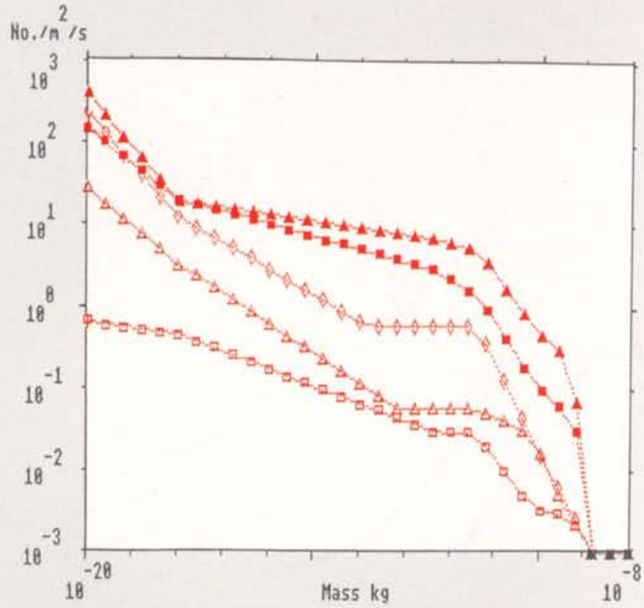
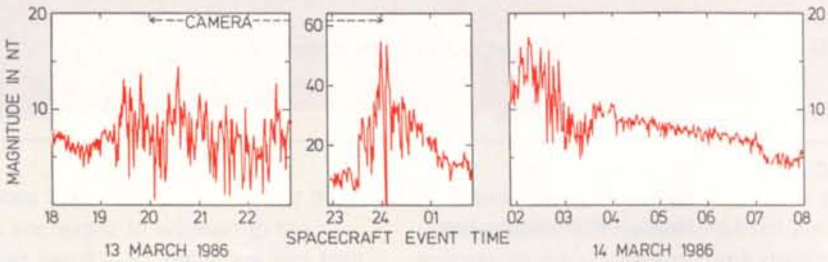



*Figure 4b — Dust mass spectra at different distances from the nucleus as observed by the Dust Impact Detection System (DID) (courtesy J.A.M. McDonnell):*
*Open squares: 291 000 km*
*Open triangles: 168 000 km*
*Open diamonds: 28 600 km*
*Solid squares: 15 600 km*
*Solid triangles: 6 360 km*

*Figure 4c — Overview of 1 min-averaged magnetic-field magnitudes during the Halley encounter as observed by the Giotto magnetometer (MAG). Closest approach was at 24:03:02 UTC Spacecraft Event Time. Note that the magnitude scale is compressed in the centre plot. The time of camera operation is indicated at the top. During this period the 1 min-average field magnitude may be disturbed by up to 0.6 nT (courtesy F.M. Neubauer)*



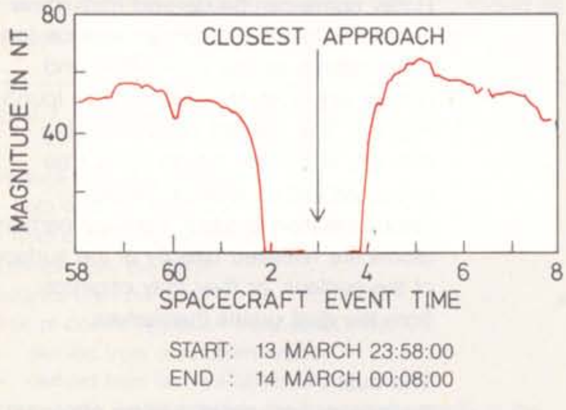




*Figure 4d — Magnetic pile-up region a few minutes before and after closest approach separated by the contact surface from the field-free cavity region (courtesy F.M. Neubauer)*

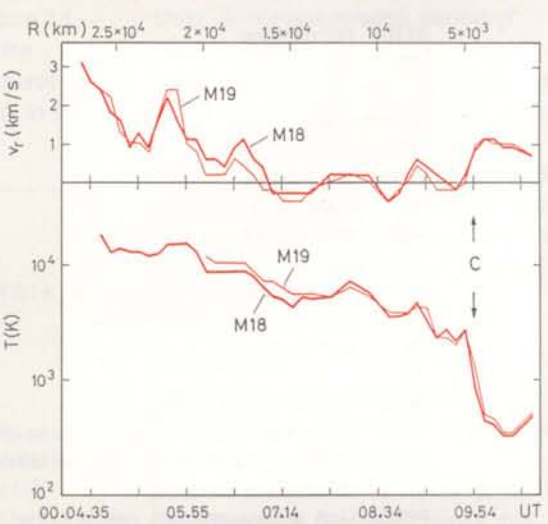



*Figure 4e — Time profiles of the ionosphere flow speed and temperature derived from an analysis of the comet rates of mass 18 ($H_2O^+$) and 19 ($H_3O^+$). as observed by the Ion Mass Spectrometer (IMS) (courtesy H. Balsiger)*

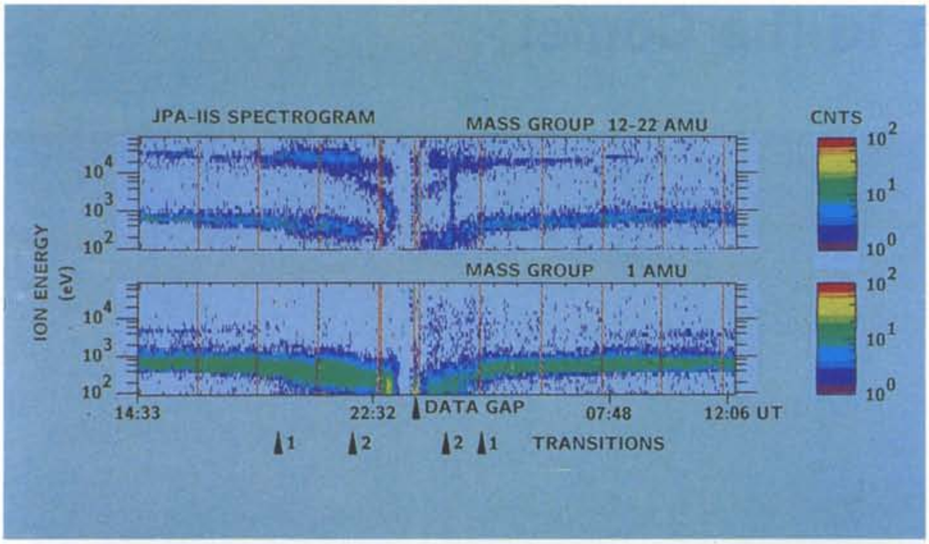



*Figure 4f — In these results from the Johnstone Plasma Analyser, the lower panel shows solar-wind protons as observed by the Implanted Ion Sensor (IIS). The energy at peak intensity (green band) is slowly decreasing, showing the deceleration of the solar wind. At the same time the green band is getting wider showing the thermalisation of the solar wind. Above the green band at ~ 3 keV are cometary protons ('pick-up' protons). The upper panel (uppermost blue band) shows cometary ions of mass 12—22 amu ('pick-up' ions). The deceleration and widening is similar to the lower panel (courtesy of A.D. Johnstone)*

The first dust-particle impact on the Giotto spacecraft was recorded by the Dust Impact Detection System at 290 000 km from the nucleus, which was further away than expected on the basis of the dust models. A total of 12 000 dust particle impacts were recorded during encounter, the impacting particles ranging in size from $10^{-17}$ to $4\times10^{-2}$ g. Figure 4b shows some representative dust-particle mass spectra at various distances from the nucleus. The dust production rate derived from measurements made shortly before closest approach was $3.1\times10^{6}$ g/s.

## The plasma

The interaction between the solar-wind plasma and the cometary ionosphere can be characterised by two distinct boundaries, the bow shock and the contact surface (Fig. 1), and several additional sharp transitions giving the impression of a multi-layered interaction region.

For several days prior to the encounter, the solar wind was relatively quiet. Its flow speed was around 350 km/s and its density between 5 and 8 $cm^{-3}$. The first hydrogen ions of cometary origin ('pick-up' ions) were detected by the Fast Ion Sensor of the Johnstone Plasma Analyser (JPA) at a distance of $7.8\times10^{6}$ km from the nucleus.

The Energetic Particles Experiment (EPA) detected pick-up ions shortly thereafter, at a distance of $7.5\times10^{6}$ km. The effect of the comet interaction on the solar-wind electron heat flux was clearly observed out to at least $7.5\times10^{6}$ km by the Electron Electrostatic Analyser of the Rème Plasma Analyser (RPA) Experiment. Magnetic-field variations resulting from the comet were unambiguously identified at a distance of $2\times10^{6}$ km from the nucleus, and less clearly further out.

The bow shock was crossed at 19:23 spacecraft event time (Fig. 4c), corresponding to a distance of $1.15\times10^{6}$ km from the nucleus. This distance was expected from scaling of the bow-shock distance detected at Comet Giacobini-Zinner by the ICE spacecraft (see ESA Bulletin No. 44, pp. 32—39) with the higher Halley gas-production rate.

Inside the bow shock, the solar-wind flow speed decreased due to mass loading by cometary ions and the flow was directed away from the usual radial outflow direction. At a distance of 16 400 km from the nucleus, the magnetic field strength reached a maximum of 57 nT.

Inside the contact surface, which was crossed at a distance of 4700 km before closest approach, the magnetic field dropped essentially to zero (Fig. 4d). This had been theoretically predicted and was expected by analogy with Venus and the 'artificial comet' of the AMPTE mission.

3800 km after closest approach, Giotto left the field-free region again. On the outbound leg, the maximum field strength was observed to be 65 nT at a distance of 8200 km from the nucleus. In contrast to the inbound pass, the evidence for an outbound bow shock was not very clear, as the reduction in the magnitude and fluctuations in the magnetic field was much more gradual. Upstream waves resulting from the comet interaction could be observed until Giotto was about $2.7\times10^{6}$ km from the nucleus.

## Conclusion

An encounter with a comet was perhaps the last purely exploratory mission left in solar system studies. Very little was known about these most active members in our solar system. We could only speculate, for example, about the existence and size of a body (the comet nucleus) that, around perihelion, when at its closest point to the Sun, is able to generate a hydrogen corona larger than the Sun itself. Most of our knowledge, gathered over many centuries, consisted of the determination of cometary orbits, phenomenological descriptions of the comas and the tails, and analysis of cometary spectra. Observations of Comet Halley from Earth (ground-based or from near-Earth space) could only provide information about molecules with strong emission lines in their spectra in suitable wavelength ranges. Now, armed with the wealth of data from the in-situ measurements made by Giotto's experiments, scientists have hopefully been given the key that they have long needed to confirm the icy-conglomerate model of the cometary nucleus, to establish the composition and abundances of the parent molecules, and to unravel the complex physical and chemical processes occurring in and around the comet. This in turn should provide a great step forward in furthering our understanding of the origins of the solar system, of which comets are believed to be one of the most original and therefore most informative remnants.

# Giotto's Approach to the Comet

*Figure 1 — The inner dust coma of Comet Halley with jets and the nucleus just resolved, seen from a distance of 124 050 km. The Sun is on the right, 7° above the horizontal and 17° behind the image plane. The frame size is 500 km*

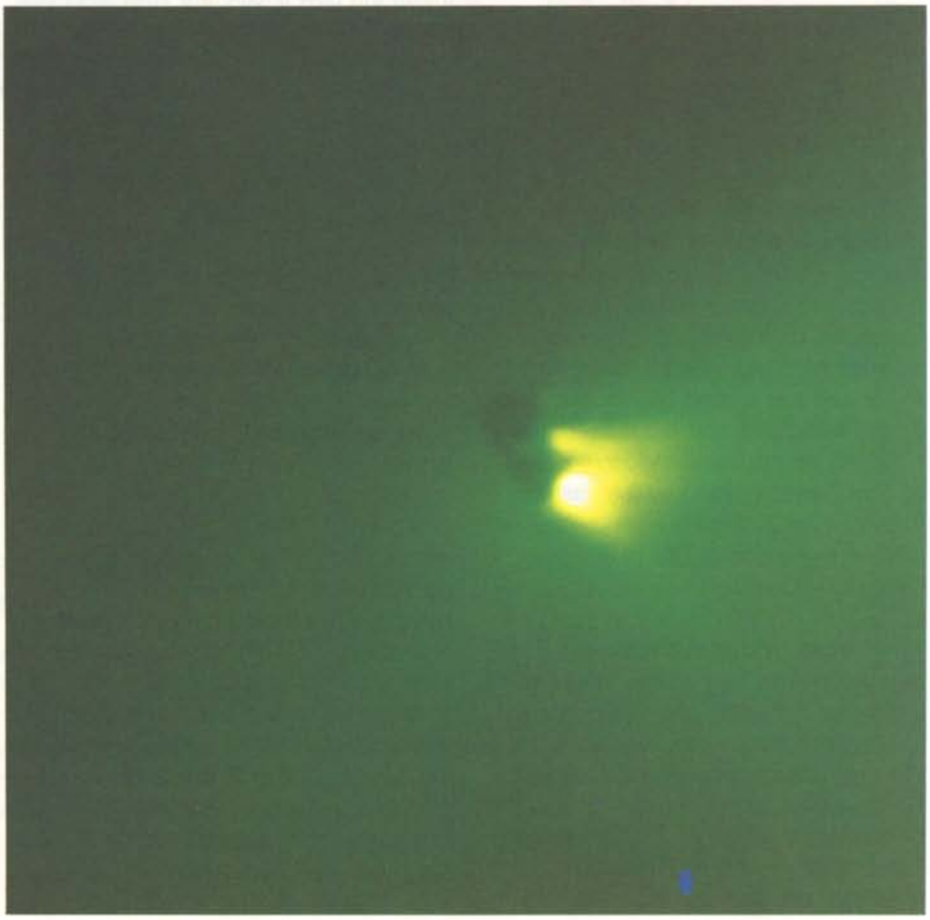


*Figure 2 — The innermost coma with dust jets and nucleus seen from a distance of 25 650 km. The Sun is on the right, 26° below the horizontal and 16° behind the image plane. Frame size is 111 km*

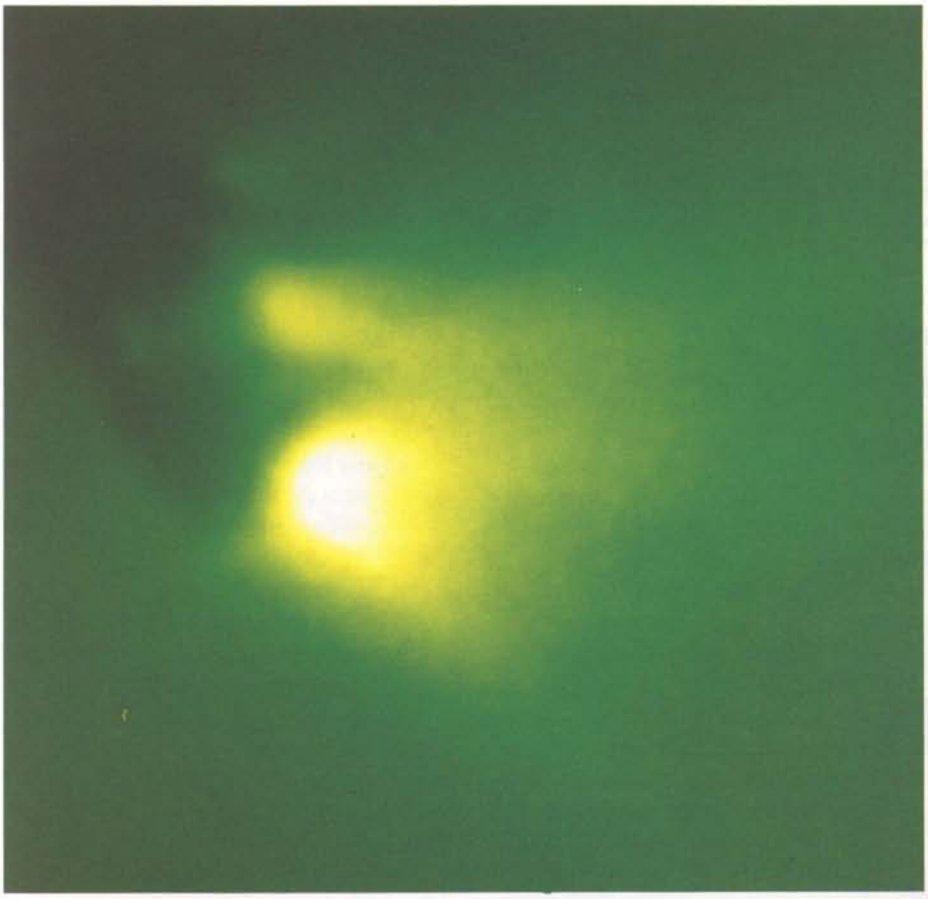


*Figure 3 — The nucleus of Comet Halley as seen from a distance of 18 270 km. The Sun is on the right, 27° below the horizontal and 15° behind the image plane. The frame size is 30 km. Two bright jets appearing near the lower tip of the nucleus are directed towards the Sun. The faint region in the centre of the nucleus is probably a morphological feature protruding from the night side of the terminator that is struck by sunlight*

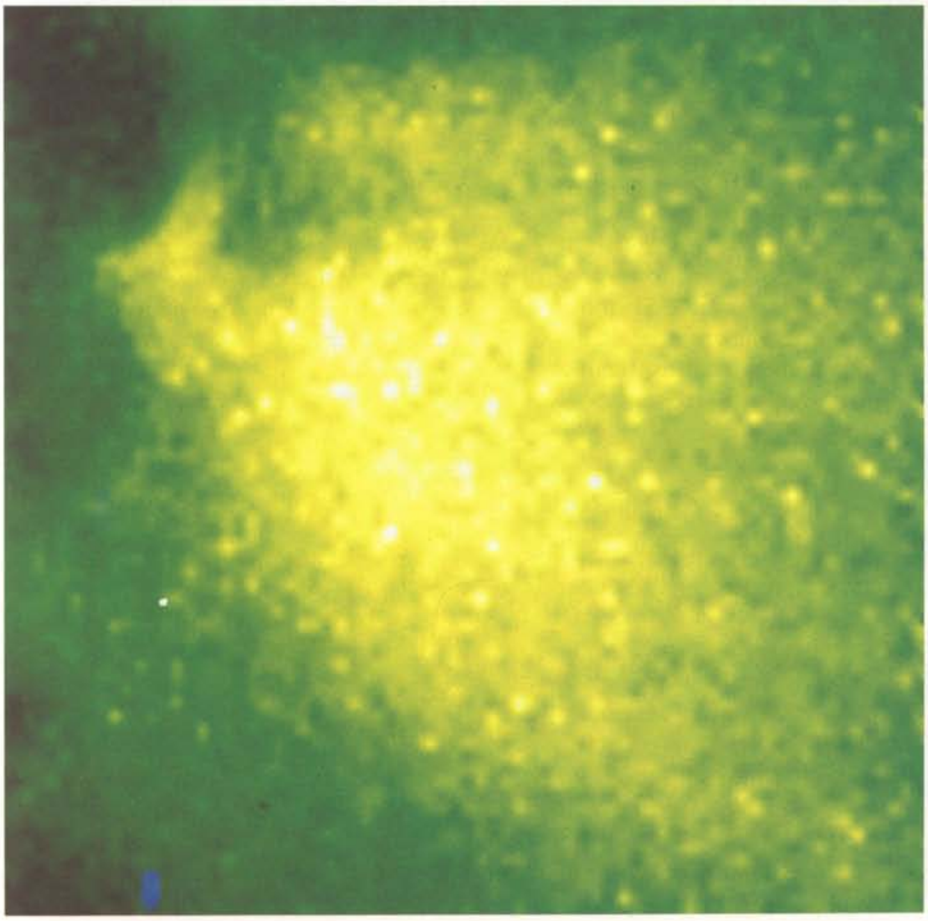


*Figure 4 — Details of a jet source in high resolution as seen from 2220 km. The Sun is on the right, 29° below the horizontal and 4° behind the image plane. Frame size 3.7 km. This is one of the last images taken by Giotto's Halley Multicolour Camera*

The accompanying images taken by Giotto's Halley Multicolour Camera show the coma and nucleus of Comet Halley as the spacecraft approached at a speed of 69 km/s at around midnight (UT) on 13/14 March. The dark 'peanut-shaped' object in the centre of Figure 2 is the non-Sun-illuminated side of the comet's solid core. Sunlight is coming from the right, initially from 17° behind the plane of the image, this angle decreasing to approximately 4° in the final image in the sequence.

**Acknowledgement**
The images shown here were kindly provided by Dr. Uwe Keller, Principal Investigator for the Halley Multicolour Camera.

# ESOC Plays Host to the World's Press — The Technical Support

*K. Blank et al., European Operations Centre (ESOC), Darmstadt, Germany*

The Giotto project in many ways represented a unique achievement for Europe. Its scientific, technical and operational achievements have been described in some detail elsewhere in this issue of ESA Bulletin. One aspect of the mission, which in retrospect turned out to be a small, self-contained 'project' in its own right, was the technical support needed to equip the European Space Operations Centre (ESOC) in Darmstadt to play host to the world's press and television and invited guests.

It was recognised that this event, due to the sheer scale of world-wide interest, would require a very different approach and a special Public Relations Working Group was established by the Director General in the summer of 1985. Initial contacts with the media (TV, radio and press) took place towards the autumn of 1985, at which time interest on the media's part was still somewhat vague, the European public having been not yet gripped by 'comet fever'. By December 1985, however, this attitude was changing rapidly and interest building around the world.

This explosive, somewhat last-minute focussing of attention meant continual changes in order to meet new demands for space and facilities and to cope with new unforeseen technical and conceptual hurdles.

The overall concept was centred around transfer of scientific and technical information emanating from the Giotto mission, with its 10 principal scientific experiments, to the media and, in parallel, to the guests assembled at ESOC to witness the encounter. It was decided to organise internal television coverage at ESOC, with an on-line satellite TV link to ESTEC in Noordwijk (NL), in order to structure the 'internal-programme' more to the scientific and technical interests of expert viewers. This decision, together with the vast number of visitors (approximately 2500 at ESOC and ESTEC), generated the need to establish a full video and audio infrastructure, including production studio and centre coordination. Large amounts of equipment had therefore to be procured and integrated at ESOC within a very short period. Moreover, some of the vital equipment, such as TV cameras which were shared between TV broadcasting stations and the completely independent 'internal-programme', only became available for integration and testing some 24 h before the event.

The broadband Local Area Network (ESALAN) became the technical work-horse for this communications infrastructure, not only allowing a relatively simple extension to the temporary installations such as the marquee and Portacabins, but also carrying all video, audio and digital information. This eliminated the need to recable the entire Centre, which would have been extremely expensive.

Aside from the in-house information flow, the connections between ESOC and the outside world were vitally important. An inviolable prerequisite was that there should be no interference whatsoever with actual spacecraft operations, and all communications facilities had therefore to be separated from the operational systems on site. This led to the installation of a completely separate public communications centre, integrated, operated and maintained by the Deutsche Bundespost. During the period 10—14 March 1986, this centre provided the following services:

- Public telephones
- Telex
- Teletex
- Telefax
- Bildschirm text (Prestel/Teletel)
- Colour TV microwave links
- Audio links
- Satellite ECS TV/audio channel
- Packet-switched data network (DATEX-P)

Most of the communications infrastructure had to be installed via mobile terminals in order to: (a) avoid any interference with on-going operations, and (b) overcome the bottleneck that would otherwise have occurred for the western region of Darmstadt's communications infrastructure.

The following statistics may serve to provide an impression of the scope of the support activities at ESOC. Approximately 1700 $m^2$ of additional floor area had to be provided at ESOC, with some 100 individual rooms allocated to specific encounter-related functions. Some 20 km of dedicated cabling had to be laid, and approximately 160 TV monitors were linked via the ESOC LAN. There were 56 TV stations reporting live from ESOC, representing 37 countries around the world. There were approximately 2500 people on site at ESOC specifically for the Giotto encounter (approx. five times the normal number of staff on site during office hours), including:

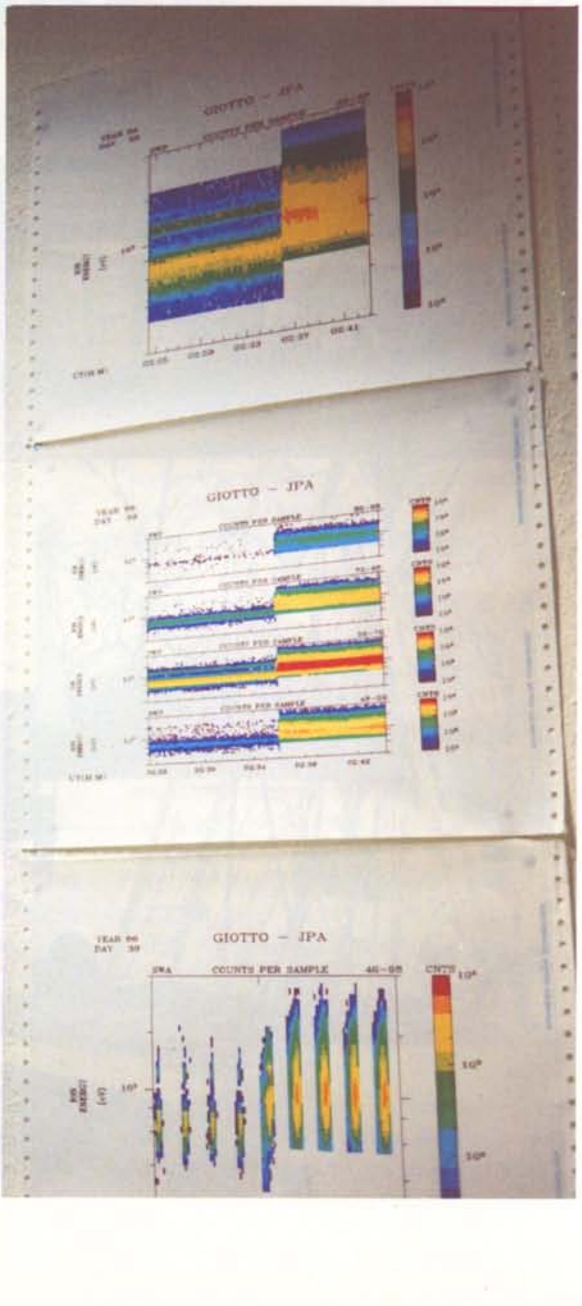
| | |
|---|---|
| 400 | TV/radio technicians |
| 200 | Journalists |
| 350 | Scientists |
| 150 | Operations support team |
| 220 | VIP guests |
| 1200 | Staff/local guests/family |

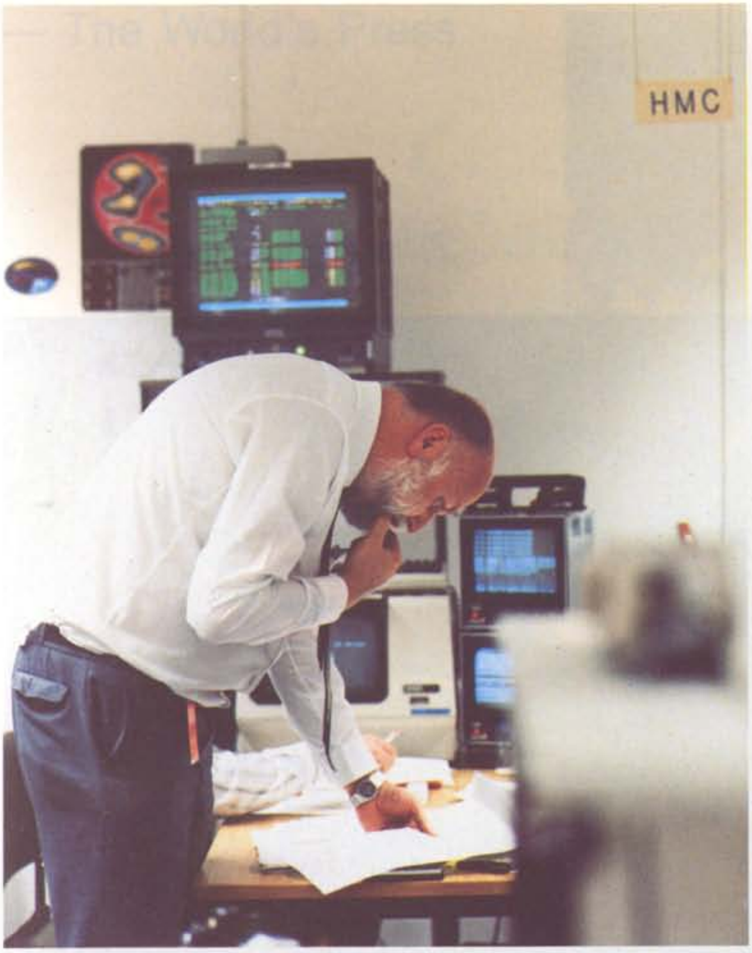
It is estimated that the worldwide television audience who looked in on the activities at ESOC on the 'Night of the Comet' was 1 500 000 000.

