Co-SIMP Miracle

Juri Smirnov

CCAPP

N3AS: 06/16/20

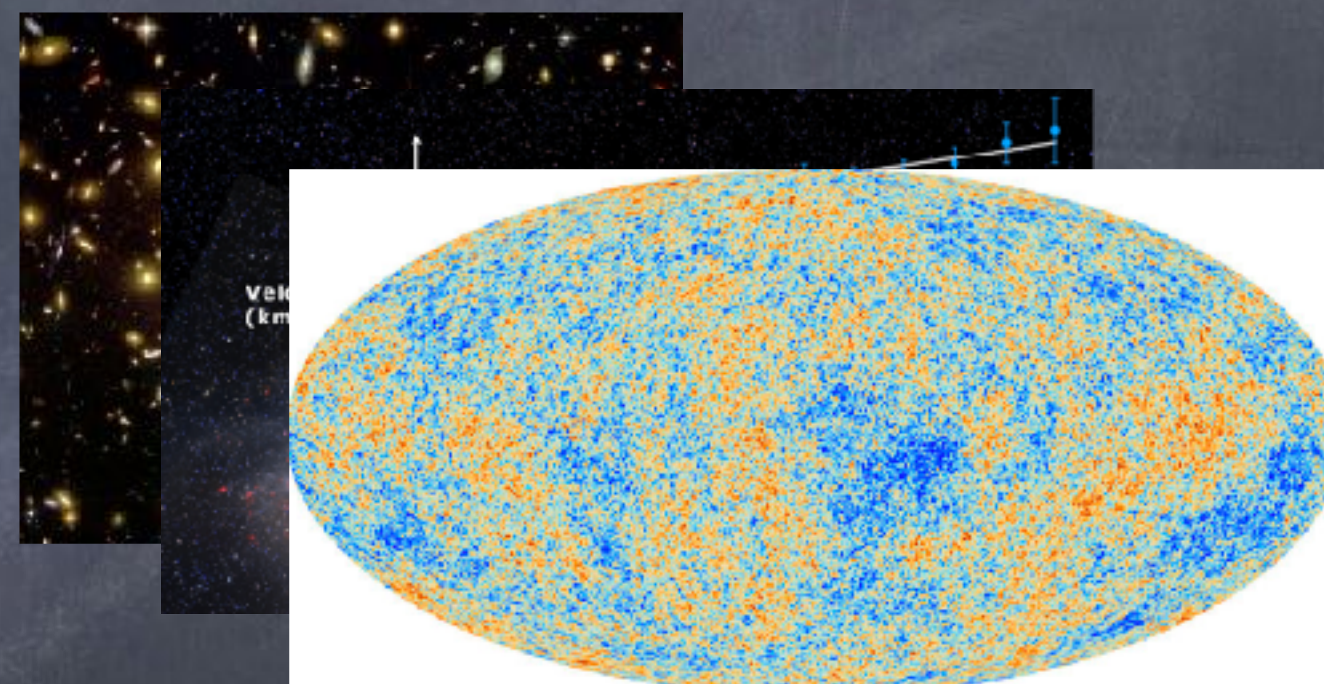
In collaboration with: John Beacom (OSU, CCAPP)

THE OHIO STATE UNIVERSITY

Dark Matter is a New Particle

Not ordinary Matter: $\Omega_{\mathrm{DM}} >> \Omega_{\mathrm{Baryons}}$

(CMB) (BBN, CMB)



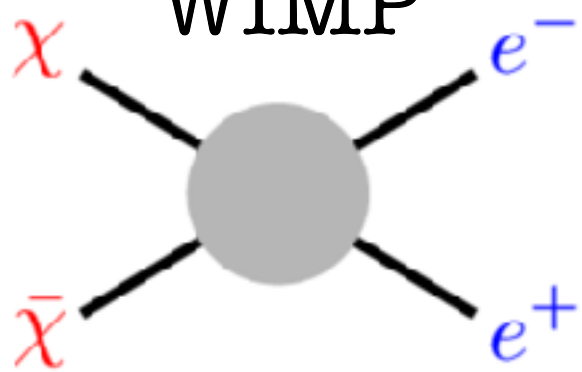
Not MOND:

Not light Neutrinos: $\Omega_\nu \approx 0.02 \left(\frac{m_\nu}{\mathrm{eV}} \right)$

Production

Freezeouts

WIMP

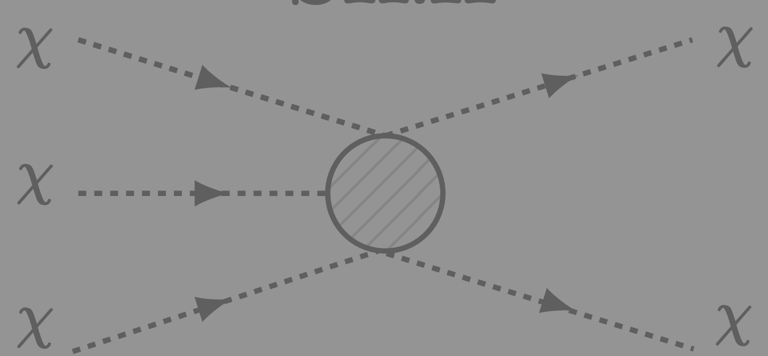


Zeldovich, Lee, Weinberg, Steigman, Turner,...

$$\Gamma_{\rm DM} = \langle \sigma v_{\rm rel.} \rangle \, n_{\rm DM} > H(T)$$

$$\Omega_{\rm DM}\, h^2 \approx \frac{0.12}{\langle \sigma v_{\rm rel.} \rangle \, [25 {\rm TeV}]^2}$$

SIMP

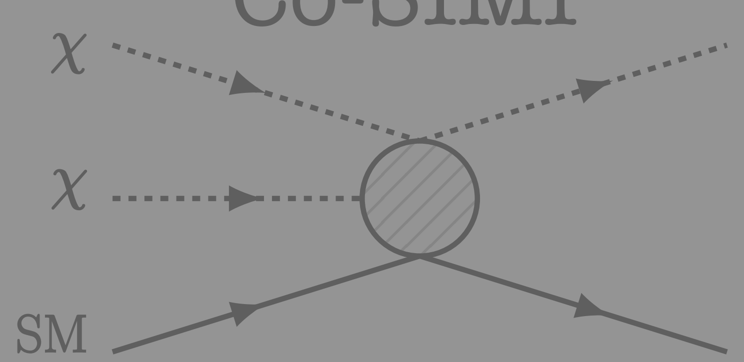


Hochberg, Kuflik, Volansky, Wacker

$$\Gamma_{\rm DM} = \langle \sigma_{3\to 2} v_{\rm rel.}^2 \rangle \, n_{\rm DM}^2 > H(T)$$

$$\Omega_{\rm DM}\, h^2 \approx \left(\frac{\rm MeV}{m_{\rm DM}}\right) \frac{0.12}{\sqrt{\langle \sigma_{3\to 2} v_{\rm rel.}^2 \rangle \, [3 {\rm MeV}]^5}}$$

Co-SIMP

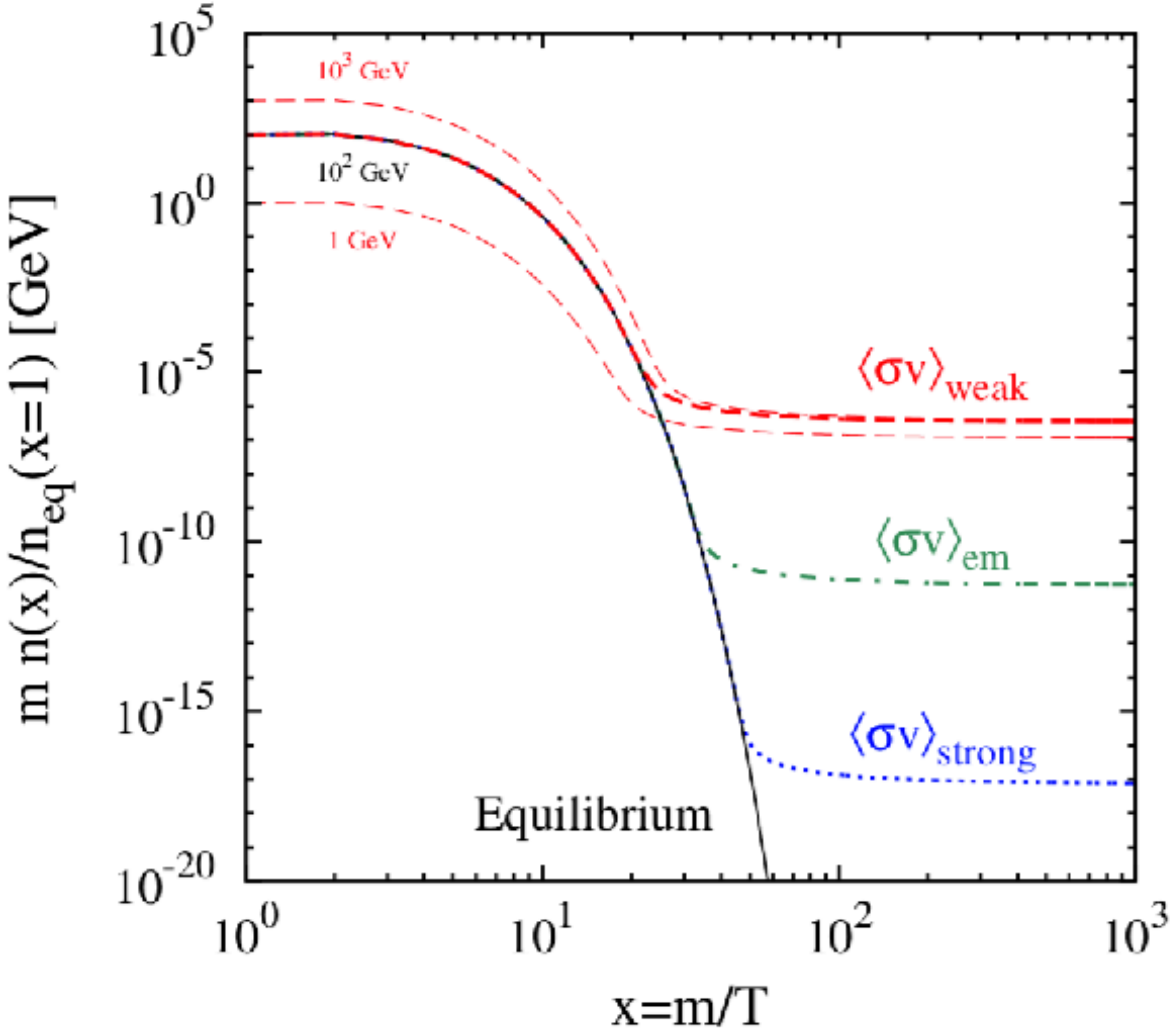


Smirnov, Beacom

$$\Gamma_{\rm DM} = \langle \sigma_{3\to 2} v_{\rm rel.}^2 \rangle \, n_{\rm DM} n_{\rm SM} > H(T)$$

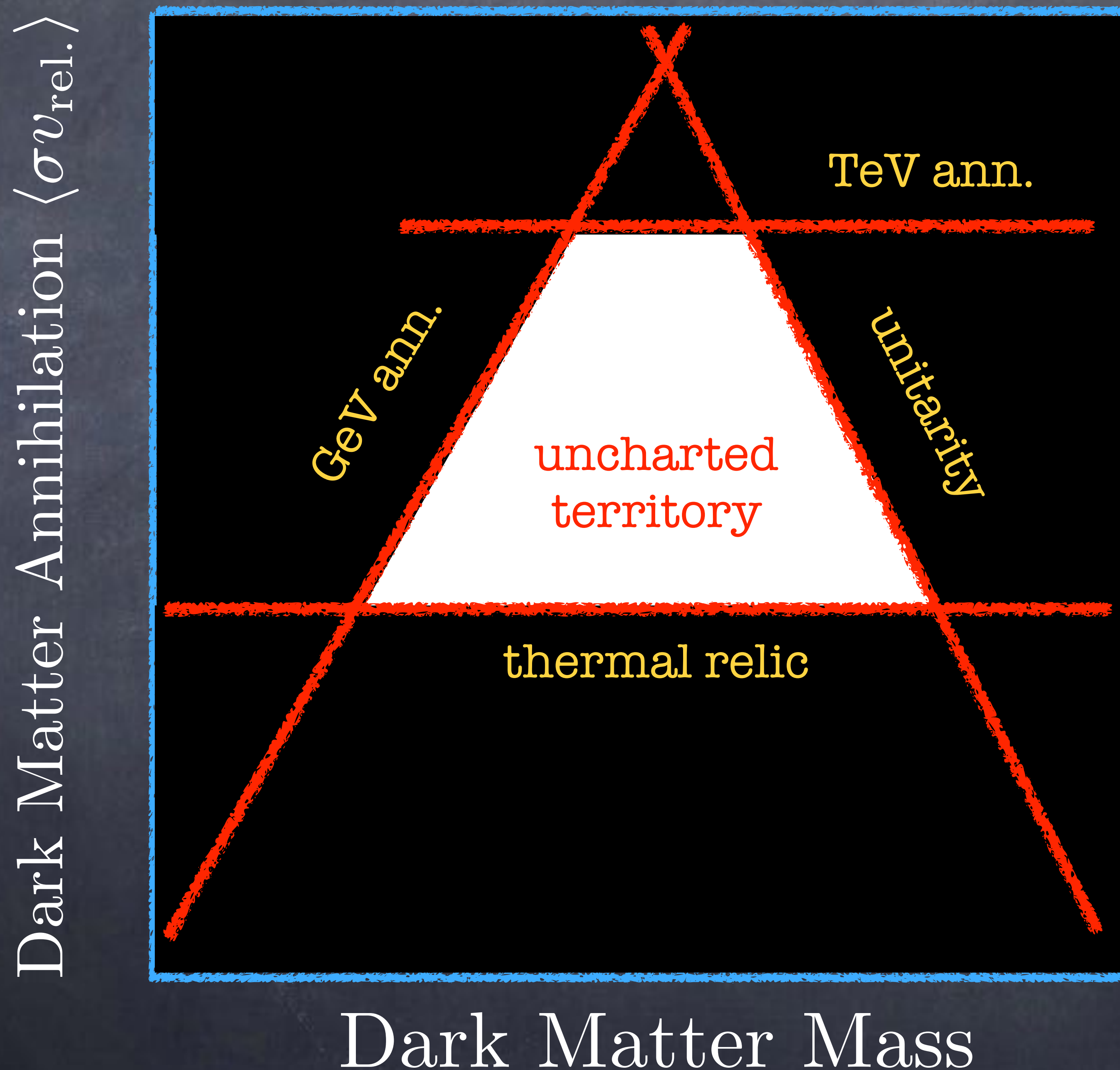
$$\Omega_{\rm DM} h^2 \approx \left(\frac{\rm MeV}{m_{DM}}\right)^3 \frac{0.12}{\langle \sigma_{3\to 2} v_{\rm rel.}^2 \rangle [100 \, {\rm MeV}]^5}$$

WIMP Freezeout



Steigman, Dasgupta, Beacom
arXiv: 1204.3622

Cartoon Overview of Approach



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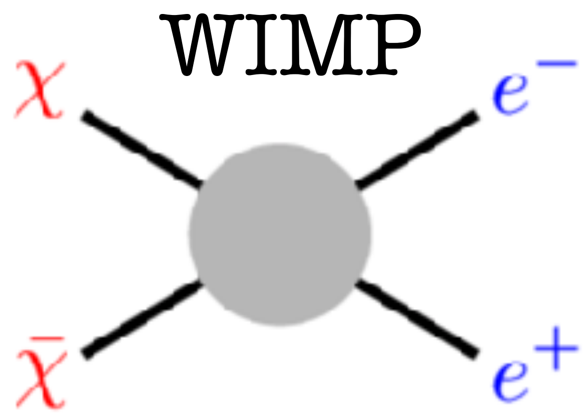
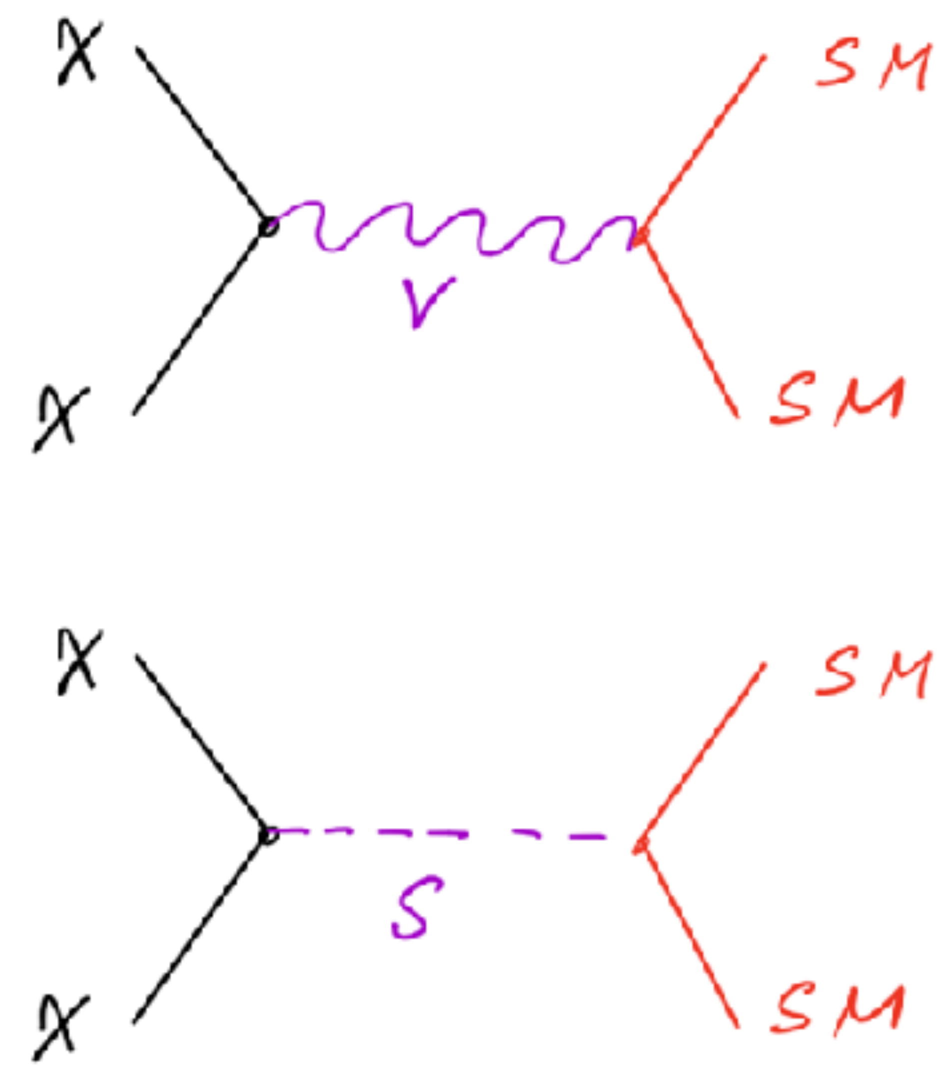
WIMP Interaction

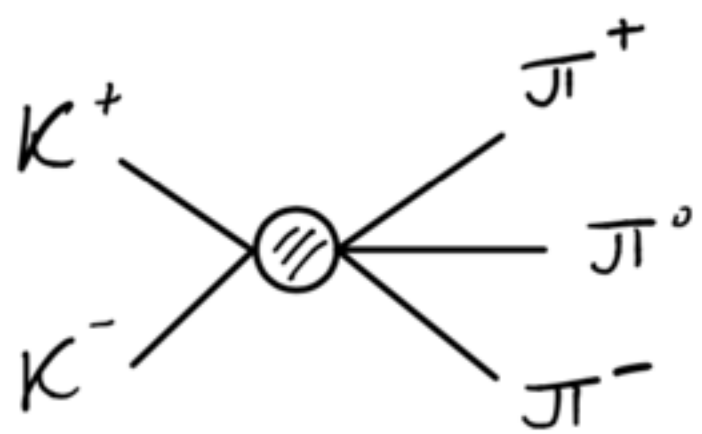


Zeldovich, Lee, Weinberg, Steigman, Turner,...



- Typically classification by portals
- Vector, Scalar, ...

More Interaction Types



$P_o = (-1)^2$ $\qquad$ $P_o = (-1)^3$

$P_M = (-1)^2$ $\qquad$ $P_M = (-1)^3$

What is the Lagrangian?

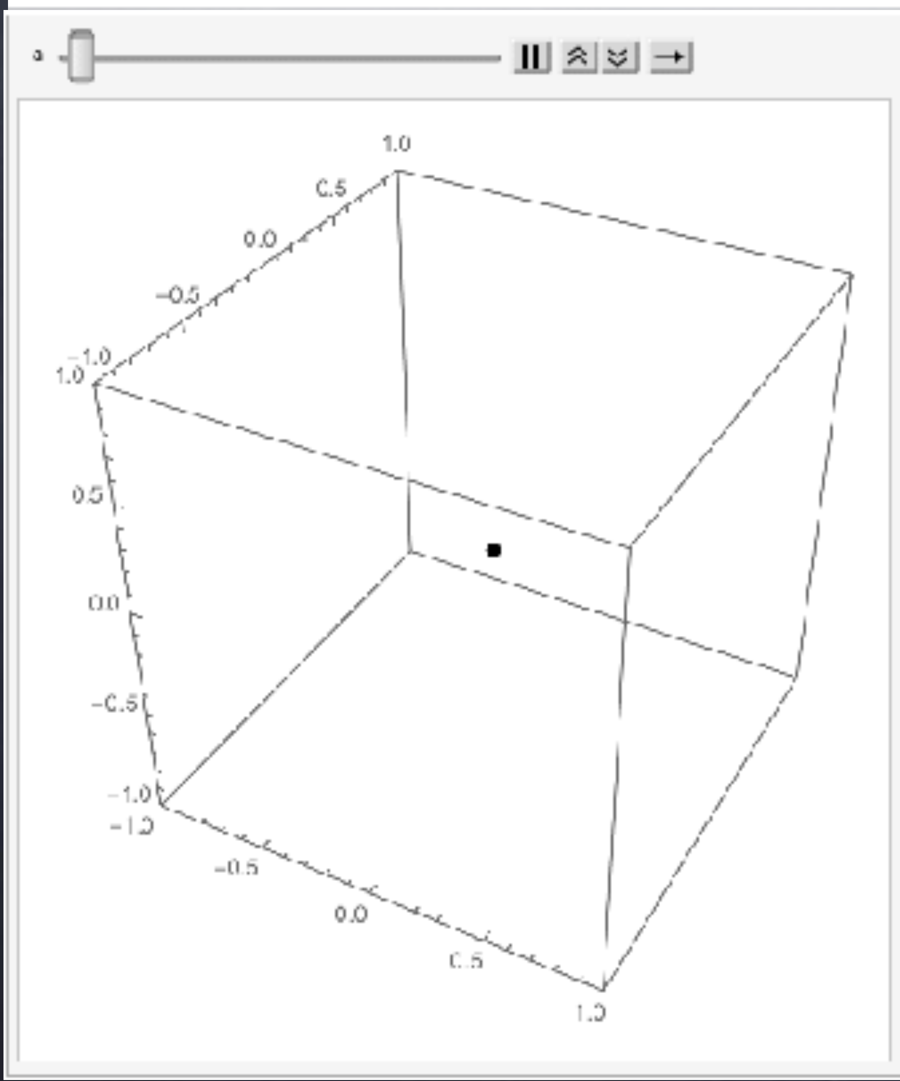
Topological Theories

GLOBAL ASPECTS OF CURRENT ALGEBRA

Edward WITTEN*

Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544, USA

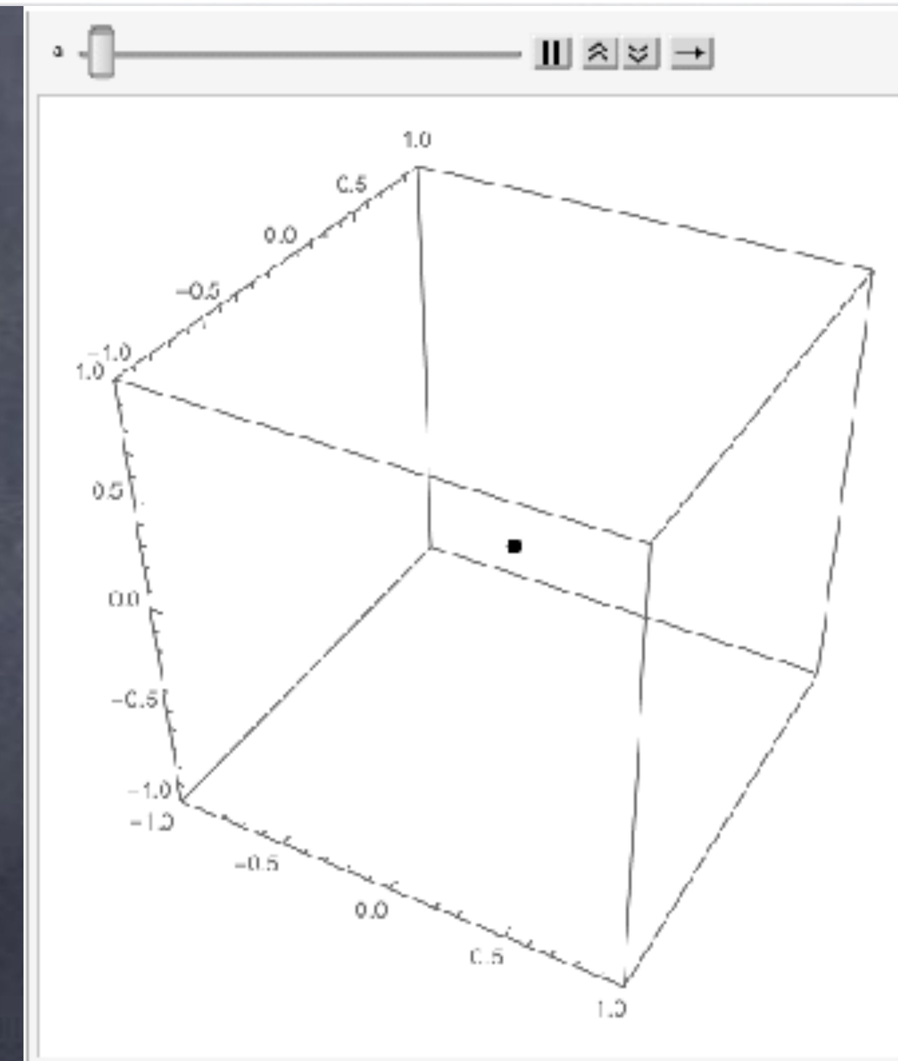
$$m\ddot{x}_i + m x_i \left(\sum_k \dot{x}_k^2 \right) = \alpha \varepsilon_{ijk} x_j \dot{x}_k ,$$



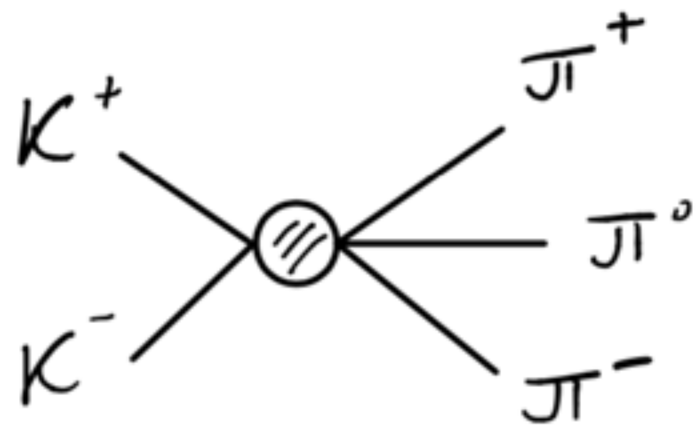
$$\vec{\nabla} \times \vec{A} \sim \frac{\vec{r}}{|r|^3}$$

$$t \to -t$$

$$-x_i \leftarrow x_i$$

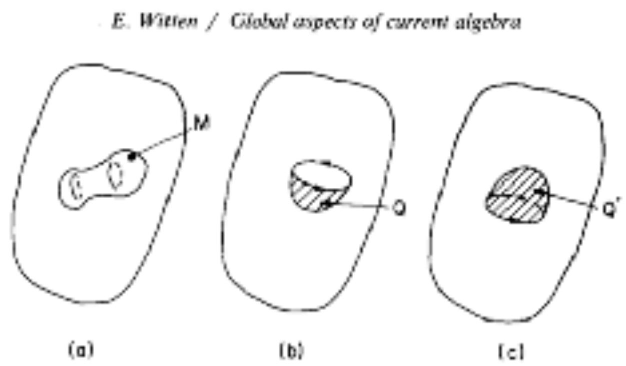


More Interaction Types



$P_0 = (-1)^2$ $\qquad$ $P_0 = (-1)^3$

$P_M = (-1)^2$ $\qquad$ $P_M = (-1)^3$



$$\mathcal{L} \supset \frac{N_c}{240\pi^2 f_\pi^5} \int d^4x \varepsilon^{\mu\nu\alpha\beta} \mathrm{Tr}\left[A\partial_\mu A \partial_\nu A \partial_\alpha A \partial_\beta A\right] ,$$

with $4\pi f_\pi \approx \Lambda_D$ and $A = \sum_a \lambda_a \pi^a$

$$\langle \sigma_{32} v_{\rm rel}^2 \rangle = \frac{5\sqrt{5}}{2^{11}\pi^5 f_\pi^5 z_\pi^2} \left(\frac{m_\pi}{f_\pi}\right)^5 \frac{N_c^2}{N_\pi^3} \underbrace{\frac{1}{5!}\sum T^2_{\{ijklm\}}}_{=t^2}$$

E. Witten (1983)

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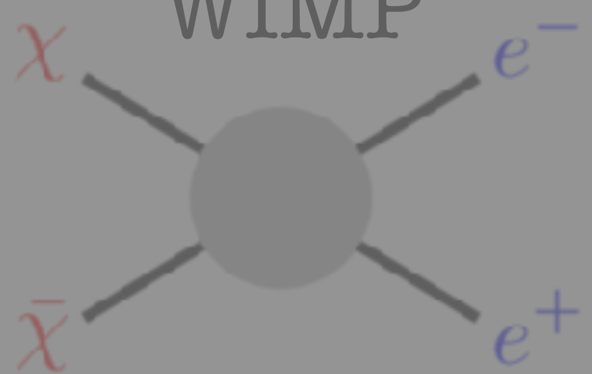
Other Types of Freezeout

WIMP



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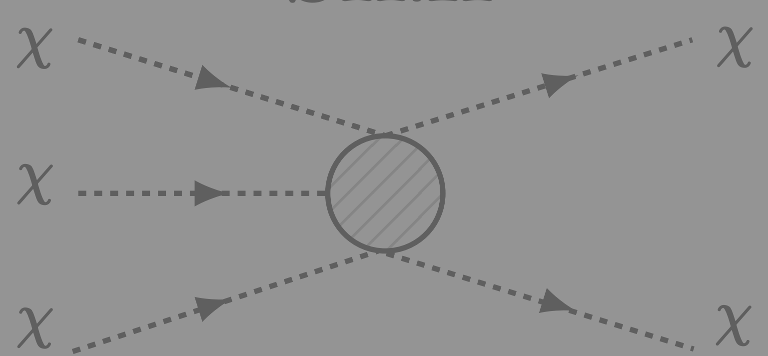
SIMP



Hochberg, Kuflik, Volansky, Wacker

$$\Gamma_{\mathrm{DM}} = \langle \sigma_{3\to 2} v_{\mathrm{rel.}}^2 \rangle \, n_{\mathrm{DM}}^2 > H(T)$$

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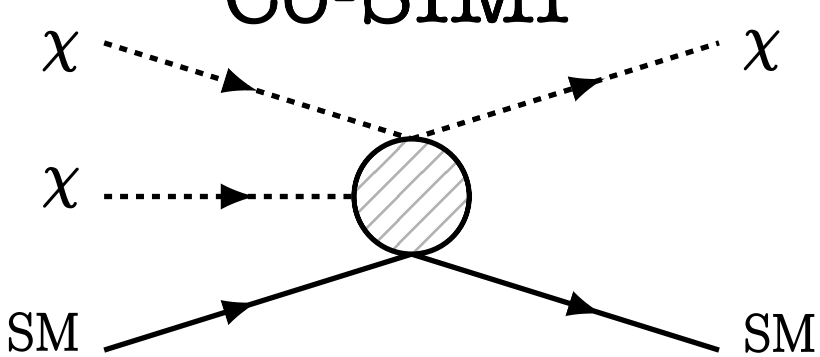
Co-SIMP



Smirnov, Beacom

$$\Gamma_{\mathrm{DM}} = \langle \sigma_{3\to 2} v_{\mathrm{rel.}}^2 \rangle \, n_{\mathrm{DM}} n_{\mathrm{SM}} > H(T)$$

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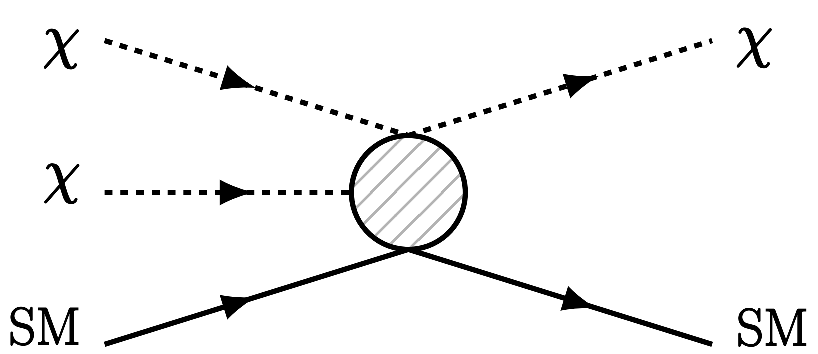
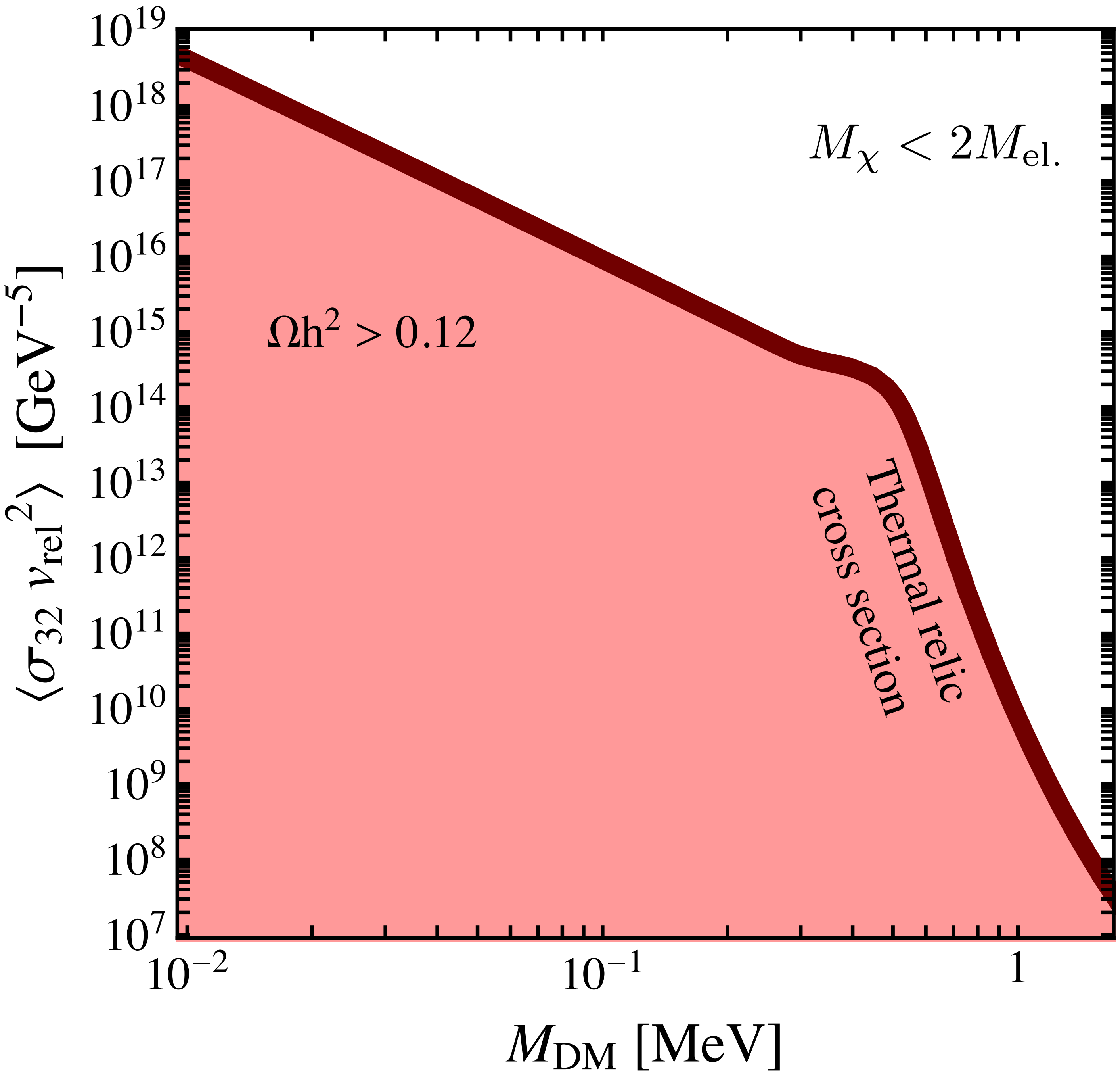
Co-SIMP Parameter Space



$$M_\chi < 2M_{\rm SM}$$



arXiv: 2002.04038; J. Smirnov, J. Beacom

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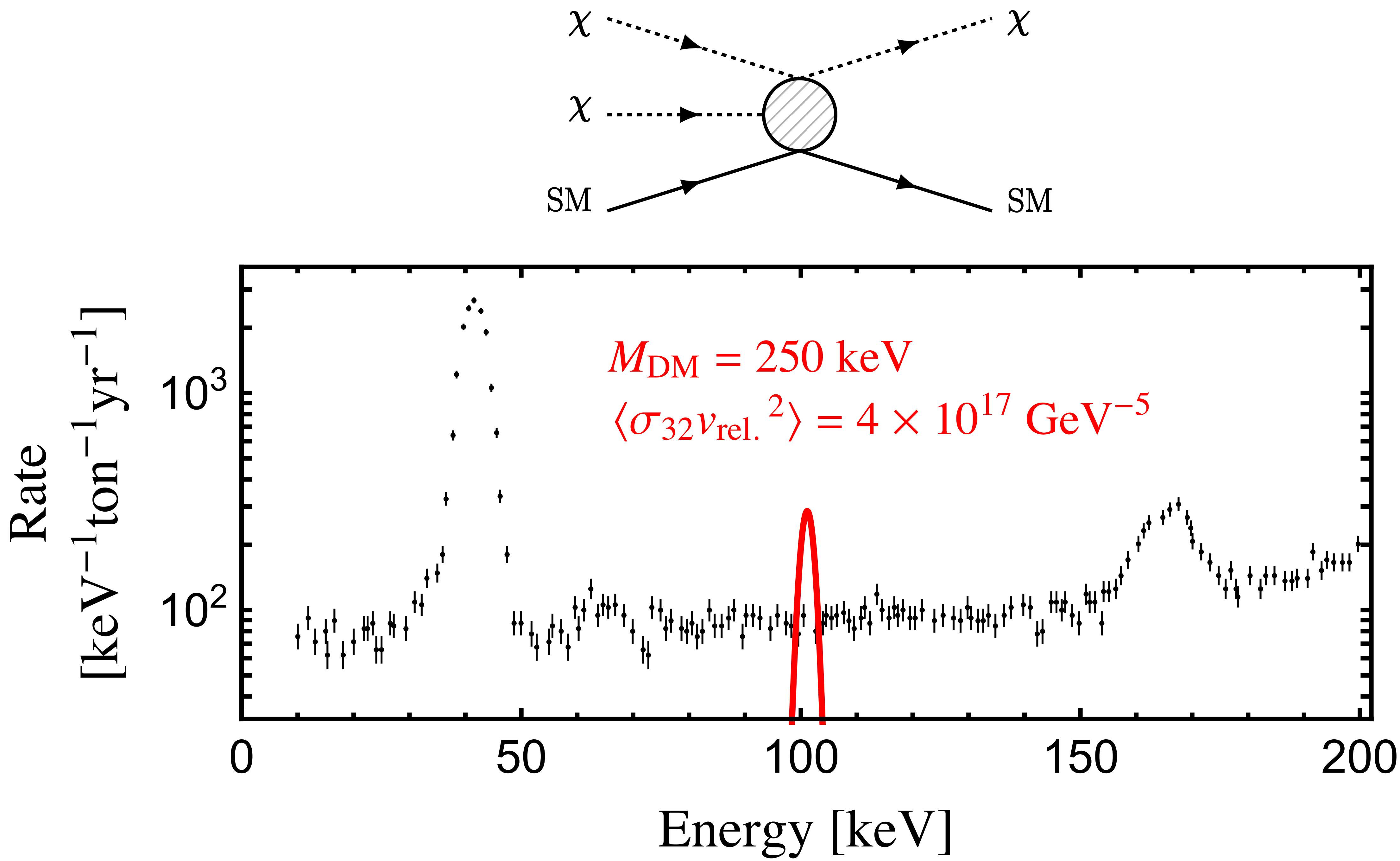
Detection

