Direct Detection of sub-GeV Dark Matter

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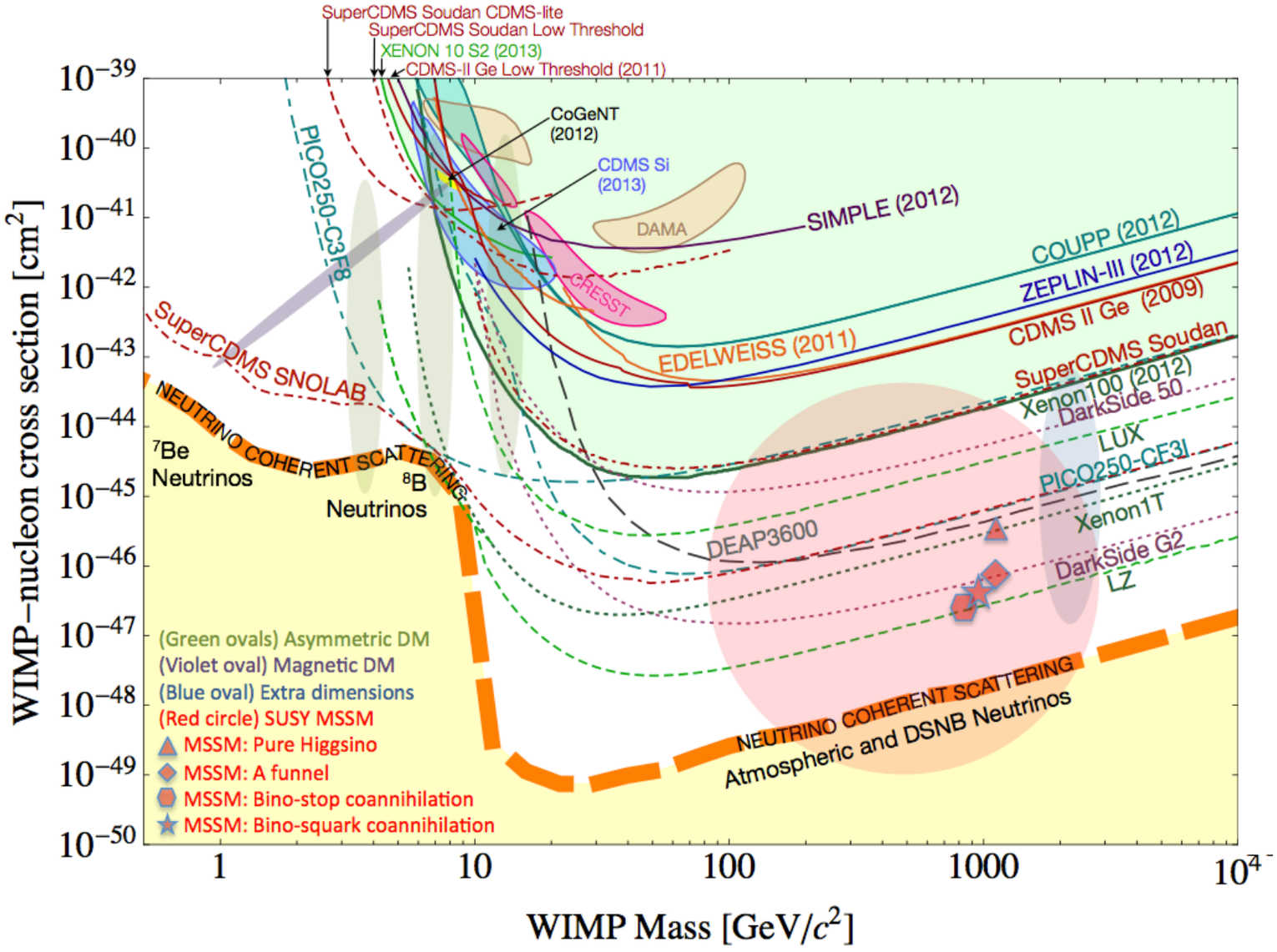
Cosmo Cruise, 6 Sept, 2015

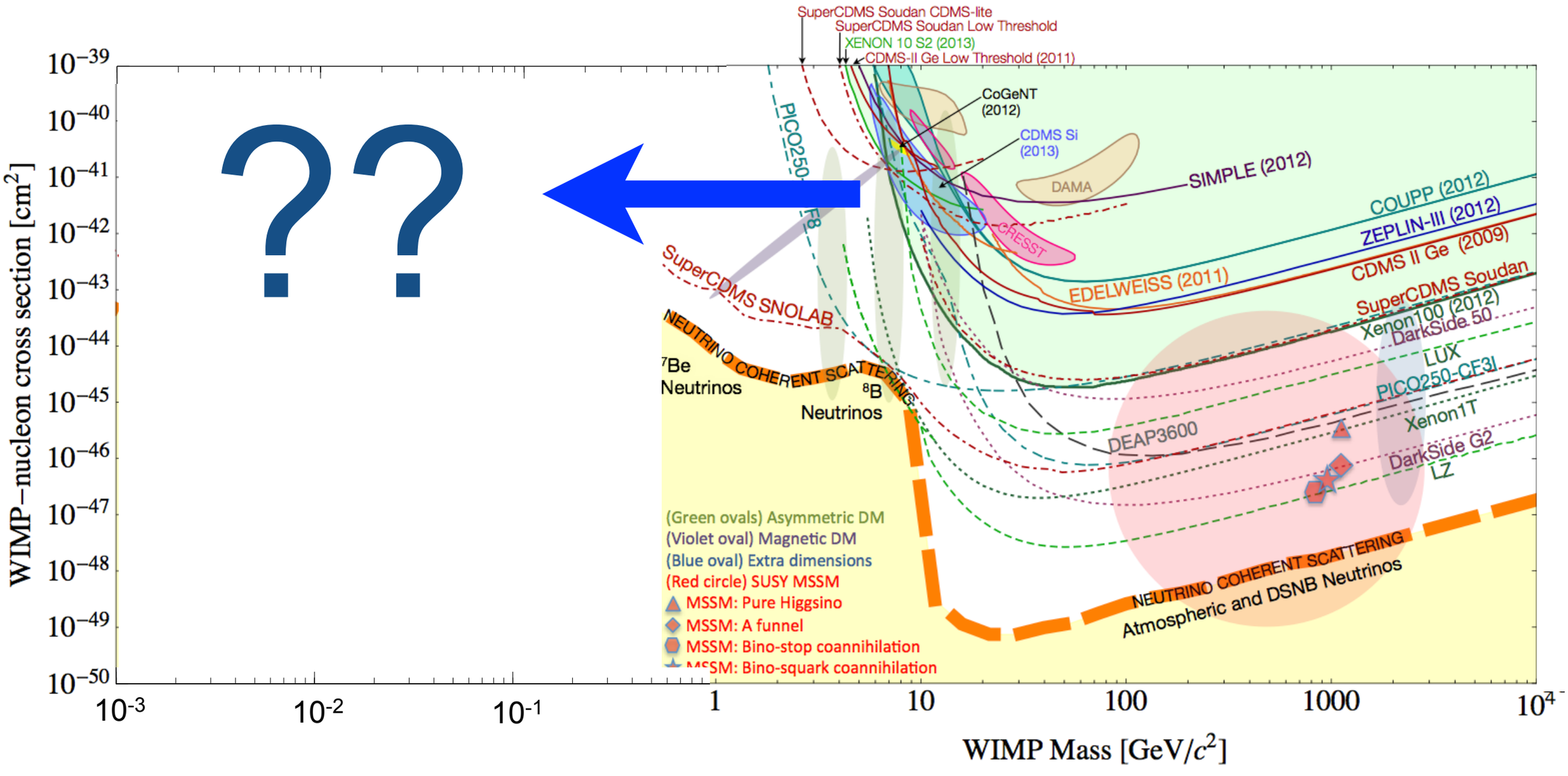
Direct Detection below 1 GeV?



