Self Destructing Dark Matter

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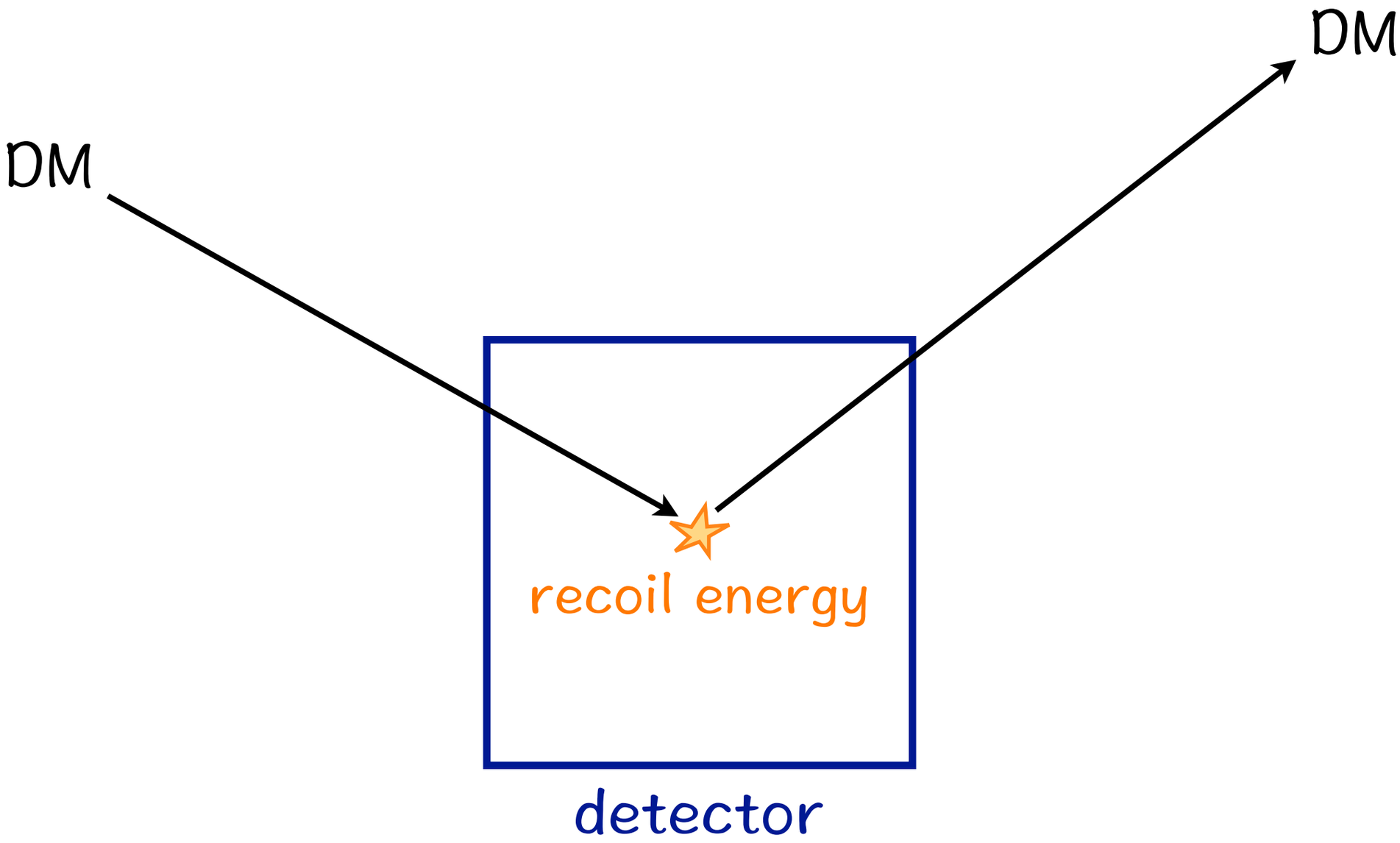
In collaboration with Yuval Grossman, Roni Harnik & Ofri Telem, to appear very soon.

Dark Matter Direct Detection

Can laboratories detect the dark matter that exists in nature?

