Emerging Concepts in Dark Matter Detection

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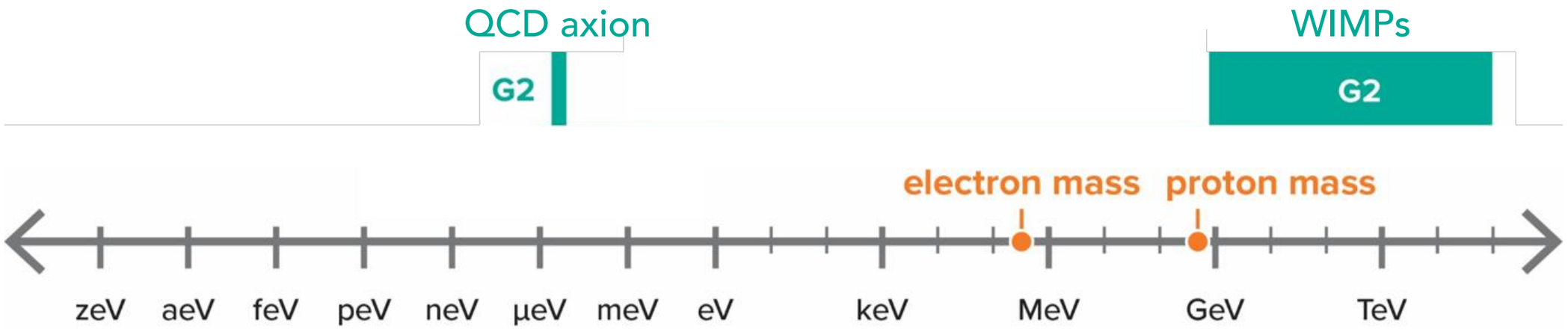
UCSD

February 22, 2023
P5 Town Hall

Dark Matter Landscape

2014 P5 recommendation

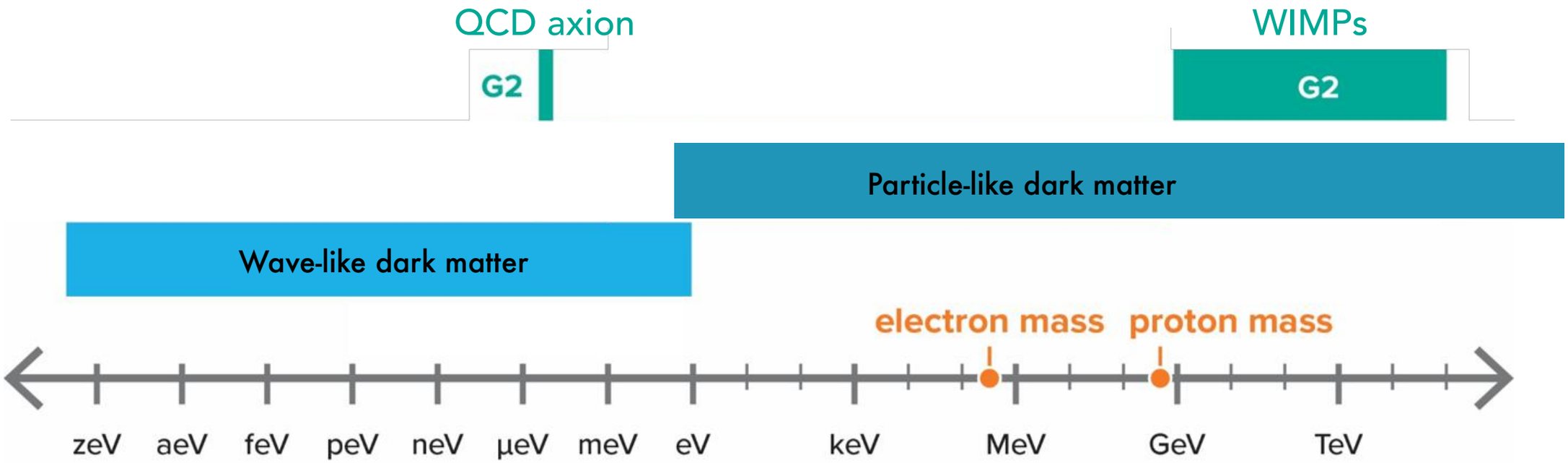


Excellent reasons to target DM in these mass ranges
Well-honed tools, familiar theory motivations

Additional P5 recommendation: portfolio of smaller projects

Basic Research Needs report:
"Dark Matter Small Projects New Initiatives"

A wider landscape of dark matter candidates



10^{-21} eV

Basic Research Needs report:
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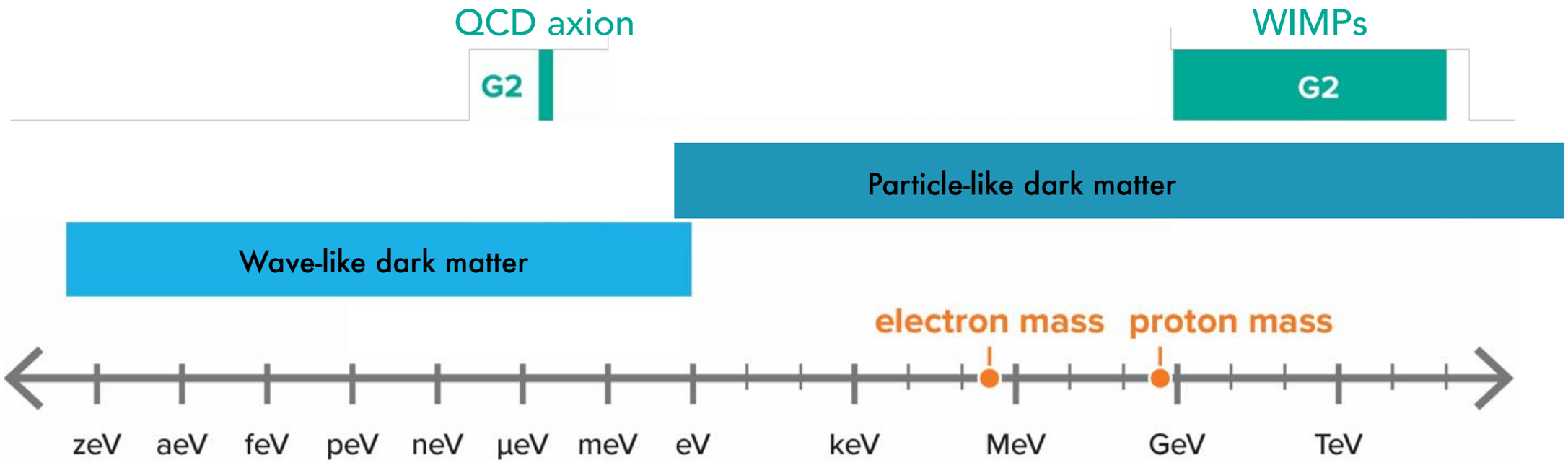
A wider landscape of dark matter candidates



10^{-21} eV

New theory targets and tools to probe them

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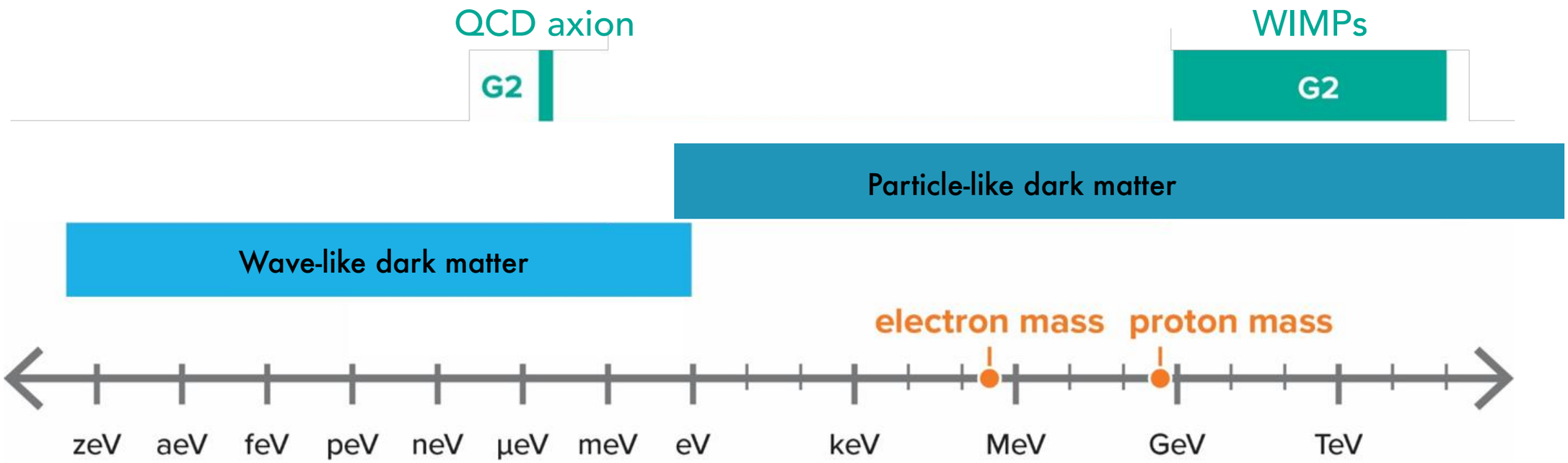


10^{-21} eV

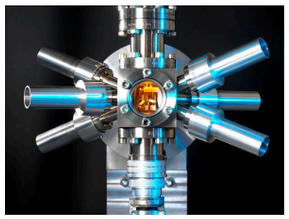
New theory targets and tools to probe them

Previous P5 recommendation of small-scale projects supported Dark Matter New Initiatives (DMNI) effort

Basic Research Needs report:
"Dark Matter Small Projects New Initiatives"

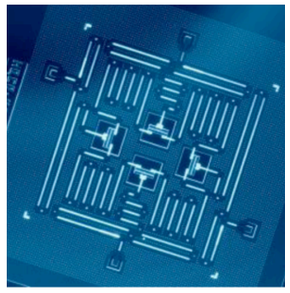
New concepts and technologies can open new windows into dark sector physics

Atomic clocks

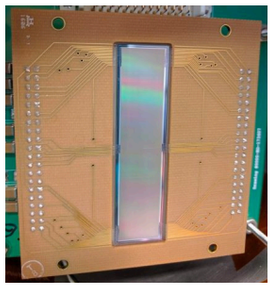


SRF Cavity

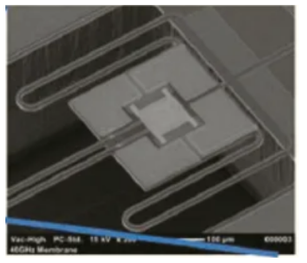
Qubits



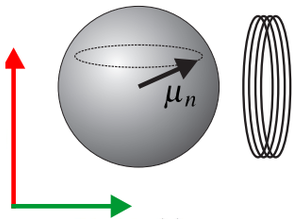
Skipper CCD



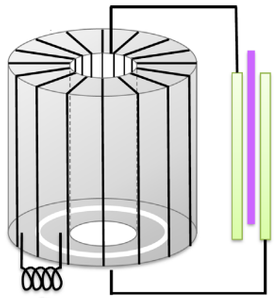
TES



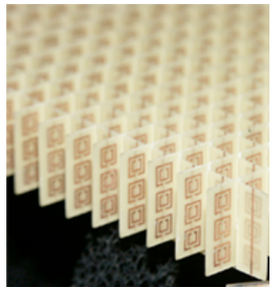
NMR



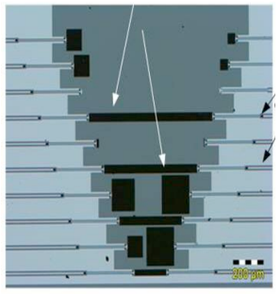
LC Resonators



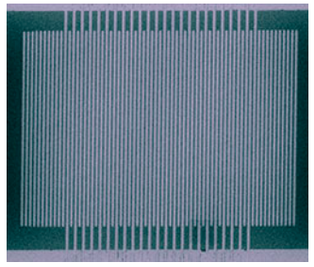
Metamaterials



KIDs



SNSPDs



and many more

Small-scale experiments can have a huge impact!

Cosmic Frontier Summary Report

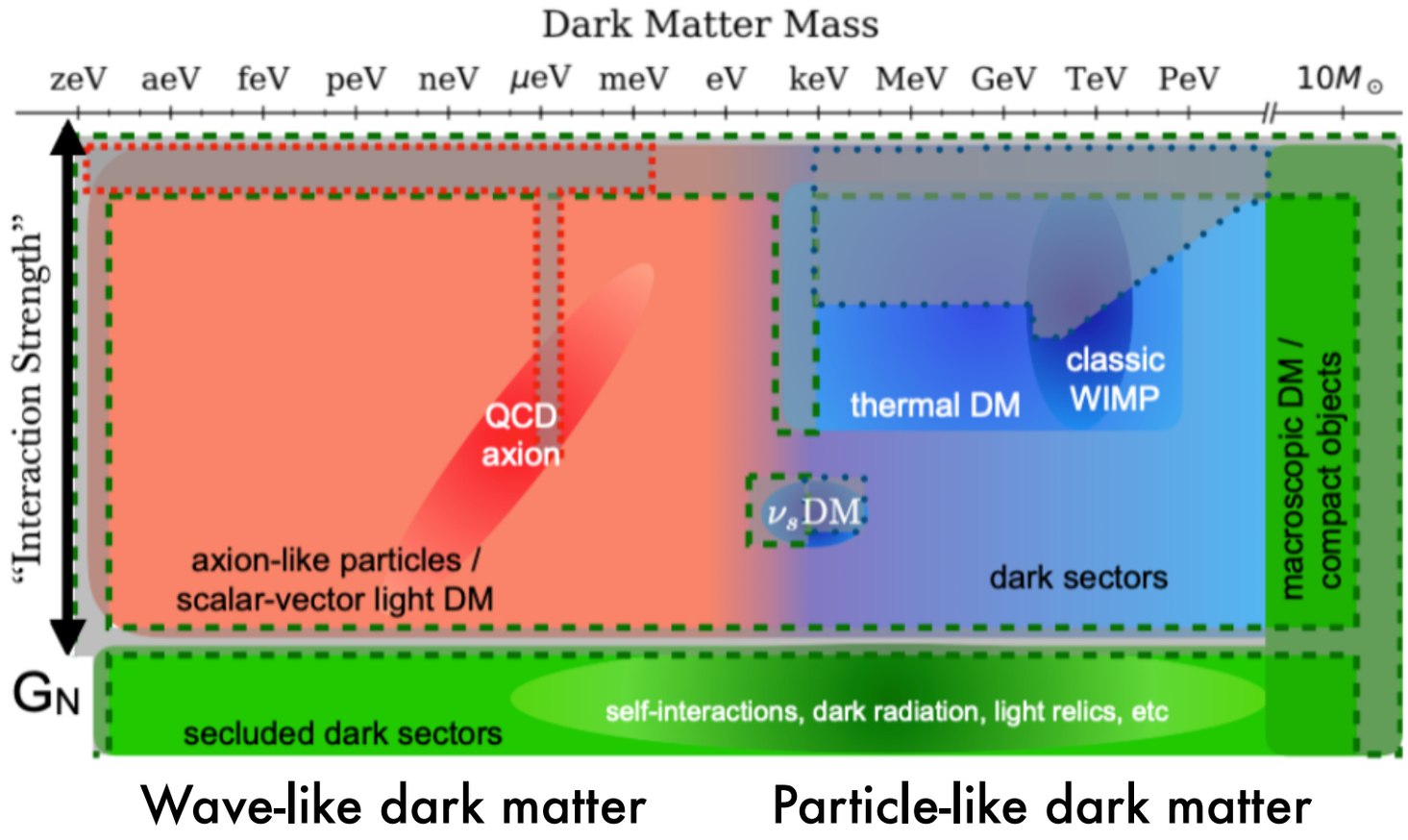
The HEP community has identified potentially transformative opportunities to address fundamental physics questions via Cosmic Frontier programs. We aspire to **Aim High**, **Search Wide**, and **Delve Deep**:

- Complete the CMB-S4 cosmic microwave background experiment and build a large spectroscopic facility (Spec-S5) to study physics including inflation, dark energy, light relics, modifications to general relativity, and dark matter.

- Pursue a broad program investigating the full landscape of dark matter candidates, including implementation of the existing Dark Matter New Initiatives (DMNI) portfolio and development of future DMNI-like programs focused on small projects; investment in new quantum technologies; and engagement of the HEP community in the development and execution of cosmic and indirect searches for dark matter, to take full advantage of the unique opportunities provided by cosmological and astrophysical probes (e.g., Rubin LSST and AugerPrime).

