The Other Messengers

Electromagnetic waves are not the only messengers from the cosmos. Meteorites provide precious data about the solar system, while cosmic rays, neutrinos and gravitational waves are testament of the violent events that produced them.

Credit : Wikipedia

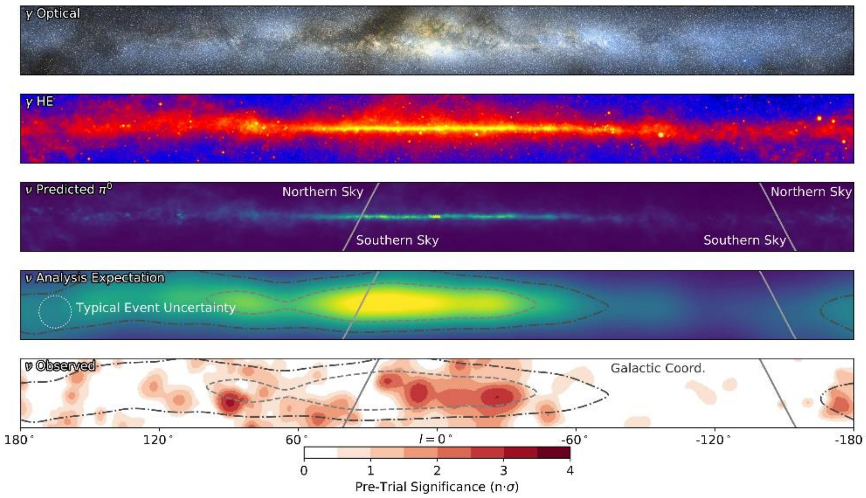
The Allende meteorite

An approx. 8-cm fragment of a meteorite that burst on 8 February 1969, as it entered the atmosphere above the village of Pueblito de Allende, Mexico. A dark crust of molten material partially masks the greyer structure of the sample, where some coloured inclusions can be observed. In-depth studies date these inclusions at 4.57 billion years old, they were the first solids to condense during the formation of the solar system.

Detailed lab analyses of meteorites – large fragments of matter from space – produce data that are altering our knowledge of our solar system's formation, evolution, or age. As long as space agencies are unable to return to Earth samples collected from places other than the Moon, meteorites will remain for the coming decades the best source of information about the solar system for decades to come.

As the only samples of matter from beyond the Solar System, cosmic rays provide unique information about the media they pass through and the sites capable of accelerating them to relativistic speeds. It has been demonstrated that most cosmic rays bombarding our planet come from sources located in the disc of our galaxy. An exception is the most energetic cosmic rays that propagate roughly in a straight line, which makes it possible to determine where their sources are located on the celestial vault. The Pierre Auger experiment studies in details their energy, angle and composition.

Neutrinos, which are sensitive only to the weak force, pass through material media without any resistance. The neutrinos produced in emissive media also escape unhindered, even in the densest environments, such as stellar cores and jets produced on the outskirts of black holes. Electrically neutral, and therefore insensitive to magnetic fields, neutrinos do not deviate from their initial directions, making them ideal messengers for astronomers. However, their weak interaction with matter makes them very difficult to detect, and a huge detection volume is needed to catch



Credit: IceCube Collaboration

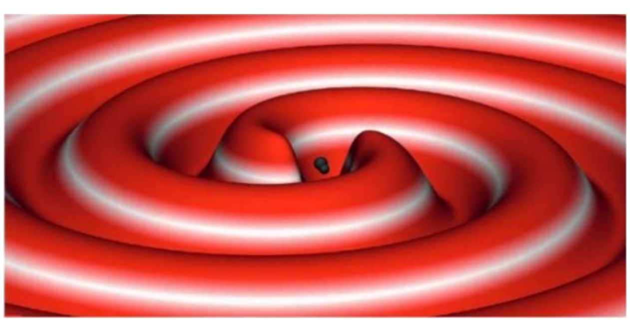
The Milky Way in gamma rays and neutrinos

Each strip shows the Milky Way using different techniques. At top is an optical image, showing clearly the dust and gas in the galactic plane. Below are gamma-ray observations from the Fermi-LAT 12-year survey. The next two strips show the neutrinos astronomers expected to receive, based on the presence of gamma rays. At bottom is neutrino sources observed using the new technique.

a few of them: thousands of tons of water, liquid scintillator or ice. It is by studying cosmic neutrinos that the first indication of their oscillation properties was discovered. The first sources of cosmic neutrinos studied were the core of the Sun and supernova SN 1987A. However, nearby galaxies (e.g. NGC 1068) are now observed, and the first map of very high energy neutrinos coming from the Milky Way was published in 2023. Rapid progress is expected in the coming years thanks to experiments IceCube (located in the South Pole) and KM3Net (in construction in the Mediterranean Sea).

Gravitational waves result from the acceleration of massive, compact bodies that produce oscillations in the curvature of space-time propagating at the speed of light. At first, we first considered detecting them with a metal cylinder which, as a gravitational wave passes through it, becomes alternatively longer and thinner, and shorter and thicker. But because of the rigidity of space-time, these effects are far too small to be observed.

We then developed detectors based on the propagation of laser beams between mirrors arranged far apart. The wave-like properties of light are used to interferometrically obtain a very precise measurement of the variations in distance between the mirrors. Thus, we can look for even the slightest disturbances caused by the passage of a gravitational wave. At the end of 2015, a vast international collaboration succeeded on two occasions (14 September and 26 December) in detecting a burst of gravitational waves whose effects were compatible with those predicted when two black holes merge far out in the Universe. Since then, the event catalogue got longer (90 candidates were listed in its 2023 edition).



Credit: LIGO/VIRGO

Emission of gravitational waves by the merger of two black holes

Simulation of the gravitational waves produced by the merger of two black holes, the very type of event detected on 14 September 2015. The wave's intensity is indicated by its elevation and its colour, with weak fields in white and strong fields in red.

Translated from 'Les autres messagers', Passeport pour les deux infinis, IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG