Dark Matter Results and Prospects with ANTARES and KM3NeT

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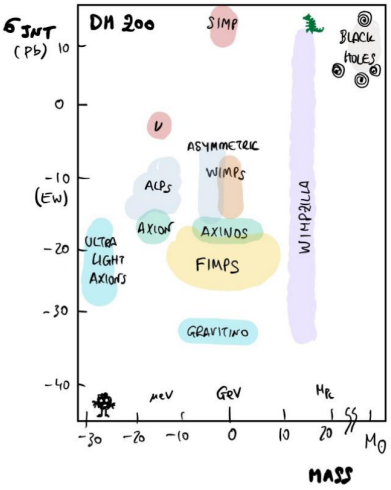
Dark Matter: the most striking missing block in the Standard Model



[Sketch by D. Cerdeño]

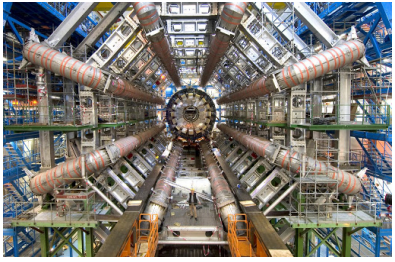
New particle outside the Standard Model, with properties learned from observational evidence

- Neutral
- Stable on cosmological scales
- Reproduces correct relic abundance
- Not excluded by current searches
- No conflicts with BBN or stellar evolution

Many candidates in particle physics (WIMPs, axions, gravitino, ...)

Dark Matter: detection

To be detected, weakly interacting dark matter particles could:

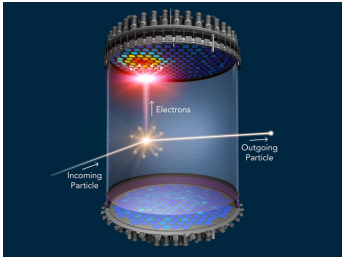


Be produced in collisions

Production searches

Colliders

Challenge: energy, luminosity

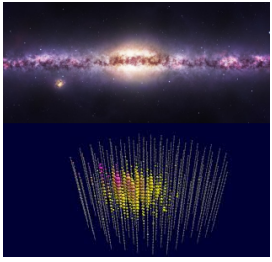


Scatter against SM particle

Direct searches

Underground facilities

Challenge: shield BG



Annihilate into SM particles

Indirect searches

Astrophysical sources

Challenge: volume (low fluxes)

Common challenge: signal identification

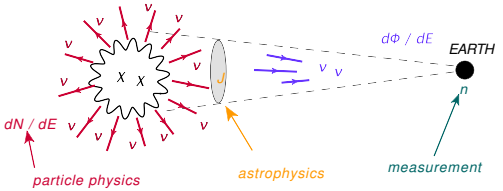
Astrophysical sources: ν (and γ) as dark matter probes

WIMP miracle: required interaction strength is of the same size as the known weak interaction. **Universality**: despite numerous models with differences in the details.$\rightarrow$

It is possible to predict fluxes of SM products from WIMPs decay or pair-annihilation.

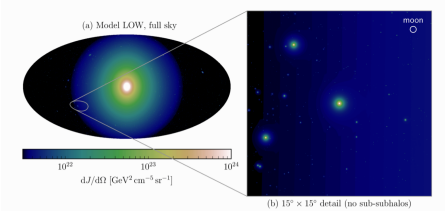
$$\mathrm{WIMP\ WIMP} \xrightarrow{\mathrm{ANN}} \mathrm{interm.\,channel} \rightarrow \nu\overline{\nu}+X$$

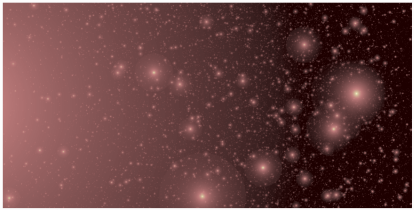
$$\mathrm{WIMP} \xrightarrow{\mathrm{DEC}} \mathrm{interm.\,channel} \rightarrow \nu\overline{\nu}+X$$



How much dark matter?

The amount of dark matter and its spacial distribution is described through the J-factor





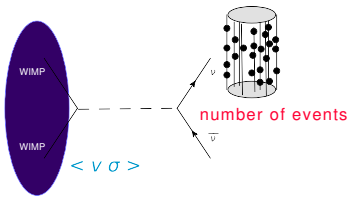
$$J_{\mathrm{ANN}} = \int_{\Omega} d\Omega \int_{l} \rho^2(r(\theta,\phi))dl \quad \text{or} \quad J_{\mathrm{DEC}} = \int_{\Omega} d\Omega \int_{l} \rho(r(\theta,\phi))dl$$

For dark matter density ρ in source at sky coord. (θ, ϕ), seen of size Ω over line of sight l

An instrument like ν 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)

Process and measurement

Measurement = number of outcoming events → translates into number of processes.



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

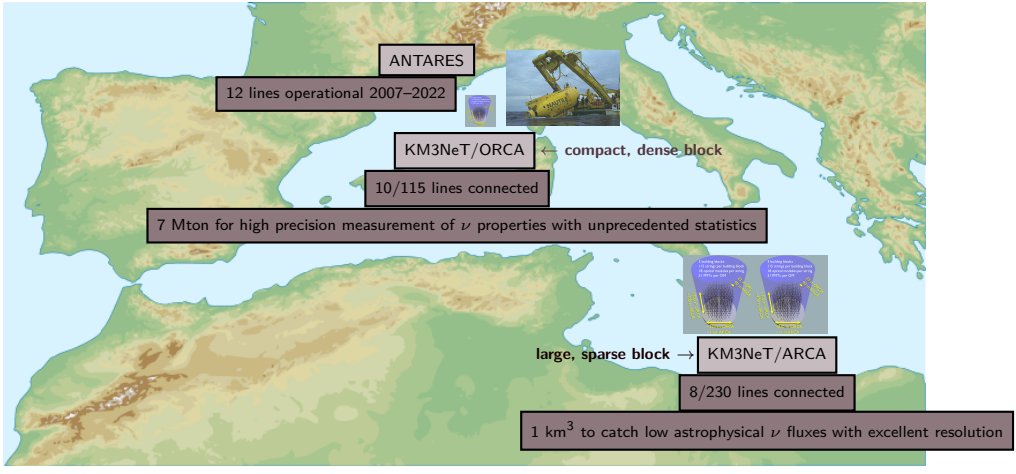
The probability for **one** process to happen is $\propto$ velocity of projectile $\times \sigma$.

But projectile (WIMPs) are non-relativistic → $v \ll c \Rightarrow$ only know a velocity distribution $\Rightarrow$ limit on velocity-averaged cross-section $\langle\sigma v\rangle$.

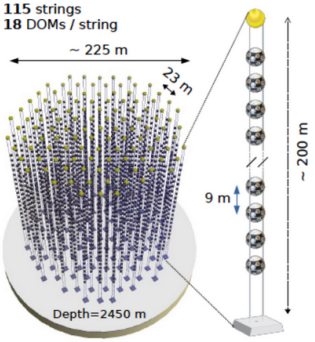
Mass: free to span a wide range: searches performed with ANTARES, ORCA and ARCA.

ANTARES and KM3NeT

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

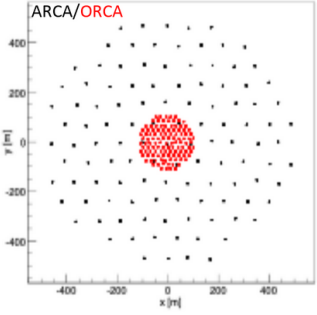


Zoom on the layout of the KM3NeT building block



ORCA and ARCA
same design

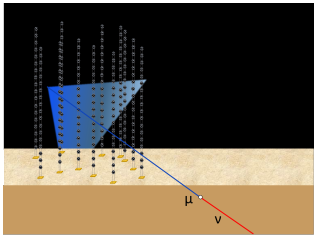
same DOM
holds 31 PMT

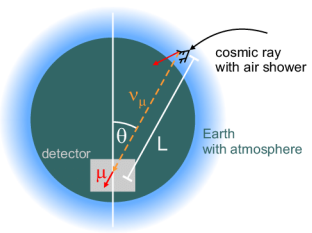


ARCA: 90 m inter-string
ARCA: 36 m inter-DOM
ORCA: 23 m inter-string
ORCA: 9 m inter-DOM

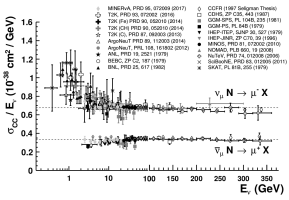
ν telescope data and working principle

Look through the Earth for lepton tracks from $\nu \to l$ conversion. $\sigma_{\nu \to l} \sim 10^{-38}$ cm^2 at 1 GeV!



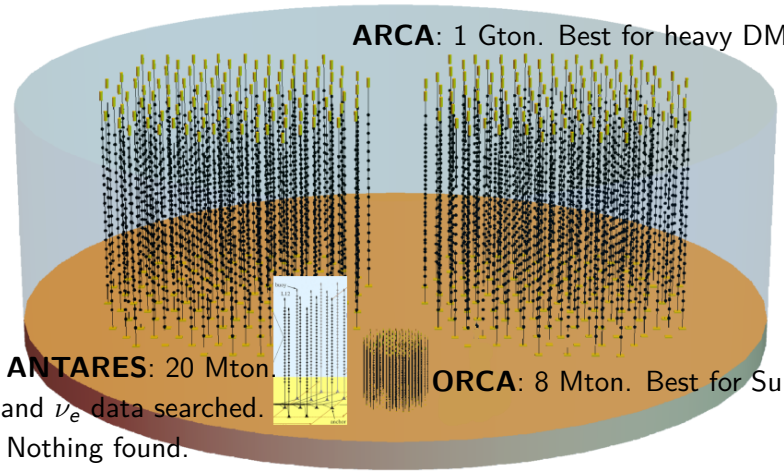


[pdg.lbl.gov/2019]



- Work at very faint signal rates instrumenting large reservoirs of transparent medium
- Need excellent angular resolution for directional reconstruction (water has larger scattering length than ice: better angular resolution)
- Need algorithms for energy reconstruction relying on Monte Carlo simulations
- BG suppression (water has noise from radioactive ^{40}K decays, natural luminescence)

Dark Matter: which detector



ARCA: 1 Gton. Best for heavy DM scenarios

ANTARES: 20 Mton.

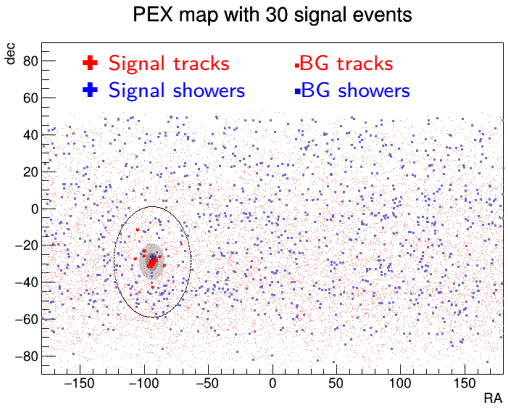
16 years of ν_μ and ν_e data searched.
Nothing found.

ORCA: 8 Mton. Best for Sun

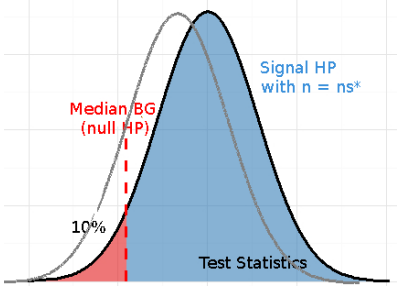
Dark Matter: example of analysis method

Unbinned maximum likelihood is used to obtain the most likely number of signal events n_s^*

$$\mathcal{L} = \prod_i^{n_{TOT}} \left[n_s \cdot P_s(\text{angle}, N_{\text{HIT}}, \beta) + n_b \cdot P_b(\text{angle}, N_{\text{HIT}}, \beta) \right]$$

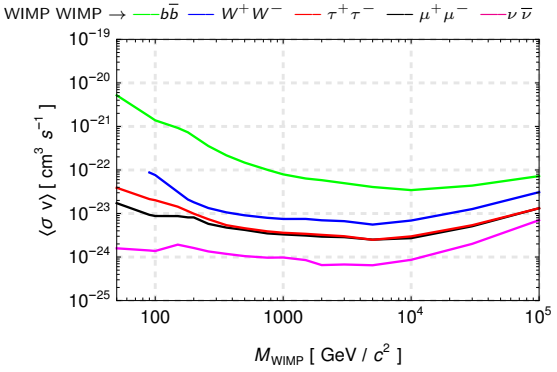


$$TS = \log \left[\frac{\mathcal{L}(n_s^*)}{\mathcal{L}_{\text{BG}}} \right]$$



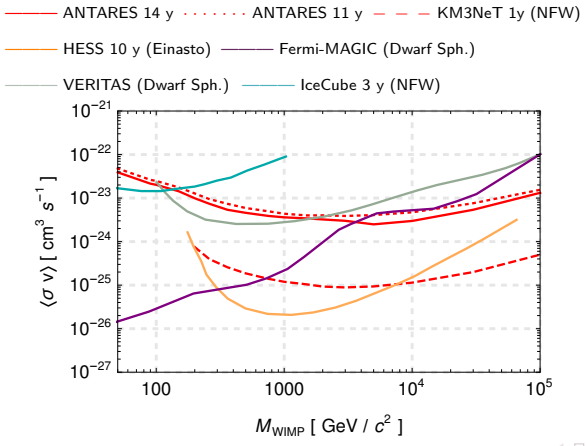
Limits on DM annihilation from the Galactic Centre: ANTARES

ANTARES data Jan. 2007 - Feb. 2020 (11174 tracks, 225 showers, 3845 days lifetime) is compatible with background [Phys. Lett. B 805, 135439 (2020)]



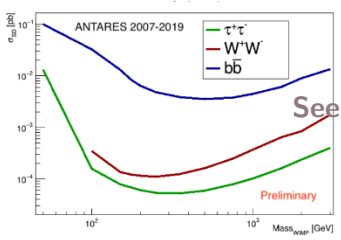
Limits on DM annihilation from the Galactic Centre: KM3NeT/ARCA

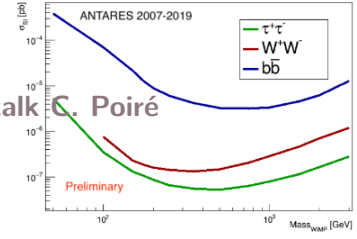
Sensitivity of ARCA-230 (1 year) [PoS(ICRC2019)552] + search in first data taken with ARCA-6 .... out soon!



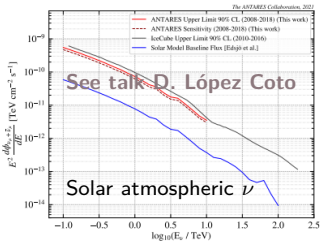
Searches towards the Sun: ANTARES

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





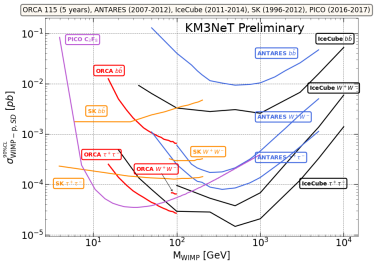
See talk C. Poiré



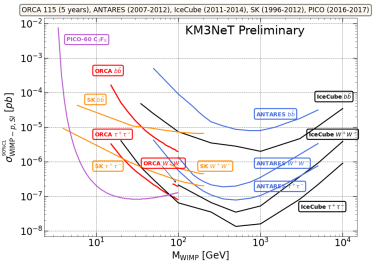
Sun has known isotopic abundance ⇒ sensitive to WIMP-nucleon cross section for spin-dependent and spin-independent case (odd or even atomic number)

Searches towards the Sun: KM3NeT

The potential of KM3NeT looking for dark matter was estimated for the Sun (ORCA) where low energies are favoured [PoS(ICRC2019)536].



Spin-dependent
ORCA-115 5 years
sensitivity



Spin-independent
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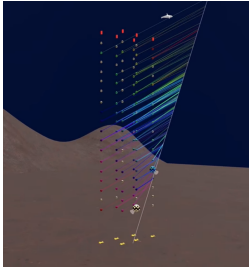
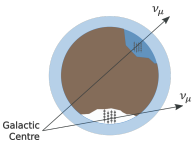
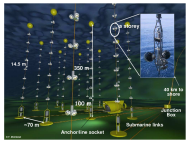


...coming soon
ORCA-6 first data!
limits

Multi-experiment combination

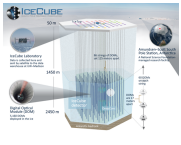
ANTARES and IceCube have conducted a combined-likelihood search in their joint data set: [Phys. Rev. D 102, 082002 (2020)]





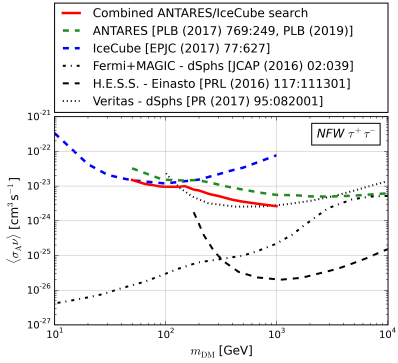
12 lines between 2

and 2.4 km underwater



86 strings between 1.5

and 2.5 km in ice



Interest in starting a joint $\gamma + \nu$ analysis, involving MAGIC, HESS, VERITAS, Fermi and ANTARES + IceCube, considering common channels and yield via EW corrections

Summary of results and references

- ANTARES has searched for dark-matter induced ν from the Galactic Centre using all-flavour data from 2007 $\rightarrow$ Feb. 2020. No dark matter.
- Same is being searched in KM3NeT/ARCA (6 lines) ... out soon
- Search for dark matter annihilations in the Sun with ANTARES in 2007-2019 data: see talks by Chiara Poiré and Daniel López Coto in this workshop.
- Same with ORCA (6 lines) ... out soon
- Expected sensitivities with KM3NeT: [PoS(ICRC2019)552] (Galactic Centre), [PoS(ICRC2019)536] (Sun).

- Search for heavy DM in secluded scenarios in ANTARES data: see talk by Filippo Sala in this workshop
- Search for very heavy (EeV) DM using ANTARES public data: see talk by Jeff Lazar in this workshop