- Scale up mature technologies for weakly-interacting massive particle (WIMP) direct detection, fully exploring the parameter space down to the neutrino fog, and support high-energy gamma-ray telescopes (e.g., SWGO and CTA) to probe thermal WIMPs up to tens-of-TeV mass scales. Move ahead with new, construction-ready DMNI experiments with the capacity to probe the QCD axion over most of its viable mass range.

Opportunity for orders of magnitude coverage in sensitivity from portfolio of small projects



From Cosmic Frontier Snowmass 2021 study

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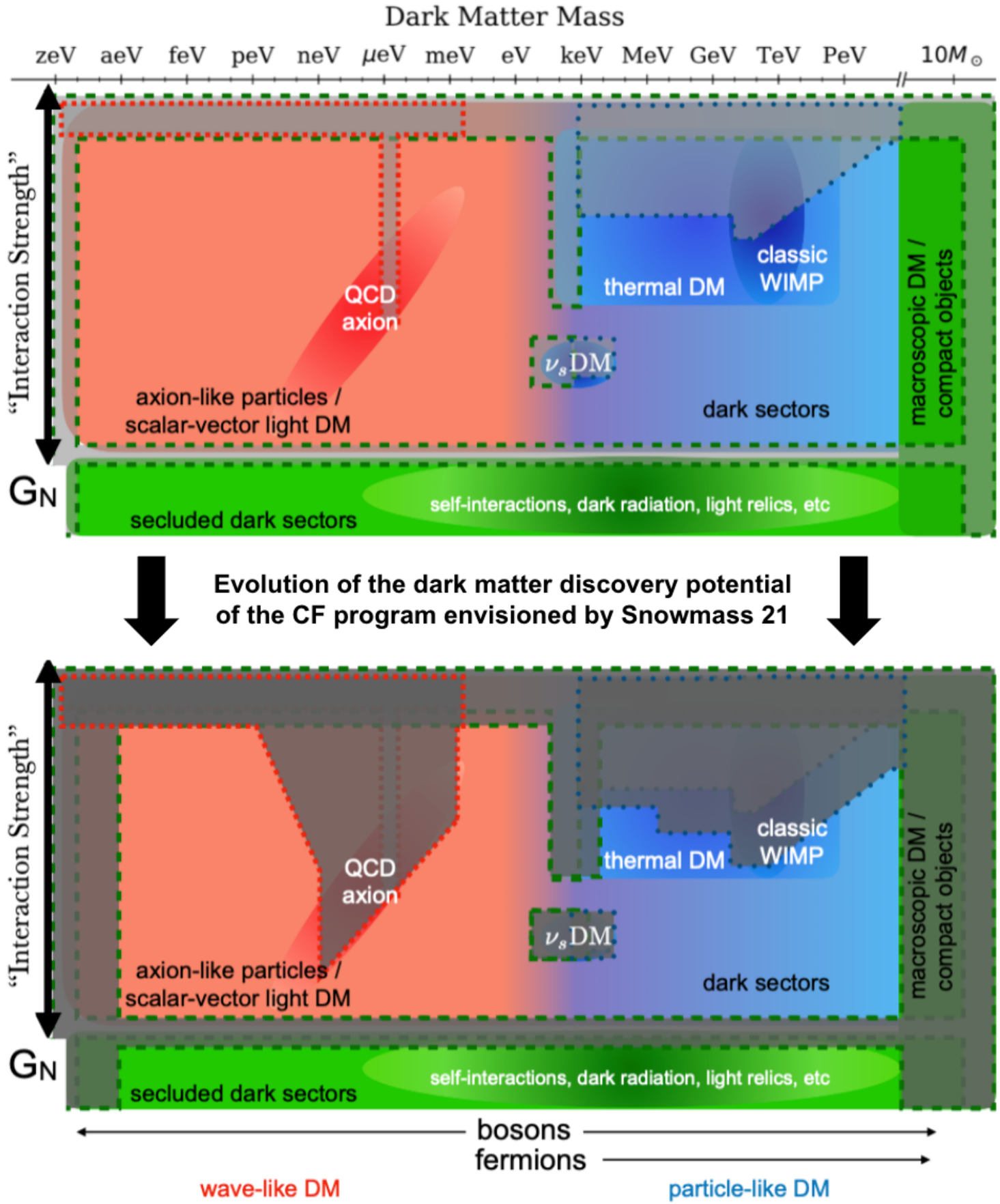


From Cosmic Frontier Snowmass 2021 study

Relic abundance from dark sectors

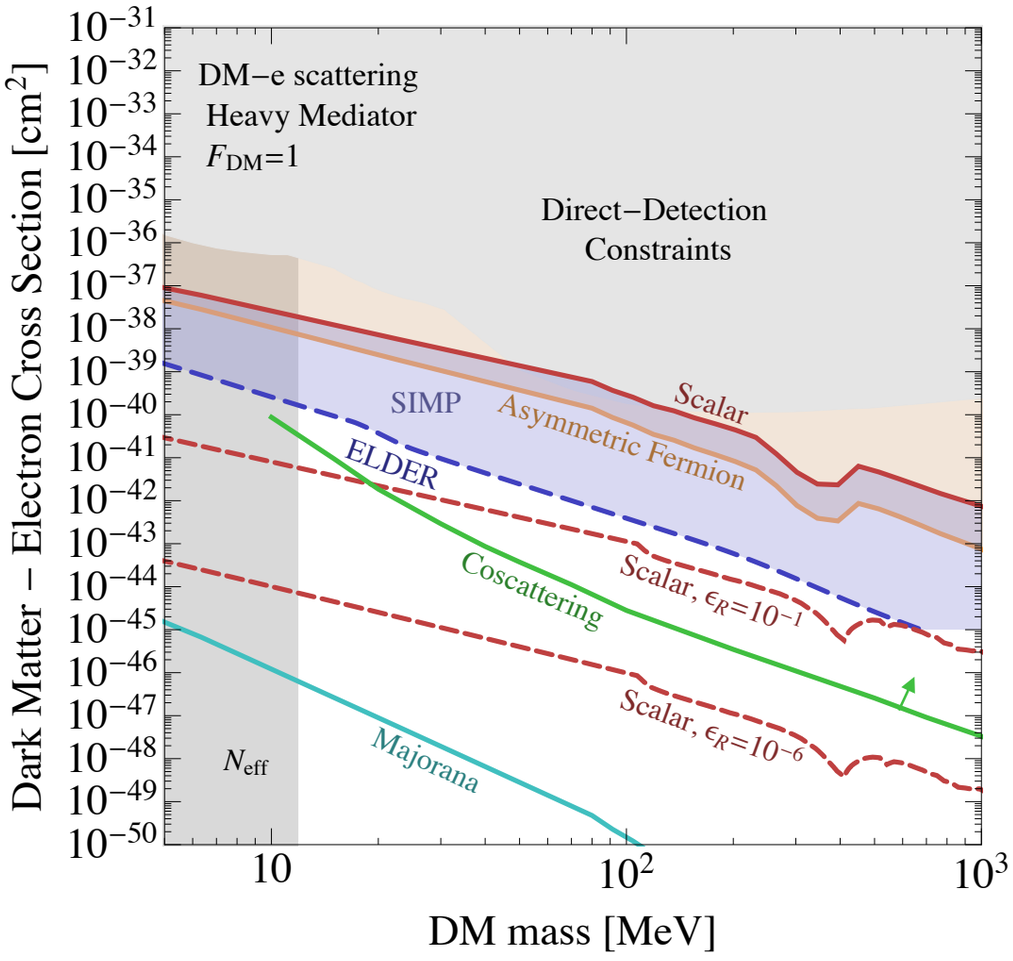
Significant theory progress in mechanisms for DM genesis.

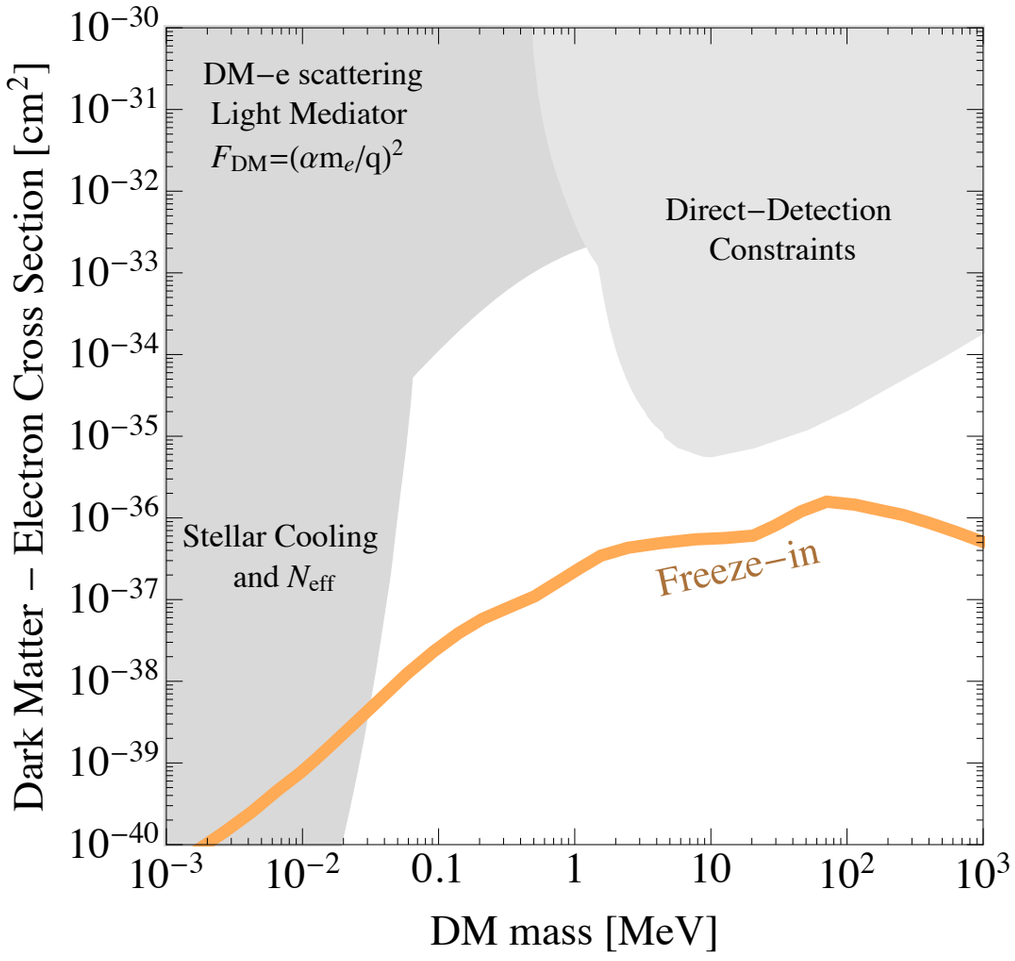
From CF1 white paper
“Landscape of low-threshold detection”

Relic abundance from dark sectors

Significant theory progress in mechanisms for DM genesis.

For $\mathrm{keV} \lesssim m_\chi \lesssim \mathrm{GeV}$, targets in DM-electron scattering:





From CF1 white paper
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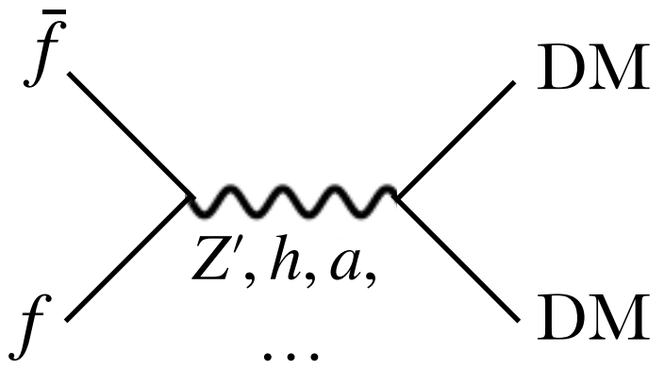
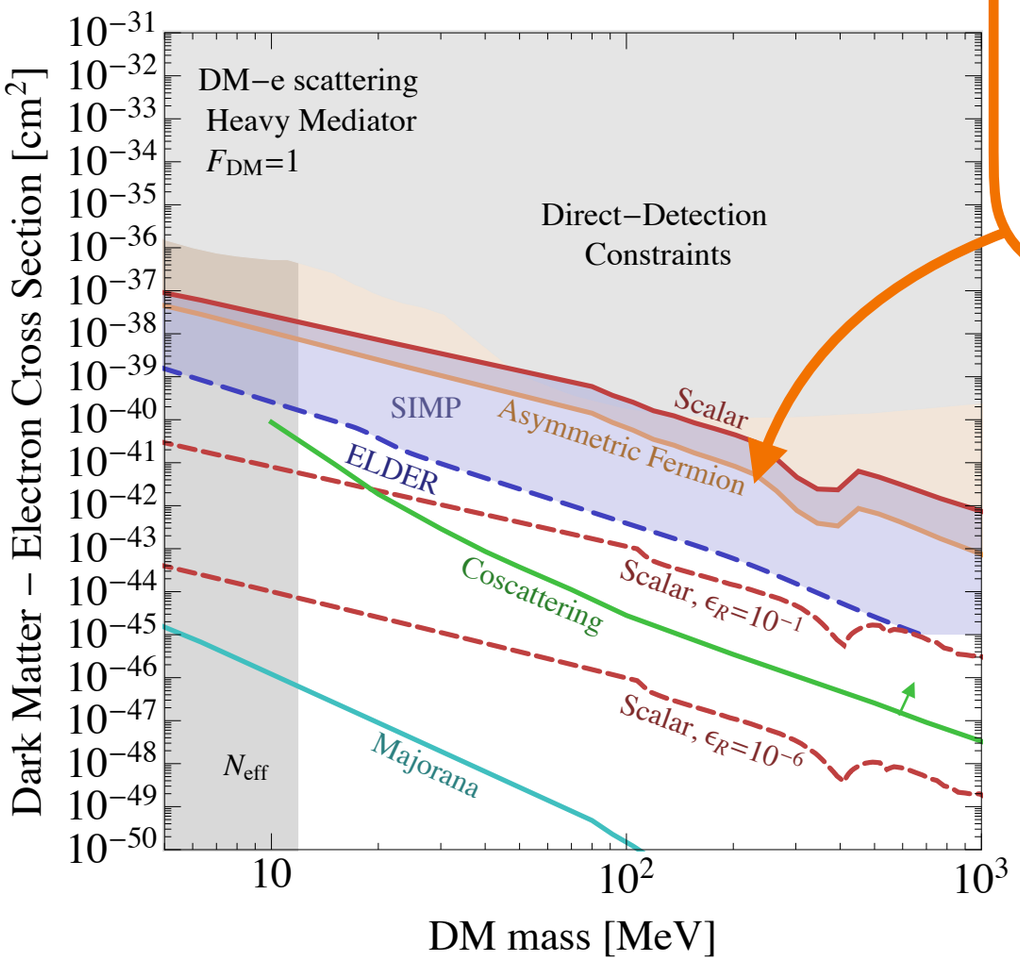
Relic abundance from dark sectors

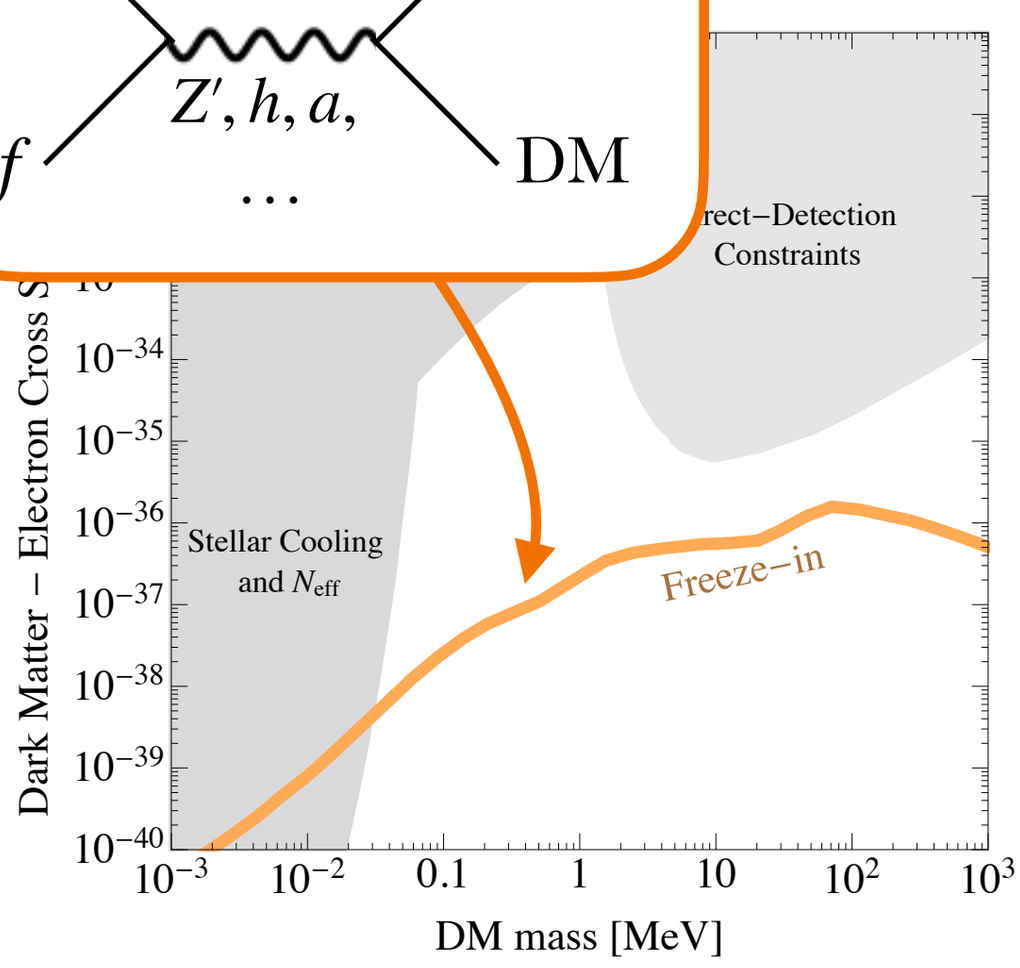
Significant theory progress genesis.

