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Italiadomani  
PIANO NAZIONALE  
DI RIPRESA E RESILIENZA



## Annual KM3NeT4RR meeting: WP7

R. Coniglione - INFN-LNS

C. Trigilio - INAF - CT

F. Bocchino - INAF -CT

A. Marinelli - Univ. Federico II - Napoli

M. Sanguineti - Univ. Genova

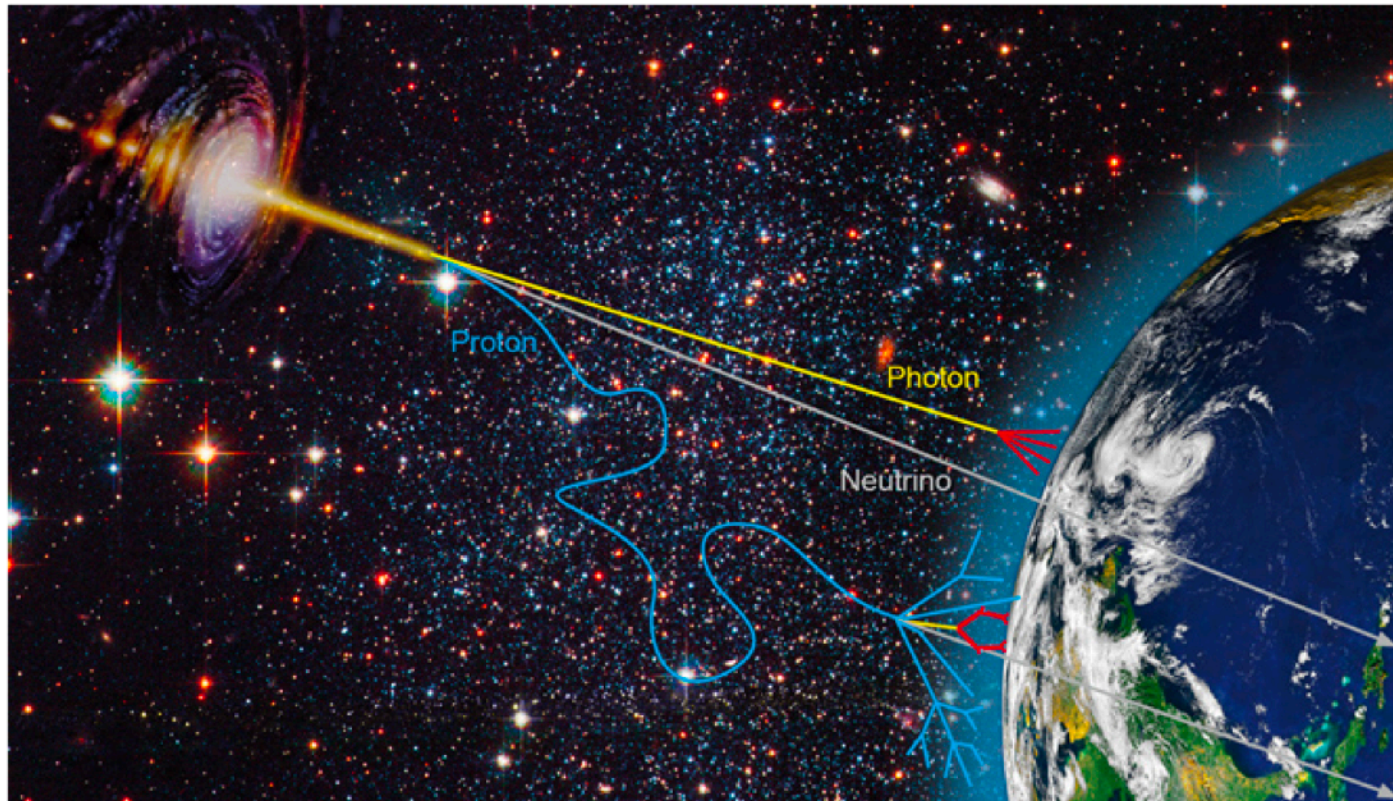
I. Tosto e Melo - Univ. Catania

M. Mastrodicasa - Univ. La Sapienza Roma



# KM3NeT4RR WP7 working package

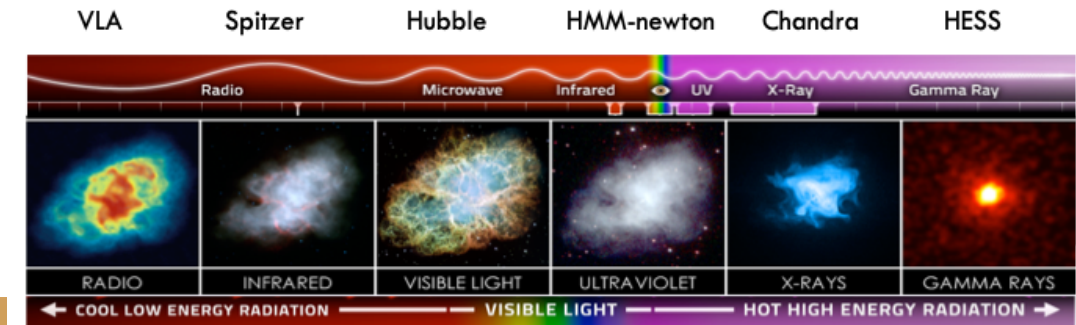
WP7 - Implementation of Multimessenger liasons 🖱️ The only WP addressing items of physics relevant for KM3NeT/ARCA



