



# Prospects of neutrino observations of the Central Molecular Zone and Cygnus OB2 with KM3NeT/ARCA

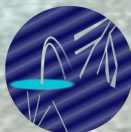
**Marouane Benhassi**\*, Riccardo M. Bozza, Aart Heijboer, Walid Idrissi Ibnsalih, Antonio Ambrosone, Antonio Marinelli,  
Pasquale Migliozzi

**on behalf of KM3NeT Collaboration**

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\* Department of Mathematics and Physics of the University of Campania Luigi Vanvitelli - Italy

\* INFN - sezione di Napoli



# Outline

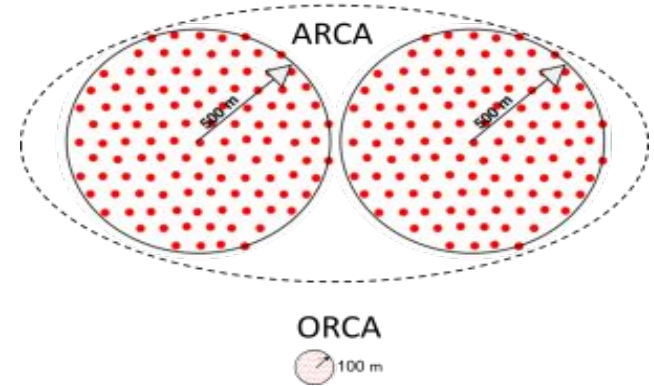
- KM3NeT experiment
- Galactic extended sources: Central Molecular Zone and Cygnus OB2
- Unblinded results

# **KM3NeT experiment**

# KM3NeT experiment

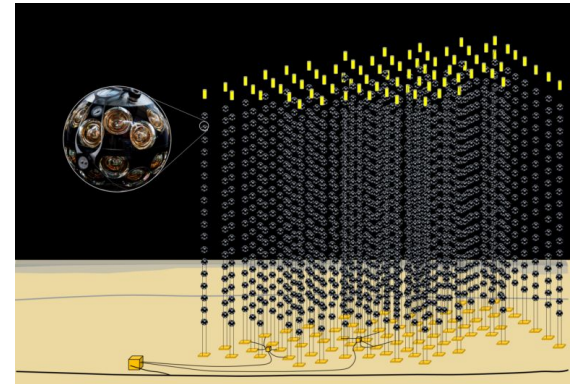
## ARCA:

- Main goal: High energy astrophysics;
- TeV-PeV energy range;
- 230 strings (115 for each block);
- 18 Digital Optical Modules (DOMs) per string with 36 m spacing;
- Depth ~3500 m, about 100 km off-shore the small town of Portopalo di Passero on Sicily, Italy.

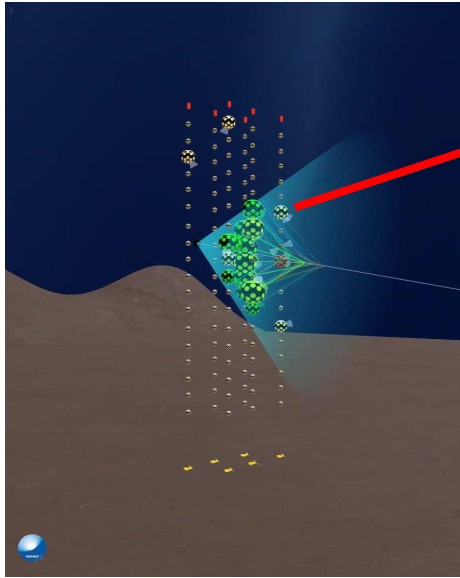


## ORCA:

- Main goal: Neutrino oscillations;
- 1-100 GeV energy range;
- 115 strings;
- 18 DOMs per string with 9 m spacing ;
- Depth ~2500 m about 40 km off-shore Toulon, France. Both detectors share same technology.



