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High Energy Physics Group, UCL**



# **Dark Matter Direct Detection**

**IOP Joint APP, HEPP and NP Conference 2021**

**12<sup>th</sup> – 15<sup>th</sup> April**



# Overview

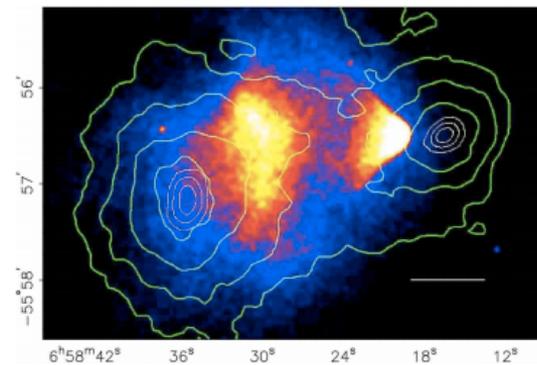
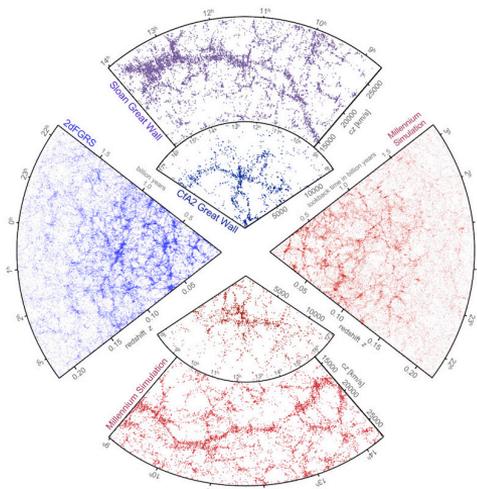
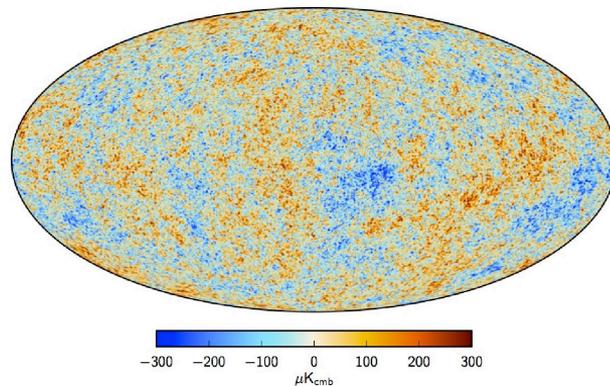
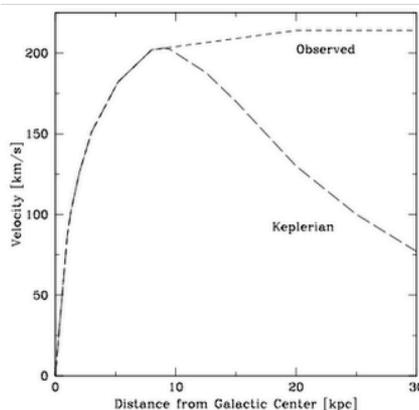
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- Recap DM candidates and DD
- Model independent tests DAMA/LIBRA excess
- Liquid nobles: LAr, LXe-TPCs
- Cryogenic searches
- Axion searches

# Evidence for Dark Matter at many scales

- Dark Matter dominated universe: 84.4% of the matter content
- Local density
- We know it's there but what is it?

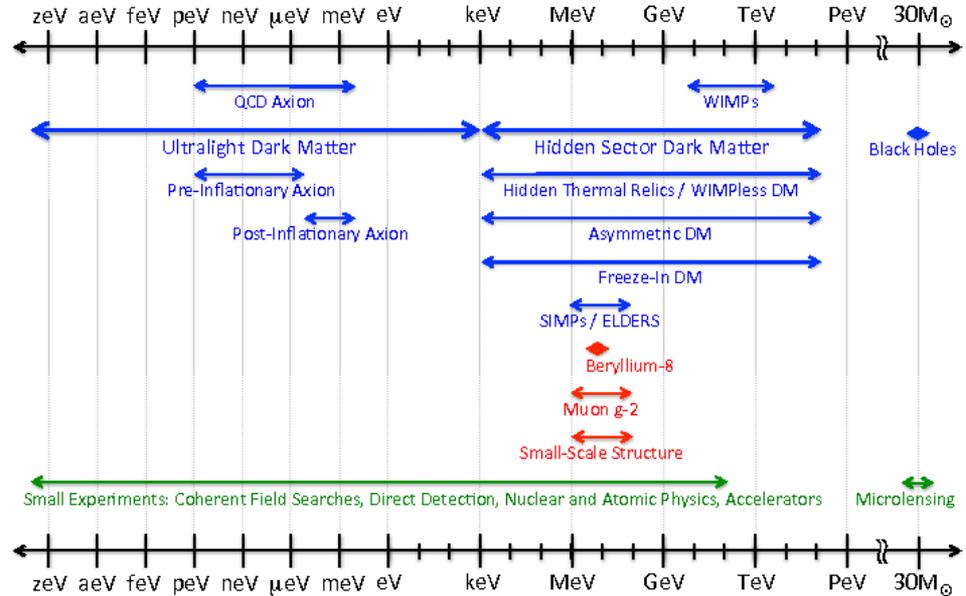
Rotation curves of galaxies



# Dark Matter Candidates

- Consistent with relic density? Cold? Neutral? Limits on self-interactions?
- ...
- DD focus to date on WIMPs , Axions as well motivated candidates

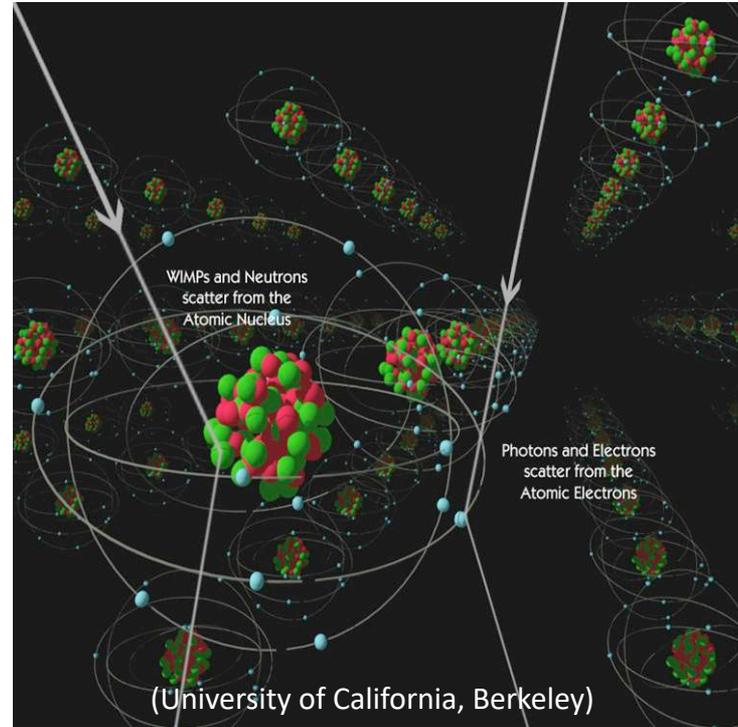
## Dark Sector Candidates, Anomalies, and Search Techniques



[US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report](#)

