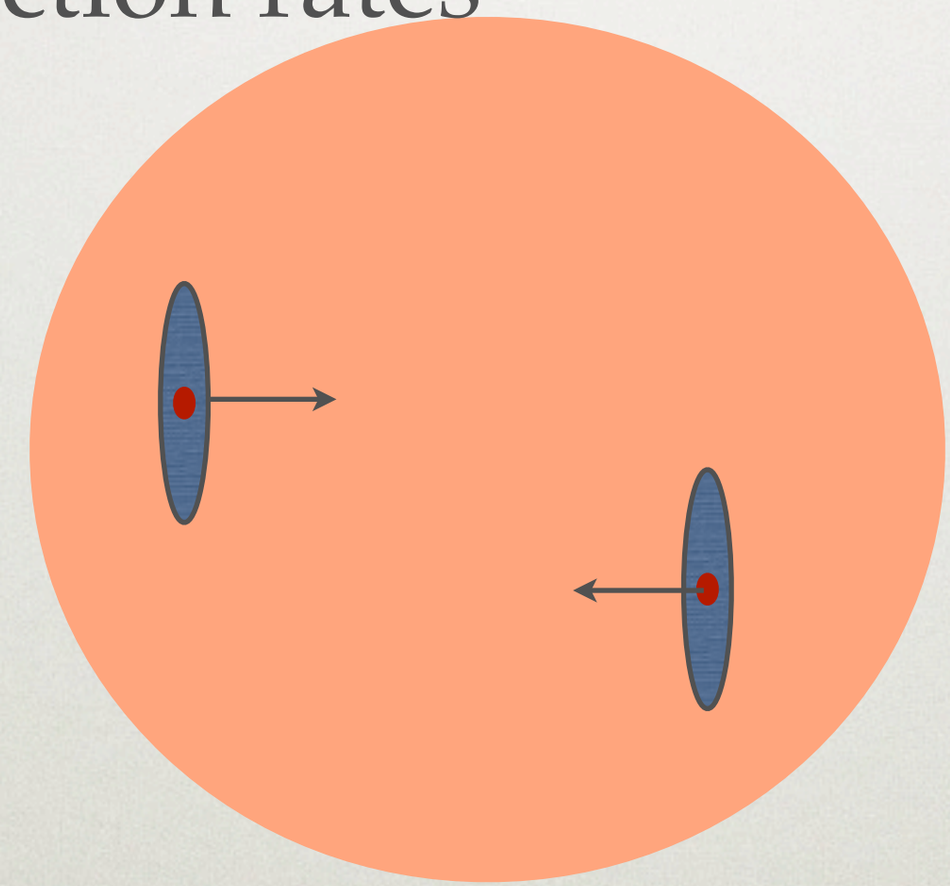
Non-SUSY WIMPs: In Search of DM

Theoretical Models and Their Experimental Signatures

Kathryn M. Zurek
University of Michigan

Why the (sub-)Weak Scale is Compelling

- Abundance of new stable states set by interaction rates



Freeze-out

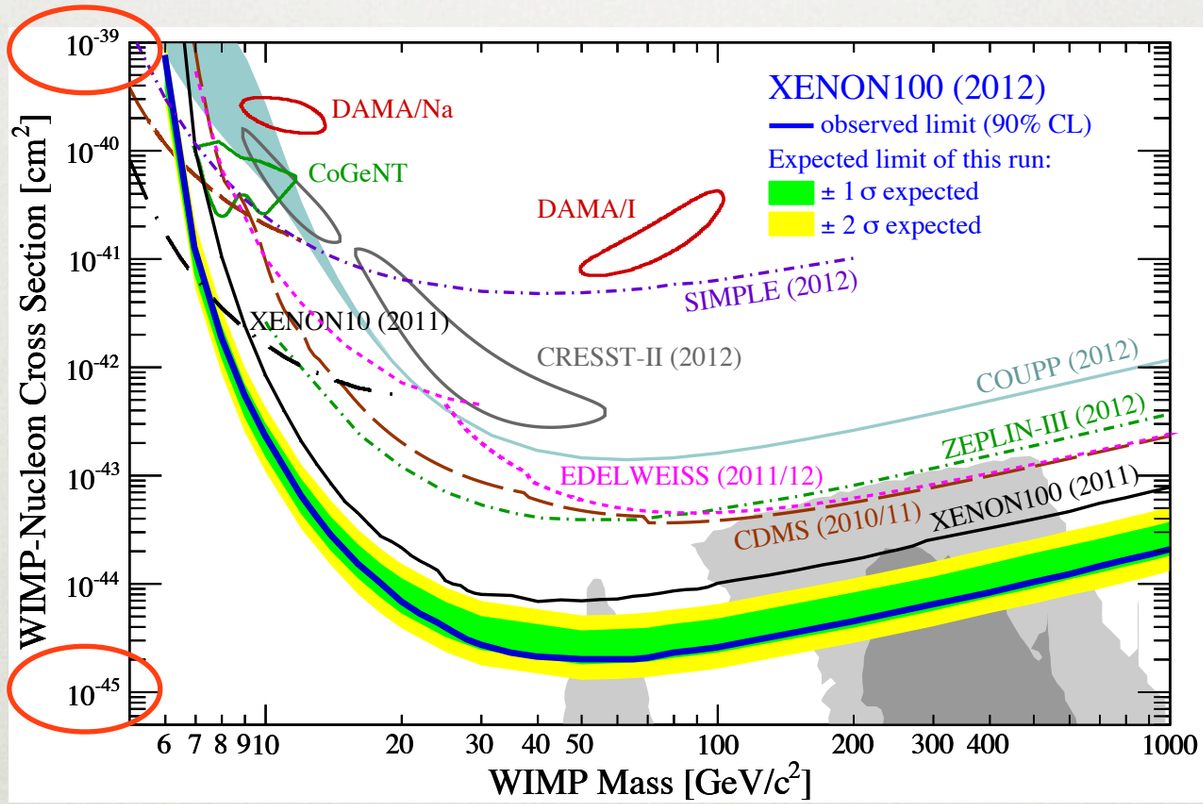
Measured by WMAP + LSS

$$\Gamma = n\sigma v = H \qquad \Longrightarrow \sigma \sim \frac{1}{(100\mathrm{GeV})^2}$$

