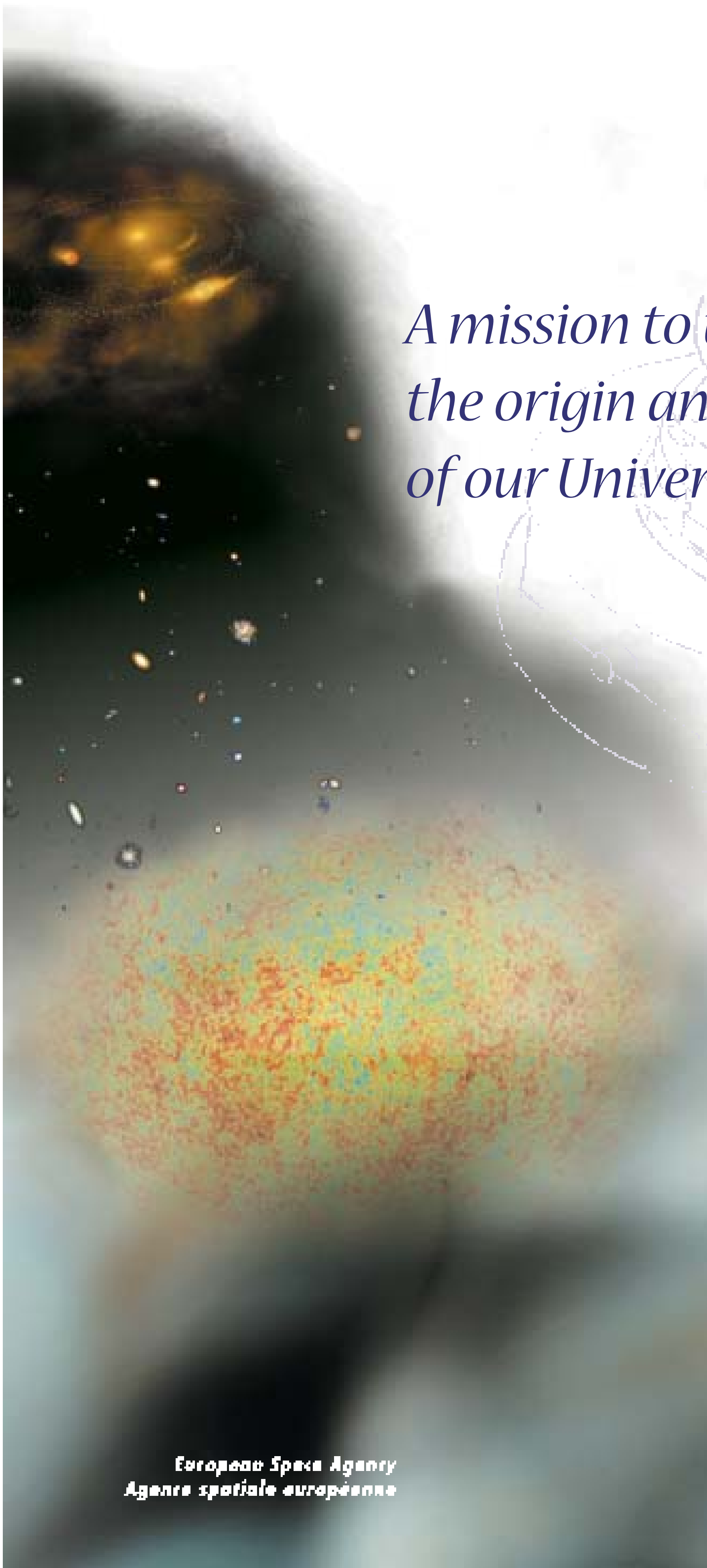
BR-159

PLANCK

A mission to understand the origin and evolution of our Universe



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.

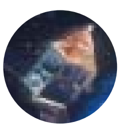
The ESA Science Programme has launched a series of innovative and successful missions. Highlights of the programme include:

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.

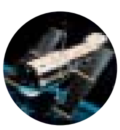
Cluster, which is a four-spacecraft mission to investigate in unprecedented detail the interaction between the Sun and the Earth's magnetosphere.

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.

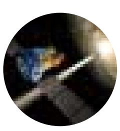
Giotto, which took the first close-up pictures of a comet nucleus (Halley) and completed flybys of Comets Halley and Grigg-Skjellerup.



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



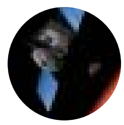
Hubble Space Telescope, a collaboration with NASA on the world's most important and successful orbital observatory.



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.

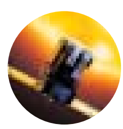
IUE, the first space observatory ever launched, marked the real beginning of ultraviolet astronomy.



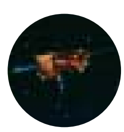
Mars Express, Europe's first mission to Mars, which consists of an orbiter and a lander looking for signs of water and life on the Red Planet.

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.

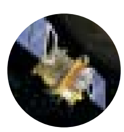
SMART-1, Europe's first mission to the Moon, which will test solar-electric propulsion in flight, a key technology for future deep-space missions.



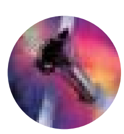
SOHO, which is providing new views of the Sun's atmosphere and interior, revealing solar tornadoes and the probable cause of the supersonic solar wind.