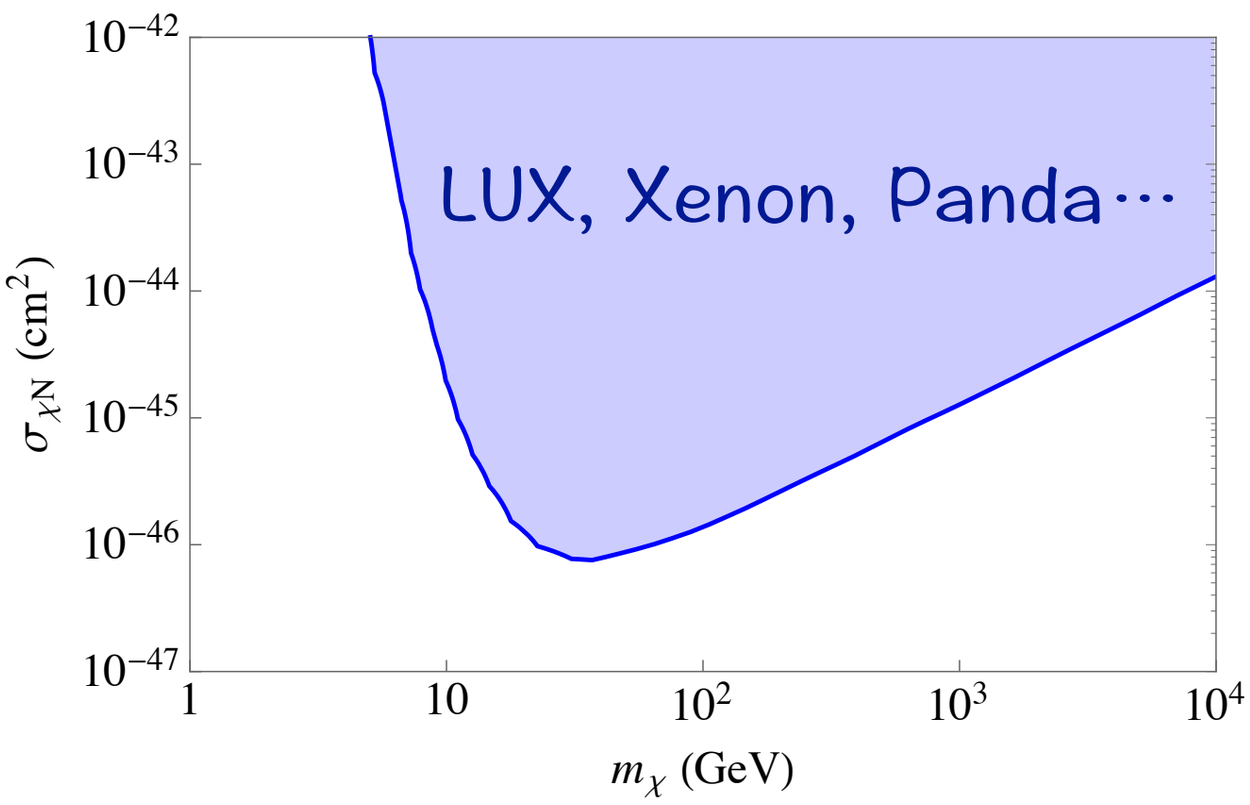


Available Energy (the usual story)

Recoil energy ~ $\mu v^2/2$, with $v \sim 10^{-3}$.

Lighter dark matter ⇒ smaller recoil energy.

Threshold for dark matter detectors ~ $10\,keV$ or lower.



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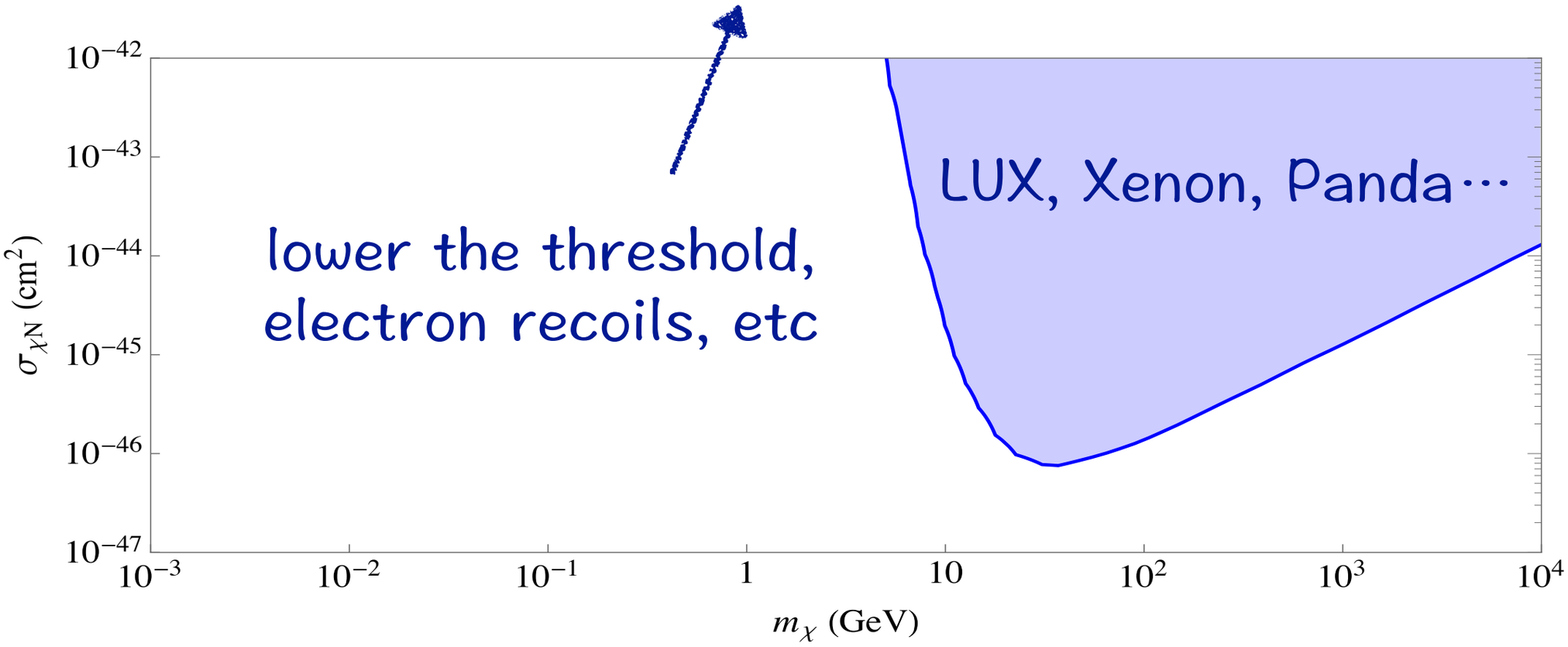


This Talk

Go beyond simple WIMP-like scattering picture:

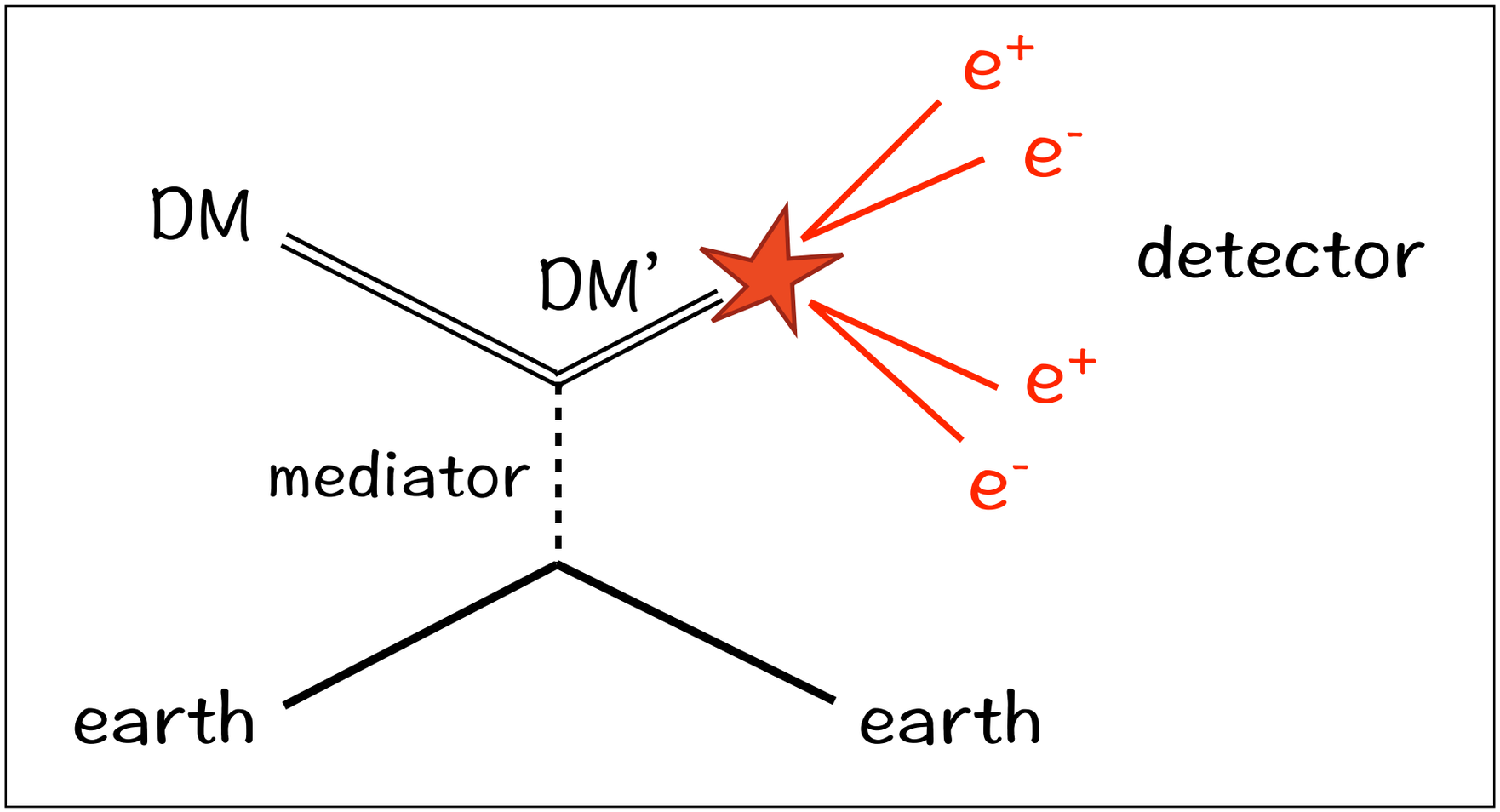
Instead of lowering thresholds, increase available energy.

