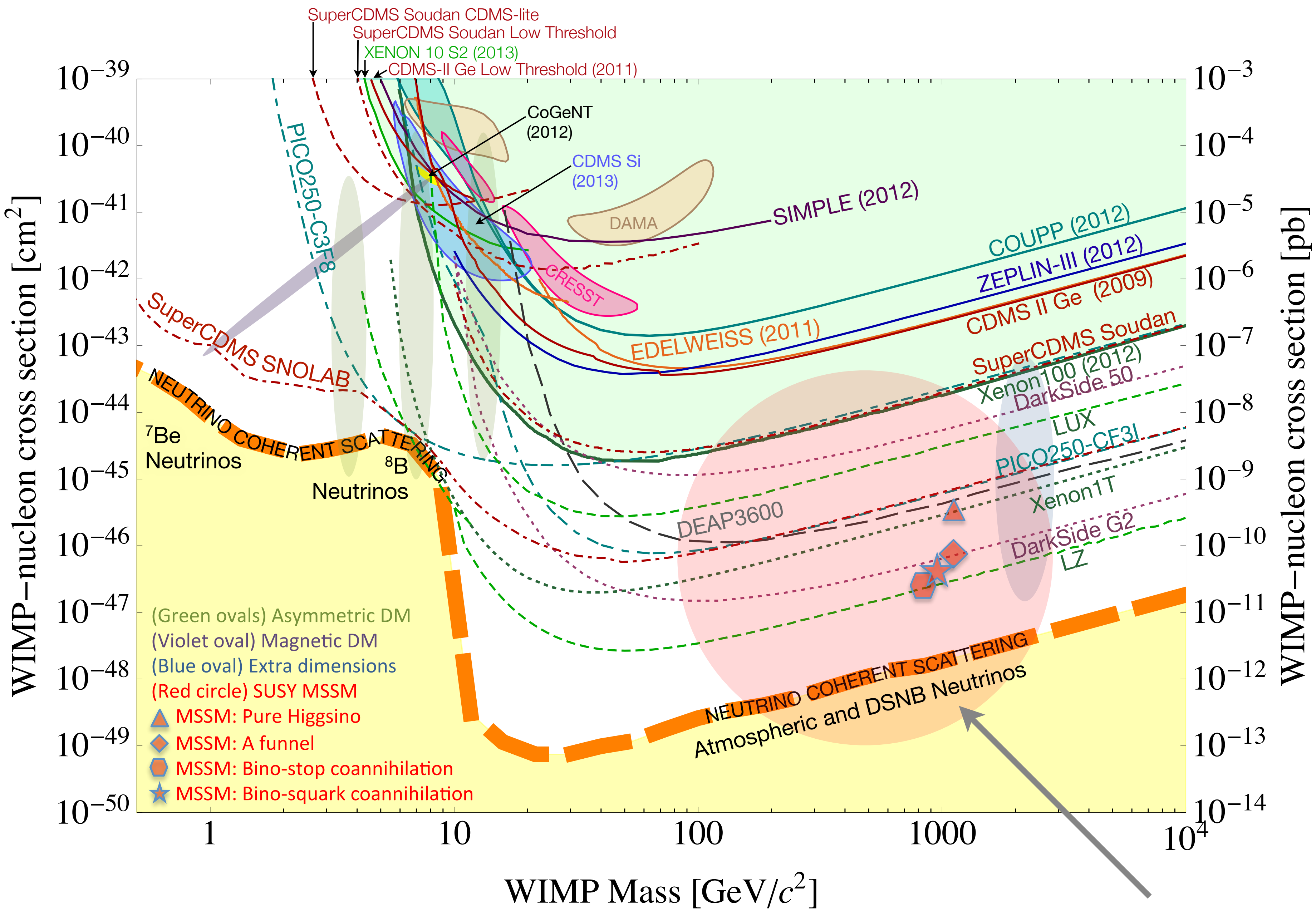
Beyond the WIMP

Kathryn Zurek

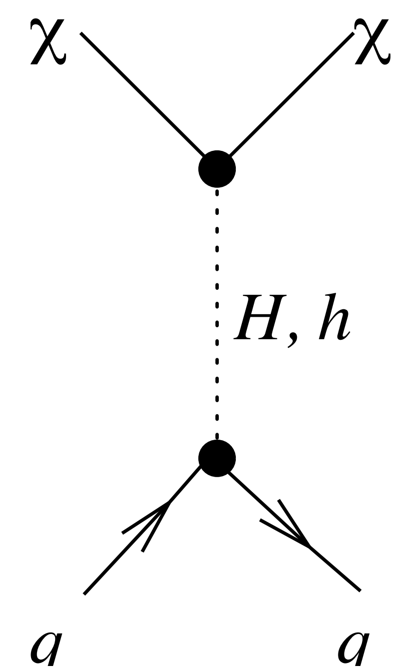
Why Beyond the WIMP?

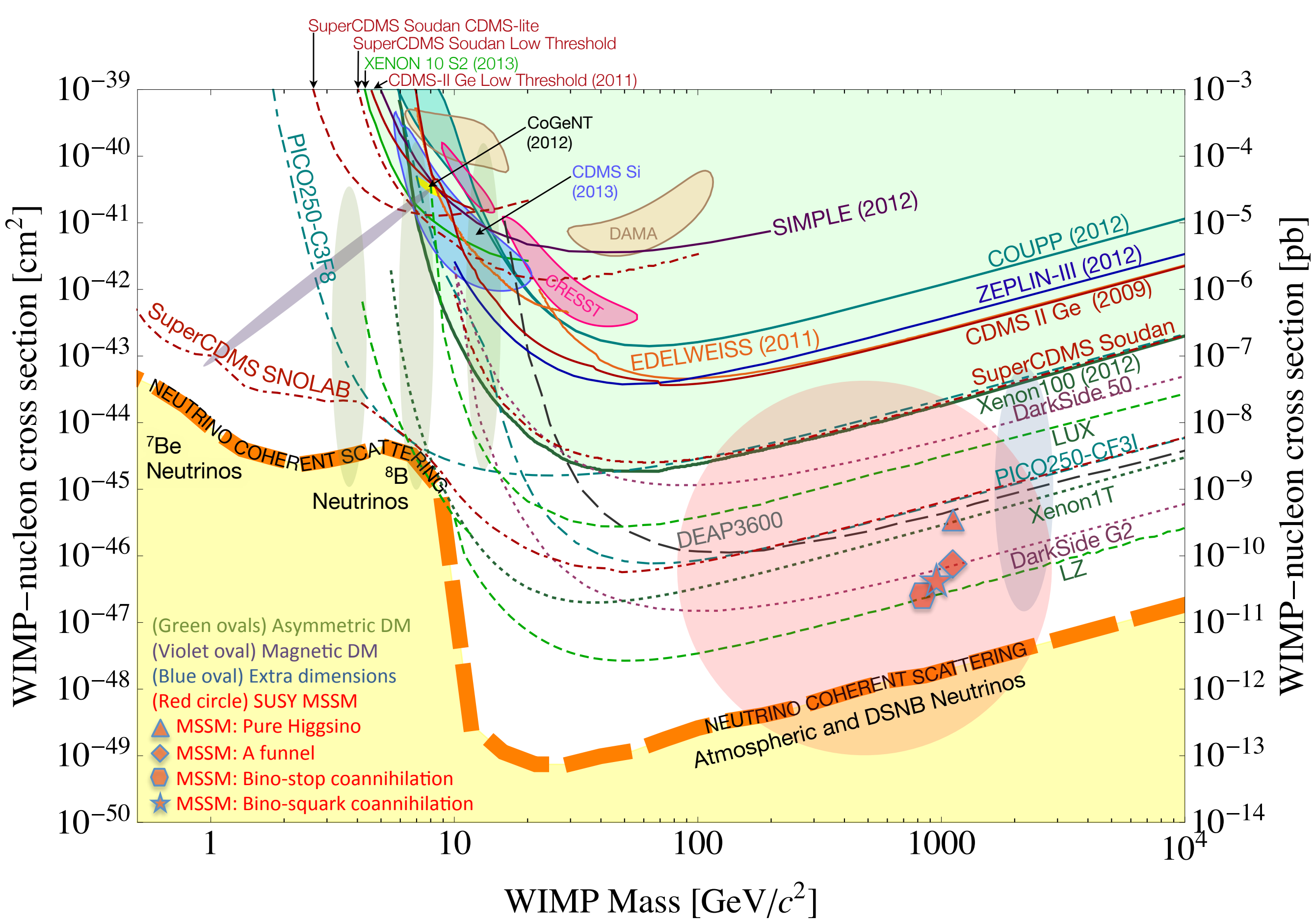


What is the anatomy of this MSSM blob?

A Tale of (two)Higgs Scattering

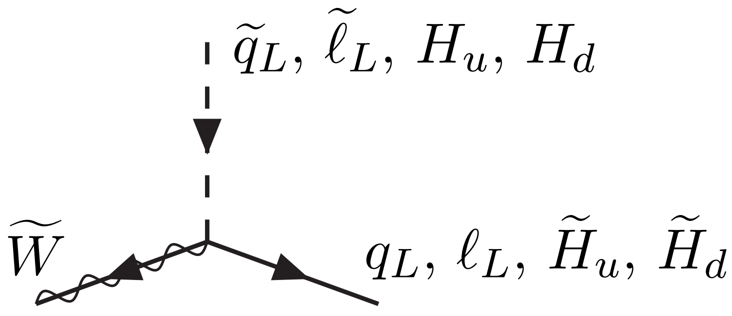
$$\sigma_n \;\approx\; 8.3\times 10^{-42}\ \mathrm{cm}^2 \left(\frac{Z_d}{0.4}\right)^2 \left(\frac{\tan\beta}{30}\right)^2 \left(\frac{100\ \mathrm{GeV}}{m_H}\right)^4$$

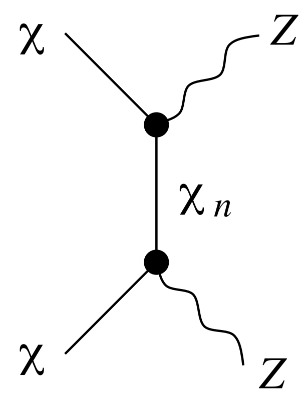




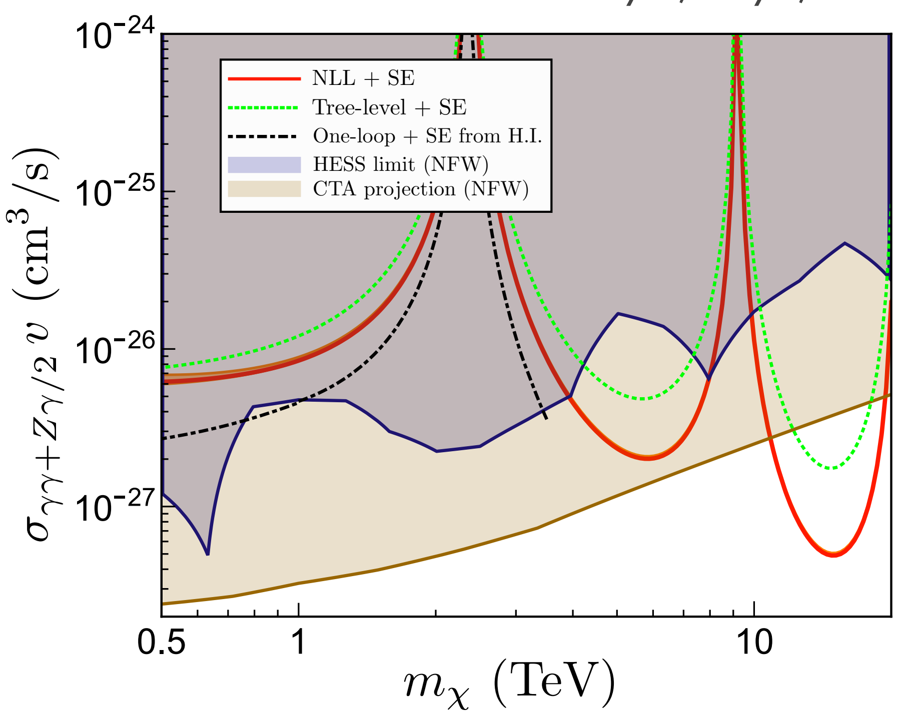
Higgs mediated scattering

- Blob closure is deceptive
- Pure states do not couple to Higgs at tree level
- Pure wino and Higgsino are viable; do not scatter off nucleon at tree level
- Indirect detection large



