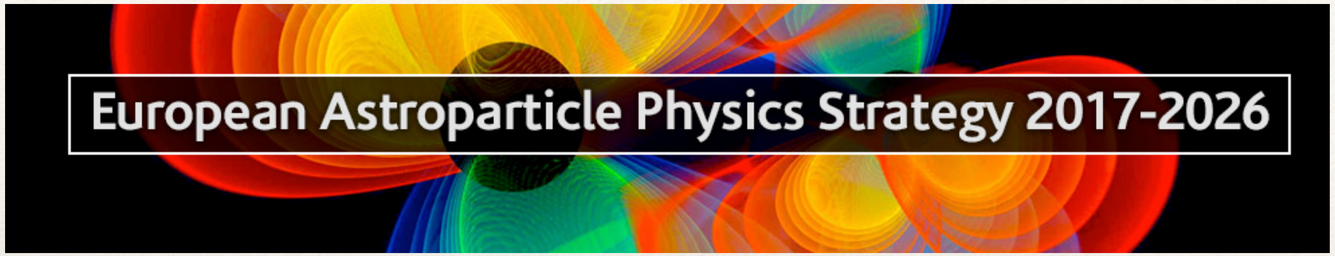
Direct Searches for Dark Matter

Kimberly Palladino

IOP 4 April 2022

Where are we, and where are we going?

Reports, Reviews, and Roadmaps



Direct Detection of Dark Matter – APPEC Committee Report *

Committee Members:

Julien Billard,[1] Mark Boulay,[2] Susana Cebrián,[3] Laura Covi,[4]
Giuliana Fiorillo,[5] Anne Green,[6] Joachim Kopp,[7] Béla Majorovits,[8]
Kimberly Palladino,[9,12] Federica Petricca,[8] Leszek Roszkowski (chair),[10] Marc Schumann[11]

arXiv:2104.07634

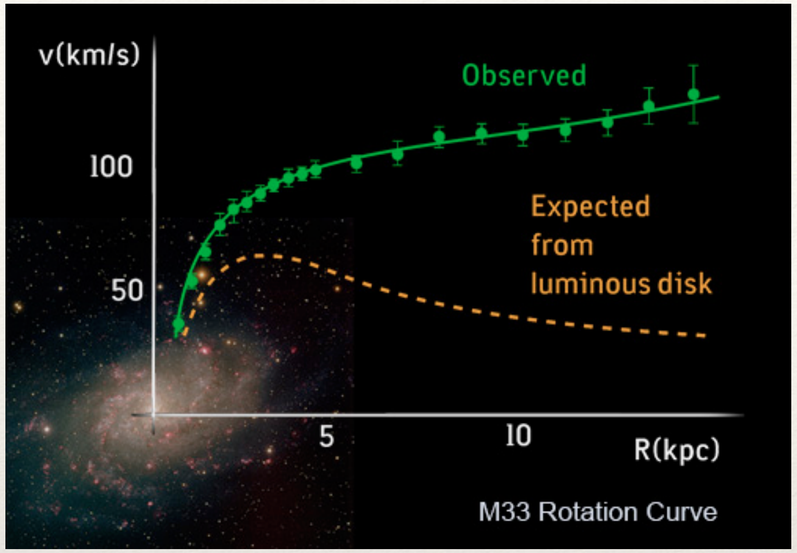
- D. S. Akerib, P. B. Cushman, C. E. Dahl, R. Ebadi, A. Fan, R. J. Gaitskell, et al. "Dark Matter Direct Detection to the Neutrino Fog", arXiv:2203.08084 [hep-ex] (pdf).
- Rouven Essig, Graham K. Giovanetti, Noah Kurinsky, Dan McKinsey, Karthik Ramanathan, Kelly Stifter, Tien-Tien Yu. "The landscape of low-threshold dark matter direct detection in the next decade", arXiv:2203.08297 [hep-ph] (pdf).
- D. Antypas, A. Banerjee, C. Bartram, M. Baryakhtar, J. Betz, et al. "New Horizons: Scalar and Vector Ultralight Dark Matter", arXiv:2203.14915 [hep-ex] (pdf). (also under RF03, TF09, IF01)
- Rebecca K. Leane, Seodong Shin, Liang Yang, Govinda Adhikari, et al. "Puzzling Excesses in Dark Matter Searches and How to Resolve Them", arXiv:2203.06859 [hep-ph] (pdf). (also under TF09)

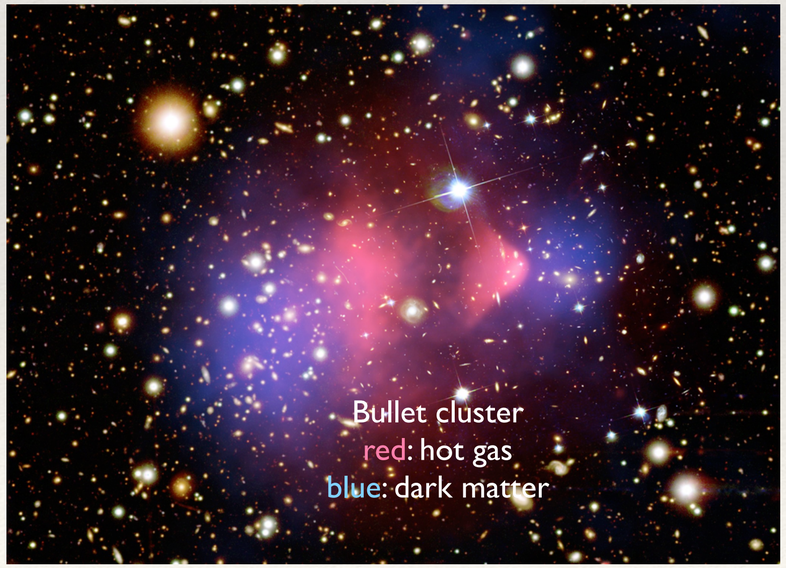
https://snowmass21.org/submissions/cf

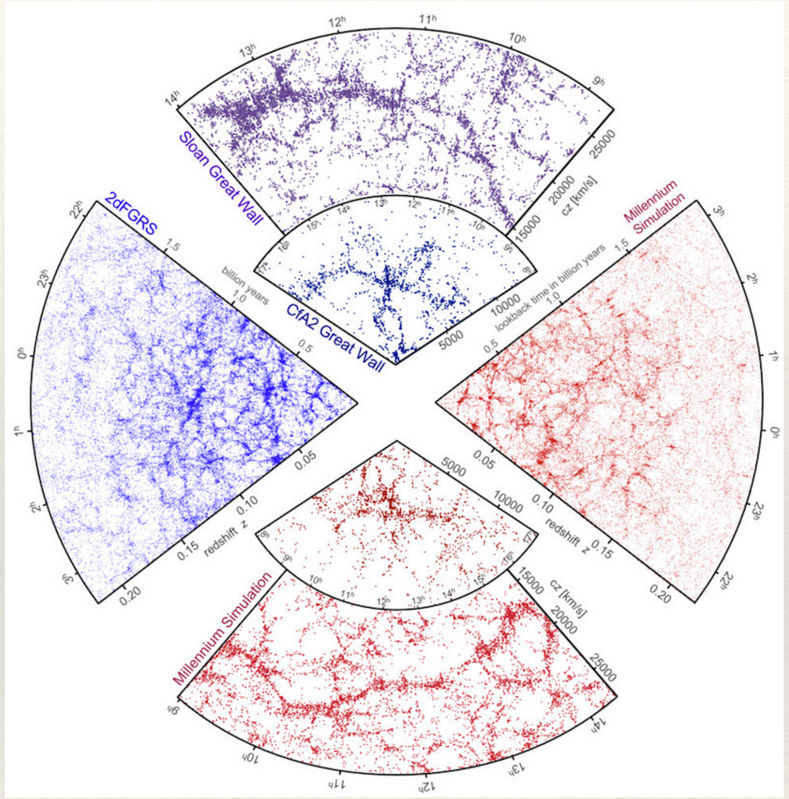
Outline

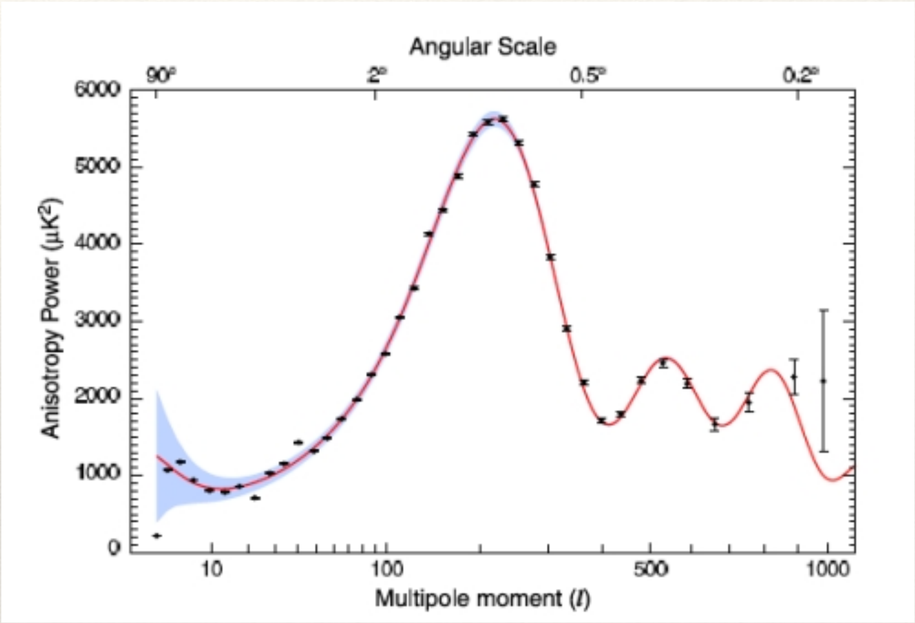
- Dark Matter Evidence
- Dark Matter Candidates
- Wavelike Dark Matter
- Light Particle Dark Matter
- Heavier Particle Dark Matter

Evidence for Dark Matter

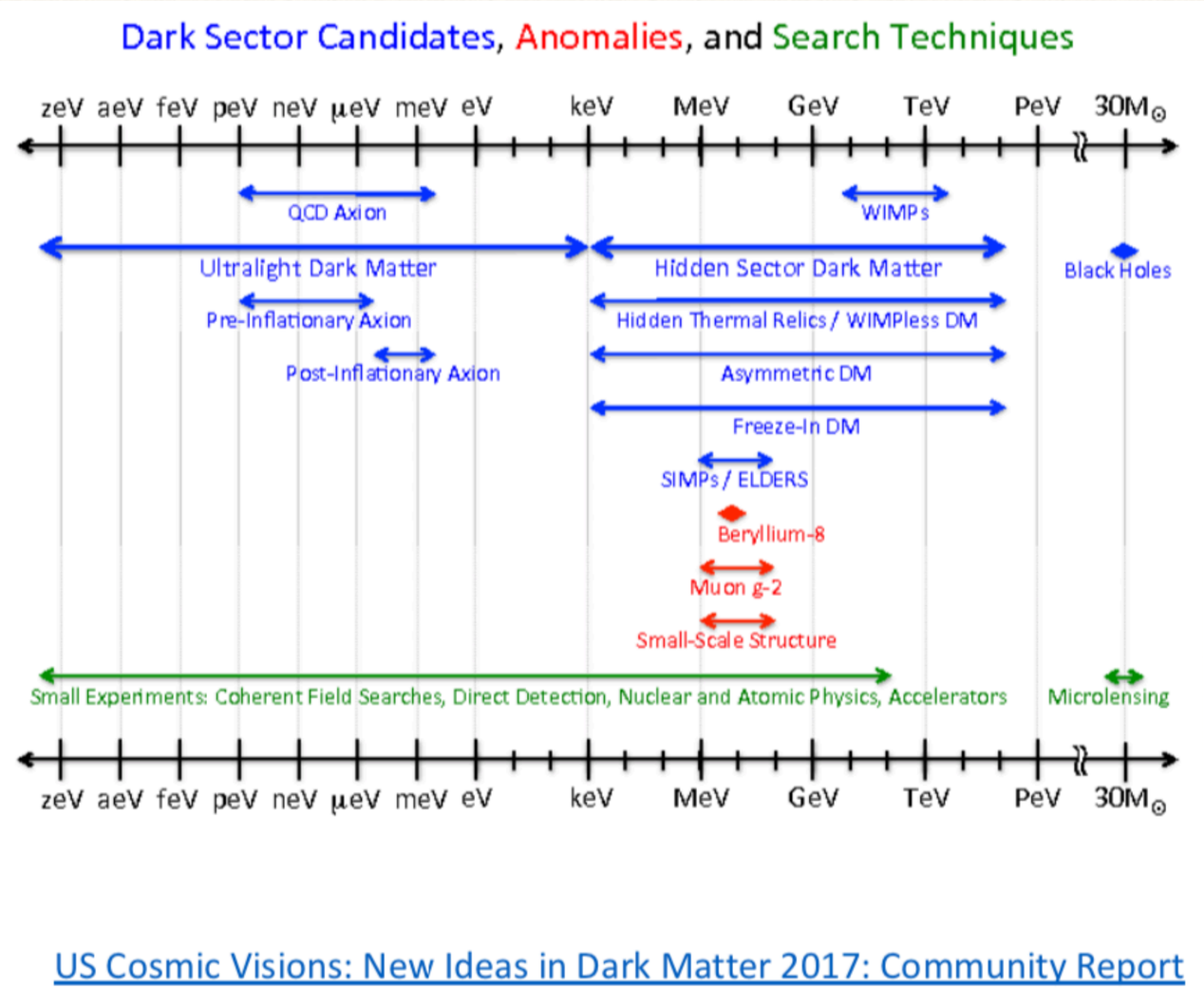






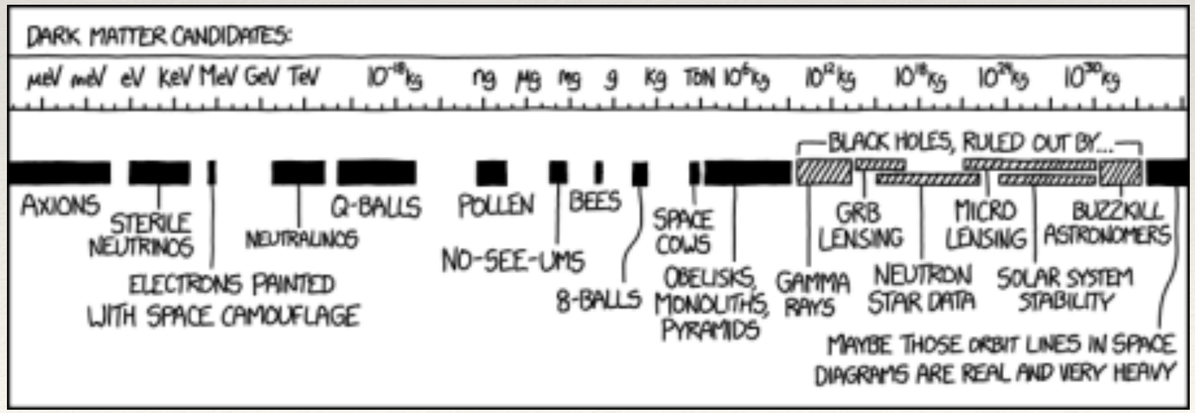


The Options

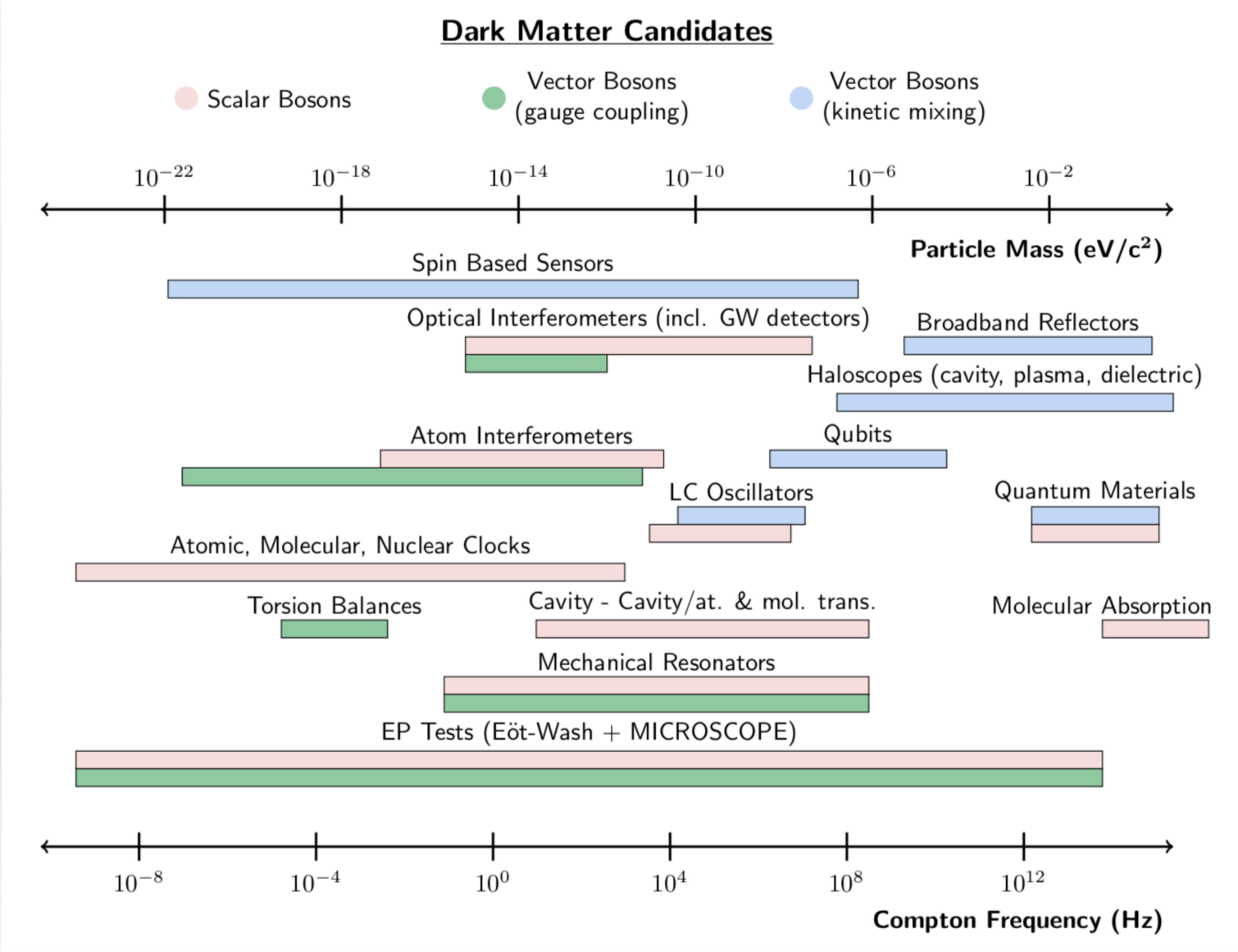


- Canonical Dark matter is:
  - non-relativistic
  - electrically neutral
  - limited self-interactions
  - density of DM ~0.3 GeV/cm^3

  - But theories push these boundaries
  - Can dark matter candidates fit with other theories
  - or open problems?

