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Recent Results of the ANTARES Neutrino Telescope

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Abstract

The discovery of cosmic neutrinos of astrophysical origin by IceCube has started a new chapter in the field of Neutrino Astronomy. Noticeably, a small accumulation of events in the region near the Galactic Centre has been observed: a telescope in the Mediterranean Sea constitutes a great opportunity for the physics quest, since it offers a perfect complementarity to IceCube and, in particular, a better visibility of the Galactic Centre. ANTARES (Astronomy with a Neutrino Telescope and Abyss Environmental RESearch) is the first operational Cherenkov neutrino telescope in the Mediterranean Sea and the largest neutrino detector in the Northern hemisphere, covering an area of about 0.1 km^2; located 40 km offshore Toulon, France, at a depth of 2475 m, it has been completed in June 2008 and it is currently taking data. It consists of a tri-dimensional array of 885 photo-multipliers tubes (PMTs), distributed in 12 lines. ANTARES has recently performed a search for an excess of high energy neutrinos in the direction of the Galactic Centre, close to the accumulation of the IceCube events, assuming both the hypotheses of a point-like and an extended neutrino source. The results of this search will be discussed in this contribution, together with other recent achievements of the experiment, as the search for point-like sources, the results on the diffuse flux of cosmic neutrino signal and the search for neutrino emission from the Fermi bubbles. ANTARES offers a first view of the Neutrino Sky from the Northern hemisphere; its successful operation and its promising results make more compelling the expectations for KM3NeT, the next generation neutrino experiment in the Mediterranean Sea.

Keywords: Neutrino Astronomy, Neutrino Telescopes, Cherenkov Detectors, Cosmic Rays, Galactic Centre

1. Introduction

Neutrino astronomy is a field of investigation of the astrophysical research that uses cosmic neutrinos as probes of astrophysical processes in the Universe. Indeed, as neutral weakly interacting particles, neutrinos are not absorbed during propagation nor deflected by magnetic fields. Retaining the directional information, they offer excellent pointing capabilities; travelling unperturbed, they have the potential for looking further away at cosmological distances, and deeper inside into astrophysical objects opaque to photons and protons.

Several astrophysical models predict the emission of high-energy and ultra-high-energy ($E_\nu < 10^5$ GeV) neutrinos. Neutrino fluxes are expected from cosmic accelerators in which particles are trapped by magnetic fields and gain energy in shock fronts ("bottom-up") via the so-called *Fermi mechanism* [1]. If hadrons are present (i.e. the astrophysical site is a source of cosmic rays), they can interact with matter and radiation in the source and produce neutral and charged pions. The pion decay gives gamma-rays and neutrinos and the flux predictions for neutrinos can be computed given

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the observations of the gamma-ray spectra. The conditions for particle acceleration can be realized in several classes of astrophysical objects, that are thus included in the list of candidate neutrino sources [2]. Among them, Supernovae Remnants (SNRs) are the most accredited steady sources in the Galaxy; Micro-Quasars are taken into account as galactic flaring emitters; Active Galactic Nuclei (AGNs) are expected as the most important extragalactic sources of cosmic rays and neutrinos; Gamma Ray Burst (GRBs) are the most powerful explosive events in the Universe and can be associated with neutrino emissions. In addition, cosmic neutrinos are a key ingredient also in Cosmology: high-energy neutrinos are predicted in so-called top-down models that have neutrinos at the end of a variety of decay chains of standard (and beyond the standard) model particles. The most important class of models of this kind regards dark matter, and neutrinos in the $GeV \div TeV$ range are expected in the self-annihilation of the hypothetical weakly interacting massive particles. See [3] for a discussion of the latest results of the ANTARES neutrino telescope in the indirect search for dark matter.

Neutrino astronomy aims at identifying cosmic neutrino sources in the Sky, providing a map with neutrino "hot spots". Such locations, if confirmed (and unambiguous identification can profit from the multi-messenger approach), will offer a crucial contribution in astrophysics, for the understanding of the nature and behaviour of cosmic engines and of explosive events in the Universe. The discovery of neutrino sources can also help in discriminating between different acceleration mechanisms (hadronic *versus* leptonic) and can solve the puzzle of the origin (sites of production and acceleration) of cosmic rays. Other impacts of neutrino astronomy include cosmology and particle physics (interaction cross section above the threshold that can be explored with particle accelerators; neutrino oscillations; hints of new physics beyond the standard model).

Weak interaction is a great opportunity for discovery, but also a challenge for detection. A cubic-kilometre scale detector is required, to offer a significant target for neutrino interactions and to collect a valid statistics of events (expected event rate at $E_\nu = 10^5$ GeV is some tens in a year on a surface of 1 km^2). To fulfil the requirements, neutrino telescopes are submarine or in-ice apparata: the oceanic mass operates, at the same time, as the target for neutrino interactions, the medium for signal generation and transmission and the shielding for the reduction of the background of atmospheric muon flux. Water and ice are indeed an effective medium for Cherenkov technique: the detection principle is based on the measurement of Cherenkov light emitted as a consequence of the propagation in water of ultra-relativistic (super-luminal) charged particles produced in neutrino interactions. Cherenkov photons are detected with 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; particle tracks are reconstructed from the measurement of the times of arrival of photons at the PMTs; the energy in estimated from the collected charge. Muon tracks are the result of charge-current interactions of muon neutrinos; particle showers originate in charged-current interactions of electron and tau neutrinos and in all-flavour neutral-current interactions. The evaluation of the neutrino direction is more accurate if muon tracks are reconstructed; on the other hand, the energy estimate is more precise for shower events. 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. An irreducible and isotropic source of background is given by atmospheric neutrinos; the discrimination of the potential signal is performed using statistical arguments (looking for excesses or event above the expected background level) and isolating an high-energy component in the sample of neutrino candidates. Indeed, the atmospheric flux is expected to fade away at energies larger than $E_\nu = 10^6$ GeV; at about the same energies, because of the increase of the neutrino cross section with energy, the Earth becomes opaque to up-going neutrinos and the sky above the detector becomes visible.
The latest IceCube results [4][5] have started a new era in Neutrino Astronomy. The IceCube experiment, deployed in-ice in Antarctica, has announced the observation of several tens of high-energy neutrino events with energy spectrum harder than any expected atmospheric background, so that any association with the atmospheric neutrino flux can be excluded. The measured event sample is compatible with an isotropic neutrino flux (diffuse flux), meaning that no statistically significant cluster has been found, and thus no candidate point source of neutrinos can be claimed so far.

2. The ANTARES Detector

ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) [6], deployed in the Mediterranean Sea, is the largest neutrino telescope in operation in the Northern hemisphere. The detector