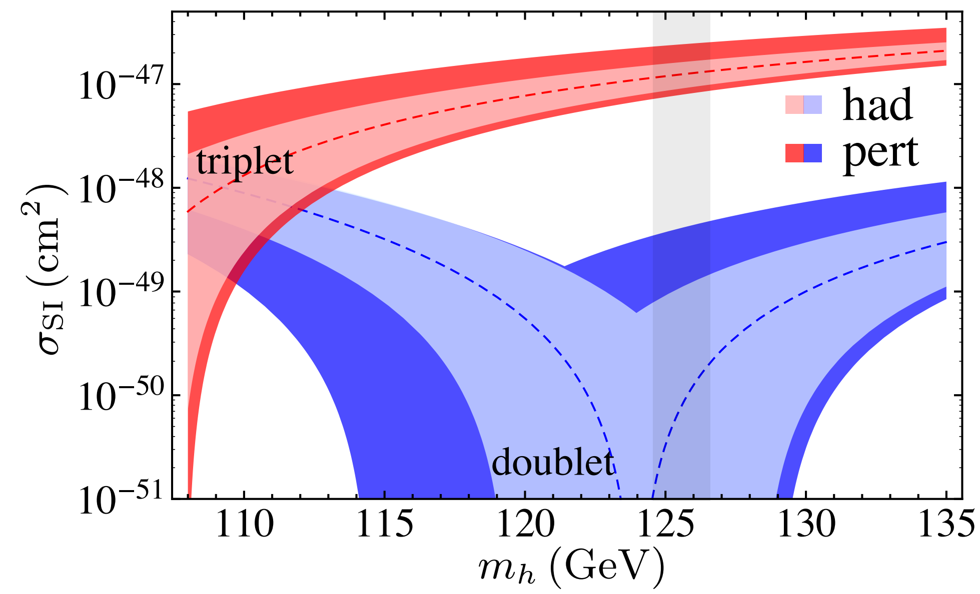


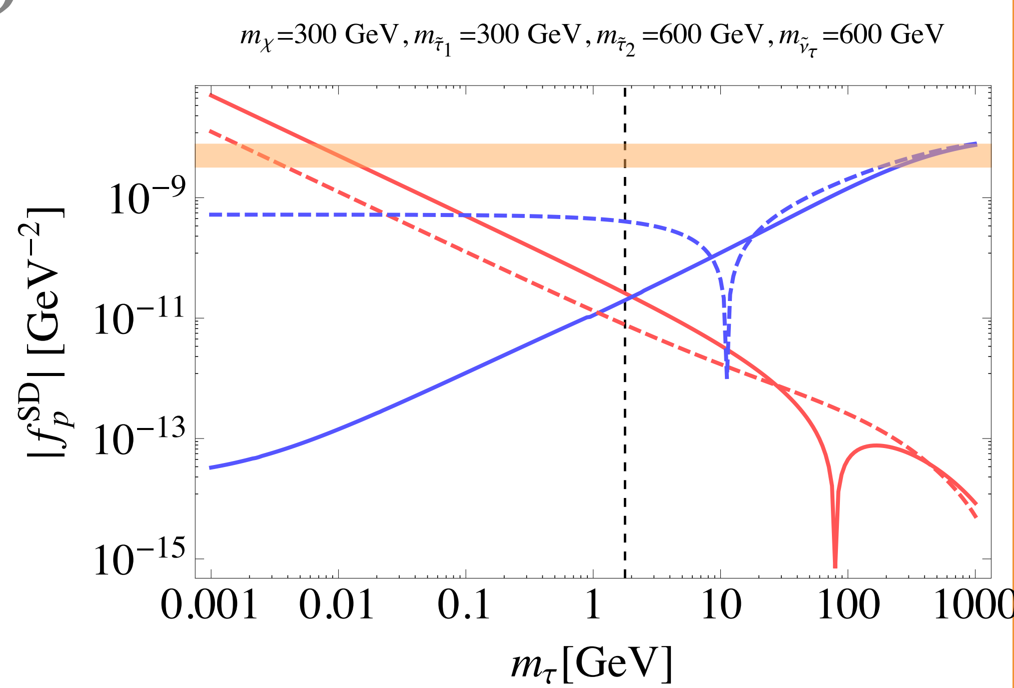
Ovanesyan, Slatyer, Stewart



- 1-loop direct detection
- Bino is hard; even 1-loop contribution is suppressed

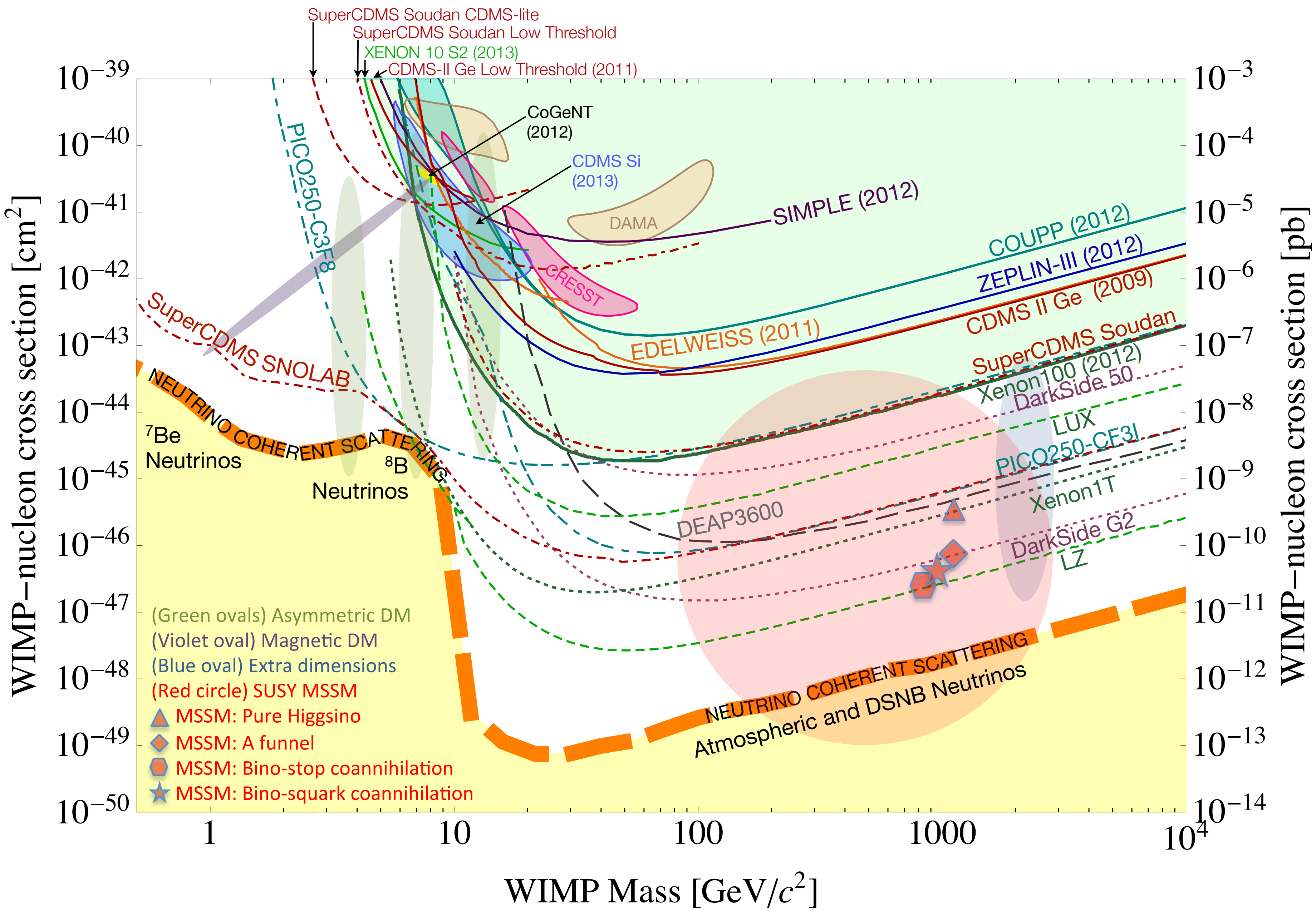
Hill and Solon





Berlin, Robertson, Solon, KZ

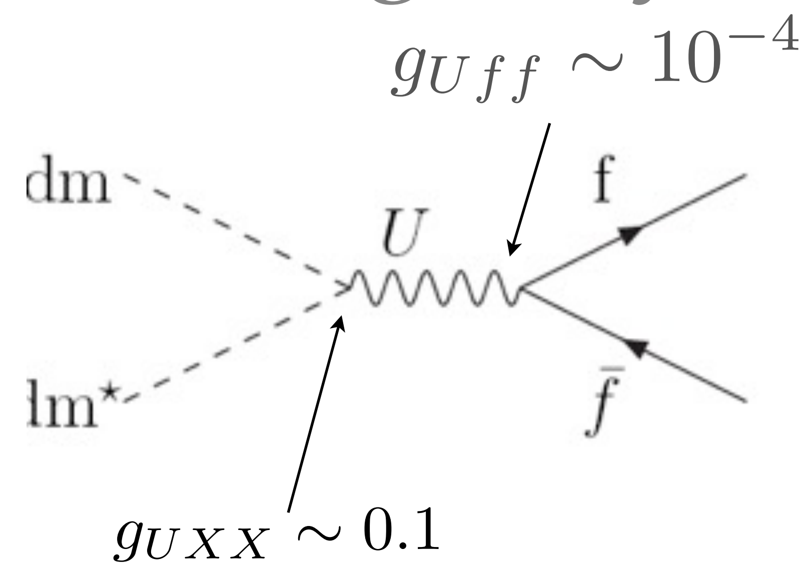
Why Beyond WIMP?

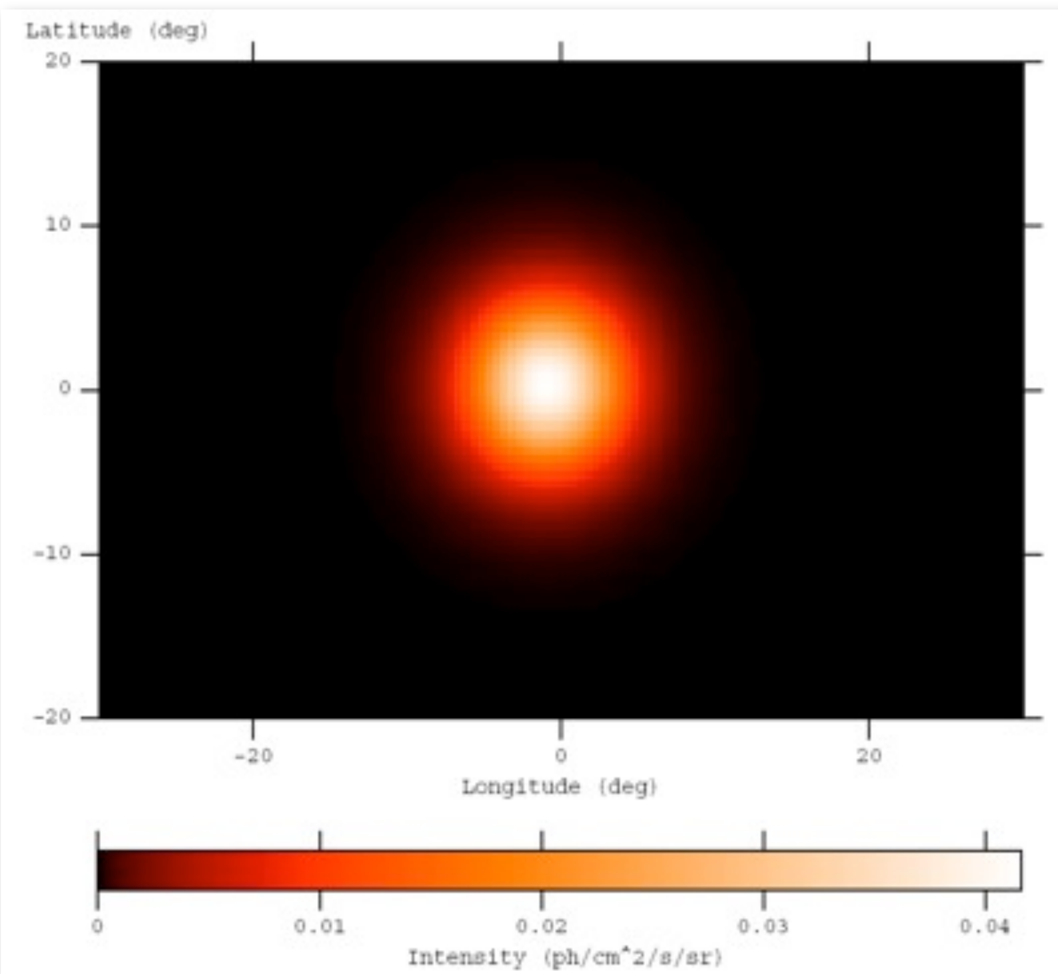


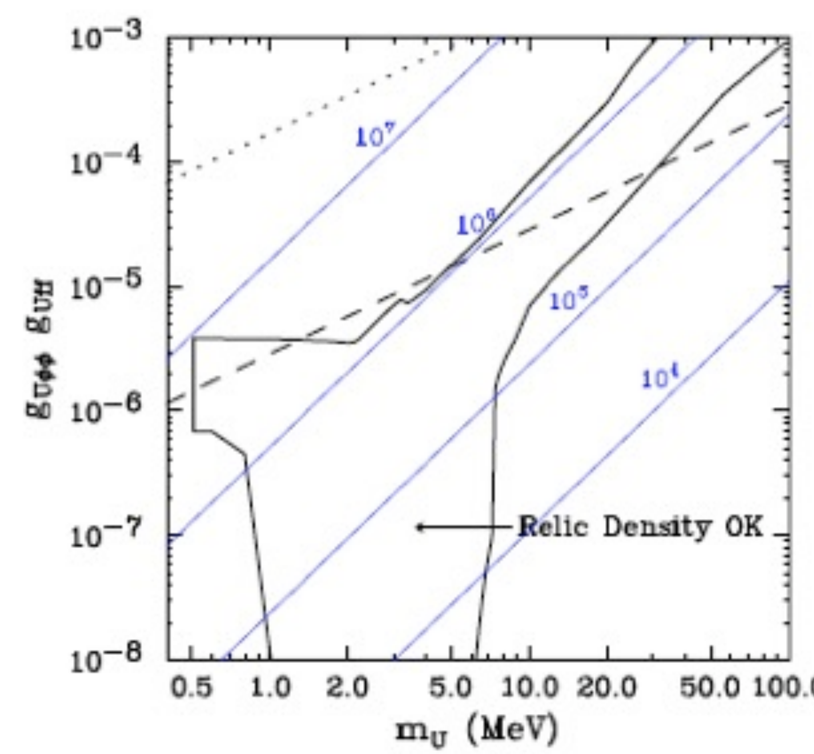
- Two reasons to move beyond WIMP:
  - Simple, “natural” models reside elsewhere
  - Experiments are pointing us in that direction

Ex: MeV DM

- in original guise, phenomenologically motivated, ugly model

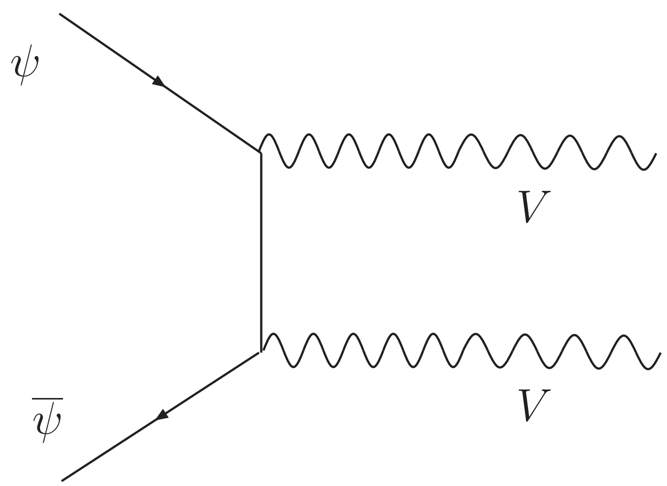




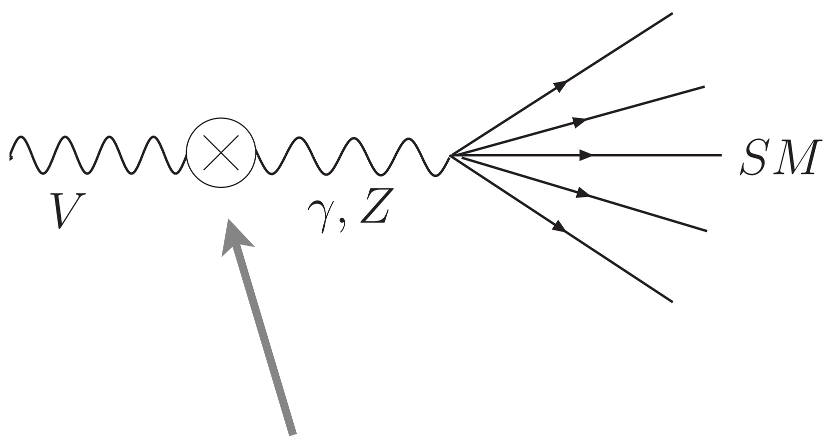


Hooper, Kaplinghat, Strigari, KZ

- Moral 1: seclude it, and everything is easier

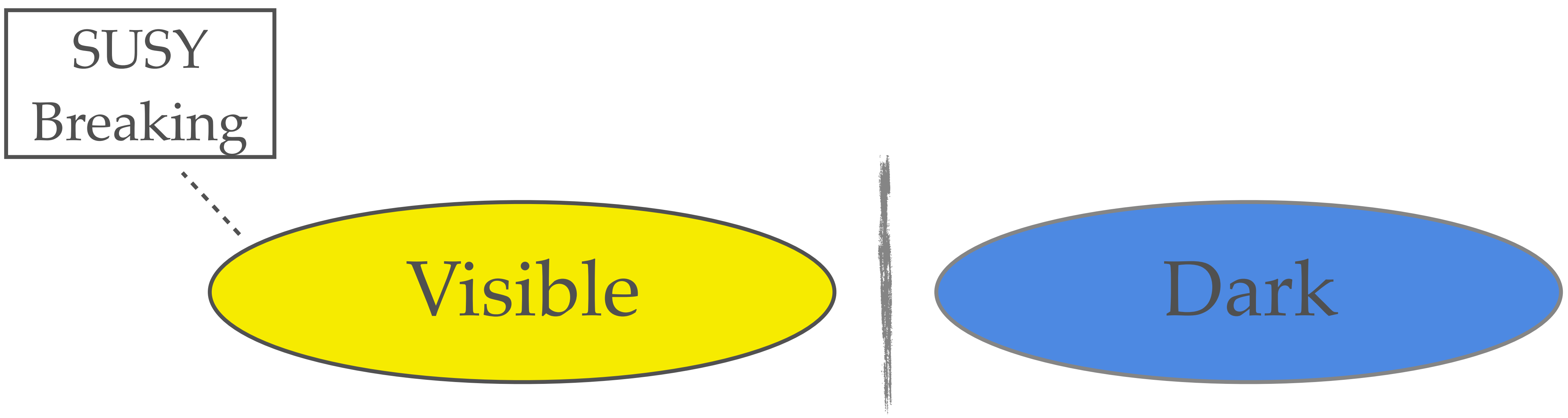


Pospelov and Ritz



Small number resides here

- Moral 2: secluded, hidden valleys can be "natural"

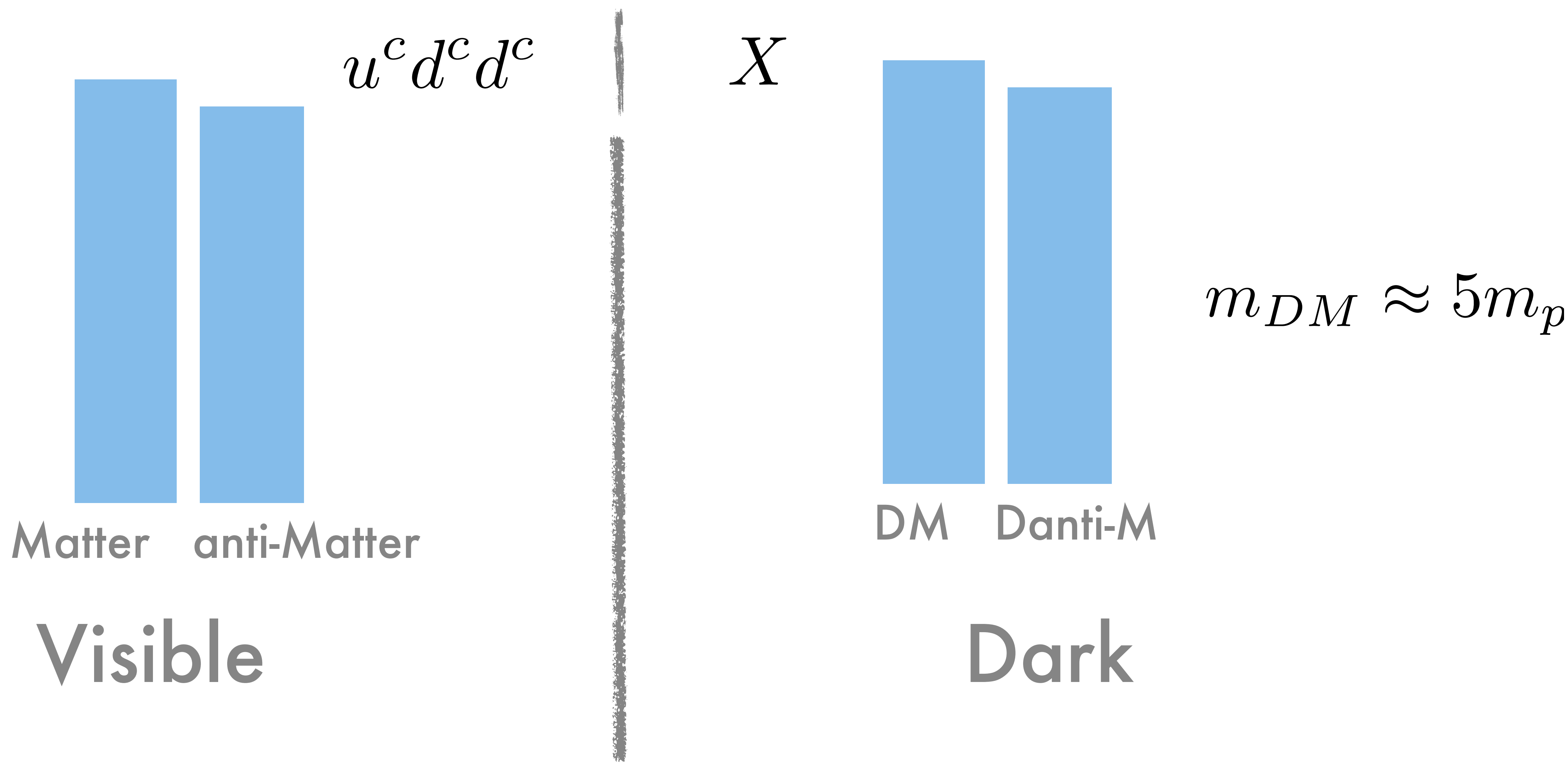


Amount of SUSY breaking transmitted sets DM mass scale
Small coupling between sectors = small mass

Hooper, KZ

Hide it!