Sub-Weakly Interacting Massive Particles

Scattering through the Z boson: ruled out

$$\sigma_n \sim 10^{-39}\ \mathrm{cm}^2$$

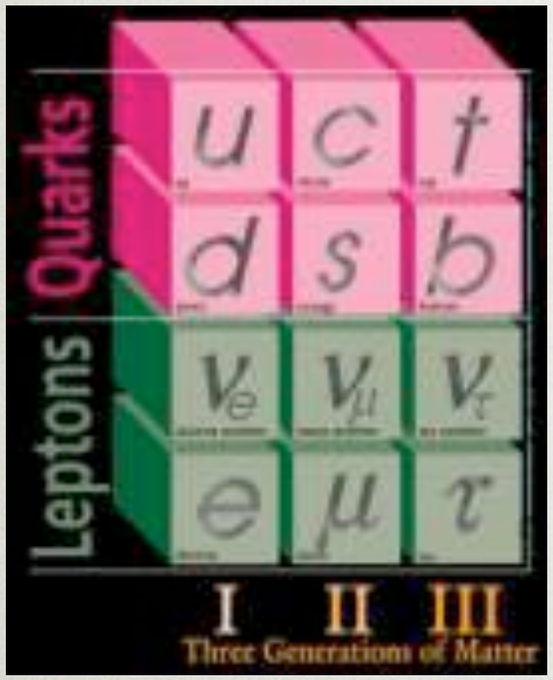


Next important benchmark:
Scattering through the Higgs

$$\sigma_n \sim 10^{-45-46}\ \mathrm{cm}^2$$

New Theoretical Landscape

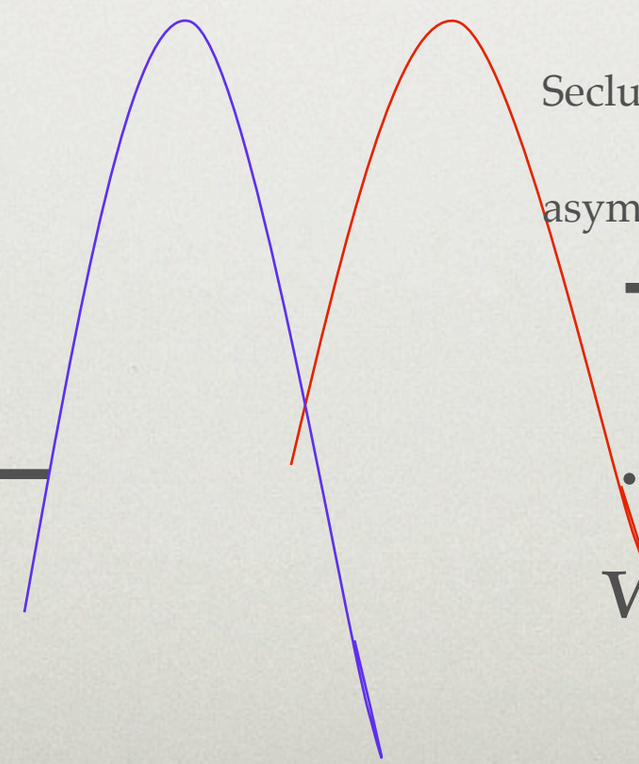
Our theoretical tools have broadened ....



From a single, stable weakly interacting particle .....
(WIMP, axion)

Models: Supersymmetric light DM sectors, Secluded WIMPs, WIMPless DM, Asymmetric DM .....
Production: freeze-in, freeze-out and decay, asymmetric abundance, non-thermal mechanicsms .....

Standard Model



...to a hidden world with multiple states, new interactions

Enormous Diversity

- Relic density mechanism
  - Freeze-out and decay
  - non-thermal production
  - asymmetric abundance
  - freeze-in
- Dark Matter mediation mechanism
  - sub-weak scale
  - weak scale
  - super-weak scale

MeV DM, WIMPless DM, Asymmetric DM, gravitino DM,
Sub-GeV DM, Multi-component DM .....

Enormous Diversity

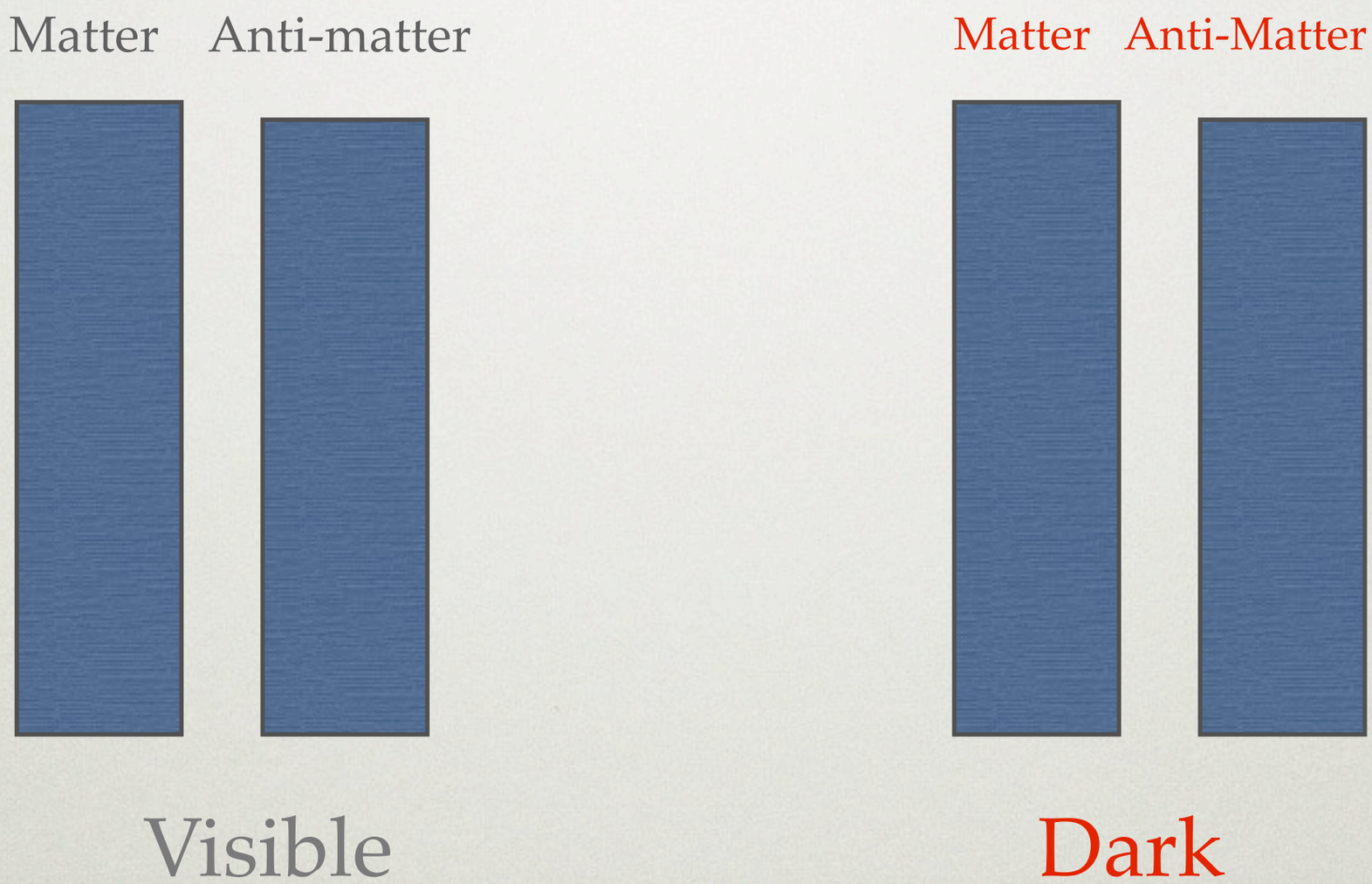
- Cosmological constraints
  - CMB
  - BBN
  - Structure formation
  - Halo shapes
- Astrophysical constraints
  - stars
  - sun and earth
  - direct and indirect detection

MeV DM, WIMPless DM, Asymmetric DM, gravitino DM,
Sub-GeV DM, Multi-component DM .....

Beyond the SUSY WIMP: Many Possibilities

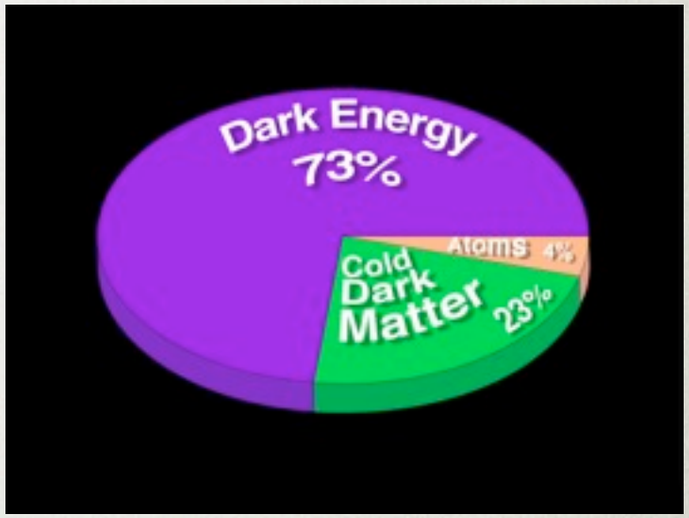
- Also many commonalities -- partially induced by cosmological constraints
- Focus on sub-10 GeV dark matter, notably
- Asymmetric Dark Matter
- Hidden Sector DM
- Many of these models incorporate SUSY

Chemical Potential Dark Matter



Baryon and DM Number Related?

