WESTERN EUROPEAN SPACE SCIENCE

Successes such as Exosat and the Giotto Comet Halley flyby have led European nations to embark collectively and individually on an ambitious series of scientific space projects for the 1990s, and to back these projects with large budgets.

Ian Axford

In Europe space research began in the early 1960s, not long after the Soviet Union and the United States launched their first satellites. In the 1970s, after proceeding for many years at a rather leisurely pace, European nations stepped up their activity in space. Today the European Space Agency—a 13-nation intergovernmental organization that is Europe's counterpart to NASA—is well known for its successes with geophysical, interplanetary, astrophysical and other scientific spacecraft, as well as for technological and commercial projects such as communications satellites and the Ariane launcher (and its launch site in Kourou, French Guiana). ESA and individual European nations have planned many scientific space projects for the next decade and have even laid out an ambitious, but reasonable and well-grounded, plan for scientific projects beyond the year 2000. This article traces European space efforts from their beginnings a quarter of a century ago to their future in the next century, discussing not only the projects but also some of the intergovernmental politics that affect them. The discussion includes national programs (see figure 1) as well as those of ESA.

Despite the apparently unfavorable circumstances, it is evident to anyone who observes the scene closely that Europe is in fact rapidly becoming a single political entity. Through ESA, European space science and technology are playing an important role in ensuring that this will soon be the case. The Europe that finally emerges may involve as many as 18 nations with common economic, social, political and technological policies, a total population of 360 million and a gross "national" product exceeding that of the United States.

Readers in the US can be forgiven if they find themselves confused by the organization of "European" space science, which potentially involves the 12 members of the European Economic Community, the 6 members of the European Free Trade Association and even Canada. Only 4 of these 19 countries are not yet connected with ESA. Two of those four—Greece and Portugal—may link up in the near future, while the other two—Luxembourg and Iceland—remain aloof for the present. Canada is loosely associated with ESA and participates mainly in special projects. The ESA countries and their respective budget contributions are listed in table 1.

Because Europe is not yet a federation and its countries remain to some extent suspicious of each other and jealous of their sovereignties, ESA members work out their relationships to a large extent at the diplomatic and governmental level. Great care is therefore taken to ensure that each country gets an industrial return of at least 90 percent of its own payments. All transactions are made in a nonexistent currency, the "accounting unit," which is referred to only in millions: 1 MAU is at present about $1.14 million. There are occasional contretemps, as occurred recently at a ministerial-level meeting in connection with a resolution on major new projects, but in general member countries have reached agreement on most major policy matters

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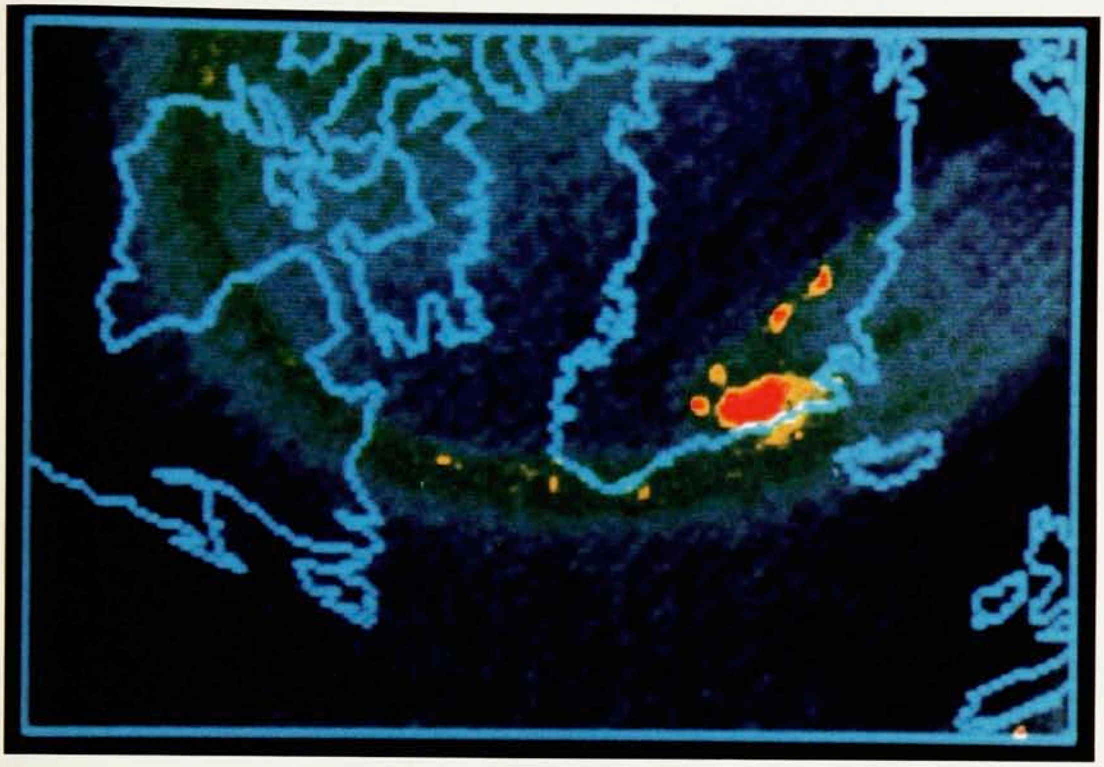


Aurora. Viking recorded this image of the northern polar aurora over Greenland and Canada. (Courtesy of John Murphree, University of Calgary.) **Figure 1**

without much difficulty.

In light of Europe's political will, it is not surprising that common projects, particularly those involving high-technology developments, are strongly supported at all levels. By now most scientific activities have their European organizations—ESA, CERN, the European Southern Observatory, the European Microbiology Laboratory, the European Center for Medium-Range Weather Forecasting, the European Incoherent Scatter Facility and the Joint European Torus, for example—and these organizations, unlike their US counterparts, have the advantage of stable budgets, because the time scale for the agreements is typically at least five years. (There is of course always the danger that too much stability might lead to complacency, but this has certainly not been the case with ESA.)

