

Science at SNOLAB

SNOLAB Student Orientation
September 8, 2026

Erica Caden

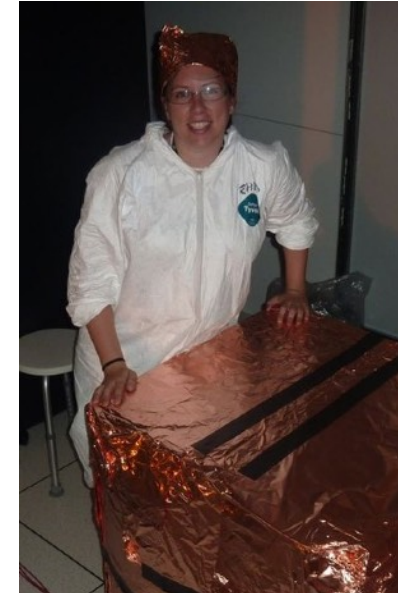
Senior Research Scientist

erica.caden@snolab.ca



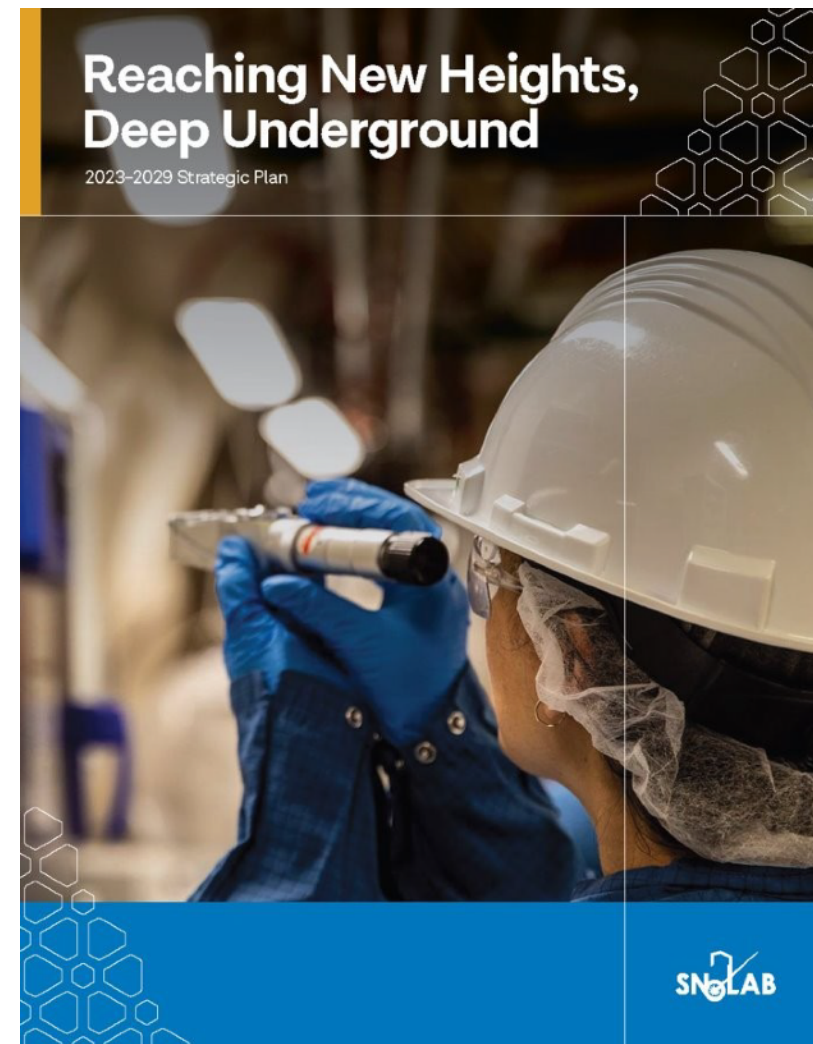
My Professional Journey

- BSc (2005) at The College of New Jersey
- PhD (2013) at Drexel University working on Double Chooz, reactor neutrino experiment to measure θ_{13}
- PostDoc at Laurentian University working on SNO+
- Joined SNOLAB in 2016 as Research Scientist
- Recipient of Sudbury's "40 under Forty" award in 2019
- Deputy spokesperson of XLZD-Canada



Science Strategy

- **The science at SNOLAB** is focused on fundamental particle physics, primarily to **investigate the nature of matter**. Specifically:
 - What is the nature of the neutrino?
 - What is the nature of the dark matter?
- **SNOLAB is interested in collaborating** on any scientific research that requires deep underground facilities. For example:
 - Neutrino observatories (solar, supernovae, geo, reactor)
 - Effects on biological systems
 - Quantum information technologies
 - Environmental monitoring



<https://www.snolab.ca/about/strategic-plan/>



Outline

- SNOLAB
- Dark Matter
- Neutrinos
- Quantum
- Life Sciences
- Future

SNOLAB's International User Community



1200+

Annual academic users and collaborators

24%

of users from Canadian institutions

166

Institutions

26

Countries

Research & Scientific Community

164

Experiment users who came to the SNOLAB site, up from 158 the year before. SNOLAB continues to serve more than 1,000 remote users.

654

Scientific publications
SNOLAB has contributed to or been referenced in. More than 100 of these have come in 2024 and 2025.

44

Student work terms filled at SNOLAB last year over three cohorts.

Education & Public Outreach

4,644

People reached through Education and Outreach programming.

40

Regional, national, and international media engagements featuring SNOLAB, SNOLAB science, and SNOLAB people.

198

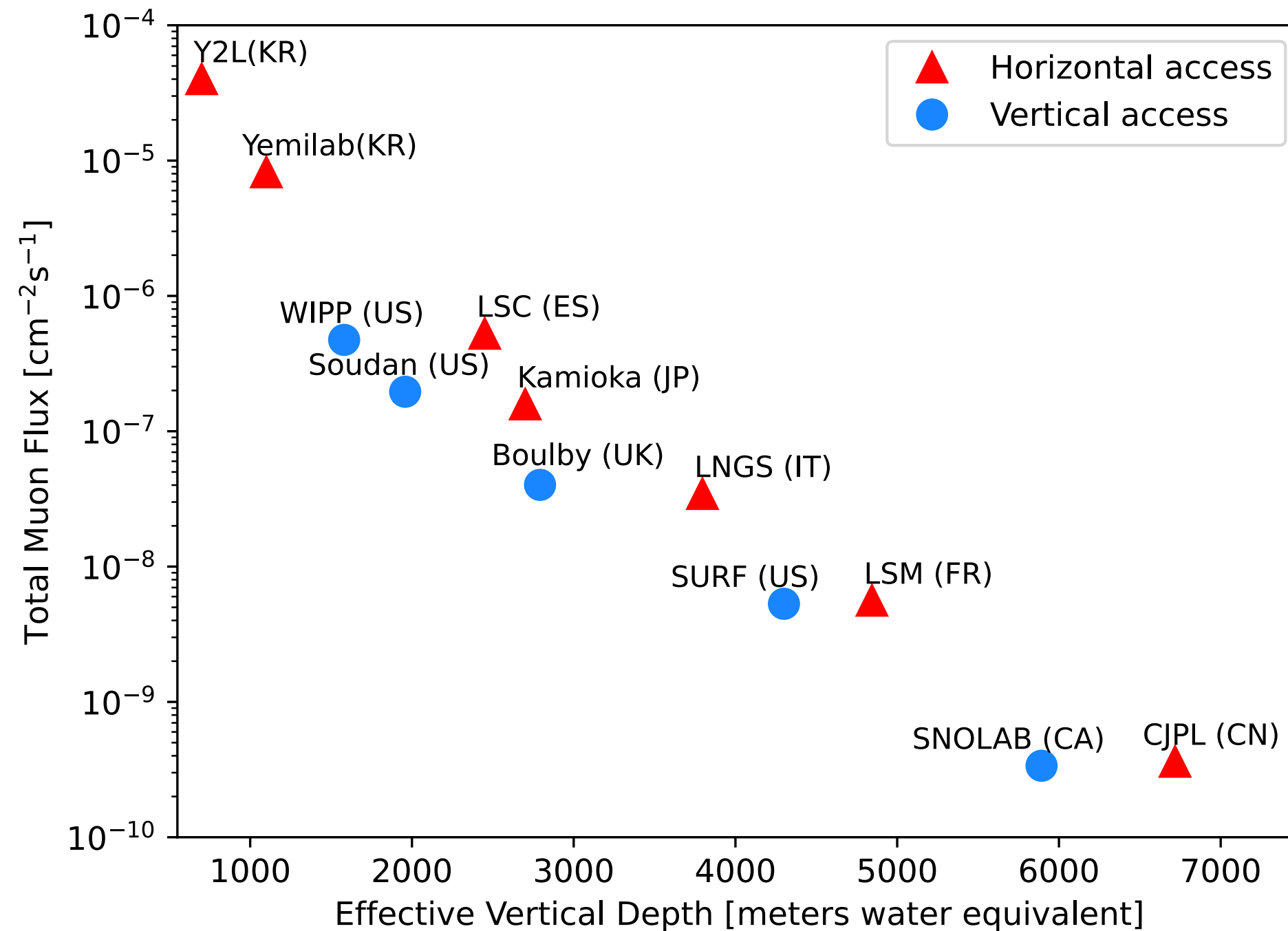
Teachers who participated in SNOLAB workshops.

438

K-12 students reached through class visits.

Why do we go underground?



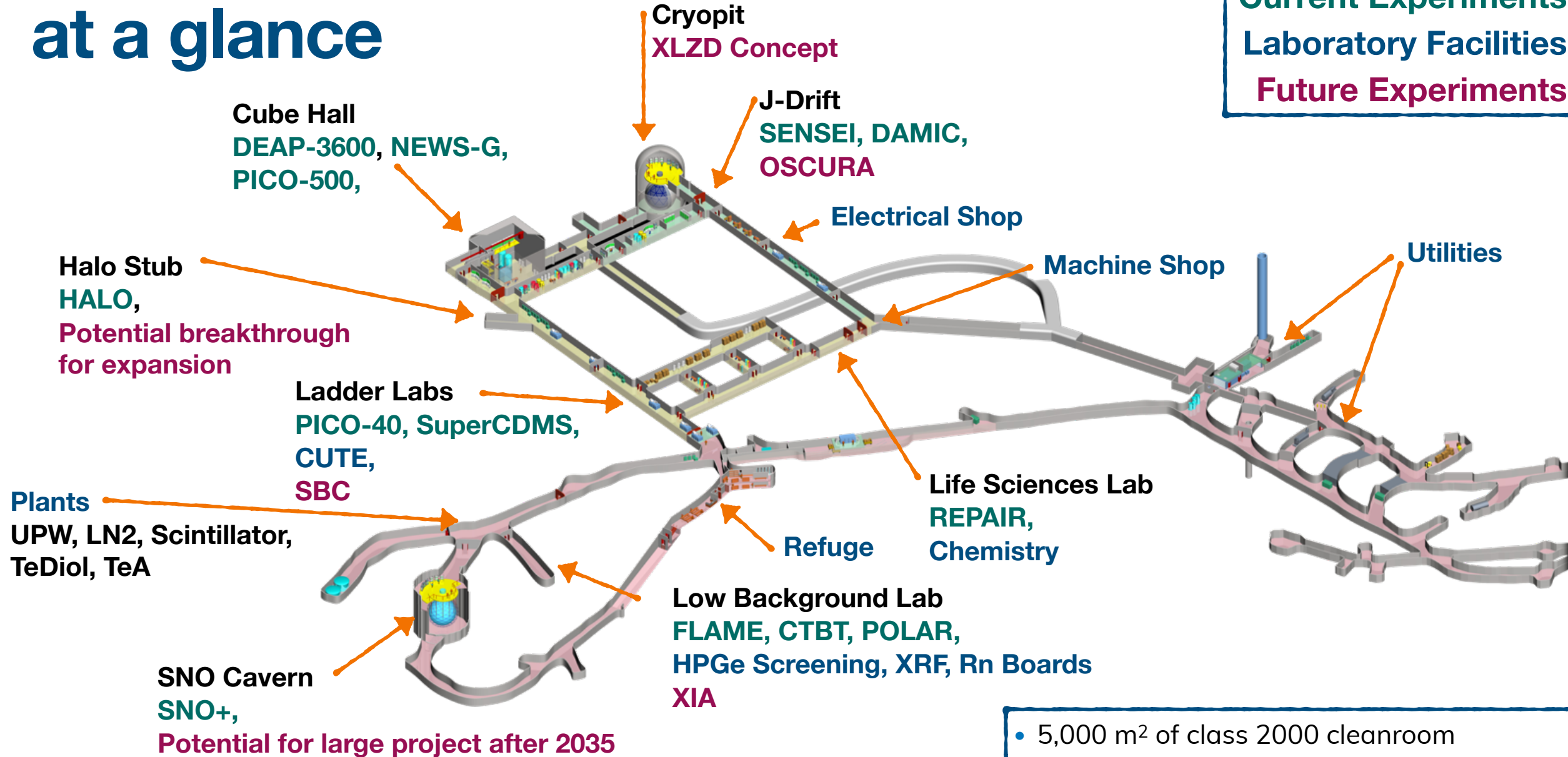


adapted from

[Chin. Phys. C 45.2 \(2021\)](#)

SNOLAB - at a glance

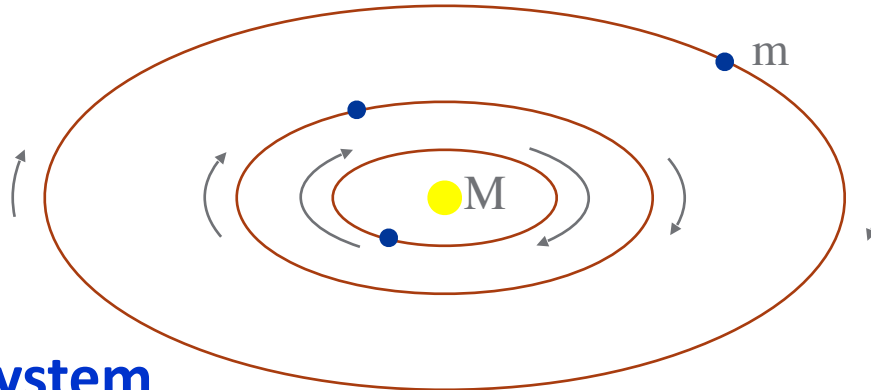
Experiment Areas
Current Experiments
Laboratory Facilities
Future Experiments



- 5,000 m² of class 2000 cleanroom
- <2000 particles >0.5 μ m in diameter per ft³

Dark Matter

Evidence for Dark Matter: Galactic Rotation Curves



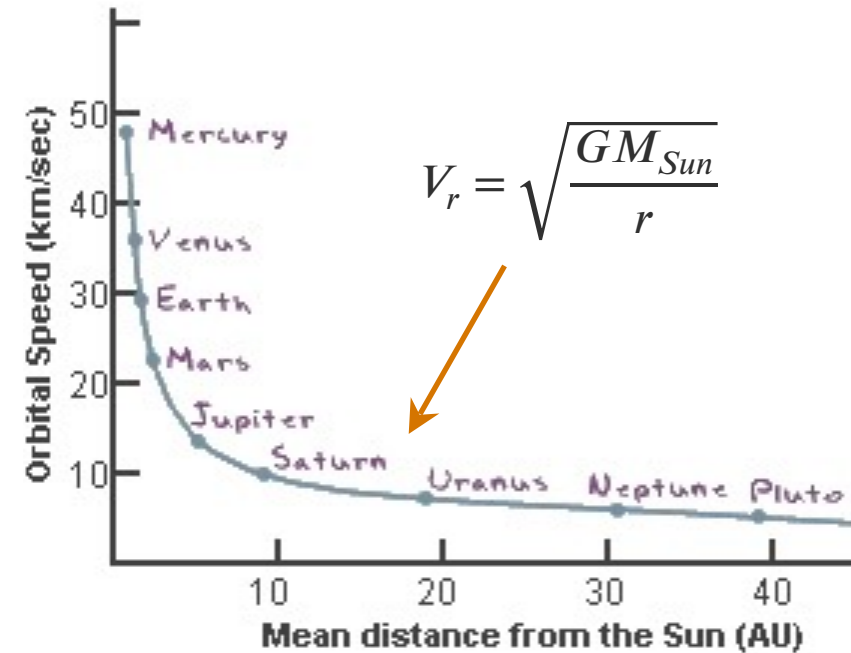
Solar System

$$F_{\text{centripetal}} = F_{\text{gravity}}$$

$$\frac{mV_r^2}{r} = \frac{GmM_{\text{total}}(r)}{r^2}$$

$$V_r = \sqrt{\frac{GM_{\text{total}}(r)}{r}}$$

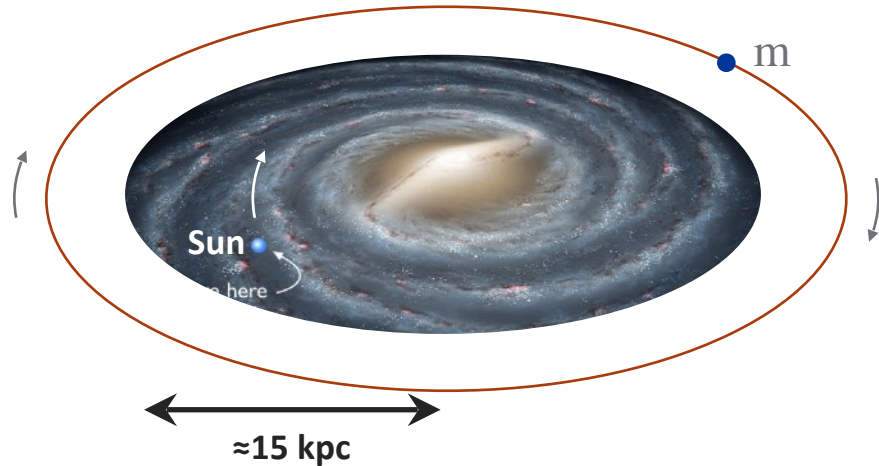
If mass of galaxy is where the light is,
 $M(r)$ is constant and $V_r \propto \frac{1}{\sqrt{r}}$ for $r > r_{\text{edge}} \approx 15 \text{ kpc}$



