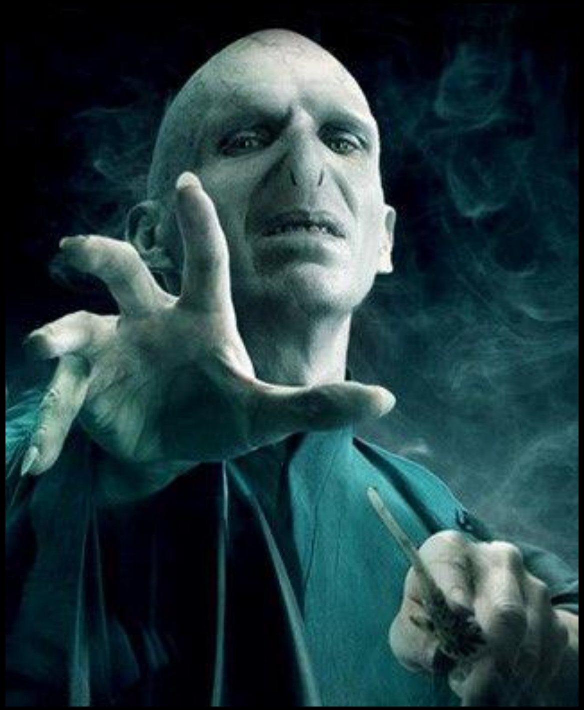
Direct Detection Dark Matter Searches



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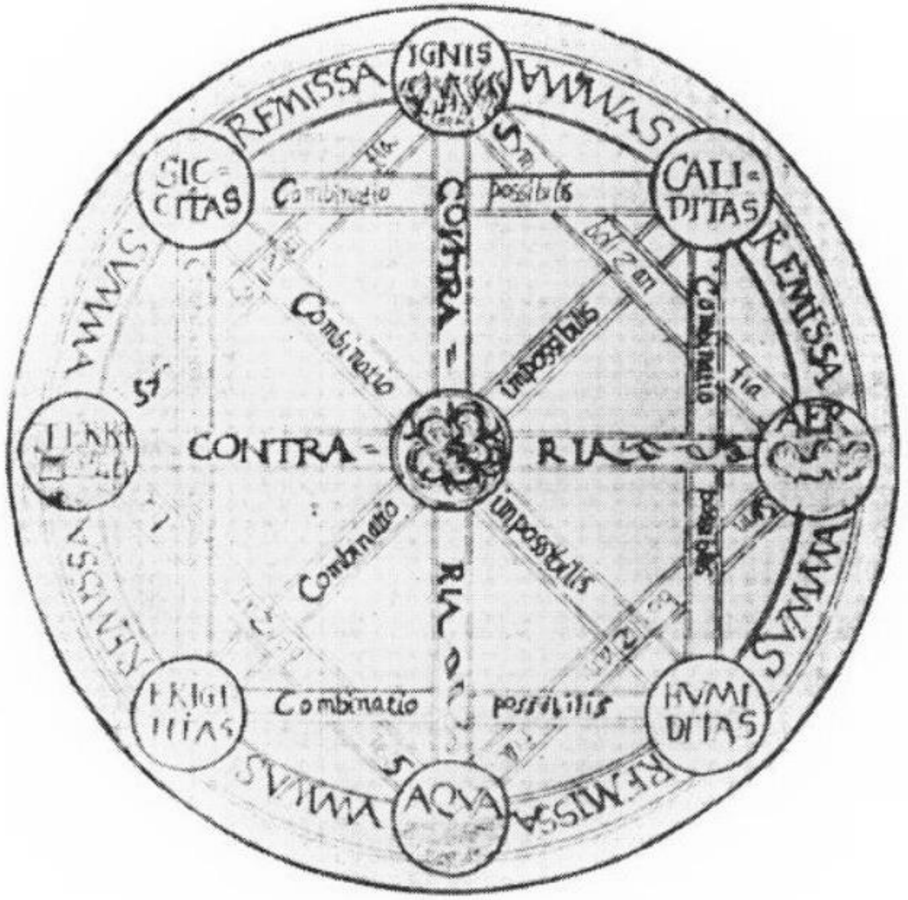
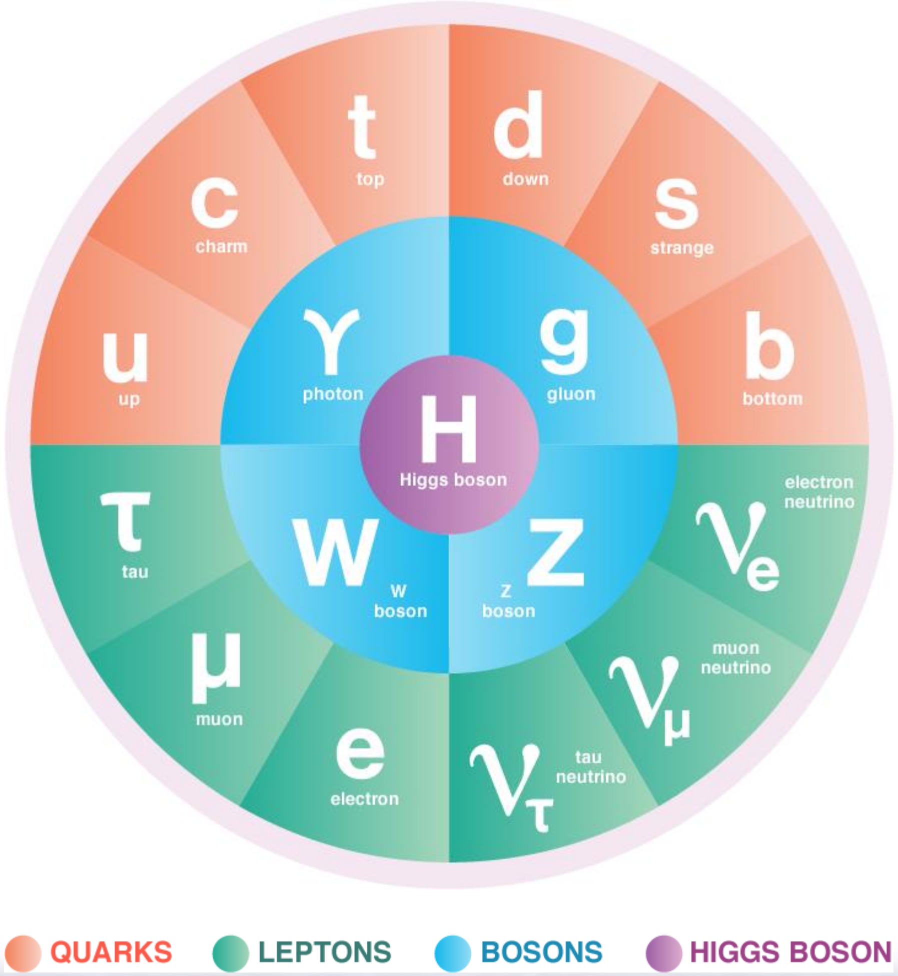
Feb 15 2019

Standard Model (SM)

2500 years ago



Today

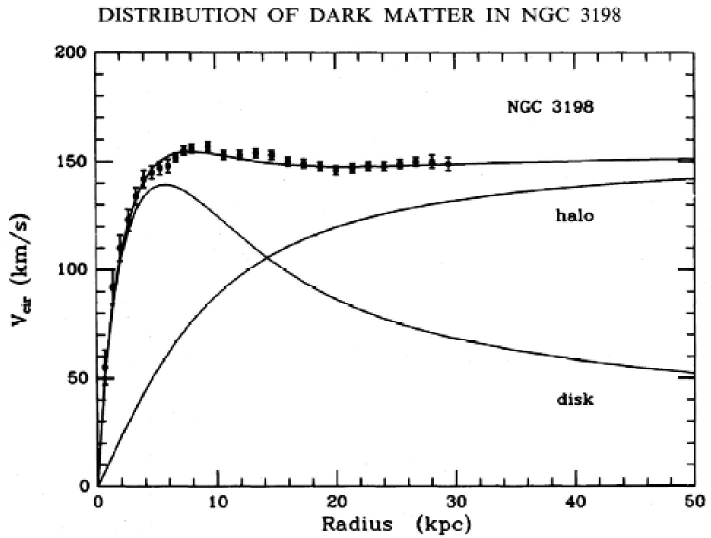


Dark Matter (DM)

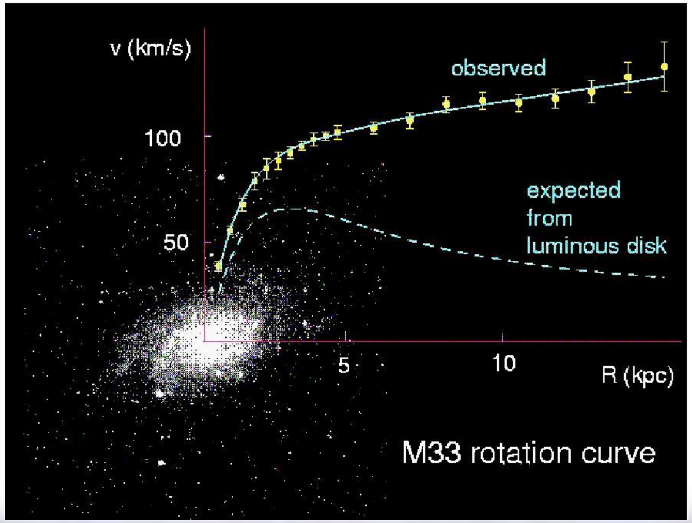
Jan Oort (1932)

It may be of some interest to compare these numbers to some other estimates of the same quantity. From the rotational velocity of the galaxy we know approximately the total mass contained in the more central parts of the galactic system. It may be put at $1{\cdot}2.10^{11}$, if we take the mass of the sun as unit. We can also form an approximate estimate of the total luminosity contained in the same part of the system by computing from VAN RHIJN's star counts the total light which we receive from the region between, say, 280° and 10° galactic longitude and ± 20° latitude. The total luminosity estimated in this way is 10^{10} units. Thus, the average mass corresponding with a unit of light would be about 12 in this case, or about 7 times larger than the value derived above. It is not necessary to conclude from this that the absolutely bright stars are relatively less frequent near the centre, or that there is a greater percentage of nebulous or dark matter in this region: we might reverse the argument

Vera Rubin (1970)



Recent surveys

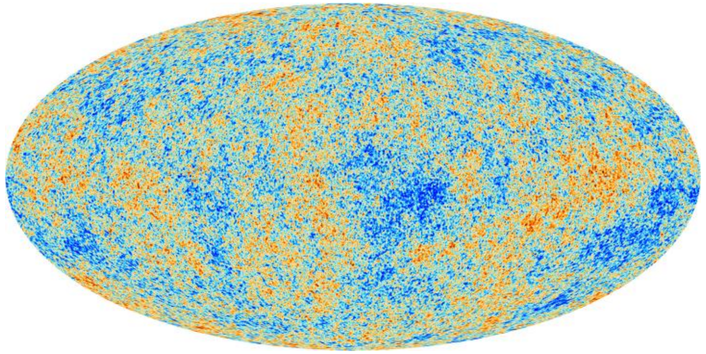


… a lot of it …

Dark Matter isn't in the Standard Model?!