1) There are models where ALL DM mass turns into energy after a scattering.

2) Such model could be detected in neutrino detectors, for DM mass between MeV to GeV scale.

Neutrino detectors: clean, large & higher thresholds (~MeV)

Self Destructing Dark Matter



Self destruction only triggered by a scattering; does not occur to DM state by itself.

Very natural to build models with dark matter bound states.

Self Destructing Dark Matter

DM has lived in the galaxy (not empty) for a long time, why would self destruction still occur at the earth today?

Place	Time spent, Δt	Density of stuff, n
Galactic Halo	10^{17} sec	~ 1 cm^{-3} (DM@1GeV)
Earth	10 sec	~ 10^{23} cm^{-3}

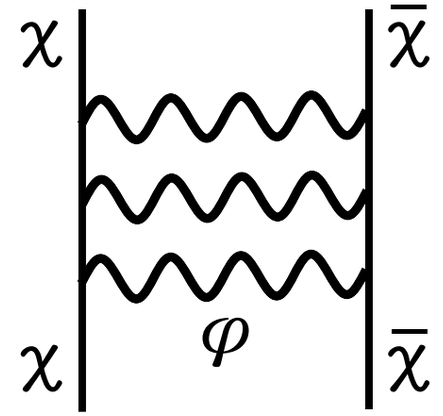
There is room for our Earth to do better

The Dark Analogy to Positronium

A light (well below MeV, this study) dark force φ for binding two particles χ and $\bar{\chi}$ together,

$$\alpha_D^2 m_\chi/4 < m_\varphi < \alpha_D m_\chi/(2n)$$

Rydberg Bohr radius



A heavier (above MeV) mediator V for talking to SM: $\kappa F_{\mu\nu} V^{\mu\nu}$,

$$\chi\bar{\chi} \to VV, \quad V \to e^+e^-$$

Mass range of V: $\alpha_D m_\chi/2 < m_V < m_\chi$

Stabilization With High ℓ

Higher angular momentum states are (much) more stable.

- Direct annihilation into V or φ.

$$\Gamma(\Psi_{n,\ell} \to VV) \sim (\alpha_D/n)^{2\ell+3}\ \alpha_D^2\ m_\chi$$

- De-excitation by radiating SM particles (3γ or 2ν) via V* strongly suppressed (Δbinding energy $\ll 2m_e$).

