2.4 Neutrino Telescopes
ANTARES & KM3NeT

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Nikhef is heavily involved in the operational neutrino telescope ANTARES and the planned telescope KM3NeT, both in the Mediterranean Sea. Nikhef is one of the largest groups in the ANTARES collaboration, which is harvesting on already eight years of data. It is also a leading institute in the KM3NeT collaboration with Nikhef's Maarten de Jong as spokesperson. The construction of the KM3NeT detector has just started. For KM3NeT in Phase I (2015/2016) 31 strings will be deployed at the French and Italian sites and thus provide a more than three times larger detector than ANTARES. On the way to the final detector with 700 strings an intermediate step with 230 strings, called phase 1.5, is planned.

This intermediate step is motivated by the recent discovery of extraterrestial neutrinos of spectacularly high energy (PeV) by the IceCube experiment. The origin of these neutrinos so far remains a mystery. Although the spatial distribution seems to show an anisotropy towards the galactic center region, the low statistics and limited angular resolution of IceCube do not allow any rigorous conclusions. Therefore, further observations especially of that region are invaluable for a better understanding.

Although ANTARES' operational size is smaller than IceCube's it offers a better angular resolution and access to lower energies. The galactic 'hot spot' region of the IceCube excess has been scrutinised for possible point sources using ANTARES data. Nikhef was majorly involved in this effort and single point sources with a hard energy spectrum could thus already be excluded as the only origin of the neutrino excess discovered by IceCube.

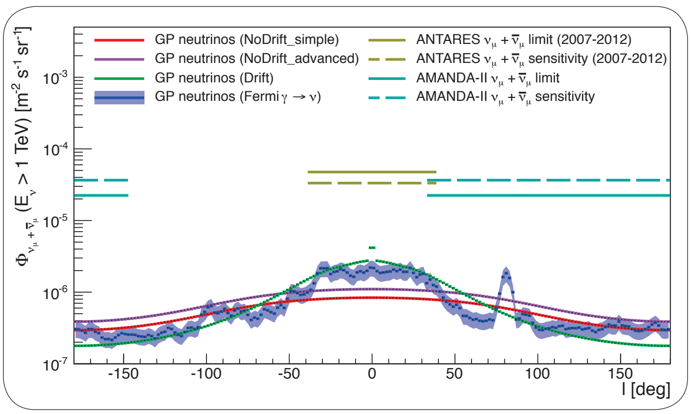

Figure 1. The diffuse neutrino flux integrated above 1 TeV shown as a function of longitude for various models together with the sensitivity and limit from Amanda and from the recent ANTARES analysis which constrains the flux in the central galactic region.

The galactic region has also been subject of another analysis at Nikhef in which the first limit on the diffuse neutrino emission expected from interactions of cosmic rays with the interstellar medium in this region has been set. For this emission a softer energy spectrum is expected than for point sources. In the meantime IceCube published energy spectra on a larger sample of their high energy extraterrestrial neutrinos which do favour soft energy spectra and still seem to show a spatial anisotropy. The new ANTARES limit can thus directly help to constrain models explaining the origin of those neutrinos with galactic emission.

With its excellent angular resolution and direct view of the galactic region KM3NeT will already within its first year of phase 1.5 be able to confirm or exclude the galactic center as the origin of the PeV neutrino signal.

For KM3NeT the construction phase has started and the building of prototypes is transitioning towards mass production. Nikhef is involved in many of the required developments of which a few are highlighted here. The Nikhef design of the optical modules with 31 photomultipliers mounted in a glass sphere has undergone its final revision and mass production has begun. The design of the electronic boards attached to the photomultipliers to produce the required high voltage was finalised and the 15,000 boards required for assembling of the first 26 strings were produced and tested. The Nikhef group was also responsible for the firmware on the central logic boards in the optical modules to establish the synchronisation in nanosecond precision using the 'White Rabbit' system and also contributed to the development of the DAQ software.

The complete production chain for a full KM3NeT string has been developed and set up at Nikhef culminating in the successful assembly of a first complete string with 18 optical modules which will be deployed in early 2015.

The mechanical structure for deploying strings for KM3NeT was developed at Nikhef in collaboration with NIOZ (Royal Netherlands Institute for Sea Research) and was this year successfully demonstrated in Motril (Spain).

In May 2014 the very first KM3NeT string with three prototype optical modules had been assembled at Nikhef and subsequently deployed in May at 3,200 m depth at the Italian KM3NeT site. The data were evaluated mostly by the Nikhef group and already with only three of the modules a full reconstruction of (downgoing) muon tracks from combined signals in the three modules was demonstrated, proving also the powerful background suppression from the correlation between the small PMTs.

Figure 2. The first fully assembled KM3NeT string with 18 optical modules at Nikhef.

Nikhef is also substantially involved in exploring the potential for the full KM3NeT detector via simulations for which a new shower reconstruction has been developed with an unprecedented resolution of a few degrees.

A new opportunity for neutrino telescopes had arisen from the establishment of a non-zero mixing angle 'theta-1-3' in the neutrino sector in 2012, namely to identify the unknown mass hierarchy of the neutrinos by evaluating the flavour changing oscillations of atmospheric neutrinos. Depending on the mass hierarchy the oscillation pattern changes in the transition of the neutrinos through the Earth in different ways. The signature of the change is very subtle and unprecedented energy and angular resolutions at low energies (around ~6–10 GeV) are then crucial for a successful distinction. The same detector technology as for KM3NeT, but in a denser configuration, has since been studied for this purpose under the name ORCA. Nikhef has been instrumental in developing the analysis and reconstruction chain and evaluating the sensitivity. A three sigma distinction of the two mass hierarchies can be expected already within three years of operation of the proposed ORCA detector. The French site of KM3NeT will be devoted to further exploring the feasibility of this exciting option by implementing densely populated strings.

Overall the neutrino telescope technology has significantly matured and excellent prospects for the measurement of both high and low energy neutrinos could already be demonstrated ensuring a bright future for neutrino astronomy.