Constraining the contribution of Gamma-Ray Bursts to the high-energy diffuse neutrino flux with 10 years of ANTARES data

A. Zegarelli, S. Celli, on behalf of the ANTARES Collaboration

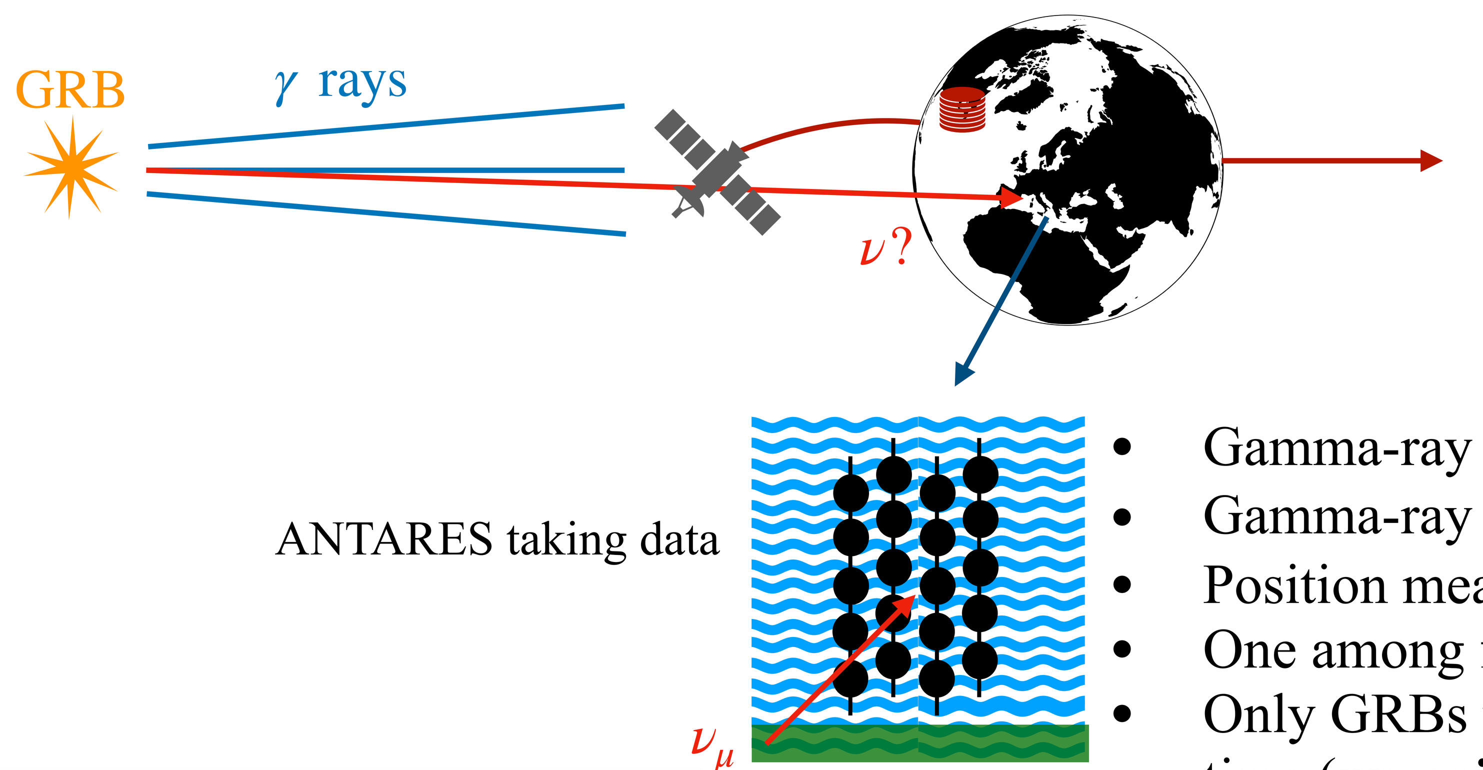
Physics Department, University "La Sapienza" and INFN, Roma, Italy, e-mail: angela.zegarelli@roma1.infn.it

ANTARES Collaboration, MNRAS 500, 5614–5628 (2021)

Abstract

Addressing the origin of the observed astrophysical neutrino flux is of paramount importance nowadays, since the sources generating such neutrinos stille remain a mystery. Among the likely astrophysical sources of detectable high-energy neutrinos (e.g. blazars, supernova remnants etc.), also Gamma-Ray Bursts (GRBs) play a fundamental role, since they are among the few astrophysical sources capable of achieving the required energy to contribute to the detected astrophysics neutrino flux. Within this context, we present the results of a stacked search for muon astrophysical neutrinos performed in coincidence with 784 GRBs in the period 2007-2017 using ANTARES data. The major improvement with respect to previous analyses is now the estimation of systematic uncertainties due to poor knowledge on some of the model parameters were computed on the diffuse flux, propagating the uncertainties on the barely characterized GRB parameters of each individual burst to the stacked limit. Given the absence of coincident neutrinos with the analyses GRBs, this analysis has allowed to constrain the contribution of the detected GRB population to the diffuse neutrino diffuse flux to be less than 10% around 100 TeV.

GRB selection



- Gamma-ray spectrum measured
- Gamma-ray T_{90}(~ duration) measured
- Position measured and satellite angular uncertainty less than 10°
- One among fluence and redshift is measured
- Only GRBs that were below the ANTARES horizon at trigger time (**up-going events**)

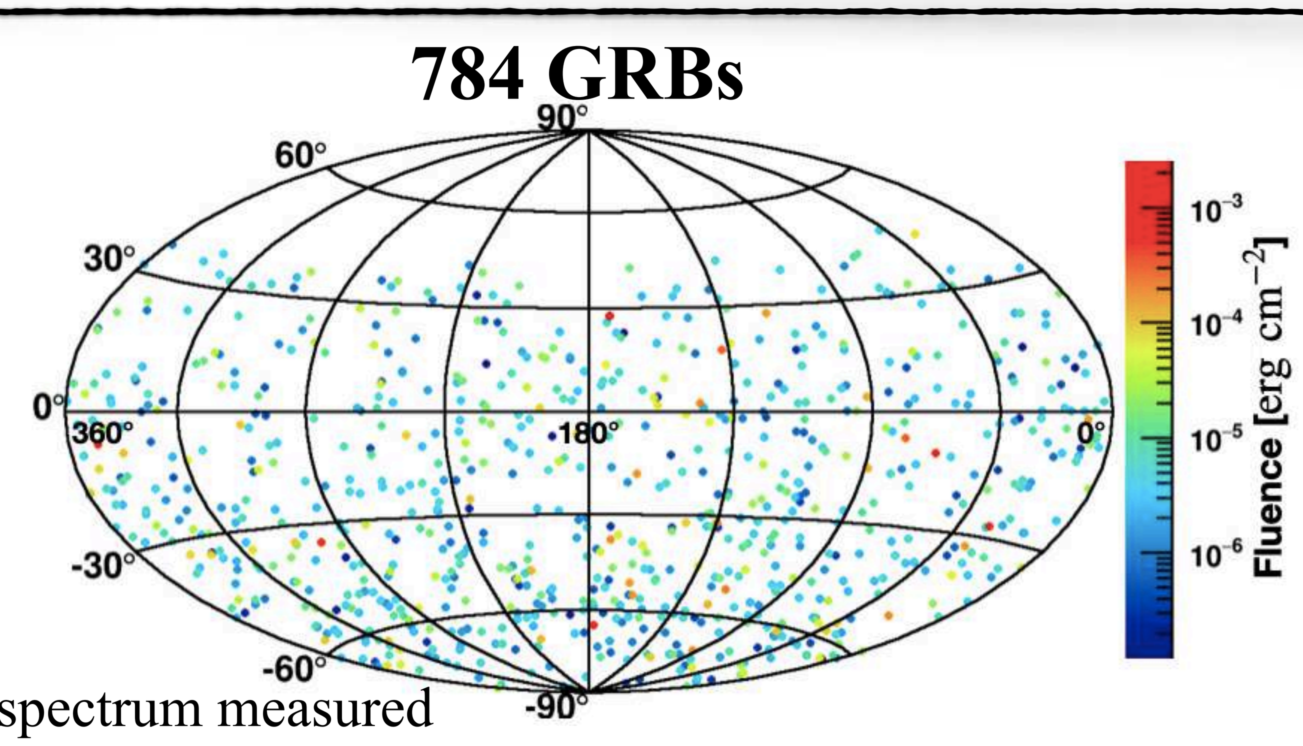
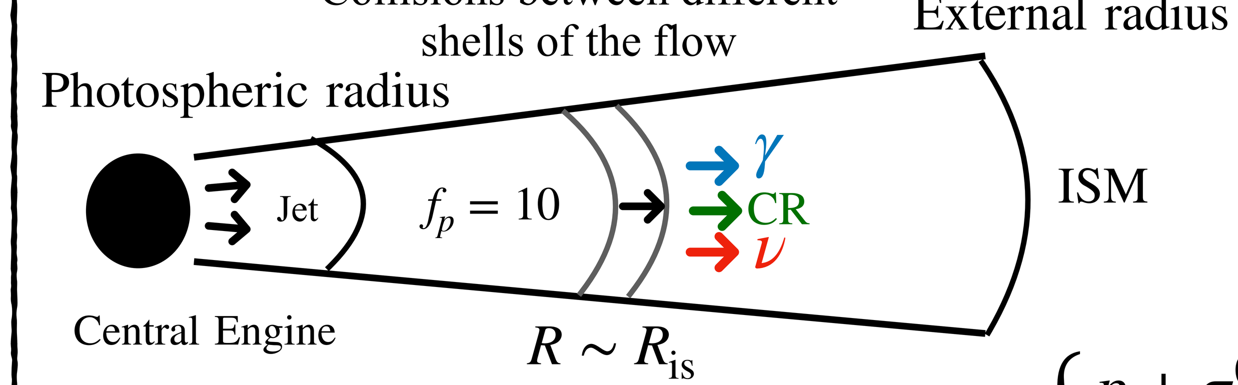


