Meteosat

Achievements: first European meteorological satellite; first European geostationary satellite; creation of Eumetsat
Launch dates: Meteosat-1 23 November 1977; Meteosat-2 19 June 1981; Meteosat-3 15 June 1988; Meteosat-4 6 March 1989; Meteosat-5 2 March 1991; Meteosat-6 20 November 1993; Meteosat-7 2 September 1997
Mission end: Meteosat-1 end-1984; Meteosat-2 end-1991; Meteosat-3 end-1995; Meteosat-4 end-1995; Meteosat-5/6/7 still in service (5-year design lives)
Launch vehicles/sites: Meteosat-1 Delta from Cape Canaveral; Meteosat-2/3/4/5/6/7 Ariane from Kourou, French Guiana
Launch mass: about 700 kg (320 kg on-station BOL)
Orbit: geostationary over 0°
Principal contractors: Aerospatiale (prime), Matra (radiometer)

ESRO approved development of Europe's first applications-satellite project in 1972, creating the system that is now an integral and indispensable part of the world's network of meteorological satellites. The success of the first three pre-operational satellites paved the way for the Meteosat Operational Programme in 1983 (Meteosat-4/5/6) and the current Meteosat Transition Programme (Meteosat-7).

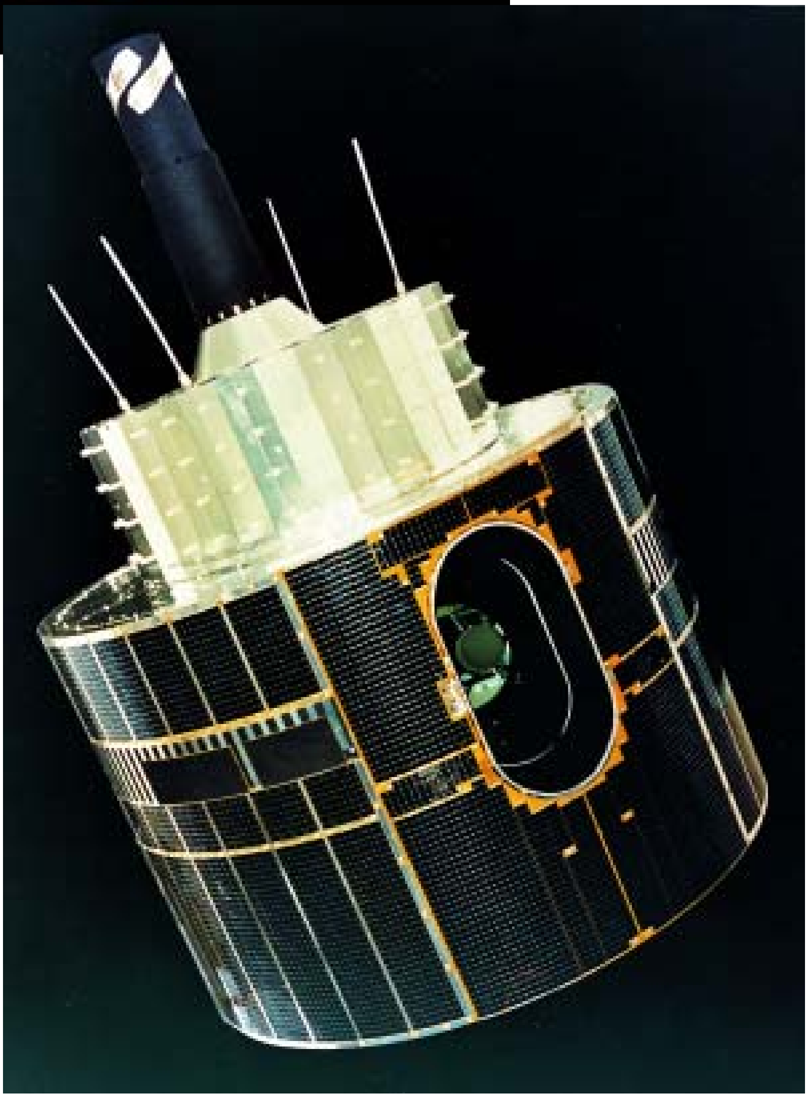
ESA was responsible for developing and operating the system on behalf of the newly-created European Meteorological Satellite Organisation (Eumetsat), which took direct operational control on 1 December 1995 as MTP began. Eumetsat's Convention was ratified in June 1986 and the organisation assumed overall and financial responsibility for MOP in January 1987. MOP began life as an ESA 'optional programme' – as did the original programme – but Eumetsat then took over all obligations from the Agency and it became a 'third party-financed programme' (as is MTP). For the one new satellite of MTP – identical to its three predecessors – ESA managed satellite procurement but Eumetsat was responsible for the ground segment, launch and operations.

The Meteosat Second Generation is now ready for introduction in 2002. ESA continues responsibility for procuring these satellites.

Meteosat-1 was on-station over the prime meridian from 7 December 1977 – as Europe's first geostationary satellite – and returned its first image soon after. Its planned 3-year life was cut short on 24 November 1979 when a design fault in an under-voltage protection unit knocked the imaging and data-dissemination systems out of action. Nevertheless, Meteosat-1 had returned more than 40 000 images and admirably fulfilled its promise. It continued in its data-collection role until the end of 1984, when its hydrazine neared exhaustion.

Meteosat-2 performed the primary role far beyond its design life, until Meteosat-3 took over on 11 August 1988. The original programme called for two satellites, but the P2 prototype was upgraded to ensure

Merged images from Meteosats-3/4 on 16 May 1993. At the time, Meteosat-4 was at Europe's prime longitude of 0°, while Meteosat-3 was at 50°W on loan to the US weather service. (ESA/Eumetsat)

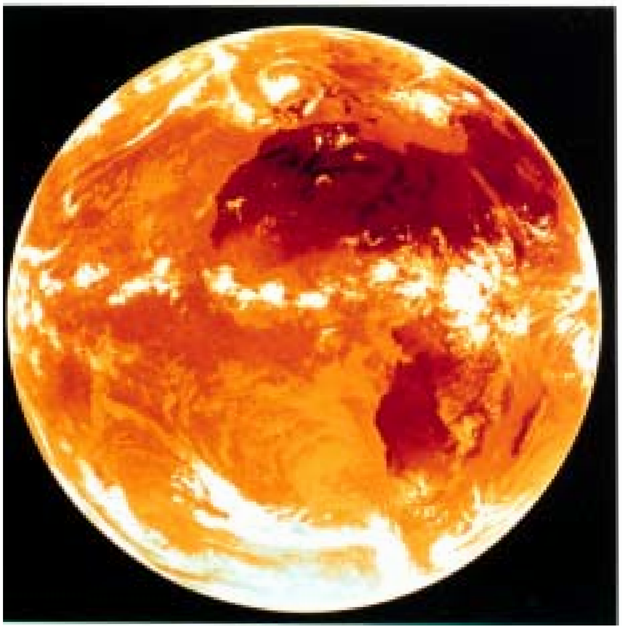


Meteosats 1-7 look identical. The second generation is a similar configuration, but larger.

continuity until the MOP was ready. Meteosat-2 was boosted above GEO in December 1991 and shut down after returning 284 000 Earth images. Meteosat-3 also proved to be a great success. Once it was replaced as the prime satellite by Meteosat-4, it spent several spells covering the eastern United States from 50°W on loan to the US because of problems in the GOES system. It was removed from GEO and retired in November 1995.

Meteosat-4 entered service as the prime satellite over 0° on 19 June 1989. Although interference between power supplies caused striping in some images, it served as prime from April 1990 to February 1994, when it was replaced by Meteosat-5. It was removed from GEO and deactivated in November 1995. Its two successors took over the prime roles in February 1994 and February 1997, respectively. Meteosat-5 began moving from storage at 10°W in January 1998 and halted at 63°E on 19 May 1998 to begin 18 months covering the Indian Ocean from

Examples of Meteosat imagery from Meteosat-3. Top left: visible full-disc; top right: visible-light Europe; bottom left: thermal-IR; bottom right: water vapour-IR. The colouring has been artificially added. During the Meteosat Operational Programme (1983-1995), ESA's European Space Operations Centre (ESOC) in Germany processed more than 1.1 million Meteosat images. (ESA/Eumetsat)

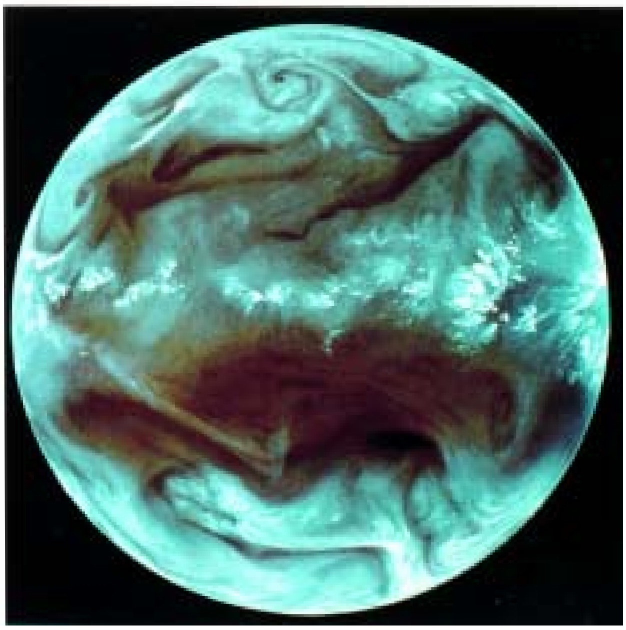


Meteosat-2 (top) is prepared for launch by Ariane in 1981. (CSG/Arianespace)

1 July 1998, providing meteorologists with a complete orbital ring of satellites. After the Indian Ocean Experiment ended in May 1999, Eumetsat decided to continue coverage there until the end of 2003. Meteosat-7 took over the system's prime role in June 1998, before Meteosat-6 moved later that month to 10°W as backup.

Satellite configuration: 2.1 m-diameter, 3.195 m-high stepped cylinder, with imaging radiometer field of view at 90° to spin axis for scanning across Earth disc.

Attitude/orbit control: operationally held within ±1° at 0° longitude by hydrazine thrusters. Spin-stabilised (by thrusters) at 100 rpm around main axis parallel to Earth's axis. Attitude



Meteosat's single Earth-observing instrument is the imaging radiometer.

information from pairs of Earth horizon and Sun sensors. Injection into GEO by solid-propellant apogee boost motor.

Power system: six Si-cell panels on cylindrical body provided 300 W BOL.

Communications payload: top cylinder carries radiating dipole antenna elements activated sequentially (electronically despun) for 333 kbit/s S-band image transmissions and TT&C operations. The imagery were received and processed at ESOC (by Eumetsat in Darmstadt from 1 December 1995) and disseminated to users at L-band through Meteosat itself. The satellite also relays data from international Data Collection Platforms.

Meteosat Radiometer Payload

Meteosat's scanning imaging radiometer return three visible/IR full-disc Earth images every 25 min, followed by a 5 min reset period. The pivoted Ritchey-Chrétien 40 cm-aperture, 365 cm-focal length telescope, is stepped 0.125 mrad by a motor every 100 rpm Meteosat rotation to scan Earth's disc at 5 km intervals south to north. The two visible (0.4-0.9 μm) Si photodiode detectors return images of 5000 scan lines, for 2.5 km resolution. The thermal-IR (10.5-12.5 μm) and the water vapour-IR (5.7-7.1 μm)) mercury-cadmium-telluride detectors assemble images of 2500 lines (each 2500 pixels), yielding 5 km resolution. The water vapour channel was experimental on the first three satellites, but was included operationally beginning with Meteosat-4.