For keV $\lesssim m_\chi \lesssim$ GeV, targ ing:

annihilation via
light mediators







From CF1 white paper
“Landscape of low-threshold detection”

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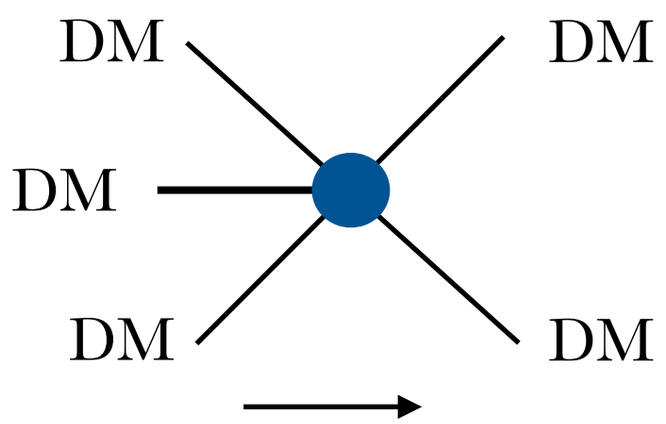
$\chi \lesssim$ GeV, targ ing:

SIMP, ELDER



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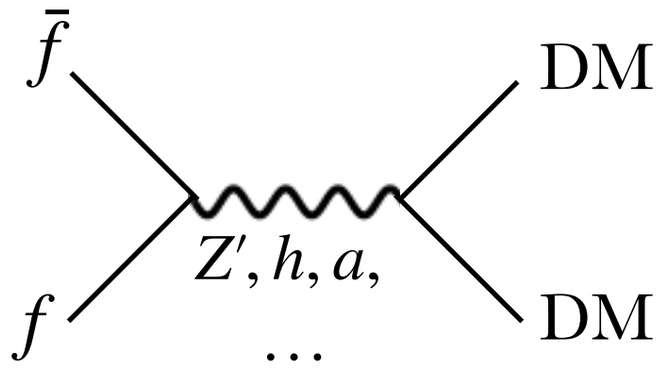

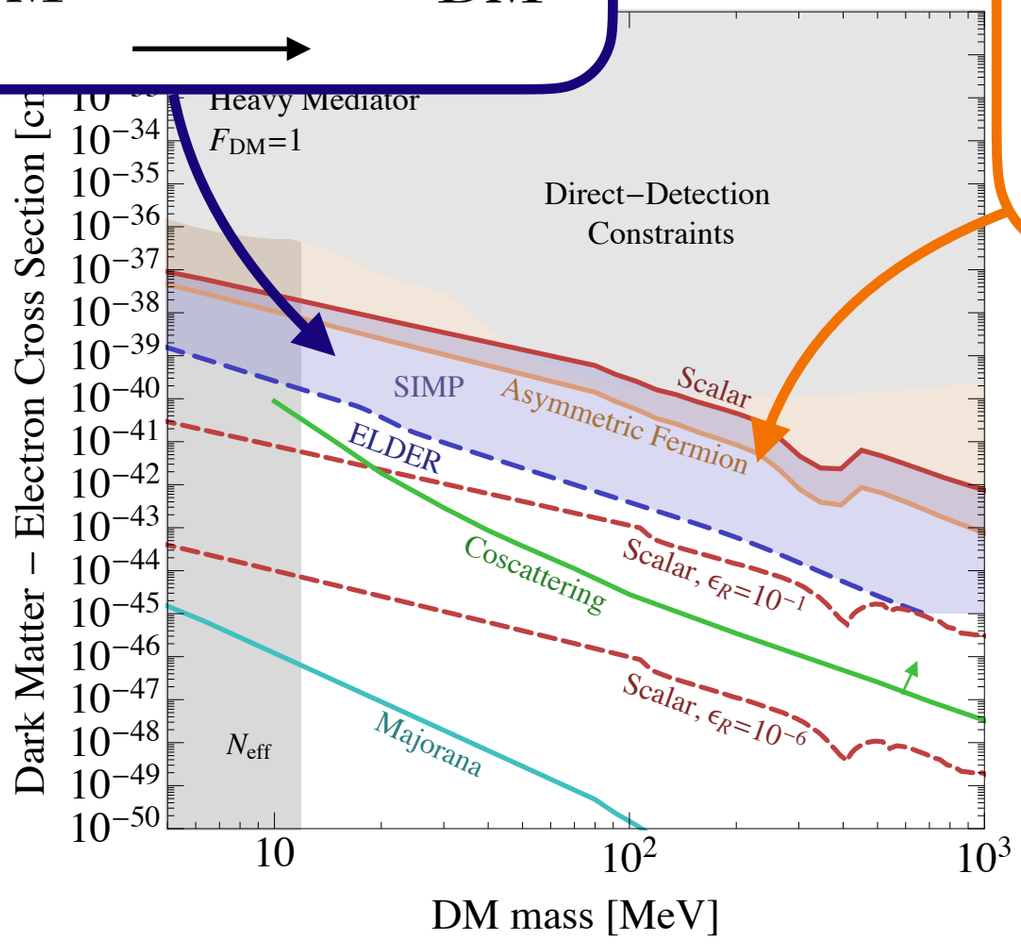

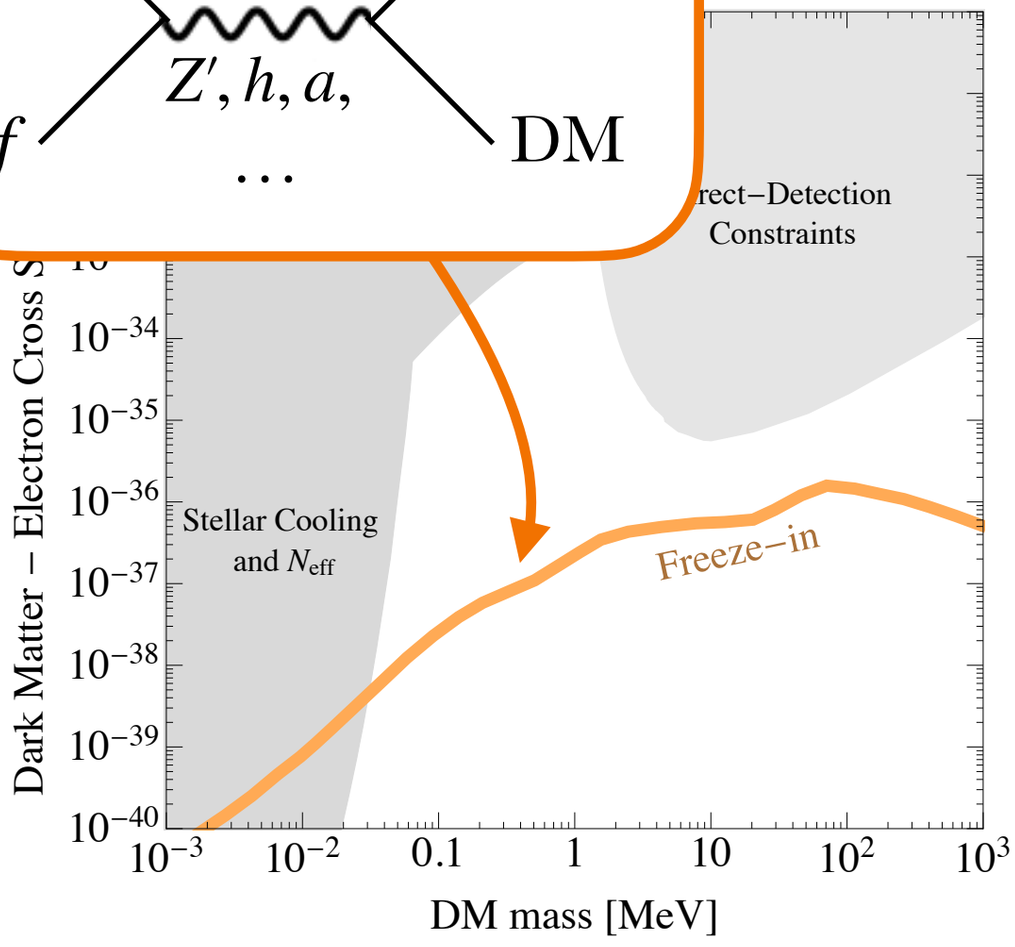

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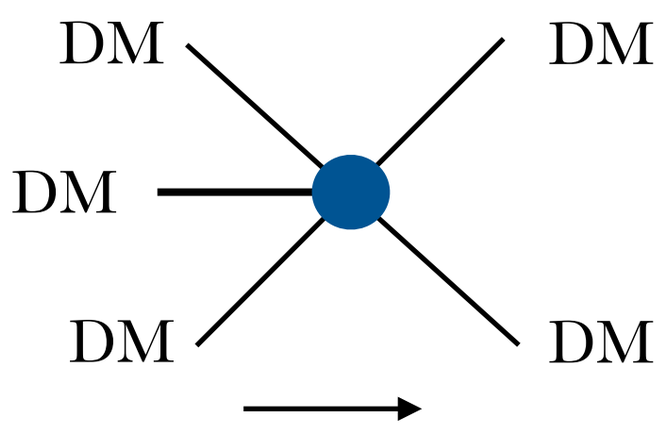

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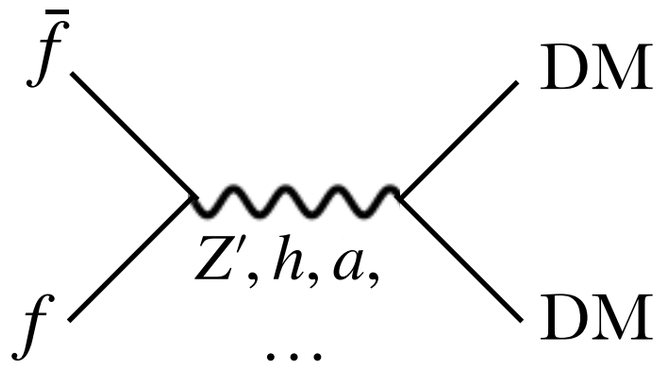
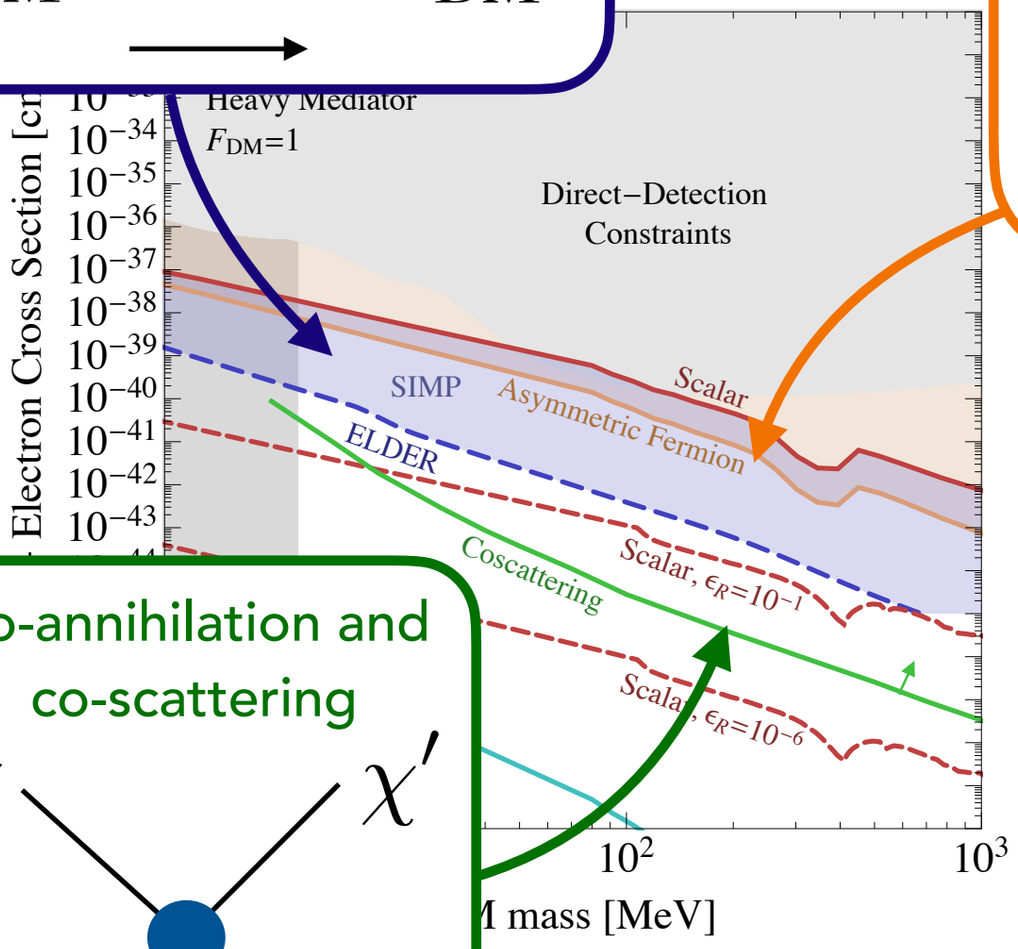
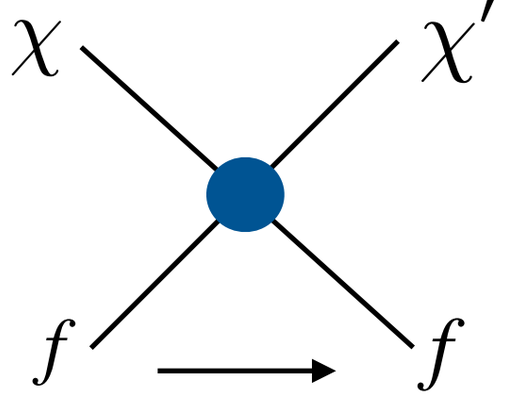
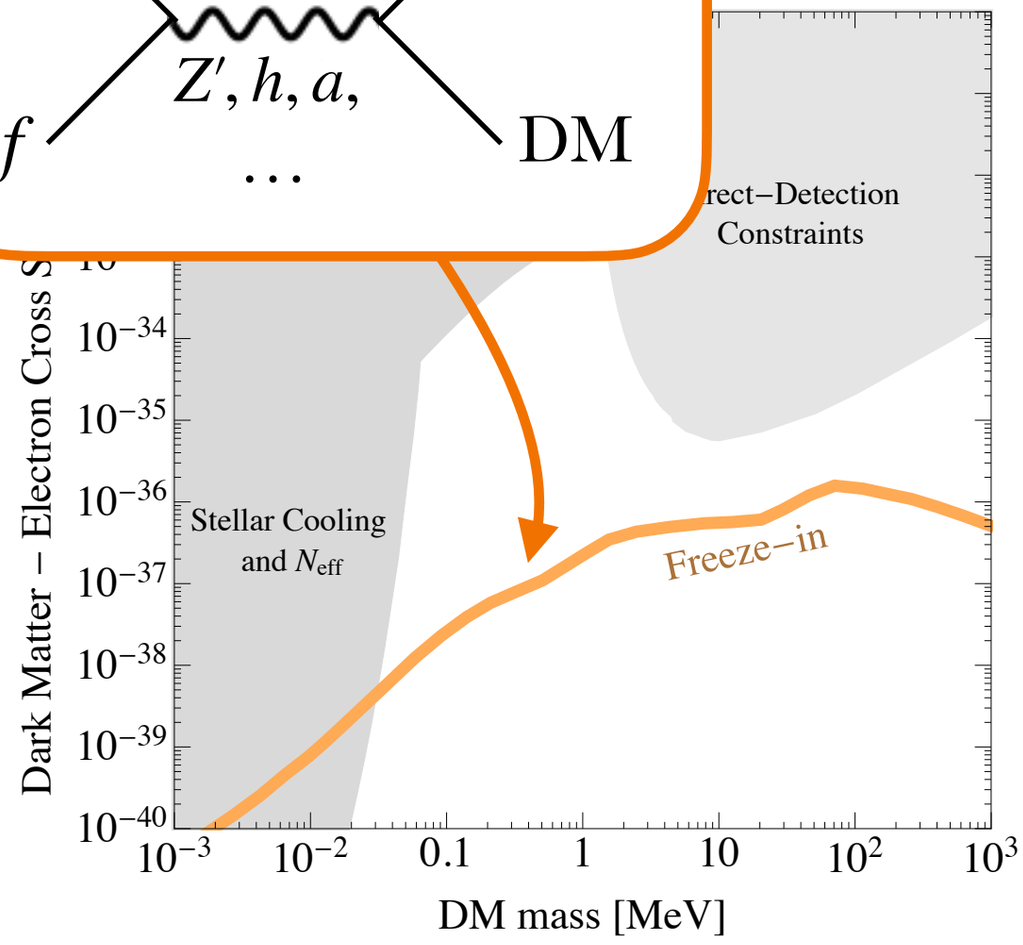




