Recent results of the ANTARES neutrino telescope

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Abstract. ANTARES, the first neutrino telescope deployed under the sea and the largest in the Northern Hemisphere, started to take data in 2007. Its main goal is the detection of high energy neutrinos coming from cosmic sources, but other studies, such as the search for WIMPs, monopoles or nuclearites, are also possible. We present here some of the latest results from the ANTARES neutrino telescope.

1. The ANTARES Neutrino Telescope

Several astrophysical objects both Galactic and extra-galactic have been proposed as sites of acceleration of protons and nuclei, but no conclusive experimental evidence has been obtained yet. The decays of mesons produced by the interactions of protons and nuclei with matter or radiation would yield neutrinos, thus indicating the presence of hadronic acceleration. The detection of high energy cosmic neutrinos can therefore shed light on the origin of cosmic rays. Several neutrino telescopes based on the detection of muons through Cherenkov light are at present operating worldwide.

The ANTARES Collaboration completed the construction of a neutrino telescope in the Mediterranean Sea in May 2008, although a partial version of the device was operating since 2007. The telescope, located 40 km off the Southern coast of France (42°48'N, 6°10'E) at a depth of 2475 m, consists in a three-dimensional array of photomultipliers housed in glass spheres, called optical modules, distributed along twelve lines anchored to the sea bottom and kept taut by a buoy at the top. Each line is composed of 25 storeys of triplets of optical modules, each housing one 10-inch photomultiplier. The lines are subject to the sea currents and can change shape and orientation. A positioning system based on hydrophones, compasses and tiltmeters is used to monitor the detector geometry with an accuracy of about 10 cm. More details of the ANTARES telescope can be found in [1].

Muons induce the emission of Cherenkov light in sea water. The arrival time and intensity of the Cherenkov light on the OMs are digitized into hits and transmitted to shore. Events containing muons are selected from the continuous deep sea optical backgrounds due to natural radioactivity and bioluminescence. The arrival time of the Cherenkov photons can be determined at the nanosecond level [2], allowing the determination of the direction of upgoing tracks with resolutions better than 0.5°.

The main goal of the experiment is to search for high energy neutrinos with energies greater than 100 GeV by detecting muons produced in neutrino charged current interactiona taking place in the vicinity of the detector. Due to the large background from downgoing atmospheric muons, the telescope is optimized for the detection of upgoing muons that can only originate from neutrinos.
2. Search for point sources

A search for point sources has been carried out using the data taken by ANTARES from 2007 to 2010. Data runs were selected requiring that most of the detector was operating and that the optical background from bioluminiscence was low in terms of the baseline rate and burst fraction. The final data sample amounted to a total of 813 live days. Only events with upgoing muons were kept for further analysis, requiring in addition that the corresponding track had a good reconstruction quality and an estimated angular error lower than 1°. The cut in quality was chosen so as to optimize the discovery potential. A total of 3058 events were selected. According to Monte Carlo simulations around 15% of them were atmospheric muons wrongly reconstructed as upgoing tracks.

Clusters of events with a significance above that expected from background fluctuations were looked for with a likelihood ratio method. The likelihood used the distribution in declination of the atmospheric background obtained scrambling the data in right ascension and an angular resolution of $(0.46 \pm 0.15)^\circ$, as given by Monte Carlo simulation. The full sky was searched for possible sources and then a list of 51 pre-selected directions in the sky corresponding to possible astrophysical neutrino sources were scrutinized. No significant excess was found in either case. An alternative search method [3] was used as a cross-check obtaining similar results. The post-trial p-value of the most significant cluster (at $\alpha = -46.5^\circ$ and $\delta = -65.0^\circ$) was 2.5% for the full sky search –a value not significant enough to claim a signal–, whilst the most significant source of the predefined list (HESS J1023-575) was fully compatible with a background fluctuation ($p=41\%$). The corresponding limits for neutrino sources emitting with an $E^{-2}$ energy spectrum are given in Figure 1, together with limits from other experiments [4]. As can be seen, our results are at present the more stringent for the Southern Sky, except for the case of the IceCube detector for which in this hemisphere very high energy neutrinos are looked for ($E > 1$ PeV). Our present limit is 2.5 times better than our previous publish result [5].

![Figure 1](image-url)  

**Figure 1.** 90% CL upper limits for a neutrino flux with an $E^{-2}$ spectrum for 51 candidates sources (blue points) and the corresponding sensitivity (dashed blue curve). Results from the MACRO, Amanda II, Super Kamiokande and IceCube telescopes [4] are also shown.

3. Multimessenger searches

The search of neutrinos in coincidence with other messengers has several advantages. Sources already known to have high-energy emission, e.g. gamma-rays, can be investigated, increasing
the chance to observe sites of hadronic acceleration. In addition, the restriction of the search to limited time windows and sky directions highly reduces the atmospheric neutrino background and therefore increases the sensitivity to possible signals, so that a handful of events can be enough to claim a signal. In the case of neutrino events coincident with gravitational waves, the same astrophysical phenomena are expected to produce both types of signals. We give below a couple of examples of this multimessenger program in ANTARES, which is too broad to be fully reported here.

A selection of flares from blazars observed by the LAT detector of the Fermi satellite during 2008 was carried out and the data taken by ANTARES in the same period investigated for neutrino coincidences with the flaring period of the blazars [6]. The selected blazars are shown in Table 1 together with the number of events required to claim a 5σ signal. Only one event —during a flare of 3C279— was detected. The post-trial p-value of such a coincidence is 10%, that is compatible with a background fluctuation. The 90% CL limits on the neutrino fluence from these blazars are given in Table 1.

| Source       | N(5σ) | Fluence | Source       | N(5σ) | Fluence |
|--------------|-------|---------|--------------|-------|---------|
| PKS0208-512  | 4.5   | 2.8     | AO0235+164   | 4.3   | 18.7    |
| PKS1510-089  | 3.8   | 2.8     | 3C273        | 2.5   | 1.1     |
| 3C279        | 5.0   | 8.2     | 3C454.3      | 4.4   | 23.5    |
| OJ287        | 3.9   | 3.4     | PKS0454-234  | 3.3   | 2.9     |
| WComae       | 3.8   | 3.6     | PKS2155-304  | 3.7   | 1.6     |

Table 1. List of blazars for which neutrinos were looked for in coincidence with their flares. $N(5\sigma)$ is the average number of events required for a 5σ discovery (50% probability) and Fluence is the upper limit (90% CL) on the neutrino fluence in GeV·cm$^{-2}$.

Several models predict the production of high energy neutrinos during gamma-ray bursts. As in the previous analysis, restricting the search to a short time window sizeably reduces the atmospheric background so that only a few events would be enough to claim a discovery. Using the 2007 ANTARES data, a search for neutrinos coming from 37 GRBs events was performed. No neutrino event was found in the corresponding time windows and within the defined search cone around each source. An overall limit of $E^{-2}\Phi_\nu < 1.8 \times 10^{-3}$ GeV cm$^{-2}$ s$^{-1}$ has been set.

4. Search for exotic particles

ANTARES could detect a variety of hypothetical particles thanks to its sensitivity to light emission. Under certain conditions monopoles would leave an extremely conspicuous signal in ANTARES. The existence of monopoles has been put forward in the context of several theories. Presently, there is no clear evidence of their existence and several limits have been set on the flux of monopoles crossing the Earth. Magnetic charges crossing the sea water at a speed larger than their Cherenkov threshold ($\beta > 0.74$ in water) would produce a huge amount of light. For one unit of magnetic charge this radiation would be 8550 times larger than that of a muon. Moreover, even below the threshold the ionization electrons produced by the monopole would also radiate a large amount of light.

Using the data taken by ANTARES during 2007 and 2008, a search for magnetic monopoles has been performed based on the number of hits and the reconstructed velocity of the tracks. The selection criteria were optimized for discovery in eight velocity intervals in the region 0.625 ≤ $\beta$ ≤ 0.995. Only one candidate was found, compatible with the total expected background. In Figure 2 the 90% CL upper limit on the flux of upgoing monopoles obtained is shown [7]. As can be seen, this limit is more stringent than the previous existing limits [8].
A search for nuclearites, massive aggregates of up, down and strange quarks, has also been performed. Nuclearites would produce in water a thermal shock wave emitting a large amount of radiation at visible wavelengths. No clear indication of nuclearites was observed using the 2007-2008 data sample and a 90% CL upper limit of $10^{-16}$ cm$^{-2}$ sr$^{-1}$ s$^{-1}$ for a flux of nuclearites with masses between $10^{-14}$ and $10^{-17}$ GeV was establish.

5. Summary
Although no signal of cosmic neutrinos has been detected yet, the results of the search for point sources indicates that the ANTARES telescope has reached the expected performances, in particular an angular resolution better than 0.5$^\circ$. Its sensitivity is at present the best for neutrino sources in the 100 GeV to 100 TeV energy range in the Southern Sky. The limits reported here on neutrino point sources in the Southern Sky and on monopoles and nuclearites are the most stringent up to date.

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