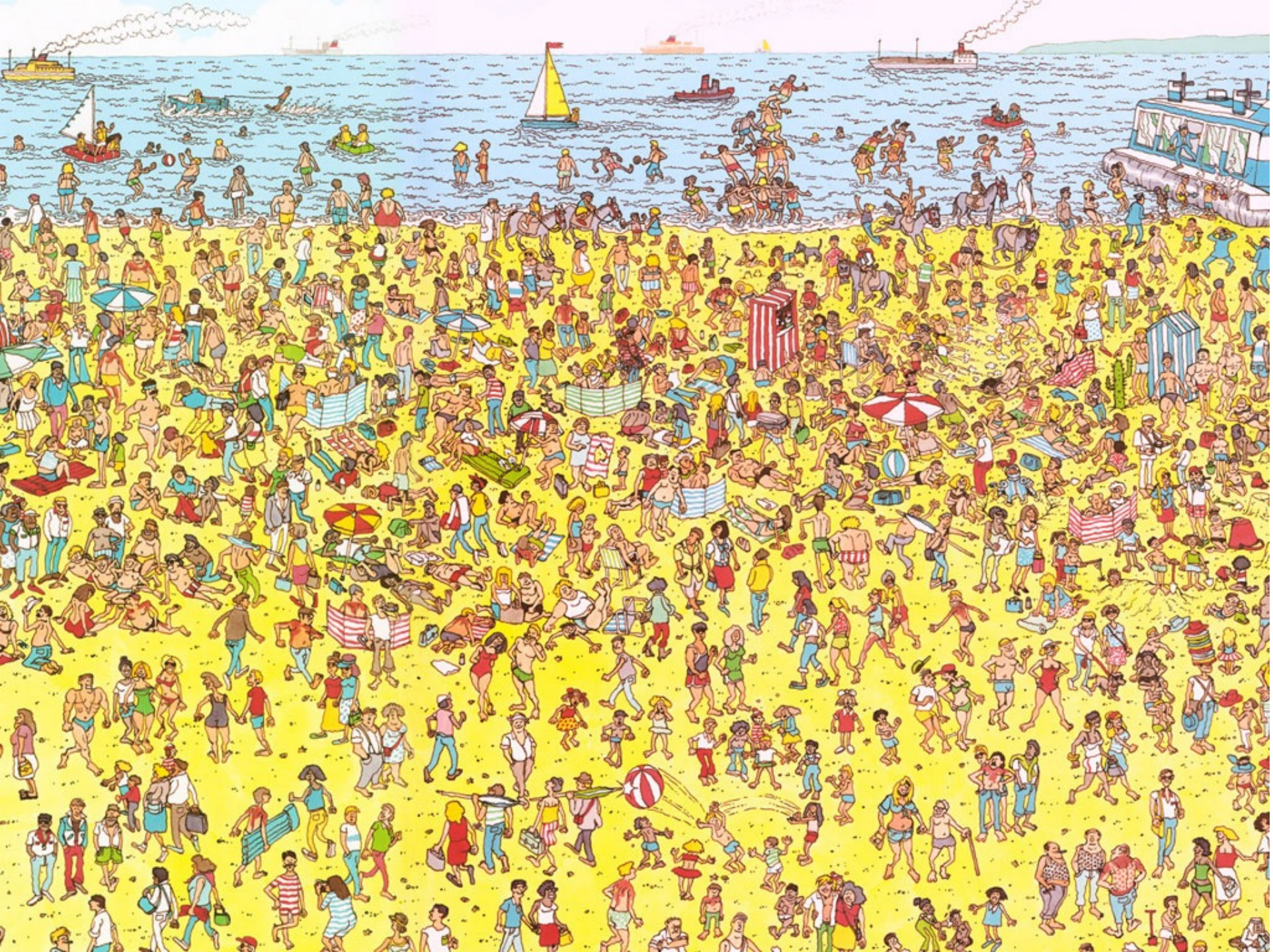
The Dark Matters @ ICRC 2025

DM Rapporteur Talk
July 24, 2025

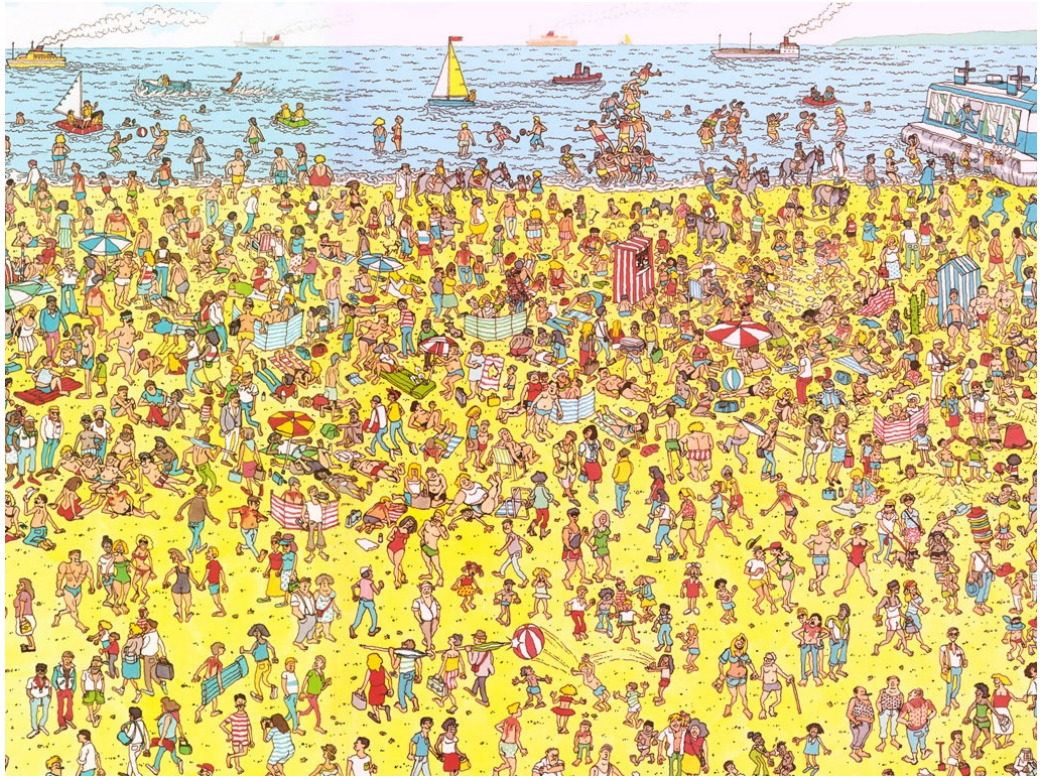
Milena Crnogorčević (she/her)
Postdoctoral Fellow
Oskar Klein Centre/Stockholm University

ICRC 2025
The Astroparticle Physics Conference
Geneva July 15-24, 2025



WHERE'S WALDO?

Caveats



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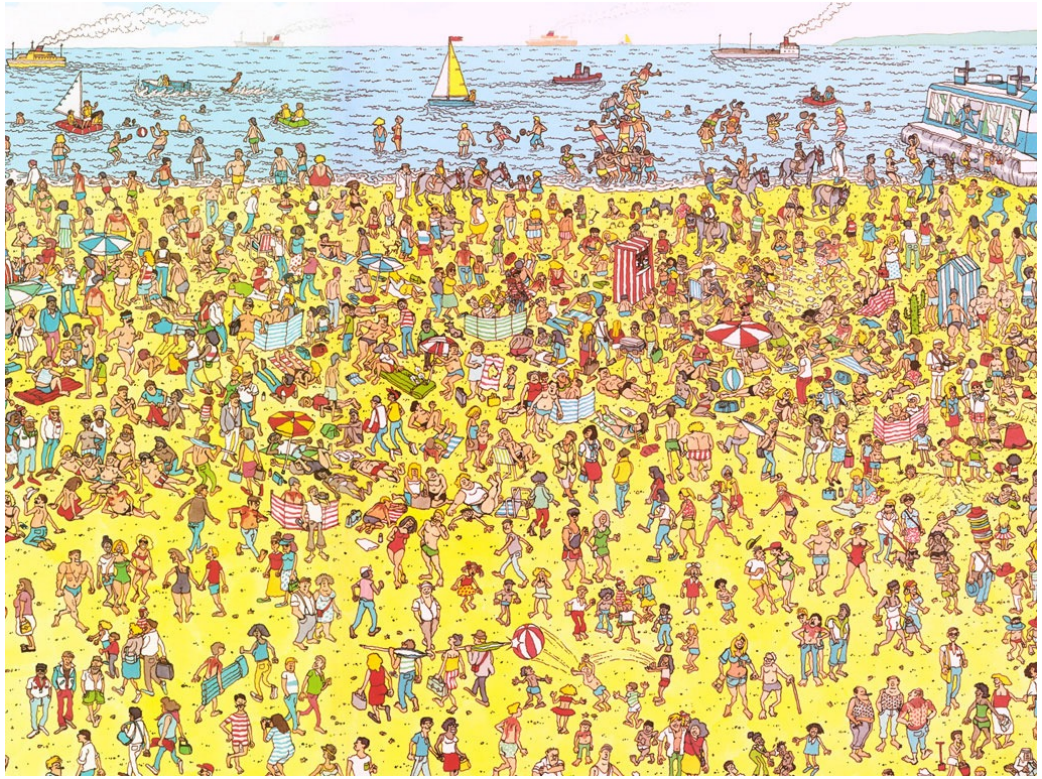

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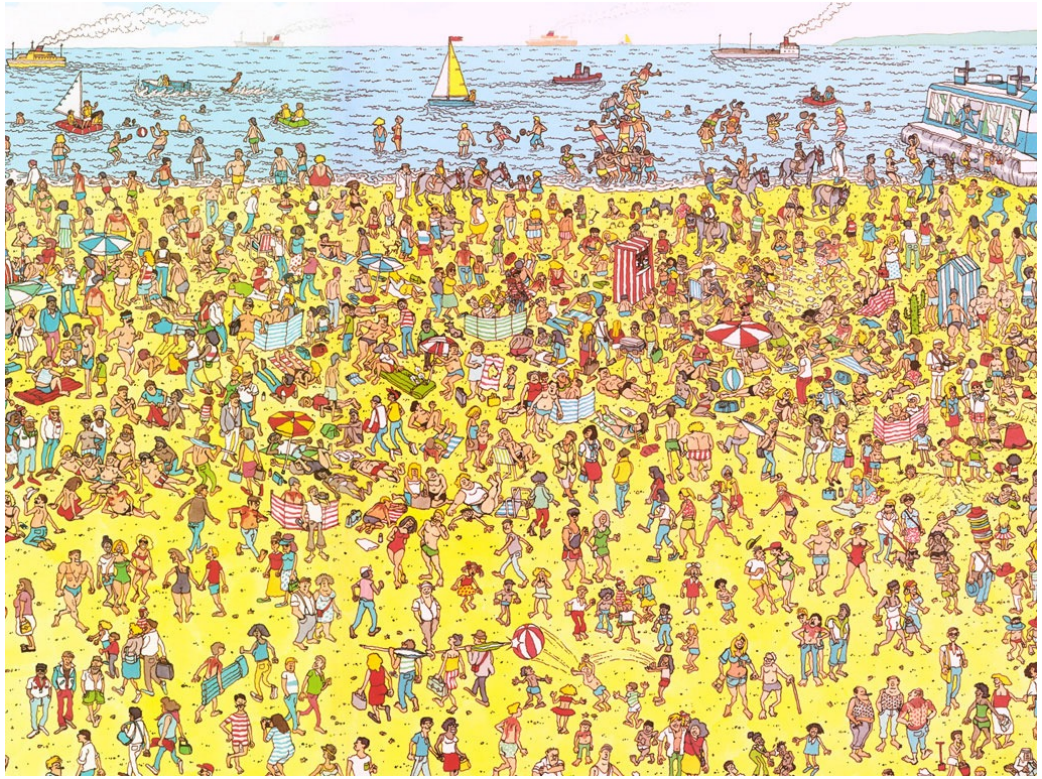

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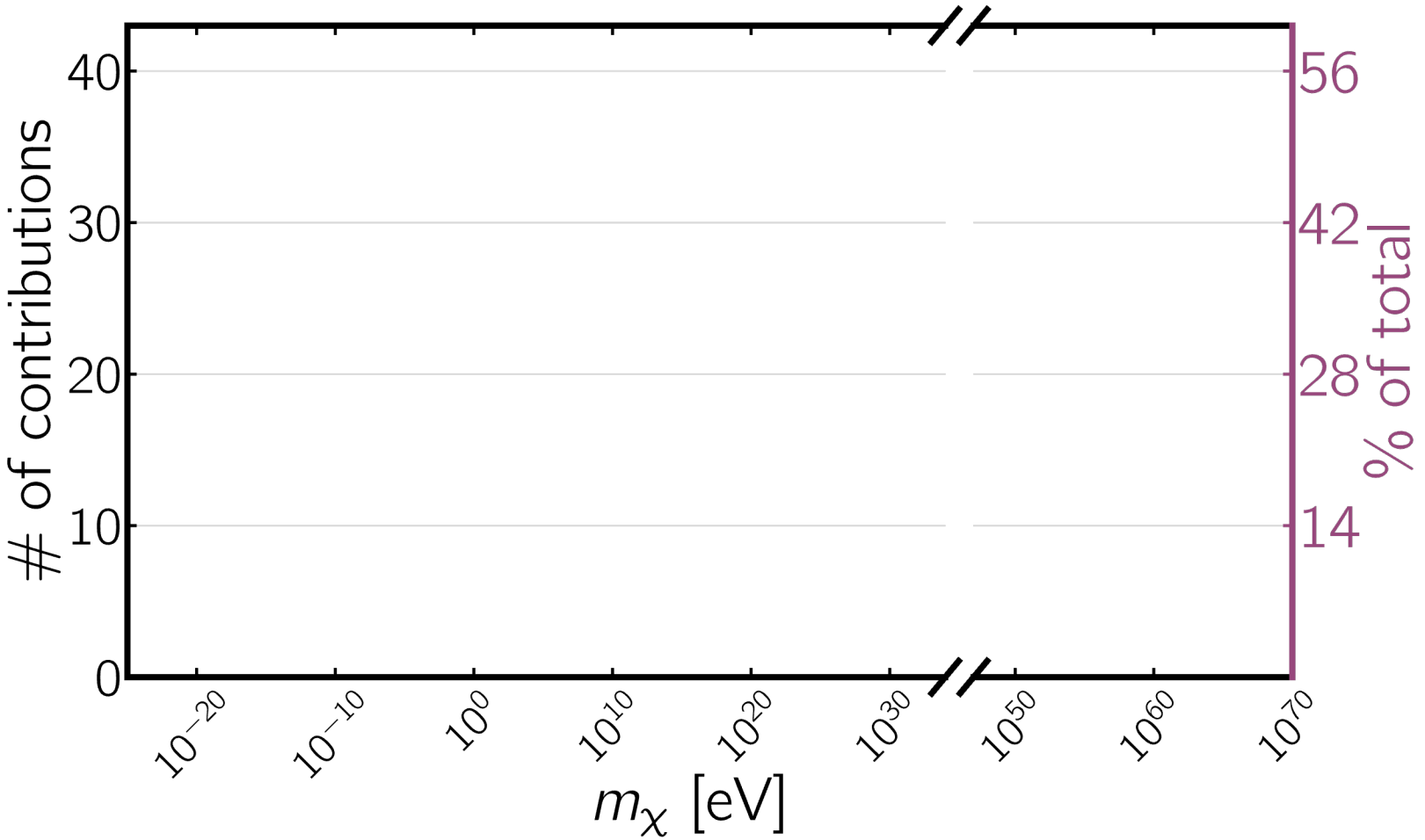

total contributions: 84 (+3 plenaries)
Talks: 61
Posters: 13
Many more across different sessions…

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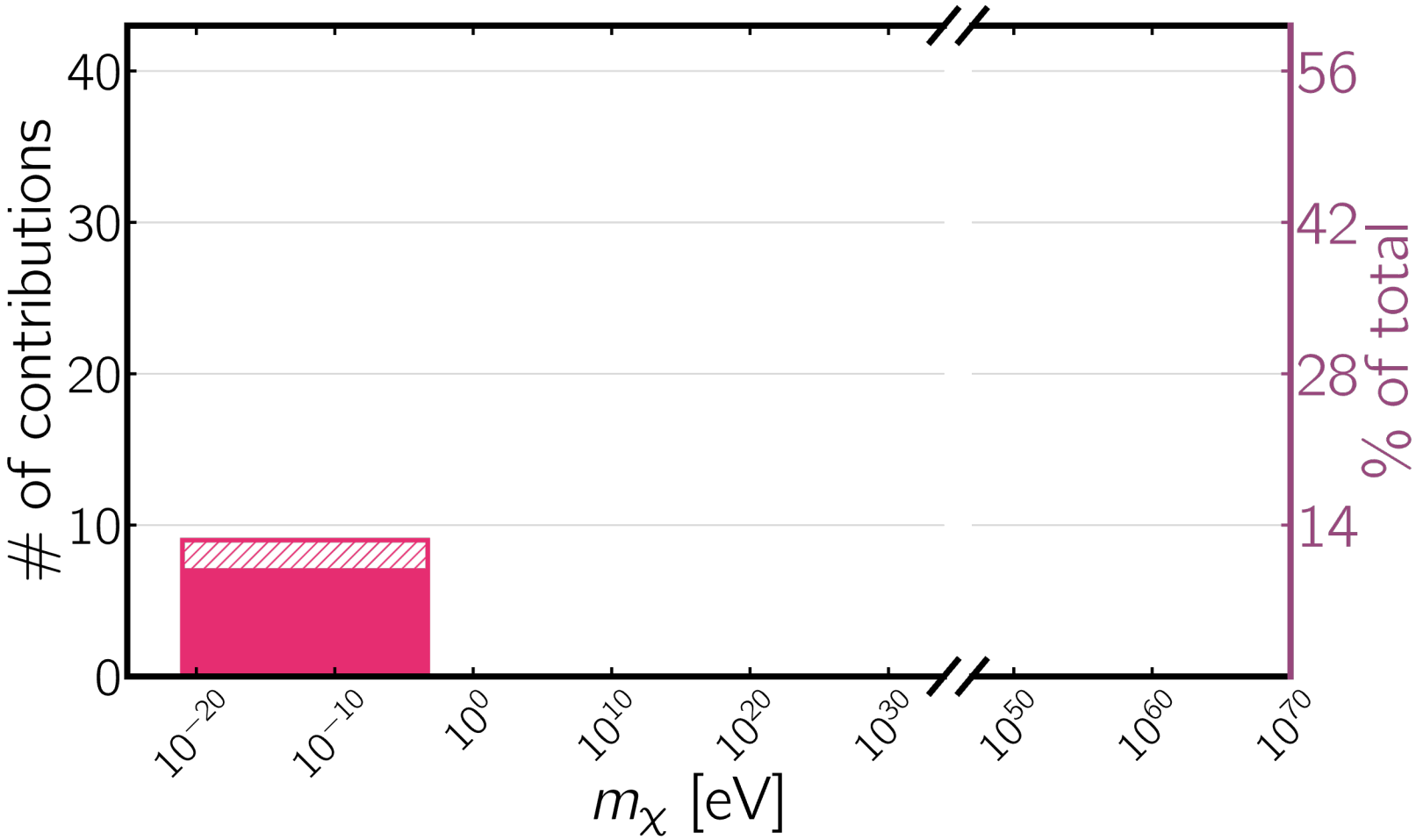
ultralight/ALPs



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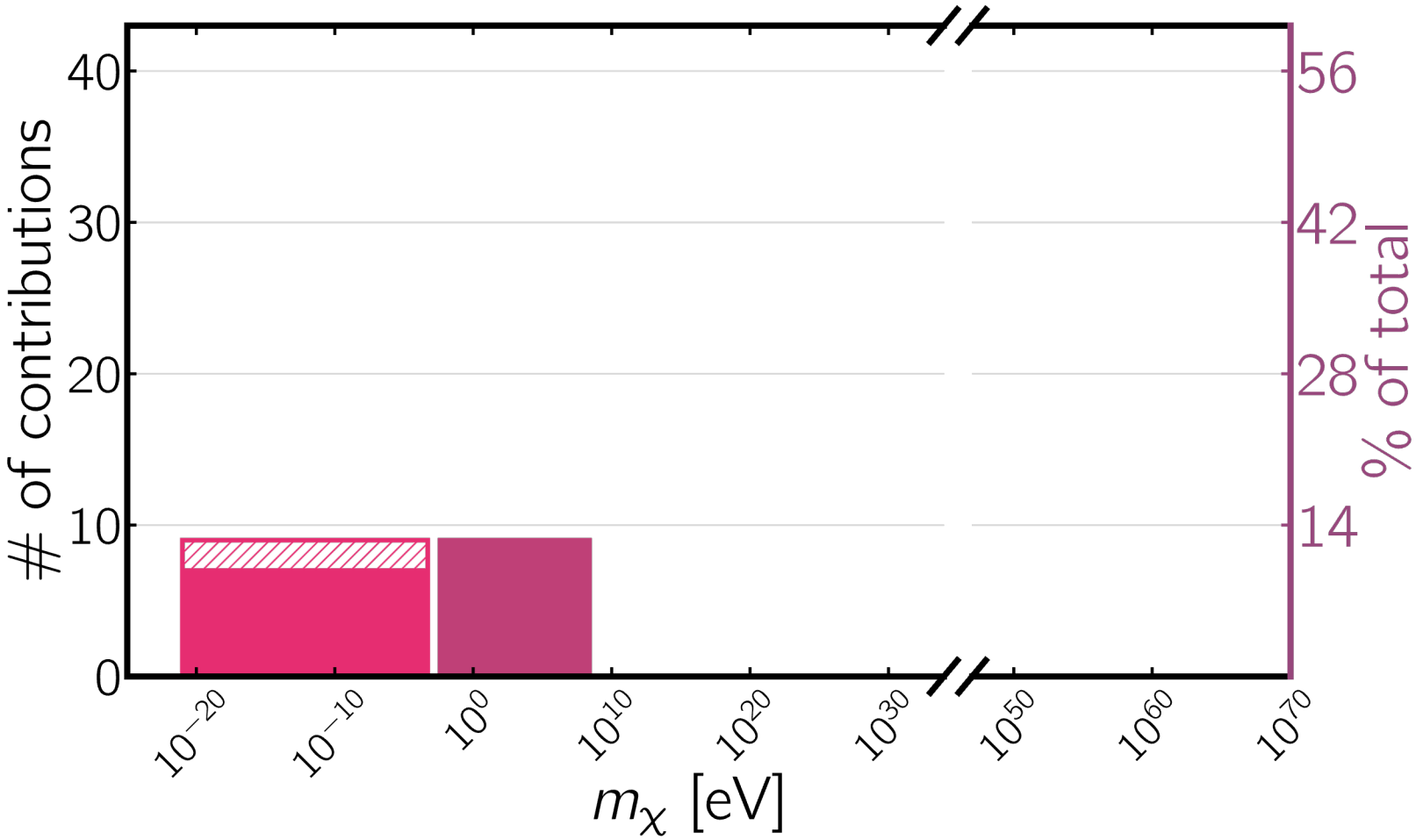
light/sub-GeV