## Neutrino astronomy with ARCA

Neutrinos, gamma rays and Gravitational Waves probably emitted in the most powerful cosmic accelerator (*Nature paper*)

Correlations between cosmic neutrinos and other particles or observation in different wave length are important 🖱️ **multi messenger astronomy**



## KM3NeT4RR WP7 - Implementation of Multi-messenger liasons

### Institutes participant:

#### Coordinated by INFN

- INAF - Osservatorio Catania (C. Trigilio) 👉 connection with radio observation (implementation of hardware)
- INAF - Osservatorio Palermo (F. Bocchino) 👉 sophisticated modelization for galactic sources and estimate of neutrino flux (implementation of hardware)
- Università Federico II - Napoli (G. Miele) 👉 model for diffuse neutrino emission
- Università di Genova (M. Sanguineti) 👉 correlation with gamma-ray observation (HAWC and LHAASO)
- Università di Catania (A. Tricomi) 👉 correlation with Gravitational waves and support to external partners
- Università La Sapienza - Roma (I. Di Palma) 👉 Fast reconstruction algorithm and event selection to alert the astronomical community in real time and follow external alert and GRB follow-ups

### Funded with 1.7M€:

- Personnel 745.6k€ 2 👉 2 researchers, 1 technologist, 5 RTDA
- Scientific instrumentation 499k€ 👉 upgrade of Noto radio antenna and Procurement of computer cluster for simulation and storage
- Training activities (PhD) 109.6k€ 👉 3 PhD
- Indirect cost (7%) 94.8k€

## KM3NeT4RR - WP7 meetings

### 3 WP7 meeting already done

- In presence @Bologna 24-25 May 2023 🖱️ focused on organizing future work 🖱️ about 33 participants
- Remote 9 October 2023 🖱️ discussed the work done and main criticalities
- In presence @Caserta 27-28 November 2024 🖱️ discussed the work done and main criticalities 🖱️ about 35 participants

In synergy with KM3NeT data analysis activity



- Refurbishment of the Noto Radiotelescopio for observations at high frequency (20-100 GHz)
- Data acquisition system for Noto Radiotelescopio  
TD (technologist): Alan Ruggeri
- Radio observations and Follow-up of neutrino sources TD (scientist): Sara Loru



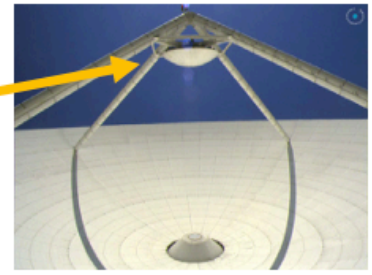
# Procurement finalized! The work is done!



20 November 2024  
Secondary mirror arrives at Noto



At the moment it remains stored in a warehouse



The mirror is will be installed in the radiotelescope next week

INAF-Osservatorio Astrofisico di Catania



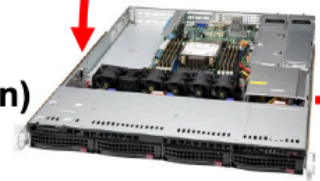
**Software:** To be refined and tested next year after completing the system



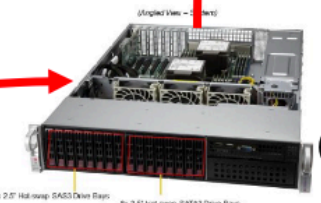
December 2023

Server (Acquisition)

INAF-Noto



100 km

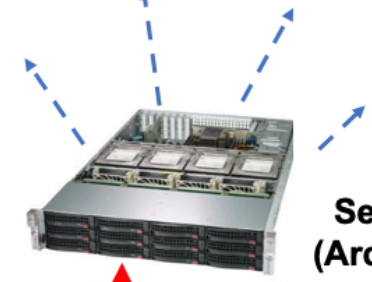


Catania-INAF-OAcT

Server (Archive)

Server (Data reduction)

World

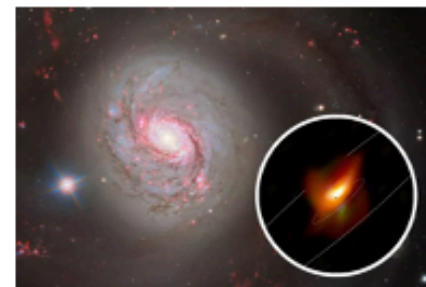


Searching for electromagnetic (radio) counterparts of neutrino sources.

- Selection of a sample of radio sources that are candidates high energy neutrinos (transient, variable radiosources).
- Monitoring a sample of neutrino source candidates with Noto 32m radio telescope.
- Regular observations of the sample at high frequency (20-100 GHz).
- Follow-up observations in case of detection with KM3NeT.
- Triggering KM3NeT search in case of high state of activity at radio.

