The Universe in my pocket

Celestial messengers

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Large Telescope of the Paris-Meudon Observatory (decommissioned)

It is difficult to leave the Earth to explore the Universe. Apart from a few space probes to explore the solar system, we have to be content with observing the messages that the sky sends us. We know of 5 types of celestial messengers:

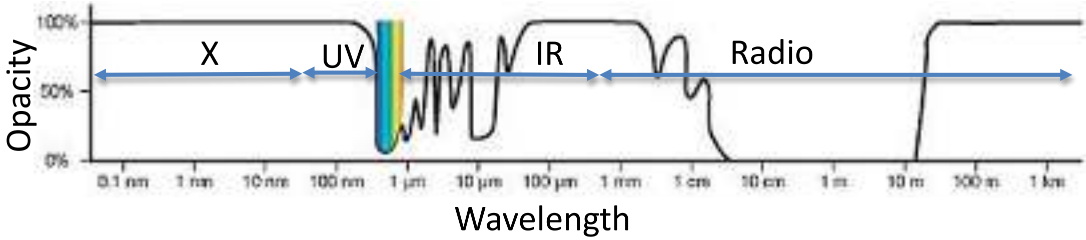
1) Light, which is much richer than what our eye perceives.

2) Neutrinos: very low mass particles that hardly interact with matter.

3) Cosmic rays: ionized matter particles of very high energy that are revealed when entering the Earth's atmosphere.

4) Meteorites (see tuimp 11): the largest survive the passage through the atmosphere to reach the ground where they are collected.

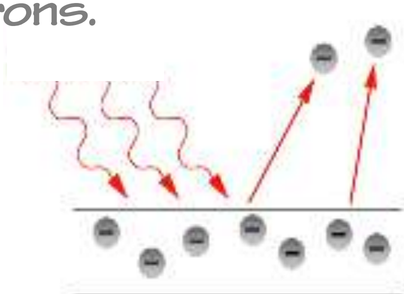
5) Gravitational waves (see tuimp 18): predicted by Einstein and detected in 2015.



Transparency of the sky as a function of wavelength. The sky is mainly transparent in the wavelengths of visible light, from 0.4 to 0.8 µm (1 µm = 0.001 mm), and in radio waves from 1 cm to 20 m. Gamma rays are not represented here, they are below 0.01 nm (1 nm = 0.000001 mm).

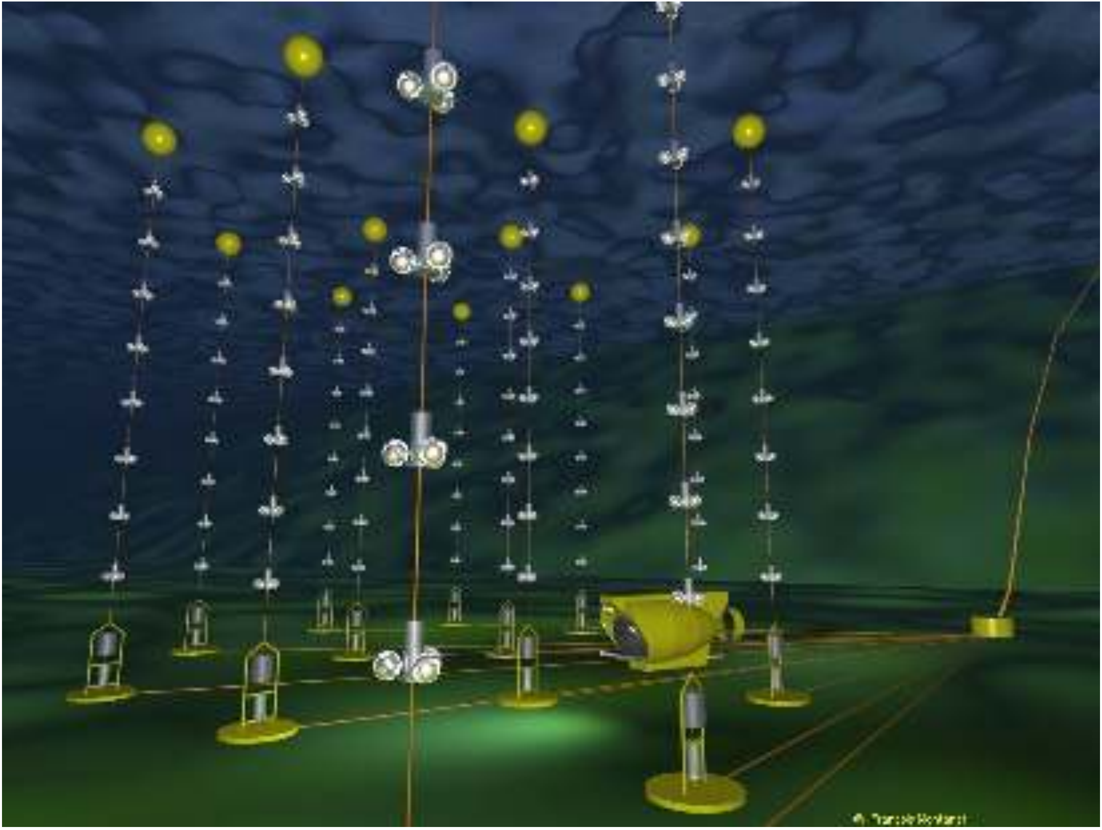
An aspect of the wave nature of light: the blue color of the sky is due to the scattering of sunlight by particles in the atmosphere (see tuimp 24).