# Direct Detection Galactic DM

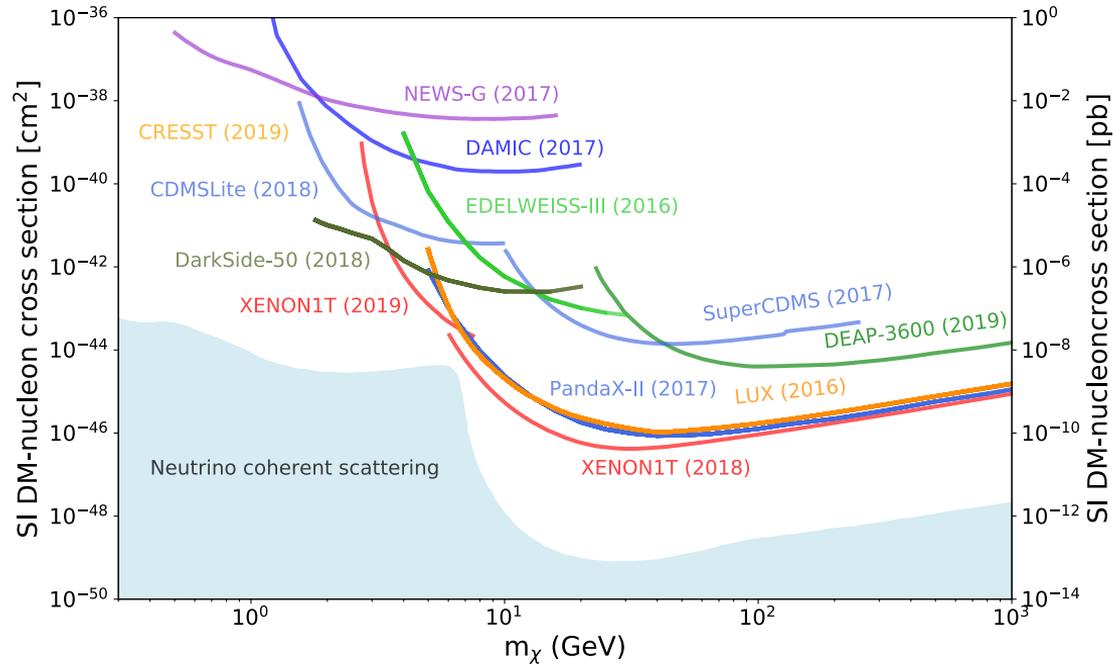
- Elastic scattering of galactic DM
- Exponentially falling recoil spectrum  $O(10 \text{ keV})$
- $A^2$  enhancement for SI WIMPs
- Now at sub-event/tonne/year



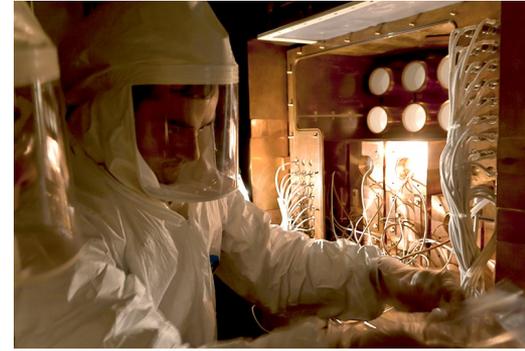
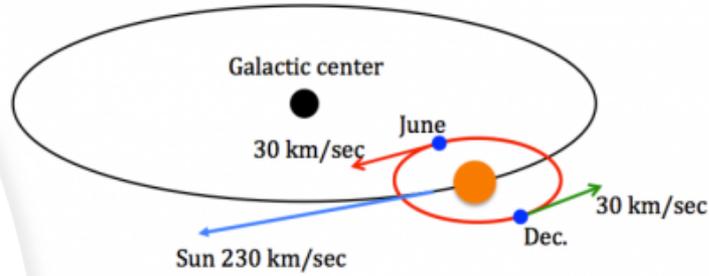
$$\frac{dR}{dE_R} = \frac{\rho_0}{m_N m_\chi} \int_{v_{min}}^{\infty} v f(v) \frac{d\sigma}{dE_R}(v, E_R) dv.$$

# Status WIMP searches

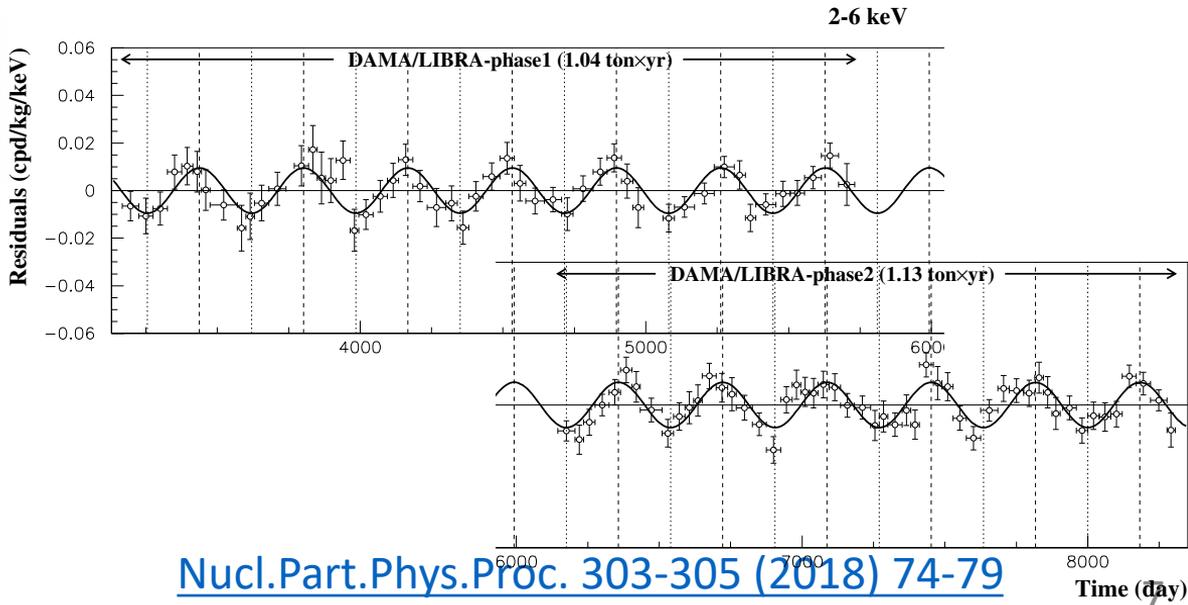
Driving factors: atomic mass and threshold; fiducial mass and time



