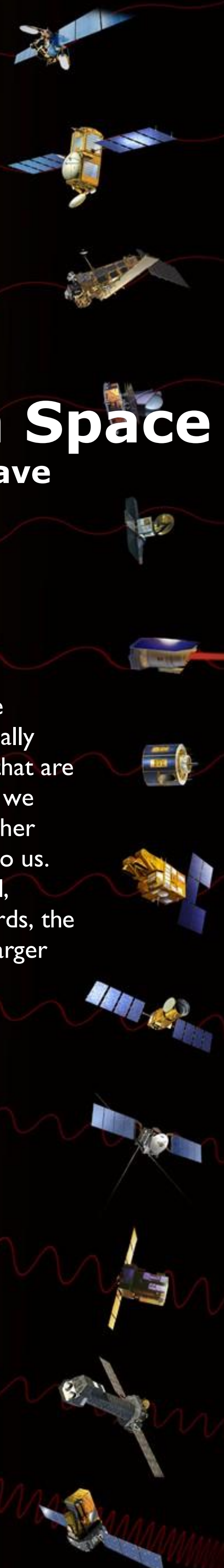

A trip through Space

from wave to wave

Most of the electromagnetic spectrum is invisible to the eye

The product of billions of years of evolution, the human eye is a formidable receptor. It is specifically adapted to some of the electromagnetic waves that are omnipresent on our planet. They make up what we commonly call light and colour. But there are other electromagnetic waves that are totally invisible to us. These include radio waves, microwaves, infrared, ultraviolet, X-rays and gamma rays. In other words, the waves that make up light are the tip of a much larger iceberg: the electromagnetic spectrum.

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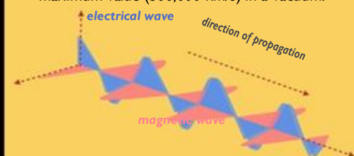
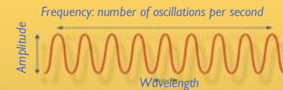
What is an electromagnetic wave?

Electricity and magnetism are closely linked. An electric current generates a magnetic field. Conversely, a variable magnetic field creates an electric field.
An electromagnetic wave is made up of an electric field and a magnetic field that propagate simultaneously through space. These waves do not need matter to move. Their speed depends on the propagation medium. It reaches its maximum value (300,000 km/s) in a vacuum.



An electromagnetic wave is characterised by its amplitude, wavelength or frequency.
The amplitude corresponds to the maximum variation in the electric or magnetic field. **The wavelength** is the distance between two successive maxima. **The frequency** is the number of oscillations per second: it is measured in hertz.



Wave and particle

At the beginning of the 20th century, physicists discovered that electromagnetic waves could also be described in the form of particles called photons. These elementary particles of zero mass and charge carry proportionally more energy the higher the frequency of the wave with which they are associated.

The electromagnetic spectrum

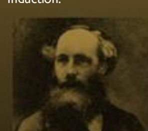
Electromagnetic waves are classified according to their wavelength. The electromagnetic spectrum ranges from radio waves, whose wavelength can reach several hundred kilometres, to gamma rays, which have a wavelength of less than a thousandth of a billionth of a metre. Between these two extremes lie microwaves, infrared, visible light, ultraviolet light and X-rays. In the visible range, each colour corresponds to a specific wavelength.

Electromagnetism in a few dates

1820 **H.C. Oersted** observed the relationship between electric current and magnetism. **A.M. Ampère** and **F. Arago** built the first electromagnet.

1831 **M. Faraday** discovered the principle of electromagnetic induction.

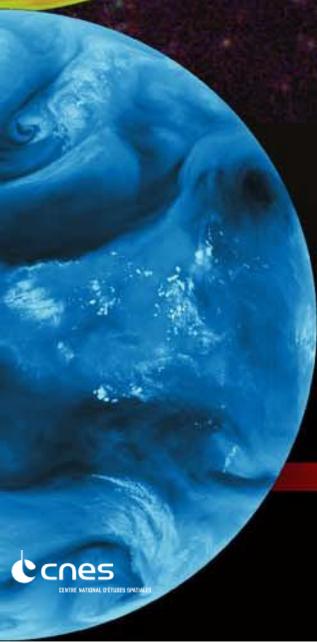
1864



J.C. Maxwell established the laws of electromagnetism.

1888 **H. Hertz** showed experimentally that light is a form of electromagnetic radiation.

1895 **W. Conrad Röntgen** discovered X-rays.



The Earth seen from space

The Earth is constantly scanned by satellites which give us astonishing images of our environment. At their altitude, they observe large areas of the globe.
But they are also capable of zooming in precisely on small areas.
Different from our eyes, these satellites look at the Earth not only in the visible range, but also in the radio, ultraviolet and infrared ranges.
These space observations are extremely useful for forecasting the weather, monitoring the evolution of natural resources, observing the oceans and ice, and studying the atmosphere.
Other satellites orbiting the Earth act as telecommunication relays, receiving and transmitting information by radio.

The Universe shines with a thousand lights - not all of which are visible to us

Planets and stars also emit different types of electromagnetic waves. These waves propagate throughout the Universe, carrying with them precious information. They tell us about the chemical composition, temperature, pressure and environment of celestial objects. However, most of these waves are blocked by the Earth's atmosphere and do not reach us. The altitude at which satellites orbit enables them to pick up these waves from the Universe.

The satellites that observe the Earth and the Universe do not see the same things as we do.
Let's discover the world around us, through their eyes, as we take a trip through the electromagnetic spectrum.