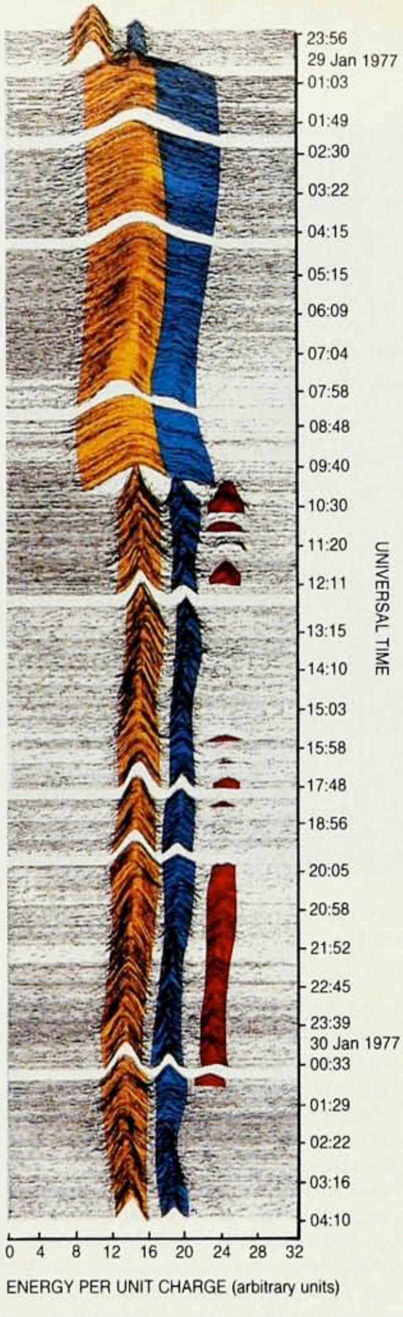
Table 1 summarizes the 1987 ESA budget for approved programs. Note that the fraction allocated to the scientific program, which is the only mandatory program, is 11.2 percent of the total. The amount for that program (170 MAU) will increase at the rate of 5 percent per year until 1989 and perhaps for a further five years, depending on the attitude of the United Kingdom in particular, because financial agreements require unanimity. It is particularly important to note that the ESA program is strictly nonmilitary. The ESA convention limits the agency to "exclusively peaceful purposes," and this has caused some difficulty in negotiations with NASA on cooperation on the space station.

The total annual expenditure on space programs in Europe is at least twice the ESA budget. The difference is accounted for by various national programs, particularly those of France and West Germany, whose contributions to ESA represent relatively small fractions of their overall expenditures on space. It is in fact difficult to estimate the total accurately, because the military space efforts of France and the United Kingdom are not small, and because it is hard to know how much of the work undertaken by research organizations such as the Max Planck institutes should be included. Nevertheless it is clear that the total expenditure on space activities by the US or by the USSR is several times larger than that by Europe. For science alone, the difference between US and European expenditures may not be as great because national programs in Europe are substantial and the costs of institutes and overhead are significant.

The early years

In the early 1960s the United Kingdom and France had programs to develop their own launchers, which had modest success, and several countries were launching rockets, particulary from Esrange, the rocket range in Sweden. There were several national programs involving cooperation with NASA, which led to a small but steady stream of spacecraft, mostly devoted to ionospheric and magnetospheric work but later also performing interplanetary, cosmic-ray and astrophysical studies. The most memorable were perhaps Helios-1 and 2, a West German and US project that provided information on the interplanetary medium between 0.3 and 1.0 astronomical units, data that are still of great importance (see figure 2).

It soon became apparent that despite the success of the national programs it would be impossible to carry out any really significant work in space without extensive



Solar wind ion energy spectra observed by Helios. The plot of time versus energy per unit charge shows the passage of a forward shock at 01:03 and a reverse shock at 10:20. The colored column on the left represents solar wind protons; the middle, He^{++} ions; and the right, He^{+} ions. The mean flow speed increases at the shocks, and the thermal speed is high in the region between the shocks. These data represent the first observation of He^{+} ions; they indicate that the plasma originated in a relatively cool region. (Courtesy of Rainer Schwenn, Max Planck Institute for Aeronomy.) **Figure 2**

cooperation. Thus 1964 saw the birth of one organization dedicated to launcher development and another dedicated to scientific space research. ELDO, the European Launcher Development Organization, was rather unsuccessful in its multinational effort to build the multistage Europa launch vehicle, but ESRO, the European Space Research Organization, produced a very effective program of scientific satellites, buying its launchers from the US. Table 2 summarizes these ESRO projects, including those later taken over by ESA.

ELDO and ESRO combined in 1975 to form the European Space Agency, with the aims of providing a more effective counterpart to NASA and of focusing activities in space science and technology in a rational manner appropriate to an emerging European federation. The first director-general was Roy Gibson, a former UK colonial administrator. ESA has headquarters in Paris and other centers throughout Europe: the European Space Research and Technology Center in Nordwijk, the Netherlands; the European Satellite Operations and Data Processing Center in Darmstadt, West Germany; ESRIN, the Information Retrieval Service, in Frascati, Italy; and several ground stations. Production of the Ariane launcher and the provision of services at the launch site in French Guiana is contracted to Arianspace, a commercial company set up for this purpose with the major share of the capital provided by France.

Member countries subscribe to the various technological programs as they see fit; in general most are represented. However, at the November 1987 Hague meeting concerning the Ariane-5, Columbus and Hermes development programs, the UK abstained from endorsing the resolution to proceed and in so doing jeopardized the planned increases in the science budget beyond 1989. The Science and Engineering Research Council of the UK, following its October 1987 meeting, stated that it did not give a further program extension sufficiently high priority, in relation to other demands, to warrant funding.

Most of the ESA missions listed in table 2 came in pairs, one astrophysical and the other involving Solar System studies. Such "package deals" were designed to satisfy the demands of all the constituents of the scientific community as far as possible. These constituents are represented by ESA's Solar System and astrophysics working groups, which traditionally offered a selection of missions and then engaged in a cutthroat competition for selection. This competition was then refereed by the Science Advisory Committee and adjudicated at a higher level by the more political Science Policy Committee. The inevitable compromises achieved by this procedure were the pairs Geos and Cos-B, and the International Sun–Earth Explorer and Exosat. Ulysses and the Faint Object Camera for the Hubble Space Telescope, as well as Giotto and Hipparchos, may in some sense also be regarded as having been package deals. In fact the procedure worked quite well in a way despite being rather unpleasant in execution in my experience, and despite the committees' usually allowing astronomy projects to win on points over Solar System projects. The new Horizon 2000 procedure, which I will describe later, is more rational and promises more and better science, provided scientists can curb their appetites for ever larger and more ambitious projects.

