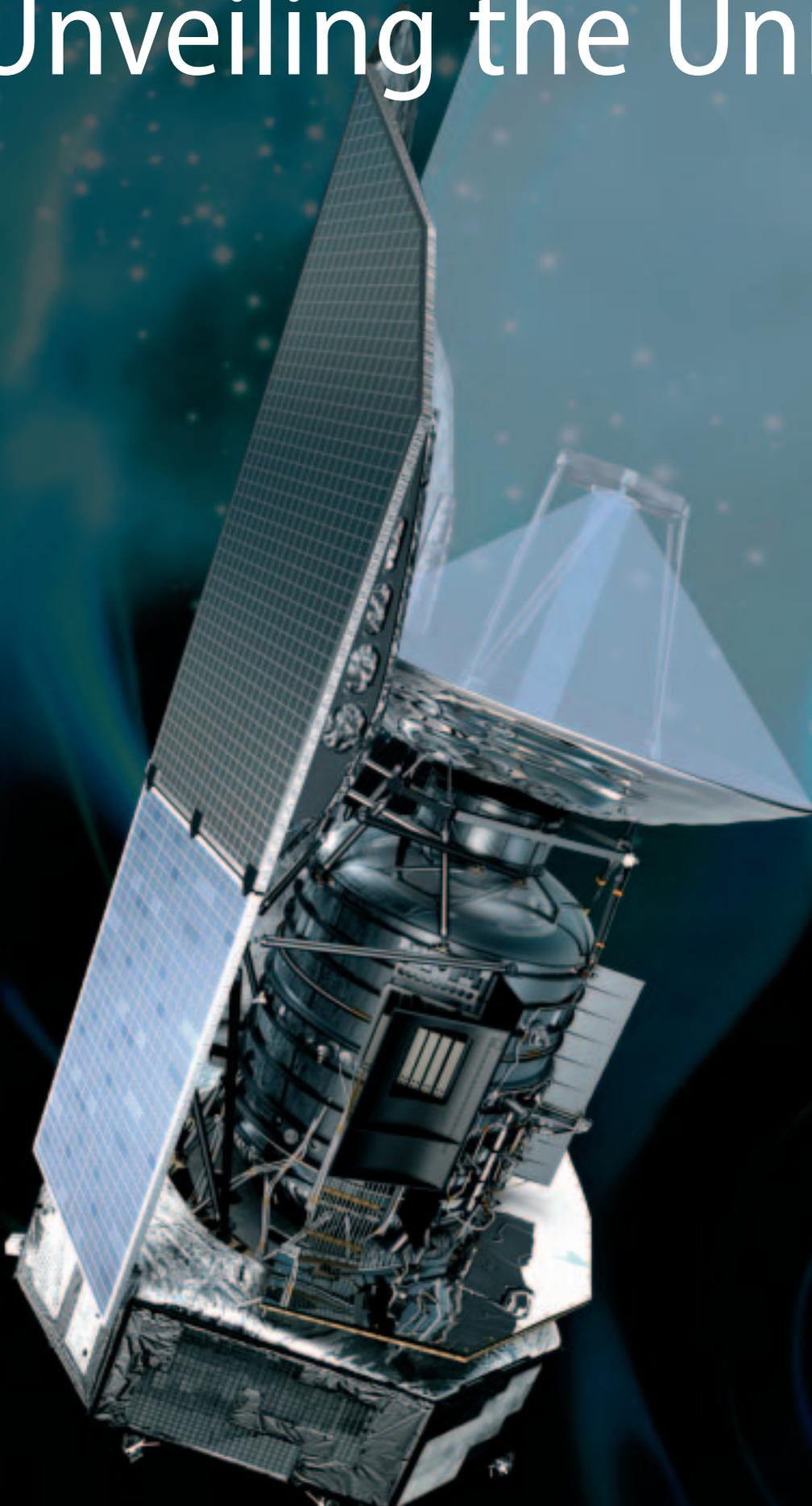
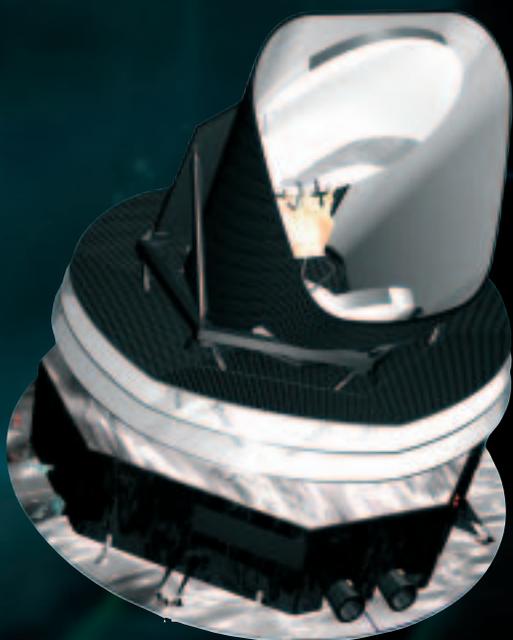