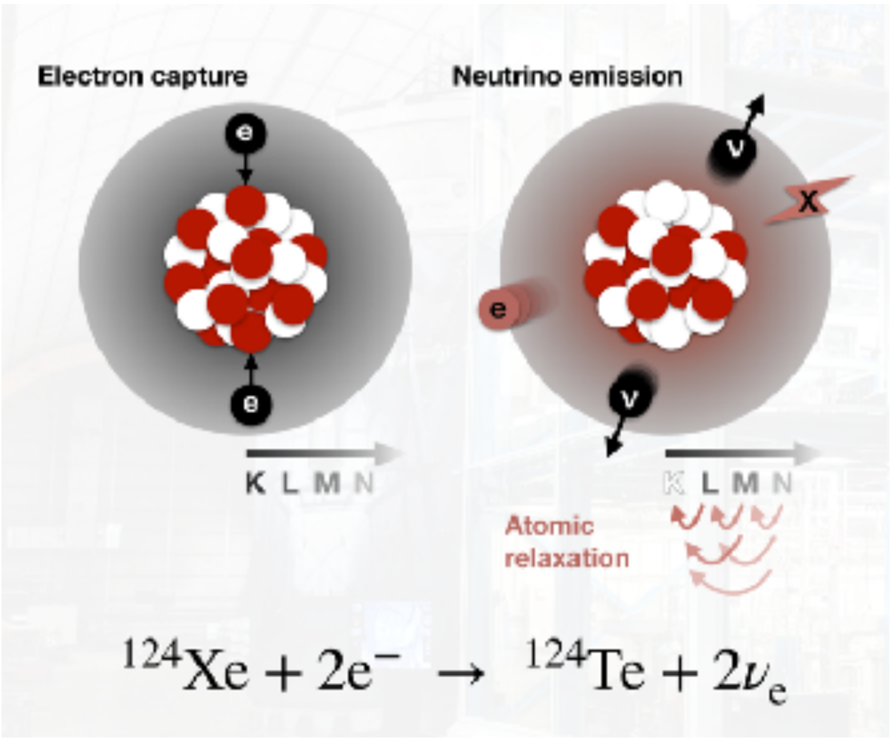
Electrophilic Co-SIMP

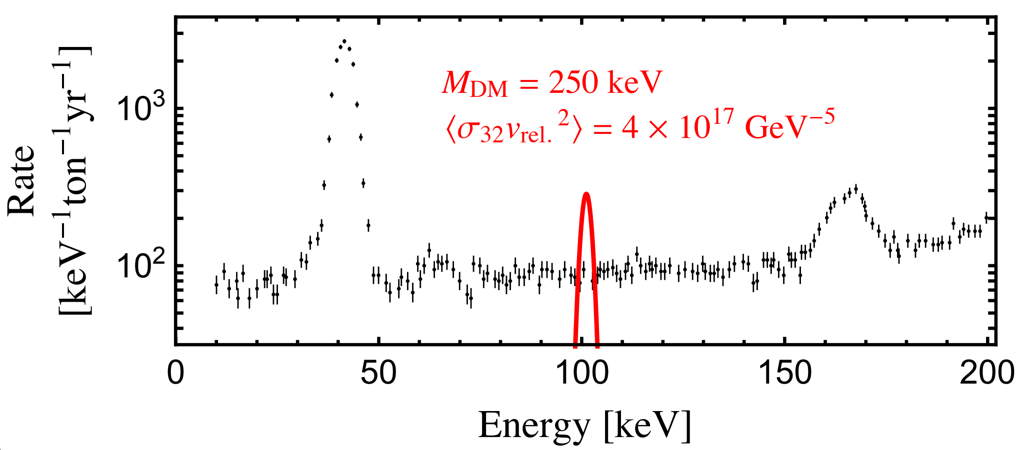
Monoenergetic Recoil

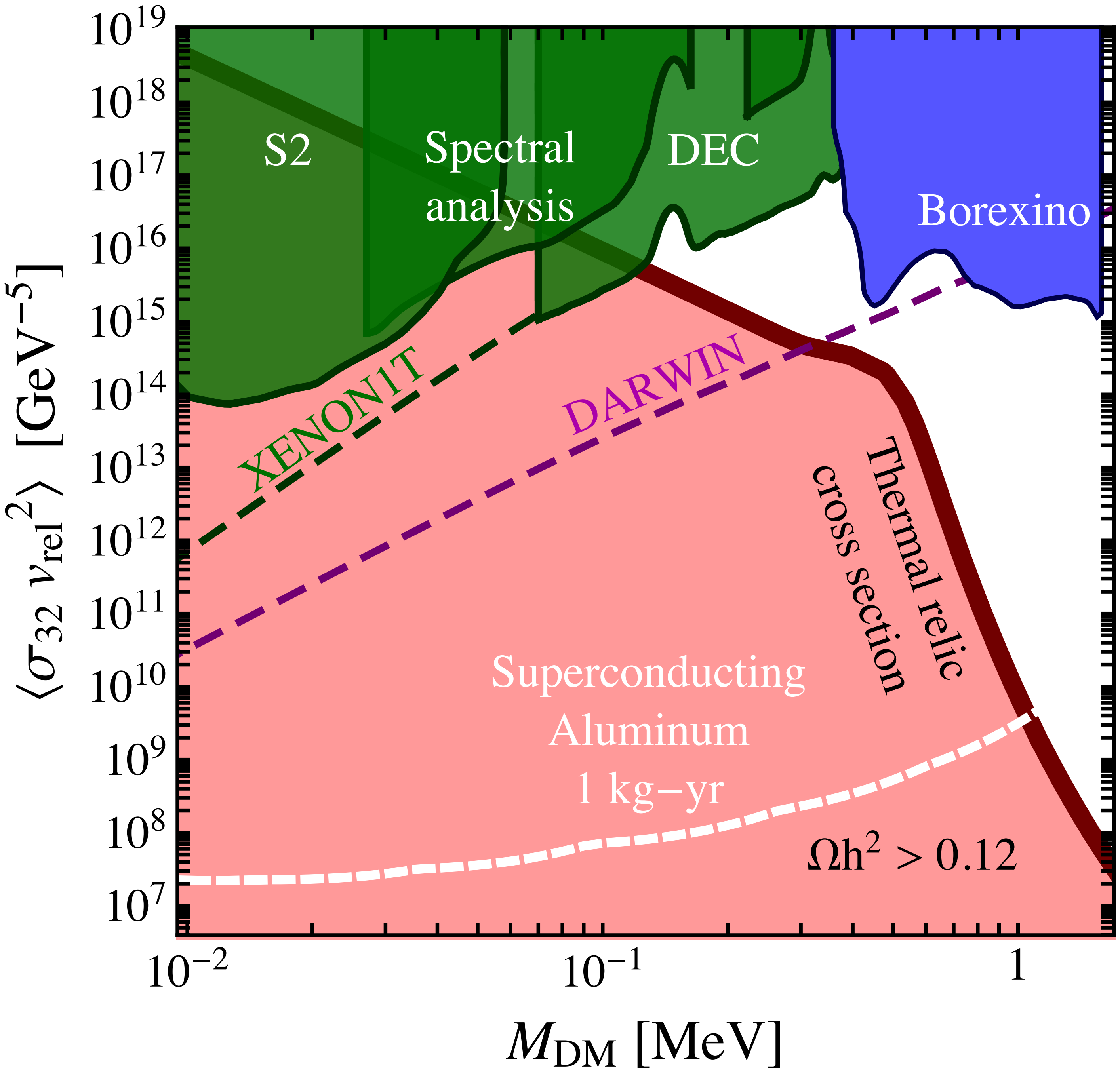


arXiv: 2002.04038; J. Smirnov, J. Beacom

Double Electron Capture







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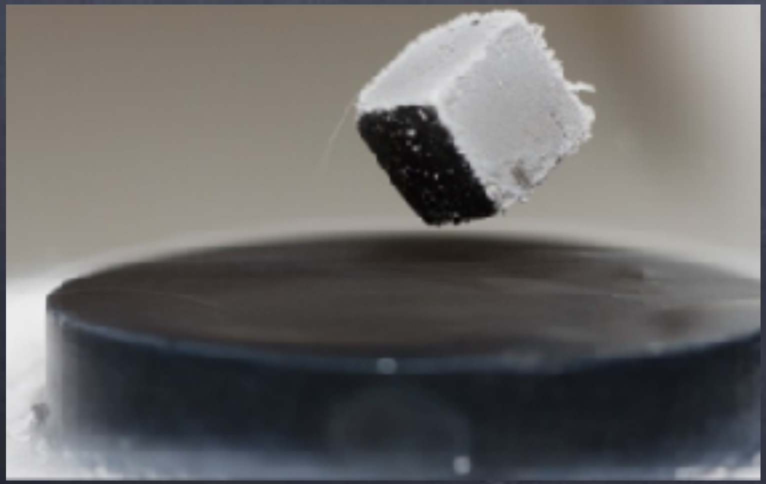
We need lower Energy Thresholds

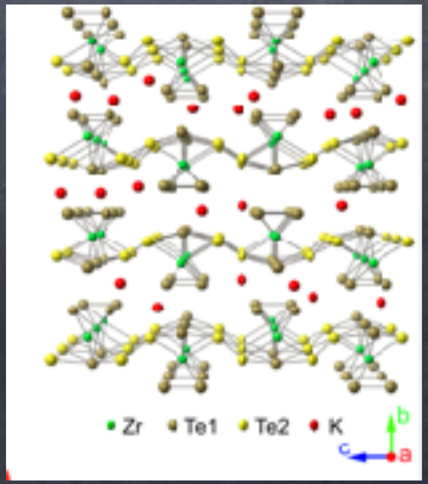
Superfluid He

Materials with Lattice Defects

Small ΔE



Superconductors



3D Dirac Materials

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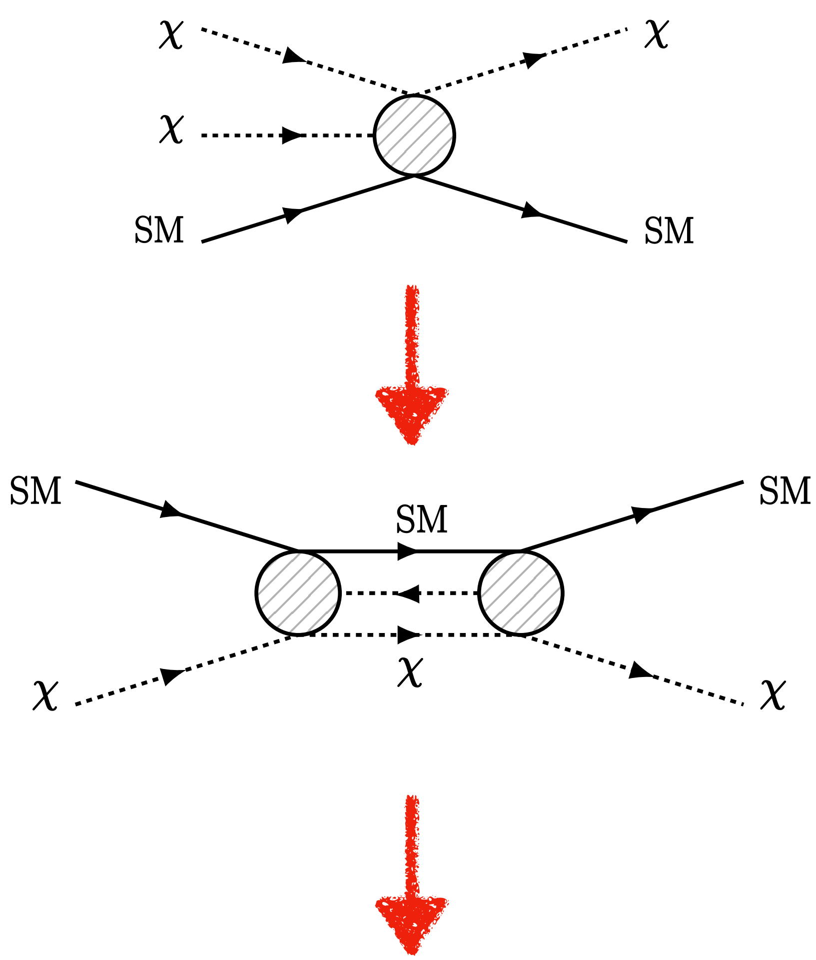
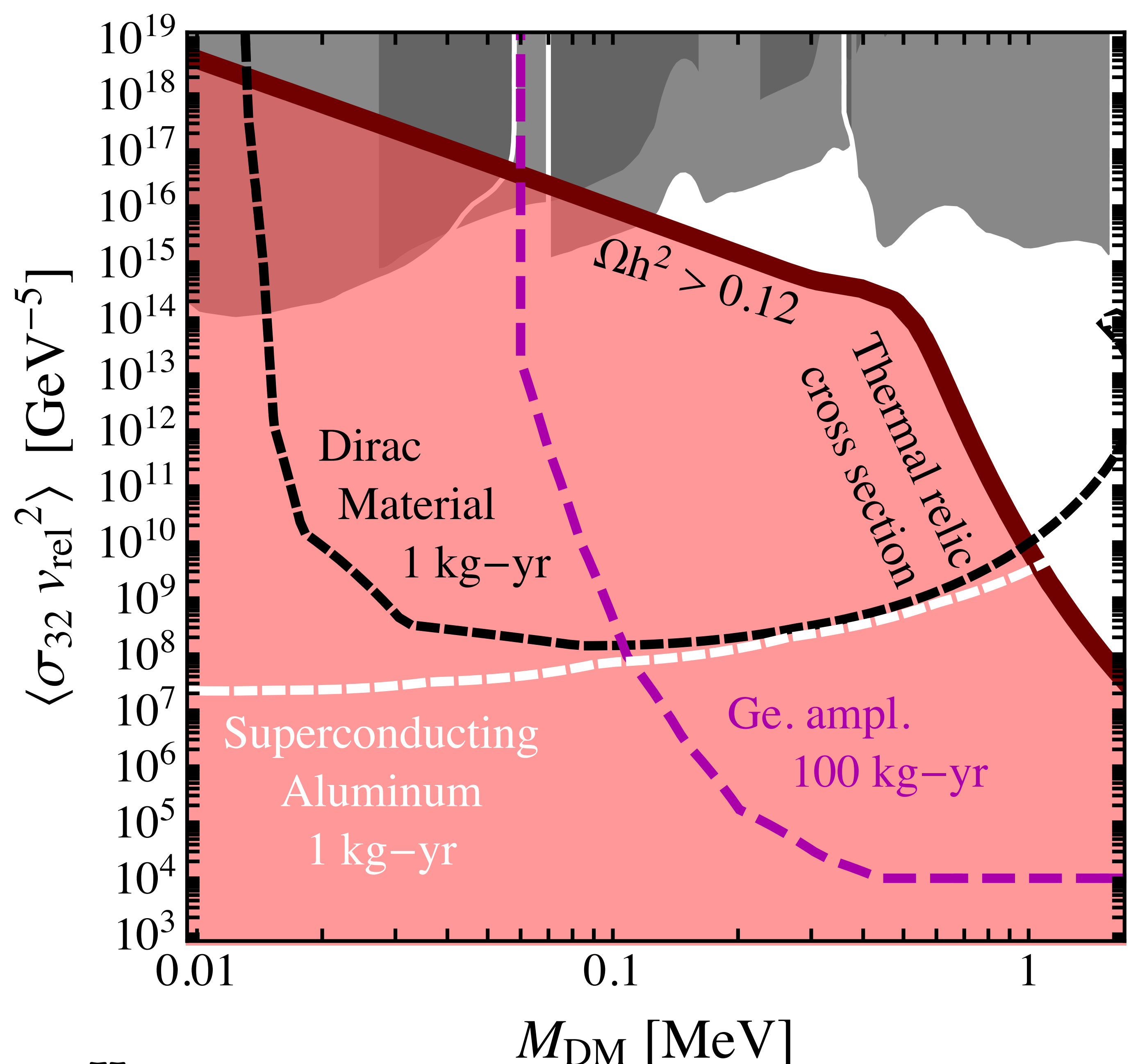
Scattering off Electrons