Figure 1. *Sky distribution of the selected GRBs in equatorial coordinates. The gamma-ray fluence of each burst is color-coded. The instantaneous field of view of the ANTARES detector for upward going events is 2π sr, i.e. within a time of 24 hours, the sky up to a declination of 47° is visible.*

Neutrino flux computation and uncertainty investigation

The neutrino flux expected from each GRB of the sample was computed through the event generator 'Neutrinos from Cosmic Accelerators' (NeuCosmA) [1]. Such numerical code follows the classical internal shock model, accounting for the full pγ cross section, thus it predicts the expected neutrino production during the so-called prompt phase of the source.

Internal shocks



$$p + \gamma \rightarrow \begin{cases} p + \pi^0 \\ n + \pi^+ \end{cases} \rightarrow \begin{cases} \pi^0 \rightarrow \gamma + \gamma \\ n \rightarrow p + e^- + \bar{\nu}_e \\ \pi^+ \rightarrow \mu^+ + \nu_\mu \\ \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu \end{cases}$$

Photomeson interactions

Neutrino production

The model parameters that set the radial distance where shock collisions occur have large impact on ν flux expectations

$$R_{is} = 2 \times 10^{13} \left(\frac{t_v}{0.01\ s}\right)\left(\frac{\Gamma}{10^{2.5}}\right)^2\left(\frac{3}{1+z}\right)\ \mathrm{cm}$$

GRB sample

z unknown (89%) — t_v unknown (68%)

For each GRB 1000 random extractions from known GRB distributions

$L_{\gamma,iso} - \Gamma$ correlation

1000 values of Γ

$L_{\gamma,iso} - \Gamma$ correlation [2]

Redshift z → $L_{\gamma,iso}$

$$\Gamma \simeq 249\left(\frac{L_{\gamma,iso}}{10^{52}\ \mathrm{erg\ s^{-1}}}\right)^{0.30}$$

For each GRB $< E^2_{\nu_\mu} F_{\nu_\mu} > \pm 2\sigma$

Stacking fluence

$$E^2_{\nu_\mu} F_{\nu_\mu} = \sum_{i=1}^{N_{GRB}=784} (E^2_{\nu_\mu} F_{\nu_\mu})^i$$