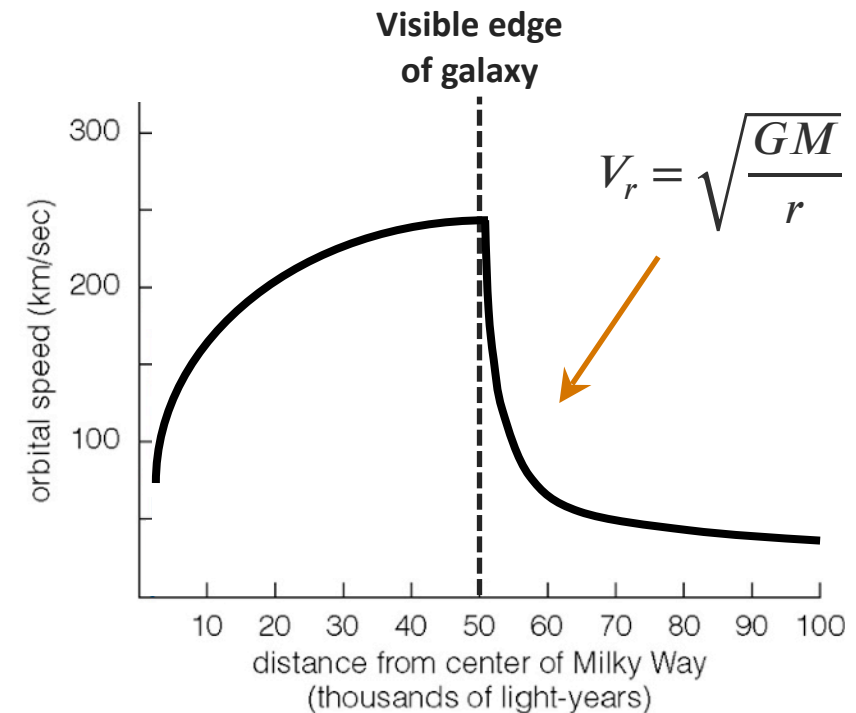
In the solar system, >99% of mass
 is in the Sun where the light is,
 (dark) planets don't count for much

Evidence for Dark Matter: Galactic Rotation Curves

Milky Way Galaxy

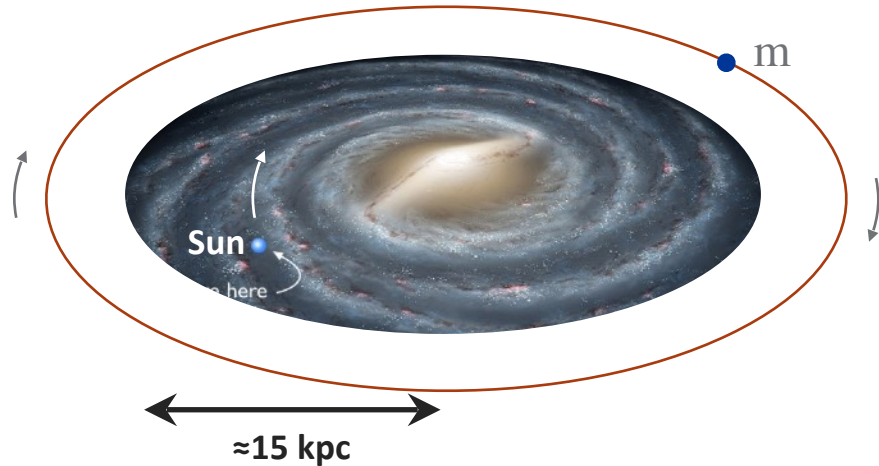


If mass of galaxy is where the light is,
 $M(r)$ is constant past the visible edge of
the galaxy: $V_r \propto \frac{1}{\sqrt{r}}$ for $r > r_{\text{edge}} \approx 15 \text{ kpc}$

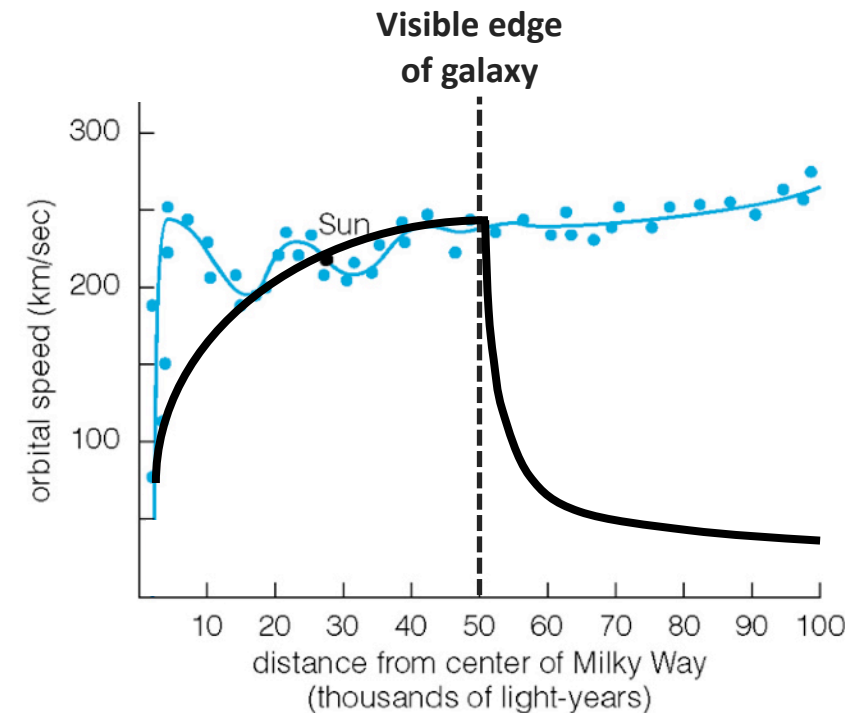


Evidence for Dark Matter: Galactic Rotation Curves

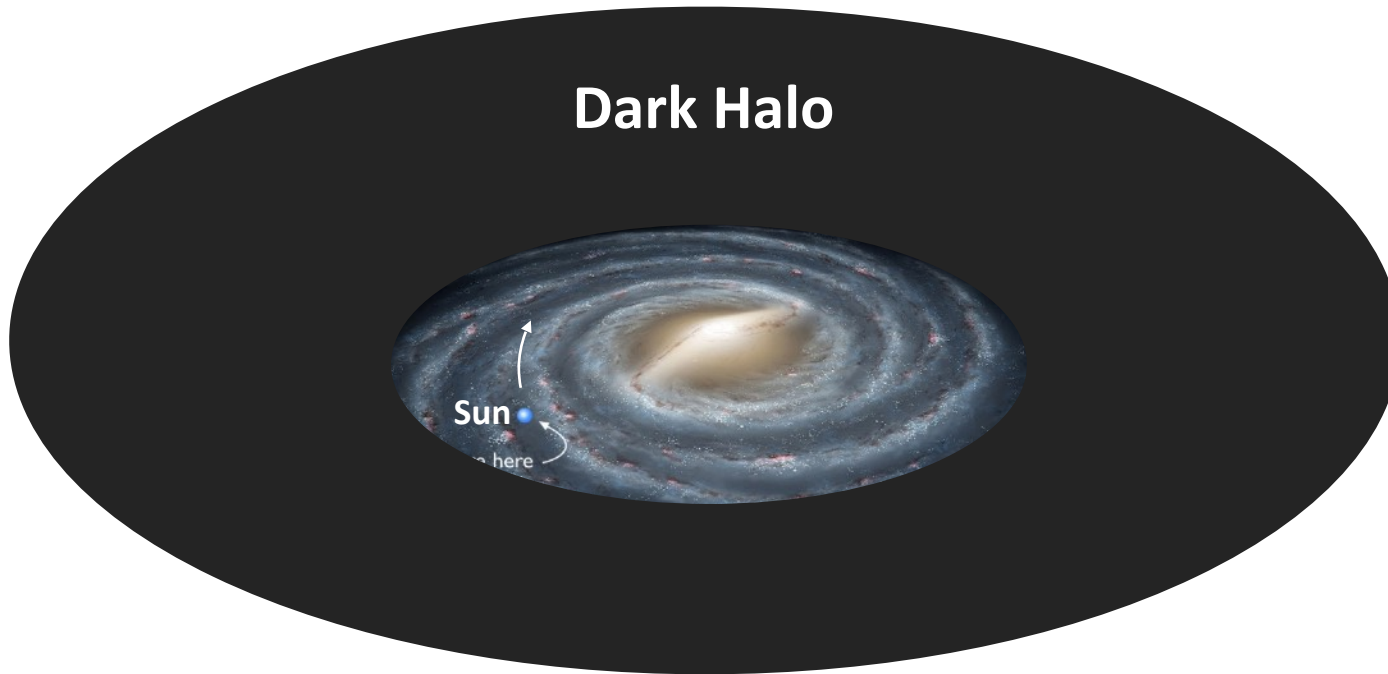
Milky Way Galaxy



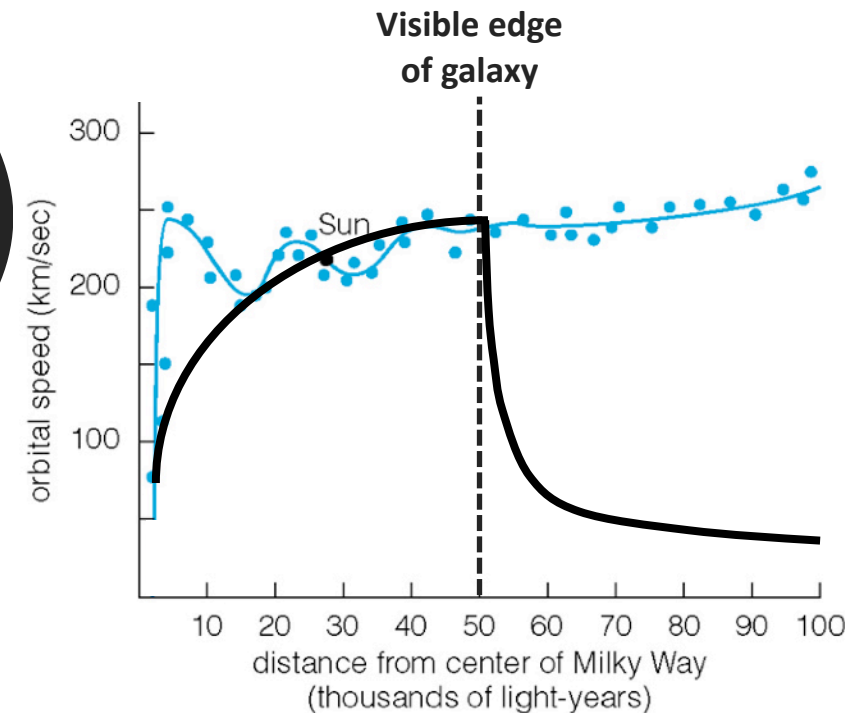
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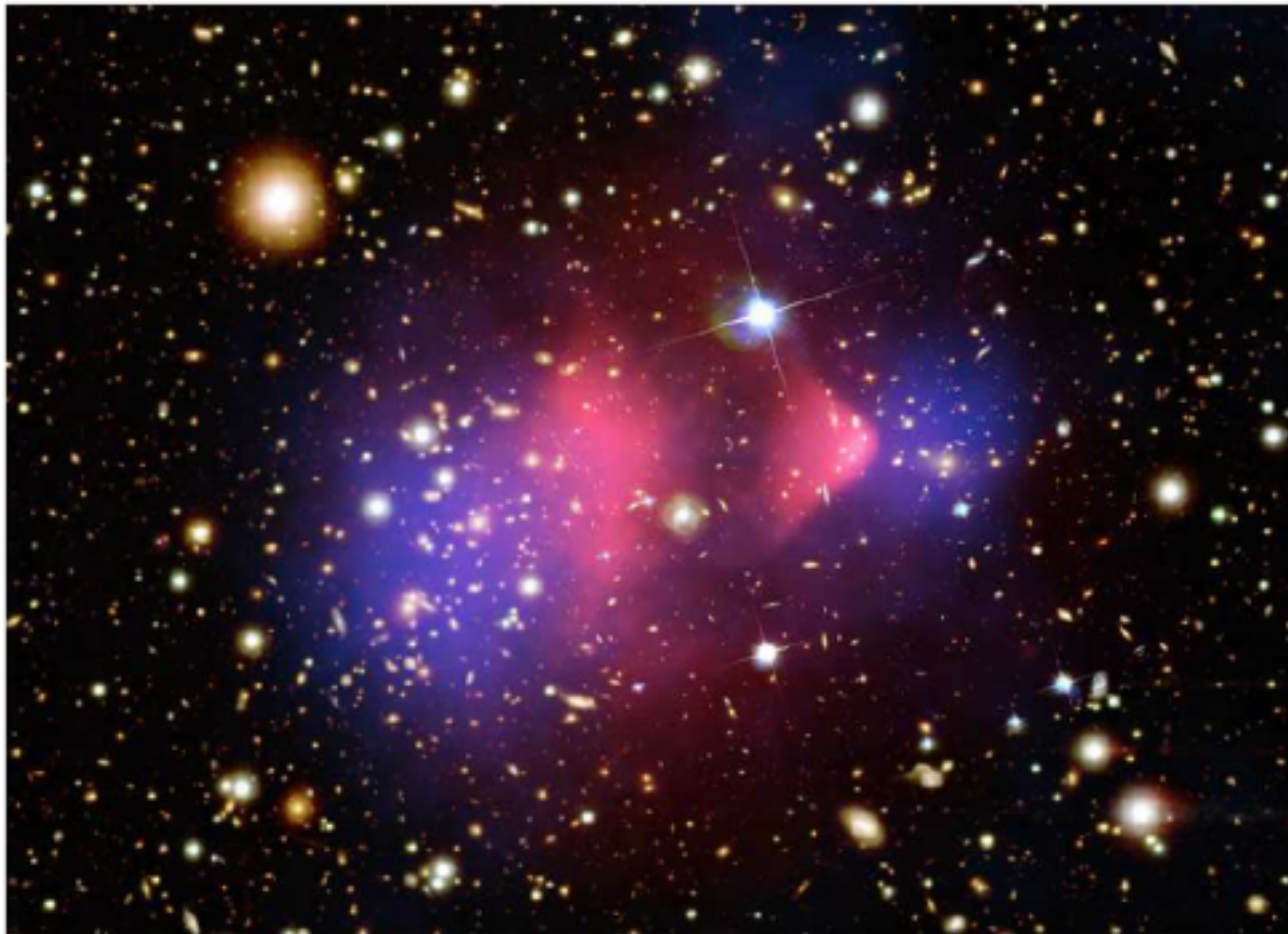
Evidence for Dark Matter: Galactic Rotation Curves



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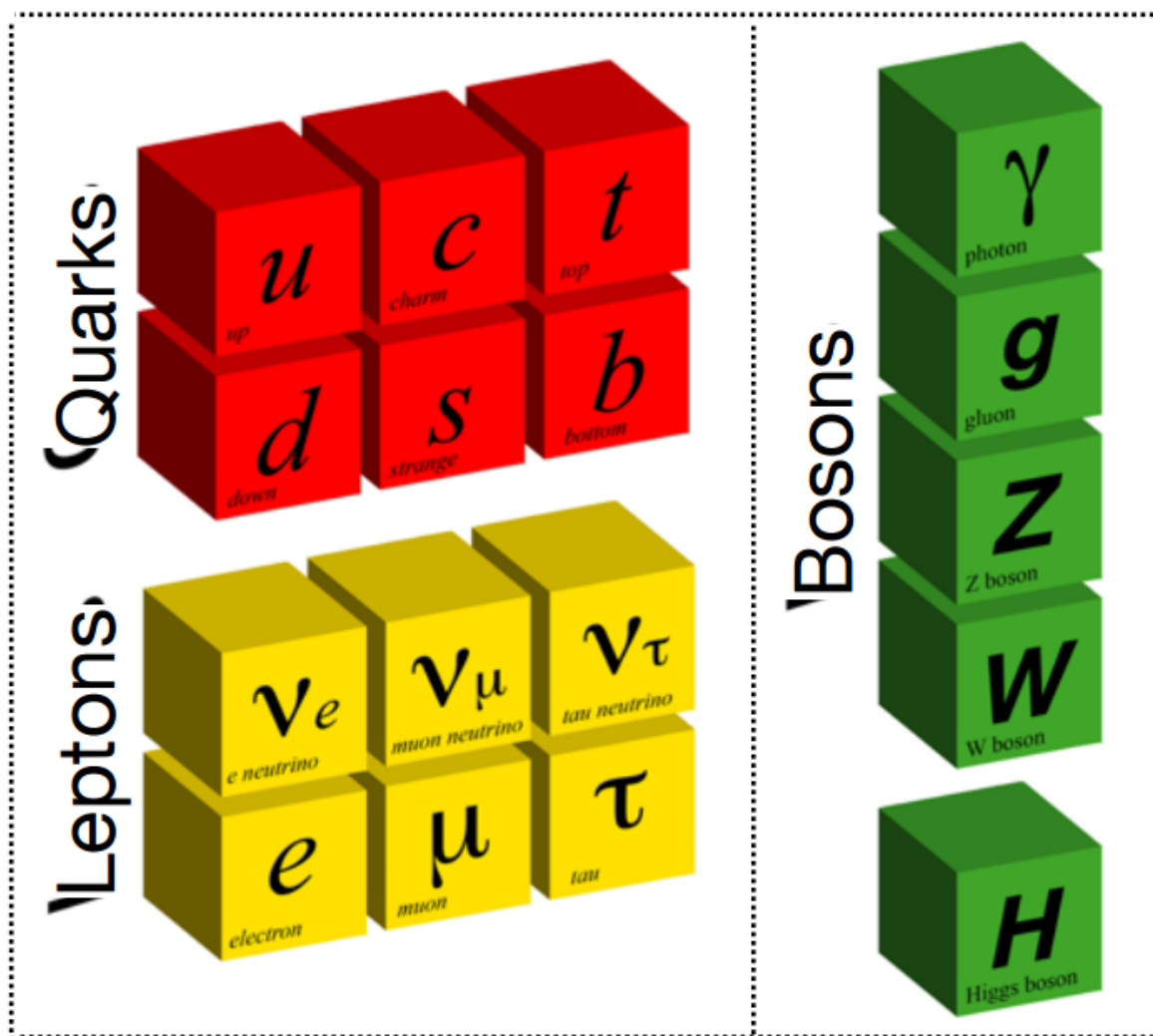


Conclusion: there must be mass where
there is no light → Dark Matter
>90% of matter in galaxy is dark matter!



Arnaud *et al.*, arXiv:0902.4890 (2009)

Normal Matter

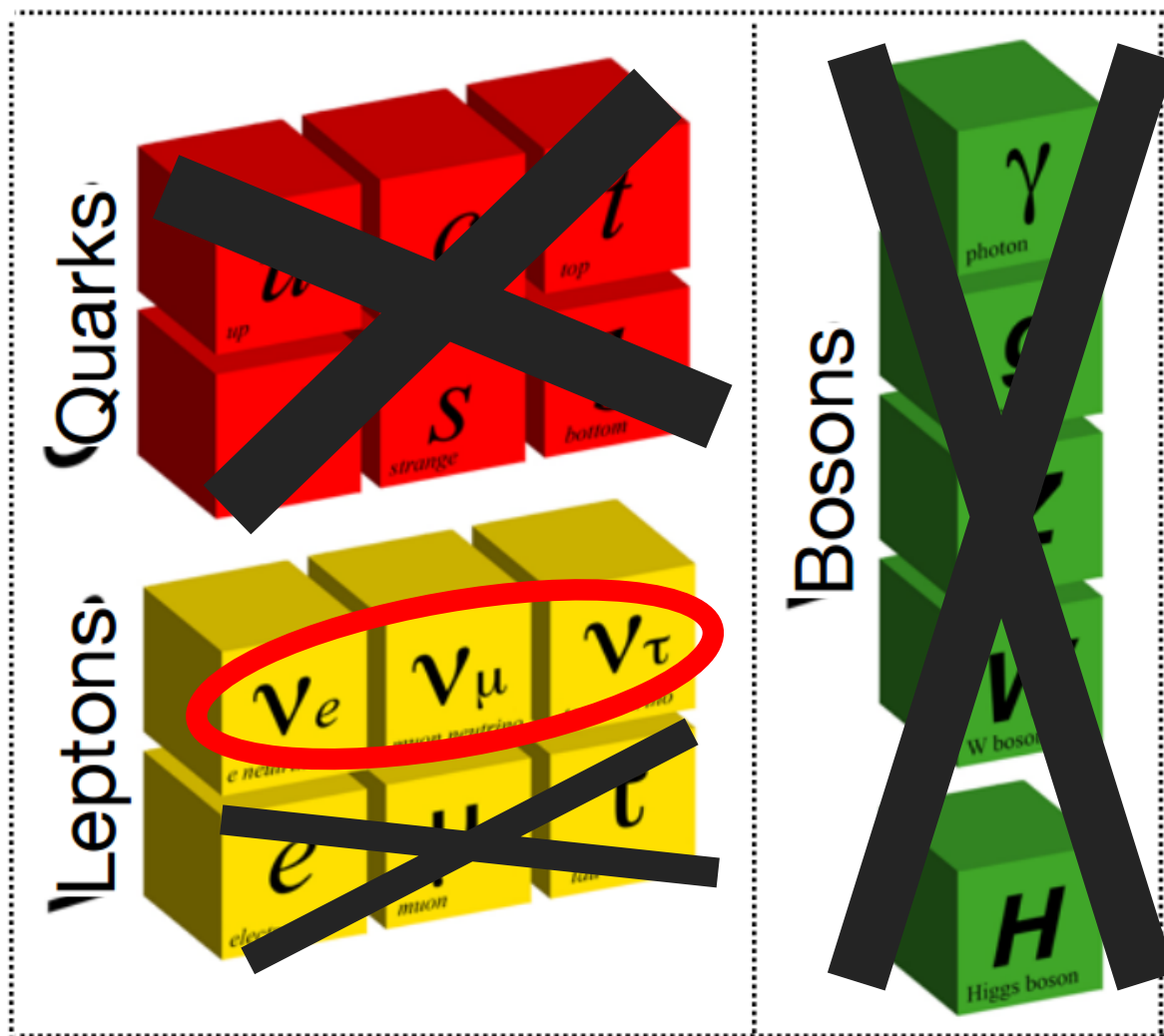


Standard Model of Particle Physics (normal matter)

Dark matter candidates?

- Doesn't decay, stable
- Doesn't interact with light

Normal Matter



Standard Model of Particle Physics (normal matter)

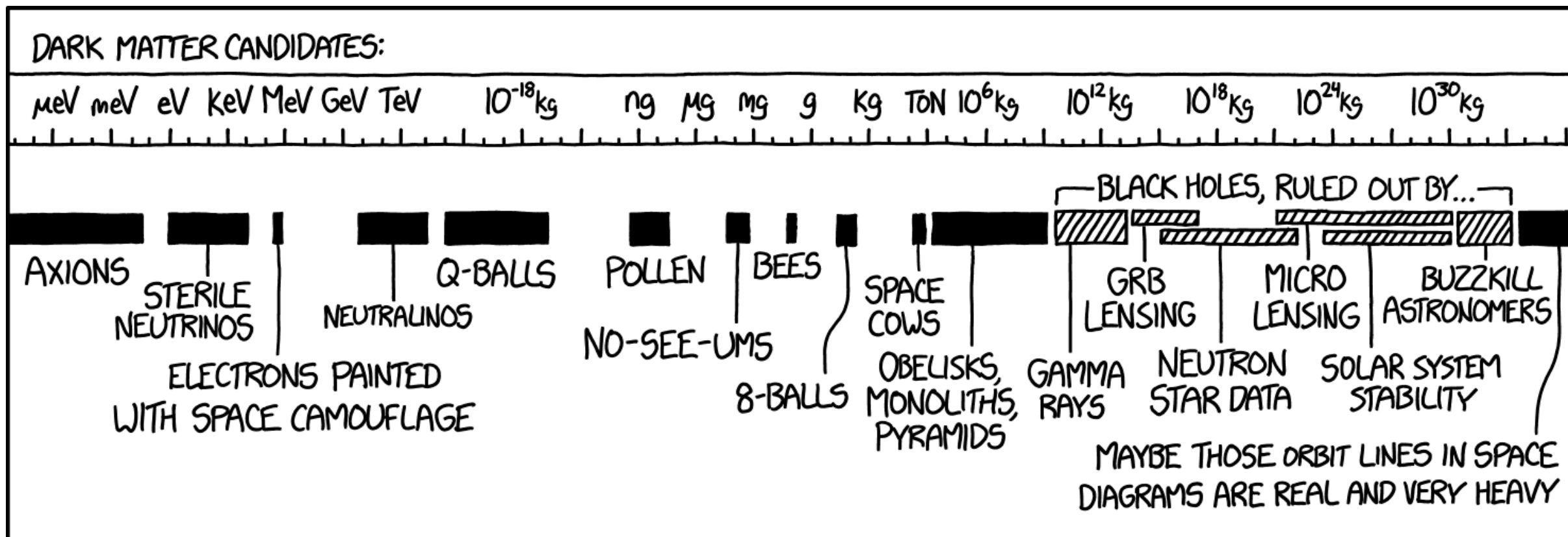
Dark matter candidates?

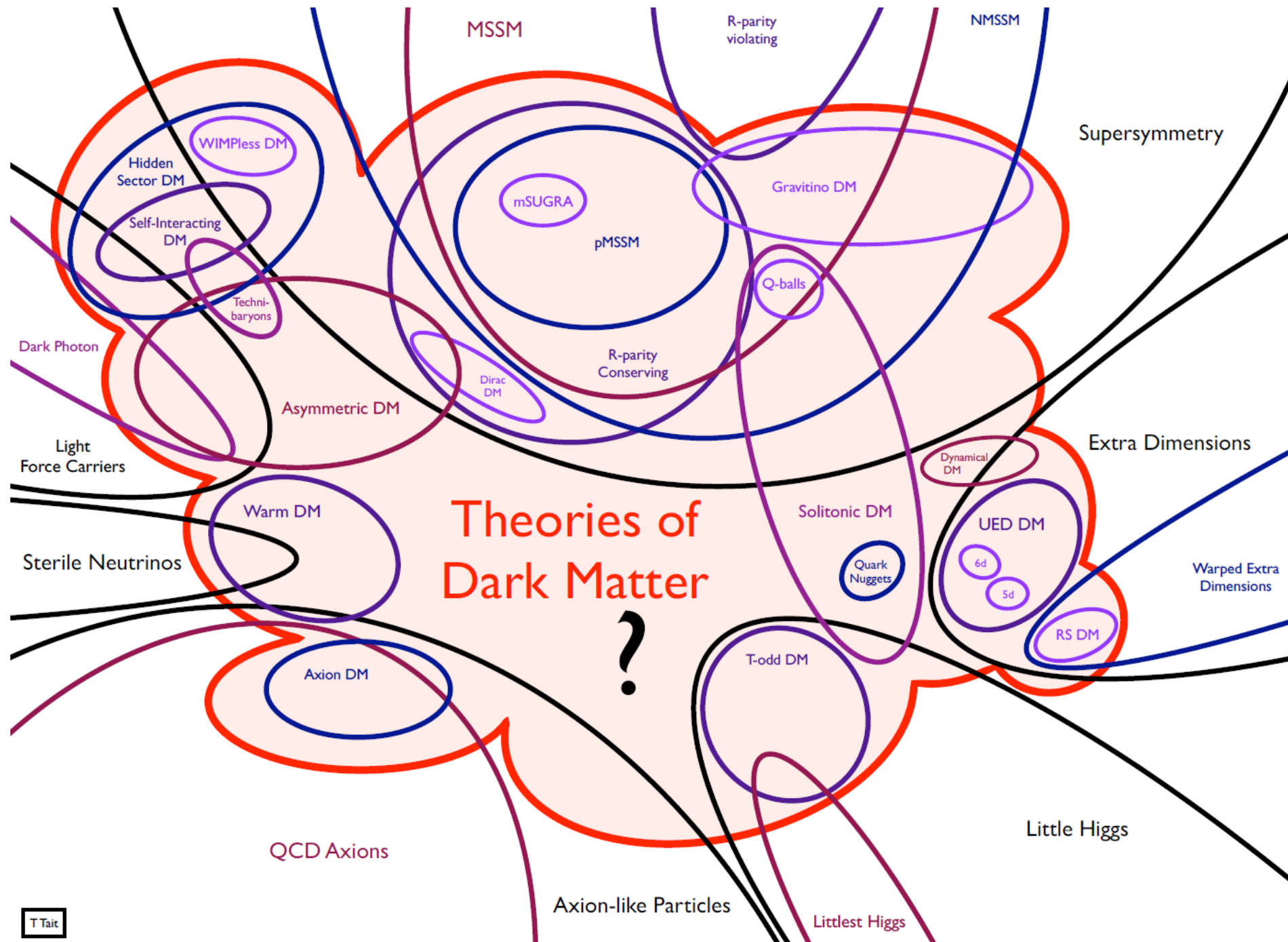
- Doesn't decay, stable
- Doesn't interact with light

Neutrinos are a type of dark matter,
but they're not massive enough

Dark Matter Introduction

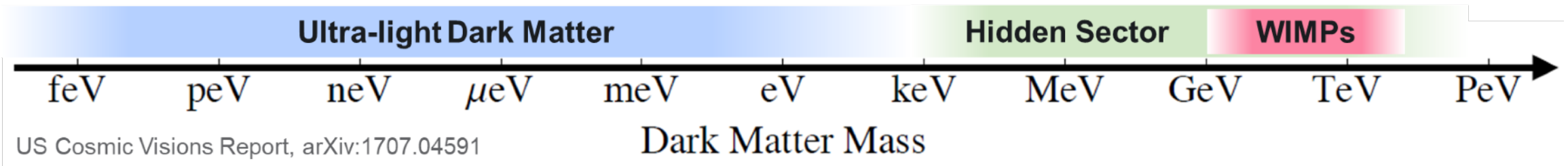
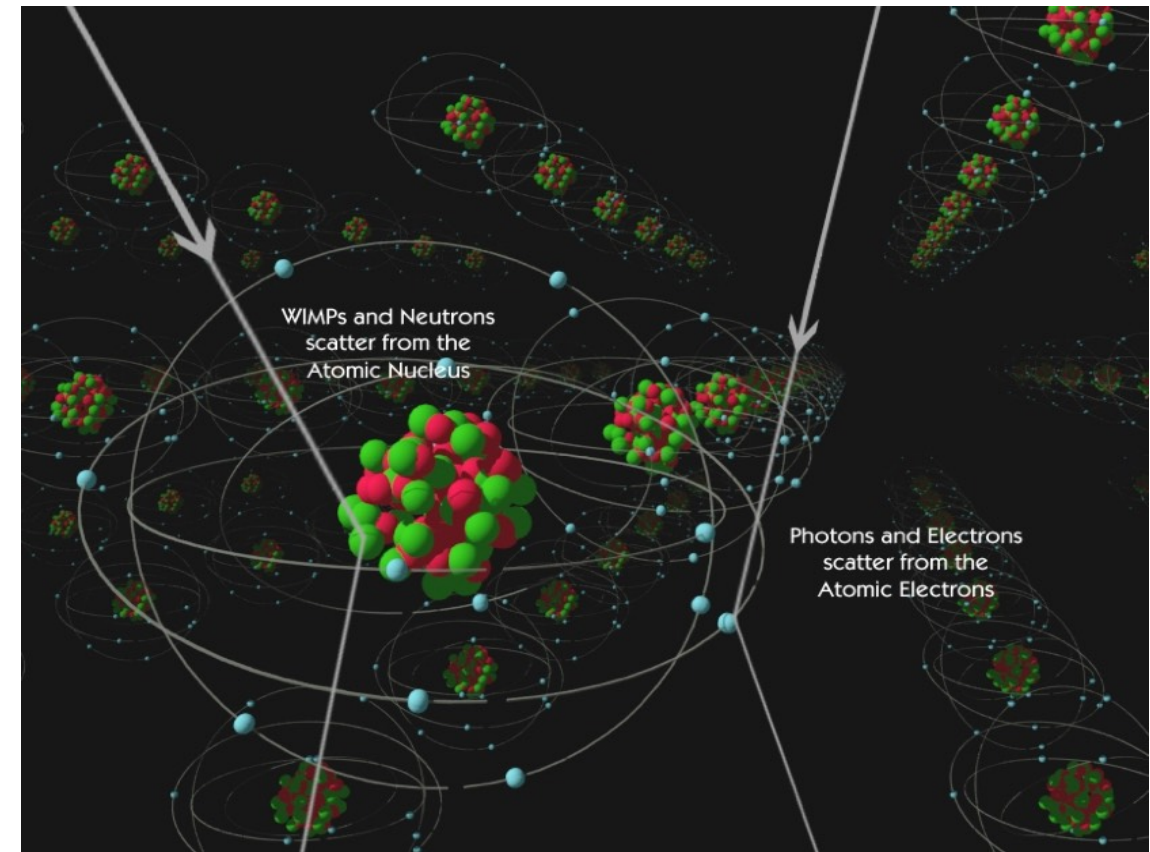
- Currently, all the dark matter experiments at SNOLAB are testing the WIMP model, looking for interactions causing small signals in their detectors: Photons, Phonons, or Electrons