1310.8327

Direct Detection below 1 GeV?

Yes, we can probe down to ~1 MeV!



An ongoing program

- "Direct Detection of sub-GeV Dark Matter", 1108.5383, PRD
  RE, Mardon, Volansky
- "First Direct Detection Limits on sub-GeV Dark Matter from XENON10", 1206.2644, PRL
  RE, Manalaysay, Mardon, Sorensen, Volansky

★ **New**

- "Direct Detection of sub-GeV DM with Semiconductor Targets", 1509.xxxxx (Tuesday)
  RE, Fernandez-Serra, Jeremy Mardon, Adrian Soto, Volansky, Tien-Tien Yu

In progress:

- "Direct Detection of sub-GeV DM with Scintillators",
  Derenzo, RE, Andrea Massari, Tien-Tien Yu
- "Search for sub-GeV Dark Matter with XENON100",
  XENON100 Collaboration w/ RE, Mardon, Volansky
- "Detection of Weakly Interacting Particles via Molecular Excitations",
  RE, Mardon, Oren Slone, Volansky

+ ongoing discussions w/ various other experimental groups…

See also:

- Graham, Kaplan, Rajendran, Walters, "Semiconductor Probes of Light Dark Matter", 1203.2531, PDU
- Va'vra, "Molecular excitations: a new way to detect Dark matter", 1402.0466, PLB
- Hochberg, Zhao, Zurek, "Superconducting Detectors for Super Light Dark Matter", 1504.07237
- Lee, Lisanti, Mishra-Sharma, Safdi, "Modulation Effects in Dark Matter-Electron Scattering Experiments", 1508.07361

Outline

- intro + motivation
- strategy & current constraints
- future prospects

The WIMP Paradigm

The search for DM is dominated by the search for

Weakly Interacting Massive Particles (WIMPs)

~ 5-1000 GeV

- theoretically motivated (e.g. appears in supersymmetry)
- naturally have correct relic abundance ("WIMP miracle")
- experimentally testable

Beyond the WIMP Paradigm

- many other DM candidates exist
- no clear evidence for WIMPs (yet?)
- no new physics at the LHC (yet?)
- several challenges
  ("small-scale crisis of cold DM")

Must search broadly for DM!

Beyond WIMPs:

MeV-to-GeV mass Dark Matter

(an old idea, e.g. Boehm, Fayet, …)

below conventional WIMP scale; above scale for which cosmological constraints can be important

natural, viable candidates exist

rich phenomenology
(like WIMPs)

today, focus on direct detection

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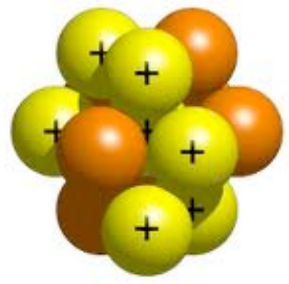
Cannot use elastic nuclear recoils for detection

Light DM $\lesssim 1$ GeV



Atom

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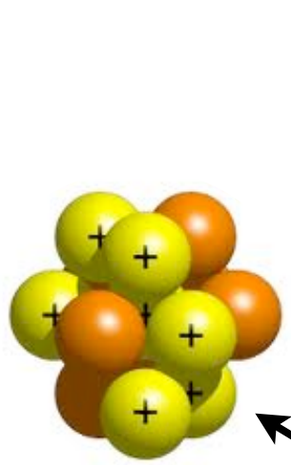
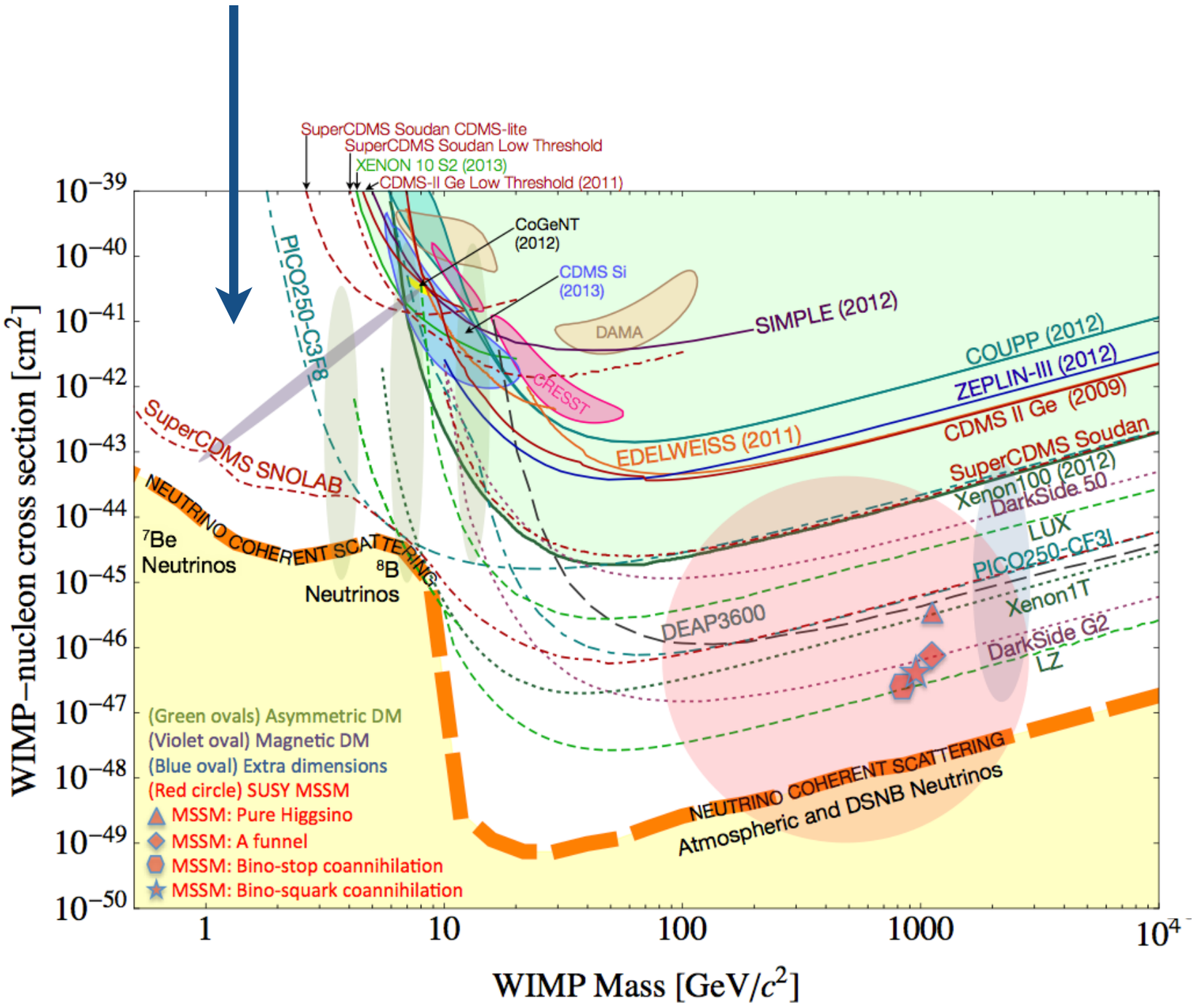


