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Recent results from the Antares underwater neutrino telescope

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Summary. — ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) is the largest neutrino telescope in the Northern Hemisphere, operative in the Mediterranean Sea in its complete set-up since 2008. The detection principle is based on the collection of Cherenkov light induced in sea water as a consequence of the passage of ultra-relativistic particles produced in neutrino interactions with matter. The main scientific goals of the experiment are the search for point-like sources of cosmic neutrinos, the measurement of the diffuse flux, the indirect search for dark matter and multi-messenger astronomy. Some of these topics will be presented here and preliminary results will be discussed.

PACS 95.85.Ry – Neutrino, muon, pion, and other elementary particles; cosmic rays.
PACS 29.40.Ka – Cherenkov detectors.
PACS 96.50.S- – Cosmic rays.

1. – Introduction

Neutrino astronomy. – Neutrino astronomy is a very promising field of investigation in the multi-messenger approach of the astrophysical research [1, 2]. Because of their peculiar interaction properties (as neutral weakly interacting particles, they are not absorbed nor deflected by magnetic fields during propagation) neutrinos not only can provide additional information to complete the picture produced by all-wavelength photon astronomy, they can also offer unique opportunities to look further away and deeper inside astrophysical objects. Possible impacts of neutrino astronomy include astrophysics (nature and behaviour of cosmic engines and explosive events in the Universe), particle physics (acceleration mechanisms, interaction cross section above the threshold that can be explored with particle accelerators, neutrino oscillations, hints of new physics beyond the standard model) and cosmology (top-down models of ultra-high-energy particle generation, dark matter, cosmic neutrino background) [3].

The challenge of neutrino detection. – The fact that neutrinos are weakly interacting is, at the same time, a great opportunity for discovery and a hard challenge for detection. A very massive detector is required to offer a significant target for neutrino interactions; in

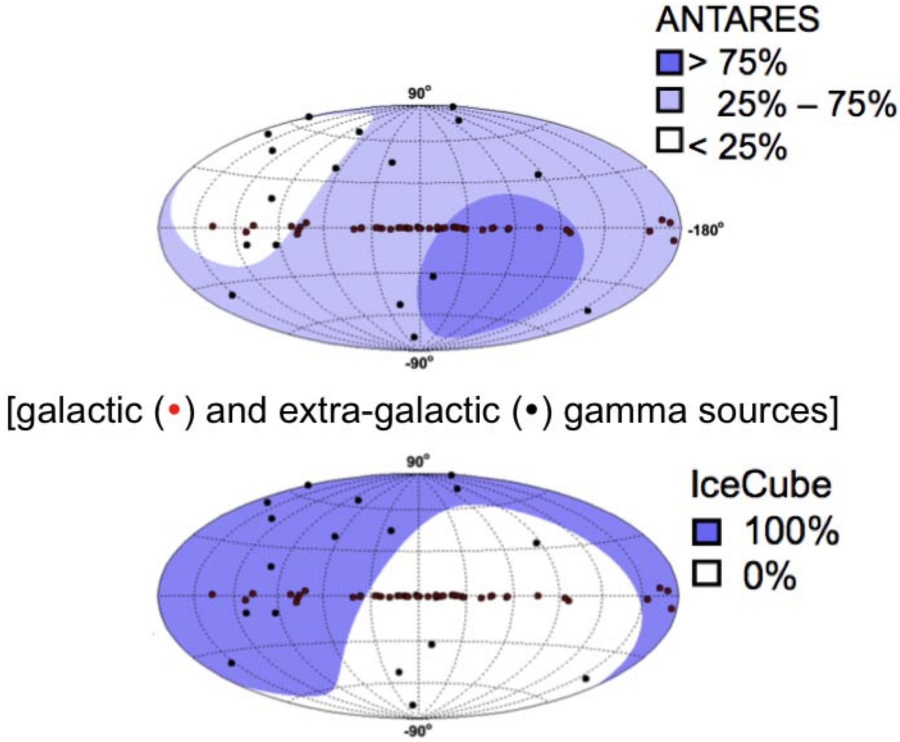

Fig. 1. – Sky coverage in Galactic coordinates for a detector located in the Mediterranean Sea (ANTARES) and at the South Pole (IceCube) with a 2π downward exposure. The percentage in the box indicates the visibility. The figure points out the complementarity of the two installations. In addition, a telescope in the Mediterranean Sea assures a good coverage of the Galactic Center. Dots indicate the position of gamma sources, potential neutrino emitters.