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, visit http://www.esa.int/science

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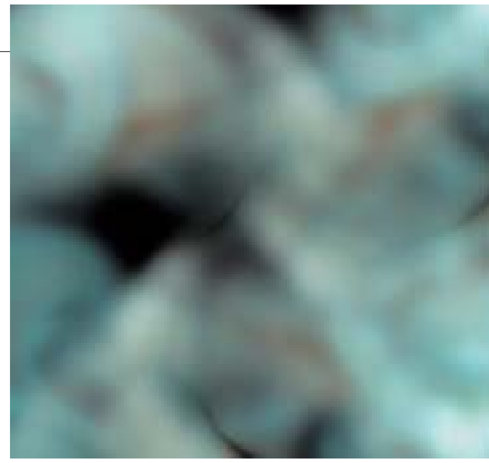
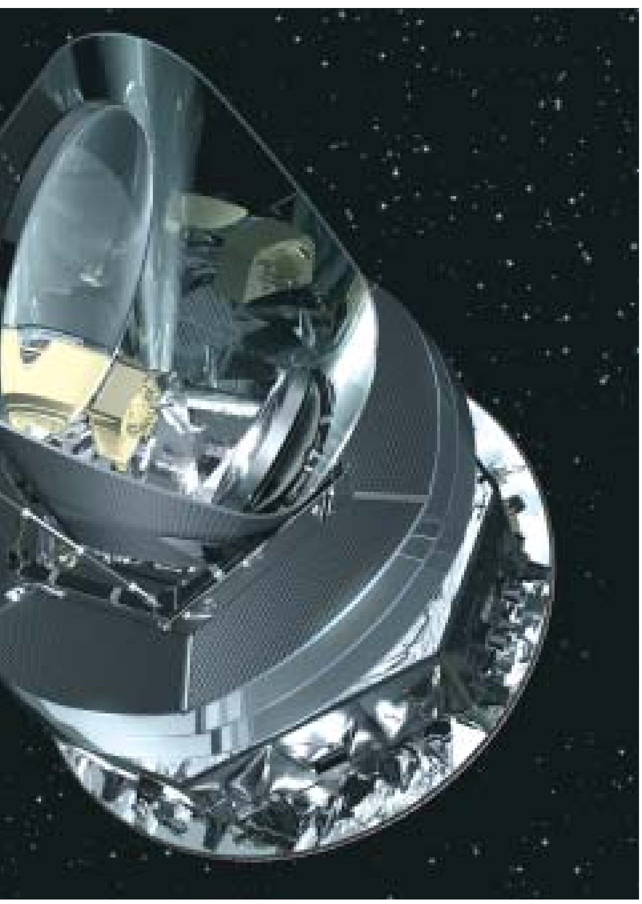
Looking back to the dawn of time



Only a century ago, the origin of the Universe was a topic that few scientists dared to touch: they simply lacked the experimental means to gather reliable data. The situation is quite different now. Cosmology, the science that aims at explaining how the Universe formed and evolves, has become one of the richest and hottest fields of experimental research.

Key discoveries made during the last eight decades show that in the past the Universe was far denser and hotter than it is today, and that it started to cool and expand – a process that is still going on today – about 14 000 million years ago. This version of events, known as the Big Bang theory, is currently considered a firm scenario. But the picture is still far from complete. Questions such as what triggered the birth of the Universe, or how it will evolve in the future, remain unanswered.



These questions, though, are no longer untouchable. Contrary to what happened a century ago, scientists now know where to look for the answers, and they are steadily gaining the means to do so. The era of experimental cosmology is indeed in full swing: ongoing experiments on Earth and in space are starting to yield new and exciting results. And in the coming years the field will be enriched with more complex space-based instruments specifically designed to tackle fundamental problems.

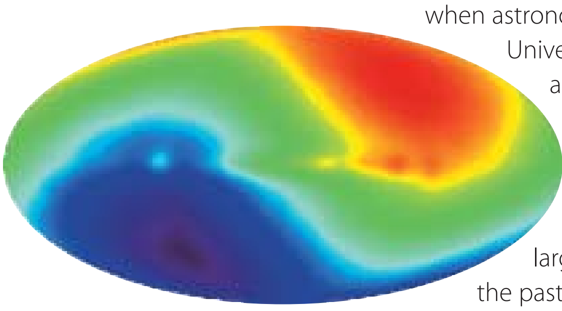
The Planck satellite, a mission of the European Space Agency due to be launched in 2008, is the most ambitious of these space missions. Planck will provide the most precise and reliable data of its kind ever obtained, and by so doing it will take scientists the closest ever to the origin of our Universe. Planck is being built and readied for launch by European industry and scientific institutes all around Europe and the USA to help solve many of the big questions still pending in cosmology.