Unveiling the Universe





Two Missions to Unlock the Secrets of the Cold Cosmos

*Two pioneering missions: Herschel
(left) and Planck (inset)*

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In 2008, an Ariane-5 will lift off from French Guiana carrying ESA's two pioneering Herschel and Planck deep space observatories to explore previously unknown regions of the Universe. Their target is the 'bright' part of the far-infrared spectrum that has tantalised scientists for decades. Until now, the technology has not existed to make precise observations of a distant domain that touches the very beginning of time.

Introduction

Herschel, detecting light emitted in the sub-millimetre and far-infrared range of the spectrum that is blocked from reaching Earth by our atmosphere, will reveal phenomena previously obscured from view, such as the very earliest galaxies and stars.

The Planck telescope, observing in a different part of the far-infrared spectrum with the highest precision ever, will investigate cosmic background radiation – the remnants of the radiation that filled the Universe immediately after the Big Bang some 14 billion years ago.

Extreme sensitivity is needed to measure the faint heat signatures of this



The Herschel spacecraft is 7.5 m high and 4x4 m across, with a launch mass of 3.3 t. The Payload Module consists of the telescope (a mirror mass-dummy is seen here at ESTEC) and an optical bench carrying the parts of the instruments that need to be cooled. A sunshield protects the telescope and cryostat from solar heating and prevents stray light from Earth entering the telescope; it also carries solar cells to generate the spacecraft's power

'cold' part of the cosmos, so the detectors on both Herschel and Planck have to operate at very low and stable temperatures. The spacecraft therefore cool their detectors close to absolute zero, ranging from 20K (-253°C) to only a few tenths of a degree above the -273°C of absolute zero.

The 3-axis stabilised Herschel fits the traditional notion of an observatory by pointing at specific targets on request or according to a flexible schedule agreed by scientists.

Herschel achieves its low cryostat temperatures by employing a 'thermos bottle' technique, boiling off helium at a controlled rate to keep the telescope receivers cool. The spin-stabilised Planck, on the other hand, uses passive cooling complemented by a series of three active refrigerators.

To provide the necessary cold and stable environment, the observatories will be positioned at the second Lagrange point (commonly known as L2), Herschel for its nominal mission lifetime of some 3.5 years and Planck for up to about 2 years. L2 is a virtual point in space, some 1.5 million km beyond the Earth as viewed from the Sun, where their gravitational forces of are balanced. Spacecraft can orbit this

point, just like circling a planet, with a period of about 6 months.

The thermally benign L2 environment offers stable radio links to Earth and unbroken observing time, making it a preferred location in the coming years for international observatories of this kind.

Herschel and Planck Science

Herschel will look deep into the far-infrared and sub-millimetre range that bridges the gap between what can be observed from ground or airborne facilities and earlier space missions, such as ESA's Infrared Space Observatory (ISO) of 1995–1998.