The satellites in a few dates

1957 Sputnik
first artificial satellite
(Soviet Union)

1960 TIROS-1
first weather
satellite
(United States)

1968 OAO: the first ultraviolet astronomy satellite (United States)

1970 SAS1: first X-ray astronomy satellite (United States)

1972 SAS2: first gamma-ray astronomy satellite (United States)

1983 IRAS: first infrared astronomy satellite (United States, United Kingdom, Netherlands).

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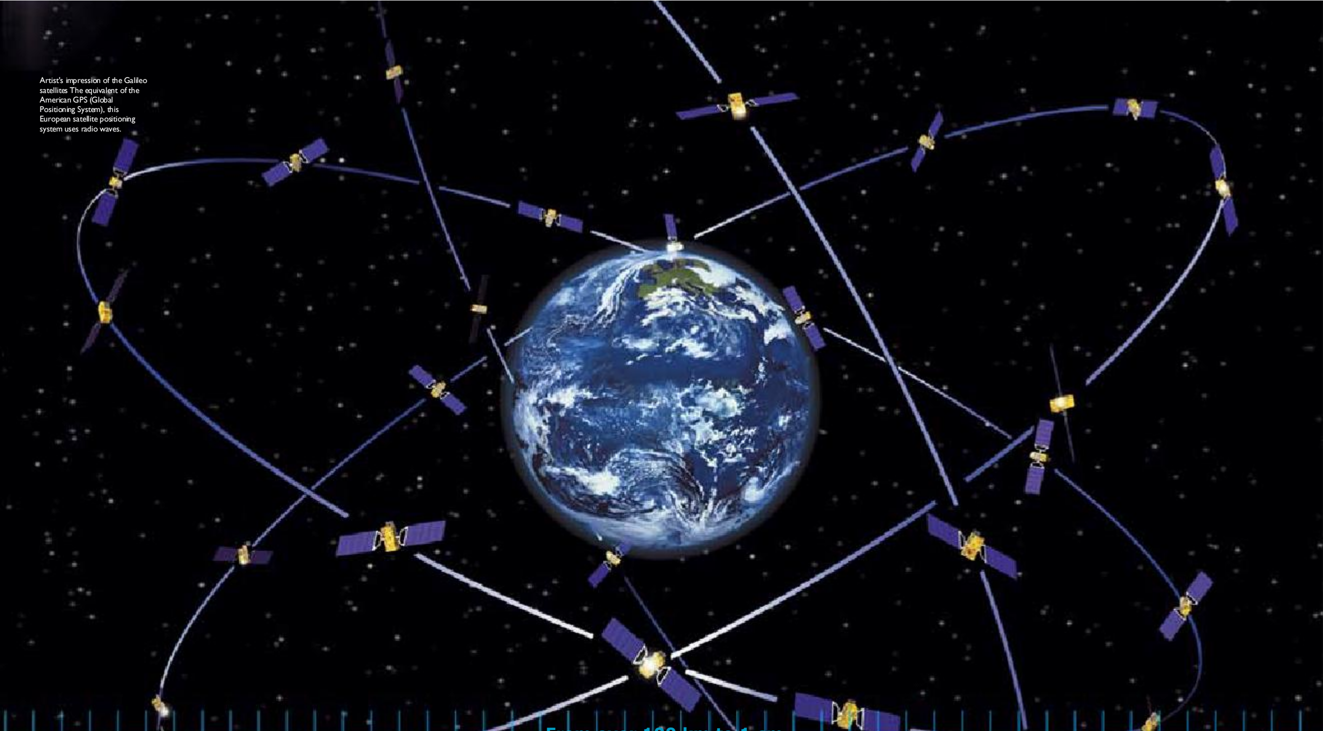

Artist's impression of the Galileo satellites The equivalent of the American GPS (Global Positioning System), this European satellite positioning system uses radio waves.

From over 100 km to 1 cm

RADIO WAVES

Eutelsat satellite

Wireless communication

Radio waves propagate rapidly and with little loss of energy in the atmosphere. They are currently widely used to transmit messages and information at great distances and wirelessly. Radio, television and mobile phones are the main applications. To obtain a sufficient number of different signals, the frequency or amplitude of these waves is varied slightly by frequency or amplitude modulation respectively. Everyone is familiar with long wave, medium wave and short wave radio, for example.

A satellite relay

Electromagnetic waves propagate in a straight line in a vacuum. As the Earth is round and has topographical relief, many relays are needed to carry radio waves over a great distance, unless you go to a great altitude. Satellites in geostationary orbit, i.e. immobile relative to the Earth at an altitude of 36,000 km, can act as relays by receiving and transmitting radio waves. So 3 satellites are enough to cover almost the entire globe.

"Mobile phones use radio waves to communicate."

Satellite television transmission.

Satellite positioning systems are used in agriculture.

Argos beacons are used to track wild animals by satellite.

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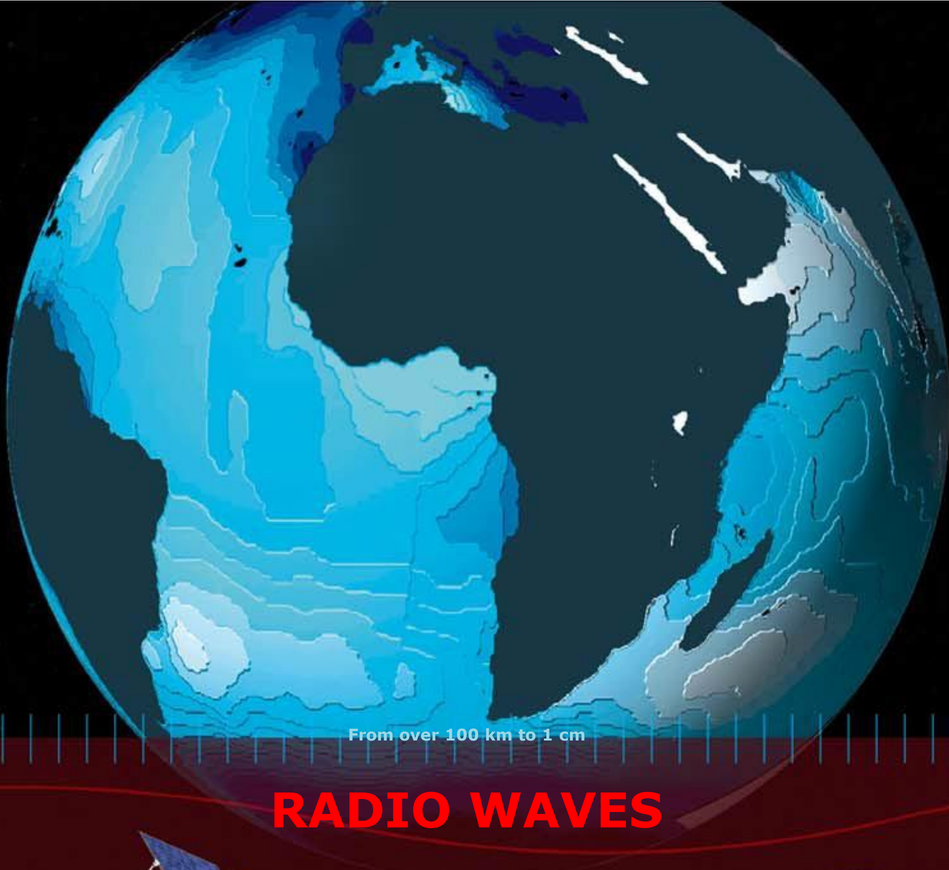
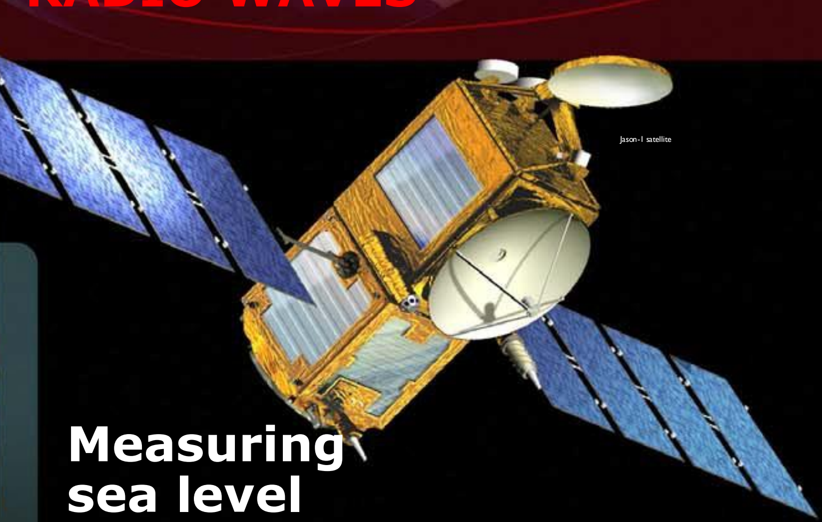


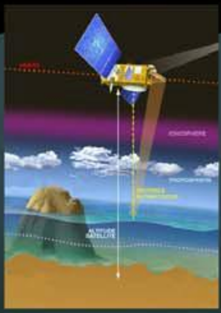
The oceans as seen by altimetry from the Topex-Poseidon satellite.

From over 100 km to 1 cm

RADIO WAVES



Jason-1 satellite



Radar altimetry

Satellite altimeters are radars that send out radio waves in the form of very short pulses. When these waves encounter an obstacle, they are reflected in the form of an echo and return to their source. In the case of Jason-1, this obstacle is the surface of the ocean. Knowing the speed at which electromagnetic waves propagate, we can deduce the distance separating the satellite from the sea from the round trip time. Altimeters calculate altitudes to within 2 cm. The amplitude and form of the echo tell us about other parameters such as wave height and wind speed at the sea surface.

Measuring sea level

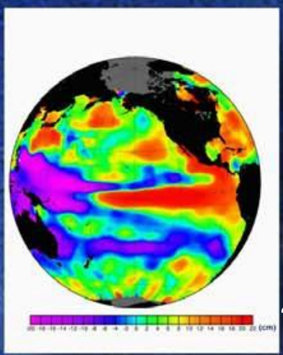
The radars on some satellites operate using radio waves. These instruments measure ranges and heights. For example, the Jason-1 satellite observes the oceans and uses its radar to calculate the mean sea height.

Scientists now estimate, on the basis of these observations and numerical models, that this level is rising by 2 mm a year.

This phenomenon could be linked to the general rise in temperature. Jason-1 also provides us with information on wave heights, marine currents and winds, and enables us to detect early signs of climate anomalies such as El Niño.

"In medical imaging, MRI (magnetic resonance imaging) uses radio waves."

The data obtained by the Jason-1 satellite is useful for fishing activities.



El Niño observed on 7 September 1997 by the radar of the Jason-1 satellite

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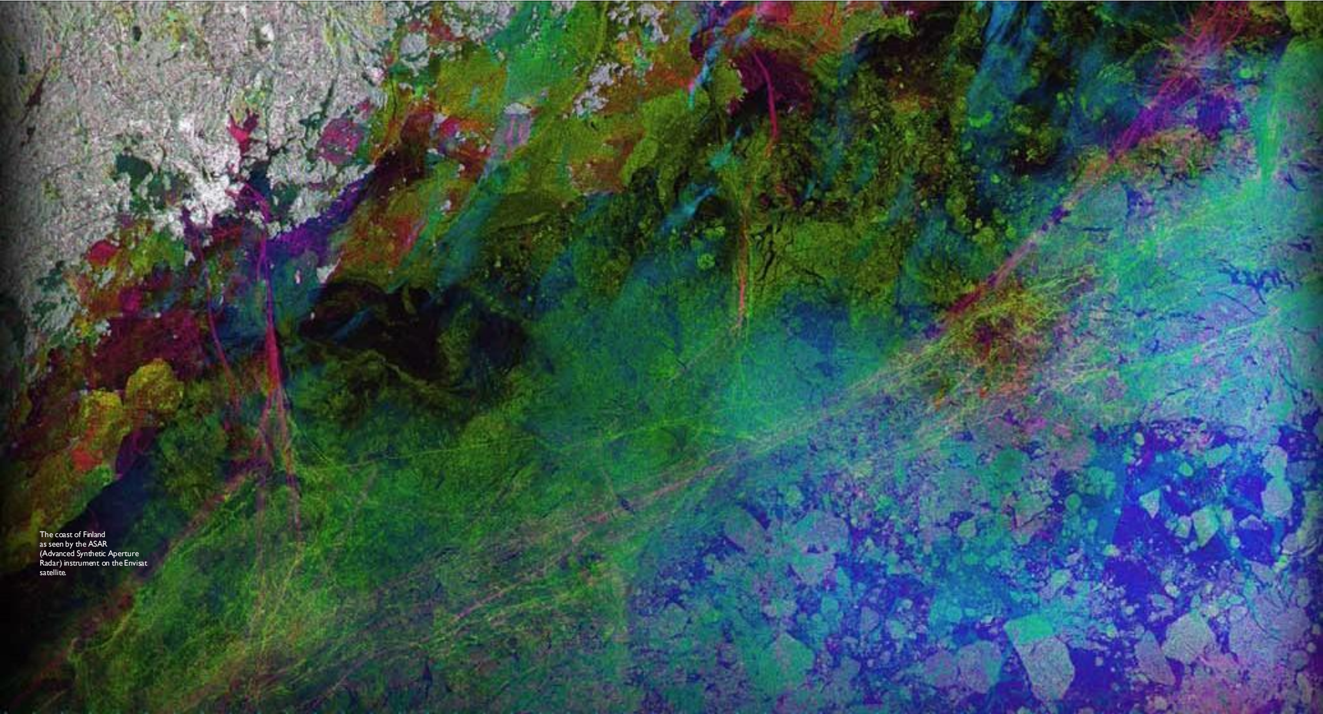

The coast of Finland as seen by the ASAR (Advanced Synthetic Aperture Radar) instrument on the Envisat satellite.

From over 100 km to 1 cm

RADIO WAVES

Monitoring the planet

To monitor the planet and protect our environment, scientists can rely on the radars carried on certain satellites.

The Envisat system is used, among other things, to map polar zones, observe ice on the surface of the oceans and spot oil spills.

In addition to its radar, this European satellite has 9 other instruments with which it monitors our planet's oceans, land masses and atmosphere.

Envisat satellite

The ASAR radar

The antenna of the ASAR (Advanced Synthetic Aperture Radar) instrument on the Envisat satellite is made up of 20 plates, each made up of 16 independent parts capable of transmitting and receiving electromagnetic waves. These 320 modules can be configured and oriented independently, enabling observations of very different sizes and resolutions. To study waves or spot ice, ASAR monitors areas 5 km x 5 km in size. But it is also capable of making observations over areas of more than 400 km_2.

The oil slick caused by the Prestige, detected by the ASAR radar on the Envisat satellite.

"Motorway speed cameras work on the same principle as altimeters."

The ASAR radar on the Envisat satellite can be used to detect and track icebergs or ships on the surface of the oceans.

