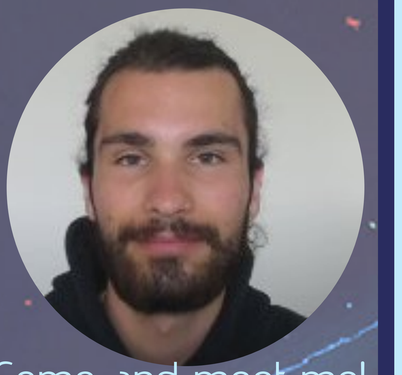
Multi-Messenger observations with KM3NeT: search for high energy neutrinos coinciding with Fast Radio Bursts



Come and meet me!

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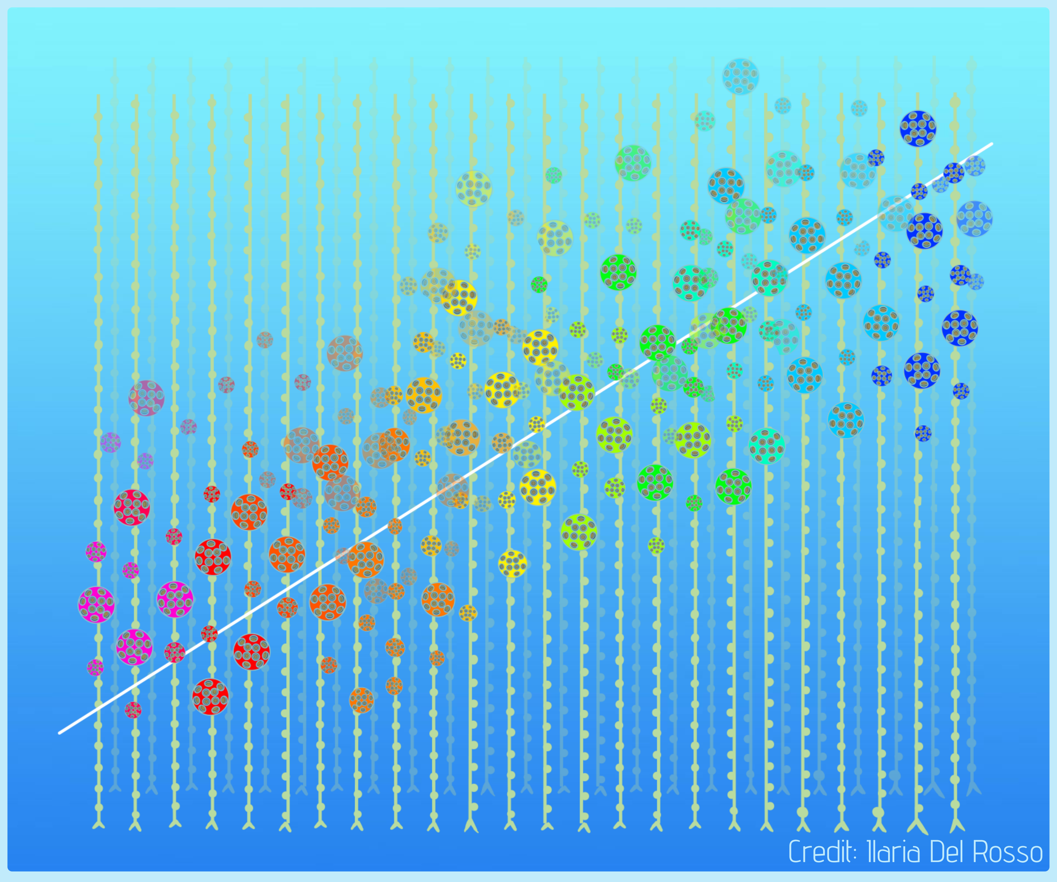
NEUTRINO 2024

- First FRB ever detected: FRB 20010824A, "Lorimer Burst"
- First repeater: FRB 20121102A "Arecibo repeater"
- First and only coincidence: FRB 20200428 associated with Hard X-Ray Burst from magnetar SGR 1935+2154
- Today: 678 One-Off FRBs and 60 Repeaters

2007 (1) · 2008 (9) · 2012 (15) · 2016 (52) · 2020 (721) · 2024 (934)

KM3NeT — Giant volume neutrino telescope in construction in the Mediterranean Sea



