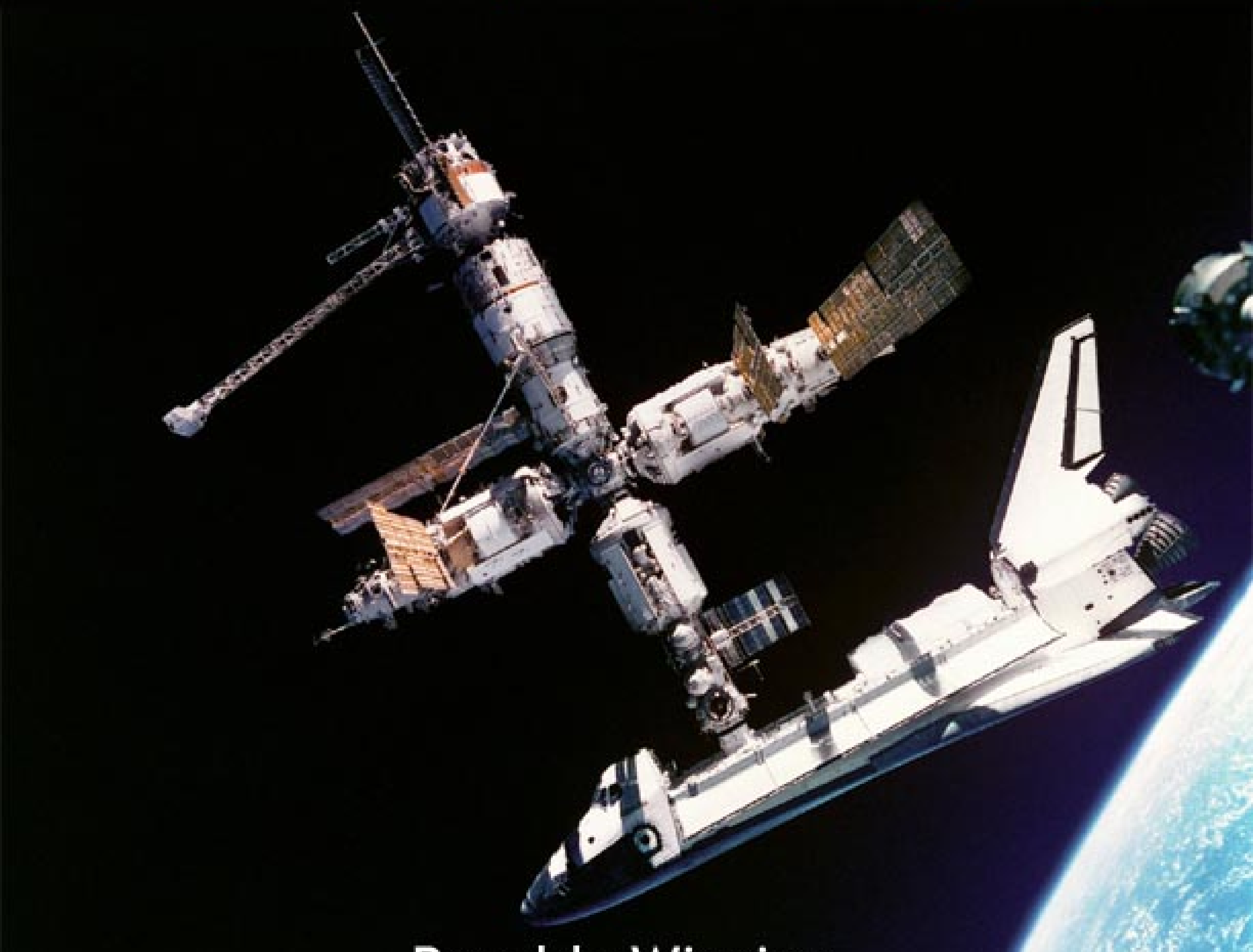
Space Probes and Missions of the European Space Agency



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Chapter- 1

Cluster (Spacecraft)

The **Cluster mission** is a European Space Agency/NASA unmanned space mission to study the Earth's magnetosphere using four identical spacecraft flying in a tetrahedral formation. The first four Cluster spacecraft were lost in the Ariane 5 flight failure on June 4, 1996, leading to the construction of four new spacecraft and their successful launching in 2000 on Soyuz-Fregat rockets. Cluster operated alongside China National Space Administration/ESA's joint Double Star mission from 2003 to 2007.

Cluster mission overview

The four identical Cluster satellites study the impact of the Sun's activity on the Earth's space environment by flying in formation around Earth. For the first time in space history, this mission is able to collect three-dimensional information on how the solar wind interacts with the magnetosphere and affects near-Earth space and its atmosphere, including aurorae. The satellites are named Rumba Salsa, Samba and Tango but are more commonly called Cluster 1, Cluster 2, Cluster 3 and Cluster 4 or even C1, C2, C3 and C4.

The spacecraft are cylindrical and are spin-stabilized at 15 rotations per minute. After launch, their solar cells provided 224 watts power for instruments and communications. The four spacecraft maneuver into various tetrahedral formations to study the magnetospheric structure and boundaries. The inter-spacecraft distances can be varied from around 17 to 10,000 kilometers (km). The propellant for the maneuvers makes up approximately half of the spacecraft's launch weight.

The highly elliptical orbits of the spacecraft reach a perigee of around 4 R_E (Earth radii, where 1 R_E = 6371 km) and an apogee of 19.6 R_E. Each orbit takes approximately 57 hours to complete. The European Space Operations Centre (ESOC) acquires telemetry and distributes the science data from the spacecraft online.

History

The Cluster mission was proposed to ESA in 1982 and approved in 1986, along with the Solar and Heliospheric Observatory (SOHO). Though the original Cluster spacecraft were completed in 1995, the explosion of the rocket carrying the satellites in 1996 delayed the mission by four years while the instruments were rebuilt.

On July 16, 2000, a Soyuz-Fregat rocket from the Baikonur Cosmodrome launched two of the Clusters (Salsa and Samba) into a parking orbit from where they maneuvered under their own power into a 19,000 by 119,000 kilometer orbit with a period of 57 hours. Three weeks later on August 9, 2000 another Soyuz-Fregat rocket lifted the remaining two Cluster spacecraft (Rumba and Tango) into similar orbits. Spacecraft 1, Rumba, is also known as the Phoenix spacecraft, since it is largely built from spare parts left over after the failure of the original mission. After commissioning of the payload, the first scientific measurements were made on February 1, 2001.

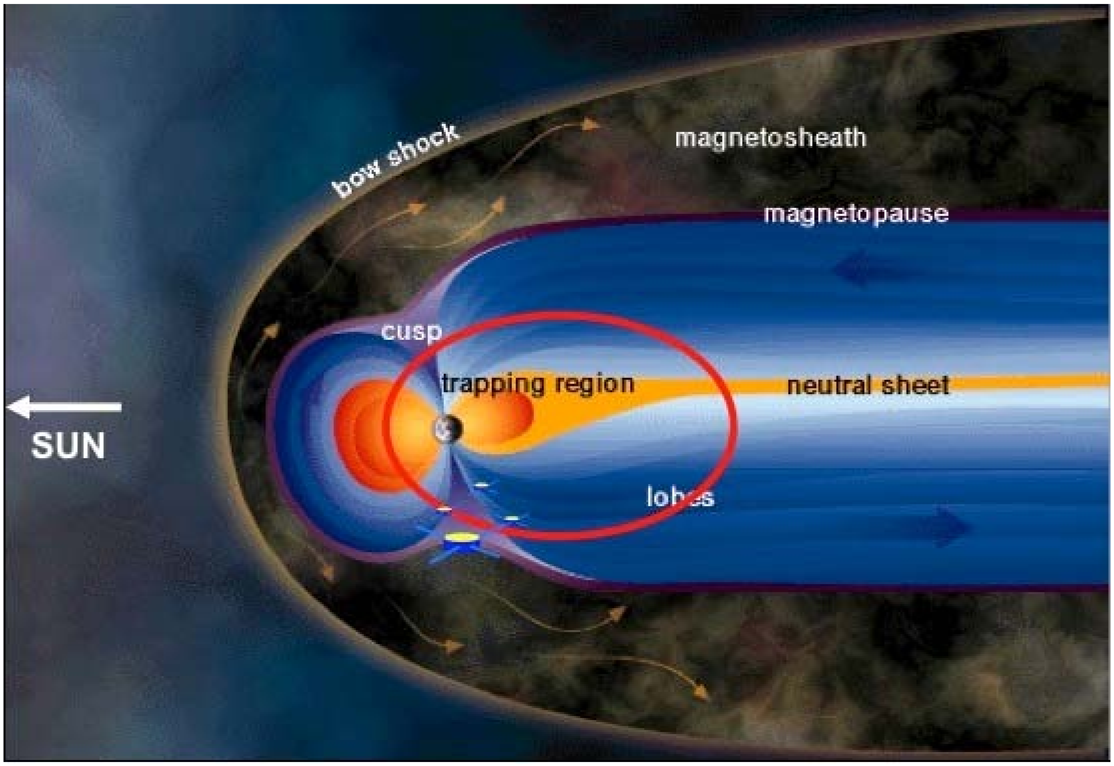
The ESA ran a competition to name the Cluster satellites, which attracted participants from many countries. Ray Cotton from the United Kingdom won with the names Rumba, Tango, Salsa and Samba. Ray's town of residence, Bristol, was awarded with scale models of the satellites in recognition of the naming and connection with the satellites.

Originally planned to last until the end of 2003, the mission has been extended several times. The first extension took the mission from 2004 until 2005, and the second from 2005 to June 2009. The mission has now been extended until end 2012.

Scientific objectives

Previous single and two-spacecraft missions were not capable of providing the data required to accurately study the boundaries of the magnetosphere. Because the plasma comprising the magnetosphere cannot presently be accessed using remote sensing techniques, satellites must be used to measure it in-situ. Four spacecraft allow scientists make the 3D, time-resolved measurements needed to create a realistic picture of the complex plasma interactions occurring between regions of the magnetosphere and between the magnetosphere and the solar wind.

Each satellite carries a scientific payload of 11 instruments designed to study the small-scale plasma structures in space and time in the key plasma regions: the solar wind and bow shock, magnetopause, polar cusps, magnetotail and the auroral zone.



An illustration of the Earth's magnetosphere and the nominal orbit of the Cluster satellites

- The **bow shock** is the region in space between the Earth and the sun where the solar wind decelerates from super- to sub-sonic before being deflected around the Earth. In traversing this region, Cluster makes measurements which help characterize processes occurring at the bow shock, such as the origin of hot flow anomalies and the transmission of electromagnetic waves through the bow shock and the magnetosheath from the solar wind.

- Behind the bow shock is the thin plasma layer separating the Earth and solar wind magnetic fields known as the **magnetopause**. This boundary moves continuously due to the constant variation in solar wind pressure. Since the plasma and magnetic pressures within the solar wind and the magnetosphere, respectively, should be in equilibrium, the magnetosphere should be an impenetrable boundary. However, plasma has been observed crossing the magnetopause into the magnetosphere from the solar wind. Cluster's four-point measurements make it possible to track the motion of the magnetopause as well as elucidate the mechanism for plasma penetration from the solar wind.

- In two regions, one in the northern hemisphere and the other in the south, the magnetic field of the Earth is perpendicular rather than tangential to the magnetopause. These **polar cusps** allow solar wind particles, consisting of ions and electrons, to flow into the magnetosphere. Cluster records the particle distributions, which allow the turbulent regions at the exterior cusps to be characterized.

- The regions of the Earth's magnetic field that are stretched by the solar wind away from the sun are known collectively as the **magnetotail**. Two lobes that reach past the Moon in length form the outer magnetotail while the central plasma sheet forms the inner magnetotail, which is highly active. Cluster monitors particles from the ionosphere and the solar wind as they pass through the magnetotail lobes. In the central plasma sheet, Cluster determines the origins of ion beams and disruptions to the magnetic field-aligned currents caused by substorms.

- The precipitation of charged particles in the atmosphere creates a ring of light emission around the magnetic pole known as the **auroral zone**. Cluster measures the time variations of transient particle flows in the region.

Double Star mission with China

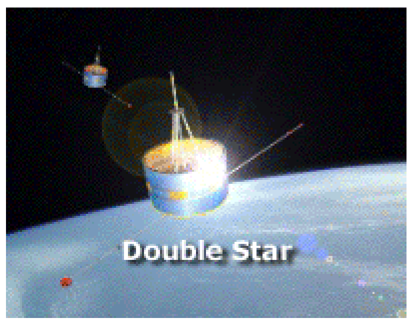


Illustration of a few scientific highlights of the Double Star CNSA/ESA mission

In 2003 and 2004, the China National Space Administration launched the Double Star satellites, TC-1 and TC-2, that worked together with Cluster to make coordinated measurements mostly within the magnetosphere. TC-1 stopped operating on 14 October 2007. Here are three scientific highlights where TC-1 played a crucial role

1. *Space is Fizzy*

Ion density holes were discovered near the Earth's bow shock that can play a role in bow shock formation. The bow shock is a critical region of space where the constant stream of solar material, the solar wind, is decelerated from supersonic speed to subsonic speed due to the internal magnetic field of the Earth.

2. *Inner magnetosphere and energetic particles*

Chorus Emissions Found Further Away From Earth During High Geomagnetic Activity. Chorus are waves naturally generated in space close to the magnetic equator, within the Earth's magnetic bubble called magnetosphere. These waves play an important role in the creation of relativistic electrons and their precipitation from the Earth's radiation belts. These so called killer electrons can damage solar panels and electronic equipments of satellites and represent a hazard to astronauts. Therefore, information on their location with respect to the geomagnetic activity is of crucial importance to be able to forecast their impact.

3. *Magnetotail dynamics*

Cluster and Double Star Reveal the Extent of Neutral Sheet Oscillations. For the first time, neutral sheet oscillations observed simultaneously at a distance of tens of thousands of kilometres are reported, thanks to observations by 5 satellites of the Cluster and the Double Star Program missions. This observational first provides further constraint to model this large-scale phenomenon in the magnetotail.

Instrumentation

Details of the 11 instruments aboard each of the four Cluster spacecraft are provided in the table below. Briefly, the instruments are dedicated to measuring the electric (**E**) and magnetic (**B**) field magnitudes and directions and the densities and distributions of particles (electrons and ions) in the plasma.

Number	Acronym	Instrument	Measurement	Purpose
1	FGM	Fluxgate Magnetometer	Magnetic field **B** magnitude and direction	**B** vector and event trigger to all instruments except ASPOC
2	EFW	Electric Field and Wave experiment	Electric field **E** magnitude and direction	**E** vector, spacecraft potential, electron density and temperature
3	STAFF	Spatio-Temporal Analysis of Field Fluctuation experiment	Magnetic field **B** magnitude and direction of EM fluctuations, cross-correlation of **E** and **B**	Properties of small-scale current structures, source of plasma waves and turbulence
4	WHISPER	Waves of High Frequency and Sounder for Probing of Density by Relaxation	In active mode, total electron density ρ; in passive mode, neutral plasma waves	Plasma density ρ measurements unaffected by fluctuations in spacecraft potential
5	WBD	Wide Band Data receiver	Electric field **E** waveforms and spectrograms of terrestrial plasma waves and radio emissions	Motion of terrestrial fluctuations, e.g. auroral kilometric radiation
6	DWP	Digital Wave	Data manipulation	Control over and

		Processing instrument		communication between instruments 2-5 to yield particle correlations
7	EDI	Electron Drift Instrument	Electric field **E** magnitude and direction	**E** vector, gradients in local magnetic field **B**
8	ASPOC	Active Spacecraft Potential Control experiment	Regulation of spacecraft's electrostatic potential	Control over and communication between instruments 2-5 and 10
9	CIS	Cluster Ion Spectroscopy experiment	Ion times-of-flight (TOFs) and energies from 0 to 40 keV	Composition and 3D distribution of ions in plasma
10	PEACE	Plasma Electron and Current Experiment	Electron energies from 0.0007 to 30 keV	3D distribution of electrons in plasma
11	RAPID	Research with Adaptive Particle Imaging Detectors	Electron energies from 30 to 1500 keV, ion energies from 20 to 450 keV	3D distributions of high-energy electrons and ions in plasma

Chapter- 2

BepiColombo

BepiColombo	
Operator	European Space Agency, Japan Aerospace Exploration Agency
Major contractors	EADS Astrium is Prime-Contractor for ESA modules.
Mission type	Orbiter
Flyby of	Moon, Earth, Venus, and Mercury
Satellite of	**Mercury**
Orbital insertion date	2020
Launch date	2014
Launch vehicle	Ariane 5
COSPAR ID	BEPICLMBO
Homepage	ESA JAXA ISAS
Power	5.5 kW available at 1 AU
Orbital elements	
Apoapsis	1508 km (MPO) and 12000 km (MMO)
Periapsis	400 km (MPO) and 400 km (MMO)
Orbital period	2.3 h (MPO) and 9.2 h (MMO)

BepiColombo is a joint mission of the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA) to the planet Mercury, due to launch in 2014. The mission is still in the planning stages so changes to the current description are likely over the next few years. Due to budgetary constraints and technological difficulties, the lander portion of the mission, the Mercury Surface Element (MSE) was cancelled.

Mission

The mission as currently envisioned involves three components: the Mercury Transfer Module (MTM) built by ESA, the Mercury Planetary Orbiter (MPO) built by ESA and the Mercury Magnetospheric Orbiter (MMO) built by JAXA (whose sunshield (MOSIF) will be built by ESA). The prime contractor for ESA is EADS Astrium. The three components are planned to be launched together on a Ariane 5 launch vehicle in 2014. The spacecraft will have a six year interplanetary cruise to Mercury using solar-electric propulsion and gravity assists from the Moon, Earth, Venus and eventual gravity capture at Mercury.

Arriving in Mercury orbit in August 2020, the spacecraft will have a 1-year nominal scientific life. The MPO will be equipped with eleven scientific instruments provided by various European countries including visible imagers, a laser altimeter and an imaging X-ray spectrometer. Russia will provide a gamma ray and neutron spectrometer. It will attempt to map the entire surface in several different wavelengths, and to find water ice in polar craters which are permanently in shadow from the Sun's rays.

One of the goals of the mission is testing general relativity measuring the parameters gamma and beta of the Parameterized post-Newtonian formalism with a high accuracy.

Mercury Transfer Module

The Mercury Transfer Module is at the base of the 'stack' and provides propulsion to escape Earth and to approach Mercury. It carries no significant scientific instruments.

Mercury Planetary Orbiter (MPO)

The Mercury Planetary Orbiter will be a 357 kg spacecraft in the shape of a flat prism with three short sides slanted at 20 degrees covered with solar cells providing 420 W at perihelion. A radiator with an area of 1.5 square meters is mounted on one side to provide thermal control. The radiator is always pointed away from the Sun and is protected from planetary IR with a 3.4 square meter shield. High efficiency insulation is also used. A 1.5 m diameter high gain antenna is mounted on a short boom on the zenith side of the spacecraft. The MPO will be 3-axis stabilized and nadir pointing with a planned lifetime of over 1 year in Mercury orbit. Communications will be on the X/Ka band with an average bit rate of 50 kbit/s and a total data volume of 1550 Gb/year. A UHF dipole antenna mounted on the nadir side will be used for possible communications with the MSE. Navigation knowledge is provided by 3 star sensors.

The MPO will carry an imaging system consisting of a wide-angle and narrow angle camera, an infrared spectrometer, an ultraviolet spectrometer, gamm, X-ray, and neutron spectrometers, a laser altimeter, an ion and neutral spectrometer, a Near Earth Object telescope and detection system, and radio science experiments.

ESA has selected Astrium as the prime contractor for the construction of the MPO.

Mercury Magnetospheric Orbiter (MMO)

The Mercury Magnetospheric Orbiter has the shape of a flat cylinder with a mass of 250 kg including Nitrogen gas for attitude control (551.16 lb). The MMO is spin stabilized at 15 rpm with the spin axis perpendicular to the equator of Mercury. The top and bottom of the cylinder act as radiators with louvers for active temperature control. The side is covered with solar cells which provide 185 W and second surface mirrors and protected by thermal blankets. Communications with Earth are maintained through a despun 1-meter diameter high-gain offset antenna and two medium-gain antennas operating in the X-band. Telemetry will return 160 Gb of data per year at about 5 kbit/s over the lifetime of the craft, which is expected to be greater than one year. A microstrip UHF patch antenna will be used for communication with the MSE. The reaction and control system is based on cold gas thrusters. Deployable booms and wire antennas are stowed until orbit is achieved. The MMO will carry a set of fluxgate magnetometers, charged particle detectors, a wave receiver, a positive ion emitter, and an imaging system.

Mercury Surface Element (MSE)

The Mercury Surface Element has been cancelled due to budgetary constraints.

At the time of cancellation, MSE was meant to be a small (44 kg) lander designed to operate for about one week on the surface of Mercury. Shaped as a 0.9 m diameter disc, it was designed to land at a latitude of 85 degrees near the terminator region. Following the release of the MMO, a burn of the 4 kN thruster would put the MSE into a 10 km orbit. Another braking maneuver controlled by gyros/accelerometers and an optical range/range-rate sensor would bring the MSE to zero velocity at an altitude of 120 meters at which point the propulsion unit would be ejected, the airbags inflated, and the module would fall to the surface with a maximum impact velocity of 30 m/s. If the landing occurs in sunlight a thermal protection cover would deploy. Since 40% of the terrain at the landing point would be in shadow, primary power would be supplied by a 1.7 kWh battery. Scientific data would be stored onboard and relayed via a cross-dipole UHF antenna to either the MPO or MMO at a data rate of 8.7 kbit/s, providing for a total of 75 Mb over 7 days, assuming 18 contact periods of 480 seconds each. The MSE would carry a 7 kg payload consisting of an imaging system (a descent camera and a surface camera), a heat flow and physical properties package, an alpha particle X-ray spectrometer, a magnetometer, a seismometer, a soil penetrating device (mole), and a micro-rover.

Propulsion

The MTM (Mercury Transfer Module) will utilise two propulsion systems. A standard CPS (Chemical Propulsion System) which is bipropellant using MMH/MON3. The CPS will be utilised for Earth escape and the Lunar fly-by. Post-Lunar escape the CPS will be pyrotechnically isolated and function in blowdown mode for the cruise. The spacecraft will be propelled in cruise by a form of ion drive dubbed solar electric propulsion, which has a very high specific impulse and very low thrust. Unlike a chemical rocket which fires for a few seconds, it will keep propelling the craft for years, building up far more speed per mass of fuel in the long run. This will be the ESA's first mission outside the Earth-Moon system using such a form of propulsion. BepiColombo is also the largest solar electric mission so far planned.