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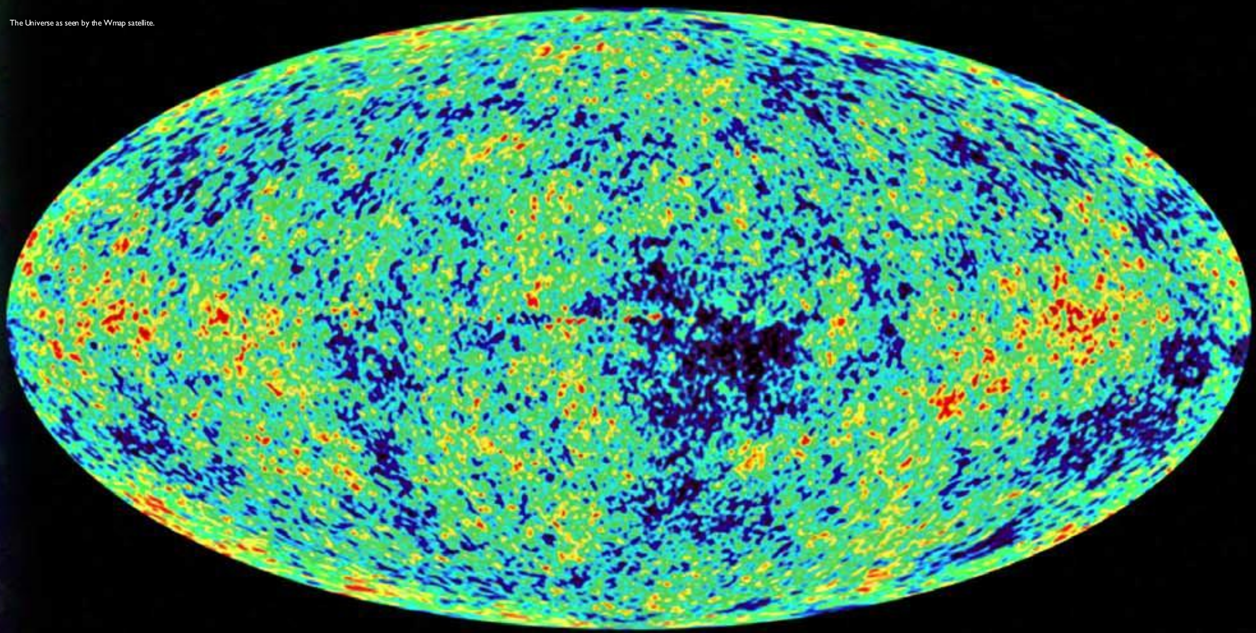
The Universe as seen by the Wmap satellite.

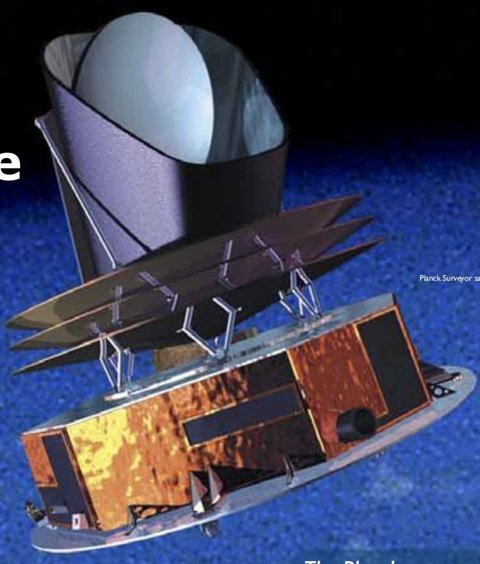


from 1cm to 1mm

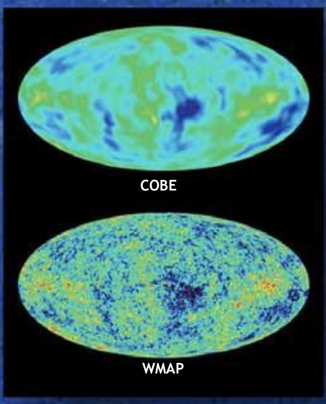
MICROWAVES

Radiation as old as the Universe

The entire Universe is bathed in low-energy microwave radiation known as the cosmic microwave background. These waves are thought to have been emitted just 380,000 years after the Big Bang, making them the oldest radiation in the Universe. By studying these electromagnetic waves, the Cobe and Wmap satellites have been able to estimate the age of the Universe at 13.7 billion years.



Planck Surveyor satellite



The Universe as seen by the Cobe satellite in 1989 and the Wmap satellite in 2003. The second image is 40 times more precise.

The Planck Surveyor mission

The Cobe satellite was the first to observe cosmic radiation in 1989. Since then, Wmap has obtained more precise data, and Planck Surveyor will make it possible to study the properties of this radiation in even greater detail, and to determine how the Universe evolved.

The Planck Surveyor telescope, with a diameter of 1.3 metres, will have a resolution 30 times greater than that of Cobe. The satellite's instruments, cooled to 0.1° above absolute zero (-273°C), will capture the radiation in the form of minute changes in temperature.

"As their name suggests, microwave ovens use microwaves to heat food."

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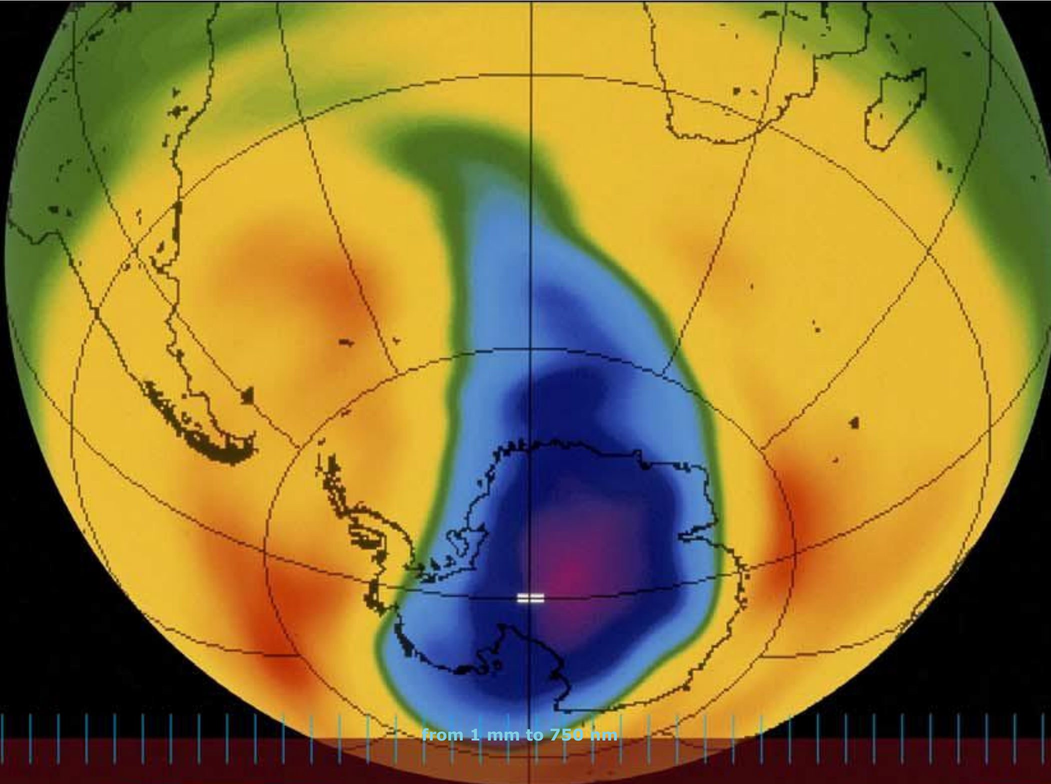


The Earth as seen by the Odin satellite radiometer. The hole in the ozone layer appears in purple and blue.

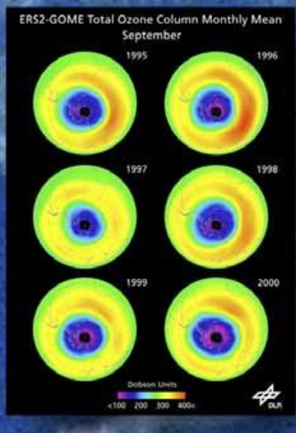
from 1 mm to 750 nm

INFRARED

Odin satellite

When the molecules of the atmosphere reveal themselves

Some types of radiation, particularly infrared radiation, emitted by celestial bodies do not penetrate the Earth's atmosphere because they are absorbed by the molecules of which it consists (water, oxygen, etc.). The Odin satellite uses this property to study the chemistry of our atmosphere. By measuring the absorption rate of this infrared radiation, it calculates atmospheric concentrations of water vapour, ozone, carbon monoxide and chlorine oxide. Odin studies and monitors the hole in the ozone layer, for example.



