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Review

Neutrino telescopy in the Mediterranean Sea

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Abstract

The observation of high-energy extraterrestrial neutrinos is one of the most promising future options to increase our knowledge on non-thermal processes in the universe. Neutrinos are e.g. unavoidably produced in environments where high-energy hadrons collide; in particular this almost certainly must be true in the astrophysical accelerators of cosmic rays, which thus could be identified unambiguously by sky observations in "neutrino light". On the one hand, neutrinos are ideal messengers for astrophysical observations since they are not deflected by electromagnetic fields and interact so weakly that they are able to escape even from very dense production regions and traverse large distances in the universe without attenuation. On the other hand, their weak interaction poses a significant problem for detecting neutrinos. Huge target masses up to gigatons must be employed, requiring to instrument natural abundances of media such as sea water or Antarctic ice. The first generation of such neutrino telescopes is taking data or will do so in the near future, while the second-generation projects with cubic-kilometre sizes are under construction or being prepared. This report focuses on status and prospects of current (ANTARES, NEMO, NESTOR) and future (KM3NeT) neutrino telescope projects in the Mediterranean Sea.

Keywords: Neutrino astronomy; Neutrino telescopes; ANTARES; NEMO; NESTOR; KM3NeT; Supernova remnants; Diffuse neutrino flux; Indirect dark matter detection

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1. Current neutrino telescope projects in the Mediterranean Sea

World-wide, two neutrino telescopes (AMANDA at the South Pole [1,2] and one in Lake Baikal [3]) are taking data, two are under construction in the Mediterranean Sea (ANTARES [4,5] and NESTOR [6,7]), and the cubic-kilometre telescope IceCube [8] is being installed at the South Pole. Preparatory work for a corresponding installation in the Mediterranean Sea is being

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performed in the R&D project NEMO [9]; from early 2006 on, all groups involved in the current Mediterranean projects will join into a 3-year EU-funded Design Study towards the future km^3-scale neutrino telescope in the Northern hemisphere (KM3NeT) [10].

1.1. Detection principle

Interactions of neutrinos with target material in the neutrino detector or its vicinity produce charged secondary particles with velocities exceeding the speed of light in water or ice, which therefore radiate Čerenkov light. This light is detected by an array of photomultipliers placed deep below the surface. The range of neutrino energies for which neutrino telescopes are sensitive is limited by this detection method to some 10 GeV at its lower end, while at energies beyond roughly 10^{17} eV the neutrino flux is expected to fade below detection thresholds even for future giant detectors.

From the photomultiplier positions, the arrival time of the light (measured to nanosecond precision) and the signal amplitudes, the direction and energy of the incoming neutrino are reconstructed. The achievable resolutions depend on the reaction type: charged-current reactions of muon neutrinos[1], $\nu_\mu N \to \mu X$, produce high-energy muons with a range of up to several kilometres in water or ice; the detection of these muons allows for a precise reconstruction of the neutrino direction[2] (resolution in water better than 0.3° for neutrino energies $E_\nu \gtrsim 10$ TeV) and an estimate of the neutrino energy accurate to within a factor of 2 for $E_\nu \gtrsim 1$ TeV. Due to the good angular resolution and the increased sensitivity resulting from the large muon range, neutrino telescopes are predominantly optimised for this reaction type. On the other hand, charged-current reactions of electron or tau neutrinos, $\nu_{e,\tau} N \to (e,\tau) X$, and neutral-current reactions, $\nu_x N \to \nu_x X$, produce hadronic and/or electromagnetic particle cascades (*showers*) which act as localised sources of intense Čerenkov light. Such reactions occurring inside the instrumented volume allow for a rather precise measurement of the shower energy, with an angular resolution degraded to several degrees in water, and even worse in ice.

In order to shield the experiments against background daylight and muons originating from cosmic ray interactions in the upward-hemisphere atmosphere (*atmospheric muons*), they are located at a depth of several kilometres. Yet, for most of the abovementioned energy range the atmospheric muon background is prohibitive for observing neutrinos arriving from above. Therefore, the field of view of neutrino telescopes is the downward hemisphere; observing the Southern sky including the Galactic Centre hence requires an experiment in the Earth's Northern hemisphere. A comparison of the fields of view from the South Pole and the Mediterranean Sea is shown in Fig. 1. At highest energies beyond roughly 10^{15} eV the atmospheric muon flux fades away and the view opens to the upper hemisphere; at the same time, the downward view becomes obscured by the fact that, due to the increase of the neutrino cross section with energy, the Earth becomes opaque even for neutrinos.

1.2. General conditions in sea water

The major challenges in constructing deep-sea neutrino telescopes are the high pressure of several 100 bar; the uncontrollable environment with currents, sedimentation and background

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[1] In the following, the term *neutrino* is generically used to denote both neutrinos and antineutrinos.

[2] When referring to angular resolution in the following, this event type is assumed.