This drive will be tested by the unusual need to actually push against the direction of travel, instead of with it; the ship will be falling toward the sun, accelerated by its gravity, and will have to constantly fight to keep its velocity slow enough to eventually enter Mercury's orbit.

Namesake

BepiColombo is named for Giuseppe (Bepi) Colombo (1920–1984), scientist, mathematician and engineer at the University of Padua, Italy, who developed the gravity-assist maneuver commonly used by planetary probes today. He helped NASA to devise the trajectory of Mariner 10, the only spacecraft to encounter Mercury during the twentieth century, exploiting this maneuver for the first time around Venus.

Chapter- 3

Darwin (Spacecraft)

Darwin	
General information	
Organization	European Space Agency (ESA)
Launched from	Guiana Space Centre French Guiana
Launch vehicle	Soyuz-2/Fregat
Orbit height	1.5 million km L_2

Darwin was a suggested ESA Cornerstone mission which would have involved a constellation of four to nine spacecraft designed to directly detect Earth-like planets orbiting nearby stars and search for evidence of life on these planets. The most recent design envisaged three free-flying space telescopes, each three to four meters in diameter, flying in formation as an astronomical interferometer. These telescopes were to redirect light from distant stars and planets to a fourth spacecraft, which would have contained the beam combiner, spectrometers, and cameras for the interferometer array, and which would have also acted as a communications hub. There was also an earlier design, called the "Robin Laurance configuration," which included six 1.5 meter telescopes, a beam combiner spacecraft, and a separate power and communications spacecraft.

The study of this proposed mission ended in 2007 with no further activities planned. To produce an image, the telescopes would have had to operate in formation with distances between the telescopes controlled to within a few micrometres, and the distance between the telescopes and receiver controlled to within about one nanometer. Several more detailed studies would have been needed to determine whether technology capable of such precision is actually feasible.

Concept

The space telescopes were to observe in the infrared part of the electromagnetic spectrum. As well as studying extrasolar planets, the telescopes would probably have been useful for general purpose imaging, producing very high resolution (i.e. milliarcsecond) infrared images, allowing detailed study of a variety of astrophysical processes.

The infrared region was chosen because in the visible spectrum an Earth-like planet is outshone by its star by a factor of a billion. However, in the infrared, the difference is less by a few orders of magnitude. According to a 2000 ESA bulletin, all spacecraft components in the optical path would have to be passively cooled to 40 Kelvin to allow infrared observations to take place.

The planet search would have used a nulling interferometer configuration. In this system, phase shifts would be introduced into the three beams, so that light from the central star would suffer destructive interference and cancel itself out. However, light from any orbiting planets would not cancel out, as the planets are offset slightly from the star's position. This would allow planets to be detected, despite the much brighter signal from the star.

For planet detection, the telescopes would operate in an imaging mode. The detection of an Earth-like planet would require about 10 hours of observation in total, spread out over several months. A 2002 design which would have used 1.5 meter mirrors was expected to take about 100 hours to get a spectrum of a possibly Earth-like planet.

After the Darwin spacecraft detected a planet, a more detailed study of its atmosphere would have been made by taking an infrared spectrum of the planet. By analyzing this spectrum, the chemistry of the atmosphere could be determined, and this could provide evidence for life on the planet. The presence of oxygen and water vapor in the atmosphere could be evidence for life. Oxygen is very reactive so if large amounts of oxygen exist in a planet's atmosphere some process such as photosynthesis must be continuously producing it.

The presence of oxygen alone, however, is not conclusive evidence for life. Jupiter's moon Europa, for example, has a tenuous oxygen atmosphere thought to be produced by radiolysis of water molecules. Numerical simulations have shown that under proper conditions it is possible to build up an oxygen atmosphere via photolysis of carbon dioxide. Photolysis of water vapor and carbon dioxide produces hydroxyl ions and atomic oxygen, respectively, and these in turn produce oxygen in small concentrations, with hydrogen escaping into space. When O_2 is produced by H_2O photolysis at high altitude, hydrogenous compounds like H^+, OH^- and H_2O are produced which attack very efficiently O_3 and prevent its accumulation. The only known way to have a significant amount of O_3 in the atmosphere is that O_2 be produced at low altitude, e.g. by biological photosynthesis, and that little H_2O gets to high altitudes where UV are present. For terrestrial planets, the simultaneous presence of O_3 , H_2O and CO_2 in the atmosphere appears to be a reliable biosignature, and the Darwin spacecraft would have been capable of detecting these atmospheric components.

Candidate planets

Planet Gliese 581 d, discovered in 2007, was considered a good candidate for the Darwin project. It orbits within the theoretical habitable zone of its star, and scientists surmise that conditions on the planet may be conducive to supporting life.

Similar initiatives

Currently awaiting funding approval, the interferometric version of NASA's Terrestrial Planet Finder mission is similar in concept to Darwin and also has very similar scientific aims. According to NASA's 2007 budget documentation, released on February 6, 2006, the project was deferred indefinitely. Antoine Labeyrie has proposed a much larger space-based astronomical interferometer similar to Darwin, but with the individual telescopes positioned in a spherical arrangement and with an emphasis on interferometric imaging. The spherical geometry reduces the amount of pathlength compensation required in re-pointing the interferometer array. This "Hypertelescope" project would be much more expensive and complex than the Darwin and TPF missions, involving many large free-flying spacecraft.

Chapter- 4

Don Quijote (Spacecraft)

Don Quixote

Operator	European Space Agency
Bus	Modified SMART-1
Mission type	Orbiter, Impactor, and Lander
Flyby of	2003 SM_{84} or 99942 Apophis
Launch date	2013 or 2015

Mass

	Orbiter (kg)	Impactor (kg)
Dry	395	532
Payload	20.6	9
Propellant	96	1162
Wet	491	1694

Don Quijote is a proposed space probe under development by the European Space Agency, which would study the effects of crashing a spacecraft into an asteroid. The mission is intended to test whether a spacecraft could successfully deflect an asteroid on a collision course with Earth. The orbiter is being designed to last for seven years.

The mission is still in the planning stages with launch dates proposed for 2013 or 2015.

Overview

The mission will consist of two spacecraft that will execute a series of maneuvers around a small, 500-metre (1,600-foot) asteroid.

- The first spacecraft, Sancho, will arrive at the asteroid and orbit it for several months, studying it. The orbiter will use a single xenon ion engine.
- After a few months, the second spacecraft, Hidalgo, will hurtle toward the asteroid on a collision course. Sancho will retreat to a safe distance while Hidalgo will hit the asteroid at around 10 km/s. The Lander will sleep for most of the trip and then steer itself using optical sensors with an accuracy of 50 meters.
- Sancho will then return to its close orbit and see how much the asteroid's shape, internal structure, orbit and rotation have been affected by the impact.
- Sancho will release the Autonomous Surface Package, which will free-fall toward the asteroid for 2 hours before landing. This package will be directed towards the interior of the impact crater where it will investigate properties of the surface.

Propulsion

The craft would be launched by a Vega launcher and a Star 48 upper stage. The ESA is currently considering two design scenarios: the "Cheap Option" using a chemical propulsion system and the "Flexible Option" using an electric propulsion system. The former would be targeted to the Amor asteroid 2003 SM84, the latter to the asteroid 99942 Apophis.

Instrumentation

Sancho (orbiter)

The instruments on the orbiter are classified into those essential to the success of the mission and those for the completion of extended mission objectives. The primary instruments are the Radio Science Experiment, Orbiter Camera, Imaging Laser Altimeter, and a LIDAR instrument. For the extended mission objectives, the orbiter carries an IR Spectrometer, a Thermal IR Imager, an X-Ray Spectrometer, and a Radiation Monitor.

Hidalgo (impactor)

Unlike many other spacecraft, the goal of the Hidalgo impactor is to be as massive as possible upon reaching the target asteroid; because of this goal, the propulsion module is not jettisoned after use. The impactor carries few subsystems to make it as low-cost and maneuverable as possible. It has no moving appendages (solar panels, etc.) to complicate orientation, it uses only its RCS thrusters for course corrections, and it has a high resolution targeting camera for ~50 m targeting accuracy on impact. The LISA Pathfinder design was considered at as an initial design reference.

Target

Originally, the ESA identified two near-Earth asteroids as possible targets: 2002 AT_4 and (10302) 1989 ML. Neither asteroid represents a threat to Earth. In a subsequent study, two different possibilities were selected: the Amor asteroid 2003 SM84 and 99942 Apophis; the latter is of particular significance to Earth as it will make a close approach in 2029 and 2036.

Names

The mission is named after the fictional Spanish knight from Miguel de Cervantes renowned novel, Don Quixote, who charged against a windmill, thinking it to be a giant. Like the Don, the Hidalgo spacecraft will 'attack' an object much larger than itself, hopefully with more impressive results. 'Sancho' is named after Sancho Panza, the Don's squire, who preferred to stay back and watch from a safe distance, which is the role assigned to that probe.

Chapter- 5

ExoMars

ExoMars	
Operator	ESA, NASA
Major contractors	Thales Alenia Space
Mission type	Orbiter, lander and 2 rovers
Orbital insertion date	2017 and 2019
Launch date	2016 and 2018 from Florida, USA
Launch vehicle	Two Atlas V rockets.
Mission duration	Few days for the static lander; 6 months for the ExoMars rover, one year for the MAX-C rover.
Homepage	ExoMars programme
Mass	TGM: 3,130 kg; Lander: 600 kg; ExoMars rover: 270 kg; MAX-C rover: 65 kg.
Power	Solar power

ExoMars (**Exo**biology on **Mars**) is a European-led robotic mission to Mars currently under development by the European Space Agency (ESA) and NASA. Originally conceived as a rover with a static ground station, ExoMars was planned to launch in 2011 aboard a Soyuz Fregat rocket. Within the framework of the new Mars Joint Exploration Initiative signed by NASA and ESA in July 2009, the drastically delayed ExoMars mission was combined with other projects to a multi-spacecraft programme divided over two Atlas V-launches: the Mars Trace Gas Orbiter (TGM) was merged into the project, piggybacking a static meteorological lander being slated for launch in 2016. In 2018 the original robotic ESA rover will be launched together with a smaller NASA rover called Mars Astrobiology Explorer-Cacher (MAX-C).

Background and mission history

An outdated ExoMars rover model at the ILA 2006 in Berlin

Another outdated representation of the rover from the Paris Air Show 2007

Since its beginnings in the early 2000s, ExoMars was subject to massive political and financial strife. Originally, the ExoMars concept consisted of one single, large robotic rover being part of ESA's Aurora programme as a *Flagship mission* and was approved by Europe's space ministers in December 2005. Initially planned to launch in 2011, Italy, a leading nation on the ExoMars mission, decided to limit its financial contribution, causing the first of three delays.

In 2007 Canadian-based technology firm MacDonald, Dettwiler and Associates Ltd. (MDA) was selected for a one-million-euro contract with EADS Astrium of Britain to design and build a prototype Mars rover chassis for the European Space Agency. Astrium was also contracted to design the final rover.

In July 2009 NASA and ESA signed the Mars Joint Exploration Initiative, which significantly altered the technical and financial setting of the ExoMars mission. On June 19, when the rover was still planned to piggyback on the Mars Trace Gas Orbiter, it was reported that a prospective agreement would require that ExoMars lose enough weight to fit aboard the Atlas vehicle with NASA's orbiter.

In August 2009 it was announced that the Russian Space Agency Roscosmos and ESA had signed a collaboration agreement that includes cooperation on two Mars exploration projects: Russia's Phobos-Grunt project and ESA's ExoMars. Specifically, ESA secured a Russian Proton rocket as a backup launcher for the ExoMars rover, which should also include Russian-made parts.

In October 2009 it was reported that under the agreed Mars Joint Exploration Initiative, the project will consist on two separate launches: a lander/orbiter mission in 2016 and a rover mission in 2018, each with a significant NASA role, including the use of two Atlas

V rockets. This initiative would apparently reconcile technological and science goals with available budgets.

On December 17, 2009, the ESA governments gave their final approval to a two-part Mars exploration programme to be conducted with NASA, confirming their commitment to spend €850 million ($1.23 billion) on missions in 2016 and 2018. Another €150 million needed for operating the mission will be solicited during a meeting of ESA government ministers in late 2011 or early 2012. Unlike some ESA programmes, the ExoMars financing will not include a 20 % margin for cost overruns, however.

Mission objectives

The ExoMars mission's scientific objectives, in order of priority, are:

- to search for possible biosignatures of Martian life, past or present.
- to characterise the water and geochemical distribution as a function of depth in the shallow subsurface.
- to study the surface environment and identify hazards to future manned missions to Mars.
- to investigate the planet's subsurface and deep interior to better understand the evolution and habitability of Mars.
- achieve incremental steps ultimately culminating in a sample return flight.

The technological objectives to develop are:

- landing of large payloads on Mars.
- to exploit solar electric power on the surface of Mars.
- to access the subsurface with a drill able to collect samples down to a depth of two metres (just below the degradating reach of UV light, oxidants and ionizing radiation.)
- to develop surface exploration capability using a rover.

Mission architecture

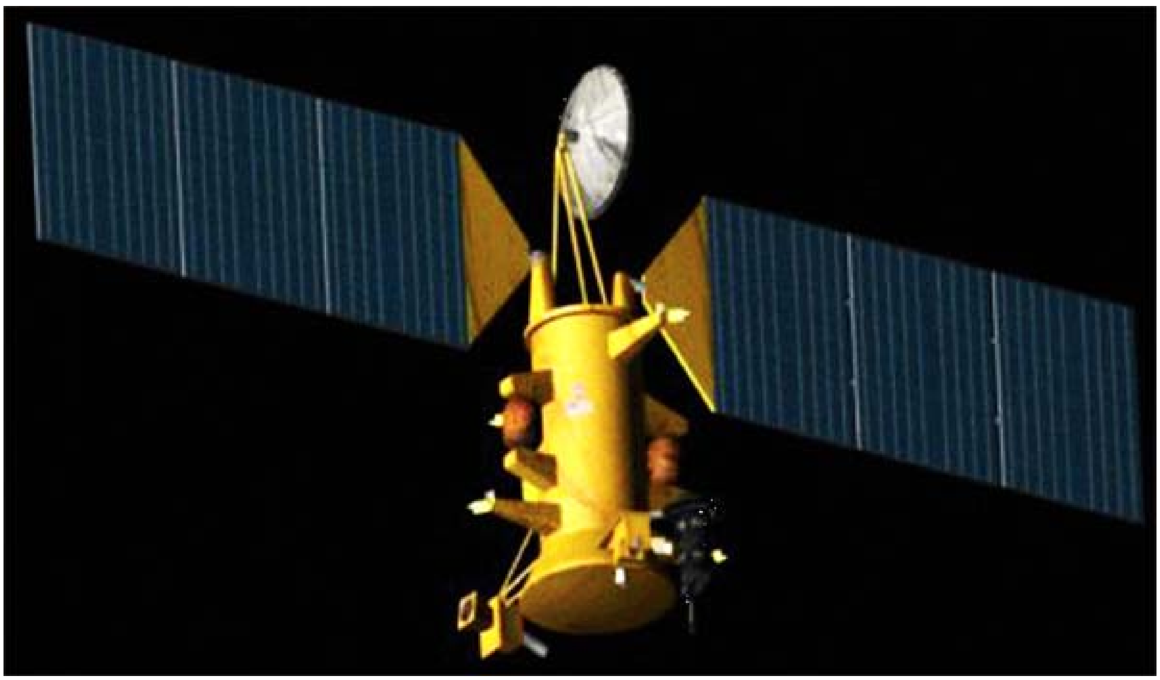
According to current plans, the ExoMars mission will comprise three, possibly four, spacecraft elements sent in two launches, both from Florida:

Contributing agency	First launch in 2016	Second launch in 2018
NASA	Launch vehicle: Atlas V 411	Launch vehicle: Atlas V 551
	One unspecified TGM-payload	Landing system: Sky-crane
		65 kg Mars Astrobiology Explorer-Cacher (MAX-C) rover

	Trace Gas Mission (TGM) orbiter	270 kg ExoMars rover
	600 kg static meteorological lander	
	Entry, descent and landing system (EDL)	

2016 launch

Mars Trace Gas Mission orbiter



The Mars Trace Gas Orbiter.

The Mars Trace Gas Mission (TGM) orbiter, to be launched on January 2016, will deliver the ExoMars static lander (a meteorological station) and then proceed to map the sources of methane on Mars and other gases, and in doing so, help select the landing site for the ExoMars rover to be launched on 2018. The presence of methane in Mars' atmosphere is intriguing because its likely origin is either present-day life or geological activity. Upon the arrival of the rover(s) in 2018/2019, the orbiter would be transferred into a suitable lower orbit where it would be able to perform analytical science activities as well as operate as a data-relay satellite. Its operation may be extended to serve future missions well into the 2020s.

Static lander

Originally, this static lander was planned to carry a group of eleven instruments collectively called the "Humboldt payload" that would be dedicated to investigate the geophysics of the deep interior, but a payload confirmation review in the first quarter of 2009 resulted in a severe descope of the lander instruments, and the Humboldt geophysical suite of lander instruments was cancelled entirely. Although the recent partnership with NASA and the decision to launch all mission elements with two rockets has generated new payload reviews, it was decided to first demonstrate ESA's new descent and landing system technology on the lander, so its payload will be very limited.

The Entry, Descent and Landing Demonstrator Module (EDM) will provide Europe with the technology for landing on the surface of Mars with a controlled landing orientation and touchdown velocity. After entering the Martian atmosphere, the module will deploy a parachute and will complete its landing by using a closed-loop Guidance, Navigation and Control system based on a Radar Doppler Altimeter sensor and on-board Inertial Measurement Units. The latter will guide a liquid propulsion system which will produce a semi-soft touchdown on the surface of Mars by the actuation of clusters of thrusters to be operated in pulsed on-off mode.

The EDM lander is expected to survive on the surface of Mars for a short time (about 8 sols) by using the excess energy capacity of its batteries. Its proposed landing site is the Meridiani Planum because it is almost flat and without too many rocks, ideal for its airbag landing system.

2018 launch

Current plans call for the use of NASA's sky crane entry, descent and landing (EDL) system to deliver both rovers together on the surface of Mars.

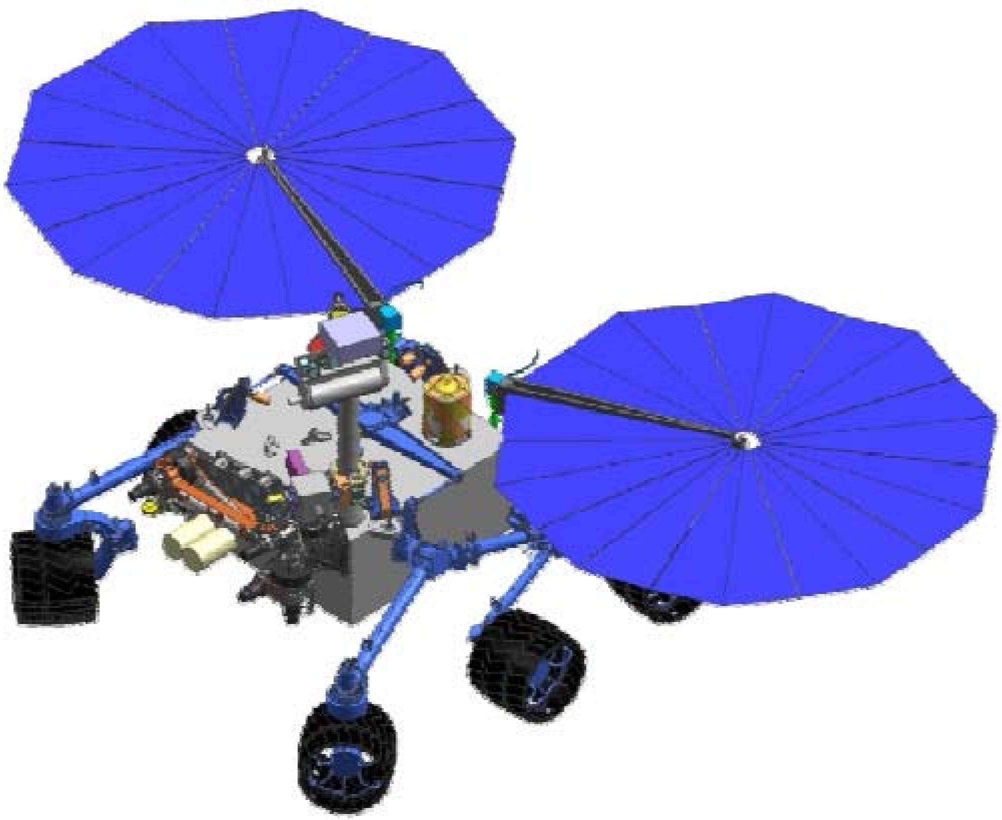
If there will be two rovers delivered to the same location on Mars, Their science objectives and instruments will be complementary in order to minimise duplication. Advantages of operating two rovers in the same area are: rover to rover imaging, cross analysis of similar geological targets, may include a low-frequency ground-penetrating radar on MAX-C and listen with WISDOM on ExoMars to construct rover to rover subsurface transects, and the MAX-C could receive and cache some of the most valuable subsurface samples collected by ExoMars.

ExoMars rover

The ExoMars rover is a highly autonomous six-wheeled terrain vehicle and will weigh 295 kg, ca. 100 kg more than NASA's Mars Exploration Rovers *Spirit* and *Opportunity*. Temporary plans considered a downsized version with a reduced weight of 207 kg. Instrumentation will consist of the 10 kg 'Pasteur Payload' containing, among other instruments, a 2 meter sub-surface drill.

The carrier module will deliver the descent module to Mars from a hyperbolic approach trajectory after which the Sky-crane landing system will ensure a soft landing with high accuracy. Once safely landed on the Martian surface the solar powered rover would begin a 218-sol mission. To counter the difficulty of remote control due to communication lag, ExoMars will have autonomous software for visual terrain navigation using compressed stereo images from mast mounted panoramic and infrared cameras and independent maintenance. For this purpose it creates digital maps from navigation stereo pair cameras and autonomously finds the adequate trajectory. Close-up collision avoidance cameras are used to ensure safety enabling the vehicle to navigate and safely travel approximately 100 meters per day. After the lander has been released and landed on the surface of Mars, the Mars Trace Gas Orbiter will operate as the rover's data-relay satellite.

MAX-C rover



Schematic depiction of the proposed Mars Astrobiology Explorer-Cacher (MAX-C) Rover

The current proposal is that ExoMars will be deployed together with smaller NASA rover, the Mars Astrobiology Explorer-Cacher (MAX-C). The fact that for the first time two rovers will be active at the same location is expected to lead to synergies, such as bistatic radar surveys between the two rovers. The MAX-C rover would collect, analyse, and cache the most valuable samples in a manner suitable for return to Earth by a future mission.