# DAMA/LIBRA excess @ LNGS, Italy

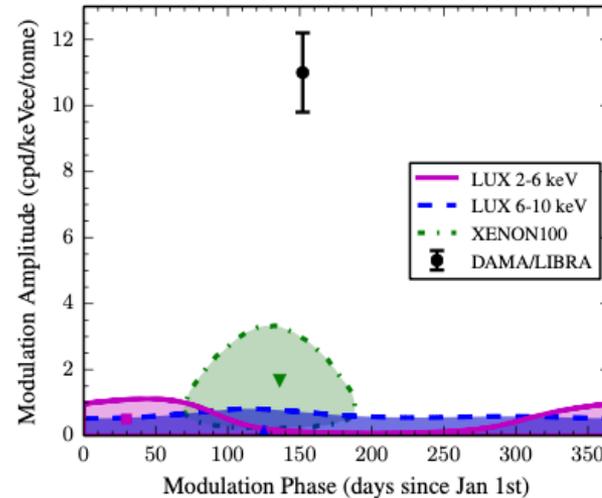
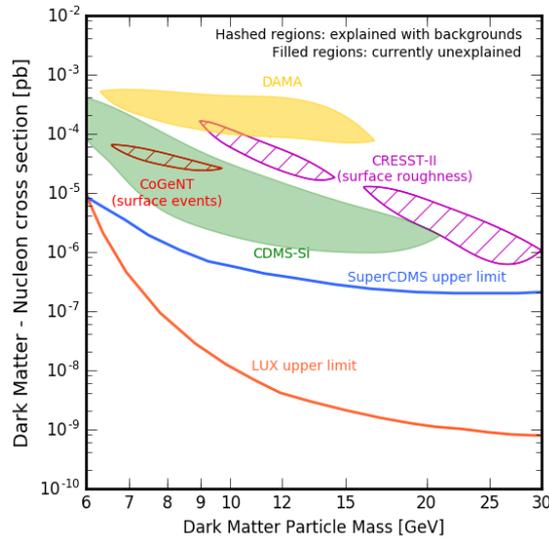


- Low-energy electron recoil excess
- Long standing (20 > yrs)  
→ now at 12 sigma
- 250 kg NaI(Tl) scintillators
- Annual modulation signal in [2-6] keV region



# Hard to reconcile w/subsequent DD exps

- Non-standard DM model?
- Detector: Target? Quenching factors?
- Seasonal effect (BG etc) unrelated to DM?



John Davies, Creative Commons

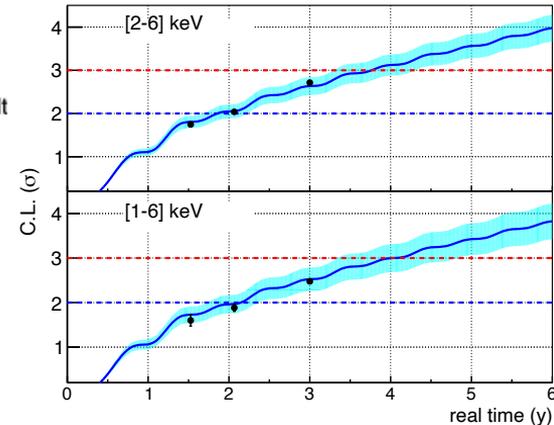
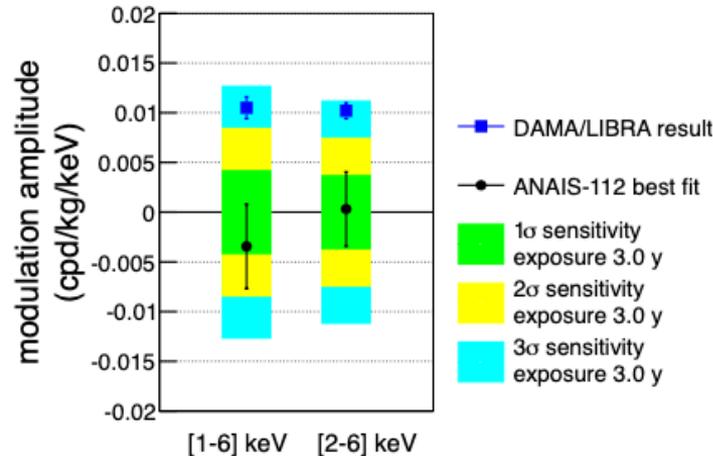
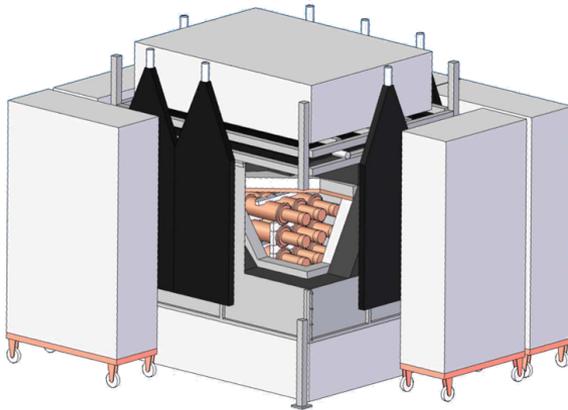
[LUX: Phys. Rev. D 98, 062005 \(2018\)](#)

# ANAIS-112

Annual modulation with NaI Scintillators @ Canfranc Underground Laboratory (LSC), in Spain

- Data taking started August 2017: 3/5 years to date. Latest results March 2021
- Incompatible with DAMA/LIBRA result at 3.3 (2.6)  $\sigma$  for 1-6 (2-6) keV range

112.5 kg NaI(Tl) scintillators.

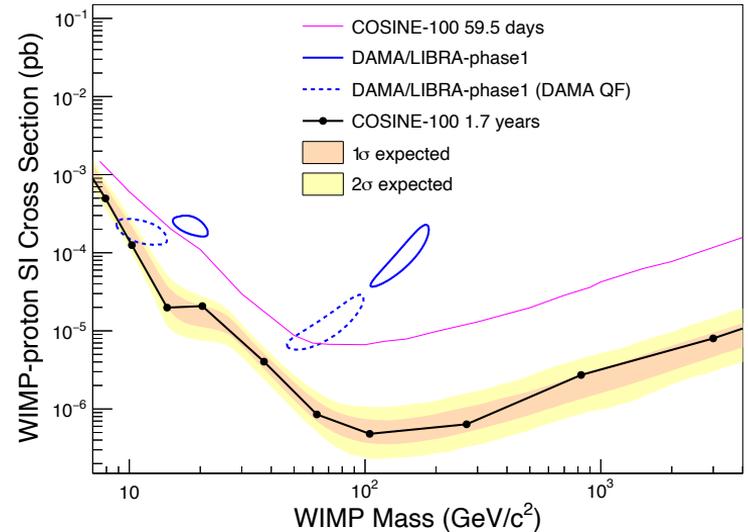
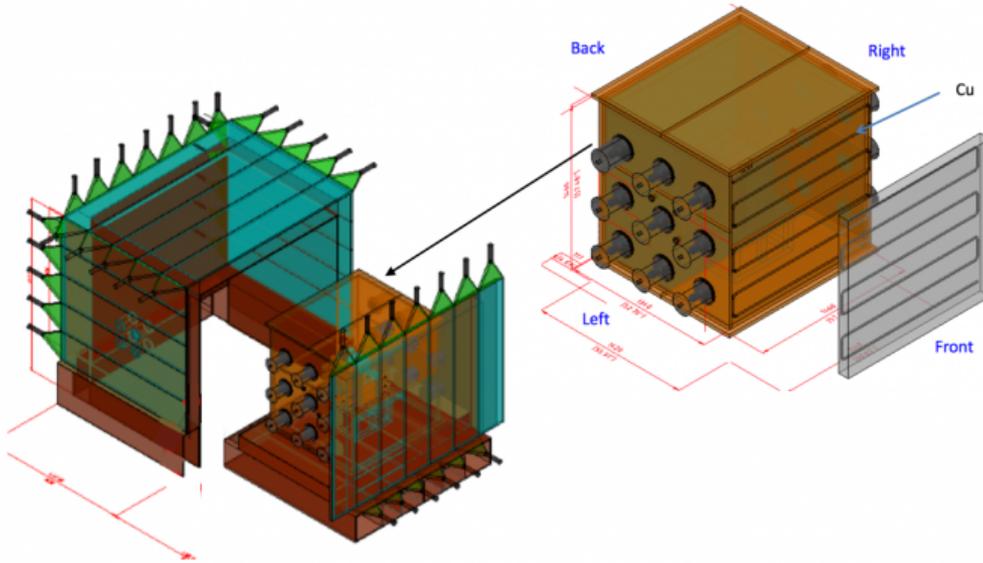