# The 'Night of the Comet' at ESOC

## — Around the Establishment

# — The Ground-Support and Science-Centre Areas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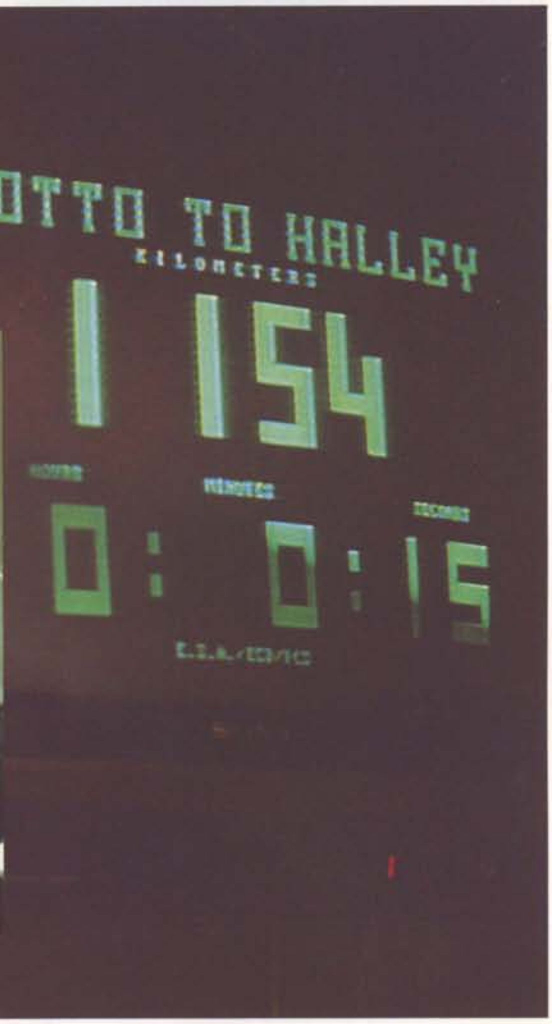
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GIOTTO TO HALLEY
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## — The Distinguished Visitors

Above Minister G.M.V. Van Ardenne (centre) of The Netherlands

Above right — Minister L. Granelli (right) of Italy

Minister H. Riesenhuber of Germany

# — The World's Press

*From right to left before the microphones: Mr. D. Dale, Giotto Project Manager; Mr. K. Heftman, ESA's Director of Operations; Dr. R. Bonnet, ESA's Director of Scientific Programmes; Prof. R. Lüst, ESA's Director General; and Dr. R. Reinhard, Giotto Project Scientist*

*Dr. U. Keller, Principal Investigator for the Halley Multicolour Camera, holding one of the first images of the comet's nucleus*

*Presentation to Prof. Fred Whipple (centre) of a gold-plated model of Giotto, by Prof. R. Lüst (left), ESA's Director General, and Dr. R. Bonnet, ESA's Director of Scientific Programmes*

# The Giotto Encounter and Post-Encounter Operations

*D.E.B. Wilkins, A. Parkes & H. Nye, Spacecraft Operations Divison, European Space Operations Centre (ESOC), Darmstadt, Germany*

**The Giotto spacecraft, having been successfully targeted to its encounter with Halley's Comet and having provided the scientific community with excellent and abundant data, is now progressing around the Sun to meet up with the Earth in 1990. The spacecraft has survived the encounter with less damage than had once been feared, but we will have to wait the test of time to see if it can be reactivated on schedule in 1990.**

## Introduction

The Giotto mission began with the lift-off of the Ariane-1 launch vehicle at 11:23 GMT on 2 July 1985. The spacecraft was first placed into a Geostationary Transfer Orbit (GTO), and its injection into heliocentric orbit took place at 19:24 GMT on 3 July 1985 when the solid-propellant Transfer Propulsion System (TPS) of Giotto was fired over the South Pacific, under command from the ESOC Operations Control Centre in Darmstadt. The spacecraft's initial velocity relative to Earth was some 12 km/s as it sped on its way to the encounter with Halley's Comet, planned for approximately 24:00 GMT on 13 March 1986.

The encounter took place on schedule and, as a world-wide television audience watched, the scientific observations were carried out with dramatic success.

## The cruise-phase of the mission

On 6 July at 10:47 GMT, the Giotto spacecraft high-gain antenna was activated and by 20:00 GMT that same day testing of all on-board systems had been completed. Giotto's 'cruise-phase' had now begun.

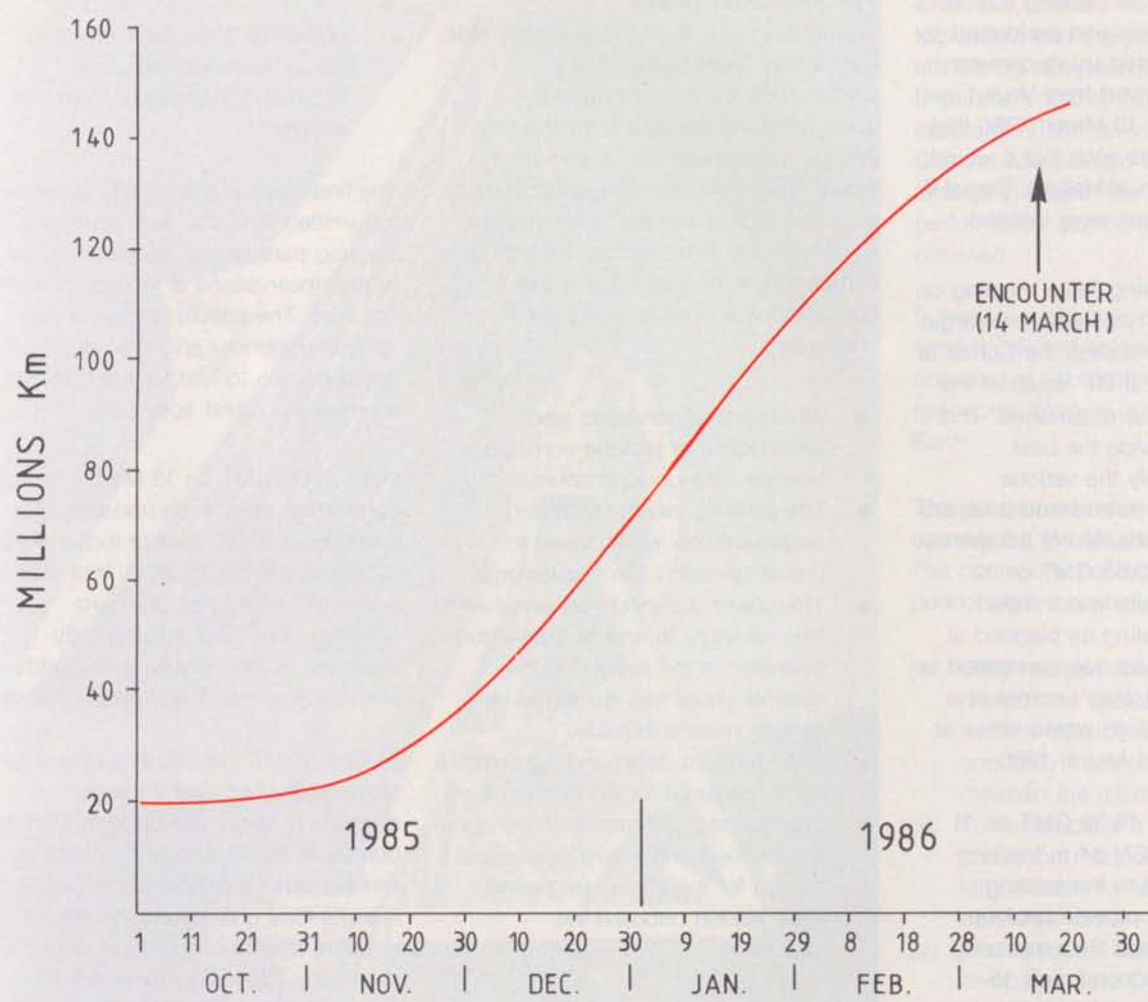
It soon became apparent that the trajectory that had been achieved after Transfer Propulsion System (TPS) firing was so precise that no large mid-course correction would be required. From tracking data it was determined that alignment of the thrust vector of the TPS was probably no greater than 0.03° from optimum at the time of firing. This was to result in Giotto arriving at the comet with approximately 60 kg of hydrazine remaining from the 69 kg loaded before launch and budgeted for orbit manoeuvres.

During the cruise phase, daily contact was established with the spacecraft for subsystem and performance monitoring and to perform attitude manoeuvres to ensure that the spacecraft attitude was maintained within a specific 'corridor'. These limits were defined before launch to provide continual contact with the Earth and a suitable thermal environment on board. In addition, small orbit manoeuvres were performed prior to the pre-encounter phase, to target the spacecraft to within 1000 km of the comet. The final targeting strategy based on data received from the Russian Vega spacecraft was to be decided subsequent to the Vega-1 and Vega-2 encounters with the comet, which had been planned for 6 and 9 March 1986, respectively.

The first period of the cruise phase, which lasted from 6 July 1985 until 31 November 1985, was fairly relaxed, with two rehearsal periods which required intense activity on the parts of the Mission Control Team and the Scientific Team. In addition, considerable 'cruise-science' data was gathered from early October until the start of the pre-encounter phase in early March.

These two rehearsals, which were designed to validate procedures and systems required for the encounter activities, revealed certain deficiencies in the Giotto ground segment. A major

*Figure 1 — Distance of Giotto from the Earth as a function of time*




effort by ESOC during December 1985 and January 1986 resulted in all deficiencies being cleared by the end of January, ready for the final series of rehearsals scheduled for 11 and 13 February and 10 March.

At the beginning of December 1985, the orbit of Giotto in relation to the Earth developed as planned, and consequently the spacecraft's distance from Earth began to increase rapidly (Fig. 1). In fact, the range increased from 39 million km on 1 December 1985 to 144 million km at encounter on 14 March 1986. This caused the angle from the centre of the Earth to the centre of the spacecraft high-gain antenna to increase, necessitating a daily spacecraft attitude precession manoeuvre in order to maintain contact by maximising the telecommunications-link signal strength. Operations during this period were conducted by means of X-band telemetry at 8.428 GHz. The beam-width of the X-band signal from Giotto was only 1.8° and hence very precise control of the spacecraft's attitude was essential to mission success.

**The pre-encounter phase**

Beginning on 10 March 1986, the flight-operations activities at ESOC entered the pre-encounter phase of the mission. At 19:30 GMT on that date the 'dress-rehearsal' began. This activity, which involved the complete Mission Control Team, the Science Team, the Spacecraft Support Team and the entire ground-support network, lasted until 01:15 GMT on 11 March 1986 and followed the planned time-line for the cometary encounter exactly. All scientific payload operations were carried out successfully and the dress-rehearsal proved the validity of the planned operations scheduled for the 13 and 14 March. All ground systems performed well and the communications between Darmstadt and the worldwide tracking network were excellent.

Ranging data from the tracking stations and the orbit determination performed by ESOC and re-evaluated using cometary ephemeris data, derived from Vega-1 and Vega-2, revealed by 10 March 1986 that Giotto's trajectory was such that it would pass within 1000 km of Halley's Comet if no further manoeuvres were initiated.

At the Science Working Team meeting on 11 March 1986, the requirement to target Giotto so that it would pass the Comet at a range of 540 km, at 20° south of the Comet—Sun line, was established. This targeting would provide the best compromise to satisfy the various scientific requirements and would require a delta-*V* (orbit) manoeuvre of 2.5 m/s lasting 32 min. At 00:53 GMT on 12 March, the manoeuvre was initiated successfully, terminating as planned at 01:25 GMT. Giotto was now committed to the encounter with Halley's comet at a range of 540 km, which would occur at 00:03:00 GMT on 14 March 1986.

From approximately 19:30 GMT on 11 March, the NASA DSN 64 m tracking stations were added to the existing network, in order to provide back-up command support and 24 h telemetry coverage of the spacecraft until 15 March. The following stations were now providing telemetry, tracking and command support to the Giotto mission and interfaced to ESOC via the international telecommunications network:

- Carnarvon, Western Australia: Primary command and ranging station
- Weilheim, Bavaria, West Germany: Secondary command and ranging station
- Parkes, New South Wales, Australia: Primary scientific data acquisition station
- Madrid (64 m), Spain
  Canberra (64 m), Australia
  Goldstone (64 m), California
  (Back-up command and 24 h telemetry support).

**The encounter phase**

During the early hours of 13 March 1986, the Control Team began final preparations for the encounter by configuring the spacecraft for the final attitude manoeuvre. This manoeuvre would ensure that the spacecraft spin-axis was aligned parallel to the relative velocity vector with Halley's Comet. Upon completion of this manoeuvre, the spacecraft was configured for the encounter:

- All plasma experiments were switched on to provide continuous science data up to encounter.
- The latching valves controlling propellant flow were closed to prevent possible thruster leakage.
- The power dumping was switched to internal shunt to ensure satisfactory operation in the event that the external shunt was damaged by dust or particle impacts.
- The on-board data-handling software was configured for encounter mode.
- The time-tag commands to configure the payload and adjust operational modes for the encounter period were loaded onboard the spacecraft.

Finally, the Halley Multicolour Camera (HMC) experiment was operated in the so-called 'observatory mode' to take a 'snap-shot' of Halley's Comet. Shortly afterwards, an extensive and final calibration of the HMC detectors was performed.

At 18:16 GMT on 13 March, the Giotto spacecraft came into view of the Parkes Station and the final activities for the encounter began. At 18:34 GMT, the Carnarvon station again became primary command station and remained so throughout the encounter.

The final payload switch-on was carried out and the spacecraft configured into encounter mode as follows:

- All battery discharge regulators were switched on.
- The second X-band amplifier (Travelling Wave Tube Amplifier No. 2) was switched on and automatic changeover logic was enabled.

The final experiment configuration was transmitted to Giotto, and optimised HMC tracking parameters, derived from on-board observations of the comet, were uplinked. The encounter phase was already underway and now all that one could do was to wait for the climactic moment of closest approach.

From 21:00 GMT on 13 March, no further commands were to be transmitted to Giotto from ESOC, except those required to resolve any contingency that may have arisen. All scheduled on-board reconfiguration was automatically executed by time-tagged commands previously uplinked and stored onboard.

At 23:01 GMT, the DID experiment team reported the first dust impacts at a distance of about 287 000 km from the comet. At 23:52 GMT, a contingency request was received from the HMC team to load commands into the onboard expansion buffer in order to permit the Camera to reacquire the comet after the point of closest approach. This request was immediately fulfilled.

At 00:05 GMT on 14 March, the DID team reported dust impacts on the rear bumper shield, indicating that the sacrificial forward shield had already been penetrated.

Just before 00:11 GMT, both the Parkes and Canberra stations reported large fluctuations in the received signal strength. This resulted in intermittent periods of data flagged as 'bad quality' being displayed in the Control Centre. At the same time, the science data being processed by the experimenters' hardware exhibited some interruptions, although not sufficient to prevent continued analysis of the data. The Flight

*Figure 2 — The Giotto ground station at Weilheim in Germany*

Control Team deduced that these fluctuations were caused by nutation of Giotto's spin axis. The telemetry continued to be received intermittently until approximately 00:43 GMT, when continuous good-quality data was again available. The onboard passive nutation damper had performed its functions well and the 'wobble' caused by large numbers of dust particle impacts beginning at 00:10:47 GMT was sufficiently damped out by 00:43 GMT to permit re-acquisition of the signal lock at the stations.

For the next 5 h the Flight Control Team were extremely busy responding to requests from Experimenters to uplink emergency commands to correct anomalous behaviour of their experiments and/or to counter damage resulting from cometary dust cloud impacts. Between 00:14 GMT and 05:50 GMT, a total of 383 contingency payload commands were uplinked to the spacecraft.

Although the encounter was formally over 15 min after the moment of closest approach, payload operations continued from the morning of 14 March right through until 02:40 GMT on 15 March when the scientific mission was terminated and the payload was switched off. During this period, a number of Experiment Teams performed damage assessment and revival attempts. The Camera was pointed to Jupiter in an attempt to assess the instrument's performance, but no image was obtained.

Subsequent analysis of data shows that Giotto's point of closest approach occurred at 00:03:00.4 (onboard spacecraft time) or 00:11:00.5 GMT on Earth.

**The post-encounter mission operations (15 March to 2 April)**

The operations conducted during this period were essentially:

(i) Daily housekeeping passes to monitor the spacecraft and perform attitude determination and daily manoeuvres to maintain the telemetry link.

(ii) Performance of a large orbit correction manoeuvre to re-target Giotto for an Earth flyby on 2 July 1990.

(iii) A subsequent tracking campaign from Carnarvon and Weilheim to determine the achieved orbit with sufficient accuracy to recover Giotto after hibernation.

(iv) A fine (correction) orbit manoeuvre prior to putting the spacecraft into hibernation on 2 April 1986.

**Attitude determination**

Shortly after encounter, it was established that there was a lack of Earth pulses in both spacecraft star mappers, and the evidence pointed to damage of the baffle leading to stray light entering the optics and preventing detection of any celestial objects on the sunward side of the spacecraft.

Subsequently, it was possible to detect Mars and bright stars at times when the

Figure 3 — The Giotto reception antenna at the Parkes ground station in Australia

attitude permitted, but since such suitable inertial objects were not always available, it was necessary to develop a procedure for extracting attitude information from the ground-station signal strength readings. The procedure involved changing the despin phase of Giotto's High Gain Antenna (HGA) by small angles, observing the change in signal level at the ground station, and interpolating these measurements to obtain a maximum. After some initial problems, the method served well to supplement the available sensor data.

It is clear that, after the hibernation phase, attitude determination for Giotto will be an interesting and most demanding task.

### Orbit manoeuvres

In order to target Giotto for an Earth flyby, a total delta-$V$ of around 110 m/s was required. This manoeuvre was broken down into two large components plus one small (used also to correct the first two), and was executed as follows:

| Date | Duration | Delta-$V$ (m/s) | Mass of hydrazine used (kg) |
|---|---|---|---|
| 19/20 March | 4 h 30 min | 63.5 | 19 |
| 20/21 March | 4 h 10 min | 46.3 | 14 |
| 21/22 March | 16 min | 2.6 | 0.75 |

After 11 d of tracking from the Carnarvon and Weilheim ground stations, two further corrections were made during the pass of 1/2 April, of 1.57 m/s and 133 cm/s, respectively.

Giotto is now on-course for an Earth flyby on 2 July 1990 at a flyby distance of 3.5 Earth radii.

### Hibernation configuration

After examining the performance of the spacecraft during and subsequent to encounter, a configuration was established in which it could survive for an extended period without ground intervention. This is a so-called 'hibernation' configuration. The attitude for hibernation was selected such that:

(i) there would be sufficient power from the solar array to power the spacecraft at all times
(ii) the thermal environment would be acceptable at both perihelion and aphelion.

The spacecraft configuration is essentially one of minimum power, with onboard autonomy enabled for detection of unit failure only. There will be no autonomous manoeuvres, which implies that revival from hibernation must be initiated by ground commands at the chosen time.

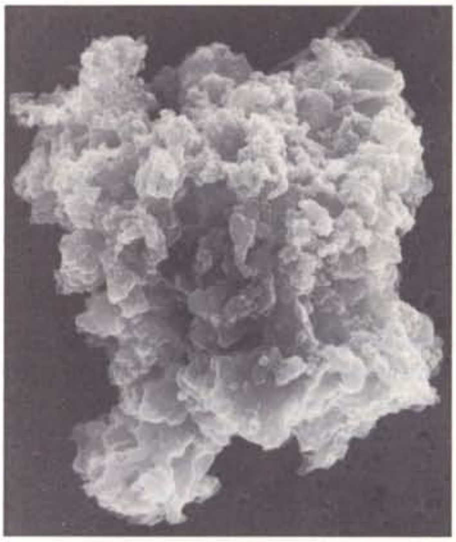
Hibernation operations were completed at 02:25 GMT on 2 April 1986 when the large attitude manoeuvre was initiated to take the spacecraft into its hibernation attitude, with the expected loss of coverage via the High Gain Antenna. The remaining configuration activities (switching off of star mappers, rotating of the HGA, switching off of the transmitter) were effected by onboard time-tagged commands.

### Conclusions

ESA's first attempt at deep-space exploration has been a resounding success and this demanding mission has been successfully controlled by the Giotto Mission Control Team (flight controllers, flight-dynamics experts, ground-systems specialists, and computer hardware and software experts). This operational success would not have been possible without the full collaboration and expertise of all of those who designed, implemented, tested and operated the ground segment of tracking stations, communications and Control-Centre systems. The international cooperation involving Western European, Soviet and United States agencies and astronomers from many countries around the world who contributed to the success of the mission must also be mentioned. It was a gratifying and rewarding experience to be part of the international team which cooperated so generously in the interest of ensuring that Giotto arrived safely and on schedule at Halley's Comet for its once-in-a-lifetime scientific mission.

### Acknowledgement

This article is based largely on information contained in the Operations Report (April 1986) prepared by A.G. Parkes (ESOC). Further navigation/orbit data was provided by T. Morley (ESOC).



# Giotto's Encounter with Comet Halley: A Braking and Shaking Experience

*T.A. Morley & J. Fertig, Orbit Attitude Division, European Space Operations Centre (ESOC), Darmstadt, Germany*

**What happens when a bullet is fired into a dust storm? For the cosmic bullet constituted by the Giotto spacecraft, travelling at more than 68 km/s, many times faster than any projectile on Earth, when it entered the turbulent dust and gas environment of Comet Halley, some of the consequences are now well-known!**

As Giotto entered Halley's coma (Fig. 1), dust-particle impacts caused disturbances to the spacecraft's orientation, and eventually nutation, or wobble, increased until, only seconds before closest approach, the communications link with Earth was lost temporarily. Giotto's Kevlar bumper shield bore the brunt of the dust storm — a case of the bullet itself wearing the bullet-proof vest? — but some parts of the spacecraft, by their very nature, could not be adequately protected and consequently suffered substantial damage (reported elsewhere in this issue).

A third, less widely known effect was also predictable. As Giotto cut its swath through the inner coma, it was subjected to a small but measurable braking effect.

**The braking effect**

In fact, as Giotto traversed Halley's coma, its velocity relative to the comet was reduced by 23 cm/s, or about 0.0003% of its total speed. Even compared with this seemingly small dynamical change, the influence of the comet's gravitational field on the spacecraft's trajectory was negligible. Perhaps more surprising is the fact that the total deceleration could be determined with an accuracy of better than 1 mm/s (Fig. 2).

The data from which these results were computed are the precise measurements of the two-way range and range-rate (Doppler) obtained during the days leading up to encounter and thereafter. This tracking data was provided both by the ESA Deep Space Tracking System (DSTS) stations at Carnarvon in Australia and Weilheim in Germany, and by the NASA Deep-Space Network (DSN) stations at Madrid in Spain and Goldstone in California.

This reduction in spacecraft velocity had to be taken into account within the orbit-determination process in order to obtain the best possible estimates for the encounter parameters. The assumption was made that the dust would strike Giotto virtually head-on, and the fact that the solar cells on the outside circumference of the spacecraft remained unscathed during the encounter shows that this must indeed have been the case.

A more interesting result, which follows directly from the application of the principle of conservation of momentum, is a realistic assessment of the total amount of dust that struck the spacecraft during the encounter period. The reduction in spacecraft velocity is consistent with its being struck by a total dust mass of just less than 2 g — in everyday terms about a teaspoonful! This result assumes inelastic impacts. Since part of the debris would have been reflected rather than adhering to the spacecraft, the true value is probably somewhat less. On the other hand a small amount of debris may also have passed right through the spacecraft structure. Typical pre-encounter estimates of the total mass of the impinging dust were 'a few grammes'.

Also of interest is the dust density profile along the flyby trajectory. Analysis of one-

*Figure 1 — Schematic of Giotto entering the coma of Comet Halley*

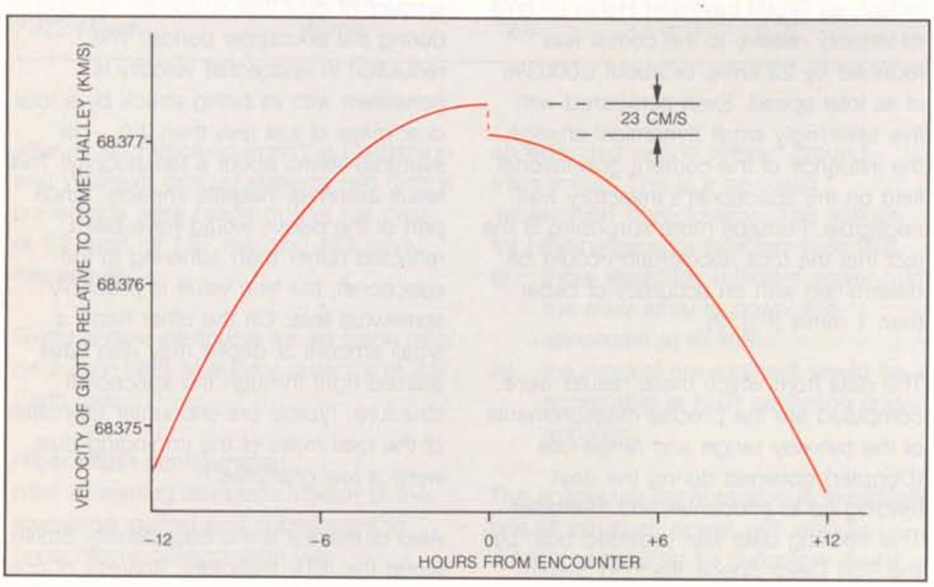



*Figure 2 — Giotto's velocity relative to Comet Halley as a function of time around encounter, reconstructed from one-way Doppler ranging data*

way Doppler data received at Carnarvon, at a frequency of one measurement per second, shows no detectable dust influence until 15 s before closest approach, at which point lock on the Doppler signal was lost for 10 min, equivalent to 40 000 km of flight. Unfortunately, therefore, the Doppler data do not provide information on the dust profile in that part of the coma where the highest dust concentrations were to be expected.

**The shaking effect**

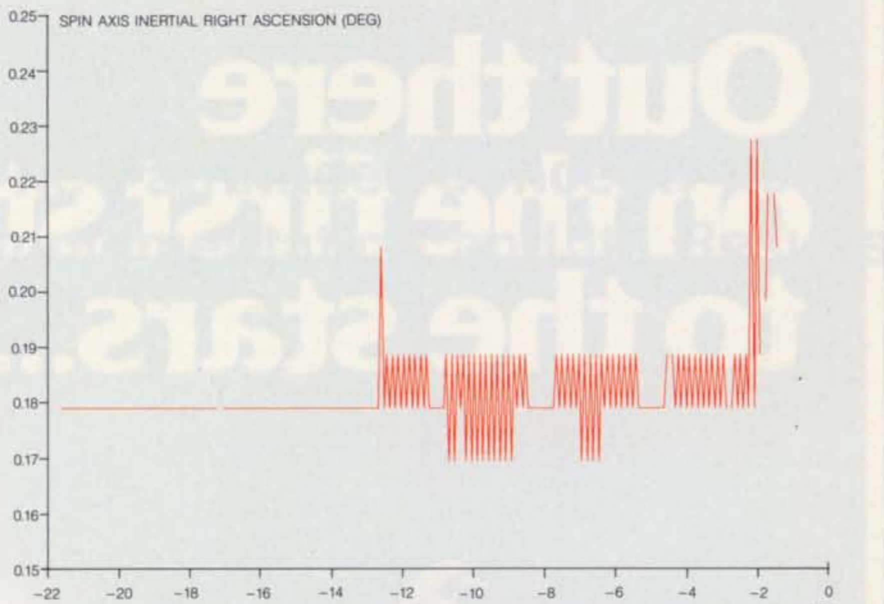
The Giotto spacecraft not only experienced the small braking effect during its flyby of Comet Halley, but was also severely shaken by the impacting dust at closest approach. It was, in fact, the large, impact-induced nutational motion of the spacecraft spin axis that led to loss of the downlink telemetry signal from the spacecraft for short intermittent periods.

As shown in Figure 3, a small dynamic motion in Giotto's spin axis was noted as the spacecraft approached the comet. The spin axis inertial right ascension and declination, derived from Sun-sensor and star-mapper data, are plotted as a function of time from closest approach, which occurred at 0 h 03 min 0.4 s on 14 March (due to a signal delay of 480.1 s, closest-approach telemetry was received on the ground at 0 h 11 min 0.5 s).