ESA achievements to date

Cos-B conducted the first complete Galactic survey in high-energy gamma rays, as shown in figure 3. This orbiting instrument, which operated at energies greater than 70 MeV, was not one of the biggest but was surely one of the most satisfying of the early ESA missions. Cos-B featured a cesium iodide scintillator beneath a spark chamber, which was triggered by a counter telescope. The scintillator measured the energies of the secondary particles produced by incident gamma rays. The mission was designed to last for 2 years but in fact survived for 6.8 years before the spark chamber and attitude control gases were depleted, costing Ernst Trendlenberg, ESA's science

Table 1. ESA budget for 1987 (in millions of "accounting units")

Contributions		Approved programs	
France	346.7	Space transportation	461
Germany	265.8	Telecommunications	276
Italy	175.8	General budget	198
UK	141.1	Space station	197
Belgium	44.1	Earth observations	190
Netherlands	40.7	Scientific program	170
Spain	38.9	Microgravity	36
Sweden	33.4		
Canada	23.0	Total	1528
Switzerland	21.9		
Denmark	11.9		
Austria	11.1		
Norway	10.3		
Ireland	2.7		
Finland	1.7		
Other income and carry-over	358.6		
Total	1527.7		

director, a considerable amount in champagne for members of the Caravane collaboration, which designed and calibrated the detector. Cos-B discovered numerous point sources in the Galactic disc as well as the first extra-Galactic source, 3C273.

Geos-1 and 2 were two of the cleanest magnetospheric spacecraft ever built and consequently were relatively expensive. The Geos payloads demonstrated the willingness of ESA to accept completely new kinds of experiments. These included a plasma mass spectrometer, which was selected at a time when most magnetospheric physicists were prepared to assume that all ions were protons, and a novel electric field experiment that used electron guns and the spacecraft's spin to determine the particle drift.

ISEE-2, the International Sun–Earth Explorer, was the first ESA contribution to a joint mission with NASA, which took the opportunity to change an advertised "mother–daughter" mission into a three-spacecraft mission, with the third spacecraft, ISEE-3, at the libration point L_1 between the Earth and the Sun. Partly as a consequence of the simple interface between the two agencies, but also because of goodwill, the collaboration was very successful and led to a flood of excellent scientific papers on such topics as bow shock structure and particle acceleration. ISEE-3, which carried some European experiments, was later transformed into the International Cometary Explorer and in this guise made the first *in situ* observations of the plasma environment of Comet Giacobini–Zinner.

Exosat was an x-ray astronomy satellite. Europe's x-ray astronomers suffered some frustration over this mission but finally must have felt well satisfied with the results. Over 700 proposals for observing time were accepted from the astronomical community at large, and the satellite made over 2000 observations of x-ray sources during its three-year lifetime. Exosat's most remarkable finding was quasiperiodic millisecond pulsations in some well-known bright sources. Extra-Galactic sources, notably active galactic nuclei, exhibited variations on time scales of minutes to days. Supernova remnants were also studied, both spectrally and, with the aid of a low-energy imaging telescope, morphologically.

Giotto, the first European planetary mission, had a difficult time in the selection process before its final approval in July 1980. During the presentations of competing new projects in January 1980, NASA withdrew from a proposed joint mission to the comet Tempel 2, which was to include an ESA-built probe targeted for Comet Halley. A petition to make a quick study of a dual mission to investigate Earth's geomagnetic tail and Halley's comet using Geos-type spacecraft was approved, and the results were presented to the Science Policy Committee in March 1980. The committee rejected the geotail component but allowed a study of the Giotto Halley mission to proceed provided the mission's total cost to ESA would not exceed 80 MAU. This small success was achieved in the face of determined opposition from the astronomers, who had the satisfaction of seeing the astrometry mission Hipparchos approved at the same meeting of the committee. Although the Science Advisory Committee had given priority to the two-component mission, the Science Policy Committee overruled this by a vote of 10 to 1. The study of the Giotto mission was completed in May 1980 and, despite suffering some buffets from supporters of a proposed US "Halley Intercept Mission," finally got the Science Policy Committee's approval in July 1980 as a low-cost, Geos-based mission, again by a vote of 10 to 1.

The full story of Giotto is much more complicated than outlined here, but it does not bear repeating, especially as it had a happy ending when the spacecraft encountered Comet Halley on the night of 13–14 March 1986. The payload was selected early in 1981, leaving little more than four years to build the experiments. Surprisingly enough, they all functioned well, particularly the camera, which with the help of some delicate processing obtained beautiful images of the comet nucleus (see figure 4).

The mission gave ESA a tremendous psychological lift, for despite some poor TV coverage and despite the decision to show false-color pictures instead of the raw black and white images, there was enormous public interest. Giotto demonstrated for the first time that Europeans could be enthused about the doings of their space agency as well as concerned about the disposal of contracts. It also gave ESA confidence in its ability to carry out difficult projects.

Although the spacecraft lost contact with Earth a few seconds before closest approach (as a result of collisions with cometary dust shifting and nutating the antenna beam by more than the 1° beam halfwidth), it recovered to a large extent and may be reusable. To maintain this option, the spacecraft was put into hibernation and redirected so that it will pass the Earth at a distance of 22 300 km on 2 July 1990. Provided enough experiments are still functional, especially the camera, the spacecraft may then be directed toward an encounter with Comet Grigg–Skjellerup two years later on 10 July 1992.

Spacelab, the orbiting laboratory, contains a pressurized module that provides a "shirt-sleeve" working environment. It has a number of pallets open to space and can be carried in the cargo bay of NASA's space shuttle. In 1973 a package deal was struck in which ESA agreed to develop the Ariane launcher, supported mainly by France, and to help develop Spacelab, supported mainly by Germany, as a contribution to the US shuttle. Spacelab-1 in 1983 was a joint ESA–NASA mission devoted primarily to technical verification of the design and performance of the laboratory. The scientific aspects were in this sense only a secondary mission objective. Spacelab carried three tons of payload, including 70 experiments, many of which provided interesting data. Thirty-nine material and fluid science experiments constituted an important first step in microgravity research, which appears to offer the most interesting possibilities for future missions of this type. Some of the European experiments that were affected by bad solar illumination during the mission were offered free reflights. Spacelab is now NASA property.

National programs

As was the case with ESRO, the first European national missions were tentative, being restricted to low altitudes and to studies of the upper atmosphere, ionosphere and magnetosphere. NASA usually supplied the launchers in return for the inclusion of US experiments in the payload. In the 1970s, however, the projects became more enterprising and began to concentrate more on astrophysical questions. Table 3 lists the scientific missions. Missions devoted to Earth observations and geodesy are not included in this list. Perhaps the most impressive feature of the list is the rapid development of astrophysics. It is evident that apart from radio wavelengths around 1 cm, which European spacecraft may eventually touch also, space missions have explored most of the spectrum from the longest radio wavelengths through the infrared to x rays. Indeed, if one takes approved European missions into account, the coverage is complete. There have also been some significant missions devoted to cosmic-ray studies, notably Ariel-6, which measured ultraheavy nuclei (figure 5), and the French and Danish contribution to High Energy Astronomy Observatory 3, which measured the spectra of major primary and secondary species with energies of 1–100 GeV/nucleon.

The International Ultraviolet Explorer is devoted to ultraviolet spectroscopy in the range 1150–3300 Å. This satellite, now accumulating about 6000 images per year, is one of the great successes of space astrophysics. Originally the brainchild of Robert Wilson of University College, London, it involved a decade of work before launch and has survived for a further decade in orbit. IUE has observed a great variety of phenomena, including cometary comas, the Io torus, stars of all types, supernovae, the interstellar medium, the Galactic halo, galaxies and active galactic nuclei. ESA provided the solar panels for the spacecraft and a ground station near Madrid. Data are deposited in the archives of NASA, ESA and the Science and Engineering Research Council of the UK, and to date have resulted in the publication of more than 1400 papers.

IRAS, the Infrared Astronomical Satellite, completed its survey of the infrared sky after 300 days of very successful operation. It also made numerous pointing observations on selected interesting sources, with high spatial or spectral resolution in four wavelength bands centered at 12, 25, 60 and 100 microns. The resulting point source catalog contains about a quarter of a million entries of spatially unresolved sources. Catalogs of small-scale structure and extra-Galactic objects also have been produced, as has an atlas of sky brightness images. A catalog with data on moving sources, including 25 comets and 1811 asteroids, is also available. The US supplied most of the infrared telescope system; the spacecraft was built in the Netherlands and operated from the UK. The mission ended when the superfluid helium supply ran out, but the spacecraft remains otherwise healthy and has proved a useful test bed for the design of ESA's Infrared Space Observatory.

AMPTE, the Artificial Magnetospheric Particle Tracer Experiment, consisted of three satellites: the Charge Composition Explorer, supplied by NASA; the Ion Release Module, supplied by West Germany; and the Subsatellite,

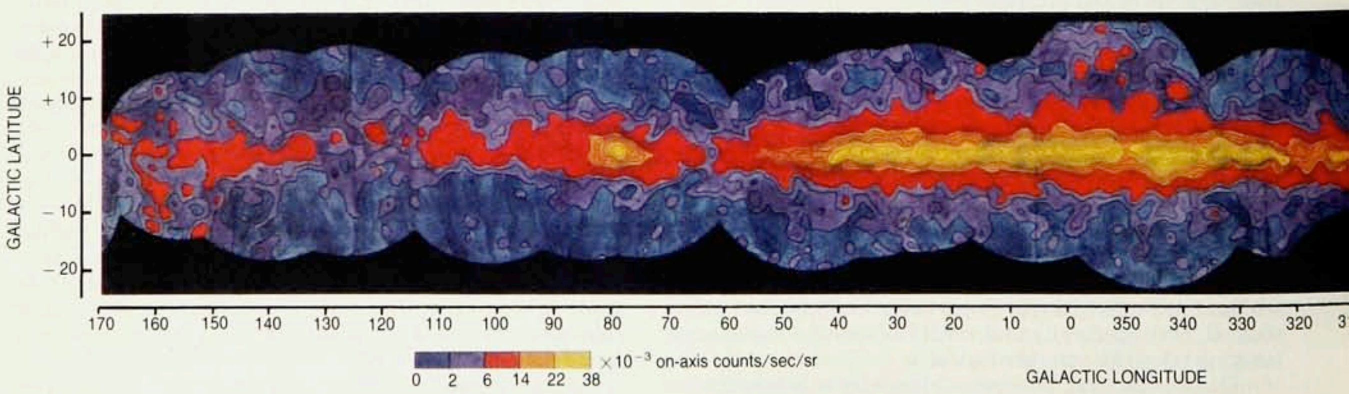


Table 2. Scientific spacecraft launched by ESA and ESRO

Spacecraft	Mission	Dates
ESRO-2	Cosmic rays, solar x rays	May 1968–May 1971
ESRO-1A	Polar ionosphere, auroral phenomena	October 1968–June 1970
HEOS-1	Solar wind, interplanetary medium	December 1968–October 1975
ESRO-1B	Polar ionosphere, auroral phenomena	October 1969–November 1969
HEOS-2	Magnetosphere, interplanetary medium	January 1972–August 1974
TD-1	Ultraviolet astronomy	March 1972–May 1974
ESRO-4	Ionosphere, solar particles	November 1972–April 1974
Cos-B	Gamma-ray astronomy	August 1975–April 1982
Geos-1	Magnetosphere	April 1977–June 1978
ISEE-2	Magnetosphere, Sun-Earth relations	October 1977–December 1987
IUE*	Ultraviolet astronomy	January 1978
Geos-2	Magnetosphere	July 1978–August 1985
Exosat	X-ray astronomy	May 1983–April 1986
Spacelab	General physics, life sciences, etc.	November 1983–December 1983
Giotto	Comet Halley flyby	July 1985

*Trilateral mission with NASA and the UK

supplied by the UK. The main objective was to trace active magnetospheric particles by releasing readily identifiable ions—barium and lithium—from the Ion Release Module and detecting them with the Charge Composition Explorer. The Subsatellite was designed to make plasma measurements in the vicinity of the release module to investigate the physics of the explosive release process. In the event, the experiment obtained only upper limits to the traceability. However, the releases, particularly of the "Christmas comet," supplied very interesting, and indeed surprising, results.

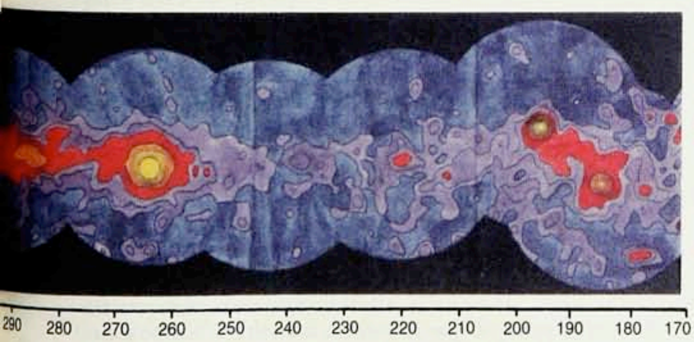
Viking, a Swedish magnetospheric satellite, was launched as a piggyback passenger with the French SPOT Earth observation satellite on an Ariane launcher. The spacecraft had its apogee at about 3 Earth radii and was designed to measure magnetospheric particles, fields and waves relevant to auroral phenomena. Scientists from seven countries, including the US and Canada, conducted five experiments, which included ultraviolet imagers for auroral observations (see figure 1). In addition to its substantial scientific return, Viking helped Swedish industry expand its capabilities in space technology.

Approved ESA missions

So far, all approved ESA missions have carried on to their conclusions. It is an advantage, of course, that the budget is assured some years in advance and that there is no possibility of year-to-year reappraisal or cancellation as a consequence of any one nation's economic difficulties. (There is always a danger of "buying in" with unrealistically low cost estimates, but ESA is well aware of this and on the whole has been able to steer clear of large overruns.) Experimenters and engineers have therefore been able to plan and carry out missions with a feeling of confidence in their stability. At present, two approved missions have suffered delays due to circumstances beyond ESA's control, but in general the agency has managed to maintain a steady flow of missions, which has kept the scientific community more or less satisfied. Table 4 lists approved programs that have payloads selected and are ready or being prepared for launch.

Hubble Space Telescope–Faint Object Camera. The Science Policy Committee approved participation in this project in 1976. ESA's participation consists of the Faint Object Camera, solar arrays and support of personnel for the Hubble Space Telescope Science Institute. In return European astronomers are guaranteed 15% of the total observing time. The Faint Object Camera, which is most sensitive in the blue and the ultraviolet, is capable of operating in four basic modes: as a direct imager with pixel sizes of 0.04, 0.02 and 0.008 arcseconds, and as a 20×0.1-arcsecond slit spectrograph.

Since the Challenger disaster the Hubble Space Telescope has been in some difficulties, but assuming all goes well and it can be launched on schedule in 1989, there is no question that European astronomers will greet it with great enthusiasm. The program includes ideas submitted by more than 100 European astronomers; these range from direct searches for extrasolar planets to detailed spectroscopic and high-resolution imaging studies



Galactic gamma-ray emission in the range 70 MeV to 5 GeV observed by Cos-B. **Figure 3**

Table 3. National scientific missions launched

Spacecraft	Nation	Mission	Launch date
Ariel-1	UK	Solar x rays and uv, cosmic rays	April 1962
Ariel-2	UK	Radioastronomy, ionosphere	March 1964
Ariel-3	UK	Radioastronomy	May 1967
Ariel-4	UK	Radioastronomy, ionosphere	December 1971
Ariel-5	UK	X-ray astronomy	October 1975
IUE	UK, US, ESA	Ultraviolet astronomy	January 1978
Ariel-6	UK	Cosmic rays, x-ray astronomy	June 1979
San Marcos-1	Italy	Atmospheric density	December 1964
San Marcos-2	Italy	Atmospheric density	April 1967
San Marcos-3	Italy	Atmospheric density	April 1971
San Marcos-4	Italy	Atmospheric density	February 1974
San Marcos-D/L	Italy, US, UK	Atmospheric density	March 1988
France-1	France	Ionosphere	December 1965
Tournesol	France	Solar radiation, geocorona	April 1971
Aureole-1	France, USSR	Auroral phenomena	December 1971
Aureole-2	France, USSR	Auroral phenomena	December 1973
Aura	France	Solar and stellar uv, gamma rays	September 1975
Aureole-3	France, USSR	Auroral phenomena	September 1981
Vega-1	France, USSR	Venus balloons, Comet Halley	December 1984
Vega-2	France, USSR	Venus balloons, Comet Halley	December 1984
Azur	Germany	Solar and magnetospheric particles	November 1969
Dial	Germany	Aeronomy, ionosphere	March 1970
Aeros-1	Germany	Ionosphere, solar uv	December 1972
Aeros-2	Germany	Ionosphere, solar uv	July 1974
Helios-1	Germany, US	Interplanetary particles, fields	December 1974
Helios-2	Germany, US	Interplanetary particles, fields	January 1976
ANS	Netherlands, US	Solar and cosmic x rays and uv	August 1974
IRAS	Netherlands, UK, US	Infrared astronomy	January 1983
Intasat-1	Spain	Ionospheric beacon	November 1974
Viking	Sweden	Auroral physics, magnetosphere	January 1986

of the most distant quasars.

Ulysses. This mission, formerly called the Out-of-Ecliptic mission and then the International Solar Polar mission, was approved by the Science Policy Committee in 1977. The mission originally consisted of a pair of spacecraft to be sent over the poles of the Sun after a Jupiter swingby. ESA's contribution amounted to supplying one spacecraft and about half of the experiments on the two spacecraft. Although Ulysses was originally intended for launch in 1983, various delays, the cancellation of the NASA spacecraft and the Challenger accident three months before the planned launch have pushed the launch to October 1990, so that the spacecraft is now expected to pass over the north and south poles of the Sun in 1994–95. The payload consists largely of experiments designed to measure the characteristics of the solar wind, the interplanetary magnetic field, solar and Galactic cosmic rays, plasma waves and interstellar neutral gas and dust. Ulysses will also carry an instrument to detect gamma-ray bursts and x and gamma rays from solar flares.

I have written with some passion of the trials and tribulations of the Giotto mission, but these were almost insignificant in comparison with those of Ulysses. The full story of the background to this mission is quite involved, and it is not yet finished. It surely contains all the twists and turns of a C. P. Snow novel—to date, everything but violence. The events growing out of the cancellation of the US spacecraft, followed by the celebrated *démarche* of European ambassadors to the US State Department to protest the cancellation, have been described elsewhere.[1] The brilliant lobbying of a US Congressional committee, which left its astonished chairman facing an almost unanimous vote against his known wish to have the mission canceled, cannot be described here in detail because the participants are still in sensitive positions, nor can the continuous efforts required earlier to get final Science Policy Committee approval on the European side. There is much more besides, but if a good book is to be written eventually, it must end with the successful launch of a spacecraft that has a still functioning radioisotope thermal generator, that passes Jupiter in the 14th month of the mission and that traverses the poles of the Sun in the 45th and 56th months, as figure 6 indicates.

One hopes that as a direct consequence of the events associated with the Ulysses mission the arrangements between ESA and NASA have been revised so that unilateral changes of plan by one side are less likely.

Hipparchos. This astrometry mission, approved by the Science Policy Committee in 1980 and scheduled for launch by Ariane in July 1988, is dedicated to obtaining precise positional measurements of some 100 000 stars brighter than magnitude 13. Typical accuracies expected are 0.002 arcsec for each component of parallax and position and 0.002 arcsec/year for each component of proper motion. Hipparchos will obtain precise magnitudes for each star in its survey program and precise positions for each of the 100 or so transits of these stars through the field of view of the telescope during the 2.5-year mission. Measurements of all stars down to a limiting magnitude of 10–11 will also be obtained, but with a lower precision.

Some of the advances to be expected from Hipparchos will come from the fivefold increase in the precision of measurements of trigonometric parallaxes as compared with typical Earth-based measurements, and from the considerably larger number of measurable stars. A much larger volume of space will be accessible, and this space includes bright but rare stars important for determining the cosmic distance scale.

