Stacking search for muon neutrinos from Gamma-Ray Bursts with ANTARES neutrino telescope using 2007 to 2017 data

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Abstract

Addressing the origin of the observed diffuse astrophysical neutrino flux is of paramount importance. In this context, Gamma-Ray Bursts (GRBs) are considered interesting candidate sources since they are potentially able to achieve the energetics required to reproduce the neutrino flux. Using ANTARES data with the aim of constraining the contribution from the GRB population to the high-energy diffuse flux, we conducted a stacking search for upgoing muon neutrinos in spatial and temporal coincidence with 784 GRBs that occurred in the years 2007 to 2017. Since no coincident neutrinos have been observed, we constrain the contribution of these GRBs to the observed diffuse astrophysical neutrino flux. We also evaluate the systematic uncertainties on our estimate of the diffuse neutrino flux, as connected to the theoretical modeling of photo-hadronic interactions in these sources.

GRB sample

The sample is constituted of 784 long GRBs, selected from available gamma-ray catalogs and satisfying the following conditions:

- Spectrum is measured;
- T_{90}(~ duration) is measured;
- Position is measured and satellite angular uncertainty is less than 10°;
- One among fluence and redshift is measured.

In addition, only GRBs that were below the ANTARES horizon at trigger time are selected (to work with a sample of up-going events), with the additional condition that the detector was taking physics data at that time.