The attitude plots show a first minute nutation of about 0.01° at −1270 s. This variation in attitude angle, equal in size to the digitisation step of the data, must have been caused by camera rotation. The first sign of impact-induced dynamics is found much later, at −208 s. In the following minute, star-mapper data were lost intermittently for several short periods. At −136 s, after a last telemetry packet filled with spurious data, star-mapper data were completely lost, to be regained only about 6 h after the encounter, when instrument parameters had been optimised to sense Mars instead of the Earth as a celestial

*Figure 3a,b — Orientation of Giotto's spin-axis as a function of time from closest approach*

*Figure 4 — Angle between Giotto's spin axis and the Sun direction as a function of time from closest approach*



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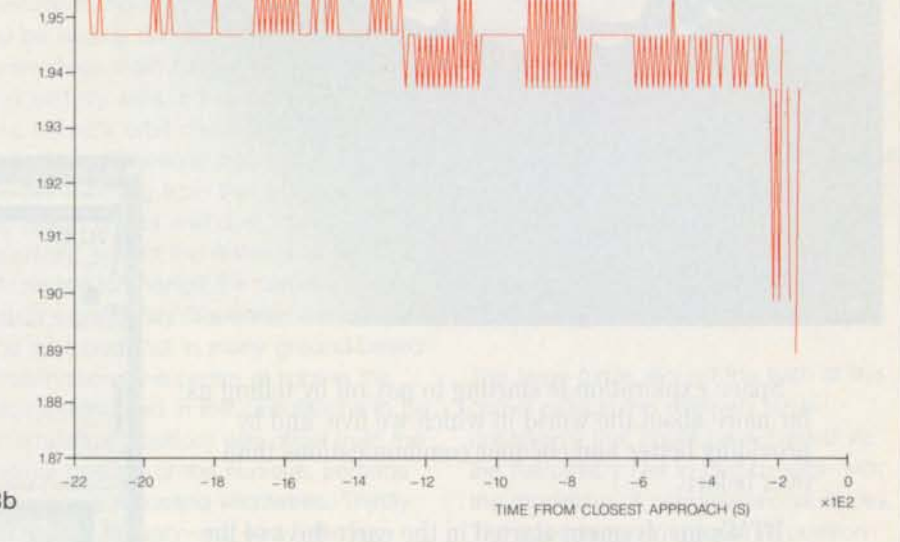

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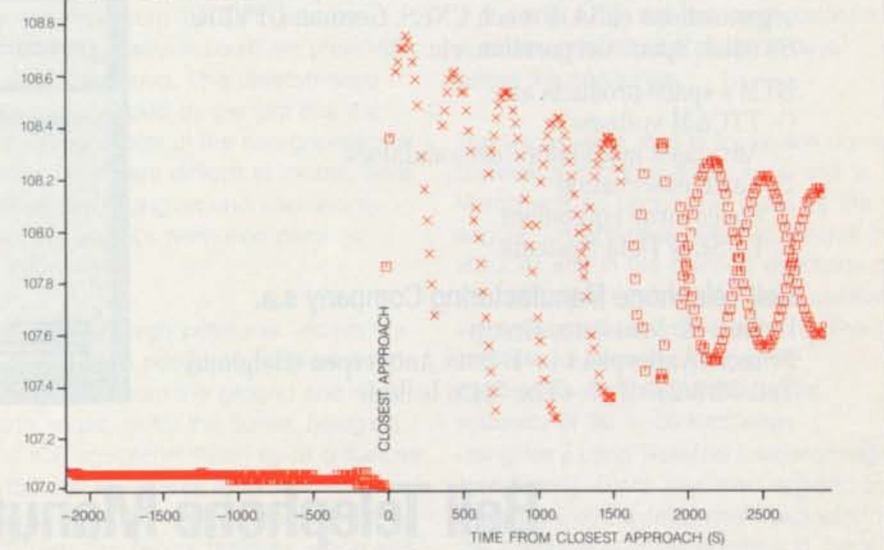

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reference. Only data from the Sun sensor, which kept working flawlessly throughout encounter, remained to tell the tale of the dynamic effects during this dramatic event.

The solar aspect angle, between spacecraft spin axis and the Sun's direction, is shown in Figure 4 as a function of time from closest approach. The data represented as squares have been obtained from standard computer processing. Data shown as crosses were reconstructed in manual detective work from raw telemetry. They were rejected by the automatic filing system for a period of about 25 min after encounter as potentially corrupt due to recurrent short interruptions of the signal. After an initial, small dynamic motion apparent in the reconstituted attitude (Figs. 3a,b), the solar aspect angle jumped from 107° to about 107.9° and oscillated around this new value with an amplitude of about 0.9° due to nutation. The actual oscillation is between the upper and lower envelopes of the data points. The beat phenomenon is a sampling effect and results from the fact that the spacecraft nutation period is close to four times the spin period. The nutation dampers on board the spacecraft caused this nutation to decay, thereby allowing recovery of a stable link after the encounter.

The smooth variation in solar aspect prior to 16 s and after 8 s before closest approach implies that the large nutation was caused by one or more large impacts within this 8 s interval. There were no other similarly large impacts before or afterwards.

All in all therefore, it was a pleasant surprise that Giotto was able to traverse Halley's dust coma and emerge only slightly braked, though somewhat shaken.


*High performance demodulator-receiver developed by Bell Telephone for ESOC deep-space missions*

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# The Pathfinder Concept, Its Implementation and Its Results

*R.E. Münch, Orbit Attitude Division, European Space Operations Centre (ESOC), Darmstadt, Germany*

**The 'Pathfinder Concept' was proposed by ESA at the first Inter-Agency Consultative Group (IACG) meeting in September 1981 in Padua, Italy. In the following years the idea was further developed and a basic document (Pathfinder Technical Project) describing all Pathfinder elements was approved by the IACG in November 1984. The Pathfinder Concept allowed Giotto to be targeted more precisely by using Comet Halley nucleus-position data provided by the Vega Project of Intercosmos (USSR). NASA supported this activity by determining the positions of the two Vega spacecraft very accurately using their Deep-Space Network (DSN) and Very-Long-Baseline Interferometry (VLBI) techniques. Thanks in large part to this historic example of inter-agency collaboration, Giotto was able to achieve a final cometary flyby distance of 600 km on the sunward side, with an uncertainty of just 40 km.**

## Introduction

In March 1986, the expected uncertainty in the nucleus position of Halley's Comet relative to the spacecraft was estimated to be several hundred kilometres. There were three main reasons for this large uncertainty. First, the accuracy with which the comet's orbit could be calculated was limited because non-gravitational forces resulting from the irregular emission of gas and dust from the sunward side of the nucleus were expected to change the comet's orbit quite significantly. Secondly, it could not be excluded that in many ground-based observations the centre of light in the coma (assumed in the calculations to be the nucleus position) was offset from the actual position of the nucleus, perhaps by up to a thousand kilometres. Thirdly from mid January until end February 1986, Halley's Comet was too close to the Sun (solar elongation angle $<30°$) to be observed from the Earth and no astrometric positions could be provided during that period. This disadvantage was compounded by the fact that the perturbing effects of the non-gravitational forces, which are difficult to model, were particularly strong around and shortly after the comet's perihelion passage (9 February).

The relatively high positional uncertainty in March 1986 posed no problem for the observations from the ground and near-Earth space, or for the Suisei, Sakigake and ICE spacecraft flying by at distances $>150\,000$ km. It was even sufficient for Vega-1 and -2 flying by at more than 8500 km. For Giotto, however, which was to be targeted to fly by a few hundred kilometres on the sunward side of the nucleus, a smaller targeting uncertainty was highly desirable.

Fortunately, Giotto was the last of the spacecraft to encounter the comet and the earlier-arriving Vega-1 and -2 spacecraft, having located the nucleus, were able to pass on this information on the nucleus' position for use in the navigation of the Giotto spacecraft. The principle of this so-called 'Pathfinder Concept' is illustrated in Figure 1.

The large circle around the path of the comet reflects the relatively large uncertainty that could be achieved via the Astrometry Net in combination with the modelling of nongravitational forces. The uncertainty in spacecraft position ($\sim 100$ km) is shown in the figure as a small circle around the spacecraft path, at the time when the last orbit correction manoeuvre had to be made, 2 days before the encounter.

The Vegas were able to locate the comet nucleus during their flybys on 6 and 9 March with an uncertainty given by the angular uncertainties in the spacecraft attitudes and in the pointing directions of the platforms on which the Vega cameras were mounted (approx. 3 arcmin). The positions of the Vega spacecraft themselves were established to an accuracy of 30 — 50 kilometres using Very Long Baseline Interferometry (see below). Giotto was then targeted to the centre of the small circle projected to the intersection of the comet and the spacecraft paths.

*Figure 1 — Principle of the 'Pathfinder Concept' (courtesy of J.F. Jordan)*

**Pathfinder responsibilities and organisation**

Three agencies were involved in the realisation of the Pathfinder Concept: IKI in Moscow was responsible for providing the Vega inertial pointing angles, JPL for DSN/VLBI tracking and orbit determination of the Vega spacecraft, and ESOC for overall technical coordination and Giotto terminal navigation. The various functions are listed in Table 1 in greater detail.

The success of all Pathfinder activities hinged on efficient data exchange between the three Agencies involved. To achieve this an operational 'hot line' was established between ESOC in Darmstadt and IKI in Moscow. This leased line, which was first established for testing purposes in December 1984, was fully operational from September 1985 onwards and was used for several types of transmission:

- direct telefax transmission in both directions
- interactive access, by an ESOC representative located in Moscow, to the ESOC computer facilities
- transfer of computer-generated data from Darmstadt to Moscow, and vice versa
- interactive dialogue between IKI and ESOC personnel via computer terminals
- voice communication.

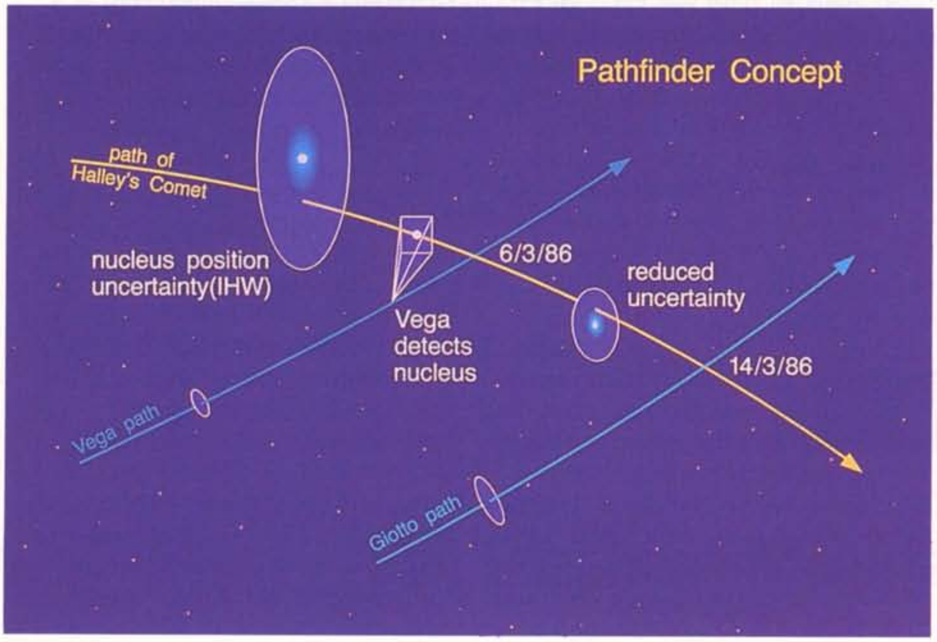
In the week leading up to the Giotto encounter, the link was used extensively for transmission of the Vega observations from Moscow to Darmstadt, and for dialogue between the Intercosmos and ESA flight dynamics teams.

**The Vega observations**

Vega-1 and Vega-2 traversed Halley's coma on 6 and 9 March 1986, respectively, Vega-1 at a distance of 8890 km from the cometary nucleus and Vega-2 at 8030 km (Figs. 2 & 3).

Three main sources of error had to be considered when transforming the relative accuracy of these observations to the absolute accuracy required for Giotto targeting:

- the Vega spacecraft orbital positions
- the inertial pointing angles from spacecraft to comet nucleus
- the error growth due to the uncertainty in the comet's velocity, which translates into an additional uncertainty in the target plane.




**Accurate determination of Vega orbital positions**

A critical element of the Pathfinder Concept was accurate determination of the Vega orbits at the times of comet encounter. Using only conventional (6 GHz) ranging and Doppler, Soviet experts predicted a geocentric Vega position accuracy of several hundred kilometres. The addition of NASA/JPL's precise L-band Very Long Baseline Interferometry, which uses two widely separated tracking stations for simultaneous reception of the wideband signal broadcast by the spacecraft, was expected to reduce this uncertainty to 40 km.

In the case of the Vegas, the two Deep-Space Network station pairs used were Madrid/Goldstone and Goldstone/Canberra (Fig. 4). Cross-correlation of the signals received at these stations furnished a precise measure of the differential time delay, which in turn allowed the angle between the interstation baseline and the spacecraft to be determined. By alternately tracking the spacecraft and a known nearby extragalactic radio source (quasar), measurements could be performed to cancel out common error sources (synchronisation of the station clocks). This exercise was performed by NASA/JPL for both Vega spacecraft from July 1985, when the two spacecraft completed the Venus-exploration element of their mission, until their encounters with Halley on 6 and 9 March.

**Determination of Vega inertial pointing angles**

This second major activity was started only after the encounter of Vega-1, and involved production of optical directional measurements from spacecraft to comet, which were later repeated for Vega-2. This process was based on spacecraft telemetry data and involved:

(i) determination of the spacecraft's inertial attitude (with the help of Sun-sensor, star-sensor and gyroscope data)
(ii) reconstruction of the moving camera platform's position relative to the spacecraft, and
(iii) location of the comet's nucleus in the camera's field of view by appropriate image-processing techniques.

**The results of Pathfinder**
In the event, the inertial pointing angles could be obtained in the periods both before and after closest approach for both Vega spacecraft, thus producing an excellent basis for improvement of our knowledge of the comet's trajectory.

Figure 5 illustrates this improvement and also shows the targeting process for the Giotto spacecraft, which was manoeuvred for the last time, using the

*Table 1 — Distribution of functions between the three Agencies*

**ESA Functions**

| | |
|---|---|
| Comet Orbit Determination | Determination of the comet's orbit by utilising ground-based observations from previous apparitions (partially improved), and from this apparation via the International Halley Watch (IHW) |
| Improved Comet Orbit Determination | Determination of the comet's orbit by utilising Vega-1 and -2 inertial angles and improved Vega orbits in addition to the ground-based observations |

**NASA Functions**

| | |
|---|---|
| Collection of Ground-Based Comet Observations (IHW) | Ground-based measurements of the comet as performed by the IHW collected centrally by NASA/JPL |
| Comet Orbit Determination | Determination of the comet's orbit by utilising ground-based observations from previous apparitions and from this apparition via the IHW |
| DSN Station Scheduling | Production of schedule for utilising the DSN stations, taking into account the totality of missions to be supported and the requirements for Vega |
| Collection of DSN Measurements | Performance of DSN measurements, pre-processing and collection of observables |
| Vega Orbit Determination | Determination of the Vega orbits by utilising the DSN measurements |

**Intercosmos Functions**

| | |
|---|---|
| Vega Mission Control | Control of the Vega spacecraft in terms of orbit correction manoeuvres, transponder performance and schedule for DSN measurements |
| Vega Orbit Determination | Orbit determination for the two Vega spacecraft utilising USSR ranging and Doppler measurements |
| Vega Inertial Angles Determination | Determination of the inertial pointing angles from the two Vega spacecraft to the comet's nucleus by evaluating the spacecraft attitude (taking due regard of the calibrated gyro performance), the platform relative position, and the image of the comet in the cameras |
| Comet Orbit Determination with Ground-Based Observations | Determination of the comet's orbit by utilising ground-based observations from previous apparitions and from this apparition via the IHW |
| Improved Comet Orbit Determination | Determination of the comet's orbit by utilising Vega-1 and -2 inertial angles and improved Vega orbits in addition to the ground-based observations |
| Collection of USSR Observations | Ground-based measurements of the comet from USSR observatories collected at the Kiev Observatory |
| VLBI Vega Orbit Determination | Determination of improved Vega orbits by utilising standard range and Doppler measurements in addition to DSN-derived VLBI measurements |

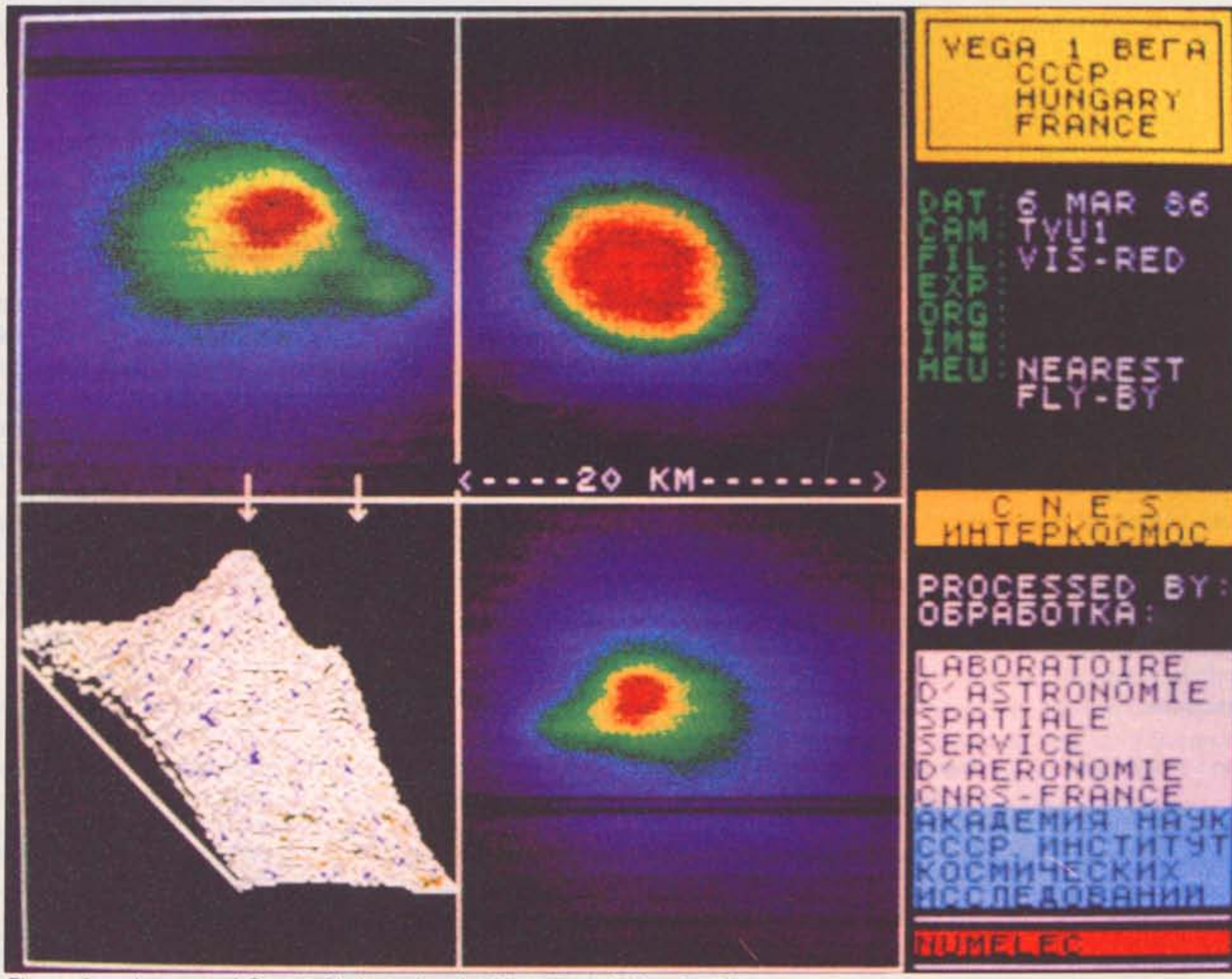



*Figure 2 — Images of Comet Halley taken by Vega-1 on 6 March 1986*

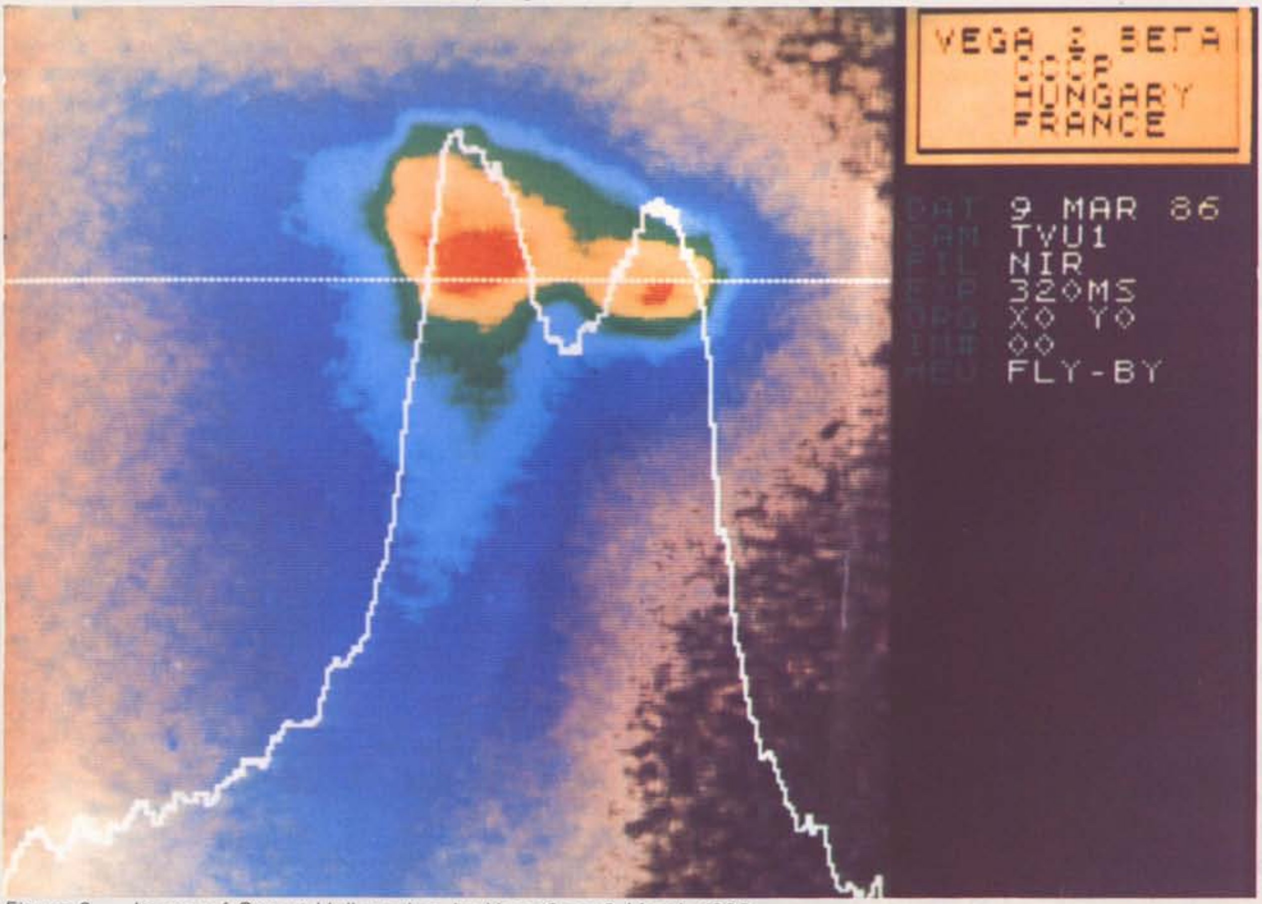



*Figure 3 — Image of Comet Halley taken by Vega-2 on 9 March 1986*

*Figure 4 — Locations of the Giotto ground stations. The NASA Deep-Space Network (DSN) 64 m stations at Goldstone, Madrid and Canberra were used for Vega spacecraft ranging for Pathfinder*

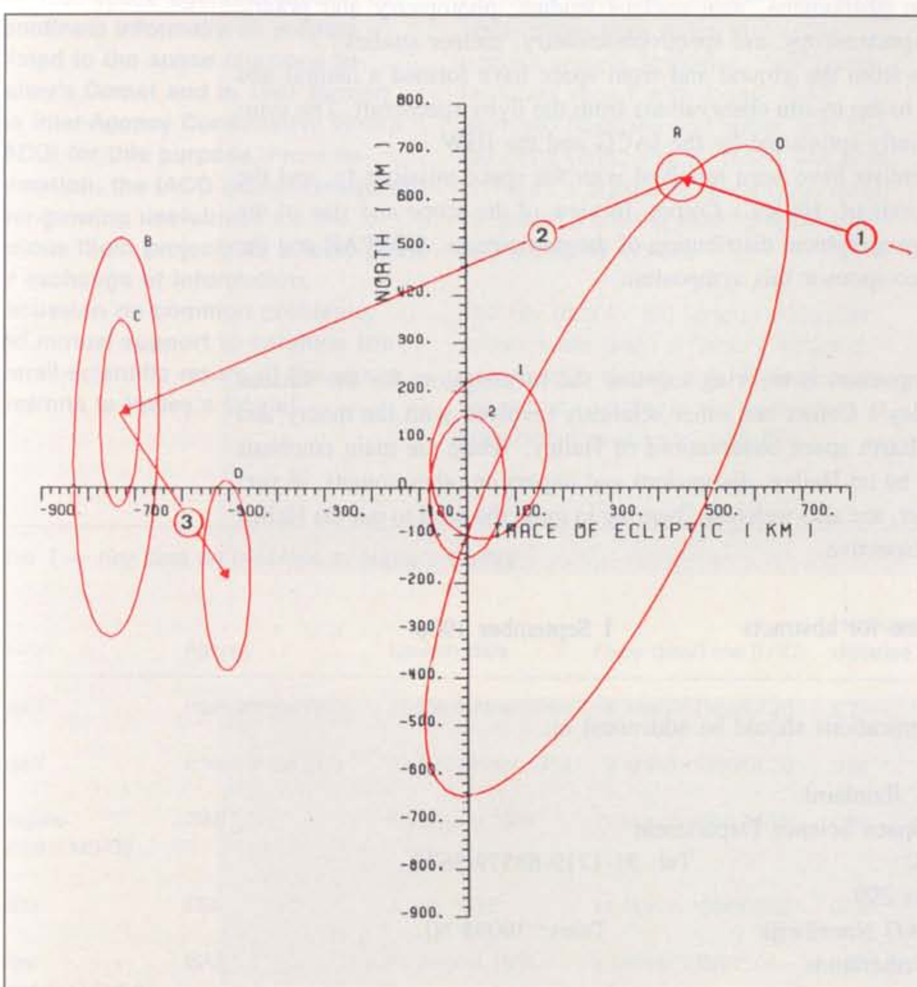
*Figure 5 — Giotto targeting history. The ellipses shown are projections of three-dimensional position-uncertainty ellipsoids into Giotto's target plane (a plane perpendicular to the spacecraft — comet relative velocity vector).*

*Ellipses nos. 0,1 and 2 refer to the position of the comet:*
*0 — from the International Halley Watch, 5 March 1986*
*1 — from Vega-1 observations*
*2 — from Vega-1 and 2 observations.*

*The origin of the coordinate system represents the position of the comet at closest approach.*

*Ellipses A — D refer to Giotto's position, on 27 August 1985, and 5, 12 and 14 March 1986, respectively.*

*Three targeting manoeuvres (1 — 3) were performed based on Pathfinder results — on 26 August 1985, 12 February 1986 and 12 March 1986, respectively — the last one just 2 days before Giotto's closest approach to the comet*


highly successful Pathfinder results, just two days prior to its encounter with the Comet on 14 March. The small ellipse in the centre represents the best estimate of the comet's position having used the data obtained from both Vega spacecraft.

Given this best estimate, computed on the basis of the Vega-provided Pathfinder data, the Giotto spacecraft controllers were able to steer the European probe to within 600 km of the comet's nucleus on the sunward side, to an accuracy of just ±40 km.

## Conclusion

The great success of the Pathfinder project is very largely attributable to the extremely good cooperation between all the technical staff involved. With both Intercosmos and NASA determining improved Vega trajectories using the NASA VLBI data, and both Intercosmos and ESA determining an improved comet trajectory, an intensive exchange of information took place which greatly facilitated thorough preparation of Giotto spacecraft operations.

The author would like to take this opportunity to thank all of those staff in the above agencies who contributed to the Pathfinder Project and whose dedication and spirit of cooperation were so essential to its success.

# EXPLORATION OF HALLEY'S COMET

## 20 th ESLAB Symposium, Heidelberg, Germany

## 27 — 31 October 1986

Each year the Space Science Department of ESA organises a symposium on a topic related to the ESA Scientific Programme. Following the flyby of Halley's Comet by ESA's Giotto spacecraft on 14 March 1986, the ESLAB Symposium in 1986 is devoted to the 'Exploration of Halley's Comet'.