# KM3NeT experiment

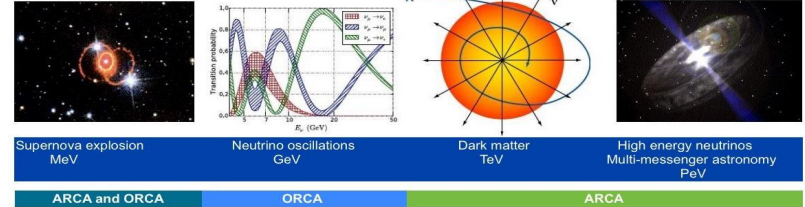


## Detection principle

Cherenkov light produced by the relativistic particle resulting from the interaction of an incoming neutrino with water medium.

## Science with KM3NeT neutrino telescope

MeV to PeV energies



Although the detectors are under construction, KM3NeT is already taking data.

This analysis uses ARCA6-21 data, representing the data collected by ARCA6, ARCA8, ARCA19, and ARCA21 setups, accounting for a total lifetime of 640 days. For the expectations with the completed detector, ARCA230, Monte Carlo (MC) simulation is used corresponding to a lifetime of 10 years.

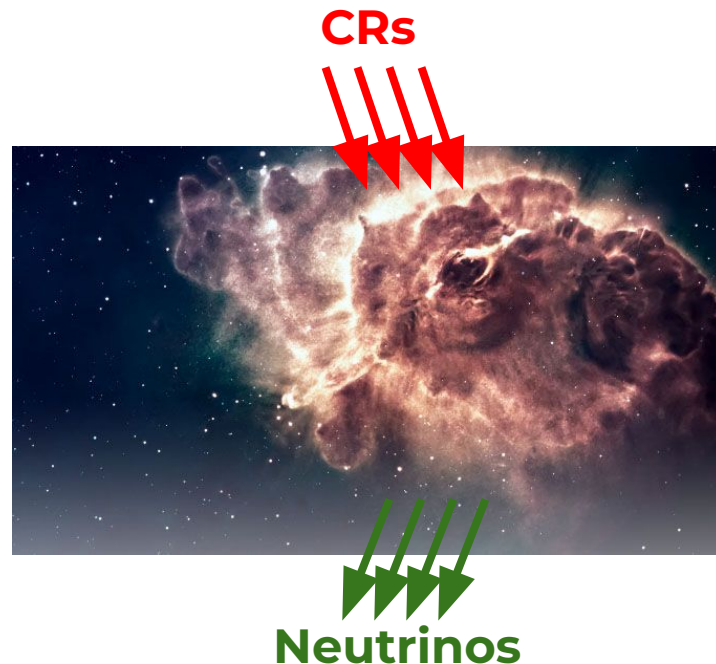
**Galactic extended  
sources: Central Molecular  
Zone and Cygnus OB2**

# Galactic extended neutrino sources emission

Galactic extended neutrino sources are astrophysical sources within our Galaxy which have an angular size from hundred of parsecs up to kiloparsec depending on their position on the sky.

We are particularly interested in those made by clouds of molecular gas, which eventually have a nearby candidate accelerator.

Neutrinos are produced through the interaction of relativistic protons from the cosmic rays and the molecular gas.



# Central Molecular Zone: Motivations

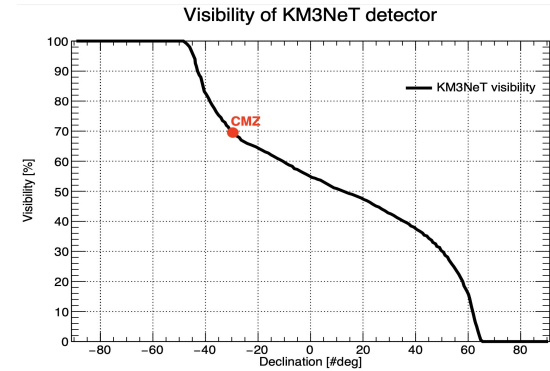
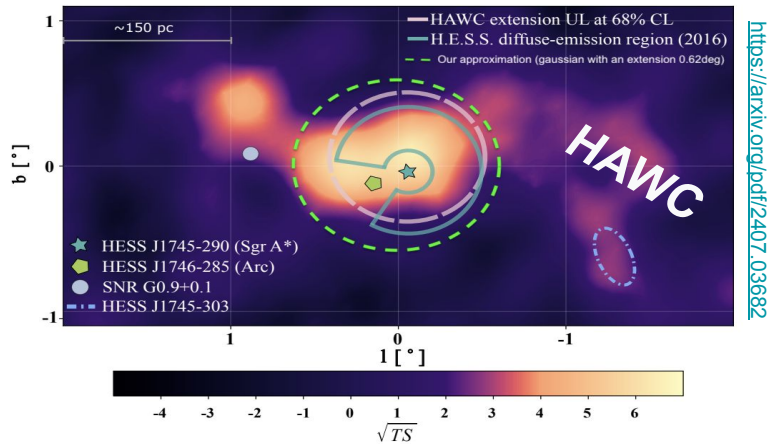
## The Central Molecular Zone (CMZ):