If α_D=0.01, m_χ=1GeV, the $n=10$, $\ell=9$ state very long-lived

$$\tau(\Psi_{10,9}) > 10^{40}\ \text{sec}$$

Scattering and Self Destruction

Turn into a lower ℓ state, $\Psi_{10,q} + (A,Z) \rightarrow \Psi_{1,0} + (A,Z)$

$$\sigma \sim g_D^2 \kappa^2 e^2 Z^2 \left(\frac{m_\chi^2}{m_V^4}\right)\left(\frac{\alpha_D}{v}\right) F(q)^2$$

α_D/v enhancement if $\alpha_D \gg v$: binding energy release enlarges the phase space of scattering,

$$|\vec{q}| \sim m_\chi \alpha_D + m_\chi v \cos\vartheta$$

Form factor for bound state transition

$$F(q) = \int dV \, \Psi_{10,q}^*(x) \, \Psi_{1,0}(x) \left(e^{iq\cdot x} - e^{-iq\cdot x} \right)$$

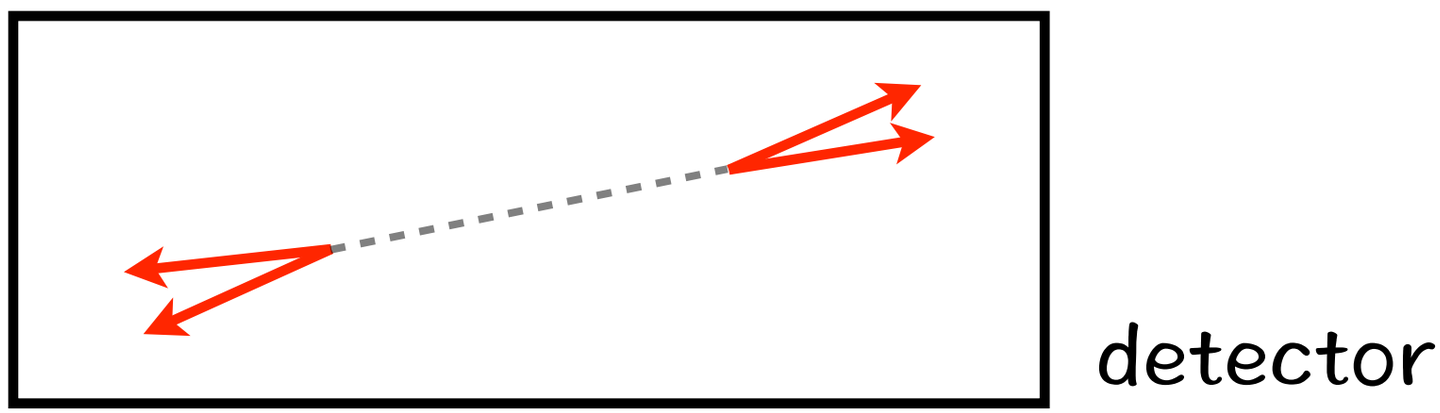
Signals of DM Self Destruction

Self destruction: final $\Psi_{1,0}$ state decays promptly into V's

$$\tau(\Psi_{1,0}) = (\alpha_D^5 m_\chi/2)^{-1} \sim 2\times10^{-14}\text{sec}\left(\frac{\alpha_D}{0.01}\right)^{-5}\left(\frac{m_\chi}{1\text{GeV}}\right)^{-1}$$

$\Psi_{1,0}\to VV\to 2(e^+e^-)$ produces two pairs of e^+e^-. Each pair carries energy dictated by mass of χ.

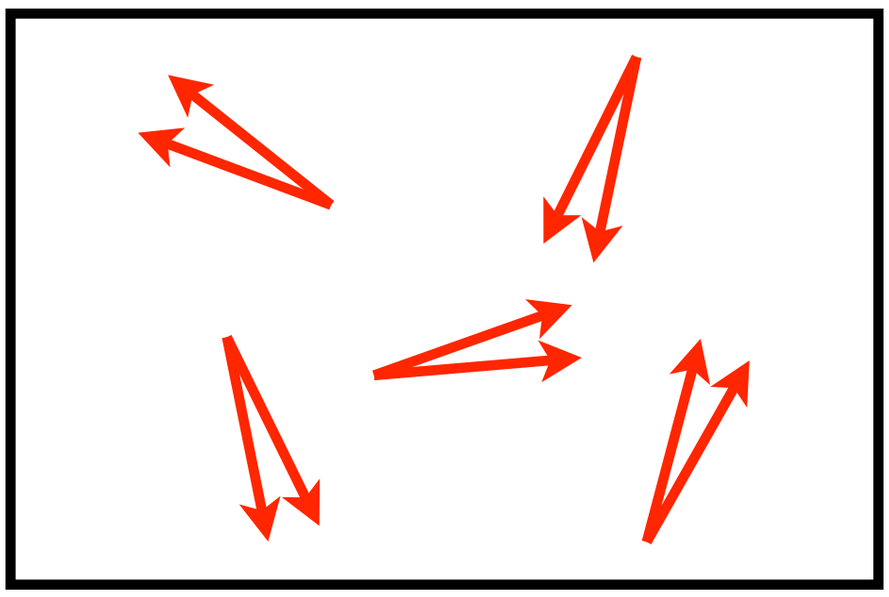
V decay length $\lesssim$ 10meter, observe both pairs, back to back.