The Giotto mission formed part of a worldwide campaign to observe Halley's Comet during its 1986 apparition. The USSR Academy of Sciences sent two spacecraft, Vega 1 and 2, to the comet, and the Japanese Institute for Space and Astronautical Science (ISAS) also sent two spacecraft, Sakigake and Suisei. The five missions overlapped and complemented each other in instrumentation, flyby distances (ranging from a few million to 500 kilometres) and flyby dates (from 6 to 14 March). NASA also contributed with a significant programme of space activities utilising existing spacecraft and sounding rockets. All space missions to Halley's Comet and all other Halley observations from space have been coordinated by the Inter-Agency Consultative Group (IACG).

All observations from the ground have been coordinated by the International Halley Watch (IHW) via eight world-wide networks: astronomy, infrared spectroscopy and radiometry, large-scale phenomena, near-nucleus studies, photometry and polarimetry, radio studies, spectroscopy and spectrophotometry, meteor studies.

Remote observations from the ground and from space have formed a natural and necessary complement to the in-situ observations from the flyby spacecraft. The symposium is therefore jointly sponsored by the IACG and the IHW.

More than 1500 scientists have been involved with the space missions to, and the ground-based observations of, Halley's Comet. In view of the scope and size of the meeting and the wide geographical distribution of the participants, COSPAR and the IAU have decided to co-sponsor this symposium.

**Purpose and scope**

The aim of this symposium is to bring together the investigators for the various space missions to Halley's Comet and other scientists involved with the theory and ground-based or near-Earth space observations of Halley. While the main emphasis of the symposium will be on Halley, discussions and papers on other comets, in particular Giacobini-Zinner, are also welcome, bearing in mind the need to put the Halley results into proper perspective.

Deadline for abstracts 1 September 1986

All communications should be addressed to:

Dr. R. Reinhard
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The Netherlands

# The Role of the Inter-Agency Consultative Group (IACG) and its Associated Working Groups

*R. Reinhard, Giotto Project Scientist, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands*

**After 76 years, Halley's Comet has again approached the inner solar system. A fleet of five spacecraft, from three space agencies — Intercosmos, ISAS and ESA — were prepared to encounter the comet in March 1986. In addition, NASA participated with a significant programme of space observations. The four space agencies agreed to coordinate informally all matters related to the space missions to Halley's Comet and in 1981 formed the Inter-Agency Consultative Group (IACG) for this purpose. From its formation, the IACG demonstrated an ever-growing usefulness for the various flight projects as a focal point for exchange of information, discussion on common problems, and mutual support to enhance the overall scientific return of the space missions to Halley's Comet.**

### The Inter-Agency Consultative Group (IACG)

Four space agencies — the Intercosmos of the USSR Academy of Sciences, the Japanese Institute of Space and Astronautical Science (ISAS), the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) — sent spacecraft to Halley's Comet or have been involved with Halley observations from space during the comet's present apparition. Intercosmos launched Vega-1 and Vega-2, ISAS launched Sakigake and Suisei, and ESA launched Giotto (Fig. 1). NASA was able to mount a significant space-observation programme utilising existing spacecraft and sounding rockets.

The key data for the various encounter missions are given in Table 1, ordered according to launch date. The encounter spacecraft complemented each other in flyby distance, ranging from 600 kilometres to 7 million kilometres, and comet heliocentric distances at the times of encounter ranging, from 0.79 to 0.89 AU. The encounters all took place in March 1986, because Halley crossed the ecliptic plane on 10 March (descending node) and the launch energy required was minimised if the encounter spacecraft could stay close to the ecliptic. The phase angles, i.e. the angle between the spacecraft trajectory in the comet's coordinate system and the direction from the comet to the Sun, were all similar and the relative flyby speeds, i.e. the speeds in the comet's frame of reference, were all very high. Unfortunately, due to Halley's retrograde orbit, only fast flyby missions were possible.

The scientific experiments on the various spacecraft are summarised in Table 2, which shows that together they provided the full complement of experiments that

*Table 1 — Key data on missions to Halley's Comet*

| Mission | Agency | Launch date | Flyby date/Time (UTC) | Heliocentric distance (AU) | Flyby distance (km) | Flyby speed (km/s) | Phase angle (deg) |
|---|---|---|---|---|---|---|---|
| Vega-1 | Intercosmos (IKI) | 15 December 1984 | 6 March 1986/07.20 | 0.79 | 8890 | 79.2 | 111.2 |
| Vega-2 | Intercosmos (IKI) | 21 December 1984 | 9 March 1986/07.20 | 0.83 | 8030 | 76.8 | 113.4 |
| Sakigake (formerly MS-T5) | ISAS | 8 January 1985 | 11 March 1986/04.18 | 0.86 | 6.99 million | 75.3 | 109.4 |
| Giotto | ESA | 2 July 1985 | 14 March 1986/00.03 | 0.89 | 600 | 68.4 | 107.2 |
| Suisei (formerly Planet-A) | ISAS | 19 August 1985 | 8 March 1986/13.06 | 0.82 | 151 000 | 73.0 | 104.2 |

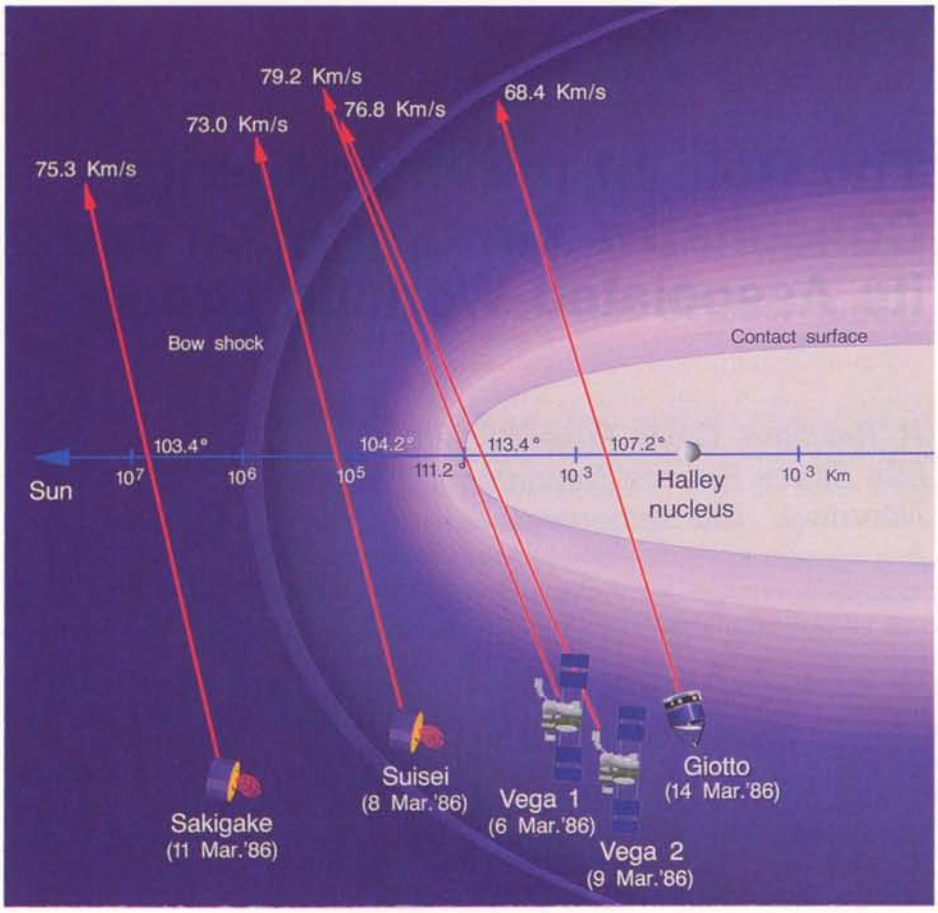



*Figure 1 — The encounter geometries for the prime spacecraft missions to Halley's Comet*

*Table 2 — Scientific experiments on the Halley spacecraft*

| | Experiment | Vega-1 & 2 (three-axis stabilised) | Sakigake (spin-stabilised) | Giotto (spin-stabilised) | Suisei (spin-stabilised) | Combined complement |
|---|---|---|---|---|---|---|
| Remote Sensing | Camera – Wide Angle | • | | | | • |
| | Camera – Narrow Angle | • | | • | | • |
| | UV Camera | | | | • | • |
| | IR Sounder | • | | | | • |
| | Photopolarimeter | | | • | | • |
| | Three-Channel Spectrometer | • | | | | • |
| Gas/Dust In-Situ Measurements | Neutral Mass Spectrometer | • | | • | | • |
| | Ion Mass Spectrometer | • | | • | | • |
| | Dust Mass Spectrometer | • | | • | | • |
| | Dust Impact Detectors | • | | • | | • |
| Plasma In-Situ Measurements | Solar-Wind Ions | • | • | • | • | • |
| | Solar-Wind Electrons | • | | • | • | • |
| | Plasma Waves | • | • | | | • |
| | Energetic Particles | • | | • | | • |
| | Magnetometer | • | • | • | | • |

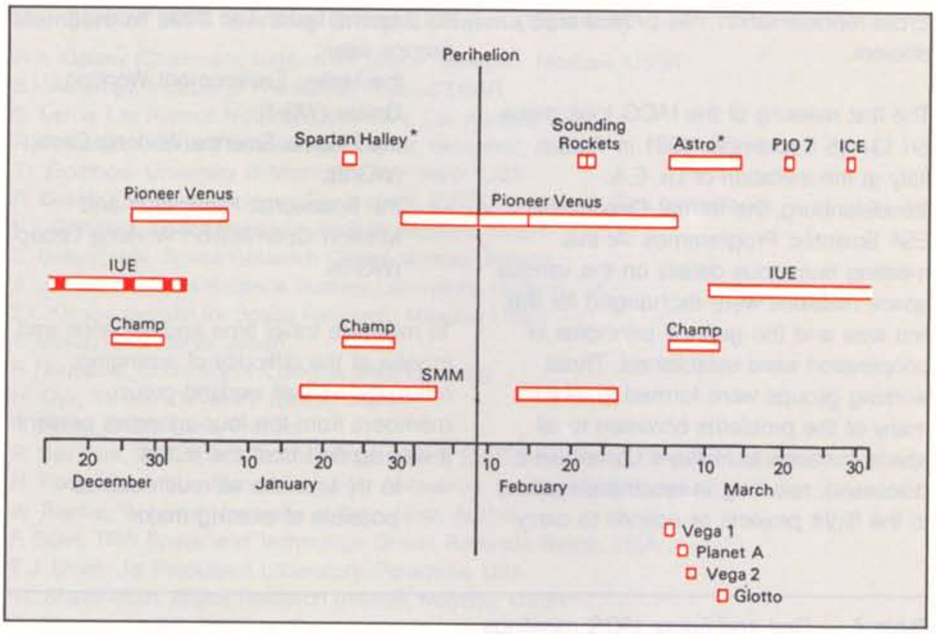
could be flown on a flyby mission (last column). Table 2 also shows that there was a large overlap between the experiments on the different spacecraft, which is providing a stimulating basis for data comparison since the encounters. The Halley encounter spacecraft also complemented each other in the sense that the two Vega spacecraft were three-axis stabilised, while Giotto, Suisei and Sakigake were spin-stabilised. (Three-axis stabilisation is more advantageous for imaging, since longer integration times can be achieved. Spin stabilisation is more advantageous for plasma experiments, because an azimuthal range of 360° is provided by the spacecraft spin and full $4\pi$ viewing is possible).

The in-situ measurements were to be complemented by a number of US space observations of Comet Halley and a very large number of observations from the ground, the latter being coordinated in the International Halley Watch. The observations from space are summarised in Table 3, with Figure 2 showing the corresponding space-observation schedule. The observations were all of the remote-sensing type, concentrated mostly on ultraviolet wavelength ranges (observations that are impossible from the ground because of atmospheric absorption), and included periods when Halley was near perihelion and difficult or impossible to observe from the ground.

As is evident from Tables 1—3, there was ample scope for optimisation of the overall encounter scenario and for useful collaboration among the experimenters before and after the launches. The missions complemented each other in instrumentation and flyby distances, they extended the total time of in-situ observations in the cometary environment, and they provided simultaneous observations from two or more spacecraft for some time periods.

Realising that many aspects of mission planning, spacecraft and experiment design, and data evaluation were

*Figure 2 — Space observation schedule for Halley's Comet (courtesy of W. Brunk)*




common to all missions and that the overall scientific return could be increased through cooperation, the four agencies agreed in 1981 to form the Inter-Agency Consultative Group. The IACG has the task of informally coordinating all matters related to the space missions to Halley's Comet and the observations of Halley's Comet from space, while all ground-based Halley observations are being coordinated by the International Halley Watch (IHW).

The IHW, not being a space agency, has participated in all IACG meetings, just as the space agencies have been represented at all general meetings of the IHW. The degree of communication and coordination achieved through this

*Table 3 — US space observations of Comet Halley*

| Name | Vehicle | Instrument technique | Date of observations |
|---|---|---|---|
| Astro-1* | Space Shuttle Payload | UV Imaging<br>UV Spectroscopy<br>UV Photometry + Polarimetry<br>Visible Imaging | 9 day flight<br>Launch approx. 6 March 1986 |
| Champ | Space Shuttle<br>Astronaut Camera | UV and Visible Imaging<br>(uses IHW filters) | 3 Shuttle flights<br>Dec. 1985, Jan. 1986, March 1986 |
| ICE | Interplanetary Spacecraft | Magnetometry<br>Plasma Analysis | Halley closest approach<br>25 March 1986<br>28 million km, sunward side |
| IUE | Earth Orbiting Observatory | UV Spectroscopy | Can observe Halley when 45° from Sun |
| Pioneer 7 | Interplanetary Spacecraft | Plasma Analysis | Halley closest approach<br>20 March 1986, 12 million km,<br>anti-sunward side |
| Pioneer Venus | Venus Orbiter | UV Spectroscopy | Halley closest approach<br>4 February 1986, 40 million km |
| Sounding Rockets | Sounding Rockets | UV Spectroscopy | 21 and 22 February 1986 |
| Spartan Halley* | Space-Shuttle-<br>Carried Free-Flyer | UV Spectroscopy<br>Visible Imaging | 48 hour duration approx. 22 January 1986 |
| Solar Maximum Mission | Earth Orbiting Observatory | Visible Imaging (coronagraph, polarimeter) | Near Halley perihelion when 20° from Sun |

* These projects could not be carried out due to the delays in the Shuttle programme incurred by the loss of Challenger in January 1986.

'cross-representation' has proved highly efficient.

The first meeting of the IACG took place on 13—15 September 1981 in Padua, Italy at the invitation of Dr. E.A. Trendelenburg, the former Director of ESA Scientific Programmes. At this meeting numerous details on the various space missions were exchanged for the first time and the general principles of cooperation were established. Three working groups were formed in which many of the problems common to all space missions to Halley's Comet were discussed, resulting in recommendations to the flight projects or actions to carry out specific tasks. The three working groups were:
— the Halley Environment Working Group (WG-1)
— the Plasma Science Working Group (WG-2)
— the Spacecraft Navigation and Mission Optimisation Working Group (WG-3).

To minimise travel time and expense and in view of the difficulty of arranging meetings with all working-group members from the four agencies present, it was agreed from the outset:
— to try to make as much use as possible of existing major conferences when arranging working-group meetings
— to communicate results achieved by sub-groups in regional meetings to all other working-group members who could not participate and to a representative of each agency
— to encourage flexibility of membership depending on the interest and changes in the subject matter of the discussions and depending on the meeting place.

The IACG has met annually, with the task of organising the meeting, and consequently the meeting place, rotating within the four agencies. An overview of past and future IACG meetings is shown in Table 4. The meetings are usually chaired by a Senior Director or the Director General of the host agency. He is supported in that task by a permanent IACG Secretary, who also prepares the meeting agenda in consultation with the agencies, produces and distributes a summary after the meeting and carries out the day-to-day work in the interim between meetings.

The annual IACG meetings have been attended by 5—10 delegation members from each agency. The meetings have usually started with reports by the various delegations on the status of their project. At earlier meetings, details on spacecraft and experiment design were exchanged, including information on dust bumper-shield design, which was of particular importance for Giotto and Vega-1 and -2. Bumper shields had never previously been carried by spacecraft, but they were absolutely essential to protect the spacecraft from hypervelocity dust-particle impacts during cometary fast-flyby encounters. After the launches, the IACG reports concentrated on spacecraft and experiment performance and mission planning, including times of experiment operation. These reports were followed by reports by the chairmen of the three Working Groups, followed by miscellaneous items, which have differed from meeting to meeting. The meetings

*Table 4 — Past and future IACG meetings*

| Date | Place | Host |
|---|---|---|
| 1981, 13—15 September | Padua, Italy | ESA |
| 1982, 21—22 November | Dobogokõ, Hungary | Intercosmos |
| 1983, 18—19 December | Kagoshima, Japan | ISAS |
| 1984, 13—16 November | Tallinn, USSR | Intercosmos |
| 1985, 10—12 September | Washington DC, USA | NASA |
| 1986, 5— 6 March | Moscow, USSR | Intercosmos |
| 1986, 3— 4 November | Padua, Italy | ESA |

**Members of IACG Working Group 1 (Halley Environment)**

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T.N. Divine, Jet Propulsion Laboratory (JPL), Pasadena, USA
H. Fechtig, MPK, Heidelberg, Germany
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T.I. Gombosi, University of Michigan, Ann Arbor, USA
M.S. Hanner, JPL, Pasadena, USA
H.U. Keller, MPAe, Lindau, Germany
S.M. Larson, University of Arizona, Tucson, USA
D.A. Mendis, University of California, San Diego, USA
V.I. Moroz, IKI, Moscow, USSR
R.L. Newburn, JPL, Pasadena, USA
J. Rahe, Dr.-Remeis Sternwarte, Bamberg, Germany
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are usually concluded with reports by the agencies on their future space mission plans, some of which might be candidates for future cooperation.

**IACG Working Group 1: Halley environment**

This Working Group had the task of providing the scientific community and the spacecraft engineers of the Halley flight projects with data on the nucleus of Halley's Comet and with dust and gas models. The group completed a dust model for the ambient Halley coma assuming homogeneous dust emission from the nucleus surface, including the proper mathematical description of all known major effects. This model was initially based on 1910 observations of Halley's Comet and was continually updated as new observational data became available during the present apparition.

The emission of dust particles from the cometary nucleus is coupled to the gas production, which increases with increasing surface temperature of the cometary nucleus as it approaches the Sun and is heated up. Maximum dust and gas production is observed when the comet is closest to the Sun (perihelion passage). The visual brightness of a comet is produced by the dust particles reflecting the sunlight and line emission from neutral particles and ions excited by sunlight (fluorescence). Consequently, the cometary brightness for the gas and dust production, and its variation with time or distance from the nucleus (called the 'light curve') was used to calculate via a photometric theory the gas and dust production rates for the times of the various flybys in March 1986. It was calculated that at the time of the Giotto flyby, the total gas production rate would be $6.2\times10^{29}$ molecules/s (approximately $2\times10^{7}$ g/s) and the total dust production rate would be $10^{7}$ g/s.

The flux of dust particles encountered by the spacecraft not only depends on the

**Members of IACG Working Group 2 (Plasma Science)**

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S.I. Anisimov, Institute of Theoretical Physics, USSR
S. Bame, Los Alamos National Laboratory, Los Alamos, USA
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R. Grard, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands
K.I. Gringauz, Space Research Institute, Moscow, USSR
S. Grzenzielski, Space Research Center, Warsaw, Poland
A. Johnstone, Mullard Space Science Laboratory, Dorking, UK
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F. Scarf, TRW Space and Technology Group, Redondo Beach, USA
E.J. Smith, Jet Propulsion Laboratory, Pasadena, USA
V.I. Shevchenko, Space Research Institute, Moscow, USSR
C. D'Uston, CNRS, Toulouse, France
D.T. Young, Los Alamos National Laboratory, Los Alamos, USA

**Members of IACG Working Group 3 (Spacecraft Navigation and Mission Optimisation)**

| | |
|---|---|
| J. Dunne (Chairman) | JPL, Pasadena, USA |
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| J. Credland | ESA/ESTEC, Noordwijk, The Netherlands |
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| K. Hirao | ISAS, Tokyo, Japan |
| F. Jordan | JPL, Pasadena, USA |
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| R. Münch | ESA/ESOC, Darmstadt, Germany |
| R. Reinhard | ESA Space Science Department, ESTEC, Noordwijk, The Netherlands |
| A. Sukhanov | IKI, Moscow, USSR |
| L. Szabó | Central Research Institute, Budapest, Hungary |
| D. Yeomans | JPL, Pasadena, USA |

**Pathfinder Implementation (since December 1983)**

*Steering Committee*
D. Dale, Chairman (ESA/ESTEC)
J. Jensen (ESA/ESOC)
R.Z. Sagdeev (IKI)
G.S. Balayan (Intercosmos)
J.F. Jordan (NASA/JPL)
C.T. Force (NASA/HQ)
K. Hirao (ISAS)

*Technical Coordinators*
R. Münch, F. Hechler (ESA/ESOC)
R. Kremnev, K. Sukhanov (Intercosmos, IKI)
C. Stelzried, J. Ellis (NASA/JPL)

total dust production rate, but also on the outflow velocities of the dust particles and how the total dust mass is distributed between the various particle sizes (dust size spectrum). The dust outflow velocities were calculated using steady-state dusty gas dynamics calculations. According to these calculations a dust particle of 0.1 g mass has an outflow velocity of 20 m/s while a dust particle of $10^{-14}$ g has an outflow velocity of 500 m/s. Large dust particles are more difficult for the solar radiation pressure to turn around than small particles; on the other hand the large particles have smaller outflow velocities. These two effects do not cancel completely and it is interesting to note that, according to calculations, the intermediate-size particles would reach the largest distances from the nucleus and would be encountered first by the spacecraft (Fig. 3). The dust size distribution was believed to follow a power law with exponent −4.2 at the source (because the outflow velocities vary with particle size the exponent is different in the coma). As no observations existed for submicron size particles, the smallest particles in the dust size distribution were assumed to be 0.1 $\mu$m ($\sim 10^{-14}$ g). It was assumed that the cometary ices consisted of 80% water ice, and that, consequently, close to the nucleus 80% of the observed gas would consist of $H_2O$ molecules.

From observations it was known that most of the cometary activity originated from the sunward hemisphere, although some activity on the nightside could not be excluded considering the effect of reradiation from the coma dust onto the nucleus. More recent observations suggested, however, that by far the strongest deviation from a spherically symmetric model came from 'active areas' on the nucleus producing 'dust jets' in the coma, i.e. regions in which the dust density was locally enhanced by a factor 3—10. Trying to locate the active areas on the nucleus, and to understand their physical characteristics and activity pattern was a major goal of WG-1, particularly in the months and weeks before the encounters, because survival was considered questionable once a spacecraft entered a dust jet.

Figure 4 shows the map of active areas on the Halley nucleus immediately before the encounters, derived by Z. Sekanina and S.M. Larson from ground-based observations. From the dust jet activity pattern, the nucleus spin vector and period could also be derived. The period was found to be 52 h, the axis pointing to right ascension 19° and declination −27°.

The Halley nucleus parameters and gas and dust models developed by WG-1 were widely used by both experimenters and spacecraft engineers. The dust-model computer program was distributed to several institutes for use by scientists and spacecraft engineers, while dust-model tables for the Giotto, Vega-1, Vega-2 and Suisei flyby times/distances were distributed to the flight projects. Based on the model it was suggested that the Suisei spacecraft, which carried no dust-protection shield, could be safely targeted to pass the comet nucleus at a distance of less than 200 000 km and would still avoid dust impacts completely.

**IACG Working Group 2: Plasma science**

This group has had the task of:

- studying the various plasma physical processes resulting from the solar-wind/comet interaction
- optimising the scientific return from the cruise phase by making use of the exceptional close co-existence of seven spacecraft (Vega-1, Vega-2, Giotto, Suisei, Sakigake, ICE, Pioneer 7) in interplanetary space, and characterising the interplanetary medium during the various flybys

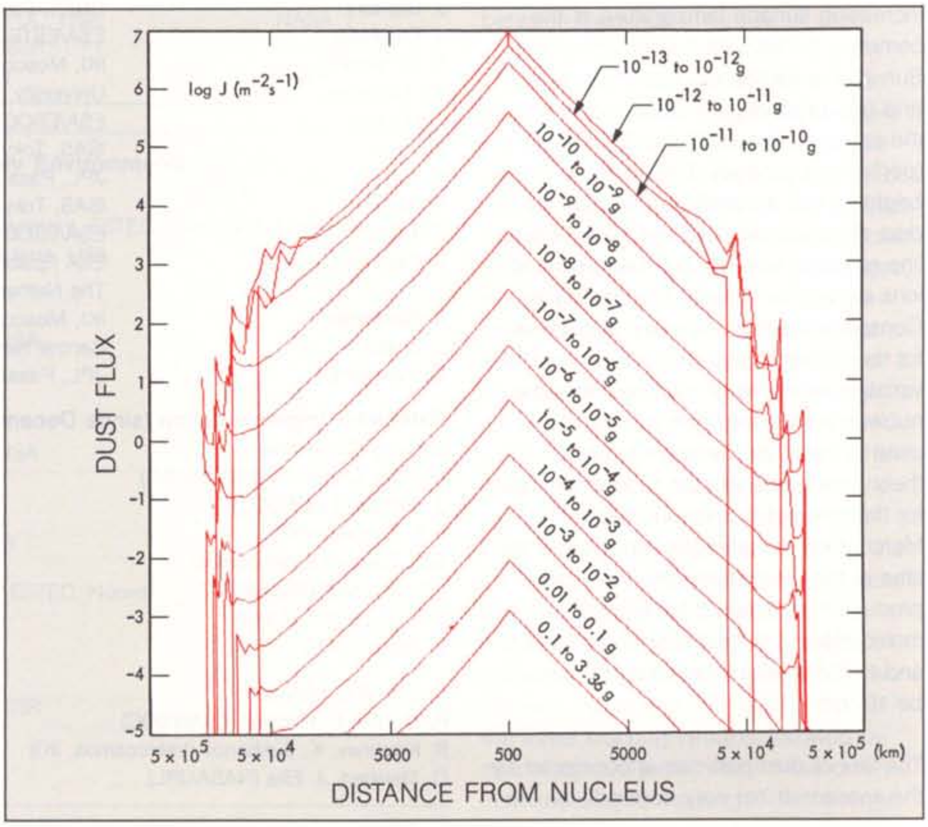



*Figure 3 — Dust flux map (dust particles/m²s) for a Giotto flyby at 500 km on the sunward side of the nucleus*

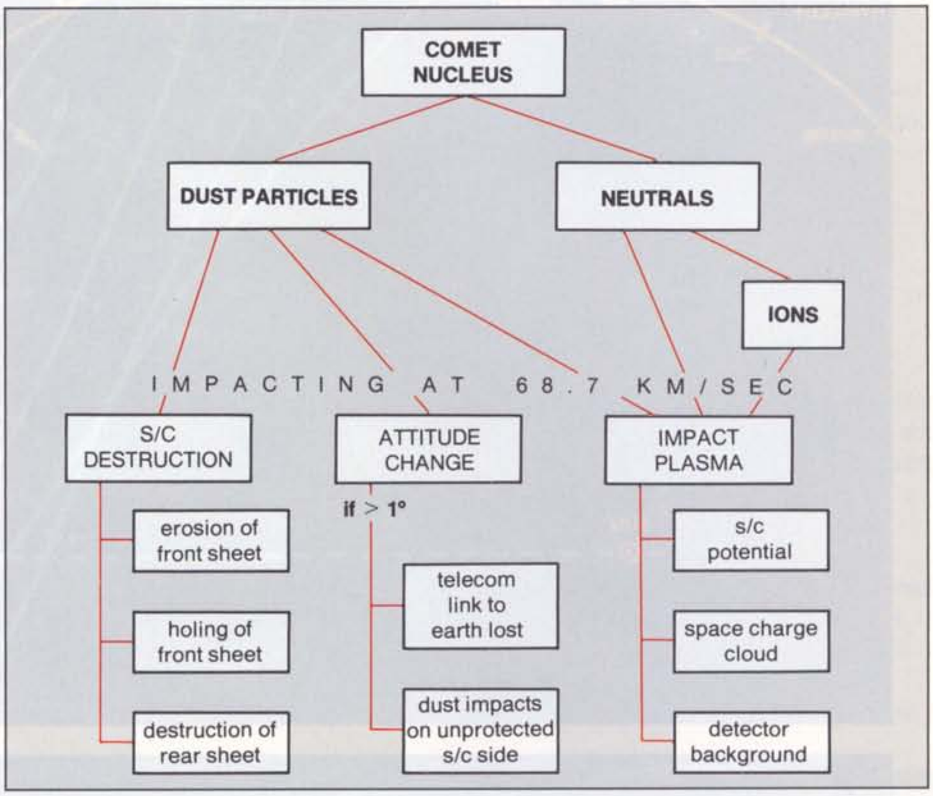
*Figure 4 — Nominal path of Giotto projected onto a map of discrete dust sources on Comet Halley's nucleus at the time of the encounter. Tick marks indicate subspacecraft points at times in seconds from the point of minimum separation. The area of the nucleus (hemisphere) not illuminated by the Sun is shaded. The point of closest approach on the actual trajectory was about 25° to the north—west of the plotted point (or south of the ecliptic), while there was little difference far from the comet (courtesy of Z. Sekanina)*

