Search for high energy neutrinos from bright GRBs with ANTARES

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Abstract. Gamma-ray bursts are thought to be cosmic-ray accelerators, thus neutrinos are expected from the decay of charged mesons, produced in pγ interactions. The search for high-energy neutrinos from astrophysical sources is one of the main goals of the ANTARES scientific project. The methods and the results of a search for neutrinos from the brightest GRBs observed between 2008 and 2013 are presented. Two scenarios of the fireball model have been investigated: the internal shock and the photospheric case. Since no events have been detected in time and space coincidence with any of these bursts, upper limits at 90% C.L. on the expected neutrino fluxes are derived, as well as constraints on some parameters used in the modeling of the neutrino yield, as the bulk Lorentz factor Γ of the jet and the baryon loading f_p.

1. Introduction

The identification of the high energy neutrino sources would probe the existence of astrophysical hadronic accelerators: Gamma-ray bursts (GRBs) are thought to be plausible environments for shock acceleration mechanisms to take place. Up to now, the searches for neutrinos from GRBs both in the IceCube [1] and ANTARES [2] data provided upper limits on the expected theoretical fluxes. A neutrino search from bright GRBs observed between 2008 and 2013 through ANTARES data is presented here. The paper is ordered as follows: models for GRB-neutrino production are introduced in Sec. 2. Then, in Sec. 3, the ANTARES detector is described. The methods and the results of the search are detailed in Sec. 4. Finally, constraints on the parameter space of the models are discussed in Sec. 5 and conclusions are derived in Sec. 6.

2. The internal shock and photospheric fireball models

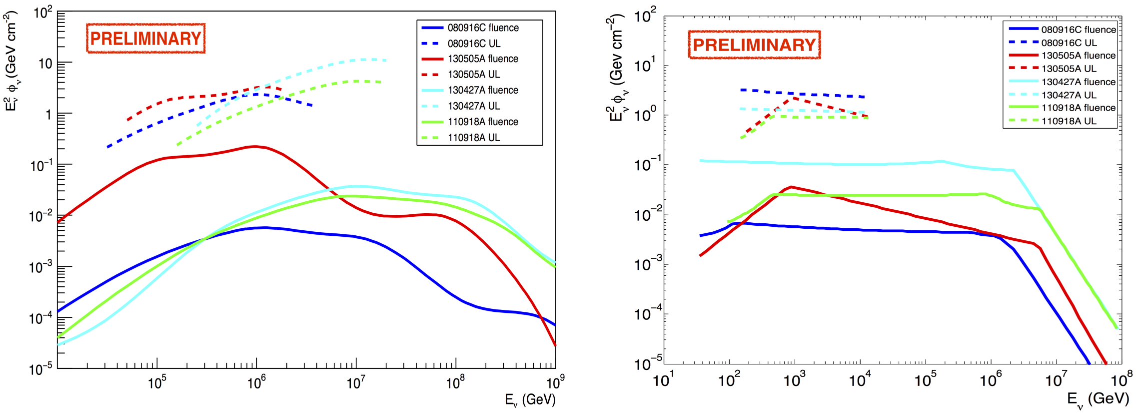
The most widely accepted paradigm for the production of the detected γ-rays is referred to as the internal shock (IS) fireball model: it predicts neutrinos mainly above 100 TeV. The photospheric (PH) scenario, instead, assumes that neutrinos are emitted closer to the central engine, where the GRB jet is optically thick: this leads to a low energy component in neutrino spectrum. The computation of the GRB neutrino spectra in the IS context is based on the numerical code 'NeuCosmA'[3]: it accounts for the full pγ cross section, including not only the Δ^+ resonance but also kaon and multi-pion production. GRB neutrino spectra expected in the PH case are derived, instead, following the analytical approach in [4]. Both predictions rely on the measured parameters of the γ-ray emission light curve and spectrum, and assume $\Gamma = 316$ and $f_p = 10$.

3. The ANTARES detector

ANTARES [5] is the largest operational neutrino telescope of the Northern hemisphere: it is a deep underwater detector, located in the Mediterranean sea (offshore Toulon, France), at a depth of about 2475 m. Its 885 photo-multipliers detect the Cherenkov light induced by the passage in water of ultra-relativistic charged particles. The main channel for neutrino detection is the charged current interaction of muon neutrinos, producing track-like events. In this search for muon neutrinos, only up-going events are considered in order to highly reduce the huge background of atmospheric muons; a statistical analysis is then needed to disentangle the signal from the atmospheric neutrino background. Indeed, the signature of a point-like source is a cluster of events in a defined direction of the sky (the source location). Since GRBs are transient sources, also a temporal coincidence with the detected γ-ray emission is applied.