Evolution of the hole in the ozone layer from 1995 to 2000, monitored by Odin.

Comet Ikeya-Zhang, whose dust and gas were studied by Odin.

Odin's dual vision

The Odin satellite scans the Earth while keeping an eye on the Universe. The instruments it uses to study our atmosphere are also used to detect the presence of water or oxygen in comets or interstellar clouds.
Its radiometer picks up electromagnetic waves corresponding to 5 wavelengths:
4 in the sub millimetre range (around 0.5 mm) and 1 in the millimetre range (3 mm).

"Remote controls send information using infrared."

cnes

The Horsehead nebula as seen by the Iso satellite's long wavelength spectrometer.

from 1 mm to 750 nm

INFRARED

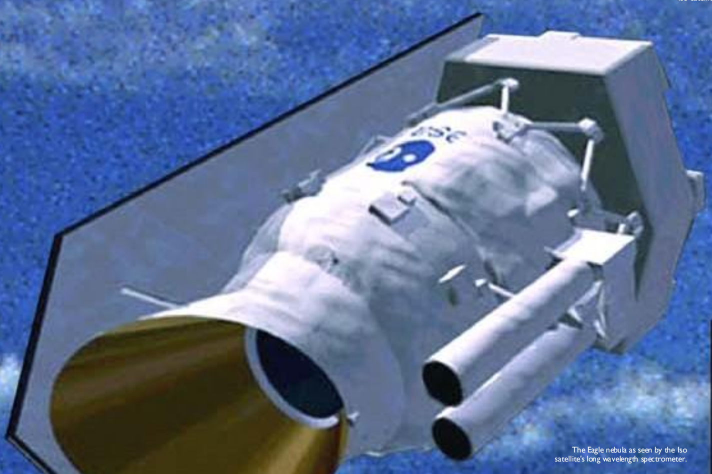
The Cold Universe

Astronomical observation in the infrared range allows us to study the cold, dusty zones of the Universe. These infrared waves are emitted by interstellar matter at a temperature a few tens of degrees above absolute zero (-273°C). The Iso satellite was the first to observe the Universe at this wavelength. In particular, it has studied the clouds of dust and gas in which stars are born at temperatures below -250°C. Launched in 2007, the Herschel satellite uses this infrared radiation to study the formation of galaxies and stars.

An air-conditioned satellite

As the objective of the Iso mission was to capture infrared radiation emitted by cold objects, the satellite had to be constantly cooled to avoid being blinded by its own heat emissions. Liquid helium was used to keep the temperature of the instruments at around -271°C. Iso worked as long as it had a supply of helium. Once this was exhausted after 28 months, instead of the 18 initially planned, the temperature of the instruments began to rise and the satellite ceased to be operational.

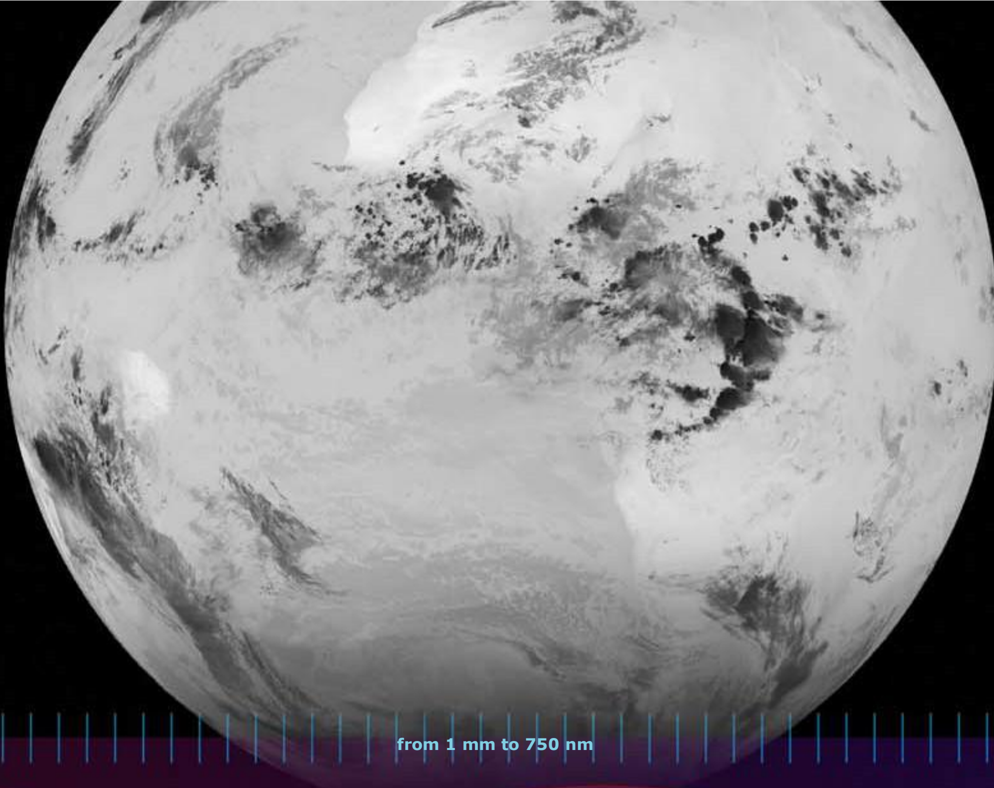
Iso Satellite



The Andromeda galaxy as seen by the spectrometer on the Iso satellite.

The Eagle nebula as seen by the Iso satellite's long wavelength spectrometer.

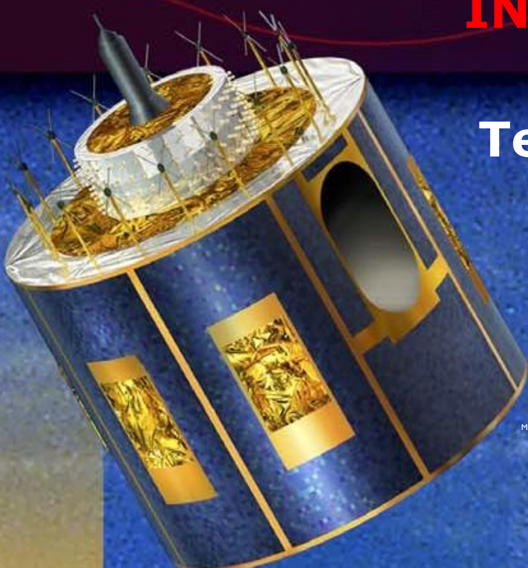
"To film at night, the cameras use a certain type of infrared."