- Standard picture: freeze-out of annihilation; baryon and DM number unrelated
- Accidental, or dynamically related?



Experimentally, $\Omega_{DM} \approx 5\Omega_b$

Mechanism $n_{DM} \approx n_b$

$\Rightarrow$ $m_{DM} \approx 5m_p$

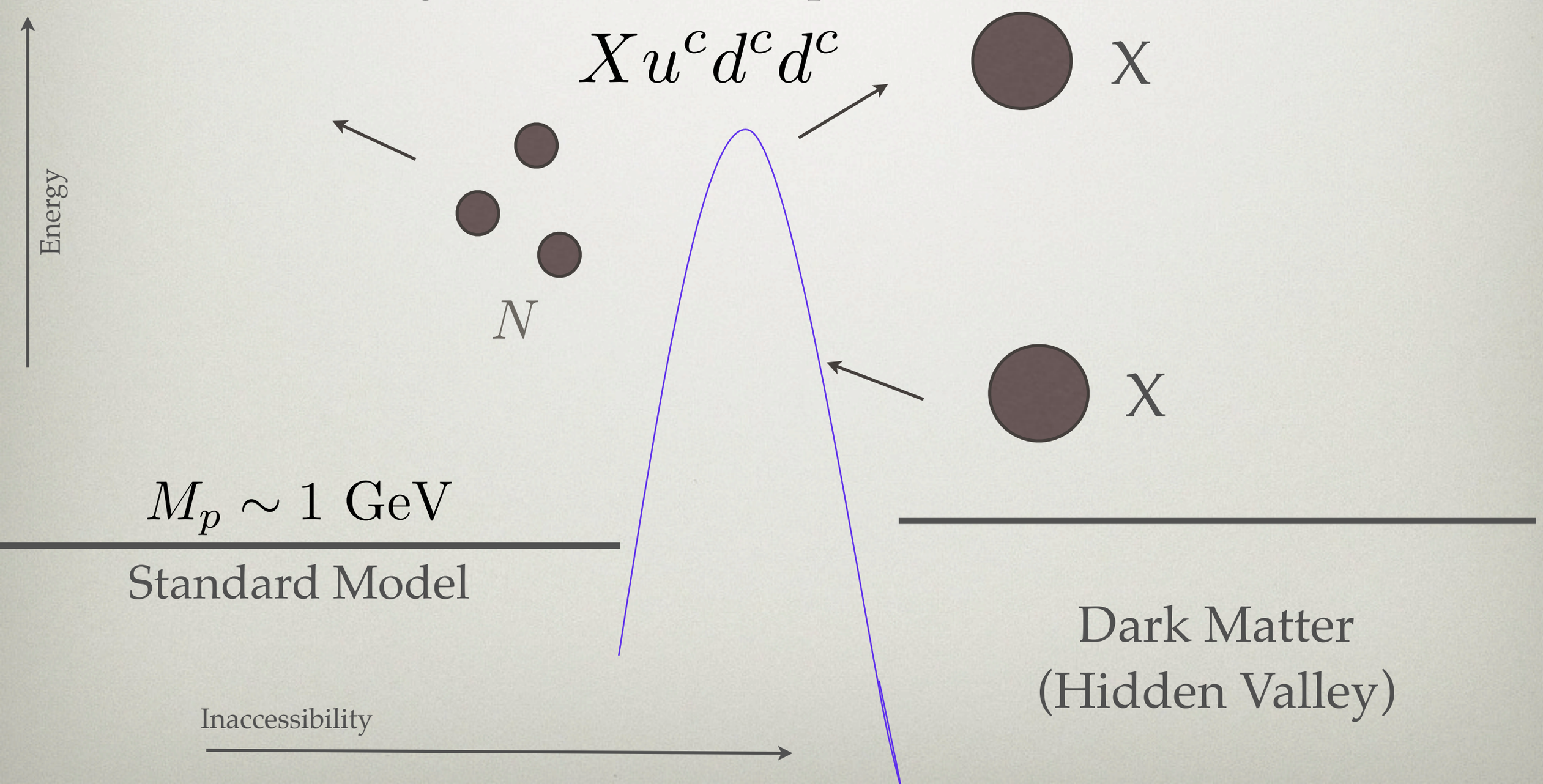
Nussinov,
Hall, Gelmini,
Barr, Chivukula, Farhi,
D.B. Kaplan

Asymmetric DM

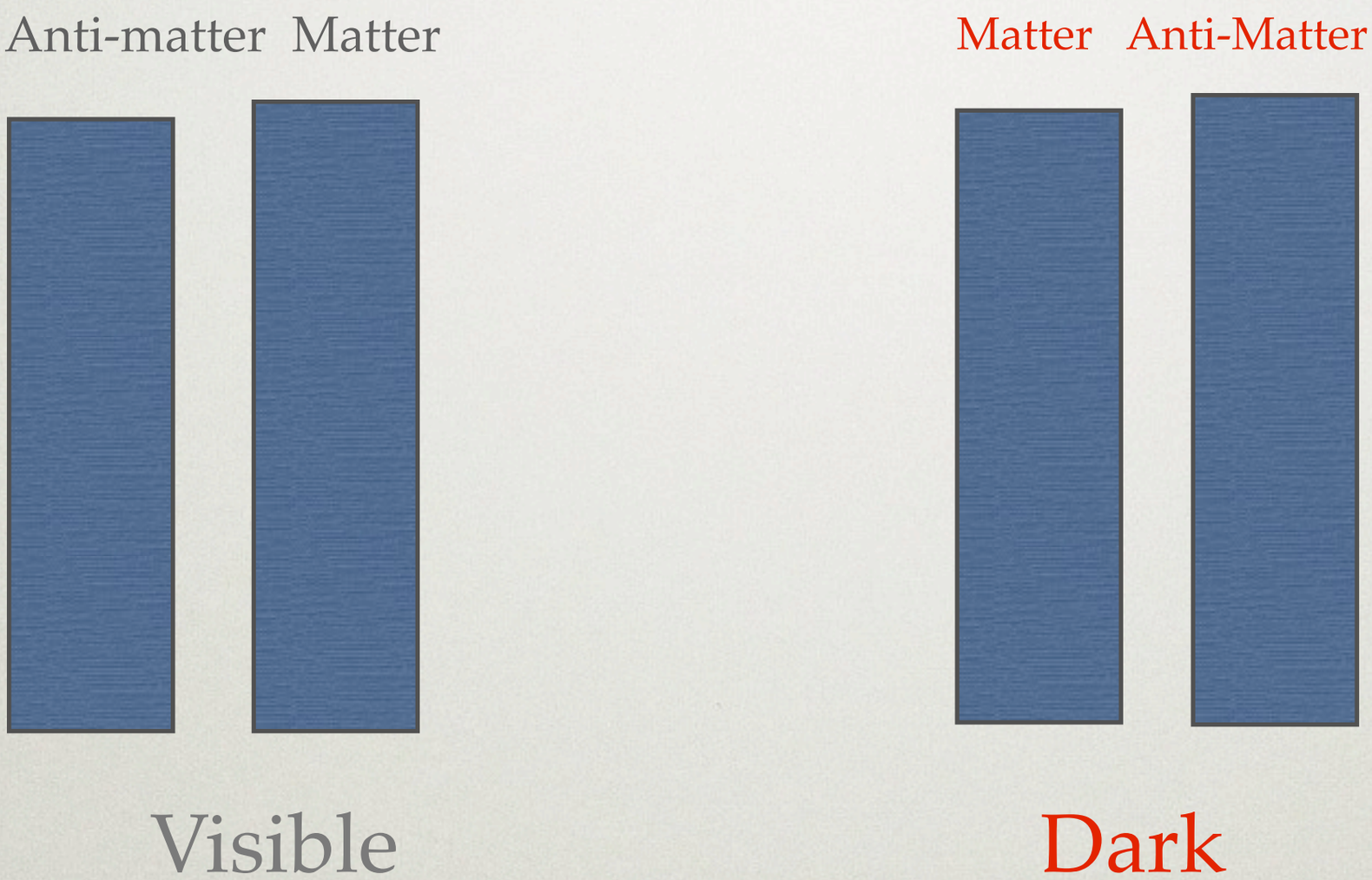
"Integrate out" heavy state
Higher dimension operators:

Luty, Kaplan, KZ
0901.4117

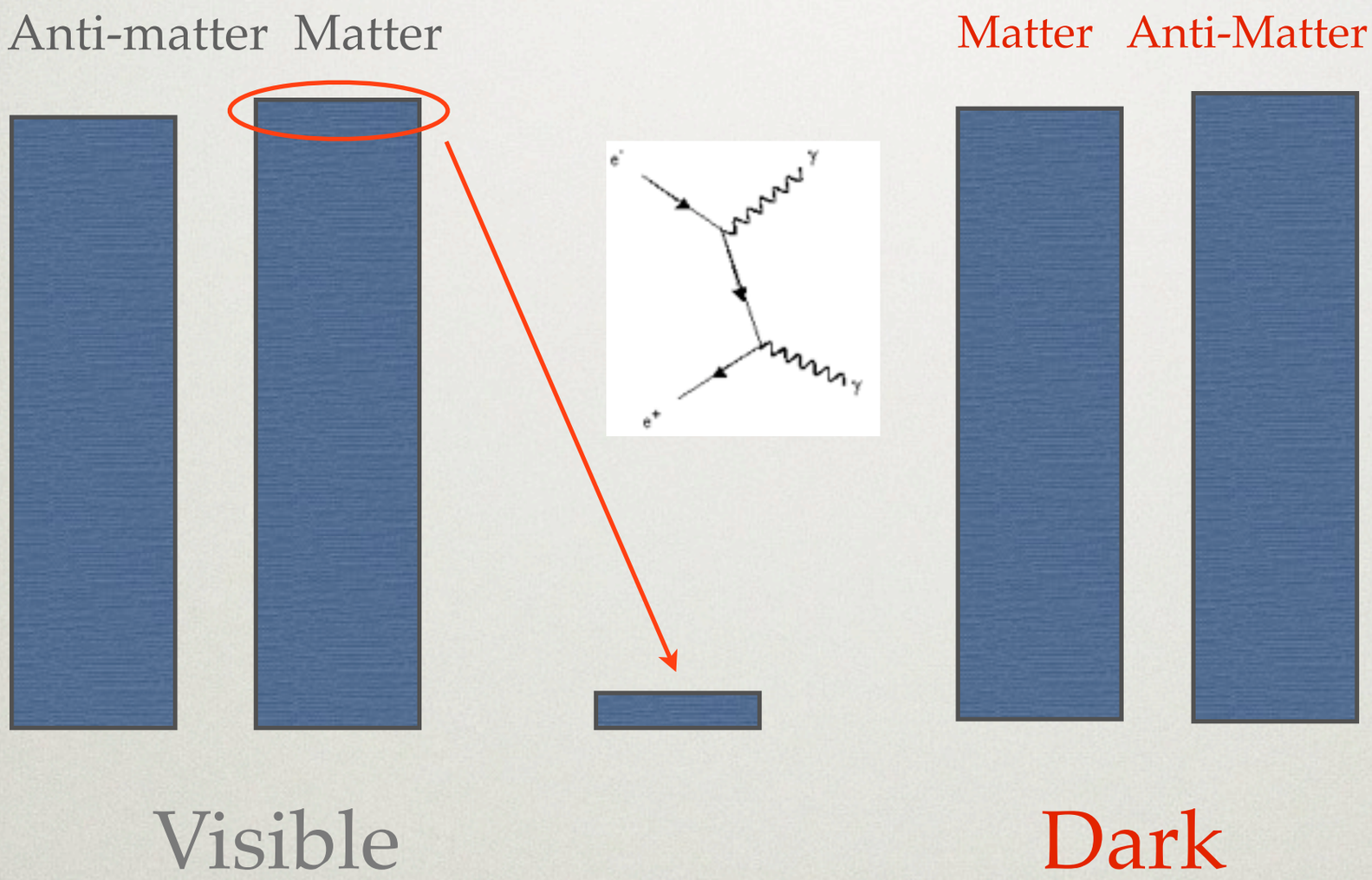
$$X u^c d^c d^c$$



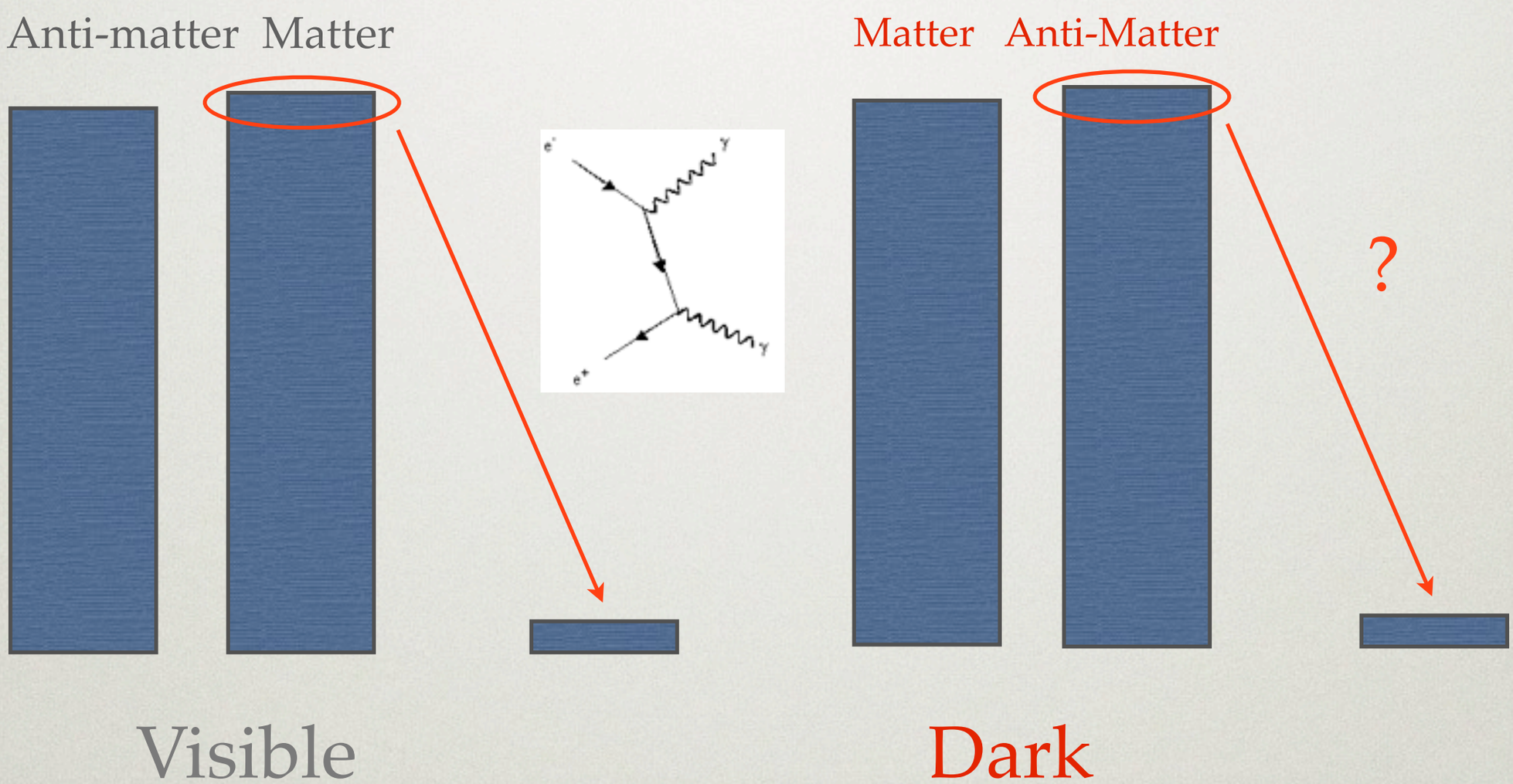
Asymmetric Dark Matter



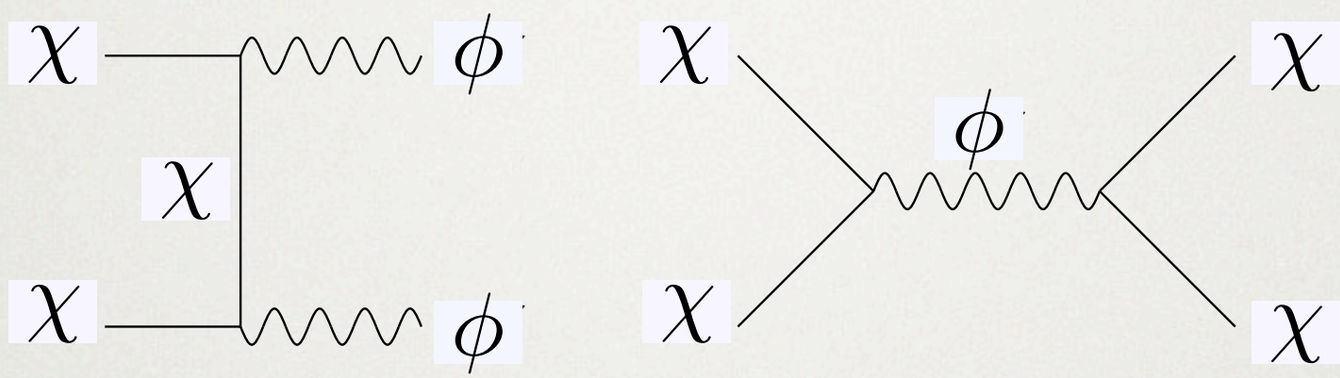
Asymmetric Dark Matter



