From deep sea to deep space

Dr Paschal Coyle provides insights into experiments in the deepest ocean, which may open a new window to study the physical processes involved in the most cataclysmic events of the Universe

Firstly, can you explain the purpose of the ANTARES collaboration, and what inspired its creation?

The primary goal of the ANTARES telescope is the search for high energy neutrinos produced by astrophysical sources in the Universe. Neutrinos are elementary neutral particles involved in all nuclear processes and are expected to be copiously produced in many energetic astrophysical processes such as the death throws of stars (Supernovae and their remnants), the accretion of matter by super-massive black holes (Blazar's), the merging of binary neutron star systems (Gamma Ray Bursts), the annihilation of dark matter in the heart of the sun. The identification of the source of even a handful of extra-terrestrial high-energy neutrinos would solve the century-long mystery of the origin of cosmic rays.

As the telescope is located deep in the Mediterranean Sea, the ANTARES infrastructure is also one of the few permanent deep sea observatories in the world. It provides real-time, high-bandwidth data transmission of measurements of oceanographic and environmental parameters from specialised sensors installed on the infrastructure.

The Cherenkov detector is located deep in the Mediterranean Sea. Why this location was selected and were other sites considered?

The ANTARES telescope is located at a depth of 2.5 km and 42 km offshore from Toulon in the South of France. The choice of this site resulted from many site evaluation campaigns, comprising more than 60 line deployments at a variety of locations and times. Extensive measurements were made of light background from bioluminescence, bio-deposition, sedimentation and light transmission. Other very important considerations for the site choice included proximity to shore and the availability of local infrastructure, such as boats, for the deployment of the lines and submersibles for the underwater connection of the lines.

How close do you believe we are to demonstrating the existence of dark matter?

Many approaches have been developed to attempt detection of dark matter particles. Such endeavours include direct detection experiments, which hope to observe the scattering of dark matter particles with the target material of the detector, and indirect detection experiments, which are designed to search for the products of the annihilation of dark matter particles. Neutrino telescopes indirectly search for the presence of dark matter by taking advantage of the Sun's ability to capture large numbers of non-baryonic dark matter over time. During billions of years, a sufficiently large number of dark matter can accumulate in the Sun's core to allow for their efficient annihilation. Such annihilations produce a wide range of particles, most of which are quickly absorbed into the solar medium. Neutrinos, on the other hand, may escape the Sun and be detected by the ANTARES experiment on the Earth. As the Sun is mainly made of hydrogen, it is particularly efficient for capturing dark matter with a large spin-dependent cross-section. Direct detection experiments, on the other hand, are more sensitive to dark matter having a large spin-independent cross-section. Consequently, the search for dark matter with neutrino telescopes is competitive and complementary to the direct search methods. Although no evidence for dark matter has yet been obtained – neither by ANTARES nor the direct detection experiments – the experimental sensitivity is improving as additional data is accumulated and more and more of the parameter space of the theoretical models are being excluded.

Could you highlight the extent to which collaboration has underpinned the project's success?

The ANTARES experiment was initiated in 1996 by the Institut National de Physiques Nucléaire et de Physique des Particules in France, in collaboration with the Commissariat à l'Energies Atomique et aux Energies Alternatives. Today, the Collaboration comprises 30 universities and laboratories across nine European countries. A total of about 150 scientists and engineers, from the fields of Astroparticle Physics and the Earth and Sea sciences, have contributed to the design, construction, maintenance and data analysis phases of the experiment. The successful conclusion of such a technically challenging project relied heavily on equitable sharing of financing, tasks and responsibilities between the various institutes of the collaboration – this work benefited particularly from the specialised expertises of certain institutes. Ensuring good communication, coordination and collaboration between the various partners was essential. A strong quality control system during the construction phase of the project was also a vital key to success.

Deepening our knowledge of the Universe

ANTARES is gathering data from a telescope in the Mediterranean Sea with hopes of advancing the study of particle acceleration mechanisms in energetic astrophysical objects

THE DARKEST CORNERS of the Universe offer much opportunity for gaining new understanding about life on Earth, as do the deepest oceans. To learn more about the Universe there is an ongoing effort to expand our observational view to include all types of particles – not just photons but also charged particles and neutrinos – and to extend the energy range over which they can be detected. Neutrinos are particularly interesting, given that they are neutral, they have very little mass, and interact only very weakly with matter. This means that unlike photons and charged particles, they are not absorbed by dust clouds and are not bent by magnetic fields. Neutrinos therefore provide the unique possibility to 'see' much further than with high-energy photons or cosmic rays, and to probe regions of high matter density where photons and charged particles would be absorbed.

