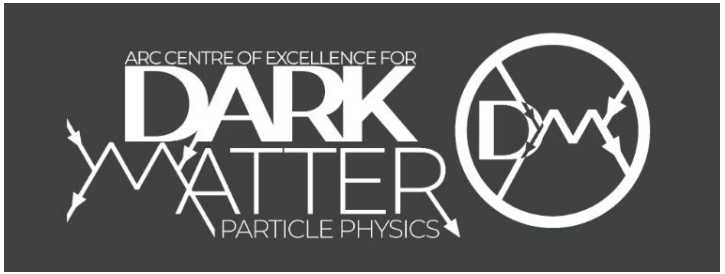
Beyond standard WIMPs with direct detection experiments

CDM Annual Workshop 2022

Geelong, Nov. 2022



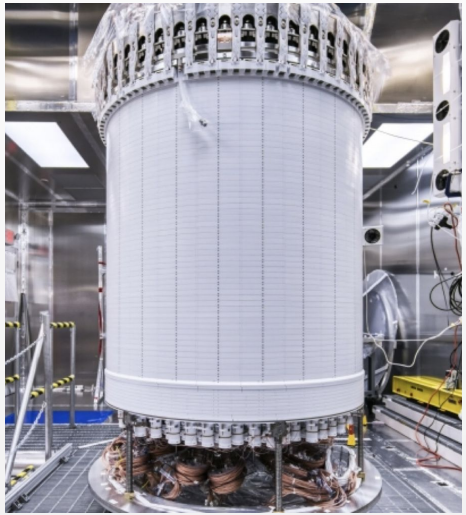
Jayden L. Newstead
The University of Melbourne

Two decades of dual-phase TPC progress

ZEPLINII & III
(photo ZIII Whitby museum)

XENON100

XENON1T



LZ

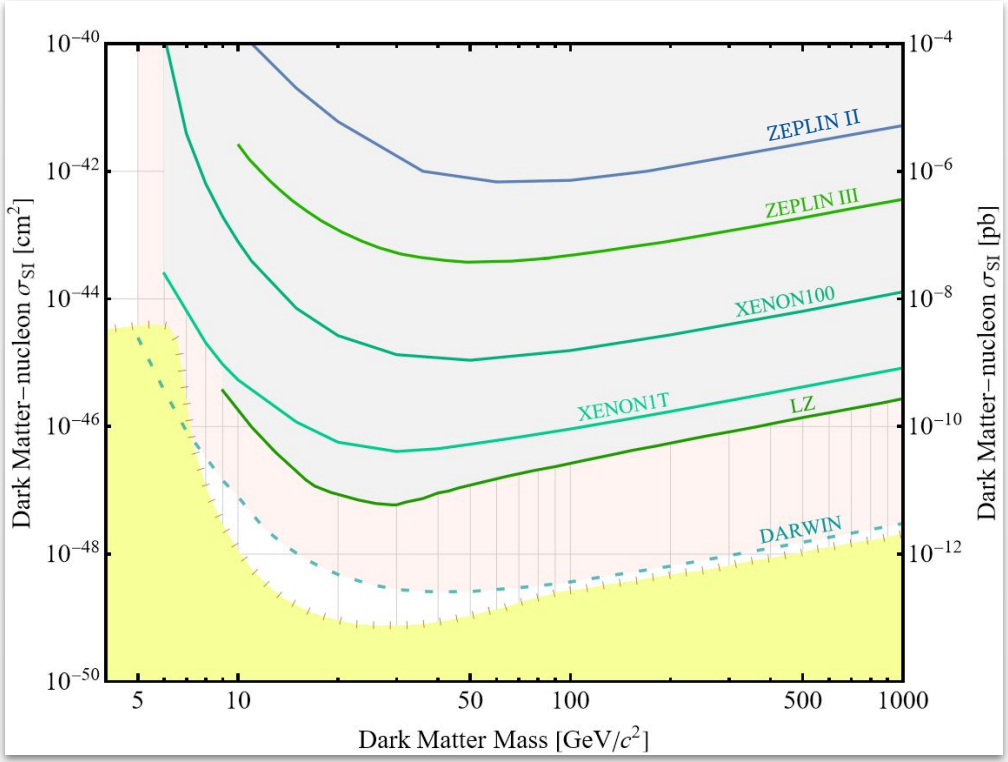
The WIMP parameter space

~10 kg

~100 kg

~1000 kg

~10,000 kg



2007

2011

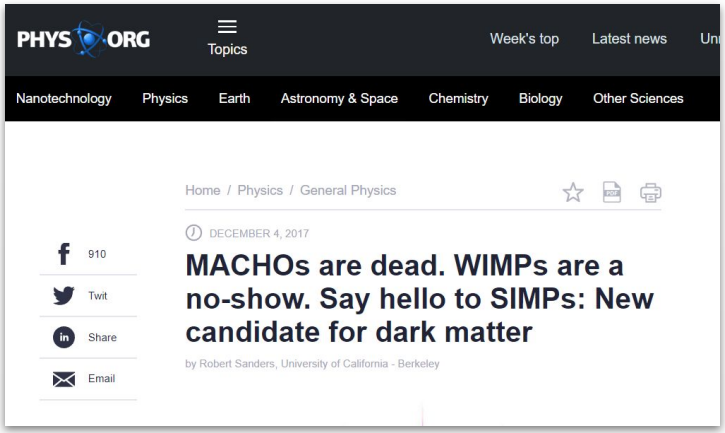
2013

2018

2022

20??

Where is the WIMP?



Where is the WIMP?

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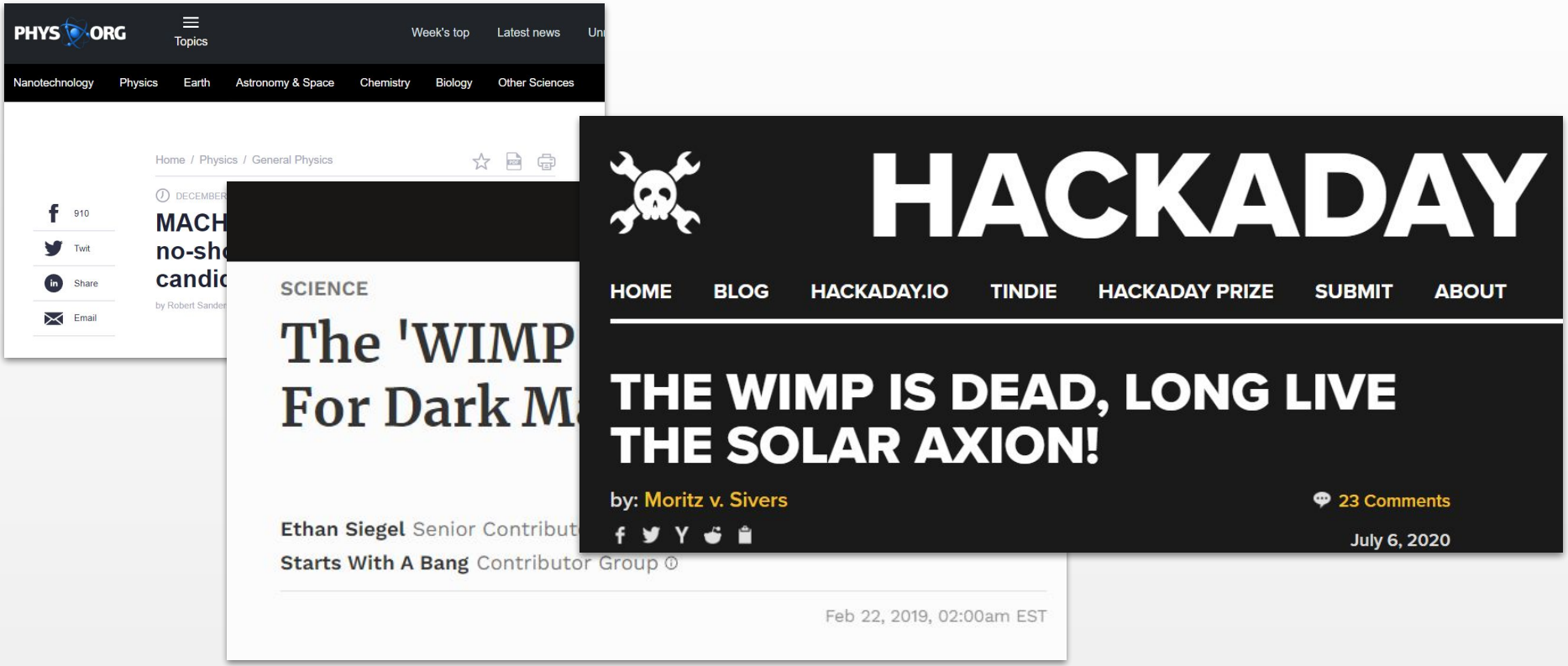
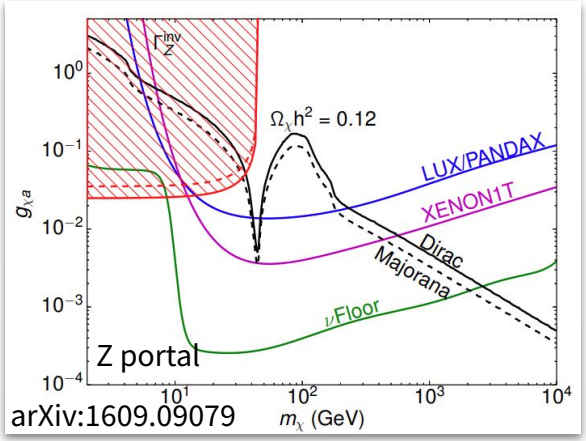
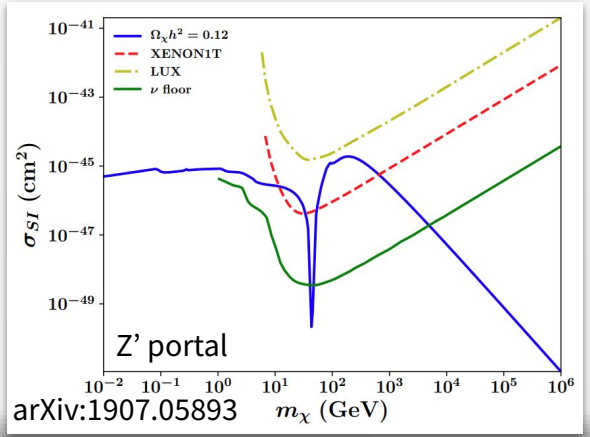


WIMPs are just fine..

