Searching for the Dark

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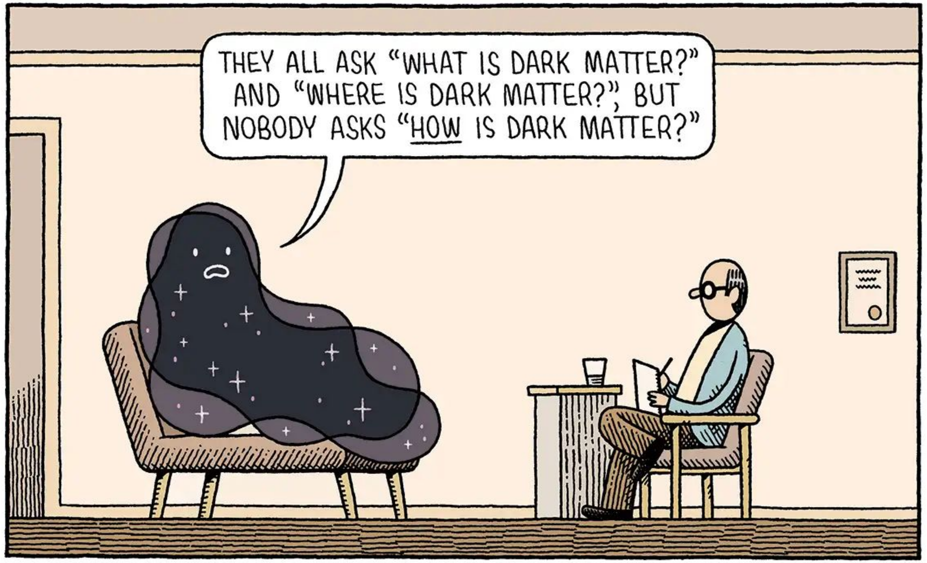
Outline

- Introduction to dark matter
  - How particle physicists think
  - Evidence for DM
- Search methods for dark matter
  - Collider
  - Indirect detection
  - Direct detection
- Direct detection
  - Different observation methods
  - Current status
  - The SuperCDMS experiment



TOM GAULD for NEW SCIENTIST

Purpose of Particle Physics

Categorise and model the fundamental particles and forces: Standard Model of particle physics.

Tells us:

- Which particles can interact with each other
- How that interaction occurs
- Probability of an interaction occurring
- Parameters that describe the particles

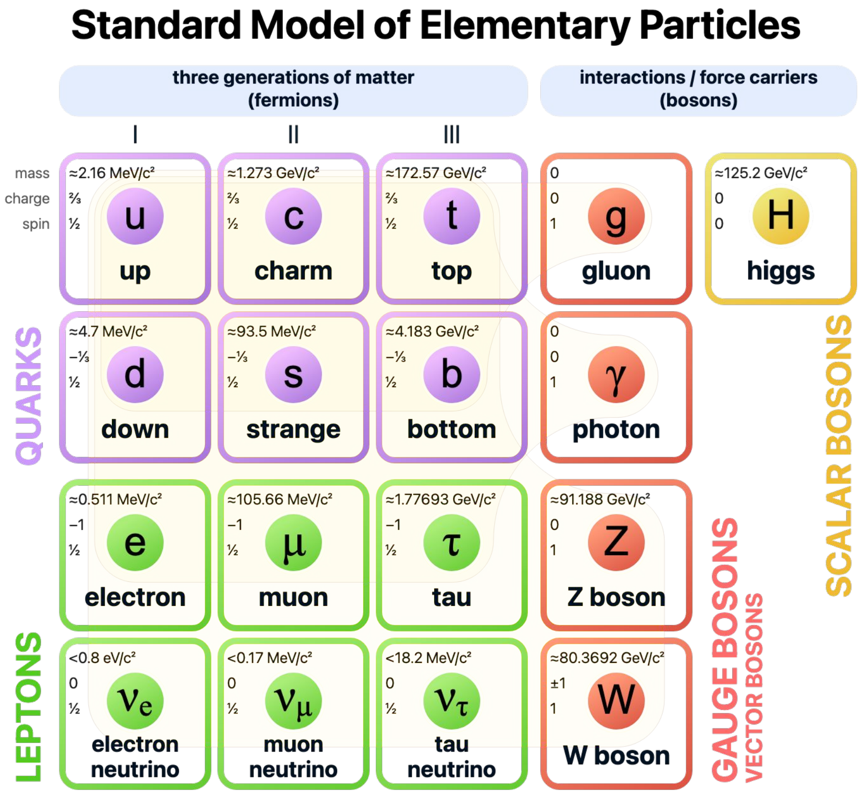
$$
\begin{aligned}
\mathcal{L}_{SM} = &-\tfrac12\partial_\nu g^a_\mu\partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \tfrac14 g_s^2 f^{abc}f^{ade}g^b_\mu g^c_\nu g^d_\mu g^e_\nu - \partial_\nu W^+_\mu\partial_\nu W^-_\mu - \\
&M^2 W^+_\mu W^-_\mu - \tfrac12\partial_\nu Z^0_\mu\partial_\nu Z^0_\mu - \tfrac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \tfrac12\partial_\mu A_\nu\partial_\mu A_\nu - igc_w(\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu\partial_\nu W^-_\mu - W^-_\nu\partial_\nu W^+_\mu)) - \\
&igs_w(\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + A_\mu(W^+_\nu\partial_\nu W^-_\mu - \\
&W^-_\nu\partial_\nu W^+_\mu)) - \tfrac12 g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \tfrac12 g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - \\
&Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w(A_\mu Z^0_\nu(W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu) - \tfrac12\partial_\mu H\partial_\mu H - 2M^2\alpha_h H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - \tfrac12\partial_\mu\phi^0\partial_\mu\phi^0 - \\
&\beta_h\left(\tfrac{2M^2}{g^2} + \tfrac{2M}{g}H + \tfrac12(H^2+\phi^0\phi^0+2\phi^+\phi^-)\right) + \tfrac{2M^4}{g^2}\alpha_h - \\
&g\alpha_h M\left(H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-\right) - \\
&\tfrac18 g^2\alpha_h\left(H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2\right) - \\
&gMW^+_\mu W^-_\mu H - \tfrac12 g\tfrac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \\
&\tfrac12 ig\left(W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)\right) + \\
&\tfrac12 g\left(W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) + W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)\right) + \tfrac12 g\tfrac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) + \\
&M\left(\tfrac{1}{c_w}Z^0_\mu\partial_\mu\phi^0 + W^+_\mu\partial_\mu\phi^- + W^-_\mu\partial_\mu\phi^+\right) - ig\tfrac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_wMA_\mu(W^+_\mu\phi^- - \\
&W^-_\mu\phi^+) - ig\tfrac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_wA_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \\
&\tfrac14 g^2W^+_\mu W^-_\mu\left(H^2+(\phi^0)^2+2\phi^+\phi^-\right) - \tfrac18 g^2\tfrac{1}{c_w^2}Z^0_\mu Z^0_\mu\left(H^2+(\phi^0)^2+2(2s_w^2-1)^2\phi^+\phi^-\right) - \\
&\tfrac12 g^2\tfrac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \tfrac12 ig^2\tfrac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \tfrac12 g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + \\
&W^-_\mu\phi^+) + \tfrac12 ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\tfrac{s_w}{c_w}(2c_w^2-1)Z^0_\mu A_\mu\phi^+\phi^- - \\
&g^2 s_w^2 A_\mu A_\mu\phi^+\phi^- + \tfrac12 ig_s\lambda^a_{ij}(\bar q^\sigma_i\gamma^\mu q^\sigma_j)g^a_\mu - \bar e^\lambda(\gamma\partial + m^\lambda_e)e^\lambda - \bar\nu^\lambda(\gamma\partial + m^\lambda_\nu)\nu^\lambda - \bar u^\lambda_j(\gamma\partial + \\
&m^\lambda_u)u^\lambda_j - \bar d^\lambda_j(\gamma\partial + m^\lambda_d)d^\lambda_j + igs_wA_\mu\left(-(\bar e^\lambda\gamma^\mu e^\lambda) + \tfrac23(\bar u^\lambda_j\gamma^\mu u^\lambda_j) - \tfrac13(\bar d^\lambda_j\gamma^\mu d^\lambda_j)\right) + \\
&\tfrac{ig}{4c_w}Z^0_\mu\{(\bar\nu^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar e^\lambda\gamma^\mu(4s_w^2-1-\gamma^5)e^\lambda) + (\bar d^\lambda_j\gamma^\mu(\tfrac43 s_w^2-1-\gamma^5)d^\lambda_j) + \\
&(\bar u^\lambda_j\gamma^\mu(1-\tfrac83 s_w^2+\gamma^5)u^\lambda_j)\} + \tfrac{ig}{2\sqrt2}W^+_\mu\left((\bar\nu^\lambda\gamma^\mu(1+\gamma^5)U^{lep}{}_{\lambda\kappa}e^\kappa) + (\bar u^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)\right) + \\
&\tfrac{ig}{2\sqrt2}W^-_\mu\left((\bar e^\kappa U^{lep\dagger}{}_{\kappa\lambda}\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar d^\kappa_j C^\dagger_{\kappa\lambda}\gamma^\mu(1+\gamma^5)u^\lambda_j)\right) + \\
&\tfrac{ig}{2M\sqrt2}\phi^+\left(-m^\kappa_e(\bar\nu^\lambda U^{lep}{}_{\lambda\kappa}(1-\gamma^5)e^\kappa) + m^\lambda_\nu(\bar\nu^\lambda U^{lep}{}_{\lambda\kappa}(1+\gamma^5)e^\kappa\right) + \\
&\tfrac{ig}{2M\sqrt2}\phi^-\left(m^\lambda_e(\bar e^\lambda U^{lep\dagger}{}_{\lambda\kappa}(1+\gamma^5)\nu^\kappa) - m^\kappa_\nu(\bar e^\lambda U^{lep\dagger}{}_{\lambda\kappa}(1-\gamma^5)\nu^\kappa)\right) - \tfrac g2\tfrac{m^\lambda_\nu}{M}H(\bar\nu^\lambda\nu^\lambda) - \\
&\tfrac g2\tfrac{m^\lambda_e}{M}H(\bar e^\lambda e^\lambda) + \tfrac{ig}{2}\tfrac{m^\lambda_\nu}{M}\phi^0(\bar\nu^\lambda\gamma^5\nu^\lambda) - \tfrac{ig}{2}\tfrac{m^\lambda_e}{M}\phi^0(\bar e^\lambda\gamma^5 e^\lambda) - \tfrac14\bar\nu_\lambda M^R_{\lambda\kappa}(1-\gamma_5)\hat\nu_\kappa - \\
&\tfrac14\overline{\bar\nu_\lambda M^R_{\lambda\kappa}(1-\gamma_5)\hat\nu_\kappa} + \tfrac{ig}{2M\sqrt2}\phi^+\left(-m^\kappa_d(\bar u^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m^\lambda_u(\bar u^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j\right) + \\
&\tfrac{ig}{2M\sqrt2}\phi^-\left(m^\lambda_d(\bar d^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m^\kappa_u(\bar d^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j)\right) - \tfrac g2\tfrac{m^\lambda_u}{M}H(\bar u^\lambda_j u^\lambda_j) - \\
&\tfrac g2\tfrac{m^\lambda_d}{M}H(\bar d^\lambda_j d^\lambda_j) + \tfrac{ig}{2}\tfrac{m^\lambda_u}{M}\phi^0(\bar u^\lambda_j\gamma^5 u^\lambda_j) - \tfrac{ig}{2}\tfrac{m^\lambda_d}{M}\phi^0(\bar d^\lambda_j\gamma^5 d^\lambda_j) + \bar G^a\partial^2 G^a + g_s f^{abc}\partial_\mu\bar G^a G^b g^c_\mu + \\
&\bar X^+(\partial^2 - M^2)X^+ + \bar X^-(\partial^2-M^2)X^- + \bar X^0(\partial^2 - \tfrac{M^2}{c_w^2})X^0 + \bar Y\partial^2 Y + igc_wW^+_\mu(\partial_\mu\bar X^0 X^- - \\
&\partial_\mu\bar X^+X^0) + igs_wW^+_\mu(\partial_\mu\bar Y X^- - \partial_\mu\bar X^+ Y) + igc_wW^-_\mu(\partial_\mu\bar X^- X^0 - \\
&\partial_\mu\bar X^0 X^+) + igs_wW^-_\mu(\partial_\mu\bar X^- Y - \partial_\mu\bar Y X^+) + igc_wZ^0_\mu(\partial_\mu\bar X^+X^+ - \\
&\partial_\mu\bar X^-X^-) + igs_wA_\mu(\partial_\mu\bar X^+X^+ - \\
&\partial_\mu\bar X^-X^-) - \tfrac12 gM\left(\bar X^+X^+H + \bar X^-X^-H + \tfrac{1}{c_w^2}\bar X^0X^0H\right) + \tfrac{1-2c_w^2}{2c_w}igM\left(\bar X^+X^0\phi^+ - \bar X^-X^0\phi^-\right) + \\
&\tfrac{1}{2c_w}igM\left(\bar X^0X^-\phi^+ - \bar X^0X^+\phi^-\right) + igMs_w\left(\bar X^0X^-\phi^+ - \bar X^0X^+\phi^-\right) + \\
&\tfrac12 igM\left(\bar X^+X^+\phi^0 - \bar X^-X^-\phi^0\right).
\end{aligned}
$$

Purpose of Particle Physics

Categorise and model the fundamental particles and forces: Standard Model of particle physics.

Tells us:

- Which particles can interact with each other
- How that interaction occurs
- Probability of an interaction occurring
- Parameters that describe the particles



Status of Particle Physics

Report Card

Name: Standard Model of Particle Physics

Subjects	*Pass*
Electromagnetism	✓
Weak force	✓
Strong force	✓
Fermion and boson mass	✓
Gravity	✗
Neutrino mass	✗
Dark energy	✗
Dark matter	✗

Remarks:

Outstanding in 3/4 fundamentals, needs work on the dark sector and neutrinos

The “discovery” of dark matter

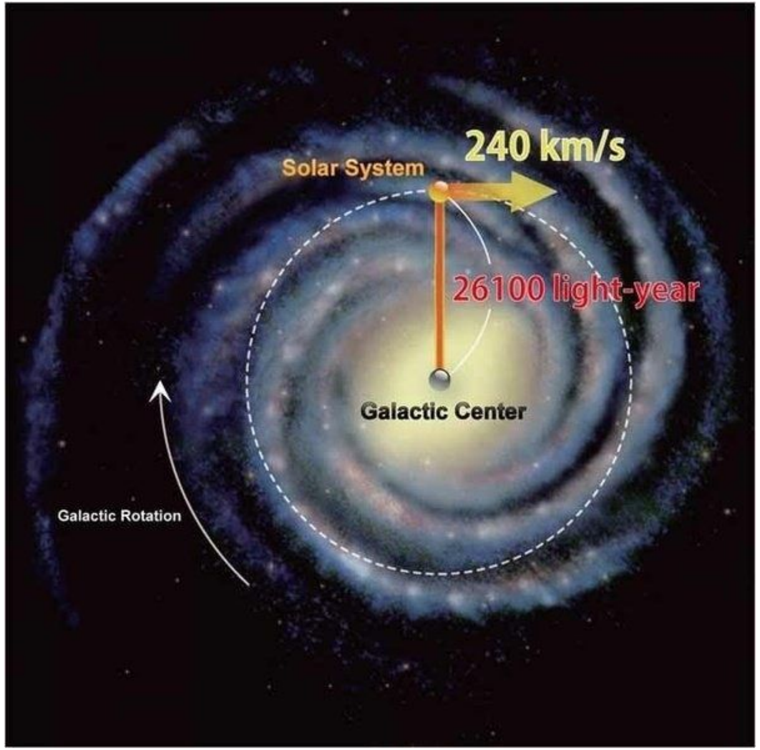
Two ways to investigate mass in the universe:

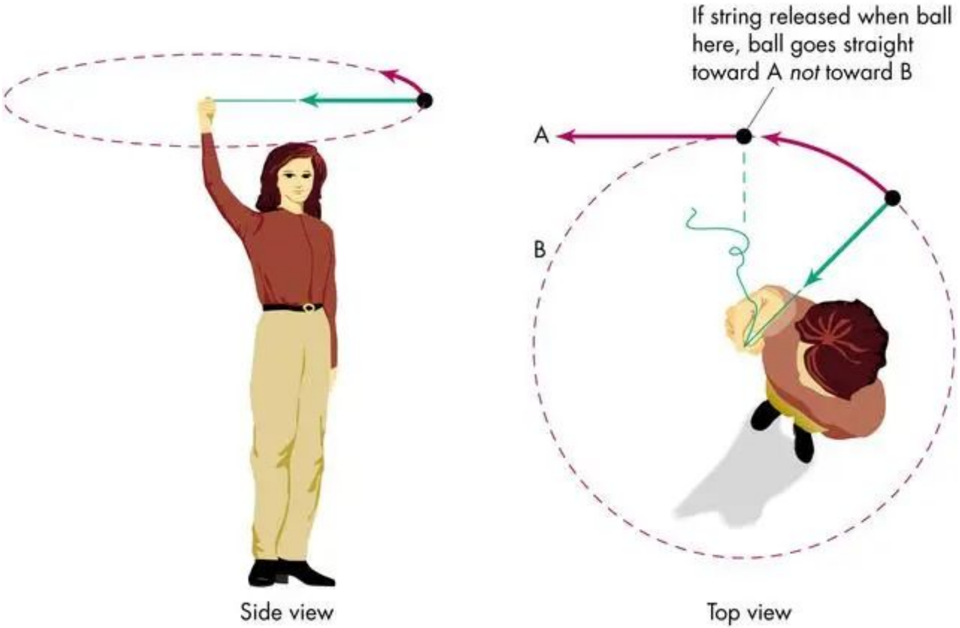
1) Looking for **light with telescopes**
2) Tracking the **movement of visible objects**

These methods give different answers!