A team of eminent scientists and researchers are delving into this topic through an experiment known as ANTARES. The primary aim of this project is to use neutrinos as a tool to study where and how cosmic rays are accelerated. Their hope is that objects such as active galactic nuclei and gamma-ray bursts may also shed light on the origin of ultra-high-energy cosmic rays. Dr Paschal Coyle is leading the team: "The multi-messenger astronomy framework we have developed offers an opportunity to exploit possible correlated signals between the gamma, cosmic rays and neutrinos," he elucidates. Observing high-energy neutrinos in the depths of the Earth's oceans provides a chance to open a new window on these 'messengers' and, consequently, the innermost workings of the Universe.

A MULTI-PRONGED APPROACH

The framework that the ANTARES group has put together is threefold, and involves investigations and experiments into the workings of charged cosmic rays, gamma-rays and neutrinos. In simple terms, ANTARES is a telescope that spends its time observing the southern hemisphere sky detecting particle acceleration. Its view of the Universe is complemented by the IceCube neutrino telescope, which observes primarily the northern hemisphere sky. Together ANTARES and IceCube provide continuous full sky coverage of the high energy neutrino Universe. Coyle explains that compared to ice, sea water is a more uniform detection medium and consequently suffers less from light scattering: "ANTARES therefore achieves a more precise angular resolution than IceCube. Furthermore, ANTARES has excellent visibility towards the centre of our Galaxy; a close-by and likely region for neutrino production".

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The researchers are hoping that the telescope will detect muons from high-energy astrophysical neutrinos. As neutrinos interact so little with matter, a very large target mass is needed to maximise the chances for their detection. Because of the location of ANTARES in the ocean it is able to use the readily available sea water and surrounding rock as the target. Coyle offers some insights into how this works: "When a high-energy muon neutrino does interact, a charged particle called a muon is created. As the muon, relativistic at these energies, travels through the seawater it induces the emission of a special sort of light, known as Cherenkov radiation". At this depth the sea is completely dark and the only flashes of light are those produced by muons, the radioactive decays of salt in the seawater and possibly bioluminescent emission from marine organisms. The large thickness of sea water above the detector acts as shield to reduce the background from down-going muons produced by cosmic ray interactions in the atmosphere above the telescope. Coyle describes how the neutrinos are separated from the remaining atmospheric muon contamination by using the Earth as a filter: "Only neutrinos can pass completely through the Earth and produce up-going muons; the characteristic signature of neutrinos".

RIGHT: Cherenkov light is detected by a three-dimensional array of about 900 photomultiplier tubes, each housed in a pressure resistant glass sphere.

FAR RIGHT: The spheres are placed in storeys of triplets along 12 vertical detector lines, which are anchored to the sea bed and held taut by a buoy.

BELOW: A detection line on its transportation platform.

GATHERING REMOTE DATA

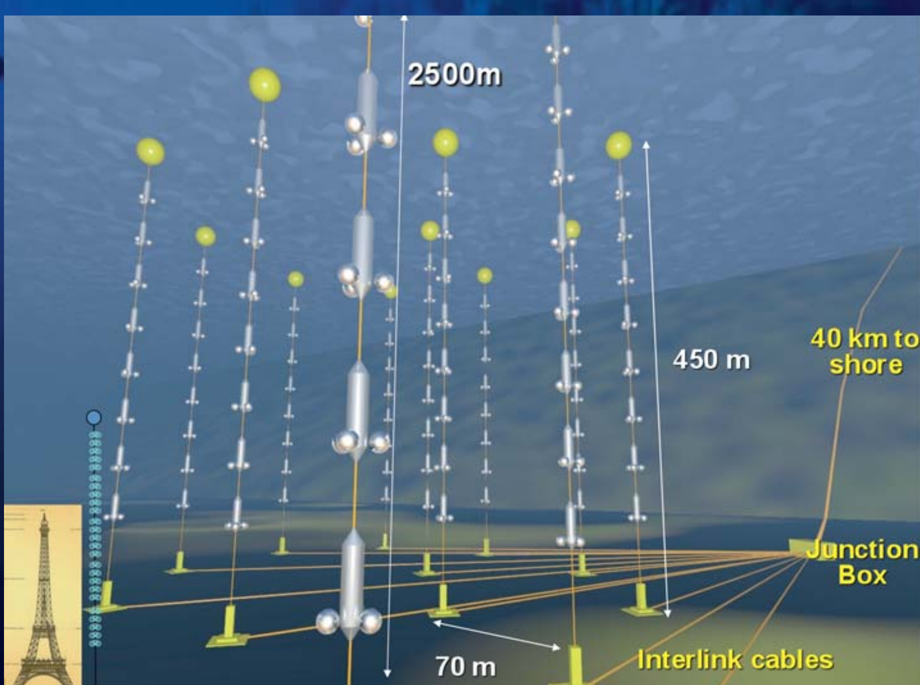
The isolated location of the ANTARES telescope means it is critical that the information gathered is available as quickly as possible. Information is transmitted to shore via optical fibres. There is an onshore control room where over 100 computers filter the data and search for time-correlated photons characteristic of the passage of a muon particle in the vicinity of the detector. The filtered data is then transferred overnight to a data centre in Lyon where it can then be analysed offline by the institutes within the ANTARES collaboration.

In the past, marine researchers and scientists would gather their data during cruises, but this method delivers only punctuated measurements. Those measurements have really proven to be inadequate to address the level of understanding needed into the fundamental process that impact on the water column and seabed. The opportunity presented by the installation of the ANTARES telescope has brought much excitement to the world of science. The sensors connected to ANTARES cover a wide range of domains including oceanology, biogeochemistry, geology and biodiversity. They allow long-term monitoring of the deep sea biodiversity on all scales, from microorganisms up to the largest marine mammals. The cabled seismometers on ANTARES also contribute to a better understanding of active tectonics and seismic hazards in the East Ligurian region, as well as to alert systems for earthquakes and tsunami.

EXPLORING NEW REGIONS OF THE UNIVERSE

ANTARES is the first, and only, neutrino telescope operating in the deep sea. Earlier attempts to build such telescopes failed due to the tremendous technological challenges of constructing such large infrastructures in the deep sea with the associated issues of resisting the high pressure and corrosive environment, as well as ensuring the necessary integrity against water leaks. It is Coyle's opinion that the key enabling technologies necessary for the success of ANTARES were the development of the vertical electro-mechanical cable of the detection lines, the wet-mateable electro-optical connectors and the availability of the remotely-operated submersible used to connect together the structures on the seabed.

Although the analysis of the first two years of the ANTARES neutrino data has not yet led to discovery of a source of cosmic neutrinos, the limits on the flux of such neutrinos in the southern sky are the best currently available. Coyle's team are eagerly awaiting the results from an additional two years of data which will be ready soon. The new results will extend data sensitivity by about a factor three into completely unexplored regions. The ANTARES consortium is excited about the future opportunities for the project. To fully exploit the physics potential of the new field of neutrino astronomy, a much larger second generation Mediterranean neutrino telescope, KM3NeT, has been proposed by the European neutrino astronomy community and the ANTARES site is proposed as a potential location for this observatory. This is a deep sea observatory that would be about 50 times more sensitive to neutrinos than ANTARES: "The technical design of KM3NeT has benefited tremendously from the lessons learnt from the ANTARES experience, as well as from smaller R&D projects such as NEMO in Sicily and NESTOR in Greece," Coyle underlines. KM3NeT also has strong links with the European Multidisciplinary Seafloor Observatory and the expectation is that it would act as a node within that distributed infrastructure.



INTELLIGENCE

ANTARES

ASTRONOMY WITH A NEUTRINO TELESCOPE AND ABYSS ENVIRONMENTAL RESEARCH

OBJECTIVES

To construct a large area water Cherenkov detector in the deep Mediterranean Sea, optimised for the detection of muons from high-energy astrophysical neutrinos.

PARTNERS

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