Multi-messenger observations with the KM3NeT telescope: search for high energy neutrinos coinciding with Fast Radio Bursts

NBIA Summer School: *Neutrinos: Here, There & Everywhere*

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Summary

1) KM3NeT

- ⇒ Overview
- ⇒ Detection Principle
- ⇒ Physics objectives

2) Fast Radio Bursts

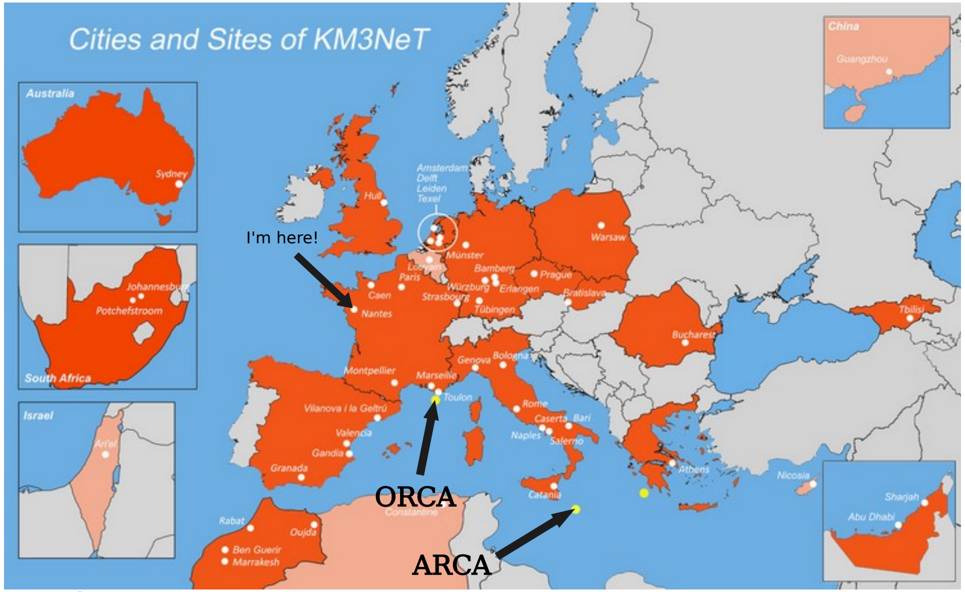
- ⇒ Multi-Messenger candidate

3) Analysis Strategy

- ⇒ Binned cut-and-count analysis

KM3NeT: Overview

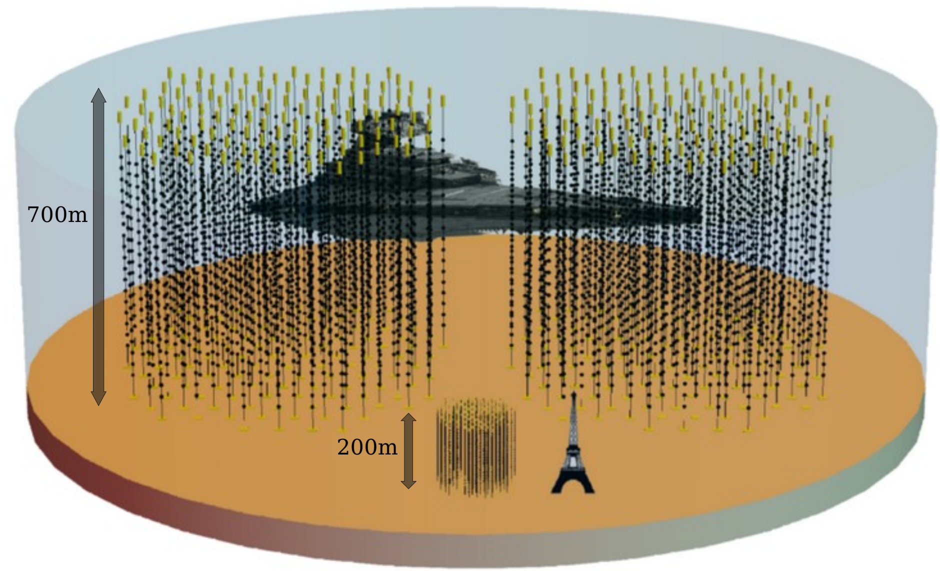
Two Detectors in the Mediterranean Sea: ORCA & ARCA



www.km3net.org

- Sucessor of the ANTARES experiment
- The construction started in 2015
- 345 strings, 6200 optical modules, 200 000 PMTs, ~1km^3 volume
- The largest neutrino detector in the Northern Hemisphere