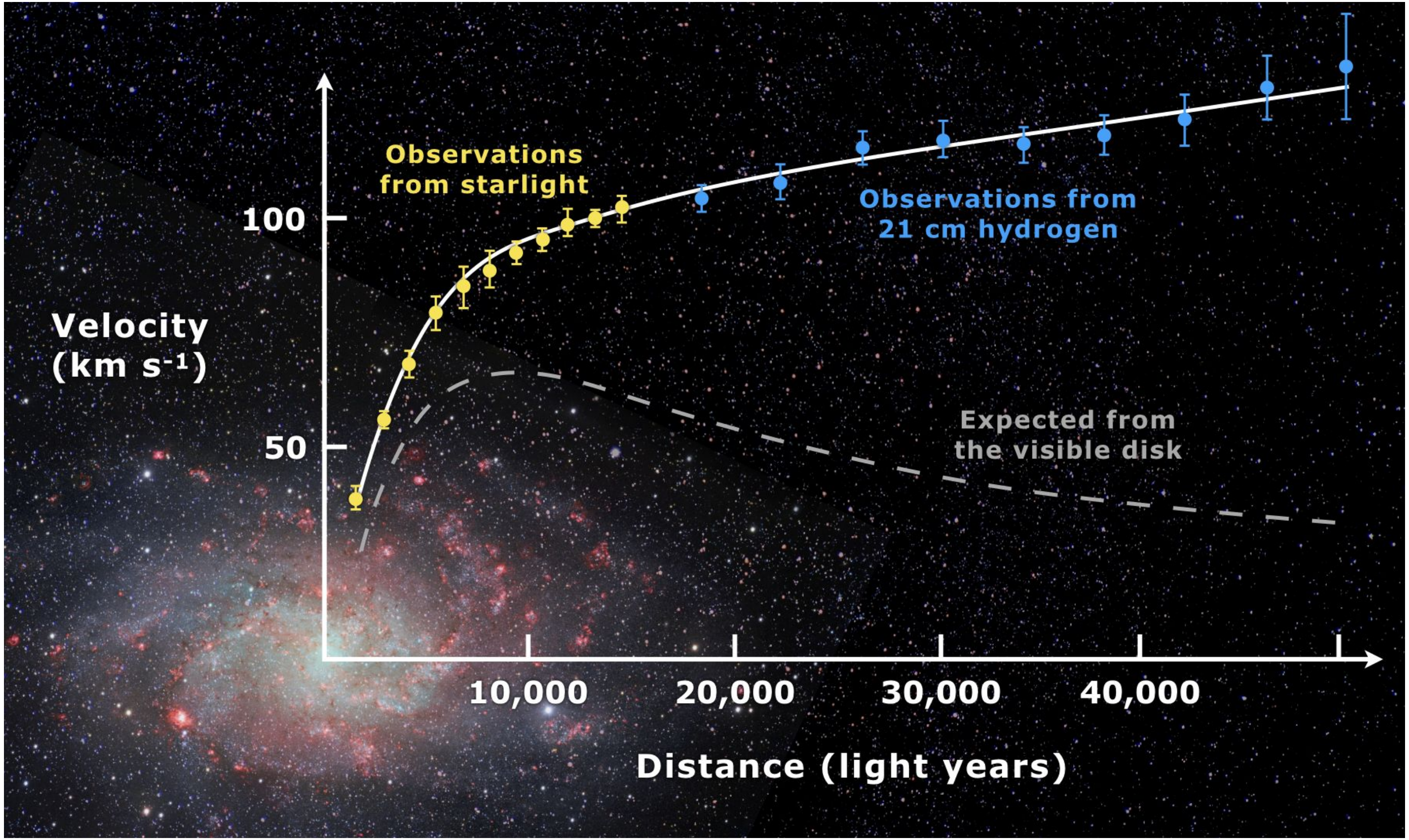
⇒ There must be mass that doesn’t interact with light

Galactic rotation curves

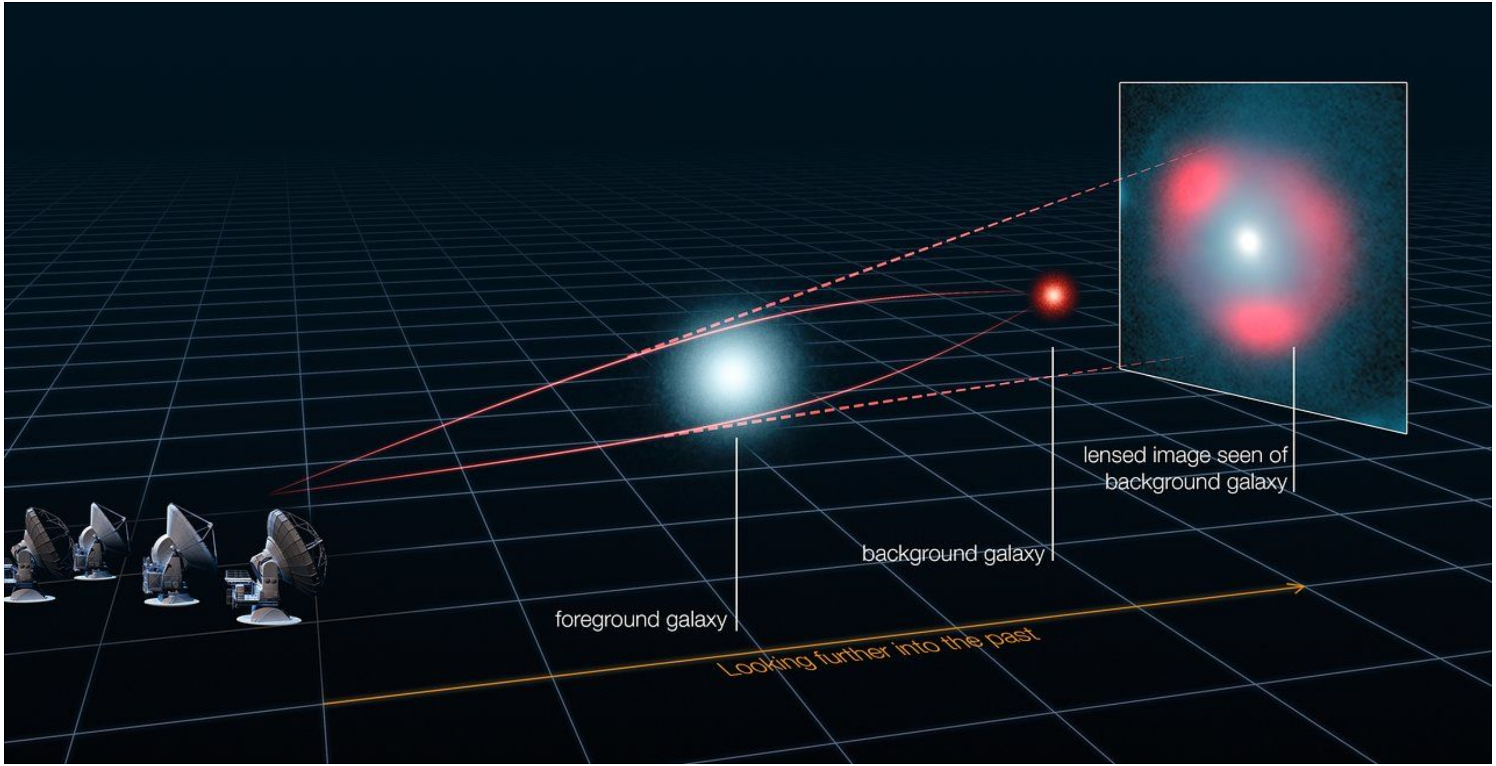




Galactic rotation curves



Other evidence for DM: gravitation lensing



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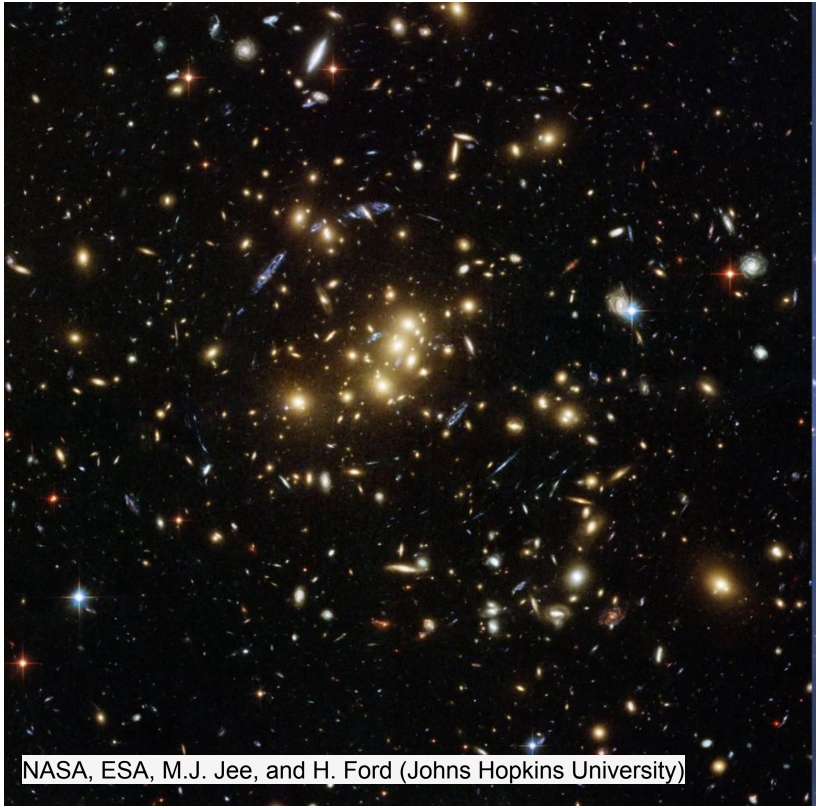
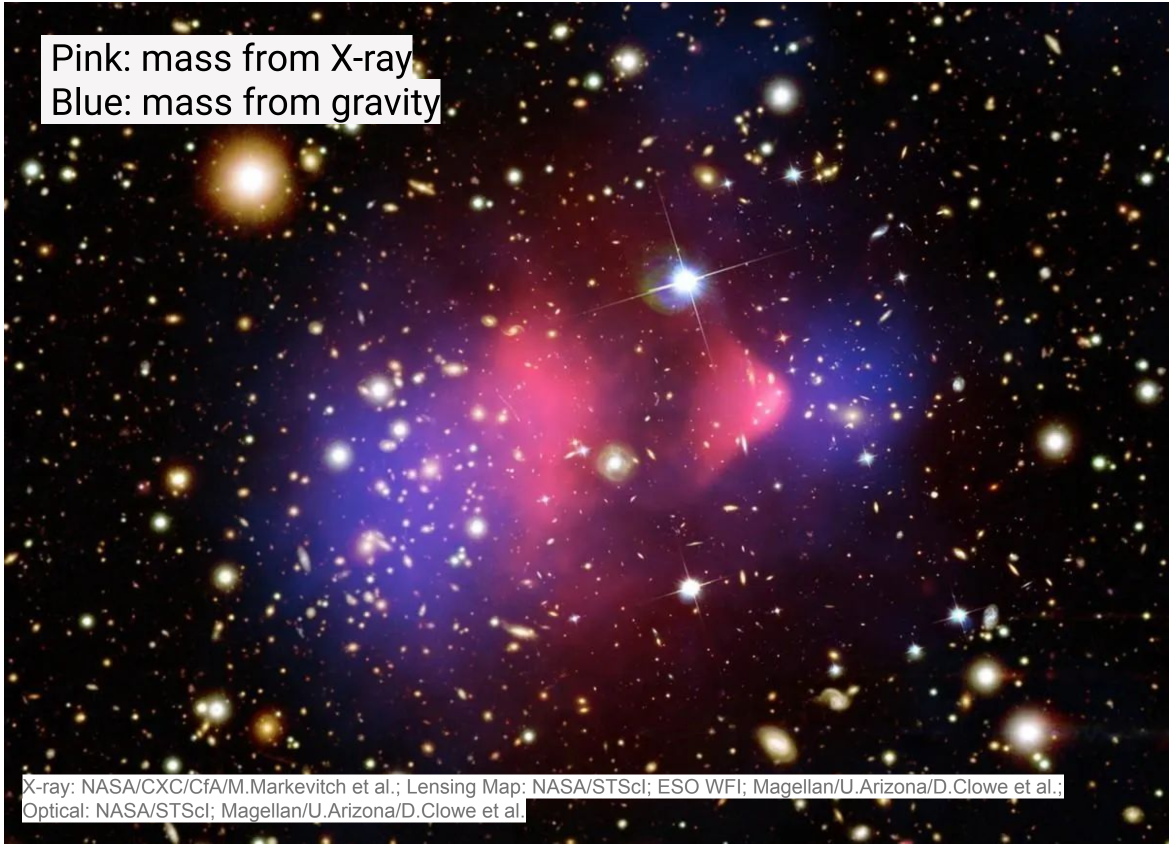


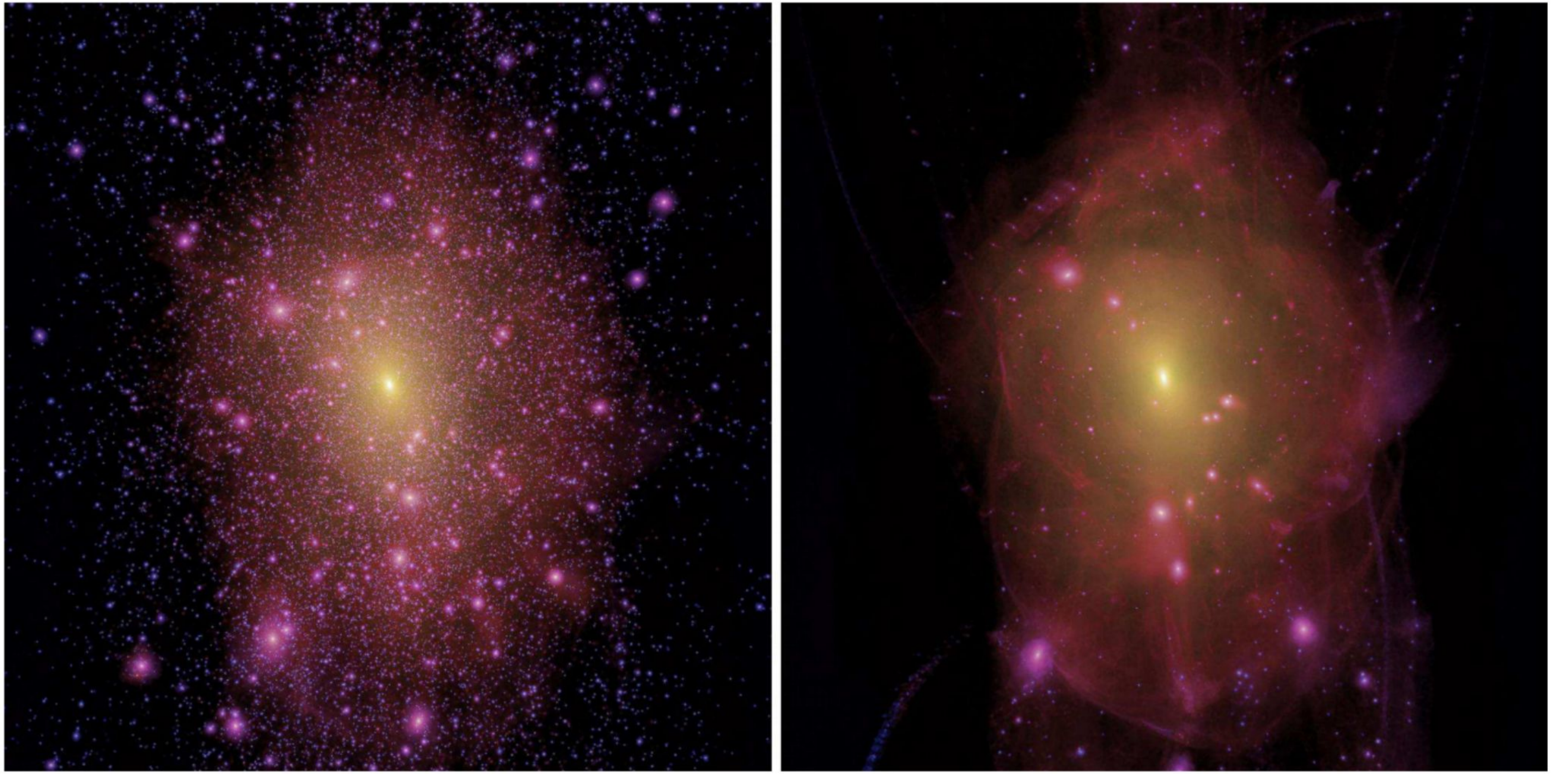
Photograph of a lensed galaxy

Blue superimposed where DM needs to be

Other evidence for DM: galaxy collisions



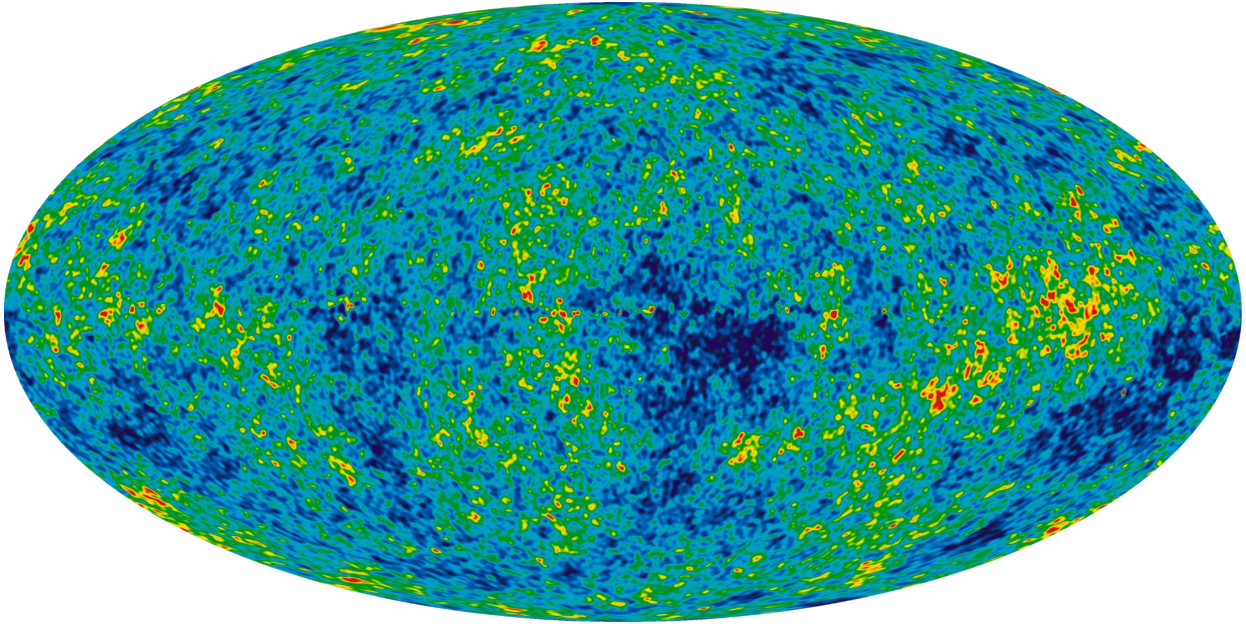
Other evidence for DM: structure formation

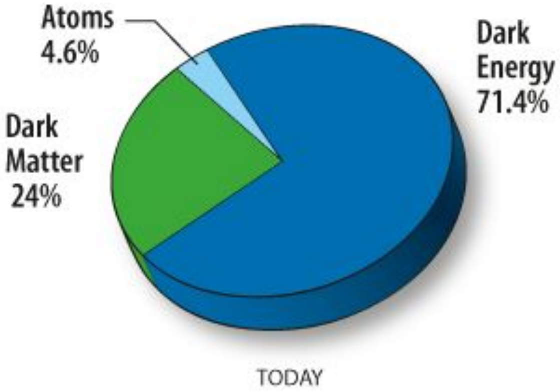


Simulated structure of a galaxy with different DM properties
Credit: Lovell et al. MNRAS420(3):2318–2324

Other evidence for DM: energy density

Measurement of temperature differences in the universe gives us the energy density





Credit: NASA / WMAP Science Team

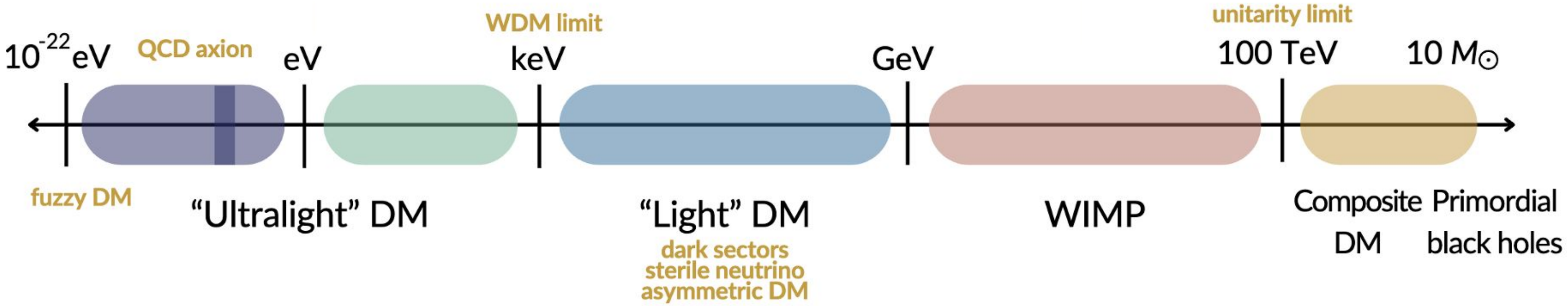
Including DM in the Standard Model

Two things particles physicists care about:

How big are Dark Matter particles?

How likely are they to interact with other particles?

Mass: how big is a DM particle?



Smallest DM mass:
10^{-57} kg

Mass of an **atom**: 10^{-27} kg
Mass of a **speck of dust**: 10^{-9} kg
Mass of an **apple**: 0.1 kg
Mass of the **Earth**: 10^{24} kg

Largest DM mass:
10^{31} kg

0.000000000000000000000000000000000000000000000000000000001 kg

10,000,000,000,000,000,000,000,000,000,000 kg

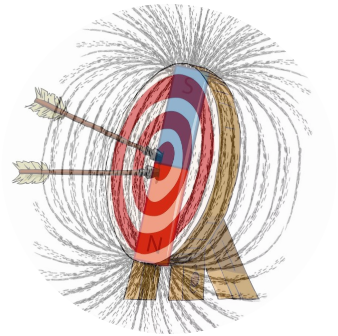
(Traditional) cross section: how likely is an interaction?

Nearby, relatively large cross section.
Easy to hit ⇒ very likely interaction

Far away, smaller cross section.
Harder to hit ⇒ less likely interaction

(Less traditional) cross section: how likely is an interaction?

Lets pretend our target also has a magnetic field
Cross section is area arrows go that result in a hit on targeet



<u>Wooden arrows:</u>

- Magnet has no effect
- Need to aim at target to hit it
- Cross section is physical size of target

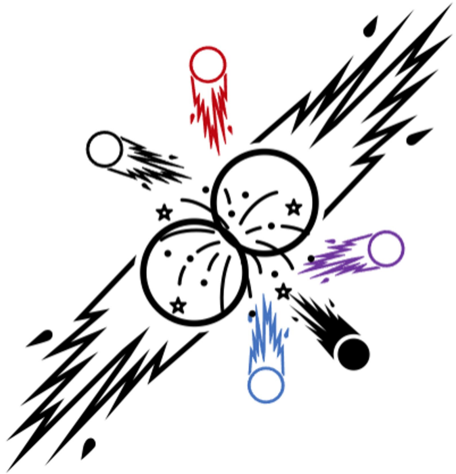
<u>Metal arrows:</u>

- Magnet can cause attraction
- If arrow is too high, field can pull it down
- Cross section is larger than the target

How do we measure these values?

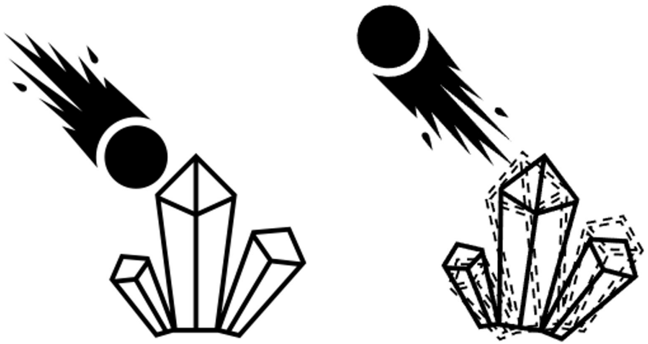
DM search methods

Make it!

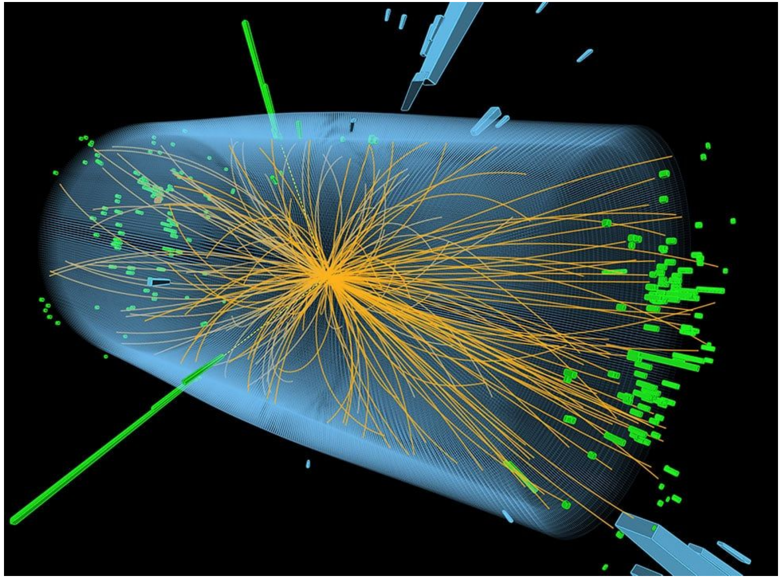


Break it!

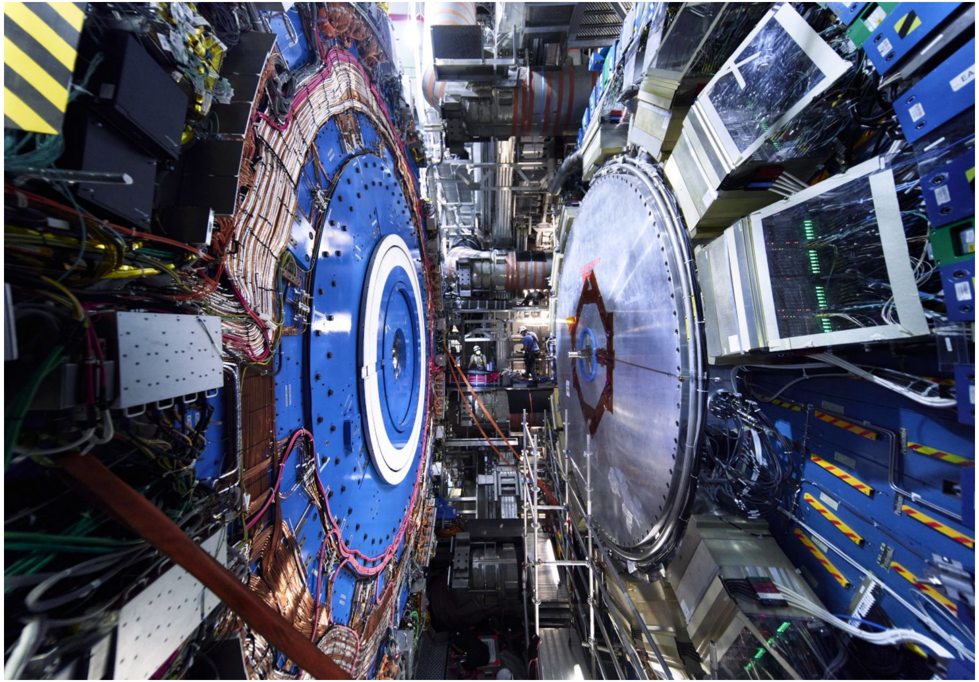
Shake it!



DM produced at particle colliders



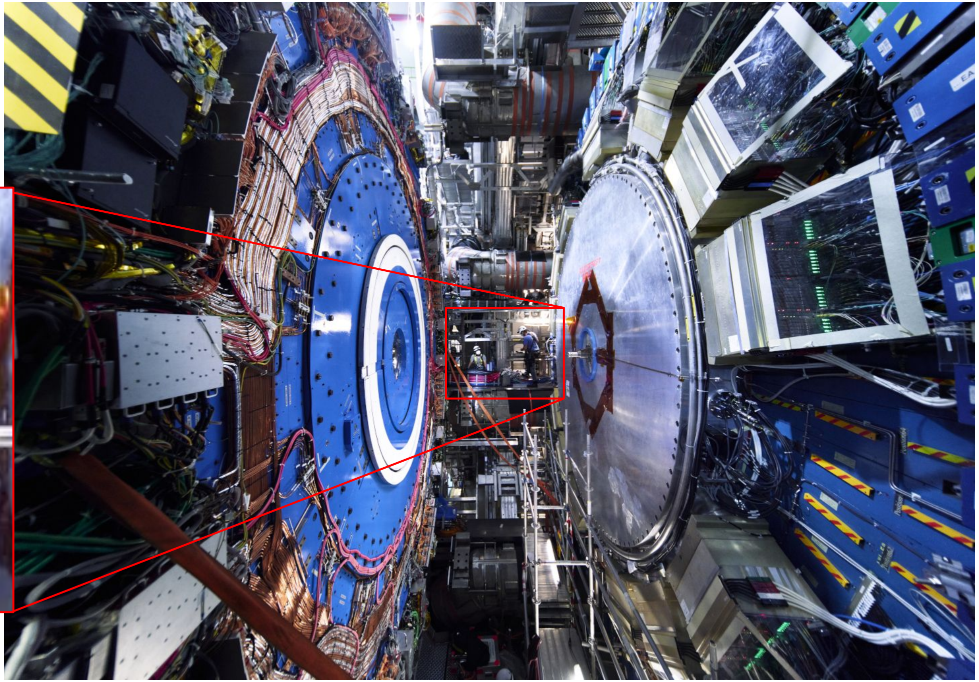
Graphic of event at CMS. Image: CMS/CERN



ATLAS detector. Image: CERN

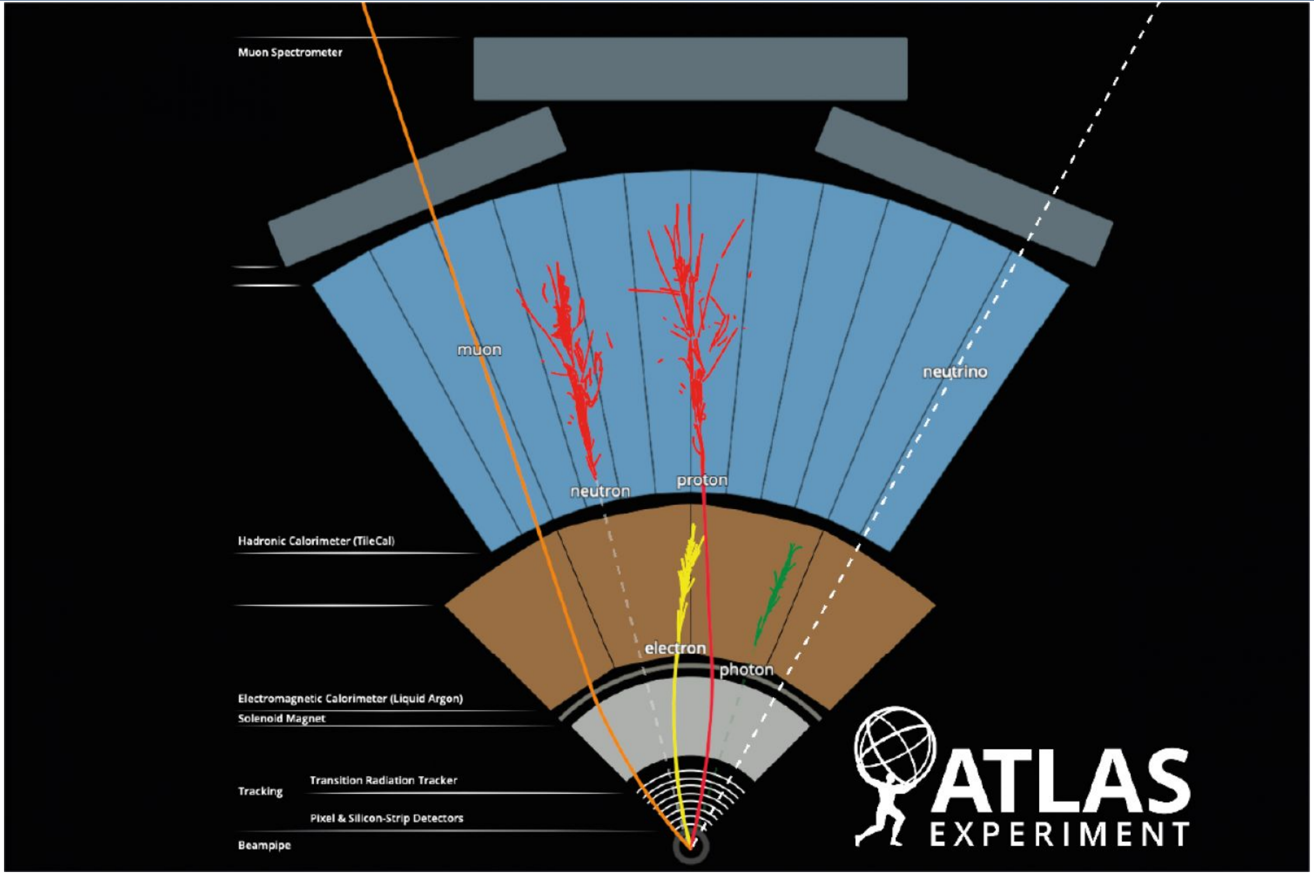
Make it!

Graphic of event at CMS. Image: CMS/CERN



ATLAS detector. Image: CERN

Make it!



Muon Spectrometer
muon
neutron
proton
neutrino
Hadronic Calorimeter (TileCal)
electron
photon
Electromagnetic Calorimeter (Liquid Argon)
Solenoid Magnet
Tracking
Transition Radiation Tracker
Pixel & Silicon-Strip Detectors
Beampipe
ATLAS
EXPERIMENT

Where are we "making"?

Fermilab

CERN

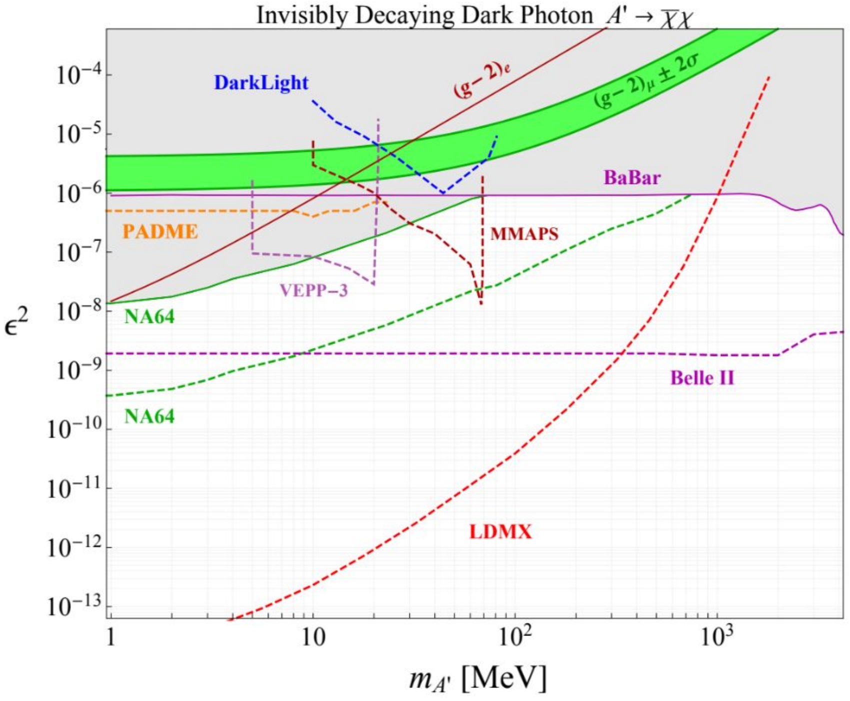
J-PARC

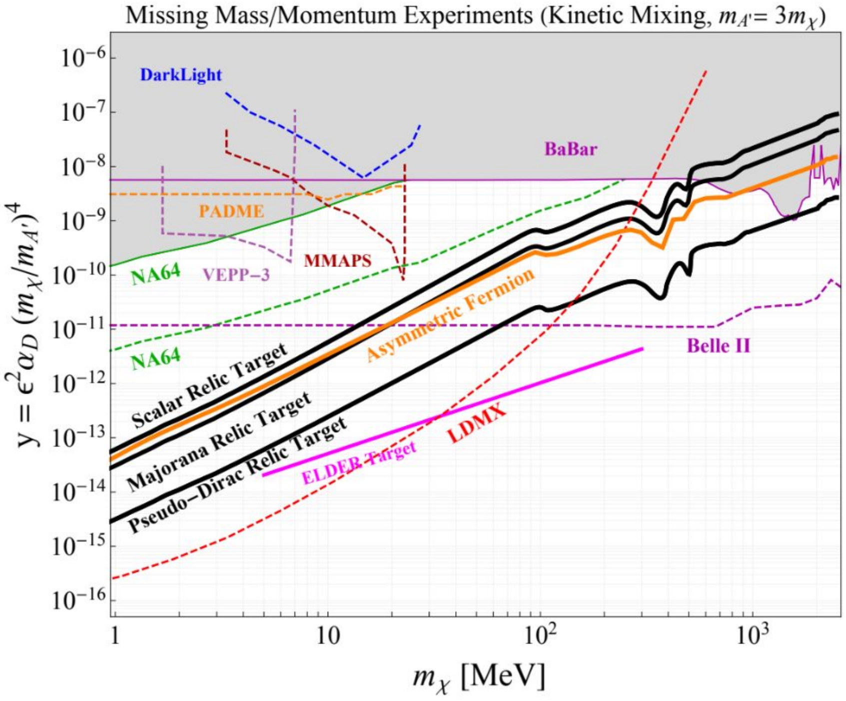
SLAC NATIONAL ACCELERATOR LABORATORY

Jefferson Lab

KEK

No successful “making”, but we know what it’s not





Annihilation of DM in galaxy produces observable signals

In space

Fermi-LAT space telescope. Image: NASA

On Earth

H.E.S.S telescope. Image: HESS

Below its surface

IceCube detector. Image: IceCube/NSF

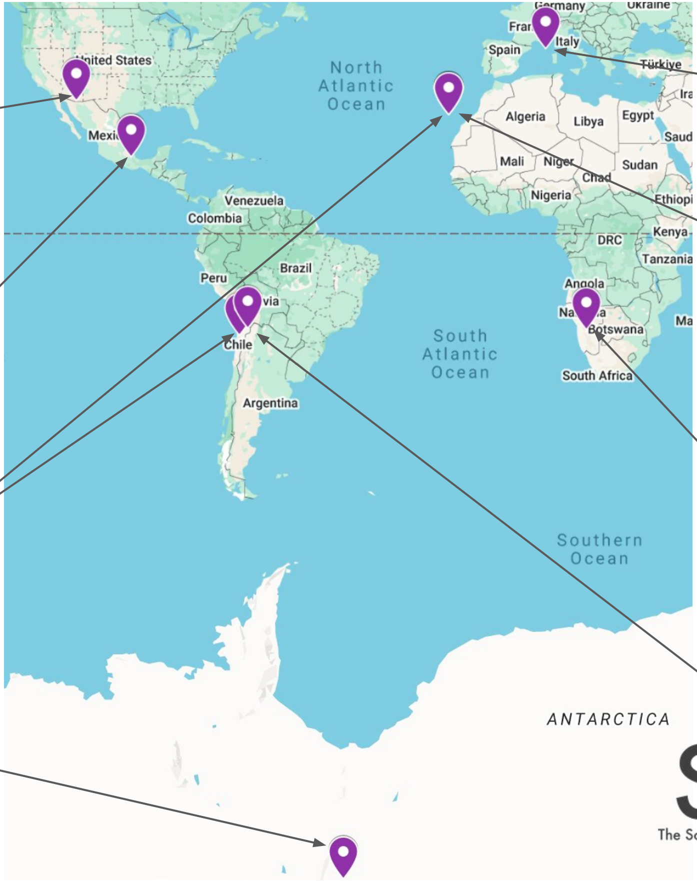
Where are we looking for “breaking”?

VERITAS

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

CTAO

ICECUBE
NEUTRINO OBSERVATORY



ANTARES

MAGIC

H.E.S.S.

SWGO
The Southern Wide-field Gamma-ray Observatory

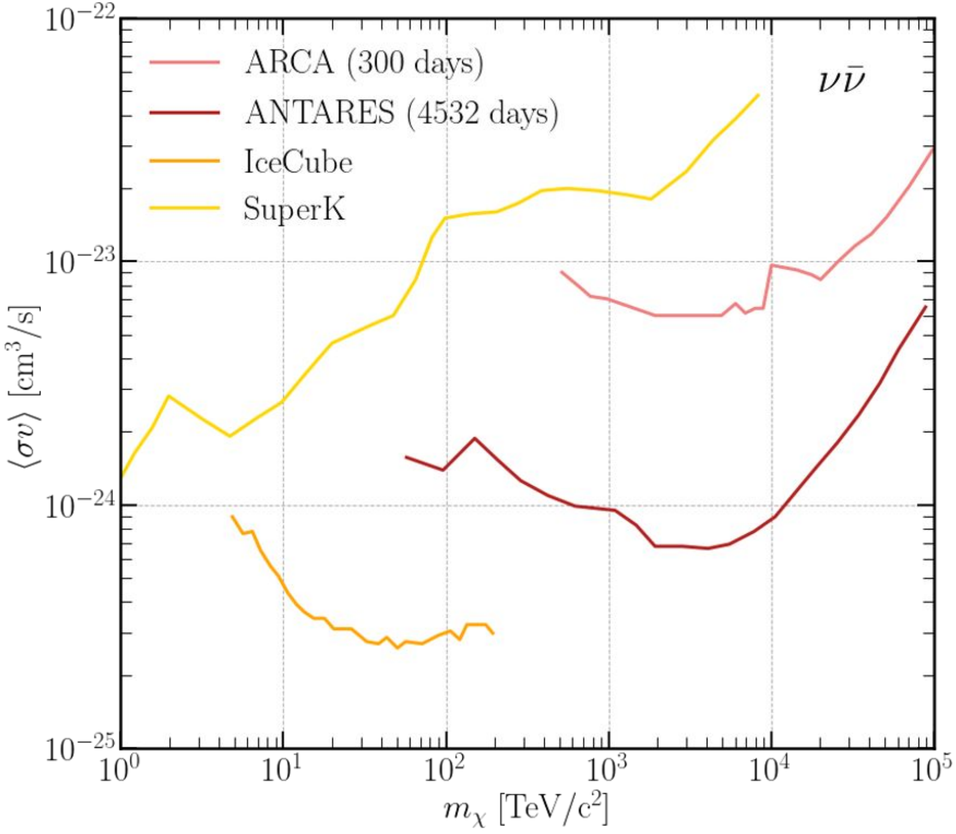
In space

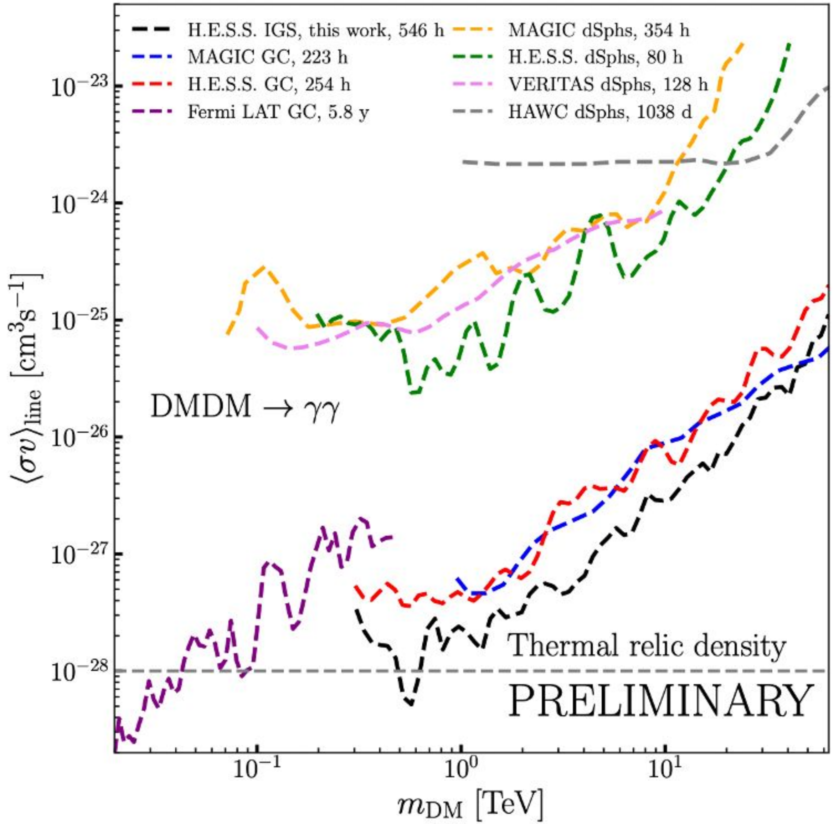
Fermi
Gamma-ray Space Telescope

Alpha Magnetic Spectrometer
AMS-02
Europe • Asia
North America

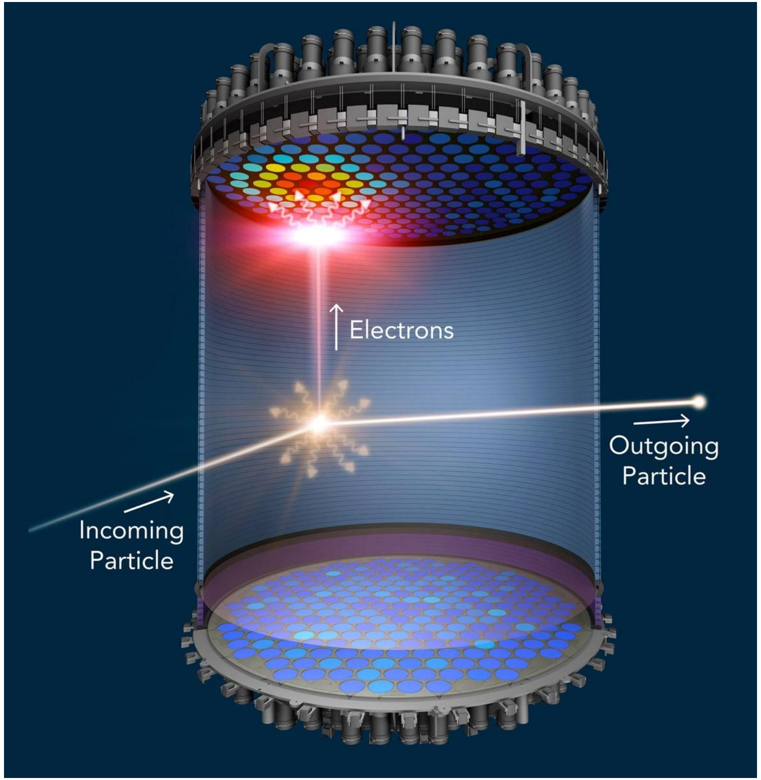
PaMeLa

No successful “breaking”, but we know what it’s not





Collision between dark and regular matter



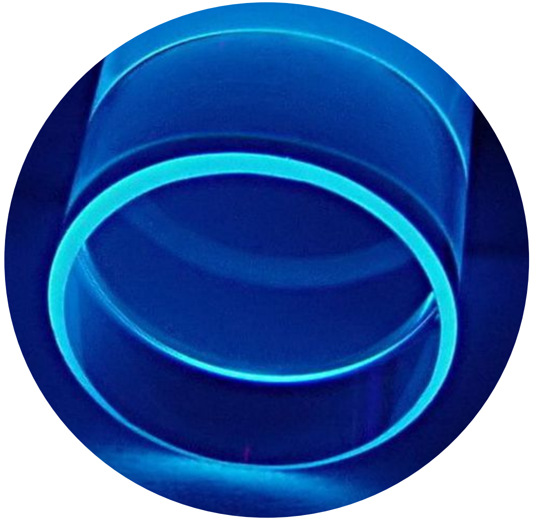
Detection principle. Image: LZ/SLAC

Inner LZ chamber. Image: Matthew Kapust/SURF

What do we (want to) see?