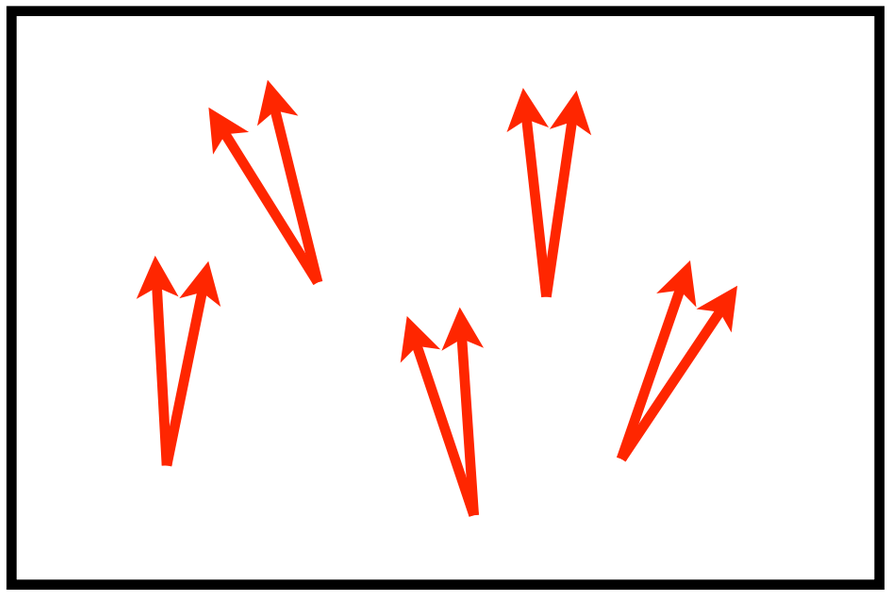
Signals of DM Self Destruction

Dark photon V could be long lived, $c\tau \gtrsim 10$ m. Scattering on earth, only one V travels to detector — see single pair.

- $c\tau \lesssim$ km: isotropic
- km $\lesssim c\tau \lesssim 10^4$ km: most pairs up-going

