SF2A 2009
M. Heydari-Malayeri, C. Reylé and R. Samadi (eds)

SEARCH FOR NEUTRINOS FROM TRANSIENT SOURCES WITH THE ANTARES TELESCOPE AND OPTICAL FOLLOW-UP OBSERVATIONS

Al Samarai, I.[1], Dornic, D.[1], Basa, S.[2], Brunner, J.[1], Busto, J.[1], Boer, M.[3], Klotz, A.[3,4], Escoffier, S.[1], Gendre, B.[2], Le Van Suu, A.[3], Mazure, A.[2], Atteia, J.L.[5] and Vallage, B.[6]

Abstract. The ANTARES telescope has the opportunity to detect transient neutrino sources, such as gamma-ray bursts, core-collapse supernovae, flares of active galactic nuclei... To enhance the sensitivity to these sources, we have developed a new detection method based on the optical follow-up of golden neutrino events such as neutrino doublets coincident in time and space or single neutrinos of very high energy. The ANTARES Collaboration has therefore developed a very fast on-line reconstruction with a good angular resolution. These characteristics allow to trigger an optical telescope network; since February 2009, ANTARES is sending alert trigger one or two times per month to the two 25 cm robotic telescope of TAROT. This optical follow-up of such special events would not only give access to the nature of the sources but also improves the sensitivity for transient neutrino sources.

1 Introduction

The ANTARES neutrino telescope is located 40 km offshore Toulon in France at 2500 m depth in the Mediterranean sea. The Detector is a three dimensional net of 900 OMs (Optical Modules) distributed on 12 lines over 25 floors (storeys) per line. Each OM is a glass sphere housing the photomultiplier and its electronics. The goal of the experiment is to detect high energy muons induced by the interaction of cosmic neutrinos with the matter surrounding the detector. When the neutrino induced-muon goes through the detector or by its vicinity, a Cherenkov light cone is emitted along its track which is detected by the photomultipliers. The detection of such neutrinos would be the only direct proof of hadronic acceleration in cosmic rays and so, allows the identification of ultra high cosmic ray acceleration sources or even their discovery without ambiguity.

2 The Rolling Search

2.1 *Principle and advantages*

Originally proposed by Kowalski & Mohr, the principle is based on the detection of either a neutrino burst (doublet, triplet or more) coming from the same direction within a defined time window or the detection of a single high energy neutrino event by requiring that its energy is higher than a certain threshold (typically higher than few tens of TeV if a Waxman−Bahcall flux is considered). This should reduce significantly the atmospheric neutrino background (Dornic et al. 2008). In contrary to searches triggered by satellite detections which are limited by the satellites field of view (e.g. SWIFT field of view is 1.4 sr), this detection can cover instantaniously a whole hemisphere. More important, no assumption can be made on the nature of the source or on its mechanisms. Therefore, it is necessary to complement it by a follow up detection using other messengers than neutrinos. This follow up can be done by X-ray satellites, optical satellites or even radio for Gamma Ray Bursts.

[1] CPPM, Faculte des Sciences de Luminy, 163 avenue de Luminy, 13288 Marseille Cedex09, France
[2] LAM, BP8, Traverse du Siphon, 133376 Marseille Cedex 12, France
[3] OHP, 04870 Saint Michel L'Observatoire, France
[4] CESR, Observatoire Midi-Pyrénées, CNRS, Université de Toulouse, BP 4346, 31028 Toulouse Cedex 04, France
[5] LATT, Observatoire Midi-Pyrénées, CNRS, Université de Toulouse, 14 avenue E. Berlin, 31400 Toulouse, France
[6] CEA-IRFU, centre de Saclay, 91191 Gif-Sur-Yvette, France

2.2 Candidate sources

Gamma-Ray Bursts are probably the most energetic explosions in the Universe releasing more than $\sim 10^{51}$ ergs on time scales of seconds. These highly energetic jets make GRBs the most promising sources for cosmic rays acceleration. Being extremely relativistic ($\Gamma \sim 100$), protons are accelerated to high energies and interact with ambient prompt photons producing pions and kaons, which in their decay produce neutrinos (Guetta et al. 2003). Neutrinos are emitted with energies ranging from few tens of TeV to EeV and are expected to be contemporaneous with the gamma ray emission. After the gamma prompt emission and the expected neutrino signal emanating from GRBs, an afterglow at longer wavelengths can be detected ranging from X-rays to radio and lasting from seconds to few days after the explosion.

