Testing secluded dark matter models with Neutrino Telescopes

A. HERRERO

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

International Conference on Neutrinos and Dark Matter (NDM-2020)
11-14 January - Hurghada, Egypt

Contents

- Secluded Dark Matter (SDM). Searches in neutrino telescopes.
- Previous studies: ANTARES SDM Search.
- SDM Search using IC79 public data.
- Dark photon model
- Conclusions

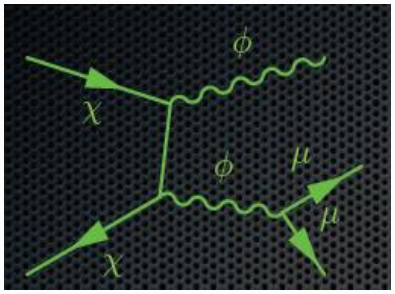
Secluded Dark Matter (SDM)

Dark Matter, χ, is secluded from 'normal' matter interacting only through a mediator, Φ.

The mediator could be some new gauge boson from the dark sector, or some other candidate.

Simplest picture: dark matter annihilates into mediators.

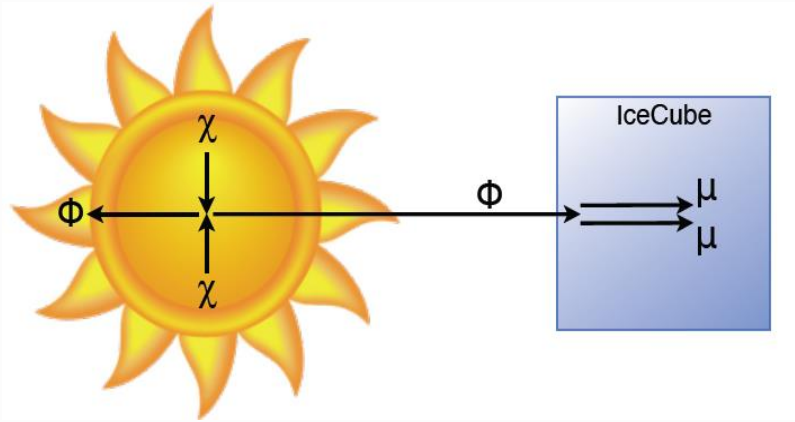
Note that: If the dark matter mass is greater than the mediator mass then the dark matter would be leptophilic.



"Typical"
$\chi \rightarrow$ ~1 TeV
$\phi \rightarrow$ ~ 1 GeV

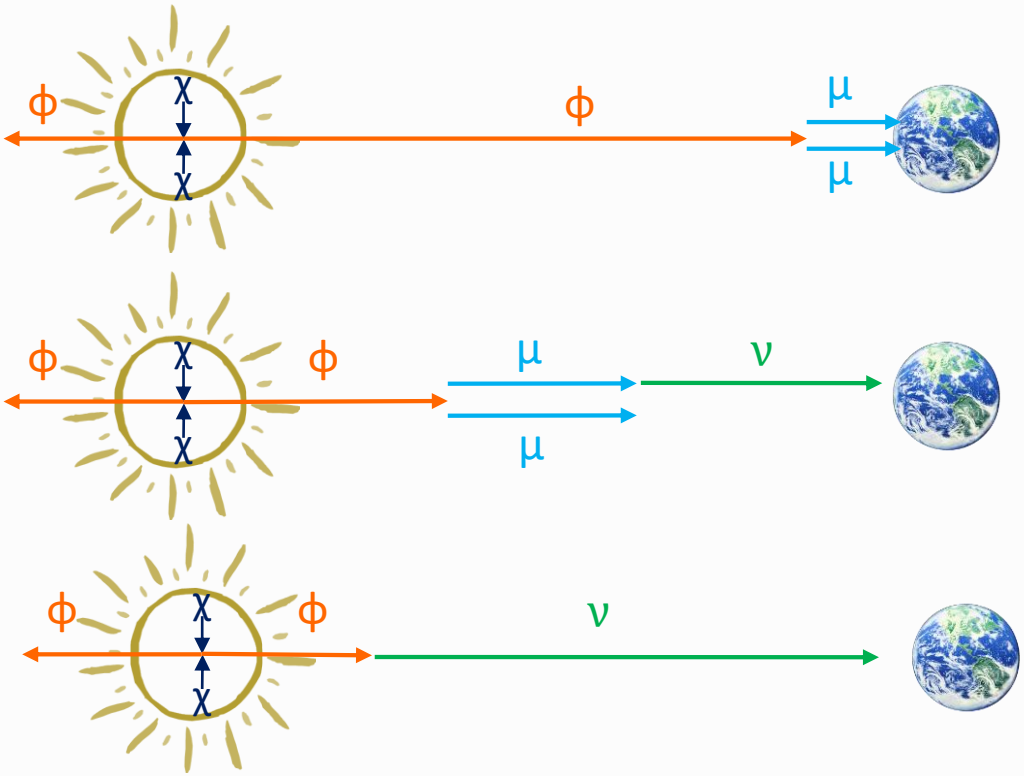
Then, celestial bodies that capture DM, as the Sun, are expected to produce mediators.

Lifetime of mediator could be long, so it could decay out of the Sun, even in the vicinity of the Earth as two co-linear muons