An aspect of the corpuscular nature of light: photovoltaic panels absorb grains of light that tear off electrons.



Light is made of massless particles called photons which sometimes behave as if they were waves. Interference and diffraction reveal light's wave aspect, while the photo-electric effect and CCD cameras reveal its corpuscular aspect. When we say 'light', we think of the visible light that we see in a rainbow but this is only a very small part of the light spectrum.

Light is characterized by its vibration frequency, ν, or by its wavelength, λ, related by $\nu \times \lambda = c$ (where c is speed of light). The wavelengths of the rainbow are located between 0.4 and 0.8 µm. Below red (0.8 µm), there is infra-red which extends to around 300 µm then radio waves up to kilometric waves and more. Beyond violet (0.4 µm), there is ultra-violet, then X-rays and gamma rays.



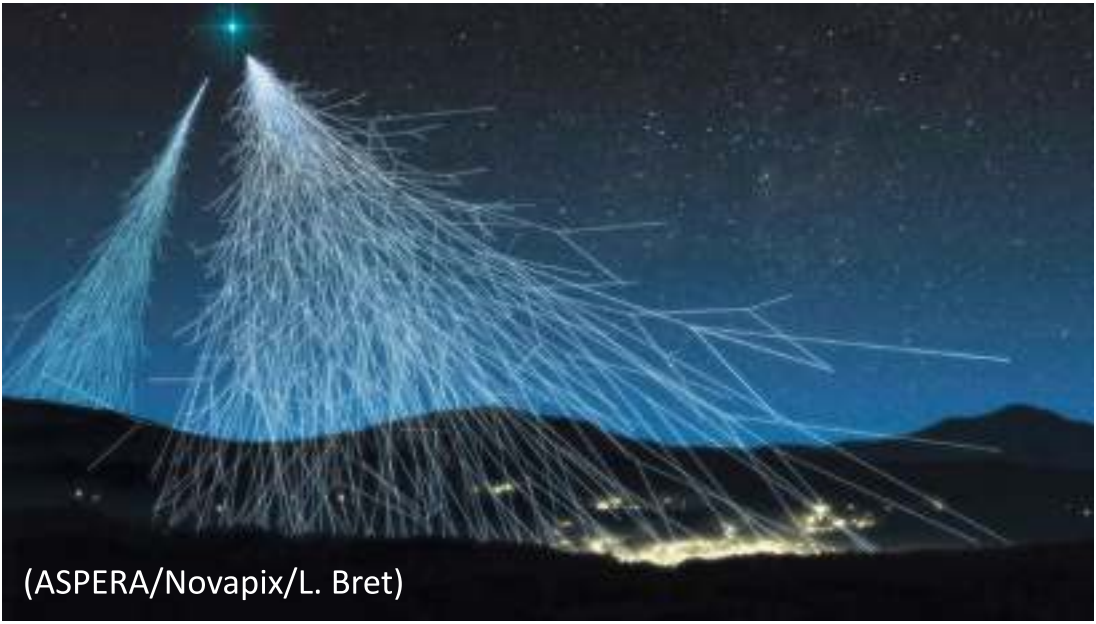
ANTARES neutrino telescope; thousands of cameras immersed up to 2500 m deep in the Mediterranean Sea monitor the occurrence of scintillations (small flashes of light) caused by the interaction of a neutrino with water.