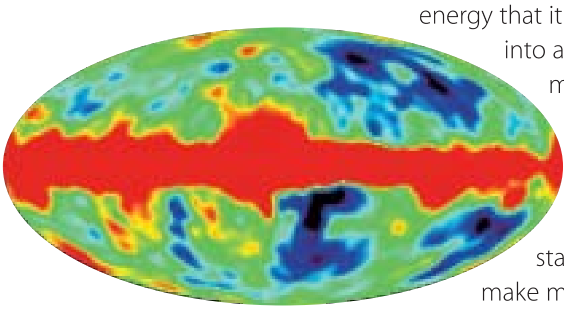
Artist's impression of ESA's Planck satellite

Detectives of the past and the future

An expanding Universe with a hot past

Scientists trying to reconstruct an event that happened about 14 000 million years ago work very much like detectives. First they have to find the right clues, then they have to squeeze all the useful information out of those 'pieces of evidence'. The case of the Big Bang is a long and difficult one. It started in the twenties, when astronomers learnt that the Universe has not always been as we see it today. They discovered that all the time, even right now, the Universe is becoming larger and larger. This means that in the past all the matter and energy that it contains were packed into a much smaller, and also much hotter, region.





Maps of the sky as seen by NASA's COBE satellite, after different stages of image processing. The top panel shows (in false colour) the temperature of the sky after removing a uniform (2.7 K) component due to the CMB; the large-scale diagonal feature (the so-called dipole) is caused by the motion of the Sun with respect to the CMB, and the faint horizontal smudge is due to emission from the Milky Way. The bottom map results when these two components are removed. What is left is residual galactic emission (seen as a bright horizontal band), and a background of hot and cold spots, due largely to a mixture of instrumental noise and the CMB.

Later on, a second clue was identified. Scientists learnt that the stars are the 'factories' that make most chemical elements in the Universe – oxygen, carbon, iron – but also that some particular elements must come from somewhere else. They postulated, and confirmed, that those few elements had been produced at the earliest epochs of the Universe, when it was still very hot.

The first light

Those findings helped to give shape to the Big Bang theory. But this general model describing the beginning of the Universe did not gain wide support from the scientific community until the discovery of yet a third 'clue'. In 1964 two researchers detected by chance a radiation coming from everywhere in the sky, a 'glow' filling the whole Universe with the same intensity. This radiation could best be interpreted as a 'fossil' of the Big Bang itself.

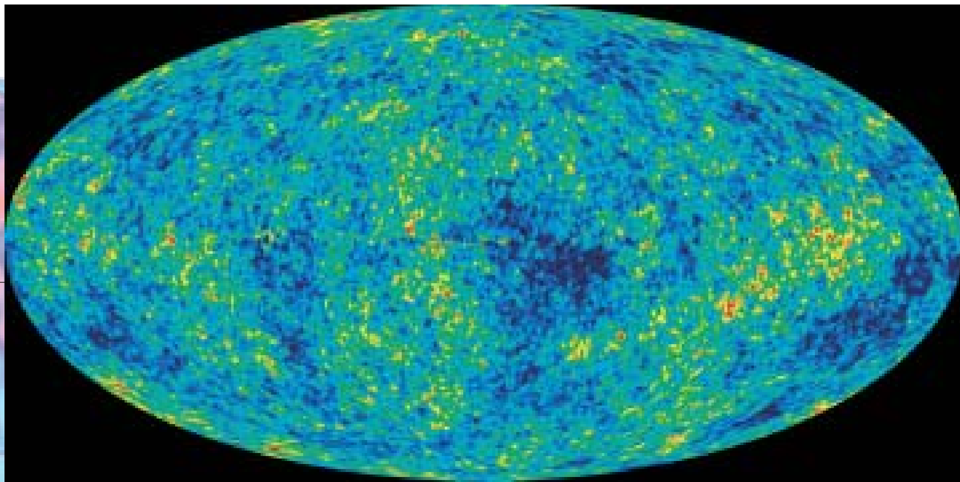
The argument goes like this: if the Universe has always been expanding, then there must have been an initial period during which all existing matter and radiation were very tightly coupled together, in a high- temperature mixture. With time the Universe cooled down, and at some point it must have reached a temperature low enough for the radiation to be released from its close embrace with matter. Light would then have travelled freely throughout the Universe for the first time. That 'first light' should still be detectable today, and it was, in fact, the glow detected in 1964.

The 'first light' is called by scientists the Cosmic Microwave Background (CMB) radiation. It is important not only because it is the third major 'piece of evidence' supporting the Big Bang theory, but also because cosmologists know that they have not yet been able to extract all the information it holds. 'Cosmo-detectives' still need to work hard on the fossil radiation.

'Clots of information'

The Cosmic Microwave Background radiation comes from every direction in the sky with almost the same brightness. However, by measuring the apparent 'temperature' of the CMB all over the sky, it was discovered that very small, in fact tiny, differences do exist from place to place. These differences can be as small as one part in a million.

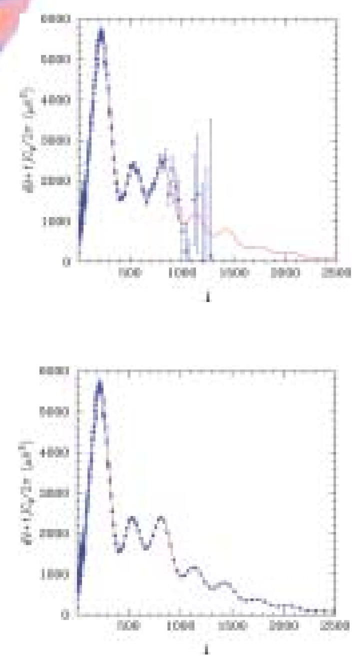
Although these variations may seem too small to be important, they are precisely what scientists are looking for. They contain a gold-mine of information. They are nothing less than