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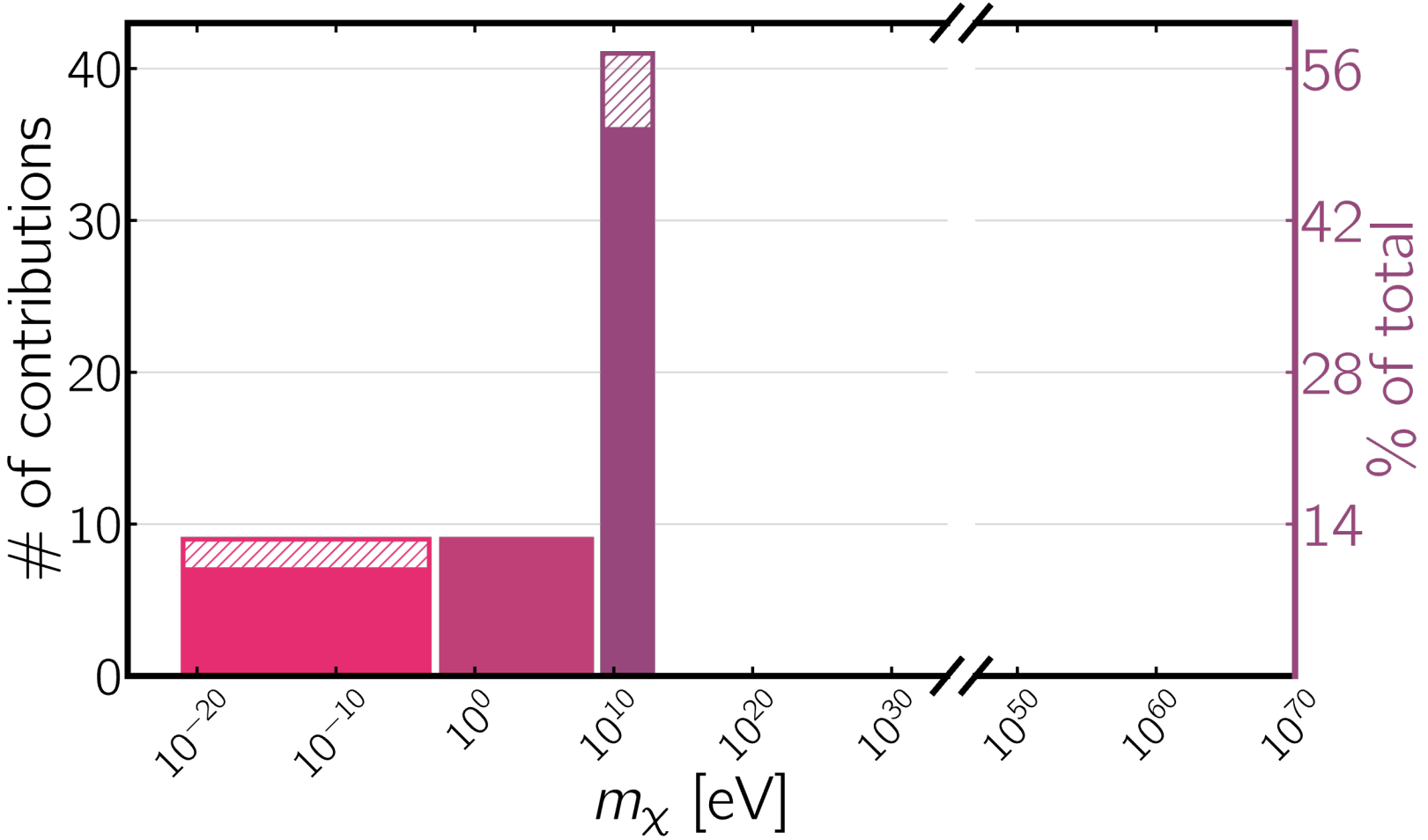
WIMPs



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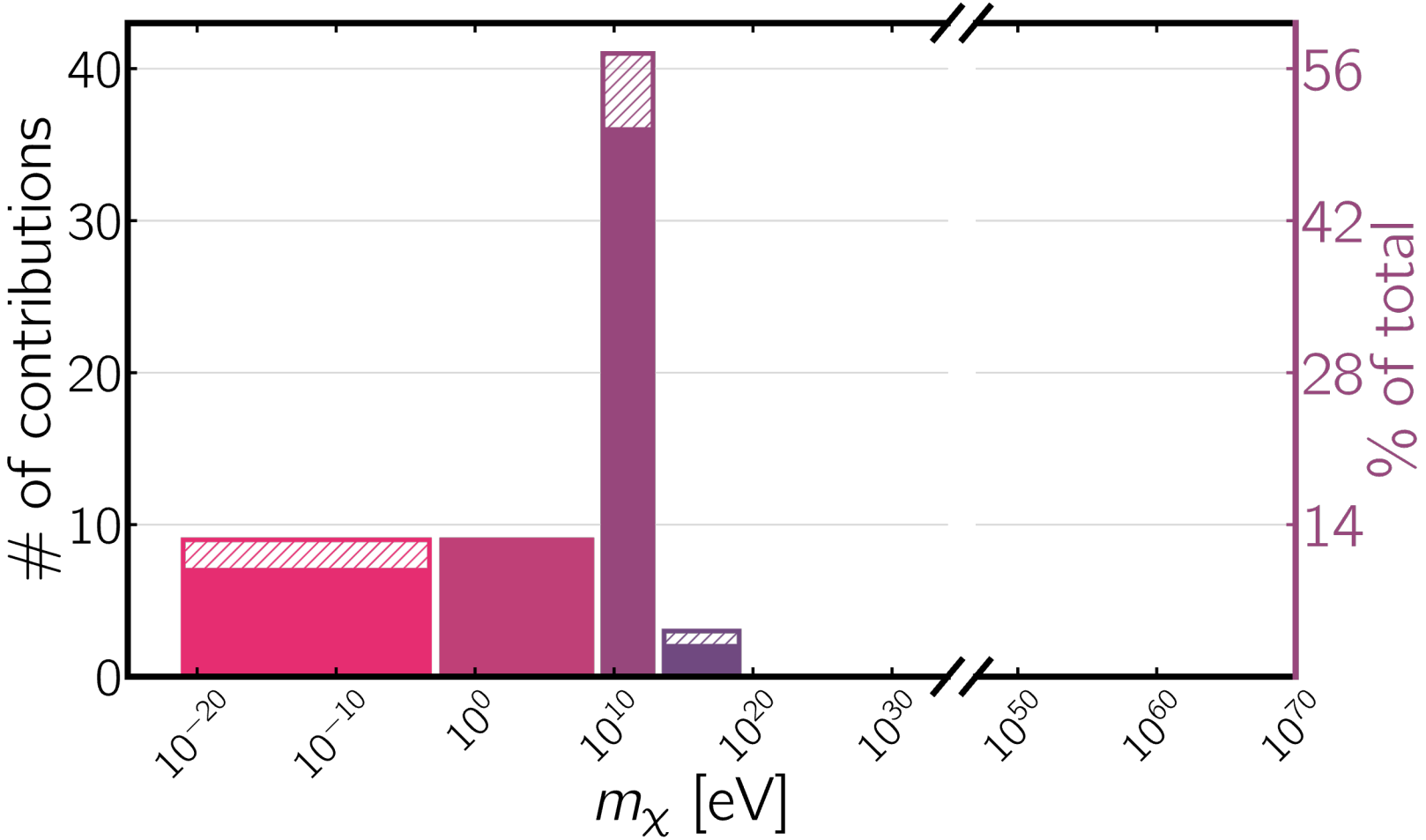
ultralight/ALPs | light/sub-GeV | WIMPs | heavy WIMPs



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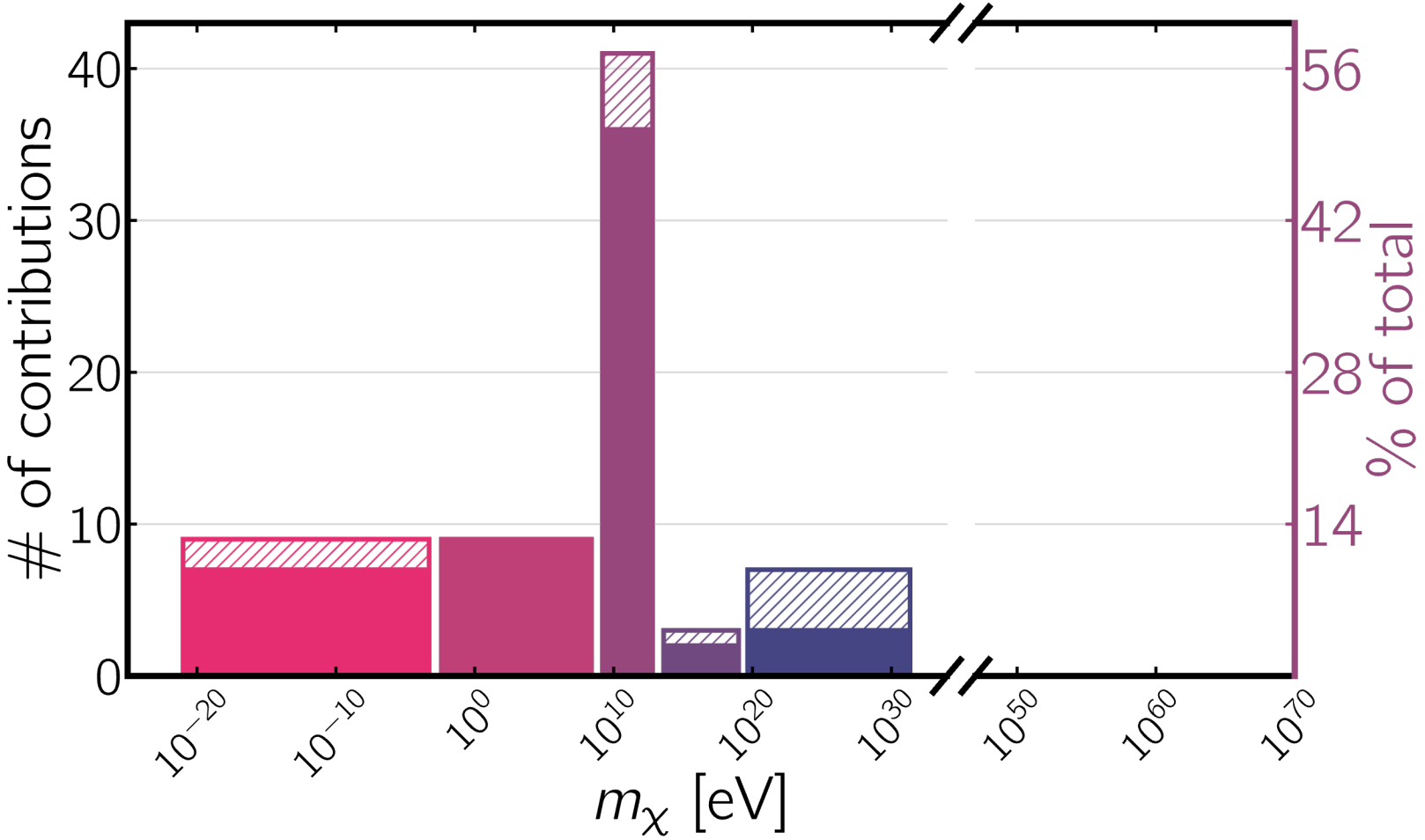

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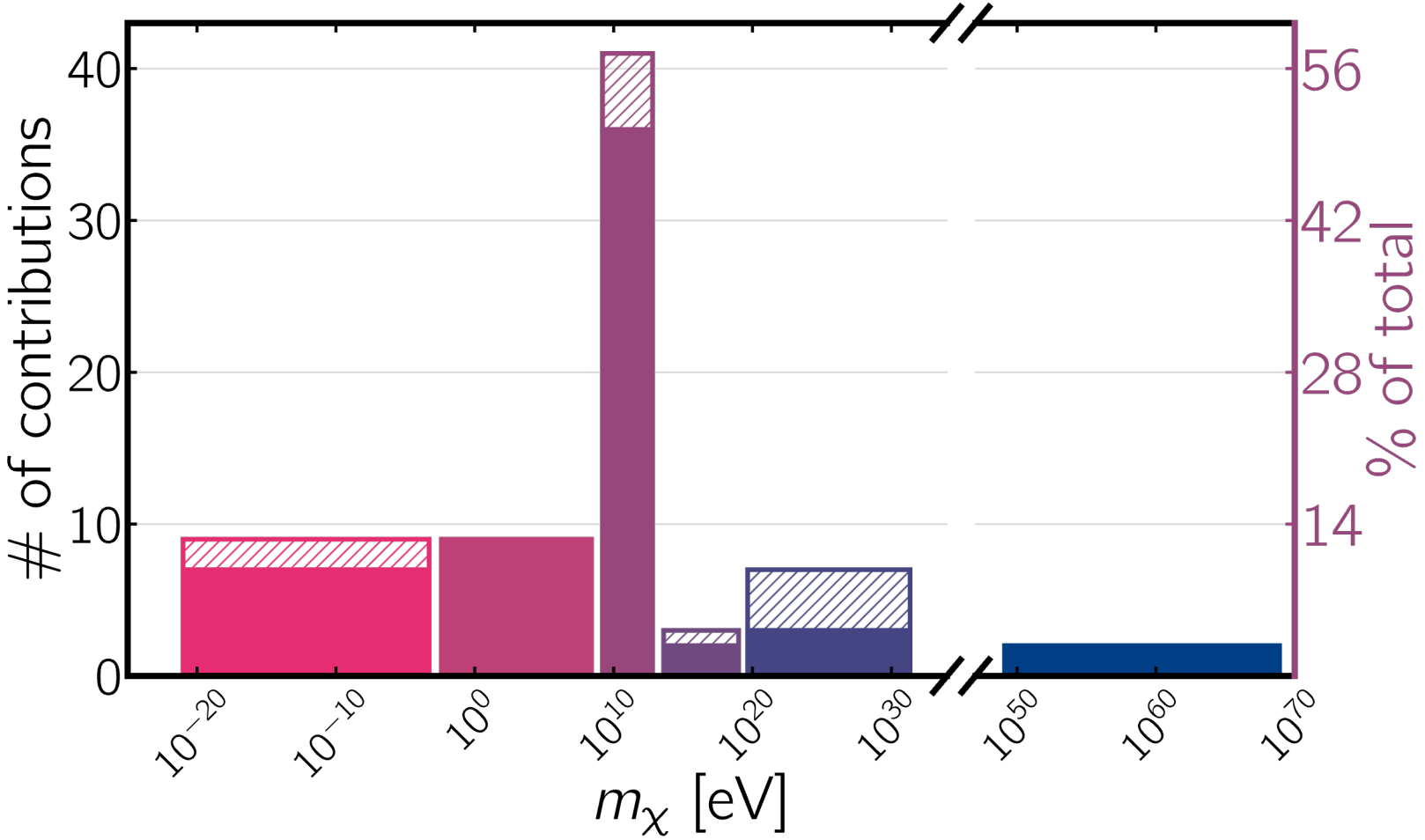

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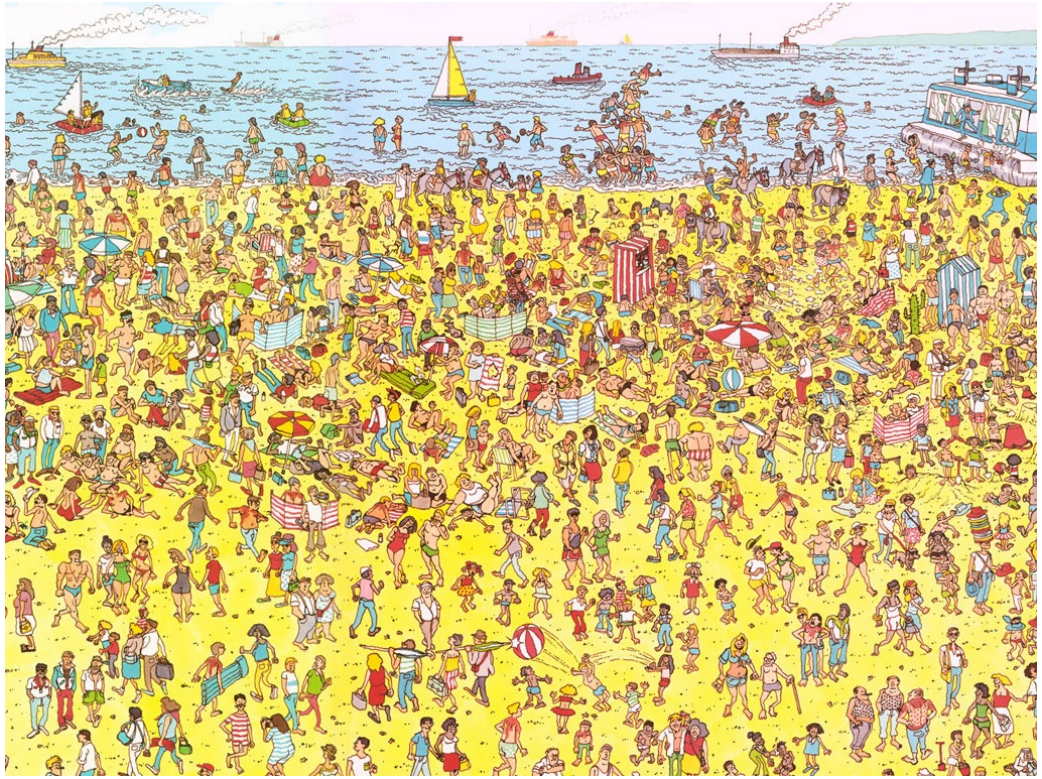

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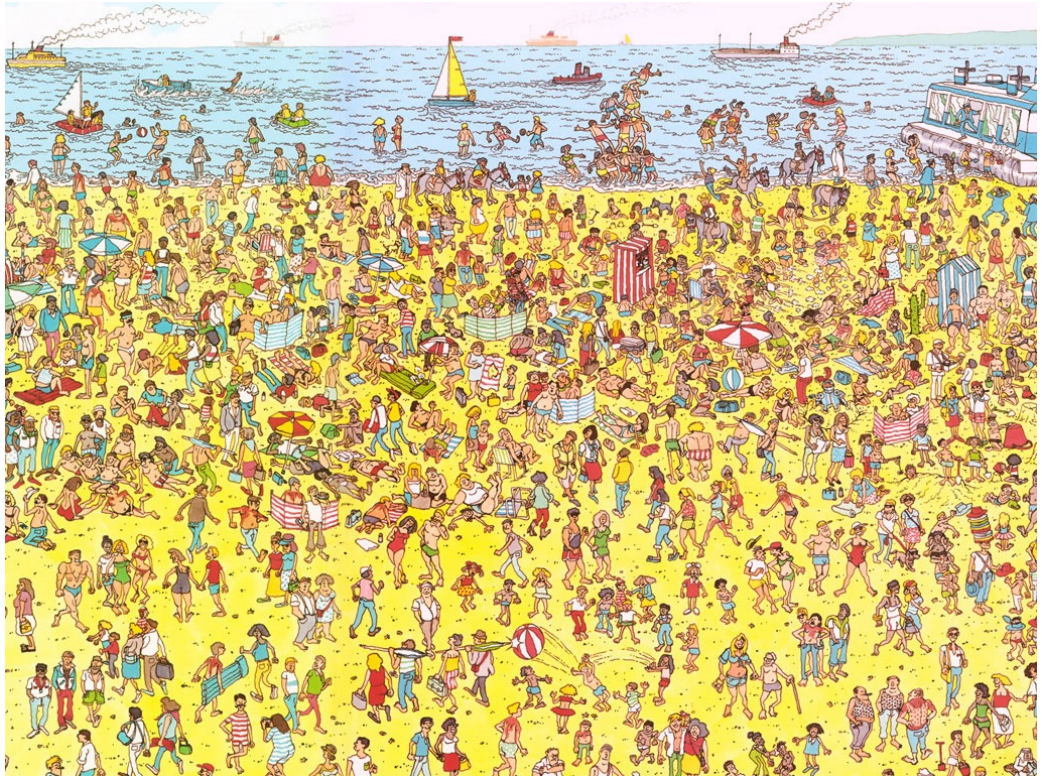
✓ particle physics



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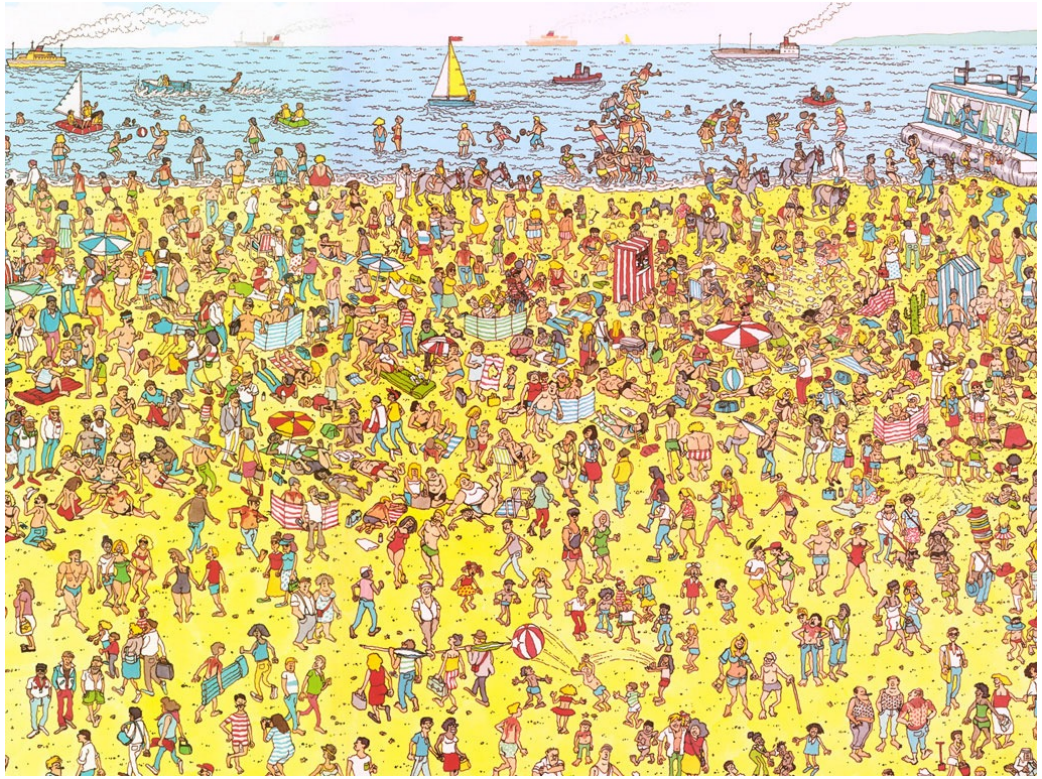

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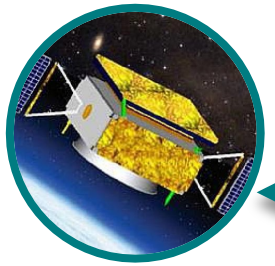
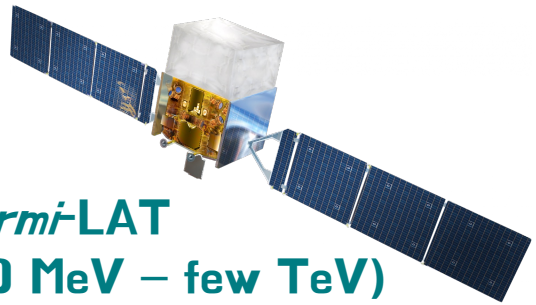
astrophysics

γ-rays (past/present)

*approximate scale
**missions mentioned in DM sessions only



DAMPE (5 GeV – 10 TeV)



Fermi-LAT
(20 MeV – few TeV)

MeV | GeV | TeV | PeV

γ-rays (past/present)

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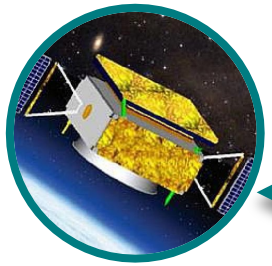
LHASSO (~hundreds GeV – few PeV)

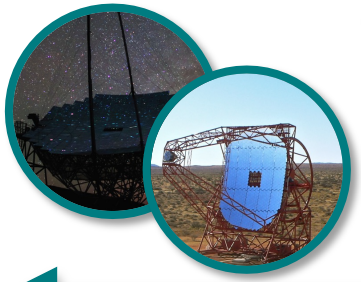
VERITAS (85 GeV – 30 TeV)



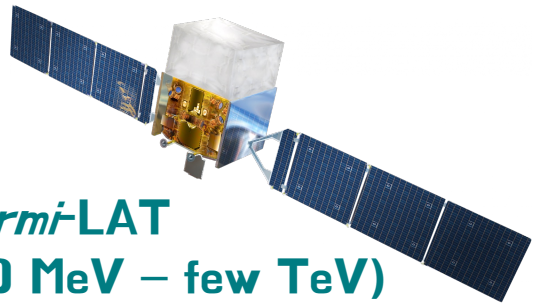
DAMPE (5 GeV – 10 TeV)

HAWC (300 GeV – 100 TeV)

MAGIC



H.E.S.S. (30 GeV – 100 TeV)



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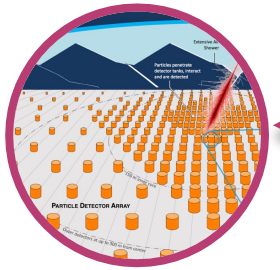
MeV | GeV | TeV | PeV