DM collisions cause a nucleus to recoil. Extra energy visible as:

Light

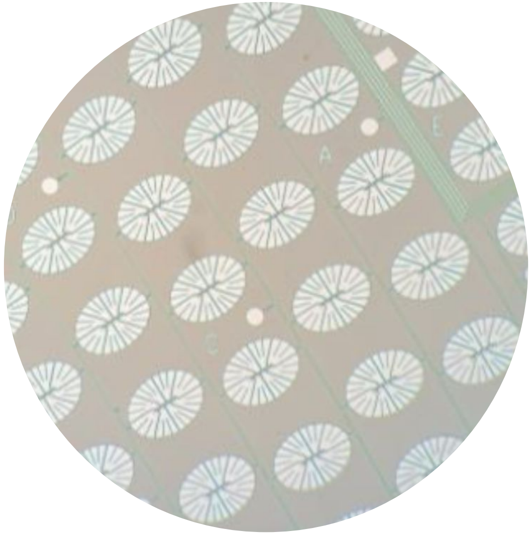


CRESST crystal
(300 g)

Charge

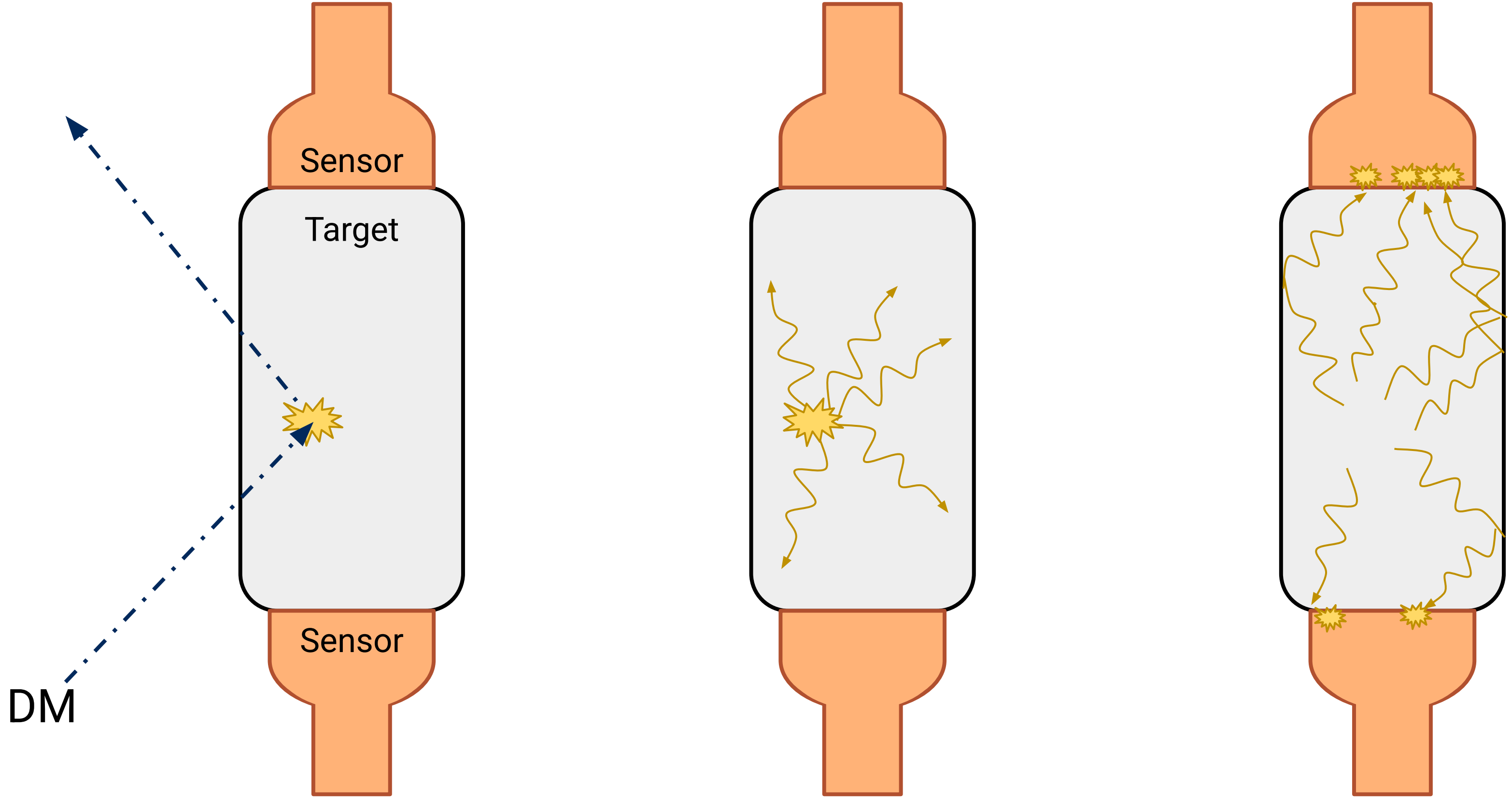
SuperCDMS charge sensor
(10 cm)

Heat

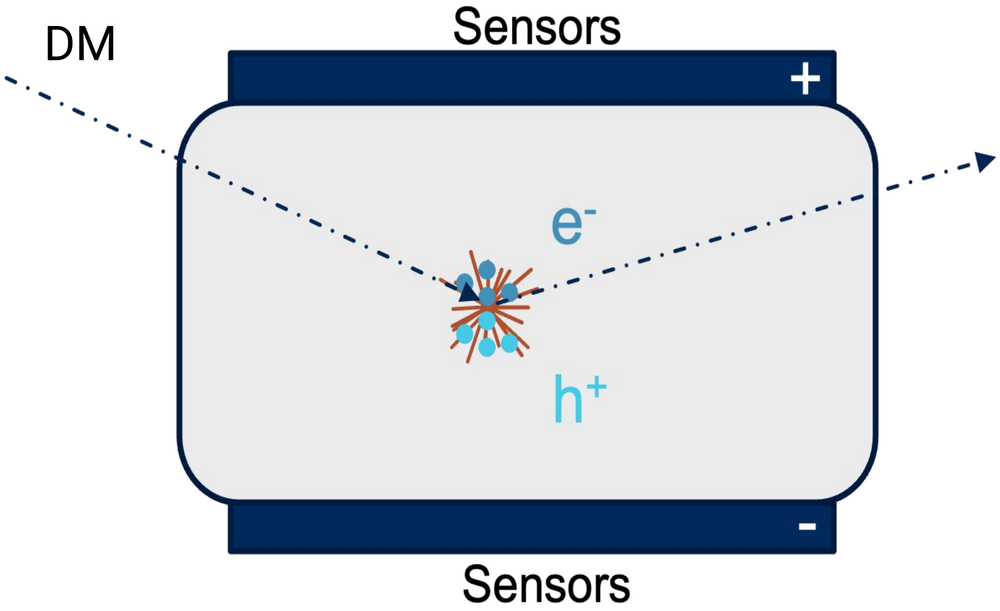


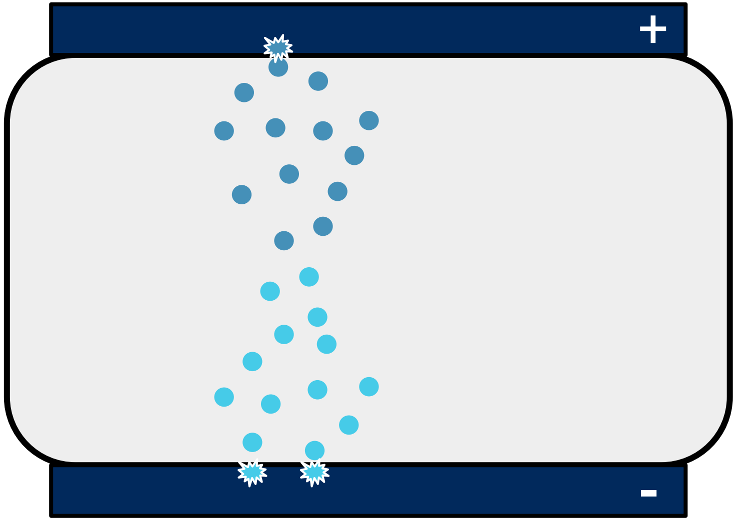
SuperCDMS TESs
(500 um long)

Seeing with light

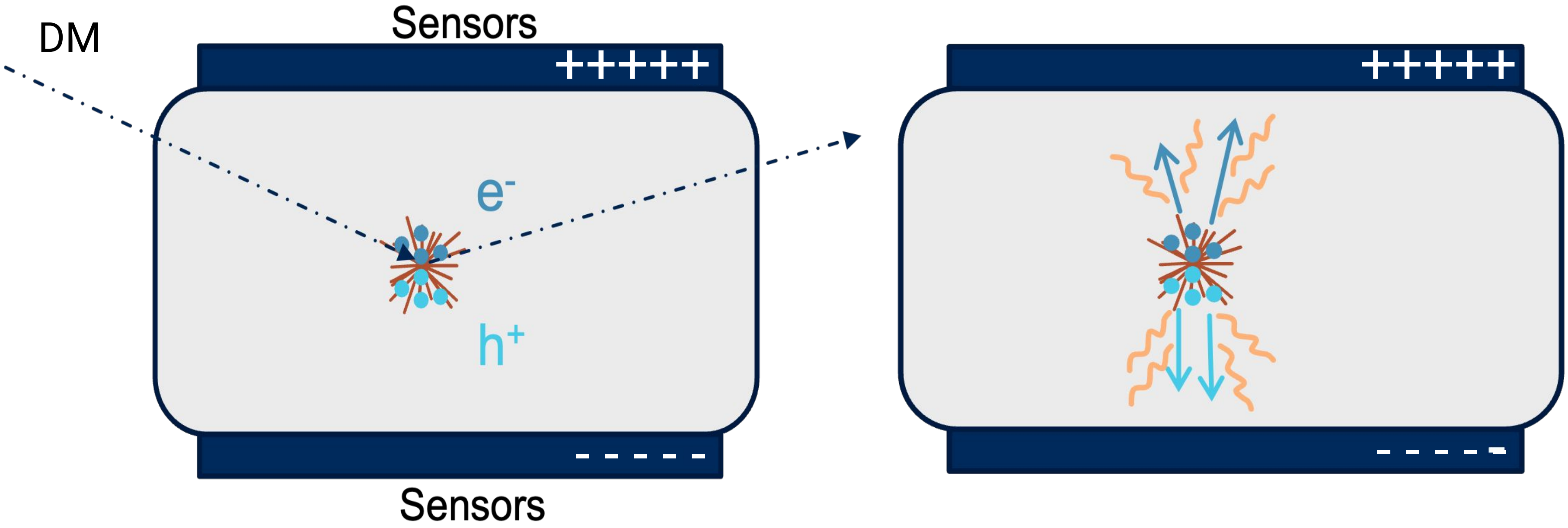


Seeing with charge





Seeing with heat



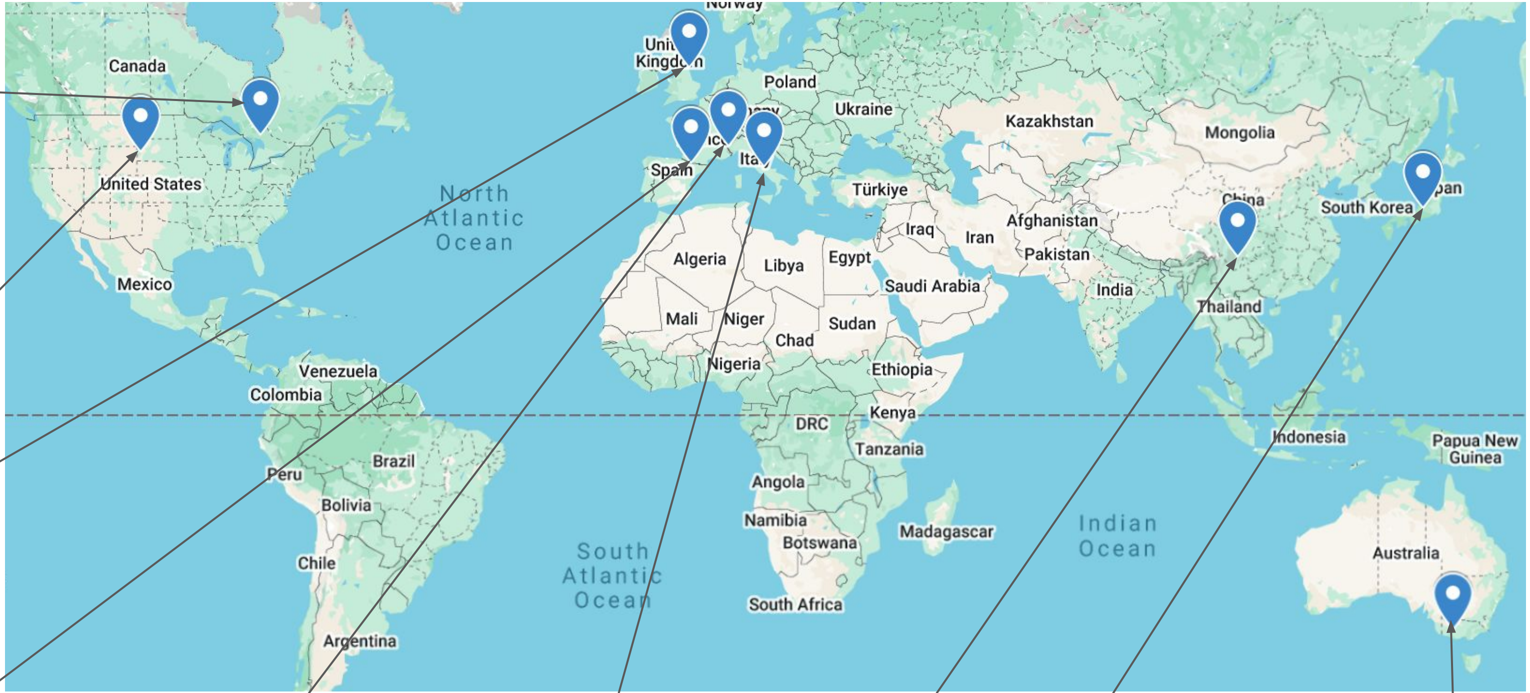
Where are we "shaking"?

SNOLAB

SANFORD UNDERGROUND RESEARCH FACILITY

BOULBY UNDERGROUND LABORATORY

LSC
Laboratorio Subterráneo Canfranc



LSM
Laboratoire Souterrain de Modane

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

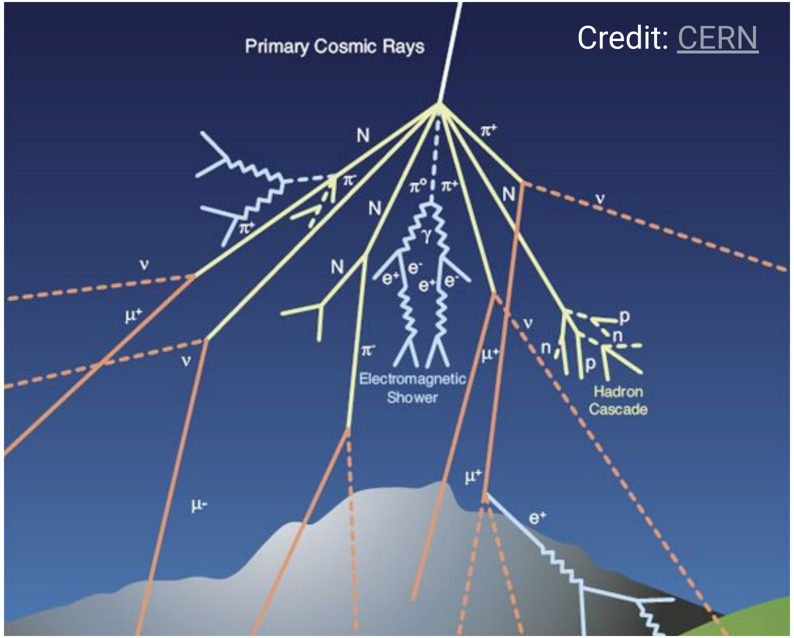
CJPL

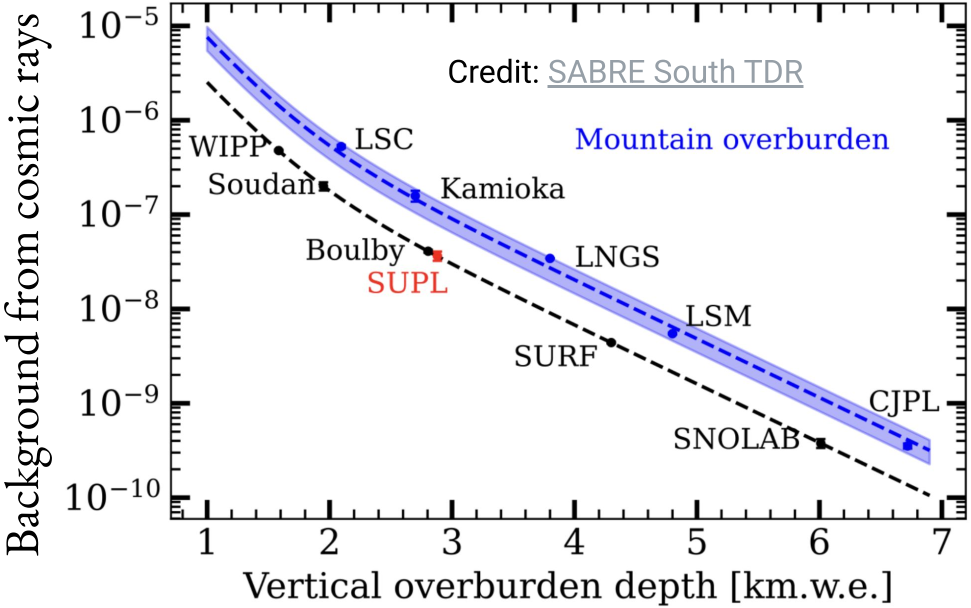
KAMIOKA OBSERVATORY

STAWELL UNDERGROUND PHYSICS LAB

Why underground?