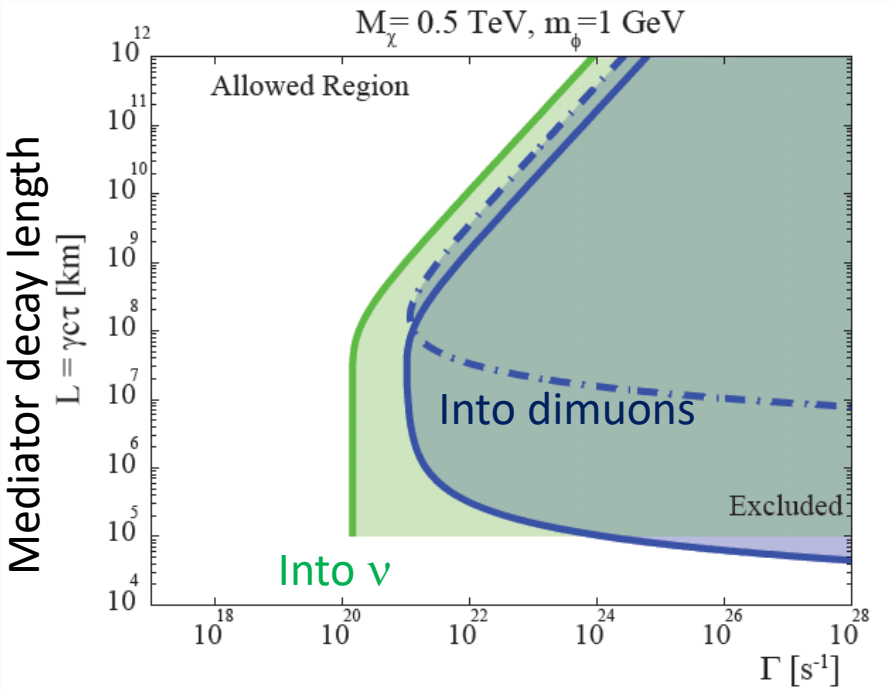
S. Adrián-Martínez et al. (ANTARES Coll.) arXiv:1602.07000, JCAP05(2016)016

Previous studies: ANTARES SDM Search

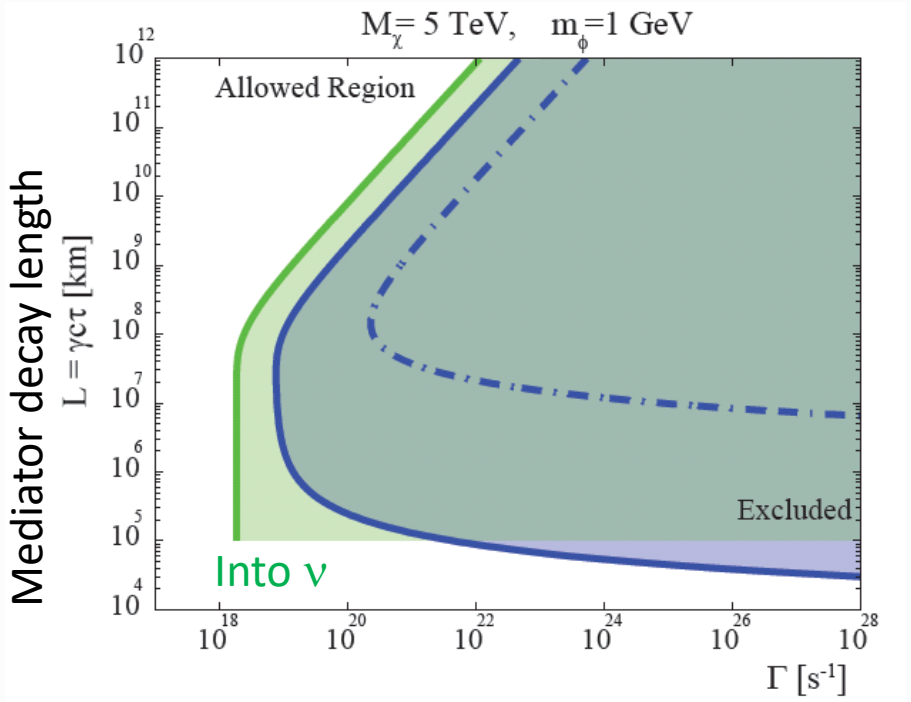


S. Adrián-Martínez et al. (ANTARES Coll.) arXiv:1602.07000, JCAP05(2016)016

Exclusion Curves



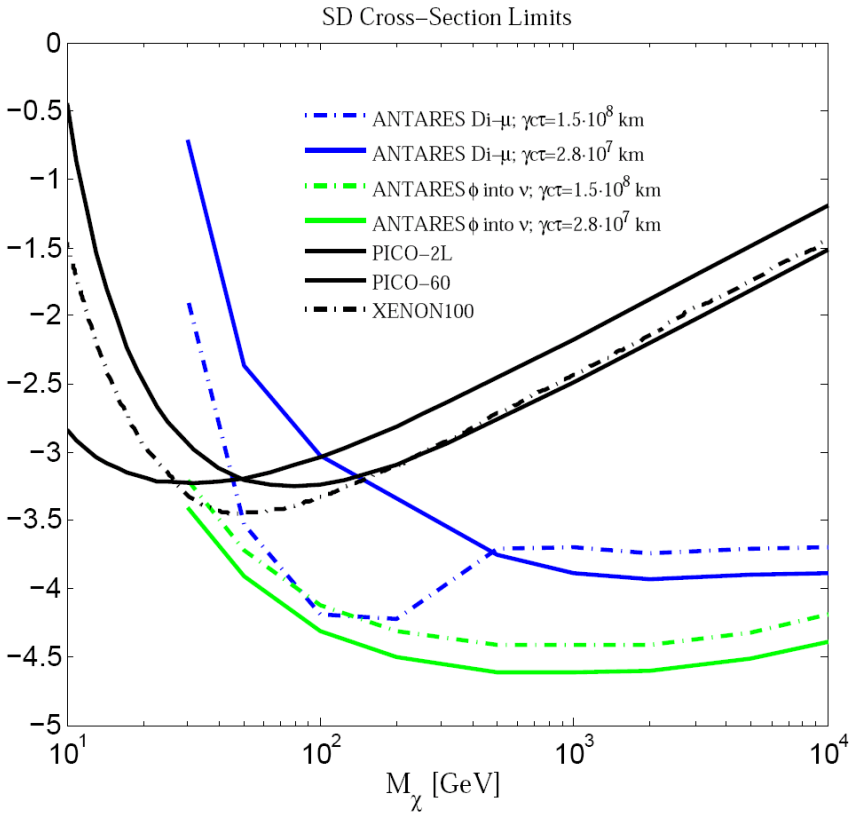
Annihilation of DM in the Sun x Branching ratio

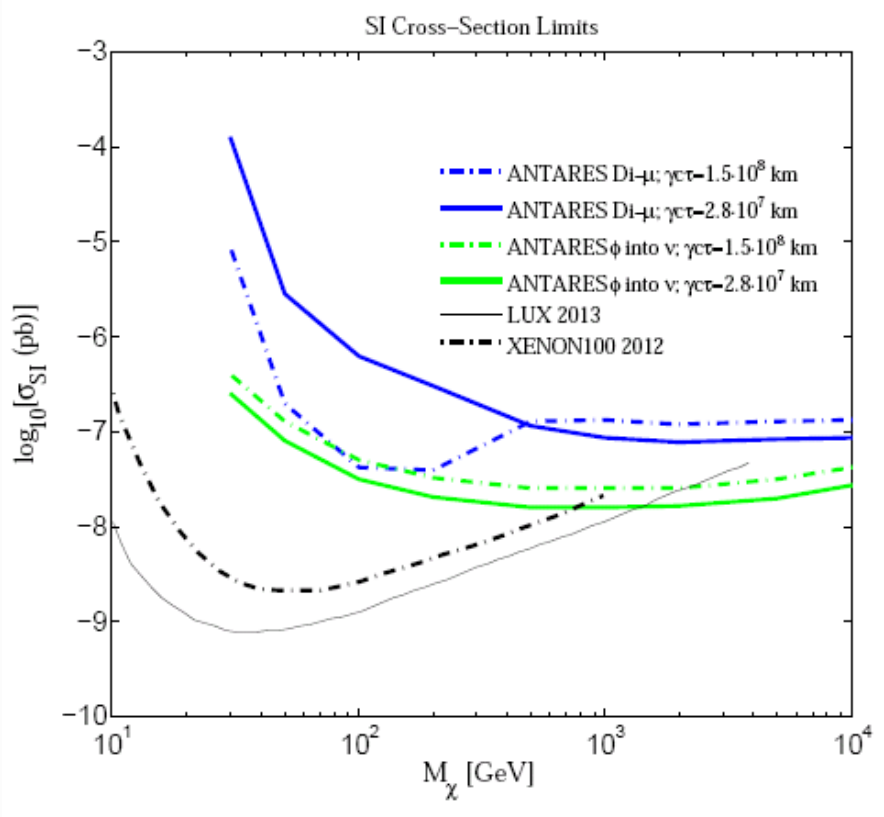


Annihilation of DM in the Sun x Branching ratio

S. Adrián-Martínez et al. (ANTARES Coll.) arXiv:1602.07000, JCAP05(2016)016

Nucleon-WIMP Cross-section Limits

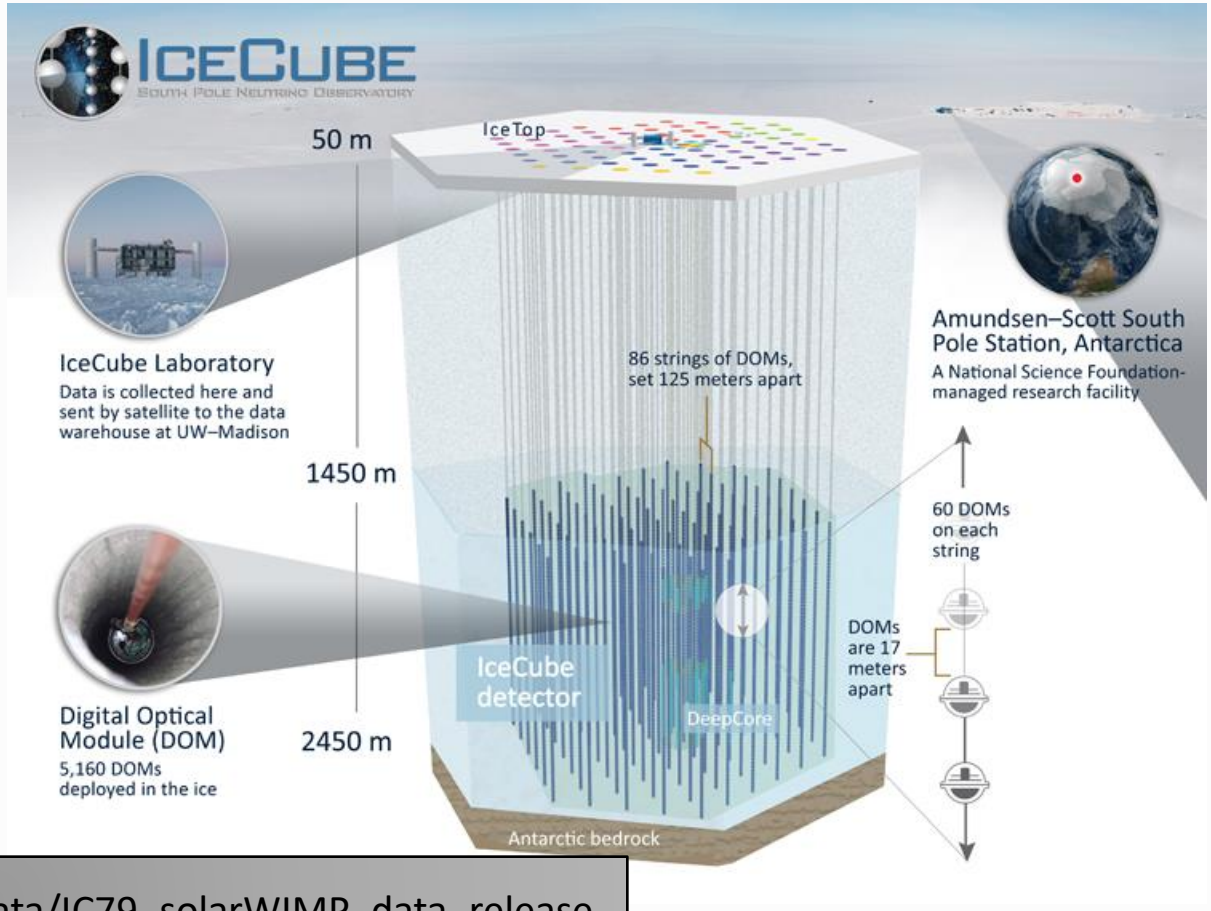




Ardid, Felis, Herrero and Martinez-Mora, JCAP04(2017)010

SDM search using IC79 data

The SDM search uses the public data released of the IC79 DM search in the Sun **arXiv:1601.00653**



http://icecube.wisc.edu/science/data/IC79_solarWIMP_data_release

SDM search using IC79 data

Public data released in January 2016 of the 79-string IceCube search for DM

In our analysis we used the Winter High-Energy set, 136 days, which contains:

IC79_Events: Reconstructed zenith, azimuth, angle of muon candidate event relative to Sun position, Energy proxy, $Nchan_{c,}$ Paraboloid sigma (uncertainty on the reconstructed direction) and event time stamp.