Meteosat-3 added the Laser Synchronisation from Stationary Orbit (LASSO) package of laser reflectors to demonstrate time standard synchronisation over large distances with 10^{-9} s accuracy. The laser pulses could also measure Meteosat's distance within 10 cm.

IUE

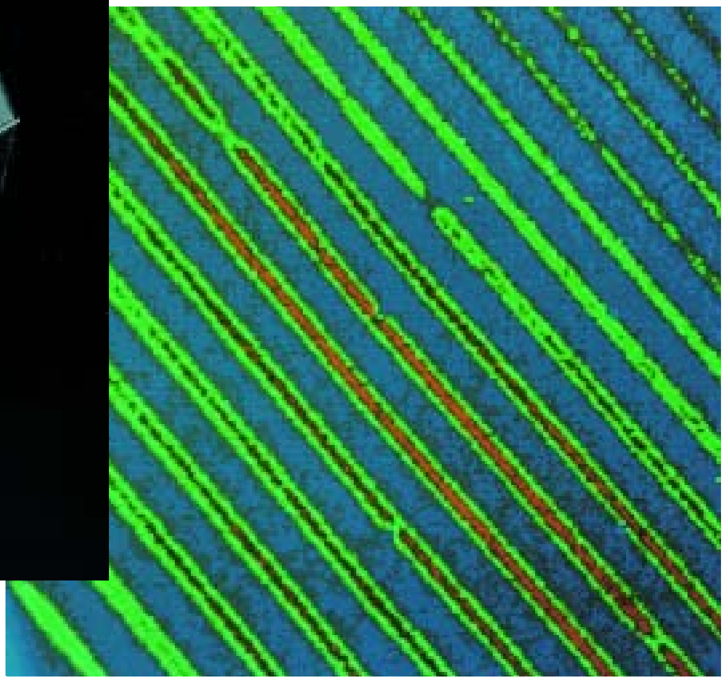
Achievements: longest spaceborne astronomy mission (18.7 years); first astronomical satellite at geostationary altitude
Launch date: 17:36 UT 26 January 1978
Mission end: 30 September 1996, terminated 18:44 UT on ground command (design life 3 years; consumables sized for 5 years)
Launch vehicle/site: Delta 2914, from Cape Canaveral, Florida
Launch mass: 671 kg (122 kg science, 237 kg apogee boost motor)
Orbit: geosynchronous over Atlantic: initially 32 050x52 254 km, 28.6°, 23.93 h, mission-end 36 360x48 003 km, 35.9°

The International Ultraviolet Observatory (IUE) is the longest-serving and most prolific astronomical satellite yet launched: its 18.7 years of operations returned 104 468 high- (~0.1 Å) and low-resolution (~6 Å) spectra from 9600 celestial sources in the 1150-3200 Å UV band. IUE provided astronomers with a unique tool, and requests for observing time even towards the end of its career remained two-three times greater than could be satisfied. Despite the appearance of the Hubble Space Telescope in 1990, IUE continued to prosper because it covered an entire spectral region not accessible in one sweep to HST's high-resolution spectrographs. It was the first scientific satellite that allowed 'visiting' astronomers to make realtime observations of UV spectra: the impressive response time of <1 h provided an unparalleled flexibility in scheduling targets of opportunity.

IUE was a trilateral project, based on the 1974 Memorandum of Understanding specifying that NASA would provide the spacecraft, telescope, spectrographs and one ground observatory, ESA the solar panels and the second observatory, and the UK the four spectrograph detectors. In addition to controlling the satellite, the ground sites acted as typical astronomical observatories, except that their telescope hovered far out in space. ESA's 'IUE Observatory' was established in 1977 at the Villafranca Satellite Tracking Station, Madrid, Spain. During IUE's life, >1000 European observing programmes were conducted from Villafranca, returning >30 000 spectra from about 9000 targets.

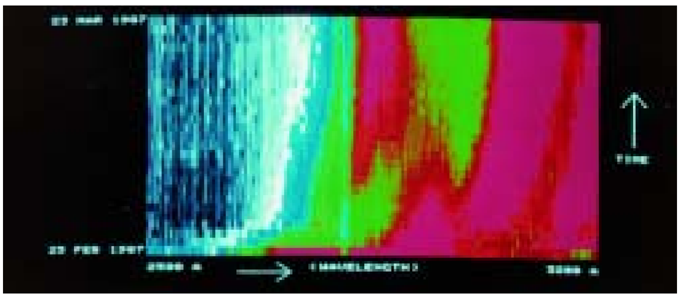
In March 2000, ESA delivered the IUE Archive to the scientific community. Spain's Laboratory for Space Astrophysics and Theoretical Physics (LAEFF, part of the National Institute for Aerospace Technology, INTA) assumed responsibility for the Archive and INES (IUE Newly Extracted Spectra), a system created by ESA for rapid and simple global access. This principal centre is mirrored by the Canadian Astronomical Data Centre. The INES system is running at 22 National Hosts, which provide local access to a subset of the data. In 2000 alone, almost 600 users from 36 different countries used INES to retrieve >6.5 Gbytes of data (66 000 files).

IUE was the first astronomical observatory based around geostationary altitude, hovering over the Atlantic Ocean in constant view of its users at Villafranca and NASA Goddard. Below: a section of IUE's high-resolution spectrum of supernova SN 1987A. The narrow lines are caused by the gas in our Galaxy, the Large Magellanic Cloud and in between.

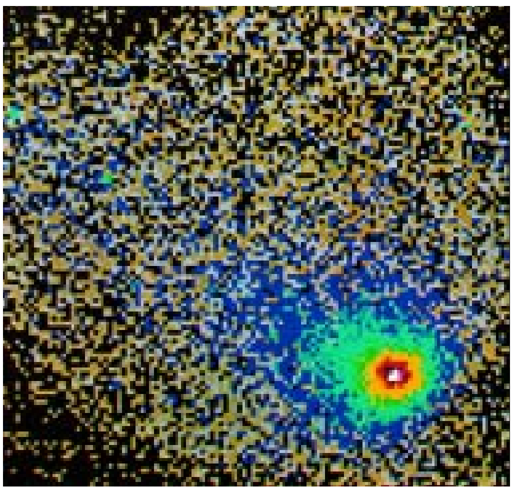


These spectra were processed and deposited in a public domain archive together with the data collected by the IUE Observatory at NASA's Goddard Space Flight Center. The IUE Data Archive remains the most heavily used astronomical archive in existence: with 500 000 data delivered in archive form and >100 000 spectra, each IUE spectrum has already been used six times.

IUE identified the star that exploded into SN 1987A – the first supernova visible to the naked eye in 383 years. The diagram below shows how the brightness at each UV wavelength changed, beginning a few hours after the supernova's discovery. The emission shifts towards longer wavelengths as the supernova rapidly cools from 13 500 K on 25 February 1987 to 5200 K by 14 March 1987.

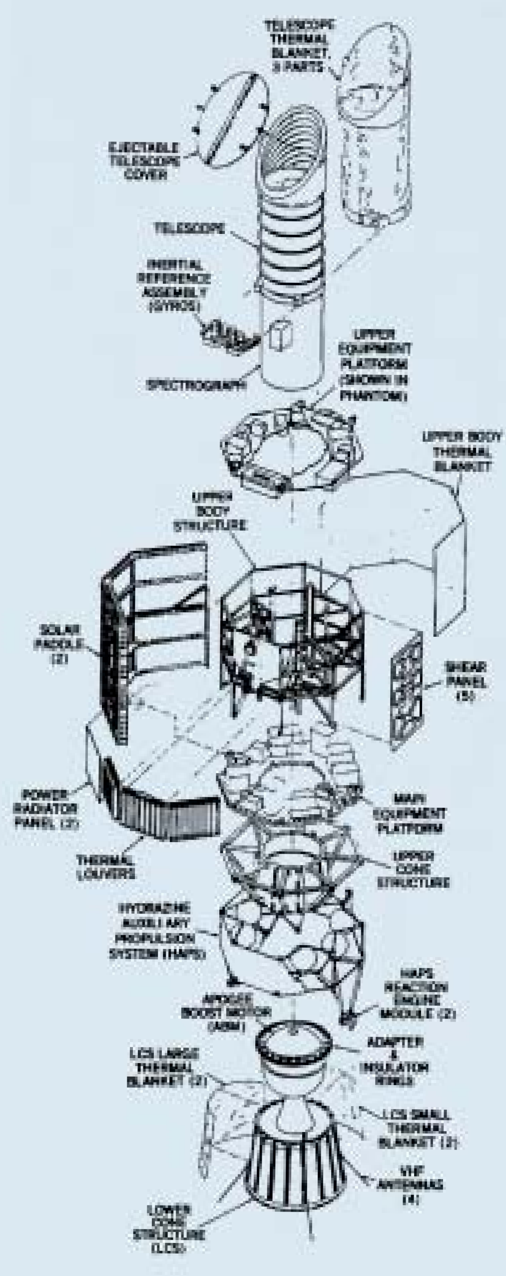


IUE's only serious problems stemmed from the failures (1979, 2x1982, 1985, 1991) of five of the six gyros in its attitude control system, although only one succumbed within the 3-year design life. When the fourth failed in 1985, IUE continued operations thanks to an innovative reworking of its attitude control system by using the fine Sun sensor as a substitute. Even with another lost in the last year, IUE could still be stabilised in 3-axes by adding star tracker measurements.

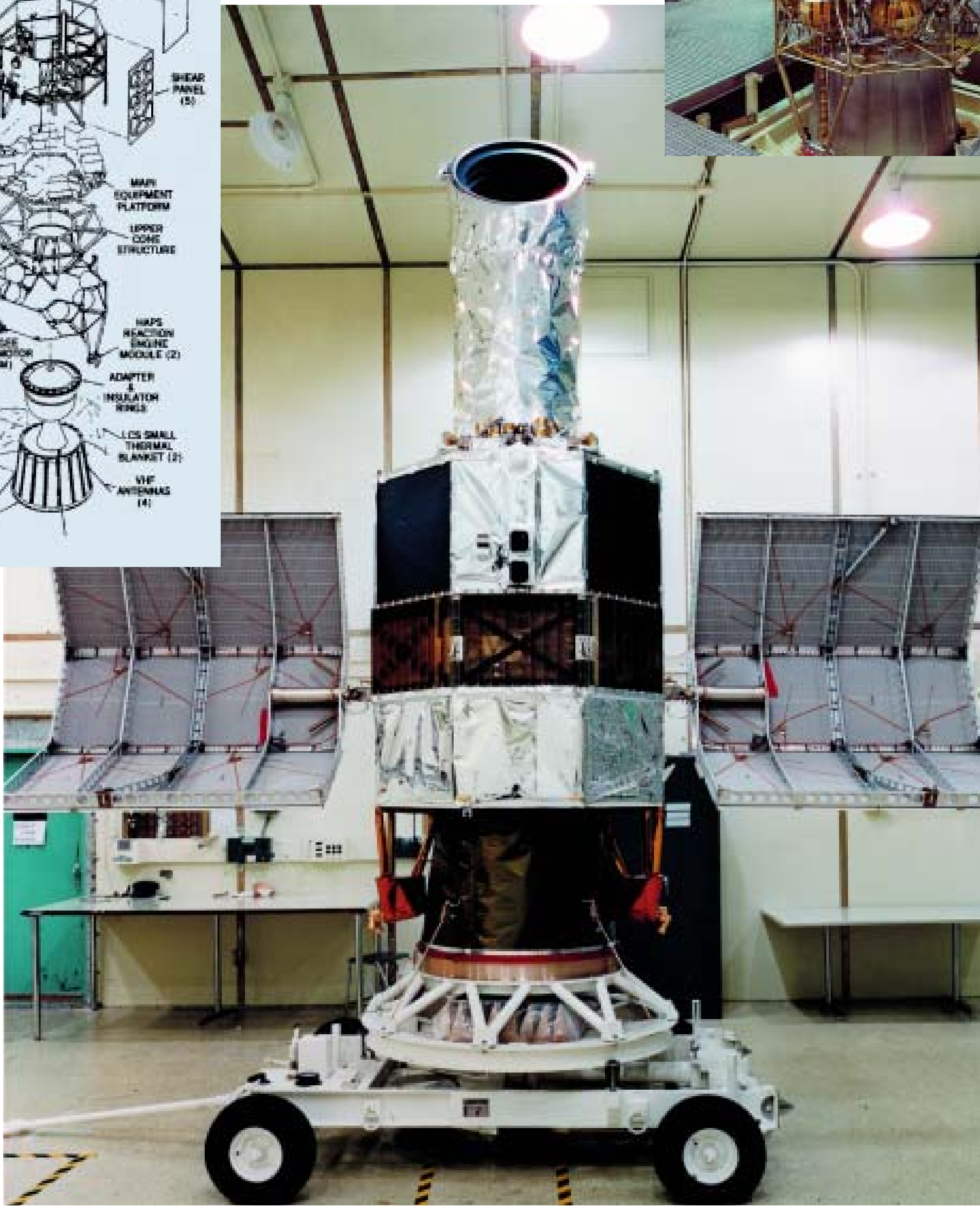


IUE carried two star trackers (Fine Error Sensors) viewing through the main telescope to provide precise positioning information. This FES image shows Halley's Comet during its closest approach to Earth in 1985.