γ-rays (past/present)

γ-rays (future)

*approximate scale

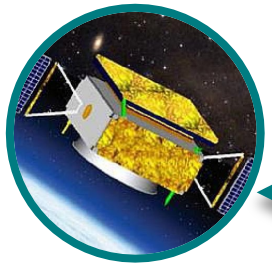


SWGO (100 GeV – ~PeV)

CTAO (20 GeV – 300 TeV)

LHASSO (~hundreds GeV – few PeV)

VERITAS (85 GeV – 30 TeV)



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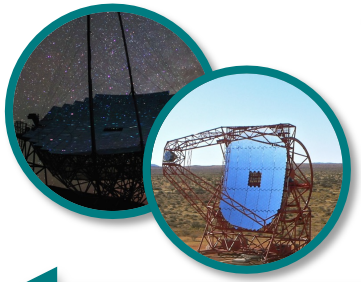

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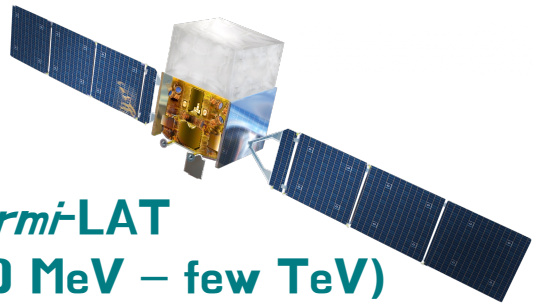

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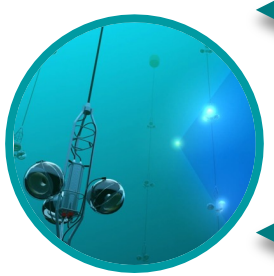
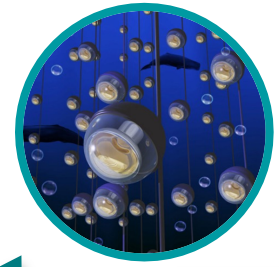
IceCube (50 GeV – several PeV)



ANTARES (50 GeV – 100 TeV)



KM3NeT/ARCA (100 GeV – several PeV)

KM3NeT/ORCA (1 – 100 GeV)

MeV | GeV | TeV | PeV

νs (past/present)

νs (future)

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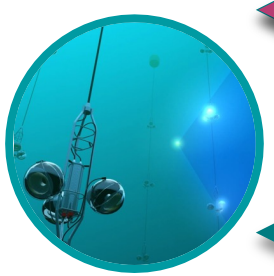
IceCube-Gen2

In the works: 8 km^3 + radio

IceCube (50 GeV – several PeV)

IceCube Upgrade



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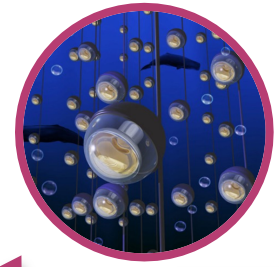

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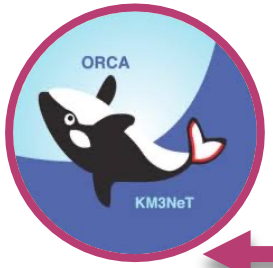

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Solar System

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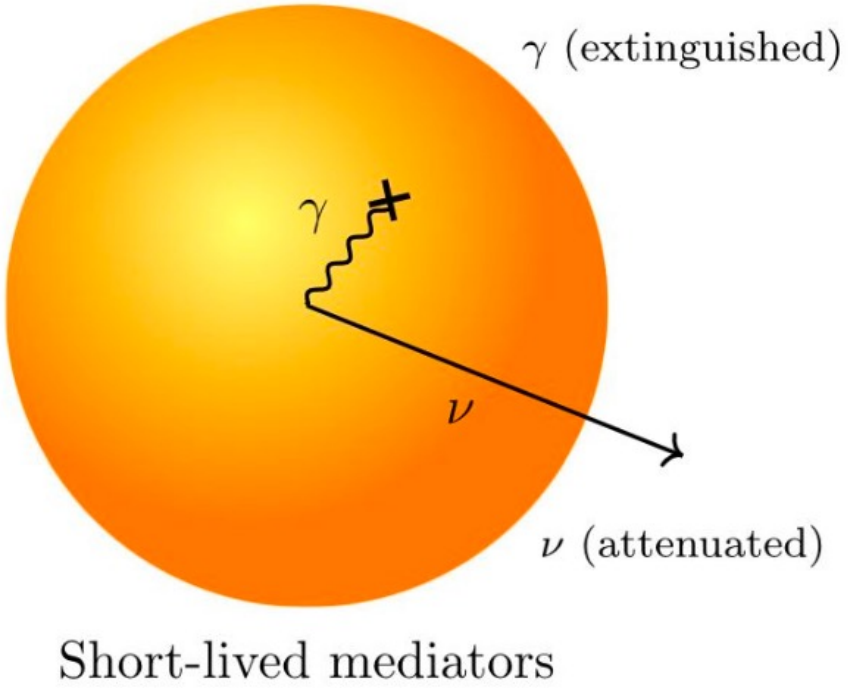
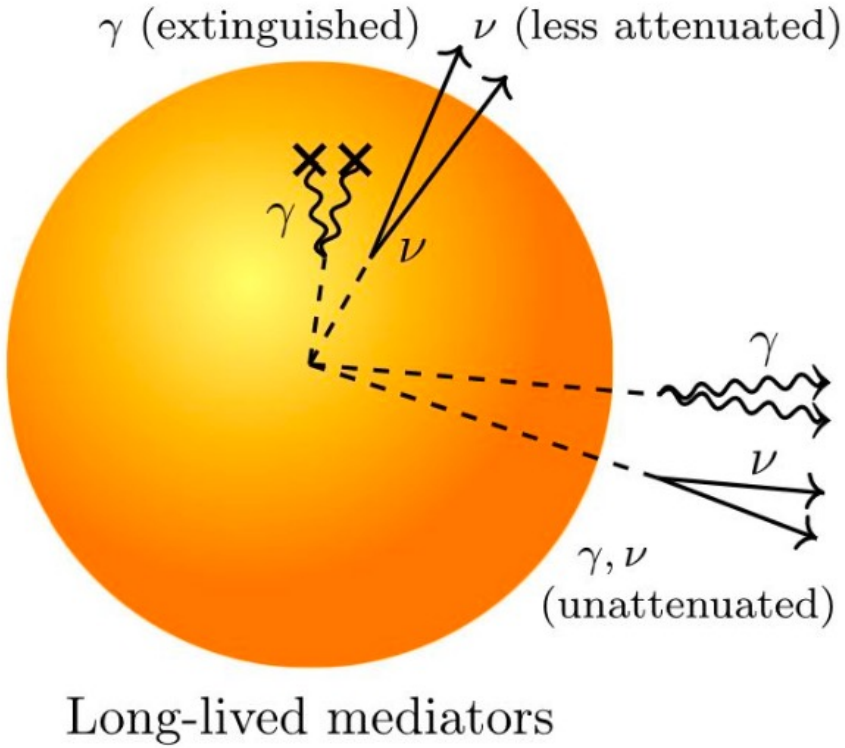
Sun: gravitational capture + 4.5 Gyr accumulation ⟶ dense DM core



Short-lived mediators



Long-lived mediators

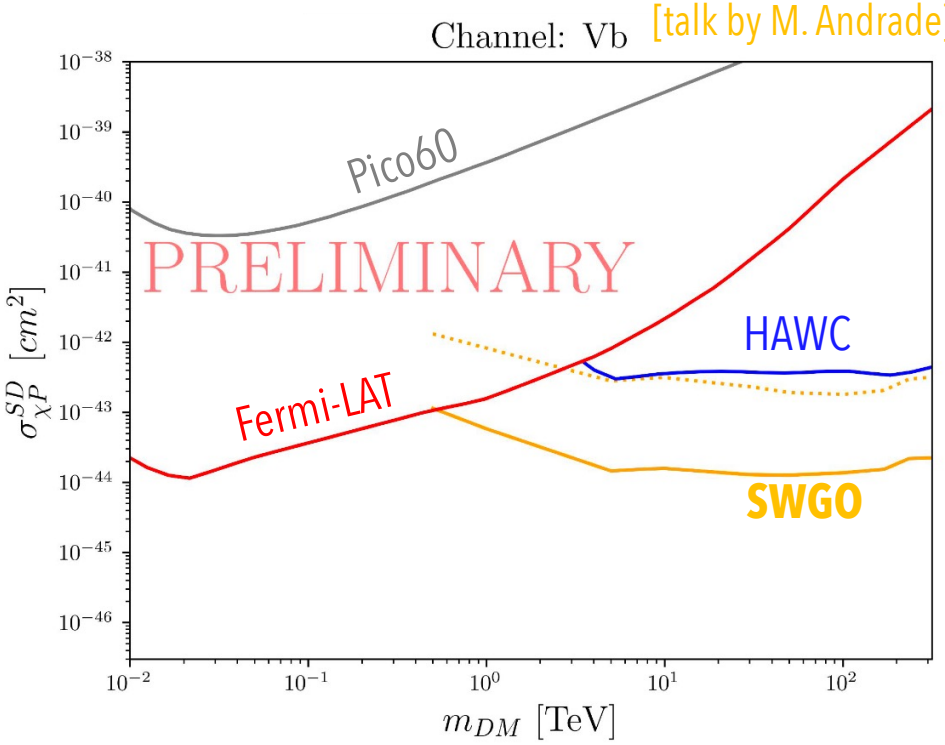
[adapted from M. Andrade]

⟶ neutrinos and γ-rays probe complementary DM scenarios (& masses)

Solar System

Sun: gravitational capture + 4.5 Gyr accumulation ⟶ dense DM core ⟶ enhanced annihilation rate $\propto \sigma_{\text{scattering}}$

[talk by M. Andrade]



SWGO (M. Andrade)

- now with real exposures!
- projected limits ~ 10^{-44} cm^2

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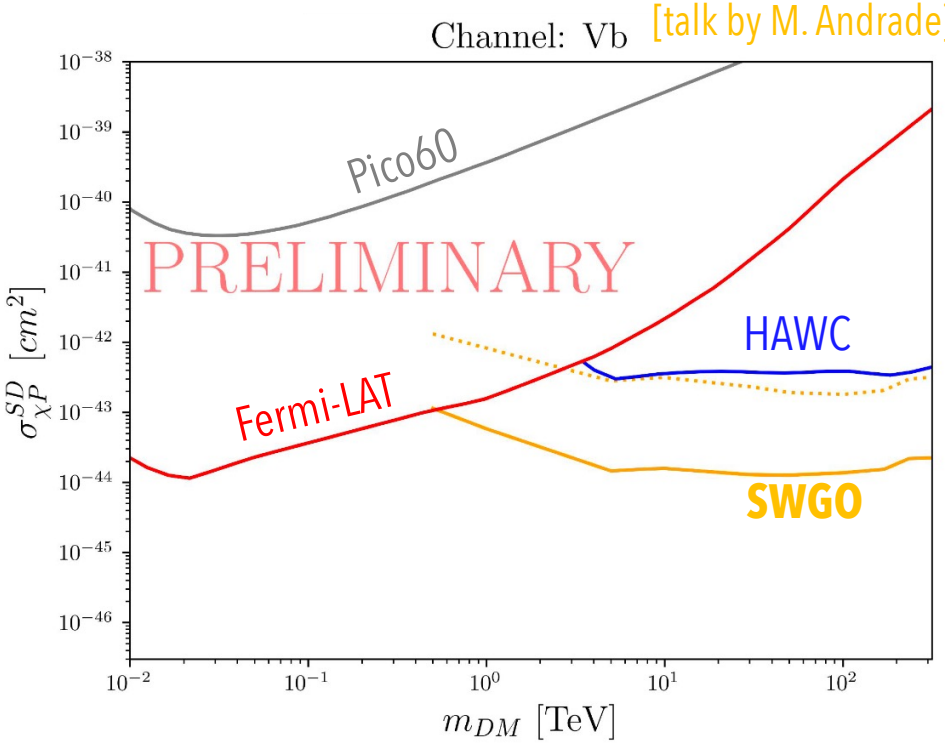

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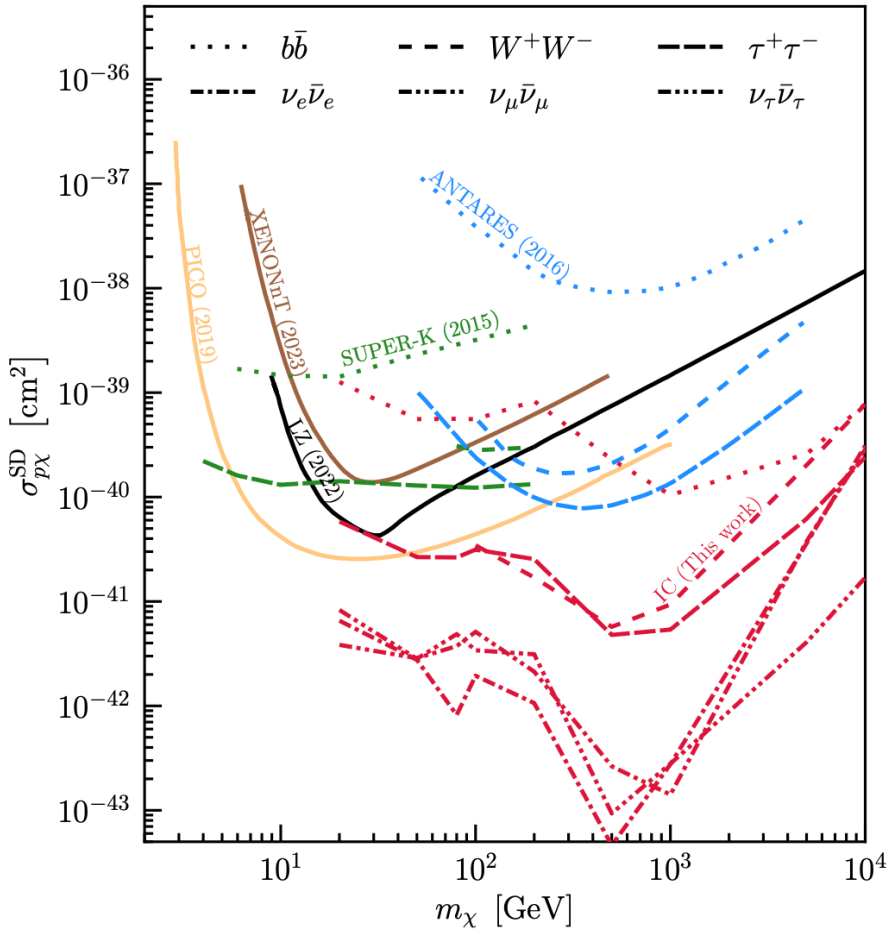
[talk by J. Lazar]



IceCube (J. Lazar)
- leading SD limits ~ 10^{-40} cm^2

ANTARES (C. Poirè)
- complete dataset (15 years)
- results comparable with IC16

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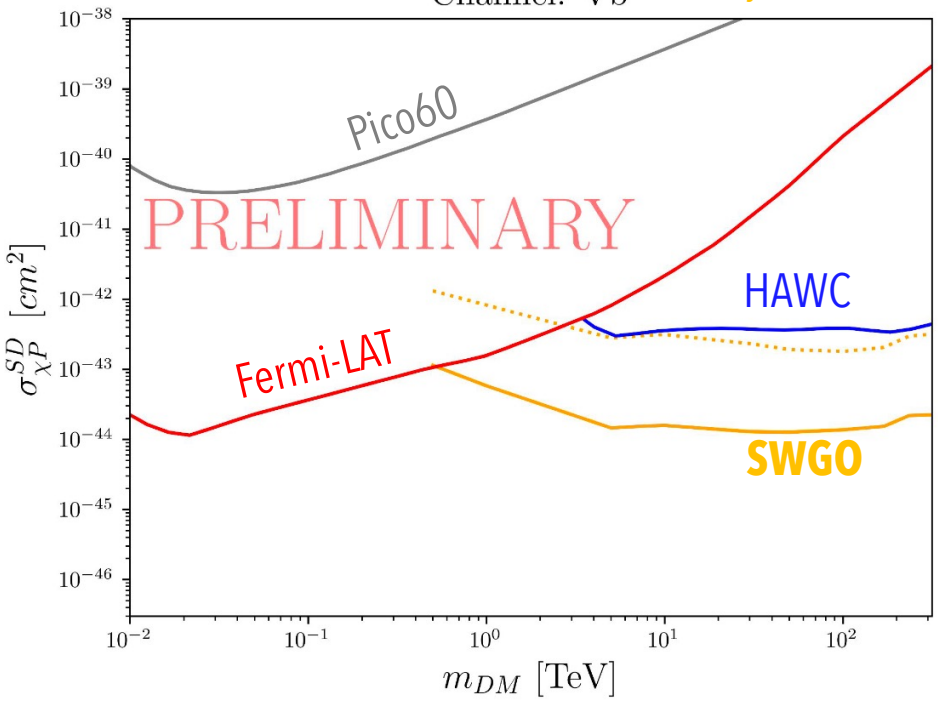

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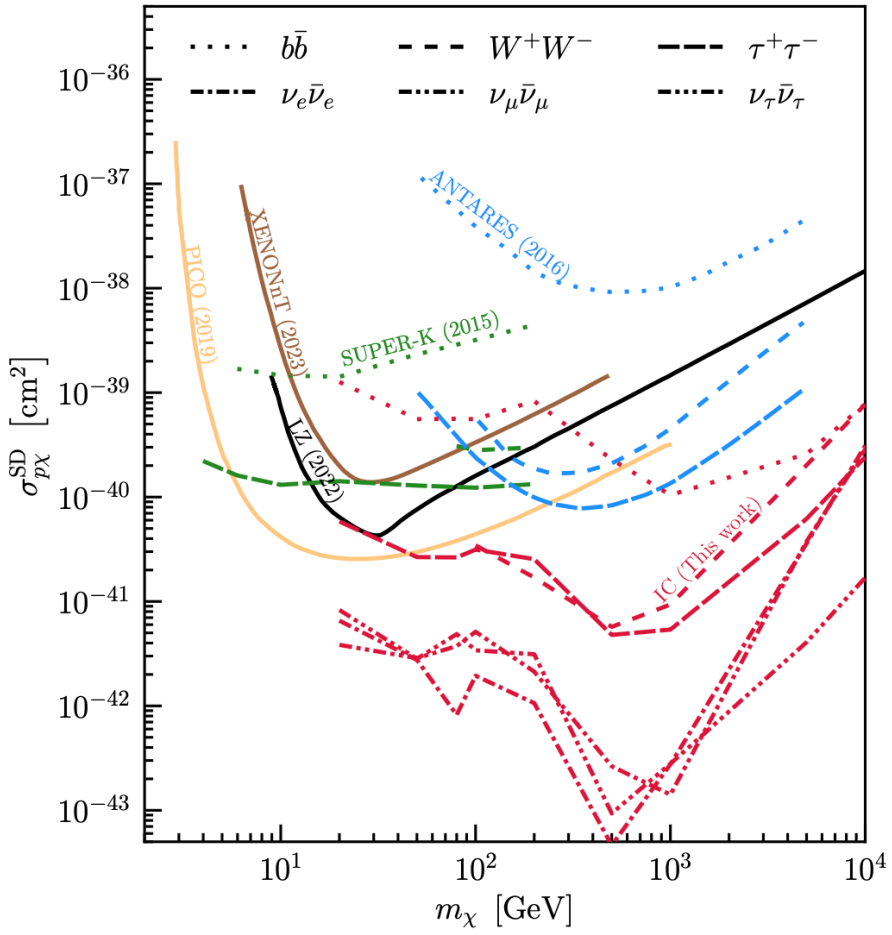

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- leading SD limits ~ 10^{-40} cm^2

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- complete dataset (15 years)
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- several orders of magnitude weaker than direct for SI DM
- complementary to underground detectors in lower/higher mass ranges

Note: for a review of solar axion searches, see the plenary by J. Jaeckel.

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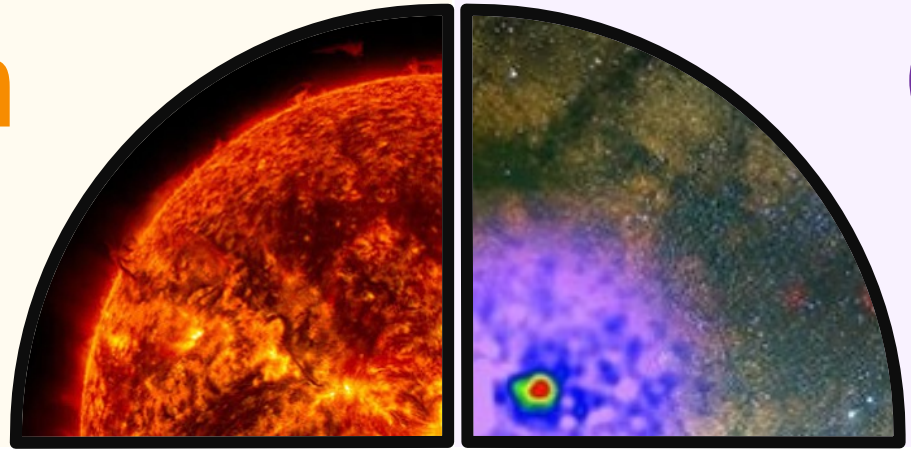
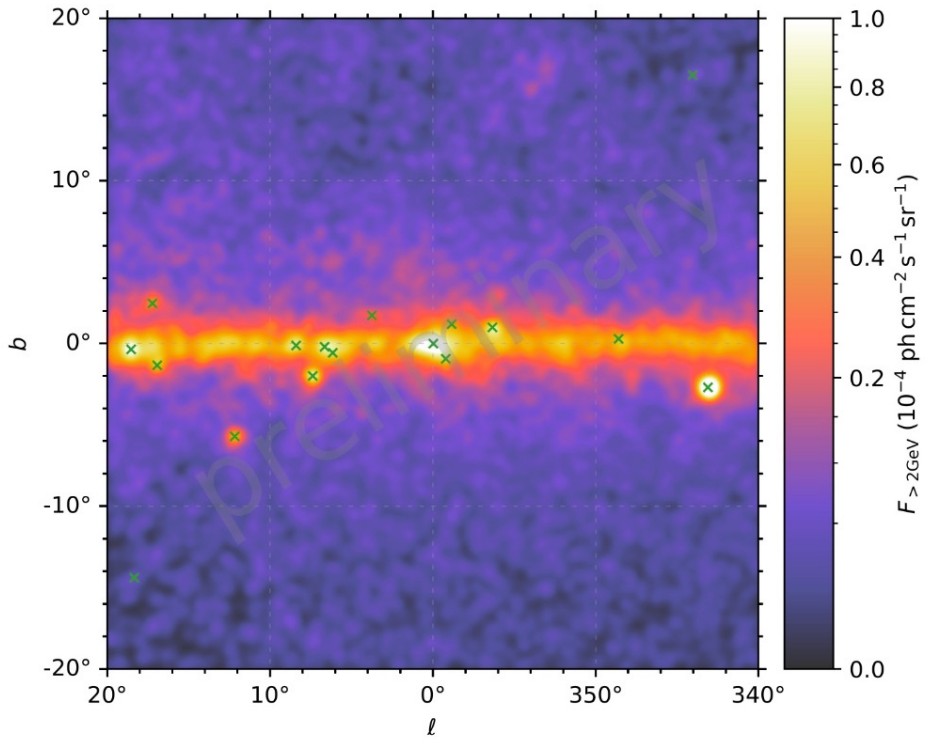
Solar System



Galactic

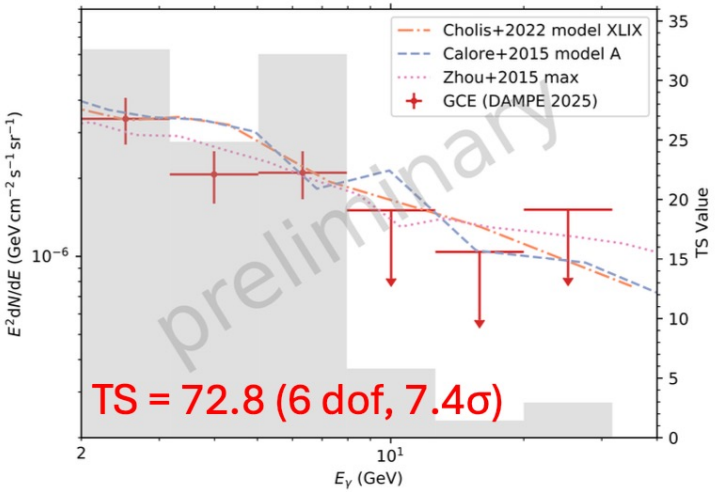
Galactic sources: Galactic center excess