- is a region of few hundred parsecs in the center of our Galaxy with an angular extensions  $||l| < 1^\circ$  and  $|b| < 0.3^\circ$  ;
- has an estimated gas density two orders of magnitude larger than the gas density in the galaxy;
- contains some of the most massive Galactic molecular clouds such as Sgr A, Sgr B, and Sgr C.

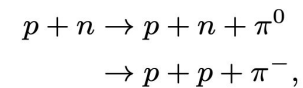
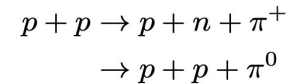


# Central Molecular Zone: Motivations

CMZ location with respect to the KM3NeT detector visibility, its gas distribution, and the mechanism of neutrino production.



## hadro-nuclear interactions



# Central Molecular Zone: Neutrino flux

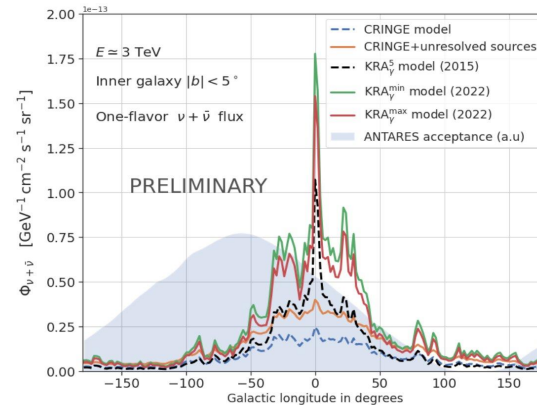
## Neutrino flux estimation (IceCube technique to rescale the flux):

The CMZ represents a small part of the galactic plane ( $-1^\circ \leq l \leq 1^\circ$  and  $-0.3^\circ \leq b \leq 0.3^\circ$ ).

Only 5% of the galactic plane flux comes from the CMZ.



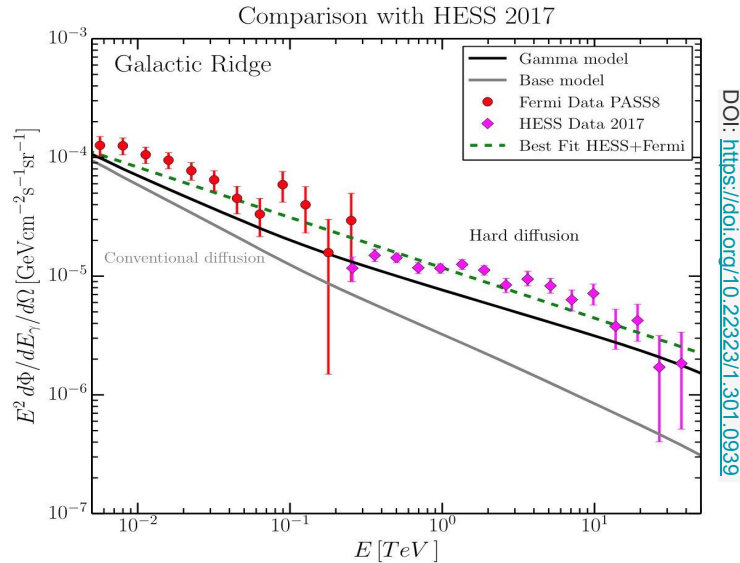
Neutrino emission from the Whole Galactic plane