Credit: François Montanet

Neutrinos

Neutrinos are particles produced by certain nuclear reactions. There are three 'flavors' of neutrinos, linked to the three families of leptons, the best known of which is the electron, then the more massive muon and the tau. As they move, neutrinos oscillate between these three flavors, which implies that they have a mass. But it is so small that we have not yet managed to measure it.

The Sun, due to the extremely high number of nuclear reactions in its core, emits a large number of neutrinos. Most of them pass through the Earth without even slowing. Some experiments manage to capture a few neutrinos, among the billions that shower the Earth at every moment. Because neutrinos hardly interact with matter, they are difficult to study and are still poorly understood, but they allow us to probe inside the Sun and supernovae.



Artistic representation of the interaction of a cosmic ray with the atmosphere causing a shower of light rays.

Photo of H.E.S.S. II, a detector of visible light showers that track cosmic rays.

Cosmic rays

Cosmic rays are charged matter particles (protons, electrons, helium nuclei) that travel at speeds very close to the speed of light and therefore have gigantic kinetic energy. Their origin is poorly understood. They could come from supernovae or from the fusion of black holes with each other. They are detected by the light they emit during their interaction with the Earth's atmosphere, creating a shower of light-emitting particles.

In very dark regions, this faint luminosity can be captured by telescopes designed to observe these light showers, such as the HESS telescope in Namibia, or the Auger experiment in Argentina which combines telescopes and particle detectors to detect the most energetic cosmic rays which are very rare: only about one such cosmic ray passes through a square kilometer on Earth during an entire century.

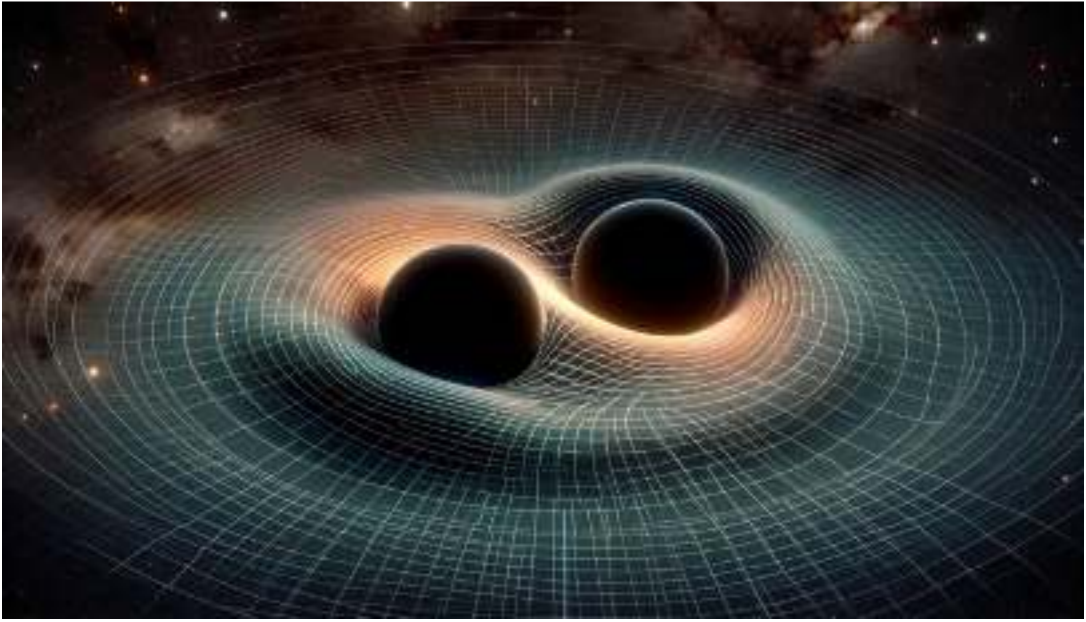
A fragment of the Murchison meteorite and individual isolated particles (in the test tube).