Infrared Space Observatory. This mission, approved by the Science Policy Committee in 1983 and scheduled for launch in 1993, is a logical successor to IRAS but has 100–1000 times the sensitivity, better spectral and angular resolution, wider wavelength coverage, more sophisticated instruments and a longer lifetime. An Ariane-4 rocket is to place the satellite in a geosynchronous transfer orbit, after which a hydrazine system will put it into its final 24-hour orbit. This will allow 22 hours of operational time per orbit.

The observatory has broad scientific aims, as one might expect of a survey mission in a wavelength range that has yet to be explored adequately. Objects of interest include planets, comets, asteroids, protoplanetary discs, regions of star formation, regions of ionized hydrogen, cool giant stars, planetary nebulas, globular clusters, the nuclei of normal and active galaxies and the halos of individual galaxies.

The satellite will carry 2000 liters of superfluid helium to cool the detectors to about 2 K and the telescope and instruments to 3–4 K. This will give the observatory a lifetime of at least 18 months.

European Retrievable Carrier. This reusable free-flying platform is designed to be launched and retrieved by the shuttle. The first mission is devoted mainly to microgravity studies and includes facilities for mirror heating, crystal growth from solution and protein crystallization as well as an assembly of 16 furnaces and a space biology radiation assembly. Space science experiments include measurements of dust particles, x-ray and gamma-ray bursts, solar radiation and vertical profiles of atmospheric water, carbon dioxide and aerosols. Launch is not expected before 1993.

Approved national missions

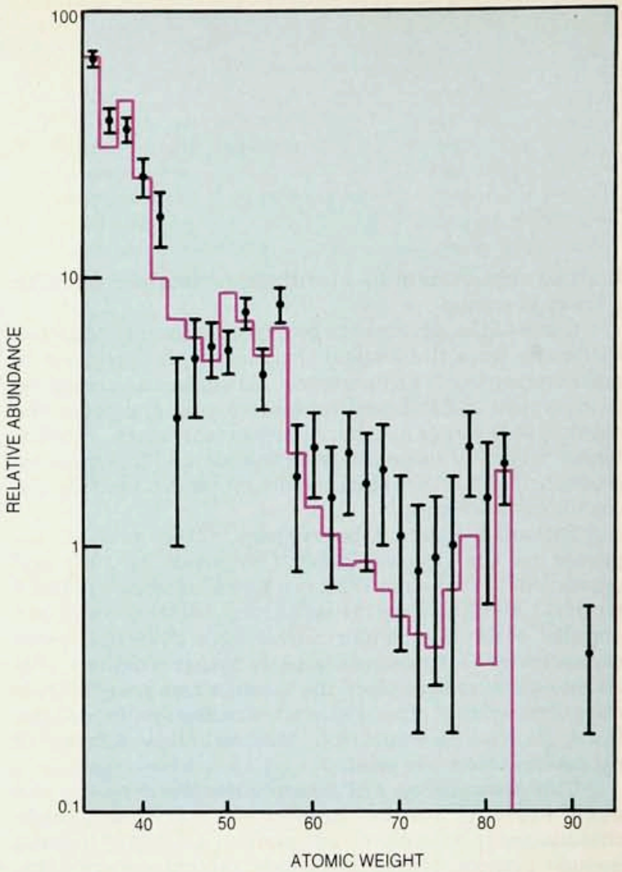
Although there is some tendency for national programs gradually to be subsumed within those of ESA, as foreseen in the ESA convention, several national remain healthy and provide something of a counterweight to the ESA program. This takes some of the pressure off ESA and allows the nations concerned to give emphasis to fields that might otherwise be neglected. The major national programs are those of France and West Germany, but other nations are also quite active, notably Italy, Sweden, the UK and the Netherlands. Most ESA nations are also involved in the Soviet Interkosmos program, at least at the level of supplying experiments. The Soviet mission to the Mars moon Phobos, which Roald Sagdeev describes in his article on page 30, is a particularly good example, as it involves Austria, West Germany, Switzerland, France, Sweden, Finland, Ireland and ESA's Space Technology Center in Nordwijk.

Comet Halley's nucleus. This image of the comet's nucleus is a composite from a multicolor camera on board Giotto. The nucleus is very dark and its outline is partly obscured on the sunward (left) side by gas jets carrying dust that scatters sunlight relatively efficiently. The dimensions of the nucleus are 16 × 8 × 8 km. (Courtesy of Horst-Uwe Keller, Max Planck Institute for Aeronomy.) **Figure 4**

Germany's most important national missions are Galileo and Rosat, an x-ray astronomy satellite. Galileo, which is a joint project with NASA, is a mission to examine Jupiter with an orbiter and probe. Germany contributes the retropropulsion unit required for inserting the spacecraft into orbit and guiding it subsequently. On the scientific side Germany will supply detectors of helium abundance, energetic particles and lightning for the probe, and detectors of energetic particles and dust for the orbiter. Unfortunately the long delayed launch—originally set for 1982 but now moved to 1989—and the slow, indirect passage to Jupiter have drained some of the enthusiasm for the mission, which will now require a total of about 20 years from payload selection to encounter with Jupiter.

Rosat, which is a joint project of Germany, NASA and the UK, has had a smoother ride, especially since the launch was switched from the shuttle to an expendable vehicle. The principal aim of this mission, which is due for launch in 1990, is to survey the sky in the soft-x-ray region of 50 eV to 2 keV and, with a wide-field camera, in the extreme ultraviolet region of 50–210 eV. The x-ray survey will be the first to be performed with an imaging telescope and will be at least two orders of magnitude more sensitive than previous surveys. In the pointing mode, the sensitivity and the angular and spectral resolution will be two to three times better than those achieved by the Einstein Observatory.

France has a strong national program based largely on cooperation with the Soviet Union. The main activity



Ultraheavy elements in Galactic cosmic rays observed by Ariel-6. The histogram shows the results of a calculation based on the propagation of Solar System material. There appears to be a slight excess of cosmic rays with atomic weights in the range 60–80, and there are three events in the actinide region. **Figure 5**

now is on the Phobos mission, which includes a number of French experiments on the spacecraft and landers. France plans a substantial contribution to the 1994 Soviet mission to Mars—notably balloons designed to carry small payloads to numerous points on the surface of the planet. One French–Soviet proposal is to launch in 1996 two additional spacecraft built by CNES, the French space organization, together with ESA (if approved by the Science Policy Committee). These spacecraft, which would constitute the Vesta mission, would each make close passes with six to eight asteroids and at least one comet. Their payloads could be devoted mainly to imaging and spectroscopy but could also include penetrators for *in situ* measurements.

Other national programs include a further Spacelab mission sponsored by Germany; Sax, an x-ray astronomy project from Italy; and the shuttle-based Tether project—a conducting line several kilometers long with an instrumented package on the end for electromagnetic and other experiments—which was conceived in Italy and involves NASA.