Simple models:

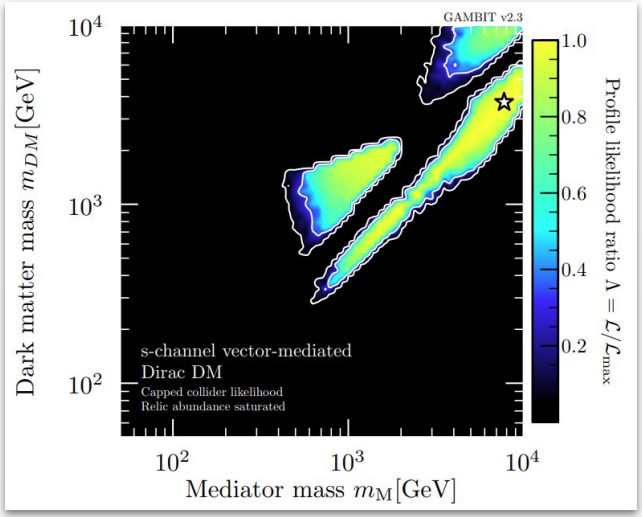


arXiv:1609.09079



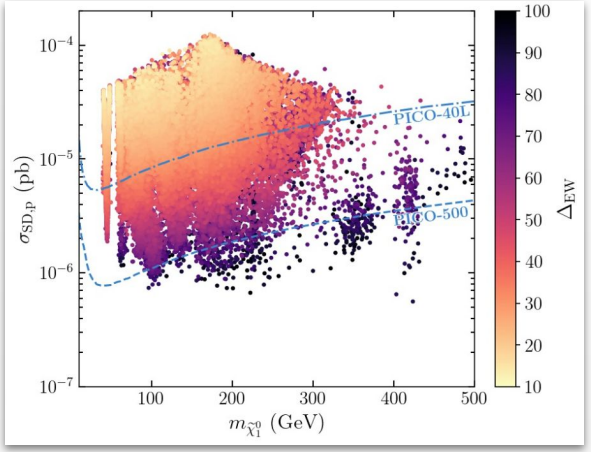
arXiv:1907.05893

Simplified models:



arXiv:2209.13266

SUSY (pMSSM):

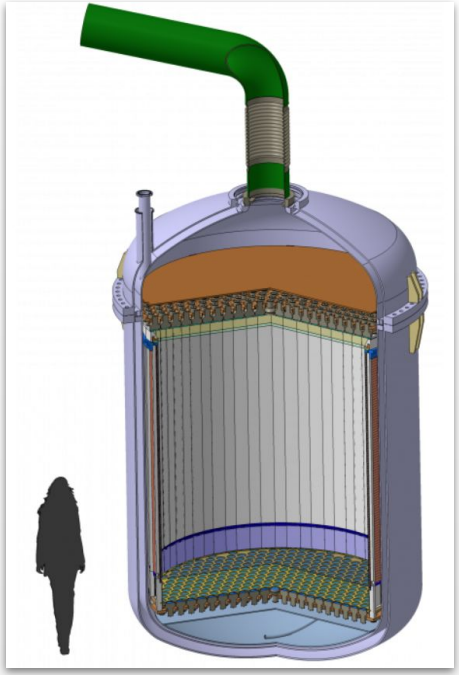


arXiv:2104.03245

What else can we do with >10t of xenon?

Dark matter physics

- Probe alternate production methods
- Bosonic dark matter absorption
- Luminous dark matter
- Planck scale dark matter



Other physics

- Neutrinos
  - Solar
  - Supernova
  - Geo
- Nuclear physics (rare decays)
- Solar axions
- Nucleon decay

Dark matter-electron scattering

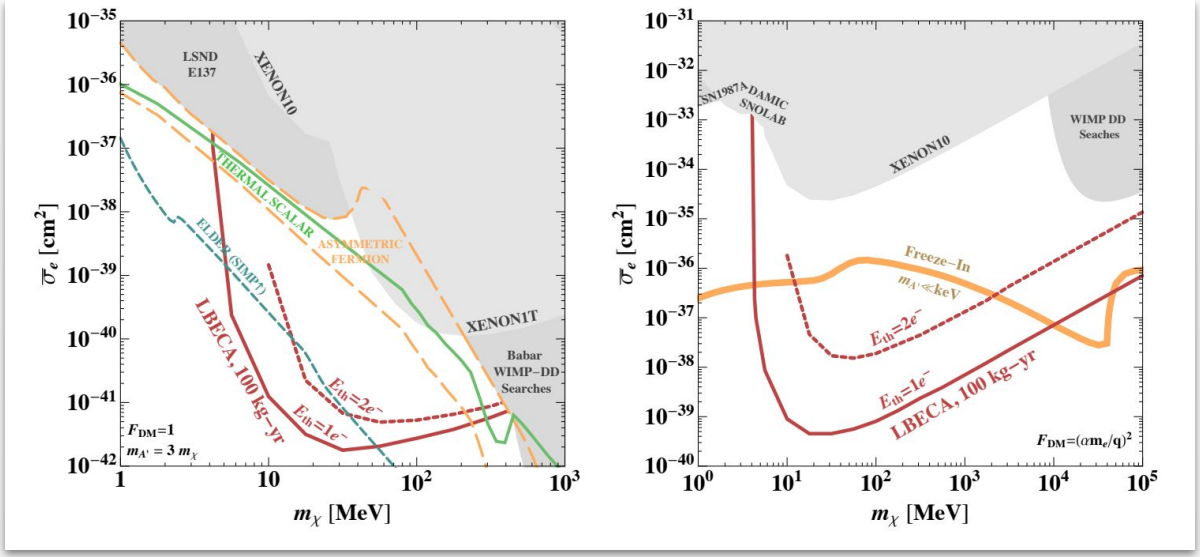
Some production mechanisms favour lighter DM e.g.:

- Freeze-in
- Asymmetric DM
- Strongly self-interacting DM

Xenon can be low-threshold too
(at the cost of ER/NR descrimination)

‘Heavy’ mediator

‘Light’ mediator

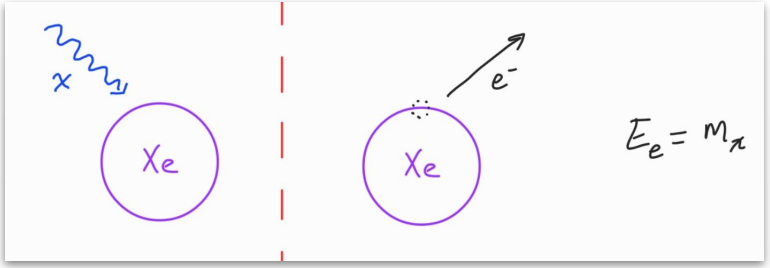


arXiv:2001.09311

Bosonic dark matter absorption

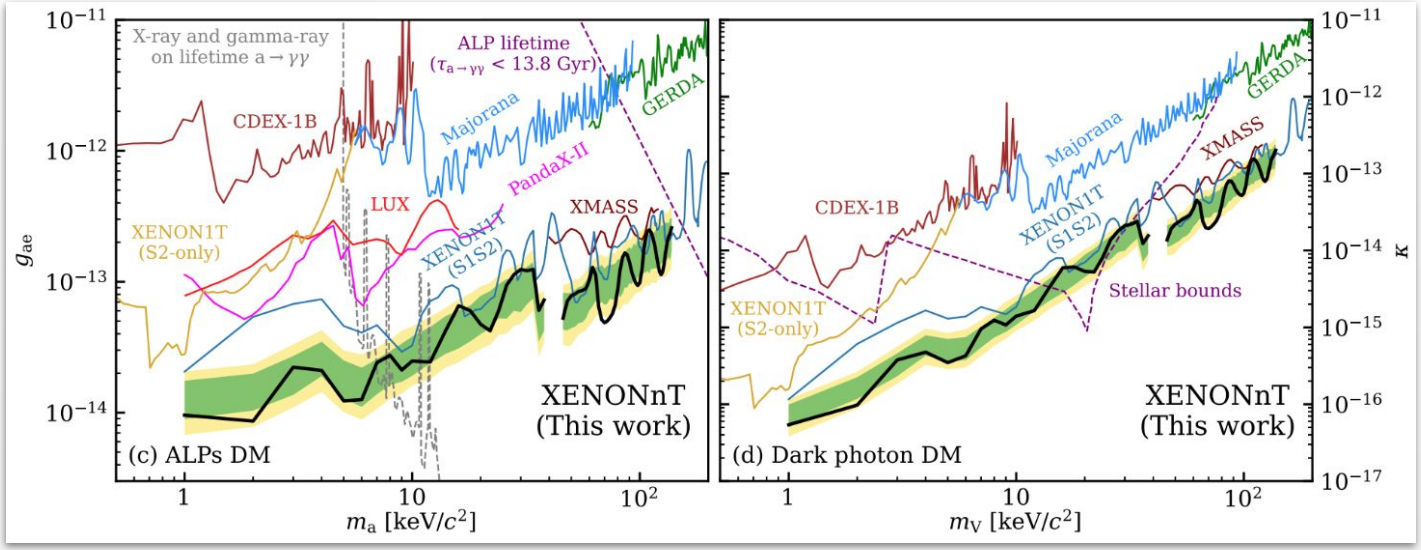
- Some models of bosonic DM don't have the usual elastic NR signatures
- WISPs are typically sub-eV, here we are looking at ~keV
- Typically these particles mix with the SM photon
- For example:
  - Axion-like particles (ALPs): generalised axions that *don't* solve the strong CP problem and don't tie f_a to m_a
  - Dark photons e.g. secluded U(1)'