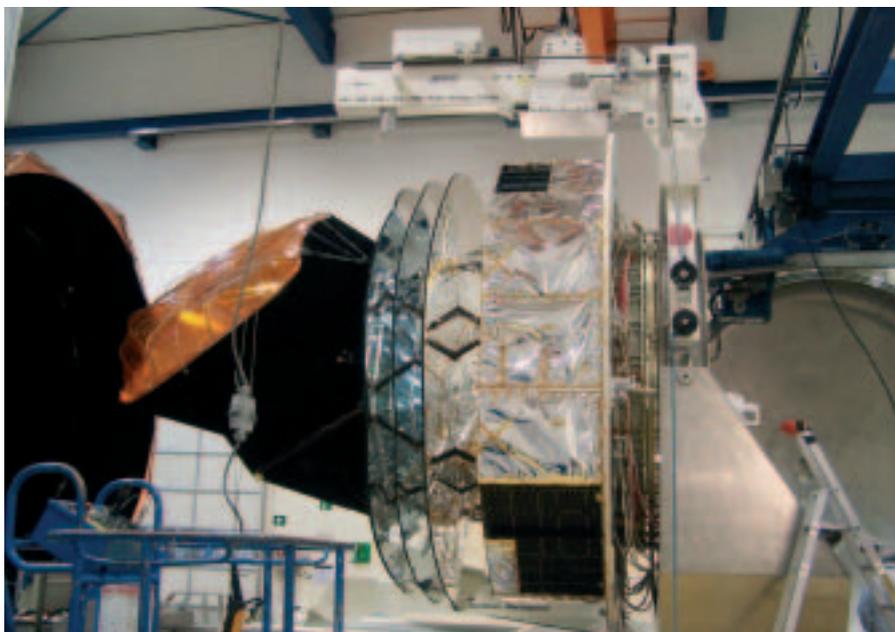
Radiation in this part of the spectrum not only passes through interstellar gas and dust but it is also emitted by the very same gas and dust. That means 'cold' objects, invisible to other types of telescopes, can be viewed.

Herschel's targets include clouds of gas and dust where new stars are being born, discs that may form planets, and the atmospheres of comets packed with complex organic molecules.

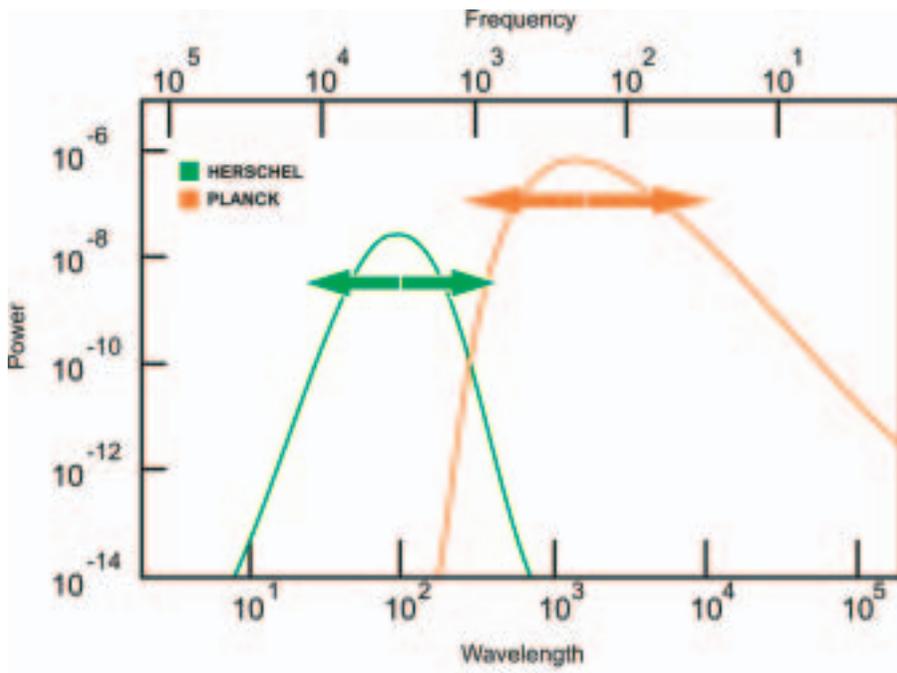
Two-thirds of Herschel's observation time will be available to the world scientific community, with the remainder reserved for the spacecraft's science and instrument teams.

Herschel's far-infrared and sub-millimetre wavelengths are considerably longer than the rainbow of colours familiar to the human eye. This is a critically important portion of the spectrum to scientists because it is here where a large part of the Universe radiates its energy.