#### Selected samples:

AGN/Blazars, Seyfert galaxies,  
Micro-quasars





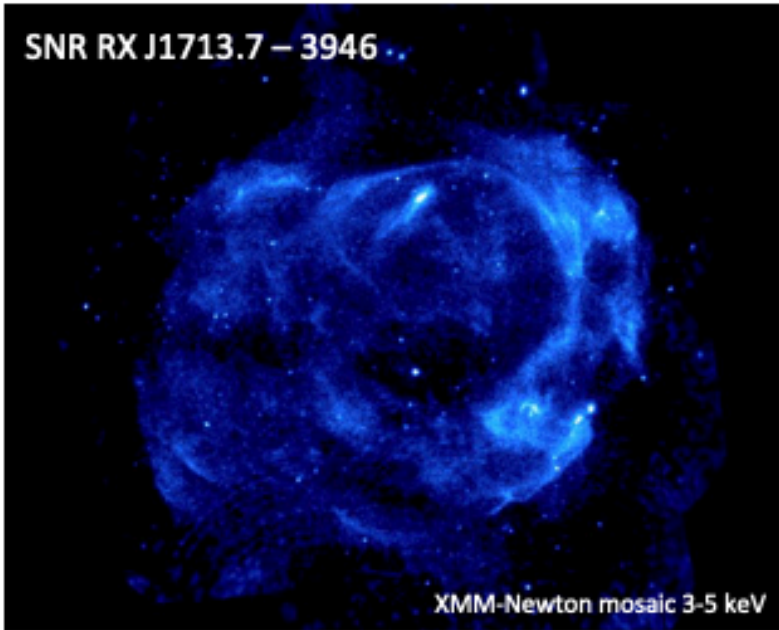


## WP-7 – Activity 2: Models of Galactic candidate neutrino sources and comparison with multi-messenger observations (Fabrizio Bocchino, Sabina Ustamujic)

researcher

This activity focuses on supernova remnants (SNRs), which are among the most promising sources of Galactic neutrinos, by means of high energy particles accelerated at their shocks and collisions with nearby molecular clouds acting as targets.

SNR RX J1713.7 – 3946



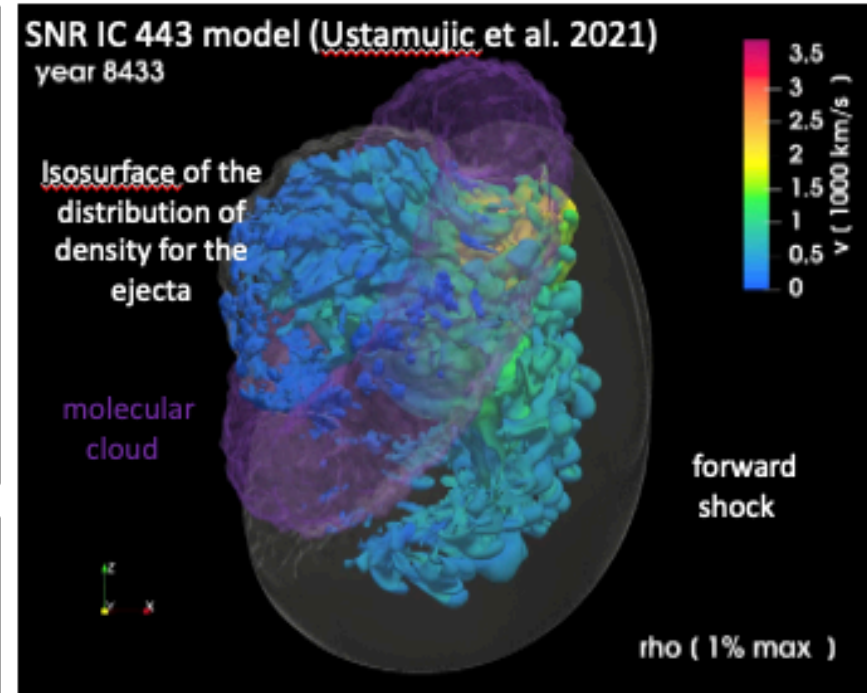
XMM-Newton mosaic 3-5 keV

1) **Selection of interacting SNRs** (molecular clouds, turbulent and clumpy ambient medium) that could show bright hadronic gamma-ray emission. **Completed.**

2) **Development of accurate 3D HD/MHD models** for the already selected SNRs where the circumstellar/interstellar medium is parametrized according to the observations. **Partially completed** (still on-going in some cases, e.g. SNR RX J1713.7 – 3946). Needs time and dedicated HPC resources.

3) **Synthesis of thermal and non-thermal multi-wavelength emission** to be compared with observations. In particular, the **hadronic gamma-ray emission**, which is crucial to infer the expected **neutrino emission**. **On-going.**

SNR IC 443 model (Ustamujic et al. 2021)  
year 8433





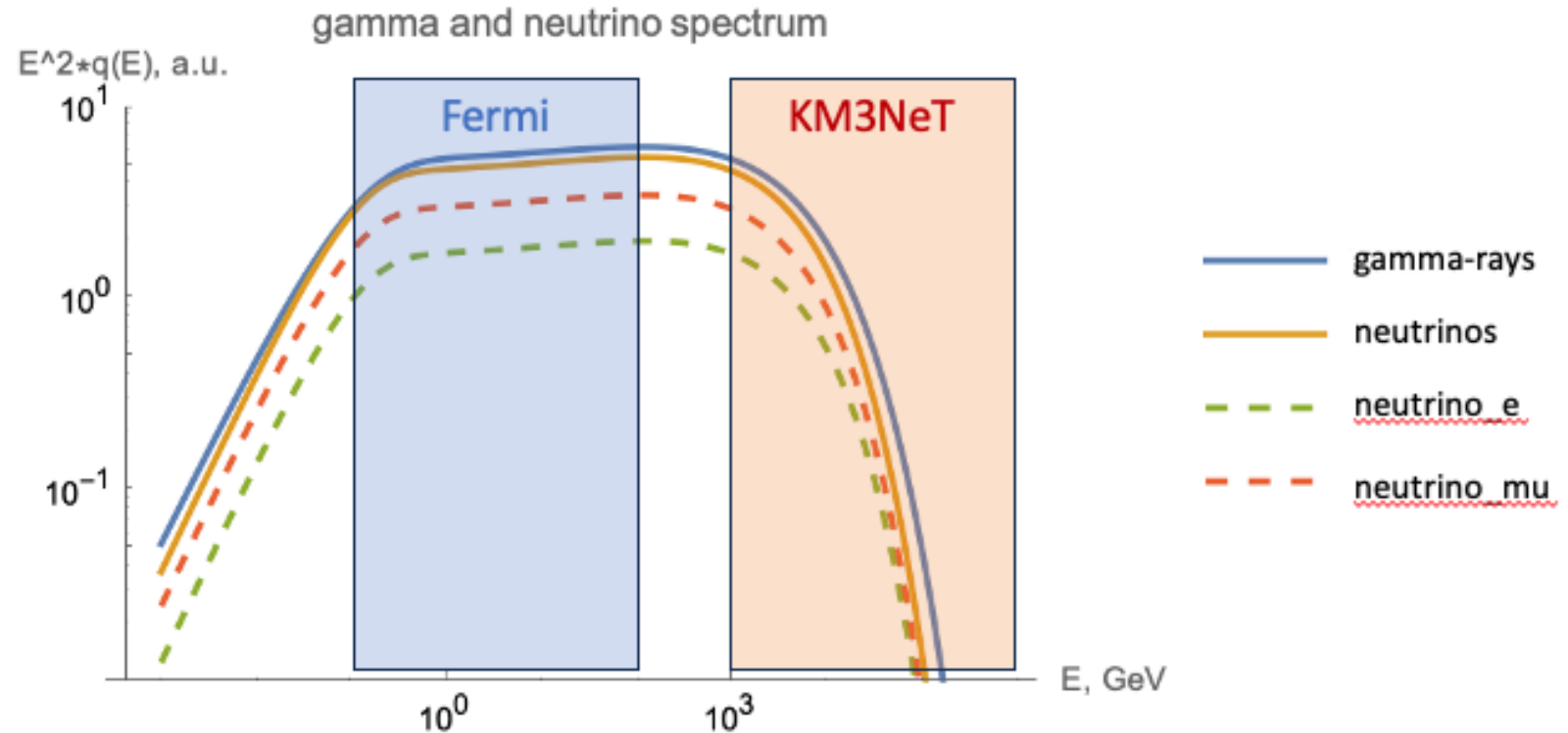


## WP-7 – Activity 2: Models of Galactic candidate neutrino sources and comparison with multi-messenger observations (Fabrizio Bocchino, Sabina Ustamujic) researcher

Estimating the neutrino emission. **On-going work.**

We are developing a tool that calculates the gamma-ray and neutrino emission from the 3D HD/MHD models.

We consider the sensitivity of ARCA/KM3NeT, which will allow to make predictions about the detectability of the sources.

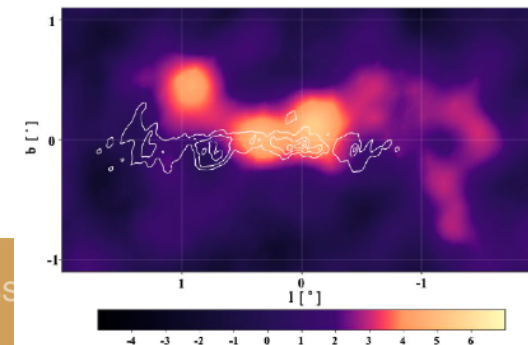
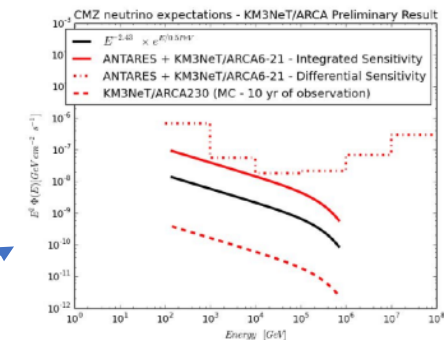
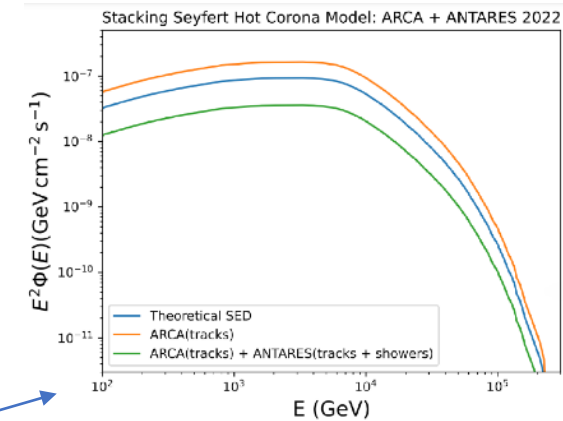


