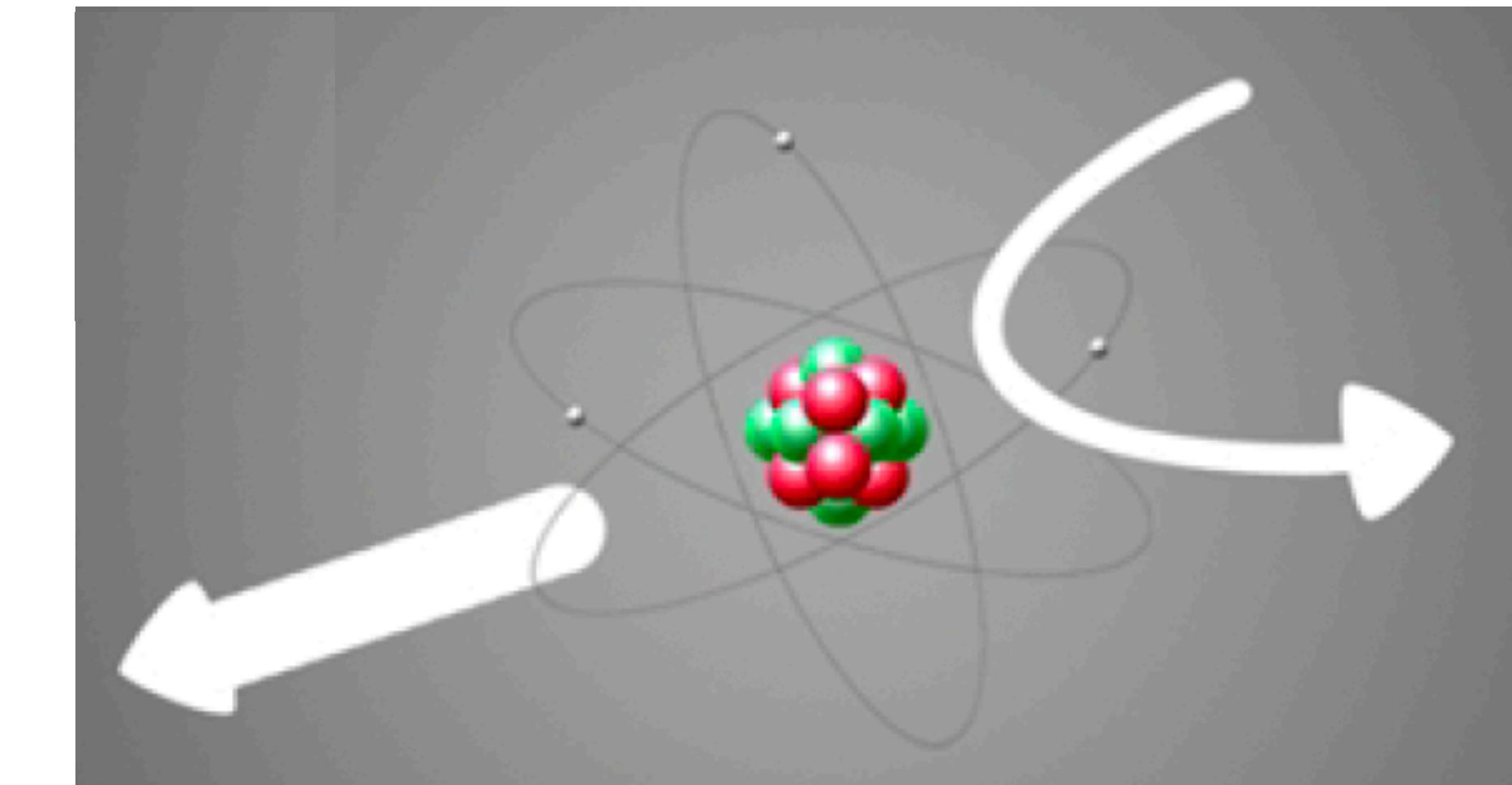
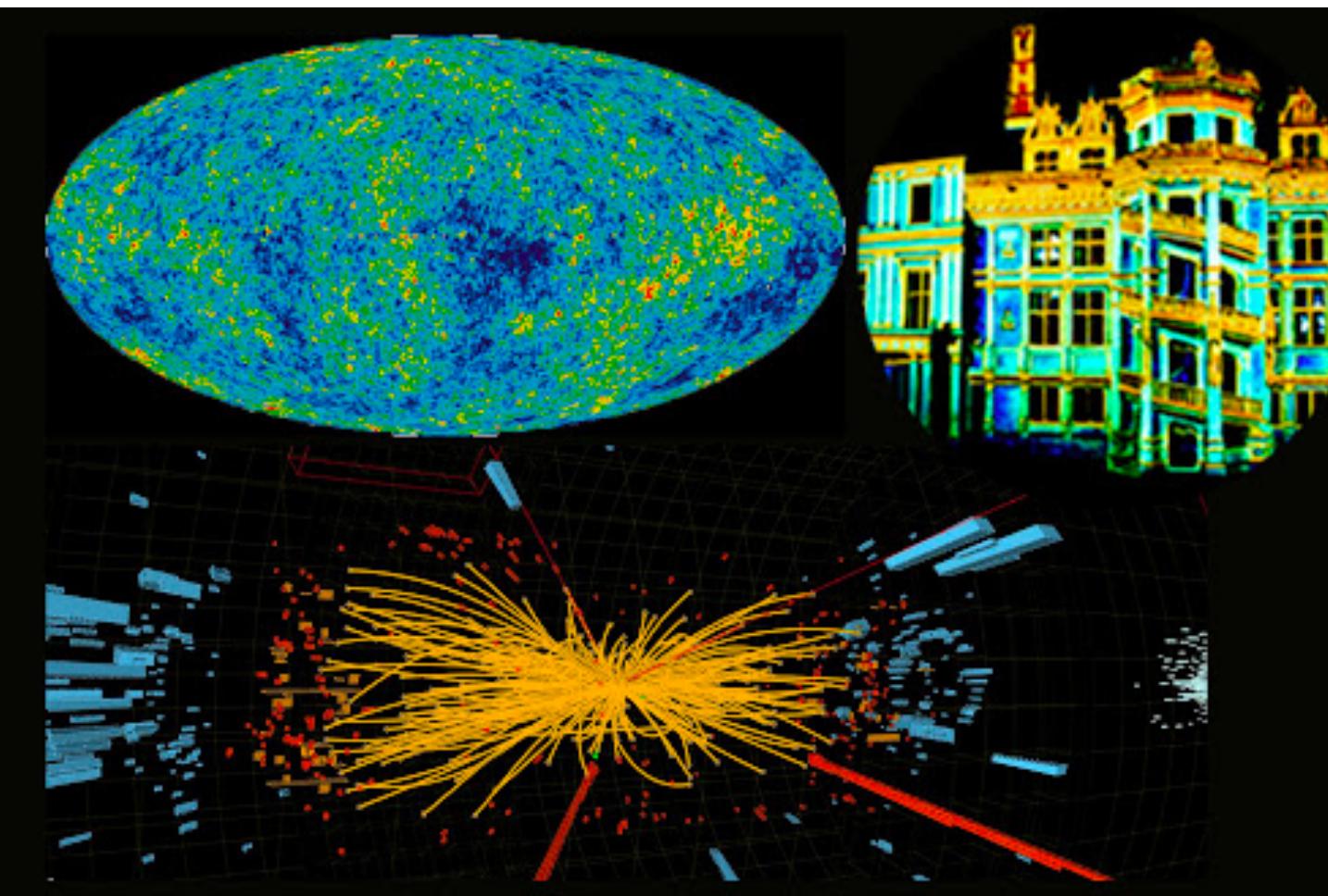


32nd Rencontres de Blois, France, 17. - 22. 10. 2021

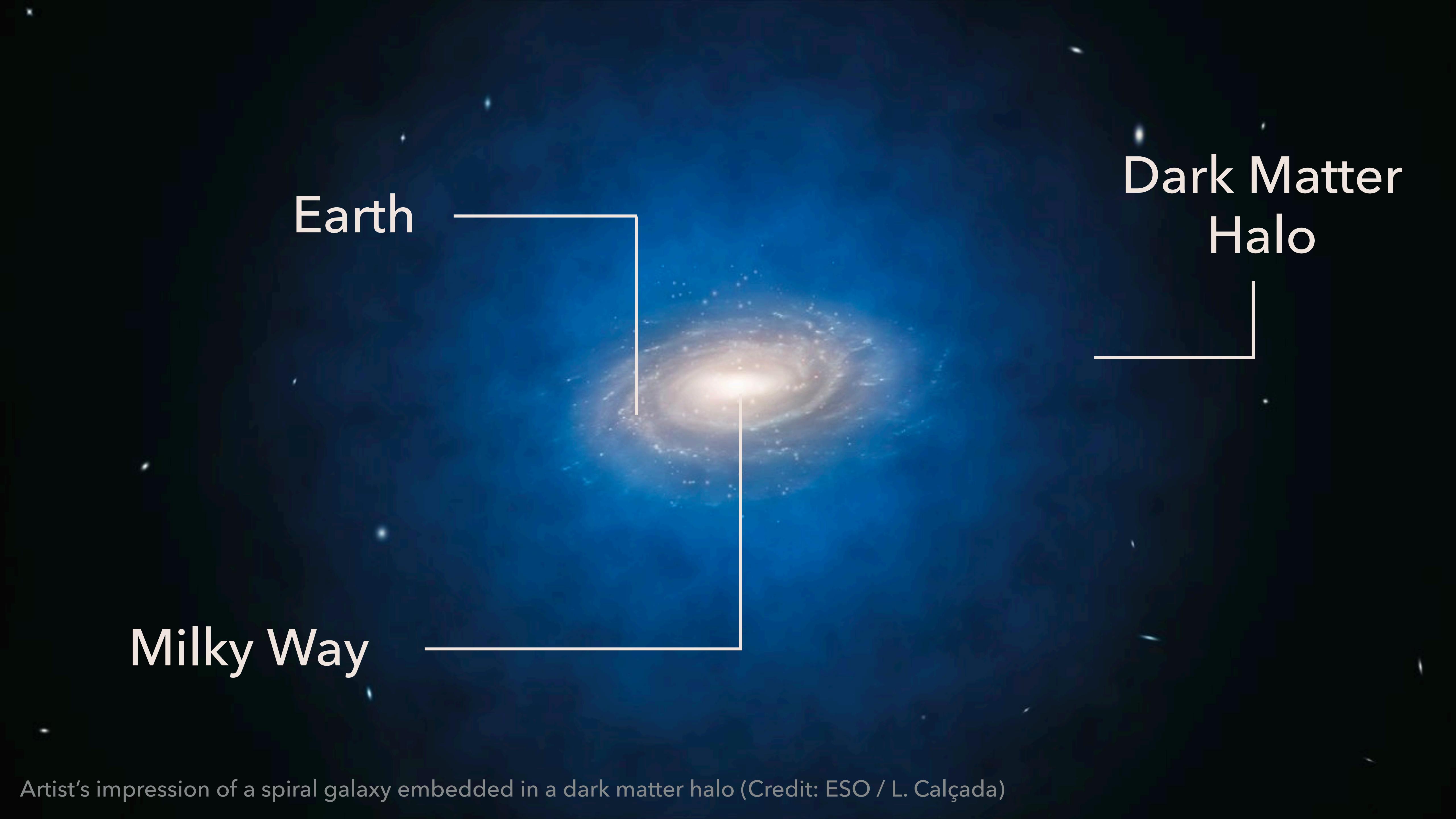
Belina von Krosigk (belina.von.krosigk@uni-hamburg.de)

DIRECT DARK MATTER SEARCHES



~ 85 %

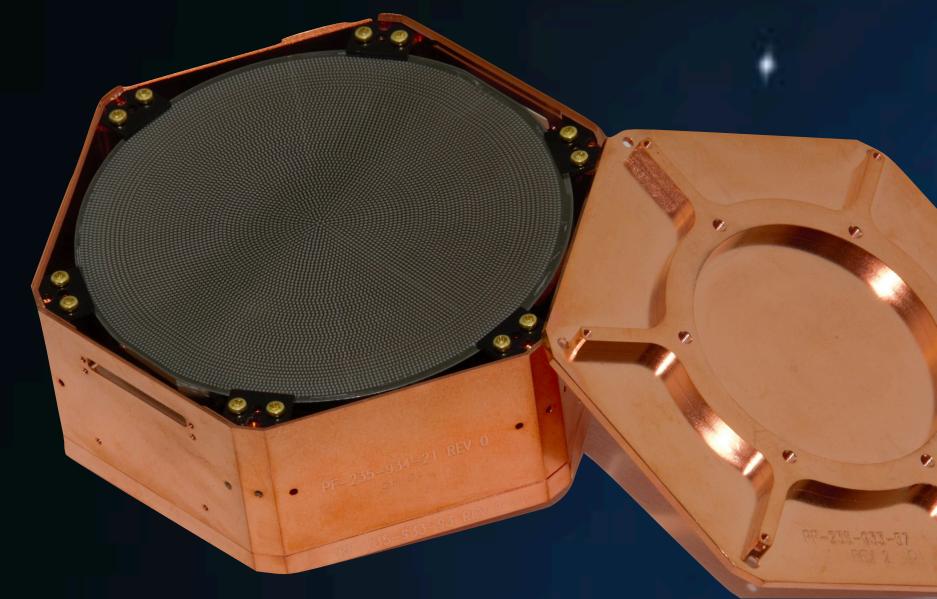
OF ALL MATTER IS DARK!



Earth

Dark Matter
Halo

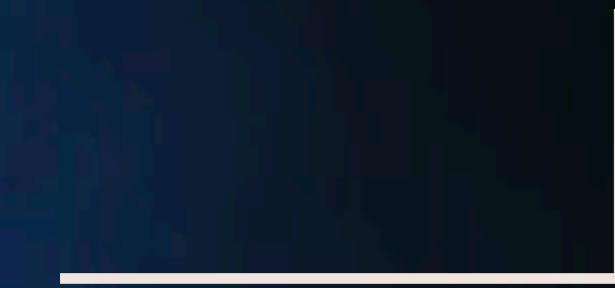
Milky Way



Milky Way

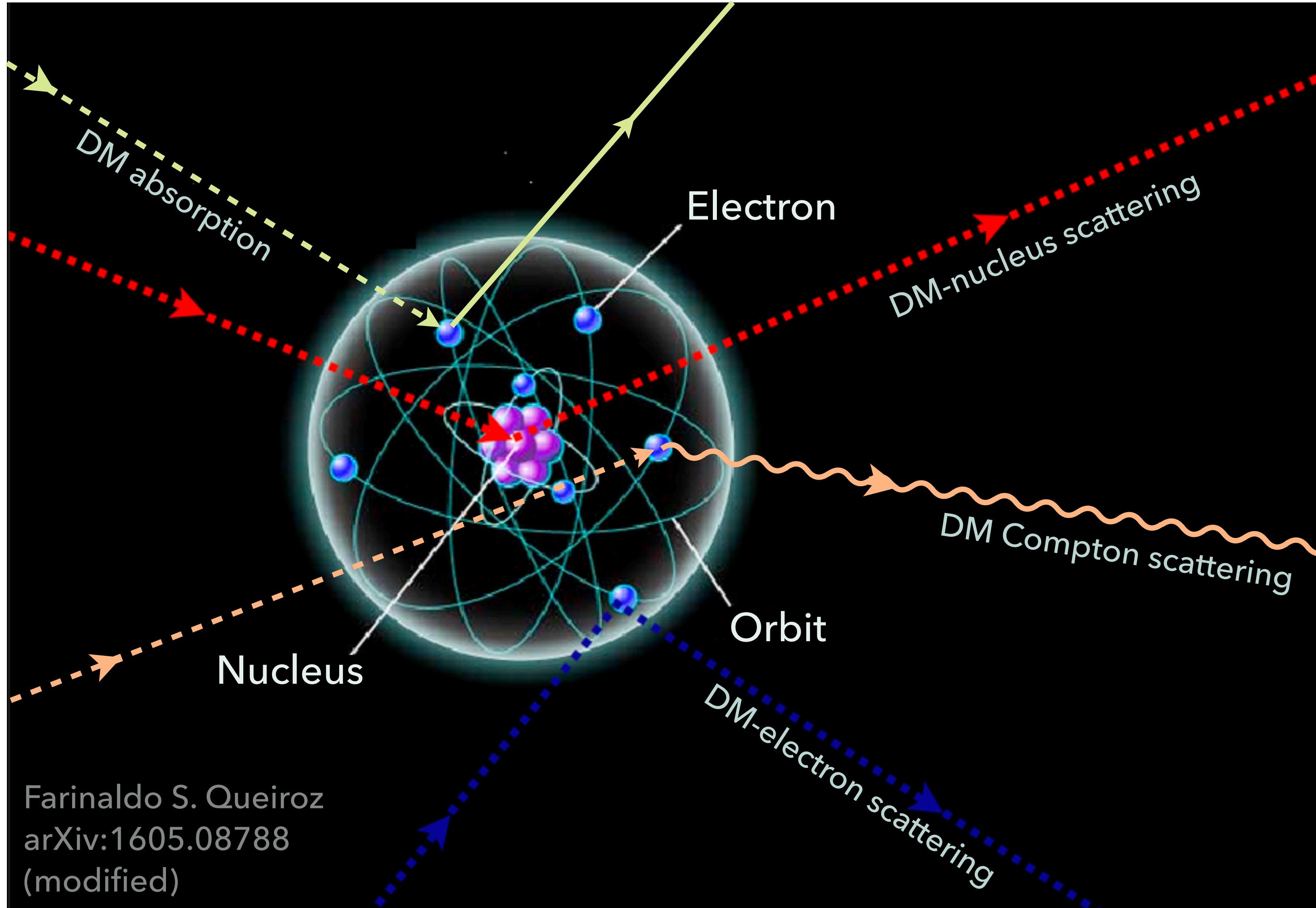


Dark Matter
Halo



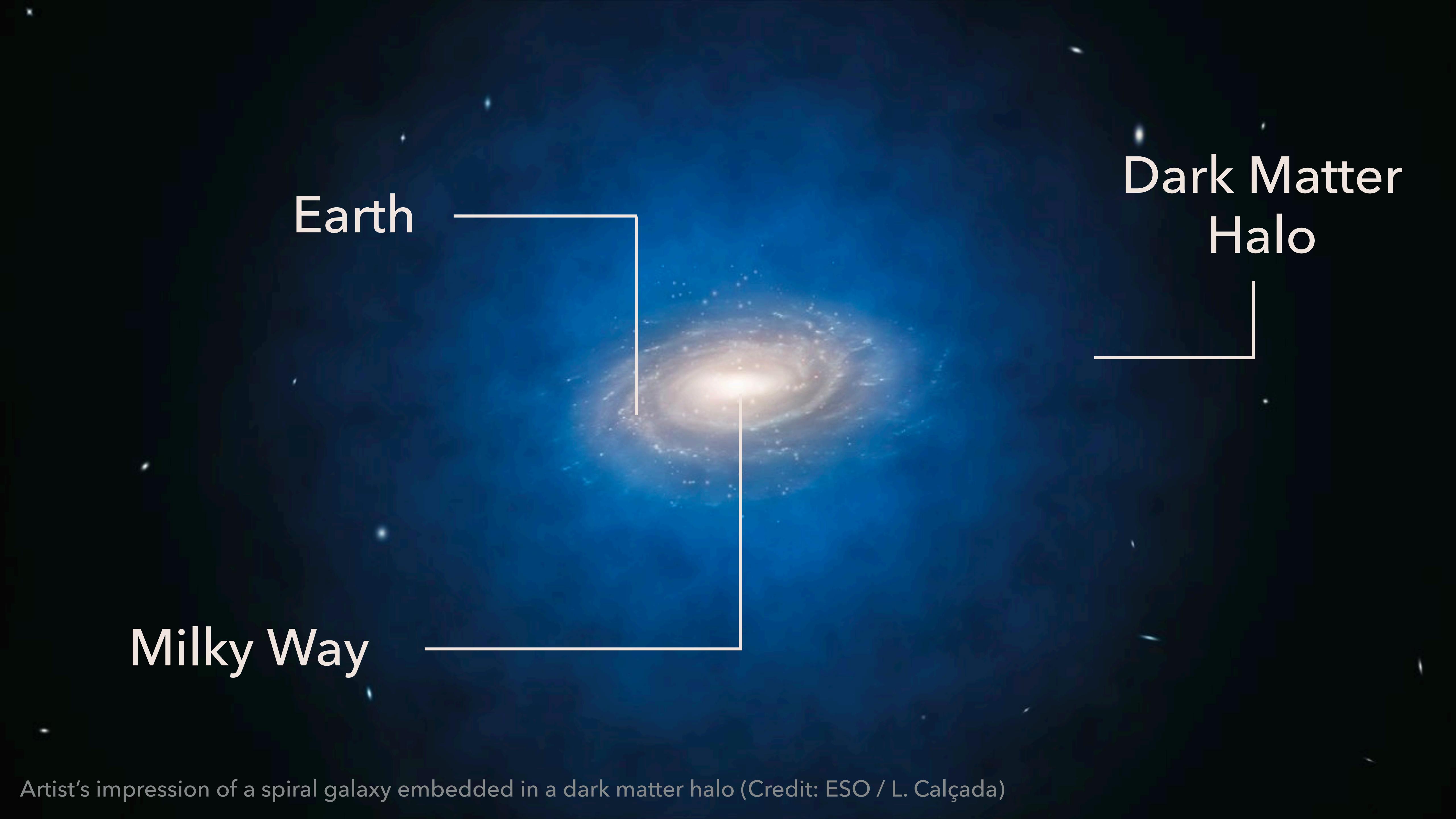
Artist's impression of a spiral galaxy embedded in a dark matter halo (Credit: ESO / L. Calçada)

DIRECT DARK MATTER DETECTION



Basic idea:

Dark Matter is made of particles which directly interact with the atoms of the detector material.

An artist's impression of a spiral galaxy against a dark background. The galaxy has a bright yellow-orange central bulge and two distinct blue spiral arms. A white rectangular bracket on the left side of the image encloses the central bulge and the start of the spiral arms, pointing towards the text 'Earth'. Another white rectangular bracket on the right side encloses the outer, darker regions of the galaxy, pointing towards the text 'Dark Matter Halo'.

Earth

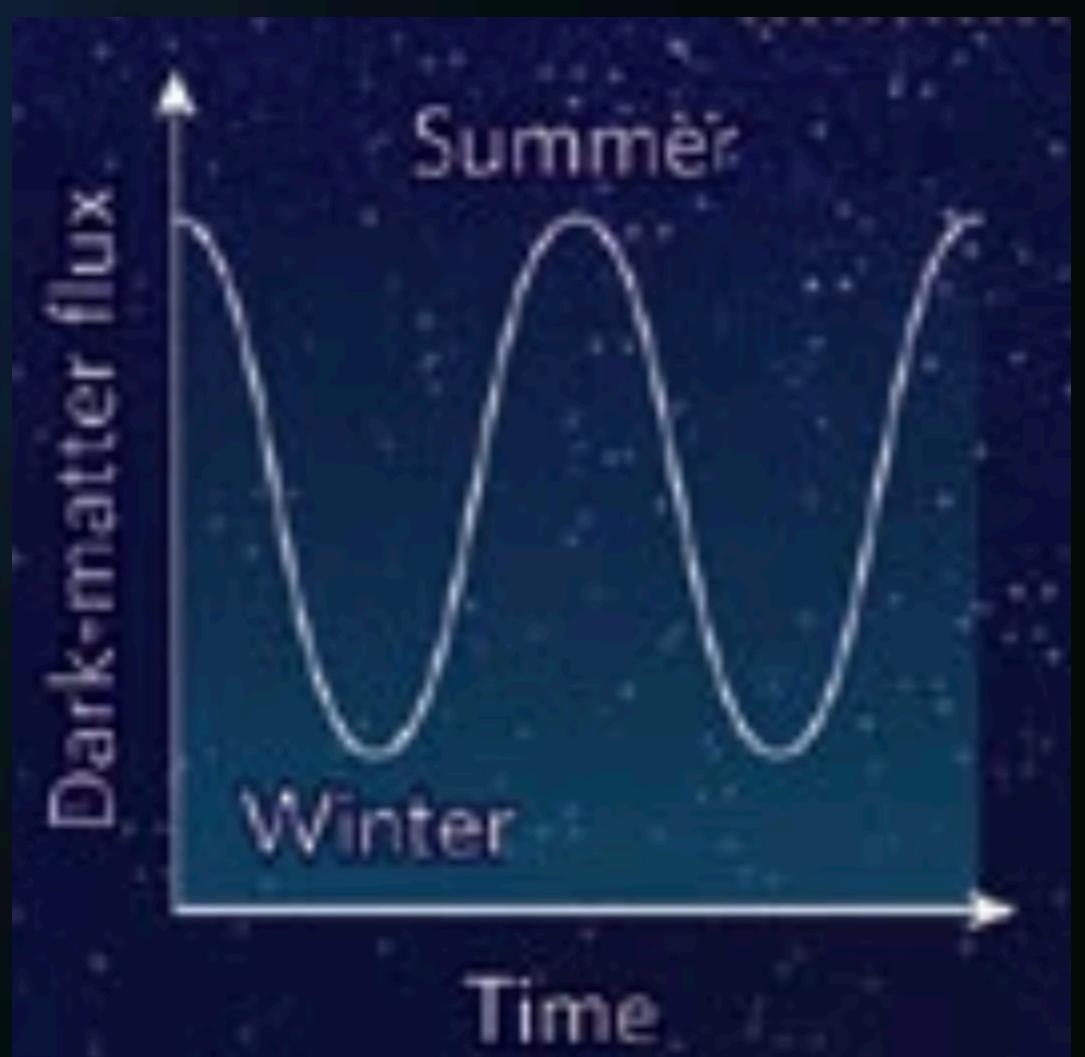
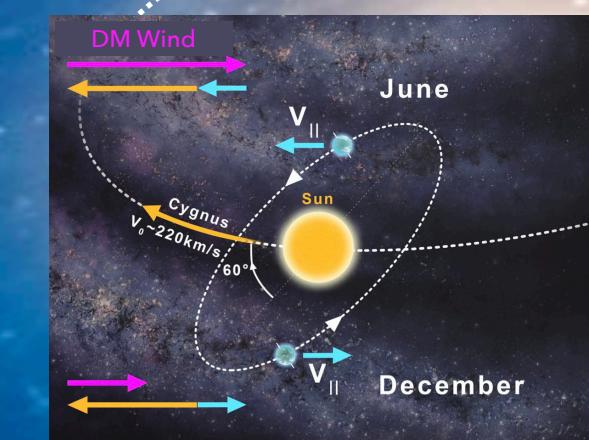
Milky Way

Dark Matter
Halo

Sun's
approx. Orbit

Dark Matter
Halo

Milky Way



DARK MATTER CANDIDATES

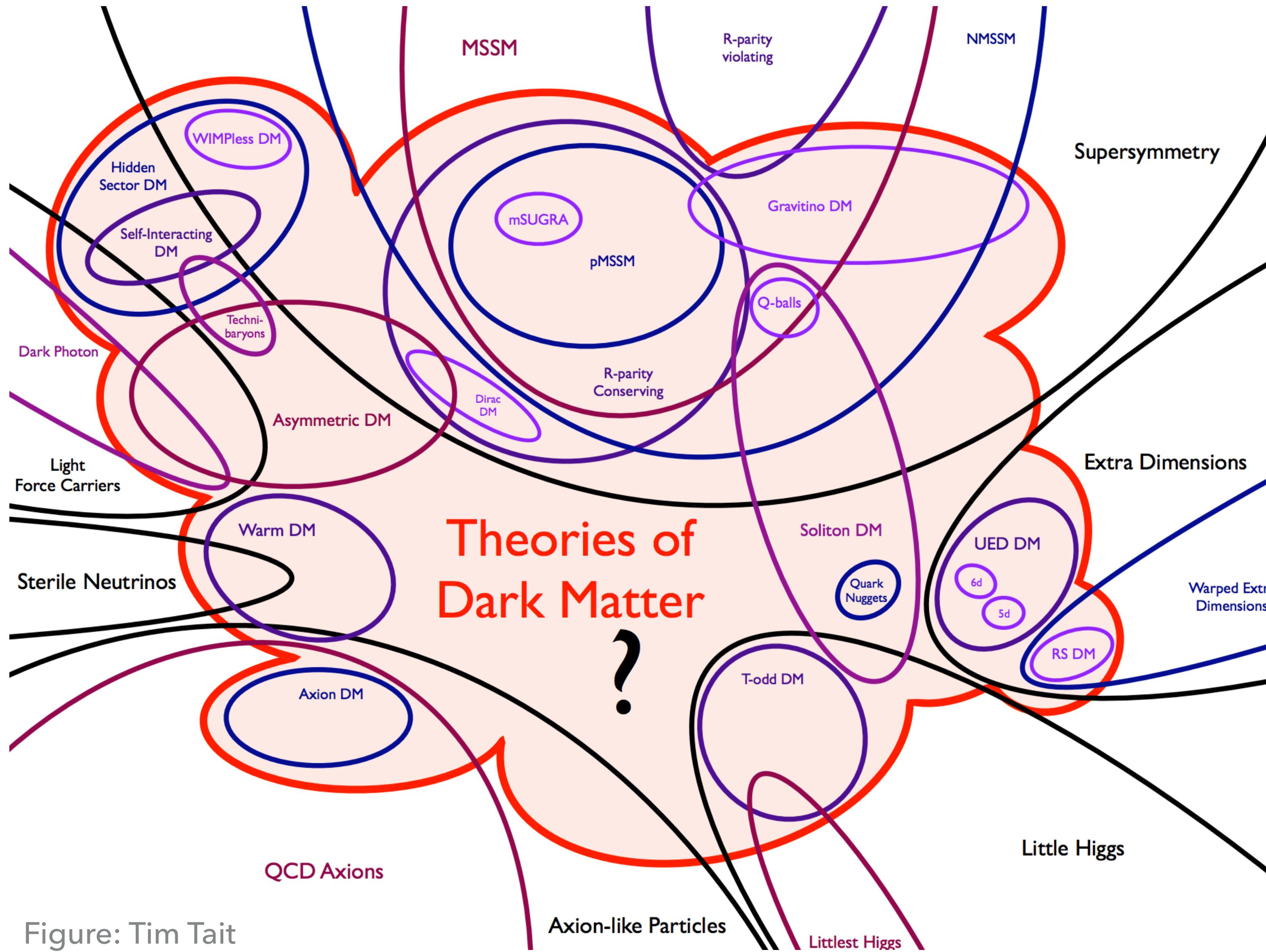
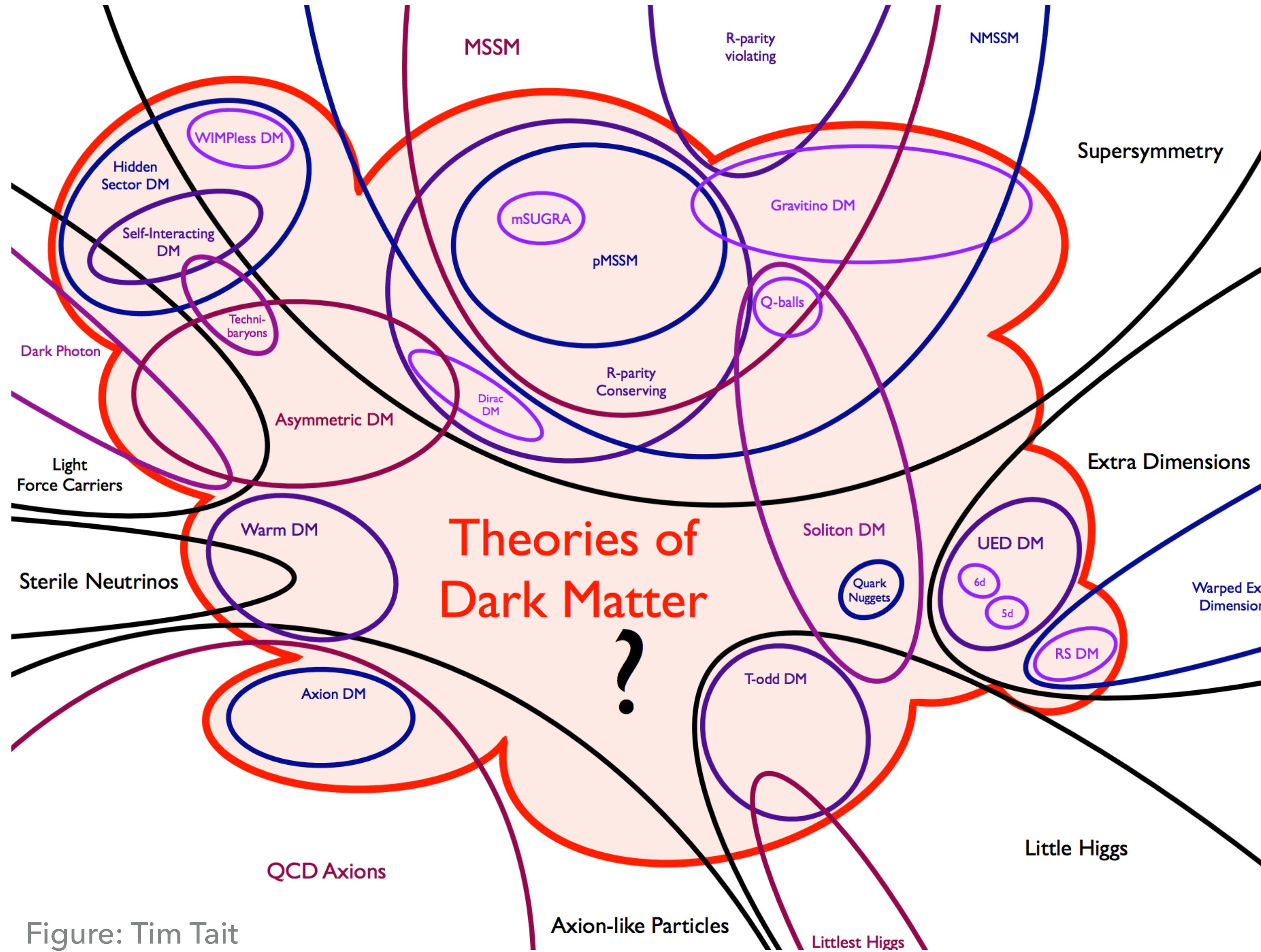


Figure: Tim Tait

DARK MATTER CANDIDATES



Direct searches primarily for

- ▶ WIMPs
- ▶ Light DM / Light WIMPs
- ▶ Axions and Axion-like Particles
- ▶ Dark Photons

Figure: Tim Tait

DARK MATTER CANDIDATES

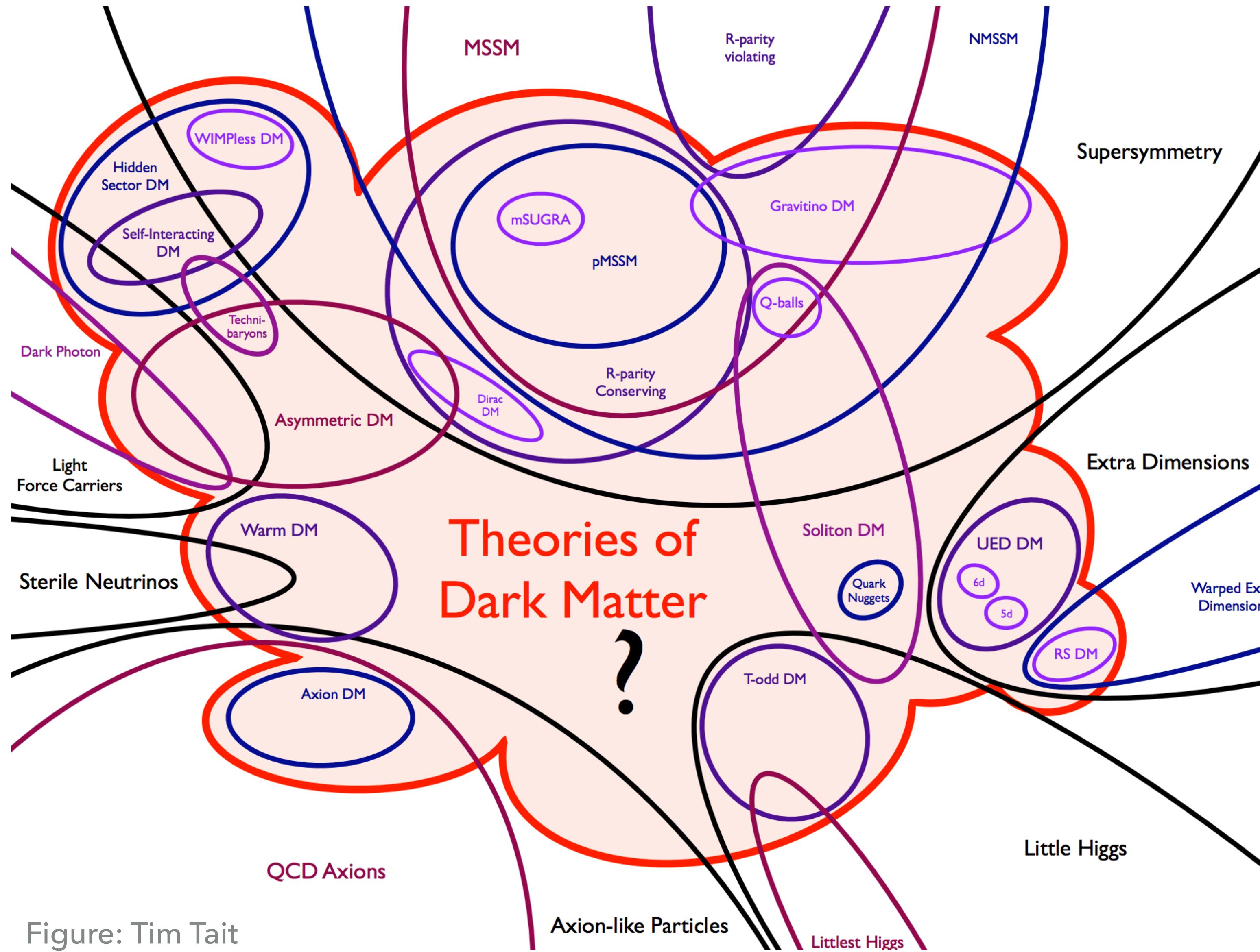


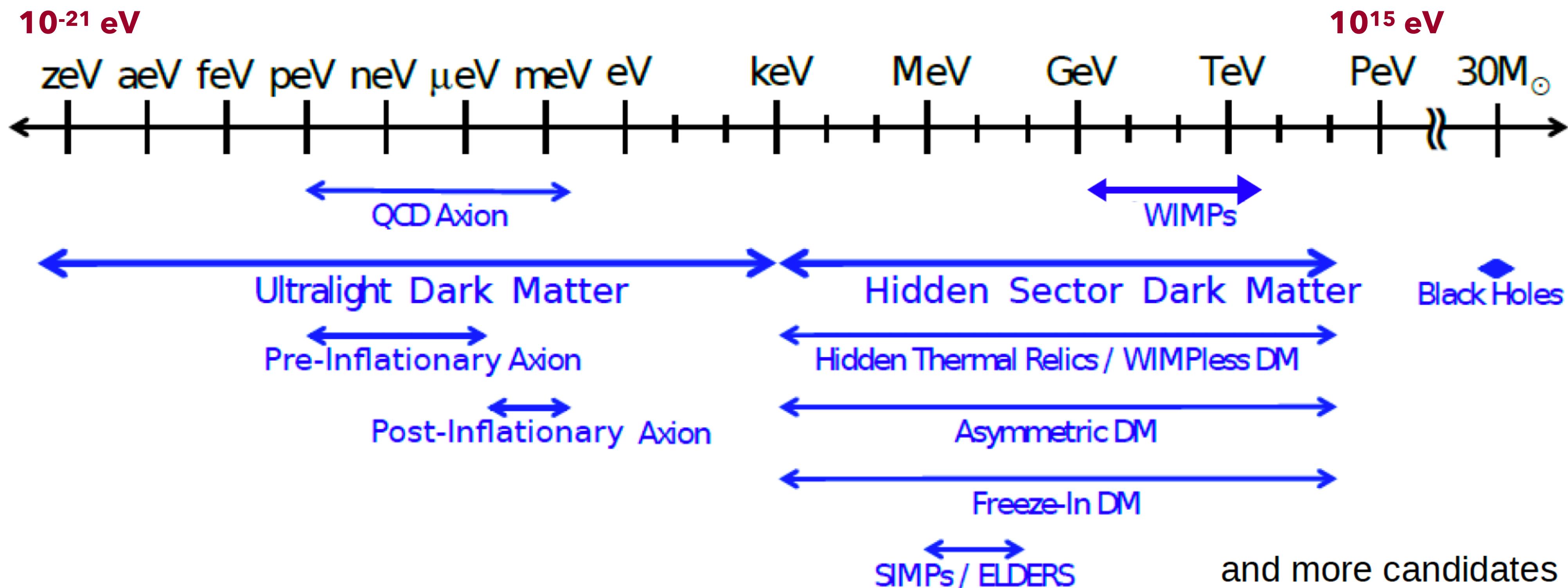
Figure: Tim Tait

- Direct searches primarily for**
- ▶ WIMPs
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 - ▶ Dark Photons

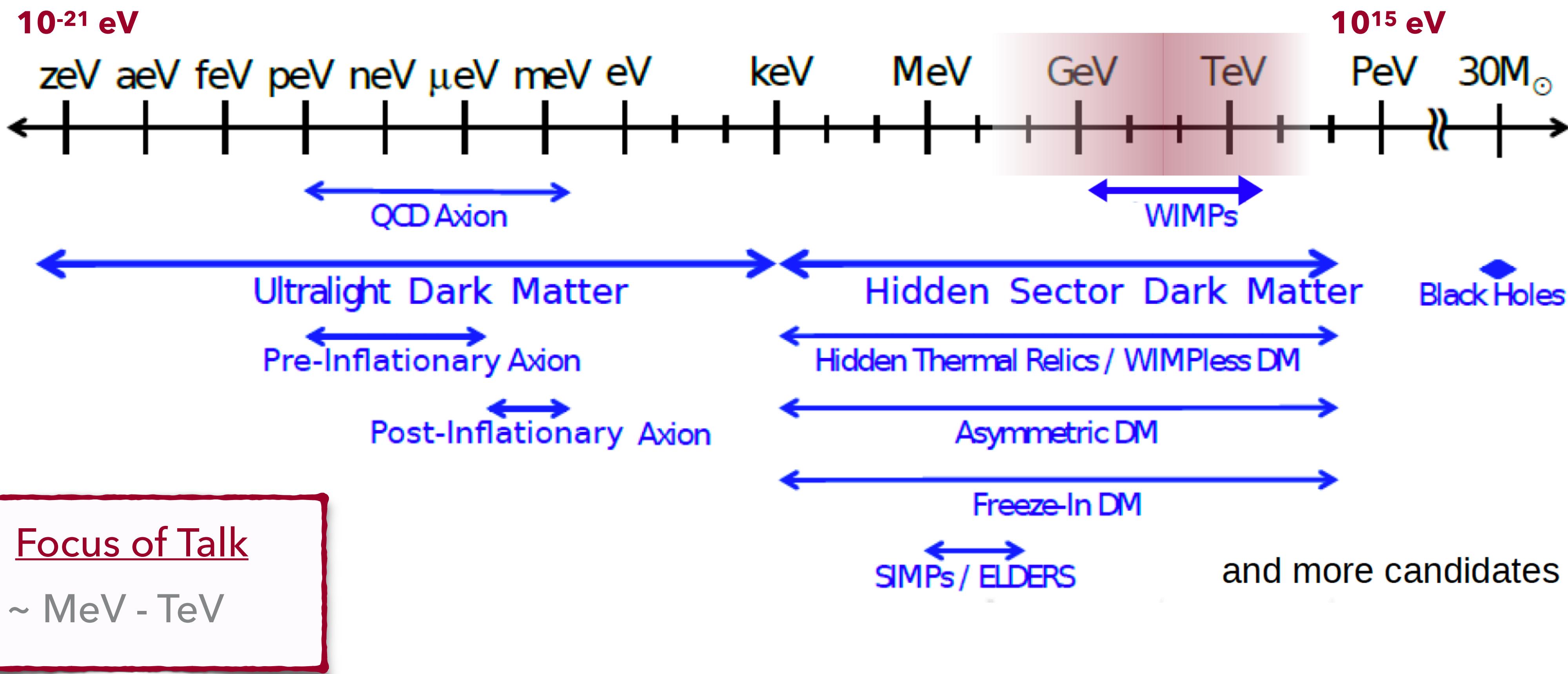
Focus of Talk

WIMPs

DARK MATTER MASSES



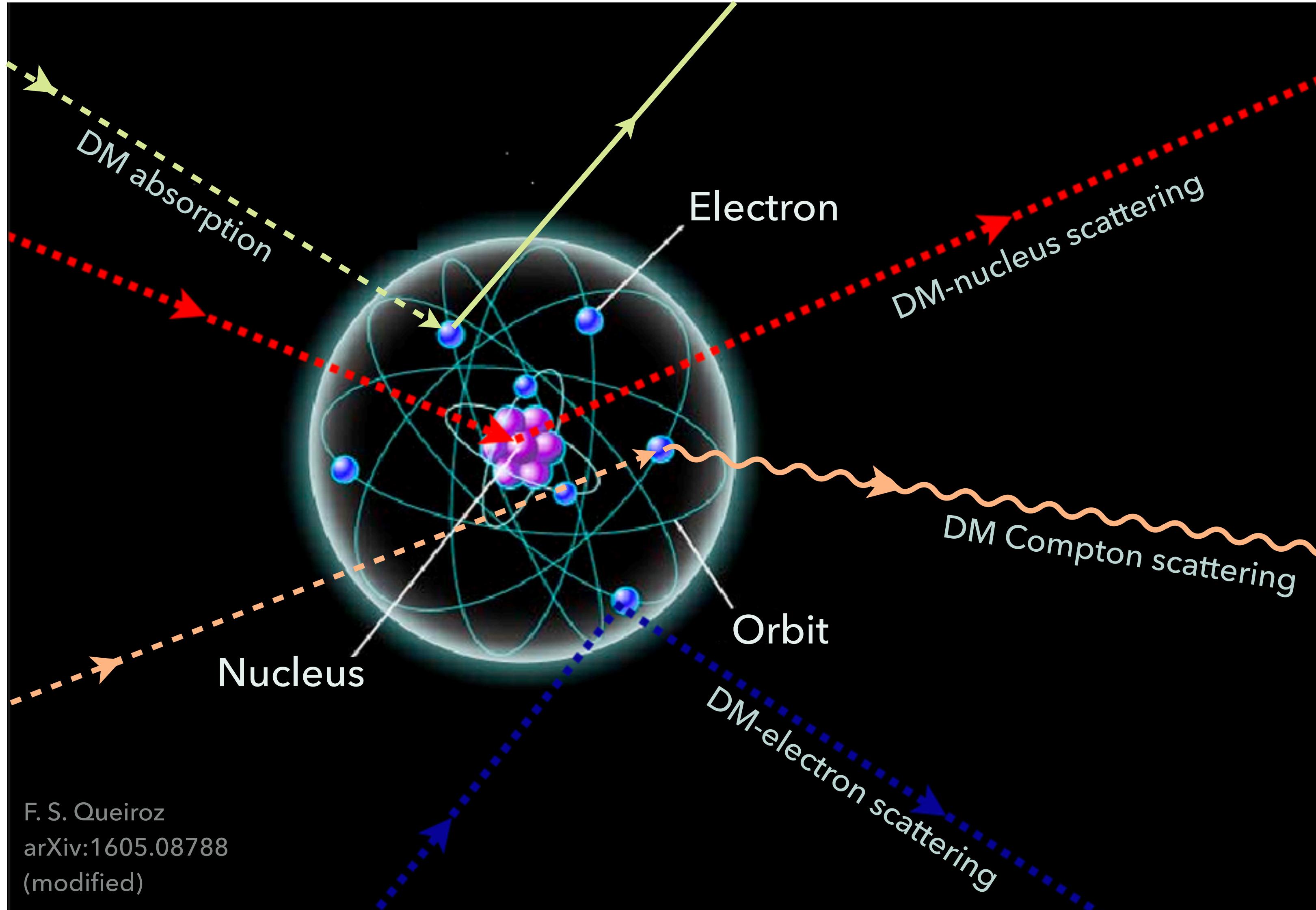
DARK MATTER MASSES



DIRECT DARK MATTER DETECTION

Basic principles

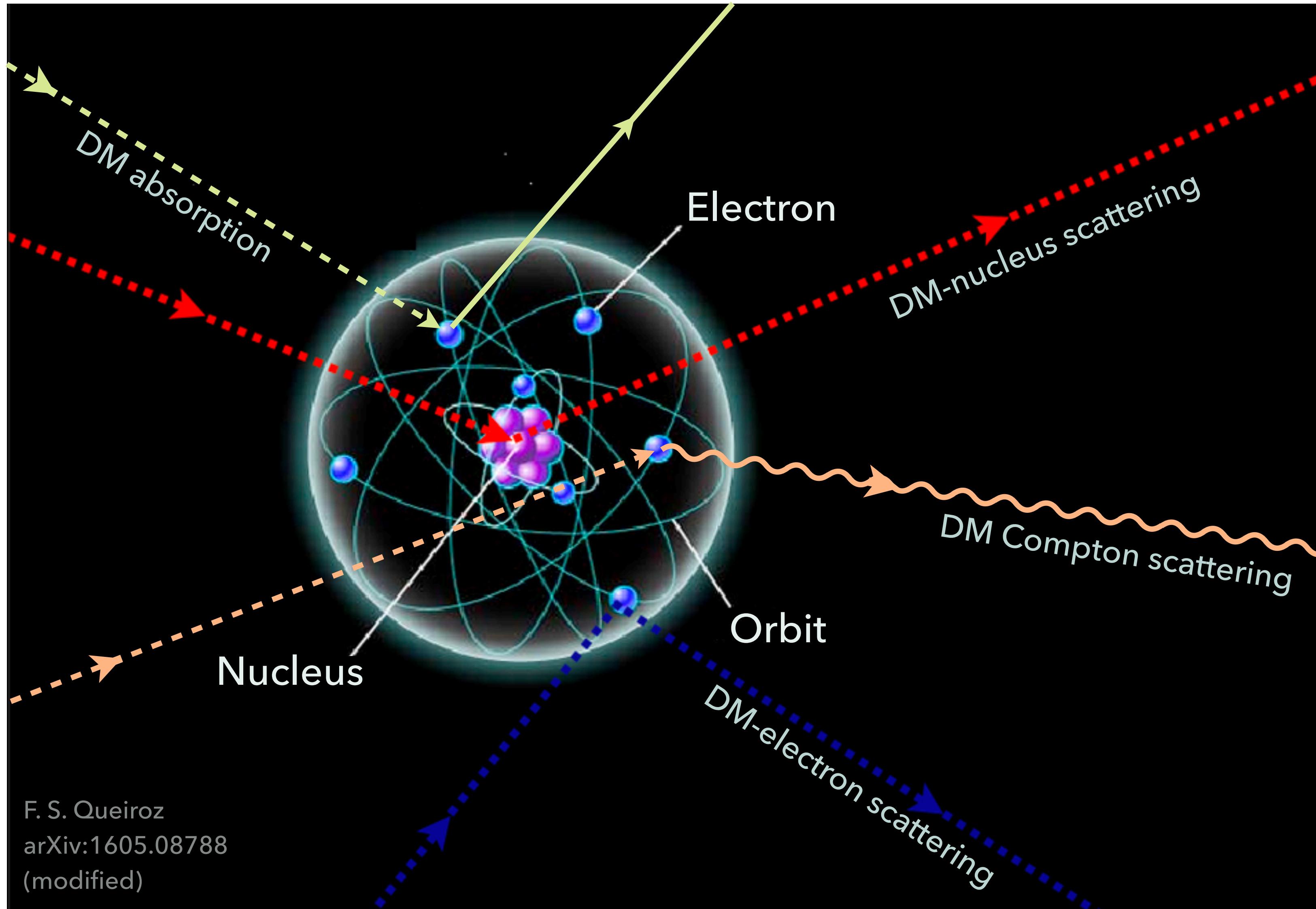
DIRECT DARK MATTER DETECTION



Signatures in detector:

- ▶ Nuclear Recoil (NR)
- ▶ Electron Recoil (ER)

DIRECT DARK MATTER DETECTION



Signatures in detector:

- ▶ Nuclear Recoil (NR)
- ▶ Electron Recoil (ER)

