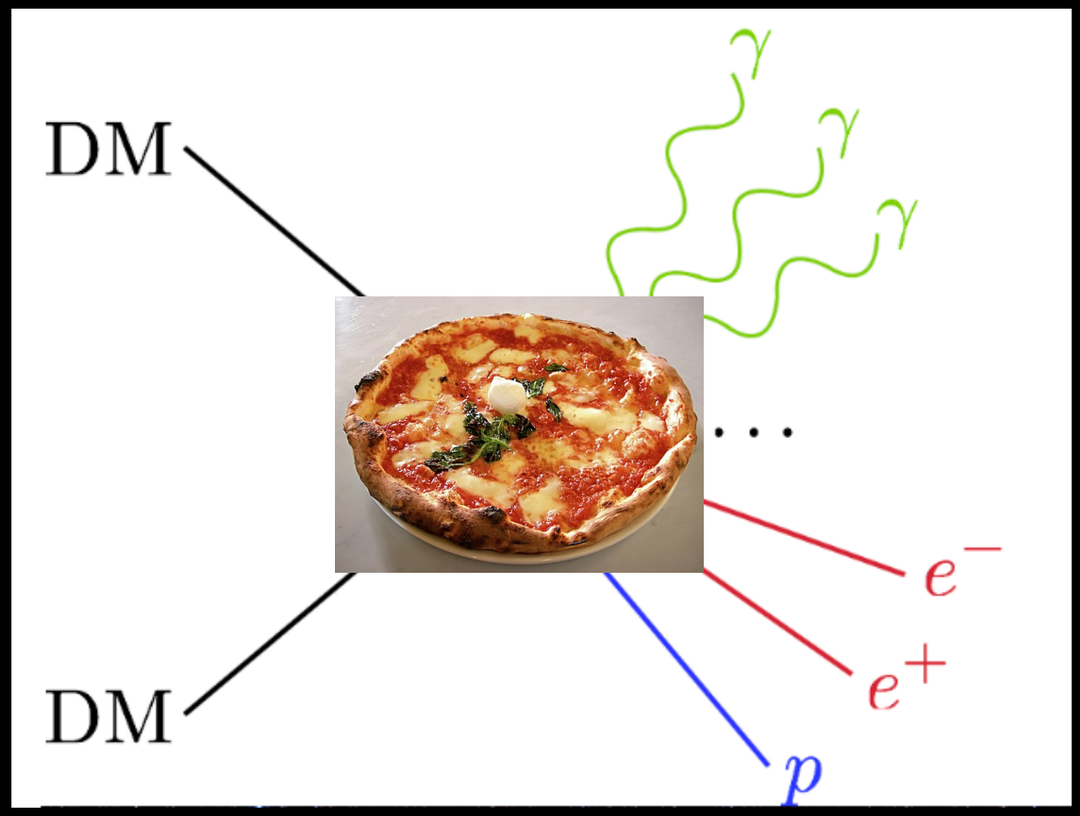
Dark Matter indirect detection news and reviews

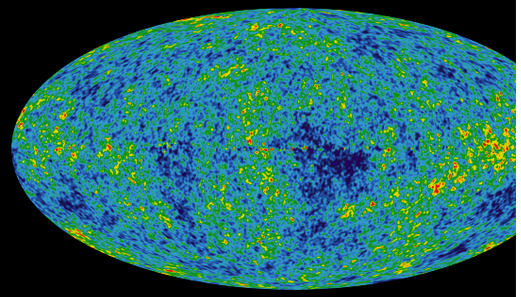


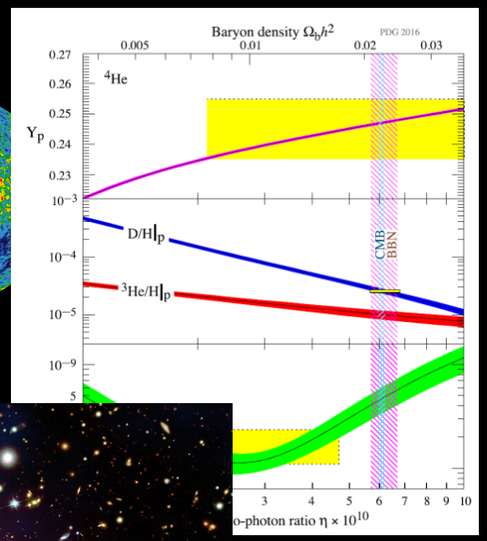
Orignal figure by N. Rodd

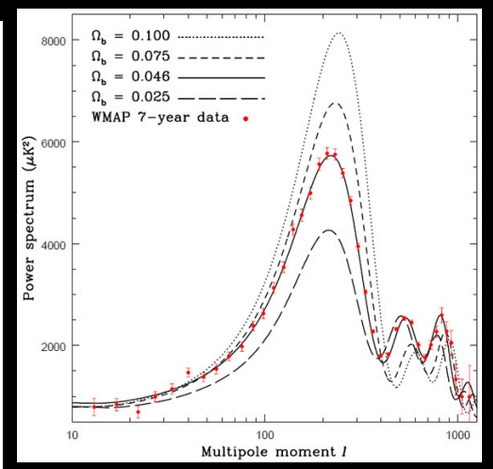
Kenny CY Ng (吴震宇)
The Chinese University of Hong Kong

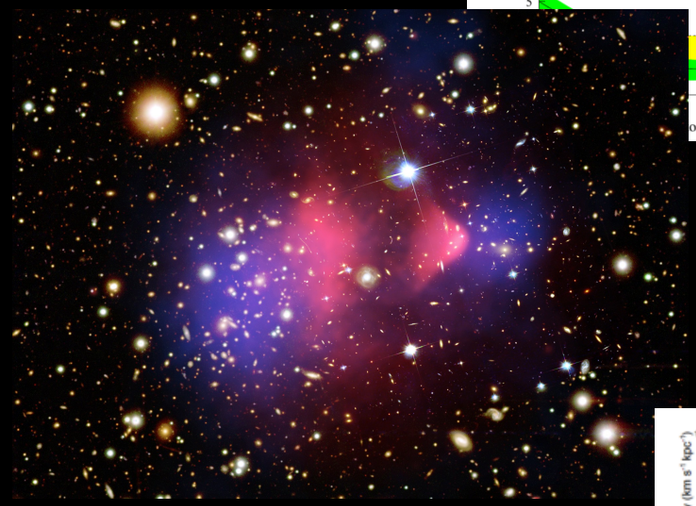
Dark Matter Evidence

- Big Bang Nucleosynthesis/ Cosmic microwave background



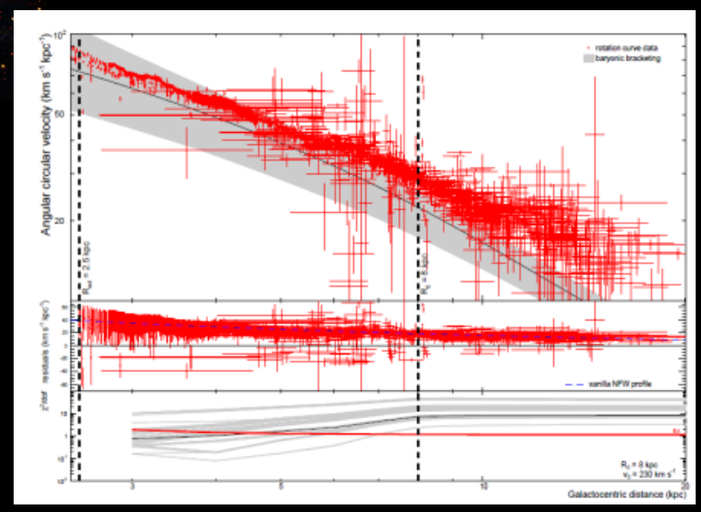


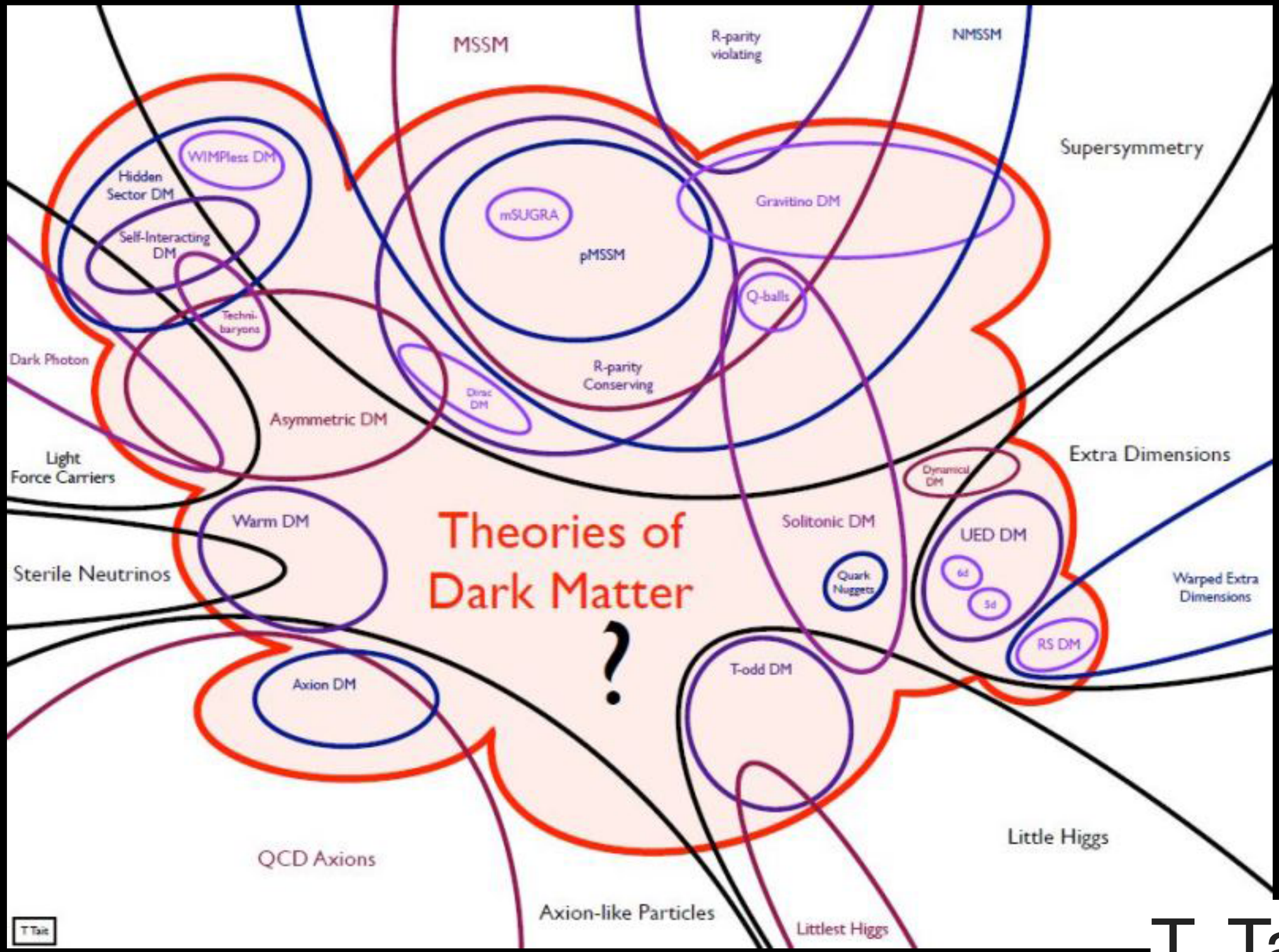




- Galaxy Clusters

- Galaxies/ local dynamics

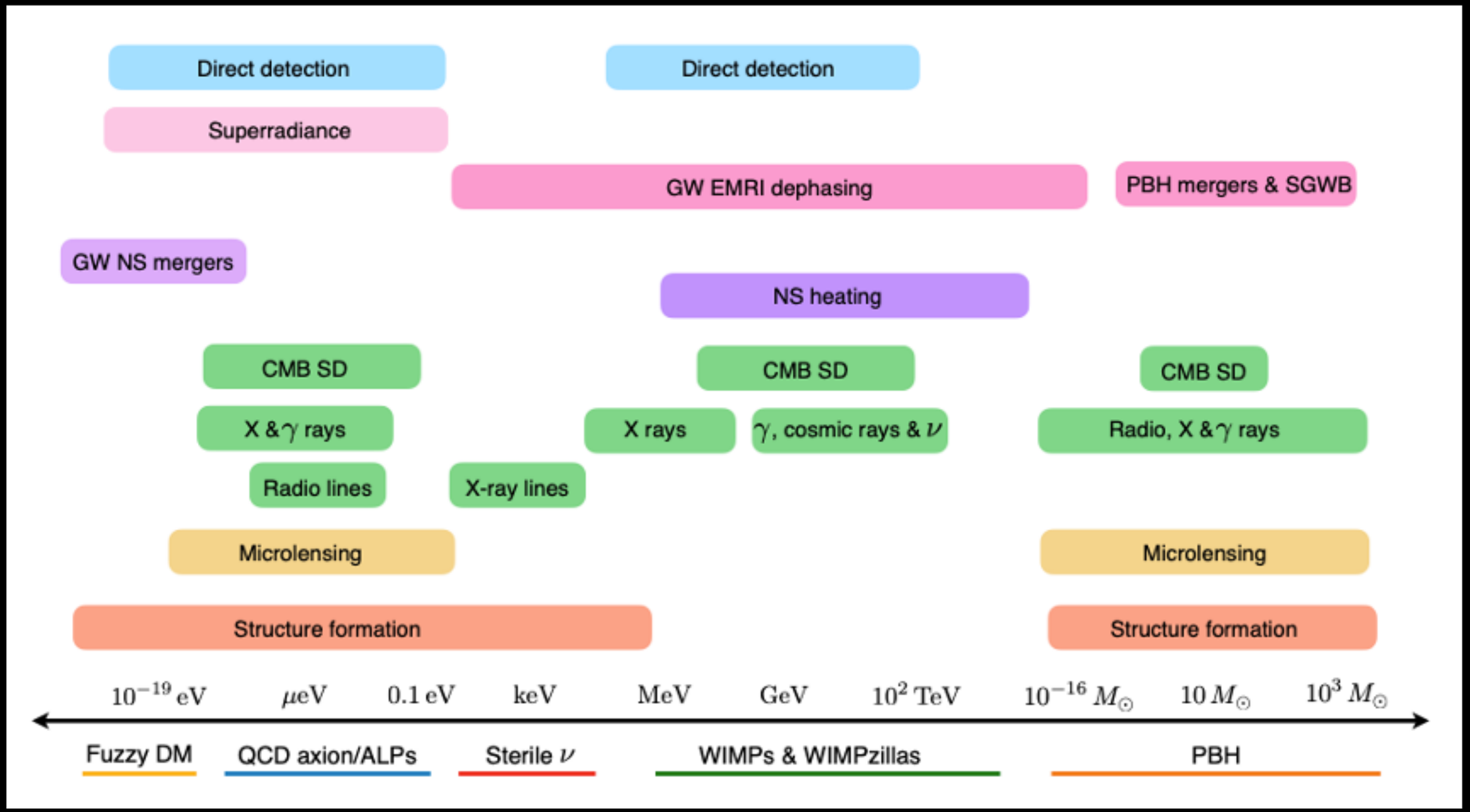




T. Tait

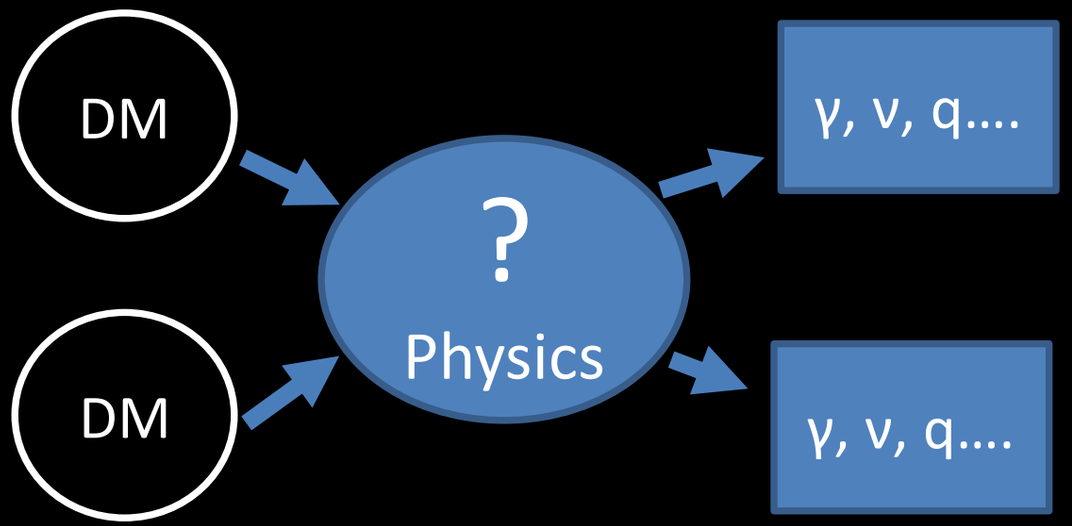
So many DM candidates!

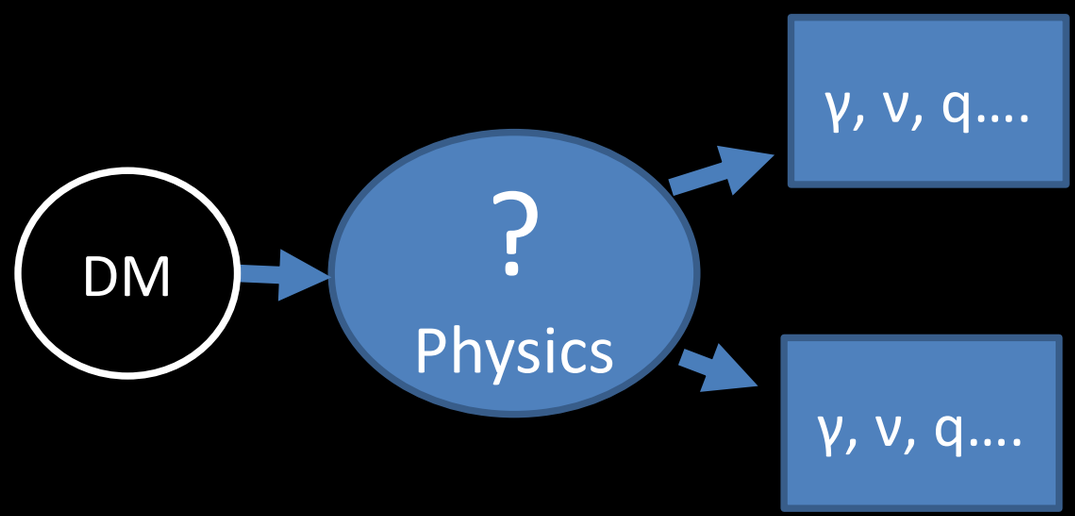
Dark Matter identification



- EuCAPT White Paper, arxiv: 2110.10074
- One must try everything

Dark Matter Indirect Detection





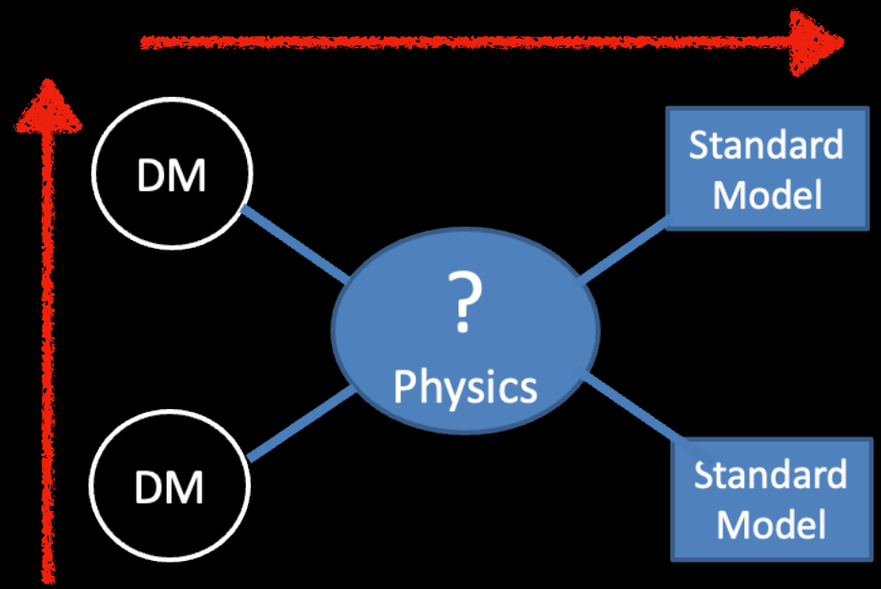
$$\frac{dF}{dEd\Omega} = \frac{\langle\sigma v\rangle}{8\pi m_\chi^2}\frac{dN}{dE}\int \rho^2 d\ell$$

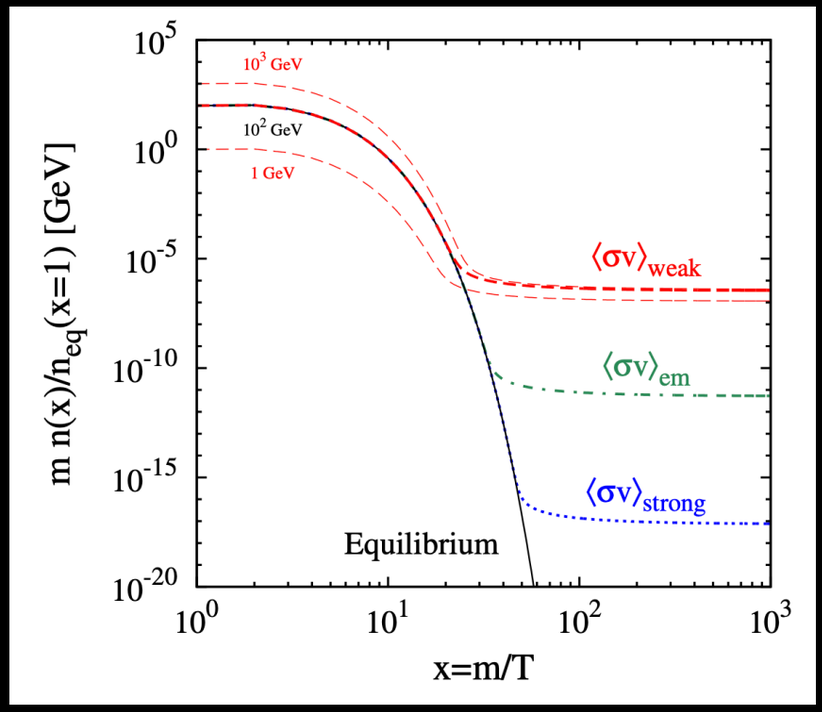
$$\frac{dF}{dEd\Omega} = \frac{\Gamma}{4\pi m_\chi}\frac{dN}{dE}\int \rho d\ell$$

+ Propagation if the final products are charged

Weakly interacting massive particles (WIMPs)

- production by
  - SM + SM -> X + X in the early universe
- Direct Detection
  - X+ SM -> SM + X
  - Recoiled nuclei or electrons
- Sets a definite prediction for annihilation cross section
  - X + X -> SM + SM
  - ~ $10^{-26}\ \mathrm{cm}^3\mathrm{s}^{-1}$ (the simplest case)

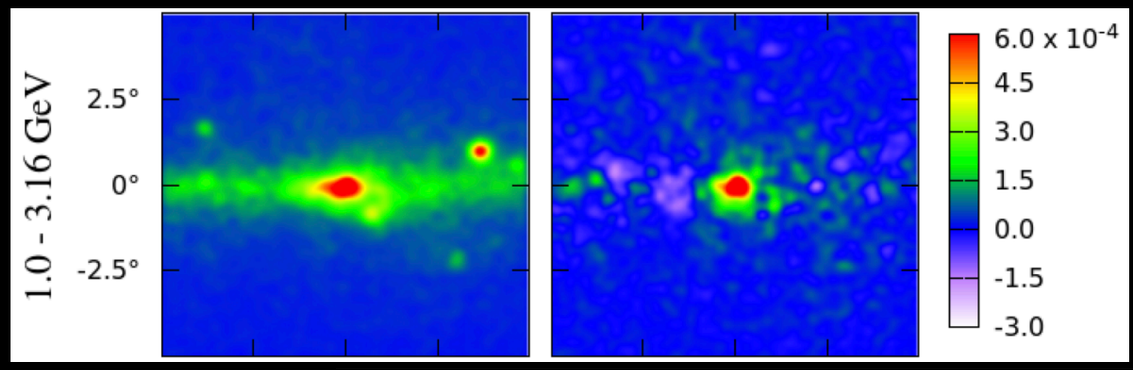




Steigmann et al 2012

Galactic Center Excess

- Excess component towards GC after subtracting the galactic diffuse background
  - Goodenough, Hooper 2009
  - Hooper, Goodenough, 2010
  - Hooper, Linden, 2011
  - +++++



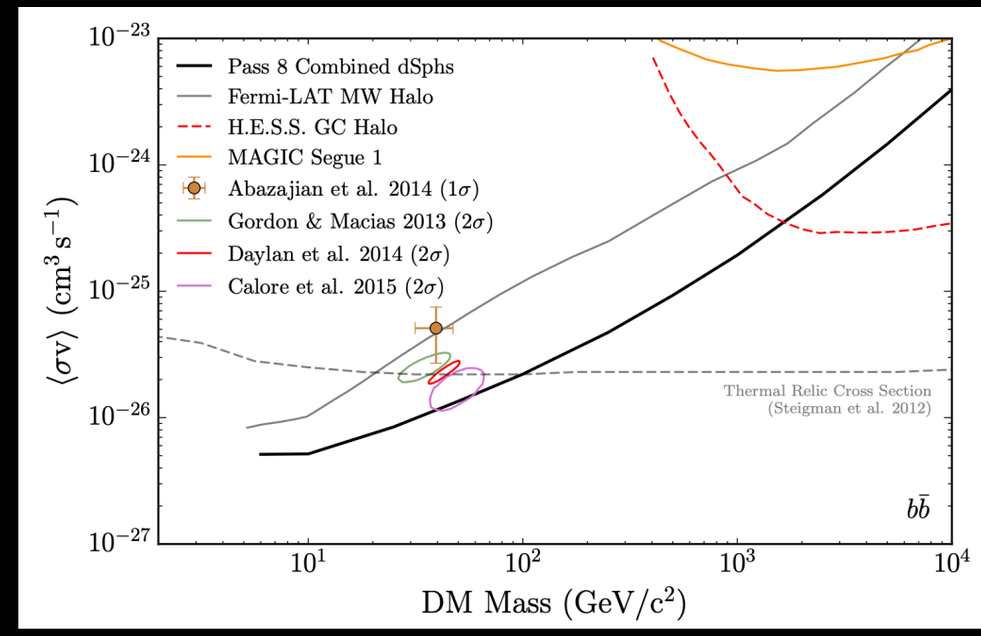
Daylan et al 2016

- WIMP DM around 40 GeV?

Calore et al 2015

- Point sources vs Smooth DM component?
- e.g, Leane, Slatyer 2020

See talk by Hooper

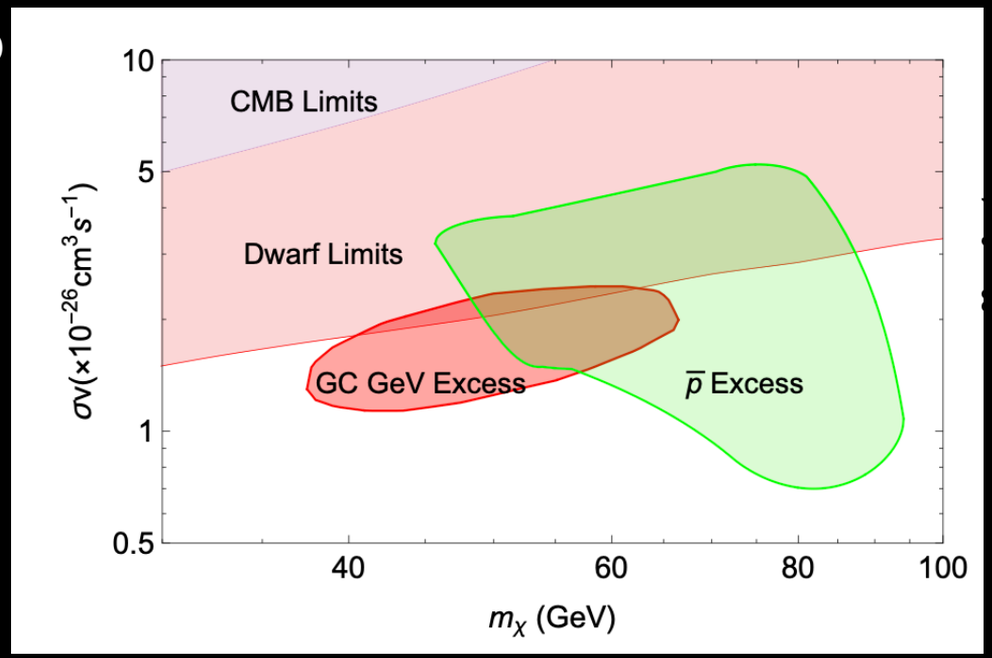


Fermi-LAT 2015

Anti-proton excess

- Anti-proton produced by DM annihilation
- e.g., Cuoco et al 2017, Cui et al 2017, Cholis et al 2019
- Consistent with GCE?

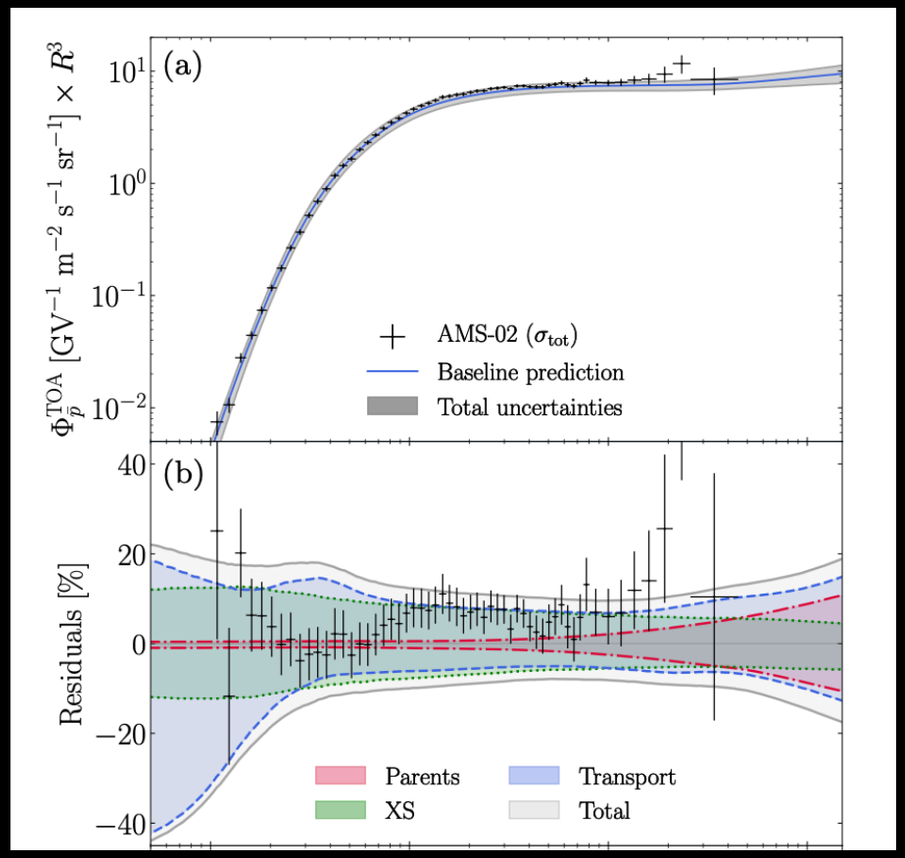
Cholis et al 2019



- Systematics from CR propagation
- e.g., Boudaud et al 2020, Heisig et al 2020, Calore et al 2022, Lv et al 2023

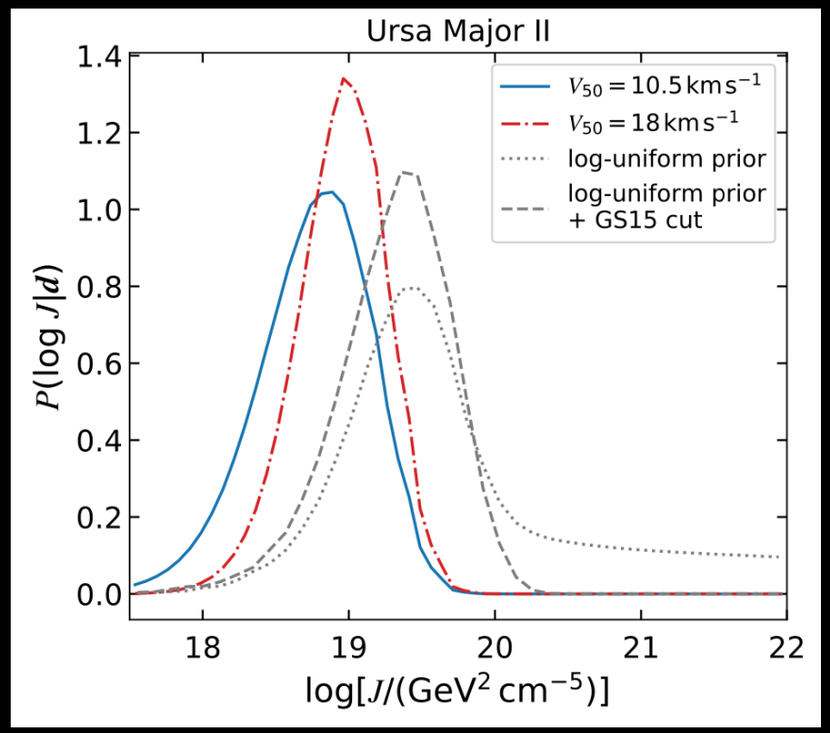
talk by Genolini

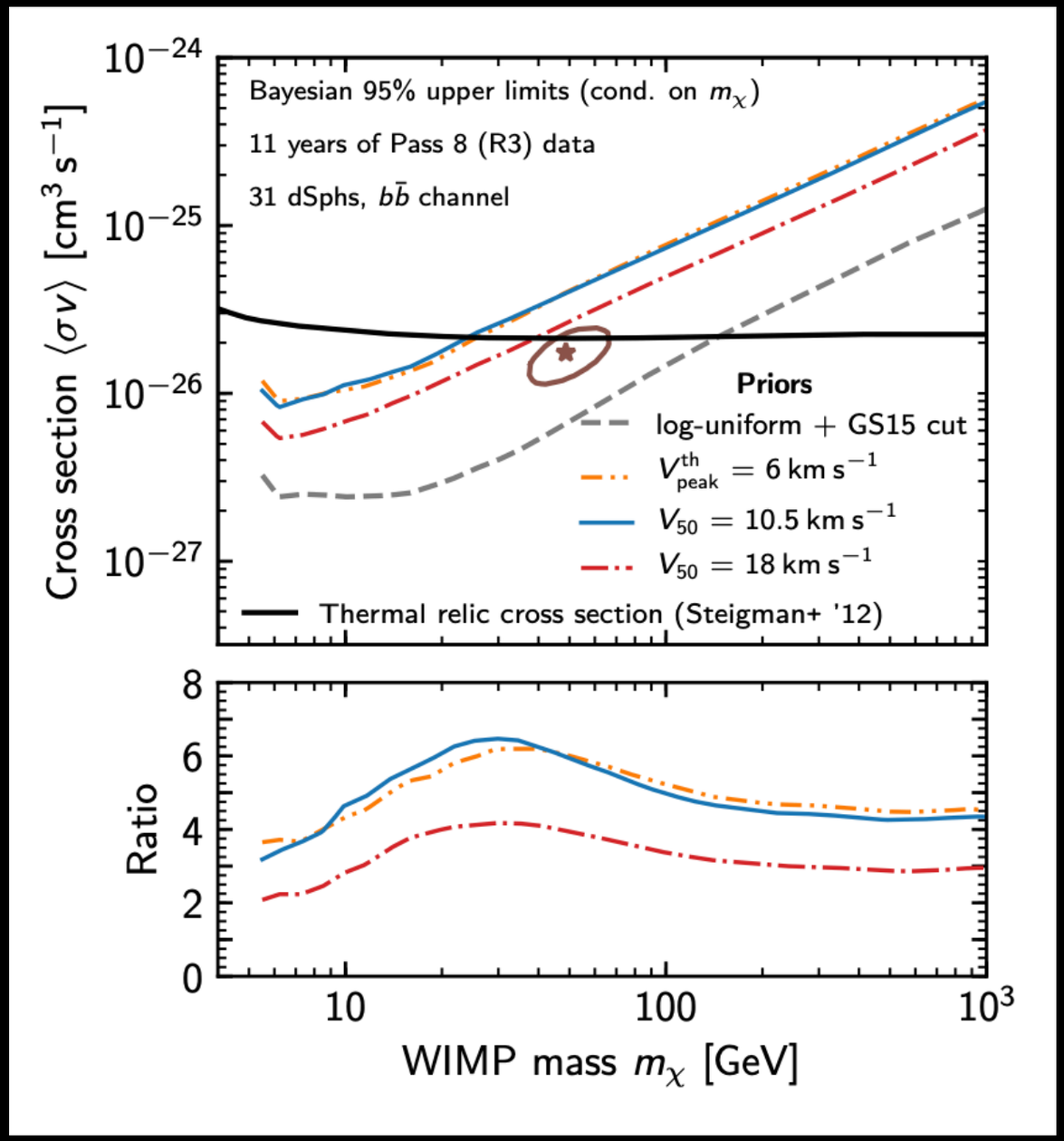
Boudaud et al 2020



Dwarf Limits

- Dwarf Spheroidals (dSphs)
- Dark matter dominated objects
  - Supposedly clean of astrophysical backgrounds
- J-factor from stellar kinematics (if available)
- Including structure formation physics for ultra-faint dSphs