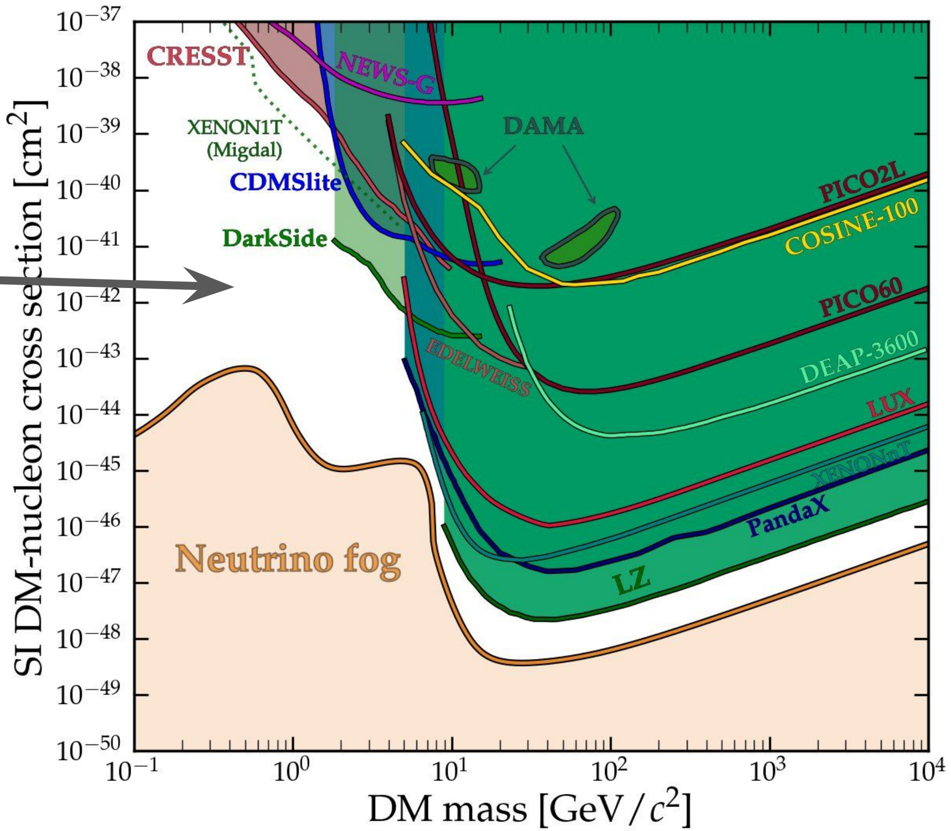
Muons interact more easily than DM, so even though there are fewer they can swamp any signal.
Use rock to shield the experiments!





No successful “shaking” but know where to go

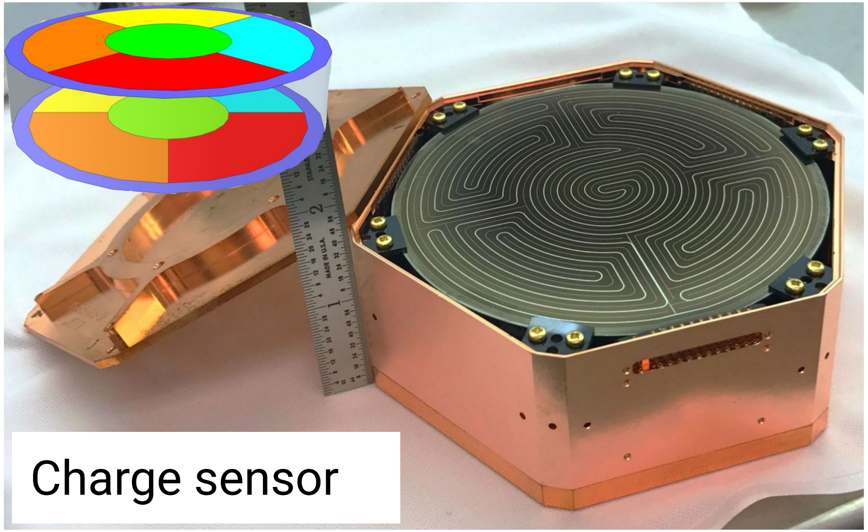
Need low energy threshold to probe this region

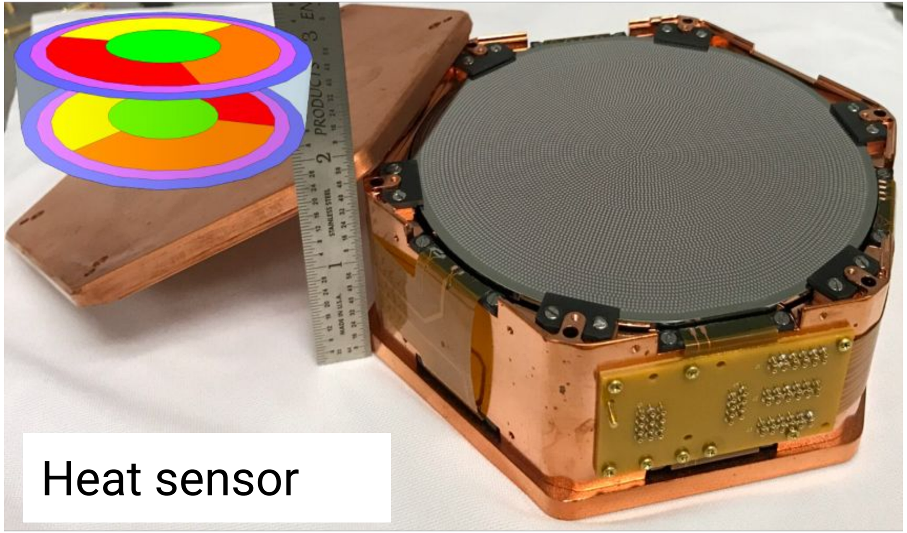


Gains in recent years (months!) from large exposure, low background searches

SuperCDMS

Two targets (Ge and Si) with **two sensor technologies** (charge and heat).
24 different detectors arranged in 4 towers and **cooled to 13 mK**

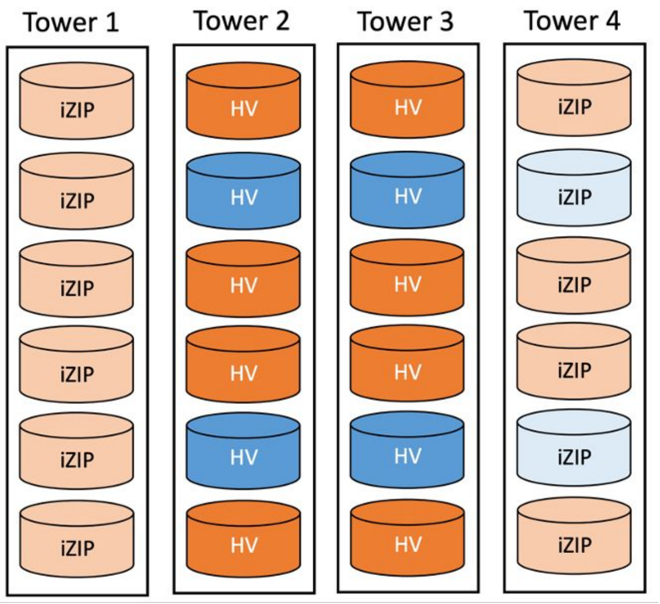


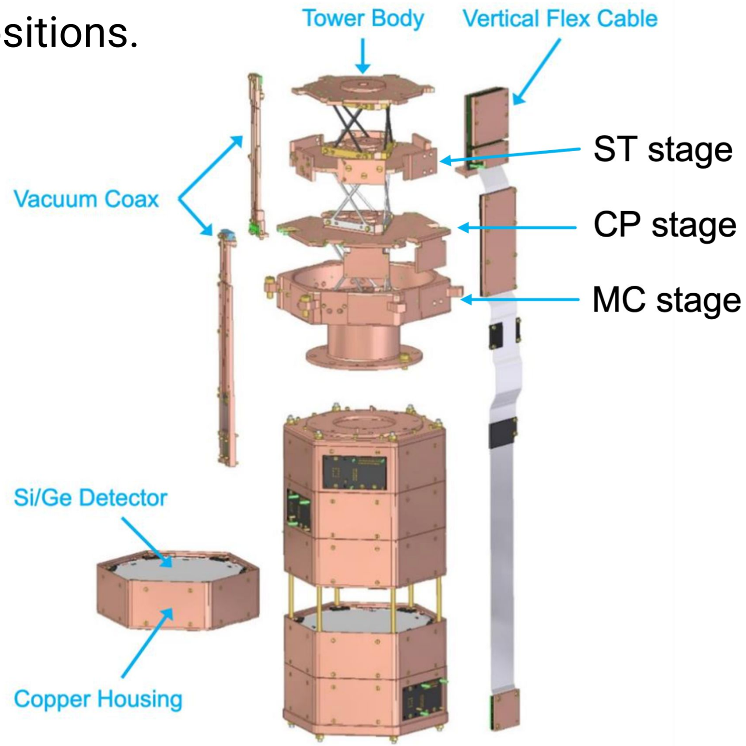


SuperCDMS

Detectors organised into 4 towers with layouts designed based on detector type and shielding/veto for different positions.

Orange ⇒ Ge, blue ⇒ Si

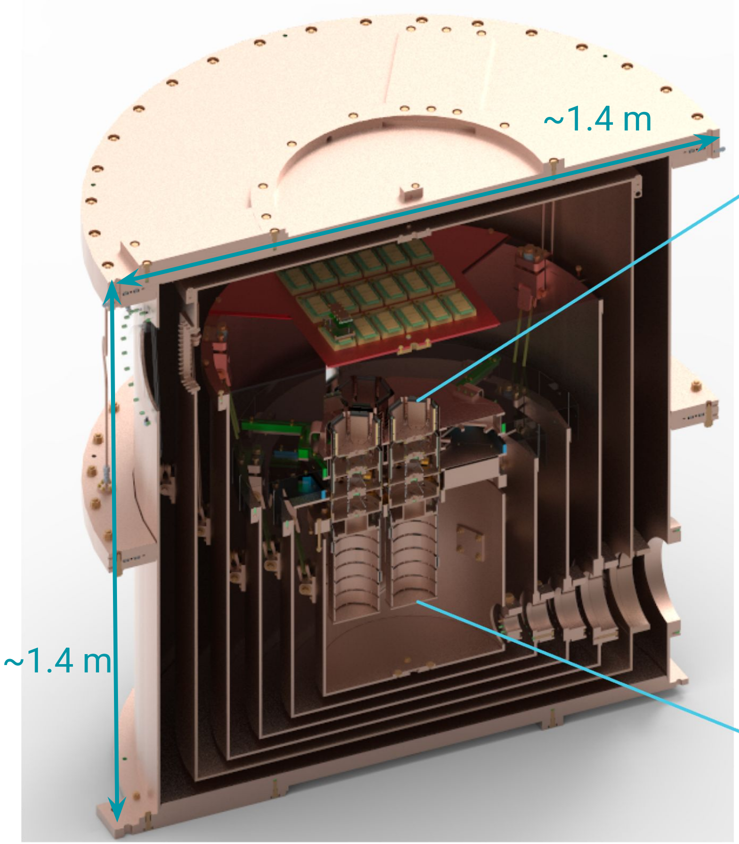




SuperCDMS

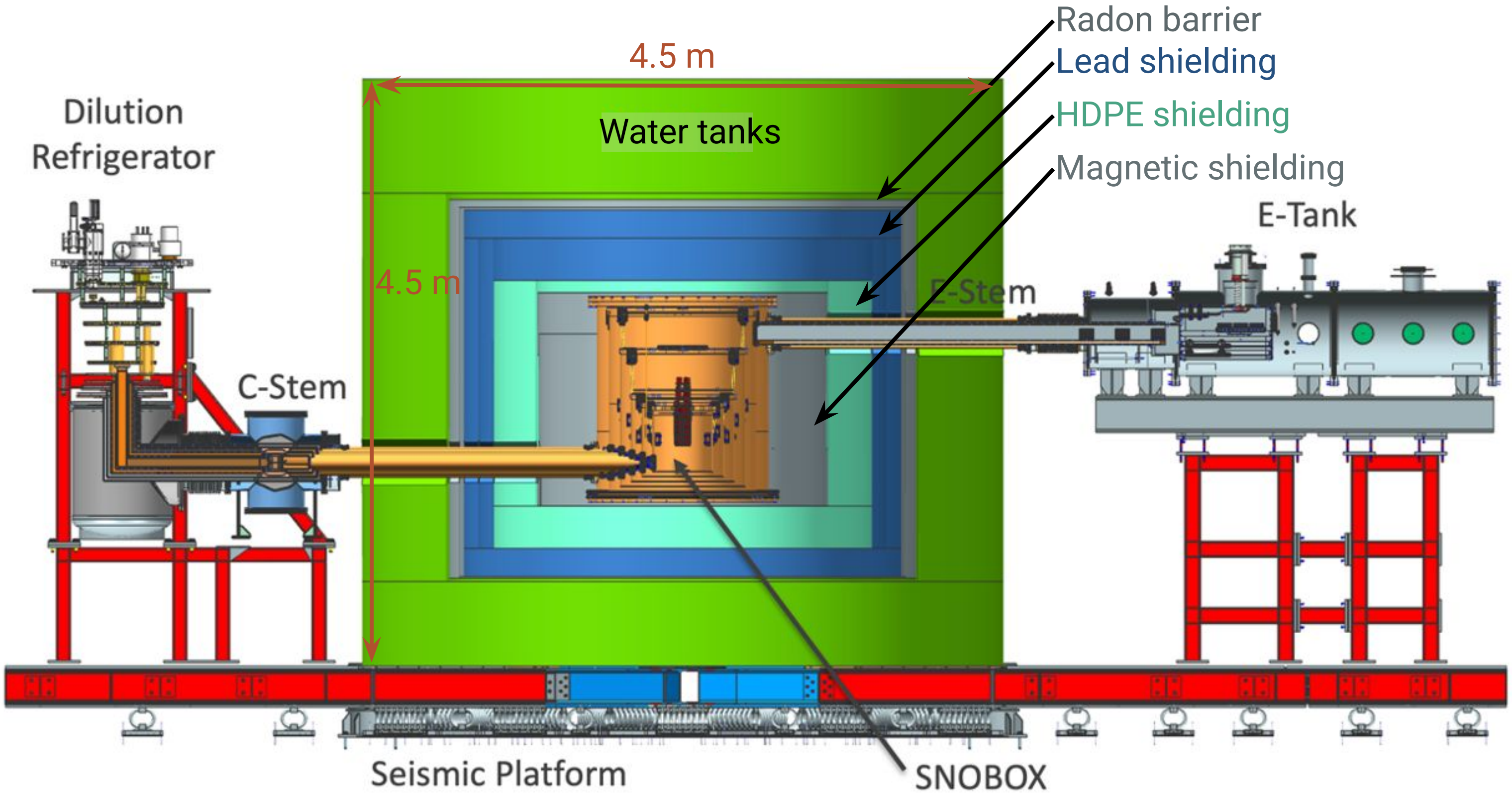
Towers placed in SNOBOX - 6 cans forming giant dilution fridge:

- Can 1 – Room temp (295 K)
- Can 2 – <50 K
- Can 3 – <5 K
- Can 4 – 1 K
- Can 5 – <230 mK
- Can 6 – <30 mK



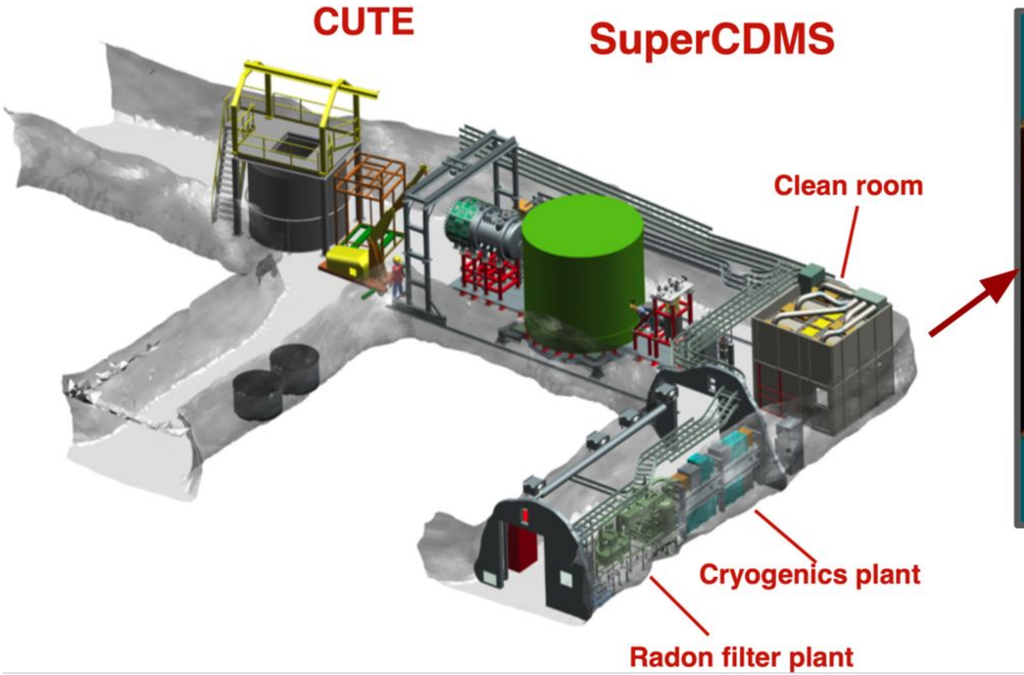
SuperCDMS

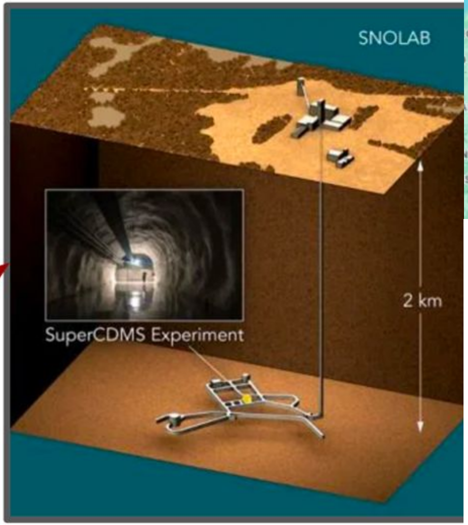
SNOBOX placed inside shielding, and connected to external DR and electronics

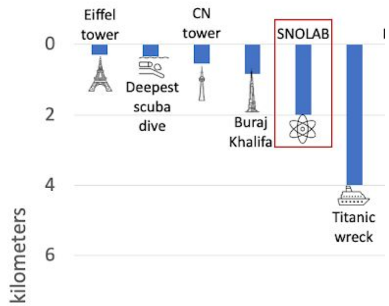


SuperCDMS

Whole apparatus then placed 2 km underground at SNOLAB







2 km = 3.5 CN towers!