Until October 1995, IUE was in continuous operation, run 16 h daily from Goddard and 8 h from Villafranca. After that, as the two agency's budgets tightened, observations were made only during the 16 h low-radiation part of the orbit, controlled from Villafranca



Right: The IUE Flight Model being prepared for a fine-pointing test. Below: IUE ready for launch. (NASA)



while NASA concentrated on creating the IUE Final Archive. IUE remained operational until its hydrazine was deliberately vented, its batteries drained and its transmitter turned off.

Satellite configuration: 1.45 m-dia octagonal-prism bus with telescope assembly along main axis, and fixed solar wings extending from opposing faces. Most of the higher-power electronics were mounted on the main equipment panel at the base, near the thermal louvres, while the experiment electronics and attitude control elements were on the upper equipment platform.

Attitude/orbit control: 3-axis control by four reaction wheels, Fine Error Sensors (2-axis star trackers using the telescope optics for 0.27 arcsec angular resolution in 16 arcmin FOV), fine/coarse Sun sensors and 8x9 N + 4x22 N hydrazine thrusters (27.3 kg hydrazine in 6 tanks) for momentum dumping and orbit adjust. The control system had to hold a 1 arcsec-dia star image within a 3 arcsec-dia spectrograph entrance for a 1 h integration by the camera.

Power system: 424 W BOL/28 Vdc (170 W after 18 yr; 210 W required) provided by two fixed 3-panel arrays carrying 4980 2x2 cm Si cells; 2x6 Ah nickel cadmium batteries.

Communications/data: 1.25-40 kbit/s 2.25 GHz 6 W S-band downlink with fixed + reprogrammable formats. 139 MHz VHF for telecommand.

Science payload: 45 cm-diameter f/15 Ritchey-Chrétien telescope with two Fine Error Sensors, echelle spectrographs (1150-1980 Å; 1800-3200 Å), resolutions 270 at 1500 Å & 400 at 2700 Å. Redundant 1150-1970 Å and 1750-3300 Å vidicon cameras, 768x768 pixels.

The Goals and Highlights of IUE

IUE's original scientific objectives were to:

- obtain high-resolution spectra of stars of all spectral types to determine their physical characteristics
- study gas streams in and around binary star systems
- observe faint stars, galaxies and quasars at low resolution, interpreting these spectra by reference to high-resolution spectra
- observe the spectra of planets and comets
- make repeated observations of objects with variable spectra
- study the modification of starlight caused by interstellar dust and gas.

Scientific highlights were the:

- first detection of aurorae on Jupiter
- first detection of sulphur in a comet
- first measurement of water loss in a comet (10 t/s)
- first evidence for strong magnetic fields in chemically peculiar stars
- first orbital radial velocity curve for a Wolf-Rayet star, allowing its mass determination
- first detection of hot dwarf companions to Cepheid variables
- first observational evidence for semi-periodic mass-loss in high-mass stars
- discovery of high-velocity winds in stars other than the Sun
- first identification of a supernova progenitor (SN 1987A)
- discovery of starspots on late-type stars through Doppler mapping
- discovery of large-scale motions in the transition regions of low-gravity stars
- discovery of high-temperature effects in stars in the early stages of formation
- discovery of high-velocity winds in cataclysmic variables
- discovery of the effect of chemical abundance on the mass-loss rate of stars
- first determination of a temperature and density gradient in a stellar corona beyond the Sun
- first detection of gas streams within and outflowing from close binary stars.
- determination that no nova ejects material with solar abundance
- discovery of 'O-Ne-Mg' novae, where the excess of these elements can be directly traced to the chemical composition of the most massive white dwarfs
- discovery of a ring around SN 1987A, a leftover from previous evolutionary stages
- first direct detection of galactic haloes
- first observations of extragalactic symbiotic stars
- first uninterrupted lightcurves of stars for more than 24 h continuously
- first detection of photons below 50 nm from any astronomical source other than the Sun
- first direct determination of the size of the active regions in the nuclei of Seyfert galaxies (mini-quasars)
- first detection of a transparent sightline to a quasar at high redshift, allowing the first abundance determination of the intergalactic medium in the early Universe
- first astronomical and satellite facility to deliver fully reduced data within 48 h to scientists

Ariane-4
Ariane-3
Ariane-2
Ariane-1

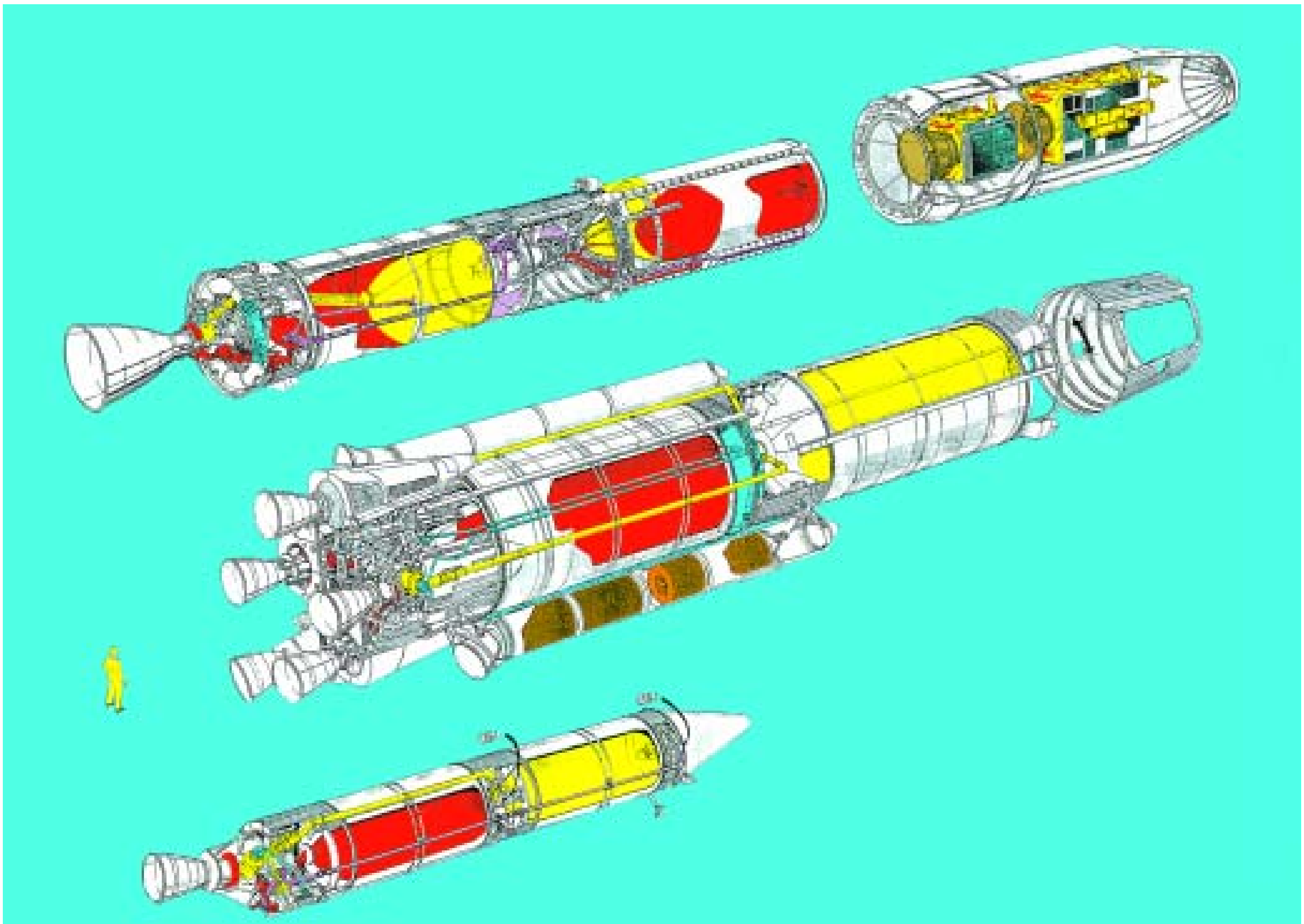
Achievements: first successful European satellite launcher; holds half of world's commercial launch market into GTO; 129 launches to end-2000 (101 Ar-4; 6 planned for 2001); 100th launch 23 Sep 1997; 100th Ar-4 launch 29 Oct 2000 (Ar-4 total 337 t orbited in 163 payloads); Ariane carried its 100th telecommunications satellite (Astra 1E) on 19 Oct 1995; heaviest payload is Anik-F1 (4711 kg, 21 Nov 2000); world record 61 consecutive successes Mar 1995 - Feb 2001 (to date)
Launch dates: 24 Dec 1979 for first of 11 Ar-1; 4 Aug 1984 for first of 17 Ar-2/3; 15 Jun 1988 for first Ar-4 (still in service)
Launch site: Ar-1/2/3 from ELA-1 pad, Ar-2/3/4 from ELA-2 pad; Kourou, French Guiana
Launch mass: 484 t for heaviest Ariane-4 version (Ar-44L), 245 t for lightest Ariane-4 version (Ar-40)
Performance: optimised for GTO. Up to 4950 kg into 7°-inclined GTO for Ar-44L from Kourou; Ar-1 1850 kg; Ar-2 2175 kg; Ar-3 2700 kg
Principal contractor: EADS Launch Vehicles (industrial architect)

Launch of the first Ariane-4 (V22), in August 1984. Note the two liquid-propellant and two solid-propellant strapons. (ESA/CNES/CSG)

The Ministers responsible for space affairs in 10 European countries decided in Brussels on 31 July 1973 to develop a competitive vehicle that would win a significant share of the launch market for applications satellites. All the signs were that 1980-90 would see the setting up of a myriad of operational and commercial space systems for telecommunications, direct TV broadcasting, meteorology and Earth observation. Several contemporary studies estimated that 180 satellites would require launches into geosynchronous orbits.