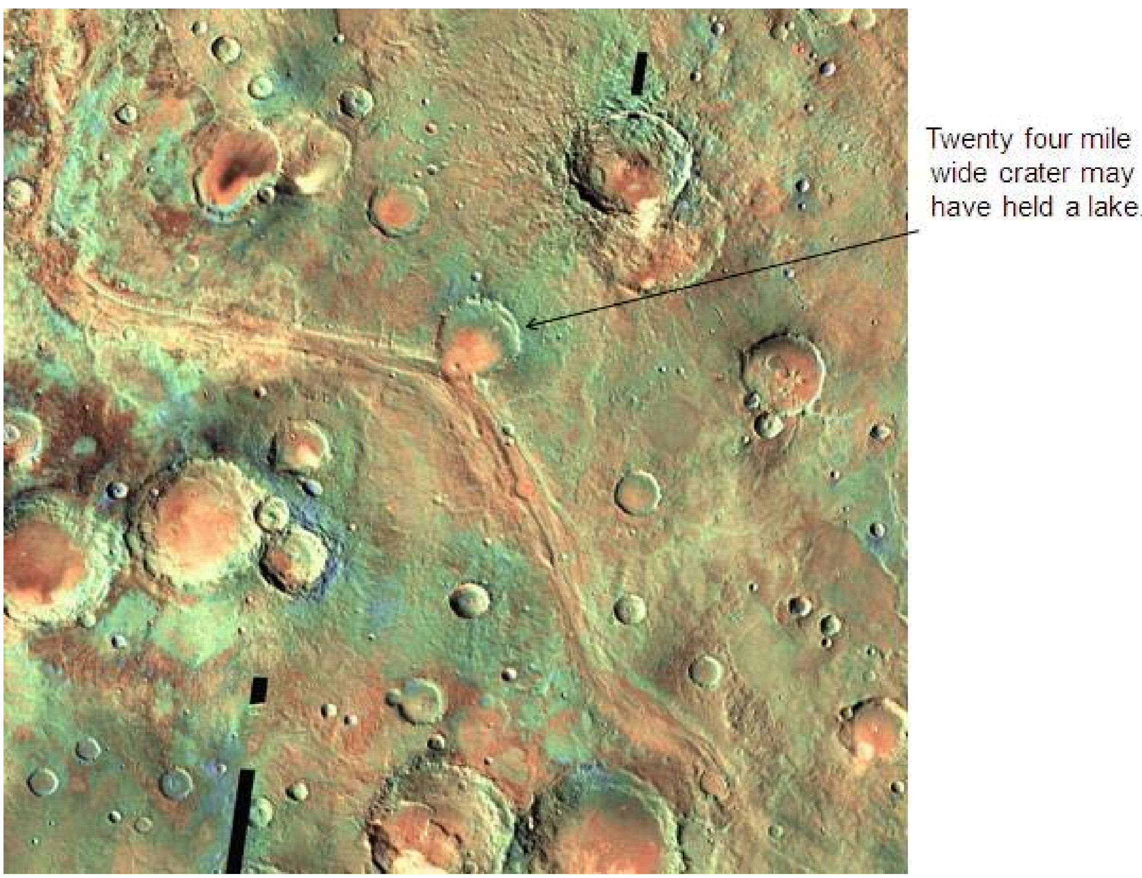
Launch vehicle

Under the agreed collaboration, NASA will provide two Atlas V rockets, as it was decided to divide the weight of the ExoMars system in two launches.

ESA has already worked out a framework agreement with the Russian Space Agency that would allow it to cooperate on ExoMars, including provision of backup launch services and a payload contribution, along with mission support. The backup launcher is the Proton rocket, which is a four-stage rocket that was previously used to launch the Salyut 6, Salyut 7, Mir and some International Space Station components.

Landing system and proposed landing sites

If the collaboration with NASA takes place as proposed, it would be possible to implement NASA's new skycrane entry and descent system to be used on the Mars Science Laboratory rover.



Mawrth Vallis with its potential clues on the history of water on Mars is a landing site-candidate.

As of November 2007, the potential landing sites are:

- Mawrth Vallis
- Nili Fossae
- Meridiani Planum
- Holden Crater
- Gale Crater

However, the 2009 discovery of methane sources on the planet makes them a high value target for exploration. The presence of methane is intriguing because its likely origin is either present-day life or geological activity; confirmation of either would be a major discovery. Methane occurres in extended plumes, and the profiles imply that the methane was released from discrete regions. The profiles suggest that there may be two local source regions, the first centered near 30° N, 260° W and the second near 0°, 310° W. To determine the optimal landing site and secure telecommunications, it was decided to include the Mars Trace Gas Mission orbiter in the 2016 launch in order to map beforehand what appears to be seasonal methane production. The rover could then investigate the methane sources identified by the orbiter.

Instrumentation of the ExoMars rover

The present environment on Mars is exceedingly hostile for the widespread proliferation of surface life: it is too cold and dry and receives large doses of solar UV radiation as well as cosmic radiation. Notwithstanding these hazards, basic microorganisms may still flourish in protected places underground or within rock cracks and inclusions. The science package in the ExoMars rover will hold a variety of instruments to study the environment for past or present habitability and possible biosignatures on Mars. The first instrument proposal (2004) is as follows:

Imaging system

The **Panoramic Camera System (PanCam)** has been designed to perform digital terrain mapping for the rover and to search for morphological signatures of past biological activity preserved on the texture of surface rocks. The PanCam assembly includes two wide angle cameras for multi-spectral stereoscopic panoramic imaging, and a high resolution camera for high-resolution colour imaging. The PanCam will also support the scientific measurements of other instruments by taking high-resolution images of locations that are difficult to access, such as craters or rock walls, and by supporting the selection of the best sites to carry out exobiology studies.

Drill

The ExoMars core drill is devised to acquire soil samples down to a maximum depth of 2 metres, in a variety of soil types. The drill will acquire a core sample (1 cm in diameter x 3 cm in length), extract it and deliver it to the inlet port of the Rover Payload Module, where the sample will be distributed, processed and analyzed. The ExoMars Drill embeds the Mars Multispectral Imager for Subsurface Studies (Ma-Miss) which is a miniaturised IR spectrometer devoted to the borehole exploration. The system will complete experiment cycles and at least 2 vertical surveys down to 2 metres (with four sample acquisitions each). This means that a minimum number of 17 samples shall be acquired and delivered by the drill for subsequent analysis.

Analytical laboratory instruments

These instruments are placed internally and used to study collected samples:

- **Mars Organic Molecule Analyzer** (**MOMA**) consists of a laser desorption ion source and a GC-MS spectrometry. The laser desorption ion source is capable to evaporate organic molecules even if they are not volatile, while the GC separates the highly volatile small molecules within the gas chromatograph. The final analysis of both instruments is done with an ion trap mass spectrometer.

- **Infrared imaging spectrometer** (**MicrOmega-IR**) is an infrared imaging spectrometer that can analyse the powder material derived from crushing samples collected by the drill. Its objective is to study mineral grain assemblages in detail to try to unravel their geological origin, structure, and composition. These data will be vital for interpreting past and present geological processes and environments on Mars. Because MicrOmega-IR is an imaging instrument, it can also be used to identify grains that are particularly interesting, and assigned them as targets for Raman and MOMA-LDMS observations.

- **Mars X-Ray Diffractometer (Mars-XRD)** - Powder diffraction of X-Rays will give exact composition of the crystalline minerals. This instrument includes also an X-ray fluorescence capability that can provide useful atomic composition information.

- **Raman spectrometer (Raman)** will provide geological and mineralogical context information complementary to that obtained by MicrOmega-IR. It is a very useful technique employed to identify mineral phases produced by water-related processes.

- **Ground-penetrating radar**, called **WISDOM** (for Water Ice and Subsurface Deposit Information On Mars) will explore the subsurface of Mars to identify layering and help select interesting buried formations from which to collect samples for analysis. It can transmit and receive signals using two, small Vivaldi-antennas mounted on the aft section of the rover. Electromagnetic waves penetrating into the ground are reflected at places where there is a sudden transition in the electrical parameters of the soil. By studying these reflections it is possible to construct a stratigraphic map of the subsurface and identify underground targets down to 2 to 3 m depth, comparable to the 2-m reach of the rover's drill. These data, combined with those produced by the PanCam and by the analyses carried out on previously collected samples, will be used to support drilling activities.

- **Mars Multispectral Imager for Subsurface Studies** (**Ma-MISS**) is an infrared spectrometer located inside the drill. Ma-MISS will observe the lateral wall of the borehole created by the drill to study the subsurface startigraphy, to understand the distribution and state of water-related minerals, and to characterize the geophysical environment. The analyses of unexposed material by Ma-MISS, together with data obtained with the spectrometers located inside the rover, will be crucial for the unambiguous interpretation of the original conditions of Martian rock formation.

Autonomous navigation

The ExoMars Rover is designed to navigate autonomously across the surface. A pair of stereo cameras allow the Rover to build up a 3D map of the terrain, which the Navigation software then uses to assess terrain around it so that it avoids obstacles and find the most efficient route.

Chapter- 6

Gaia (Spacecraft)

Gaia	
General information	
Organization	European Space Agency
Launch vehicle	Soyuz
Type of orbit	Lissajous orbit around Sun-Earth L_2
Wavelength	Optical
Statistics as of October 2010.	

Gaia is a European Space Agency (ESA) astrometry space mission, and a successor to the ESA *Hipparcos* mission. It was included within the context of the ESA Horizon 2000 Plus long-term scientific programme in 2000. Arianespace expects to launch Gaia for the ESA in March 2013, using a Soyuz rocket. It will be operated in a Lissajous orbit around the Sun-Earth L_2 Lagrangian point.

Gaia will compile a catalogue of approximately one billion stars to magnitude 20. Its objectives comprise:

- astrometric (or positional) measurements, determining the positions, distances, and annual proper motions of stars with an accuracy of about 20 µas (microarcsecond) at 15 mag, and 200 µas at 20 mag
- spectrophotometric measurements, providing multi-epoch observations of each detected object
- radial velocity measurements.

Gaia will create an extremely precise three-dimensional map of stars throughout our Milky Way galaxy and beyond, and map their motions which encode the origin and subsequent evolution of the Milky Way. The spectrophotometric measurements will provide the detailed physical properties of each star observed, characterising their luminosity, effective temperature, gravity and elemental composition. This massive stellar census will provide the basic observational data to tackle a wide range of important problems related to the origin, structure, and evolutionary history of our Galaxy. Large numbers of quasars, galaxies, extrasolar planets and solar system bodies will be measured at the same time.

Gaia will also be capable of discovering asteroids with orbits that lie between Earth and the Sun, a region that is difficult for Earth-based telescopes to monitor since this region is only in the sky during or near the daytime.

Satellite

Gaia will be launched on a Soyuz-FG rocket and will fly to the Lagrange point L2 located approximately 1.5 million kilometers from Earth. The L2 point will provide the spacecraft with a very stable thermal environment. There it will describe a Lissajous orbit which will avoid eclipses of the Sun by the Earth, which would otherwise limit the amount of solar energy the satellite can retrieve through its solar panels and also disturb the thermal equilibrium.

Measurement principles

Similarly to its predecessor Hipparcos, Gaia consists of two telescopes providing two observing directions with a fixed, wide angle between them. The spacecraft rotates continuously around an axis perpendicular to the two telescopes' lines of sight (LOS). The spin axis in turn has a slight precession across the sky, while maintaining the same angle to the Sun. By precisely measuring the relative positions of objects from both observing directions, a rigid system of reference is obtained.

Each celestial object will be observed on average about 70 times during the mission, which is expected to last 5 years. These measurements will help determine the astrometric parameters of stars: 2 corresponding to the angular position of a given star on the sky, 2 for the derivatives of the star's position over time (motion) and lastly, the star*s parallax.* The radial velocity of the star is measured using the Doppler Effect by a spectrometer, which is integrated into the Gaia telescope system.

Features

The Gaia payload consists of

- a 1.4 x 0.5 square metre primary mirror for each telescope
- A 1.0 x 0.5 m focal plane array on which light from both telescopes are projected. This in turn consists of 106 CCDs of 4500 x 1966 pixels.

Gaia contains 3 separate instruments:

- The astrometry instrument (ASTRO), which is dedicated to measuring the angular position of the stars of magnitude 5.7 to 20.
- The photometric instrument, which allows the acquisition of spectra of stars over the 320-1000 nm spectral band, over the same magnitude 5.7-20.
- The high-resolution spectrometer to measure the radial velocity of the stars by acquiring high-resolution spectra in the spectral band 847-874 nm (field lines of calcium ion) for objects up to magnitude 17 ,

The telemetric link with the satellite is about 1 Mbit/s on average, while the total content of the focal plane represents several Gbit/s. Therefore only a few dozen pixels around each object can be downlinked. This means that detection and monitoring of objects on board is mandatory. Such processing is particularly complex when scanning dense stellar fields.

Mission

The mission was adopted by ESA as cornerstone mission number 6 on 13 October 2000 and the B2 phase of the project was authorized on February 9, 2006, with EADS Astrium taking responsibility for the hardware. The launch is planned for March 2013. The total cost of the mission is around 650 million euros, including the manufacture, launch and ground operations.

The overall data volume that will be retrieved from the spacecraft during the 5-year mission assuming a nominal compressed data rate of 1 Mbit/s is approximately 60 TB, amounting to about 200 TB of usable uncompressed data on the ground. The responsibility of the data processing, not funded by ESA, has been entrusted to a European consortium (the Data Processing and Analysis Consortium, or DPAC) which has been selected after its proposal to the ESA Announcement of Opportunity released in November 2006.

DPAC is a collaboration of about 400 astronomers and IT engineers from 20 European countries, including a significant participation of an ESA group based at the European Space Astronomy Centre (ESAC), one of the ESA centres in Europe located near Madrid. The funding is provided by the participating countries and has been secured until the production of the Gaia final Catalogue scheduled for 2020.

Objectives

The Gaia space mission has the following objectives:

- To determine the intrinsic luminosity of a star requires knowledge of its distance. One of the only ways to achieve without physical assumptions is through the star's parallax. Ground-based observations would not measure such parallaxes with sufficient precision due to the effects of the atmosphere and instrumental biases.

- Observations of the faintest objects will provide a more complete view of the stellar luminosity function. We must observe all the objects up to a certain magnitude in order to have unbiased samples.
- You need a large amount of objects to examine the more rapid stages of stellar evolution. Observing a large number of objects in the galaxy is also important in order to understand the dynamics of our galaxy. Note that a billion stars represents less than 1% of the content of our galaxy.
- Measuring the astrometric and kinematic properties of a star is necessary in order to understand the various stellar populations, especially the most distant.

Gaia is expected to:

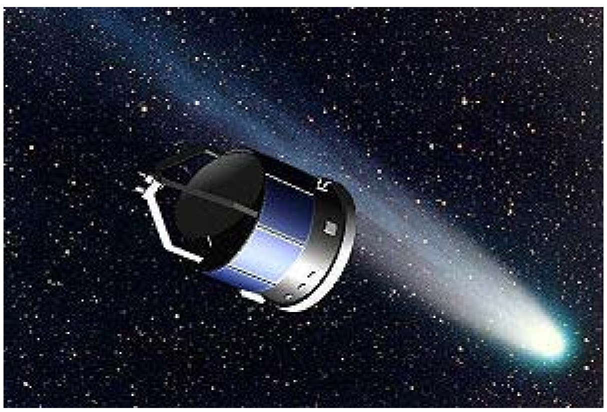
- Measure the astrometric properties of over a billion stars down to a magnitude of V = 20
- Determine the positions of stars at a magnitude of V=10 down to a precision of 7 millionths of an arcsecond (μas) (this is equivalent to measuring the diameter of a hair from 1000 km away); between 12 and 25 μas down to V = 15, and between 100 and 300 μas to V = 20, depending on the color of the star

- Determine the distances to the nearest stars within 0.001%, and to stars near the galactic center, 30,000 light years away, within 20%
- Measure the tangential speed of 40 million stars to a precision of better than 0.5 km/s
- Measure the orbits and inclinations of a thousand extrasolar planets accurately, determining their true masses

Chapter- 7

Giotto (Spacecraft)

Giotto



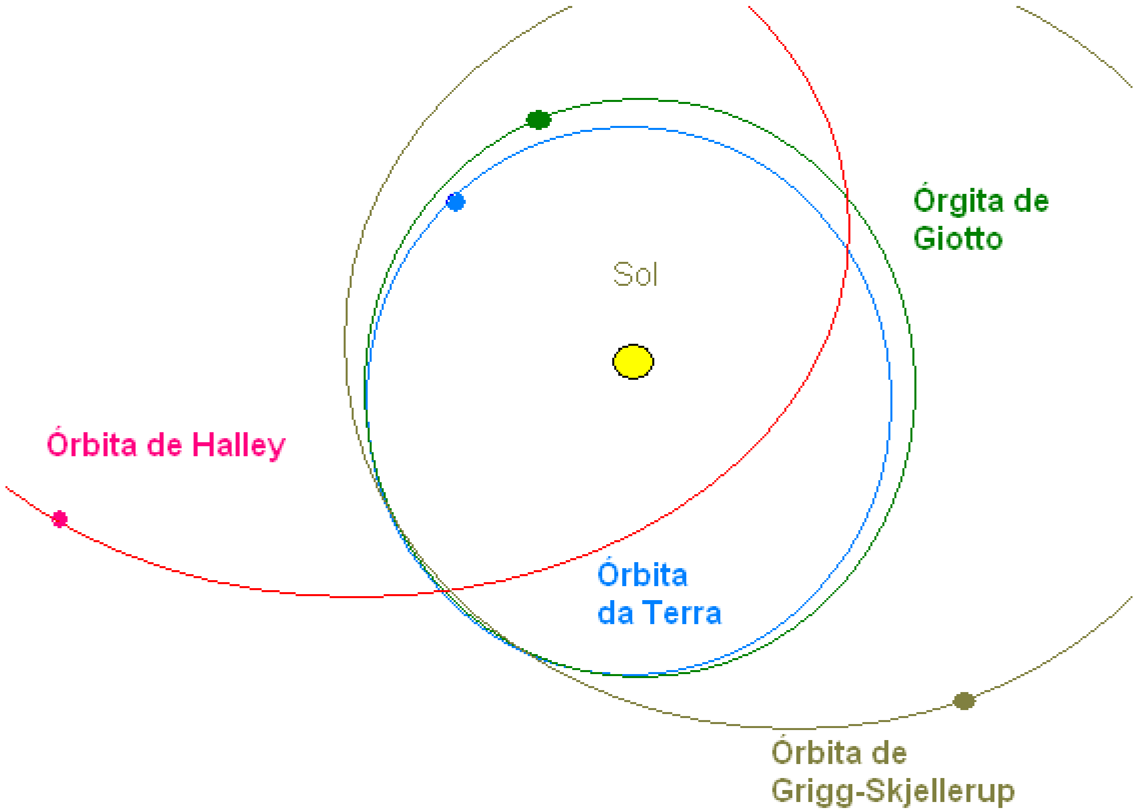
Artist's concept of Giotto spacecraft

Operator	European Space Agency
Mission type	Fly-by
Flyby of	Comet Halley, Comet Grigg-Skjellerup, Earth
Flyby date	(Halley) 14 March 1986, (Grigg-Skjellerup) 10 July 1992
Launch date	2 July 1985
Launch vehicle	Ariane 1 rocket
Launch site	Guiana Space Centre Kourou, French Guiana

Mission duration	Ended on 23 July 1992
COSPAR ID	1985-056A
Mass	582.7 kg
Power	196 W
Orbital elements	
Periapsis	596 km (Halley), 200 km (Grigg-Skjellerup)

Giotto was a European robotic spacecraft mission from the European Space Agency, intended to fly by and study Halley's Comet. On 13 March 1986, the mission succeeded in approaching Halley's nucleus at a distance of 596 kilometers. The spacecraft was named after the Early Italian Renaissance painter Giotto di Bondone. He had observed Halley's Comet in 1301 and was inspired to depict it as the star of Bethlehem in his painting Adoration of the Magi.

Mission



Giotto trajectory

Originally a United States partner probe was planned that would accompany Giotto, but this fell through due to budget cuts at NASA. There were plans to have observation equipment on-board a Space Shuttle in low-Earth orbit around the time of Giotto's fly-by, but they in turn fell through with the Challenger disaster.

The plan then became a cooperative armada of five spaceprobes including Giotto, two from the Soviet Union's Vega program and two from Japan: the Sakigake and Suisei probes. The idea was for Japanese probes and the pre-existing American probe International Cometary Explorer to make long distance measurements, followed by the Russian Vegas which would locate the nucleus, and the resulting information sent back would allow Giotto to precisely target very close to the nucleus. Because Giotto would pass so very close to the nucleus ESA was mostly convinced it would not survive the encounter due to bombardment from the many high speed cometary particles. The coordinated group of probes became known as the Halley Armada.

The craft

The spacecraft was derived from the GEOS research satellite built by British Aerospace, and modified with the addition of a dust shield as proposed by Fred Whipple which comprised a thin (1 mm) aluminium sheet separated by a space and a thicker Kevlar sheet. The later Stardust spacecraft would use a similar Whipple shield. A mock up of the spacecraft resides at the Bristol Aero Collection hanger, at Kemble Airport, UK.

Timeline

Launch

The mission was given the go-ahead by ESA in 1980, and launched on an Ariane 1 rocket (flight V14) on 2 July 1985 from Kourou. The craft was controlled from the European Space Agency ESOC facilities in Darmstadt (then West Germany) initially in Geostationary Transfer Orbit (GTO) then in the Near Earth Phase (NEP) before the longer Cruise Phase through to the encounter. While in GTO a number of slew and spin-up manoeuvres (to 90 RPM) were carried out in preparation for the firing of the Apogee Boost Motor (ABM), although unlike orbit circularisations for geostationary orbit, the ABM for Giotto was fired at perigee. Attitude determination and control used sun pulse and IR earth sensor data in the telemetry to determine the spacecraft orientation.

Halley encounter

The Soviet Vega 1 started returning images of Halley on 1986 4 March, and the first ever of its nucleus, and made its flyby on 6 March, followed by Vega 2 making its flyby on 9 March.

Giotto passed Halley successfully on 14 March 1986 at 600 km distance, and surprisingly survived despite being hit by some small particles. One impact sent it spinning off its stabilized spin axis so that its antenna no longer always pointed at the Earth, and importantly, its dust shield no longer protected its instruments. After 32 minutes Giotto re-stabilized itself and continued gathering science data.