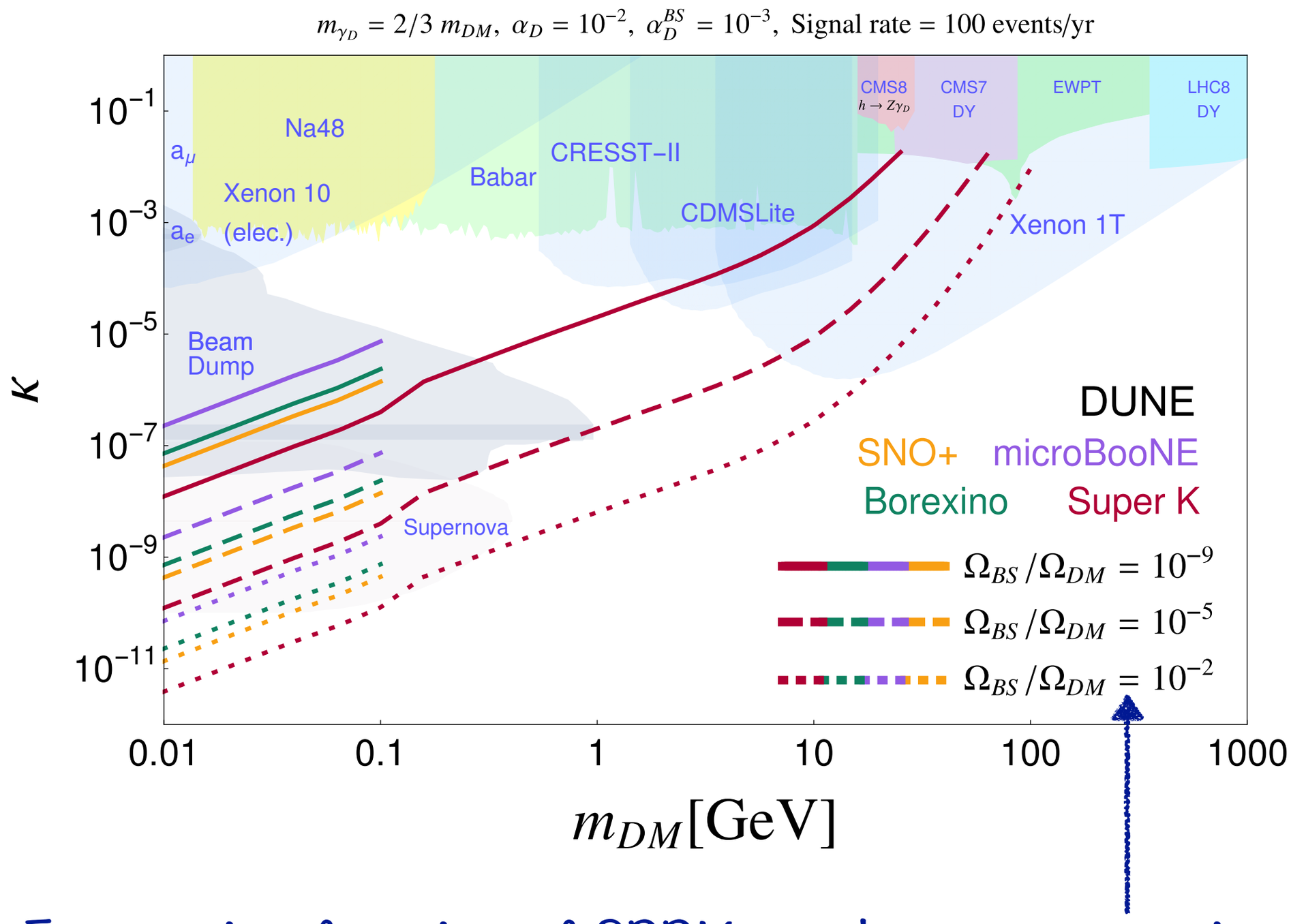


detector



detector

New Constraints

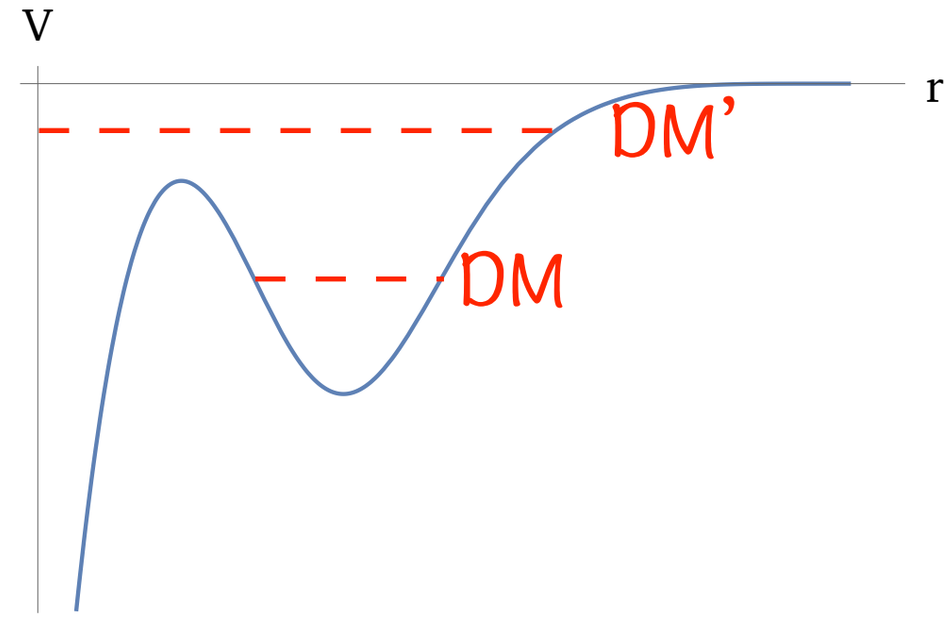


Even a tiny fraction of SDDM can have a strong impact

Other SDDM Models

Tunneling stabilization:

- Ground state wavefunction exponentially suppressed at origin.
- Unsuppressed for excited state.
- Analogy to D_2 molecule $\rightarrow$ ^4He (add a confining potential).