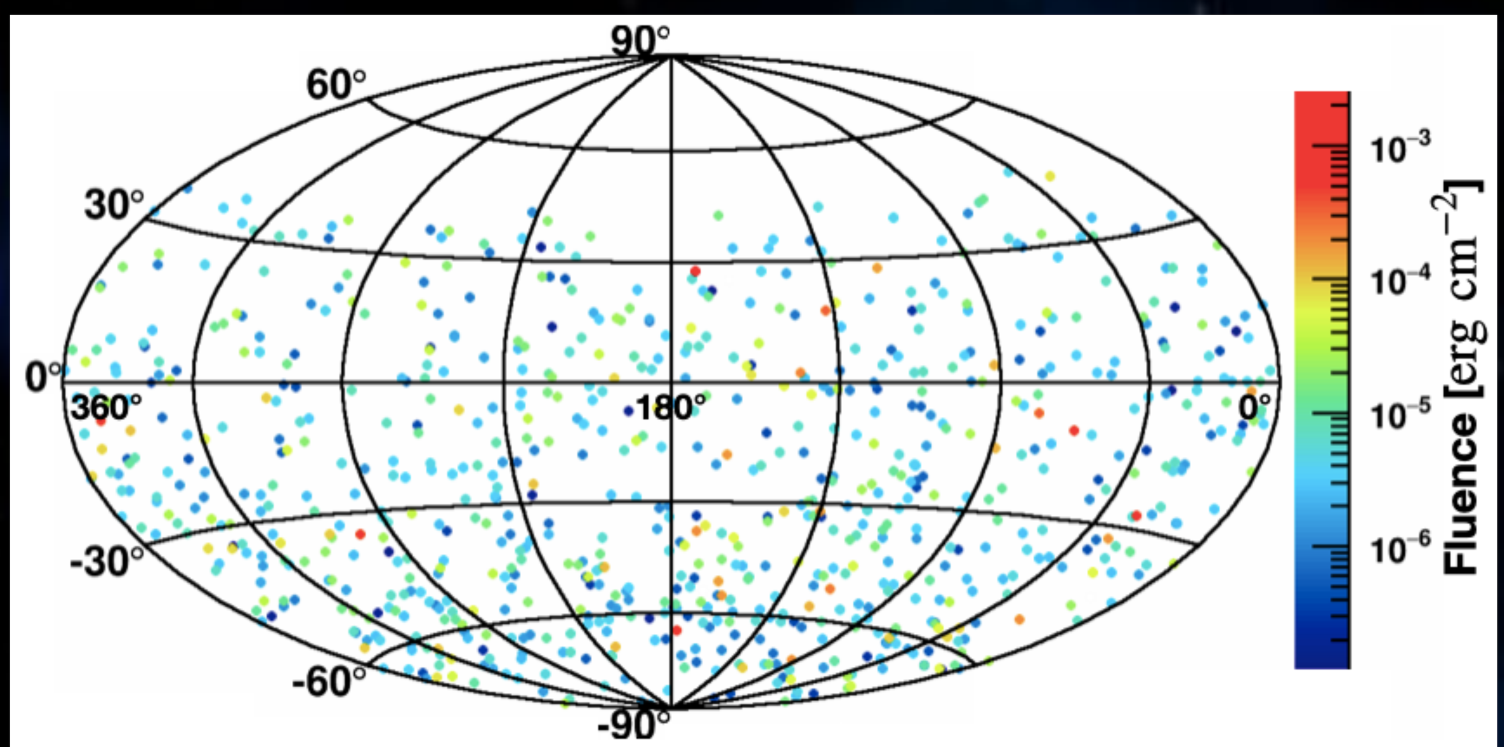


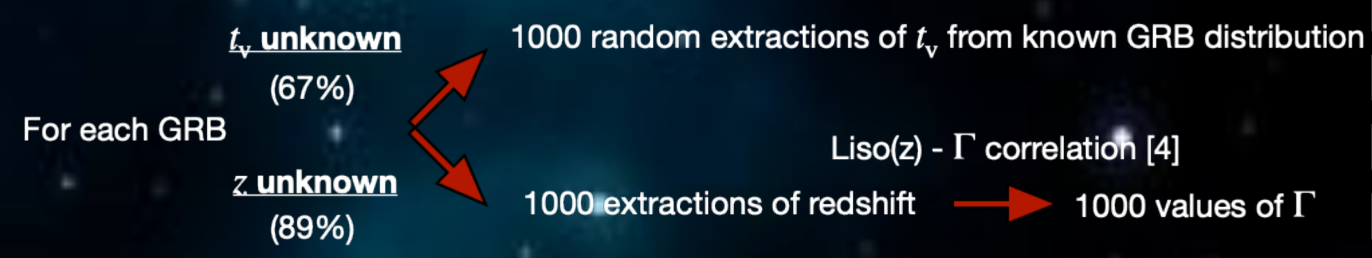
Figure 1. Sky distribution of the selected 784 GRBs in equatorial coordinates. The gamma-ray fluence of each burst, in erg cm^{-2}, is color-coded. The instantaneous field of view of the ANTARES detector for upward going events is 2π sr, i.e. within a period of 24 hours, the sky up to a declination of 47° is visible.

High-energy neutrino production at Internal Shocks

The neutrino flux expected from each GRB of the sample was computed through the event generator 'Neutrinos from Cosmic Accelerators' (NeuCosmA) [3]. Such numerical code follows the classical internal shock model and, accounting for the full pγ cross section, predicts the expected neutrino production during the so-called prompt phase of the source. Unfortunately, the normalization of the neutrino fluence depends on some intrinsic parameters of the emission region, like the boost Lorentz factor Γ, the variability timescale t_v and the baryonic loading f_p, which cannot reliably be determined on a source-by-source basis. The simulation assumes a baryonic loading $f_p = 10$.

Uncertainties on neutrino flux

In order to obtain a **more realistic estimate of the final neutrino fluence with respect to the past**, the several uncertainties in the neutrino flux computation were considered.



To evaluate the statistical uncertainty on the neutrino fluence the following procedure was adopted:

- The average neutrino fluence was calculated from the 1000 simulations;
- Percentiles were used to infer the uncertainty σ on the average fluence;
- Results were provided in terms of $E^2_{\nu_\mu} F_{\nu_\mu} \pm 2\sigma$.

In this way, we were able to investigate how the uncertainties affect the neutrino spectra identifying that **the minimum variability timescale appears to be the most contributing variable to the uncertainty on the neutrino fluence expected from GRBs.**

Data analysis

MC simulations were performed individually for each burst, while the background at the GRB position was evaluated from off-time data. For the selected sources, ANTARES data were analyzed, maximising the discovery probability of the stacking sample through an extended maximum-likelihood strategy. In the analysis, the search time window is coincident with to the gamma-ray GRB prompt emission, while the angular window is a cone around the source position with semi-aperture α=10°.