The highly successful and profitable Ariane programme has since more than vindicated that original agreement of the 10 countries: France (63.9%), Germany (20.1%), Belgium (5.0%), UK (2.5%), The Netherlands (2.0%), Spain (2.0%), Italy (1.7%), Switzerland (1.2%), Sweden (1.1%) and Denmark (0.5%). The vehicle has long captured half of the world's commercial launch contracts annually. In 1998 alone, the profit reported by Arianespace – established by CNES in 1980 to contract, manage production, finance, market and conduct the launches – was €12.6 million on sales of €1.07 billion from 11 launches involving 14 satellites.

A study of the direct economic effects of the Ariane-1 to -4 programmes showed a financial return of slightly more than a factor of 3. In other words, the revenues generated for Arianespace and European industry are more than three times the initial



Arianespace

public investment in Ariane, taking into account the €6 billion invested by ESA and national institutions between 1974 and 2000 and the more than €18 billion generated by launch contracts. These figures also cover the public expenditure related to the Kourou launch site.

ESA is responsible (as design authority) for Ariane development work, owning all the assets produced. It entrusts technical direction and financial management to CNES, which writes the programme specifications and places the industrial contracts on its behalf. EADS Launch Vehicles (the former Aerospatiale) acts as industrial architect. ESA/CNES were directly responsible for the L01-L04 development launches and the L5-L8 promotional launches, before Arianespace assumed responsibility beginning with flight 9. The 3-stage launcher was optimised for direct ascent into GTO, beginning with Ariane-1's capacity of 1850 kg. The 47.4 m-high, 210 t Ariane-1 was powered by four Viking 5 engines on stage-1, a single Viking 4 on stage-2 and the cryogenic liquid oxygen/liquid hydrogen HM-7 engine of stage-3. The Ariane-1 vehicle flew 11 times during 1979-86, with its nine successes a remarkable achievement for a new design.

Ariane-4 Variants

		Launch thrust	*Launch mass*	*7° GTO capacity*
Ar-40	no strapons	2720 kN	245 t	2130 kg
Ar-42P	2 solids	3945 kN	324 t	2970 kg
Ar-44P	4 solids	5140 kN	356 t	3530 kg
Ar-42L	2 liquids	4060 kN	363 t	3560 kg
Ar-44LP	2 solids/2 liquids	5270 kN	421 t	4310 kg
Ar-44L	4 liquids	5400 kN	484 t	4950 kg

Ariane-4 V34 included four liquid-propellant strapons to help deliver the Intelsat 6 telecommunications satellite into GTO. (ESA/CNES/CSG)

Ariane's first launch, on 24 December 1979, was a complete success. (ESA/CNES/CSG)

Ariane V10 in August 1984 saw the first use of solid-propellant strapons to increase performance. On this occasion, the boosters carried recoverable cameras to film the separation sequence 4.8 km high. The other booster can be seen as Ariane accelerates away with its four Viking engine bells glowing red hot. (ESA/MAN)

Ariane-4 Principal Characteristics

Stage-1

Principal contractor: EADS-LV (Aerospatiale)

Size: 28.39 m (including 3.31 m interstage) long; 3.80 m diameter, 17.5 t dry mass

Powered by: four Snecma Moteurs Viking 5 engines providing total of 2720 kN at launch for up to 205 s (qualified to 300 s), gimballed for attitude control, drawing on up to 227 t of nitrogen tetroxide (NTO) and UH25 (unsymmetrical dimethyl hydrazine + 25% hydrazine hydrate)

Design: propellants are carried in two identical 10.1 m-long, 3.80 m-diameter steel tanks, separated by a 2.69 m-long interstage. An 8200-litre toroidal water tank sits on top of the lower tank, used for engine cooling

Solid-propellant strapons: 0, 2 or 4 carried, ignited at launch, 4.2 s after main engines. Each 650 kN thrust, 33 s burn (ejected >1 min after launch), 1205 cm long, 107 cm diameter, 12 660 kg (9500 kg propellant). EADS-LV prime contractor

Liquid-propellant strapons: 0, 2 or 4 carried, ignited with stage-1 engines. Each 670 kN thrust, 142 s burn (ejected 149 s after launch), 1860 cm long, 222 cm diameter, 43 550 kg (39 000 kg propellant). Powered by single, fixed Viking 6; design similar to stage-2. Astrium GmbH prime contractor

Stage-2

Principal contractor: Astrium GmbH

Size: 11.61 m long; 2.60 m diameter, 3.4 t dry mass

Powered by: Snecma Moteurs Viking 4 engine providing 798 kN for 125 s, drawing on up to 35 t of NTO/UH25

Design: propellants are carried in aluminium cylinder, 652 cm long, divided into two vessels by an internal bulkhead. Rear conical skirt, 157 cm long, connects with stage-1 interstage and houses Viking's toroidal water coolant tank. 125 cm-long front skirt connects with stage-3's interstage

Stage-3

Principal contractor: EADS-LV (Aerospatiale)

Size: 11.05 m long; 2.60 m diameter, 1.24 t dry mass

Powered by: gimballed Snecma Moteurs HM-7B cryogenic engine providing 64.8 kN for 780 s, drawing on 11.9 t of liquid oxygen/liquid hydrogen

Design: propellants are housed in an aluminium cylinder, with tanks separated by an internal bulkhead. 45 cm-long front skirt connects to Ariane's equipment bay; 273 cm-long rear skirt connects with stage-2.

Vehicle Equipment Bay (VEB)

Principal contractor: Astrium SA

Purpose: carries equipment for vehicle guidance, data processing, sequencing, telemetry and tracking

Size: 104 cm high; 4.0 m diameter, 520 kg

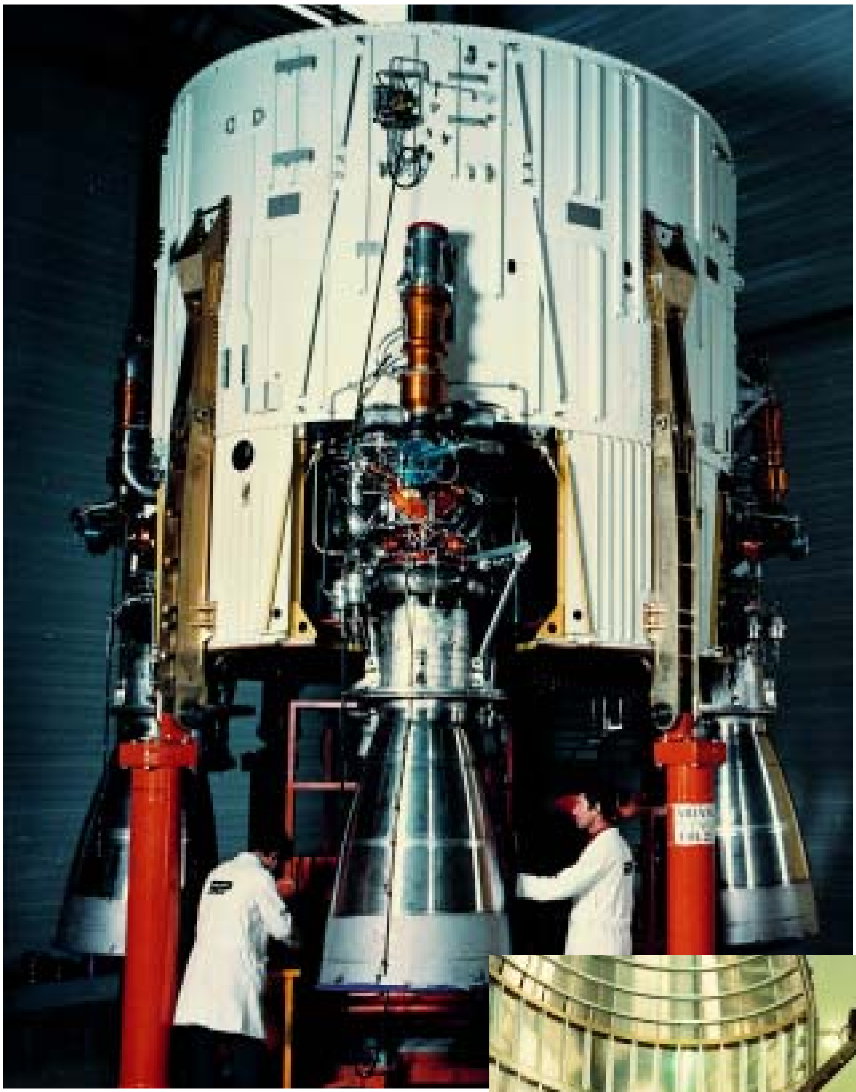
Design: internal cone provides 1920 mm-diameter attachment to payload; external cone connects with payload fairing/carrier; annular platform carries the electronics

Payload Fairing and Carriers

Payloads are protected by a 2-piece aluminium fairing until it is jettisoned after about 285 s during the stage-2 burn. Prime contractor is Oerlikon Contraves. Three basic lengths are available: 8.6 m, 9.6 m and 11.1 m; diameter is 4 m. The main payload carrier is the Spelda, which sits between the fairing and stage-3, housing one satellite internally and a second on its top face, under the fairing. A range of sizes for matching payload requirements is available. Some missions can also carry up to six 50 kg satellites as passengers.

But each Ariane-1 could carry only two GTO satellites of up to 700 kg each, when it was clear that the market would soon demand greater capacities. The Ariane-3 design thus made its debut in 1984, capable of delivering two 1195 kg satellites (or one of 2700 kg) into GTO. This was achieved mainly by uprating the engines, stretching stage-3 by 1.3 m, adding two solid-propellant strapons to stage-1 and enlarging the payload fairing. Ariane-2, capable of placing 2175 kg in GTO, was identical but flew without the strapons. Ten of the 11 Ariane-3s were successful 1984-89 and 5 out of 6 Ariane-2s during 1986-89.

The development of a more powerful variant to become the standard vehicle through the mid-1990s was



The engine bay of Ariane's first stage carries four Viking 5 engines. (Snecma Moteurs)

The Giotto Halley's Comet probe installed on top of its Ariane-1 launcher. The Vehicle Equipment Bay carries the rocket's control electronics. Behind, to the left is one half of the fairing. (ESA/CNES/CSG)

The night launch of Ariane-4 V48 in December 1991 carried the Inmarsat-2 F3 and Telecom-2A telecommunications satellites. (ESA/CNES/CSG)

Stage-2 is powered by a single Viking engine. (ESA/CNES/CSG)

formally approved by ESA's Council in January 1982 and management responsibility assigned to CNES. A total of 116 vehicles is planned (101 had been launched by the end of 2000) until the new-generation Ariane-5 completely replaces it in 2003. Six Ariane-4 variants are created by mixing pairs of solid and/or liquid strapon boosters; in order of increasing performance, they are shown in the earlier table.

Ariane-4 was not merely an upgrading but a significant redesign to meet the increasing needs of the commercial market. From Ariane-3, stage-1 was stretched by 6.7 m to increase propellant capacity from 144 t to 227 t, and the Viking 5 engines increased their burn times from 138 s to 205 s. Stage-1 can also carry up to four liquid-propellant strapons comparable in size and performance with stage-2; a stretched version of Ariane-3's solid-propellant strapons is also available. Initially, stage-3 was similar to that on Ariane-3, but it was stretched by 32 cm in April 1992 to add another 340 kg of cryogenic propellants, and then another redesign was introduced in December 1994 that increased capacity from 4460 kg to 4720 kg into GTO. In January 1996, other adjustments produced 4820 kg. The record now stands at 4947 kg, for the launch of 28 October 1998; 5000 kg is attainable. In addition, Ariane-4 offers a range of payload fairings and carriers to handle mixes of up to two major satellites and six 50 kg payloads on each launch.