Focus of Talk
WIMP-nucleus
scattering

WIMP-NUCLEUS SCATTERING

Expected
interaction
rate

$$\frac{dR}{dE_R}$$

Particle
theory

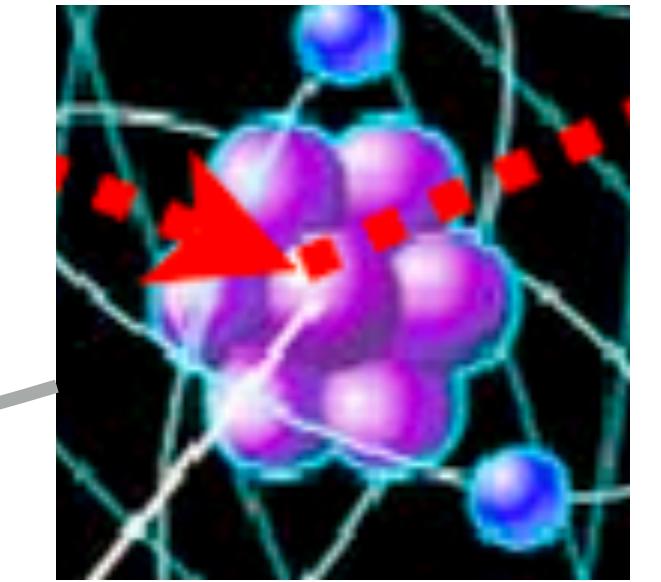
$$\frac{\sigma_n}{m_{\text{DM}}}$$

Local
properties of
DM halo

$$\frac{\rho_{\text{DM}} T(E_R)}{v_{\text{DM}} \sqrt{\pi}}$$

Nuclear
structure

$$\frac{F^2(E_R)}{\mu_n^2}$$



F. S. Queiroz
arXiv:1605.08788



Credit: ESO / L. Calçada

WIMP-NUCLEUS SCATTERING

Expected interaction rate

$$\frac{dR}{dE_R}$$

Particle theory

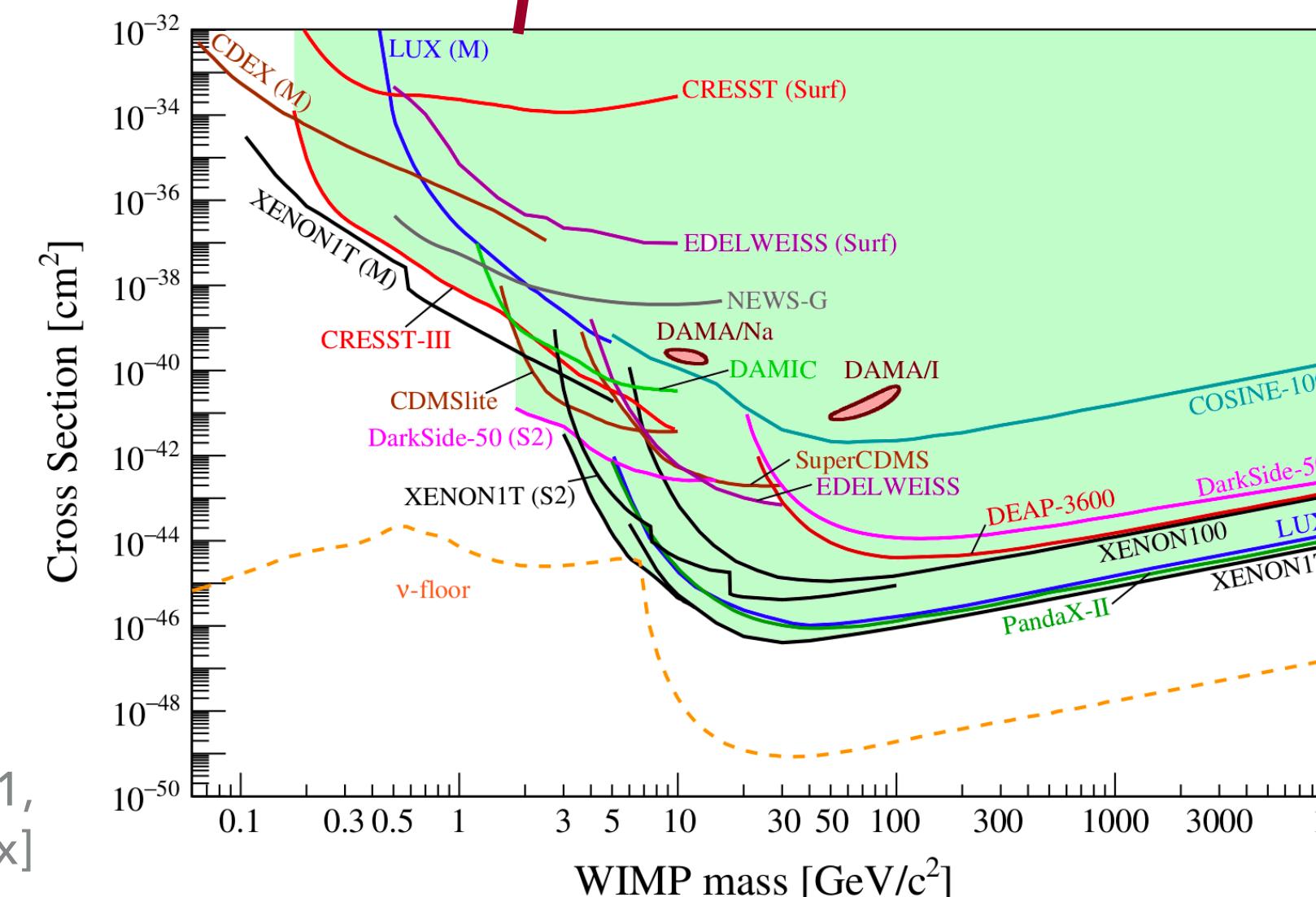
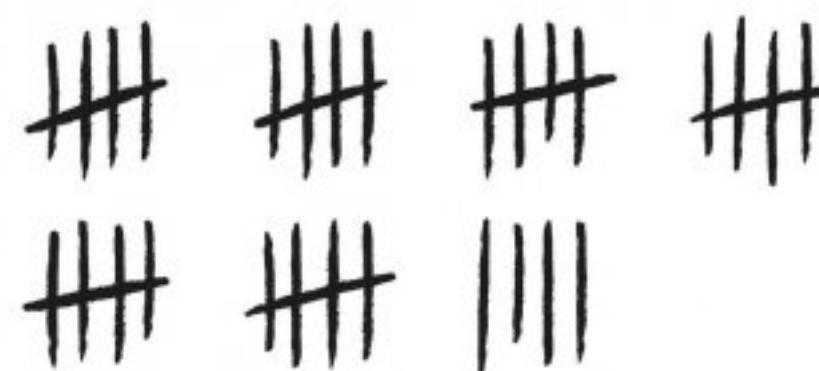
$$\frac{\sigma_0}{m_{\text{DM}}}$$

Local properties of DM halo

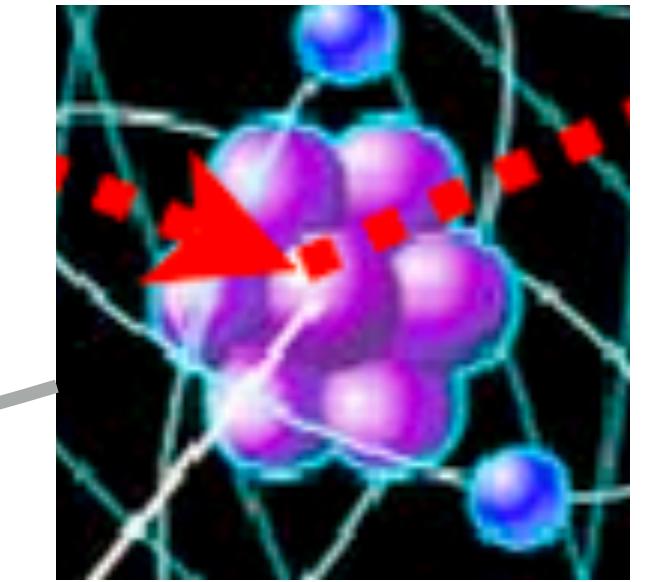
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APPEC Committee Report 2021,
arXiv:2104.07634 [hep-ex]



F. S. Queiroz
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WIMP-NUCLEUS SCATTERING

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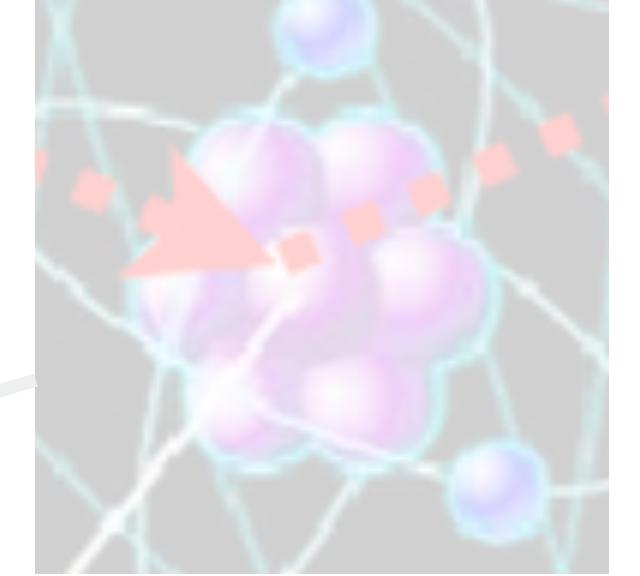
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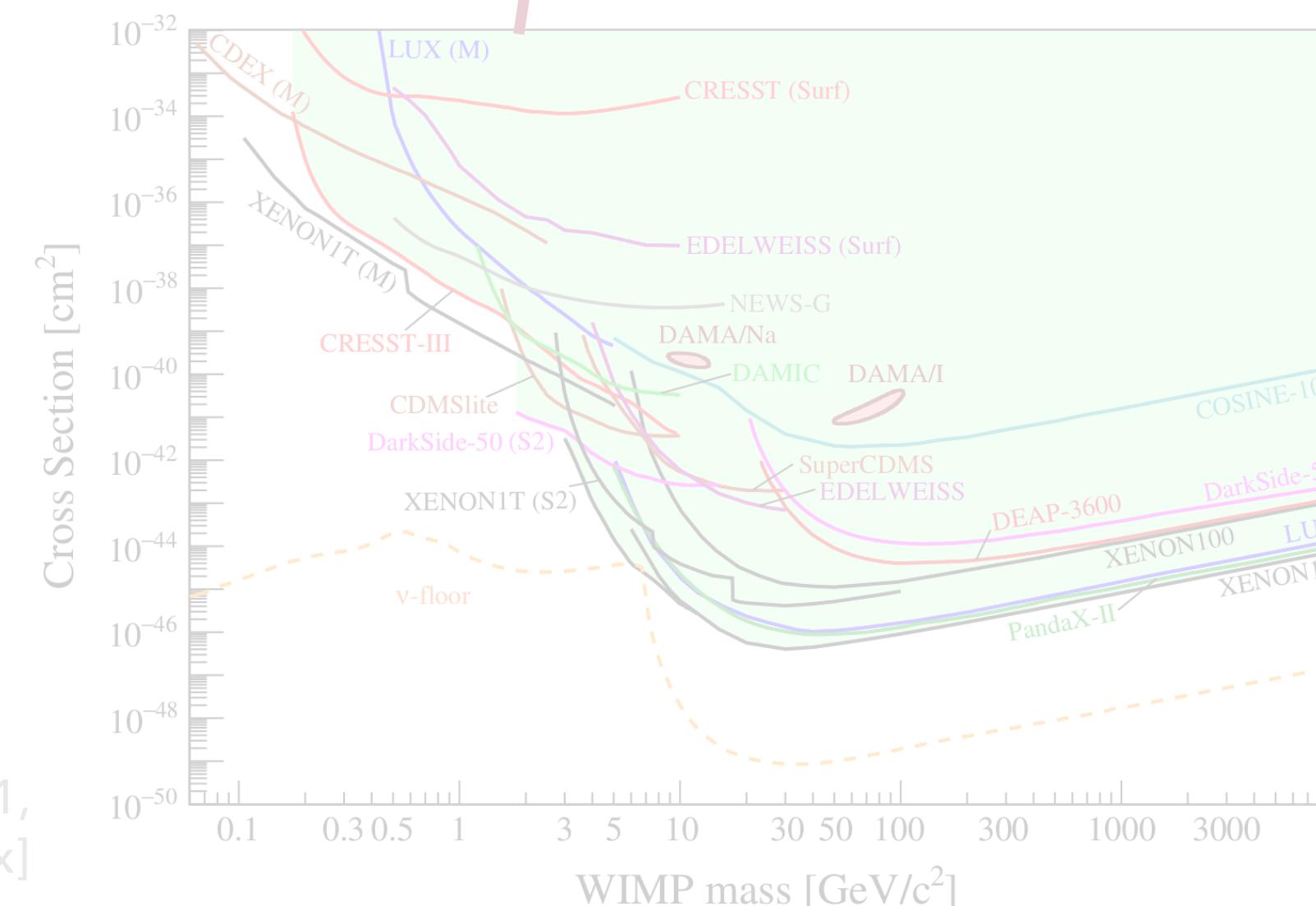
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F. S. Queiroz
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WIMP-NUCLEUS SCATTERING CROSS SECTION

Spin-independent (SI) scattering

$$\sigma_{\text{SI}} \propto \frac{\mu^2}{m_{\text{DM}}^2} \left[Zf_p + (A - Z)f_n \right]^2 \propto A^2$$

scalar couplings to n and p

Nuclei with large mass number A favorable.

Spin-dependent (SD) scattering

$$\sigma_{\text{SD}} \propto \mu^2 \frac{J_N + 1}{J_N} \left[a_p \langle S_p \rangle + a_n \langle S_n \rangle \right]^2$$

expectation values of n, p spins within nucleus

effective couplings to n and p

Nuclei with non-zero angular momentum required.

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Focus of Talk

SI scattering

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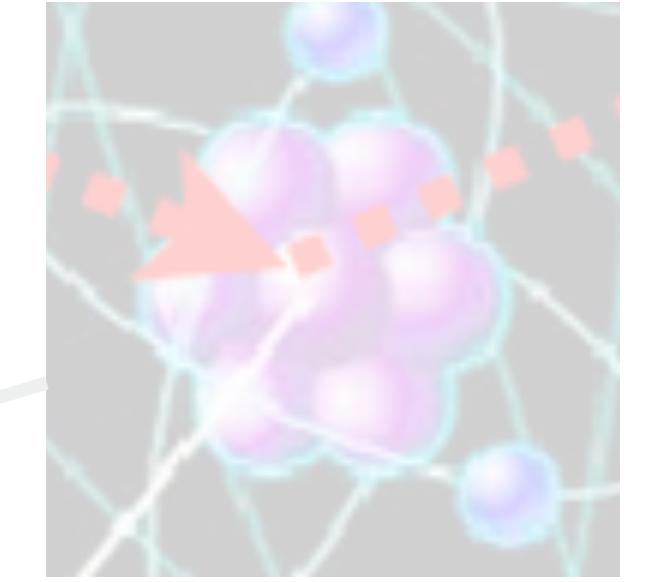
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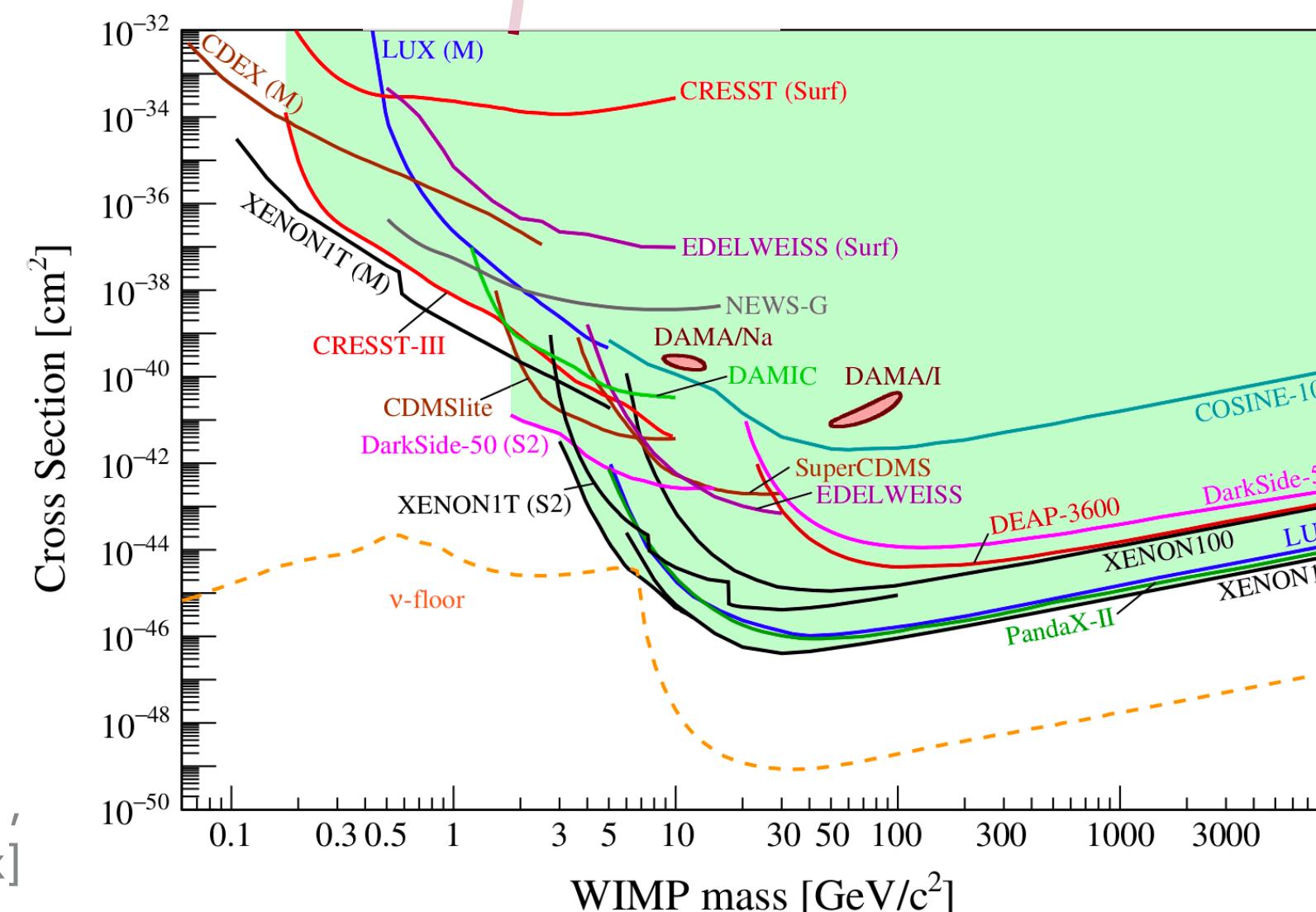
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F. S. Queiroz
arXiv:1605.08788



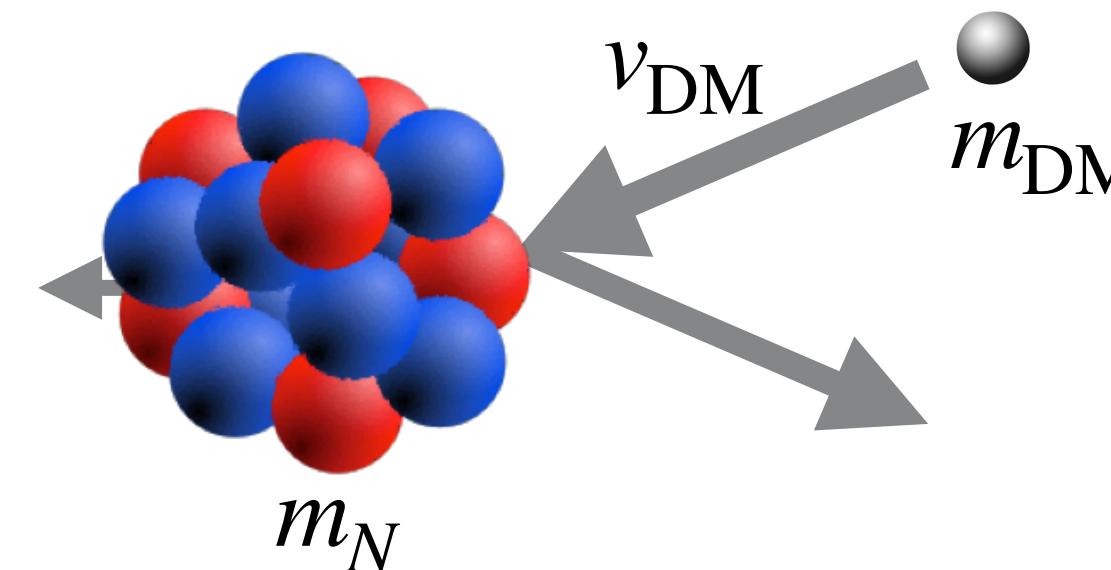
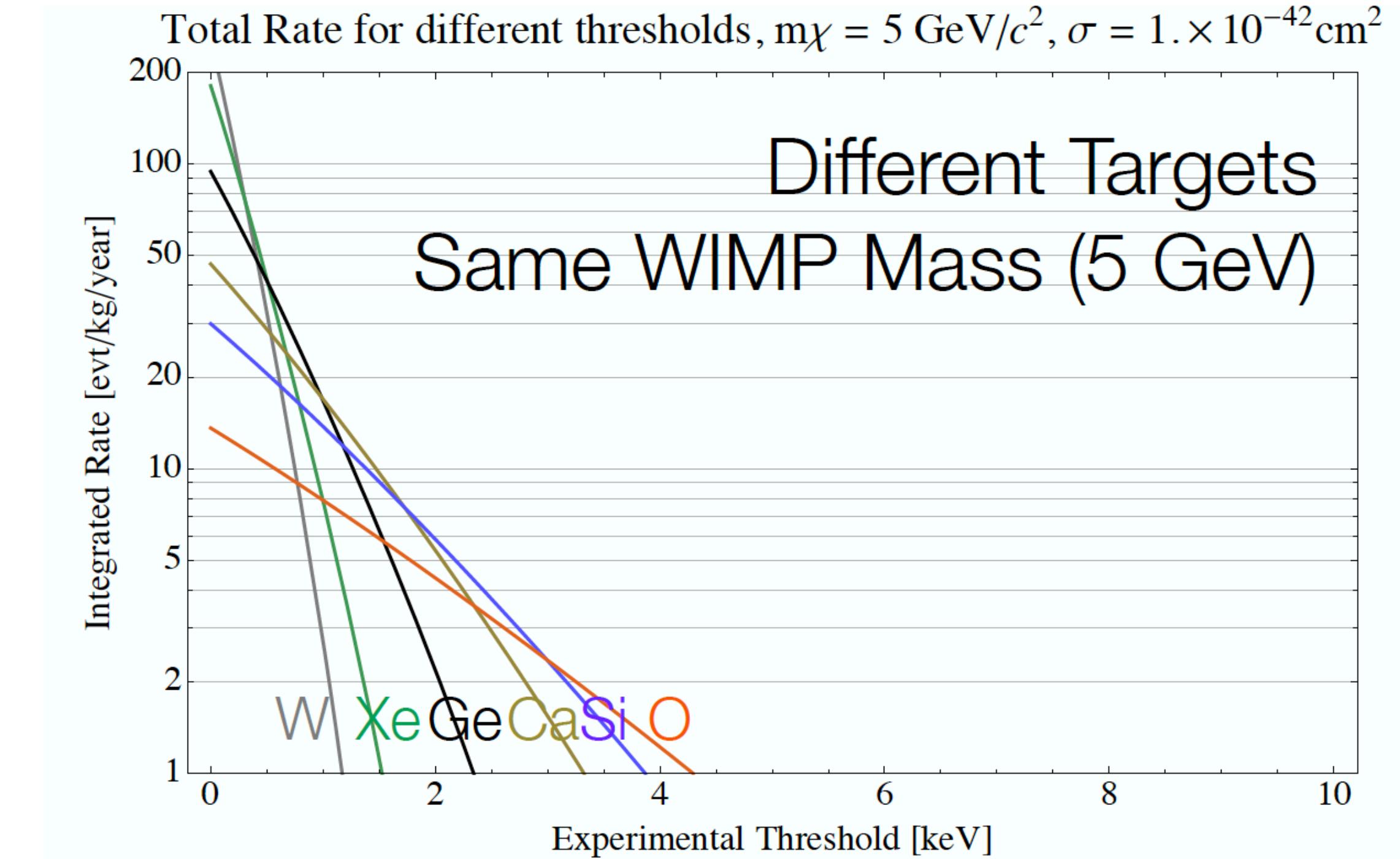
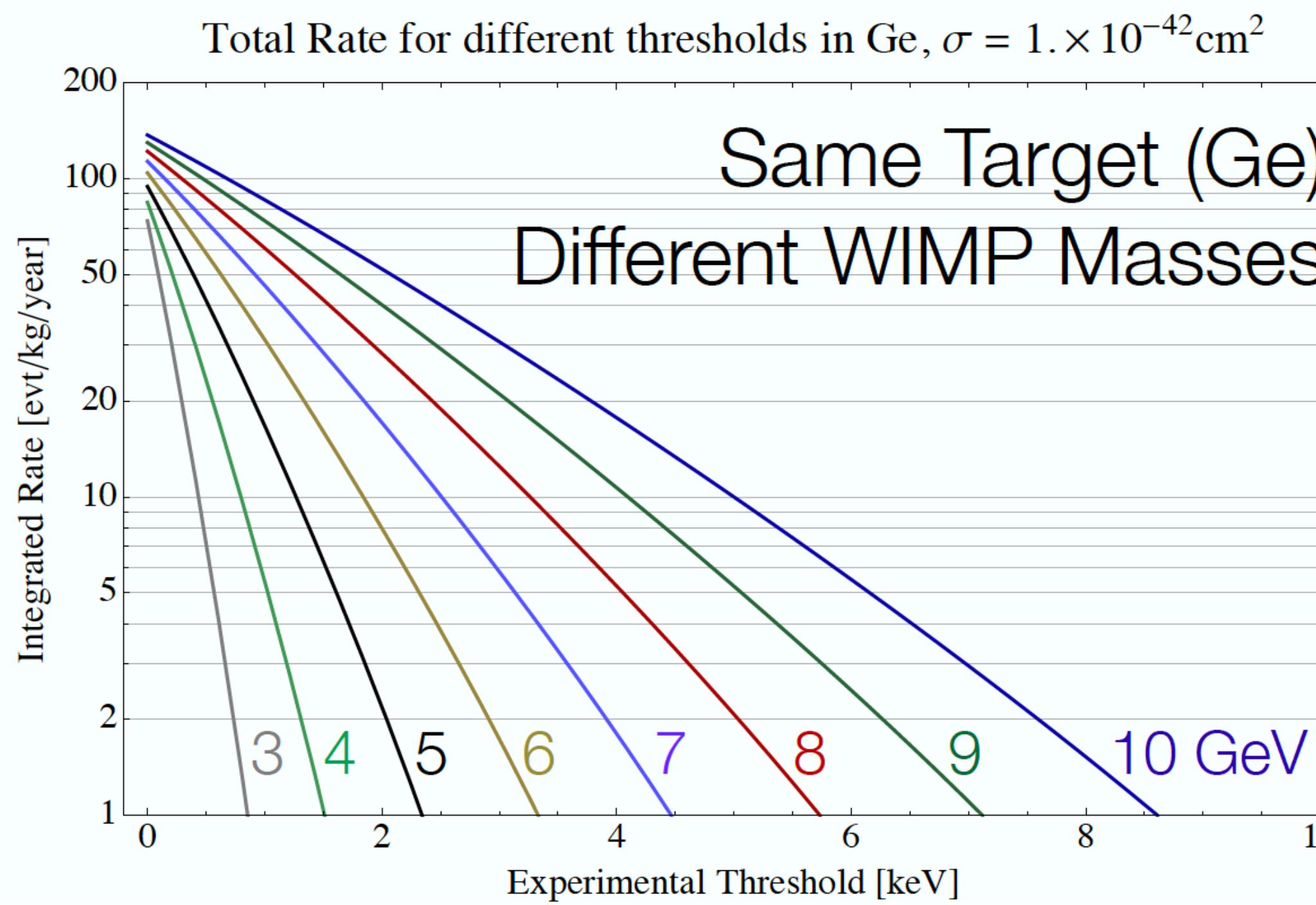
APPEC Committee Report 2021,
arXiv:2104.07634 [hep-ex]