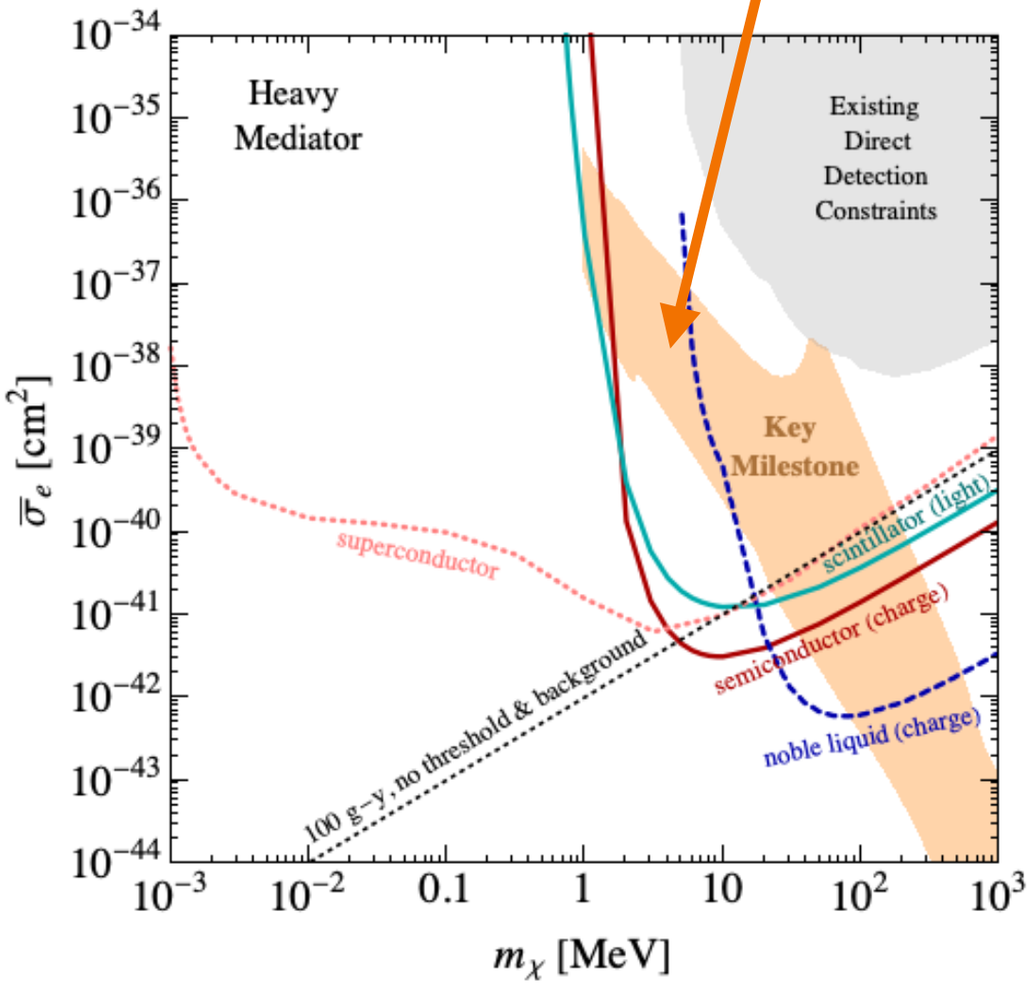
co-annihilation and
co-scattering

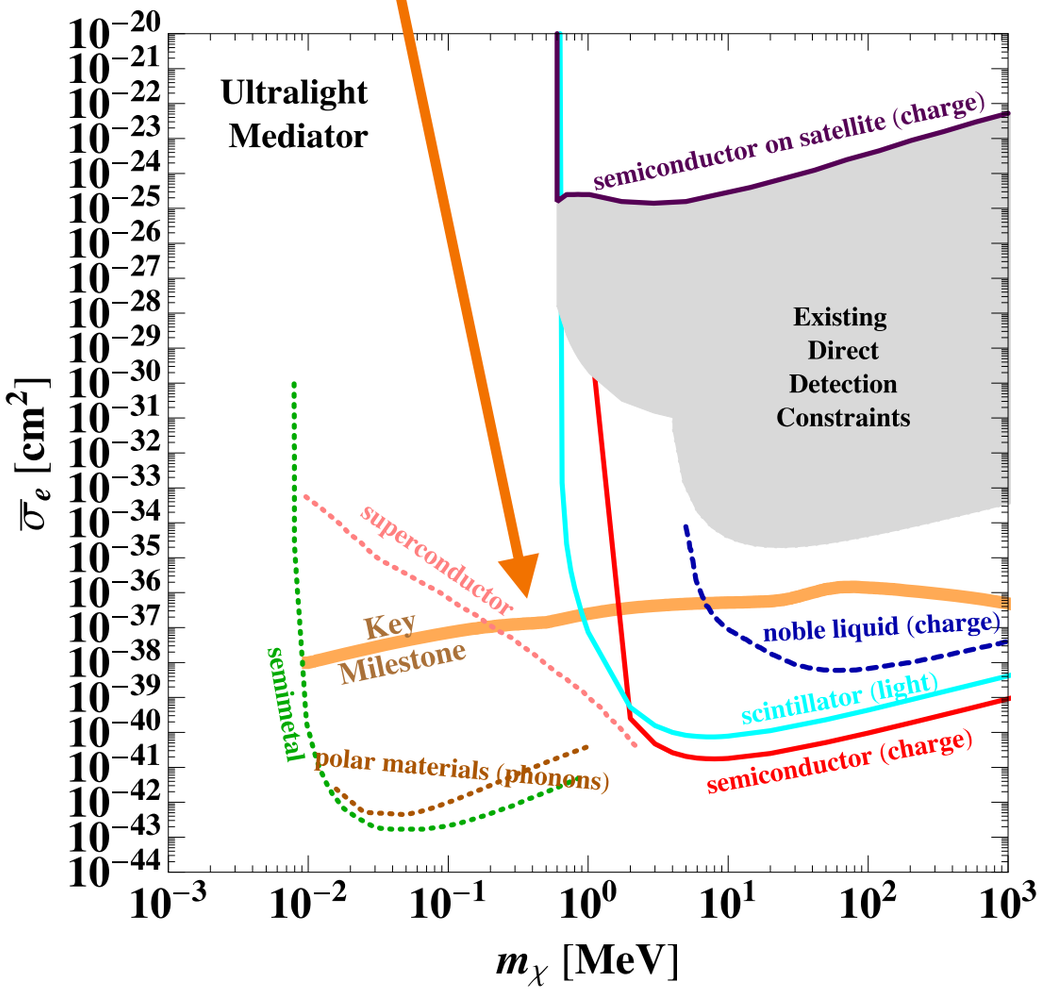




From CF1 white paper
“Landscape of low-threshold detection”

Opportunity to probe DM targets with a variety of small-scale detector concepts





DM-electron interactions for $m_{\mathrm{DM}} \gtrsim \mathrm{keV}$

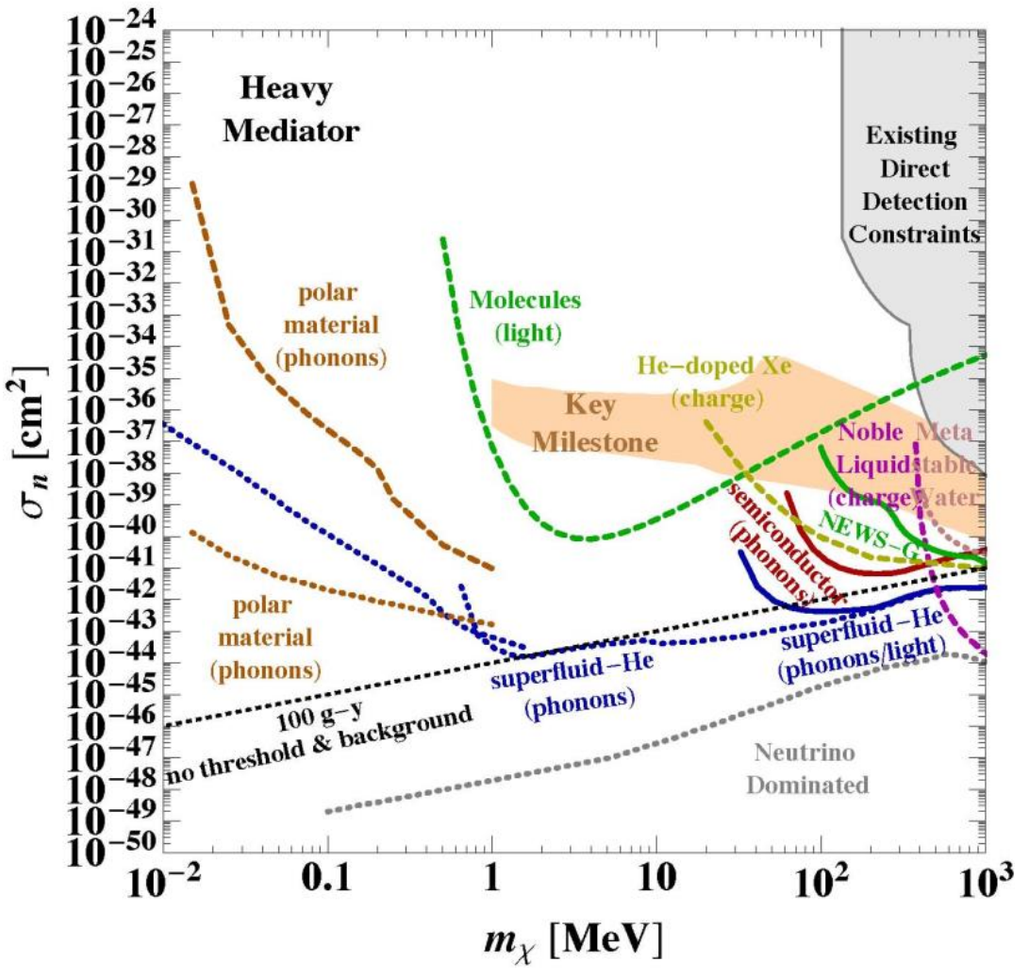
Lines assume O(kg-yr) exposure

Basic Research Needs report:
"Dark Matter Small Projects New Initiatives"

Dark sector interactions

DM-nucleon interactions

$m_{\rm DM} \gtrsim {\rm keV}$



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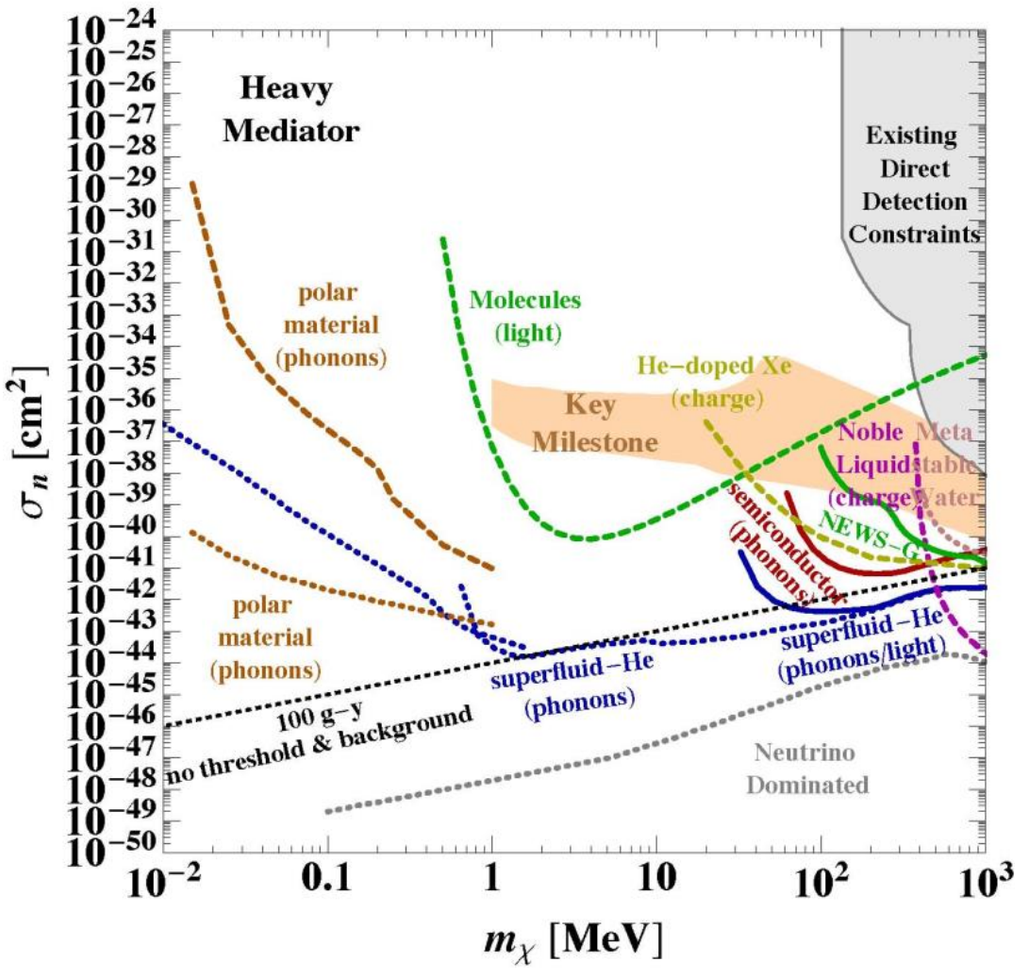
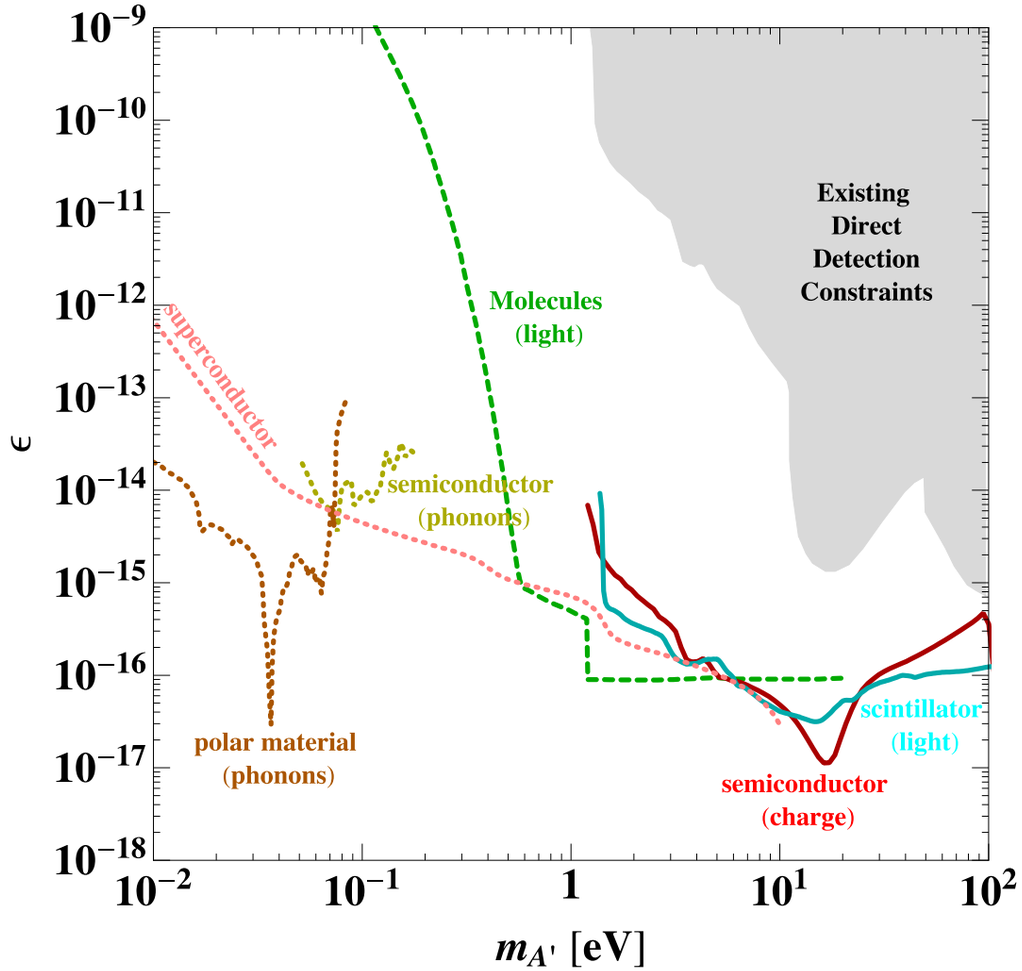


Dark photon DM absorption
$\mathrm{meV} \lesssim m_{\rm DM} \lesssim \mathrm{keV}$



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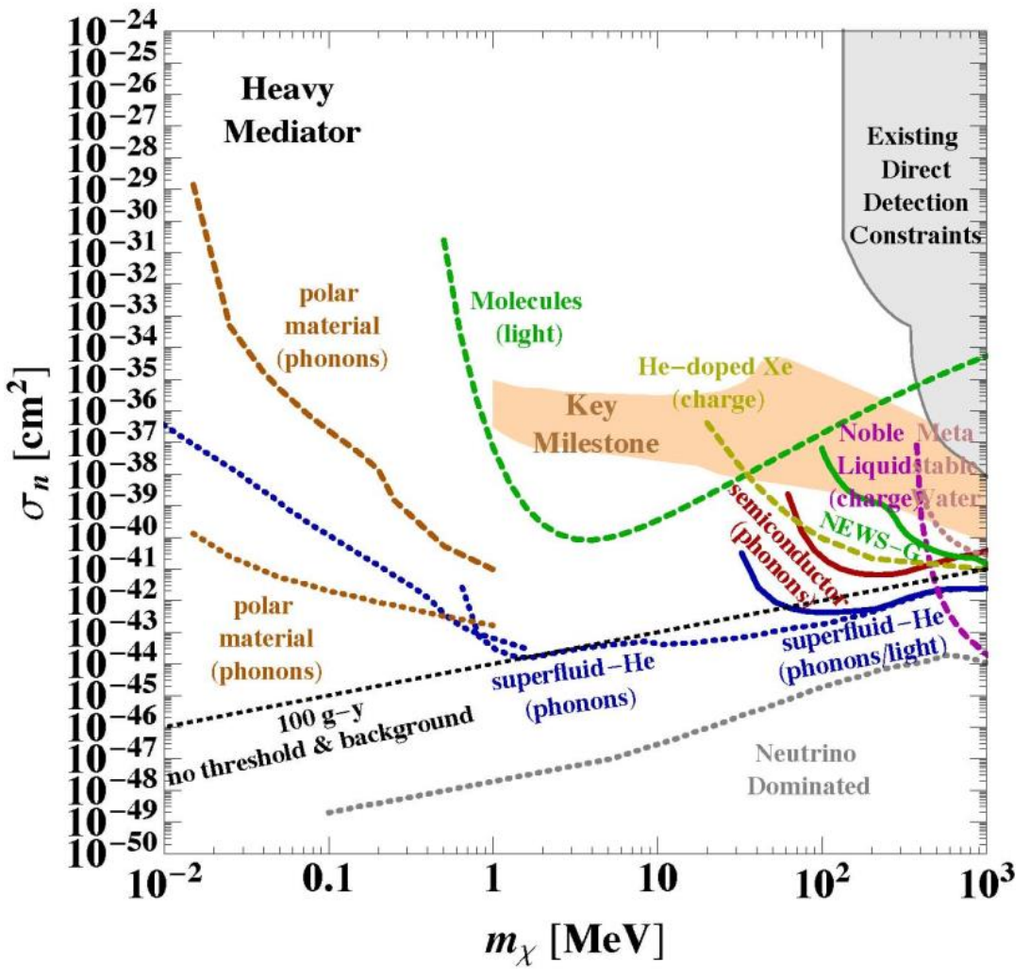

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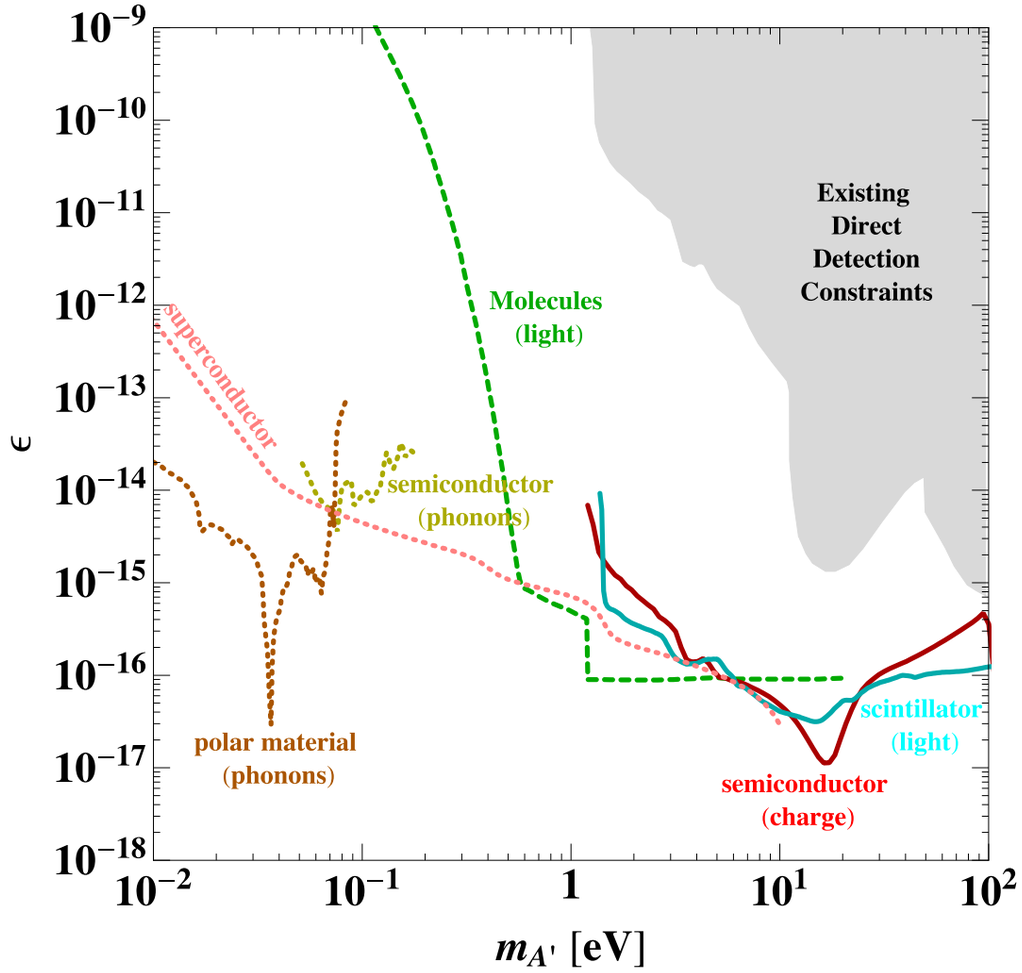
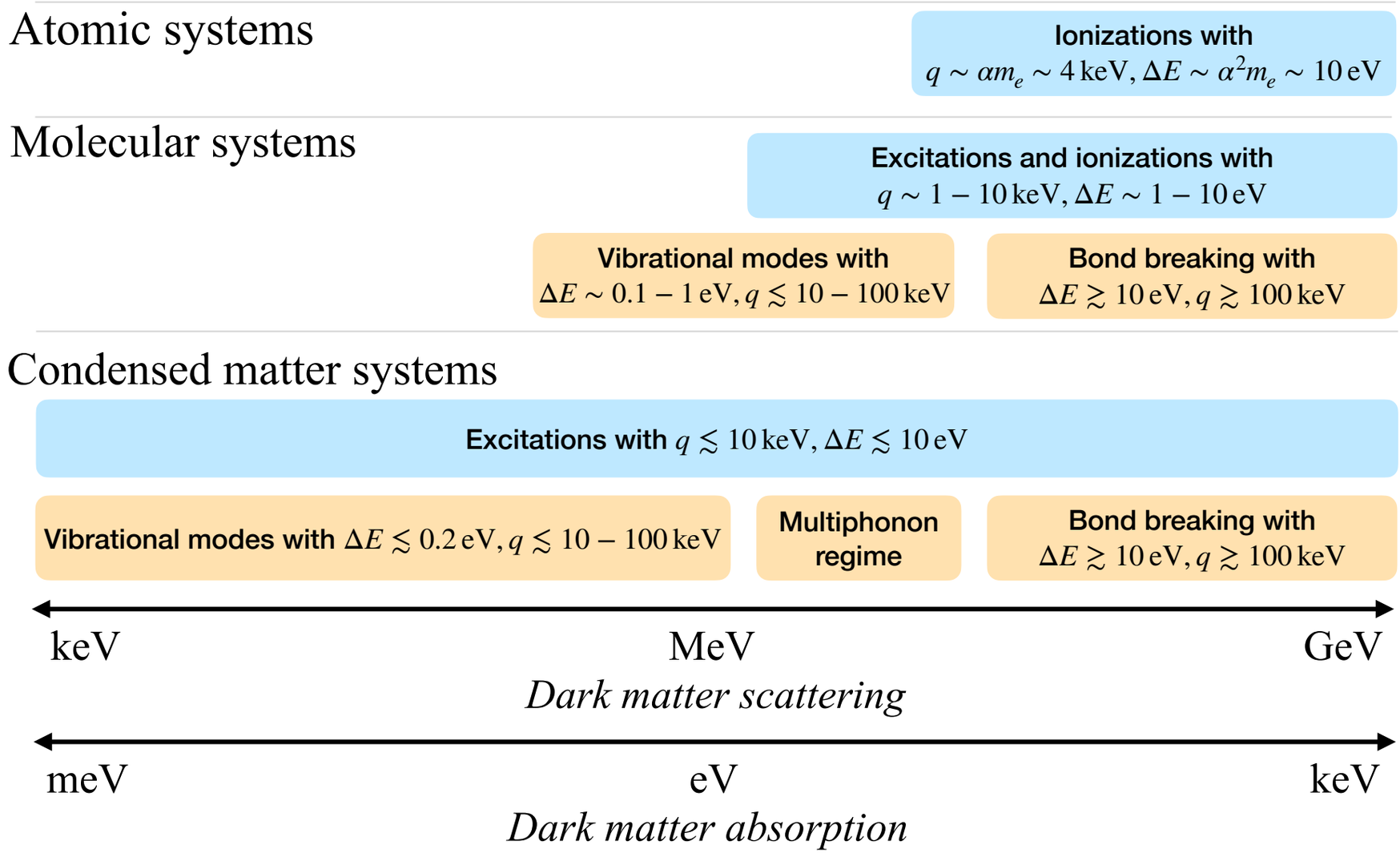


Many concepts from theorists *and* experimentalists

Basic Research Needs report:
"Dark Matter Small Projects New Initiatives"

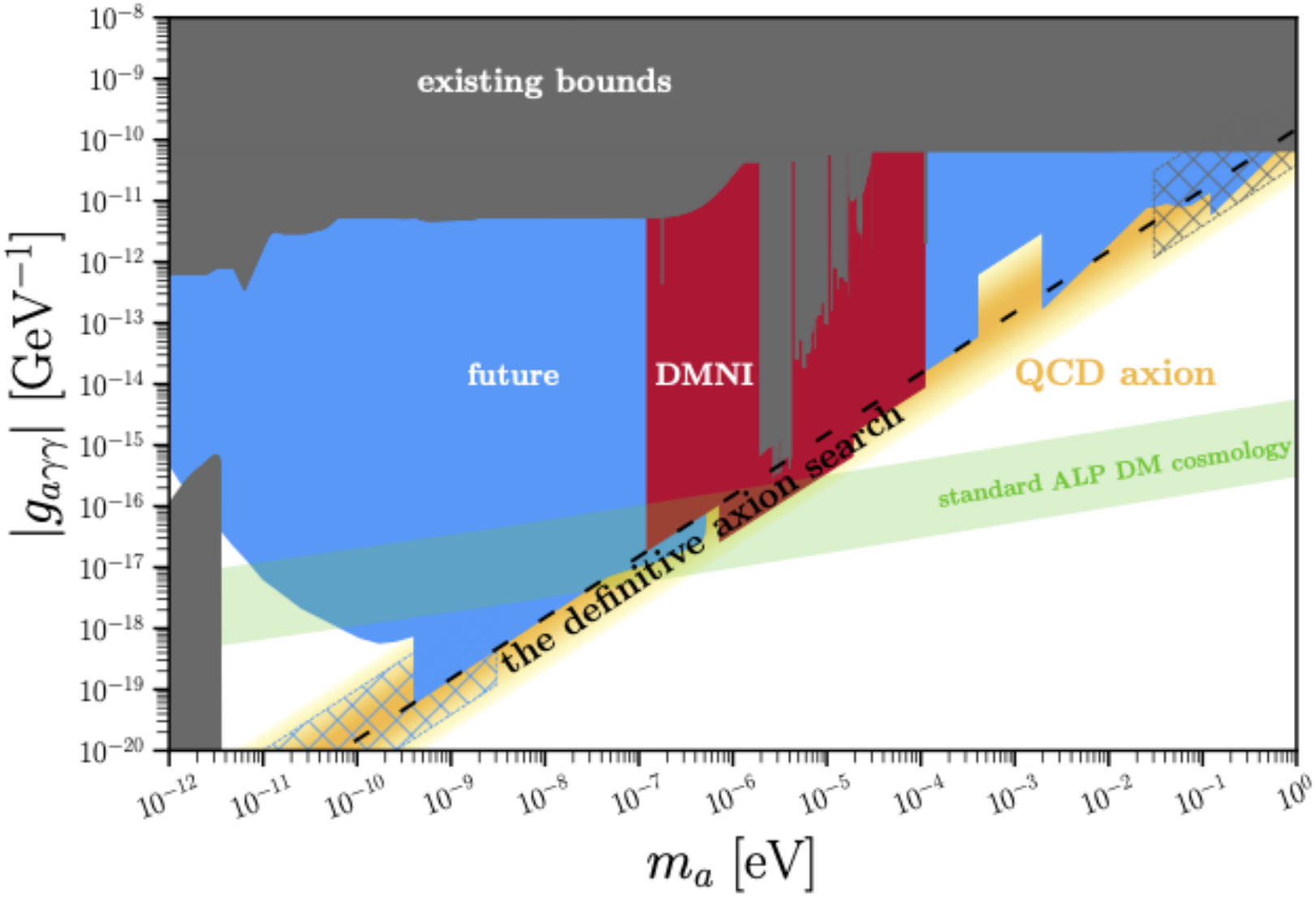
Detection concepts for particle-like DM

Utilize diversity of excitation modes in nature and advances in neighboring fields including materials science, quantum sensing.



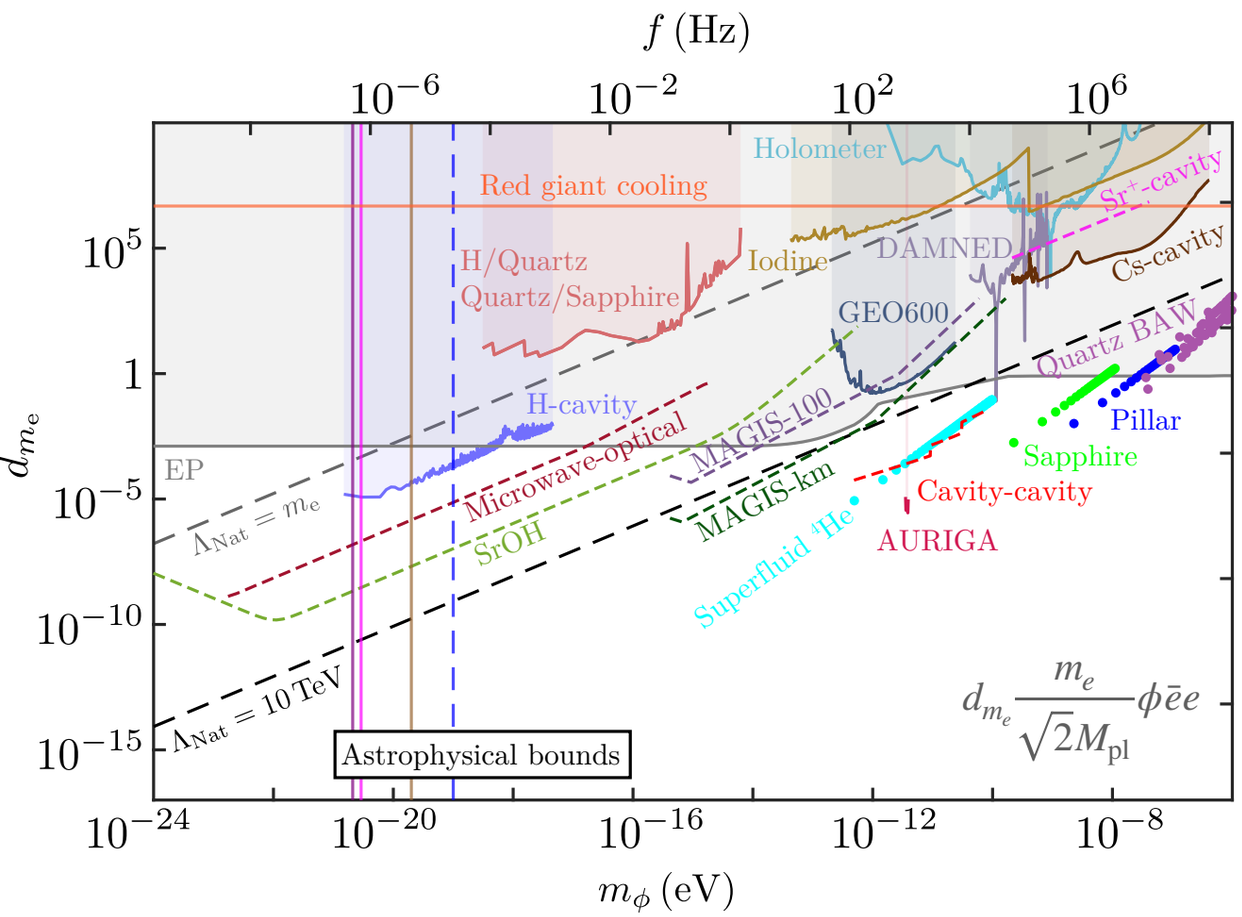
Bosonic (wave-like) dark matter

QCD axion DM and axion-like particles (ALPs)



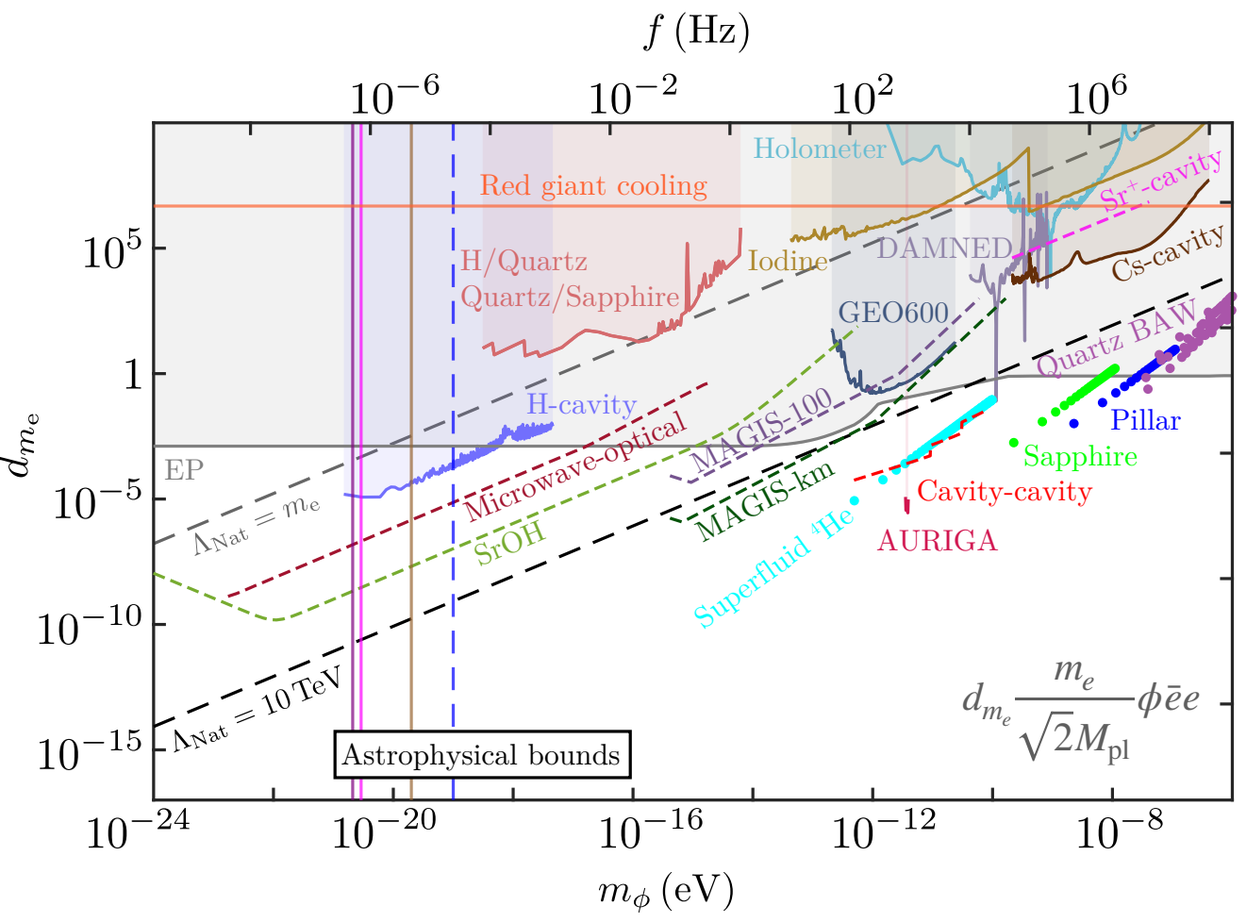
From CF2 “Wave-like DM” report

Scalar DM with $m_{\rm DM} \gtrsim 10^{-21}$eV

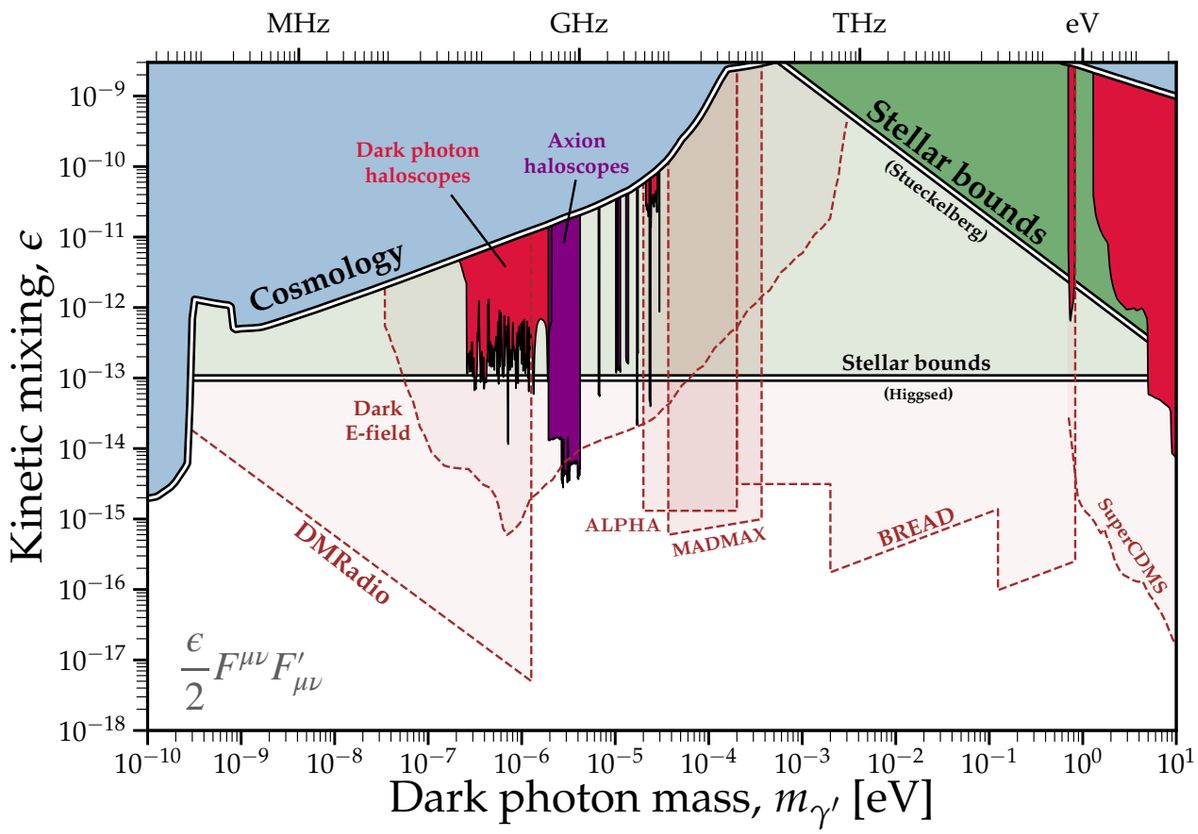


From Snowmass white paper on
"Scalar and Vector Ultralight Dark Matter"

Scalar DM with $m_{\rm DM} \gtrsim 10^{-21}$eV



Vector DM with $m_{\rm DM} \gtrsim 10^{-10}$eV



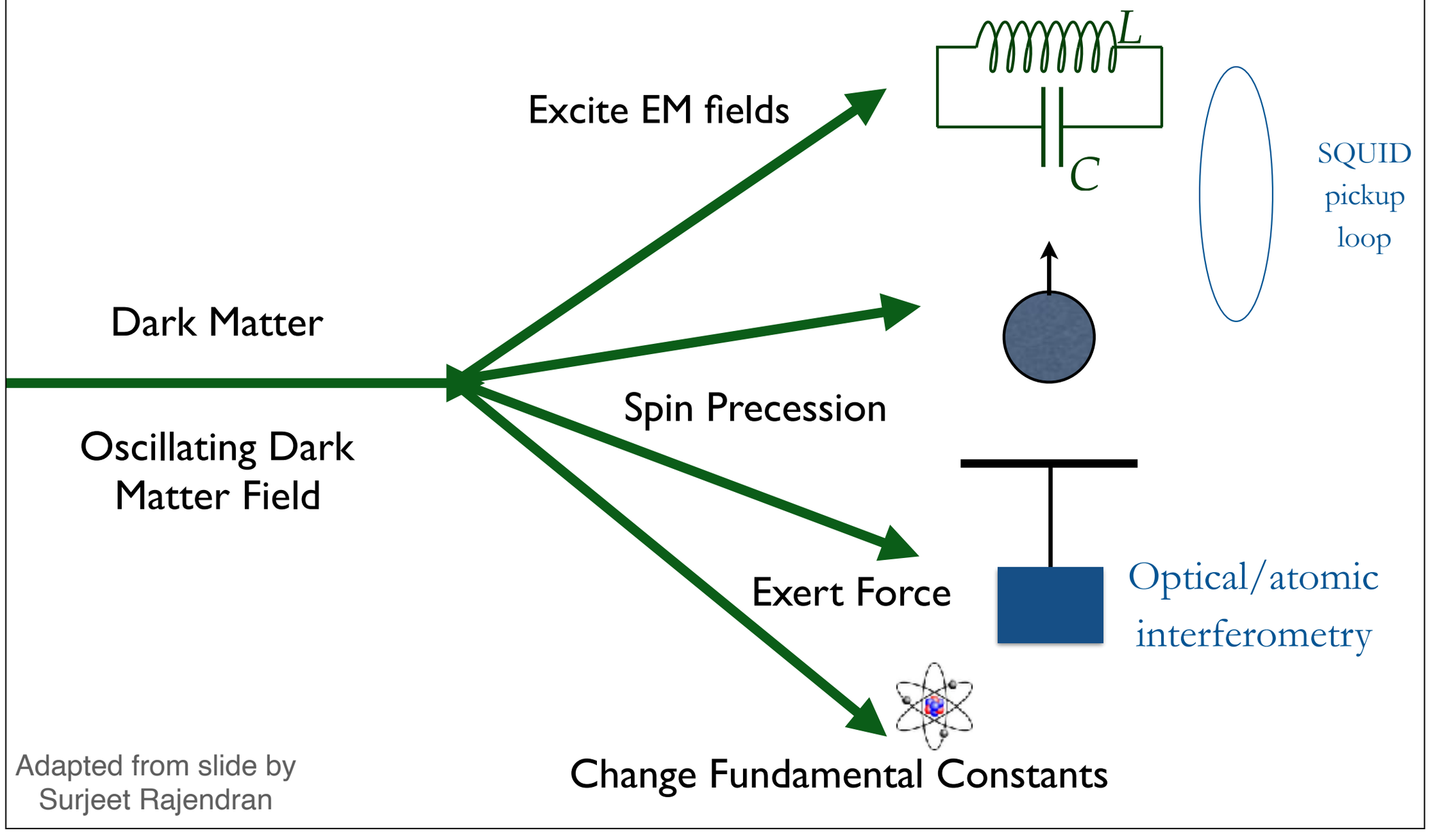
From Snowmass white paper on
"Scalar and Vector Ultralight Dark Matter"

Detection concepts for wave-like DM

Observable Effects

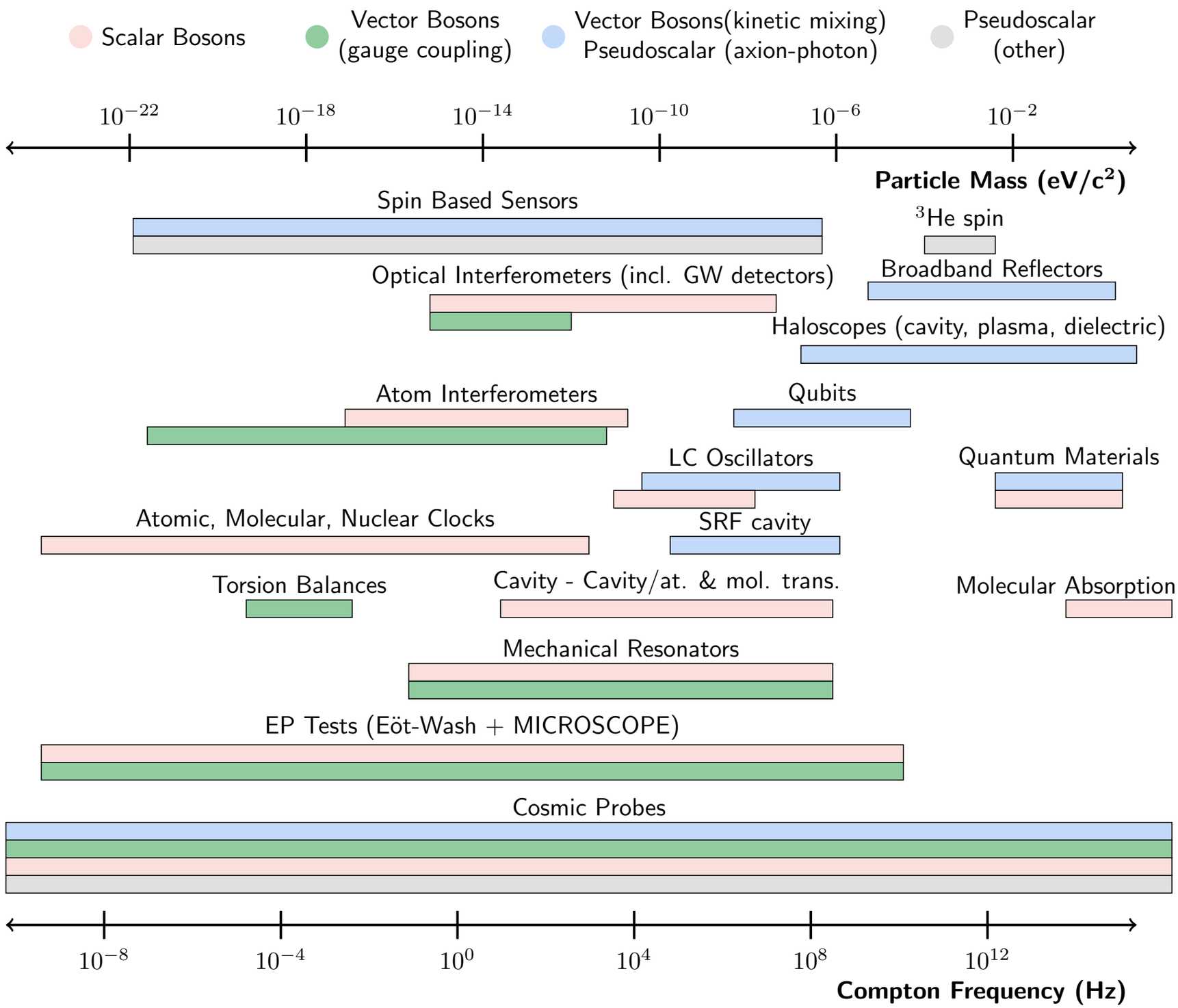
What can the dark matter wind do?

