discussion session #41: Indirect dark matter detection with photons and neutrinos

Your conveners: Jim Buckley, Silvia Manconi

21 July, 2021

@ ICRC 2021 Berlin (online)

Proposed Agenda

Structure of this discussion session:

- 3 main topic blocks
- $\sim$3 minutes slot for each contribution: 2 minute presentations by authors + 2-3 questions (specific for each talk) + topic discussion at the end
- General discussion (to be continued in breakout rooms/coffee break)

Main topics:

1. Galactic center: photon excess, line searches and neutrinos
2. Decaying/heavy/secluded dark matter, ALPs
3. Neutrinos, X-ray to MeV bands, future instruments

see Plenary talks: T. Slatyer, J. Lazar, M. Schumann, ...

Some guidelines:

1. Speakers: stay in your 2 minutes. We all saw your video, this is just a recap!
2. All: raise your hand to ask questions
3. Please try to not start the most interesting and long discussions in the chat while speakers are presenting ;)
4. Please be kind and polite to each other (see code of conduct)

Let's use this opportunity to understand better each others' work, discuss current problems, and be inspired for what to do next!

Galactic center: photon excess, line searches and neutrinos

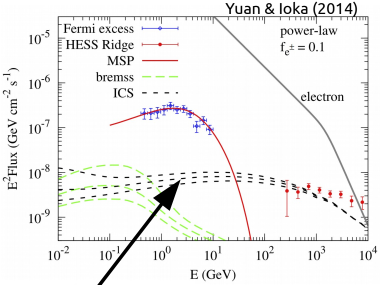
- **Oscar Macias**: Cherenkov Telescope Array Sensitivity to the Putative Millisecond Pulsar Population responsible for the Galactic Center Excess
- **Christopher Eckner** Sensitivity of the Cherenkov Telescope Array to a dark matter signal from the Galactic centre
- **Mattia Di Mauro**: Multimessenger constraints on the dark matter interpretation of the Fermi-LAT Galactic center excess
- **Tomohiro Inada**: Search for Gamma-ray Line emission from Dark Matter annihilation in the Galactic Centre with the MAGIC telescopes
- **Sara Rebecca Gozzini**: Indirect dark matter searches with neutrinos from the Galactic Centre region with the ANTARES and KM3NeT telescopes

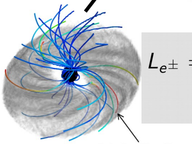
See also in other discussion sessions:

- **Joanna Berteaud**: Multi-wavelength probes of the Fermi GeV excess
- **Chris Gordon**: HI absorption and Galactic center excess
- **Silvia Manconi**: Dissecting the inner Galaxy with gamma-ray pixel count statistics

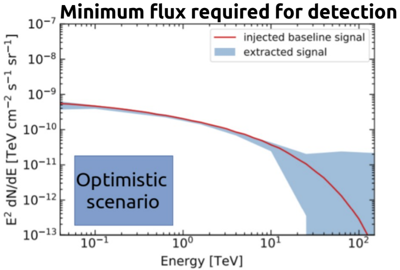
CTA Sensitivity to the high-energy tail of the GCE

- Oscar Macias





$$L_{e^\pm} = f_{e^\pm}\dot{E} = \frac{f_{e^\pm}}{f_\gamma} L_{\gamma,\mathrm{prompt}} \simeq 10 f_{e^\pm} L_{\gamma,\mathrm{prompt}},$$



Minimum $f_{e^\pm}$ for detection [%]				
Baseline	**Inj1**	**Inj2**	**Inj3**	**Inj4**
FB$_{\mathrm{min}}$, perfect GDE.				
10.5%	2.9%	158.4%	24.3%	8.2%
FB$_{\mathrm{max}}$, mismodeling of the GDE.				
72.9%	51.8%	326.7%	70.4%	74.1%

cherenkov
telescope
array

Sensitivity of the Cherenkov Telescope Array to a dark matter signal from the Galactic centre

Christopher Eckner (eckner@lapth.cnrs.fr),
on behalf of the CTA Consortium

We gratefully acknowledge financial support from the agencies and organizations listed here:
http://www.cta-observatory.org/consortium_acknowledgments

Data analysis — "benchmark" setup

Template Fitting (3D analysis)

$$(\mu_\mathrm{K})_k = \mu_k^{\mathrm{CR}} + \mu_k^{\mathrm{GDE}} + \Delta B_k + A^{\mathrm{DM}}\mu_k^{\mathrm{DM}}$$

Generic setup:

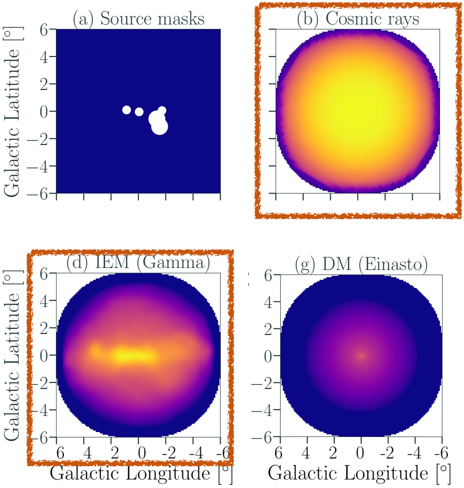
CTA Mock Data:
- **Asimov** data set
- **CR + IEM**
- spatial binning: 0.1°
- spectral binning: 54 bins (width corresponding to 2σ energy resolution of CTA) from [0.03, 100] TeV
- PS mask