Another impact destroyed the Halley Multicolor Camera, but not before it took spectacular pictures of the nucleus at closest approach.

First Earth flyby

Giotto's trajectory was adjusted for an Earth flyby and its science instruments were turned off on 1986 15 March at 02:00 UT.

Grigg-Skjellerup encounter

Giotto was commanded to wake up on 2 July 1990 when it flew by Earth in order to sling shot to its next cometary encounter.

The probe then flew by the Comet Grigg-Skjellerup in 10 July 1992 which it approached to a distance of about 200 kilometres. Afterwards, Giotto was again switched off on 23 July 1992.

Second Earth flyby

In 1999 Giotto made another Earth flyby but was not reactivated.

Results

Scientific results

Images showed Halley's nucleus to be a dark peanut-shaped body, 15 km long, 7 to 10 km wide. Only 10% of the surface was active, with at least three outgassing jets seen on the sunlit side. Analysis showed the comet formed 4.5 billion years ago from volatiles (mainly ice) that had condensed onto interstellar dust particles. It had remained practically unaltered since its formation.

Measured volume of material ejected by Halley:

- 80% water,
- 10% carbon monoxide
- 2.5% A mix of methane and ammonia.
- Other hydrocarbons, iron, and sodium were detected in trace amounts.

Giotto found Halley's nucleus was blacker than coal, which suggested a thick covering of dust.

The nucleus's surface was rough and of a porous quality, with the density of the whole nucleus as low as 0.3 gram per cubic centimetre (g/cm^3). Sagdeev's team estimated a density of 0.6 g/cm^3, but S. J. Peale warned that all estimates had error bars too large to be informative.

The quantity of material ejected was found to be 3 tonnes per second for seven jets, and these caused the comet to wobble over long time periods.

The dust ejected was mostly only the size of cigarette smoke particles, with masses ranging from 10^{-20} kg to $40x10^{-5}$ kg (10 attograms to 40 milligrams). Although the one particle impact that sent Giotto spinning was not measured, from its effects - it also probably broke off a piece of Giotto - its mass has been estimated to lie between 0.1 and 1 gram.

Two kinds of dust were seen: one with carbon, hydrogen, nitrogen and oxygen; the other with calcium, iron, magnesium, silicon and sodium.

The ratio of abundances of the comet's light elements excluding nitrogen (i.e. hydrogen, carbon, oxygen) were the same as the Sun's. The implication is that the constituents of Halley are among the most primitive in the solar system.

The plasma and ion mass spectrometer instruments showed Halley has a carbon-rich surface.

Spacecraft achievements

- Giotto made the closest approach to Halley comet and provided the best data for this comet.
- Giotto was the first spacecraft to provide pictures of a cometary nucleus.
- Giotto was the first spacecraft do a close flyby of two comets. Young and active comet Halley could be compared to old Grigg-Skjellerup.
- Giotto was the first spacecraft to return from interplanetary space and perform an Earth swing by.
- Giotto was the first spacecraft to be re-activated from hibernation mode.

Chapter- 8

Gravity Field and Steady-State Ocean Circulation Explorer

GOCE

Operator	European Space Agency
Mission type	Orbiter
Satellite of	Earth
Launch date	March 17, 2009
Launch vehicle	Rockot
Homepage	www.esa.int
Mass	1,100 kg (2,400 lb)
Orbital elements	
Eccentricity	Near circular
Inclination	96.70°
Periapsis	270 km (170 mi)

The **Gravity Field and Steady-State Ocean Circulation Explorer (GOCE)** is an ESA satellite that was launched on March 17, 2009. It is a satellite carrying a highly sensitive gravity gradiometer which detects fine density differences in the crust and oceans of the Earth.

GOCE data will have many uses, probing hazardous volcanic regions and bringing new insight into ocean behaviour. The latter, in particular, is a major driver for the mission. By combining the gravity data with information about sea surface height gathered by other satellite altimeters, scientists will be able to track the direction and speed of geostrophic ocean currents. The low orbit and high accuracy of the system will greatly improve the known accuracy and spatial resolution of the geoid (the theoretical surface of equal gravitational potential on the Earth).

The satellite's arrow shape and fins help keep the GOCE stable as it flies through the wisps of air still present at an altitude of 260 km. In addition, an ion propulsion system will continuously compensate for the deceleration of air-drag without the vibration of a conventional chemically-powered rocket engine, thus restoring the path of the craft as closely as possible to a purely inertial trajectory. The craft's primary instrument is three pairs of highly sensitive accelerometers which will measure gravitational gradients along three different axes.

Mission objectives

- To determine gravity-field anomalies with an accuracy of 10^{-5} ms^{-2} (1 mGal). To increase resolution, the satellite will fly in an unusually low orbit.
- To determine the geoid with an accuracy of 1–2 cm.
- To achieve the above at a spatial resolution better than 100 km.

Discoveries and applications

The final gravity map and model of the geoid will provide users worldwide with well-defined data product that will lead to:

- A better understanding of the physics of the Earth's interior to gain new insights into the geodynamics associated with the lithosphere, mantle composition and rheology, uplift and subduction processes.
- A better understanding of the ocean currents and heat transport.
- A global height-reference system, which can serve as a reference surface for the study of topographic processes and sea-level change.
- Better estimates of the thickness of polar ice-sheets and their movement.

Initial Findings

Initial results of the GOCE satellite mission were presented at the American Geophysical Union (AGU) 2010 Fall Meeting by Dr Rory Bingham from Newcastle University, UK. The maps produced from the GOCE data show ocean currents in much finer detail than previously available. Even very small details like the Mann Eddy in the North Atlantic are visible in the data, as was the effect of Hurricane Igor (2010).

Launch and operations

GOCE was launched from the Plesetsk Cosmodrome in northern Russia with a Rockot vehicle at 15:21 CET (14:21 UT). The Rockot is a modified SS-19 intercontinental ballistic missile that was decommissioned after the Strategic Arms Reduction Treaty. The launcher uses the two lower liquid fuel stages of the original SS-19 and is equipped with a Briz-KM third stage developed for precise orbit injection. GOCE was launched into a Sun-synchronous dusk-dawn orbit with an inclination of 96.70° and an ascending node at 18:00. Separation from the launcher was at 295 km. The satellite's orbit will then decay over a period of 45 days to an operational altitude, currently planned at 270 km. During this time, the spacecraft will be commissioned and the electrical propulsion system will be checked for reliability in altitude control.

The first launch attempt on 16 March 2009, was aborted due to a malfunction with the launch tower. Liftoff occurred successfully at 14:21 GMT on 17 March 2009. The Rockot launcher delivered the satellite northward over the Arctic. About 90 minutes later, after one orbital revolution and two Briz-KM upper-stage burns, the spacecraft was successfully released into a circumpolar orbit at 280 km altitude with 96.7° inclination to the Equator. Soon after the separation, contact was successfully established with the satellite.

In February 2010 a fault was discovered in the satellite's computer, which meant controllers were forced to switch control to the backup computer. In July 2010, GOCE suffered a serious communications malfunction, when the satellite suddenly failed to downlink scientific data to its receiving stations. Extensive investigations by experts from ESA and industry revealed that the issue was almost certainly related to a communication link between the processor module and the telemetry modules of the main computer. The recovery was completed in September 2010: as part of the action plan, the temperature of the floor hosting the computers was raised by some 7°C – resulting in restoration of normal communications.

The first Earth global gravity model based on GOCE data was presented at ESA's Living Planet Symposium, in June 2010.

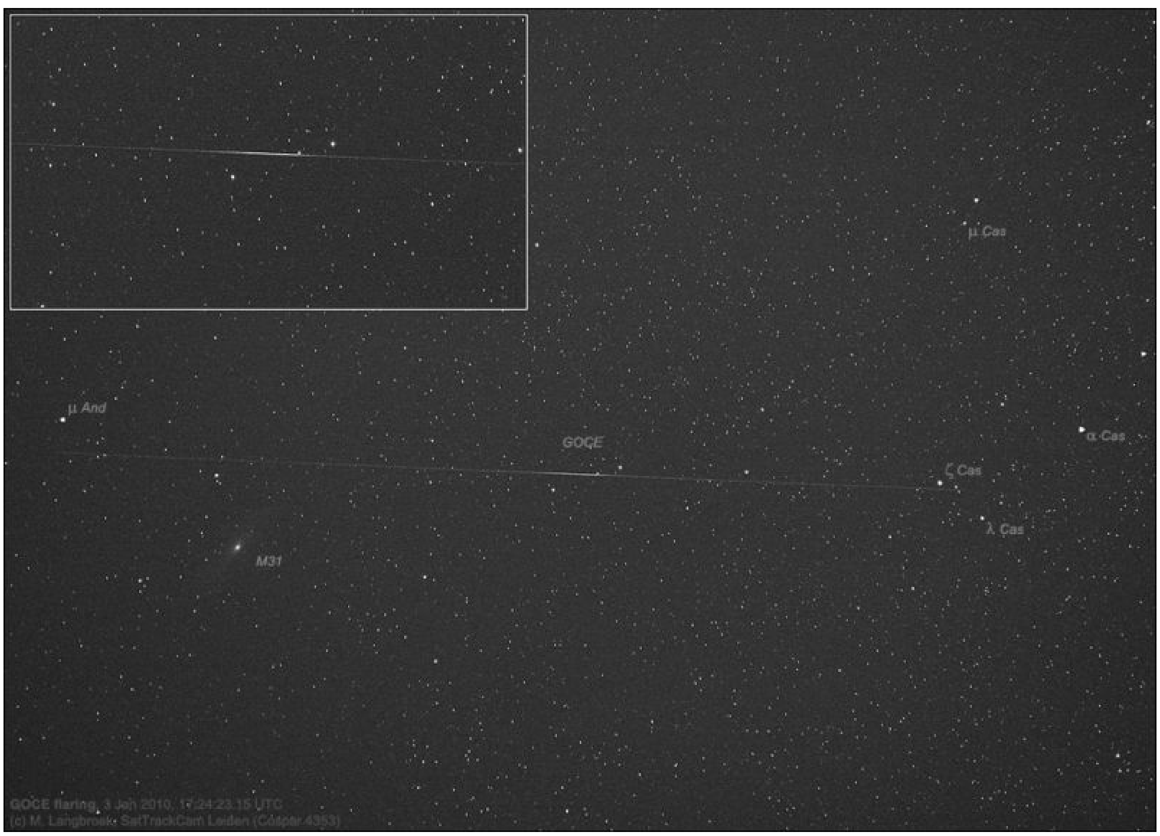
In November, 2010, it was decided to extend the mission lifetime of 18 months, till the end of 2012, in order to improve the collected data.

Payload

The satellite's main payload is the Electrostatic Gravity Gradiometer (EGG) to measure the gravity field of Earth. They are arranged in three pairs of ultra-sensitive accelerometers arranged in three dimensions that respond to tiny variations in the 'gravitational tug' of the Earth as it travels along its orbital path. Because of their different position in the gravitational field they all experience the gravitational acceleration of the Earth slightly differently. The three axes of the gradiometer allow the simultaneous measurement of the five independent components of the gravity gradient tensor.

Other payload will be an onboard GPS receiver used as a Satellite-to-Satellite Tracking Instrument (SSTI); a compensation system for all non-gravitational forces acting on the spacecraft. The satellite is also equipped with a laser retroreflector to enable tracking by ground-based lasers.

Power



GOCE (09-013A) flaring briefly to magnitude +2 on this image as the 67.5 degree solar panel briefly mirrors sunlight to the observer. This photograph was taken by Marco Langbroek (Leiden, the Netherlands), the flaring occurred at 17:24:23.15 UTC (Jan 3, 2010).

GOCE has fixed solar panels, which will produce 1,300 W of power and cover the Sun-facing side of GOCE.

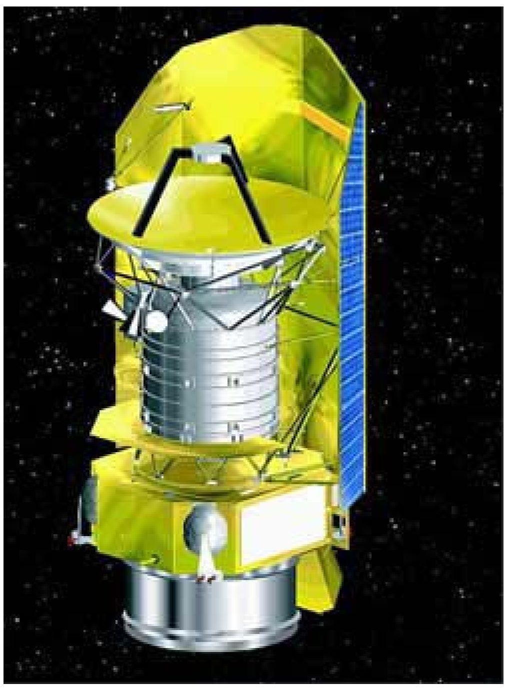
The ion propulsion electric engine ejects xenon ions at velocities exceeding 40,000 m/s, which will compensate for the orbital decay losses. GOCE's mission will end when the 40 kg xenon fuel tank empties (with a predicted lifetime of about 20 months). However, the ESA has reported that unusually low solar activity (meaning a calmer upper atmosphere, and hence less drag on the craft) may mean the mission could extend past its predicted 20 months due to fuel savings - possibly into 2014.

The 5 m × 1 m frame incorporates the fixed solar panels as fins to stabilise the spacecraft while it orbits through the residual air in the ionosphere (also called thermosphere).

Chapter- 9

Herschel Space Observatory

Herschel Space Observatory



General information	
NSSDC ID	2009-026A
Organization	European Space Agency (ESA) NASA
Major contractors	Thales Alenia Space
Launch date	2009:05:14, 13:12:02 UTC
Launched from	Guiana Space Centre

	French Guiana
Launch vehicle	Ariane 5 ECA
Mission length	planned: 3 years elapsed: 1 year, 9 months, and 10 days
Mass	3,300 kg (7,300 lb)
Type of orbit	Lissajous orbit
Orbit height	1,500,000 km (930,000 mi)
Orbit period	1 year
Orbit velocity	7,500 m/s (27,000 km/h)
Location	Lagrangian point L_2
Telescope style	Ritchey-Chrétien
Wavelength	60-670 μm (far-infrared)
Diameter	3,500 mm (140 in), f/0.5 (Primary Mirror)
Collecting area	9.6 m^2 (103 sq ft)
Focal length	28.5 m (94 ft), f/8.7
	Instruments
HIFI	Heterodyne Instrument for the Far Infrared
PACS	Photodetector Array Camera and Spectrometer
SPIRE	Spectral and Photometric Imaging Receiver
Website	herschel.esac.esa.int

The **Herschel Space Observatory** is a European Space Agency space observatory sensitive to the far infrared and submillimetre wavebands. It is the largest space telescope ever launched, carrying a single mirror of 3.5 meter in diameter.

The observatory was carried into orbit in May 2009, reaching the second Lagrangian point (L2) of the Earth-Sun system, 1,500,000 kilometres (930,000 mi) from the Earth, about two months later. Herschel is named after Sir William Herschel, the discoverer of the infrared spectrum and planet Uranus, and his sister and collaborator Caroline.

The Herschel Observatory is capable of seeing the coldest and dustiest objects in space; for example, cool cocoons where stars form and dusty galaxies just starting to bulk up with new stars. The observatory will sift through star-forming clouds—the "slow cookers" of star ingredients—to trace the path by which potentially life-forming molecules, such as water, form. The United States through NASA is participating in the ESA built and operated observatory. It is the fourth 'cornerstone' mission in the ESA science program, along with Rosetta, Planck, and the Gaia mission.

Science

Herschel will specialise in collecting light from objects in our Solar System as well as the Milky Way and even extragalactic objects billions of light-years away, such as newborn galaxies, and is charged with four primary areas of investigation:

- Galaxy formation in the early universe and the evolution of galaxies;
- Star formation and its interaction with the interstellar medium;
- Chemical composition of atmospheres and surfaces of Solar System bodies, including planets, comets and moons;
- Molecular chemistry across the universe.

Instrumentation

The mission, formerly titled the **Far Infrared and Sub-millimetre Telescope** (**FIRST**), involves the first space observatory to cover the full far infrared and submillimetre waveband. At 3.5 meters wide, its telescope incorporates the largest mirror (made not from glass but from sintered silicon carbide) ever deployed in space. The light is focused onto three instruments with detectors kept at temperatures below 2 K (−271 °C). The instruments are cooled with liquid helium, boiling away in a near vacuum at a temperature of approximately 1.4 K (−272 °C). The 2,000-litre supply of helium on board the spacecraft will limit its operational lifetime; nonetheless, it is expected to be operational for at least 3 years.

Herschel carries three detectors:

PACS (Photodetecting Array Camera and Spectrometer)

An imaging camera and low-resolution spectrometer covering wavelengths from 55 to 210 micrometres. The spectrometer has a spectral resolution between R=1000 and R=5000 and is able to detect signals as weak as −63 dB. It operates as an integral field spectrograph, combining spatial and spectral resolution. The imaging camera can image simultaneously in two bands (either 60–85/85–130 micrometres and 130–210 micrometres) with a detection limit of a few millijanskys.

Herschel in a clean room

SPIRE (Spectral and Photometric Imaging Receiver)

An imaging camera and low-resolution spectrometer covering 194 to 672 micrometre wavelength. The spectrometer has a resolution between R=40 and R=1000 at a wavelength of 250 micrometres and is able to image point sources with brightnesses around 100 millijanskys (mJy) and extended sources with brightnesses of around 500 mJy. The imaging camera has three bands, centered at 250, 350 and 500 micrometres, each with 139, 88 and 43 pixels respectively. It should be able to detect point sources with brightness above 2 mJy and between 4 and 9 mJy for extended sources. A prototype of the SPIRE imaging camera flew on the BLAST high-altitude balloon. NASA's Jet Propulsion Laboratory in Pasadena, Calif., developed and built the "spider web" bolometers for this instrument, which is 40 times more sensitive than previous versions.

HIFI (Heterodyne Instrument for the Far Infrared)

A heterodyne detector which is able to electronically separate radiation of different wavelengths, giving a spectral resolution as high as $R=10^7$. The spectrometer can be operated within two wavelength bands, from 157 to 212 micrometres and from 240 to 625 micrometres. NASA developed and built the mixers, local oscillator chains and power amplifiers for this instrument.

Service module

A common service module (SVM) was designed and built by Thales Alenia Space in its Turin plant, for the Herschel and Planck missions combined into one single program.

Structurally, the Herschel and Planck SVM's are very similar. Both SVM's are of octagonal shape and for both, each panel is dedicated to accommodate a designated set of warm units, while taking into account the dissipation requirements of the different warm units, of the instruments as well as the spacecraft.

Furthermore, on both spacecraft a common design for the avionics, the attitude control and measurement system (ACMS) and the command and data management system (CDMS), and power subsystem and the tracking, telemetry and command subsystem (TT&C) has been achieved.

All spacecraft units on the SVM are redundant.

Power subsystem

On each spacecraft, the power subsystem consists of the solar array, employing triple-junction solar cells, a battery and the power control unit (PCU). It is designed to interface with the 30 sections of each solar array, provide a regulated 28 V bus, distribute this power via protected outputs and to handle the battery charging and discharging.

For Herschel, the solar array is fixed on the bottom part of the baffle designed to protect the cryostat from the sun. The three-axis attitude control system maintains this baffle in direction of the sun. The top part of this baffle is covered with optical solar reflector (OSR) mirrors reflecting 98% of the sun energy, avoiding heating of the cryostat.

Attitude and orbit control

This function is performed by the attitude control computer (ACC) which is the platform for the ACMS. It is designed to fulfil the pointing and slewing requirements of the Herschel and Planck payload.

The Herschel spacecraft is three-axis stabilized, the absolute pointing error needs to be less than 3.7 arc sec.

The main sensor of the line of sight in both spacecraft is the star tracker.

Launch and orbit

The spacecraft, built in the Cannes Mandelieu Space Center, under Thales Alenia Space Contractorship, was successfully launched from the Guiana Space Centre in French Guiana at 13:12:02 UTC on 14 May 2009, aboard an Ariane 5 rocket, along with the Planck spacecraft, and placed on a very elliptical orbit (perigee: 270.0 km (intended 270.0±4.5), apogee: 1,197,080 km (intended 1,193,622±151,800), inclination 5.99 deg (intended 6.00±0.06)), on its way towards the second Lagrangian point.

On June 14, 2009, ESA successfully sent the command for the cryocover to open which will allow the PACS system to see the sky and transmit images in a few weeks. The lid had to remain closed until the telescope was well into space to prevent contamination. Herschel is reported to have completed 90% of the distance to its orbit 1.5 million km away from Earth.

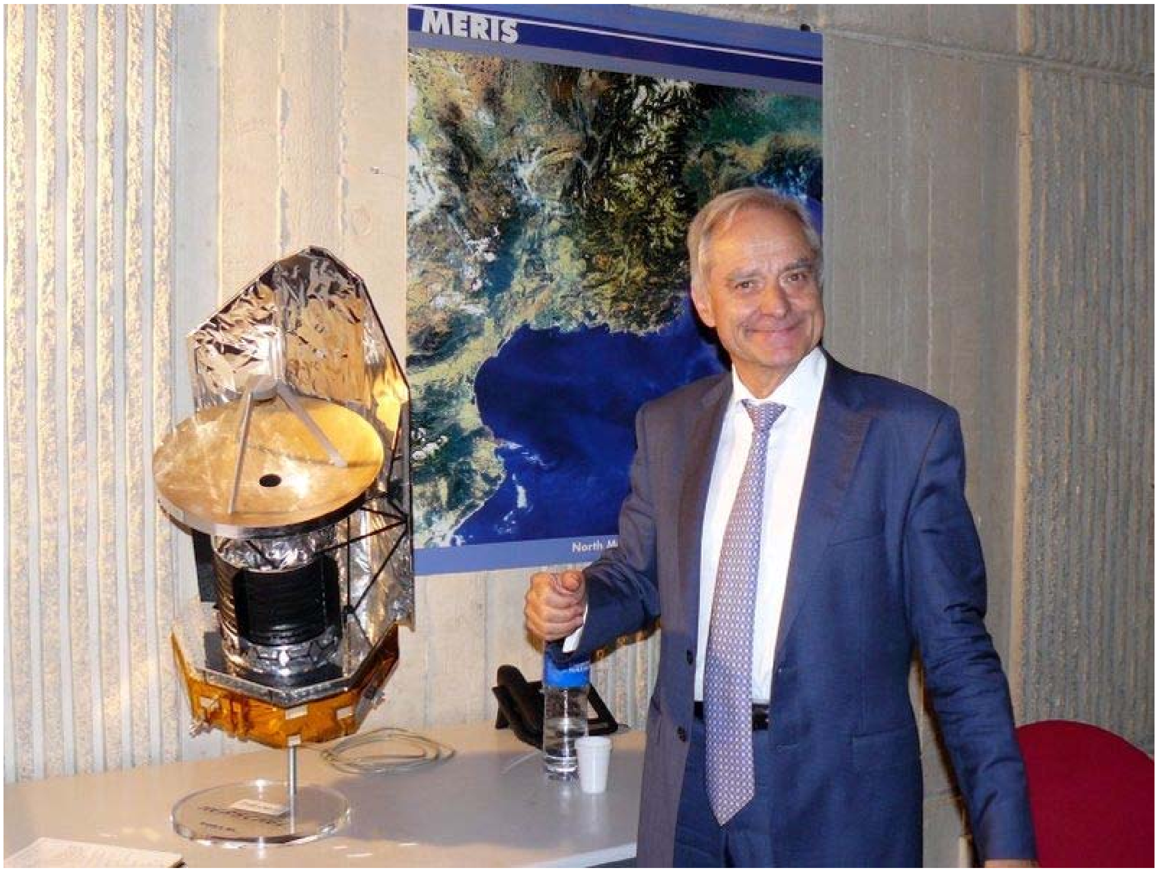
Five days later the first set of test photos, depicting M51 Group, was published by ESA.