Symmetry stabilization: χ carries baryon number

- $(\chi\chi)$ and $(\chi\bar{\chi})$ are bounded by an SU(2) confining dark force.
- $(\chi\chi) + (A,Z) \rightarrow (\chi\bar{\chi}) + (A\text{-}1,Z)$, steal a neutron away.

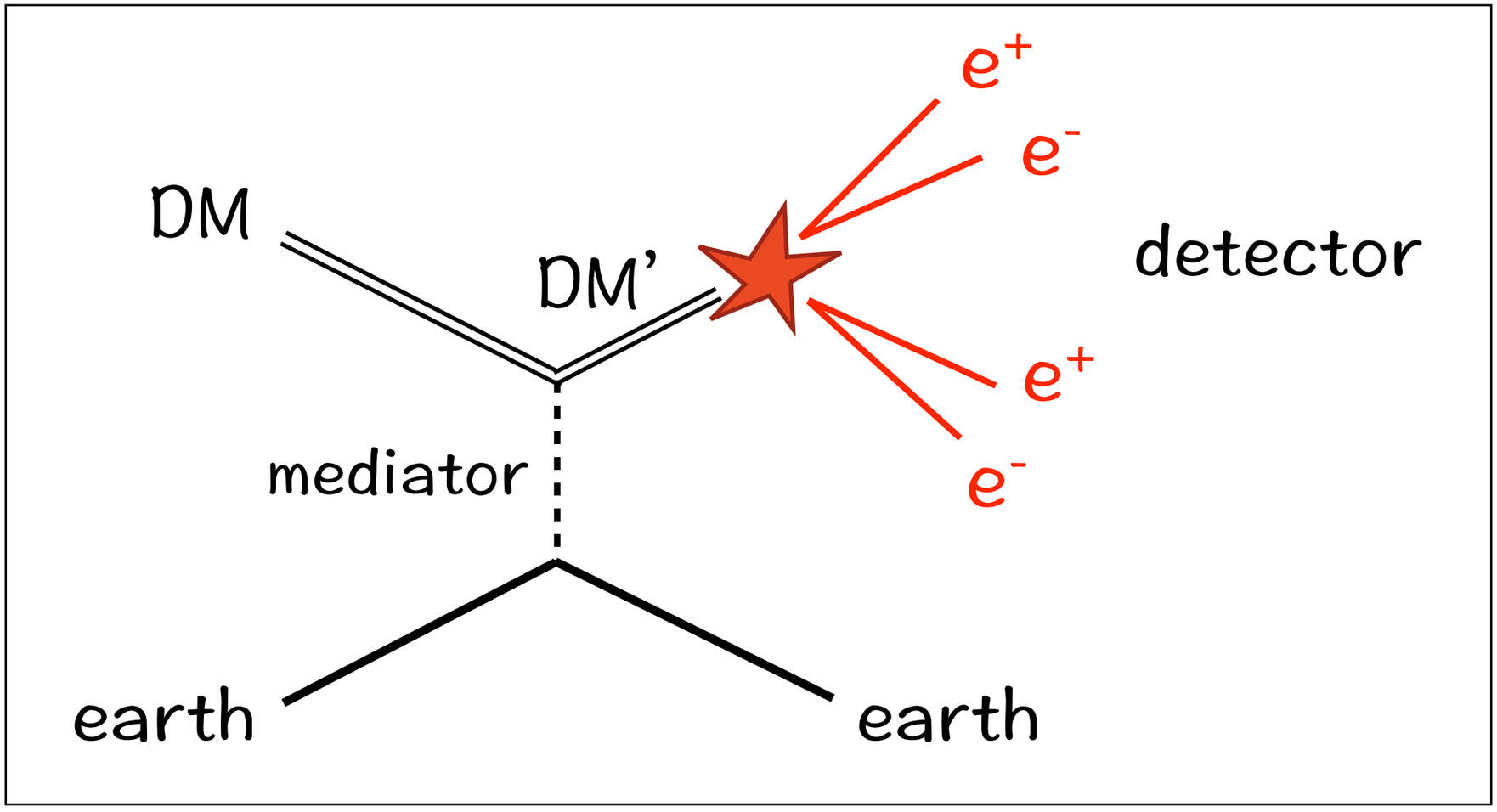
Conclusion

Light dark matter is harder to leave a signal in direct detection if only the kinetic energy is available.

There is a class of models where all the DM mass turns into energy after a scattering.

Such a DM with mass MeV-GeV can be searched for using neutrino detectors

I discussed a few models where DM bound states can be the self destructing dark matter.



Thank you!