addition, detector surface has to be large in order to collect the largest number of events, since the predicted flux of cosmic neutrinos is very low and decreases with increasing neutrino energy (expected event rate at $E_\nu = 10^5$ GeV is some tens in a year on a surface of $1\,\mathrm{km}^2$) [4]. Therefore, a "traditional" laboratory (a detector built inside a closed place) has to be ruled out and a natural target is required. A straightforward choice is considering submarine apparata (or, alternatively, in-ice apparata), so that the oceanic mass can work, at the same time, as the target for neutrino interactions, the medium for signal transmission and the shielding for reduction of the atmospheric muon flux. This is a key point, since atmospheric muons (*i.e.* muons produced as secondaries in interactions of cosmic rays with the atmosphere) are the main source of background for neutrino telescopes. To prevent atmospheric muon contamination, an optimal installation site is at large depth; in addition, a further background reduction is gained rejecting down-going events. As a consequence, the visibility of a telescope in the Mediterranean Sea is the one reported in fig. 1, to be compared with the visibility of an apparatus located at the South Pole: a detector in the Northern hemisphere offers a perfect complementarity to the observations of the IceCube experiment [5].

Cherenkov detectors. – The detection principle is based on the collection of Cherenkov light emitted as a consequence of the propagation in water of ultra-relativistic (superluminal) charged particles produced in neutrino interactions. Cherenkov photons are detected through a three-dimensional grid of light collectors, or photo-multipliers tube (PMTs). The geometry of the emission is fixed by the refractive index of the medium: in sea-water, the Cherenkov angle is $\phi \sim 43°$; particle tracks are reconstructed from the measurement of the times of arrival of photons at the PMTs and of the PMT positions. Cherenkov telescopes are mainly tuned to detect muon tracks; once the direction of the muon track has been identified, pointing properties of the telescope are assured by the fact that, in relativistic neutrino interactions, the muon direction is almost collinear to the primary neutrino and therefore to the astrophysical source. For ANTARES, studies of the detector timing indicate a median angular resolution of $(0.5 \pm 0.1)°$.

2. – The ANTARES detector

ANTARES [6] is the first prototype of a Cherenkov telescope operating in the Mediterranean Sea. The detector, located at about 40 km offshore Toulon, France, and deployed at about 2500 m depth, consists of 12 detection lines, or *strings*, deployed according to an octagonal pattern on the seabed; the average distance between lines is about 70 m. A detection line consists of 25 storeys, each hosting 3 optical modules (OM) with the housing for the PMTs; the distance between storeys is 14.5 m. ANTARES has been completed in June 2008; data taking is on-going and data analysis is in progress, first results have been published. Additional details on the detector set-up, including information on the electronics of data acquisition and transmission, on the trigger algorithms and on the calibration, can be found in [7].

3. – Selected results

Search for point-like sources. – Possible neutrino emitters in the Universe are both galactic (supernova remnants, pulsar wind nebulae, microquasars) and extra-galactic (active galactic nuclei); a candidate source is any site in which there is an indication of cosmic ray acceleration, whose signature can be an emission of gamma rays. High-energy neutrinos are expected with gamma rays if the latter are produced according to an hadronic mechanism, to be compared with the alternative scenario of leptonic emission of photons [8]. The first ANTARES result on the search for point-like sources [9] includes data collected in the period 2007–2008, for a total integrated live time of 304 days. The analysis was carried out considering two approaches: a list of selected 24 candidate sources and a full-sky search. No cosmic neutrino sources were observed; the neutrino flux sensitivity obtained is $7.5 \times 10^{-8}(E_\nu/\text{GeV})^{-2}\,\text{GeV}^{-1}\,\text{s}^{-1}\,\text{cm}^{-2}$ for the part of the sky that is always visible ($\delta < 48°$) (fig. 2); the value is is the best limit in the Southern Sky.

Diffuse flux. – Cosmic neutrinos are expected to have an energy spectrum harder than atmospheric neutrinos; as a consequence, at high energy, astrophysical neutrinos should dominate over the atmospheric background. The analysis requires the study of an energy estimator for the measurement of the spectrum of collected events. Results published in [10] are obtained considering a total equivalent live time of 334 days and a $(0.83\times 2\pi)$ sr sky monitor. Assuming an E^{-2} spectrum, a 90% CL upper limit on the diffuse flux ϕ of ν_μ in the energy range 20 TeV–2.5 PeV is obtained, $E^2\phi_{90\%} = 5.3\times 10^{-8}\,\text{GeV}\,\text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}$. Results are compared with theoretical expectations and outcomes from other experiments (fig. 3).