Model Data:
- template preparation like mock data
- **CR + IEM + DM**

  —> systematic uncertainty added via covariance matrix

$$(K_\mathrm{S})_{jj'} = \sigma_\mathrm{S}^2 \exp\left(-\frac{1}{2}\frac{\left\|\vec{r}_j - \vec{r}_{j'}\right\|^2}{\ell_\mathrm{S}^2}\right)$$

Implementation via python package swordfish [Edwards & Weniger; arXiv:1712.05401]



Summary

We derive the CTA's sensitivity to a DM signal in the Galactic centre by

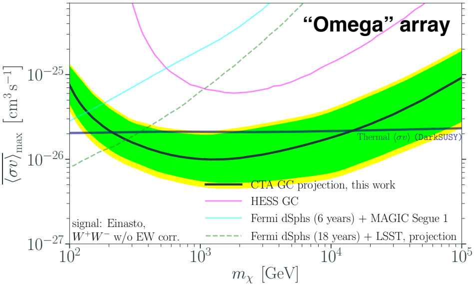
— defining the **most promising data analysis approach** (template-based analysis),

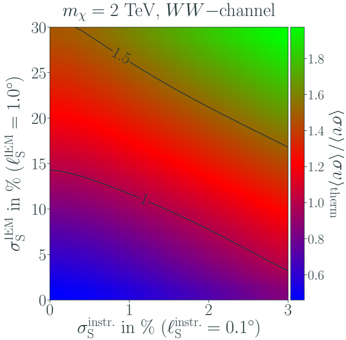
— **studying the impact of instrumental systematic uncertainties** in an agnostic manner (for a possible input of future CTA performance optimisation),

— **quantifying the robustness** of the expected limits with respect to uncertainties of astrophysical emission components like the interstellar emission

—> Will the measured interstellar emission at TeV energies match the current theoretical models?

—> Do we expect surprises in terms of TeV source populations?

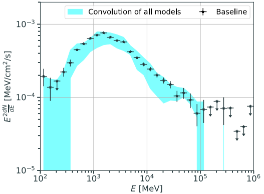




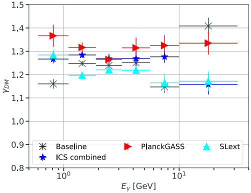
CTA offers the opportunity to probe the uncharted territory of the WIMP parameter space beyond the thermal annihilation cross-section at the TeV scale!

Characteristics of the GCE: Summary

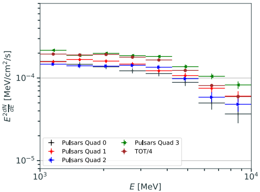
Spectrum peaked at a few GeV



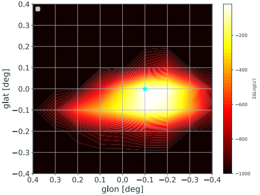
No energy dependence of spatial morphology.



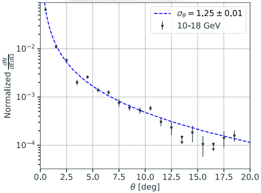
The GCE is approximatively spherically symmetric.



Centered in the GC



gamma=1.25



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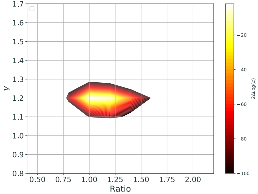
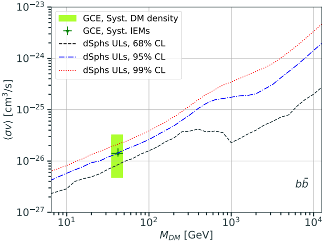
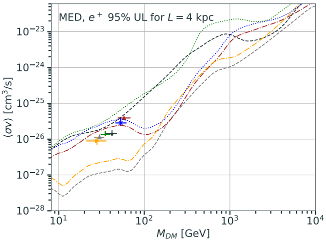
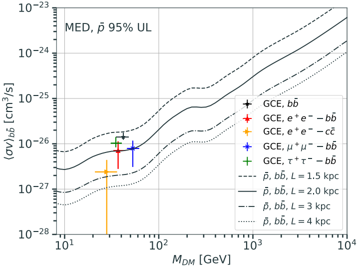
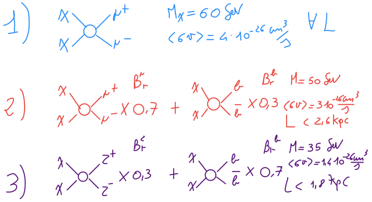


Multimessenger and multitarget search for dark matter









Search for Gamma-ray Line emission from Dark Matter annihilation in the Galactic Centre with the MAGIC telescopes

Tomohiro Inada (ICRR, UTokyo)
Daniel Kerszberg, Moritz Hütten, Masahiro Teshima
Javier Rico, Daniele Ninci, for the MAGIC Collaboration