- GCE: hinted at by EGRET (2005), detected by *Fermi*-LAT (2009)

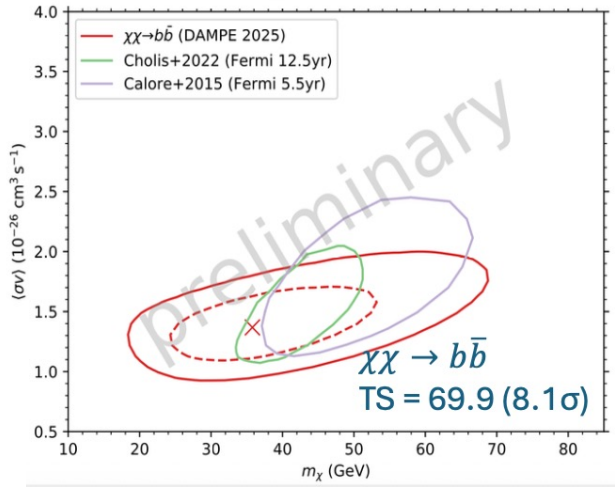


- 7.4σ with 8.5 yr of data
- If $\chi\chi \to b\bar{b}$:
  $m_\chi = (36 \pm 9)$ GeV
  $\langle\sigma v\rangle = (1.37 \pm 0.21)\times10^{-26}\mathrm{cm}^3/\mathrm{s}$

[talk by C. Perrina (GA session), also in C. Yue (plenary)]



$$\frac{dN}{dE} = \frac{\langle\sigma v\rangle}{8\pi\, m_\chi^2}\frac{dN_\gamma}{dE}\int_{\mathrm{l.o.s.}} ds\ \rho^2(r(s,\psi))$$

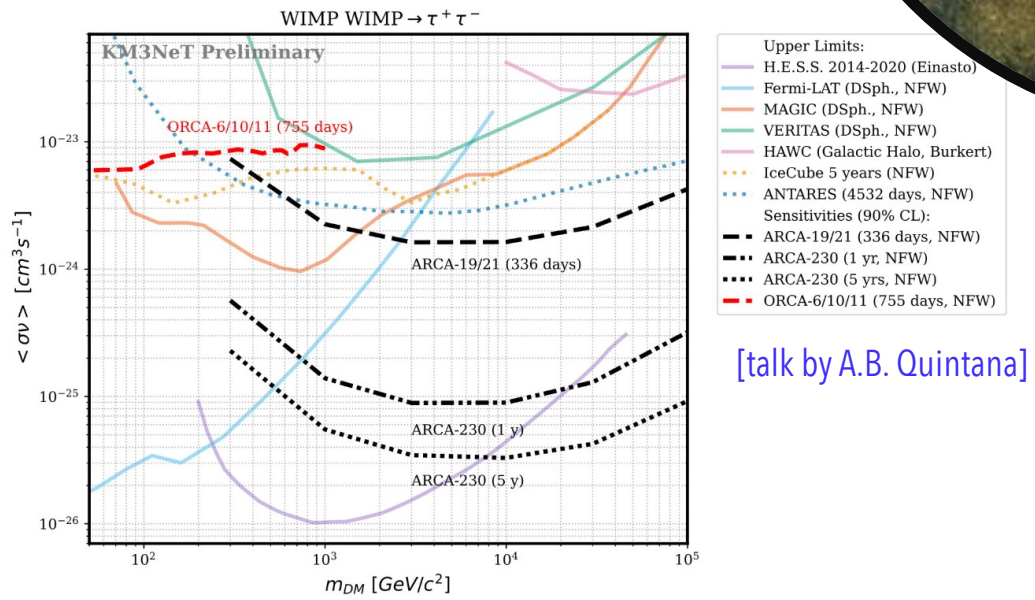


DAMPE provided the **first independent confirmation** of the **Galactic Center excess!**

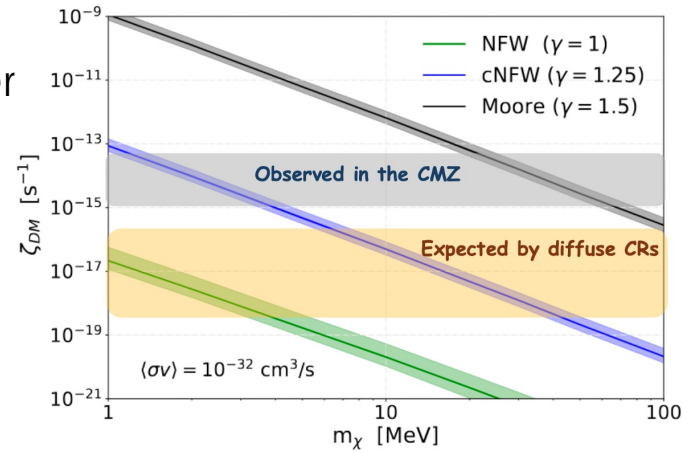
Galactic sources: Galactic center

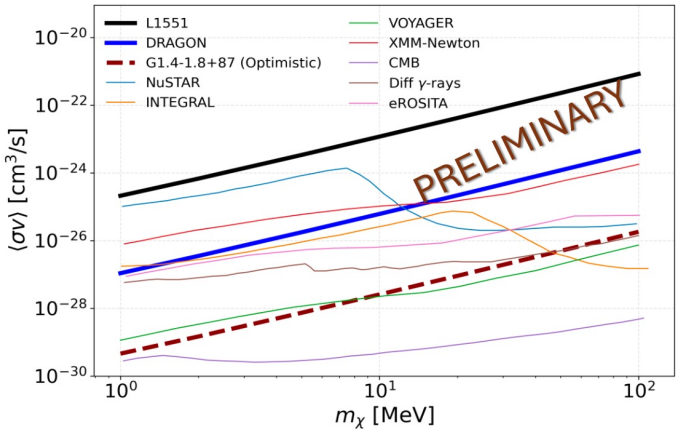
- GC: high DM signal, high backgrounds

- **[A. Abhishek] LST-1 (CTAO)**
  - ⟶ first sensitivity results; significant improvement above ~30 TeV w/ limited observation time
  - ⟶ directly benchmarks upcoming CTAO capabilities
  - ⟶ near future potential: competitive with current CTAs (MAGIC, HESS)
- **[N. Châu] IceCube DeepCore/Upgrade**
  - ⟶ best current neutrino-line limits at GeV-TeV scale and anticipation for significant gains from IceCube Upgrade (2025-26)
- **[A.B. Quintana] KM3NeT (ARCA/ORCA)**
  - ⟶ robust complement to IceCube searches: ORCA extends to lower masses, ARCA230 improves limits by few orders of magnitude
- **[P. de la Torre Luque] CMZ Ionization (MeV DM)**
  - ⟶ novel search linking MeV-scale DM to previously unexplained astrophysical anomaly (CMZ ionization rate)
  - ⟶ also correlates with longstanding 511-keV excess



[talk by A.B. Quintana]





[talk by P. de la Torre Luque]

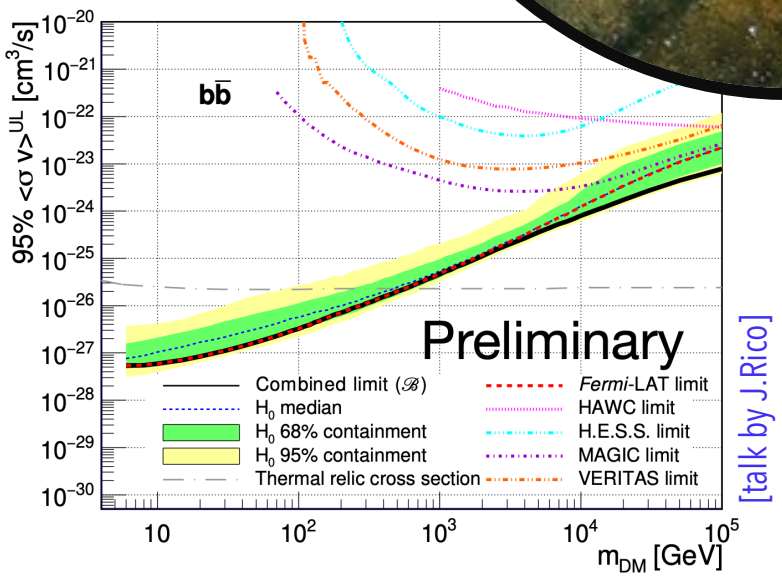
Galactic sources: dSphs

- dSphs: DM rich, minimal backgrounds, faint, J-factor inference is non-trivial

- **[J. Rico] Multi-instrument (*Fermi*-LAT, HAWC, H.E.S.S., MAGIC, VERITAS)**

  ⟶ Herculean effort in combing data, systematics, and responses across 5 instruments

  ⟶ UL driven by LAT in lower energies, and CTAs in higher: sets a precedent for these kinds of searches and undertakings (including e.g., joining likelihoods with IceCube)



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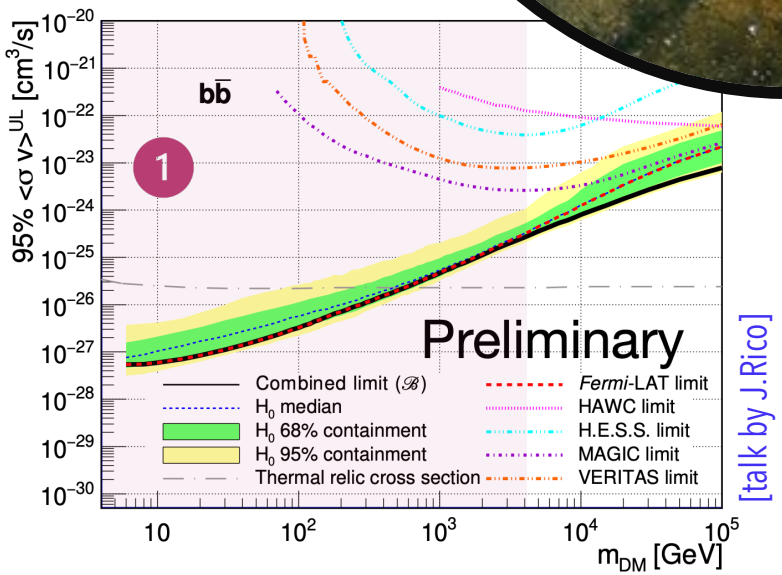
1 dominated by *Fermi*-LAT



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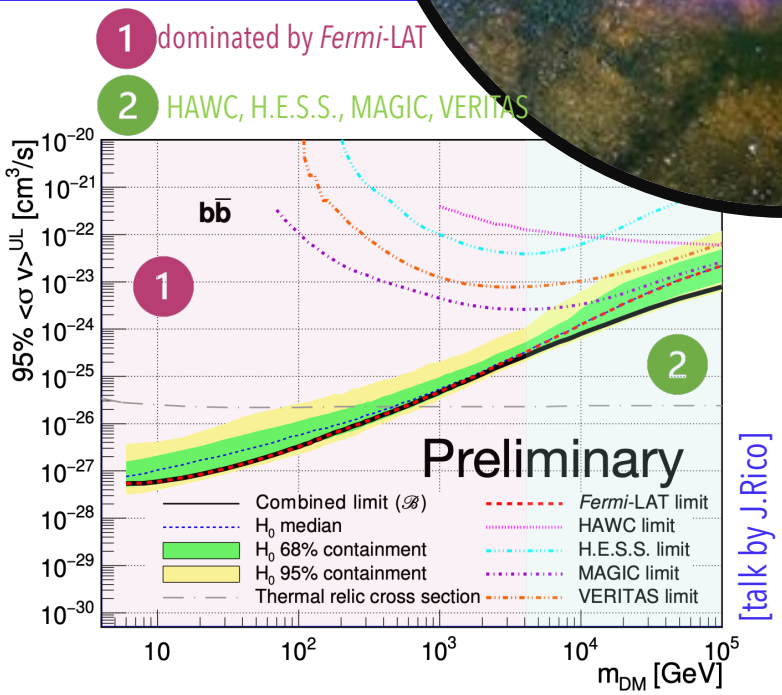

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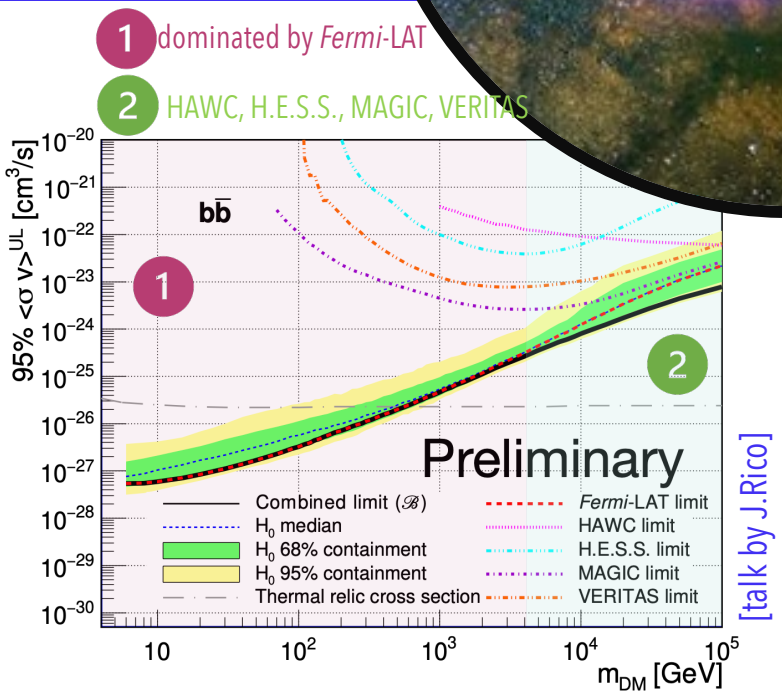

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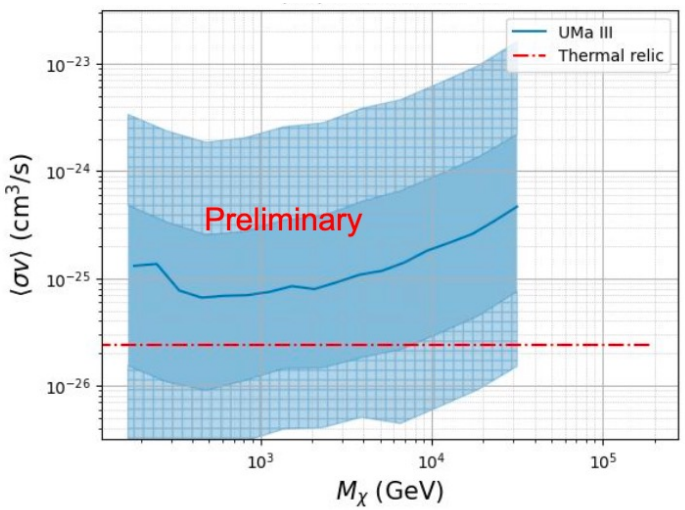

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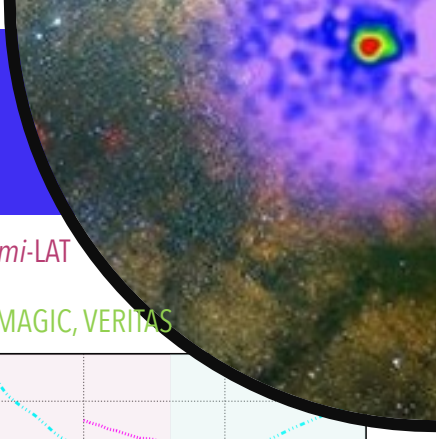
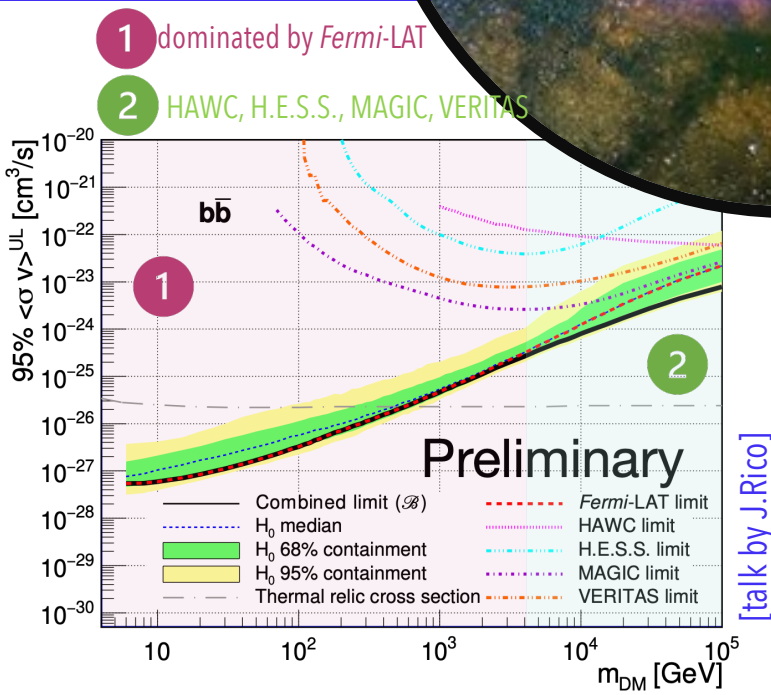
- **[S. Semane] MeerKAT (Reticulum II)**
  - ⟶ first radio-interferometry DM search w/ MeetKAT, significantly surpasses previous radio constraints (ATCA)
  - ⟶ SKA expected to dramatically improve sensitivity (10-100 x)
- **[D.N. Salazar-Gallegos] IceCube Tracks**
  - ⟶ first IceCube dSph analysis that distinguishes neutrino flavor signatures from DM
  - ⟶ competitive at highest DM masses (>100 TeV) – complementary to **γ**-ray and other indirect searches
  - ⟶ noveltry: combination of track channel sensitivity and stacking
- **[A. Aravinthan] Theoretical modeling improvements**
  - ⟶ focusing on a different source class: transition dwarfs
  - ⟶ simulation of primary and secondary DM signatures + astrophysics ⟶ morphological differences





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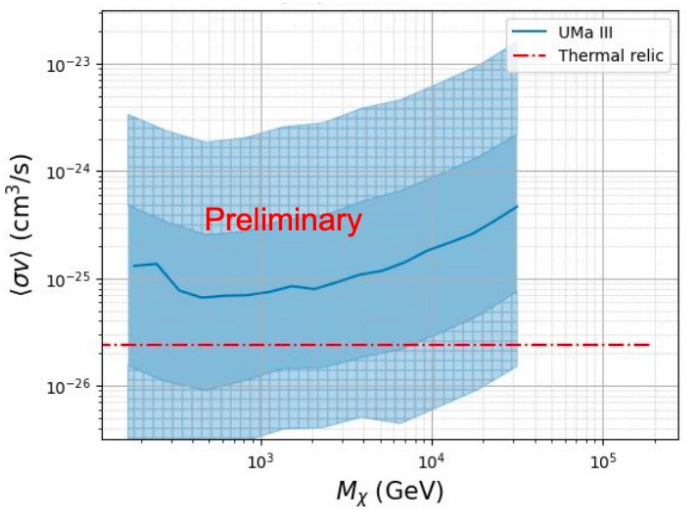


[talk by C. McGrath]

Galactic sources: Antimatter

[K. Yee, A. Stößl, K. Aoyama] GAPS

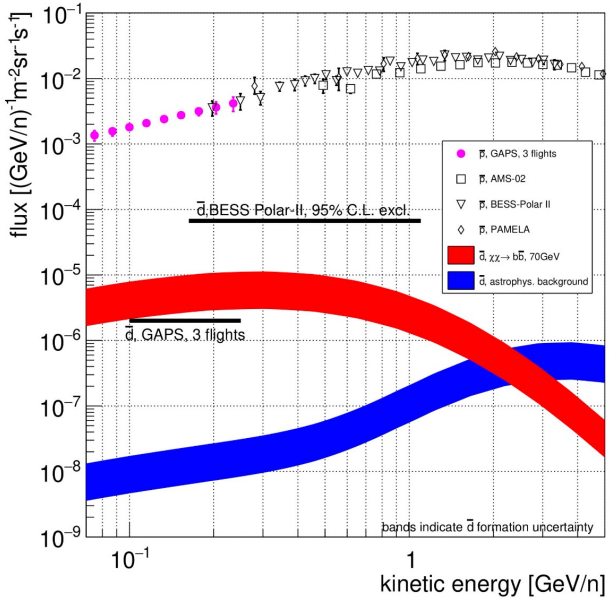
⟶ novel technique (exotic-atom based): sensitivity improvement 1-2 orders of magnitude for 70 GeV WIMP

⟶ interest: antiprotons in unexplored range + leading antideuteron/antihelium sensitivity in low-energy range

⟶ low energy antideuterons: uniquely low-background DM signature vs. current anomalies (see AMS-02 plenary by Zhili Weng)

⟶ technical readiness: validated and flight-ready; 7/7 times weather prevented launch

⟶ awaiting favorable weather for first balloon flight in 2025/2026



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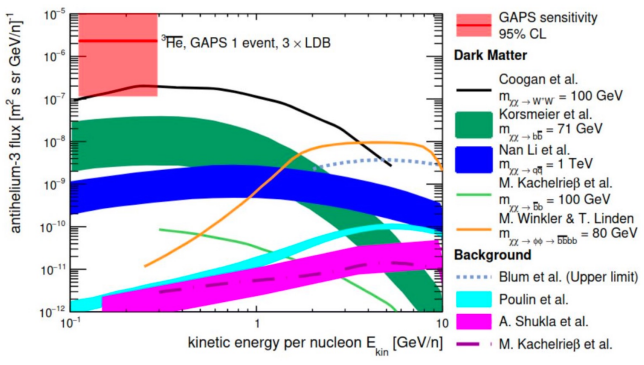


[T. Aramaki, M. Sasaki] GRAMS

⟶ dual mission: MeV γ-ray + indirect DM using large-scale LArTPC

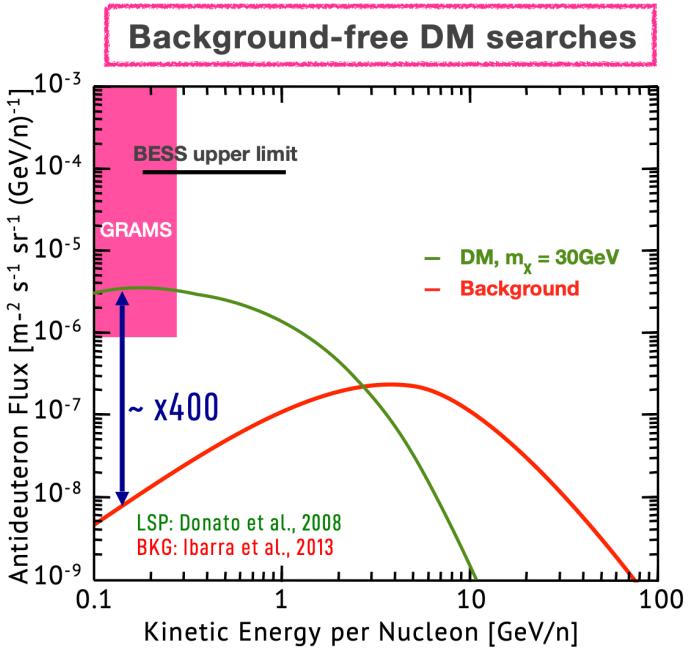
⟶ sensitivity**:** 1-2 orders of magnitude improvement over previous balloon missions

⟶ Probes *Fermi* GCE and AMS-02 antiproton excess signatures

⟶ technical status: engineering flight completed (2023), antiproton beam test validated (2025), **pGRAMS** prototype flight (Spring 2026)

⟶ Funded by APRA2022

[talk by T. Aramaki]



[L-E. Ghezzer] PlastiCAMI

⟶ new detector design with clean separation of bar-p/bar-d signals using timing (prompt/delayed) and multi-pion signatures