- **O**scillation **R**esearch with **C**osmic in the **A**byss
- **A**strophysics **R**esearch with **C**osmic in the **A**byss



ARCA and ORCA relative sizes.
Eiffel tower: 330m high ; Star Destroyer from Star Wars: 1600m long*

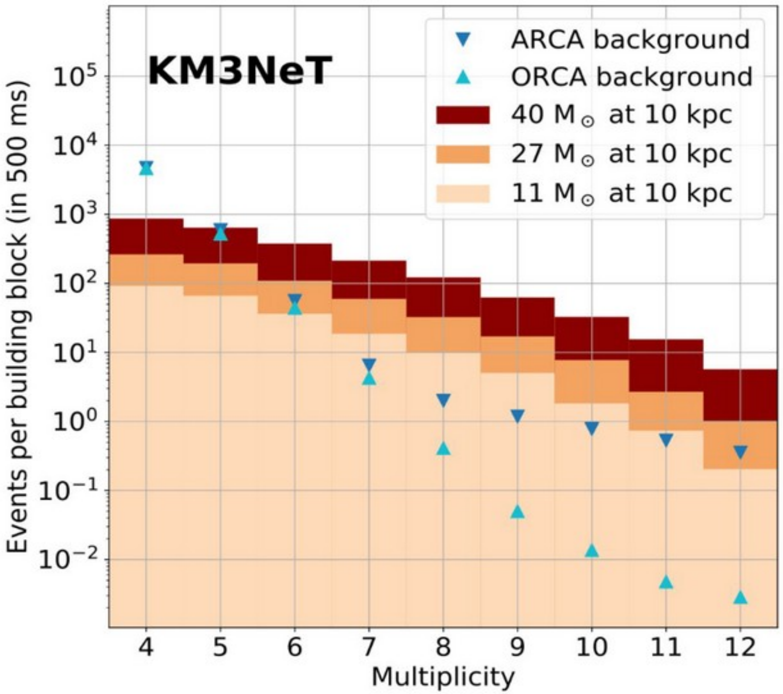
KM3NeT: Detection Principle

Digital Optical Module

- 31 PMTs
- Digitalising board
- Compass, Piezo sensor, ...

Redundancy enables:

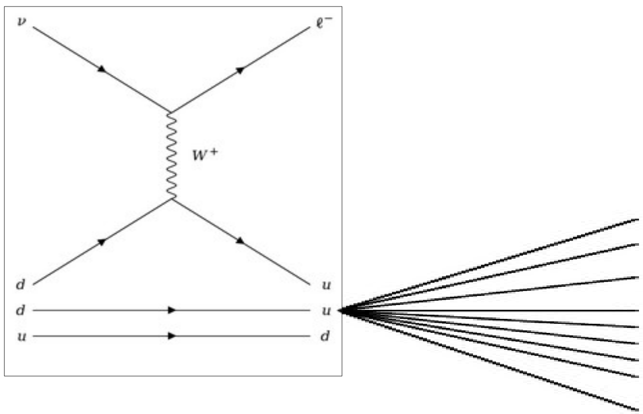
- Hardware failure
- Background discrimination
- High coverage
- SuperNova detection



KM3NeT's DOM performances at the MeV energy: Event rate for SuperNovae of different masses. A high enough multiplicity enable to observe an excess that can be attributed to a SuperNova. The background (mainly ^{40}K) is dominating for multiplicities below 6 coincidences only.