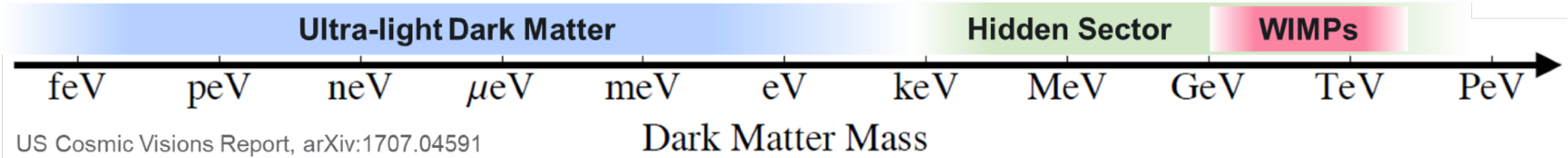
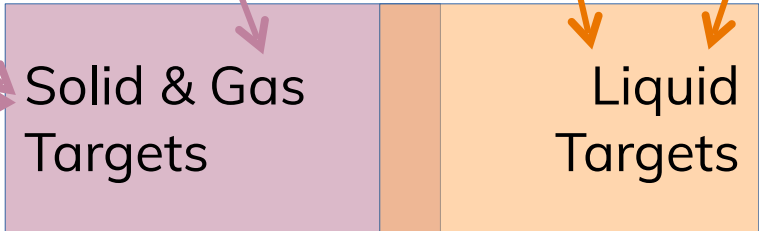
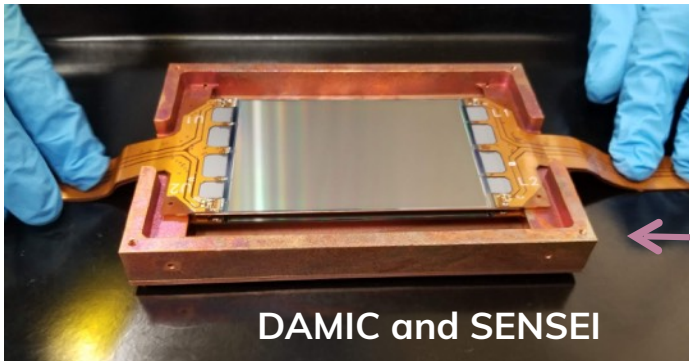


Dark Matter Detection

- Direct detection of particle-like dark matter is a possibility:
 - But it's apparently very weakly interacting
 - Challenging radiation background requirements!
- Dark matter mass is also a challenge
 - ... very broad range of possibilities
 - Requires different detector technologies to target different models



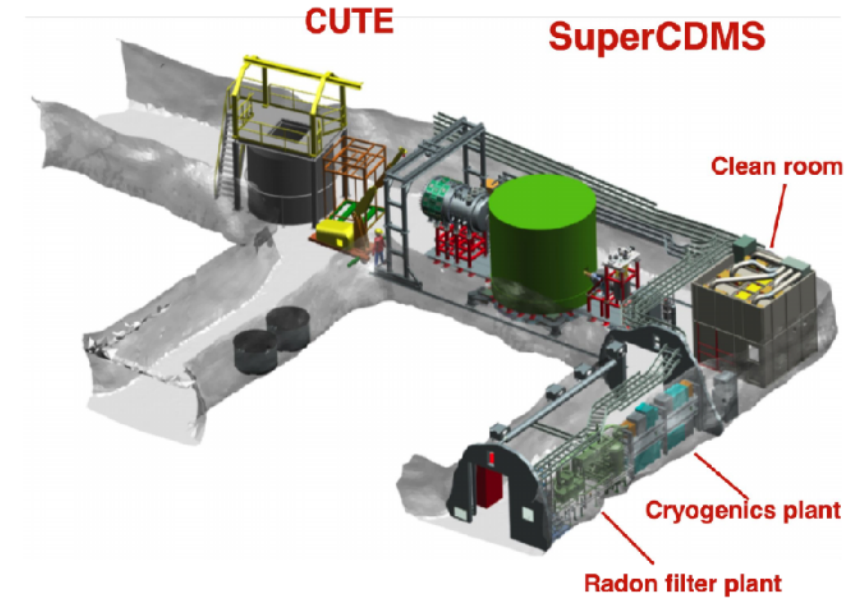
Dark Matter Detection at SNOLAB



Solid-State-Based: SuperCDMS

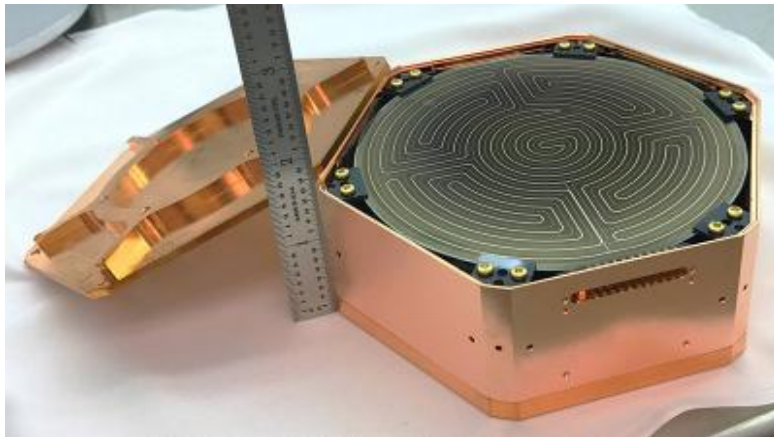


SuperCDMS @ SNOLAB



Use ultra-cold semiconducting crystals as tuning forks for dark matter: an interaction causes vibrations, read out as heat.

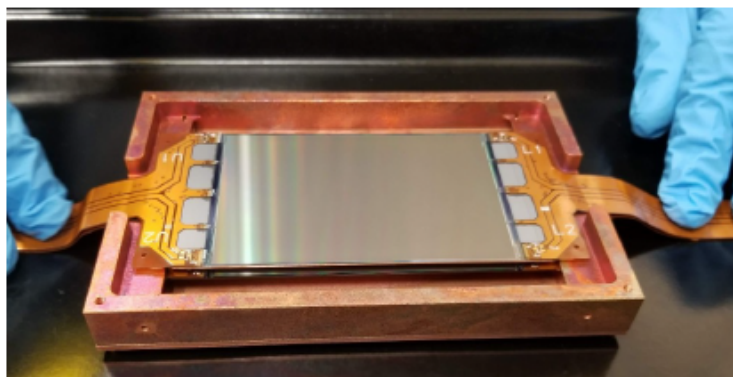
SuperCDMS has received the approval to proceed to operations – this is a very exciting time for this program!



“Ultra-cold, crystalline tuning forks that sing when struck by particles.”

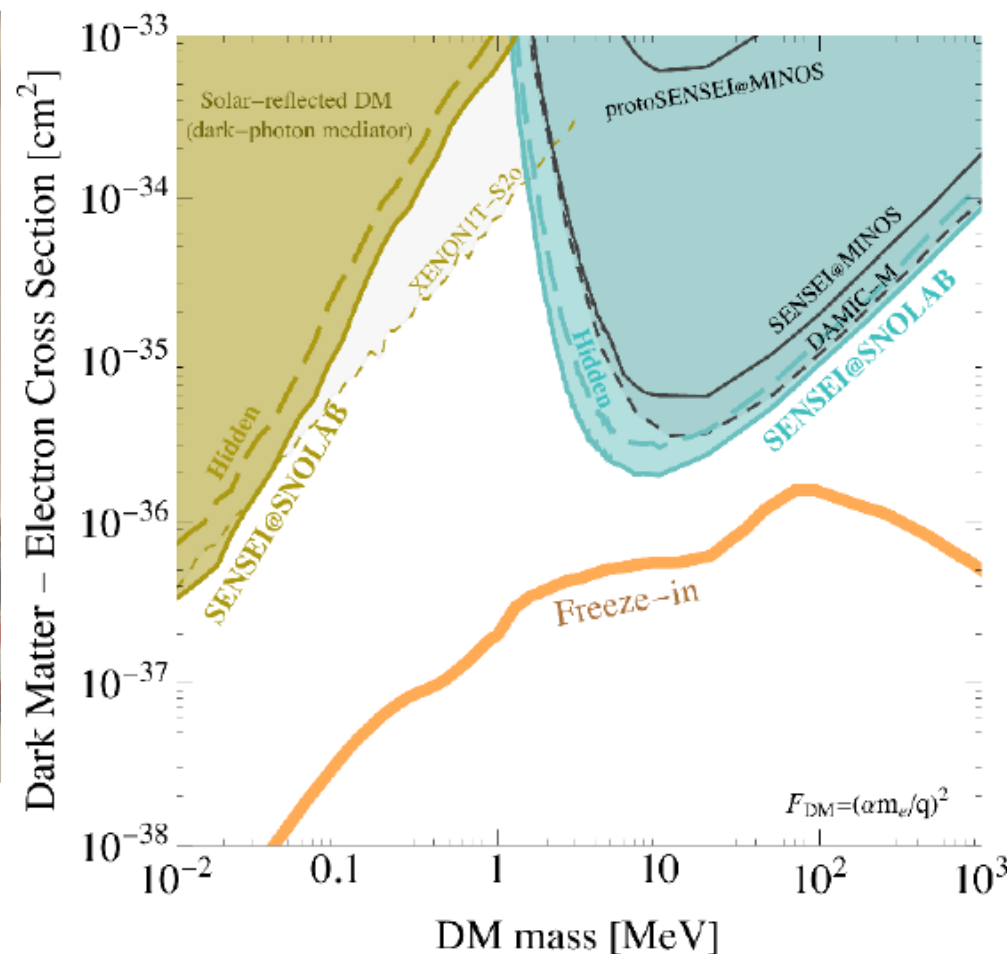
SNOLAB!

CCD-Based Detectors: DAMIC & SENSEI

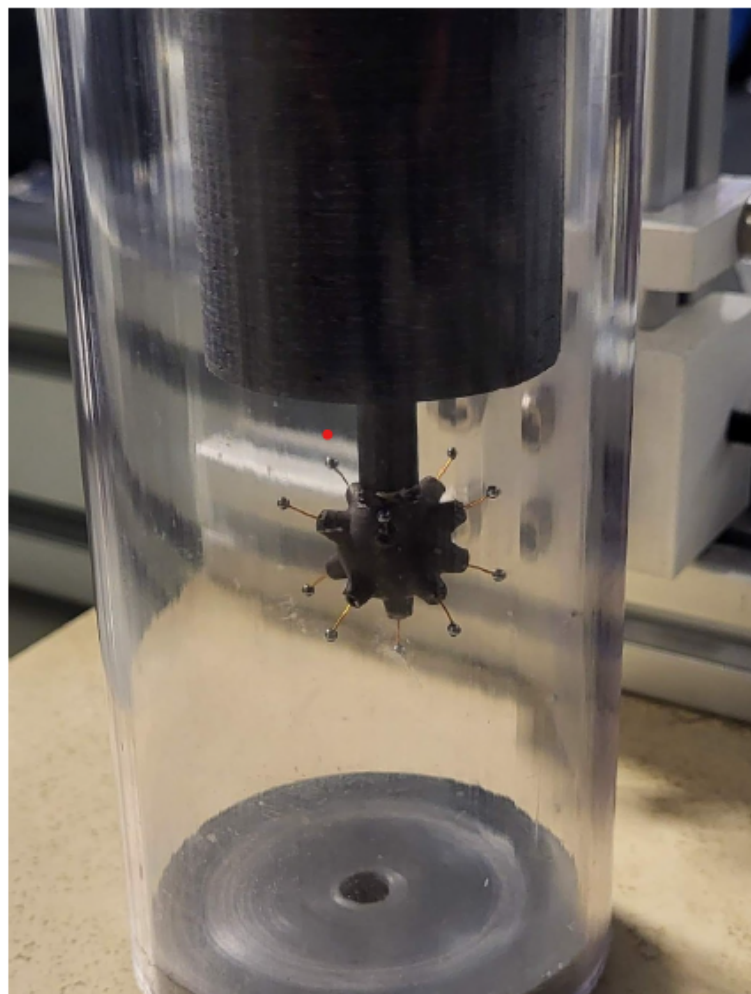


“Cameras taking pictures of themselves in the dark.”

SENSEI is pushing sensitivity boundaries in low-mass dark matter space, and SENSEI and DAMIC together are exploring low-energy noise common to many experiments.



Gas-Based Detector: NEWS-G

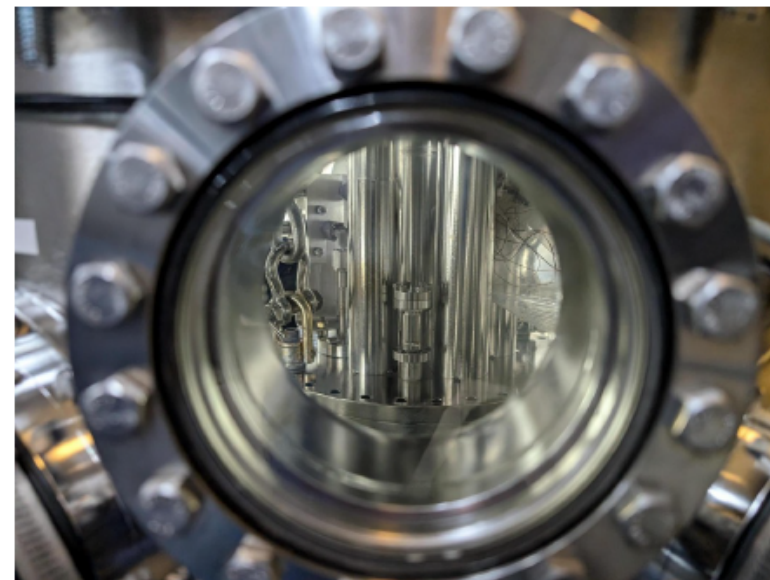
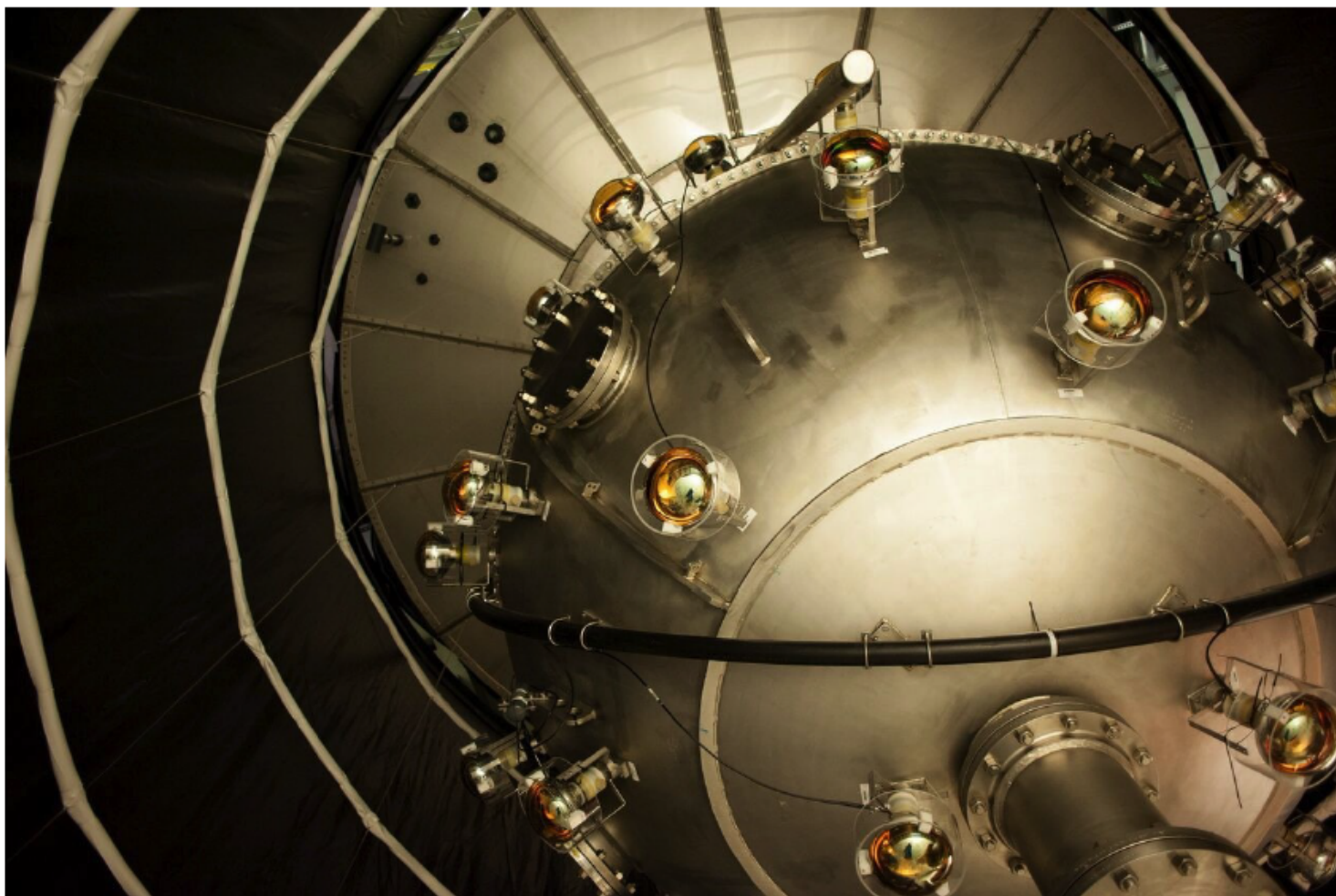


"An amplifier for the gentle notes from dark matter's plucking."