⟶ construction of a prototype detector ongoing @ INFN-TIFPA

Galactic sources: MW halo and individual source classes

- **[A. Aguirre-Santaella] Tidal Tracks & Subhalo Survival**

  ⟶ high-resolution simulations to characterize subhalo tidal tracks with great particle resolution of O(10^7) particles

- **[S. Porras] Baryonic Suppression of Subhalos**

  ⟶ MHD simulations providing a more accurate prediction for the brightest dark satellites and their detectability with Fermi-LAT

- **[J. Mamprim] Oscillating DM Solves Cusp/Core**

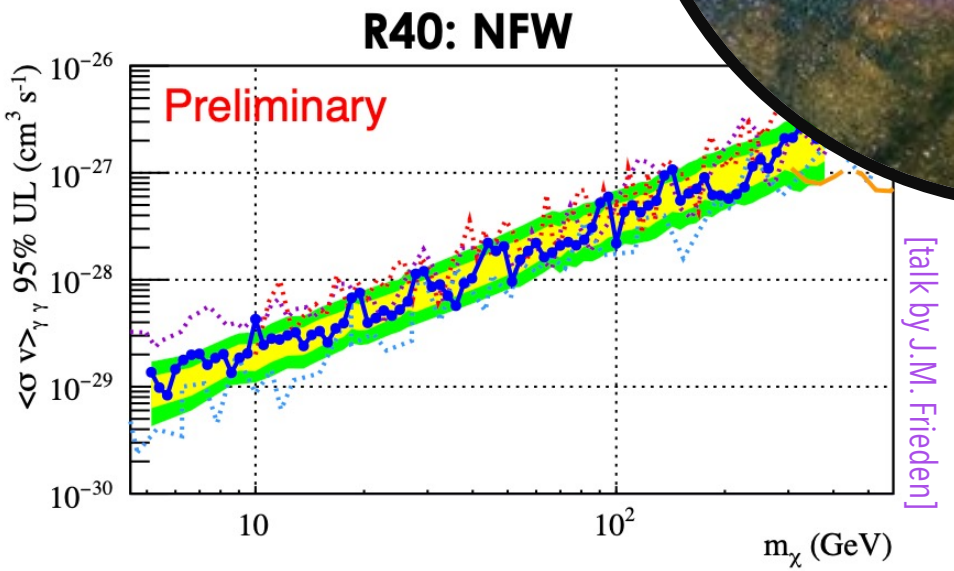
  ⟶ OADM model transforms cuspy to cored profiles, matching galaxy rotation curves–offers new route to solve the cusp/core problem

- **[J.M. Frieden] DAMPE: No Gamma-ray Lines Found**

  ⟶9-year DAMPE gamma-ray line search sets strong new upper limits, 20–500 GeV, no significant features across halo models

- **[M. Giliberti] Fermi-LAT: Tightest Line/Box Limits**

  ⟶15.5-year all-sky Fermi-LAT line/box search: ×100 improvement in limits over 2015, no detection; advanced likelihood + background modeling (energy sliding window)



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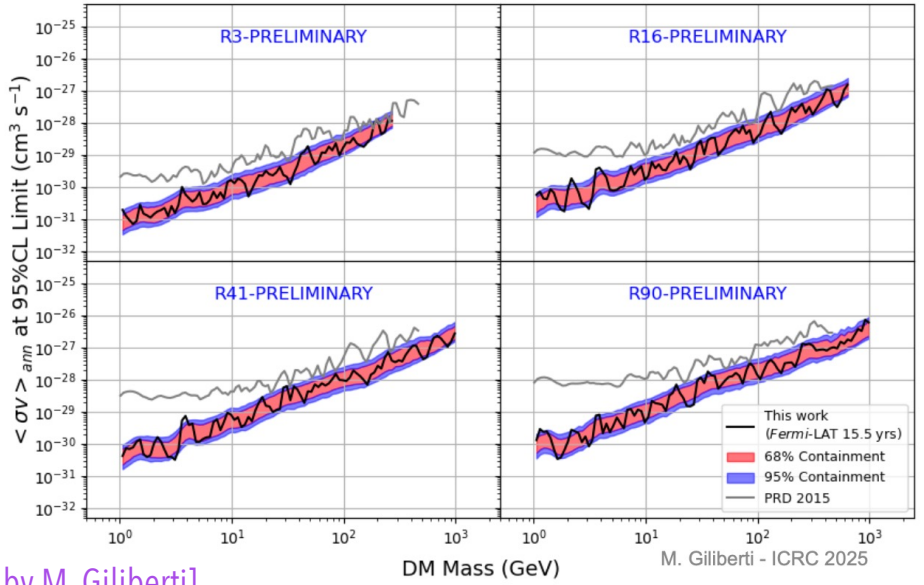
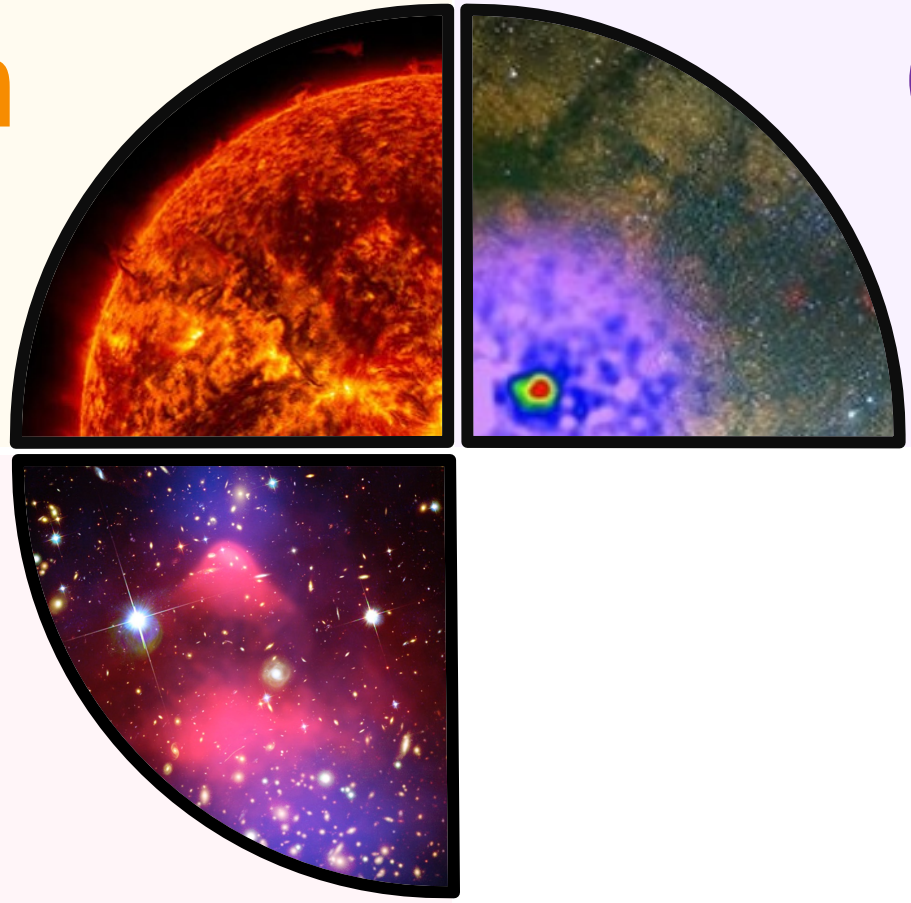


[talk by M. Giliberti]

Solar System

Galactic



Extragalactic

Extragalactic sources

Galaxy Clusters

- **[N. Lavis, S. Semane] MeerKAT searches**

⟶ Galaxy Cluster Legacy Survey (115 sources)
⟶ computationally expensive, pipeline development for the SKA-era

- **[Z. Shen] 43 GeV gamma-ray line in galaxy clusters**

⟶ 3.7σ post-trial significance (13 clusters), 4.3σ (top 3 clusters: Virgo, Fornax, Ophiuchus)
⟶ multiple consistency checks: monochromatic width, virial radius extent, Earth limb control -- but instrumental effects possible
⟶ in tension with GCE

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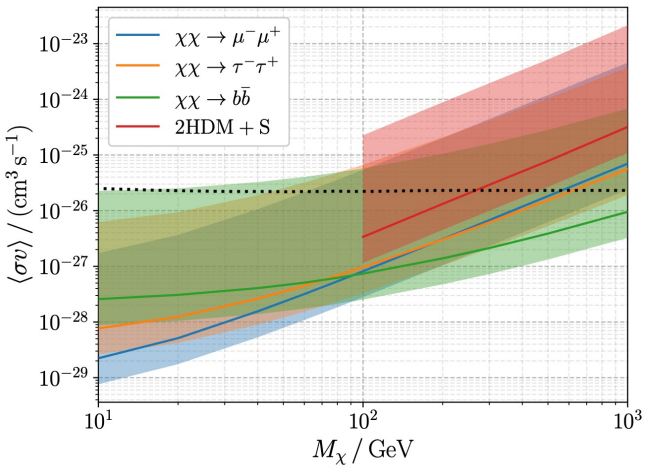

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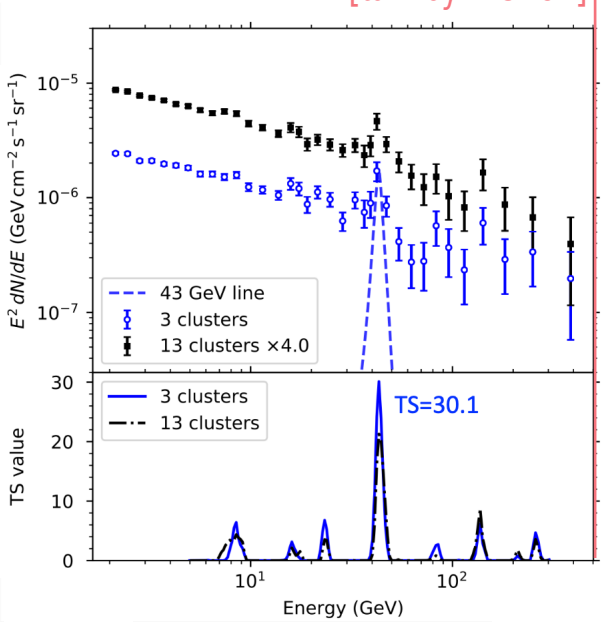

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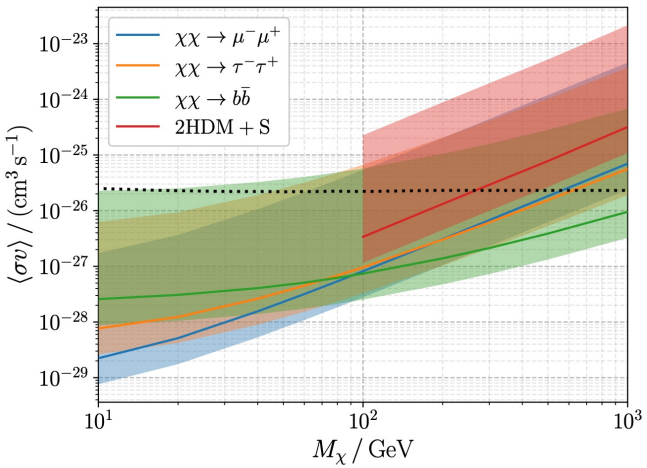

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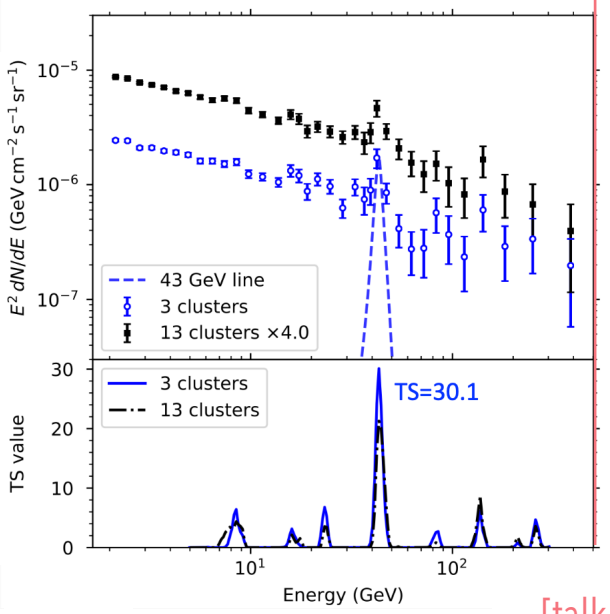


Jetted Objects

- **[I.J. Watson, J. Serna] HAWC ALP searches**

⟶ three blazars (VER J0521+211, 1ES 0229+200, PG 1553+113) with up-to-date HAWC data --- extends existing constraints in neV-scale ALP
⟶ M87: robust statistical framework circumventing Wilk's theorem; 7 years of data & new constraints!

- **[D. Kantzas] Jets Constraining DM via CR-DM Interactions**

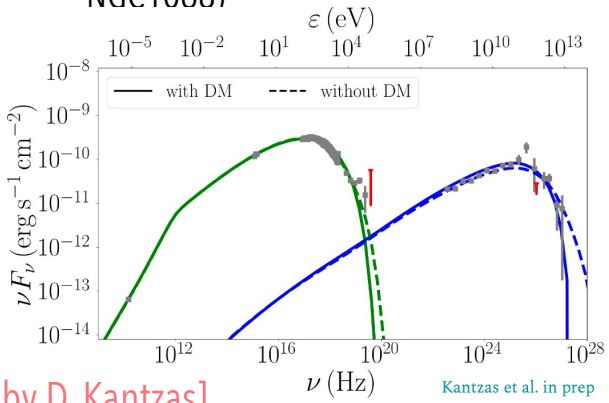
⟶ first realistic jet modeling of CR-DM elastic/inelastic collisions using BHJet multi-zone framework; Markarian 421 case study

- **[O. Ghosh] Heavy ALPs Disrupting GRBs**

⟶ photophilic ALPs (MeV-GeV scale) produced in leptonic fireballs can completely suppress GRB emission, but they don't! Strong limits!

- **[P. Kivokurtseva] Neutrinos from DM spikes**

⟶ Neutrino flux from SMBHs can come from DM interactions in dense regions (case study NGC1068)



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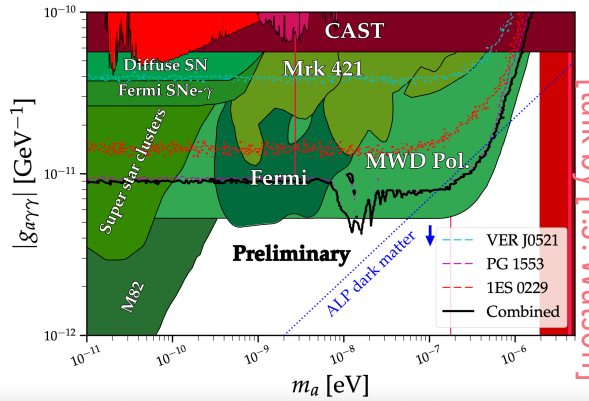

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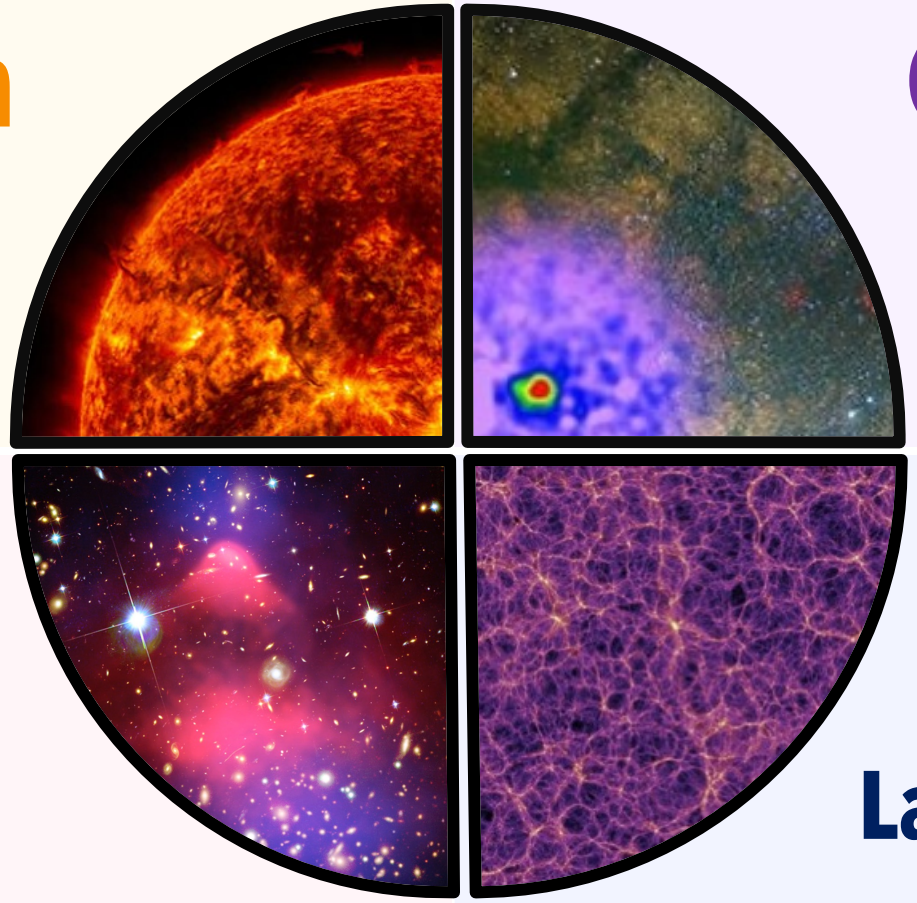


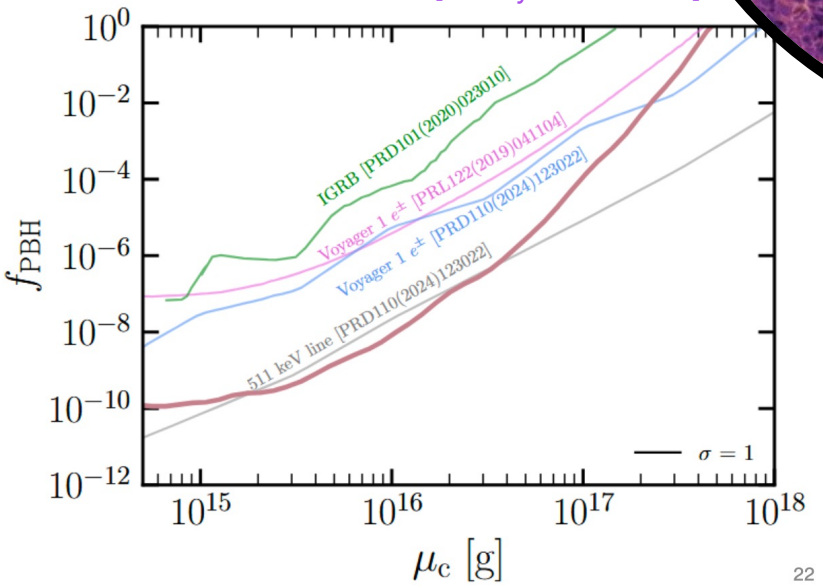
Extragalactic

Large Scale Structure

Large Scale Structure & early Universe

- **[H. Jiang] LHAASO PBH Burst Search**
  - ⟶all-sky search for PBH bursts using uniform spatial coverage; burst rate limits derived assuming local, large-scale uniform PBH distribution
  - ⟶the upper limit of the local PBH burst rate density is set to be as low as 181 $pc^{-3}yr^{-1}$
- **[S. Porras] ALP Decay in Cosmic Background**
  - ⟶obtain ALP decay by modeling LSS-averaged extragalactic background light; strong synergy with New Horizons excess studies and CB upper limits
- **[L. Stefanuto] Cosmic Antinuclei from PBHs**
  - ⟶ Galactic propagation and spatial distribution (NFW profile) of PBHs directly informed by LSS modeling;
  - ⟶constraints on local PBH density f_{PBH} depend on assumed large-scale structure and DM halo properties.
- **[M. Vecchi] IMBHs and DM Spikes (H.E.S.S.)**
  - ⟶mock IMBH catalogues built from hydrodynamical LSS simulations (EAGLE)
  - ⟶ search for DM annihilation enhanced by LSS-informed spatial distributions; no point-like excesses found, but placed upper limits
- **[J. Häußler] Relativistic Magnetic Monopoles in IceCube**
  - ⟶ projected sensitivity: magnetic monopole fluxes two orders of magnitude below current best upper limit

[talk by L. Stefanuto]



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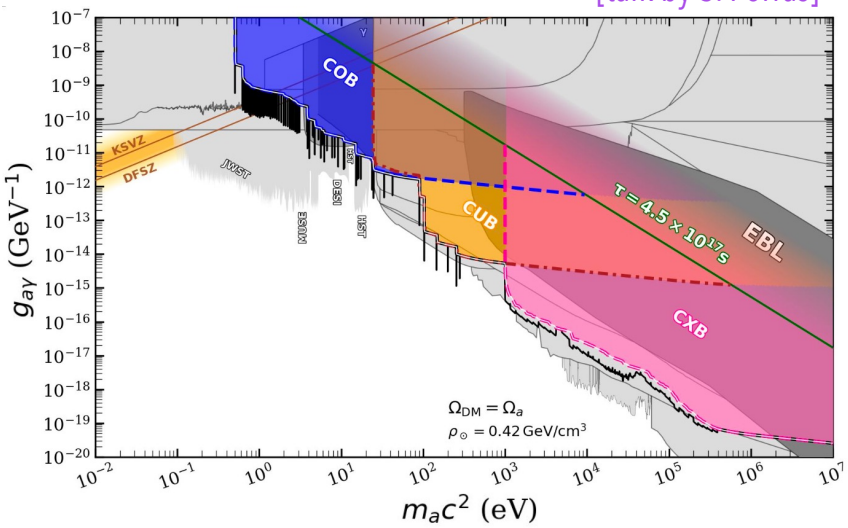
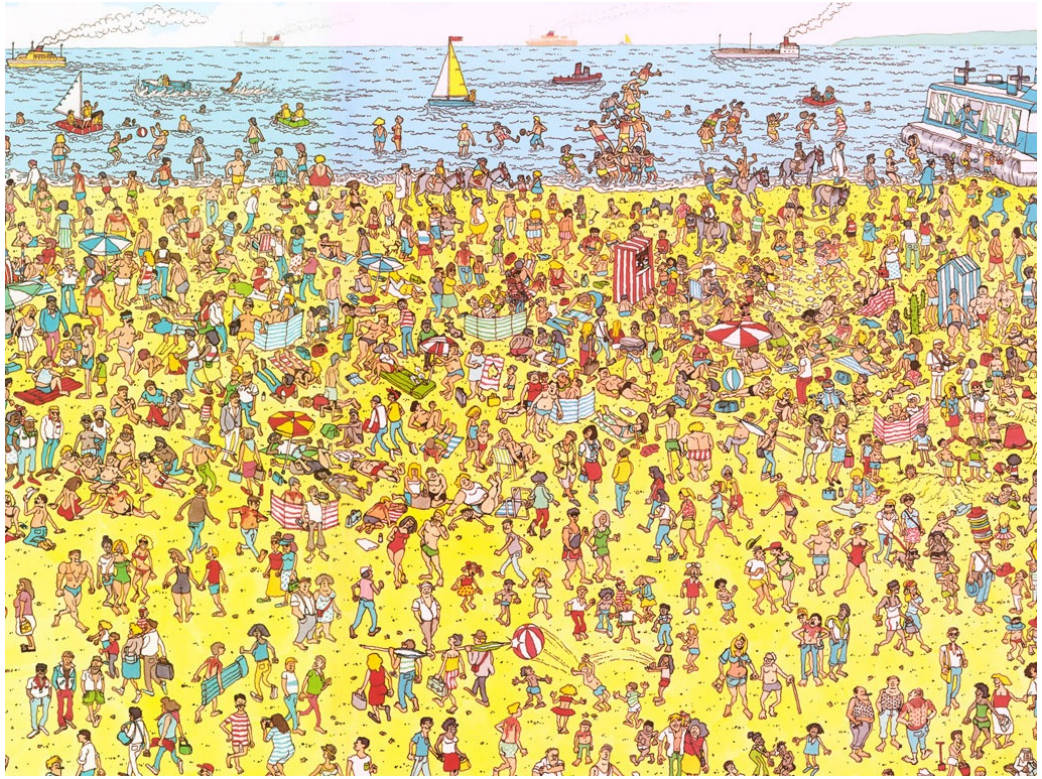
[talk by S. Porras]