KM3NeT: Detection Principle

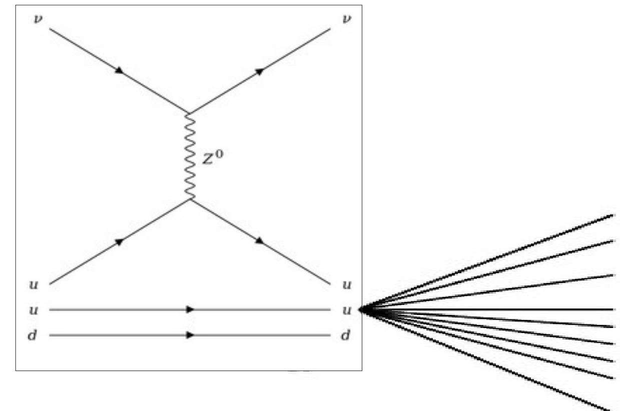
- **Detection Principle: Čerenkov light** from the interaction products
- Charged current interaction (**CC**)

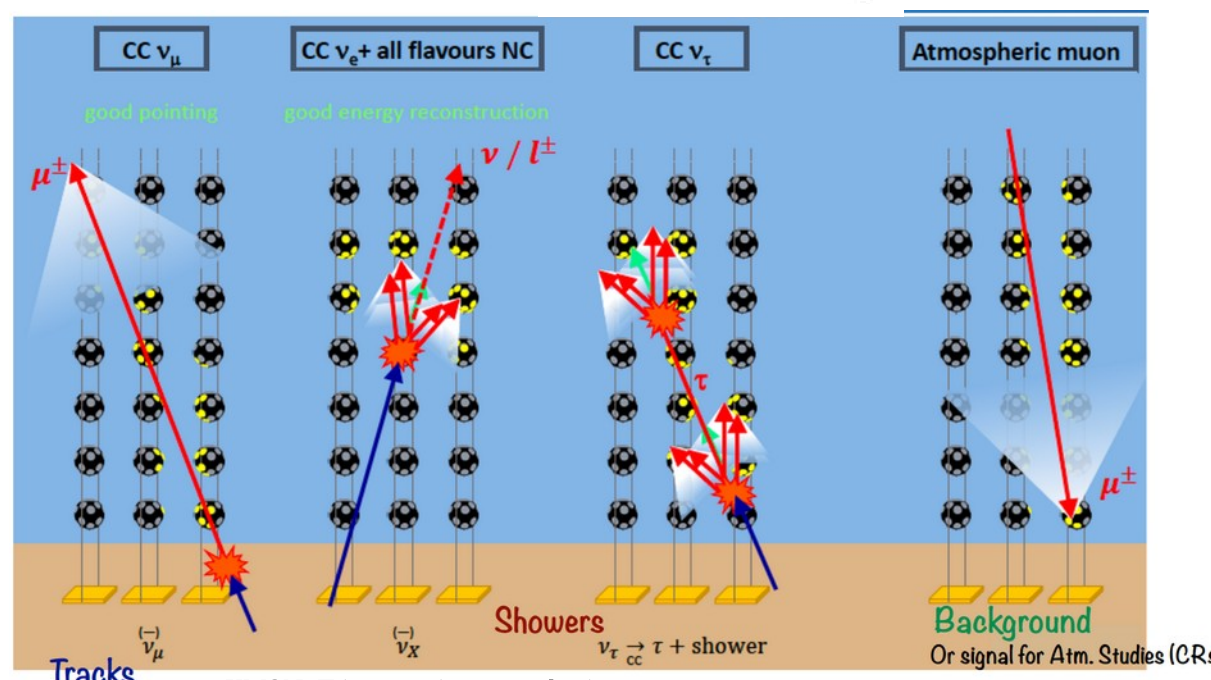


- The muons from CC interactions with E > 1GeV make a **track** in the detector
- Electrons + taus + NC interactions make **hadronic showers** in the detector
- The main background come from **atmospherical muons**

  ⇒ KM3NeT observes the **South Hemisphere**

- Neutral current interaction (**NC**)