References

[1] Adrián-Martínez S. et al. (ANTARES Collaboration), 2013, A&A 559A
[2] Aartsen M. G. et al. (IceCube Collaboration) 2017, ApJ, 843, 2
[3] Hümmer S., Rüger M., Spanier F., Winter W., 2010, ApJ, 721, 630
[4] Lü J., Zou Y. C., Lei W. H., 2012, ApJ, 751, 49
[5] Schneider A. et al. (IceCube Collaboration), Proceedings of Science (ICRC2019) 1004
[6] Stettner J. et al. (IceCube Collaboration), Proceedings of Science (ICRC2019) 1017

Stacking neutrino fluence

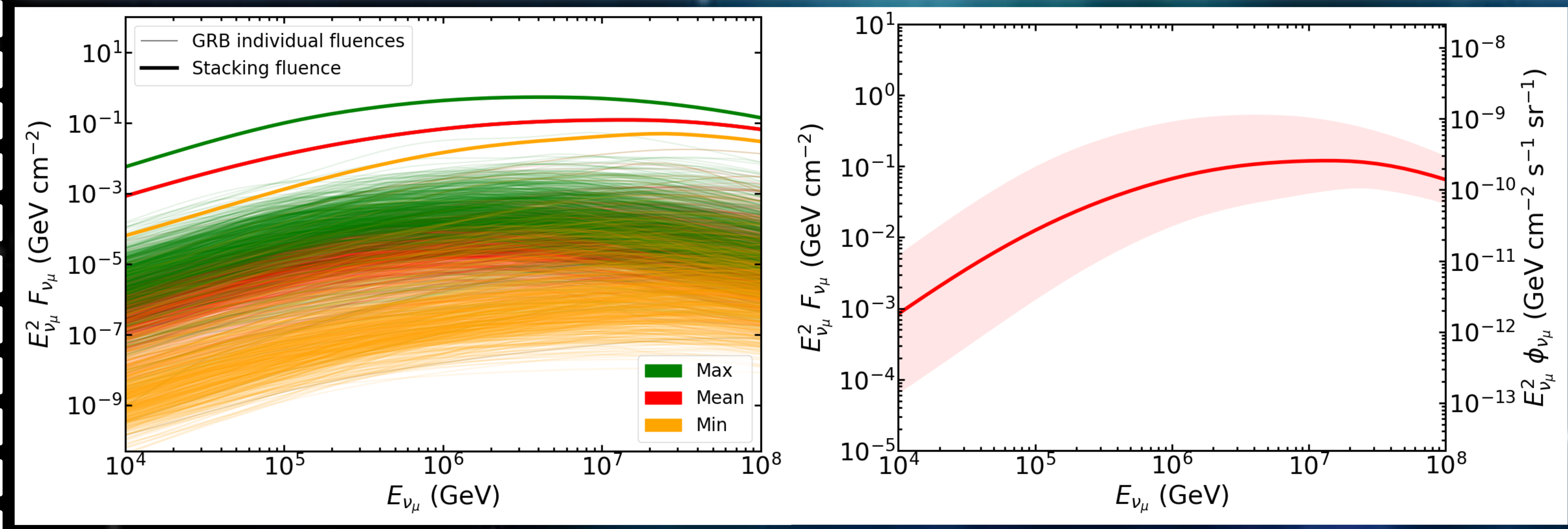


Figure 2. Left: Individual fluences calculated for each GRB of the 784 in the sample (thin lines) and the relative stacking fluence (thick line). The mean, minimum and maximum fluences are shown in red, orange and green, respectively. Right: Total neutrino fluence expected from the GRBs in the sample (left-hand axis) and the corresponding quasi-diffuse neutrino flux (right-hand axis). The shaded region indicates the error band obtained from the stacking maximum and minimum fluences.