Asymmetric Dark Matter

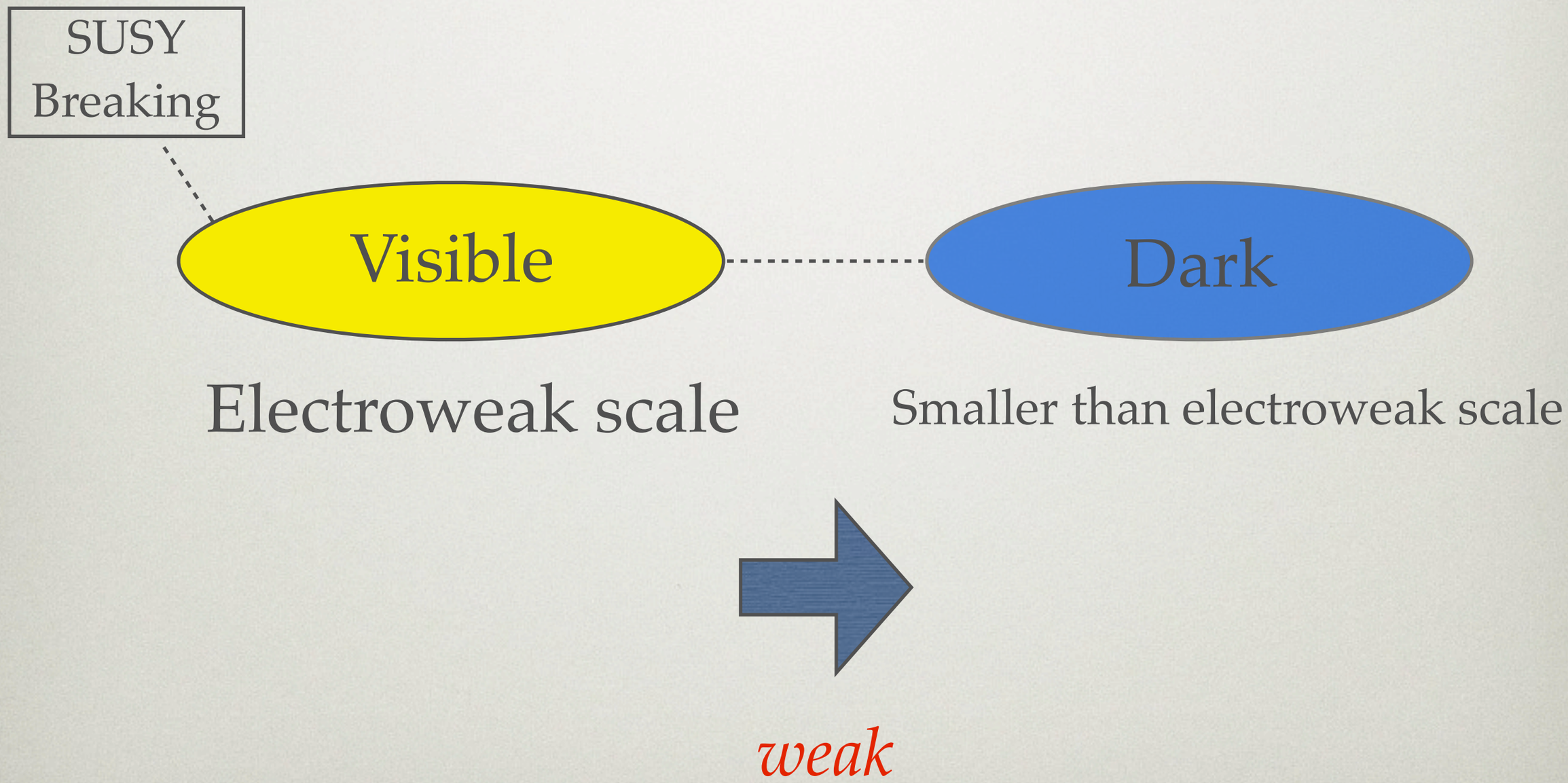


Dark Forces and DM Self-Interactions



- Dark Forces Very Important for Asymmetric Dark Matter!
- Massive dark forces imply dark Higgs

