# Modelling the observability of neutrinos from quiescent blazars with KM3NeT.

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## Abstract

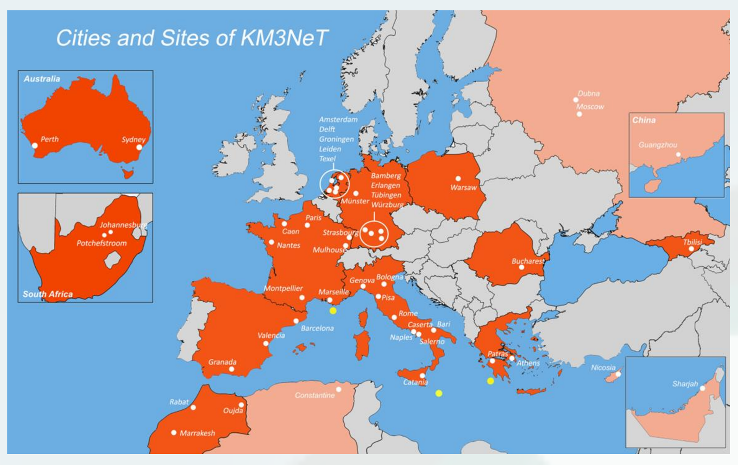
*After the compelling association of neutrinos with blazar TXS 0506+056 in a flaring state, there have been advancements in neutrino astronomy including an association of neutrinos with tidal disruption events. These sources were observed by the first-generation neutrino telescopes during transient states. The spectral energy distributions of blazar jet emissions can be explained by two types of models, leptonic and hadronic models, whether in a steady or a transient state. In leptonic models, the high energy contribution is only from electron interactions while in hadronic models, the high energy contribution is mainly from hadronic interactions. Both types of scenarios are generally consistent with blazar observations. The detection of TXS 0506+056 as a neutrino source hints that blazars are sites of hadron acceleration. In this study, we simulate blazar jet emission using OneHaLe[3,4] - a tool for numerical modelling of AGN jet emissions with hadronic models - and aiming at determining the detectability of neutrinos from steady state blazars with KM3NeT, a second-generation neutrino telescope which is currently under construction in the depth of the Mediterranean Sea.*


## Aims

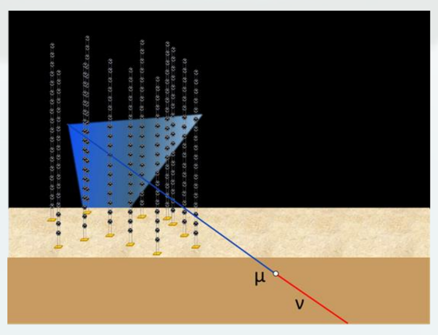
- *Calculate sensitivities towards neutrinos from quiescent blazars by KM3NeT.*
- *Determine the nature of blazar jet emissions.*

### What is the KM3NeT?

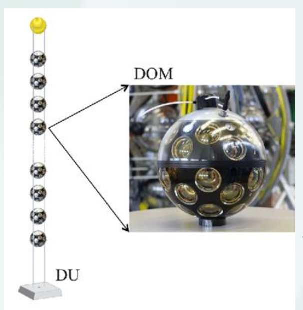
- *Second generation neutrino telescope arrays, located in the Mediterranean Sea.*
- *Composed of two telescope arrays: Astroparticle Research with Cosmics in the Abyss (ARCA, located at a depth of 3500 m) optimized for the high energy (TeV - PeV) and Oscillation Research with Cosmics in the Abyss (ORCA, at a depth of 2500 m) designed for the low energy (GeV - TeV)Currently under construction.*



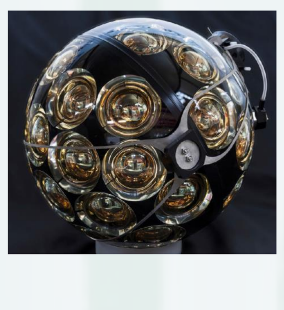

### KM3NeT ARCA and ORCA



*Cherenkov radiation from the interaction passage of ultrarelativistic muons in water.*