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✓ particle physics

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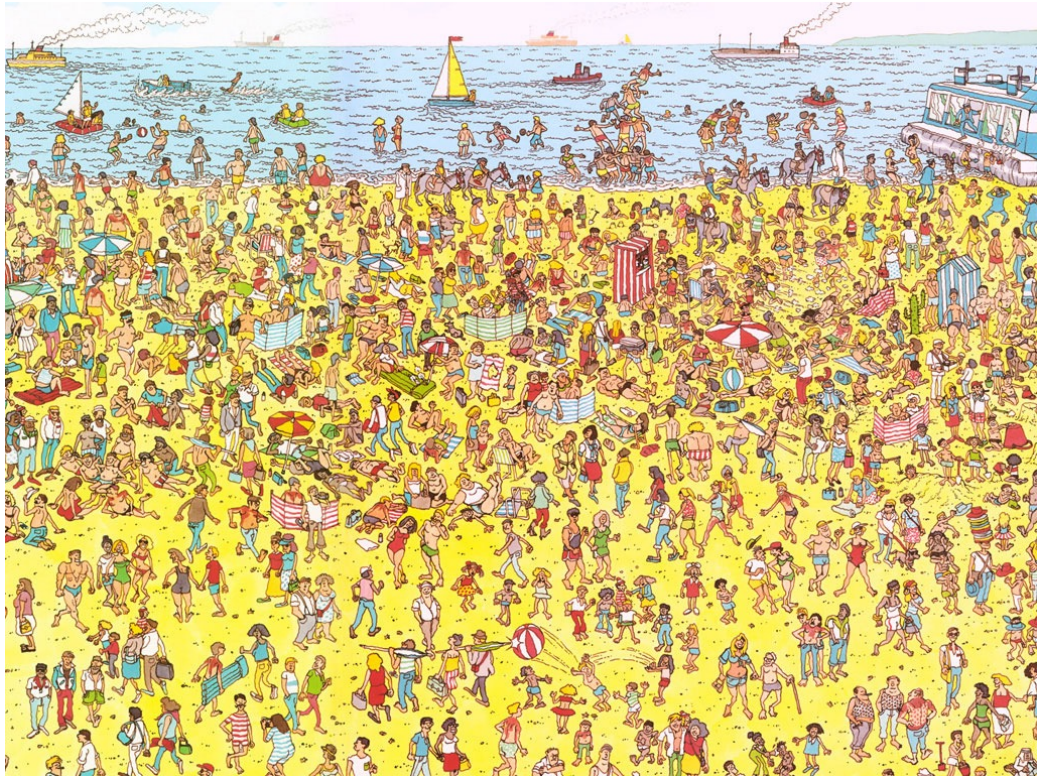
✓ astrophysics



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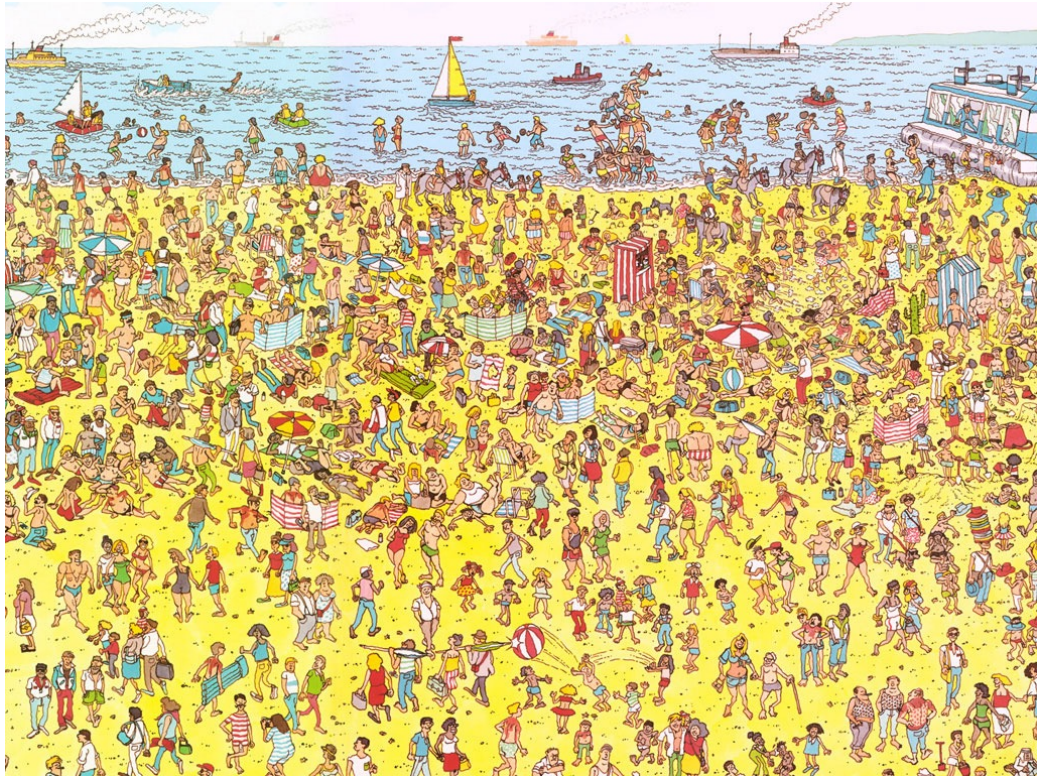

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⟶ liquid argon (DEAP-3600, DarkSide-20k)

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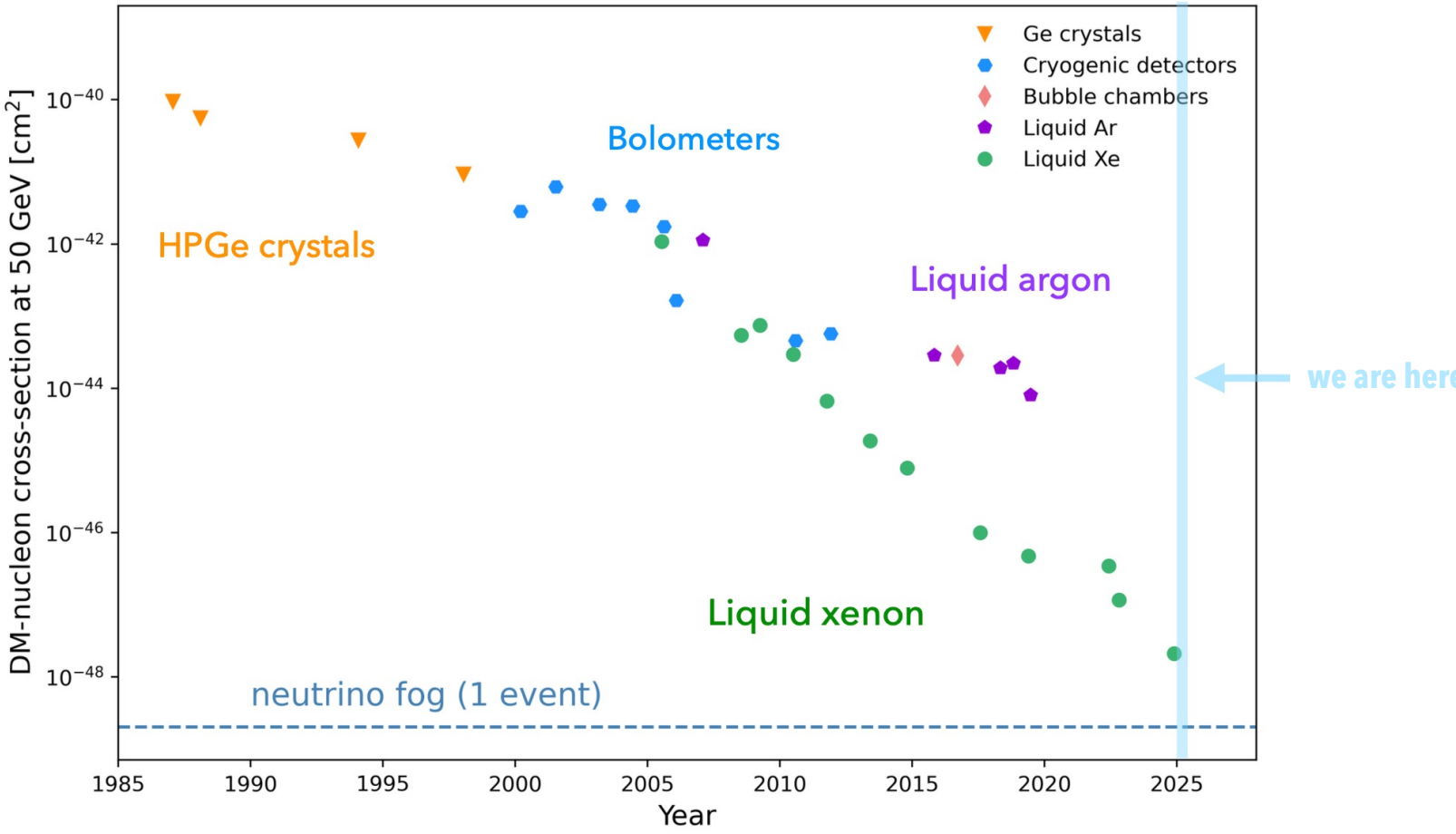
⟶ non-traditional detectors (IceCube, RES-NOVA)

[plenary by L. Baudis]



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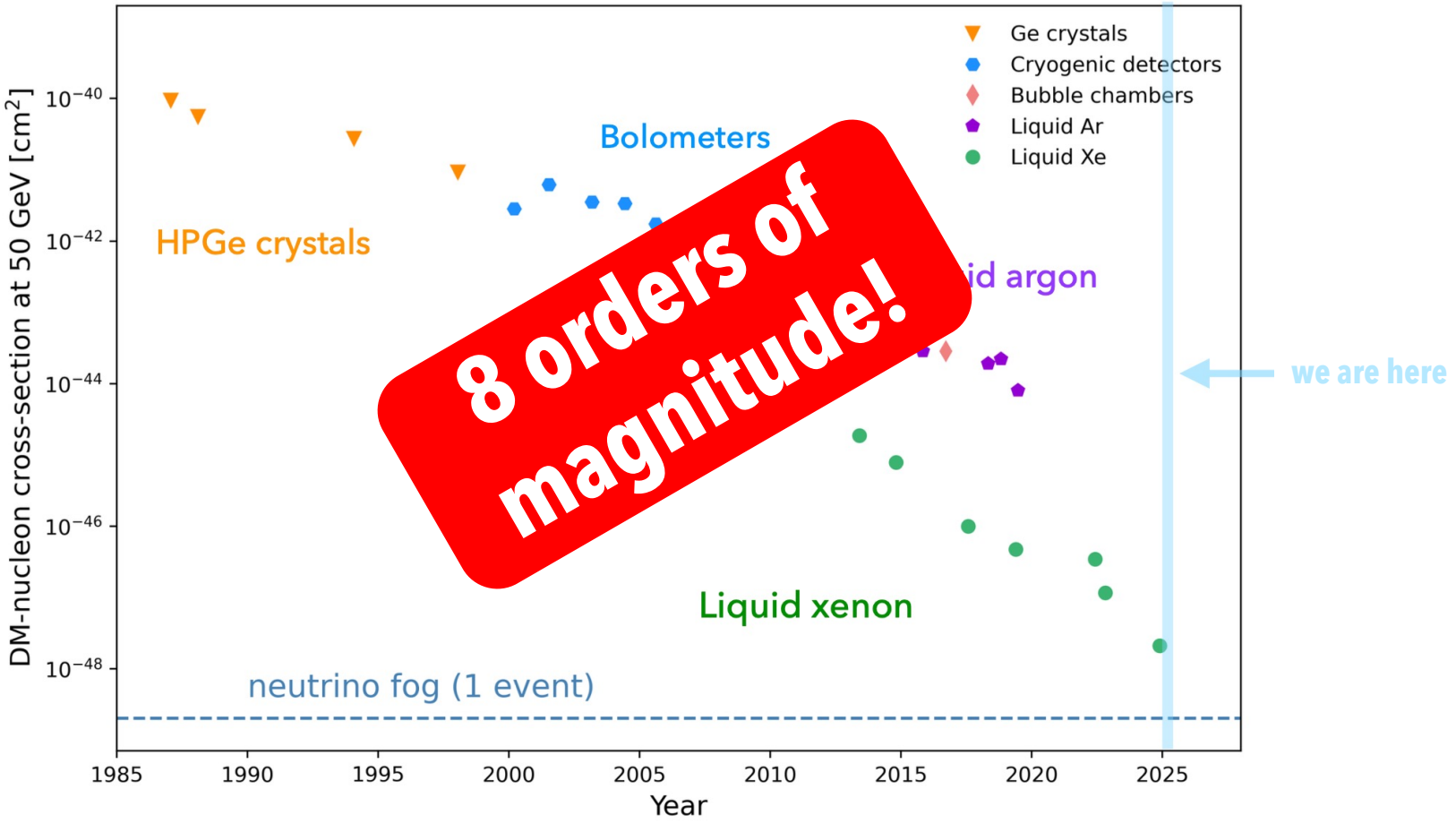
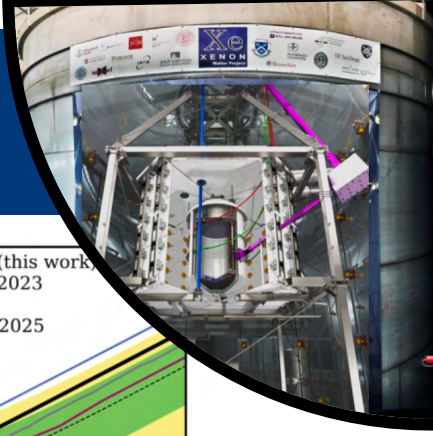


Liquid Noble Targets



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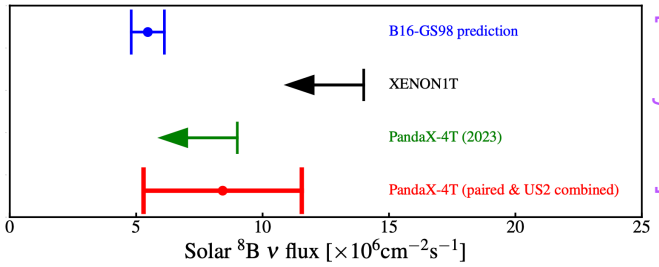
  - ⟶ **first indication of solar ^{8}B Neutrino CEvNS: 2.73σ significance**
  - ⟶ enhanced WIMP Limits: $\sigma_{SI} < 1.7\times10^{-47}$ cm² @ 30 GeV (1.8× improvement over SR0)
  - ⟶ Ultra-Low Background: ER rate reduced to 0.9 μBq/kg (solar pp-neutrino level) via Radon Removal System
- **[Y. Tao, C. He] PandaX-4T**
  - ⟶ Run0+Run1 exposure (1.54tonne·year)
  - ⟶competitive limits on axions/ALPs and dark photons.
  - ⟶ **first indication of solar ^{8}B CEvNS (2.64σ)**



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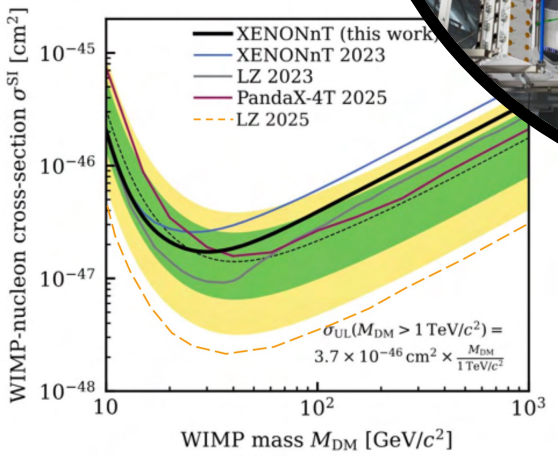

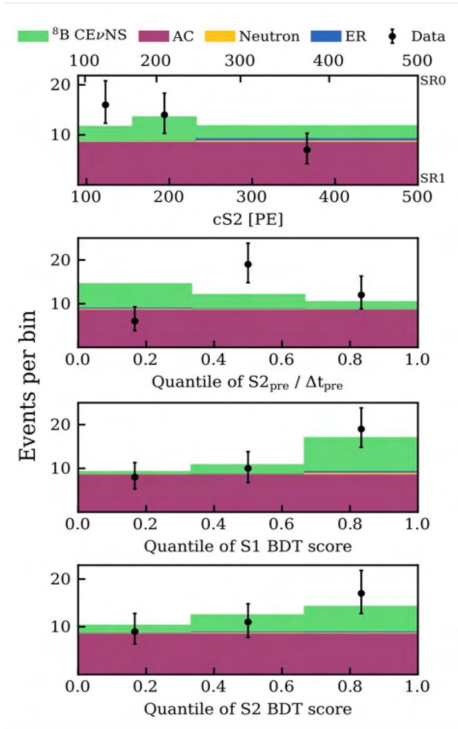

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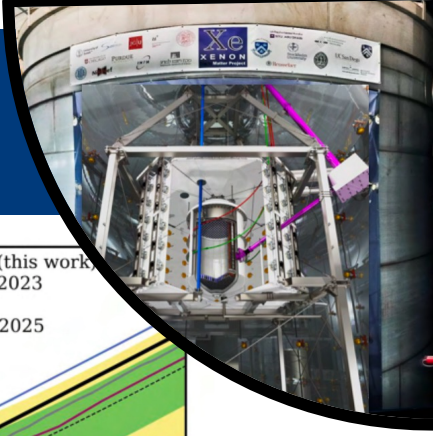

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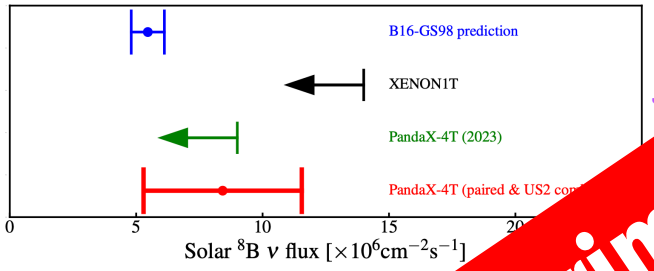

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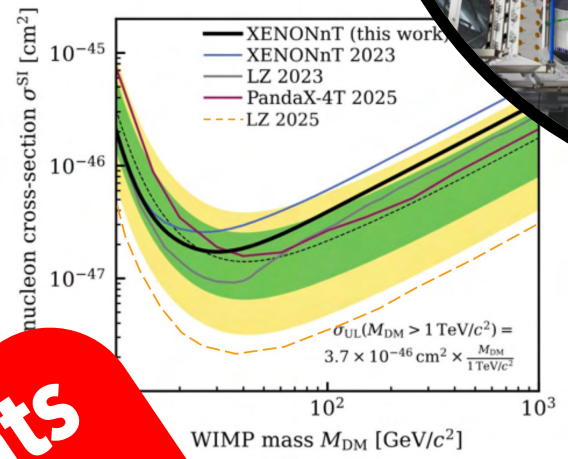
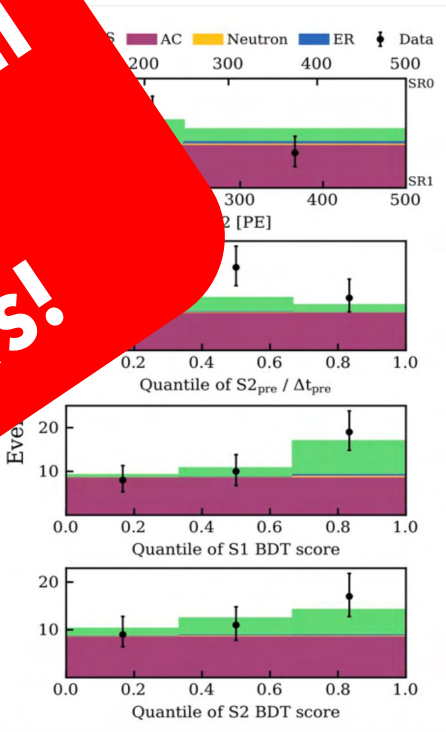


[talk by E. Angelino]

DD experiments as astrophysical neutrino detectors!



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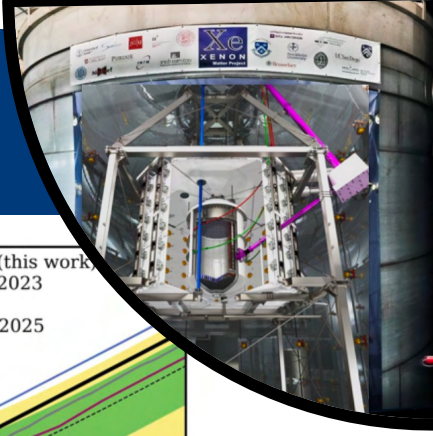

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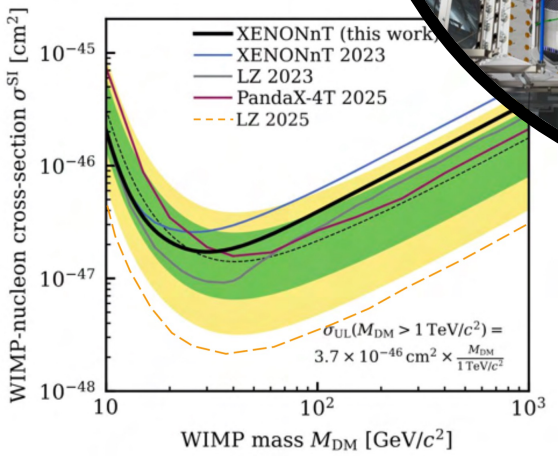
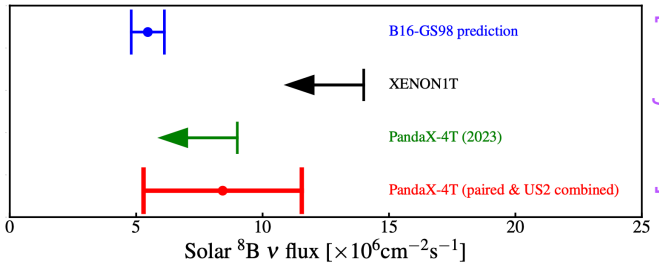


[talk by E. Angelino]

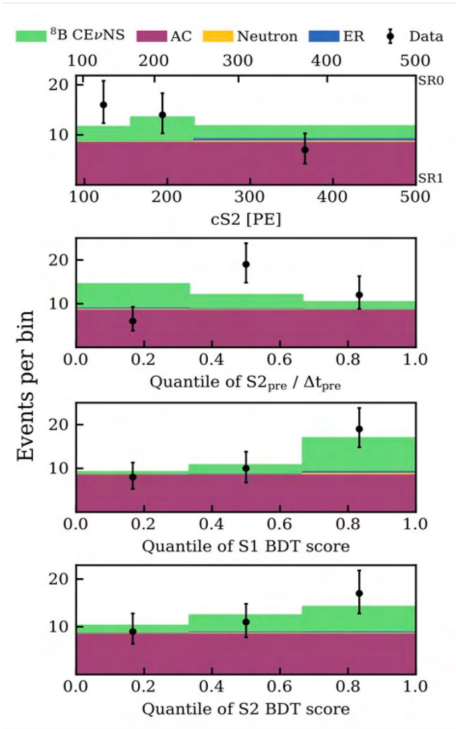
- **[Y. Tao, C. He] PandaX-4T**
  - ⟶ Run0+Run1 exposure (1.54tonne·year)
  - ⟶competitive limits on axions/ALPs and dark photons.
  - ⟶ **first indication of solar ^{8}B CEvNS (2.64σ)**



[talk by Y. Tao]

- **[O-A. Taborda, M-B. Walczak] DarkSide-20k**
  - ⟶ construction underway for the next-generation dual-phase LAr TPC (20 t fiducial, 50 t total)
  - ⟶operation expected 2027
  - ⟶ novel use of underground argon (UAr) for ultra-low backgrounds.
  - ⟶ custom cryogenic SiPM arrays for light readout, advanced DAQ to handle high event rates and triggerless operation
  - ⟶ aimed to reach sensitivities at or beyond the neutrino floor.