22 November 2024: Presentation of our activities in a seminar entitled "**Interacting supernova remnants as high-energy and neutrino sources**", and inauguration of the dedicated HPC facility installed at INAF-OAPa

## Large activity both on modelization and data analysis

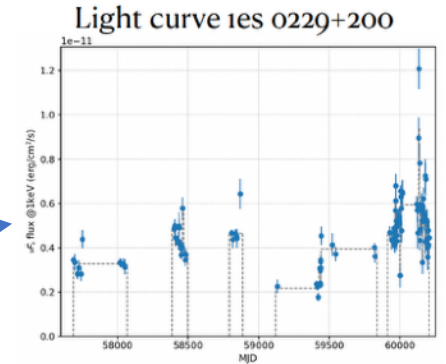
- Expectation of KM3NeT/ARCA for Starburst Galaxies, diffuse and point-like case for full ARCA detector.
  - Differential sensitivity and discovery potential obtained for the most promising scenario applied to this kind of sources
  - Status 🖱️ Everything done and published
- Stacking analysis with ARCA21 for samples of ultra luminous infrared galaxies (SBG) and Seyfert galaxies.
  - SBG ARCA21 track-like events
  - Seyfert ARCA 21 (track-like event) + ANTARES (Track-like and shower-like events)
  - Status 🖱️ Done all the preliminary studies, unblinding to be finalized
- Study of extended region of our Galaxy, where massive molecular clouds and possible hadronic Pevatrons are placed, with the intermediate phases of ARCA (ex. Central Molecular Zone, Cygnus region)
  - Status 🖱️ Done the expectations with MC next Upper Limits with ARCA

🖱️ PhD R. M. Bozza



## Large activity both on modelization and data analysis

- Template fitting analysis considering the data of ANTARES and ARCA in partial configuration using the template provided by the **LHAASO experiment for the diffuse Galactic emission**.
  - Differential sensitivity and discovery potential obtained for the most promising scenario applied to this kind of sources
  - Status 👉 Preliminary studies on the MAP info to be used, likelihood analysis to be finalized.
- **Off-line time dependent follow up of the extreme-blazars**. Using a catalog of XRT observatory, applying a bayesian block analysis to the x-ray light curve and apply a likelihood study to ARCA intermediate steps data. Created a catalog of extreme blazars with the bayesian analysis finalized.
  - Status 👉 Likelihood analysis to be done with unbinned framework.

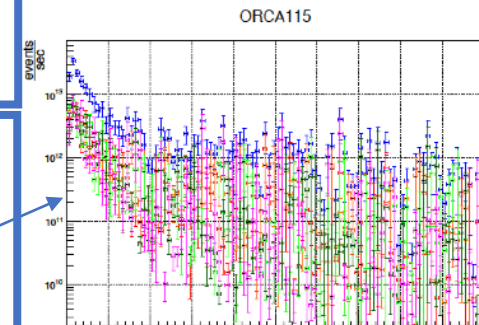


- **Off-line time dependent follow up of Core Collapse Supernovae** at high energy with intermediate steps of ARCA. Created a catalog of supernovae happened from ARCA 9 on.
  - Status 👉 Likelihood analysis to be done with unbinned framework.

👉 PhD V. Oliviero

- **Study of CR mass composition** through the analysis of atmospheric muon imprint in the ORCA detector. Through CORSIKA simulation we searched for a possible correlation with the atmospheric muon signal observed with ORCA and the mass composition of primary CR interacting in the atmosphere. MC studies finalized, a dedicated BDT need to be studied.

👉 RTDA A. Condorelli





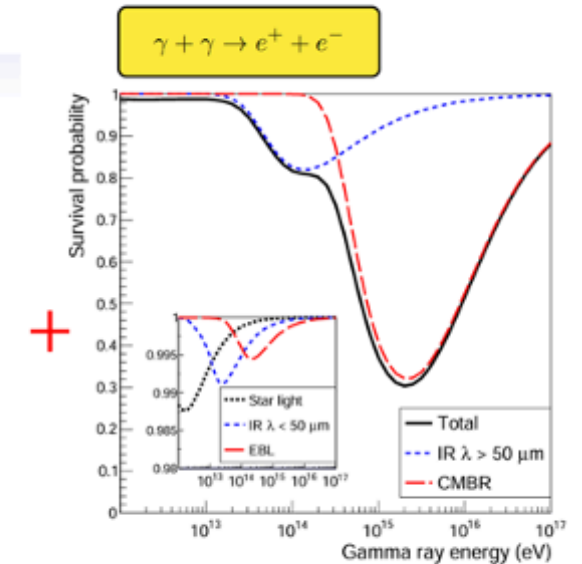
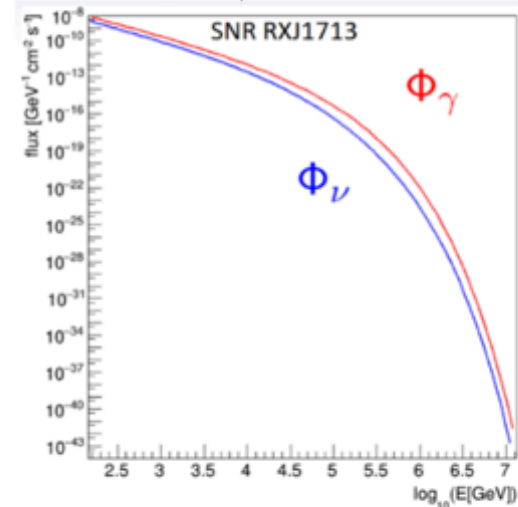