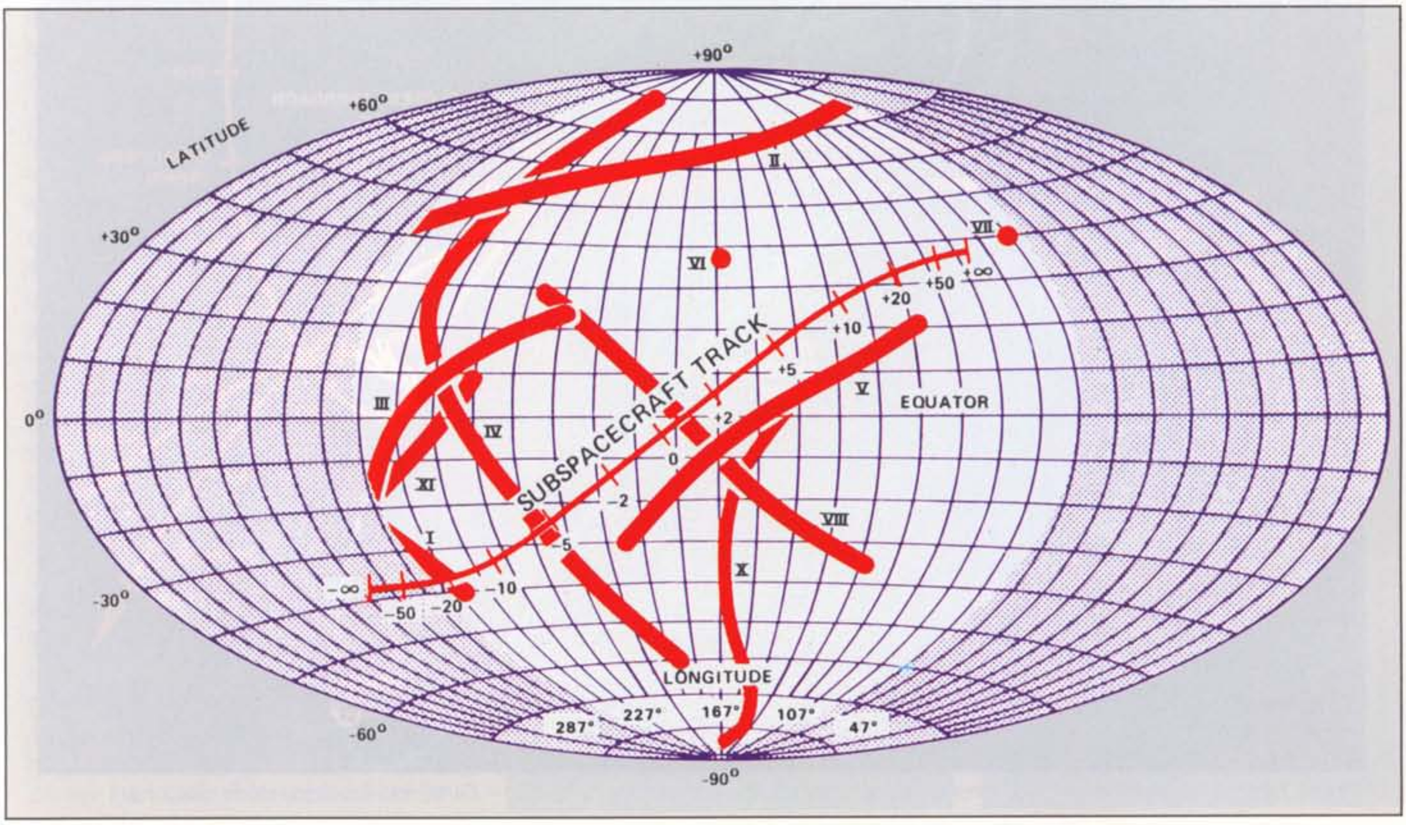
*Figure 5 — Overview of environmental effects*

- stimulating discussion between the plasma experimenters on the various spacecraft
- investigating the effects of the impact-generated plasma around the spacecraft.

As part of the activity of this working group, R. Farquhar (NASA/GSFC) produced plots that showed the trajectories of the various Halley spacecraft relative to a fixed Sun—Earth line (Figs. 6a & b). These plots were very useful in identifying special time intervals during which the acquisition of plasma data could be maximised. These intervals were:

- *15 May—30 June 1985:* During this period Vega-1, Vega-2, MS-T5, Pioneer-Venus and ICE were closely aligned with the expected position of the Venus magnetotail and wake.
- *1 September—30 September 1985:* This period included the ICE traversal of the Giacobini-Zinner tail.



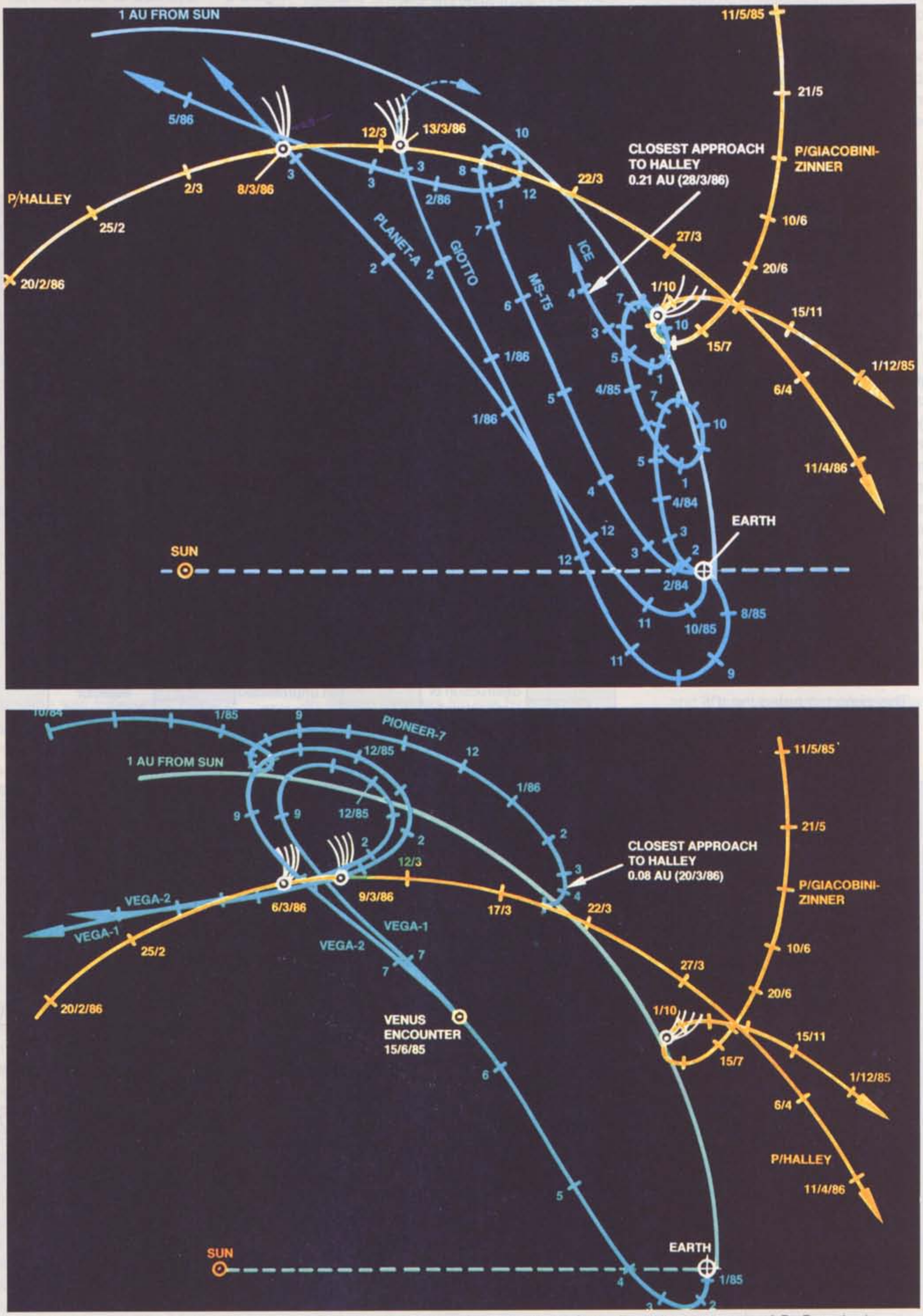



*Figure 6a,b — Trajectories of the various Halley spacecraft relative to a fixed Sun—Earth line (courtesy of R. Farquhar)*

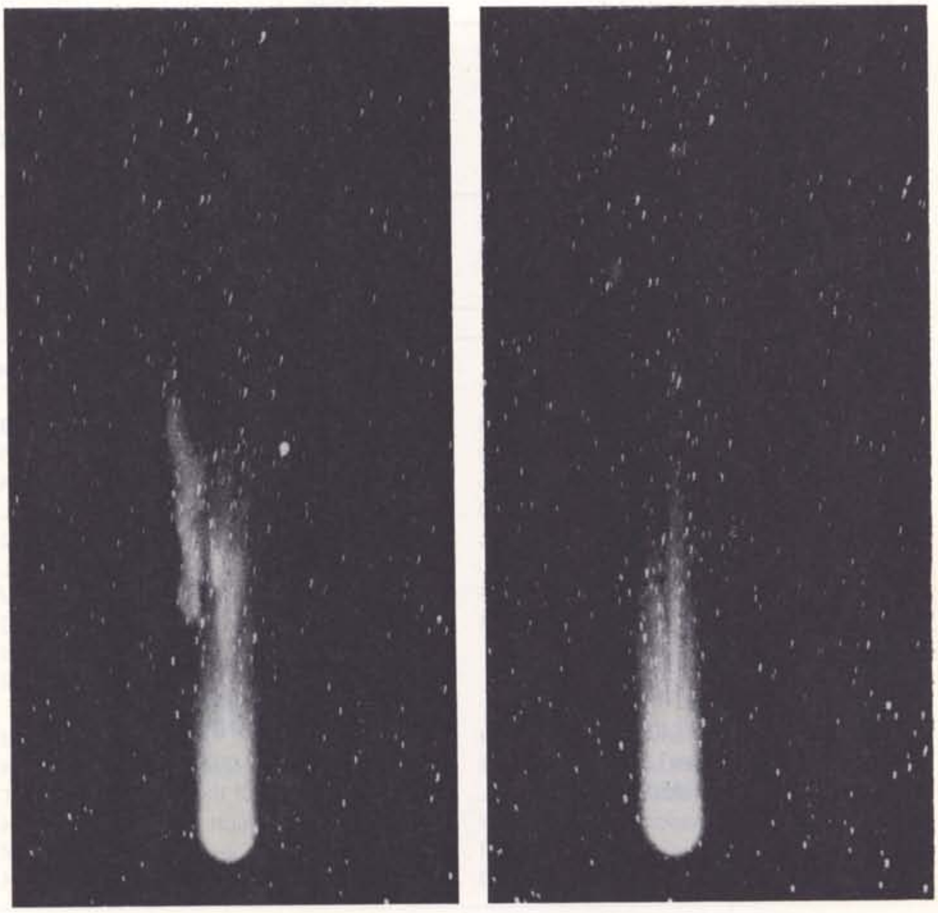


*Figure 7 — Photographs of Halley's Comet taken on 6 June 1910, showing an ion-tail disruption event (courtesy of Lick Observatory, University of California)*

In addition, Giotto, Planet-A, MS-T5, Vega-1, Vega-2 and ICE were all near 1 AU, and they were spread out in solar longitude so that almost one quarter of the inner solar system (about one sector) was covered.

— *1 March—20 March 1986:* During this period, which included the Halley encounters, five spacecraft were very closely aligned in a small solar longitude interval near 1 AU, while ICE was able to provide precursor information on co-rotating streamliners.

Characteristic features of the solar wind (high-speed streams, sector boundaries, etc.) co-rotate with the Sun (sidereal rotation period 25.38 d) and were therefore observed successively by different spacecraft at different azimuthal positions around the Sun. It was important to monitor these solar-wind features with this network of interplanetary spacecraft as the solar-wind/comet interaction processes depend on them. Ion-tail disruption events (Fig. 7), for example, are believed to be caused by sector boundaries interacting with comets.

Intercalibration of the plasma experiments onboard the various spacecraft was important because the experiments were all different. Experience has shown that even carefully but independently calibrated experiments on different spacecraft can give different results.

The studies on the impact-generated plasma were largely carried out to support the plasma experiments onboard Giotto, because they were most directly concerned. As Giotto approached the comet nucleus 14 times closer than any of the other spacecraft, it experienced an impact-generated plasma density around the spacecraft 200 times higher (the cometary dust and gas fluxes increase quadratically towards the nucleus). The impact plasma led to spacecraft charging and produced an ambient plasma denser than the cometary plasma to be measured. Fortunately, the impact-generated ions can be distinguished from the cometary ions by their distinctly different velocity distributions.

Extensive studies were carried out to calculate the degree of ionisation of dust-particle impacts, to measure the secondary electron and ion yield after neutral and ion impact and to computer-simulate the spacecraft plasma environment. (Further information on these aspects of the mission is contained in a number of papers in ESA Special Publication SP-224, available from ESA Publications Division.)

**IACG Working Group 3: Spacecraft navigation and mission optimisation**
This Working Group had the following tasks:

— Improvement of spacecraft-encounter targeting accuracies through:
- dissemination of Halley ephemeris information obtained by the IHW Astrometry Network to all flight projects
- use of Vega-1 and -2 as pathfinders for Giotto.

— Optimisation of flyby trajectories through:
- real-time dissemination of information on cometary behaviour obtained by the IHW (e.g. jets) to all flight projects and information obtained by the early-arriving spacecraft (e.g. dust fluxes) to the later-arriving spacecraft
- exchange of information on shield design to reduce mission risk.

— Optimisation of spacecraft data acquisition during the encounters

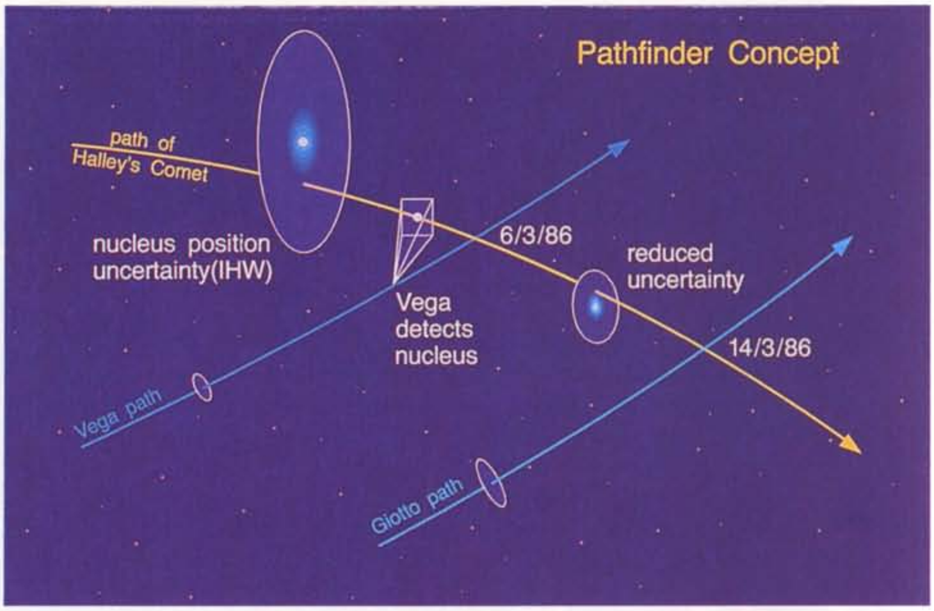



*Figure 8 — Principle of the 'Pathfinder Concept' (courtesy of J.F. Jordan)*

through:

- cooperation in sequencing the experiment-active times and investigation of the possibilities of simultaneous observations from two or more spacecraft
- real-time dissemination of information on cometary phenomena (bow shock and dust envelope) obtained by earlier-arriving spacecraft.

Targeting of the spacecraft with respect to the comet nucleus was a major problem as the nucleus, being disguised by the gas and dust in the coma, could not be observed from Earth. The IHW Astrometry Net had the task of providing the cometary ephemeris to the scientific community, i.e. to all the astronomers who wanted to observe Halley's Comet and to the flight projects that were flying to it.

In March 1986 the expected 1 $\sigma$ uncertainty in the target plane was 370×100 km, achieved by ground-based observations over a long period. The reduced comet positions were used as input for a model that included the effects of the nongravitational forces. These are due to the emission of gas and dust from the heated side of the nucleus, i.e. towards the Sun ('rocket effect'). This uncertainty was more than sufficient for all observations from the ground and near-Earth space, and also for the Japanese Sakigake and Suisei spacecraft flying by at distances >100 000 km. It was even sufficient for the Russian Vega-1 and Vega-2 flying by some 10 000 km away. For Giotto, which was intended to be targeted a few hundred kilometres on the sunward side of the nucleus, a smaller targeting uncertainty was highly desirable. Fortunately, Giotto was the last of the spacecraft to encounter the comet, and the earlier-arriving Vega-1 and Vega-2 spacecraft, having located the nucleus, could pass this information on to Giotto.

This was the so-called 'Pathfinder Concept' (see elsewhere in this issue), the principle of which is illustrated in Figure 8. The four agencies agreed to proceed with the Pathfinder Concept at the IACG meeting in Kagoshima, Japan, in December 1983. ESA's Science Programme Committee (SPC), after reviewing the scientific merits of the Concept, gave its go-ahead on 12 March 1983.

The uncertainty in spacecraft position (30 — 50 km) is shown in Figure 8 as a small circle around the Giotto path, at the time when the last orbit-correction manoeuvre was made. The large circle around the path of the comet reflects the relatively large 1 $\sigma$ uncertainty that could be achieved via the Astrometry Net. Vega located the comet nucleus during its flyby on 6 March 1986 with an uncertainty given by the angular uncertainties in spacecraft attitude and pointing direction of the platform on which the camera was mounted. The Vega position uncertainty also contributed to the error. Using only conventional (6 GHz) ranging and Doppler, Soviet experts expected a geocentric Vega position accuracy of several hundred kilometers. It was estimated that the Vega position uncertainty could be reduced to ~40 km by using Very Long Baseline Interferometry (VLBI) techniques. This was achieved by NASA using the widely separated tracking stations of its Deep Space Network (DSN) and precise L-band VLBI. After processing all the data, the position of the comet nucleus was known with much better accuracy, represented by the small circle around the Halley path. Giotto was targeted to the centre of the small circle projected to the intersection of the comet and the spacecraft paths. Between the time of nucleus detection by Vega and the Giotto encounter, the uncertainty grew slightly due to the nongravitational forces, which cannot be modelled precisely. In fact, both Vega-1 and -2 were used as pathfinders (Fig. 8 shows one Vega for simplicity). The Pathfinder Concept reduced the targeting uncertainty to 40 km (see elsewhere in this issue).

Working Group 3 was dissolved after its last meeting in Kagoshima. By then, its main task, to study the feasibility and achievable improvements of the Pathfinder Concept, had been completed and handed over to a Technical Implementation Group. Its other tasks, in the area of mission optimisation, were split into a scientific definition part, to be carried out by WGs-1 and 2, and a technical part (means of data transfer), under the responsibility of the Technical Implementation Group, because the same lines of communication were used for these data as for the Pathfinder data.

**Near-real-time exchange of scientific data**

The exchange of scientific data in near-real-time, i.e. within days of each encounter, was agreed at the Washington IACG meeting in September 1985. Naturally, the complete data set obtained by all experiments was of interest, but for practical reasons data exchange was limited to:

— dust data
— images
— key Halley parameters

- basic data on the comet/solar-wind interaction
- interplanetary plasma data.

Table 5 shows which type of data were provided by which project. All data that one agency provided on a best-effort basis as input for the data-exchange pool were distributed to all other agencies, with the exception of dust data. The latter were only exchanged between Vega and Giotto, as this exchange involved a large quantity of data, requiring the use of the direct IKI—ESOC computer link established specifically for the Pathfinder Technical Project.

The scientific data that were exchanged during the agreed periods were provided in a form suitable for transmission by contact persons identified for each experiment (usually the Principal Investigators). All science data that were traded as part of this data exchange were not to be published or released to the public in any way or transmitted to persons who might promulgate such

*Table 5 — Near-real-time Halley-environment data exchange. The acronyms refer to the experiments providing the data and participating in the exchange*

| | Vega-1 & 2 | Sakigake | Giotto | Suisei | ICE | IHW |
|---|---|---|---|---|---|---|
| Dust fluxes | SP-2<br>SP-1<br>DUCMA | | MSM (DID-4)<br>CIS<br>IPM | | | |
| Images | TVS | | HMC | UVI | | NNSN |
| Basic data on comet/solar-wind interaction | MISCHA<br>APV-V<br>PLASMAG-1 | | MAG<br>FIS<br>EESA | Solar-Wind Experiment | | |
| Key parameters (nucleus location, dust and gas production rates) | TVS<br>SP-2<br>SP-1<br>DUCMA<br>ING | | HMC<br>MSM (DID-4)<br>CIS<br>IPM<br>NMS | UVI | | |
| Interplanetary plasma data (1-day plots) | | Faraday Cup<br>Magnetometer | MAG<br>FIS<br>EESA | Solar-Wind Experiment | Magnetometer<br>Plasma Electron Experiment | |

**Delegation Members at the Fifth IACG Meeting, Washington DC, USA**

**Chairman**
B.I. Edelson, NASA

**Secretary:**
R. Reinhard, ESA

**ESA Delegation**
R.M. Bonnet, Head of Delegation
K. Barbance
J. Credland
D. Dale
J. Jensen
V. Manno
D.E. Page
I. Pryke
R. Reinhard

**NASA Delegation**
G.A. Briggs, Head of Delegation
J.C. Brandt
C.T. Force
J.W. Head
J.F. Jordan
P.D. Rausch
F.L. Scarf

**Intercosmos Delegation**
R.Z. Sagdeev, Head of Delegation
A.A. Galeev
T.I. Gombosi
N. Ivanov
R.S. Kremnev

**ISAS Delegation**
K. Hirao, Head of Delegation
T. Itoh
H. Oya
M. Shimizu
H. Yamamoto

**IHW Representatives**
R.L. Newburn, Leader Western Hemisphere
J. Rahe, Leader Eastern Hemisphere
S.M. Larson
F.L. Whipple
D.K. Yeomans

data without the permission of the person providing it. All Vega data that were part of this data exchange were provided between 10 and 13 March 1986 to maximise the scientific return of the Giotto encounter, while all Giotto data were provided between 14 and 21 March.

Additionally, observatories participating in the Near-Nucleus Studies Net of the International Halley Watch provided their observations, with a very fast turn-around time, to the Net/Discipline Specialists, who analysed the images and derived from them a set of parameters containing information on the dust jets in the coma and their source locations (active regions) on the nucleus. This dust-jet information was made available to all flight projects, but was particularly useful for Vega and Giotto.

**Use of common coordinate systems**

To avoid unnecessary confusion by using too many different coordinate systems for scientific analysis and for encounter in-situ measurements, the IACG recommended that the flight project experimenters should all use the same set of coordinate systems and asked Working Group 1 to work out a detailed proposal. The WG-1 proposal was distributed in final form, after several revisions, in January 1986, and includes the following five coordinate systems:

(a) Heliocentric
- Comet Orbit Fixed System (COF)

(b) Cometocentric
- Cometocentric Bipolar System (CBS)
- Cometocentric Solar Ecliptic (CSE)
- Topocentric Non-rotating System (TNS)
- Topocentric Rotating System (TRS)

They were derived from Earth-centred analogues and based on practical experience. They are all useful for different applications, and they are general in the sense that they not only apply to Halley investigations, but also to other comets and future, much more

## AGREEMENT

between the European Space Agency and
the Academy of Sciences of the USSR
on Coordination of the International Projects
for Comet Halley's Investigation

The European Space Agency and Academy of Sciences of the USSR,

- taking guidance from the Agreement between the European Space Agency* and Academy of Sciences of the USSR of 12 February 1971, and considering mutual interest in promoting collaboration in peaceful exploration of outer space,
- proceeding from the fact that the European Space Agency and Academy of Sciences of the USSR are interested in obtaining the most complete scientific data on Comet Halley from their Giotto and Vega space missions,
- following up the preliminary understanding reached between technical experts from the European Space Agency and Academy of Sciences of the USSR on the subject, have agreed on the following:

1. Necessary efforts will be made to coordinate the international space missions for Comet Halley's exploration carried out by the European Space Agency (the Giotto project) and by the Academy of Sciences of the USSR (the Vega project).
2. With the aim of improving the Comet Halley ephemeris and Giotto spacecraft trajectory, the Academy of Sciences of the USSR will make efforts for timely delivery of the navigation information obtained with the help of technical means onboard the Vega spacecraft to the European Space Agency. The European Space Agency will make efforts for timely delivery of the data on ground-based astrometric observations of Comet Halley and VLBI observations of the two Vega spacecraft.
3. Timing of exchange and the extent of data to be exchanged according to para 2 of the Agreement will be determined by technical experts of both sides supervised by a Steering Committee including authorized representatives of the European Space Agency and Academy of Sciences of the USSR.
4. In the course of coordination of the Giotto and Vega international projects, as provided by the Agreement, each side will assume scientific technical and financial responsibility for the implementation of its own project only.
5. This Agreement becomes effective upon signing.

| for European Space Agency | for Academy of Sciences of the USSR |
|---|---|
| R.M. Bonnet<br>Director of Scientific Programmes<br>for ESA | R.Z. Sagdeev<br>Director of Space Research<br>for USSR Academy<br>of Sciences |

* European Space Research Organisation before 1975

## AGREEMENT

between the European Space Agency and
the Academy of Sciences of the USSR
on the Exchange of Halley Environment Science Data
in Near-Real Time

The European Space Agency and the Academy of Sciences of the USSR,

— taking guidance from the Agreement between the European Space Agency* and the Academy of Sciences of the USSR of 12 February 1971, and considering their mutual interest in promoting collaboration in peaceful exploration of outer space,
— proceeding from the fact that the European Space Agency and the Academy of Sciences of the USSR are interested in obtaining the most complete scientific data on Comet Halley from the Giotto and Vega missions,
— following up the preliminary understanding on the subject reached between the European Space Agency and the USSR Academy of Sciences at their meeting on 20 and 22 June in Vienna

have agreed on the following:

1. The USSR Academy of Sciences will make the necessary efforts for a timely delivery of the Vega Project science data specified in Appendix 1.
2. The European Space Agency will make the necessary efforts for a timely delivery of the Giotto Project science data specified in Appendix 2.
3. The science data to be exchanged will be from comparable experiments on the different spacecraft and will be similar in quantity.
4. The scientific data to be exchanged during the agreed periods will be provided in a form suitable for transmission by contact persons identified in the Appendices for each experiment participating in the data exchange.
5. All Vega data will be provided to Giotto as a function of Universal Time Coordinates (UTC), all Giotto data will be provided to Vega as a function of Spacecraft Time. Separately provided software will allow the Vega Project to transform Giotto Spacecraft Time into distance from the nucleus.
6. Vega data will be provided to Giotto between 10 and 14 March, and Giotto data will be provided to Vega between 14 and 21 March 1986.
7. Vega and Giotto dust data will be transmitted via the IKI-ESOC computer link established for the Pathfinder Technical Project. It is agreed that Pathfinder data have priority. For system verification, test data will be transmitted via this computer link in February. The tests and the near-real time transmissions during the agreed periods will be coordinated by the Pathfinder Technical Coordinators. In case the line is not available during the agreed period (Pathfinder priority, line drop-out), an identified data subset will be transmitted by fax, telex or voice communication.
8. Both Agencies will make best efforts to ensure that all science data exchanged under this Agreement will not be published or released to the public in any way or transmitted to persons who might publish or release such data without the permission of the person providing the data.
9. In the course of coordination of the Giotto and Vega Projects, as provided by the Agreement, each side will assume scientific, technical and financial responsibility for the implementation of its own project only.
10. This Agreement becomes effective upon signing.

Moscow, 15th January 1986

| | |
|---|---|
| For the European Space Agency | For the Academy of Sciences of the USSR |
| R.M. Bonnet<br>Director of Scientific Programmes<br>European Space Agency | R.Z. Sagdeev<br>Director of Space Research<br>USSR Academy of Sciences |

* European Space Research Organisation before 1975

detailed investigations (e.g. landing on a comet).