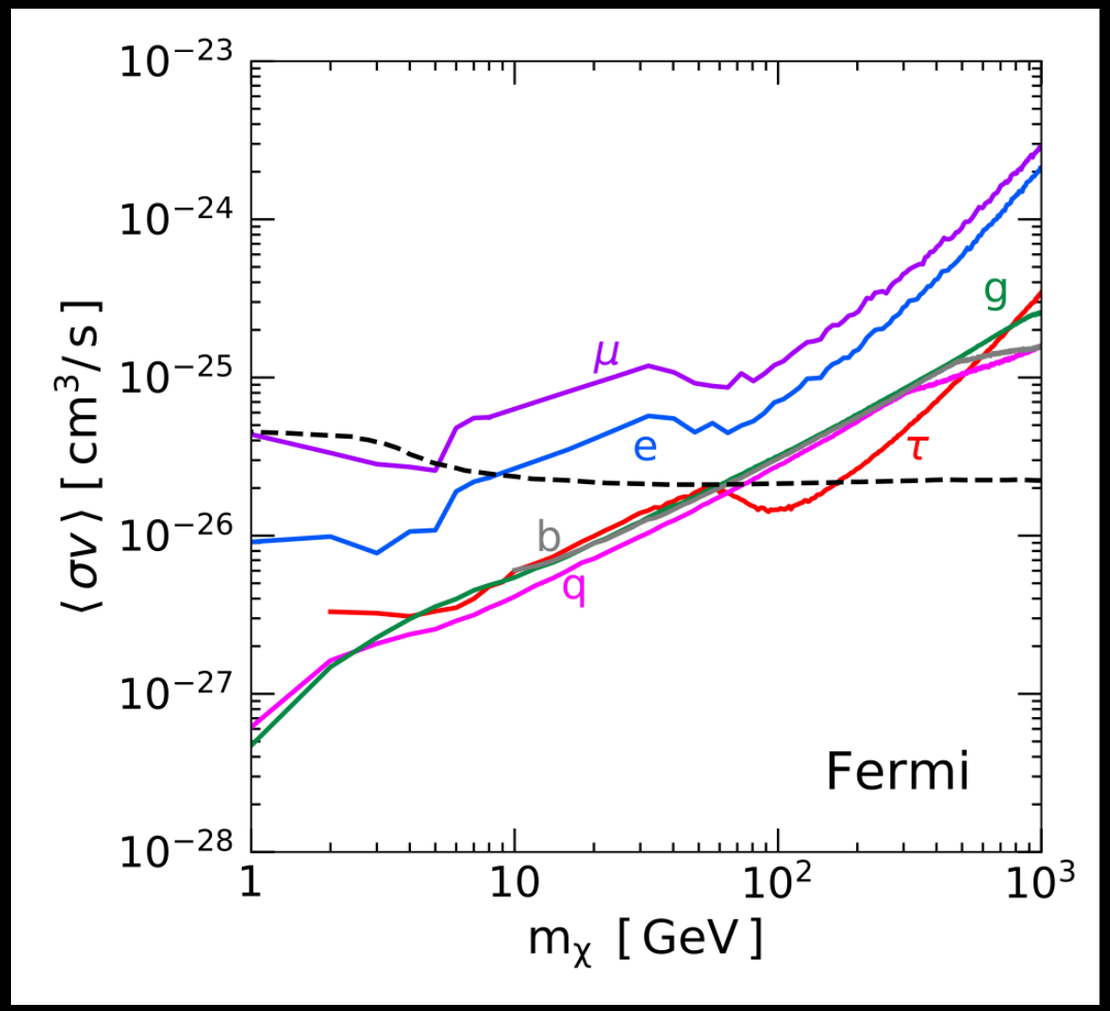
Ando et al 2002.11956

Talks by Morselli, McDaniel, Tak, Kerszberg

Constraints on total cross section

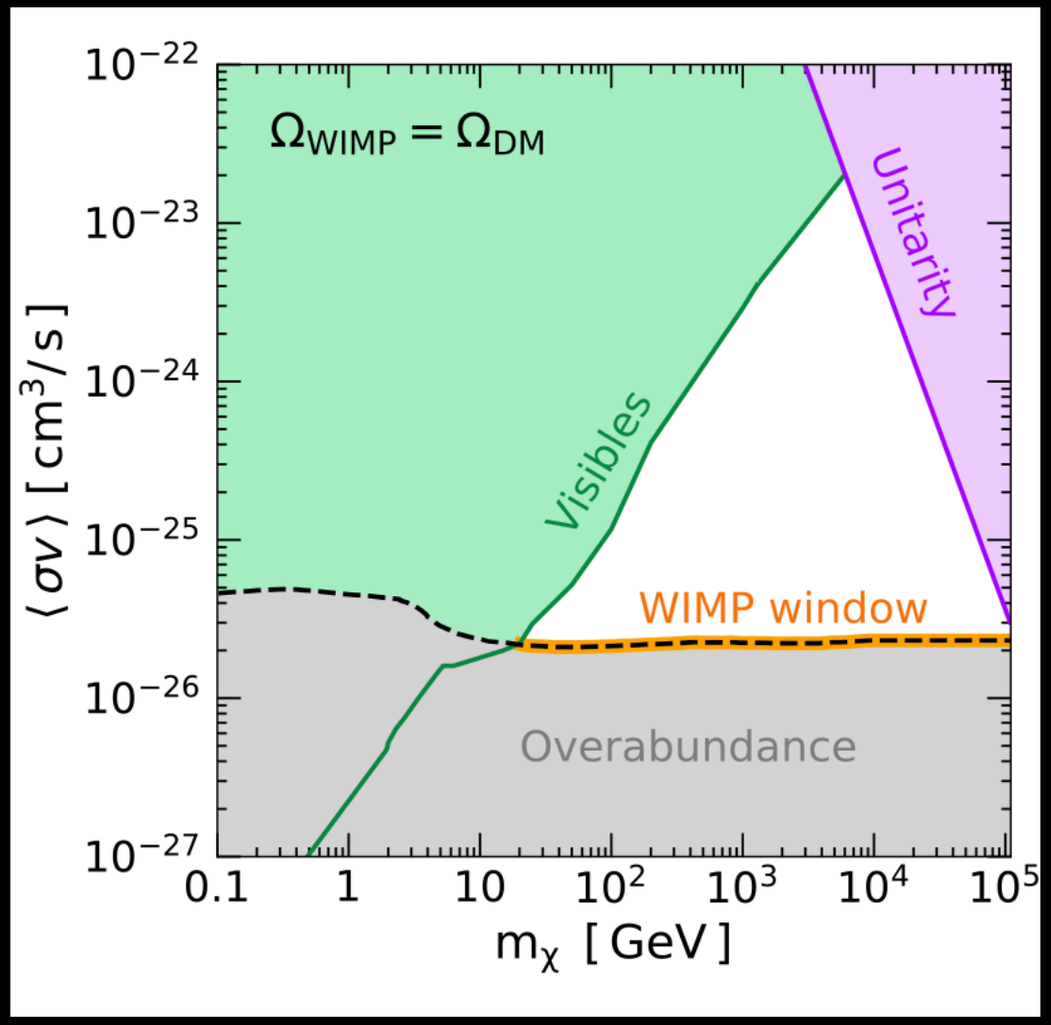
$$\frac{dF}{dEd\Omega} = \frac{\langle\sigma v\rangle}{8\pi m_\chi^2}\sum_i Br_i \frac{dN_i}{dE}\int \rho^2 d\ell$$

- ~ $10^{-26}\,\mathrm{cm^3 s^{-1}}$ is the ***Total Xsec***



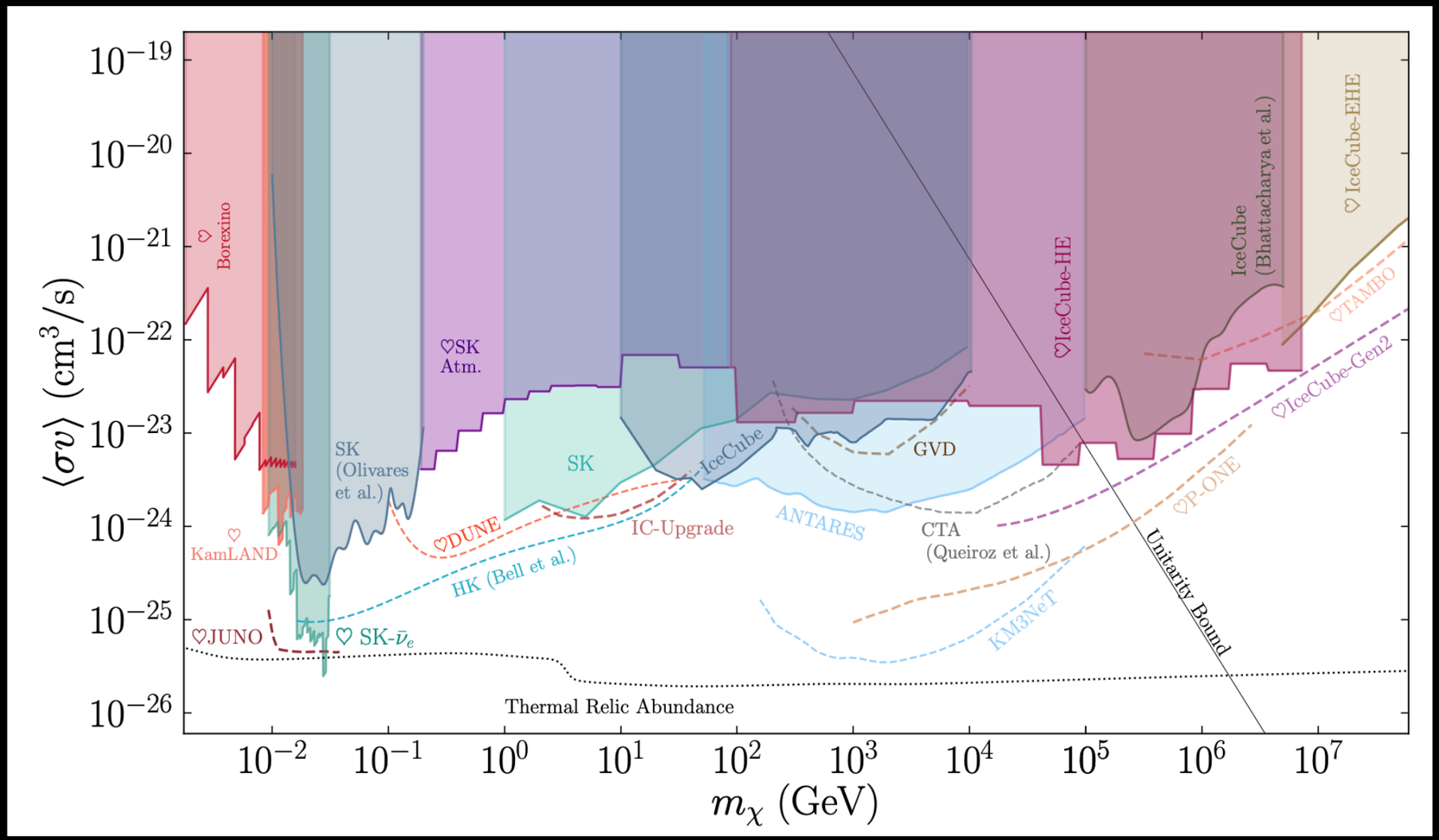
1805.10305
Leane, Slatyer, Beacom, KCYN

Planck + Fermi + AMS
Least constraining combination



Neutrinos not included!

Neutrino limits



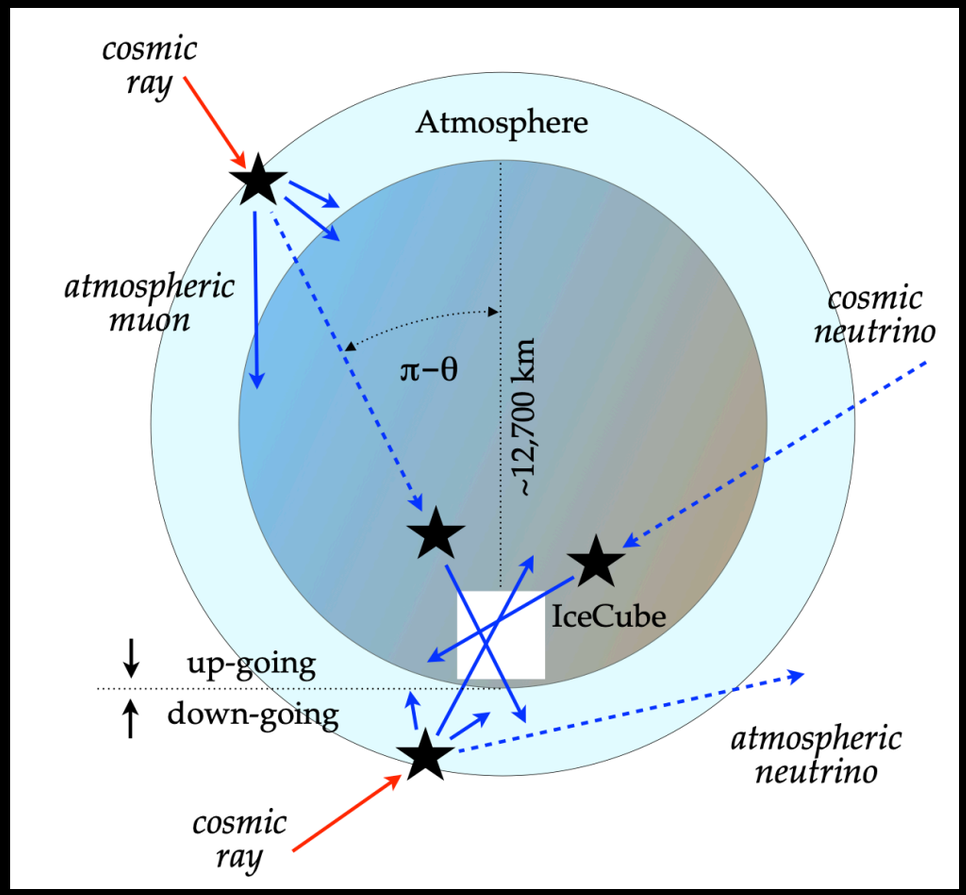
Arguelles et al
1912.09486

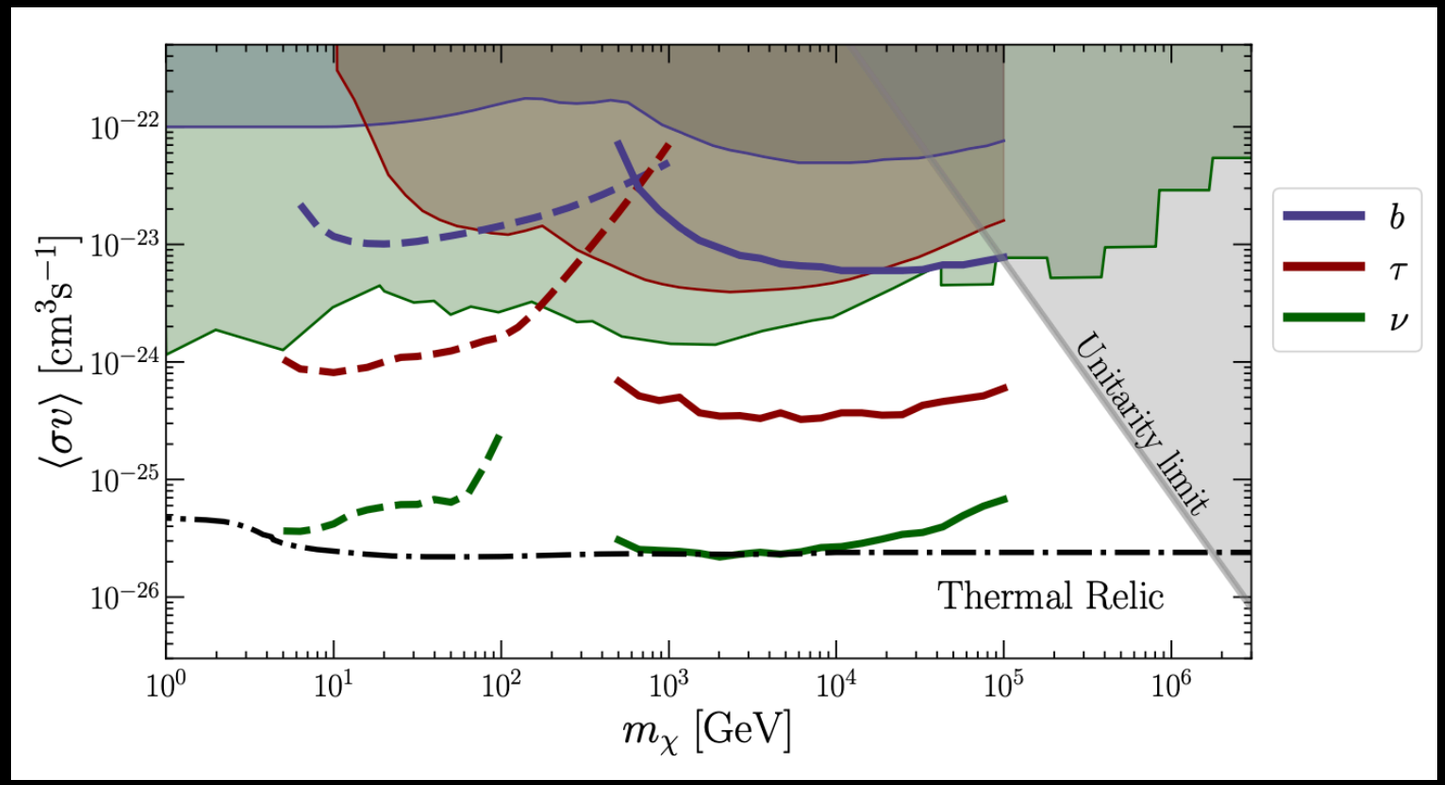
Neutrinos are the least constraining!
But perhaps the most important for testing WIMP hypothesis