Results and discussion

After data unblinding, **no neutrino events passed the quality cuts set by the optimization procedure**, 90% confidence level upper limit as well as the related uncertainty on the total expected diffuse neutrino flux were derived, according to the model.

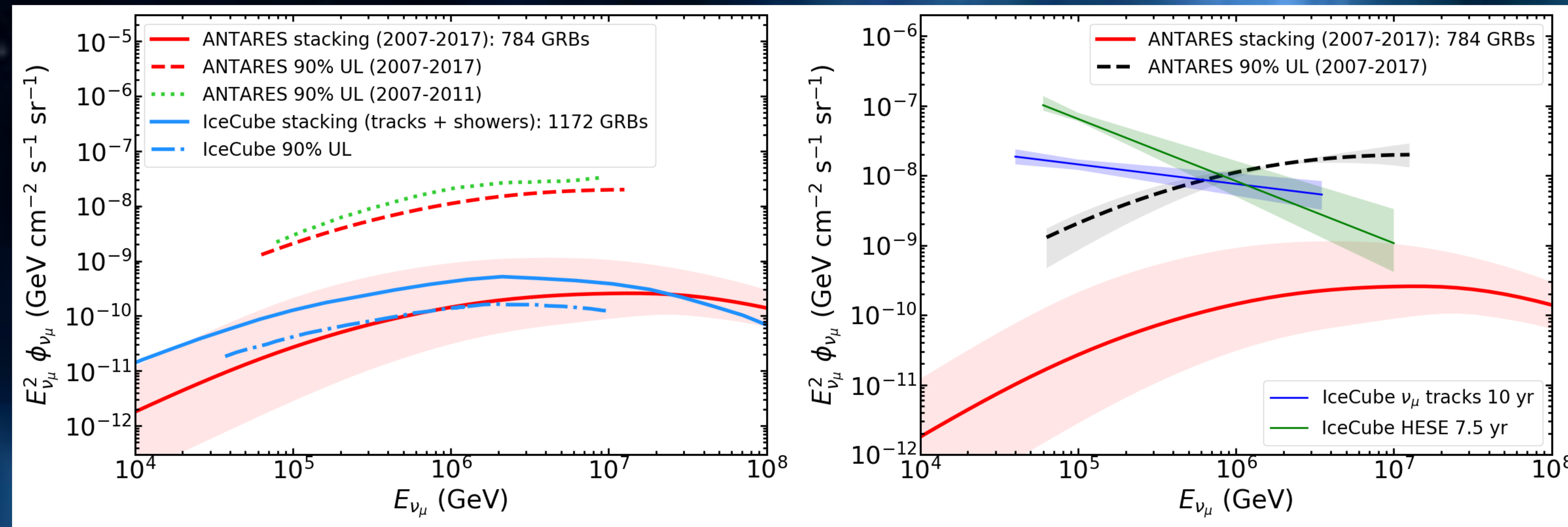


Figure 3. Left: Comparison between the ANTARES quasi-diffuse flux expected from 784 GRBs (red thick line) and the IceCube quasi-diffuse flux from 1172 GRBs [2] (cyan thick line). The red dashed, green dashed and dash-dotted cyan lines represent the 90% confidence level upper limits (in the energy range in which the 90% of the fluence is expected to be detected) on GRB quasi-diffuse flux of the present, previous ANTARES analysis [1] and the latest IceCube search [2], respectively. Right: GRB ANTARES quasi-diffuse flux for 784 GRBs (red solid line) and the corresponding upper limit (dashed black line). IceCube best fits for ν_μ tracks in 10 years [6] and for HESE events in 7.5 years [5] of collected data are shown in blue and green, respectively. The shaded regions show the uncertainty band of each estimation.

With respect to the latest ANTARES search [1], this analysis improves the previous limit by a factor of ~2 in the diffuse flux, being still a factor 100 above limits set by IceCube [2]. Comparing the upper limit derived from this search with the diffuse neutrino flux measured by IceCube [5][6], we conclude that **GRBs contribute to less than 10% to the astrophysical neutrino flux at energies below 100 TeV**, if the baryonic loading is $f_p = 10$.