

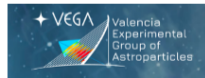
# Search for dark matter signatures with ANTARES and KM3NeT

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on behalf of the ANTARES Collaboration

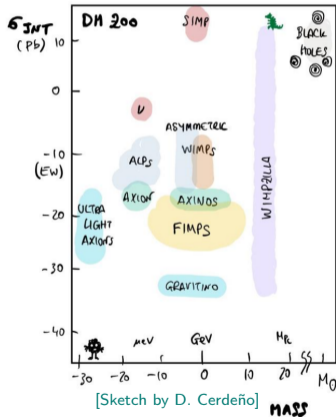
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TeVPA - August 8, 2022



# Dark matter as a target for indirect searches

Unique assumption: the non-ordinary “substance” that makes up to a 27% of energy budget of the Universe comes in form of a **new elementary particle**.



Properties?

- Neutral
- Stable on cosmological scales
- Relic abundance matches amount observed nowadays
- Not excluded by current searches
- No conflicts with BBN or stellar evolution

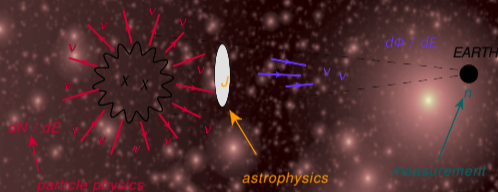
Mass and interaction strength: very unconstrained

# Target: astrophysical environment

Need to **predict fluxes** of high-energy  $\nu$  from dark matter decay or pair-annihilation.

$$\text{WIMP WIMP} \xrightarrow{\text{ANN}} \text{interm. channel} \rightarrow \nu\bar{\nu} + X$$

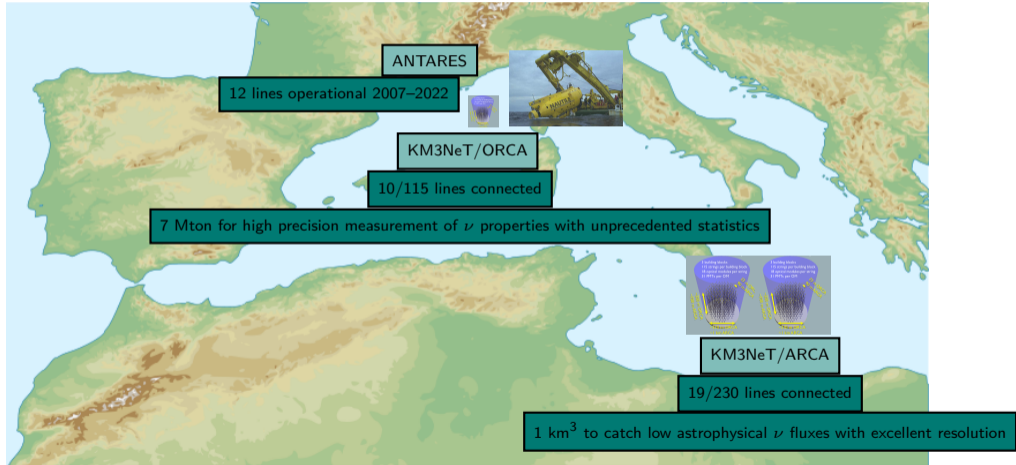
$$\text{WIMP} \xrightarrow{\text{DEC}} \text{interm. channel} \rightarrow \nu\bar{\nu} + X$$



