Europa

Achievements: first European satellite launcher development programme
Launch dates: 11 launches 1964-1971
Launch site: Woomera (Australia) and Kourou (French Guiana)
Launch mass: 104 t Europa 1; 112 t Europa 2
Performance: 1150 kg LEO, 170 kg GEO from Kourou

The impetus for creating an independent space power in Europe began in the early 1960s. Belgium, France, Germany, Italy, the Netherlands and the United Kingdom (associated with Australia) signed the Convention in 1962 to create the European Launcher Development Organisation (ELDO), with the goal of developing a satellite launch vehicle independently of the two great space powers. The UK began development of the medium-range Blue Streak nuclear missile in 1955 under prime contractor de Havilland. The 2500 km range was increased to 4000 km in 1958 but the concept was overtaken by changes in the political and military landscapes – Blue Streak was cancelled as a missile on 13 April 1960. Rather than cancel it altogether, the UK government took up the idea of recycling it as a satellite launcher, using the UK Black Knight research rocket as stage 2. A 3-day conference in Strasbourg beginning 30 January 1961 produced an Anglo-French memorandum declaring that an organisation should be set up to develop a launcher using a Blue Streak first stage and a French second. Germany declared its intention in June 1961 to provide the third stage. The Lancaster House, London meeting of 30 October - 3 November 1961 agreed on the guiding principles of the ELDO Convention, which was signed on 30 April 1962 and came into force on 29 February 1964. Italy was to provide the fairing and test satellites, Belgium the downrange guidance station and The Netherlands the long-range telemetry links. Australia's contribution was the Woomera launch site.

ELDO A (later renamed Europa 1) was to be capable of delivering 500-1000 kg satellites into LEO orbits. The first three tests (see table) were promising but by now it was clear that Europe would need a vehicle capable of delivering telecommunications satellites into GEO by the early 1970s. In July 1966, the participants agreed to develop the ELDO PAS (Europa 2) version. The Perigee-Apogee System would use a solid-propellant motor at perigee and the satellite's own apogee motor to deliver 170 kg into GEO. The UK replaced the radio guidance system with inertial guidance, Italy provided the perigee motor and STV and France the operational launches from its Kourou base. There were also proposals to replace the second and third stages successively with hydrogen-oxygen stages, to deliver 1 t into GEO.

Spiralling costs and disappointing tests of the upper stages increasingly threatened the whole organisation. With hindsight, there were two major problems: ELDO did not have genuine technical and management authority (which belonged to the Member States) and there was no overall prime contractor. The UK, under a different government since 1964, became lukewarm towards a European heavy launcher. In April 1969, the UK and Italy withdrew from Europa 2, while the other ELDO states resolved to begin studies of a Europa 3 to deliver 400-700 kg into GEO, indicative of French determination in particular to develop a heavy launcher that did not depend on Blue Streak.

The 5th European Space Conference (ESC) in December 1972 agreed to Europeanise the French L3S project (which became Ariane) and cancel Europa 3. ELDO's Council on 27 April 1973 decided to close the Europa 2 programme and to wind down the organisation. The 6th ESC in July 1973 paved the way for ESA's creation to merge the activities of ELDO and ESRO.

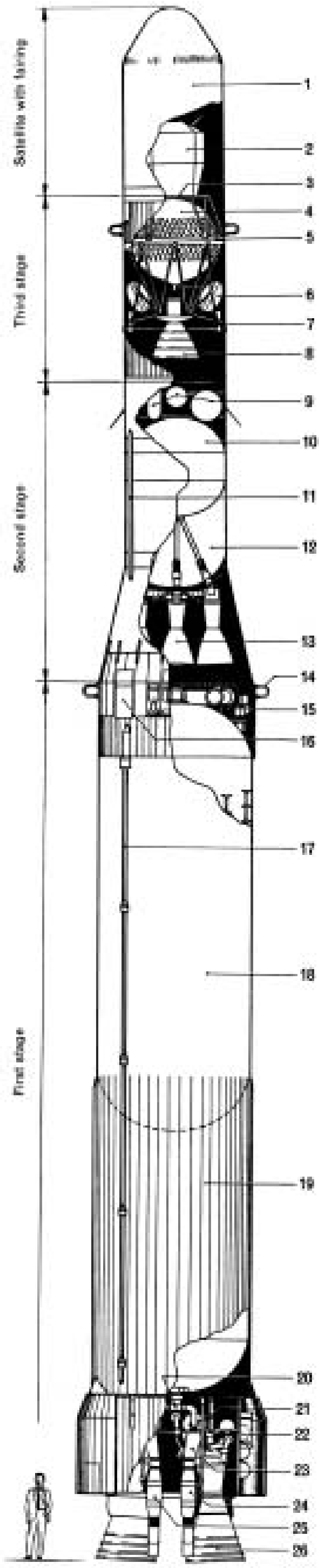
Europa 2 on the ELA-1 pad at Kourou. Facing page: the F11 launch. The same pad was later used for Ariane.

Europa 1 Characteristics
Launch mass: 104 t
Length: 31.7 m
Principal diameter: 3.05 m
Guidance: radio
Performance: 850 kg into 500 km circular orbit launched northwards from Woomera, 1150 kg launched eastwards from equatorial site. 800 km: 700 kg & 950 kg; 400x5000 km: 350 kg & 550 kg

Stage 1 (Blue Streak)
Principal contractor: Hawker Siddeley Dynamics
Propulsion: 2x Rolls-Royce RZ-2 (US Rocketdyne S3 under licence), total 1334.4 kN sea-level thrust
Propellants: 84950 kg LOX/kerosene
Length: 18.7 m
Principal diameter: 3.05 m
Mass: 95025 kg (dry 6168 kg)
Burn duration: 160 s

Europa 1 at Woomera.

Stage 2 of Europa 2 F11 at Kourou.



Europa Launch Record

	Date	Vehicle	Comments
F1	5 Jun 1964	Europa 1	Blue Streak-only. Success. Altitude 177 km, downrange 965 km. Engines shut down 6 s early (147 s) because of lateral oscillations induced by propellant sloshing (planned downrange 1500 km)
F2	20 Oct 1964	Europa 1	Blue Streak-only. Success. Altitude 241 km, downrange 1609 km
F3	22 Mar 1965	Europa 1	Blue Streak-only. Success
F4	24 May 1966	Europa 1	BS/inert upper stages/STV. Success
F5	15 Nov 1966	Europa 1	BS/inert upper stages/STV. Success
F6-1	4 Aug 1967	Europa 1	BS/stage 2/inert stage 3/STV. Success. Stage 2 failed to ignite
F6-2	6 Dec 1967	Europa 1	BS/stage 2/inert stage 3/STV. Stage 2 sequencer did not start; stage did not separate
F7	30 Nov 1968	Europa 1	All live + STV. Stage 3 burned 6 s. First orbital attempt
F8	3 Jul 1969	Europa 1	All live + STV. Stage 3 failed to ignite. Second orbital attempt
F9	12 Jun 1970	Europa 1	All live + 260 kg STV. Fairing failed to separate and stage 3 under-performed. Third orbital attempt
F11	5 Nov 1971	Europa 2	Europa 1/stage 4/360 kg STV. Inertial guidance failed at 105 s, vehicle broke up at 150 s. Fourth orbital attempt (GTO)

All launches from Woomera, except F11 (Kourou). BS = Blue Streak; STV = Satellite Test Vehicle. F12 was ready at Kourou when the programme was cancelled (before F11 failure, F12 launch was scheduled for Apr 1972). F13 is at the Deutsches Museum, Munich (D); F14 at East Fortune Field, Edinburgh Science Museum (UK); F15 at Redu (B). F13/F14 were earmarked for the Franco-German Symphonie telecommunications satellites, launched instead by US Deltas in Dec 1974/Aug 1975; F15 was planned for Cos-B.

Stage 2 (Coralie)
Principal contractors: SNIAS, Lab de Recherches Balistiques et Aérodyanmiques (engines)
Propulsion: 4 engines providing total 265 kN vac; SI 280 s
Propellants: NTO/UDMH
Length: 5.50 m
Principal diameter: 2.00 m
Mass: 12186 kg (dry 2263 kg)
Burn duration: 96.5 s

Stage 3 (Astris)
Principal contractors: Bölkow, ERNO
Propulsion: 22.5 kN vac + 2x0.4 kN verniers
Propellants: NTO/Aerozine 50
Length: 3.82 m
Principal diameter: 2.00 m
Mass: 4007 kg (dry 885 kg)
Burn duration: 36 s

Fairing
Length: 4.00 m
Diameter: 2.00 m
Mass: 300 kg

Left: principal characteristics of Europa 1 (Europa 2 was identical but the satellite perched on a perigee kick stage). 1: fairing. 2: Satellite Test Vehicle. 3: payload adapter. 4: Aerozine tank (NTO tank is lower half). 5: support ring. 6: He tank (x2). 7: vernier (x2). 8: main engine. 9: pressurant tanks. 10: NTO tank. 11: interbay ducting. 12: UDMH tank. 13: main engines (x4). 14: telemetry antenna. 15: equipment bay. 16: access door. 17: LOX tank pressurisation pipe. 18: LOX tank. 19: kerosene tank. 20: low-pressure feed pipes. 21: turbopumps. 22: GN_2. 23: turbine exhaust. 24: LN_2-GN_2 heat exchanger. 25: LOX-GOX heat exchanger. 26: expansion bell.

Europa 2 Characteristics (where different from Europa 1)
Launch mass: 111.6 t
Guidance: inertial (Marconi Space & Defence Systems)
Performance: 400/170 kg into GTO/GEO from Kourou

Stage 4
Principal contractors: AERFER Pomigliano d'Arco Napoli, Matra
Propulsion: 41.2 kN vac, solid propellant. Spun-up to 120 rpm by 4x1250 N solids
Length: 2.02 m
Principal diameter: 73 cm
Mass: 790 kg (dry 105 kg)
Burn duration: 45 s

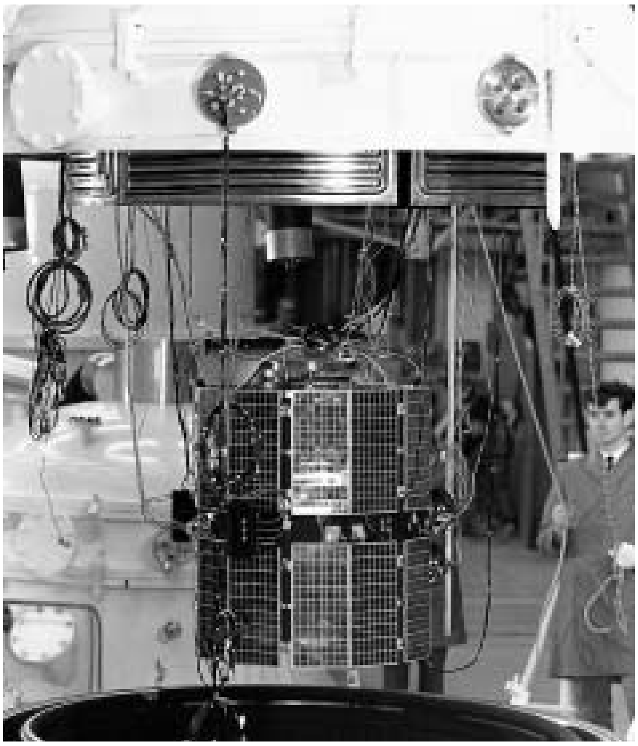
ESRO-2

Achievements: first ESRO satellite; significant contributions to understanding near-Earth space
Launch dates: ESRO-2A 29 May 1967 (launch failure); ESRO-2B (Iris) 17 May 1968
Mission end: ESRO-2A 29 May 1967 (launch failure); ESRO-2B 9 May 1971 (reentry; 12-month design life)
Launch vehicle/site: NASA Scout from Western Test Range, California
Launch mass: 74 kg (21.3 kg scientific payload)
Orbit: 334x1085 km, 98.9° Sun-synchronous
Principal contractor: Hawker Siddeley Dynamics (UK)

ESRO's first satellites concentrated on solar and cosmic radiation and its interaction with the Earth. ESRO-2 looked at solar X-rays, cosmic radiation and Earth's radiation belts, while ESRO-1A simultaneously examined how the auroral zones responded to geomagnetic and solar activity. Direct measurements were made as high-energy charged particles plunged from the outer magnetosphere into the atmosphere.

ESRO's HEOS-1 also played its part through simultaneous measurements of the interplanetary magnetic field and the particles en route to Earth. This meant the particles could be used to trace out the magnetosphere's structure and how it connected with the interplanetary field. ESRO-2 and -1 contributed significant pieces to this puzzle. ESRO-2 was particularly fruitful on the arrival of solar particles over the polar caps, highlighting striking intensity variations between the two regions, when uniformity had been expected.

ESRO-2A was lost when the fourth stage of its Scout launcher failed to ignite, leaving the satellite to burn up on reentry. The prototype was refurbished as a replacement, carrying the same seven experiments (see table) and renamed 'Iris' once in orbit. Although its design life was only 1 year, most of the subsystems worked well throughout and four experiments were still returning data by the time atmospheric drag precipitated reentry after 16 282 orbits. The tape recorder failed after 6.5 months, reducing average data recovery from more than 90% to around 20%.



Satellite configuration: 12-sided cylinder, 86 cm long, 78 cm diameter. Six aluminium panels (carrying the solar array) were attached to six magnesium alloy longerons, bolted to two honeycomb floors and stabilised by end frames. Central thrust tube.

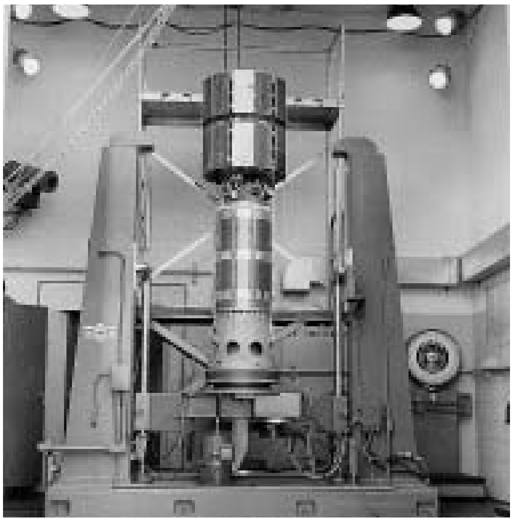
Attitude/orbit control: spin stabilised at 40 rpm along main axis, 90° to Sun direction. Spin-up by gas jets; spin axis controlled by magnetorquer.

Power system: 3456 20.5 mm^2 Si cells on body panels. Supported by 3 Ah nickel cadmium battery.

Communications: 128 bit/s realtime telemetry on 137 MHz. Tape recorder stored 128 bit/s for 110 min; playback at 4096 bit/s on 136 MHz. TC at 148 MHz. Controlled from ESOC.

ESRO-2 thermal-vacuum testing at ESTEC.

ESRO-2 attached to the final stage of its Scout launcher at the Western Test Range in California.



Right: ESRO-2 attached to the Scout stage 4 undergoing spin-balancing at the Western Test Range.

ESRO-2 Scientific Instruments

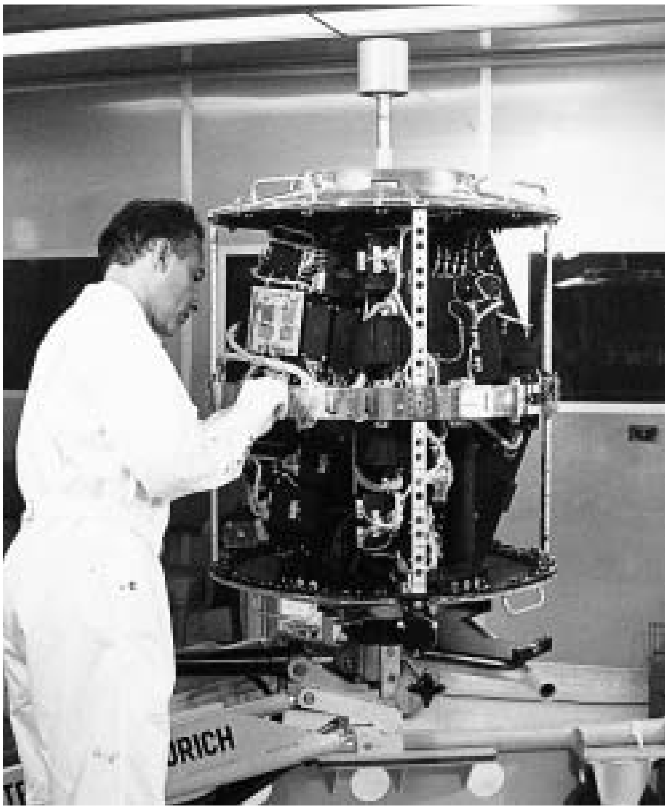
S25	Two Geiger-Müller counters measured time variations in Van Allen belt population. Imperial College London (UK)
S27	Four solid-state detectors measured solar and Van Allen protons (1-100 MeV) and α-particles. Imperial College London (UK)
S28	Scintillator, proportional counters and Cerenkov detectors measured 0.4-0.8 GeV solar protons/α-particles. Imperial College London (UK)
S29	Scintillator/Cerenkov detector for flux/energy spectrum of 1-13 GeV electrons. Univ of Leeds (UK)
S36	Proportional counters measured 1-20 Å solar X-rays. University College London/Leicester Univ (UK)
S37	Proportional counters measured 44-60 Å solar X-rays. Lab voor Ruimteonderzoek, Utrecht (NL)
S72	Two solid-state detectors measured solar and galactic protons (0.035-1 GeV) and α-particles (140-1200 MeV). Centre d'Etudes Nucleaires de Saclay (F)

ESRO-1

Achievements: significant contributions to understanding near-Earth space
Launch dates: ESRO-1A (Aurora) 3 October 1968; ESRO-1B (Boreas) 1 October 1969
Mission end: ESRO-1A 26 June 1970; ESRO-1B 23 November 1969 (reentry; 6-month design lives)
Launch vehicle/site: NASA Scout from Western Test Range, California
Launch mass: 74 kg (22 kg scientific payload)
Orbit: ESRO-1A 258x1538 km, 93.7° Sun-synchronous; ESRO-1B 291x389 km, 86.0°
Principal contractors: Laboratoire Central de Telecommunications (Paris), with Contraves (CH) and Bell Telephone Manufacturing (B) as main associates

ESRO's first satellites concentrated on solar and cosmic radiation and its interaction with the Earth. ESRO-2 looked at solar X-rays, cosmic radiation and Earth's radiation belts, while ESRO-1A simultaneously examined how the auroral zones responded to geomagnetic and solar activity. Direct measurements were made as high-energy charged particles plunged from the outer magnetosphere into the atmosphere.

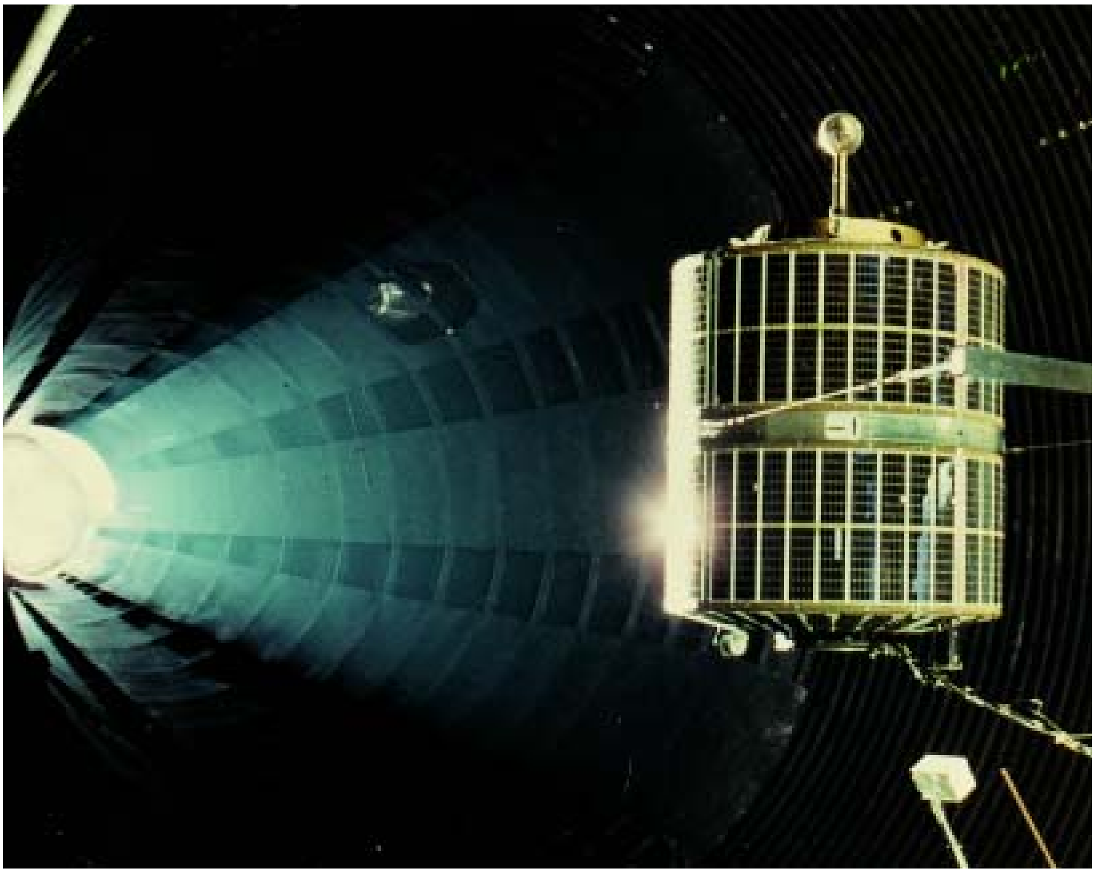
ESRO-1 was built, unusually, around a conical thrust tube and four vertical walls.



ESRO's HEOS-1 also played its part through simultaneous measurements of the interplanetary magnetic field and the particles en route to Earth. This meant the particles could be used to trace out the magnetosphere's structure and how it connected with the interplanetary field. ESRO-2 and -1 contributed significant pieces to this puzzle. ESRO-1B aimed at a lower circular orbit to provide complementary measurements, but it was lower than planned and reentry was inevitable after a few weeks.

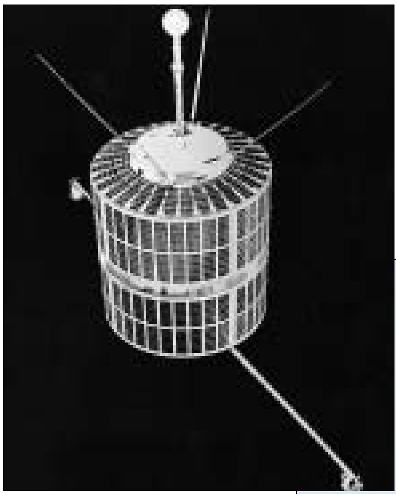
The satellites were stabilised so that, over the North Pole, the particle experiments looked up or across the magnetic field, while two photometers looked down to measure absolute auroral luminosity. This was one of the first dual-satellite arrangements tried in the magnetosphere, preceding the more sophisticated ISEE mission by 8 years. Two satellites made it possible to distinguish spatial from temporal variations.

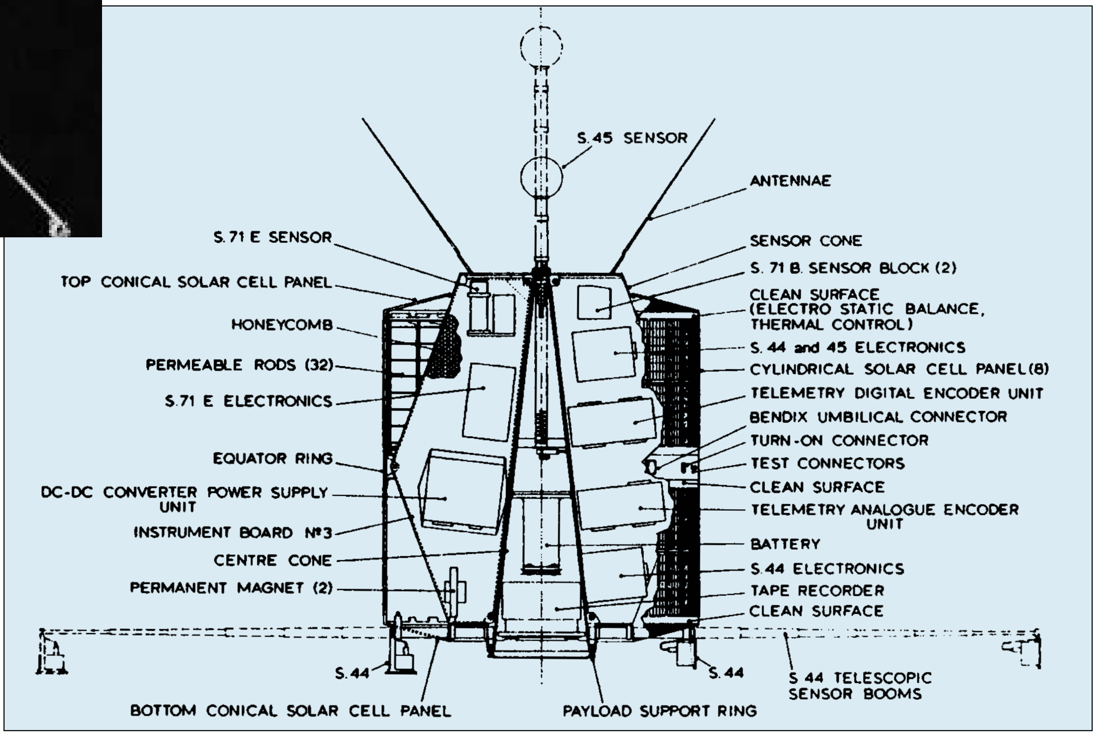
Both satellites continued transmitting data until reentry. ESRO-1A's tape recorder failed on 29 April 1969, reducing the data take from 80% to 20%, but those data (over the North Pole) were the most important.



Installation of ESRO-1B on its Scout launcher at the Western Test Range, California.

ESRO-1 solar simulation testing at ESTEC.





ESRO-1 principal features.

ESRO-1 Scientific Instruments

S32	Two photometers registered northern auroral brightness. Norwegian Institute of Cosmic Physics (N)
S44	Two boom-mounted Langmuir probes for ionosphere electron temperature/density. University College London (UK)
S45	Boom-mounted Langmuir probe for ionosphere ion composition/temperature. University College London (UK)
S71A	Scintillator for electron flux/energy spectra (50-400 keV). Radio & Space Research Station (UK)
S71B	Electrostatic analysers + channeltrons for electrons and protons (1-13 keV) with high time resolution. Kiruna Geophysical Observatory (S)
S71C	Three solid-state detectors for 0.01-6 MeV protons. Univ of Bergen/Danish Space Research Institute (N/DK)
S71D	Four Geiger counters for pitch angles of electrons (>40 keV) and protons (>500 keV) with high time resolution. Norwegian Defence Research Establishment/Danish Space Research Institute (N/DK)
Ratemeter	Geiger counter for trapped electrons (>40 keV) and protons (>500 keV). ESLAB (Space Science Dept) of ESRO
S71E	Solid-state detector and scintillator telescope for flux/energy spectra of 1-30 MeV solar protons. Radio & Space Research Station (UK)

Satellite configuration: 90 cm-high, 76 cm-diameter cylindrical bus. Conical magnesium thrust tube supported four vertical aluminium honeycomb walls for attaching experiments and subsystems. Total height 153 cm. Forward axial boom extended to 50 cm in orbit; two 99 cm booms released from base.

Attitude/orbit control: injection spin of 150 rpm removed by yo-yo masses, for satellite to stabilise itself to within 5° along the magnetic field lines using two 25.2 Am^2 bar magnets.

Power system: 6990 2 cm^2 Si cells on body panels provided 23 W orbit average. Supported by 3 Ah nickel cadmium battery.

Communications: 5120 bit/s realtime telemetry on 1.2 W/137 MHz, or 320 bit/s on 0.2 W/136 MHz. Tape recorder stored 320 bit/s for playback at 10.24 kbit/s on 137 MHz. Telecommand at 148 MHz. Controlled from ESOC.

HEOS

Achievements: first European probe into cislunar space; first magnetically clean European satellite; first highly-eccentric polar orbit
Launch dates: HEOS-1 5 December 1968; HEOS-2 31 January 1972
Mission end: HEOS-1 reentered 18 October 1975; HEOS-2 reentered 2 August 1974
Launch vehicle/sites: HEOS-1 Delta from Cape Canaveral, Florida; HEOS-2 Delta from Western Test Range, California
Launch mass: HEOS-1 108 kg; HEOS-2 117 kg
Orbits: HEOS-1 injected into 424x223 428 km, 28.3°; HEOS-2 injected into 405x240 164 km, 89.9°
Principal contractors: Junkers Flugzeug- und Motorenwerke GmbH (prime)

HEOS-1 (Highly Eccentric Orbit Satellite-1) was the first European spacecraft to venture beyond near-Earth space, in order to study the magnetic fields, radiation and the solar wind outside of the Earth's magnetosphere. This required an orbit stretching two-thirds of the way to the Moon and launch during a period of high solar activity. The scientific experiments also demanded a magnetically clean vehicle, another first for Europe and requiring a new facility at ESTEC for testing the integrated satellite.

HEOS-1 performed admirably for 7 years, for the first time providing scientists with continuous observations of interplanetary conditions over most of a solar cycle. Precise calibration of the magnetometer meant that these data have been used ever since as a fundamental reference. Another feature – novel at the time – was the magnetometer's memory, which allowed measurements with very high time resolution. HEOS-1 also released a canister of barium and copper oxide on 18 March 1969 some 75 000 km out from Earth – igniting it 40 km from HEOS – in order to trace distant magnetic field lines.

HEOS-2 was equally successful, this time investigating northern polar regions by climbing into a high-inclination orbit. It discovered a layer of plasma flow ('plasma mantle') inside the tail magnetosphere. In addition, it observed interplanetary conditions during most of its orbit. In August 1972 it was ideally placed to study some of the most dramatic interplanetary and magnetospheric events ever recorded following major solar activity.

HEOS' 1.7 m boom held the magnetometer away from the body's magnetic influence. HEOS-2 (seen here) was similar to its predecessor but notably carried a loop antenna just above its main body for solar radio observations.

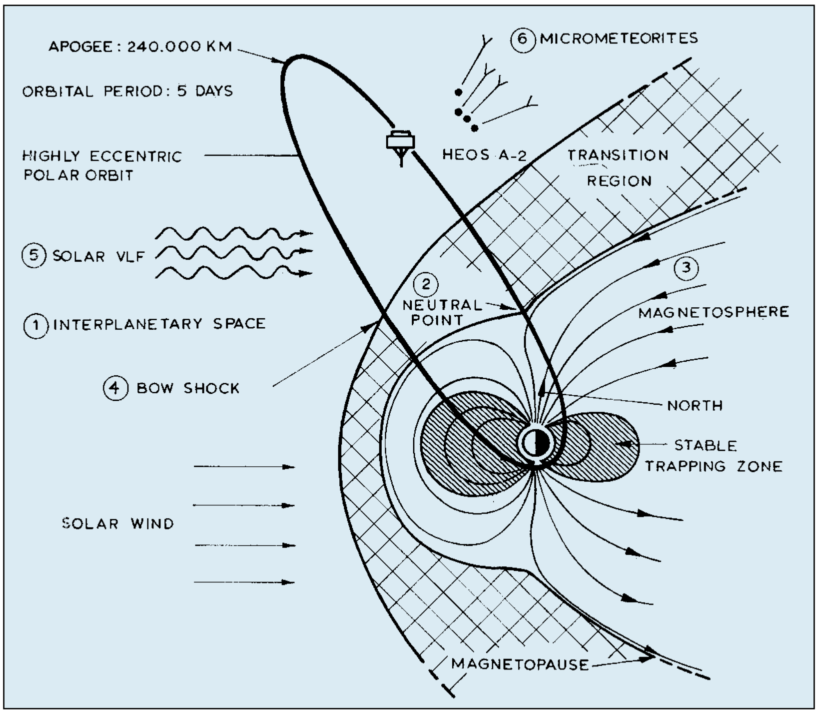
HEOS-1 Scientific Instruments

S24A	Triaxial fluxgate magnetometer on 1.70 m tripod boom. Measured ±64-gamma magnetic fields with 0.5-gamma accuracy. 3.8 kg. Imperial College London (UK)
S24B	Cerenkov and scintillation counters detected high-energy cosmic ray protons of >350 MeV and their anisotropies. 2.9 kg. Imperial College London (UK)
S24C	Solid-state detector telescopes detected 0.9-20 MeV solar protons and their anisotropies. 2.1 kg. Imperial College London (UK)
S58/ S73	Measured the energy and angular distributions of solar wind protons. 0.7/2.2 kg. Universities of Rome, Florence and Brussels
S72	Solid-state telescope measured electrons, protons and α-particles over wide energy ranges. 1.8 kg. Centre d'Etudes Nucleaires de Saclay (F)
S79	Measured 50-600 MeV cosmic ray electrons. 5.0 kg. Centre d'Etudes Nucleaires de Saclay (F) & University of Milan (F/I)
S16	Released barium canister to highlight magnetic field lines. 8.2 kg (capsule 7.7 kg). Max-Planck-Institut für Extraterrestrische Physik, Garching (D)

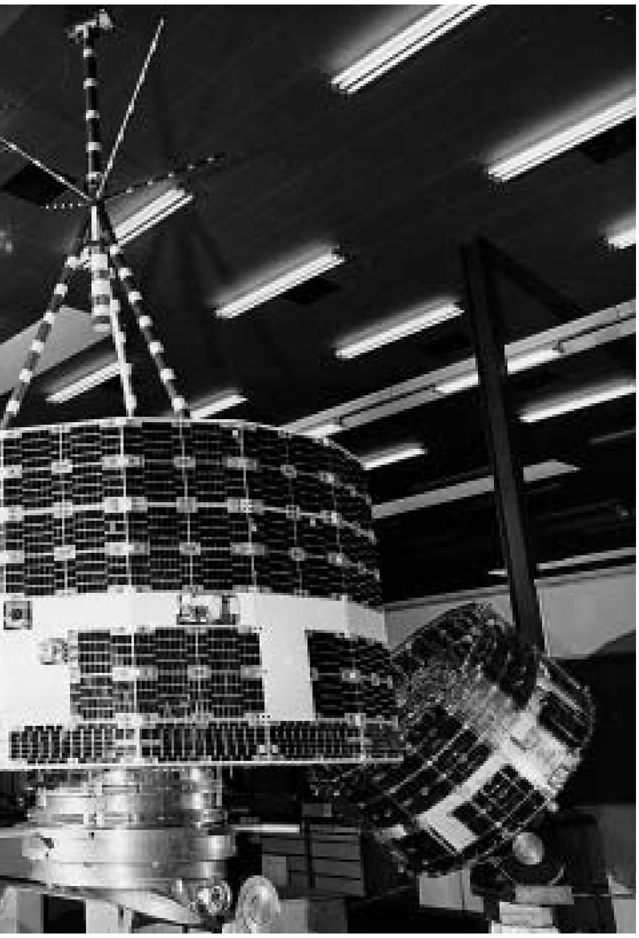
HEOS-2 Scientific Instruments

S201	As S24A on HEOS-1 but range/accuracy improved to ±144-gamma with 0.25-gamma accuracy in lower range
S202	Measurement of 20 eV-50 keV electrons and protons. Univ of Rome (I)
S203	Solar VLF observations at 20-236 Hz by a 1.4 m^2 loop antenna and two spherical wire-cage antennas. Danish Space Research Institute
S204	Particle telescopes to measure 0.5-3 MeV electrons, 9-36 MeV protons and 36-142 MeV α-particles. Space Science Dept of ESRO/ESTEC
S209	As S79 on HEOS-1
S210	Solar wind's velocity and angular distributions. Max-Planck-Institut für Extraterrestrische Physik, Garching (D)
S215	Mass/velocity determination of 10^{-17}-10^{-9} g micrometeoroids. Max-Planck-Institut für Kernphysik, Heidelberg (D)

Satellite configuration: 16-sided bus, 75 cm high, 130 cm diameter across faces. 1.70 m-high fixed boom along spin axis for magnetometer and antennas. Equatorial belt reserved for experiments, attitude sensors and spin nozzles. Central aluminium honeycomb octagonal thrust tube, with outrigger structures on alternating panels supporting four solar array panels. Electronic boxes bolted on thrust tube, with sensors on cantilever supports. HEOS-1's S16 experiment and its ejection mechanism was on lower adapter (on HEOS-2, this space housed the S215 micrometeoroid impact detector); the upper part housed the nitrogen bottle near the centre of gravity.



The orbits of both HEOS were designed to slice through Earth's magnetosphere and penetrate deep into interplanetary space. The high inclination of HEOS-2 made it the first spacecraft to explore the outer polar cusp, searching for a neutral point.



The prototype and two flight models of HEOS-1 in the integration hall at ESTEC.

HEOS-2 was the first to probe the Earth's northern polar region from a highly-eccentric orbit. Right: HEOS-1 released a barium canister to create an artificial ion cloud tracing the Earth's magnetic field lines.

Attitude/orbit control: spin-stabilised at 10 rpm around axis perpendicular to Sun direction. Spin axis determined to ±2° by Sun/Earth sensors. Spin axis adjusted by pulsing single 0.2 N thruster on bottom skirt; spin-up/down by paired 0.2 N equatorial belt thrusters; 1.9 kg of nitrogen stored at 250 bar in single central titanium sphere.

Power system: four solar panels formed HEOS outer surface. 8576 Si cells provided 60 W BOL (42 W after 1 year) at 16 V. Supported by 5 Ah silver cadmium battery.

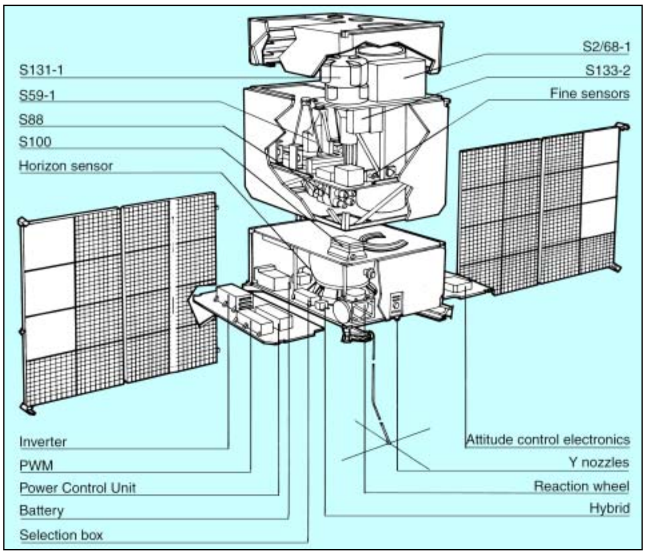
Communications payload: 12 bit/s data (32 bit/s on HEOS-2) returned at 136 MHz by 6 W transmitter in realtime (no onboard storage). Primary stations Redu (Belgium) and Fairbanks (Alaska, US), controlled from ESOC. Telecommand at 145.25/148.25 MHz HEOS-1/2.

TD-1

Achievements: ESRO's first astronomy satellite; important advances in UV astronomy
Launch date: 12 March 1972
Mission end: 4 May 1974 (design life 6 months; reentered 9 January 1980)
Launch vehicle/site: Thor Delta (hence name of satellite) from Western Test Range, California
Launch mass: 473 kg (scientific payload 120 kg)
Orbit: 531x539 km, 95.3° (Sun-synchronous)
Principal contractors: Engins Matra (prime), ERNO (structure, thermal control, housekeeping subsystems), Saab (communications), HSD (power supply, gyros)

TD-1 was ESRO's most ambitious satellite project of that era, carrying a large and complex scientific payload to survey the whole sky in ultraviolet, X-rays and gamma-rays, monitor heavy cosmic ray nuclei and measure X/gamma-rays from the Sun.

It was the organisation's first satellite to carry astronomical telescopes, with heavy emphasis on UV observations of stars. One telescope used a wide aperture for scanning the whole sky in this little-studied section of the spectrum, while another made high-resolution measurements of UV spectral lines from individual stars. The resolution of 1.8 Å was a major advance over anything flown previously.



The mission was seriously jeopardised soon after launch, when both onboard tape recorders failed after only 2 months. A dramatic rescue operation by ESRO set up 40 ground stations around the world in collaboration with other space agencies to capture most of the realtime data.

As a result of the rescue, 95% of the celestial sphere was scanned, and spectral measurements on more than 30 000 stars were catalogued and published. The measurement of UV spectral line shapes and positions revealed, for example, that some stars are rapidly shedding their atmospheres. Significant advances were also made in identifying interstellar dust and plotting its distribution throughout the Galaxy.

The mission had been planned to end in October 1972 when the orbit had shifted such that the Earth began eclipsing the attitude system's Sun sensors. In view of the data lost from the recorder failures and TD-1's otherwise good health, it was decided to try a manoeuvre for which the satellite had not been designed. As the eclipses began, TD-1 was spun faster around its Sun-pointing axis for stability and placed in hibernation. The reverse operation was successful in February 1973, to the delight of its controllers and scientists. 70% data coverage was

TD-1 in the integration hall at ESTEC, July 1971. The attitude control system held this side square on to the Sun.

achieved in the second scan period of March-October 1973, the most productive phase of the mission. One tape recorder even began working again, in October 1973.

Hibernation was successful again October 1973-March 1974. All of the instruments were still working in May 1974 when attitude control was lost following exhaustion of the onboard gas supply, and the mission ended. By that time, TD-1 had achieved 2.5 celestial scans and the mission was declared a total success.

Satellite configuration: box-shaped bus, 0.9x1 m, 2.2 m high. Experiments housed in upper box; subsystems in lower box.

Attitude/orbit control: X-axis (solar array face) Sun-pointing with 1 arcmin accuracy, while TD rotated at 1 rev/orbit about X-axis for the four instruments pointing along the +Z-axis (anti-Earth) to scan the whole sky in 6 months. Sun/Earth sensors, momentum wheels and cold-gas jets (11 kg gas supply).

Power system: two deployed solar wings continuously faced Sun (Sun-synchronous orbit) to provide power from 9360 2x2 cm Si cells; supported by nickel cadmium battery.

Communications: 1700 bit/s realtime on 0.3 W transmitter, with simultaneous recording on tape recorders for playback at 30.6 kbit/s on 3 W transmitter. Both recorders failed by 23 May 1972, but one resumed working in October 1973.

This internal view of TD-1 highlights the complexity. Compare it with the photographs of its ESRO contemporaries on other pages.

TD-1 Scientific Instruments

S2/68	Telescope/spectrometer: whole-sky scan at 1350-3000 Å. Inst d'Astrophysique, Liège (B)/Royal Obs Edinburgh (UK)
S59	Telescope/spectrometer gimballed for star-tracking: UV stellar spectroscopy 2000-3000 Å (1.8 Å resolution). Space Research Lab, Utrecht (NL)
S67	Two solid-state detectors/Cerenkov detector: spectrometry of primary charged particles. Centre d'Etudes Nucléaires, Saclay (F)
S77	Proportional counter: spectrometry of 2-30 keV celestial X-rays. Centre d'Etudes Nucleaires de Saclay (F)
S88	Solar gamma-rays (50-500 MeV). Univ of Milan (I)
S100	CsI scintillation crystal: solar X-rays (20-700 keV). Space Research Lab, Utrecht (NL)
S133	Spark chamber, vidicon camera, particle counters and Cerenkov counter: celestial gamma-rays (70-300 MeV). CENS/Univ of Milan/MPI Garching (F/I/D)

ESRO-4

Achievements: significant contributions to upper atmosphere, ionosphere and magnetosphere research
Launch date: 22 November 1972
Mission end: 15 April 1974 (reentry; 18-month design life)
Launch vehicle/site: NASA Scout from Western Test Range, California
Launch mass: 114 kg
Orbit: 245x1087 km, 99.2°
Principal contractor: Hawker Siddeley Dynamics (UK)

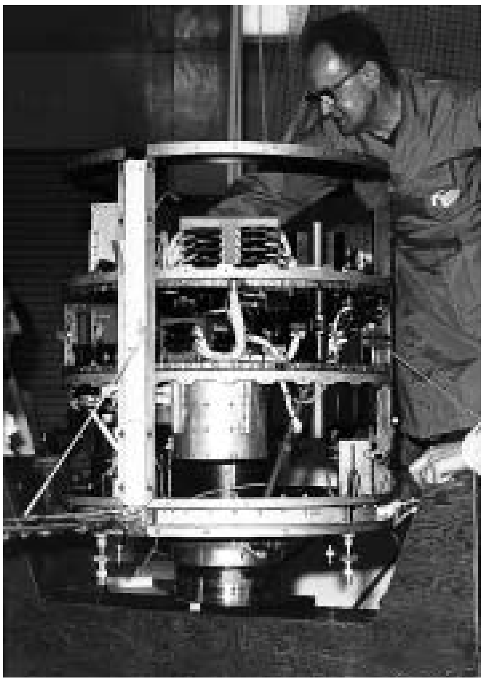
ESRO-4 was based on the proven ESRO-2 design and carried five experiments concentrating on the Earth's ionosphere, atmosphere, radiation belts and penetration of solar particle radiation into the magnetosphere. Achievements included unique high-quality measurements of the atmosphere's constituents between 240 km and 320 km altitude. Detailed global maps were produced for the concentrations of nitrogen, oxygen, helium and argon and their seasonal variations. Their movement following ionosphere and geomagnetic disturbances was plotted, and their variations with longitude were established.

ESRO-4's results feature prominently in the world's scientific literature on the upper atmosphere. This small satellite significantly advanced our basic understanding of the relationships between solar radiation and the Earth's atmosphere and magnetic environment.

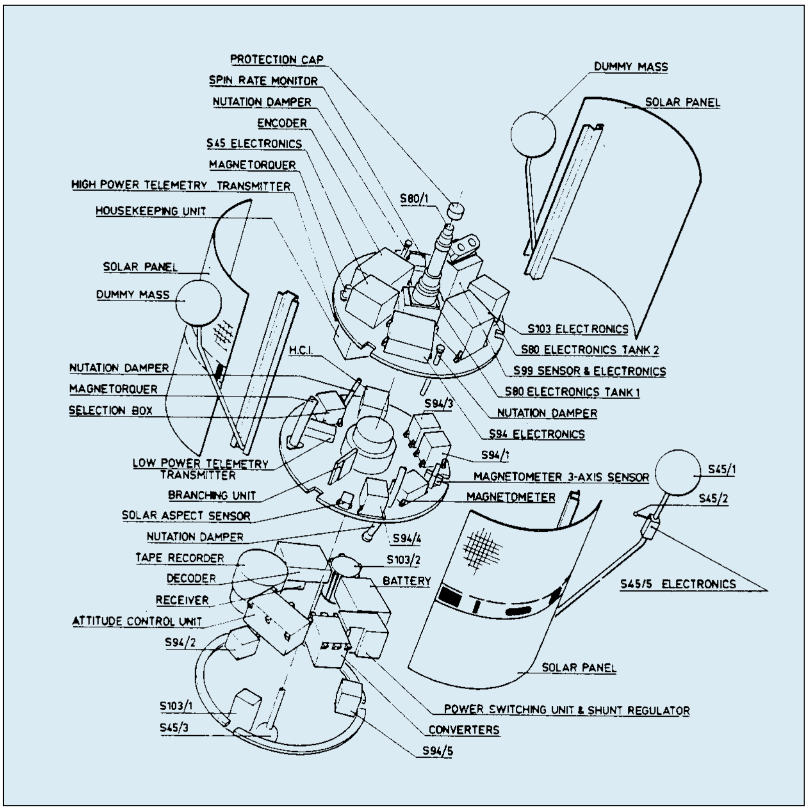
A total of 3x10^{10} data bits were returned before reentry in 1974, and even the tape recorder was still

ESRO-4 Scientific Instruments

S45	Boom-mounted spherical probes: density, temperature and composition of positive ions. University College London (UK)
S80	Monopole mass spectrometer: density and composition of 1-44 amu atmosphere constituents. University of Bonn (D)
S94	Electrostatic analysers, Geiger counters and solid-state detectors: angle/energy spectra of 0.5-150 keV electrons and protons. Geophysical Observatory Kiruna (S)
S99	Two solid-state detector telescopes: solar protons (2-100 MeV) and α-particles (4-240 MeV) over poles. Space Research Lab, Utrecht (NL)
S103	Solid-state detectors: solar protons (0.2-90 MeV) and α-particles (2.5-360 MeV), mainly over poles. MPI Garching (D)



ESRO-4 flew some of the experiments planned for TD-2, cancelled in 1968 on cost grounds. It used the ESRO-2 bus, whereas the alternative ESRO-3 proposal would have been derived from ESRO-1.



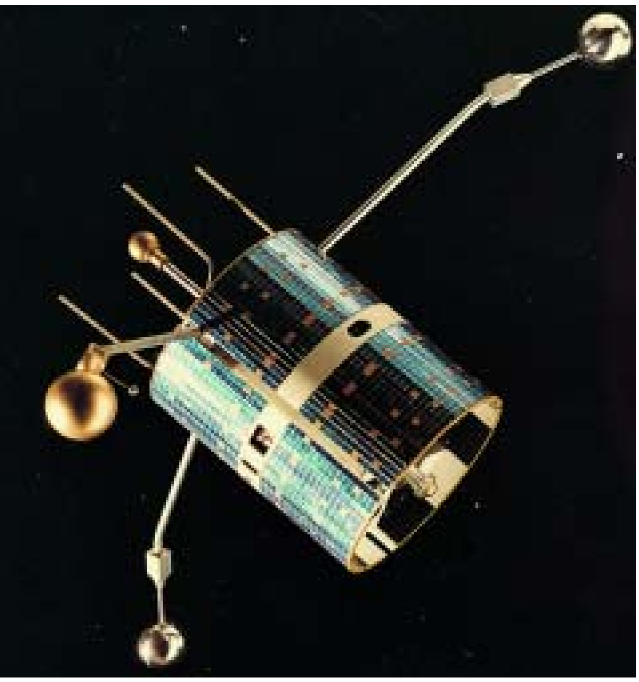
running – a European record. NASA's launcher placed ESRO-4 in a low orbit (perigee 245 km instead of 280 km), which reduced its orbital life from the planned 3 years to 17 months but which also allowed it to sample a deeper slice of atmosphere.

Satellite configuration: 90 cm-high, 76 cm-diameter cylindrical bus. Central thrust tube supported two equipment floors, enclosed by outer shell of solar array. Four booms deployed for experiment S45: one axial and three 130 cm-long radial.

Attitude/orbit control: magnetorquers could precess the spin axis to different geomagnetic attitudes.

Power system: Si cells on body panels provided 60 W orbit average.

Communications: 640 bit/s or 10.24 kbit/s realtime data or 20.48 kbit/s tape recorder playback, at 137.2 MHz using 0.3 W or 2.8 W transmitters. Controlled from ESOC.



Cos-B

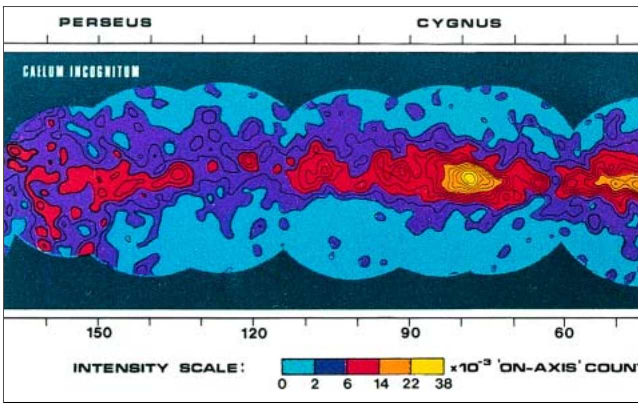
Achievements: first complete galactic survey in high-energy gamma-rays
Launch date: 9 August 1975 (1-year design life; 2-years' consumables)
Science operations began/ended: first data returned 12 August 1975, routine science operations began 17 August 1975, Cos-B deactivated 25 April 1982
Launch vehicle/site: Delta 2913 from Western Test Range, California
Launch mass: 278 kg (including 118 kg scientific payload)
Orbit: initially 337x99 067 km, 90.2°; evolved to 12 155x87 265 km, 98.4° by mission-end. Orbit maximised time above interfering radiation belts, on average allowing observations for 25 h on each 37 h orbit
Principal contractors: MBB (prime, spacecraft), Aerospatiale (structure, thermal), BAC (AOCS, solar array), ETCA/TERMA (power supply), Selenia (data handling, telecommunications)

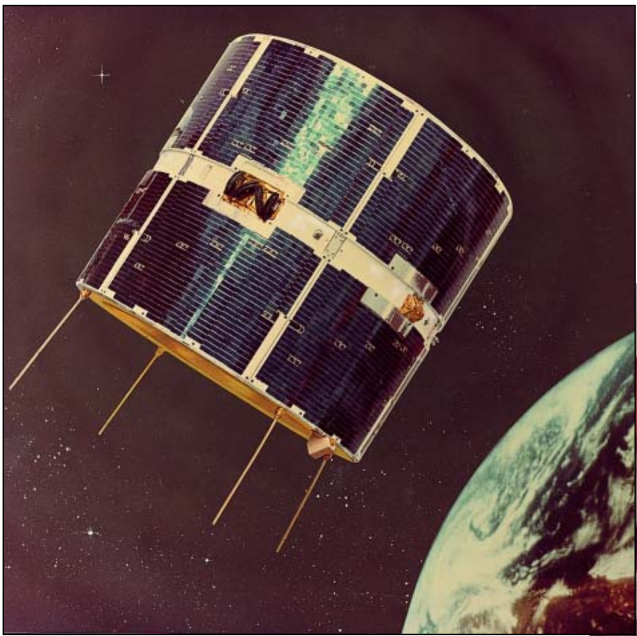
Cos-B was the first ESA/ESRO satellite devoted to a single payload: a gamma-ray telescope designed to perform an extensive, pioneering survey of the Galaxy at energies of 50 MeV to 5 GeV. Before Cos-B, this high-energy range had been only partially explored. Major achievements included observations of the Crab and Vela pulsars, discovery of numerous point sources in the galactic disc, pinpointing the mysterious Geminga object to within 0.5°, and the first observation of gamma-rays from an extragalactic source (quasar 3C273).

The satellite operated in a pointing mode with its spin axis directed towards fixed points in the sky for periods of 4-5 weeks early in the mission and up to 3 months in later observations. In total, 64 pointings were carried out: a broad band along the galactic equator was studied deeply by repeated and overlapping observations. About 50% of the celestial sphere was covered. The database was formally released to the scientific community on 27 September 1985.

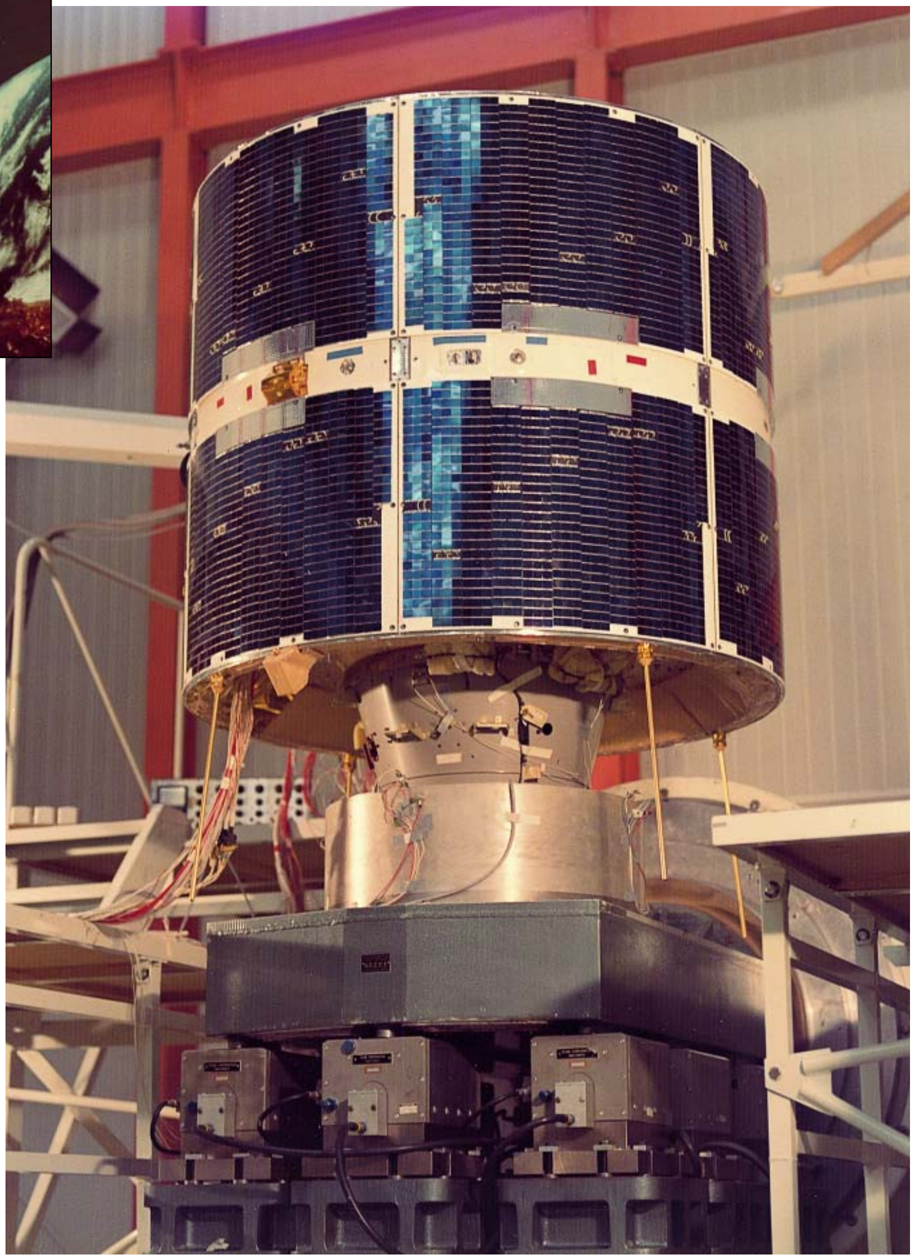
The telescope performed well throughout the mission, the only complication being occasional erratic performance of the spark chamber and the inevitable reduction in performance as the chamber gas aged. This ageing was minimised by emptying and refilling the neon, and, as the rate of gas deterioration slowed, the intervals between flushings rose from the initial 6 weeks to about 36 weeks before the last in November 1981. The payload was still working when the attitude control gas was exhausted in April 1982.

Cos-B (and, simultaneously, Geos) was formally approved by the ESRO Council in July 1969 in competition with other science missions because it placed Europe at the forefront of a new field. The proposed Cos-A included an X-ray detector, but it was felt that Europe should leapfrog to the next generation in order to compete with NASA; this led directly to Exosat.



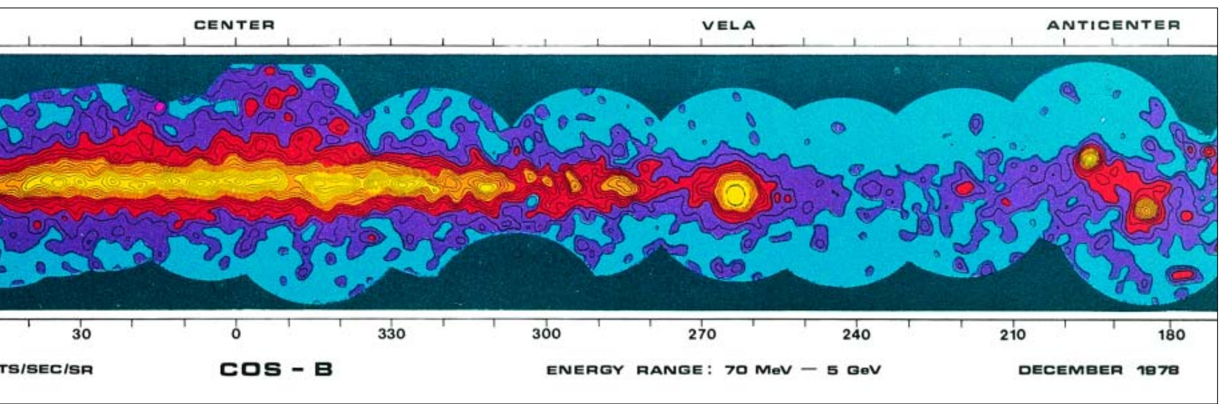


Artist's impression of Cos-B in operational configuration.

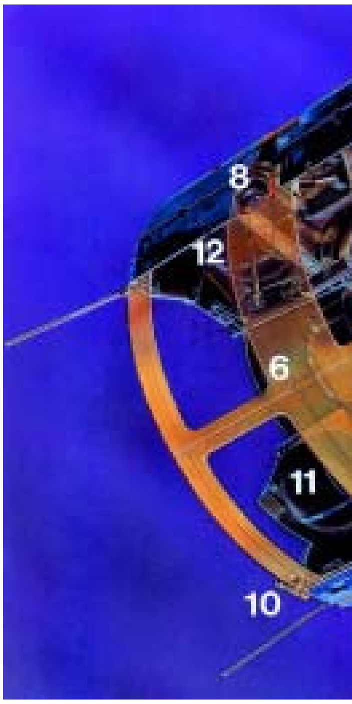


Cos-B prototype vibration testing at ESTEC.

The Galaxy's gamma-ray emission as observed by Cos-B.



Integration of the Cos-B detector package and spacecraft prototypes at MBB.



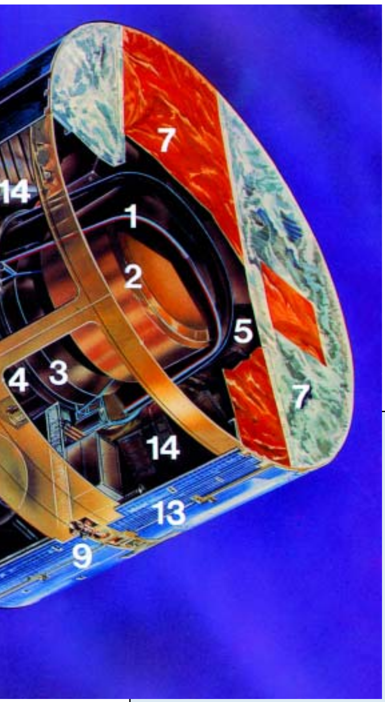
Satellite configuration: 1200 mm-high, 1488 mm-diameter cylinder with science payload in centre. 1712 mm total height, including antennas. Aluminium central cone, platform, struts and outer cylinder.

Attitude/orbit control: spin-stabilised at 10 rpm about main axis, maintained and pointed by simple cold gas attitude control system: 2 spin-up/down + 2 precession jets; 9.9 kg nitrogen at initial 250 bar. Sun/Earth sensors provided attitude determination to 0.5°.

Power system: 12 solar panels on cylindrical surface designed to provide 83 W at 16 V after 2 years; 9480 Si cells. Supported by 6 Ah nickel cadmium battery. Experiment required 25 W.

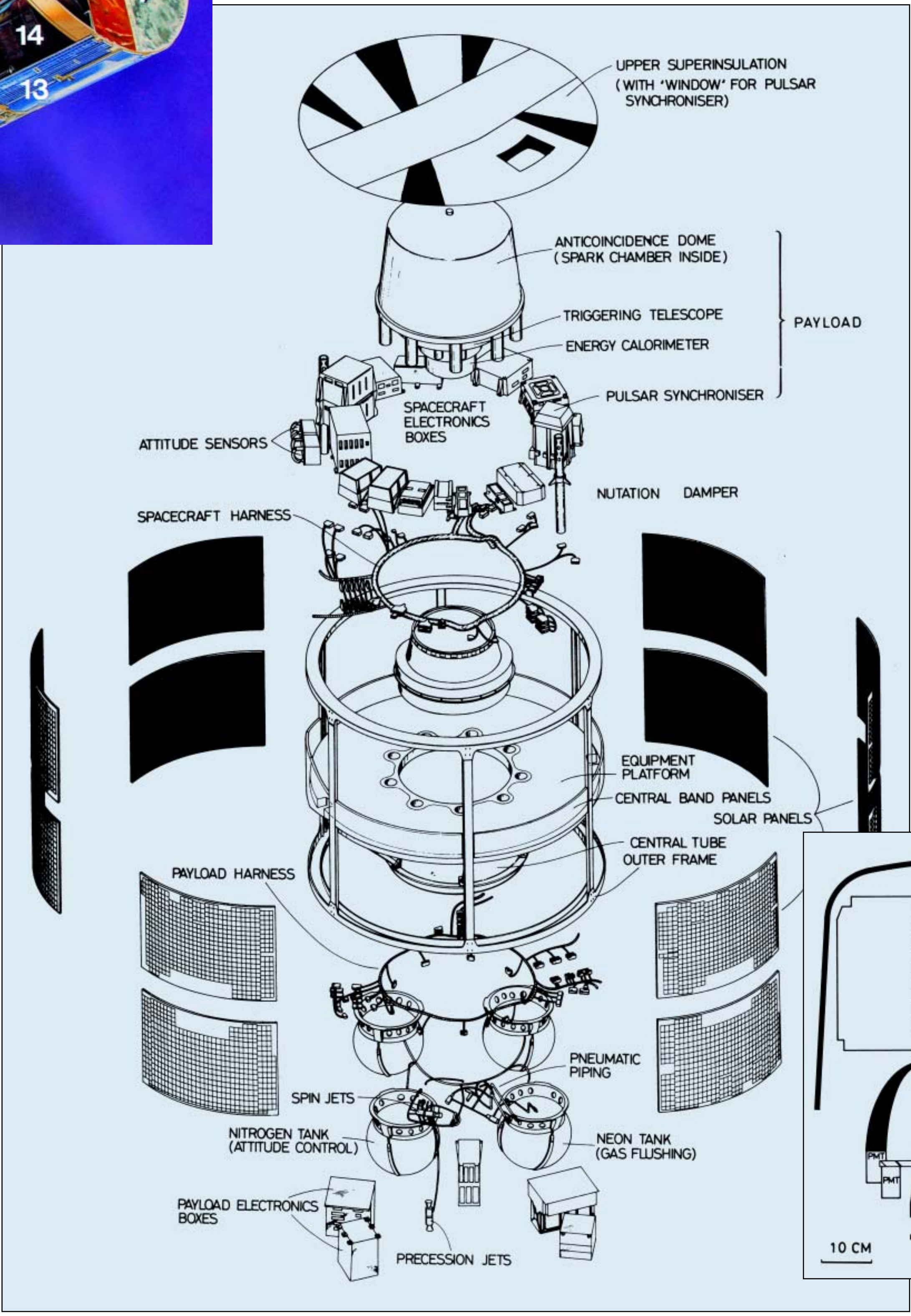
Communications/data: 6.5 W 137 MHz transmitter provided 80/160/320 bit/s, 8 Kbit buffer (typical gamma event 1100 bit). Telecommand at 148 MHz. Primary ground stations Redu (B) & Fairbanks (Alaska, USA).

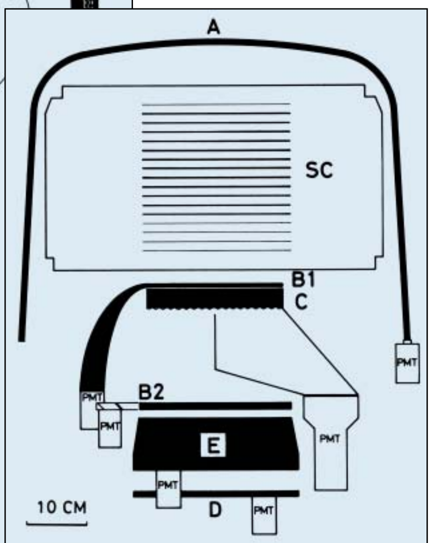
Science payload: the gamma-ray detector's effective sensitive area peaked at 50 cm^2 at 400 MeV. Angular resolution 2° at high energies; energy resolution peaked (~40% FWHM) at 150 MeV, and was >100% up to at least 3 GeV. It featured a 24x24x24 cm spark chamber (SC, see labelled diagram) with 16 paired wire grids. Tungsten sheets between the grids converted some gamma-rays into electron pairs. The particles' ionisation trail through the 2-bar neon gas was located and timed by applying a high voltage across the grids. The field of view was defined by the Triggering Telescope, which triggered the voltage when its scintillation (B1/B2) and Cerenkov (C) counters, with their photomultiplier tubes (PMTs), generated simultaneous signals. Cosmic rays (~1000/s) were rejected when the surrounding anti-coincidence scintillation counter (A) and its nine PMTs produced a signal simultaneous with the Triggering Telescope. Below, the caesium iodide scintillator Energy Calorimeter (E/D) absorbed the electron pairs, PMTs recording the light pulse strength as a direct measure of the original energy. A 2-12 keV 1° FOV 'Pulsar Synchroniser' argon proportional counter monitored X-rays for correlation with gamma variations. For the SC, 1.1 kg of neon was stored at 13 bar to flush/refill the chamber at 2 bar up to 13 times.