## Follow-up of the neutrino emission from known gamma-ray celestial sources

### ACTIONS:

- combining information from gamma-ray observatories and neutrino telescopes → neutrino candidate list
- gamma-ray spectra + correction for gamma-ray absorption used to estimate the neutrino flux from a source

$$\Phi_\nu(E_\nu) = \int \frac{dE_\gamma}{E_\gamma} K_\nu(E_\nu, E_\gamma) \Phi_\gamma(E_\gamma)$$



Neutrino to gamma-ray  
conversion

Villante-Vissani 2008  
Mascareti-Vissani 2019

gamma-ray absorption

Papescu et al 2017  
Lipari-Vernetto 2016

👉 PhD V. Parisi

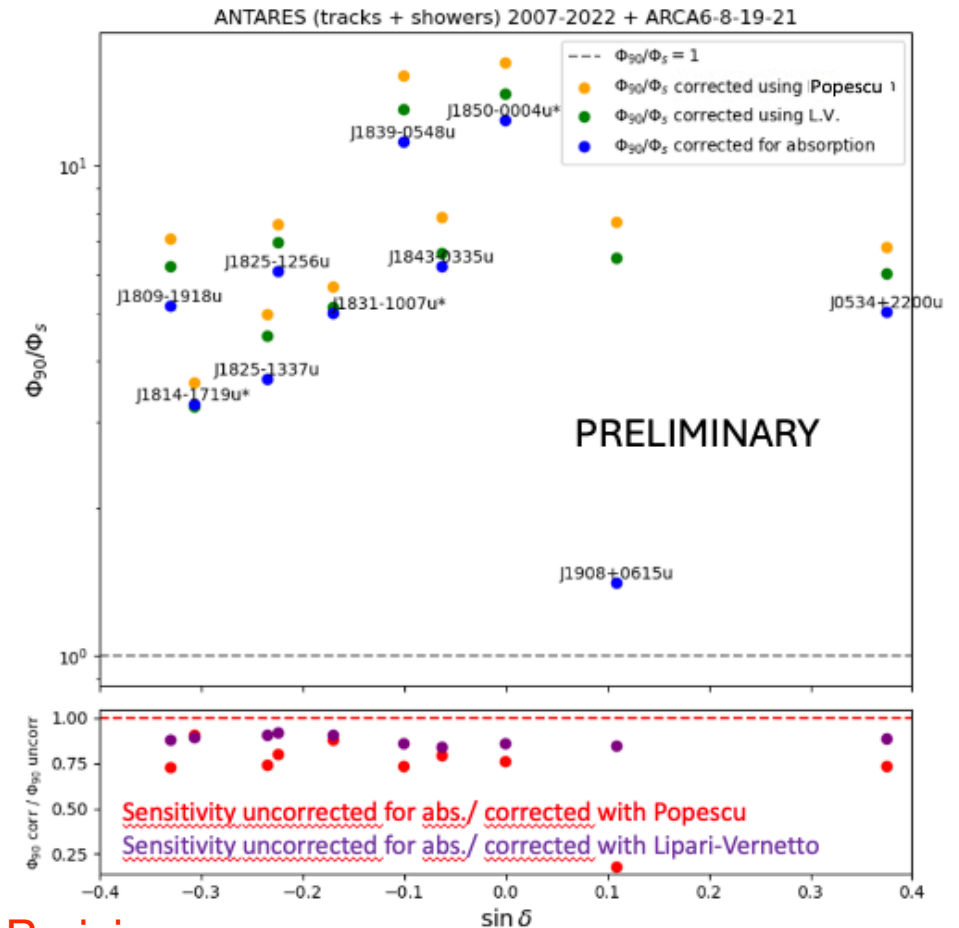
## Follow-up of the neutrino emission from known gamma-ray celestial sources

### ACTIONS:

- combining information from gamma-ray observatories and neutrino telescopes → neutrino candidate list
- gamma-ray spectra + correction for gamma-ray absorption used to estimate the neutrino flux from a source
- binned likelihood approach to estimate the sensitivity and discovery for a candidate source.
- 1<sup>st</sup> test : 10 Pevatrons candidate, selected from the 1<sup>st</sup> LHAASO catalog

### FUTURE STEPS:

- extend the source list to all the sources in the catalogues from LHAASO and HAWC.
- implement a stacking analysis to improve the performance