In mid-July 2009, approximately sixty days after launch, it entered a Lissajous orbit of 800,000 km average radius around the second Lagrangian point (L2) of the Earth-Sun system, 1.5 million kilometres from the Earth.

Operational mission

On 21 July 2009, Herschel commissioning was declared successful, allowing the start of the operational phase. A formal handover of the overall responsibility of Herschel was declared from the programme manager Thomas Passvogel to the mission manager Johannes Riedinger.

Discoveries



André Brahic, astronomer, one of the fathers of **Herschel** and Planck programmes, during a conference he made in the Cannes Mandelieu Space Center

Herschel was instrumental in the discovery of an unknown and unexpected step in the star forming process. The initial confirmation and later verification via help from ground based telescopes of a vast hole of empty space, previously believed to be a dark nebula, in the area NGC 1999 shed new light in the way newly forming star regions discard the material which surrounds it.

On July 16, 2010, a special issue of *Astronomy and Astrophysics* was published with 152 papers on initial results from the observatory.

Chapter- 10

Hipparcos

Hipparcos

Hipparcos satellite in the Large Solar Simulator, ESTEC, February 1988

General information

NSSDC ID	1989-062B
Organization	European Space Agency
Major contractors	Matra Marconi Space, Alenia Spazio
Launch date	8 August 1989
Launched from	Kourou, French Guiana

Launch vehicle	Ariane 4 (V33)
Mission length	3.5 years Mission end: March 1993
Mass	1140 kg (at launch)
Type of orbit	Geostationary transfer orbit
Orbit height	507 to 35,888 km
Orbit period	10 hours 40 min
Wavelength	Visible light
Diameter	29 cm
Focal length	1.4 m
Website	http://www.rssd.esa.int/hipparcos

Hipparcos (an acronym for "**Hi**gh **p**recision **par**allax **co**llecting **s**atellite") was a scientific mission of the European Space Agency (ESA), launched in 1989 and operated between 1989 and 1993. It was the first space experiment devoted to astrometry, the accurate measurement of star positions, distances from the earth, parallaxes, and proper motions. The Hipparcos Catalogue, a high-precision catalogue of more than 100,000 stars, was published in 1997. The lower precision Tycho Catalogue of more than a million stars was published at the same time, while the enhanced Tycho-2 Catalogue of 2.5 million stars was published in 2000.

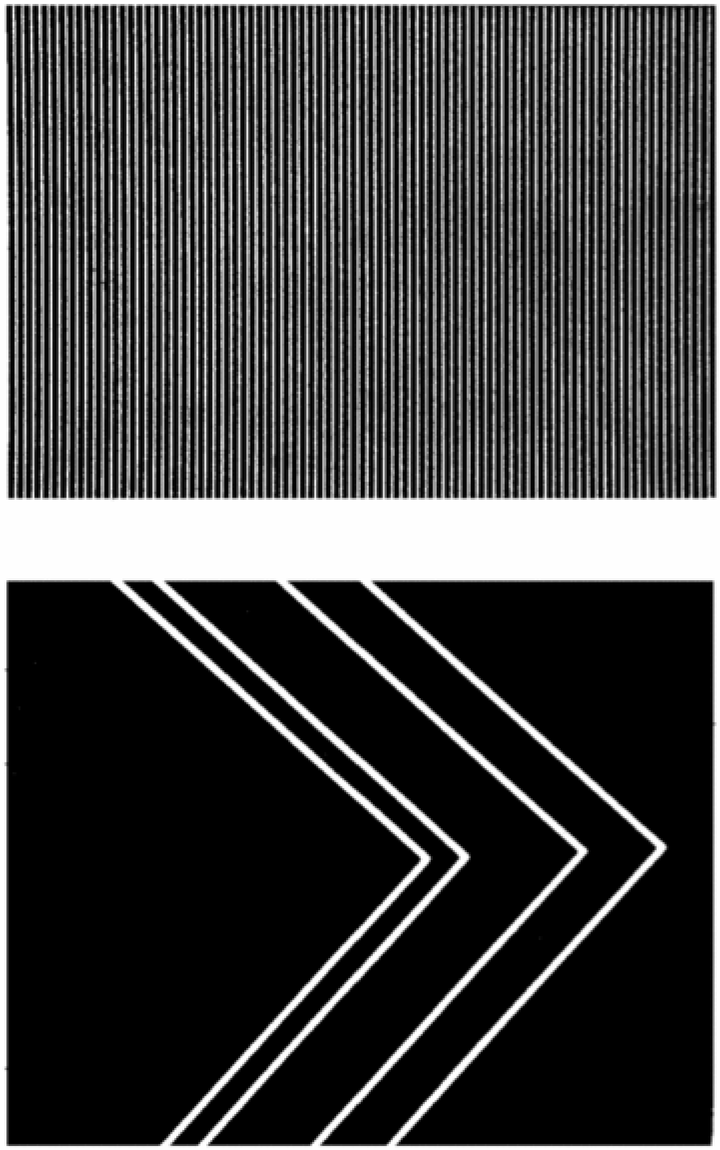
Background

By the second half of the 20th century, the accurate measurement of star positions from the ground was running into essentially insurmountable barriers to improvements in accuracy, especially for large-angle measurements and systematic terms. Problems were dominated by the effects of the Earth's atmosphere, but were compounded by complex optical terms, thermal and gravitational instrument flexures, and the absence of all-sky visibility. A proposal to make these exacting observations from space was first put forward in 1967.

Although originally proposed to the French space agency CNES, it was considered too complex and expensive for a single national programme. Its acceptance within the European Space Agency's scientific programme in 1980 was the result of a lengthy process of study and lobby. The underlying scientific motivation was to determine the physical properties of the stars through the measurement of their distances and space motions, and thus to place theoretical studies of stellar structure and evolution, and studies of galactic structure and kinematics, on a more secure empirical basis. Observationally, the objective was to provide the positions, parallaxes, and annual proper motions for some 100,000 stars with an unprecedented accuracy of 0.002 arcseconds, a target in practice eventually surpassed by a factor of two. The name of the space telescope *Hipparcos* was an acronym for *High Precision Parallax Collecting Satellite*, and also reflected the name of the Greek astronomer Hipparchus.

Satellite and payload

The spacecraft carried a single all-reflective eccentric Schmidt telescope, with an aperture of 29 cm. A special beam-combining mirror superimposed two fields of view, 58 degrees apart, into the common focal plane. This complex mirror consisted of two mirrors tilted in opposite directions, each occupying half of the rectangular entrance pupil, and providing an unvignetted field of view of about 1°×1°. The telescope used a system of grids, at the focal surface, composed of 2688 alternate opaque and transparent bands, with a period of 1.208 arc-sec (8.2 micrometre). Behind this grid system, an image dissector tube (photomultiplier type detector) with a sensitive field of view of about 38 arc-sec diameter converted the modulated light into a sequence of photon counts (with a sampling frequency of 1200 Hz) from which the phase of the entire pulse train from a star could be derived. The apparent angle between two stars in the combined fields of view, modulo the grid period, was obtained from the phase difference of the two star pulse trains. Originally targeting the observation of some 100,000 stars with an astrometric accuracy of about 0.002 arc-sec, the final Hipparcos Catalogue comprised nearly 120,000 stars with a median accuracy of slightly better than 0.001 arc-sec (1 milliarc-sec).



Optical micrograph of part of the main modulating grid (top) and the star mapper grid (bottom) The period of the main grid is 8.2 micrometre.

An additional photomultiplier system viewed a beam splitter in the optical path and was used as a star mapper – to monitor and determine the satellite attitude, and in the process to gather photometric and astrometric data of all stars down to about 11th magnitude. These measurements were made in two broad bands approximately corresponding to B and V in the (Johnson) UBV photometric system. The positions of these latter stars were to be determined to a precision of 0.03 arcssec, which is a factor of 25 less than the main mission stars. Originally targeting the observation of around 400,000 stars, the resulting Tycho Catalogue comprised just over 1 million stars, with a subsequent analysis extending this to the Tycho-2 Catalogue of about 2.5 million stars.

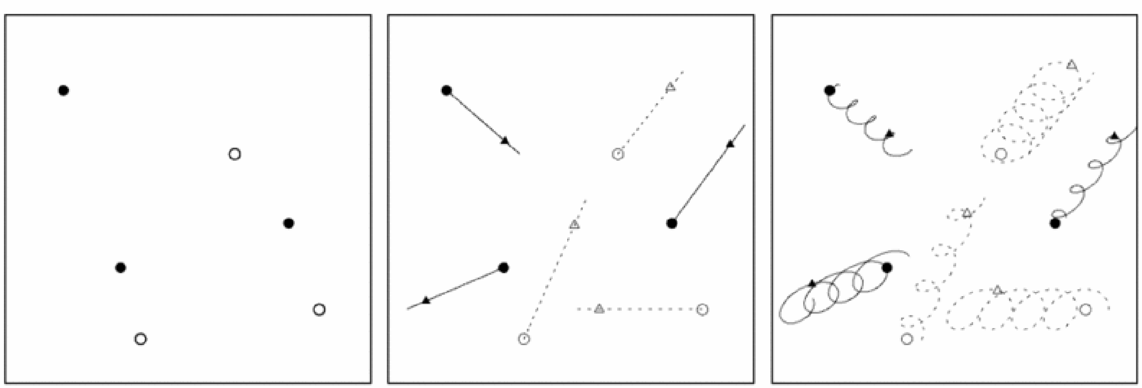
The attitude of the spacecraft about its center of gravity was controlled to scan the celestial sphere in a regular precessional motion maintaining a constant inclination between the spin axis and the sun direction. The spacecraft spun around its Z-axis at the rate of 11.25 rev/day (168.75 arc-sec/sec) at an angle of 43° to the sun. The Z-axis rotated about the sun-satellite line at 6.4 rev/year.

The spacecraft consisted of two platforms and six vertical panels, all made of aluminum honeycomb. The solar array consisted of three deployable sections, generating around 300W in total. Two S-band antennas were located on the top and bottom of the spacecraft, providing an omni-directional downlink data rate of 24 kbit/s. An attitude and orbit-control subsystem (comprising 5 Newton hydrazine thrusters for course manoeuvres, 20 milli-Newton cold gas thrusters for attitude control, and gyroscopes for attitude determination) ensured correct dynamic attitude control and determination during the operational lifetime.

Principles

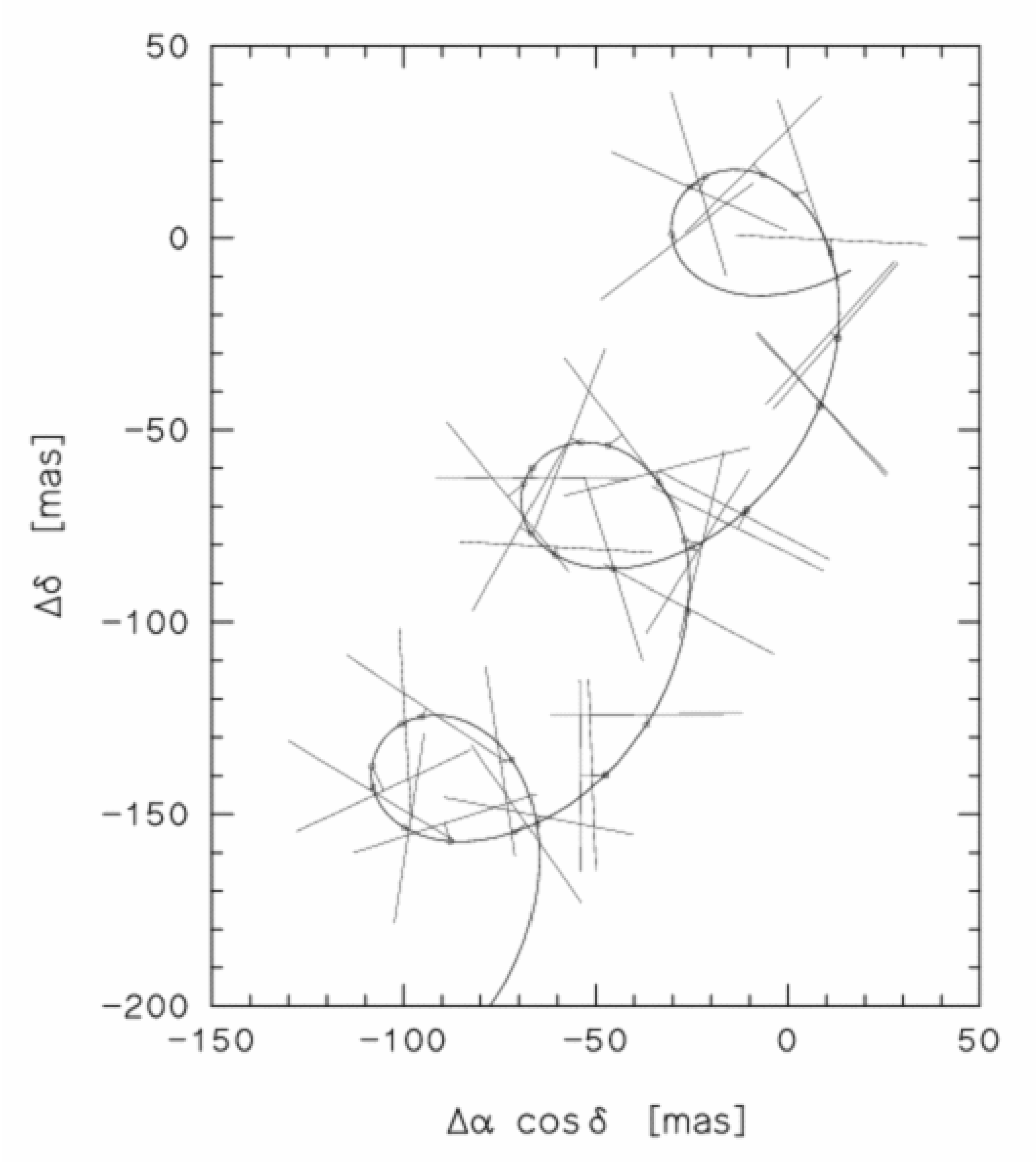
Some key features of the observations were as follows:

- through observations from space, the effects of astronomical seeing due to the atmosphere, instrumental gravitational flexure and thermal distortions could be obviated or minimised;
- all-sky visibility permitted a direct linking of the stars observed all over the celestial sphere;
- the two viewing directions of the satellite, separated by a large and suitable angle (58°), resulted in a rigid connection between quasi-instantaneous one-dimensional observations in different parts of the sky. In turn, this led to parallax determinations which are absolute (rather than relative, with respect to some unknown zero-point);
- the continuous ecliptic-based scanning of the satellite resulted in an optimum use of the available observing time, with a resulting catalogue providing reasonably homogeneous sky density and uniform astrometric accuracy over the entire celestial sphere;



Principles of the astrometric measurements. Filled circles and solid lines show three objects from one field of view (about 1° in size), and open circles and dashed lines show three objects from a distinct sky region superimposed by virtue of the large basic angle. Left: object positions at one reference epoch. Middle: their space motions over about four years, with arbitrary proper motion vectors and scale factors; triangles show their positions at a fixed epoch near the end of the interval. Right: the total positional changes including the additional apparent motions due to annual parallax, the four loops corresponding to four Earth orbits around the sun. The parallax-induced motions are in phase for all stars in the same region of sky, so that relative measurements within one field can only provide relative parallaxes. Although the relative separations between the stars change continuously over the measurement period, they are described by just five numerical parameters per star (two components of position, two of proper motion, and the parallax).

- the various geometrical scan configurations for each star, at multiple epochs throughout the 3-year observation programme, resulted in a dense network of one-dimensional positions from which the barycentric coordinate direction, the parallax, and the object's proper motion, could be solved for in what was effectively a global least squares reduction of the totality of observations. The astrometric parameters as well as their standard errors and correlation coefficients were derived in the process;
- since the number of independent geometrical observations per object was large (typically of order 30) compared with the number of unknowns for the standard model (five astrometric unknowns per star) astrometric solutions not complying with this simple five-parameter model, could be expanded to take into account the effects of double or multiple stars, or non-linear photocentric motions ascribed to unresolved astrometric binaries;
- a somewhat larger number of actual observations per object, of order 110, provided accurate and homogeneous photometric information for each star, from which mean magnitudes, variability amplitudes, and in many cases period and variability type classification could be undertaken.



The path on the sky of one of the Hipparcos Catalogue objects, over a period of three years. Each straight line indicates the observed position of the star at a particular epoch: because the measurement is one-dimensional, the precise location along this position line is undetermined by the observation. The curve is the modelled stellar path fitted to all the measurements. The inferred position at each epoch is indicated by a dot, and the residual by a short line joining the dot to the corresponding position line. The amplitude of the oscillatory motion gives the star's parallax, with the linear component representing the star's proper motion.

Development, launch and operations

The Hipparcos satellite was financed and managed under the overall authority of the European Space Agency. The main industrial contractors were Matra Marconi Space (now EADS Astrium) and Alenia Spazio (now Thales Alenia Space).

Other hardware components were supplied as follows: the beam-combining mirror from REOSC at Saint Pierre du Perray; the spherical, folding and relay mirrors from Carl Zeiss AG in Oberkochen; the external straylight baffles from CASA in Madrid; the modulating grid from CSEM in Neuchatel; the mechanism control system and the thermal control electronics from Dornier Satellite Systems in Friedrichshafen; optical filters, the experiment structures and the attitude and orbit control system from Matra Marconi Space in Velizy; instrument switching mechanisms from Oerlikon-Contraves in Zurich; the image dissector tube and photomultiplier detectors assembled by the Dutch Space Research Organisation, SRON in The Netherlands; the refocusing assembly mechanism designed by TNO-TPD in Delft; the electrical power subsystem from British Aerospace in Bristol; the structure and reaction control system from Daimler-Benz Aerospace in Bremen; the solar arrays and thermal control system from Fokker Space System in Leiden; the data handling and telecommunications system from Saab-Ericsson Space in Gotenborg; and the apogee boost motor from SEP in France. Groups from the Institut d'Astrophysique in Liege and the Laboratoire d'Astronomie Spatiale in Marseille contributed optical performance, calibration and alignment test procedures; Captec in Dublin and Logica in London contributed to the on-board software and calibration.

The Hipparcos satellite was launched (with the direct broadcast satellite TV-SAT2 as co-passenger) on an Ariane 4 launch vehicle, flight V33, from Kourou, French Guiana, on 8 August 1989. Launched into a geostationary transfer orbit, the Mage-2 apogee boost motor failed to fire, and the intended geostationary orbit was never achieved. However, with the addition of further ground stations, in addition to the primary ground station at Odenwald in Germany, the satellite was successfully operated in its geostationary transfer orbit for almost 3.5 years. All of the original mission goals were, eventually, exceeded.

The satellite was operated by the ESA operations control centre at ESOC, Darmstadt (Germany).

Including an estimate for the scientific activities related to the satellite observations and data processing, Hipparcos mission cost some 600 MEuro (2000 economic conditions), and its execution involved some 200 European scientists and more than 2000 individuals in European industry.

Hipparcos Input Catalogue

The satellite observations relied on a pre-defined list of target stars. Stars were observed as the satellite rotated, by a sensitive region of the image dissector tube detector. This pre-defined star list formed the Hipparcos Input Catalogue: each star in the final Hipparcos Catalogue was contained in the Input Catalogue. The Input Catalogue was compiled by the INCA Consortium over the period 1982—89, finalised pre-launch, and published both digitally and in printed form Although fully superseded by the satellite results, it nevertheless includes supplemental information on multiple system components as well as compilations of radial velocities and spectral types which, not observed by the satellite, were not included in the published Hipparcos Catalogue.

Constraints on total observing time, and on the uniformity of stars across the celestial sphere for satellite operations and data analysis, led to an Input Catalogue of some 118,000 stars. It merged two components: first, a survey of around 58,000 objects as complete as possible to the following limiting magnitudes: $V<7.9 + 1.1\sin|b|$ for spectral types earlier than G5, and $V<7.3 + 1.1\sin|b|$ for spectral types later than G5 (b is the Galactic latitude). Stars constituting this survey are flagged in the Hipparcos Catalogue.

The second component comprised additional stars selected according to their scientific interest, with none fainter than about magnitude V=13 mag. These were selected from around 200 scientific proposals submitted on the basis of an Invitation for Proposals issued by ESA in 1982, and prioritised by the Scientific Proposal Selection Committee in consultation with the Input Catalogue Consortium. This selection had to balance 'a priori' scientific interest, and the observing programme's limiting magnitude, total observing time, and sky uniformity constraints.