ESA's long-term plan

The desire to take on larger and more sophisticated projects made it natural for ESA to adopt a long-term plan. Thus in 1983–84 the agency entered a new phase of planning and development with the appointment of Reimar Lüst as director-general and Roger Bonnet as director of scientific programs. Planning of technological projects has taken the course already outlined, namely undertaking as major projects the development of the large Ariane-5 launcher, the shuttle-type reusable vehicle Hermes and a permanent laboratory module for the US space station Columbus. In the case of scientific projects, planning was a rather new concept, but clearly needed, not least because of the relative unpleasantness of previous procedures. This has led to an ambitious but reasonable and well-rounded plan called Horizon 2000, which figure 7 summarizes. This plan requires an increased science budget, and the January 1985 ministerial meeting in Rome took the first step in this direction by agreeing to increase the science budget by 5% per year until 1989. Unfortunately, the continuance of this increase until 1994, which was agreed to in principle, is now endangered as a result of its recent rejection by the UK. It is not yet clear how this will affect the long-term plan, but it will certainly lead to some difficulties.

The Horizon 2000 plan is designed to allow European scientists to make contributions at the forefront of space science, to select projects that are major technological challenges to industry, to allow Europe to be a major participant in the worldwide development of space science and to offer the European scientific community a variety of opportunities for frontline research.

As figure 7 indicates, Horizon 2000 consists of four large "cornerstone" missions, covering four basic areas of science, along with several medium-scale and perhaps four small-scale missions, including the European Retrievable Carrier missions, that provide balance and an opportunity to bring new concepts into consideration continuously. The cornerstone missions are considered to be projects in the 400-MAU class, the medium-sized missions about 240 MAU and the small missions 160 MAU. As now envisioned, the program as a whole will stretch over 20 years. The concept is clearly a very reasonable one that gives every space scientist the possibility of involvement and covers the essential elements of space research in a balanced and logical manner.

The four cornerstone missions are the following:

▷ A Solar–Terrestrial Science Program. This joint ESA–NASA mission has two parts: the Solar and Heliospheric Observatory and a four-spacecraft magnetospheric mission known as Cluster. The multidisciplinary Solar and Heliospheric Observatory is aimed at examining the internal structure of the Sun through oscillation measurements and at studying coronal heating and the origin of the solar wind through spectroscopy and imaging. Cluster aims to make detailed measurements of plasma, electric fields and magnetic fields. The program's spacecraft are scheduled for launch in 1994–95.

▷ A Comet Nucleus Sample Return mission aimed at bringing to Earth a sample of a cometary nucleus to learn more about primitive Solar System material. This is seen as a logical follow-up to the Giotto Halley mission.

▷ An x-ray astronomy mission aimed at studying x-ray sources with high spectral and spatial resolution and at using an imaging instrument with as large an area as possible—the X-Ray Multimirror Telescope, or XMM. This mission is scheduled for launch in 1998 and is a logical continuation of the work that began with ANS, Ariel-3 and Exosat and that Rosat will have advanced.

▷ A Far-Infrared and Submillimeter Space Telescope designed for studies of the physical characteristics of infrared sources by means of heterodyne detectors. This is a logical successor to IRAS and the Infrared Space Observatory.

The payload for the Solar Terrestrial Science Program has recently been selected from responses to a 1987 announcement of opportunity. Both the XMM and the Far-Infrared and Submillimeter Space Telescope projects are undergoing extensive study and analysis by ESA and industry. ESA is still studying the Comet Nucleus Sample Return mission to determine the most effective and feasible way to proceed. One hopes ESA can take a decision on the full program of launches in 1991, when results from the studies of these missions will have been digested.

Various medium-sized missions are also under study, including:

▷ Lyman, aimed at high-throughput ultraviolet spectroscopy at wavelengths of 900–1200 Å. Australia and Canada may participate in this project.

▷ Quasat, aimed at extending the worldwide very-long-baseline interferometry network and thus achieving very-high-resolution maps of radio sources, especially quasars and the nuclei of galaxies. Canada may participate in this project.

▷ The Gamma-ray Astronomy with Spectroscopy and Positioning mission, aimed at gamma-ray spectroscopy with accurate positioning obtained using coded aperture techniques.

▷ Cassini, a joint ESA–NASA mission aimed at exploring in detail the Saturnian system, especially Titan. ESA's contribution would be the Titan atmospheric probe.

▷ Vesta, the joint mission with Interkosmos—the Soviet international collaborative organization for space research—and CNES described above.

These missions would fill out the overall menu in a very satisfactory manner. Cassini and Vesta, together with the Comet Nucleus Sample Return mission, would constitute a balanced planetary program, and the three astronomy missions would complete coverage of the full electromagnetic spectrum from the radio to the gamma-ray regions.

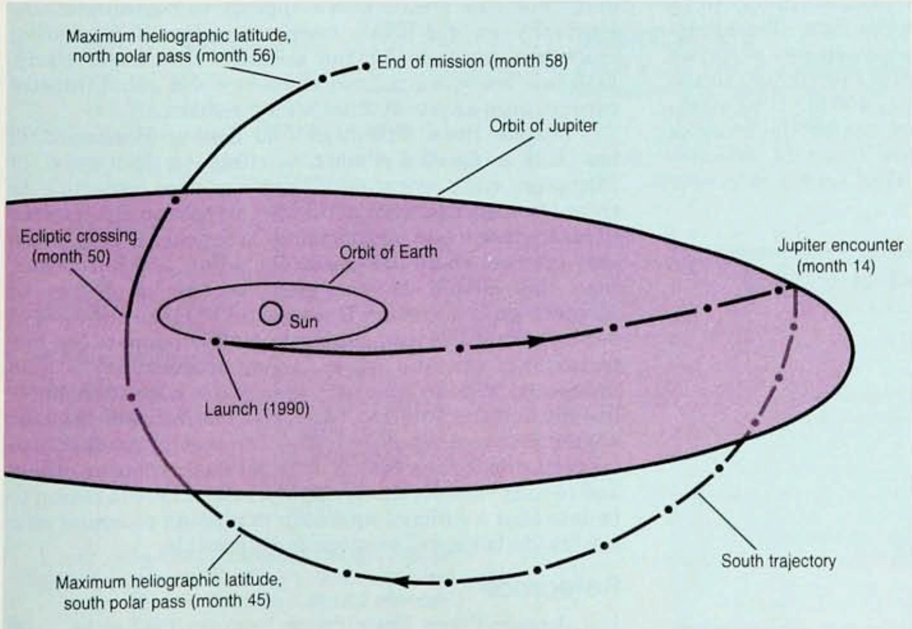
There are possibilities for scientific work within ESA other than those covered by Horizon 2000. In particular, remote Earth sensing and life and materials sciences research are conducted within the framework of optional programs. A major program of this type is the Earth Resources Satellite, which is designed to study coastal zones, oceans and meteorology with a synthetic aperture radar as the key instrument. Subsequent missions will also cover meteorology, climatology and atmospheric sciences. The Earth observation program is budgeted at 210–235 MAU per year.