Credit: Ilaria Del Rosso

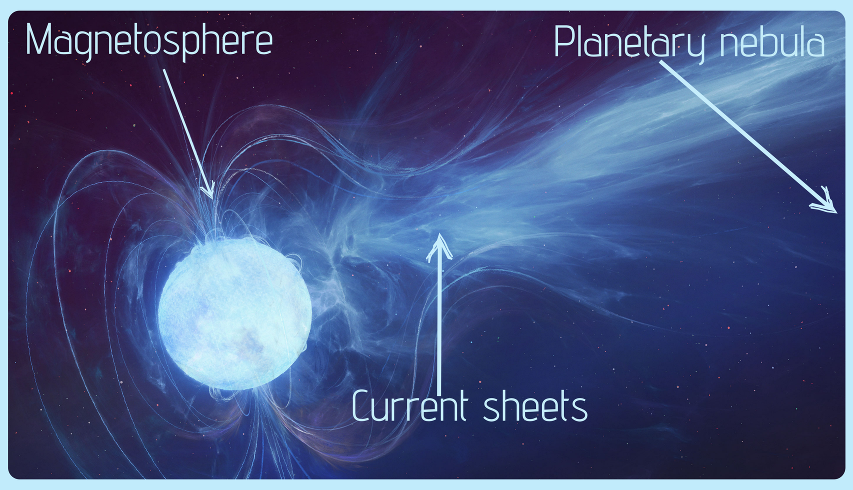
- 3D Arrays of light sensors: "Digital Optical Modules" (DOMs) each holding 31 PhotoMultiplier Tubes (PMTs)
- ORCA offshore Toulon with 21 lines (up to 115 in total), 200 m high and separated by 20 m, working in the GeV-TeV range
- ARCA offshore Sicily with 32 lines (up to 230 in total), 700 m high and separated by 90 m, working in the TeV-100PeV range
- Acoustic beacons and compasses for position and rotation calibrations

Detection principle: captures Cherenkov light from interaction products of high-energy neutrinos

- "Track-like" topology, from muon neutrinos, producing muons through Charged Current interactions: Good angular resolution for astrophysics
- "Shower-like" topology, from other Charged Current and all Neutral Current interactions: Good energy resolution for oscillations

Main background: Atmospheric muons making downgoing tracks in the detector.

Fast Radio Bursts — Puzzling extra-galactic radio transients of unprecedented energies



FRB models [1]:

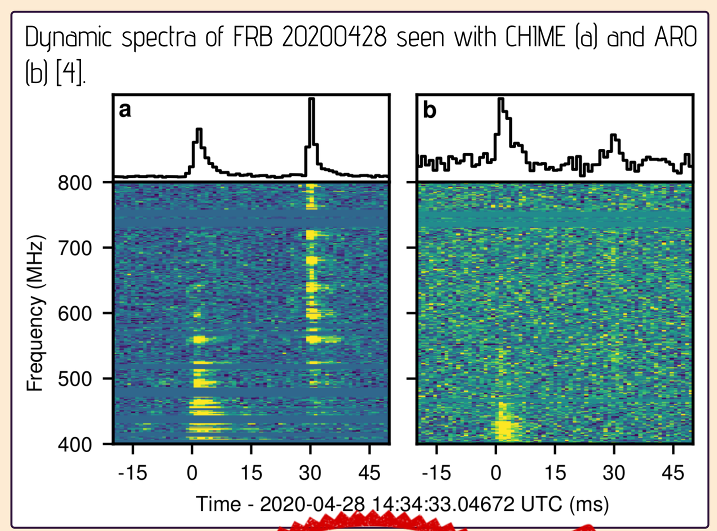
- Magnetospheric or shock-like models
- Binary coalescence models
- Repeaters versus one-off events

Models for neutrino counterparts to FRBs:

- Based on FRB 20200428A [2,3]
- No strong energetic or timing constraints

Name	Fast Radio Burst
Observables	
Energy (isotropic)	10^{35} - 10^{46} erg
Duration	Millisecond
Traits	Large dispersion (DM)
	Polarized signal (RM)
	Pulse broadening
Repeating	Sometimes
Inferred characteristics	
Sources	Extra-galactic sources
	Magnetars (?)
Mechanism	Coherent emission
Environment	Energetic, dense, magnetized, perturbed plasma

Dynamic spectra of FRB 20200428 seen with CHIME (a) and ARO (b) [4].