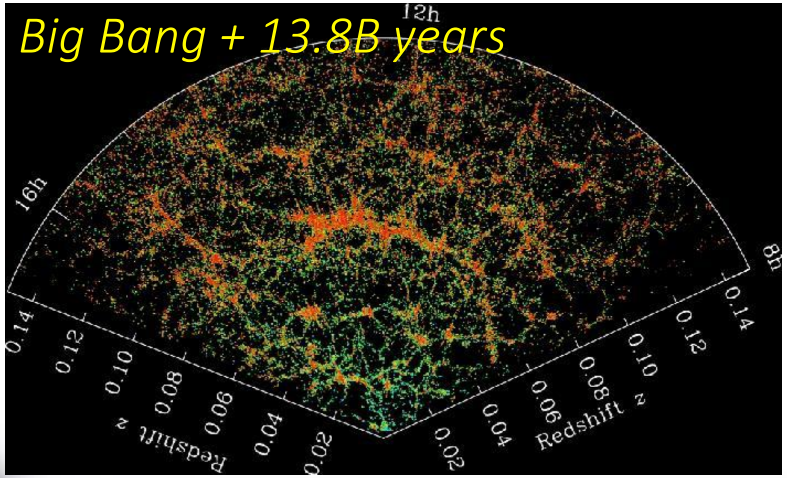
Cosmic Microwave Background (Planck)

Big Bang + 380K years

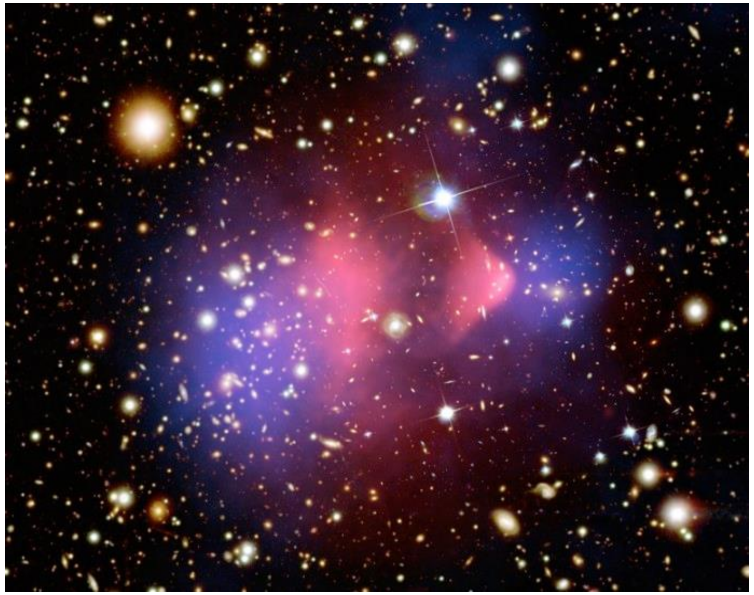


Large-Scale Structure (SDSS)

Big Bang + 13.8B years



Collisions between galaxy clusters



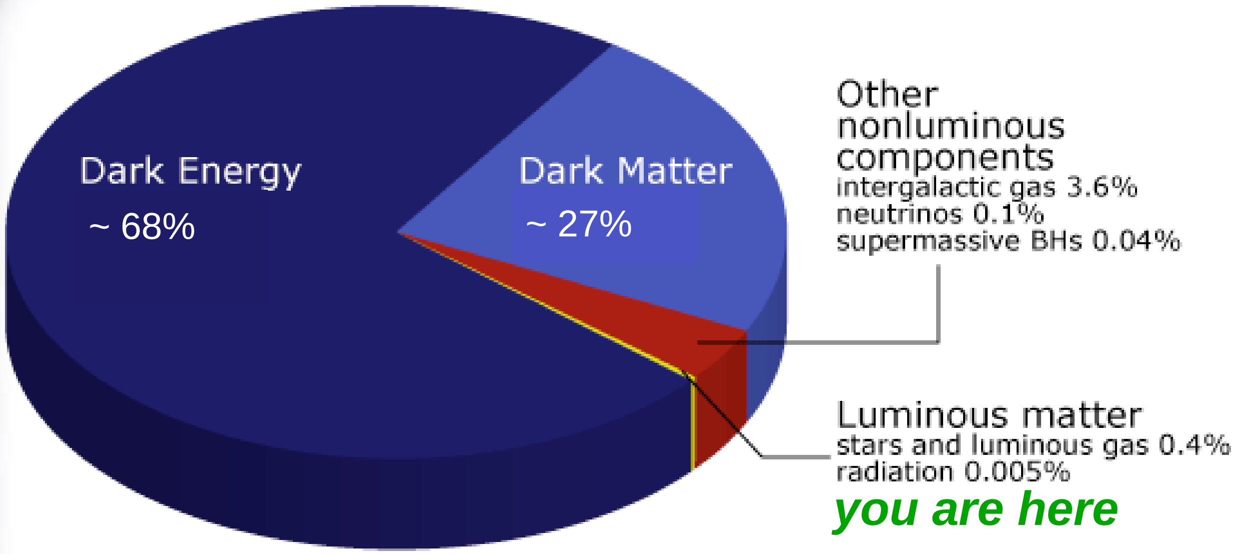
- Cold (non-relativistic)
- Little interaction with regular matter

DM seems to be some new kind of matter

Dark Outline

- Dark Matter
  - What is it?
  - Thermal production
  - Candidate particles
- Detection Strategies
  - Collider, Indirect, **Direct**
- Search Status
- Next-Generation Direct Detection
  - Nobel liquid/gas, **Cryogenic solid-state**
  - **SuperCDMS at SNOLAB**

What is Dark Matter?



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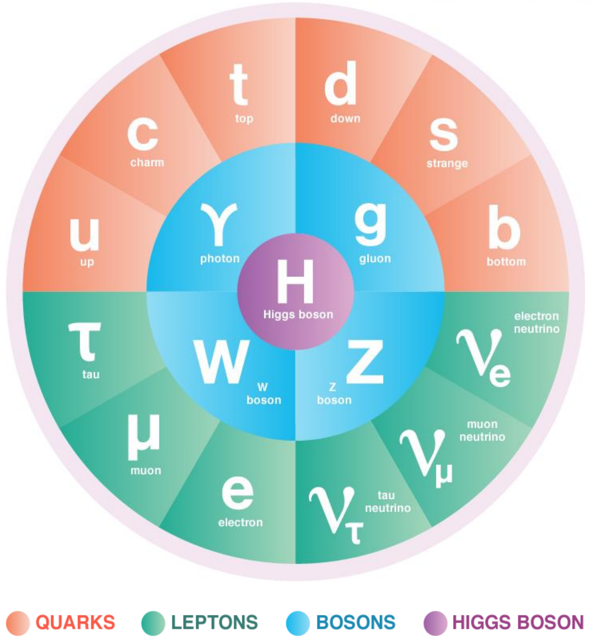

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Other questions to consider …

What mechanism(s) set the amount of dark matter? And its ratio to the amount of regular matter?

How did this amount change over cosmic timescales?

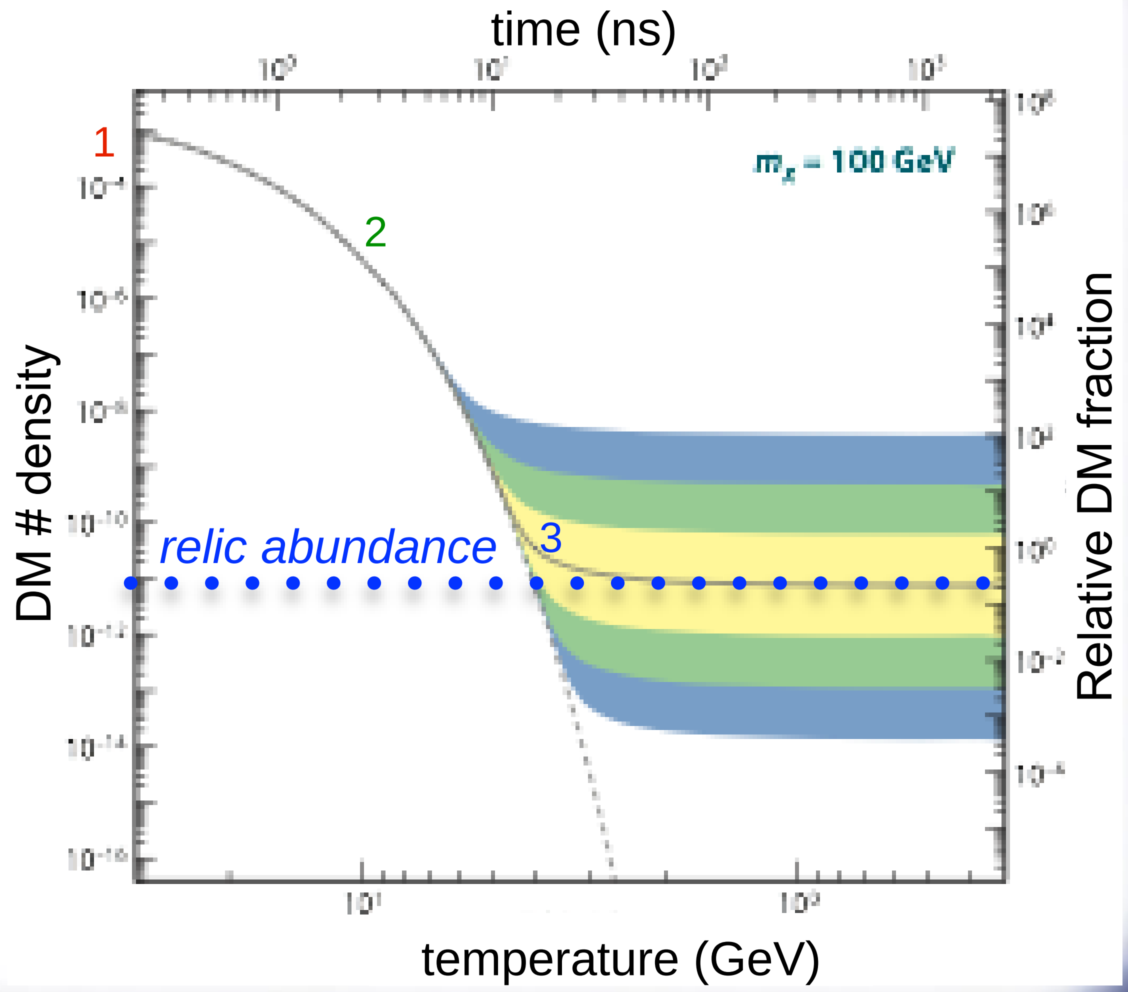
Thermal Production

General, simple mechanism for DM production in early universe:

1. Assume DM initially in thermal equilibrium with regular matter, in hot "soup"
   $\chi\bar{\chi} \leftrightharpoons f\bar{f}$

2. Universe cools, SM no longer energetic enough to produce DM pairs, DM begins annihilating away
   $\chi\bar{\chi} \rightharpoonup f\bar{f}$

3. Universe expands so DM stops annihilating ("freeze-out")
   $\chi\bar{\chi} \not\leftrightharpoons f\bar{f}$



DM Candidates

“Weakly Interacting Massive Particles” (WIMPs):

~100 GeV (~100x the proton mass)