$$E_R \approx v_{\rm rel}^2 \frac{\mu^2}{M_{\rm SM}}$$

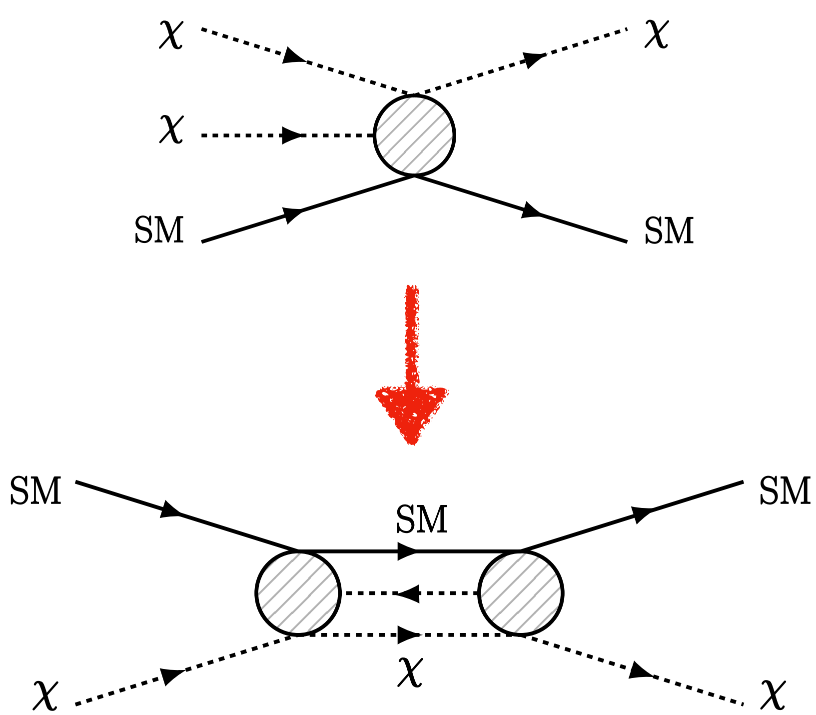


Detectors with lower energy thresholds ≈ eV

arXiv: 2002.04038; J. Smirnov, J. Beacom

Nucleophilic Co-SIMP

Scattering off Nucleons



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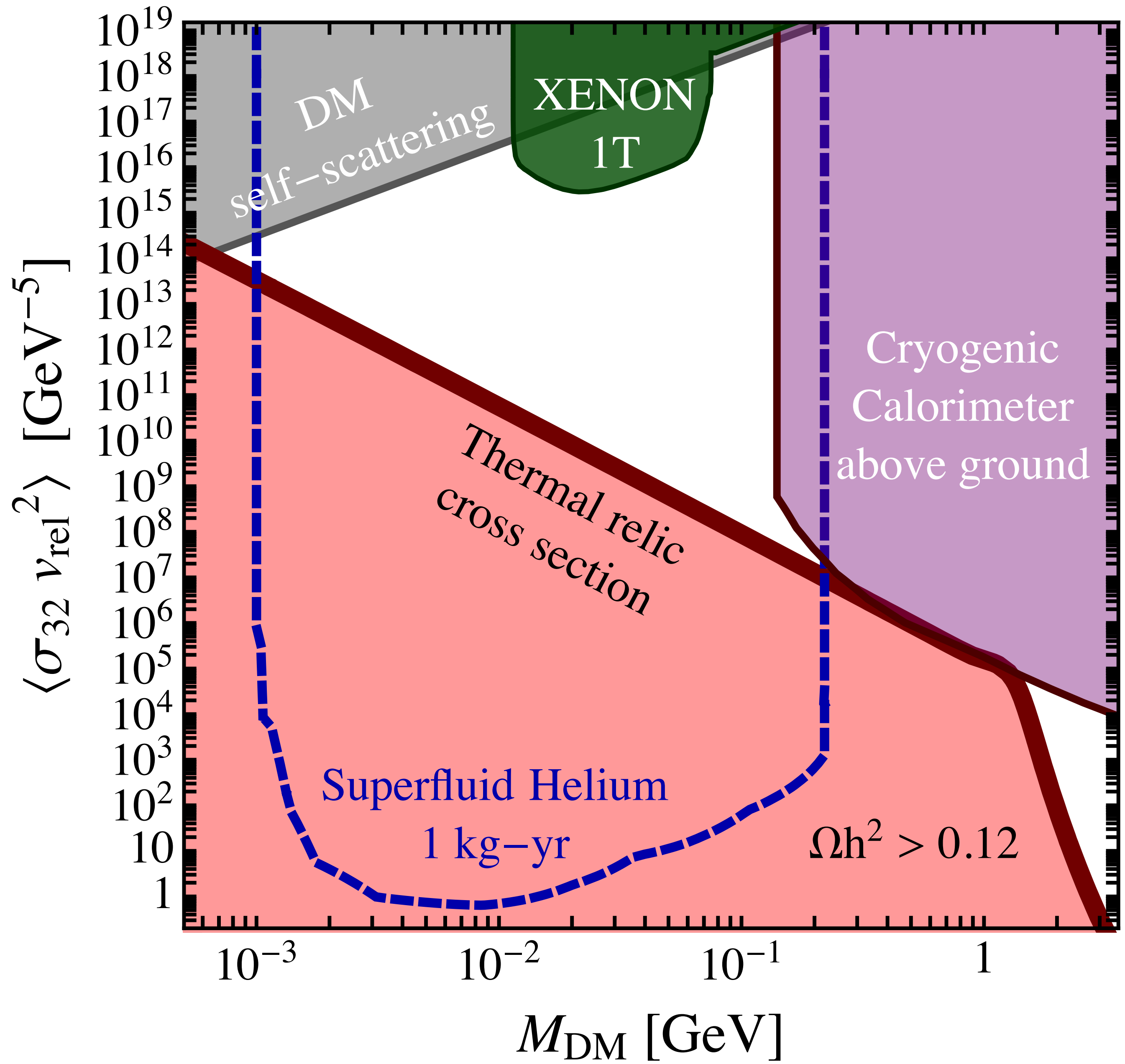