**Post-encounter data exchange**
Realising that all flight projects would benefit from the exchange of all Halley-encounter science data, it has been agreed to exchange data-pool tapes no later than two years after the encounters. These tapes will also be provided to the IHW Archive, where they will be stored together with all other data (ground-based and near-Earth) on Halley's Comet. The IHW has selected the 12 cm CD ROM as the medium for the primary archive, each holding 540Mbytes of data.

This exchange of all encounter imaging data could allow the first complete map of any cometary nucleus to be constructed, as the cameras on each flyby mission essentially observed only one half (the day side) of the nucleus.

**The 1986 Symposium on Halley's exploration**
In order to limit the amount of travelling necessary in the post-Halley-encounter period and at the same time allow all scientists from the various space missions to get together, the IACG decided in 1983 to support only one major conference on the exploration of Halley's Comet. This Symposium will take place from 27—31 October 1986 in Heidelberg, Germany, and is being jointly organised by the Space Science Department of ESA and the Max-Planck-Institut für Kernphysik in Heidelberg. It is sponsored by the IACG and the IHW, and co-sponsored by COSPAR and the IAU.

The aim of this Symposium is to bring together the investigators of the various space missions to Halley's Comet and other scientists involved with the theory, ground-based or near-Earth space observations of the Comet. While the main emphasis of the Symposium will be on Halley, discussion of and papers on other comets, in particular Giacobini-Zinner, are also being welcomed, bearing in mind the need to put the Halley results into proper perspective.

The Symposium will be preceded (one week earlier) by a General Meeting of the IHW and by three IACG Topical Workshops on 'Imaging', 'Dust', and 'Plasma, Ion Composition and Neutral Gas'. It will be followed by a Meeting of the IACG and by the Annual Meeting of the Division of Planetary Sciences (DPS).

**Future of the IACG**
All agencies agree that it is desirable to continue the IACG beyond 1986 on an informal, non-institutionalised basis, as this will allow greater flexibility in maximising the information exchanges and the planning of cooperative activities to investigate Halley.

At the Washington meeting of the IACG, three candidate areas were identified for cooperation within the framework of an IACG:
— Solar-terrestrial science
— Planetary and primitive bodies
— Radio astronomy.

In order to be able to discuss this matter in more detail at the next meeting in Padua, the IACG delegations agreed to set up three Working Groups, one for each of the areas identified above. These Working Groups will consider mission possibilities and agency planning and will explore the scope for further cooperation. Based on their reports at the Padua meeting, the IACG will select the project that is most appropriate for future cooperation.

**Conclusion**
From the IACG's formation in 1981, it demonstrated an ever-growing usefulness for the various projects as a focal point for exchange of information, discussion on common problems, and mutual support to enhance the overall scientific return from the space missions to Halley's Comet.

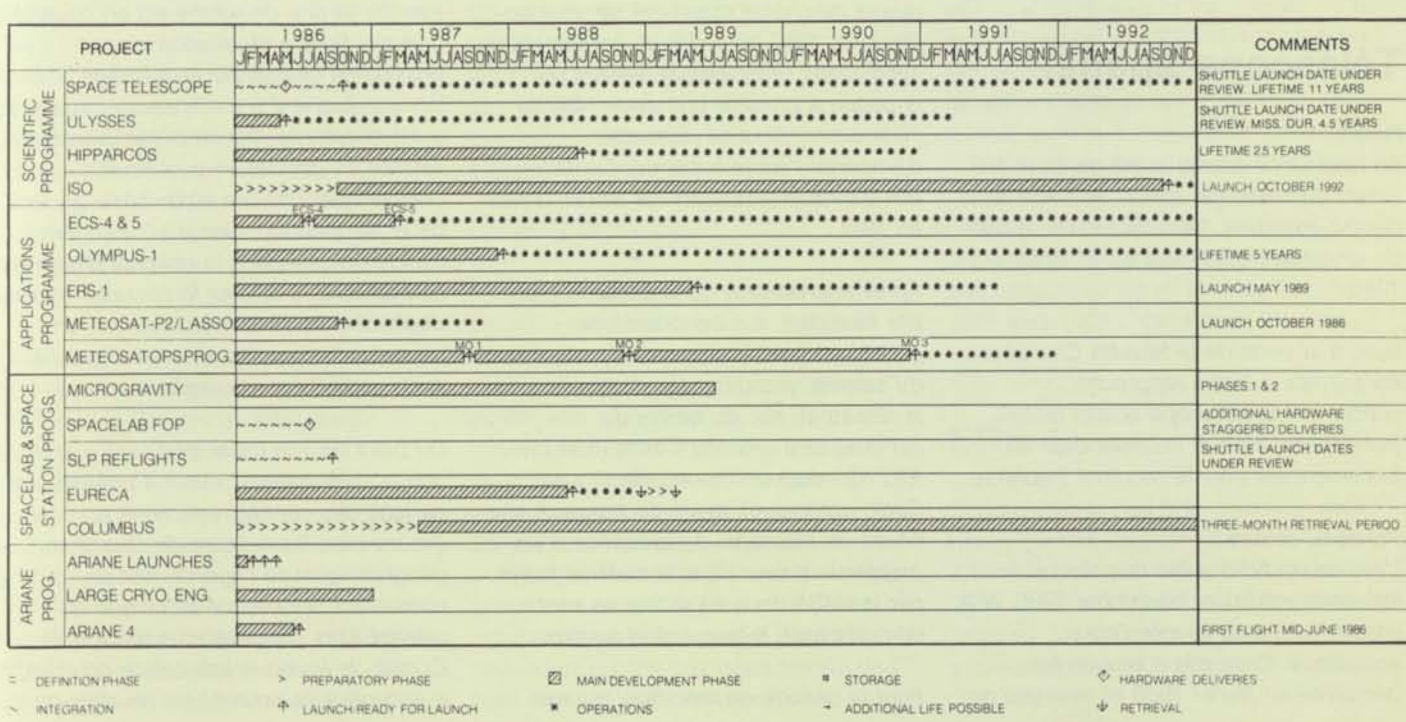
The achievements to date of the IACG and its three associated Working Groups include:
— exchange of information on spacecraft (in particular the dust bumper shield) and experiment design
— intercalibration of experiment sensors
— implementation of the 'Pathfinder Concept'
— development and distribution of Halley gas and dust models, including dust jets, determination of parameters for the nucleus
— exchange of results of models on impact-generated plasma which will develop around the spacecraft during the flybys
— exchange of Halley spacecraft orbital data
— exchange of information on spacecraft and experiment performance and mission planning, and in particular on experiment operation times
— use of common coordinate systems
— definition of special periods for cruise science
— near-real-time exchange of scientific data, i.e. within days of the encounters
— organisation of topical Workshops and a major Halley Symposium (in Heidelberg in October 1986)
— exchange of all encounter science data within two years after the encounter
— exchange of information on future mission plans with the possibility of future cooperation.

The IACG and its counterpart on the ground, the IHW, have formed the cornerstones of a global effort to explore Halley's Comet as completely as possible during its present apparition. By the end of the 1980s, when it will disappear again into the outer solar system, Halley's Comet will be the most thoroughly studied comet ever, with more data having been collected on it than on all other comets put together.

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

## In Orbit / En orbite


## Under Development / En cours de réalisation



## Marecs

*Marecs-A, lancé en décembre 1981 et en service pour Inmarsat au-dessus de la région de l'Océan Atlantique depuis mai 1982, a maintenant passé plus de quatre ans en orbite. Marecs-B2, lancé en novembre 1984, a achevé sa première année de service opérationnel dans la région de l'Océan Pacifique le 31 décembre 1985.*

*Le trafic d'Inmarsat dans la région de l'Océan Atlantique, qui s'est développé au cours des quelques dernières années à une cadence supérieure à celle qui était prévue au départ et qui constitue maintenant quelque 70% du trafic global total, saturera bientôt la capacité de Marecs-A aux heures de trafic de pointe. Marecs-B2 a une capacité un peu supérieure à celle de Marecs-A, et c'est pourquoi Inmarsat a récemment demandé à l'ESA d'échanger les deux satellites.*

*Marecs-B2, dans une manoeuvre de rétablissement amorcée le 15 janvier 1986, a été déplacé vers l'ouest de 5 degrés par jour à partir de la longitude de 177,5° E. Il a atteint la longitude de 26° W le 24 février, et le transfert de trafic de Marecs-A à Marecs-B2 a eu lieu le 28 février. Le rétablissement de Marecs-A a commencé le 4 mars, et Marecs-A dérive maintenant vers l'ouest de 3 degrés par jour vers la longitude de 177,5° E, qu'il atteindra le 10 mai.*

## Téléscope spatial

**NASA**
*En raison des retards subis pendant les essais du téléscope spatial, la NASA a décidé en janvier 1986 de reculer la date de lancement du 8 août au 27 octobre 1986.*

*Suite à la perte de la Navette Challenger, les activités à terme rapproché concernant le téléscope spatial restent inchangées, mais la nouvelle date de lancement est pour le moment inconnue.*

**Panneau solaire**
*L'aile de vol N° 1 a été montée sur le téléscope spatial en décembre 1985, et a ensuite subi avec succès l'essai acoustique. Cette aile a ensuite été démontée en février 1986 et renvoyée en Europe pour y compléter son programme de vérification.*

*L'aile en vol N° 2 a été transportée à l'IABG à Munich pour y subir son essai acoustique, et se trouve maintenant avec l'aile N° 1 chez British Aerospace à Bristol pour y compléter son programme de vérification avant livraison finale.*

**Caméra à objets faibles**
*La caméra à objets faibles a été démontée, ainsi que tous les autres instruments, en décembre pour réfection. Les unités d'interface à distance fournies par la NASA ont été remplacées, ainsi que le détecteur f/96 suspect. Le détecteur suspect a été renvoyé pour examen.*

## Ulysse

*Les préparatifs pour le lancement d'Ulysse (l'ancien ISPM), qui était prévu en mai de cette année, ont subi un arrêt brutal quand la Navette Challenger explosa une minute après le décollage. Il était prévu qu'Ulysse serait sa prochaine charge utile. Bien qu'il ait été annoncé officiellement qu'il n'y avait aucune possibilité de lancement en 1986, aucune déclaration n'a encore été faite quant à la date à laquelle le lancement pourrait avoir lieu.*

*Des occasions de lancement d'Ulysse se présentent tous les treize mois, si bien que la prochaine possibilité se situe en juin-juillet 1987 et, à défaut, en juillet-août 1988. Dans l'intervalle, la NASA s'est engagée à modifier une autre Navette ('Discovery') pour lui permettre d'emporter l'étage supérieur Centaure, afin d'avoir la possibilité de lancer Ulysse en 1987.*

*Après appréciation de la situation créée par l'accident, il a été décidé de poursuivre tous les essais préparatoires du satellite, y compris les interfaces avec le réseau au sol, du centre de commande à JPL, du Centaure et du RTG (Générateur Thermo-électrique Radio-isotopique), avant de passer à une phase de stockage. A l'exception d'un problème mineur dans le matériel fourni par la NASA, tous les essais se sont déroulés avec le plus grand succès.*

*Pour la période de stockage, qui est supposée devoir durer un an environ, le satellite doit être maintenu dans son conteneur de transport dans une chambre propre au Centre Spatial Kennedy (KSC), avec une purge d'air sec. Les pièces de rechange de vol et le matériel similaire doivent également être stockés dans cette chambre propre. Le reste du matériel électronique dont on n'a pas besoin en Europe doit être stocké dans une chambre climatisée au KSC, et le gros matériel au sol dans un entrepôt local. Le matériel dont on a besoin en Europe a été retransporté par bateau ou par avion, suivant le cas. L'ensemble de ces activités, concernant plus de 60 tonnes de matériel, a été achevé en moins de cinq semaines après la perte de la Navette, et la campagne de lancement d'Ulysse a officiellement pris fin le 5 mars.*

## ISO

*A mesure que les mois passent, des progrès sont faits sur de nombreux fronts, scientifique, technique et gestion. Suite aux efforts d'optimisation des expériences qui ont été faits à l'automne de 1985, les quatre groupes de chercheurs sont tous en train de faire de nets progrès dans la conception de leurs instruments et dans la définition des interfaces détaillées avec le satellite.*

*Une modification technique très importante a été apportée au concept du satellite, et une deuxième est en cours d'étude. Suite à l'évaluation des possibilités offertes par le passage d'un lanceur Ariane 2 à un lanceur Ariane 4, il a été décidé de réduire la complexité du satellite en utilisant un seul liquide cryogénique, l'hélium superfluide, au lieu de le 'tamponner' avec de l'hydrogène liquide comme dans le concept d'origine. La possibilité d'enlever le panneau solaire déployable et de le remplacer par un panneau fixe sur l'écran solaire est elle aussi activement envisagée.*

*Du point de vue de la gestion, il y a eu une activité majeure visant à produire un partage des contrats industriels en accord avec les besoins de répartition géographique de l'Agence tout en conservant l'excellence technique du satellite. Lors d'une récente réunion, le Comité de Politique Industrielle de l'ESA a accepté à l'unanimité les résultats de*

## Marecs

Marecs-A, launched in December 1981 and in operation for Inmarsat over the Atlantic Ocean Region since May 1982, has now completed more than four years in orbit. Marecs-B2, launched in November 1984, completed its first year of operational service over the Pacific Ocean Region on 31 December 1985.

Inmarsat traffic in the Atlantic Ocean Region, which has grown in the last few years at a greater rate than originally predicted and now constitutes some 70% of total global traffic, will soon saturate the capacity of Marecs-A at peak traffic times. Marecs-B2 has a somewhat greater capacity than Marecs-A and Inmarsat therefore recently asked ESA to exchange the two spacecraft.

In a relocation manoeuvre commenced on 15 January 1986, Marecs-B2 was moved westwards at 5 deg/day from 177.5°E longitude. It arrived at 26°W on 24 February 1986, and transfer of traffic from Marecs-A to Marecs-B2 took place on 28 February. Relocation of Marecs-A commenced on 4 March, and it is now drifting in a westerly direction at 3 deg/day towards 177.5°E, where it will arrive on 10 May.

## Space Telescope

**NASA**
Due to delays experienced during the testing of the Space Telescope, NASA decided in January to slip the launch date from 8 August to 27 October 1986. Following the loss of the Shuttle Challenger, the near-term activities on Space Telescope remain unchanged, but the new launch date is currently unknown.

**Solar array**
Flight-wing 1 was fitted to the Space Telescope in December 1985, and subsequently successfully passed the acoustic test. This wing was then removed in February 1986 and returned to Europe to complete its verification programme.

Flight-wing 2 was transported to IABG in Munich for its acoustic test, and is now with Flight-wing 1 at BAe in Bristol completing its verification programme prior to final delivery.

**Faint Object Camera**
The Faint Object Camera was removed, together with all the other instruments, in December 1985 for reworking. The NASA-provided remote interface units were replaced as well as the suspect f/96 detector. The suspect detector has been returned for investigation.

## Ulysses

Preparations for the launch of Ulysses (formerly ISPM) in May of this year came to an abrupt halt when the Shuttle Challenger exploded one minute after lift-off. Ulysses was scheduled to be its next payload. Although it has been announced officially that there will be no possibility to launch in 1986, no statement has yet been made as to when launch may take place.

Opportunities to launch Ulysses arise every thirteen months, so that the next possibility is in June/July 1987 and, failing that, in July/August 1988. In the meantime, NASA has committed itself to modifying another Shuttle 'Discovery' to enable it to carry the Centaur Upper Stage, in order to have the possibility of a launch in 1987.

After appraisal of the situation created by the accident, it was decided to continue with all preparatory testing of the spacecraft, including interfaces with the ground network, the control centre at JPL, the Centaur and the RTG (Radio-isotope Thermoelectric Generator), prior to entering a storage phase. With the exception of one minor problem in NASA-supplied equipment, all tests were extremely successful.

For the storage period, assumed to be approximately one year, the spacecraft is to be kept in its transport container in a clean-room at Kennedy Space Center (KSC), with a purge of dry air. Flight spares and similar equipment are also to be stored in the clean room. Other electronic equipment not needed in Europe is to be stored in an air-conditioned room at KSC and the heavy ground equipment in local warehouse accommodation. Equipment that is needed in Europe has been transported back by sea or air, as appropriate. All of this activity, involving over 60 tons of equipment, was completed in less than five weeks after the Shuttle's loss and the Ulysses launch campaign was officially terminated on 5 March.

## ISO

As the months pass, progress is being made on many fronts, scientific, technical and managerial. Following the experiment optimisation efforts in the autumn of 1985, all four investigator groups are making good progress with the design of their instruments and in the definition of the detailed interfaces with the satellite.

One very significant technical change has been made in the satellite concept and a second one is under study. Following evaluation of the possibilities offered by the change from an Ariane-2 to an Ariane-4 launch vehicle, it has been decided to reduce the complexity of the spacecraft by using a single cryogenic liquid (superfluid helium) instead of buffering it with liquid hydrogen as in the original concept. The possibility of removing the deployable solar array and replacing it with a fixed array on the Sun shield is also being actively considered.

On the management front, there has been a major activity aimed at producing a partition of industrial contracts in line with the geographical-distribution needs of the Agency whilst still maintaining the technical excellence of the satellite. At a recent meeting, the ESA Industrial Policy Committee unanimously accepted the results of this effort and gave permission for the issue of a Request for Quotation (RFQ) for the detailed Phase-B study to a consortium headed by Aerospatiale (France). The reply to this RFQ is expected in late June and, following evaluation, it is hoped to have Member-State approval to start Phase-B in early October.

## ERS-1

Good progress has been made in areas where the Development Baseline Review (DBR), conducted in October/November 1985, concluded that further work was required. Manufacture of structural and engineering-model hardware has also commenced.

*cet effort et a donné son autorisation pour l'émission d'une demande d'offre de prix (RFQ) pour l'étude de Phase B détaillée à un consortium mené par l'Aérospatiale (France). La réponse à cette RFQ est attendue à la fin du mois de juin et, suite à une évaluation, on espère avoir l'approbation des Etats membres pour commencer la Phase B début octobre.*

## Olympus

*La Revue de Conception Critique de la charge utile de diffusion d'émissions de télévision a eu lieu en février, et la revue équivalente de la charge utile de répéteurs de 20 et 30 GHz aura lieu en mars.*

*Les essais dynamiques du modèle structurel de satellite ont été achevés vers la fin de 1985, et une revue d'essai concluante s'est tenue à la mi-décembre. Le satellite a ensuite été renvoyé chez le maître d'oeuvre, où il subit actuellement une série d'examens postérieurs aux essais.*

*Les essais infrarouges hors ligne utilisant le modèle thermique de satellite ont été achevés. Les résultats, après traitement, seront finalement comparés aux essais de simulation solaire de base qui ont déjà été effectués sur ce modèle. Le modèle thermique de satellite est actuellement préparé en vue d'une série d'essais spéciaux pour vérifier la libération correcte des panneaux solaires et des antennes dans des conditions d'ambiance correspondant au pire des cas.*

*Le module d'intervention du modèle d'identification de satellite a été transporté à Rome à la fin de l'année dernière, et l'intégration initiale du sous-système de commande d'attitude et d'orbite se déroule en parallèle avec les activités concernant la charge utile qui sont en cours. Les modules d'intervention et de communications devraient être accouplés pendant le mois de mars et être prêts pour le début des essais de base et de compatibilité avec la charge utile. Les panneaux de la charge utile de communications nord et sud du modèle de vol de satellite ont été livrés aux contractants de la charge utile, et l'intégration des charges utiles de vol a commencé.*

*La fabrication de cinq types différents de stations sol d'essai, de démonstration et de surveillance est en cours. L'évaluation des propositions concernant les deux autres types est elle aussi en cours. Le groupe de travail sur les stations terriennes d'Olympus s'est réuni en janvier 1986.*

## ERS-1

*De nets progrès ont été faits dans de nombreux secteurs dans lesquels la revue de base de mise au point (DBR), effectuée en octobre-novembre 1985, avait conclu que des travaux complémentaires étaient nécessaires. La fabrication du matériel du modèle structurel et du modèle d'identification a également commencé.*

*L'établissement de documents contractuels majeurs tels que le cahier des charges du système de satelite, le plan de conception et de mise au point, et le cahier des charges de l'interface entre le satellite et le secteur sol, a encore progressé.*

*Des progrès ont également été faits dans la résolution de plusieurs problèmes relatifs à la compatibilité de la plate-forme avec la charge utile. Des modifications ont été apportées aux propulseurs pour qu'ils puissent recevoir un satellite à centre de gravité plus haut, ainsi qu'à l'électronique de distribution d'énergie pour qu'elle permette une puissance suffisante pour le chauffage de la charge utile. La conception et la mise au point de la charge utile se déroulent bien, et de nombreuses maquettes sur table et de nombreux modèles de mise au point sont actuellement en cours d'essais.*

*Le contrat entre l'ESA et Arianespace pour la fourniture d'un lanceur Ariane 4 et des services correspondants a été signé.*

*Une campagne de diffusiométrie en bande C au-dessus de la Méditerranée à proximité de l'Espagne a été menée à bien entre la mi-janvier et le début de février 1986. Sept vols ont été effectués, et des vitesses de vent variant entre 4 et 25 noeuds ont été observées. Il est prévu de continuer la campagne en effectuant des mesures dans le détroit de Sicile à la fin de février.*

## Météosat

### Programme pré-opérationnel

*Le modèle Météosat-P2 a subi de nouveaux essais en préparation de son lancement. Un essai de radiomètre a été parfaitement concluant et a permis de vérifier le fonctionnement correct des chaînes infrarouge et vapeur d'eau complètes. Un essai acoustique au niveau de recette avec le satellite connecté a lui aussi été effectué de manière satisfaisante.*

*Le matériel Lasso a été livré et monté sur le satellite. Des mesures de masse ont été effectuées avant que le satellite soit préparé pour des essais acoustiques.*

*Le 'mini-EGSE' (EGSE = Matériel Electrique de Prise en Charge au Sol), qui avait été commandé pour résoudre les problèmes de calendrier, a été livré et accepté.*

*Le lancement d'Ariane 4-01 a encore été retardé et n'aura pas lieu maintenant avant le 15 octobre 1986.*

*Pour préparer le satellite MOP-1 en vue de son lancement en septembre 1987, l'ESA et l'Aérospatiale sont convenues de diviser la campagne de lancement de P2 en deux phases. La première phase aura lieu en juillet, et pendant cette phase le satellite et le moteur auxiliaire d'apogée seront préparés puis stockés à la base de lancement jusqu'à trois semaines avant le lancement, quand les préparatifs finals auront lieu.*

*Pour cette seconde phase, seul un équipage réduit de l'Aérospatiale sera nécessaire, pour permettre à la société de maintenir ininterrompues les activités parallèles du MOP-1.*

Lasso

*Le sous-système du modèle de vol de Lasso a été livré à l'Aérospatiale à la mi-janvier. Le sous-système intégré a été soumis à des essais utilisant un matériel d'essai électrique et optique. La précision obtenue dépassait nettement celle du cahier des charges. La compatibilité de l'expérience Lasso avec le satellite et le radiomètre a été démontrée par des séquences d'essais extensives.*

*Le rétroréflecteur du modèle de vol sera assemblé ultérieurement pour éviter une dégradation du revêtement métallique des cubes d'angle. L'application de ce*

Major contractual documents such as the satellite system specifications, the Design and Development Plan, and the Satellite to Ground Segment Interface Specification have been further advanced.

Progress has also been made towards solving several problems related to the compatibility of the platform with the payload: modifications have been made to the thrusters to accommodate a higher satellite centre of gravity, and to the power-distribution electronics to allow sufficient power for payload heating. Payload design and development is proceeding well and many breadboards and development models are currently under test.

The contract between ESA and Arianespace for the provision of an Ariane-4 launcher and associated services has been signed.

A C-band scatterometer campaign over the Mediterranean near Spain was successfully carried out between mid-January and the beginning of February 1986. Seven flights have been made, with observed wind speeds varying between 4 and 25 knots. It is planned to continue the campaign with measurements in the straits off Sicily at the end of February.

## Olympus

The Critical Design Review for the television-broadcast payload was held in February and the equivalent review of the 20/30 GHz repeater payload will take place in March.

Dynamic testing of the structural-model spacecraft was completed towards the end of 1985 and a successful test review was held in mid-December. The spacecraft was then returned to the Prime Contractor's facility, where it is now being subjected to a series of post-test examinations.

The offline infrared tests using the thermal-model spacecraft have been completed. The processed results will eventually be compared with the baseline solar-simulation tests already conducted on that model. The thermal-model spacecraft is currently being prepared for a series of special tests to verify the correct release of the solar arrays and antennas under worst-case environmental conditions.

The service module of the engineering-model spacecraft was transported to Rome at the end of last year and initial integration of the attitude and orbit control subsystem is proceeding in parallel with ongoing payload activities. The service and communications modules are expected to be coupled during March ready for the start of payload baseline and compatibility testing. The north and south communications payload panels of the flight-model spacecraft have been delivered to the payload contractors and integration of the flight payloads has started.

Manufacture of five different types of test, demonstration and monitoring ground stations is in progress. Evaluation of proposals for the remaining two types is in progress. The Olympus earth-station working group met in January 1986.

## Meteosat

### Pre-Operational Programme

The Meteosat P2 model has undergone further testing in preparation for its launch. A radiometer test was completely successful and verified the proper operation of the complete infrared and water-vapour chains. An acceptance-level acoustic test with the spacecraft switched on was also performed satisfactorily.

The Lasso equipment has been delivered and mounted on the satellite. Mass measurements were performed before the satellite was prepared for acoustic tests.

The 'mini-EGSE' (EGSE = Electrical Ground-Support Equipment) ordered to relieve schedule problems has been delivered and accepted.

The launch of Ariane-4 01 has slipped further and will not now take place earlier than 15 October 1986.

To prepare the MOP-1 satellite for launch in September 1987, ESA and Aerospatiale have agreed to split the P2 launch campaign into two phases. The first phase will take place in July, during which the satellite and the apogee boost motor will be prepared and then stored at the range until three weeks before launch, when the final preparations will take place.

For this second phase, only a skeleton crew from Aerospatiale will be required, allowing the company to maintain the parallel MOP-1 activities uninterrupted.

### Lasso

The Lasso flight-model subsystem was delivered to Aerospatiale in mid-January. The integrated subsystem was tested using electrical and optical test equipment. The precision obtained is well within specification. The compatibility of the Lasso experiment with the satellite and the radiometer has been demonstrated by extensive sequences of tests.

The flight-model retro-reflector will be assembled later to avoid degradation of the metallic coating of the corner-cubes. This coating process is currently underway at Matra-Vélizy.

At the Third Lasso Experimenters' Meeting, held on 4—5 February 1986, growing interest in the present experiment was apparent and also in a second generation of the Lasso package.

A fourth meeting is foreseen for 3—4 June at the San Fernando laser station.

### Operational Programme

*Space segment*

All Engineering Qualification Model subsystems have been delivered to Aerospatiale, where they have been integrated into the P1 R (Refurbished Protoflight-1) model. Testing at system level has progressed smoothly. A few problems were detected and the causes of these are under investigation. An EMC test was also carried out and indicated a sensitivity at the S/C/radiometer interface. Corrective measures for this are under discussion between the project team and the Prime Contractor.

With the EQM subsystem delivered by the co-contractors, the manufacture of flight hardware has started and some units have already been delivered: the MOP-1 harness has been delivered by CASA and the structural subsystem, with the AOCS subsystem integrated, by MBB/MSS.