IC79_Background_distributions: the total number of background events per event selection with the background probability density functions (PDFs) of the angular distribution between the reconstructed track and the position of the Sun in 1-degree bins. The PDFs of the background in $Nchan_c$ is also provided.

Neutrino **IC79_Effective_Area** and Muon **IC79_Effective_Volume**

IC79_energy_histograms: the energy response for different intervals in truth muon energy (E_μ in GeV) in form of probability distributions in N*c han* are also provided

SDM search using IC79 data Analysis

- A sensitivity study has been done to select the best cuts:
  - No very significant gain using Nchan$_c$ (energy information), so no selection cut on this paremeter
  - The angle cut selection is obtained by having the better sensitivity using Feldman-Cousins statistics.

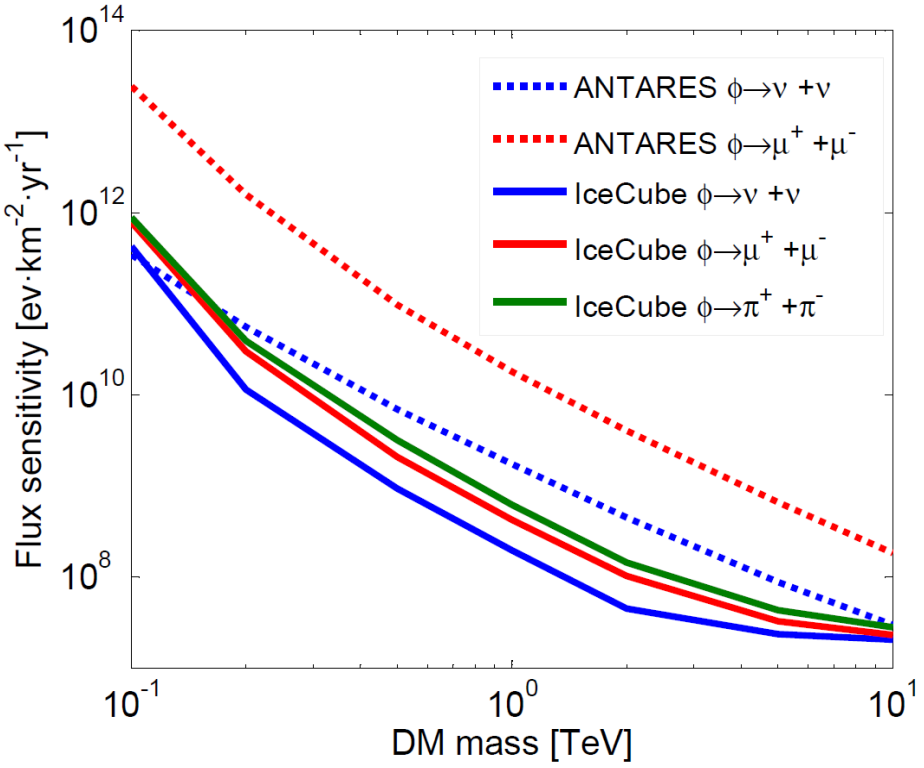


Figure 1. Sensitivities to muon neutrino flux for DM annihilation in the Sun for possible SDM channels from this search with IC79 compared with the ANTARES search [27].

SDM search using IC79 data
Results

DM mass (TeV)	ϕ decay channel	$\Psi_{\rm cut}$(degree)	$N_{\rm back}$	$\bar{\mu}^{90\%}$	$N_{\rm obs}$	$\mu_{90\%}$ UL
0.1	μ, π, ν	3.0	60.4	12.8	70	25
0.2	μ, π, ν	1.5	15.2	8.0	19	12.4
0.5	μ, π, ν	1.2	9.8	6.7	13	10.3
1	μ, π	1.1	8.2	6.3	10	8.3
1	ν	1.0	6.8	5.8	8	7.2
2	μ, π	0.9	5.6	5.4	6	5.9
2	ν	0.8	4.5	5.0	3	3.2
5	μ, π, ν	0.8	4.5	5.0	3	3.2
10	μ, π, ν	0.8	4.5	5.0	3	3.2

Table 1. $\Psi_{\rm cut}$ used for the different DM masses and ϕ decay channel. The expected background $N_{\rm back}$, $\bar{\mu}^{90\%}$, the number of observed events $N_{\rm obs}$ and the resulting 90% confidence level upper limit are also shown ($\mu_{90\%}$ UL).