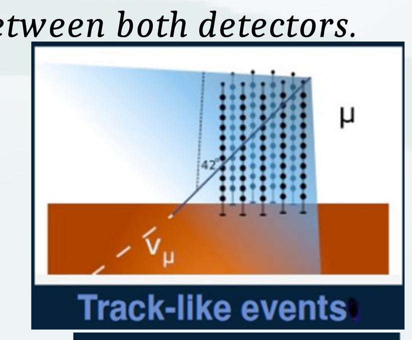


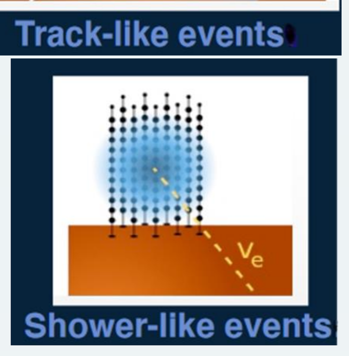

*DOM contains 31 photomultipliers. 18 DOMs are connected to form a Detection Unit (DU) or a string.*



*A single Digital Optical Module [2]. The Cherenkov light is detected by the photomultiplier tubes inside the Digital Optical Module (DOM).*

*Can detect both shower-like and track-like events, only the density of the OMs changes between both detectors.*




*ARCA will have 230 DUs and ORCA will have 115 DUs at the end of construction.*

## Methodology

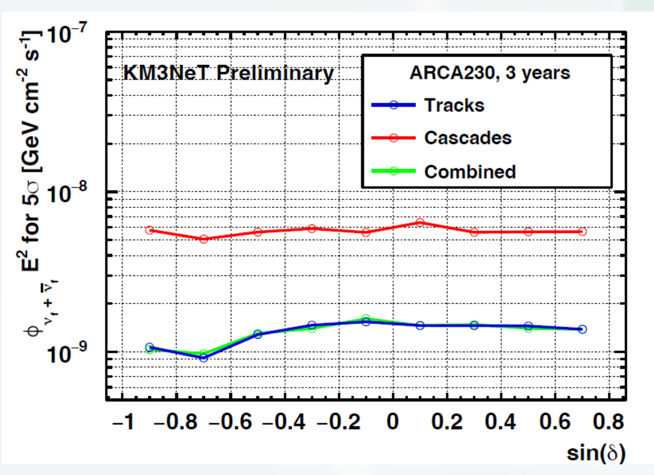
- *A lepto-hadronic model [3] is adopted to reproduce to the data from a source.*
- *Neutrino fluxes are then extracted from the fitted model.*
- *Using the KM3NeT ARCA instrument response functions (IRFs), neutrino rates can be calculated.*
- *Neutrino rates will be used to derive KM3NeT sensitivities.*

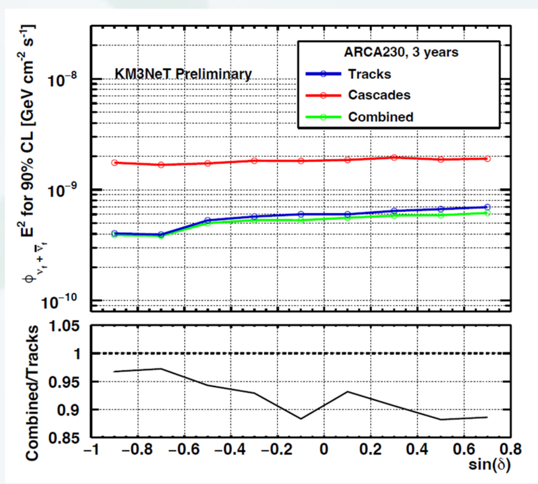
### Lepto-hadronic model

- *Time dependent one-zone lepto-hadronic model used is called OneHaLe [3,4]*
- *The time evolution of the different particle species is tracked using Fokker-Plank equations.*
- *Primary electron and proton injection terms are defined using a simple power-law.*
- *Photo-hadronic interactions of protons with external photon fields are simulated to produce secondaries such as muons and pions.*
- *Injection terms (production terms) of secondary particles are determined from the process the particles are produced from.*
- *Primary electrons interact via inverse Compton with external photon fields and via synchrotron self-Compton.*
- *External photons are from Accretion Disk, Dust Torus, CMB and Broad Line Region.*
- *Neutrinos are produced through muon decay and pion decay.*
- *Neutron interactions were not included.*

## Previous collaboration results
### KM3NeT ARCA230 IRF

- *ARCA230 (final configuration of ARCA) will be used.*
- *Both tracks and shower interactions are considered.*
- *Precuts were made to select shower and track events with good reconstruction and reject the background.*
- *Only upgoing events were selected.*
- *Cascade selection covers all the zenith angles.*
- *Boosted decision tree (BDT) was used to make cuts on horizontal events and the selection of clear signals.*
- *Background sources chosen are atmospheric neutrinos and muon, bioluminescence and Potassium-40 decay.*

