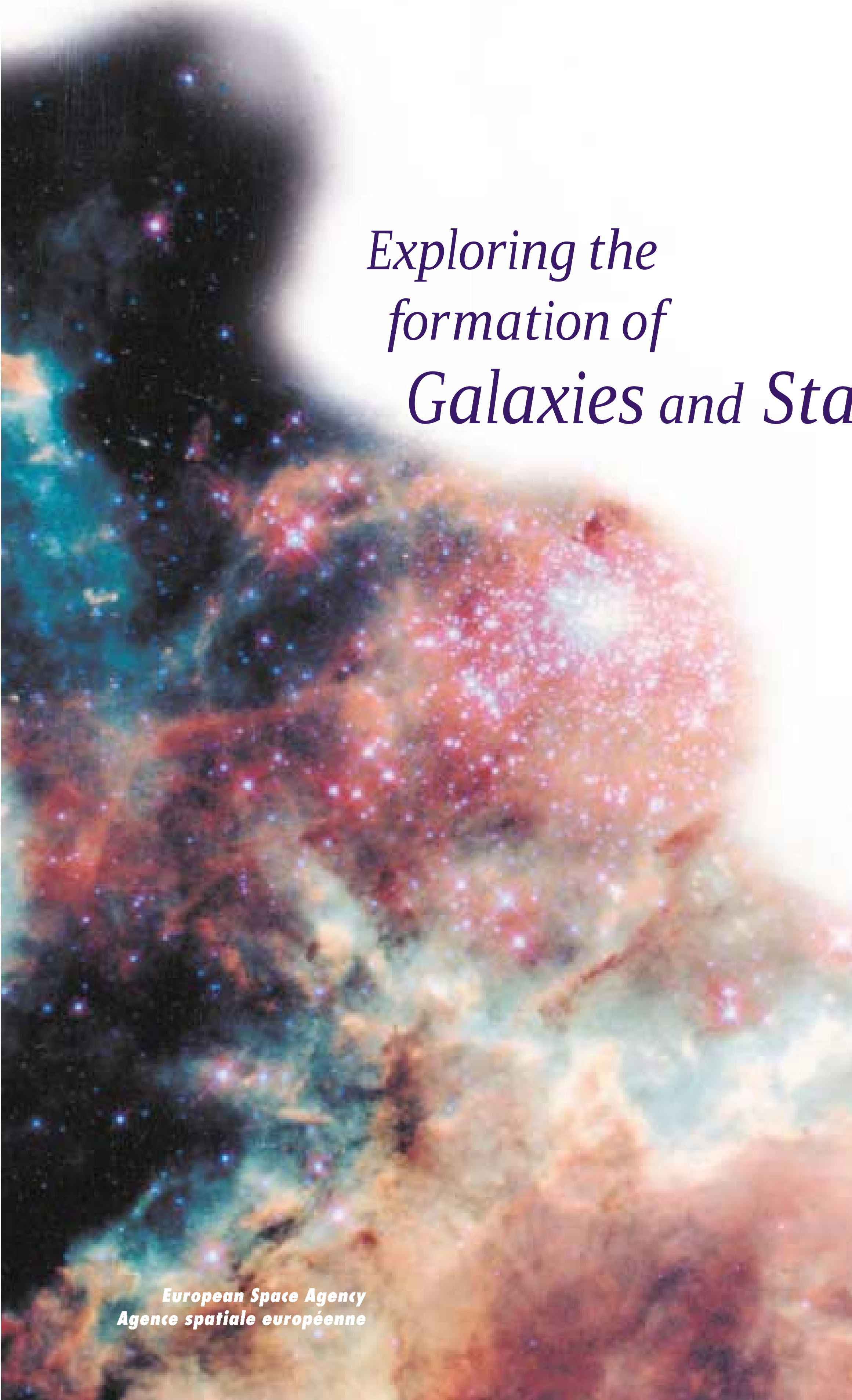
BR-158
July 2000

Exploring the formation of Galaxies and Stars

FIRST



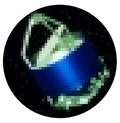
European Space Agency
Agence spatiale européenne

About ESA

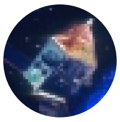
The European Space Agency (ESA) was formed on 31 May 1975. It currently has 14 Member States: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. Canada is also a partner in some of the ESA programmes.

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

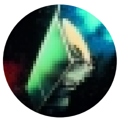
IUE, the first space observatory ever launched, marked the real beginning of ultraviolet astronomy.



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

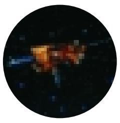


Hipparcos, which fixed the positions of the stars far more accurately than ever before and changed astronomers' ideas about the scale of the local Universe.



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

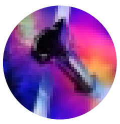
SOHO, which is providing new views of the Sun's atmosphere and interior, revealing solar tornadoes and the probable cause of the supersonic solar wind.



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

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

Huygens, a probe to land on the mysterious surface of Saturn's largest moon, Titan in 2004. Part of the international Cassini mission.