MAGIC

ICRR
Institute for Cosmic Ray Research
University of Tokyo

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

The GC observation by MAGIC

The GC observation by MAGIC

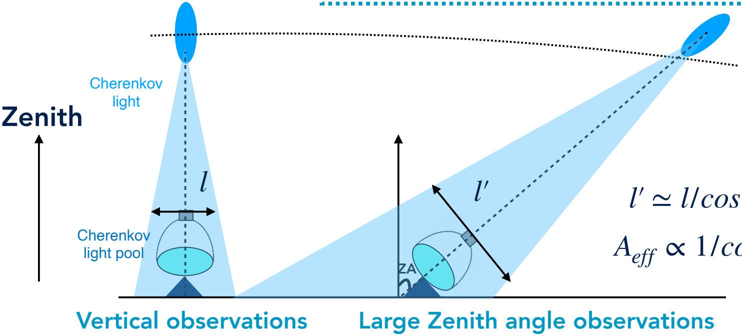
- Zenith angle : 58 - 70 [deg]
  - Large zenith angle observation, LZA

Pros

- Increase the γ-ray detectable area
  - Get larger statistics in higher energies

Cons

- Increase the energy threshold



$$l' \simeq l/cos(Zd)$$

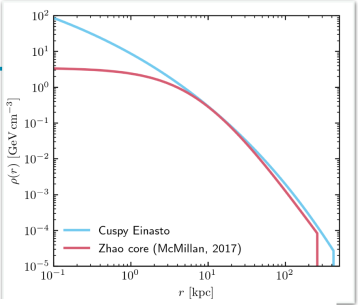
$$A_{eff} \propto 1/cos^2\theta_{Zd}$$

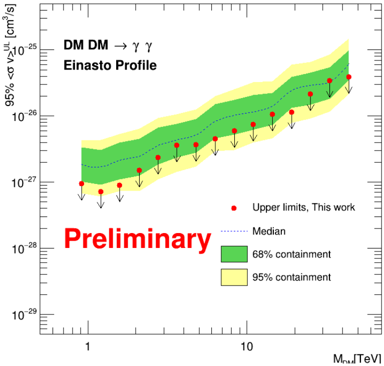
<u>Large Zenith angle observations boost the sensitivity for line signals from TeV DM!!</u>

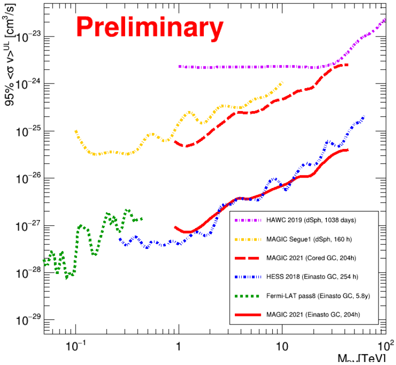
Results

No significant excess

- Set upper limits with 95% C.L. on 15 masses
- 912 GeV - 43 TeV
- with Einasto (cuspy) and cored profile.
- <u>E > 10 TeV : competitive</u>







Summary

- Search for line-like signals in VHE gamma rays can test some promising TeV DM particle models

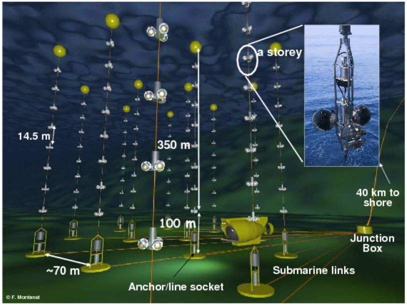
- We reported observations with the MAGIC telescopes located on La Palma, Spain
  - Performed large zenith angle observations to focus on TeV DM
  - First search for DM lines at the GC with MAGIC

- No significant excess was found and upper limits were set on the annihilation cross section $\chi\chi \rightarrow \gamma\gamma$
  - Competitive limits for both cuspy and core DM profiles

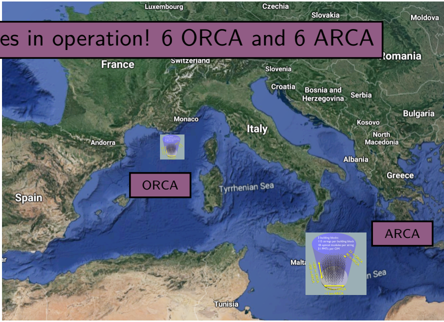
- For the future (CTA era)
  - Large zenith angle observations of the GC are well suited to search for heavy DM candidates
  - High potential of the northern site to contribute to next-generation DM searches

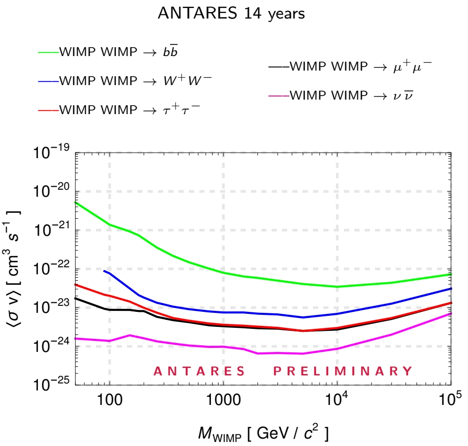
Indirect dark matter searches with ANTARES and KM3NeT - S.R. Gozzini

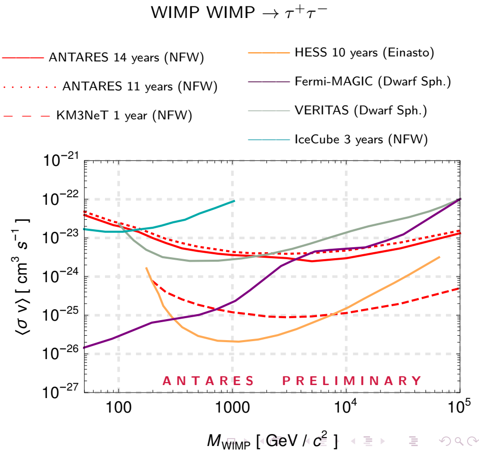
High-energy ν fluxes from WIMP WIMP $\to \tau^+\tau^-$, $\mu^+\mu^-$, W^+W^-, $b\bar{b}$, $\nu\bar{\nu}$
Jan. 2007 to Feb. 2020, lifetime 3845 days, all-flavour (11174 tracks + 225 showers)
Unbinned maximum likelihood. Data TS is compatible with BG for all parameter combs.



12 lines in operation! 6 ORCA and 6 ARCA




ANTARES 14 years
WIMP WIMP → $b\bar{b}$
WIMP WIMP → W^+W^-
WIMP WIMP → $\tau^+\tau^-$
WIMP WIMP → $\mu^+\mu^-$
WIMP WIMP → $\nu\bar{\nu}$
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
$\langle\sigma v\rangle$ [cm^3 s^{-1}]
ANTARES PRELIMINARY
100
1000
10^4
10^5
$M_{\rm WIMP}$ [GeV / c^2]


WIMP WIMP → $\tau^+\tau^-$
ANTARES 14 years (NFW)
ANTARES 11 years (NFW)
KM3NeT 1 year (NFW)
HESS 10 years (Einasto)
Fermi-MAGIC (Dwarf Sph.)
VERITAS (Dwarf Sph.)
IceCube 3 years (NFW)
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
$\langle\sigma v\rangle$ [cm^3 s^{-1}]
ANTARES PRELIMINARY
100
1000
10^4
10^5
$M_{\rm WIMP}$ [GeV / c^2]

Galactic center: photon excess, line searches and neutrinos

Discussion

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Decaying/heavy/secluded dark matter, ALPs

- **Clarissa Siqueira**: Indirect Searches for Secluded Dark Matter
- **Marco Chianese**: Constraints on decaying dark matter with LHAASO-KM2A
- **Andrea Addazi**: Dark Matter Searches for heavy Dark Matter with LHAASO
- **Manuel Meyer**: Search for axion-like-particle induced gamma-ray bursts from core-collapse supernovae with the Fermi LAT

Indirect Searches for Secluded Dark Matter

Clarissa Siqueira - IFSC/USP

1. What is this contribution about?

Indirect gamma-ray searches for Secluded DM, where instead of annihilating directly into SM particles, the DM annihilates into metastable mediators.

2. Why is it relevant / interesting?

Secluded models can escape from the current stringent bounds from direct/collider searches. For the first time, we also showed the sensitivity of the Southern Hemisphere future telescopes to Secluded DM.

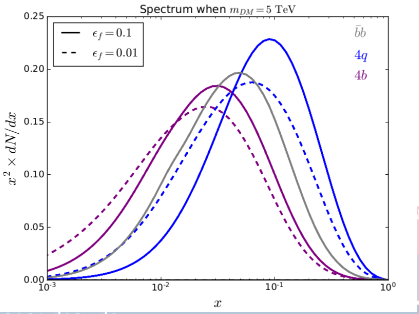
3. What have we done?

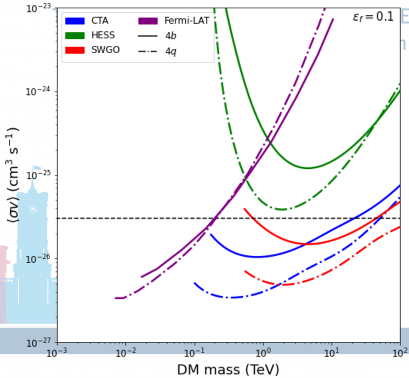
We used data from H.E.S.S. and the prospects to CTA and SWGO to compute the limits/sensitivity on the velocity averaged annihilation cross-section versus DM mass to secluded scenarios. We also compared with previous studies using Fermi-LAT data, looking at dSphs.

4. What is the result?

We showed that CTA and SWGO will be able to probe a large fraction at TeV DM mass scale, which provides the thermal annihilation cross-section.