Much of the Universe consists of gas and dust that is far too cold to radiate in visible light or at shorter wavelengths such as X-rays. However, even at temperatures well below the most frigid spot on Earth, they do shine in the far-infrared and sub-millimetre. Stars and other cosmic objects that are hot enough



Planck is 4.2 m high and has a maximum diameter of 4.2 m, with a launch mass of 1.8 t



The infrared sky background showing the frequency ranges targeted by Herschel and Planck

to radiate in visible light are often hidden behind vast dust clouds that absorb the energy and reradiate it at Herschel’s wavelengths.

There is a lot to see at these wavelengths, and much of it has been virtually unexplored. Previous space-based infrared telescopes have had neither the sensitivity of Herschel’s large mirror nor the ability of Herschel’s three instruments to do such a comprehensive job of sensing this important part of the spectrum.

Planck, on the other hand, will continuously map the whole sky at a wide range of frequencies, enabling the separation of the galactic and extragalactic foreground radiation from the primordial background. Its ultimate goal is to produce a map of the tiny irregularities known to exist in the Cosmic Microwave Background (CMB) field.

Work in this area began with NASA’s Cosmic Background Explorer (COBE) and Wilkinson Microwave Anisotropy

Probe (WMAP) spacecraft, both of which detected temperature fluctuations in the CMB radiation, leading to strong support of what is known as the ‘inflationary’ Big Bang model to explain the origin and evolution of the Universe.

In spite of the importance of the COBE and WMAP measurements, however, many fundamental cosmological questions remain open. Planck’s main objective takes it beyond its predecessors: measuring the CMB fluctuations with far greater precision. This will allow scientists to address fundamental questions, such as the initial conditions for evolution in the Universe’s structure, the origin of structure in the Universe, the nature and amount of dark matter and the nature of dark energy (see box). Planck will also set constraints on theories involving high-energy particle physics that cannot be reached by experiments on Earth.

The mission’s main observational result will be an all-sky map of the temperature fluctuations in the CMB. To achieve this, Planck will survey the sky at nine frequencies that bracket the ‘peak’ of the CMB infrared spectrum. These maps will include not only the CMB itself but also all the foreground emissions, whether galactic or extragalactic in origin. All nine maps will be combined by careful processing to create a single map of the CMB variations (see box).

A Common Heritage

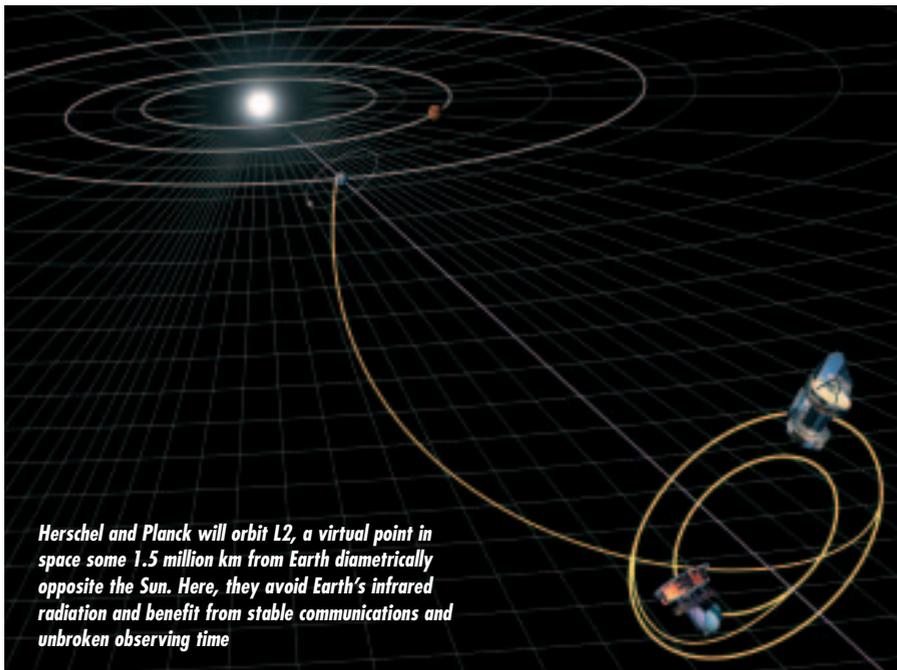
The Herschel and Planck spacecraft are broadly similar in that they have clear separations between the Service Module (housing all the electronics for spacecraft and instrument command and control) and the Payload Module, which carries the sensitive detectors and cryogenic telescopes.

