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Search for diffuse fluxes of cosmic neutrinos with the ANTARES telescope

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Summary. — The ANTARES neutrino telecope is the largest operating underwater telescope. Searches for high-energy cosmic sources of neutrinos have been conducted looking at data collected from 2007 to 2013. Good sensitivity is reached in searching for diffuse fluxes of cosmic neutrinos, both in all sky and in defined regions. The most recent results of these searches are reported in this contribution.

1. – Introduction

Neutrinos are predicted to be produced nearby the expected Cosmic Rays (CR) accelerators, such as Supernova Remnants, Active Galactic Nuclei or Gamma Ray Bursts. A diffuse flux of cosmic neutrinos is expected from unresolved individual sources. The energy spectrum of these neutrinos should be similar to that of primary CRs, produced by Fermi shock acceleration, and flatter than the observed atmospheric neutrino background.

The IceCube Collaboration has recently reported [1] the observation of a diffuse, all flavour excess of high energy neutrinos, not compatible with atmospheric expectations. This observation has opened the path to high-energy neutrino astronomy. The ANTARES detector [2] is currently the largest neutrino telescope in the Northern Hemisphere, located at a depth of 2475 m in the Mediterranean Sea, 40 km from Toulon, France, and continuously operated since 2007. It consists of almost 900 photomultiplier tubes (PMT), distributed on 12 vertical strings anchored to the sea bed. It detects neutrinos using the Cherenkov light emitted by particles produced after neutrino interactions in the surroundings of the detector. Good pointing accuracy is achieved in reconstructing the arrival direction of the neutrino [3-5].

2. – Full sky searches

An update of the analysis on diffuse ν_μ fluxes reported in [6], extending the data sample until 2011 has been done. The equivalent livetime is 885 days, about a factor three larger than the previous analysis. Upgoing events are selected and the quality parameter

Λ from the track reconstruction algorithm together with the angular error estimation β are used to reject wrongly reconstructed atmospheric muons [3]. Atmospheric neutrinos are rejected by applying an energy-related cut, based on the estimation of the muon energy loss in the detector [7]. The optimal cut on this variable is chosen through a Model Rejection Factor (MRF) procedure [8], determining the best sensitivity flux $E^2\hat{\Phi}^{90\%}_{track} = 4.7 \cdot 10^{-8}\,\text{GeV cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$. After all cuts 8.4 events are expected from the background and 1.4 events should be observed from the [1] signal. The central 90% of the expected signal after cuts corresponds to an energy range from 45 TeV to 10 PeV. After unblinding 8 events are found in data. Using the method from [9] the upper limit at 90% confidence level is $E^2\Phi^{90\%}_{track} = 5.1 \cdot 10^{-8}\,\text{GeV cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$. The error on the normalisation of the atmospheric neutrino flux measurement [7] with respect to the Bartol flux [10] is take as systematic error on the background. Systematics on the signal are evaluated by varying water properties, PMT efficiency and angular acceptance in the simulation.

An all flavour analysis for cascade events [11] is also performed. A vertex likelihood fit, followed by an energy and direction fit is performed with a reconstruction algorithm. This leads to an energy resolution of 0.2–0.3 for the $\log_{10} E_{shower}$ and a median angular resolution of 6° in the hundred TeV region. Improved angular resolution is achieved with a more sophisticated reconstruction technique [5]. The analysis collects all data from 2007 to 2012, with a total livetime of 1247 days. An event pre-selection is done using a cut on the vertex log-likelihood and requiring signal hits to be present on at least three detector lines. This selection significantly reduces the contribution from track events, including atmospheric muon background. The MRF optimisation is done on the fitted shower energy and zenith. The optimal cut is found to be $E_{shower} > 10\,\text{TeV}$ and $\theta > 94°$, leading to a sensitivity with $E^2\hat{\Phi}^{90\%}_{showers} = 2.2^{+0.9}_{-0.7} \cdot 10^{-8}\,\text{GeV cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$. 5 ± 3 background events are expected, and the IceCube flux would correspond to $2.1^{+0.5}_{-0.7}$ cosmic events added to the atmospheric expectations. 8 events are observed in data after unblinding. The excess over background has a significance of 1.5σ. Considering an E^{-2} spectrum, the 90% C.L. upper limit on the cosmic neutrino diffuse flux is $E^2\Phi^{90\%}_{showers} = 4.9 \cdot 10^{-8}\,\text{GeV cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$, including systematics on signal and background. The validity energy range for this limit is 23 TeV–7.8 PeV.

3. – Special regions

Fermi/LAT data [12] have revealed the presence of two large γ ray emission regions above and below the Galactic plane. If hadronic mechanisms are responsible for the production of such a signal, diffuse neutrino emissions are expected from these regions with various possible energy cut-offs, from few to some hundreds of TeV [13].

Data collected in the ν_μ CC channel with the ANTARES telescope from 2007 to 2011 are considered in the analysis [14]. Event selection, based of the MRF procedure, involves the quality of upgoing reconstructed tracks and the energy estimation through an Artificial Neural Network (ANN) [15]. The final selection cut is $\Lambda > -5.14$ and $E_{ANN} > 11\,\text{TeV}$, when optimising for the sensitivity to a neutrino flux with a cut-off at 100 TeV. After the unblinding of the on-zone, 16 events are observed, while 11 are expected, on average, from the off-zones. The significance of this excess can be estimated, following the prescription of [16], as 1.2σ and upper limits are calculated. A further analysis with two additional years of data is reported in [17]. Preliminary results report an excess over the background with a significance of 1.9σ.

A diffuse neutrino flux is expected from the decays of charged mesons produced in CR interactions in the interstellar medium in the Galactic Plane. The corresponding emission from neutral mesons is clearly visible in γ ray observation of the sky [18]. Different models for the neutrino flux coming from CR propagation are proposed, each leading to different expectations. Broken power law spectra with spectral index $\Gamma = 2.4$–2.5 can describe these behaviours. The same MRF optimisation was produced, leading to a sensitivity (per flavour) $E^{2.4(2.5)}\Phi_{gal}^{90\%} = 2.0(6.0) \cdot 10^{-5}\,\mathrm{GeV\ cm^{-2}s^{-1}sr^{-1}}$ in the energy range 3–300 TeV. No significant excess is observed in data and the corresponding upper limit is equal to the sensitivity [19].

4. – Conclusions

The ANTARES neutrino telescope is in its 7th year of operation. Despite its moderate size it yields good diffuse flux sensitivity in the relevant range and the best limits for the Galactic Plane and the Fermi bubble regions thanks to its location and good event reconstruction performances. A joint track and shower analyses is being performed, improving the overall sensitivity of the telescope [20]. The next generation KM3NeT neutrino telescope will eventually further improve the results for diffuse flux sensitivities [21].

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