# KM3NeT

Astroparticle & Oscillations Research with Cosmics in the Abyss

KM3NeT is a large distributed research infrastructure that comprises a network of deep-sea neutrino telescopes in the Mediterranean Sea with user ports for Earth and Sea sciences. The main objectives of KM3NeT are the discovery and subsequent observation of high-energy neutrino sources in the Universe (ARCA) and the determination of the mass hierarchy of neutrinos (ORCA). The prospects of the different phases of the implementation of KM3NeT are summarised.

## Science

The objective of ARCA is the detection of high-energy neutrinos of cosmic origin. The world-wide effort in this field is concentrated in three large research centres, namely: IceCube (South Pole), KM3NeT (Mediterranean Sea) and GVD (Lake Baikal). The successful construction and operation of the ANTARES detector (Mediterranean Sea) has demonstrated the feasibility of deep-sea neutrino telescopes. Furthermore, the transparency of the deep waters, the size of the detector and the geographical location make KM3NeT an ideal instrument to study sources of high-energy neutrinos in our Galaxy and beyond. Following the observations of cosmic rays and high-energy gamma rays, the questions remain which astrophysical objects accelerate sub-atomic particles to such high energies and the acceleration processes involved. In answering these questions, one is confronted with the ambiguity of the production mechanism of gamma rays and the difficulty to point back charged cosmic rays. This impasse can be broken by the observation of high-energy neutrinos. The neutrino signal recently reported by IceCube motivates a multi-messenger approach in which astrophysical particle accelerators can be identified and studied through the combined observations of cosmic rays, gamma rays and neutrinos. So, the next challenge is to identify the sources of cosmic neutrinos.

The objective of ORCA is the determination of the mass hierarchy of neutrinos. This mass hierarchy is, together with the CP-violating phase and possible Majorana nature of the neutrino, an outstanding unknown of the Standard Model of Particle Physics. With the ORCA detector it is possible to determine the mass hierarchy using oscillations of atmospheric neutrinos in the Earth. The ORCA detector provides in addition sensitivity to low-mass dark matter (via annihilation in e.g. the Sun) and possibly also to the composition of the Earth interior (via neutrino tomography).

Further science perspectives include the synergy with Earth & Sea sciences and acoustic detection of ultra-high energy neutrinos when they interact in the sea water.

## Technology

The detection principle is based on the measurement of the Cherenkov light induced by relativistic charged particles emerging from an interaction of a neutrino in the vicinity of the detector. The angular resolution is primarily determined by the lever arm between the light sensors and the measurement precision of their positions and the arrival time of the Cherenkov light. Of the different types of neutrino interactions, the charged current interaction of a muon neutrino yields the best angular resolution because the muon emerging from such an interaction has the longest range. The light transmission properties of the sea water combined with the presently feasible position (10 cm) and time (1 ns) resolutions of the light sensors make it possible to reconstruct the direction of high-energy muons with a precision of about 0.1 degrees. In a recent study, the angular resolution of other neutrino interactions (so-called cascades) was estimated to be better than 2 degrees for neutrinos with energies in excess of 100 TeV, along with a rather precise (5%) measurement of their energy. As a result, neutrino astronomy with all flavours is possible for the first time

The KM3NeT technology makes it possible to instrument, at minimal cost and maximal reliability, the largest possible volume of sea water with a three dimensional spatial array of light sensors. A new generation of 3-inch photo-multiplier tubes (PMTs) has been developed for KM3NeT. These PMTs combine good timing (RMS less than 2 ns), relatively high quantum efficiency (around 30%) and low price (per unit photo-cathode area less than 10-inch PMTs). The PMTs and the readout electronics are enclosed in pressure-resistant glass spheres. These optical modules are distributed in space along flexible strings, one end of which is fixed to the sea floor and the other end is held close to vertical by a submerged buoy. An optimal building block consists of 115 such strings. The concept of building blocks is modular. Hence, the construction and operation of the research infrastructure allows for a phased and distributed implementation.