Although the Payload Modules are quite different, the Service Modules feature many common aspects, with almost identical electrical and avionics systems.

‘Dark matter’ is a term coined to describe matter that does not emit or reflect enough electromagnetic radiation (such as light or X-rays) to be detected directly, but whose presence may be inferred from its gravitational effects on visible matter. Observed phenomena hinting at dark matter include the rotational speeds of galaxies, the orbital velocities of galaxies in clusters, and the temperature distribution of hot gas in galaxies and clusters of galaxies. It has been suggested that such objects, and the Universe as a whole, contain far more matter than is directly observable, indicating that the remainder is dark. Its composition is unknown but may include elementary particles.

The hypothetical ‘dark energy’ permeates all of space and has a strong negative pressure. According to the Theory of Relativity, the effect of such a negative pressure is similar to a force acting in opposition to gravity at large scales. Invoking this effect is currently the most popular method for explaining recent observations that the Universe appears to be expanding at an accelerating rate, as well as accounting for a significant portion of the energy in the Universe.

Discovered in 1965, the **Cosmic Microwave Background** was produced in the Universe’s infancy and now fills it entirely. Most cosmologists consider it to be one of the fundamental pieces of evidence for the Big Bang model of the Universe.



Herschel and Planck will orbit L2, a virtual point in space some 1.5 million km from Earth diametrically opposite the Sun. Here, they avoid Earth's infrared radiation and benefit from stable communications and unbroken observing time

The main functional difference between the two spacecraft is in attitude measurement and control. Herschel uses reaction wheels for 3-axis stabilisation, while Planck carries small thrusters for accurately reorienting its spin axis.

Even so, the observatories have a significant number of identical units, such as the star trackers which use the same hardware but different software to accommodate for the varying requirements of each mission.

The propulsion systems of both Service Modules also employ identical components. Planck has three propellant tanks for adjusting its injection into L2 after release by Ariane-5 and to feed the main push into the tighter orbit around L2, while two tanks are sufficient for Herschel's injection corrections. Ariane-5 will release the two into a direct transfer orbit that means they would naturally circle L2 without further propulsion.

Though the same thrusters are used, they are laid out differently to cater for the specific directional requirements and unique attitude restrictions of the two spacecraft.

The structure of each Service Module is essentially the same, although the majority of the equipment panels differ in their detailed designs in order to

satisfy the specific thermal-mechanical requirements of the instruments.

Mission control

ESA's single ground station for controlling both missions is in New Norcia, Australia. The L2 orbital parameters mean that contact with each spacecraft occurs for just a few hours every night (daytime in Europe).

As a result, Herschel and Planck are both designed for minimal ground intervention during normal operations, functioning independently of ground control by following an onboard timeline programme that contains all the commands necessary to carry out the regular operations of the day.

During the daily periods of contact, lasting about 3 hours, science data recorded during the previous day are downloaded and the commands for the next autonomous period uploaded.

Each spacecraft is also programmed to continue nominal science operations in the event of a single onboard equipment failure, when a spare unit would automatically switch on to take over.