SDM search using IC79 data
Results

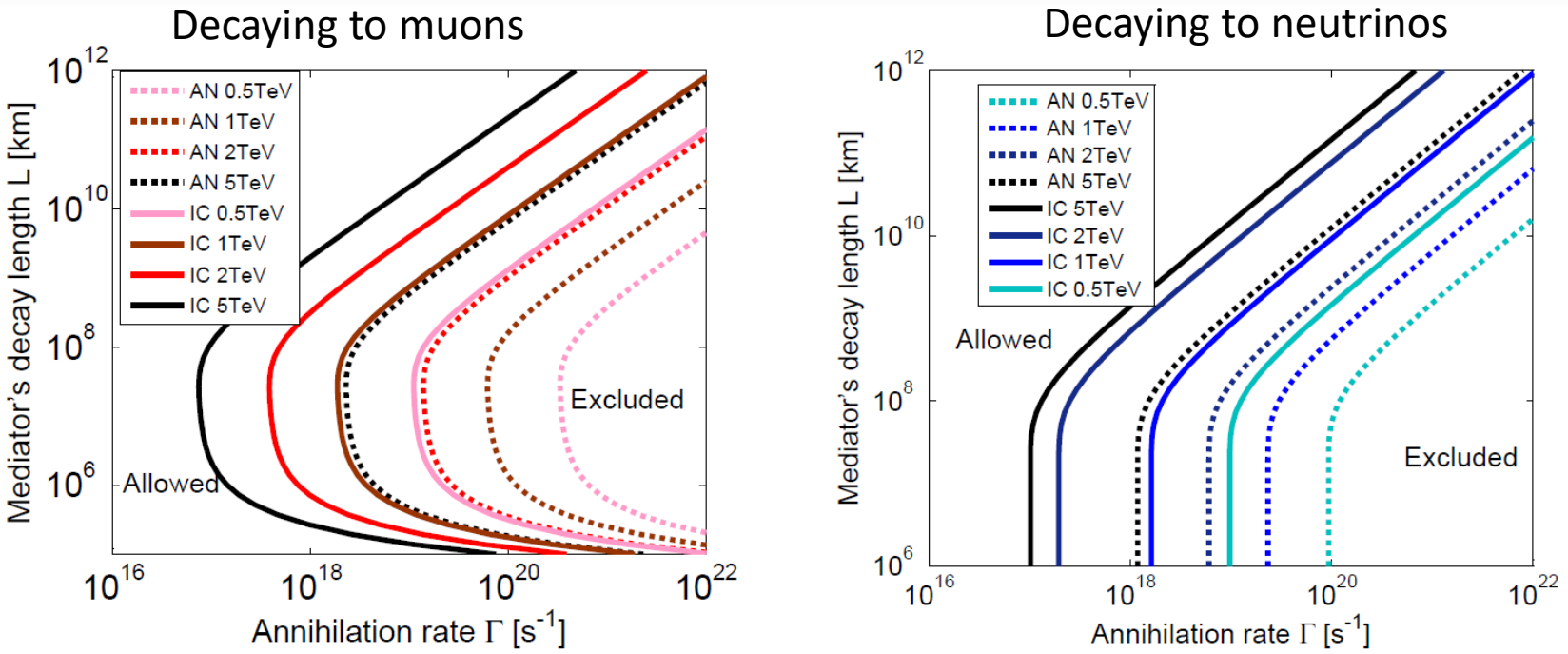
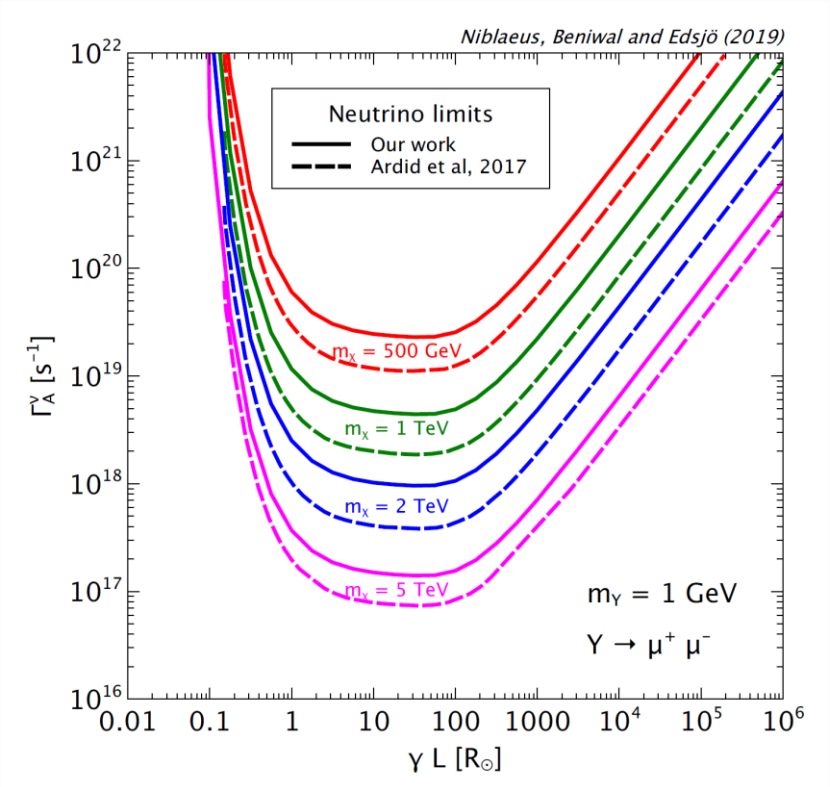


Figure 2. IC79 exclusion limits for the SDM cases studied by products of DM annihilation in the Sun through mediators decaying into muons (left) and into neutrinos (right) as a function of the annihilation rate (Γ) and the decay length ($L = \gamma c\tau$). ANTARES results from [27] are also shown. The right side of the line corresponding to a certain DM mass is the excluded region.