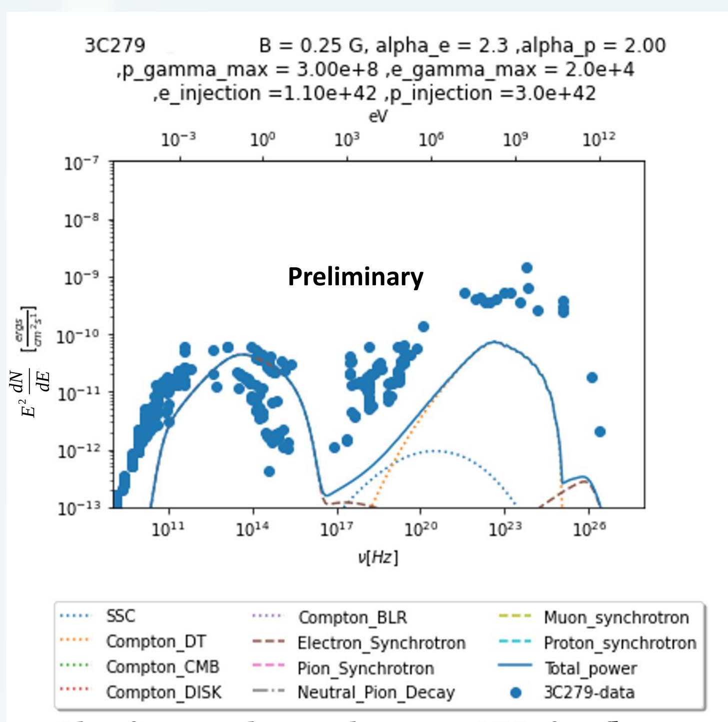



- *The results above the sensitivities of ARCA230 to point-like sources using cascade and track events.*
- *Point-sources were simulated to obtain the 5σ discovery flux normalization (left) and the 90% confidence level which is the limit on the flux normalization.*

## Ongoing analysis

### 3C 279: A case study




*The figure above shows a SED for fluxes simulated using OneHaLe. Optimization of the model is a work in progress.*

*3C 279 was chosen as a representative blazar as it has been extensively studied and observed in gamma-ray and x-ray. OneHaLe takes physical input parameters and calculates simultaneously electromagnetic and neutrino broadband spectral energy distributions (SEDs). While certain parameters, such as redshift, mass of the central black hole, strength of broad lines and bulk Lorentz factor are constrained by observations at multiple wavelengths, others, including electron spectral index, proton injection index, the minimum and maximum Lorentz factor for both electron and proton injection mostly dealing with properties of particle injection inside the jet, are free parameters. We seek to find a physically plausible model which produces a good fit to the observed electromagnetic spectrum, and then use the corresponding predicted neutrino spectrum and the IRFs of KM3NeT to determine the sensitivity to blazars described by this model.*

## Conclusions and further analysis

- *Cutting edge KM3NeT infrastructure and instrumentation provides more ways of probing the universe and understanding physics.*
- *KM3NeT will complement IceCube as it is based on the Northern Hemisphere.*
- *Within the KM3NeT collaboration, a framework for calculating rates and sensitivities already exists.*
- *This framework will be used to evaluate KM3NeT sensitivity to the quiescent blazar 3C279.*
- *More work needs to be done on the SED model fitting.*


*[1] Hayasaki, K. (2021). Neutrinos from tidal disruption events. Nature Astronomy 5, 436–437*

*[2] KM3NeT Collaboration (2022). The KM3NeT multi-PMT optical module. arXiv:2203.10048 [astro-ph, physics:physics]. [online] Available at: https://arxiv.org/abs/2203.10048v1.*

*[3] Diltz, C. and Böttcher, M. (2016). LEPTONIC AND LEPTO-HADRONIC MODELING OF THE 2010 NOVEMBER FLARE FROM 3C 454.3. The Astrophysical Journal, 826(1), p.54.*

*[4] Zacharias, M., Reimer, A., Boisson, C. and Zech, A. (2022). EXHALE-JET: an extended hadro-leptonic jet model for blazars - I. Code description and initial results. Monthly Notices of the Royal Astronomical Society, [online] 512, pp.3948–3971.*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