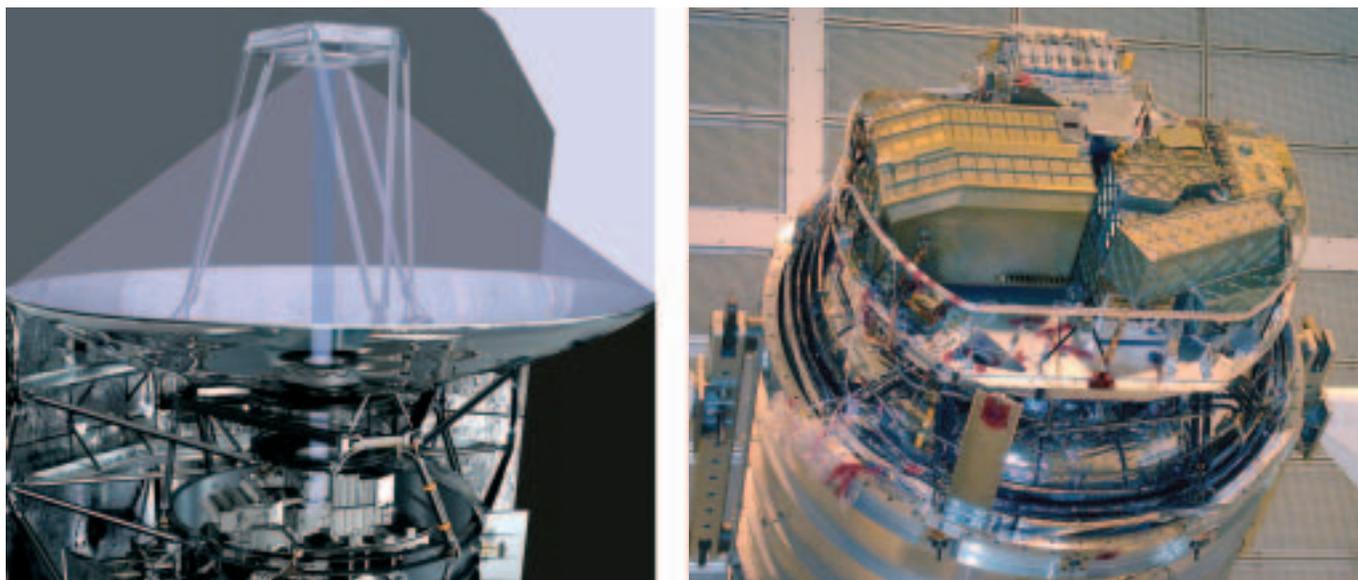
However, failures of more complex functions (perhaps within the computers) or combinations of failures leading to unspecified situations will not have autonomous recovery. If that happens, the effects are contained as far as possible and the spacecraft reconfigured automatically into its safe mode until ground controllers can restore operations.

The Herschel Payload

The Herschel telescope is a Cassegrain



By space standards, Herschel's 3.5 m-diameter mirror is a giant, the largest ever sent into space and a technological challenge. In comparison, the Hubble Space Telescope has a 2.4 m-diameter main mirror



The Focal Plane Units of PACS, SPIRE and HIFI are mounted above Herschel's cryostat at the telescope's focus

design with a primary mirror diameter of 3.5 m (the largest ever built for space) to focus light on three supercooled instruments.

In order to have the sensitivity to detect far-infrared and sub-millimetre radiation, parts of the instruments have to be cooled almost to absolute zero. The shared optical bench that carries all of the instruments is contained within the cryostat to maintain the low temperature. Some 2300 litres of liquid helium (at 1.7 K) will be used during the mission for primary cooling. To achieve the very lowest temperatures, individual detectors are equipped with additional, specialised cooling systems.

The elaborate cooling system maximises the overall cooling power, providing just the right amount at different temperature stages to satisfy local needs. Around 180 gm of helium is used per day, allowing the 3.5-year mission lifetime.

The whole cryostat assembly is protected from direct sunlight by a fixed shade, which also doubles as a solar panel to generate the 1500 W required to operate the entire satellite. The shield also significantly reduces any stray light and heat from the Earth and Moon in the orbit around L2.

International teams have developed Herschel's three scientific instruments.

Both direct-detection instruments, the Photodetector Array Camera and Spectrometer (PACS) and the Spectral and Photometric Imaging Receiver (SPIRE), incorporate cameras. The third instrument, the Heterodyne Instrument for the Far-Infrared (HIFI), is a complementary very high-resolution spectrometer.

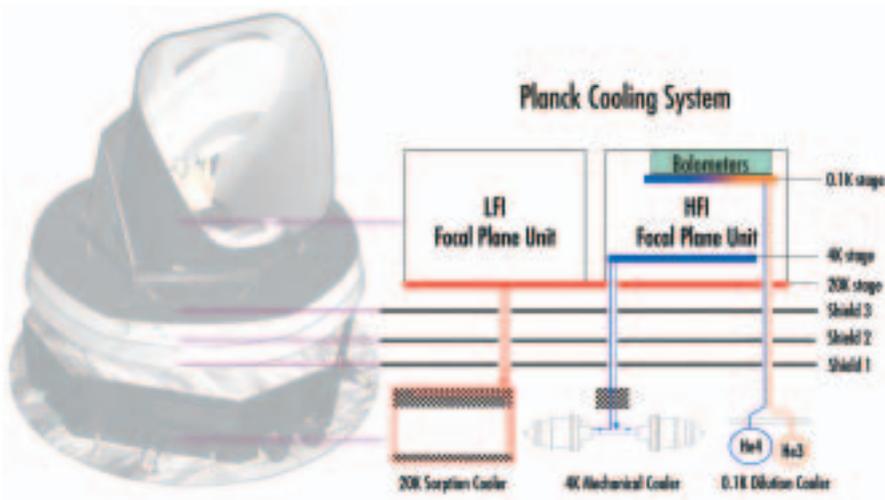
The size of Herschel's mirror meant that it could not be built in a single piece but instead had to be constructed from