[Annual Modulation Results from Three Years Exposure of ANAIS-112: arXiv:2103.01175](https://arxiv.org/abs/2103.01175)

# COSINE-100

Yangyang underground laboratory, South Korea

- 106 kg low-background NaI(Tl)
- 1.7 years of data → disfavors DAMA/LIBRA
- No annual modulation analysis yet



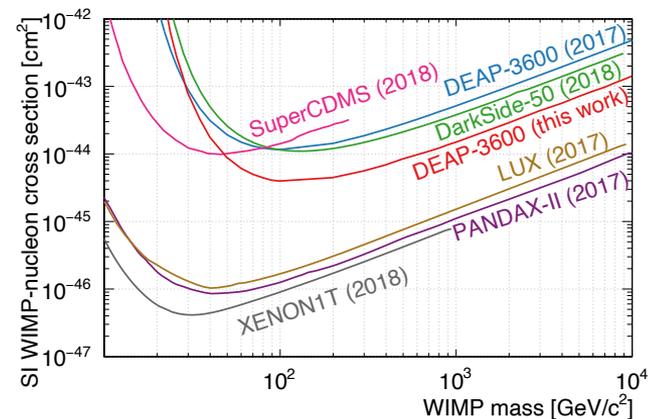
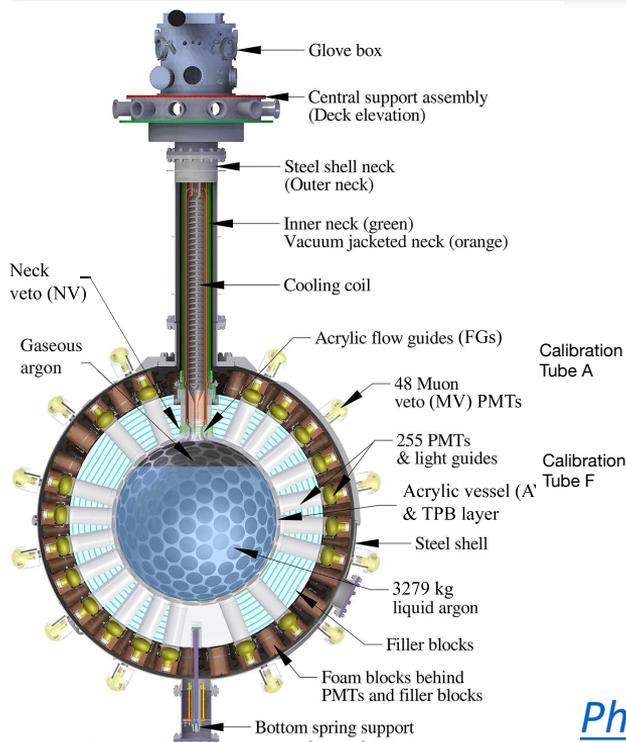
# DEAP-3600

SNOLAB, Canada

Single-phase LAr

Operated 2 km UG SNOLAB

Final result with 231-livedays



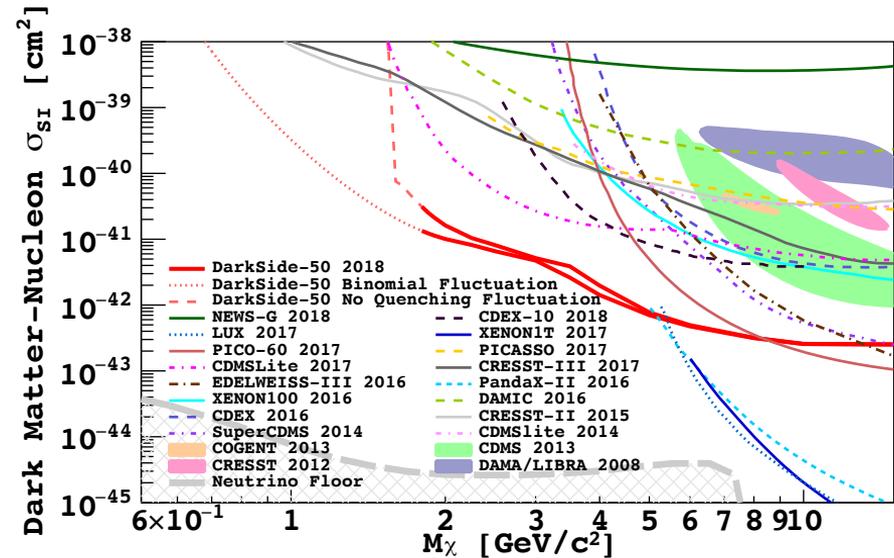
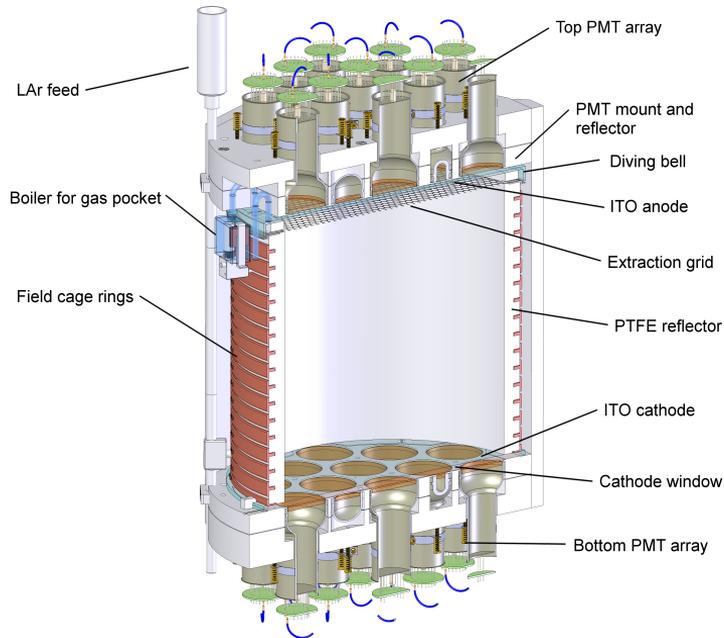
[Phys.Rev.D 100 \(2019\) 2, 022004](https://arxiv.org/abs/1812.07862)