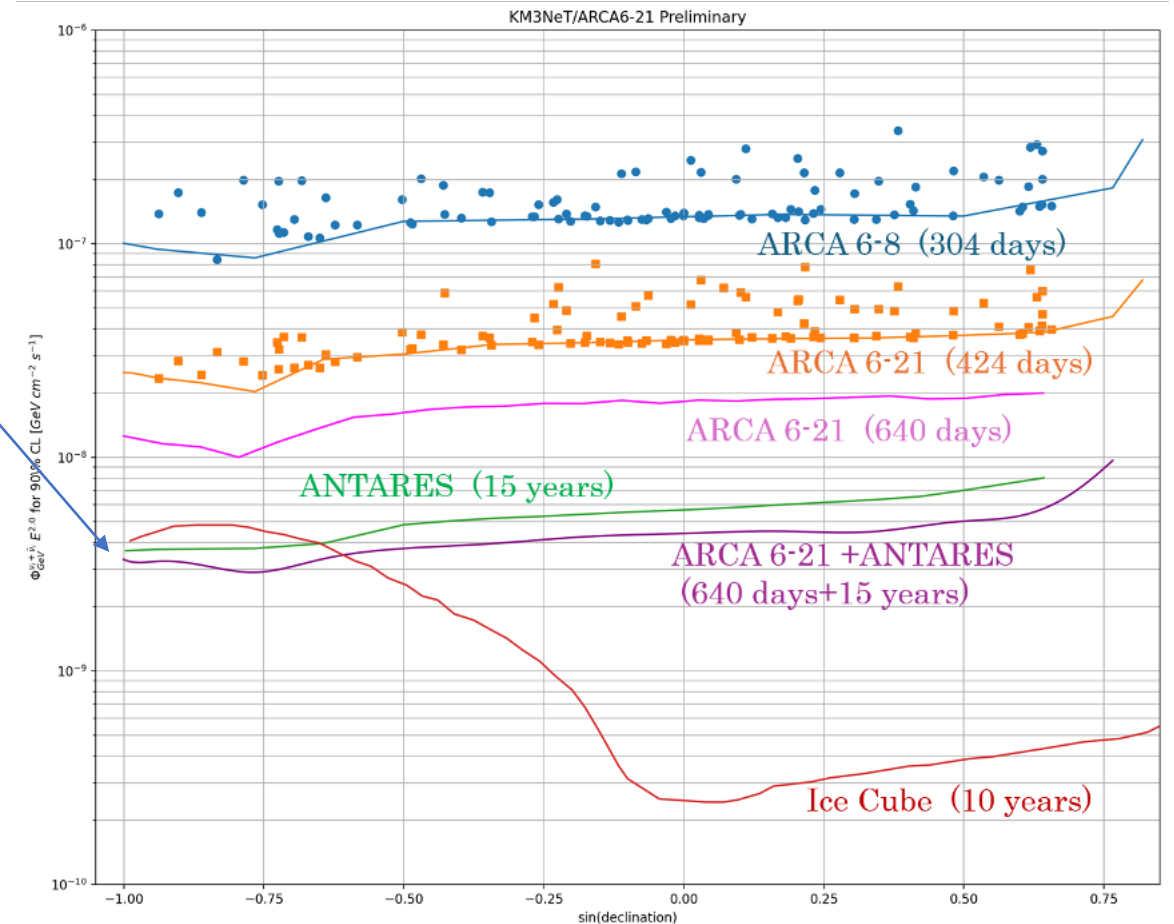
👉 PhD V. Parisi

## OTHER ANALYSES USING THE SAME FRAMEWORK:

- combined KM3NeT/ARCA-ANTARES point-source analysis  
B. Caiffi, V. Kulikovskiy, V. Parisi, M. Sanguineti, S. Zavatarelli

- ARCA6-21 all sky point-source analysis  
👉 PhD **V. Parisi** in collaboration with R. Muller (INFN Bologna)

- Mass production of data used for multi-messenger analysis
- Enhancement of the acoustic data filter and its implementation
- Calibration at the Genova DU Integration site (dark room calibration)  
👉 RTDA **F. Badaracco**





👉 RTDA I. Tosta e Melo

## Gravitational Waves High Energy Neutrino (GWHEN) analysis:

- Sub-threshold joint analysis using low significance events:

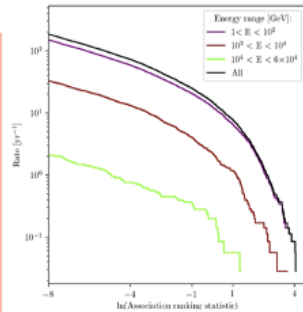
Joint multimessenger analysis aimed at detecting weak GW transients associated with weak neutrino.

Results got so far:

Background estimation to compute a False Alarm Rate with shuffled time:

USED GW AND KM3NeT DATA AROUND  
FEB/MARCH 2020 (~45 DAYS)

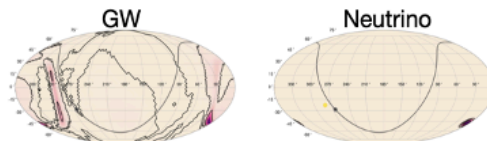
### Results: Background



- Highest ranked background association

GW candidate	KM3Net candidate
GPS time: 1267389195.61	KM3Net mjd: 58913.869
Mchirp: 3.4 SM	Reco energy: 8.242 GeV
Source classification: Terrestrial -1	BDT score: 3
FAR: ~ 1 Hz	$Q_s \sim 0.09$ (signal like)
$Q_g \sim 0.14$ (slightly signal like)	

Joint properties  
Time delay: ~ 324 s  
Sky overlap: ~ 176  
Association rank: ~ 58



Next up:  
Background computation will be updated to include a sky shift in addition to the real time

- Triggered analysis both modelled and unmodeled:

We take to sky position and time of the HEN trigger and look if there was a GW in coincidence.

Results got so far:

Analysis design is done:

- Time window: -500;500 for Xpipeline
- Waveforms to be simulated: long GRBs, inspirals. Short GRBs burst from f-modes.
- Tested X-pipeline

Expected results in line with unmodeled searches:

Next up: Ready to run with KM3NeT triggers - A catalog of well-localized neutrinos only during O3 is being prepared

- Manual search development for the shifter tools of KM3NeT:

Manual analysis - one analysis which does not start automatically allowing the user to use any trigger of interest.