12 separate petals, thus becoming the first segmented space mirror as well as the largest to date, weighing 240 kg with an average thickness of about 20 cm and a front face thickness of 2–3 mm.

Although the main technical challenges were in the instruments' focal-plane units (such as the optics, detectors and mechanisms), low-noise readout electronics and coolers, similar issues had to be faced within the spacecraft itself.



The Focal Plane Unit of Herschel's HIFI being prepared for cryogenic vibration testing at 20K



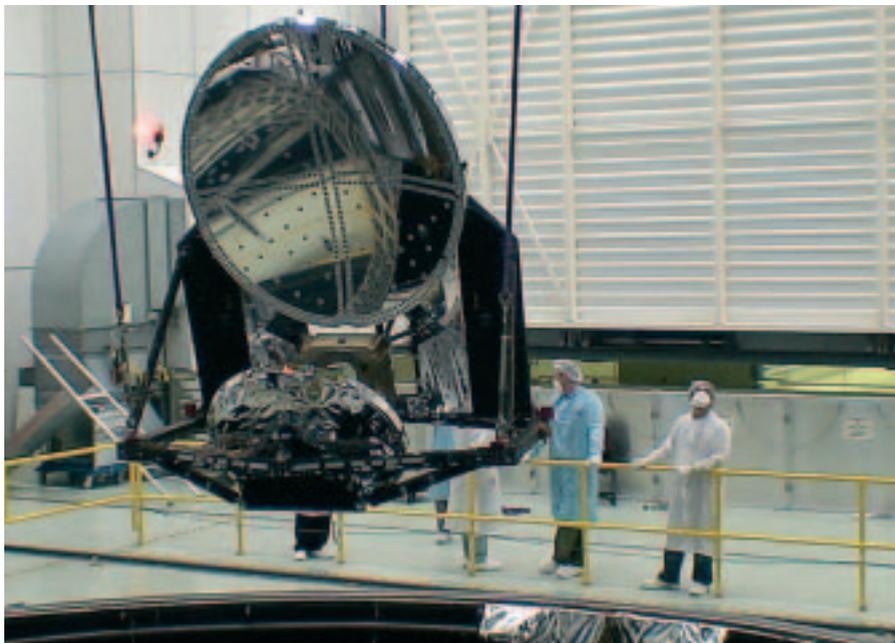
Planck's cryocooling chain

Herschel's cryostat design was inherited from ESA's successful ISO mission, but it was still a major challenge to design capable instruments with very low heat demands on the cryogenic cooling system in order to reach the mission's desired lifetime.

The lightweight carbon-fibre sunshield was difficult to build and, owing to the high operating temperature (140–170°C) of the solar cells, its triple-junction gallium arsenide cells had to be further qualified beyond their standard usage of 80–100°C.

Other technical issues that had to be overcome during manufacture included the mass-optimised carbon-fibre face sheets, which had to be re-manufactured several times to find the best compromise between flatness, strength and mass.

The design requirements on the primary mirror were also demanding. It has to be light enough to be placed into a distant orbit 1.5 million km from Earth but have an extremely smooth surface, polished to make it so uniform that its bumps are smaller than a few



Planck's LFI, an array of radiometers, under calibration testing

thousandths of a millimetre. Equally important, it has to be strong enough to withstand harsh conditions. At launch it will be shaken with a force several times that of Earth gravity before going through drastic temperature changes, from about 20°C at launch to an average of –200°C in space.

The mirror segments are built from silicon carbide, a stable material with the combined advantages of metal and glass. It is light and easily polishable, resists stress and fatigue, and withstands low and high temperatures without any notable changes of mechanical and thermal properties.