Cos-B principal features. 1: Anti-coincidence Counter. 2: Spark Chamber. 3: Triggering Telescope. 4: Energy Calorimeter. 5: Pulsar Synchronizer. 6: structure. 7: super-insulation. 8: Sun/Earth attitude sensors. 9: spin thruster. 10: precession thruster. 11: nitrogen tank. 12: neon tank. 13: solar array. 14: electronics. (MBB)

Bottom right: schematic of Cos-B's gamma-ray detector package. See the text for a description.





Geos

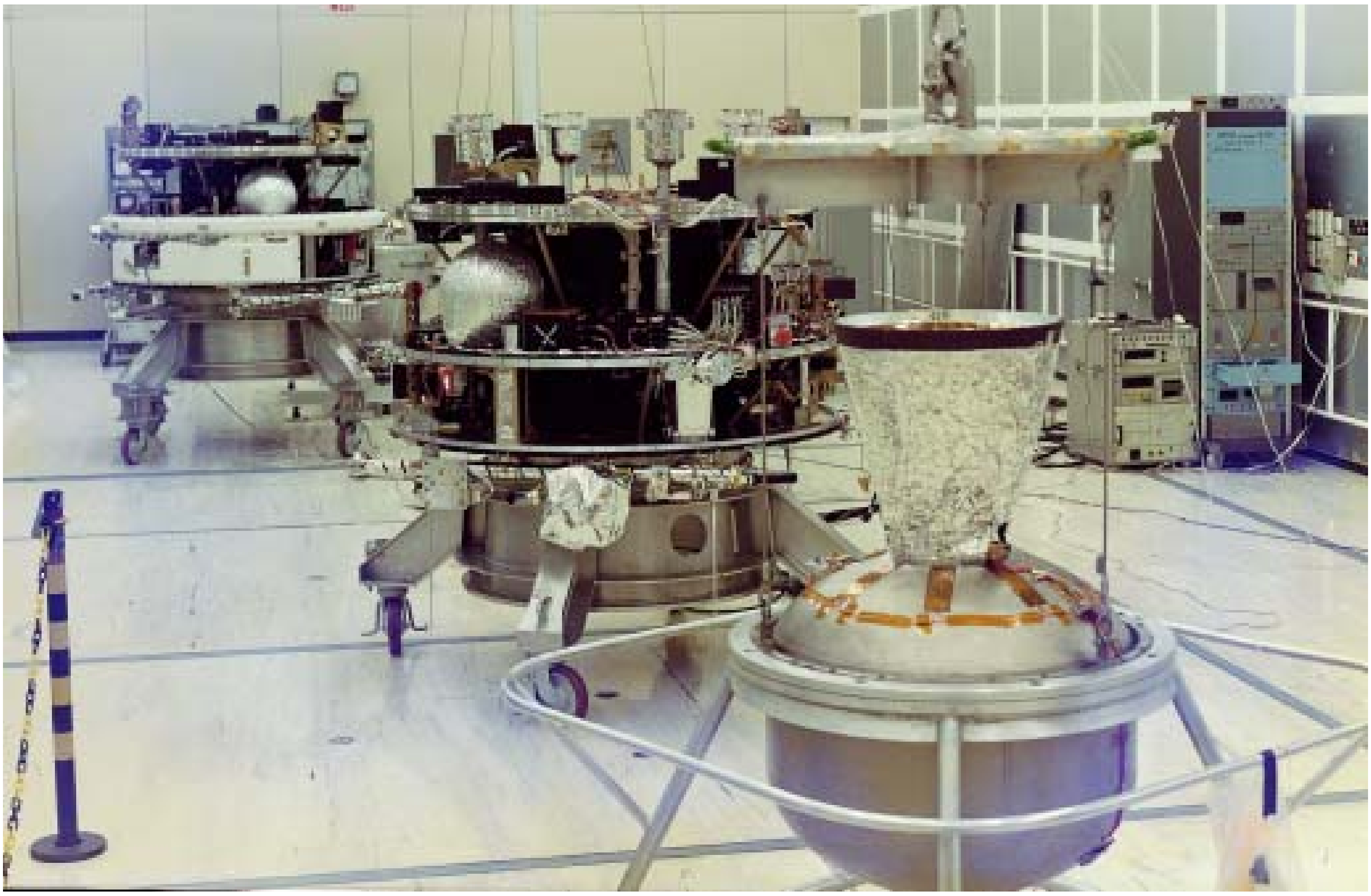
Achievements: major contributions to magnetospheric research
Launch dates: Geos-1 20 April 1977; Geos-2 14 July 1978
Mission end: Geos-1 April 1980; Geos-2 October 1985 (24-month goal)
Launch vehicle/sites: Geos-1 Delta from Cape Canaveral, Florida; Geos-2 Delta from Cape Canaveral
Launch mass: Geos-1 573 kg; Geos-2 573 kg
Orbits: Geos-1 injected into 2682x38 475 km, 26.6°; Geos-2 initial science operations over 37°E geostationary
Principal contractors: British Aircraft Corp heading Star consortium of Dornier, Sener, Ericsson, Thomson-CSF, Contraves, CGE-FIAR, Montedel

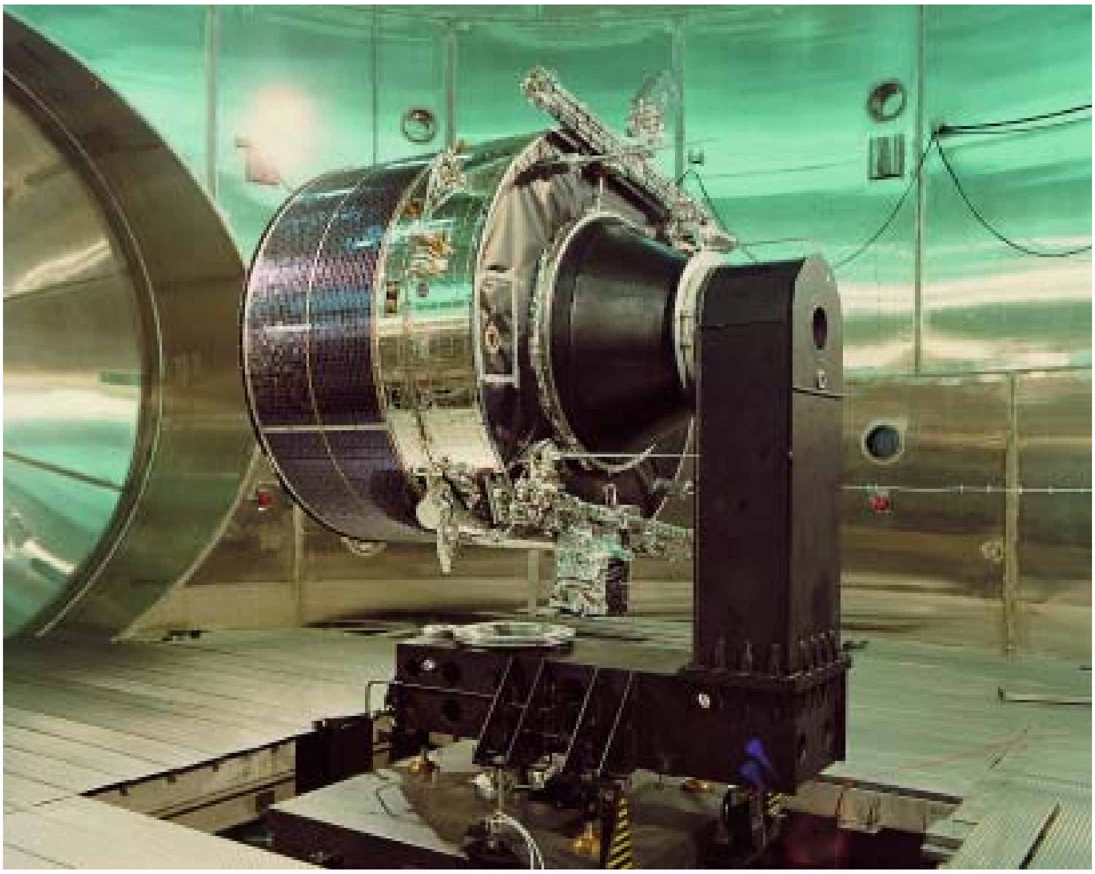
Geos was designed for geostationary (GEO) orbit to study the particles, fields and plasmas of the Earth's magnetosphere using seven instruments provided by ten European laboratories. Because of its unique orbit and the sophistication of its payload, Geos was selected as the reference spacecraft for the worldwide 'International Magnetospheric Study'. Unfortunately, Geos-1 was left in a low transfer orbit because of a stage-2/3 separation problem on its US Delta launcher. As a result, the Qualification Model was launched with an identical payload and successfully reached GEO.

In spite of its orbit, Geos-1 made a significant contribution to IMS, ending its mission formally on 23 June 1978, when the ground system had to be handed over to prepare for Geos-2. That second craft was highly successful, creating a huge database for magnetospheric studies and plasma research in general.

Geos was the first ever spacecraft to carry a totally conductive coating – even over its solar cells. An electron beam experiment and a pair of probes 40 m apart provided independent measurements of the electric field at GEO altitude, yielding not only excellent science but also confirming the surface-treatment technology. The lessons proved extremely valuable for designing commercial satellites operating in this regime.

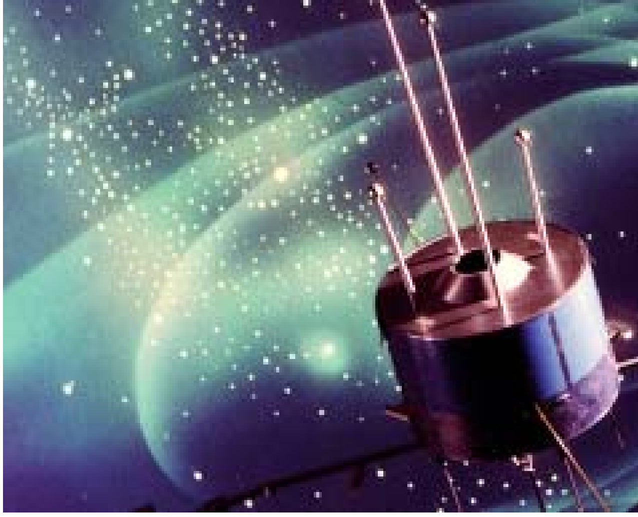
Geos-1/2 Scientific Instruments	
S300	AC-magnetic fields to 30 kHz; DC/AC electric fields & plasma resonances to 80 kHz; mutual/self-impedance. CRPE (F)
S302	Thermal plasma to 500 eV by 2 electrostatic analysers. Mullard Space Science Laboratory (UK)
S303	Ion composition (1-140 amu) and energy spectra to 16 keV by combined electrostatic and magnetic analyser. University of Bern/MPI Garching (CH/D)
S310	Pitch-angles of 0.2-20 keV electrons/protons by 10 electrostatic analysers. Kiruna Geophysical Observatory (S)
S321	Pitch-angles for 20-300 keV electrons & 0.020-3 MeV protons by magnetic deflection system followed by solid-state detectors. Max-Planck-Institut Lindau (D)
S329	DC electric field by tracing electron beam over one or more gyrations. Max-Planck-Institut Garching (D)
S331	DC & ULF magnetic field by fluxgate magnetometer. CNR/NASA Goddard Space Flight Center (I/US)