Signal vs backgrounds

Expected # DM events: **<5 hits every year** in each detector!
Need to **reduce and model interactions from non-DM** particles for conclusive observation

Material contamination

Material activation

Environmental backgrounds

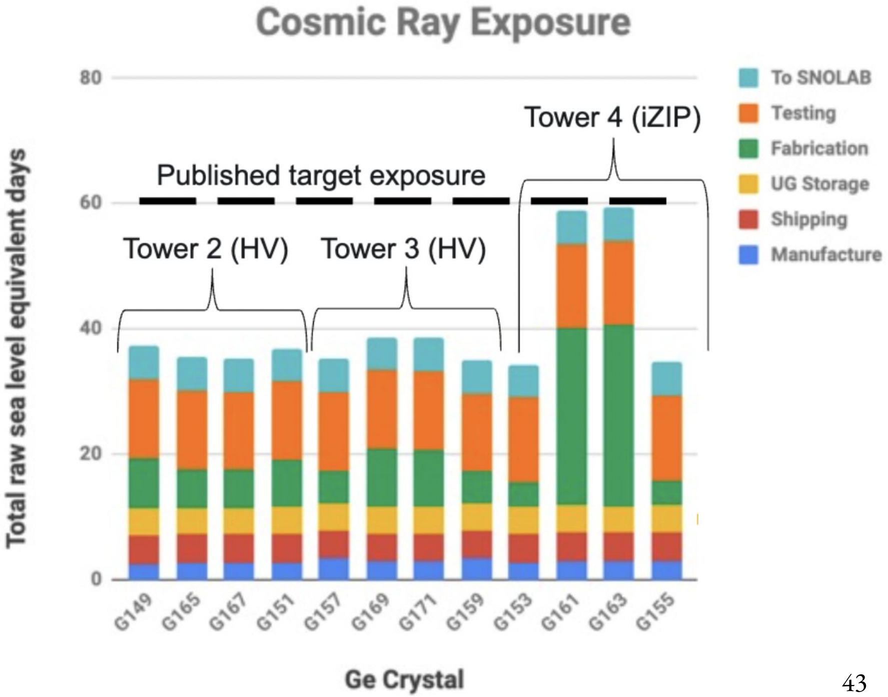
Material contamination: ~40% of background

All materials have low levels of **uranium**, **thorium**, and **potassium**
Measure many (many!) samples and **select lowest radioactivity** then **clean carefully** before install

No.	Sample	#	Mass (g)	U	Th
1	Copper, commercial, post nitric etch	1	0.39	0.093 ± 0.012	< 0.0644
2	Copper, commercial, post nitric etch	1	2.23	0.0400 ± 0.0008	0.034 ± 0.009
3	Copper, Aurubis high purity OFHC sample 1	1	1.16	<0.0117	<0.0202
		2	0.92	<0.0147	<0.0254
4	Copper, Aurubis high purity OFHC sample 2	1	0.94	<0.0145	<0.0249
		2	0.95	<0.0142	<0.0246
5	Copper, Aurubis high purity OFHC sample 3	1	0.95	<0.0142	<0.0245
		2	0.95	<0.0143	0.037 ± 0.010
6	Copper, Aurubis high purity OFHC sample 4	1	0.93	<0.0146	<0.0252
		2	0.93	<0.0146	<0.0251
		3	0.93	<0.0146	<0.0252
7	Copper, Aurubis high purity OFHC sample 5	1	0.93	<0.0146	<0.0252
8	Copper, Southern Copper MKM Plate", Piece 1	1	3.67	0.011 ± 0.001	0.012 ± 0.003
		2	3.67	0.01 ± 0.003	0.012 ± 0.003
		3	3.67	0.011 ± 0.003	0.015 ± 0.005
9	Copper, Southern Copper MKM Plate", Piece 2	1	3.30	0.012 ± 0.003	0.020 ± 0.004
		2	3.30	0.011 ± 0.002	0.021 ± 0.005
		3	3.30	0.01 ± 0.002	0.017 ± 0.007
10	Copper, Southern Copper MKM Plate", Piece 2	1	2.16	0.081 ± 0.006	0.010 ± 0.005
		2	2.16	0.275 ± 0.028	0.008 ± 0.005
11	Copper, 17 mm x 17 mm x 5 mm cube	1	5.68	275 ± 17	236 ± 17
12	Copper, 18 mm x 17 mm x 7 mm cube	1	6.50	267 ± 15	196 ± 16
13	Copper, Sequoia Brass and Copper inc, IR shielding	1	0.66	< 0.14	< 0.59
		2	0.64	< 0.14	< 0.59
		3	0.75	0.24 ± 0.21	< 0.60
14	Copper, SC5 from Southern Copper	1	0.34	<0.9	<0.9
		2	0.51	<0.9	<0.9
		3	0.25	<0.9	<0.9
15	Copper, SC5 from Southern Copper	1	0.46	<1.0	<0.9
		2	0.27	<1.0	<0.9
		3	0.27	<0.9	<0.9
16	Copper, PR2125 inner bulk	1	0.95	<0.9	<0.9
		2	0.72	<0.9	<0.9
		3	0.63	<1.0	<0.9
17	Copper, VA326516 inner bulk	1	0.86	1.10 ± 0.40	<0.9
		2	0.43	<0.9	<0.9
		3	0.41	<0.9	<0.9
18	Copper, VA326517 inner bulk	1	0.52	<1.0	<0.9
		2	0.23	<0.9	<0.9
		3	0.36	<0.9	<0.9
19	Copper, VA326518 inner bulk	1	0.87	1.0 ± 0.5	<1
		2	0.94	<1.0	<1
		3	0.77	<0.9	<0.9
20	Copper, Luvata Tubing	1	0.55	<1.0	<0.9
		2	0.54	<1.0	<0.9
		3	0.62	<1.0	<0.9
21	Copper block, Aurubis grade OF01	1	0.44	0.37 ± 0.14	0.17 ± 0.17
		2	0.53	0.48 ± 0.15	0.36 ± 0.17
		3	0.58	0.3 ± 0.2	0.3 ± 0.4

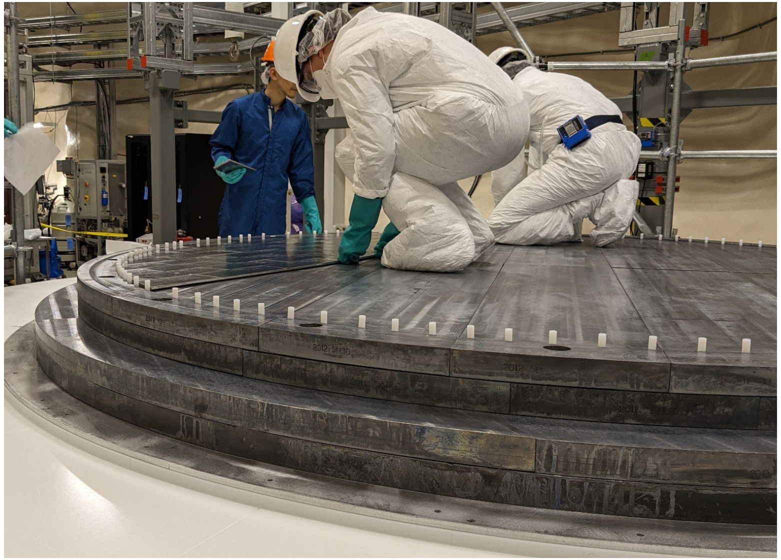
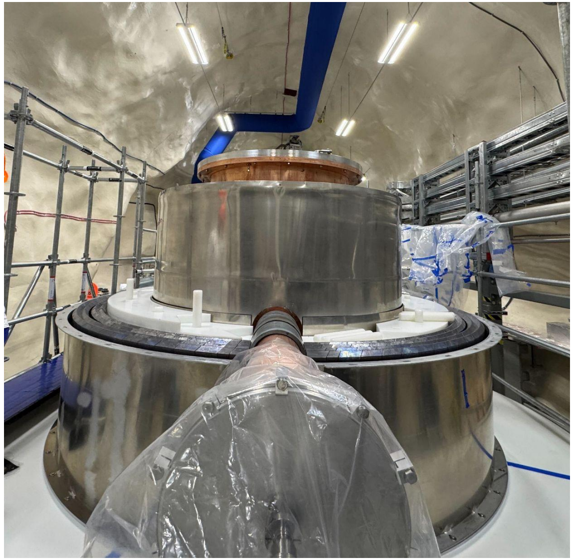
Material activation: ~40% of background

Exposure to cosmic rays produces radioactive isotopes in copper, germanium, and silicon
Carefully **track exposure at sea level**, and **use shielding** where needed for shipping



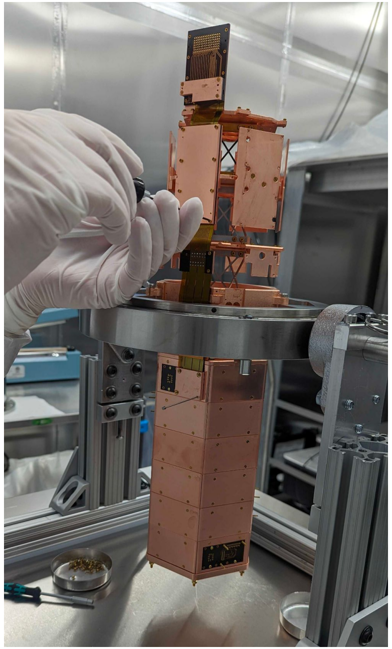
Environmental sources: ~20% of background

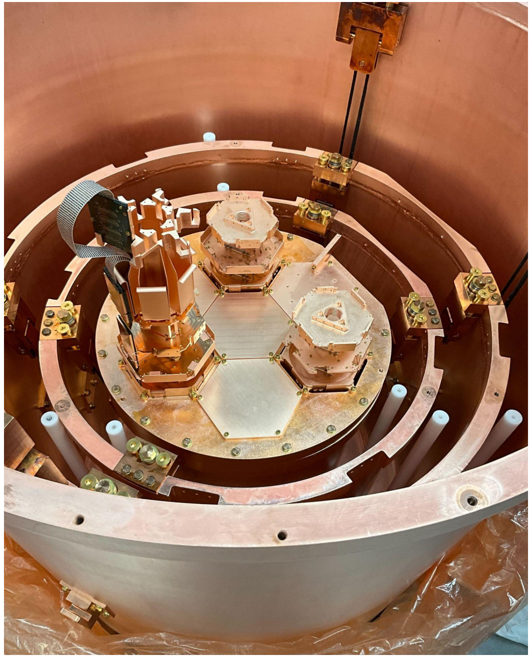
Dust, rock in lab walls and human activity carry trace amounts of **uranium**, **thorium**, and **potassium**
Radon gas underground produces **lead**
Can’t prevent any of these from occuring, so **protect and shield** as best we can

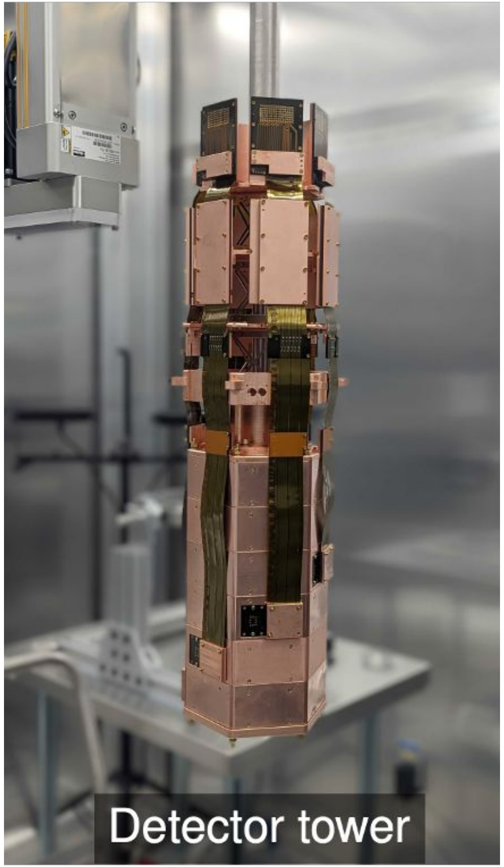
Installation status

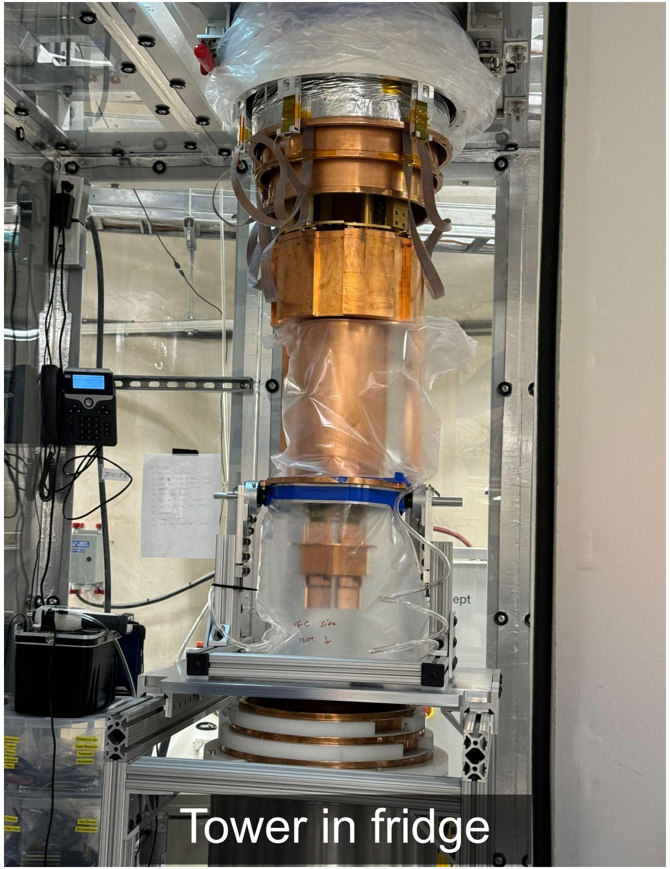
All four **detector towers now underground** and tested that connections are secure.
Currently stored in **sealed transport vessels to prevent radon contamination**.
Trial runs for installation into cans underway