- Higher dimension operator coupling

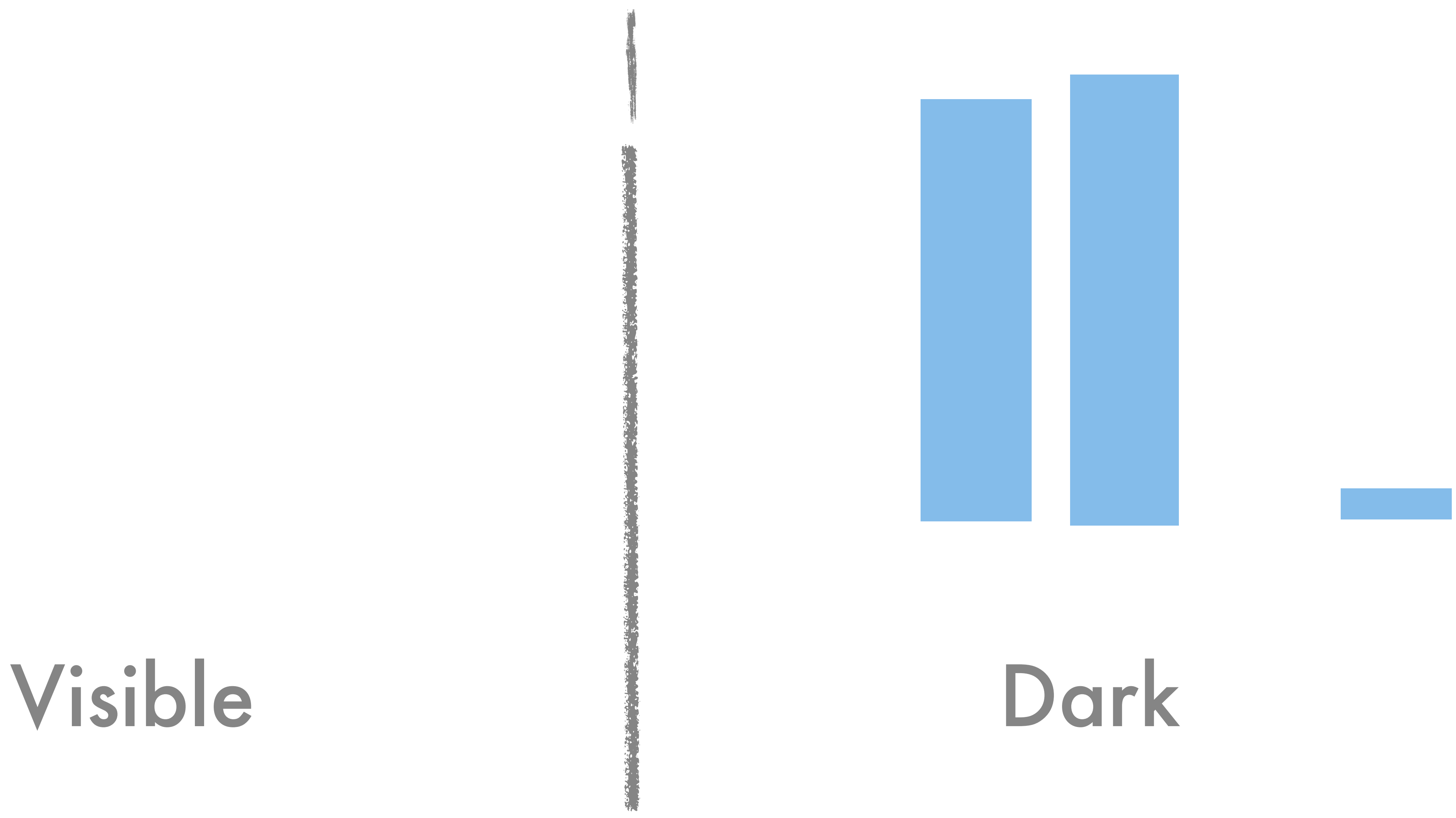


KLZ 0901.4117

Barrier carries B or L

Hide it!

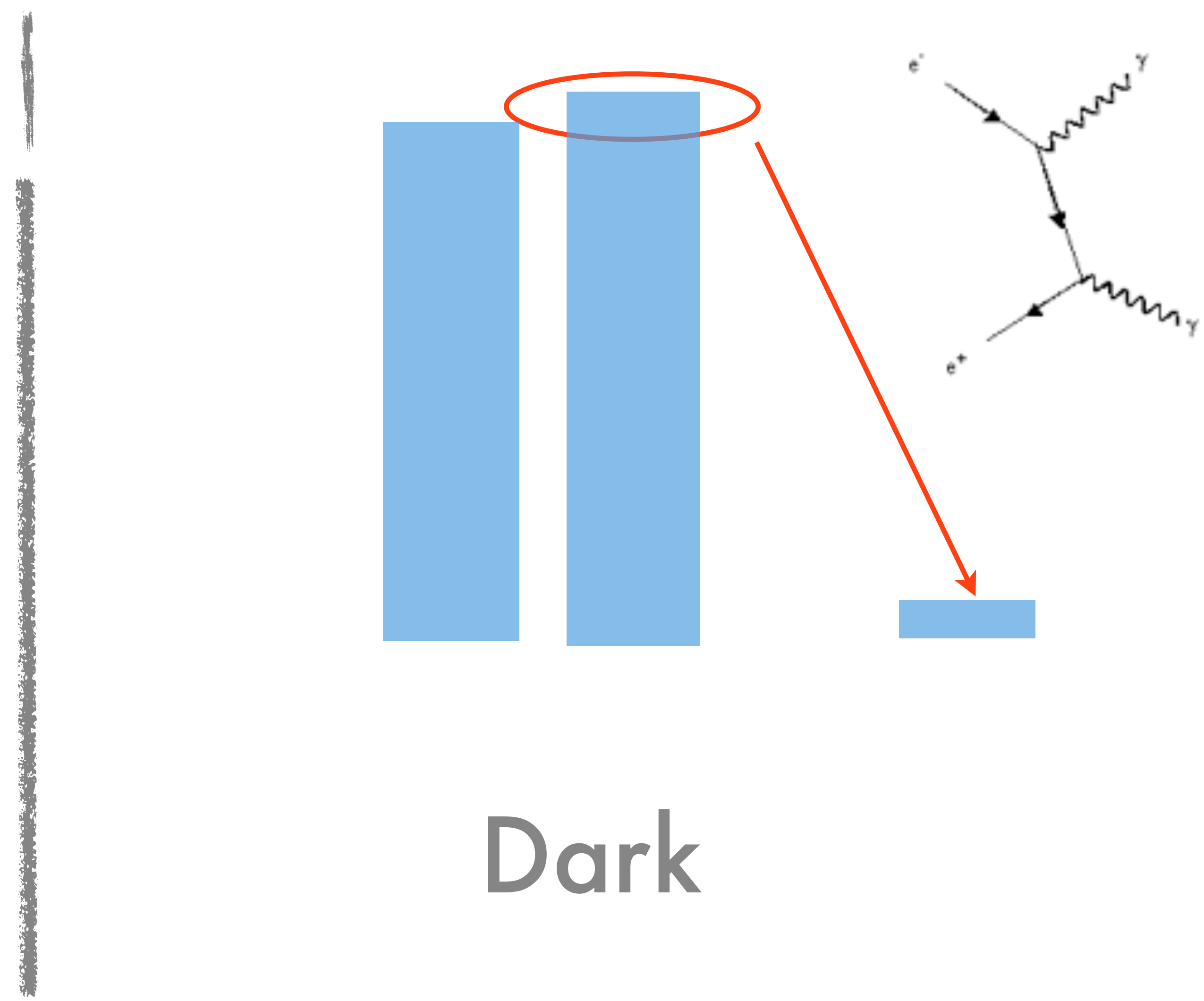
- Higher dimension operator coupling



Barrier carries B or L

Hide it!

- Higher dimension operator coupling



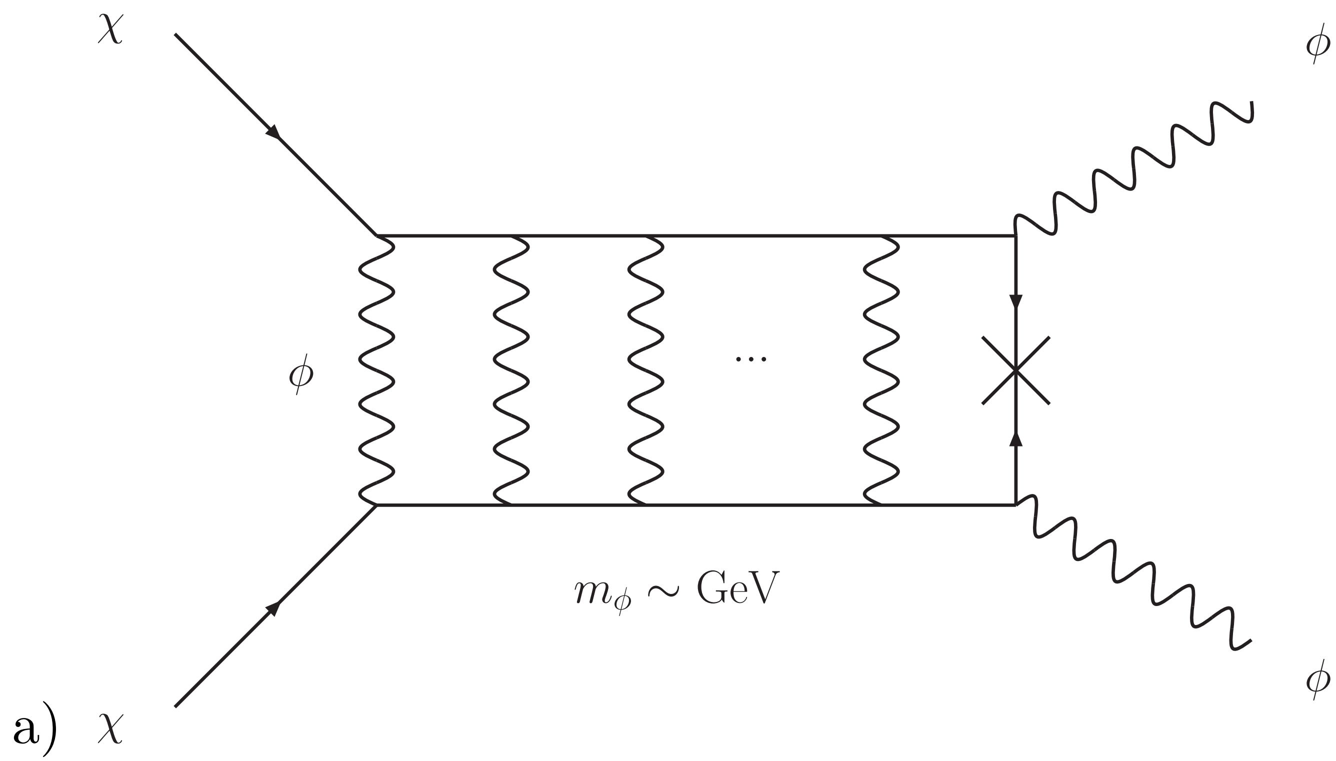
Visible

Dark

Barrier carries B or L

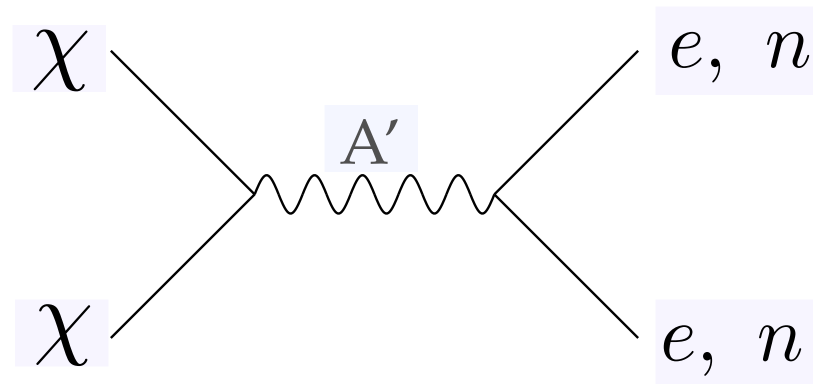
Experiments Alight

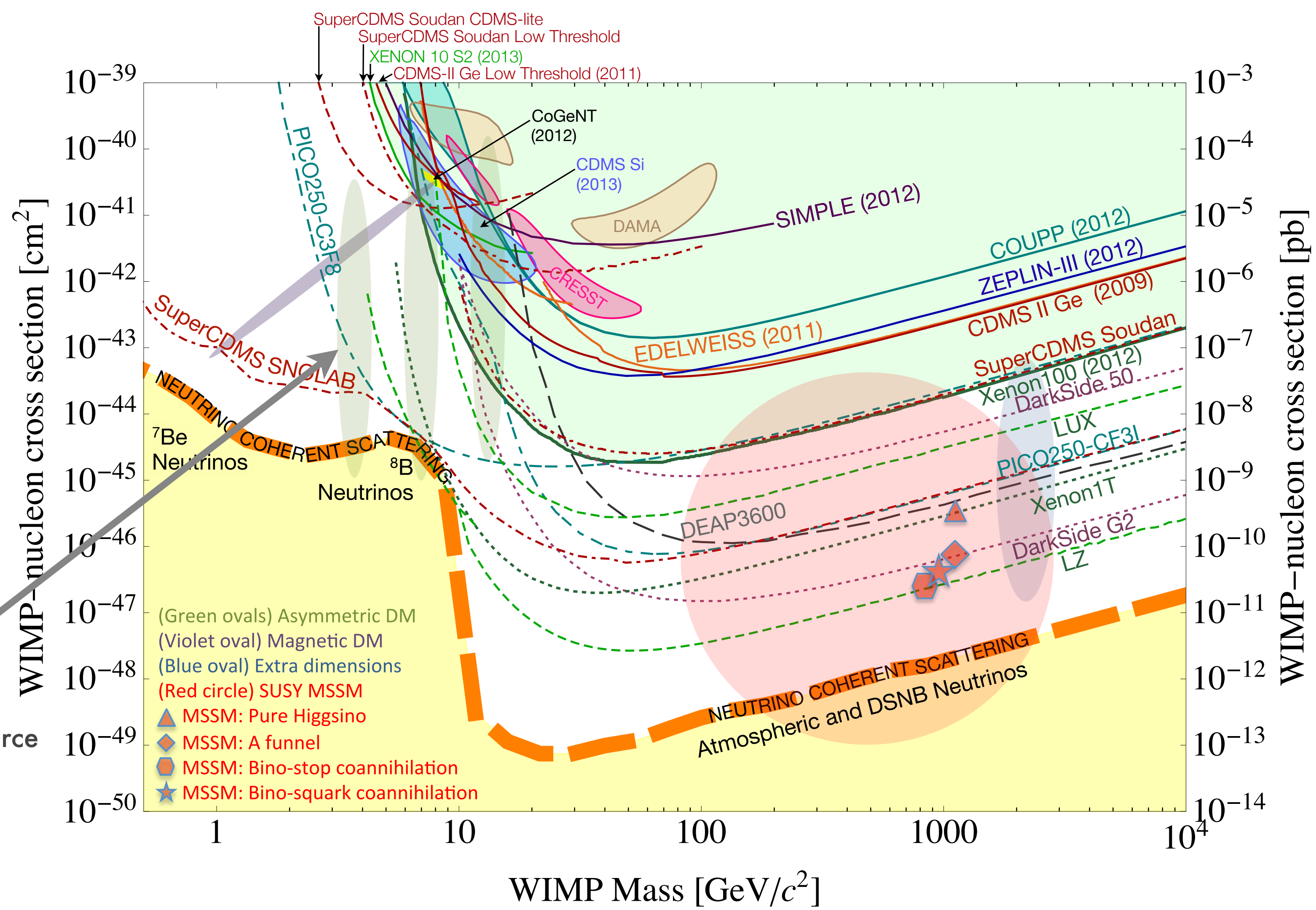
- PAMELA / ATIC / DAMA / Integral



Arkani-Hamed, Finkbeiner, Slatyer, Weiner

- Presence of dark force mediates DD



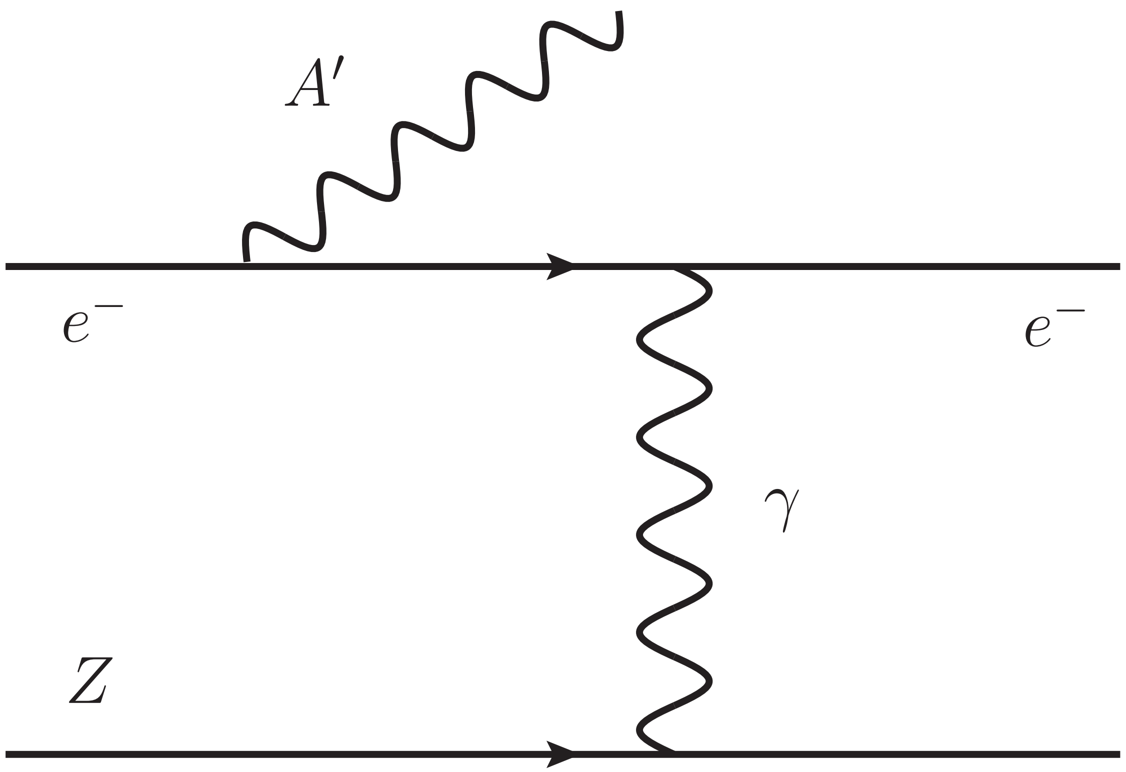


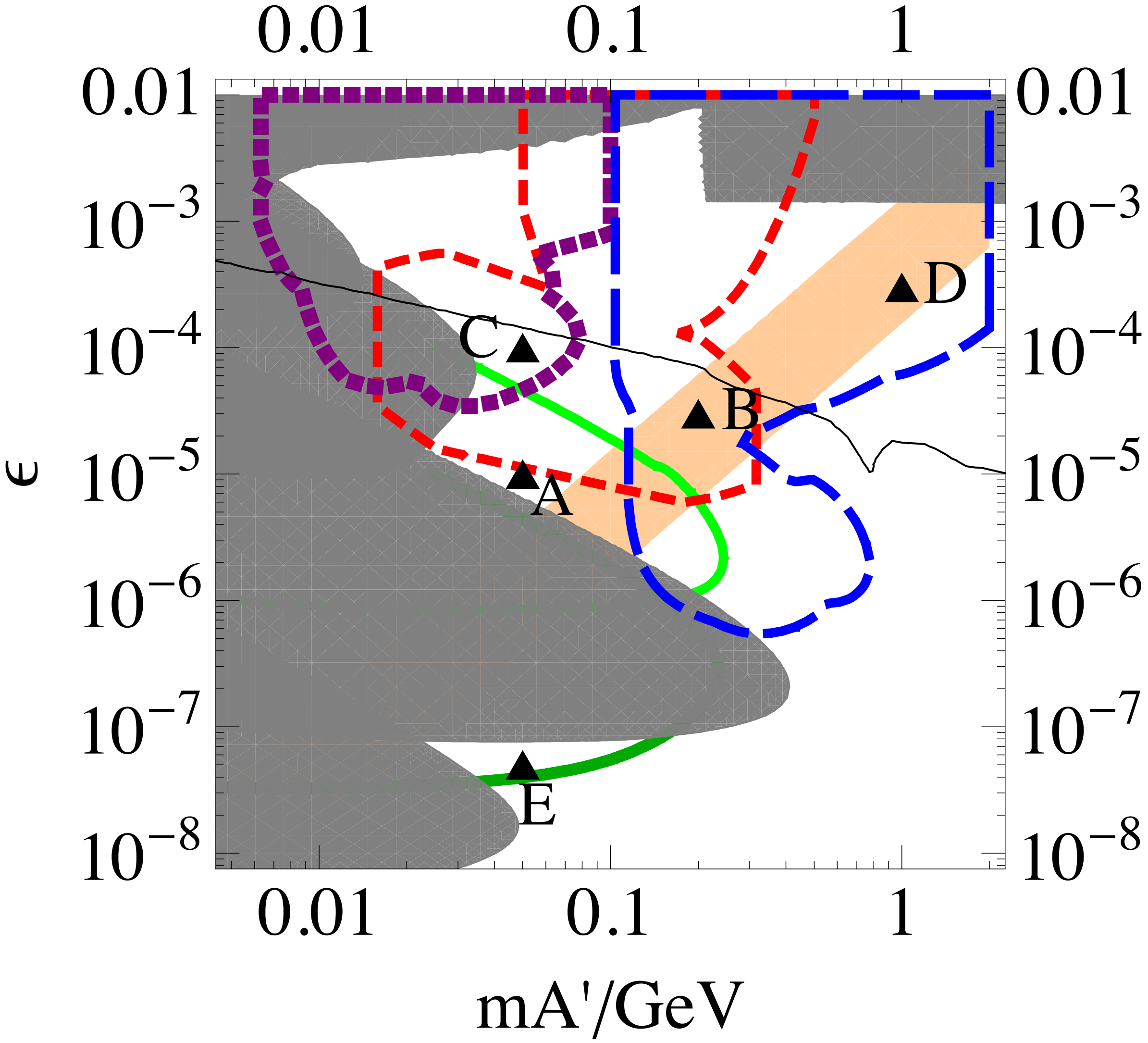
ADM model with dark force
1005.1655

Theorists Alight

- with new experiments

Bjorken, Essig, Schuster, Toro

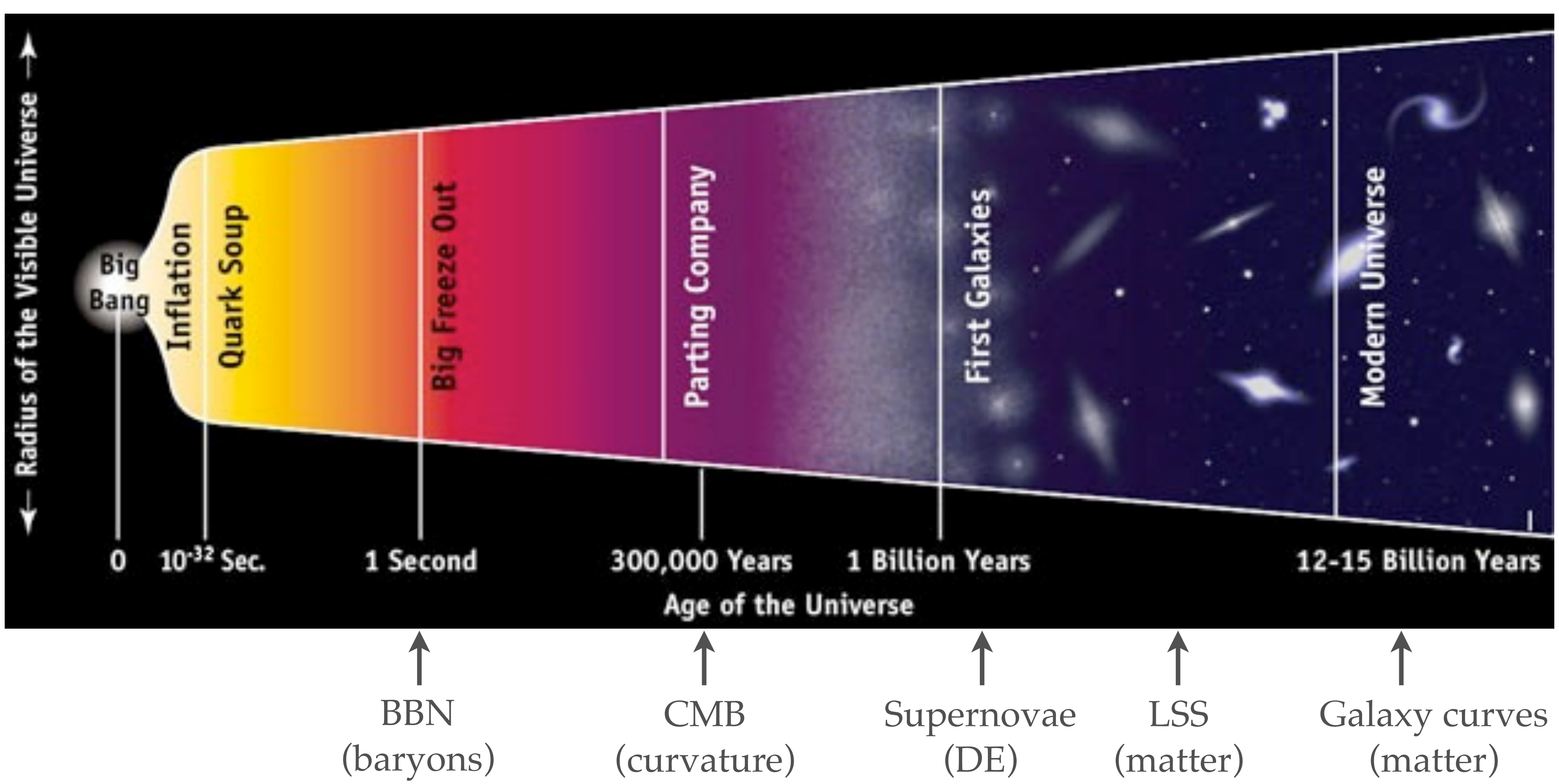




- What else can we design?

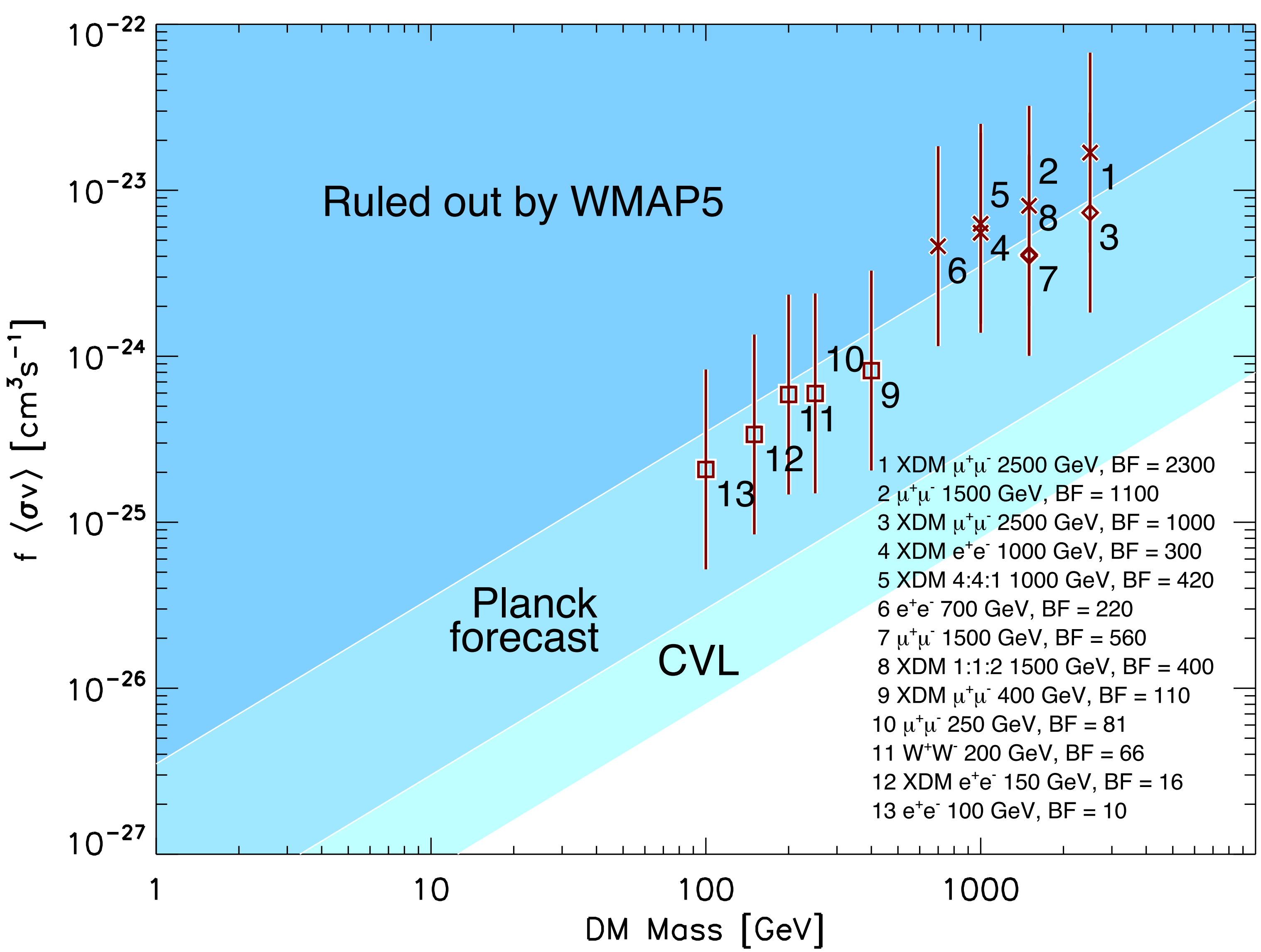
Everything does not go.

- Should not fear the great unknown when walking away from naturalness
- The Universe gives direction
- Cosmo/astro is strongly constraining



e.g.

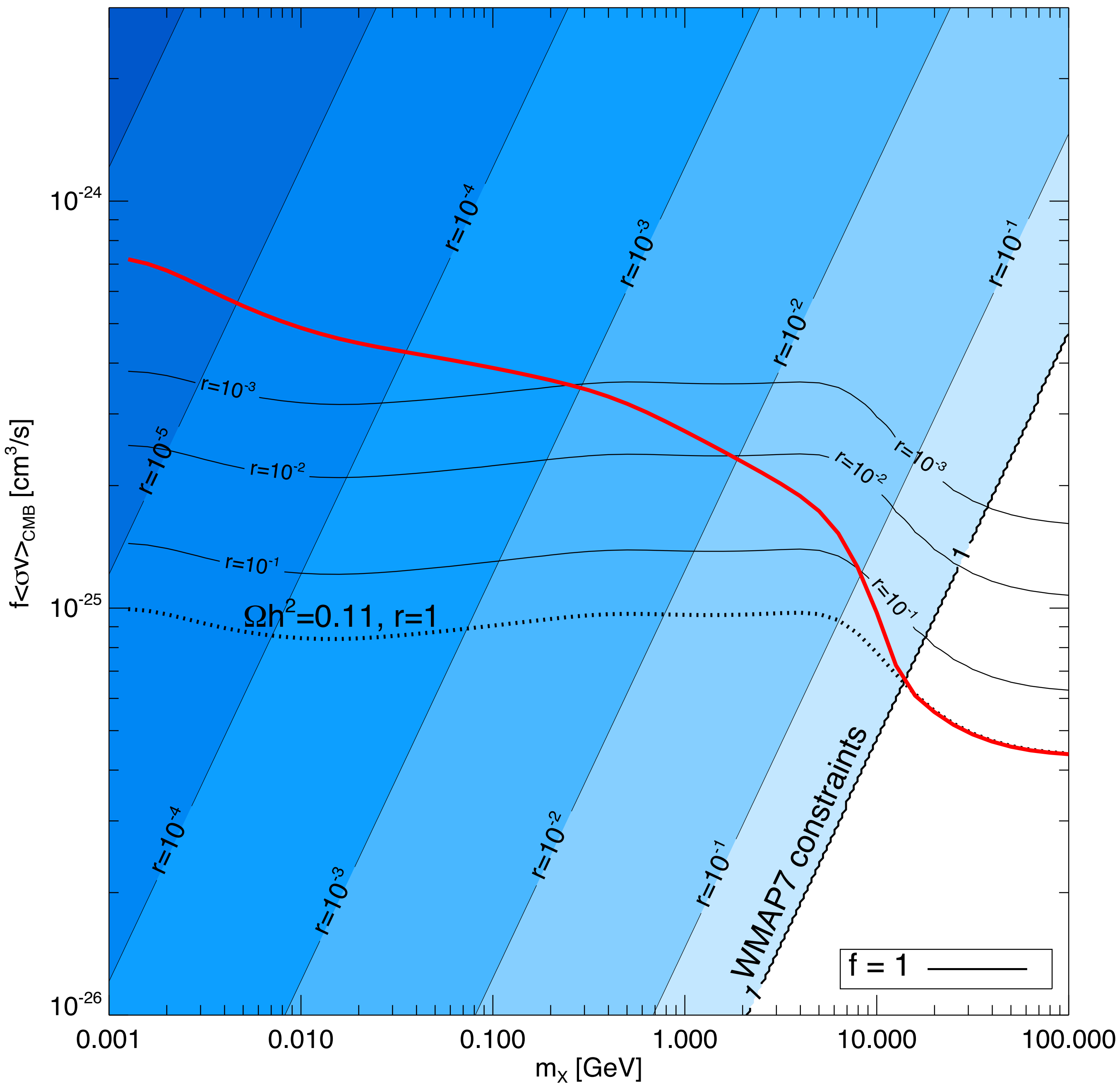
- Thermal DM has its mass limits



Finkbeiner, Padmanabhan, Slatyer 0906.1197

e.g.