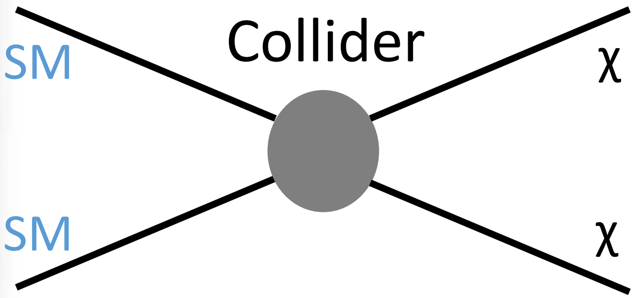
Other DM Possibilities:

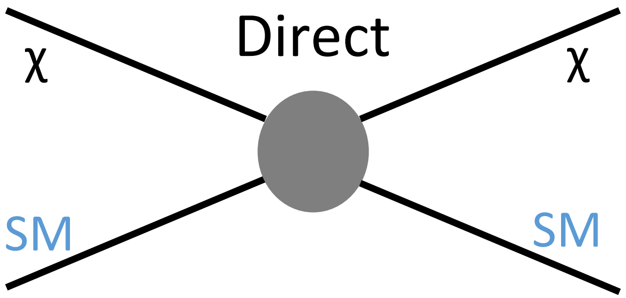
- DM particles have only gravitational interactions and/or self-interactions: no interactions with SM particles
- DM “particles” are axions: at least 10^{10} times lighter than protons, so they behave like waves instead
- DM is composed of MACHO (Massive Compact Halo Object)-like objects, such as black holes
- There is no DM, only modified [quantum / super-] gravity

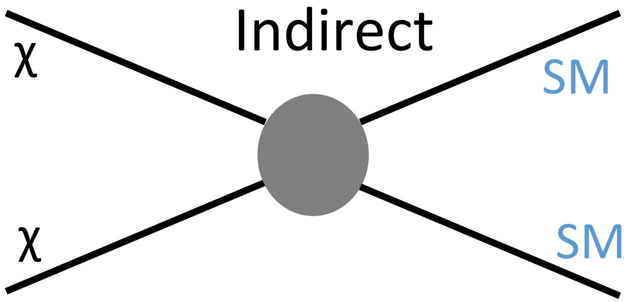
But these would be different seminars entirely!

WIMP Search Strategies

Complementarity between different types of experiments

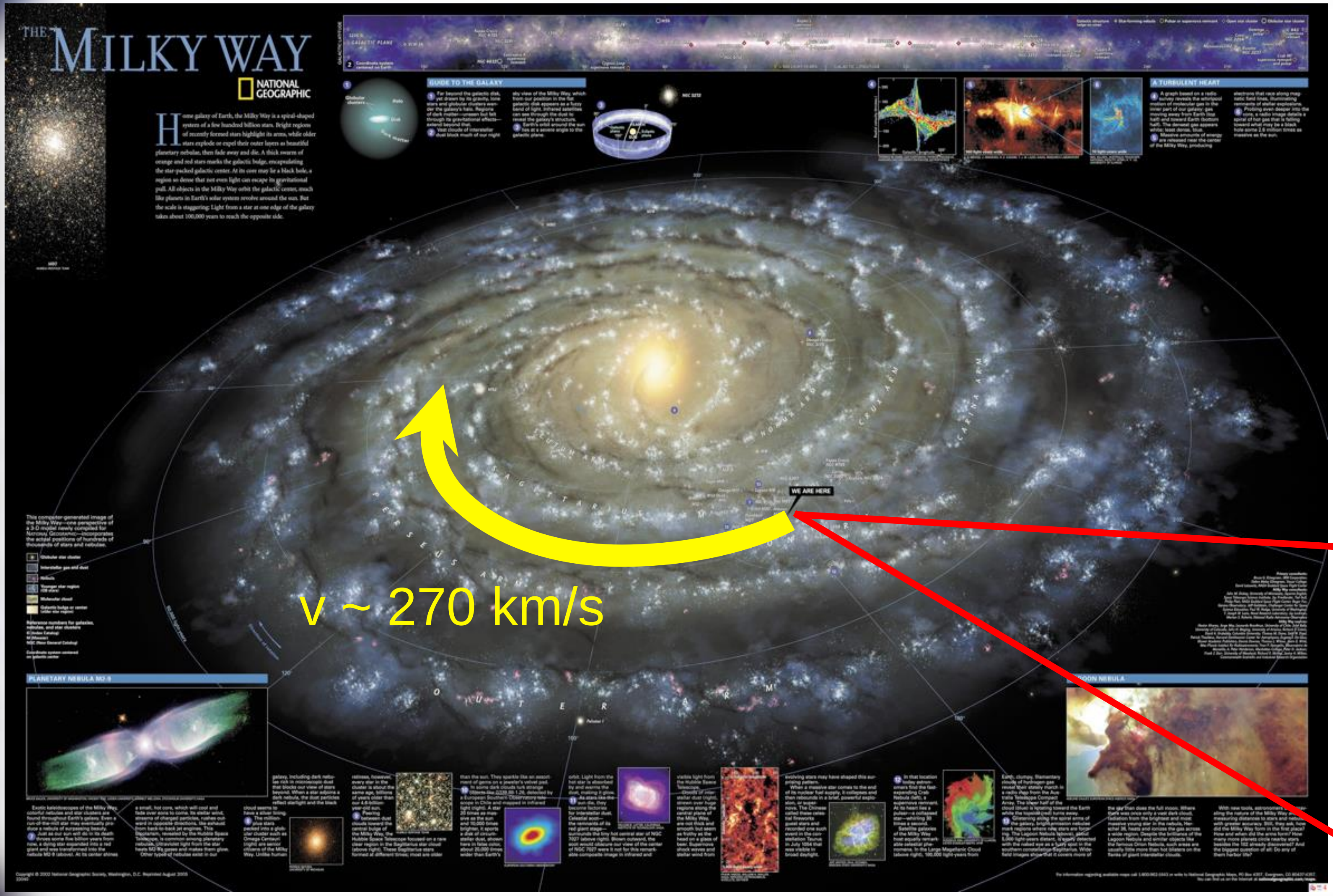






Sometimes, but not always, in the context of supersymmetric (SUSY) models that predict weak-scale “superpartners” of SM particles

