Martina Marconi

PhD annual report - second year

Supervisors: M. Sanguineti (UniGe), V. Kulikovskiy (INFN-GE), D. Dornic (CPPM)

Summary of research activity

I carry out my research as part of the KM3NeT experiment. KM3NeT is an underwater neutrino telescope under construction in the Mediterranean Sea. It detects the Cherenkov light produced by neutrino interactions in seawater using multi-PMT Digital Optical Modules (DOMs), each equipped with 31 3-inch photomultiplier tubes (PMTs). The DOMs are arranged vertically along flexible lines, called detection units (DUs), which are anchored to the seafloor; each DU hosts 18 DOMs. The infrastructure includes two detectors: KM3NeT/ARCA, optimised for the detection of high-energy neutrinos, and KM3NeT/ORCA, optimised for lower energies. Together, they provide sensitivity to cosmic neutrinos across a broad energy range, from a few MeV to hundreds of PeV. Both detectors are already taking data with about 23% of the planned detection units currently deployed.

KM3NeT alert system for real-time multi-messenger astronomy The KM3NeT real-time framework consists of three main components: (1) real-time reconstruction and classification of events from the ARCA and ORCA detectors; (2) reception and processing of external alerts from other facilities, followed by rapid follow-up analyses; and (3) a continuous alert-sending system that monitors data streams through dedicated pipelines, identifies potential cosmic neutrino events, and dispatches KM3NeT alerts when predefined criteria are met. So far, the main focus of my PhD has been the design, development, and implementation of the KM3NeT alert-sending system (3). KM3NeT neutrino alerts are selected through a dedicated pipeline composed of multiple modules that evaluate both the properties of the neutrino candidates and the presence of potential astrophysical counterparts, identified via an automatic real-time search. An initial preselection is applied to reduce the background for both detectors. This is followed by specialized selection pipelines, each optimized for a specific objective: one for identifying single, track-like high-energy events, and another for detecting event multiplets that are correlated in time and space. All candidate alerts are then processed by a module that searches for potential astrophysical counterparts. If a neutrino event is individually significant according to high-energy or multiplet criteria, it is sent as an alert, along with any associated astronomical context if a correlation is found. Otherwise, a combined neutrino–astro significance is calculated, and an alert is issued only if this combined significance exceeds a predefined threshold. During my second year, I focused my activity on the development of the preselection and high-energy selection modules for both ARCA and ORCA. The selection I implemented in the high-energy pipeline is specifically tuned to minimize atmospheric background contamination and to favour well-reconstructed cosmic neutrino candidates with high angular resolution. In addition, I conceived and developed a new statistical metric, now adopted in both the high-energy and multiplet pipelines, which assigns an event-by-event significance in real time. This metric, functionally similar to a p-value, quantifies the probability that a candidate event is not of atmospheric origin. It is entirely model-independent and based solely on data-driven methods.

Search for high-energy neutrinos from Tidal Disruption Events with KM3NeT Tidal Disruption Events (TDEs) are astrophysical phenomena that occur when a star passes close enough to a supermassive black hole to be torn apart by tidal forces. If the disruption happens outside the event horizon, part of the stellar debris is accreted, forming a disk and producing a luminous flare. In recent years, TDEs have gained significant attention in the context of multi-messenger astrophysics. Three TDEs have so far been potentially associated with neutrino events, establishing TDEs as candidate sources of PeV neutrinos. These neutrino-associated TDEs share several observational features, including the detection of infrared dust echoes, X-ray emission, and neutrino arrival times delayed by about 100 days with respect to the optical/UV peak. These signatures point to the presence of dense photon fields — particularly in the IR range — that can serve as targets for hadronic interactions producing neutrinos. I have started working on a dedicated analysis to search for high-energy neutrinos from TDEs using KM3NeT data. The analysis strategy involves selecting a sample of TDEs that exhibit dust echoes in their light curves and performing a space-time correlation search for neutrino emission. So far, I have completed the construction of the TDE catalog for this analysis and will soon begin the neutrino-flare correlation study using an ON/OFF technique. In parallel, I supervised a master's thesis project by Lucia Barigione, titled *Search for Extremely-High-Energy Neutrinos from Tidal Disruption Events with the KM3NeT/ARCA Detector*, which applied a cut-and-count method to have a preliminary estimation of the sensitivity of KM3NeT to the neutrino flux from TDEs.

Search for a cosmic neutrino source from the direction of KM3-230213A On 13 February 2023, KM3NeT/ARCA detected an ultra-high-energy neutrino event, designated KM3-230213A, with an estimated energy of approximately 220 PeV — the most energetic neutrino ever observed to date [1]. Given the possibility that the hypothetical astrophysical

source that produced KM3-230213A could also emit lower-energy neutrinos, a dedicated analysis has been performed to search for a point-like neutrino source consistent with the direction of KM3-230213A. My contribution focused on the neutrino source search using the KM3NeT/ORCA online datasets. The KM3NeT Collaboration published the observation of KM3-230213A in [1], with the article including my contribution to the analysis. I presented an oral contribution regarding this work at the ICRC 2025 conference in July.

KM3NeT/ARCA optimization for very-high-energy neutrinos I carried out simulation-based astronomy potential studies on an alternative design for the second building block of KM3NeT/ARCA, featuring increased spacing between detection units and digital optical modules. This sparser configuration aims to enhance sensitivity to neutrinos with energy above the PeV scale. I finalized this preliminary investigation and presented the results in November at "KM3NeT4RR WP7 meeting: Implementation of Multi-Messenger Liaison".

Publications

[1] KM3NeT collaboration, *Observation of an ultra-high-energy cosmic neutrino with KM3NeT*, *Nature* **638** (2025) 376 *Personal contribution:* search for a cosmic point-like neutrino source in the direction of KM3-230213A with KM3NeT/ORCA online datasets (Sections: Celestial origin, Methods - Search for point-like neutrino sources).

[2] KM3NeT collaboration, *Astronomy potential of KM3NeT/ARCA*, *Eur. Phys. J. C* **84** (2024) 885 [2402.08363].

[3] KM3NeT collaboration, *Measurement of neutrino oscillation parameters with the first six detection units of KM3NeT/ORCA*, *JHEP* **10** (2024) 206 [2408.07015].

[4] KM3NeT collaboration, *Search for quantum decoherence in neutrino oscillations with six detection units of KM3NeT/ORCA*, *JCAP* **03** (2025) 039 [2410.01388].

[5] CORSIKA collaboration, *gSeaGen code by KM3NeT: An efficient tool to propagate muons simulated with CORSIKA*, *Comput. Phys. Commun.* **314** (2025) 109660 [2410.24115].

[6] KM3NeT collaboration, *First searches for dark matter with the KM3NeT neutrino telescopes*, *JCAP* **03** (2025) 058 [2411.10092].

[7] KM3NeT collaboration, *Search for non-standard neutrino interactions with the first six detection units of KM3NeT/ORCA*, *JCAP* **02** (2025) 073 [2411.19078].

[8] KM3NeT collaboration, *Probing invisible neutrino decay with the first six detection units of KM3NeT/ORCA*, *JHEP* **04** (2025) 105 [2501.11336].

[9] KM3NeT collaboration, *Ultrahigh-Energy Event KM3-230213A within the Global Neutrino Landscape*, *Phys. Rev. X* **15** (2025) 031016 [2502.08173].

[10] KM3NeT collaboration, *On the Potential Cosmogenic Origin of the Ultra-high-energy Event KM3-230213A*, *Astrophys. J. Lett.* **984** (2025) L41 [2502.08508].

Proceedings

[1] KM3NeT collaboration, *KM3NeT Online Multi-Messenger Results*, *EPJ Web Conf.* **319** (2025) 08004 *Personal contribution:* developer of the KM3NeT realt-time alert system. *Main author.*

[2] KM3NeT collaboration, *The KM3NeT alert system for online multi-messenger astronomy*, *PoS* **ICRC2025** (2025) 920 in pubblication. *Personal contribution:* development of the preselection module and high-energy neutrino identification module for ARCA and ORCA. *Main author.*

[3] KM3NeT collaboration, *Search for a cosmic point-like neutrino source from the direction of the ultra-high-energy event KM3-230213A*, *PoS* **ICRC2025** (2025) 1110 in pubblication. *Personal contribution:* search for a cosmic point-like neutrino source in the direction of KM3-230213A with KM3NeT/ORCA online datasets. *Corresponding author.*

Note: Only proceedings with my direct personal contribution are reported.

Conferences

- Talk at "International Cosmic Ray Conference (ICRC 2025)", *Search for a cosmic point-like neutrino source from the direction of the ultra-high-energy event KM3-230213A*, Geneve, Switzerland, 14-24/07/2025;
- Talks at "KM3NeT4RR - WP7 meeting: Implementation of multi- messenger liaisons", Caserta, 27-28/11/2024 *KM3NeT optimization for very high energy neutrinos: preliminary results* and *KM3NeT/ARCA Alert System*.
- Talks at "KM3NeT Collaboration Meeting": *Status of the KM3NeT Online Framework*, Online, 04-08/11/2024 and *Status of the KM3NeT Online Framework*, Louvain-la-Neuve, Belgium, 27-31/01/2025.

Attended courses

Astrophysical Experimental Methods (F. M. Zerbi)

Other activities

- Research period abroad in Marseille (France), 25/09/2024 - 24/10/2024.
  Invitation at Centre de Physique des Particules de Marseille (CPPM) to "collaborate on the definition and implementation of the alert sending system within the CPPM KM3NeT group".
- Teaching assistant for "Fisica generale - modulo B" class at the Mechanical Engineering bachelor course and "Fisica 2" class at the Management Engineering bachelor course.