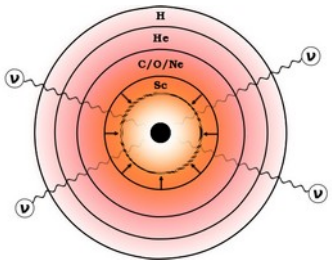


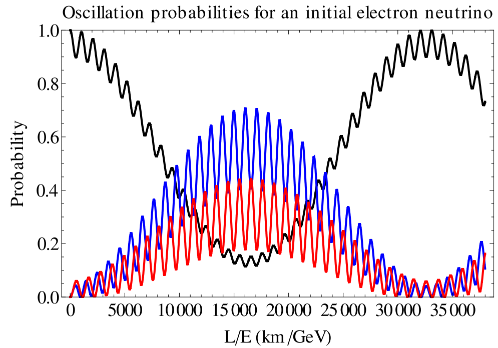


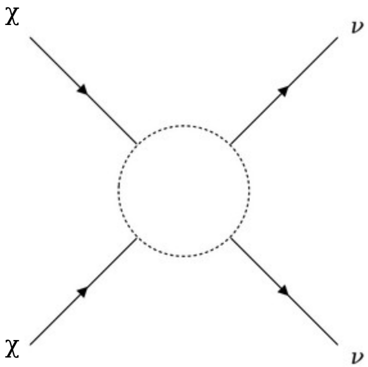
KM3NeT interactions topologies

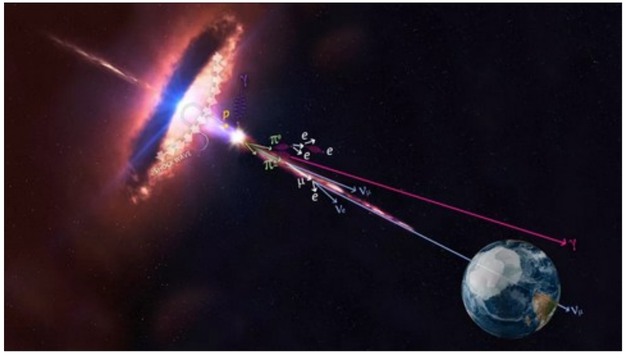
KM3NeT: Physics Objectives

Supernovæ	Neutrino oscillation	Dark matter search	Multi-Messenger Studies



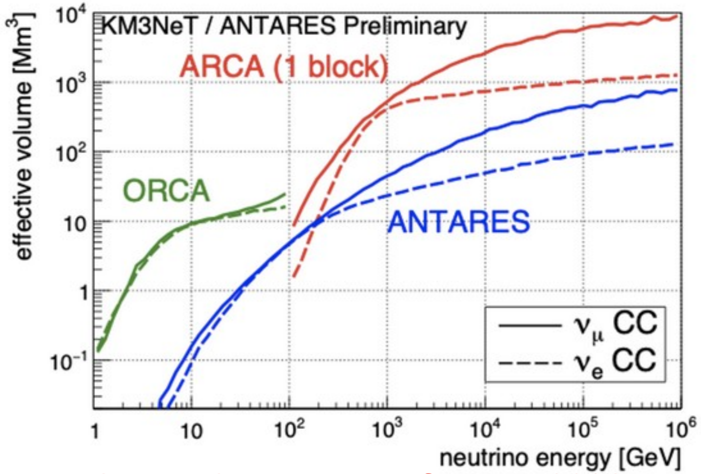






MeV — GeV — TeV — PeV

- ORCA: [1GeV-1TeV] range + MeV
- ARCA: [100GeV-1PeV] range + MeV



→ See KM3NeT Letter of Intent, 2016

S. Adrián-Martínez et al, 2016, J. Phys. G: Nucl. Part. Phys. 43 084001

Fast Radio Burst: Multi-Messenger candidate

Name: Fast Radio Burst (FRB)

Observables

Energy (isotropic): 10^{35}–10^{46} erg [1]