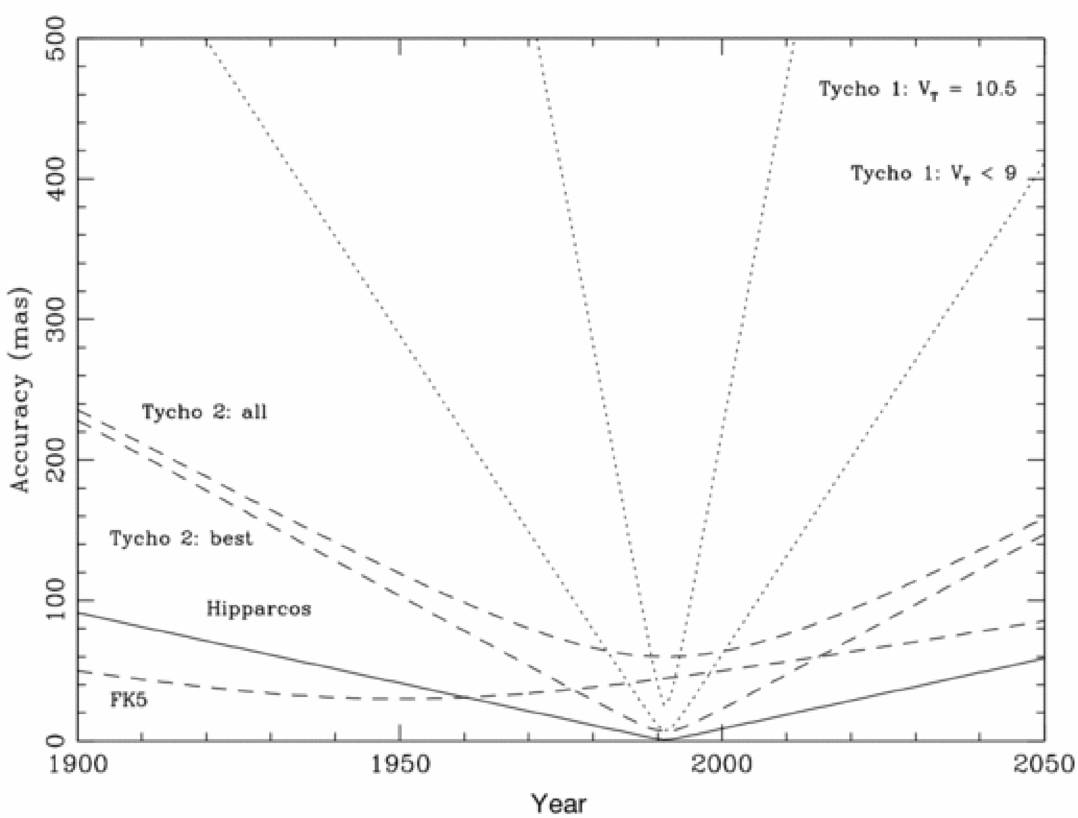
Data reductions

For the main mission results, the data analysis was carried out by two independent scientific teams, NDAC and FAST, together comprising some 100 astronomers and scientists, mostly from European (ESA-member state) institutes. The analyses, proceeding from nearly 1000 Gbit of satellite data acquired over 3.5 years, incorporated a comprehensive system of cross-checking and validation, and is described in detail in the published catalogue.

A detailed optical calibration model was included to map the transformation from sky to instrumental coordinates. Its adequacy could be verified by the detailed measurement residuals. The Earth's orbit, and the satellite's orbit with respect to the Earth, were essential for describing the location of the observer at each epoch of observation, and were supplied by an appropriate Earth ephemeris combined with accurate satellite ranging. Corrections due to special relativity (stellar aberration) made use of the corresponding satellite velocity. Modifications due to General Relativistic light bending were significant (4 milliarc-sec at 90° to the ecliptic) and corrected for deterministically assuming $\gamma=1$ in the PPN formalism. Residuals were examined to establish limits on any deviations from this General Relativistic value, and no significant discrepancies were found.

The Hipparcos reference frame

The satellite observations essentially yielded highly accurate relative positions of stars with respect to each other, throughout the measurement period (1989–93). In the absence of direct observations of extragalactic sources (apart from marginal observations of quasar 3C273) the resulting rigid reference frame was transformed to an inertial frame of reference linked to extragalactic sources. This allows surveys at different wavelengths to be directly correlated with the Hipparcos stars, and ensures that the catalogue proper motions are, as far as possible, kinematically non-rotating. The determination of the relevant three solid-body rotation angles, and the three time-dependent rotation rates, was conducted and completed in advance of the catalogue publication. This resulted in an accurate but indirect link to an inertial, extragalactic, reference frame.



Typical accuracies of the FK5, Hipparcos, Tycho-1, and Tycho-2 Catalogues as a function of time. Tycho-1 dependencies are shown for two representative magnitudes. For Tycho-2, a typical proper motion error of 2.5 milliarc-sec applies to both bright stars (positional error at J1991.25 of 7 milliarc-sec) and faint stars (positional error at J1991.25 of 60 milliarc-sec).

A variety of methods to establish this reference frame link before catalogue publication were included and appropriately weighted: interferometric observations of radio stars by VLBI networks, MERLIN and VLA; observations of quasars relative to Hipparcos stars using CCDs, photographic plates, and the Hubble Space Telescope; photographic programmes to determine stellar proper motions with respect to extragalactic objects (Bonn, Kiev, Lick, Potsdam, Yale/San Juan); and comparison of Earth rotation parameters obtained by VLBI and by ground-based optical observations of Hipparcos stars. Although very different in terms of instruments, observational methods and objects involved, the various techniques generally agreed to within 10 milliarc-sec in the orientation and 1 milliarc-sec/yr in the rotation of the system. From appropriate weighting, the coordinate axes defined by the published catalogue are believed to be aligned with the extragalactic radio frame to within ±0.6 milliarc-sec at the epoch J1991.25, and non-rotating with respect to distant extragalactic objects to within ±0.25 milliarc-sec/yr.

The Hipparcos and Tycho Catalogues were then constructed such that the Hipparcos reference frame coincides, to within observational uncertainties, with the International Celestial Reference System (the ICRS), and representing the best estimates at the time of the catalogue completion (in 1996). The resulting Hipparcos reference frame is thus the materialisation of the ICRS in the optical. It extends and improves the J2000(FK5) system, retaining approximately the global orientation of that system but without its regional errors.

Double and multiple stars

Whilst of enormous astronomical importance, double stars and multiple stars provided considerable complications to the observations (due to the finite size and profile of the detector's sensitive field of view) and to the data analysis. The data processing classified the astrometric solutions as follows:

- single star solutions: 100,038 entries, of which 6,763 were flagged as suspected double
- component solutions (Annex C): 13,211 entries, comprising 24,588 components in 12,195 solutions
- acceleration solutions (Annex G): 2,622 solutions
- orbital solutions (Annex O): 235 entries
- variability-induced movers (Annex V): 288 entries
- stochastic solutions (Annex X): 1,561 entries
- no valid astrometric solution: 263 entries (of which 218 were flagged as suspected double)

If a binary star has a long orbital period such that non-linear motions of the photocentre were insignificant over the short (3-year) measurement duration, the binary nature of the star would pass unrecognised by Hipparcos, but could show as a Hipparcos proper motion discrepant compared to those established from long temporal baseline proper motion programmes on ground. Higher-order photocentric motions could be represented by a 7-parameter, or even 9-parameter model fit (compared to the standard 5-parameter model), and typically such models could be enhanced in complexity until suitable fits were obtained. A complete orbit, requiring 7 elements, was determined for 45 systems. Orbital periods close to one year can become degenerate with the parallax, resulting in unreliable solutions for both. Triple or higher-order systems provided further challenges to the data processing.

Photometric observations

The highest accuracy photometric data were provided as a by-product of the main mission astrometric observations. They were made in a broad-band visible light passband, specific to Hipparcos, and designated Hp. The median photometric precision, for Hp<9 mag, was 0.0015 mag, with typically 110 distinct observations per star throughout the 3.5-year observation period. As part of the data reductions and catalogue production, new variables were identified and designated with appropriate variable star identifiers. Variable stars were classified as periodic or unsolved variables; the former were published with estimates of their period, variability amplitude, and variability type. In total some 11,597 variable objects were detected, of which 8237 were newly-classified as variable. There are, for example, 273 Cepheid variables, 186 RR Lyr variables, 108 Delta Scuti variables, and 917 eclipsing binary stars. The star mapper observations, constituting the Tycho (and Tycho-2) Catalogue, provided two colours, roughly B and V in the Johnson UBV photometric system, important for spectral classification and effective temperature determination.

Radial velocities

Classical astrometry concerns only motions in the plane of the sky and ignores the star's radial velocity, i.e. its space motion along the line-of-sight. Whilst critical for an understanding of stellar kinematics, and hence population dynamics, its effect is generally imperceptible to astrometric measurements (in the plane of the sky), and therefore it is generally ignored in large-scale astrometric surveys. In practice, it can be measured as a Doppler shift of the spectral lines. More strictly, however, the radial velocity does enter a rigorous astrometric formulation. Specifically, a space velocity along the line-of-sight means that the transformation from tangential linear velocity to (angular) proper motion is a function of time. The resulting effect of secular or perspective acceleration is the interpretation of a transverse acceleration actually arising from a purely linear space velocity with a significant radial component, with the positional effect proportional to the product of the parallax, the proper motion, and the radial velocity. At the accuracy levels of Hipparcos it is of (marginal) importance only for the nearest stars with the largest radial velocities and proper motions, but was accounted for in the 21 cases for which the accumulated positional effect over two years exceeds 0.1 milliarc-sec. Radial velocities for Hipparcos Catalogue stars, to the extant that they are presently known from independent ground-based surveys, can be found from the astronomical data base of the Centre de Données astronomiques de Strasbourg.

The absence of reliable distances for the majority of stars means that the angular measurements made, astrometrically, in the plane of the sky, cannot generally be converted into true space velocities in the plan of the sky. For this reason, astrometry characterises the transverse motions of stars in angular measure (e.g. arcsec per year) rather than in km/sec or equivalent. Similarly, the typical absence of reliable radial velocities means that the transverse space motion (when known) is, in any case, only a component of the complete, three-dimensional, space velocity.

Published catalogues

Principal observational characteristics of the Hipparcos and Tycho Catalogues. ICRS is the International Celestial Reference System.	
Property	**Value**
Common:	
Measurement period	1989.8—1993.2
Catalogue epoch	J1991.25
Reference system	ICRS
• coincidence with ICRS (3 axes)	±0.6 mas
• deviation from inertial (3 axes)	±0.25 mas/yr
Hipparcos Catalogue:	
Number of entries	118,218
• with associated astrometry	117,955
• with associated photometry	118,204
Mean sky density	≈3 per sq deg
Limiting magnitude	V≈12.4 mag
Completeness	V=7.3-9.0 mag
Tycho Catalogue:	
Number of entries	1,058,332
• based on Tycho data	1,052,031
• with only Hipparcos data	6301
Mean sky density	25 per sq deg
Limiting magnitude	V≈11.5 mag
Completeness to 90 per cent	V≈10.5 mag
Completeness to 99.9 per cent	V≈10.0 mag
Tycho 2 Catalogue:	
Number of entries	2,539,913
Mean sky density:	
• at b=0°	≈150 per sq deg
• at b=±30°	≈50 per sq deg
• at b=±90°	≈25 per sq deg
Completeness to 90 per cent	V≈11.5 mag
Completeness to 99 per cent	V≈11.0 mag

The final Hipparcos Catalogue was the result of the critical comparison and merging of the two (NDAC and FAST consortia) analyses, and contains 118,218 entries (stars or multiple stars), corresponding to an average of some three stars per square degree over the entire sky. Median precision of the five astrometric parameters (Hp<9 mag) exceeded the original mission goals, and are between 0.6–1.0 mas. Some 20,000 distances were determined to better than 10%, and 50,000 to better than 20%. The inferred ratio of external to standard errors is ≈1.0–1.2, and estimated systematic errors are below 0.1 mas. The number of solved or suspected double or multiple stars is 23,882. Photometric observations yielded multi-epoch photometry with a mean number of 110 observations per star, and a median photometric precision (Hp<9 mag) of 0.0015 mag, with 11,597 entries were identified as variable or possibly variable.

For the star mapper results, the data analysis was carried out by the TDAC consortium. The Tycho Catalogue comprises more than one million stars with 20–30 milliarc-sec astrometry and two-colour (B and V band) photometry.

The final Hipparcos and Tycho Catalogues were completed in August 1996. The catalogues were published by ESA on behalf of the scientific teams in June 1997.

A more extensive analysis of the star mapper (Tycho) data extracted additional faint stars from the data stream. Combined with old photographic plate observations made several decades earlier as part of the Astrographic Catalogue programme, the Tycho-2 Catalogue of more than 2.5 million stars (and fully superseding the original Tycho Catalogue) was published in 2000

The Hipparcos and Tycho-1 Catalogues were used to create the Millennium Star Atlas: an all-sky atlas of one million stars to visual magnitude 11. Some 10,000 nonstellar objects are also included to complement the catalogue data.

Between 1997 and 2007, investigations into subtle effects in the satellite attitude and instrument calibration continued. A number of effects in the data that had not been fully accounted for were studied, such as scan-phase discontinuities and micrometeoroid-induced attitude jumps. A re-reduction of the associated steps of the analysis was eventually undertaken. This has led to improved astrometric accuracies for stars brighter than Hp=9.0 mag, reaching a factor of about three for the brightest stars (Hp<4.5 mag), while also underlining the conclusion that the Hipparcos Catalogue as originally published is generally reliable within the quoted accuracies.

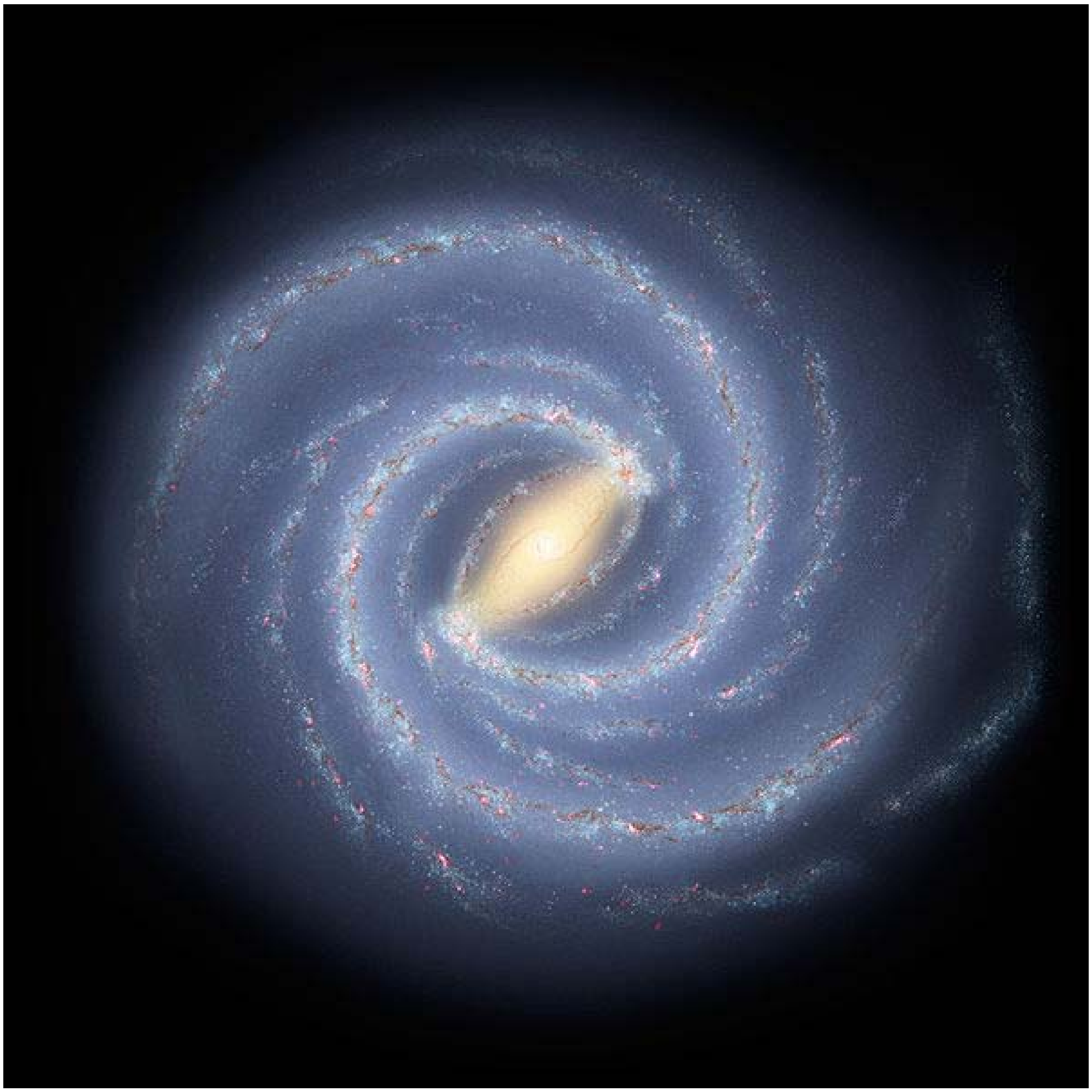
All catalogue data are available online from the Centre de Données astronomiques de Strasbourg.

Scientific results

The Hipparcos results impact a very broad range of astronomical research, which can be classified into three major themes:

(a) the provision of an accurate reference frame: this has allowed the consistent and rigorous re-reduction of historical astrometric measurements, including those from Schmidt plates, meridian circles, the 100-year old Astrographic Catalogue, and 150 years of Earth-orientation measurements. These, in turn, have yielded a dense reference framework with high-accuracy long-term proper motions (the Tycho-2 Catalogue). Reduction of current state-of-the-art survey data has yielded the dense UCAC2 Catalogue of the US Naval Observatory on the same reference system, and improved astrometric data from recent surveys such as the Sloan Digital Sky Survey and 2MASS. Implicit in the high-accuracy reference frame is the measurement of General Relativistic light bending, and the detection and characterisation of double and multiple stars;

(b) constraints on stellar structure and stellar evolution: the accurate distances and luminosities of 100,000 stars has provided the most comprehensive and accurate data set of fundamental stellar parameters to date, placing constraints on internal rotation, element diffusion, convective motions, and asteroseismology. Combined with theoretical models and other data it yields evolutionary masses, radii, and ages for large numbers of stars covering a wide range of evolutionary states;



Artists concept of our Milky Way galaxy, showing two prominent spiral arms attached to the ends of a thick central bar. Hipparcos mapped many stars in the solar neighbourhood with great accuracy though this represents only a small fraction of stars in the galaxy.

(c) Galactic kinematics and dynamics: the uniform and accurate distances and proper motions have provided a substantial advance in understanding of stellar kinematics and the dynamical structure of the solar neighbourhood, ranging from the presence and evolution of clusters, associations and moving groups, the presence of resonance motions due to the Galaxy's central bar and spiral arms, determination of the parameters describing Galactic rotation, discrimination of the disk and halo populations, evidence for halo accretion, and the measurement of space motions of runaway stars, globular clusters, and many other types of star.

Associated with these major themes, Hipparcos has provided results in topics as diverse as Solar System science, including mass determinations of asteroids, Earth's rotation and Chandler Wobble, the internal structure of white dwarfs, the masses of brown dwarfs, the characterisation of extra-solar planets and their host stars, the height of the Sun above the Galactic mid-plane, the age of the Universe, the stellar initial mass function and star formation rates, and strategies for the search for extraterrestrial intelligence. The high-precision multi-epoch photometry has been used to measure variability and stellar pulsations in many classes of objects. The Hipparcos and Tycho Catalogues are now routinely used to point ground-based telescopes, navigate space missions, and drive public planetaria.

Since 1997, several thousand scientific papers have been published making use of the Hipparcos and Tycho Catalogues. A detailed review of the Hipparcos scientific literature between 1997–2007 was published in 2009. Some examples of notable results include (listed chronologically):

- studies of Galactic rotation from Cepheid variables
- the nature of Delta Scuti variables
- studies of local stellar kinematics
- testing the white dwarf mass-radius relation
- the structure and dynamics of the Hyades cluster
- kinematics of Wolf-Rayet stars and O-type runaway stars
- subdwarf parallaxes: metal-rich clusters and the thick disk
- fine structure of the red giant clump and associated distance determinations
- unexpected stellar velocity distribution in the warped Galactic disk
- refining the Oort and Galactic constants
- Galactic disk dark matter, terrestrial impact cratering and the law of large numbers
- vertical motion and expansion of the Gould Belt
- the use of gamma ray bursts as direction and time markers in SETI strategies
- evidence of a galaxy merger in the early formation history of the Milky Way
- study of nearby OB associations
- close approaches of stars to the Solar System
- studies of binary star orbits and masses
- the HD 209458 planetary transits
- formation of the stellar Galactic halo and thick disk
- the local density of matter in the Galaxy and the Oort limit
- ice age epochs and the Sun's path through the Galaxy
- local kinematics of K and M giants and the concept of superclusters
- an improved reference frame for long-term Earth rotation studies

- the local stellar velocity field in the Galaxy

One controversial result has been the derived proximity, at about 120 parsecs, of the Pleiades cluster, established both from the original catalogue as well as from the revised analysis. This has been contested by various other recent work, placing the mean cluster distance at around 130 parsecs.

People

- Pierre Lacroute (Observatory of Strasbourg): proposer of space astrometry in 1967
- Michael Perryman: ESA project scientist
- Catherine Turon (Observatoire de Paris-Meudon): leader of Input Catalogue Consortium
- Erik Høg: leader of the TDAC Consortium
- Lennart Lindegren: leader of the NDAC Consortium
- Jean Kovalevsky: leader of the FAST Consortium
- Adriaan Blaauw: chair of the observing programme selection committee
- Hipparcos Science Team: Uli Bastian, Pierluigi Bernacca, Michel Crézé, Francesco Donati, Michel Grenon, Michael Grewing, Erik Høg, Jean Kovalevsky, Floor van Leeuwen, Lennart Lindegren, Hans van der Marel, Francois Mignard, Andrew Murray, Michael Perryman (chair), Rudolf Le Poole, Hans Schrijver, Catherine Turon
- Franco Emiliani: ESA project manager (1981–85)
- Hamid Hassan: ESA project manager (1985–89)
- Dietmar Heger: ESA/ESOC spacecraft operations manager
- Michel Bouffard: Matra Marconi Space project manager
- Bruno Strim: Alenia Spazio project manager

Chapter- 11

Huygens (Spacecraft)

Huygens probe

An actual-size replica of the probe, 1.3 metres across.

Operator	ESA/ASI/NASA
Major contractors	Aérospatiale, now Thales Alenia Space
Mission type	Lander
Satellite of	**Saturn**
Launch date	December 25, 2004
Launch vehicle	Cassini orbiter
COSPAR ID	1997-061C
Homepage	Huygens Homepage
Mass	319 kg

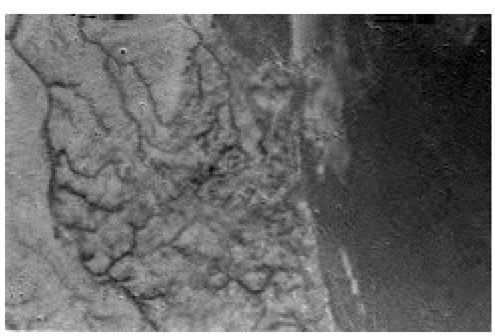
Artist's impression of Huygens on Titan.