What can a classical field do?



Adapted from slide by Surjeet Rajendran

Detection concepts for wave-like DM



From Snowmass white paper on
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Progress in the past decade

DM-electron scattering

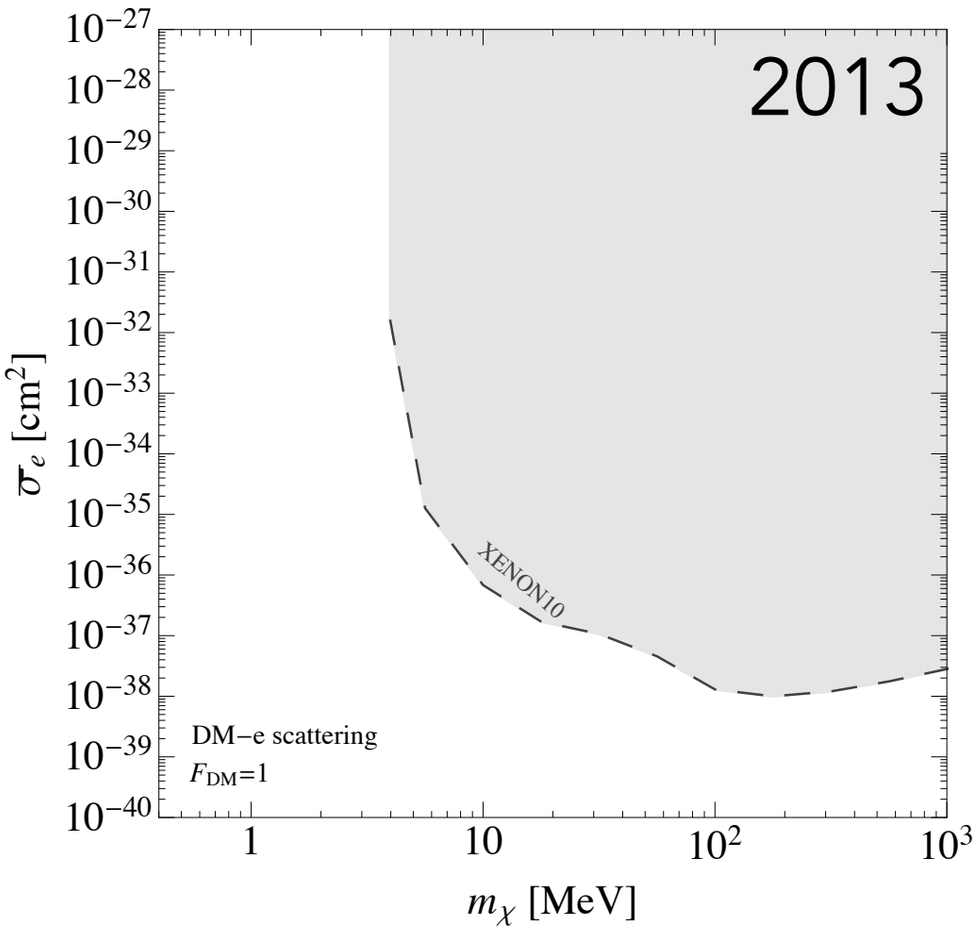
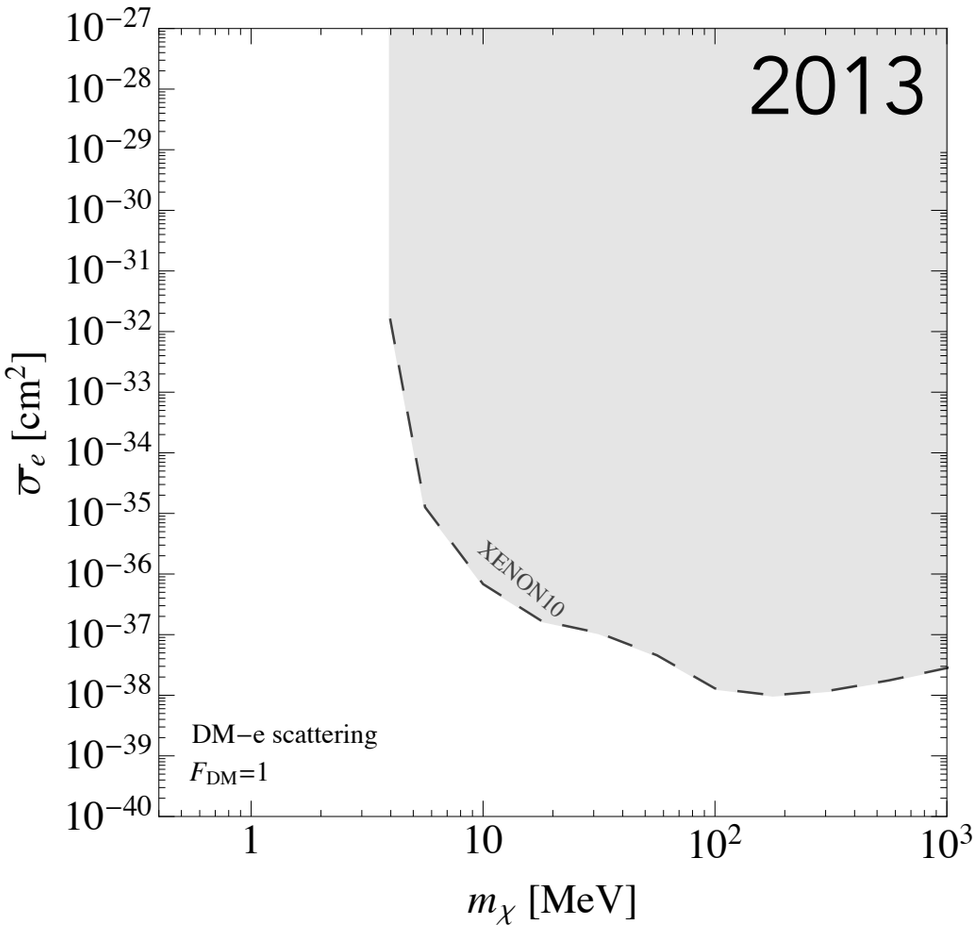
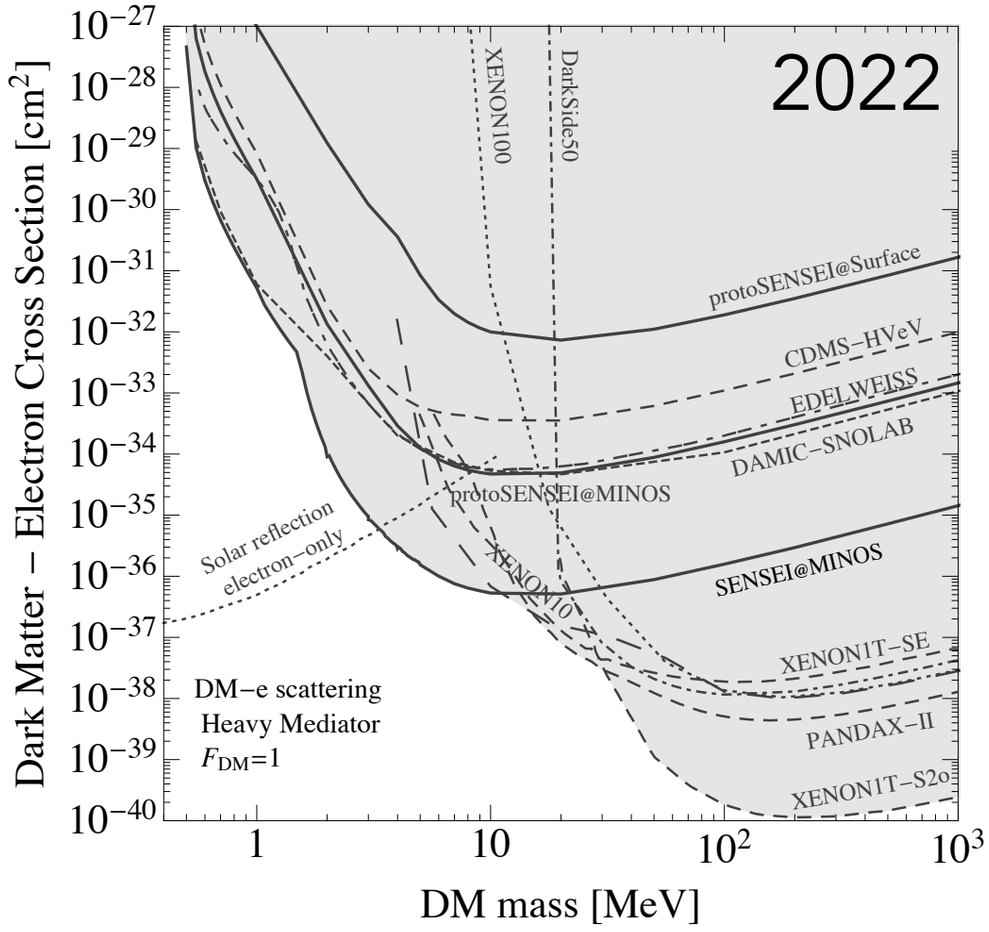


Fig from R. Essig and CF1 white paper
“Landscape of low-threshold detection”

Progress in the past decade

DM-electron scattering





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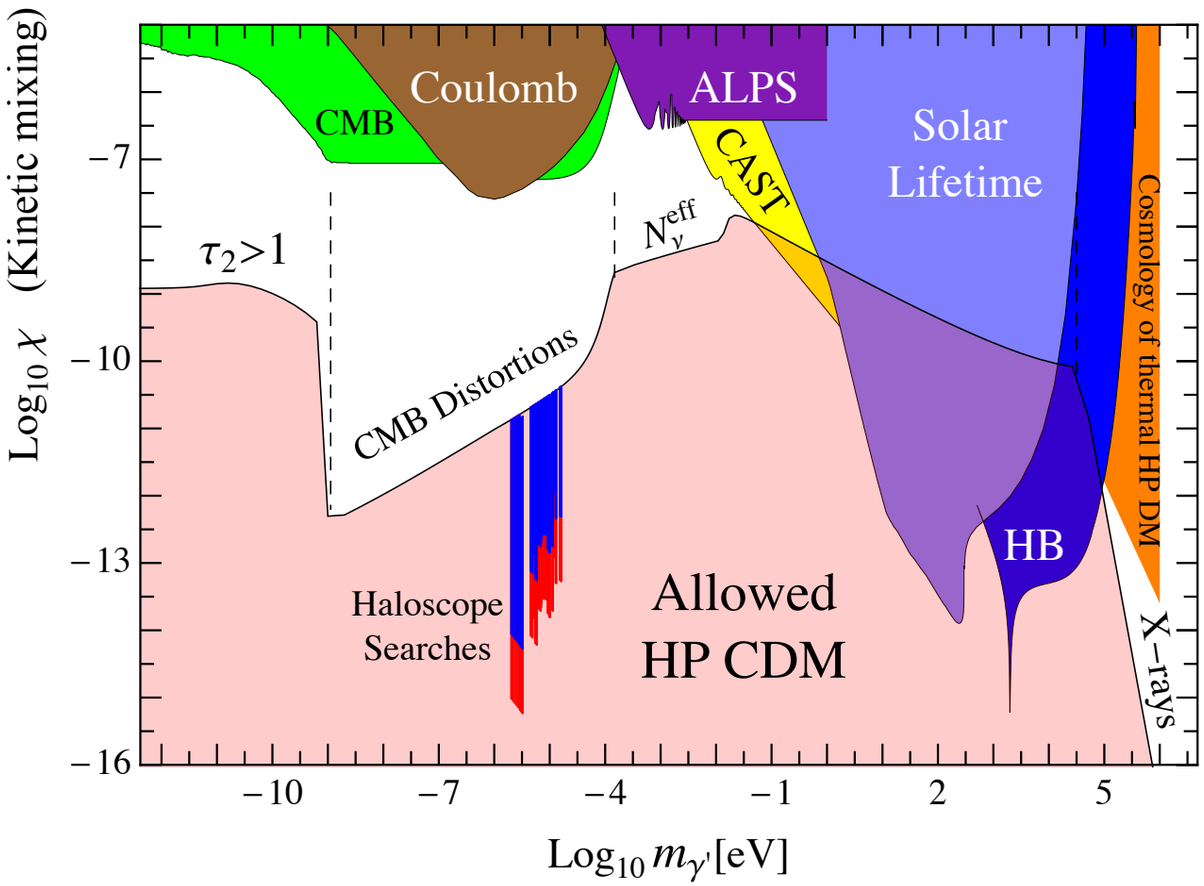
Progress in the past decade