# DarkSide-50 LAr

@ LNGS, Italy

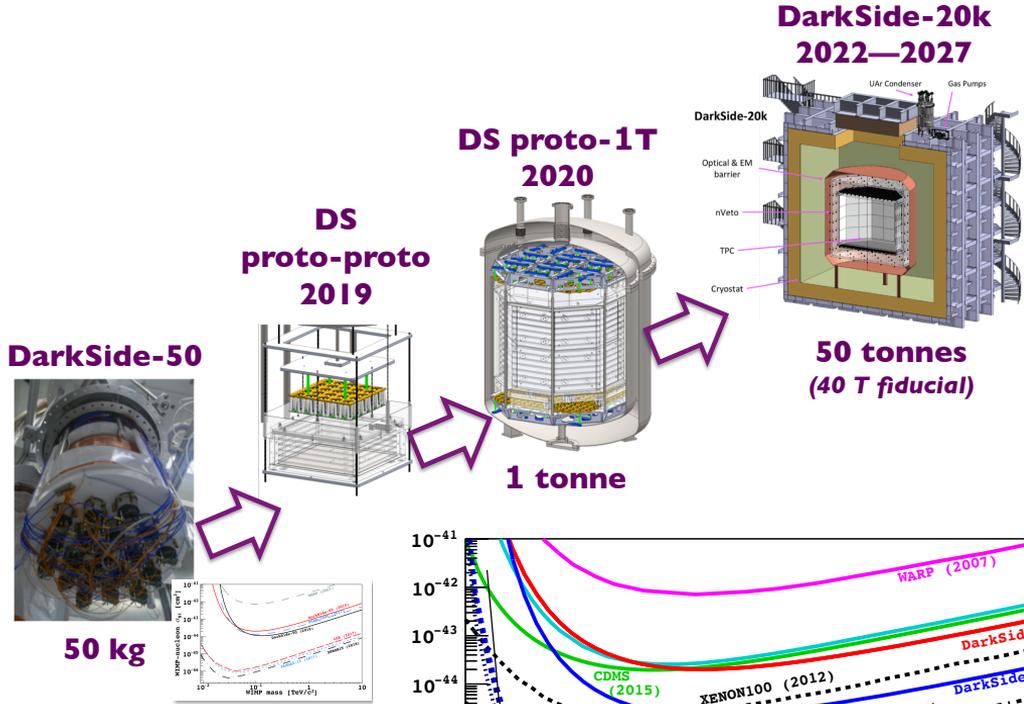
50 kg LAr TPC, first use of UG Argon

Recent Ionization-only search  $\rightarrow$  lowers threshold

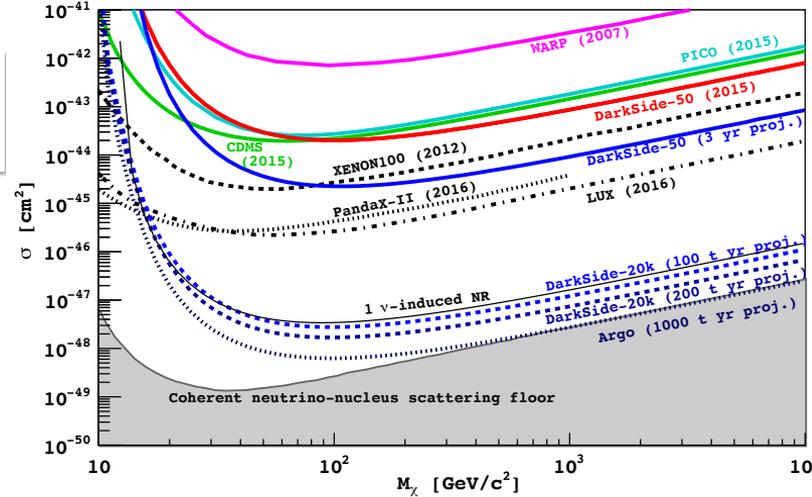
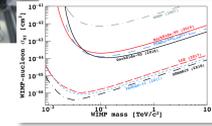


# Global Argon Dark Matter Collaboration (GADMC)

- Consolidation of Ar collaborations (ArDM, DarkSide-50, DEAP, MiniCLEAN)
- Staged to 40t LAr TPC & eventually 500t Argo
- UAr + distilled to remove  $^{39}\text{Ar}$
- Complementarity of targets

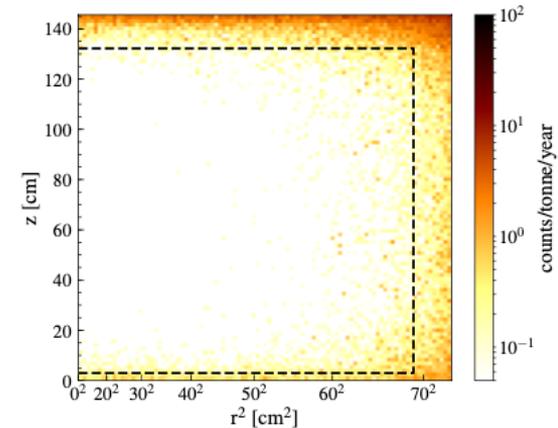
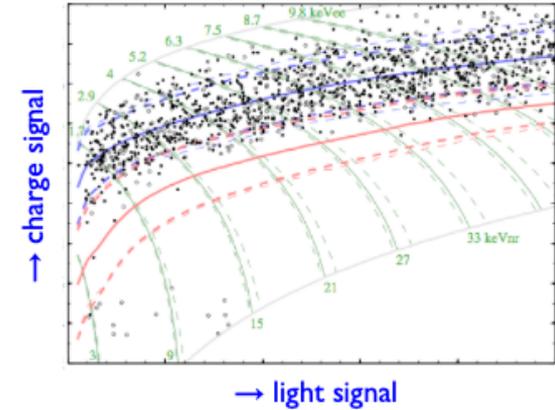
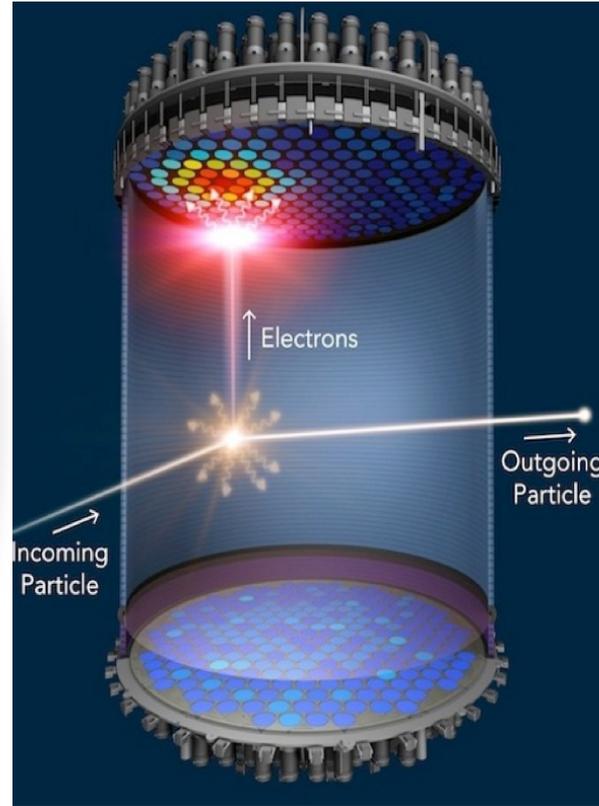