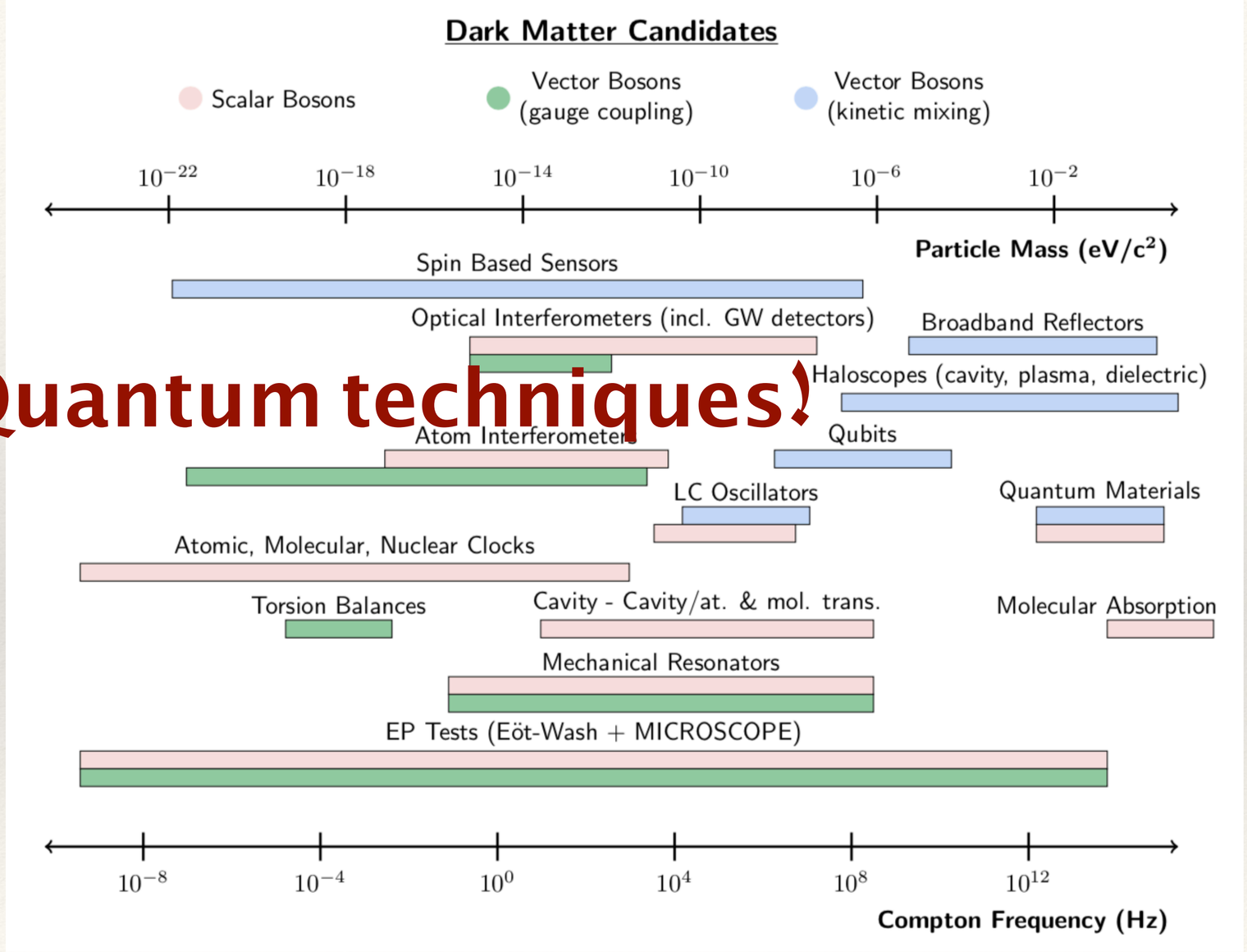


Wavelike Dark Matter



arXiv:2203.14915

Wavelike Dark Matter



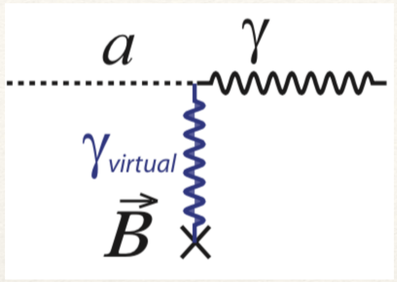
Quantum techniques!

See Kai Bongs' plenary Tuesday afternoon

QSHS and AION parallels Tuesday morning

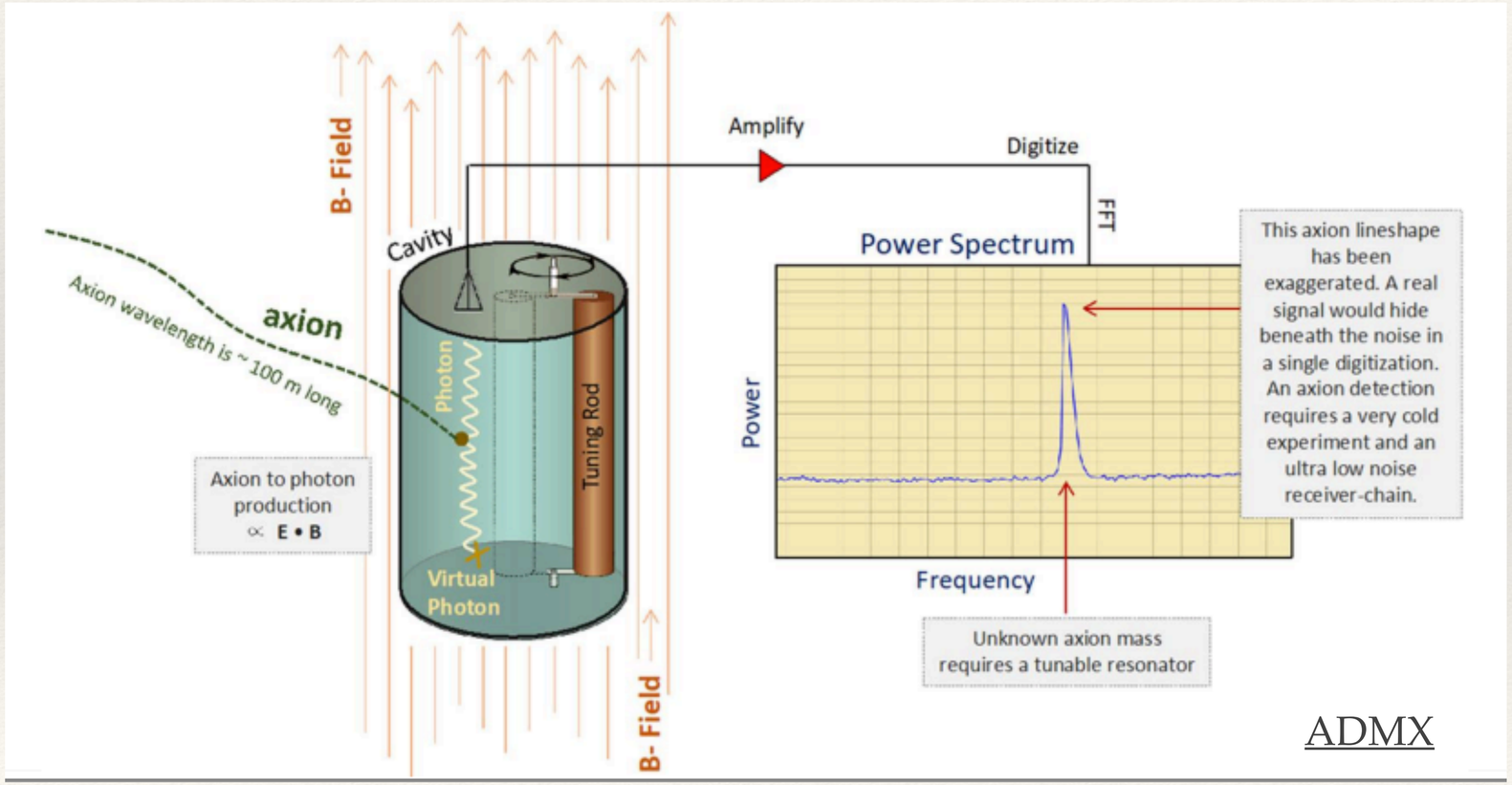
arXiv:2203.14915

Cavity Haloscope: ADMX

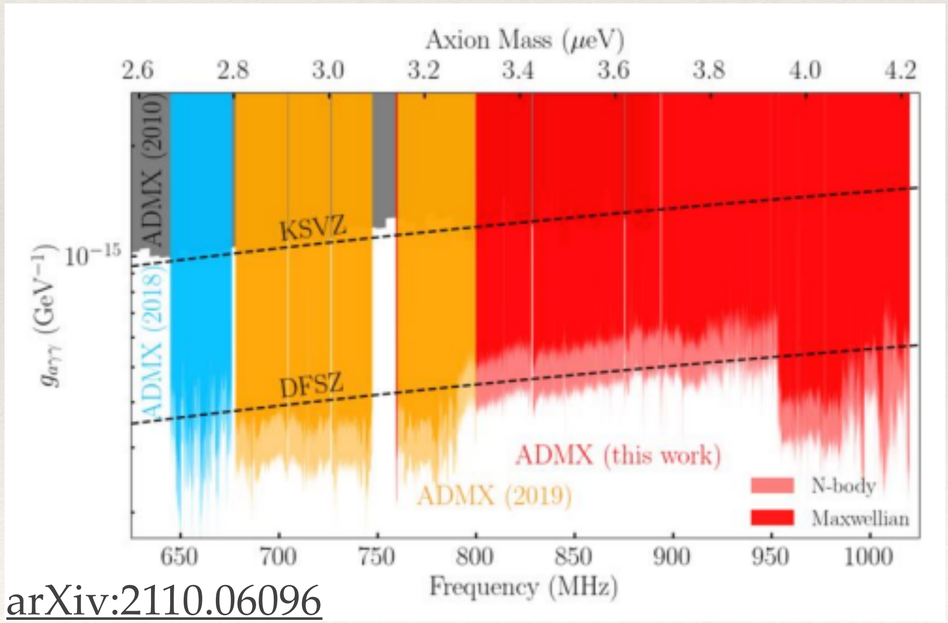


ADMX
AXION DARK MATTER EXPERIMENT

- ADMX G2 runs ongoing
  - previous exclusion to DFSZ sensitivity for $2.7 - 3.3$ μeV
  - next run will use a new tuning rod for 1–1.4 GHz
- Future proposal 14 supercunducting cavity array to cover $2 - 4$ GHz



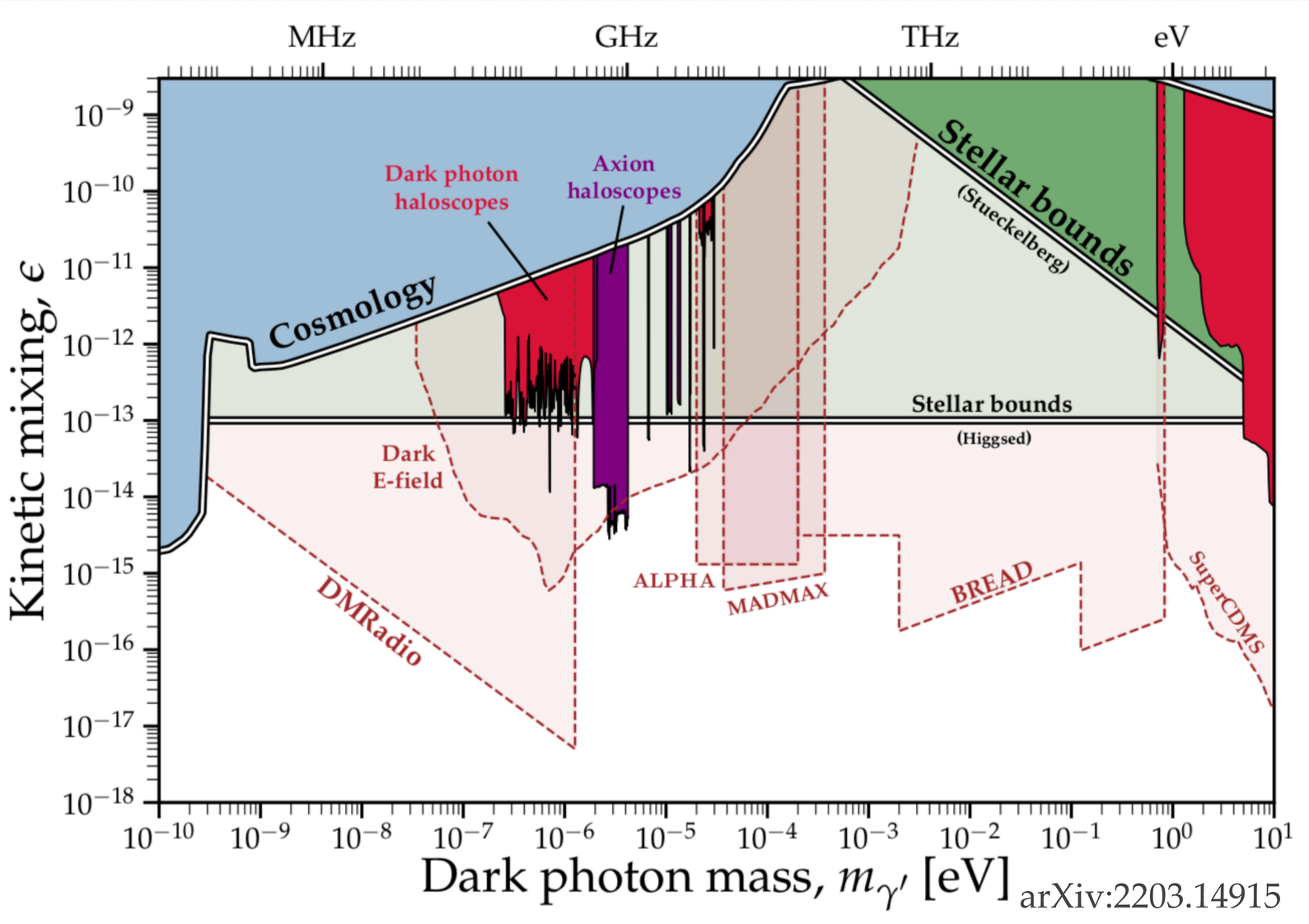
ADMX

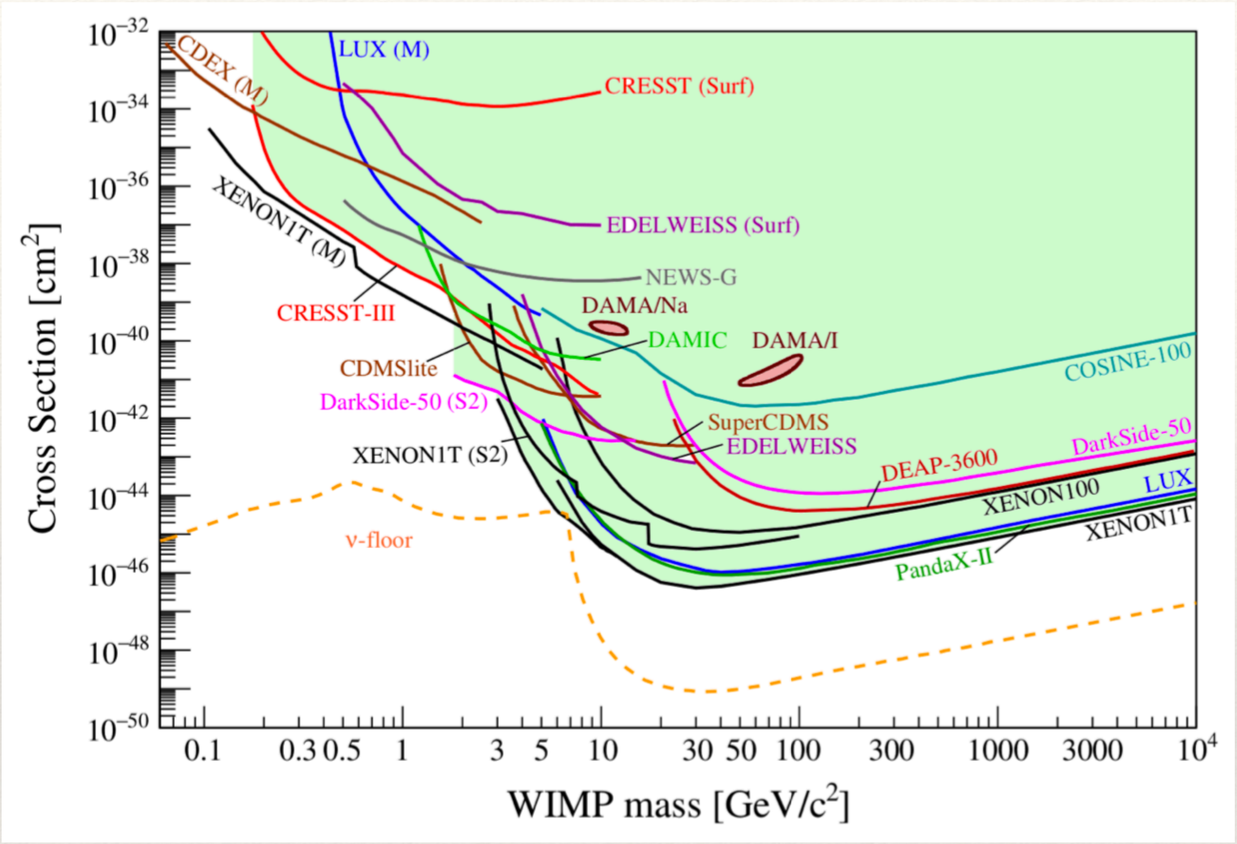


arXiv:2110.06096

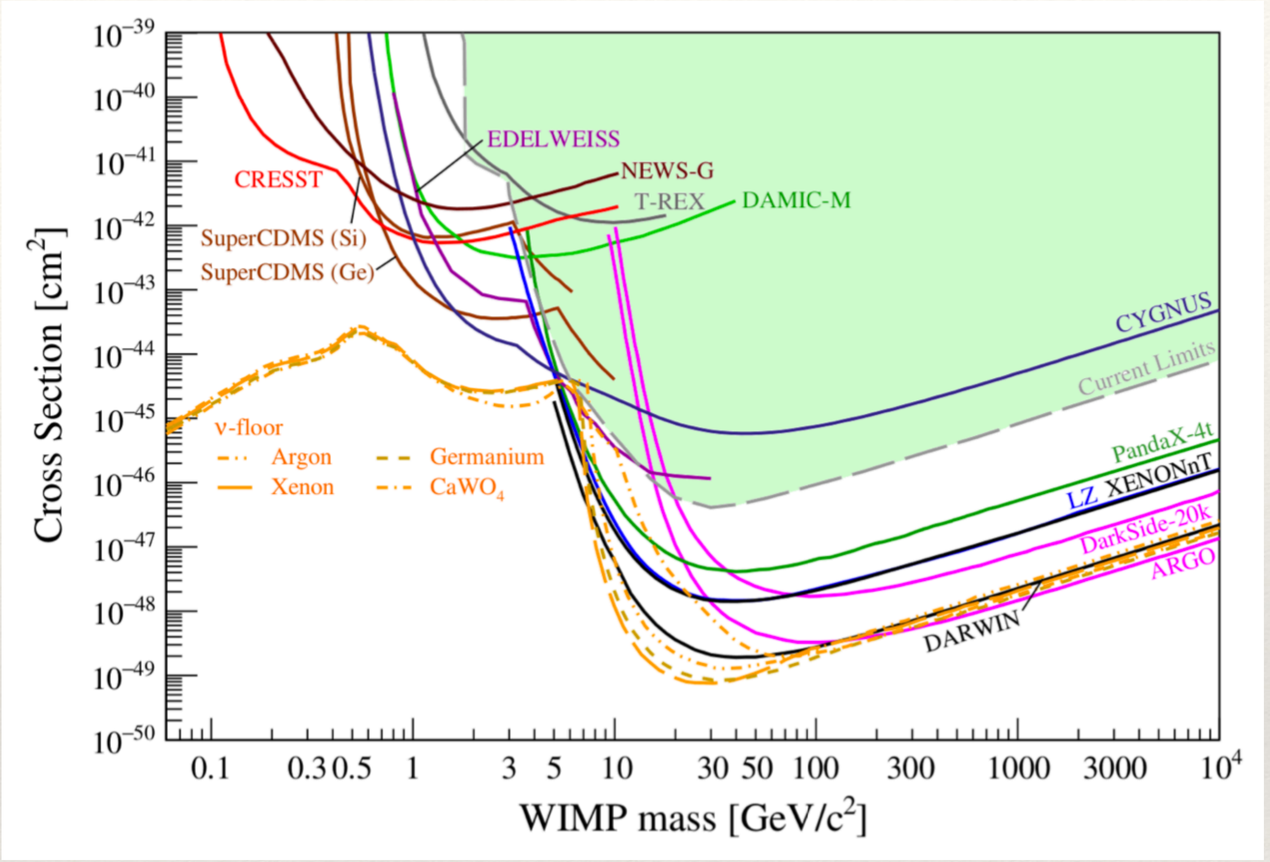
Wavelike Projections

- Not just axions and axion-like-particles
- Heavy photons make another broad class, with similar couplings
- Particle direct detectors can also look for interactions with electrons





Limits!