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 the Science Programme Communication Service on (tel.) +31-71-5653223

More information can also be obtained via the ESA Science Web Site at: http://www.sci.esa.int

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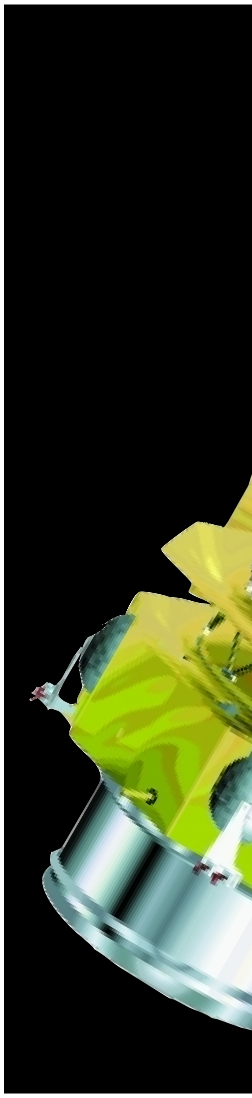
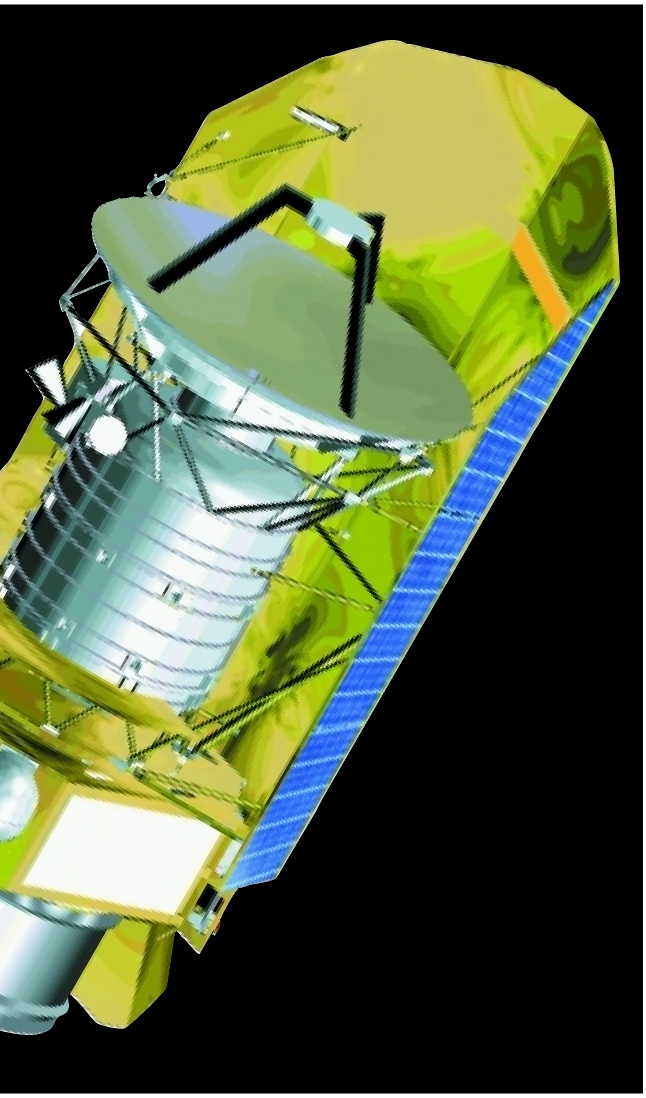


http://sci.esa.int/first

In search of the First Galaxies

If it were possible to look at the Universe from the outside it would probably appear as a foamy structure, with the galaxies distributed in curved walls surrounding huge areas of emptiness – like bubbles in a foam bath. Such is the overall picture of the present-day Universe. But it was not always like that. There was a time when galaxies weren't there, simply because they didn't even exist. When did galaxies form? And how? Did they all form at about the same time, or is there a non-stop galaxy-making machine at work? Were the first galaxies like those we see now? The galaxies are made of stars... Did the stars form first and then get together to form galaxies, or was it the other way round?



These questions, immune to the most advanced instruments so far, remain as some of the key problems in astronomy today. Astronomers dream of a telescope able to address them, one that fulfils at least two requirements. It has to be a giant space telescope, able to collect light from very distant galaxies; and it must also be able to observe objects completely enshrouded by dust, as the primeval galaxies will certainly be.

ESA's Far-Infrared and Submillimetre Telescope, FIRST, due to be launched in 2007, has been designed specifically to achieve these goals. With its ability to detect far-infrared light, FIRST will let astronomers see, for the first time, dusty and cold regions that have been hidden so far. And with its 3.5-metre mirror, FIRST will mark the beginning of a new generation of 'space giants'.

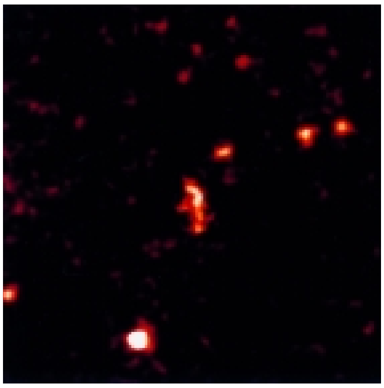
A conceptual view of ESA's Far-Infrared and Submillimetre Telescope, FIRST

How to revolutionise astronomy

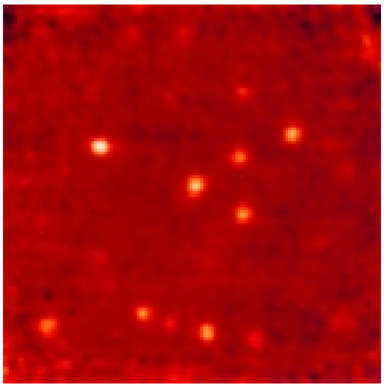
Baby galaxies at work

For current astronomers, the 'darkest' epoch of the Universe is the time when the first galaxies started to be born: no instrument today can see clearly into that era. The reason is twofold. Firstly, the epoch when the first galaxies formed was most likely already dusty, and dust is an impenetrable wall for most telescopes now. Secondly, today's instruments are simply not sensitive enough.

The epoch of galaxy formation has therefore so far remained a true 'dark age'. Pioneering infrared satellites, such as ESA's Infrared Space Observatory (ISO), have helped to outline a general scenario. Sometime after the Big Bang the first stars formed, possibly in small clusters; with time they started to merge and grow, and the mere accumulation of matter triggered the formation of more stars; these stars produced dust, which in turn was 'recycled' to make more stars. By then the first galaxies were already in place, and they too would merge to form larger systems. These galactic collisions triggered an intense formation of stars in the Universe. To confirm and complete this picture, astronomers will have to wait until FIRST's launch. FIRST will see the emission from dust illuminated by the first big star-bursts in the history of the Universe.



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



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

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.

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

Star-birth in dark and cold clouds of dust

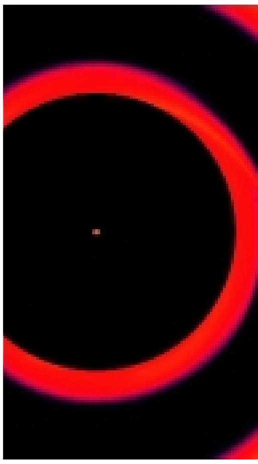
Stars are shy, at least during the earliest stages of their life. They start to form within thick cocoons of dust that protect them until the moment they hatch. Within the pre-stellar core, as these 'cocoons' are called, gravity squeezes gas and dust towards the centre, while cooling mechanisms keep the system at very low temperatures to avoid a quick collapse of the embryonic star – a premature death.

Both the dust cover and the incredibly cold temperatures – they are at around -260°C – make the pre-stellar cores invisible to all telescopes other than radio or infrared telescopes. The earliest stages of the star-birth are therefore as yet poorly known, even though ESA's ISO has unveiled more than a dozen of these 'cocoons' so far. FIRST will swell the list, and will fill in the many gaps in the knowledge of these objects.

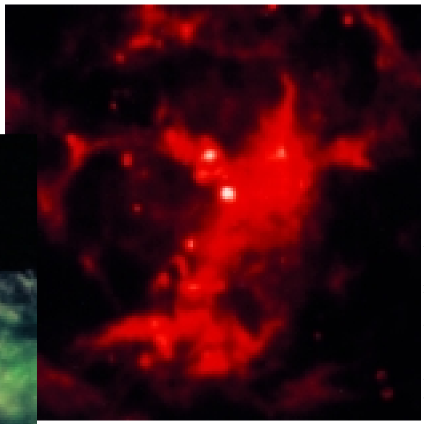
Recipe for a planet

Making a planet is simple. After the starbirth, left-over gas and dust remain swirling around the young star, forming a so-called 'protoplanetary disk'. The grains of dust in this disk will be the seeds of the future planets. Once the new planetary system is formed the disk disappears, leaving behind only a thin ring of debris.

Both protoplanetary disks and debris rings are a favourite target for infrared space telescopes. They have telescopes that have already detected a number of them.

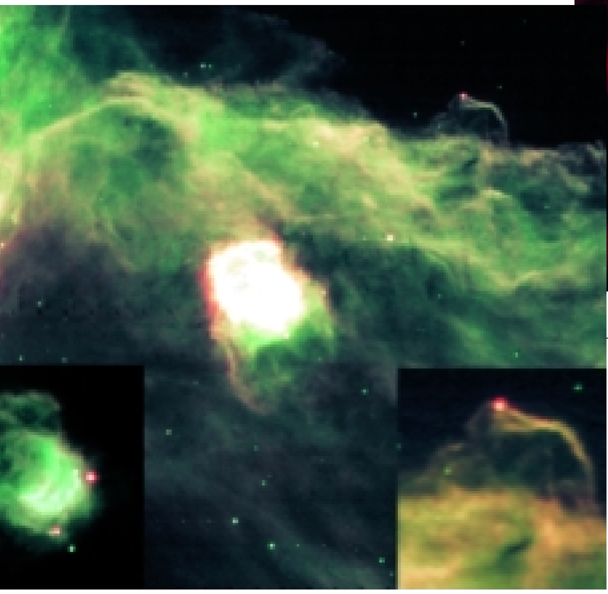


Infrared-bright regions in the Trifid Nebula reveal dense clouds of cool dust which may be sites of new star formation.



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

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

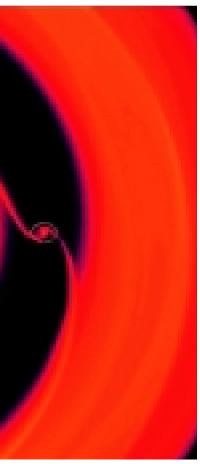


Actually, ESA's ISO has shown that the formation of extrasolar planets must be a very common event. According to the observations, almost all young stars are surrounded by a thin disk of debris, in which astronomers believe the planet-making process is not completely over yet and small bodies like comets are still very conspicuous. FIRST will shed additional light on all of these theories.

The origin of the Solar System

Our Solar System was formed 4500 million years ago, out of the same raw material that about 500 million years earlier had served to build the Sun itself – the so-called 'proto-solar nebula'. To reconstruct precisely how the formation of the Solar System took place astronomers need to study in detail the chemical composition of the planets' atmospheres and surfaces, and especially the chemical composition of the comets. Comets are the best 'fossils' of the earliest Solar System. They are made of unprocessed material from that primeval cloud, including water-ice, while the reactions taking place in the planets' atmospheres, for instance, mask the original components of the proto-solar nebula.

The study of the chemical composition of comets will also help to solve the question of what is the origin of the Earth's oceans.



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

According to some hypotheses, most water on our planet comes from the impacts of many comets during an early epoch of the history of the Solar System. This cannot be confirmed unless much more chemical data are gathered. FIRST spectrographs will have an unprecedented sensitivity to analyse the chemical composition of the Solar System bodies, especially with respect to water.

The chemistry of the Universe

Stars are the chemical factories of the Universe: most chemical elements are made in the nuclear oven burning in the stars' core, and many chemical compounds, even those essential for life, are produced in the stars' environment. Huge amounts of water, and very complex molecules of carbon – the most basic building blocks for life – have been detected in the material surrounding stars. Human beings – and all living systems, for that matter – are literally 'stardust'.

Most molecules show their unmistakable 'chemical signature' at infrared and submillimetric wavelengths, which makes FIRST an ideal tool to detect them. FIRST will study the chemistry of many regions in the Universe, from the stars and their environment to other galaxies. It will observe objects as chemically rich as the molecular clouds in the interstellar medium, where nearly a hundred different molecules – many of which were detected in space even before they were ever seen in laboratories – have been discovered.

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

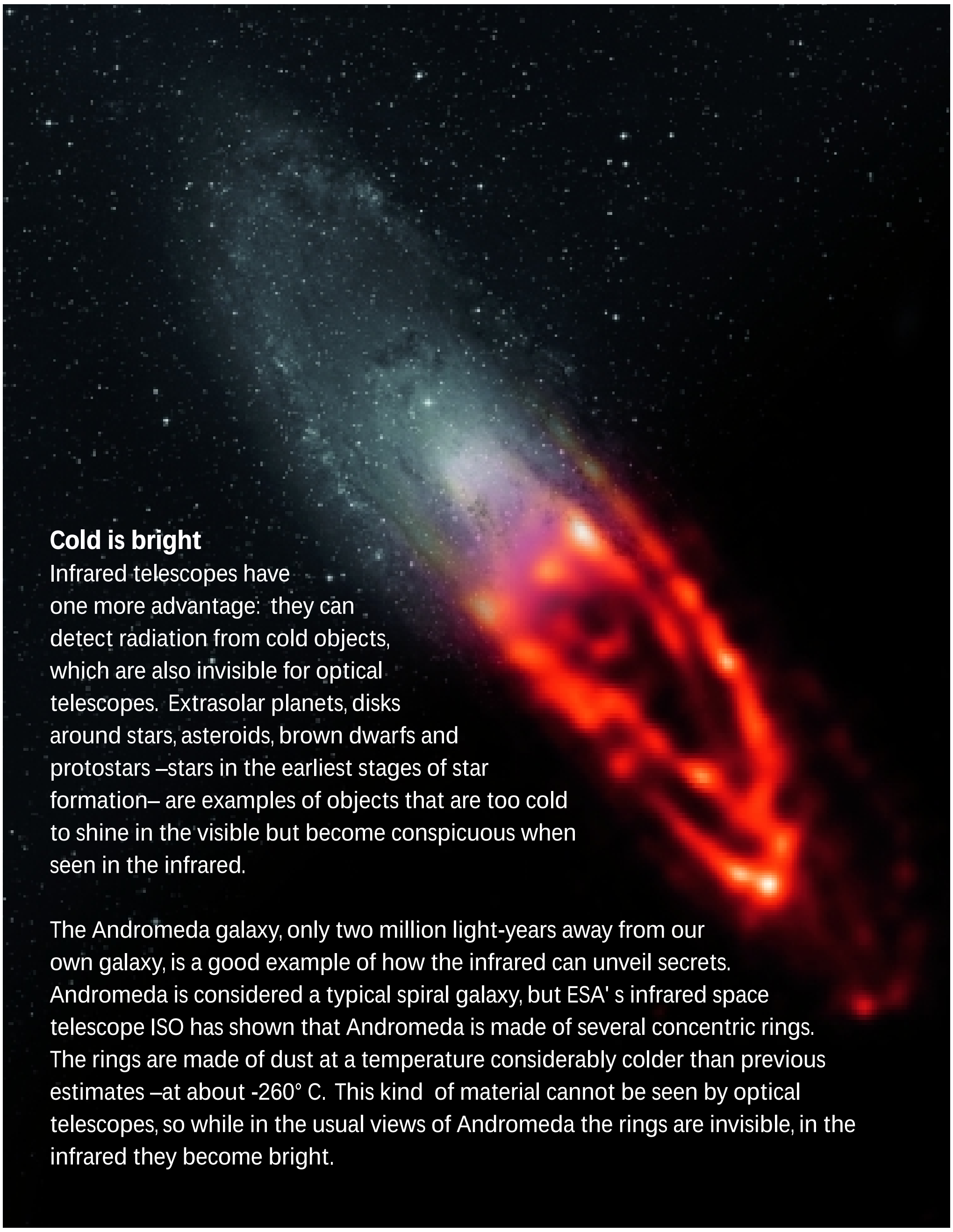
The dusty revolution

Human eyes are blind to most types of light: they can't see infrared light, nor ultraviolet light... only the so-called -obviously- 'visible' light. And because each kind of light reveals different phenomena, in practice human vision gets only one 'version' of the story. It's the same with telescopes. Optical telescopes, like the human eye, only detect visible light: they miss the infrared face of the Universe.