NEWS-G has been taking high-quality data in SNOLAB since 2022. The copper sphere houses methane, providing a low-mass target (hydrogen) sensitive to light dark matter collisions.

A great deal of effort has been put by the collaboration into improving the electric field inside the sphere and reducing noise in the detector. We look forward to increasing science results from this effort!

Liquid Noble Targets: DEAP-3600

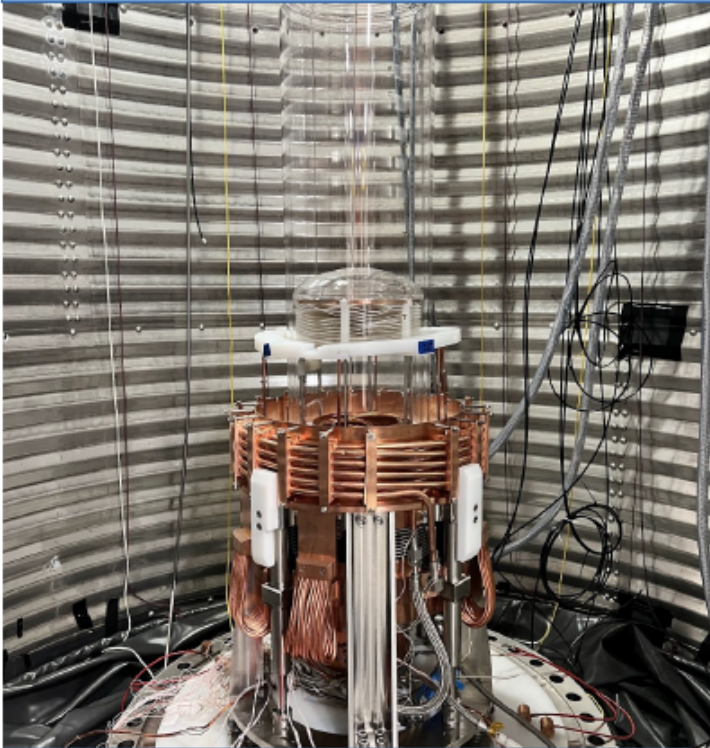


"A liquid lamp that shines when struck by the dark."

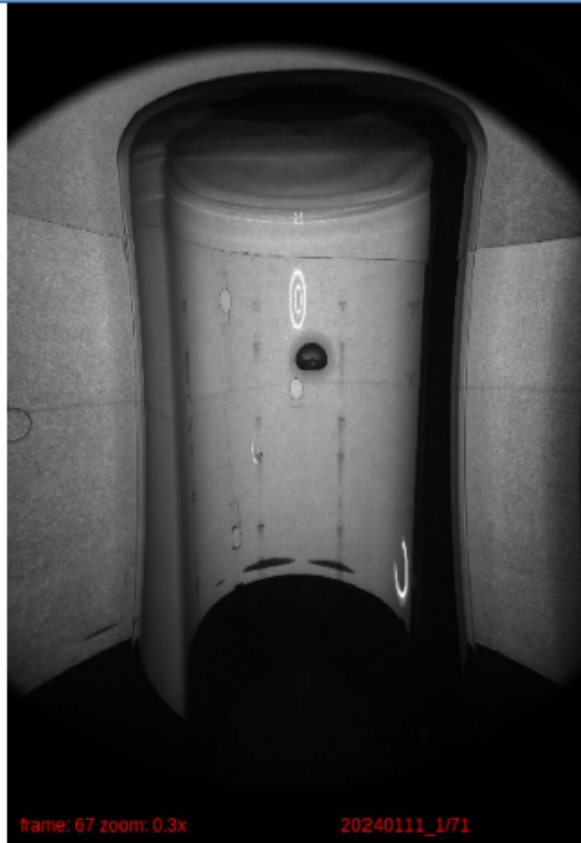
DEAP-3600 has just concluded a period of important upgrades and recently started operations! DEAP has strong sensitivity for higher-mass dark matter.

Superheated Fluid Targets for Dark Matter: PICO

PICO-40L (70kg freon target)



Operations



frame: 67 zoom: 0.3x

20240111_1/71

PICO-500 (250kg freon target)



In Construction

"A bottle of freon that boils at the slightest touch."

Neutrinos

Neutrino Introduction

What we know about neutrinos!

- Postulated in 1930 to solve momentum conservation in beta decay
 - Discovered in 1956
- Fermion: spin $1/2$, electrically neutral
- Only experience the weak force, rarely interacting with anything
- They come in three flavours associated with partner leptons:
 - electron, muon and tau
- They change, or oscillate, from one flavour to another

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What we ^{don't} know about neutrinos!

- What is the neutrino's mass?
 - $U_{PMNS} \neq \delta_{ij}$; $m_i \neq m_\alpha$
- Which neutrino is the heaviest, *i.e.*, what is the mass hierarchy?
 - Normal: $m_1 < m_2 \ll m_3$ ($\Delta m^2 > 0$)
 - Inverted: $m_3 \ll m_1 < m_2$ ($\Delta m^2 < 0$)
- Why is their mass so much smaller than anything else?
- Does the universe treat neutrinos and anti-neutrinos the same?

The massive Sudbury Neutrino Observatory (SNO) captures elusive neutrinos ... solves solar neutrino problem.



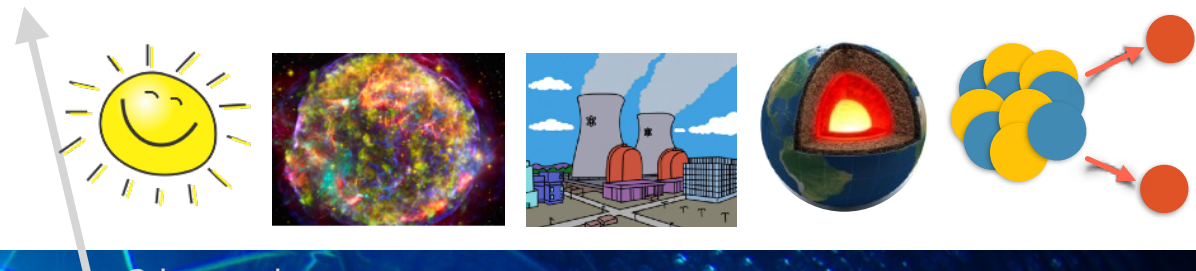
The upgraded SNO+ experiment

Image Credit: SNOLAB



will probe the nature of the neutrino and its mass.

The SNO+ Experiment



~900 tonnes water
~780 tonnes scintillator

2 km rock
overburden

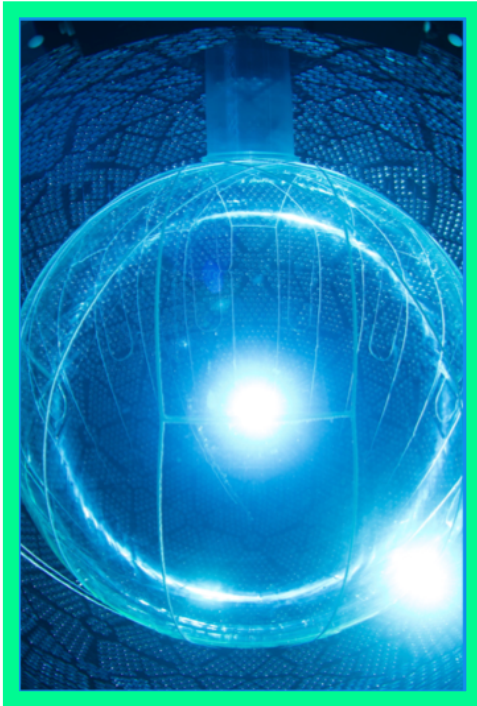
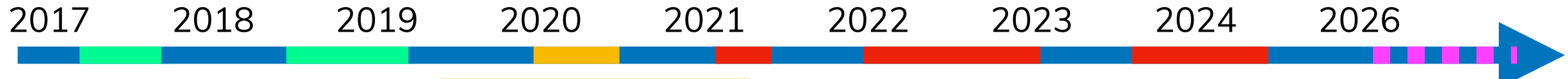
Ropes to hold
detector "up"
and "down"

~7000 tonnes
water shielding

Acrylic Vessel
(AV) $\varnothing$ 12 m

~9300 photo-
multiplier tubes

SNO+ Timeline



- Water Phases
 - High Rn
 - Low Rn



- Partial Fill Phase
 - Scintillator atop Water
 - Paused fill due to Covid

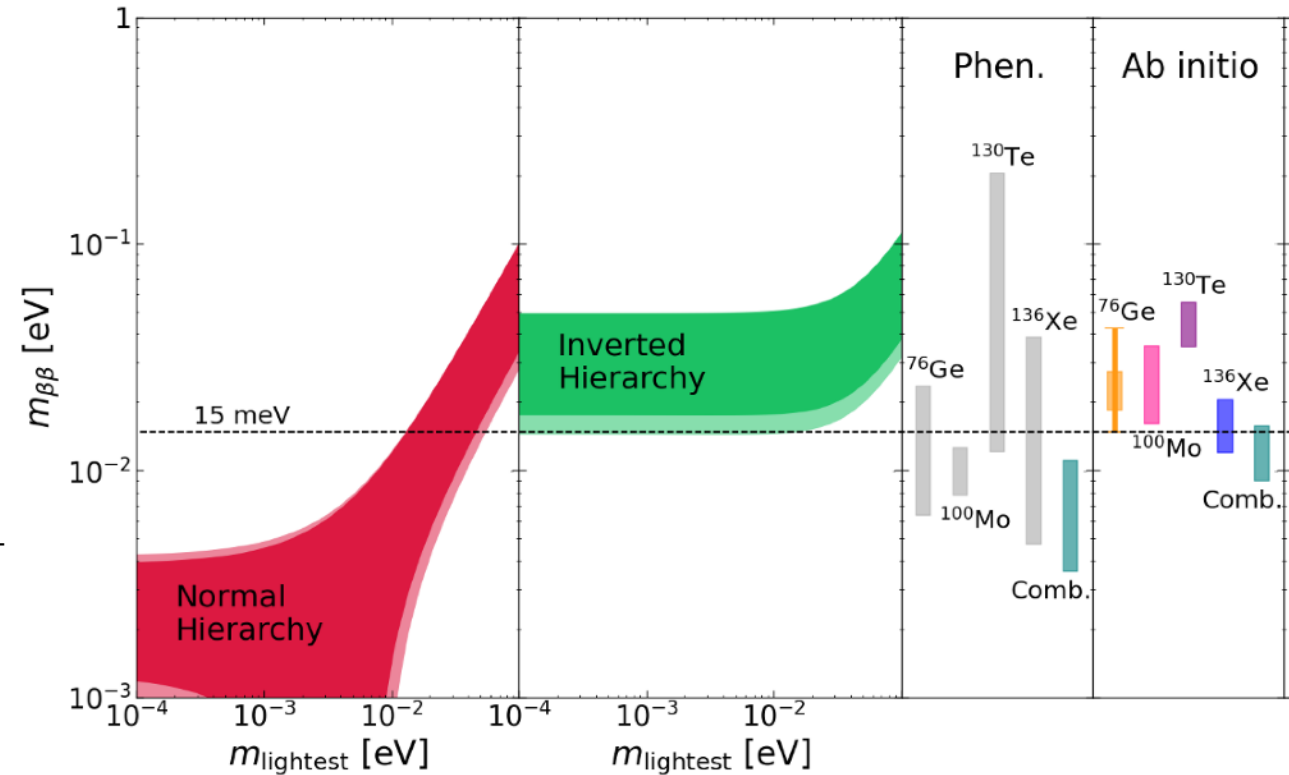
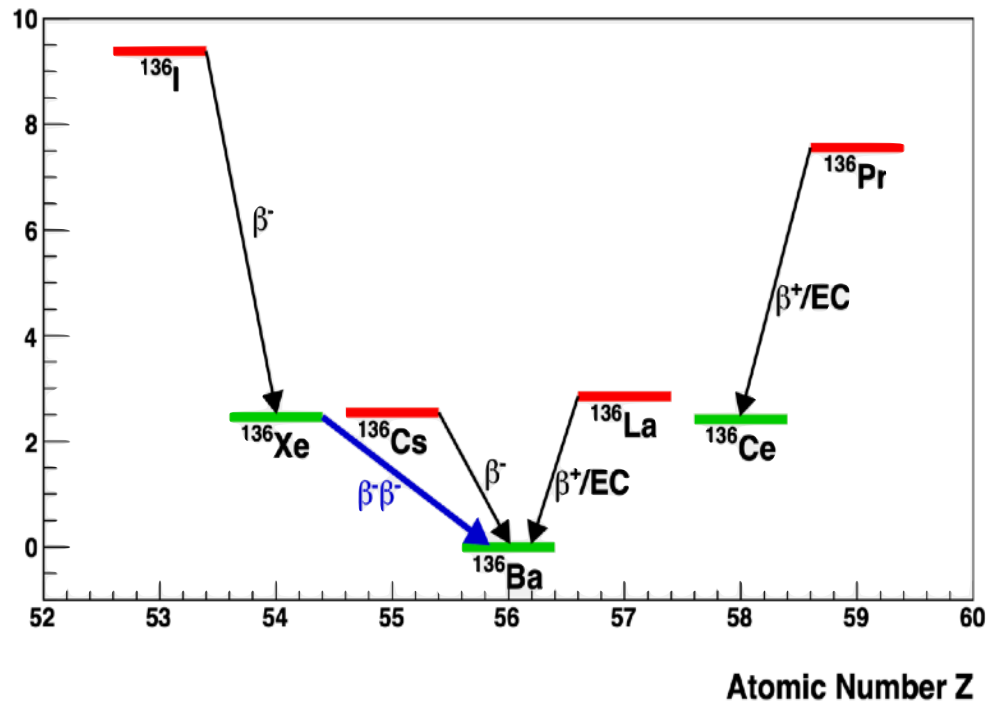
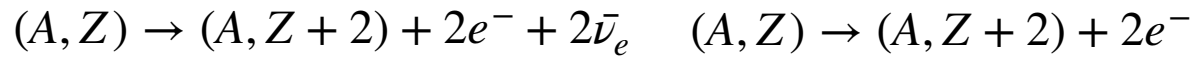
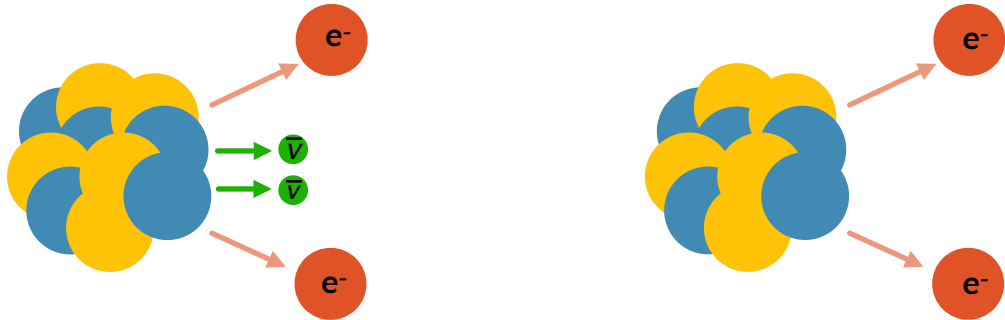


- Scintillator Phases
 - Low PPO
 - Nominal PPO
 - Added bis-MSB



- Next:**
- Tellurium loading

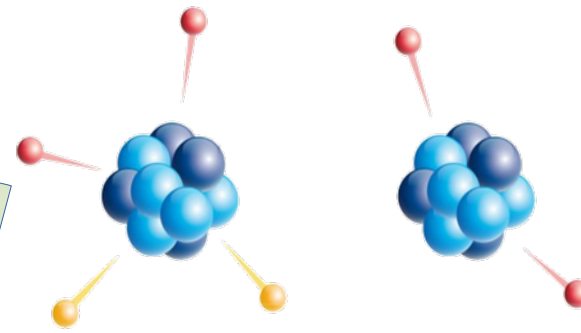
Double Beta Decay



$$(T_{1/2}^{0\nu})^{-1} = \frac{\langle m_{\beta\beta} \rangle^2}{m_e^2} G^{0\nu}(Q, Z) |M^{0\nu}|^2$$

- Observe Lepton Number Violation
- Observe Majorana neutrinos
- Probe new mass mechanism up to the GUT scale
- Probe key ingredients in generating cosmic baryon asymmetry

SNO+ $0\nu\beta\beta$ Decay

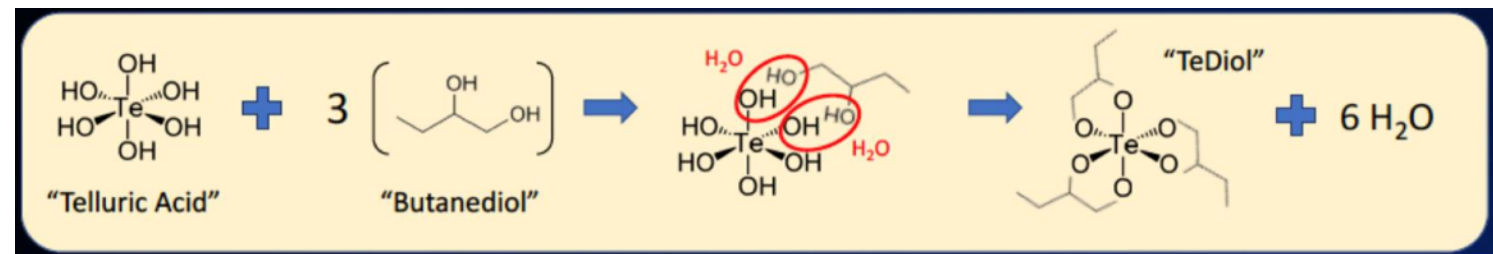


Tellurium-130 undergoes double-beta decay and has a high natural abundance (34%)

→ but it needs to be synthesized into a scintillator-soluble molecule at industrial scale

(1.3 tonnes of Te-130 = 3.9 tonnes of Te)

Chemistry Challenge:
load tonnes of tellurium into
oil-based liquid scintillator



[NIM A, Volume 1051, 2023, 168204](#)

LAB + 2.2 g/L PPO + 2.2 mg/L bisMSB + 5.4 mg/L BHT + TeBD (0.5%) + DDA (0.2%)

SNO+ Tellurium Plants

TeA and Te-Diol production test-batch operations are underway



Telluric Acid (TeA) Plant

“Can we make a metal dissolve in a detergent and glimpse the mass of the neutrino?”