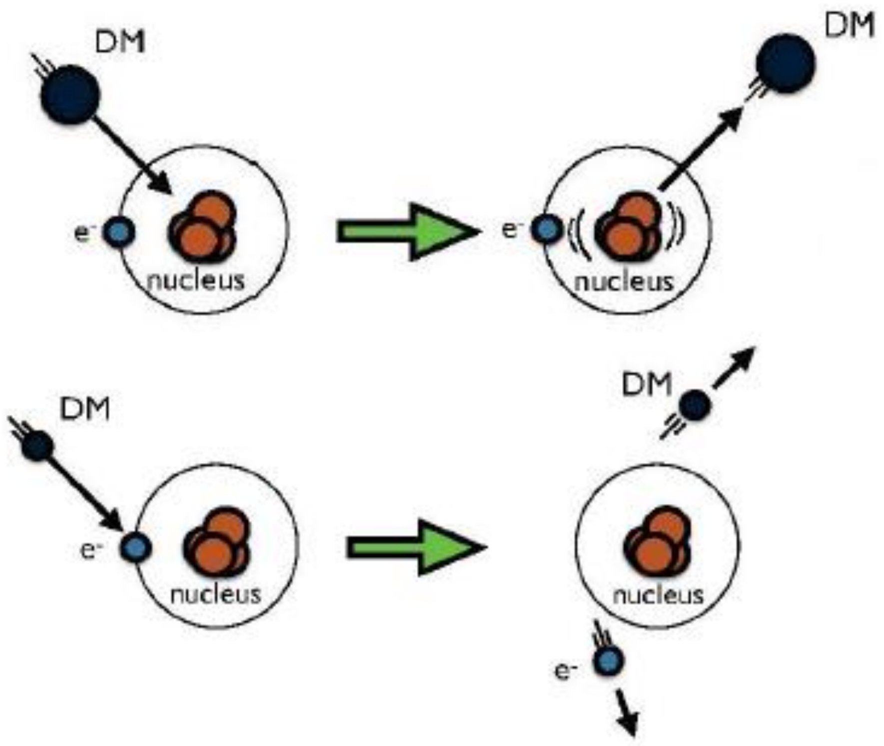
Direct Detection

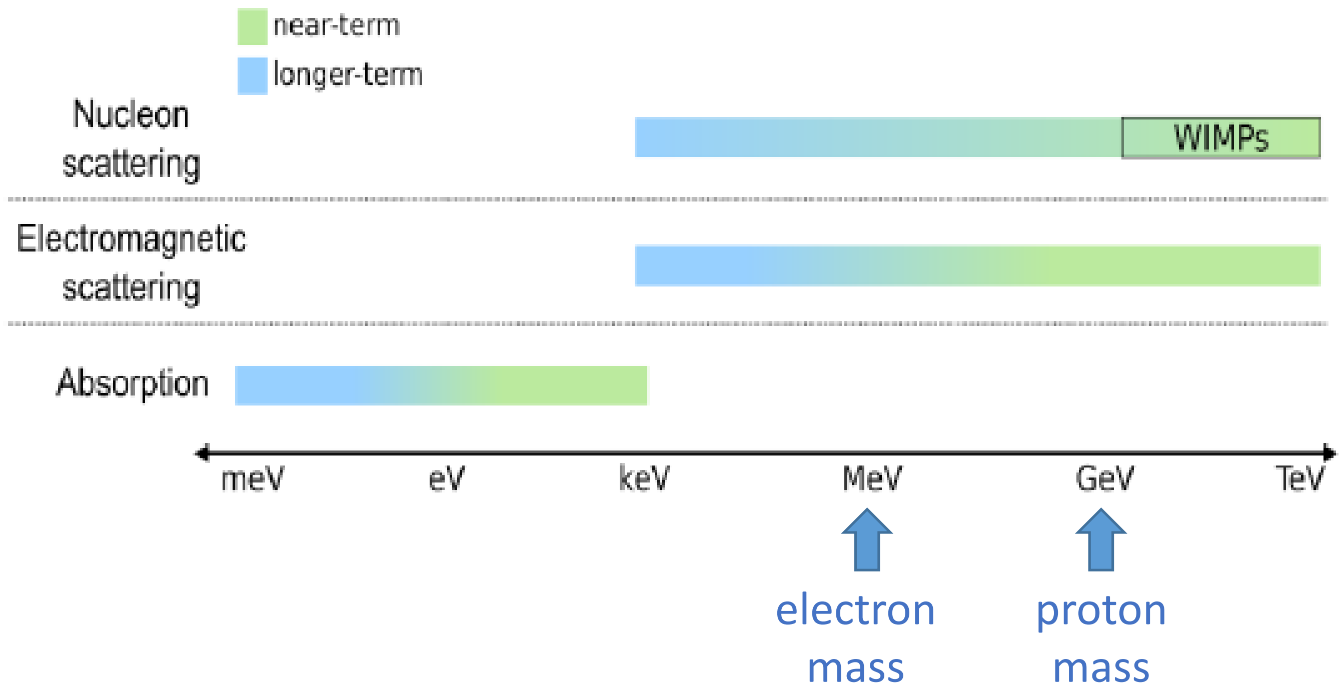


Collisions of galactic DM with SM particles in detector

Direct Detection

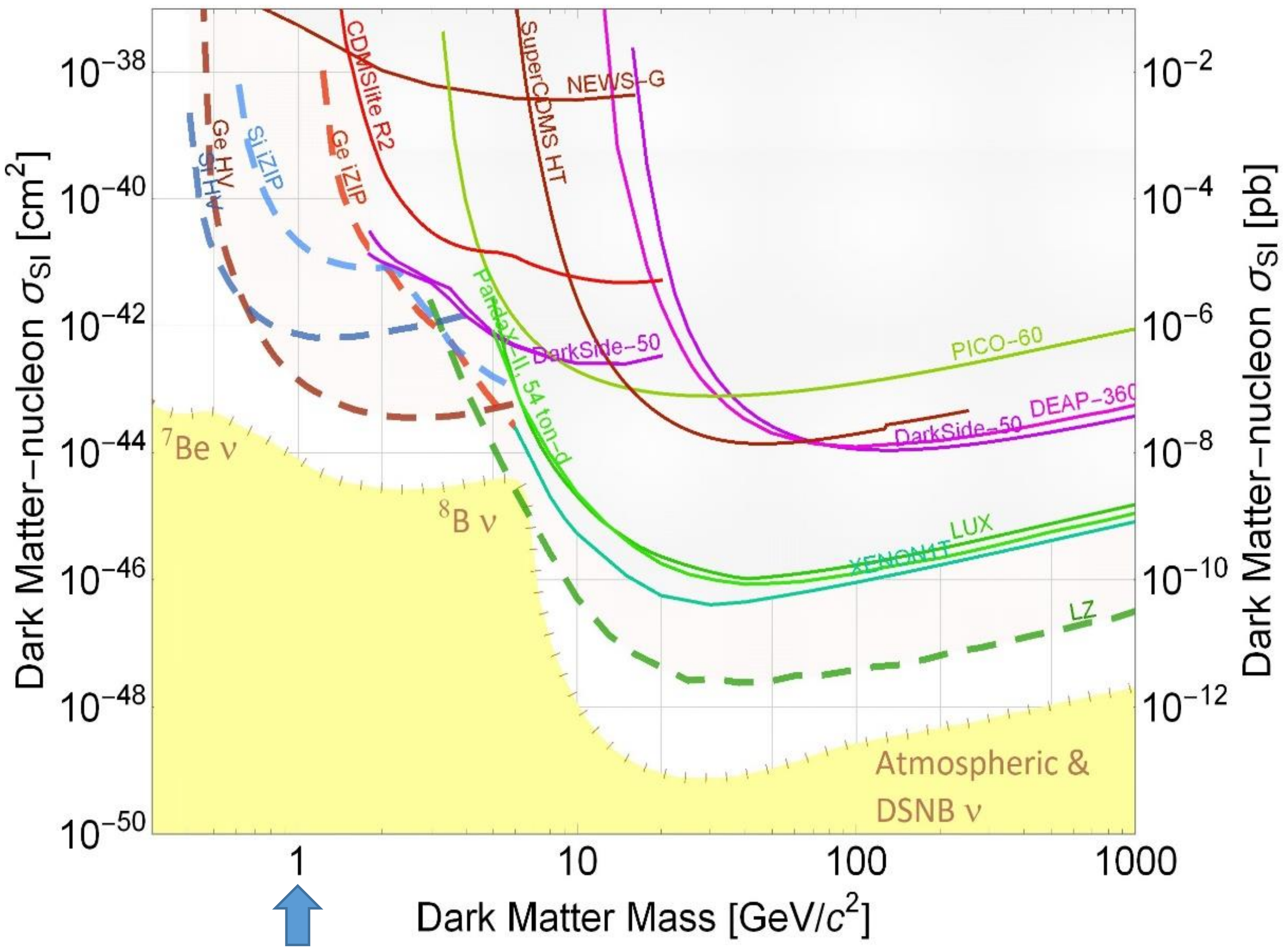
DM particles collide with SM particles in detector "target" and are absorbed, or cause nuclear and/or electronic recoils





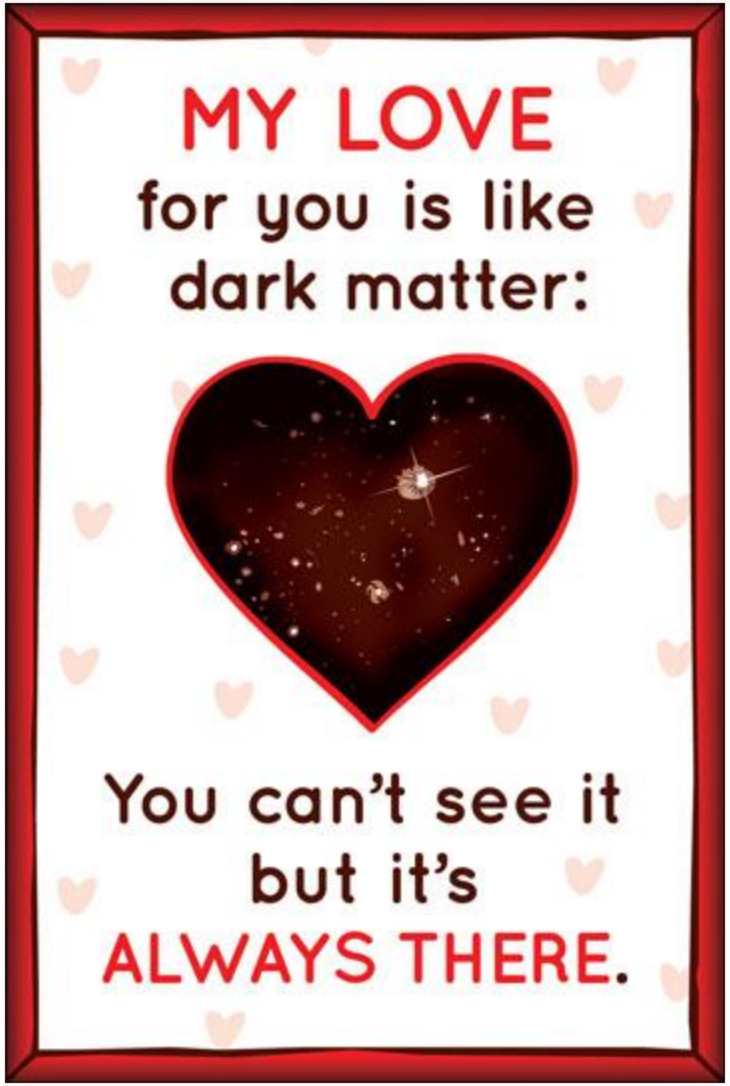
Search Status

Searches *where we most expect to find WIMPs* haven't found them!

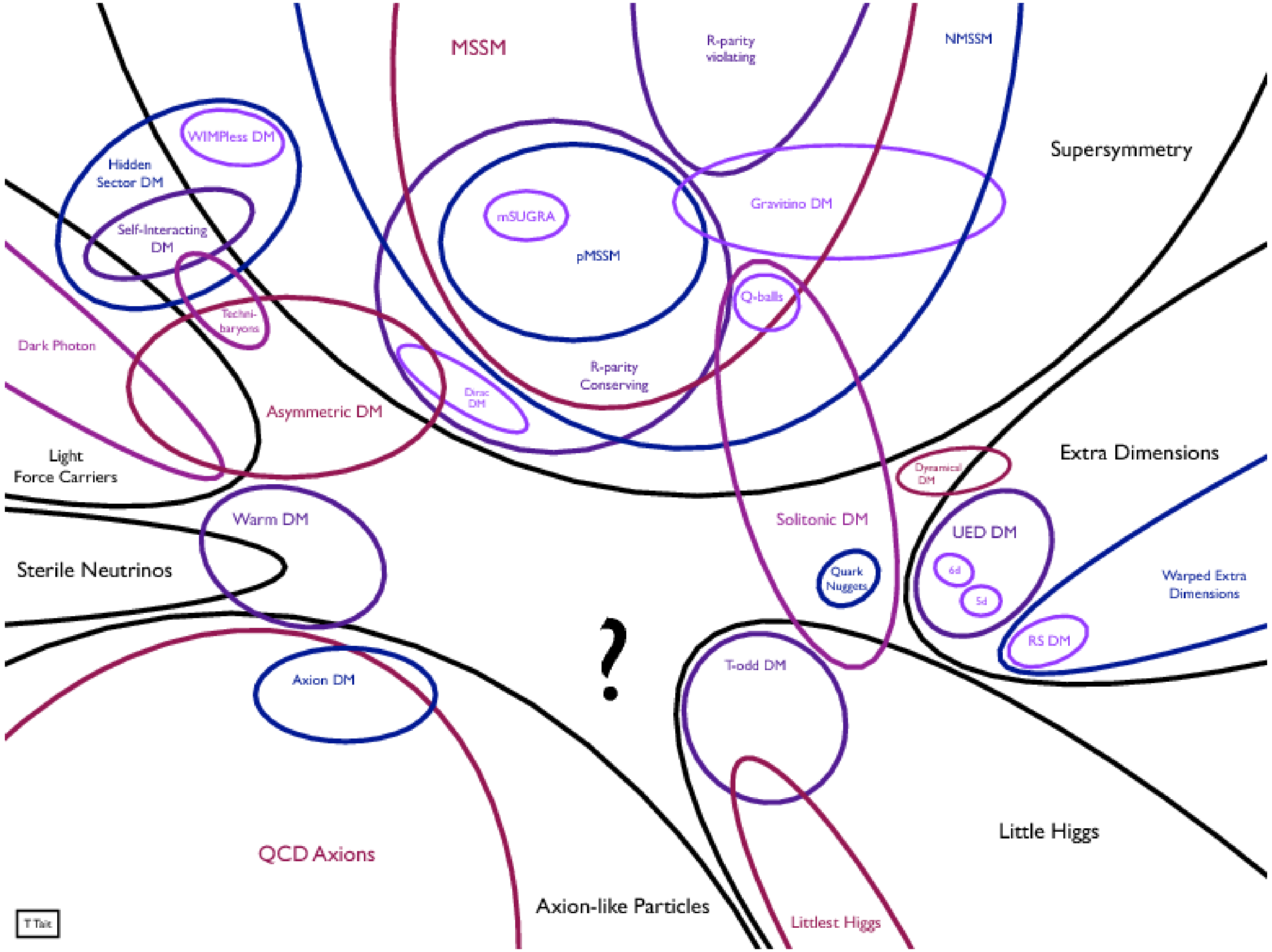


proton mass

Search Status



What now?


MSSM
R-parity violating
NMSSM
Supersymmetry
WIMPless DM
Hidden Sector DM
Self-Interacting DM
mSUGRA
pMSSM
Gravitino DM
Q-balls
Techni-baryons
Dark Photon
R-parity Conserving
Dirac DM
Asymmetric DM
Light Force Carriers
Extra Dimensions
Dynamical DM
Warm DM
Solitonic DM
UED DM
Sterile Neutrinos
Quark Nuggets
6d
5d
Warped Extra Dimensions
RS DM
?
T-odd DM
Axion DM
Little Higgs
QCD Axions
Axion-like Particles
Littlest Higgs
T Tait

Dark Sectors?

Standard Model is only ~5% of the universe.
It includes 3 forces.

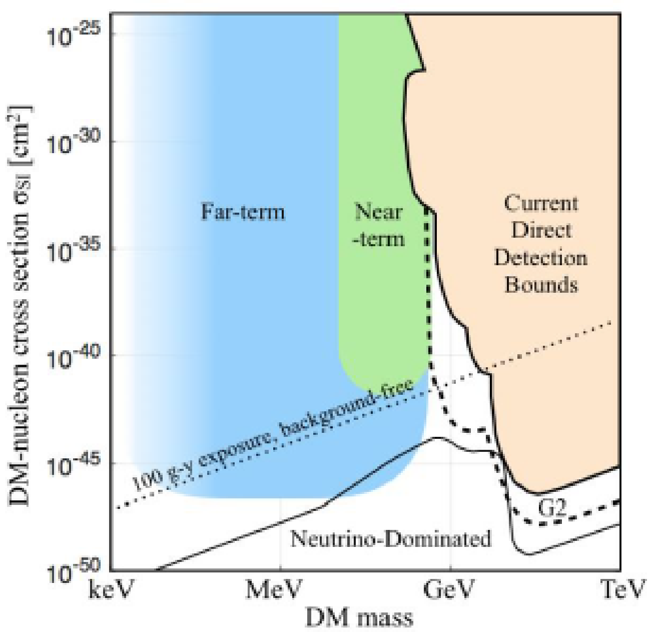
Why should the ~25% that is Dark Matter be any simpler?
Dark Forces?

How would DM interact with the SM?
Mediator particles?

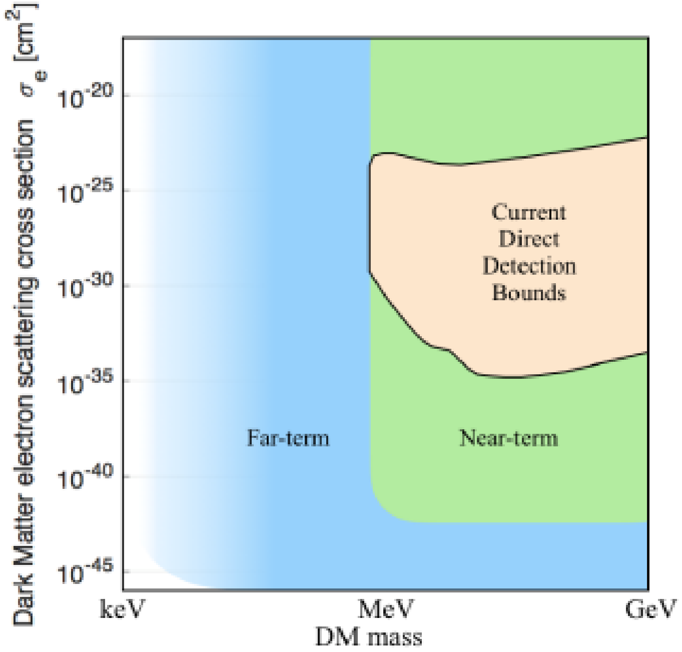
Next-Generation Direct Detection

Next few years will either *find WIMPs* or *rule them out.*

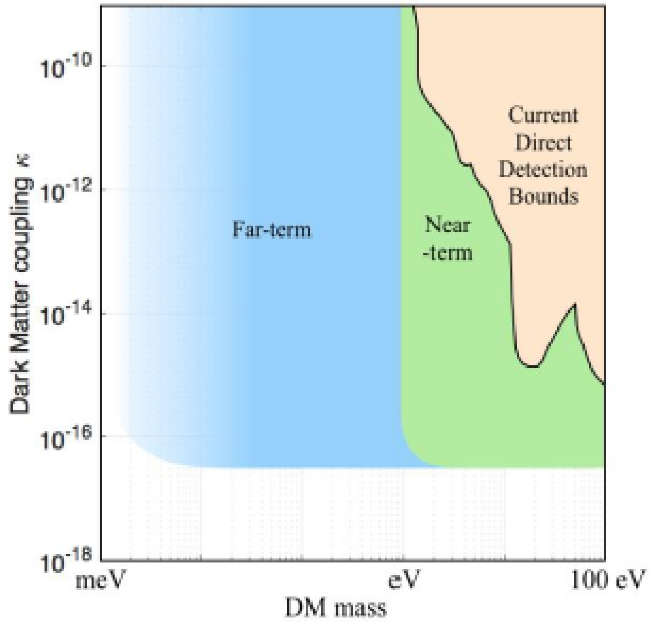
Lowering *mass* and/or *interaction* thresholds mean tougher backgrounds, and we will encounter "floor" where neutrinos drown out WIMP signal



Galactic dark matter scattering off nuclei

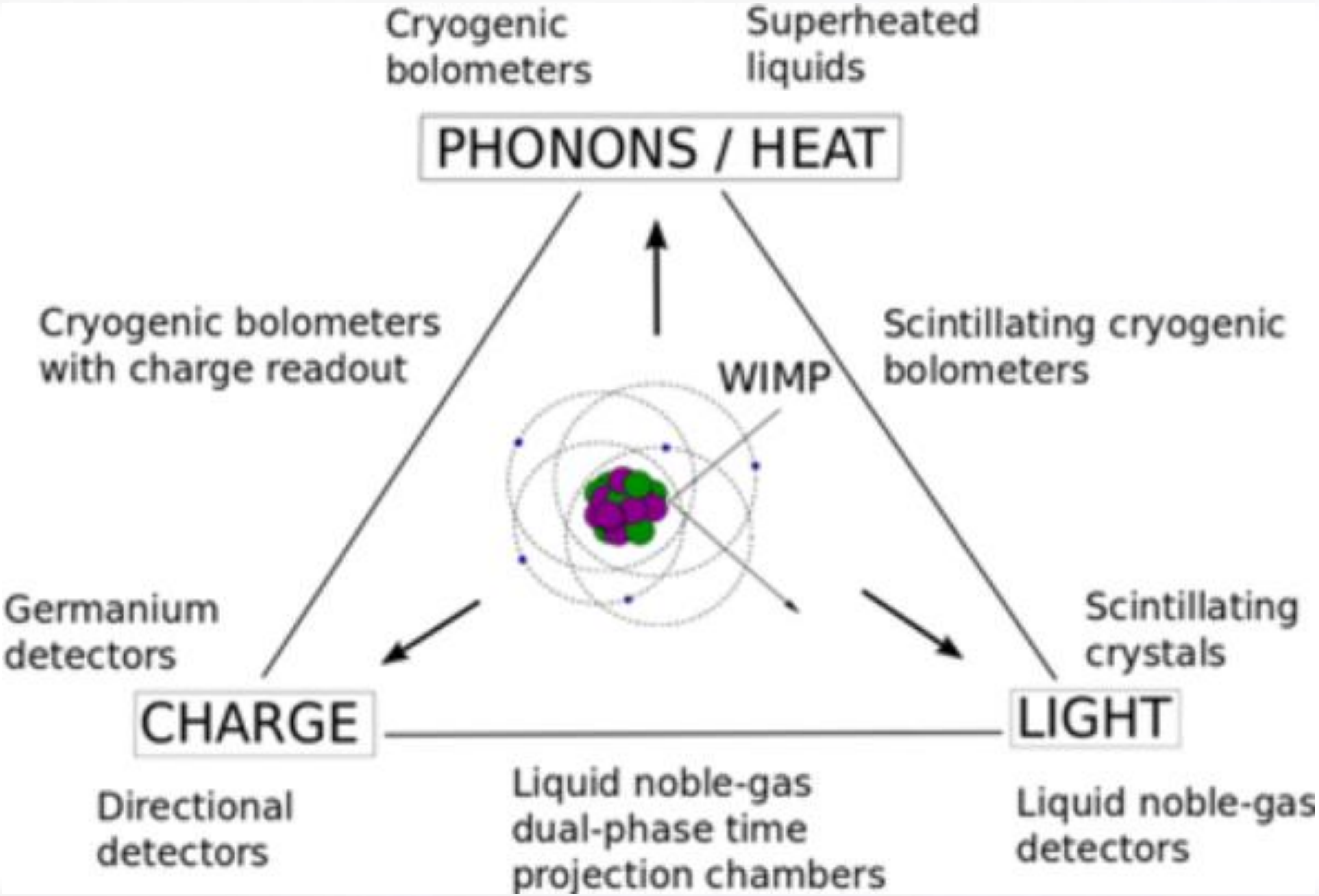


Galactic dark matter scattering off electrons



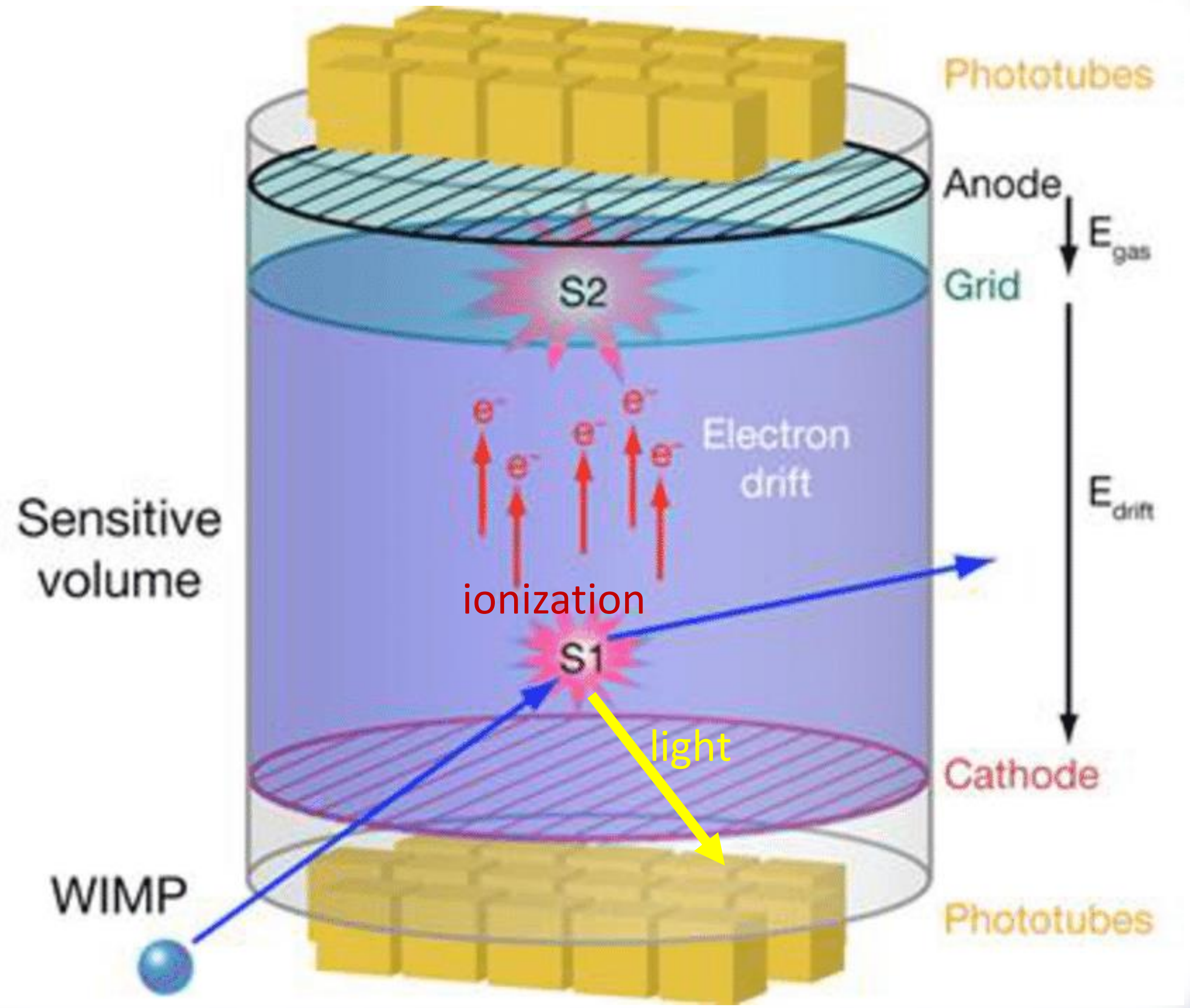
Galactic dark-photons absorbed by electrons

Next-Generation Direct Detection



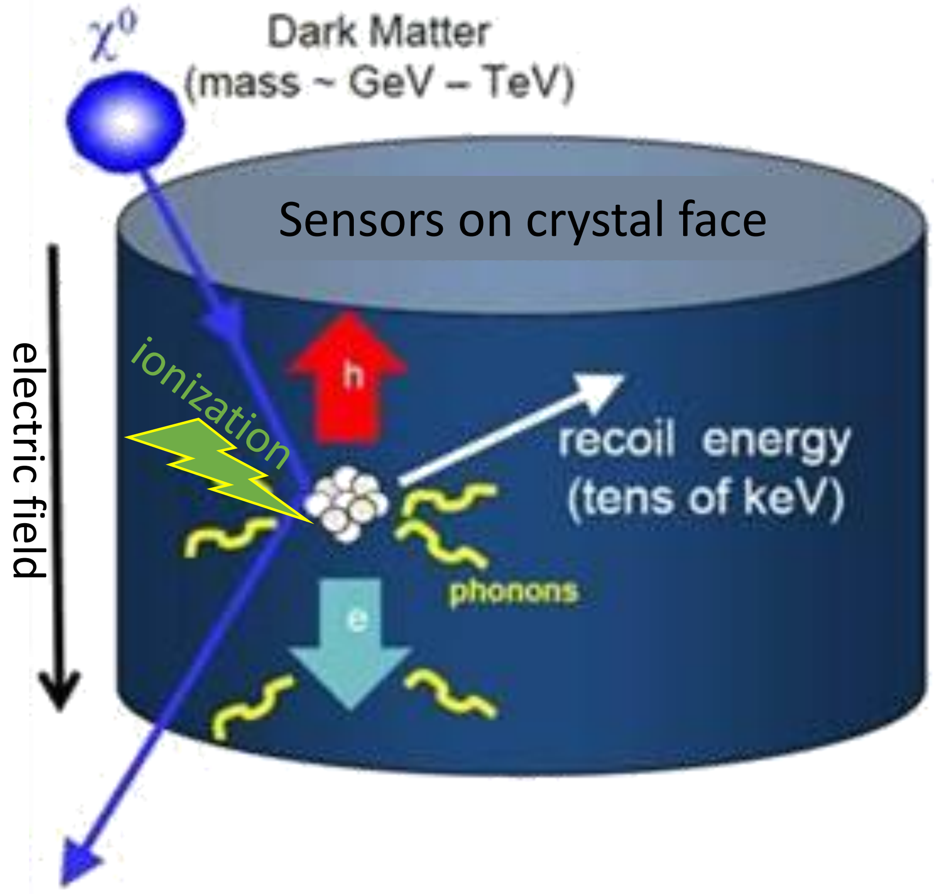
Noble Liquid/Gas Detectors

- Large tank of liquid noble element (xenon or argon) attached to sensors for light and ionization energy of particle interactions
- May also have gaseous layer
- Shielded, and often underground, to avoid interference from cosmic rays and ambient radiation



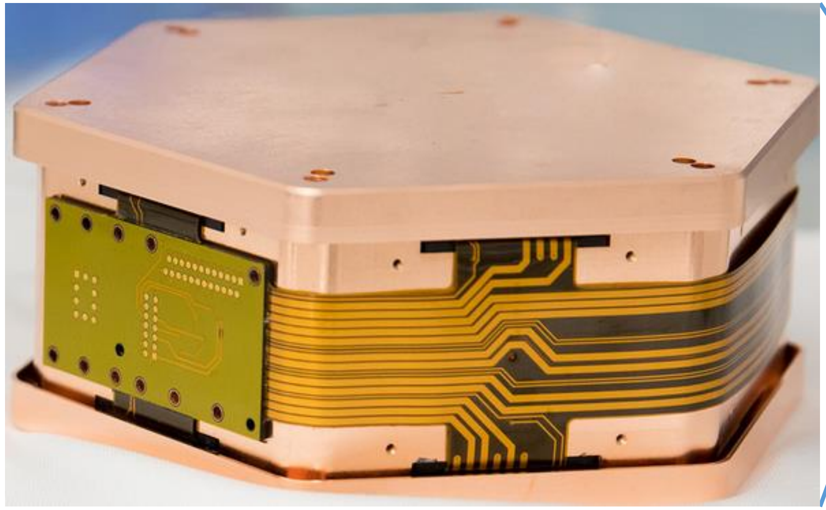
Cryogenic Solid-State Detectors

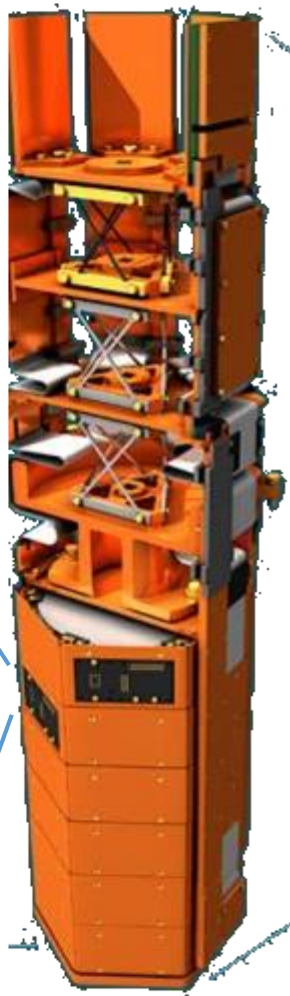
- Crystals, often semiconductors, attached to sensors for thermal and ionization energy of particle interactions
- Shielded, and often underground, to avoid interference from cosmic rays and ambient radiation
- Operated at very cold temperatures to avoid thermal noise

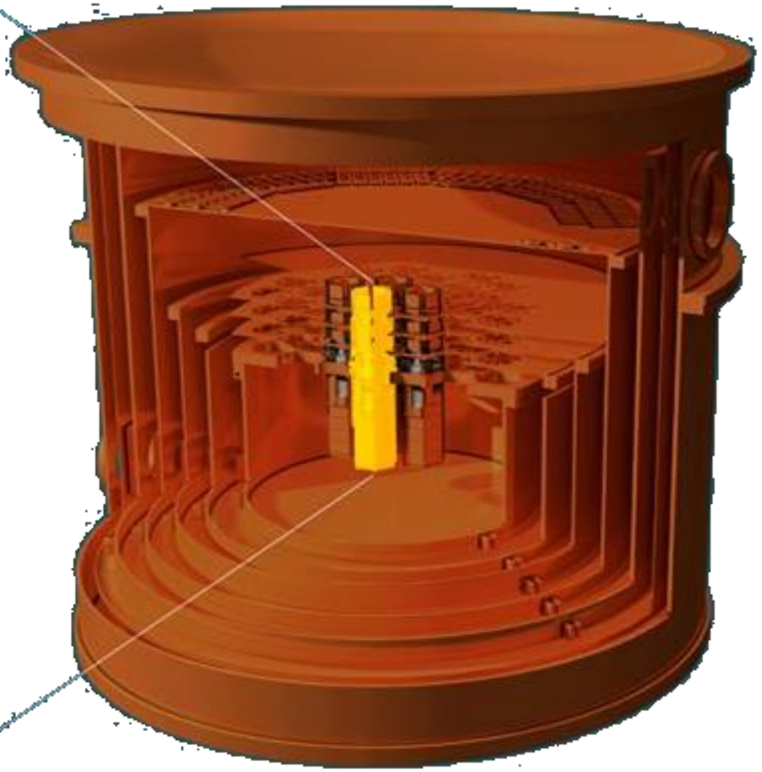


Super Cryogenic Dark Matter Search

- Silicon and germanium detectors
- Extremely low detection thresholds provide sensitivity to very feebly-interacting WIMPs, and lower-mass DM