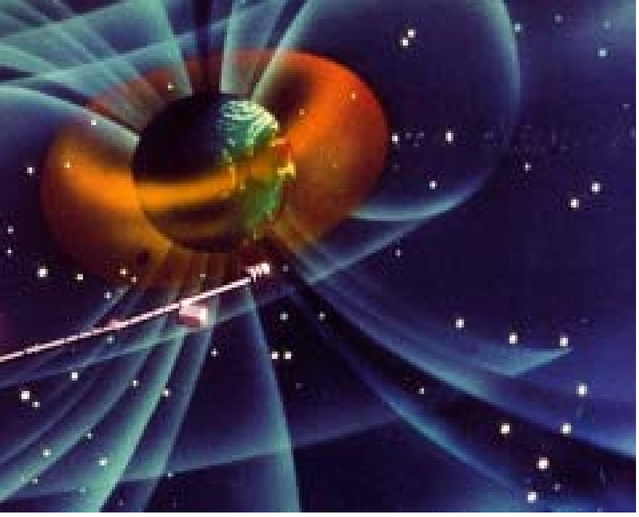


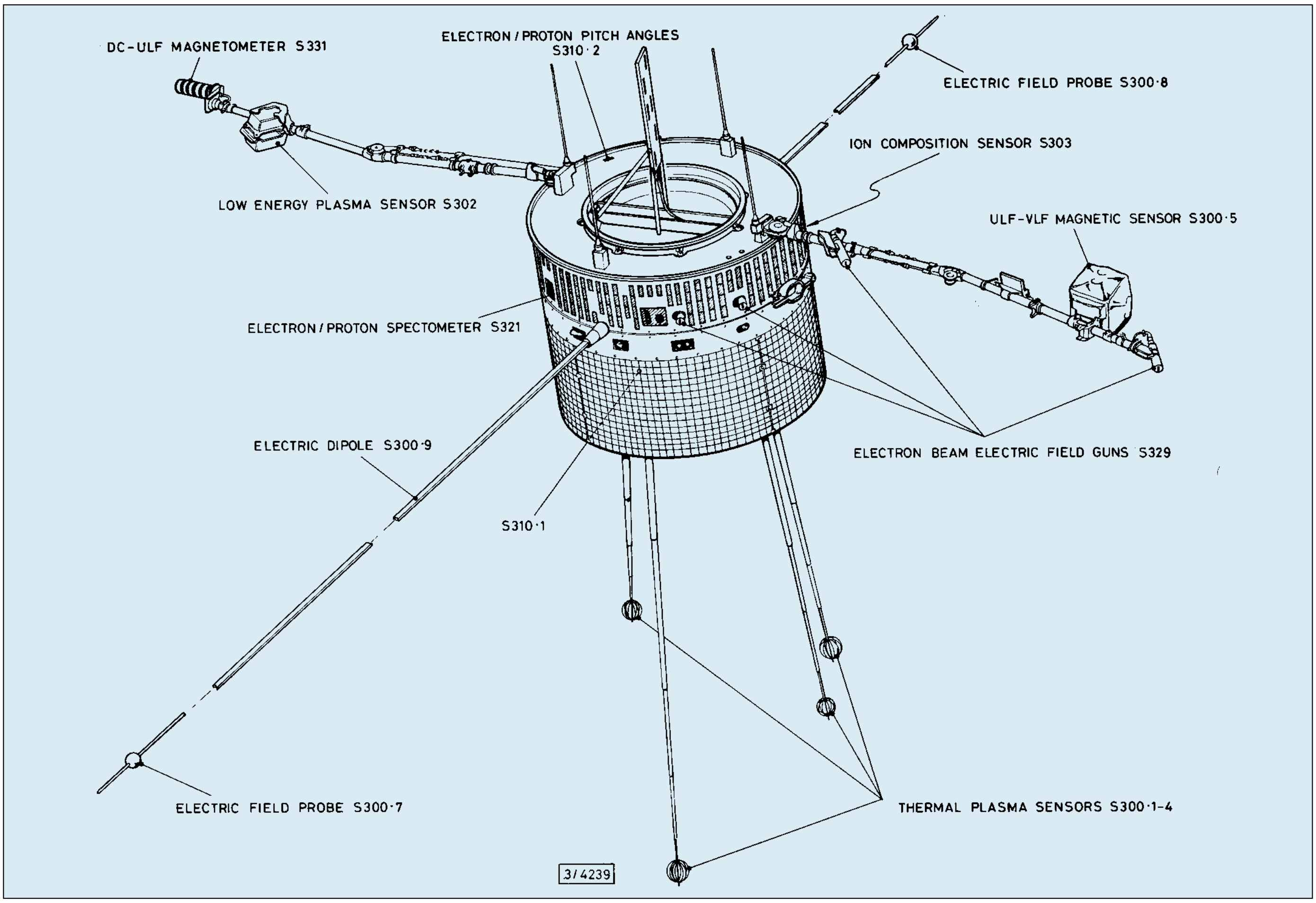
Geos in the Integration Hall at ESTEC. In front of Geos-1 is the Apogee Boost Motor. In the background is the Geos Qualification Model, later modified as Geos-2.

The Geos Qualification Model (which became Geos-2) on the moment-of-inertia measurement machine in the Dynamic Test Chamber at ESTEC.



Geos-1 being prepared for boom deployment tests in the Dynamic Test Chamber at ESTEC.





Satellite configuration: cylindrical bus, 132 cm high, 164.5 cm diameter. Maximum dimensions 477 cm from UHF antenna tip to S300 long axial boom tip; 42.6 m tip-to-tip of long radial booms.

Attitude/orbit control: apogee kick motor (269 kg solid propellant) for injection into GEO. Six 15 N thrusters provided reaction control (30.6 kg hydrazine): 2 axial thrusters (tilt/precess), 2 radial (orbit adjust) + spinup/down; 2 fluid nutation dampers. Attitude measurement by Sun and Earth sensors plus accelerometer.

Power system: >110 W BOL provided from 7200 solar cells on cylindrical bus.

Communications payload: data 100 kbit/s continuous at 2299.5 MHz (no onboard storage). Telecommand at 149.48 MHz.

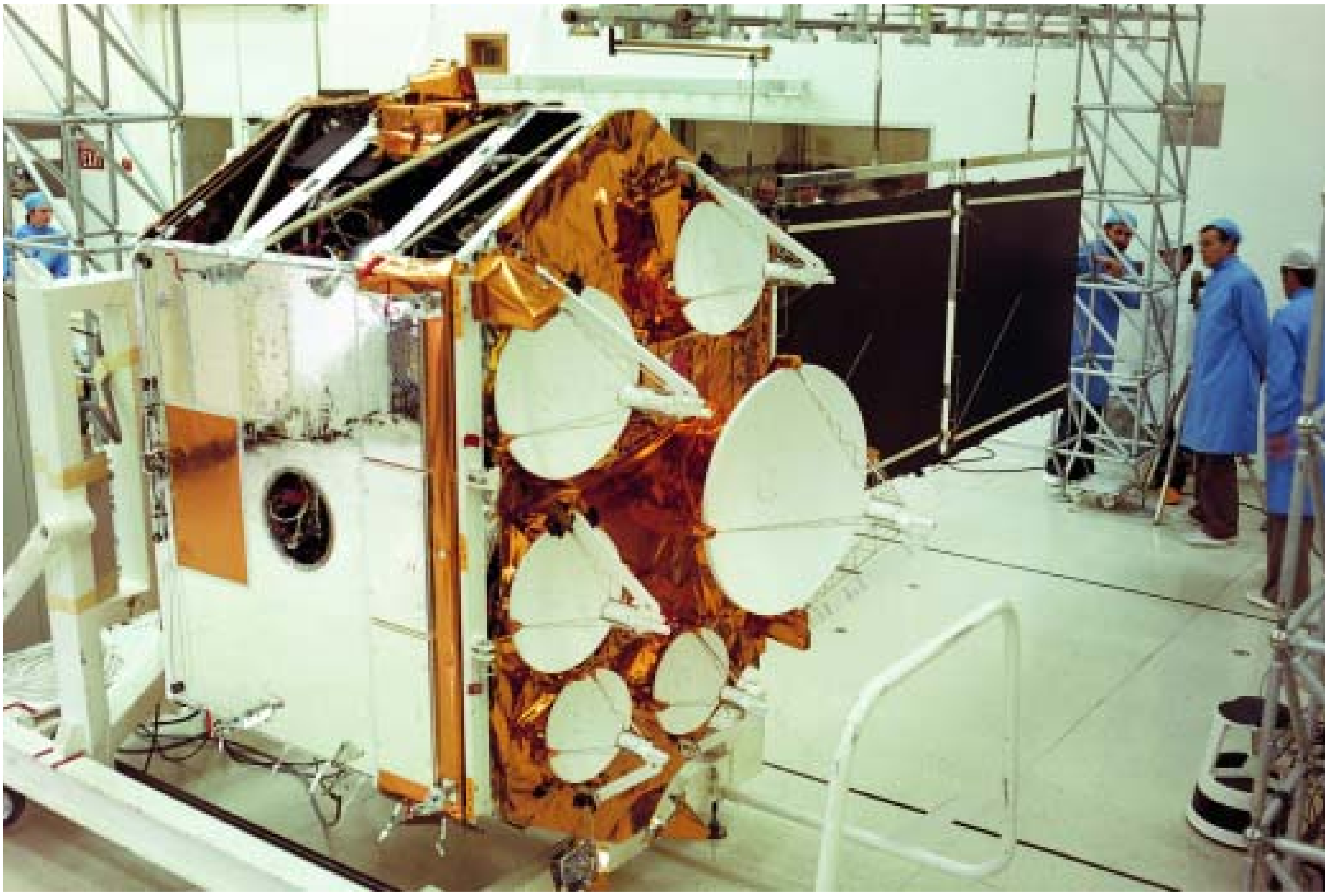
OTS

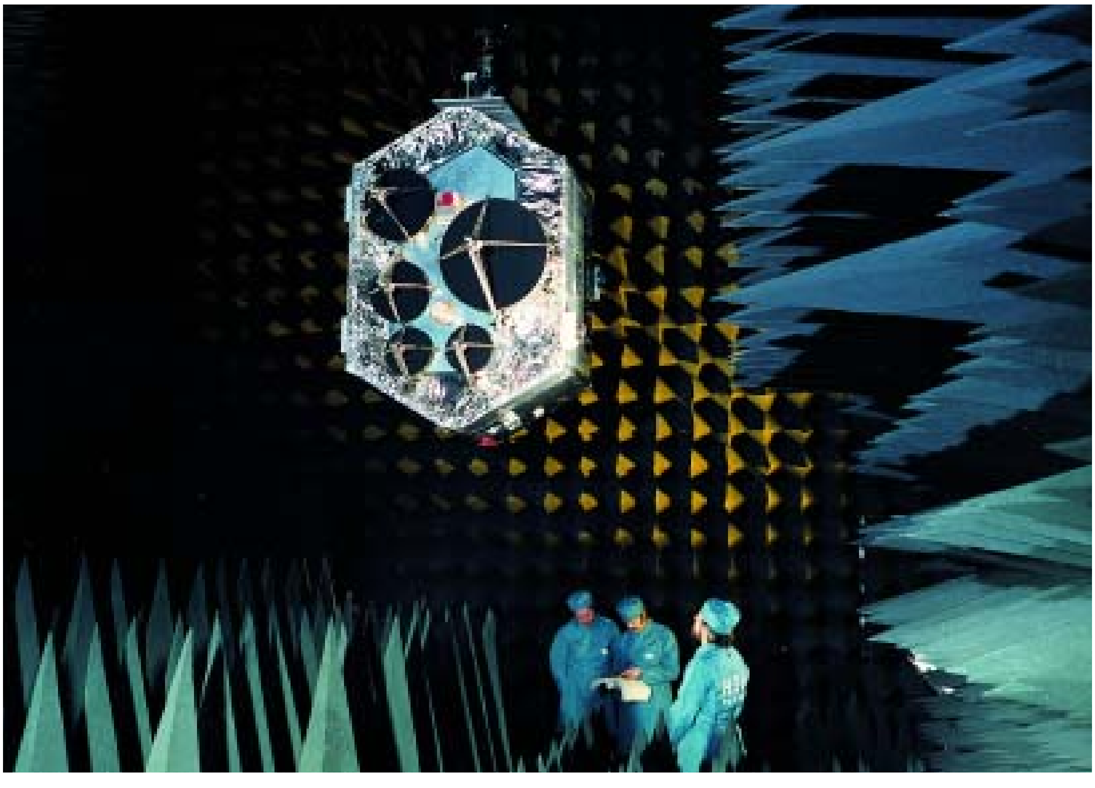
Achievements: first ESA telecommunications satellite; first European 3-axis Ku-band satellite; far exceeded design life
Launch dates: OTS-1 14 September 1977 (launch failure); OTS-2 12 May 1978
Mission end: OTS-2 retired operationally end-1983; deactivated January 1991
Launch vehicle/site: Delta 3914 from Cape Canaveral
Launch mass: 865 kg (444 kg on-station BOL); including 432 kg apogee boost motor
Orbit: geostationary, over 10°E
Principal contractors: British Aerospace, heading MESH consortium (Matra AIT, EGSE, AOCS; ERNO structure, RCS; Saab-Scania TT&C; AEG-Telefunken repeater payload)

The Orbital Test Satellite (OTS) was ESA's first communications satellite programme, and was crucial in demonstrating the technology for the European Communications Satellite (ECS) and Marecs maritime derivatives. It was instrumental in the creation of the European Telecommunications Organization (Eutelsat). Although the programme suffered the worst of all beginnings – its US Delta launcher exploded only 54 s after launch from Cape Canaveral – OTS ultimately went on to become one of the world's most successful telecommunications projects. Eight months later, the second flight model was launched successfully and placed in a geostationary orbit over 10°E, its three transmit antennas covering Western Europe, the Middle East, North Africa and Iceland.

OTS was the first satellite under 3-axis control to demonstrate use of the Ku-band (11-14 GHz) for the next generation of satellites, seeking to ease the growing congestion at C-band (4-6 GHz). It offered four wideband channels with a total capacity of 7200 telephone circuits or eight TV transmissions. OTS demonstrated the commercial potential of the Ku-band within its first year of operations, including telephone, data transmission and TV exchanges between Europe and North Africa. An important element of the utilisation programme was the development and testing of the Time Division Multiple Access (TDMA) system for use later in the operational ECS telephony network. The first videoconferencing experiments using small ground antennas between Germany and the UK were successful by 1980, and using small terminals suitable for community TV reception aroused the interest of cable distribution companies. OTS' TV distribution

OTS-2 is installed on its Delta launcher at complex 17, Cape Canaveral.