Te-Diol Plant

SNO+ Cavity Access for Repairs



Stars can die spectacularly and explosively.

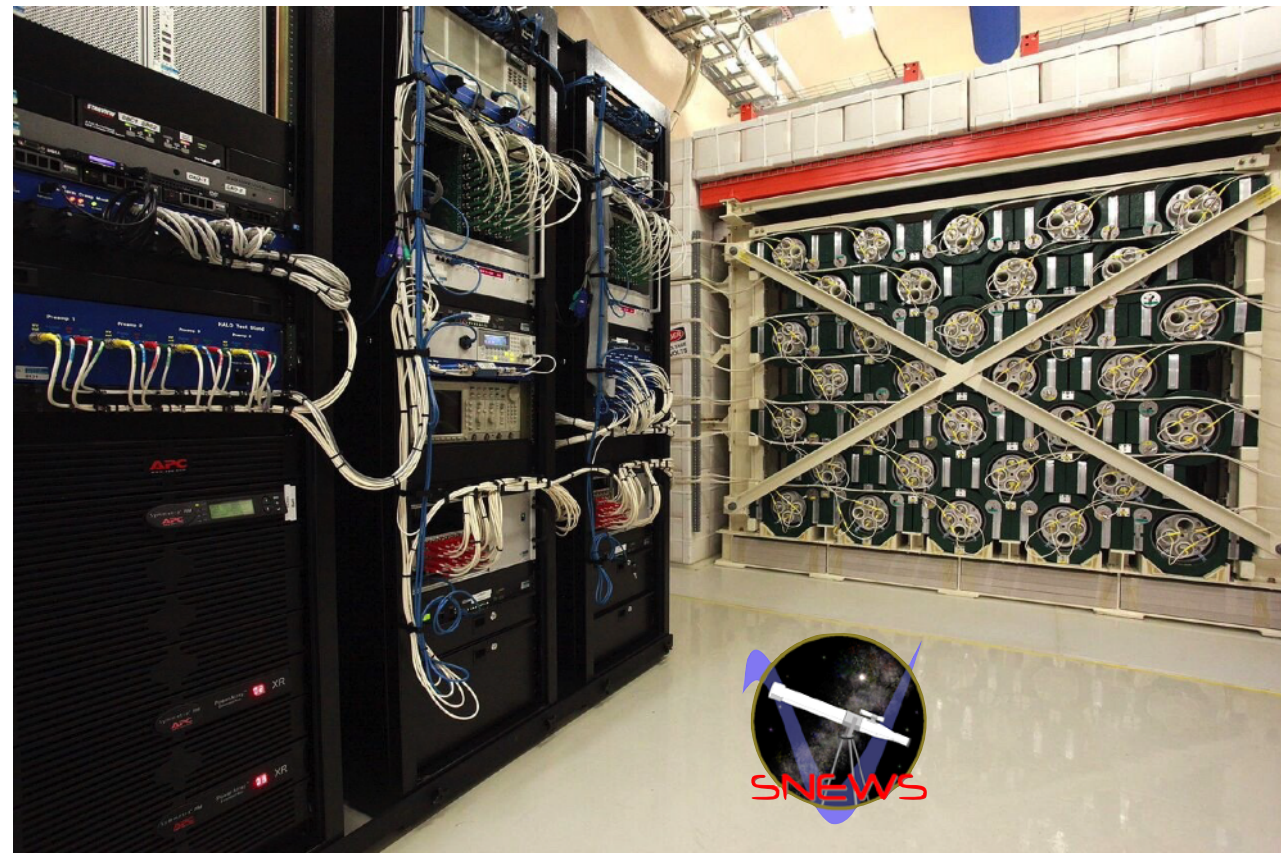


Image Credit: NASA, ESA, CSA, STScI; D. Milisavljevic (Purdue University), T. Temim (Princeton University), I. De Looze (University of Gent)

Most of the energy leaves as neutrinos.

HALO = Helium And Lead Observatory

- Compelling science case:
 - Supernova physics
 - New particles & interactions
- Most large neutrino & dark matter detectors are sensitive to supernovae
- But a dedicated detector has advantages:
 - Low-cost, simple technology for long-duration, high uptime
 - Data are simple to interpret; low-latency signal to the SNEWS network
- HALO:
 - 79 tonnes of recycled lead & 128 recycled SNO neutral current detectors
 - Longest continuously running experiment at SNOLAB (13 years), with >99% uptime



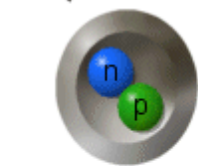
Neutrino Factoid!

SNOLAB is the only place where solar neutrinos have been detected using a real-time, charged current reaction!

SNO:

electron neutrino

ν_e



Deuteron

electron

e^-

Cerenkov Light



p

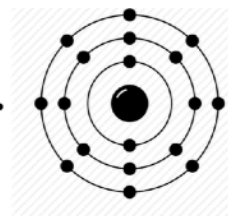
p

protons

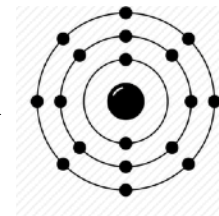
DEAP:



+



^{40}Ar



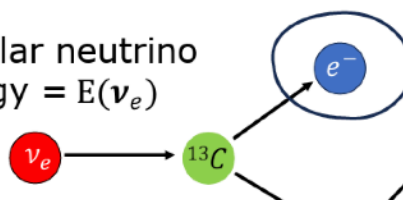
$^{40}\text{K}^*$

+

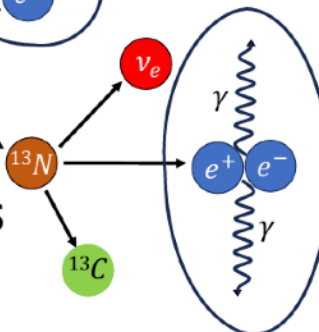


SNO+: Prompt e^- energy = $E(\nu_e) - 2.2 \text{ MeV}$

^8B solar neutrino
energy = $E(\nu_e)$



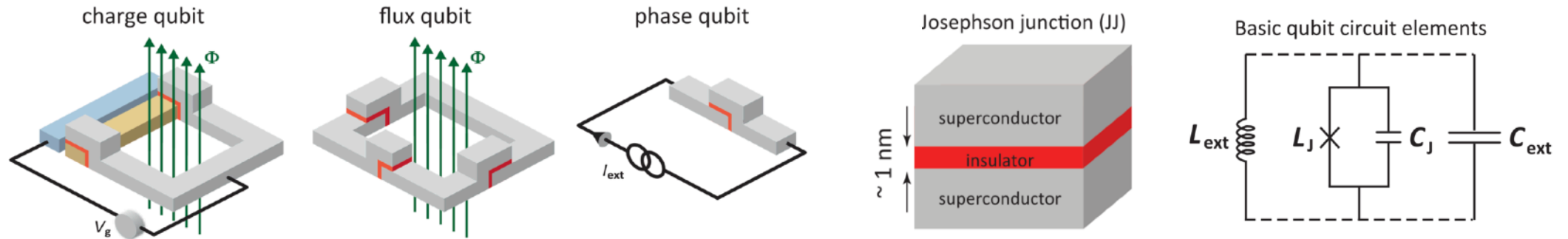
$\tau = 862.6 \text{ s}$



Delayed e^+
annihilation
[1.01, 2.20] MeV

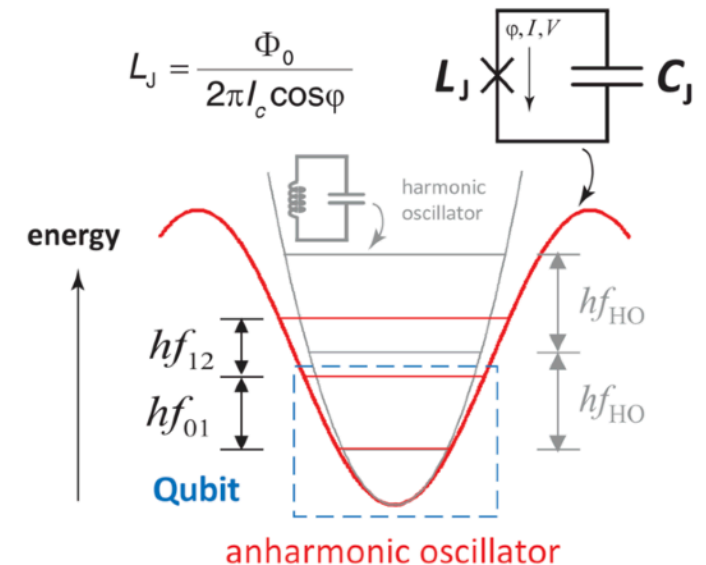
Quantum

Introduction to Superconducting Qubits



- Superconducting qubits:
 - Essentially an LC circuit = harmonic oscillator
 - But contains a Josephson Junction, which
 - Introduces nonlinear inductance (L_J)
 - Turns it into an *anharmonic* oscillator
 - A quantum anharmonic oscillator has uniquely addressable transition energies
 - Two lowest states serve as qubit states 0 and 1
 - Prepare & readout states with microwave photons
 - Manipulate with magnetic and electric fields
- Several qubit modalities (many more beyond what's shown here)
- Superpositions of many qubits enables quantum computing

Josephson junction: nonlinear inductance



Radiation Influence on Superconducting Qubits

- Superconducting qubits are a leading technology for quantum computing
- Interactions of qubits with the environment can cause the quantum states to decohere, resulting in errors
- Errors that correlate across many qubits are especially problematic
- Ionizing radiation can cause correlated errors ... characterization & mitigation are high priorities of QIS community

Article

Impact of ionizing radiation on superconducting qubit coherence

<https://doi.org/10.1038/s41586-020-2619-8> Antti P. Vepsäläinen^{1,2}, Amir H. Karamlou¹, John L. Orrell^{2,3}, Akshunna S. Dogra^{1,4}, Ben Loer², Francisca Vasconcelos¹, David K. Kim², Alexander J. Melville², Bethany M. Niedzielski¹, Jonilyn L. Yoder², Simon Gustavsson¹, Joseph A. Formaggio¹, Brent A. VanDevender² & William D. Oliver^{1,3}

Received: 25 January 2020
Accepted: 5 June 2020
Published online: 26 August 2020

Article

Correlated charge noise and relaxation errors in superconducting qubits

<https://doi.org/10.1038/s41586-021-03557-5> C. D. Wilen^{1,2}, S. Abdullah¹, N. A. Kurinsky^{2,3}, C. Stanford⁴, L. Cardani⁵, G. D'Imperio³, C. Tomei¹, L. Faoro^{1,6}, L. B. Ioffe¹, C. H. Liu¹, A. Opremcak¹, B. G. Christensen¹, J. L. DuBois² & R. McDermott^{1,2}

Received: 14 December 2020
Accepted: 15 April 2021
Published online: 16 June 2021

The central challenge in building a quantum computer is error correction. Unlike

ARTICLE

<https://doi.org/10.1038/s41467-021-23032-z> **OPEN**

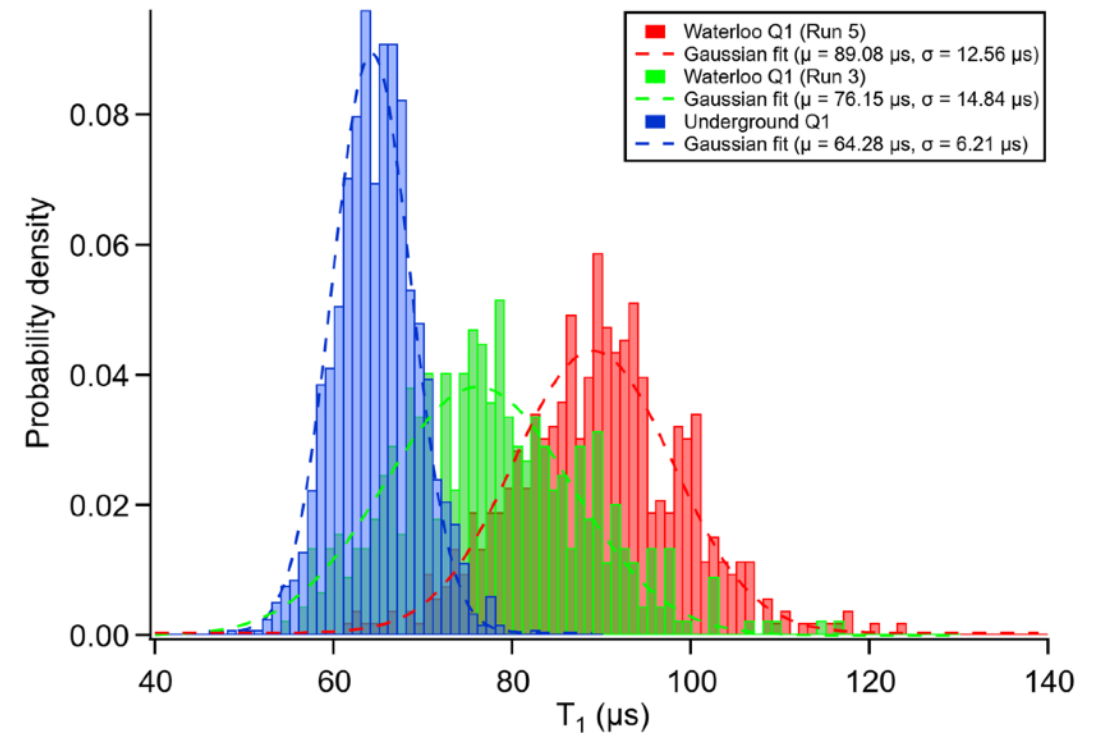
Reducing the impact of radioactivity on quantum circuits in a deep-underground facility

L. Cardani^{1,17}, F. Valenti^{2,3,17}, N. Casali¹, G. Catelani^{1,4}, T. Charpentier^{1,2}, M. Clemenza^{5,6}, I. Colantoni^{1,7}, A. Cruciani¹, G. D'Imperio¹, L. Gironi¹, L. Grünhaupt^{1,2}, D. Gusenkova², F. Henriques², M. Lagooni², M. Martinez^{1,8}, G. Pettinari^{1,9}, C. Rusconi^{1,10,11}, O. Sander³, C. Tomei¹, A. V. Ustinov^{2,12,13}, M. Weber³, W. Wernsdorfer^{1,14,15}, M. Vignati^{1,16}, S. Pirro^{1,10} & I. M. Pop^{1,2,14}

Quantum Science at SNOLAB



- First qubit data comparison between surface and underground operations shows some interesting differences
- Smaller standard deviation of T_1 coherence time observed underground at CUTE (blue) versus at the surface at University of Waterloo (green & red)
- Broadening of distributions also observed when qubits exposed to gamma rays from ^{133}Ba source
- Analysis is ongoing... stay tuned!

