IL NUOVO CIMENTO **42 C** (2019) 80
DOI 10.1393/ncc/i2019-19080-3

Colloquia: EuNPC 2018

KM3NeT and ANTARES status and results

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received 5 February 2019

Summary. — The latest results from the ANTARES neutrino telescope will be presented regarding the search for a diffuse high energy neutrino flux, the analysis to identify astrophysical neutrino point sources and the various searches for multi-messenger coincidences between neutrinos and other cosmic probes, like photons or gravitational waves. KM3NeT, the new generation of underwater neutrino telescopes, is currently under construction in the Mediterranean sea. Thanks to its large size and improved detection capabilities, KM3NeT will open new perspectives in neutrino astronomy.

1. – Introduction

Neutrino astronomy is the youngest branch of astroparticle physics. TeV neutrino astronomy is even younger, since only recently the IceCube detector provided the first ever observation of high energy neutrinos of cosmic origin [1]. This has opened a new window of observation on the Universe. The observation of neutrinos of extra-terrestrial origin can solve a fundamental question in astroparticle physics: the origin, the sources and the acceleration mechanisms of charged cosmic rays. Since neutrinos could be produced in the dense environment surrounding the acceleration site, they can directly point to the cosmic ray source and accelerator. A possible way to detect high energy neutrinos using huge volumes of transparent natural material such as ice or sea water was proposed by Markov in 1960 [2]. High energy neutrinos undergoing weak interactions with one of the nucleons of the medium would produce charged particles. Cherenkov photons induced by these charged particles that travels through a medium, can then be detected by a lattice of photomultipliers. Given the low cross section of νN interactions and the predicted astrophysical neutrino fluxes, the typical size of the detector should be of the order of km^3.

2. – Mediterranean neutrino telescopes

The ANTARES [3] neutrino telescope is a three-dimensional array of 885 photomultipliers (PMTs) distributed over 12 vertical lines 450 m long, installed in the Mediterranean

Sea, 40 km off-shore Toulon, France, anchored 2475 m below the sea level. The detector has been operated in partial configurations since March 2006 and was completed in May 2008. It is taking data continuously since then. The time and the position of the photons produced by the charged particles generated in neutrino interactions are detected by the PMTs and used to reconstruct the direction and the energy of the interacting neutrinos.

KM3NeT is a future research infrastructure comprising the ARCA and ORCA detectors [4]. The former will be located about 100 km off-shore from the coast of Portopalo di Capo Passero, Sicily, Italy at a depth of 3500 m and is designed for the investigation of high energy neutrino astrophysics and the search for the sources of cosmic neutrinos. The latter will be located close to the ANTARES site about 10 km apart from it and is optimised for the study of low energy neutrino oscillation physics and for the measurement of the neutrino mass ordering. Both detectors will use the same technology. In particular, photons will be detected with Digital Optical Modules (DOM), a sphere resistant to high pressure that contains 31 PMTs. The DOMs are arranged in a vertical string called Detection Units (DU) and the difference between ARCA and ORCA is the relative distance between the DOMs and between the DUs, sparser in ARCA and denser in ORCA. The ARCA detector will be built in two phases: the first phase, already funded, will consist in 24 strings, 3 of them were already deployed and the construction will be completed in 2019. The second phase, partially funded, will consist on two building-blocks (BB), each one made of 115 DUs to reach an instrumented volume larger than 1 km^3 and will be done approximately by the end of 2021. The ORCA detector will have two phases like ARCA: in the first one, already funded, 6 DUs will be deployed and one of them is already under the sea. The second phase will consist in one BB of 115 DUs.

There are two event topologies that can be identified in a high energy neutrino telescope: *track*-like and *shower*-like events. The track events are produced when a muon is generated in a charge current (CC) interaction of a muon neutrino in the proximity of the detector. Thanks to the long muon range the direction of the interacting neutrino can be reconstructed with an angular resolution that is below 1° for ANTARES and in the order of 0.1° for KM3NeT-ARCA. Shower events are produced when an electromagnetic and hadronic cascade are generated in a neutral current interaction (NC) of a neutrino independently from its flavor, or in a charge current interaction (CC) of an electron or tau neutrino. All the energy of the cascade is deposited within a few meters from the interaction vertex hence they are reconstructed as point-like source of light, thus providing a poorer angular resolution as compared to the track channel, in the order of $\sim 5°$ for ANTARES and $\sim 2-3°$ for KM3NeT-ARCA. On the other hand this kind of events allow a very precise energy estimation of the interacting neutrino that is $\sim 15\%$ for ANTARES and $\sim 5\%$ for KM3NeT-ARCA.

3. – Cosmic neutrino searches

There are three main strategies to detect a cosmic neutrino, the first one being the search for a diffuse high energy neutrino flux where one looks for an excess of high energy neutrinos over the atmospheric neutrino background, without any request on the neutrino direction in the sky.