Not enough energy transfer

Can't see recoiling nucleus

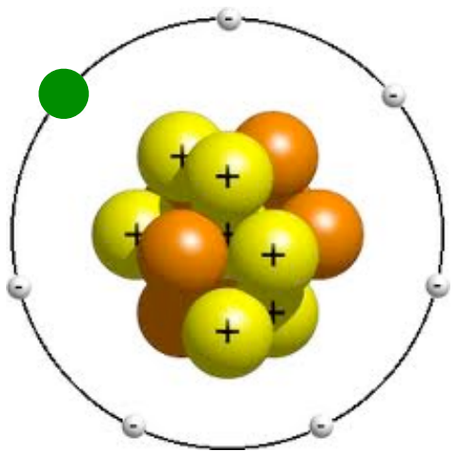
Cannot use elastic nuclear recoils for detection

⟹ limits absent below ~few GeV



But DM could also scatter off electrons!

DM



Atom

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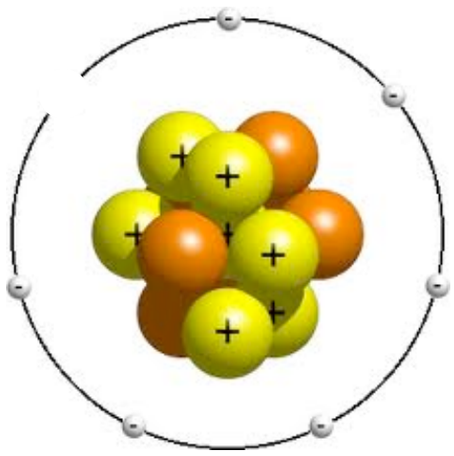


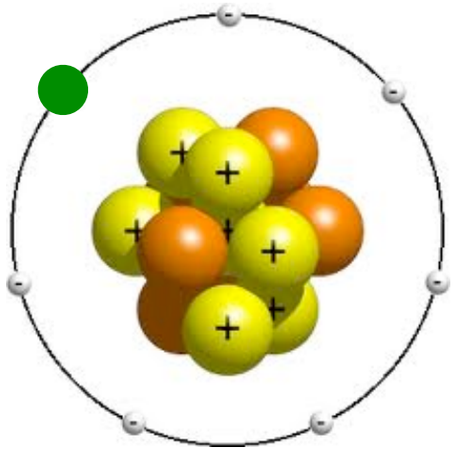
Atom

this can transfer most of DM energy

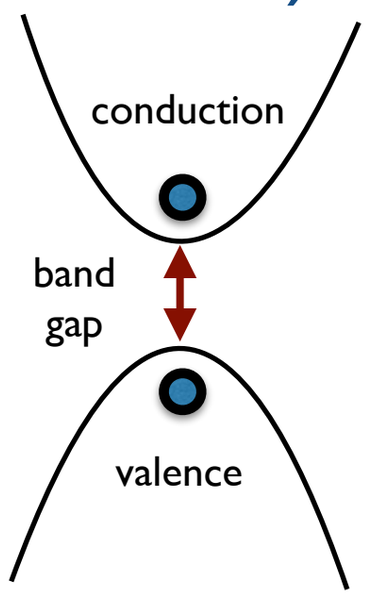
Signal: one or a few electrons

DM-electron scattering

- Noble liquids (xenon, argon, helium)
  threshold ~ 10 eV



- Semiconductor targets (germanium, silicon)
  threshold ~ 1 eV (band gap)



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sensitive to $m_{\rm DM} \sim 10\ {\rm MeV}$

Done w/ XENON10 data!