From D. Price, DMUK 2019



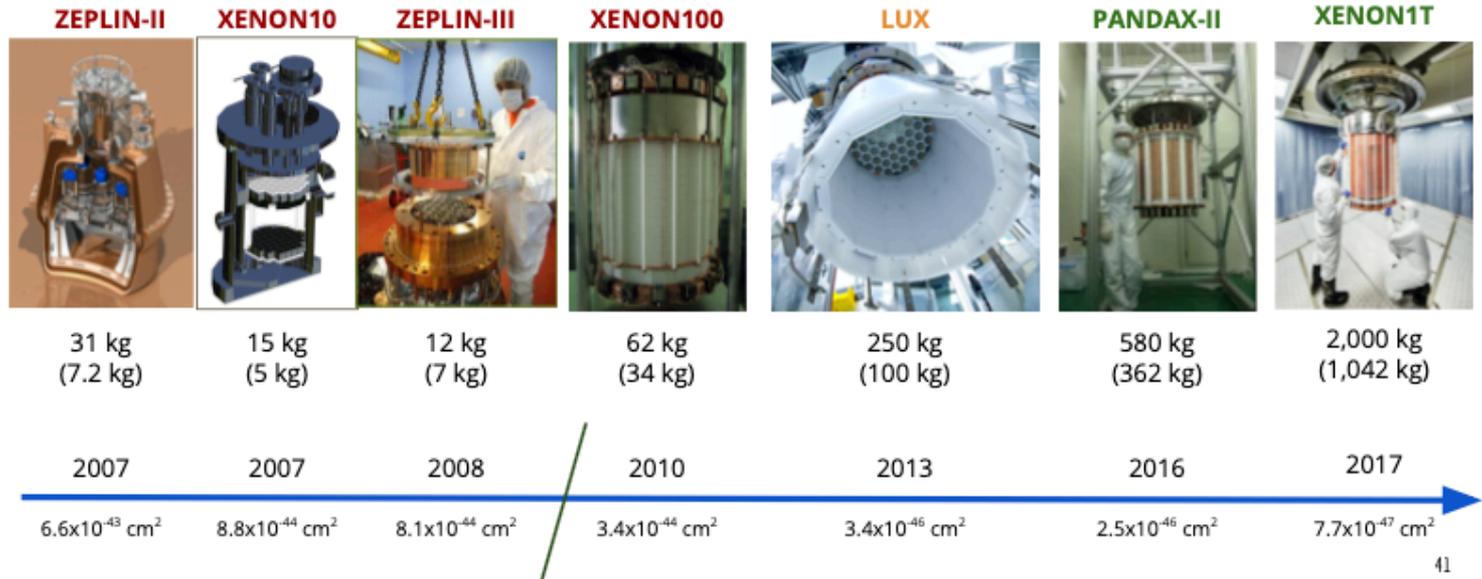
# LXe dual-phase TPCs

- 3D position reconstruction + self-shielding
- No long-lived radioisotopes
- Versatile target: SI, SD, e-scattering, 0 $\nu$ BB, solar- $\nu$
- Scalable



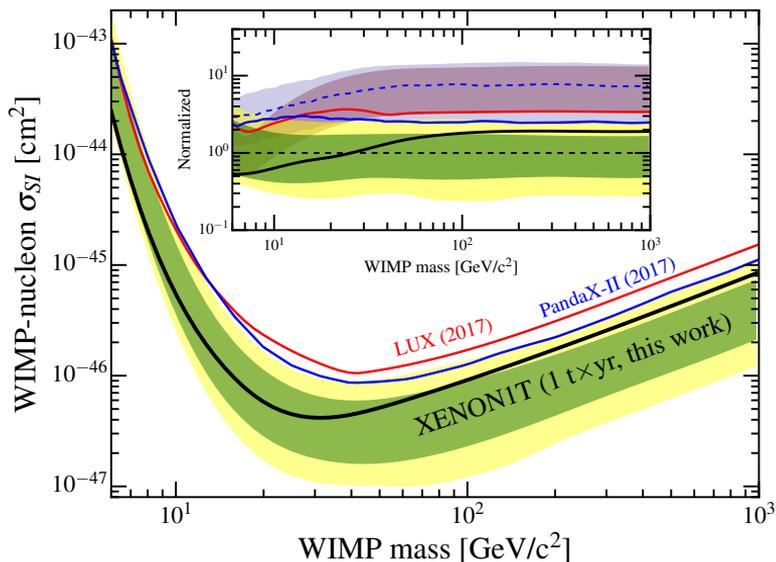
# Technology pioneered in UK

- Leading search for WIMPs above ~few GeV since 2010

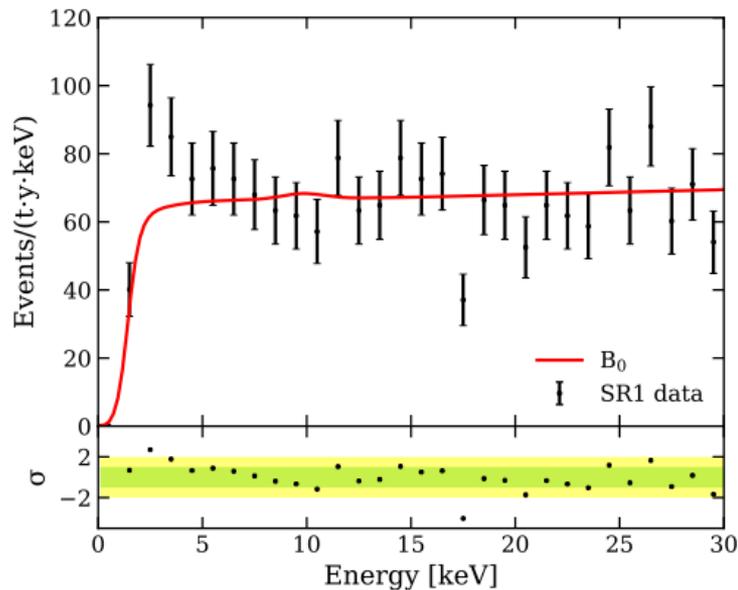


# XENON1T final results

- SI WIMPs excluded to  $4.1 \times 10^{-47} \text{ cm}^2$
- Low-energy excess in ER band: BSM signal? Unknown BG?



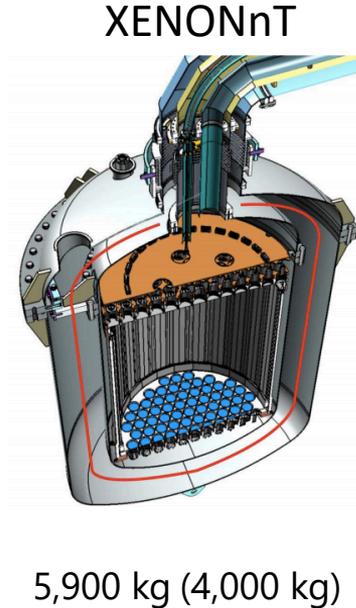
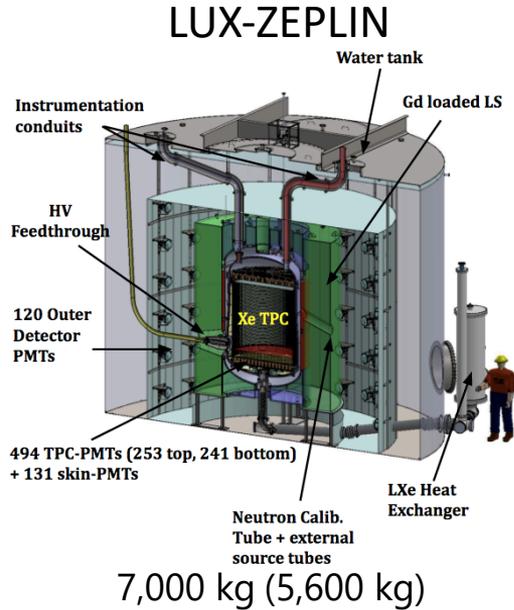
[Phys. Rev. Lett. 121, 111302 \(2018\)](#)



[Phys. Rev. D 102, 072004 \(2020\)](#)

# Up next: LUX-ZEPLIN and XENONnT

## Generation-2 multi-tonne scale instruments



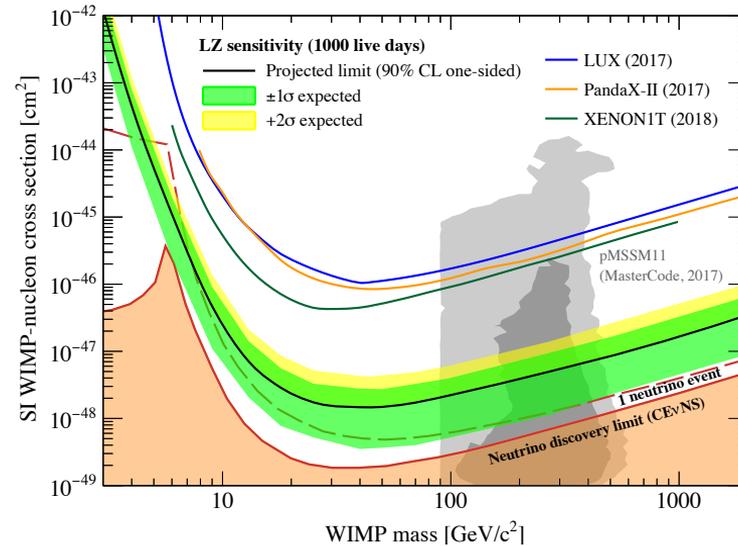
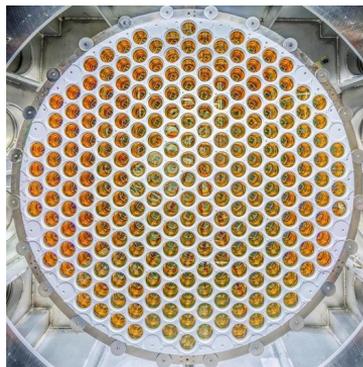
2021 + 3 live-years

2021 + 5 live-years

# LUX-ZEPLIN @ SURF, USA

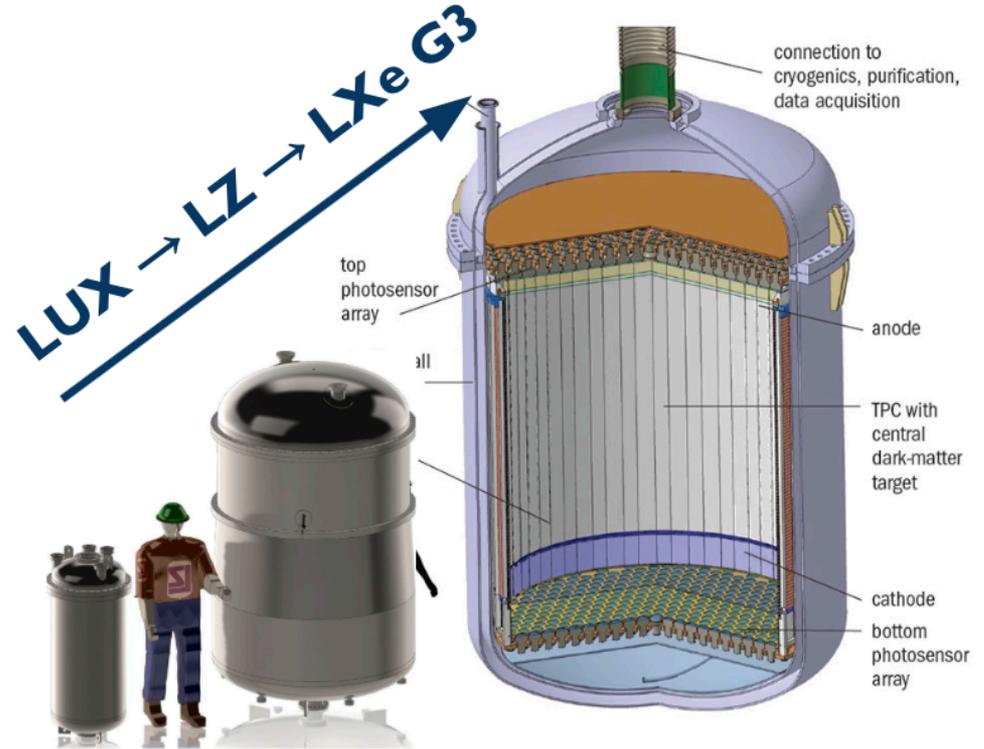
Construction complete → UG  
commissioning ongoing

First physics data this year



# R&D for next-generation LXe observatory

- 50-100 tonne scale
- Reach neutrino floor + host of non-WIMP physics
- LXe community



# Next phase of Super-CDMS

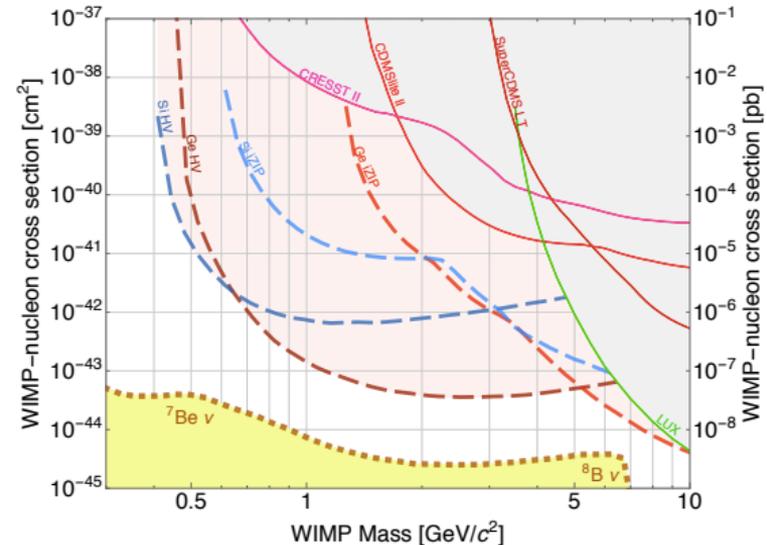
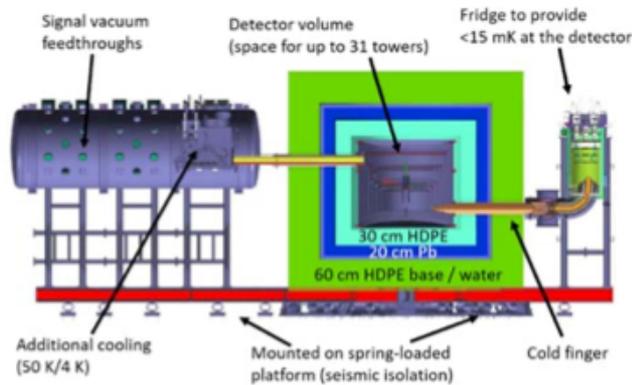
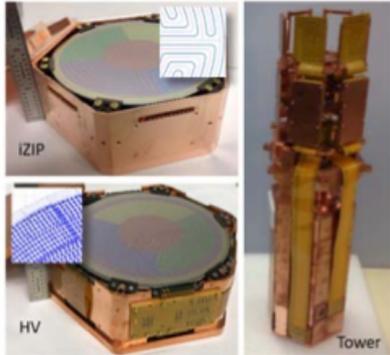
SNOLAB, Canada

1.4 kg Ge and 0.6 kg Si crystals (eventual  
~200 kg total)