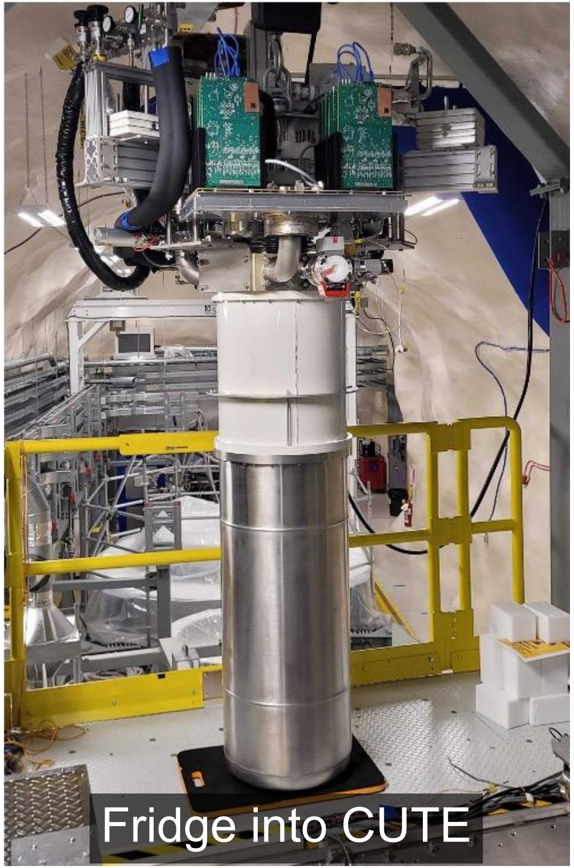




Installation status

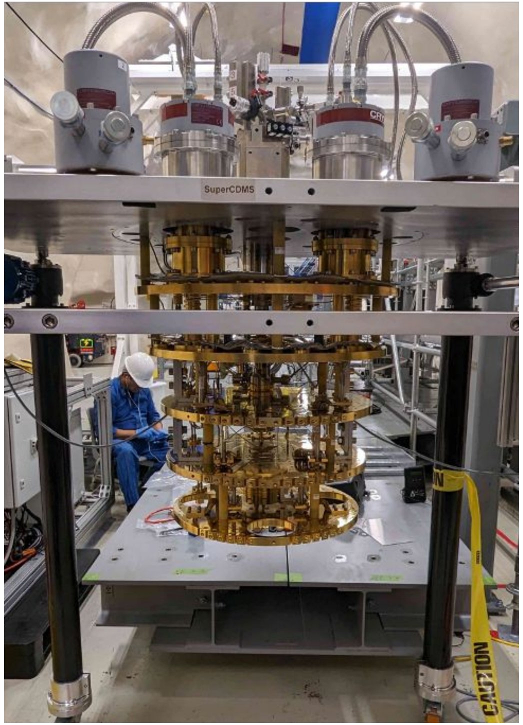


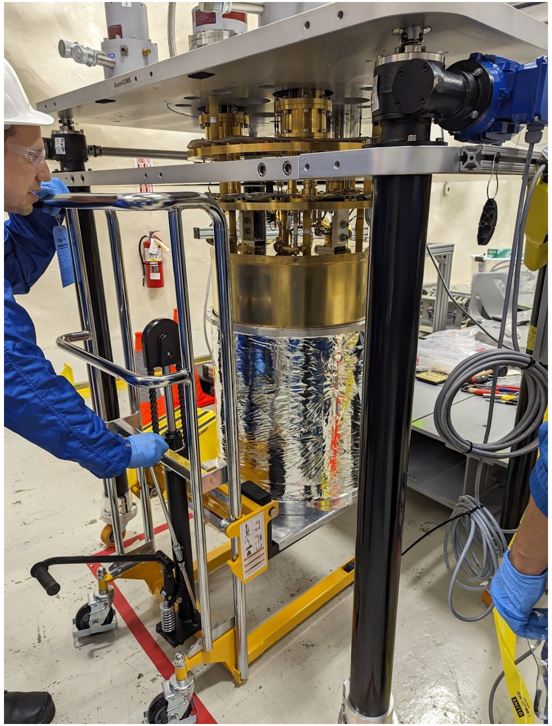




Installation status

Fridge is installed and has undergone a number of successful cold tests



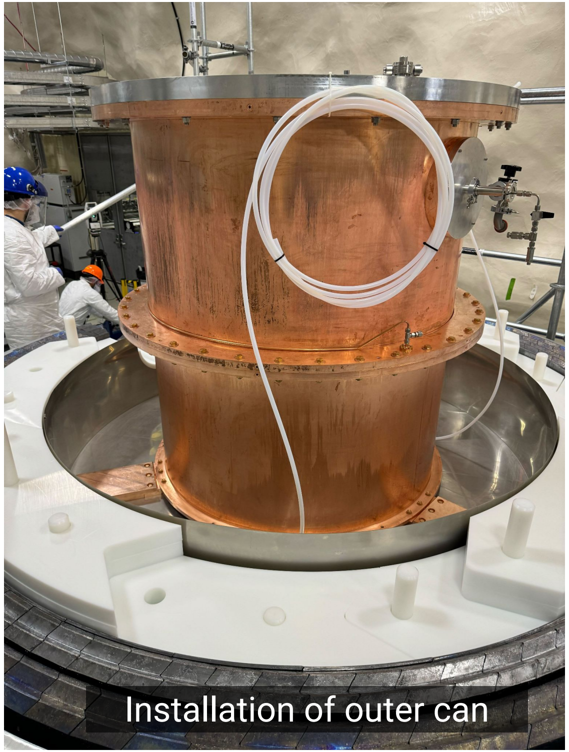


Installation status

SNOBOX cans have been shipped to SNOLAB and are going through cleaning (etching and passivation) and install procedures

Testing cleaning technique

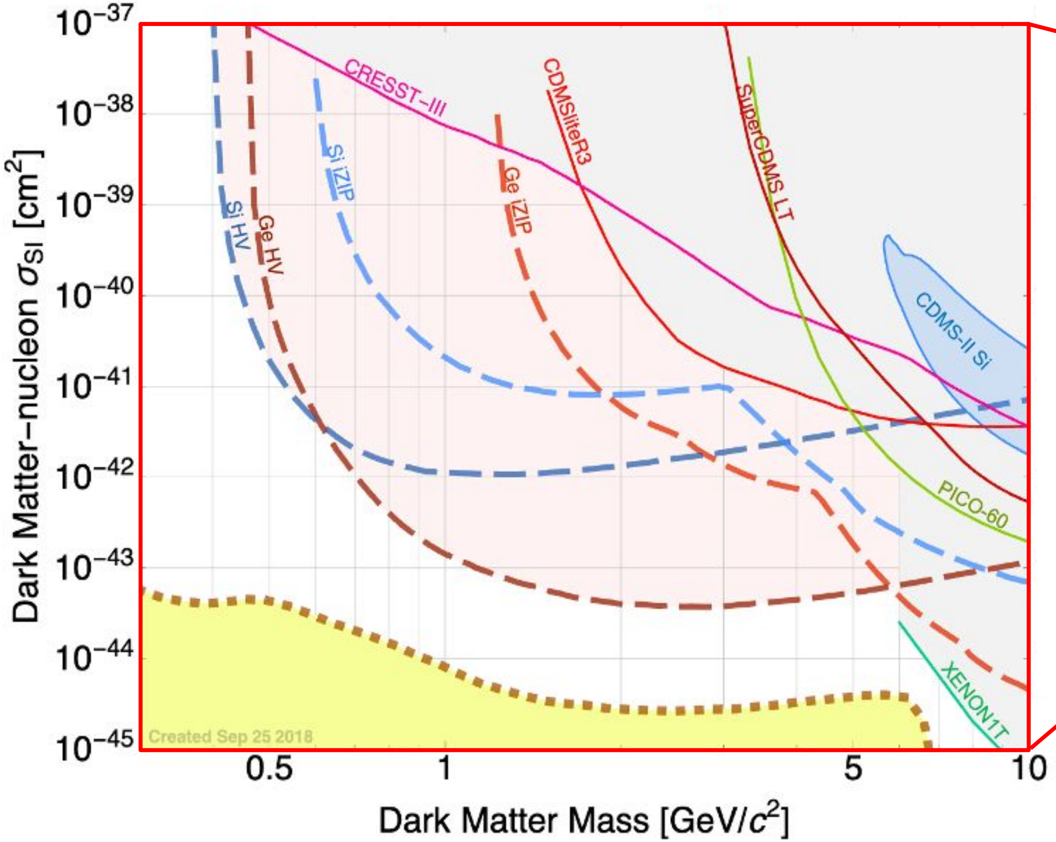
Preparations for underground travel



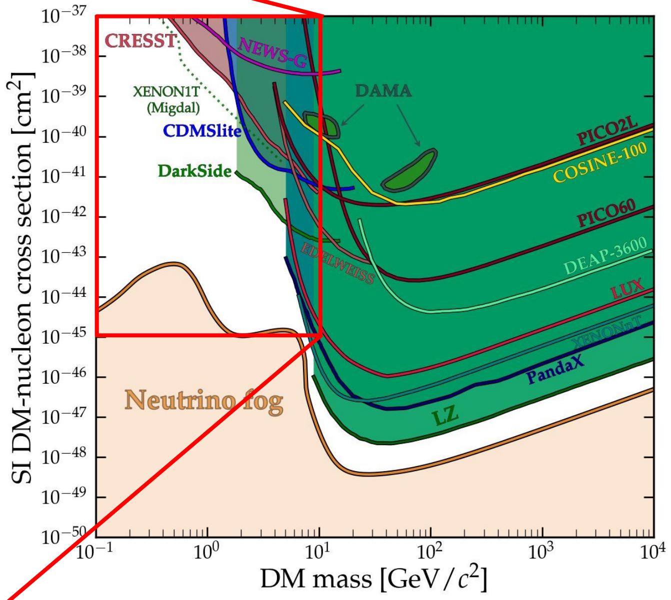
Installation of outer can

Installation status

SuperCDMS



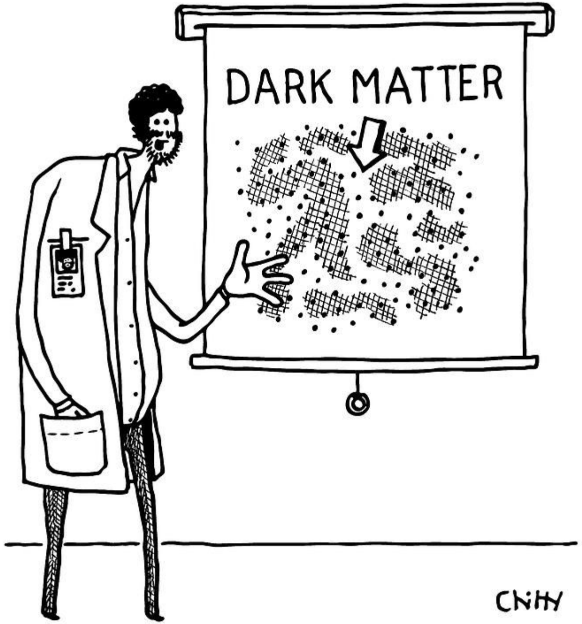
Dark Matter–nucleon σ_{SI} [cm^2]
Dark Matter Mass [GeV/c^2]
CRESST-III
CDMSliteR3
SuperCDMS LT
Si iZIP
Ge iZIP
Si HV
Ge HV
CDMS-II Si
PICO-60
XENON1T
Created Sep 25 2018



SI DM-nucleon cross section [cm^2]
DM mass [GeV/c^2]
CRESST
NEWS-G
XENON1T (Migdal)
CDMSlite
DarkSide
DAMA
PICO2L
COSINE-100
PICO60
DEAP-3600
EDELWEISS
LUX
XENONnT
PandaX
LZ
Neutrino fog

Summary

- Dark matter is an extremely active field of research
  - >80% of the matter in the Universe, but what is it?
  - HUGE range of possibilities for its nature
- Many different search methods needed to span these
  - Collider
  - Indirect detection
  - Direct detection
- SuperCDMS is one experiment under construction in Canada
  - Coldest place on Earth (the Universe?) is in our fridge!
  - One of the least radioactive environments on Earth
  - Exploring new sensor technologies and parameter space not yet probed
  - A leader in the field in coming years



"We're quietly confident that it smells of cinnamon."

Still have questions?
Scan QR code for my details

Acknowledgements

@SuperCDMS supercdms.slac.stanford.edu

Back up

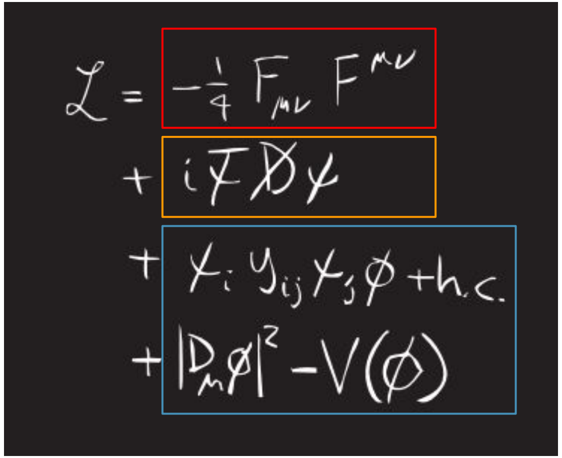
Putting together the outer can

Copper cleaning

Purpose of Particle Physics

Mathematically write this as: $\mathcal{L} = a\psi_i X_{ij} \psi_j$ where

- ψ_i and ψ_j are the particles interacting,
- a is the interaction probability/strength
- *X* is an operator that dictates how the interaction occurs

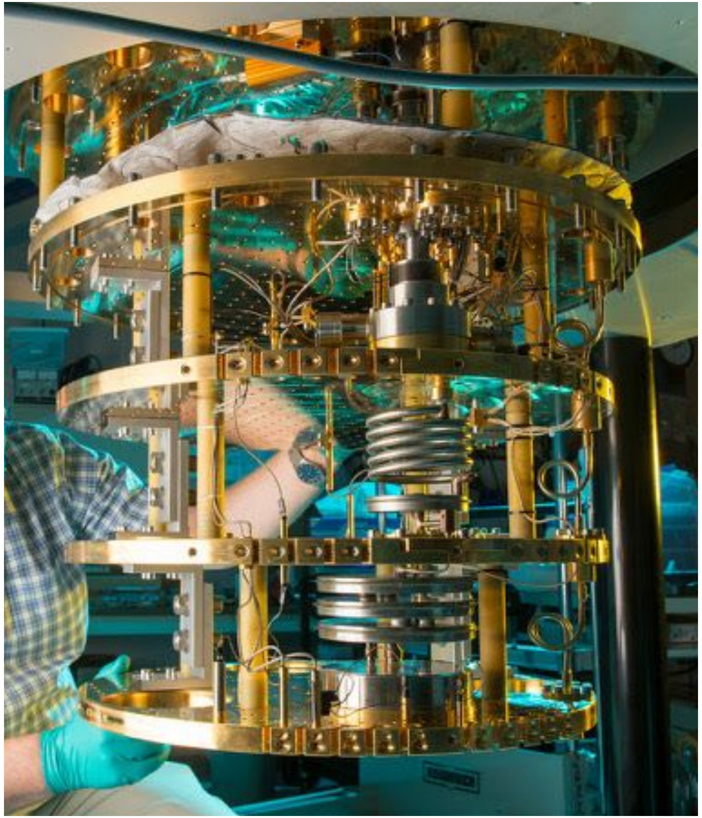


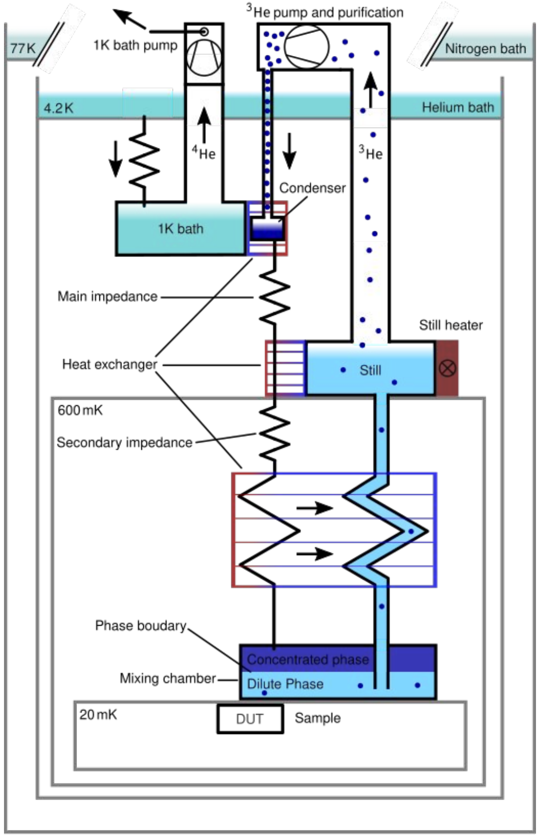
Information about the forces

How the forces and particles interact

How particles get mass

Dilution refrigerator





<u>Basic concept:</u>
forces the **mixing of ^{3}He and ^{4}He**, which **uses heat,** thus providing cooling

HV detectors

R. Agnese *et al.* Phys. Rev. D **95**, 082002

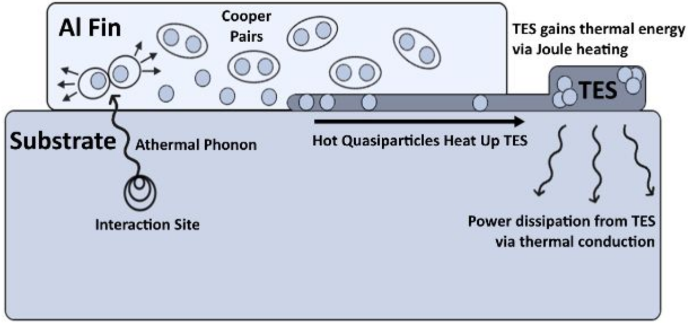
Key concept: use NTL effect to reduce energy threshold.

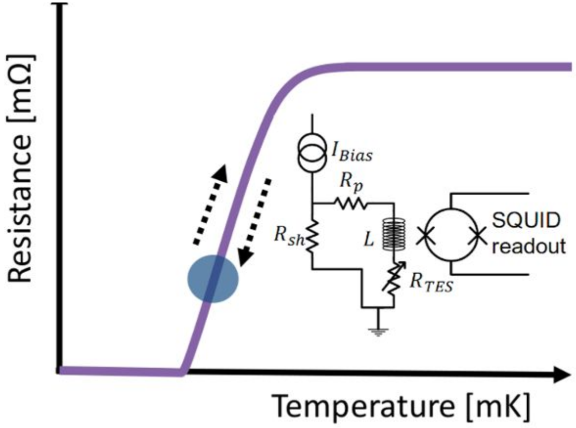
- NTL effect: drifting electron-hole pairs across potential produces phonons:

$$E_t = E_R + n_{eh} eV$$

Total phonon energy (E_t); Initial recoil energy (E_R); Number of eh pairs (n_{eh}); Potential difference (V)

- Increased potential ⇒ increased total energy for the same recoil
- Phonons detected using TES at ~50% bias point
- 12 equal area channels across each HV detector





iZIP detectors

Key concept: use charge and phonon signals for ER/NR discrimination with a higher energy threshold

- Amount of charge generated depends on <u>ionisation yield</u> of interaction:

$$n_{eh} = \frac{y(E_R)}{\epsilon_{eh}} E_R$$

Number of charge pairs

Energy to produce single pair

Initial recoil energy

- Ionisation for ER is 1, for NR<1. Comparing the ratio of this to phonons gives discriminant metric
- Charge detected using electrodes on crystal as part of HEMTs (charge amplifier circuit)
- 4 charge channels, 12 phonon channels for each detector