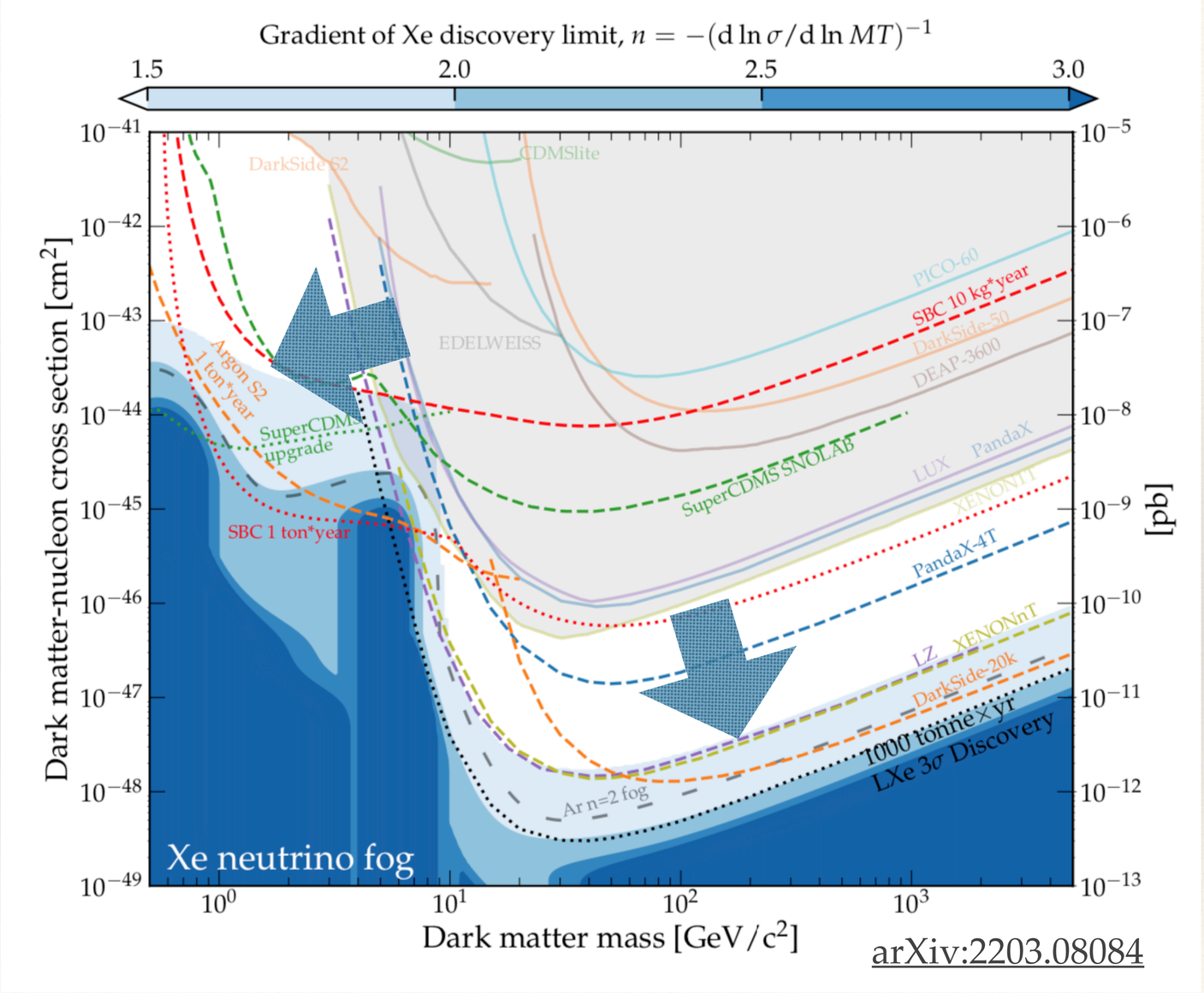


Projections!

arXiv:2104.07634

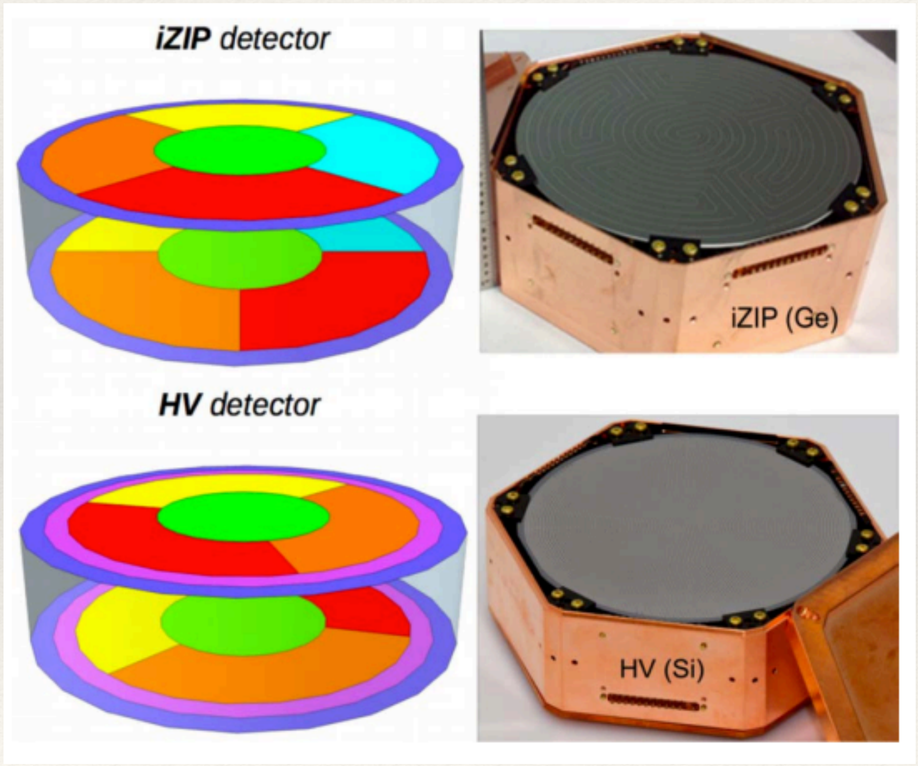
Particle Dark Matter

New targets,
technologies,
and lower thresholds

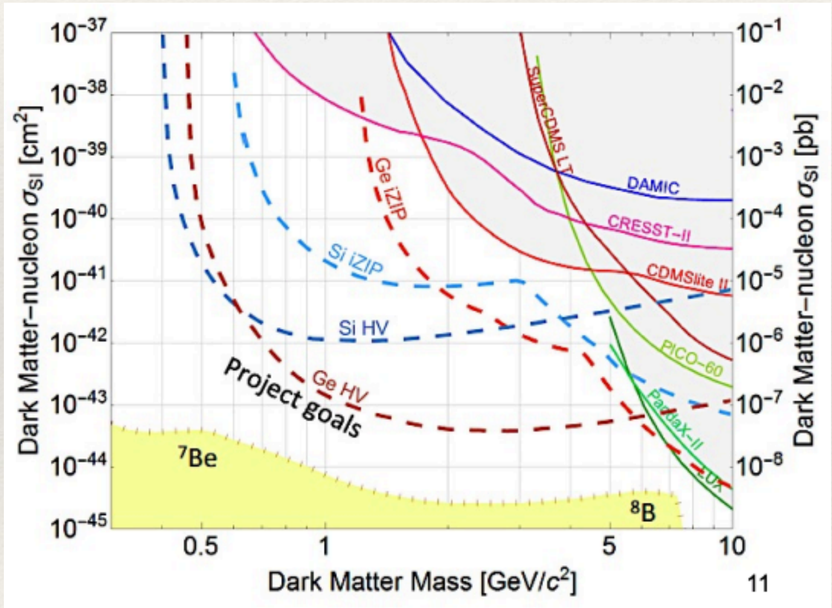


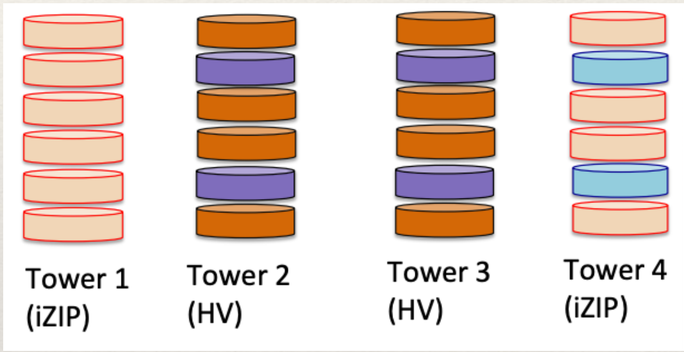
SuperCDMS SNOLAB

- Cryogenic thermal phonon technology
  - iZIP (phonon and ionization) and HV sensors
  - Ge (1.4 kg) and Si (0.6 kg)
- Under construction at SNOLAB
- Operations beginning Fall 2023



	Germanium	Silicon
HV	Lowest threshold for low mass DM Larger exposure, no ^{32}Si bkgd	Lowest threshold for low mass DM Sensitive to lowest DM masses
iZIP	Nuclear Recoil Discrimination Understand Ge Backgrounds	Nuclear Recoil Discrimination Understand Si Backgrounds

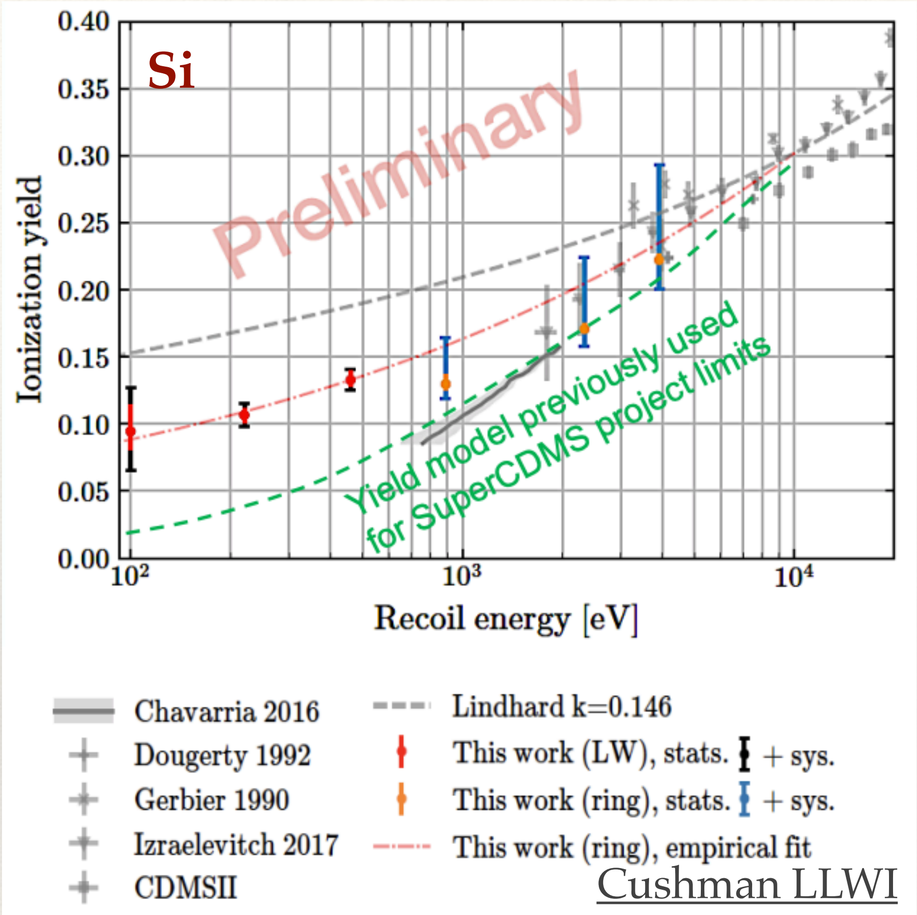


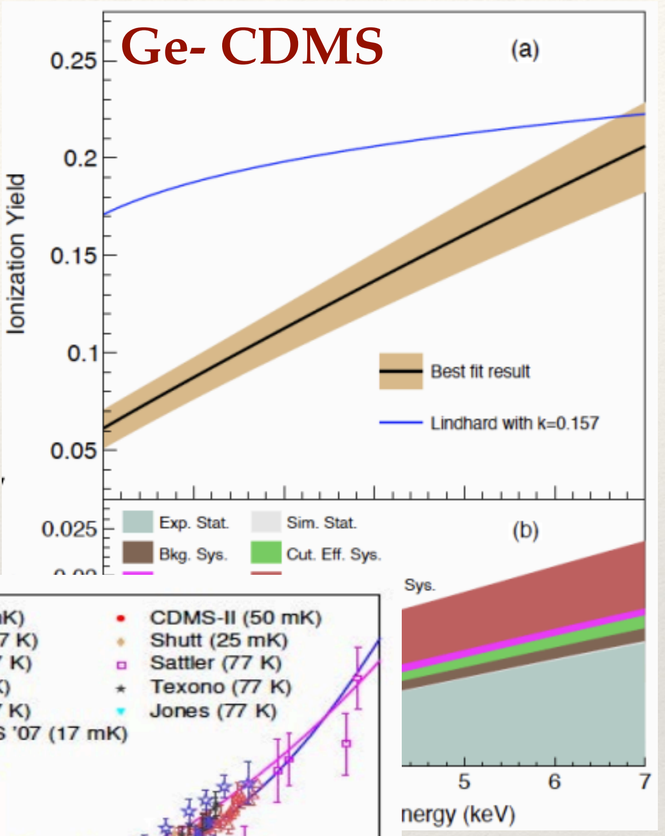


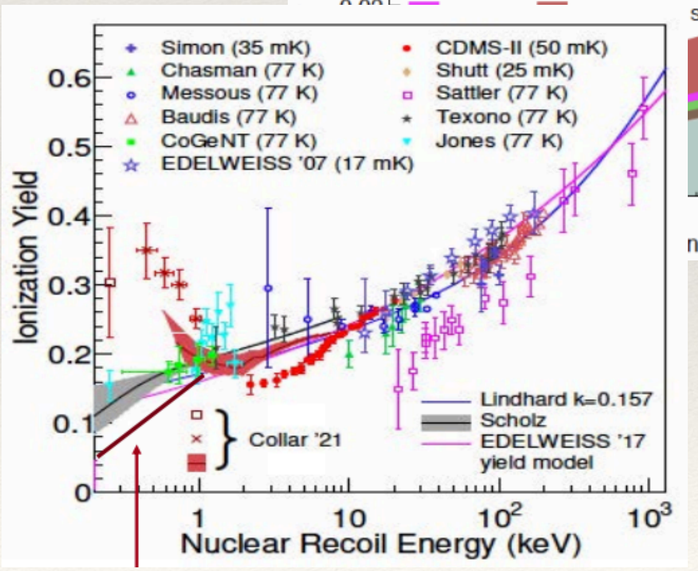
SUPER CDMS
Cryogenic Dark Matter Search

SuperCDMS Calibrations

- Calibrating low energy nuclear recoils is difficult
- Discrepancies in the field
- Definitely divergent from Lindhard theory
- Projections for Si more conservative than preliminary measurements

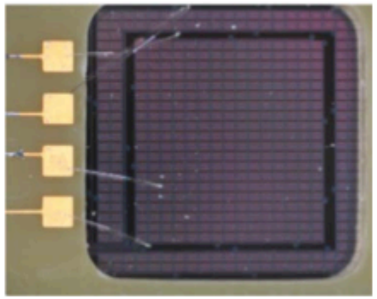






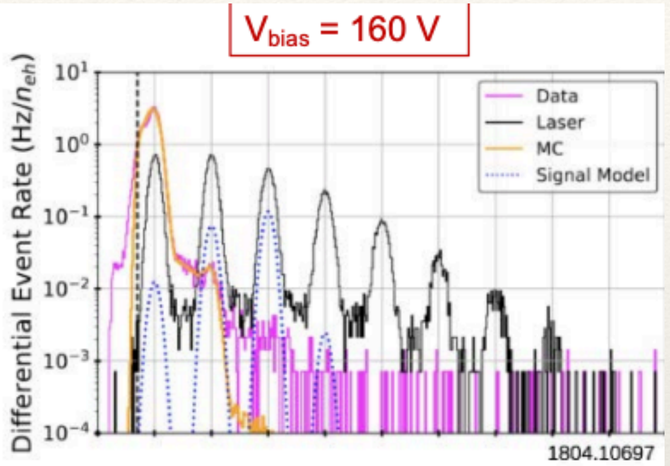
SuperCDMS: Science with new prototypes

HVeV (Si or Ge, 1 x 1 cm^2 x 4 mm). 2 equal area QET sensors



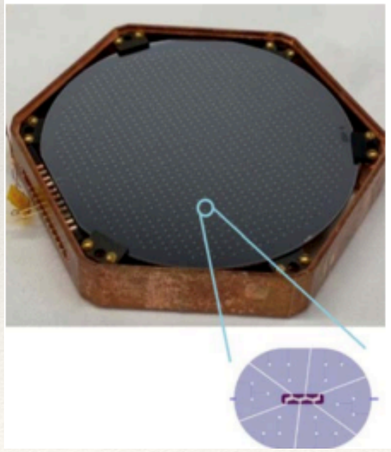
R. Agnese *et al.* Phys. Rev. Lett. **121**, 051301 (2018)

- Study charge transport in Si and Ge, minimize charge leakage
- Improve phonon resolution, study single e-h devices
- Physics runs in NEXUS (FNAL) and CUTE ongoing
- Used in the TUNL ionization yield measurements.

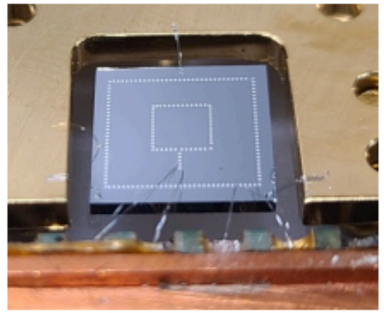


A mosaic of these on 2 SuperCDMS towers can get us to the ν-fog in 0.5 – 5 GeV range

0V, CPD (cryogenic photon detector) 1 mm thick (45.6 cm^2) Si wafer with CDMS phonon readout



- Study phonon resolution and test facility noise performance
  especially "environmental" sub-keV phonon-only backgrounds
- Phonon resolution in the σ_{pt} ~ 1 eV range now.
- New prototype (with new hanging support) may have σ_{pt} ~ 50 - 100 meV

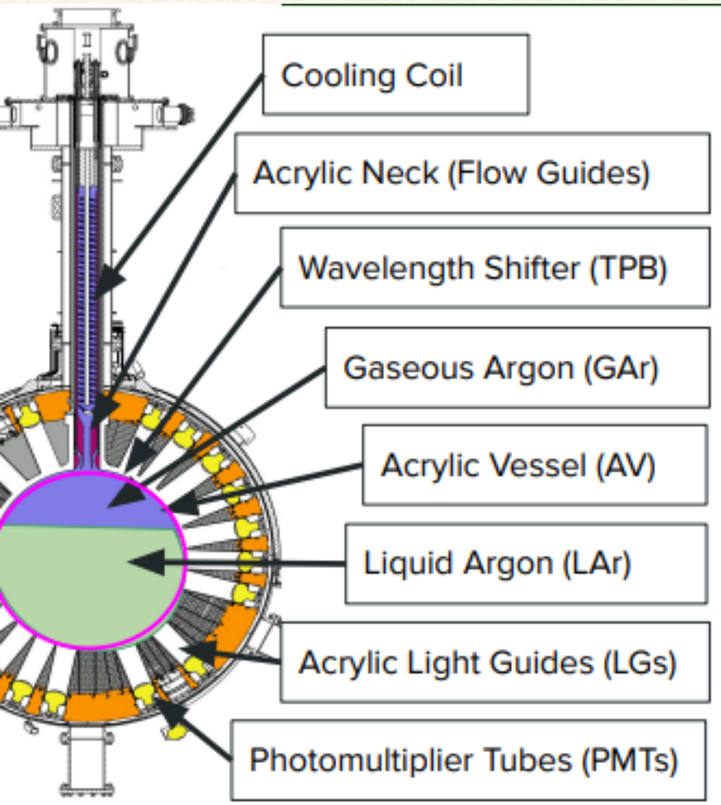


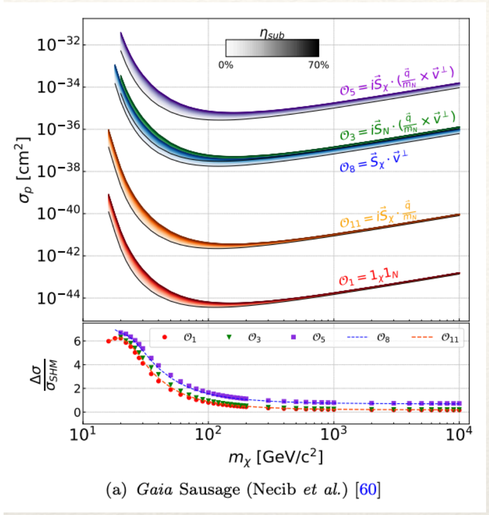
A mosaic of the current CPDs on 2 SuperCDMS towers can get us to DM masses of 100 MeV now and down to 50 MeV if the new prototype has sub-eV resolution