Average one-flavor  $\nu + \bar{\nu}$  flux in the inner Galactic disk as a function of the Galactic longitude

# Central Molecular Zone: Neutrino flux

Neutrino flux estimation (conversion of gamma flux):



The gamma-ray spectrum in the CMZ region  $|| < 1.0^\circ$  and  $|b| < 0.3^\circ$

Gamma emission is proportional to:

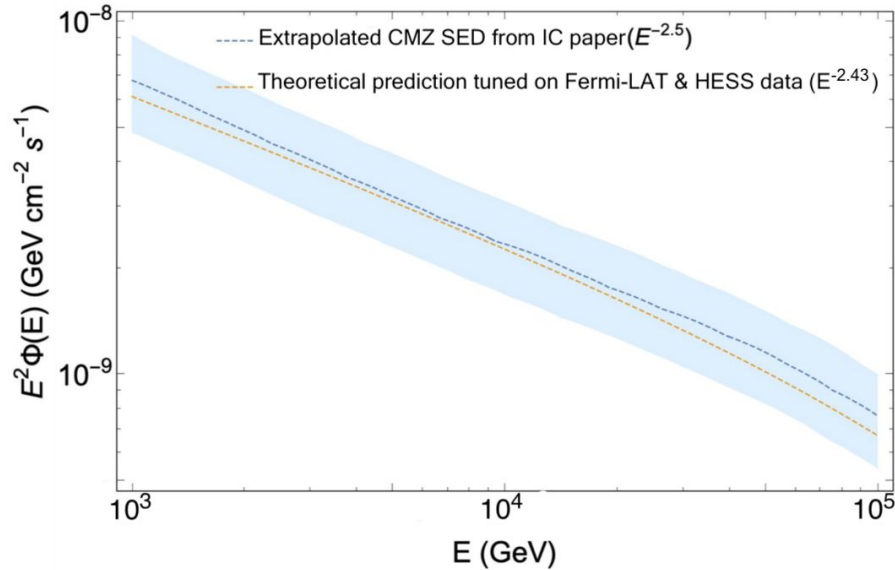
$$\Phi_\gamma \propto E^{-2.42}$$

$$E_\nu^2 \Phi_\nu = \left(\frac{1}{2}\right) \left[ E_\gamma^2 \Phi_\gamma \right]_{E_\gamma = 2E_\nu}$$

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## Central Molecular Zone: Neutrino flux

Comparison between the two neutrino flux estimation methods.



The two expectations match. The second method based on a conversion of a gamma flux to a neutrino flux is used in this analysis to model the neutrino signal from the CMZ.

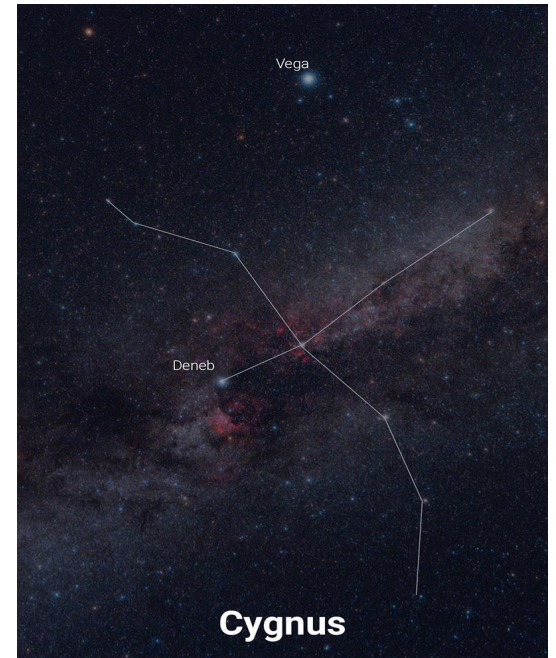
$$\Phi_{\nu} \propto (E/GeV)^{-2.43} e^{\left(\frac{-E}{0.5 PeV}\right)}$$

# Cygnus OB2: Motivations

**Cygnus OB2** is one of the first extended regions observed at energies above 10 TeV by the Milagro experiment, representing the inner part of the Cygnus region. It contains a young stellar cluster that can act as a cosmic ray accelerator.