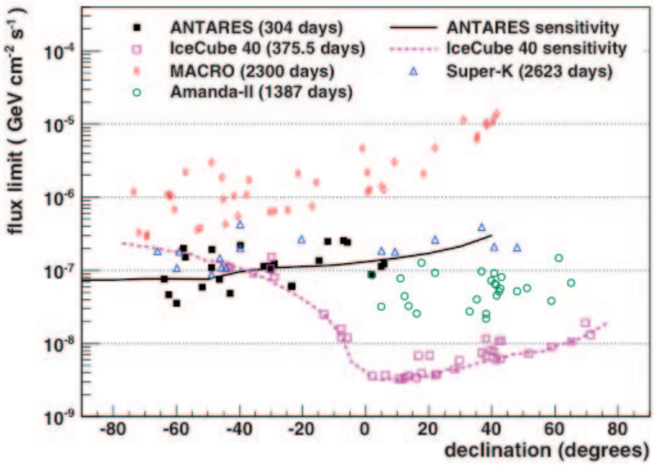

Fig. 2. – Limits on the neutrino flux are computed assuming an E^{-2} spectrum for the signal. The points show the 90% CL limit at the declination of the candidate source (from [9]).

Multi-messenger astronomy. – One of the most promising class of studies in the analysis target of ANTARES is the set of multi-messenger searches. The basic assumption is that violent phenomena, candidate as neutrino emitters, are potential source of other astrophysical "messengers" or "probes", as optical photons, gamma rays, cosmic rays and gravitation waves. The multi-messenger approach can increase the discovery potential, by observing the same object or the same phenomenon with different probes. Moreover, the statistical significance of the observations can be improved by coincident

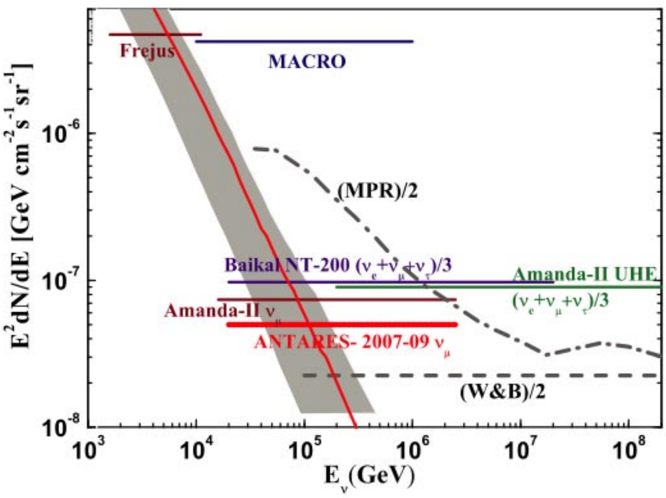

Fig. 3. – The grey band represents the expected spectrum of the atmospheric ν_{mu} flux, including fluctuations on the models and the "prompt" contribution. Dashed lines identify theoretical expectations.

detection (sustained by the developing of alert systems between the experiments) and the efficiency of the detection can be refined profiting of relaxed cuts. Currently, several project are ongoing in ANTARES. The TAToO project (Telescopes and ANTARES Target of Opportunity) [11] is an alert system implemented with a fast on-line muon track reconstruction; the system is used to trigger a network of small automatic optical telescopes, for coincident observations of the optical counterpart of transient emitters, such as gamma ray bursts, core collapse supernovae and flaring active galactic nuclei. Data analysis is in progress. The study of flaring blazars is carried out also considering possible coincidences with high-activity periods of photon emission registered by gamma ray experiments. Preliminary results obtained with a restricted data sample have been submitted for publication [12]. Other studies searched for correlations with cosmic rays and with gravitational waves. The first analysis has considered the arrival direction of neutrino candidates detected by the ANTARES telescope and ultra-high-energy cosmic rays observed by the Pierre Auger Observatory [13]. The correlation with gravitational waves, in which ANTARES events trigger gravitational data in search for bursts, has been discussed in [14].

4. – Conclusions and perspectives

ANTARES is the most advanced project of a neutrino telescope in the Mediterranean Sea. Scientific achievements accomplished by the ANTARES collaboration have already produced significant scientific results, providing a very profitable step for the future cubic-scale experiment in the Mediterranea Sea [15], in which Italian resources and INFN will play a key role.

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