In 1992, NASA's COBE satellite confirmed for the first time that the temperature of the Cosmic Microwave Background (CMB) was not identical all over the sky. The COBE measurements indicated that over angular scales larger than 10º, the CMB temperature varies by about one part in 100 000 from the average value of 2.73 K. The background image shows the map of the sky from which these conclusions were drawn. In 2003, COBE's successor WMAP was able to improve dramatically the map's clarity and sharpness; the image shows the tiny irregularities in the temperature of the CMB across the sky.]

the imprints left in the past by matter, a reminder of the period when matter and radiation were closely coupled to each other. At that time matter already hosted the 'seeds' out of which the huge structures we see today in the Universe – galaxies, galaxy clusters – were formed. The tiny variations in the measured temperature of the Cosmic Microwave Background are the 'fingerprints' left by those 'clots' of matter.

In fact, all of the valuable information that the Cosmic Microwave Background can provide lies in the precise shape and intensity of these temperature variations, often called 'anisotropies'. In 1992, NASA's satellite COBE obtained the first blurry maps of the anisotropies in the CMB. In 2003, its successor, the WMAP satellite, was able to make maps that have started to reveal their detailed properties. The objective of Planck is to complete the picture by mapping these features as fully and accurately as possible.



Simulations of observations of the CMB show the dramatic improvement that can be achieved by increasing the angular resolution and sensitivity of an experiment from the level of WMAP (top panel) to the level of Planck (bottom panel). The quantity shown on these plots (the 'angular power spectrum') encodes the amount of cosmologically relevant information available in the maps, reflected in the bumps and wiggles of the red curve. The blue bars show that Planck will be able to recover about 15 times more such information than WMAP.

Some pending questions that Planck will help to answer

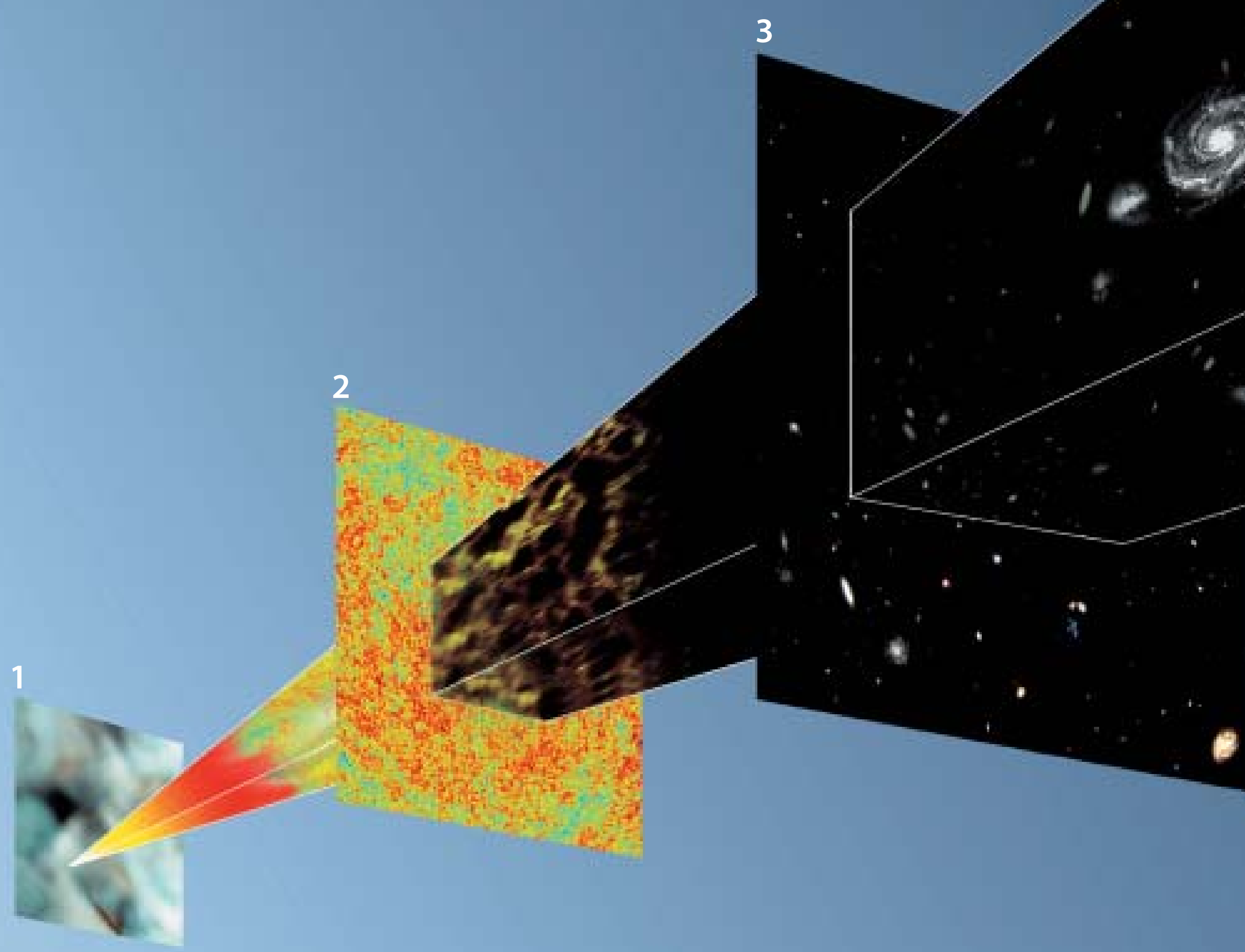
The anisotropies in the cosmic background hold the answers to many key questions in cosmology. Some refer to the past of the Universe, such as what triggered the Big Bang, and how long ago it happened. But some other questions look deep into the future. For instance, what is the density of matter in the Universe and what is the true nature of this matter? These parameters will tell us if the Universe will continue its expansion forever or if, on the contrary, it will end up collapsing on itself in an inverse process to the Big Bang, which one might call the 'Big Crunch'. Now, thanks to the WMAP satellite, we know that our Universe will most likely not crunch; however, new insights are telling us that the fate of the Universe is even less predictable than we thought.