The ***Huygens* probe** was an atmospheric entry probe carried to Saturn's moon Titan as part of the *Cassini-Huygens* mission. The probe was supplied by the European Space Agency (ESA) and named after the Dutch 17th century astronomer Christiaan Huygens.

The combined *Cassini-Huygens* spacecraft was launched from Earth on October 15, 1997. *Huygens* separated from the *Cassini* orbiter on December 25, 2004, and landed on Titan on January 14, 2005 near the Xanadu region. This was the first landing ever accomplished in the outer solar system. It touched down on land, although the possibility that it would touch down in an ocean was also taken into account in its design. Even though it was never officially designated a lander, the probe continued to send data for about 90 minutes after reaching the surface.

Overview

Huygens was designed to enter and brake in Titan's atmosphere and parachute a fully instrumented robotic laboratory down to the surface. When the mission was planned, it was not yet certain whether the landing site would be a mountain range, a flat plain, an ocean, or something else, and it was hoped that analysis of data from *Cassini* would help to answer these questions.



The first image released, taken from an altitude of 16 km, showing what are speculated to be drainage channels flowing to a possible shoreline. The darker areas are flat plains, while the lighter areas represent high ground.

Based on pictures taken by *Cassini* at 1,200 km away from Titan, the landing site appeared to be, for lack of a better word, shoreline. Assuming the landing site could be non-solid, the *Huygens* probe was designed to survive the impact and splash-down on a liquid surface on Titan and send back data for several minutes on the conditions there. If that occurred it was expected to be the first time a human-made probe would land in an extraterrestrial ocean. The spacecraft had no more than three hours of battery life, most of which was planned to be taken up by the descent. Engineers only expected to get at best 30 minutes of data from the surface.

The *Huygens* probe system consists of the 318 kg probe itself, which descended to Titan, and the probe support equipment (PSE), which remained attached to the orbiting spacecraft. *Huygens*' heat shield was 2.7 m in diameter; after ejecting the shield, the probe was 1.3 m in diameter. The PSE included the electronics necessary to track the probe, to recover the data gathered during its descent, and to process and deliver the data to the orbiter, from which it transmitted or "downlinked" to the ground.

The probe remained dormant throughout the 6.7-year interplanetary cruise, except for bi-annual health checks. These checkouts followed preprogrammed descent scenario sequences as closely as possible, and the results were relayed to Earth for examination by system and payload experts.

Prior to the probe's separation from the orbiter on December 25, 2004, a final health check was performed. The "coast" timer was loaded with the precise time necessary to turn on the probe systems (15 minutes before its encounter with Titan's atmosphere), then the probe detached from the orbiter and coasted in free space to Titan in 22 days with no systems active except for its wake-up timer.

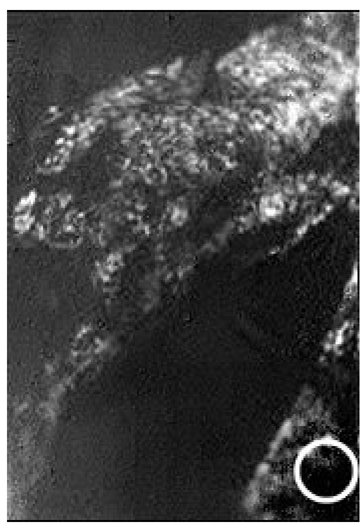
The main mission phase was a parachute descent through Titan's atmosphere. The batteries and all other resources were sized for a *Huygens* mission duration of 153 minutes, corresponding to a maximum descent time of 2.5 hours plus at least 3 additional minutes (and possibly a half hour or more) on Titan's surface. The probe's radio link was activated early in the descent phase, and the orbiter "listened" to the probe for the next 3 hours, including the descent phase, and the first thirty minutes after touchdown. Not long after the end of this three-hour communication window, *Cassini*'s high-gain antenna (HGA) was turned away from Titan and toward Earth.

Very large radio telescopes on Earth were also listening to *Huygens*' 10-watt transmission using the technique of very long baseline interferometry and aperture synthesis mode. At 11:25 CET on January 14, the Robert C. Byrd Green Bank Telescope (GBT) in West Virginia detected the carrier signal from the *Huygens* probe. The GBT continued to detect the carrier signal well after *Cassini* stopped listening to the incoming data stream. In addition to the GBT, eight of the ten telescopes of the continent-wide VLBA in North

America, located at Pie Town and Los Alamos, New Mexico; Fort Davis, Texas; North Liberty, Iowa; Kitt Peak, Arizona; Brewster, Washington; Owens Valley, California; and Mauna Kea, Hawaii, also listened for the *Huygens* signal.

The signal strength received on Earth from *Huygens* was comparable to that from the *Galileo* probe (the Jupiter atmospheric descent probe) as received by the VLA, and was therefore too weak to detect in real time because of the signal modulation by the (then) unknown telemetry. Instead, wide-band recordings of the probe signal were made throughout the three-hour descent. After the probe telemetry was finished being relayed from *Cassini* to Earth, the recorded signal was processed against a telemetry template, enabling signal integration over several seconds for determining the probe frequency. It was expected that through analysis of the Doppler shifting of *Huygens*' signal as it descended through the atmosphere of Titan, wind speed and direction could be determined with some degree of accuracy. A determination of Huygens' landing site on Titan was found with exquisite precision (within one km - one km on Titan measures 1.3' latitude and longitude at the equator) using the Doppler data at a distance from Earth of about 1.2 billion kilometers. The probe landed on the surface of the moon at 10.2°S, 192.4°W. A similar technique was used to determine the landing site of the Mars exploration rovers by listening to their telemetry alone.

Findings



Huygens landing site as determined by descent imagery

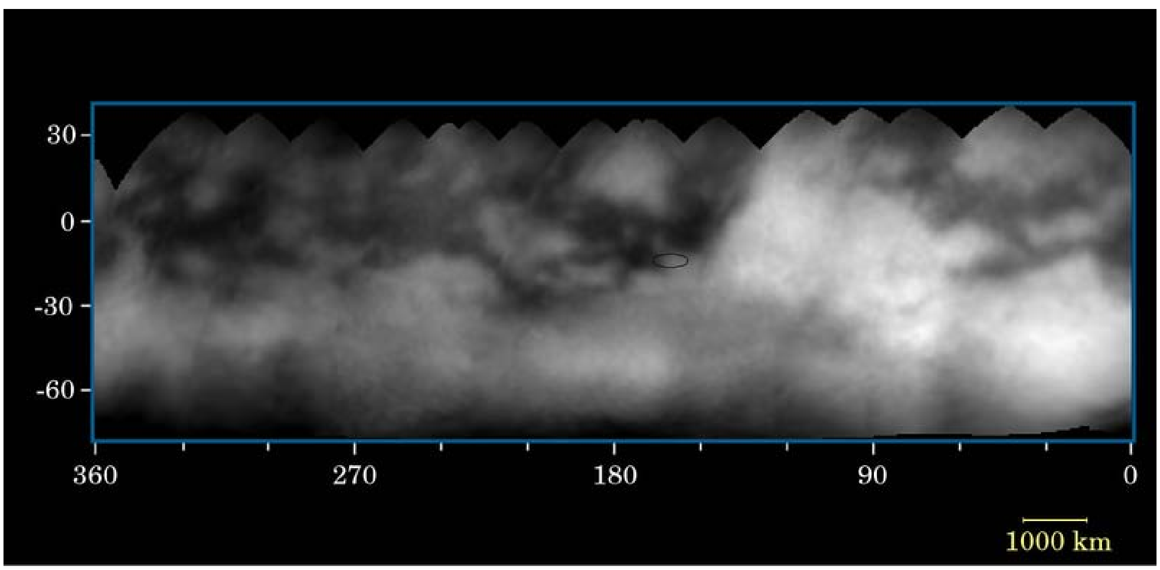
Preliminary findings seemed to confirm the presence of large bodies of liquid on the surface of Titan. The photos showed what appear to be large drainage channels crossing the lighter coloured mainland into a dark sea. Some of the photos even seem to suggest islands and mist shrouded coastline. On January 18 it was reported that *Huygens* landed in "Titanian mud", and the landing site was estimated to lie within the white circle on the picture to the right. Mission scientists also reported a first "descent profile", which describes the trajectory the probe took during its descent.

However, further work done on the probe's trajectory indicate that in fact it landed within the dark 'sea' region in the photos. Photos of a dry landscape from the surface contradict the original theory that the dark regions were liquid seas, leading researchers to conclude that while there was evidence of liquid acting on the surface recently, the much anticipated hydrocarbon seas of Titan were in fact absent.

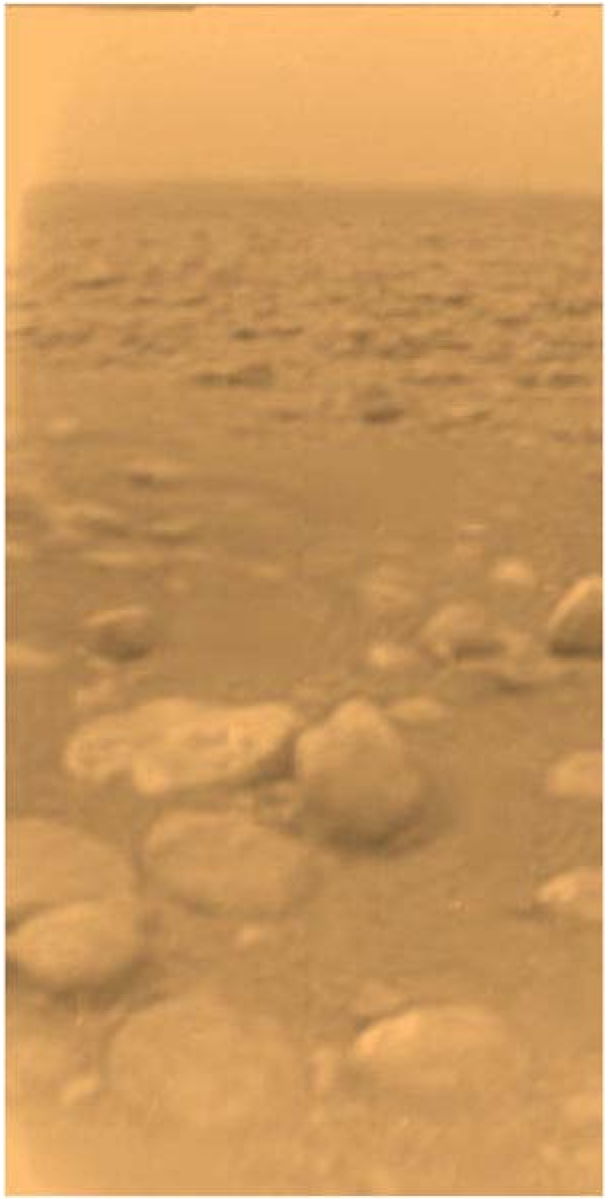
At the landing site there were indications of chunks of water ice scattered over an orange surface, the majority of which is covered by a thin haze of methane. The instruments revealed "a dense cloud or thick haze approximately 18-20 kilometers from the surface". The surface itself was reported to be a clay-like "material which might have a thin crust followed by a region of relative uniform consistency." One ESA scientist compared the texture and colour of Titan's surface to a Crème brûlée, but admitted this term probably would not appear in the published papers.

However, subsequent analysis of the data suggests that surface consistency readings were likely caused by *Huygens* displacing a large pebble as it landed, and that the surface is better described as a 'sand' made of ice grains. The images taken after the probe's landing show a flat plain covered in pebbles. The pebbles, which may be made of water ice, are somewhat rounded, which may indicate the action of fluids on them.

Detailed *Huygens* activity timeline



Ellipse shows approximate landing site on this image taken earlier by *Cassini*. The bright region to the right is Xanadu Region.



Coloured image released from the landing site.


Contrast-enhanced version of surface image

- *Huygens* probe separated from *Cassini* orbiter at 02:00 UTC on December 25, 2004 in Spacecraft Event Time.
- *Huygens* probe entered Titan's atmosphere at 10:13 UTC on January 14, 2005 in SCET, according to ESA.
- The probe landed on the surface of the moon at about 10.2°S, 192.4°W around 12:43 UTC in SCET (2 hours 30 minutes after atmospheric entry).(1.)

There was a transit of the Earth and Moon across the Sun as seen from Saturn/Titan just hours before the landing. The *Huygens* probe entered the upper layer of Titan's atmosphere 2.7 hours after the end of the transit of the Earth, or only one or two minutes after the end of the transit of the Moon. However, the transit did not interfere with *Cassini* orbiter or *Huygens* probe, for two reasons. First, although they could not receive any signal from Earth because it was in front of the Sun, Earth could still listen to them. Second, *Huygens* did not send any readable data to the Earth; it transmitted data to *Cassini* orbiter, which relayed the data received to the Earth later.

Instrumentation

The *Huygens* probe had six complex instruments aboard that took in a wide range of scientific data after the probe descended into Titan's atmosphere. The six instruments are:

Huygens Atmospheric Structure Instrument (HASI)

This instrument contains a suite of sensors that measured the physical and electrical properties of Titan's atmosphere. Accelerometers measured forces in all three axes as the probe descended through the atmosphere. With the aerodynamic properties of the probe already known, it was possible to determine the density of Titan's atmosphere and to detect wind gusts. The probe was designed so that in the event of a landing on a liquid surface, its motion due to waves would also have been measurable. Temperature and pressure sensors measured the thermal properties of the atmosphere. The Permittivity and

Electromagnetic Wave Analyzer component measured the electron and ion (i.e., positively charged particle) conductivities of the atmosphere and searched for electromagnetic wave activity. On the surface of Titan, the electrical conductivity and permittivity (i.e., the ratio of electric displacement field to its electric field) of the surface material was measured. The HASI subsystem also contains a microphone, which was used to record any acoustic events during probe's descent and landing; this was the first time in history that audible sounds from another planetary body had been recorded.

Doppler Wind Experiment (DWE)

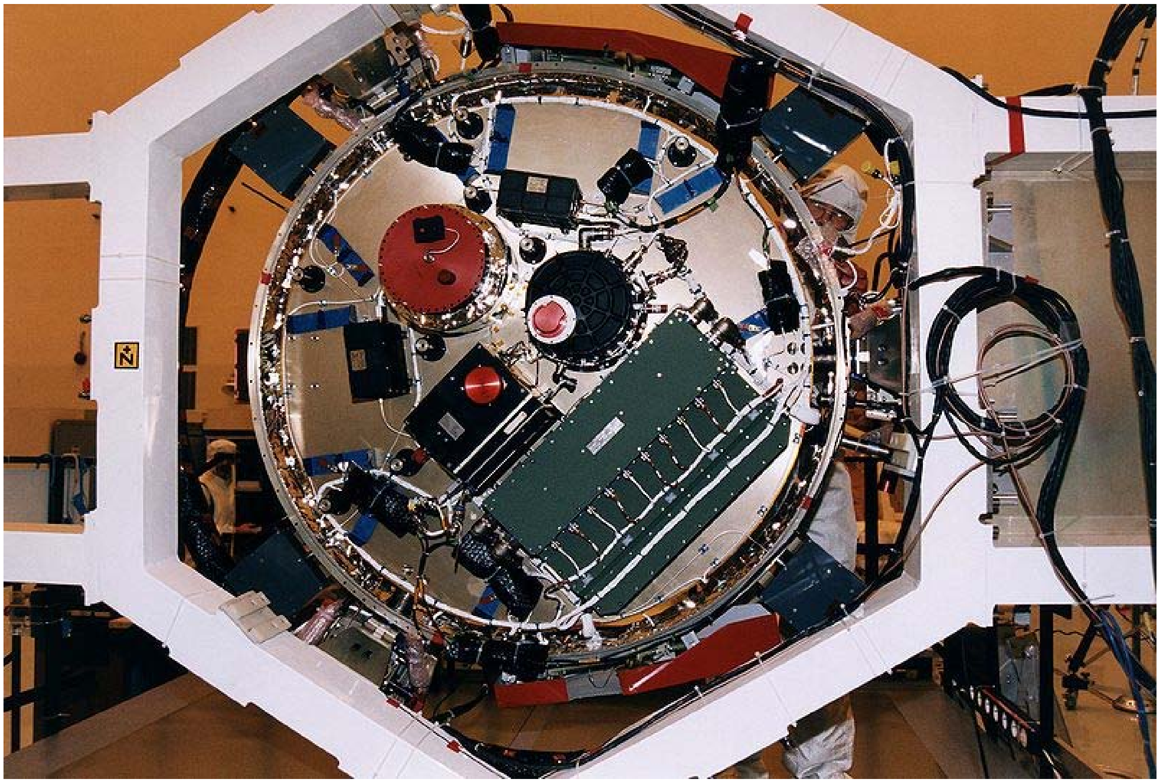
This experiment used an ultra-stable oscillator to improve communication with the probe by giving it a very stable carrier frequency. This instrument was also used to measure the wind speed in Titan's atmosphere by measuring the Doppler shift in the carrier signal. The swinging motion of the probe beneath its parachute due to atmospheric properties may also have been detected. Failure of ground controllers to turn on the receiver in the *Cassini* orbiter caused the loss of this data. Earth-based radio telescopes were able to reconstruct some of it. Measurements started 150 kilometres above Titan's surface, where *Huygens* was blown eastwards at more than 400 kilometres per hour, agreeing with earlier measurements of the winds at 200 kilometres altitude, made over the past few years using telescopes. Between 60 and 80 kilometres, *Huygens* was buffeted by rapidly fluctuating winds, which are thought to be vertical wind shear. At ground level, the Earth-based doppler shift and VLBI measurements show gentle winds of a few metres per second, roughly in line with expectations.

Descent Imager/Spectral Radiometer (DISR)

As Huygens was primarily an atmospheric mission, the DISR instrument was optimized to study the radiation balance inside Titan's atmosphere. Its visible and infrared spectrometers and violet photometers measured the up- and downward radiant flux from an altitude of 145 kilometers down to the surface. Solar aureole cameras measured how scattering by aerosols varies the intensity directly around the Sun. Three imagers, sharing the same CCD, periodically imaged a swath of around 30 degrees wide, ranging from almost nadir to just above the horizon. Aided by the slowly spinning probe they would build up a full mosaic of the landing site, which, surprisingly, became clearly visible only below 25 kilometers altitude. All measurements were timed by aid of a shadow bar, which would tell DISR when the Sun had passed through the field of view. Unfortunately, this scheme was upset by the fact that Huygens rotated in a direction opposite to that expected. Just before landing a lamp was switched on to illuminate the surface, which enabled measurements of the surface reflectance at wavelengths which are completely blocked out by atmospheric methane absorption.

DISR was developed at the Lunar and Planetary Laboratory at the University of Arizona under the direction of Martin Tomasko, with several European institutes contributing to the hardware.

Gas Chromatograph Mass Spectrometer (GC/MS)



A worker in the Payload Hazardous Servicing Facility (PHSF) stands behind the bottom side of the experiment platform for the Huygens probe.

This instrument is a versatile gas chemical analyzer that was designed to identify and measure chemicals in Titan's atmosphere. It was equipped with samplers that were filled at high altitude for analysis. The mass spectrometer, a high-voltage quadrupole, collected data to build a model of the molecular masses of each gas, and a more powerful separation of molecular and isotopic species was accomplished by the gas chromatograph. During descent, the GC/MS also analyzed pyrolysis products (i.e., samples altered by heating) passed to it from the Aerosol Collector Pyrolyser. Finally, the GC/MS measured the composition of Titan's surface. This investigation was made possible by heating the GC/MS instrument just prior to impact in order to vaporize the surface material upon contact. The GC/MS was developed by the Goddard Space Flight Center and University of Michigan's Space Physics Research Lab.

Aerosol Collector and Pyrolyser (ACP)

The ACP experiment drew in aerosol particles from the atmosphere through filters, then heated the trapped samples in ovens (using the process of pyrolysis) to vaporize volatiles and decompose the complex organic materials. The products were flushed along a pipe to the GC/MS instrument for analysis. Two filters were provided to collect samples at different altitudes. The ACP was developed by a (French) ESA team at the Laboratoire Inter-Universitaire des Systèmes Atmosphériques (LISA).

Surface-Science Package (SSP)

The SSP contained a number of sensors designed to determine the physical properties of Titan's surface at the point of impact, whether the surface was solid or liquid. An acoustic sounder, activated during the last 100 meters of the descent, continuously determined the distance to the surface, measuring the rate of descent and the surface roughness (e.g., due to waves). The instrument was designed so that if the surface were liquid, the sounder would measure the speed of sound in the "ocean" and possibly also the subsurface structure (depth). During descent, measurements of the speed of sound gave information on atmospheric composition and temperature, and an accelerometer recorded the deceleration profile at impact, indicating the hardness and structure of the surface. A tilt sensor measured pendulum motion during the descent and was also designed to indicate the probe's attitude after landing and show any motion due to waves. If the surface had been liquid, other sensors would also have measured its density, temperature, thermal conductivity, heat capacity, electrical properties (permittivity and conductivity) and refractive index (using a critical angle refractometer). A penetrometer instrument, that protruded 55 mm past the bottom of the *Huygens* probe descent module, was used to create a penetrometer trace as *Huygens* landed on the surface by measuring the force exerted on the instrument by the surface as the instrument broke though the surface and was pushed down into the planet by the force of the probe landing itself. The trace shows this force as a function of time over a period of about 400 ms. The trace has an initial spike which suggests that the instrument hit one of the icy pebbles on the surface photographed by the DISR camera.

The *Huygens* SSP was developed by Space Sciences Department of the University of Kent and the Rutherford Appleton Laboratory Space Science Department under the direction of Professor John Zarnecki. The SSP research and responsibility transferred to the Open University when John Zarnecki transferred in 2000.

Spacecraft design

Application of multi-layer insulation shimmers under bright lighting during final assembly. The gold colour of the MLI is due to light reflecting from the aluminium coating on the back of sheets of amber coloured Kapton.

Huygens was built under the Prime Contractorship of Aérospatiale in its Cannes Mandelieu Space Center, France, now part of Thales Alenia Space. The heat shield system was built under the responsibility of Aérospatiale near Bordeaux, now part of EADS SPACE Transportation.

Parachute

Martin-Baker Space Systems was responsible for *Huygens'* parachute systems and the structural components, mechanisms and pyrotechnics that control the probe's descent onto Titan. IRVIN-GQ was responsible for the definition of the structure of each of *Huygens*' parachutes. Irvin worked on the probe's descent control sub-system under contract to Martin-Baker Space Systems.