Seen in the infrared the sky changes completely. One of the peculiarities of infrared light is that it does not get 'blocked' by the dust. If a star is enshrouded by dust, an optical telescope will not be able to see it, but the infrared telescope will receive perfectly 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 board the NASA/ESA Hubble Space Telescope working at near-infrared wavelengths. Although near-infrared wavelengths are still close to the wavelengths detectable by optical telescopes, the NICMOS image already shows many more stars than the optical image of the same region.

FIRST will not only see 'through' the dust, it will be able also to detect the emission from the dust itself. This is one of the reasons why FIRST will be an ideal tool to study the first galaxies, which are thought to already contain dust.

NASA/ESA/HST. Illustration by Medialab.



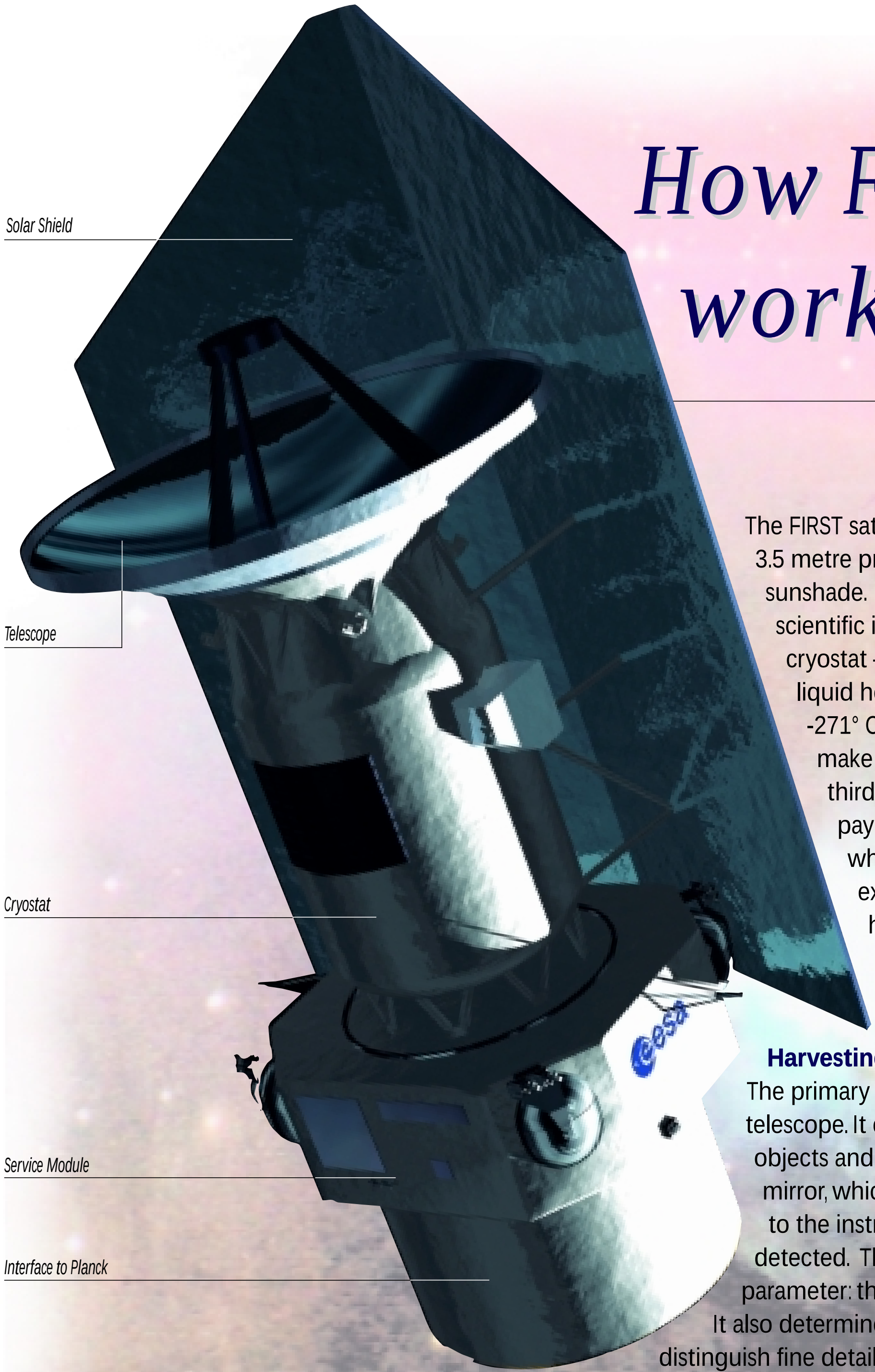
Cold is bright

Infrared telescopes have one more advantage: they can detect radiation from cold objects, which are also invisible for optical telescopes. Extrasolar planets, disks around stars, asteroids, brown dwarfs and protostars –stars in the earliest stages of star formation– are examples of objects that are too cold to shine in the visible but become conspicuous when seen in the infrared.

The Andromeda galaxy, only two million light-years away from our own galaxy, is a good example of how the infrared can unveil secrets. Andromeda is considered a typical spiral galaxy, but ESA' s infrared space telescope ISO has shown that Andromeda is made of several concentric rings. The rings are made of dust at a temperature considerably colder than previous estimates –at about -260° C. This kind of material cannot be seen by optical telescopes, so while in the usual views of Andromeda the rings are invisible, in the infrared they become bright.