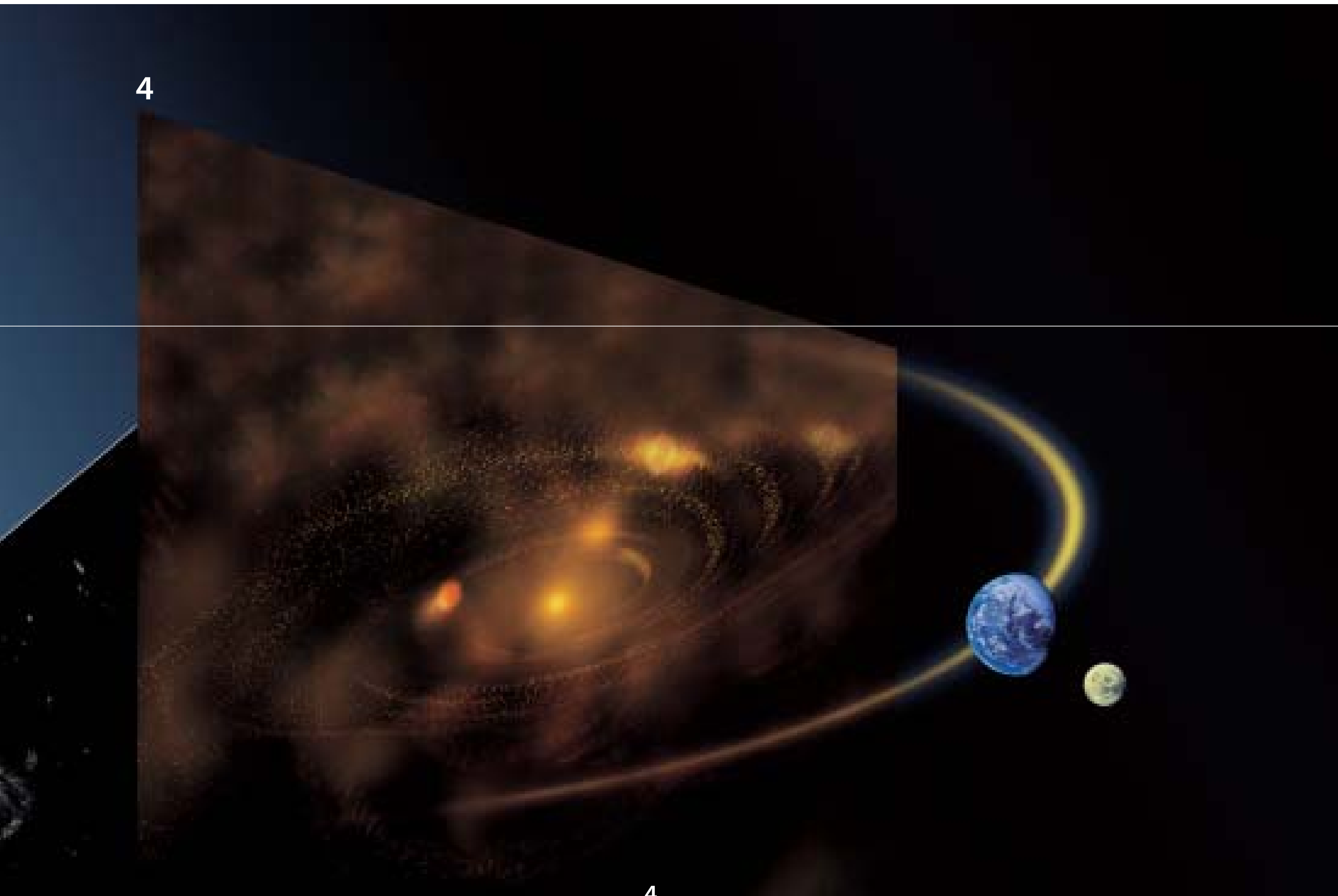
Some of the new uncertainties are related to the existence of a 'dark energy' which may exist in large quantities in our Universe, as indicated by recent observations that measure the light from distant exploding stars. Is it really there? And if so, what are its effects? ESA's Planck satellite will shed light on these issues, because it will be the most powerful tool to analyse the anisotropies in the Cosmic Microwave Background.