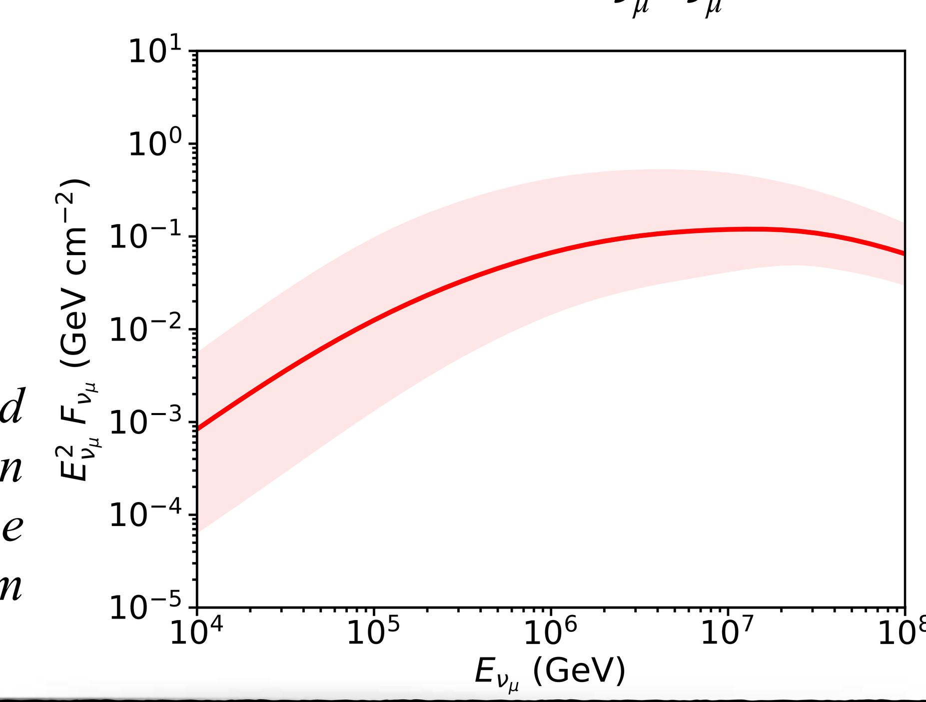


Figure 2. *Total neutrino fluence expected from the 784 GRBs. The shaded region indicates the error band, obtained from the sum of the individual maximum and minimum fluences for each GRB.*

Data analysis

- MC simulations were performed individually for each burst
- 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** [3].

- Search time window = coincident with the gamma-ray GRB prompt emission
- Angular window = cone around the source position with semi-aperture α=10°.

[1] Hümmer S., Rüger M., Spanier F., Winter W., 2010, ApJ, 721, 630

[2] Lü J., Zou Y. C., Lei W. H., 2012, ApJ, 751, 49

[3] Barlow R., 1990, Uncl. Instr. Meth., A, 297, 496

[4] Schneider A. et al. (IceCube Collaboration), Proceedings of Science (ICRC2019) 1004

[5] Stettner J. et al. (IceCube Collaboration), Proceedings of Science (ICRC2019) 101

Results

Figure 3. *GRB ANTARES quasi-diffuse flux for 784 GRBs (red solid line) and the corresponding upper limit (dashed red line). IceCube best fits for ν_μ tracks in 10 years [5] and for HESE events in 7.5 years [4] of collected data are shown in blue and green, respectively. The shaded regions show the uncertainty band of each estimation.*