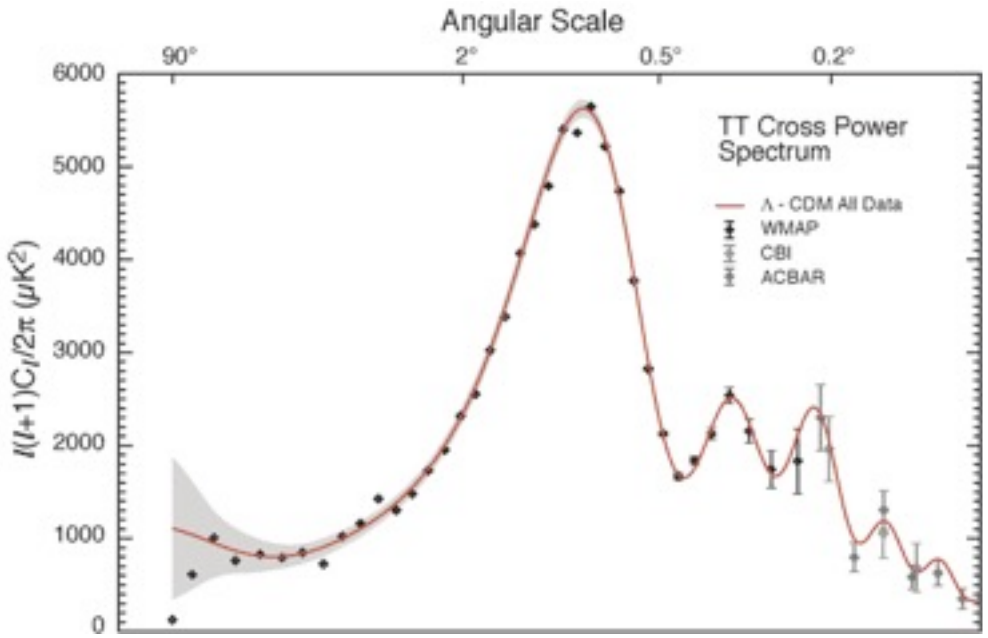
- ADM has its (lower) annihilation limits

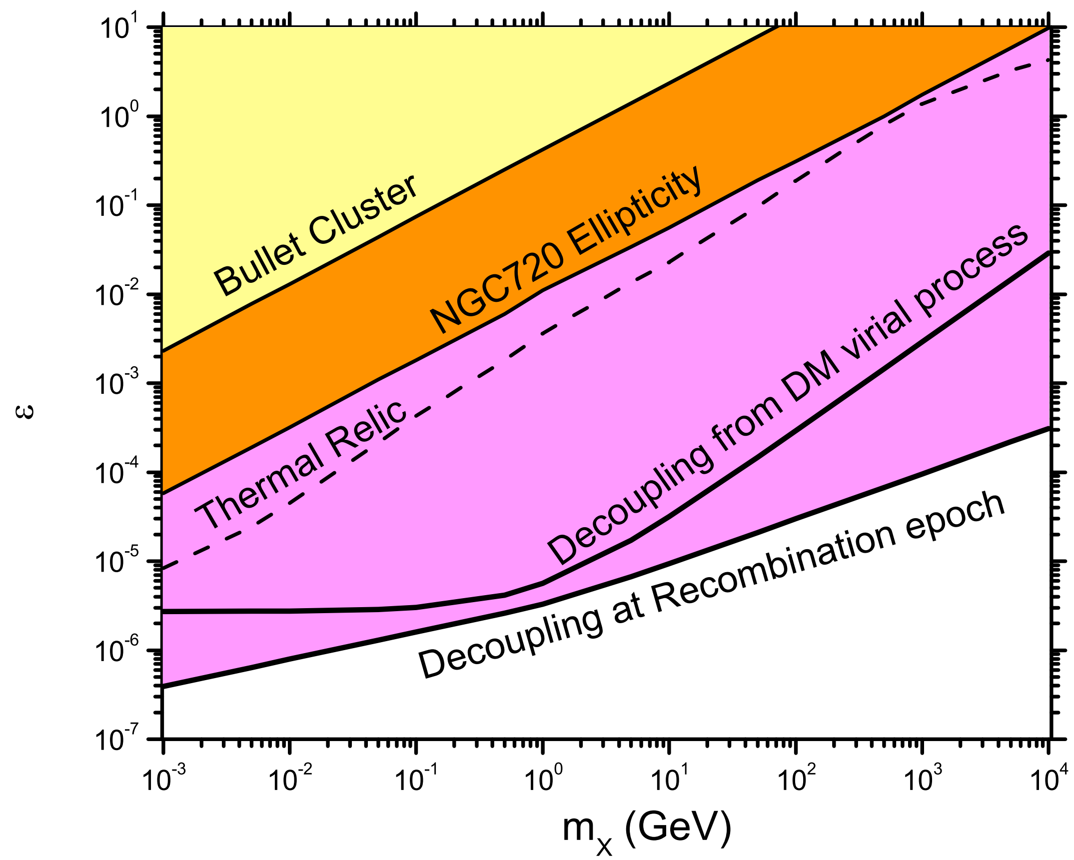


Lin, Yu, KZ 1111.0293

e.g.

- DM must be decoupled from baryons on CMB epoch





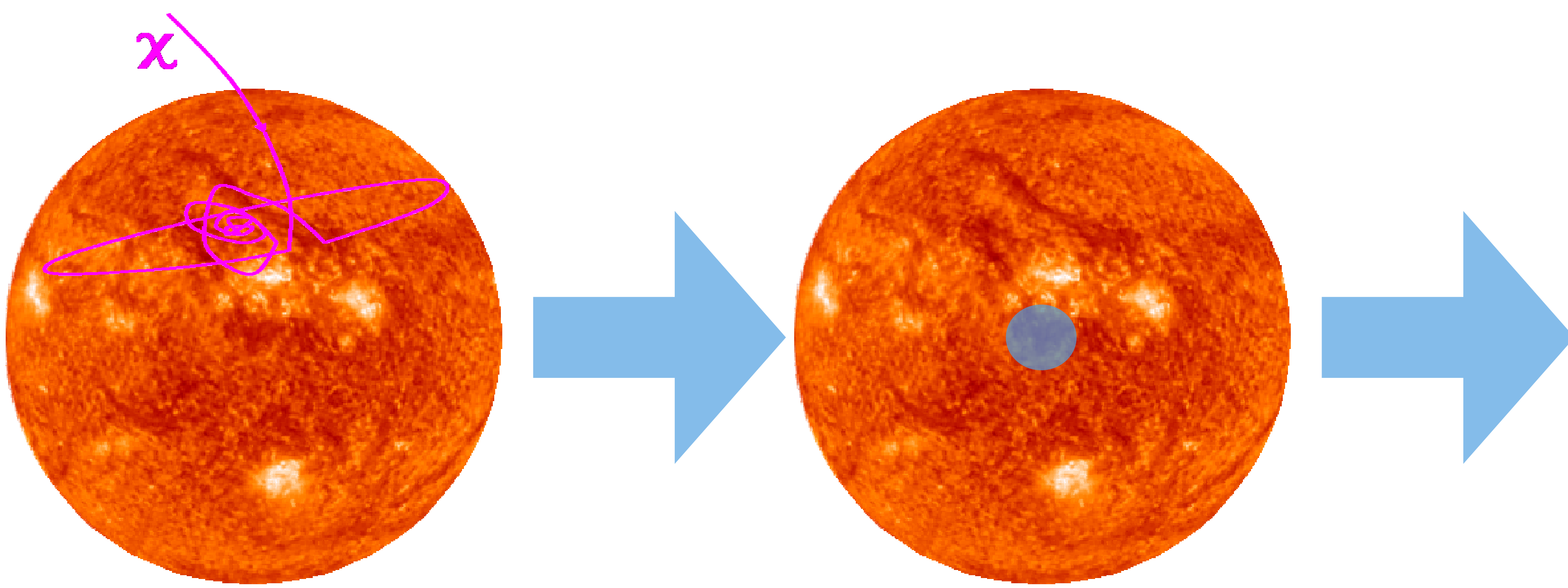
McDermott, Yu, KZ 1011.2907

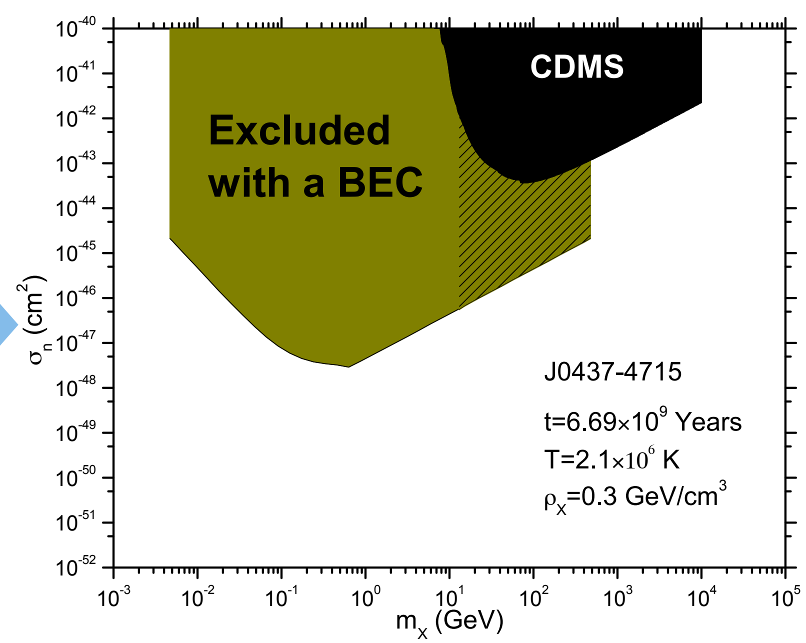
- Esp. for dark (massless) photon mediators

$$\frac{\mathrm{d}\sigma_{Xb}}{\mathrm{d}\Omega_*} = \frac{\alpha_{\rm em}^2 \epsilon^2}{4\mu_b^2 v_{\rm rel}^4 \sin^4(\theta_*/2)}$$

e.g.

- Make sure no stars are destroyed on the way ....

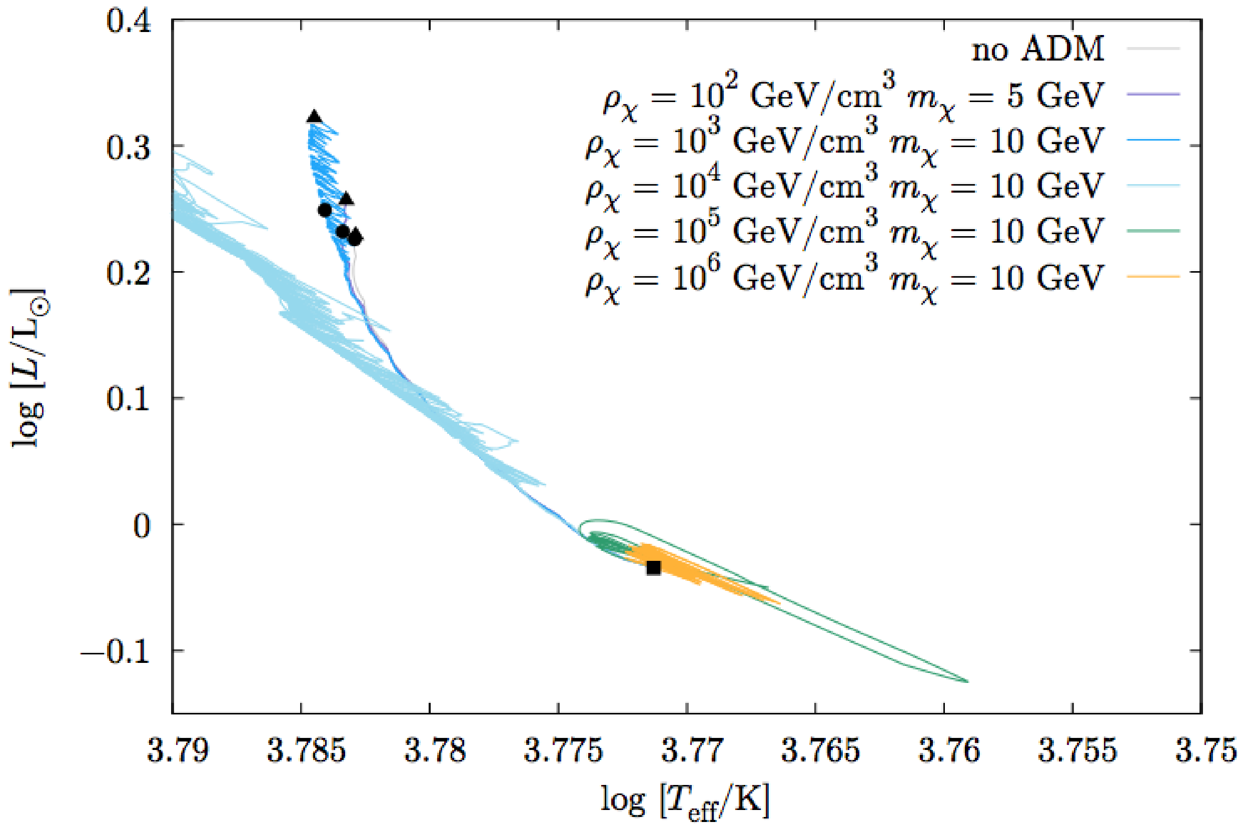




McDermott, Yu, KZ 1103.5472

e.g.

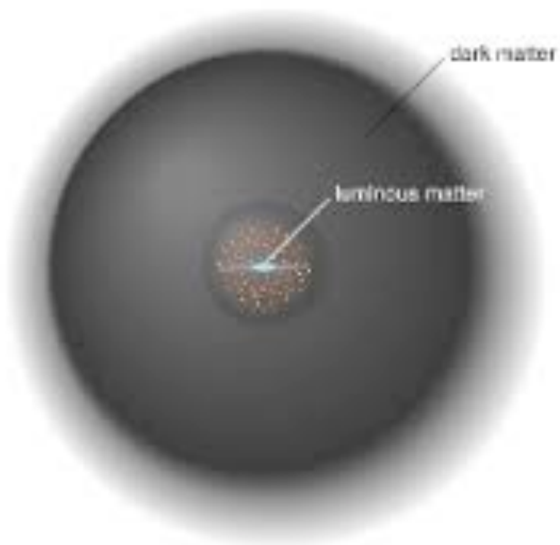
- And that stars still evolve as usual on the HR diagram

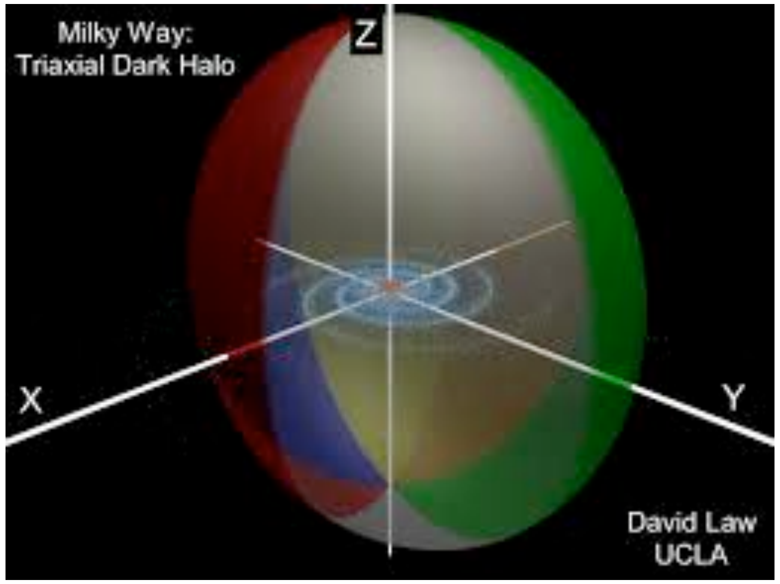


Taoso et al, 1005.5711

e.g.