Peering into the origins of space and time

The birth of the Universe

The period up to a millionth of a second after the birth event is full of uncertainties: there are no solid observations or speculation-free arguments to confirm or disprove theories covering this period. According to the most accepted hypothesis, at the beginning of this epoch a very brief 'inflation' process took place. During this 'inflation' the Universe expanded extremely quickly by a huge factor, after which it expanded and cooled much more slowly. If this is what actually happened, the inhomogeneities in the Cosmic Microwave Background radiation will reflect some details of the event, and Planck will provide us with the most reliable information about it.





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About 5000 million years ago

Our Sun was formed from the collapse of a cloud of dust and gas contained in our galaxy, the Milky Way. 500 million years later, the Earth – formed from the leftovers of the birth of the Sun – was already in place.

3

One thousand million years after the Big Bang

When the Universe was maybe a sixth of its present size stars and galaxies already existed. They formed through the accretion of matter around primeval dense 'clots' that were present in the early Universe and left their imprint in the radiation, at the period when both were closely coupled. Today, the fingerprints of matter are detected as very slight differences in the apparent temperature of the CMB.

2

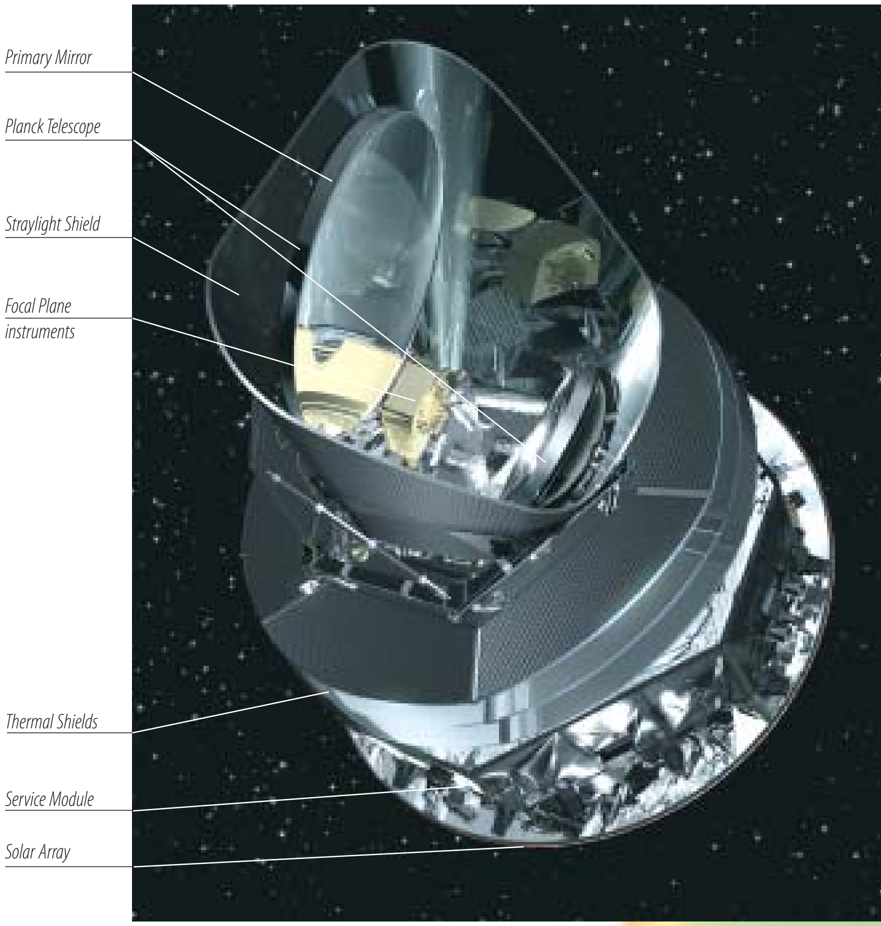
300 000 years after the Big Bang

The Universe is about 1000 times smaller than its present size, and it has cooled down to about 3000 degrees. This is cold enough to allow hydrogen atoms to form, so light and matter can now exist independently: light travels freely for the first time. The Cosmic Microwave Background (CMB) radiation is that 'first light', a fossil light carrying information both about the past and the future of the Universe.

1

From one second until three minutes after the Big Bang

One second after its birth, the temperature of the Universe has dropped to 10 000 million degrees. The first atomic nuclei are formed. Meanwhile the Universe keeps expanding and cooling. But it is too hot yet for neutral atoms to form: electrons roam about freely and interact strongly with radiation. As a result, matter and radiation are closely coupled together.



How Planck will work

Sensing the temperature of the Universe

Planck will study the Cosmic Microwave Background radiation by measuring its temperature all over the sky. Planck's large telescope will collect the light from the Cosmic Microwave Background and will focus it onto two arrays of radio detectors, which will 'translate' the signal into a temperature.

The detectors on board Planck are highly sensitive, since they will be looking for variations in the temperature of the cosmic background about a million times smaller than one degree.

The coldest detectors

A key requirement is that Planck's detectors will have to be cooled down to temperatures very close to the coldest temperature reachable in the Universe: the 'absolute zero' – minus 273.15 degrees Centigrade, or, expressed in the scale used by scientists, zero degrees Kelvin.