The Earth in infrared as seen by the SEVIRI (Spinning Enhanced Visible & InfraRed Imager) sensor on the Msg-1 satellite.

from 1 mm to 750 nm

INFRARED



Msg-1 satellite

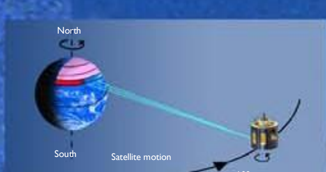
Temperature maps

On Earth, hot bodies emit infrared or thermal radiation with wavelengths of between 10 and 15 µm. Weather satellites use this property to determine the temperature of clouds or the Earth's surface from a distance. This data can then be converted into maps. For example, a very hot surface, such as a desert, emits a lot of infrared radiation and will appear white on the map. Conversely, cold clouds at high altitudes will be shown in black. This data is used to produce weather forecasts.

The SEVIRI sensor

The Msg-1 satellite is equipped with a SEVIRI (Spinning Enhanced Visible & InfraRed Imager) sensor. With its 12 channels, this sensor can simultaneously take 12 images of the Earth in different wavelengths. 3 channels allow the Earth to be observed in the visible range and 9 in the infrared range (particularly thermal infrared).

To stabilise itself, the satellite, in geostationary orbit, spins around its axis. In a single rotation, its sensor scans a narrow strip of the Earth's surface from west to east. On the next rotation it shifts slightly to the north. In about 1,250 rotations, completed in less than 15 minutes, the sensor reconstitutes a complete image of the half of the globe it is observing.



"Night vision systems spot thermal infrared emissions."

It is important to monitor droughts ...

... and to be able to detect the extent of storms and hurricanes at an early stage.

Precise weather data are essential to agriculture.

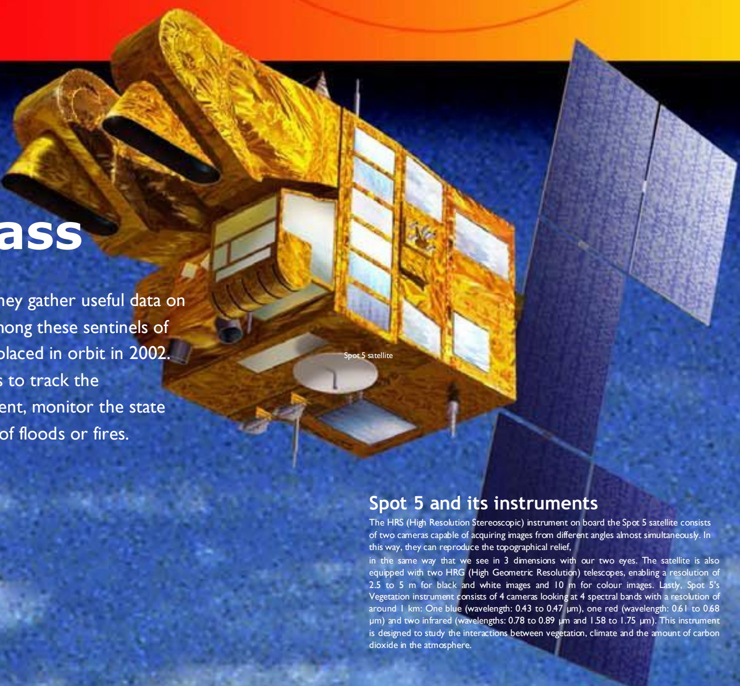
The Millau Viaduct as seen by the HRS (High Resolution Stereoscopic) instrument on the Spot 5 satellite.

from 750 nm to 400 nm

VISIBLE

Continents under the magnifying glass

Some satellites specialise in land observation. They gather useful data on our environment. France's Spot satellites are among these sentinels of the sky. The most recent of these, Spot 5, was placed in orbit in 2002. Since then, specialists have been using its images to track the development of crops, manage urban development, monitor the state and nature of vegetation, and assess the effects of floods or fires.



Spot 5 satellite

Spot 5 and its instruments

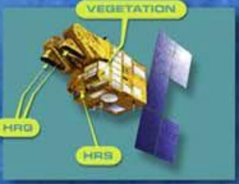
The HRS (High Resolution Stereoscopic) instrument on board the Spot 5 satellite consists of two cameras capable of acquiring images from different angles almost simultaneously. In this way, they can reproduce the topographical relief,

in the same way that we see in 3 dimensions with our two eyes. The satellite is also equipped with two HRG (High Geometric Resolution) telescopes, enabling a resolution of 2.5 to 5 m for black and white images and 10 m for colour images. Lastly, Spot 5's Vegetation instrument consists of 4 cameras looking at 4 spectral bands with a resolution of around 1 km: One blue (wavelength: 0.43 to 0.47 µm), one red (wavelength: 0.61 to 0.68 µm) and two infrared (wavelengths: 0.78 to 0.89 µm and 1.58 to 1.75 µm). This instrument is designed to study the interactions between vegetation, climate and the amount of carbon dioxide in the atmosphere.

"The lenses of a telescope magnify the image by deflecting light rays."

Cultivated fields in the Cairo region of Egypt as seen by the Spot 5 satellite.

Iguazu on the border of Brazil and Argentina as seen by the Spot 5 satellite.



Central region of the planetary nebula NGC 6543, known as the Cat's Eye, as seen by the Hubble telescope.

from 750 nm to 400 nm

VISIBLE

Corot satellite

Stars as far as the eye can see..

Observing the visible Universe from space allows us to produce images of a quality that would be impossible to obtain from the ground. Those taken by the Hubble telescope have led to major scientific advances.
The French space telescope Corot, placed in orbit in 2006, was designed to track telluric exoplanets like Earth and observe the luminous oscillations of stars to better understand their internal structures, which affect their evolution.

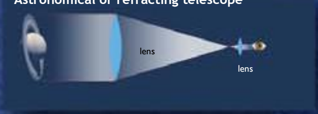
"The pages of a book reflect visible electromagnetic waves towards the reader's eyes."

The Tarantula Nebula as seen by the Hubble telescope

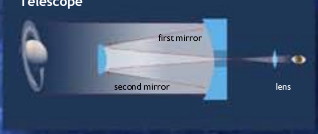
What's the difference between a refracting telescope and a reflecting telescope?

Astronomical observation instruments and telescopes behave rather like light funnels. They concentrate the light rays coming from a distant object at a point called the focal point. At this point, a tiny image is formed that needs to be enlarged to make it observable.
The difference between the two instruments is that refracting telescopes use lenses to make light rays converge, whereas mirrors perform this role in reflecting telescopes. Because mirrors distort images less than lenses, they can have larger diameters and capture more light rays. This is one of the reasons why reflecting telescopes are sharper and more precise than refracting telescopes when it comes to observing the deep sky.

Astronomical or refracting telescope



Telescope



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Valles Marineris on Mars as seen by the HRSC (High Resolution Stereo Camera) instrument on the Mars Express probe.

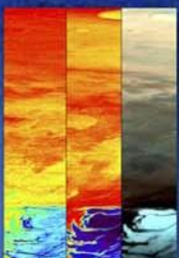
from 750 nm to 400 nm

VISIBLE

Mars Express satellite

Get closer for a better view

Several probes exploring the planets of the Solar System are observing in the visible range and sending fascinating images back to Earth. This is the case, for example, of the European probe Mars Express, placed in Martian orbit on 25 December 2003, to study the surface and atmosphere of the Red Planet. Thanks to one of its instruments, called Omega, which operates in the visible and near infrared ranges, Mars Express has mapped the polar caps of our intriguing neighbour.