- ... and the shapes of halos and clusters of galaxies come out right

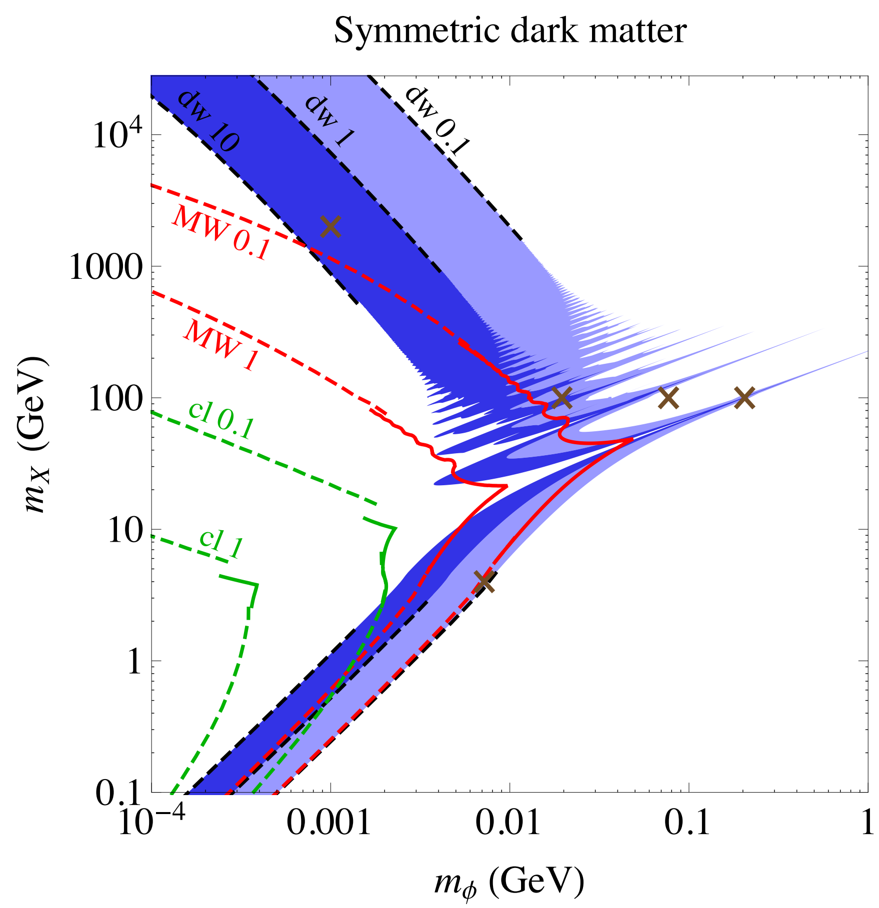




- Self-interactions change these

e.g.

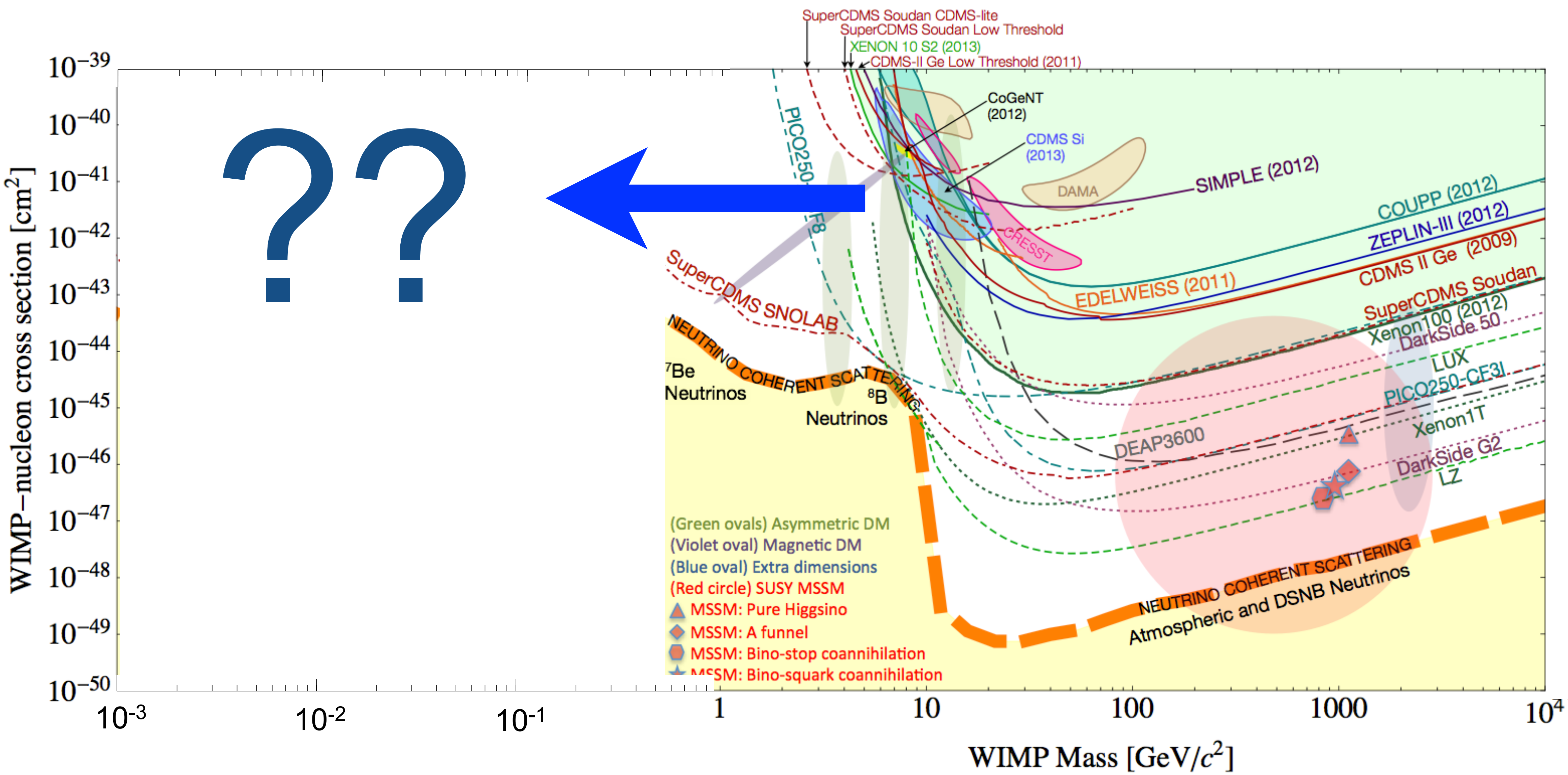
- ... and the shapes of halos and clusters of galaxies come out right



- Self-interactions change these

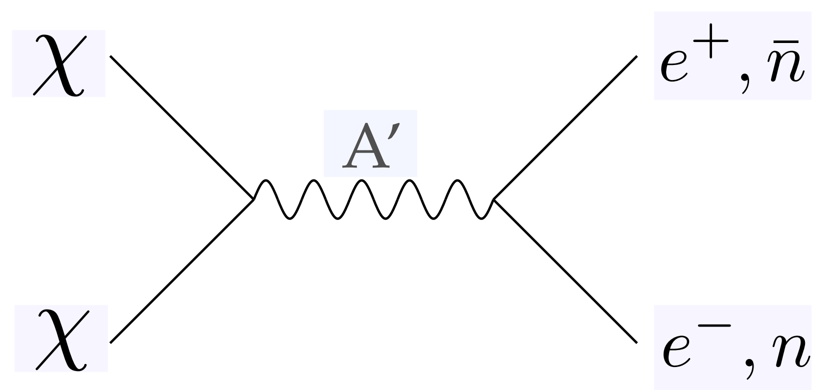
Tulin, Yu, KZ 1302.3898

- All of which are important when it comes to designing a new experiment



Plot from R. Essig

- All of which are important when it comes to designing a new experiment

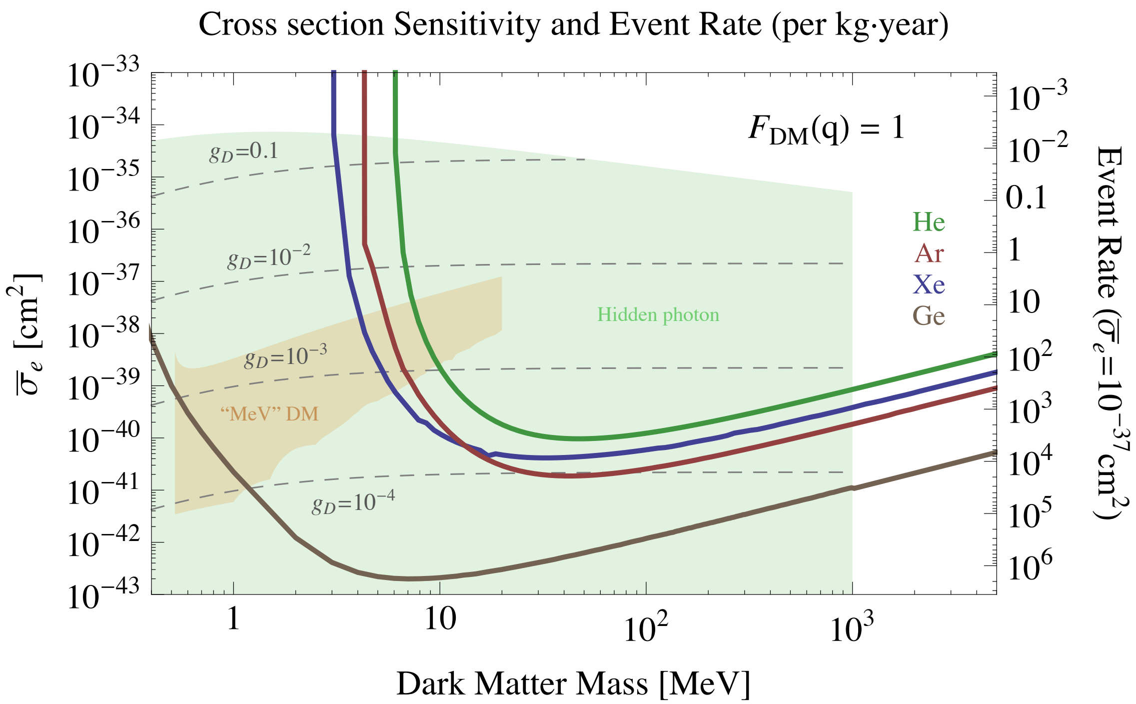


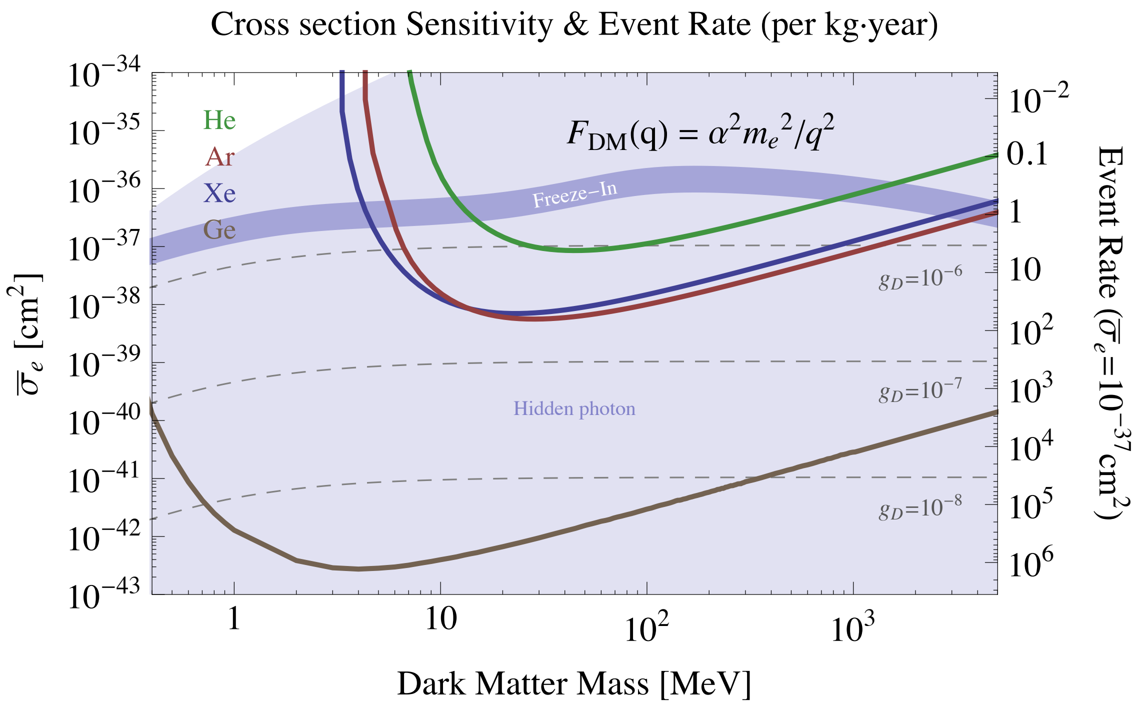
Constrained by halo shapes

$$\sigma_n \approx \frac{g_\chi^2 g_n^2 \mu_n^2}{\pi m_{A'}^4} \qquad \sigma_e \approx \frac{g_\chi^2 g_e^2 \mu_e^2}{\pi m_{A'}^4}$$

Constrained by stars, terrestrial experiments

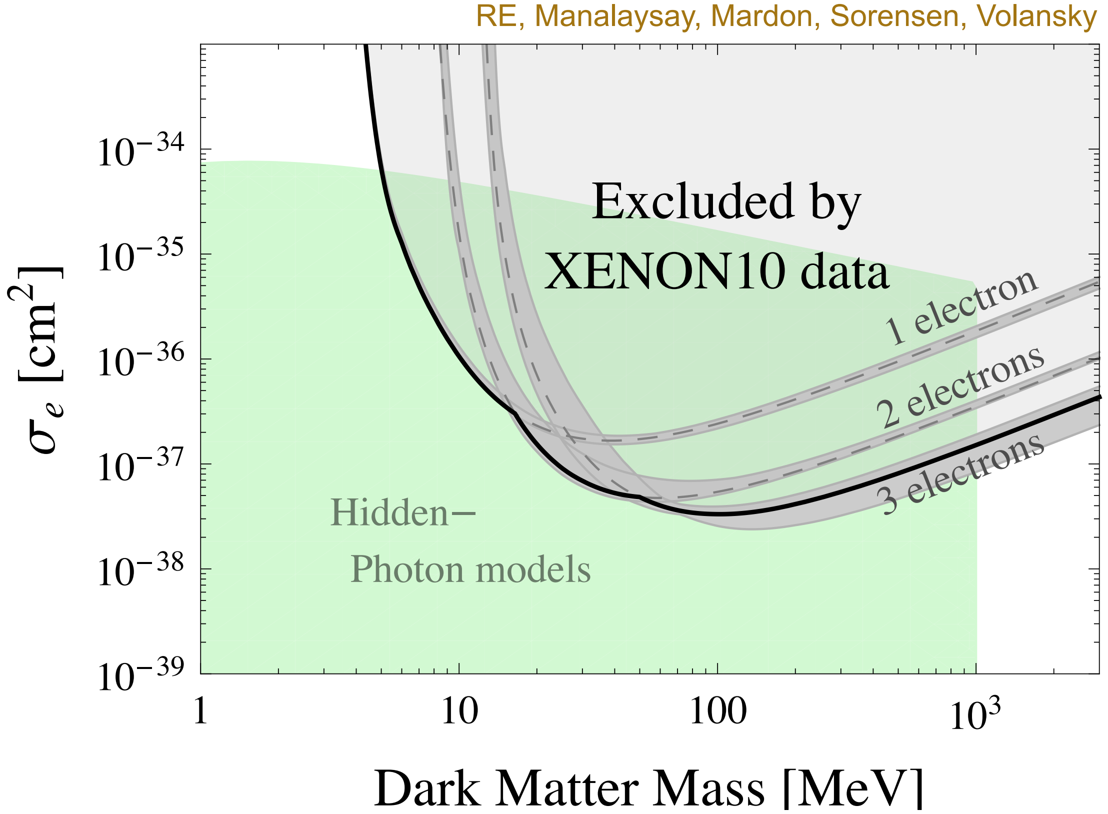
- # What kinds of models can you look for?