At the time of its release, only about 300 000 years after the Big Bang, what we detect today as the Cosmic Microwave Background had a temperature of some 3000 degrees; but now, with the expansion and cooling of the Universe, the 'temperature' of this radiation appears to be just about 3 degrees above absolute zero. The detectors on board Planck have to be very cold to ensure that their own temperature does not swamp the signal from the sky. All of them will be cooled down to temperatures around or below -253 degrees Centigrade, and some of them will reach the amazingly low temperature of just one tenth of a degree above absolute zero.

Sharp vision

Planck will provide very accurate measurements of the cosmic background thanks also to its higher 'angular resolution'.

The angular resolution indicates the smallest separation between regions in the sky that the detectors are able to distinguish; the smaller the separation, the sharper (better) will be the information gathered on the temperature of the cosmic background. The angular resolution can be compared to the ability to distinguish finer details, the 'sharpness' of vision. Planck's sharpness of vision is such that it can distinguish objects on the sky whose apparent size is about one-fifth of the size of the Moon, a much higher angular resolution than any other space mission to study the cosmic background. With its sharp vision and high sensitivity, Planck will extract most of the information that the CMB holds.

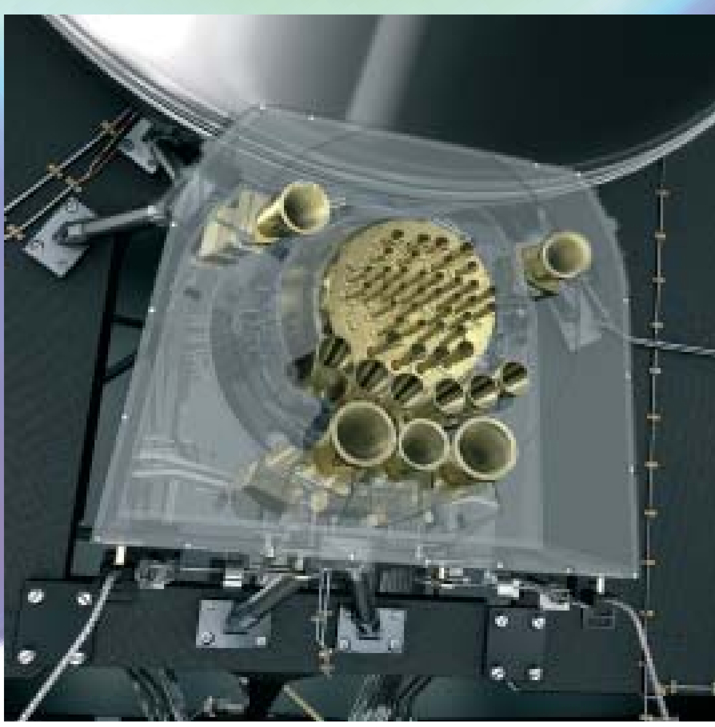
Planck telescope

The Planck telescope collects the CMB from the sky and delivers it to the detectors. Its mirrors are being provided by a collaboration between ESA and a Danish Consortium of scientific institutes led by the Danish Space Research Institute. These mirrors are very large for a space mission (between one and two metres in size), and they must simultaneously be very accurately shaped, very light, and very stiff. These demanding requirements can be met using novel materials based on carbon fibre.

Broad wavelength coverage

Microwaves are a specific kind of electromagnetic radiation. Electromagnetic radiation, which is simply 'light', can be thought of as a wave which carries a certain energy. Light of different energies needs different detectors to be 'seen'. Microwaves, for instance, cannot be detected by our eyes, which are instead perfectly 'tuned' to see a more energetic kind of light called, for obvious reasons, visible light. The energy of light is often described in terms of 'wavelength' (a length scale) or 'frequency' (a time scale). The typical wavelength of microwaves is in the order of millimetres.

The Planck detectors are specifically designed to detect microwaves at wavelengths in the range between one third of a millimetre and one centimetre. This wide coverage is required to face a key challenge of the mission: to differentiate between the useful scientific data and the many other undesired signals that introduce spurious noise. The problem is that many other objects, such as our own galaxy, emit radiation at the same wavelengths as the Cosmic Microwave Background itself. These confusing signals have to be monitored and finally removed from the measurements; Planck will be able to do this by dedicating many of its wavelength channels to measuring signals other than the CMB.