South polar cap of Mars (bottom of image) seen by Omega at three different wavelengths.
Left: infrared image showing water ice (present under the dry ice)
Centre: infrared image showing dry ice
Right: image taken in the visible range

Omega on Mars Express

Omega is one of two French instruments aboard the Mars Express probe. It maps the surface of the Red Planet using 352 spectral channels covering the visible range and part of the infrared (wavelengths: 0.35 to 5.2 μm). In this region of the spectrum, most solids and gases emit electromagnetic waves that are specific to them. This is known as a "signature". By analysing these waves, Omega can determine the mineralogical composition of the surface with a resolution of a few hundred metres.

As the instrument is capable of detecting water ice, water vapour and water trapped in rocks, it should make it possible to assess the overall volume of water available on Mars today.

"Whether digitally or on film, a camera needs light to capture images"

A lake of frozen water at the centre of a Martian crater as seen by the HRSC (High Resolution Stereo Camera) instrument on the Mars Express probe.

The Reull Vallis canyon on Mars as seen by the HRSC (High Resolution Stereo Camera) instrument on the Mars Express probe.

cnes

The Sun as seen by the EIT (Extreme Ultraviolet Imaging Telescope) instrument on the Soho satellite.

from 400 nm to 10 nm

ULTRAVIOLET

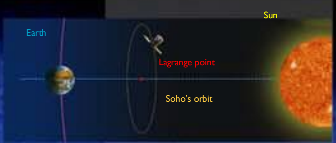
A little closer to the stars – and their composition

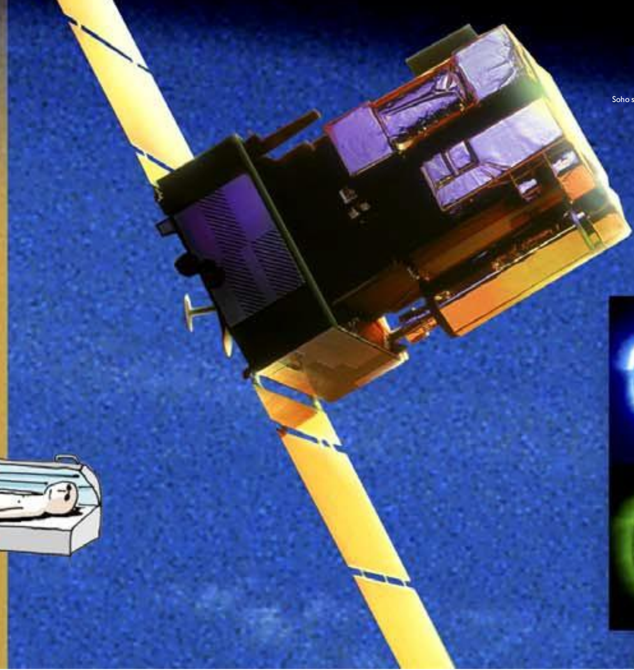
We know that the Sun emits ultraviolet rays. Many other stars, from white dwarfs to giant stars, emit in this range of the electromagnetic spectrum. Observing these stars in the ultraviolet provides scientists with information about their temperature, motion, magnetism and chemical composition. Looking at the sky in the ultraviolet range also enables us to identify young stars and gather valuable information about their evolution.

A place in the Sun for Soho

Launched in 1996, the European Soho satellite provides an uninterrupted, comprehensive view of the Sun. In other words, for this space observatory, it's daylight all the time.

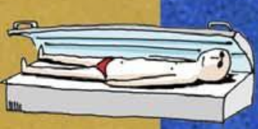
Soho is located between the Earth and the Sun, 1.5 million kilometres from the blue planet, close to one of the five "Lagrange points". These points, determined in the 18th century by the French mathematician Joseph-Louis de Lagrange, are where the gravitational forces of our planet and its star cancel out. Soho thus orbits the Sun at the same time as the Earth, occupying a relatively stable position in relation to the two stars. This makes it an ideal place for observation.

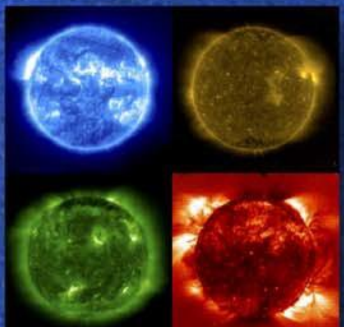




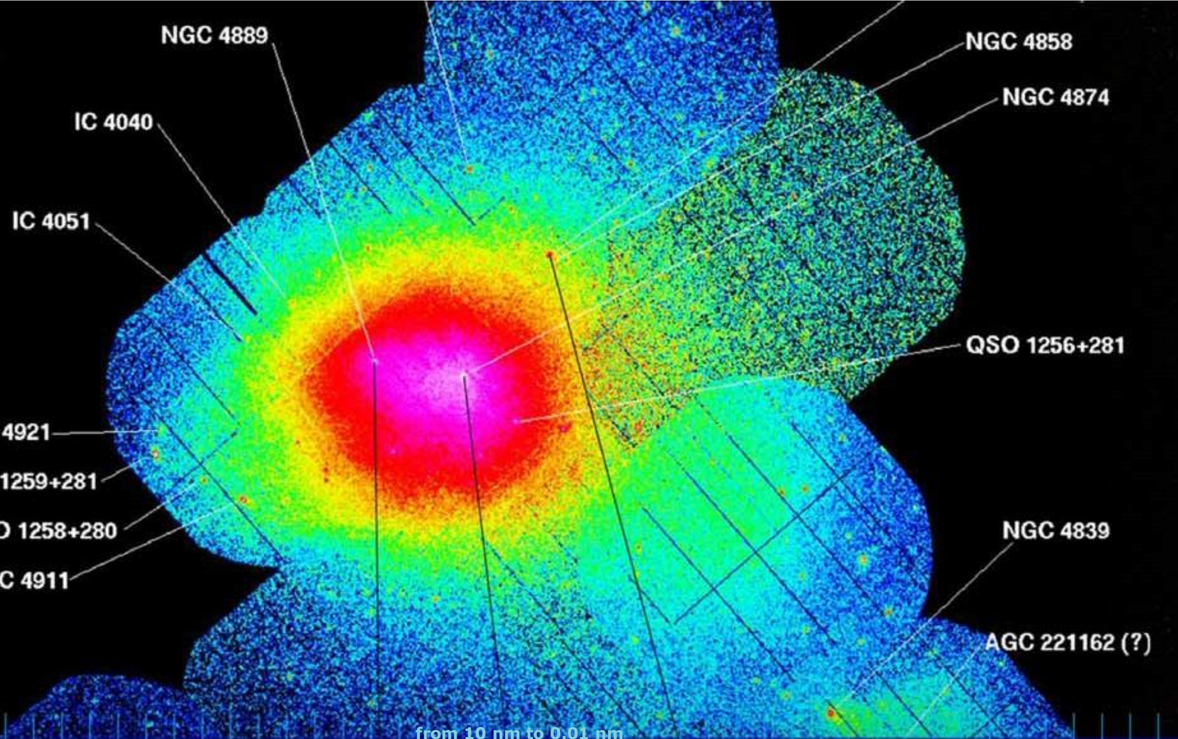
Soho satellite

"Tanning lamps emit ultraviolet rays to turn the skin brown."