Seal

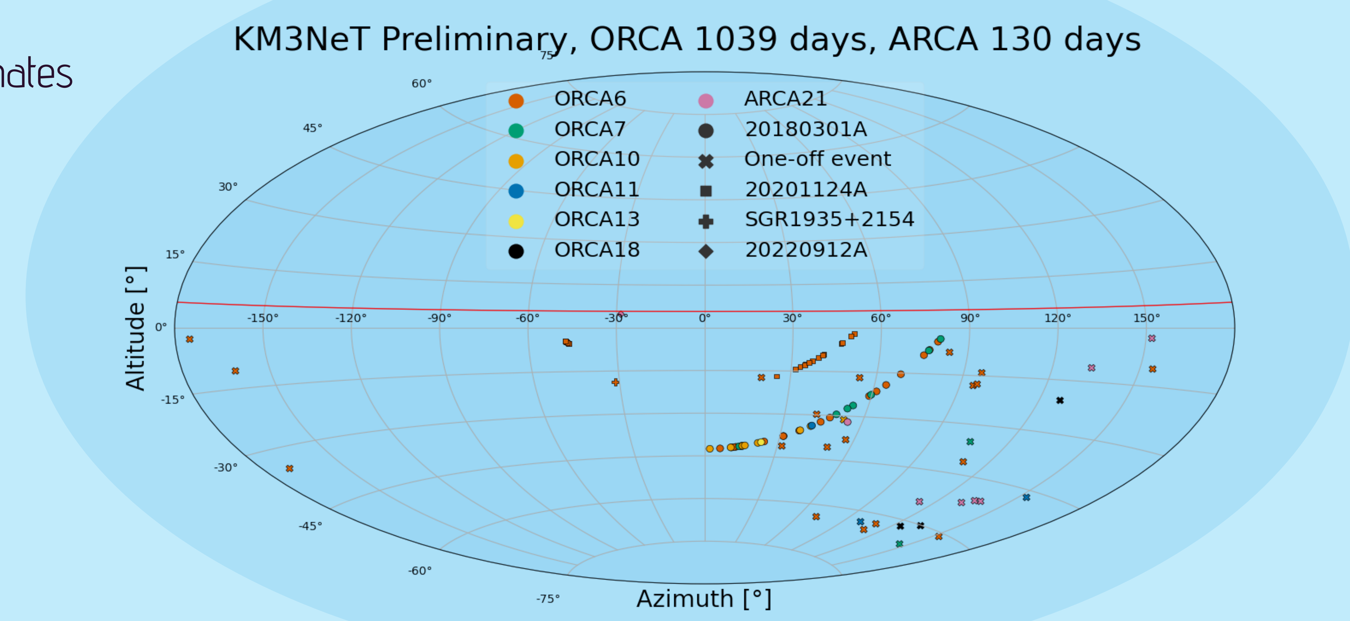
Multi-Messenger observations consist of studying different types of astrophysical messengers (neutrinos, photons, cosmic rays or gravitational waves) from the same source to infer the multiple aspects of the emitting source.

Methods — ON/OFF analysis

Skymap in local coordinates of FRBs studied in this analysis. The upgoing region is defined for altitude less than $\cos(\vartheta_{zen})$ = 0.1 (5.74°).

$\cos(\vartheta)$ = 1 ⇔ zenith

$\cos(\vartheta)$ = -1 ⇔ nadir



Detector configurations: ORCA: 6 to 18 lines – ARCA: 19 and 21 lines (no bursts usable with ARCA19). The used cumulated livetime is 970 days for ORCA and 340 days for ARCA.