- **[A. Garai] DEAP-3600**
  - ⟶ extended dataset (813 days live time); improved background model
  - ⟶ upgraded hardware for further background reduction; improved event reconstruction using neural networks.
  - ⟶ direct 39Ar half-life measurement, tension with previous nuclear data sheets



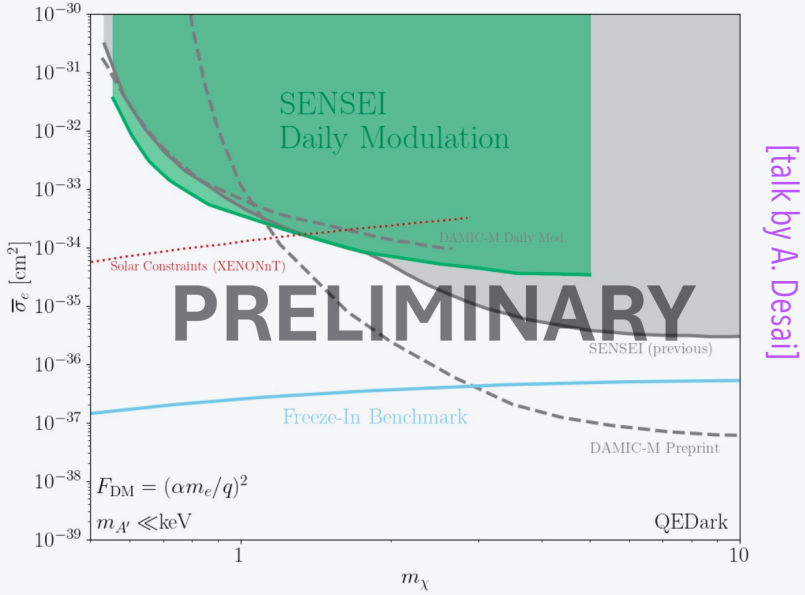
Solid State (SENSEI, SuperCDMS)

- **[A. Desai] SENSEI**

⟶ skipper CCD: world-record low noise in Silicon (or NIR/UV photodetector); 10×improvement

⟶first dedicated daily modulation search for low-mass DM

⟶ 3rd science run with new cryocooler is resuming soon!



[talk by A. Desai]

- **[M. Elwan] SuperCDMS**

⟶ successful detector commissioning at SNOLAB CUTE facility

⟶ ultra-low energy threshold: sub-50 eV phonon detection

⟶ 30 kg payload deployment 2025, first science run 2026

⟶ broad DM mass coverage from eV to multi-GeV scale

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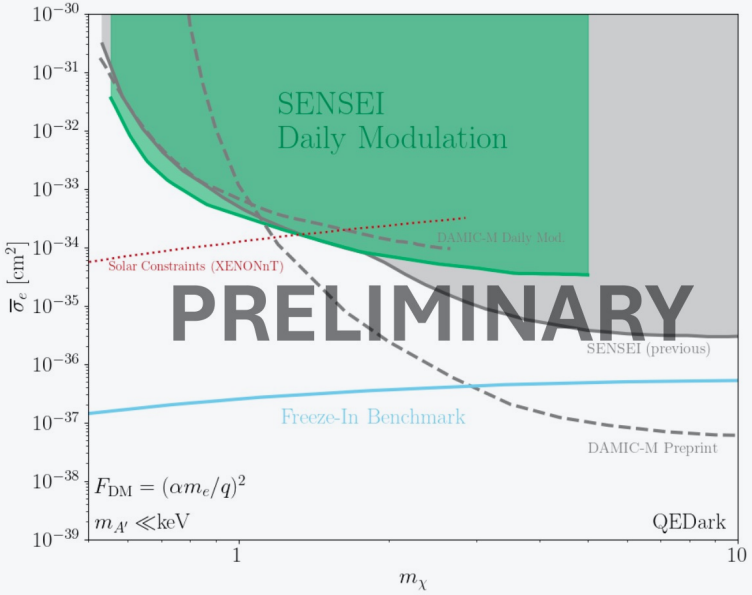

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Gaseous (NEWS-G)

- **[J-M. Coquillat, N. Panchal] NEWS-G**

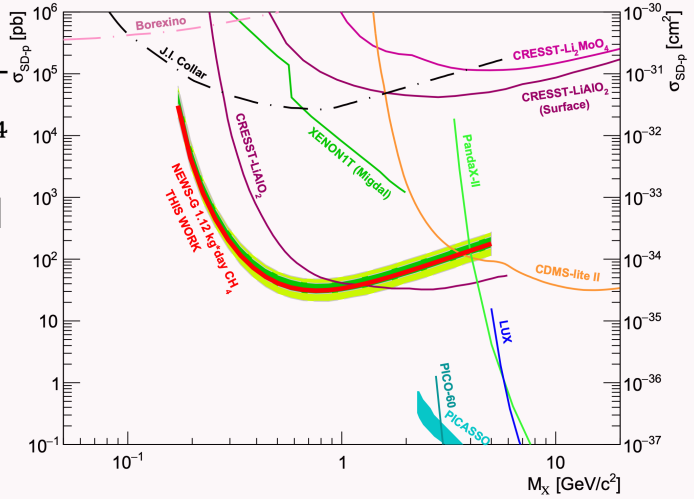
⟶ leading proton spin-dependent WIMP limits 0.2-1 GeV

⟶ neon analysis ongoing with MCMC + technology improvements; He+10%CH_4 data taking

⟶ DarkSPHERE: 3m fully electroformed sphere (under consideration), NEWS-G^3: completed shield at Queen's for CEνNS (testing phase)

⟶ new Li-doped backing detector at UdeM: 6× lower recoil threshold for quenching factor measurements

[talk by J-M. Coquillat]



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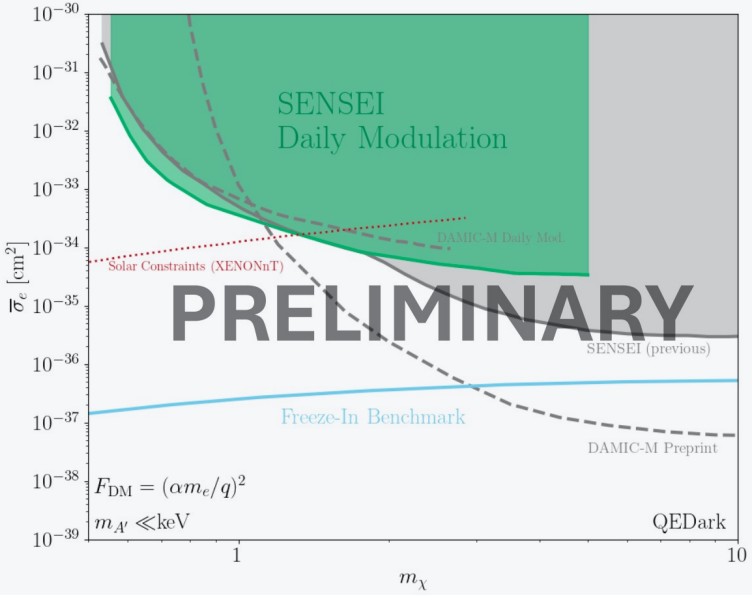

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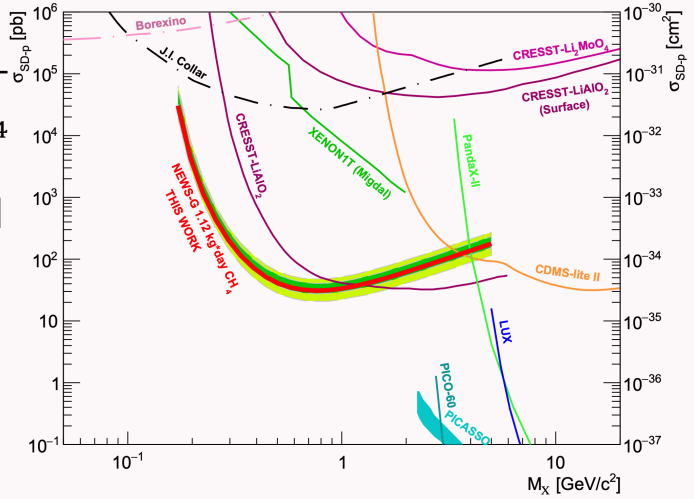


Scintillator (SABRE)

- **[I. Bolognino] SABRE South**

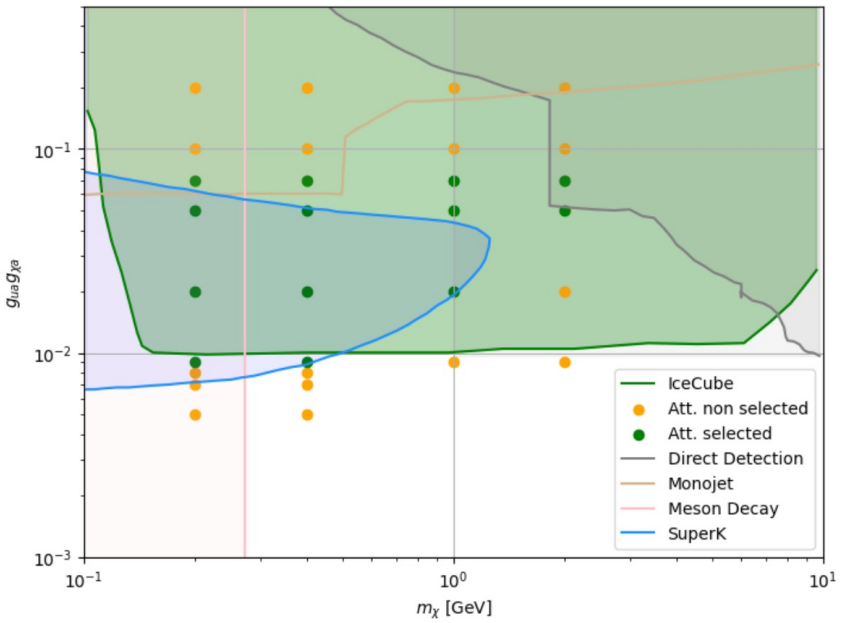
⟶ dual-site NaI(Tl) experiment to test DAMA/LIBRA modulation claim
⟶ ultra-pure crystals: 4.3 ppb natK (vs 13-35 ppb in other experiments)
⟶ first Southern Hemisphere deep underground lab (SUPL, 1025m)
⟶ liquid scintillator veto: factor 10 ^{40}K reduction, 0.72 cpd/kg/keV background
⟶ discovery/exclusion results expected within 2 years

Astrophysical neutrino detectors as DD experiments

same infrastructure serves neutrino astrophysics and DD DM searches!

Astrophysical neutrino detectors as DD experiments

Figure 16: Contour Plot for pseudoscalar mediator with $m_a = 1$ GeV.



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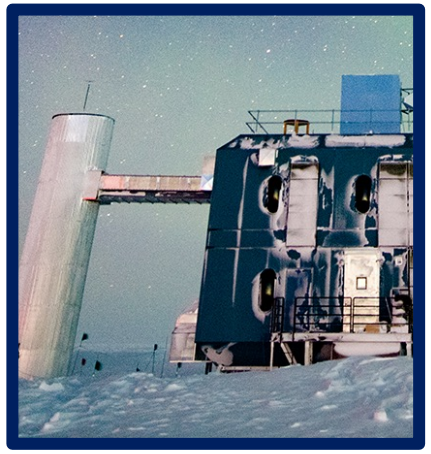
[talk by A. Cavicchi]

⟶ **Concept:** CRs upscatter halo DM to relativistic speeds ⟶ detectable at Earth
⟶ **Key insight:** sub-GeV DM sensitivity
⟶ **Advantage:** Gigaton detector volume + directional signature from galactic center
⟶ **Results:** Competitive sensitivity for pseudoscalar-mediated DM



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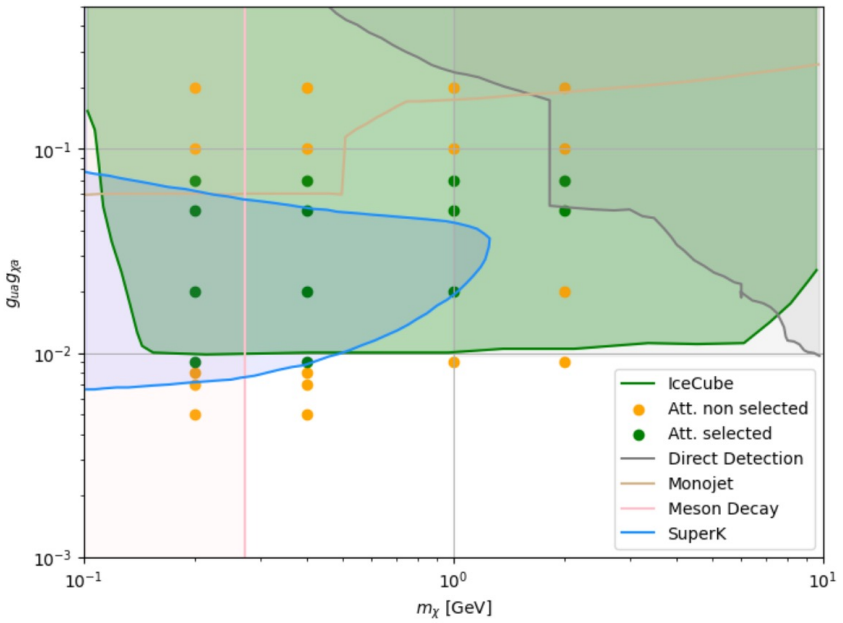

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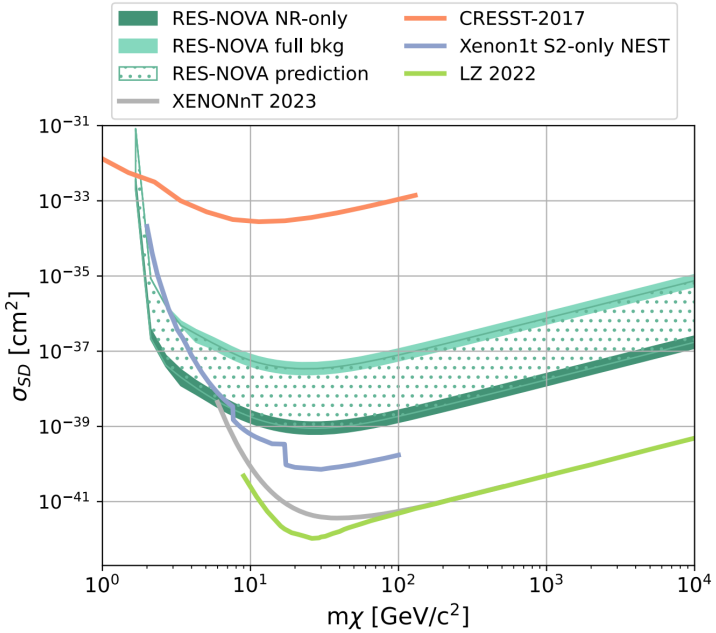

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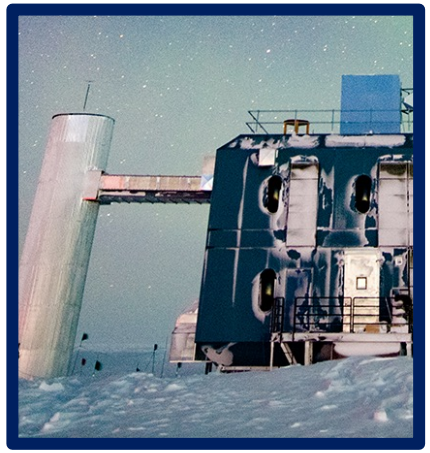

[talk by N-F. Iachellini]

RES-NOVA

⟶ **Concept**: SN neutrino bursts create nuclear recoils via CEνNS --- same signature as DM
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⟶ **Technology**: $PbWO_4$ crystals with 2000-year-old archaeological lead
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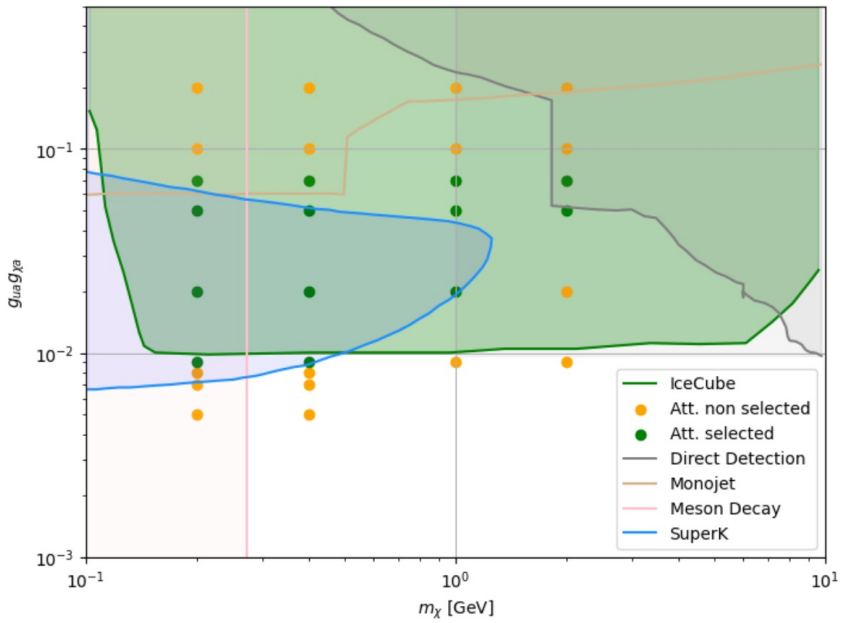

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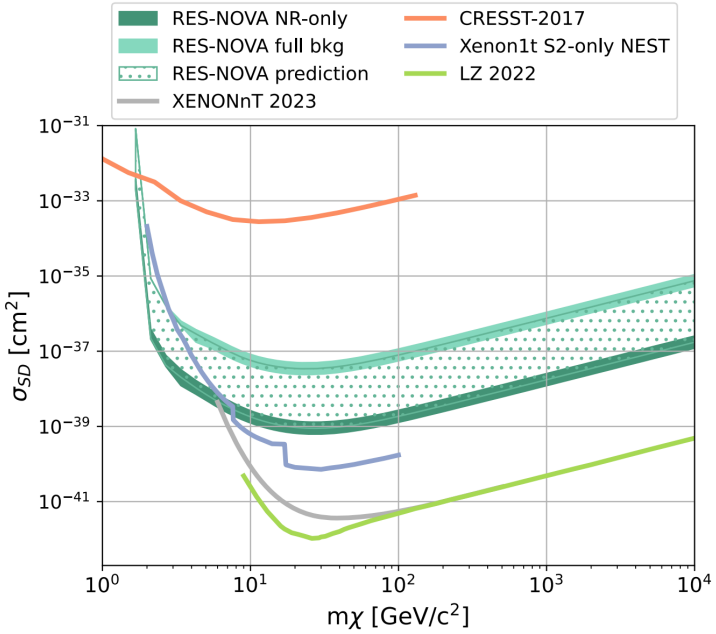
Another example: planning to build a lab for dark matter detection @ Bedretto (main purpose: Earthquake research). [plenary by L. Baudis]



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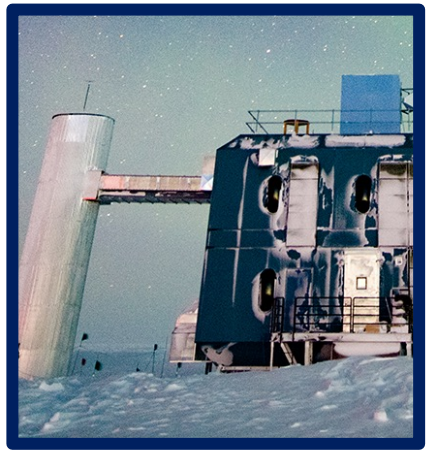

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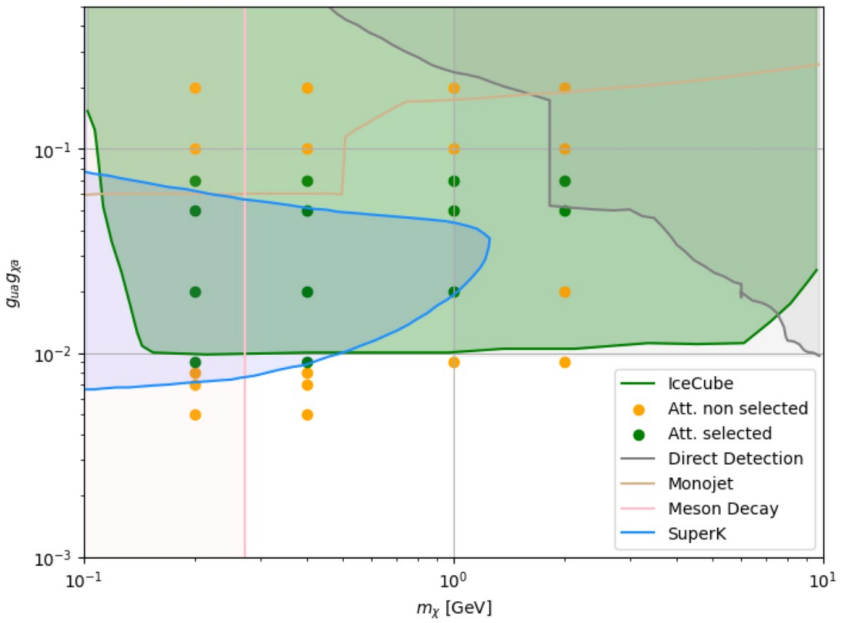

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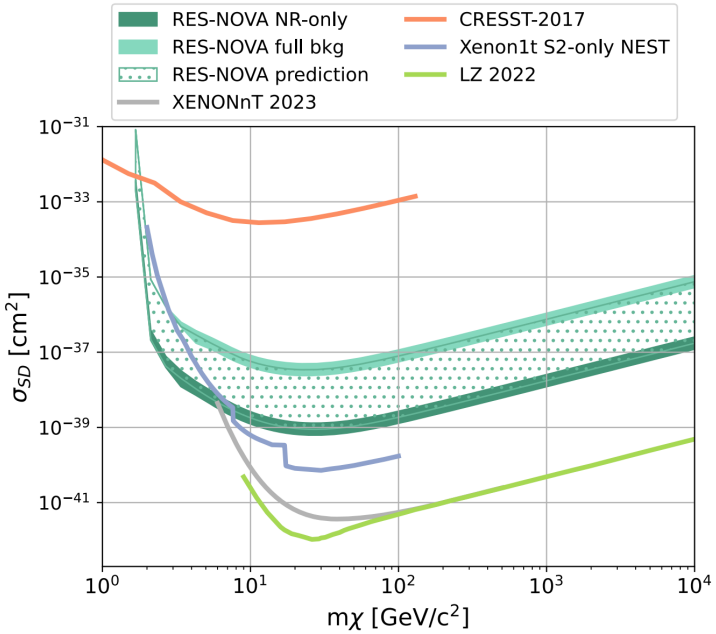
There's more!
The FUNK experiment recycling Auger mirror for hidden-photon searches. [plenary by J. Jaeckel]



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Direct detection: take-home message

No significant signal reported @ ICRC. What's next?