The Planck Payload

The overall design of Planck's Payload Module emerged from a design process that had to satisfy competing needs: shielding the sensitive radiometers from the heat of the satellite and microwave radiation from the Sun, Earth and Moon, while generating an all-sky map by slowly spinning once every minute around an axis pointing directly away from the Sun.

Planck's highly sensitive detectors have to work at temperatures very close to absolute zero, or else their own heat emissions would spoil the measurements. The satellite therefore has a sophisticated system of coolers.

Planck's off-axis aplanatic telescope combines a clear optical path with compactness. The eccentricity and tilt of the secondary mirror and the off-axis angle allow a large focal plane detector array, while minimising the polarisation introduced by the telescope. The telescope is seen here being prepared for thermal-vacuum testing at ESTEC

The telescope's line-of-sight is inclined at 85° to the spin axis so that the instruments scan a ring of the celestial sphere once per spacecraft revolution, and the whole sky in half a year. In order to view the celestial poles, the spin axis can be moved up to 10° away from the anti-Sun direction.

The Payload Module is dominated by three conical radiators that thermally insulate the two reflectors, the detector focal plane and the surrounding black baffle from the Service Module.

The black baffle is a powerful radiator for passively precooling the active three-stage cooling chain to around 60K. Further cooling of the detectors is performed via a cascade: 20K by a continuous hydrogen sorption cooler, 4K by a mechanical cooler and 100mK by mixing normal helium with a rare helium isotope.

Planck's two scientific instruments are the Low Frequency Instrument (LFI), an array of radio receivers using high electron mobility transistor mixers, and the High Frequency Instrument (HFI), an array of highly sensitive microwave detectors known as bolometers. They share the off-axis aplanatic telescope, which has a primary mirror measuring 2.0x1.5 m.

Verifying the cryogenic performance of Planck under realistic conditions was a true challenge. A dedicated test centre demonstrated the performance of the passive radiators at about 60K by cooling the facility's inner surfaces to below 20K with liquid helium.

Equally challenging was the verification of the alignment and radio-frequency performance at the operational 60K. Measurement at the Planck frequencies and in cryogenic conditions is not possible on Earth, so verification has to be done by combining analyses and test results.

Planck's detectors will convert the strengths of the microwave signals into units of temperature. The average temperature of the CMB is well known at -270.3°C but there are variations of roughly one part in 100 000 around the sky.



Herschel (top) and Planck will be launched jointly by the most powerful version of Ariane-5 into a direct transfer orbit to L2

Planck will be able to find and map regions where the temperature varies from the average by a few parts in a million. These tiny differences in the CMB are like the marks in a fossil, revealing details about the organism they come from – in this case, the physical processes at the beginning of the Universe.

Planck's baseline mission calls for two complete scans of the sky during an initial 15 months of observations.

Status

Planck's flight instruments are now being integrated into the satellite at Alcatel Alenia Space in Cannes (F). Herschel's instruments will closely follow: they will be integrated into the

satellite in early 2007 at Astrium in Friedrichshafen (D). These parallel programmes are approaching their final integration and test period before the launch in 2008.

Conclusion

Engineers from numerous European space companies have worked together on the design, construction and testing of ESA's Herschel and Planck observatories, overcoming many challenges that have pushed technology to new limits.

Credit must also go to the hundreds of scientists from specialist institutions across Europe and the United States for designing and developing the suite of highly sensitive instruments that will operate to the tightest of tolerances at temperatures close to absolute zero.

Infrared astronomy itself is still a young and exciting science, but astronomers studying this part of the spectrum have already unveiled tens of thousands of new galaxies and made surprising discoveries.

Yet scientists know there is still much more to find and processes such as the growth of structure in the early Universe and consequent birth of galaxies and other objects can best be studied with (far-) infrared telescopes situated in deep space, well away from the restrictions imposed by the Earth and its atmosphere.

ESA's Herschel and Planck observatories will help to provide answers to some of the most vexing questions now being asked in modern science: how did the Universe begin, how did it evolve to what we see today, and how will it evolve in the future? They will be throwing new light on an old story.

Acknowledgement

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*Detailed information on Herschel and Planck can be found at www.esa.int/science
Scientific information is available at sci.esa.int/herschel & sci.esa.int/planck*