Duration: ~Millisecond

Traits: Dispersion Measure

Rotation Measure

Scattering

Repeating: Sometimes

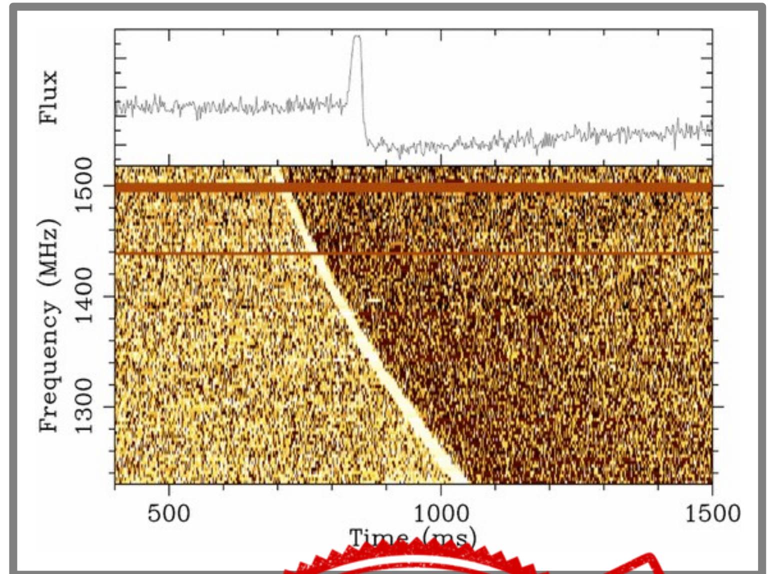
Inferred characteristics

Source: Extra-galactic sources

Magnetars(?)

Mechanism: Coherent emission

Environment: Energetic, dense, magnetized perturbed plasma



Petroff, Emily & Hessels, J. & Lorimer, D.. (2019). Fast radio bursts. The Astronomy and Astrophysics Review. 27. 10.1007/s00159-019-0116-6.

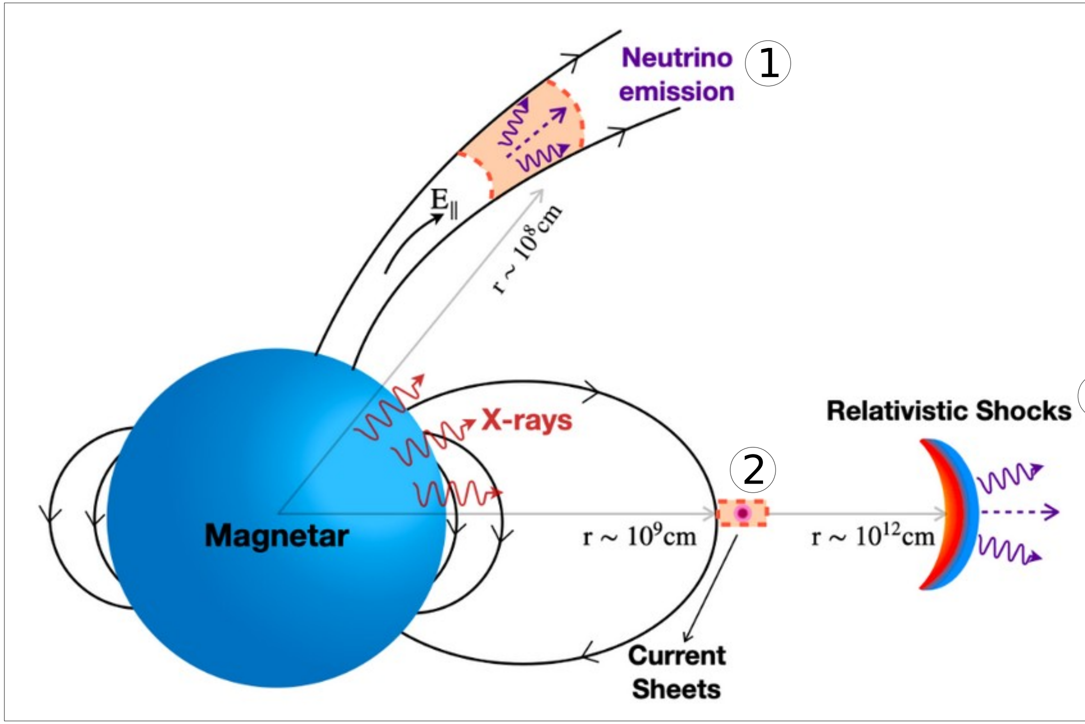
Seal:

1: The Physics of Fast Radio Bursts, Bing Zhang, 2022, arXiv:2212.03972

Fast Radio Burst: Multi-Messenger candidate

→ Dual emission of FRB and neutrino

Promising candidate : Magnetar → Energetic, dense, magnetized and perturbed plasma



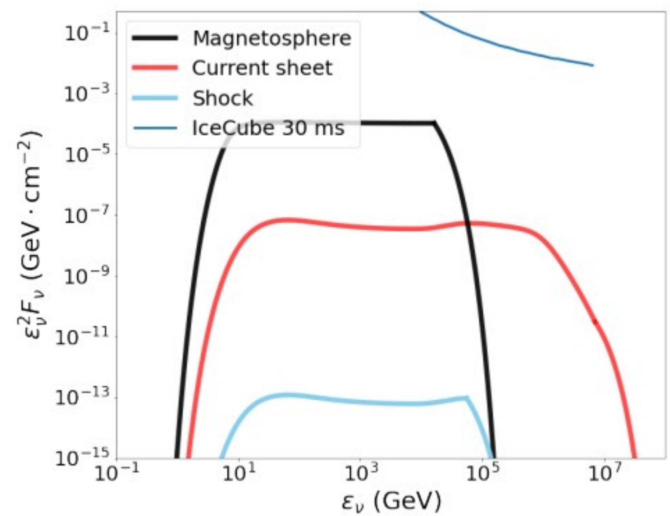
Envisaged neutrino production in the environment of a magnetar[1]. Three emission sites are studied: the magnetosphere, the current sheets region and the relativistic shocks region. The neutrinos are shown in purple.

From the coincidence of FRB20200428, many models for neutrino-FRB MM emissions. Here[1], three emission sites :

⇒ Magnetosphere (1)

⇒ Current sheet regions (2)

⇒ Shocked regions (3)



Neutrino spectra of FRB20200428[1] for each studied region. IceCube sensitivity for a window of 30ms is shown[2].

1: Neutrino emission from fast radio burst-emitting magnetars, Y. Qu & B. Zhang, doi:10.1093/mnras/stac117, 2022, Oxford University Press, MNRAS
2: Neutrino Counterparts of Fast Radio Bursts, Metzger et al., The Astrophysical Journal Letters, 902:L22 (9pp), 2020 October 10

Analysis Strategy

Binned cut-and-count analysis

1) Define an ON zone around the FRB, an OFF zone in the same region

2) Optimize cuts performed on the event dataset with the Model Rejection Factor [1]

3) Estimate the background in the ON zone from the OFF zone with scrambled data

4) Compare the signal rate to the background rate

$$\mathrm{MRF} = \frac{\bar{\mu}_{90}(n_{bg})}{n_s}$$ [2]