Marecs

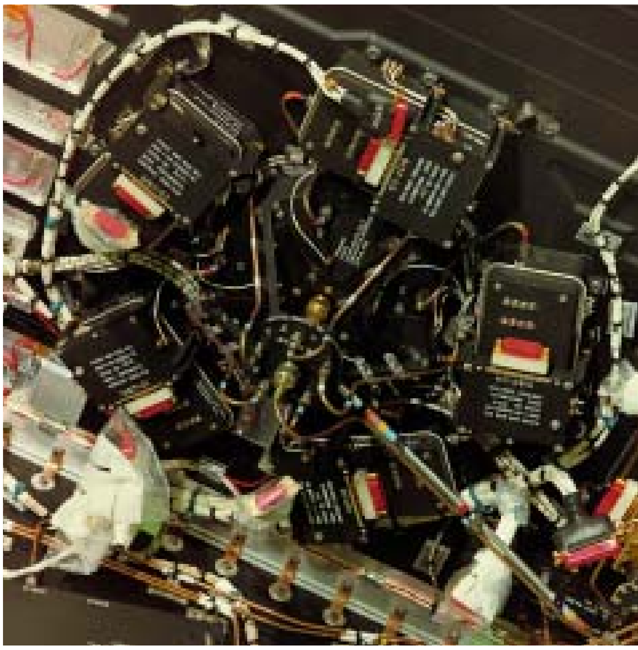
Achievements: first European maritime communications satellites; inaugurated Inmarsat; greatly exceeded 7-year design lives
Launch dates: Marecs-A 20 December 1981; Marecs-B 10 September 1982 (launch failure); Marecs-B2 10 November 1984
Mission end: Marecs-A retired from Inmarsat service in 1991 and ESA deactivated it in August 1996; Marecs-B2 retired from Inmarsat service in December 1996 and is now leased to Comsat General Corp
Launch vehicle/site: Ariane from Kourou, French Guiana
Launch mass: 1060 kg (562 kg on-station BOL; communications payload 96 kg)
Orbit: geostationary, Marecs-A initially 26°W (retired from 22.5°E August 1996), Marecs-B2 initially 177.5°W (now 26°W, 9° inclination)
Principal contractors: British Aerospace (prime); Marconi Space Systems (payload)

Conceived as an experimental project, Marecs evolved to provide Europe with a major breakthrough in mobile telecommunications expertise. Several ESA Member States undertook in 1973 to fund a satellite programme that would demonstrate communications between ships and land stations linking into the public networks, at a time when vessels could call only on unpredictable short-wave radio.

In fact, Marecs (so named because it adapted ESA's ECS design for a maritime application) became the agency's first venture into the commercial satellite business. The two successfully-launched satellites were leased initially for 10 satellite-years to the Inmarsat (International Maritime Satellite Organisation), which formally inaugurated its service on 1 February 1982. Marecs was designed to provide high-quality realtime voice, data and telex services for maritime users. This included about 60 telephone channels linked into the public system (including fax and data transmissions), 1200 telex channels working through the international telex system, priority relay of distress signals, and the broadcasting of material such as weather forecasts to whole groups of users simultaneously.

With Marecs-A and -B2 providing coverage over the Atlantic and Pacific Oceans, 130 ships carried Inmarsat transceivers on inauguration day. More than 100 000 terminals have been commissioned, today including systems on aircraft and land vehicles, and even briefcase sets for business travellers. Inmarsat has now changed the 'Maritime' in its name to 'Mobile' to better reflect its growing business.

Developing Marecs placed Europe at the forefront of mobile communications technology, so that when Inmarsat requested bids for



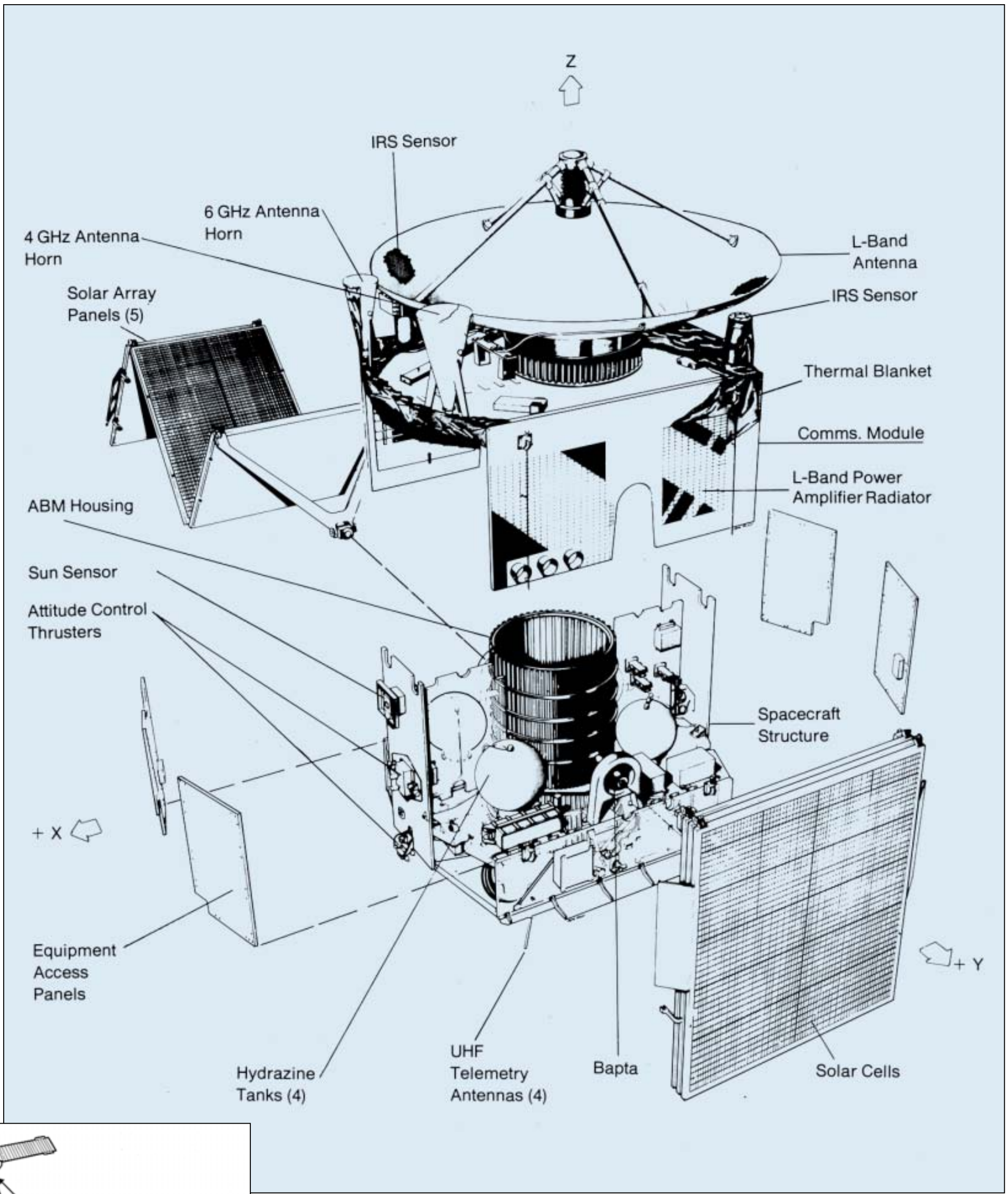
One of the two L-band Solid State Power Amplifier (SSPA) clusters for transmitting to maritime users. Three of the five SSPAs in both clusters were grouped to generate a 75 W output.

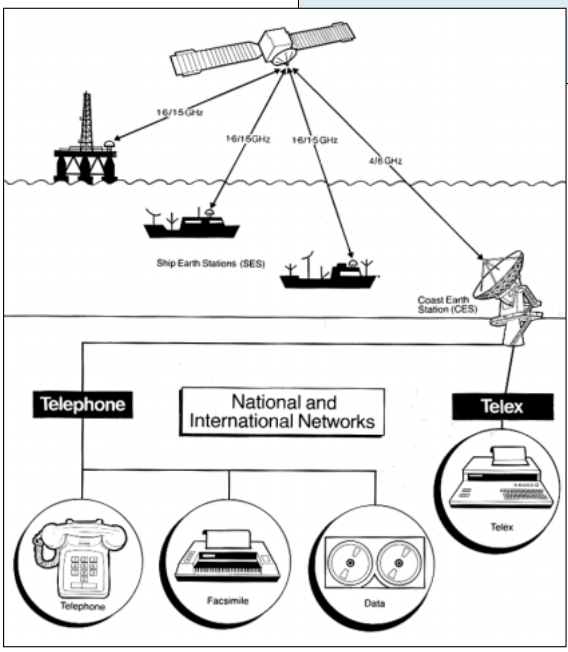
Marecs-A in orbital configuration.

Marecs-A assembly at British Aerospace in Stevenage, UK.

building its first generation of dedicated satellites a consortium headed by British Aerospace won the prime contract, drawing on the Marecs heritage. These four satellites were launched 1990-1992, and are now augmented by third-generation satellites carrying payloads provided by Astrium.

Despite the advent of the new satellites, the two Marecs continued in service with Inmarsat far beyond their 7-year design lives. Marecs-A was removed from service in 1991 because of its ageing solar arrays, but ESA continued to use it for experiments at 22.5°E until it was boosted above geostationary orbit in August 1996 and deactivated. Inmarsat's Marecs-B2 lease expired at the end of 1996 and the veteran satellite was moved to 26°W, where it was leased by Nuovo Telespazio (Italy) August 1997 - January 2000. A Nuovo Telespazio customer, Fugro, disseminated GPS navigation system updates to users primarily in South America. It is expected that, from mid-2001, it will be leased to Comsat General Corp to provide links with the US National Science Foundation at the South Pole, from where it is visible for 2 h each day.





Marecs principal features. The service module was directly derived from the ECS satellite.

Marecs-A is prepared for launch from Kourou on an Ariane vehicle.

Marecs pioneered maritime satellite communications, providing reliable links with the land-based public networks.

Marecs-A undergoes a solar array deployment test at British Aerospace.

Satellite configuration: maritime version of ECS satellite, 2.2x3.1x1.8 m at launch, solar array deployed span 13.8 m.

Attitude/orbit control: 3-axis stabilisation and maintained in GEO by momentum wheels and redundant 0.5 N and 2 N hydrazine thrusters (90 kg hydrazine in four tanks; 26 kg remained as of Feb 2001). Earth and Sun sensors provide Earth pointing with 0.04° accuracy. Transfer from GTO to GEO by solid-propellant apogee boost motor.

Power system: two 3-panel Si solar wings generated 1050 W; 425 W required by communications payload. Powered by 2x21 Ah nickel cadmium batteries during eclipse.