Credit: ESO / L. Calçada

WIMP-NUCLEUS SCATTERING SENSITIVITY

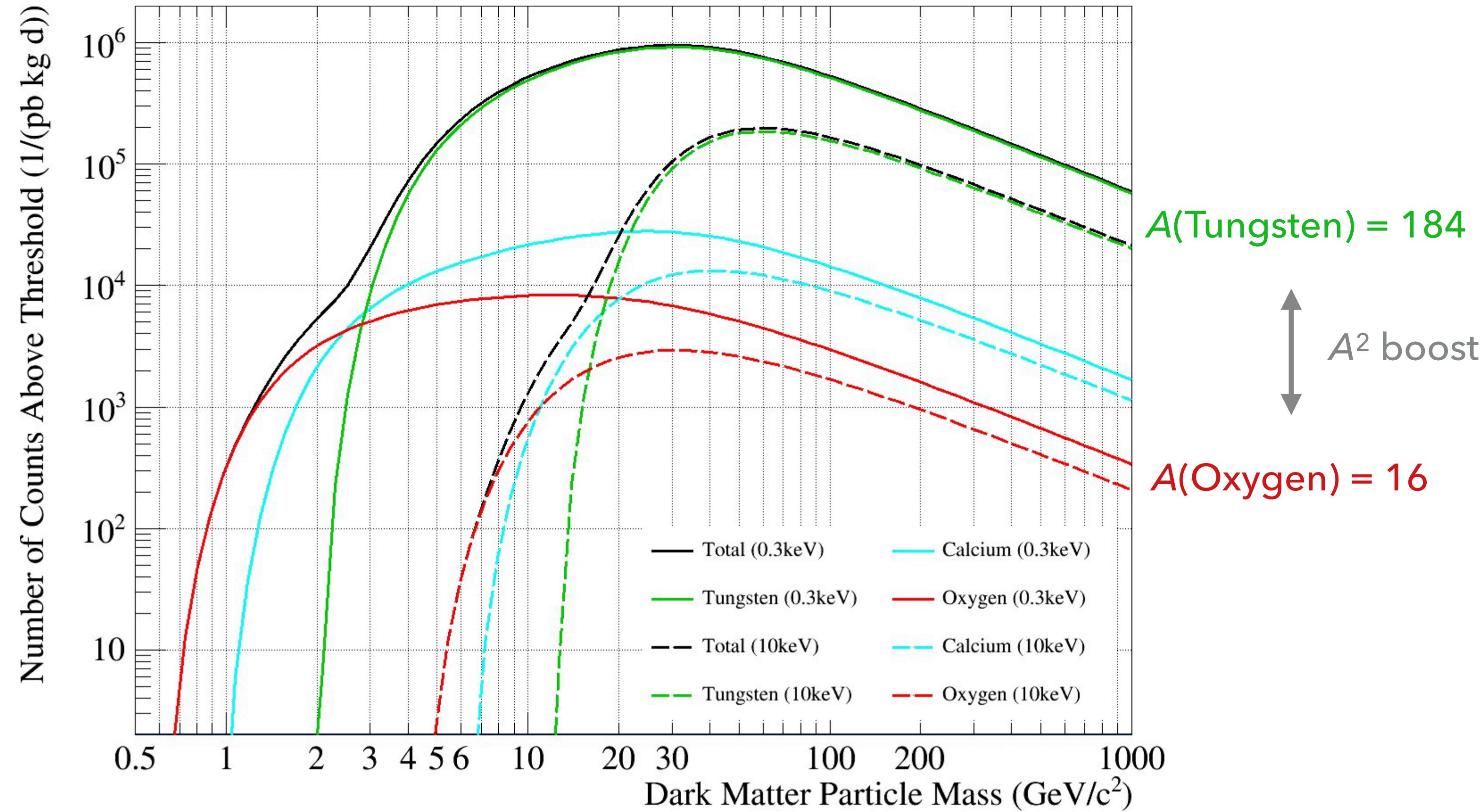
E. Figueroa-Feliciano, International Cosmic Ray Conference (2015)



$$\Delta E = \frac{1}{2} \frac{\Delta p^2}{m_N} \lesssim \frac{2 m_{\text{DM}}^2 v_{\text{DM}}^2}{m_N}$$

WIMP-NUCLEUS SCATTERING SENSITIVITY

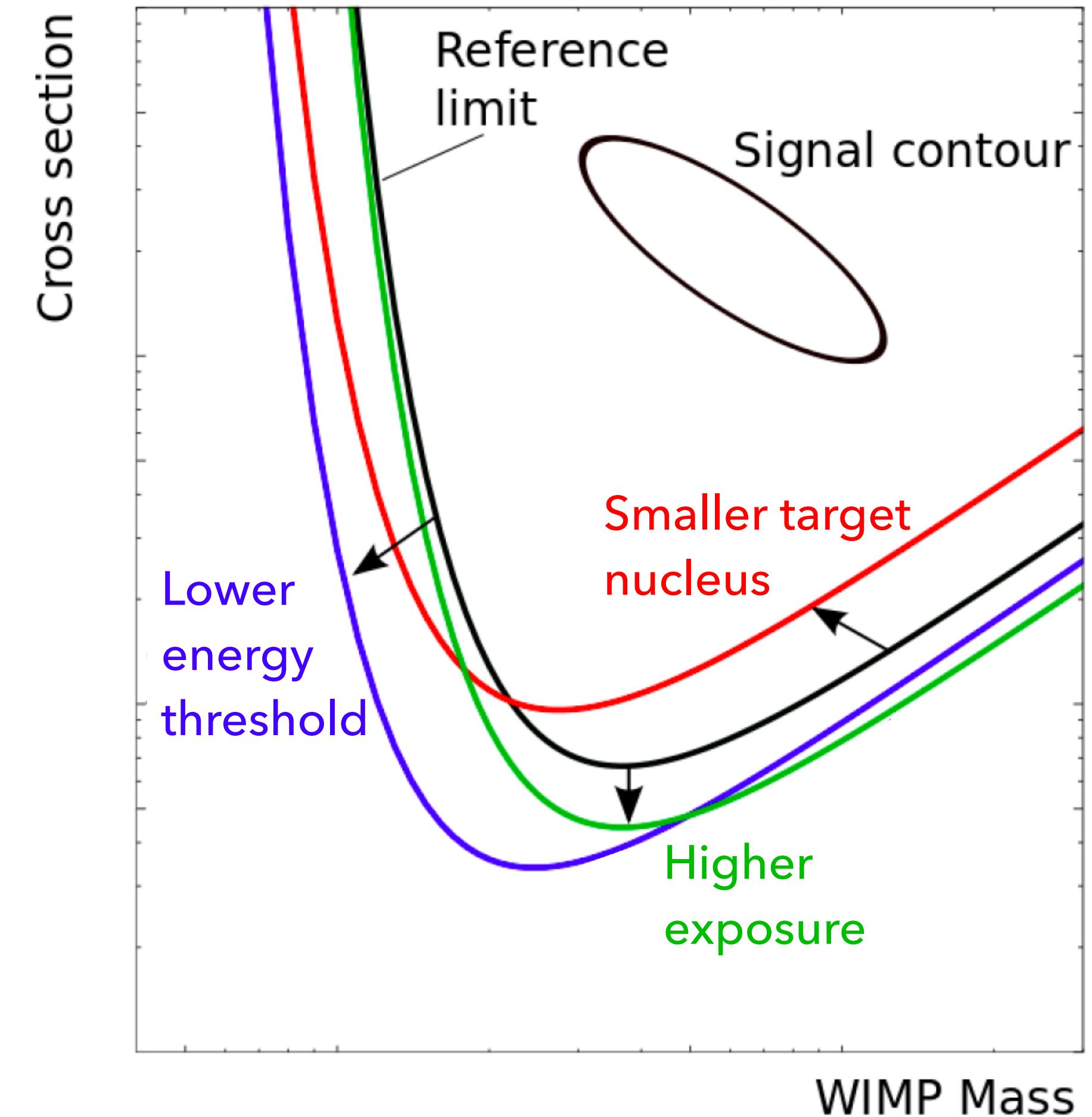
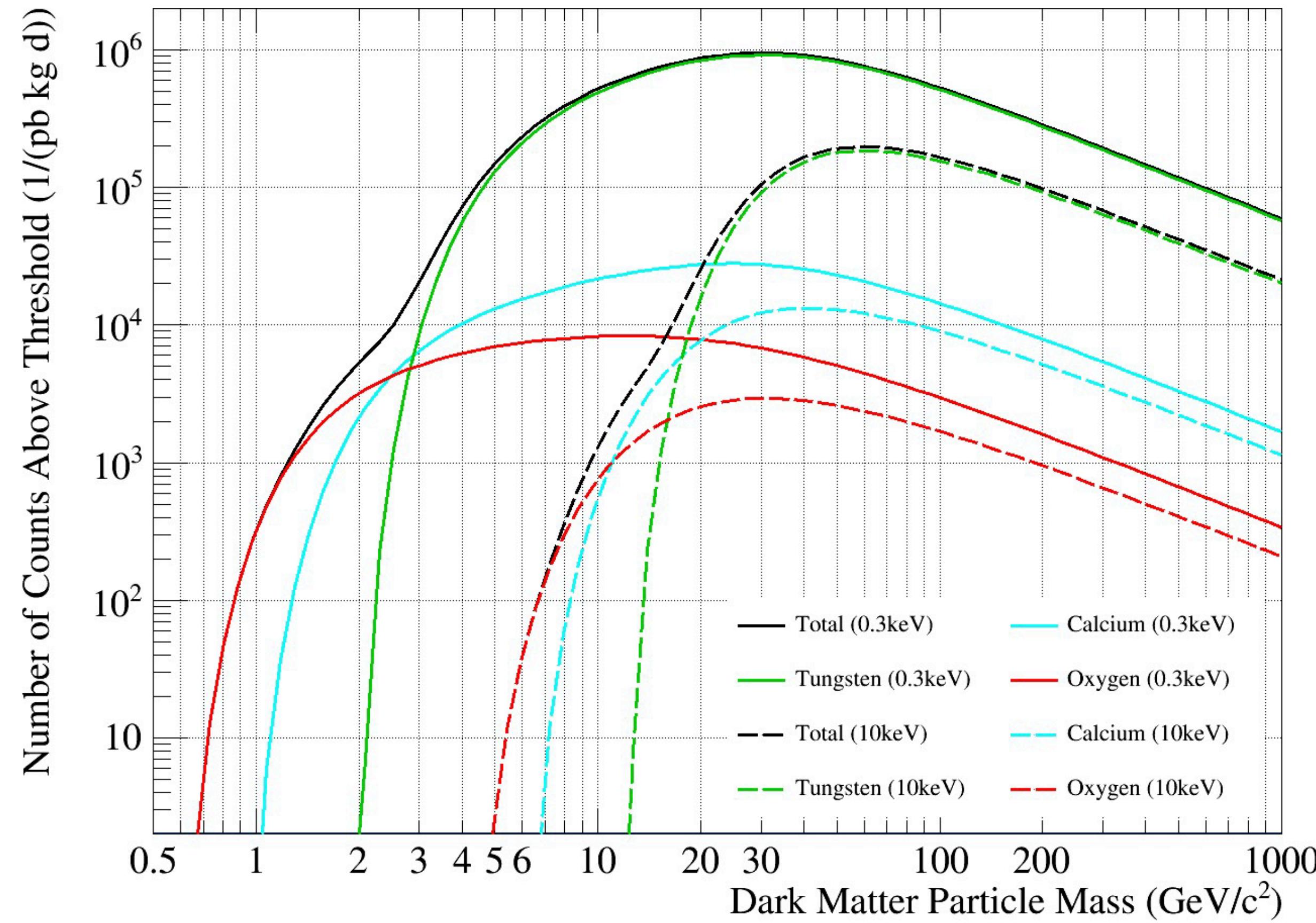
F. Petricca, DPG Spring Meeting, (2021)