But significant improvements possible

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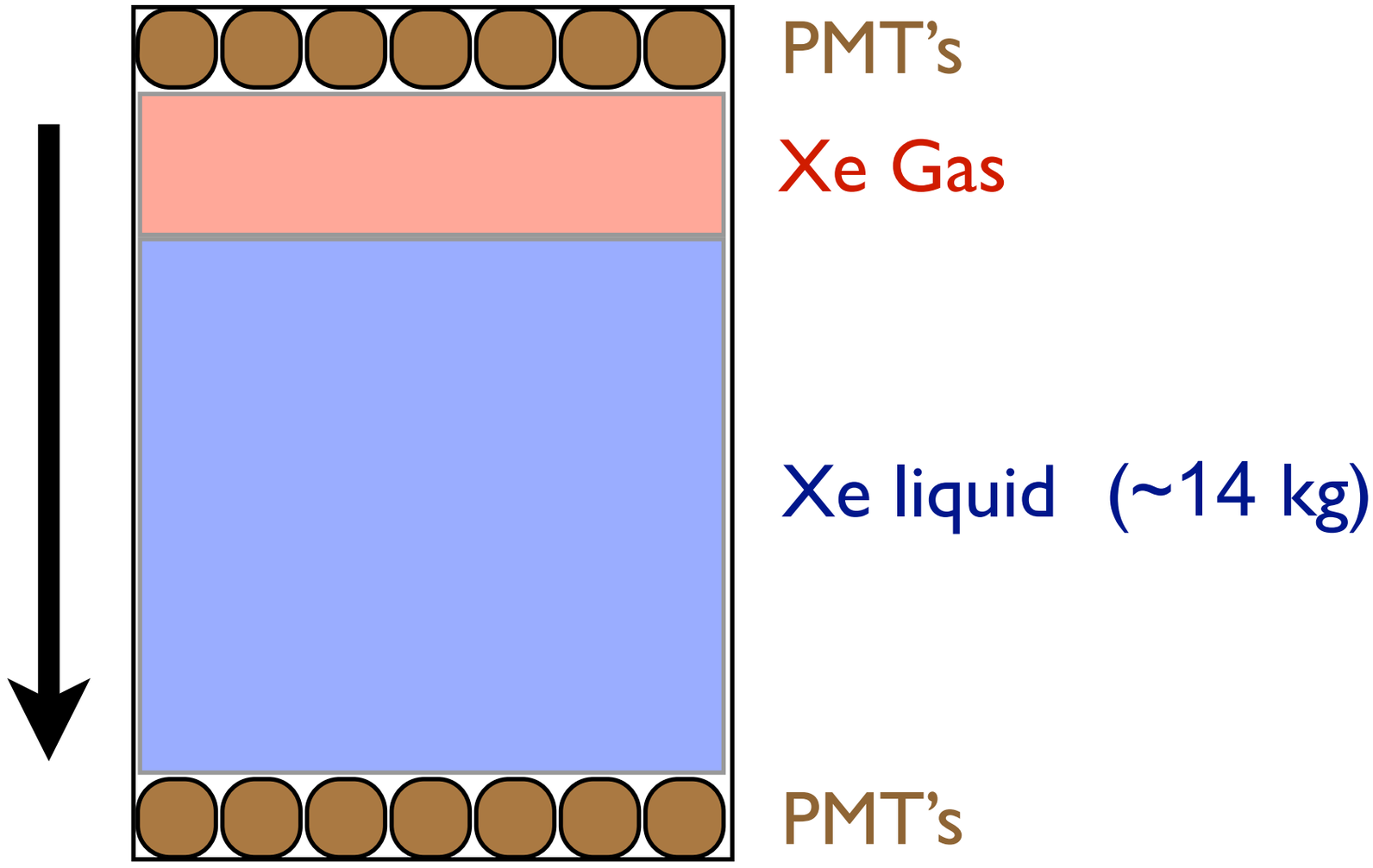
The XENON10 experiment

detector schematic



operated for ~1 year in 2006/2007

was sensitive to single electrons (exposure 15 kg-days)!

Proof-of-principle for direct detection down to DM masses of a few MeV

RE, Manalaysay, Mardon, Sorensen, Volansky (PRL)

Outline

- intro + motivation
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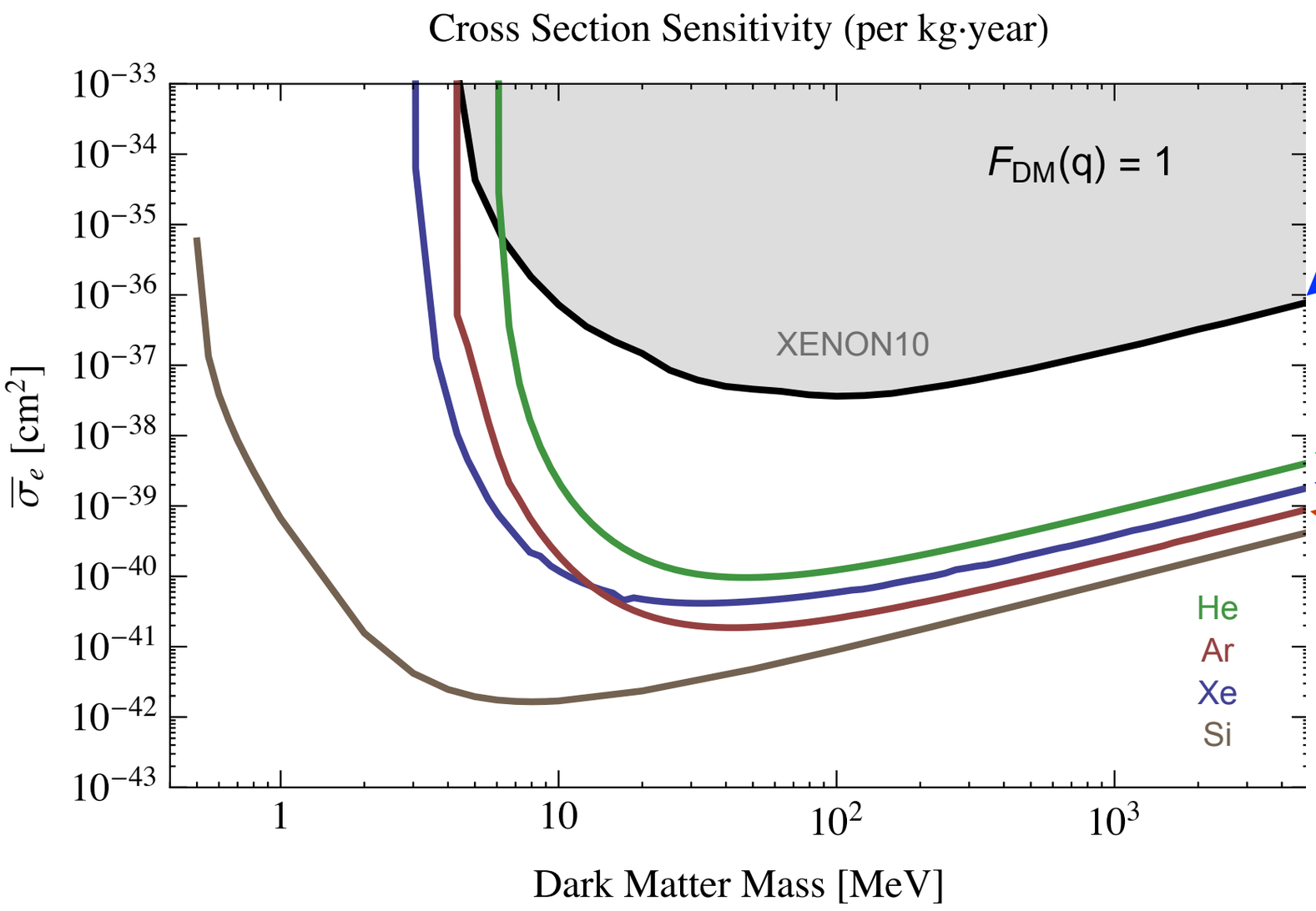
- future prospects
  - noble gases
  - semiconductors

Prospects for noble liquids

RE, Mardon, Volansky



XENON10 limit

helium

xenon

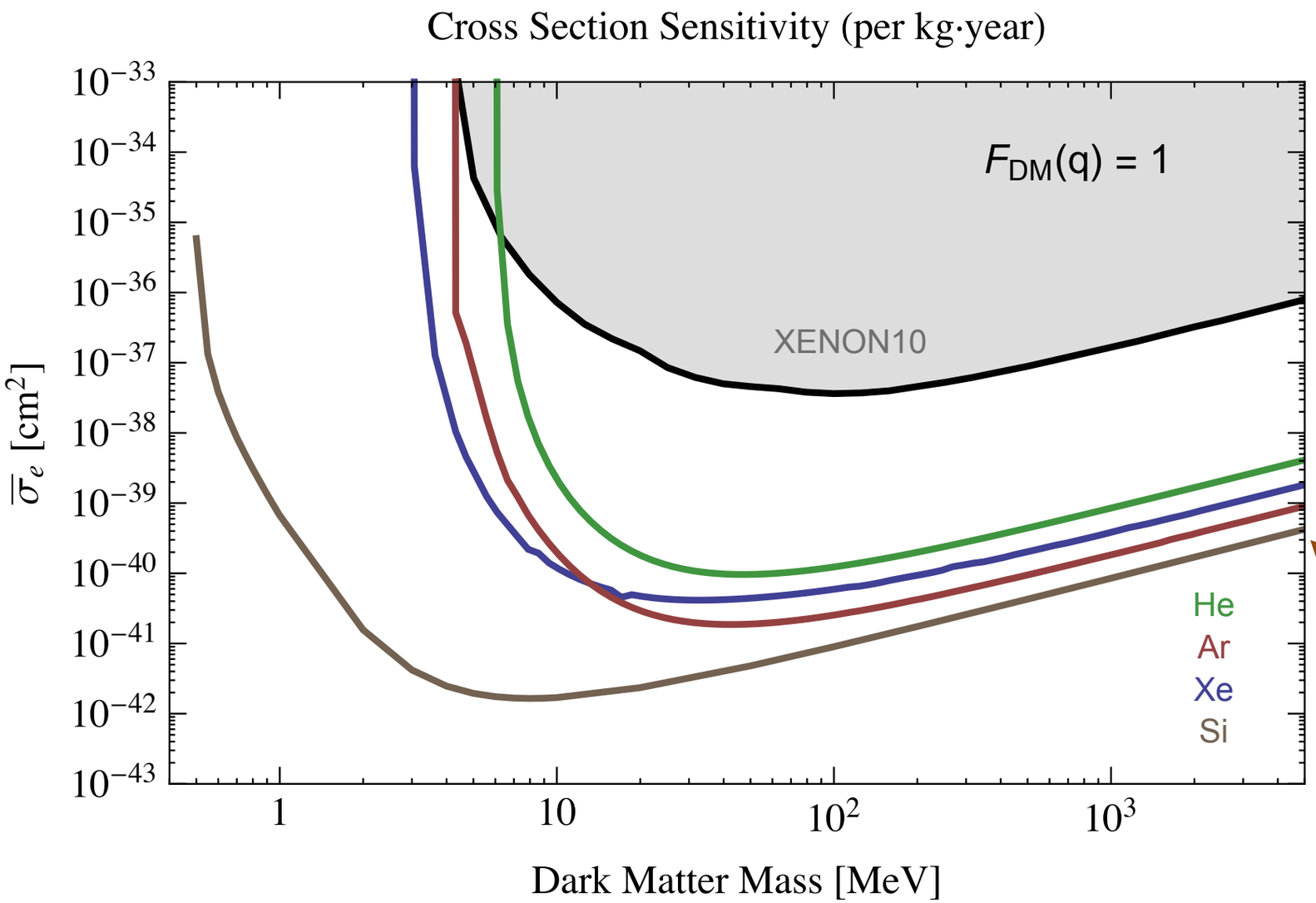
argon

possible improvements by XENON100, LUX, …

Prospects for semiconductors

RE, Mardon, Volansky

see also Graham, Kaplan, Rajendran, Walters



semiconductors
(Si, but Ge similar)

can *potentially* reach *very* low masses!

Calculating rates accurately is challenging

electrons are part of interacting many-body system

- analytic approximation — how accurate?

  Graham et.al.

  Lee, Lisanti, Mishra-Sharma, Safdi

- numerical approach

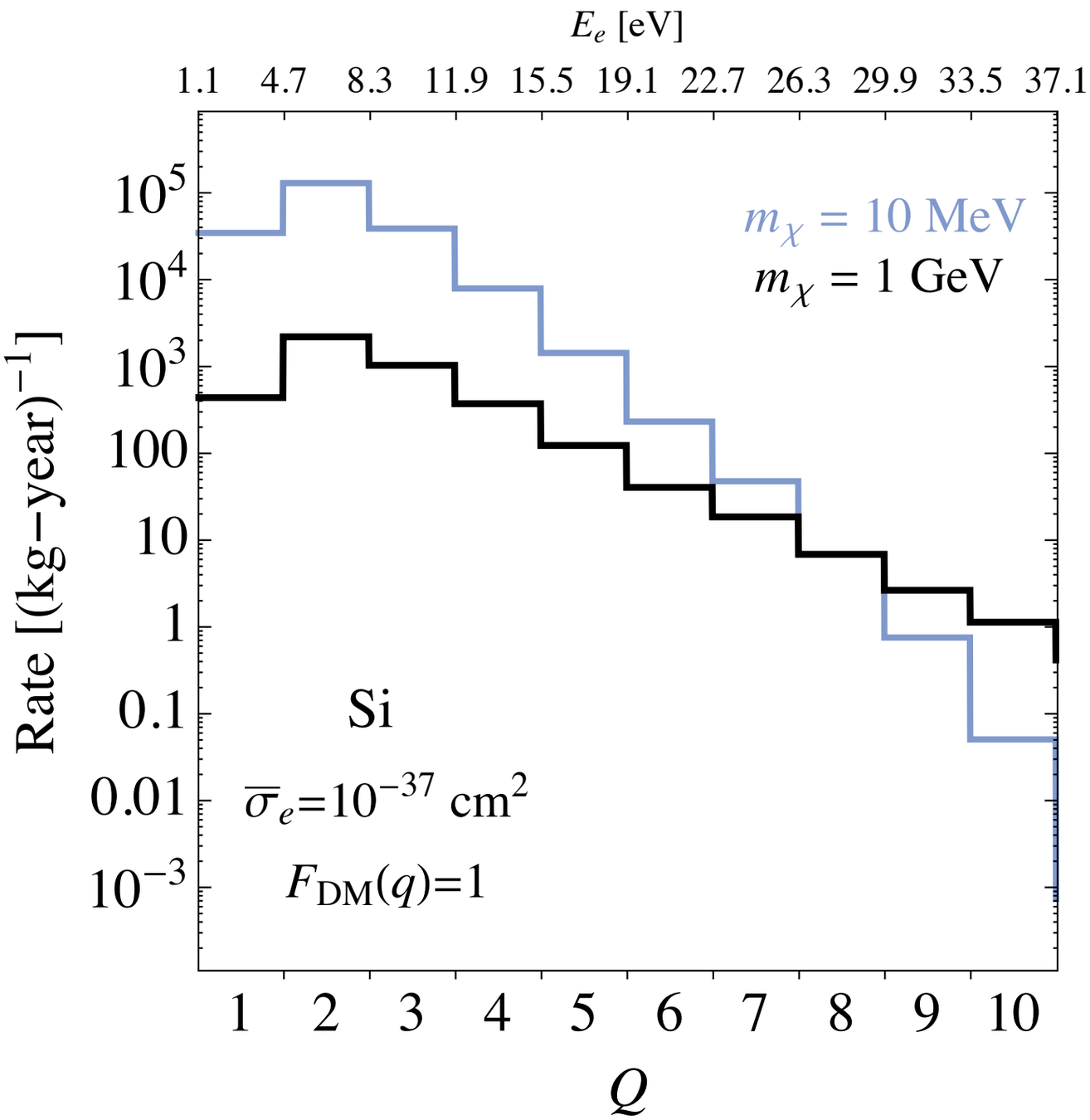
  RE, Mardon, Volansky

RE, Fernandez-Serra, Mardon, Adrian Soto, Volansky, Tien-Tien Yu (1509.xxxx)

http://ddldm.physics.sunysb.edu

Recoil energy spectrum

RE, Fernandez-Serra, Mardon, Adrian Soto, Volansky, Tien-Tien Yu (1509.xxxx)



Current thresholds, e.g.

CDMSlite: ~170 eV

(1309.3259)

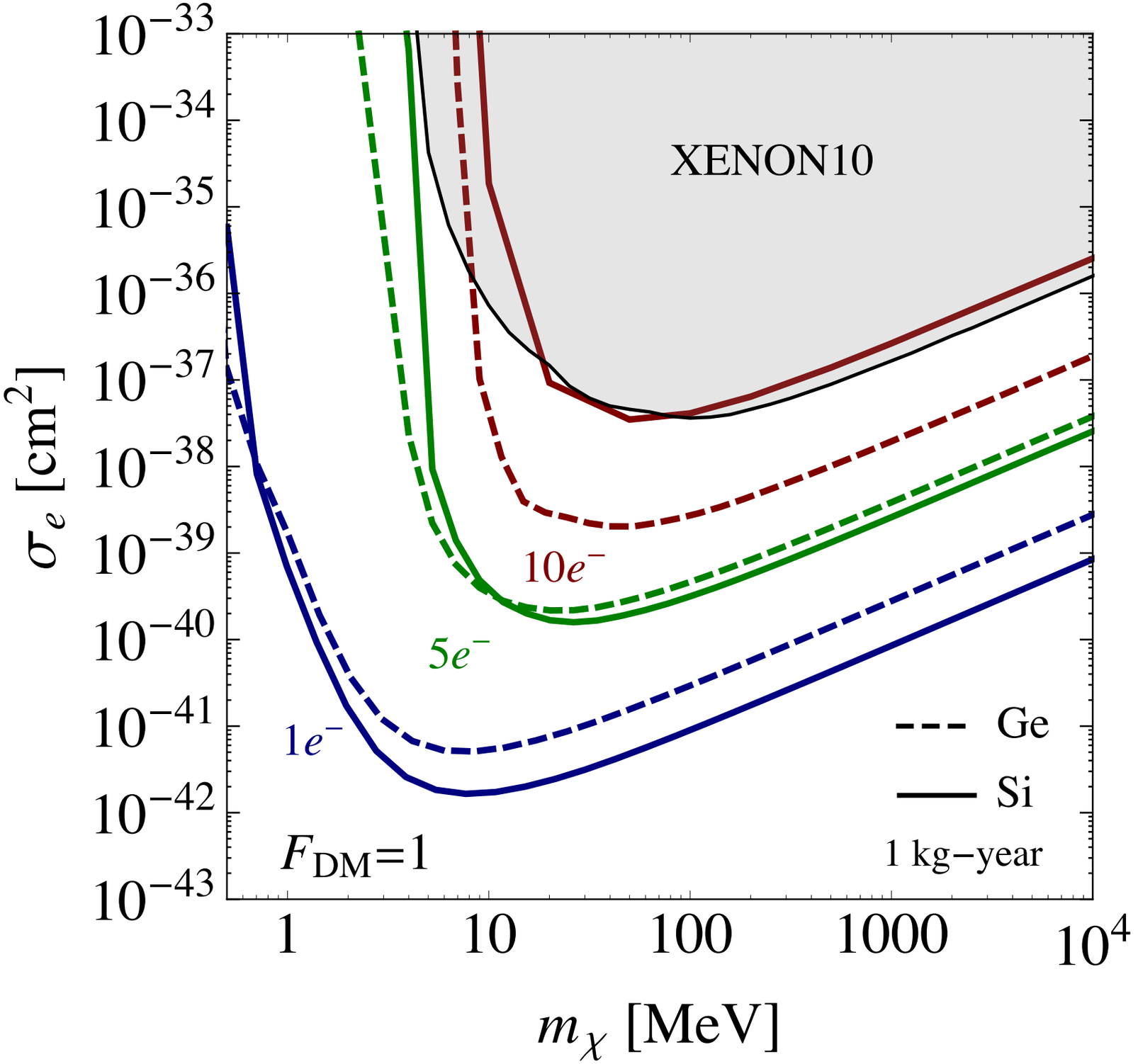
DAMIC: ~40 eV

(1105.5191)

Lowering threshold gives *HUGE* increase in rate

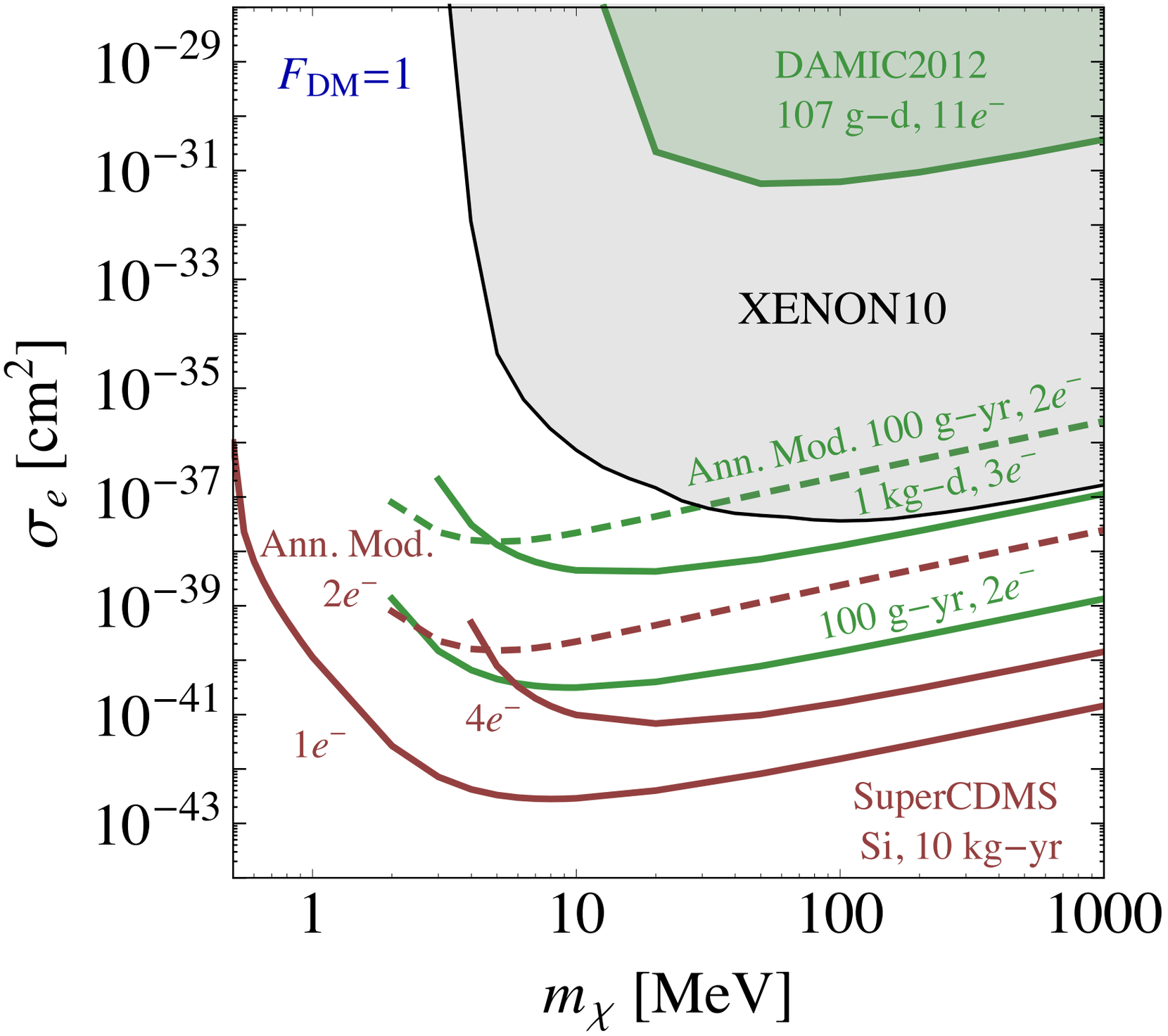
Sensitivity increases dramatically for lower thresholds

RE, Fernandez-Serra, Mardon, Adrian Soto, Volansky, Tien-Tien Yu (1509.xxxx)



Prospects for upcoming experiments

RE, Fernandez-Serra, Mardon, Adrian Soto, Volansky, Tien-Tien Yu (1509.xxxx)



Other direct detection avenues for sub-GeV DM

- ✔ ionization
- excitation

S. Derenzo, RE,
Andrea Massari, Tien-Tien Yu
(work in progress)

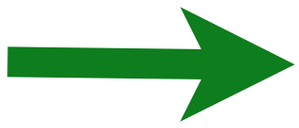
- molecular dissociation

RE, Mardon, Oren Slone, Volansky
(work in progress)

see also Va'vra

Other direct detection avenues for sub-GeV DM

✔ • ionization


(briefly)

• excitation

S. Derenzo, RE,
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• molecular dissociation

RE, Mardon, Oren Slone, Volansky
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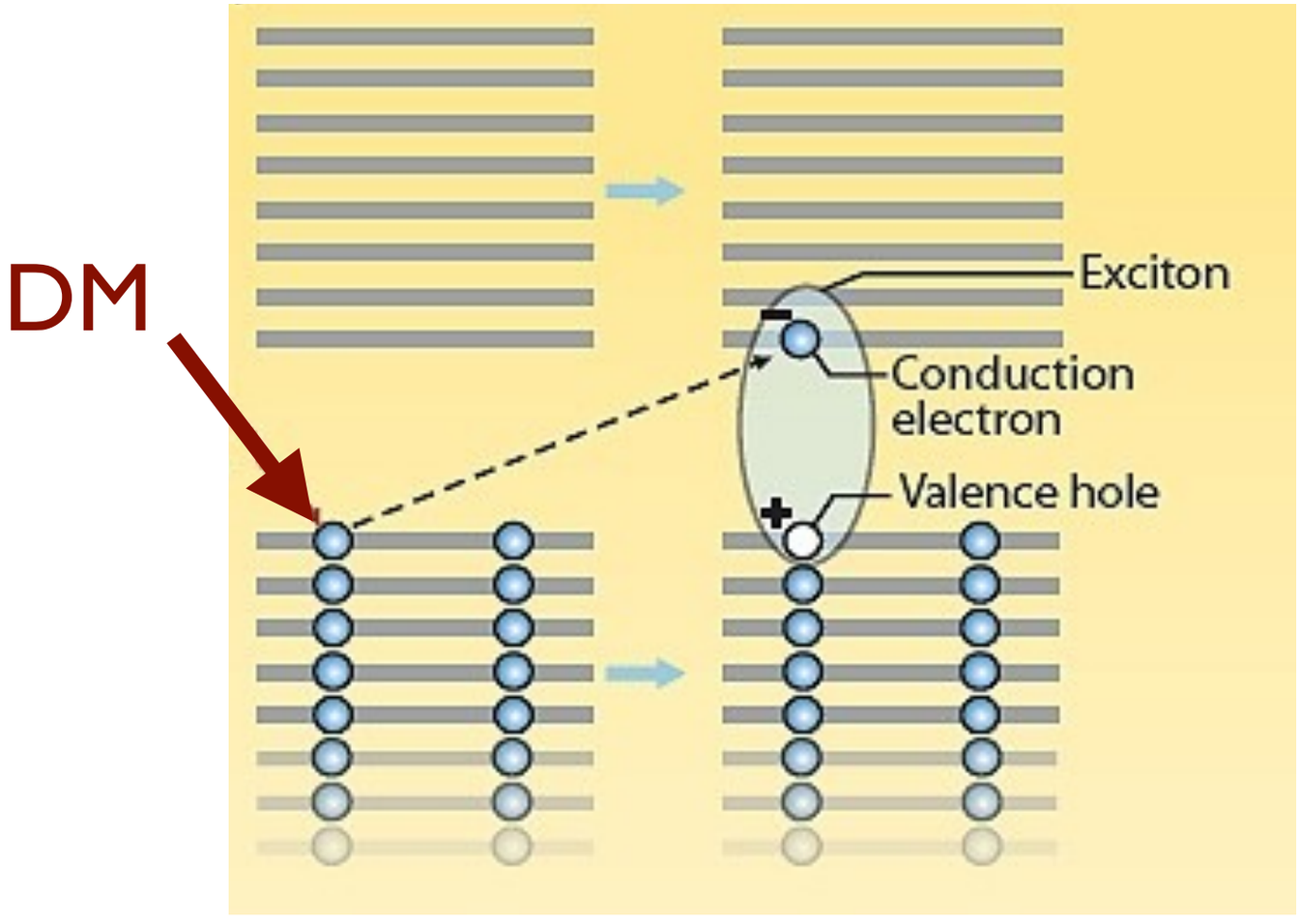
see also Va'vra

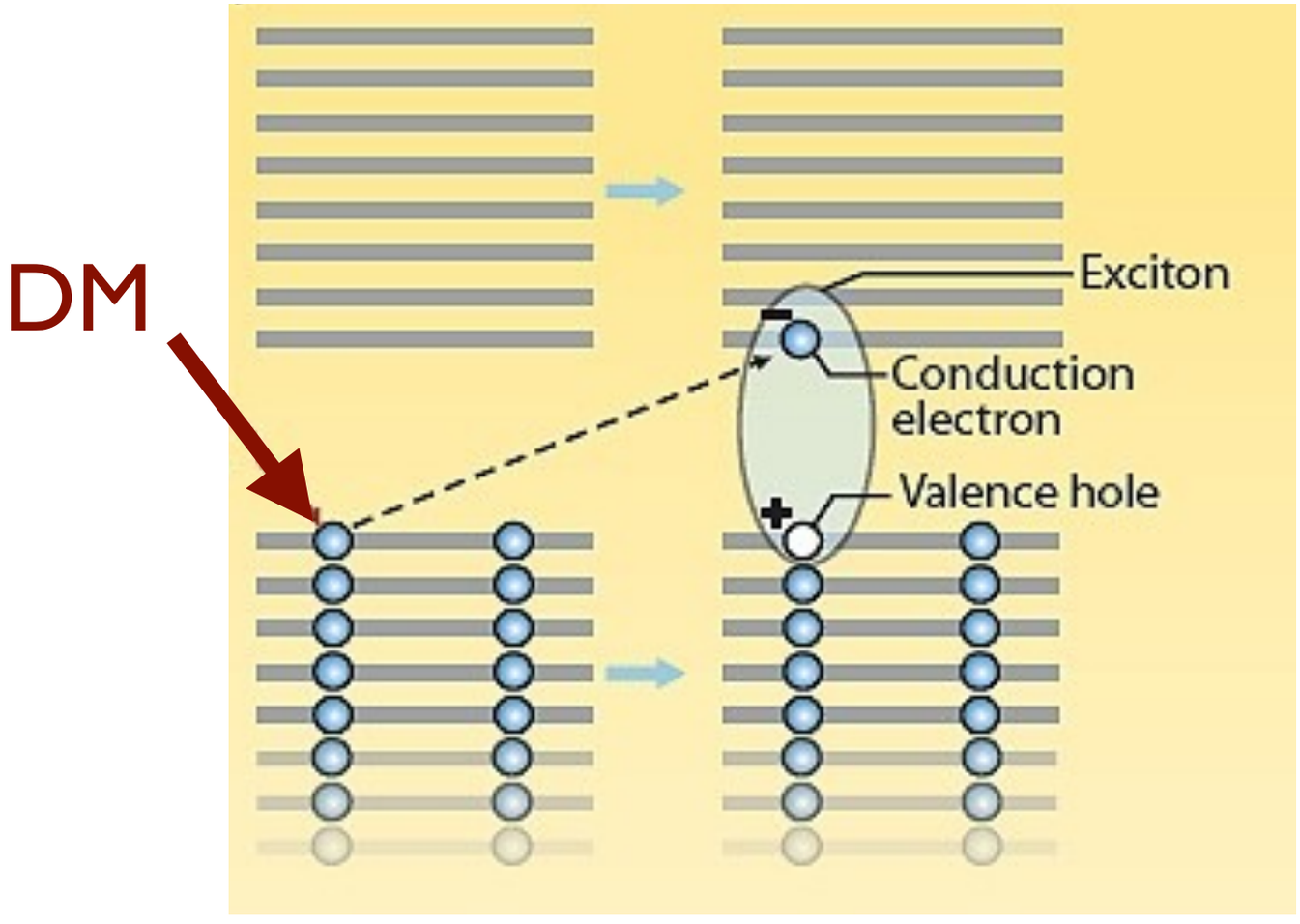
Example: Excitons in scintillating crystals



adapted from www.lanl.gov/science/1663/june2010/story2a.shtml

- DM creates exciton

Example: Excitons in scintillating crystals



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- DM creates exciton
- Exciton de-excites

Signal:
one (or a few) photons

Summary

- sub-GeV DM is a motivated, viable possibility
- excellent prospects for direct detection experiments
- many opportunities for significant progress over next few years