Long gamma-ray bursts have been found to be tightly connected with core-collapse supernovae (Hjorth et al. 2003) but few core-collapse SNe might have mildly relativistic jets (∼1%). In contrary to those expected to give birth to GRBs, these jets have a bulk Lorentz factor of a few ($\Gamma \sim 3$) which is insufficient for the jet to go through the progenitor outer layers. Nevertheless, neutrinos could be produced as protons can still be accelerated in such conditions. Hence, neutrinos are the only prompt emission which can be detected from these gamma-hidden sources (Ando & Beacom 2005). Using the mildly relativistic jet model from Paper I, the total expected neutrino flux from one core collapse supernova situated at 10 Mpc in ANTARES is presented in Fig. 1. The neutrino flux issued from pion decay and kaon decay are shown separately. A neutrino energy cut off at 20 TeV related to the cooling break energy of the parent meson and the parameters choice used in the model was applied as suggested in Paper I. ANTARES is sensitive to energies above 100 GeV. As a consequence, neutrinos from kaon decay are more likely to be detected by ANTARES.

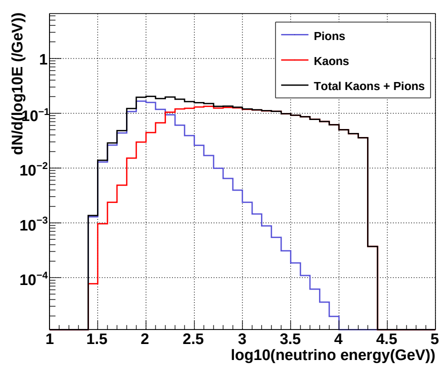

Fig. 1. Neutrino event spectrum in ANTARES from pion and kaon decay in the mildly relativistic jet model of Ando and Beacom for a core collapse supernova at 10 Mpc

3 ANTARES Neutrino alerts

Since the beginning of 2008, ANTARES has implemented an on-line event reconstruction. The trigger is based on local clusters of photomultiplier hits. Since this reconstruction was intended to work on-line, it takes 5 to 10 ms per event and has an acceptable angular resolution. The minimal condition for an event to be reconstructed is to contain a minimum of six storeys triggered on at least two lines. To select a background free sample of up-going neutrino candidates, a quality cut on χ^2 minimization based on the time and the charge of the muon track is applied. A key of success for the follow up procedure is a very fast event reconstruction so the dynamic reconstruction of the detector lines geometry is not used. As a consequence, the angular resolution is degraded comparing to the standard off-line reconstruction($0.2°$-$0.3°$) which includes the detector positioning. Hence, the off-line reconstruction will also be used afterwards to have the refined position of the emitted neutrino.

Two trigger types can actually induce an alert emission to the telescope. It could be a high energy event detection (around 10 TeV) or a detection of a burst of two or more neutrinos coming in $3° \times 3°$ angular window and 15 mn temporal window. The probability to have a high energy event in ANTARES is quite large since atmospheric neutrinos which might be very energetic account for an irreductable noise (around 1000 per year).

Doublets are expected to be detected around 5 10^{-3} per year, hence, their detection is almost significant. The detection of higher order multiplets are of course even more significant.

Currently, alerts sent to the telescope are caused mostly by highly energetic events selected with cuts on the number of touched floors and the amplitude of the hits. The selection is constrained by the fact that a reasonable number of one to two alerts per month should be sent to the telescope.

Fig. 2 represents the events distribution as a function of the touched floors used in the fit. With a cut on the number of touched floors greater than 19 and an amplitude greater than 150 photoelectrons, we are able to select 1.5 high energy events per month with a mean energy around 5 TeV calculated with the ANTARES 12 lines configuration. Furthermore, the angular resolution of the so selected events have to be lower than the telescope field of view (∼1° radius). Fig. 3 points out the improvement of the angular resolution after cuts for high energy events selection. A mean angular resolution of 0.8° for 5 TeV events mean energy is found with the on-line reconstruction.

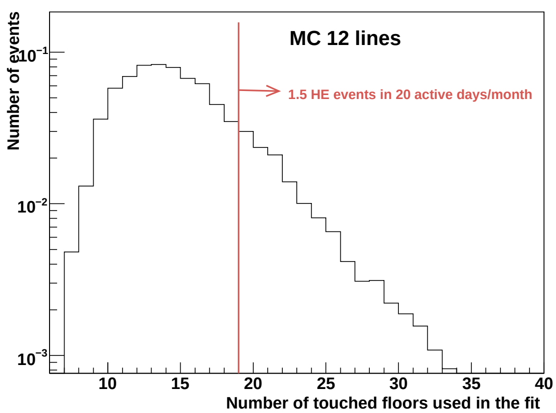

Fig. 2. Event distribution according to the number of touched floors used in the fit