14

Cushman LLWI

DEAP-3600

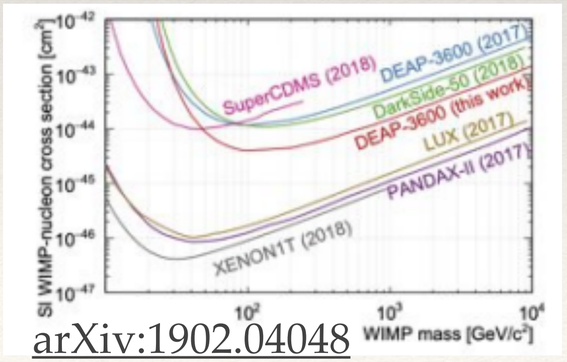




(a) *Gaia* Sausage (Necib *et al.*) [60]

- Single phase Liquid Argon (3.3 t)
- Operating since 2016 at SNOLAB in Canada
- Results:
  - SI and EFT framework limits from 231 live days
  - Planck-scale DM Multi-scatter limits from 813 live-days
- Hardware upgrades coming:
  - Fill to neck
  - tag neck alphas
  - filter dust

arXiv:2005.14667



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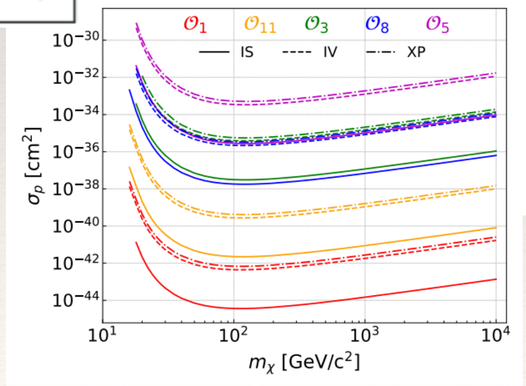
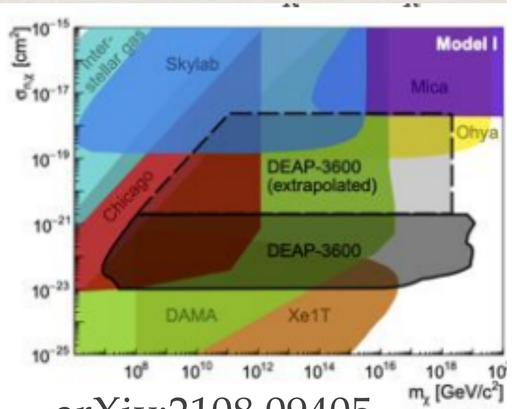
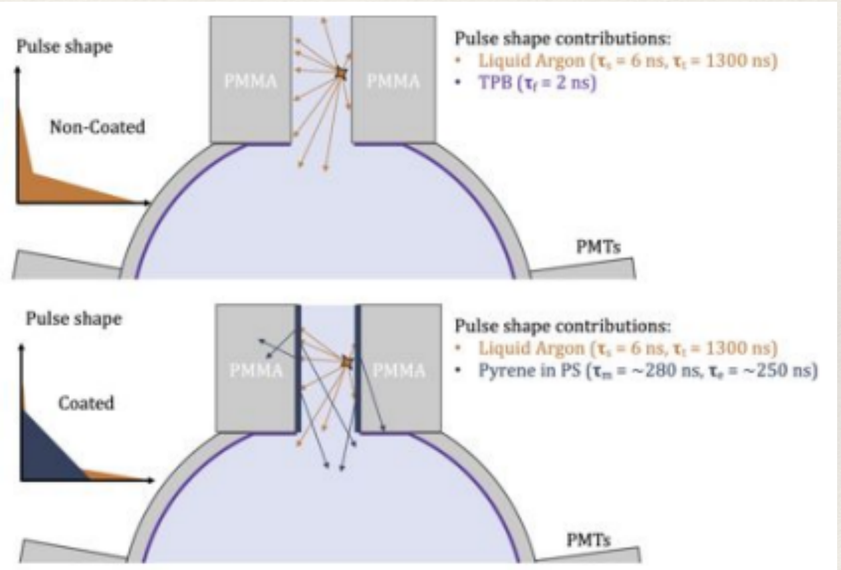




arXiv:2108.09405



- WLS characterization published in JINST
- Technical paper on slow WLS coating for background rejection in LAr submitted to NIMA

Mielnichuk LLWI

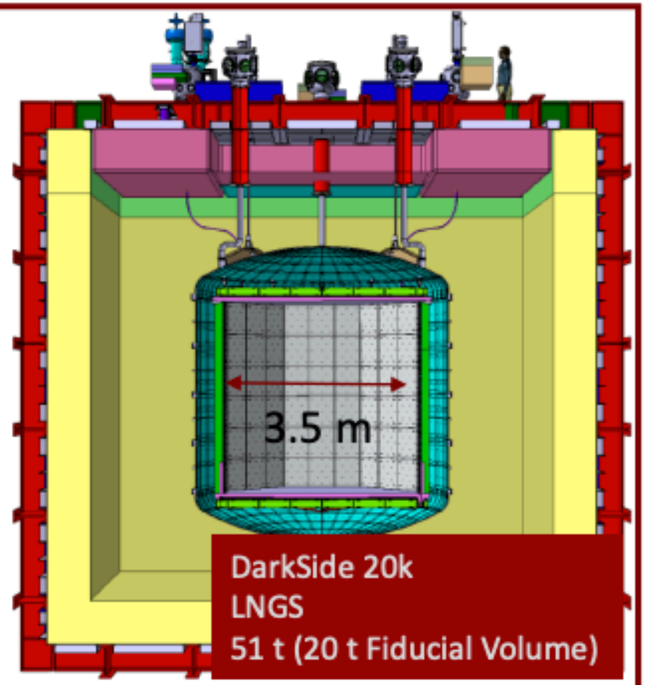
GADM programme

DarkSide 50
LNGS

DEAP 3600
Snolab

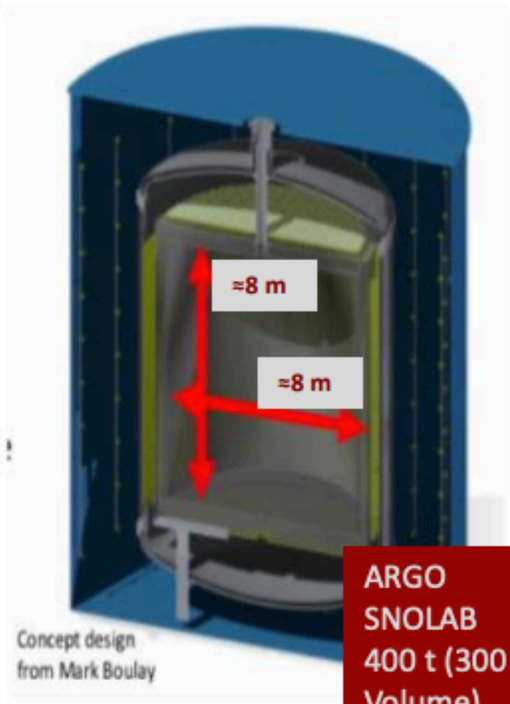
Mini Clean
Snolab

ArDM
Canfranc



DarkSide 20k
LNGS
51 t (20 t Fiducial Volume)

Construction starts in 2022
Data taking from 2025
Nominal run time: 10 years



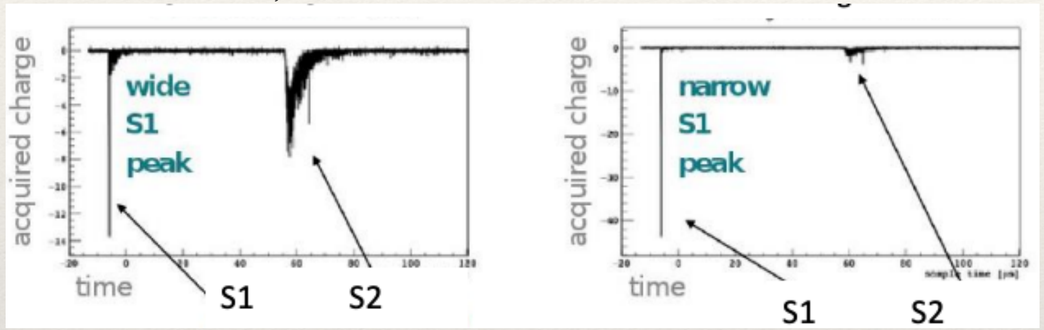
ARGO
SNOLAB
400 t (300 t Fiducial Volume)

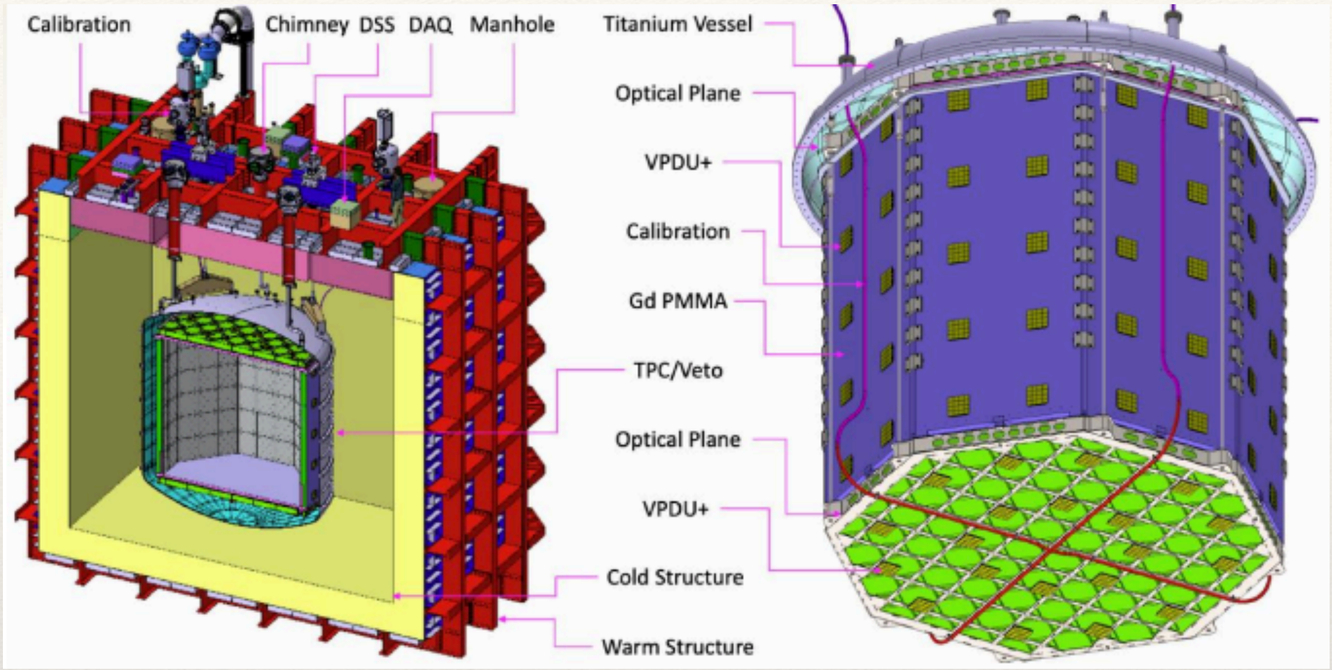
Conceptual studies in progress
Nominal run time: 10 years (3 kt x year)

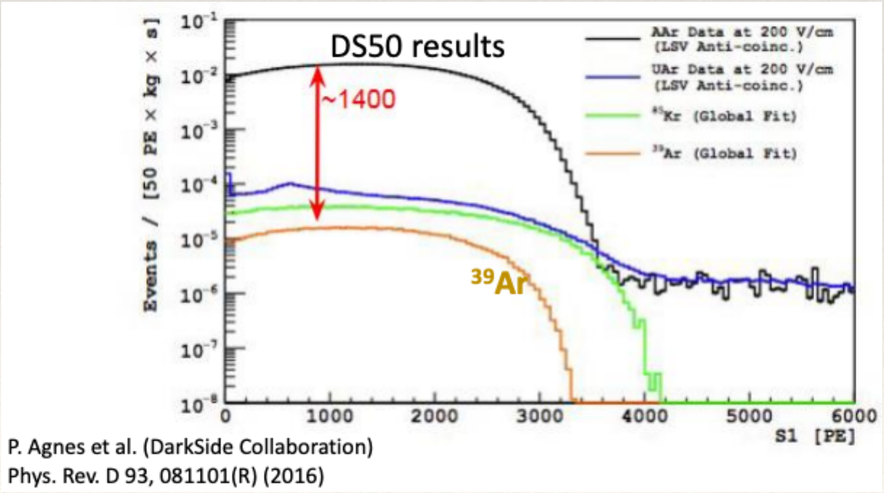
Testera LeptonPhoton21

DarkSide20K

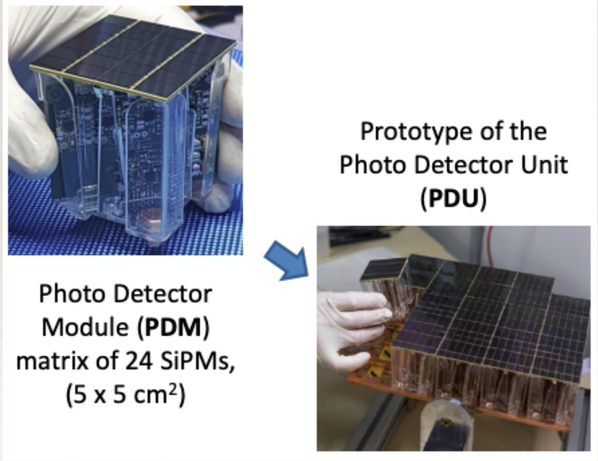
- ~50 t liquid argon time projection chamber
- Under construction at LNGS in Italy
- Innovations in photosensors, underground argon production (reduced Ar-39 background)

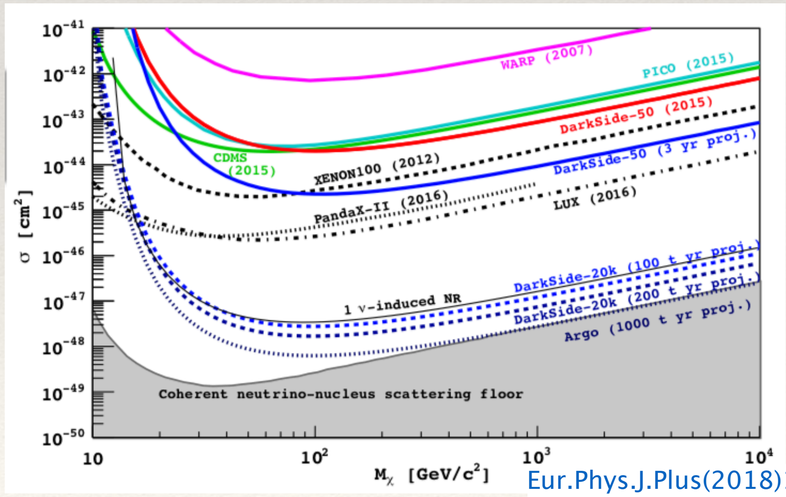






P. Agnes et al. (DarkSide Collaboration)
Phys. Rev. D 93, 081101(R) (2016)



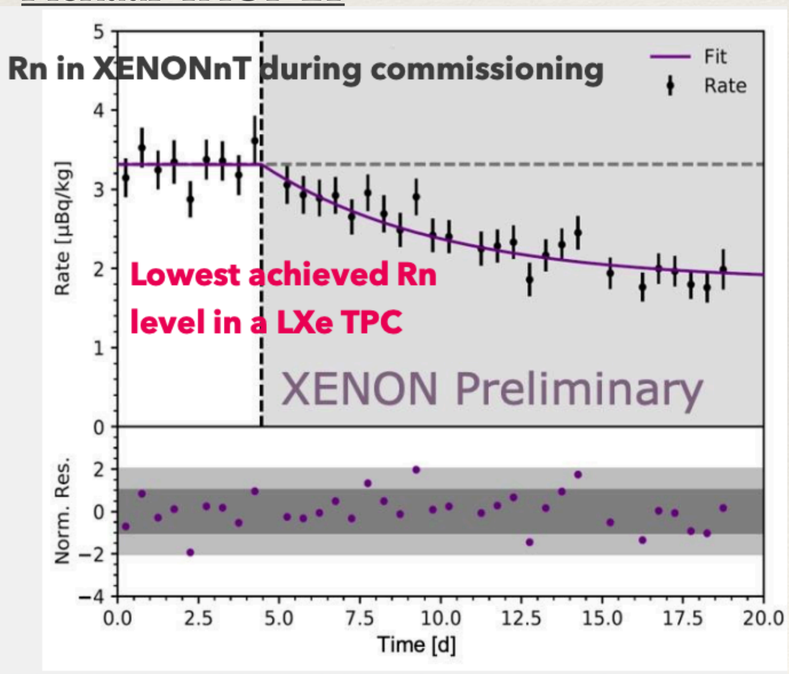


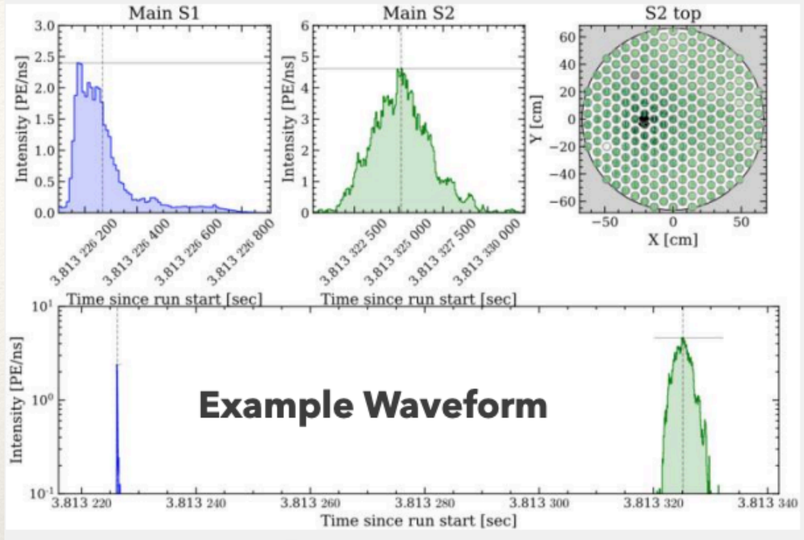
Eur.Phys.J.Plus(2018)133:131

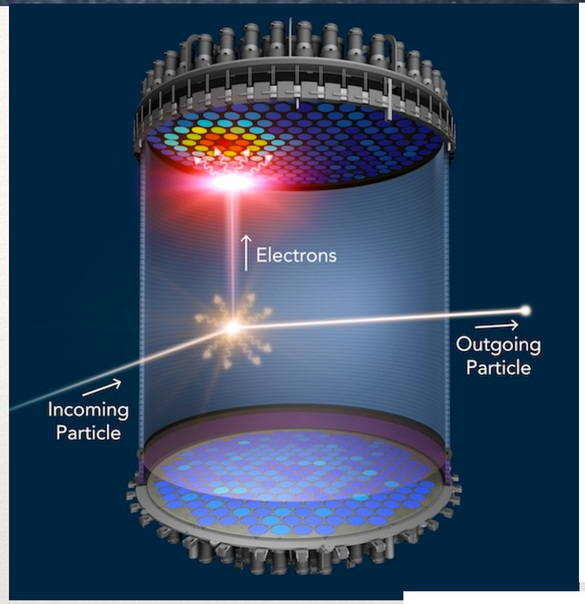
XENONnT

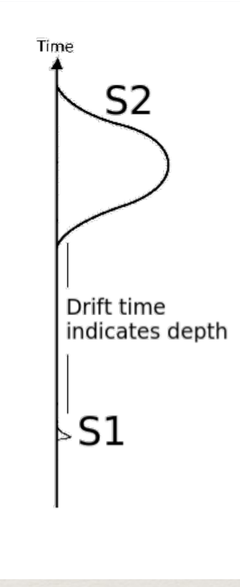
- 5.9 t liquid xenon TPC
- Operating at LNGS in Italy since Sept '21
- Radon/krypton reduction with cryogenic distillation and custom pump
- Drift field is a little low

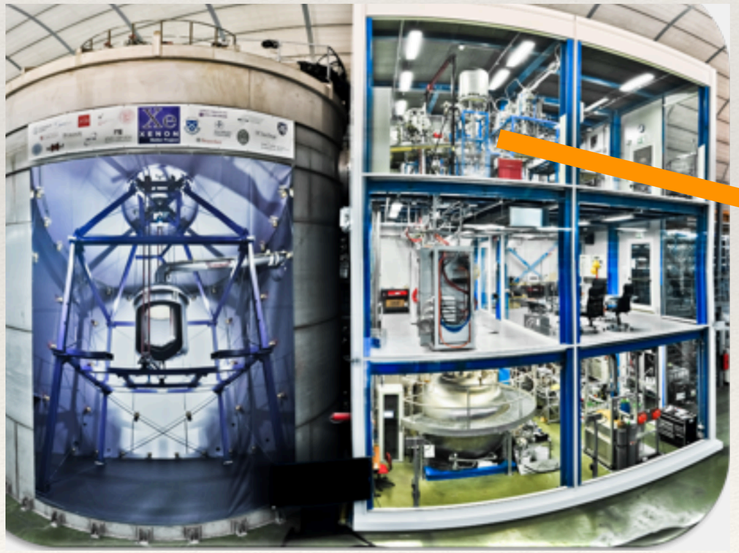
Pienaar TAUP 21

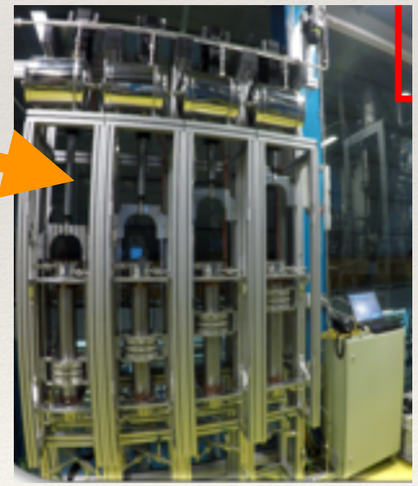


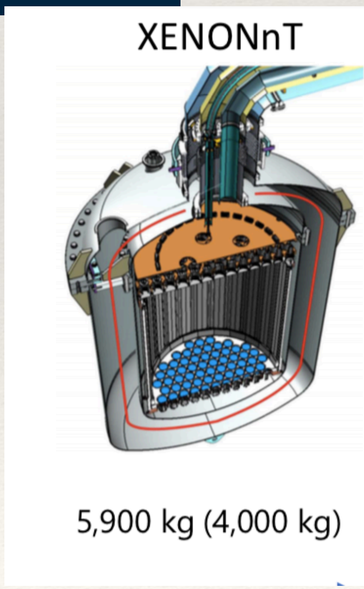




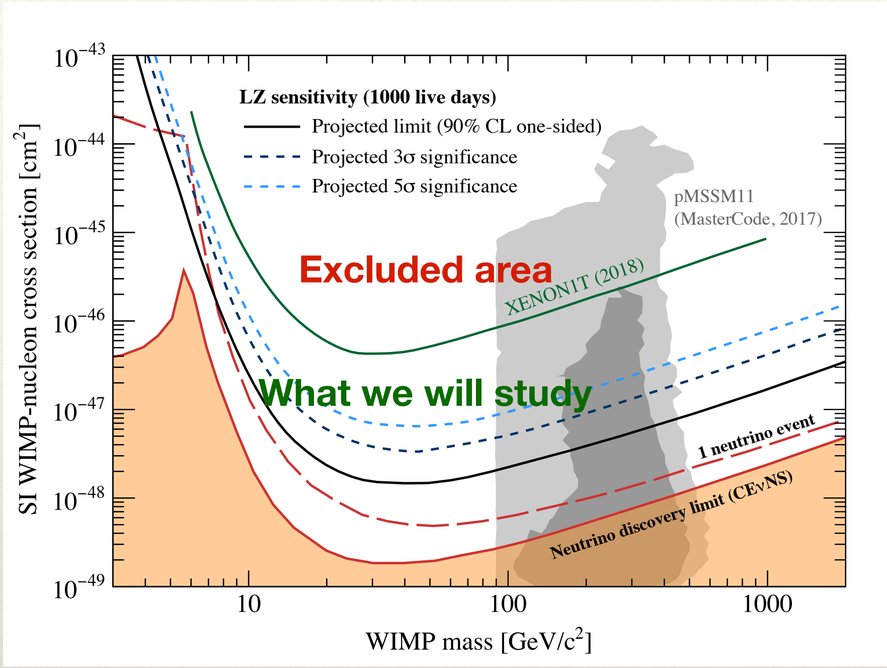




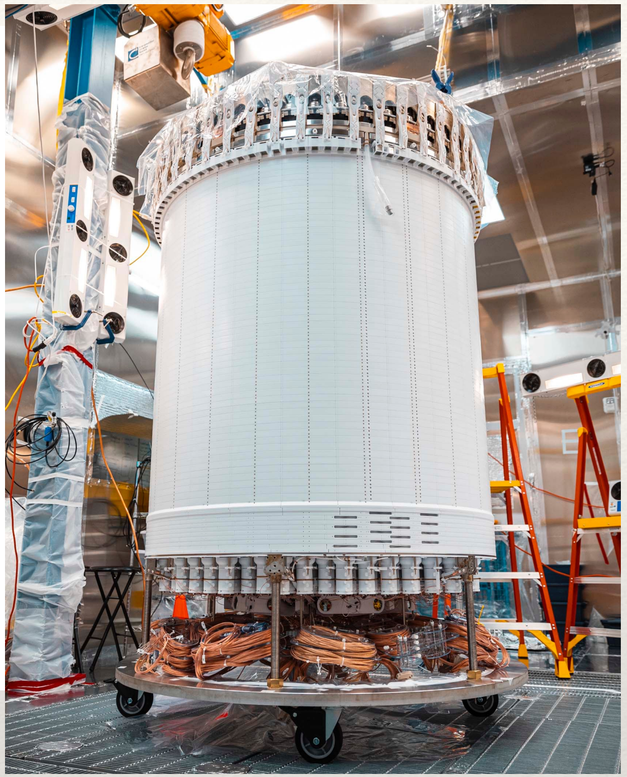


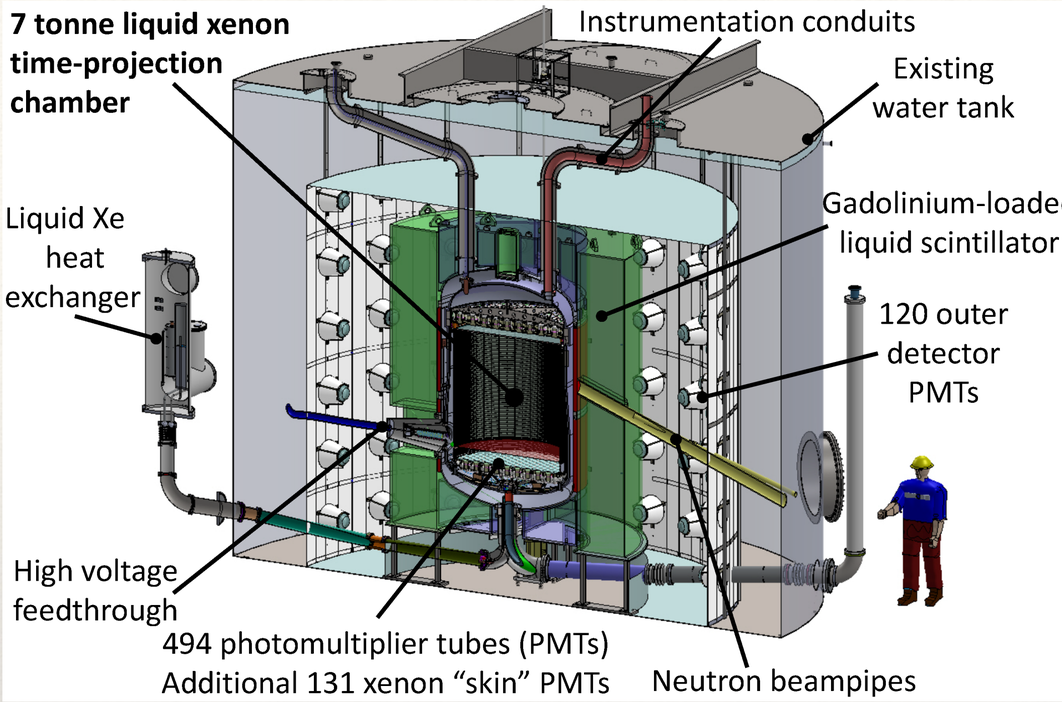


LZ

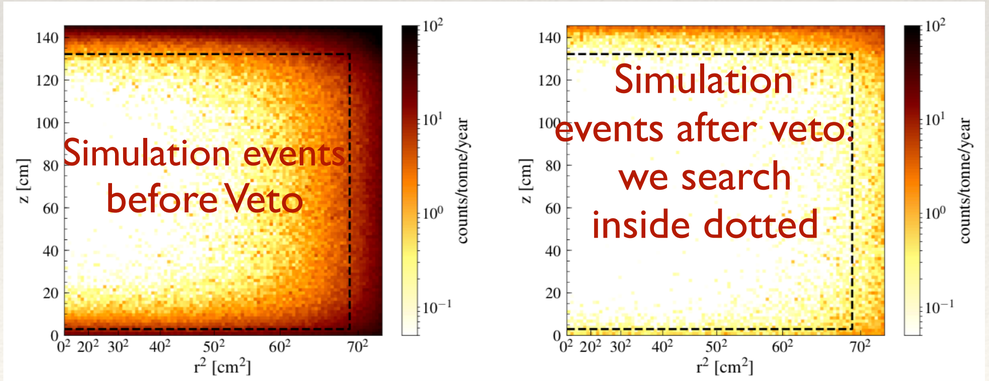


arXiv:1802.06039





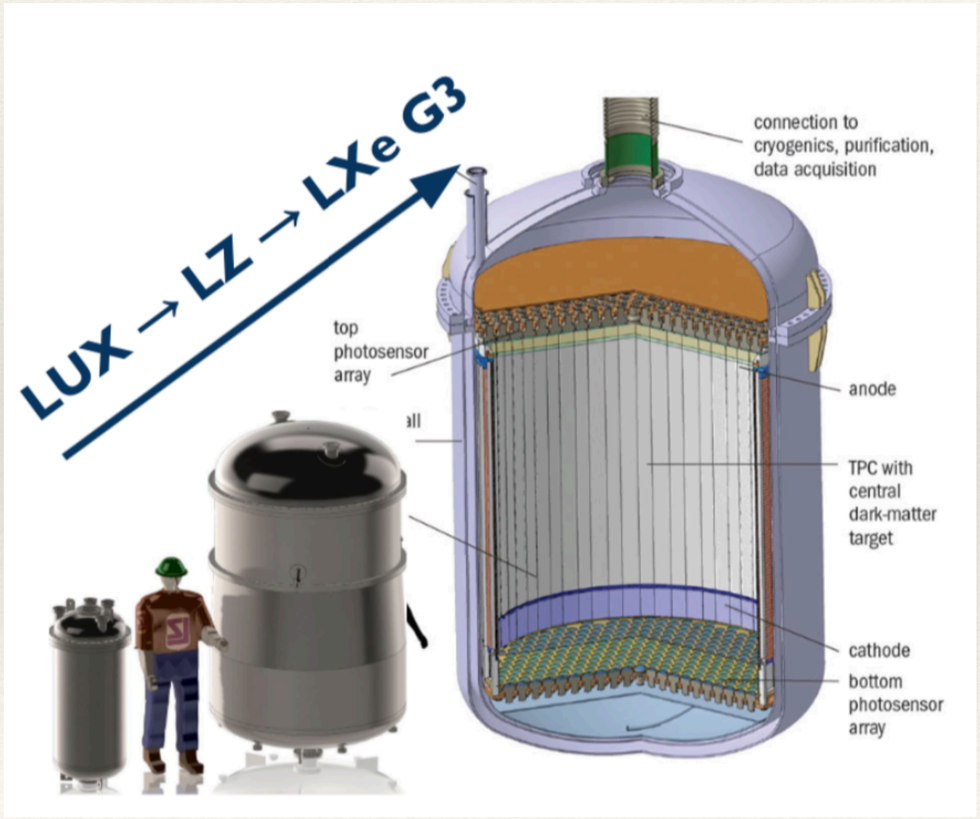
- 10 t liquid xenon
- Operating at SURF in South Dakota USA
- Planned for 1000 live days over ~5 years

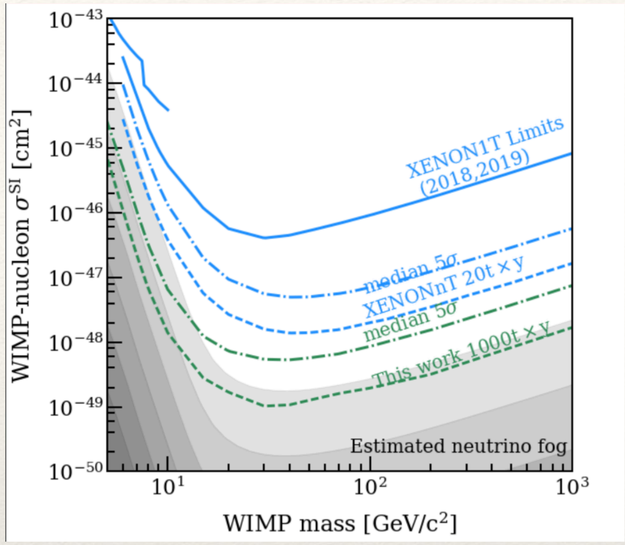


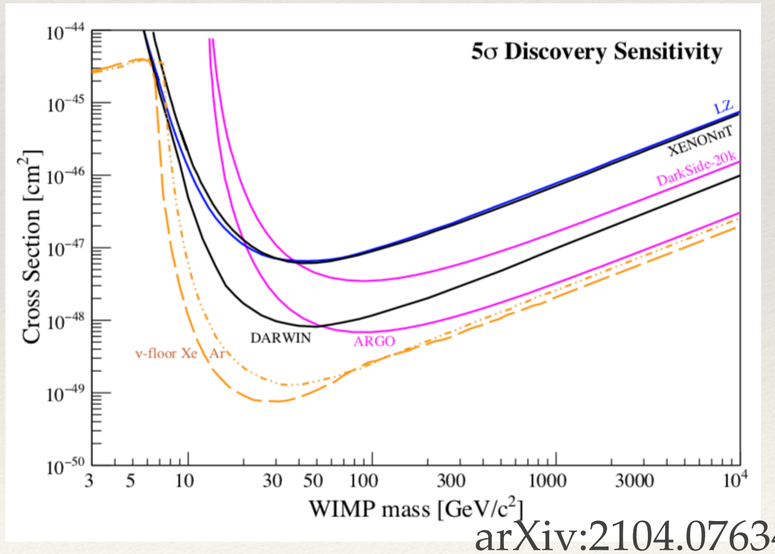
- Many talks in parallels this afternoon and tomorrow

Next Generation Liquid Xenon

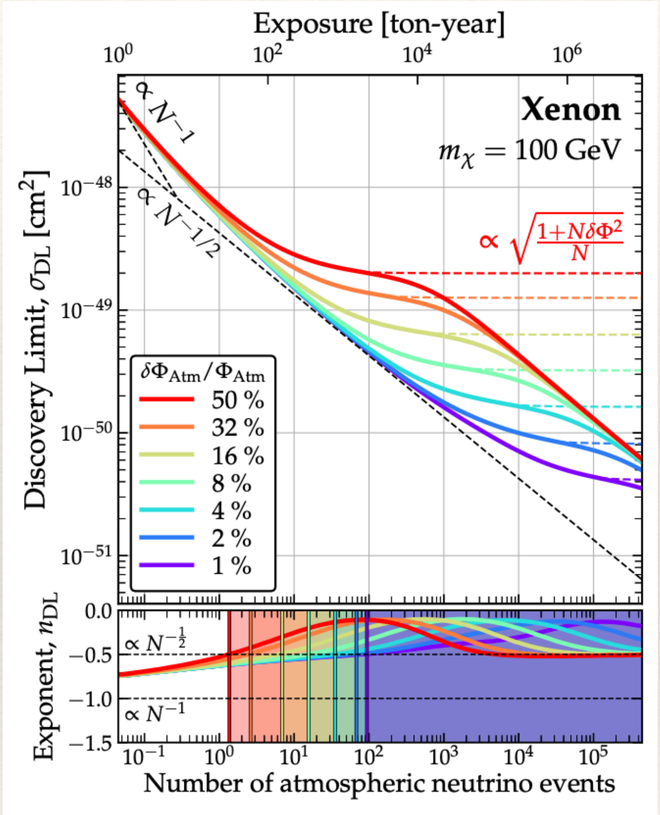
- 50–100 t liquid xenon TPC
- Combination of XENONnT/DARWIN and LZ collaborations
- Location TBD
- Joint workshop last spring, meeting this summer





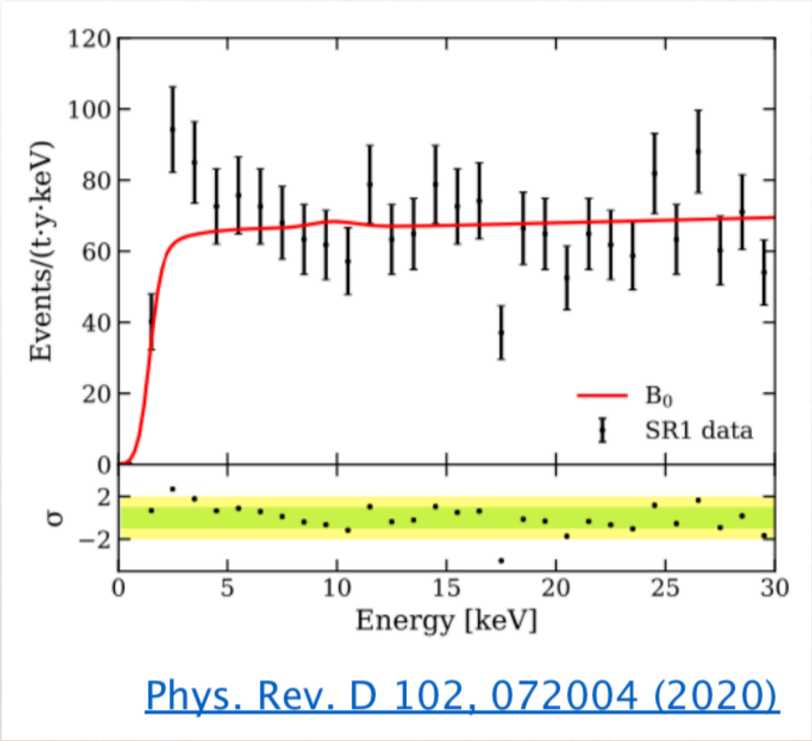


arXiv:2203.02309



arXiv:2104.07634

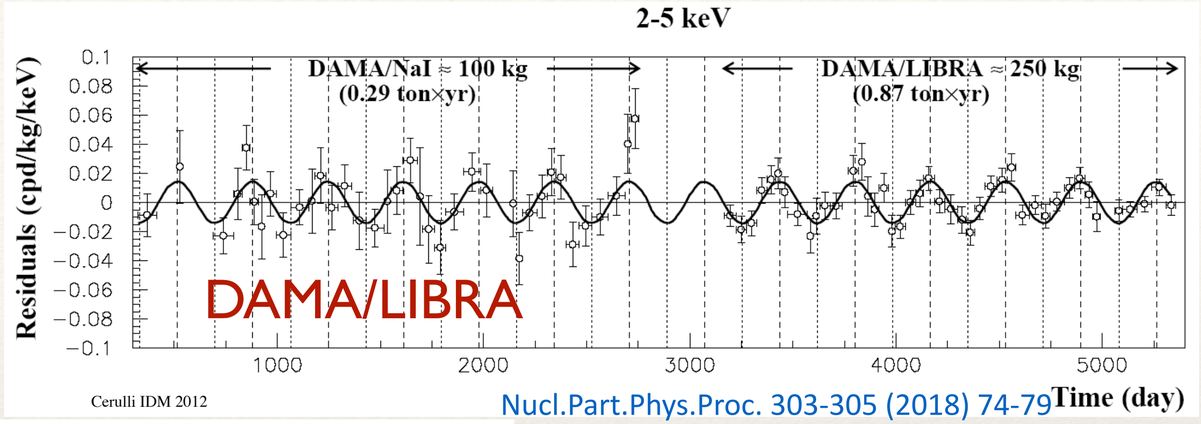
2 Mysteries to follow



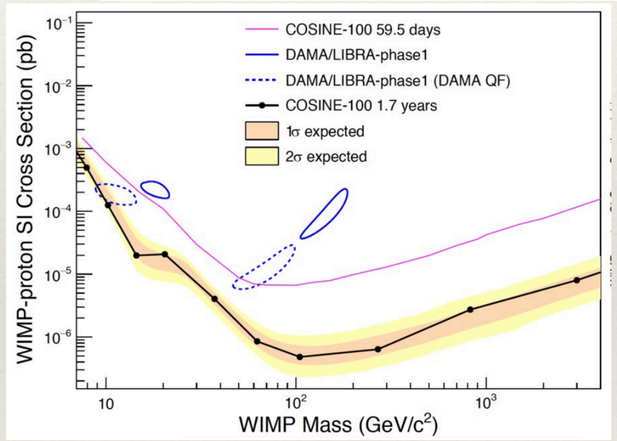
Phys. Rev. D 102, 072004 (2020)

