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Search for neutrinos from gamma-ray bursts with the ANTARES telescope

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Abstract. Gamma-ray bursts (GRBs) are powerful cosmic particle accelerators producing a highly variable flux of high energy gamma-rays. Under the assumption of hadronic acceleration in jets, a copious flux of neutrinos can be expected. Among the possible astrophysical sources, GRBs offer one of the most promising perspectives for the detection of cosmic neutrinos thanks to an almost background free search. The ANTARES neutrino telescope is running in a completely finished state since May 2008. The collaboration has implemented two different methods to search for GRBs: the first one is based on the search for neutrino candidates relying on the time and position information provided by an external trigger and the second one is based on the optical follow-up of special neutrino events. The use of these two complementary techniques provides enhanced sensitivity to transient sources.

Keywords: underwater telescope; neutrinos; gamma ray-bursts; transient source

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INTRODUCTION

Gamma-ray bursts (GRBs) are among the most fascinating celestial objects in the Universe, releasing radiation energy in γ -rays of 10^{51} ergs within a few seconds. Since their accidental discovery in the late 1960's by Vela military satellites [1], the study of GRBs has known deep revolutions over the past decades. The BATSE experiment has observed more than 2700 bursts between 1991 and 2000, leading to the identification of a bimodal distribution of the GRB population [2]. Then the cosmological origin of GRBs, a highly debated topic until early 1990's, was resolved only in 1997 when the BeppoSAX satellite succeeded in obtaining accurate positions of bursts, which allowed the measurement of redshift distances [3]. More recently, a new revolution occurred with the launch of the Swift mission, opening multi-wavelength detections and allowing observations of early afterglows in a time domain previously unexplored (see reviews [4] [5]). Progress has been made in understanding the progenitors of GRBs, and it is now accepted that long bursts are associated with the collapses of massive, low-metallicity stars [6] [7] in star forming regions in galaxies [8], while short bursts arise from the coalescence of two compact objects, likely two neutron-stars [9] [10] or a neutron-star and black hole binary system [10][11] in regions with lower star formation rates [12].

However, ongoing or future observatories will bring new challenges and maybe new revolutions to our understanding of these most violent explosions in the Universe. Indeed GRBs are one of the few viable candidates to produce ultra high energy cosmic rays, and the multi-messenger approach can give fruitful information on these high energy transient events as did the multi-wavelength approach.

This paper discusses the observation strategies of the ANTARES neutrino telescope to search for neutrinos from GRBs. Two different triggers have been implemented in ANTARES, the Triggered Search and the Rolling Search [13]. The former is based on the accurate timing and positional information provided by an external source, typically GRB alerts from GCN circulars. The later is based on the search for very high energy or multiplets of neutrino events coming from the same direction and within the same time window. For this, an optical follow-up program has been implemented.

THE TRIGGERED SEARCH

The search for neutrinos from individual bursts relies on the temporal, directional and spectral informations obtained from γ -ray observations. When a GRB is discovered by a γ -ray satellite, information is distributed through the Gamma-ray burst Coordinate Network (GCN), to which ANTARES is linked [14]. The search of γ -neutrino coincidence on a restricted time window and inside a narrow opening angle provides a powerful background rejection. After a short description of the ANTARES telescope, we will focus on a special GRB event, the burst GRB080916C, and will give a summary of the analysis strategy which is performed in a blind way.

The ANTARES detector [15] is an underwater telescope installed at 2,500 m depth in the Mediterranean Sea, 20 miles off the French Riviera coast. Designed to detect light produced by high energy muons induced by neutrino interactions in matter, ANTARES comprises a three-dimensional array of 885 photomultiplier tubes arranged on 12 flexible lines of 450 m height, each line consisting of 25 storeys. The ANTARES telescope has been fully operational since May 2008 and records data on a 24 hours per day basis, over a 2π sky coverage.

On 2008 September 16th, at 00:12:45 UT [16], an extremely energetic burst, GRB080916C, was detected by the GBM and the LAT instruments onboard the Fermi satellite [17]. With an afterglow photometric redshift measured at $z = 4.35 \pm 0.15$ [18], GRB080916C released an apparent isotropic γ -ray energy of $\sim 9.10^{54}$ erg. The LAT provided localization of the burst with an accuracy better than 0.1° at right ascension (RA) $07^h59^m31^s$, declination (Dec) $-56^\circ35.4'$. GRB080916C is a long burst with a duration $T_{90} = 66$ s. The highest photon energy reaches 13.2 GeV, measured with a delay of around 16.5 s.

The expected prompt neutrino spectrum of GRB080916C is computed in the internal shock scenario of the fireball model following [19][20], and assuming the knowledge of the γ -ray spectrum. The analysis strategy consists in the optimization of selection cuts performed on Monte Carlo simulations, using the directional and spectral information of bursts. Optimization is based on the Model Discovery Potential technique [21], such that a discovery could be claimed at a 5σ of significance level with a probability of 90%. For the calculation of the expected sensitivity, the optimized cuts are applied on data in a *OFF* period defined outside the GRB event, that defines the background. After unblinding, the *ON*-time data are analyzed using same selections, and results will allow either to claim a discovery or to give an upper limit. This latest step is in progress. This method, used by the IceCube Collaboration [22], allows to enhance significantly the sensitivity for transient sources.

THE ROLLING SEARCH

In a complementary way, neutrino detection can be used to trigger an optical follow-up, as suggested by [23]. The method is based on the detection of a multiplet of neutrinos from the same direction and within a short time interval. The expected background rate from a doublet of coincidence neutrinos detected by ANTARES is lower than 0.01 event per year, for an angular accuracy of $\Delta\Omega = 2^\circ \times 2^\circ$ and a duration of 10 minutes. The implication is that the detection of a doublet is not significant, unless an optical counterpart is observed in coincidence.

For multiplet events, as well as for very high energy neutrinos, an alert is sent to a follow-up network involving TAROT [24] (two 25 cm robotic telescopes) and ROTSE-III [25] (four 45 cm telescopes) collaborations, since spring 2009 and March 2010 respectively. The observational strategy consists typically of 8 images of one minute exposure each, during ten nights.

Due to the wide field of view of a neutrino telescope (2π if only up-going events are analyzed, 4π otherwise), this program is very efficient, enhancing the ANTARES sensitivity to neutrinos from GRBs or SNe, with no assumption of the nature of the source.

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