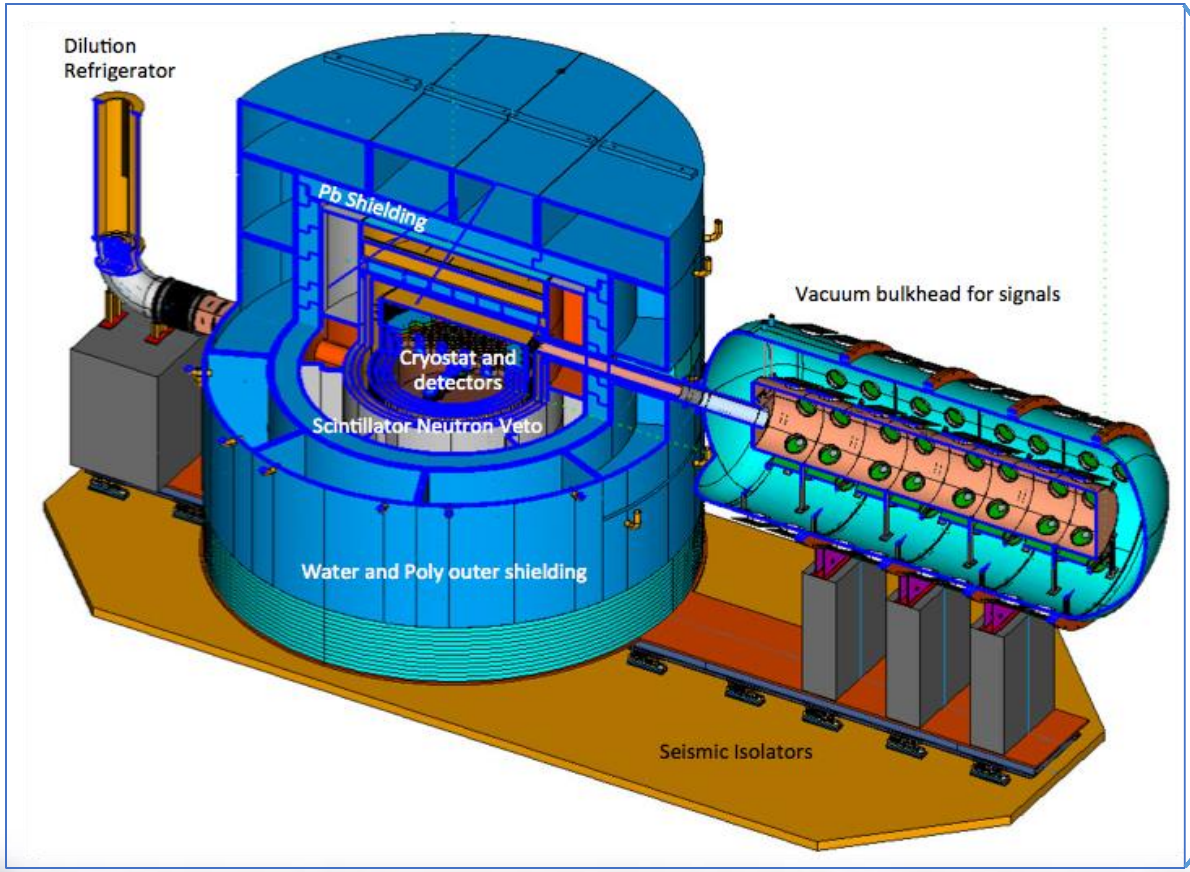


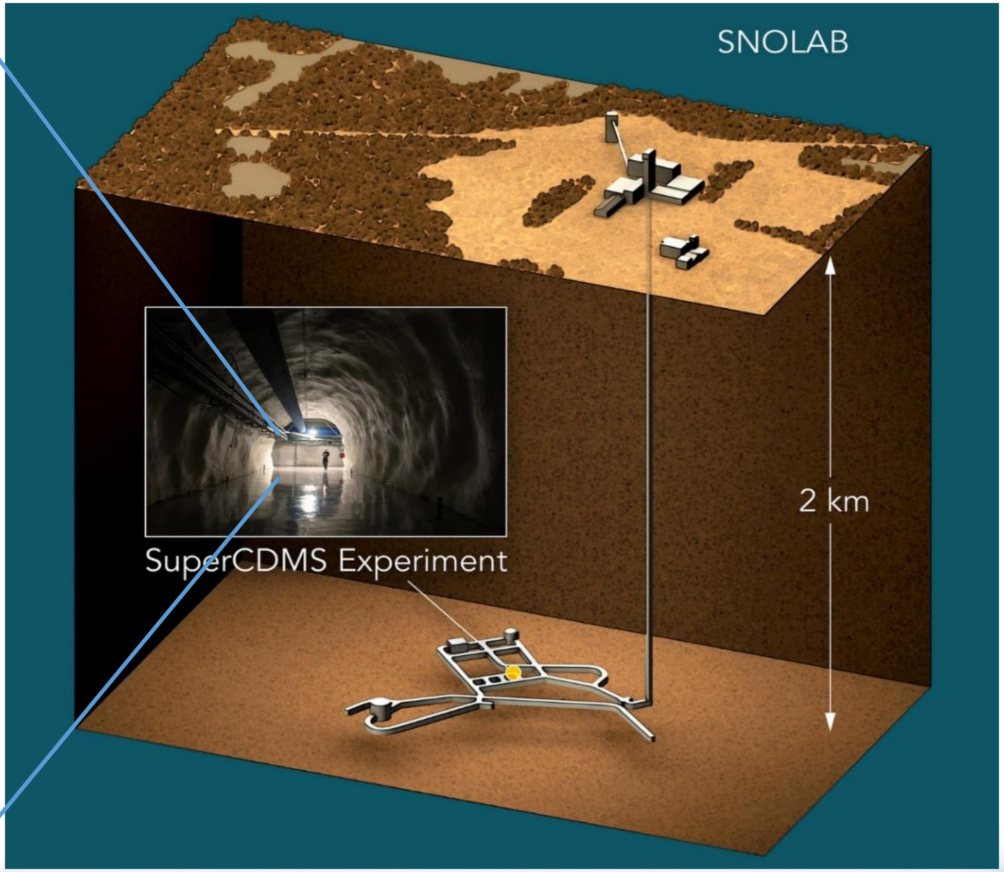


Super Cryogenic Dark Matter Search

Operated in a Soudan, Minnesota underground lab until 2015

More powerful version now being constructed in Canada's world-leading astroparticle physics facility, 2 km underground in the Vale Creighton Mine near Sudbury





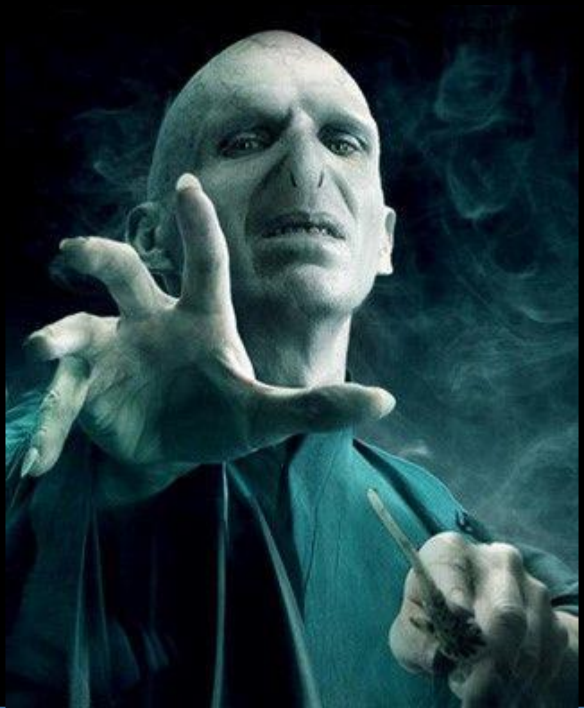
Super Cryogenic Dark Matter Search at SNOLAB

- First operations expected in 2020

Join the Dark Side

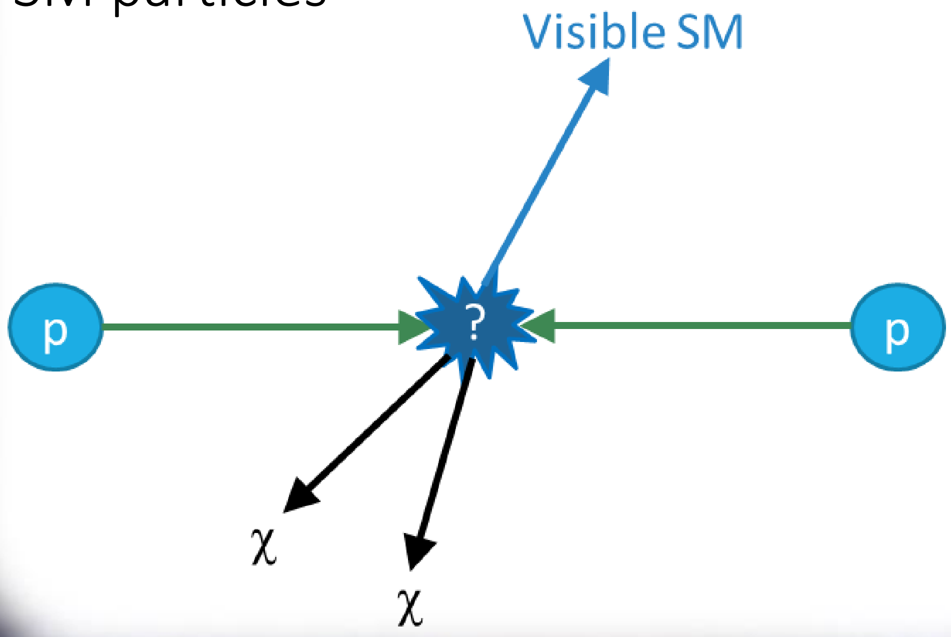
Beyond the Standard Model

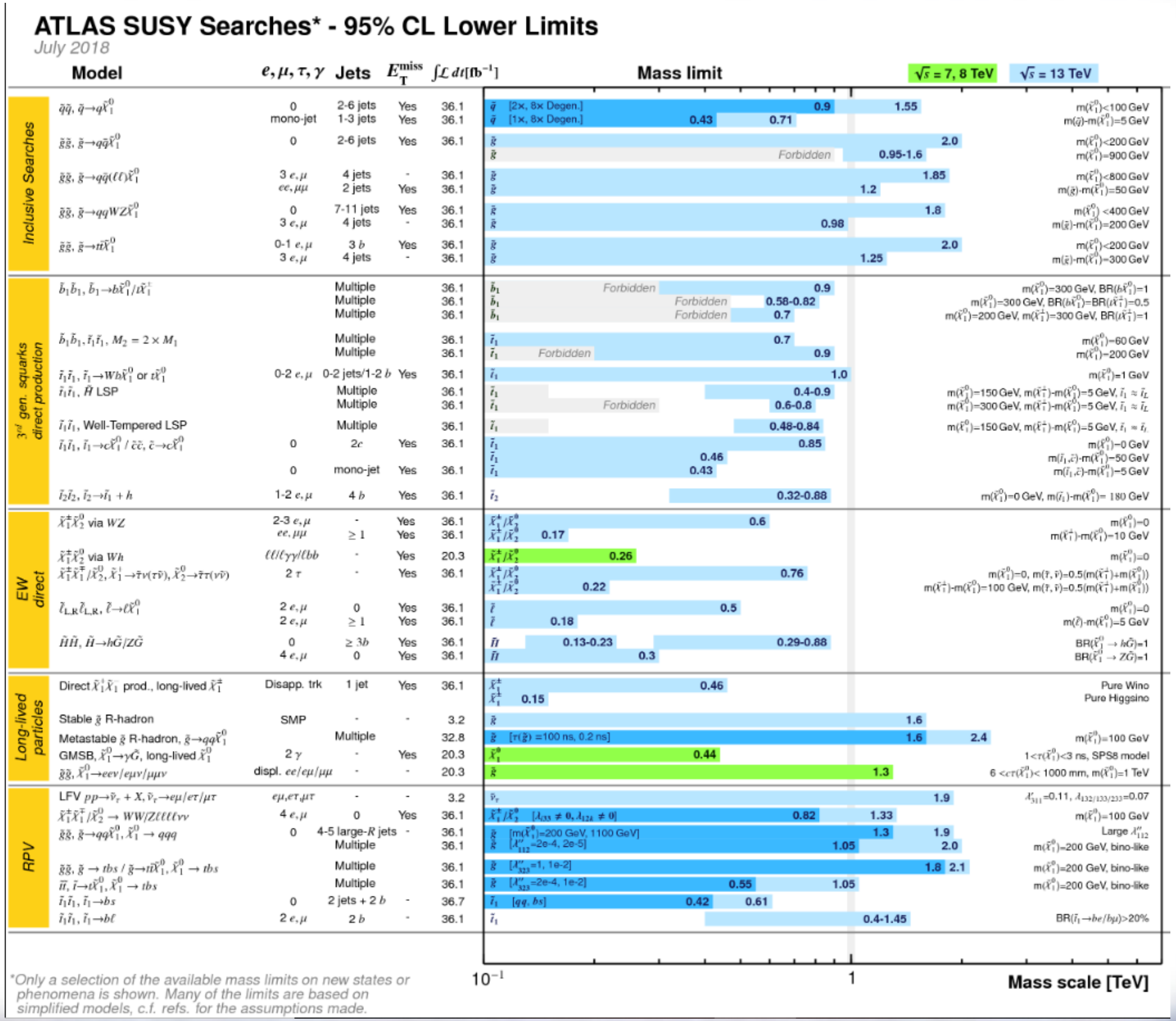




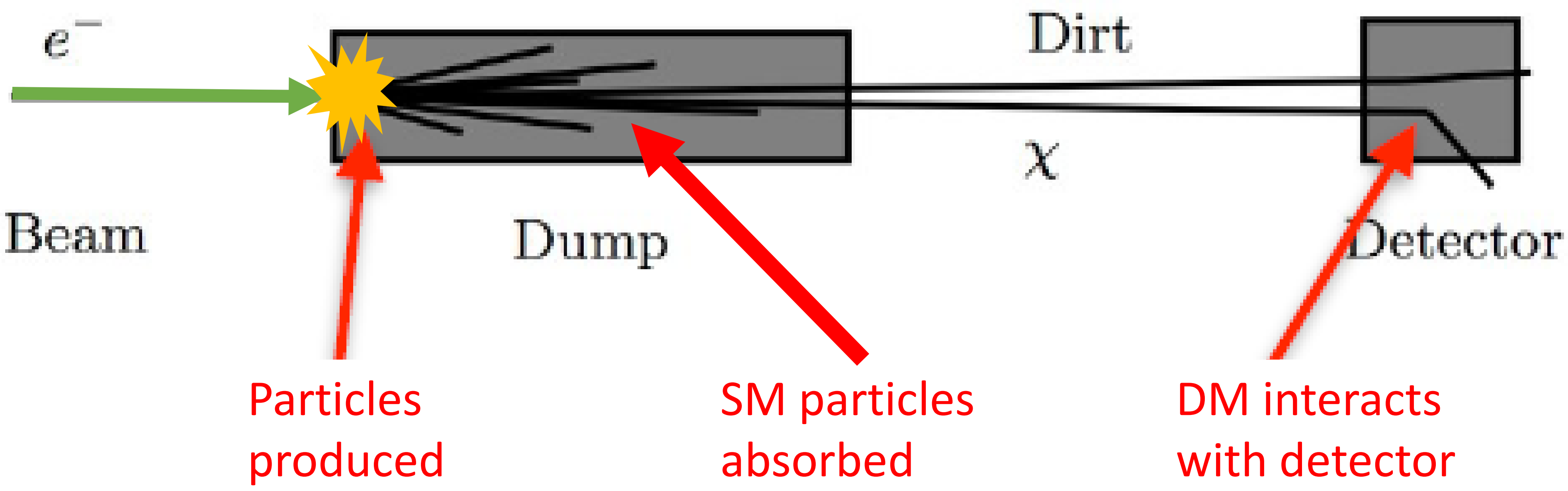

Collider Searches

- Most recent at Large Hadron Collider
- Often look for "missing transverse energy" carried off by WIMPs produced in association with visible SM particles