A critical design flaw resolved

Long after launch, a few persistent engineers discovered that the communication equipment on *Cassini* had a potentially fatal design flaw, which would have caused the loss of all data transmitted by the *Huygens* probe.

As *Huygens* was too small to transmit directly to Earth, it was designed to transmit the telemetry data obtained while descending through Titan's atmosphere to *Cassini* by radio, which would in turn relay it to Earth using its large 4-meter diameter main antenna. Some engineers, most notably ESA Darmstadt employees Claudio Sollazzo and Boris Smeds, felt uneasy about the fact that, in their opinion, this feature had not been tested before launch under sufficiently realistic conditions. Smeds managed, with some difficulty, to convince superiors to perform additional tests while *Cassini* was in flight. In early 2000, he sent simulated telemetry data at varying power and Doppler shift levels from Earth to *Cassini*. It turned out that *Cassini* was unable to relay the data correctly.

The reason: under the original flight plan, when *Huygens* was to descend to Titan, it would have accelerated relative to *Cassini*, causing the Doppler shift of its signal to vary. Consequently, the hardware of *Cassini*'s receiver was designed to be able to receive over a range of shifted frequencies. However, the firmware failed to take into account that the Doppler shift would have changed not only the carrier frequency, but also the timing of the payload bits, coded by phase-shift keying at 8192 bits per second.

Reprogramming the firmware was impossible, and as a solution the trajectory had to be changed. *Huygens* detached a month later than originally planned (December 2004 instead of November) and approached Titan in such a way that its transmissions traveled perpendicular to its direction of motion relative to *Cassini*, greatly reducing the Doppler shift.

The trajectory change overcame the design flaw for the most part, and data transmission succeeded, although the information from one of the two radio channels was lost due to an unrelated error.

The trajectory change was not the only mitigation to the Doppler shift problem, and software patches were uplinked to several instruments on the probe from the Deutsche Aerospace facility in Darmstadt to further reduce the risk of data loss.

Channel A data lost

Huygens was programmed to transmit telemetry and scientific data to the *Cassini* orbiter for relay to Earth using two redundant S-band radio systems, referred to as Channel A and B, or Chain A and B. Channel A was the sole path for an experiment to measure wind speeds by studying tiny frequency changes caused by *Huygens*'s motion. In one other deliberate departure from full redundancy, pictures from the descent imager were split up, with each channel carrying 350 pictures.

As it turned out, *Cassini* never listened to channel A because of an operational commanding error. The receiver on the orbiter was never commanded to turn on, according to officials with the European Space Agency. ESA announced that the program error was a mistake on their part, the missing command was part of a software program developed by ESA for the *Huygens* mission and that it was executed by *Cassini* as delivered.

The loss of Channel A means only 350 pictures were received instead of the 700 planned. Also all Doppler radio measurements between *Cassini* and *Huygens* were lost. Doppler radio measurements of *Huygens* from Earth were made, though not as accurate as the expected measurements that *Cassini* would have made; when added to accelerometer sensors on *Huygens* and VLBI tracking of the position of the *Huygens* probe from Earth, reasonably accurate wind speed and direction measurements could still be derived.

Chapter- 12

Planck (Spacecraft)

Planck

General information

NSSDC ID	2009-026B
Organization	European Space Agency with Thales Alenia Space as Prime Contractorship
Launch date	2009-05-14 13:12:02 UTC
Launched from	Guiana Space Centre French Guiana
Launch vehicle	Ariane 5 ECA

Mission length	elapsed: 1 year, 9 months, and 10 days
Location	1.5 million km (L2 Lagrangian point)
Wavelength	350 to 10,000 μm
Instruments	
Low Frequency Instrument (LFI)	30–70 GHz receivers
High Frequency Instrument (HFI)	100–857 GHz receivers
Website	Planck Science Team Home

Planck is a space observatory launched in 2009 designed to observe the anisotropies of the cosmic microwave background (CMB) over the entire sky, using high sensitivity and angular resolution. Planck was built in the Cannes Mandelieu Space Center by Thales Alenia Space and created as the third Medium-Sized Mission (M3) of the European Space Agency's Horizon 2000 Scientific Programme. The project, initially called COBRAS/SAMBA, is named in honour of the German physicist Max Planck (1858–1947), who won the Nobel Prize for Physics in 1918.

Planck was launched in May 2009, reaching the Earth/Sun's L_2 Lagrangian point in July, and by February 2010 had successfully started a second all-sky survey. Preliminary data from these surveys have been released, and results are said to indicate that the data quality is excellent. Planck is expected to yield definitive data on a number of astronomical issues by 2012. The mission will complement and improve upon observations made by the NASA Wilkinson Microwave Anisotropy Probe (WMAP), which has measured the anisotropies at larger angular scales and lower sensitivity than Planck. Planck will provide a major source of information relevant to several cosmological and astrophysical issues, such as testing theories of the early universe and the origin of cosmic structure.

Objectives

The mission has a wide variety of scientific aims, including:

- High resolution detections of both the total intensity and polarization of the primordial CMB anisotropies
- Creation of a catalogue of galaxy clusters through the Sunyaev-Zel'dovich effect
- Observations of the gravitational lensing of the CMB, as well as the integrated Sachs–Wolfe effect

- Observations of bright extragalactic radio (active galactic nuclei) and infrared (dusty galaxy) sources
- Observations of the Milky Way, including the local interstellar medium, distributed synchrotron emission and measurements of the galactic magnetic field.
- Studies of the local Solar System, including planets, asteroids, comets and the zodiacal light.

Planck represents an advance over WMAP in several respects.

- It has higher resolution, allowing it to probe the power spectrum of the CMB to much smaller scales (x3).
- It has higher sensitivity (x10).
- It observes in 9 frequency bands rather than 5, with the goal of improving the astrophysical foreground models.

It is expected that most Planck measurements will be limited by how well foregrounds can be subtracted, rather than by the detector performance or length of the mission. This is particularly important for the polarization measurements. The dominant foreground depends on frequency, but examples include synchrotron radiation from the Milky Way Galaxy at low frequencies, and dust at high frequencies.

Instruments

The spacecraft carries two instruments; the Low Frequency Instrument (LFI) and the High Frequency Instrument (HFI). Both instruments can detect both the total intensity and polarization of photons, and together cover a frequency range of 30 to 857 GHz. The cosmic microwave background spectrum peaks at a frequency of 160.2 GHz

Low Frequency Instrument

Frequency (GHz)	Bandwidth ($\Delta\nu / \nu$)	Resolution (arcmin)	Sensitivity (total intensity) $\Delta T / T$, 14 month observation (10^{-6})	Sensitivity (polarization) $\Delta T / T$, 14 month observation (10^{-6})
30	0.2	33	2.0	2.8
44	0.2	24	2.7	3.9
70	0.2	14	4.7	6.7

The LFI has three frequency bands, covering the range of 30–70 GHz. The detectors use High Electron Mobility Transistors.

High Frequency Instrument

Frequency (GHz)	Bandwidth (Δν / ν)	Resolution (arcmin)	Sensitivity (total intensity) $\Delta T / T$, 14 month observation (10^{-6})	Sensitivity (polarization) $\Delta T / T$, 14 month observation (10^{-6})
100	0.33	10	2.5	4.0
143	0.33	7.1	2.2	4.2
217	0.33	5.5	4.8	9.8
353	0.33	5.0	14.7	29.8
545	0.33	5.0	147	N/A
857	0.33	5.0	6700	N/A

The HFI has six frequency bands, between 100 and 857 GHz. They use bolometers to detect photons. The four lower frequency bands have sensitivity to linear polarization; the two higher bands do not.

Telescope

The telescope design is an off-axis tilted Gregorian system , offering the advantages of no blocking of the optical path combined with compactness. Both the primary mirror and the secondary mirror are off-axis. The eccentricity and tilt angle of the secondary mirror and the off-axis angle obey the Dragone-Mizuguchi condition, which allows the system to operate without significant degradation over a large focal plane array, while simultaneously minimizing the polarization effects introduced by the telescope.

The baffling system is composed of two elements. The shield element is a large, self-supporting and roughly conical structure covered with multi-layer insulation (MLI), which surrounds the telescope and focal plane instruments. Together with the optical bench, it defines the optical enclosure. It has two important functions, reducing the level of stray light (which at the chosen orbit is in large part due to the spacecraft itself) and promoting the radiative cooling of the optical enclosure towards deep space. The baffle element consists of one half of a conically shaped surface that links the focal plane instruments to the bottom edge of the sub-reflector. The function of the baffle is to shield the detectors from thermal radiation originating within the optical enclosure.

Telescope characteristics

Type: Off-axis tilted Gregorian

Primary mirror: 1.9 × 1.5 m, off-axis paraboloid

Secondary mirror: 1.1 × 1.0 m, off-axis paraboloid

NASA

NASA played a role in the development of the mission and will contribute to the analysis of science data. Its Jet Propulsion Laboratory built components of the science instruments, including bolometers for the high-frequency instrument, a 20 Kelvin cryocooler for both the low- and high-frequency instruments, and amplifier technology for the low-frequency instrument.

Service Module – a common development for Herschel and Planck

A common service module (SVM) was designed and built by Thales Alenia Space in its Turin plant, for both the Herschel Space Observatory and Planck missions, combined into one single program.

Structurally the Herschel and Planck SVM's are very similar. Both SVM's are of octagonal shape and for both, each panel is dedicated to accommodate a designated set of warm units, while taking into account the dissipation requirements of the different warm units, of the instruments as well as the spacecraft.

Furthermore, on both spacecraft a common design for the avionics, the attitude control and measurement system (ACMS) and the command and data management system (CDMS), and power subsystem and the tracking, telemetry and command subsystem (TT&C) has been achieved.

All spacecraft units on the SVM are redundant.

Power Subsystem

On each spacecraft, the power subsystem consists of the solar array, employing triple-junction solar cells, a battery and the power control unit (PCU). It is designed to interface with the 30 sections of each solar array, provide a regulated 28 V bus, distribute this power via protected outputs and to handle the battery charging and discharging.

For Planck, the circular solar array is fixed on the bottom part of the satellite, facing always the sun, as the satellite is spinning around its vertical axis.

Attitude and Orbit Control

This function is performed by the attitude control computer (ACC) which is the platform for the ACMS. It is designed to fulfil the pointing and slewing requirements of the Herschel and Planck payload.

The Planck satellite is spun at one revolution per minute, the absolute pointing error needs to be less than 37 arc min. For Planck being a survey platform, there is also a requirement to be met on pointing reproducibility error to be less than 2.5 arc min over 20 days.

The main sensor of the line of sight in both spacecraft is the star tracker.

Launch and orbit

The satellite was successfully launched, along with the Herschel Space Observatory, at 13:12:02 on 14 May 2009 aboard an Ariane 5 ECA heavy launch vehicle. The launch placed the craft into a very elliptical orbit (perigee: 270 km, apogee: more than 1,120,000 km), bringing it near the L_2 Lagrangian point of the Earth-Sun system, 1.5 million kilometers from the Earth.

The maneuver to inject Planck into its final orbit around L_2 was successfully completed on July 3, 2009, when it entered a Lissajous orbit of 400,000 km radius around the L_2 Lagrangian point. The temperature of the High Frequency Instrument reached just a tenth of a degree above absolute zero (0.1 K) on July 3, 2009, placing both the Low Frequency and High Frequency Instruments within their cryogenic operational parameters, making Planck fully operational.

Results

A part of the *Herschel Planck team*, from left to right : Jean-Jacques Juillet, Head of scientific programmes Thales Alenia Space ; Marc Sauvage, CEA, responsible Herschel PACS Experience ; François Bouchet, IAP, responsible Planck exploitation ; Jean-Michel Reix, Head of Herschel & Planck Programmes, Thales Alenia Space, for the presentations of the first results of Herschel & Planck missions, Cannes, October 2009

Planck started its First All-Sky Survey on 13 August 2009. In September 2009, the European Space Agency announced the preliminary results from the *Planck First Light Survey* (performed to demonstrate the stability of the instruments and the ability to calibrate them over long periods). The results indicated that the data quality is excellent.

On 15 January 2010 the mission was extended by 12 months, with observation continuing until at least the end of 2011. After the successful conclusion of the First Survey, the spacecraft started its Second All Sky Survey on 14 February 2010, with more than 95% of the sky observed already and 100% sky coverage being expected by mid-June 2010.

Some planned pointing list data from 2009 have been released publicly, along with a video visualization of the surveyed sky. The first results are scheduled for release during a conference in Paris from the 10–14 January 2011, and the final results (with all processed data) are expected to be delivered to the worldwide community towards the end of 2012.

On 17 March 2010 the first Planck photos were published, showing dust concentration within 500 light years from the Sun.

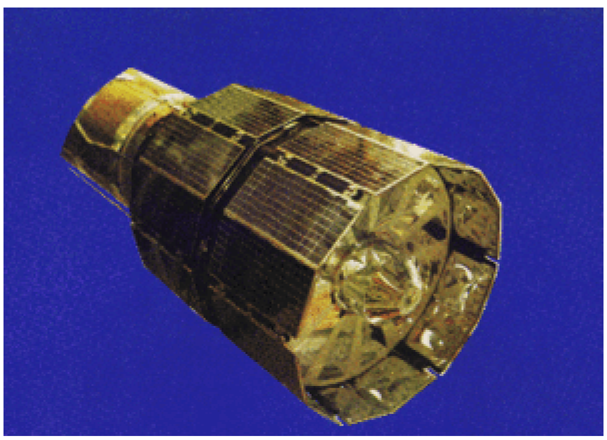
On 5 July 2010, the Planck mission delivered its first all-sky image.

Chapter- 13

Other European Space Agency Probes

ESRO 2B

ESRO 2B



Iris was mainly intended to study X-ray and particle emissions from the Sun; however, it is credited with some extra-solar observations.

Operator	European Space Research Organization (ESRO)
Mission type	Solar Physics
Satellite of	Earth
Orbits	16,282
Launch date	May 17, 1968 at 02:09:00 UTC
Launch vehicle	Scout #62

Launch site	Vandenberg AFB, United States
Mission duration	1104 days
COSPAR ID	1968-041A
Mass	89.8 kg
	Orbital elements
Regime	near polar orbit
Eccentricity	0.0529
Inclination	97.2°
Apoapsis	1085.0 km
Periapsis	334.0 km
Orbital period	98.9 min.
Orbits per day	14.56

After many revisions of the original satellite program, **ESRO 2B** (Iris) became the first successful European Space Research Organization (ESRO) satellite. ESRO was an international organization founded in 1964 by 10 European nations with the intent to jointly pursue scientific research in space.

Iris was launched on May 17, 1968, had an elliptical orbit with initially apogee of 1086 km, perigee 326 km, and inclination 97.2°. Its orbital period was 98.9 minutes. It re-entered the Earth's atmosphere on May 8, 1971.

Instruments

The satellite carried seven instruments to detect high energy cosmic-ray electrons, determine the total flux of solar X-rays, and measure trapped radiation, Van Allen belt protons, and cosmic ray protons. Of special significance for X-ray astronomy were two X-ray instruments: one designed to detect wavelengths 1-20 Å (0.1-2 nm) (consisting of proportional counters with varying window thickness) and one designed to detect wavelengths 44-60 Å (4.4-6.0 nm) (consisting of proportional counters with thin mylar windows).

Wavelength dispersive X-ray spectroscopy

Wavelength dispersive X-ray spectroscopy (WDS) is a method used to count the number of X-rays of a specific wavelength diffracted by a crystal. WDS only counts X-rays of a single wavelength or wavelength band. In order to interpret the data, the expected elemental wavelength peak locations need to be known. For the ESRO-2B WDS X-ray instruments, calculations of the expected solar spectrum had to be performed and were compared to peaks detected by rocket measurements.

Scientific accomplishments

Iris has been used to investigate changes in the geomagnetic cutoff latitude for low-energy (> 2 MeV) solar protons and comparisons with changes in the high-latitude boundary of trapped energetic electrons during a magnetically disturbed period. These solar protons become trapped and are transported during magnetospheric substorms to lower latitudes.

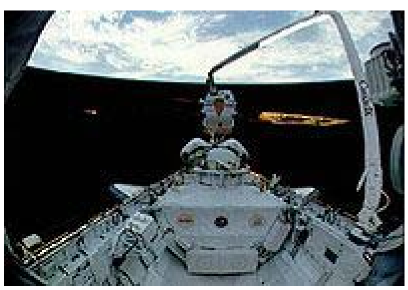
Geomagnetically trapped protons in the inner Van Allen zone have been investigated in the energy range of 30 - 300 MeV with the solid state telescope aboard ESRO 2B. Two separate proton injection mechanisms appear to be operating:

1. a main component (first population) at energies lower than 25 MeV and
2. a second population at energies higher than 30 MeV combined with the high-energy tail of the first component.

The spectrum of the second population has a characteristic shape suggestive of a spectrum altered by ionization losses and generated by a continuous source.

European Retrievable Carrier

European Retrievable Carrier



EURECA deployment in 1992

Operator	ESA
Mission type	Orbiter
Satellite of	Earth
Launch date	1992-08-02
Launch vehicle	Shuttle

COSPAR ID	1992-049B
Mass	4490 kg
Power	1000 W
	Orbital elements
Eccentricity	6.597756873816252E-4
Inclination	28.5°
Apoapsis	447 km
Periapsis	438 km
Orbital period	93.4000015258789 min

EURECA retrieval in 1993

The **European Retrievable Carrier** (**EURECA**) was an unmanned 4.5 tonne satellite with 15 experiments. It was an ESA mission and the acronym was derived from Archimedes' bathtub revelation; Eureka!

It was built by the German MBB-ERNO and had automatic material science cells as well as small telescopes for Solar observation (including x-ray).

It was launched 31 July 1992 by STS-46 - *Atlantis*, and put into an orbit at an altitude of 508 km. EURECA was retrieved on 1 July 1993 by STS-57- *Endeavour* and returned to Earth. It was designed to fly five times with different experiments but the following flights were cancelled.

EURECA is one of the few unmanned space vehicles that have been returned to the Earth unharmed. EURECA has been on display at the Swiss Transport Museum in Lucerne since 2000.

Configuration

EURECA was made of high-strength carbon-fiber struts and titanium nodal points joined together to form a framework of cubic elements. Thermal control on EURECA combined both active and passive heat transfer and radiation systems. Active heat transfer was achieved by means of a freon cooling loop which dissipated the thermal load through two radiators into space. The passive system made use of multilayer insulation blankets combined with electrical heaters.

The electrical subsystem was powered by deployable and retractable solar arrays together with four 40 amp-hour nickel-cadmium batteries. When EURECA was in the Shuttle cargo bay, power was supplied by the Shuttle. The modular attitude and orbit control subsystem (AOCS) maintained attitude and spacecraft orientation and stabilization. An orbit transfer assembly, consisting of four thrusters, was used to boost EURECA to its operational attitude (515 km) and return it to retrievable orbit (about 300 km).

EURECA was three-axis stabilized by means of a magnetic torque assembly together with a nitrogen reaction control assembly (RCA). Data handling was carried out by EURECAs data handling subsystem (DHS) supported by telemetry and command subsystems providing the link to the ground station.

Experiments

EURECA consisted of 15 experiments:

- Solution Growth Facility (SGF) (Belgium)
- Protein Crystallization Facility (PCF) (Germany)
- Exobiology and Radiation Assembly (ERA) (Germany)
- Multi-Furnace Assembly (MFA) (Italy)

- Automatic Mirror Furnace (AMF) (Germany)
- Surface Forces Adhesion Instrument (SFA) (Italy)
- High Precision Thermostat Instrument (HPT) (Germany)
- Solar Constant and Variability Instrument (SOVA) (Belgium)
- Solar Spectrum Instrument (SOSP) (France)
- Occultation Radiometer Instrument (ORI) (Belgium)
- Wide Angle Telescope (WATCH) (Denmark)
- Timeband Capture Cell Experiment (TICCE) (Great Britain)
- Radio Frequency Ionization Thruster Assembly (RITA) (Germany)
- Inter-Orbit Communications (IOC) (France/the Netherlands)
- Advanced Solar Gallium Arsenide Array (ASGA) (Italy)

Solar Orbiter

	Solar Orbiter
Operator	European Space Agency (ESA) NASA
Mission type	Orbiter
Satellite of	The Sun
Launch date	January 2017
Carrier rocket	Atlas V-401 or Delta IV (backup)
Mission duration	7 years (nominal)
Homepage	http://sci.esa.int/solarorbiter
	Orbital elements
Inclination	30°
Altitude	3,340,000 km (2,080,000 mi)
Apoapsis	~60 R_S (0.284 AU)

Solar Orbiter (**SOLO**) is a proposed Sun-observing satellite, under study by the European Space Agency (ESA). The main mission scenario is a launch by an Atlas V from the Kennedy Space Center in Florida in January 2017. If selected, SOLO will perform unprecedented detailed measurements of the inner heliosphere and nascent solar wind, and perform close observations of the polar regions of the Sun, which is difficult to do from Earth, both serving to answer the question 'How does the Sun create and control the heliosphere?' The Solar Orbiter will make observations of the Sun from distances as close as 60 solar radii (R_S), or 0.284 astronomical units (AU). (Just inside Mercury's perihelion of 0.3075 AU.)

Scientific objectives

- How and where do the solar wind plasma and magnetic field originate in the corona?
- How do solar transients drive heliospheric variability?
- How do solar eruptions produce energetic particle radiation that fills the heliosphere?
- How does the solar dynamo work and drive connections between the Sun and the heliosphere?

Payload

Observation packages of baseline mission definitions:

Heliospheric in-situ instruments

- Solar Wind Analyser (SWA): To measure solar wind properties and composition
- Energetic Particle Detector (EPD): To measure suprathermal ions, electrons, neutral atoms, as well as energetic particles in the energy range from few keV/nuc to relativistic electrons and ions up to 100 MeV (protons) and 200 MeV/nuc (heavy ions)
- Magnetometer (MAG): will provide detailed measurements of the magnetic field
- Radio and Plasma Wave analyser (RPW): To measure magnetic and electric fields at high time resolution

Solar remote-sensing instruments

- Polarimetric and Helioseismic Imager (PHI): To provide high-resolution and full-disk measurements of the photospheric magnetic field
- EUV full-Sun and high-resolution Imager (EUI): To image various layers of the solar atmosphere
- EUV spectral Imager (SPICE): To provide spactral imaging of solar disk and corona, characterize plasma properties at the Sun
- X-ray spectrometer/telescope (STIX): To provide imaging spectroscopy of thermal and non-thermal solar X-ray emission from 4 to 150 keV
- Coronagraph (METIS/COR): To provide broad-band, narrow-band, and polarized imaging of the corona
- Heliospheric Imager (SoloHI): To image quasi-steady and transient flows of the solar wind