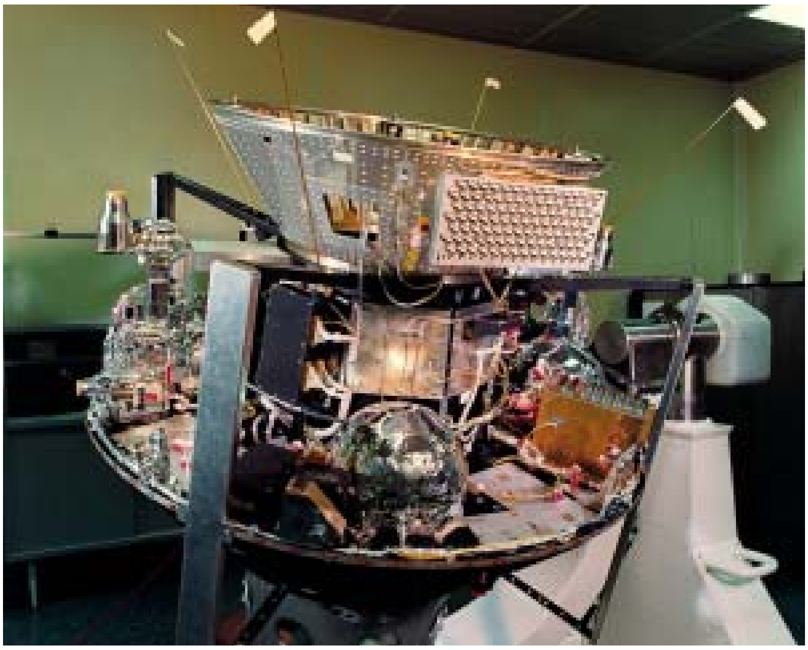
Communications payload: up to six L-band SSPAs (out of 10) with total 75 W output (EIRP 33.1 dBW hemispherical beam edge) relayed >35 voice channels at 1.54 GHz to ships, and could receive >50 at 1.64 GHz. One C-band 1 W 6.4 GHz TWTA provides link to land station. Flight Control Centre at ESOC (Redu since March 1997), working via C-band station at Villafranca.

Sirio

Launch date: 10 September 1982 (launch failure)
Mission end: launch failure; 2-year nominal mission planned
Launch vehicle/site: Ariane from Kourou, French Guiana
Launch mass: 420 kg (on-station BOL 237 kg; payload 50.0 kg, apogee motor 203 kg, hydrazine/nitrogen 34 kg)
Orbit: orbit not achieved, planned to be geostationary over 25°W
Principal contractor: Compagnia Nazionale Satelliti per Telecommunicaziono SpA

Italy expressed an interest in 1977 in using the spare flight model of its successful domestic Sirio-1 telecommunications satellite for applications on a broader European basis. ESA's proposal, after consulting national meteorological services and the World Meteorological Organisation, was accepted by the Agency's Council in December 1978 and spacecraft development (Phase-C/D) began in January 1979.

One payload was for the **Meteorological Data Distribution** (MDD) mission. Sirio-2 was to be positioned in geostationary orbit over Africa, so that its MDD transponder would allow meteorological centres on that continent to relay weather data using simple receive/transmit stations. Sirio provided 24x100 bit/s and 12x2.4 kbit/s 2105/1695 MHz up/down channels working to <40 dBw EIRP stations. On Sirio, the despun 70x99 cm 45° planar reflector directed incoming signals to the fixed 70 cm parabolic reflector and its antenna feed.



The other payload was **Laser Synchronisation from Stationary Orbit** (Lasso) for synchronising high-precision clocks at widely-separated locations with 1 ns accuracy at low cost. Lasso consisted of a 155x340 mm panel of 98 20 mm-diameter laser retro-reflectors mounted on the Ariane interface adapter, photodetectors for sensing ruby and neodyme laser pulses, and an ultrastable oscillator/counter to time-tag the pulse arrivals. Different ground stations could thus observe the reflected pulses and use the time-tagging to compare their clocks.

Satellite configuration: total height 2.400 m, diameter 1.438 m, based on cylindrical body 9.954 m high, 1.438 m diameter. Four principal elements: main structure; solar array structure; payload platform; interface adapter. Main structure was aluminium honeycomb thrust cone supporting apogee motor at one end, the main load platform on its mid-section, and payload platform on top end. The main load platform accommodated the four propellant

Sirio-2 complete, with the solar array panels removed.

Facing page: Sirio's main platform carried most of the spacecraft systems. Prominent at top is the launcher interface adapter, carrying the panel of 98 laser reflectors.

Sirio-2 ready at Kourou for encapsulation in the Ariane payload fairing. The despun antenna is covered by a protective cylinder (top). (ESA/CNES/CSG)

tanks, thrusters, attitude detection units and main services such as power, telemetry & command. Solar array cylindrical structure of four 90° sections attached to main load platform at mid-height and to thrust cone by struts at both ends.

Attitude/orbit control: Auxiliary Propulsion Subsystem of two radial and two axial 22 N hydrazine thrusters; spin-stabilised at 90 rpm. Attitude determination by four 2 kg Earth/Sun IR sensor packages.

Insertion into GEO by solid-propellant apogee motor.

Power system: 8496 2x2 cm Si cells on cylindrical body main array, supported by 300 2x2 cm Si cells for battery charging. Total output 133 W BOL at summer solstice.

Communications payload: telemetry & command at 148/136 MHz up/down VHF using redundant 8 W transponders; 512 bit/s telemetry. Controlled from Fucino, Italy.

Exosat

Achievements: detailed observations of celestial X-ray sources
Launch date: 26 May 1983
Mission end: reentered 6 May 1986 (designed for 2-year life, science operations began August 1983)
Launch vehicle/site: Delta from Vandenberg Air Force Base, California
Launch mass: 510 kg (science instruments 120 kg)
Orbit: 2919x189 000 km, 71.4°
Principal contractors: MBB headed the Cosmos consortium: SNIAS-Cannes (F)/CASA (E)/Contraves (CH)/BADG (UK) (structure/thermal/mechanisms/solar array mechanical); MBB (D)/SNIAS-LM (F)/MSDS (UK)/Sodern (F)/Ferranti (UK)/SEP(F)/TPD-TNO (NL)/NLR (NL) (AOCS); Selenia (I)/Laben (I)/Saab (S)/Crouzet (F)/LM-Ericsson (S) (data handling/RF); ETCA (B)/Terma (DK)/Saft (F)/AEG (D) (power/solar array electrical)

ESA's X-ray Observatory Satellite (Exosat) studied the X-ray emissions from most classes of astronomical objects, including active galactic nuclei, white dwarfs, stars, supernova remnants, clusters of galaxies, cataclysmic variables and X-ray binaries, in 1780 observations. It measured the locations of cosmic X-ray sources, their structural features and spectral, as well as temporal, characteristics in the wavelength range from extreme-UV to hard X-rays. Its primary mission was to study sources already detected by earlier satellites, although it did discover many new ones serendipitously as it slewed from one target to the next or focused on specific areas.

Exosat was the first ESA/ESRO science satellite totally funded by the Agency. Its observations and data were not restricted to the groups that had built the three instruments, but were made available to a wider community. The satellite was operated as a true astronomical observatory. A unique feature was the highly eccentric orbit which, although it subjected Exosat to higher background radiation dependent on solar activity, provided up to several days at a time for uninterrupted viewing of a source. More than 450 publications of Exosat data in leading scientific journals have been made. Notable discoveries include:

— Exosat searched for neutron stars in double-star X-ray sources, by looking for regular flashes. None was found but quasi-periodic oscillations were discovered. In GX 5-1, a narrow pulse was replaced by an irregular flickering – apparently caused by gas falling into a neutron star or black hole from a companion star.

— Exosat discovered two stars orbiting each other every 11 min – the shortest period known. XB 1820-30 emits X-rays 10^{11} more intense than from the Sun as material falls onto its neutron star.

— The X-ray binary SS433 is probably a massive star feeding a black hole 10 times the mass of the Sun. Two giant jets near the black hole are ejecting material at a quarter the speed of light. The X-ray jets wave back and forth every 167 days, which Exosat discovered is the same period as variations in the optical lines. This is helping to explain the enigmatic nature of jets from black holes – still one of the hot topics in astrophysics.

Exosat in operating configuration. On the front, from left to right, are two startrackers, the two low-energy imaging telescopes and the four quadrants of the medium-energy instrument. The gas scintillation proportional counter is visible to the right of the medium energy instrument.

Exosat Mission Objectives

Precise location of sources: within 10 arcsec at 0.04-2 keV, 2 arcmin for 1.5-50 keV.

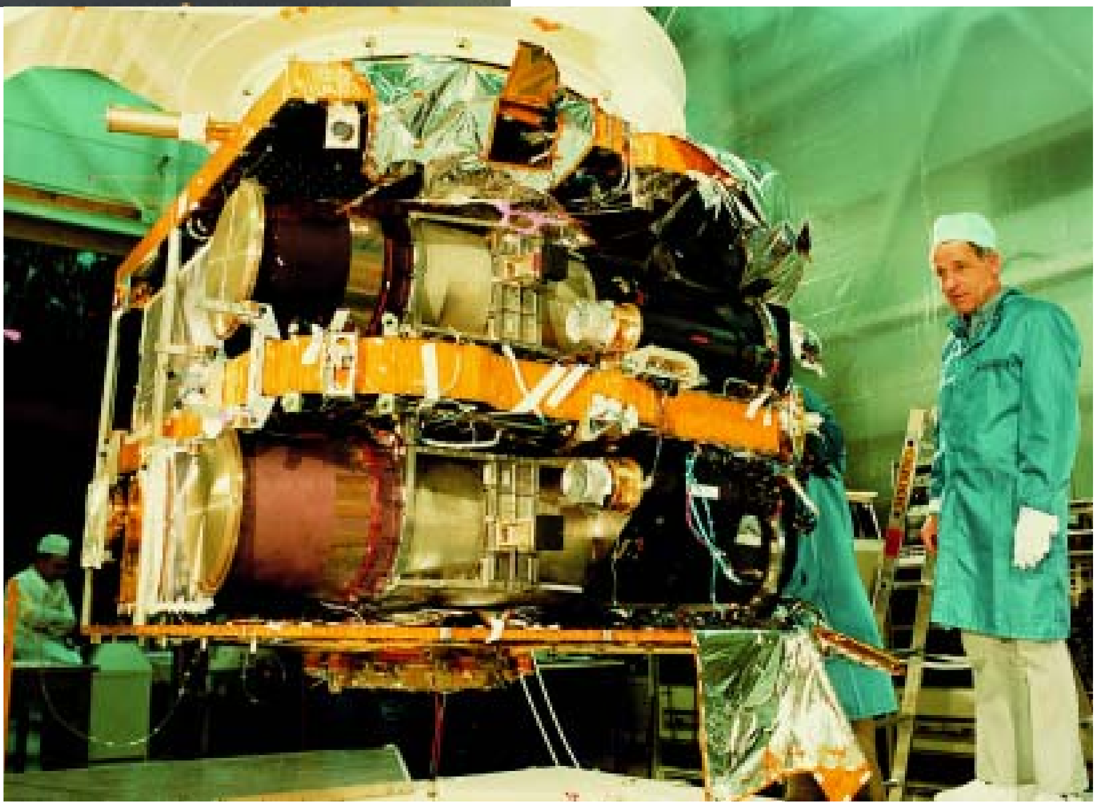
Mapping diffuse extended objects: at low energies using imaging telescopes.

Broadband spectroscopy of sources: with all instruments between 0.04 keV & 80 keV.

Dispersive spectroscopy: of point sources using gratings with imaging telescopes.

Time variability of sources: from days to sub-millisec.

New sources: detection.



Inside Exosat. The two low-energy imaging telescopes are prominent, with their apertures at left and their detectors at right.

— Exosat surveyed 48 Seyfert galaxies, which have giant black holes at their centres and are strong X-ray emitters. Exosat discovered a soft X-ray component, now thought to be emission from matter swirling into an accretion disc before disappearing into a black hole.

— observations of the pulsing X-ray nova EXO 2030+375 provided new insights into how material from a companion is captured by the intense magnetic field of a pulsing neutron star.

Exosat Scientific Instruments

Low-Energy Imaging Telescope *(LE)*

Two grazing incidence telescopes, 0.04-2 keV, 1 m focal length, 1° FOV to provide X-ray images using channel-multiplier arrays. Passband filters provided coarse spectral information; diffraction gratings for high-resolution spectroscopy (mechanical failure limited grating use to first few months of operations). Each telescope 30 kg, 5 W.