Quasi-diffuse flux

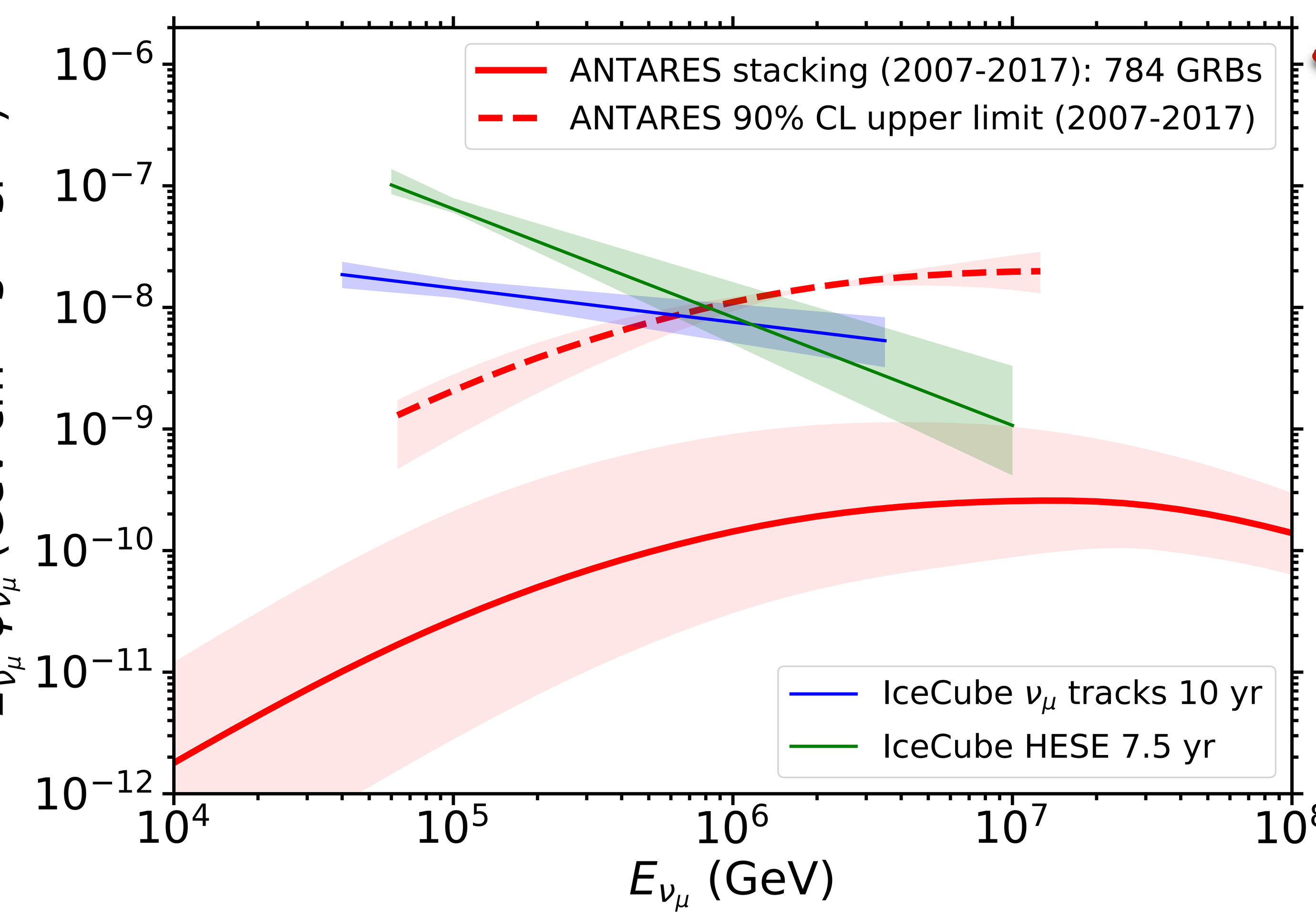
$$E^2_{\nu_\mu}\phi_{\nu_\mu} = \sum_{i=1}^{N_{GRB}} (E^2_{\nu_\mu} F_{\nu_\mu})^i \frac{1}{4\pi}\frac{1}{N_{GRB}}\, 667\,\mathrm{yr}^{-1}$$

Number of long GRBs per year

After data unblinding, **no 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.

$$\phi^{90\%}_{\nu_\mu} = \phi_{\nu_\mu}\frac{n^{90\%}_{up}}{n_s} = \phi_{\nu_\mu}\frac{2.3}{n_s}$$

The Poisson probability to detect at least one event at a mean rate of 2.3 is exactly 90%



The upper limit derived from this search, as compared to the diffuse neutrino flux measured by IceCube [4][5], indicates that **GRBs contribute to less than 10% to the astrophysical neutrino flux at energies below 100 TeV, if $f_p = 10$.**