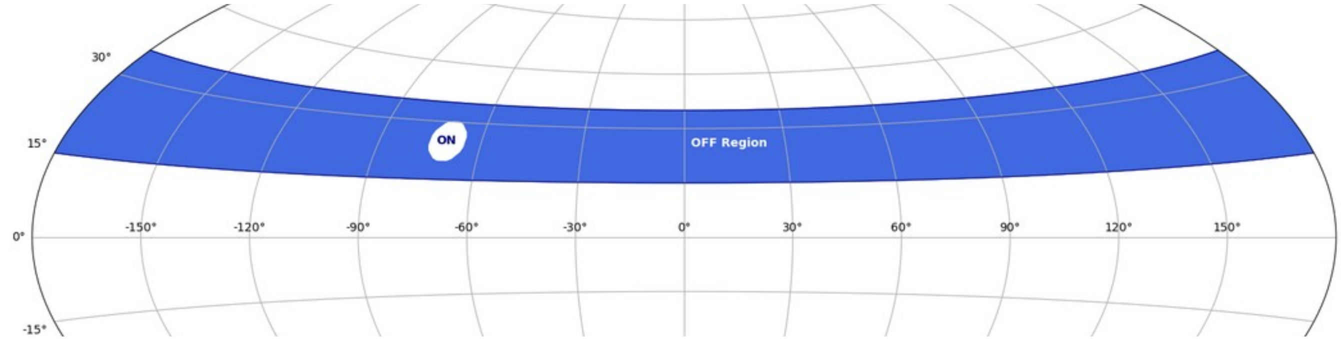


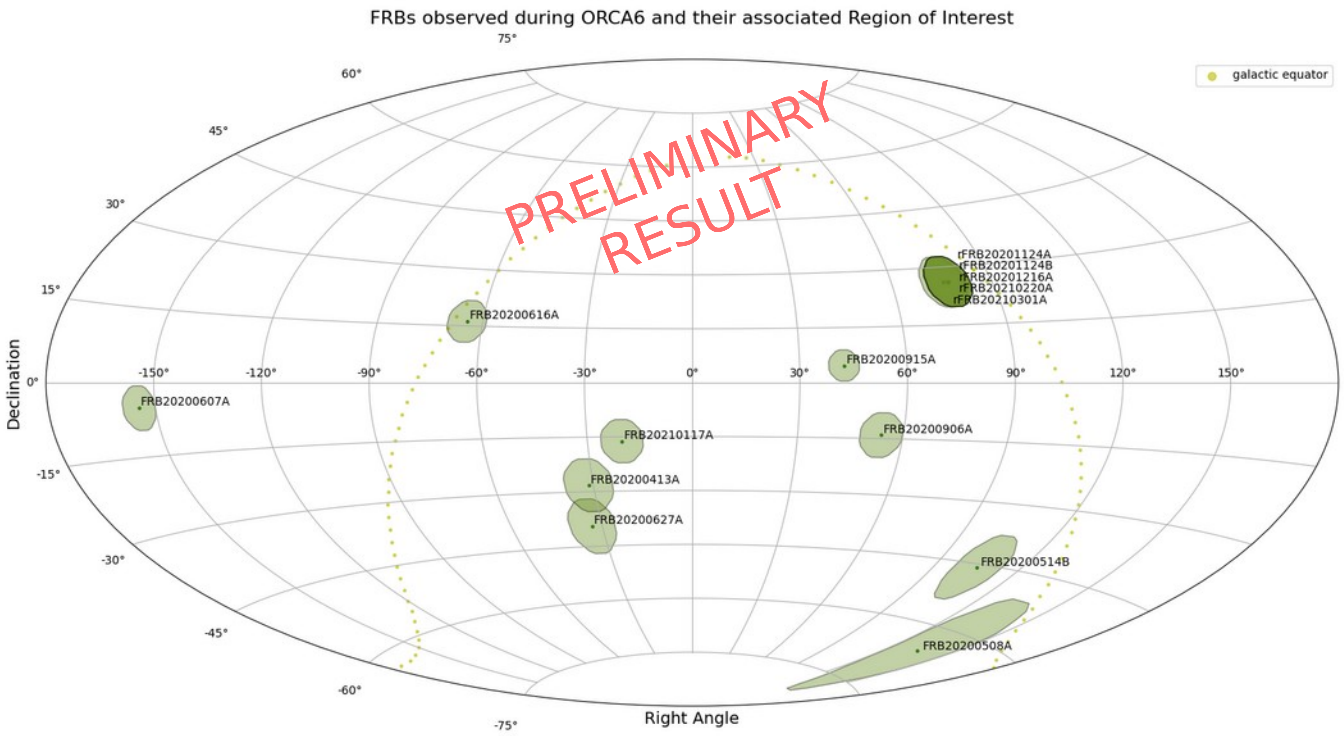
Illustration of the ON/OFF method in equatorial coordinates

1: Hill, Rawlins, 2003, doi:https://doi.org/10.1016/S0927-6505(02)00240-2
2: Feldman & Cousins, 1997, arXiv:9711021v2

Analysis Strategy

Data

- From January 1st, 2021 to March 31st, 2022, KM3NeT-ORCA was taking data with 6 Detection units
- During this time 43 FRB were observed, 14 of which were visible in the ORCA field of view
- The chosen time window is [t_{FRB} - 500s ; t_{FRB} + 500s]



Skymap (in RA-DEC coordinates) showing the optimized regions of interest optimized with the Model Rejection technique, for each of the 14 FRB studied. The green discs around each burst are the ON regions where neutrino events could be associated to significant signal.