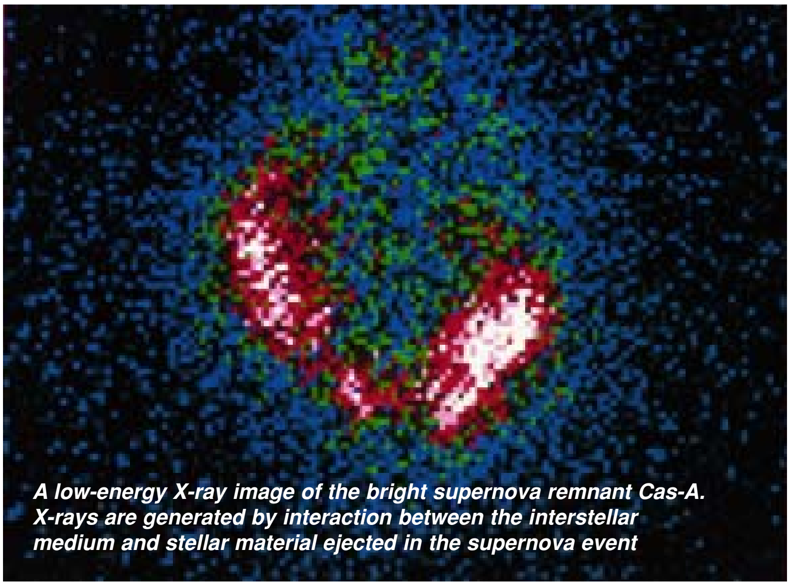
Medium Energy Experiment *(ME)*

Array of eight proportional counters, total area 1600 cm², 1.5° FOV, for moderate spectral resolution over 1-50 keV. Four detectors could be offset by up to 2° for simultaneous off-target background monitoring. 48 kg, 17 W.

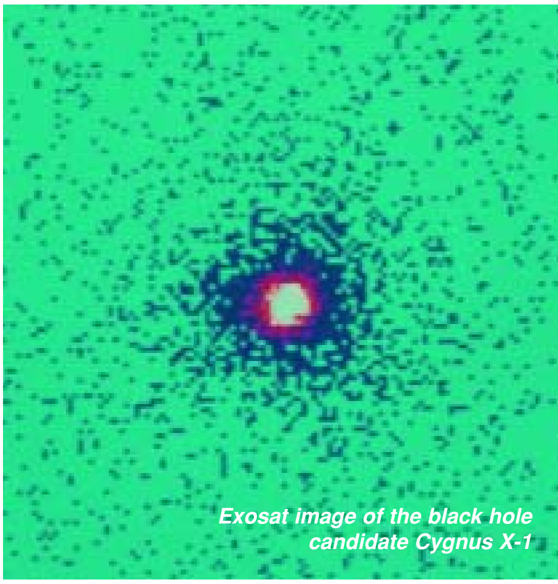
Gas Scintillation Proportional Counter *(GSPC)*

Higher-resolution spectrophotometry, collecting area 100 cm², 2-20 keV, 1.5° FOV. 8 kg, 1.5 W.

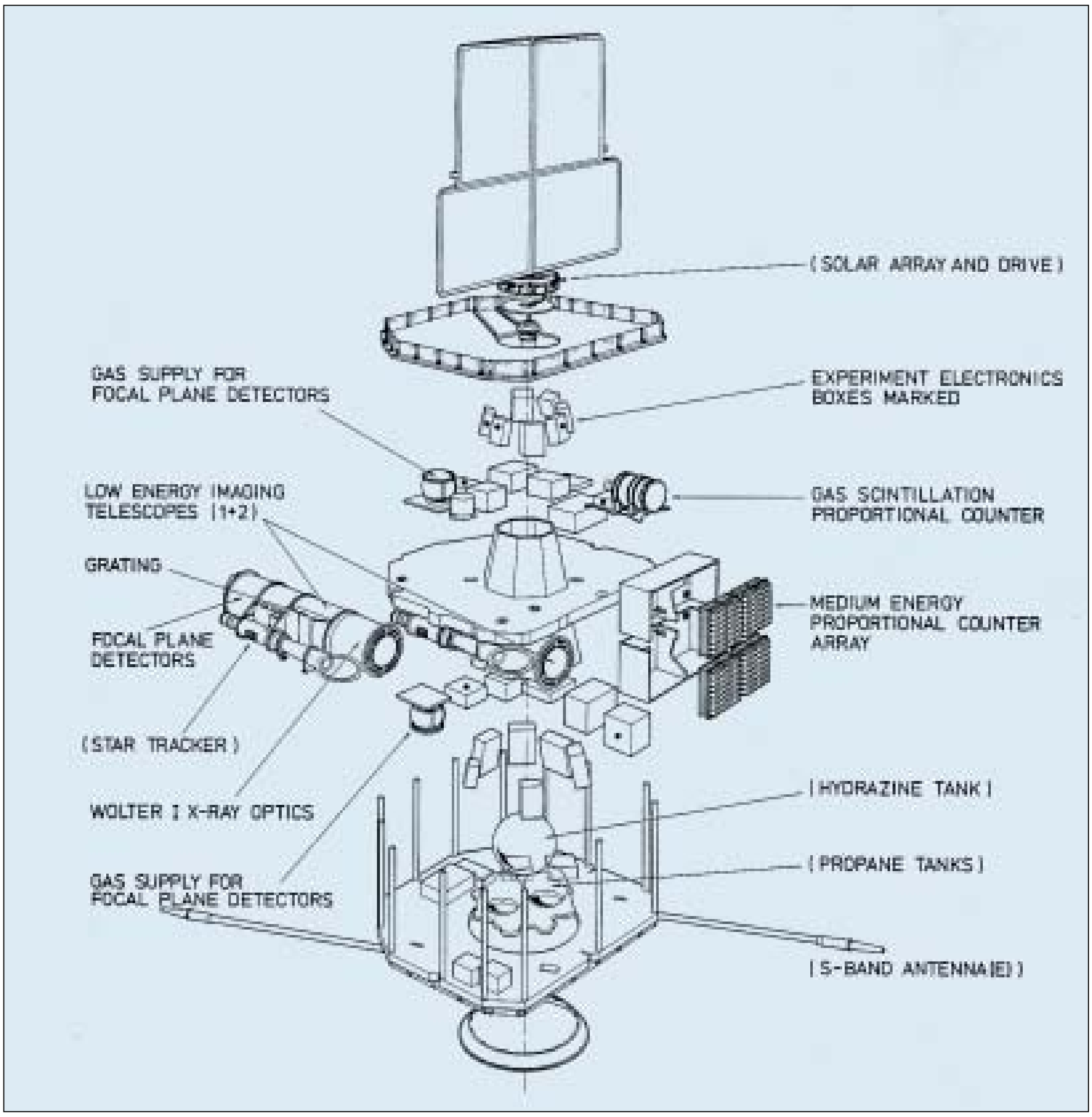
Exosat being prepared for launch from Vandenberg Air Force Base, California. The medium-energy and low-energy instruments are protected by their shutters on the left-hand face. These shutters were opened in orbit to act as sun shades for the telescopes.



A low-energy X-ray image of the bright supernova remnant Cas-A. X-rays are generated by interaction between the interstellar medium and stellar material ejected in the supernova event



Exosat image of the black hole candidate Cygnus X-1



Satellite configuration: box-shaped bus, 2.1 m square, 1.35 m high, topped by 1.85 m-high solar array. The science instruments viewed through one wall, covered by flaps during launch that opened in orbit to act as thermal and stray-light shields. Primary structure comprised central cone supporting one main and two secondary platforms. All alignment-sensitive units (science instruments and fine attitude-measurement units) were mounted on the highly-stable carbon fibre main platform.

Attitude/orbit control: 3-axis control by redundant sets of six 0.05-0.2 N propane thrusters. Attitude determination by gyros, Sun sensors and star trackers to 10 arcsec for Y/Z-axes and few arcmin for X-axis. Orbit adjust by 14.7 N hydrazine thrusters; delta-V measured by redundant accelerometers. AOCS equipment housed in central cone, with thrusters mounted on edges of platforms.

Power system: 260 W provided by 1-degree-of-freedom solar sail, following Sun to within 3°. Supported by two 7 Ah NiCd batteries.

Communications: the orbit was designed for Exosat to be in continuous realtime contact with Villafranca in Spain for the scientifically significant part of the orbit – the 76 h out of the 90 h orbital period when it was beyond the disturbing influence of Earth's radiation belts. Spacecraft control and science operations were conducted from ESOC. Science/engineering data returned at 8 kbit/s (no onboard recorder) via 6 W S-band transmitter.

ECS

Achievements: first European regional satellite communications system; far exceeded design lives; accumulated >340 channel-years of communications service by May 2001
Launch dates: ECS-1 16 June 1983; ECS-2 4 August 1984; ECS-3 12 September 1985 (launch failure); ECS-4 16 September 1987; ECS-5 21 July 1988
Mission end: ECS-1 December 1996; ECS-2 November 1993; ECS-3 launch failure; ECS-4 remains operational; ECS-5 May 2000 (7-year design lives)
Launch vehicle/site: Ariane, from Kourou, French Guiana
Launch mass: about 1185 kg (about 700 kg on-station BOL)
Orbit: geostationary; initially/now ECS-1 10/-°E, ECS-2 10/-°E, ECS-4 10/33°E, ECS-5 16/-°E
Principal contractors: British Aerospace (prime) heading MESH consortium

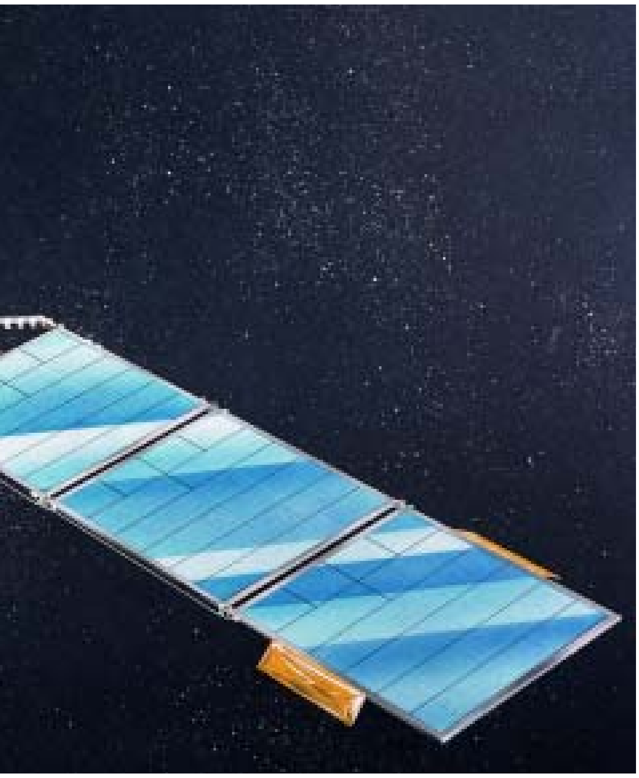
The success of ESA's first communications satellite programme, OTS, led directly to the development of the European Communications Satellite (ECS) and the creation of the European Telecommunications Satellite Organization, (Eutelsat) in 1977 as an inter-governmental entity to operate Europe's first regional satellite system on behalf of, by 2001, 48 member states (Eutelsat was expected to be privatised in mid-2001). Under a 10-year agreement, ESA provided the first-generation space segment for Eutelsat, which became the owner and manager of each satellite after in-orbit testing. The last was handed over in 1988, operating for almost 12 years.