Using nine year of the ANTARES data a search of a diffuse flux [5], like the one discovered by the IceCube experiment [1], has been performed. The result of the analysis is shown in the left and central plots of figure 1. Here a slightly excess of events, both in the track and shower channels, of 33 events, when 24 ± 7 were expected from the background, has been found. After a maximum-likelihood fit of the energy estimators

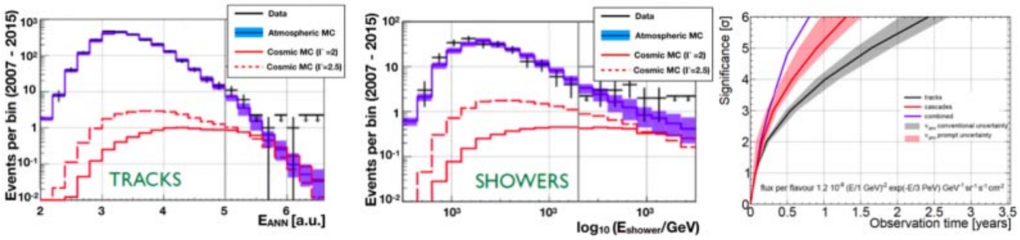

Fig. 1. – Left and middle: distribution of reconstructed neutrino energy for the track and shower channels in the ANTARES diffuse flux analysis [5]. The uncertainties, depicted as a shaded area, take into account the detector efficiency and the water properties systematics. Right: significance as a funcion of time for the detection of the IceCube diffuse flux using the KM3NeT-ARCA detector in the phase two configuration [4].

distributions the hypothesis of a null cosmic flux has been excluded with a significance of 1.6σ. In the right plot of figure 1 is shown the significance as a function of time for the detection of an IceCube-like diffuse flux with the ARCA detector with two building blocks. With the two building blocks of KM3NeT-ARCA, the IceCube-like diffuse flux will be observed with a 5σ significance in only six months.

The second strategy observe cosmic neutrinos is the so-called point source search. In this case a correlation between the neutrino direction and the position of an already known astrophysical object is searched for. The results of the ANTARES point source analysis, that uses a 9 year data sample and both the track and shower channel and investigate 106 astrophysical candidate neutrino sources, is shown in the left plot of figure 2. No significant evidence of cosmic neutrino sources has been found [6]. Nevertheless, these searches provide the most sensitive limits for the predicted neutrino fluxes for a large fraction of the Southern Sky region. The KM3NeT-ARCA [4] detector will improve the ANTARES sensitivity by an order of magnitude as shown in the right plot of the figure 2.

The third strategy to find cosmic neutrinos is the multimessenger approach. The

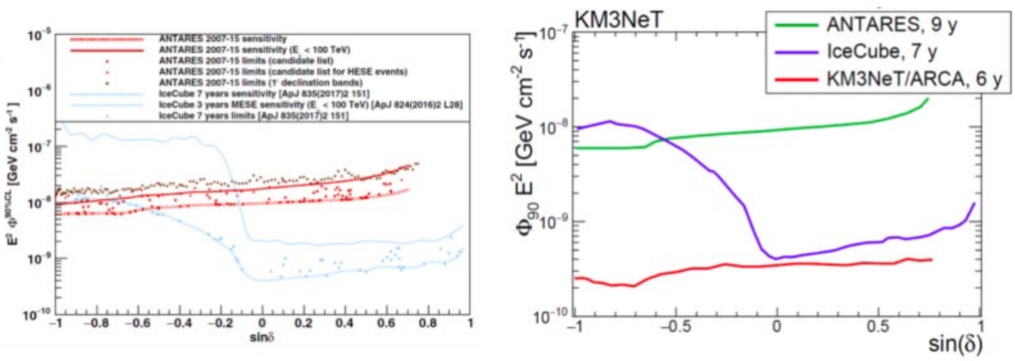

Fig. 2. – Left: ANTARES sensitivity and limits, as a function of the declination, to the astrophysics candidate neutrinos sources [6]. Right: Estimated sensitivity for point like sources as a funcion of the declination for a 6 years observation with the KM3NeT-ARCA detector in phase two configuration [4].

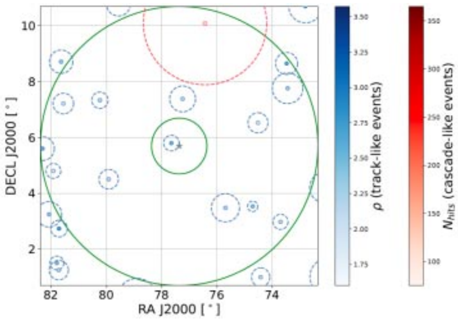

Fig. 3. – Distribution of ANTARES events in the right ascension and declination coordinates around the position of TXS 0506+056 [7]. The read point denotes a shower-like event, whereas the blue points indicate track-like events. The size of the circle around each event indicate the associated angular error.

search is done by sharing information with various detectors ranging from electromagnetic observatories (optical, radio, X-ray, gamma-ray) to cosmic rays and gravitational wave detectors. The goal of this kind of search is to detect neutrinos from transient phenomena therefore using a space-time coincidences between the different probes, which heavily reduces the background contamination. An example of a multimessenger analysis done by ANTARES is the one done in blazar TXS 0506+056. The 22 of September 2017 IceCube recorded a neutrino with an arrival direction consistent with this blazar [8] that was observed to be in flaring state. This source has been investigated using the ANTARES data but no muon neutrino candidate event has been found within 3° around the IceCube neutrino directino within ±1hr centered on the event time. A point source like search has been done with ANTARES looking to the blazar as a candidate neutrino source and in figure 3 are shown the neutrino candidate event. No significant excess above the expected backgound is found [7].

4. – Conclusions and Perspectives

The ANTARES neutrino telescope continues taking data and producing relevant physics results after 10 years of continuous data taking. It produced solid results from various searches of astrophysical neutrino emission and it has a very active multimessenger program. KM3NeT, the new generation of Mediterranean neutrino telescopes, will benefit from the best practice coming from the ANTARES experience and will be soon competitive in astrophysical neutrino searches and in the basic neutrino physics.

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