WIMP-NUCLEUS SCATTERING SENSITIVITY

F. Petricca, DPG Spring Meeting, (2021)

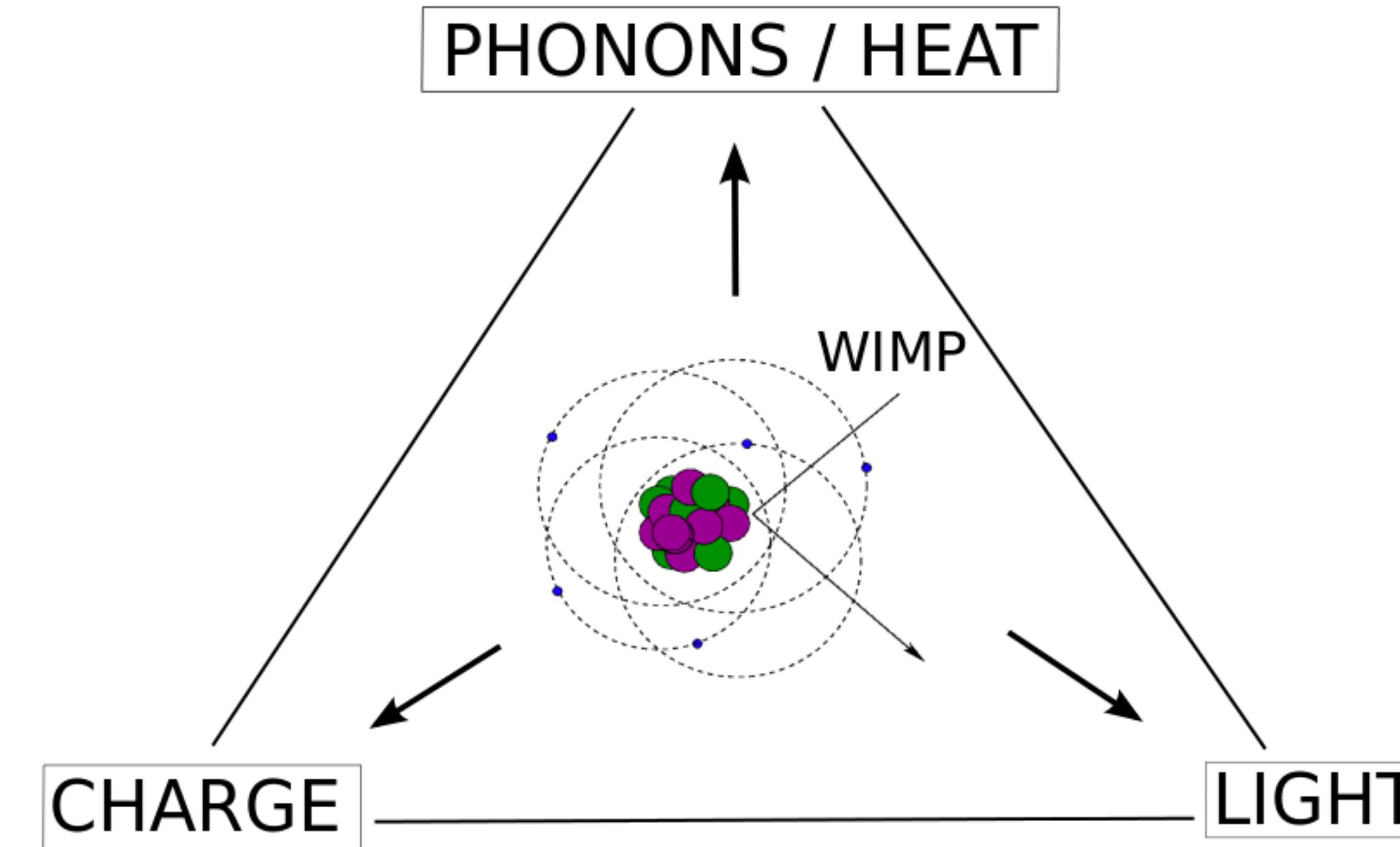
J. Phys. G43 (2016) 1, 013001



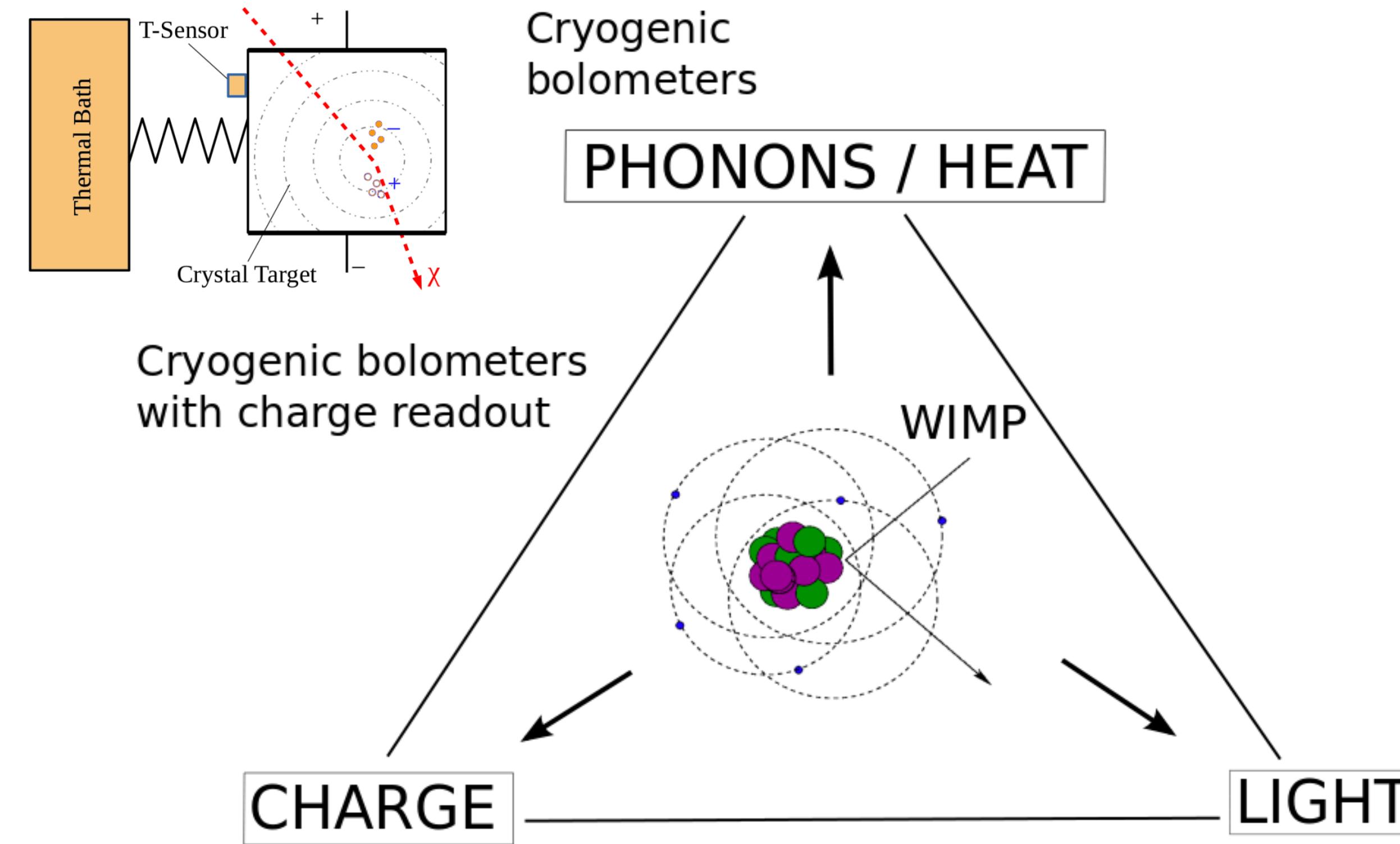
DIRECT DARK MATTER DETECTION

Detector concepts

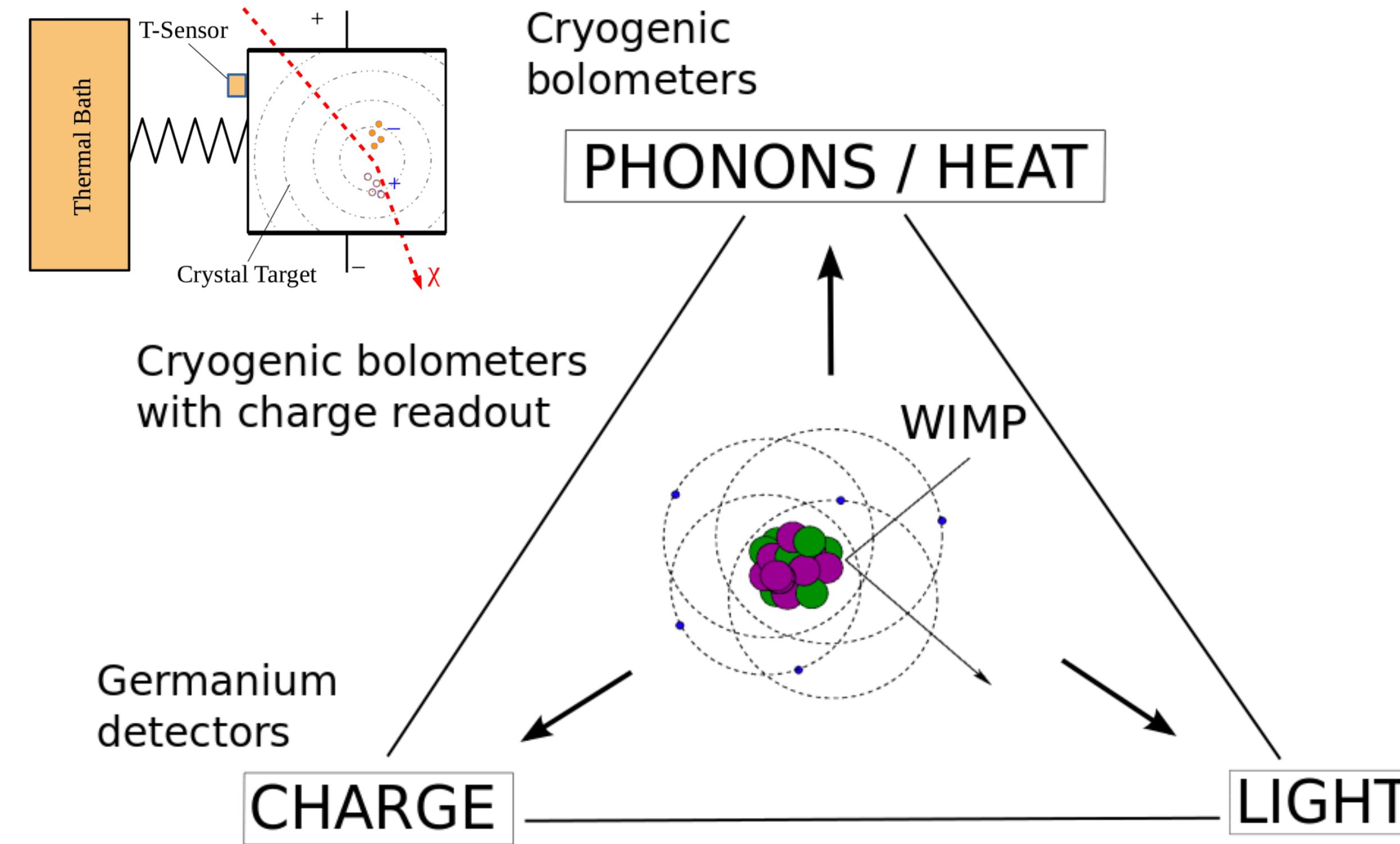
DIRECT DARK MATTER DETECTION STRATEGIES



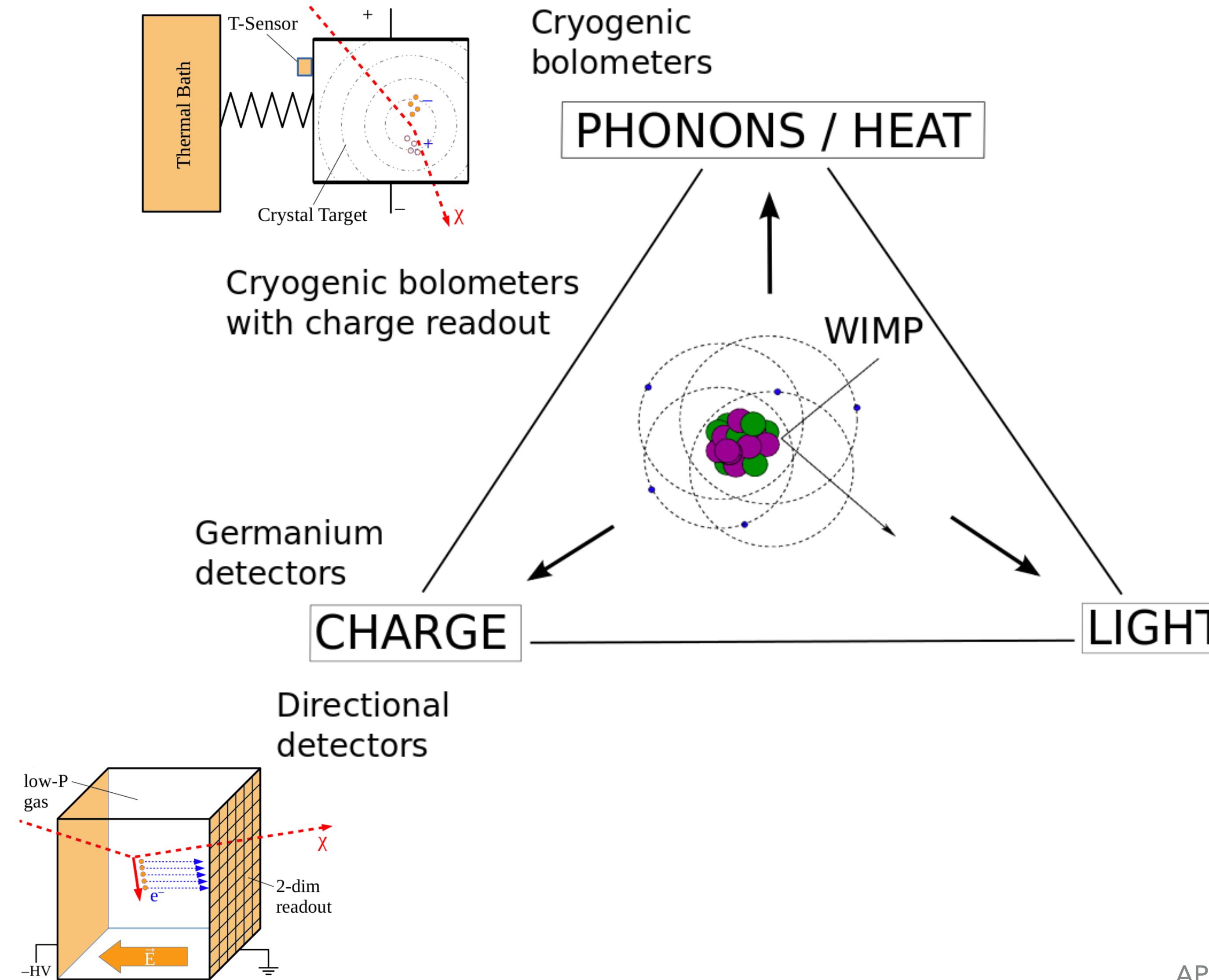
DIRECT DARK MATTER DETECTION STRATEGIES



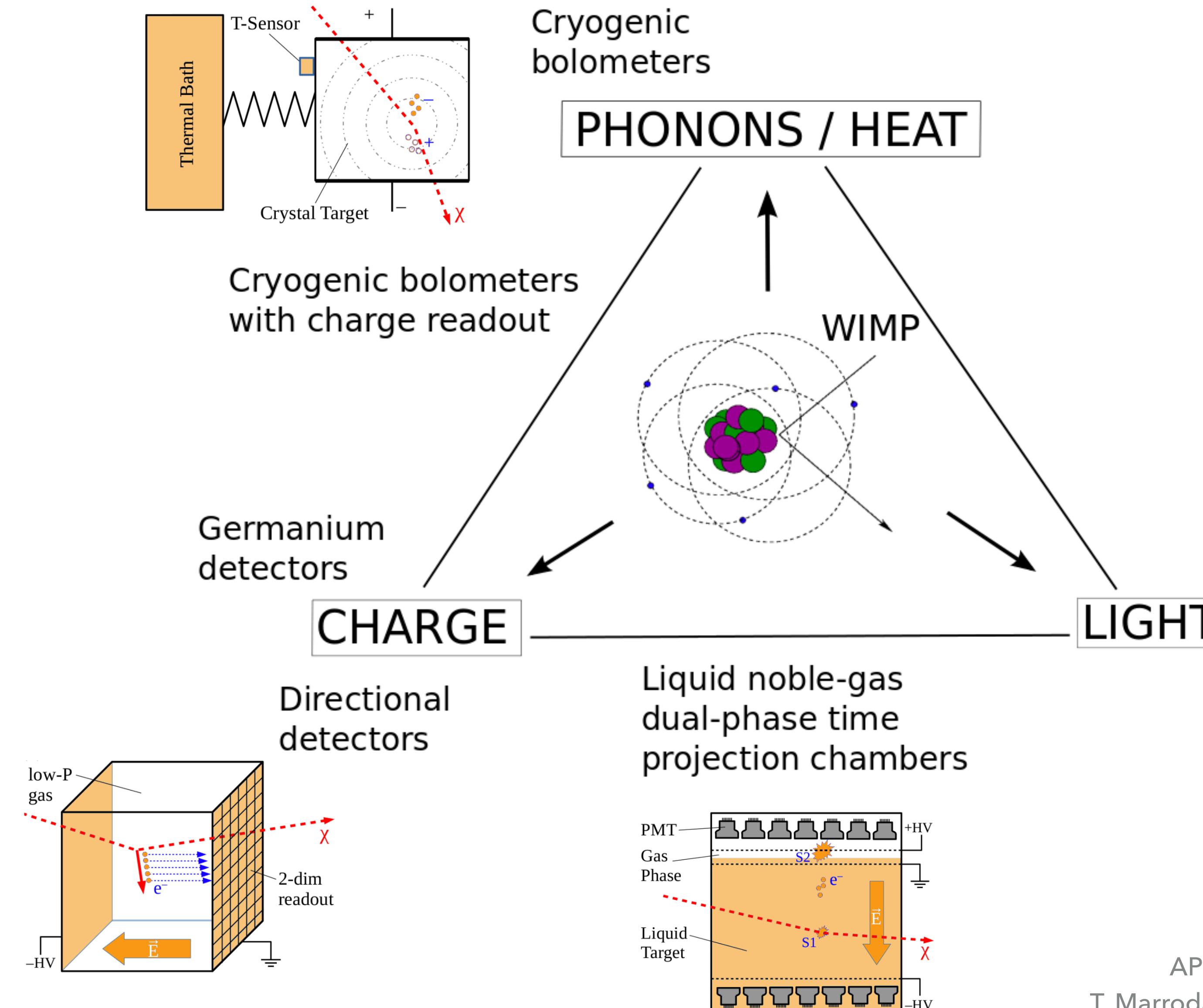
DIRECT DARK MATTER DETECTION STRATEGIES



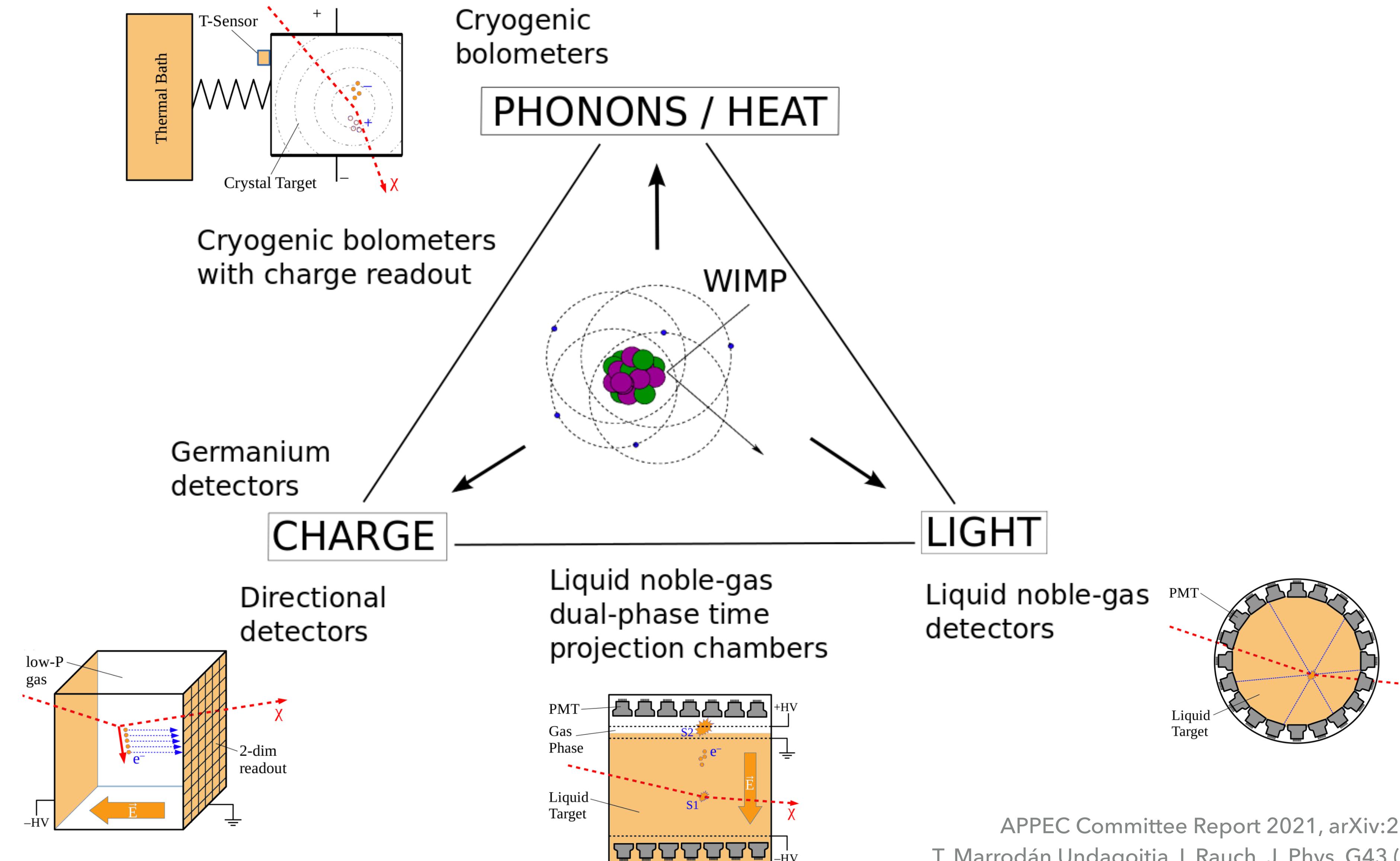
DIRECT DARK MATTER DETECTION STRATEGIES



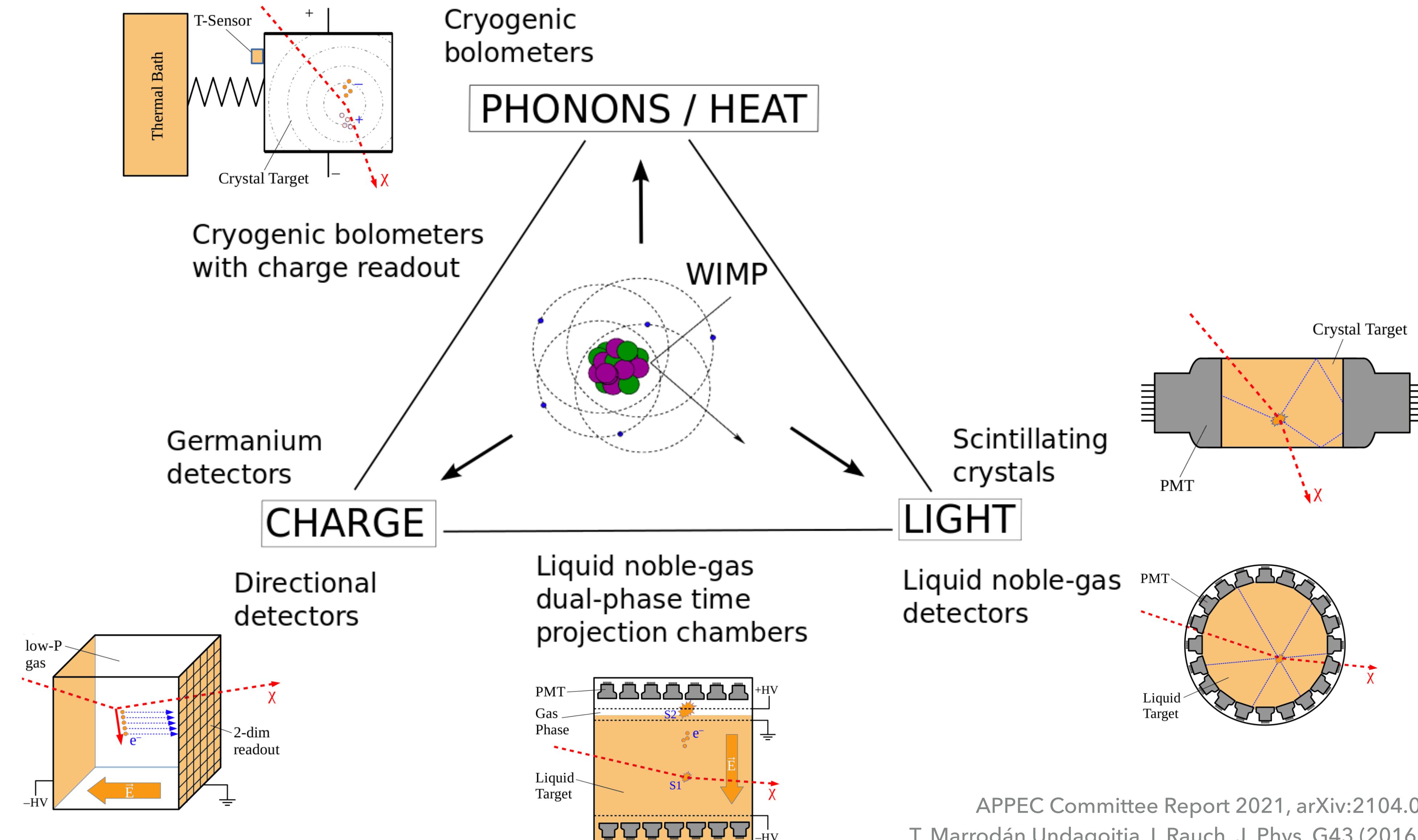
DIRECT DARK MATTER DETECTION STRATEGIES



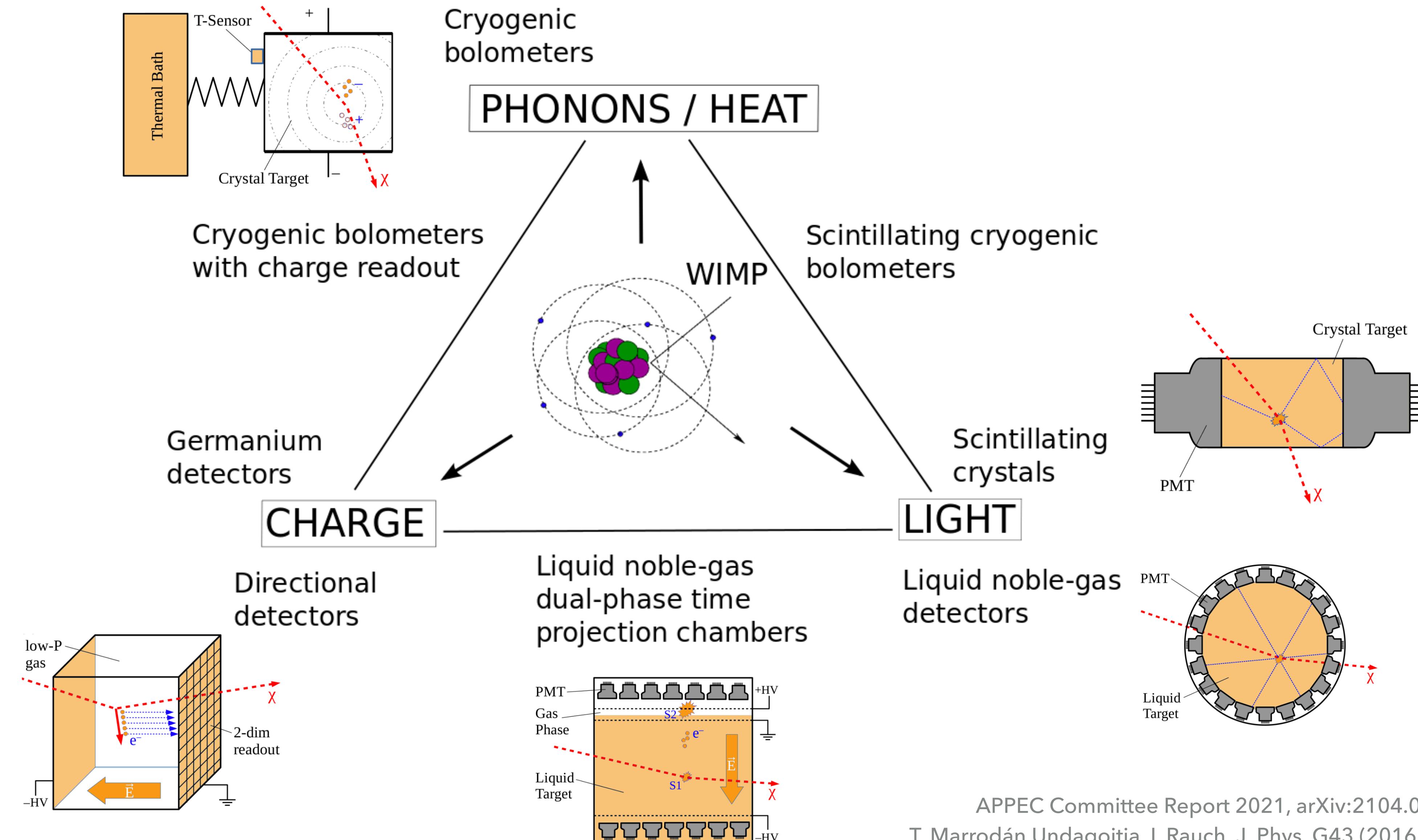
DIRECT DARK MATTER DETECTION STRATEGIES



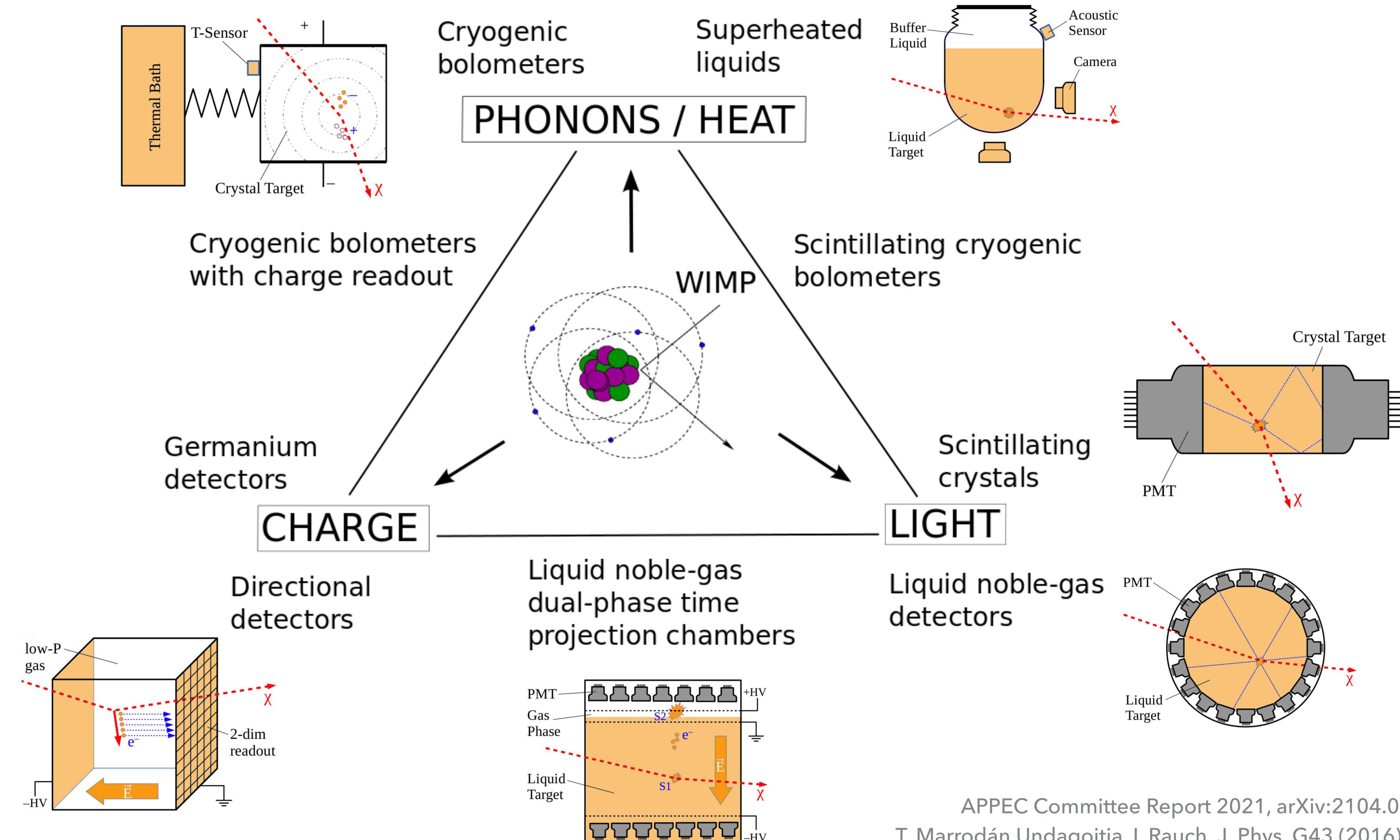
DIRECT DARK MATTER DETECTION STRATEGIES



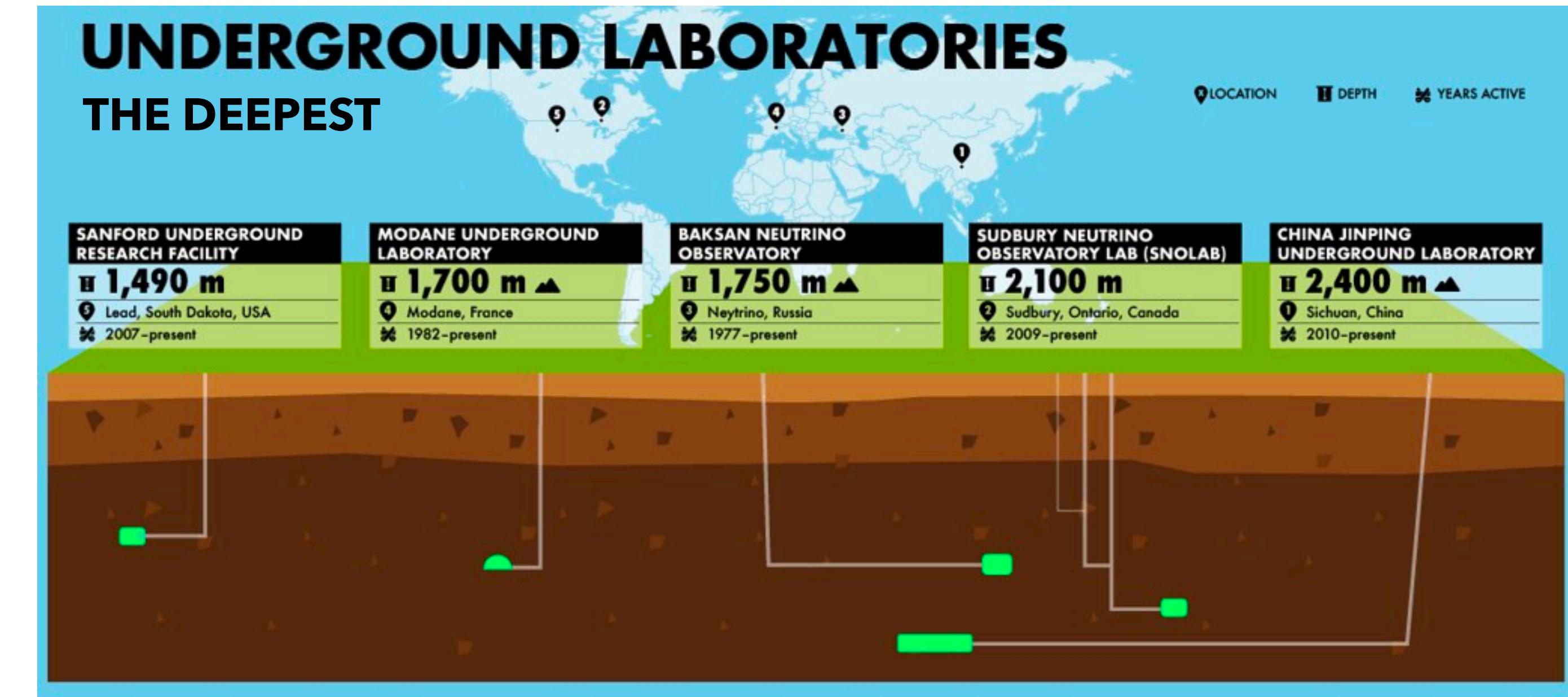
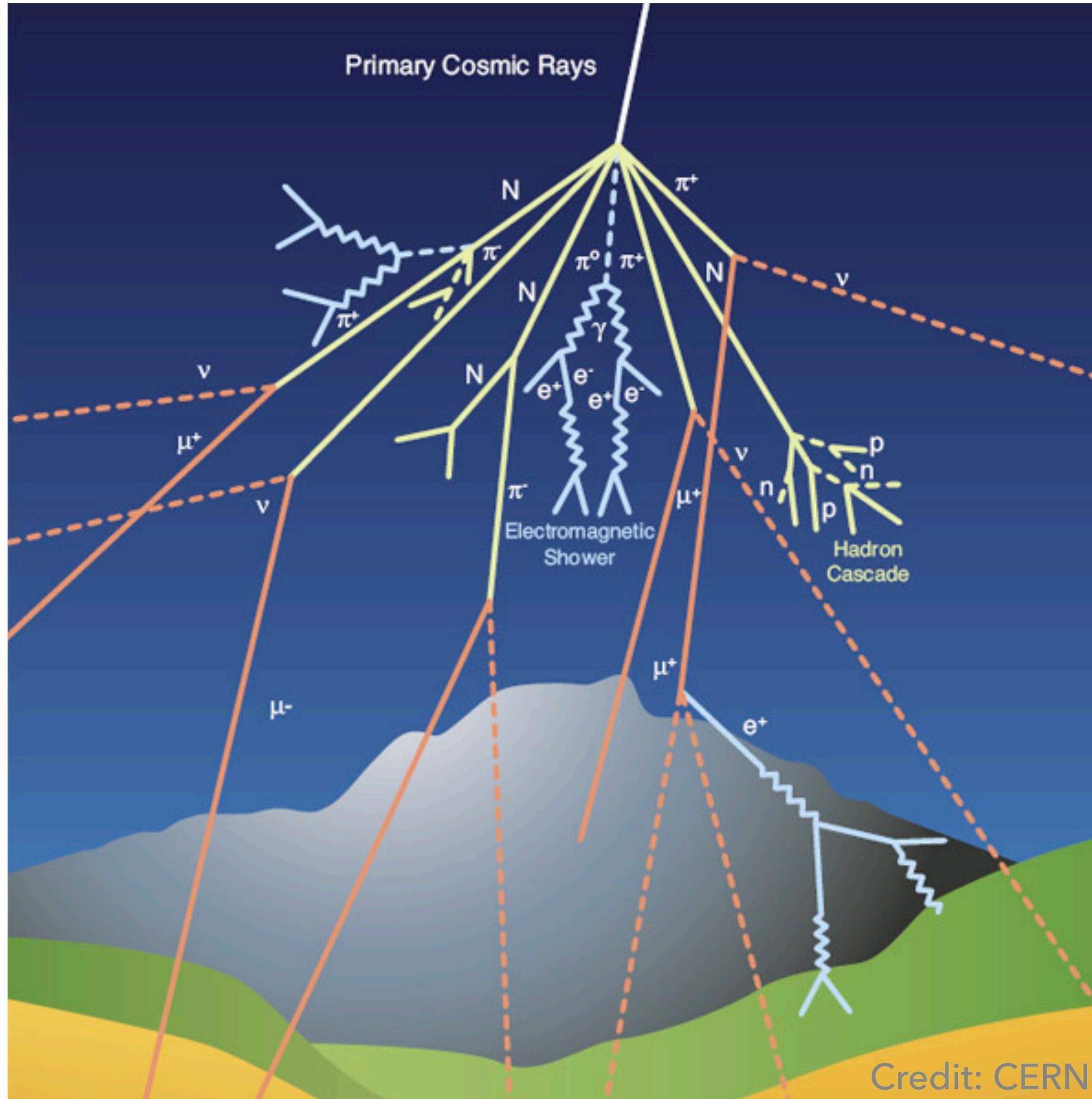
DIRECT DARK MATTER DETECTION STRATEGIES