Illustration by Medialab. Infrared: ESA/ISO

How FIRST will work



The FIRST satellite will have a telescope with a 3.5 metre primary mirror telescope protected by a sunshade. This telescope will focus light onto three scientific instruments, which will be kept inside a cryostat – like a giant 'thermos bottle' containing liquid helium at a temperature of less than -271° Celsius. The instruments and the cryostat make up the so-called 'payload module'. The third element of the satellite (below the payload module) is the 'service module', which provides the infrastructure – for example, for Earth communications – and houses the 'warm' electronics of the instruments.

Harvesting infrared light with the largest mirror

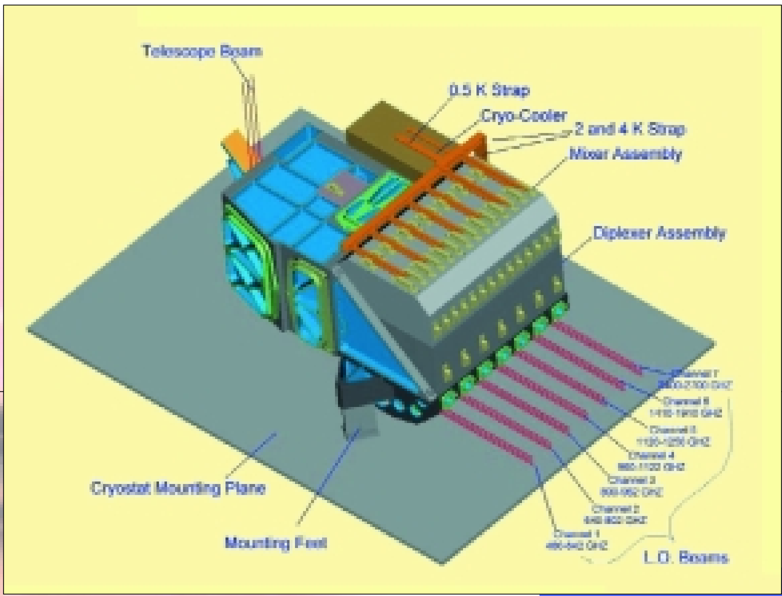
The primary mirror is the 'light collector' of the telescope. It captures the light from the astronomical objects and then directs it towards a second smaller mirror, which in turn sends it to the focus and finally to the instruments – where the light is really detected. The size of the primary mirror is a key parameter: the bigger it is, the more light it will collect. It also determines the ability of the telescope to distinguish fine details. The surface of the mirror is very important too: it has to be very precisely shaped and perfectly smooth, since the slightest roughness causes the image of the astronomical objects to deform.

FIRST's primary mirror will be the largest ever built for a space telescope so far. It represents a true technological challenge. It has to be very light – a requirement for every component in a space mission; it has to withstand the extreme conditions of the launch and the cold temperatures of outer space; and any 'bump' on its surface must be less than a thousandth of a millimetre high.

Three powerful eyes

The instruments of a telescope are its 'eyes', that is, where the light from the astronomical objects is really 'seen'. They analyse the light in many different ways. FIRST will carry three scientific instruments.

- **HIFI** (Heterodyne Instrument for FIRST), which is a very high-resolution spectrometer
- **PACS** (Photoconductor Array Camera and Spectrometer), and
- **SPIRE** (Spectral and Photometric Imaging REceiver) are cameras and imaging spectrometers.



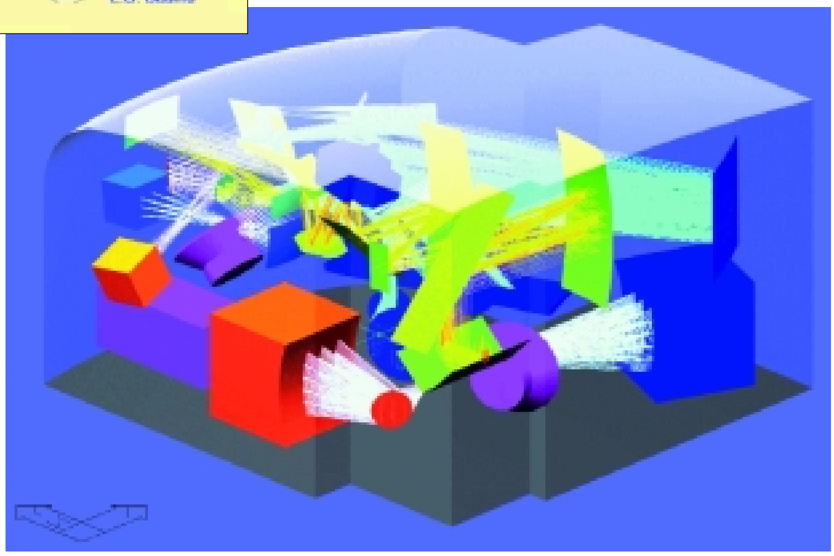
The Heterodyne Instrument for FIRST (HIFI) takes very high-resolution spectra in thousands of frequencies simultaneously. It covers the bands 480-1250 GHz and 1410-1910 GHz, using superconducting mixers as detectors. It is being developed by a consortium led by SRON (Groningen, The Netherlands).

These instruments are being developed by nearly 40 institutes, mainly European with participation from the USA and Canada.