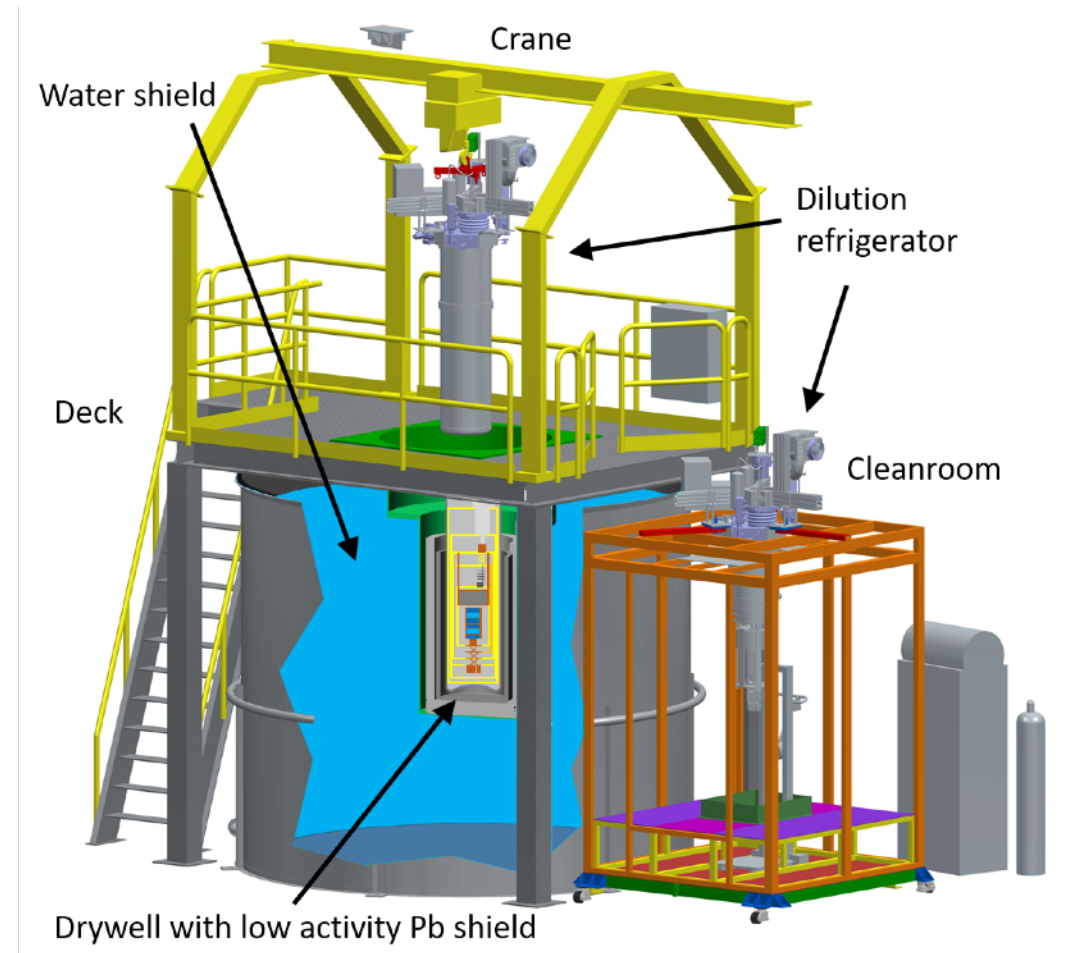


CUTE

Cryogenic Underground TEST Facility



- CUTE facility provides a unique low-background environment for investigating radiation backgrounds:
 - 1.5 m water shield
 - 10 cm of low-activity lead
 - 20 cm polyethylene lid
 - Mu-metal and copper shields
 - 15 cm of internal lead plug + Cu box
- Qubit chips installed and operated summer 2025
→ Deepest, low-background qubit operations ever!



Quantum Science at SNOLAB



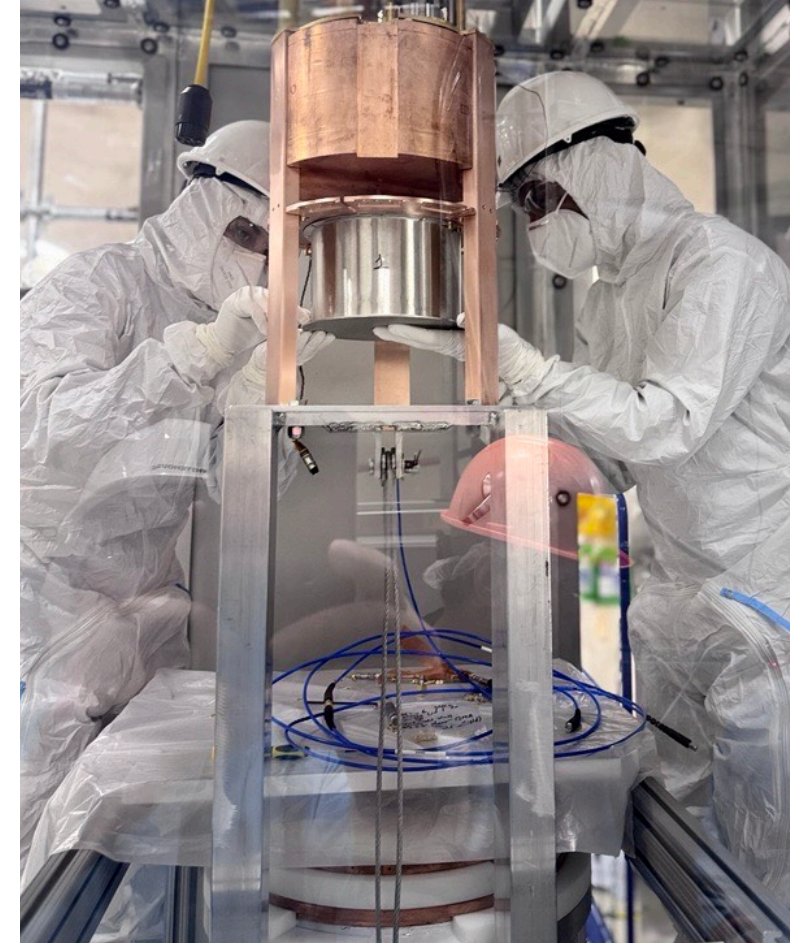
CUTE water tank & cleanroom



Lowering of DR into drywell



Qubit installation in cleanroom



Life Sciences

REPAIR:

Researching the Effects of the Presence and Absence of Ionizing Radiation

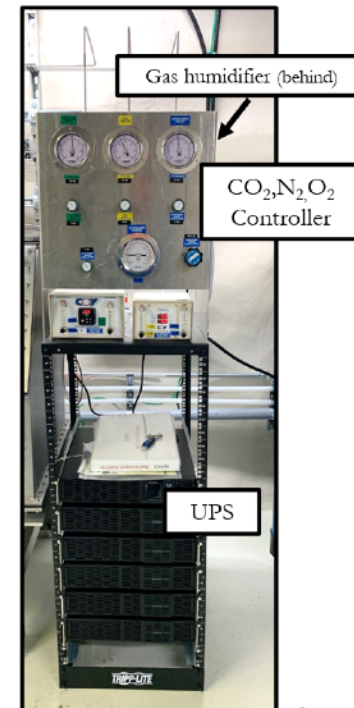
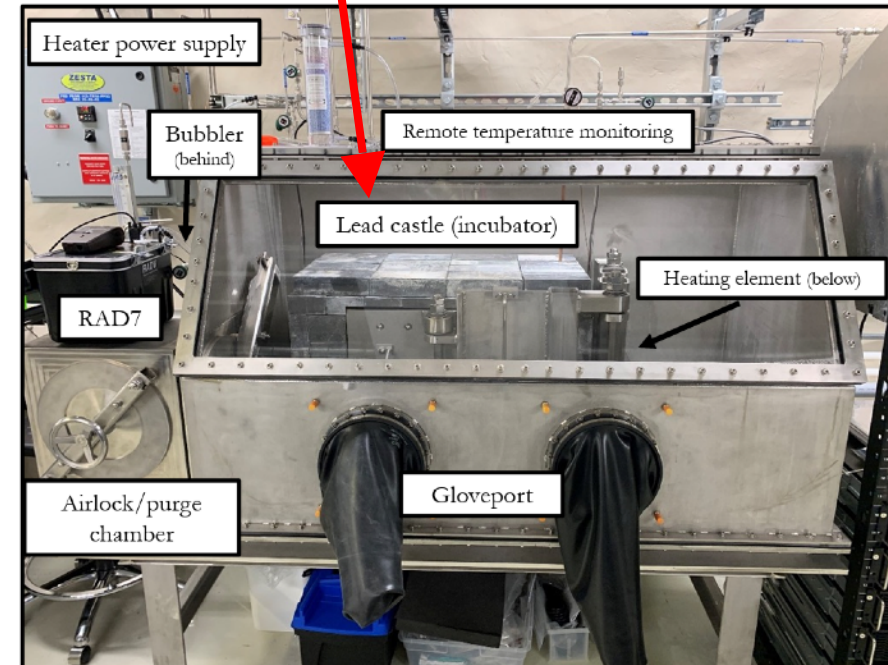
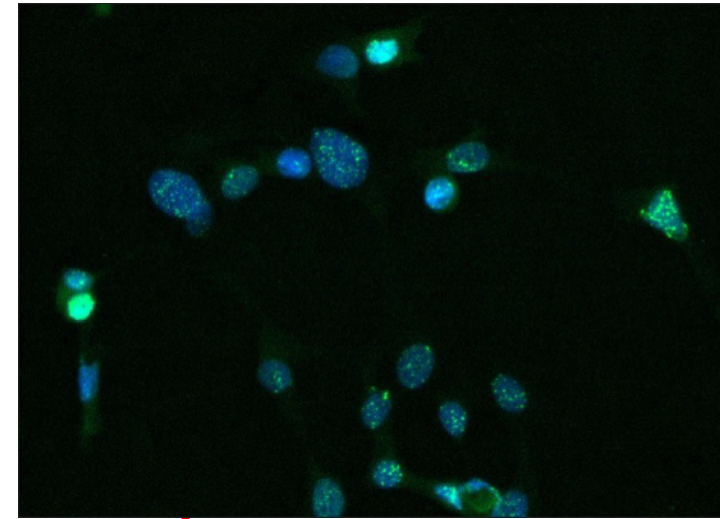
- Natural radiation has an essential biological role
- Study the effects of very low background radiation levels on living organisms
- Assess the markers for carcinogenesis and alterations to DNA in human cells as well as whole organism development and growth using lake whitefish embryos

“We know there is such a thing as too much radiation. Is there such a thing as too little?”

Michel Lapointe et al. *Health Physics* 2024 126(6):397-404.

Protracted Exposure to a Sub-background Radiation Environment Negatively Impacts the Anhydrobiotic Recovery of Desiccated Yeast Sentinels.

[doi:10.1097/HP.0000000000001804](https://doi.org/10.1097/HP.0000000000001804).

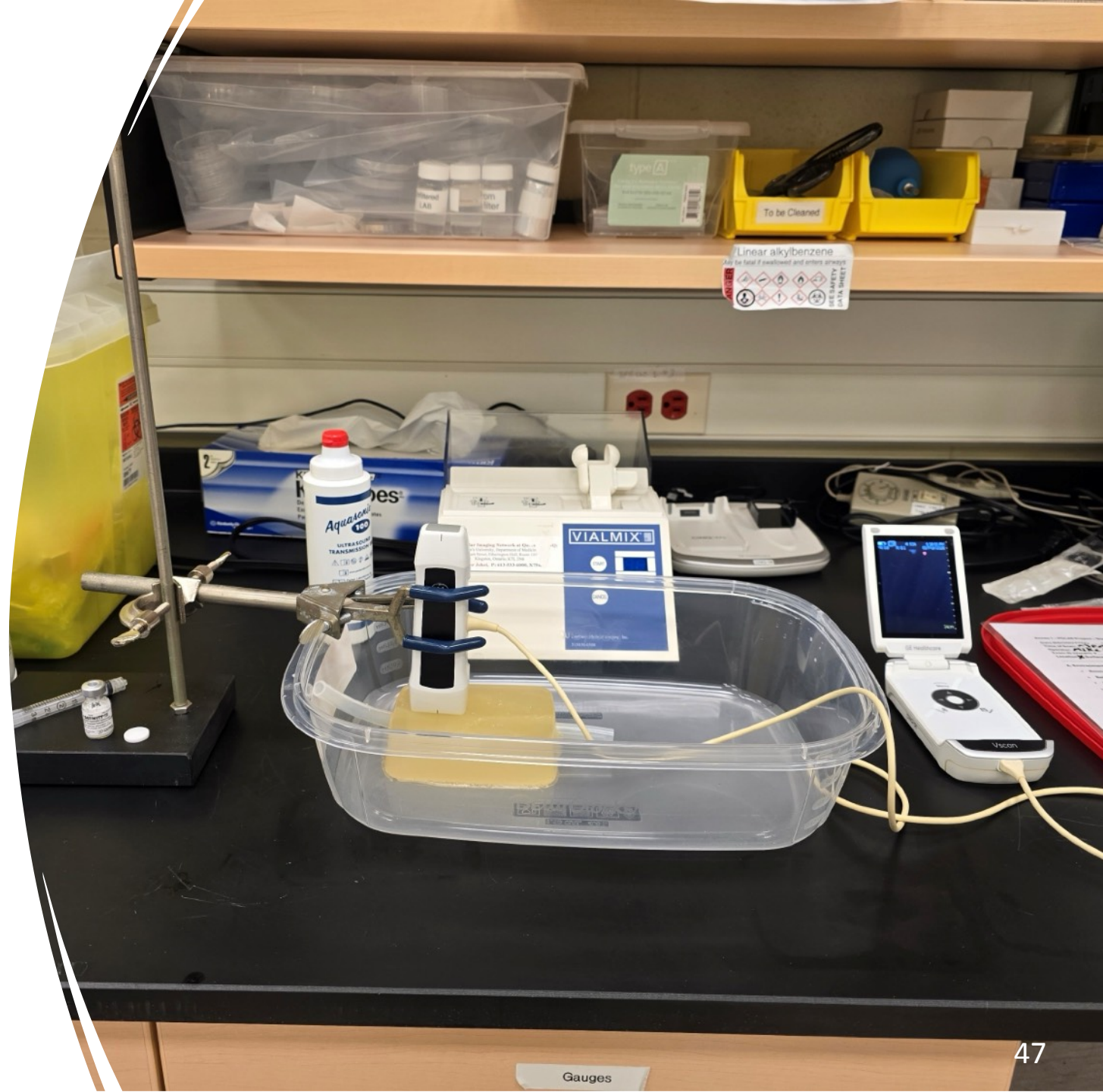


POLAR:

POUCS Lessons from Austere and Remote Environments

- Focused on use of Point-of-Care UltraSound (POCUS) in remote or austere environments
- This new project started testing hand-held ultrasound equipment underground at SNOLAB without human subjects in 2026.
- The next phase will enlist local volunteers for real-world testing and measurement of medical responses of humans in the underground environment.

“Portable ultrasound has been demonstrated in many remote environments; will it ‘just work’ 2km underground?”



Applied Radiation Detection

Nuclear Forensics

- Dual High-Purity Germanium (HPGe) detector deployed by Health Canada for nuclear forensics
- SNOLAB is working to improve sensitivity to isotopes with γ - γ coincidences (and γ - β using additional PIPS detectors)

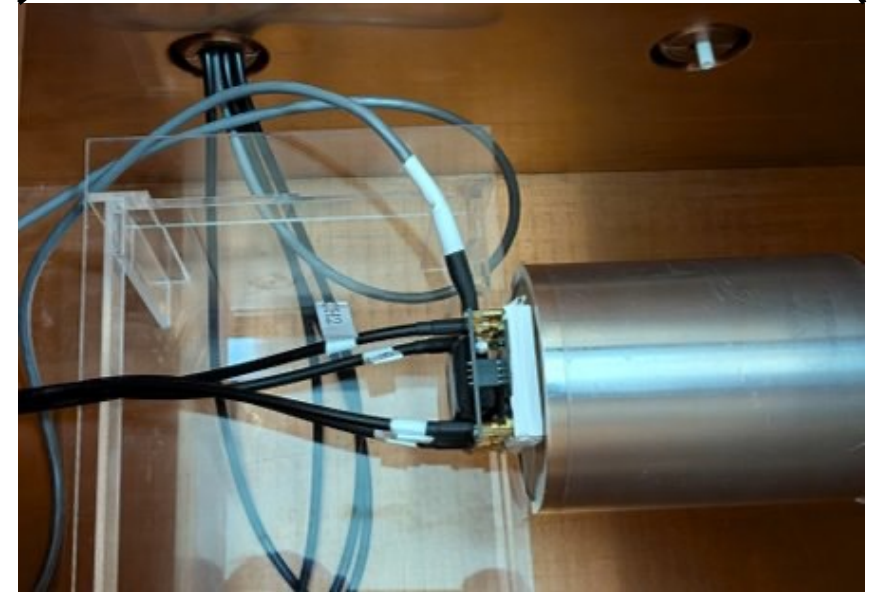
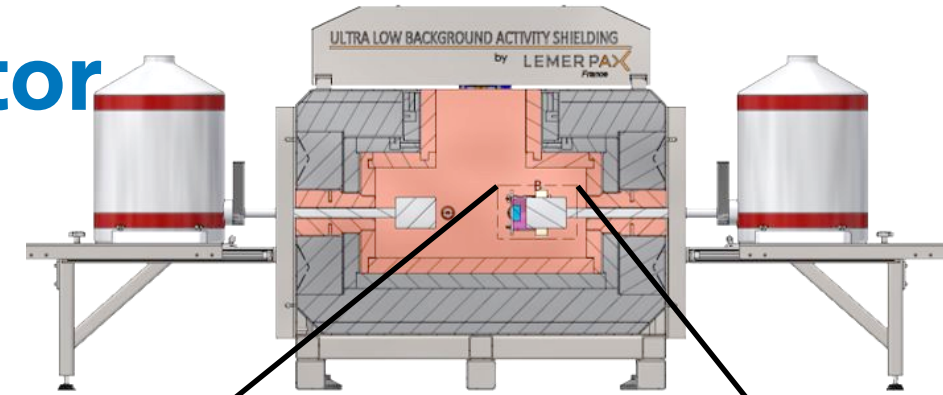
"Can we fingerprint interesting phenomena in the environment using radioisotopes?"