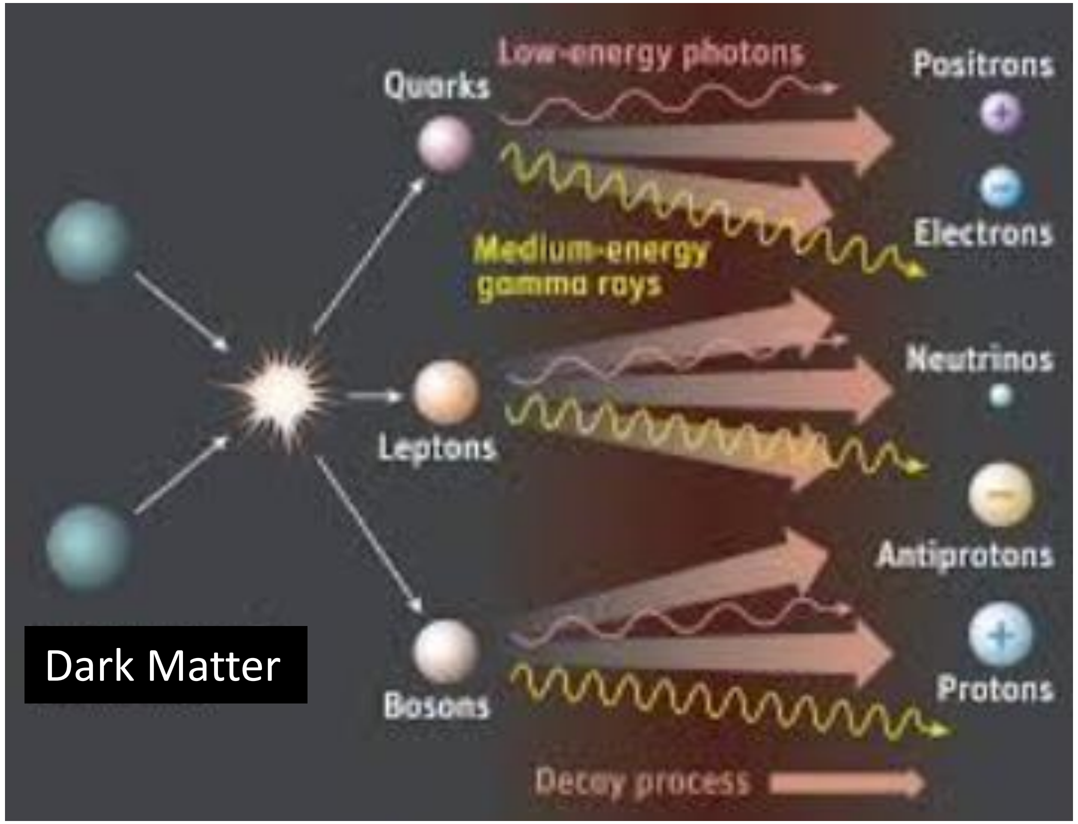
Fixed-Target Searches



When particle beam collides with fixed target, DM produced in association with visible SM particles

Only the DM reaches detector behind “beam dump” and dirt

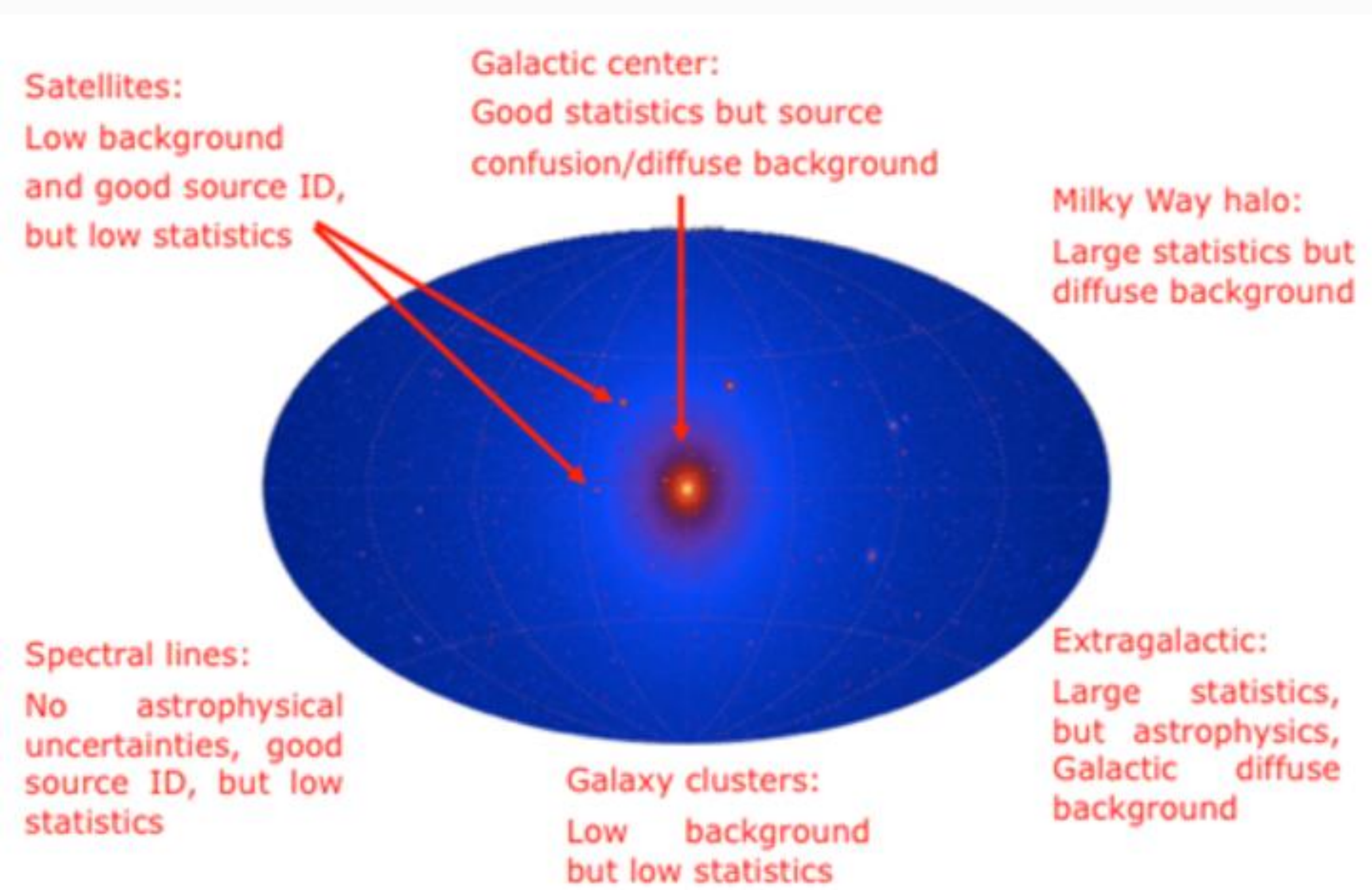
Indirect Detection



Collisions of WIMPs in outer space could produce SM particles that travel to Earth

“Signals” (e.g. excess photons of a certain frequency) detected by ground- or space-based telescopes

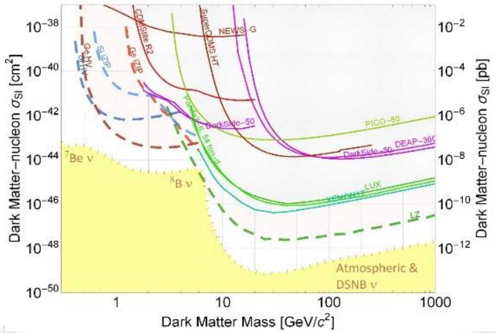
Indirect Detection

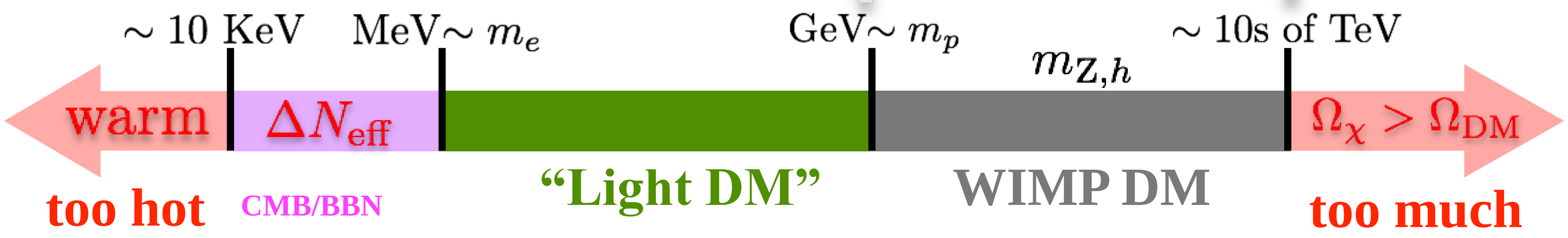


Expect some cosmic neighborhoods to have more DM than others

But some also give off more backgrounds

Lower-mass Thermal Relics?





- Thermal relic dark matter works fine at least down to 2 x $m_{electron}$
- But "light WIMP-like DM" requires new, comparably low-mass "dark mediators" (dark force carriers)

WIMP Miracle

"relic abundance" of DM particle χ

$$\Omega_\chi h^2 \simeq \frac{0.1\ \mathrm{pb} \cdot c}{\langle \sigma v \rangle}$$ *cross section*

$$\Omega_\chi h^2 \approx 0.1 \Longrightarrow \langle \sigma v \rangle \approx 3 \times 10^{-26}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$$

$$\langle \sigma v \rangle \propto \frac{m_\chi^2}{m_Z^4} \Longrightarrow m_\chi \approx 100\ \mathrm{GeV}$$

weak scale

"Weakly Interacting Massive Particles" (WIMPs)