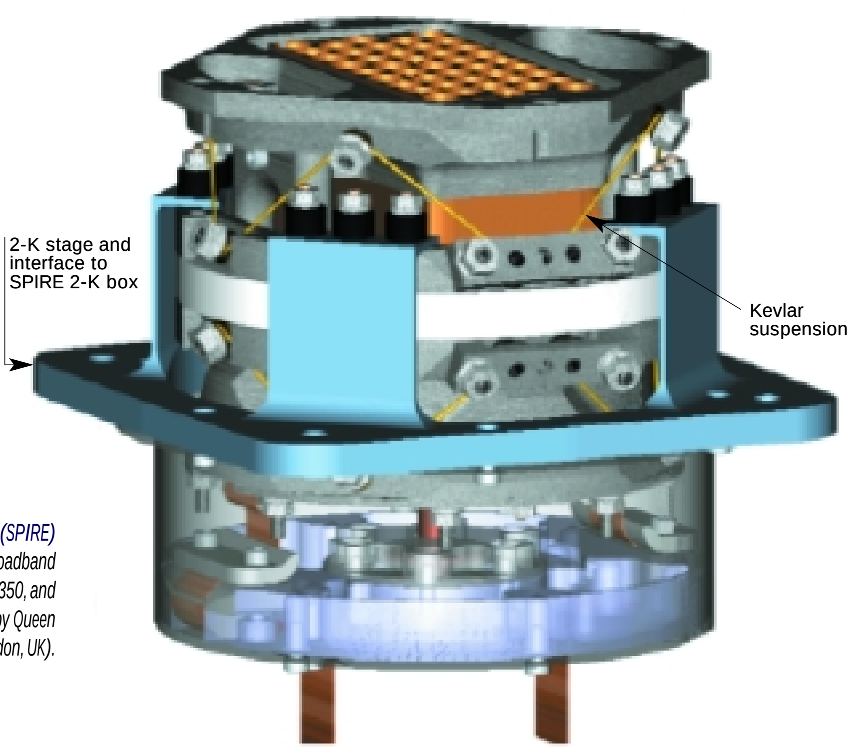
The coldest detectors

Infrared detectors have to be cooled down to very low temperatures, otherwise they will be warmer than the radiation they are trying to measure. The temperature of some astronomical objects is close to the absolute zero (-273.15° Celsius, which is equivalent to 0° Kelvin); trying to observe them with an instrument 'warmer' than just a few degrees above that temperature would be like trying to see a star at noon.

Parts of all three FIRST instruments will be kept at -271° Celsius, thanks to a cryostat that will be filled with more than 2000 litres of the coolant superfluid helium. Even further cooling down – to just a few tenths of a degree above absolute zero (-273.3° Celsius) will be required for the SPIRE and PACS bolometer detectors. The role of the cryostat is fundamental: it determines the lifetime of the observatory. The coolant liquid helium is constantly evaporating; when it is exhausted the instruments' temperature will start to rise, and as a result FIRST will no longer be able to make observations.

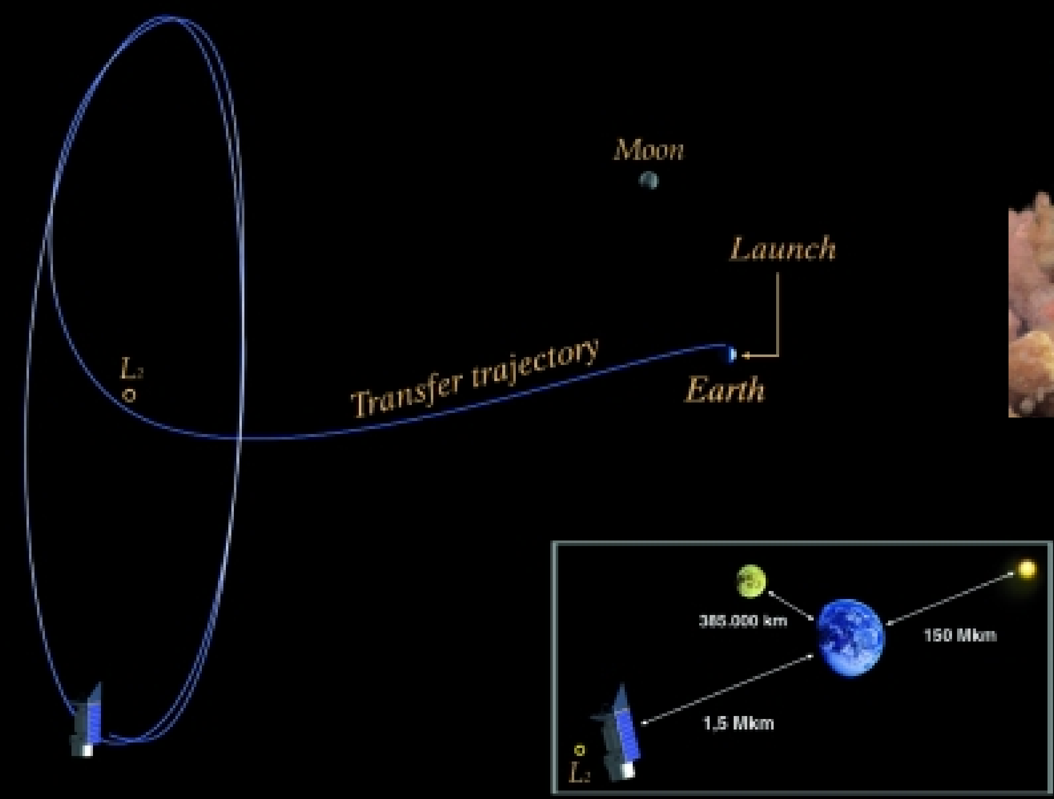


The Photoconductor Array Camera and Spectrometer (PACS) is an infrared camera and a spectrometer. It will operate simultaneously in two wavelength bands – the 60-130 micron and the 130-210 micron bands – with bolometer and photoconductor array detectors. It is being developed by a consortium led by the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