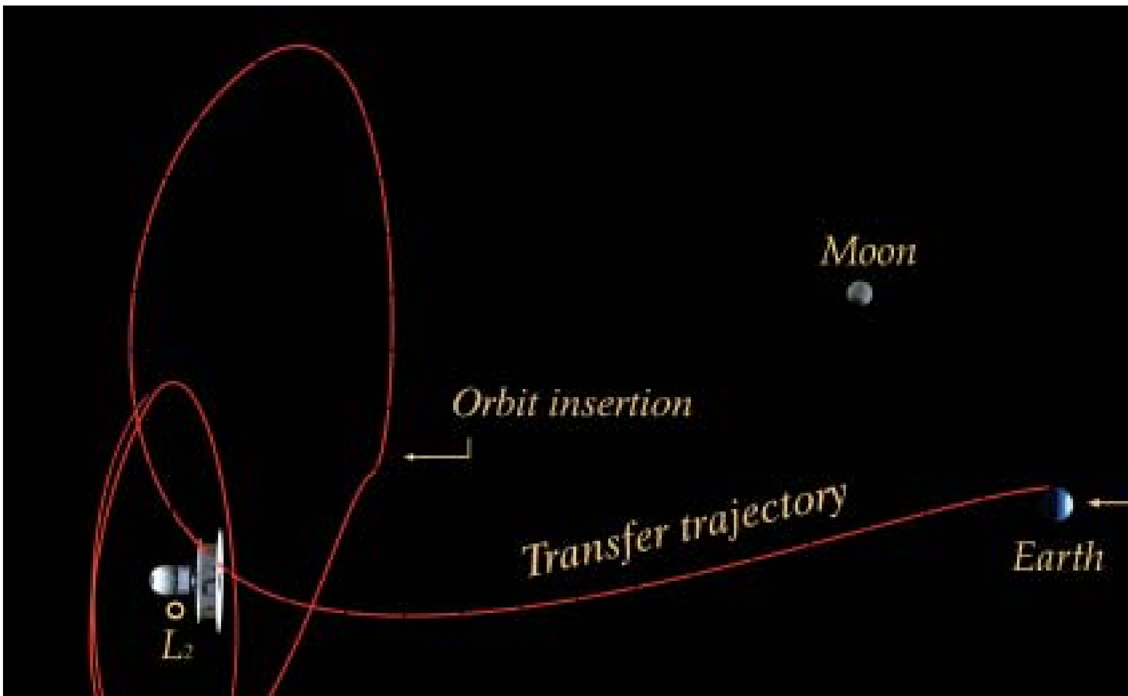


The High Frequency Instrument (HFI) *is an array of 50 so-called 'bolometric' detectors, which work by converting radiation to heat. They are operated at a temperature only one tenth of one degree above absolute zero. The HFI detectors will gather data in six wavelength channels between three mm and one third of a mm. The instrument is being built by a Consortium of more than 20 institutes, led by the Institut d'Astrophysique Spatiale in Orsay (France).*

The Low Frequency Instrument (LFI)

is an array of 22 tuned radio receivers that will be operated at -253 °C and will take measurements in three wavelength channels, between about four mm and one cm. Based on devices called HEMTs (High Electron Mobility Transistors), these detectors work very much like transistor radios: the transistors amplify the signal collected by the telescope from the sky, and this amplified signal is then detected and stored for analysis. The instrument is being built by a consortium of more than 20 institutes, led by the Istituto di Fisica Spaziale e Fisica Cosmica in Bologna (Italy). The HFI is also visible in this image, inserted in the centre of the LFI ring of horns

1.5 million kilometres away from the Earth



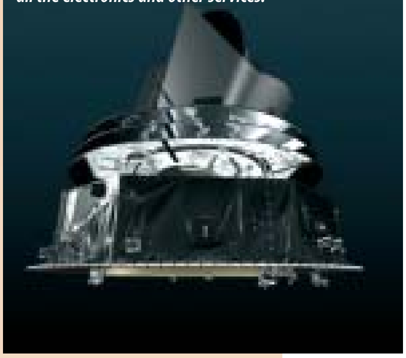
Planck will be launched in 2008 by an Ariane-5 rocket together with another space observatory, ESA's Herschel Space Observatory. The two satellites will separate shortly after launch and proceed to different orbits. They will be operated independently.

Within less than six months of launch Planck will reach its final destination: a so-called 'Lissajous orbit' around a virtual point in space known as the 2nd Lagrangian point of the Sun-Earth-Moon system(L2). The L2 point is located about 1.5 million kilometres away from the Earth – four times the distance to the Moon. From this position Planck will be able to elude the emission from the Earth, the Moon and the Sun, which would otherwise confuse the signal from the cosmic background.

Planck in a nutshell


The Planck payload cavity is kept in the shade and has a temperature of about –220ºC.

Concept:
The Planck satellite is a mission of the European Space Agency which has been designed to help answer key questions for humankind: how did the Universe come to be and how will it evolve. Planck's objective is to analyse with the highest accuracy ever achieved the first light that filled the Universe after the Big Bang, the so-called Cosmic Microwave Background radiation (CMB).


The bottom part of the satellite is warm and contains all the electronics and other services.

Launch and orbit:
Planck will be launched in 2008, together with ESA's Herschel Space Observatory. The two satellites will separate after launch to operate independently at a distance of 1.5 million kilometres from Earth.

Telescope and instruments:
Planck will carry a 1.5-metre telescope. It will focus radiation from the sky onto two arrays of highly sensitive radio detectors, the Low Frequency Instrument and the High Frequency Instrument. Together they will measure the temperature of the Cosmic Microwave Background radiation over the sky, searching for regions very slightly warmer or colder than the average.


An intricate maze of pipes, wires and waveguides connects the warm and cold parts of the satellite

Participants:
More than 40 European and some US scientific institutes participate in the design and construction of the instruments.

Wavelength coverage:
From one cm to one third of a mm, corresponding to a range from the microwave to the far-infrared.

Dimensions:
Approximately 4.2 metres high and 4.2 metres wide.

Launch mass:
About 1.9 tonnes

Operations:
Planck will rotate slowly and sweep a large swath of the sky each minute. In about 15 months it will have covered the sky fully, twice over. It will operate in a completely autonomous way and will dump the acquired data each day to a ground station within a three hour period.

Ground station:
During routine operations, Planck will be controlled from ESA's ground station in New Norcia, Australia.

Operational duration:
15 months of routine operations are foreseen.

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