DIRECT DARK MATTER DETECTION STRATEGIES

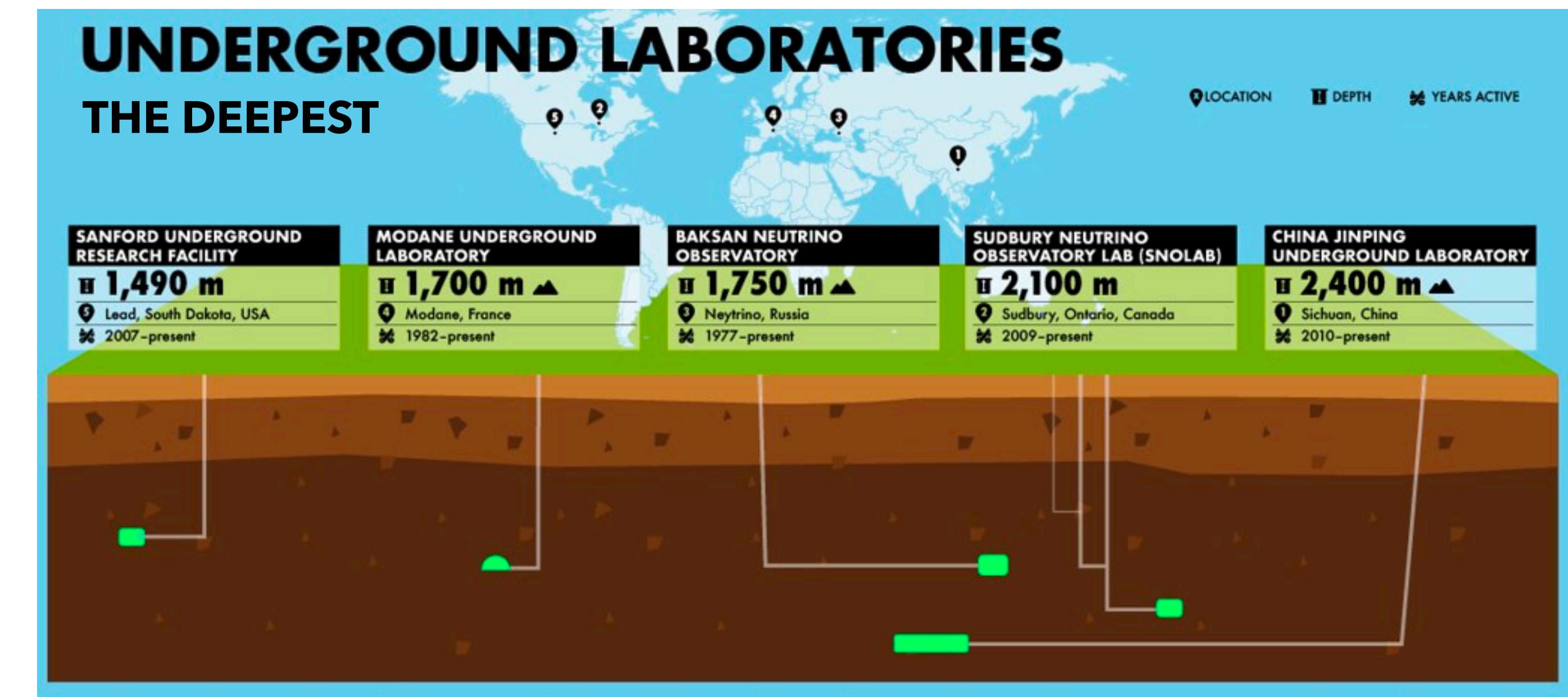
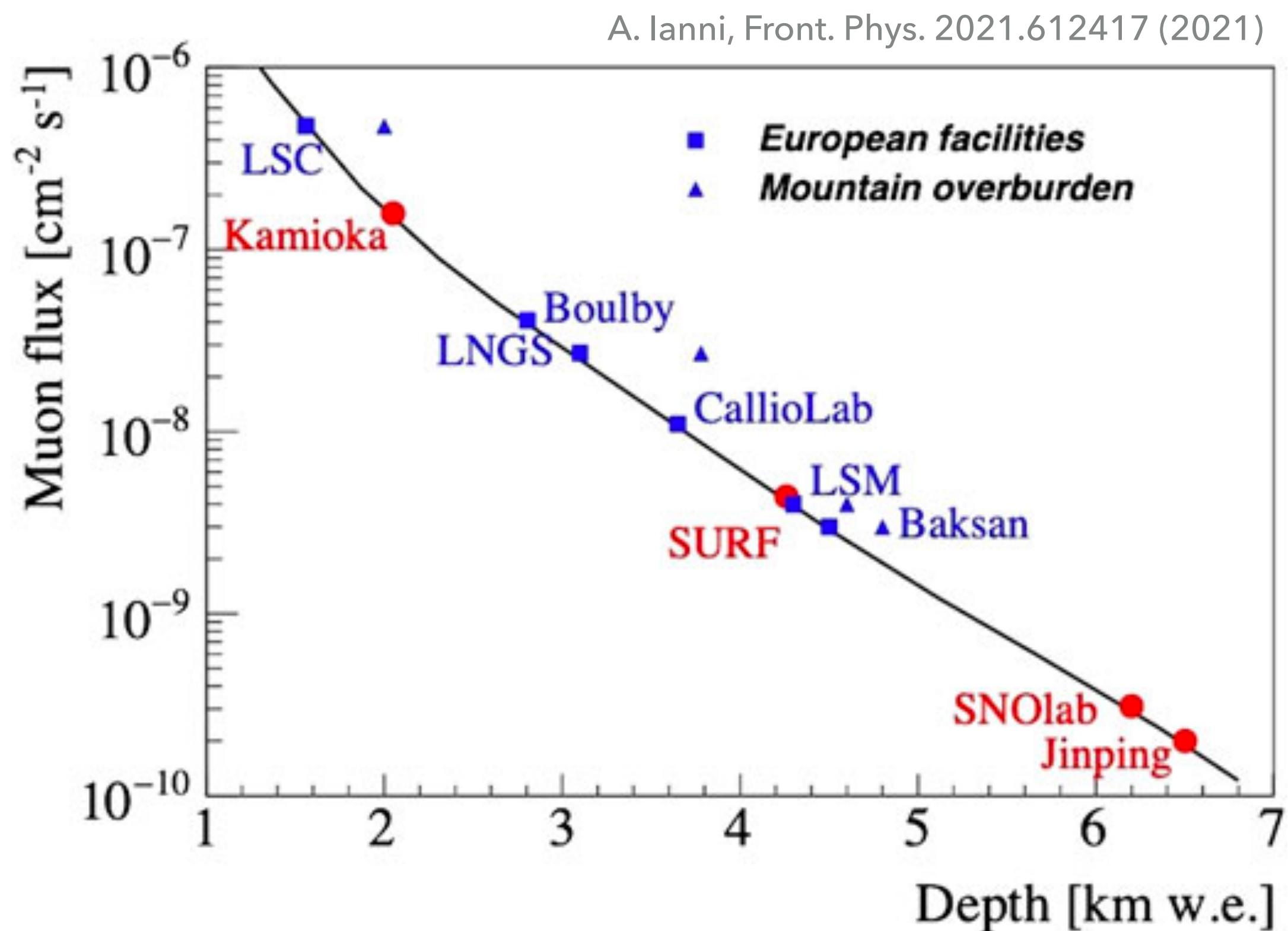


BACKGROUNDS: COSMIC RAYS



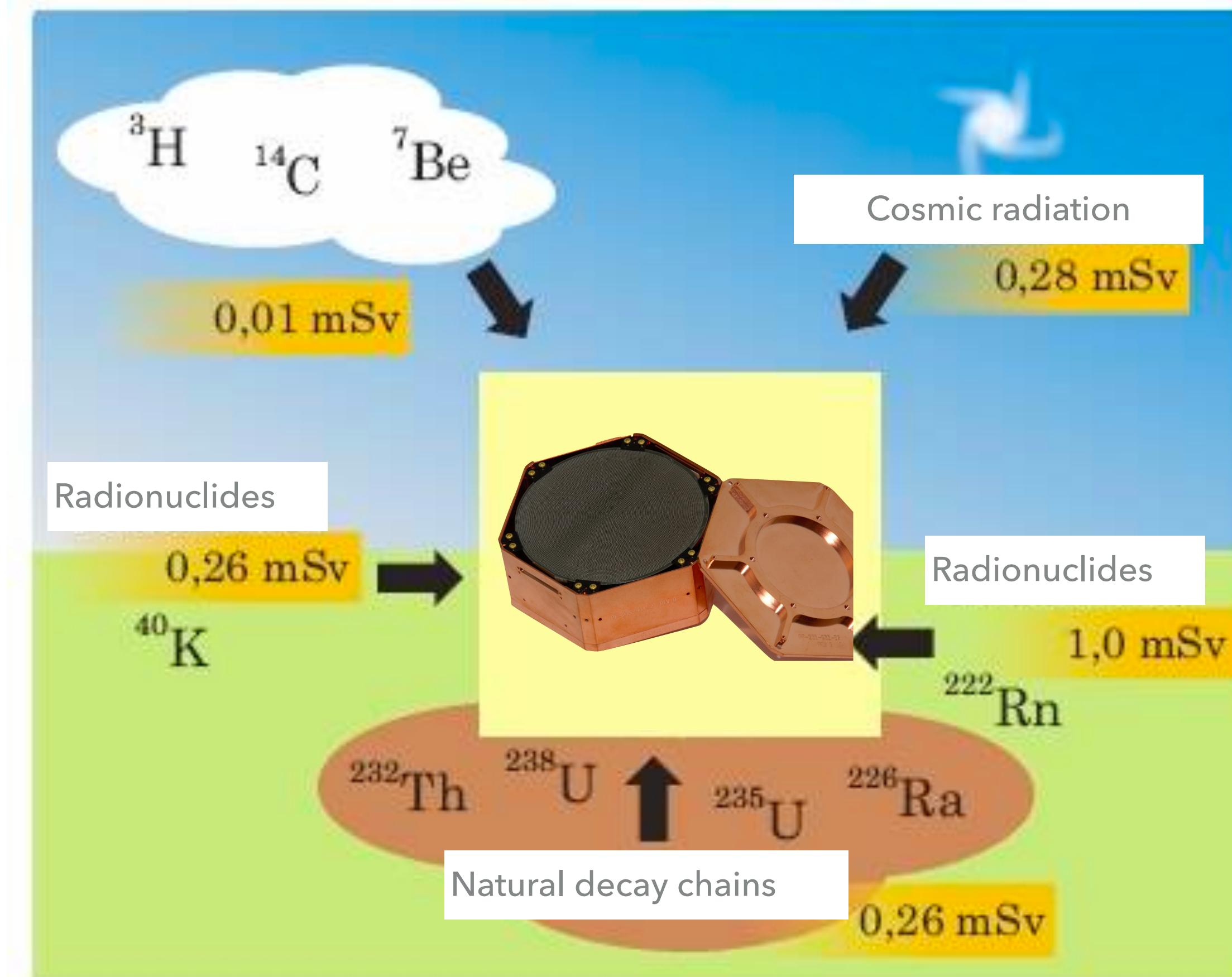
Mitigation strategy: going underground

BACKGROUNDS: COSMIC RAYS



Mitigation strategy: going underground

BACKGROUNDS: RADIOACTIVE DECAYS



Mitigation strategies

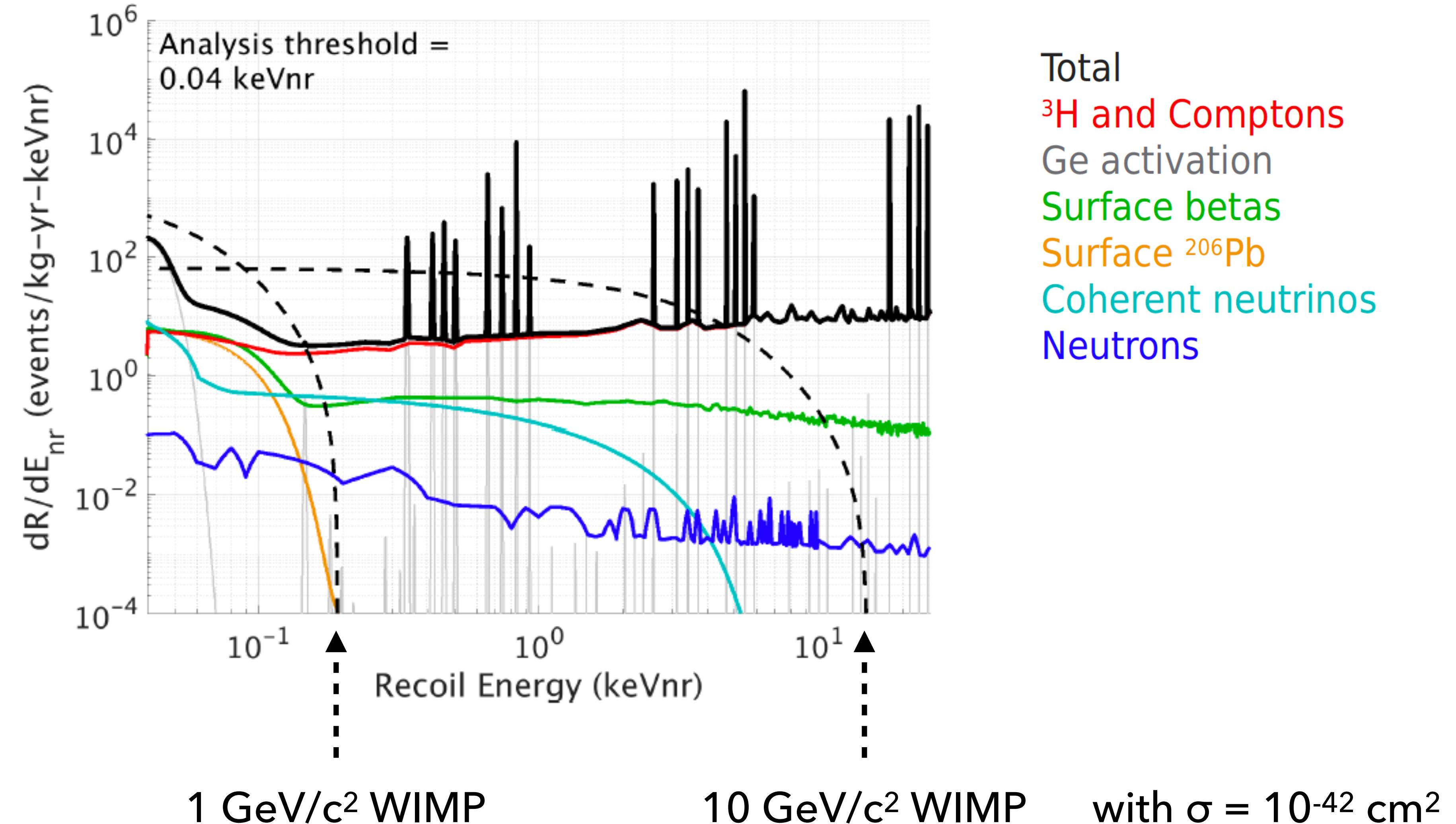
- ▶ going underground
- ▶ storing materials underground
- ▶ passive and active shielding
- ▶ Radon mitigation
- ▶ use of materials with high purity
- ▶ ...

<http://www.goerudio.com/izpratnes-lapa/radioaktivitate>
(modified)

WIMP NUCLEAR RECOIL SPECTRUM AND BACKGROUNDS

Example:

Prediction for
SuperCDMS SNOLAB
(Ge HV detectors)

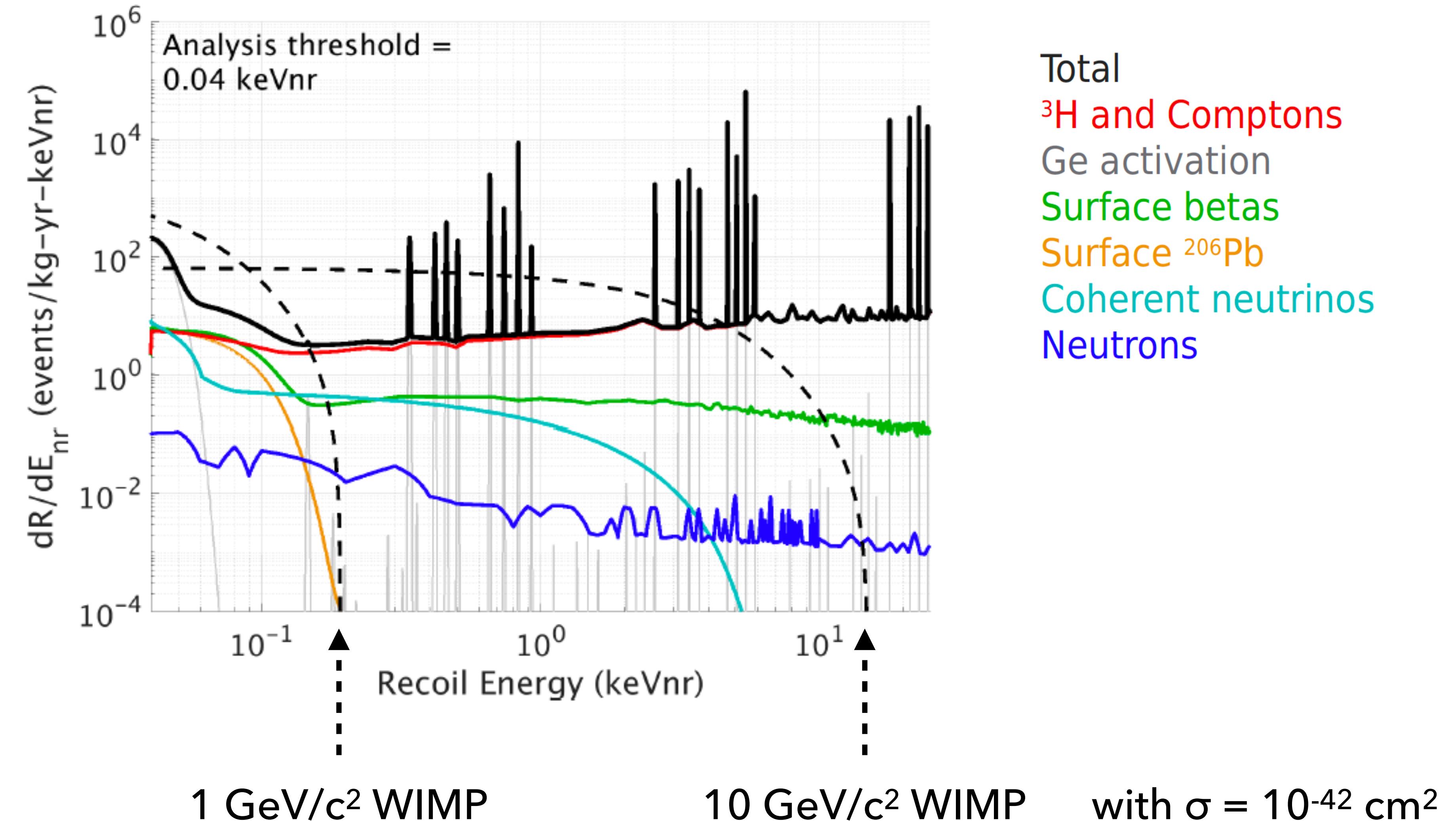


WIMP NUCLEAR RECOIL SPECTRUM AND BACKGROUNDS

Example:

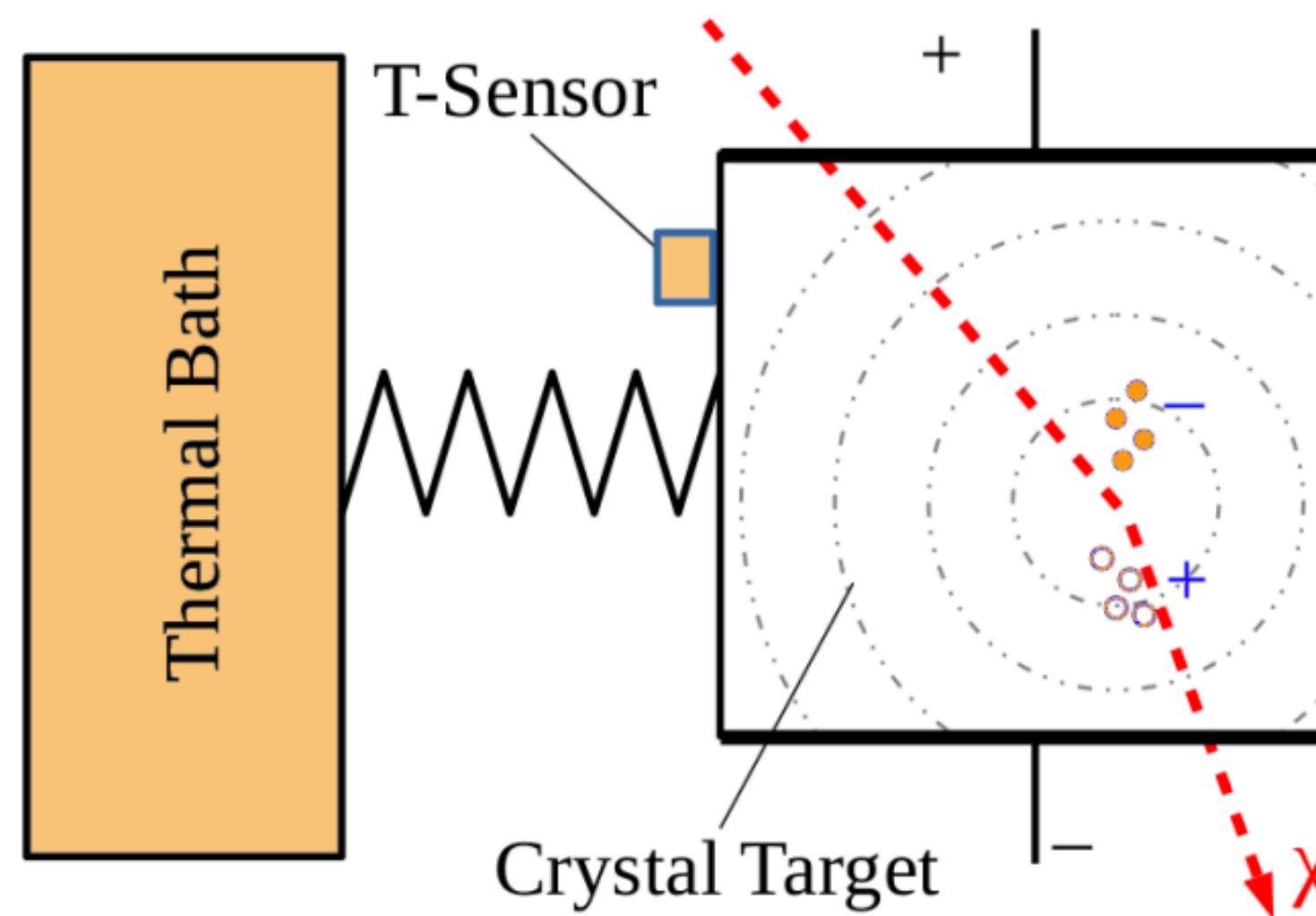
Prediction for
SuperCDMS SNOLAB
(Ge HV detectors)

Still not background
free!