- XENON1T low energy ER excess
- Is is New Physics?
- Is is Ar-37?
- XENONnT and LZ should be able to comment on it, once cosmogenically created Ar-37 decays away

arXiv:2201.02858



Nucl.Part.Phys.Proc. 303-305 (2018) 74-79



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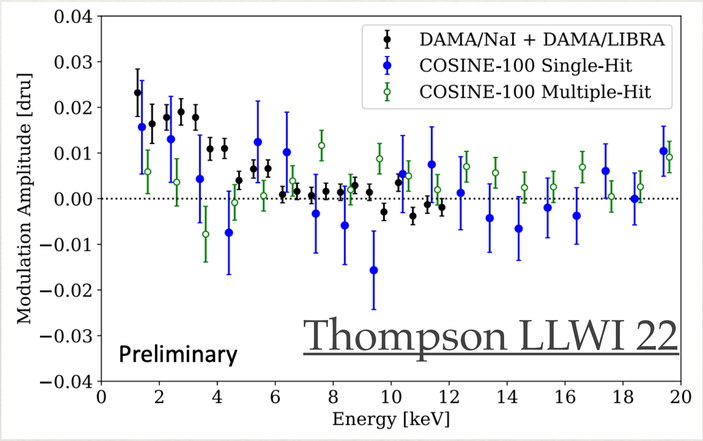
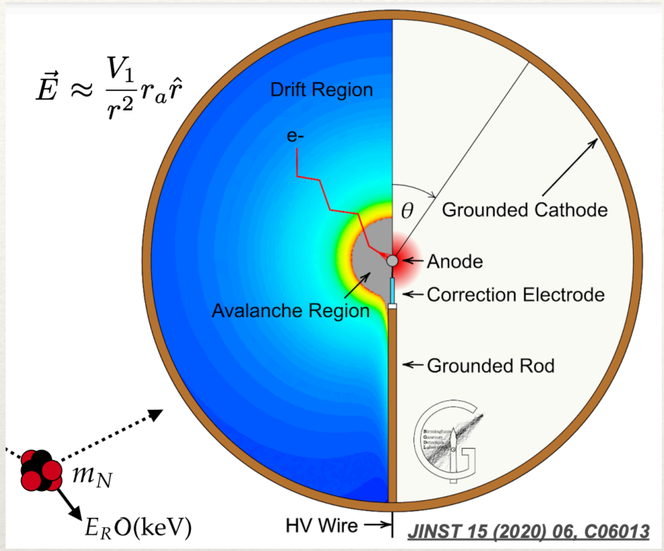


Thompson LLWI 22

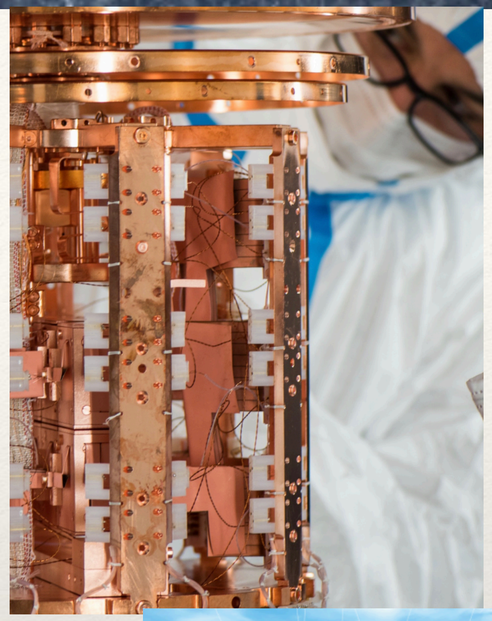
- DAMA/LIBRA 13 sigma annual modulation signal (no ER discrimination)
- COSINE-100 limits with discrimination, annual modulation less clear
- ANAIS and COSINE will continue to run

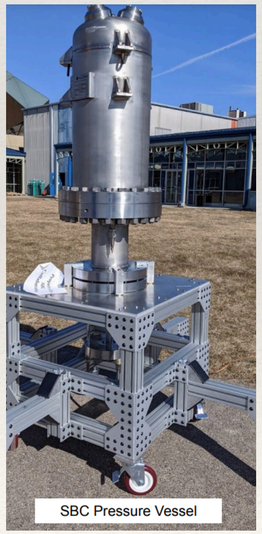
What I didn't get to talk about…

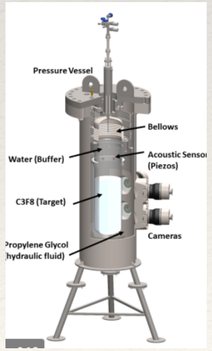


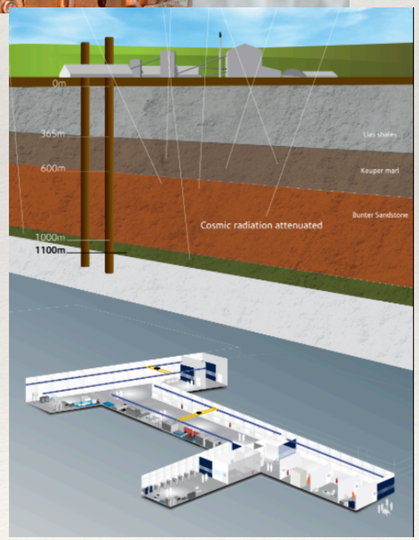
- Mostly low mass DM experiments:
  - NEWS-G
  - PICO
  - SENSEI & other Si
  - SBC
  - TESSERACT
  - QUEST-DMC & other He
  - CRESST & other cryo bolometers
  - Many new ideas
- Boulby Lab

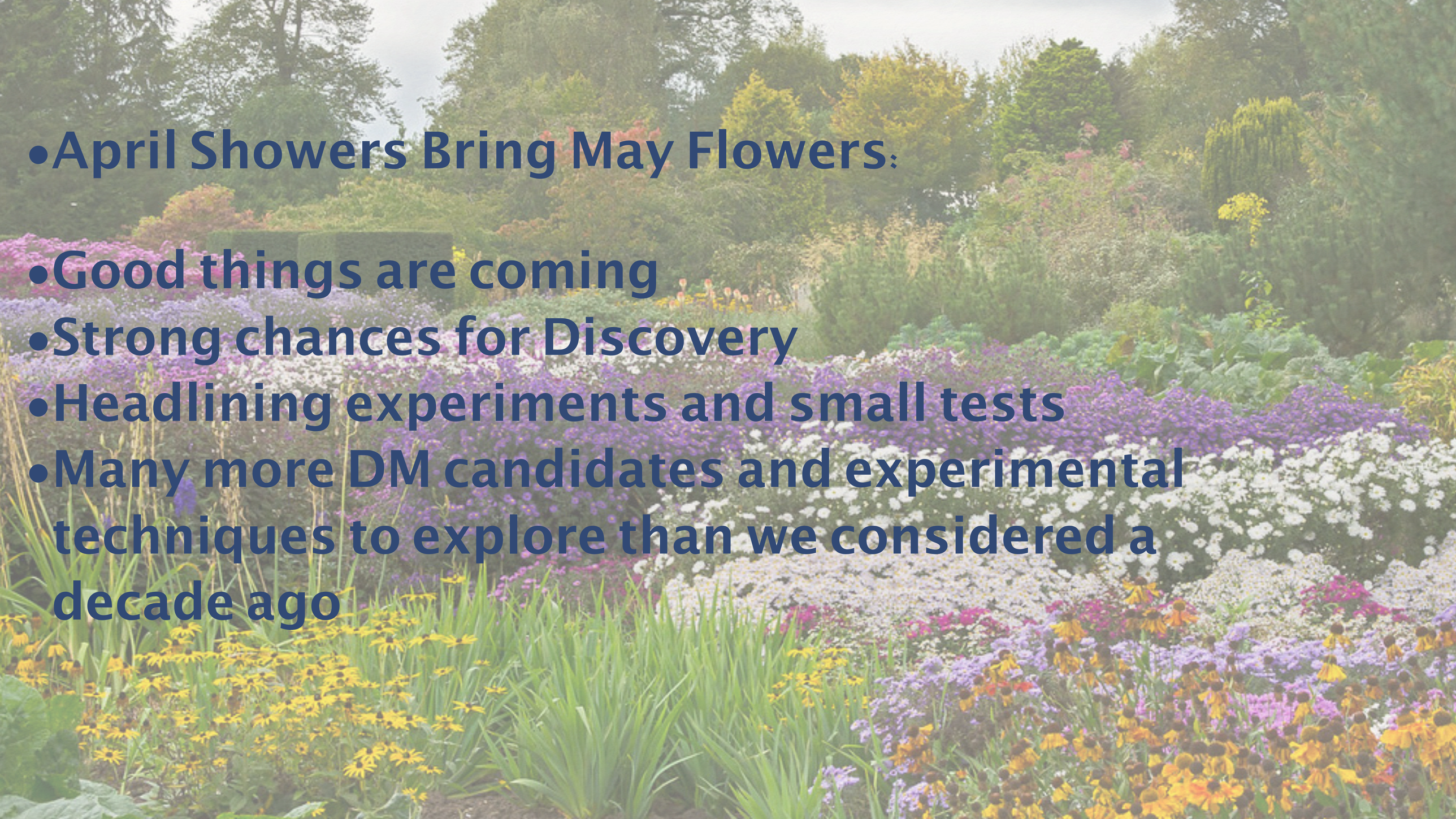
- Other talks and posters on some of these:





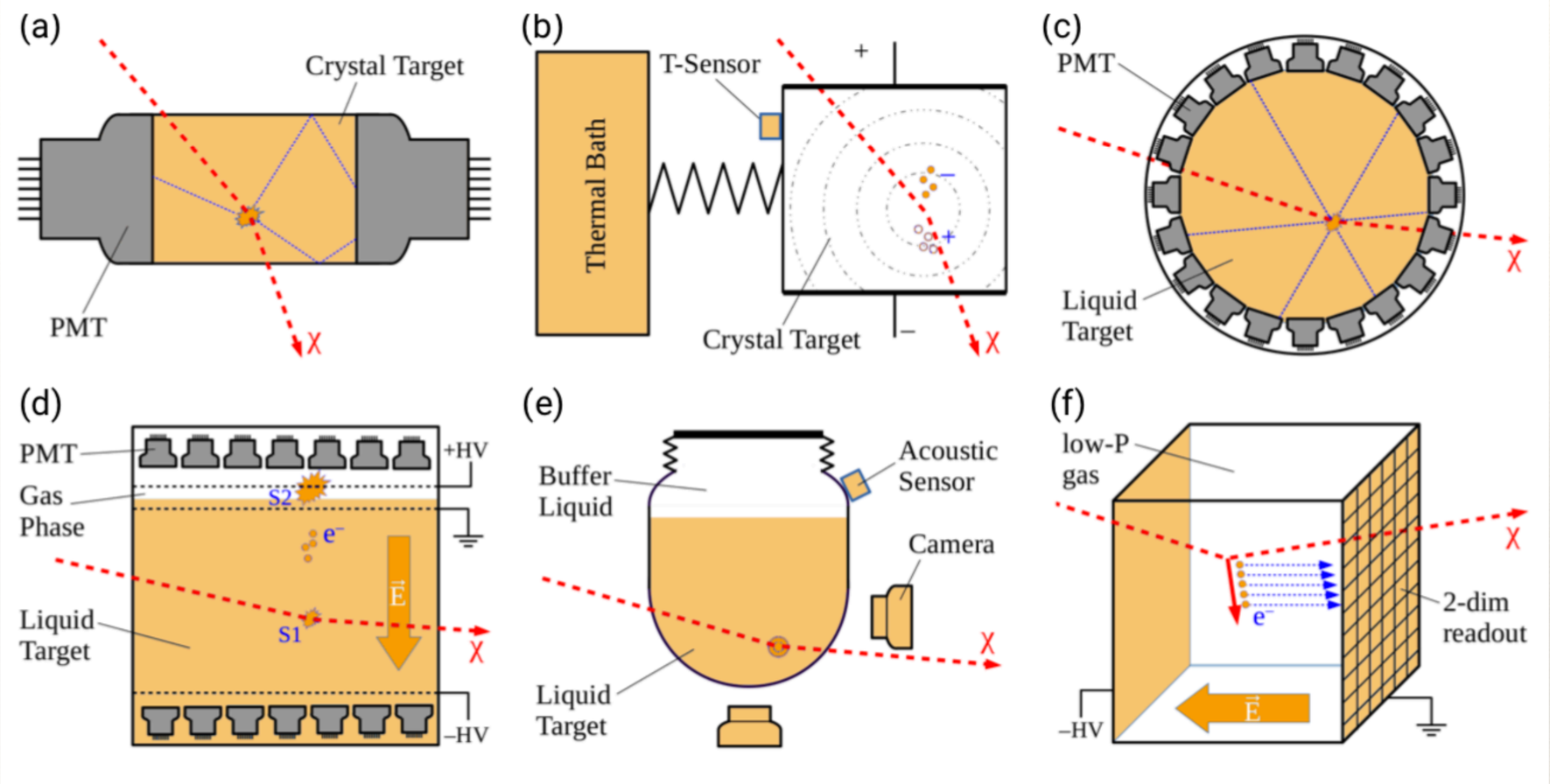




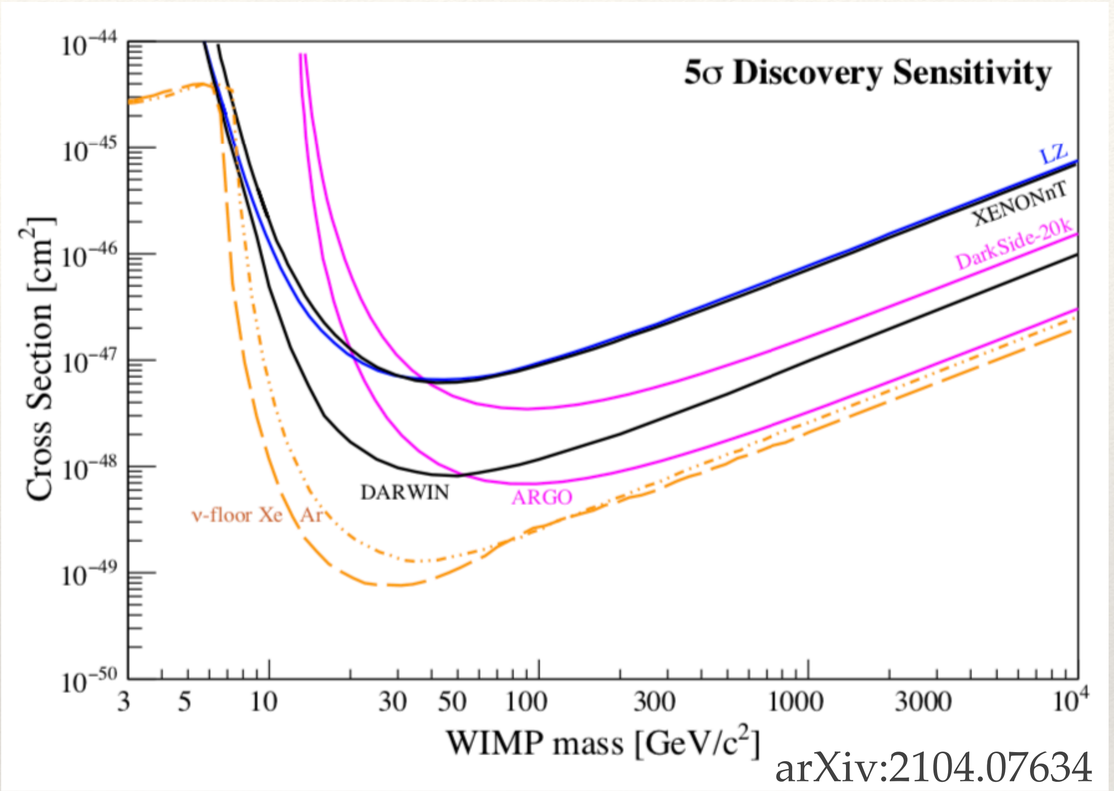


- April Showers Bring May Flowers:

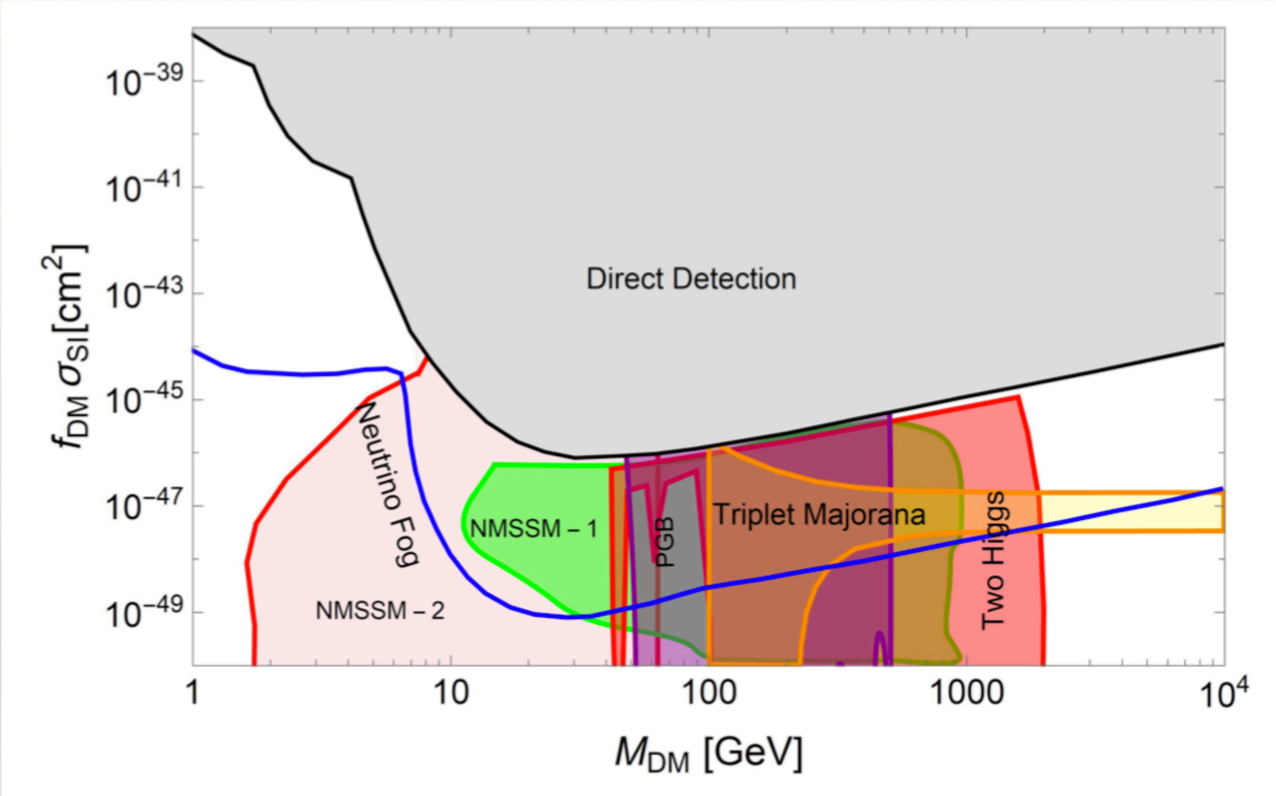
- Good things are coming
- Strong chances for Discovery
- Headlining experiments and small tests
- Many more DM candidates and experimental techniques to explore than we considered a decade ago