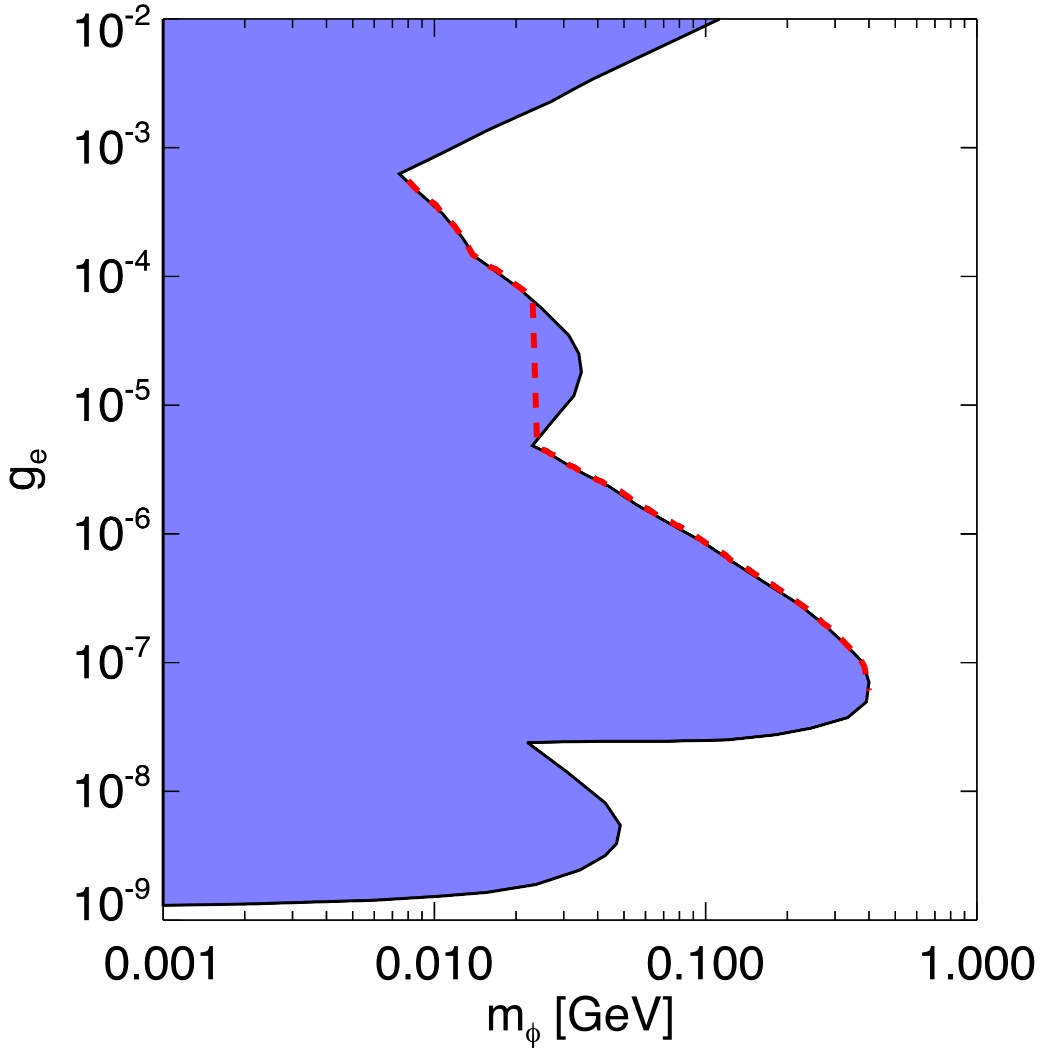


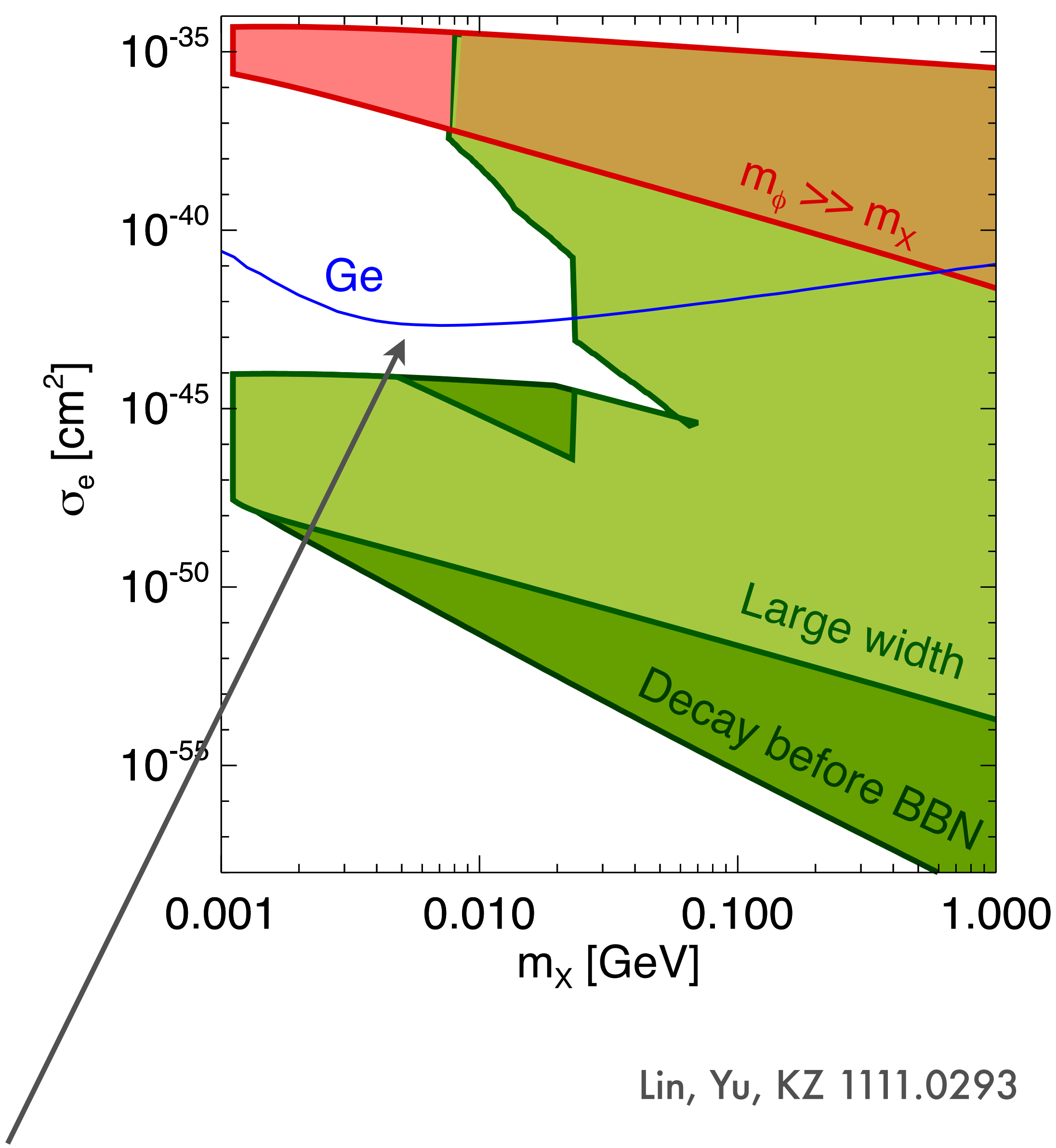
Essig, Mardon, Volansky 1108.5383

RE, Manalaysay, Mardon, Sorensen, Volansky



- Complementarity





Lin, Yu, KZ 1111.0293

Projected maximum sensitivity of direct detection experiment

Cut-out gives combined constraints of beam dump + supernova + g-2

Even lower masses...

- To the warm DM limit around keV
- Available kinetic energy in scattering

$$E_D \simeq \mu_{e,X} v^2$$

$$m_X \sim 1 \text{ MeV} \implies E_D \simeq 1 \text{ eV} \qquad m_X \sim 1 \text{ keV} \implies E_D \simeq 1 \text{ meV}$$

- .... requires new technology; sub-eV thresholds
- Semi-conductors have ~eV thresholds

Superconductors

(Superconducting Detectors for Super Light Dark Matter; Hochberg, Zhao, KZ 1504.07237)

- Superconductors! Cooper pairs have ~meV binding energies
- Above this threshold electrons behave as free electrons in Fermi degenerate metal
- Ram an electron; create quasiparticles which random walk until absorbed by TES

Superconductors

- Need to beat noise; current demonstrated noise levels in TES

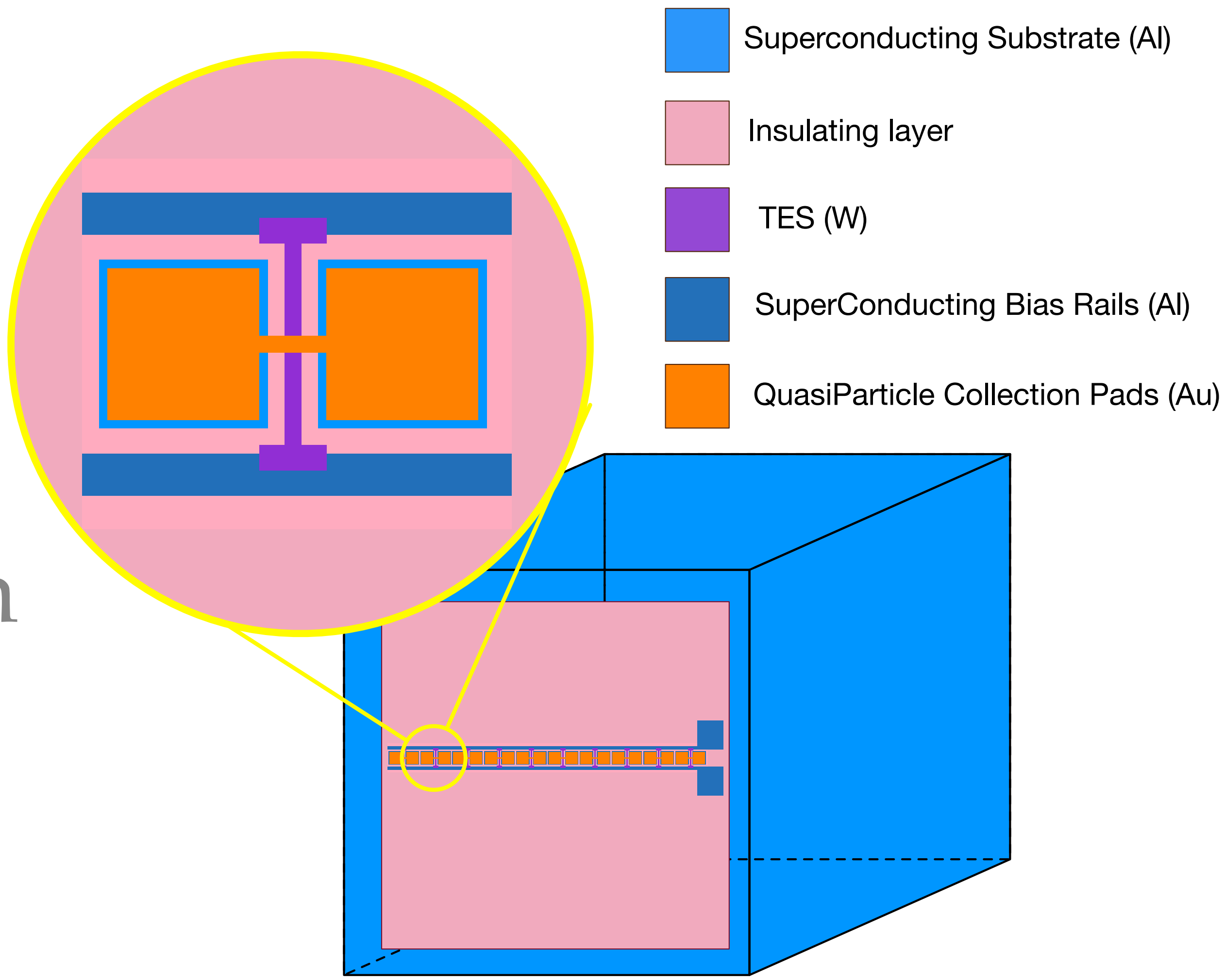
$$10^{-19} - 10^{-20}\mathrm{W}/\sqrt{\mathrm{Hz}}$$

- Corresponds to ~50-300 meV of energy over readout time of ~ms

Detector concept

(Superconducting Detectors for Super Light Dark Matter; Hochberg, Zhao, KZ 1504.07237)

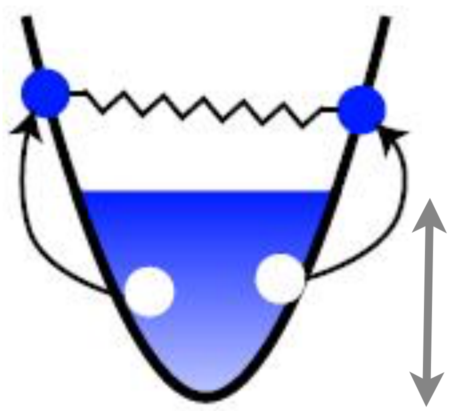
- Quasiparticle lifetime in excess of microsecond
- With velocity of $10^{-2}c$, plenty of time to random walk before being absorbed



Design by M. Pyle

Rates & Constraints

- Scattering off electron in Fermi-degenerate metal: Pauli blocking



Hochberg, Zhao, KZ 1504.07237

$$E_F \sim 10 \text{ eV}$$

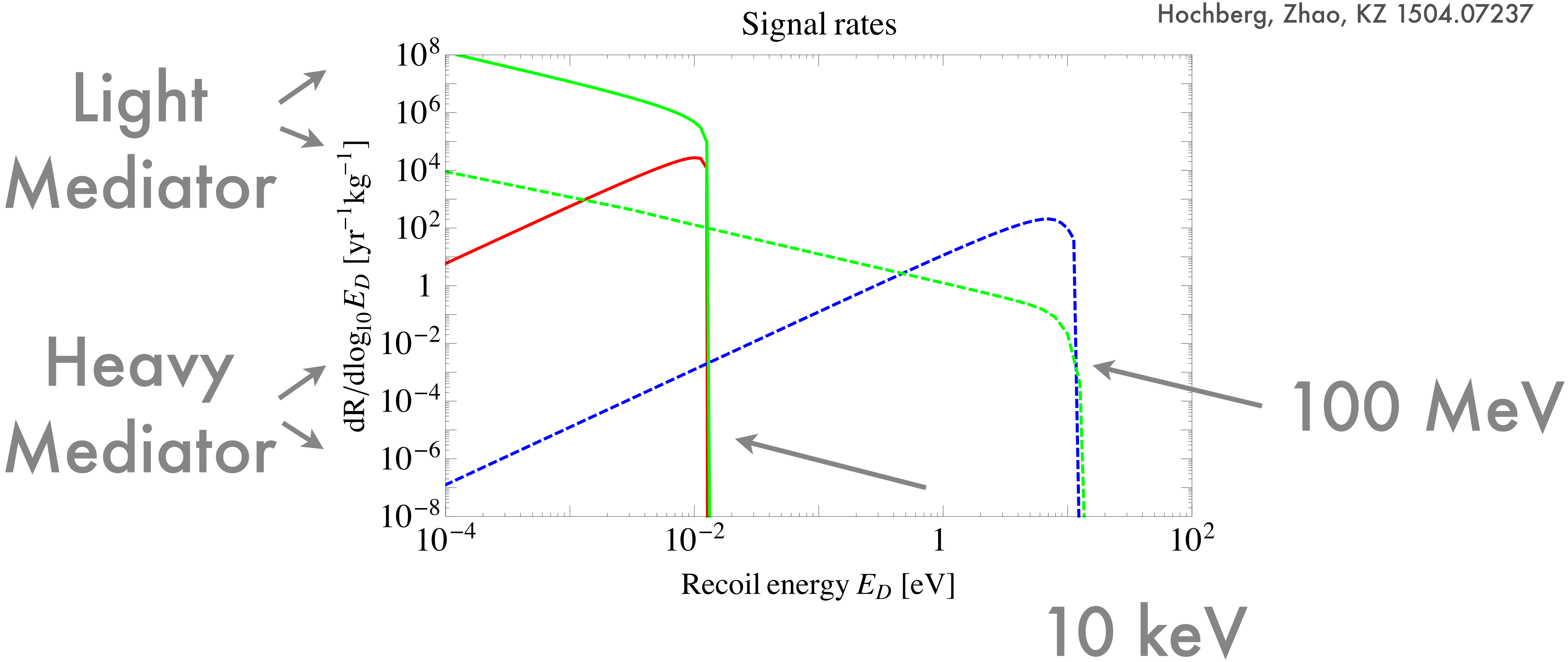
$$\langle n_e \sigma v_{\rm rel} \rangle = \int \frac{d^3 p_3}{(2\pi)^3} \frac{\langle |\mathcal{M}|^2 \rangle}{16 E_1 E_2 E_3 E_4} S(E_D, |\mathbf{q}|) \,, \qquad (1)$$

$$S(E_D, |\mathbf{q}|) = 2 \int \frac{d^3 p_2}{(2\pi)^3} \frac{d^3 p_4}{(2\pi)^3} (2\pi)^4 \delta^4 (P_1 + P_2 - P_3 - P_4) \times f_2(E_2)(1 - f_4(E_4)),$$

Rates & Constraints

Rate curves consistent with all astrophysical, cosmological and terrestrial constraints

Hochberg, Zhao, KZ 1504.07237



Rates & Constraints

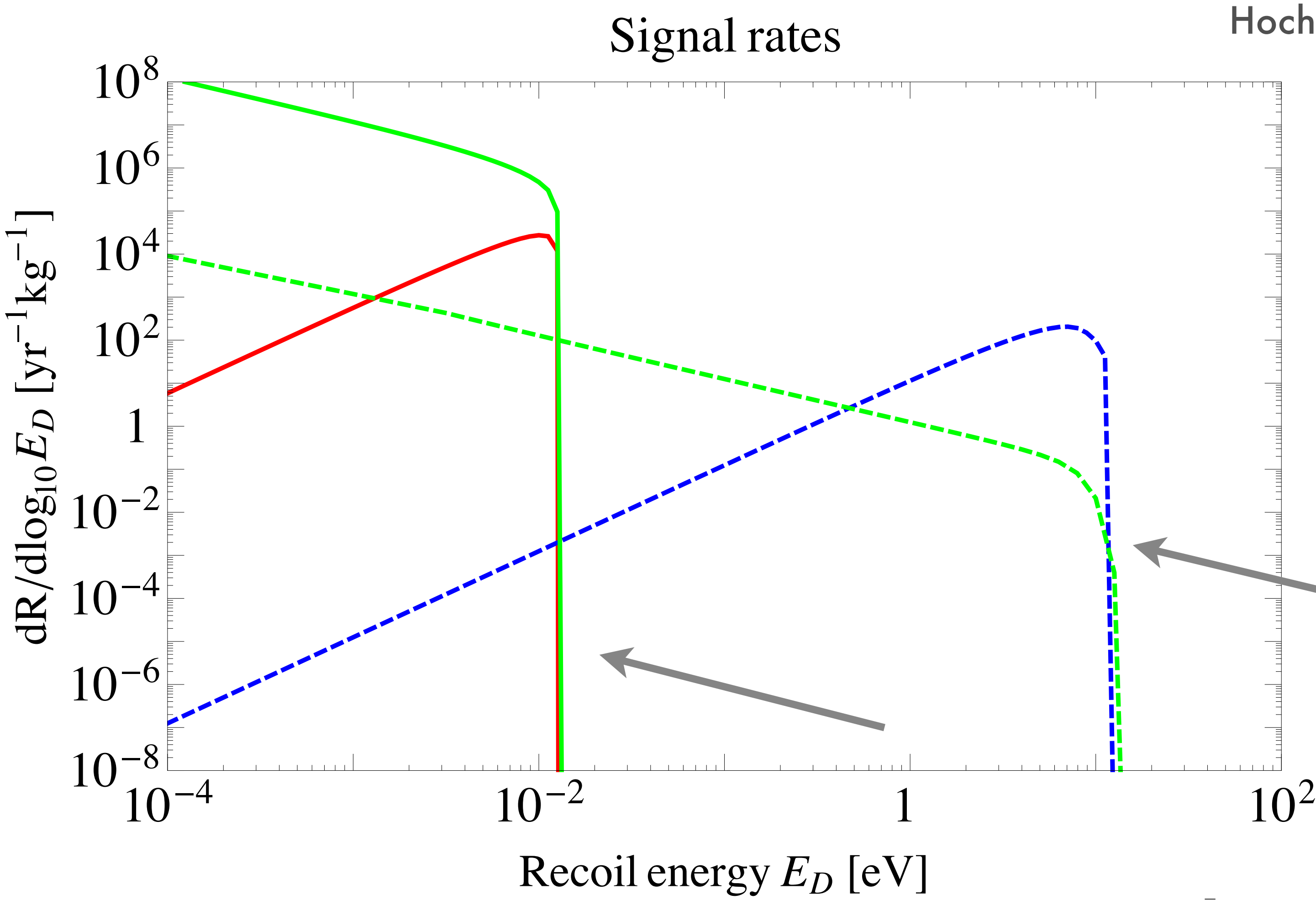
Rate curves consistent with all astrophysical, cosmological and terrestrial constraints

Low momentum dominates

$$\sigma = \frac{16\pi\alpha_e\alpha_X\mu_{eX}^2}{(m_\phi^2+q^2)^2}$$

Pauli blocking dominates

Hochberg, Zhao, KZ 1504.07237

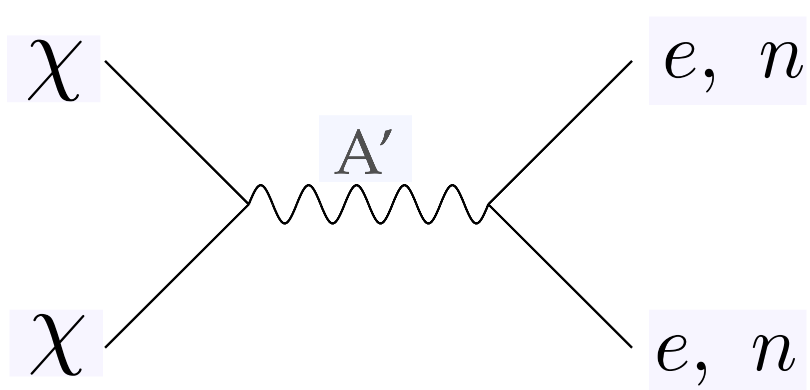


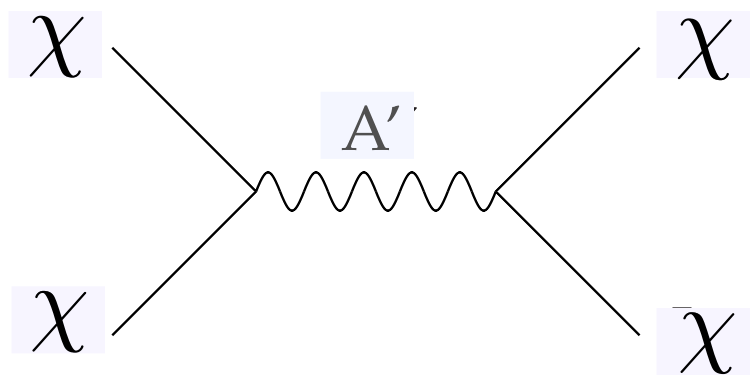
100 MeV

10 keV

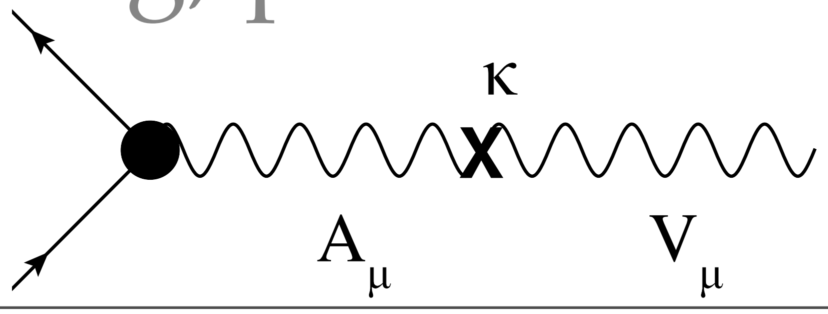
Constraints

- Sample simplified model
- Same process that mediates scattering with electrons mediates self-scattering



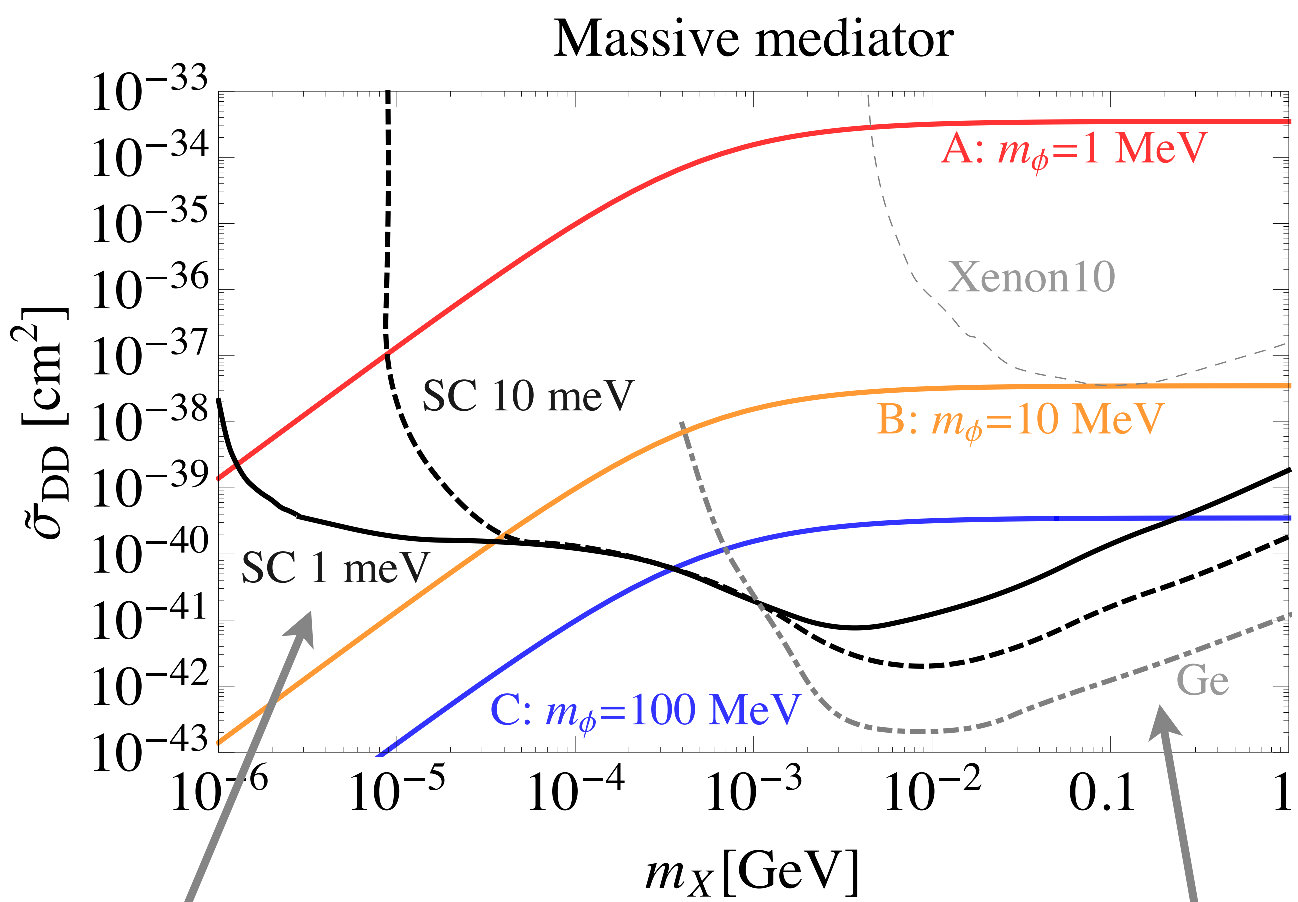


- Sufficiently light mediator can lead to stellar cooling; plasmon decay



Reach

Hochberg, Zhao, KZ 1504.07237



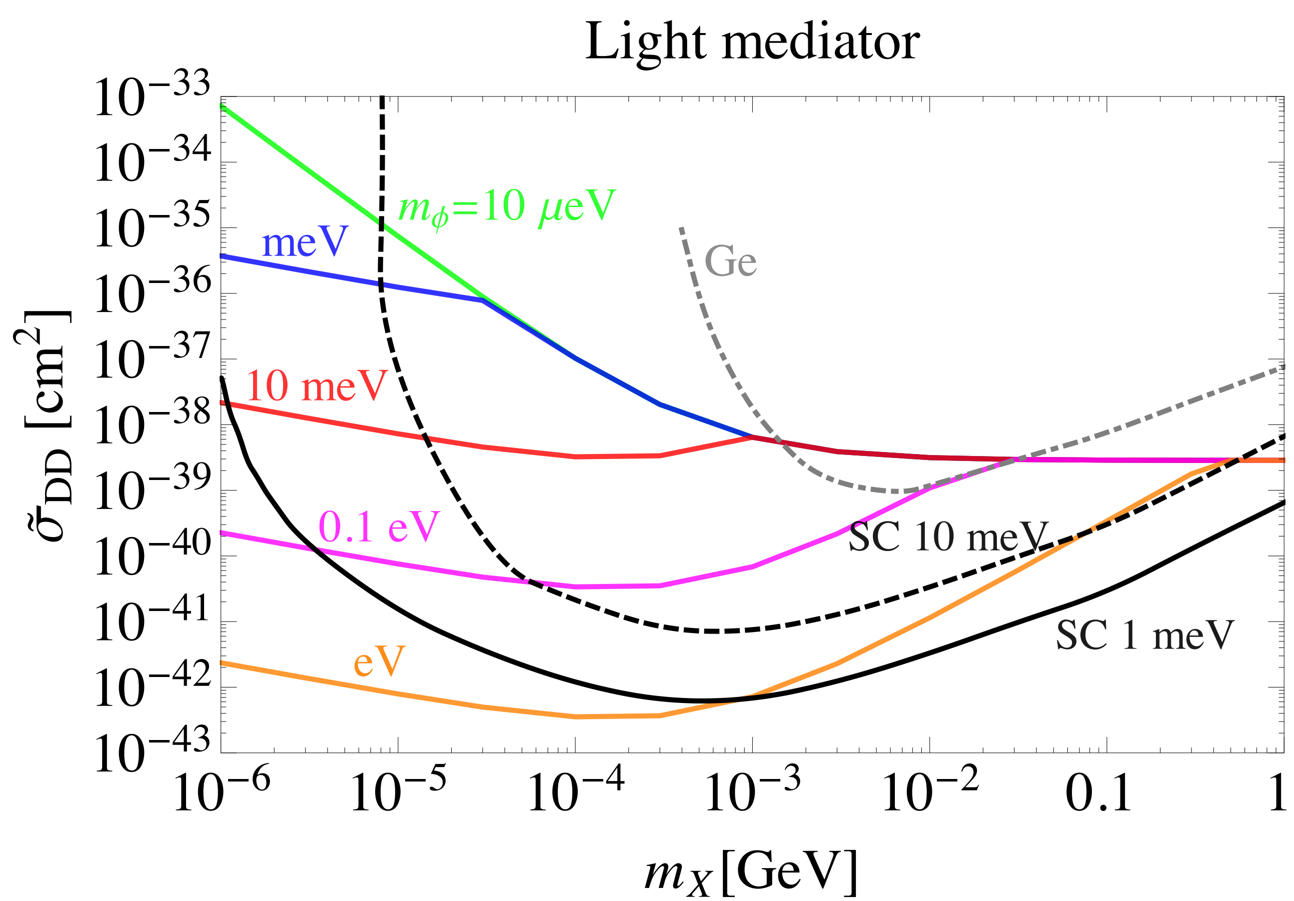
Models satisfy astro and terrestrial constraints

Superconductor with 1 or 10 meV threshold

Ge Semiconductor

Reach

Hochberg, Zhao, KZ 1504.07237



For light mediator, superconductors win over semiconductors because of low threshold

Prospects

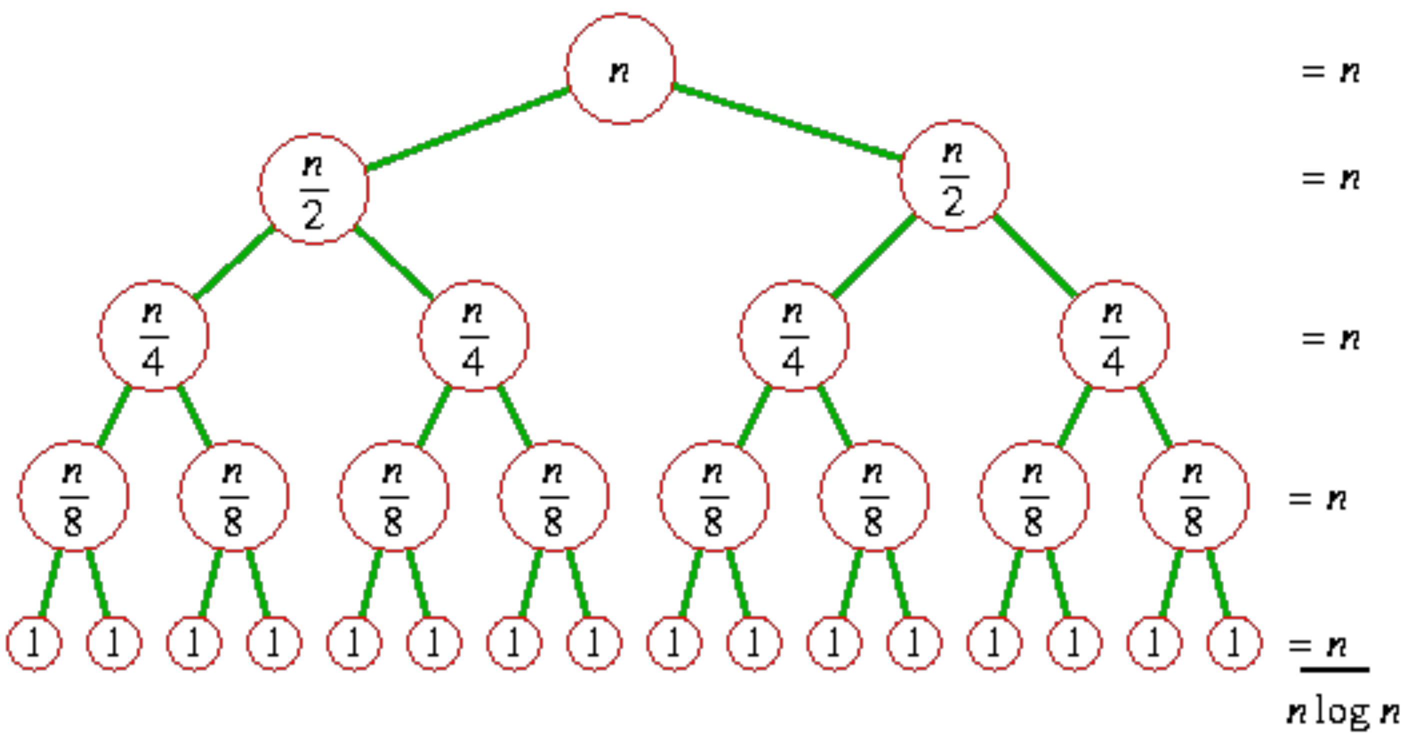
- Substantial R&D will be necessary to lower noise to level that meV energies are detectable. However, everything currently being done for semiconductors can be ported
- Models satisfying all constraints are within reach; more work remains on relic density mechanisms

Conclusions, Lessons for Future

- Moving beyond the WIMP happens as we move beyond the weak scale; if we fail to find new physics at weak scale, hunt for DM must continue
- Leverage development of technology for WIMP to broaden searchlight --> natural place to go is lighter
- Astrophysics and cosmology will continue to be crucial companions

Conclusions, Lessons for Future

- Need systematic, multi-pronged approach; probably still too self-limited



Astro
Objects
AMS
CDMS
COUPP
CoGeNT
Cresst
DM ICE
Fermi
Icecube
KIMS
LHC
LUX
PAMELA
Panda-X
XENON
....