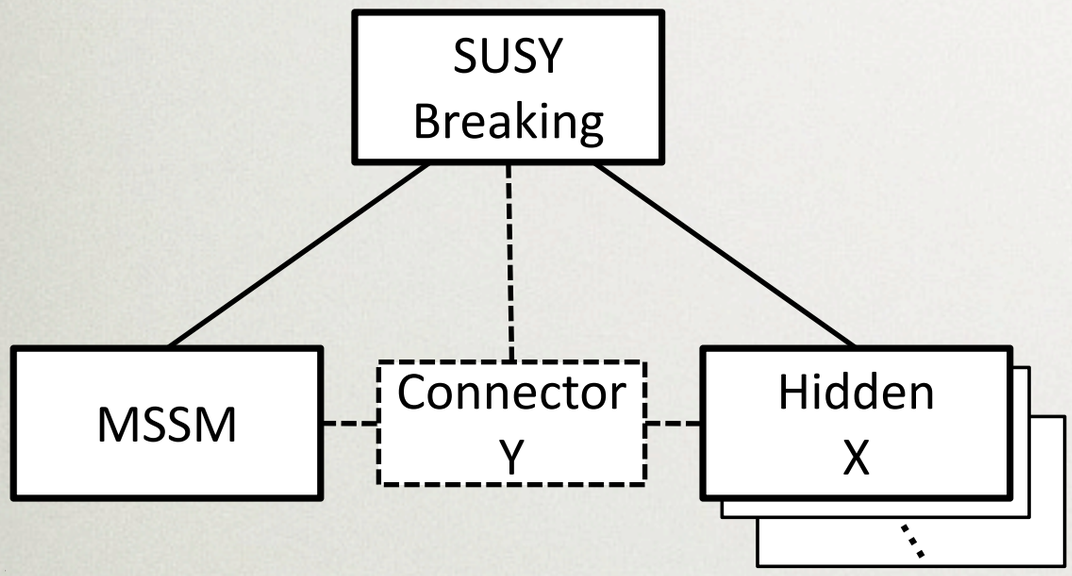
Light WIMPs: Hidden Supersymmetric DM



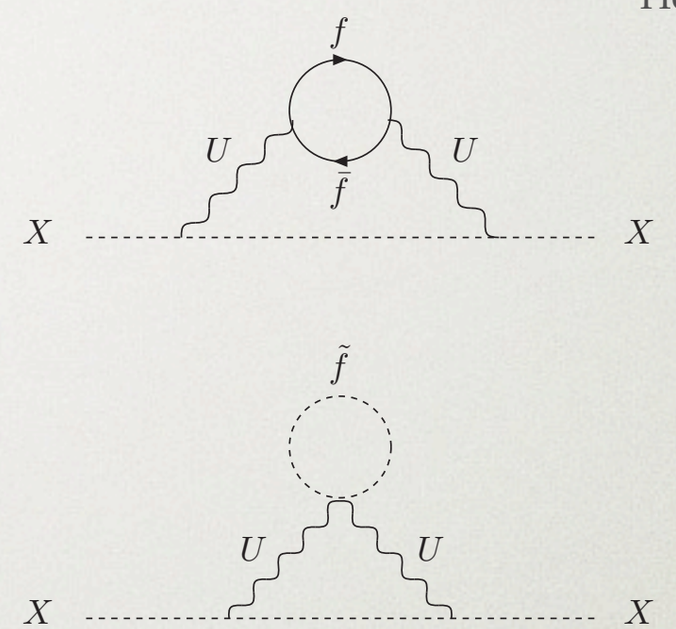
Hooper, KZ '08
Feng, Kumar '08
Arkani-Hamed, Finkbeiner, Slatyer, Weiner '08

Dynamical Generation of "Low" Scale

Feng, Kumar '08



Hooper, KZ '08



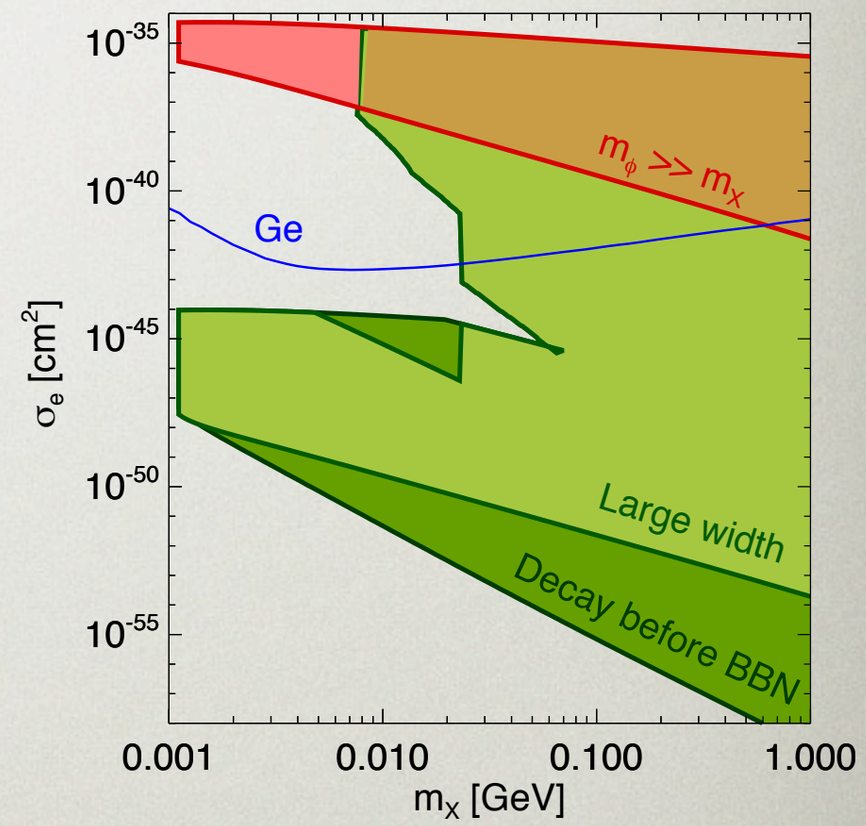
WIMP miracle preserved!

$$\sigma v \simeq \frac{g_{vis}^2 g_X^2}{16\pi m_X^2}$$

$$m_X^2 \simeq \frac{g_{vis}^2 g_X^2 m_{SUSY}^2}{16\pi^2}$$

Concrete Models

- Good: definite mass predictions
- Bad: prediction for scattering cross-section in direct detection model dependent
- For very light DM, scattering off electrons is most important process



Lin, Yu, KZ 1111.0293
Ge line from Essig, Mardon, Volansky

Can We Develop Benchmarks?

Cohen, Phalen, Pierce, KZ

$$W = \lambda S T H' + S^2 L H$$ + Kinetic Mixing

Mass generation

ADM term

Communication mechanism!

Can We Develop Benchmarks?

$$W = \lambda S T H' + S^2 L H$$

+ Kinetic Mixing

Mass generation

ADM term

Communication mechanism!

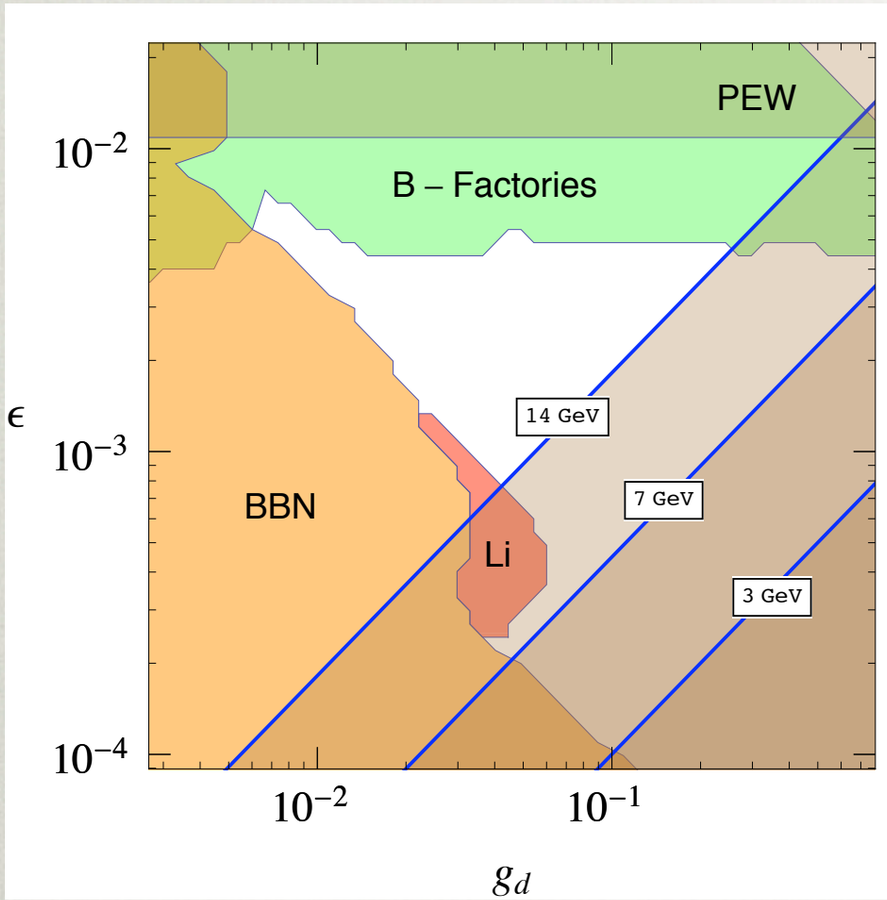
$$V = \lambda^2 |H'|^2 (|S|^2 + |T|^2) + \lambda^2 |S|^2 |T|^2 + \frac{g_d^2}{2}(-|T|^2 + |H'|^2 - \xi)^2$$