Prospects and problems

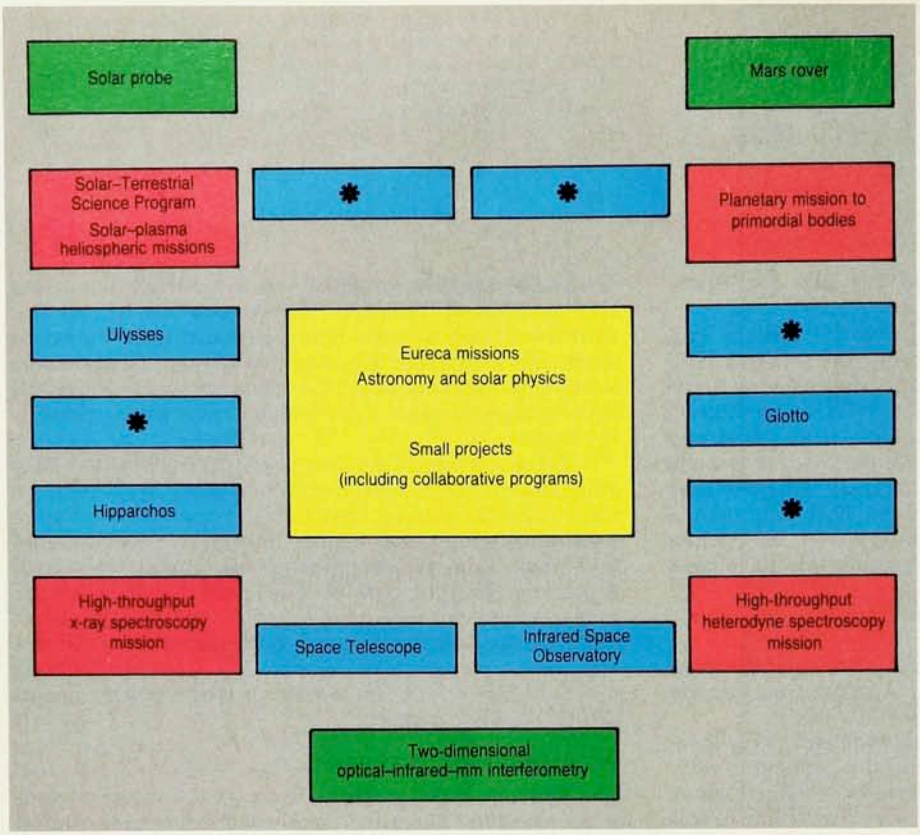
The Horizon 2000 program has given European space science a sound and scientifically defensible basis that, if all goes well, should allow ESA to achieve its scientific and political goals. Inevitably, however, there are problems that will have to be dealt with:

▷ The loss of the expected 5% annual increase in the science budget beyond 1991 will amount to about 500 MAU in the following ten years, a sum roughly equivalent to the loss of one cornerstone and one small mission. This would indeed be serious and would endanger the balance and structure of the whole program.

▷ It has been difficult to enforce budgetary discipline on scientists themselves when it comes to defining and



Trajectory of Ulysses. The Jupiter swingby maneuver will direct the spacecraft into a solar polar orbit that passes first over the south pole of the Sun. Solid dots are shown at 100-day intervals. **Figure 6**



Horizon 2000, ESA's long-term program. Red boxes show the four large "cornerstone" missions; blue, medium-scale missions; and yellow, small missions and projects. The stars mark projects that have yet to be determined. Candidates include missions involving ultraviolet spectroscopy, very-long-baseline interferometry, gamma-ray astronomy with spectroscopy and accurate positioning, exploration of Titan and the Saturnian system, and a mission to asteroids and comets. **Figure 7**

selecting missions. In some cases it seems that a "blue sky" approach has prevailed as far as the cornerstones are concerned; it is as if 400 MAU is regarded as a starting bid, so that the missions are defined with little care for the final costs. This problem was clearly apparent in the case of the first cornerstone, which burst out of the financial limits quite soon. However, the balanced structure of the whole program at least puts pressure on each cornerstone to remain within budget. ESA has followed a careful approach of designing missions around their budgets.

▷ A related problem is that some ministries have not been fully aware that large experiment costs are likely to be associated with large missions. In the Solar–Terrestrial Science Program there were some unwelcome surprises when the requests for support arrived. Indeed, it would be quite uneconomical if ESA were to pay 400 MAU for a mission and the experiment costs were not on the order of 100–150 MAU. The difficulties are fewer in missions where ESA supplies a spacecraft that serves as a user facility, as in the large astronomical missions. However, the aims of the agency would not be met if the European scientific community were given only the task of data analysis.

▷ A quite natural tendency, as a way out of the problem of costs generated by the blue-sky approach, has been to invite another agency—usually NASA—to be a partner. But one cannot assume that the partner will be willing to cooperate, or that if it is willing, it will be able to act in the same time frame. Furthermore it would be very unsatisfactory for ESA to carry out only a very few missions on its own. For this reason there appears to be considerable sympathy among ESA's member nations for securing more independence for the missions now under study. ESA has therefore defined the x-ray and submillimeter cornerstones as purely European missions.

Despite these difficulties and doubts, Horizon 2000 has had a decidedly positive effect on the mood of European space scientists. They are now beginning to show confidence in their ability to compete on equal terms in both science and experimental technology. It is in the best interest of all scientists, including non-Europeans, that this should be the case, because a degree of competition is necessary if we are all to make the most of our opportunities and maintain public support for our endeavors. On the other hand, cooperation is also necessary, because no single agency can hope to monopolize all fields of interest. Agencies can achieve the best results and coverage only if they can reach agreements to cooperate on some missions, to avoid duplication on others and to share results where appropriate. There is reason to believe that a rational approach to mission planning on a worldwide basis will eventually be possible.

Table 4. ESA approved missions as of 1987

Spacecraft	Mission
Hubble Space Telescope*	Faint Object Camera for telescope
Ulysses*	Solar polar interplanetary fields and particles
Hipparchos	Space astrometry
Infrared Space Observatory	Infrared astronomy
European Retrievable Carrier	General space experiments

*Joint with NASA

Reference

1. J. Johnson-Freese, Space Policy, February 1987, p. 24. ■