The Sun as seen by the EIT (Extreme Ultraviolet Imaging Telescope) instrument on the Soho satellite
The images were taken in 4 different ultraviolet wavelengths.



A cluster of galaxies seen by the EPIC (European Photon Imaging Camera) instrument on the XMM-Newton satellite.

from 10 nm to 0.01 nm

X-RAYS

XMM-Newton satellite

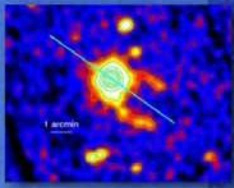
What the atmosphere hides

X-rays and gamma rays from space cannot be detected from Earth because the atmosphere forms a screen that is almost completely opaque to this type of radiation. Observation satellites have been sent beyond the Earth's atmosphere to lift the veil. Today, X-ray and gamma ray astronomy has become an important tool for studying the Universe. For example, it has confirmed the existence of black holes by studying the radiation emitted by matter falling into these celestial objects.

To detect X-rays, it's EPIC

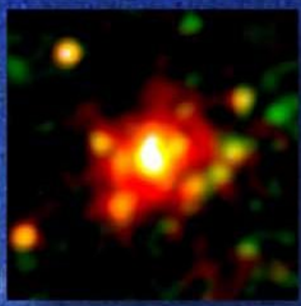
The EPIC (European Photon Imaging Camera) X-ray detector is installed on the European Space Agency's XMM-Newton satellite. It consists of 3 X-ray cameras.
To date, EPIC is the world's most sensitive X-ray detector. For example, it has enabled scientists* to discover the presence of a hot spot the size of a football pitch on the surface of a neutron star called Geminga, located 500 light years from Earth.

"X-rays pass through flesh and are stopped by bone, a property used for medical imaging."



The neutron star Geminga as seen by the EPIC (European Photon Imaging Camera) instrument on the XMM-Newton satellite

* This result was obtained by teams from the Space Astrophysics Institute of the CNR (*Consiglio Nazionale delle Ricerche*) in Milan and the CNRS (*Centre d'Etude Spatiale des Rayonnements* - Université Paul Sabatier) in Toulouse.



The galaxy M100 as seen by the EPIC (European Photon Imaging Camera) instrument on the XMM-Newton satellite

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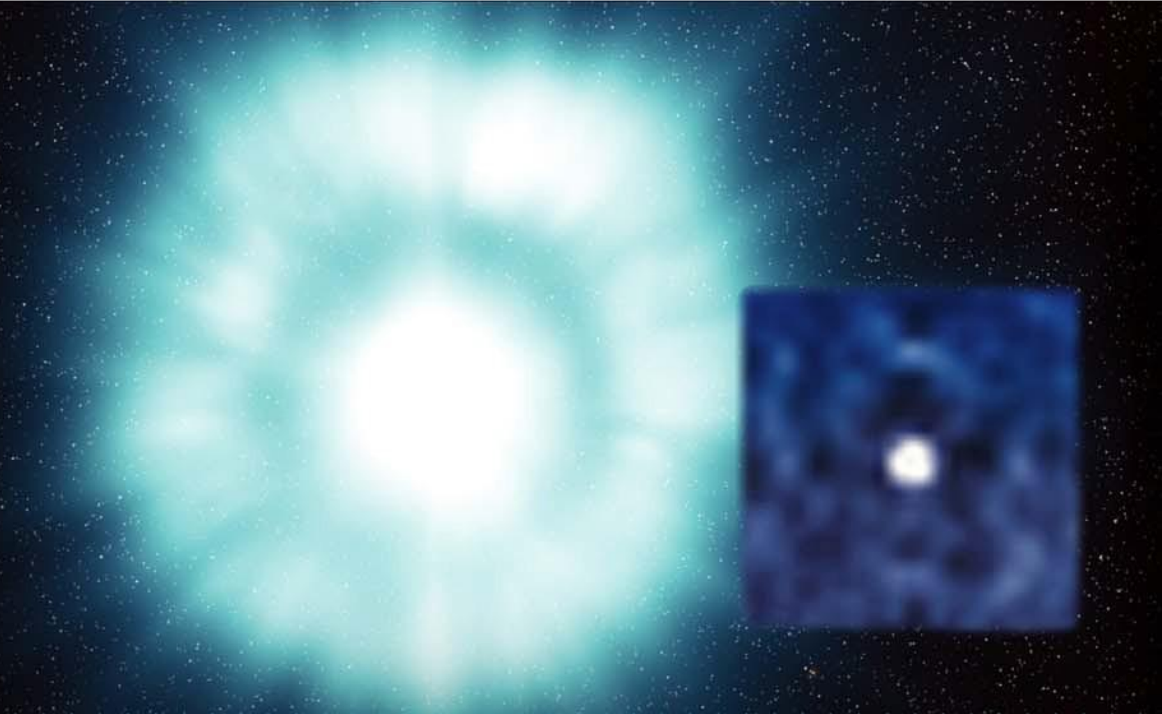


The GRB02112 gamma-ray burst as seen by the IBIS (Imager on Board the Integral Satellite) instrument on the Integral satellite

from 0.01 nm to 0.0001 nm

GAMMA RAYS

Integral satellite

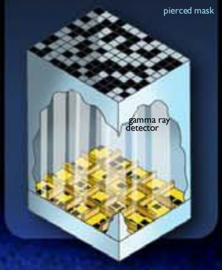
The highest energy phenomena in the Universe

In the electromagnetic spectrum, gamma rays are the waves that carry the most energy. Astronomy using this type of radiation provides a better understanding of violent processes in the Universe, such as gamma-ray bursts, powerful emissions of gamma-ray photons that are probably linked to the final phases in the evolution of massive stars. The study of gamma rays emitted by supernovae or black holes provides scientists with information about the formation and evolution of the Universe. Since its launch in October 2002, the Integral satellite has been helping to observe these phenomena.

"Nuclear reactions emit gamma rays."

The coded mask technique

Gamma rays are so energetic that they cannot be focused by lenses or mirrors, as is the case with light rays in a refracting telescope or a reflecting telescope working in the visible range. To detect these rays, scientists have developed the coded mask technique. This involves replacing the mirrors or lenses with a mask pierced with multiple openings. The shadow cast by this mask on a gamma-ray detector can be computed to locate the source of the radiation, just as the shadow of an object can be used to determine the position of the Sun in the sky.



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Promenade spatiale

au fil des ondes

This stroll through the waves found in space has been organised by the French Space Agency, CNES

> CNES is the public agency responsible for developing and managing France's space programmes. Its mission is to guarantee autonomous access to space and its use for all French and European needs.
As a space agency and technical development centre, CNES has end-to-end technical expertise in the design and implementation of space systems.

> CNES's activities are structured around five main areas:

- Space transportation,
- Sustainable development,
- Defence security,
- Consumer applications,
- Science and innovation.

> CNES has four sites (Paris, Evry, Toulouse and Kourou).
It is supported by high-performance research laboratories and manufacturers.
Its activities are part of a national dynamic, in collaboration with ESA, the European Union or other countries.

> Through its programmes and its capacity for innovation and anticipation, CNES contributes to the advancement of knowledge and the emergence of new applications for the benefit of all.

Our thanks to CNRS for its contribution

The space programmes mentioned are: CNES, ESA, SNSB and NASA.

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