KM3NeT

- Next-general neutrino telescope in the Northern hemisphere

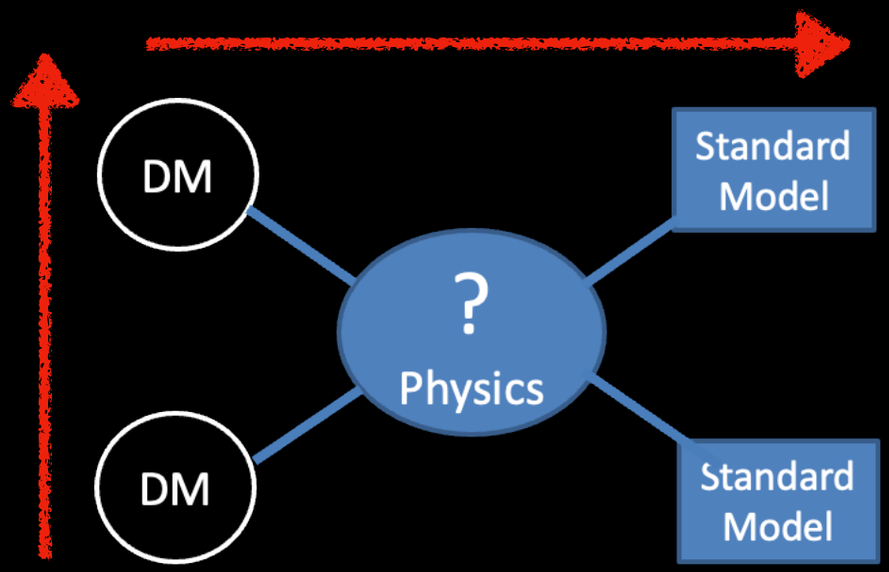
- Can see the **Southern** Neutrino sky!
- Good angular resolution
- Water medium



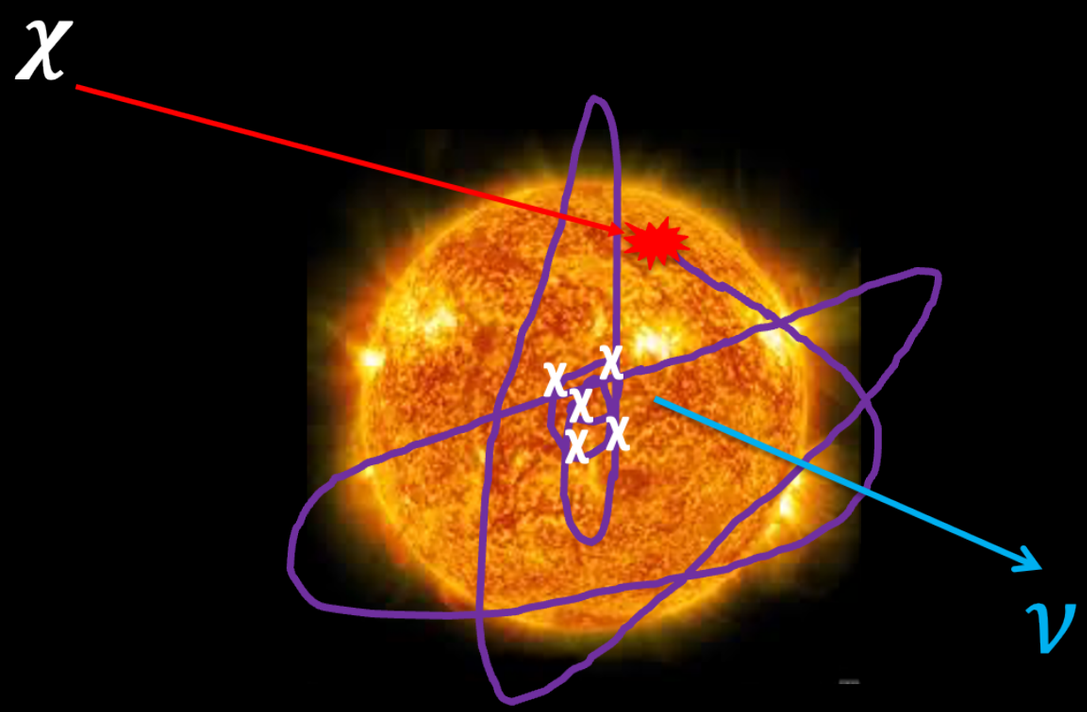


Salvador Miranda et al (+KCYN)
2211.12235

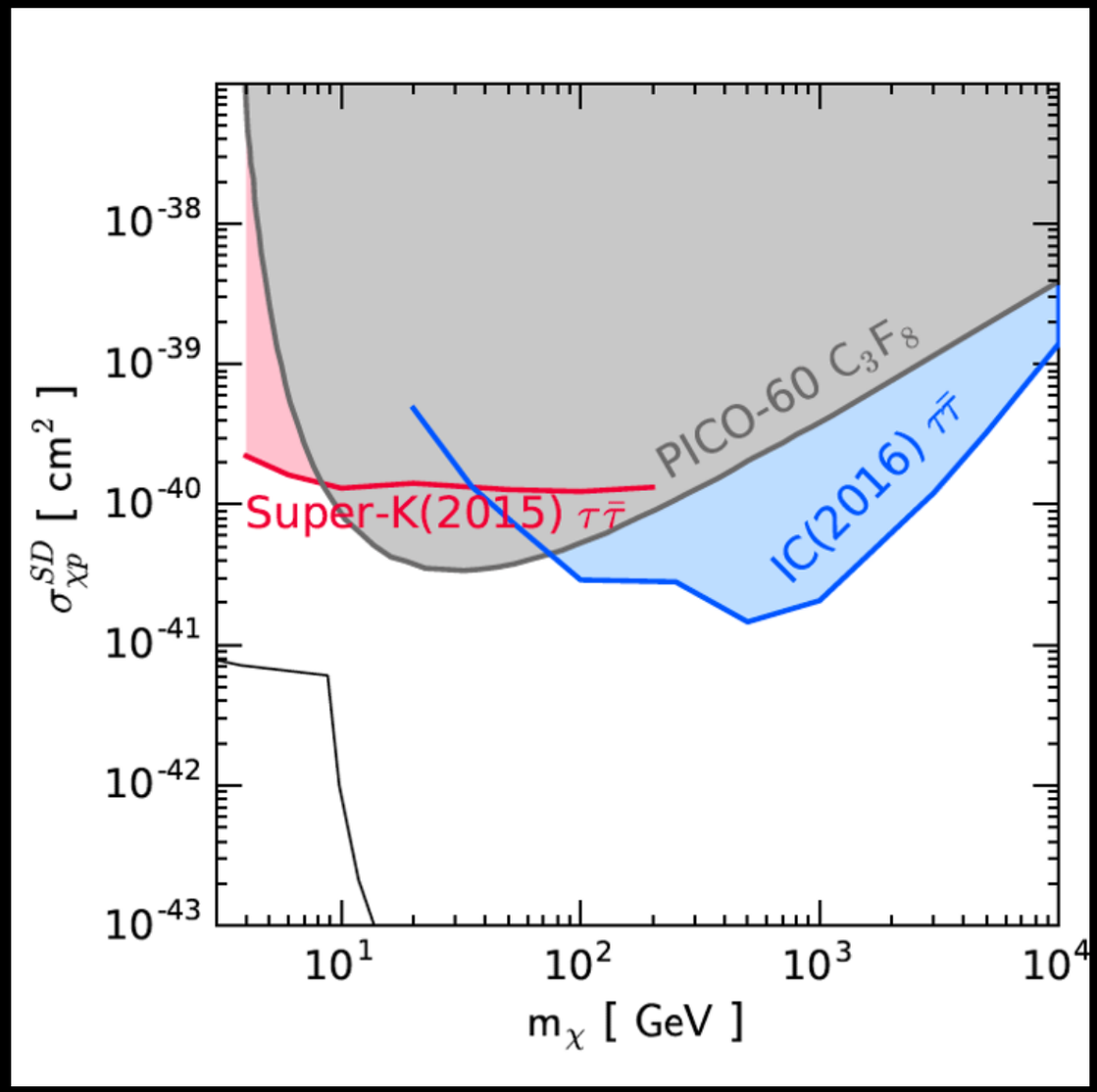
Solar WIMP Search



- Competitive with Direct Detection experiments.



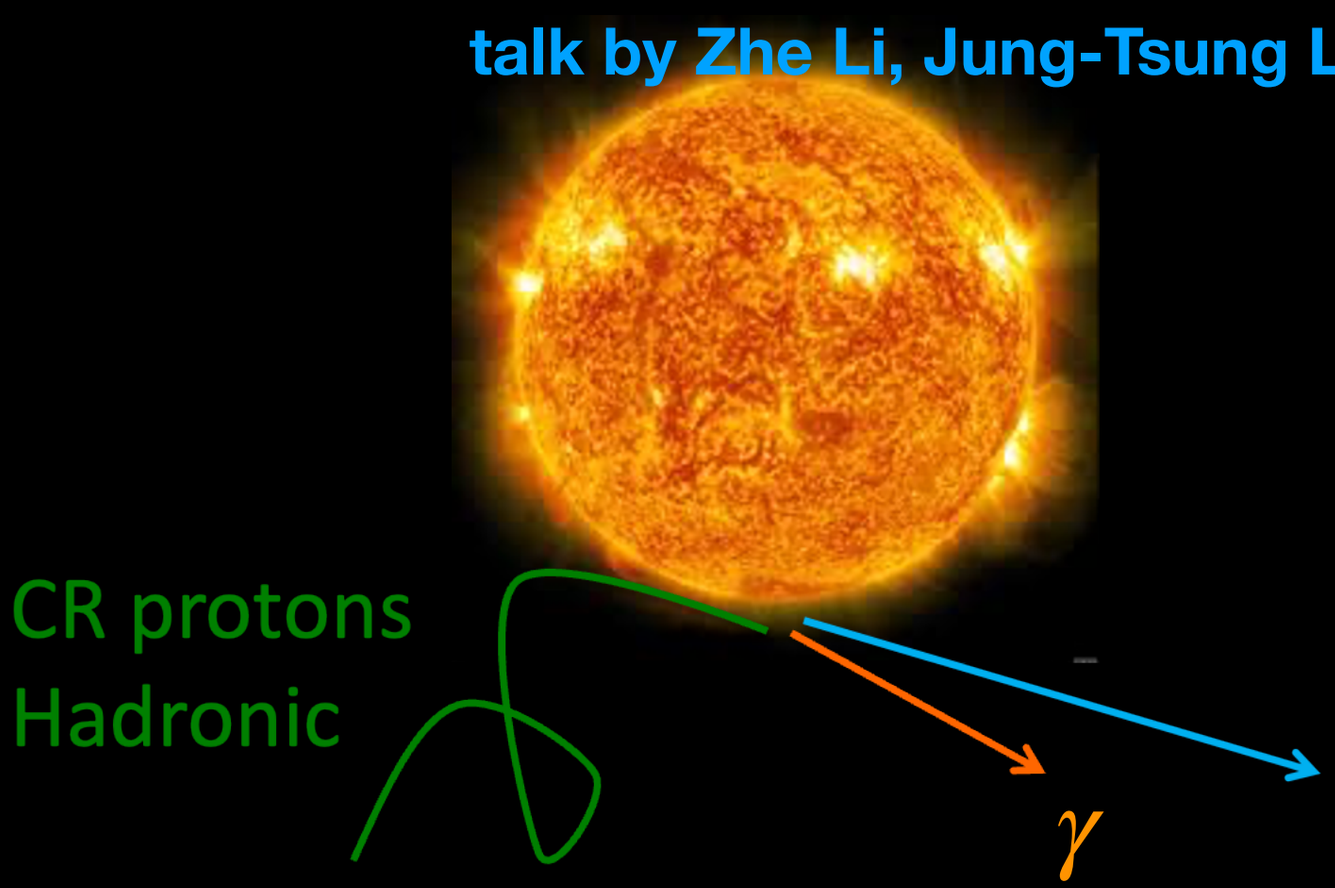
Press, Spergel (1985)
Krauss, Freese, Press, Spergel (1985)
Silk, Olive, Srednicki (1985)



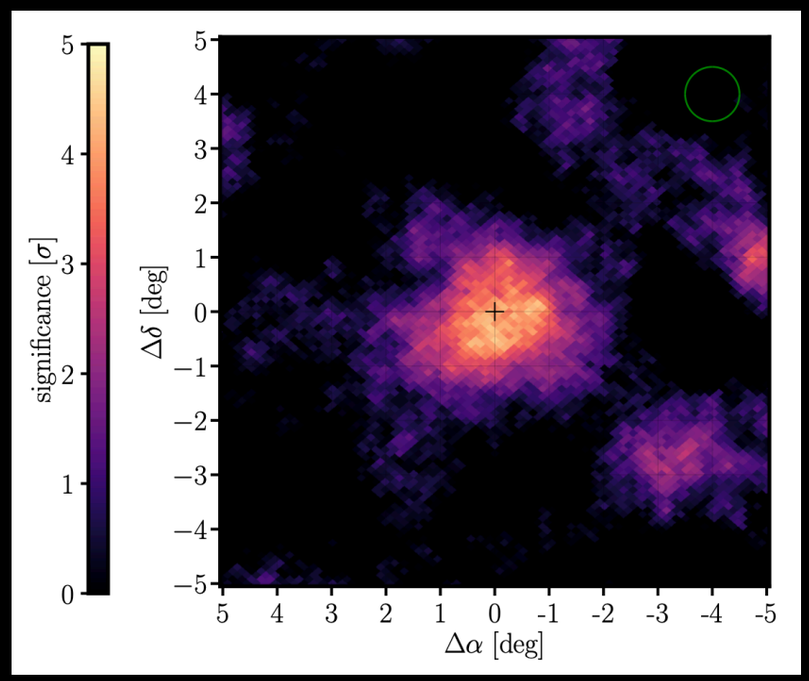
Solar WIMP background

talk by Zhe Li, Jung-Tsung Li

- IceCube could soon see Solar Atmospheric Neutrinos
- Very uncertain background due to solar magnetic fields

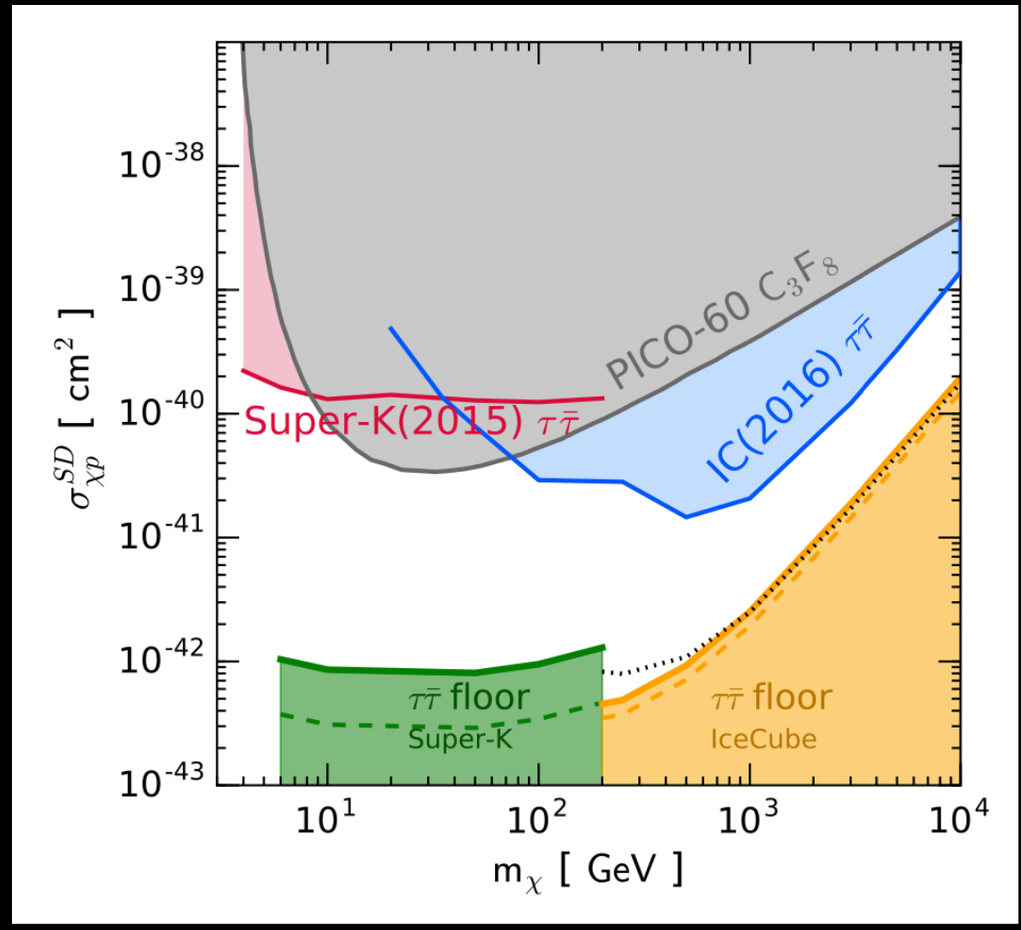


- Recent HAWC observation of TeV solar gamma rays



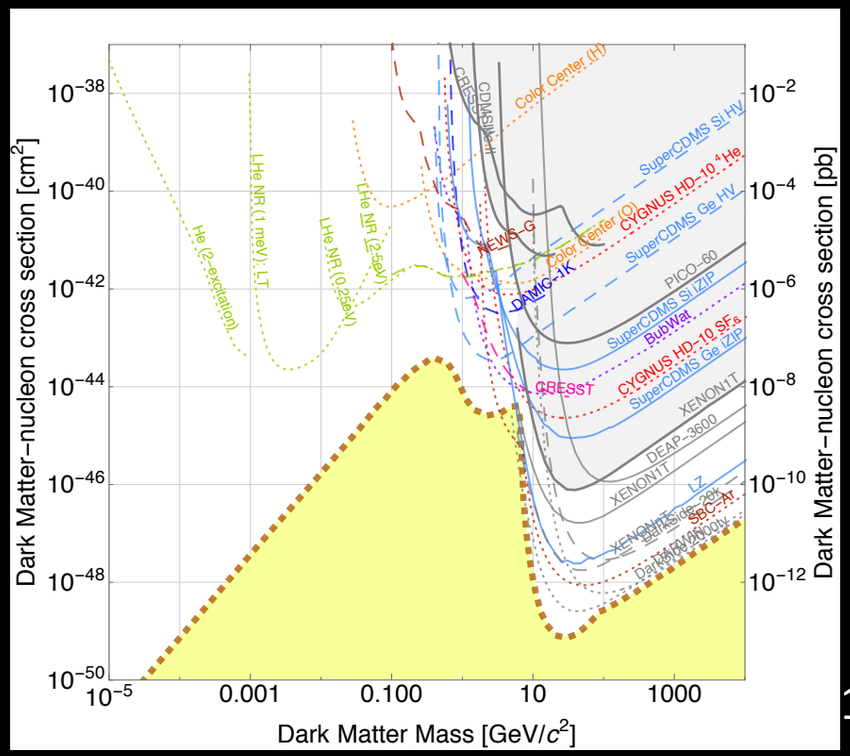
HAWC+Beacom, Linden, KCYN, Peter, Zhou 2212.00815