Targeting  $< 10 \text{ GeV}/c^2$  mass range –  
sensitivity to sub-GeV

Band gap in Ge is 0.7 eV, Si is 1.1 eV

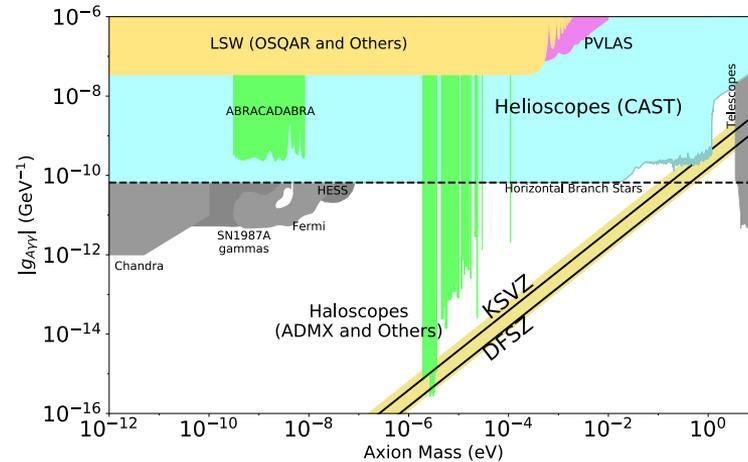
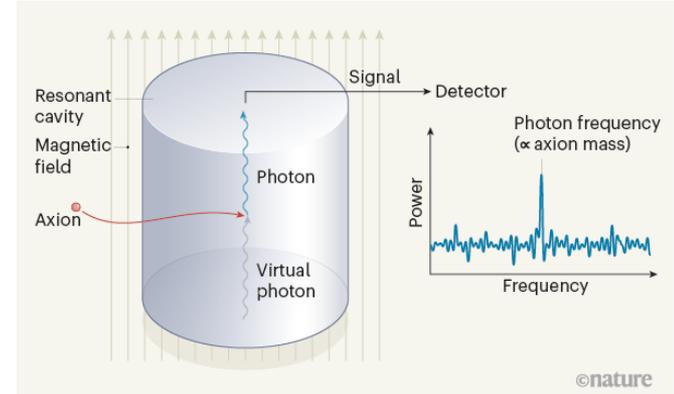
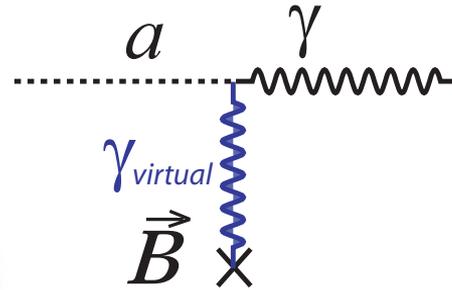
- Energy thresholds in tens of eV range



Expect Operation at SNOLAB from 2021/22

# Galactic axion searches

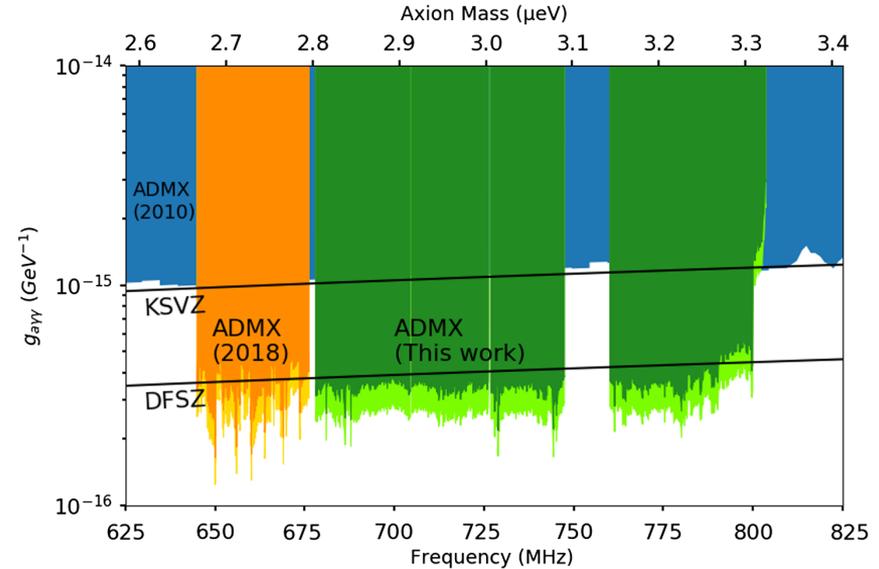
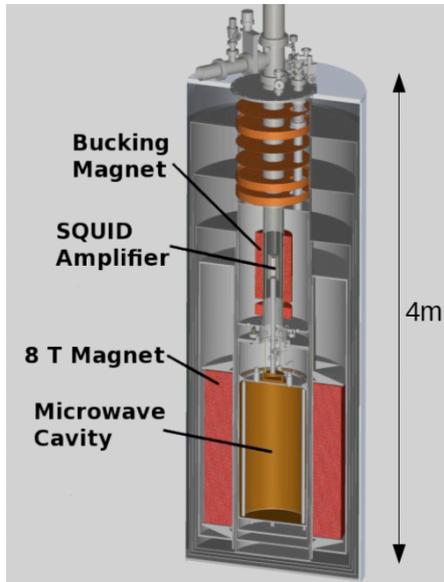
- Well motivated & could account for 100% of relic density
- Arise from PQ solution to strong CP problem
- Axion haloscope to detect relic DM



# Axion Dark Matter eXperiment (ADMX)

New ADMX G2 results (2020)

Large cavity; Low-noise amplifier; 100 mK dilution refrigerator



[Phys. Rev. Lett. 124, 101303](#)

# Future axion searches leveraging QSFP

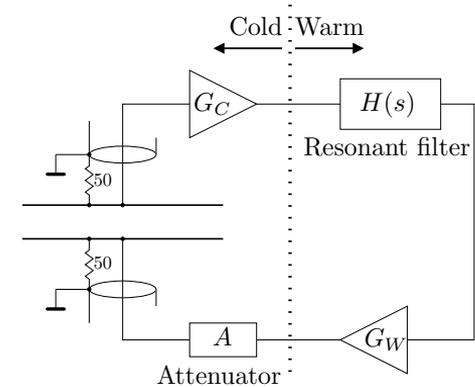
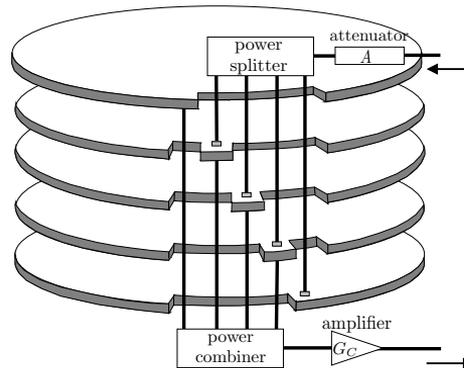
## Resonance feedback circuits as alternative to conducting wall cavities



members

QUANTUM SENSORS FOR THE HIDDEN SECTOR

- No need for manual tuning devices
- Simultaneous scan 2-40  $\mu\text{eV}$  mass range DFSZ axions on  $\sim$ month timescale



[E. Daw, NIMA 921 \(2019\) 50-56](#)

## Not covered:

- Many other searches: leading spin-dependent WIMP searches (PICO); other low-mass (NEWS-G); QSFP; directional detection (DRIFT/CYGNUS)
- Low-BG screening/Boulby FS

## What to look out for:

- Exiting times ahead → explore well motivated parameter space
- Results from LZ and XENONnT
- R&D (LXe & LAr) for next generation of experiments in progress