Dark photon dark matter

2012



From Arias et al. 1201.5902 and
Caputo et al. 2021 / C O'Hare's repository

Progress in the past decade

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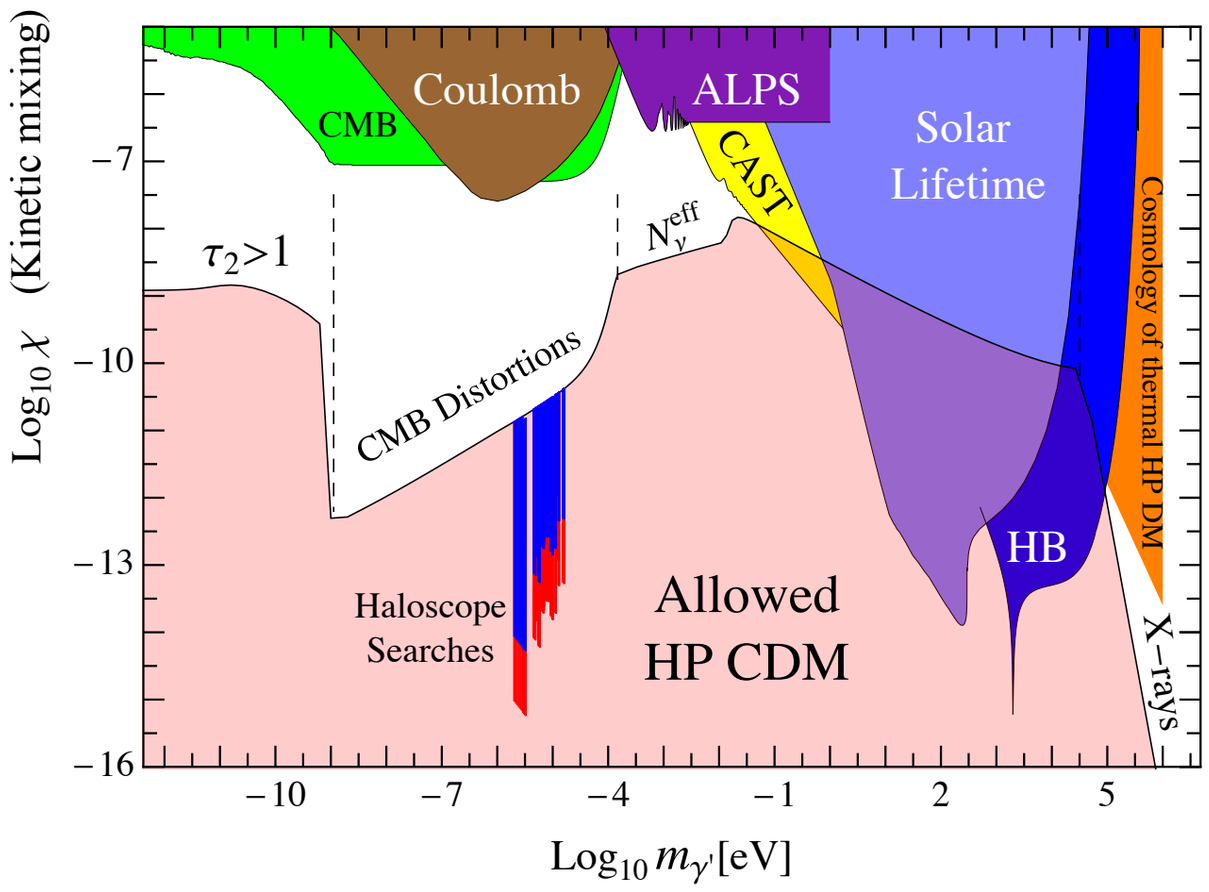
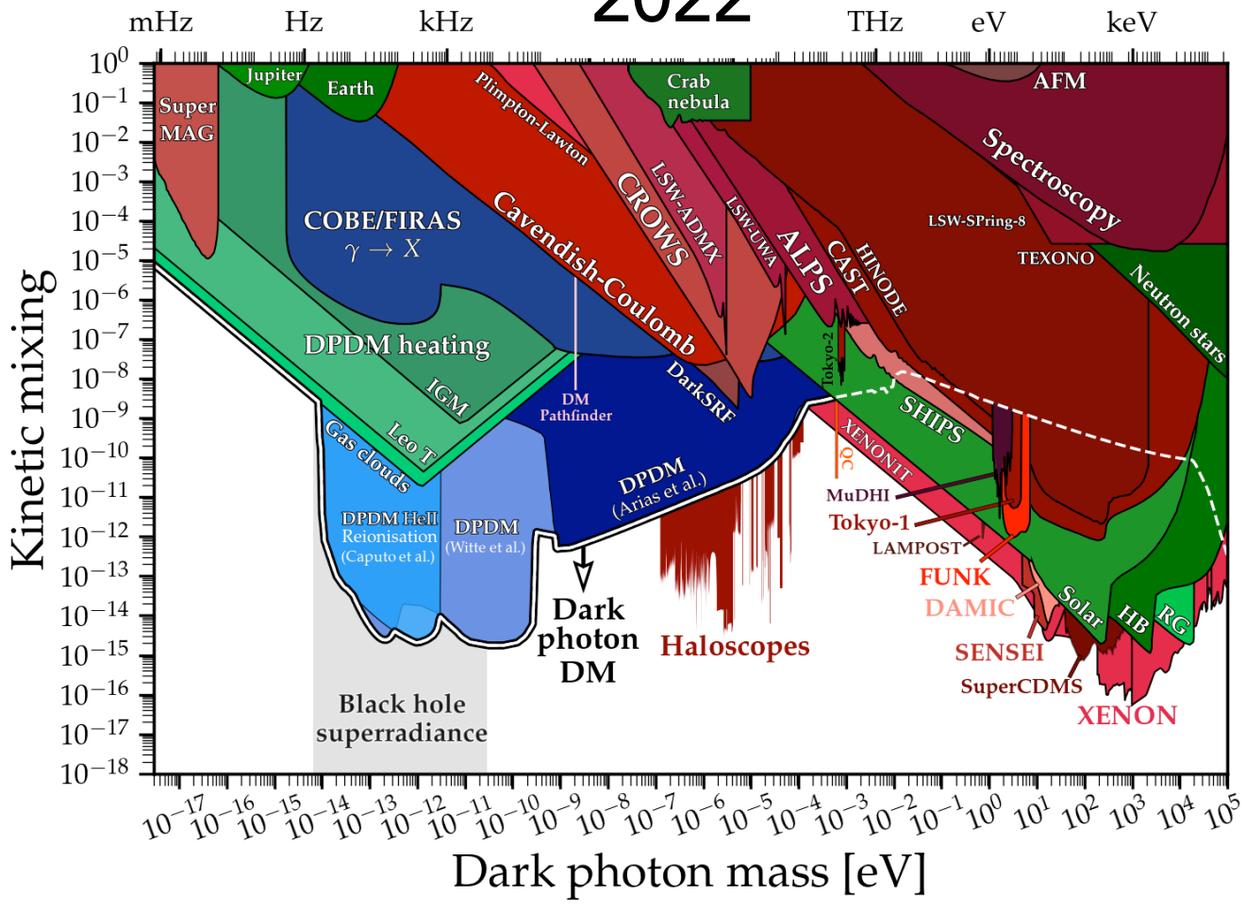


2022



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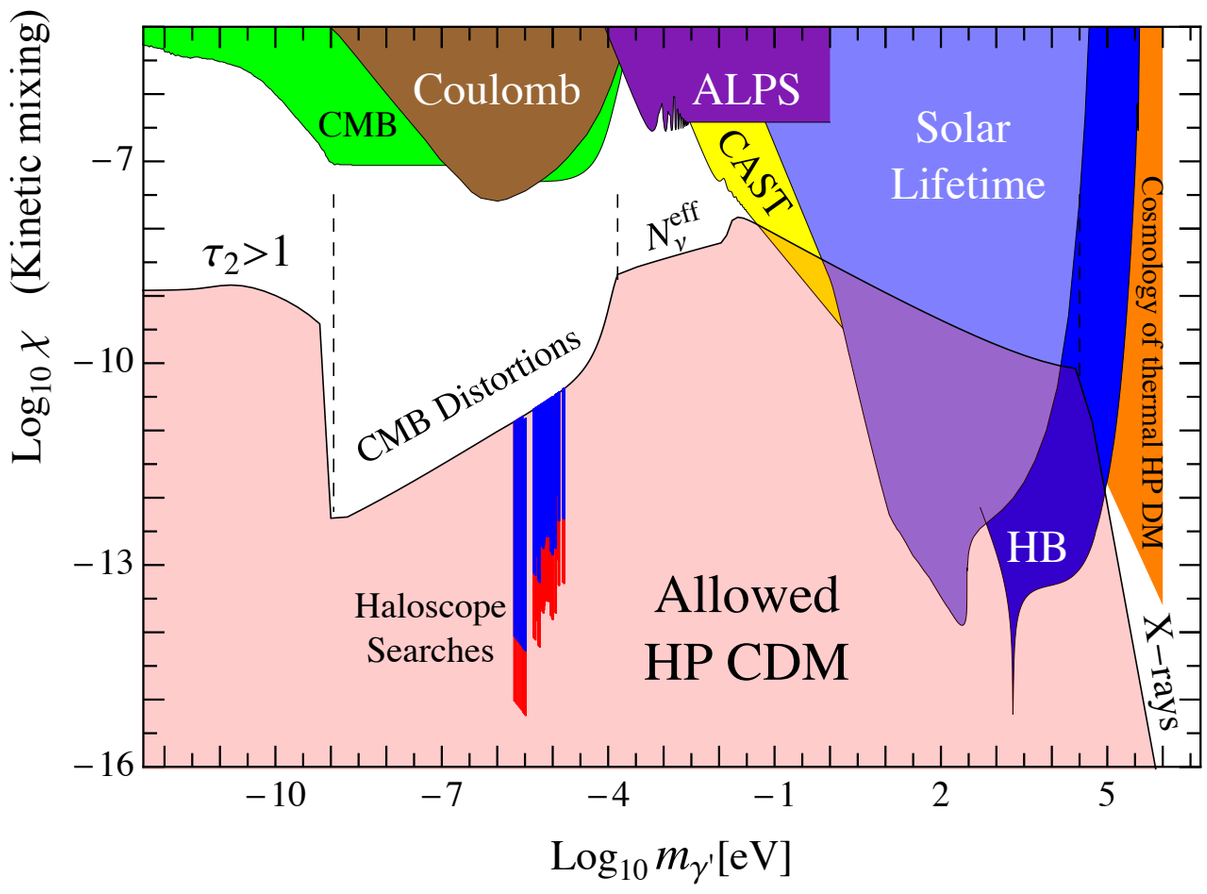
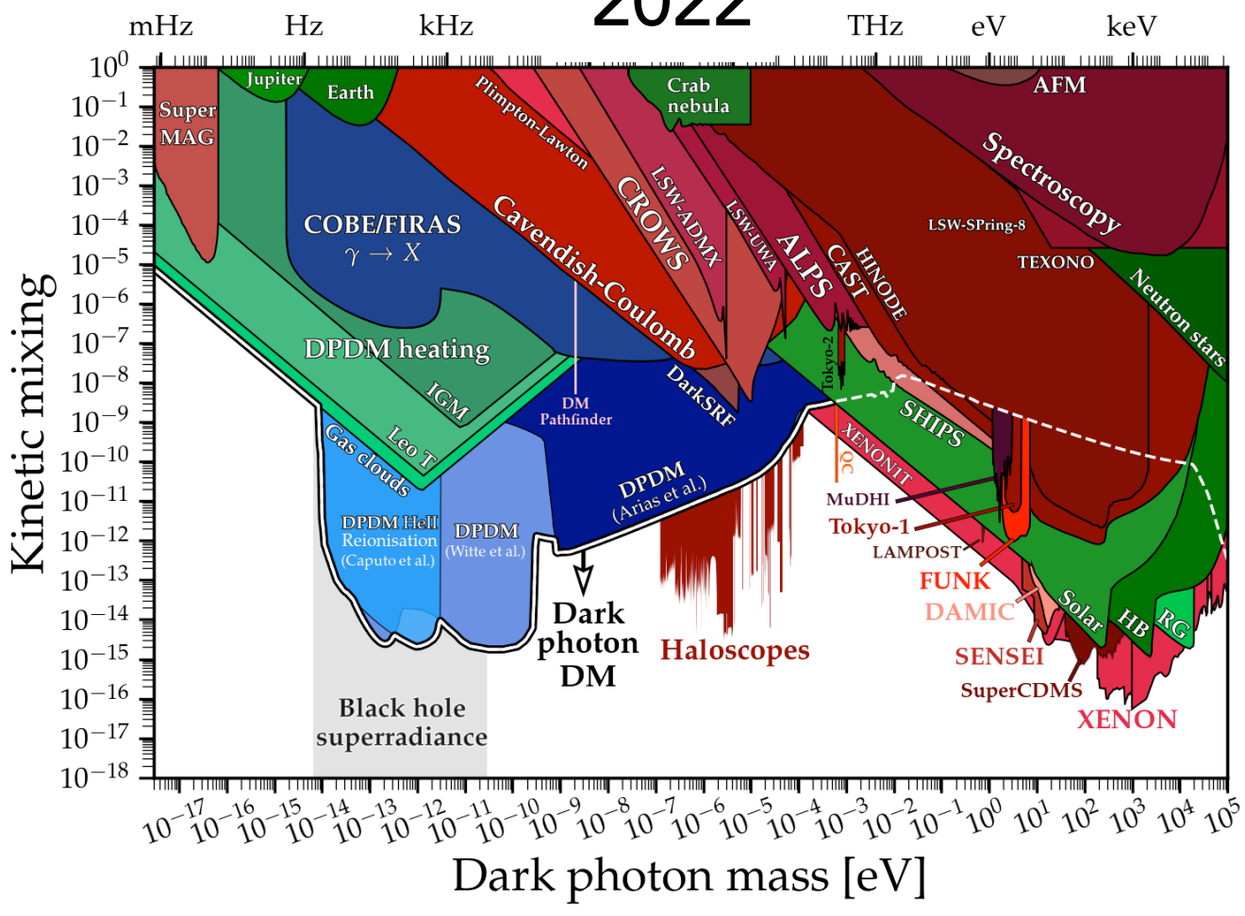
Dark photon dark matter

2012



2022



(and more!)

From Arias et al. 1201.5902 and
Caputo et al. 2021 / C O'Hare's repository

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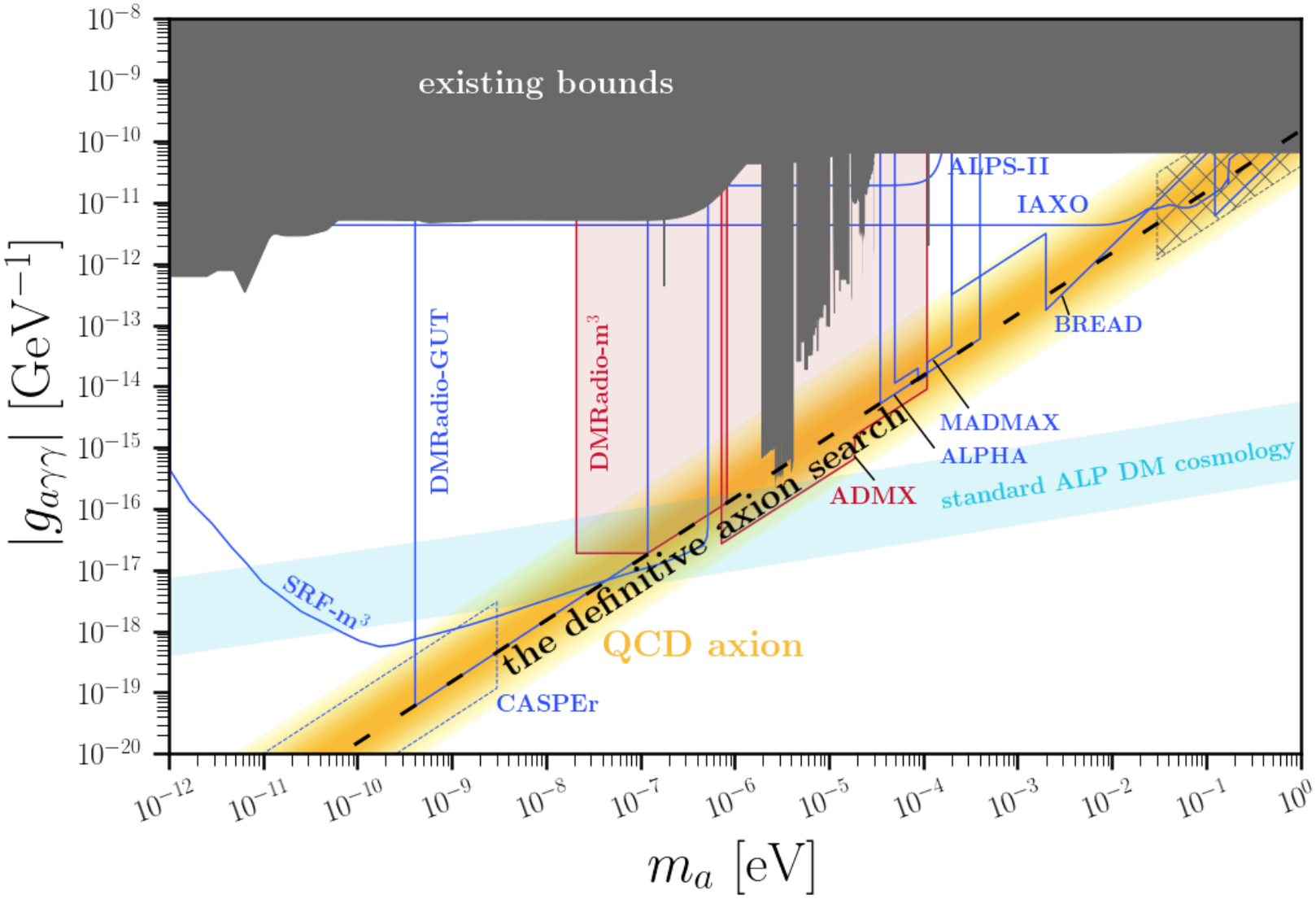
We want to find the right keys to unlock a discovery!

Extra

Bosonic (wave-like) dark matter

QCD axion DM and axion-like particles (ALPS)



Plot by A. Berlin