Bosonic dark matter absorption



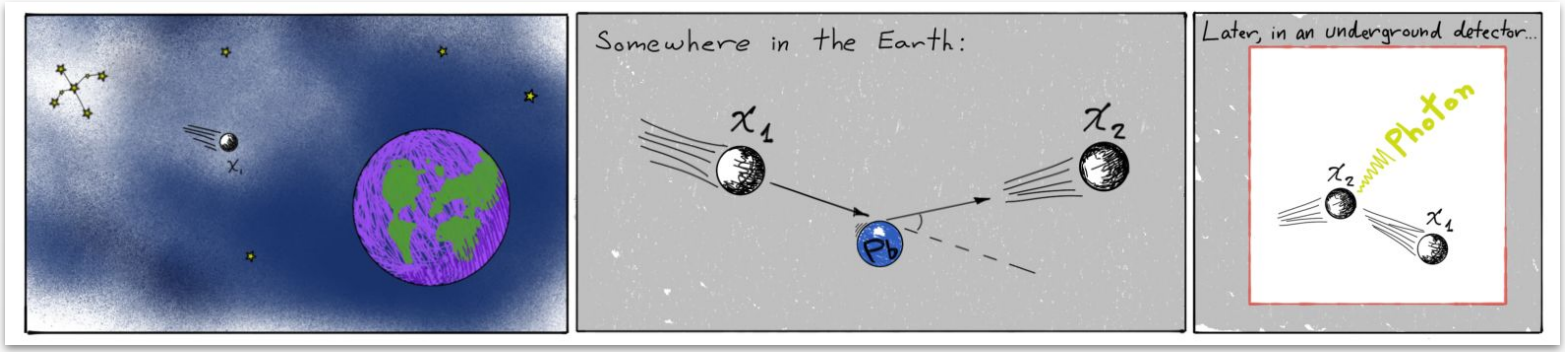
Axion-like particle DM

Dark photon DM



arXiv:2207.11330

Luminous dark matter

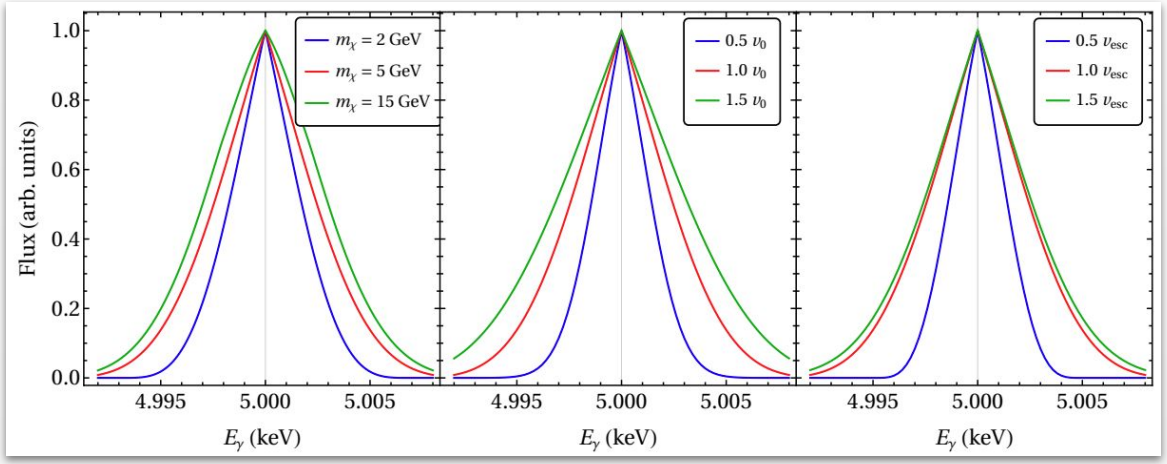


arXiv:1904.09994

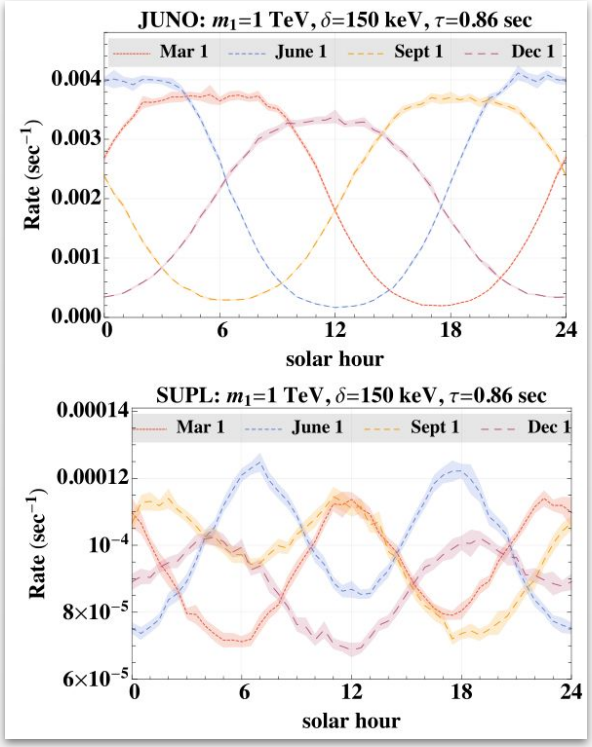
- Inelastic DM upscatters and then decays via photon emisson
- Originally used to explain DAMA (arXiv:1008.1988)
- Rate scales with detector volume
- If the lifetime is short enough the upscatter and decay can occur in the detector
  → giving rise to a ‘double bang’ event

Luminous dark matter

- This type of model has unique signatures and opportunities:



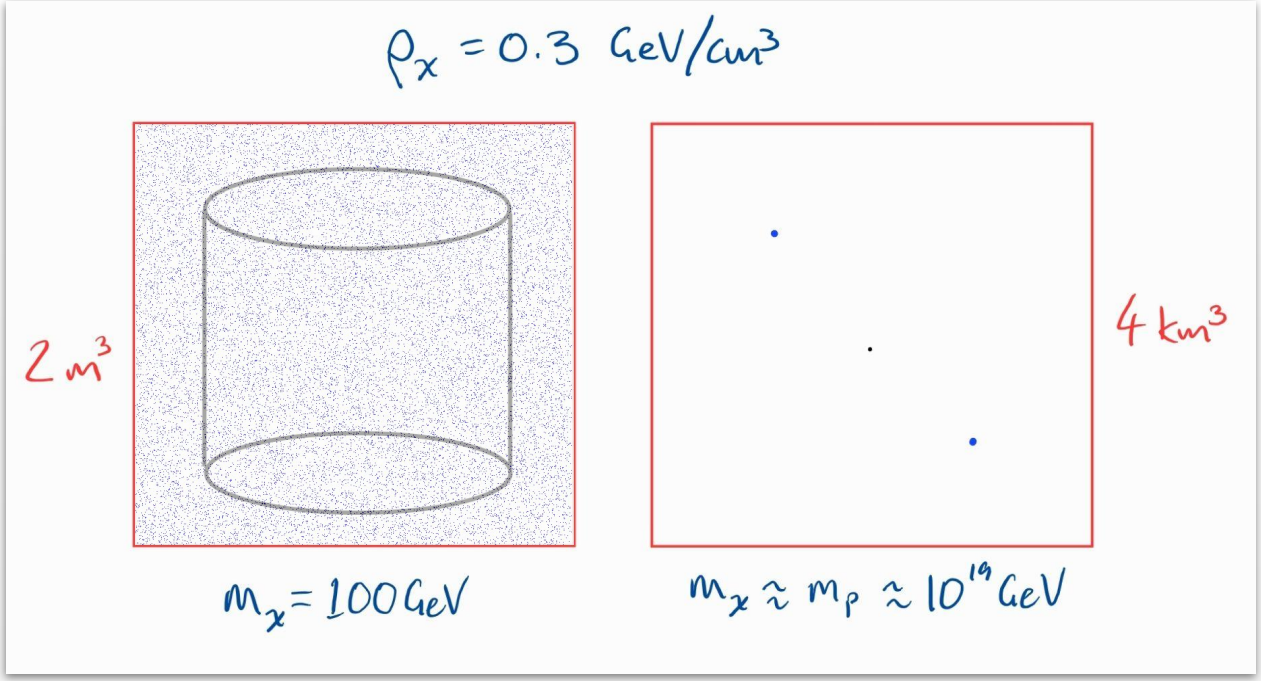
arXiv:2208.08020



arXiv:1904.09994

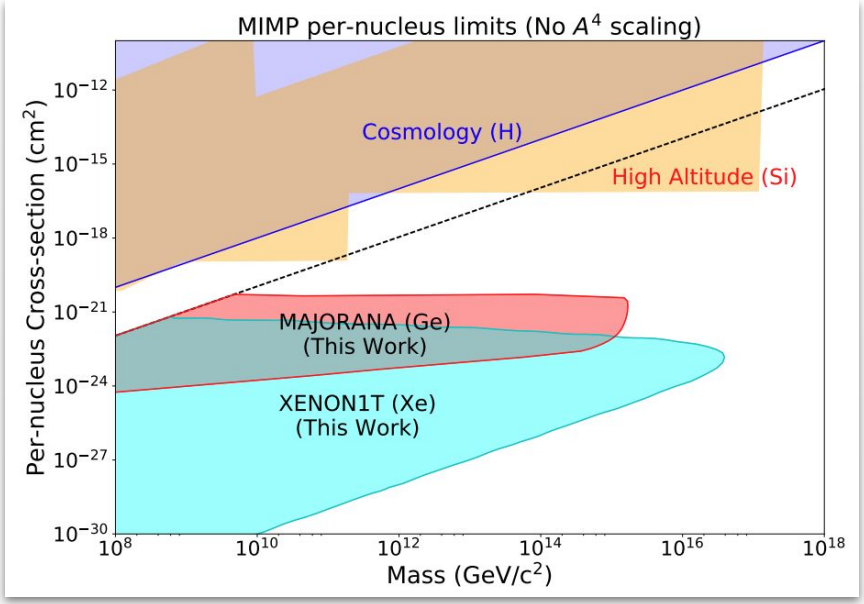
Ultra-heavy dark matter

- High scale physics (e.g. GUTs) could produce planck scale relics e.g. WIMPzillas, Q-balls, quark nuggets
- Much lower density puts un in a regime where a different analysis is required



Ultra-heavy dark matter

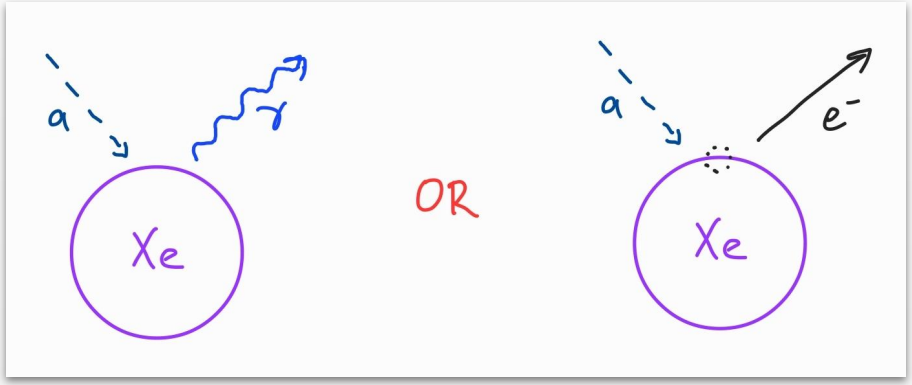
- The low flux means limits can only be set on large cross sections
- In this regime scattering is guaranteed and leaves tracks, but therefore can be attenuated in the overburden



