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INSTITUT NATIONAL DE PHYSIQUE NUCLÉAIRE
ET DE PHYSIQUE DES PARTICULES

JLR/IN2P3/COM-6/2/08

CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

IN2P3 INSTITUT NATIONAL DE PHYSIQUE NUCLÉAIRE ET DE PHYSIQUE DES PARTICULES

L'EXPOSITION ASTROPARTICULE

ASPERA

Réseau ERANET Astroparticule

JLR/IN2P3/COM-6/2/08

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GENEALOGIE DU PROJET

LE PROJET ASPERA

PROJET DE COM

OBJECTIFS

CAHIER DES CHARGES

CIBLE(S)

METHODE DE TRAVAIL

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LA CELLULE ASPERA « EXPO »

Un groupe de travail
Adapté au projet
Adapté à la démarche

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LES CHIFFRES

CONCEPTION/REDACTION…
et VALIDATIONS !
6 mois

MAQUETTE/GRAPHISMES
1 mois

FABRICATION
1 mois

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LE MATERIEL

3 panneaux 3m x 2m

3 Totems

3 valises

3 structures

(montage/démontage rapides)

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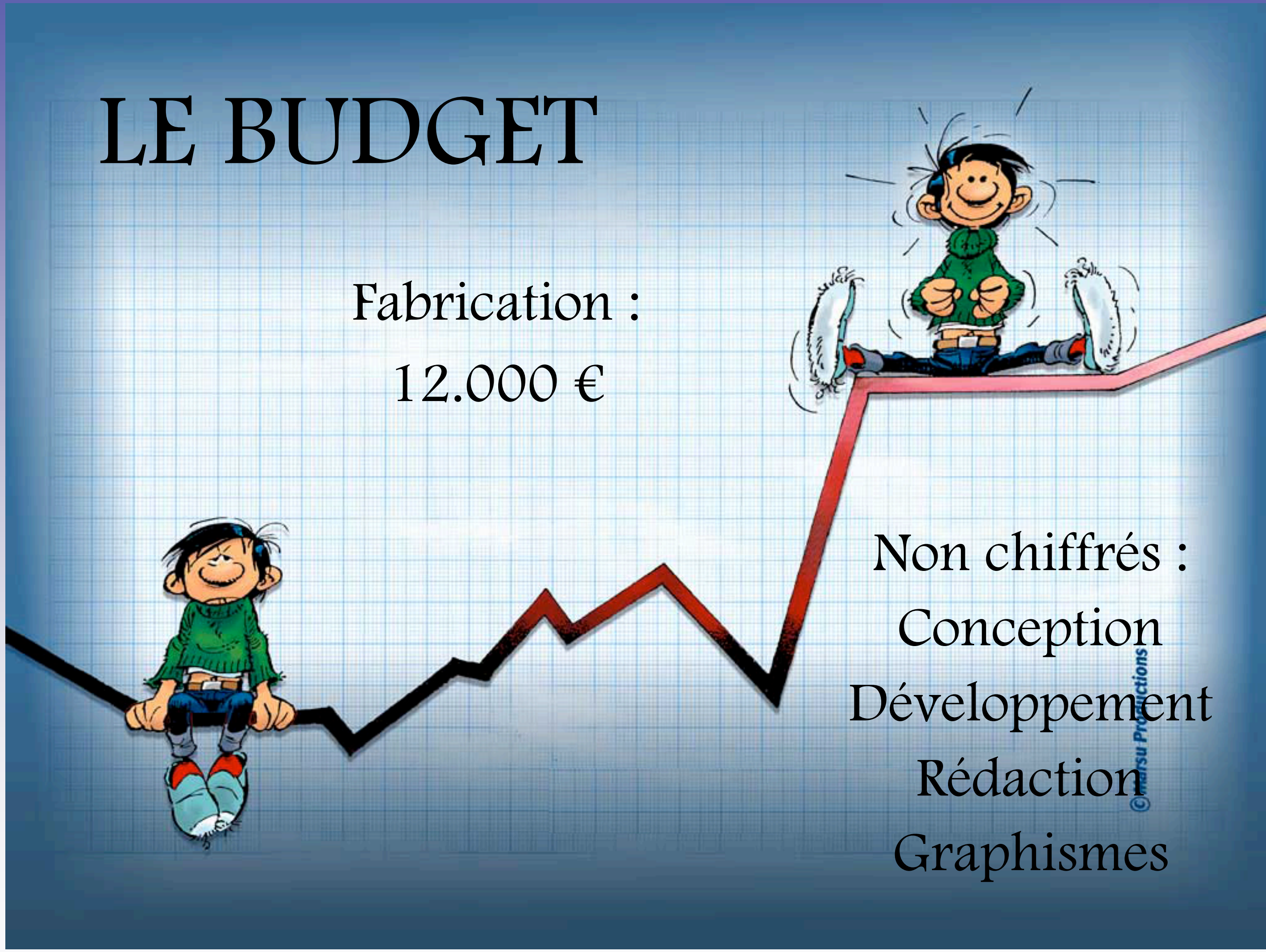

LE BUDGET
Fabrication :
12.000 €
Non chiffrés :
Conception
Développement
Rédaction
Graphismes

SYNTHESE

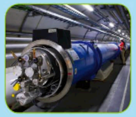
NEGATIF	POSITIF
	METHODE
TRADUCTIONS	UTILISATION
DISPONIBILITE	DELAIS
CIRCULATION	COHERENCE
	BUDGETS
	RESULTATS

Astroparticle Physics for Europe

MESSENGERS FROM THE EARLY UNIVERSE

The Universe was born 13.7 billion years ago and time as we know it began with it. Understanding the story of the Universe and the Big Bang is a quest for the past. A split second after the birth of the Universe, all matter and radiation appeared and were contained at one very dense point. Physics at the smallest and largest scales are both needed to understand these origins; this is the aim of cosmology and astroparticle physics.

A MANMADE TIME MACHINE



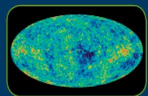
▲ LHC - © CERN -

Astroparticle physics is a new field emerging from the convergence of astrophysics and particle physics. It is closely linked with accelerator-based physics trying to produce particles that will allow us to learn about the Universe. The Large Hadron Collider (LHC) at CERN is a particle accelerator that will provide a new range in energies to explore matter and the Universe by recreating the conditions of the very early Universe. Studying the very big and the very small with the LHC or astroparticle physics experiments are complementary to understanding our Universe.

FIRST PICTURE OF THE UNIVERSE

Light is the first messenger to tell us the story of the Universe. By studying light, we can observe the distant past. In the Big Bang story, the Universe became transparent to light when it was 300 000 years old.

In 1992, the COBE satellite and later WMAP, measured very tiny fluctuations in the cosmic microwave background radiation. These fluctuations can be interpreted as the future big structures of the Universe. The European PLANCK satellite, which is scheduled to be launched in 2008, will increase the resolution of this very first "picture of the Universe".



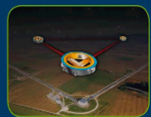
▲ - © NASA / WMAP Collaboration -

Then light began to travel through space to present times. As it travelled, its frequency changed from the visible to microwave.

This Cosmic Microwave Background is a "picture of this very early Universe", the echo of the Big Bang and one of the main proofs of its existence. The very tiny fluctuations in the temperature of radiation measured by space satellites are the clues to density differences that became the seeds of galaxy formation. They are seen as coloured ripples on the first map of the Universe.

TRACKING BACK TO THE BIG BANG

Today many observations of the cosmos are performed outside the visible light domain. As the field of astroparticle physics grows, it is opening up new windows to our understanding of the Universe.



▲ - © VIRGO/LISA/ASPERA -

Gravitational waves (GW) are a direct consequence of general relativity and should distort space-time as waves on the surface of a pond. They are produced when large masses are submitted to strong accelerations and could be detected by very small changes in the distance between free masses in GW detectors around the world like GEO600 in Germany or VIRGO in Italy. The space project LISA will widely increase the sensitivity of GW detection in the next decade.

For the first time, light is not the only messenger from distant cosmic objects, as we begin to observe very high-energy cosmic rays and high-energy photons. We also hope to observe high-energy neutrinos and gravitational waves, which probe even earlier times than light in the evolution of the Universe. The gravitational waves - ripples of the space-time fabric predicted by Einstein's Theory of General Relativity - track violent events in the Universe. In particular, they track the most violent event that occurred in the Universe: the very first instants of the Big Bang.

IMPORTANT MILESTONES

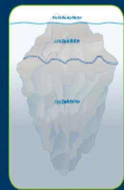
- **1912:** Victor Hess climbs to 5200 metres in a balloon and demonstrates the existence of radiation coming from the sky.
- **1930:** Pierre Auger discovers particle showers, which come from the collisions between cosmic rays and particles of the atmosphere.
- **1932:** Carl Anderson discovers the positron; the first antiparticle.
- **1937:** For the first time, muons are observed in the tracks of a particle shower in a bubble chamber.
- **1956:** Frederick Reines & Clyde Cowan bring the neutrinos to the fore.
- **1965:** Arno Penzias & Robert Wilson discover the Cosmic Microwave Background.
- **1987:** Neutrino emissions by Supernova SN 1987A confirm theories about the origin of elements.
- **1989:** The first source of high-energy gamma rays is discovered.
- **1992:** The COBE satellite discovers the anisotropy of the Cosmic Microwave Background.
- **1998:** Cosmic neutrinos reveal the oscillatory nature of these particles.

▲ *1912- The Austrian physicist Victor Hess in the basket of his balloon used for his experiments.*

DARK SIDE OF THE UNIVERSE

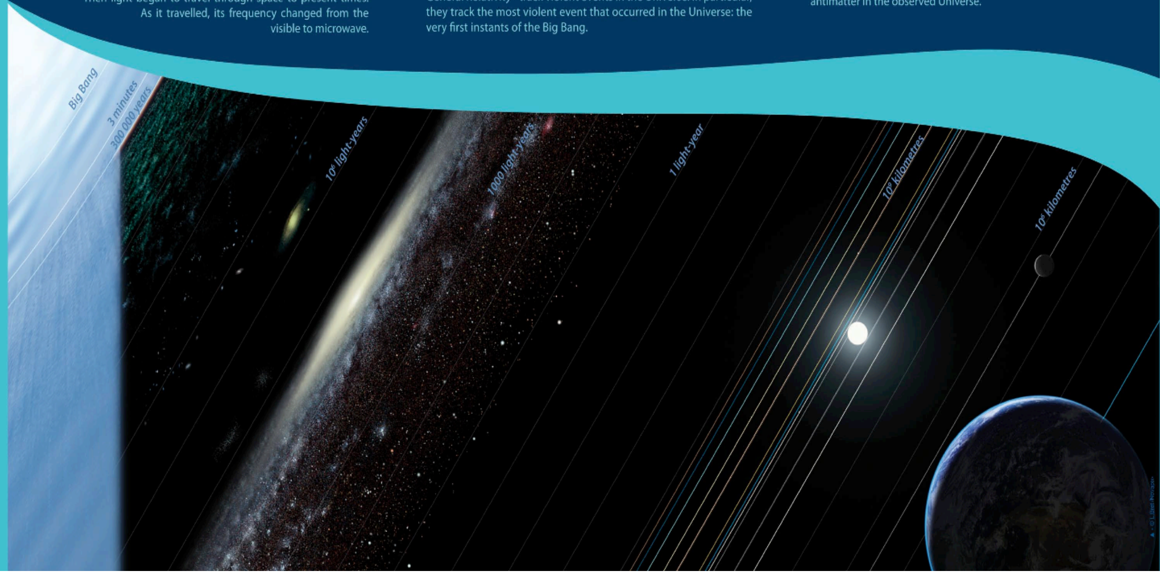
Until the early 1950s, cosmic rays and spontaneous radioactive decays were our main source of information on the nature of matter in the Universe. Then, particle accelerators made tremendous progress, providing high-energy particle beams to investigate the structure of matter. Today, new techniques allow scientists to study cosmic rays at energies far beyond the limits of accelerators. Astroparticle physics is trying to answer the most exciting questions about the Universe. For instance, we know today that only 4% of the Universe is composed of ordinary matter.

Matter as we know it is only the tip of the iceberg and only 4% of the matter in the Universe is ordinary matter. Astroparticle physics seeks to understand the nature of the unknown matter. For instance dark matter should make up 23% of the existing matter and be composed of hypothetical particles known as weakly interacting massive particles (WIMPs) and axions.



▲ - © ASPERA -

Dark matter and a hypothetical repulsive force, dubbed "dark energy", constitute the rest of the matter and energy content of the Universe. Another enigma is the absence of symmetry between matter and antimatter in the observed Universe.



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• Graphic Design •
Séverine Lebrun (CEA-France)

• Special thanks to •
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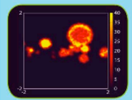
Astroparticle Physics for Europe

ASPERA

MESSENGERS FROM THE VIOLENT UNIVERSE

Discovered nearly 100 years ago, cosmic rays remain a big mystery. Passing perpetually through space between stars or galaxies, these particle messengers are coming from all directions nearly at the speed of light. We are in the process of understanding their origin. Cosmic rays track very violent phenomena happening in the Universe, such as supernova explosions or accretion of matter by black holes at the centre of galaxies. In the near future, space and ground experiments will allow us to discover many new sources of cosmic rays.

A VERY LARGE TELESCOPE ARRAY



▲ - © W. Hofmann/CTA Collaboration -

The CTA project -Cherenkov Telescope Array- will strongly increase the sensitivity of actual experiments and will extend the accessible energy range. Consisting of arrays of many telescopes, it should allow the discovery of many new high-energy sources as shown in this simulated CTA image of supernova remnants in a 4 degree by 4 degree field of the Milky Way. Current instruments would have barely detected the most intense supernova. In a single field of view, CTA is expected to detect more remnants than seen by current instruments in the entire sky. To cover the whole sky, the observatory will be divided in two places in the northern and in the southern hemispheres. CTA is already considered as an "Emerging Proposal" in the 2006 roadmap report of the European Strategy Forum on Research Infrastructures (ESFRI).

NEWS FROM EXOTIC SOURCES

▲ - © NASA HST / CXC / ASU / J.Hester et al -

Among the most probable sites for the production of galactic cosmic rays are the shock waves of supernova remnants. The traces of these exploding stars, expanding clouds of gas, can last for thousands of years. Bouncing back and forth in the remnants' magnetic field, some particles can attain very high energies, sufficient to escape their own galaxy, travel intergalactic space and be detected here on the Earth. High-energy electrons are accelerated in the shock waves of supernova remnants such as the Crab Nebula, a remnant seen in this X-ray and visible light picture. These electrons in turn produce very high-energy gamma rays.

Cosmic rays rain down on the Earth from space, which give us evidence of existing violent phenomena and exotic sources in the Universe such as supernovae, active galactic nuclei and pulsars. Mainly made of protons (about 90%), but also of other subatomic particles, cosmic rays have energies in a very wide range: from the less energetic ones coming from the Sun, to the most energetic from galactic and extragalactic sources.

The entire range of these energies covers at least 12 orders of magnitude. In order to reveal and study cosmic rays, various techniques are used based on particular cosmic rays' nature and energies. They can be "captured" directly, or indirectly using the atmosphere as a detector.

THE ATMOSPHERE AS A DETECTOR

▲ *MAGIC, a large Cherenkov telescope, made with a mirror surface of 240 m² in the Canary Islands.* - © MAGIC Collaboration -

◀ *KASKADE-Grande, an extensive array detector covering an area of 0.5 km² in Germany.* - © FZK, Karlsruhe -

▲ *ARGO-YBJ, an air shower array of detectors covering an area of about 6700 m² in Tibet.* - © INFN -

▲ *Pierre Auger Observatory consists of 1600 detectors distributed on a 3000-km² area in Argentina.* - © Pierre Auger Observatory -

▲ *H.E.S.S, an array of four 13-metre Cherenkov telescopes, 120 metres apart in Namibia.* - © HESS Collaboration -

When cosmic rays hit the atmosphere, the secondary particle shower they form can move at higher speeds than the speed of light in the air. Then, like the shock wave of a supersonic movement, a bluish flash of Cherenkov light is emitted. This light can be detected using very large Cherenkov telescopes, like H.E.S.S or MAGIC, giving information about the original cosmic ray. The same effect can be obtained in water tanks such as in the Auger detector. The extensive air shower arrays like ARGO-YBJ or KASKADE-Grande also detect the direct signals left by the secondary particle showers.

PHYSICS PUSHES THE LIMITS OF TECHNOLOGY

▲ - © 2006, Shcherbakov Sergey -

Astroparticle physicists need to detect rare events with large arrays of sensors deployed on the Earth's surface, underground or underwater. For this, they have developed distributed systems of sensors, exhibiting low energy consumption or energetic autonomy (solar panels), sometimes capable of operating in hostile environments (deep sea) and large data bandwidth. These systems produce avant-garde concepts and technology for monitoring large areas for environmental or risk preventing purposes (earthquake, wildfire, pollution).

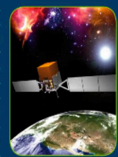
They also produce high-sensitivity, high-resolution detectors (new types of CCD or photon sensors, cryogenic detectors) with applications in biomedical, security and commercial areas.

Before reaching the Earth's surface, cosmic ray messengers interact with the constituents of the atmosphere, changing their nature and energy. A large variety of secondary particles, which decay or make new collisions, is produced. So, a cosmic ray getting into the atmosphere gives birth to a particle shower that can be detected by ground detectors. The atmosphere plays a crucial role in the detection of cosmic rays, which can be studied from the secondary particles they produce. On the Earth's surface, various types of detectors are used to identify air showers.

SEARCHING IN OUTER SPACE

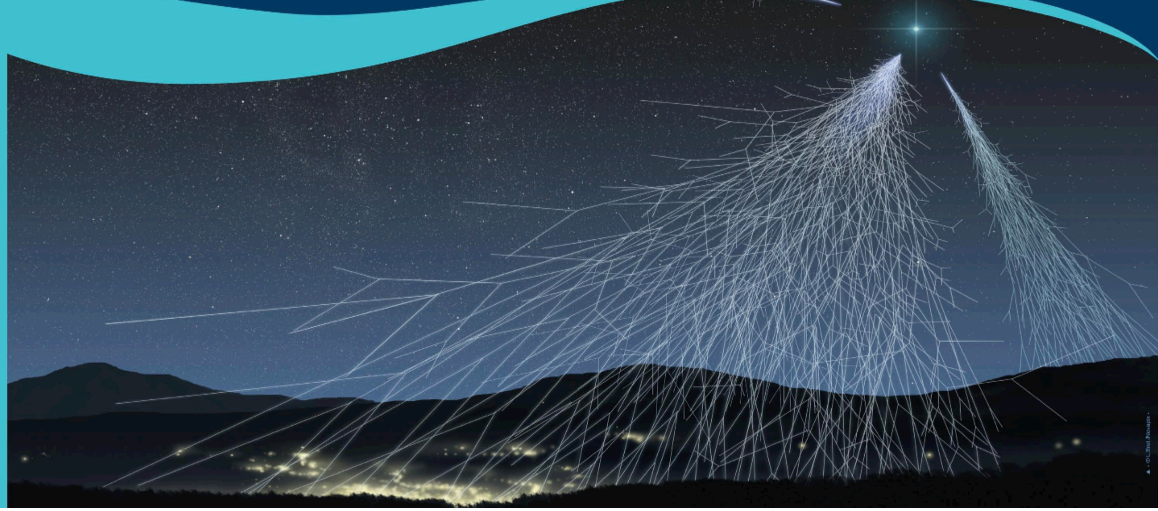
▲ *AMS* - © LMES (Lockheed Martin Energy Systems) -

New space detectors like GLAST, which should be launched in 2008 or the AMS02 experiment will give fundamental contributions in the comprehension of the most energetic phenomena in the Universe and processes such as the formation of new chemical elements and the way matter overcame antimatter.



▲ *GLAST* - © SLAC -

To detect cosmic rays directly, while avoiding their interaction with our atmosphere, scientists put detectors on board space satellites. Space can tell us many things about these messengers and we are just starting to find the sources they come from. Of the 40 violent sources of extreme gamma radiation so far detected, a handful corresponds to mysterious "dark accelerators" of cosmic rays, which had not yet been seen at any other wave-lengths. One of the most important recent high-energy astroparticle physics discoveries is the evidence of high-energy radiation coming from the region around the black hole in the heart of our galaxy.



- © L. Bret /Novapix -

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Astroparticle Physics for Europe

ASPERA

MESSENGERS FROM THE INVISIBLE UNIVERSE

For the development of our theories, we perform experiments focused on the detection of very elusive particles or on the observation of very rare phenomena. The results can shed new light on our understanding of the Universe, but their detection is a real challenge. Trillions of neutrinos, for instance, go through our body every second without stopping. This means that very few events will be recorded in our detectors, in some cases only a few per year! So any spurious signal, induced, for instance, by particles generated in the cosmic ray showers may overpower the expected signals in the same way sunlight hides stars during the day. We can get a "cosmic night" by going underground or undersea, where cosmic rays are mostly absorbed.

A VERY LARGE UNDERSEA TELESCOPE

ANTARES, NEMO and NESTOR are three high-energy neutrino experiments being deployed in the Mediterranean Sea. They are pilot projects towards a future large deep-sea infrastructure. A unique proposal called KM3NeT for a one cubic kilometre array is now being studied.

It is included in the European Strategy Forum on Research Infrastructures (ESFRI) panel and will be complementary to the South Pole experiment, IceCube, which will use the Antarctic ice as detector. With both experiments a complete coverage of the full sky will be possible.

KM3net a future large infrastructure ▶

• Artist's view of KM3net ©Marco J.Kraan / NIKHEF •

FURTHER APPLICATIONS

▲ • © J.J. Bigot/CEA/Dapnia •

Underground laboratories were conceived for research in astroparticle physics, but they have offered an ideal environment for other types of research. Studies of seismicity, biological behaviour under low radiation conditions, measurement of extremely low contamination in samples or even precise dating of wine are among the unexpected uses that can be found in the underground laboratories in Europe. Neutrino detectors could also help in monitoring nuclear activities. Undersea sites may also have further applications, such as bioluminescence monitoring or other oceanographic studies, making such infrastructures true deep-sea observatories. In many cases the technical challenges faced by the experiments have stimulated the industry in many fields and the detectors developed have found applications outside pure science.

GHOST PARTICLES

▲ *BOREXINO: a scintillation detector to study neutrinos from the Sun.* • © Borexino collaboration-LNGS/INFN •

▲ *DAMA: a dark matter experiment using highly radio-pure scintillators.* • © DAMA-/LIBRA Collaboration •

▲ *EDELWEISS: a hybrid detector to search for dark matter.* • © J.J. Bigot/ CEA/Dapnia •

▲ *XENON10: a dark matter experiment using xenon as detector.* • © XENON Collaboration •

The experiments for underground physics are placed in an environment with the least amount of radiation in the world. Cosmic rays are absorbed by the Earth, but also extremely low radioactivity techniques are applied, such as archaeological lead to shield the detectors.

Most of the matter in our Universe does not emit light. This dark matter may consist of exotic particles not yet discovered, such as Weakly Interacting Massive Particles (WIMPs) or axions. Their discovery is very important for understanding what the Universe is made of. But they are very difficult to observe. An innumerable number of neutrinos go through the Earth every second but they are also very elusive.

They can travel extremely long distances as they interact very weakly with matter, bringing information from the past and from the interior of cosmic bodies. This advantage also becomes a handicap, since the probability of interacting with our detectors is also extremely small. Very large detectors are then needed to increase our chance of detection. Going underground and using special shielding are essential to avoid any spurious signal that would spoil the possibility of observing those particles. Underground laboratories are the cleanest environments in the world from this point of view.

VERY RARE PHENOMENA

Apart from looking for particle messengers from astrophysical origin, theories are also challenged by searching for special processes related to the stability of matter, which have extremely low expected probabilities but may help solve critical problems in fundamental physics. Some of these rare processes have equally unusual names, such as "neutrinoless double beta decay" or "proton decay".

▲ *NEMO: tracking detector for the search of neutrinoless double beta decay in various nuclei.* • © NEMO Collaboration •

◀ *CUORICINO: cryogenic experiment for the search of neutrinoless double beta decay in Tellurium.* • © CUORICINO Collaboration •

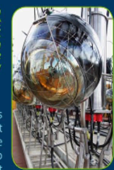
The use of very different techniques to search for the same process helps to reduce the theoretical uncertainties associated with these phenomena when extracting conclusions from the experimental data.

If we had to look for this kind of event in a single nucleus, we would have to wait several times the age of the Universe to observe it. Here also, huge detectors are placed underground and the use of ultra pure techniques is mandatory to avoid spurious signals that may hide the searched-for effect.

IN NEPTUNE'S KINGDOM

The more messengers we use, the more information we can extract from the same sources. Low-energy neutrinos can give information about the Sun or supernovae and are already being studied in underground laboratories.

A photomultiplier is a widely used instrument in astroparticle physics experiments, it converts light into an electrical signal, acting as an "electronic eye". When a high-energy neutrino interacts, it produces an up-going muon in the sea, which will give rise to blue Cherenkov light, which in turn will be seen by an array of photomultipliers.



▲ • © L.Fabre/CEA •

On the other hand, high-energy neutrinos can give precious information about violent processes in the Universe, but the size needed to detect enough neutrinos to perform neutrino astronomy is so large that detectors would not fit in underground sites. Physicists have conceived the construction of large deep undersea infrastructures where water itself acts as detector and shield from cosmic rays. Such telescopes use arrays of optical modules distributed in large volumes to detect the light induced by particles interacting in the sea water.

▲ • © ESA/Novaspace

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C'EST TOUT
POUR AUJOURD'HUI !

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