KCYN et al 2017, also Arguelles+ 1703.07798 Edsjo+ 1704.02892



Connection to direct detection

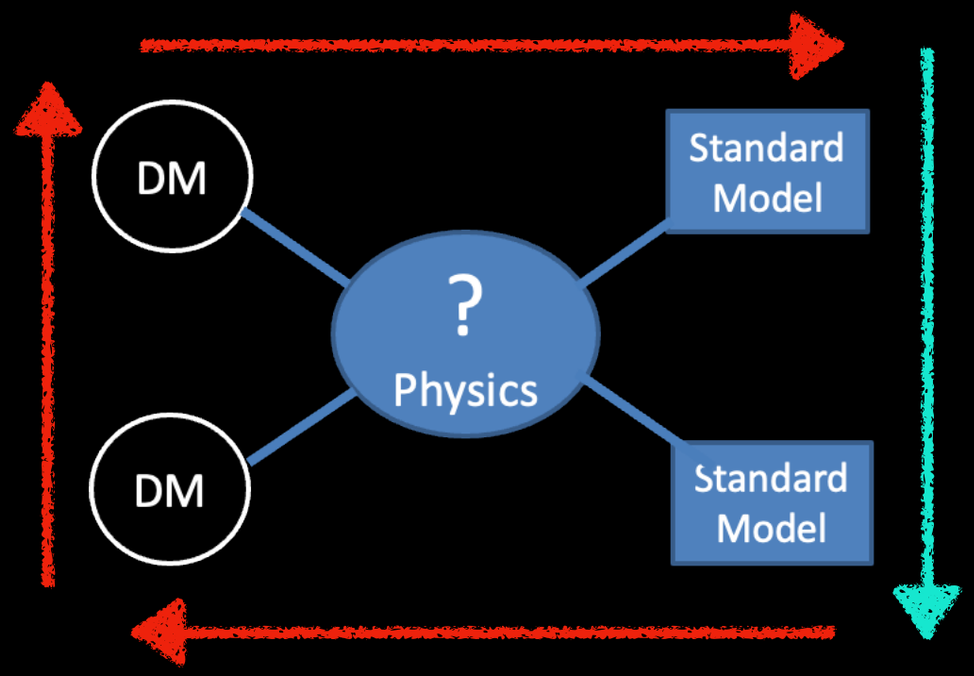
- GeV-TeV range
- Neutrino floor is closing
  - Coherent scattering of solar, atm, SN neutrinos
- New opportunities at low energies?



1707.04591

- Reverse direct detection
  - Cappiello, KCYN, Beacom 2019

- CR boosted dark matter
  - Bringmann, Pospelov 2019
  - Ema, Sato 2019



Effects of Dark Matter-nucleon scattering in astrophysics and cosmology

- Cosmic-ray Energy loss in MW
  - Cappiello, KCYN, Beacom 2019

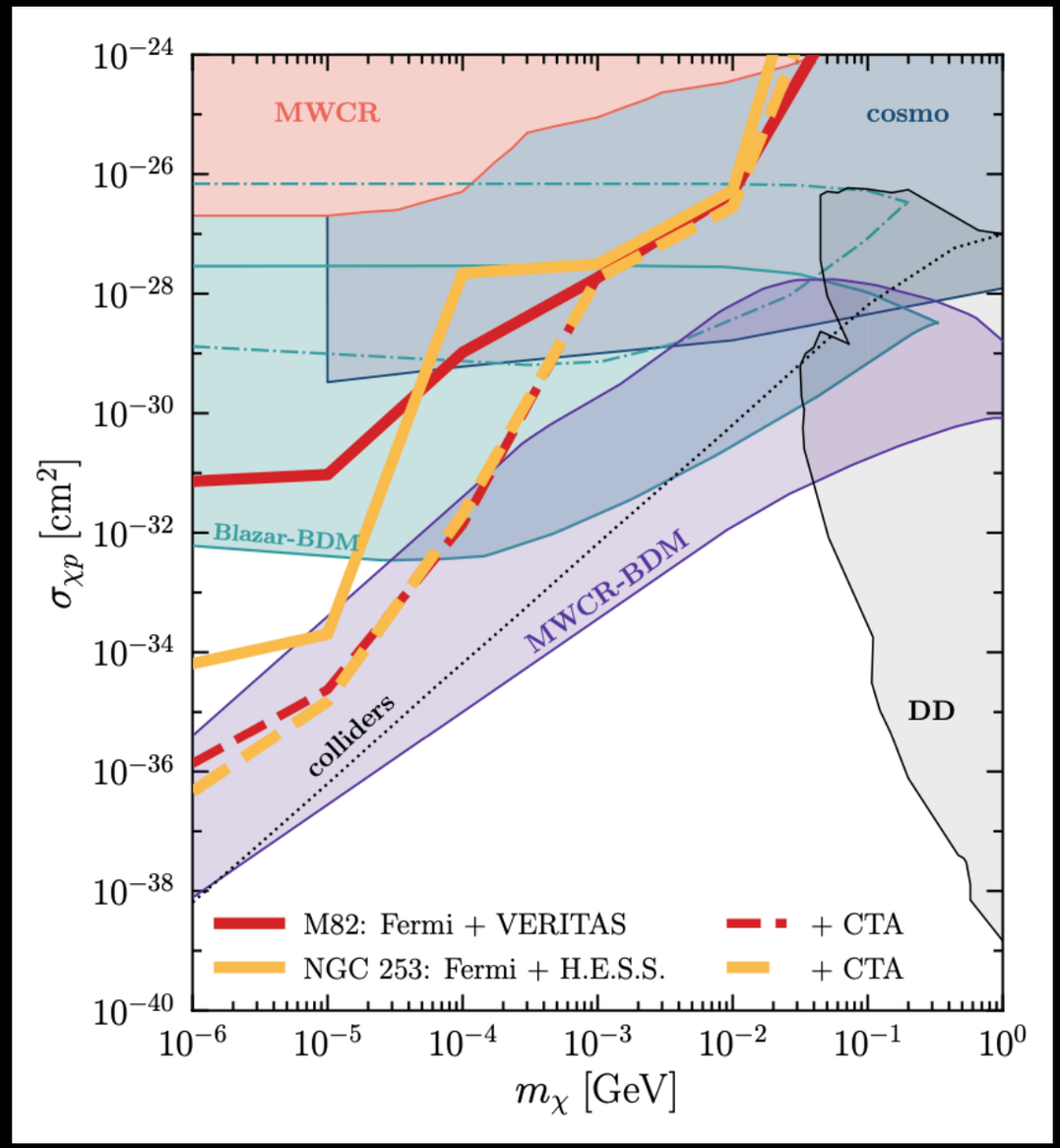
- CR energy loss in star-burst galaxies
  - Changes gamma-ray output
  - Ambrosone et al 2022

- Dark Matter boosted by CR-DM scattering
  - Can be detected by DD and ν detectors
  - Bringmann, Pospelov 2019
  - Ema, Sato 2019