Below: the Meteor crater in Arizona. The largest meteorites make craters in the ground like this one. Most craters have disappeared on Earth. On the other hand, the Moon, which has no active erosion, retains many craters (see tuimp 27).

Meteorites

Meteorites can have several origins (see tuimp 11). Dust left behind by comets, collisions between asteroids in the asteroid belt located between Mars and Jupiter, or rocks ejected from the surface of Mars or the Moon following a collision with an asteroid. In the latter case, the meteorites provide us with direct information on the composition of the Moon, Mars or the asteroids themselves which retain a certain memory of the state of the solar nebula at the time of planet formation, about 4.5 billion years ago.

The smallest meteorites burn up completely in the atmosphere (as shooting stars), while the largest ones survive and reach the ground. We can recover them and analyze their chemical composition.



Artistic representation of the fusion of two black holes with a visualization of the deformation of space-time around it. This deformation, huge near the black holes, has a very small amplitude when it reaches the Earth and is only detectable by very sensitive instruments such as LIGO and VIRGO.

(Image by Gianluca Inguglia generated by DALL-E from OpenAI)

Gravitational waves

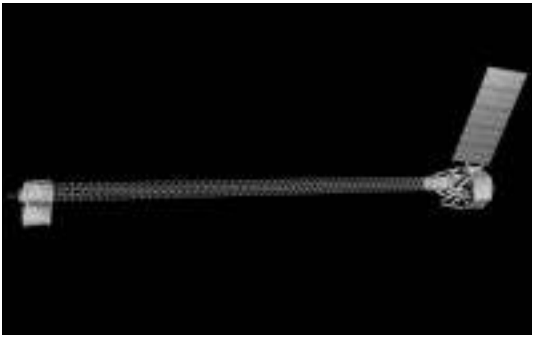
2015 was the year of the first detection of gravitational waves (see tuimp 18). Predicted 100 years earlier by A. Einstein, their intensity is so weak that the physicist was convinced that they could never be detected.

Extremely energetic events such as the fusion of two black holes are necessary for the emitted waves to be detected by current instruments. It is only the very particular shape of the signal that makes it possible to extract it from the noise (due, in particular, to the residual vibrations of the instrument's mirrors which cause movements much greater than the displacement caused by the passage of the wave). The numerous fusions of black holes and neutron stars that detectors have observed since 2015 reveal a universe that was invisible until now.

Quiz

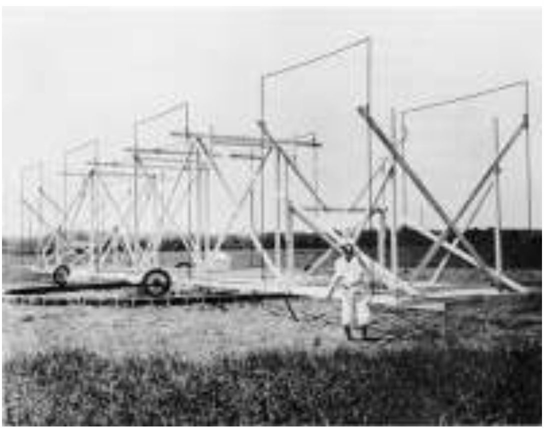
Which of these telescopes does not detect photons?

Answer on the back



In radio, infrared, ultraviolet, X-ray or gamma rays, as in visible light, it's always photons.

Only Auger observes cosmic rays.



Answer

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This booklet was written in 2025 by Laurent Pagani from the Paris Observatory and the CNRS and reviewed by Grażyna Stasińska (from Paris Observatory) and Stan Kurtz (from IRYA, Mexico).

Cover image: Meteor shower known as the Perseids. The Earth's orbit regularly crosses the debris path left by comets. These very numerous dust grains enter the atmosphere in groups, ignite, and seem to come from the same direction. The one in August seems to come from the constellation Perseus. (Photo by CGTN).

To find out more about this collection and the themes presented in this booklet visit http://www.tuimp.org

Translation: Stan Kurtz