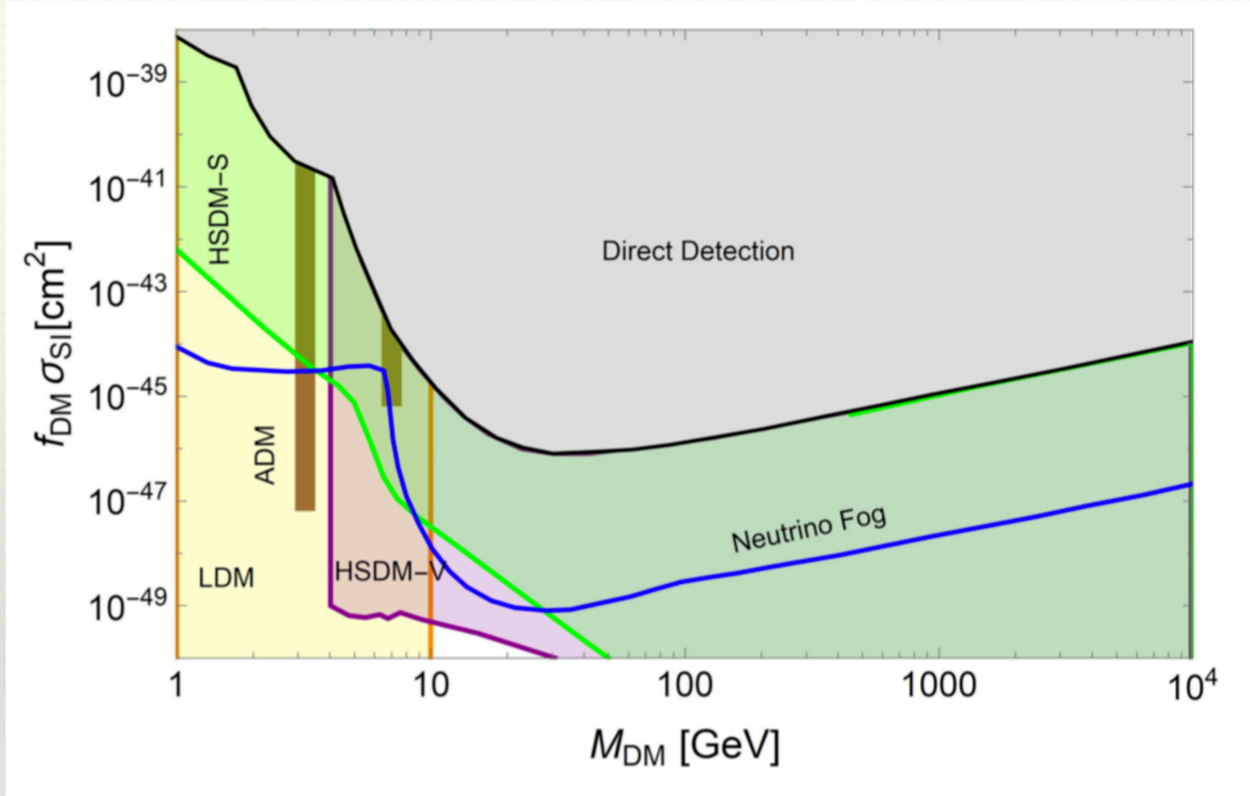


arXiv:2104.07634

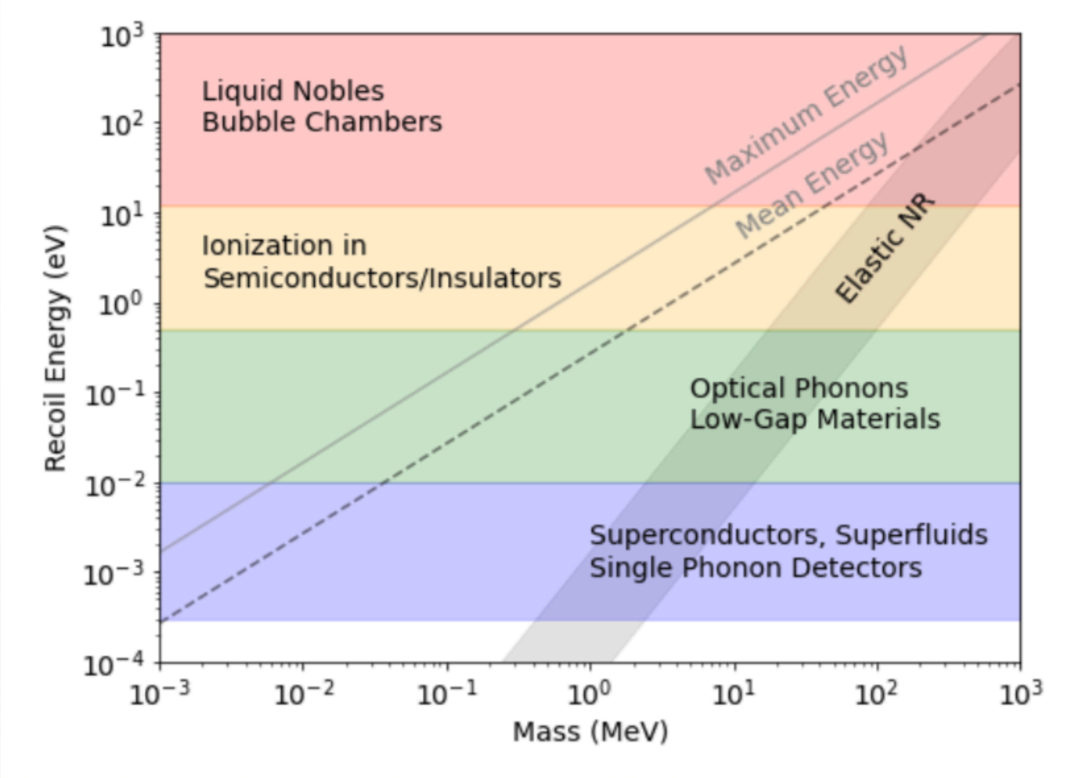

5σ Discovery Sensitivity
Cross Section [cm^2]
WIMP mass [GeV/c^2]
LZ
XENONnT
DarkSide-20k
DARWIN
ARGO
ν-floor Xe
Ar
arXiv:2104.07634

Particle Models to be tested

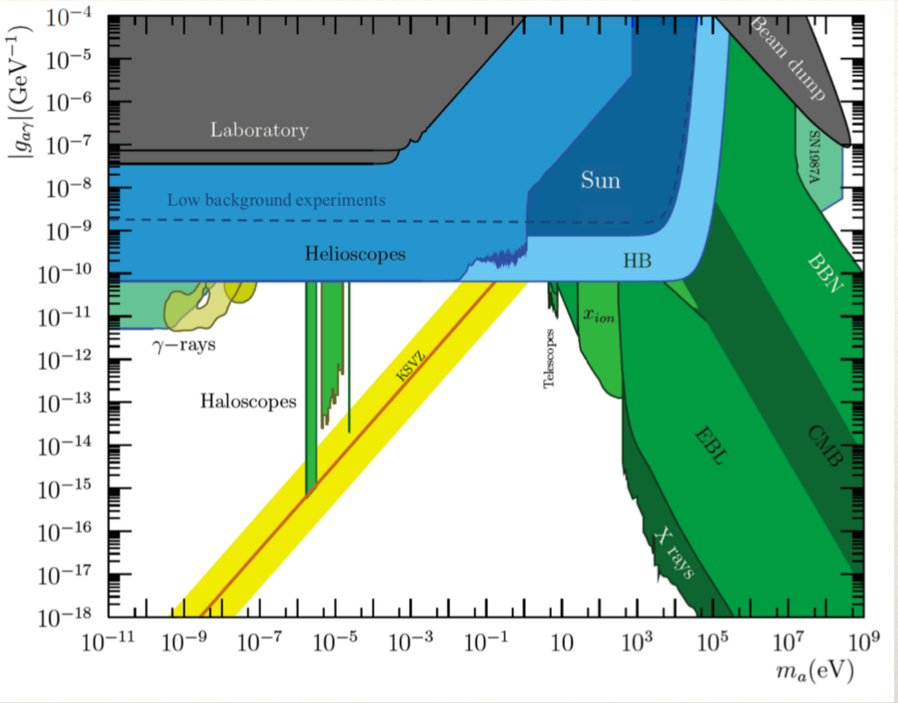




arXiv:2203.08084



arXiv:2203.08297



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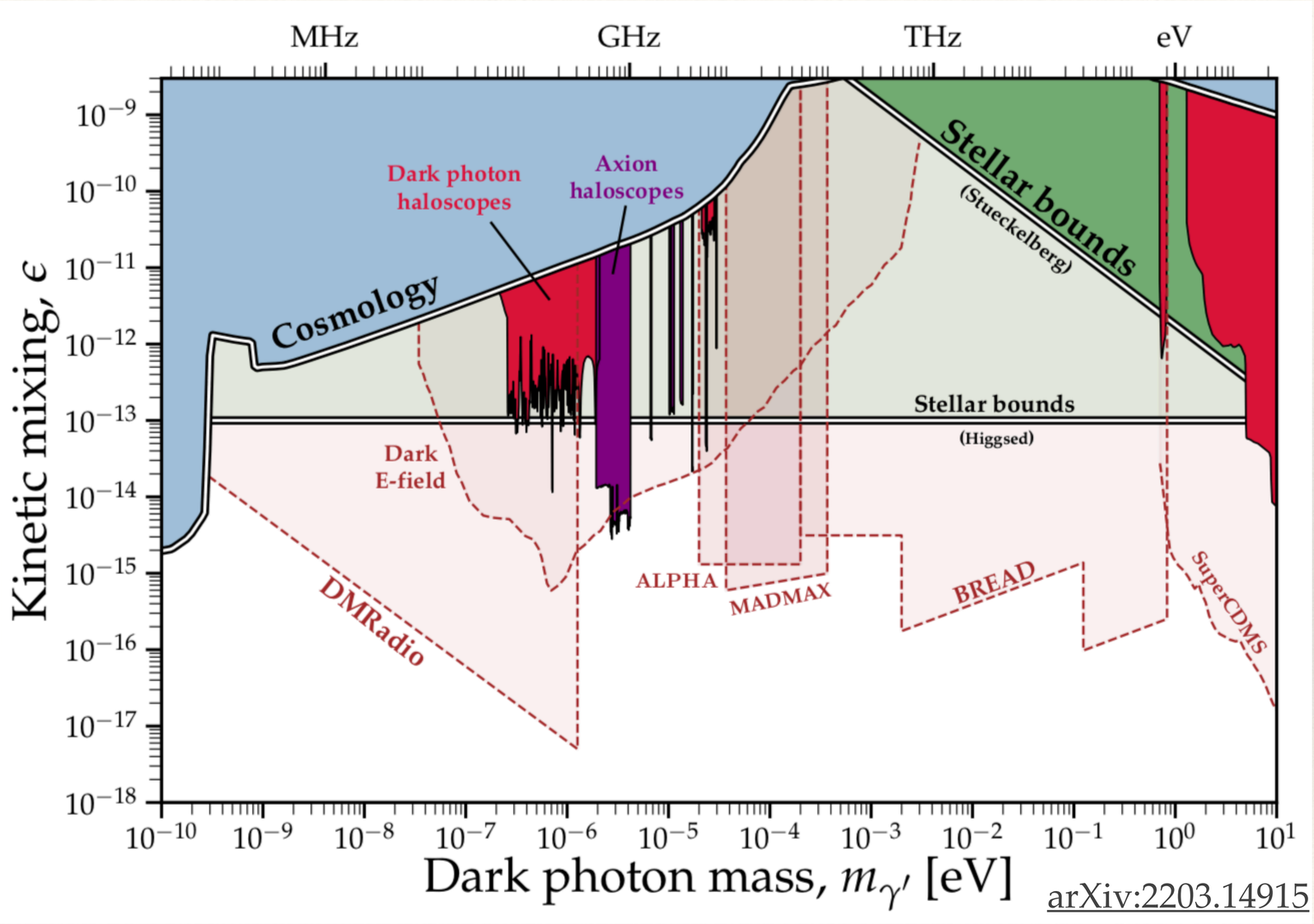
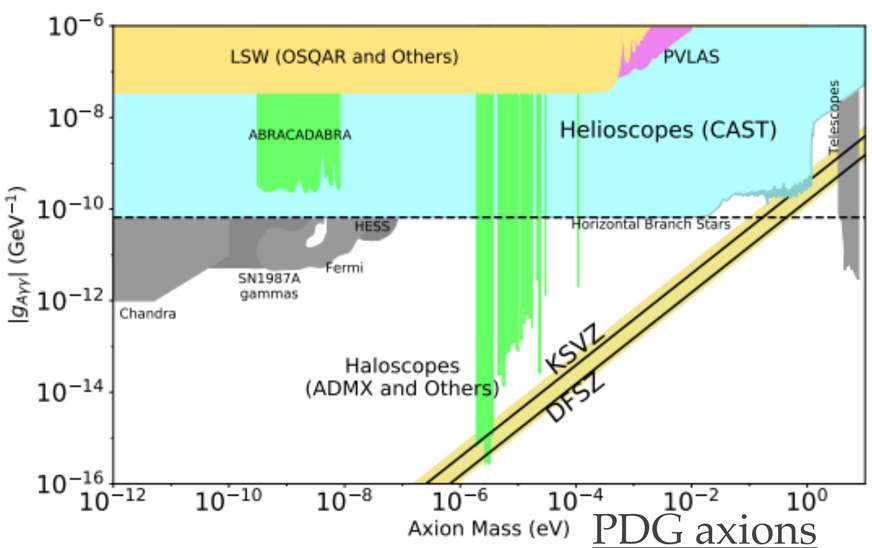
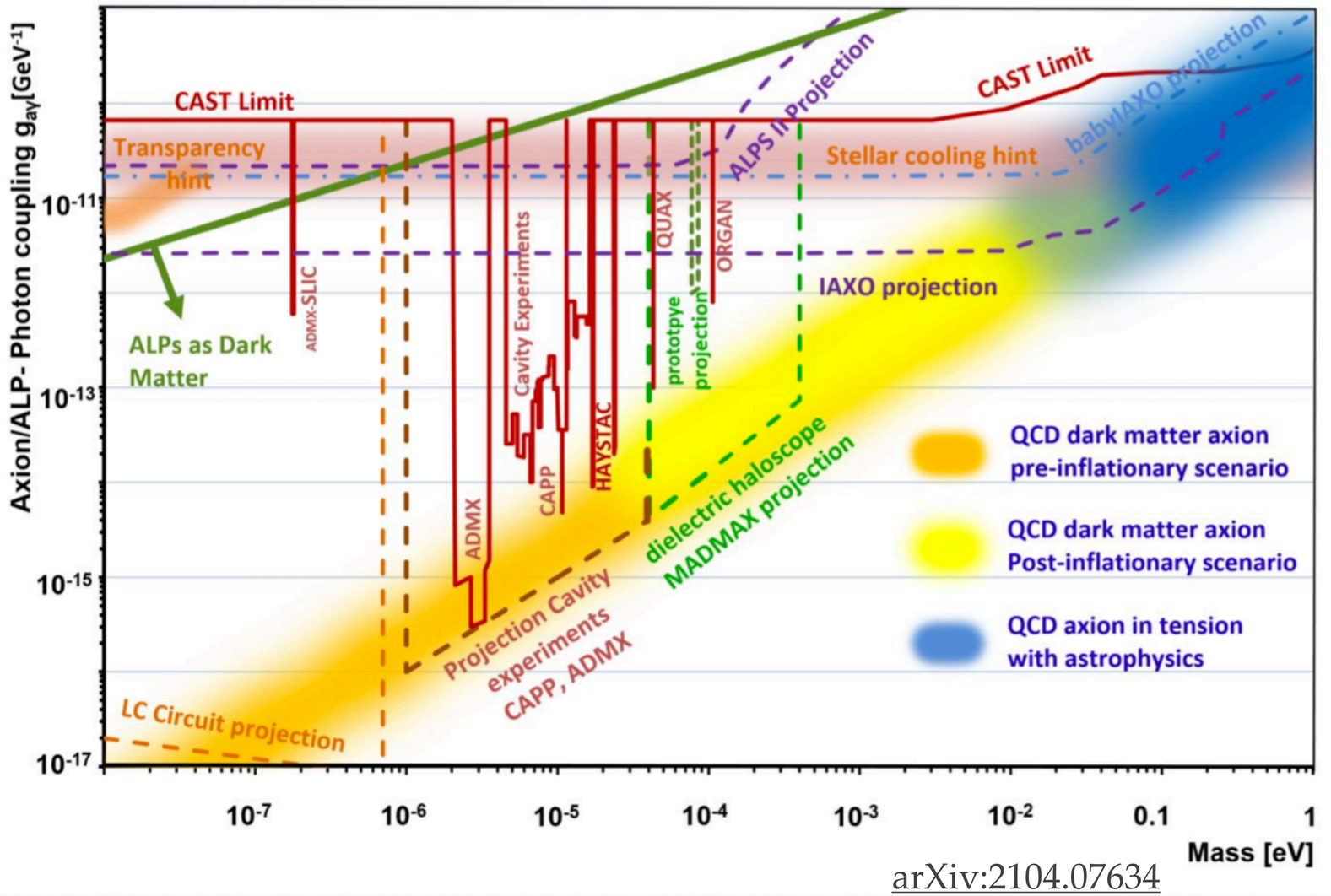