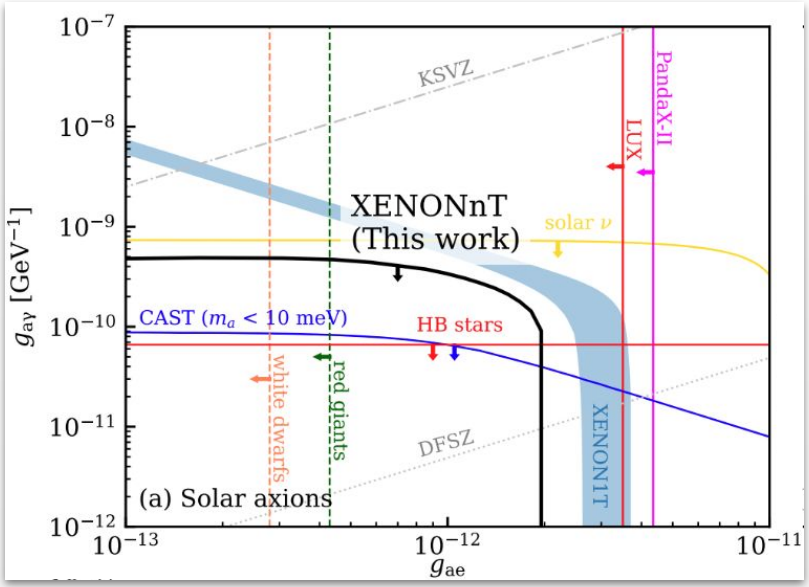
arXiv:2009.07909

Solar axion detection

- Axions produced in the Sun will produce ER signals in xenon, both via the axioelectric effect and via inverse-Primakoff scattering



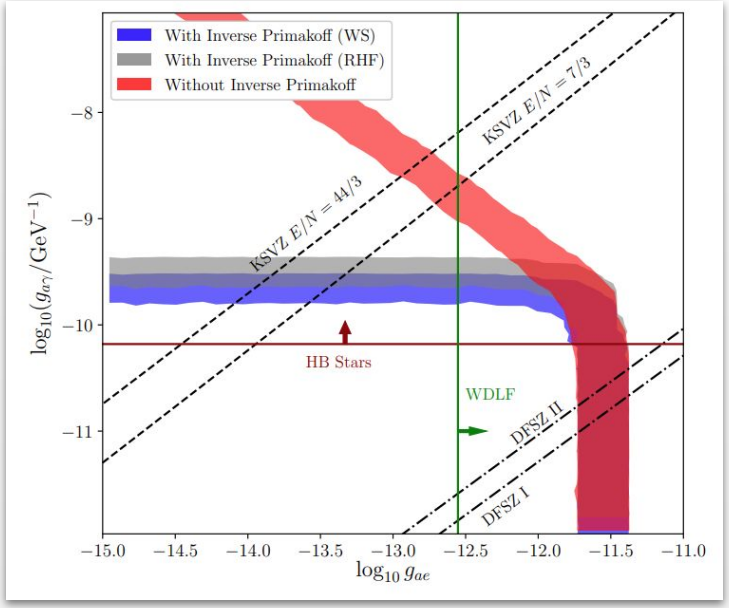
Inverse Primakoff *Axioelectric effect*



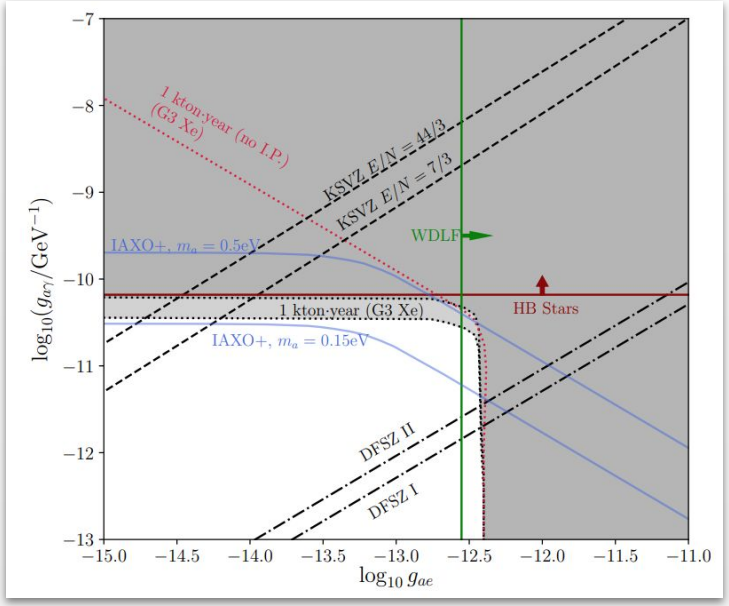
arXiv:2207.11330

Solar axion detection

- Side note: we pointed out the inverse-Primakoff channel in 2020 (along with 2006.14598)



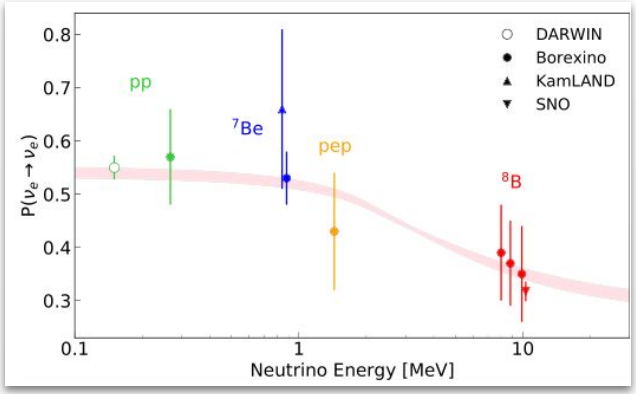
- Greatly improves sensitivity making xenon competitive with haloscopes



arXiv:2006.15118

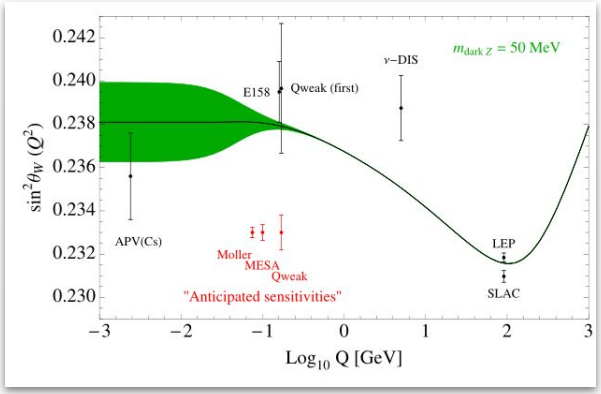
Neutrino physics

Measure survival probability:



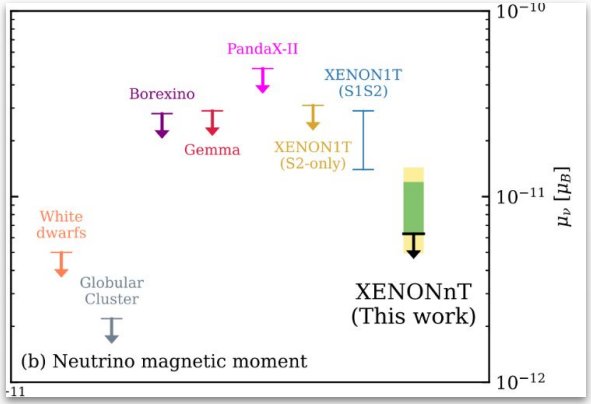
arXiv:2006.03114

Weinberg angle at low Q:



arXiv:1402.3620

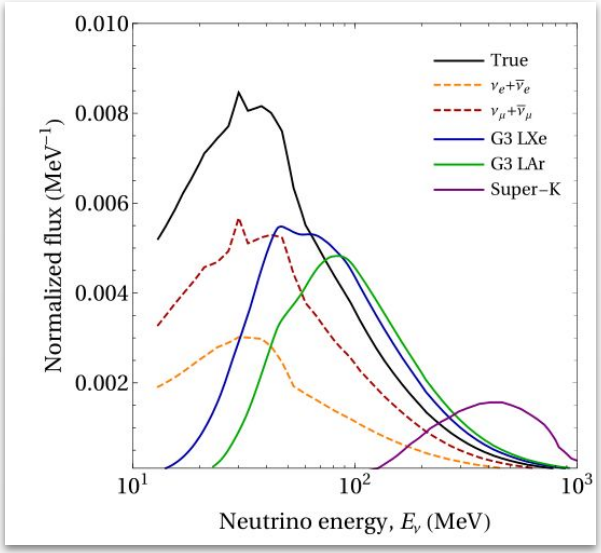
Constrain magnetic moment:



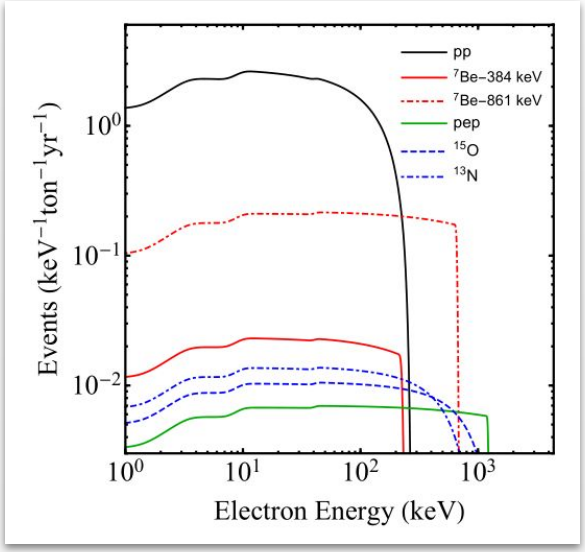
arXiv:2207.11330

Neutrino astrophysics

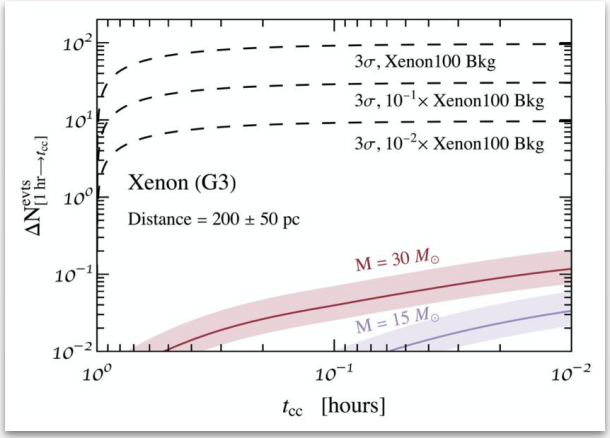
Atmospheric neutrinos:



Solar CNO neutrinos:



Supernova neutrinos:



From Xe G3 whitepaper

Conclusions

- There are many opportunities to explore with direct detection beyond the standard WIMP paradigm
- Xenon detectors are still leading the sensitive race to non-standard DM candidates
- Now that Australia (CDM) has officially joined XLZD we should look for ways to continue to contribute on the experimental-theoretical boundary