The visible detectors are still on a critical path and the situation is being closely *revêtement est actuellement en cours chez Matra à Vélizy.*

*Lors de la troisième réunion des expérimentateurs de Lasso, qui s'est tenue les 4 et 5 février 1986, un intérêt croissant pour l'expérience actuelle s'est manifesté, ainsi que pour une seconde génération du matériel d'expérience Lasso.*

*Une quatrième réunion est prévue pour les 3 et 4 juin 1986 à la station laser de San Fernando.*

**Programme opérationnel**

Secteur spatial

*Tous les sous-systèmes de l'EQM (Modèle de Qualification d'Identification) ont été livrés à l'Aérospatiale, où ils ont été intégrés au modèle de P1R (Prototype de Vol N° 1 Reconstruit). Les essais au niveau du système ont progressé régulièrement. Quelques problèmes ont été decelés, et leurs causes sont en cours d'examen. Un essai de compatibilité électromagnétique a également été effectué et a révélé une certaine sensibilité à l'interface SIC-radiomètre. Des mesures correctrices sont en cours de discussion entre l'équipe de projet et le maître d'oeuvre.*

*Avec le sous-système d'EQM livré par les cocontractants, la fabrication du matériel de vol a commencé, et certaines unités ont déjà été livrées: le faisceau de câbles du MOP-1 a été livré par CASA et le sous-système structurel, avec le sous-système AOCS intégré, par MBB/MSS.*

*Les détecteurs visibles se trouvent encore sur un chemin critique, mais la situation fait l'objet d'une surveillance étroite. Les préparatifs de la prochaine revue au niveau du système, la Revue de Base de Production, ont été achevés, et cette revue aura lieu en avril.*

*Un lancement en septembre 1987 a été confirmé avec Arianespace.*

Secteur sol

*La reconstruction du secteur sol s'effectue selon des calendriers préétablis. Des études ont été entamées pour résoudre les problèmes de calendrier au cas où le lancement de Météosat P2 serait encore retardé.*

Performances du satellite

*Les performances globales du satellite Météosat F2, qui a actuellement en charge la mission de diffusion des images et des données, ont largement dépassé celles du cahier des charges pendant la période concernée par ce rapport. La mission de collecte de données est à l'heure actuelle prise en charge par le satellite GOES-4. Ce système s'est lui aussi bien comporté, bien qu'une certaine reconfiguration du matériel embarqué ait été requise pour maintenir les performances nécessaires.*

# Microgravité

**Plan du programme**

*Une proposition préliminaire pour la Phase-3 du Programme de Recherche en Microgravité a été présentée au Bureau du Programme de Microgravité. Cette proposition de programme couvre la période qui va de la mi-1987 à 1993. Un certain nombre d'études préparatoires pour cette nouvelle phase ont déjà été entamées pour élaborer des données techniques, de délai et de coût.*

**Mission D2**

*La Phase-2 du Programme de Recherche en Microgravité prévoit un vol des installations multi-utilisateur suivantes de l'Agence sur la mission allemande Spacelab-D2:*

- *Anthrorack*
- *Traîneau vestibulaire (nouveau vol)*
- *Module Autonome de Physique des Fluides*
- *Installation de Point Critique*

*Les propositions d'expériences qui ont été reçues pour les installations précédentes en réponse aux annonces d'occasions de vol font actuellement l'objet d'un évaluation scientifique et technique. La prise en charge de ces installations est en cours d'étude par l'état-major de la mission D2, en coopération étroite avec l'ESA. La date de lancement de la mission D2, programmée à l'origine pour septembre 1988, devra être révisée du fait de l'accident survenu à la Navette Spatiale le 28 janvier 1986, et on s'attend à un certain retard.*

**Biorack**

*Les résultats du vol de Biorack sur la mission Spacelab-D1 ont été présentés par les chercheurs lors d'une réunion qui s'est tenue à l'ESTEC les 25 et 26 mars 1986. Des préparatifs pour un nouveau vol de Biorack sur la mission IML se déroulent et les contrats nécessaires pour la reconstruction de Biorack et l'extension de ses capacités ont été passés.*

**Charges utiles de noyau de microgravité sur Eureca**

*La mise au point des cinq charges utiles de noyau progresse. Les revues de conception critique, permettant d'établir la base de fabrication des modèles de vol, commencent actuellement. Le Centre de Prise en Charge des Utilisateurs de la Microgravité (MUSC) de DFVLR, à Porz-Wahn (Allemagne) sera utilisé par l'Agence pour prendre en charge la mise au point des expériences et l'évaluation des données pendant leur vol sur la première mission Eureca. Le contrat correspondant avec DFVLR doit être passé à brève échéance.*

# Eureca

*La Revue de Conception d'Eureca (EDR) a commencé par la livraison et la présentation du progiciel de données le 18 décembre 1985.*

*Pendant la revue interne de l'ESA, qui a duré jusqu'au 21 janvier 1986, 68 réviseurs venant du projet Eureca, des services techniques de l'ESTEC, de l'ESOC, et du HQ et l'ESA, travaillant dans quatre équipes de révision à orientation disciplinaire, ont produit 550 avis de non-conformité. Dans le nombre, 282 (51,3%) ont pu être fermés pendant la revue conjointe ESA/ERNO qui s'est tenue début février, étant donné que des réponses satisfaisantes avaient été fournies par le maître d'oeuvre. Les avis restants ont donné lieu à des mesures avec des temps d'exécution allant jusqu'à la fin du mois de juin 1986 au plus tard.*

*Les problèmes qui restent à résoudre se situent essentiellement dans les secteurs de la détection, de l'isolement et de la reprise des défaillances, de l'interface entre la mémoire à bulles magnétiques et l'ordinateur, du système de commande d'attitude et d'orbite, et du système de régulation thermique.*

*L'EDR s'est conclue par une réunion d'état-major entre l'ERNO et l'ESA le 14 février 1986, à laquelle étaient invités les membres du bureau de révision de conception d'Eureca. L'ERNO a présenté* monitored. Preparations for the next system-level review, the Production Baseline Review, have been completed and this review will take place in April.

A launch in September 1987 has been confirmed with Arianespace.

*Ground segment*
Refurbishment of the ground segment is being performed according to pre-established schedules. Studies have been initiated to overcome schedule problems in the event that the Meteosat P2 launch is further delayed.

**Satellite performance**
The overall performance of the Meteosat F2 satellite, which currently supports the imagery and data-dissemination mission, has been well within specification during the reporting period. The data-collection mission is at present supported by the Goes-4 satellite. This system has also been performing well although some on-board reconfiguration was required to maintain the necessary performance.

# Microgravity

**Programme planning**
A preliminary proposal for Phase 3 of the Microgravity Research Programme has been presented to the Microgravity Programme Board. The programme proposal covers the period from mid-1987 to 1993. A number of preparatory studies for this new phase have already been initiated to elaborate technical, schedule and cost data.

**D2 mission**
Phase-2 of the Microgravity Research Programme foresees flight of the following Agency multi-user facilities on the German Spacelab-D2 mission:
- Anthrorack
- Vestibular Sled (reflight)
- Autonomous Fluid Physics Module
- Critical Point Facility.

The experiment proposals received for the above facilities in response to the Announcements of Flight Opportunity are now under scientific and technical evaluation. The accommodation of these facilities is being studied by the D2 mission management in close cooperation with ESA. The launch date for the D2 mission, originally scheduled for September 1988, will have to be revised due to the Space-Shuttle accident on 28 January, and some delay is expected.

**Biorack**
The results from the flight of Biorack on the Spacelab D1 mission were presented by the investigators at a meeting in ESTEC on 25 and 26 March 1986. Preparations for the reflight of Biorack on the IML mission are proceeding and the necessary contracts for refurbishment of Biorack and extension of its capabilities have been placed.

**Microgravity core payloads on Eureca**
Development of the five core payloads is progressing. The Critical Design Reviews, to establish the manufacturing baseline for the flight models, are starting. The Microgravity User Support Centre (MUSC) at DFVLR, Porz-Wahn (Germany), will be used by the Agency to support experiment development and data evaluation during their flight on the first Eureca mission. The related contract with DFVLR is to be placed shortly.

# Eureca

The Eureca Design Review (EDR) commenced with the delivery and presentation of the data package on 18 December 1985.

During the ESA internal review, which lasted until 21 January 1986, 68 reviewers drawn from the Eureca project, the ESTEC technical departments, ESOC, and ESA HQ, working in four discipline-oriented review teams, generated 550 discrepancy notices. Of those, 282 (51.3%) could be closed during the ESA/ERNO joint review in early February, since satisfactory answers were provided by the prime contractor. The remainder were converted into action items with running times until the end of June at the latest.

Problems still to be resolved are primarily in the areas of failure detection, isolation, and recovery, the magnetic-bubble-memory/computer interface, the attitude and orbit control system, and the thermal-control system.

The EDR was concluded by a management meeting between ERNO and ESA on 14 February 1986, to which the members of the Eureca Design Review Board were invited. ERNO presented an updated schedule which shows that delays in the ESA deliveries of the overall checkout equipment, as well as the later than foreseen deliveries of the data-handling electrical ground-support equipment by the contractors, are at present projected to delay the launch date of Eureca by about three months.

Studies on further missions and system enhancements are proceeding as scheduled, with results expected to be presented by 15 April 1986.

In response to the numerous Eureca experiment proposals received by the ESA Science Directorate, the Executive has proposed a Eureca Utilisation Programme within the Space Science Horizon 2000 implementation plan approved by the Science Programme Committee. An Announcement of Opportunity for experiments will be made in April 1986.

During late 1985, NASA surveyed the US scientific communities for potential interest in utilising Eureca. Sixty letters of intent have been received as a result, and a joint ESA/NASA meeting addressing Eureca utilisation has been scheduled for the end of March 1986.

# Spacelab and IPS

The last formal ESA/NASA Joint Spacelab Working Group (JSLWG) meeting was held in mid-January 1986. The prime objective was to assess the state of completion of obligations defined in the Spacelab Memorandum of Understanding (MOU) and to determine the desirable period of validity of the MOU. The agreement reached comprised the following:

(a) Except for two ESA commitments related to the close-out of known open Phase-C/D programme items and one NASA commitment related to the Spacelab-1 and -2 missions and experimenters, there are no further obligations requiring additional funding.

(b) Those Articles of the MOU containing general rights and obligations will remain in force until the end of 1991.

*un calendrier mis à jour qui montre que, selon les projections actuelles, les retards de livraison, par l'ESA, du matériel de contrôle global, ainsi que les livraisons, plus tardives que prévu, du matériel électrique de prise en charge au sol du traitement des données, retardent la date de lancement d'Eureca de trois mois environ.*

*Les études sur de nouvelles missions et de nouvelles améliorations du système se déroulent comme prévu, leurs résultats devant être présentés d'ici au 15 avril 1986.*

*En réponse aux nombreuses propositions d'expériences Eureca qui ont été reçues par la Direction Scientifique de l'ESA, l'Exécutif a proposé un programme d'utilisation d'Eureca dans le cadre du plan de mise en oeuvre de la science spatiale à l'Horizon 2000 qui a été approuvé par le Comité du Programme Scientifique. Une annonce d'occasions d'expériences sera faite en avril 1986.*

*Dans la dernière partie de 1985, la NASA a sondé les milieux scientifiques américains quant à leur intérêt potentiel pour l'utilisation d'Eureca. Soixante lettres d'intention ont été reçues en réponse à ce sondage, et une réunion conjointe de l'ESA et de la NASA concernant l'utilisation d'Eureca a été fixée à la fin du mois de mars 1986.*

## Spacelab et IPS

*La dernière réunion formelle du Groupe de Travail Spacelab conjoint ESA/NASA (JSLWG) s'est tenue à la mi-janvier 1986. L'objectif premier était d'évaluer dans quelle mesure les obligations qui sont définies dans le Protocole d'Accord (MOU) de Spacelab avaient été remplies, et de déterminer la période souhaitable de validité du MOU. L'accord qui a été conclu comprenait les points suivants:*

*(a) A l'exception de deux engagements de l'ESA relatifs à la clôture d'éléments non décidés connus du programme de la Phase C/D, et d'un engagement de la NASA relatif aux missions et aux expérimentateurs de Spacelab 1 et 2, il n'y a plus d'obligations nécessitant un complément de financement.*

*(b) Les articles du MOU qui contiennent des droits et des obligations généraux resteront en vigueur jusqu'à la fin de 1991.*

*(c) L'industrie européenne sera invitée par la NASA à soumettre des propositions pour un ordinateur Spacelab modifié dans le cadre des plans de la NASA pour une fourniture concurrentielle. L'ESA participera à l'évaluation des propositions.*

*Les autres activités de réparation se déroulent de manière satisfaisante. Les problèmes de la mission Spacelab-2 qui étaient liés à l'Ordinateur d'Expérience et à l'Unité d'Affichage des Données (DDU) ont été résolus. Ces unités ont été renvoyées à la NASA après avoir été réparées par les fournisseurs européens.*

*L'anomalie rencontrée dans le bloc capteur optique de l'IPS a été examinée par Dornier System. La panne a été reproduite et on a découvert qu'elle se situait dans le boîtier électronique de l'un des trois suiveurs stellaires à tête fixe. Cette unité se trouve maintenant chez le fournisseur (Sodern) pour complément d'analyse et réparation.*

*La revue de qualification de l'Adaptateur d'Interface de Processeur (PIA) est prévue pour la fin du mois de mars 1986. Le maître d'oevre a annoncé des retards importants dans la livraison des unités de vol, ce qui aura une incidence sur le programme Eureca.*

*La qualification du système global de Spacelab a été achevée en février 1986 avec la signature du 'Certificat de Qualification du Système'.*

**Suivi de production (FOP)**

*La NASA, l'ESA, et MBB/Erno sont convenues à la fin du mois de janvier 1986 de transformer les engagements restants du FOP de Spacelab, en vertu du contrat de FOP conclu entre la NASA et l'ESA, en un accord contractuel direct entre la NASA et MBB/Erno. En même temps, un contrat de services d'assistance, approuvé par le Conseil lors de sa réunion de décembre 1985, a été conclu entre l'ESA et la NASA. En vertu de cet accord, l'ESA fournira une assistance remboursable limitée au Centre de Vols Spatiaux de Marshall de la NASA dans les domaines de l'assurance produit, de l'ingénierie de Spacelab et de la révision des conditions financières appliquées par les contractants européens dans les propositions soumises à la NASA.*

*Les obligations de FOP de l'Agence en ce qui concerne le Système de Pointage des Instruments (IPS) sont pratiquement terminées, et prendront fin avec la livraison du dernier élément contractuel actuel, laquelle est prévue d'ici à la mi-1986.*

## Station Spatiale/ Columbus

*Les activités majeures de la Phase-B1 se sont concentrées sur les réunions de niveau A entre l'ESA et la NASA, et sur le dépouillement des résultats de la Revue Programmatique. La seconde revue des systèmes (SR2) a eu lieu à l'ESTEC à la fin du mois de janvier.*

*Des réunions de niveau A entre l'ESA et la NASA se sont tenues en décembre 1985 et en février 1986. L'issue de la réunion du mois de décembre n'a pas été concluante, des points importants relatifs au module pressurisé (engin à vol libre habité et attaché ou module intégré) et à l'allocation fonctionnelle (laboratoire de microgravité ou laboratoire de science générale) restant non résolus. Pendant la réunion de février, un texte de compromis couvrant le module pressurisé, les plates-formes polaire et co-orbitale et l'Engin à Vol Libre Habité (MTFF) a été élaboré. Le Bureau du Programme Columbus, après révision de ce texte de compromis, a reconfirmé la retenue du MTFF comme option de Communications Inter-Orbitales (IOC) et de la microgravité comme fonction première du module pressurisé. La question a été revue pendant la réunion du Conseil de l'ESA qui a eu lieu les 5 et 6 mars, et de nouvelles négociations au niveau intergouvernemental sont prévues.*

*Dans le domaine programmatique, des réunions ont eu lieu avec les contractants d'étude pour revoir les points critiques de délais et de coût dans les données qui ont été présentées au moment de la Revue Programmatique à la mi-novembre 1985. L'objectif premier est de ramener les estimations de coût de la Phase C/D (phase de mise au point principale) en deçà du plafond de financement du programme qui a été établi lors de la réunion du Conseil de janvier 1985 à*

FUTURE MANIFESTED SPACELAB MISSIONS
(Prior to Challenger Disaster)

| MISSION NAME | MISSION OBJECTIVE | COMPONENTS USED | STS FLIGHT | PLANNED LAUNCH | ORBITER NAME |
|---|---|---|---|---|---|
| ASTRO-1 | U.V. Astronomy | Igloo/2 Pallets | 61-E | 6. 3. 86 | Columbia |
| EOM -1/2 | Environmental Observation | Short Module & Pallet | 61-K | 18. 8. 86 | Atlantis |
| ASTRO-2 | U.V. Astronomy | Igloo/2 Pallets | 71-A | 12. 1. 87 | Atlantis |
| SRL-2 | Radar Laboratory | 1 Pallet | 72-A | 18. 3. 87 | Discovery |
| SLS-1 | Life Sciences | Long Module | 71-E | 16. 3. 87 | Atlantis |
| IML-1 | Internl. Microgravity | Long Module | 71-I | 27. 5. 87 | Columbia |
| ASTRO-3 | U.V. Astronomy | Igloo/2 Pallets | 71-M | 18. 8. 87 | Challenger |
| SUNLAB-1 | Solar Telescope | Igloo & Pallet | 71-O | 28. 9. 87 | Columbia |
| EOM-3 | Environmental Observation | Igloo & Pallet | 81-F | 2. 2. 88 | Columbia |
| S/LAB-J | Japanese Spacelab | Long Module | 81-G | 23. 2. 88 | Challenger |
| SLS-2 | Life Sciences | Long Module | 81-M | 20. 7. 88 | Challenger |

(c) European industry will be invited by NASA to submit proposals for a modified Spacelab computer as part of NASA's plans for a competitive procurement. ESA will participate in the proposal evaluation.

Remaining repair activities are proceeding satisfactorily. The Spacelab-2 mission problems associated with the Experiment Computer and Data Display Unit (DDU) have been resolved. The units have been returned to NASA following repair by the European suppliers.

The anomaly experienced with the IPS Optical Sensor Package has been investigated by Dornier System. The failure was reproduced and found to lie in the electronics box of one of the three fixed-head star trackers. The unit is now at the supplier (Sodern) for further analysis and repair.

The Processor Interface Adaptor (PIA) qualification review is planned for end March 1986. The contractor has announced significant delays in the flight-unit deliveries, which will affect the Eureca programme.

The overall system qualification of Spacelab was completed in February 1986 with signature of the 'System Certificate of Qualification'.

**Follow-on Production (FOP)**
NASA, ESA, and MBB/ERNO agreed at the end of January 1986 to convert the remaining Spacelab FOP commitments under the NASA/ESA FOP contract into a direct contract arrangement between NASA and MBB/ERNO. At the same time, a support-services Agreement, approved by Council at its December 1985 meeting, was concluded between ESA and NASA. Under this Agreement, ESA will provide limited reimbursable support to NASA Marshall Space Flight Center in the fields of product assurance, Spacelab engineering and the review of financial rates applied by European contractors in proposals submitted to NASA.

The Agency's FOP obligations for the Instrument Pointing System (IPS) are nearly complete and will terminate with delivery of the last presently contracted item which is foreseen to take place by mid-1986.

## Space Station/ Columbus

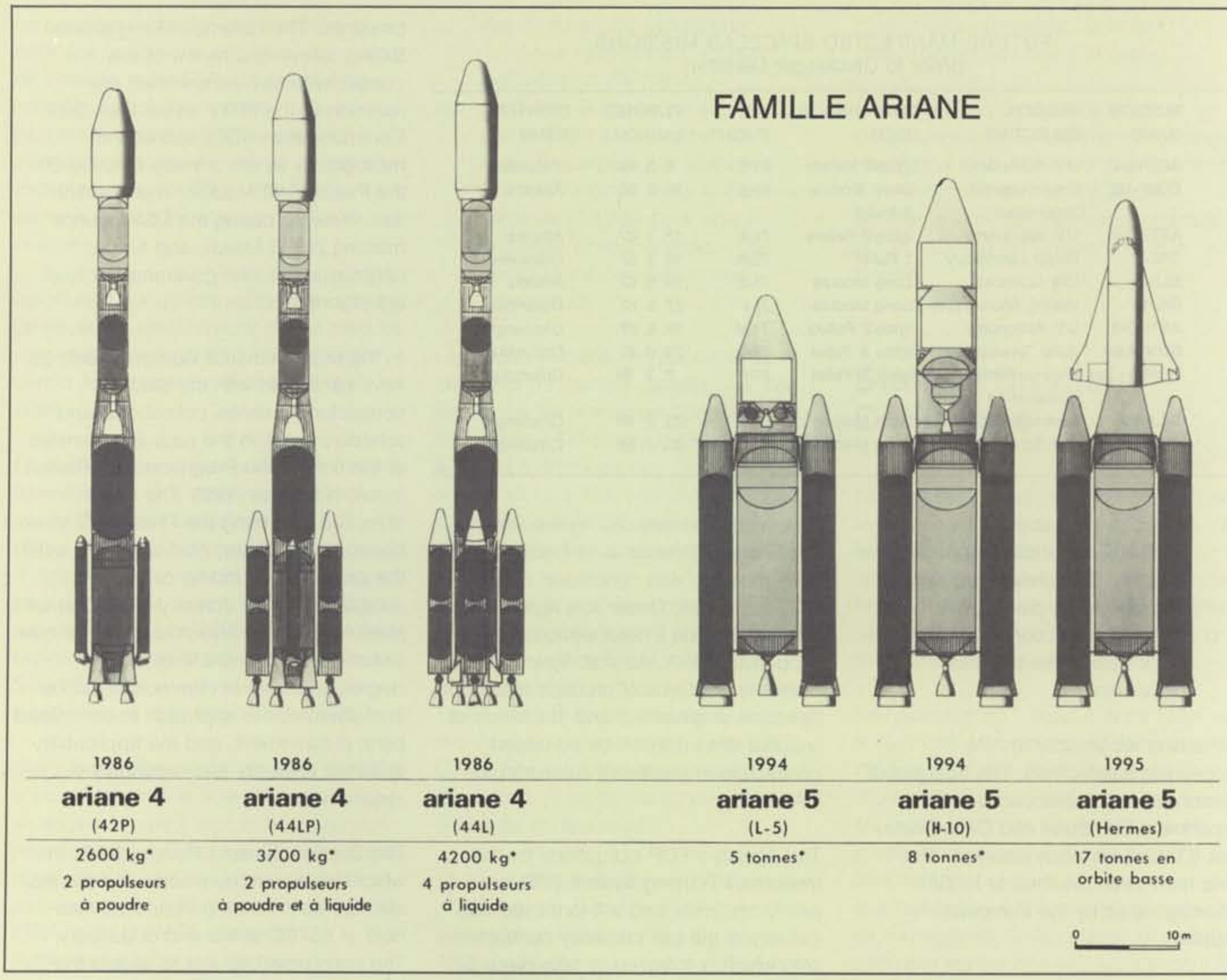
The major Phase-B1 activities have been focussed on the ESA/NASA Level-A meetings and on the scrutiny of the Programmatics Review results. The Second Systems Review (SR2) was held at ESTEC at the end of January.

Level-A meetings between ESA and NASA were held in December 1985 and in February 1986. The outcome of the December meeting was inconclusive, with significant areas related to the Pressurised Module (attached man-tended free-flyer versus integrated) and functional allocation (microgravity laboratory versus general science laboratory) remaining open. During the February meeting, a compromise text covering the Pressurised Module, Polar and Co-orbiting Platforms and the Man-tended Free-Flyer (MTFF) has been prepared. The Columbus Programme Board, following a review of this compromise text, reconfirmed the retention of the MTFF as an Inter-Orbit Communication (IOC) option and microgravity as the primary function of the Pressurised Module. The question was reviewed during the ESA Council meeting of 5/6 March, and further negotiations at inter-governmental level are planned.

In the programmatics domain, meetings have been held with the study contractors to review critical cost and schedule areas in the data as submitted at the time of the Programmatics Review in mid-November 1985. The prime objective is to bring the Phase-C/D (main development phase) cost estimates within the programme funding ceiling established at the January 1985 Council Meeting in Rome. Potential areas for cost reductions at element level are the degree and level of commonality to be implemented, the approach to centralised parts procurement, and the applicability of safety, reliability and redundancy requirements.

The Second Systems Review (SR2), in which the system contractor and the four element contractors participated, was held at ESTEC at the end of January. The main objective was to assess the latest element reference-configuration data and updated programmatics data. The review showed a clear downward cost trend. The main technical change since the Mid-Term Review has been the introduction of a smaller 5 kW Polar Platform. It has also been recommended that studies on the unmanned Service Vehicle be discontinued.

The majority of the studies planned under the Preparatory Supporting Technology Programme have been initiated with industry. Kick-off meetings for the Columbus Utilisation Studies have also taken place. The Mid-Term Review for the operations studies was conducted by ESOC/GSOC in December 1985. Present programme planning foresees initiation of early Phase-B2 tasks under an extension of the existing Phase-B1 contractual arrangements from April to July 1986. The full Phase-B2 is planned to be conducted between October 1986 and April 1987, but the actual duration could be influenced by NASA Space-Station Phase-B activities.




*Rome. Les secteurs potentiels de réduction de coût au niveau des éléments sont le degré et le niveau de banalisation à mettre en oeuvre, l'approche vers une acquisition centralisée des pièces, et l'applicabilité des exigences de sécurité, de fiabilité et de redondance.*

*La seconde revue des systèmes (SR2), à laquelle participaient le contractant du système et les quatre contractants d'éléments, s'est tenue à l'ESTEC à la fin du mois de janvier. L'objectif principal était d'évaluer les toutes dernières données de configuration de référence des éléments ainsi que les données programmatiques mises à jour. La Revue a fait apparaître une nette tendance à la diminution des coûts. La principale modification technique depuis la Revue de mi-durée a été l'introduction d'une plate-forme polaire de 5 kW plus petite. Il a également été recommandé d'interrompre les études sur le véhicule d'intervention non habité.*

*La majorité des études prévues en vertu du Programme Technologique de Soutien Préparatoire ont été entamées avec l'industrie. Des réunions de démarrage pour les études d'utilisation de Columbus ont également eu lieu. La Revue de mi-durée concernant les études d'opérations a été menée par l'ESOC/GSOC en décembre 1985.*

*Le plan de programme actuel prévoit la mise en route des tâches du début de la Phase-B2 en vertu d'une prolongation d'avril à juillet 1986 des accords contractuels de Phase-B1 existants. Il est prévu que la totalité de la Phase-B2 sera menée entre octobre 1986 et avril 1987, mais la durée réelle pourrait être influencée par les activités de Phase-B de la Station Spatiale de la NASA.*

# In Brief

## Comet Halley Observed from the International Cometary Explorer (ICE) Spacecraft

At the end of March 1986, the International Cometary Explorer (ICE) spacecraft came within 30 million kilometres (0.2 Astronomical Units) of the sunward side of Comet Halley. To the surprise of many of the scientific investigators, several instruments on board ICE observed very clear signatures of the interaction of the comet with the solar wind at that large distance.

These signatures were very similar to the observations made during the ICE encounter with Comet Giacobini-Zinner last September (see ESA Bulletin No.44, November 1985, p.32).

Energetic heavy ions — most likely oxygen ions of water-vapour origin — were detected for several days. These ions escaped the comet nucleus as neutral molecules and, after a long travel, were ionised by solar photons, and then accelerated by the electric field of the solar wind (so-called 'pick-up' ions) to be subsequently detected as an ion beam by the European energetic-particle instrument on ICE. As predicted by theory, the ion flux was most intense when the solar plasma velocity was high, and changed with the magnetic-field direction, both of which were measured by other instruments. In addition, the plasma wave instrument observed the electromagnetic turbulence created by the pick-up ions.

These effects were not expected at such a large distance from the comet as 30 million kilometres. In comparison, Giotto saw the first signs of pick-up ions about 8 million kilometres before closest approach. One difference was that the solar wind blew much faster in late March than during the Halley encounters in the first half of the month. ICE was lucky to catch these signs of Halley 'waving goodbye' until its next return in 2061.

## Two Complementary Missions 'Soho' and 'Cluster' Selected as ESA's New Scientific Project

On 7 February, ESA's Science Programme Committee gave its unanimous approval to the Soho and Cluster missions, which together form the Solar Terrestrial Physics cornerstone of ESA's Scientific Long-Term Plan. In the coming months, the Agency will request the scientific community to put forward proposals for experiments to be carried on-board these missions. These proposals will be evaluated early next year and the complete mission will be presented to the Science Programme Committee before the start of detailed systems studies and pre-development work (Phase-B) in 1988.

Soho (for 'Solar and Heliospheric Observatory') is a multi-disciplinary mission designed to investigate, using remote-sensing techniques, the outer layers of the Sun, to measure in-situ the solar-wind streams and associated wave phenomena, and to probe the interior structure of the Sun by monitoring the velocity and luminosity oscillations of the solar surface.

The Cluster mission has been designed primarily to study small-scale structures in the Earth's plasma environment and the associated turbulence. Cluster takes its name from the fact that the mission will consist of four spacecraft orbiting in different planes in the Earth's magnetopause, geomagnetic tail and plasma sheet.

Present planning foresees the launch of the five spacecraft in the 1993—1995 time frame.

## Two Commercial Satellites Launched Successfully by Ariane Flight V17

On Friday 28 March at 20.30 h Kourou time (23.30 h GMT), two communications satellites were successfully placed into geostationary transfer orbit [perigee 203.2 km (200 km predicted); apogee 36 243 km (36 237 km predicted); inclination 7° (7° predicted)] by an Ariane-3 vehicle: G-Star 2 for the American corporation GTE-Spacenet, and Brasilsat S2 for the Brazilian company Embratel.

This first launch from the new ELA-2 pad at Kourou took place less than 5 weeks after the Ariane launch of the Spot and Viking satellites (flight V16). It validated ESA's new launch facility, from which Ariane-4 will fly for the first time in the last quarter of 1986.

A novel feature of ELA-2's design is the fact that it consists essentially of two main zones, the Launcher Preparation Zone and the Launch Zone, about one kilometre apart. This configuration offers considerable flexibility and allows the yearly launch rate to be increased from the average of five launches per year from ELA-1 to aproximately ten per year from ELA-2. This is due to the fact that one launcher can be assembled and checked-out in the Preparation Zone whilst another is undergoing final checkout operations in the Launch Zone.