Some results





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Strong constraints on decaying dark matter with LHAASO

Marco Chianese[a]

Email: marco.chianese@unina.it

WORK WITH

Shin'ichiro Ando[b,c], Damiano F.G. Fiorillo[a], Gennaro Miele[a,d], Kenny C.Y. Ng[e], and LHAASO data analyzed by Zhe Li[f] (on behalf of LHAASO collaboration)

AFFILIATIONS

[a] Università di Napoli Federico II & INFN - Sezione di Napoli, Italy;
[b] GRAPPA Institute & University of Amsterdam, The Netherlands;
[c] Kavli Institute IPMU, Japan;
[d] Scuola Superiore Meridionale, Italy;
[e] The Chinese University of Hong Kong, China
[f] Institute of High Energy Physics, China

Executive summary

- We present **the first dark matter analysis in LHAASO-KM2A**, which is a ground-based full-duty EAS array dedicated to VHE gamma-ray astronomy above 10 TeV

- We analyze the first 340 days of data taken with 1/2-KM2A in LHAASO.

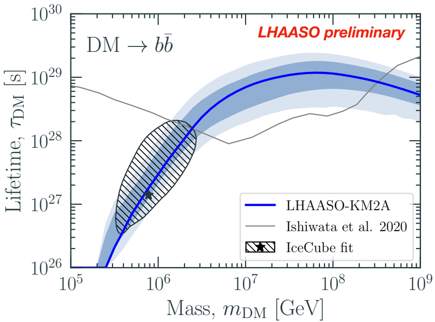
- We find no evidence for a dark matter signal in the energy range 10^5 to $10^{6.2}$ GeV.

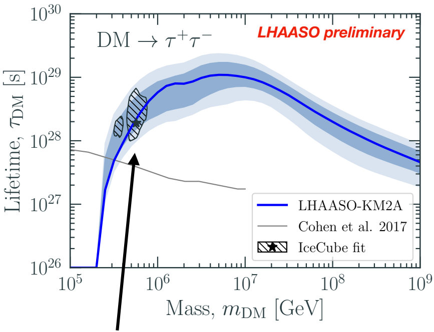
- We place some of the strongest gamma-ray limits on decaying dark matter particles for different decay channels and dark matter masses (from 10^5 to 10^9 GeV).

- LHAASO is already offering unprecedented sensitivity in DM indirect-detection searches, with an **immediate impact on the DM interpretation of IceCube high-energy neutrino events**.

Main results

Constraints at 95% CL and exclusion bands from Monte Carlo simulations





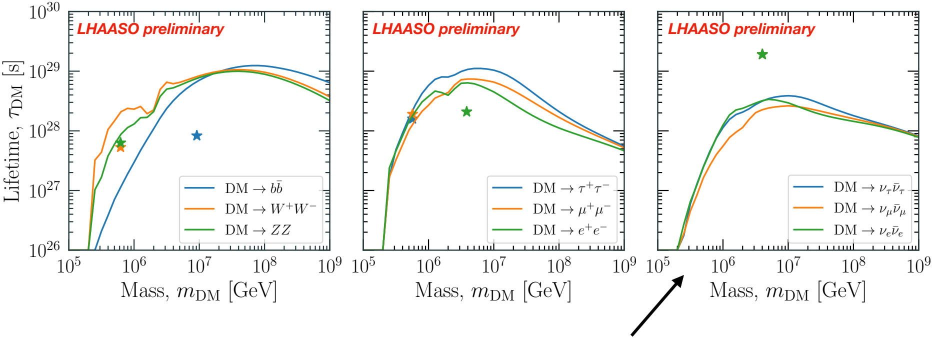
Significant improvement with respect to previous constraints

Tension with the parameter regions favored by IceCube neutrino data

Chianese et al., ***JCAP 1911***

Different DM decay channels

Constraints on DM lifetime at 95% CL for different DM decay channels

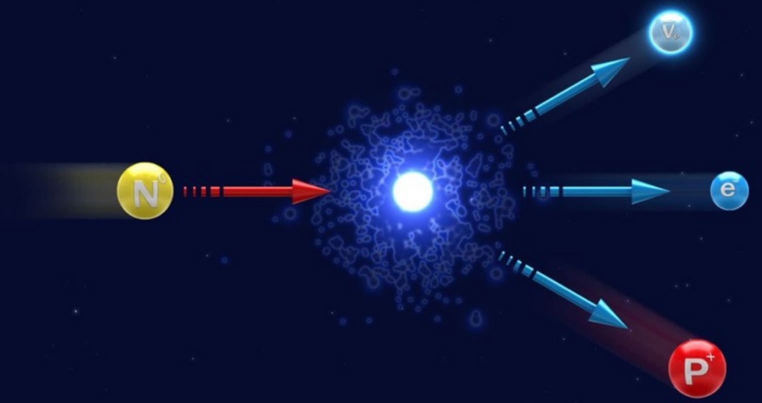


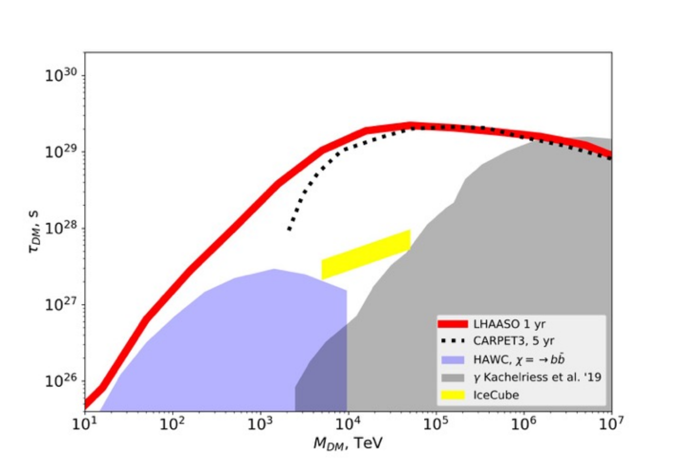
Prompt gamma-rays mainly produced through EW radiative corrections