Conclusion

- Data will be unblinded soon to obtain results;
- A more time-independent method is under investigation: *Unbinned likelihood analysis*
- KM3NeT FRB analyses will be added to those of IceCube[1,2,3] and ANTARES[4]

1: A Search for Neutrino Emission from Fast Radio Bursts with Six Years of IceCube Data, M.G. Aartsen et al., 2018, The Astrophysical Journal, 857:117 (13pp), doi:https://doi.org/10.3847/1538-4357/aab4f8

2: A Search for MeV to TeV Neutrinos from Fast Radio Bursts with IceCube, M.G. Aartsen et al., 2020, arXiv: 1908.09997v2

3: A Search for Coincident Neutrino Emission from Fast Radio Bursts with Seven Years of IceCube Cascade Events, M.G. Aartsen et al., 2022, arXiv: 2212.06702v1

4: Search for high-energy neutrinos in coincidence with Fast Radio Bursts with the ANTARES neutrino telescope, The ANTARES Collaboration, 2018, arXiv:1807.04045v2

Thank you for your attention!

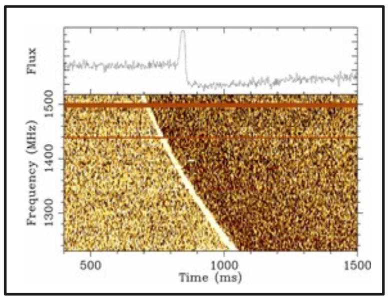
Backup

Fast Radio Bursts

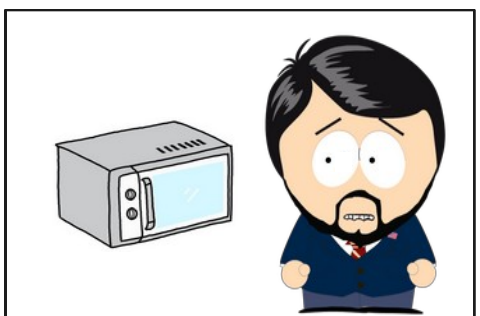
Historical development

2002 2005 2008 2011 2014 2017 2020 2023

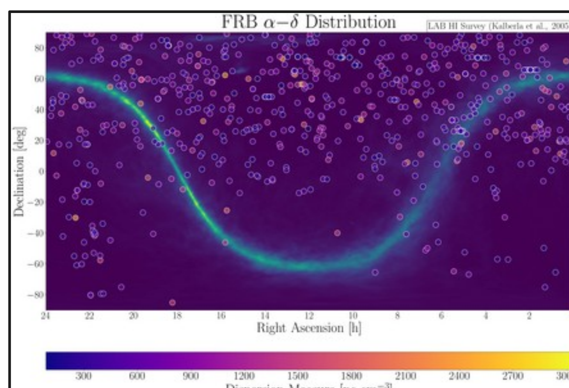
"Lorimer Burst"



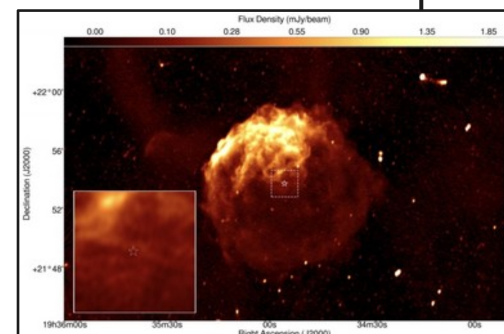
Parkes "perytons":
micro-wave oven signals



FRB 20121102: first
repeater identified



FRB 20200428: galactic
FRB from SGR J1935+2154,
with HXRB coincidence



Today: 825 FRBs from
which 24 repeaters

Method: ON/OFF

- ON/OFF binned analysis
- "ANTARES Strategy": ±6h of observation around the FRB observation time
- Declination band of ±10° for the OFF zone
- MRF optimization for the choice of minimal BDT score and ROI size

Procedure: