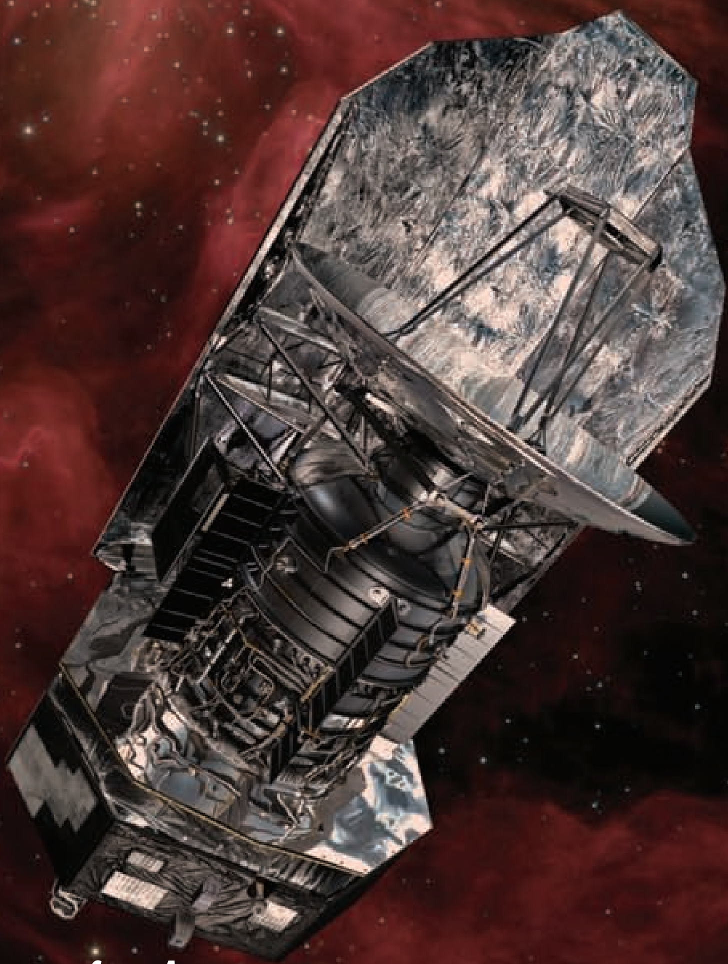
BR-262

HERSCHEL

Exploring the formation of Galaxies and Stars



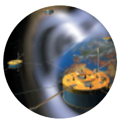
European Space Agency
Agence spatiale européenne

About ESA

The European Space Agency (ESA) was formed on 31 May 1975. It has 17 Member States: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

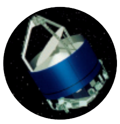
The ESA Science Programme has launched a series of innovative and successful missions. Highlights of the programme include:

Cassini-Huygens is one of the most ambitious planetary exploration efforts ever attempted. After a seven-year journey, the Cassini orbiter began studying the Saturnian system in great detail, and the Huygens probe descended onto Saturn's giant moon Titan, unveiling an amazing cold but Earth-like world.



Cluster, which is a four-spacecraft mission to investigate in unprecedented detail the interaction between the Sun and the Earth's magnetosphere.

Double Star, following in the footsteps of the Cluster mission, with its two spacecraft it studies the effects of the Sun on the Earth's environment.

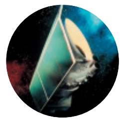


Giotto, which took the first close-up pictures of a comet nucleus (Halley) and completed flybys of Comets Halley and Grigg-Skjellerup.

Hipparcos, which fixed the positions of the stars far more accurately than ever before and changed astronomers' ideas about the scale of the Universe.

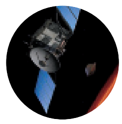
Hubble Space Telescope, a collaboration with NASA on the world's most important and successful orbital observatory.

Integral, which is the first space observatory that can simultaneously observe celestial objects in gamma rays, X-rays and visible light.

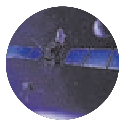


ISO, which studied cool gas clouds and planetary atmospheres. Everywhere it looked, it found water in surprising abundance.

IUE, the first space observatory ever launched, marked the real beginning of ultraviolet astronomy.



Mars Express, Europe's first mission to Mars, which consists of an orbiter and a lander looking for signs of water and life on the Red Planet.

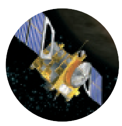


Rosetta, Europe's comet chaser, will be the first mission to fly alongside and land on a comet, probing the building blocks of the Solar System in unprecedented detail.

SMART-1, Europe's first mission to the Moon, which tested solar-electric propulsion in flight, a key technology for future deep-space missions.

SOHO, which is providing new views of the Sun's atmosphere and interior, revealing solar tornadoes and the probable cause of the supersonic solar wind.

Ulysses, the first spacecraft to fly over the Sun's poles.



Venus Express, is probing the mysteries of Venus's atmosphere with a precision never achieved before

XMM-Newton, with its powerful mirrors, is helping to solve many cosmic mysteries of the violent X-ray Universe, from enigmatic black holes to the formation of galaxies.

For further information on the ESA Science Programme please contact: +31 71 565 3223

More information can also be obtained via the ESA Science website at: www.esa.int/science

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background: Spitzer image of the Orion nebula, NASA/JPL-Caltech/T. Megeath (University of Toledo)

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Unlocking the Secrets of Galaxy Formation

An artist's view of ESA's Herschel far-infrared and submillimitre space observatory.
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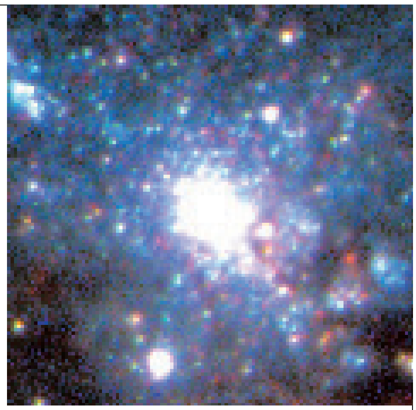
Today, galaxies fill the Universe. They are distributed in curved walls surrounding huge areas of emptiness – like bubbles in a foam bath. Each galaxy contains several hundred billion stars. However, it has not always been like this. There was a time when galaxies simply did not exist. Astronomers have long been asking: when did the galaxies form, how did they form, did they all form at about the same point in cosmic history, were the first galaxies like those we see now? Galaxies are made of stars and this raises other questions: did the stars form first and then pull together to form galaxies, or was it the other way round, with huge clouds of gas that can be thought of as young galaxies accumulating first before fragmenting into individual stars?



These questions have so far proved impervious to even the most advanced instruments, and remain as some of the key problems in astronomy today. Astronomers dream of a telescope that could help to find the answers. Such a telescope would have to fulfil at least two requirements. Firstly, it would have to be a giant sensitive space telescope, able to collect light from very distant galaxies. Secondly, it would need to observe light reprocessed by dust into infrared 'light', as even primieval galaxies contain dust.

Now the dream is coming true. ESA's far-infrared and submillimetre observatory, Herschel, due to be launched in 2009, is designed specifically to achieve those goals. With its ability to detect infrared light, Herschel will let astronomers see, for the first time, the infrared light emitted by dusty and cold regions hidden from the gaze of optical telescopes. With its huge 3.5 m-diameter mirror, Herschel is the first of a new generation of space giants.

Herschel is named after the German-musician-turned-British-astronomer William Herschel, who discovered infrared radiation in 1800. ESA's Herschel observatory was named in his honour in 2000, the bicentenary year of his discovery.

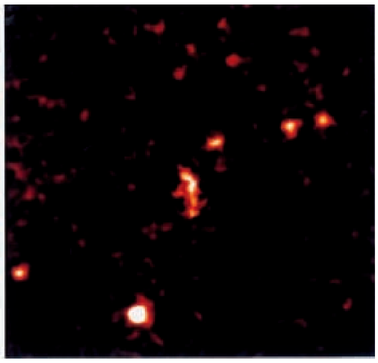
ESA/ISO/ISOCAM and L. Nordh et al.

How to Revolutionise Astronomy

Baby galaxies at work

Astronomers call the era before 'first light' and galaxy formation the dark ages. It is an appropriate name. No current instrument can peer into that era. The reason is twofold. Firstly, when the first galaxies formed, the Universe was most likely already dusty. This dust is an impenetrable wall for most telescopes. Secondly, today's instruments are simply not sensitive enough to see any faint light that does escape from the dark ages.

However, pioneering infrared satellites, such as ESA's Infrared Space Observatory (ISO), have helped to outline the general scenario of galaxy formation. Sometime after the Big Bang, the first stars formed, possibly in small clusters; with time they started to merge and grow. This accumulation of matter triggered the formation of more stars and at the end of their lives these stars produced dust, which in turn helped to make more stars. By then the first galaxies were in place as vast collections of star clusters. These would often collide and merge to form larger galaxies. The galactic collisions triggered intense bouts of star formation. To take a step ahead in confirming and completing this picture astronomers have had to wait for Herschel's launch. Herschel will be able to see the emission from dust heated by the Universe's stellar 'baby booms'.



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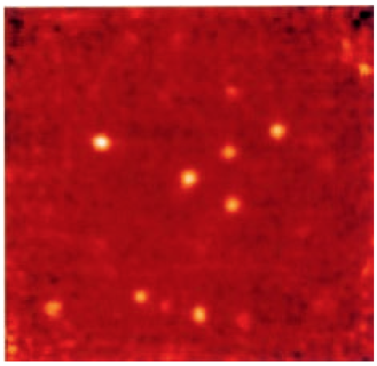

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Gravitational arcs are distorted and magnified images of distant objects. The upper image shows the first gravitational arcs seen at infrared wavelengths, in the galaxy cluster Abell 370. Below, lensed galaxies in galaxy cluster Abell 2390. They might be young galaxies in collision.

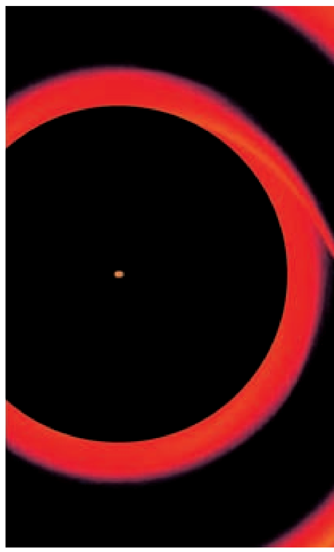
Starbirth in dark and cold clouds of dust

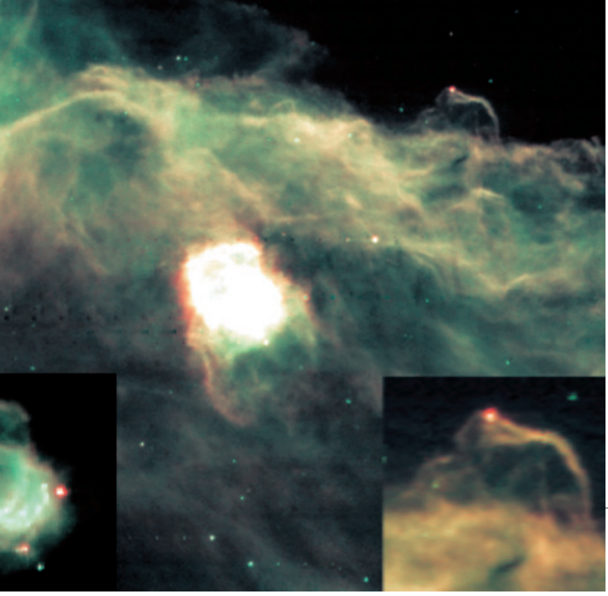
Stars are shy, at least during their early lives. They begin to form inside thick cocoons of dust that protect them until the moment they hatch. Within the pre-stellar core, as these cocoons are called, gravity squeezes gas and dust into the centre of the clump. This heats the gas. The heat must radiate into space before the embryonic star can complete its collapse and finish its formation.

Both the dusty cover and the incredibly low temperatures make the pre-stellar cores invisible to all telescopes except those designed to collect radio or infrared radiation. ISO unveiled more than a dozen of these cocoons, but the earliest stages of starbirth are still poorly known. ESA's Herschel will fill many gaps in our knowledge of these objects.

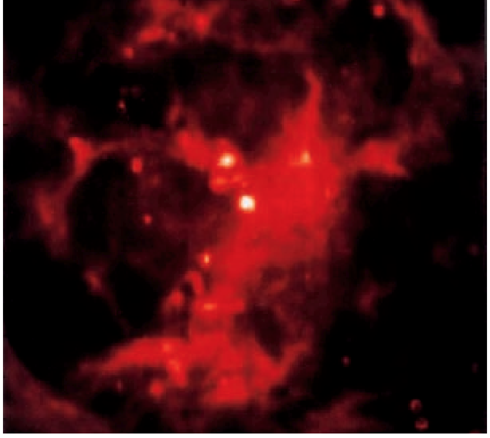
Recipe for a planet

Making a planet is simple. After a star is born, leftover gas and dust remain swirling around the young star, forming a protoplanetary disc. The grains of dust in this disc are the seeds of future planets. Once most of the dust has collapsed together to form the planets, the disc disappears, leaving behind only a thin ring of debris.





Bright dots seen in the Horsehead Nebula in Orion include young, newly formed stars detected by their infrared emissions.



ESA/ISO/ISOCAM and J. Cernicharo et al.

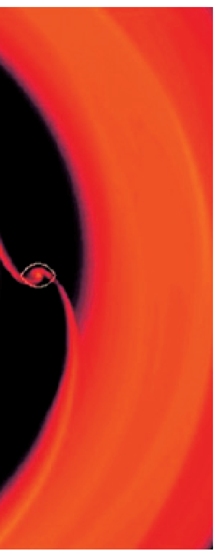
Infrared-bright regions in the Trifid Nebula reveal dense clouds of cool dust which may be sites of new star formation.

Both protoplanetary discs and debris rings are favourite targets for infrared space telescopes. They have already detected quite a few. ESA's ISO has shown that the formation of planets around stars must be a common event. According to the observations, a thin disc of debris surrounds almost all young stars. Astronomers believe that the planet-making process is not quite complete in these debris discs and that small bodies like comets are still delivering icy material to the new planets. Herschel will thoroughly investigate these ideas.

The origin of the Solar System

Our Solar System formed about 4500 million years ago, out of the proto-solar nebula. This primieval cloud contained the raw material that had served to build the Sun itself. To reconstruct precisely how the process took place, astronomers need to study the detailed chemical composition of the planets' atmospheres and surfaces, and especially the chemical composition of the comets. Comets are mostly made of water ice, methane and carbon dioxide. They are the best fossils of the early Solar System because they are made of unprocessed material from the pre-solar nebula. In a planet's atmosphere, the original components will be altered by subsequent chemical reactions; in a comet, they are held in a deep freeze.

Studying the chemical composition of comets will also help to solve the question of the origin of the Earth's oceans. According to some hypotheses, impacting objects of various kinds, such as comets and asteroids, brought most of the water on our planet early in the history of the Solar System. Herschel has unprecedented sensitivity to analyse the chemical composition of the Solar System's various bodies.

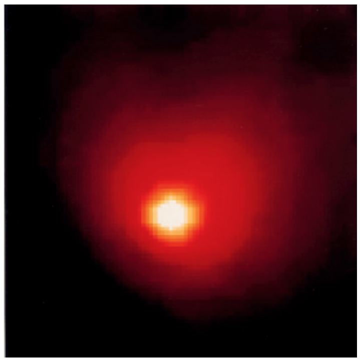


A Jupiter-like planet evolves in a disk around a young star, in a computer model by Pawel Artymowicz (Stockholm University).

The chemistry of the Universe

Stars are the chemical factories of the Universe. Most of the chemical elements in the Universe are made in the nuclear fires that burn in each star's core. Many chemical compounds, including those essential for life, are produced around stars. Huge amounts of water and complex molecules of carbon – which together form the most basic building blocks for life – have been detected in the material surrounding stars. Human beings and all other living systems are literally stardust.

Most molecules show their unmistakable chemical signature at infrared and submillimetre wavelengths. This makes Herschel the ideal tool for detecting them. Herschel will study the chemistry of many regions in the Universe, from the stars and their environments to other galaxies. It will observe chemical-rich objects such as molecular clouds, where over a hundred different molecules have been discovered. Some of these molecules need the isolation of space to exist. On Earth, they would quickly react with other molecules and so can be created only in laboratories.



ESA/ISO/ISOCAM and P. Lamy et al.

Courtesy of K. Leech

ISO observations of Comet Hale-Bopp produced valuable information about the composition of the comet's dust and vapour. Below, a view of Comet Hale-Bopp over the castle near the ISO Data Centre, based at Villafranca, Madrid.

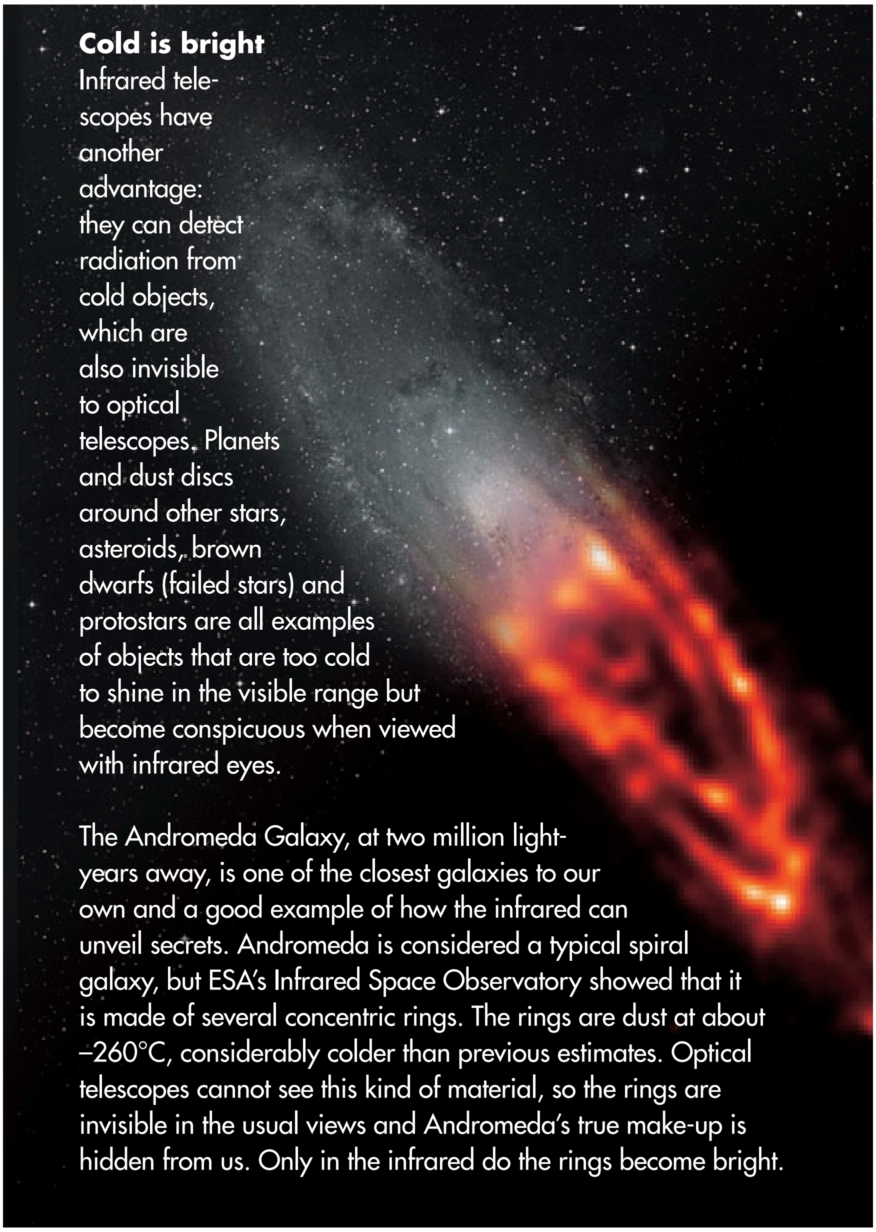
Unveiling the Hidden Universe

The dusty revolution

Human eyes are blind to most types of light. They cannot see infrared nor ultraviolet light. Only visible light registers in our eyes. Because each kind of light reveals different natural phenomena, human vision provides us with only one part of the full story. It is the same with telescopes: optical telescopes detect only visible light.

Previous infrared satellites have allowed astronomers to glimpse the infrared face of the Universe. They have seen enough to realise the Universe's infrared face is completely different from the visible one. One of the virtues of near-infrared light is that dust in space does not block its passage. If a star is enshrouded by dust, an optical telescope cannot see it, while an infrared telescope will detect the star's emission. This can be easily appreciated in this composite image showing the dusty central region of the Orion nebula. The upper triangle is an image taken with NICMOS, a camera on the NASA/ESA Hubble Space Telescope that works at near-infrared wavelengths. Although these wavelengths are close to detectable by optical telescopes, the NICMOS image already shows many more stars than the optical image of the same region.

Herschel will even detect the emission from the dust itself. This is one reason why Herschel is an ideal tool to study the build-up of galaxies, where interactions often create massive bursts of star formation in dusty regions that, sometimes, emit almost exclusively in the infrared.

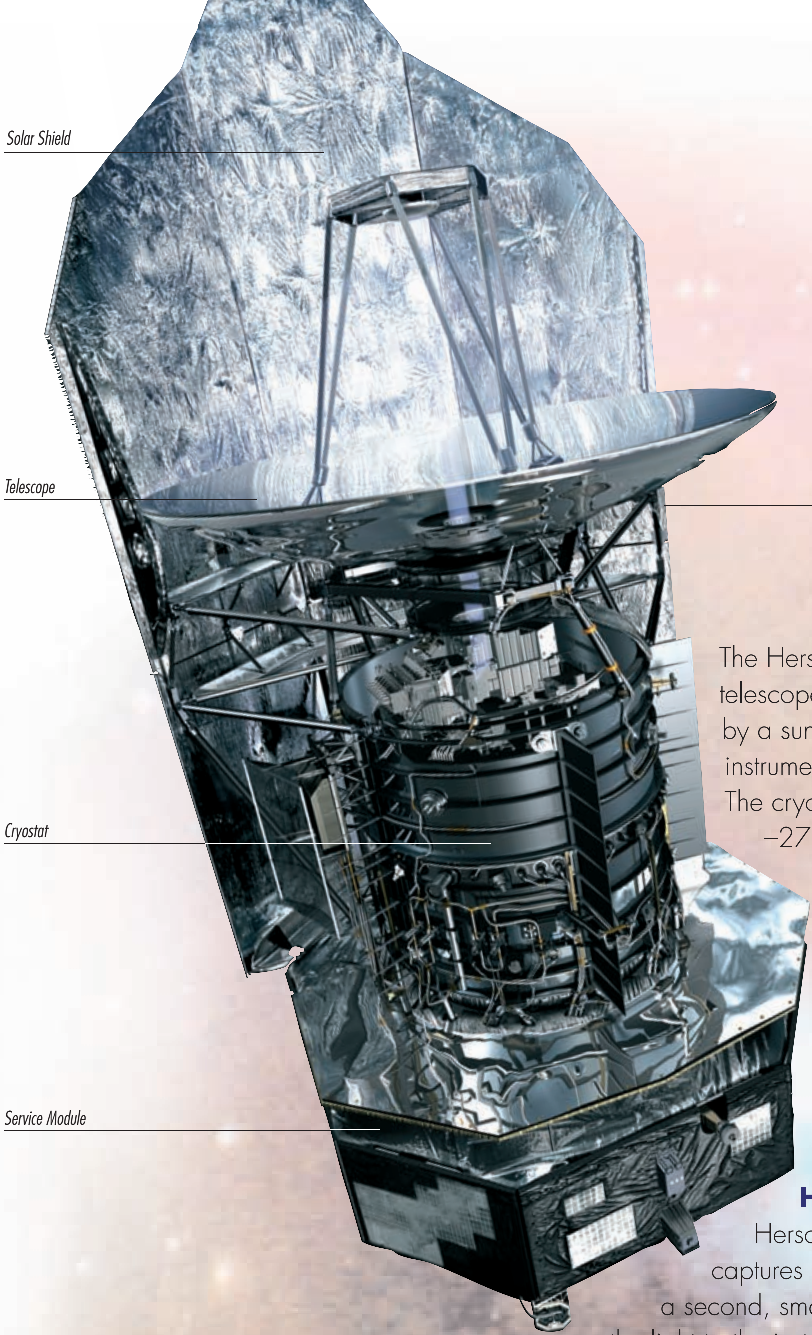


Cold is bright

Infrared telescopes have another advantage: they can detect radiation from cold objects, which are also invisible to optical telescopes. Planets and dust discs around other stars, asteroids, brown dwarfs (failed stars) and protostars are all examples of objects that are too cold to shine in the visible range but become conspicuous when viewed with infrared eyes.

The Andromeda Galaxy, at two million light-years away, is one of the closest galaxies to our own and a good example of how the infrared can unveil secrets. Andromeda is considered a typical spiral galaxy, but ESA's Infrared Space Observatory showed that it is made of several concentric rings. The rings are dust at about –260°C, considerably colder than previous estimates. Optical telescopes cannot see this kind of material, so the rings are invisible in the usual views and Andromeda's true make-up is hidden from us. Only in the infrared do the rings become bright.

Illustration by Medialab. Infrared: ESA/ISO



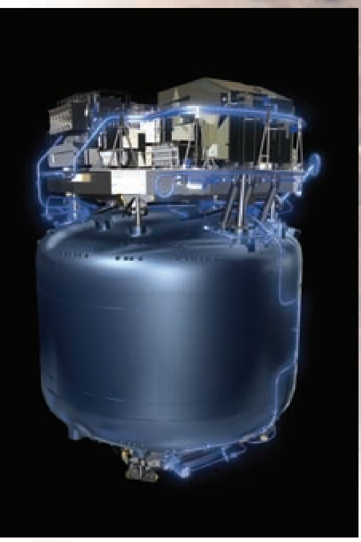
How Herschel will Work

The Herschel satellite is composed of three sections. First is the telescope, which has a 3.5 m-diameter primary mirror protected by a sunshade. The telescope focuses light onto three scientific instruments housed in a giant thermos flask, known as a cryostat. The cryostat contains liquid superfluid helium colder than −271°C to make the instruments as sensitive as possible. The instruments and the cryostat make up the second section – the payload module. The third element of the satellite is the service module below the payload module. It houses the instrument electronics and the components for making the satellite function, such as the hardware for communicating with Earth. The service module hosts the data processing and spacecraft control electronics, operating at ambient temperature.

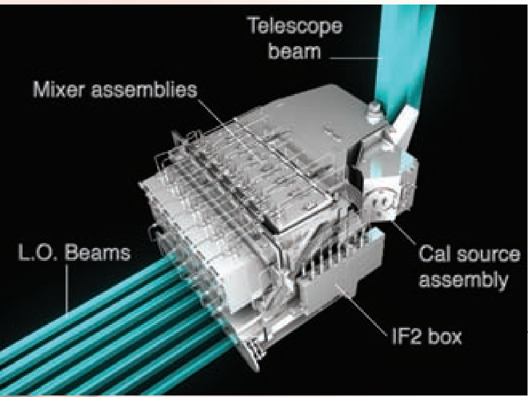
Harvesting infrared light with the largest mirror

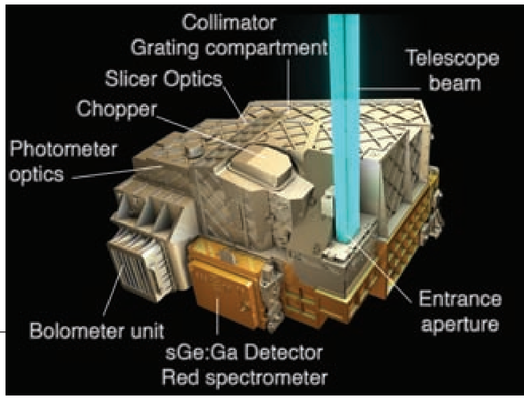
Herschel's primary mirror is the telescope's light collector. It captures the light from astronomical objects and directs it towards a second, smaller mirror. This completes the focusing and sends the light to the instruments, where the light is detected and recorded by computer. The size of the primary mirror is the key to a telescope's sensitivity: the bigger it is, the more light it collects and so the fainter the objects it sees. It also determines the telescope's ability to distinguish fine details. The surface of the mirror is very important, too. It has to be the precisely shaped and perfectly smooth, since the slightest roughness distorts the final image.

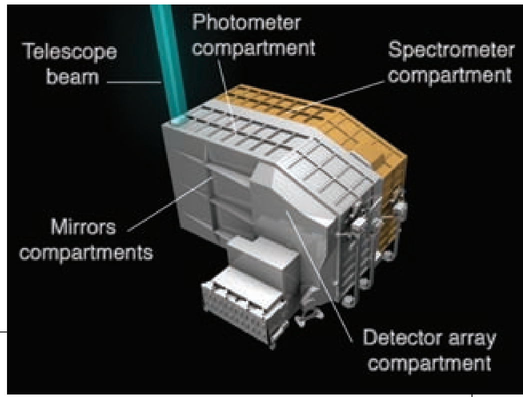
Herschel's mirror is the largest ever built for a space telescope. It was a true technological challenge successfully met. The mirror has to be very light (as do all satellite components); it



Left: Herschel's superfluid helium tank, where the helium is kept at boiling temperature (1.65K or −271.5°C). The helium liquid and gas cools the science instruments' focal plane units and the shields. The liquid boils and produces gas that slowly flows from the tank into pipes around the payload to cool it to between 1.7K (−271.4°C) and 4K (−269°C). Centre: The gas continues into the rings of three thermal shields to cool them to 30K (−241°C), 50K (−221°C) and 60K (−211°C), respectively. Right: the cryostat vacuum vessel containing the superfluid helium tank. The gas is ejected in space. The cryostat vacuum vessel is radiatively cooled to about 70K (−203°C).







The Heterodyne Instrument for FIRST (HIFI) (left) takes very high-resolution spectra in thousands of frequencies simultaneously. It covers the bands 480-1250 GHz and 1410-1910 GHz, using superconducting mixers as detectors. It is being developed by a consortium led by SRON (Groningen, The Netherlands).
©ESA/C. Carreau

The Photoconductor Array Camera and Spectrometer (PACS) (centre)is an infrared camera and a spectrometer. It will operate simultaneously in two wavelength bands – the 60-130 micron and the 130-210 micron bands – with bolometer and photoconductor array detectors. It is being developed by a consortium led by the MPE (Garching, Germany).
©ESA/C. Carreau

The Spectral and Photometric Imaging REceiver (SPIRE) (right) is a camera and spectrometer. It provides broadband photometry simultaneously in bands centred on 250, 350, and 500 micron. It will be developed by a consortium led by Queen Mary and Westfield College (London, UK).
©ESA/C. Carreau

has to withstand the extreme conditions of launch and the low temperatures of outer space; and any bump on its surface must be less than a thousandth of a millimetre high.

Three powerful eyes

A telescope's instruments turn it from a mere light collector into a set of technological eyes. The instrument detectors form the retina, where the light from astronomical objects is really seen. The instruments detect and analyse the light in many different ways. Herschel carries three scientific instruments:

- **HIFI** (Heterodyne Instrument for the Far Infrared), a high resolution spectrometer;
- **PACS** (Photoconductor Array Camera and Spectrometer);
- **SPIRE** (Spectral and Photometric Imaging REceiver), a camera.

These instruments were developed by nearly 40 institutes, mainly European but with American and Canadian participation.

The coolest detectors

An infrared detector must be cooled to an extremely low temperature so that it is not warmer than the radiation it is trying to measure. Because the temperature of some astronomical objects is close to absolute zero (–273.15°C or 0K), trying to observe them with a warmer instrument would be like trying to see a star against the glare of the midday Sun.

All three Herschel instruments will be cooled by the cryostat filled at launch with more than 2000 litres of superfluid helium kept colder than –271°C. Further cooling – down to 0.3K – is required for the SPIRE and PACS 'bolometer' detectors. The role of the cryostat is fundamental because it determines the lifetime of the observatory. The superfluid helium evaporates at a constant rate, gradually emptying the tank. When it has all gone, the temperature of the instruments will start to rise and Herschel will no longer be able to perform observations. However, the data that Herschel will have supplied will keep astronomers busy for decades.

The Heterodyne Instrument for the Far Infrared (HIFI) produces high-resolution spectra with thousands of frequencies simultaneously. It covers two bands, 480–1250 GHz and 1410–1910 GHz, and uses superconducting mixers as detectors. It was developed by a consortium led by SRON (Groningen, The Netherlands).

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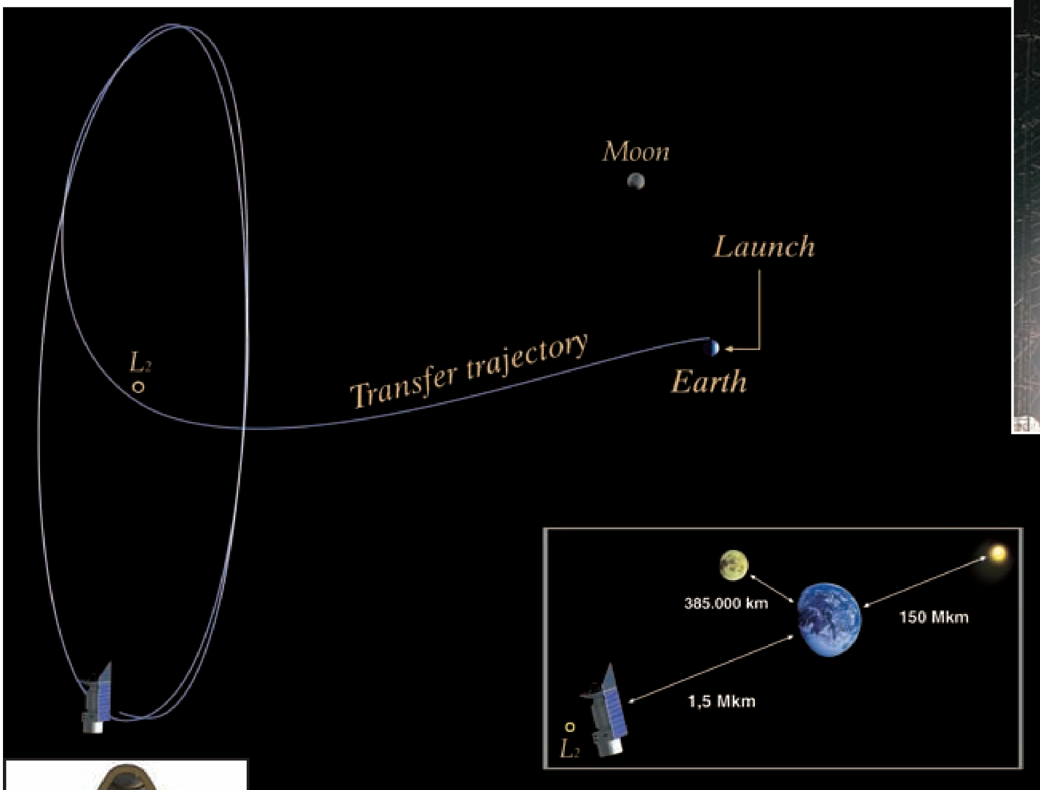
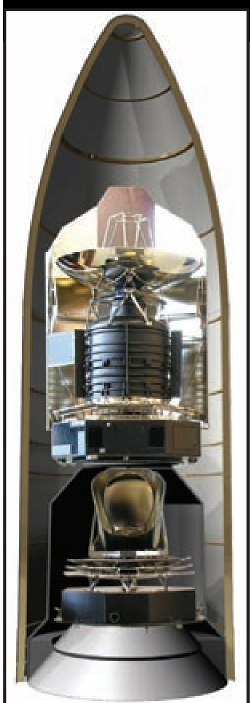
Leaving Behind the Earth and Moon





Herschel will be launched together with another ESA mission, Planck, which will study the Cosmic Microwave Background radiation. At launch, the Herschel/Planck combination will measure approximately 11 m high and 4.5 m wide, weighing about 5700 kg. An Ariane-5 ECA launcher will carry them. They will separate soon after launch and head into different orbits. The two spacecraft will be operated independently.

It will take Herschel about 3 months to arrive at its final position, an orbit around a virtual point in space known as the second Lagrangian point (L2) in the Sun-Earth system. This point is some 1.5 million km from Earth (about four times the distance of the Moon), in the opposite direction from the Sun. It has two important advantages. Firstly, Herschel's instruments will not be disturbed by the strong far-infrared emission from the Earth and Moon. Secondly, because the Earth and the Sun are in the same general direction, it offers good sky visibility for performing the astronomical observations.

Herschel's will circle L2 at a distance of about 350 000 km. Because of this large orbit, Herschel's distance to the Earth will vary between 1.2 and 1.8 million km. In addition, orbits around L2 are unstable and subtle movements of the Earth will cause the satellite to drift away. Herschel will have to make small correction manoeuvres every month.

Herschel in a Nutshell

Concept: ESA's Herschel is the first space observatory covering the full far-infrared and submillimetre waveband. It is also the largest to work at those wavelengths. Thanks to this, Herschel will be able to see dusty and cold regions that are opaque to other telescopes, unveiling a face of the early Universe so far hidden. Herschel's main goal is to study how galaxies and stars form and evolve. Other targets include the clouds of gas and dust where new stars are being born, discs out of which planets may form, and cometary atmospheres packed with complex organic molecules.

Primary mirror: 3.5 m in diameter.

Launch: Herschel will be launched in 2009 together with another ESA scientific mission, Planck. Both satellites will separate shortly after launch to operate independently.

Orbit: Herschel will orbit a the L2 virtual point in the Sun-Earth system, located 1.5 million km from Earth.

Instruments: HIFI (Heterodyne Instrument for the Far Infrared), a high-resolution spectrograph; PACS (Photoconductor Array Camera and Spectrometer); and SPIRE (Spectral and Photometric Imaging REceiver). These instruments cover the 60–670 micron waveband. They will be cooled to temperatures very close to absolute zero.

Launch mass: about 3 t.

Dimensions: about 7.5 m high and 4.5 m wide.

Operations: Herschel will be operated as an observatory. About two-thirds of its observing time will be available to the world's scientific community. The rest is guaranteed time mainly belonging to the instrument consortia.

Primary ground station: New Norcia, Australia.

Operational Lifetime: a minimum of 3 years for routine science observations.

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