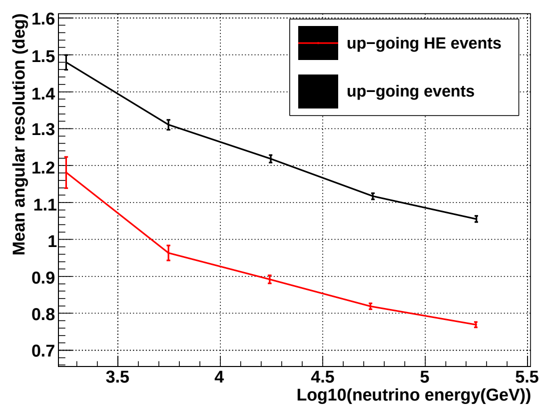

Fig. 3. Mean angular resolution as a function of the events mean energy

4 Optical Follow-up

TATοO is the project gathering ANTARES and TAROT telescopes for a follow up program. TAROT (*Télescope à Action Rapide pour les Objets Transitoires*, Rapid Action Telescope for Transient Objects; (Bringer, Boer et al. 1999)) is composed of two 25 cm robotic telescopes located at Calern in France and at La Silla in Chile. Its large field-of-view (1.86° × 1.86°) matches ideally the resolution of the ANTARES telescope. Moreover, its short repositionning time (around 10 seconds from the alert reception) is a great asset for the observation of the first moments after the neutrino signal.

The optical telescope observation strategy is of course specific to each detected object. While the optical afterglow from a GRB needs to be observed quite rapidly, core collapse supernovae can still be visible several days after the neutrino detection. For this reason, the observation strategy consists of a real time optical observation followed by others distributed over the month. Each observation involves six images of 3 minutes each.

5 Core collapse supernova detection in ANTARES

Considering the core collapse supernova jet model suggested in Paper I, we find that around 2 upward-going muon neutrino events coming from one core collapse supernova at 10 Mpc within 10 s should be expected. This rate is quite high, but for our particular triggers, this will be greatly reduced. In Fig. 4, one can see the distribution of the expected high energy neutrino events in ANTARES from one supernova as a function of its distance and the distribution of events with no conditions on energy which are multiplet candidates. Using a rate of core collapse supernovae of about 1 per year within a 10 Mpc sphere (Ando, Beacom, Yuksel 2005), one can calculate the number of detectable core collapse supernovae with our particular triggers.

The distance at which we obtain a maximal detection proability is around 4.5 Mpc for doublets comparing to 1.6 Mpc for high energy singlets. Poissonian fluctuations around the number of expected events was included leading to a large increase in the number of detectable supernovae, as one samples from a larger volume. The doublet trigger is more efficient for core collapse detection. In fact, when applying high energy conditions for singlets, the number of expected events is considerably reduced. Hence, high energy singlets are found to be less than doublets causing by this fact supernova-jet detection to be restricted within shorter distances. Furthermore, when using the model, a cut off energy around 20 TeV has been applied implying the rejection of highest energy events. The number of detectable supernovae within the distance of maximum detection probability is 2 10^{-3} per year for high energy singlets and 6 10^{-2} for doublets.

The rate of core collapse supernovae used is a lower limit. Indeed, the rate is expected to be 2 to 3 times higher as suggested in Paper II, especially for nearby galaxies (less than 4 Mpc) allowing a core collapse supernova detection within 5 years using the doublet trigger. This detection is not yet significant but the probability for a core collapse supernova detection with TAROT is not included. This should make the detection meaningful when considering the visibility volume and the efficiency of TAROT for supernova detection.

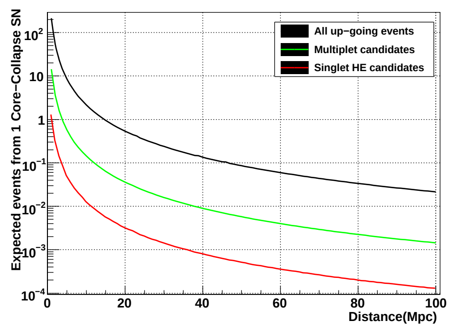

Fig. 4. Number of expected high energy events and candidate multiplet events in ANTARES from one core collapse supernova at 10 Mpc using Ando and Beacom supernova -jet model

6 Conclusion

TAToO is a transient sources search program using neutrino detection to trigger an optical telescope. At this time, two trigger types are used to send an alert to the telescope: the high energy singlets and the multiplet events. The angular resolution obtained with the on-line reconstruction can be reduced down to 0.2°-0.3° using the off-line reconstruction and hence the source direction can be refined after the alert sending. The on-line alert processing takes less than a minute for the direction to be sent to the telescope and can still be ameliorated. TAToO is now running efficiently and 8 alerts triggered by high energy events have already been sent successfully to the telescope. The image analysis is still in progress.

References

Kowalski, M. & Mohr, A. 2007, Astroparticle Physics, 27, 533-538

Dornic, D., et al, 2008, arXiv:astro-ph/0810.1452

Guetta, D., Hooper, D., et al. 2003, arXiv:astro-ph/0302524v2

Hjorth, J., et al. 2003, Nature 423, 847

Ando, S. & Beacom, J.F. 2005, arXiv:astro-ph/0502521v2 (Paper I)

Bringer M., Boer M., et al 1999, A&AS, 138 581

Ando, S., Beacom, J.F., Yuksel, H. 2005, Phys. Rev. Lett. 95 (2005) 171101 (paper II)