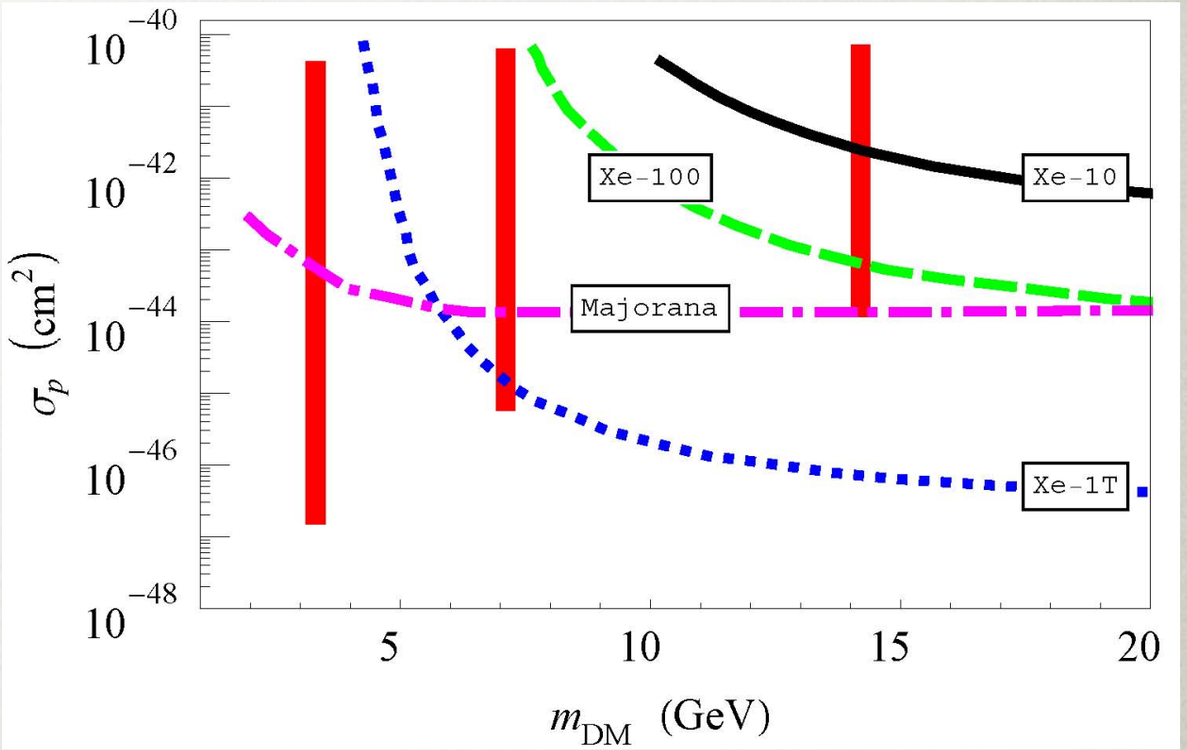
$$\xi = -\epsilon \frac{g_Y}{2} c_{2\beta} v^2$$

$$\langle S \rangle = \langle T \rangle = 0 \qquad \langle H' \rangle = \sqrt{\xi}$$

Constraints Yield Detection Benchmarks

Benchmarks!

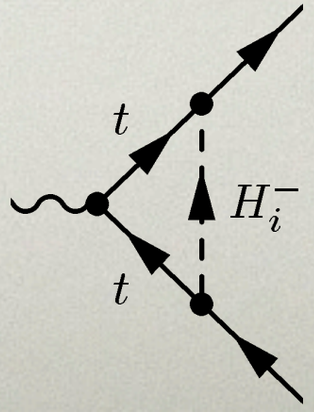




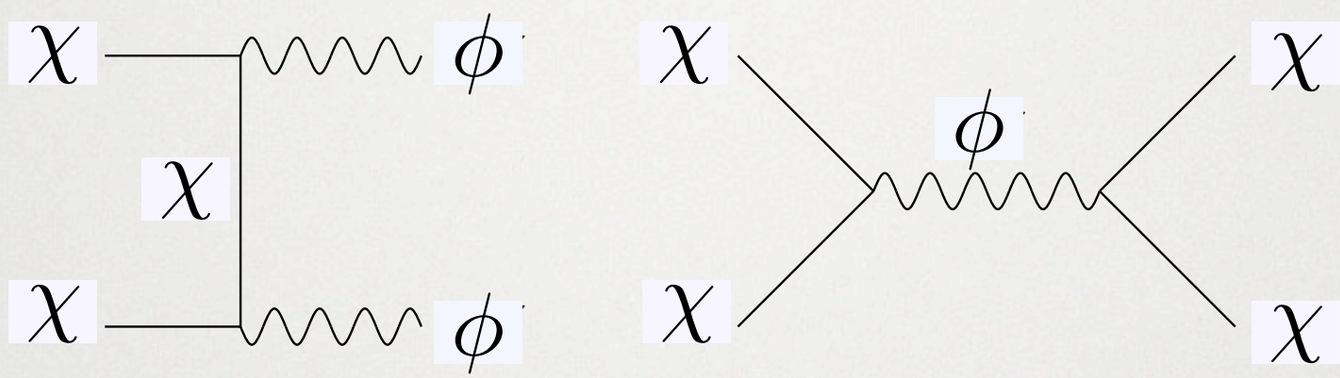
DM is singlet, but couples to dark photon via 1-loop

$$\tau(\tilde{\gamma}_d \to \gamma \tilde{G}) = 190 \text{ s} \left(\frac{10^{-3}}{\epsilon}\right)^2 \left(\frac{\text{GeV}}{m_{\tilde{\gamma}_d}}\right)^5 \left(\frac{\sqrt{F}}{50 \text{ TeV}}\right)^4$$

$$\langle \sigma_{\tilde{\gamma}_d} v \rangle \simeq \frac{g_d^4}{16\pi m_{\tilde{\gamma}_d}^2} v_{f.o.} \simeq 7 \times 10^{-24} \text{cm}^3/\text{s} \left(\frac{g_d}{0.1}\right)^4 \left(\frac{1 \text{ GeV}}{m_{\tilde{\gamma}_d}}\right)^2 \left(\frac{v_{f.o.}}{0.3}\right)$$



Look Also Cosmologically

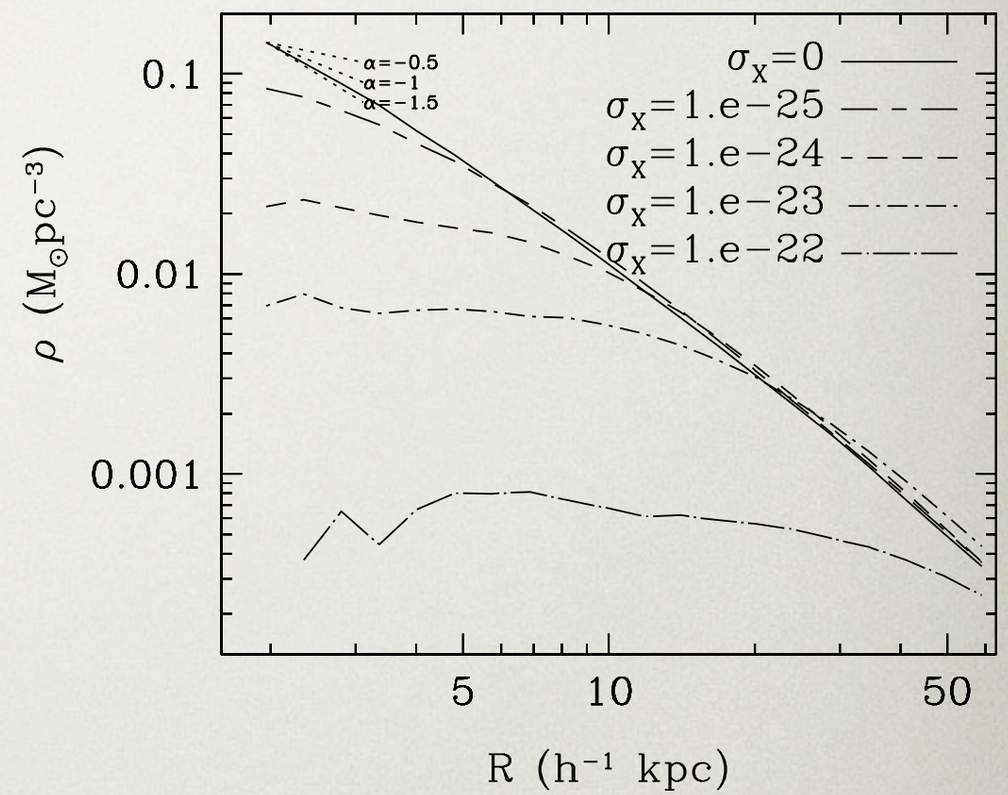


- Dark Forces Very Important for cosmological abundance, direct detection
- Self scattering can be important for structure of DM halos