Heavy Dark Matter searches with LHAASO. Summary

Andrea Addazi,
Sichuan University (Chengdu, China)
INFN LNF Frascati

DM decays





Sensitivity of LHAASO for the measurement of dark matter decay time (for DM decaying into quarks). Yellow band shows the range of decay times for which DM decays give sizable contribution to the IceCube neutrino signal. Blue and gray shaded regions show the existing bounds imposed by HAWC and ultra-high-energy cosmic ray experiments. and dashed curves are from the HAWC search of the DM decay signal in the Fermi Bubble regions.

Conclusions

Heavy DM decays beyond electroweak WIMPs can be tested by LHAASO

Important from theoretical model building from symmetry principle or to test model of DM genesis in the early Universe

IceCube neutrino events can be compared with LHAASO gamma rays data. Multi-messenger DM searches

SEARCH FOR AXION-LIKE PARTICLE INDUCED γ-RAY BURSTS FROM CORE COLLAPSE SUPERNOVAE WITH THE FERMI-LAT

[PRL, VOL. 124, 23, 231101 (2020), ARXIV:2006.06722]

MANUEL MEYER & TANJA PETRUSHEVSKA
FOR THE FERMI-LAT COLLABORATION

JULY, 2021

ICRC 2021

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$B \approx 1\,\mu\mathrm{G}$

$L = 10\,\mathrm{kpc}$

$P_{a\gamma} \approx 0.1$

$A \approx 0.5\,\mathrm{m}^2$

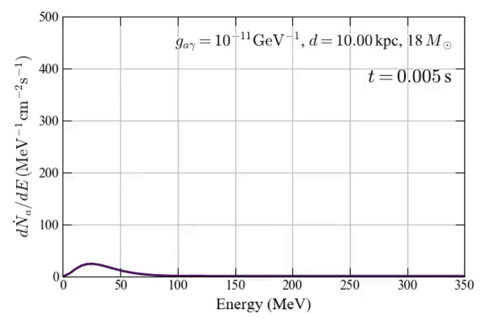
$\phi_a \approx 10^5\,\mathrm{s}^{-1}\mathrm{cm}^{-2}(g_{a\gamma}/2 \times 10^{-11}\,\mathrm{GeV}^{-1})^2$

a

B

FERMI LARGE AREA TELESCOPE (LAT)

$30\,\mathrm{MeV} \lesssim E \lesssim 1\,\mathrm{TeV}$



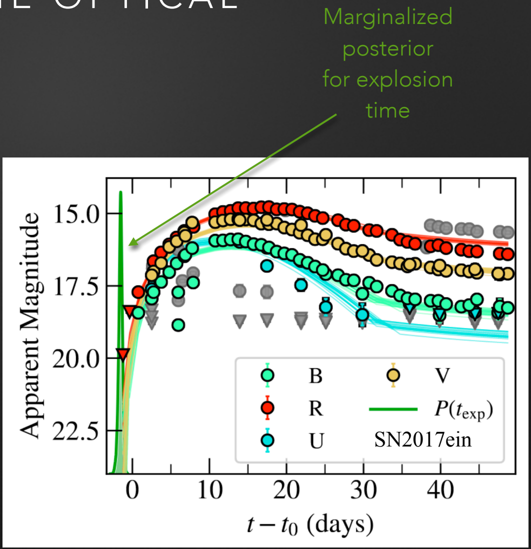
$\phi \approx 4 \times 10^7$ photons s^{-1}

(for 20 seconds, scales as $g_{a\gamma}^4$)

[MM et al. 2017]

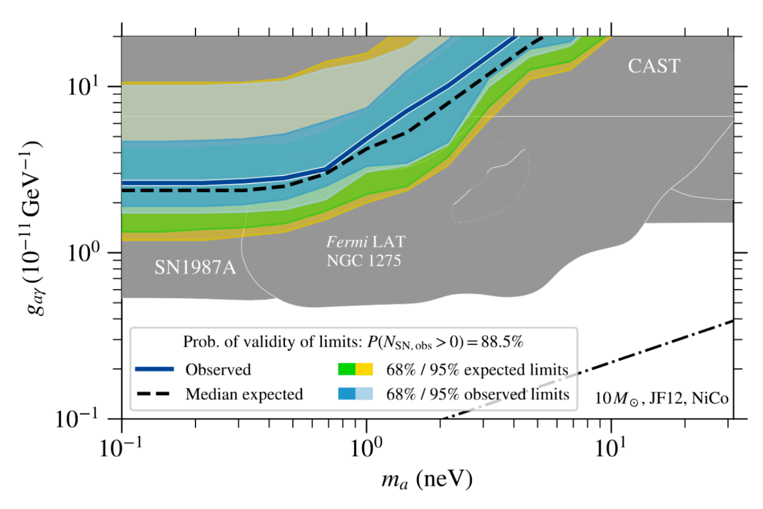
DETERMINING THE OPTICAL EXPLOSION TIME

- Light curve fitted with **MOSFiT** package
  [Guillochon et al. 2018]