arXiv:2203.14915



PDG axions



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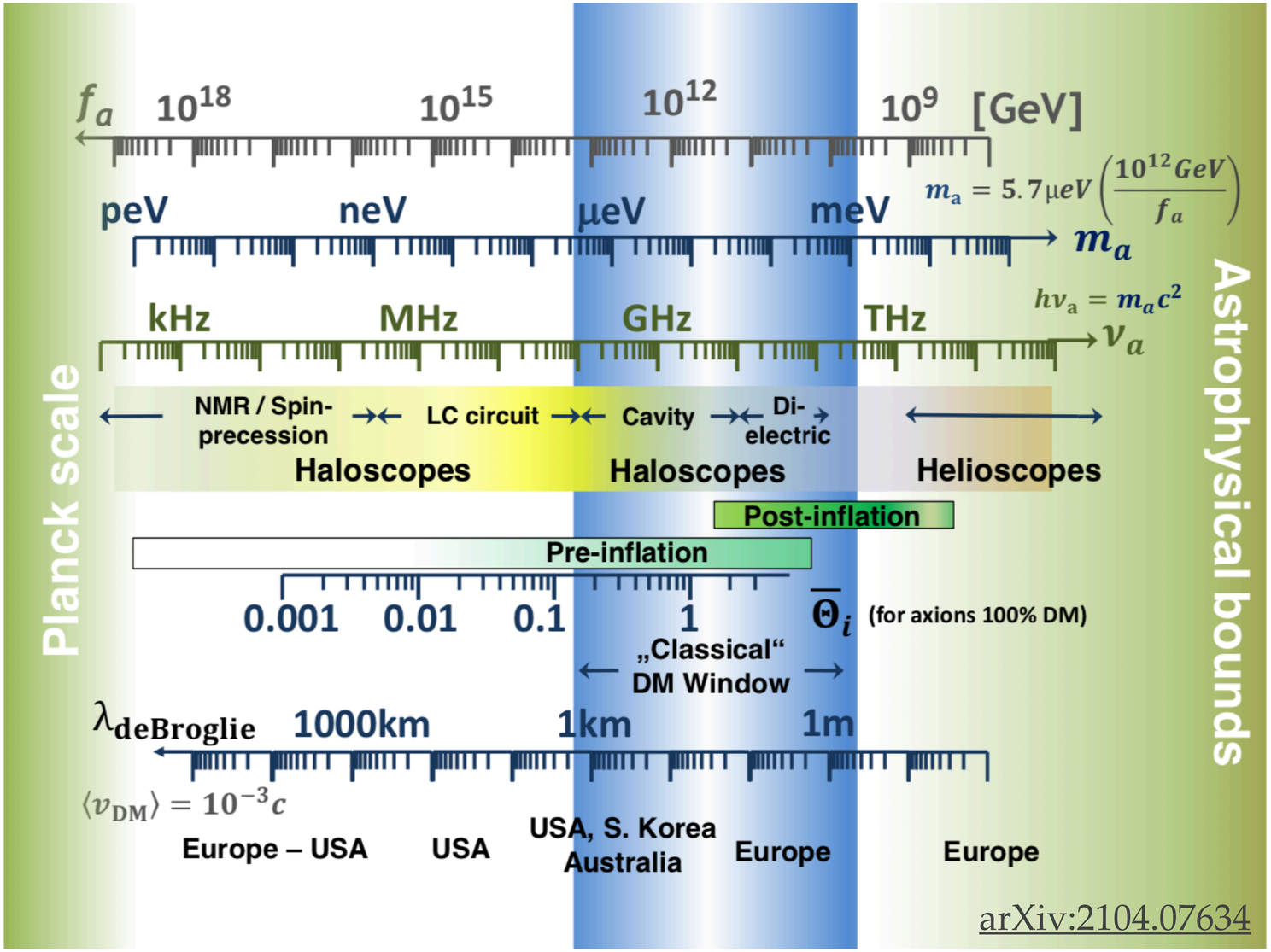
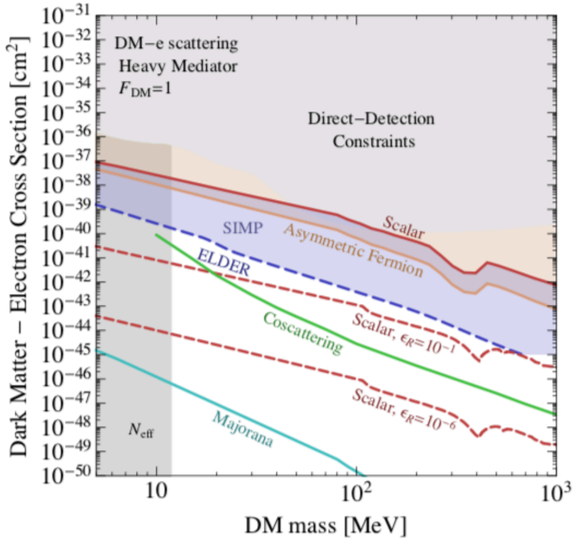
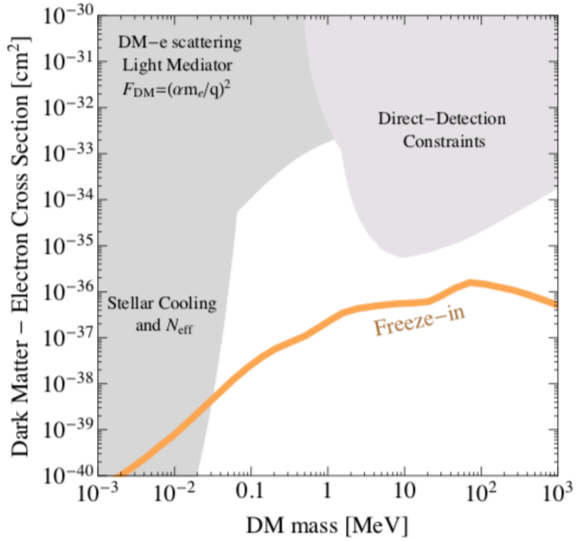
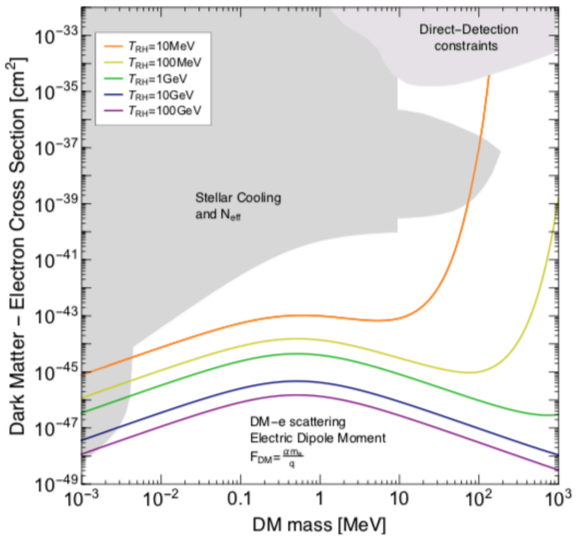
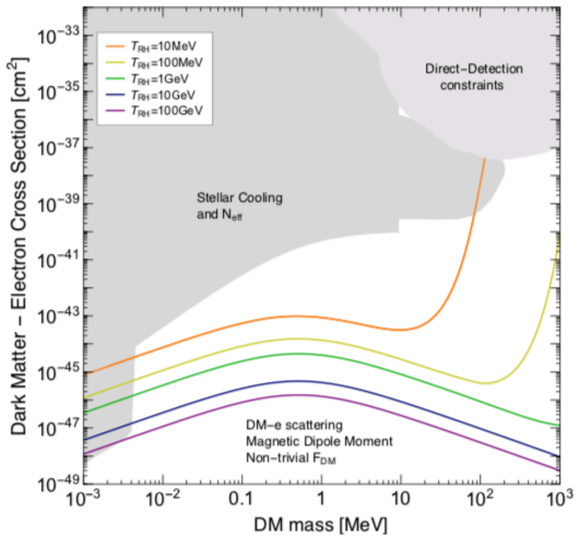
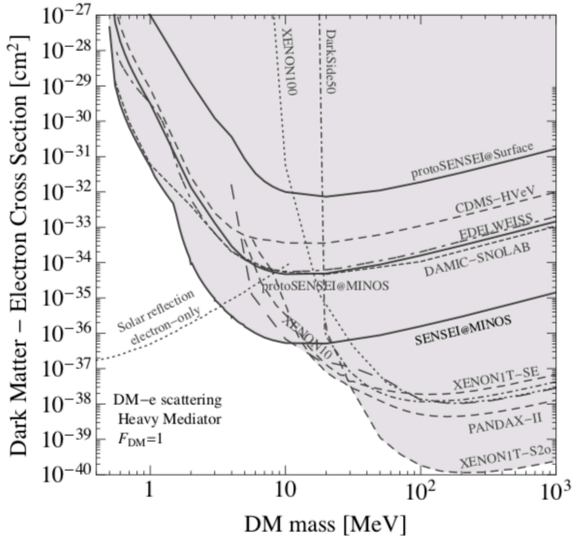

f_a 10^{18} 10^{15} 10^{12} 10^{9} [GeV]
$m_a = 5.7\mu eV\left(\frac{10^{12}GeV}{f_a}\right)$
peV neV μeV meV
m_a
$h\nu_a = m_a c^2$
kHz MHz GHz THz
ν_a
Planck scale
Astrophysical bounds
NMR / Spin-precession
LC circuit
Cavity
Di-electric
Haloscopes
Haloscopes
Helioscopes
Post-inflation
Pre-inflation
0.001 0.01 0.1 1
$\overline{\Theta}_i$
(for axions 100% DM)
„Classical“ DM Window
$\lambda_{deBroglie}$ 1000km 1km 1m
$\langle v_{DM} \rangle = 10^{-3}c$
Europe – USA
USA
USA, S. Korea Australia
Europe
Europe
arXiv:2104.07634

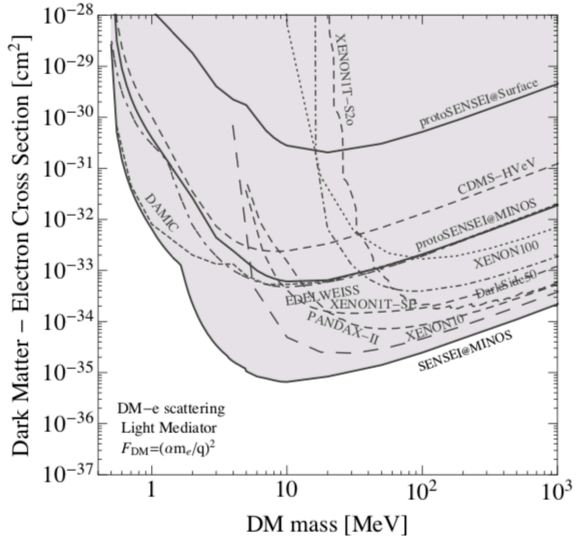


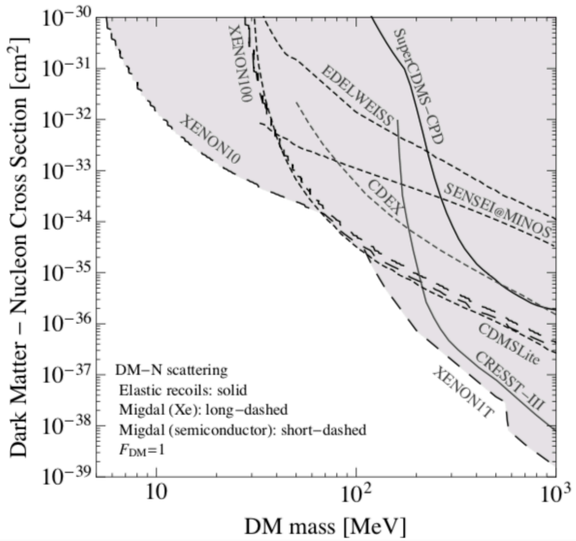


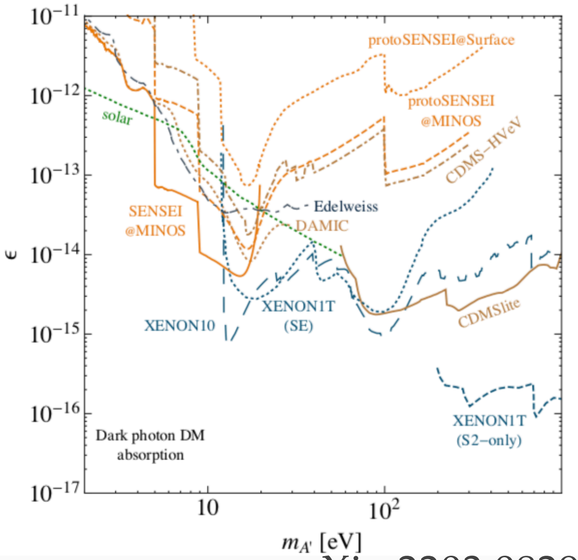




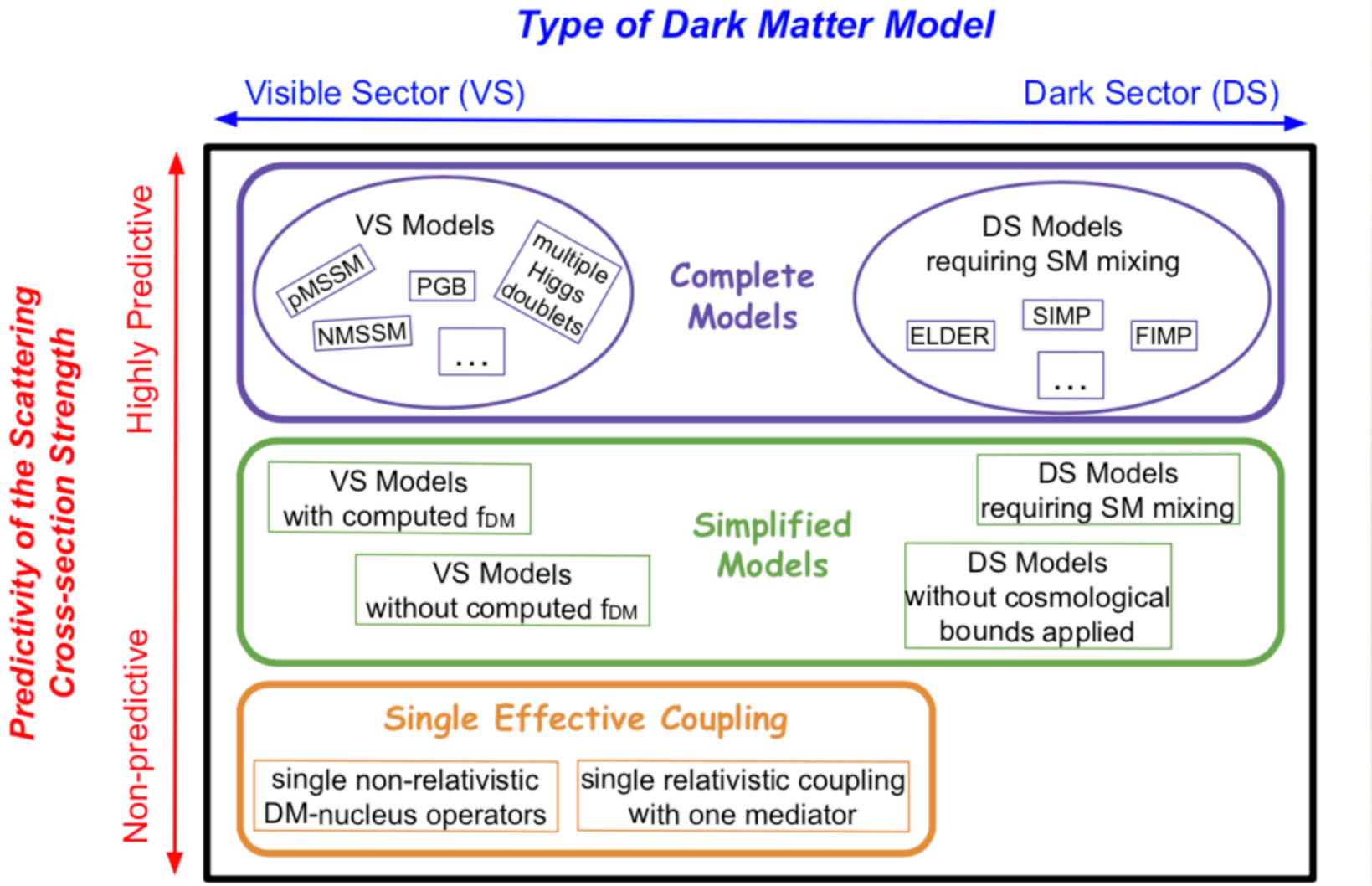






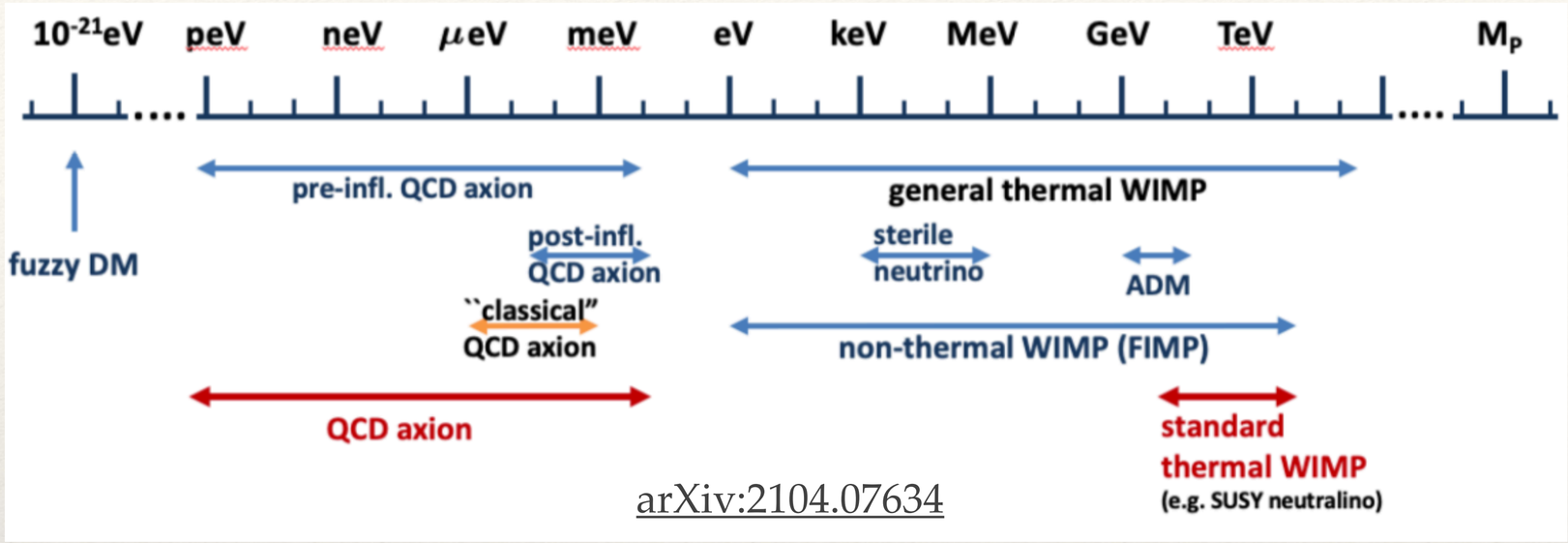


arXiv:2203.08297



arXiv:2203.08084

The Main Options



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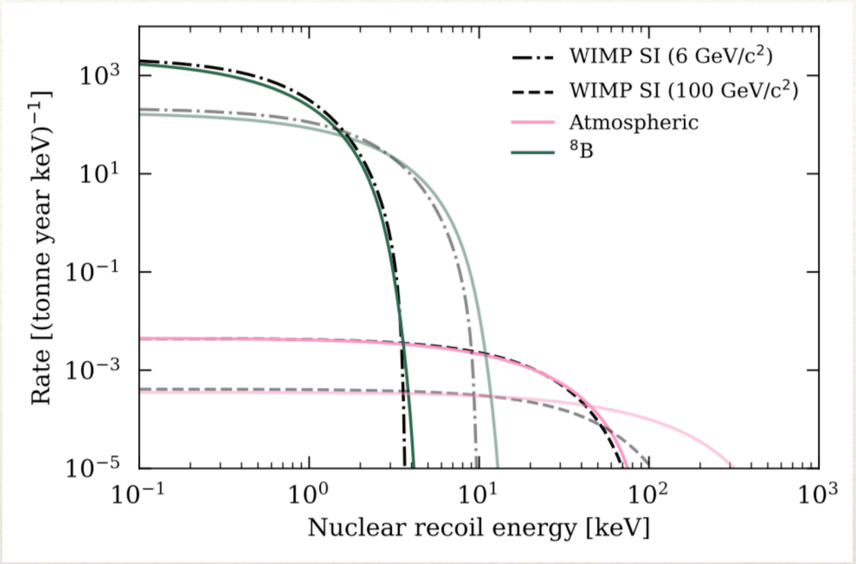

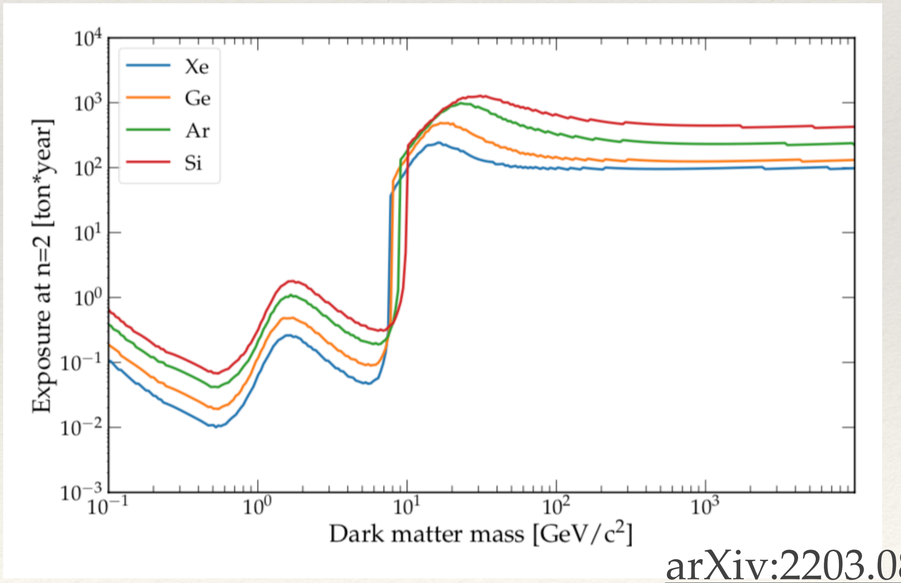

arXiv:2203.08084