4. Methodology

Bright sources are promising candidates because neutrino flux is linearly scaled with the gamma-ray flux: therefore GRBs are selected with gamma-ray fluence higher than 10^{-4} erg/cm^2. They also have to be below the ANTARES horizon at the trigger time and have redshift measured. GRB080916C, GRB110918A, GRB130427A and GRB130505A satisfy these criteria. Events are selected in an angular window equal to a cone centered on each source with semi-aperture of 10° and in a time window corresponding to the burst total duration, with a symmetric extension of 2 seconds. MC signal simulations are realized for each burst, while background is evaluated from data: the signal and background angular probability density functions are obtained in order to perform pseudo-experiments, relying on an extended maximum likelihood ratio test statistic, as defined in [2]. Both the IS and PH analyses are optimised to yield the maximum Model Detection Power (MDP). In the PH case, the search strategy was adapted using a special data sample of raw data, able to enhance the sensitivity of the detector in the low energy range, where the signal is expected. After data unblinding at the optimal cuts, no neutrino event was found in space and time correlation with any of the GRBs, therefore 90% C.L. upper limits have been set: they are reported in Fig. 1(a) and 1(b) respectively for the IS and for the PH case.



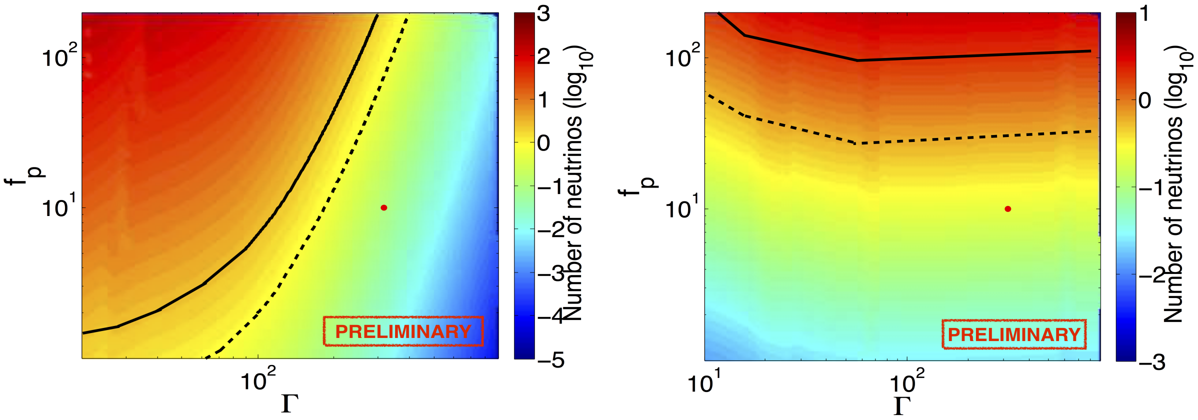
(a)

(b)

Figure 1. Expected $\nu_\mu + \bar{\nu}_\mu$ fluences (solid lines) and ANTARES 90% C.L. upper limits (dashed lines) on the selected GRBs, in the energy band where 90% of the signal is expected to be detected, for the IS (a) and the PH (b) models.

5. GRB constraints

Since no neutrino was detected, upper limits could be derived on the parameters that significantly affect the neutrino yield, according to the theoretical models. For each GRB, several spectra were simulated with $\Gamma \in [10; 900]$ and $f_p \in [1; 200]$ for both the IS and the PH case, assuming these parameters as uncorrelated. The most stringent results are presented in the exclusion limits of Fig. 2(a) and Fig. 2(b): ANTARES is significantly challenging the IS scenario of GRB130505A up to $\Gamma \sim 200$, while for GRB130427A a high baryonic content of the jet is ruled out ($f_p < 100$ at 90% C.L.) in the context of the PH model. Results from GRB080916C and GRB110918A are not showed: concerning GRB080916C, constraints are highly affected by its distance.



(a)

(b)

Figure 2. Constraints on the $\Gamma - f_p$ plane. The solid (dashed) black line corresponds to the exclusion limits at 90 (50)% C.L. The red dot shows the benchmark values $f_p = 10$ and $\Gamma = 316$. (a) IS constraints on GRB130505A. (b) PH constraints on GRB130427A.

6. Conclusions

A search for muon neutrinos in space and time coincidence with the prompt emission of four bright GRBs has been performed through ANTARES data: events satisfying the optimised selection criteria have been considered in two independent analyses. Concerning the internal shock model, the flux predictions were relying on the numerical model NeuCosmA; for the photospheric model, instead, an analytical approach was adopted. Both analyses were optimised to give the highest Model Detection Power for each burst. No events have been detected in any of the searches, so that 90% C.L. upper limits were derived, together with constraints in the parameter space of the fireball model. These constraints also affect the production of UHECRs: the non observation of neutrinos from GRBs still agrees with the paradigm of GRBs as viable sources of UHECRs. The incoming generation of neutrino detectors, as KM3NeT-ARCA [6], will deeply investigate this scenario in the next future.

References

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