To date Arianespace has signed 44 launch contracts, and currently has orders for the launching of 28 satellites.

G-Star 2 and Brasilsat S2 were the 13th and 14th satellites to be put into orbit by Arianespace.

## Signature of ECS-5 Launch Contract

On 30 January 1986, Prof. Reimar Lüst, ESA's Director General, and Mr. Charles Bigot, Director General of Arianespace, signed the launch contract for ECS-5, the fifth European telecommunications satellite. This launch is scheduled to take place in 1987.

## New Milestone Reached in ESA's Columbus Programme

Of the decisions taken by the Ministers of ESA's Member States at the Council meeting in Rome in January 1985, one of the most exciting was their acceptance of President Reagan's invitation to participate in the American Space Station programme, subject to the negotiation of a mutually satisfactory Agreement for the development, operation and utilisation phases of this cooperative programme.

For the last year, detailed definition studies (Phase-B1 studies) have been carried out by European industry, within the framework of ESA's Columbus Programme, on the various technical solutions and options, with a view to identifying the Space-Station element or elements that the Agency will propose to NASA for development. A major milestone during this period was the signature, on 13 June 1985, by Prof. Reimar Lüst, ESA's Director General, and the NASA Administrator at that time, Mr James Beggs, of the Memorandum of Understanding providing a legal basis for the conduct of this cooperative study programme.

At its meeting on 17 April 1986, the Columbus Programme Board reviewed the results of that detailed definition study phase. In addition, it assessed the outcome of the ESA/NASA negotiations conducted during the period December 1985 to March 1986 in order to identify the potential for further definition studies on the space-segment elements.

Bearing in mind the major programme objectives set by the Rome Council Meeting for a coherent long-term ESA programme covering, inter alia:

- the setting up of a European in-orbit infrastructure
- the use of the European potential available, or to be developed, in the areas of space transportation (Ariane-5 and, possibly, Hermes) and data transmission (DRS) in particular
- the definition and development of a utilisation programme consistent with the potential of the in-orbit infrastructure
- cooperation with NASA in the framework of the Space-Station programme;

the Programme Board identified the scope for the continuation of the definition of the space segment under what are known as Phase-B2 activities, which will provide for completion of the definition of the Space Station element or elements to be retained in common with NASA for development.

The Programme Board reconfirmed that the hardware elements proposed for cooperation with NASA would be the Pressurised Module, the Polar Platform and the Co-orbiting Platform.

The detailed Phase-B2 studies should, therefore, cover:

- a Pressurised Laboratory Module for permanent attachment to the international Space Station. This laboratory will be used primarily for materials-science, life-sciences and fluid-physics
- a man-tended Free Flyer, consisting of a smaller laboratory and a resource module to be launched together on a single Ariane-5 vehicle
- an unmanned Polar Platform, primarily for Earth-observation applications, considering in particular the objectives and requirements of the ESA Earth Observation Programme. This platform will be designed for launch by Ariane-5.

In addition, a further option, consisting of the development of a small co-orbiting platform based on an enhanced version of the Eureca platform currently under development, will also be studied.

## Exosat Ceases Operation after 1050 Days in Orbit

Exosat, the Agency's X-ray observatory satellite launched on 26 May 1983, completed one thousand and fifty days of in-orbit operation on 9 April 1986. During this time, over 2000 observations of cosmic X-ray sources were carried out from the Exosat Observatory based at the European Space Operations Centre (ESOC) in Germany. These observations covered the complete range of celestial objects, from the very familiar planets and stars that we see in the night sky, to such mysterious objects as quasars, neutron stars, black holes, supernova remnants, active galactic nuclei and clusters of galaxies.

Scientists from all branches of astronomy have been extremely excited by the results of these Exosat observations which, in addition to forming a rich database that will be a source of research for years to come, will also provide a strong scientific base within Europe for the Agency's next X-ray astronomy mission, planned for the 1990s.

Exosat's orbital operations were originally planned and funded for two years (until May 1985), but the mission was so successful and returned so much exciting new scientific data that the ESA Member States had approved an extension of the mission until the latter part of 1986, when it was anticipated that the supply of attitude-control gas would finally be exhausted. Recently, however, a malfunction in the attitude-control system placed the spacecraft into an uncontrollable attitude, and the remaining gas reserves were exhausted in an unsuccessful attempt to recover the situation. Scientific operations consequently ceased on 9 April and the spacecraft is now expected to re-enter the Earth's atmosphere, where it will burn up, on 6 May.

## ESA to Provide Eutelsat with a Fourth Communications Satellite

On 12 March, Prof. R. Lüst, ESA's Director General, and Mr A. Caruso, Director General of Eutelsat, signed the second revision of the Arrangement which provides for the Agency to supply Eutelsat with four ECS-generation satellites to be operated simultaneously in orbit.

Seven years ago, in 1979, when the two organisations signed the original Arrangement, provision was made for ESA to supply Eutelsat with just two operational communications satellites. By 1983, traffic had increased to such an extent that the original Arrangement was amended to increase the number of in-orbit spacecraft to three. Now a fourth satellite is to be put into orbit which will act as a backup for the other three.

This four-satellite European Communications Satellite System will provide the European PTTs with a fully-protected space segment for the simultaneous transmission of trunk telephone calls, television programmes and specialised multi-services.

The next ECS spacecraft, ECS-4, is scheduled for launch in July of this year, and ECS-5 in early 1987.

## Scientists Continue to Prepare for the Ulysses Mission

For more than two decades, it has been realised that the heliosphere, i.e. the Sun and its sphere of influence, is intrinsically three-dimensional. We know, for example, that the magnetic field and the solar wind structure are very complex near the solar equatorial plane. Over the solar poles, however, the field is expected to be nearly radial and the solar wind originating from the polar coronal hole to be uniform and fast.

The 1985 ESA/ESLAB Symposium, one of an annual series of Symposia organised by ESA's Space Science Department, was devoted to a review of our current knowledge of the structure and dynamics of the three-dimensional heliosphere. This, the 19th ESLAB Symposium, was entitled 'The Sun and the Heliosphere in Three Dimensions' and was held at Les Diablerets, Switzerland from 4—6 June 1985. It was attended by more than 100 scientists from many European countries, the United States, Canada, Japan and India. Particular emphasis was placed on the conditions and processes that Ulysses, formerly known as the International Solar Polar Mission (ISPM), is expected to observe during its out-of-the-ecliptic journey.

Ulysses, a joint ESA/NASA cooperative programme in which ESA provides the spacecraft and NASA the launch and tracking network, will be the first mission to explore the heliosphere in three dimensions. It was expected to be launched in May 1986 but, as a consequence of the Challenger accident, launch will not now take place before June 1987. Following a gravity-assist manoeuvre at Jupiter 15 months later, the spacecraft will achieve its first polar passage over the Sun's southern pole about 3½ years after launch.

The Les Diablerets Symposium served to document* the many different scientific questions that can be addressed only with detailed knowledge of the conditions and processes occurring on the Sun and in the heliosphere in three dimensions. The launch of Ulysses is therefore eagerly awaited, as there is no substitute for these in-situ observations which it is designed to provide. The participants at Les Diablerets recognised that this will be only the beginning of the exploration of the heliosphere in three dimensions; Ulysses will provide many answers, but will also, as is true of exploratory work in any scientific field, raise new questions that cannot be anticipated in advance.

* The Symposium Proceedings have been published in the Reidel Astrophysics and Space Science Library Series

## ESA to Participate in Satellite Aeronautical Data Communication Trials

When it was decided in 1970 to establish a European telecommunication satellite programme, the objective assigned to ESA was the setting up of a satellite network to meet the requirements both of the PTT administrations for international telephone traffic in Europe and of the European Broadcasting Union for Eurovision, its TV programme exchange network. A further objective was added very shortly afterwards, namely the provision of a maritime communications satellite system, which was adopted by Inmarsat as part of its initial space segment within the framework of its global maritime communications network.

Today, several operational satellites are already in service: two of the ECS series, which have been handed over to Eutelsat for use by the European PTTs for telephony and television purposes, and two Marecs spacecraft leased to Inmarsat. Another satellite, Olympus, which is twice as heavy as ECS and Marecs and is capable of meeting the requirements of future missions that will be much more exacting in terms of transmission capacity and on-board power, is scheduled for launch in 1987.

Preparations are also in hand for future communication satellite systems, including a data-relay satellite system and a navigation system. The overall ESA communication programme therefore includes a number of smaller, and perhaps less well-known, projects aimed specifically at the development, testing and demonstation of advanced systems and equipment. The Prosat programme, which got underway in 1982, is an excellent example of this type of activity, directed as it is towards the development of the future generations of mobile satellite systems that will emerge during the next decade. It consists of an initial experimental engineering phase designed in particular to investigate signal-propagation problems, and a second phase, begun in mid-1984, which involves the development of the appropriate communication systems and a series of demonstrations using different types of terminals installed on board all three types of mobile: aeronautical, maritime and land-based.

The aeronautical part of this programme is now to be exploited in a global test programme to be carried out by SITA (Société Internationale de Télécommunications Aéronautiques), a company providing communications facilities to airline companies, and ESA, using the Inmarsat network of spacecraft (including ESA's Marecs maritime communications spacecraft leased to Inmarsat) and the ESA ground stations at Villafranca in Spain and Ibaraki in Japan.

In the last few months, ESA has placed contracts with a number of European firms for the manufacture of an initial batch of terminals to be installed onboard civil aircraft, and for ground-station equipment. These items will be used in a series of trials to provide a direct link between aircraft and their companies, connections with the public telex network for passengers, and a link for air-traffic-control demonstrations. Discussions are currently taking place between SITA and a number of European airline companies on their potential involvement in these trials, which will start in April 1987.

# 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.


## ESA Journal

The following papers have been published in ESA Journal Vol. 10, No. 1:

GIOTTO ELECTRICAL GROUND-SUPPORT EQUIPMENT: ITS DESIGN AND USAGE
*J CREDLAND & J NOYES*

RESULTS OF THE GROUP AGROMET MONITORING PROJECT (GAMP)
*A ROSEMA*

ANOMALOUS CURRENT COLLECTION AND ARCING OF SOLAR-CELL MODULES IN A SIMULATED HIGH-DENSITY, LOW-EARTH-ORBIT PLASMA
*H THIEMANN & K BOGUS*

RIT-10 LOW-THRUST CONTROL OF EURECA'S ORBITAL DECAY
*R MUGELLESI & J C VAN DER HA*

GROUND ANTENNA POINTING PERFORMANCE FOR GEOSTATIONARY ORBIT DETERMINATION
*S KAWASE & E M SOOP*

DOSAGE DU MONOXYDE D'AZOTE DANS LES MÉLANGES D'OXYDE D'AZOTE PAR SPECTROPHOTOMÉTRIE VISIBLE ET PROCHE INFRAROUGE
*G FALLOURD, S FOUCHÉ & H LEMAITRE*

EQUIVALENT DYNAMIC MODELS FOR A SPACECRAFT AND ITS SUBSYSTEMS
*M SAMBASIVA RAO, P S NAIR & S DURVASULA*

## Special Publications

ESA SP-231 // VII + 319 PP
SECOND EUROPEAN SPACE MECHANISMS & TRIBOLOGY SYMPOSIUM (DEC 1985)
*GUYENNE T D & HUNT J J (EDS)*

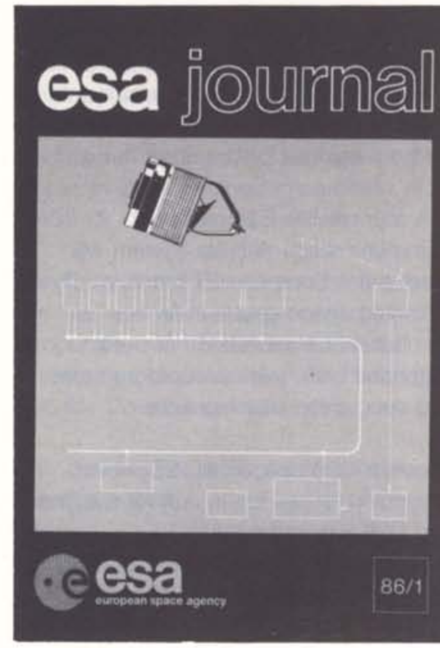
ESA SP-232 // VII + 284 PP
SPACECRAFT MATERIALS IN SPACE ENVIRONMENT (DEC 1985)
*GUYENNE T D & HUNT J J (EDS)*

ESA SP-237 // 252 PP
2ND INTERNATIONAL CONFERENCE ON SPACE PHYSIOLOGY, TOULOUSE, FRANCE, 20—22 NOVEMBER 1985 (FEB 1986)
*J J HUNT (ED)*

ESA SP-243 // 374 PP
COMPOSITES DESIGN FOR SPACE APPLICATIONS — PROCEEDINGS OF A WORKSHOP HELD AT ESTEC, NOORDWIJK, THE NETHERLANDS, 15—18 OCTOBER 1985 (FEB 1986)
*BURKE W R (ED)*

ESA SP-246 // PP 85
RE-ENTRY OF SPACE DEBRIS, ESOC, DARMSTADT, GERMANY, 24—23 SEPTEMBER 1985 (FEB 1986)
*LONGDON N (ED)*

ESA SP-247 // 580 PP
SPECTRAL SIGNATURES OF OBJECTS IN REMOTE SENSING, 3RD INTERNATIONAL COLLOQUIUM, LES ARCS, 16—20 DECEMBER 1985 (DEC 1985)
*T D GUYENNE (ED)*

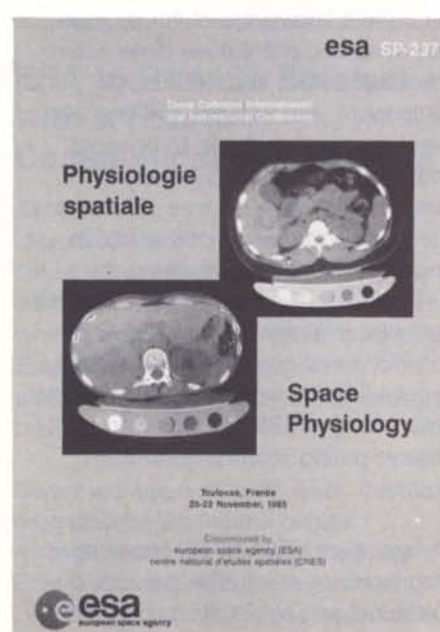


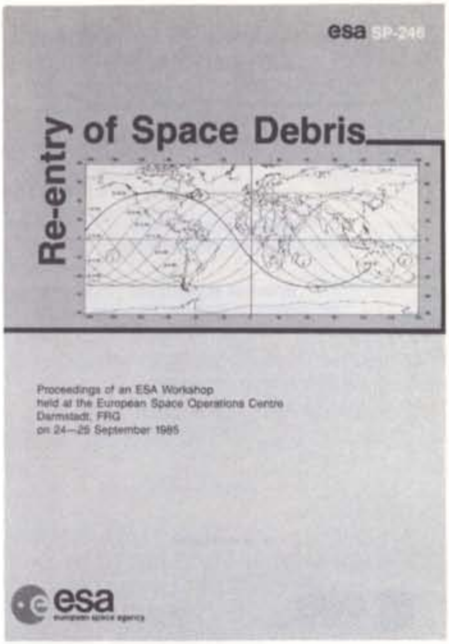

ESA SP-248 // 580 PP
PARAMETERIZATION OF LAND-SURFACE CHARACTERISTICS, USE OF SATELLITE DATA IN CLIMATE STUDIES & FIRST RESULTS OF ISLSCP, PROCEEDINGS OF AN ISLSCP CONFERENCE, ROME, ITALY, 2—6 DECEMBER 1985 (MAY 1986)
*ROLFE E J & BATTRICK B (EDS)*

## Contractor Reports

ESA CR(P)-2118 // 234 PP
THE REDUCTION OF RADIATION DAMAGE IN SOLAR CELLS — A STUDY OF RADIATION DEFECTS IN SILICON (JAN 1983)
*CNRS, FRANCE*

ESA CR(P)-2119 // 49 PP
SUB-MILLIMETRE (FAR IR) HETERODYNE SPECTROMETER (DEMONSTRATION MODEL) — FINAL REPORT (JUNE 1985)
*FARRAN TECHNOLOGY LTD, IRELAND*






**ESA CR(P)-2121 // 66 PP**
ADVANCED DATA SYSTEM INTERCONNECTION STUDY — FINAL REPORT (JUNE 1985)
*SESA ITALIA SPA, ITALY*

**ESA CR(P)-2124 // 134 PP**
CONFORMAL ARRAY ANTENNA SUBSYSTEM — FINAL REPORT (APR 1985)
*CASA, SPAIN*

**ESA CR(P)-2125 // 81 PP**
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*CROUZET, FRANCE*

**ESA CR(P)-2126 // 195 PP**
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*DORNIER SYSTEM, GERMANY*

**ESA CR(P)-2127 // 172 PP**
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*SYSTEMBERATUNG INFORMATIK, GERMANY*

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ENSEMBLE DE COMMUNICATION POUR ERS-1 — RAPPORT DE FIN DE PHASE II (FEB 1985)
*THOMSON-CSF, FRANCE*

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*AEG-TELEFUNKEN, GERMANY*

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HEAT REJECTION SYSTEM: TECHNOLOGY DEMONSTRATION MODEL — PHASE 3 FINAL REPORT (FEB 1985)
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A CAD TOOL FOR LEO SPACECRAFT POWER SUBSYSTEM DESIGN (EBLOS UPGRADING) — FINAL REPORT (AUG 1985)
*MATRA ESPACE, FRANCE*

**ESA CR(P)-2133 // 152 PP/131 PP/127 PP/2 P**
FLUID PHYSICS INSTRUMENTATION STUDY — FINAL REPORT — PART 1: SYSTEM ASPECTS — PART 2 : DESIGN REPORT — PART 3: BREADBOARD DESCRIPTION AND TEST RESULTS — PART 4: EXECUTIVE SUMMARY, CONCLUSIONS AND RECOMMENDATIONS (JAN 1985)
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STUDY ON THE ANALYTIC REPRESENTATION OF HALO ORBITS — FINAL REPORTS (JUL 1985)
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ESA SAFETY OPTIMISATION STUDY (AUG 1985)
*HERNANDEZ ENGINEERING, INC., USA*

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GROWTH CAPABILITIES OF EUROPEAN RETRACTABLE SOLAR ARRAYS — FINAL REPORT (JUNE 1985)
*AEG-TELEFUNKEN, GERMANY*

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KEY DESIGN PARAMETERS FOR A VERY LOW GRAVITY IN-ORBIT FACILITY — FINAL REPORT (APR 1985)
*MATRA ESPACE, FRANCE*

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THE COMPLETE ELECTRICAL PART OF THE ARA SOLAR ARRAY (ADVANCED RIGID ARRAY) (UNDATED)
*AEG-TELEFUNKEN, GERMANY*

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FURTHER WORK ON POPSAT — RIDER STUDY — FINAL REPORT — VOLUME I: EXECUTIVE SUMMARY — VOLUME II: TECHNICAL RESULT (AUG 1985)
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SAR PRODUCT SIMULATION — FINAL REPORT (JULY 1985)
*UNIV STUTTGART, GERMANY*

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FIELD EMISSION ELECTRIC PROPULSION: FURTHER STUDIES ON COLD CATHODE ELECTRON EMITTERS — FINAL REPORT (FEB 1985)
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EVALUATION OF TECHNIQUES FOR DETERMINATION OF LOADS DUE TO FLUID/STRUCTURE INTERACTION (JUNE 1983)
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*OFFICINE GALILEO, ITALY*

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STUDY ON USE AND CHRACTERISTICS OF SAR FOR LAND SNOW AND ICE APPLICATIONS — FINAL REPORT (MAY 1985)
*INSTITUT FÜR METEOROLOGIE UND GEOPHYSIK, UNIVERSITÄT INNSBRUCK, AUSTRIA*

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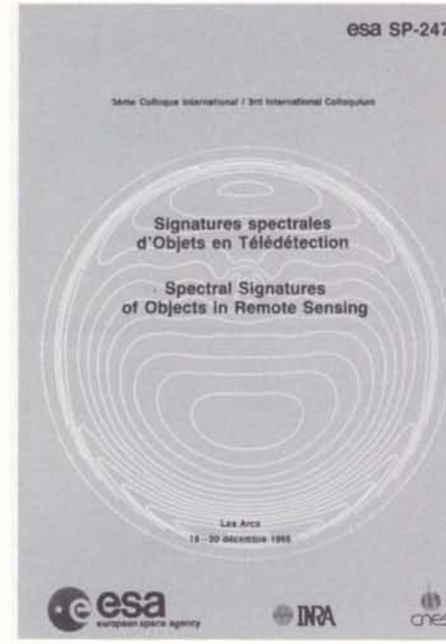
## Technical Translations

ESA-TT-839 // 147 PP
THE EXPERIMENTAL-ANALYTICAL DETERMINATION OF THE REAL NORMAL MODE PARAMETERS OF A STRUCTURE WITH LIMITED ACCESSIBILITY (JUNE 1985)
*NIEDBAL N, DFVLR, GERMANY*




ESA-TT-891 VOL 1 // 142 PP
SPACE ENVIRONMENT SIMULATION TO TEST SATELLITE THERMAL CONTROL COATINGS, VOL. 1 (AUG 1985)
*DUTAT M, MARCO J & PAILLOUS A, ONERA, FRANCE*

ESA-TT-891 VOL 2 // 138 PP
SPACE ENVIRONMENT SIMULATION TO TEST SATELLITE THERMAL CONTROL COATINGS. VOL. 2, APP. 1: DETAILED RESULTS OF OPTICAL MEASUREMENTS MADE AFTER THE VARIOUS STAGES OF THE FIRST TEST (AUG 1985)
*ONERA, FRANCE*

ESA-TT-891 VOL 3 // 261 PP
SPACE ENVIRONMENT SIMULATION TO TEST SATELLITE THERMAL CONTROL COATINGS, VOL. 2, APP. 2, 3, AND 4. APPENDIX 2: DETAILED RESULTS OF OPTICAL MEASUREMENTS MADE AFTER THE VARIOUS STAGES OF THE SECOND TEST APPENDIX 3: SUMMARY OF OPTICAL RESULTS OBTAINED DURING THE FIRST TEST APPENDIX 4: SUMMARY OF OPTICAL RESULTS OBTAINED DURING THE SECOND TEST (AUG 1985)
*ONERA, FRANCE*

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MAXIMUM-LIKELIHOOD ESTIMATION OF PARAMETERS IN LINEAR SYSTEMS FROM FLIGHT TEST DATA. A FORTRAN PROGRAM (JUNE 1985)
*PLAETSCHKE E & MACKIE D B, DFVLR, GERMANY*

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LA RECHERCHE AEROSPATIALE, BIMONTHLY BULLETIN, 1984—6 (MAY 1985)
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*ONERA, FRANCE*

**ESA-TT-916 // 63 PP**
DESIGN OF A BASIC PROFILE FOR A SLIGHTLY SWEPT WING. PART 2: EXPERIMENTAL INVESTIGATION ON THE AIRFOIL DFVLR-W1 IN THE BRAUNSCHWEIG TRANSONIC WIND TUNNEL (TWB) (SEPT 1983)
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*GRUNDMANN R, DFVLR, GERMANY*

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**ESA-TT-929 // 113 PP**
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*WEISSER M & WAEGEL K H, DFVLR, GERMANY*

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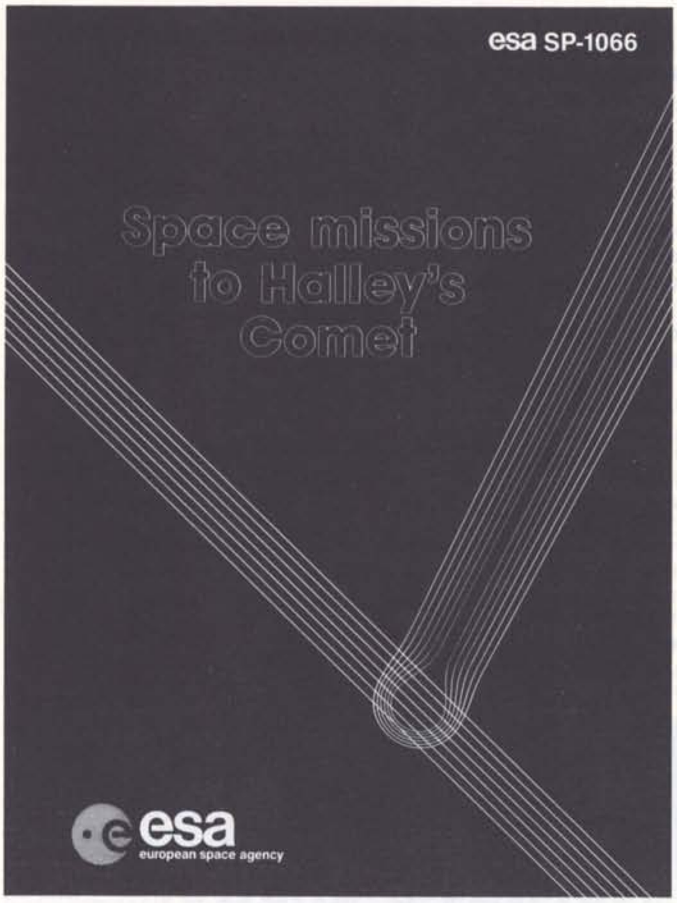
INVESTIGATIONS ON A SUPERCRITICAL AIRFOIL WITH BOUNDARY LAYER SUCTION THROUGH A PERFORATED STRIP IN THE SHOCK REGION (SEPT 1985)
*KROGMANN P, DFVLR, GERMANY*

**ESA-TT-941 // 53 PP**
COMPARATIVE FLIGHT MEASUREMENT OF ICING PARAMETERS FOR THE D0 28 D2 PROPELLER-DRIVEN AIRCRAFT OF THE GERMAN ARMY TESTING OFFICE 61 (ERPROBUNGSSTELLE 61 DER BUNDESWEHR) AND FOR DFVLR'S FALCON 20 E JET AIRCRAFT IN STRATUS CLOUDS (SEPT 1985)
*SCHICKEL K-P & UWIRA K, DFVLR, GERMANY*

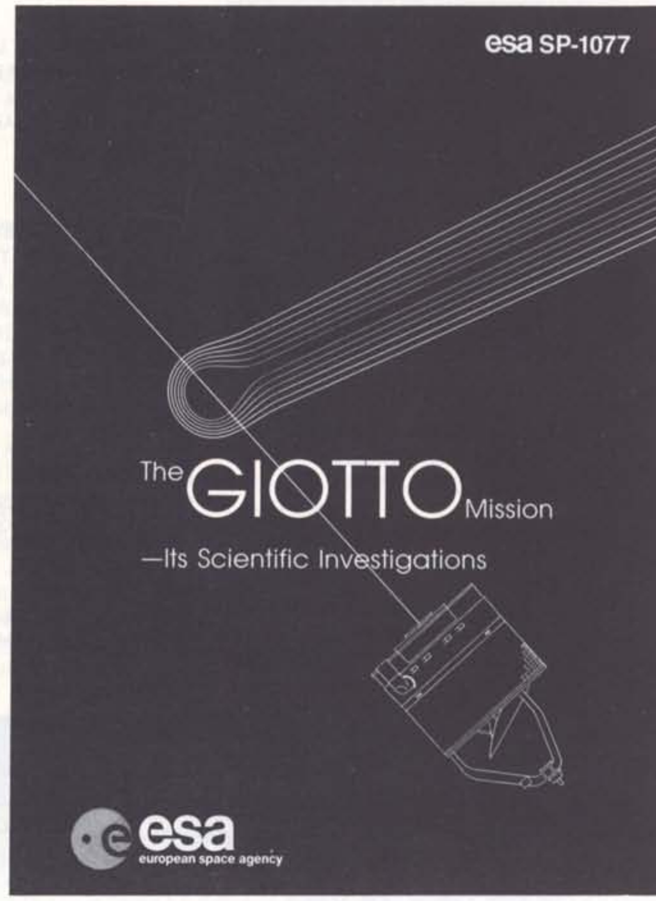
**ESA-TT-942 // 93 PP**
INVESTIGATION OF DENSITY GRADIENT FLUCTUATIONS IN A TURBULENT JET BY MEANS OF THE LASER SCHLIEREN CROSSED-BEAM METHOD (OCT 1985)
*KOMPENHANS J, HOEFER H R & RANNENBERG S, DFVLR, GERMANY*




**ESA SP-1066 Space Missions to Halley's Comet**

(Eds. R. Reinhard & B. Battrick)

This volume contains detailed scientific descriptions of the major space missions (European, Russian, Japanese and American) being undertaken to study Halley's Comet during its March 1986 apparition.

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