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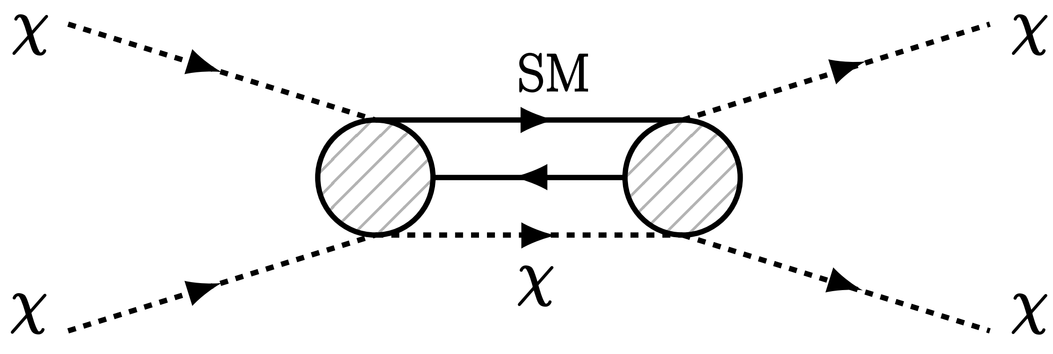
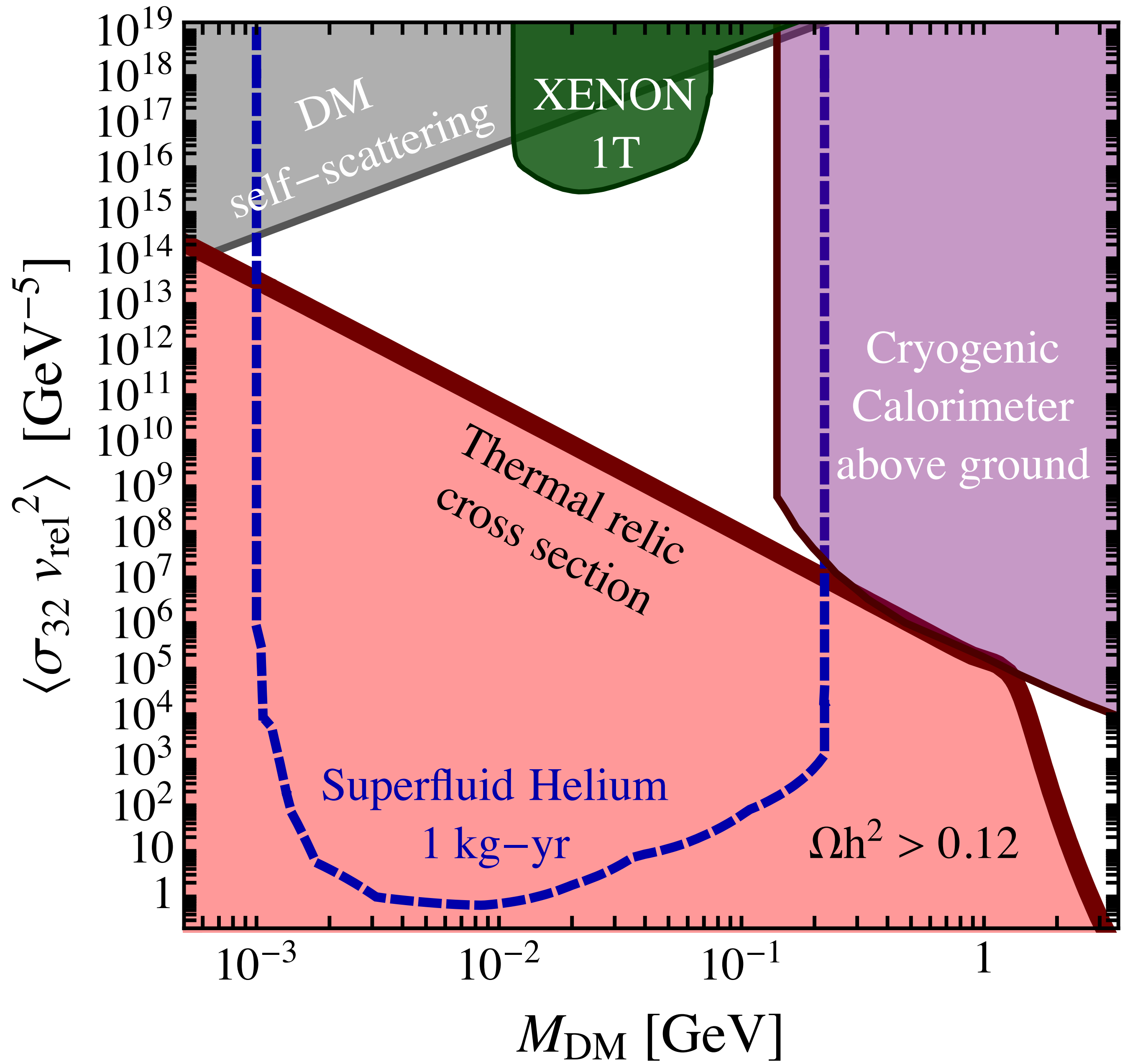
Dark Matter Self Interactions



$$\frac{\sigma_{\chi\chi}}{m_\chi} < \frac{\mathrm{cm}^2}{\mathrm{g}}$$



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Questions for UV completions

A. Emerging Showers?

Hadronic and

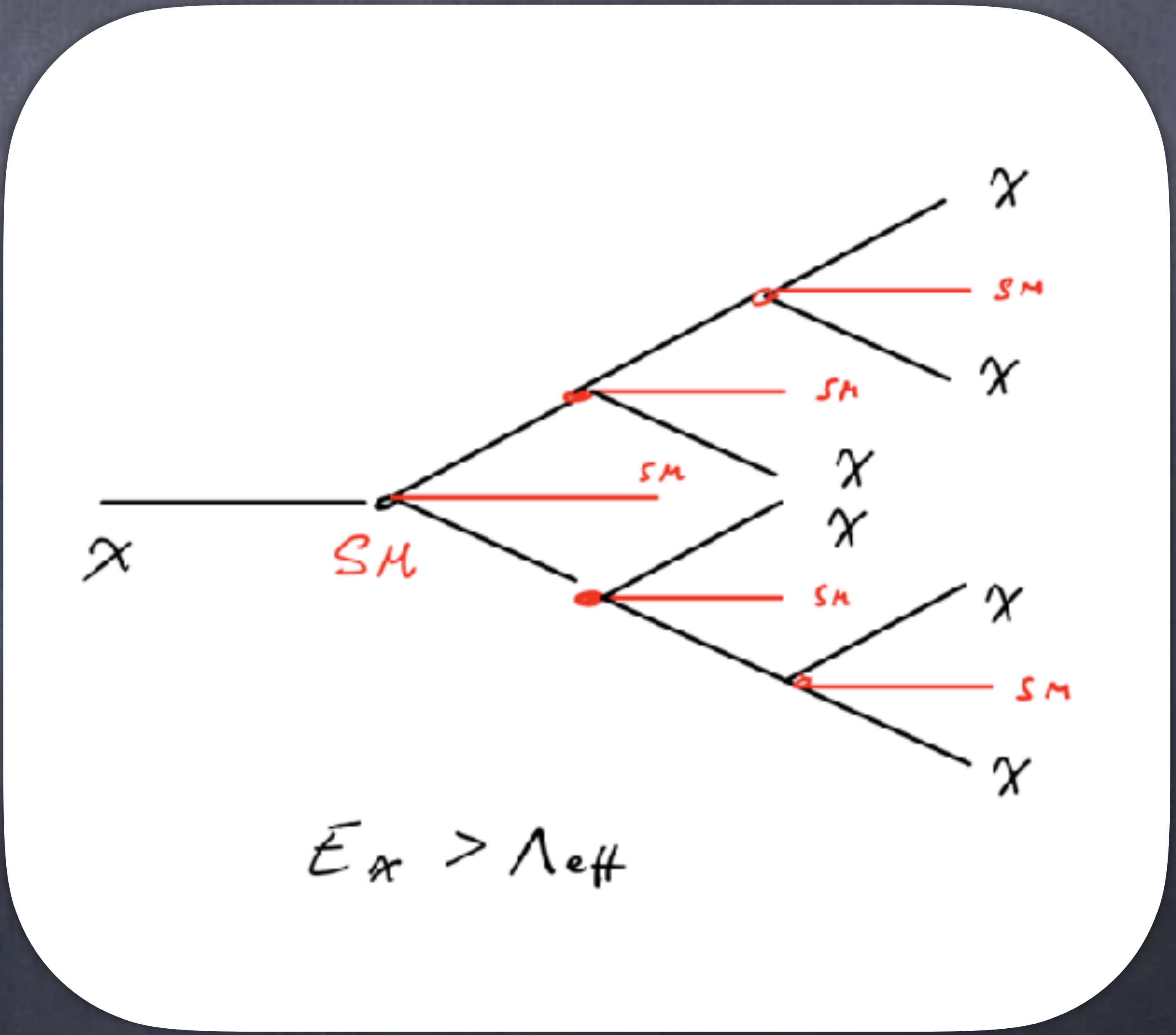
Electromagnetic

B. Stellar cooling

C. Loop coefficients

-> Work in progress with:

Bei Zhou and John Beacom



Summary

A. New thermal Dark Matter production mechanism proposed

B. The fundamental process can be directly tested in laboratory experiments

C. Induced processes and other associated phenomena possible

Thanks!