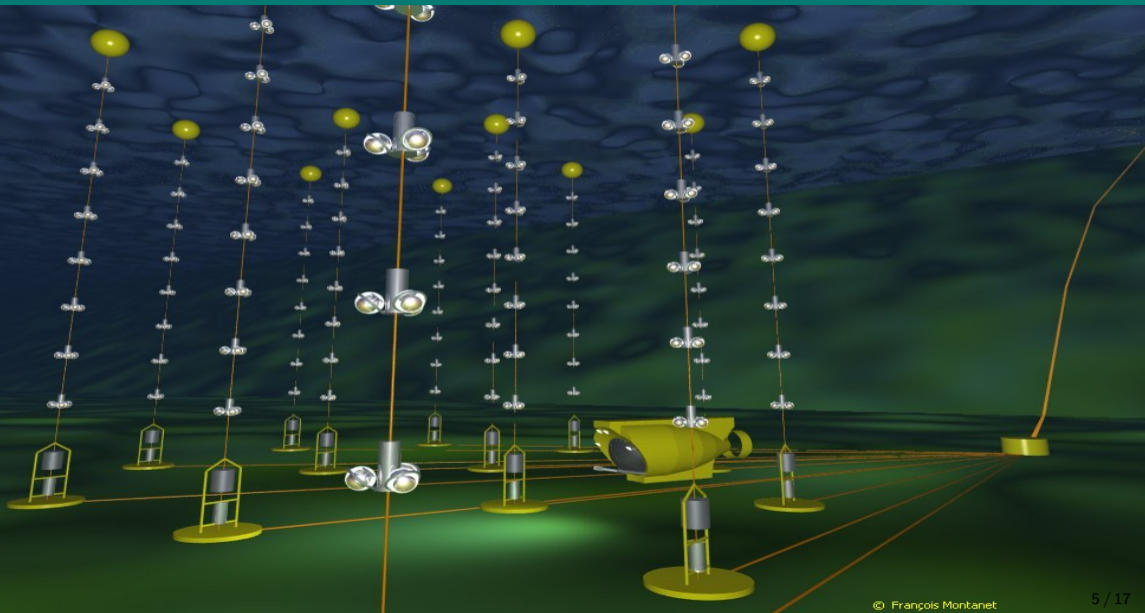
An instrument like  $\nu$  telescope does not point to a specific sky direction  $\rightarrow$  best dark matter sources are: Galactic Centre (extended and relatively close) or Sun (very close)

# Mediterranean telescopes: ANTARES and KM3NeT

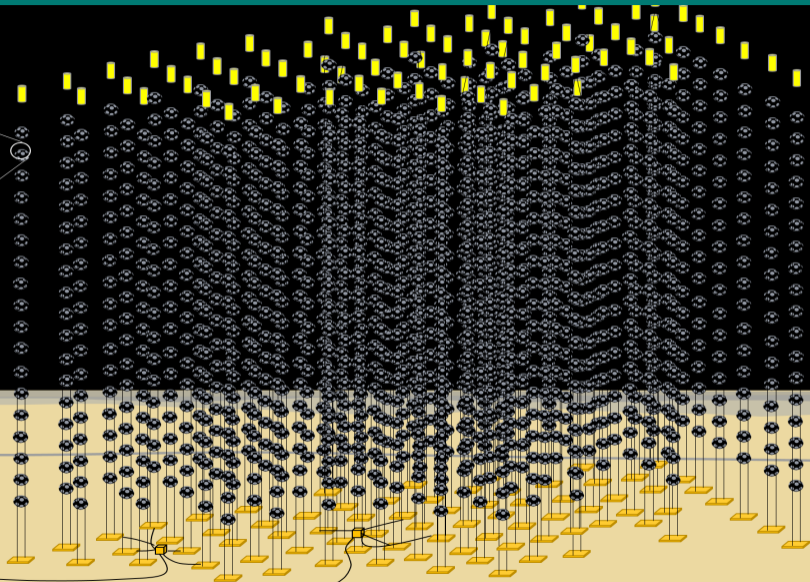
Cherenkov detectors instrumenting water with a grid of photomultipliers organised in lines