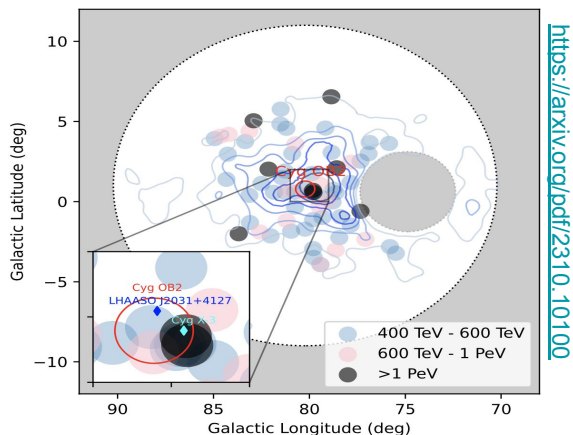
Different studies have been taken into account with different emitting regions observed from LHAASO, Fermi/LAT, depending on the topic and methods.

Recent LHAASO observations have revealed a vast gamma-ray 'bubble' in the Cygnus X region, indicating the presence of powerful PeVatrons.



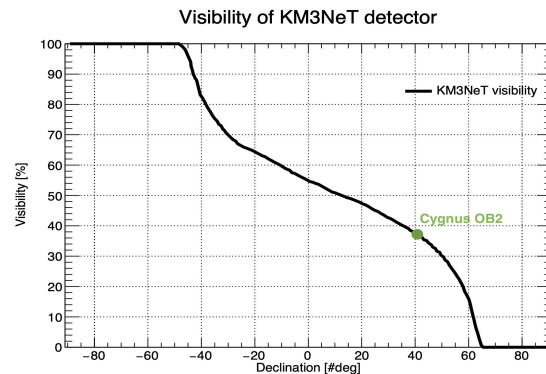
# Cygnus OB2: Motivations

Cygnus OB2 location with respect to the KM3NeT detector visibility, energy emission map of Cygnus X, and the mechanism of neutrino production.



[Neronov et al.](#) flux is used to study Cygnus OB2.

$$\phi_{\nu} \propto E^{-3}$$



**hadro-nuclear  
interactions**

$$p + p \rightarrow p + n + \pi^{+}$$

$$\rightarrow p + p + \pi^{0}$$

$$p + n \rightarrow p + n + \pi^{0}$$

$$\rightarrow p + p + \pi^{-},$$

**Unblinded results**

# Analysis method

## Goal:

Looking at the CMZ and Cygnus OB2 and testing the KM3NeT/ARCA capabilities.

## Method:

Calculate the sensitivity at 90% CL using a binned likelihood method.

The likelihood is defined using a Poissonian Probability Density function

$$L = \prod_{i \in \text{bins}} P(N_i | \xi_i)$$

where  $N_i$  and  $\xi_i$  are respectively, the observed and expected number of events in the energy bin  $i$ .

# Analysis method

## Method:

The test statistic is given by:

$$\lambda = \log L(\mu = \hat{\mu}) - \log L(\mu = 0)$$

The likelihood can be written as:

$$\log L = \sum_{i \in \text{bins}} N_i \log (\mathcal{B}_i + \mu \mathcal{S}_i) - \mathcal{B}_i - \mu \mathcal{S}_i$$

Where  $\mu$  is the signal strength and  $\hat{\mu}$  is the value that maximizes the  $\log L$ .  $\mathcal{S}_i$  and  $\mathcal{B}_i$  represent the signal and the background PDFs.