- DM heating, suppressed structure formation
  - Rogers, Dvorkin, Peiris 2022

- BBN constraints relativistic light DM
  - Krnjaic, McDermott 2020

+ much more

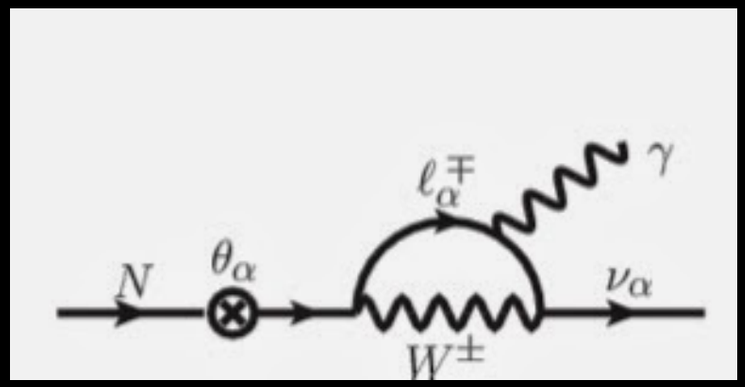


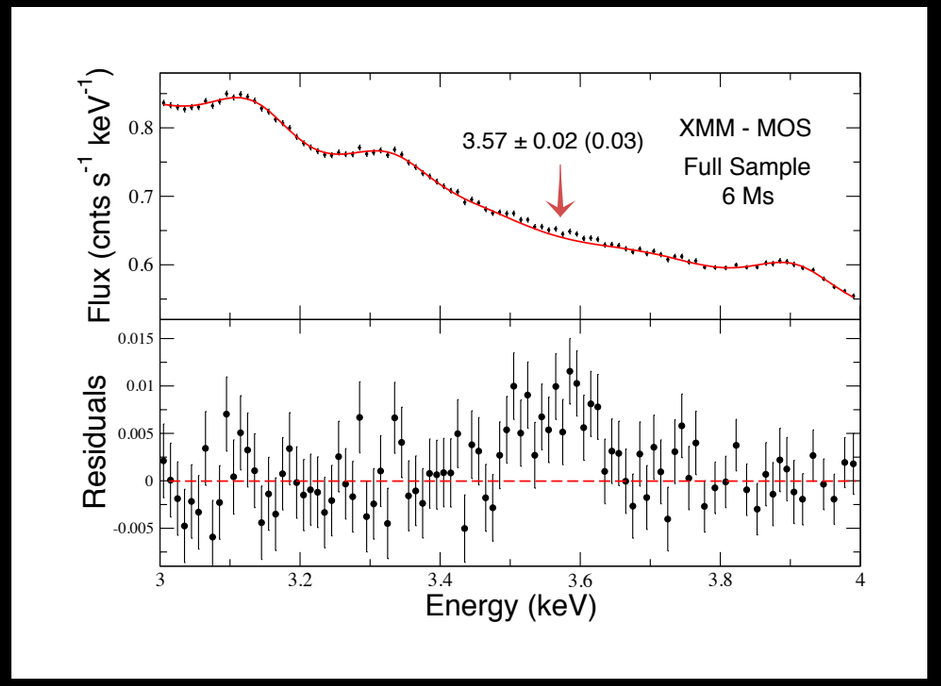
Ambrosone et al 2210.05685

See talks by
- **Ambrosone**
- **Bringmann**

3.5 keV Saga

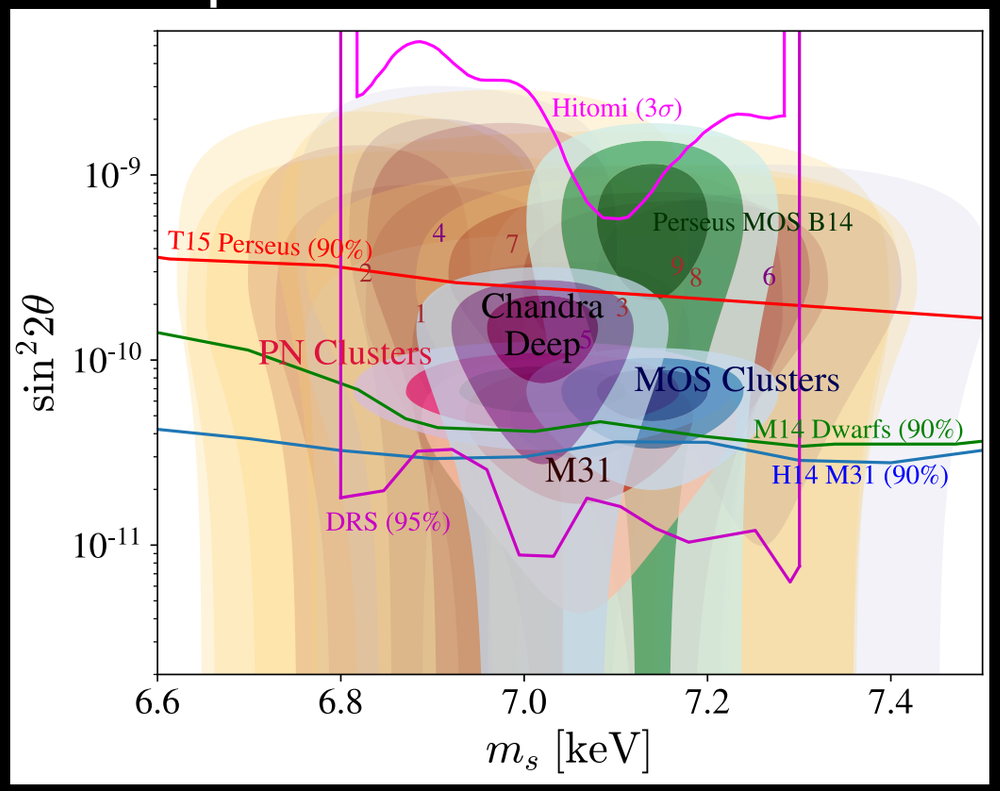
- X-ray line
  - e.g. sterile neutrinos



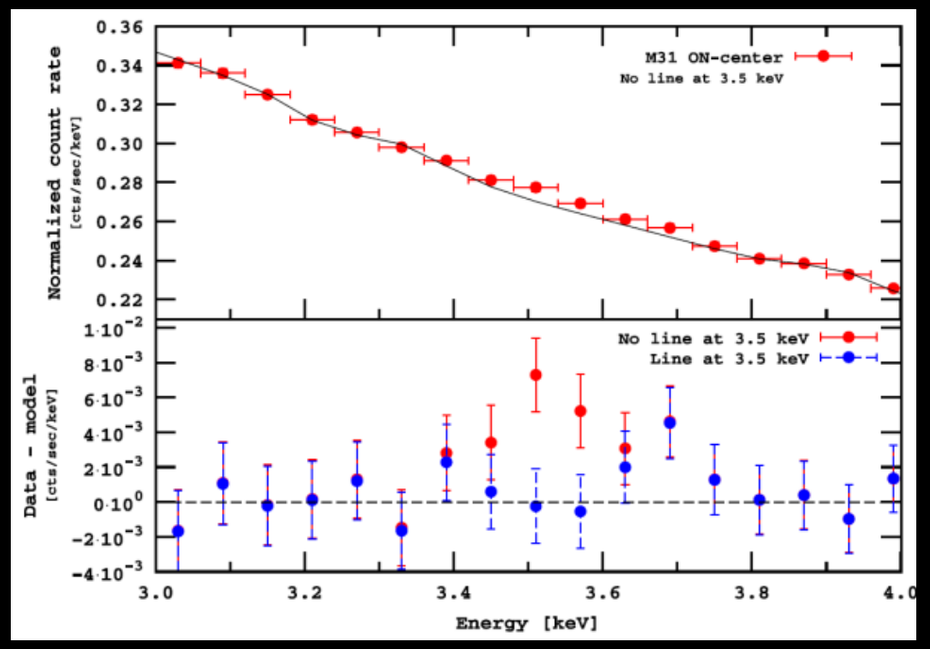


Bulbul et al. 1402.2301

- Stacked Galaxy cluster analysis
- M31 & Perseus cluster
- + follow up works



Abazajian 2020



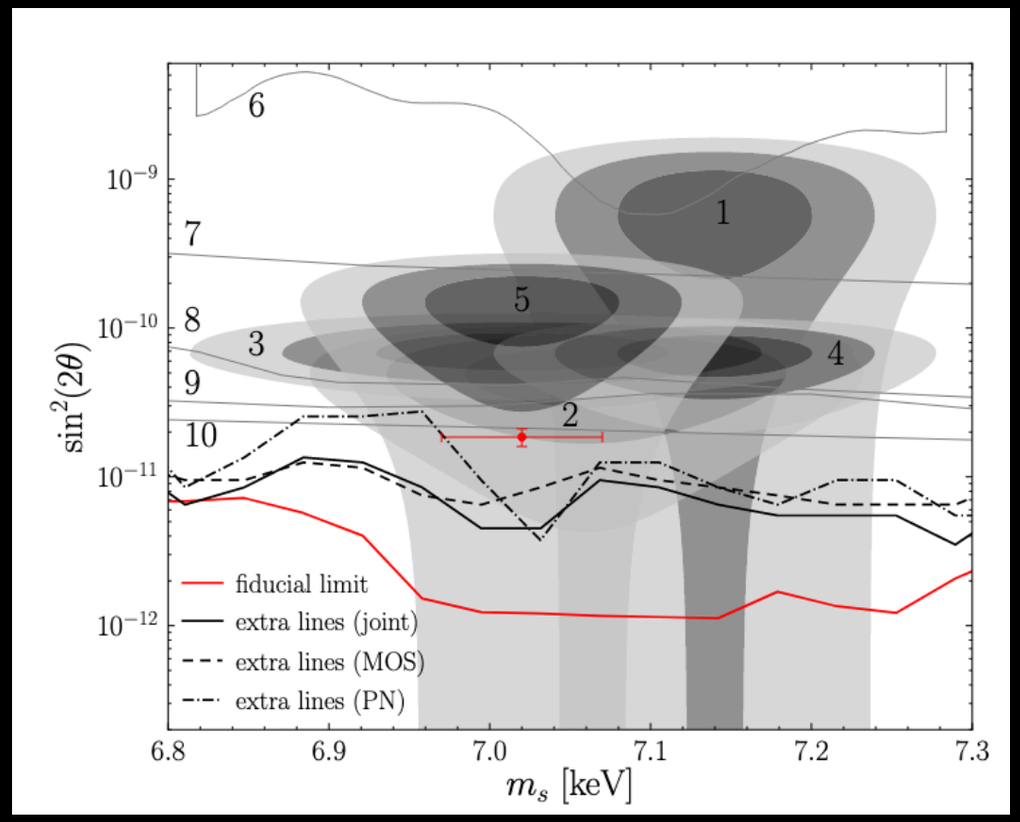
Boyarsky et al. 1402.4119

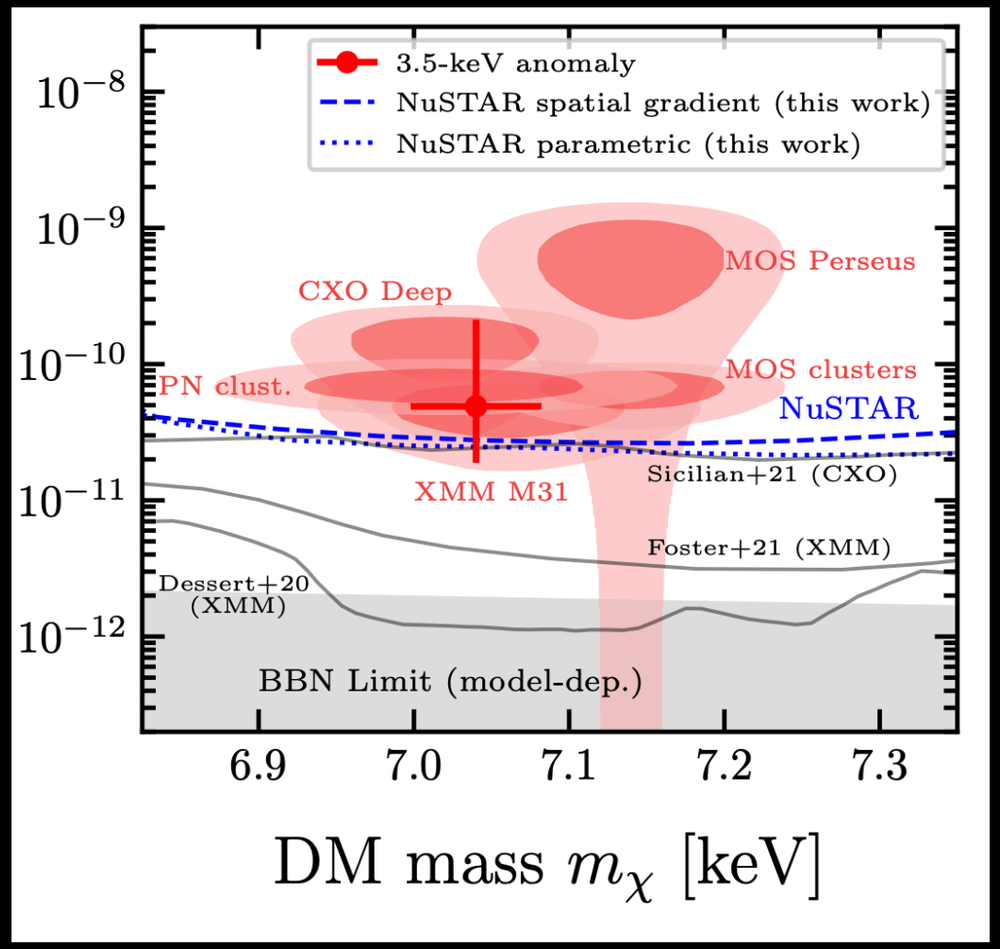
Recent news

- Dessert, Rodd, Safdi 2006.03974
- vs Abazajian 2004.06170 / Boyarsky+ 2004.06601
  - DRS-2018 energy window too small
  - Known background lines changes the results

- More non-detections
  - XMM Halo (Foster et al 2021)
  - NuSTAR Halo
    - Roach et al (+KCYN) 2022
  - Chandra Halo (Sicilian et al 2020)
  - HaloSat Halo (Silich et al 2021)
  - Swift-XRT Halo (Sicilian et al 2022)

Dessert et al 2020

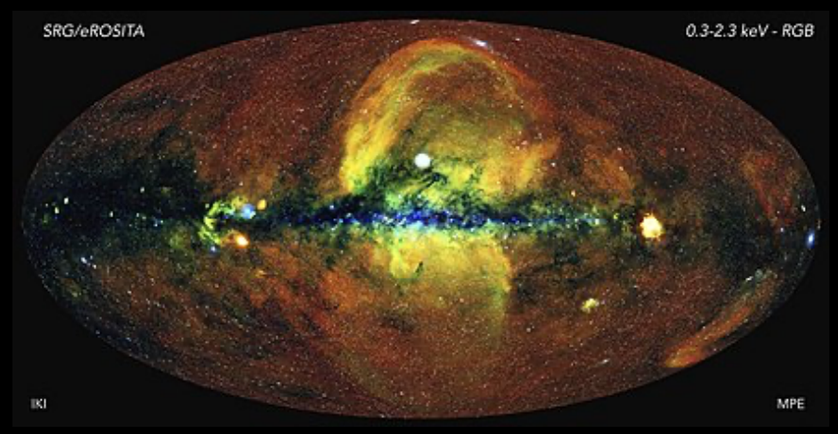




Roach et al 2022

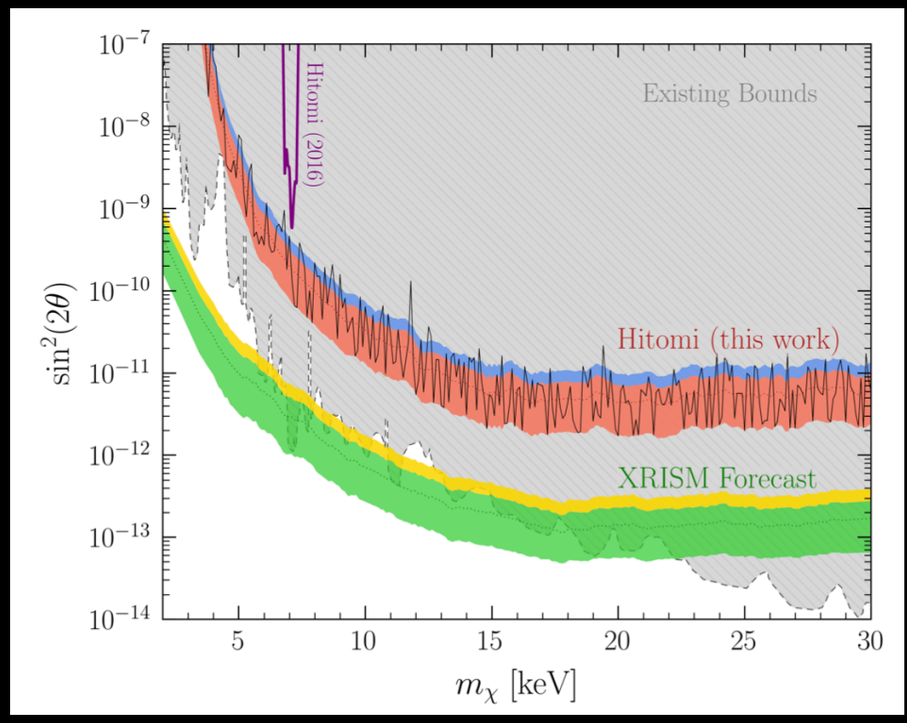
Recent news

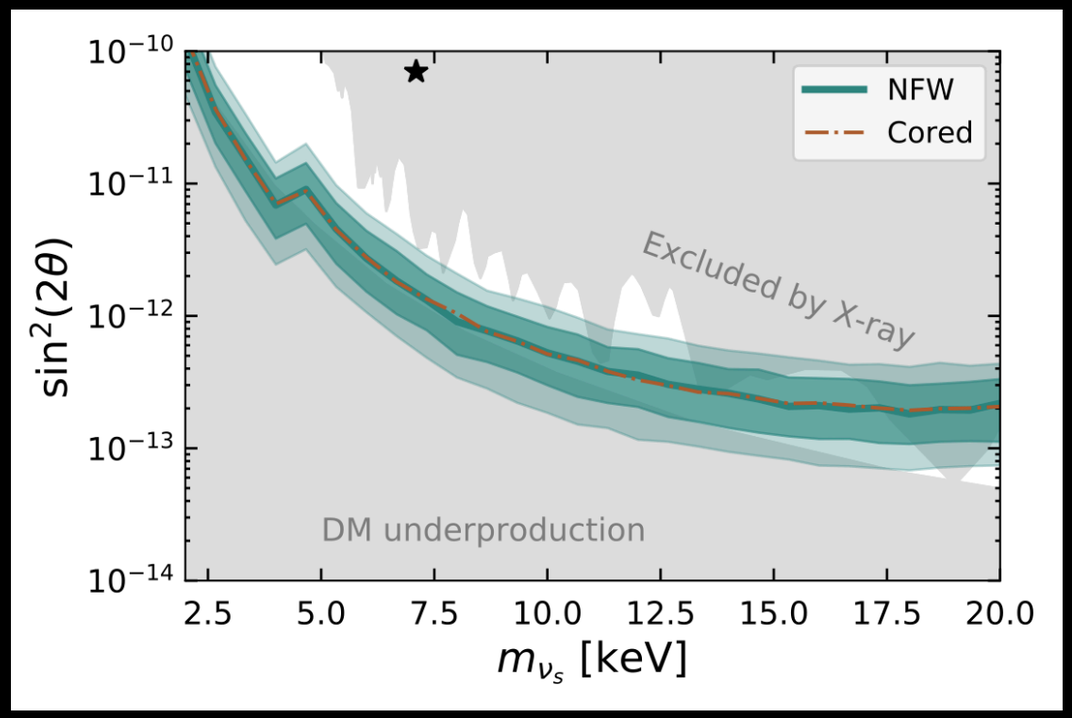
- **"Was There a 3.5 keV Line?"**
- Reanalysis of the Clusters' data
  - Dessert, Foster, Park, Safdi 2309.03254
  - Local minima? Parametric modelling vs Window analysis
- **eROSITA forecast**
- Dekker, Peerbooms, Zimmer, KCYN, Ando 2103.13241



Also Malyshev et al 2020 for eXTP

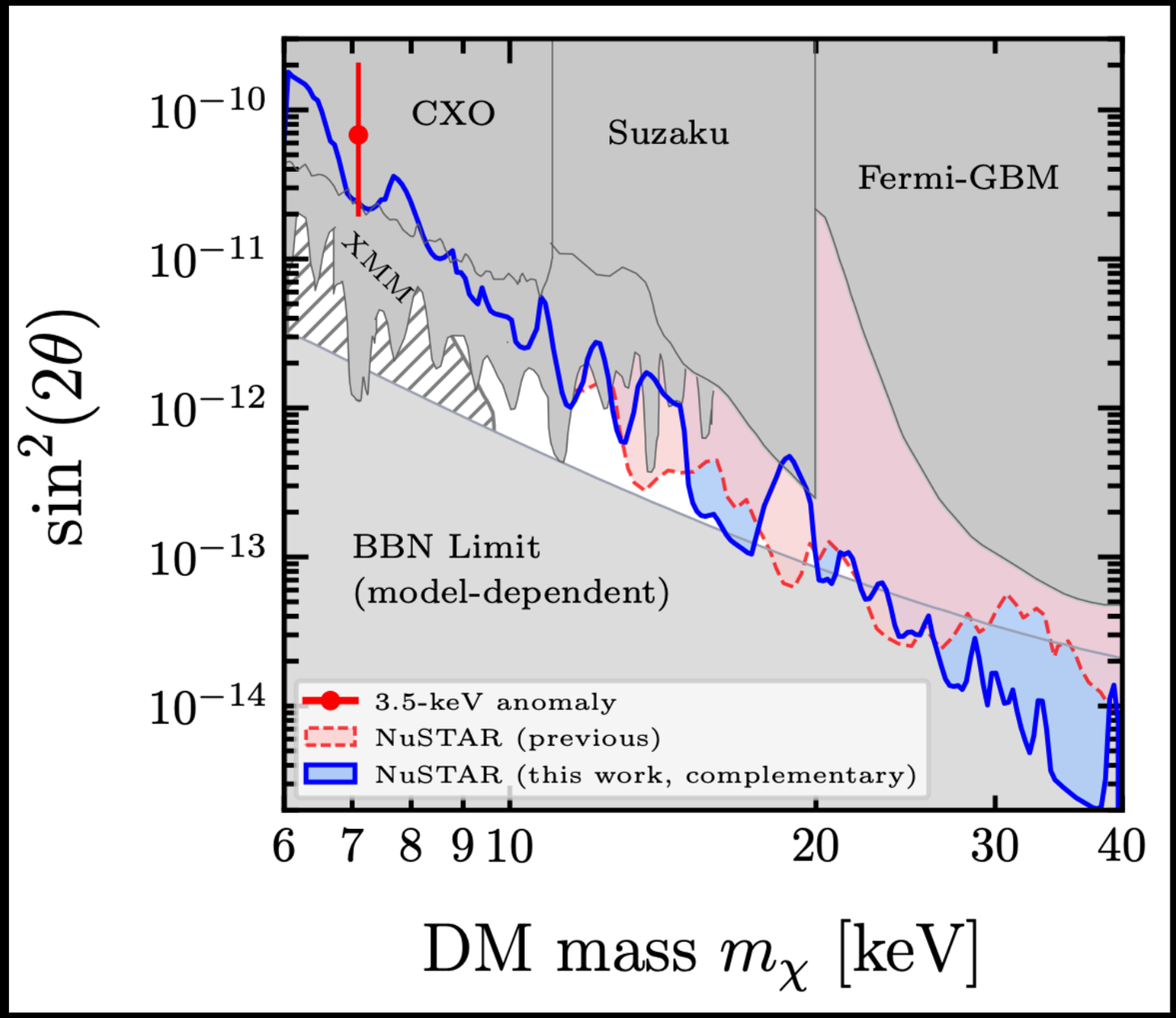
- **XRISM forecast**
- Dessert, Ning, Rodd, Safdi 2305.17160



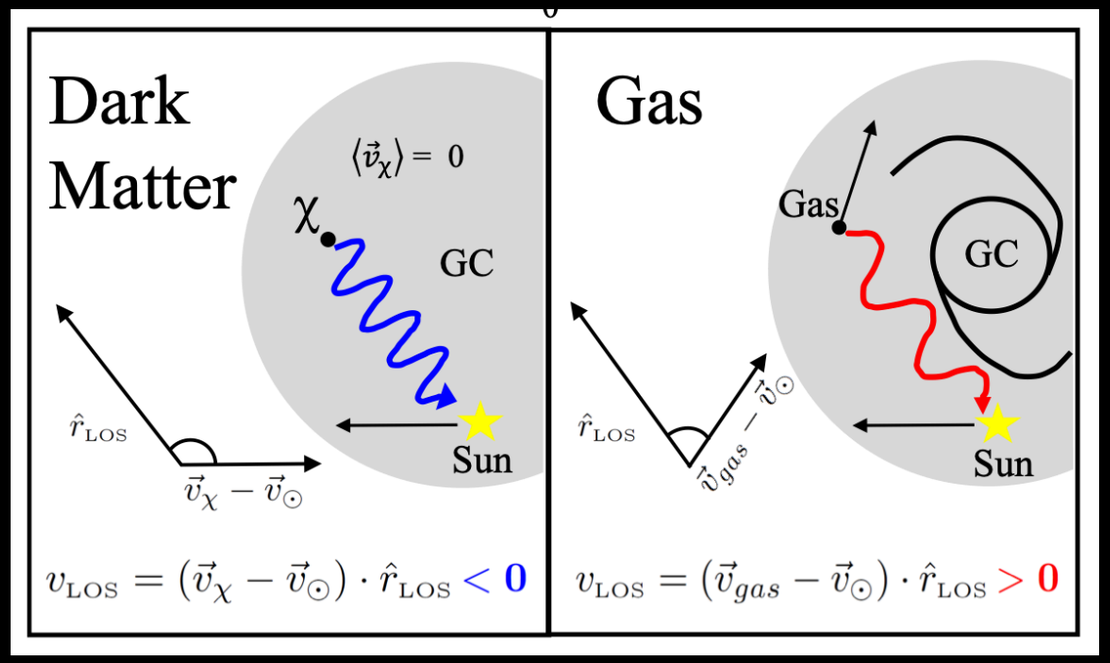


Sterile Neutrino DM from mixing

- X-ray limits
- Production requirement
  - Dodelson Widrow 1994
  - Shi-Fuller 1999
  - (See Venumadhav et al 2015)
- Warm dark matter constraints
  - e.g.,
  - Cherry et al 2017
  - Nadler et al 2021
  - Dekker et al (+KCYN) 2022
- New production methods
  - e.g., Bringmann et al, 2023
    - $\nu_s + \nu_a \to \nu_s + \nu_s$

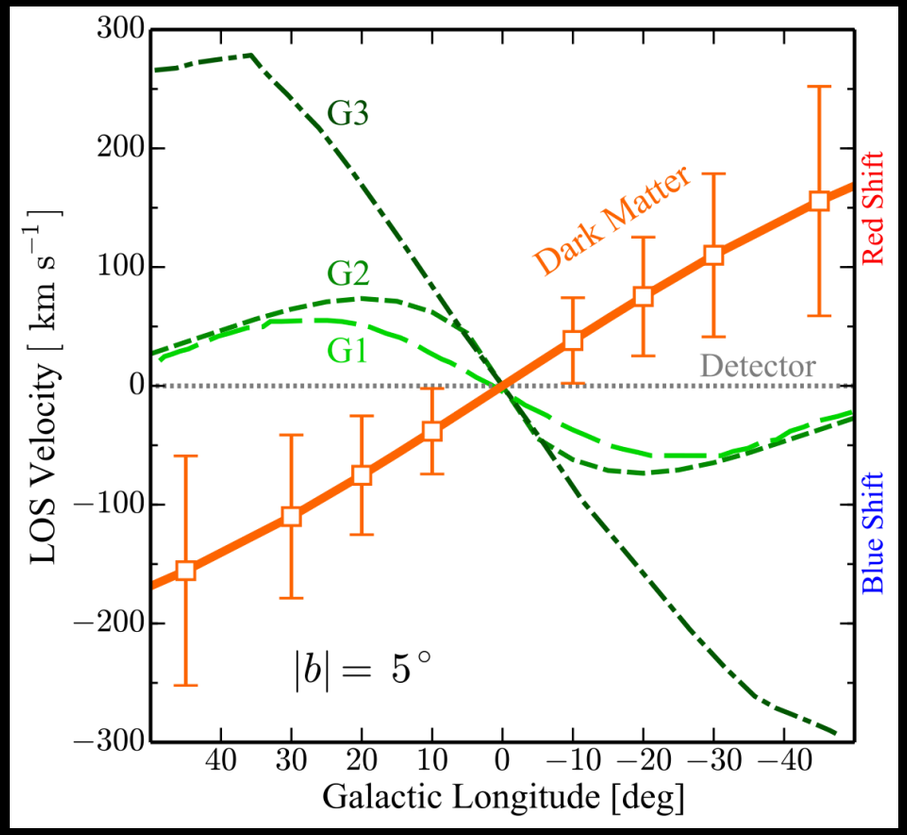


Velocity Spectroscopy



Launch of XRISM
7th September

Speckhard et al 2016



- Micro-calorimeter (vs CCD)
- ~ 0.1% energy resolution (vs ~ 5%)
- Speckhard et al 2016 (+KCYN)
- Powell et al 2017 (+KCYN)
- Zhong et al 2020
- *Future mission: Athena (2030s)*

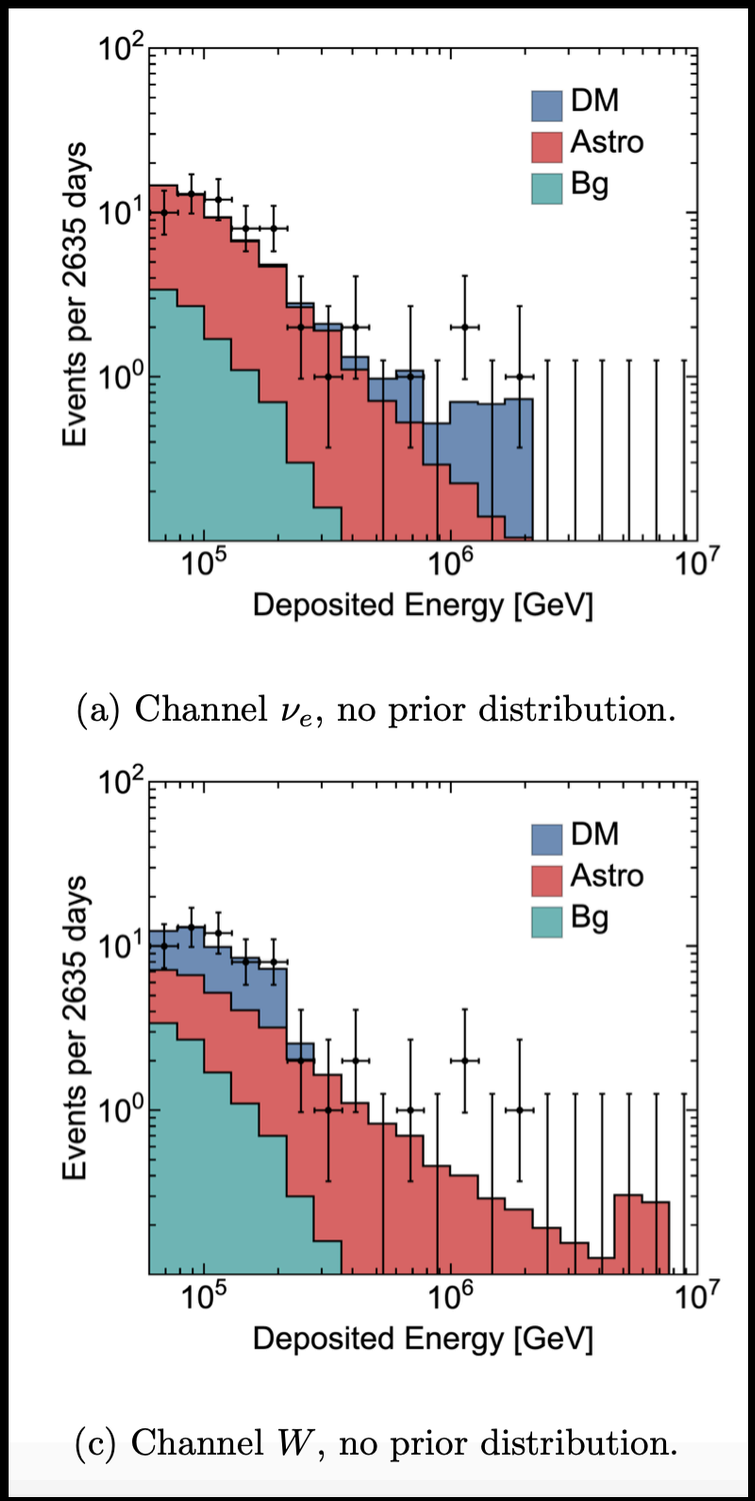
$$\frac{dF}{dEd\Omega} = \frac{\Gamma}{4\pi m_\chi} \int \rho \frac{d\tilde{N}}{dE}(E(\ell))d\ell$$

Heavy Dark Matter

- "Heavier" than typical WIMP window
  - Decay is more popular
  - *(Tak et al 2022, Ann. beyond Unitarity)*

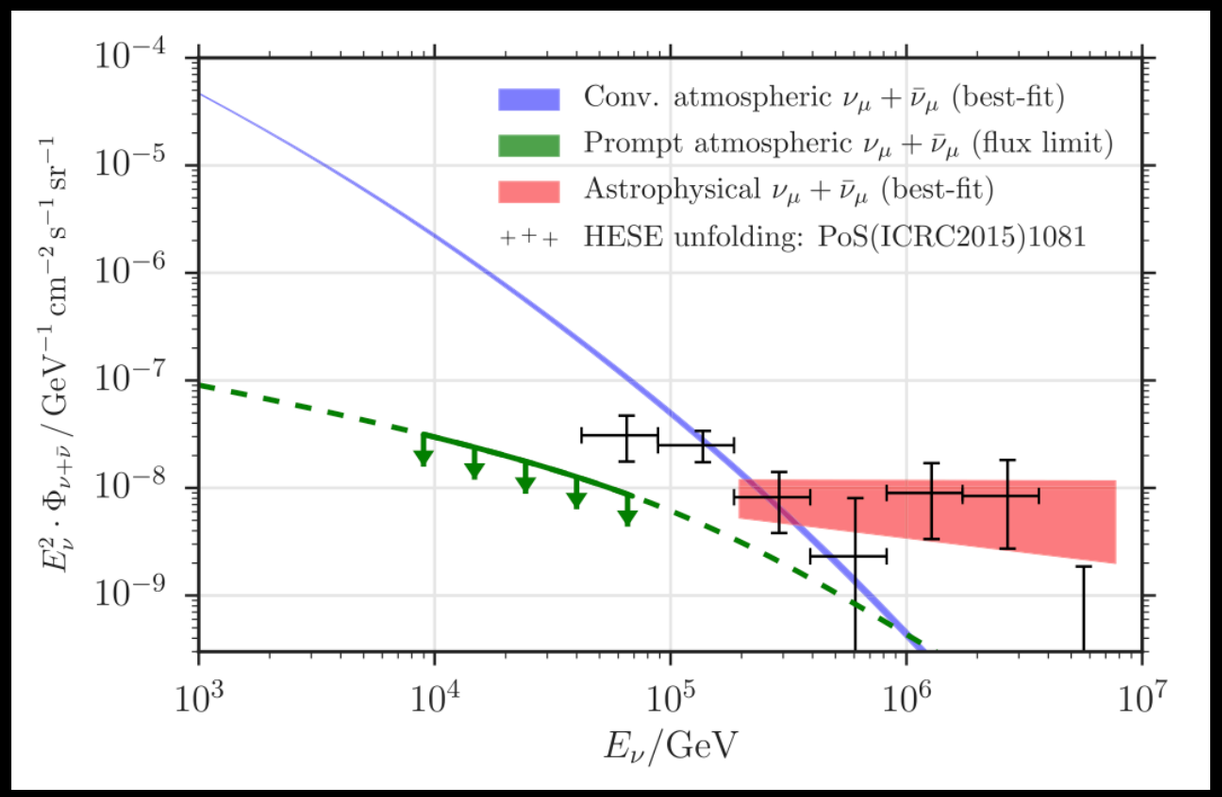
- IceCube diffuse astrophysical neutrinos
- DM interpretation?
- e.g., Feldstein et al 2013, Esmaili et al 2013, ++++

Chianese et al 2019
7.5 yr IceCube HESE



(a) Channel ν_e, no prior distribution.

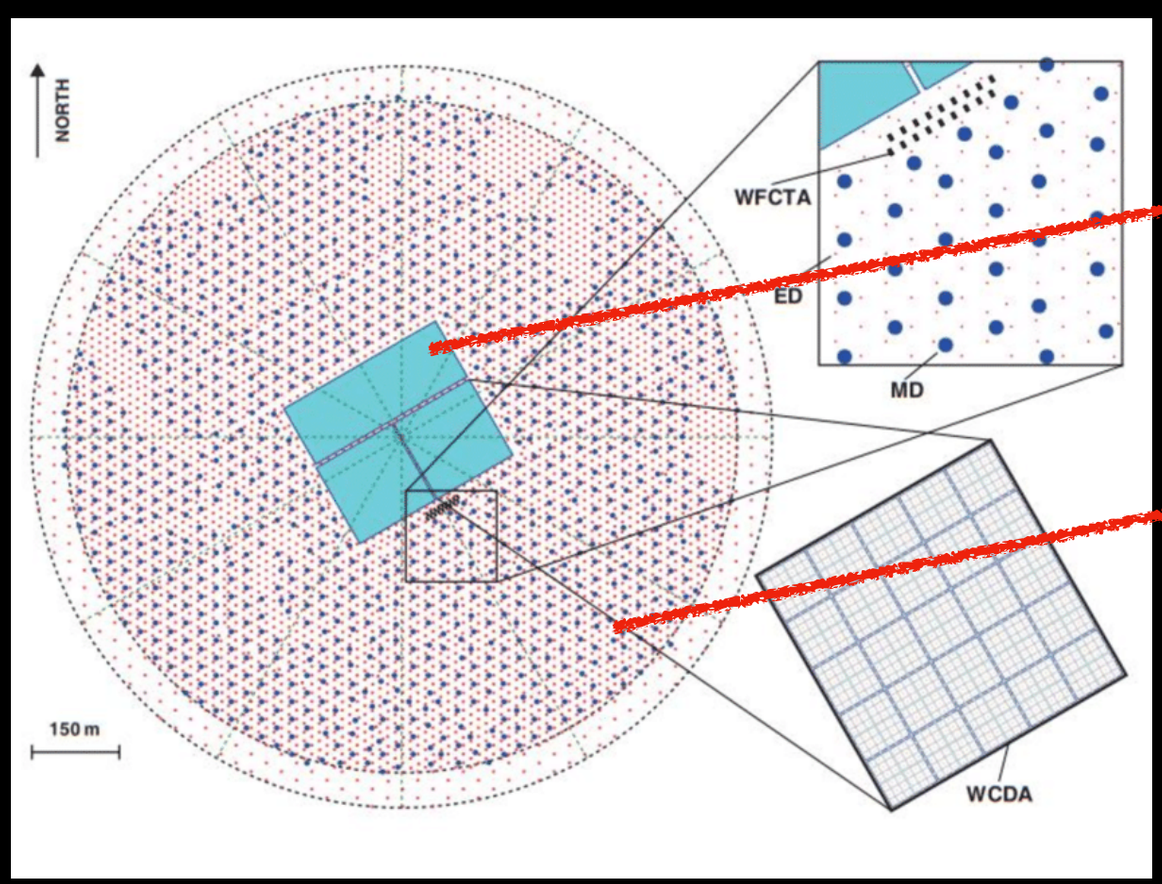
(c) Channel W, no prior distribution.