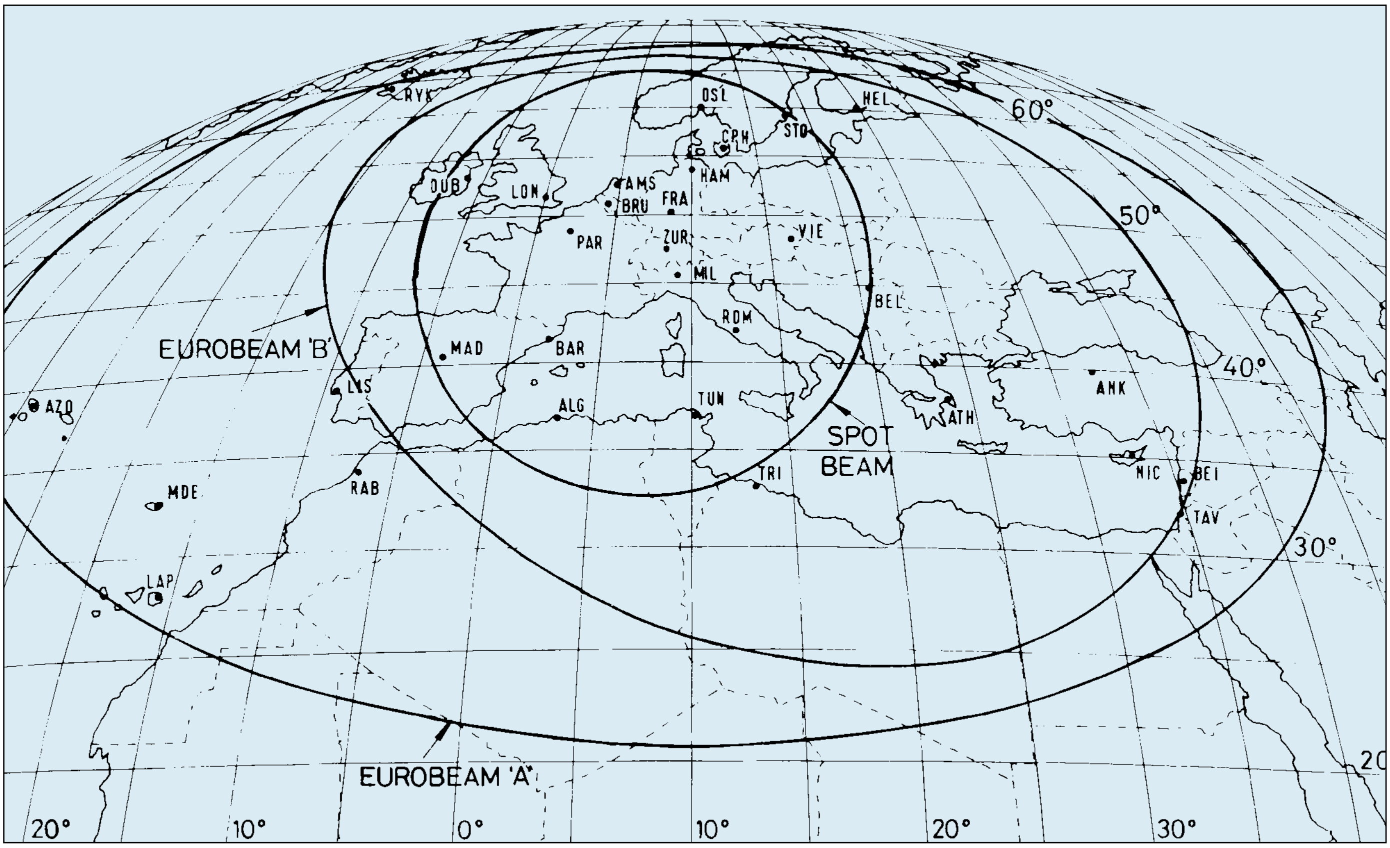


OTS-2 final tests.

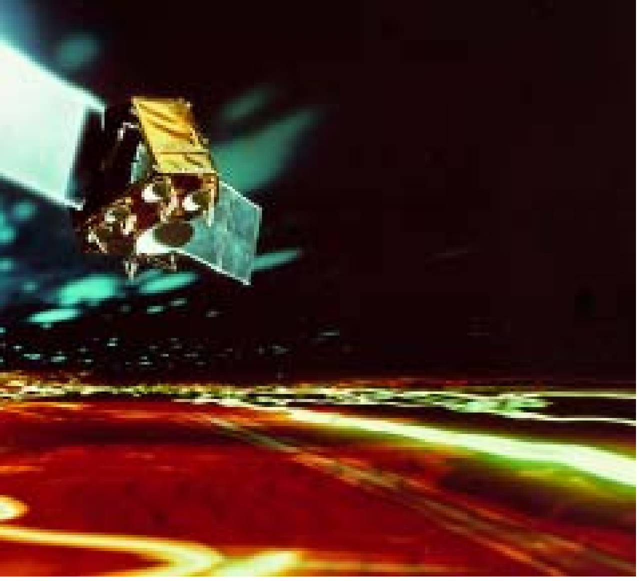
OTS-2 in the anechoic test chamber at British Aerospace at Stevenage, UK.

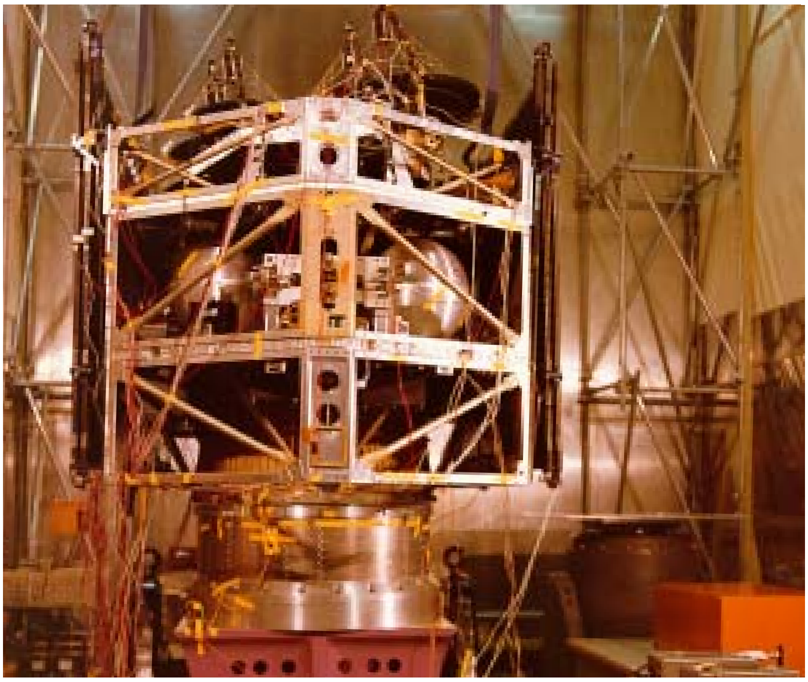
OTS was instrumental in ushering Europe into regional satellite telecommunications.

OTS pioneered the coverage of Europe planned for ECS.



ESA's first telecommunications satellite, OTS-1, was lost in September 1977 when its US launch vehicle exploded.





experiments were so successful that ECS-1 was almost entirely dedicated to this function. The rapid response of satellite systems for coping with emergencies was demonstrated in November 1981 when the French PTT system at Lyons was destroyed by fire. Within hours, OTS and a transportable station had been brought into use to handle priority telephone traffic.

OTS more than doubled its target operational life of 3 years and was used by Eutelsat for commercial operations until the end of 1983. Before it was retired, ESA experimented with some risky manoeuvres, including recovery from a flat spin, a first for a 3-axis geostationary satellite. ESA also pioneered a new method of 'solar sailing' that tightened stationkeeping without consuming significantly more propellant. Solar sailing was also used operationally for more than 2 years for attitude control during normal mode control. OTS was placed in hibernation from late 1984 for final studies of long-term subsystem degradation, but in May 1988 it was reactivated to broadcast celebrations marking its 10th anniversary. The last of its channels failed in late 1990, so ESOC in January 1991 boosted it above the geostationary arc and into a well-earned retirement.

Satellite configuration: hexagonal-prism bus, 2.39 m high and 2.13 m wide; span 9.26 m across solar array. Service module (43 kg structure) based around central conical tube housing ABM; the module carried the propellant tanks, momentum wheels, gyros, most of the electronic units and the solar wing mounts. The communications module (20 kg structure) housed the repeater package and, on a separate panel, the six Ku-band antennas and Earth sensors.

Attitude/orbit control: fixed momentum wheel in conjunction with hydrazine thrusters provided normal Earth-pointing, using 2-axis Earth sensor (pitch/roll); rate gyro provided yaw error. Antenna Earth accuracy ±0.2°. Aerojet SVM-7 solid-propellant ABM provided transfer from GTO into GEO.

Power system: twin 2-panel Si-cell solar wings powered the 50 V bus. Nickel cadmium battery sized to continue operating two channels through 72-min eclipse.

Communications payload: two 11.5 GHz 20 W 40 MHz-bandwidth with 4.25x7.5° Eurobeam-A coverage; two 11.6 GHz 20 W 120 MHz-bandwidth with 2.5° Spotbeam coverage; two 11.8 GHz 20 W 5 MHz-bandwidth with 3.5x5° Eurobeam-B coverage.

ECS and Marecs adopted the general design proved by OTS.

ISEE-2

Achievements: unprecedented observations, with ISEE-1, of Earth's magnetosphere
Launch date: 22 October 1977
Mission end: reentered 26 September 1987 (design life 3 years)
Launch vehicle/site: US Delta from Cape Canaveral complex 17
Launch mass: 165 kg (27.7 kg science payload)
Orbit: operational 2400x135 830 km, 23.0°
Principal contractors: Dornier-System GmbH, heading the STAR consortium

The International Sun-Earth Explorer (ISEE) was a joint ESA/NASA 3-spacecraft mission designed to study the dynamic properties of the Earth's magnetosphere and the solar wind in front of the magnetosphere. ESA's 'daughter' ISEE-2 was launched in tandem with NASA's 'mother' ISEE-1 and released into almost the same highly-elliptical orbit that provided good coverage of all the magnetosphere features over the period of a year. The separation between the spacecraft could be varied between 50 km and 5000 km, according to the scale of the feature being studied. The pairing allowed differentiation between spatial and temporal phenomena.

ISEE-2 in the Dynamic Test Chamber at ESTEC.

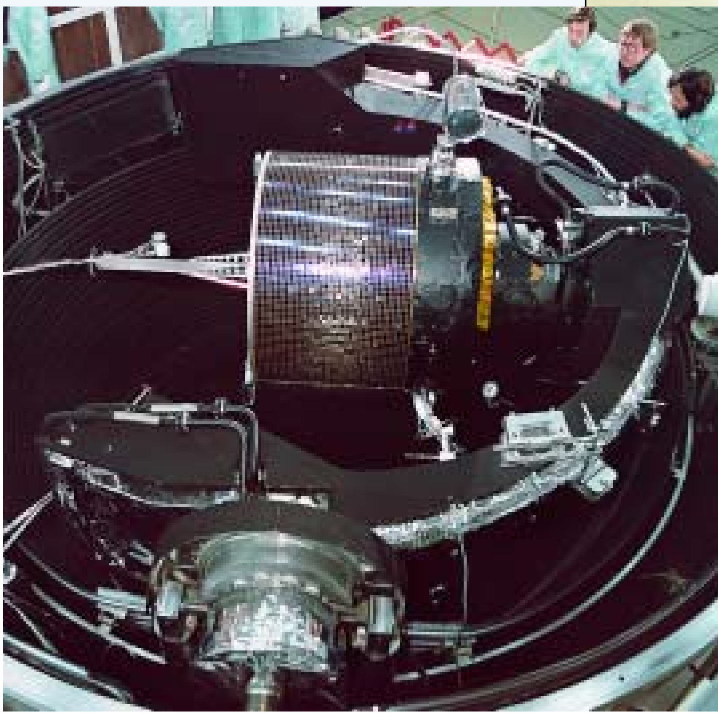
NASA's ISEE-3 was launched in August 1978 to monitor the solar wind, fields and cosmic rays before they arrived at Earth. More than 100 investigators, representing most of the magnetospheric community, from 33 institutes were involved in the ISEE mission and its 28 instruments. The satellites were planned with 3-year lives but the ISEE-1/2 pair both operated for almost 10 years until their reentries in 1987. It is remarkable that no ISEE-2 units failed, apart from the expected loss of its battery.

Mission objectives included quantifying the picture of the magnetosphere known at the time, identifying how the solar wind affects the near-Earth environment, exploiting the plasmasphere and bow shock magnetosheath for plasma and particle physics studies, and measuring the isotopic composition of solar and galactic cosmic rays. For example, the satellites provided the first reliable measurement of the thickness of the magnetopause, the boundary between the Earth's magnetic field and the solar wind.

Satellite configuration: spin-stabilised cylindrical bus with three deployed instrument booms. Strict measures were followed to eliminate interference from the spacecraft to some of the experiments: the entire

Mating ESA's ISEE-2 (top) with NASA's ISEE-1 at Cape Canaveral in preparation for launch.

ISEE-2 installation in the HBF 3 facility at ESTEC for thermal-vacuum testing.



Only two ISEE-2 models were built: the vibration-test version (later converted to engineering/prototype standard) and the flight model.

exterior was made conductive to reduce potential difference to 1 V, the use of non-magnetic materials restricted ISEE's DC field to <0.25-gamma at the magnetometer, and stringent limits were imposed on the electromagnetic radiation emitted by ISEE's interior.

Attitude/orbit control: 20 rpm spin-stabilised about longitudinal axis, perpendicular to ecliptic plane; 4 spin nozzles, 2 precession nozzles, also used for separation manoeuvres from ISEE-1. Cold gas propellant: 10.7 kg Freon-14. Attitude determined by two Earth albedo and solar aspect sensors.

Power system: Si cells on cylindrical panels generated >100 W (65 W after 10 years; 27 W required by science payload), supported by nickel cadmium battery (failed, as predicted, after 2 years).

Communications payload: S-band data returned at 8192 bit/s (high) or 2048 bit/s (low). Controlled from NASA Goddard.

ISEE-2 Scientific Instruments

AND	8-380 keV protons & 8-200 keV electrons at high time resolution. K.A. Anderson, Univ. California at Berkeley (US)
EGD	0.001-10 keV/N solar wind ions. G. Moreno, CNR Frascati (I)
FRD	0.001-50 keV protons & 0.001-250 keV electrons at high angular resolution. L. Frank, Iowa Univ. (US)
GUD	10 Hz-2 MHz electric waves & 10 Hz-10 kHz magnetic waves. D. Gurnett, Iowa Univ. (US)
HAD	Total electron density between ISEE-1/2. C.C. Harvey, Meudon (F)
KED	0.025-2 MeV protons & 20-250 keV electrons at high angular resolution. D. Williams, NOAA Boulder (US)
PAD	0.005-40 keV protons & 0.005-20 keV electrons at high time resolution. G. Paschmann, MPI Garching (D)
RUD	Magnetometer, range 8192-gamma sensitivity 0.008-gamma. C. Russell, Univ. California at Los Angeles (US)