Sensitivity is defined as:

$$\Phi_{90} = \mu_{90} * \Phi_0$$

Median upper limit of  
the signal strength

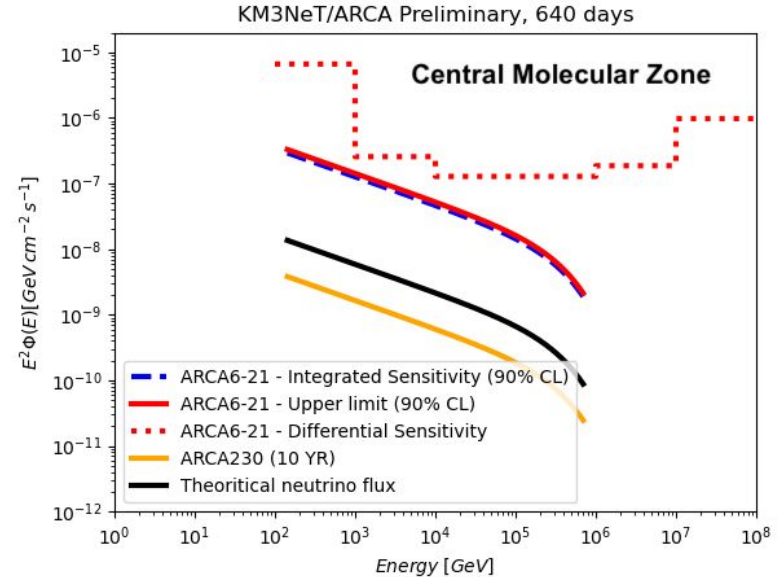
Neutrino flux

# Central Molecular Zone: Sensitivity of KM3NeT/ARCA

The sensitivities of ARCA6-21 and ARCA230 are shown.

A gaussian smearing was used to take into account the extension of this source with a  $\sigma = 0.618^\circ$ .

We used track like events and all flavours with 0.5 PeV as neutrino cut-off.



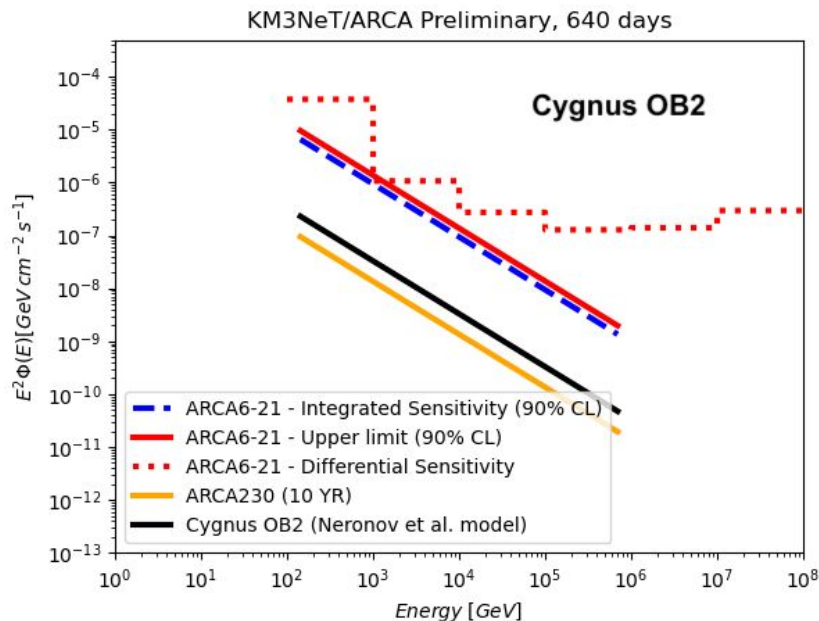
# Cygnus OB2: Sensitivity of KM3NeT/ARCA

The sensitivities of ARCA6-21 and ARCA230 are shown.

A gaussian smearing was used to take into account the extension of this source with a  $\sigma = 0.7^\circ$ .

We used track like events and all flavours.

In future, we will combine track and shower events, which will be crucial for studying this source.



# Conclusions

KM3NeT/ARCA is a key experiment to understand the extended and point-like emission from our Galaxy

- No significance has been seen neither from the CMZ nor the Cygnus OB2 with ARCA6-21 data.
- Upper limits were set for both CMZ and Cygnus OB2.
- We expect to constrain the neutrino emission predicted for the two sources with the full ARCA230.
- MoU with VHE gamma ray experiments will be crucial to take into account the expected morphology of these regions.

***Thank you for your attention***