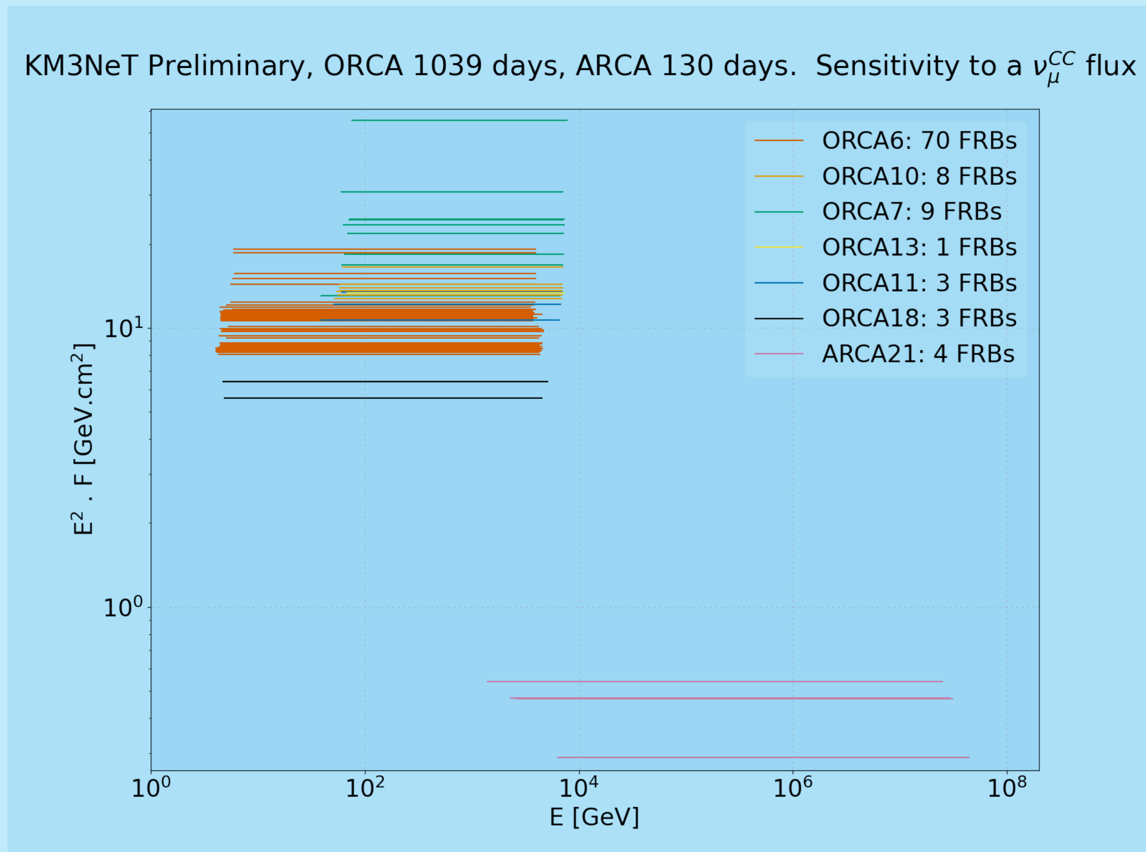
Analysis method: Binned ON/OFF with a cut-and-count technique.

- ON time period = ±500 s around the FRB observation time and ON Region of Interest (RoI) with an optimized radius centered on the FRB direction
- OFF time period = dozens of days of livetime and OFF region = ±10° band around FRB altitude
- Select events on reconstruction variables or Boosted Decision Tree (BDT) score to reduce background to 2.7 x 10^{-3} events (i.e. 1 event in the ON zone has a p-value of 0.27% = 3σ), while maximizing signal rate (studied through Monte-Carlo simulations)
- Reconstruction variables for the selection: track length, track likelihood, angular reconstruction, number of PMT hits, RoI radius

Results

Sensitivities

- Before unblinding, set sensitivities to neutrino fluxes.
- After unblinding, if neutrinos are found in ON zones, compute p-values to reject the background-only hypothesis



Sensitivities to a ν cosmic flux for each burst studied in this analysis using a 1000 s time window. The limit is computed using the 90% CL Feldman-Cousins upper limit. ARCA21 (purple) has better sensitivity due the difference in energy spectrum of the cosmic signal and the muon background. Only ORCA6 (vermillion) and ORCA18 (black) use a BDT score for the event selection. Energy bounds in the X-axis are defined using 5% and 95% quantiles of the energy distributions of the selected events.

Perspectives

Whether or not there are neutrinos found in the ON regions, this Neutrino-FRB analysis will constrain the neutrino emission from FRB sources and bring new information to develop models. **Stay tuned for the outcome of the un-blinding!**

- Un-blind data to look for signal candidates
- Proceed with a complementary stacking analysis, that will allow for a more time-independent search troughout the detector lifetime, while allowing faint sources to contribute to the signal
- The KM3NeT detectors will continue to grow in size, and the reconstruction, simulation and analysis tools will be further developed to increase their efficiency

Acknowledgements

This work has been supported with a grant by Nantes Métropole

Nantes Métropole · 30 ans Subatech · IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom · CNRS IN2P3 Les deux infinis · Nantes Université

References

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[2] Neutrino Counterparts of Fast Radio Bursts. Metzger et al, 2020. ApJL 902 L22

[3] Neutrino emission from fast radio burst-emitting magnetars, Qu and Zhang, 2022. MNRAS, 511-1, 972-979.

[4] A bright millisecond-duration radio burst from a Galactic magnetar. The CHIME/FRB Collaboration, 2020. Nature 587, 54-58.

KM3NeT