Capability Update: CTBT Detector

RAMPS Science Run 1 completed (March 9-13)

- Attempting to measure very rare ^{176}Lu decay
- Over 20 TB of data taken!
- Now starts the data analysis
- And looking forward to other isotopes ...

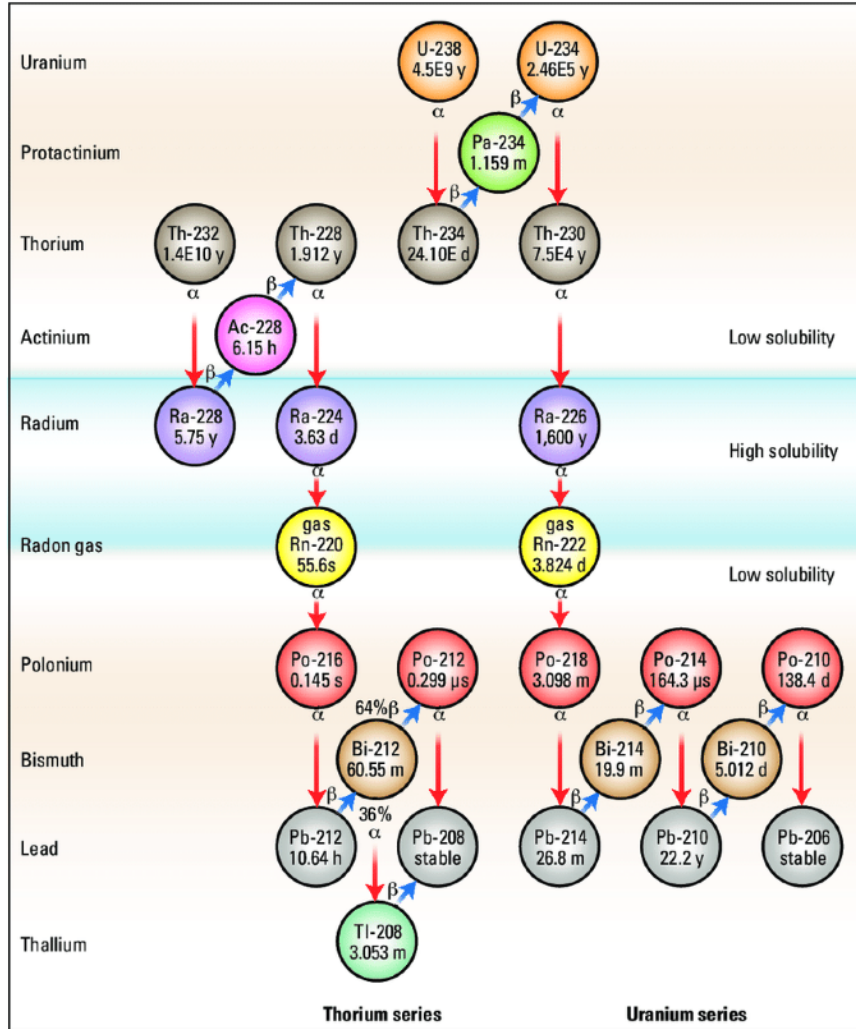


Capability Update – CTBT Detector



10x Speed!

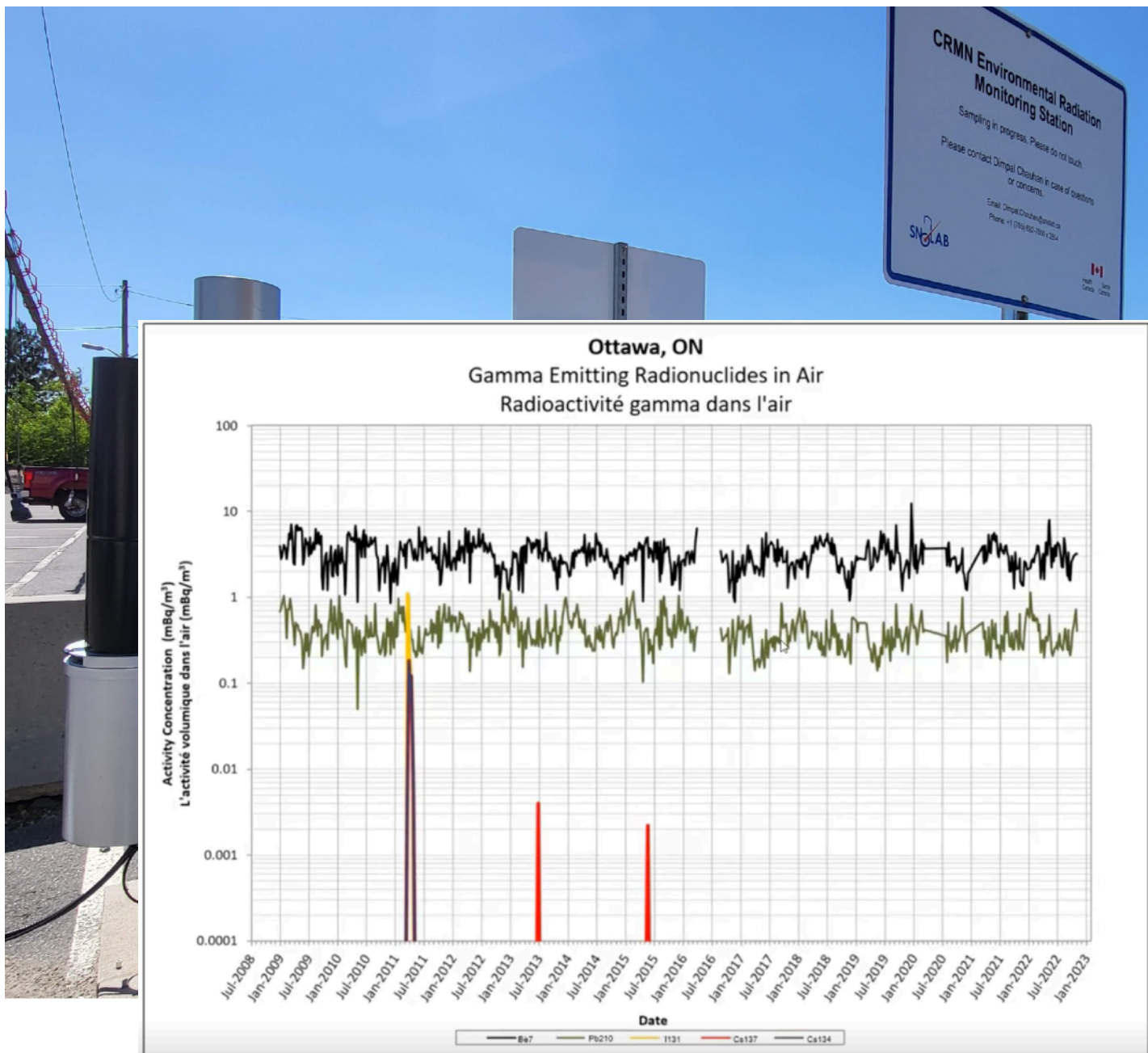
Low Background Counting



- The Low Background Counting Facility provides both material assay and screening and environment monitoring capabilities
 - 5 HPGe detectors
 - 2 sodium iodide detectors for gamma detection;
 - XIA alpha counter for the detection of alpha particles;
 - inductively coupled plasma mass spectrometer (ICP-MS).
 - 3 radon emanation chambers and two radon emanation boards;
 - Many other detectors
- *Measurement of low ^{222}Rn concentration in N_2 using an activated charcoal trap*
[Nucl.Instrum.Meth.A, Volume 1076](https://doi.org/10.1289/ehp.1408855)

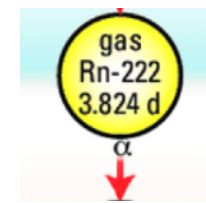
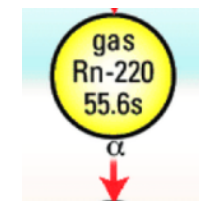


- Air monitoring station that is used as part of a collaborative effort with Health Canada
- The program is made up of two networks, the Fixed Point Surveillance Network (FPSN), and the Canadian Radiological Monitoring Network (CRMN)
 - Air and water sampling
 - Live radiation monitoring (e.g., dosimetry)
 - naturally occurring ^7Be and ^{210}Pb , and the anthropogenic: ^{134}Cs , ^{137}Cs , and ^{131}I .
- Results are publicly available in real time on [Open Maps](#).



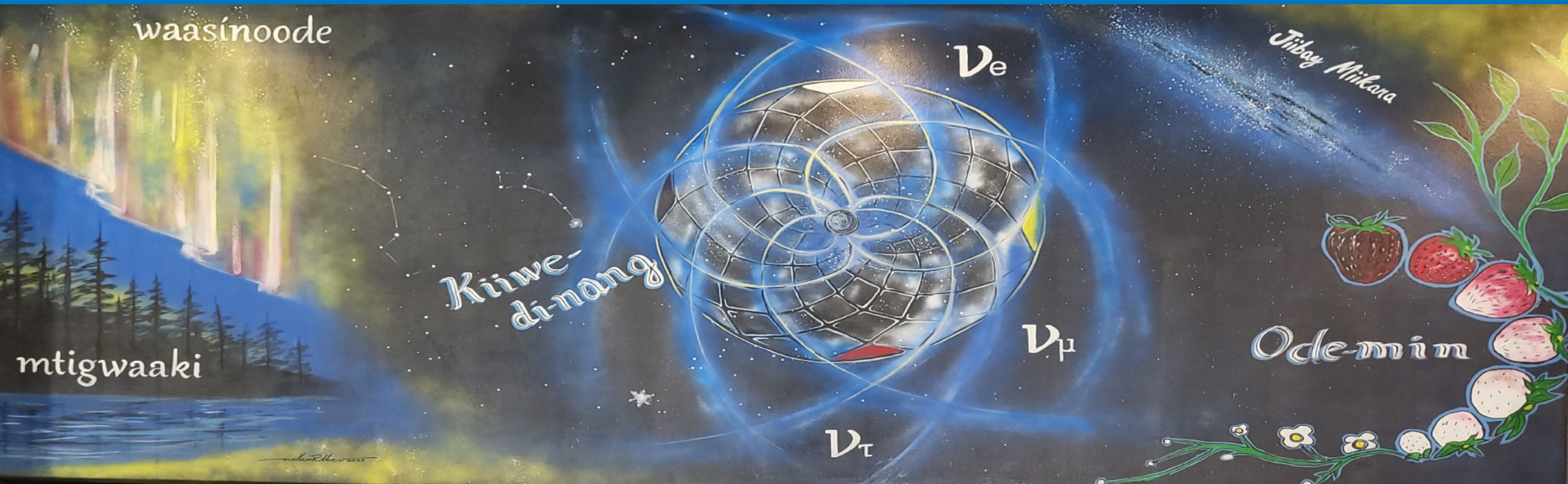
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Radon Monitoring



- Health Canada used SNOLAB's unique underground environment to test several commercial grade radon monitors.
- Tests are continuing with additional monitors for long-term stability tests and comparison to calibrated science grade radon monitors.
- *Performance Evaluation of Electronic Radon Monitors Available to the General Public, [Health Physics, May 2, 2025](#)*

Intersections of Science and Culture



“Agaashiinyi: It is Small”

Artist: Will Morin

Location: Lobby, SNOLAB Surface Building



"Star stories"

Artist: Mishiikenh Kwe

Location: 2nd Floor,
SNOLAB Surface Building

Emerging artist from
Magnetawan First Nation
-combines traditional
woodland style with pop
art and modernism.

Inspired by creation stories
from Turtle Island told to
her by her grandmother.
Each of the animals
depicted in the mural
represents a different
aspect of Anishinaabe
creation stories.

Outlook

15 Year Planning



SNOLAB was asked by its federal funding agency to provide detailed & reliable budget estimates for the next 15 years under 3 budget scenarios:

1. Maintaining the current level of operations
2. Fully supporting the needs of the Canadian research community
3. Increasing global competitiveness

New Underground Lab Space

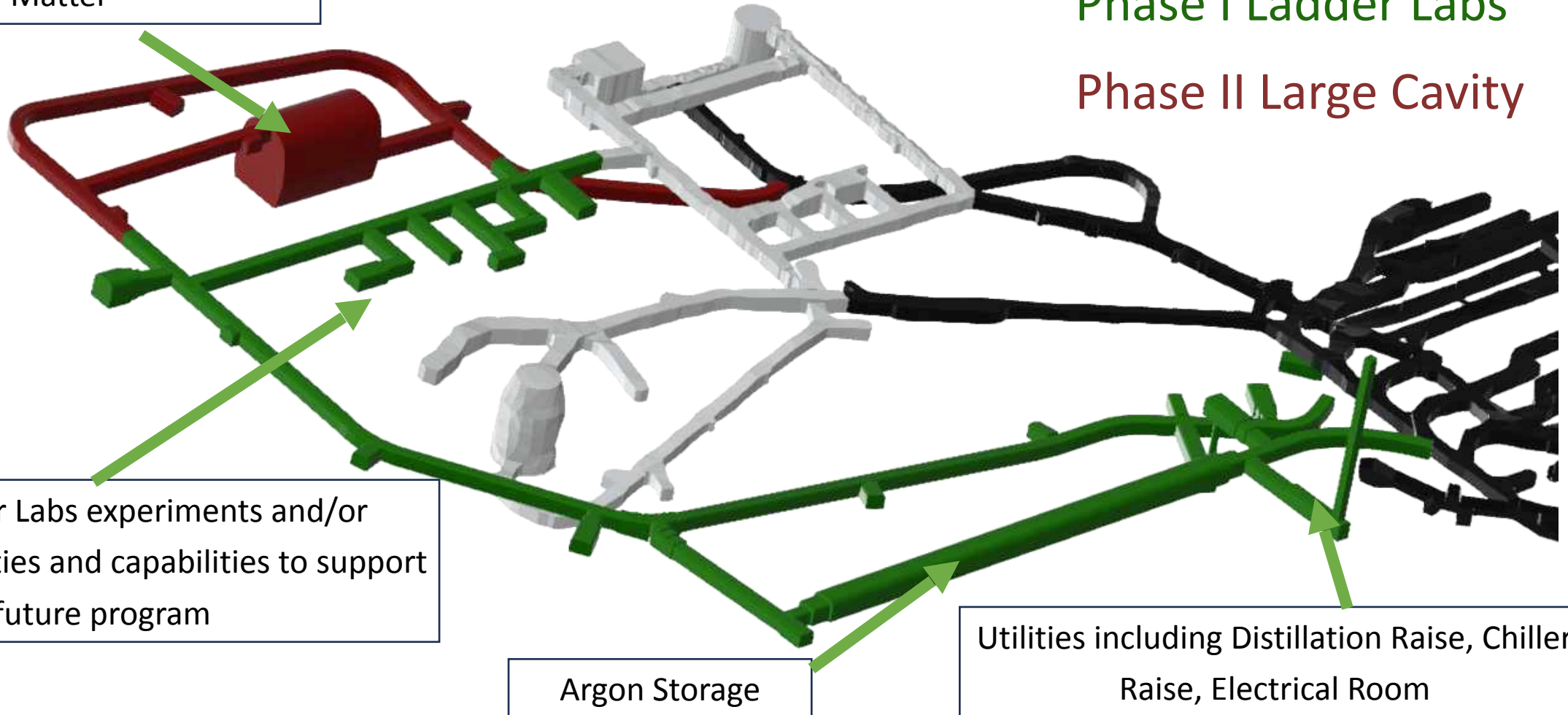


Large Cavity for Beyond Tonne
Scale $0\nu\beta\beta$ decay or Future Dark
Matter

Existing Lab

Phase I Ladder Labs

Phase II Large Cavity



New Ladder Labs experiments and/or
expanded facilities and capabilities to support
future program

Argon Storage

Utilities including Distillation Raise, Chiller
Raise, Electrical Room

Ask Questions.

Seek Answers.

Go Deep.

Reaching New Heights, Deep Underground

2023-2029 Strategic Plan



Reaching New Heights, Deep Underground

2023-2029 Implementation Plan