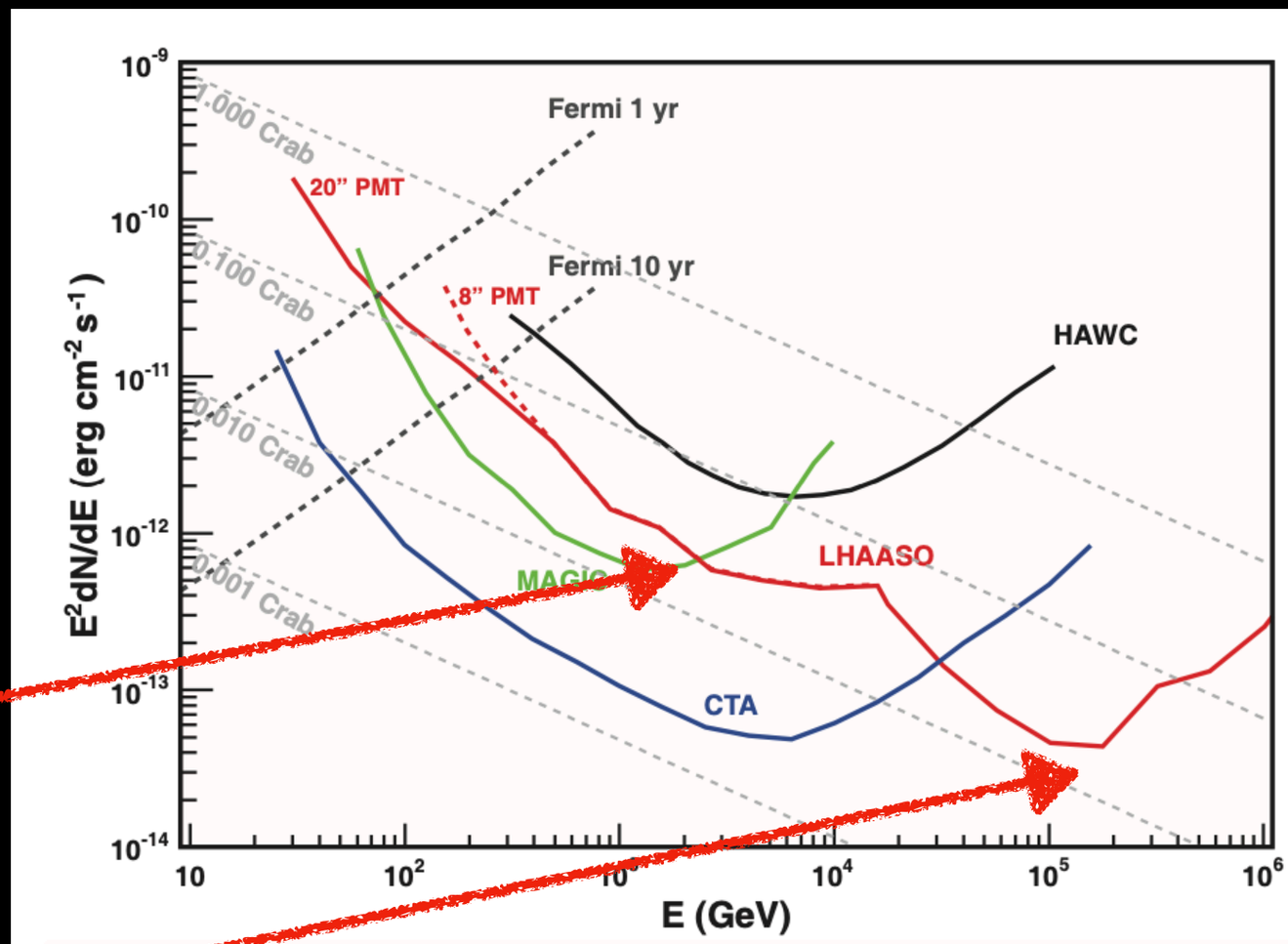


IceCube 2016

Heavy Dark Matter

- LHAASO Complementary to IceCube
- WCDA + KM2A + WFCTA





LHAASO Science book
Cao et al 2021

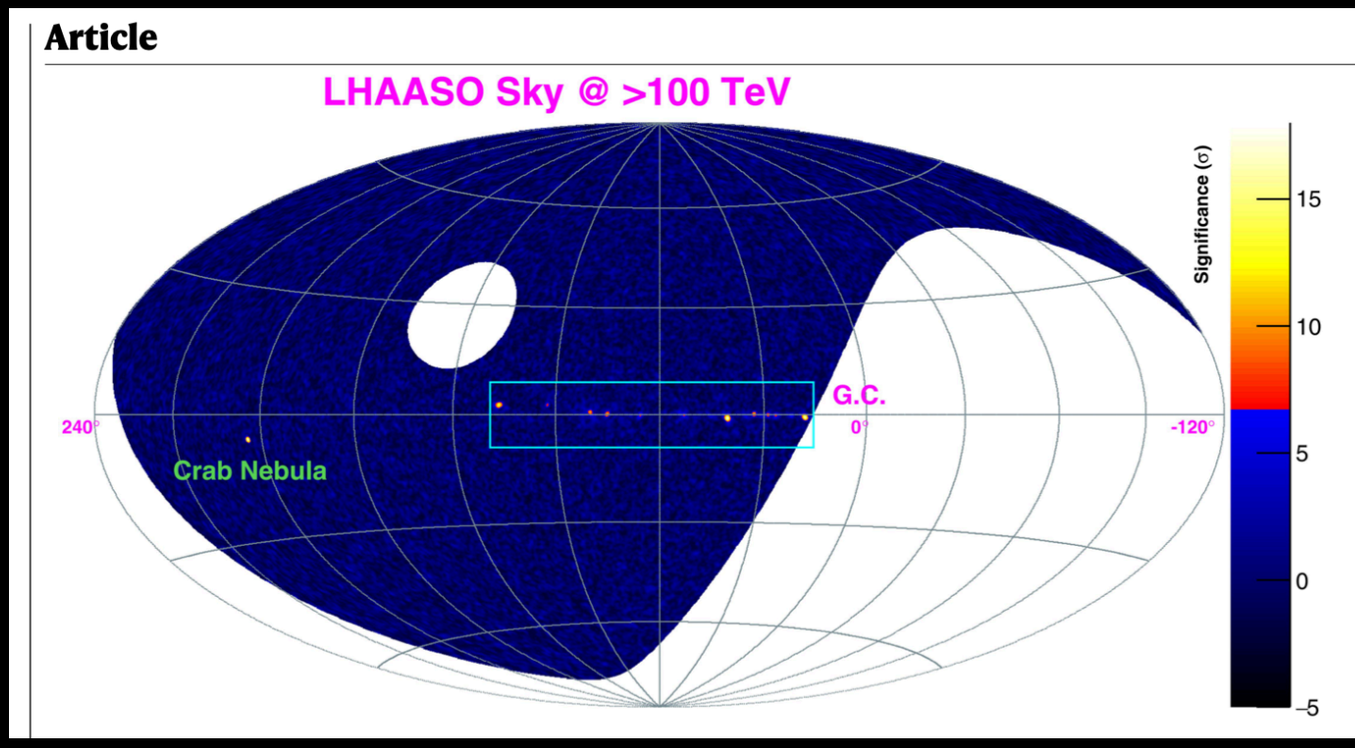
LHAASO talk by Yao

LHAASO DM search

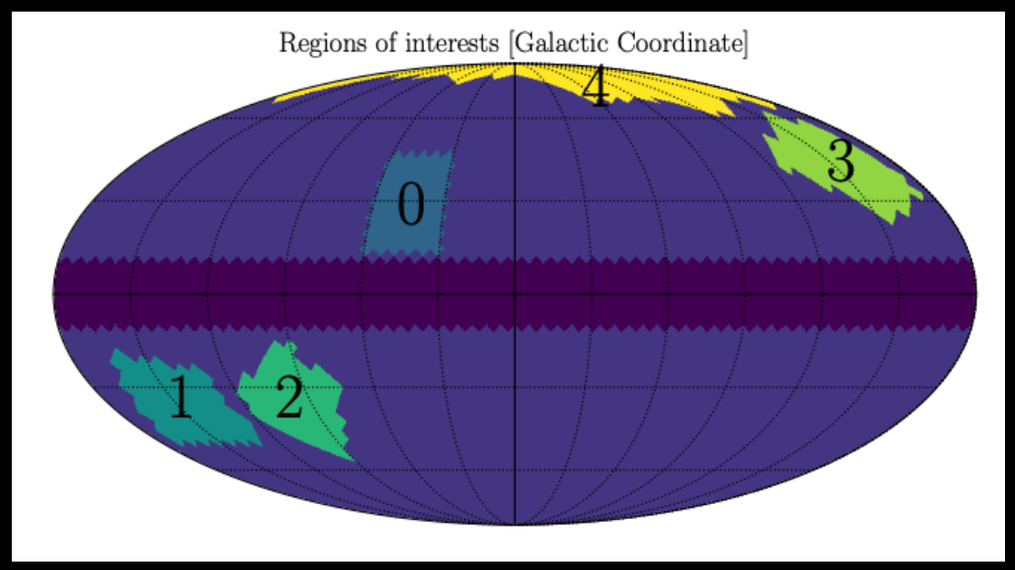
Cao et al 2021

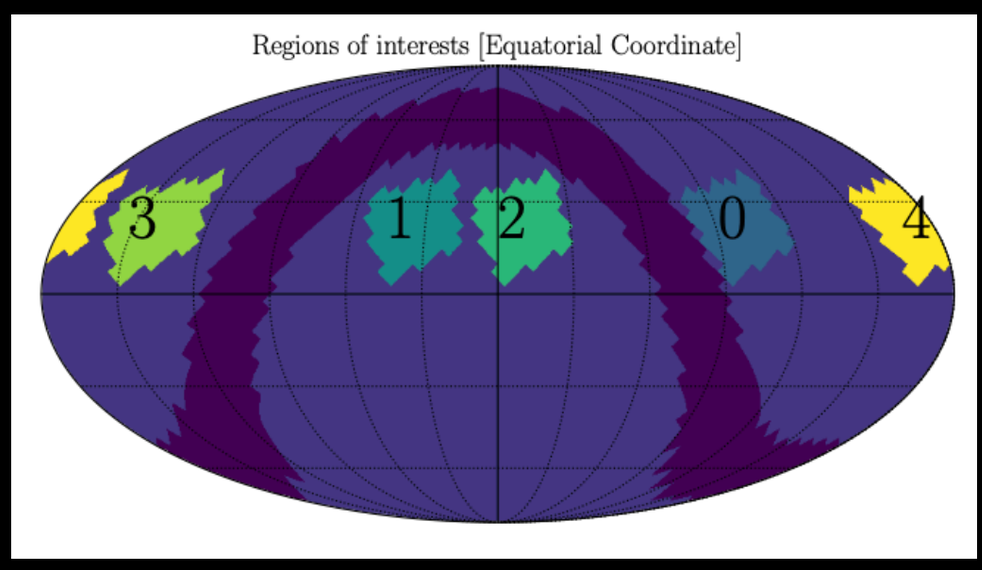
LHAASO + Ando, Chianese, Fiorillo, Miele, KCYN 2022

- Gamma rays form LHAASO
- Large field of view observation
- See the northern sky (no GC…)



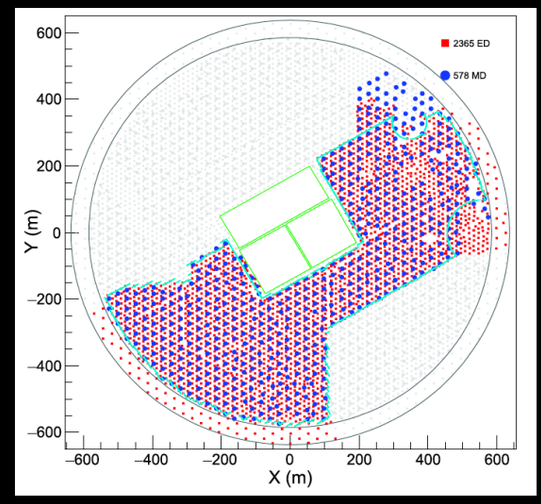
- Multiple sky regions for background control

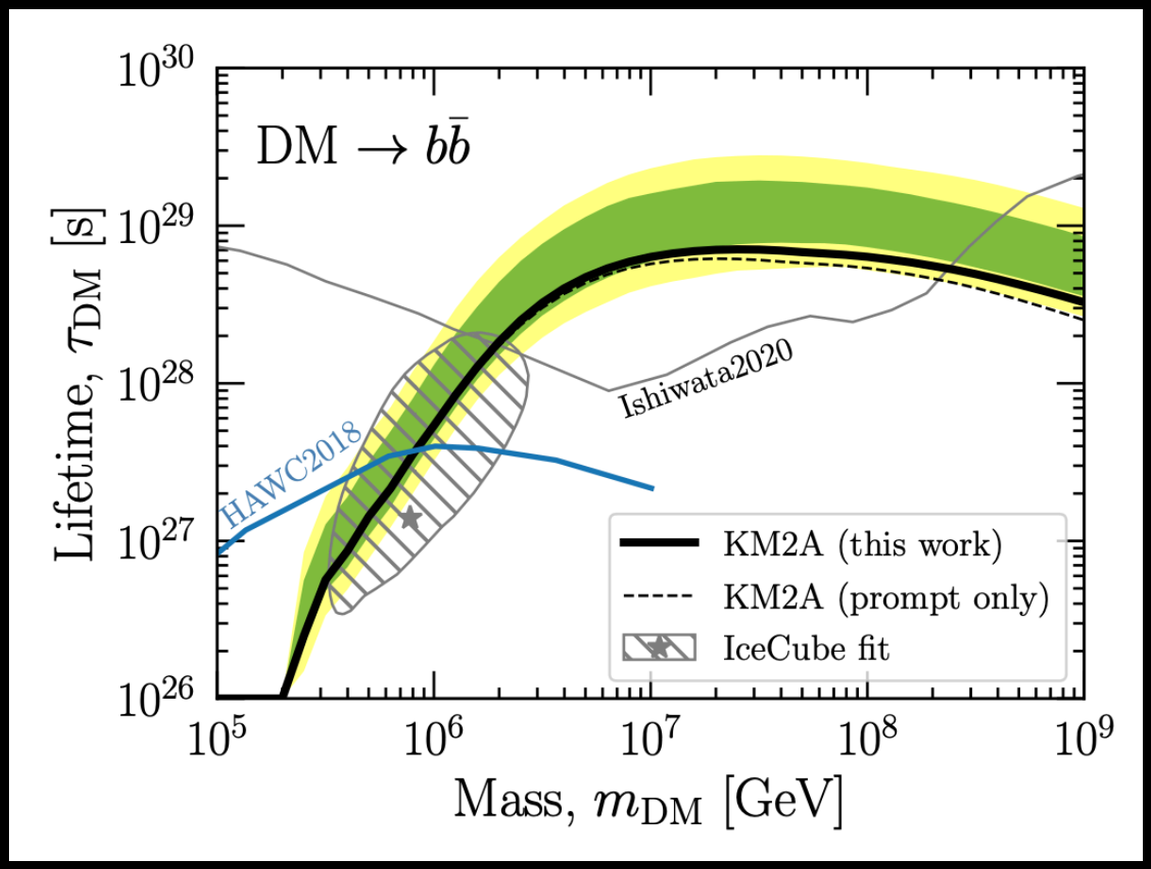


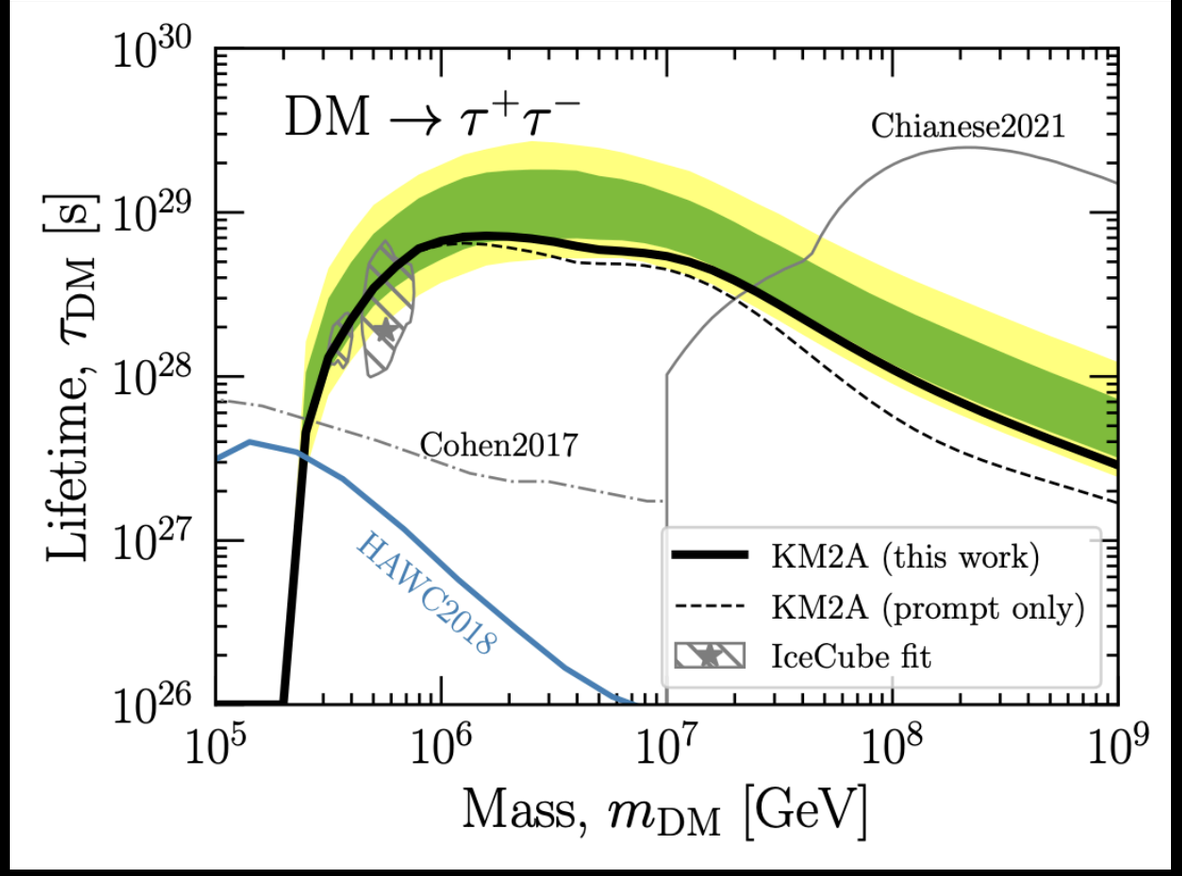


LHAASO DM search

- Testing the IceCube DM interpretation
  - 570 days of 1/2 and 3/4 KM2A data only!







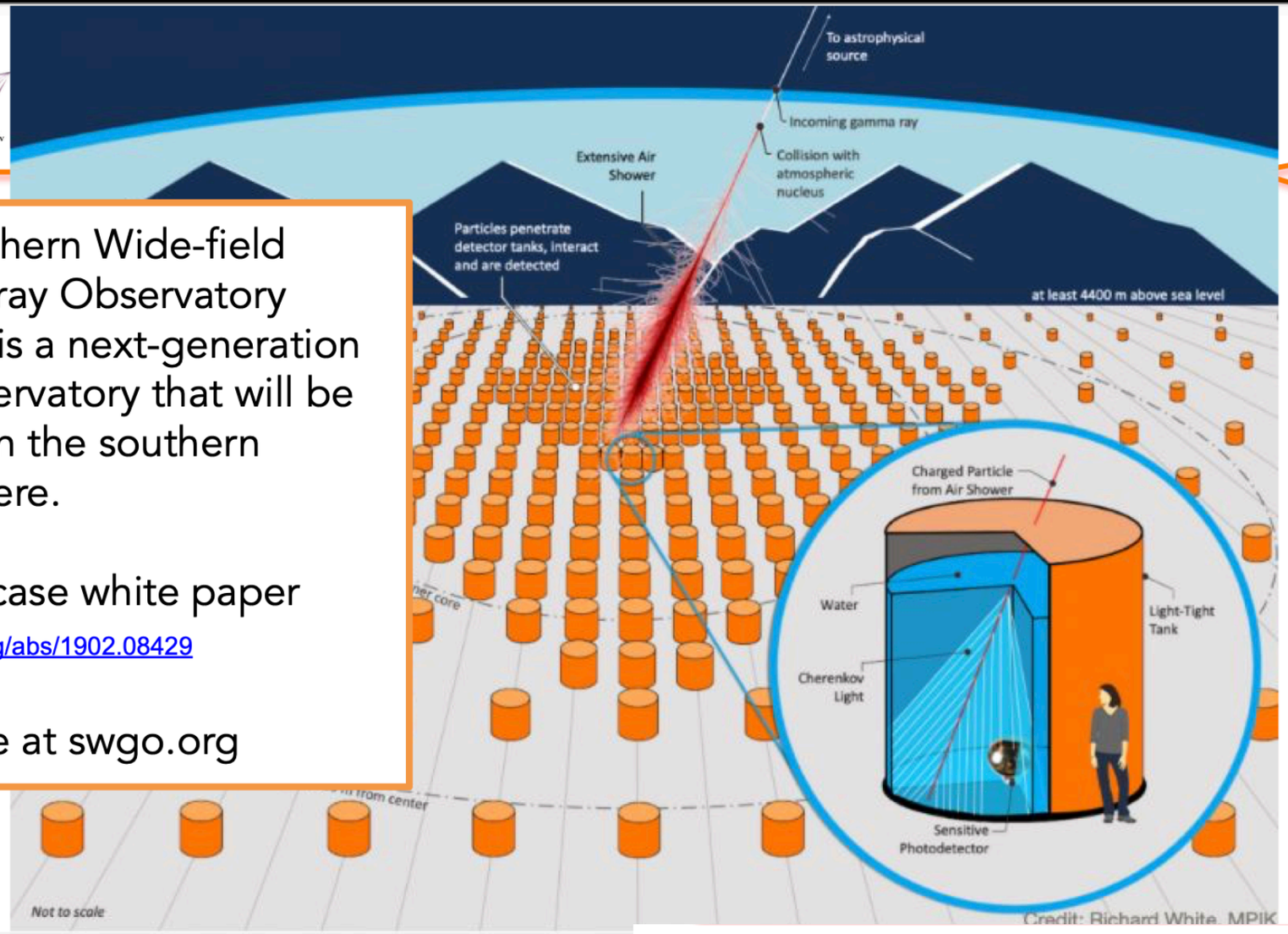
LHAASO + Ando, Chianese, Fiorillo, Miele, KCYN 2022

The Southern Wide-field Gamma-ray Observatory (SWGO) is a next-generation TeV Observatory that will be located in the southern hemisphere.

Science case white paper

https://arxiv.org/abs/1902.08429

See more at swgo.org



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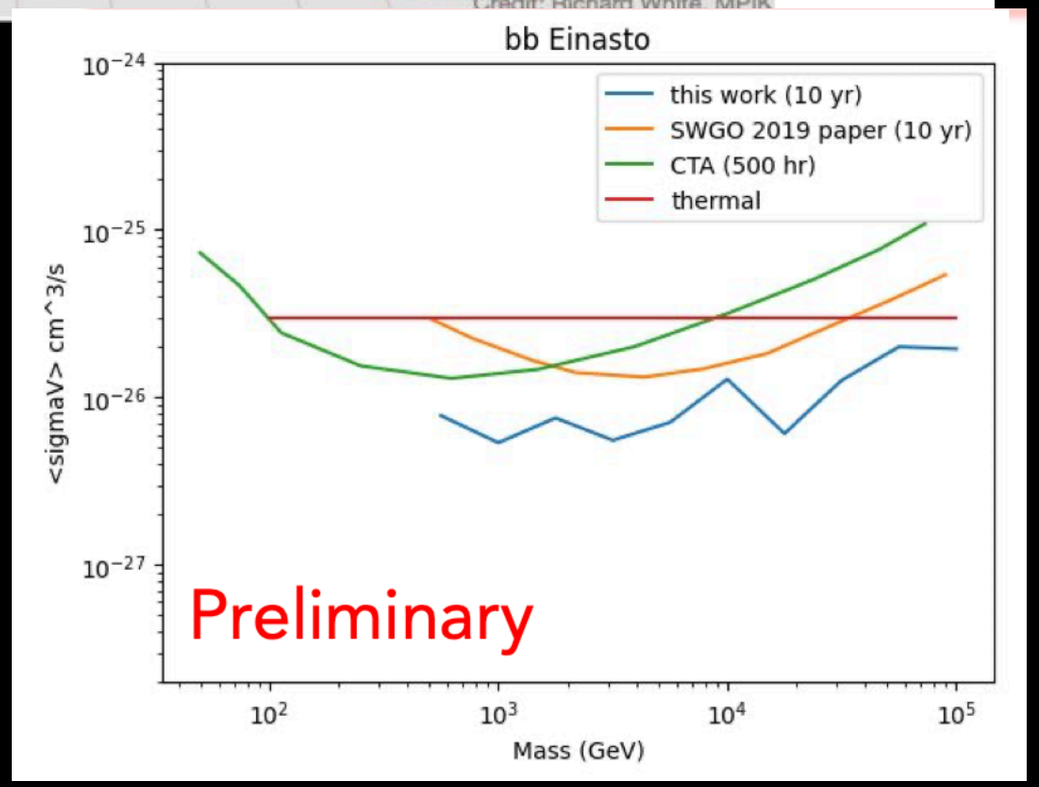
Talk by Andrea Albert



Conclusion

- Dark Matter indirect detection (DMID)
  - Full of exciting discoveries
  - Challenges from Systematics and Astrophysics
  - More data and opportunities ahead