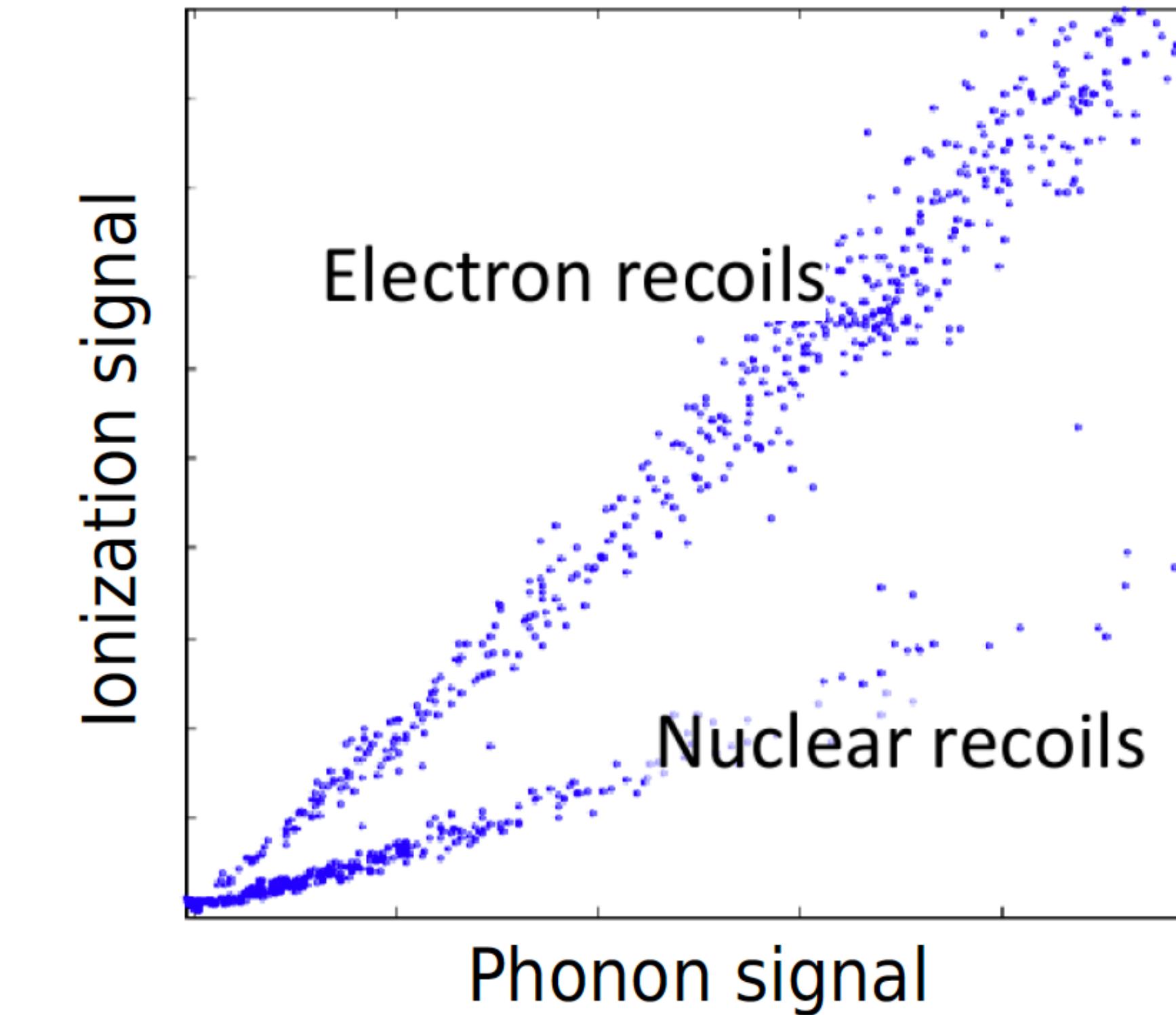


BACKGROUND DISCRIMINATION USING TWO SIGNALS

Example: measurement of PHONON/HEAT and IONIZATION signals



Cryogenic bolometers
with charge readout

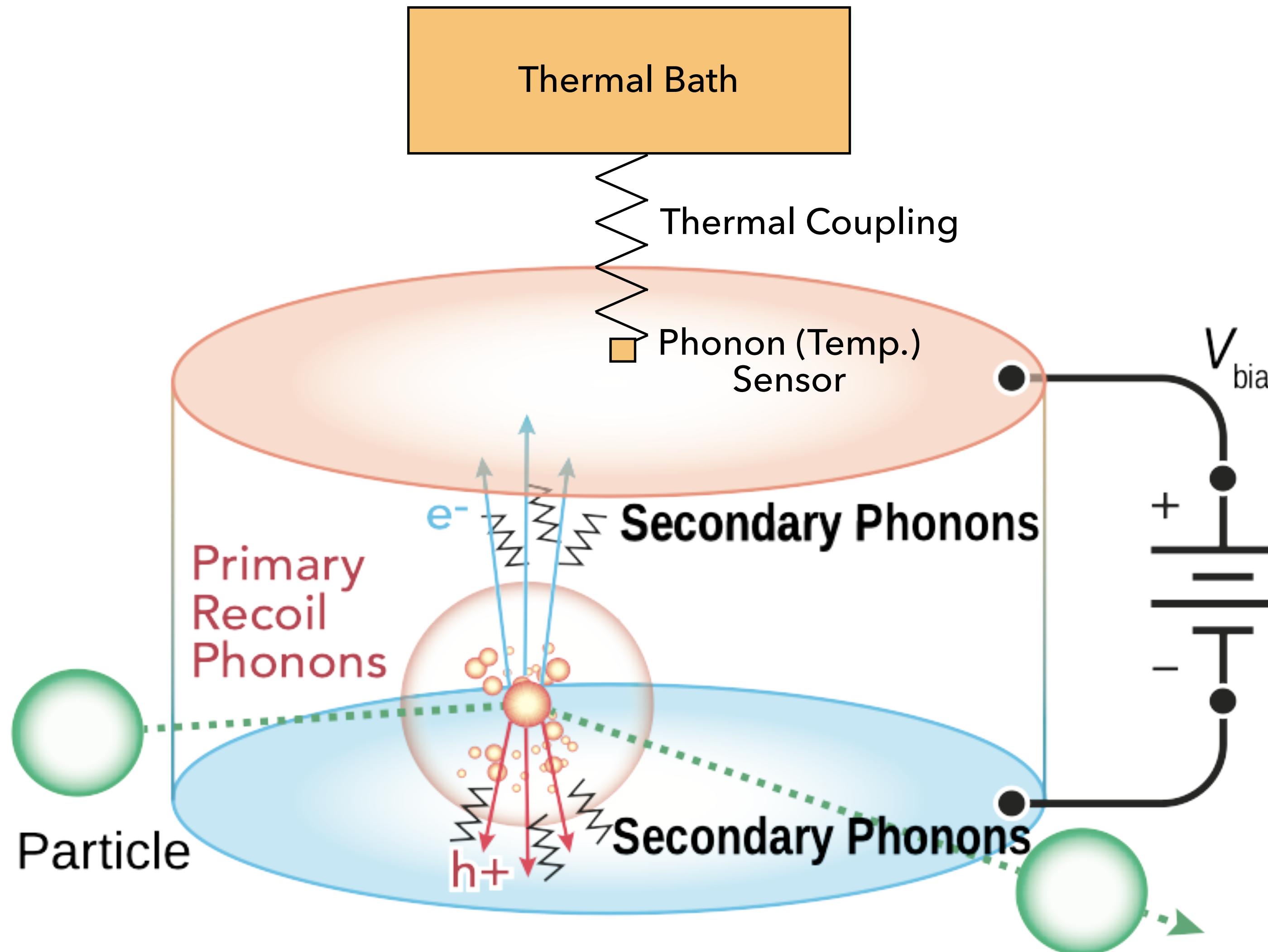


Two signals offer strong discrimination power between WIMP NR signals and backgrounds with ER signatures!

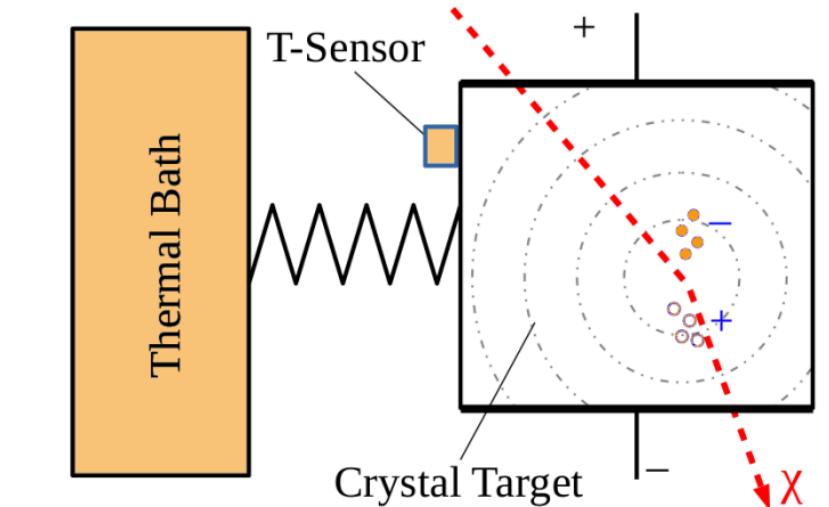
EXPERIMENTS

Disclaimer: Only highlighting a few examples.
For a more complete list please see e.g. APPEC Committee Report 2021, arXiv:2104.07634.

CRYOGENIC BOLOMETERS WITH CHARGE READOUT

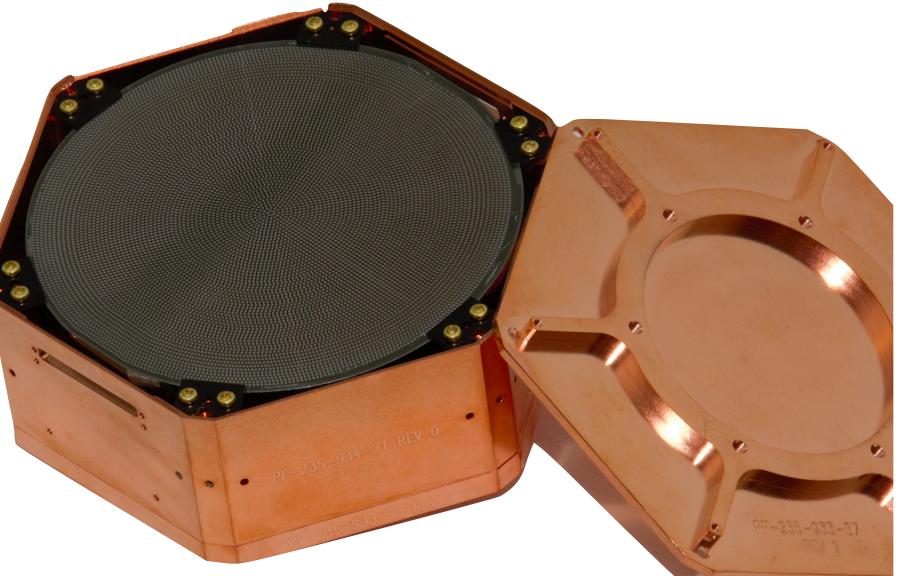
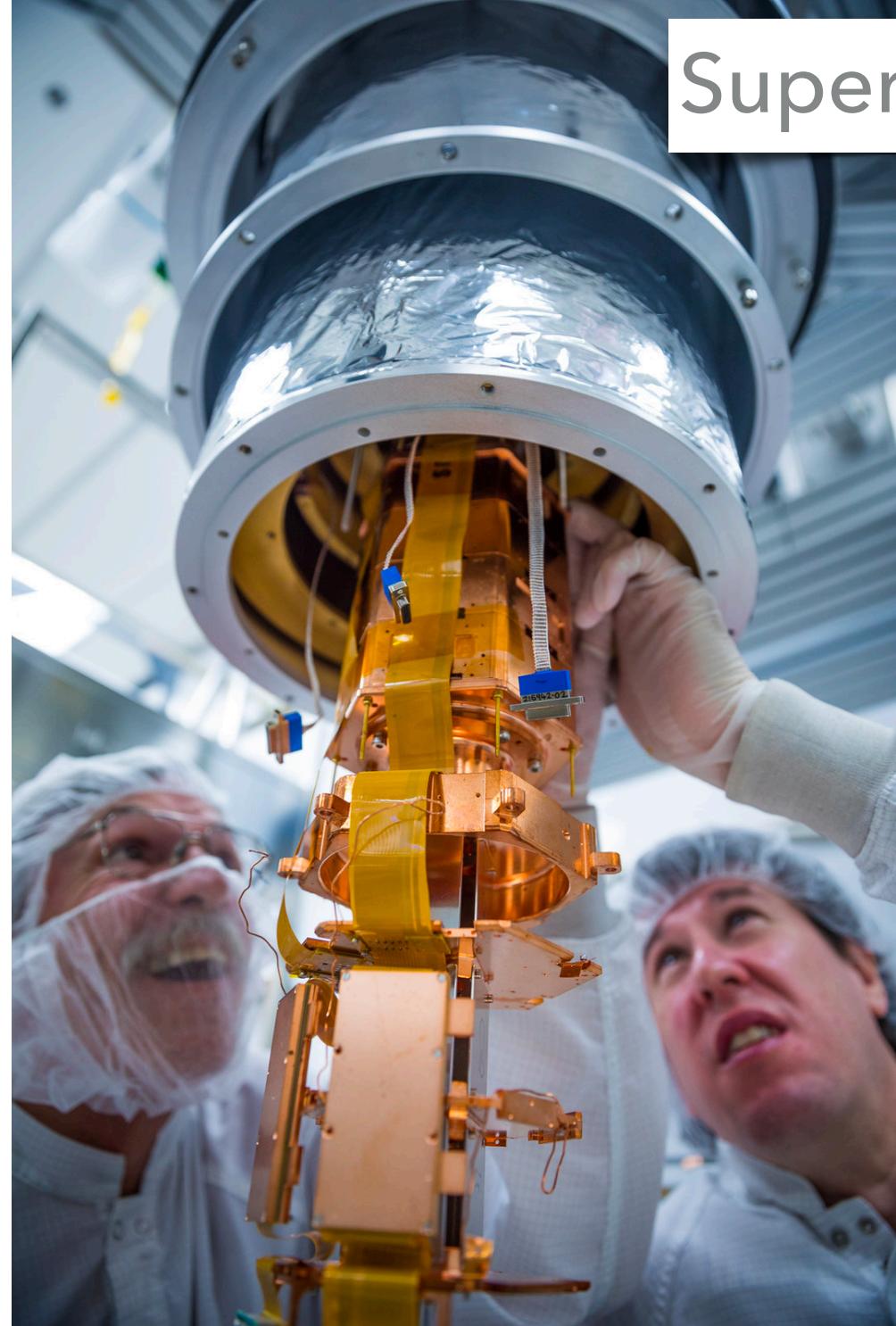


Phonon/Heat + Ionization

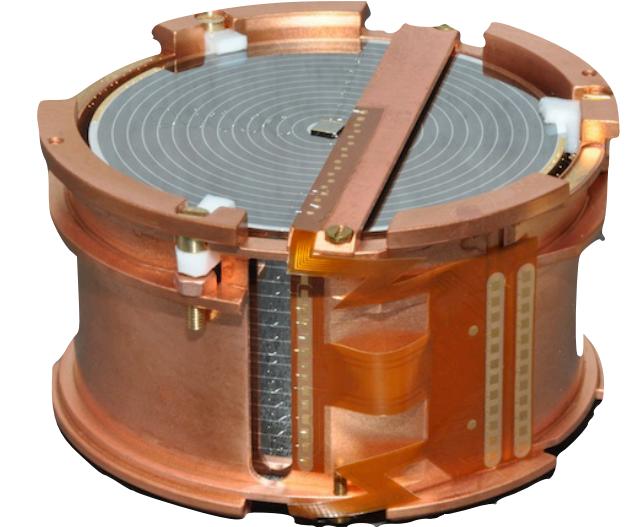


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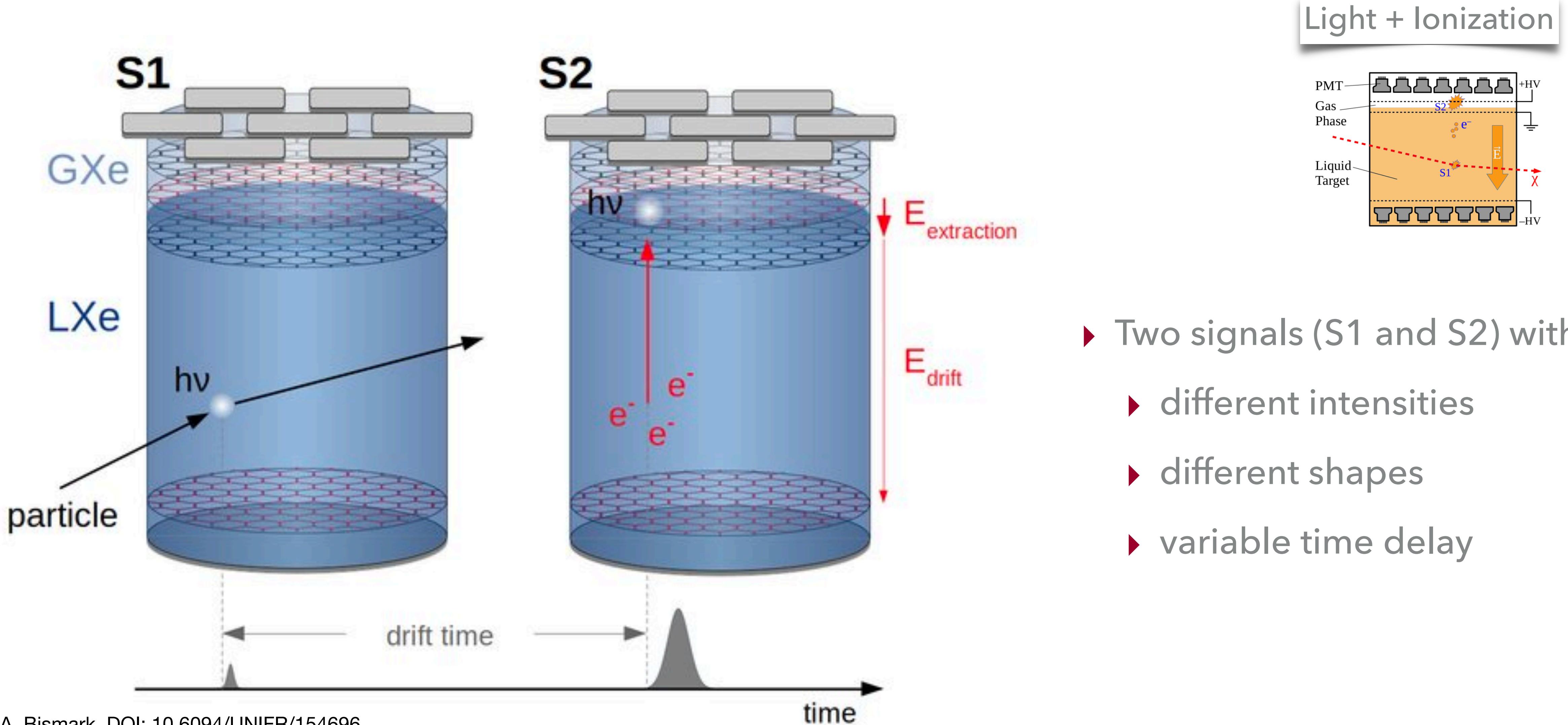
Some examples



- ▶ Pro: Measurement of ~100% of deposited energy
- ▶ Pro: Low energy threshold
- ▶ Con: Difficult to increase target mass for large exposures



DUAL-PHASE TIME PROJECTION CHAMBERS (TPC)



DUAL-PHASE TIME PROJECTION CHAMBERS (TPC)

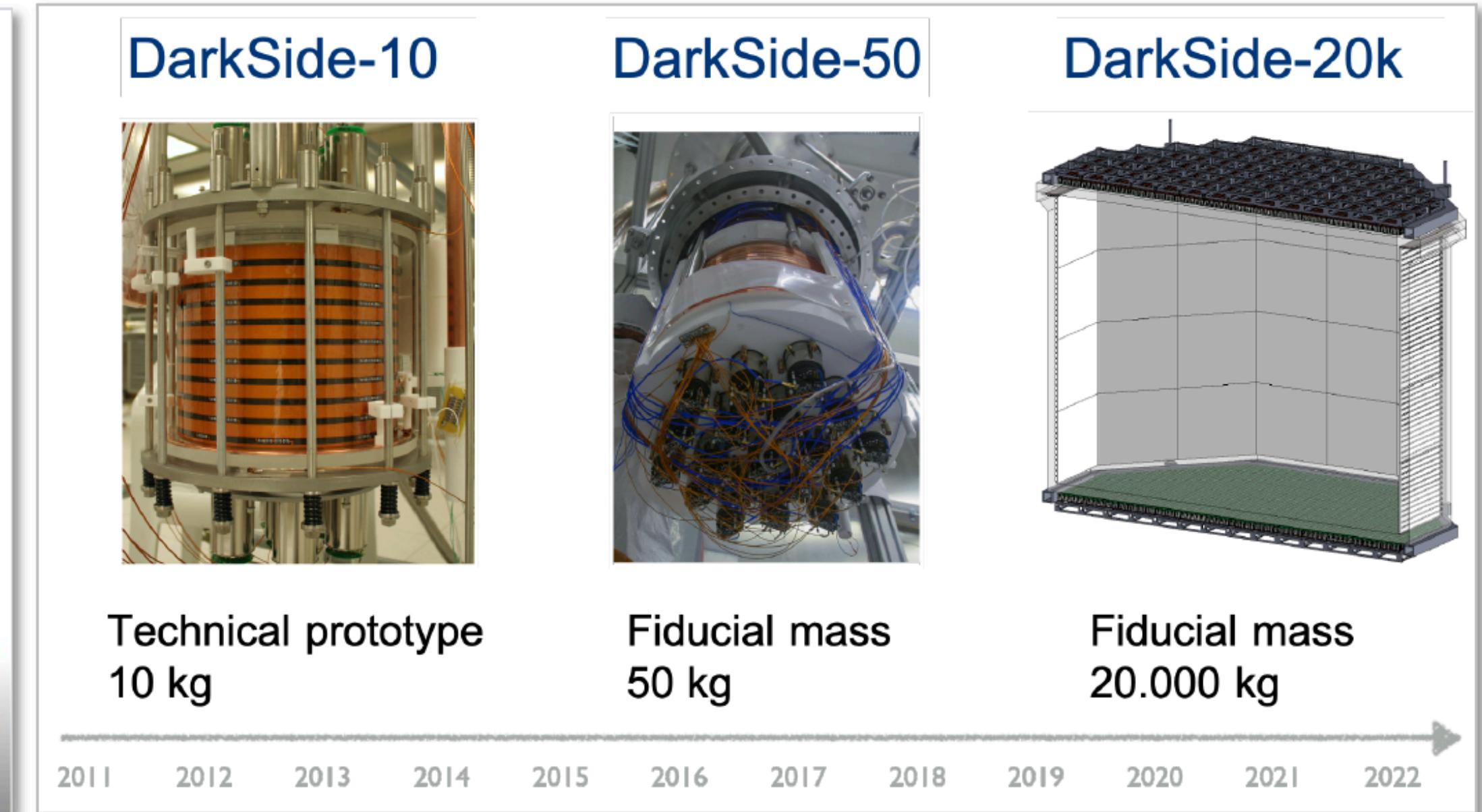
Some examples

F. Petricca, DPG Spring Meeting, (2021)

Pictures courtesy XENON Collaboration



XENONnT is under commissioning and the German community (including new groups) is moving towards the multi-tonne scale detector DARWIN



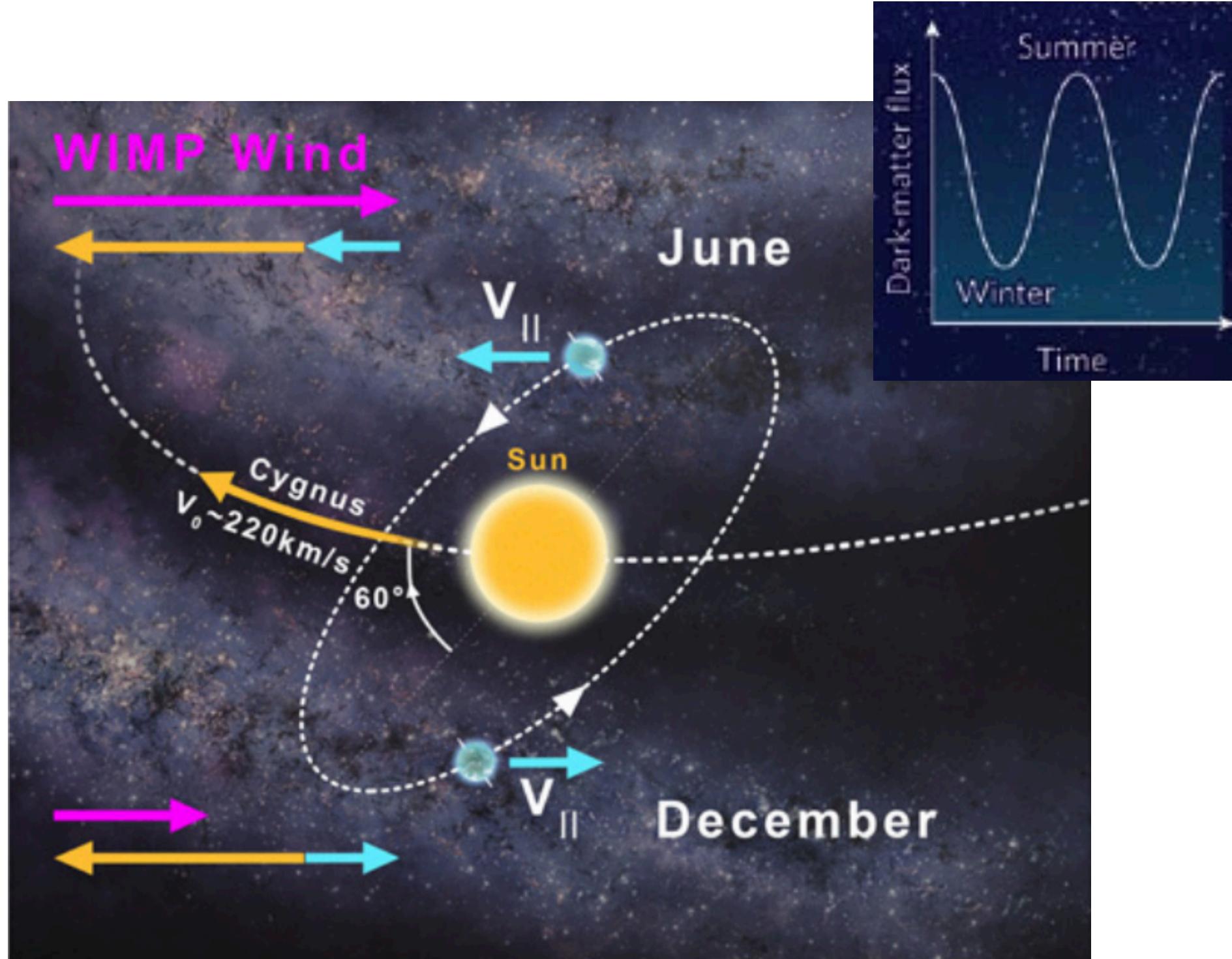
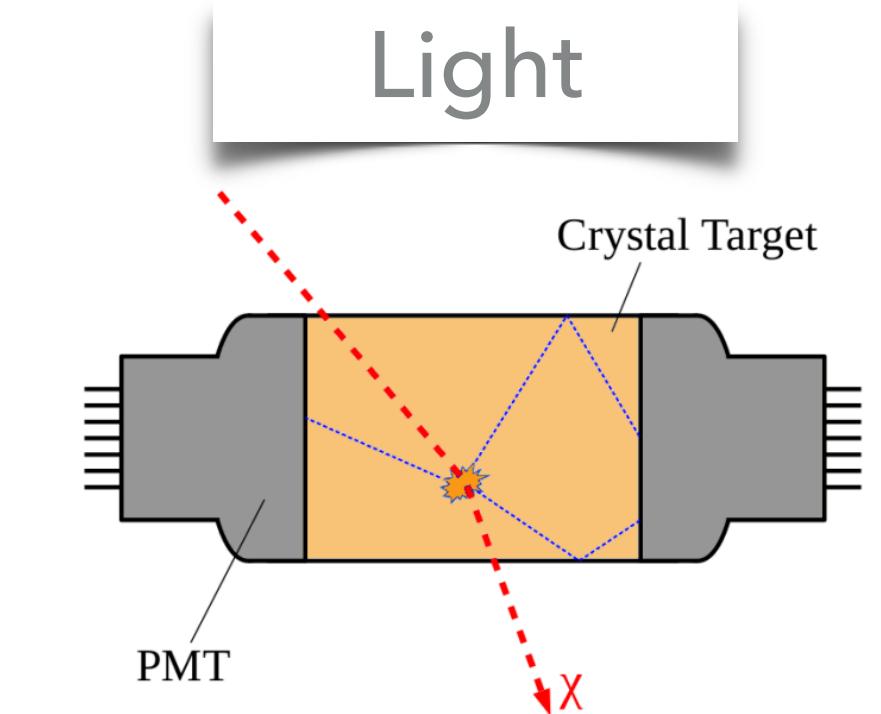
Global Argon Dark Matter Collaboration is currently building the DarkSide-20k