## Prospects

Recently, the Collaboration started the first construction phase (Phase-1). During 2015–2016, 31 strings equipped with 558 optical modules will be assembled and deployed at the French and Italian sites. The resulting arrays will be different in size, the setup at the Italian site being significantly larger and providing the equivalent of about 10% of the size of the IceCube detector (and more than 3 times the size of the ANTARES detector). For this, the detector configuration which is optimal for the discovery of high-energy neutrino sources in the Universe will be pursued. The strings at the French site will be arranged in a more dense configuration appropriate for the measurement of the neutrino mass hierarchy.

The next phase of KM3NeT (Phase-2) will allow for an independent measurement of the IceCube signal with different methodology, better angular resolution and complementary field of view (ARCA). In addition, the predicted angular resolution of cascade events offers the breakthrough capability of doing all flavour neutrino astronomy. At the same time, the neutrino mass hierarchy will be determined (ORCA). During the Neutrino 2014 conference, it became apparent that ORCA is competitive if completed before 2020. An early determination of the neutrino mass hierarchy by ORCA will also help to interpret results of ongoing experiments on the Majorana nature of the neutrino and to define the optimal configuration of future experiments dedicated to the measurement of the CP-violating phase.

The ultimate goal is to fully develop the KM3NeT research infrastructure to comprise a distributed installation at the three foreseen sites (Italy, France and Greece), with almost 700 strings equipped with 12,400 optical modules in total (Phase-3). The sensitivity of the Phase-3 neutrino telescope will not only exceed that of the current IceCube detector by a substantial factor, it will bring possible neutrino sources in our Galaxy within reach.

The proposed scenario is to simultaneously build the ORCA and ARCA detectors in France and Italy, respectively. The phased implementation of KM3NeT is summarised in Table 1 and an overview of the prospects of Phase-2 (ORCA and ARCA) and Phase-3 are shown in Figure 1.

| Phase | Blocks | Primary deliverables |
|---|---|---|
| 1 | 0.2 | Proof of feasibility and first science results; |
| 2 | 2 | Measurement of the neutrino signal reported by IceCube;<br>All flavour neutrino astronomy; |
| | 1 | Determination of the neutrino mass hierarchy; |
| 3 | 6 | Neutrino astronomy including Galactic sources; |

Table 1: Summary of the phased implementation of the KM3NeT research infrastructure.

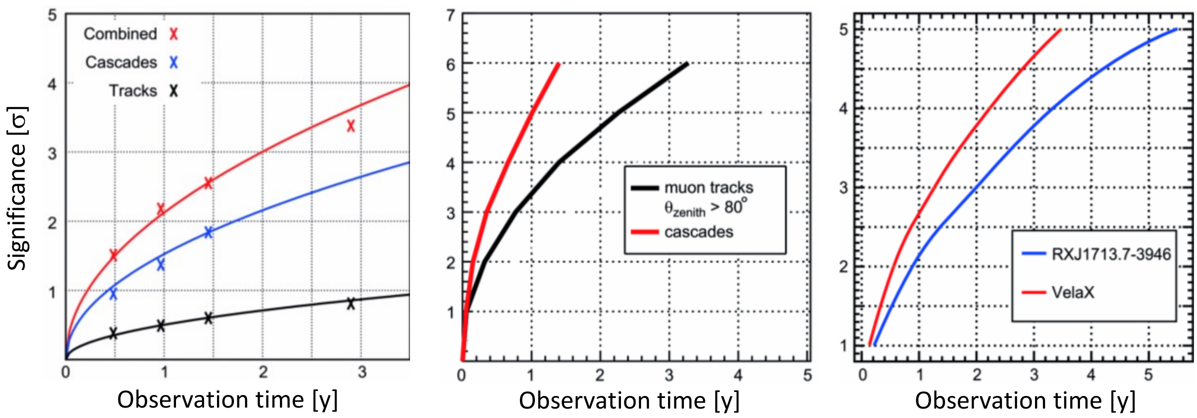


Figure 1: The significance (σ) as a function of the observation time (years) for a determination of the neutrino mass hierarchy using ORCA (left), the signal reported by IceCube using ARCA (middle) and the assumed neutrino signals from the Supernova Remnant RXJ1713 and the Pulsar Wind Nebula Vela X using Phase-3 (right).