# ANTARES: switched off in Feb. 2022 and dismantled in May-June 2022



# KM3NeT: 19 lines ARCA + 8 lines ORCA connected





ANTARES



KM3NeT

# Mediterranean telescopes to scale

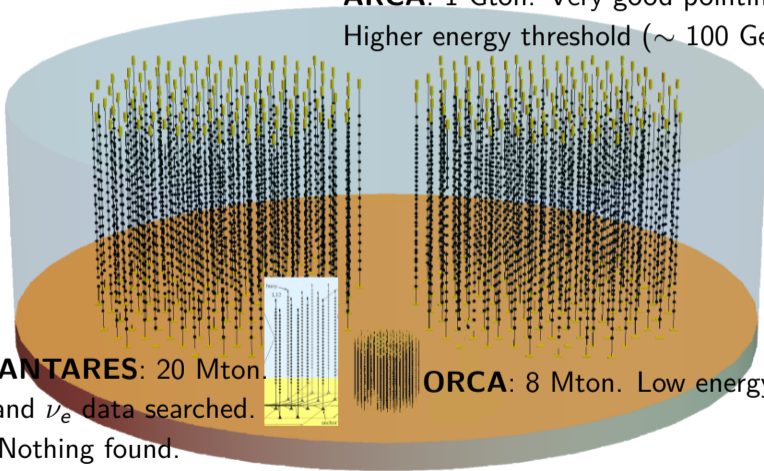
**ARCA:** 1 Gton. Very good pointing resolution.  
Higher energy threshold ( $\sim 100$  GeV)

**ANTARES:** 20 Mton.

16 years of  $\nu_\mu$  and  $\nu_e$  data searched.

Nothing found.

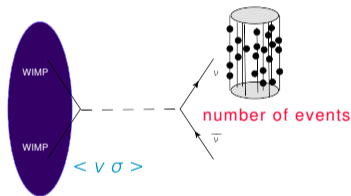
**ORCA:** 8 Mton. Low energy. Best for Sun



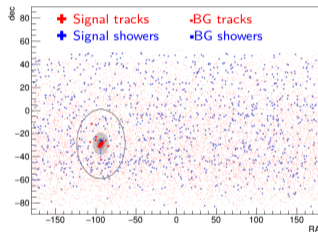


# Structure of $\nu$ indirect searches

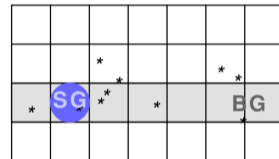
Measurement = arrival directions of two topologies: track- and shower-like, and energy proxy.  
 Signal = a cluster of  $n$   $\nu$ -induced events daughters of dark matter pair annihilation process.



$$n = \frac{1}{2} \langle \sigma v \rangle \int_0^{M_{\text{DM}}} \frac{dN}{dE} dE \frac{1}{4\pi} J \frac{1}{M_{\text{DM}}^2} \mathcal{A}(M_{\text{DM}}) t$$



Unbinned likelihood

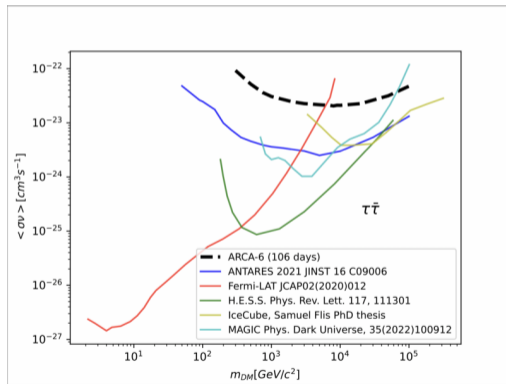
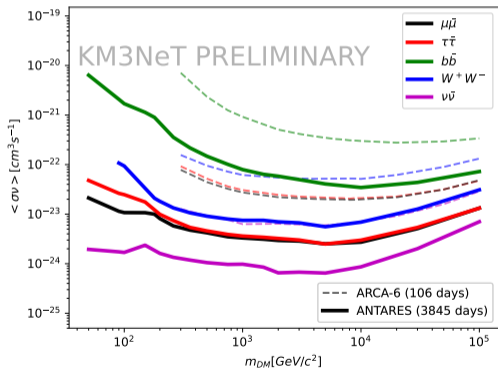


Binned likelihood

The probability for **one** process to happen is  $\propto$  velocity of projectile  $\times \sigma$ . Translate limit on flux into limit on **velocity-averaged pair annihilation cross-section**  $\langle \sigma v \rangle$ .

# Limits on pair annihilation of dark matter in the Galactic Centre

ANTARES data 2007 - 2020 is compatible with background [Phys.Lett B 805, 135439 (2020)]  
First sensitivities with 6-line configuration of ARCA.

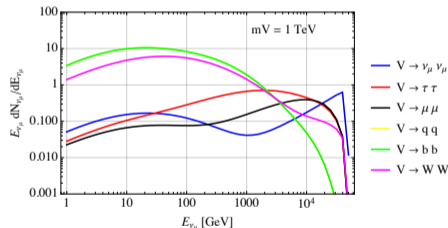
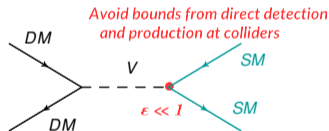
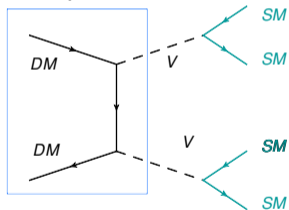


# Heavy dark matter in secluded scenarios

## No evidence for WIMP at the GeV-TeV scale; where to search next?

Above 10-100 TeV, in line with recent interest for BSM physics in heavy sectors at colliders

- 1 Unitarity bound on the dark matter mass naturally evaded with a modified cosmology implying a change of freeze-out point
- 2 Spectra of relevance for experiments can be computed from 'boosted' PPC [JCAP 2019 014]

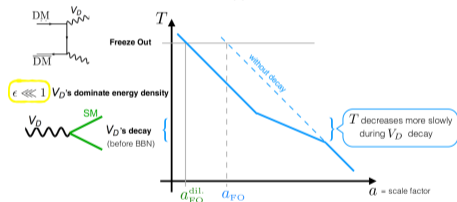
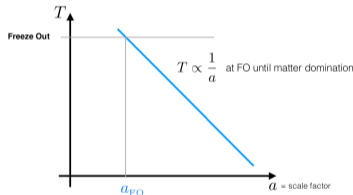
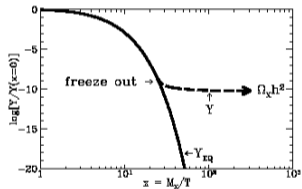


The  $\nu$  signal at ANTARES arises from the annihilation of DM pairs into two mediators, then decaying into SM particles that produce  $\nu$ s via decays and showering.

# Standard / secluded dark matter freeze-out

Standard cosmological evolution:  $\Omega_{\text{DM}} \propto \frac{1}{\sigma v}$ .

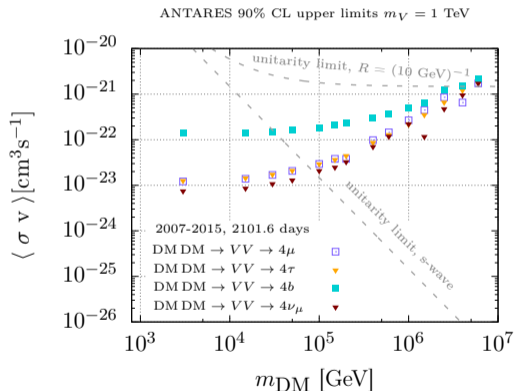
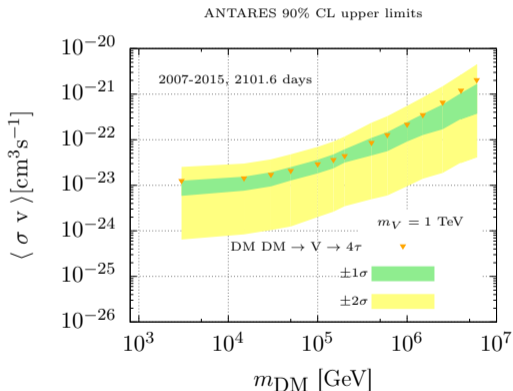
Secluded: universe at freeze-out is smaller  $\Rightarrow$  the same amount of DM is later more diluted  $\Rightarrow$   $\sigma v(\text{DM DM} \rightarrow VV)$  smaller  $\Rightarrow$  DM can be heavier



Standard WIMP mass constraint at  $m_{\text{DM}} = \mathcal{O}(100)$  TeV [PRL 64 (1990) 615] can be evaded in new cosmological scenario.

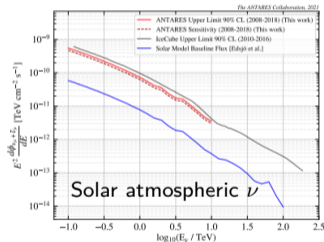
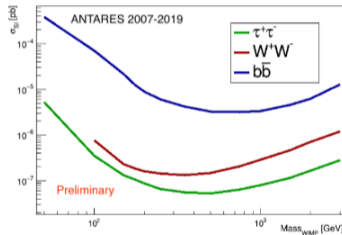
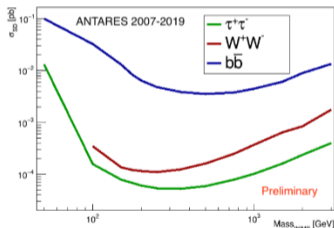
# Limits on heavy secluded dark matter

Upper limits span for first time dark matter masses up to 6 PeV [JCAP06(2022)028]



# Search for dark matter in the Sun

- In equilibrium between capture and annihilation
- Sensitive at low velocities (= easier capture)
- Clean: if signal  $\rightarrow$  direct interpretation (astro bg well known)



Sun has known isotopic abundance  $\Rightarrow$  sensitive to WIMP-nucleon cross section for spin-dependent and spin-independent case (odd or even atomic number)

# Testing minimal dark matter models with angular power spectrum method

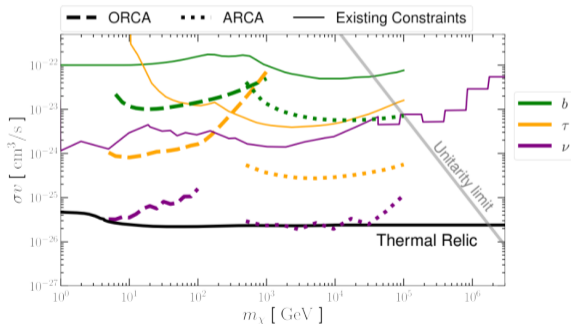
Maximum likelihood based search with angular power spectrum, 10-year expectation, preliminary detector acceptance taken from letter of intent.

Signal spectra from PPC4DMID under 100 GeV, and HDM from 100 GeV to 100 TeV.

[Work of external collab. S. du Pree, K. Ng, L. S. Miranda, C. Arina, A. Cheek]

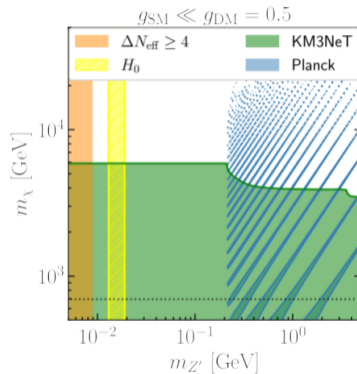
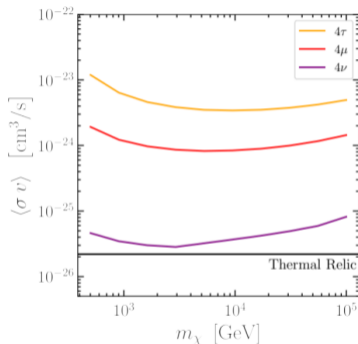
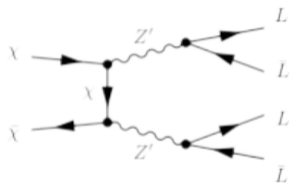
## Minimal DM model

- Vector mediator s-channel
- scalar mediator t-channel
- Anomaly free L-L models



# Testing minimal dark matter models with angular power spectrum method

Leptophilic models with different annihilation channels were studied: example with  $L_\mu - L_\tau$



Very promising in case of low-mass  $Z'$  decaying into  $\nu$  only (when  $m_{Z'} < 2M$  BR 100% to neutrinos). Dark matter can only annihilate via diboson channel Next-generation  $\nu$  telescopes will provide crucial information complementary to other searches.



Neutrino telescopes are very versatile and adapt to different search channels

## WIMP searches, Galactic Centre and Sun

- ANTARES has searched for dark-matter induced  $\nu$  from the **Galactic Centre** using all-flavour data from 2007  $\rightarrow$  Feb. 2020. No dark matter. [[Phys.Lett B 805, 135439 \(2020\)](#)]
- Search for dark matter annihilations in the **Sun** with ANTARES in 2007-2019 data: no dark matter either.

## Other dark matter models

- Search for heavy DM in secluded scenarios in ANTARES data [[JCAP06\(2022\)028](#)]

KM3NeT has already picked up. Search in 6-line configuration for existing lifetime.