- ▶ Pro: Easily scaled up to tonne-scale masses
- ▶ Pro: Self-shielding (fiducial volume)
- ▶ Con: typically higher threshold than bolometers

Pictures courtesy DarkSide Collaboration

SCINTILLATING CRYSTALS

- ▶ Only the scintillation light is measured
- ▶ Relatively high background level
- ▶ Focus on annual modulation search

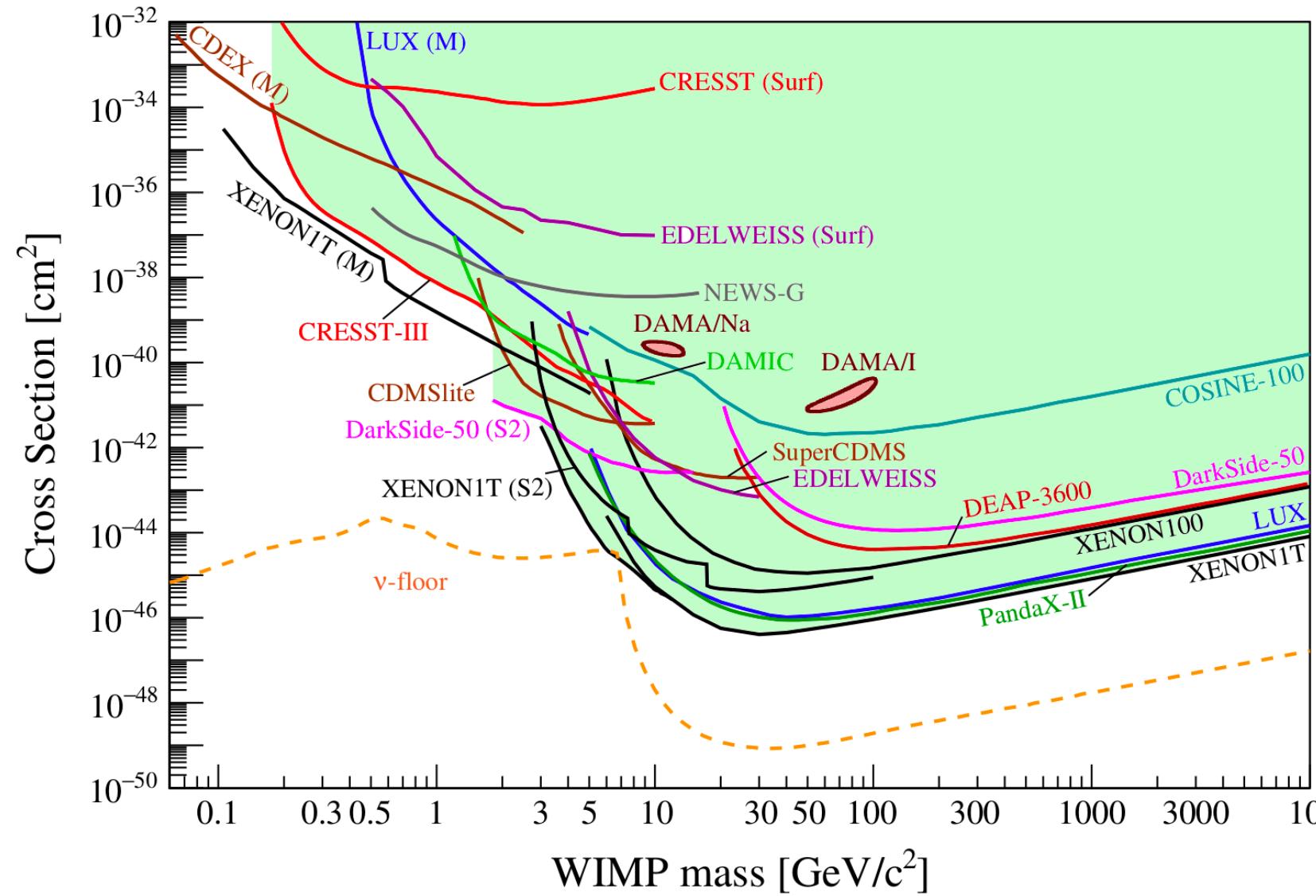
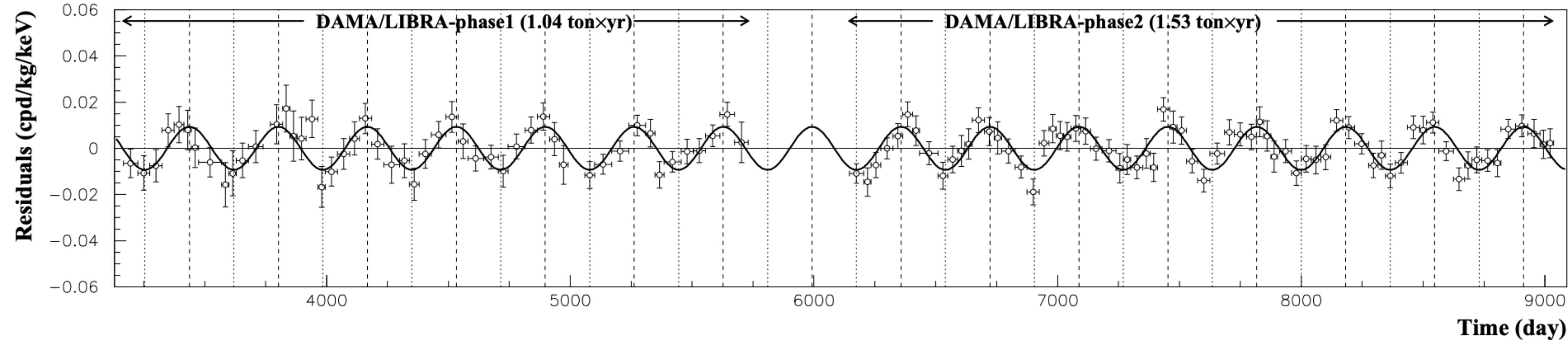


- ▶ Pro: Good background discrimination based on time dependence of Dark Matter model
- ▶ Con: signal prediction is model dependent

SCINTILLATING CRYSTALS

2-6 keV

DAMA/LIBRA Collaboration, arXiv:2110.04734

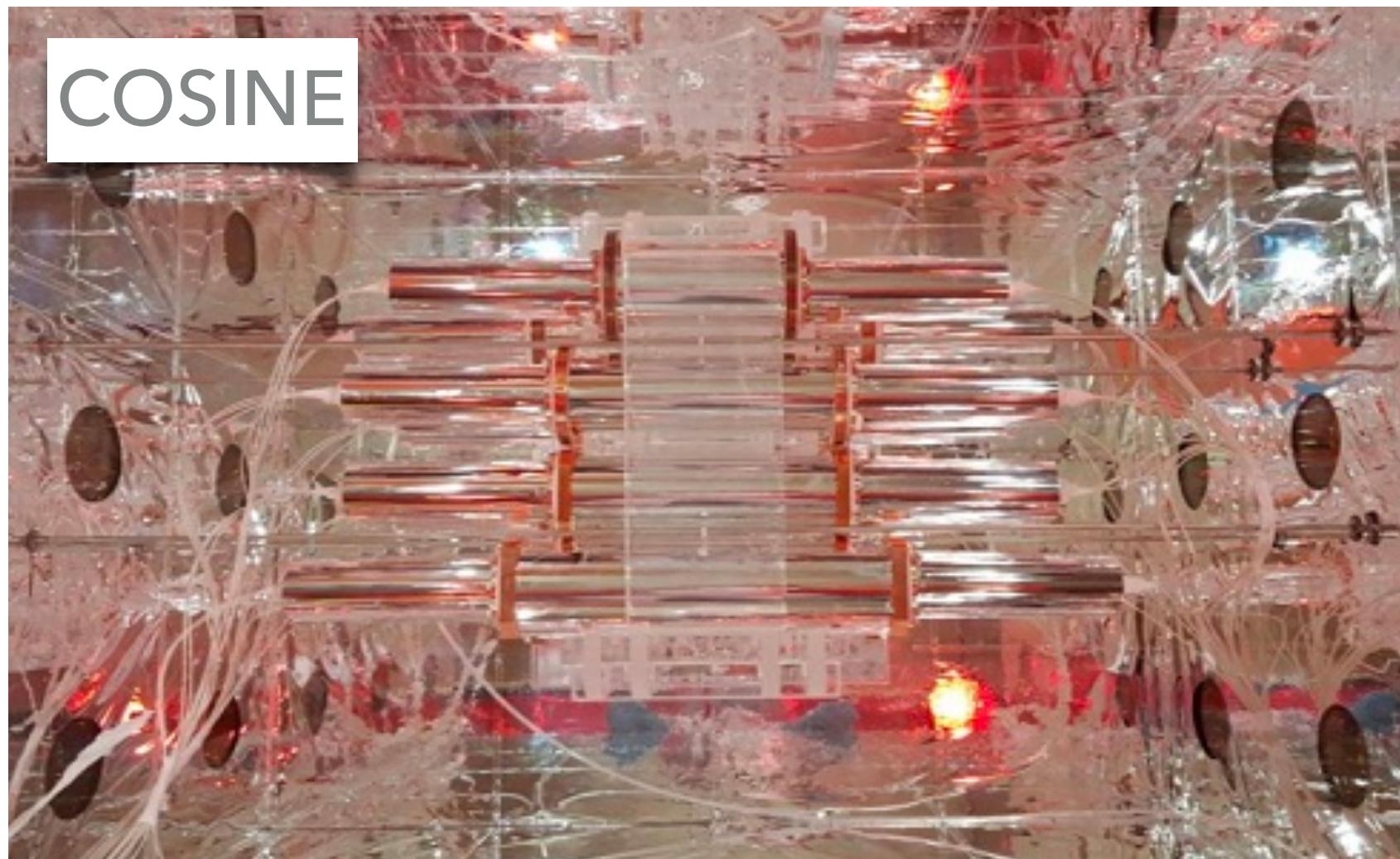


- ▶ 250 kg highly radio-pure NaI(Tl)
- ▶ 15 annual cycles
- ▶ Favors the Dark Matter annual modulation signal hypothesis at 13.7σ C.L.
- ▶ BUT so far no confirmation by any other experiment

Nal SCINTILLATING CRYSTALS



DAMA/LIBRA



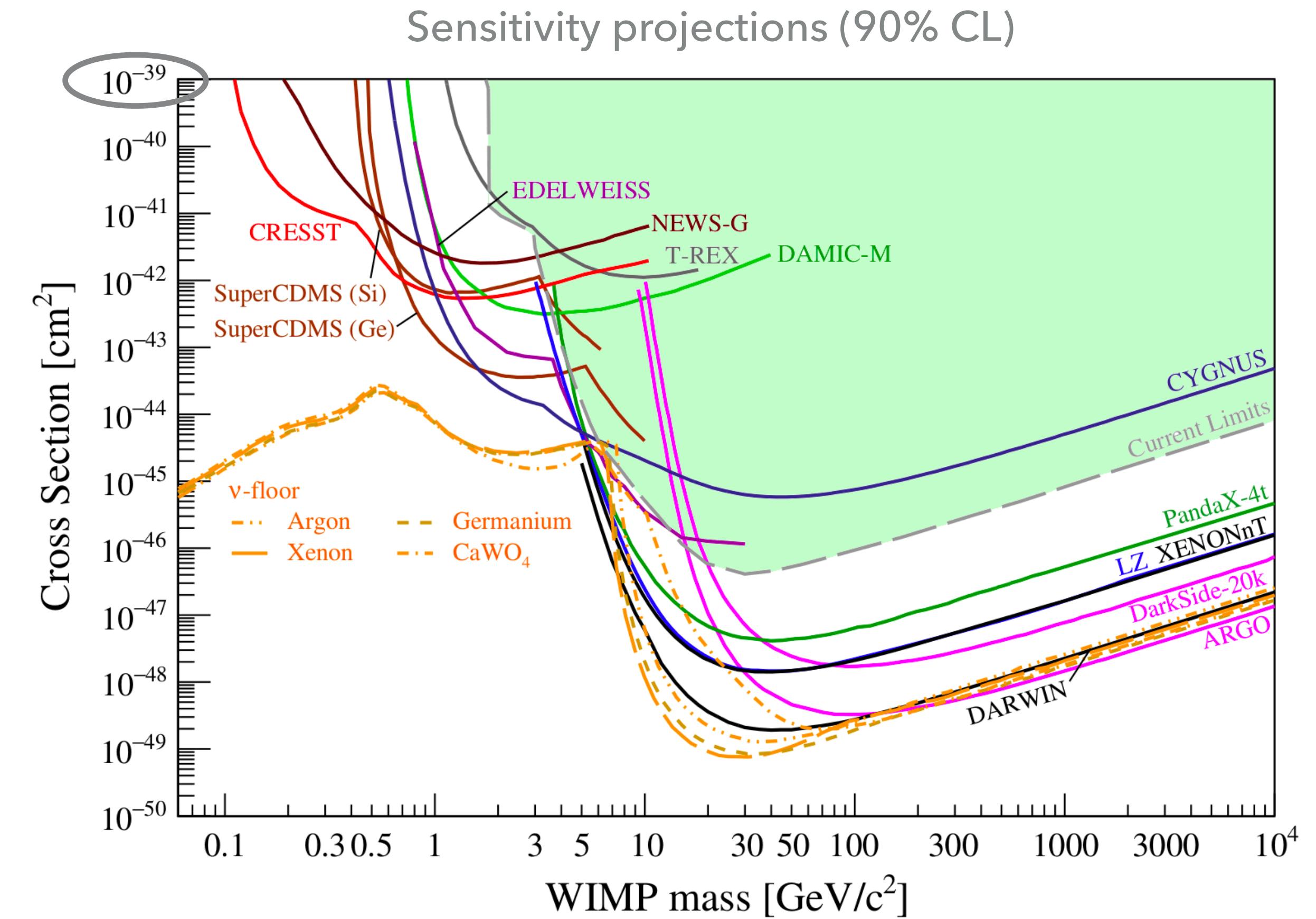
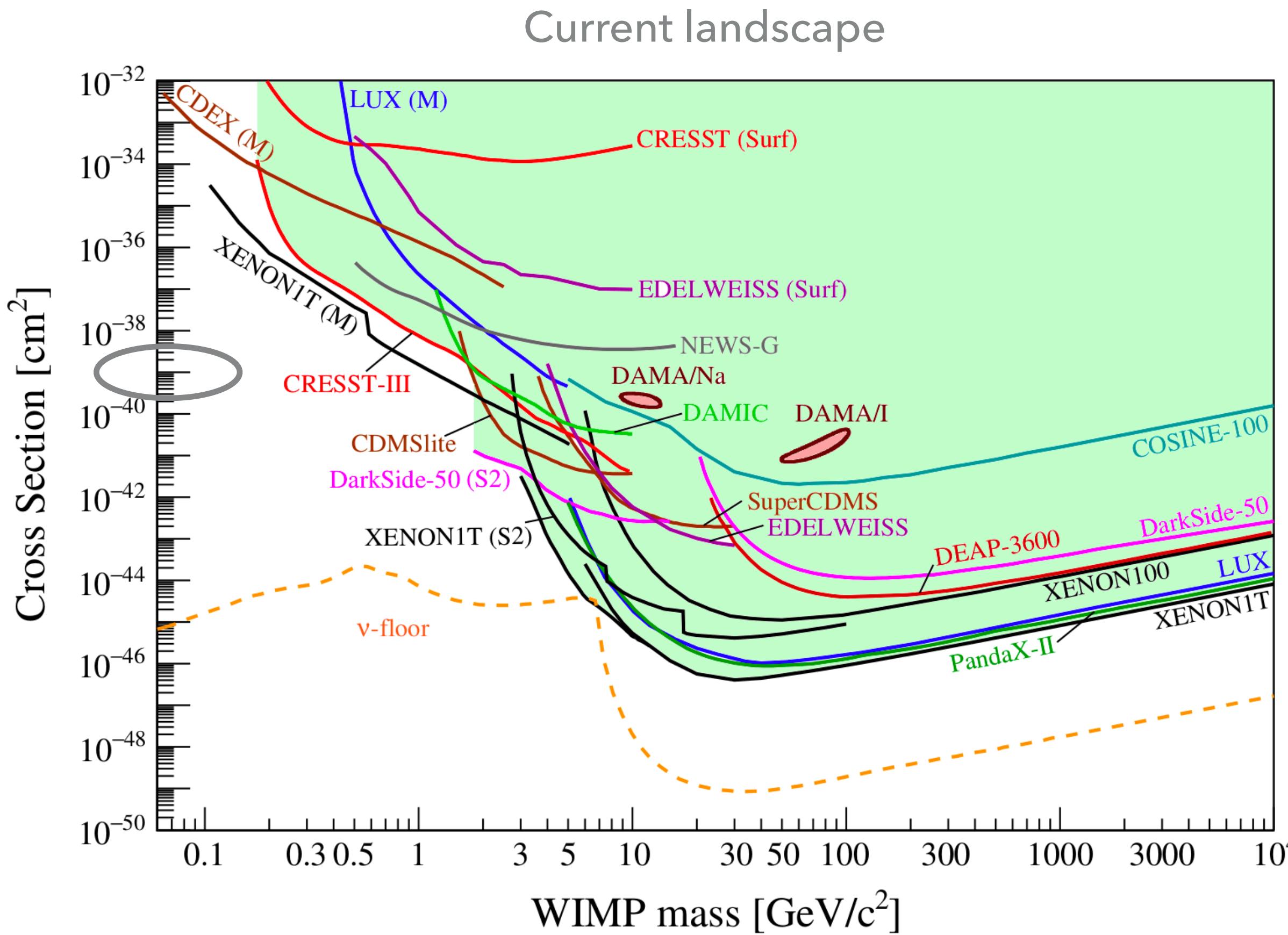
COSINE



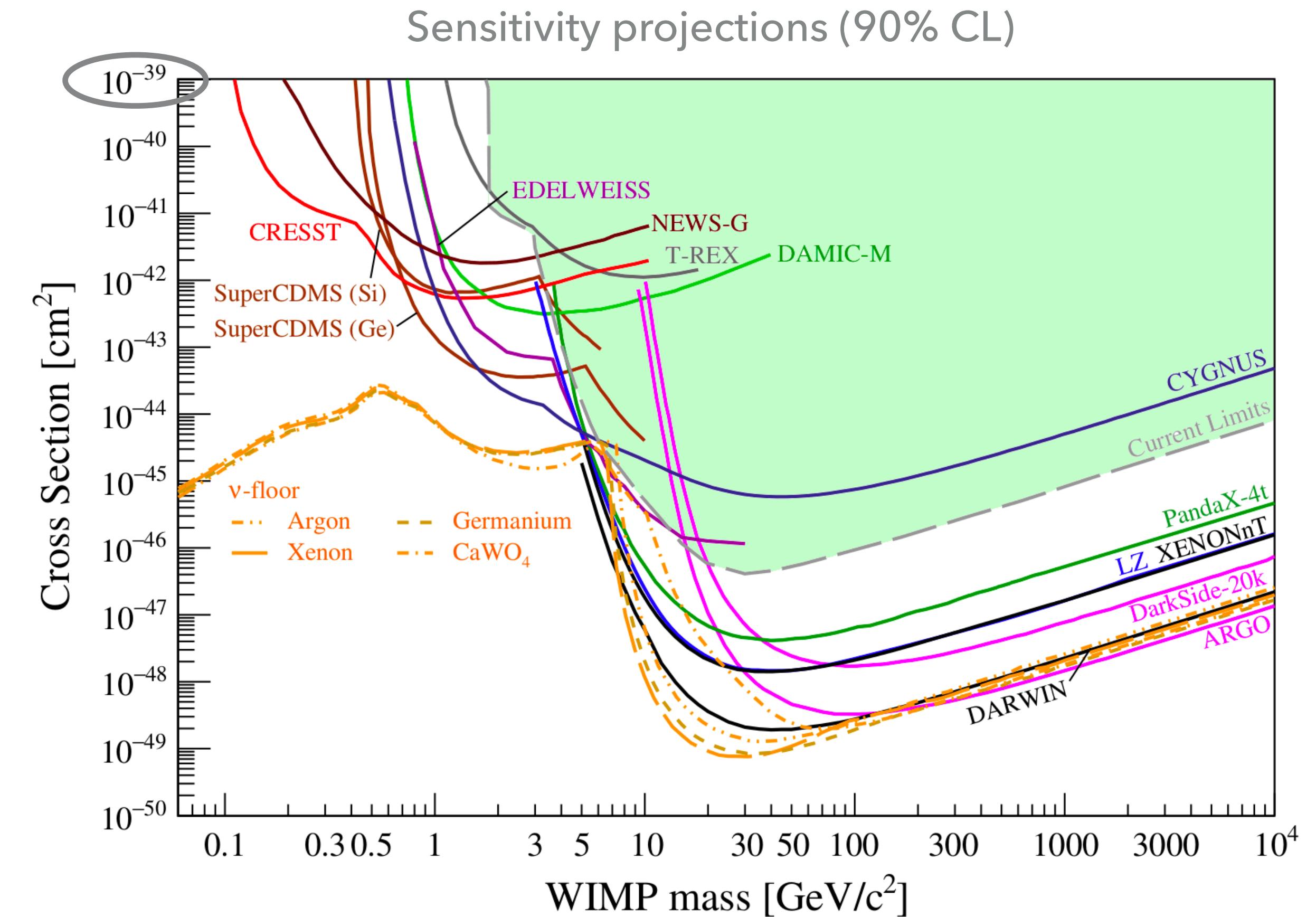
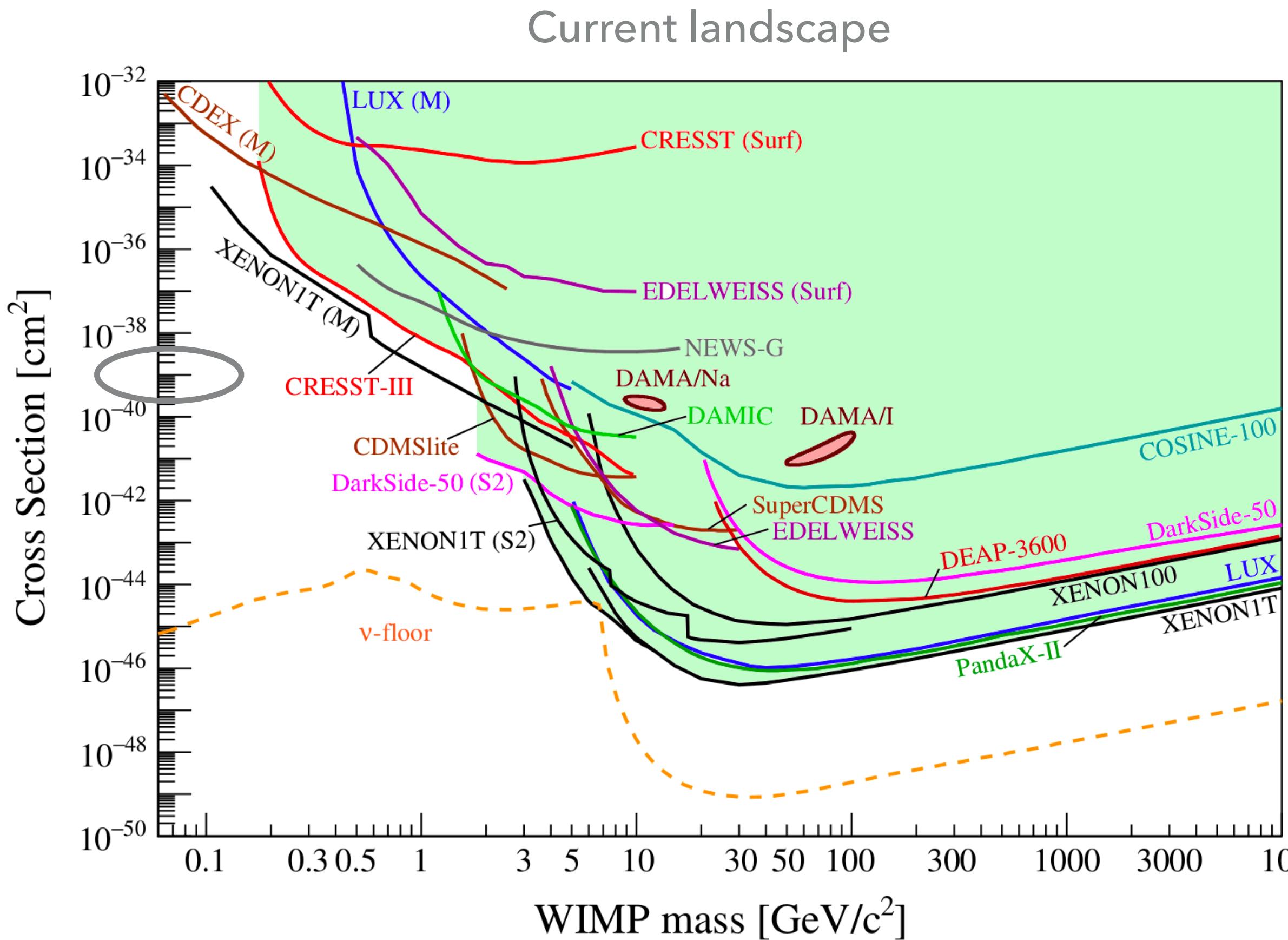
ANAIS

- ▶ BUT those other experiments use different targets, methods, ...
- ▶ Need (and have!) dedicated Nal experiments to probe the DAMA/LIBRA observation
- ▶ Stay tuned!

SPIN-INDEPENDENT WIMP-NUCLEON SCATTERING LANDSCAPE



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Stay tuned!