SDM search using IC79 data
Results

Recent similar study by Niblaeus, Beniwal and Edsjo, JCAP11 (2019) 011



Mediator
decaying to muons

SDM search using IC79 data
Results

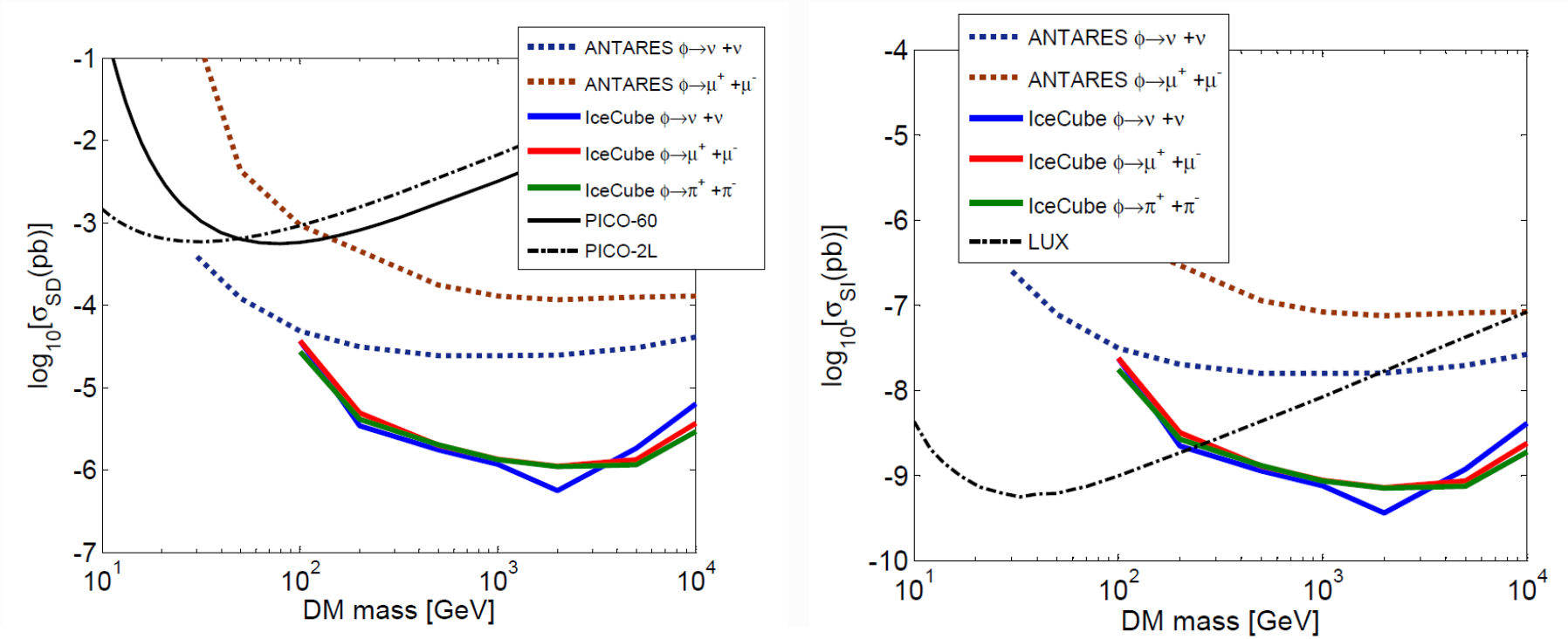
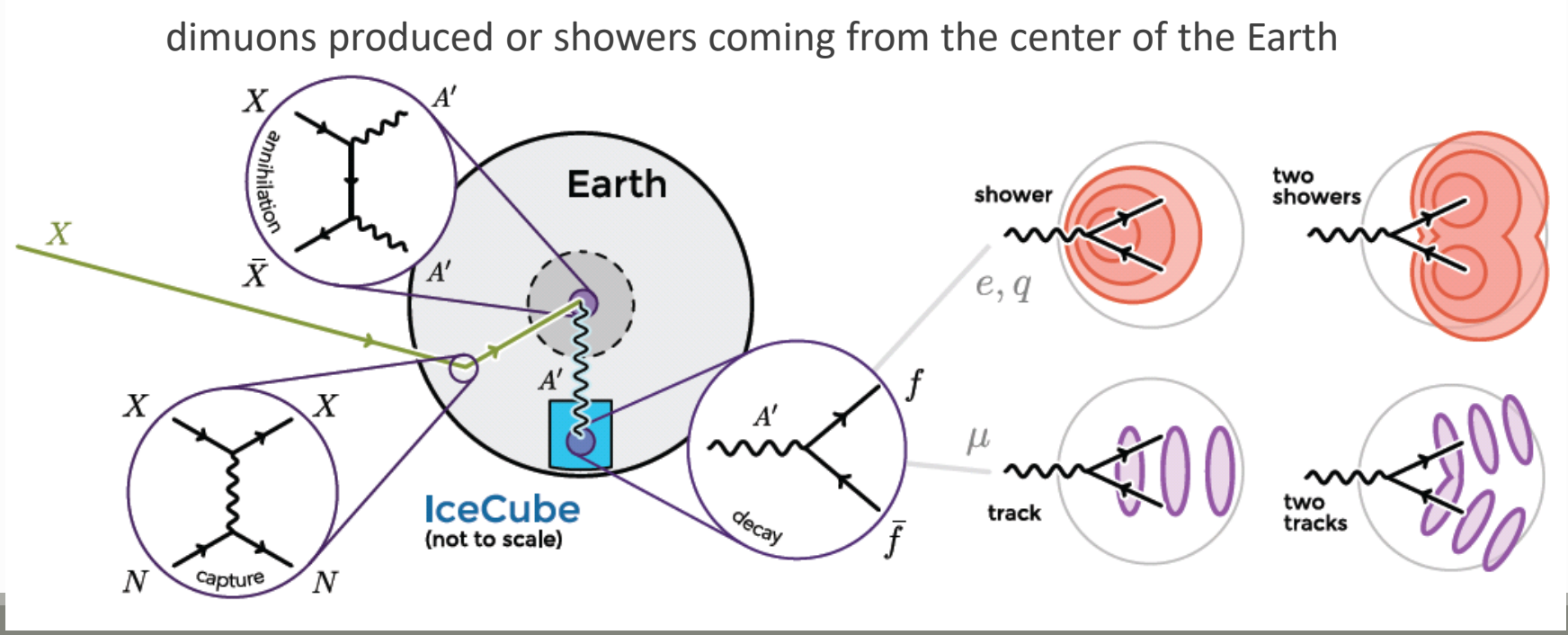


Figure 3. IC79 90% CL upper limits on WIMP-proton cross section as a function of WIMP mass. The top panel refers to spin-dependent and the bottom one to spin-independent WIMP interactions. A decay length of 2.8×10^7 km is considered. The results from an ANTARES search [27], as well as the current bounds from PICO [33–35] and LUX [36] are also shown.

Dark photon model

- Proposed SDM model: DM may be charged under dark electromagnetism with a dark photon that kinetically mixes with the Standard Model photon
- Feng et al. (arXiv:1509.07525) proposed to use IceCube to detect the dimuons produced or showers coming from the center of the Earth



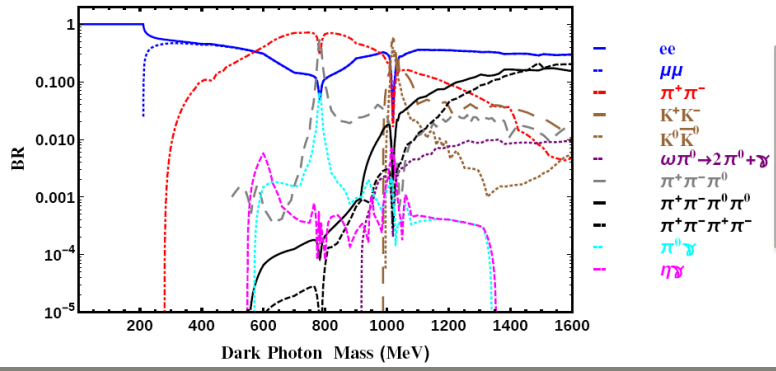
Dark photon model

- There are four parameters in the model:
  - (1) the dark photon mass ($m_{A'}$)
  - (2) the dark matter mass (m_X)
  - (3) the kinetic mixing parameter (ε): controls the interaction with ordinary matter.
  - (4) the dark fine structure constant, α_X: controls the interaction with dark matter.
- The decay length is given by:

$$\sigma_{Xn} \sim \alpha_X \varepsilon^2$$

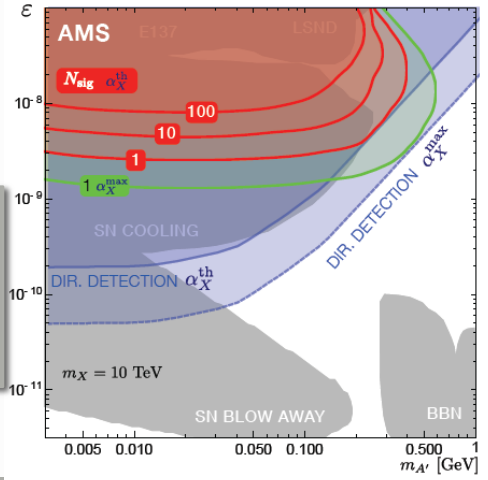
$$\alpha_X^{\rm th} = 0.035 \left(\frac{m_X}{\rm TeV}\right) \qquad \alpha_X^{\rm max} = 0.17 \left(\frac{m_X}{\rm TeV}\right)^{1.61}$$

$$L = R_\odot \, {\rm Br}(A' \to e^+e^-) \left(\frac{1.1\times10^{-9}}{\varepsilon}\right)^2 \left(\frac{m_X/m_{A'}}{1000}\right) \left(\frac{100\ {\rm MeV}}{m_{A'}}\right)$$



Feng et al. (arXiv:1602.01465) proposed to use AMS to detect positrons from dark photons coming from the Sun

$$10^{-11} \lesssim \varepsilon \lesssim 10^{-8}$$



Constraints to Dark Photon model using IC79 data

We can transform the constraints in the decay into dimuons and dipions into bounds to the dark photon model

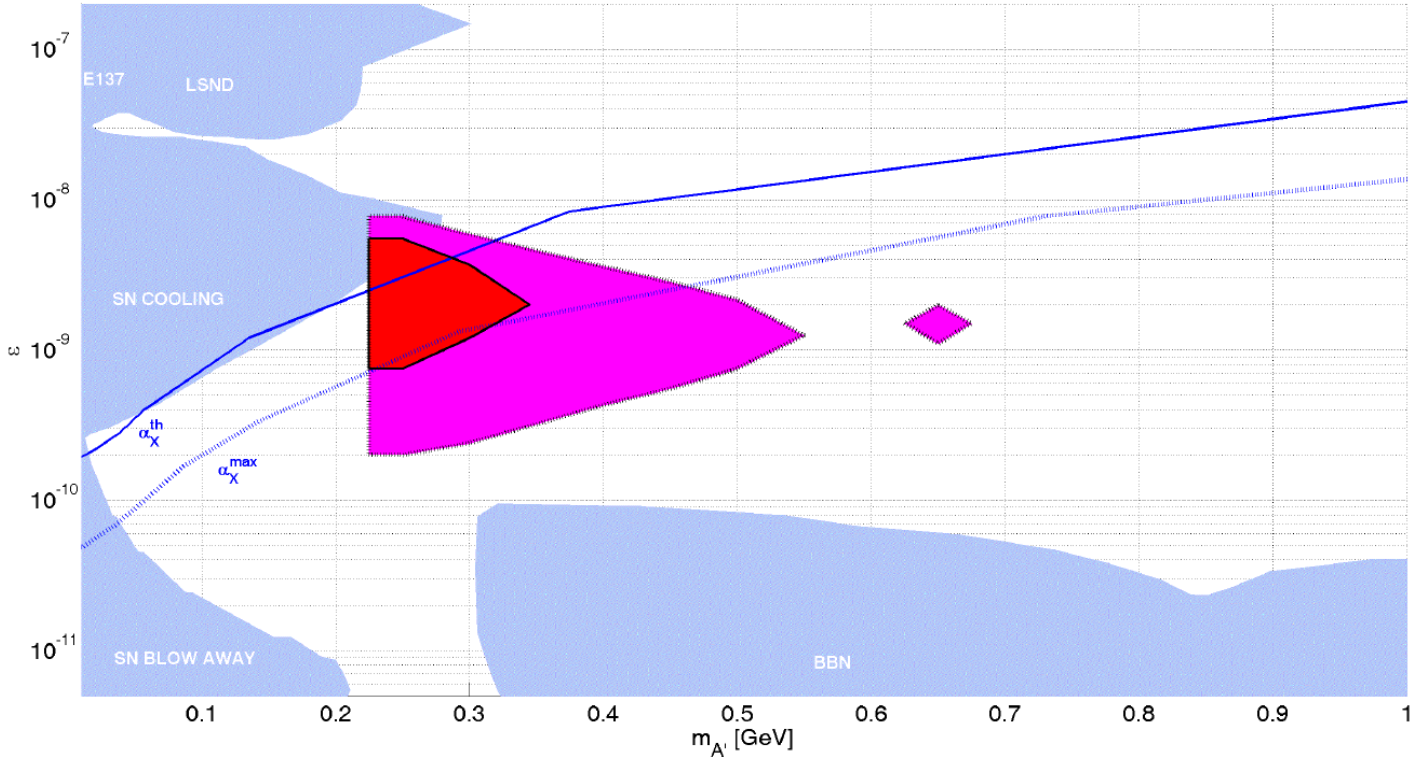


Figure 4. Excluded regions in the $(m_{A'}, \varepsilon)$ plane by this analysis (using IC79 data) for a DM mass of 10 TeV and $\alpha_X = \alpha_X^{\rm th}$ (red) or $\alpha_X^{\rm max}$ (magenta). Bounds from direct detection and regions probed by accelerators and astrophysics are also shown, taken from [25].

[25] arXiv:1602.01465

Constrains to Dark Photon model using IC79 data

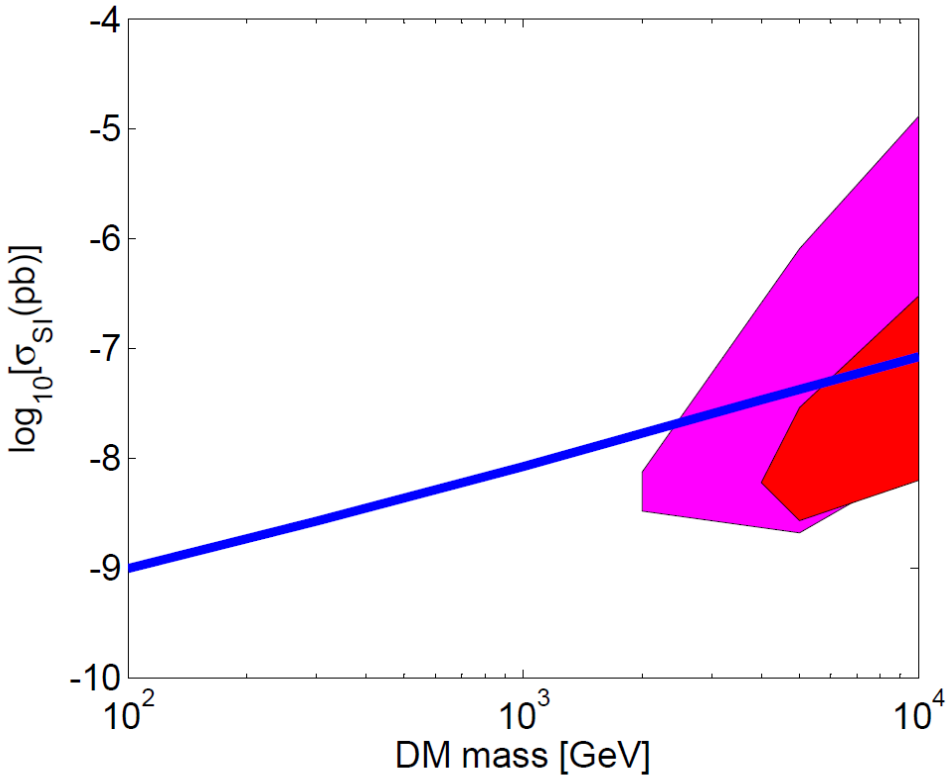


Figure 5. Constraints in the (m_X, σ) plane from this analysis (IC79 data)for $m_{A'} = 250\,\mathrm{MeV}$ and assuming $\alpha_X = \alpha_X^{\mathrm{th}}$ (red) or α_X^{max} (magenta). The bounds from LUX [36] are also shown.

Conclusions

- Different Secluded Dark Matter models have been proposed to explain DM and other experimental anomalies observed. Among them, Dark photon model is one of the most promising.
- It is possible to test some of the parameter of space of these models with searches in neutrino telescopes
- A search for SDM in the Sun has been done with IC79 public data
- Some first constrains for Dark Photon in neutrino telescopes have been derived
- Possibility to test it in the future using ICECUBE or KM3NeT-ARCA/ORCA, with the Earth, Sun and GC as sources

Thank you very much for your attention

A. HERRERO

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

International Conference on Neutrinos and Dark Matter (NDM-2020)
11-14 January - Hurghada, Egypt

Backup slides

ANTARES Coll. and Sala PoS(ICRC2019)519

SDM search in the GC

ANTARES Sensitivity for SDM search in the Galactic Center

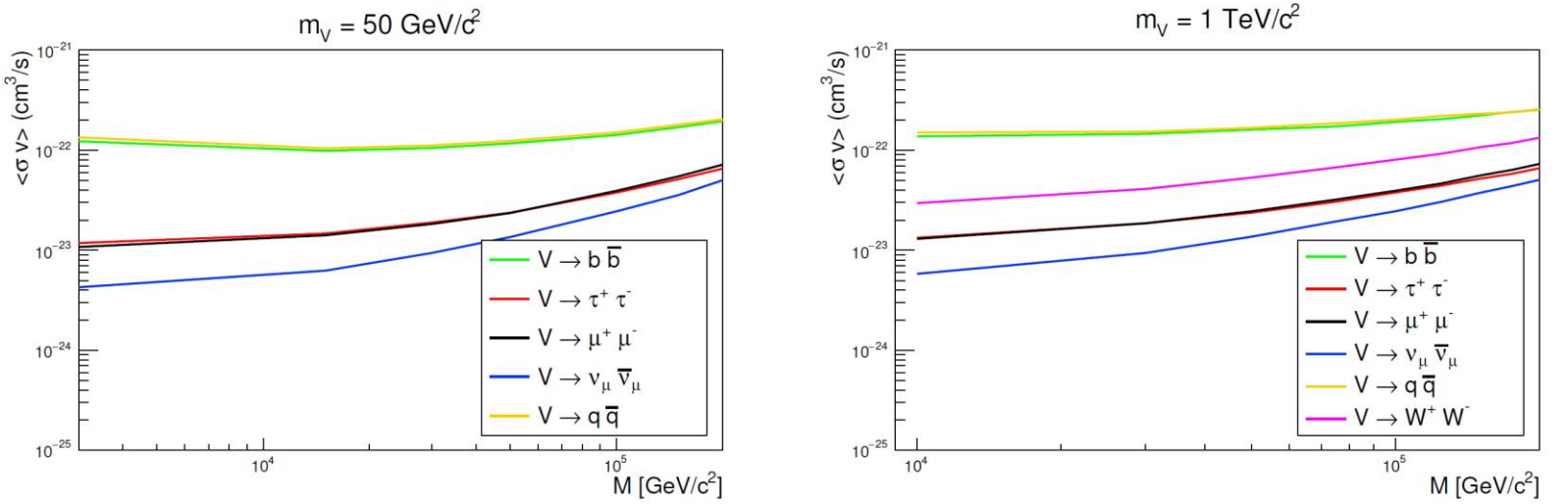


Figure 3: Sensitivities reached with 9 years of ANTARES data on the effective cross-section for DM pair-annihilation into a mediator pair, where the label in the figure indicates the decay channel of a single mediator. The mediator mass is $m_V = 50$ GeV/c^2 (left) and $m_V = 1$ TeV/c^2 (right)