- A framework is currently being developed to submit custom requests.
- Done so far:
  - Code development ongoing
  - Test the latest modifications



## ● KM3NeT and Unifal (Brazilian University):

- **Prof. Cassius de Melo:** new associate member of KM3NeT
  - Fundings awarded for in-coming and out-coming visits between the departments
  - Perspectives of creating a KM3Net group in Brazil
  - **Lucas Marques:** Master student *Master thesis: Multimessenger analysis with KM3Net (portoghese version: Analise multi mensageira usando dados do experimento km3net)*

## ● MoU with Metsahovi Radio Observatory:

A 14-metre radio telescope in Finland.

- **Proposal:**  
FINCA+Metsähovi AGN/multimessenger + KM3NeT to discuss potential ways of collaborating on the blazar-neutrino connection: perform a spatio-temporal association analysis between a sample of blazars in the radio band and the most up-to-date KM3NeT neutrinos



👉 RTDA I. Tosta e Melo

## ● Calibration of the detector

- **Provide calibrated detector file for data acquisition.**

Merging of all the time offsets measured during the DU integration stage (dark room calibration), in situ calibration (atm. Muons and nanobeacon) and time offset due to asimmetries.

- **Maintain a clear documentation**
- **Coordination of on shore detector calibration at the integration site of Catania**
- **Support for external users**

👉 RTDA G. Ferrara



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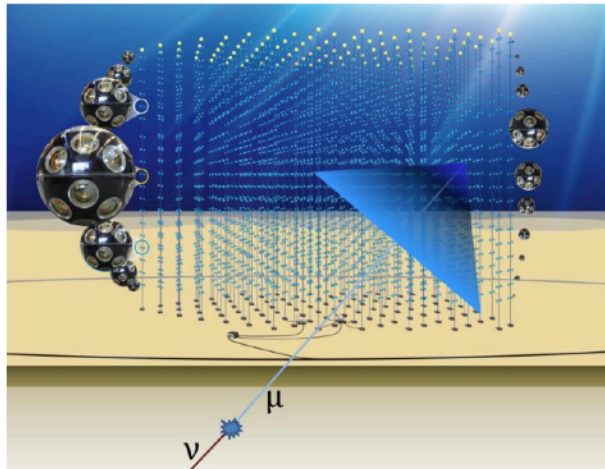
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SAPIENZA  
UNIVERSITÀ DI ROMA

👉 RTDA M. Mastrodicasa

# KM3NeT multi-messenger program

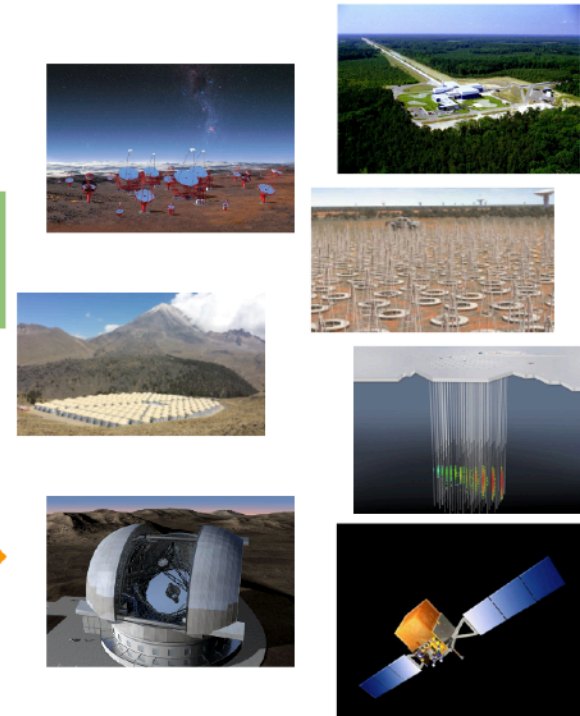


KM3NeT ARCA and ORCA

Follow-up of external alerts received from the multi-messenger community and search for spatial and temporal coincidences

LOADING...

Sending of alerts when interesting events are detected to trigger follow-ups



Multi-messenger community

- **Dedicated software installed at both shore stations** for real-time analyses (RTA)
- **Events reconstructed and classified** in real-time, within 7 seconds (RTA platform active since more than 3 years)
- **Receiving alert system operative** (automatic online analyses running since ~2 years)
- **Sending alert system almost defined**

**Significant contributions from the Rome group to these activities**



# Contributions of the Rome group to online activities

- ✔ Setup of the whole complex framework of softwares adopted in ARCA online processing
- ✔ Fast reconstruction algorithms for real-time reconstruction implemented
- ✔ Fast machine learning methods for real-time classification implemented
- ✔ Monitoring tools to continuously check all real-time processes and outcomes implemented
- ✔ Automated module to use the last available calibration infos in real-time analyses implemented but dynamical calibration needed
- 🔄 24/7 Continuous maintenance and update of the ARCA RTA framework + continuous support to online shifters (very demanding and time-consuming task, but essential)
- 🔄 Loading... Adaptation of the ARCA online system in order to be able to send alerts (work in progress)

👉 RTDA [M. Mastrodicasa](#)