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

Leaving behind the Earth and the Moon

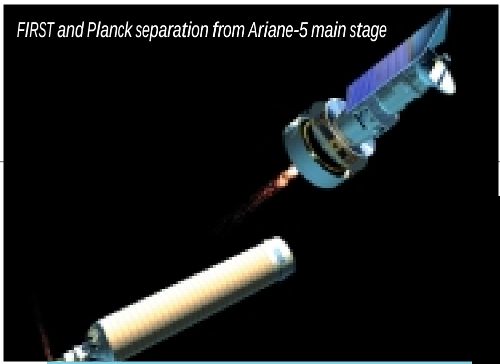


FIRST will be launched by an Ariane-5 launcher together with another ESA mission, Planck, which will study the Cosmic Microwave Background radiation. Both spacecraft will be separated soon after launch and directed to different orbits, where they will be operated independently. At launch, the FIRST/Planck combination will measure approximately 11 m in height and 4.5 m in width, with a mass of approximately 5300 kg.

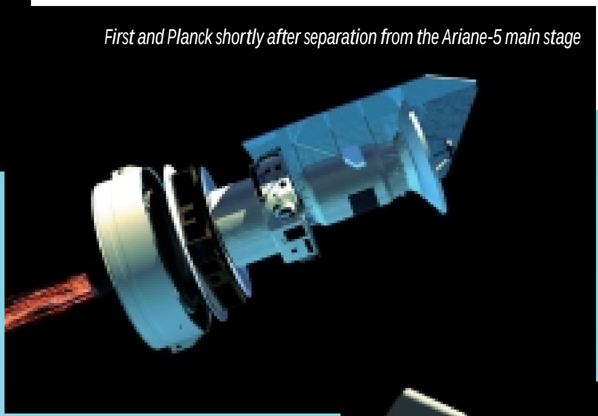
It will take FIRST about four months to get into its operational orbit around a virtual point in space known as the 2nd Lagrangian point (L2) in the Sun-Earth system. This point is located 1.5 million kilometres away from Earth (about four times the distance of the Moon), in the opposite direction to the Sun. This position has two important advantages: it will allow FIRST to avoid the strong far-infrared emission from the Earth and the Moon, and because the Earth and the Sun are in the same general direction, it offers good sky visibility for performing the astronomical observations.

FIRST's orbit around L2 will have an amplitude of about 700 000 km. Because of this large orbit, FIRST's distance to the Earth will vary between 1.2 and 1.8 million km. The orbits around L2 are unstable – subtle relative movements of the Earth cause the satellite to quickly drift – so small correction manoeuvres will have to be applied monthly.

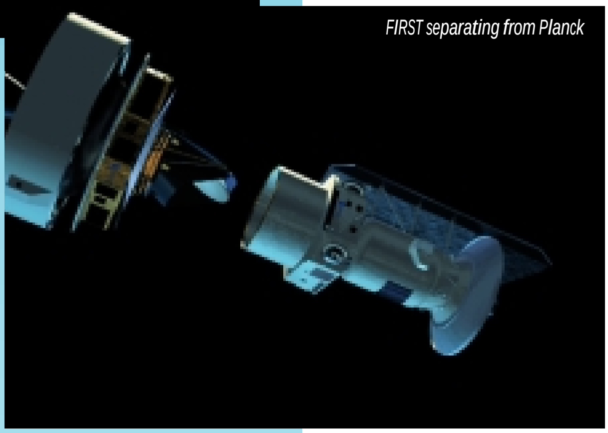
FIRST in a nutshell



FIRST and Planck separation from Ariane-5 main stage



First and Planck shortly after separation from the Ariane-5 main stage



FIRST separating from Planck

Concept:
The European Space Agency's Far-Infrared and Submillimetre Telescope, FIRST, will be the first space observatory covering the full far-infrared and submillimetre waveband, and the largest to work at those wavelengths. Thanks to this, FIRST will be able to see dusty and cold regions that are opaque for other telescopes, and thus it will unveil a face of the early Universe that has remained hidden so far. FIRST's main goal is to study how the first galaxies and stars formed and evolved. Other targets will be the clouds of gas and dust where new stars are being born; disks out of which planets may form; and cometary atmospheres packed with complex organic molecules.

Primary mirror:
3.5 metres in diameter.

Launch:
FIRST will be launched in 2007 together with another ESA scientific mission, Planck. The two satellites will separate shortly after launch and will be operated independently.

Orbit:
FIRST will orbit a virtual point in space called 'the 2nd Lagrangian point (L2) in the Sun-Earth system', located 1.5 million kilometres away from Earth.

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

Launch Mass:
Approximately 3.3 tonnes

Dimensions:
Approximate height, 9 metres. Approximate width, 4.5 metres.

Operations:
FIRST will be operated as an observatory. About two-thirds of FIRST's observing time will be open to the World scientific community. The rest will be guaranteed time mainly belonging to the instrument consortia.

Ground Station:
Perth, Australia

Operational Lifetime:
Minimum 3 years of routine science operations.

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