[plenary by L. Baudis]

Canonical WIMP

⟶ liquid xenon experiments (XENONnT, PandaX-4T) now detecting solar neutrino CEνNS - ultimate background achieved

⟶ Approaching the neutrino fog: Traditional DD experiments nearing fundamental limit

What's the game for canonical WIMPs? Two key goals:

⟶ Probe to neutrino floor: Scale up detector mass + perfect background modeling

⟶ Observe Migdal effect: Access lower mass WIMPs via atomic excitation signatures

Beyond Canonical WIMPs: Extending Parameter Space

⟶ model reexamination: If DM was never in thermal equilibrium ⟶ sub-GeV candidates natural

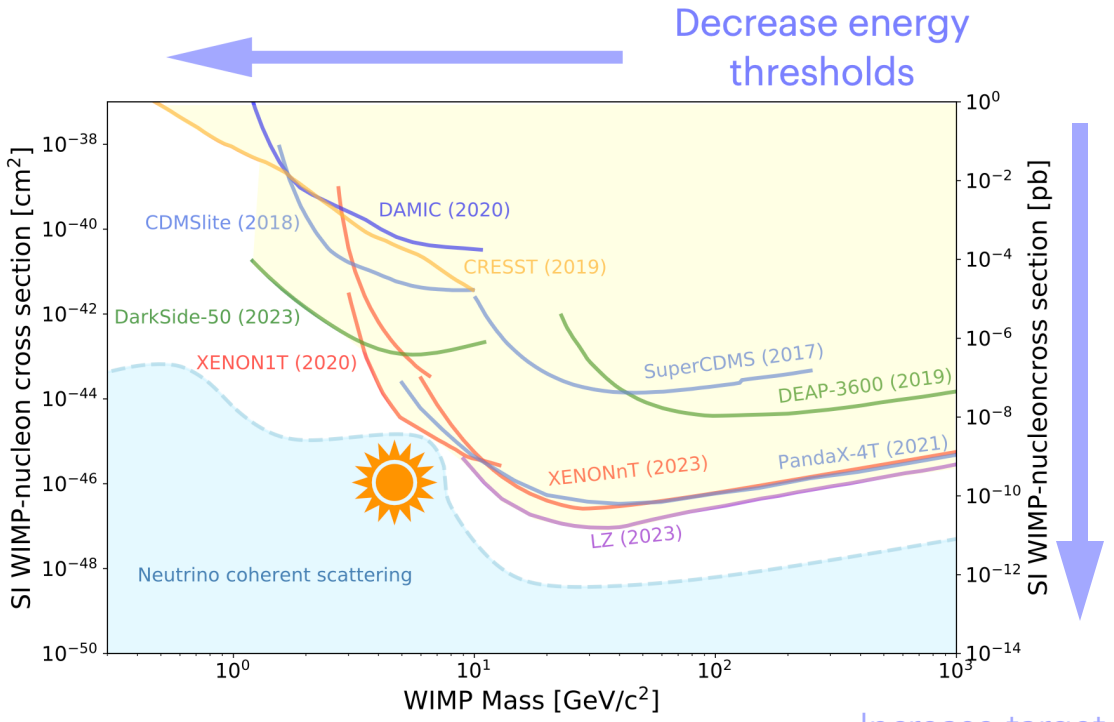
⟶ new targets: keV-GeV DM, axions

Technology Frontiers

⟶ quantum sensing: Skipper-CCDs (SENSEI) reaching eV thresholds, DAMIC-M first to probe the sub-GeV theory benchmarks

⟶ cryogenic detectors: SuperCDMS sub-50 eV phonon detection

⟶ DD experiments as neutrino detectors and vice versa!



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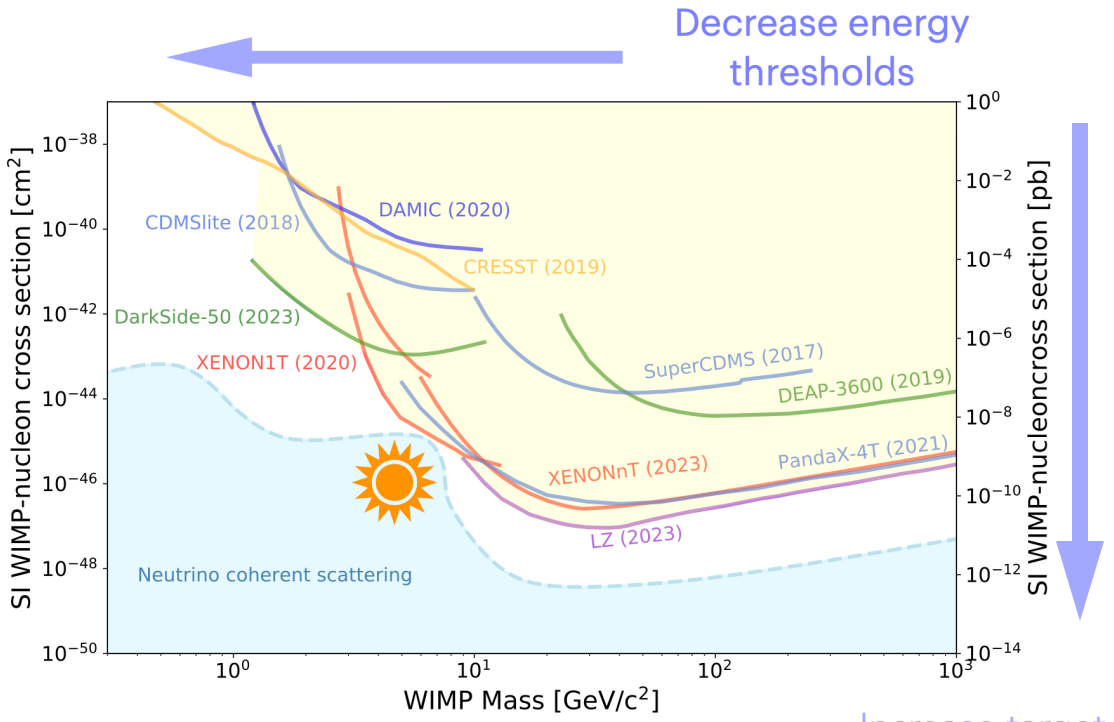
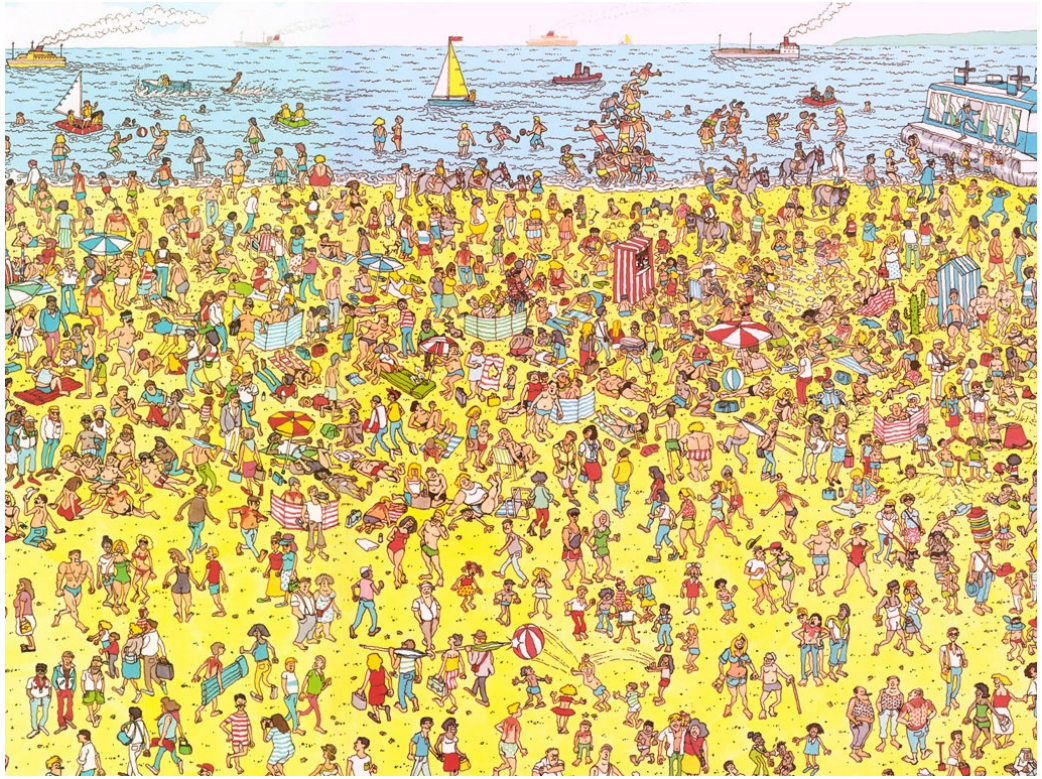


Bottom Line: Field pivoting from "canonical WIMP endgame" to a "broad light DM program," with quantum sensors rising and noble liquids reaching fundamental limits in WIMP searches (but exciting from astrophysics PoV!)



Caveats

…We don't know what Waldo **looks like exactly**.

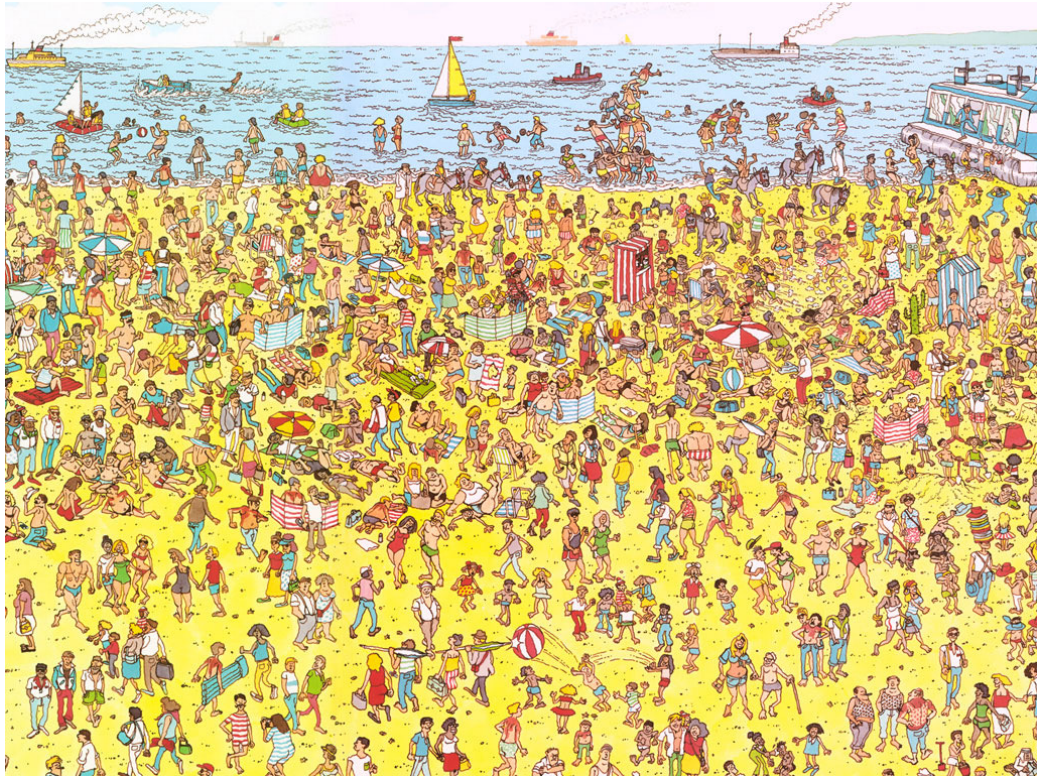
✓ particle physics

…Instead of a beach, we search **the whole Universe.**

✓ astrophysics

…we may need **different visual aids**.

✓ direct detection



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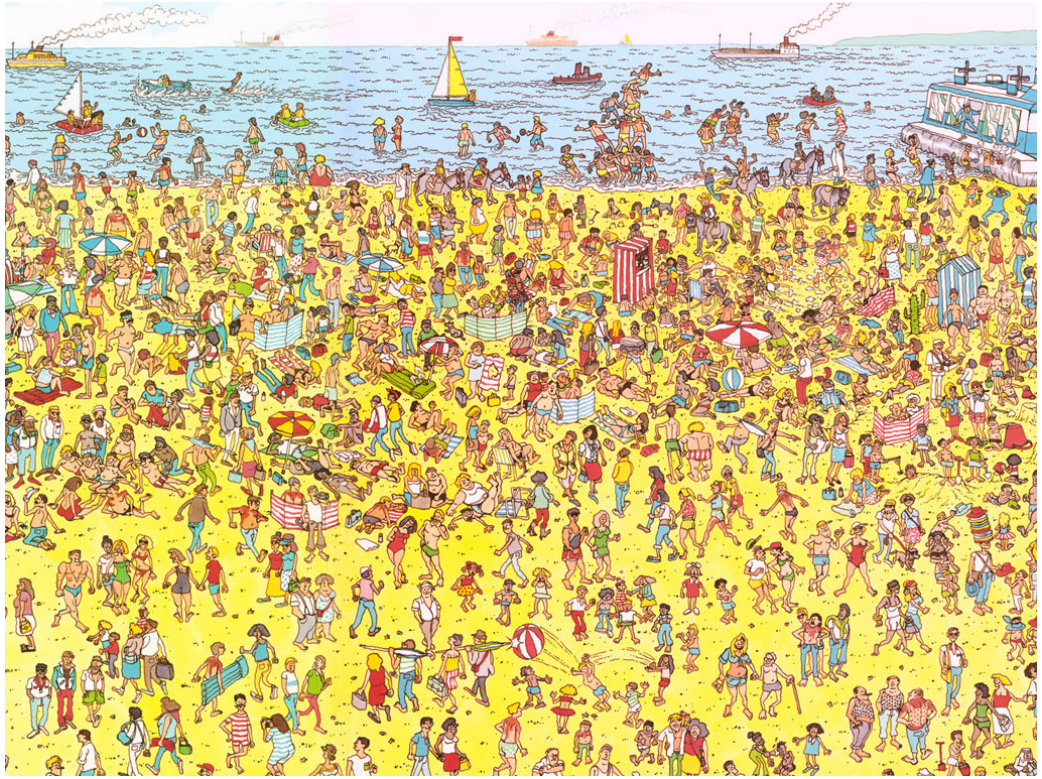

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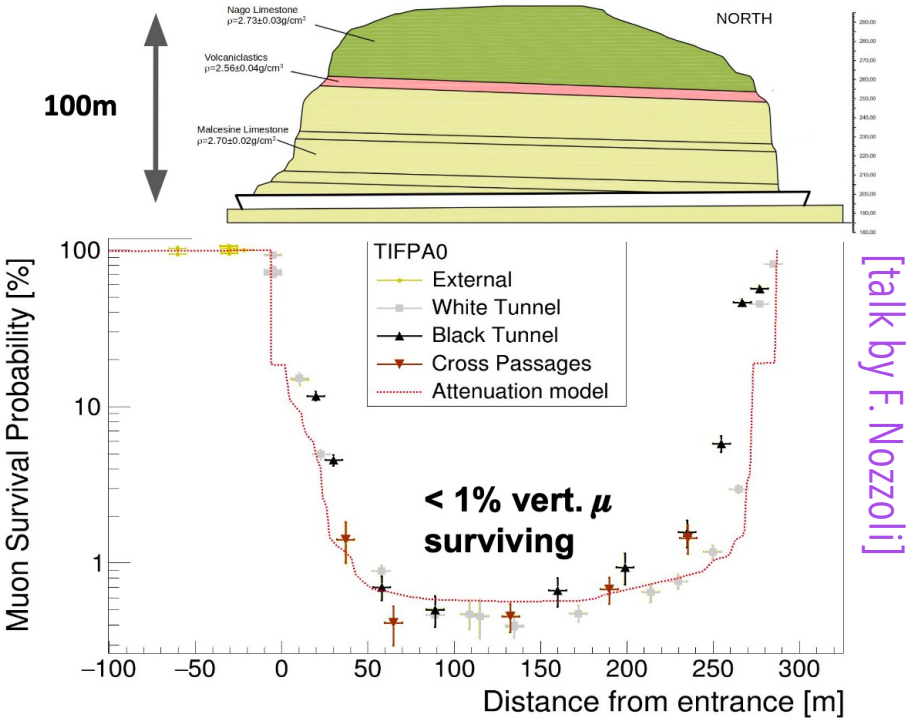
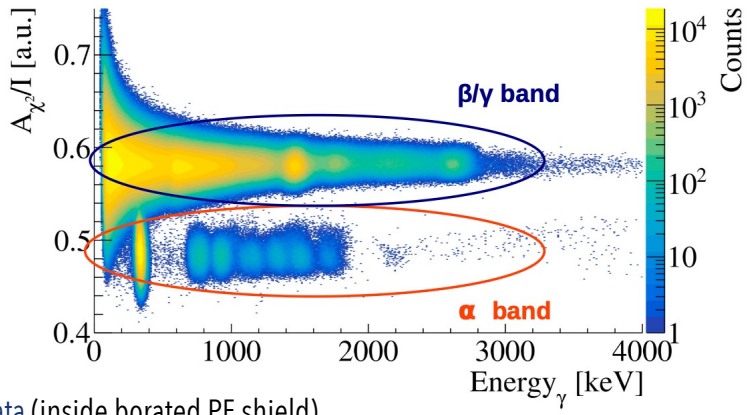
backgrounds

Background characterization

- **[Z. Zhou] PandaX R12699 low-background PMT**
  - ⟶ major background sources: radioactivity from Kovar and glass components (Co-60, U, Th chains)
  - ⟶ achieved large reduction in intrinsic radioactivity (up to ×8) through material selection, careful production, and testing under cryogenic conditions
  - ⟶ key for next-gen xenon detectors aiming at lower backgrounds for rare event searches
- **[Y. Liu] Cryogenic readout electronics**
  - ⟶backgrounds from electronic noise, voltage ripple, and instability at low temperature can mimic or obscure real signals
  - ⟶Stable operation of DCDC, LDO, clock, and FPGA modules demonstrated at 165 K; voltage deviations <1 mV over 9+ hours, low output ripple
  - ⟶Enables clean, low-noise readout for multi-ton scale detectors
- **[A. Molinario] GAGG-based low-background neutron detector**
  - neutron and alpha/gamma backgrounds characterized and suppressed via shielding and pulse-shape discrimination; RoI reaches <1 event/day
- **[F. Nozzoli] Piedicastello tunnels site characterization**
  - ⟶ site study: even underground, cosmic-ray muons and environmental gammas persist; muon attenuation and gamma mapping are vital for background control.

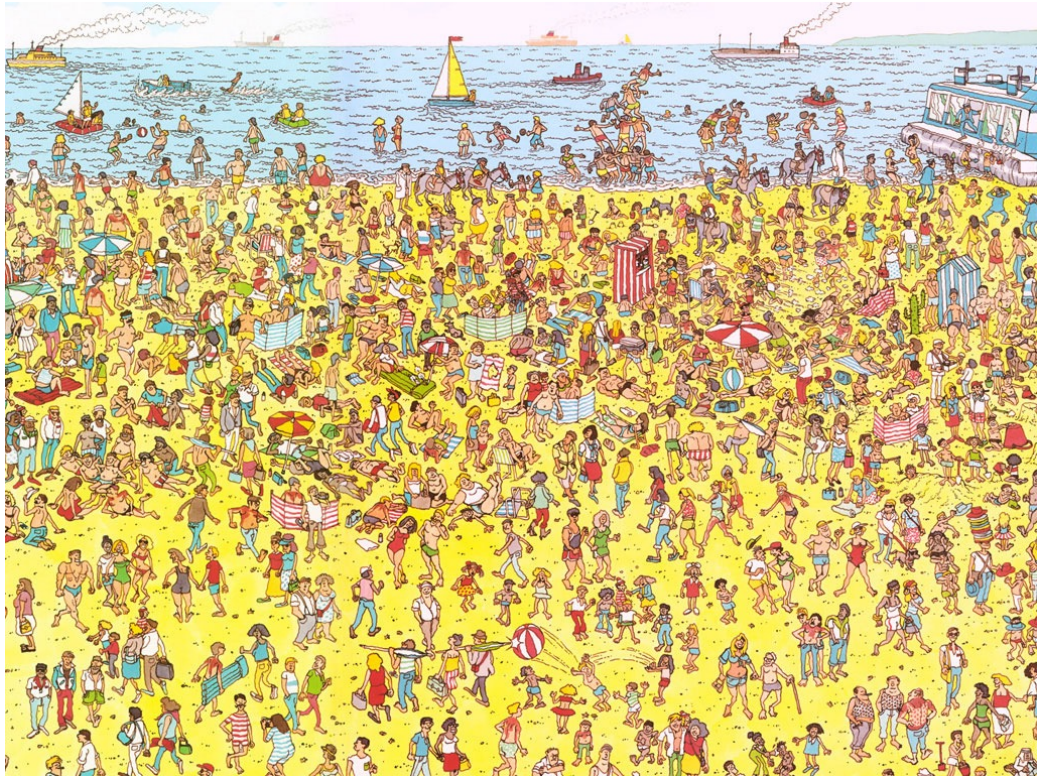


[talk by F. Nozzoli]



[talk by A. Molinario]

77.5 days of intrinsic background data (inside borated PE shield)



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✓ backgrounds

My take on this whole situation

Maturing experiments & shrinking parameter spaces

WIMP paradigm: diversified

Shifted from anomaly chasing to systematic, robust searches

Every major astrophysics discovery in the last decade came from combining multiple messengers. DM will be no different.

Future: put the dark matter into "multimessenger"

Overheard @ ICRC 2025

paraphrased and shared with permission.

The Astroparticle Physics Conference
Geneva July 15-24, 2025

"The current satellites are not optimal for the galactic CCSN detection; it would be **incredibly powerful** to have an instrument that goes **below 100 MeV.** That would allow us not to only to go to the higher axion masses, but also potentially reach the axion DM line."

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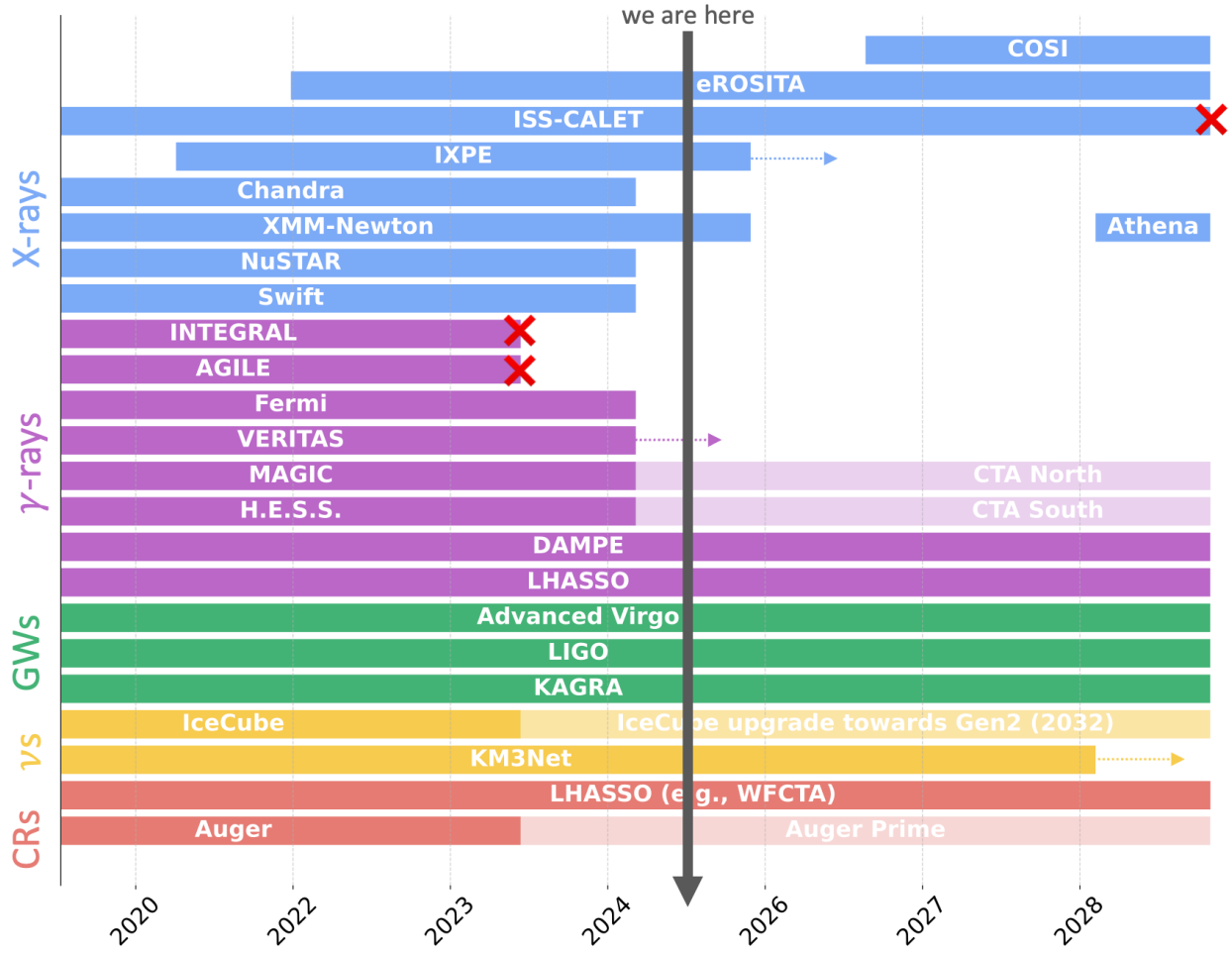

Wolfgang Amadeus Mozart, oil on canvas by Barbara Krafft, 1819.

Credit: ©Tristram Kenton

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