Apart from the Ariane launch loss of ECS-3, the satellites proved remarkably successful and served well beyond their 7-year design goals. Each operated up to nine Ku-band transponders working simultaneously through five beams around Europe, with an equivalent capacity of 12 000 telephone circuits or 10 TV channels. They provided all types of telecommunications and audiovisual services, such as telephony, European Broadcasting Union TV and radio distribution, business TV and communications, satellite newsgathering and, since 1991, the Euteltracs two-way messaging and position-reporting service for small mobile terminals. The antenna module generated three adjacent spot beams for the telecommunications services, a lower-intensity broad 'Eurobeam' and (after ECS-3) the Satellite Multiservice System (SMS) beam dedicated to business data transmissions.

ECS-1 was handed over to Eutelsat by ESA on 12 October 1983 to begin

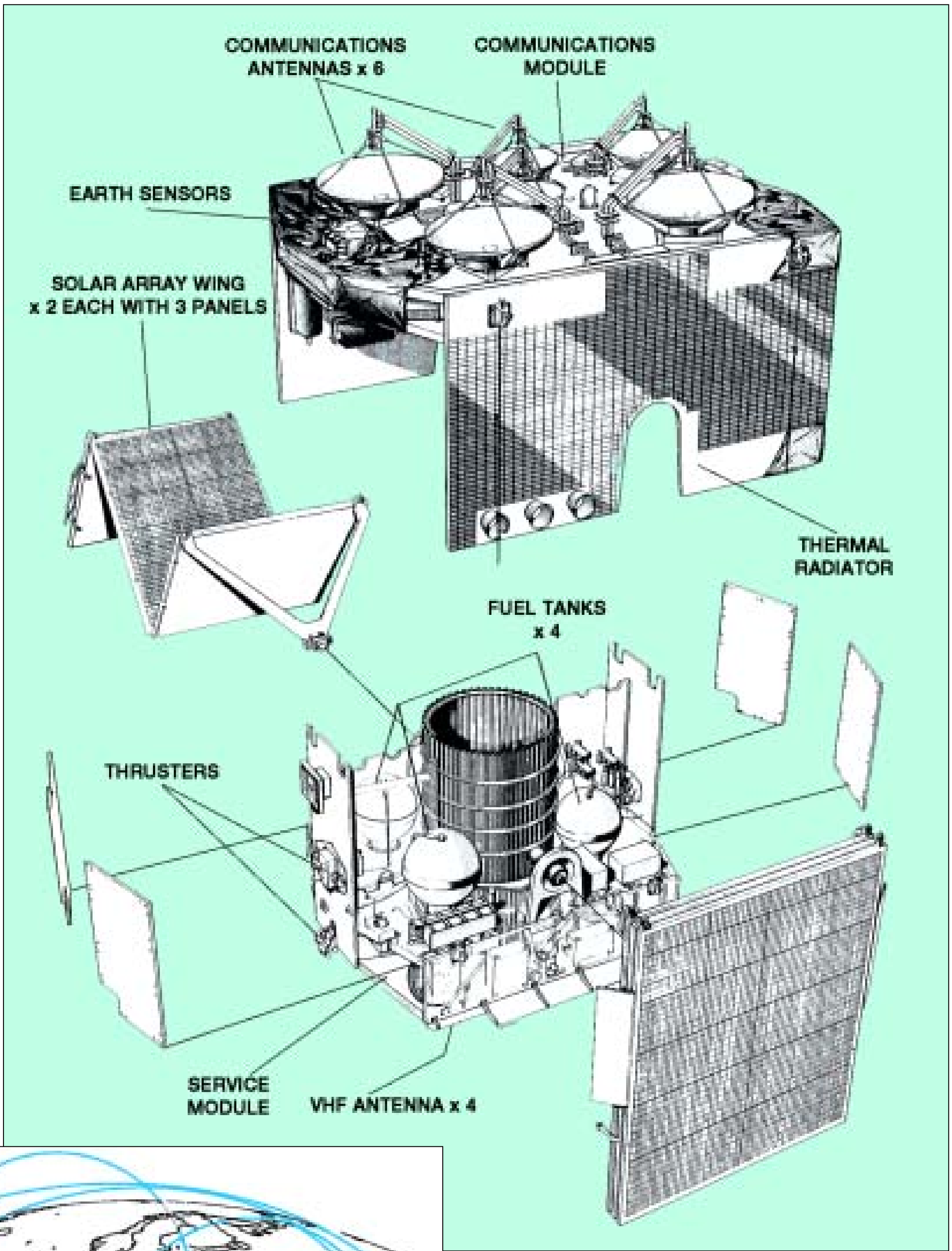
ECS-1 undergoing solar array deployment tests at Matra.

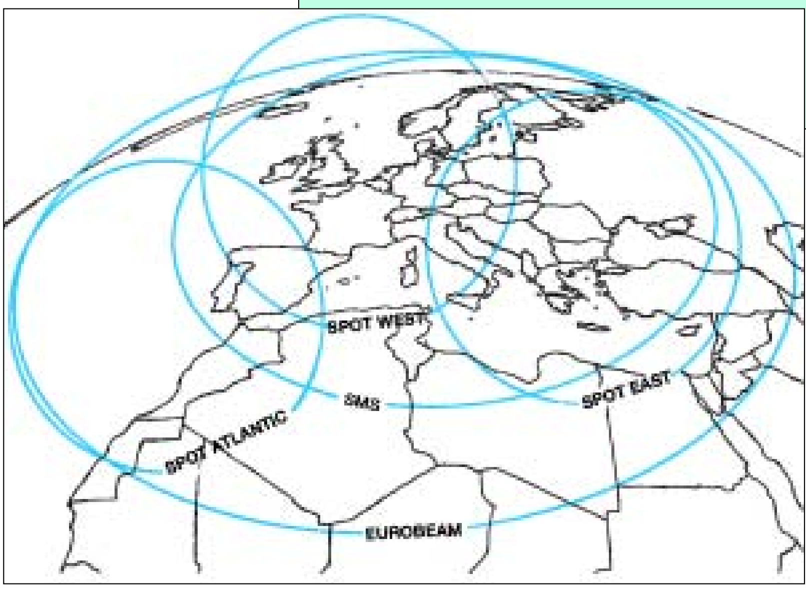
Europe's new phase of satellite-based communications. It served at a number of GEO positions and, after the Eutelsat-procured second generation was well established, it was moved to 48°E in December 1993 to provide services to the newly-independent ex-Soviet countries. It retired in December 1996 at 36°E – almost doubling its design life and having accumulated 710 562 channel-hours of communications service (ECS-2 634 576; ECS-4 882 162 as of 3 May 2001; ECS-5 779 727).



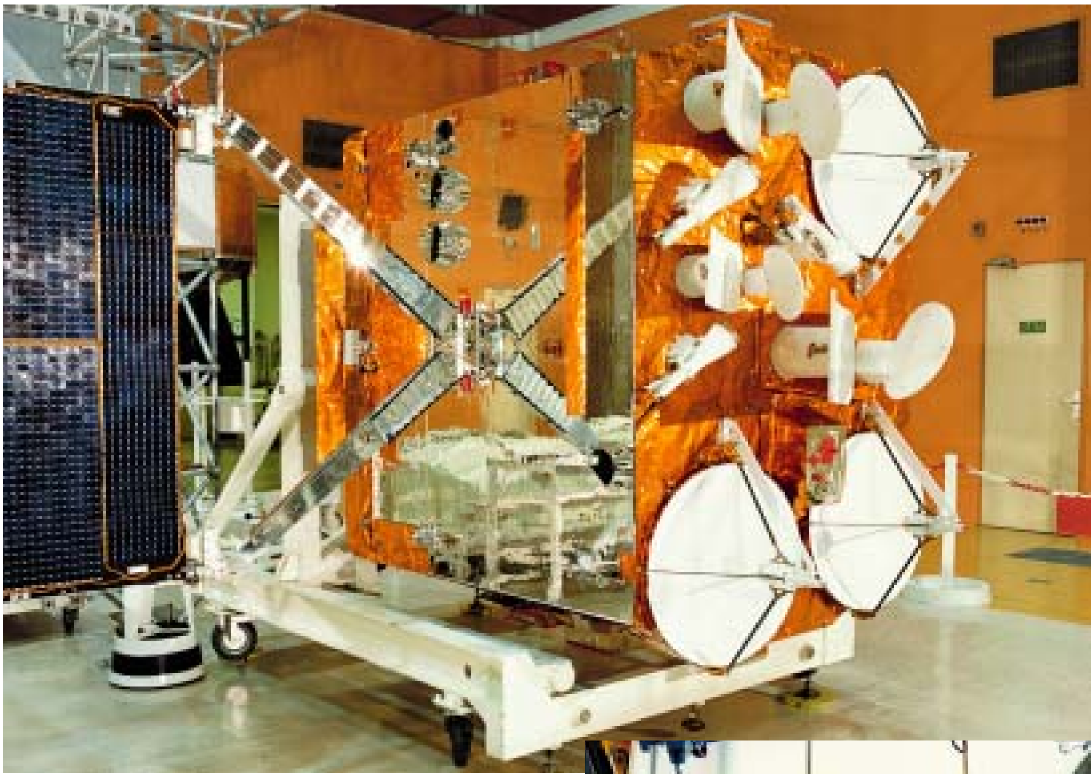
Successor satellites added SMS to provide companies with a European network of dedicated links for 2.4-2000 kbit/s data transmission, video conferencing, facsimile and remote printing. ECS-2 retired from service at 1°E on 13 September 1993 and was boosted by its hydrazine thrusters 400 km above GEO in November 1993, the first Eutelsat retirement. ECS-5 was last used at 12°W (arriving March 1999) for Internet traffic between Canada & Turkey, with two transponders available. In March 2000, it arrived at 4°E, from where it was retired in May 2000.

Despite Eutelsat completing its second-generation network of six satellites and beginning its third, ECS-4 is still operational, held at 33°E with its four usable transponders leased until mid-2002 to a state communications agency in Georgia for Internet links. Until 2000, it was at 25.5°E for Euteltracs, TV and news gathering. ESA continues to control ECS-4 from its ground station site at Redu (B). Of the 54 TWTAs reaching orbit aboard four satellites, it is remarkable that four remain usable.





ECS-1 provided services to Europe and north Africa via three spot beams and a single Eurobeam. Its successors added the Satellite Multiservice System for business users.



ECS-2 and subsequent satellites reconfigured the antenna platform, adding the Satellite Multiservice System for business data transmissions.

ECS-1 ready for launch. The black Sylda canister carried a second satellite. (CSG/Arianespace)

Satellite configuration: 1.91 m-length, 1.46 m-width, 1.42 m-height (1.95 m with antennas) hexagonal bus, derived from OTS, using service and communications modules of aluminium construction. Built around central cylindrical thrust cone housing apogee boost motor. Span across solar array 13.8 m.

Attitude/orbit control: 3-axis control by two momentum wheels + one reaction wheel, and 8x2 N + 12x0.5 N thrusters (4 yaw backup on later models) drawing on 117-122 kg hydrazine in four spheres. Injection into GEO by solid-propellant apogee boost motor.

Power system: two 1.3x5.2 m 3-panel wings of Si cells generated 1.26 kW BOL. 2x24 Ah NiCd batteries provided power during eclipses.

Communications payload: 9 of 14 (ECS-1 9 of 12) 20 W Ku-band (10.95-11.2/11.45-11.7 GHz) TWTAs active simultaneously providing three spot beams (EIRP 46 dBw), one Eurobeam (41 dBw) and (after ECS-1) SMS 12.5-12.75 GHz beam (43.5 dBw).