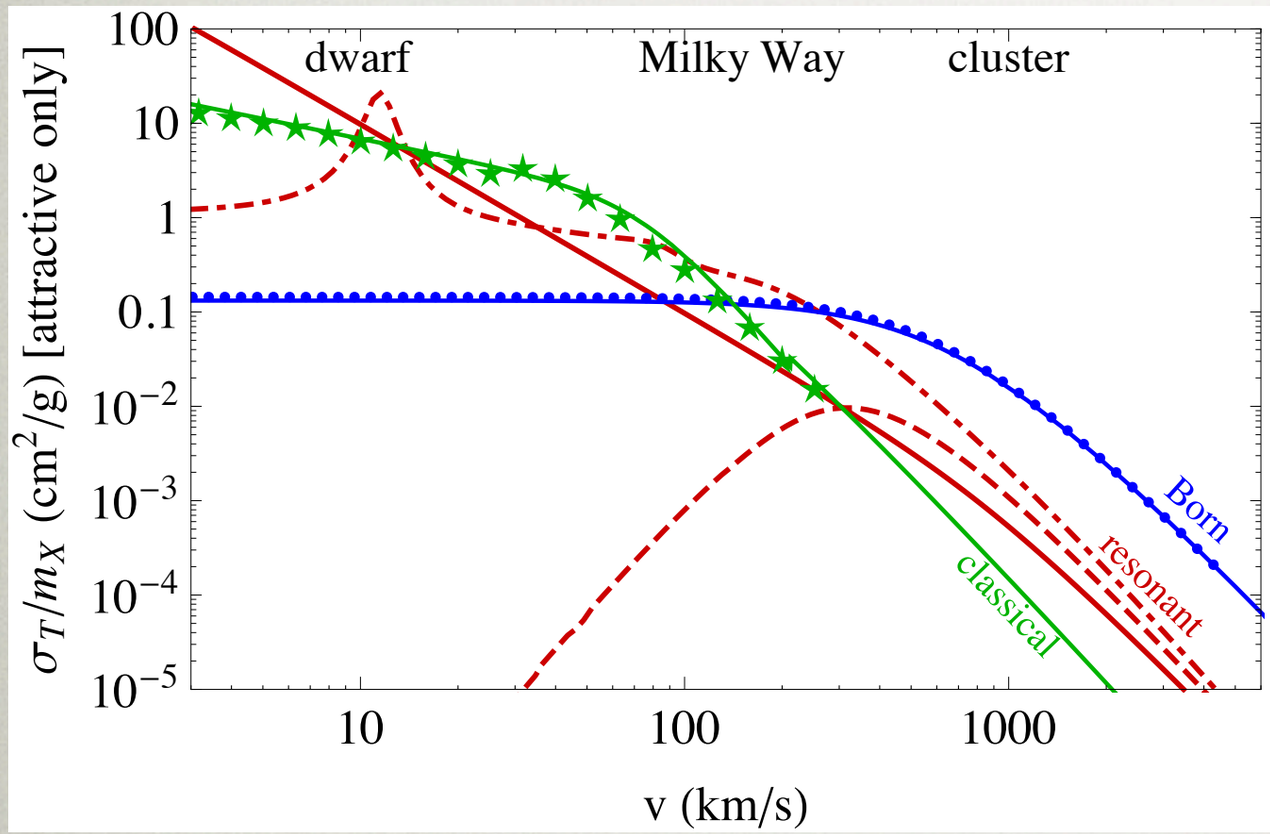
DM Interactions and DM Halos

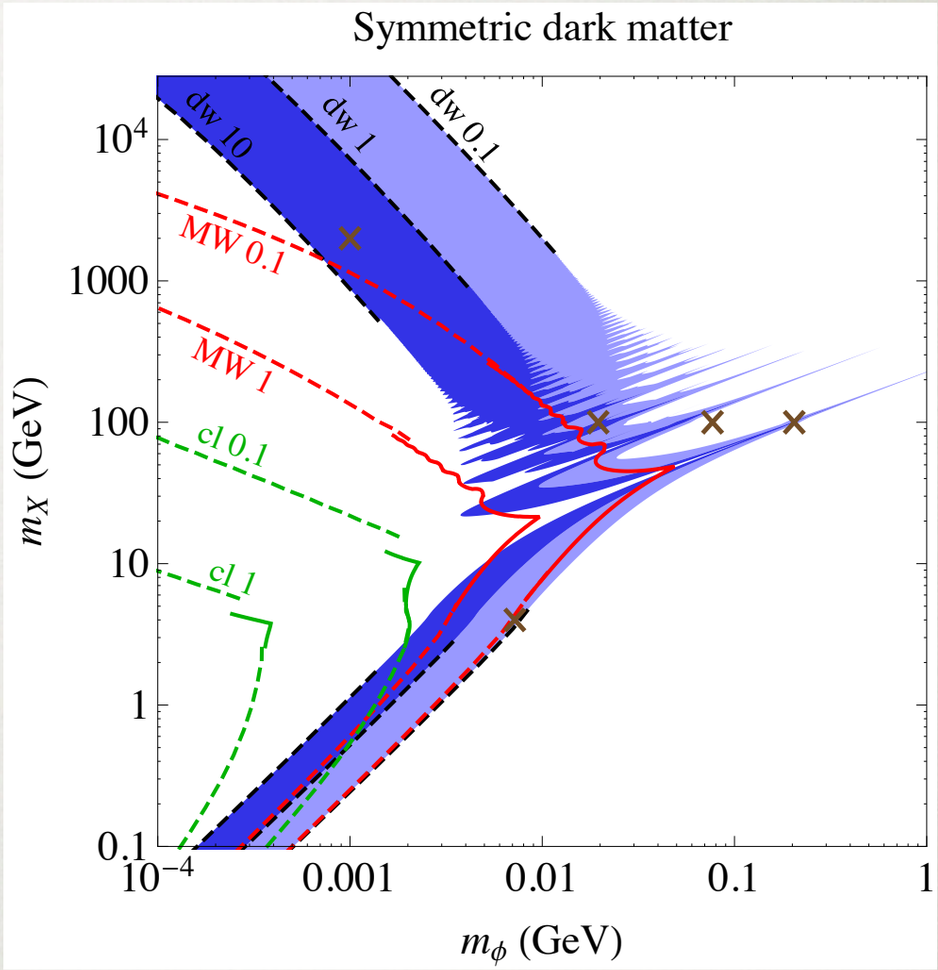
- Dark matter self-interactions randomize momenta and isotropize halos
- Lead to lower density dark matter halo cores
- Dark matter halos (including baryon poor dwarf galaxies) seem to have cores rather than cusps (still controversy as to cause)

Dave, Spergel, Steinhardt, Wandelt



Particle Dynamics in DM Halos





Quantum Resonances and Strongly Coupled Dyanamics in DM Halos

Tulin, Yu, KZ, 1302.3898

Tulin, Yu, KZ, 1210.0900

Non-SUSY Questions

- What are the best models to focus on for detection?
- Can we develop benchmarks which are not the most general models possible but which are nevertheless descriptive?
- Are there new search techniques?