[MM & Petrushevska 2020]

COMBINED LIMITS FROM SAMPLE OF 20 SNe



$$P(N_{\mathrm{obs}} \geqslant 1) = 1 - \prod_i \left(1 - p_{\mathrm{obs},i}\right) \approx 89\,\%$$

[MM & Petrushevska 2020]

Decaying/heavy/secluded dark matter, ALPs

Discussion

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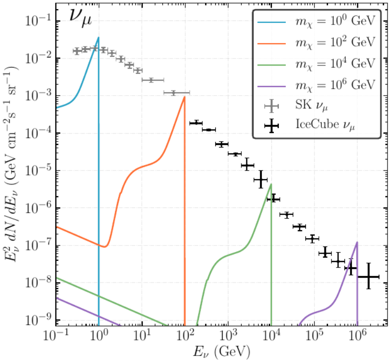
Neutrinos, X-ray to MeV bands, future instruments

- **Ali Kheirandish**: Dark Matter annihilation to neutrinos: New limits and future prospects
- **Elena Pinetti**: Integral X-ray constraints on sub-GeV dark matter
- **Aion Viana**: Searching for Dark Matter with the Southern Wide-field Gamma-ray Observatory (SWGO)
- **Stefano Profumo**: Hunting for Dark Matter and New Physics with (a) GECCO

Dark Matter Annihilation to Neutrinos: New Limits and Future Prospects

- Thermal production of WIMPs in early Universe implies possible ongoing self-annihilation of DM.
- Neutrinos could present the key portal from Standard Model to the dark sector.
- **Neutrino portal:** *the most invisible channel*, hardest to detect, difficult to rule out!
- The limits on DM annihilation to neutrinos serves as an upper bound on total DM annihilation cross section to SM particles.
- Annihilation of DM to neutrinos would lead to features in the energy spectrum and arrival direction of neutrinos.

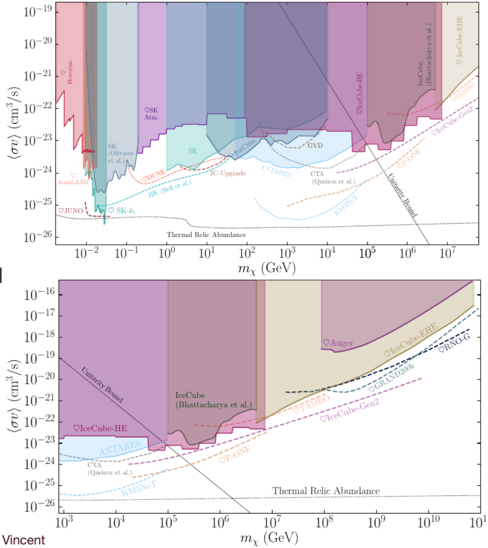


Direct DM annihilation to neutrinos would create spikes in atmospheric and cosmic neutrino flux

Ali Kheirandish | ICRC 2021 | 1

UL on DM annihilation to neutrinos

- Experimental advances in neutrino detections has made it possible to obtain comprehensive, uninterrupted set of limits on DM annihilation directly to neutrino-antineutrino pairs, for a DM mass range spanning 15 orders of magnitude.
- Future neutrino experiments will be closing in on the parameter space of direct dark matter annihilation to neutrinos.
- Future neutrino telescopes targeting ultra high energy sky will offer new opportunities to search for superheavy DM.



Argüelles, Kheirandish, Diaz, Olivares-Del-Campo, Safa, Vincent [hep/ph:1912.09486] to appear in *Reviews of Modern Physics*

Ali Kheirandish | ICRC 2021 | 2

INTEGRAL X-RAY CONSTRAINTS ON SUB-GEV DARK MATTER

Elena Pinetti

ICRC 2021

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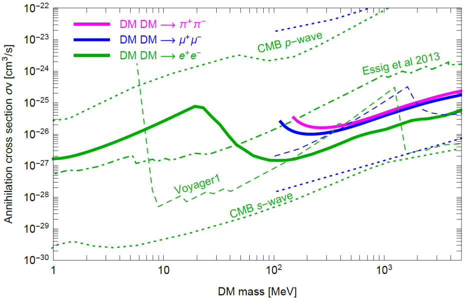
Summary

- $1\ \text{MeV} \leq m_\chi \leq 5\ \text{GeV}$
- Inverse Compton scattering on the low-energy photons
- X-ray data from INTEGRAL telescope

Strongest bound (if p-wave):

$150\ \text{MeV} \leq m_\chi \leq 1.5\ \text{GeV}$



Searching for Dark Matter with the Southern Wide-field Gamma-ray Observatory (SWGO)

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FAPESP
SÃO PAULO RESEARCH FOUNDATION

SWGO
The Southern Wide-field Gamma-ray Observatory

- Wide-angle air shower particle detector for gamma-rays, complementary to CTA South
- Located at a high-altitude site in South America,
- Covering the energy range 100 GeV to 100 TeV,
- Significant sensitivity improvement over HAWC
- Various detector concepts under study

Sensitivity to Dark Matter annihilation or decay

Towards

➢ Galactic Center

- Search for signal in the inner 10° of the Galaxy
- Einasto and Burkert profile
- $\tau^+\tau^-$, W^+W^- and $b\bar{b}$ channels

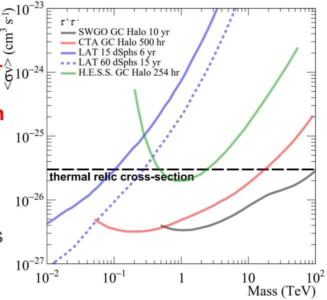
➢ Dwarf galaxies

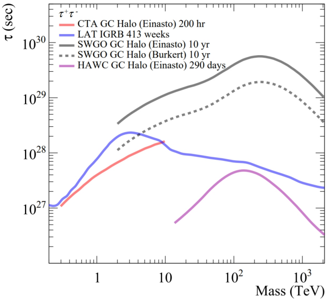
- Search for signal in present and future 30 dwarf galaxies
- J-factor and D-factor follows current dwarf galaxies

Main results

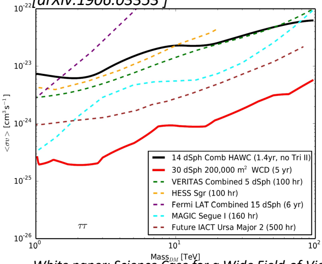
- Combination of Fermi-LAT (dSph), CTA (GC) and SWGO (GC) will be **sensitive to cross-section below the thermal relic value for all masses from ~80 TeV down to GeV range**
- **DM decay**: SWGO will reach **unprecedented sensitivity** in the TeV mass range
- For masses > 10 TeV, SWGO can be **complementary to CTA**

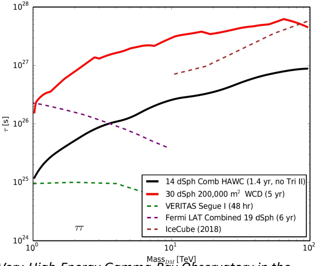
  -> confirmation of a spectrum cut-off
- **SWGO dSph: improvement of an order of magnitude** from current, and more sensitive than dSph searches from current and future detectors like HAWC, H.E.S.S. and CTA





AV, H. Schoorlemmer, A. Albert, V. de Souza, J. P. Harding, J. Hinton JCAP 2019 [arXiv:1906.03353]





White paper: Science Case for a Wide Field-of-View Very-High-Energy Gamma-Ray Observatory in the Southern Hemisphere, SGSO-alliance [arXiv:1902.08429]

Stefano Profumo

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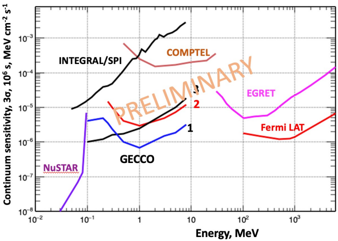
UC SANTA CRUZ

Searching for Dark Matter with (a) GECCO

GALACTIC COMPTON AND GECCO CODED APERTURE MASK EXPLORER

- Proposed *Mission Concept*: Galactic Explorer with a Coded Aperture Mask Compton Telescope (GECCO): high-sensitivity observations of the sky from ~50 KeV to ~10 MeV combining a coded aperture mask technique with high angular resolution for source detection, and a Compton telescope providing for diffuse emissions

- GECCO is ideally suited to **explore MeV dark matter candidates** unveiling dark matter signals up to **four orders of magnitude fainter** than the current observational sensitivity, and would make it possible to detect a dark matter signal from **multiple astrophysical targets**, reducing the intrinsic background and systematic effects that could otherwise obscure a **conclusive discovery**



- GECCO would enable **direct detection of Hawking evaporation** from primordial black holes with masses in the 10^{16} - 10^{18} grams range, if they constitute a sizable fraction of the cosmological dark matter.

- GECCO will **elucidate the nature of the 511 keV line**, by virtue of its unprecedented **line sensitivity** and **point-source angular resolution**: GECCO should be able to observe a 511 keV line from a variety of **extra-Galactic targets**, such as nearby clusters and massive galaxies and, potentially, even from nearby dwarf galaxies; in addition, GECCO should be able to detect **single sources of the 511 keV emission**, as long as they are reasonably close

Neutrinos, X-ray to MeV bands, future instruments

Discussion

- **Ali Kheirandish**: Dark Matter annihilation to neutrinos: New limits and future prospects
- **Elena Pinetti**: Integral X-ray constraints on sub-GeV dark matter
- **Aion Viana**: Searching for Dark Matter with the Southern Wide-field Gamma-ray Observatory (SWGO)
- **Stefano Profumo**: Hunting for Dark Matter and New Physics with (a) GECCO

General discussion

1. What are the relative strengths of MeV, GeV, 100 TeV - gammas, neutrinos as indirect probes?
2. If you really want to make progress, what is the portfolio of complementary techniques needed in the near future?
3. How do we make a compelling case for current (and possible future) tentative signals and extract these signals from astrophysical backgrounds?
4. ...