SUMMER STUDENT PROGRAMME 2026

THE B.O.A.T

The Brightest Of All Time

FOLLOW-UP OF NEUTRINO EMISSION FROM GRB 221009A

A blind, time-dependent search with KM3NeT/ARCA

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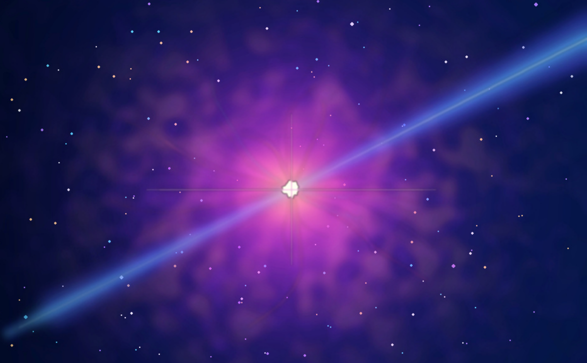

Research roadmap

1. **Cosmic sources** Why neutrinos?
2. **KM3NeT** A telescope in the deep Mediterranean Sea
3. **THE B.O.A.T** GRB 221009A as a transient target
4. **Data analysis** Alerts, event cuts and search windows
5. **Statistical analysis** H_0, Poisson, evidence and discovery
6. **Conclusions** Interpretation and next steps

Cosmic sources: more than one messenger

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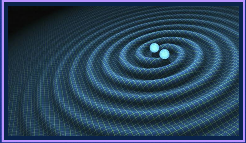
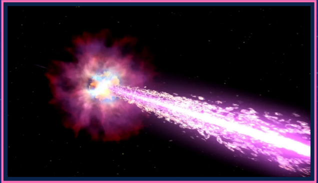
The cosmos sends different signals and powerful transient sources.

- Photons: bright and abundant, but absorbed by matter.
- Neutrinos: low interaction probability, neutral and able to cross dense matter.
- Gravitational waves: produced by moving compact objects.
- Gamma-ray bursts: brief, extremely energetic cosmic explosions.

PHOTONS + NEUTRINOS

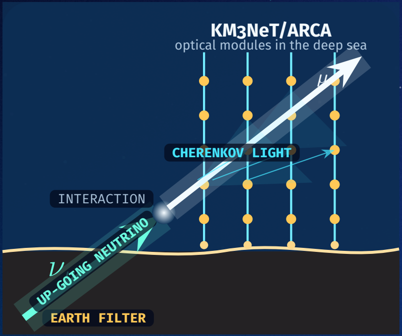


GRAVITATIONAL WAVES



GAMMA-RAY BURST

Why cosmic neutrinos?



01 NEUTRAL
It points back to its source.

02 PENETRATING
It escapes dense environments.

03 PROTON SIGNATURE
It reveals interactions of accelerated protons.

04 LOW INTERACTION
Most neutrinos cross the detector unnoticed.

A neutrino can reveal an otherwise hidden cosmic accelerator.

KM3NeT/ARCA: a cubic-kilometre neutrino telescope

ARCA reconstructs a neutrino through the light left behind.

1. A neutrino interaction produces a charged particle.
2. The particle emits Cherenkov light in seawater.
3. Optical modules record photon positions and arrival times.
4. A fit reconstructs direction and an energy proxy.

THE B.O.A.T: GRB 221009A

SWIFT

RECEIVED 14:39 GMT

GCN CIRCULAR 32632

New bright hard X-ray and optical transient

BAT TRIGGER 14:10:17 UT

Swift slewed immediately. XRT began observing 143 seconds later and found a bright, fading X-ray source.

RA $288.263°$ Dec $+19.803°$

BAT uncertainty: $3'$ radius

FERMI–GBM

RECEIVED 20:54 GMT

GCN CIRCULAR 32636

Detection of an extraordinarily bright GRB

GBM TRIGGER 13:16:59 UT

Reported as the brightest among GBM-detected GRBs, with an exceptional episode about 180 seconds after trigger.

RA $290.4°$ Dec $+22.3°$

Localisation uncertainty: $\pm 3°$; consistent with Swift

From the satellite trigger to the ARCA dataset

WHAT THE SATELLITE ALERT FIXES

SEARCH CENTRE
use the reported GRB position

TIME ZERO
set T_0 to the trigger time: 13:16:59 UTC

SEARCH PERIOD
inspect 101 minutes of data around T_0

ONLINE-RECONSTRUCTED EVENTS

From event selection to the coincidence search

EVENT SELECTION

156 493 trigger-level events

153 625 minimum-quality sample

$E > 10$ GeV and physical reconstruction values

10 840 final analysis sample

$E > 100$ GeV · quality > 100 · track length > 100 m

TEMPORAL WINDOW

$$-60\ \text{s} < t - T_0 < 6000\ \text{s}$$

101 minutes around the trigger

SPATIAL WINDOW

$$\Delta\psi < 2^\circ$$

angular distance from the GRB

Only clean tracks coincident in both time and direction enter the signal region.

From control data to the background-only model

How many background events should appear in the signal region?

1 • COUNT OFF EVENTS

1872

measured away from the source

2 • RESCALE TO ON

$\alpha = 5.20 \times 10^{-4}$

relative ON/OFF exposure

3 • EXPECTED IN ON

0.9736 ± 0.0225

background events

NULL HYPOTHESIS H_0

No neutrino signal

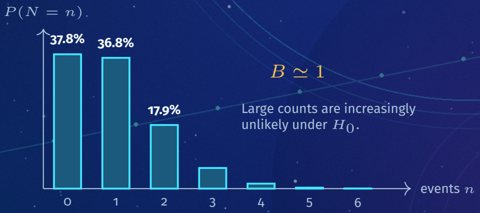
Every ON event is produced by background.

$$N \sim \mathrm{Poisson}(B)$$

with $B = 0.9736$

Predicts probabilities for counts of 0, 1, 2 and more.

BACKGROUND COUNT PROBABILITIES



After unblinding: p-value = probability of obtaining at least the observed count.

The estimate is obtained blindly and assumes stable rates and equal ON/OFF efficiency.

How many events would count as evidence?

EVIDENCE · ONE-SIDED POISSON TAIL

6 events

DISCOVERY · ONE-SIDED POISSON TAIL

10 events

$$p = 5.17 \times 10^{-4}$$

$Z \simeq 3.28\sigma$ · above the 3σ evidence criterion

$$p = 8.73 \times 10^{-8}$$

$Z \simeq 5.22\sigma$ · above the 5σ discovery criterion

Simplified thresholds for fixed $B = 0.9736$; systematic uncertainties are not included.

Unblinding: what did the data contain?

EXPECTED BACKGROUND

0.97 ± 0.02

OBSERVED CANDIDATES

Unblinding: what did the data contain?

EXPECTED BACKGROUND

0.97 ± 0.02

OBSERVED CANDIDATES

0

The observation is fully compatible with the background-only hypothesis.

Conclusions

1. **THE SOURCE** GRB 221009A was an exceptional multi-messenger target.
2. **THE DETECTOR** KM3NeT/ARCA provided a clean sample of reconstructed tracks.
3. **THE METHOD** A blind ON/OFF analysis predicted 0.9736 background events.
4. **THE OBSERVATION** Zero candidates were found, fully compatible with background.

NO CORRELATED NEUTRINO EMISSION OBSERVED

NEXT STEP derive an upper limit on the neutrino fluence from GRB 221009A